# Gruppo 1 Padova

## Stato Esperimenti, Anagrafica e Preventivi

CdS

2/7/2024

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Slides by Martino, Ale, Ezio, Patrizia, Christian, Luca, Filippo, Andrea, Lorenzo, Enrico, Gabriele, Gianmaria, Mauro, Piero e tanti altri …

# Outline

- General Summary
- Belle II
- CMS / Fase2_CMS
- LHCb
- LUXE
- MuonE
- RD FCC
- RD MuColl
- TwoCryst
- IGNITE
- ENUBET_NP06
- DUNE
- ICAR_US
- HYPER-K

Neutrini

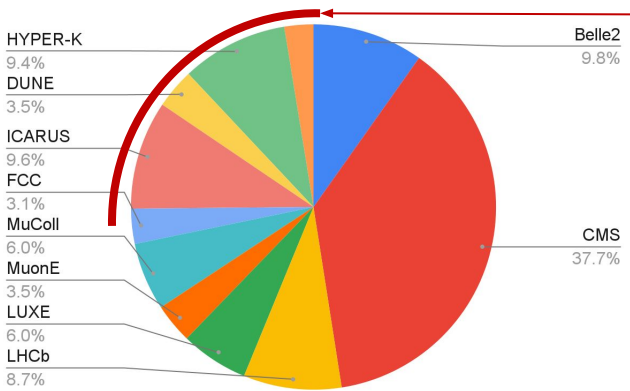
NB:
- Da 2024 ICAR_US e Dune in CSN1
- Dal 2025 anche T2K ⇒ HYPER-K e ENUBET

**Disclaimer:**
Ho di gran lunga troppe slides, che, in molti casi, ho ricevuto senza il tempo di studiarle bene.
Mi scuso se saltero' attivita' o le raccontero' in modo approssimativo.
L'anno prossimo sto pensando a mettere una soglia hard: eg 1 slide per FTE

L'anagrafica potrebbe essere soggetta a piccole variazioni come al solito

# FTE e persone per sigla

| | Belle 2 | | CMS | | FASE2 | | LHCb | | LUXE | | MuonE | | MuColl | | RD_FCC | | ICAR_US | | DUNE | | HyperK | | ENUBET | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | FTE | Px | FTE | Px | FTE | Px | FTE | Px | FTE | Px | FTE | Px | FTE | Px | FTE | Px | FTE | Px | FTE | Px | FTE | Px | FTE | Px |
| **2021** | 5.15 | 11 | 19.55 | 24 | 9.3 | 22 | 4.8 | 10 | | | 3.25 | 9 | 3.95 | 15 | 0.3 | 2 | | | | | | | | |
| **2022** | 4.5 | 9 | FTE | 26.3 | Px | 37 | 5.5 | 9 | 3.7 | 7 | 1.35 | 5 | 3.4 | 15 | 0.9 | 6 | | | | | | | | |
| **2023** | 5.5 | 10 | FTE | 23.5 | Px | 32 | 6.2 | 10 | 3.45 | 8 | 2.75 | 9 | 3.6 | 13 | 1.1 | 9 | 8.6 | 11 | 1.5 | | | | | |
| **2024** | 5.4 | 9 | FTE | 23.3 | Px | 35 | 7.35 | 12 | 3.2 | 9 | 2.45 | 9 | 3.6 | 13 | 1.3 | 10 | 7.2 | 11 | 2 | | | | | |
| **2025** | 6.95 | 7 | FTE | 26.7 | Px | 39 | 6.15 | 10 | 4.25 | 13 | 2.5 | 9 | 4.25 | 14 | 2.2 | 11 | 6.8 | 10 | 2.5 | 7 | 6.68 | 11 | 1.82 | 5 |
| **Δ** | 1.55 | -2 | 3.4 | | 4 | | -1.2 | -2 | -0.25 | 1 | -0.3 | 0 | 0.65 | 1 | 1.9 | 1 | -0.4 | -1 | 0.5 | | | | | |

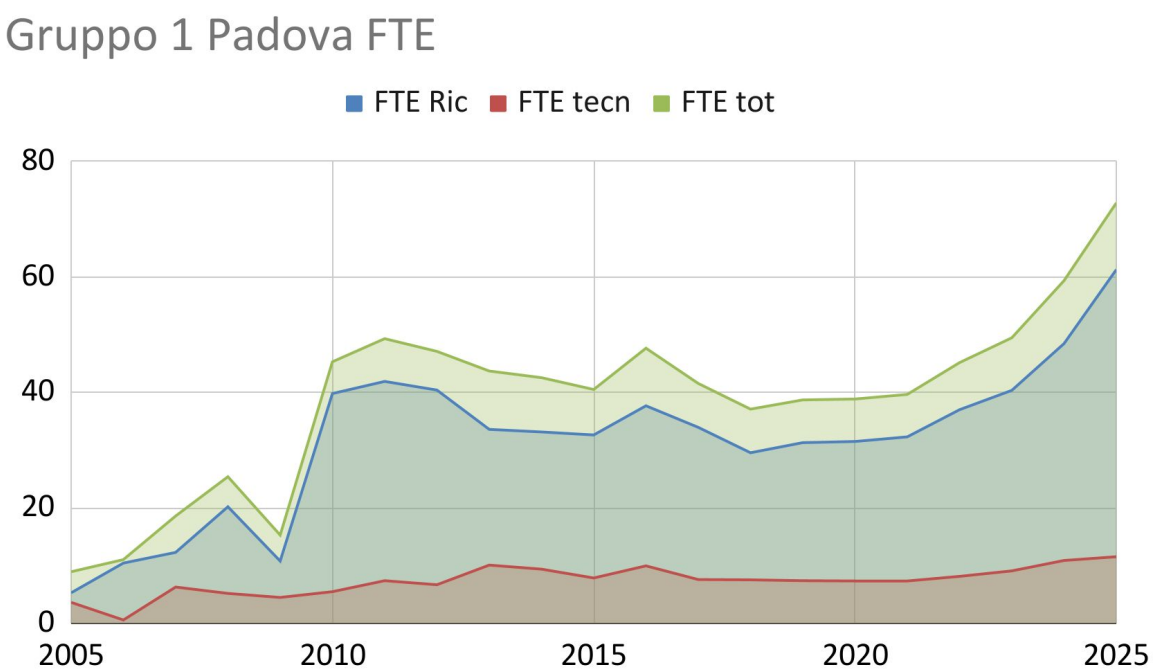



Neutrini ~25%

Totale: **Ricercatori+Tecnologi: 70.08 FTE (98 px)**
**2024 49.45 FTE**
**2023 46.8 FTE**

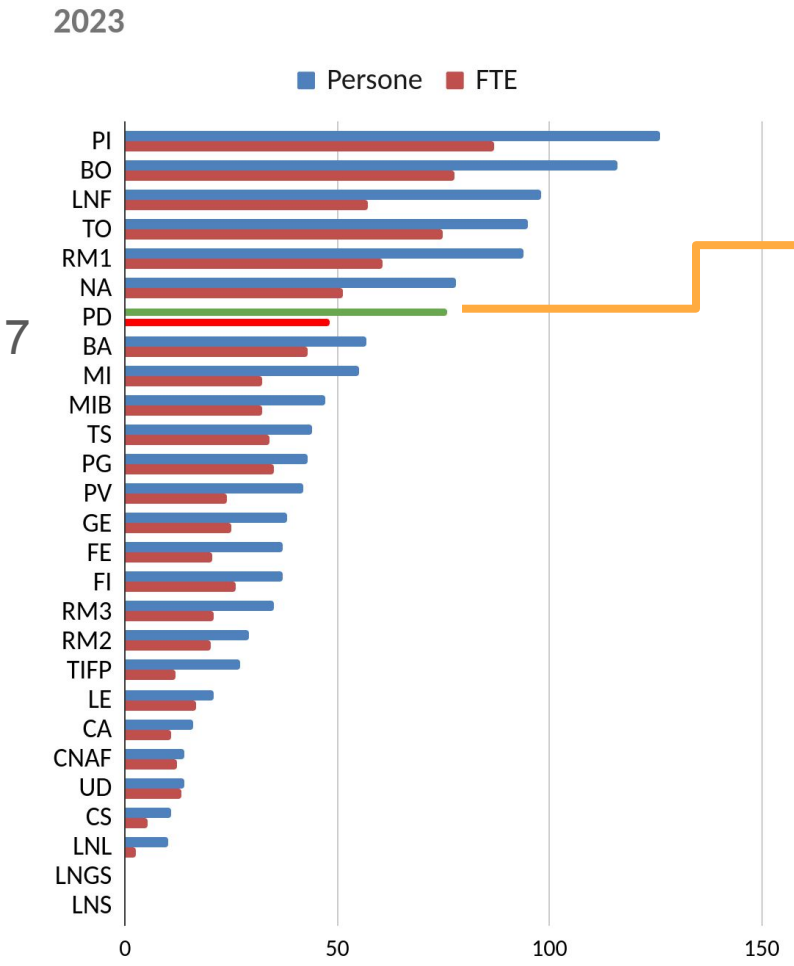
NB anagrafiche da confermare

# Anagrafica Gruppo1 ultimi 10 anni




Nel 2025

- Persone: 98
- FTE: 72.6

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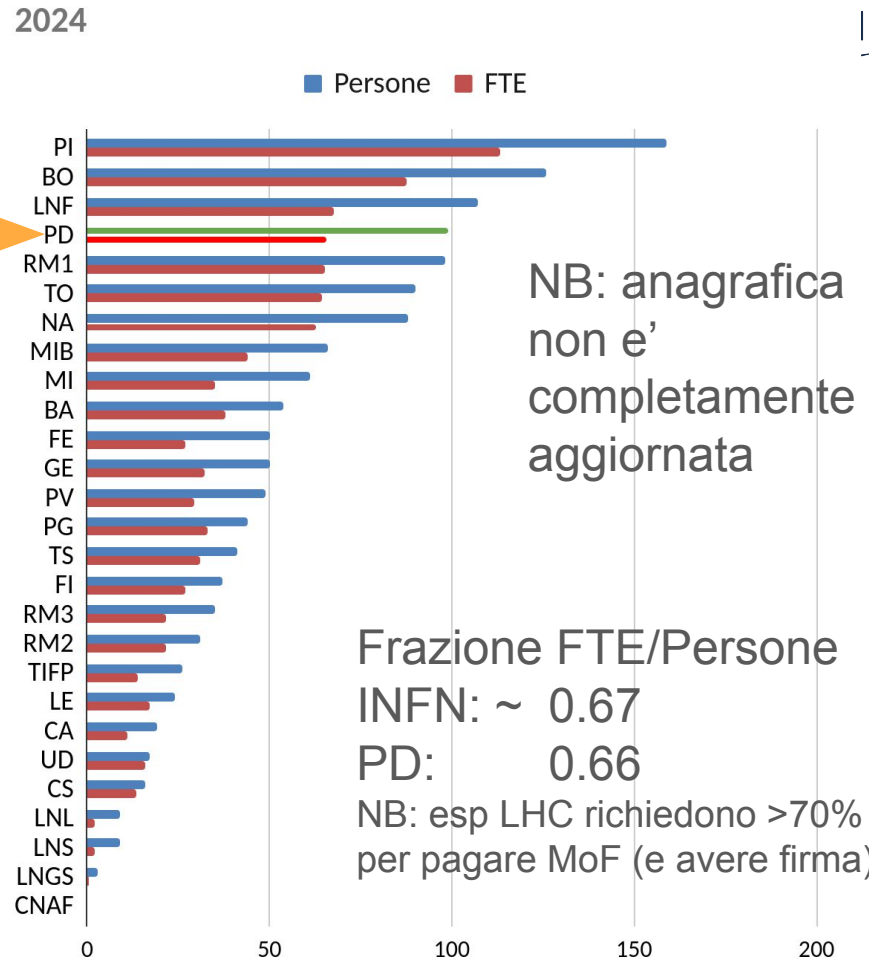
4

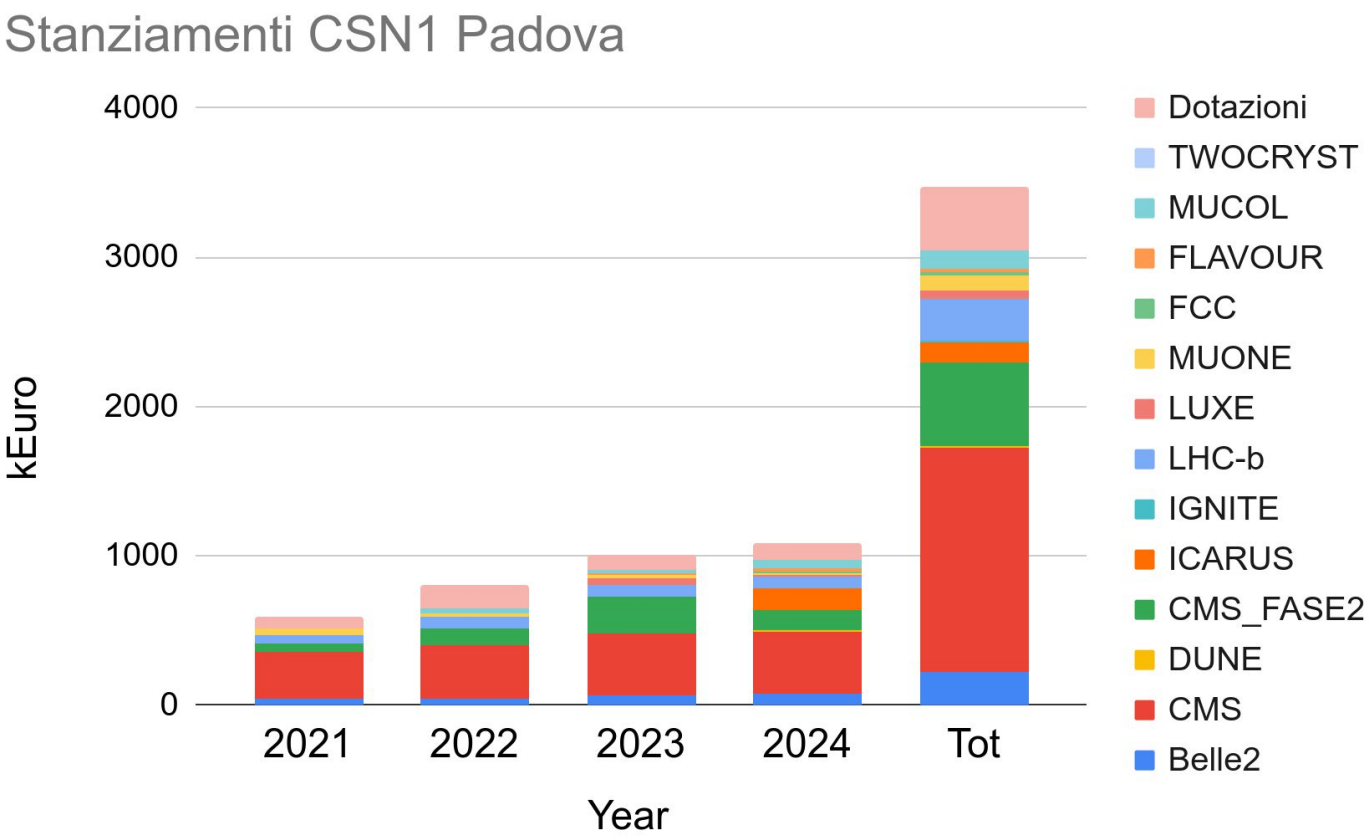



NB: anagrafica non e' completamente aggiornata

Frazione FTE/Persone
INFN: ~ 0.67
PD: 0.66

NB: esp LHC richiedono >70% per pagare MoF (e avere firma)

# Finanziamenti da CSN1




Inclusi:

- common-fund (MoU-A/B)
  - Con qualche incertezza
- Finanziamenti diretti per CMS-FASE2 (fondi LHC-FOE)
- Nel 2024:
  - ~16kE/FTE
  - ~10kE/Persona

# Belle II

RL: Stefano L.

# Run Plan 2024-26

We are here

| Fiscal year | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 1 | 2 | 3 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2021 | 2021b | | | | | | | 2021c | | | | 2022a |
| 2022 | 2022b | | | LS1 | | | | | | | | |
| 2023 | | | | | | | | | ~~2023c~~ | ① | 2024a | |
| 2024 | 2024b | | | | | ③ | 2024c | | | ② | | 2025a |
| 2025 | 2025b | | | | | | | 2025c | | ① | 2026a | |
| 2026 | 2026b | | | | | | | 2026c | | ① | 2027a | |

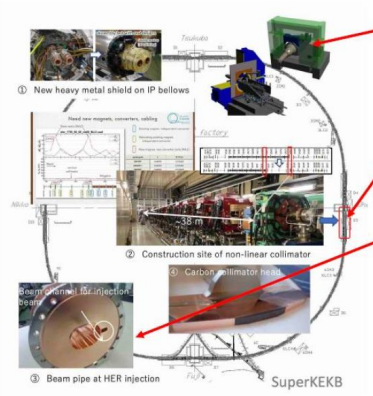
Assumption: 7 months operation per fiscal year with sufficient budget

① Pause of operation for new year holidays instead of a usual winter shutdown
(decided to try it first in FY2023; to be discussed for FY2025 and beyond)

② Power restriction due to renewal of the central electric power substation

③ Renovation work of the roof of Tsukuba Hall in parallel to the operation

# Principali interventi su SUPERKEKB durante LS1



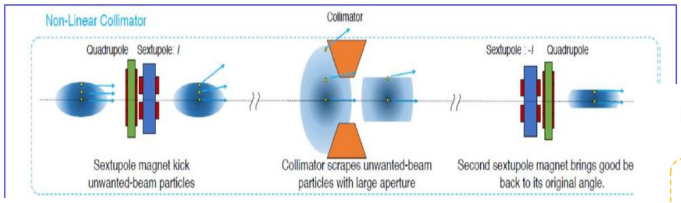

(1) Reinforcement of radiation shielding around the IP, replacement of the cap at the head of the QCS cryostat
→ Background reduction

(2) Installation of a new type of collimator (Non-Linear Collimator) in the Oho straight section
→ reduction of beam instability caused by the collimator, collimator protection, and etc.

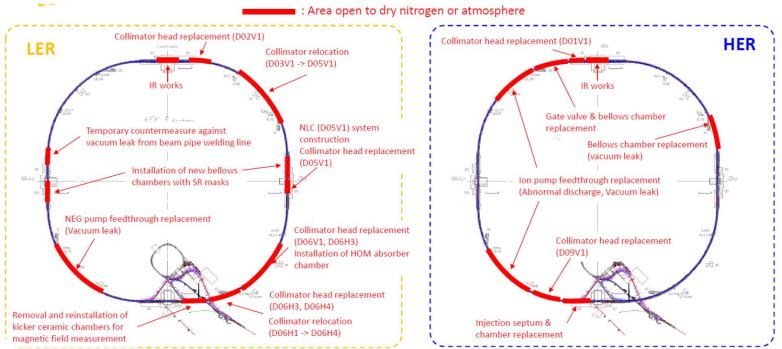
(3)Chamber modification of the HER injection section
→ injection injection efficiency improvement

(4) Replacement of collimator head
→ installation of more robust collimator, replacement of damaged collimators, Cu coating on the collimator head (against SBL from "fireball," etc.)

**Non-linear collimator system:**
thanks to its large aperture has much lower impedance than conventional collimators




**Interventi sui due anelli durante LS1 che hanno comportato l'interruzione del vuoto nella beam pipe**



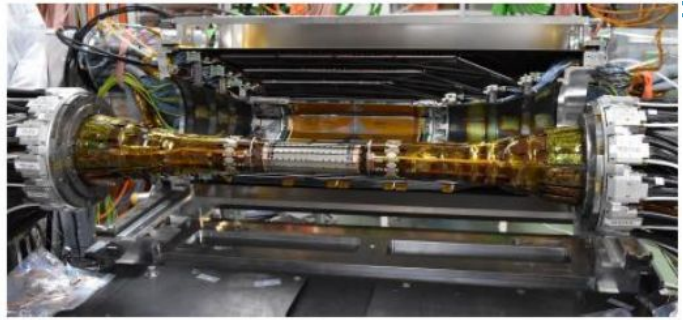

Un periodo di vacuum scrubbing è stato necessario a inizio del nuovo run: integrati circa 600 Ah per anello.

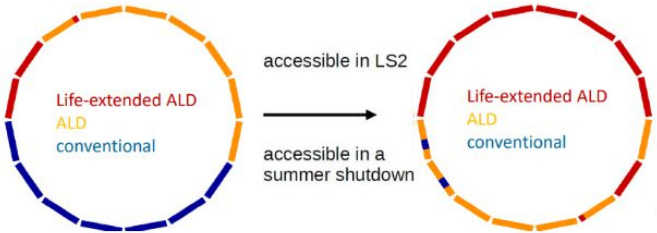
## Interventi sul rivelatore Belle2 durante LS1:

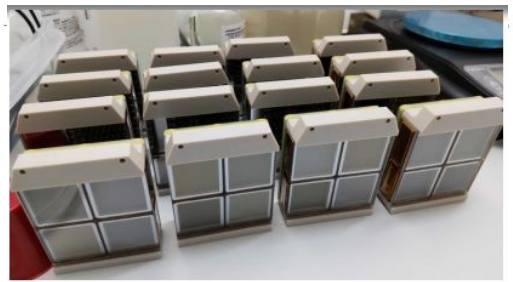
Coinvolgimento italiano

| | | |
|---|---|---|
| PI, TS | PXD/SVD | PXD commissioning plan in KEK (done)<br>VXD reinstallation |
| | CDC | HV resister replacement<br>Improvement in gas circulation and monitoring |
| PD, TO | TOP | TOP MCP-PMT replacement (done) |
| PG, NA | ECL | Improvement in pedestal correction<br>Gain adjustment on ShaperDSP (done) |
| RM3, LNF | KLM | Reinforcement of monitoring system + update of scintillators firmware<br>NH3 injection for BB2 efficiency recovery |
| | TRG | Improvements in CDCTRG, ECLTRG, KLMTRG<br>Optimization of trigger veto, and TOPTRG |
| | DAQ | PCIe40 long-term stability test<br>with realistic high-occupancy data |
| TS | Background | Additional neutron shields + additional shield around QCS bellows |
| TS | MDI | Installation of additional loss monitors + modified diamond abort during injection (still in preparation)<br>Non-linear collimator |

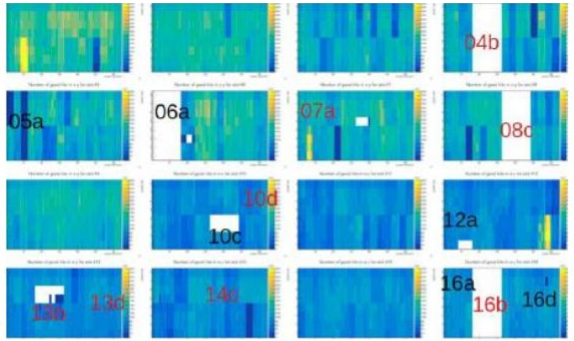
Studied in lab but not (yet) implemented





# TOP hit map
# in global Cosmic run



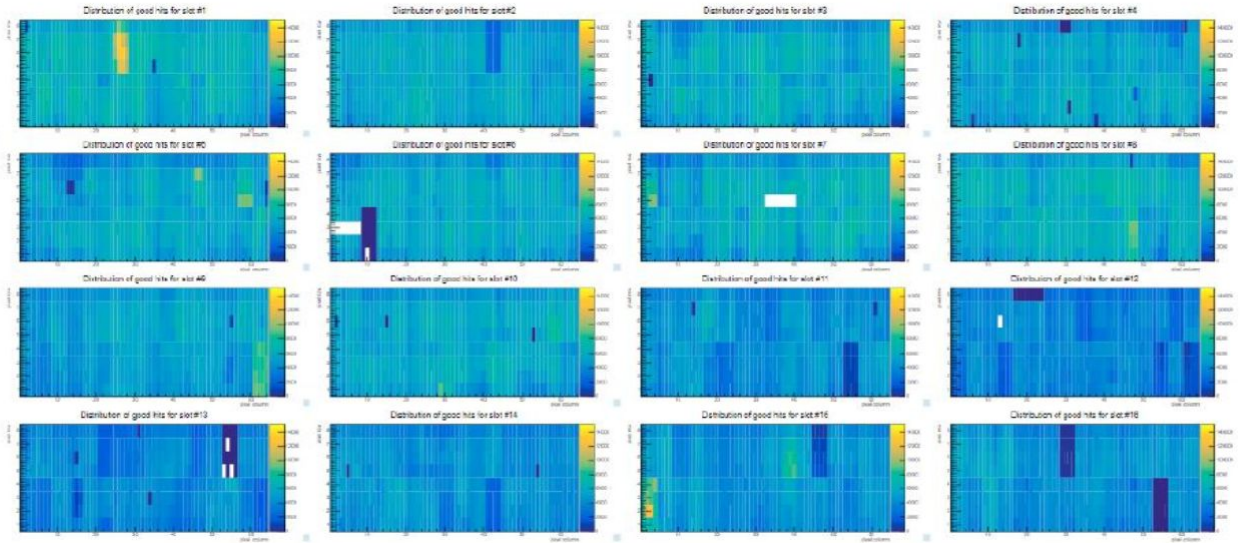

↑ Before LS1
↓ After

dead channel count:

600-700 before LS1

~60 after LS1
* 2-3 dead asics
* 2-3 dead PMTs
* few bad pins

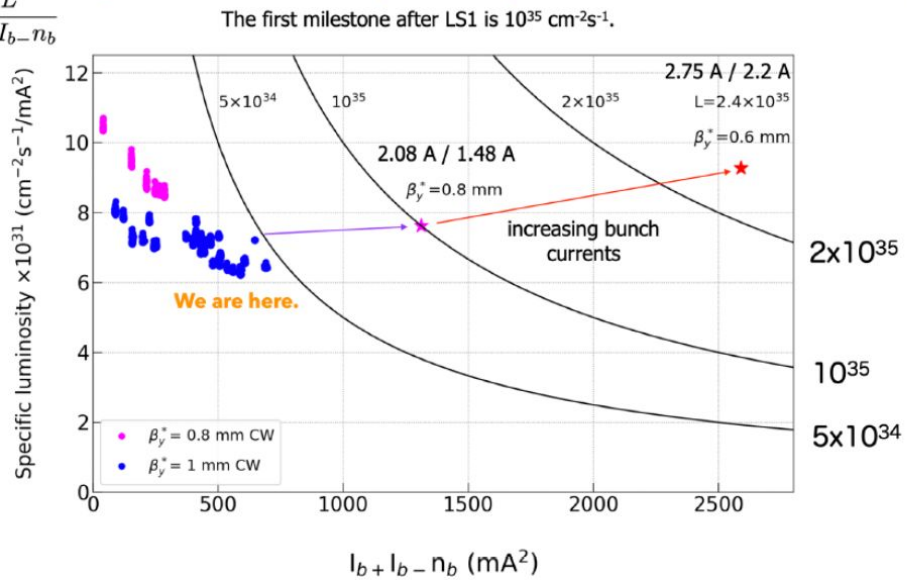
PMT HV optimized
both for 0 and 1.5 T



- Jan29th beam operation resumed
  - 2024ab run (Jan29th—Jul1st)
- Jan29th-Feb20th
  - Vacuum scrubbing, Machine tuning, Machine study
- Feb20th First Run2 collision


## Target di luminosità specifica per il Run2

$$L_{sp} = \frac{L}{I_{b+} I_{b-} n_b}$$




## Performance raggiunte al termine del Run 1

| | |
|---|---|
| $L_{peak}$ | $4.7 \times 10^{34}$ cm$^{-2}$s$^{-1}$ |
| $I_{beam}$ (LER) | 1.3 A |
| $I_{beam}$ (HER) | 1.1 A |
| $N_{bunch}$ | 2249 |
| β* | 1 mm |
| tot $L_{int}$ | 428 fb$^{-1}$ |
| max daily $L_{int}$ | 2.5 fb$^{-1}$ |

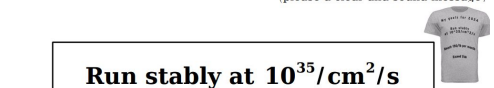
# Luminosity in 2024ab run

- About 100/fb collected
  - Initial (very optimistic) goal: 360/fb
  - Realistic goal: 150/fb
- Max ~2/fb/day or 9/fb/week

L(tot)=530 /fb

**What are our goals for 2024 ?**

(please a clear and sound message)

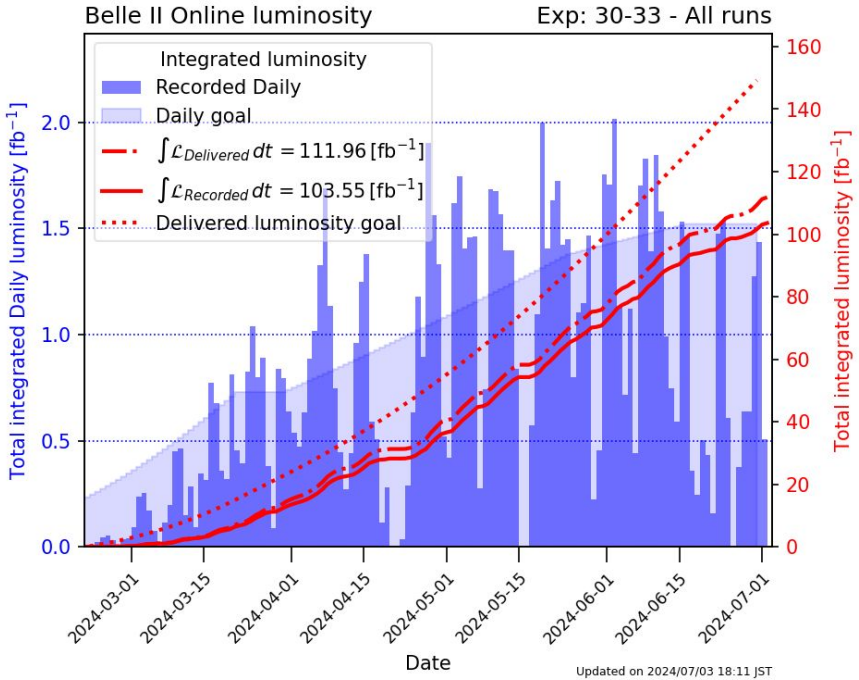


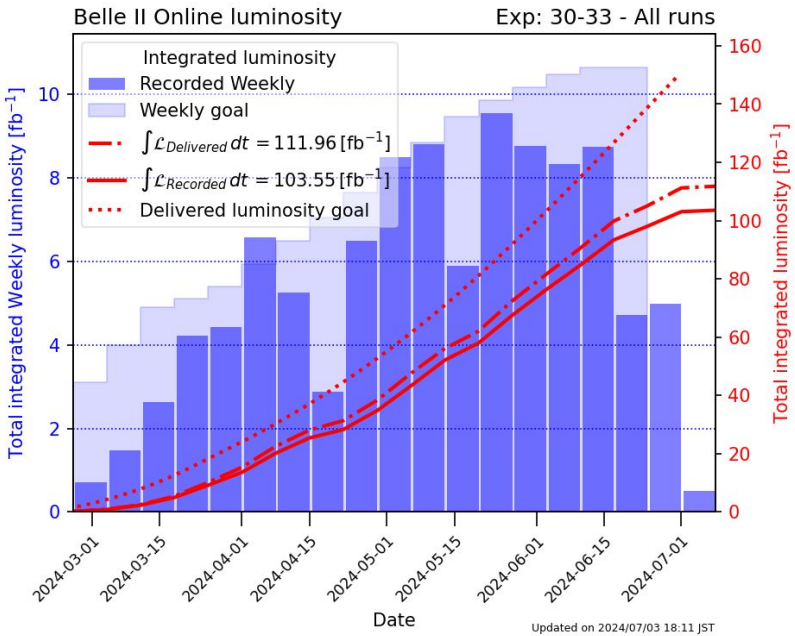
**Run stably at $10^{35}/cm^2/s$**

**Reach 150 $fb^{-1}$ per month**

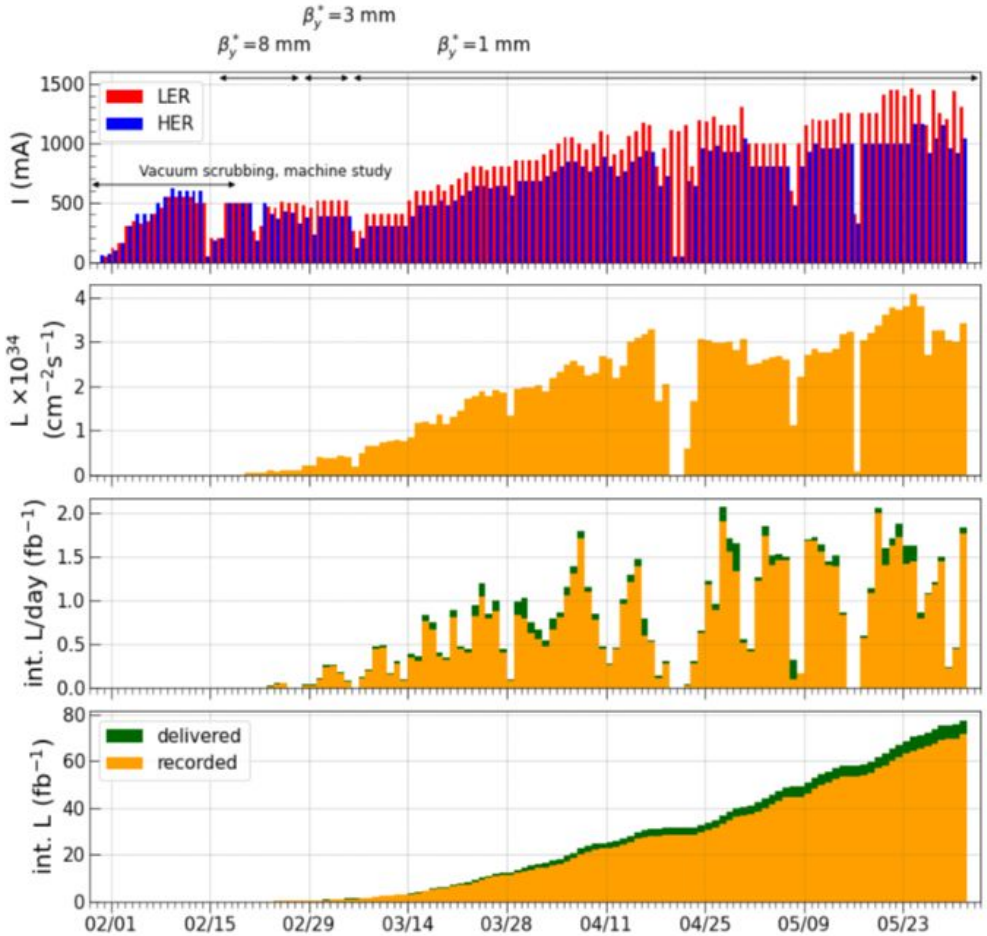
**Exceed 1 $ab^{-1}$**

(setting the pace for run 2)
(while doing good physics and working for the upgrade)



# SUPERKEKB run 2024




- Achievements until May 31
  - LER Current: 1450 mA
  - HER Current: 1160 mA
  - Number of Bunches: 2346
  - Peak Luminosity: 4.47 x $10^{34}$ $cm^{-2}s^{-1}$
  - Integrated Luminosity: 103/112 /fb

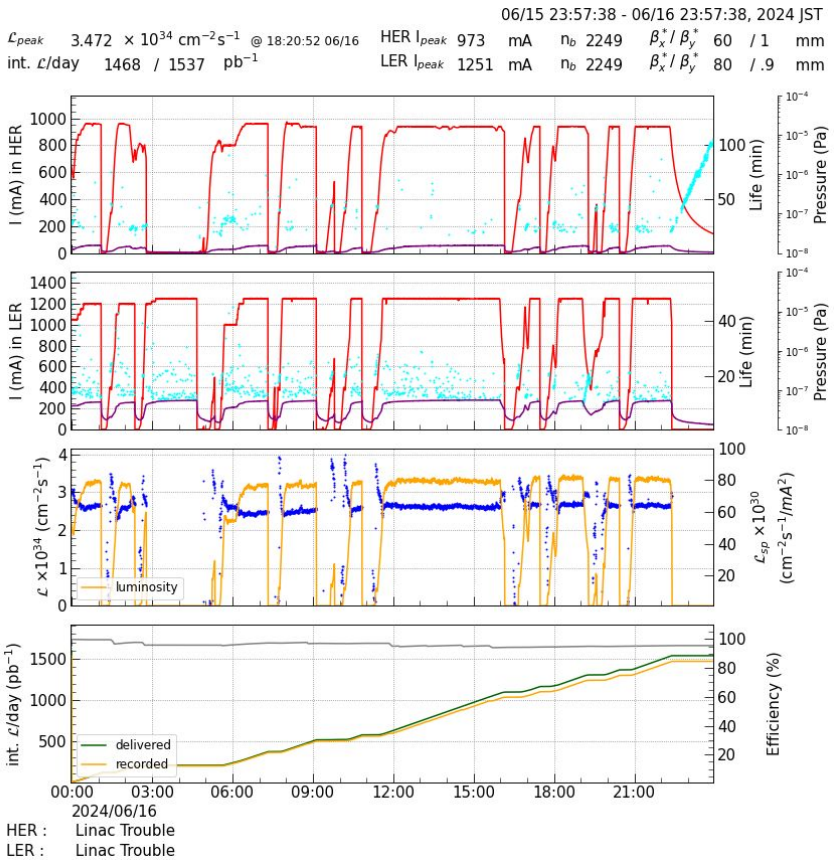
Last running day
$\beta^*$=0.9mm

Reproduced 2022 run conditions

Still large fraction of beam time is used for machine development

>50%

# A typical (good) day




- Smaller vertical beam emittance
  - ⇒ smaller vertical beam size
- Good specific luminosity
- Data taking eff very good: 92% (-2.8%)
- Beam background a bit higher than Run1 (for same lumi)
  - Machine config different, difficult to compare
- **Frequenti beam abort**
- **Sudden beam loss (163 in total)**
  - Specie su Low energy Ring ($e^+$)
  - Origine non chiara
- High energy Ring beam loss in fase di iniezione
- Injection tuning ancora instabile

## Sudden beam losses

*«Beam loss that occurs within 1 turn (10 μs) without precursory phenomena»*

They are the most important limiting factor that SuperKEKB is facing now. Observed also in Run1, but with lower rate. 3 possible causes are being studied:

a. Dust falling occasionally from upper beam pipe inner surface (grooved in the bending magnets)
b. Possible fireball formation in RF cavities
c. Electron cloud formation in LER

SBL reproduced by knocking the beam pipe in wiggler sections where clearing electrodes are installed in the upper shell of the pipe, thus supporting dust hypothesis. More studies ongoing.
→ Now considering to turn upside down the beam pipe in some wigglers sections during summer. Tests in october, if successful will extended to the whole machine.

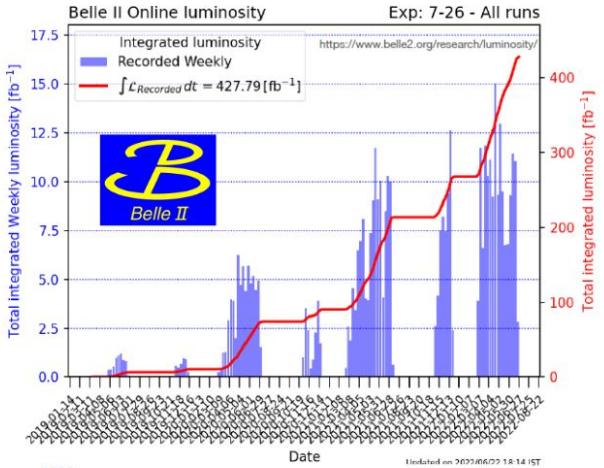
Two SBL events on april 22 and may 6 affected PXD detector and diamond electronics:

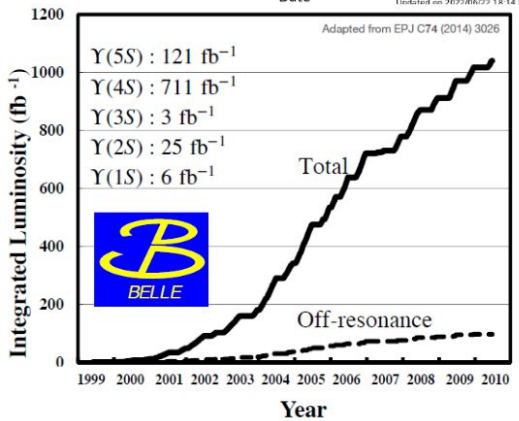
- Diamond amplifiers have been replaced and they are fully operational
- Damages to PXD detectors are limited but permanent → Belle II decided to keep PXD off until safer beam conditions will be reached.

# Highlight from physics program

**47 articoli pubblicati/sottomessi**

## Nuovi risultati @Moriond 2024 ( o un po' prima...)




**EW-radiative penguins:**
- BR, $A_{CP}$ and $\Delta_{+0}$ of $B \to K^* \gamma$
- search for $B^0 \to \gamma\gamma$
- $b \to d \ell\ell$ (*)

**Semileptonic decays:**
- $V_{ub}$ untagged $B \to \pi/\rho \ell \nu$
- Update of $B \to D^* \ell \nu$

**Time dependent CPV:**
- $B^0 \to \eta' K_S$ (*)
- $B^0 \to K_S \pi^0 \gamma$ (*)

**b, c hadronic decays:**
- BR of $B^- \to D^0 \rho^-$
- BR of $B \to D^{(*)} K^- K^{(*)0}$
- BR of $\Xi^0_c \to \Xi^0\pi^0, \Xi^0\eta, \Xi^0\eta'$

**low multiplicity and $\tau$**
- $\sigma(e^+e^- \to \pi^+\pi^-\pi^0)$
- LFU in $\tau$ decays (*)
- $\tau \to \mu\mu\mu$ (*)

(*) out since few months

Molte analisi utilizzano il data sample combinato Belle+Belle II. Malgrado la minore statistica disponibile Belle II ottiene misure più precise di Belle grazie a un detector più performante e a tecniche di analisi più efficienti. → Alcuni highlights nelle prossime slides

# A gluonic penguin: $B^0 \rightarrow \eta' K_S$

arXiv:2402.03713

Two sub-channels $\eta' \rightarrow \eta_{\gamma\gamma}\pi\pi, \rho\gamma$.

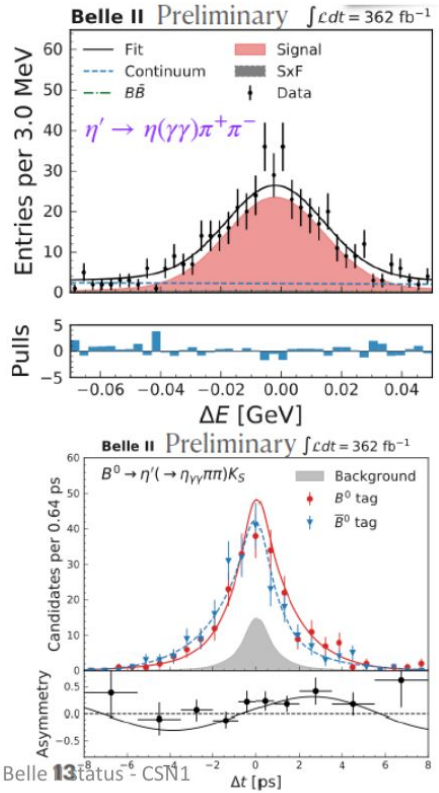
Signal extraction via fit to $\Delta E$, $M_{bc}$ and continuum suppression via dedicated BDT

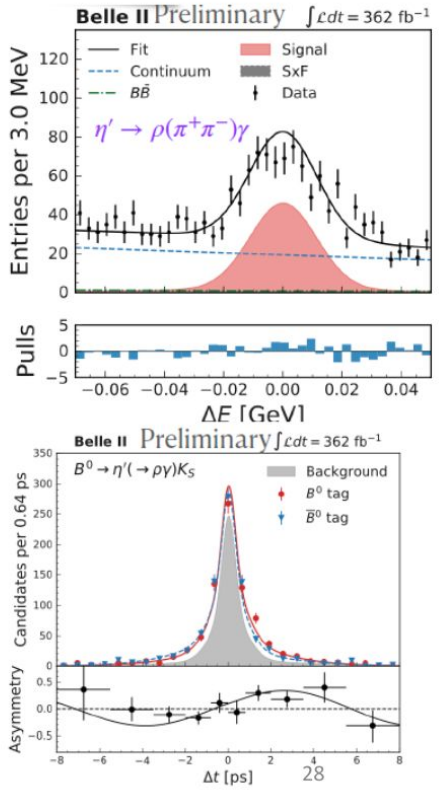
- Bkg $\Delta t$ shape from sideband
- Bkg asymmetry included in the fit
- Validation on control sample $B^+ \rightarrow \eta' K^+$

$$S = 0.67 \pm 0.10 \pm 0.04$$
$$C = -0.19 \pm 0.08 \pm 0.03$$

HFLAV: $S = 0.63 \pm 0.06$, $C = -0.05 \pm 0.04$

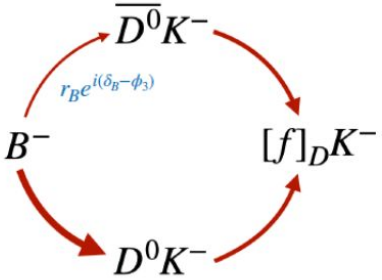
Precision comparable with Belle/BaBar in spite of smaller sample



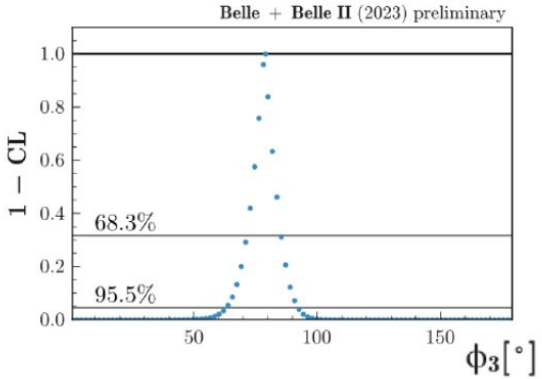



# Belle + Belle II determination of $\phi_3/\gamma$ angle

- SM benchmark — very reliably predicted ($10^{-7}$ relative)
- Tree level decays — no (large) BSM
- First combination of all Belle and Belle II $\phi_3$-measurements
- **Total 60 input observables and 16 auxiliary *D*-decay inputs**




| $B$ decay | $D$ decay | Method | Data set (Belle + Belle II) [fb$^{-1}$] | |
|---|---|---|---|---|
| $B^+ \to Dh^+$ | $D \to K^0_S h^- h^+$ | BPGGSZ | 711 + 128 | [JHEP 02 063 (2022)] |
| $B^+ \to Dh^+$ | $D \to K^0_S \pi^- \pi^+ \pi^0$ | BPGGSZ | 711 + 0 | [JHEP 10 178 (2019)] |
| $B^+ \to Dh^+$ | $D \to K^0_S \pi^0, K^- K^+$ | GLW | 711 + 189 | [arxiv:2308.05048] |
| $B^+ \to Dh^+$ | $D \to K^+ \pi^-, K^+ \pi^- \pi^0$ | ADS | 711 + 0 | [PRL 106 231803 (2011)] |
| $B^+ \to Dh^+$ | $D \to K^0_S K^- \pi^+$ | GLS | 711 + 362 | [JHEP 09 (2023) 146] |
| $B^+ \to D^* K^+$ | $D \to K^0_S \pi^- \pi^+$ | BPGGSZ | 605 + 0 | [PRD 81 112002 (2010)] |
| $B^+ \to D^* K^+$ | $D \to K^0_S \pi^0, K^0_S \phi, K^0_S \omega, K^- K^+, \pi^- \pi^+$ | GLW | 210+0 | [PRD 73 051106 (2006)] |




$\phi_3/\gamma(^\circ) = 78.6^{+7.2}_{-7.3}$

HFLAV WA

$\phi_3/\gamma\ (^\circ) = 66.2^{+3.4}_{-3.6}$

LHCb: $\phi_3 = (63.8 \pm 3.6)^\circ$ LHCb-CONF-2022-003

Few ab$^{-1}$ needed for a meaningful comparison

# Toward $\phi_2/\alpha$: $B^0 \to \pi^0\pi^0$

**New for FPCP 2024**

Previous results
[PRD107 (2023) 112009]

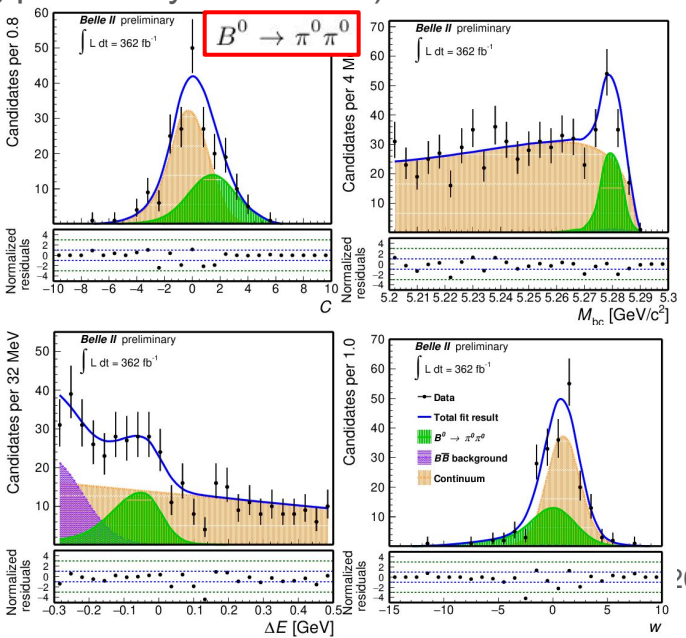
- Update on $\mathcal{B}$ and $A_{CP}$ using full Run1 statistics:
- Improved selections, new flavour tagger (GFlaT), reduction of systematics
  - Background dominated by continuum, then $B\bar{B}$ ( $B^+ \to \rho^+(\to \pi^+\pi^0)\pi^0$, $B^0 \to K^0_S(\to \pi^0\pi^0)\pi^0$ )
  - Photons selected with BDT, continuum suppression trained on off-resonance data
  - 4D fit including $M_{BC}$, $\Delta E$, cont.suppression, w (wrong tag probability - unbinned)
  - Validated on $B^+ \to K^+\pi^0$ / $B^0 \to \bar{D}^0(K^+\pi^-\pi^0)\pi^0$

$\mathcal{B} = (1.26 \pm 0.20 \pm 0.11)\times10^{-6}$
$A_{CP} = 0.06 \pm 0.30 \pm 0.06$

- Compatible with known values
- World-best $B$ determination.
- $A_{CP}$ on par with world best

$\mathcal{B} = (1.59 \pm 0.26)\times10^{-6}$
$A_{CP} = 0.30 \pm 0.20$ WA

Signal enhanced region



# Limit on τ → μμμ

Signal side: 3 muons

Tag side: up to 3 tracks

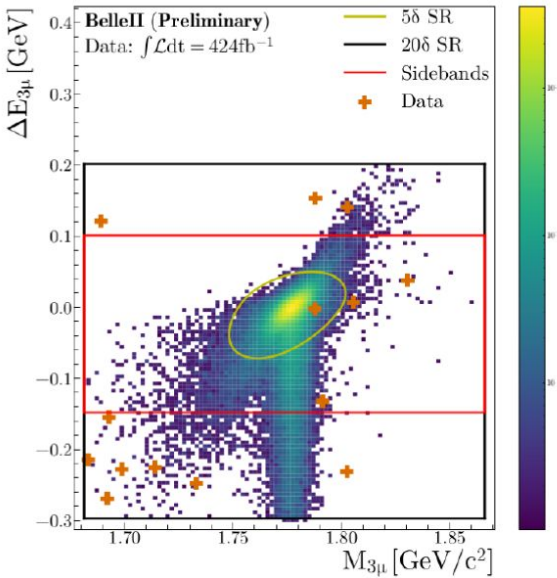
Background reduction by BDT

2D signal region: ε = 20.42% x3 larger than Belle

Expected Bckgr 0.5 events (estimated from sidebands)

→ 1 event observed in signal region.

$\Delta E_{3\mu} = E_{\tau,\,sig} - E_{beam}$ vs $M_{3\mu}$



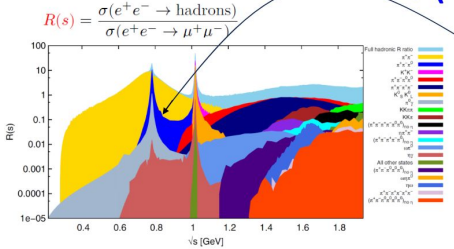

- **No significant excess found** in 424 fb$^{-1}$ of data
- Obtained **most stringent limits** at 90% CL
  - → 1.9 x 10$^{-8}$ on $B(\tau \to \mu\mu\mu)$

*Better limit with smaller dataset thanks to the more inclusive tag technique (3-prong vs only 1-prong)*

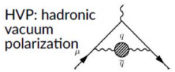
| | UL at 90% CL on $B(\tau \to 3\mu)$ |
|---|---|
| Belle | $2.1 \times 10^{-8}$ ($\mathcal{L}_{int} = 782\text{fb}^{-1}$) |
| BaBar | $3.3 \times 10^{-8}$ ($\mathcal{L}_{int} = 468\text{fb}^{-1}$) |
| CMS | $2.9 \times 10^{-8}$ ($\mathcal{L}_{int} = 131\text{fb}^{-1}$) |
| LHCb | $4.6 \times 10^{-8}$ ($\mathcal{L}_{int} = 2.0\text{fb}^{-1}$) |
| Belle II | $1.9 \times 10^{-8}$ ($\mathcal{L}_{int} = 424\text{fb}^{-1}$) |

## $\sigma(e^+e^- \to \pi^+\pi^-\pi^0)$

arXiv:2404.04915




Is the second largest contribution to HVP below 1 GeV.

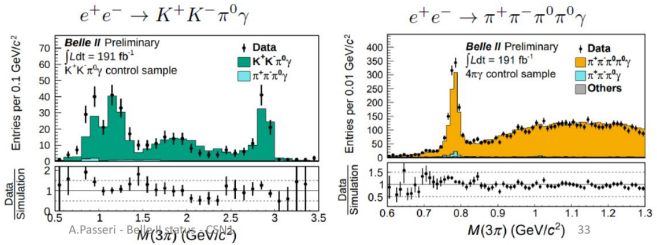



HVP produces the largest uncertainty in the prediction of the muon (g-2)

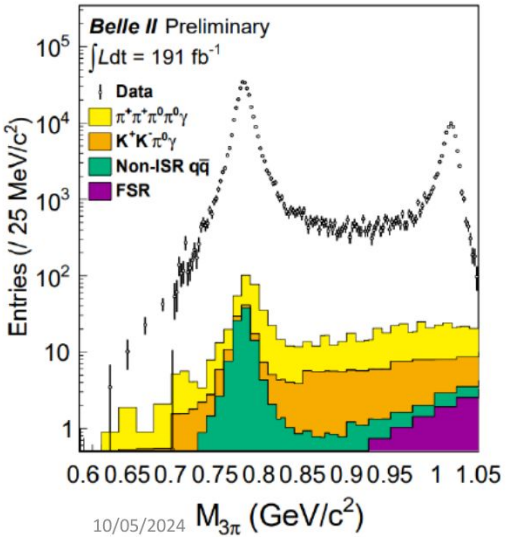
Measured at Belle II exploiting $e^+e^- \to \pi^+\pi^-\pi^0\gamma_{ISR}$

→ Scan the region $0.7 < \sqrt{s} < 3.5$ GeV by $\gamma_{ISR}$ reconstruction

- Used a 191 fb$^{-1}$ sample
- Kinematic fit with beam momentum constraint to suppress background
- Signal efficiency 8.8-6.6% over the studied mass range
- Control samples to measure residual background








Integrate over $3\pi$ cross section from $0.62 - 1.8$ GeV (Preliminary):

$$a_{\mu,0.62\text{-}1.8}^{3\pi} \times 10^{10} = 48.91 \pm 0.23_{\text{stat.}} \pm 1.07_{\text{syst.}}$$

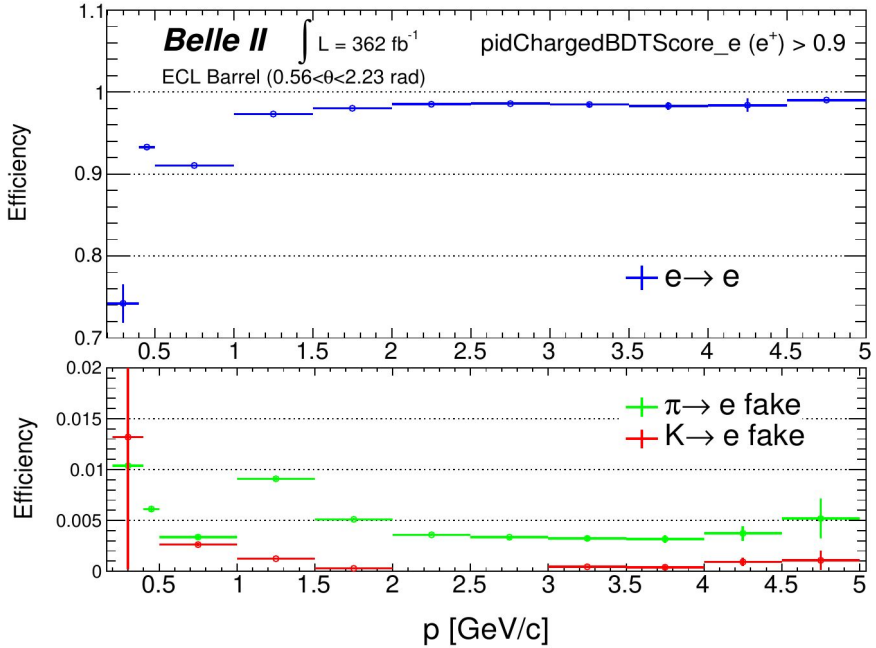
$6.7\%$ or $2.5\sigma$ higher than current global average, obtained from BABAR, CMD-2 and SND

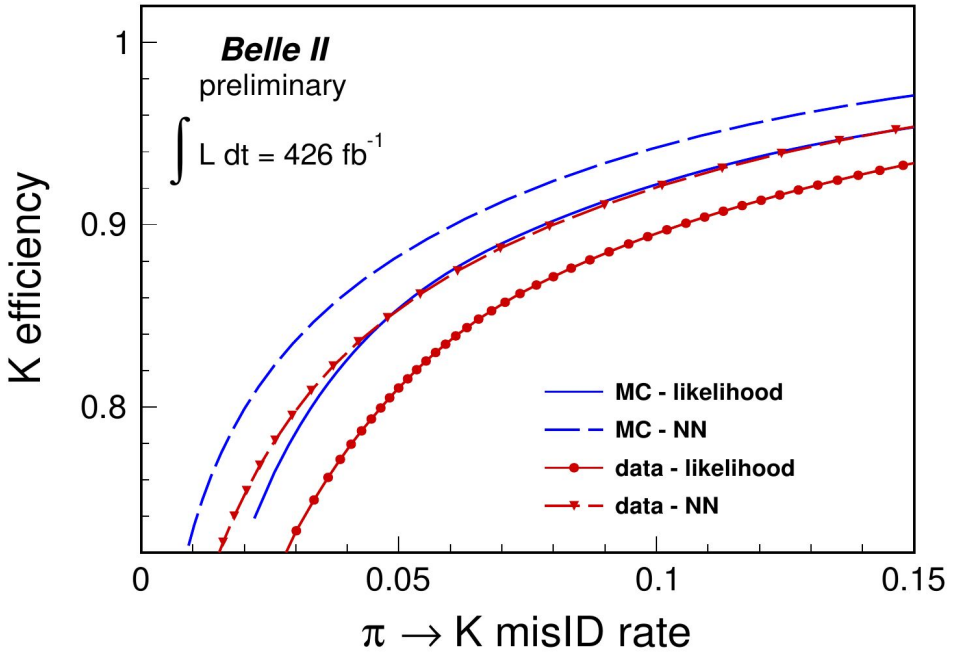
→ *Slighlty smaller $a_\mu$ anomaly*

Leading systematics are $\pi^0$ efficiency and missing NNLO in generator

# PID performance monitoring

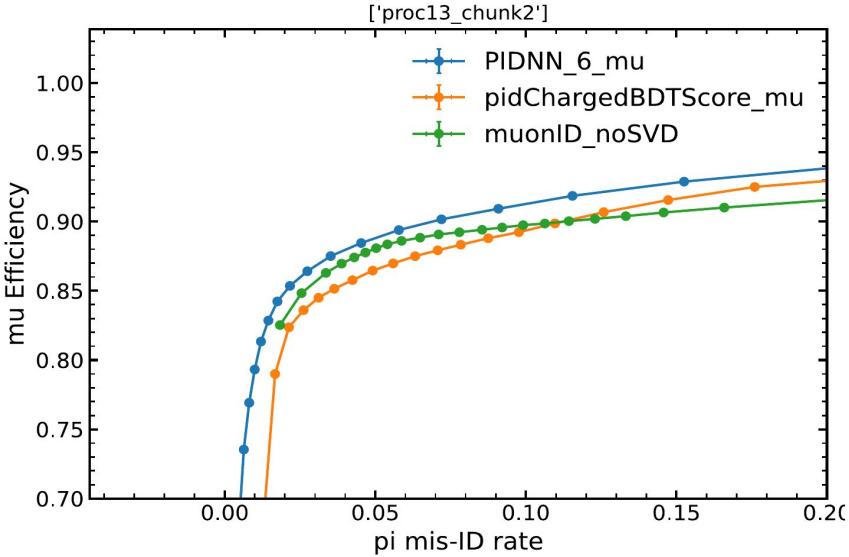
- Mandate of the group: measure the PID performance of the detector and provide efficiency corrections / systematic uncertainties to be used in analysis:

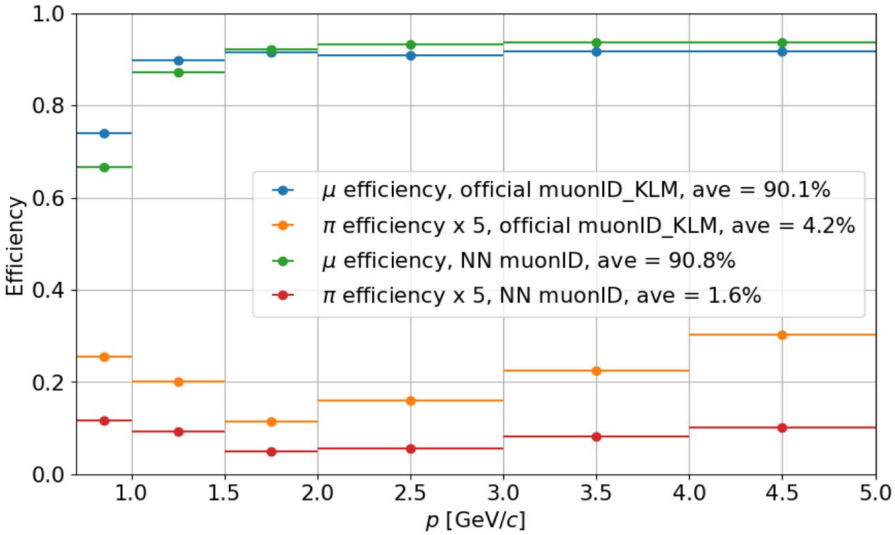


# Developments in PID

- Pushing beyond the default Belle II approach, based on likelihood ratios from all the subdetectors contributing to PID;
- Binary K vs π NN already used in physics analysis, now extending to all six particle species (e, μ, π, K, p, d). Prototype exist and are being tested by the analysts!




The NN outperforms the likelihood based discriminators and the older BDT based selectors

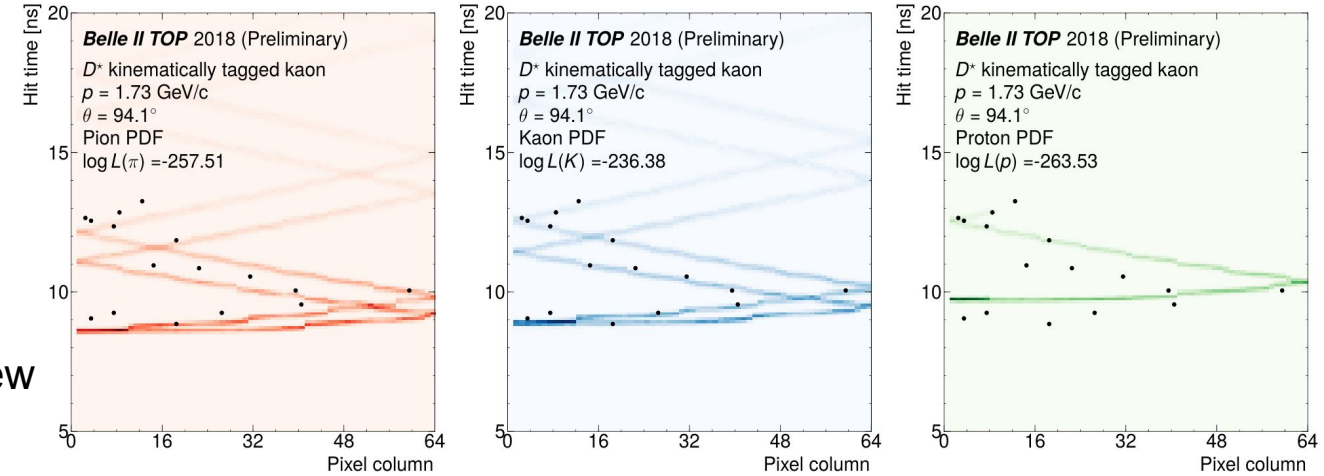
# TOP with machine learning

- The TOP PID relies on pattern matching between the measured position and time of arrival of the Cherenkov photons, and the pdf's, which depend on the particle hypothesis and track parameters

- Right now, the pdf computation is done analytically;

- Significant drawbacks, as this requires a ~perfect MC modeling of the detector;

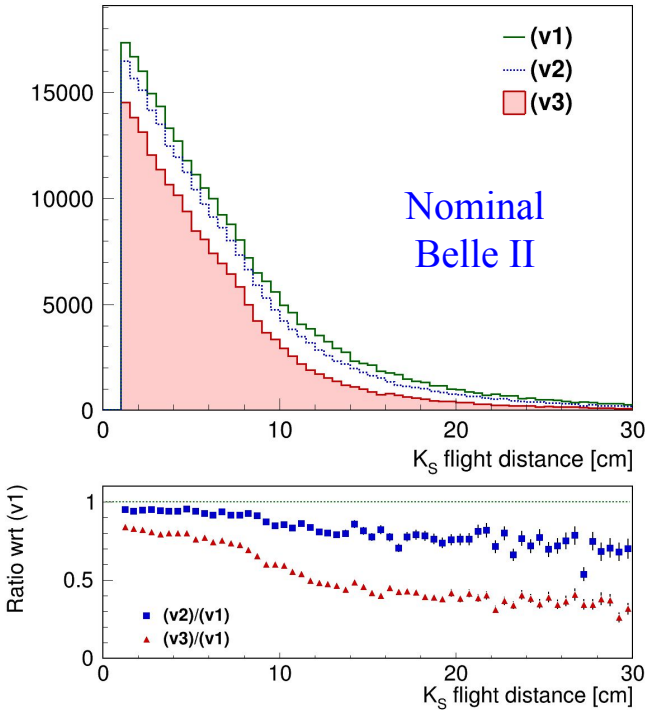
- We started developing a new approach, in which the pattern recognition is performed by a more sophisticated tool, based on machine learning.




PhD student with scholarship on PNRR funds started last Fall

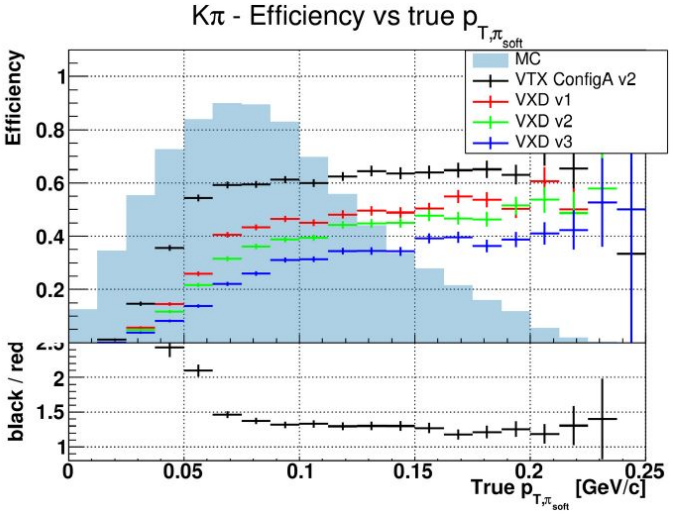
# Belle II Upgrade

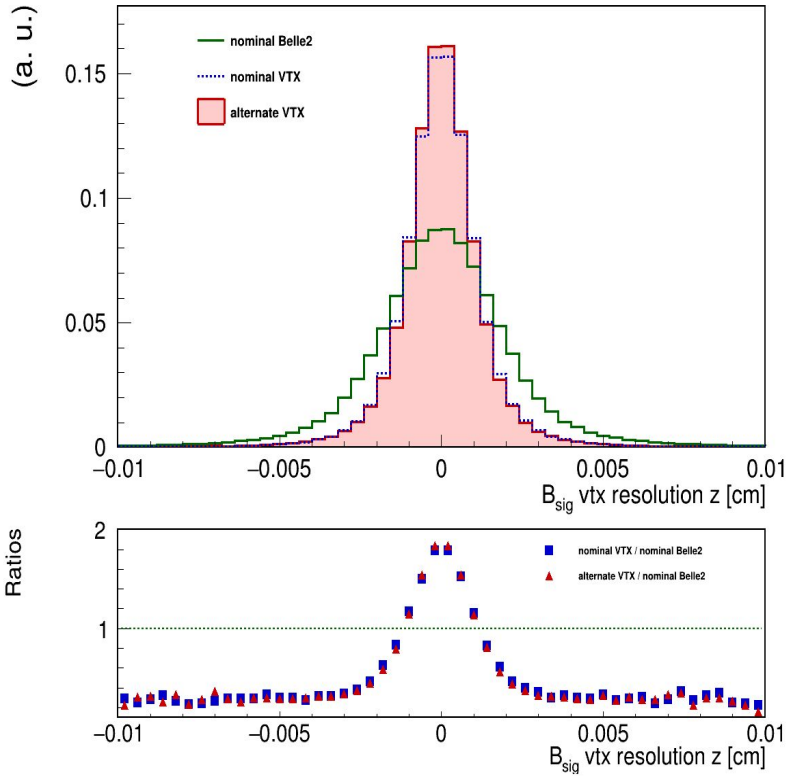
- We are exploring the options for an upgrade of Belle II, to happen in the medium term future;
- Main motivation: recover the performance that is lost due to the higher than anticipated machine-related backgrounds;
- Two projects currently on the table:
  - VTX: 5 layer pixelated silicon detector, to replace PXD and SVD;
  - instrumenting the KLM barrel with scintillators (replacing the RPC's), and adding TOF capabilities;
- Framework Conceptual Design Report submitted to arXiv! http://arxiv.org/abs/2406.19421




Impact on $K_S$ reconstruction efficiency in different background scenarios (optimistic, realistic, pessimistic)

# Belle II Upgrade – VTX



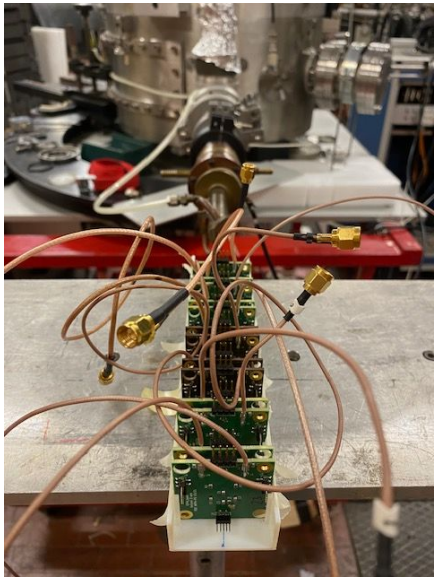

Very significant improvement of VTX over the currently installed VXD (PXD+SVD) in terms of soft $\pi$ reconstruction efficiency and vertexing resolution.

# SiPM studies

## Available SiPMs

| SiPMs Producer | Code | Dimensions ($mm^2$) | Pitch (μm) | Max $V_{bias}$ (V) | #SiPMs |
|---|---|---|---|---|---|
| Hamamatsu | S13360-1350PE | 1.3x1.3 | 50 | 65 | 8 |
| FBK | NUV-HD-RH-3015 | 3.0x3.0 | 15 | 43 | 3 |
| FBK | NUV-HD-RH-1015 | 1.0x1.0 | 15 | 43 | 4 |
| Hamamatsu | S14160-3050HS | 3.0x3.0 | 50 | 43 | 5 |
| Kektek(*) | PM3315-WL | 3.0x3.0 | 15 | 37 | 5 |
| Kektek(*) | PM3335-WL | 3.0x3.0 | 35 | 37 | 5 |
| OnSemi | 10035 | 1.0x1.0 | 35 | 30 | 6 |
| OnSemi | 30035 | 3.0x3.0 | 35 | 30 | 6 |
| Hamamatsu | S13360-3025PE | 3.0x3.0 | 25 | 65 | 5 |
| Hamamatsu | S13360-3050PE | 3.0x3.0 | 50 | 65 | 5 |
| Hamamatsu | S14160-3015PS | 3.0x3.0 | 15 | 48 | 5 |

New FBK SiPMs with low field technology
paid with AIDAinnova funds will be available in November 2024

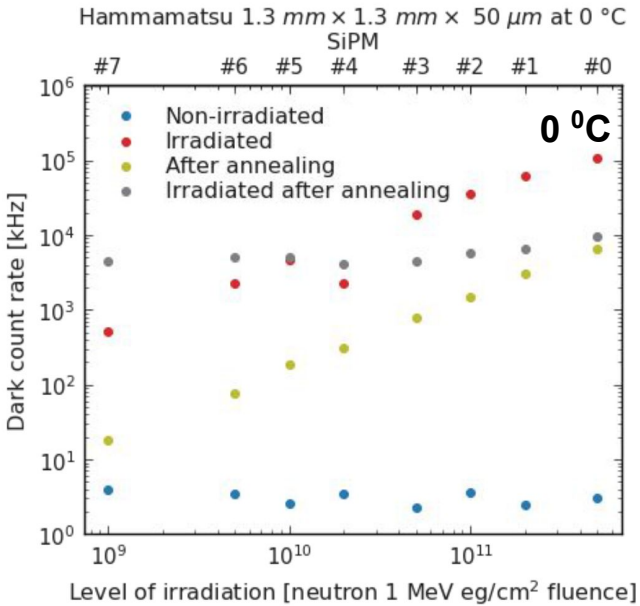


All the available type of SiPMs have been irradiated at LNL in 3 campaigns:
Nov. 2022, July 2023, April 2024

After the the 2nd campaign SiPMs have been annealed for 60 days at 150 $^0$C.

SiPM tested between 20 and -35 $^0$C

Annealing partially recover DCR increase due to irradiation




Irradiated after annealing with 1x10$^{10}$ n/cm$^2$

# JENNIFER3 project approved by EU

JENNIFER3, evolution of the 2 previous RISE project, has been recently selected for funding in the MSCA Staff Exchange call 2023, receiving top scores in the evaluation report.

JENNIFER3 overall budget is 1,55 M€ , out of which 464.600,00 € for INFN (covering both Belle II and T2K/HyperK activities).

Project will start between january and april in 2025, for 4 years.

# Anagrafica e Richieste

- Antonioli 0 → 100% PhD
- Benettoni 10 → 0%
- Dal Corso 40 → 40%
- Gaz 100 → 100%
  - EB member, HadronID conv. (L2)
- Lacaprara 100 → 100%
  - Data Production manager (L1), EB/IB member
- Lin 0 → 100% PhD
- Kandra 100 → 100%
- Stroili 100 → 70%
- Torassa 90 → 85+10%
  - **Totale 5.3 6.95**

**Richieste servizi:**

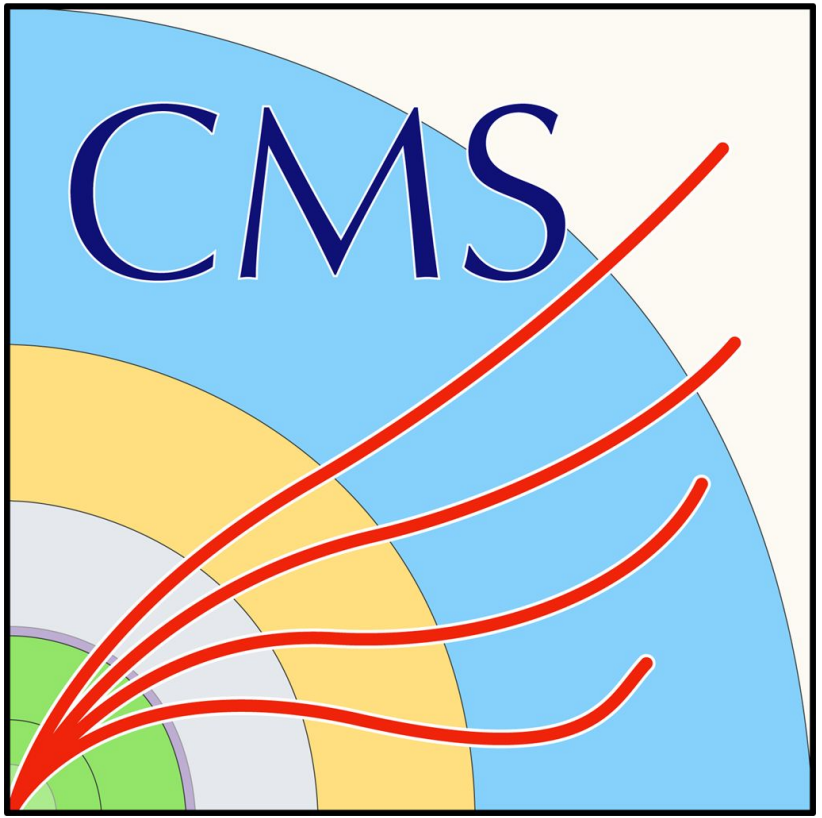
- Servizio progettazione ed officina Elettronica
  - PCB per SiPM forniti da FBK
  - **0.5 m. u.**

**Richieste in CSN1**

- Missioni: 64k
- Metabolismo: 10k
- CAEN DT5204 7k

# CMS

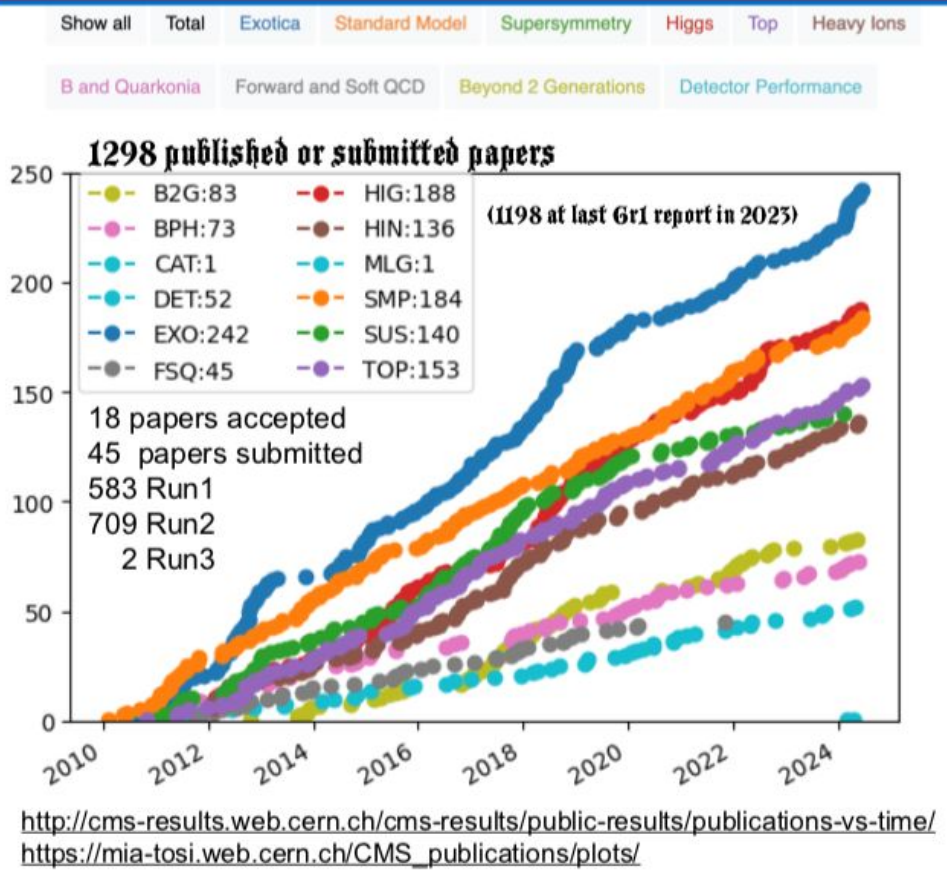
## RL: M.Margoni



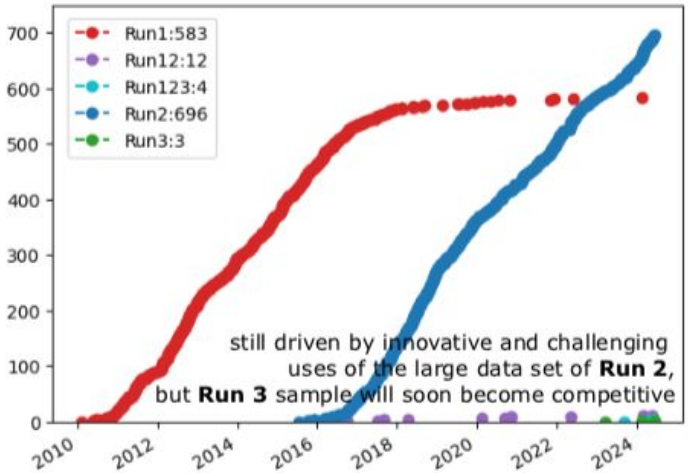
# Sommario

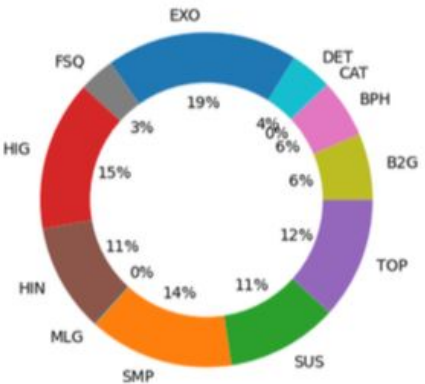
- Highlights da CMS
- Fisica padovana in CMS
  - Analisi & Preparazione Run3
  - Outreach
  - Detector
- Anagrafica 2024 → 2025
- Responsabilità
- Richieste 2025

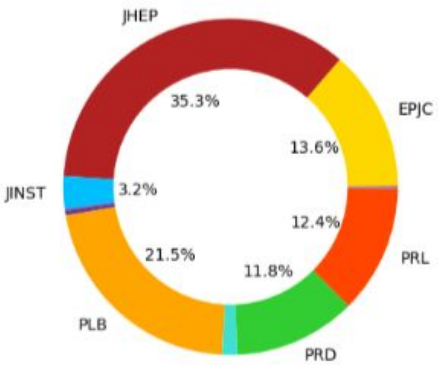
# CMS e` arrivato a ~1300 pubblicazioni con dati LHC




http://cms-results.web.cern.ch/cms-results/public-results/publications-vs-time/
https://mia-tosi.web.cern.ch/CMS_publications/plots/



# CMS e` arrivato a ~1300 pubblicazioni con dati LHC

among the 7 review papers, one is dedicated to prof. Higgs

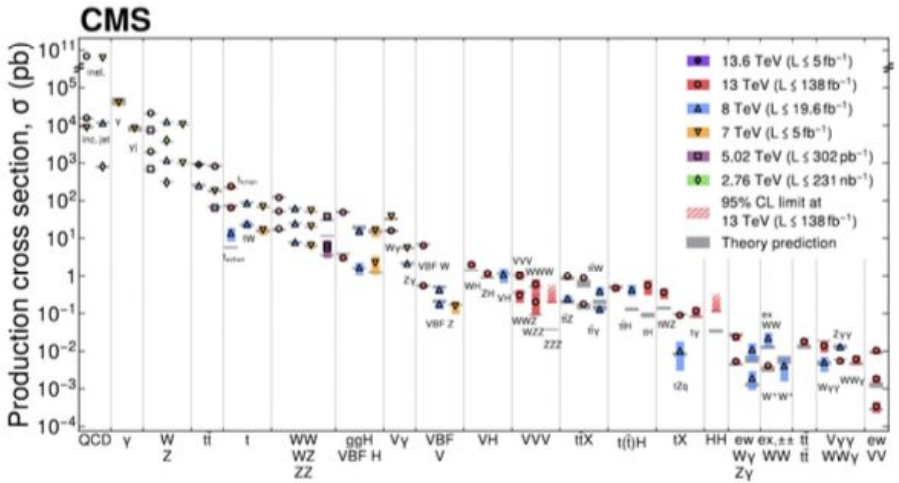



Figure 1: Cross sections of selected high-energy processes measured by the CMS experiment. Measurements performed at different LHC pp collision energies are marked by unique symbols and the coloured bands indicate the combined statistical and systematic uncertainty of the measurement. Grey bands indicate the uncertainty of the corresponding SM theory predictions. Shaded hashed bars indicate the excluded cross section region for a production process with the measured 95% CL upper limit on the process indicated by the solid line of the same colour.

http://cms-results.web.cern.ch/cms-results/public-results/publications-vs-time/
https://mia-tosi.web.cern.ch/CMS_publications/plots/

Stairway to discovery: a report on the CMS programme of cross section measurements from millibarns to femtobarns

The CMS Collaboration*

**Abstract**

The Large Hadron Collider at CERN, delivering proton-proton collisions at much higher energies and far higher luminosities than previous machines, has enabled a comprehensive programme of measurements of the standard model (SM) processes by the CMS experiment. These unprecedented capabilities facilitate precise measurements of the properties of a wide array of processes, the most fundamental being cross sections. The discovery of the Higgs boson and the measurement of its mass became the keystone of the SM. Knowledge of the mass of the Higgs boson allows precision comparisons of the predictions of the SM with the corresponding measurements. These measurements span the range from one of the most copious SM processes, the total inelastic cross section for proton-proton interactions, to the rarest ones, such as Higgs boson pair production. They cover the production of Higgs bosons, top quarks, single and multibosons, and hadronic jets. Associated parameters, such as coupling constants, are also measured. These cross section measurements can be pictured as a descending stairway, on which the lowest steps represent the rarest processes allowed by the SM, some never seen before.

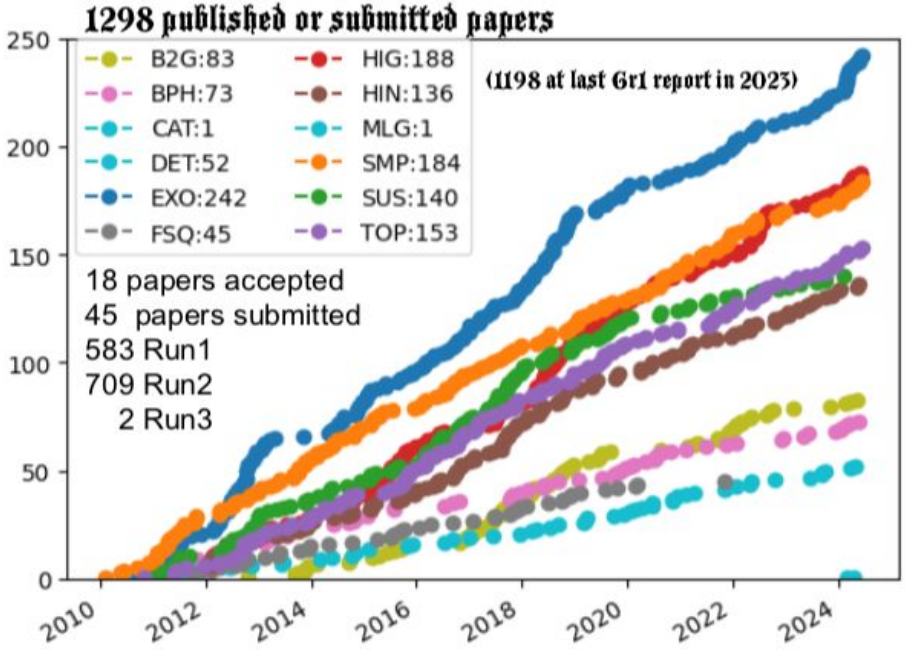
*We dedicate this work to the memory of Prof. Peter Ware Higgs, whose transformative and groundbreaking ideas laid the foundation for the physics of the standard model and of the Higgs particle, which are the subjects of this Report.*

*Submitted to Physics Reports*

# CMS e` arrivato a ~1300 pubblicazioni con dati LHC

Show all | Total | Exotica | Standard Model | Supersymmetry | Higgs | Top | Heavy Ions

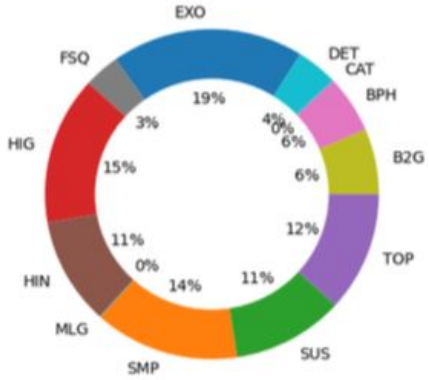
B and Quarkonia | Forward and Soft QCD | Beyond 2 Generations | Detector Performance

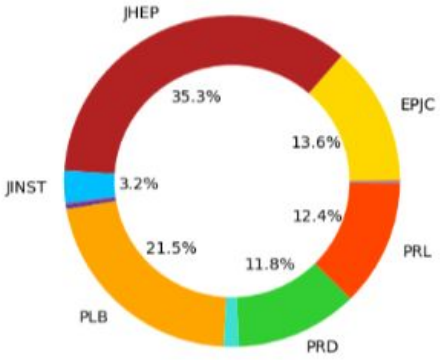



http://cms-results.web.cern.ch/cms-results/public-results/publications-vs-time/
https://mia-tosi.web.cern.ch/CMS_publications/plots/

Padova Group strongly involved in

- B physics
- Standard Model
- Higgs
- Exotic searches




M. Tosi

# CMS highlights

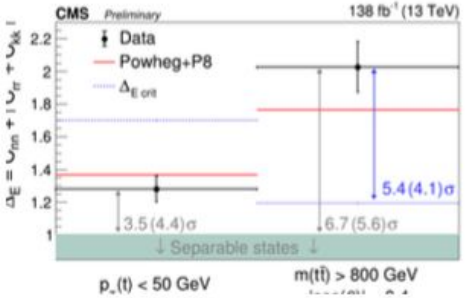
**top physics**:
- observation of tt entanglement w/ l+jets
- measurement of the tt cross section at 13.6 TeV

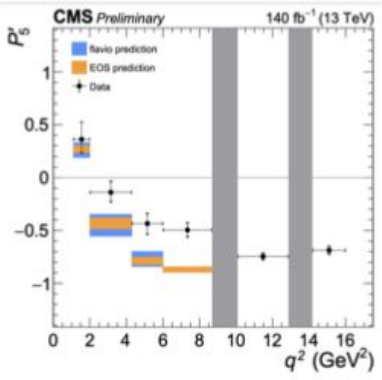
**Higgs physics**:
- combination of H measurements
  and searches for the HH to constrain λHHH
- Higgs boson mass and width measurements

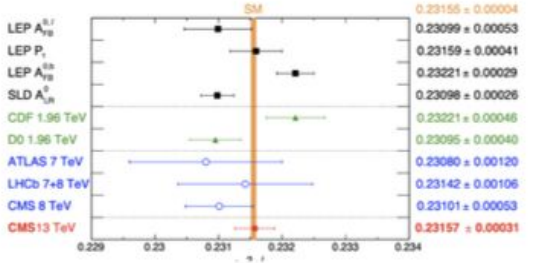
**standard model physics**:
- precision measurement of weak mixing angle
- first observation of γγ → ττ in pp collisions ⇒ limits on τ g-2
- measurement of the Z cross section at 13.6 TeV

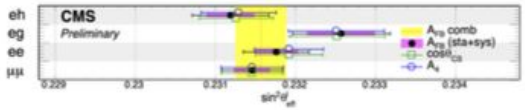
**heavy flavour physics**:
- observation of the J/ψ → μ+μ−μ+μ− decay
- measurement of CPV in the interference between mixing and decay of Bs→J/ψ ϕ
- measurement of the complete set of CP averaged variables B0→K*0μ+μ−
- search for CP violation in D0→KSKS decays
- R(K)/R(J/ψ): lepton flavour universality violation tests

**search for new physics**:
- search for LLP w/ Run3 data [improved sensitivity w.r.t. Run2 (~4x int. luminosity)]
- search for HNLs



# Fisica padovana in CMS: Analisi

Stefano Lacaprara, INFN Padova

# Summary Analisi @ Padova

- Misura sezione d'urto di produzione del processo Vector Boson Scattering ZVjj semi-leptonic, e studio della sensibilità EFT di dim-8 operators nella combinazione VBS WV+ZV semileptonici. (P. Azzi)
- Contributo alla combinazione di tutti canali VBS per lo studio della sensibilità EFT, con lo studio del fondo di produzione ZZ in ssWW. (P. Azzi)
- Contributo all'articolo di Review EXO-23-006 "Review of searches for vector-like quarks, vector-like leptons, and heavy neutral leptons in proton-proton collisions at $\sqrt{s}$ = 13 TeV at the CMS experiment" con l'analisi HNL pubblicata in 2022. (P. Azzi)

- Misura della violazione della simmetria CP nel canale $B_s \rightarrow J/\psi\Phi$. Grazie a un tagging di flavor innovativo e a un nuovo trigger di muone singolo, la precisione e` paragonabile a quella di LHCb.
- (A. Bragagnolo, E. Lusiani, M. Margoni, P. Ronchese, F. Simonetto)

- Ricerca di decadimenti rari Z, H → J/ψγ. (R. Ardino, U. Gasparini, A. Zucchetta)

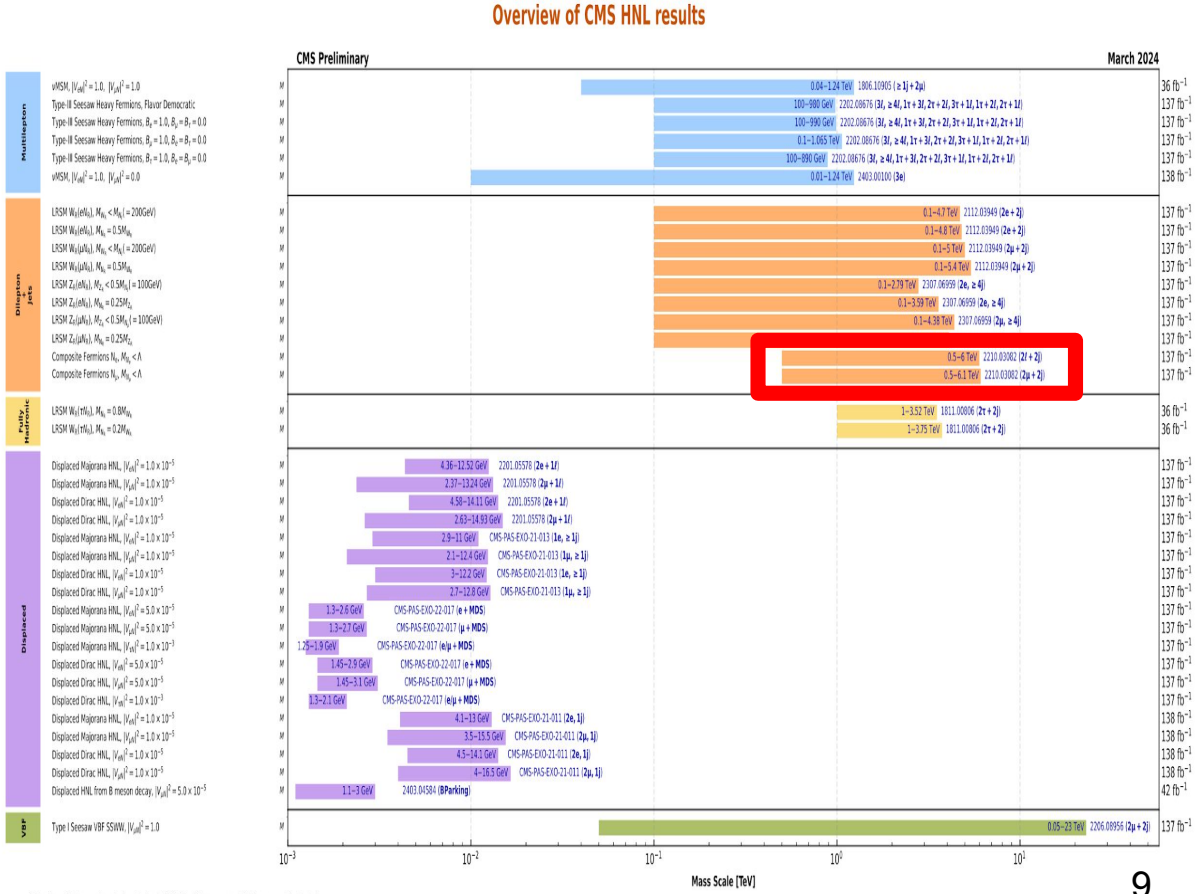
- Studio di produzione di tWZ (U. Gasparini)

- Ricerca del decadimento H → μμ (A. Bulla, P. Bortignon, M. Tosi)
- Studio di Vector Boson Fusion con W → νl (A. Bulla, P. Bortignon, M. Tosi)

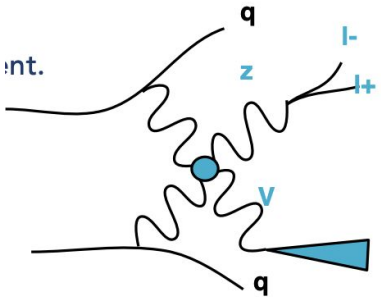
# EXO Review paper

**EXO-23-006 "Review of searches for vector-like quarks, vector-like leptons, and heavy neutral leptons in proton-proton collisions at $\sqrt{s}$=13 TeV at the CMS experiment"**

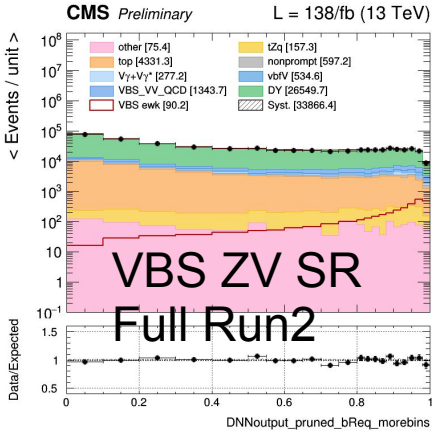
- Paper accepted by Physics Report in 2024 and contains the review of run2 results from VLQ, VLL and HNL searches at CMS with some global considerations and combinations.
- Contributed with the description of the HNL analysis for Heavy Majorana Neutrinos published in PLB (PLB-D-22-01412)



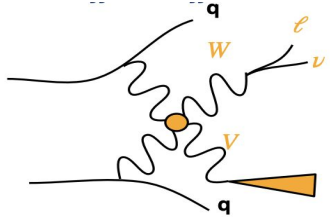
# SMP VBS - VBS ZVjj + EFT Interpretation

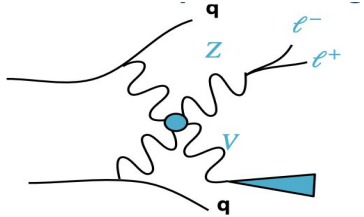



**EWK ZV VBS** sensitivity **never measured before.**

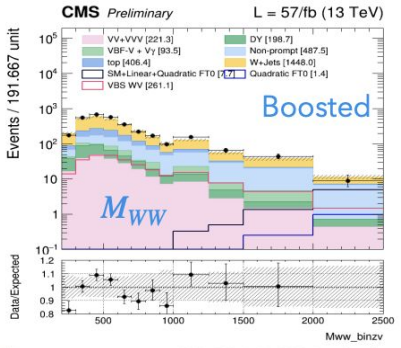


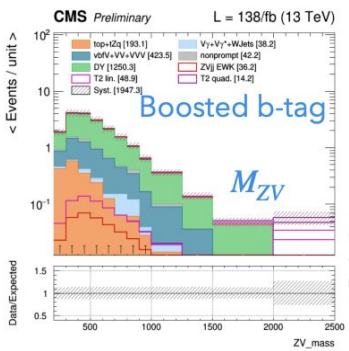

- **VBS ZV analysis SMP-22-011** (**P. Azzi(PD)**, Presilla(KIT)+FNAL)
  - Analysis unblinded, under ARC review. Very good agreement data/predictions:
  - **Sensitivity sigma(EWK)=1.24 obs (1.75 exp).**
  - **EFT combination with WVjj channel for dim-8 EFT** ongoing, last step for completing the analysis. Analysis unblinded under ARC review.

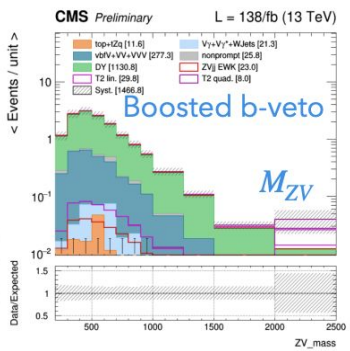



Anomalous QGC

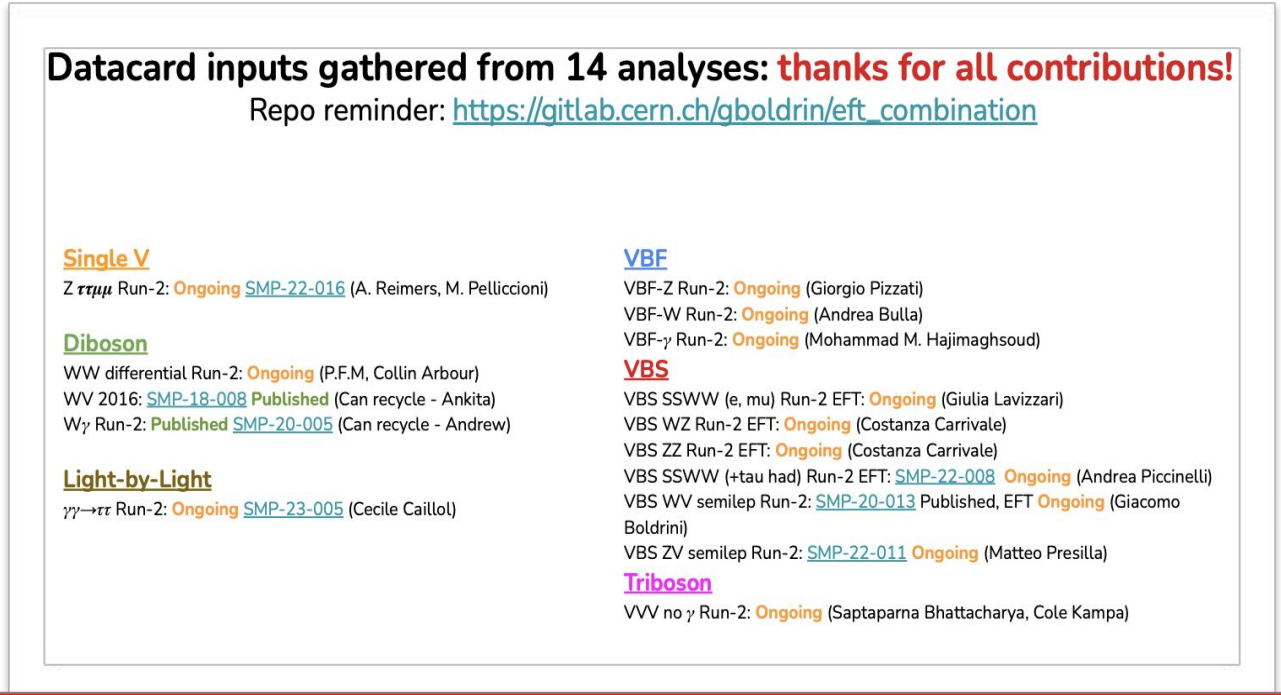


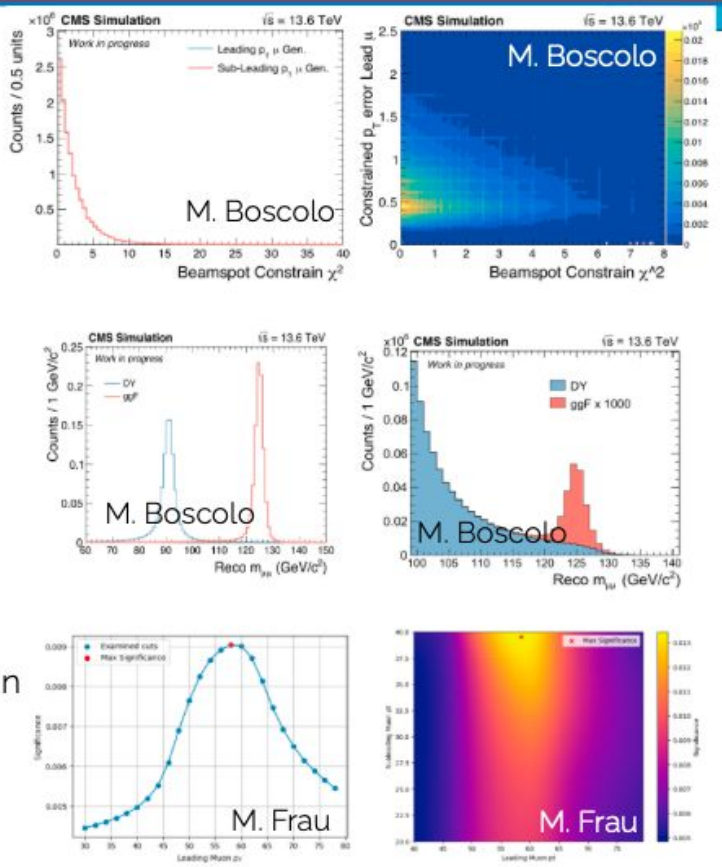
# SMP-PAG EFT Combination within CMS

- Ongoing CMS combination for dim-6 EFT in the EWK sector, involving several Italian contributions and including the ZVjj semileptonic analysis as one of the inputs. (**P. Azzi** collaborating with M. Presilla(KIT), C. Carrivale(PG), D.Ceballos(Lyon))



# Higgs to Muons

- VH, **Hcc** published - *Phys. Rev. Lett. 131 (2023) 041801*
- H To **Muons** - Run3
  - MC availability and coordination with other groups involved
  - Run3 MC validation of signals (ggF, VBF) and main backgrounds (DYJets, ttbar) using NanoAOD
    ( Bachelor thesis - M. Boscolo - 11/4/2024 - UniPd )
  - Validation and Study of the impact on the Higgs peak resolution of the muon refitting with beamspot
    ( Bachelor thesis - M. Boscolo - 11/4/2024 - UniPd )
  - Cut and count optimisation of the significance for GGF signal using Run3 MC
    ( Bachelor thesis M. Frau - 26/7/2024 - UniCa )
  - Muon FSR corrections studies and their impact of the resolution and sensitivity of the analysis
    ( Master thesis - UniPd )



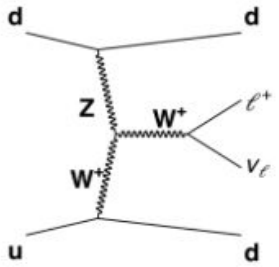
# VBF W Run2

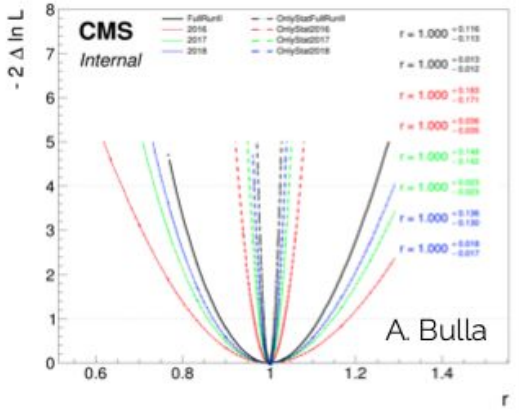
Motivation:

- Test of the SM gauge sector, **complementary** to Higgs boson measurements
- Sensitive to new (BSM) physics: a**TGC, EFT**

Signature:

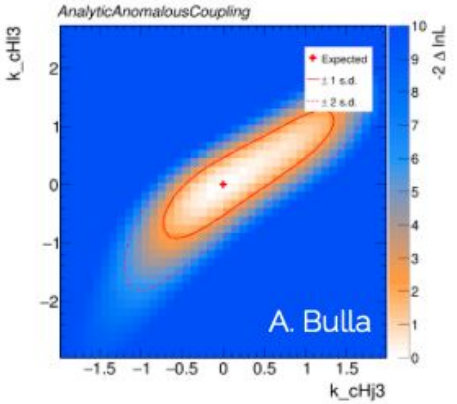
- 2 highly energetic jets ("tagging" jets) :
  - Large gap in η (**|Δηjj|**)
  - high jet invariant mass (**mjj** )
- 1 charged lepton and neutrino pTmiss
  - Central with respect to the VBF jets



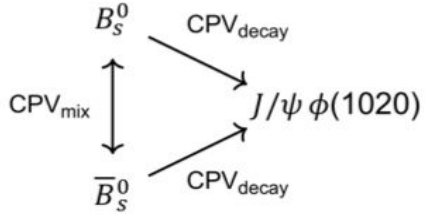

Signal Extraction:

- **Control regions** used to constrain the normalizations of the main backgrounds. **Signal region** used to perform the fit.
- Combined binned maximum likelihood fit of the **DNN output** distribution with signal and background templates
- DNN trained with **10** physical variables and 3 hidden-layer with 64 neurons each
- Expected 10% precision on cross-section measurement for both channels (only with 2018 data)
- Results include **unfolding** and **EFT** interpretation

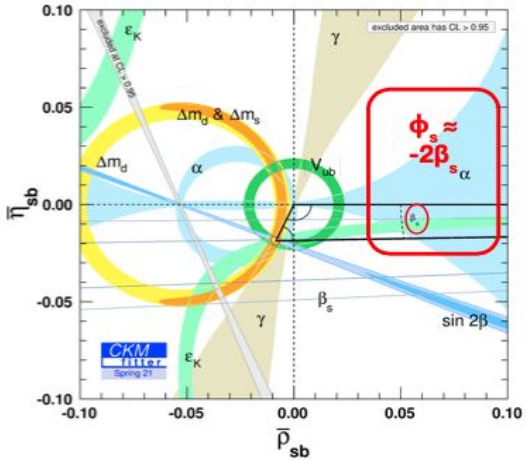


# Precision measurement of CP-violation in $B_s \rightarrow J/\psi\phi(1020)$

- Precise characterization of the $B_s$ meson system with a **time-** and **flavour**-dependent **angular** analysis of the final state
- Several physics parameters extracted with a single measurement
  - $\boldsymbol{\phi_s}$: CPV in the decay/mixing interference
  - $\boldsymbol{|\lambda|}$: CPV in the decay
  - $\boldsymbol{\Gamma_s}$: average decay width
  - $\boldsymbol{\Delta\Gamma_s}$: decay width difference between eigenstates
  - $\boldsymbol{\Delta m_s}$: mass difference between eigenstates
  - 6 polarization parameters
- Comprehensive test of the physics of CPV and flavour mixing, with room for **New Physics**
- Flagship CMS flavour physics analysis
- Heavily statistically limited
  - Long-term commitment (LHC Run-3, HL-LHC)




$$\Gamma\left(B_{s\,(\rightsquigarrow \overline{B}_s^0)}^0 \rightarrow f\right)(t) \stackrel{?}{\neq} \Gamma\left(\overline{B}_{s\,(\rightsquigarrow B_s^0)}^0 \rightarrow f\right)(t)$$

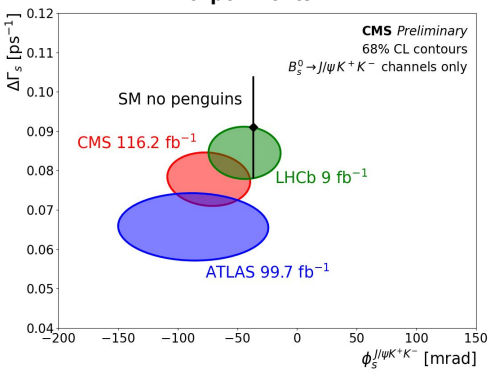



A. Bragagnolo, E. Lusiani, M. Margoni, P. Ronchese, F. Simonetto

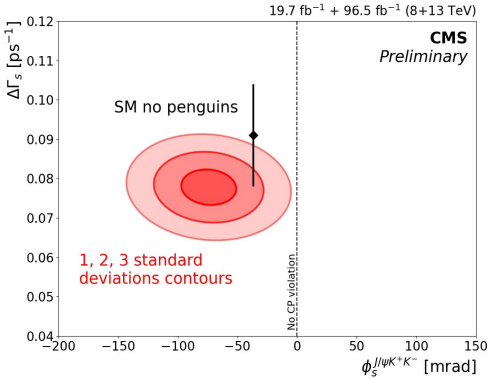
# CPV in $B_s$ ➜ J/ψ ϕ(1020): status and outlook

- The Padova group led the analysis team
- Developed an innovative flavour-tagging framework that enhances performance by 300%
- The analysis was presented for the first time at the Moriond conference:
  - Factor ~2 improvement wrt the previous CMS result
  - Precision is **close to best single measurement** for **ϕs**
  - **Best single measurement** for **ΔΓs**
  - **First evidence** of CPV in the **Bs ➜ J/ψ K+K-** decay
- Close to entering the last stage of CMS internal review before being sent to the journal
  - Aiming for PRL

**Comparison with other LHC experiments**

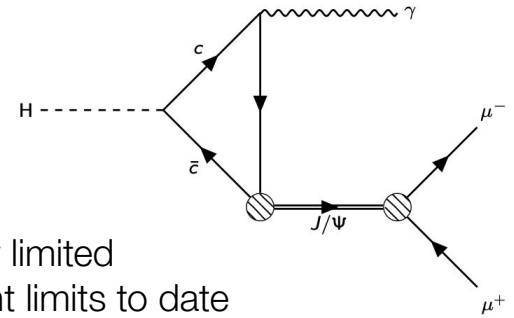


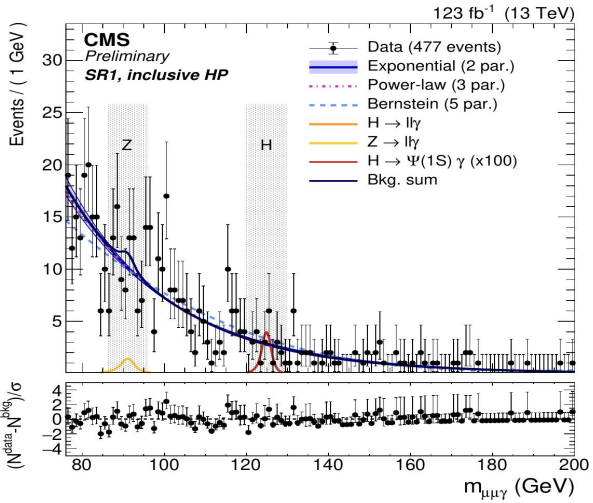

**1, 2, 3 standard deviations contours**



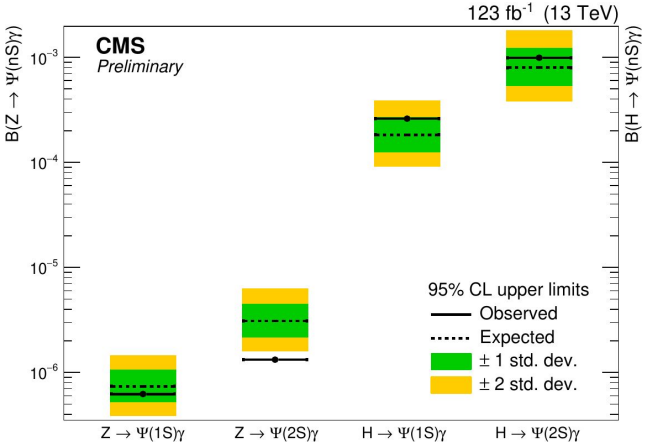
# Rare SM Higgs and Z decays

- The **Higgs** and **Z** bosons are expected to decay to a J/$\Psi$ meson and a photon, also through the *Higgs coupling to the c quark*
- Never observed before, because branching ratios are small:
  - B(Z→J/$\Psi$ $\gamma$) = 9 x $10^{-8}$
  - B(H→J/$\Psi$ $\gamma$) = 3 x $10^{-6}$
- With the J/$\Psi$ decaying to $\mu\mu$, the final state is clean and the backgrounds are very limited
- CMS analysis completed and approved in 2024 [1, 2], providing the most stringent limits to date




- Close to observe the decay of the Z→J/$\Psi$ $\gamma$: upper limit at 7.2 times the SM
- Higgs boson excluded up to 88 times the SM: this is a possible target for HL-LHC
- Able to constrain the Higgs-charm quark coupling: in the k-coupling modifier framework,
  -157 < kc/k$\gamma$ < 199 at 95% CL



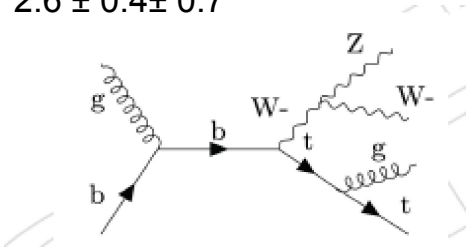

- Check out the official CMS Physics Briefing

R. Ardino, U. Gasparini, A. Zucchetta

# tWZ Production study

CMS recently published the result of an inclusive analysis (based on multi isolated leptons + b-jets topologies; arXiv:2312.11668 , subm. to Phys.Lett.B) showing evidence of the production of single top in the tWZ channel, with a μ strength substantially larger than the SM prediction:

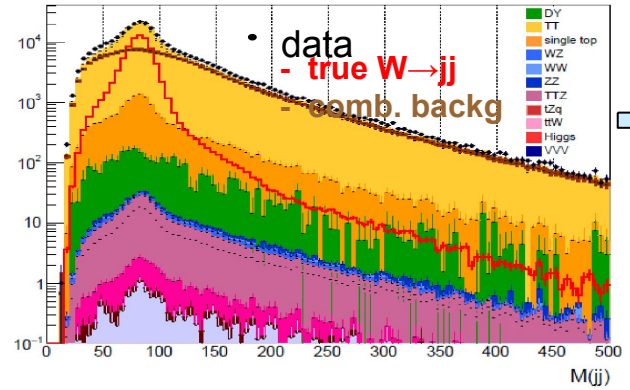
μ= 2.6 ± 0.4± 0.7

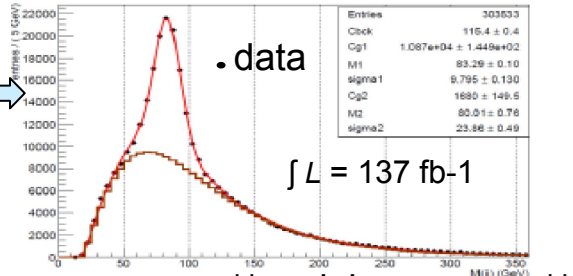



This may suggest possible BSM interpretations involving non standard values of (some)Wilson coefficients for operators relevant to this production process

A complementary approach based on **exclusive reconstruction** of *W→jj* decays accompaining b-jets , Z→*ll* and W→*lν* decays is going to be developed to better characterize the event topology

## *W→jj* reconstruction in *tt* **single-lepton control region**:

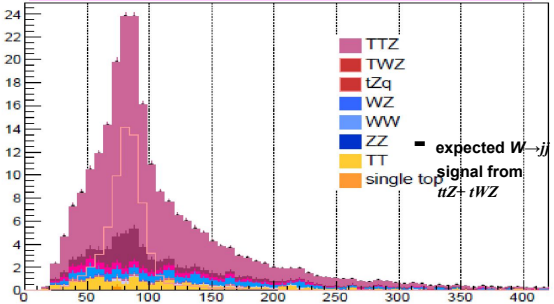



**work in progress **

U. Gasparini

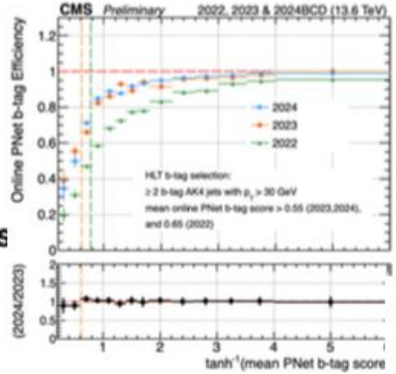
## *W→jj* reconstruction in *tWZ+ttZ* **3-leptons + b-jets signal region** (MC data):



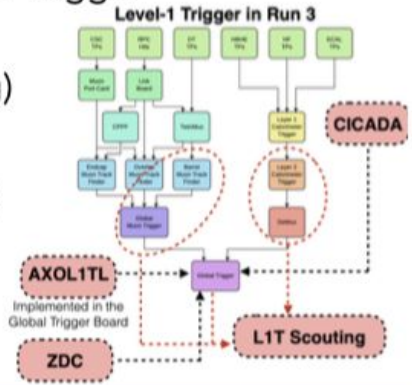
# Run 3 trigger strategy

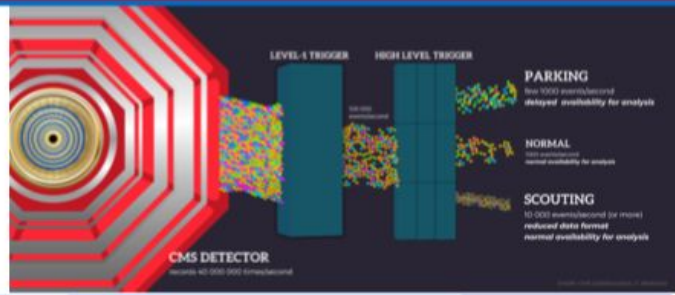
**Run3**

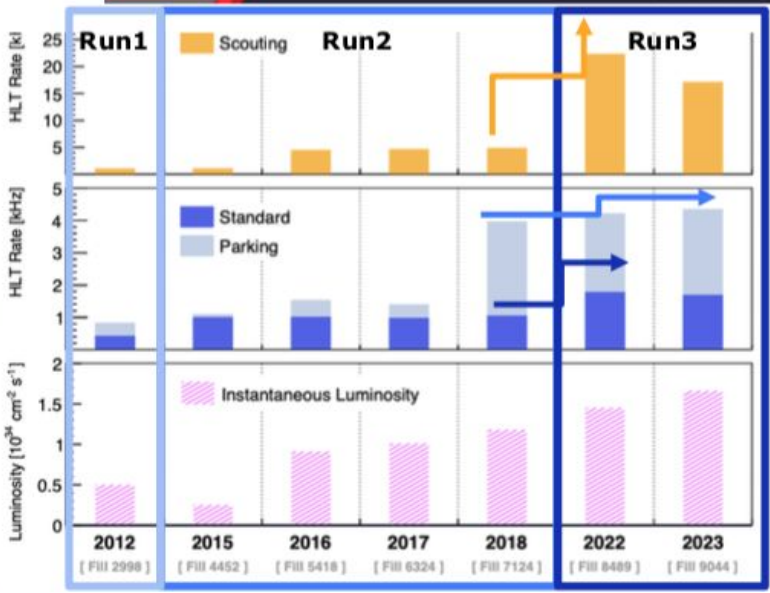
- new c.o.m energy 13.6 TeV
  ⇒ cross section measurements
- opportunity to do something new
  → new ideas for **searches for new physics**
  → new approaches for **shrinking uncertainties**
  → **new measurements**




wide CMS physics program
→ exploit the CMS resources adjusting the trigger
→ improve the trigger efficiency
(PNet for flavour jet and tau tagging)
→ add new trigger strategies
(LLP, VBF, hh, di-muon, single muon)
→ push the purity of collected events
(low pT single muon)
→ new anomaly detection algos at L1



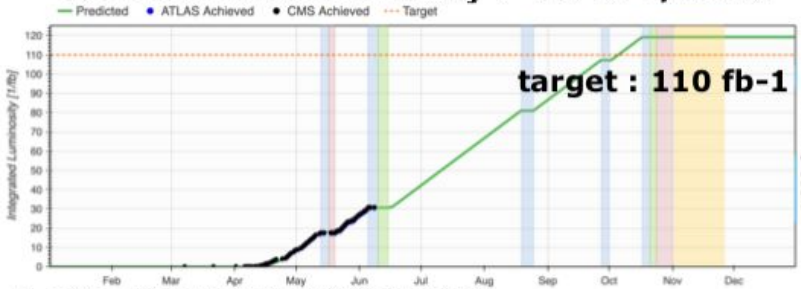



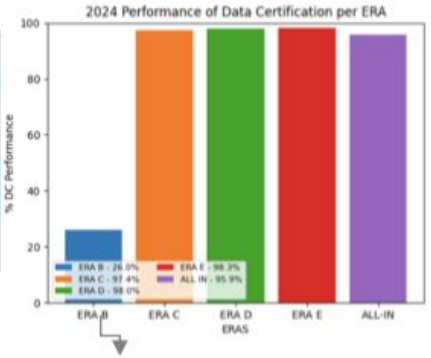

M. Tosi

# CMS status –so far

LHC is working fine [few optimizations still to be performed]

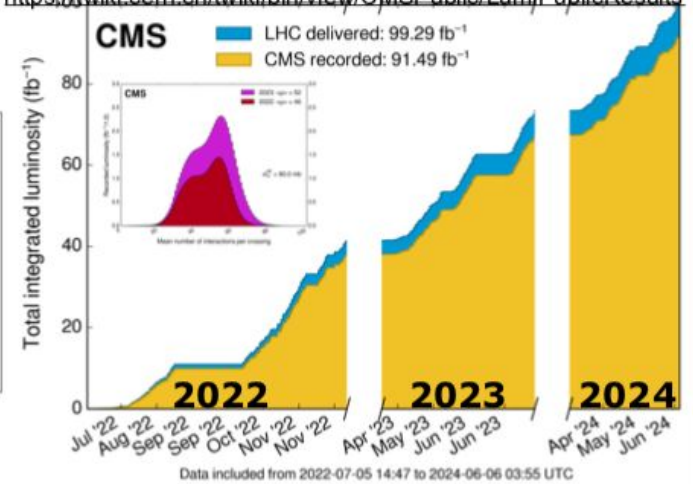
→ LHC delivered luminosity : ~30 fb-1, so far




LHC luminosity ramp up data largely used to synchronize and calibrate different subsystems

https://twiki.cern.ch/twiki/bin/view/CMSPublic/LumiPublicResults



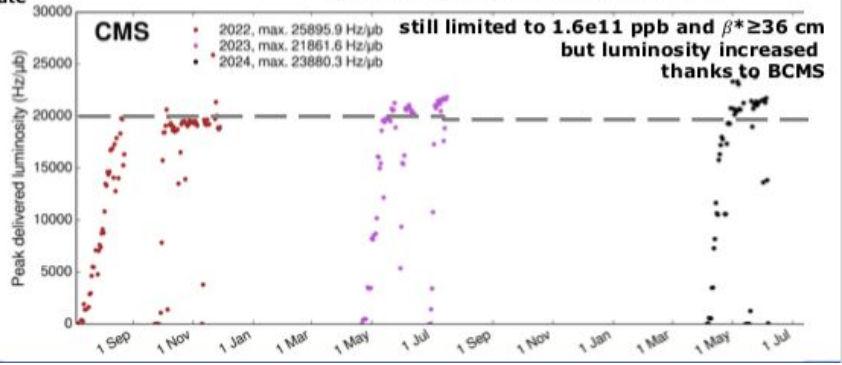

CMS is running smoothly

→ L1 trigger rate (pre-deadtime) :

~115 kHz during lumi-leveling (PU~63)

→ collected 93% of the delivered luminosity

→ good data quality >98%



# Outreach

## HEPscape! https://web.infn.it/hepscape/

**the first High Energy Physics escape room**

→ synergy between DFA and INFN-Sezione di Padova

→ CC3M n 2024 (w/ Rome and Perugia)

NB:

- the performance at Science4All 2023
  involved people from other experiments as well ;)
  [thanks to Alessandro Gaz, Andrea Rossi, Lorenzo Sestini, Anna Lupato]

→ Science4All 2023
(Padova): 75 + 100 visitatori

**sinergy w/ DFA and other Gr1 groups**

→ La Thuille 2024
(Verres, AO): 200 visitatori

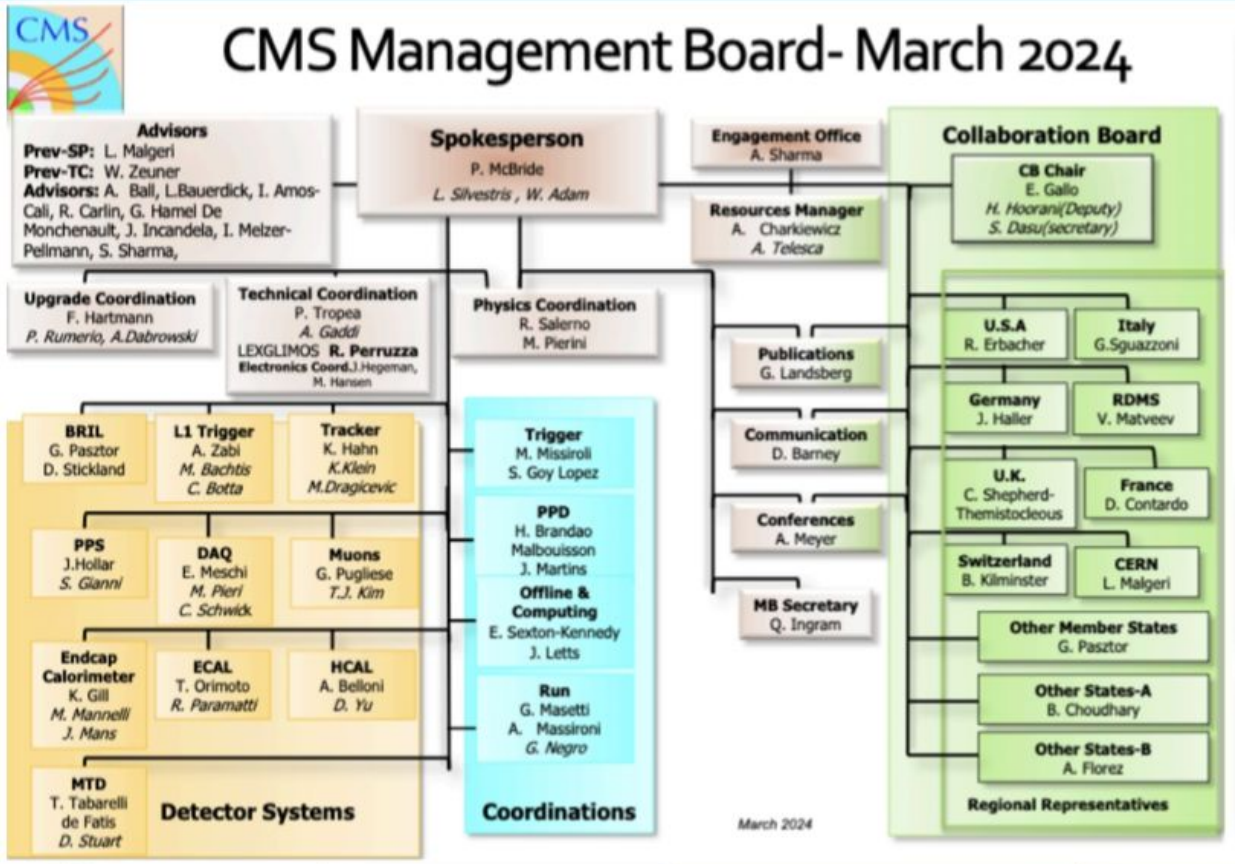
**invited and synergy w/ Rome1**

→ Science4All 2024
(Padova)

→ Festival della Scienza dell'Alto Vicentino 2024
(Schio, VI)



# CMS Management Board- March 2024




## Incoming Spokesperson Team

**To start 1 September 2024**

**Gautier Hamel de Monchenault (SP)**

**Anadi Canepa - FNAL (DSP)**

**Hafeez Hoorani - NCP (DSP)**

**DSPs to be approved by CB**

Mia Tosi
(UNIPD/INFN-PD)
**Trigger co-coordinator**
Sep-2024 to Aug-26

# LHC schedule


https://edms.cern.ch/ui/file/2872429/2.0/2024-LHC-V2.0.pdf

**Four weeks of pp moved from 2025 to 2024**

- End of 2024 pp run will be on Oct 17th, 2024
- Pb-Pb ion run to start on Nov 5th
- ppref setup starts on Oct 24th

**Start of 2024-2025 YETS moved from Oct 28th to Nov 25th.**

- The new schedule preserves the length of the 2024-2025 YETS — as requested.

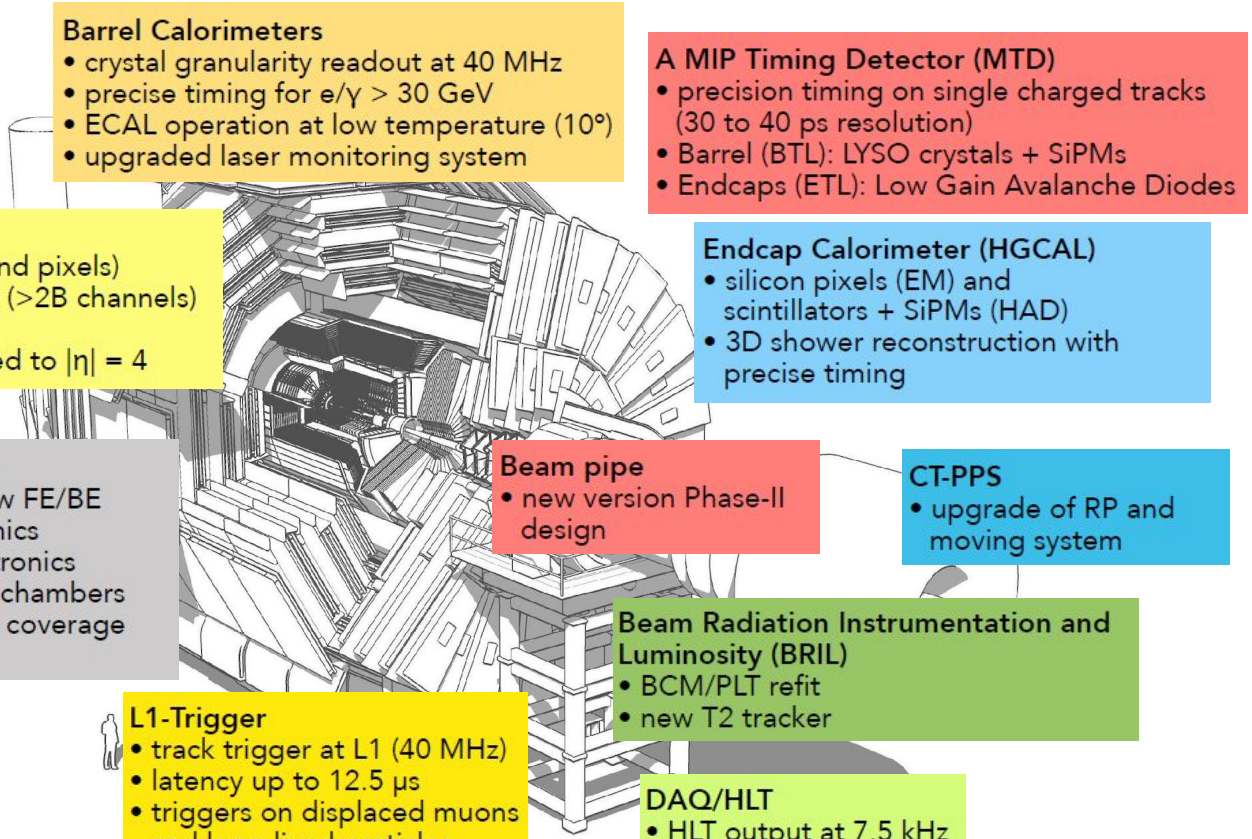
**Exact 2025 schedule is still under discussion.**

- Current LHC plan is to start LS3 on 17 Nov 2025

# Fisica padovana in CMS: Rivelatore

Stefano Lacaprara, INFN Padova

# Run3 e preparazione a HL-LHC




- Molti lavori di manutenzione e improvements sono stati eseguiti con contributo padovano nei DT e nei Pixels

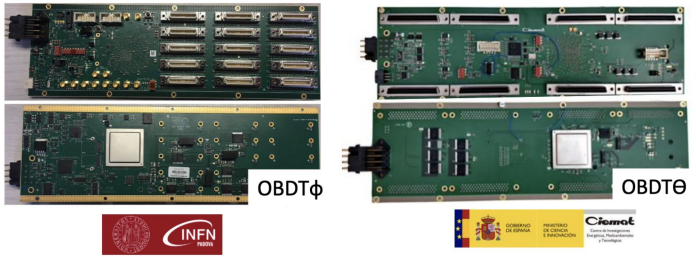
# Summary Detector @ Padova

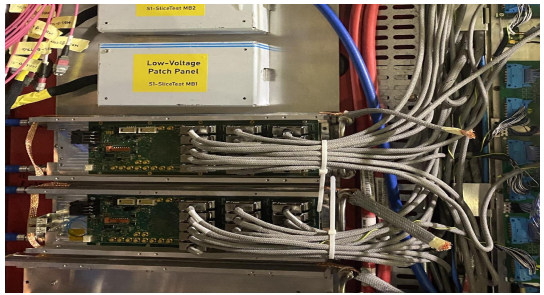
- DT Phase 2 (M. Bellato, A. Bergnoli, F. Gonella, A. Triossi, S. Ventura)
- 40 Mhz L1-Scouting (R. Ardino, L. Borella, S. Giorgetti, N. Lai, M. Migliorini, J. Pazzini, A. Triossi, M. Zanetti)
- Neuromorphic Computing (T. Dorigo, M. Tosi)
- Phase 2 Tracker Upgrade: MaPSA Testing (N. Bacchetta, E. Lusiani, D. Pantano, R. Raffagnato, P. Azzi, M. Tosi)
- Barrel Timing Layer (A. Benato, M. Benettoni, E. Borsato, R. Carlin, M. Giorato, R. Isocrate, D. Mazzaro, R. Rossin, L. Silvestrin, M. Tosi, M. Turcato, S. Ventura, F. Veronese)

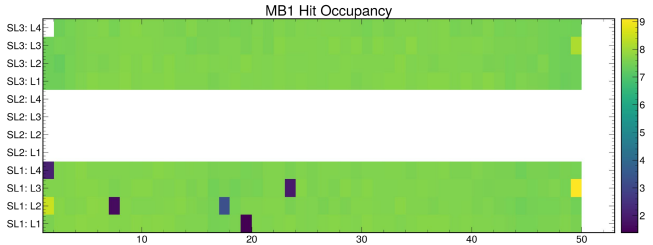
# DT Phase 2: Demonstrators

## New Slice Test in Sector 1

- The demonstrator is extended to test the final version of OBDT, the DSS system (MONSA) and the new Timing/Slow Control backend boards, with new installations in Sector 1
- Both the mechanics (cables, low voltage distribution boxes, board supports, fibers, DSS cables, cooling) and the new boards (2 OBDT Theta and 6 OBDT Phi, of which one in the final version) were installed.
- The system was finalised Feb, 10th.
    - The legacy system was re-tested and no problems were observed.
    - The commissioning of the new electronics just started, a first look to occupancy and noise show excellent status



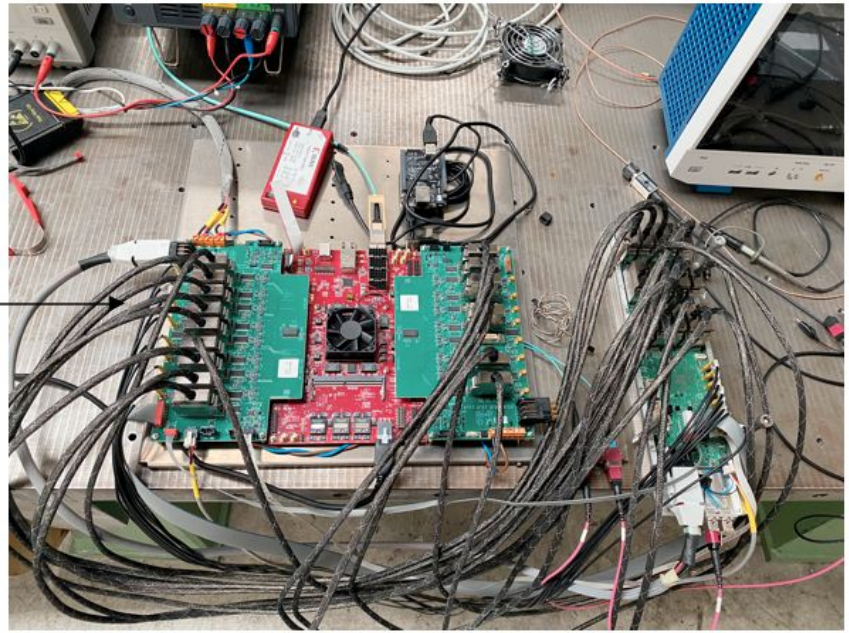




M.Bellato, A. Bergnoli, F. Gonella, A. Triossi, S. Ventura

Stefano Lacaprara, INFN Padova

# DT Phase 2

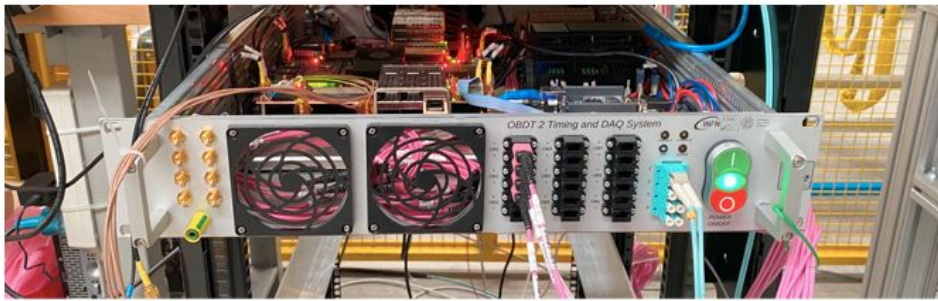
- OBDT Pronta per la produzione
  - test finale di immunità alla radiazione in Luglio 2023 **DONE w/splitter board**
  - gare **Assegnate** per PCB, assemblaggio, componenti, cavi
  - produzione di 900 unita' a partire da ultimo quarto 2024
  - qualifica di 900 schede OBDT a Legnaro 2024 - 2025
  - sistema di test **Pronto**
- Sistema di timing & slow control
  - prototipo funzionante su hardware commerciale
  - hardware per la produzione : **Serenity S-1**
- Sviluppo firmware: 2 tecnologi coinvolti, 1.5 FTE



M.Bellato, A. Bergnoli, F. Gonella, A. Triossi, S. Ventura

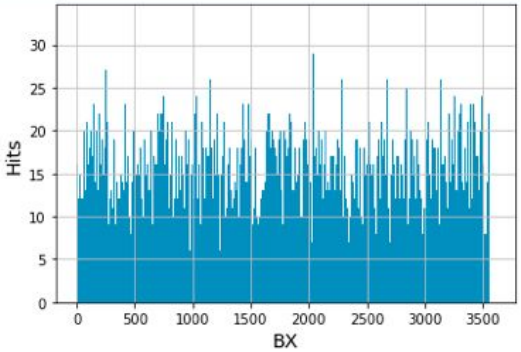
# DT Phase 2

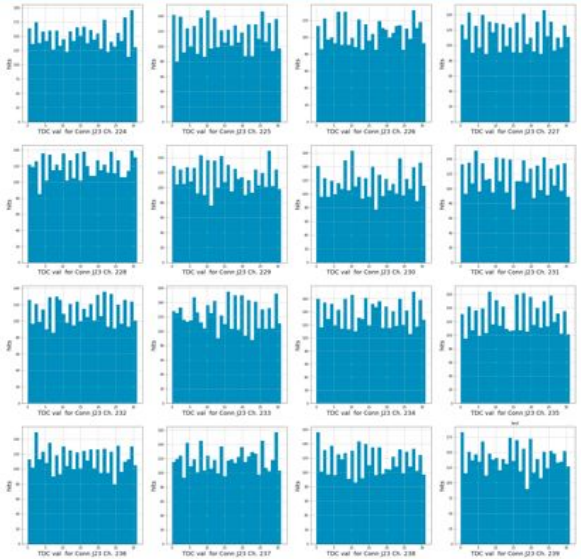
- Produzione minicrate:
  - Padova deve allestire e qualificare 60 minicrate tipo MB3
  - Sito di produzione pronto a LNL
- Padova fornisce il sistema di test dei minicrate a tutta la collaborazione DT
- Padova fornisce il Mockup di qualifica pre-installazione dei minicrate al CERN
- Padova fornisce il sistema di qualifica post installazione a tutta la collaborazione: realizzate due Rack-unit denominate OBDT2 Timing and DAQ (Torino, LNL) e supportata la collaborazione per la preparazione di unità analoghe (Madrid, AAchen, Bologna, CERN-P5)




M.Bellato, A. Bergnoli, F. Gonella, A. Triossi, S. Ventura

# DT Phase 2



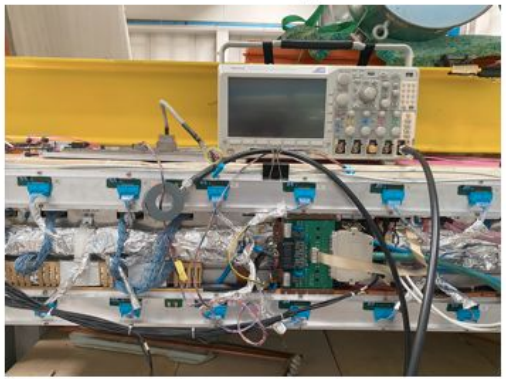
- minicrate fase 2 MB3 (3 OBDT Phi, 1 Theta) installato a LNL
- controllo completo di camere e Front End
- run di cosmici e Test Pulses con OBDT2 Timing and DAQ
- inviato al CERN (P5 SXA5 per altri test)

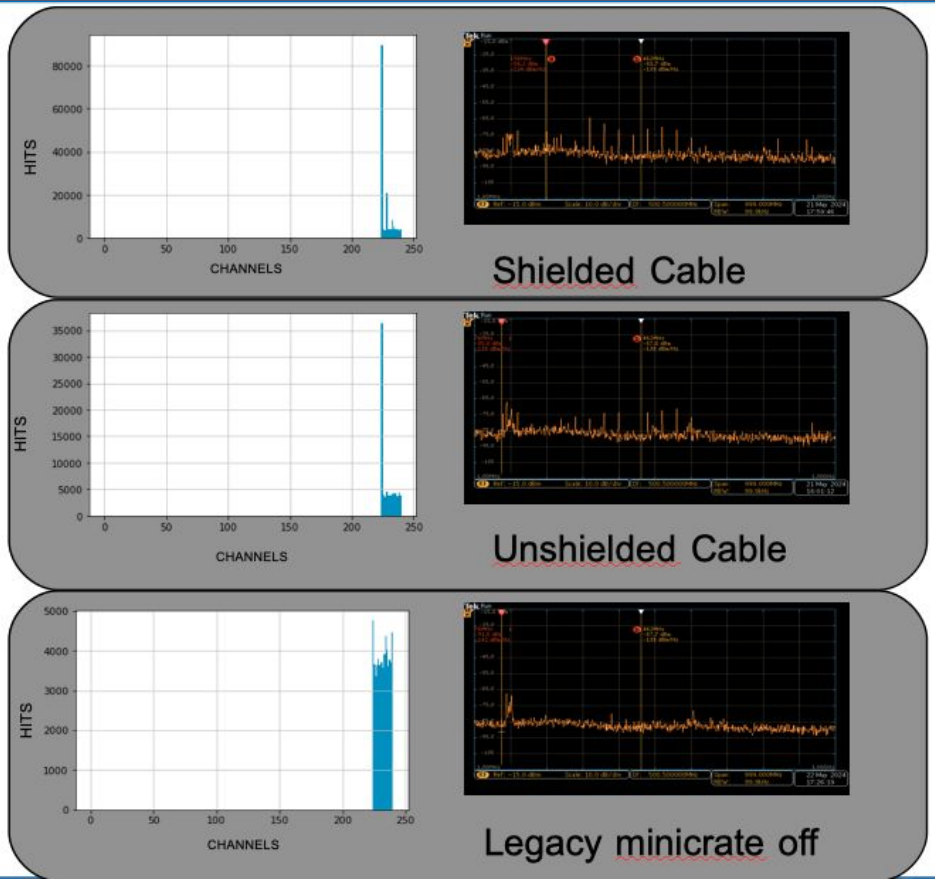
M.Bellato, A. Bergnoli, F. Gonella, A. Triossi, S. Ventura

# DT Phase 2

- Tesi di Laurea di Elham Norouzimehmandoustolia studentessa ICT (rel: Prof. A.Triossi; supervisor: A.Bergnoli)
  *"Field measurements to study the effect of common-mode current noise in wiring for the Phase 2 upgrade of CMS Drift Tubes"*

Studiata la correlazione tra il rumore di modo comune (corrente) presente nei cavi di connessione Front-End <-> OBDT attraverso misure con *Common mode probe* ed analizzatore di spettro confrontate con HITS count



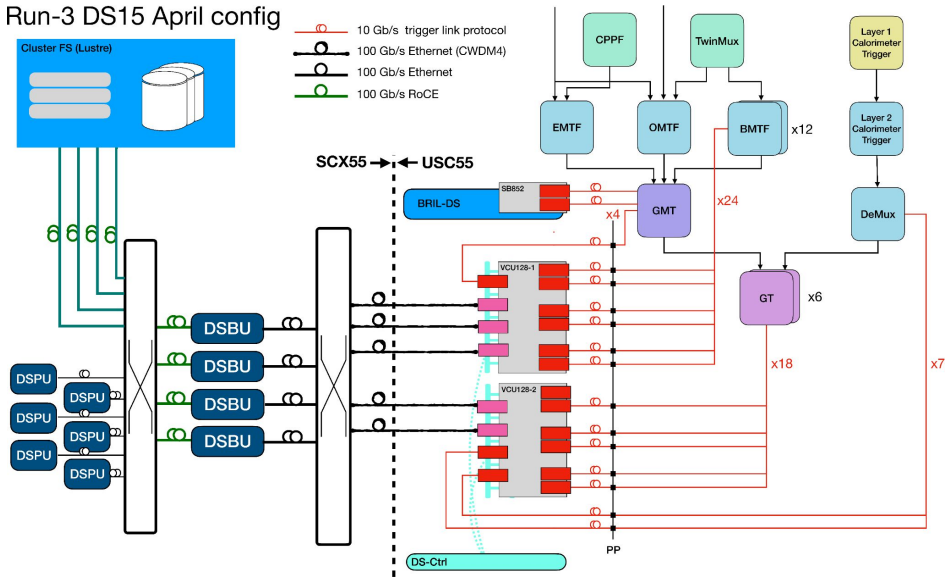



M.Bellato, A. Bergnoli, F. Gonella, A. Triossi, S. Ventura

# 40 Mhz Level-1 Scouting

L1T Scouting demonstrator from 2024

- **Acquisition of L1 trigger primitives at the full BX rate**
  - 8 μ from Global Muon Trigger
  - 12 e/γ, jets, τ and missing ET from Calo
  - Local μ trigger primitives in the CMS barrel
  - BITs from Global Trigger
- **A completely new system is getting ready for the start of LHC 2024 program**
- New scouting board VCU128 with TCP/IP output and more resources available
  - VCU128-1: μGMT and BMTF links
  - VCU128-2: DeMux and μGT output
- Improved DAQ software running on DSBUs
  - Receiving n × TCP streams on DSBUs
  - Performing basic processing

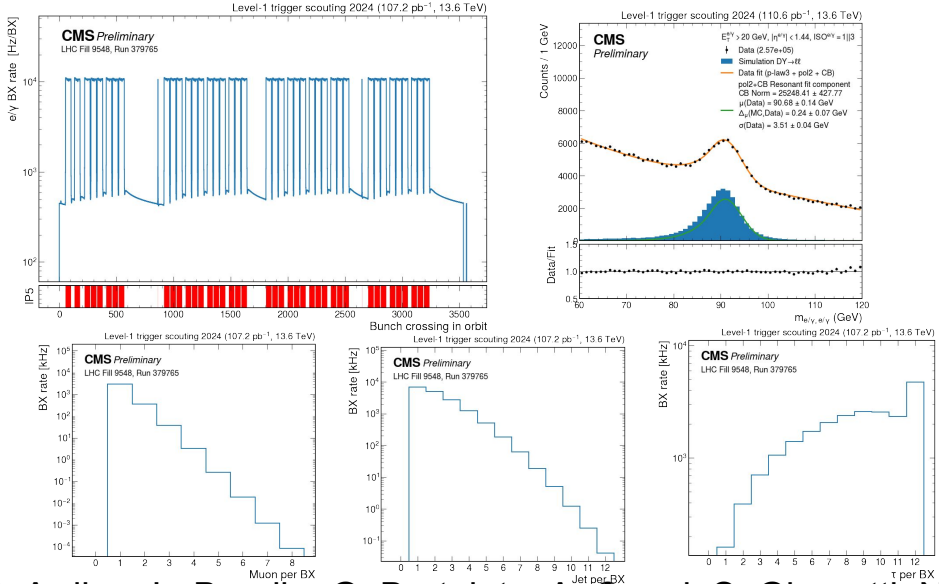


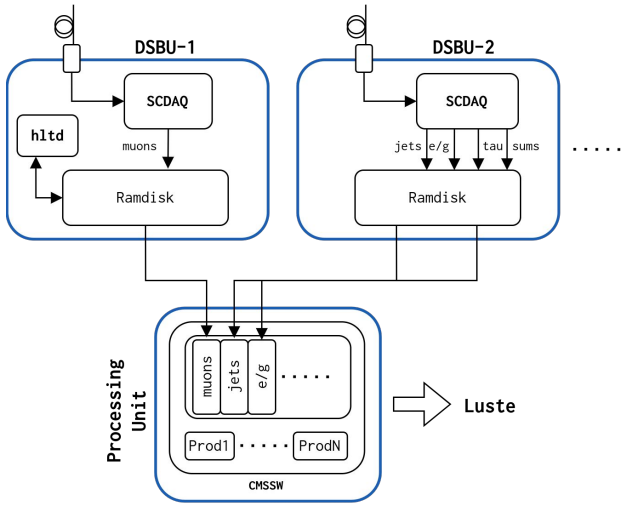

R. Ardino, L. Borella, G. Bortolato, A. Coppi, S. Giorgetti, N. Lai, M. Migliorini, J. Pazzini, A. Triossi, M. Zanetti
Stefano Lacaprara, INFN Padova

# 40 Mhz Level-1 Scouting

L1T Scouting demonstrator from 2024

- **New CMSSW-based online processing**
  - “Orbit builder”: merge data from all scouting streams
  - Core of online selections and analyses
  - ZeroBias and OnlineSelection stream
  - Running on daq3val processing units
  - Link to Tier0 for repacking and redistribution




R. Ardino, L. Borella, G. Bortolato, A. Coppi, S. Giorgetti, N. Lai, M. Migliorini, J. Pazzini, A. Triossi, M. Zanetti
Stefano Lacaprara, INFN Padova

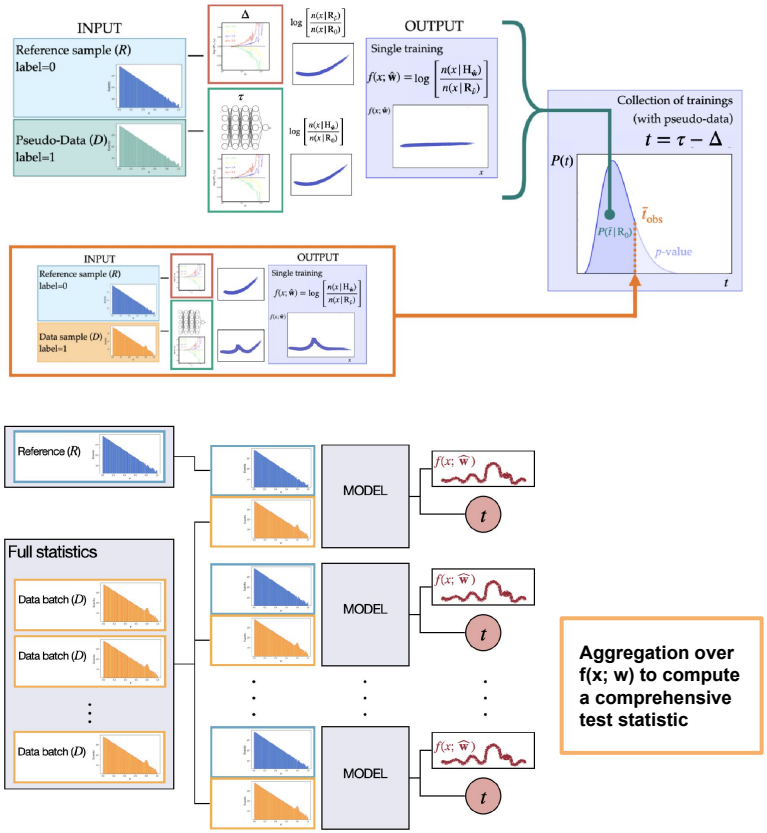
# 40 Mhz Level-1 Scouting

Signal-model-independent search for New Physics in CMS

- **Exploring the di-muon final state in a completely signal-agnostic fashion with the New Physics Learning Machine (NPLM)**
  - Not targeting any specific New Physics signal but rather spotting **anomalies** in the data using machine learning
  - Performs a **likelihood-ratio hypothesis test** where the null is given by MC and the alternative is learned from data

- **Produced an extended version of NPLM that enables processing large datasets in multiple batches via neural network aggregation**
  - Issue with processing full Run 2 luminosity is solved with the **split-aggregation strategy**
  - Procedure validated for systematic uncertainties
  - Studies on signal benchmarks show **no loss in discovery potential** wrt the standard NPLM

- **Ongoing validation of systematic uncertainties with full Run 2 luminosity**



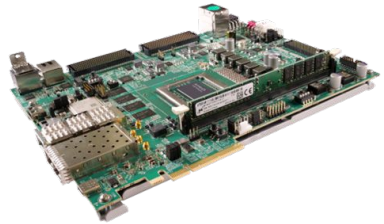

R. Ardino, L. Borella, G. Bortolato, A. Coppi, S. Giorgetti, N. Lai, M. Migliorini, J. Pazzini, A. Triossi, M. Zanetti

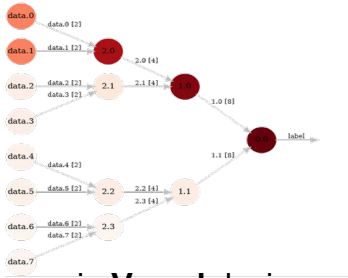
# 40 Mhz Level-1 Scouting

HW activities

## Quantum ML for online classification

- SW training of **Tree Tensor Network** binary classifiers for physics
- Inference deployment on **FPGA** with latency <1us
- Feasibility studies for **NGT**



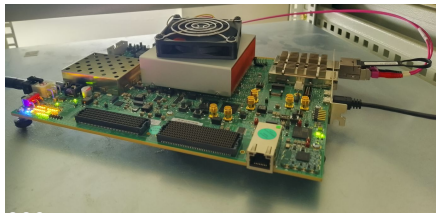


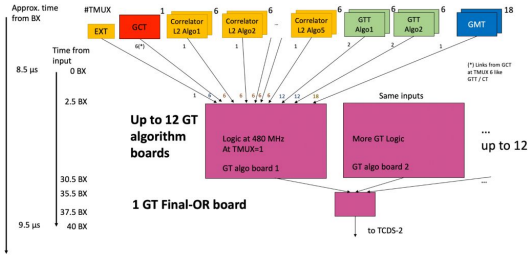

## AI Engine benchmarking

- Performance study of AI Engine processor in **Versal** device
- R&D scouting on Versal technology (pre-processing)

## 40MHz hardware developments

- Firmware development for 40MHz scouting
- New 100Gbps RDMA based link (from FEROCE GrV)
- Next: integration on the 40MHz hardware setup






## Phase-2 Global Trigger

- Firmware development for trigger monitoring and pre-scaling
- ML-based algorithms development and their hardware implementation
- Internal slice tests and with upstream systems

R. Ardino, L. Borella, G. Bortolato, A. Coppi, S. Giorgetti, N. Lai, M. Migliorini, J. Pazzini, A. Triossi, M. Zanetti
Stefano Lacaprara, INFN Padova

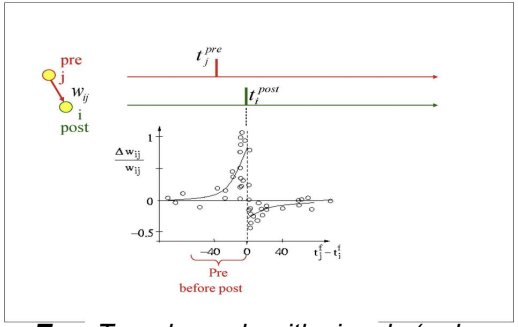
# Neuromophic Computing

**Neuromorphic computing for tracking**
Emanuele Coradin, Fabio Cufino, Muhammad Awais
With T.D., Mia Tosi, and Fredrik Sandin (LTU)

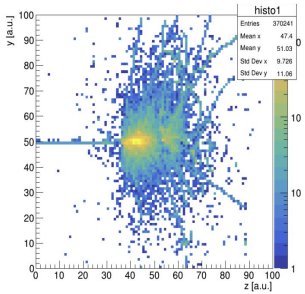
We study the application of unsupervised learning through a Spiking Neural Network (SNN) to the problem of tracking in **CMS Phase 2** silicon detector

The network implements Spike-Time-Dependent plasticity to learn the delays to apply to presynaptic pulses, and distinguish the signal of true charged particle tracks from noise
The SNN parameters require optimization, performed by a genetic algorithm. High tracking efficiency at low background noise has been achieved; we are working to increase the specificity of neuron response to tracks of different momentum

- Potential application to high-luminosity online tracking

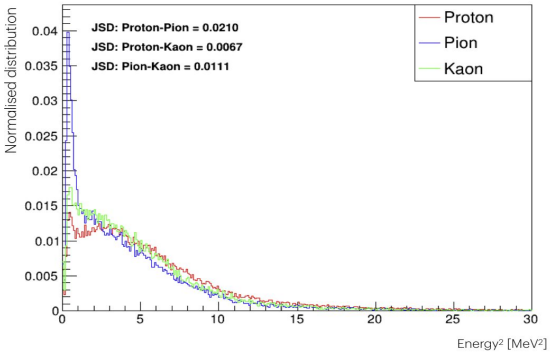



***Top**: Two channels with signals (red, green)
are shown to produce a potentiation or a depotentiation of the neuronal soma depending on their arrival time*




***Above**: simulated interaction of a 100 GeV proton*

***Right**: example of a discriminant variable, with Jensen-Shannon divergences for the three separation powers*

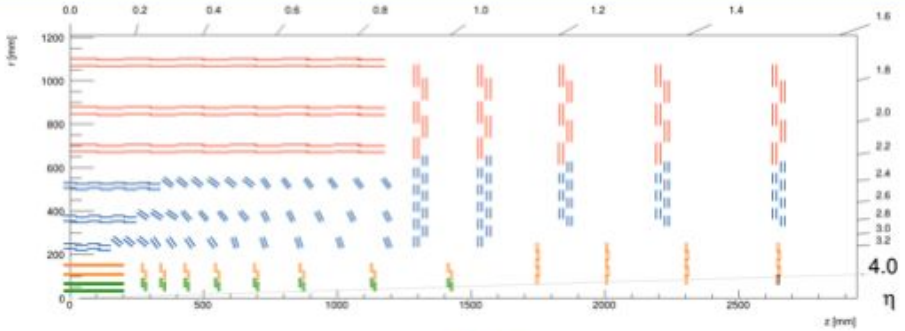



**Neuromorphic computing for calorimetry**
Enrico Lupi, Muhammad Awais, Xuan-Tung Nguyen, Andrea de Vita
With T.D., Fredrik Sandin (LTU), Nicolas Gauger (RPTU),
and A. Mikkelson (Lund)

We study the discrimination of different hadrons (p,pi,K) in homogeneous granular calorimeter with deep learning and with neuromorphic computing implemented in nanowires arrays, without photon transduction into electrical signals (network is entirely based on nanophotonics)

Photons time and number are encoded by nanowires in signal that gets processed by NC network, providing fast local primitives sensitive to particle ID

# Phase II Tracker Upgrade: MaPSA testing in Padova

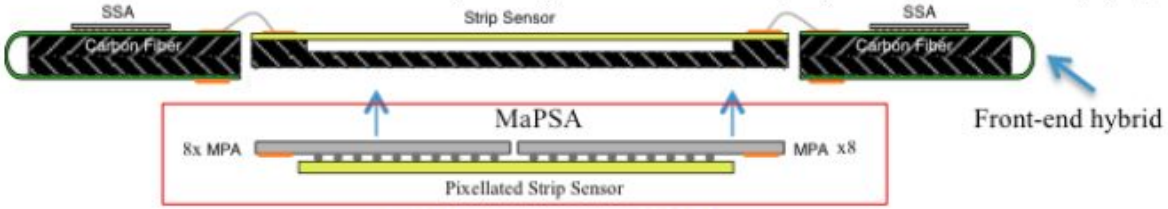



*Tracker layout (OT616_IT616). In **blue** the PS modules location.*

| Module types | Flat TBPS | Tilted TBPS | TEDD |
|---|---|---|---|
| 2S 1.8 mm | | | 2768 |
| 2S 4.0 mm | | | 424 |
| PS 1.6 mm | 826 | | |
| PS 2.6 mm | 126 | 1336 | |
| PS 4.0 mm | | 584 | 2720 |
| Total | 952 | 1920 | 5912 |

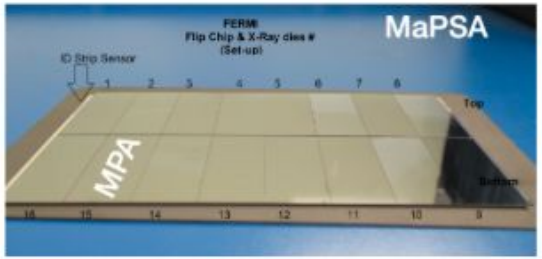
- PS modules are a sandwich of Strips/Pixel sensors separated by 1.6, 2.6 or 4.0 mm.
- A total of 5592 PS modules needs to be built
- MaPSA is the sensor (Pixel)/ Readout-chip (MPA) assembly (flip-chip bump

Number of MaPSA for the INFN production




MaPSA assembly in RED box

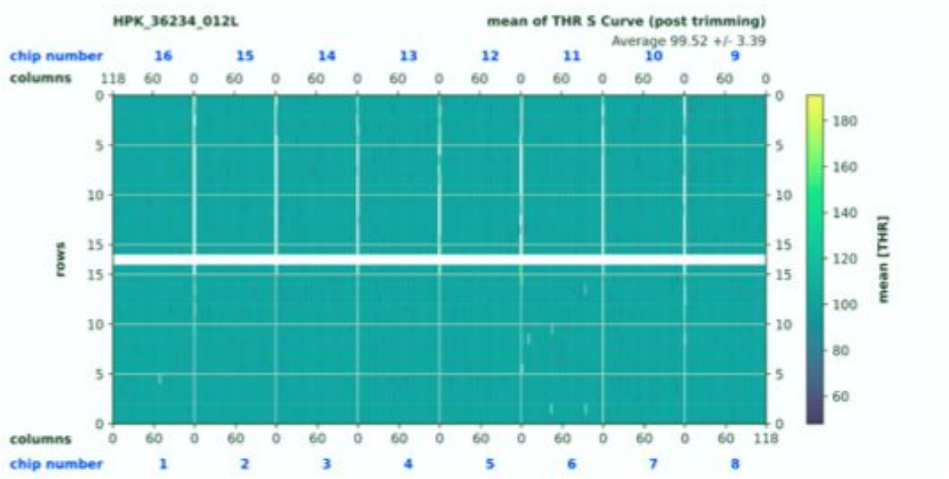
*PS module cross-section.*

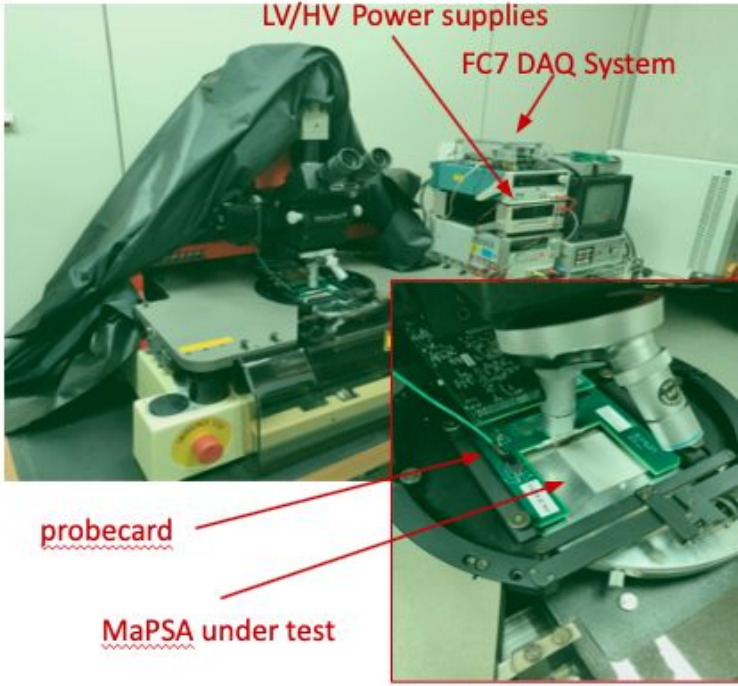



N. Bacchetta, E. Lusiani, D. Pantano, R. Raffagnato, P. Azzi, M. Tosi

# Phase II Tracker Upgrade: MaPSA testing in Padova

- Test setup in Padova is now ready for continued testing
  - Automatic movement was implemented
  - Time required for each test: 2.5h (to be reduced soon with a software update)
  - Some instability remains, still debugging with help from FNAL
- 5 MaPSAs from first batch of pre-production were tested in Padua
  - MaPSAs will be sent to DESY for a cross check

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# Phase II Tracker Upgrade: MaPSA testing in Padova

- Due to change in schedule, Padova is expected to test ~10 MaPSA/week during production phase
  - Production will span from the Q4 2024 until Q3 2026
  - Additional person-power necessary ⇒ **requested additional help (1 person for 1 year)**

Borsa di studio per diplomati

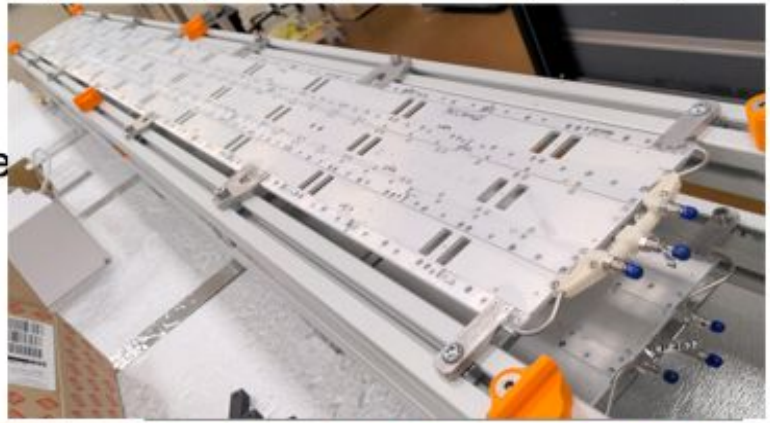
| Pre-Production | | | | |
|---|---|---|---|---|
| | Vendor | MaPSAs | First MaPSA Delivered | Last MaPSA Delivered |
| Batch 1 | QPT | 50 | Sept. 2023 ✓ | Apr. 2024 (?) |
| | HPK | 50 | Feb. 2024 ✓ | Feb. 2024 ✓ |
| Batch 2 | QPT | 100 | Apr. 2024 (?) | Aug. 2024 |
| | HPK | 100 | July 2024* | July 2024* |
| **Production** | | | | |
| | Vendor | MaPSAs | First MaPSA Delivered | Last MaPSA Delivered |
| 10 Production Batches | QPT | 2800 | Oct. 2024 | Aug. 2026 |
| | HPK | 2800 | Oct. 2024 | Aug. 2026 |

We are here

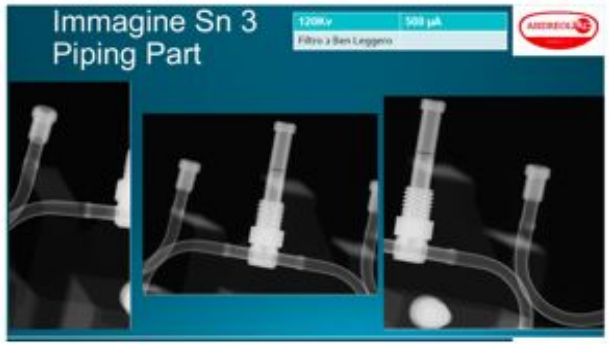
N. Bacchetta, E. Lusiani, D. Pantano, R. Raffagnato, P. Azzi, M. Tosi

# Barrel Timing Layer

BTL trays, 4 mm thick with 3mm I.D. evaporative CO2 cooling loops, prototyped and qualified, production in progress by external suppliers
450 machined Cold plates and 3600 clamping laminas delivered
Assembly jigs and transport frames designed and produce
Masks for preliminary QC designed and produced
Instructions manual for BTL tray assembly steps
Swagelok glands custom machined @ Padova



Each cooling loop received at Cern qualified by:
X-ray of orbital weldings @ supplier
He Leak test @Cern leak rate< $1.10^{-8}$ mbar.l.s$^{-1}$
CO2 leak test @Cern leak rate< 5g/year
Pressure test at 160 bar in bunker facility @Cern




Set up in progress to thermally qualify each 2.5 m tray by IR camera and PT1000

A. Benato, M. Benettoni, N. Bez, E. Borsato, R. Carlin, M. Giorato, R. Isocrate, D. Mazzaro, M. Tosi, R. Rossin, L. Silvestrin, M. Turcato, S. Ventura, F. Veronese
Stefano Lacaprara, INFN Padova

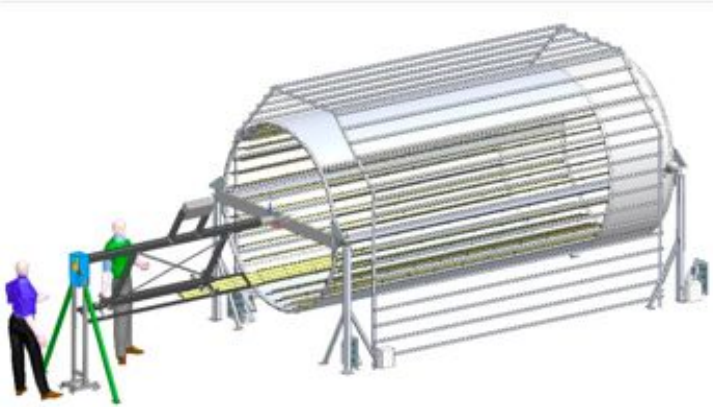
# Barrel Timing Layer

3m stroke plotter to evenly distribute thermal interface material
Qualified thermal compound: Arctic MX-4
Plotter designed produced and commissioned @ Padova
Allows to speed up and improve uniformity of thermal compound distribution wrt manual operators

A. Benato, M. Benettoni, N. Bez, E. Borsato, R. Carlin, M. Giorato, R. Isocrate, D. Mazzaro, M. Tosi, R. Rossin, L. Silvestrin, M. Turcato, S. Ventura, F. Veronese
Stefano Lacaprara, INFN Padova

# Barrel Timing Layer

Integration jig produced, tested and moved to CERN, already in use for tray insertion trials



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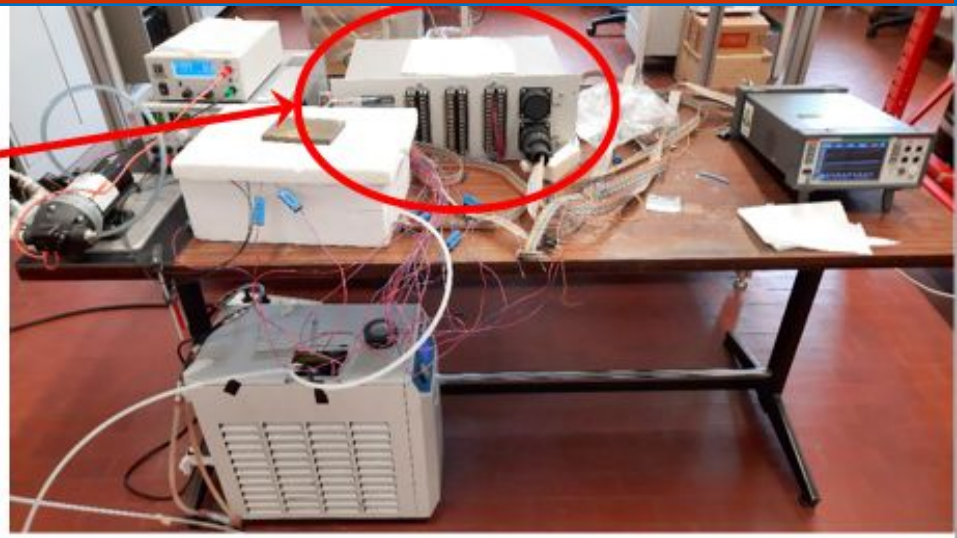
Stefano Lacaprara, INFN Padova

# Barrel Timing Layer

- Thermal compounds to be used for the coupling btw steel pipes and plates have been extensively tested in the “Gr1 Lab”.
- Extensive use of the Kaye Ice point reference for high precision (0.05 C) temperature measurements
- Samples have been irradiated in Croatia and thermally tested before/after irradiation. Small (2.5%) loss in performance measured.
- Qualified thermal compound: Arctic MX-4



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Stefano Lacaprara, INFN Padova

# Anagrafica 2025

- Out:
  - A. Bragagnolo (Assegnista)

- In:
  - L. Borella (Dottorando)
  - N. Lai (Dottorando)
  - M. Awais (Dottorando)
  - X.T. Nguyen (Assegnista)

- Strutturati (cambiamento FTE%):
- M. Bellato 50 → 40

| Ruolo | Persone | FTE |
|---|---|---|
| Ricercatori e Studenti CMS | 15 | 12.4 |
| Tecnologi CMS | 6 | 3.3 |
| Ricercatori e Studenti Fase 2 | 13 | 9.1 |
| Tecnologi Fase 2 | 5 | 1.9 |
| **Ricercatori e Studenti Totale** | **28** | **21.5** |
| **Tecnologi Totale** | **11** | **5.2** |

# Responsabilità CMS 2025

| Responsabilità | Cognome | Nome | Livello | Descrizione Responsabilità | Inizio | Fine |
|---|---|---|---|---|---|---|
| | | | | | | |
| DEI | Azzi | Patrizia | | Member of DFC Committee | | continua |
| DT | Bellato | Marco | L3 | TM7 HW Coordinator | | continua |
| FIS | Bortignon | Pierluigi | L4 | Higgs to muon working group convener | | continua |
| PH | Bulla | Andrea | | TRK Release Validator (DATA) | 11/2022 | 11/2025 |
| FIS | Dorigo | Tommaso | | Statistics Committee member | | continua |
| PH | Lusiani | Enrico | L3 | TRK @ HLT Convener | | continua |
| PH | Margoni | Martino | | Membro PubComm top/b | | continua |
| DT | Triossi | Andrea | L3 | DSS Coordinator | 01/2023 | continua |
| TSG | Tosi | Mia | L1 | Trigger co-coordinator | 09/2024 | 08/2026 |
| PH | Tosi | Mia | L1.5 | Trigger Officer | | 08/2024 |
| CMS Italia | Tosi | Mia | L2 | Coordinatore Italiano della Fisica | | 9/2024 |
| TK | Tosi | Mia | L2 | Tracker Conference Committee Chair | 10/2022 | continua |
| DT | Ventura | Sandro | L2 | Electronics Coordinator | | continua |
| DT | Ventura | Sandro | L3 | Online Software Coordinator | | continua |
| PH | Zucchetta | Alberto | | Jornal submission editor (JSE) | | continua |

# Responsabilità CMS/Fase 2 2025

| Responsabilità | Cognome | Nome | Livello | Descrizione Responsabilità | Inizio | Fine |
|---|---|---|---|---|---|---|
| | | | | | | |
| TK | Bacchetta | Nicola | L2 | Tracker Upgrade Technical Coordinator | | continua |
| TK | Bacchetta | Nicola | L2 | TBPS Coordinator | | continua |
| TK | Bacchetta | Nicola | L3 | Integration, Cooling&Services Coordinator | | continua |
| DT | Bellato | Marco | L3 | OBDTφ, Slow Contol & Timing Backend | | continua |
| DT | Bergnoli | Antonio | L3 | OBDTφ, Slow Contol & Timing Backend | | continua |
| DT | Triossi | Andrea | L2 | Deputy Upgrade Coordinator | | continua |
| DT | Triossi | Andrea | L3 | OBDTφ, Slow Contol & Timing Backend | | continua |
| CMS Italia | Ventura | Sandro | L2 | Upgrade Coordinator | | continua |

# Richieste CSN1

**Missioni**

- Metabolismo+shifts/services: 203.0 keu
- Responsabilità: 34.2 keu
- Specifiche:

| | |
|---|---|
| DT(manutenzione) | 4.0 keu |
| DT(integrazione OBDT) | 23.0 keu |
| MTD(integr./install.) | 5.5 keu |
| MTD(produzione) | 9.5 keu |

**Consumi**

- Metabolismo+camera pulita: 44.0 keu

# Richieste in Sezione

| Officina elettronica | | Mesi uomo |
|---|---|---|
| Tracker | Test in camera pulita | 6 |
| Totale | | 6 |

Tecnologie avanzate (Adriano)

| SPE | | Mesi uomo |
|---|---|---|
| DT | Manutenzione camere al CERN | 2 |
| | Qualifica produzione elettronica Fase 2 e assembl. minicrate | 50 |
| Totale | | 52 |

| Ufficio tecnico | | Mesi uomo |
|---|---|---|
| BTL | Produzione disegni e documentazione | 1 |
| | Benettoni | 2 |
| Totale | | 3 |

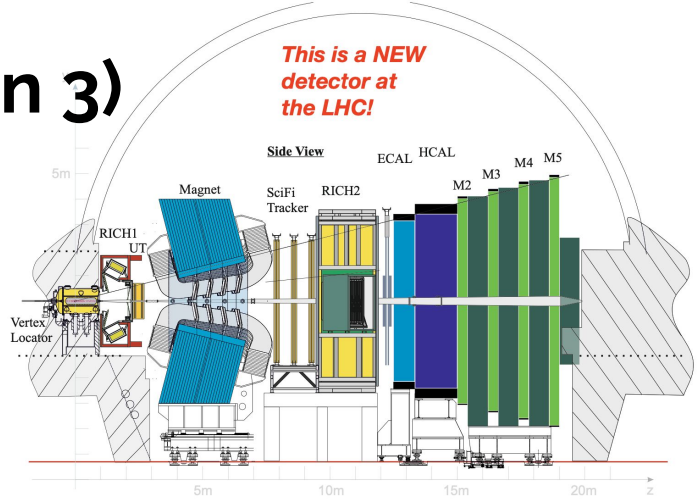
| Officina Meccanica | | Mesi uomo |
|---|---|---|
| BTL | Lavorazione assemblaggio e installazione | 1 |
| Totale | | 1 |

| Calcolo | | Mesi uomo |
|---|---|---|
| | Supporto cluster locale, cloud | 3 |
| | Supporto produzione locale dati | 3 |
| | Connessione, operazione, mant. TIER2 PD-LNL | 18 |
| Tracker | Supporto Computing & Networking | 1 |
| Totale | | 25 |

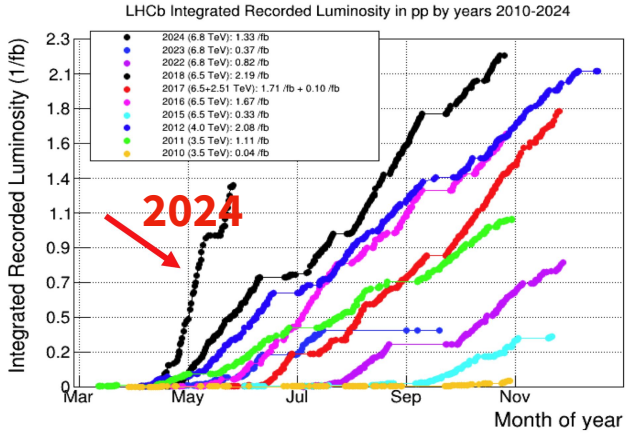
# LHCb status update
# Riunione preventivi 2025

Lorenzo Sestini
per il gruppo LHCb-Padova
5 luglio 2024

# Stato LHCb: Upgrade 1 (Run 3)




- Nel Run 3 quasi tutti i rivelatori (90%) sono stati sostituiti: **detector praticamente nuovo!**
- **Significativo contributo di Padova per il RICH e per software di acquisizione dati**
- Il 2023 è essenzialmente stato un anno di commissioning (caratterizzato da un incidente al VELO che ne impediva la chiusura)
- Il problema del VELO è stato risolto e l'ultimo detector (Upstream Tracker) installato
- **Nel 2024 LHCb ha già raccolto un ordine di grandezza in più di dati rispetto al 2023 (e di buona qualità!)**



# Upgrade 1 a Padova

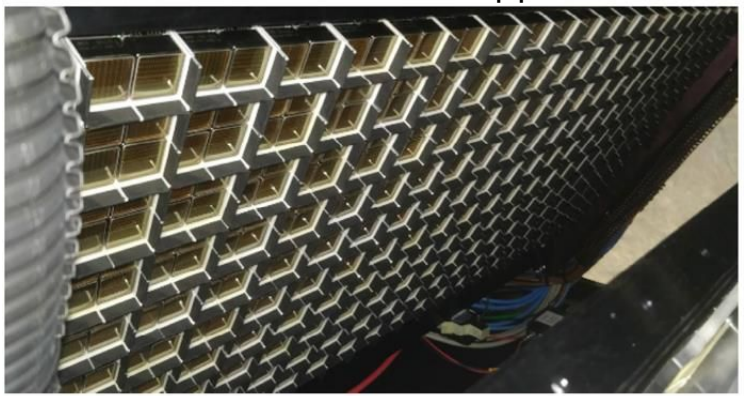
Borgato, Lupato, Simi

# LHCb RICH Upgrade I

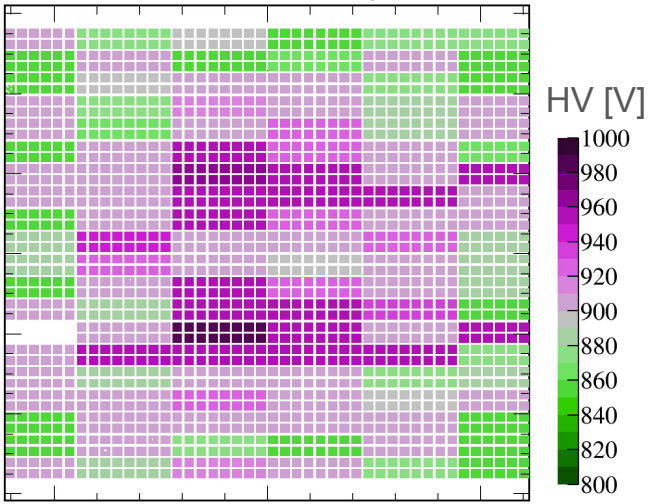
- RICH PID tratto distintivo di LHCb, fondamentale per il programma di fisica di LHCb
- Padova coinvolta nel design e nella costruzione ‘19-’22
- Responsabilita’ nella
  - caratterizzazione dei PMT [**Simi**]
  - meccanica, cooling [**Benettoni**]
  - calibrazione del rivelatore [**Simi**]
  - commissioning
  - installazione
- Installazione `21-‘22
  - Analisi dei threshold scan per estrazione guadagni
  - Sviluppo calibrazione/equalizzazione dei guadagni dei PMT [**F. Borgato**]
- 2024: Detector Commissioning & Calibration
  - 2024: sviluppo online monitoring dei guadagni per misurare invecchiamento PMT [**F. Borgato**]
  - 2024: Fine tuning delle alte tensioni con threshold scans dedicati per uniformare guadagni [**F. Borgato**]

Articolo su performances del RICH in Run3 in preparazione

RICH1: MaPMTs installed upper side



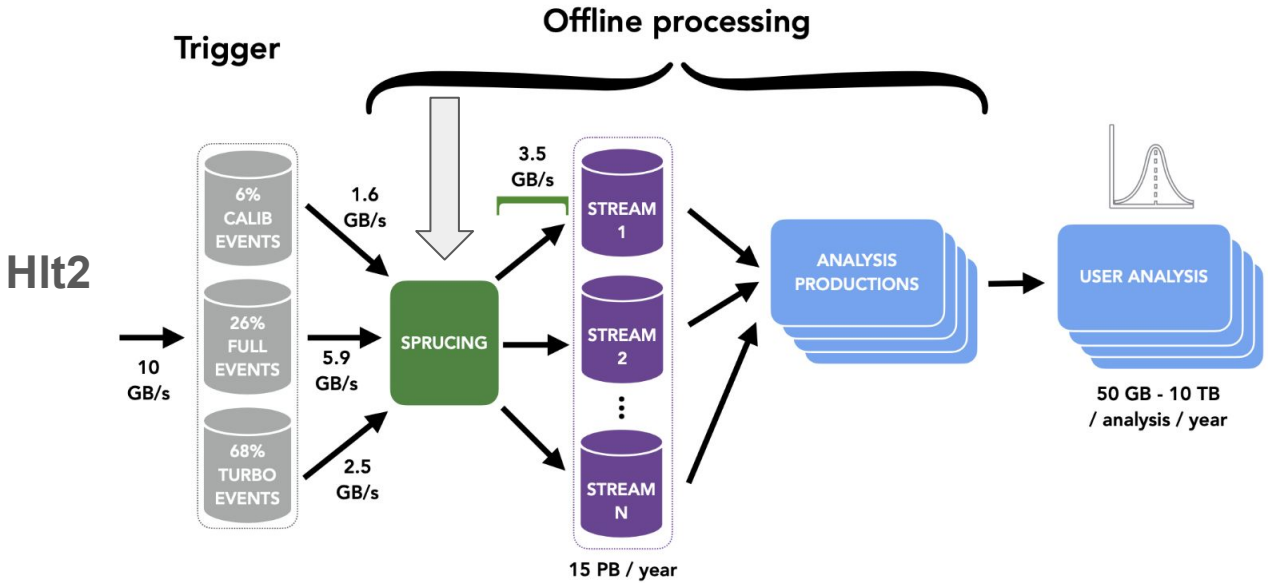
RICH1: HV for physics runs



# Upgrade 1 data processing: spruce

A. Bertolin

spruce == selections and streaming that runs on the output of HLT2 in Run 3 and beyond

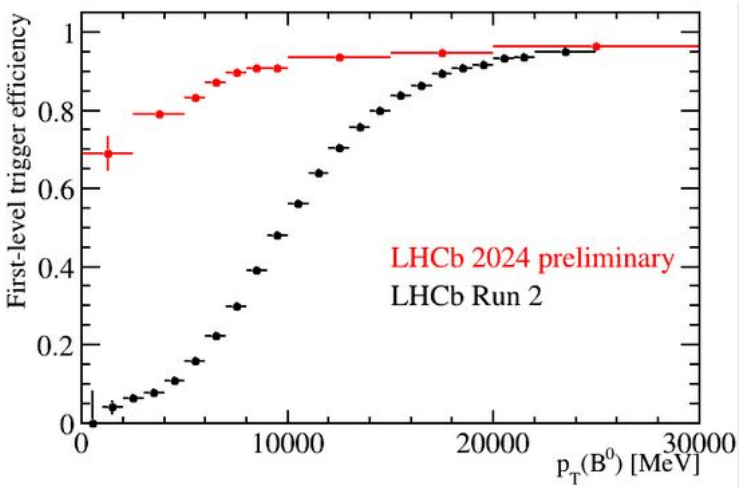



A. Bertolin was concurrent spruce manager and becomes spruce coordinator

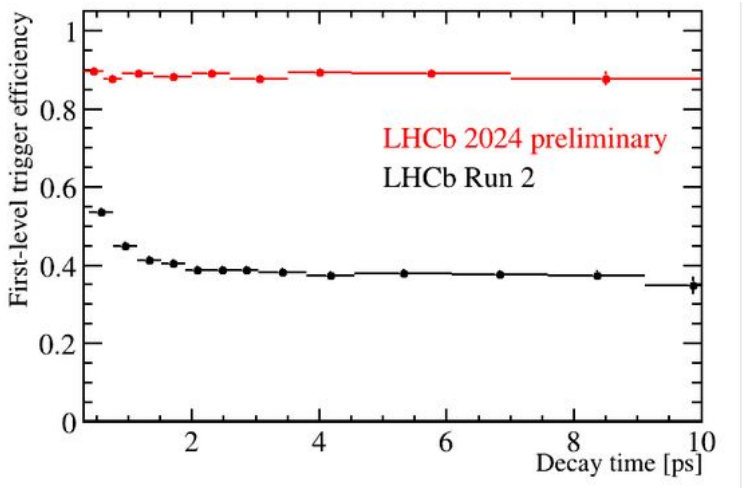
# Data processing: validation of the first-level hadronic triggers

A. Bertolin

https://lbfence.cern.ch/alcm/figure/details/3573




First-level trigger efficiency as a function of the $B_d$ transverse momentum. The bin boundaries are at 0., 2500., 5000., 6000., 7000., 8000., 9000., 10000., 15000., 20000. and 30000. MeV. The efficiencies are computed using the TIS/TOS method as discribed in . In Run 2 the first-level trigger consisted of a hardware stage, based on information from the calorimeter and muon systems, followed by a software stage. In Run 3 the first-level trigger is only software based. This is the reason of the efficiency improvements.

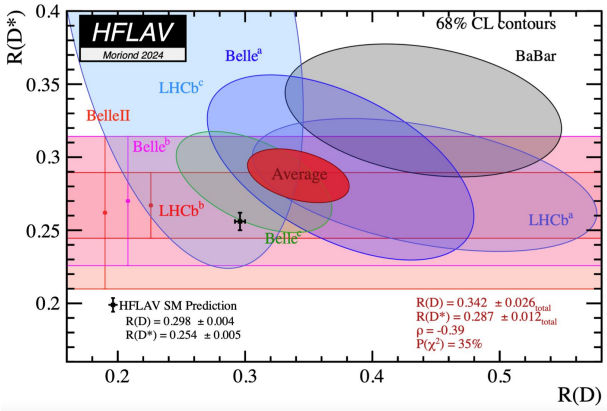



First-level trigger efficiency as a function of the $B_d$ decay time, in the decay time fit the $B_d$ meson is constrained to the associated PV. The bin boundaries are at 0.3, 0.6, 0.9, 1.4, 2.0, 2.6, 3.5, 4.5, 7. and 10. ps. The efficiencies are computed using the TIS/TOS method as discribed in . In Run 2 the first-level trigger consisted of a hardware stage, based on information from the calorimeter and muon systems, followed by a software stage. In Run 3 the first-level trigger is only software based. This is the reason of the efficiency improvements.

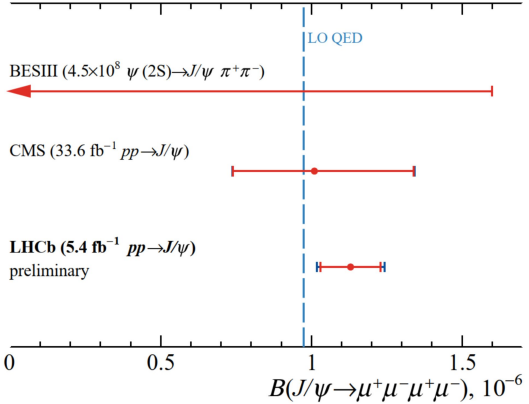
demonstrate the effectiveness of the removal of the hardware (L0) trigger

# LHCb physics highlights

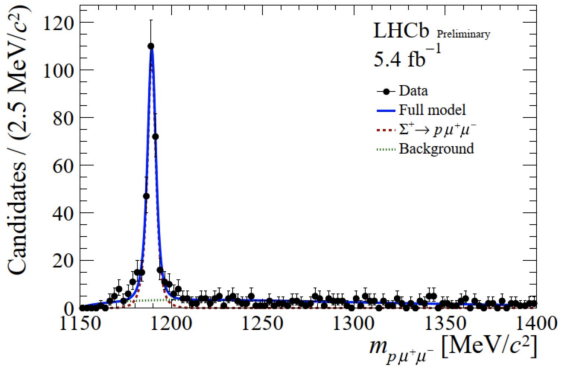
## R(D)-R(D*) combination



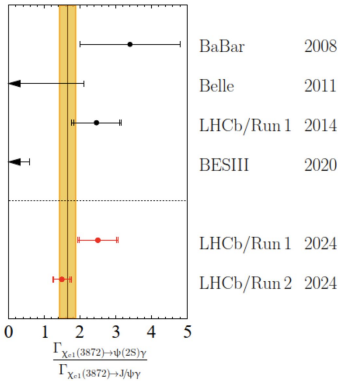

## LHCb observes the rare decay J/ψ→μ+μ-μ+μ-




## Observation of the rare Σ+→pμ+μ- decay




## Probing the nature of the mysterious particle χc1(3872)

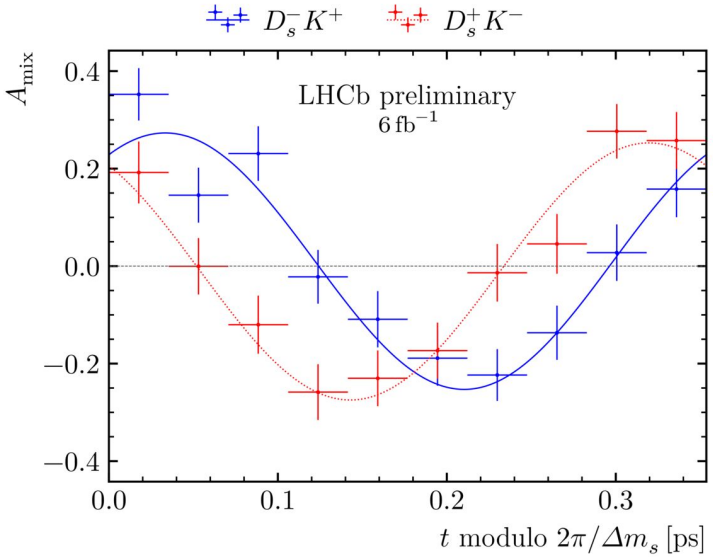


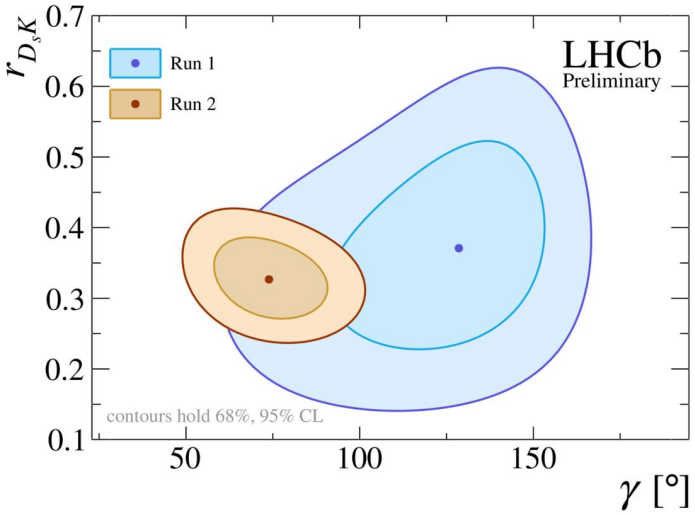
# Analisi Padovane

# CKM gamma from Bs2DsK

**A. Bertolin, A. Lupato**

https://lhcbproject.web.cern.ch/lhcbproject/Publications/LHCbProjectPublic/LHCb-CONF-2023-004.html



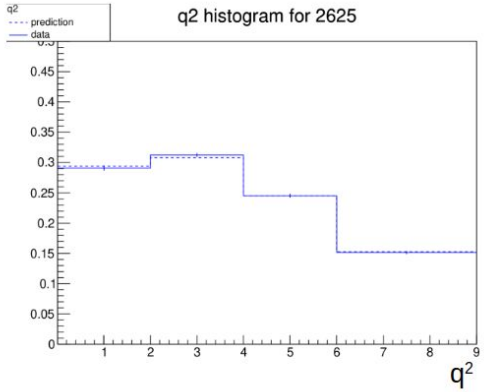

very significant accuracy improvement with Run 2

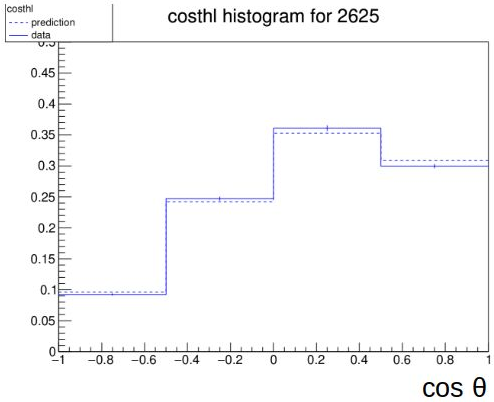
Run 1 value (3 /fb): 128 + 17 - 22
Run 2 value (6 /fb): 74 +- 11
new LHCb gamma combination available for ICHEP
look forward to results with Run 3 data (due to the improved hadronic triggers, see slide ?)

# Universalità Leptonica $R(\Lambda_c^*) = \frac{B(\Lambda_b^0 \to \Lambda_c^* \tau^- \bar{\nu}_\tau)}{B(\Lambda_b^0 \to \Lambda_c^* \mu^- \bar{\nu}_\mu)}$

Per la misura dell'universalità leptonica nei b-barioni $\Lambda_b$ con i dati del run2 è necessario ridurre l'errore sistematico (A. Lupato, G. Simi LCHB-ANA-2018-026) dominato da

- Fattori di forma del decadimento $\Lambda_b^0 \to \Lambda_c^* \mu^- \bar{\nu}_\mu$
- Fondo da $\Lambda_b^0 \to \Lambda_c^* D_s^{(*)}$




Fattori di Forma

- Prima misura in questo decadimento
- Analisi completata, in review
- Timescale: conferenze invernali
- Persone coinvolte: A. Lupato, G. Simi

# Universalità Leptonica

$$R(\Lambda_c^*) = \frac{B(\Lambda_b^0 \to \Lambda_c^* \tau^- \bar{\nu}_\tau)}{B(\Lambda_b^0 \to \Lambda_c^* \mu^- \bar{\nu}_\mu)}$$

- Branching ratios ratio
  - $B_1$=B($\Lambda_b \to \Lambda_c$ (2565)μν)·B($\Lambda_c$ (2595) → $\Lambda_c\pi^+\pi^-$)
  - $B_2$=B($\Lambda_b \to \Lambda_c$ (2625)μν)·B($\Lambda_c$ (2625) → $\Lambda_c\pi^+\pi^-$)

$$\frac{B_1}{B_2} = 0.81 \pm 0.02_{stat}$$

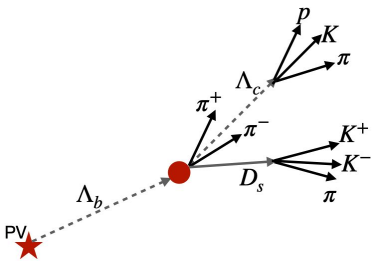
- From arXiv:1907.05747, assuming
  - B($\Lambda_c$ (2595) → $\Lambda_c\pi^+\pi^-$)=0.185
  - B($\Lambda_c$ (2625) → $\Lambda_c\pi^+\pi^-$)=0.550

$$\frac{\mathcal{B}_1}{\mathcal{B}_2} = 2.42 \pm 0.05_{stat}$$

- Persone coinvolte: A. Lupato, G. Simi

- Misura del $\dfrac{BR(\Lambda_b^0 \to \Lambda_c^{*+} D_s^{(*)-})}{BR(\Lambda_b^0 \to \Lambda_c^{+} D_s^{(*)-})}$

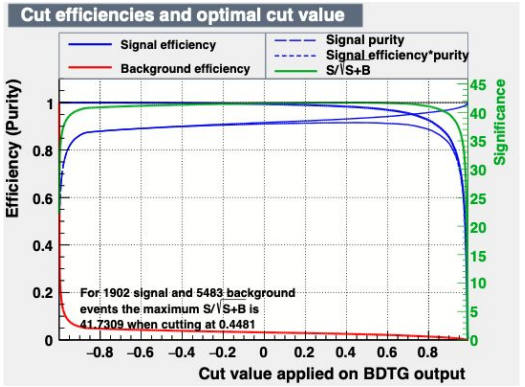
- Prima osservazione del decadimento $\Lambda_b^0 \to \Lambda_c^{*+} D_s^{(*)-}$
- Studio degli stati $\Lambda_c(2625)^+$ e $\Lambda_c(2595)$
- Fondo principale per la misura di $R(\Lambda_c^*)$
- Persone Coinvolte: Borgato, Lupato, Simi

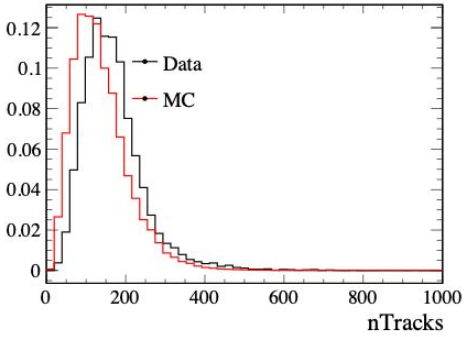


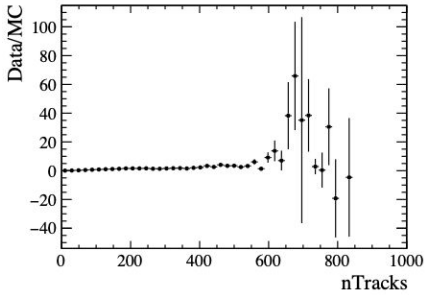
# Misura di $\frac{BR(\Lambda_b^0 \to \Lambda_c^{*+} D_s^{(*)-})}{BR(\Lambda_b^0 \to \Lambda_c^{+} D_s^{(*)-})}$

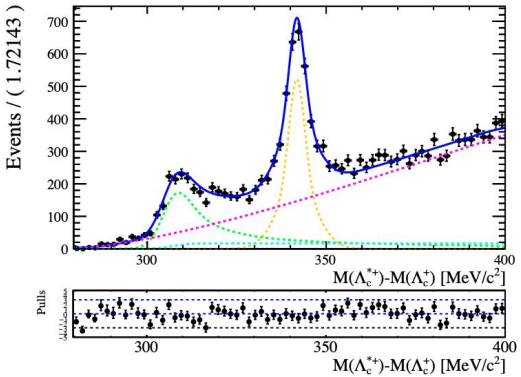
Stato dell'analisi:

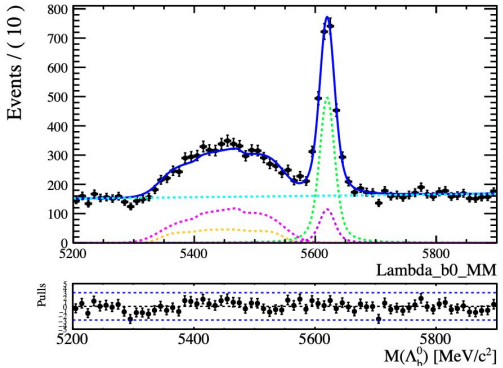
- Selezione (veti di massa, TMVA, candidati multipli)
- Calibrazione MC
- Efficienza
- Estrazione delle shape per il fit dal campione MC
- Fit bidimensionale
- Incertezze sistematiche



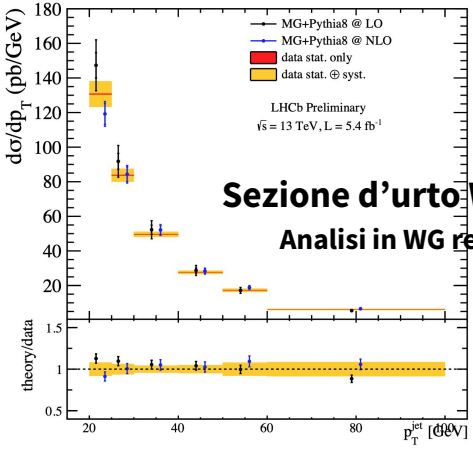



# Fisica Elettrodebole

**A. Gianelle, D. Lucchesi, L. Sestini, D. Zuliani**

- **Determinazione delle sezioni d'urto W+jets e Z+jets**
  - sensibili alle Parton Distribution Functions in una regione complementare rispetto ad ATLAS e CMS
  - prime misure a 13 TeV nella forward region
  - Bosoni W e Z ricostruiti nei decadimenti muonici
  - sono considerati stati finali con 1 e 2 jets
  - sezioni d'urto misurate in modo differenziale in funzione della cinematica

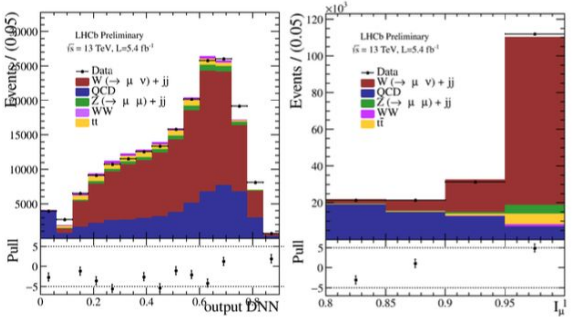



**Sezione d'urto W+jets**

**Analisi in WG review**

- **Produzione di dibosoni (WW, WZ, ZZ) nella regione in avanti**
  - Importante verifica del SM nella regione in avanti
  - per aumentare la statistica, un bosone viene ricostruito nel decadimento adronico in 2 jets
  - Deep Neural Network per separare WW from W+jets (main background)
  - prima misura di questi processi ad LHCb, dominata dalla statistica nel Run 2

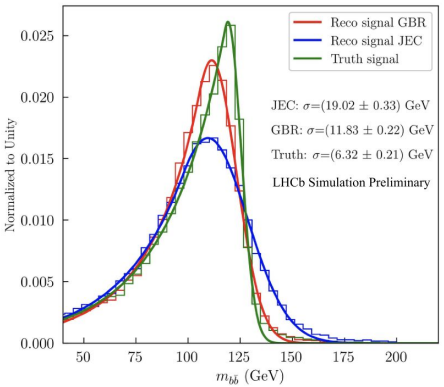
**Fit estrazione WW**

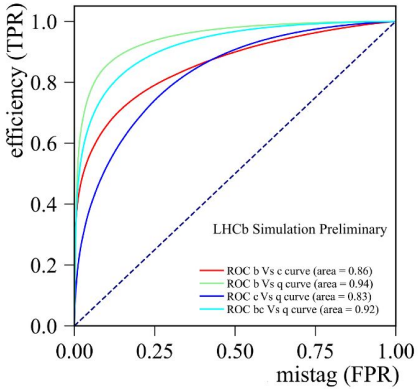


# b-jets e c-jets

**A. Gianelle, D. Lucchesi, L. Sestini, D. Zuliani**

- **Ricerca H → cc (e H→bb) nella regione in avanti**
  - grazie all'eccellente sistema di tagging LHCb può contribuire alla ricerca dell'H→cc
  - Deep Neural Network per separare i flavour dei jets
  - GBR per estrarre massa invariante dei di-jets
  - Metodo data-driven per determinazione fondo QCD
  - Determinazione upper limits con il full Run 2 in corso

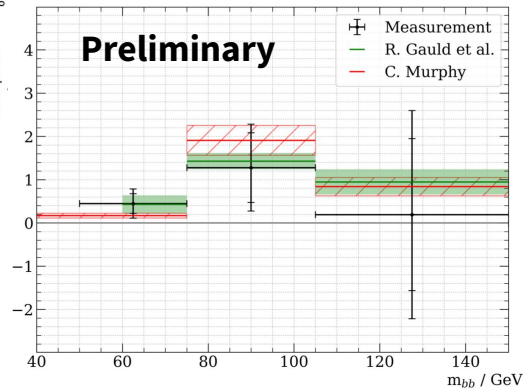



- **Asimmetria angolare di carica nei b-dijets**
  - sensibile a contributi di nuova fisica
  - cruciale la separazione tra b-jets e b-bar-jets
  - prima misura di questa quantità a 13 TeV
  - analisis simile in corso anche per **c-jets e c-bar-jets**
  - collaborazione Padova-Edimburgo

$$A^{b\bar{b}} \equiv \frac{N(\Delta\eta > 0) - N(\Delta\eta < 0)}{N(\Delta\eta > 0) + N(\Delta\eta < 0)}$$

$$\Delta\eta = \eta_b - \eta_{\bar{b}}$$

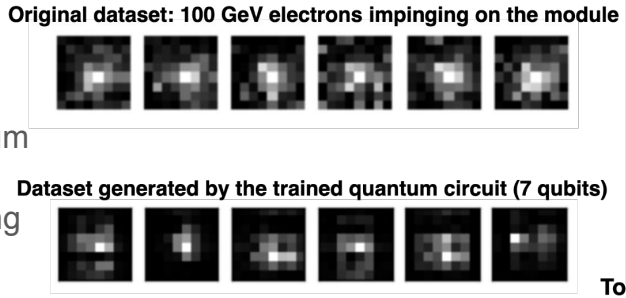


# Quantum computing

A. Gianelle, J. Hagen, D. Lucchesi,
L. Sestini, D. Zuliani

- Ormai da diversi anni continua l'attività di sviluppo di algoritmi quantistici per l'analisi dei dati di LHCb
- Padova è leader nella collaborazione per queste attività
- Alcuni studi recenti:
  - Simulazione con generatori quantistici
  - Classificazione con Variational Quantum Circuits
  - Classificazione con Quantum Annealing
- Lavoro inquadrato nello Spoke 10 del Centro Nazionale di Calcolo (ICSC-PNRR)

**Simulazione di un modulo del calorimetro con Quantum Generative adversarial Network**



# Upgrade futuri a Padova

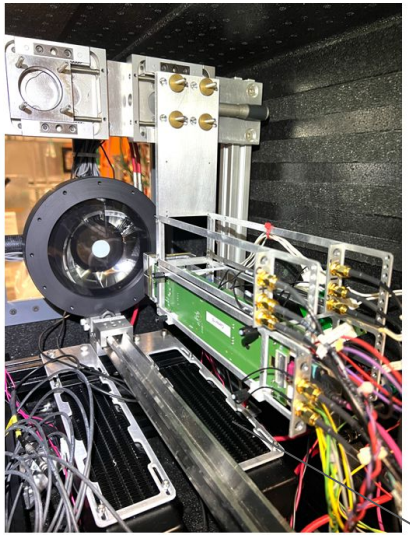
# LHCb RICH Upgrade 1b (Run4)

- During LS3: 2026-2028 -> Run4, Lumi~20 $10^{32}$
- Goal: nuova elettronica di front-end [FastRICH] **con buona risoluzione temporale e time gating 2ns**, nuova meccanica adatta per estrazione del calore, nuovo sistema di calibrazione
  - Upg Ib responsabilità Padovane:
    - Test sotto fascio di prototipi elettronica + rivelatori
      - ['23/'24] test con prototipo elettronica finale [FastRICH]
      - Estrazione risoluzione temporale [**Responsabile F. Borgato**]
      - Sviluppo SW di acquisizione [**F. Borgato**]
      - Caratterizzazione risoluzione temporale con laser [**F. Borgato**]
    - Caratterizzazione resistenza alla radiazione dell'elettronica [**Simi, Borgato, Lupato**]
      - Schedule moved to Q1 2025
    - QA, Assemblaggio e Commissioning at CERN

## Prototipo elettronica

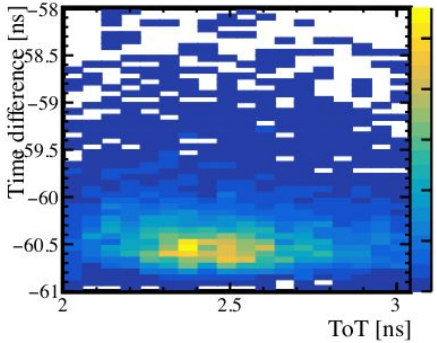
Nel FastRICH il calore viene generato vicino ai PMT -> nuovo sistema di dissipazione

## RICH Test beam setup

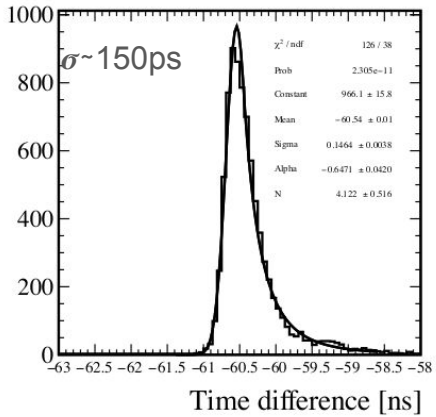


Parallel talk at EPS (August 2023) + proceedings
• Testbeam paper on 2022 data soon to be published

## After correction



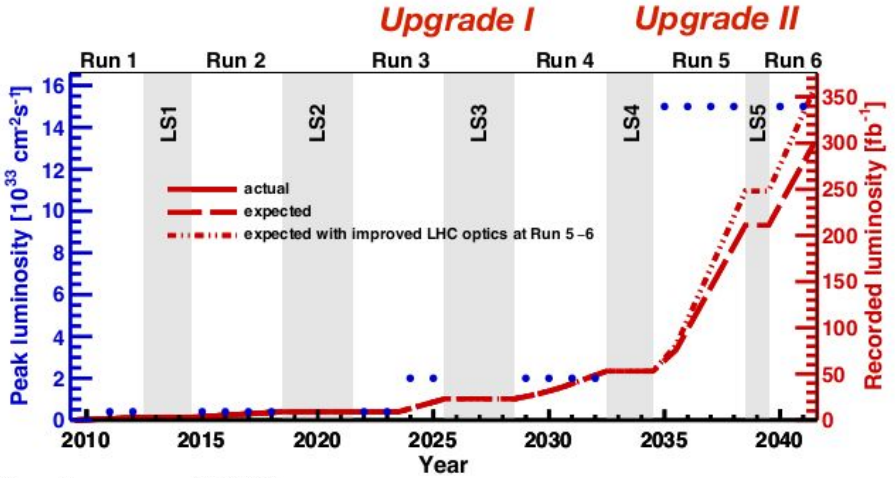

## After correction



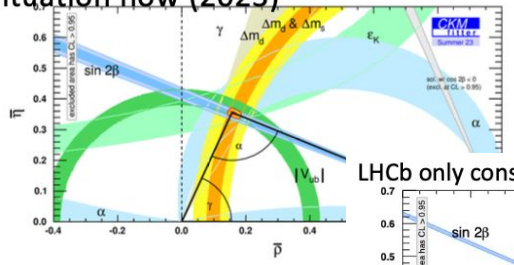

[CERN-LHCb-DP-2023-004]

# LHCb Upgrade 2 (Run 5-6)

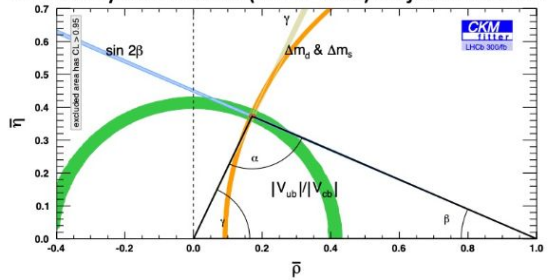
- During LS4: (2033 – 2034) 2035, a major upgrade (HL-LHC, Lumi ~ 150 $10^{32}$);
- Motivation
  - UNIQUE PHYSICS programme with BSM discovery potential
    - Unprecedented sensitivity for B and D physics
    - Broad (general purpose) programme
      - Unique forward acceptance
      - Spectroscopy, EW precision measurements, top quark and Higgs physics, dark sector, heavy ions and xed target
  - EXCITING TECHNOLOGY roadmap
    - high granularity, fast timing, extreme radiation hardness
    - the developments needed to face the harsh experimental conditions of HL-LHC
  - in the forward direction will represent a bridge towards projects based at future accelerators




Situation now (2023)




LHCb only constraints (CKMFitter)Projected 300 fb



# LHCb Upgrade 2: RICH (Run 5-6)

## Requirements on the new RICH

- Single photon sensitivity, with large QE
- Single-photon Cherenkov angle uncertainty 0.4/0.2 mrad (RICH1/RICH2), a factor 2 better than expected for Run3
- Number of detected photons per saturated track: ~40/30 (RICH1/RICH2)
- Able to sustain very high photon rates within a LHC bunch crossing (25 ns)
  - In the current RICH detector we expect a maximum channel occupancy of ~25% with ~9 $mm^2$ pixel area (~1 $MHz/mm^2$)
  - For Upgrade II we expect a photon hit density of ~10 $MHz/mm^2$ (assuming current geometry/optics)
- High granularity (hence electronics channel density) to keep maximum channel occupancy below ~25%
  - Translates in a pixel size of ~$1 \times 1$ $mm^2$ assuming current geometry/optics (might be relaxed if geometry/optics is optimized)
- Excellent time resolution within a 25 ns bunch
  - Ideally <100 ps r.m.s. for single photon (the smaller the better)
- Signal/noise ratio: average Dark Count Rate occupancy <0.001
- Radiation hardness
  - Extrapolating from Upgrade I (using a factor ×10): ~2 Mrad TID, ~$3 \times 10^{13}$ 1 MeV $n_{eq}/cm^2$, ~$1 \times 10^{13}$ HEH/$cm^2$

# LHCb RICH Upgrade 2 (Run 5-6)

- Coordination of SiPM Irradiation program [**G. Simi**]
- Planned activities
  - FBK run to produce SiPM with improved radiation hardness (BSI)
  - Study radiation tolerance of SiPM in conditions similar to real detector
    - Liquid nitrogen temperature (baseline solution for current design) to reduce dark counts
    - 40MHz readout, 30% occupancy
    - -> need a cryostat with transparent window to illuminate SiPM with laser

# RICH Upgrade 2: Anagrafica & Richieste

Anagrafica

- F. Borgato
  - 70% LHCb
  - A. Lupato 70%
- M. Benettoni
  - 40% LHCb
- G. Simi
  - 70% LHCb

Richieste

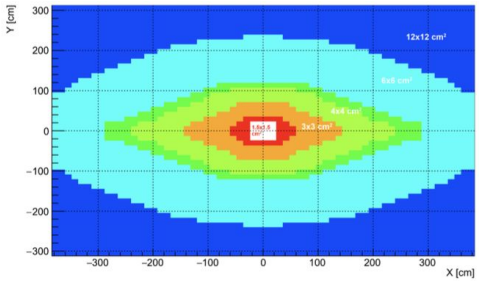
- ~15kE criostato con finestra
- 2kE prototipi schede/cavi per lettura a freddo
- 1kE per irraggiamenti a Pavia [comune per tutto LCHb RICH]

Servizi

- 1 m.u. progettazione meccanica
  - Modifiche criostato
- 1 m.u. progettazione meccanica
  - R&D meccanica Upgrade II
- 2 m.u. progettazione elettronica
  - Schede per irraggiamenti
  - Schede per Quality Assurance
- 1 m.u. officina meccanica
  - Modifiche Criostato per SiPM

# Upgrade 1b/2: ECAL

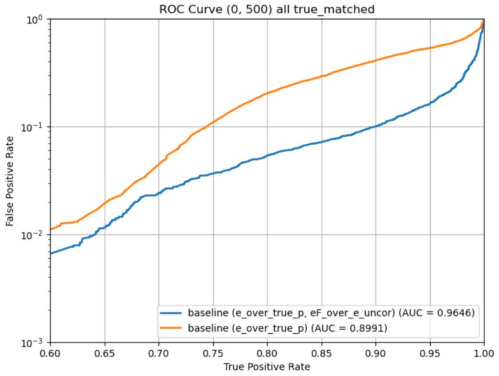
**P. Andreetto, L. Arnone, A.Gianelle, L. Sestini, D. Zuliani, D. Lucchesi**

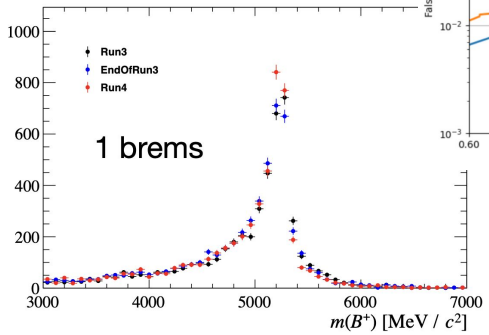



**Attività di simulazione degli upgrade futuri di ECAL**

**Attività sinergica con RD_Mucol**

- Performance di ricostruzione degli elettroni
  - studi a basso (B→K*ee) e alto (Z→ee) regime di energia
  - si tiene in considerazione anche la bremsstrahlung recovery e la saturazione dell'ADC (tuning del range dinamico)
- Studi di PID e separazione elettroni/pioni
  - fondamentale per eliminare fondo di B->K*ππ
  - BDT per sfruttare informazione su segmentazione longitudinale



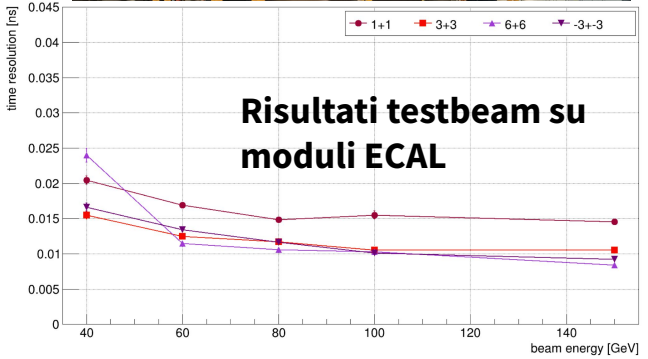



# Upgrade 1b/2: ECAL

**P. Andreetto, L. Arnone, A.Gianelle, L. Sestini, D. Zuliani, D. Lucchesi**

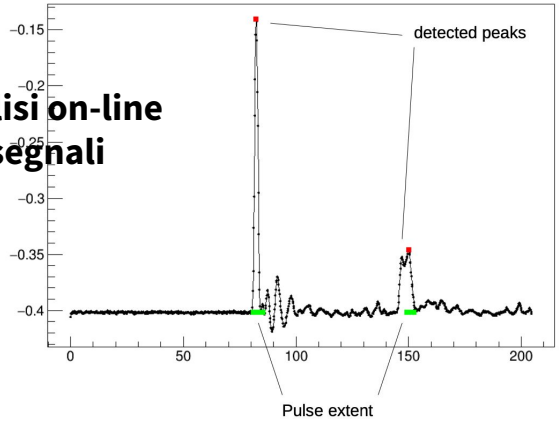
**Sinergico con i tests beam per RD_Mucol**

- **Contributi alle campagne di test-beam a DESY ed SPS**
  - analisi dati (time and energy resolution)
  - simulazioni nuovi moduli
  - shifts per data taking
- **Ricostruzione on-line su FPGA**
  - determinazione dell'altezza dei segnali
  - clustering real-time, utilizzando tecniche innovative (es. basate su machine learning)
  - per questa attività necessario il supporto del servizio di Progettazione elettronica
- **Richieste**
  - **Progettazione elettronica 1 m.u.** → Supporto per programmazione FPGA usate nella ricostruzione on-line di ECAL
  - DAQ per test beams: in definizione con la collaborazione




**Risultati testbeam su moduli ECAL**

**Analisi on-line dei segnali**



# LHCb-Padova: responsabilità

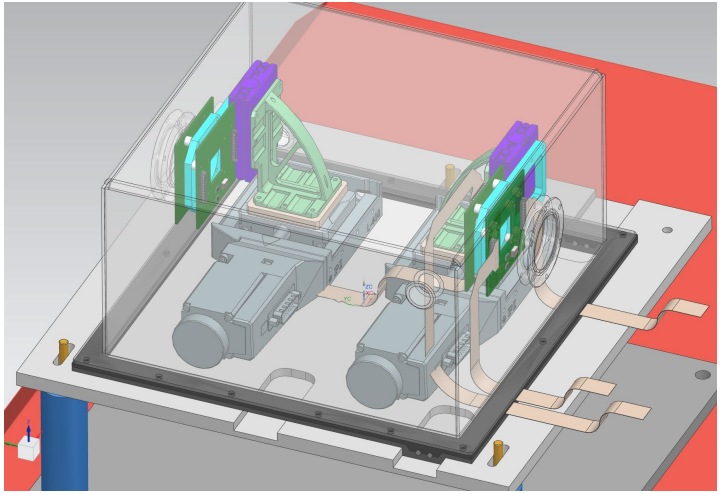
| Nome | Responsabilità |
|---|---|
| A. Bertolin | Sprucing coordinator (2a) |
| A. Lupato | Convener of the “Semileptonic decays Physics WG” (2a) |
| L. Sestini | Member of the Collaboration Board |
| D. Zuliani | Convener of “Trigger, Online data processing and jets” for the “QCD, Electroweak and Exotica” group (2b) |

# LHCb-Padova: anagrafica e richieste

| Nome | Profilo | FTE |
|---|---|---|
| P. Andreetto | Tecnologo | 0.25 |
| M. Benettoni | Primo Tec. | 0.40 |
| A. Bertolin | Ricercatore | 0.70 |
| F. Borgato | PhD | 0.80 |
| A. Gianelle | Tecnologo | 0.50 |
| Q. Han | Post Doc | 0.70 |
| D. Lucchesi | Prof. Ord. | 0.70 |
| A. Lupato | RTDB | 0.70 |
| G. Simi | Prof. Ass. | 0.70 |
| L. Sestini | Ricercatore | 0.70 |
| D. Zuliani | Post Doc | 0.70 |

- **6.85 FTE in totale**
  - 3 tecnologi INFN: P. Andreetto (25%), M. Benettoni (40%), A. Gianelle (50%)
- **Richieste finanziarie**
  - Missioni secondo formule standard
  - Materiale per test RICH upgrade
  - Meteriale per test ECAL upgrade
- **Richieste servizi Sezione di Padova**
  - **Progettazione meccanica 2 m.u.** → RICH Upgrade
  - **Officina meccanica 1 m.u.** → RICH Upgrade
  - **Progettazione elettronica 3 m.u.** → RICH Upgrade (2 m.u.) + ECAL Upgrade (1 m.u)

# Attività per LUXE nel 2025

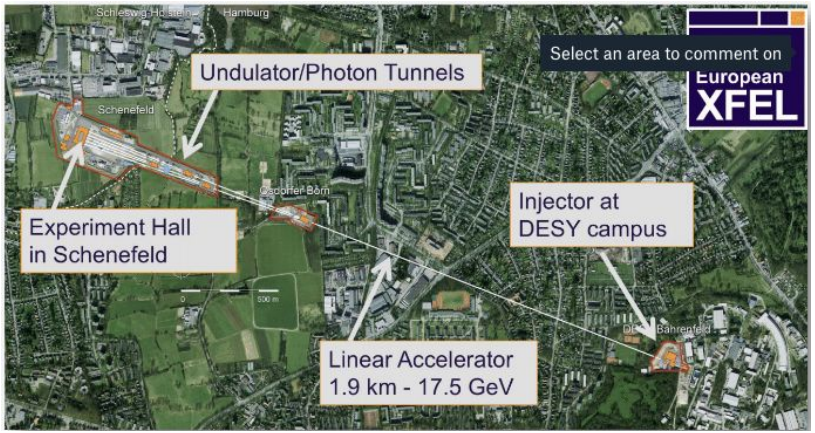


M. Morandin
INFN- PD

CdS - Padova
5/7/24

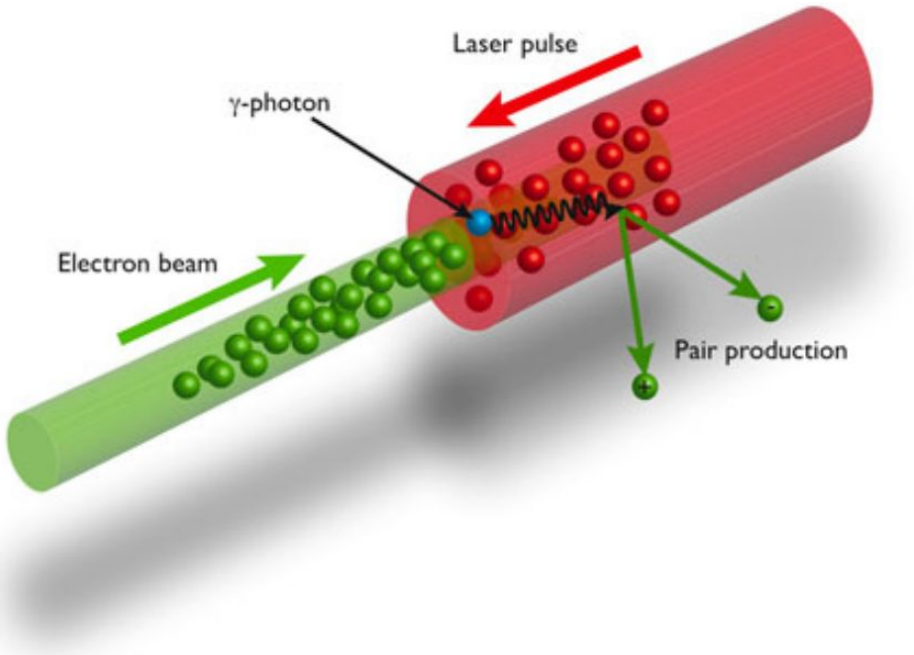
# LUXE (Laser Und XFEL) a DESY

- Nuovo esperimento HEP proposto a DESY e Eu.XFEL
  - l'Italia è partner di European XFEL, rappr. INFN e CNR nel Council
  - paesi membri XFEL GmbH: Denmark, **France**, **Germany**, Hungary, **Italy**, **Poland**, Russia, Slovakia, **Spain**, **Sweden**, Switzerland, and the **United Kingdom** **[also in LUXE collab. that also include Israel and Romania ]**
- Collisioni inizialmente di fascio di elettroni **XFEL e Laser ad alta potenza**
  - in una seconda fase di fascio gamma con Laser
- Collaborazione internazionale
  - ~100 membri (20 istituzioni a Apr. 2024)
- Gruppi INFN coinvolti: **Bologna, Padova**
- Documentazione
  - WEB LUXE: https://luxe.desy.de/documents



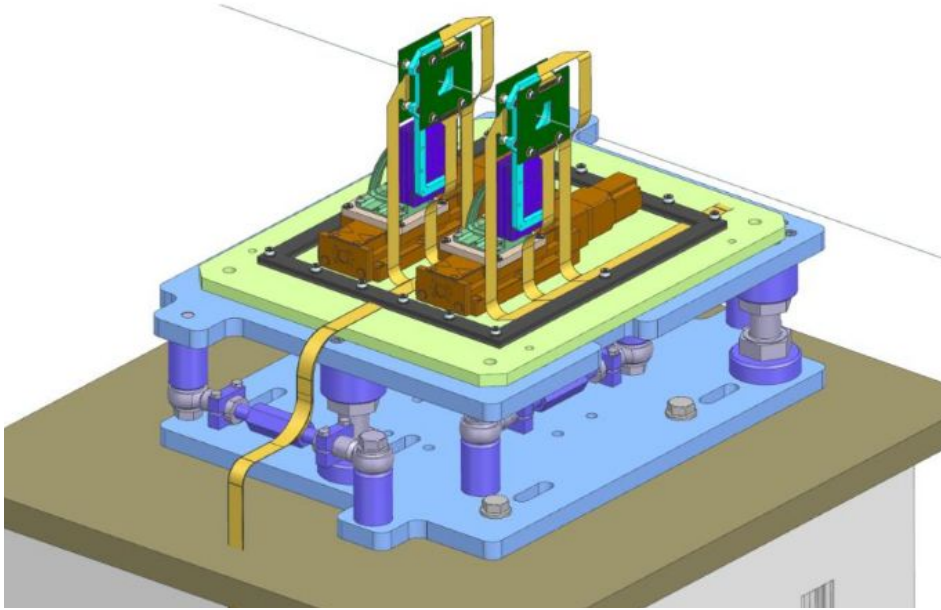
# Obiettivi di LUXE

- esplorare le **interazioni di fotoni reali con elettroni e positroni** in un regime di intensità del campo e.m. dove gli accoppiamenti con le cariche diventano **non-lineari a non-perturbativi (Strong Field QED)**
- effettuare **misure di precisione** di tali interazioni in particolare **nella regione di transizione fra il regime perturb. e non perturb.** della QED
- utilizzare i processi di strong-field QED per effettuare una ricerca di nuove particelle BSM



# Il rivelatore GBP

- Il rivelatore proposto per misurare il profilo del fascio utilizza due sensori a micro-strip di zaffiro con passo 100 um di 2x2 $cm^2$, con le strip ortogonali
  - zaffiro è un buon match  per un fascio intenso con fino a $10^9$ fotoni per bunch, data:
    - notevole resistenza alla radiazione
    - corrente di leakage che non aumenta con la dose assorbita
    - bassa CCE che è compensata dal poter utilizzare di spessori sottili
- L'obiettivo è di arrivare ad una misura della larghezza del fascio < 10 um
- Sistema ottimale per la misura consiste di DUE STAZIONI completamente strumentate
  - Ridondanza
  - Calibrazioni (movimenti micrometrici di un sistema rispetto all'altro mantenuto fisso)
- L'elettronica di readout utilizzata è il sistema FERS della CAEN



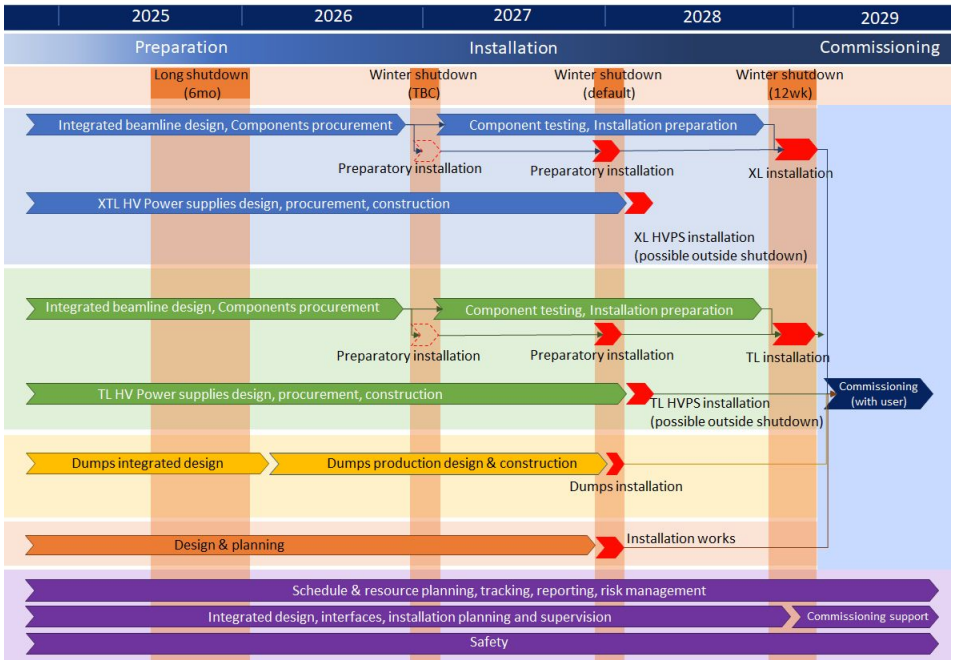
# Recenti avvenimenti

- **A seguito della guerra in Ucraina:**
  - **EU-XFEL ha messo in seconda priorità la realizzazione della linea di fascio,** che doveva essere usata inizialmente da LUXE, e non ha quindi più reso disponibili le risorse per realizzarla
  - La collaborazione ha **cercato di ottenere fondi** per sopperire alle principali necessità, sottomettendo due progetti a call Europee, ma a fine 2023 nessuno era passato
  - DESY non aveva risorse nel 2023 per finanziare la linea di fascio e quindi la **possibilita' di installare la linea nel 2025 è venuta meno**
    - al momento EU-XFEL non ha in programma altri shut-down di durata sufficiente per installare la linea del fascio che serve a LUXE
  - nel 2024, la CE ha comunicato che uno dei due progetti, **quello dedicato alla realizzazione della linea di fascio per LUXE (ELBEX) sarebbe stato finanziato** e si ritiene ora che potrà partire nel 2025, ma non prevederà più l'installazione della linea prima della sua conclusione

# Progetto ELBEX e contributo PD

- il progetto ELBEX viene ripescato dalla CE a inizio 2014
  - il Project Officer della CE alla fine accetta e viene discussa una nuova schedule con **partenza del progetto ritardata a gennaio 2025**
  - per i beam dumps prevediamo 1.5 anni di progettazione e 1.5 per la costruzione
  - avviata ora la negoziazione del Grant Agreement con la CE
- Electron beam dump
  - Cu + Al, as in the CDR doc.
  - INFN manpower needed: 0.7 FTE-year
  - critical aspects: **compatibility with limits on background**
- Photon beam dump
  - Pb: 1000mm x 500mm (diam.)
  - W: 600mmx300 mm (diam.)
  - INFN manpower: 0.3 FTE-year
  - **size should be the minimum possible to leave space for BSM detectors**

nuova schedule



# Attività GPB recente

- articoli accettati per la pubblicazione :
  - **TDR di LUXE**
  - articolo in cui si mostra come può essere parametrizzata l'intensità del laser $a_0$ in funzione delle distribuzioni angolari parallela e trasversa dei fotoni gamma in modo da poterla estrarre direttamente dalla misure fatte con il GBP:
    - sono stati studiati gli errori sistematici, mostrando che rimangono accettabili per $a_0 > 5$

arXiv > physics > arXiv:2402.03454

Physics > Plasma Physics

[Submitted on 5 Feb 2024]

**Dependence on laser intensity of the number-weighted angular distribution of Compton-scattered photon beams**

K. Fleck, T. Blackburn, E. Gerstmayr, M. Bruschi, P. Grutta, M. Morandin, G. Sarri

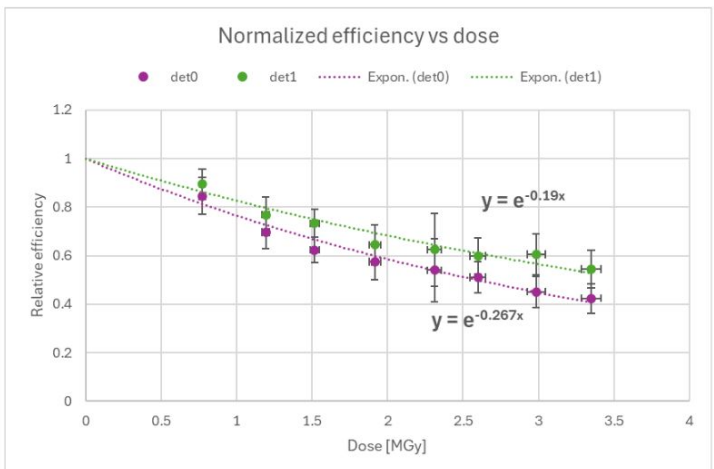
Inverse Compton scattering of an ultra-relativistic electron in the field of a high-intensity laser produces photon beams with angular and spectral distributions that are strongly dependent on the laser intensity. Here, we show that the laser intensity at the interaction point can be accurately inferred from the measurement of the angular number-density distribution of Compton-scattered photon beams. The theory, corroborated by numerical simulations, is accurate to within 10\% in a wide range of laser intensities (dimensionless intensity $5 \leq a_0 \leq 50$) and electron energies (250 MeV $\leq E \leq$ 15 GeV), and accounts for experimental features such as the finite transverse size of the electron beam, low-energy cut-offs in the photon detector, and the possibility of a transverse misalignment between the electron beam and the laser focus.

- misure di resistenza alla radiazione eseguite a CLEAR nella primavera del 2024 sono stati presentati al XVI Pisa Meeting e i proceeedings sono in corso di pubblicazione

**Development of a sapphire microstrip detector for gamma beam monitoring**

G. Avoni[c], M. Benettoni[d], M. Bruschi[c], A. Cian[e], F. Dal Corso[d], U. Dosselli[d], K. Fleck[a], E. Gerstmayr[a], M. Giorato[b], P. Grutta[b,d,*], F. Lasagni Manghi[c], B. Margesin[e], M. Morandin[d], G. Sarri[a], S. Vasiukov[d], M. Zuffa[c]

[a] Centre for Light-Matter Interactions, School of Mathematics and Physics, Queen's University Belfast, BT7 1NN, Belfast, United Kingdom
[b] Department of Physics and Astronomy, University of Padova, Via Marzolo, 8, 35131, Padova, Italy
[c] INFN Bologna, Viale Carlo Berti Pichat, 6/2, 40127, Bologna, Italy
[d] INFN Padova, Via Francesco Marzolo, 8, 35131, Padova, Italy
[e] Fondazione Bruno Kessler, Trento, Italy



# Prospettive

- in questo momento LUXE non ha una più **una timeline definita**
  - stiamo lavorando nel Collaboration Board per definire **una roadmap** che possa motivare la collaborazione a proseguire le attività, ma non e' detto che ci si riesca
- noi vorremmo comunque **terminare l'R&D sul sensore a micro-strip**, migliorando il sistema di trasmissione dei segnali e facendo poi un test finale nel 2025, probabilmente a LNF, per la caratterizzazione finale delle prestazioni
  - il rivelatore a zaffiro puo' trovare applicazioni in esperimenti simili, come anche per applicazioni in generale di monitoring di fasci intensi, carichi o neutri
- abbiamo considerato la possibilità di trasferire l'attività in GR. 5, ma sembra in questo momento più sensato che essa rimanga ancora per un anno in CSN1, anche in attesa di capire se LUXE avra' un possibile futuro.

# Partecipazione LUXE 2025

- missioni
- consumo per nuove transition boards e cavi
- partecipazioni a PD(FTE):
  - 0.5 S. Vasiukov
  - 0.5 M. Morandin
  - 0.1-0.2 P. Grutta
  - M. Giorato + Dal Corso
  - 0.4 Benettoni + disegnatori
-

# Servizi di Sezione

- Impegno sui beam dump (progetto Europeo)

- Montaggio movimentazione meccanica I stazione
  - 1 m.u. O.M.

| Servizio | Attività | Durata | Periodo |
|---|---|---|---|
| Calcolo e reti | | | |
| Elettronica | | | |
| Meccanica | La produzione dei pezzi meccanici si prevede venga eseguita da ditte esterne. Possibili attività da svolgere presso l'OM riguardano l'assistenza nei test di assemblaggio e di contatto termico fra il core di alluminio e ls shell in rame, | 2 mesi-uomo | 2026-2027 |
| Servizio Progattazione Meccanica | Progettazione dei due beam dump, preparazione e gestione tecnica delle gare, effettuazione controlli e misure di validazione, spedizione a DESY e collaborazione per l'installazione finale. | 14 mesi-uomo | 2025-2027 |


INFN

# MUONE

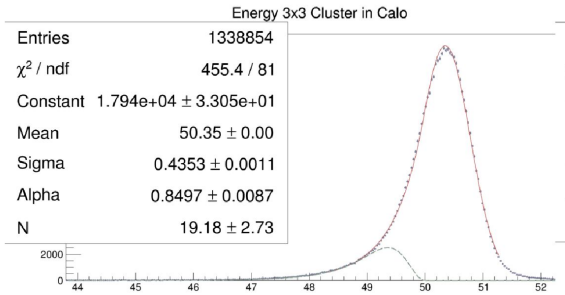
E. Conti

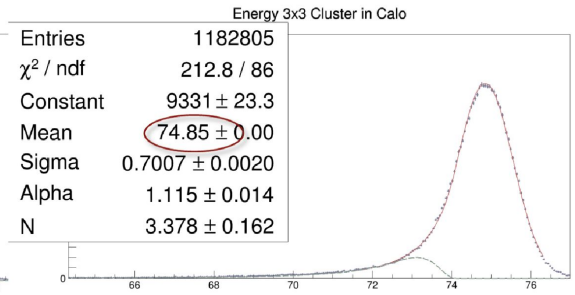
# Activity 2023

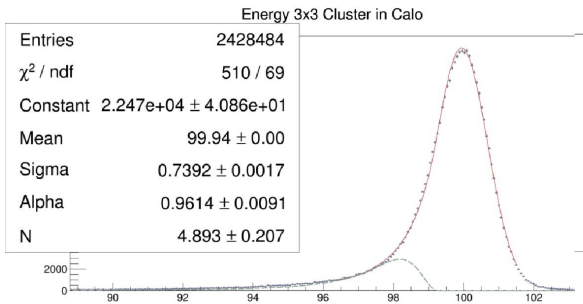
- ECAL Calibration test beams at low energy (CERN beamline T9) and high energy (CERN, beamline H2)
- test beam in M2 beamline with MUONE prototype (2 Tracker stations, 1 target) and high intensity muon beam

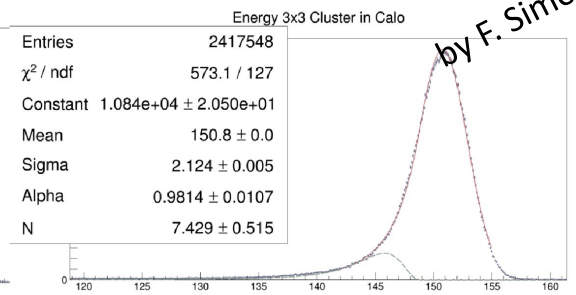
# ECAL calibration analysis results

## Results after laser correction




Correct gain in each crystal, 75 GeV run only

- The core resolution is compatible with the beam width

| E beam (GeV) | 50 | 75 | 100 | 150 |
|---|---|---|---|---|
| sigma( E )/E (%) | 0.86 | 0.94 | 0.74 | 1.40 |

- Laser calibration allows the correction of a tiny non-linearity observed at 75 GeV (only)
  - LE runs
    - Crystal gains do not scale, with differences as large as factor two
    - Laser does improve a bit, but it does not allow for a full correction

by F. Simonetto

At High Energy, Resolution is 1-2%, comparable to beam momentum spread, so need a better beam  TB2024

Low Energy calibration not good, possibly due to internal mechanical movements and change of optical coupling APD-crystal originated during the transportation of the ECAL from one site to another

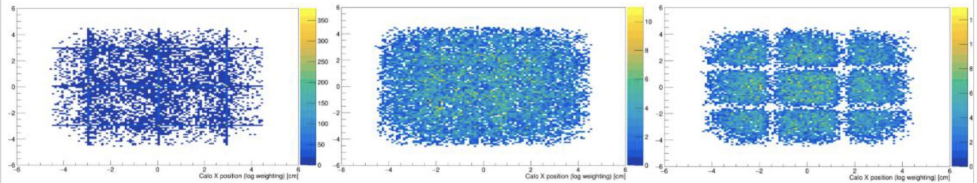
# ECAL Position resolution (1)

- in 2022, Test beam with Tracker station in front of ECAL @E = 40 GeV

## X reconstruction algo in MC

**Reconstructed calorimeter hit positions**

- Centroid algorithm from LOI: $\vec{x}_{PoI} = \frac{\sum_i w_i \vec{x}_i}{\sum_i w_i}, \quad w_i = \max\left\{0, \left[W_0 + \ln\left(\frac{E_i}{E_T}\right)\right]\right\}$



- $W_0$ = 4.0: too small
- Events pushed to crystal centers

- $W_0$ = 5.4: near ideal
- Most uniform distribution, but still not perfectly uniform

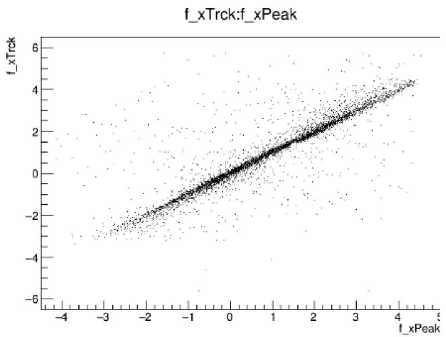
- $W_0$ = 7.8: too large
- Events pushed away from crystal boundaries

4.0 used in the previous analysis

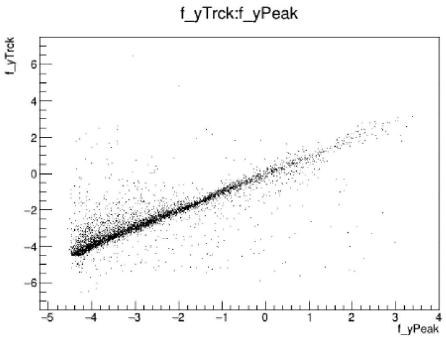
(Frederick Grey)

## Correlation plots

X(Tracker) vs X(Calo)




Y(Tracker) vs Y(Calo)




The beam was
well centered along X
displaced toward the bottom (Y)

by F. Simonetto

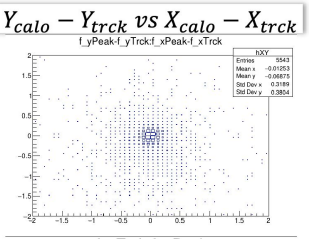
# Position resolution (2)

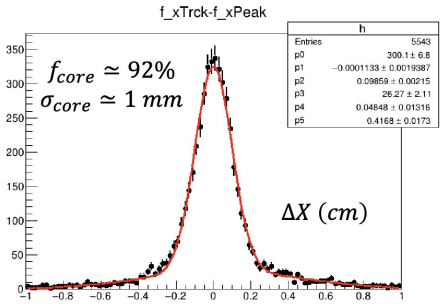
## Resolution Plots

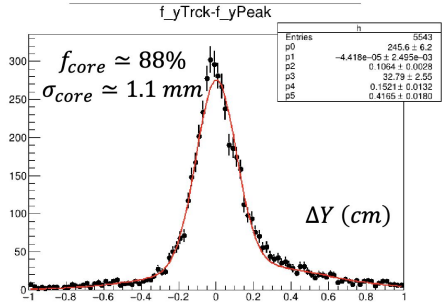


- Fit with double gauss function to match the tails

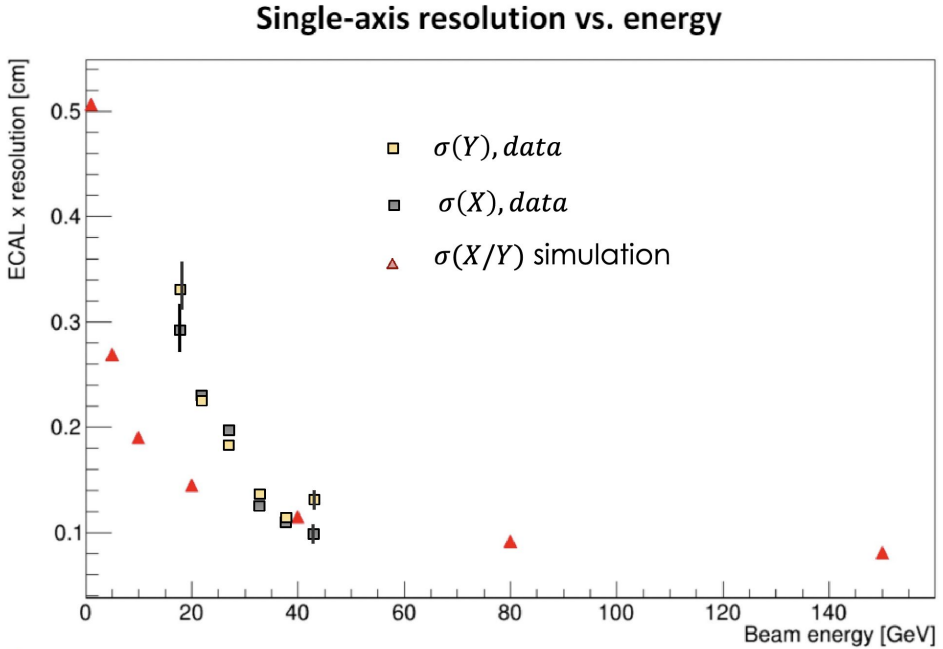
$Y_{calo} - Y_{trck}$ *vs* $X_{calo} - X_{trck}$




## Comparison with MC (F.G.)



# Position resolution (3)

## Conclusions



- The shower reco algo needs optimization
  - Simulation favors W0 ~ 5.4
  - Data at high and very high energy prefer ~ 4.5 (4.8 used)
  - About 5000 events collected in 2022 allow a simple comparison between tracker extrapolation and calo reconstruction. With those we obtain:
    - $\sigma(X) \sim \sigma(Y) \sim 1\ mm$ @ $40\ GeV$ , consistent with MC
    - Energy dependence is observed, resolution looks definitely worse than expected at low energy
    - O(%) loss in the support structure is not an artifact of the algorithm
  - New $e$ data with precise tracking is badly needed for a proper comprehension of the detector performances

# Activity 2024: proposal

- we wrote the **proposal** for MUONE-phase 1 or "MiniMUONE":
  3 tracker stations, 2 targets, ECAL (+ muon ID detector)
  document available CERN-SPSC-2024-015 / SPSC-P-370 (2024)
  submitted to the CERN SPSC for formal approval of the experiment. We expect a decision in autumn.

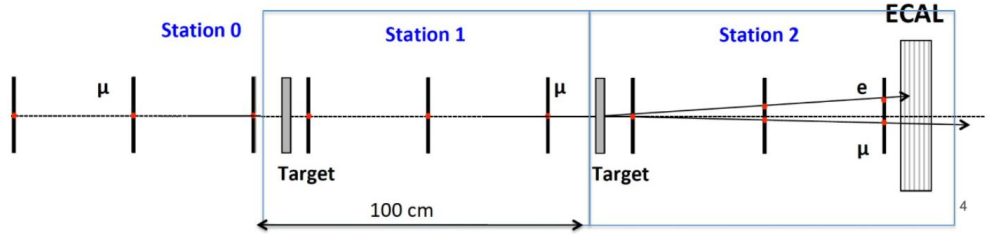



**Fig. 4:** (*Not to scale)* A schematic of three tracking stations, the configuration which will be used in the 2025 running (there will be 40 such stations in the final apparatus). As explained in the text, in each station the position measurement utilises two sensor layers, so there are 12 sensor layers in each tracking station.

In addition to measuring elastic events, an important supplementary goal is to study backgrounds and systematic errors, in view of the fact that the final experiment must understand systematic uncertainties with very high precision, comparable to the expected $\sim 0.3\%$ statistical error.

Data collected in 2025 will also be used for development of analysis tools since many detector parameters, such as tracking system acceptance and efficiency, and angular resolution, can be obtained from data, supplemented by well understood simulations.

# Activity 2024: beam tests

- *ongoing*: ECAL precise Calibration at CERN beamline H6, with beam momentum spread < 1%
  1 week at mid July
- new Run with 2 Tracker stations and 1 target at M2 beamline, very high intensity muon beam, preparatory for the "MiniMUONE" 2025 run. We attempt to measure alpha leptonic running
  2 weeks in Sept-Oct
- Improvements/developments wrt last year:
  - hopefully better ECAL calibration;
  - better zero suppression filter (a.k.a. trigger) for scattered electron trigger

# Activity in 2025

- MUONE collaboration:
  Beam test:
  (if approved by SPSC) in M2, 4 weeks run with the Mini-MUONE to measure:
  $\Delta\alpha_{lep}$ to ~ 0.2% precision
  $\Delta\alpha_{had}$ with O(20%) precision

- Padova:
  data analysis;
  MC studies: ECAL capable to measure $\Delta\alpha_{had}$ alone with similar sensitivity;
  DAQ: upgrade of ECAL standalone DAQ to speed up acquisition rate (standalone)

# Anagrafica – Risorse sezione - Budget

| Name | % 2025 |
|---|---|
| Benettoni | 10 |
| Conti | 100 |
| Mastrolia | 10 |
| Montecassiano | 30 |
| Passera | 10 |
| Ronchese | 30 |
| Simonetto | 30 |
| Lusiani | 10 |
| Rossin | 20 |
| **TOTALE FTE** | **2.5** |

(2.45 in 2024)

**Risorse sezione:**
1 m.p. Elettronica (Nicoletto)

**Richieste finanziarie:**
Missioni: 4 settimane x 3 persone @CERN + riunione di collab
 20 kEu
Consumo/computing: PC per sviluppo DAQ + varie  5 kEu

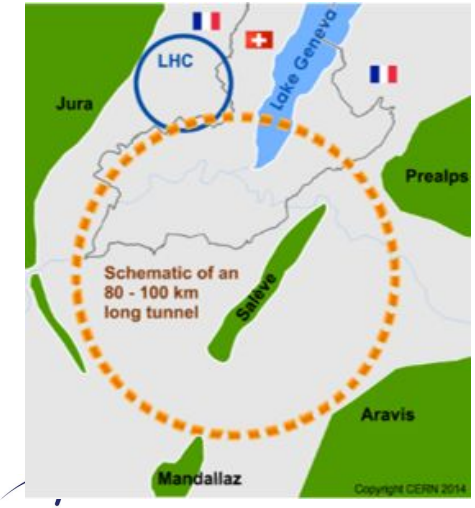

# RD-FCC @PD

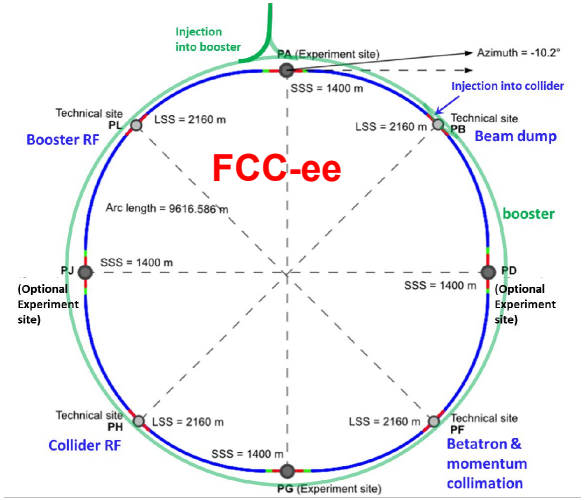
**RL: Patrizia Azzi(INFN)**

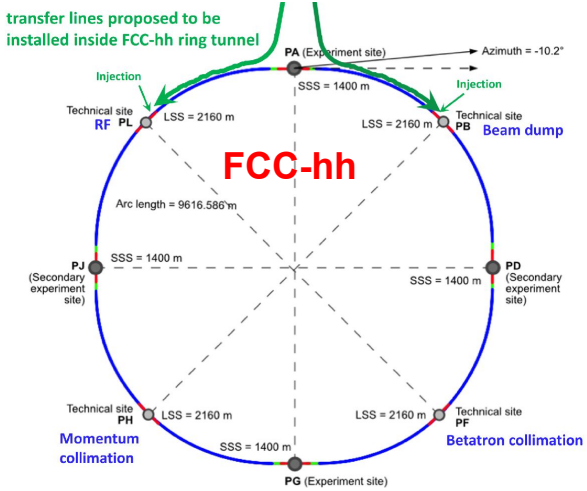
# Il progetto FCC

**Progetto a lungo termine per massimizzare l'output di fisica: tunnel di 90.7km che ospiterebbe:**

- **stage 1: FCC-ee (Z, W, H, ) as Higgs factory, electroweak & top factory at highest luminosities**
- **stage 2: FCC-hh (~100 TeV) as natural continuation at energy frontier, pp & AA collisions; e-h option**
- Inizio previsto dopo il termine di HL-LHC. Progetto simile in Cina: CepC/SppC
- **Strategia Europea inizierà nel Marzo 2025.**




2020 - 2040 | 2045 - 2063 | 2070 - 2095

# Attività a Padova

## Vari fronti

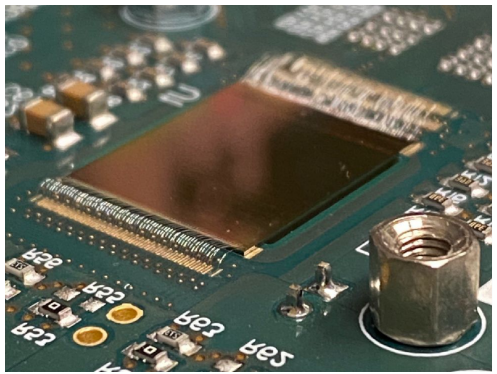
- **Hardware:** studio sensori monolitici (sinergie con ex-Arcadia/IGNITE e ALICE)
  - Partecipazione a DRD7
- **Software:** simulazione, ricostruzione ML, e validazione per rivelatore IDEA
- **Analisi di Fisica:** interesse di studi di ricerca di particelle FIP (HNL, altro)
- **Responsabilita'**
  - P. Azzi :
    - Coordinatore RD-FCC WG1 "Software e Fisica" per CSN1
    - Coordinatore "Physics Performance" di "FCC Physics Experiment and Detector" (CERN)
    - Convener del ECFA-WG2 per attività Higgs/EWK/Top Factories

# RD-FCC - R&D on MAPS

ARCADIA

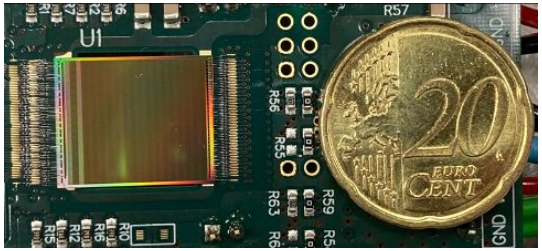
INFN

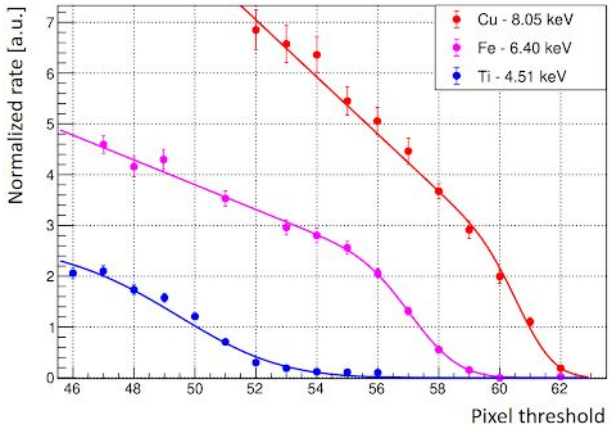
- **The ARCADIA collaboration (2019-2022) has developed a full-chip prototype targeting requirements for different applications (future colliders, space, medical)**
  - Low power→ O(20 mW cm−2) in high rate mode
    - Scale down to O(10 mW cm−2) in Low Rate mode for space applications
  - Small pixel pitch → 25 × 25 μm2
  - Thin sensors → 100 μm
  - Scalability to large area → up to 4 × 4 cm2
  - High particle rate→ up to 100 MHz cm−2
  - Timing resolution → O(1 μs)
    - Investigating more advanced solutions for O(10 ns) timing
- **Sinergie con sigla IGNITE**
- **Sensori da utilizzare per rivelatore di vertice a FCC-ee**

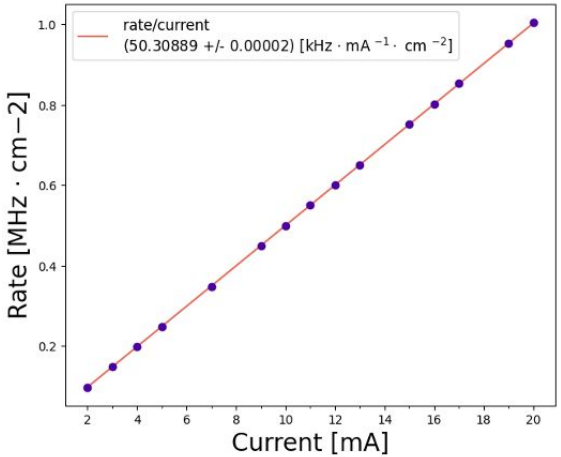


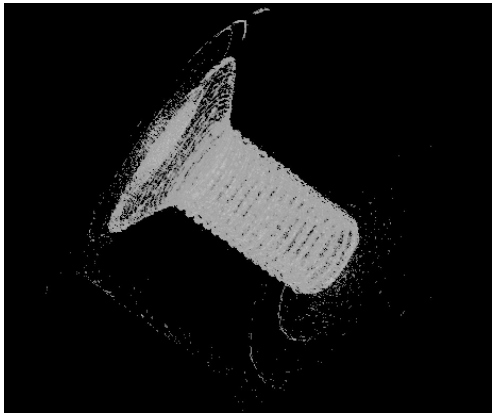
# RD-FCC - R&D on MAPS

- Attività 2023:
  - Acquisto di un alimentatore HV multicanale su fondi di Dotazione Gr 1 (CAEN WDT5519EXMAA, 4.5k€ + iva)
  - Installazione del setup per leggere un singolo chip
  - Misure con raggi X (studio della soglia, stima del particle rate sostenibile, ricostruzione tomografica di un'immagine)



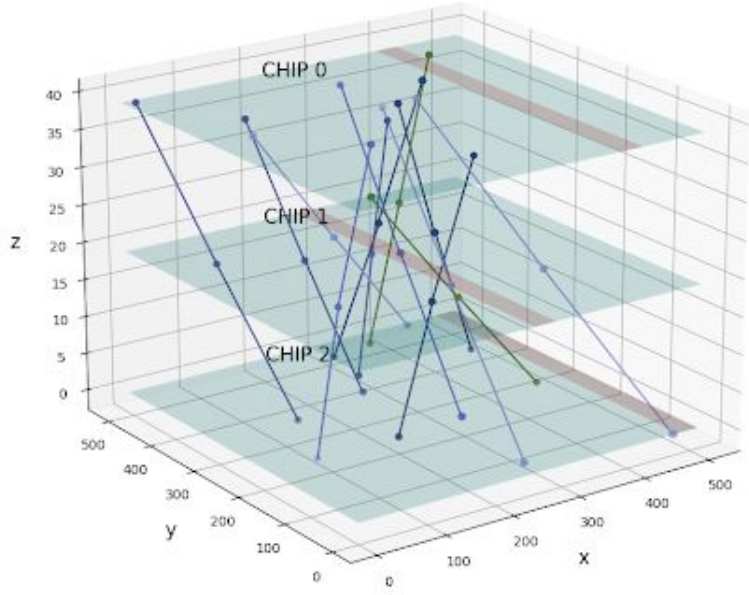



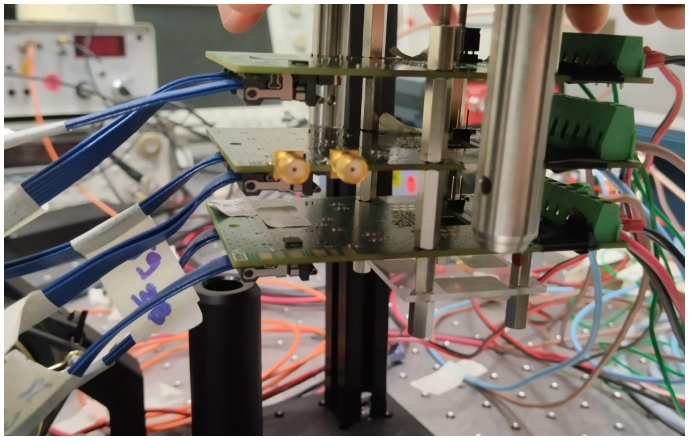



# RD-FCC - R&D on MAPS

- Attività 2024:
  - Misure IV-CV su strutture di test
  - Preparazione del setup per un telescopio a 3 piani e tracking di raggi cosmici
  - Test-Beam @ FNAL (26 giugno-2 Luglio) con MIP (protoni da 120 GeV) per misura di efficienza di tracking e risoluzione spaziale
  - Test-Beam @ CERN in Agosto (completare le misure non coperte nel testbeam di FNAL)
- Attività 2025:
  - Test-Beam con protoni da 230 MeV (CNAO/Trento)



# Attività Software & Fisica

- **Sviluppo simulazione** rivelatore di vertice (co-supervision Master Student Lione), **ricostruzione** tracce con ML in vertex+drift chamber IDEA (2 studenti Master internship PD e PD/CERN)
  - Task sinergica con AIDA-INNOVA 12.5.2 terminata
  - **Analisi per ricerca di Heavy Neutral Lepton**. Articolo in preparazione (collaborazione con KIT)
- **Preparazione del Final Report** del Feasibility Study per la Strategia per il Marzo 2025.
  - P. Azzi editore sezione “Detector Requirements”
  - Pubblicazione Mid-term report in Dec 2023
- **Organizzazione “2nd FCC France-Italy Workshop”** a Venezia 4-6 Novembre 2024.
  - https://agenda.infn.it/event/37960/

# Richieste 2025

| Capitolo | Descrizione | Parziali (k€) | | Rimuovi | Modifica | Totale (k€) | |
|---|---|---|---|---|---|---|---|
| | | Richieste | SJ | | | Richieste | SJ |
| consumo | Produzione e assemblaggio di board per i test di Surface Damage e Total Ionizing Dose sulle strutture dell'MD3 (Il tubo per la macchina a raggi X da utilizzare per questi test richiesto a IGNITE) | 2.00 | 0.00 | | | 2 | 0 |
| missioni | Responsabilita' (P. Azzi) : Coordinatore "Physics Performance" FCC-ee PED (https://fcc-ped.web.cern.ch/content/ped-study-coordination) Coordinatore WG2 "Physics Analysis and methods" ECFA "Future ee EWK/Higgs/Top Factories (https://ecfa.web.cern.ch/ecfa-study-higgs-ew-top-factories) | 4.00 | 0.00 | | | 19 | 0 |
| | Partecipazione a test beam a Trento, protoni 200MeV | 2.00 | 0.00 | | | | |
| | Metabolismo per 3.0FTE (3.0x1.2)= 3.6 arrotondati 3.5 Conferenze/Workshop/Meetings: 4.5x3FTE=13.5, di cui 9.5 assgnati e 4.0 SJ | 13.00 | 0.00 | | | | |
| **Totale** | | | | | | 21 | 0 |

# Anagrafica RD-FCC

- Molti progressi e ottima attivita' sui MAPS (sinergia con IGNITE e ALICE)
- Nuovo lavoro anche su software di ricostruzione per FCC con Master Students
  - due stagisti nel 2024 (A. De Vita "CERN Training program", C. Paris "Borsa G. Cecchettin"

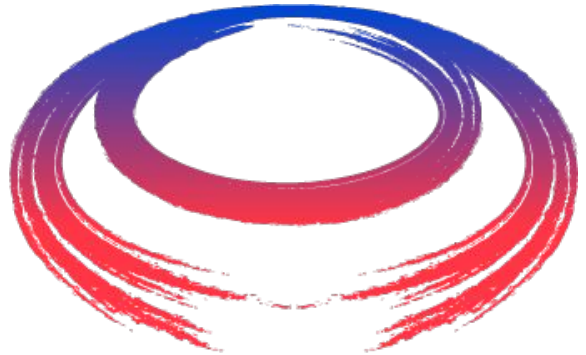
| Table 1-1 | | | |
|---|---|---|---|
| **ANAGRAFICA** | **Percentuale %** | **Synergies** | **NOTE** |
| **Azzi Patrizia** | 30 | | |
| **Bacchetta Nicola** | 10 | | |
| **Carlin Roberto** | 10 | | |
| **Fanzago Federica** | 10 | | |
| **Piero Giubilato** | 0 | 10 | IGNITE |
| **Margoni Martino** | 10 | | |
| **Mattiazzo Serena** | 0 | 10 | IGNITE |
| **Rossin Roberto** | 10 | | |
| **Tosi Mia** | 20 | | |
| **Wyss Jeffery** | 30 | 50 | IGNITE |
| **Alessandra Zingaretti** | 30 | 70 | IGNITE |
| **TOTALE** | 160 | 140 | 0 |

# Richiesta per il Laboratorio Silici

- Richiesta di una micro-bonding machine manuale per la camera pulita del Laboratorio Silici al Piano Terra:
  - La macchina attuale è obsoleta (>30 anni, pezzi di ricambio ormai introvabili) e poco affidabile per produzioni di piccola/media scala;
  - La definizione del modello è in fase di indagine (ingombri, flessibilità, costi, etc)
- La richiesta e' supportata da una serie di gruppi che sono a vari livelli di studi di R&D e/o costruzione dei rivelatori:
  - EPIC(EIC) (Gr3)
  - CMS
  - RD-FCC
  - RD-MUCOLL
- Vorremmo un suggerimento su come inserire/menzionare  la richiesta nei diversi DB delle richieste delle varie sigle.

# RD MuColl

D. Lucchesi



International MUON Collider Collaboration

# RD_Mucol status

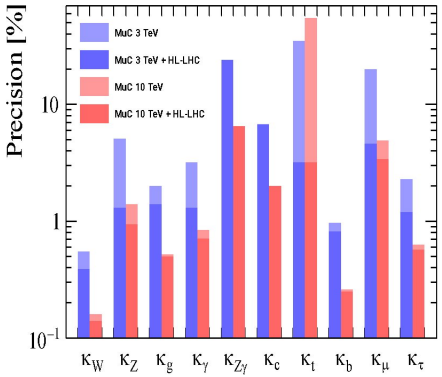
P5 report re-considered the US position on Muon Collider

*Although we do not know if a muon collider is ultimately feasible, the road toward it leads to a series of proton beam improvements and neutrino beam facilities, each producing world-class science while performing critical R&D* ***towards a muon collider****. At the end of the path is an unparalleled global facility on* ***US soil****.* ***This is our Muon Shot****.*

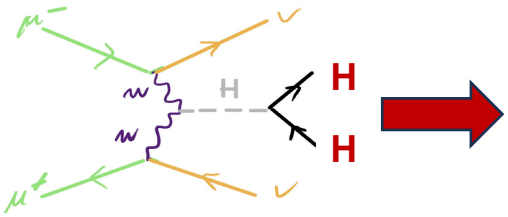
Progress in all the project areas documented in:
Towards a Muon Collider, *Eur.Phys.J.C* 83 (2023) 9, 864, 2303.08533
Experimentation at a Muon Collider submitted to *Annual Reviews of Nuclear and Particle Science*
M. Casarsa, D. Lucchesi, L. Sestini
Higgs Physics at a s√=3 TeV Muon Collider with detailed detector simulation submitted to *The European Physical Journal C,* P. Andretto *et al.*

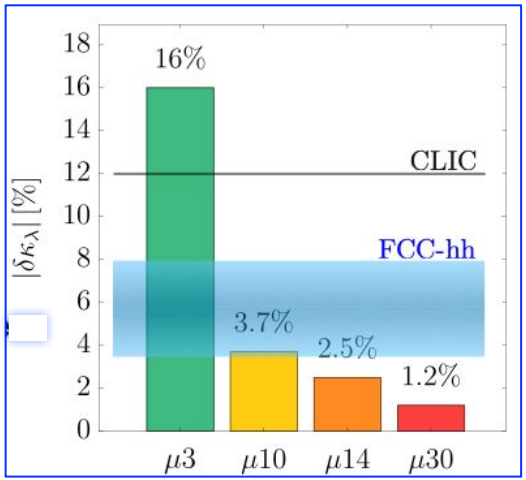
# Higgs boson physics possibilities

Fermions & bosons Higgs couplings measured at % level needed to test SM

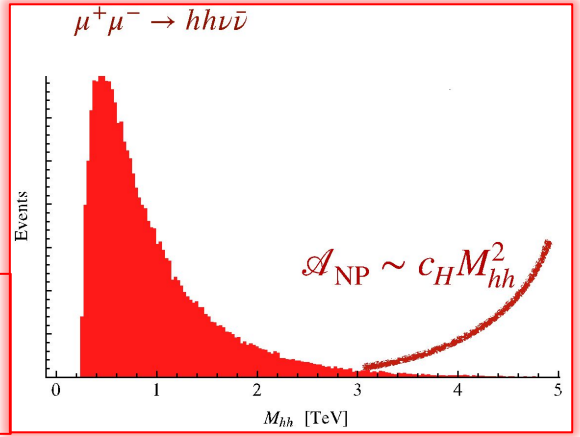



Trilinear Higgs coupling → access to the Higgs potential



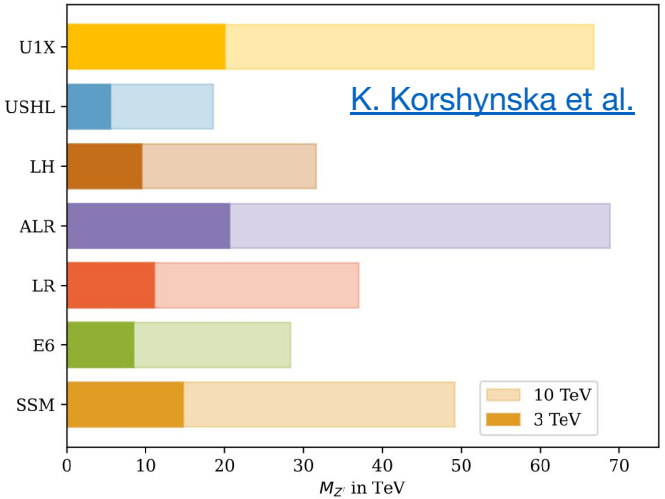

Most precise measurement with 10 $ab^{-1}$ ~5 years of data taking (FCC-hh 30 $ab^{-1}$ ~50 years)




New Physics effects can appear at high double Higgs invariant mass

# Zillions of other physics searches

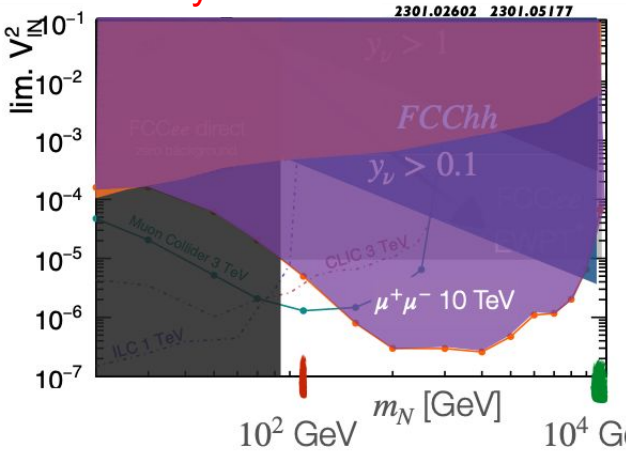
Effective $Z'$-model with new gauge boson couplings to the SM fermions

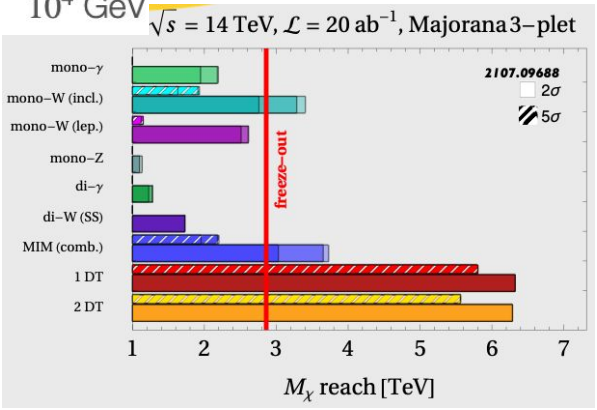



K. Korshynska et al.

Excluded masses at 95% CL:
MuC: up to 70 TeV
LHC: 5 TeV, HL-LHC: 8 TeV
Future $e^+e^-$: 20 TeV

Heavy neutrino



# Toward the update of the particle physics strategy

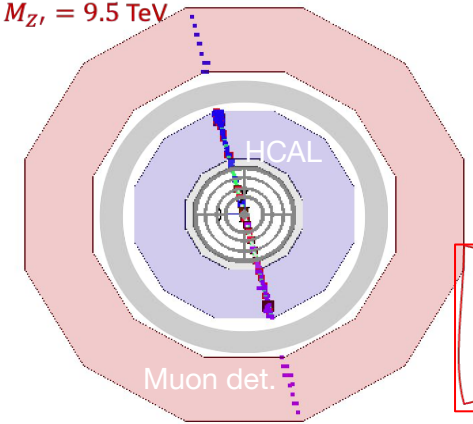
Documents describing:

1. Collider complex at two different center-of mass energies: 3, 10 TeV based on re-using the existing infrastructure in Europe.
2. Detector concepts for 10 TeV center of mass energies
3. R&D: accelerator and detector technologies
4. Demonstrator facility

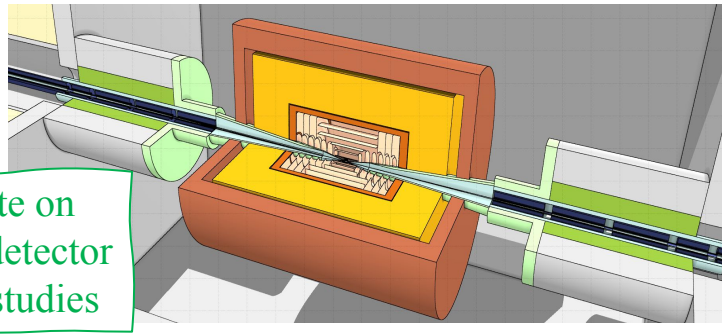
# Activities in Padova -1

$\mu^+\mu^- \rightarrow Z'X \rightarrow \mu\mu X \sqrt{s} = 10$ TeV

$M_{Z'} = 9.5$ TeV

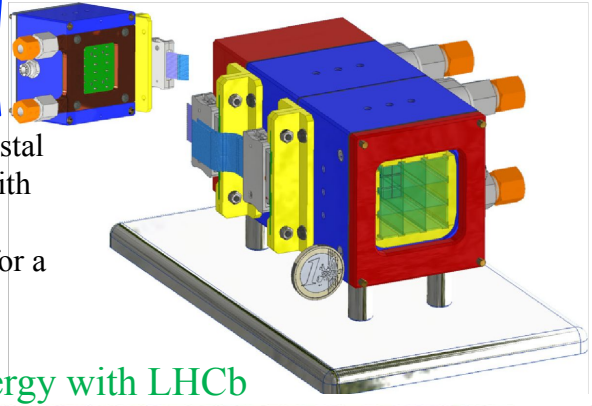



Study of detector & physics performance at $\sqrt{s} = 10$ TeV



Collaborate on machine detector interface studies

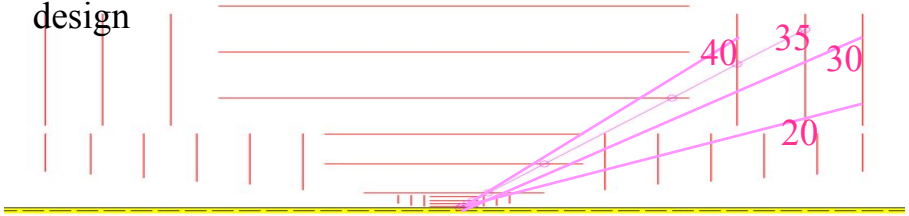
Participate to calorimeter design & tests beam



CRILIN: CRystal calorImeter with Longitudinal InformatioN for a future Muon Collider

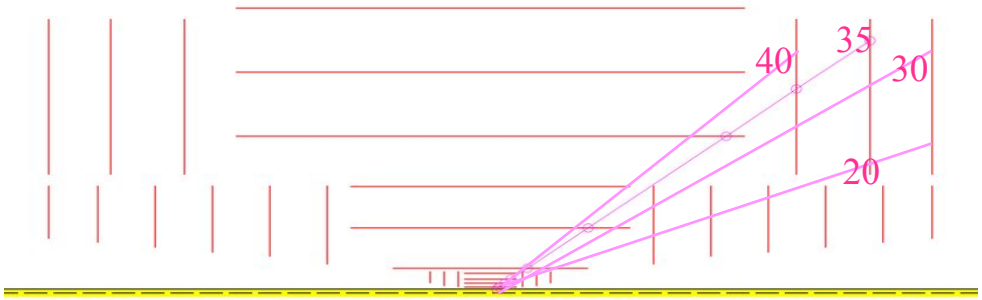
Sinergy with LHCb

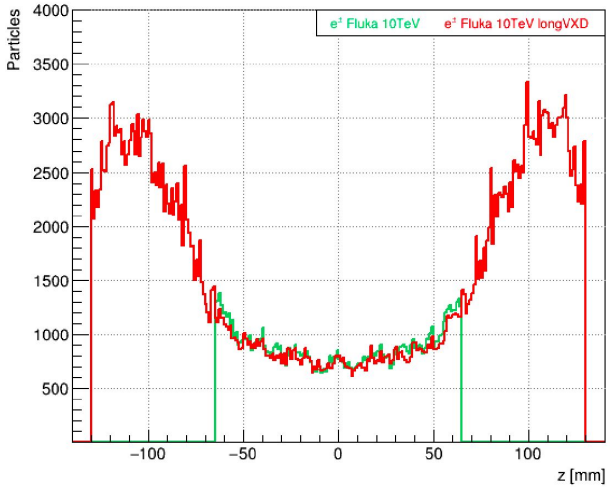
Tracker design



# Activities in Padova -2

Tracker design
Optimization of barrel layers and endcap disks to cope with high hits multiplicity in the forward region




Investigate the usage of MAPS technology with the Padova group

# Activities in Padova - 3

Software and computing: P. Andreetto, A. Gianelle
Activity: Support code, migrate to new tools,
manage the resources for the **whole collaboration**

**Software**
- HowTo
- Delphes Card
- Software installation
- Releases notes
  - v02-08-MC → April 2023
  - v02-07-MC → November 2021
  - v02-06-MC → March 2021
  - v02-05-MC → December 2020
  - v02-04-MC → November 2020
  - v02-03-MC → November 2020
  - v02-02-MC → October 2020
- Tutorials
  - CERN 2023
  - Fermilab 2022
  - Snowmass 2021

v02-08-MC → April 2023

## Risorse calcolo RD_MUCOL

L. Sestini

- **Cloud-Veneto**: 200 VCPU, 740 GB di RAM, ~100 TB di storage
- **CNAF**: batch system basato su HTCondor, 150 TB di storage, 6 CE
- **IBISCO-Bari**: risorse condivise con altri progetti allocate al momento della richiesta
- **CERN**: batch system basato su HTCondor, 300 TB di storage su CERN EOS
- **Risorse locali**: Farm Trieste (modalità opportunistica), Pavia etc.
- **Richieste 2024 (ancora da acquisire)**: 150 TB storage e 512 GB di RAM su Terabit/Cloud-INFN
- **Richieste 2025**: altri 150 TB di storage su Cloud-Veneto o Cloud-INFN

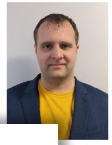
## The task force

Meet the members


Paolo Andreetto


Nazar Bartosik


Alessio Gianelle


Krizka


Lawrence Lee


Thomas Madlener


Federico Meloni (chair)

**Mandate**
**Review and re-organize software activities**

# Anagrafica

| | |
|---|---|
| Bertolin Alessandro | 30 |
| Calzolari Daniele | 100 |
| Collazuol Gianmaria | 10 |
| Ciarlantini Sabrina | 30 |
| Dorigo Tommaso | 10 |
| Dosselli Umberto | 15 |
| Lucchesi Donatella | 30 |
| Lupato Anna | 30 |
| Nardi Federico | 30 |
| Sestini Lorenzo | 30 |
| Zingaretti Alessandra | 10 |
| Zuliani Davide | 30 |
| | |
| | 3.55 |
| | |
| Andreetto Paolo | 25 |
| Gianelle Alessio | 45 |
| | 0.7 |
| | 4.25 |

A post-doc Qundong Han will arrive as soon as he will get visa and he will be partially LHCb and RD_MuCol

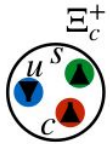
# TwoCryst

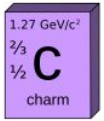
Stefano Lacaprara, INFN Padova

# Prova di principio dell’estrazione di fascio da LHC con due cristalli curvi

C. Maccani, G. Simi, A. Triossi, M. Zanetti, F. Borgato

# Obiettivi di fisica: MDM e EDM


- Misura preliminare per un esperimento dedicato alla misura del momento di dipolo elettrico (EDM) e magnetico (MDM) di barioni charmati $\Xi_c$ e $\Lambda_c$. Prima misura sperimentale.
  - Semplice modello a quark legati prevede MDM=$\mu_c$
  - Previsioni per MDM basate su HQET richiedono una precisione sperimentale del 10% per essere testate
  - le previsioni per l'EDM sono minuscole ~ $10^{-31}$ ecm

$\delta$= electric dipole moment (EDM)
$\mu$= magnetic dipole moment (MDM)

$$\delta = d\frac{q\hbar}{2m}\frac{S}{\hbar} \qquad \mu = g\frac{q\hbar}{2m}\frac{S}{\hbar}$$


Hamiltonian

$$H = -\boldsymbol{\mu}\cdot\boldsymbol{B} - \boldsymbol{\delta}\cdot\boldsymbol{E}$$

Time reversal, Parity:

$$d\mu_N \boldsymbol{S}\cdot\boldsymbol{E} \xrightarrow{T,P} -d\mu_N \boldsymbol{S}\cdot\boldsymbol{E}$$

The EDM violates *T* and *P* and, via *CPT* theorem, violates *CP*

- Produzione barioni charmati in collisione su targhetta fissa
- Purtroppo hanno vite medie brevi (0.2-0.4 ps) -> precessione nel channelling in un cristallo curvo

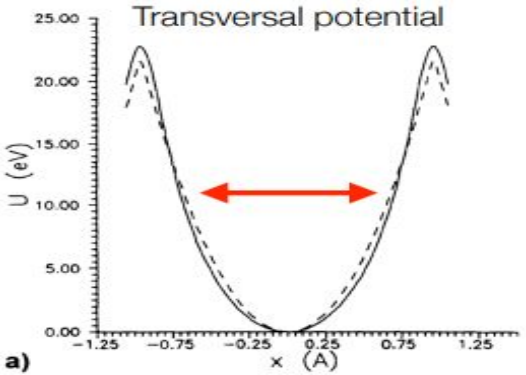
# Tecnica sperimentale: precessione in cristallo curvo

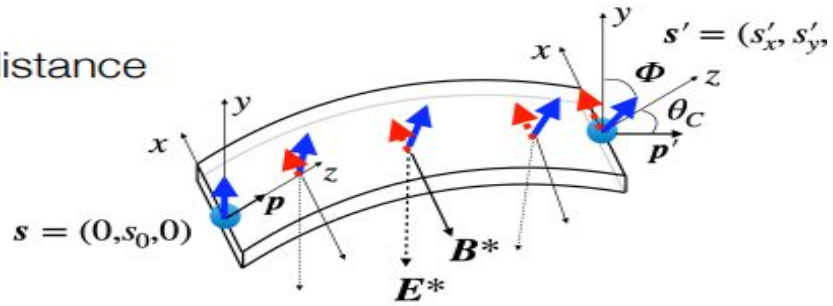
## Channeling in bent crystals

- Positively charged particles with momentum parallel to crystal plane (within few μrad) can be trapped
  - Electric field $E \approx 1$ GV/cm
  - Effective magnetic field B≈500 T
- **Steer** charged particles trajectories at a given angle
- Induces **spin precession** in short distance

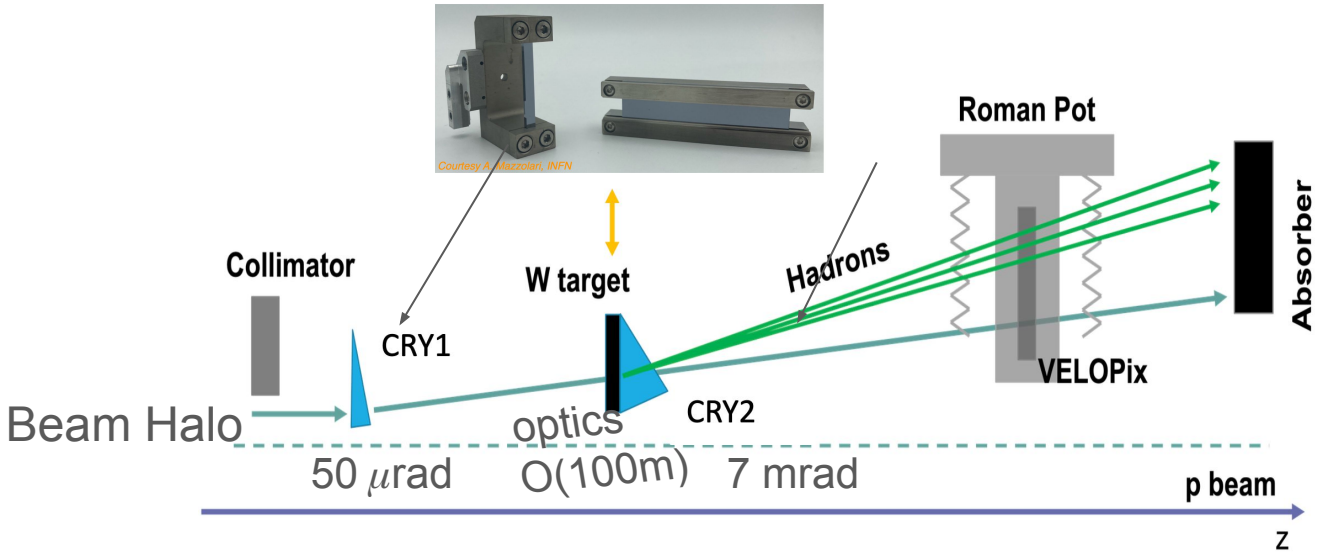
$$\Phi \approx \frac{g-2}{2}\gamma\theta_C$$

$$s'_x \approx s_0 \frac{d}{g-2}[\cos(\Phi) - 1]$$



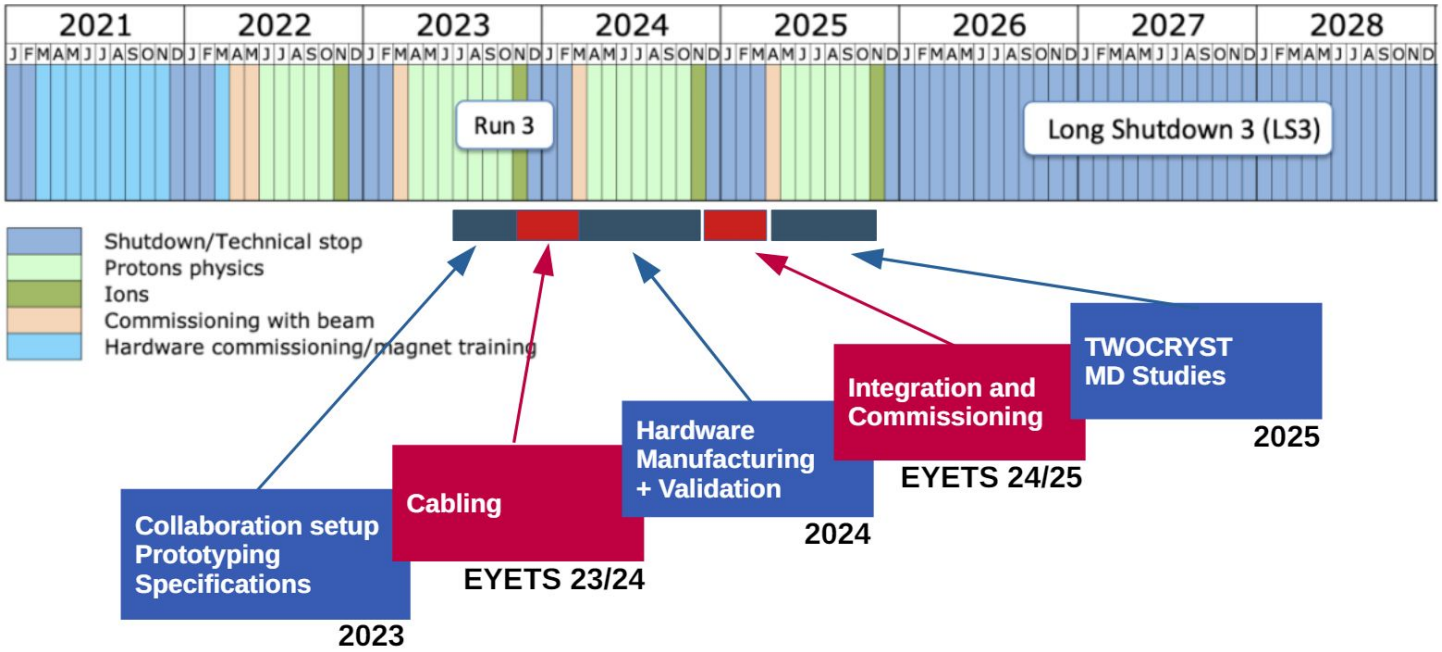
# Twocryst: estrazione del fascio di LHC con 2 cristalli curvi




Obiettivo: prova di principio dell'estrazione con due cristalli

- Dimostrare la fattiblità delle  operazioni di LHC a 1TeV
- Confermare il rate di protoni realizzabile
- Misurare l'efficienza di estrazione a energie del TeV
- Studiare i fondi
- Approvata dal LHC Machine Committe

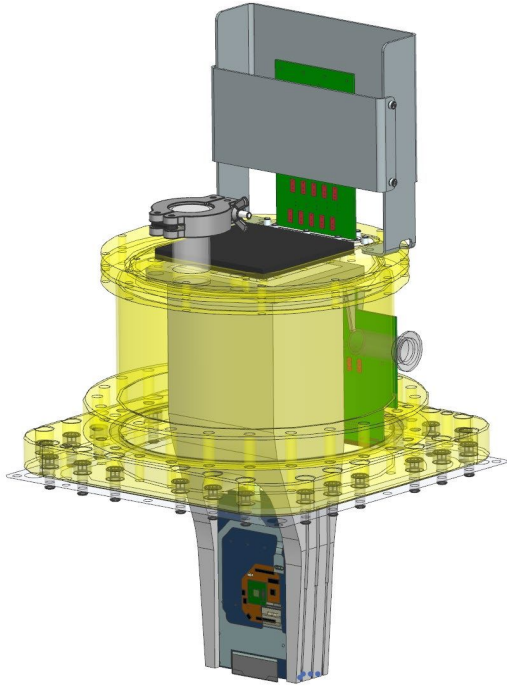
# Twocryst: sviluppo temporale

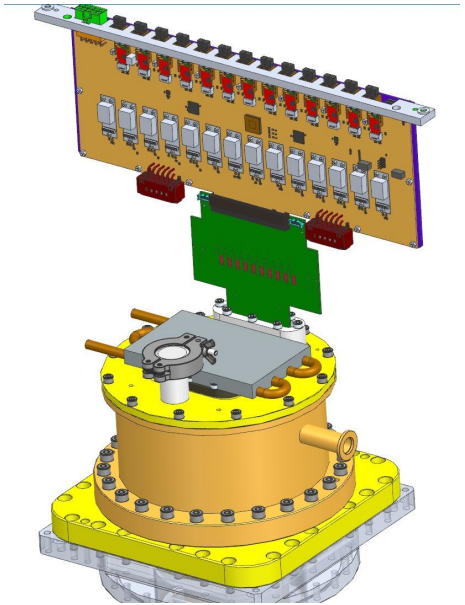


# Twocryst attività a Padova: VELO Pixel Tracker

M. Benettoni, G. Simi

- Integrazione Meccanica del rivelatore nelle Roman Pots
  - basate su design di Totem, rivelatore in vuoto secondario
- Sistema di Raffreddamento: 45W, temperatura rivelatore 20C





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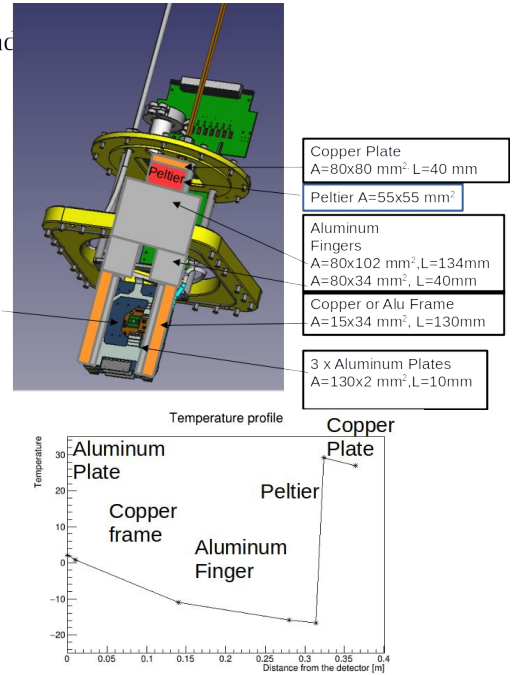
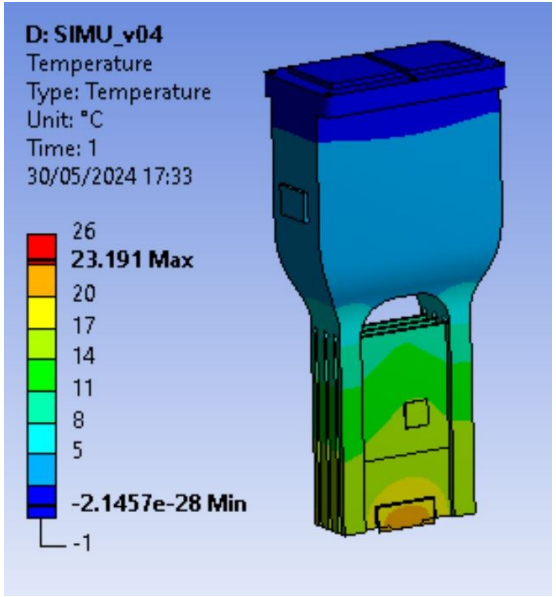
M. Benettoni, G. Simi

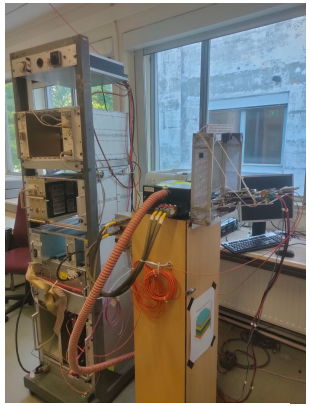
- Click to ad



# Twocryst attività a Padova: fiber tracker e validazione cristallo

C. Maccani, M. Zanetti

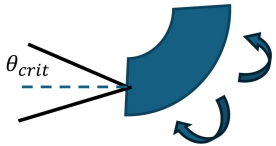


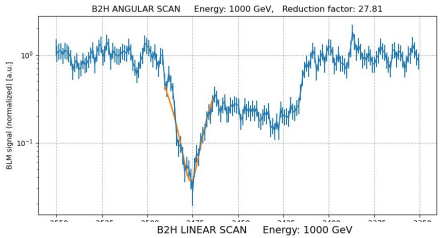
Fiber Tracker

- Goals:
  - reconfigure the electronics based on FPGAs and the DAQ system to TWOCRYST purposes
  - test the photomultipliers (without fibers)
  - All the electronics and hardware was mounted:
    - Power suppliers, DAQ modules
    - Black box, cooling, remote control

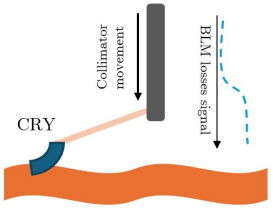
Validazione cristallo a LHC

- Scan angolare



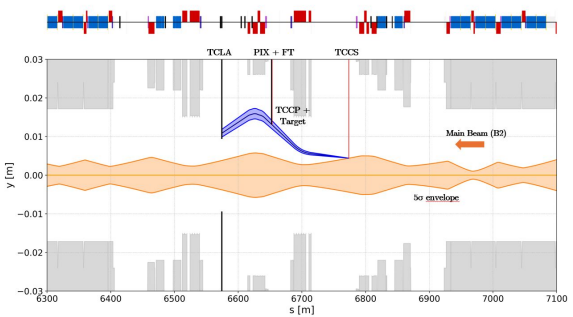

- Scan Lineare

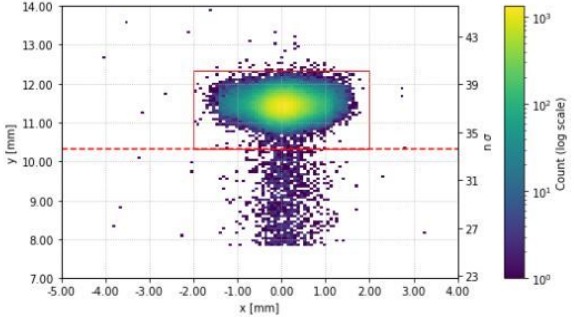


# Attività a Padova: MD Program e Simulazioni

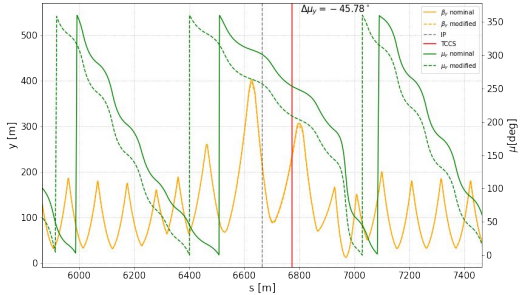
C. Maccani, M. Zanetti

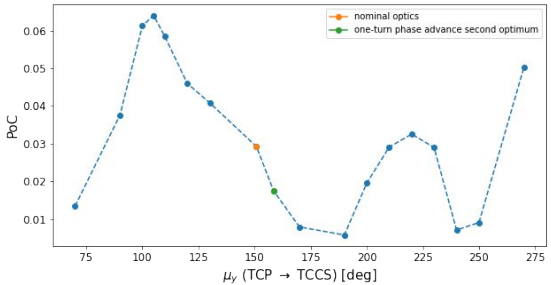
- Si devono validare i vari scenari di MD con la simulazione
- Beam dynamics, proton on target estimation, lossmaps checks



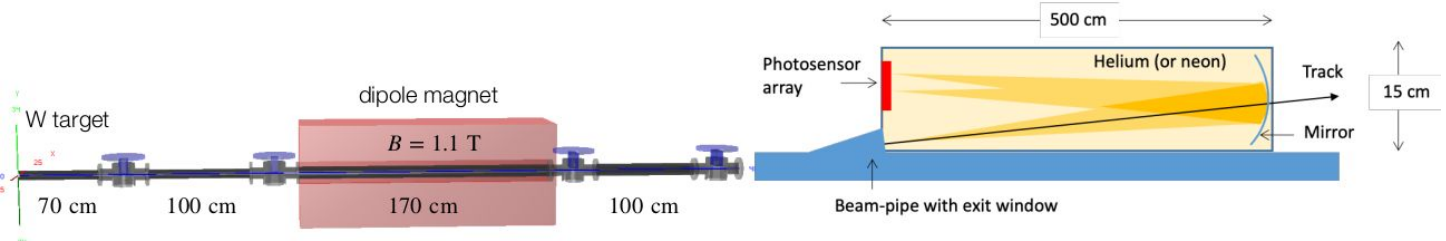

- Optics studies to optimize proton on crystal (PoC) and proton on target (PoT)



# Futuro: esperimento Aladdin (An LHC Apparatus for Direct Dipole Moment INvestigation)

- Iniziato setup della collaborazione per misura di MDM e EDM (LOI in preparazione)
- Se la prova di principio ha successo-> esperimento con $10^{13}$ PoT
- Zona sperimentale di twocryst (IR3) adatta per l'esperimento
  - Spectrometer: pixel detectors in 4 Roman Pot stations (440 cm length)
  - RICH: Helium radiator gas with SiPM photosensor array (500 cm length)




- Tracker: Risoluzione Dp/p=2% @ 500GeV, σθ=10urad, $\sigma_{xy}$=20um
- RICH: σθ = 42 μrad
- Physics reach: First measurements of charm baryon dipole moments in 2 years data taking assuming $10^6$ p/s
  - Sensitivity on MDM 2 · $10^{-2}$μN and EDM 3 · $10^{-16}$e cm with 1.4 · $10^{13}$ PoT
  - Exploration of τ g-2 and EDM (improvements are required)
  - ‣Additional physics topics: charm hadron cross-section measurements and J/ψ photo production in the very forward region at pseudorapidity η > 5

# Attività in sezione/anagrafica

- Sigla
  - La sigla passa da dotazioni a una vera sigla
- Servizi
    - finalizzazione integrazione modulo VELO nelle roman pot
      - 0.5 m.u. disegnatore meccanico
      - 1 m.u officina meccanica
- Richieste
    - Missioni
      - 1 m.u. per installazione
      - 1 m.u. per presa dati, workshop, test-beam
    - R&D RICH ~ 10kE
      - Discussione in corso (acquisto SiPM con pixel < 0.5 mm, elettronica per test beam, meccanica)

- Anagrafica
  - F. Borgato 10%
  - C. Maccani 100%
  - G. Simi 20%
  - M. Zanetti 10%
  - M. Benettoni 10%


RL. P. Giubilato

INFN Ground-up iNITiative for µElectronics development

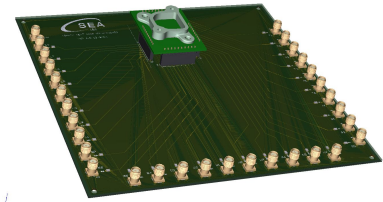
**Medium-to-large area ASICs, capable to read-out and process information from 4D pixel arrays (high density sensor arrays with precise timing capabilities)**

BA - Francesco Licciulli
BO - Davide Falchieri
CA - Adriano Lai
FI - Antonio Cassese
GE - Claudia Gemme
LNF - Paolo Ciambrone
MI - Alberto Stabile
MIB - Marcello De Matteis
**PD** - Piero Giubilato
PG - Mauro Menichelli
PI - Roberto Beccherle
PV - Gianluca Traversi
TIFP - Philippe Velha
TO - Luca Pacher

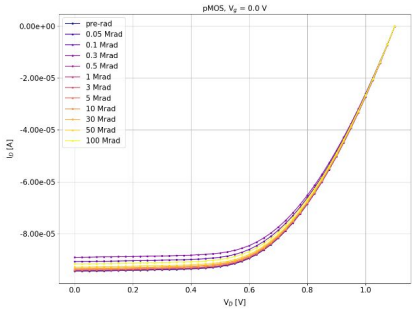
# IGNITE$_{\mu d}$ Padova 2024

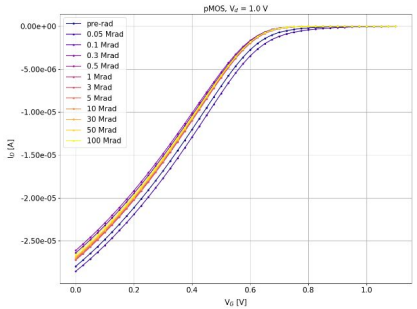
Test di Total Ionizing Dose su strutture di test in tecnologia CMOS bulk in 28 nm

- p-MOS e n-MOS
- W/L diversi
- Numero di finger diverse
- Rad dose up to 100 Mrad – dose rate = 3.8 Mrad/h

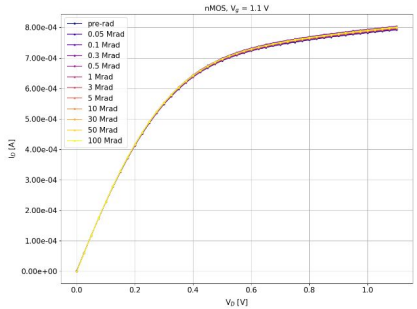


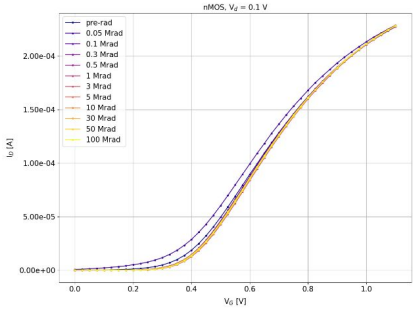
$I_d$-$V_d$ $I_d$-$V_g$ pMOS: W/L = 3um/1um, 2 fingers



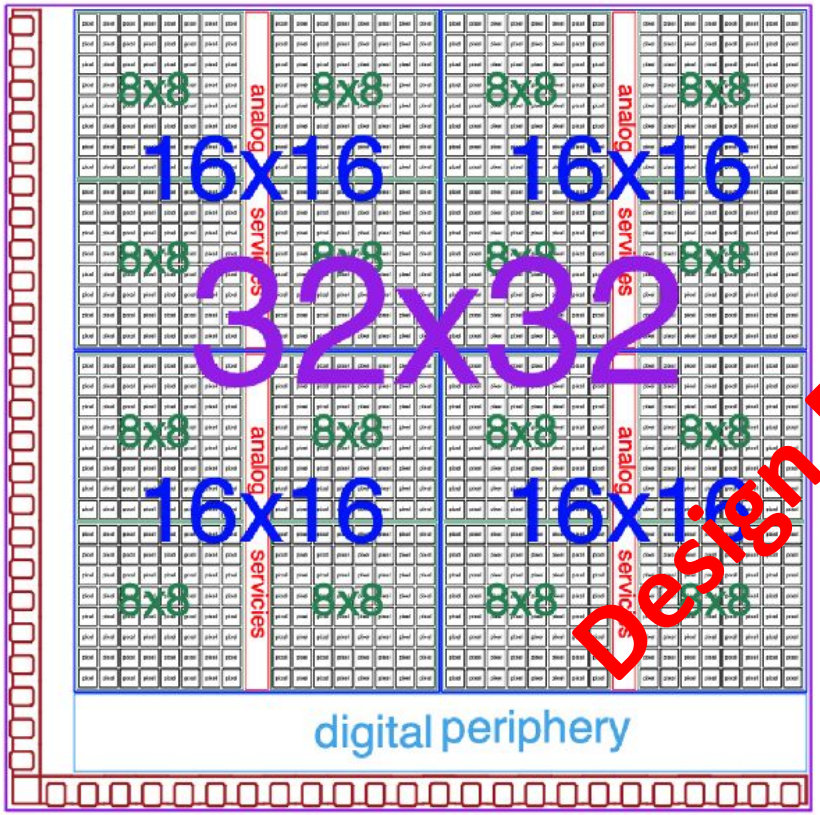

$I_d$-$V_d$ $I_d$-$V_g$ nMOS: W/L = 1um/60nm, 1 finger

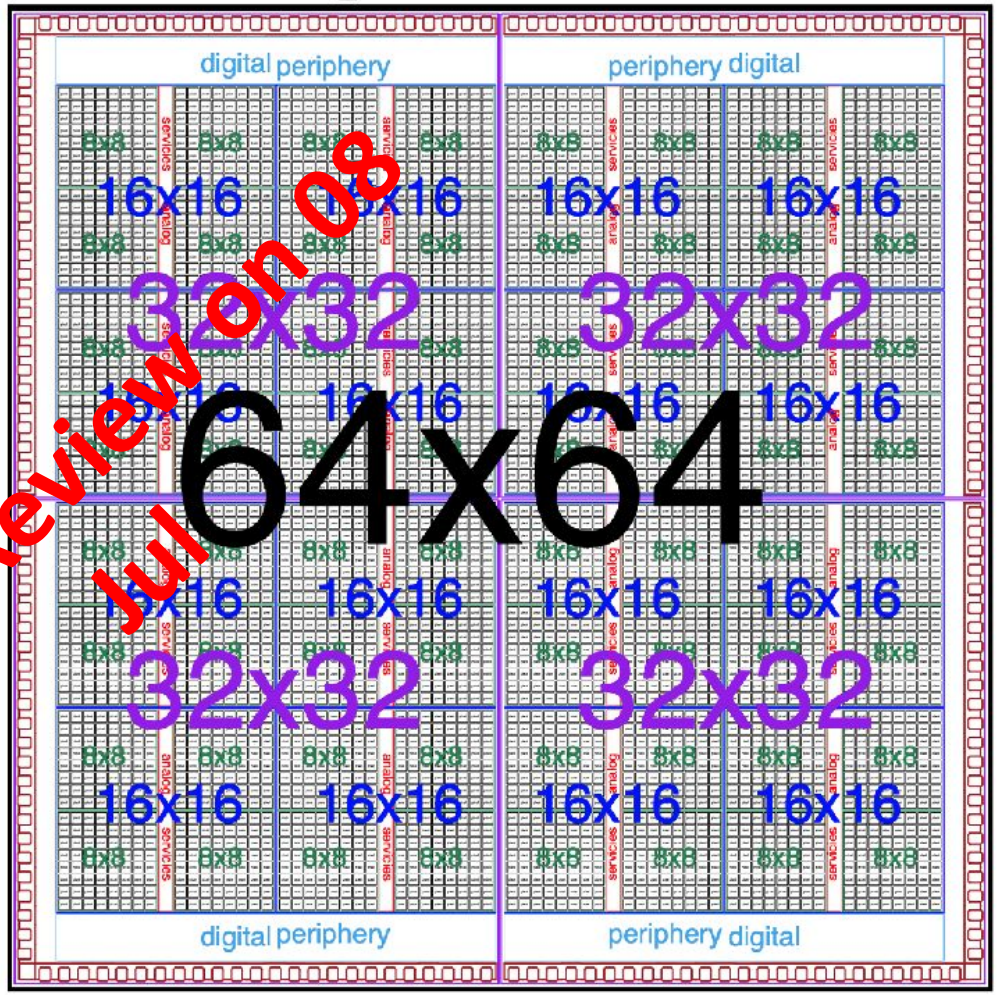



- Development of a nominal-size, detector-grade ASIC (≈1-2 cm$^2$) in CMOS 28-nm technology
- Silicon Photonics integrated device for high-bandwidth data communications

# IGNITE µd News 2025

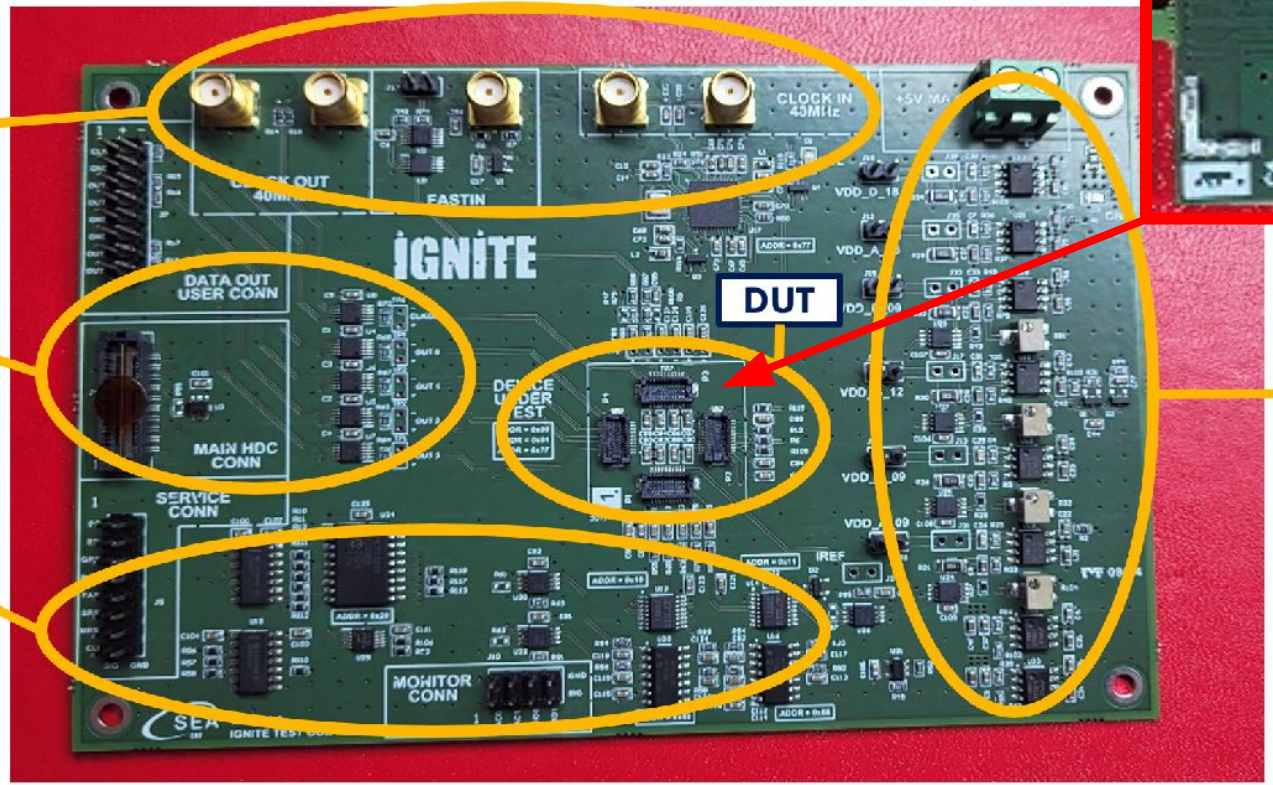



Design Review on 08 Jul

# IGNITED News 2025

Motherboard and mezzanine ready for sensor testing and characterization




# IGNITE µEd Padova 2025

## ANAGRAFICA (PD) 2025

| People | FTE |
|---|---|
| Bagatin M. | 20% |
| Bonaldo S. | 10% |
| Borgato F. | 10% |
| Candelori A. | 20% |
| Gerardin | 10% |
| Giubilato P. | 10% |
| Mattiazzo S. | 10% |
| Paccagnella A. | 15% |
| Vogrig D. | 10% |
| Wyss J. | 50% |
| Zingaretti A. | 40% |

## FINANZIARIA (PD) 2025

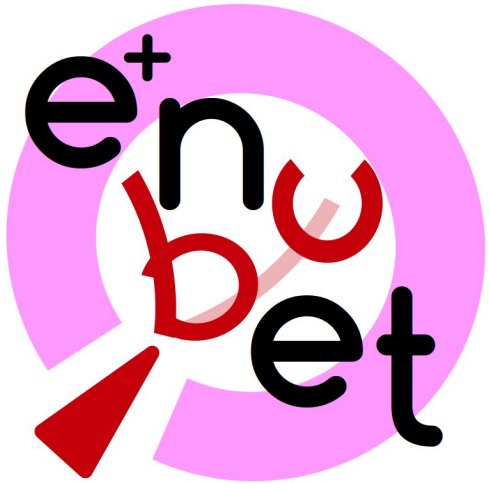
| Activity | funding |
|---|---|
| X-Ray tube | 6000 |
| Methabolism | 0 |
| Missions | 0 |

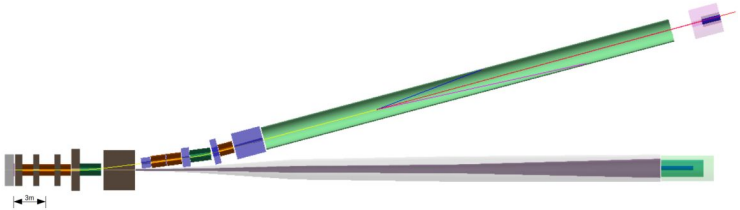
## SERVIZI (PD) 2025

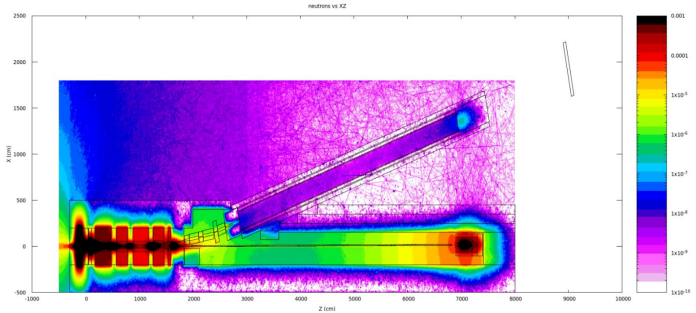
| Activity | funding |
|---|---|
| Lab. Elettronica | 1 m.u. |

# ENUBET_NP06

RL F. Pupilli





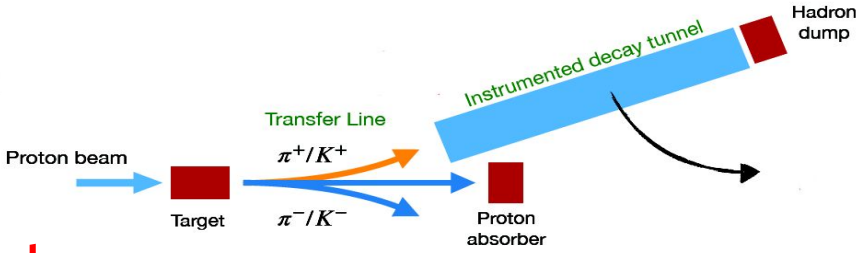


# ENUBET/NP06 presentazione Gr1-PD

- **Outline**
  - Goals of the project
  - Achievements in 2023-24
  - Foreseen activities for 2025
  - Group in Padova and requests

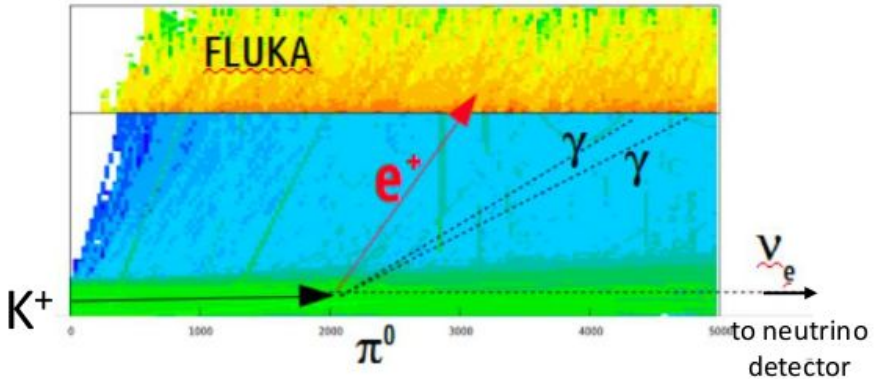
# Monitored neutrino beams

ENUBET the first **"monitored neutrino beam":**




**the production of neutrino-associated leptons is monitored at single particle level in an instrumented decay region**

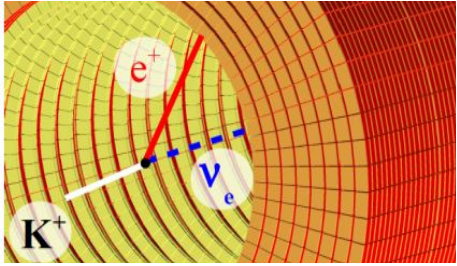
- **Instrumented decay region**
  $K^+ \longrightarrow e^+ \nu_e \pi^0 \longrightarrow$ (large angle) $e^+$
  $K^+ \longrightarrow \mu^+ \nu_\mu \pi^0$ or $\longrightarrow \mu^+ \nu_\mu \longrightarrow$ (large angle) $\mu^+$
- **$\nu_e$ and $\nu_\mu$ flux prediction from $e^+/\mu^+$ rates**




- Needs a **collimated momentum-selected hadron beam** → **only the decay products hit the tagger**
  - → manageable rates and irradiation in the detectors
- Needs a **"short", 40 m, decay region** : ~all $\nu_e$ from K, only ~1% $\nu_e$ from μ (large flight length)

NB: it requires a specialized beam, not a "pluggable" technology for existing super-beams (unfortunately!)

# Project development




- A dedicated short baseline neutrino beam
- with a 1% precision in $\nu_e$ and $\nu_\mu$ fluxes aimed to a refined near detector
- Reduce the dominant systematics on flux → precise cross section measurements → consolidate the **long-baseline program (DUNE, HK)** with high quality experimental inputs

A. Longhin, L. Ludovici, F. Terranova,
EPJ C75 (2015) 155

https://www.pd.infn.it/eng/enubet/

@enubet

ERC project 6/2016- 12/2022

PI: A. Longhin, F. Terranova. Techn. Coord: V. Mascagna

**E**nhanced **N**e**U**trino **BE**ams from kaon **T**agging ERC-CoG-2015, G.A. 681647,
PI A. Longhin, **Padova University, INFN**

- **CERN Neutrino Platform :**
- **NP06/ENUBET**
- **Physics Beyond Colliders**

Present collaboration: 74 auth, 17 institutions

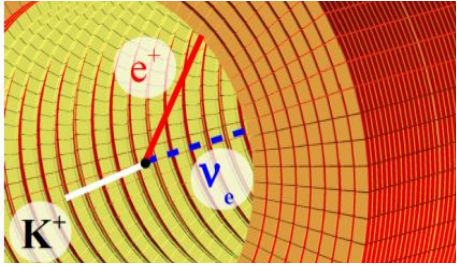
# ENUBET plenary @ Neutrino 2024

https://agenda.infn.it/event/37867/contributions/234018/attachments/122067/178257/ENUBET_Brunetti_neutrino2024.pdf

**2024 annual report e presentazione all'SPSC**

https://cds.cern.ch/record/2896594/files/SPSC-SR-349.pdf
https://indico.cern.ch/event/1401555/contributions/5891555/attachments/2847113/4985904/ENUBET_Longhin_SPSC_May2024_v5.pdf

# Achievements of 2023-2024



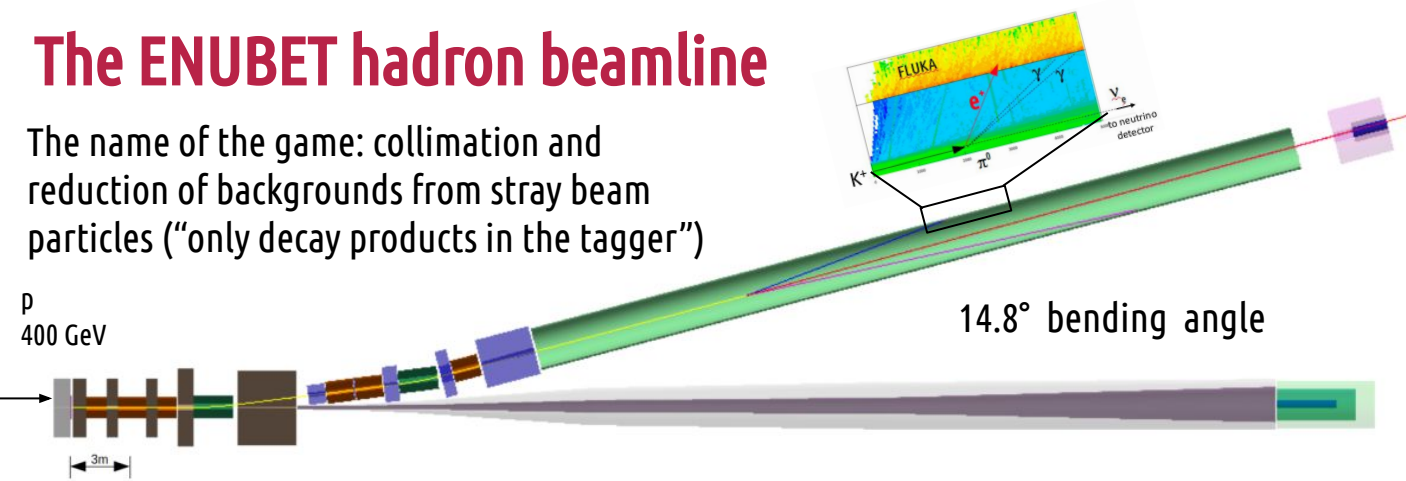

→ Publication of the hadron beamline baseline design

Reduction of the systematic error

Finalization and tests of the demonstrator

# The ENUBET hadron beamline

The name of the game: collimation and reduction of backgrounds from stray beam particles (“only decay products in the tagger”)




EPJ-C 83, 964, (2023)

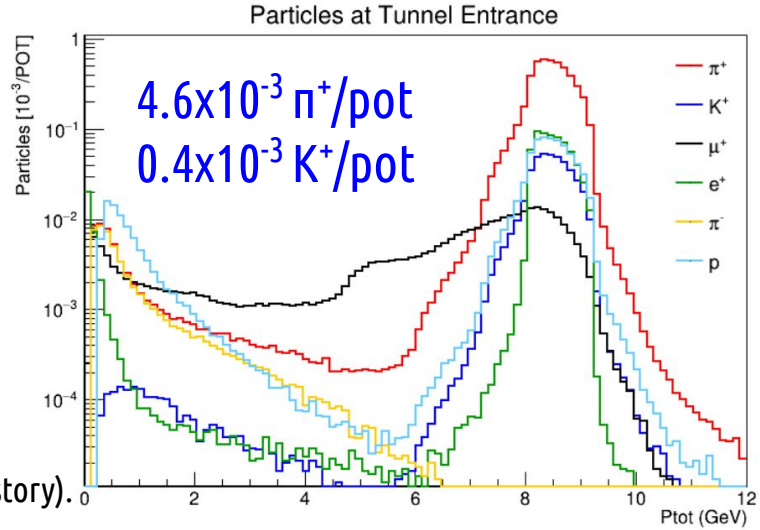
**Design and performance of the ENUBET monitored neutrino beam**

F. Acerbi[1], I. Angelis[21], L. Bomben[2,3], M. Bonesini[3], F. Bramati[3,4], A. Branca[3,4], C. Brizzolari[3,4], G. Brunetti[3,4], M. Calviani[6], S. Capelli[2,3], S. Carturan[7], M.G. Catanesi[8], S. Cecchini[9], N. Charitonidis[5], F. Cindolo[9], G. Cogo[10], G. Collazuol[4,10], F. Dal Corso[3], C. Delogu[3,10], G. De Rosa[11], A. Falcone[3,4], B. Goddard[6], A. Gola[7], D. Guffanti[12], L. Halić[20], F. Iacob[3,10], C. Jollet[16], V. Kain[6], A. Kallitsopoulou[13], B. Kliček[20], Y. Kudenko[14], Ch. Lampoudis[21], M. Laveder[3,10], P. Legou[22], A. Longhin[4,5,10], L. Ludovici[15], E. Lutsenko[2,3], L. Magaletti[8,14], G. Mandrioli[9], S. Marangoni[3,4], A. Margotti[9], V. Mascagna[22,23], N. Mauri[9,18], J. McElwee[16], L. Meazza[3,4], A. Mereggaglia[16], M. Mezzetto[3], M. Nessi[6], A. Paoloni[17], M. Pari[3,10], T. Papaevangelou[23], E.G. Parozzi[4], L. Pasqualini[9,18], G. Paternoster[1], L. Patrizii[9], M. Pozzato[9], M. Prest[2,3], F. Pupilli[3], E. Radicioni[8], A.C. Ruggeri[11], G. Saibene[2,3], D. Sampsonidis[21], C. Scian[16], G. Sirri[9], M. Stipčević[20], M. Tenti[9], F. Terranova[3,4], M. Torti[3,4], S.E. Tzamarias[21], E. Vallazza[3], F. Velotti[6], L. Votano[17]

https://arxiv.org/pdf/2308.09402.pdf

https://link.springer.com/article/10.1140/epjc/s10052-023-12116-3

- **The baseline design has been documented in EPJ-C 83, 964, 2023**
  - Uses existing standard (warm) magnets
  - Focuses **8.5 GeV +/- 10%** pions and kaons (drives the ν spectrum!)
  - Target: graphite L = 70 cm, r = 3 cm (optimized)
  - W foil: downstream of target to absorb background from $e^+$
  - Inermet optimized absorber @ tagger entrance
  - p-dump: three cyl. layers (graphite core → aluminum → iron)
  - H-dump: ~ p-dump to reduce back-scattering in the tunnel
  - Simulation: optics optimization (TRANSPORT).
  - Particle transport, interactions: G4beamline.
  - Irradiation (FLUKA). Systematics (GEANT4, fully parametric, access to particle history).

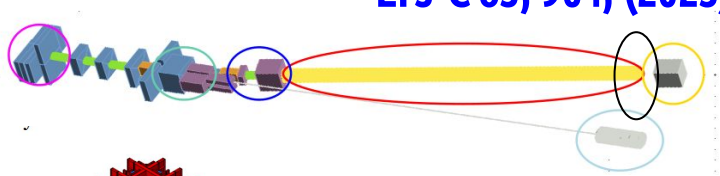


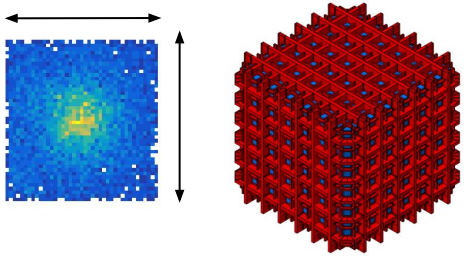
# $\nu_\mu^{CC}$ spectra at detector

EPJ-C 83, 964, (2023)

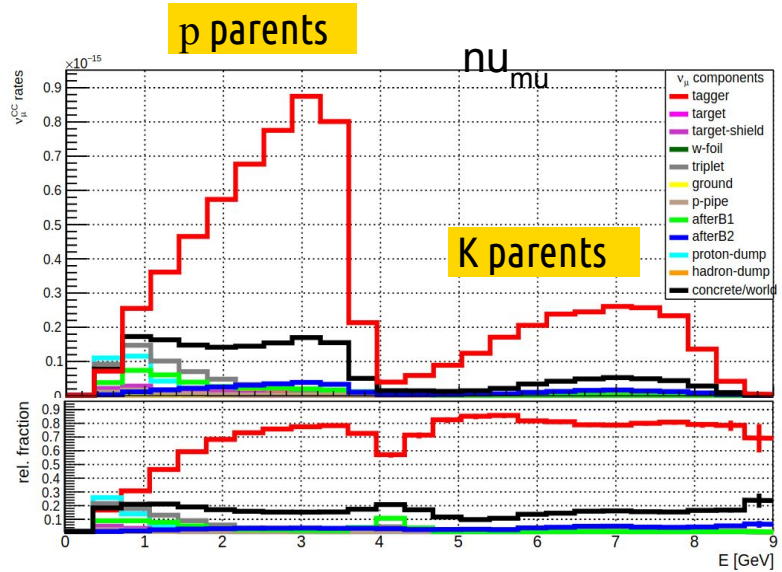
500t @ 50 m after the hadron dump
@ 400 GeV → **0.7 M** $\nu_\mu^{CC}$ with 1e20 POT

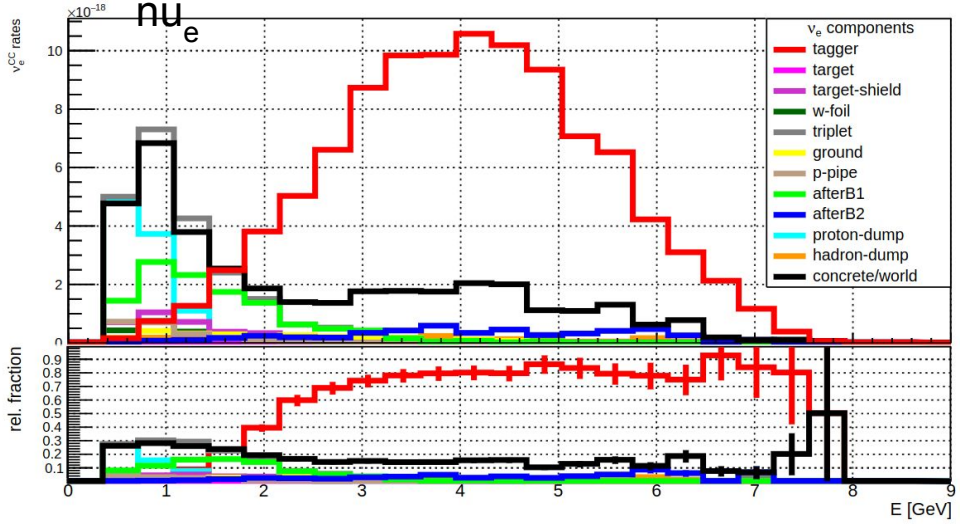
→ **10000** $\nu_e^{CC}$ with ~1e20 POT (~2.3 years)



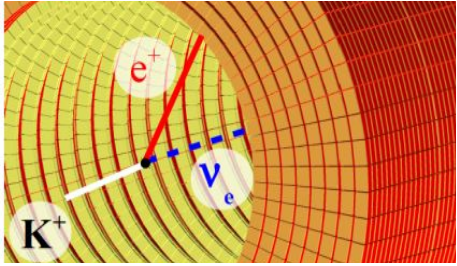


The protoDUNE(s) could be such a detector (an evident asset for a possible siting at CERN)



# Achievements of 2023-2024




Publication of the hadron beamline baseline design

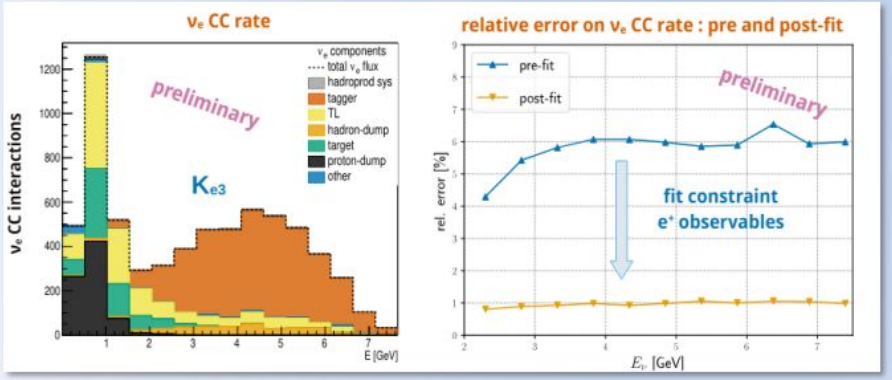
→ Reduction of the systematic error

Finalization and tests of the demonstrator

# Precision on the neutrino flux determination

To establish the flux precision, we performed the same systematic assessment analysis performed by experiments like Minerva or T2K. In particular:

- We considered the **dominant systematics** (hadroproduction) extracted from hadroproduction experiments at the SPS (NA56/SPY), which gives a 6% uncertainty on flux
- We added as an additional prior the rate, position and energy distributions of **positrons from kaon decay reconstructed in the tunnel**



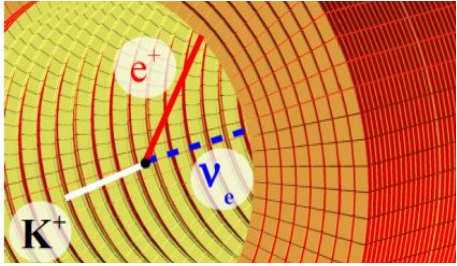

The flux uncertainty for $\nu_\mu$ and $\nu_e$ **drops from 6% to 1%** using positrons only

Further improvements are expected by adding the reconstructed muons

See **Poster #13** by F. Bramati

- In progress: add subdominant systematics (detector effects, magnet current, beam component material budget uncertainty, and exploit the additional constraints from reconstructed muons (paper in preparation)

# Achievements of 2023-2024




Publication of the hadron beamline baseline design

Reduction of the systematic error

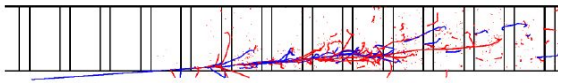
→ Finalization and tests of the demonstrator

# The lepton tagger

Light r/o (SiPM)

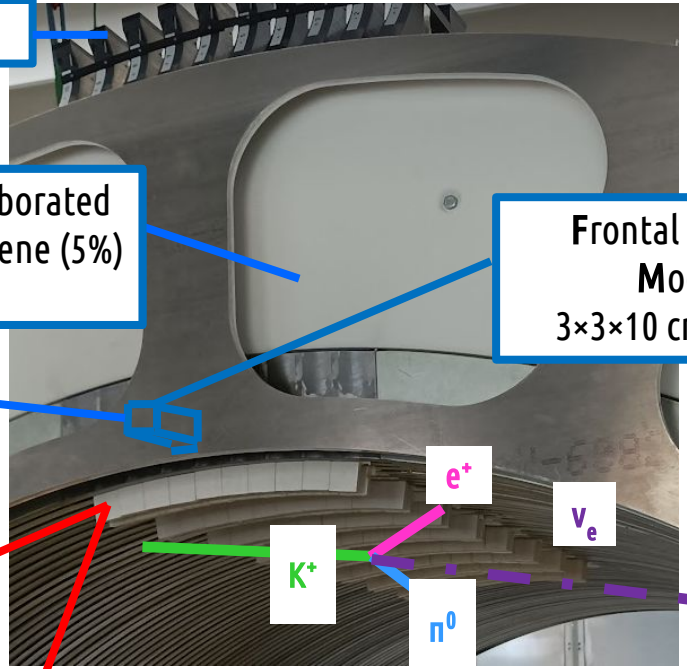
- **Calorimeter**
- Longitudinal segmentation
- Plastic scintillator + Iron absorbers
- Integrated light readout with SiPM

→ $e^+/\pi^\pm/\mu$ separation



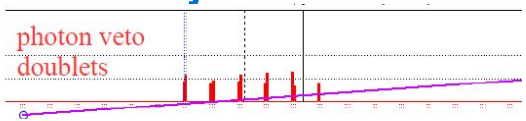
30 cm of borated polyethylene (5%)

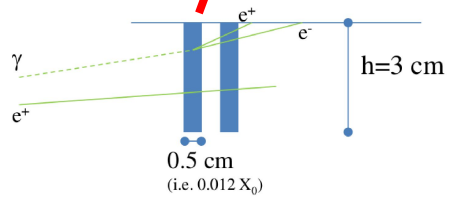
**F**rontal **C**ompact **M**odule
$3\times3\times10\ cm^3 - 4.3\ X_0$




- **Integrated photon veto**
- Plastic scintillators rings of $3\times3\ cm^2$ pads

→ $\pi^0$ rejection



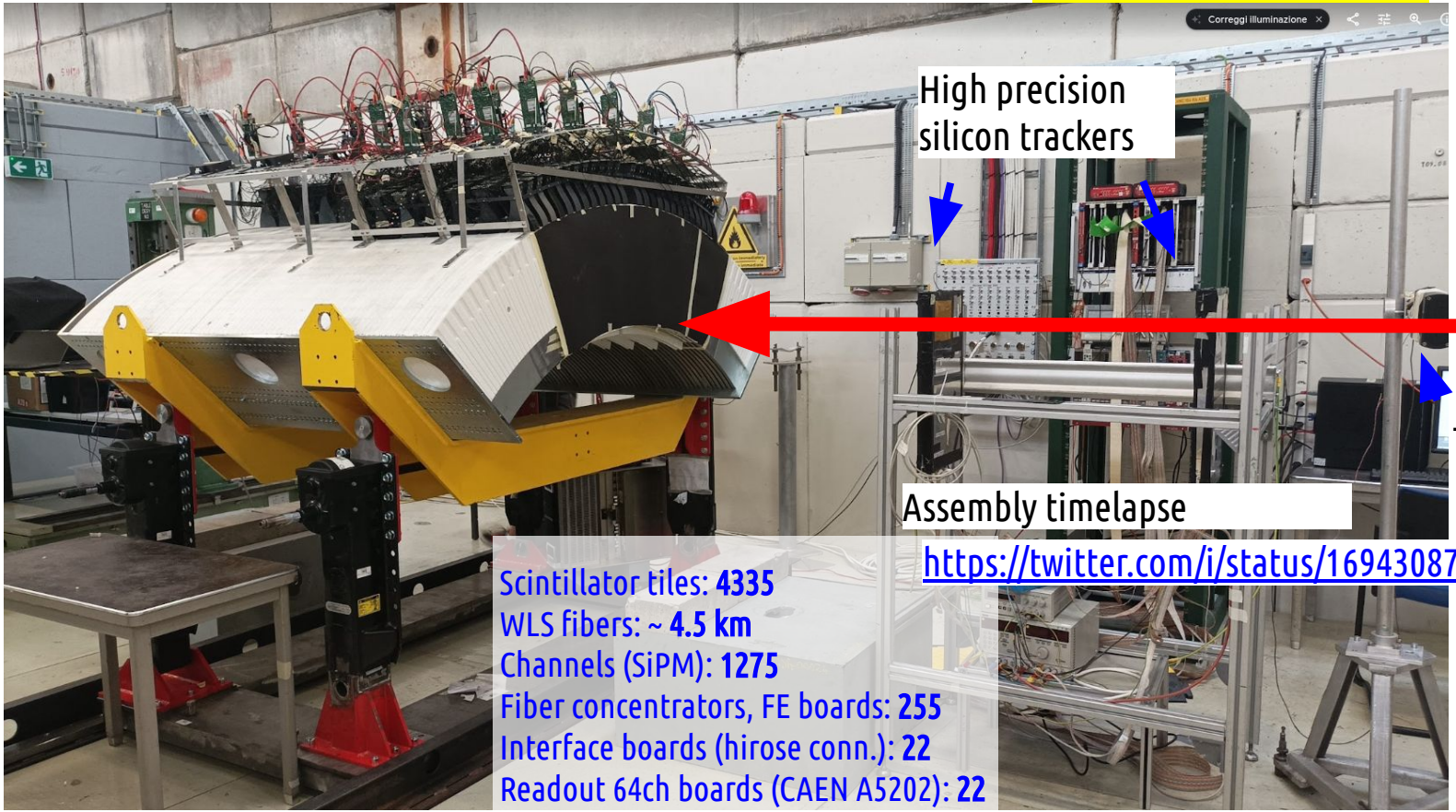

$e^+$ (signal) topology

$p^0$ (background) topology

$p^+$ (background) topology

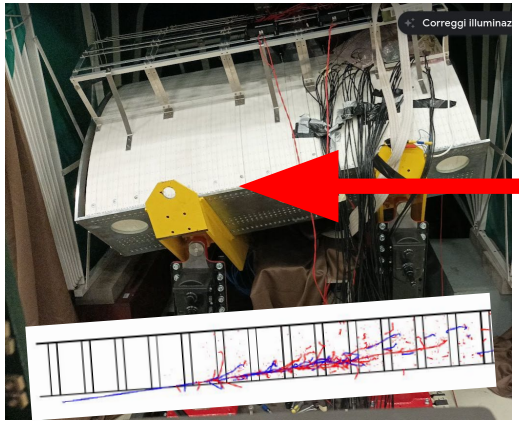
# The ENUBET tagger demonstrator

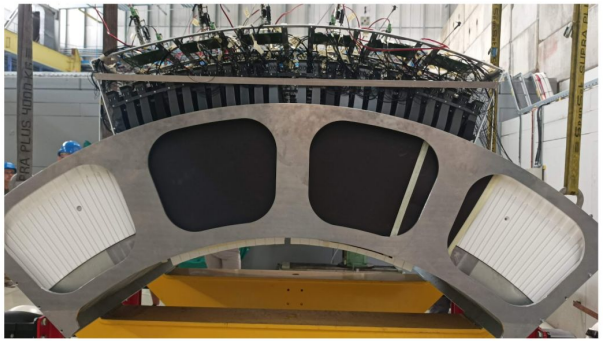
**August 2023** CERN-PS-T9



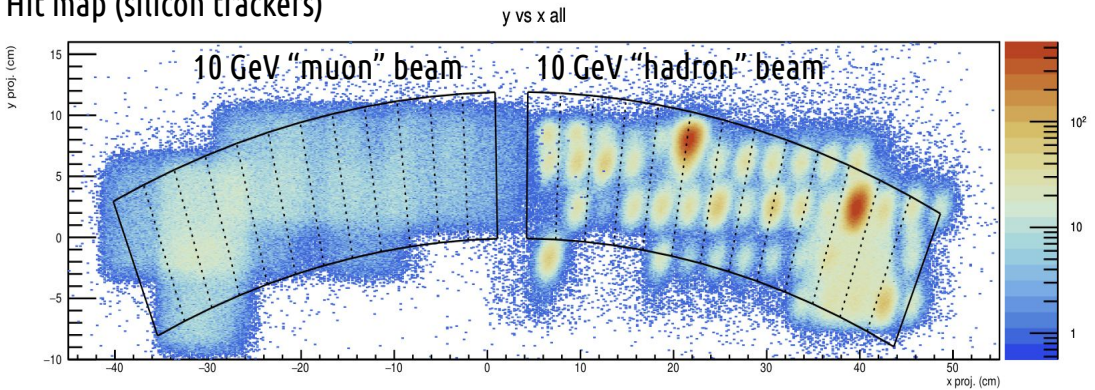
# Examples: inclined and calibration runs

200 mrad tilt run

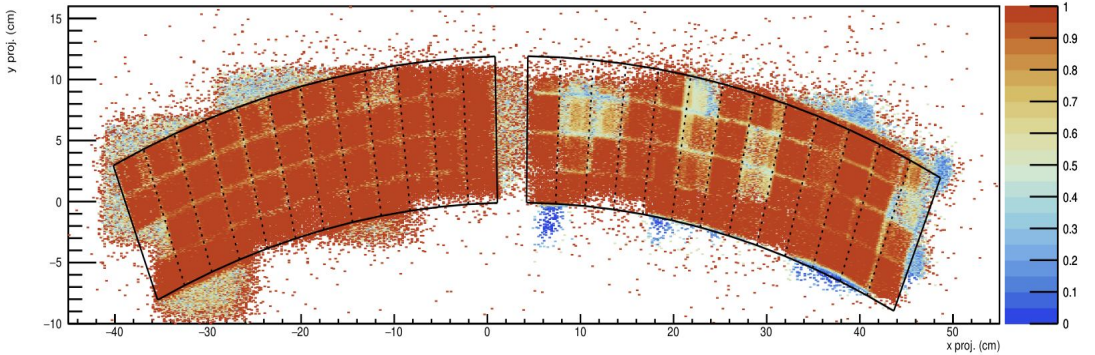


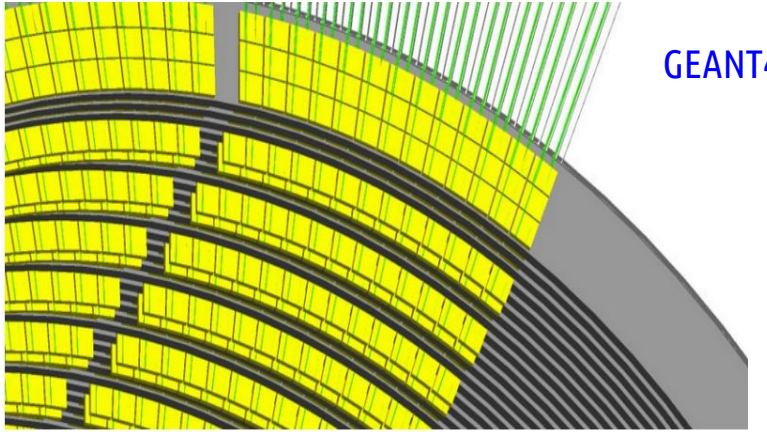
Hit map (silicon trackers)



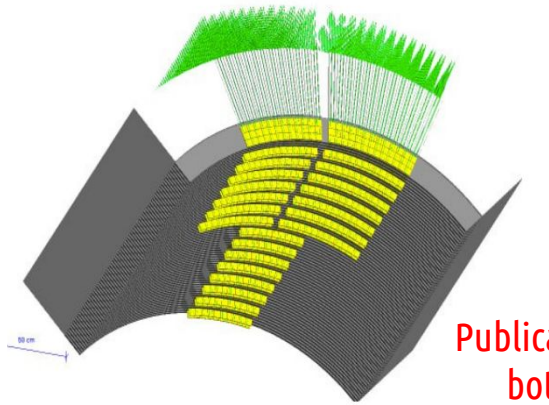

Efficiency map

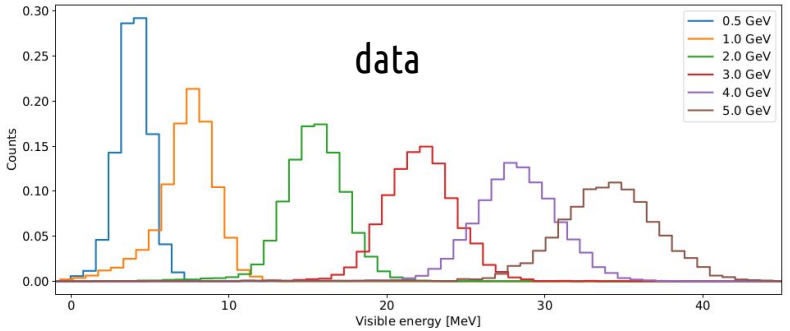


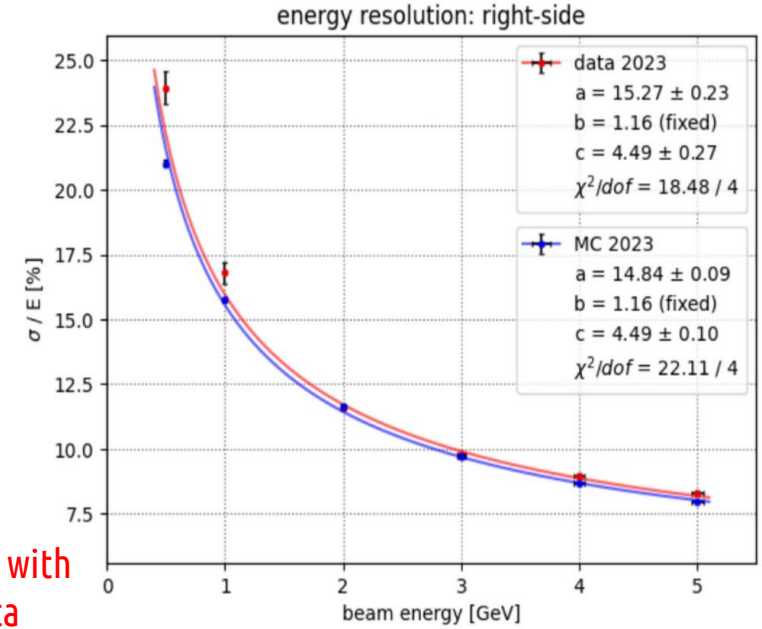
# Electron energy resolution



GEANT4

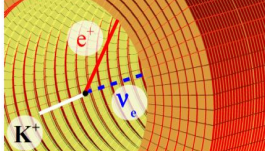





Publication in the pipeline with both 2022 and 2023 data

# Activities and requests for 2025




- Prepare a **robust proposal for a full-fledged experiment for the European Strategy**
  - Implementation studies at CERN in progress in the context of **Physics Beyond Colliders**
    - A dedicated CERN fellow post-doc full time on:
      - an improved beamline with a better efficiency
      - possibility to enrich the physics potential using 4D silicon trackers (~NA62 gigatracker)
      - Siting, study interference with other experiments, proton-economics

- A **test-beam at CERN** for instrumentation to tag muons in the forward region (picosec MicroMegas)

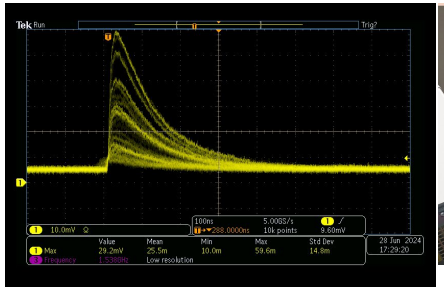
- **Overall requests** : essentially ~travel for test beams and some instrumentation support for the test

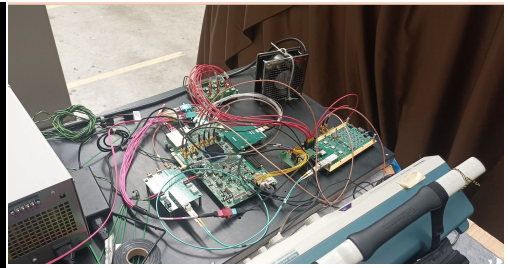
- **FTE**: F. Pupilli (RL) 55%, A. Longhin 60%, M. Mezzetto 20%, F. Dal Corso (20%), M. Laveder (20%)
- **Addendum** :
- Working also on a low energy version of ENUBET (monitoring muons from pion decays) exploiting the ESS as proton driver in the framework of the European Project **ESSnuSB+** *(synergic project)*
  - → F. Pupilli (RN) 5%, M. Mezzetto 2%, A. Longhin

# Attivita' coi servizi e richieste 2025

**Ufficio progettazione elettronica** : goal immediato: leggere una decina di canali col digitizer sviluppato per SiPM camera di CTA+ col dimostratore al test al CERN di Agosto 2024. Se tutto funziona bene **nel 2025 vorremmo pensare and una versione adattata per ENUBET**

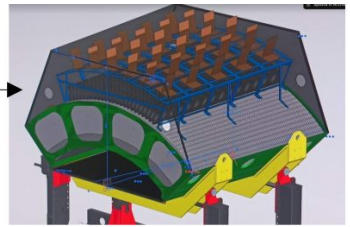
1 mp



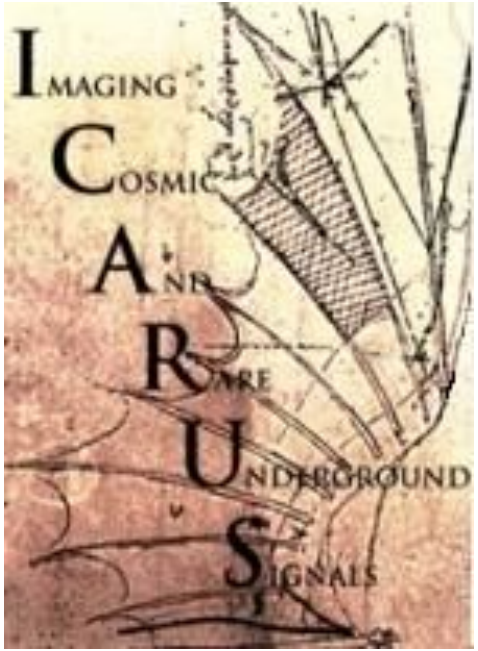


**Officina meccanica** → movimentazione dimostratore per trasporto CERN (**ne avremo bisogno di nuovo a fine luglio** ).
Probabilmente no nel 2025.

**Ufficio tecnico** → nel 2024 sviluppata una dark box per oscurare il dimostratore senza tenerlo nel "garage" coi teli



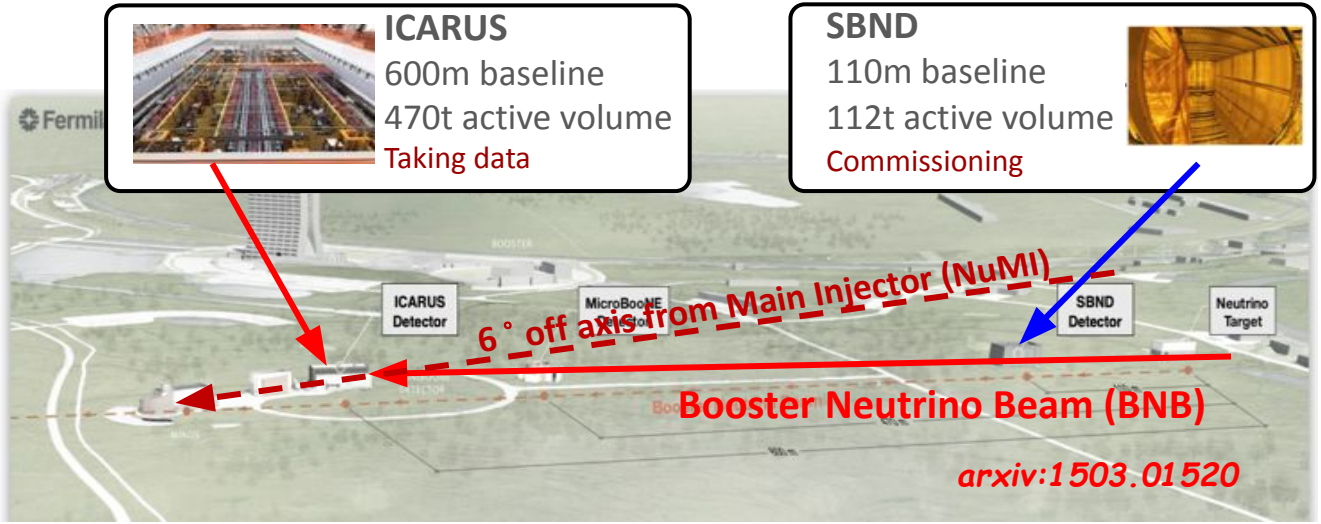
Un sentito grazie ai servizi della sezione per il suppporto dato finora in particolare a Loris, Marino, Marco B., Massimo.

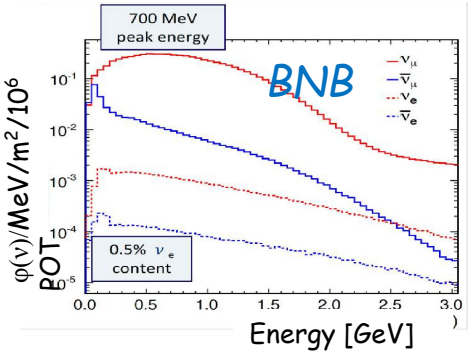


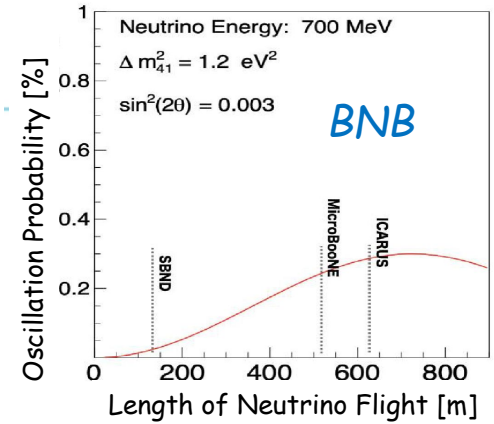

# ICAR_US

RL: Cristian Farnese

# ICARUS and the Short Baseline Neutrino (SBN) at FNAL:
## *a definitive answer to sterile neutrinos ?*



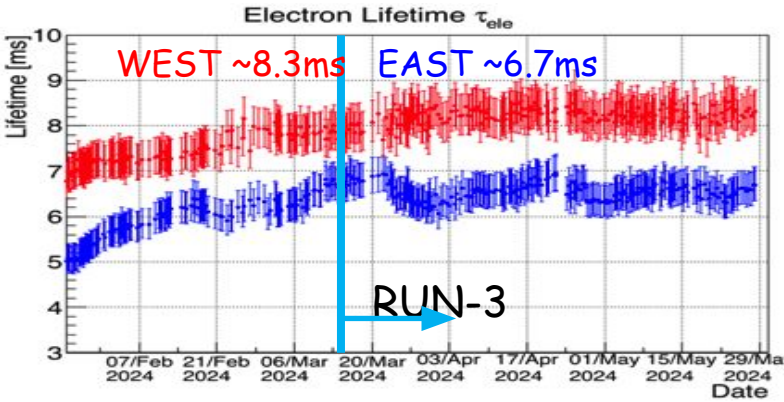




- ICARUS LAr-TPC is presently taking data at shallow depth installed at 600 m from the Booster target within the SBN experiment
  - The SBN program is addressing the question of sterile neutrinos with the BNB beam comparing $\nu_e$ and $\nu_\mu$ interactions at different distances from target as measured by ICARUS and SBND LAr-TPCs.
  - In addition, ICARUS is exposed to the NuMI beam at ~6° off-axis ($\nu$ cross-section and BSM searches).

# ICARUS - FNAL operation, runs, collected statistics

- June 2022: start of data taking for physics with TPCs, PMT light detection system and CRT fully operational;
- Events are triggered requiring at least 4 fired PMT pairs inside a 6 m longitudinal T600 slice in coincidence with BNB, NuMI beam spills, >90% efficiency for $E_{dep}$ >200 MeV;
- Data acquisition is largely successful, currently with >97% collection efficiency;
- The cryogenic and purification system performed smoothly keeping residual impurities in LAr at ~40 p.p.t. of [O2] equivalent:
  - The free electron drift lifetime $\tau_{ELE}$ ≈7-8 ms, results in an almost full track detection efficiency in the whole 1.5 m drift (t ~ 1 ms).

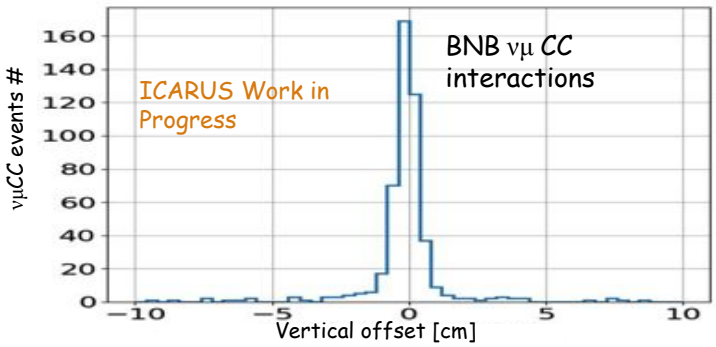



| Collected Protons on target (PoT) | | BNB (FHC) positive focusing | NuMI (FHC) positive focusing | NuMI (RHC) negative focusing |
|---|---|---|---|---|
| RUN-1 | (Jun-Jul 2022) | 0.41 $10^{20}$ | 0.68 $10^{20}$ | - |
| RUN-2 | ( Dec 2022-Jul 2023) | 2.05 $10^{20}$ | 2.74 $10^{20}$ | - |
| RUN-3* | ( Mar-Jun 13, 2024 ) | 0.95 $10^{20}$ | - | 2.02 $10^{20}$ |
| TOTAL | (PoT) | 3.41 $10^{20}$ | 3.42 $10^{20}$ | 2.02 $10^{20}$ |

* Reduced exposure for RUN-3 due to the prolonged accelerator shutdown

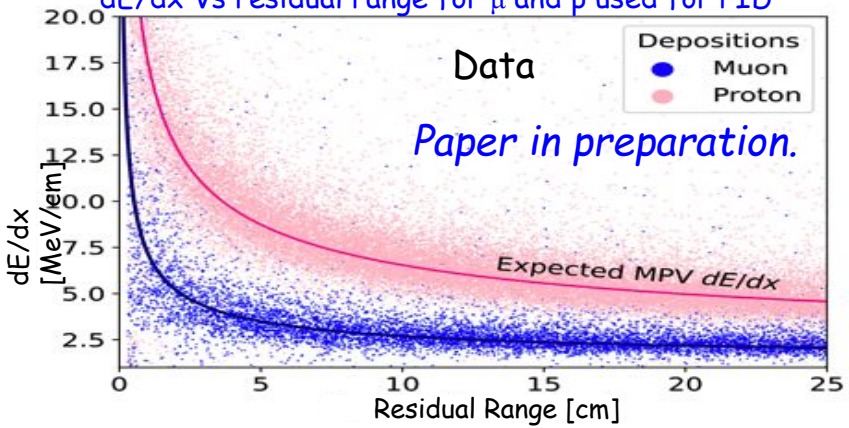
# Calibration, detector performance and event reconstruction - highlights

Neutrino vertex reconstruction

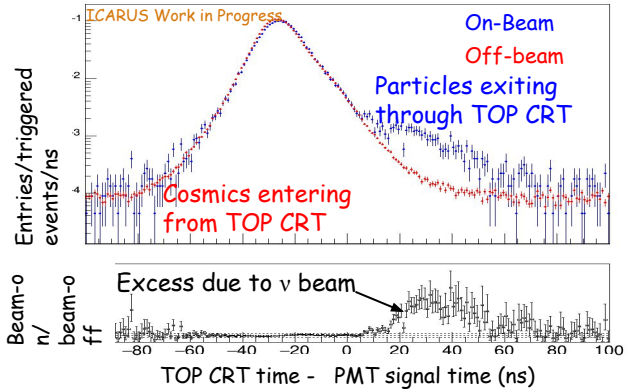



Offset between automatic and visual reconstructi of ν interaction vertex

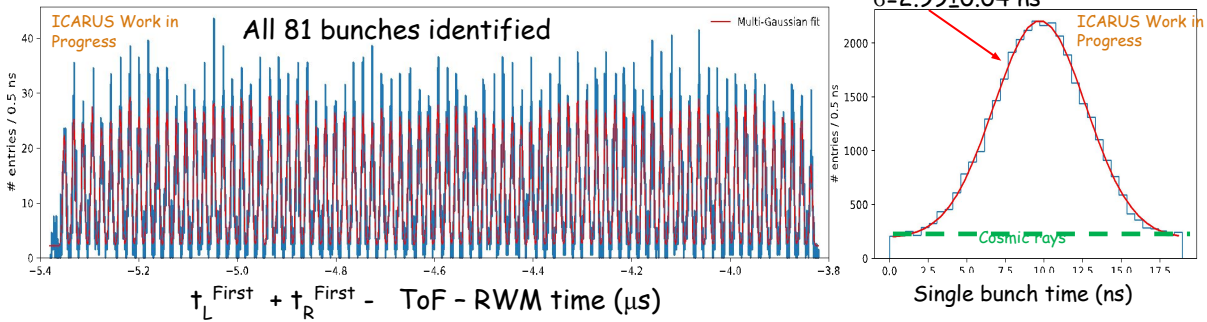
dE/dx Vs residual range for μ and p used for PID




Rejection of incoming cosmics by tof [2)]




Reconstruction of bunched structure of beam spill



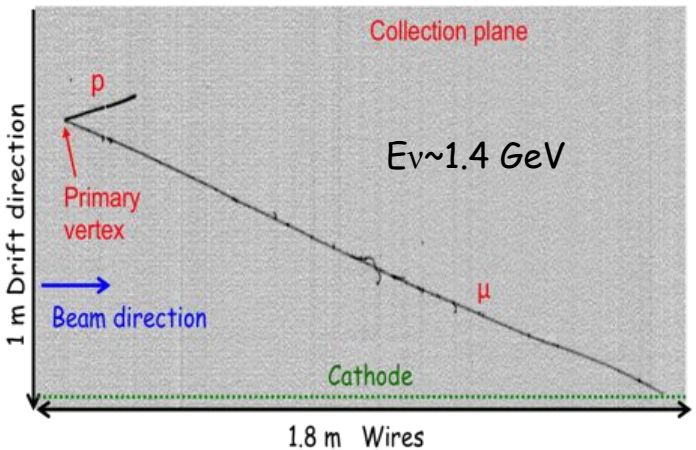

ν event time (PMTs only) wrt beam extraction time (RWM counters) after rejecting incoming cosmics (CRT) and correcting for ν flight

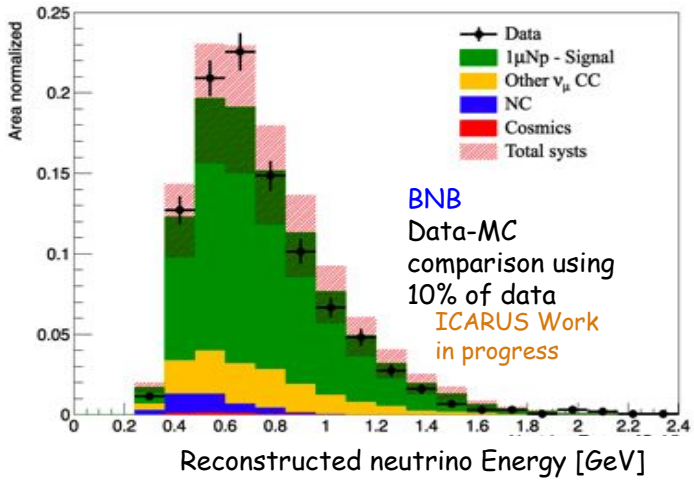
# ICARUS Research Program

- Before the start of joint SBN operation, ICARUS is focusing on standalone physics program, also in preparation for the SBN oscillation analyses:

  - Investigation of $\nu_\mu$ disappearance with BNB $\nu$ beam: focus on fully contained $\nu\mu$CC events with a muon $L_\mu$ >50 cm and at least one proton with $E_K$ >50 MeV ($L_p$ >2.3 cm);

    - ✔ Data-MC agreement within systematics for all studied event kinematic variables; (10% of RUN-2 data analyzed, 20 time more data available)




  - Study of $\nu_e$, $\nu_\mu$ events from NuMI beam, to measure $\nu$-Ar interaction cross sections and optimize $\nu$ reconstruction/identification in an energy range of interest for DUNE.

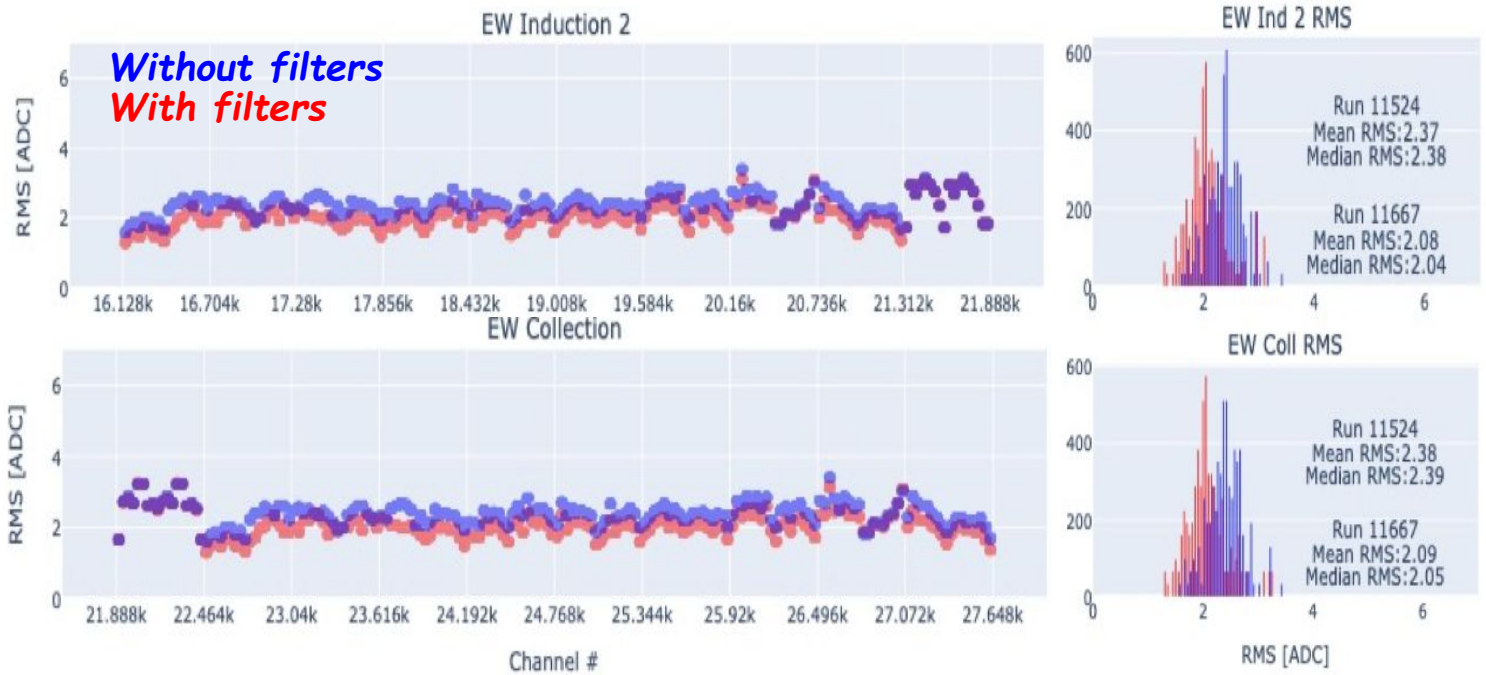
  - Exploit the off-axis NuMI beam to investigate sub-GeV Beyond Standard Model (BSM) signals;

# TPC status: reducing the wire noise for RUN-3

- Chebyshev low-pass filters installed on frontend supply of all 136 A2795 TPC readout boards of Induction 1 wires (8704 channels) reduced coherent noise propagating through +7 V line.
- An improved filter version (cut-off freq. lowered from 2 to 1 kHz) was prepared/installed in all the **Induction 2, Collection boards (648 boards, 41472 chs)** connected to 3.6 m wires.

***As a result the coherent noise is reduced by 15-20 % also in these wire planes.***

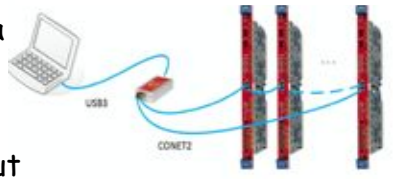
*Chebyshev filter installed on A2795 CAEN board*



# Improving the TPC read-out electronics

- New read-out firmware with the on-line TPC data compression was installed in all TPC read-out boards reducing by a further factor 2 the TPC event size.

- A test-stand is operational at Fermilab for checking anomalous TPC boards before sending to CAEN in Italy for repairing. A2795 boards on a spare Mini-Crate powered by a Power Supply are read out by CAEN A4818 USB 3.0 to CONET adapter connected to a Lap-top.


- Two custom ICARUS_Test _SIG boards to directly access signals coming from each TPC wire without ADC's interface has been constructed, now under test:
  - Each wire has a dedicated electronic chain with a frontend preamp, a shaping circuit and a Bessel filter.

- Replacing the old Bertan Power Supplies for the TPC wires polarization:
  - Original Bertan modules (2008) are out of production and present issues, only 1 spare module recuperated from faulty units.
  - A new module from ISEG (SHR 42 20r:SHR desktop unit 4 x 2kV / 6mA high precision, common floating-GND), was successfully tested replacing Bertan PS. 3 modules are under procurement within the present funds to guarantee TPC biasing functionality for several years.
  - In addition custom passive spare modules for the wire polarization have been produced within the present 2024 funds.

# TPC read-out electronics: activities planned for 2025

- A2795 boards maintenance

  Some financial support for the A2795 board maintenance is required because ~ 50 % of the boards will be out of warranty in 2024. According to the past experience order of 5 faulty boards per year are expected.

- HP servers (35 servers, out of warranty)

  Some issues have been find with the HP servers (2018) reading the TPC/PMT electronics. Two new HPE DL 380 model P24842-B21 fully equivalent/compatible with the old P05524-B21 bought in 2018 have been tested/installed, 3 servers are in procurement (2024 budget). We ask continuing the replacement with 5 new computers in 2025.

- Custom electronics maintenance

  Finally the maintenance of the custom electronics (Linear Power Supplies, Minicrates, black-planes…) is necessary.

- Consumables

  LAr procurement for the LAr-TPC test facility at LNL for electronics tests. The LAr purity filter is exhausted and it requires to be replaced with a new Cu type, Cr-free.

# Gruppo ICARUS Padova

- ICARUS Pd: 10 physicists/engineers, 6.8 FTE inseriti nel RISE INTENSE e nel RISE PROBES:
  - M. Artero-Pons (Post-doc.), B. Baibussinov , C. Farnese, D. Gibin , A. Guglielmi (Senior Associate), G. Meng, L.Stanco, R.Triozzi (PhD stud.), F. Varanini, S. Ventura.
- Sinergia con gruppo DUNE:
  - B. Baibussinov, F. Pietropaolo e F. Varanini: R&D per DUNE con realizzazione/test a Legnaro di specifiche Multilayer LEM TPC in collaborazione con Proto-DUNE al CERN!
- Grosso impegno del Gruppo Padovano nella gestione hardware/software dell'elettronica di read-out della TPC e nello sviluppo del trigger dell'esperimento.
- Il Gruppo Padovano è fortemente impegnato nel software di ricostruzione degli eventi e analisi dati: esprime anche uno dei 2 Software/Analysis Coordinator per tutto il programma SBN al FNAL,~ 250 fisici impegnati in ICARUS e nel rivelatore Near SBND. Componenti del gruppo coordinano anche attività nei Working Groups di TPC, Trigger, Detector Calibration, TPC Track reconstruction e Neutrino Identification.
- Al Gruppo di Padova è sempre stato riconosciuto un ruolo di preminenza con il diritto di esprimere uno dei due Deputy della Collaborazione.

# Attivita' in ICARUS/ SBN e oltre: paving the way

- Padova è richiesta garantire l'impegno in SBN nei prossimi ~ 3 anni per la prevista presa dati e quindi per il completamento delle analisi.
- L'attività hardware prevista per la fine 2024 e il 2025 da Padova include interventi dedicati alla mitigazione del rumore residuo presente nella TPC, la naturale manutenzione dei 54000 canali elettronici della TPC e del sistema di Trigger (slide 7).
  In parallelo l'analisi dei dati raccolti impegnerà buona parte del gruppo.
- Continuerà inoltre l'attività di R&D a Legnaro con lo studio di configurazioni di TPC alternative al sistema a filo per ProtoDUNE.
- Sarà quindi naturale, in prospettiva, aumentare gradualmente l'impegno in DUNE trasferendo tutto il bagaglio di conoscenze sull'interazione del neutrino con l'argon liquido accumulate con ICARUS ai fasci Booster e NuMI Off Axis (misure di sezioni d'urto, software di ricostruzione degli eventi, …)

# Financial requests 2025: upgrades, maintenance, missions

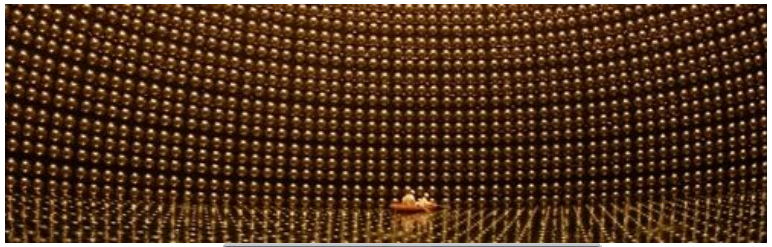
| PADOVA | | Request (k€) |
|---|---|---|
| APPARATI | Substitution of 5 HP servers (out of warranty) | 17.5 |
| | Substitution of LAr Cu filter at LNL | 7.5 |
| MANUTENZIONI | TPC read-out CAEN board maintenance (50 % out of warranty) | 8 |
| TRASPORTI | Transports of electronic boards, to CERN/FNAL | 10 |
| CONSUMO + | Electronics Service/custom electronics repairs | 6 |
| ALTRI CONSUMI | LAr procurements for LAr-TPC test facility at LNL | 5 |
| SP SERVIZI | Mechanics workshop (Mini-crates recovery, ) | 3 |

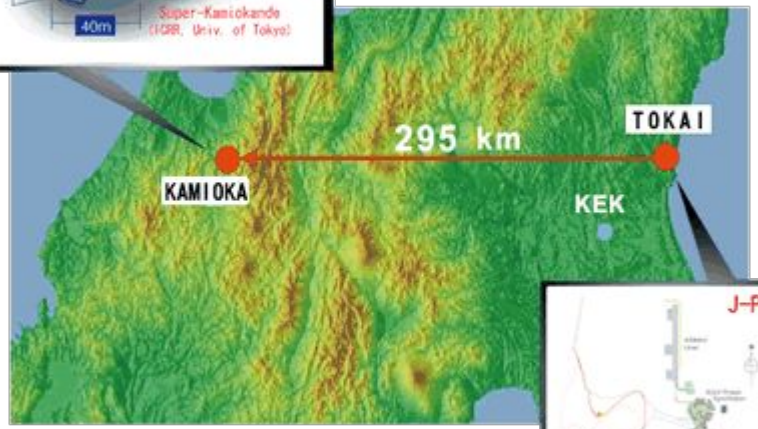
Richieste Servizi Padova 2025:

- 20 MU Servizio di Elettronica: manutenzione/test elettronica TPC a Padova/FNAL
- 1 MU Servizio Off. Meccanica
- 3 MU Calcolo e Reti.

| Missioni PADOVA | FNAL on-site expert, Run-Coord maintenance | 4 Analysis Workshops | 3 Collab. Meetings PAC, SBN OB | Tot. (k€) |
|---|---|---|---|---|
| | 3.5 MU maintenance 20 k€<br>3 MU Run-Co 17 k€ | 4 people 25 k€ | 15 + 5 (Deputy) k€ | 82 |

Expert shifts, RUN Coordinator periods are mandatory, as well as the participation to FNAL Boards/Committees.




# RL. Gianmaria Collazuol

# Esperimenti T2K / Super-K / Hyper-K

Intensa attivita` **neutrini in Giappone** da diversi anni e **prospettiva per molti anni ancora**
- T2K Near Detector upgrade → installati nuovi rivelator e primo run di fisica Giugno 2024
- Super-K nuova fase H2O + Gd → “Run 7”
- Hyper-K approvato INFN nel 2022 → fase di costruzione dal 2024

Transizione “T2K” / CSN2 → “Hyper-K” / CSN1

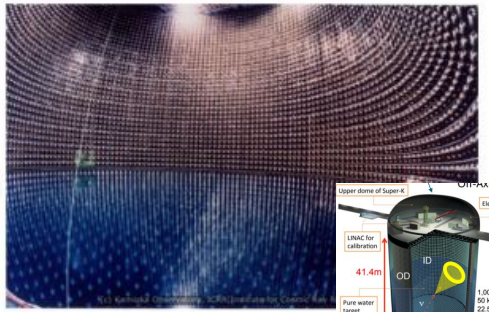
**Gruppo locale** in costante espansione
Staff: G.Collazuol, M.Grassi, M.Laveder, A.Longhin, M.Mezzetto, F.Pupilli, S.Levorato
Post-Doc: D.D’Ago, D.Henaff, M.Mattiazzi
Dottorandi: M.Feltre
Laureandi: C.Forza, L.Mareso

## Overview

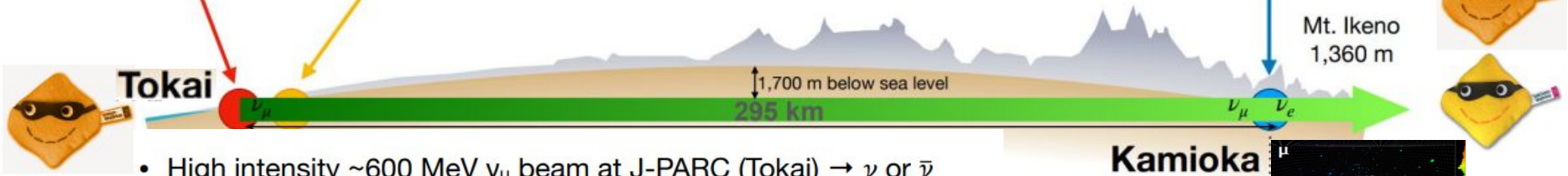
Activity ’24 and Perspective ’25 for T2K *
and for HK *
FTE, Budget & Local resources request *

G.Collazuol
CdS 2024/7/5


# T2K



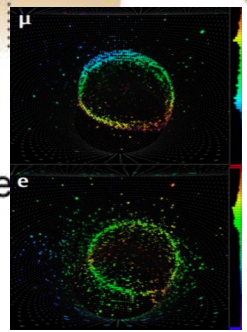

J-PARC | Near Detectors | Super-Kamiokande




$\nu_\mu$ beam

- High intensity ~600 MeV $\nu_\mu$ beam at J-PARC (Tokai) → $\nu$ or $\bar{\nu}$ mode by changing the horn polarity
- Neutrinos detected at the Near Detector (ND280) and at the Far Detector (Super-Kamiokande)
  - $\nu_e$ and $\bar{\nu}_e$ appearance → determine $\theta_{13}$ and $\delta_{CP}$
  - Precise measurement of $\nu_\mu$ disappearance → $\theta_{23}$ and $|\Delta m^2_{32}|$

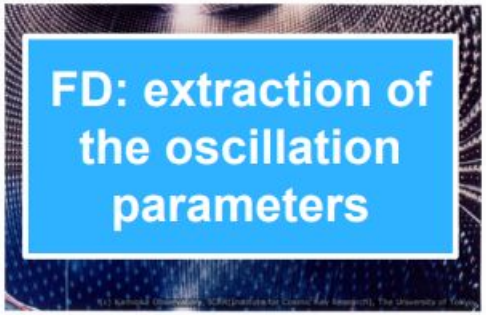
$\nu_e$ appearance & $\nu_\mu$ disappearance



ND: flux and ν interaction model tuning + ν xsec measurements

T2K

FD: extraction of the oscillation parameters



ND280

J-PARC

Near Detectors

Super-Kamiokande

Mt. Ikeno
1,360 m

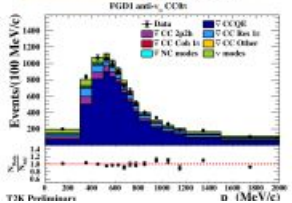
1,700 m below sea level

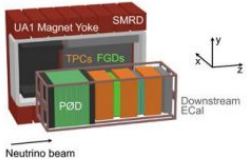
295 km

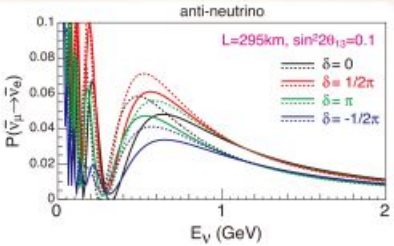
$\nu_\mu$ $\nu_\mu$ $\nu_e$

Tokai

$\bar{\nu}_\mu$ beam

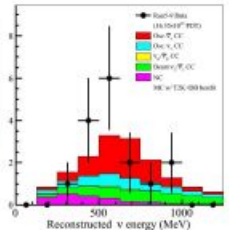




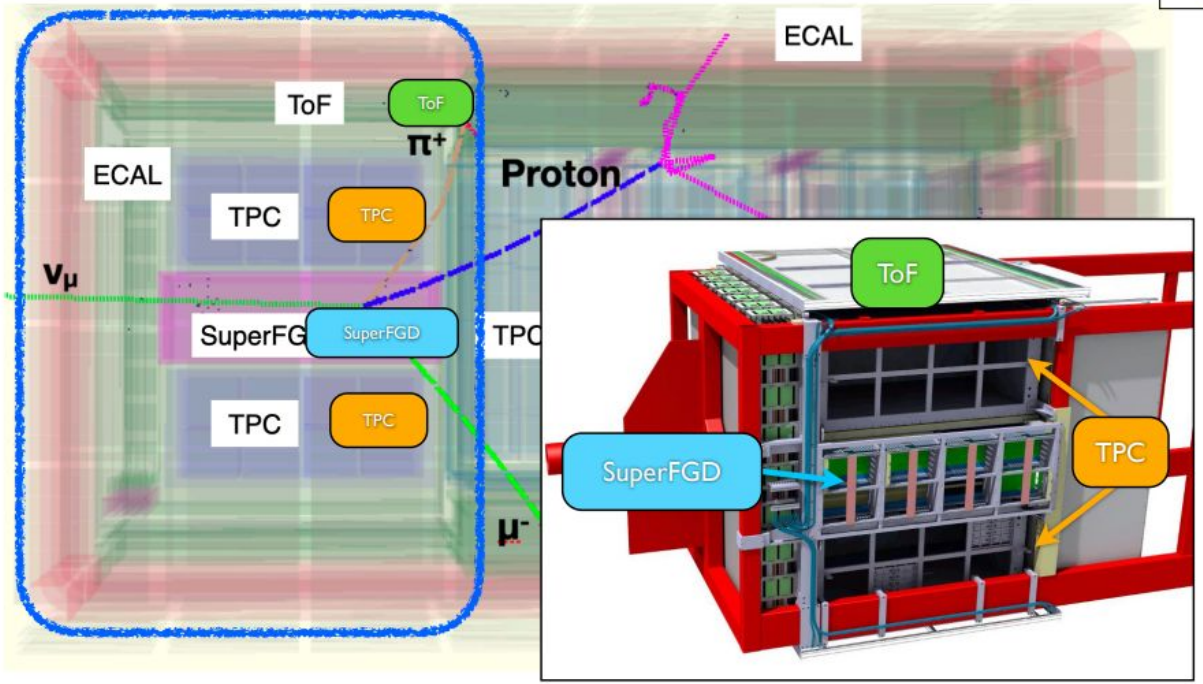

Kamioka

$\bar{\nu}_e$ appearance
&
$\bar{\nu}_\mu$ disappearance




ND to measure un-oscillated beam flux and ν cross sections

# The ND280 Upgrade detectors







arXiv:1901.03750

France (CEA Saclay, LLR, LPNHE), Germany (RWTH), Italy (INFN Sezioni di Bari, Napoli, Legnaro, Padova, Roma 1), Poland (IFJ Pan, NCBJ, WUT), Russia (INR and Dubna), Spain (IFAE), Switzerland (University of Geneva, ETHZ) + CERN

Japan: University of Tokyo, KEK, Kyoto University, Tokyo Metropolitan University

USA: Louisiana State University, University of Colorado, University of Pennsylvania, University of Pittsburgh, Stony Brook University, University of Rochester

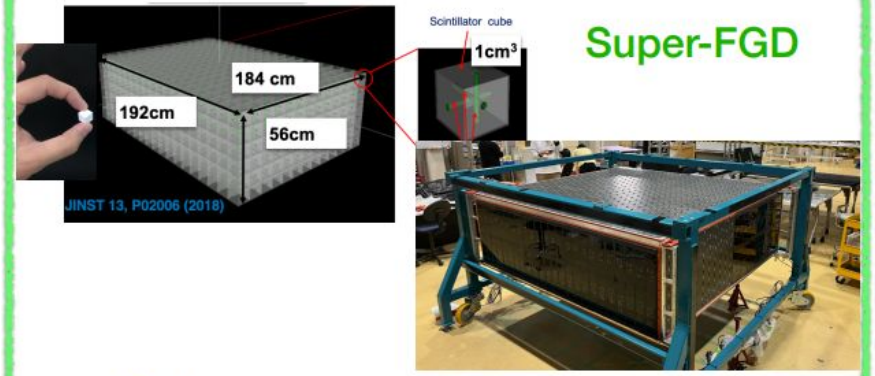
**MoU signed in 2020 → NP-07**

New detectors to extend acceptance for tracks at high angles

# ND280 Upgrade detectors

**INFN PD : ruolo primario nella costruzione delle nuove TPC**

## Super-FGD




- New concept of detectors, $2x10^6$ $1cm^3$ cubes
- Each cube is read by 3 WLS → 3D view

## High-Angle TPCs

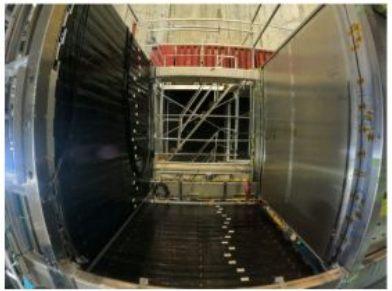
New TPCs instrumented with Encapsulated Resistive Anode MicroMegas (ERAM)

## TOF

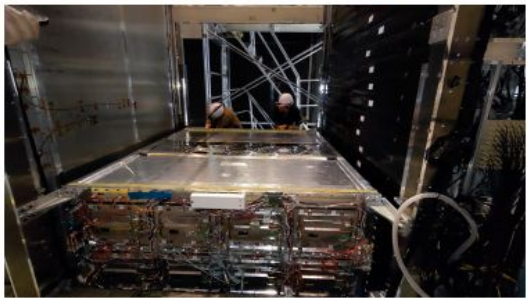

6 TOF planes to reconstruct track direction
Time resolution ~150 ps

# New detectors installation at JPARC

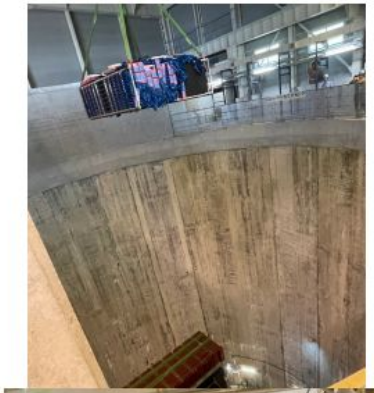
TOF installation (July 2023)



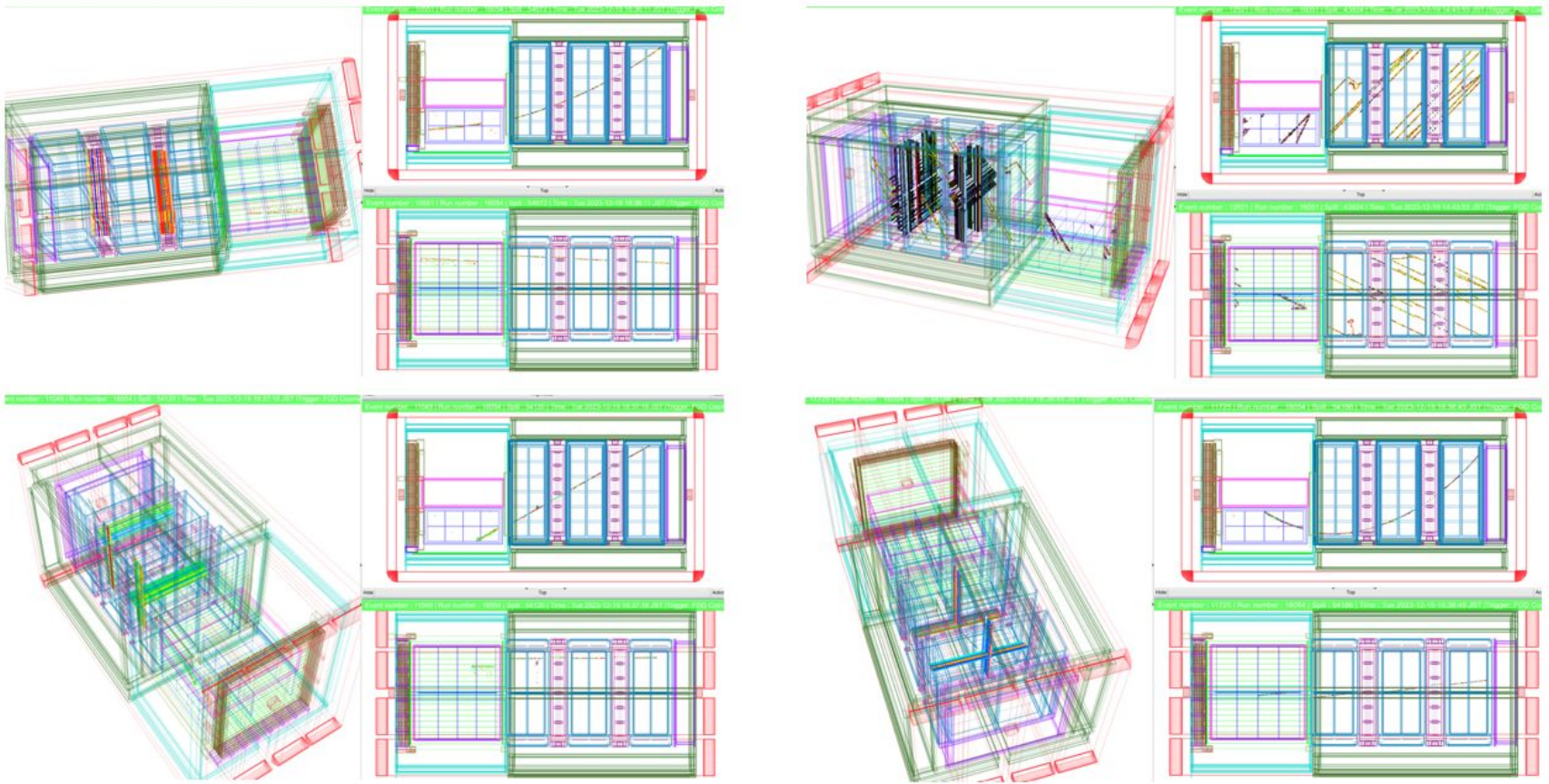
Bottom TPC
installation (September 2023)



Super-FGD
installation (October 2023)

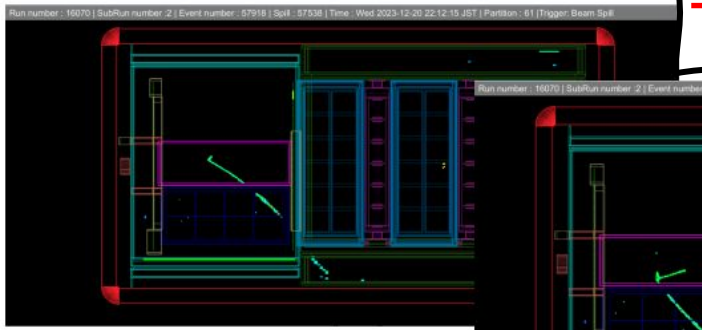


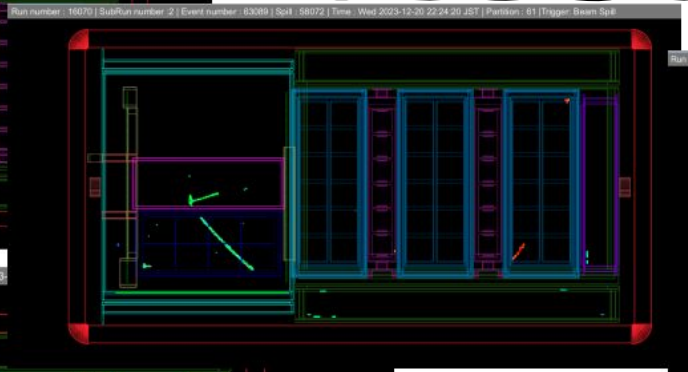
# Commissioning with Cosmics in Nov ‘23

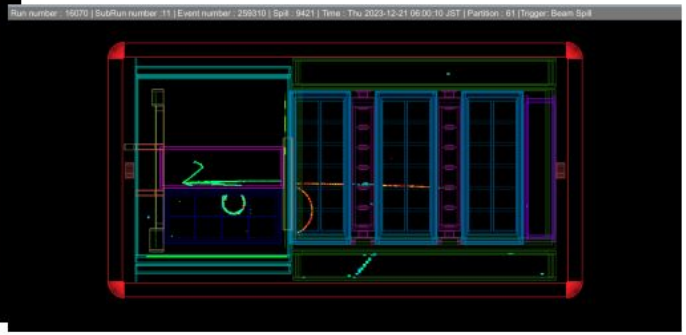


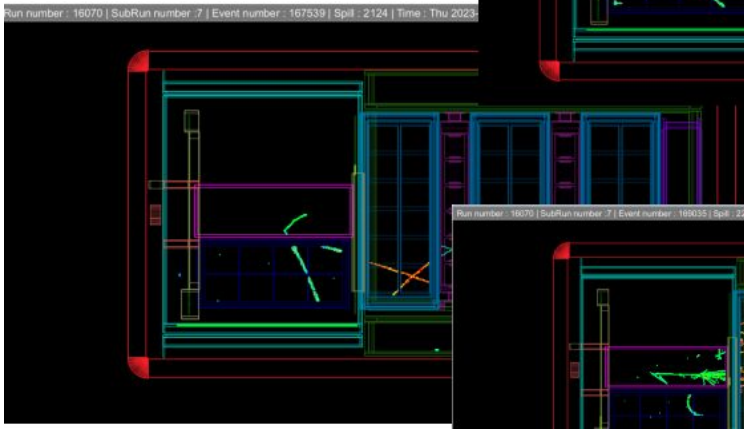
# Commissioning with Neutrino Beam Runs

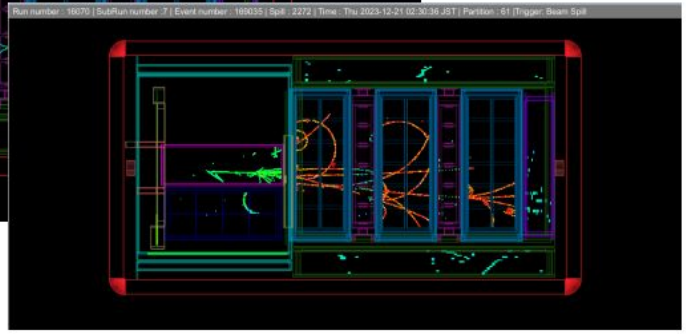
## Technical Runs in Dec‘23 and in Feb‘24

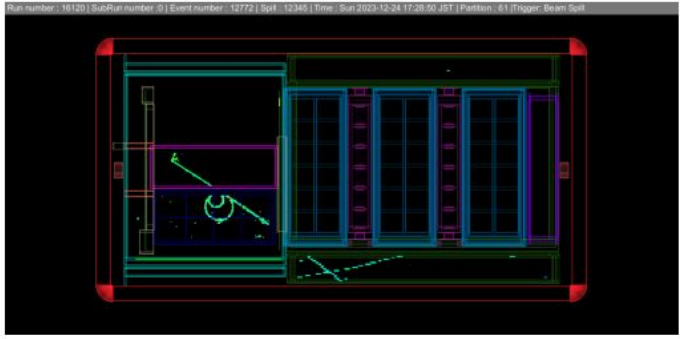


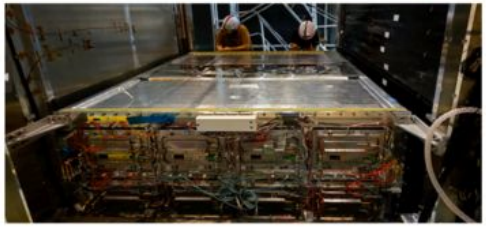



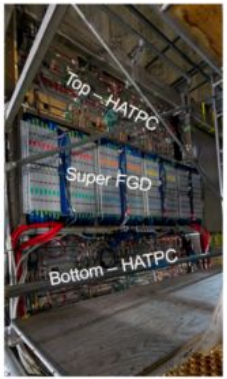
# 2nd HATPC (“top”) installed April 2024


Lowering bottom HATPC
2023.9.8

Top – HATPC in ND280

Bottom – HATPC in ND280

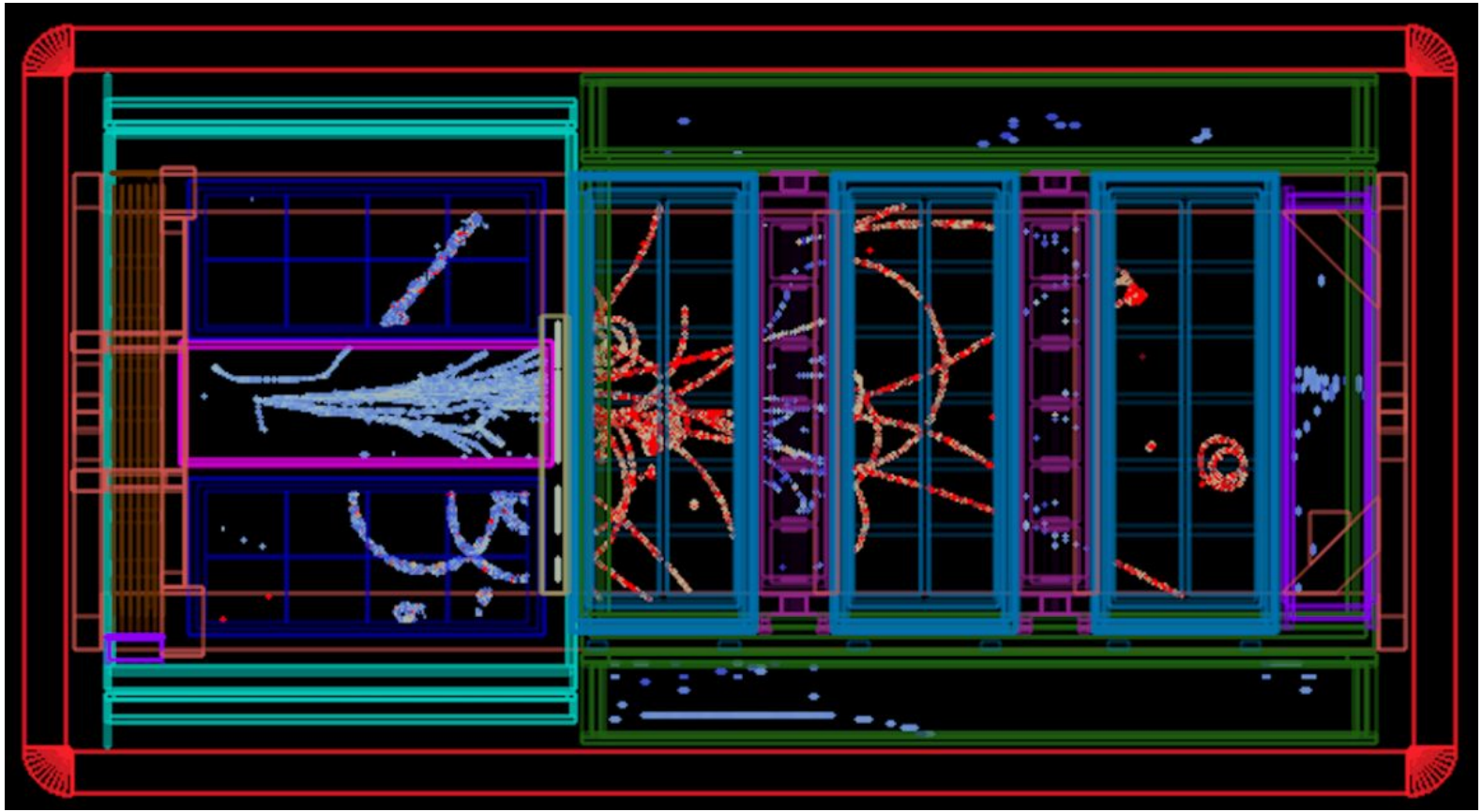





ND280 after lowering of top HATPC
2024.4.25

ND280 fully upgraded detector ready for next
→ Neutrino Beam Run 2024/6/1 – 7/8

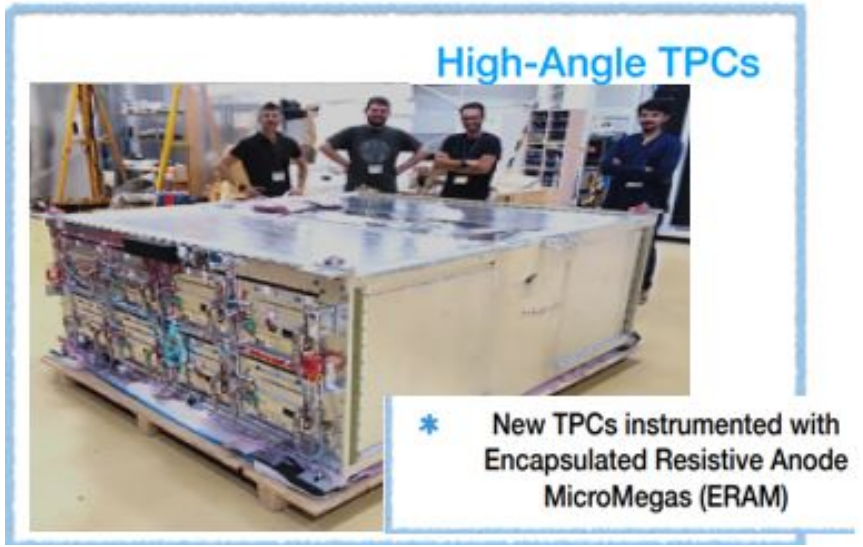
# Beam Run for Physics 2024/6/1 – 7/8



# ND280 Upgrade - INFN PD

Importante coinvolgimento INFN PD in costruzione delle TPC "orizzontali" (High Angle TPC):

→ **coordinamento intero progetto** di HA-TPC → **G.Collazuol**
→ **disegno e costruzione Field Cage (FC)** guidato da **INFN-PD** con LNL e Bari
→ **coord. tecnico FC e costruzione sensori MicroMegas** guidato al CERN da **Stefano Levorato**




## Attivita' 2018-24 in breve

. realizzazione e test prototipi (2018-21)

. **Costruzione Field Cages & Assemblaggio HA-TPC**
@ CERN bld 182 (2022-24) -> next slides

. **Installazione & Commissioning HA-TPC**
@ JPARC (2023-24) -> next slides

Grazie al **Servizio Officina Meccanica** per realizzazione molte parti meccaniche e mockup meccanici/elettrici vari

Grazie ad **Amministrazione** INFN PD e naturalmente al **Direttore** per importante supporto

# Upgrade HATPC highlights
# Talk GC 2024/5/31 - La Biodola

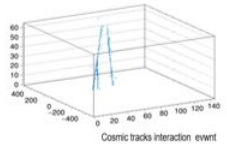
G.Collazuol on behalf of the ND280 Upgrade collaboration
Department of Physics and Astronomy
University of Padova and INFN

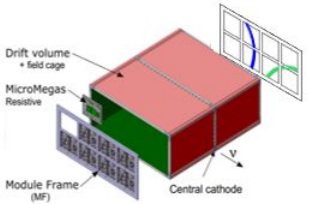
16th Pisa Meeting on Advanced Detectors
La Biodola, isola d'Elba
27/5 – 1/6 2024

## The new TPCs for the Upgraded Near Detector of T2K

### Overview

- Introduction
- Highlights TPC Field Cages
- Highlights TPC ERAMs
- TPC performaces



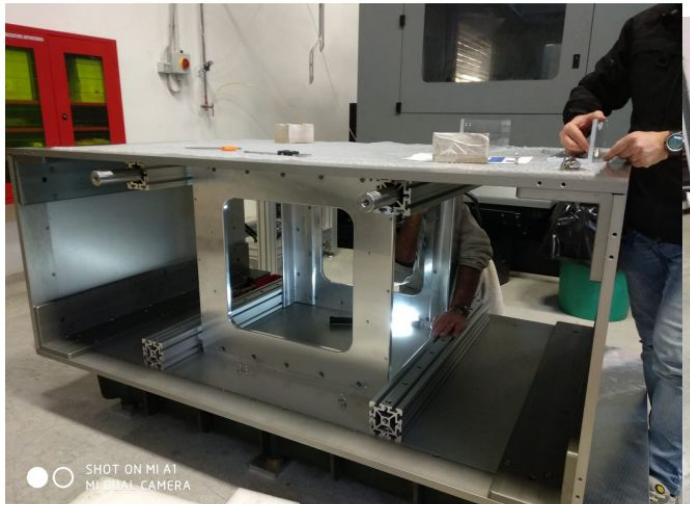
# Field Cage building, assembling and characterization

Production at NEXUS company (Barcelona) ~ 10 weeks
Validation, QC, electrical and mechanical assembly at CERN ~ 4 weeks

## Field Cage building on a mould

Mold features

- 1cm thick Alu walls
- Anodyzd. Surfaces
- Waviness compl. iso1302 N8
- Surfaces ⊥ and ∥ better than 80μm/m
- Mount / unmount geom. reproducibility with high precision




Parts and materials

- Mold → INFN
- Double layer strip foil → CERN
- Structural parts = Flanges & Bars (G10 → ORVIM company (TV, Italy)
- Composite material & Production → NEXUS company (Barcelona)

# Field Cage building, assembling and characterization

Production at NEXUS company (Barcelona) ~ 10 weeks
Validation, QC, electrical and mechanical assembly at CERN ~ 4 weeks

- Mold preparation
- Inner Vacuum bag
- Strip Foil positioning

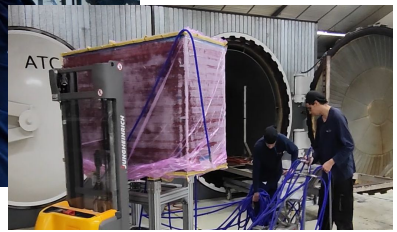
- Thick corners w/ Kapton tape
- Eletrical tests on surfaces
- Resin samples electrical Tests

5 m perimeter x 1m height (drift length)

Strip foil alignment and
lamination of 3 Kapton layers

- Kapton lamination
- Curing at 40C (fast)
- Eletrical tests on surfaces
- and resin samples

# Field Cage building on a mould at NEXUS



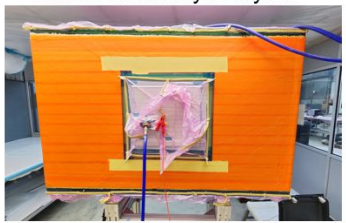
- Kapton lamination
- Curing at 40C (fast = 12h) in autoclave
- Eletrical tests on surfaces and resin samples

- First Twaron layer lamination
- Curing at 40C (fast) in autoclave

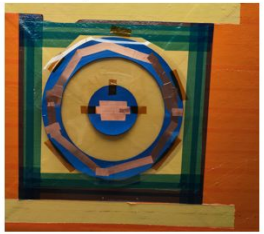
Inner Twaron peel lamination and electrical insulation QC

## Quality controls – Resistivity of early Layers

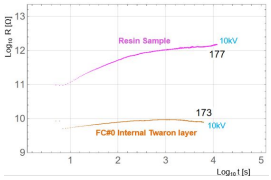
1) Resistance between mold and 40x45cm2 electrode
-> volume resistivity of layers

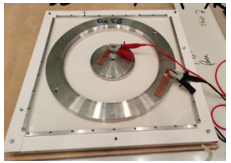


2) Surface resistivity of last layer Twaron



3) Resistance between two 6x80cm2 electrodes
-> mix of surface and volume resistivity



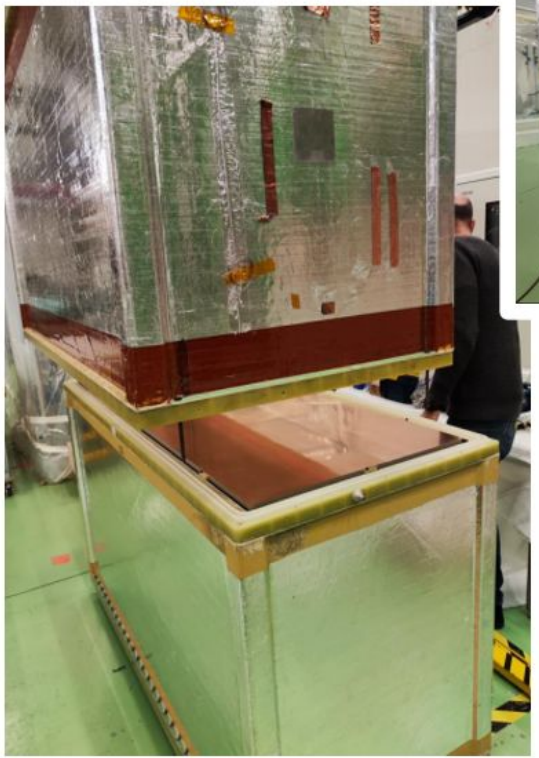
Resin sample
(Resoltech Epoxy)

1) various methods and electrode types (optimizing contact)
→ consistent measurements

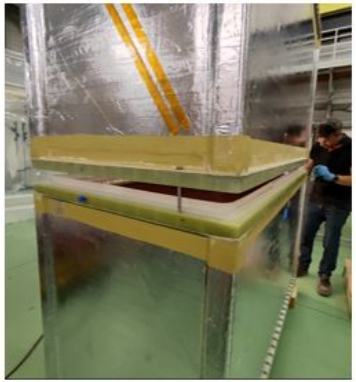
2) Resin sample $\rho_S$ ~ 10 TΩ/□
→ very good

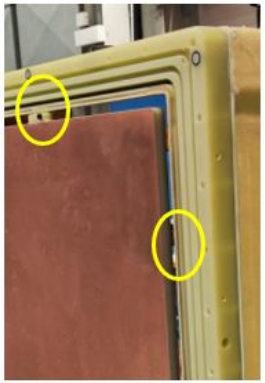
# Field Cage assembling, characterization at CERN

Vertical assembly of
two Field Cages into HATPC



Cathode assembly



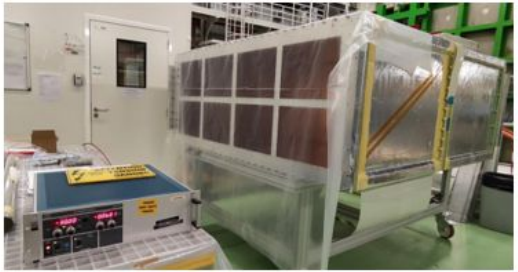


Cathode assembly

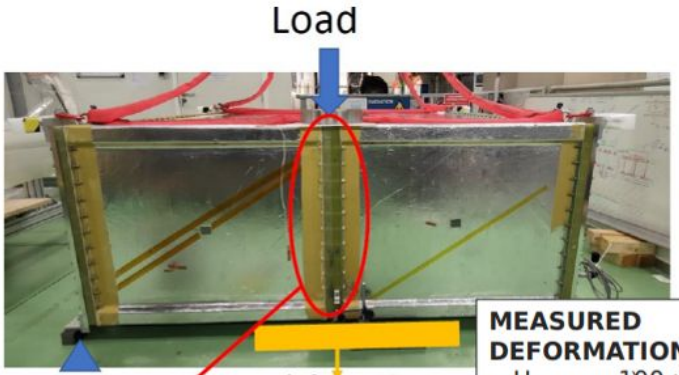
High Voltage feedtrough
external connection

Connection of last strips to cathode
and to high voltage feedtrough

High voltage tests after assembly

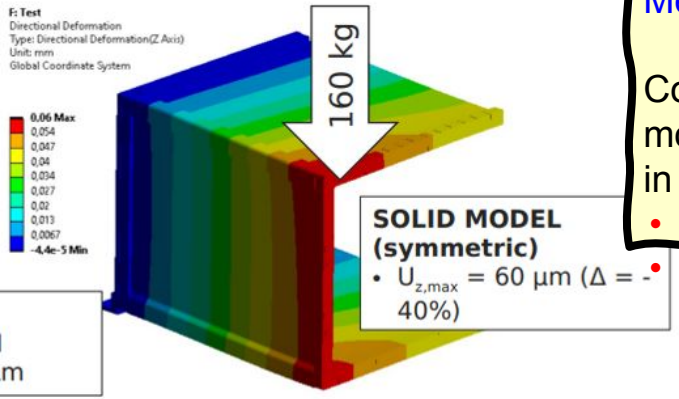


# Field Cage assembling, characterization at CERN

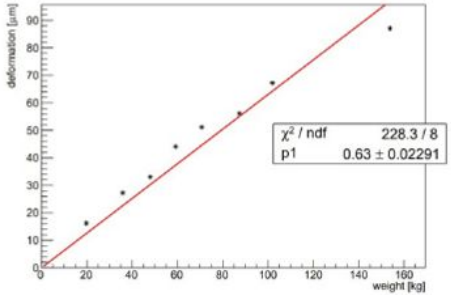



G10 screws
(No metal near cathode)

**MEASURED DEFORMATION**
- $U_{z,meas}$ = 100 µm

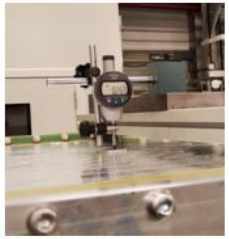


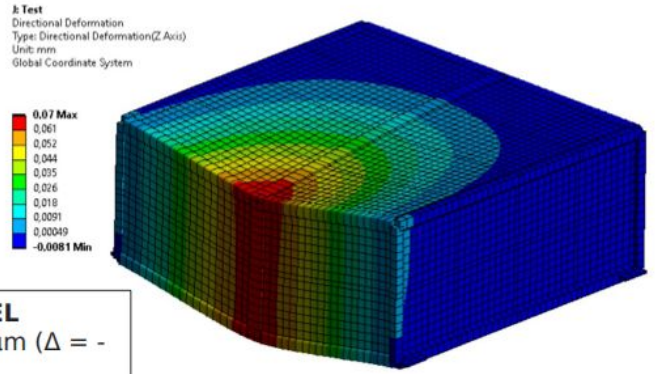

**SOLID MODEL (symmetric)**
- $U_{z,max}$ = 60 µm (Δ = -40%)




Load test performed up to 160 kg

Around ~ $0.6 \frac{\mu m}{kg}$ of deformation w.r.t. horizontal position



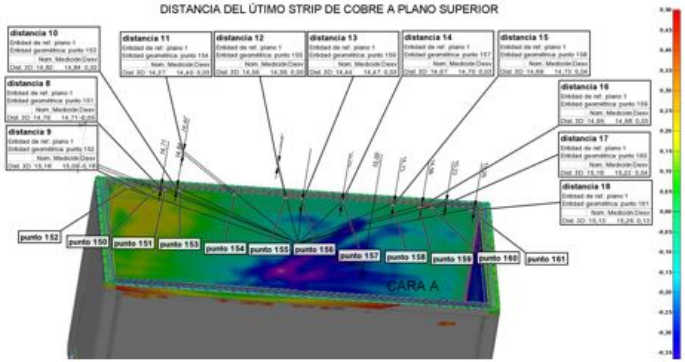


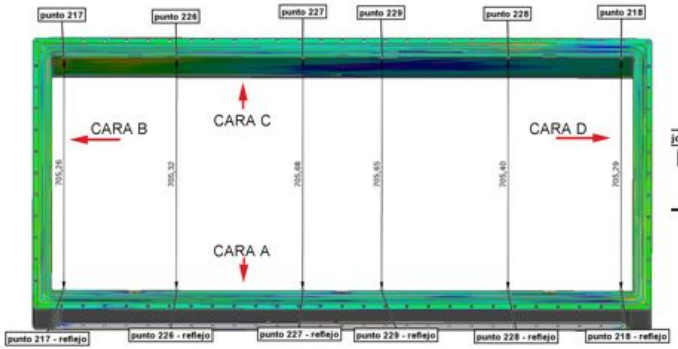

**SHELL MODEL**
- $U_{z,max}$ = 70 µm (Δ = -30%)

**Mechanical qualification**

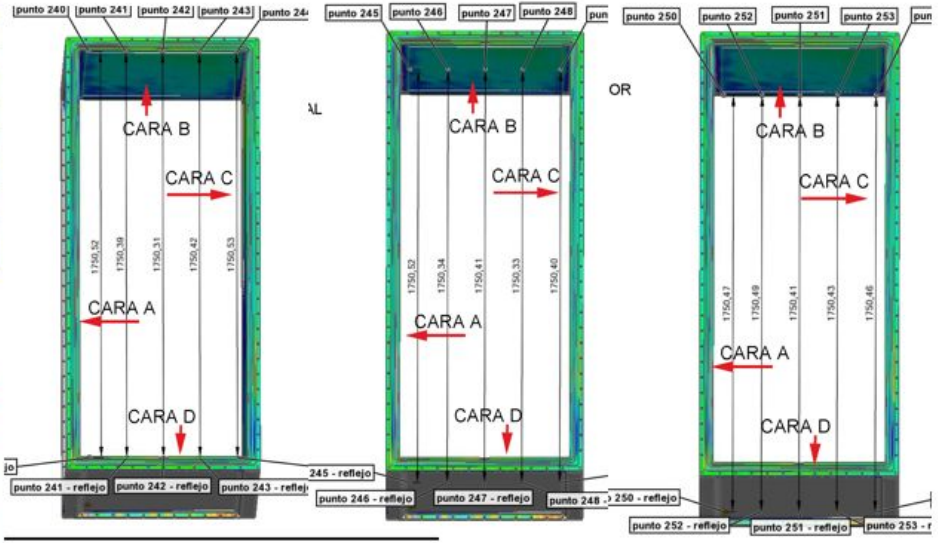
Comparison with FEM models
in fair agreement with
- load tests and
- deformation vs pressure

# Field Cage assembling, characterization at CERN




Metrology NEXUS – single Field Cage box



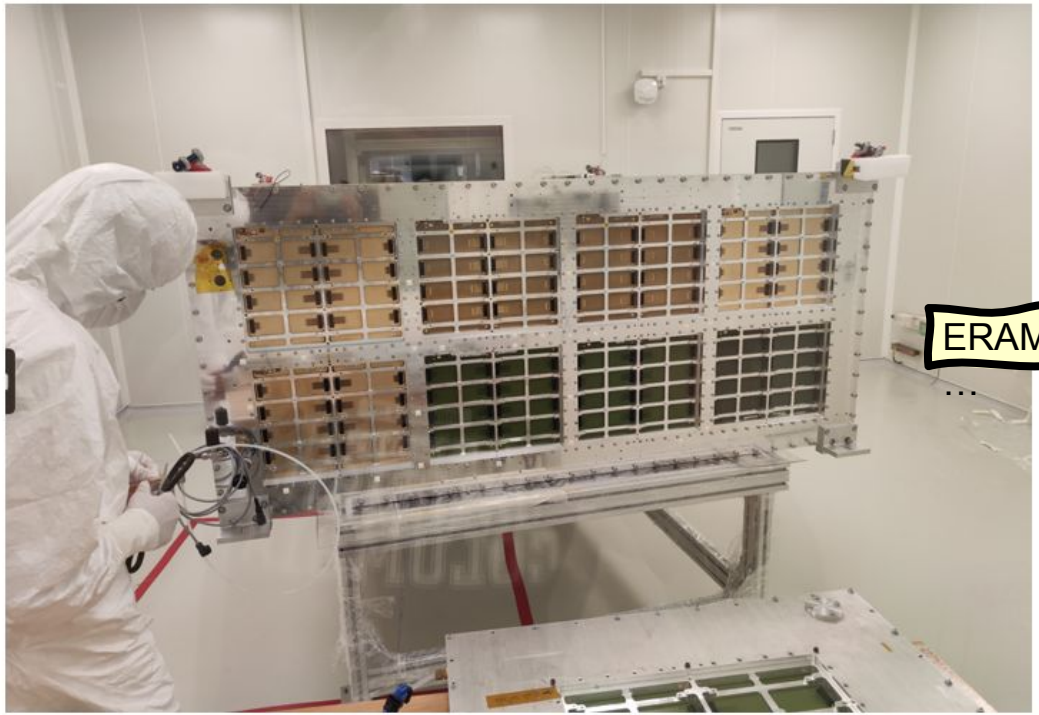

Reached limits of composite material technique

Large dimensions and hand lay-up

Tolerances and specifications at a level better than 300μm/m for planes parallelism and ortogonality and better than ISO1302-N8 for waviness are respected with few localized acceptable exceptions

# Field Cage assembling, characterization at CERN

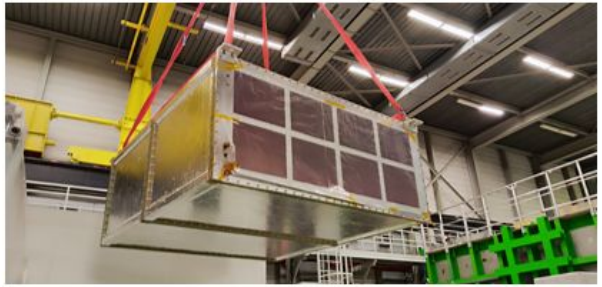
Assembly 16 ERAMs in Clean room



Grey tent area in front of Clean Room
large entrance for enhanced clean conditions

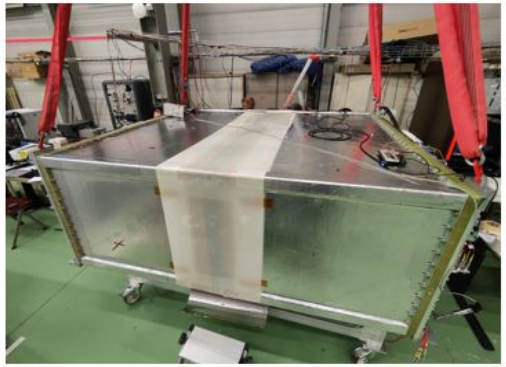
ERAMs very sensitive to dust

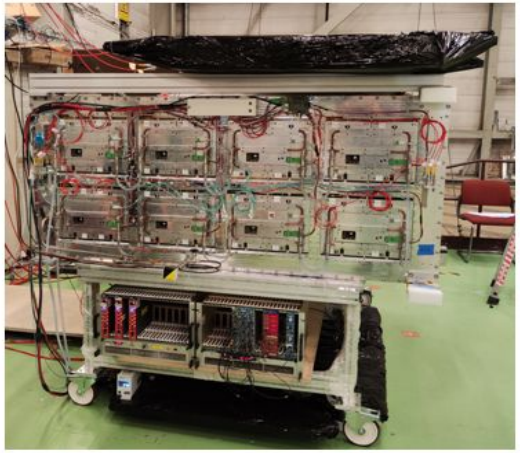
…

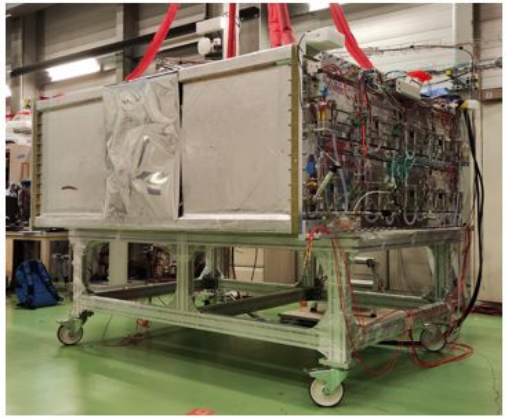


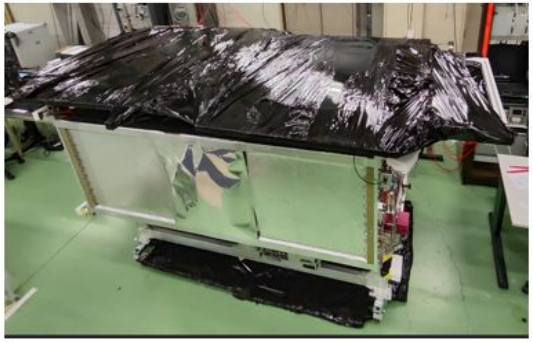
# Field Cage assembling, characterization at CERN

Commissioning at CERN with Cosmic Rays



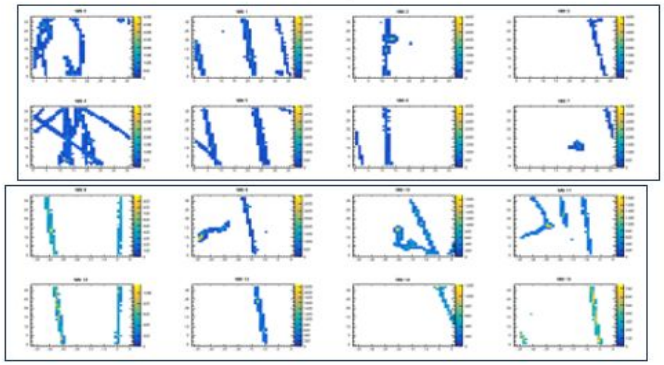




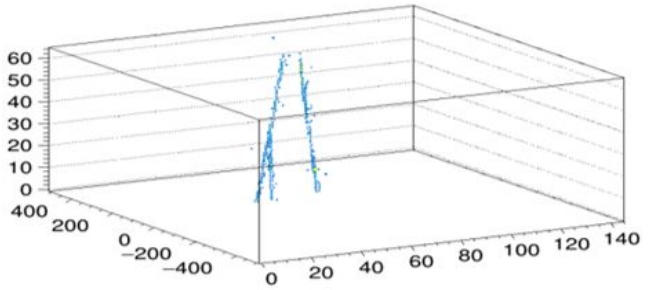


Cosmic shower evwnt

Projection on Anode End Plate 2



Projection on Anode End Plate 1




Cosmic tracks interaction evwnt

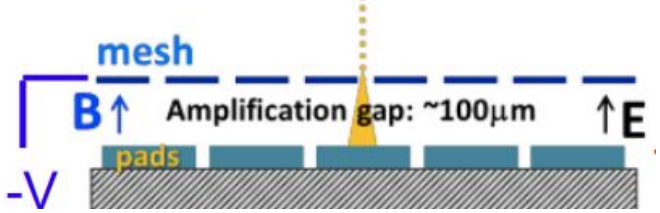
# Charge readout – MicroMegas w/ resistive foil

**Resistive layer** enables Charge spreading
→ space resolution below 500μm with larger pads
→ less FEE channels (lower cost)
→ improved resolution at small drift distance
(where transverse diffusion cannot help)

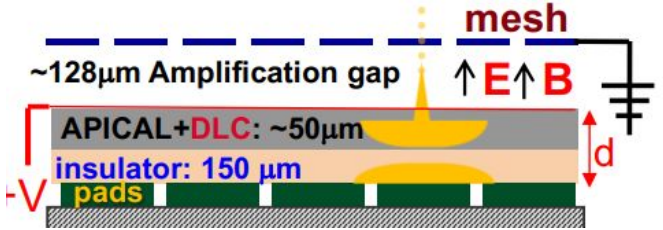
**Resistive layer** prevents charge build-up and hides sparks
→ enables operation at higher gain
→ no need for spark protection circuits for ASICs
→ compact FEE → max active volume

**Resistive layer encapsulated** and properly insulated from GND
→ Mesh at ground and Resistive layer at +HV
→ improved field homogeneity → reduced track distortions
→ better shielding from mesh and DLC → potentially better S/N

Standard bulk-MM (<=old TPC ND280)



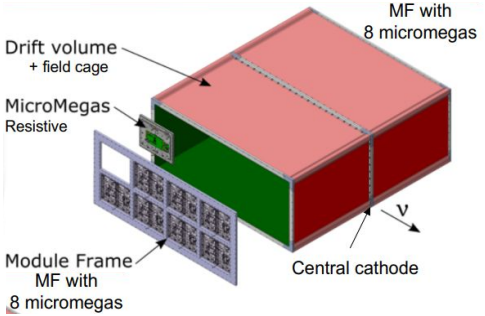

New HATPC => **ERAM**
= Encapsulated Resistive Anode MM

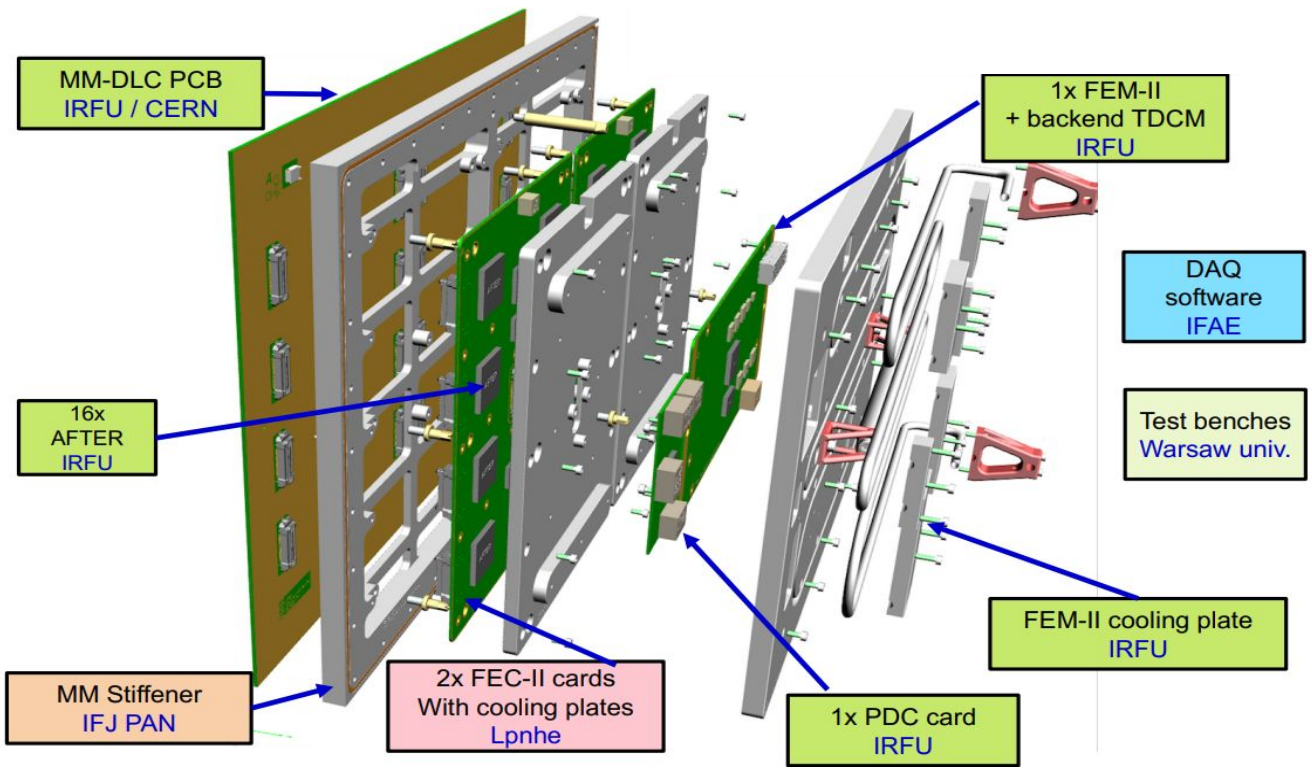



First use of Encapsulated Resistive foil in detector for regular experiment

# ERAM module

8 + 8 ERAMs per HATPC




**Very compact electronics**

36x32=1152 pads : 2 x 576 ch. FEC + 1 FEM2 + 1 PDC

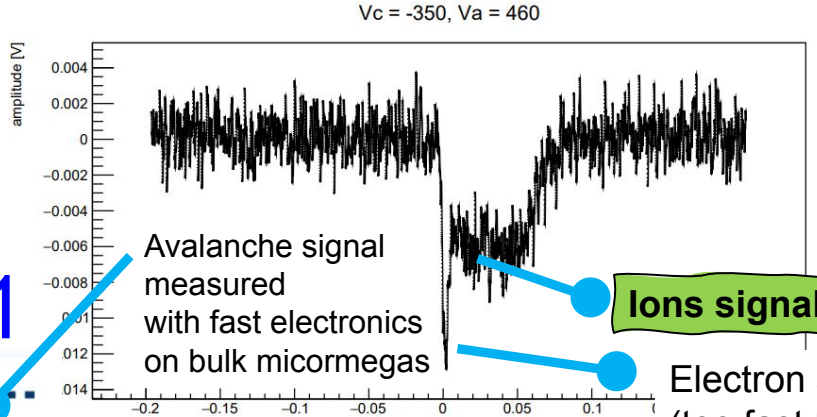
# ERAM response – Signal formation model

## Main ingredients

In the time scale ot our shaping time O(100ns)
Charge spread is properly described by

**Solutions of 2D diffusion eqn.**

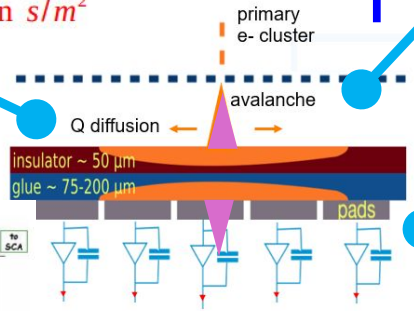
$$\Rightarrow \frac{\partial^2 \rho}{\partial^2 t} = \frac{1}{RC}\left(\frac{\partial^2 \rho}{\partial^2 x} + \frac{\partial^2 \rho}{\partial^2 y}\right) \text{ with } RC = \frac{C_s}{\sigma} \text{ in } s/m^2$$




1 Avalanche signal measured with fast electronics on bulk micormegas

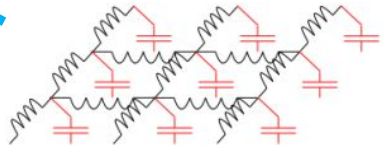
**Ions signal (slow)**

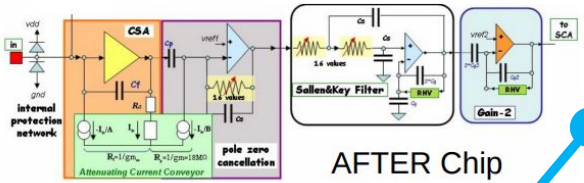
Electron signal (too fast for our shaping times)




2

3 **Electrical model of the sensor**






4 **FEE Response Function**

$$f(t; w_s, Q) = e^{-w_s t} + e^{\frac{-w_s t}{2Q}}\left|\sqrt{\frac{2Q-1}{2Q+1}}\sin\left(\frac{w_s t}{2}\sqrt{4-\frac{1}{Q^2}}\right) - \cos\left(\frac{w$$

$w_s$~1/Peaking time and Q quality factor

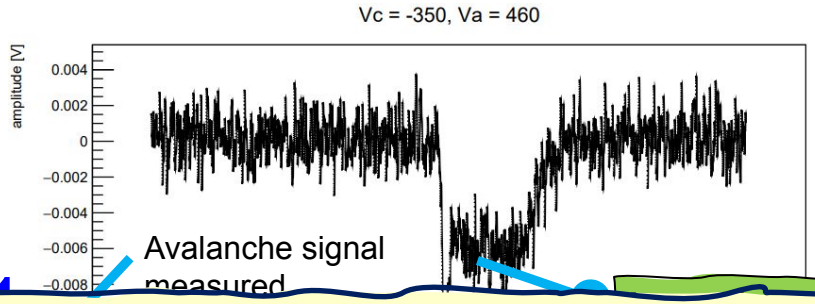
INFN PD □ important contributions
Daniele D'Ago, Stefano Levorato, David Henaff

# TPC calibration and detector studies

## Main ingredients

In the time scale ot our shaping time O(100ns)
Charge spread is properly described by

**Solutions of 2D diffusion eqn**




Deep involvement of the Padova group in

- TPC calibrations (laser ionization => Eloss calibration and Electric Field charact.)
- sensor calibration
- signal formation studies

 activity 2025 at CERN

Future (long term) activities

 DRD1 x charge readout for future gas detectors (MPGD / High pressure)

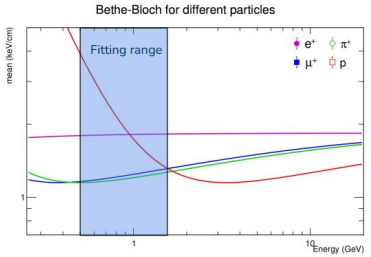
 DRD4 x light readout for future detectors (digital SiPM e TIMEPIX4 chip)

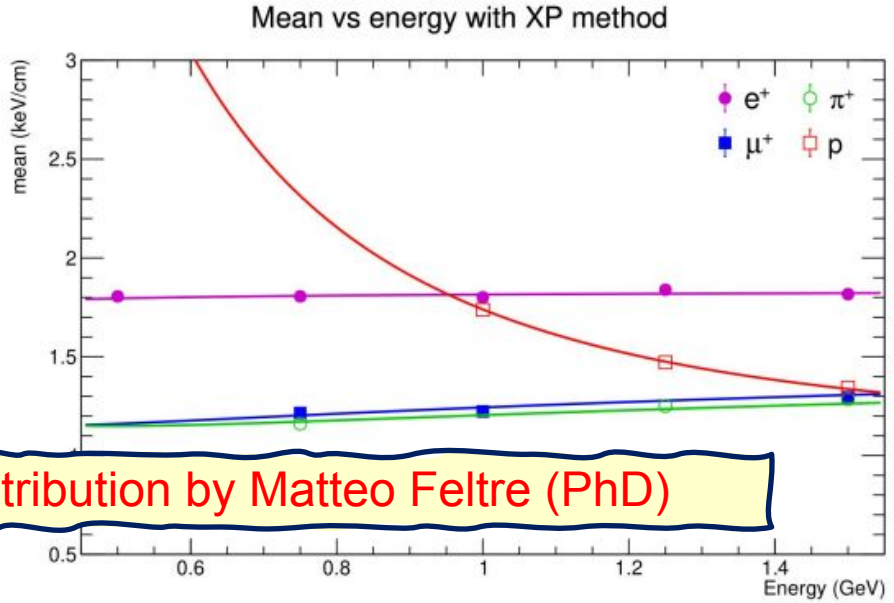
⇒ nuove sigle TIMEPIX4 e ASPIDES in gruppo 5

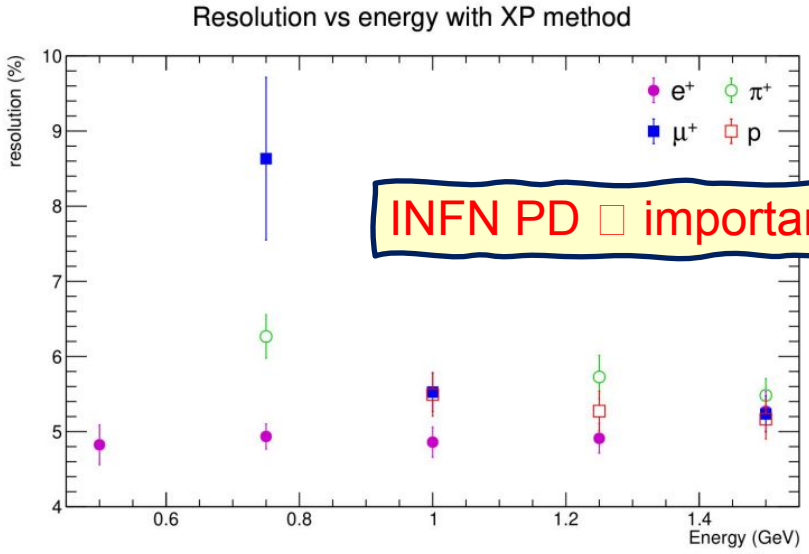
$w_s$~1/Peaking time and Q quality factor

# dE/dx preliminary results

dE/dx (160cm long tracks) – XP method on Test Beam data (CERN PS T10)



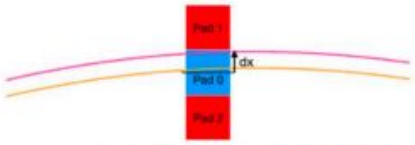

INFN PD □ important contribution by Matteo Feltre (PhD)

- Resolution < 6.5% (except low stat)
- $e^+$ stable < 5%

# Reconstructing tracks – trajectory fitting

LogQ Method based on clustering & Log[Qprimary /Qsecondary]

- logQ method to reconstruct position in each cluster
- Helix fit performed on those reconstructed positions




Full Waveform fit Method – based on model & no clustering

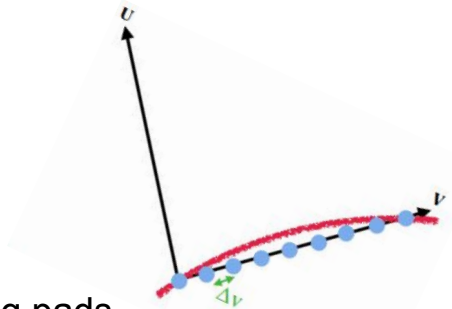
INFN PD □ important contribution by Matteo Feltre (PhD)

1) Use all the pads associated to a track (Qmax values) … d (v,u) local frame

2) Distribute "arbitrary" point charges alon… parated by Δv (5mm)
Q per each point is a free param…

3) diffusion model to … waveform generated by point charges in surrounding pads

4) Move a… along the u axis to minimize the chi-square difference between measured waveforms and templates using RungeKutta method to fit (u0, du/dv, q/p, t0, dt/dv)

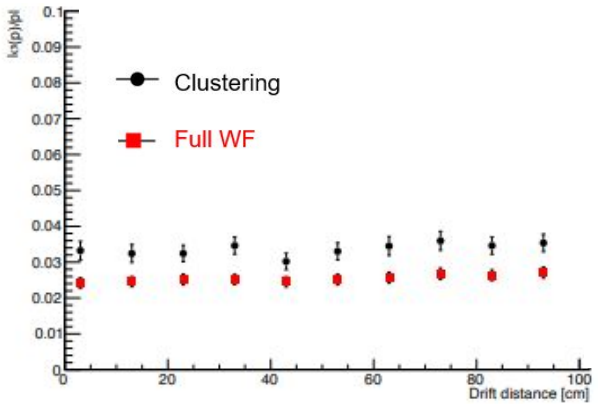



$$\chi^2 = \sum_{i(pad)} \sum_{j(timebin)} \frac{(Q_{i,j}^{obs} - Q_{i,j}^{Dixit})^2}{\sigma_{i,j}^2}$$

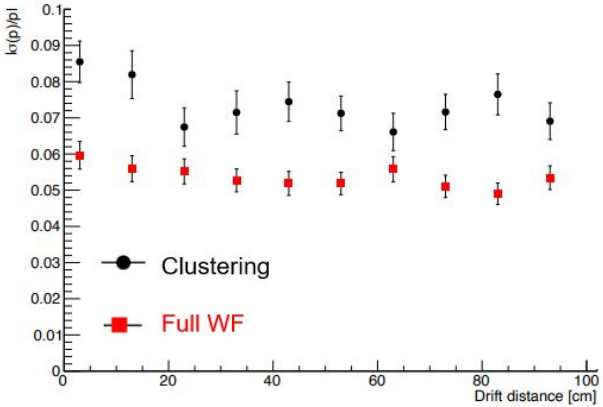
# Reconstructing tracks – momentum resolution

$\sigma_p/p$ Momentum resolution as a function of track drift distance -- simulated 700 MeV/c muons

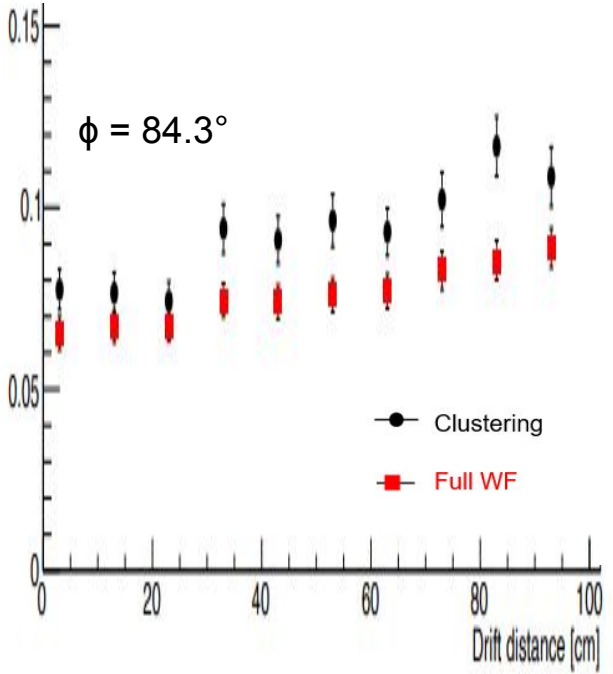
ϕ = 5.7°




ϕ = 45°




ϕ = 84.3°



# T2K “detector activities” - INFN PD

Responsablita` attuali
→ **Detector convener** delle (5) TPC di ND280 & **T2K Executive Commettee member**
G.Collazuol
→ **TPC system and Gas system Experts**
Stefano Levorato, David Henaff
→ **Run coordinators**
David Henaff, G.Collazuol
→ **Coordinamento calibrazioni TPC**
Daniele D’Ago
→ **TPC Data Quality Expert**
David Henaff

## Attivita’ 2024 in breve

CERN = preparazione nuova TPC con field cage spare FC0

JPARC = secondo run neutrino in Nov/Dic

## Attivita’ 2025 in breve

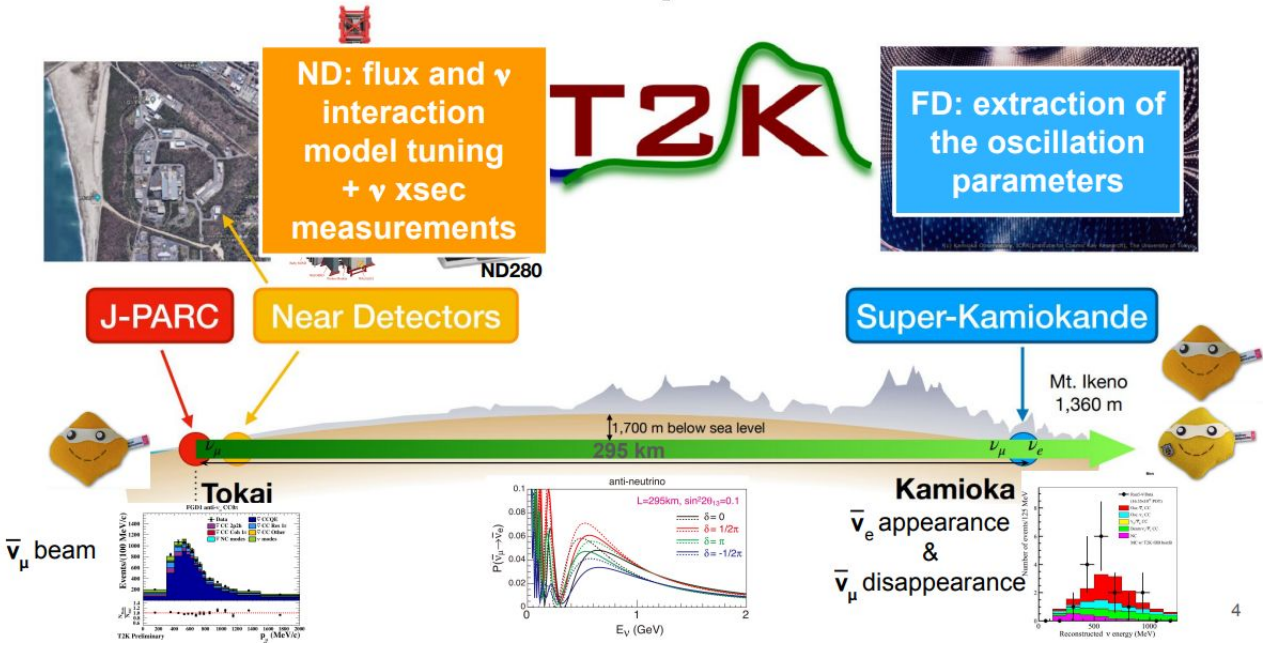
CERN: - Calibrazioni con Laser system TPC
- Test Beam CERN PS (Spring 2025)
- Detector studies

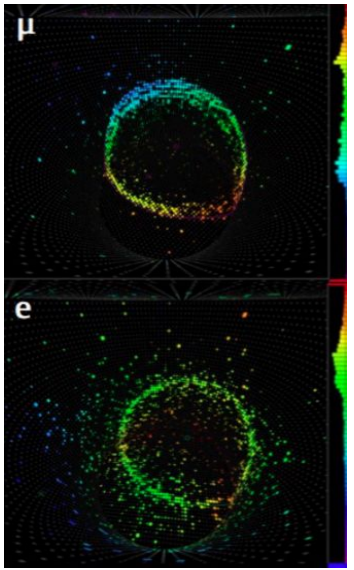
JPARC: 4 mesi di neutrino beam run in 2025

# T2K “analysis activities” - INFN PD

Responsablita` attuali
→ **Oscillation Analysis Convener**
**Andrea Longhin**

T2K uses difference in the process $\nu_\mu \rightarrow \nu_e$ and $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$ to study the matter-antimatter asymmetry over a 295 km “travel”.



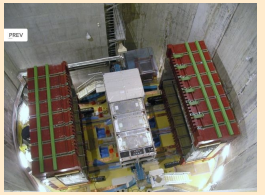



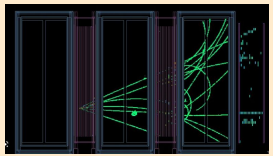

Super-Kamiokande separate $\nu_\mu$ from $\nu_e$

# Oscillation Analysis

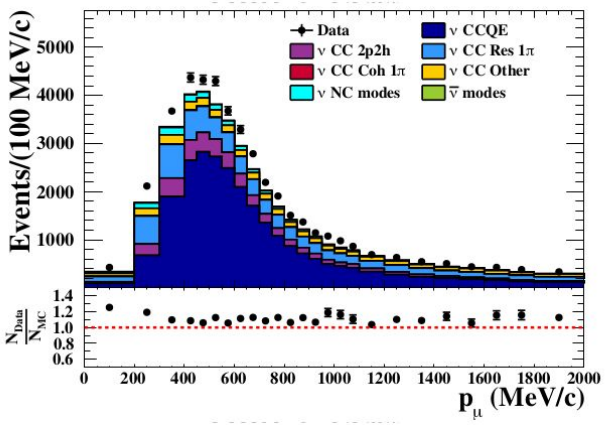
Responsablita` attuali
→ **Oscillation Analysis Convener**
**Andrea Longhin**

The “Near detector fit”

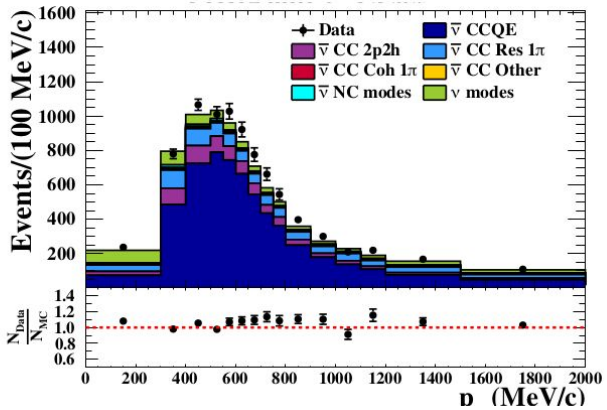


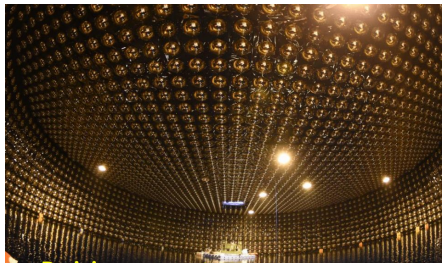


**Near detector data BEFORE fit**

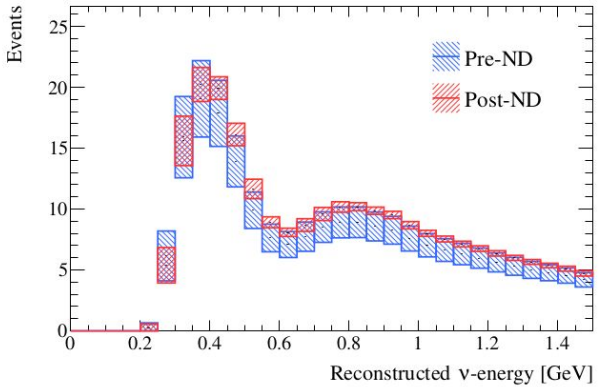



**Near detector data AFTER fit**

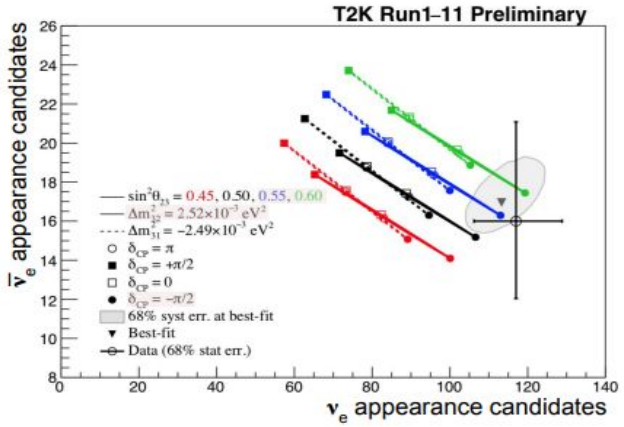


Uncertainty on the prediction at far BEFORE ad AFTER the near detector fit:

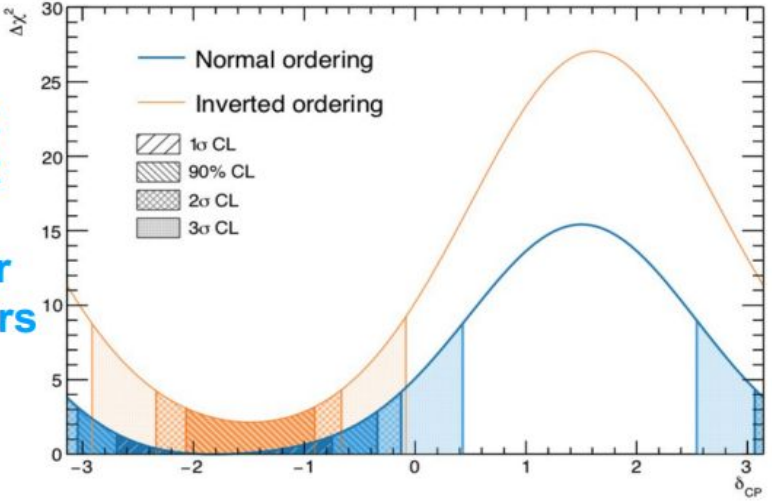


# OA results @ Neutrino'24

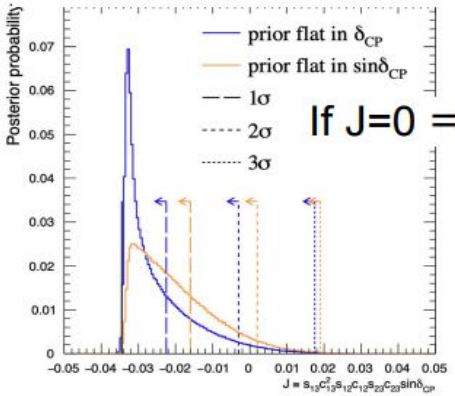



## Latest Results: $\delta_{CP}$

Very consistent results wrt previous analysis for all parameters




$$J = s_{13}c_{13}^2 s_{12}c_{12}s_{23}c_{23}\sin\delta_{CP}$$




If J=0 ⇒ CPC

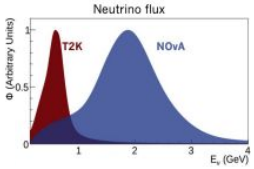
*Results just released at the Neutrino 2024 conference. Paper planned*

As before, almost 2σ exclusion of CP conservation!

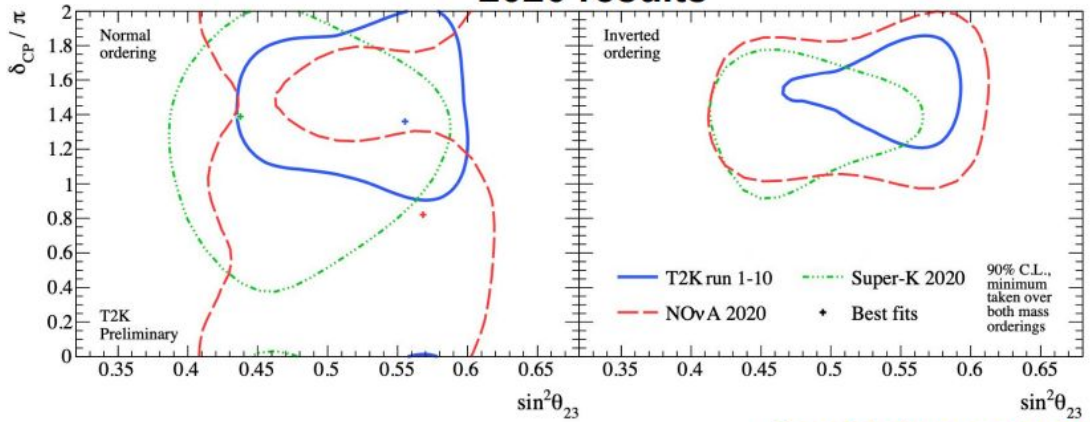
Preference for Normal Ordering

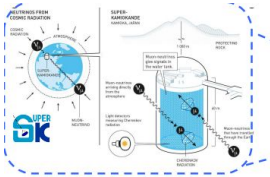
# T2K oscillation analysis joint fits

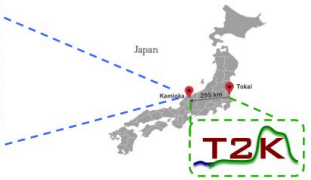
## T2K joint fits: motivations


### 2020 results





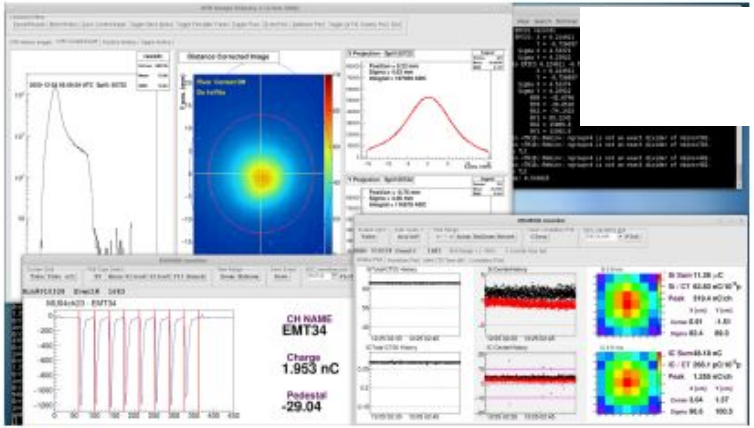

| | baseline | sensitivity $\delta_{CP}$ | sensitivity MO |
|---|---|---|---|
| **T2K** | 285 km (accelerator) | ++ | + |
| **NOvA** | 800 km (accelerator) | ++ | |
| **SK** | up to 12000 km (atmospheric) | + | ++ |

**Combining experiments to break degeneracies and gain sensitivity to MO and $\delta_{CP}$**

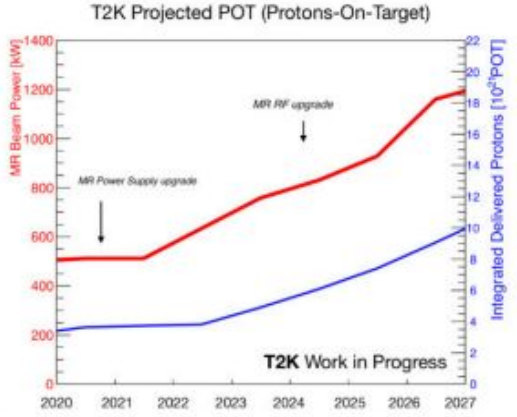
**T2K+SK:** short paper submitted last month, a long one planned

**T2K+NOvA:** analysis released in Feb. 2024, paper in preparation

# Towards higher beam power


- December 2023 → Beam power increased from 500 to 760 kW and to 800 kW since last week!
- Steady improvements to reach 1.3 MW by 2027 → increase T2K statistics by a factor of 3 by 2027
- Larger statistics → need to reduce systematic uncertainties



# Prospects

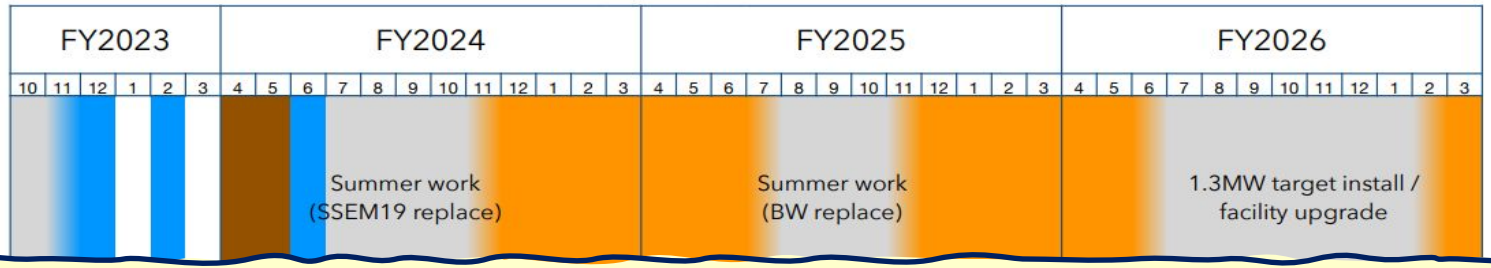
- By 2027, we aim to accumulate ~1x10$^{22}$ POT, toward precise measurements of neutrino interactions and the search for the neutrino CP violation.

- Currently, we are collecting data at 800 kW. We will increase the beam power and continue data taking for four months each fiscal year (according to the 2020 KEK DG's plan) or more using the fully upgraded near detector and the SK-Gd detector.

  - *For FY2024: 1 month (June) + 1.7 months in Nov.-Mar. (previous PAC recommended) + additional request 1.3months*

Plan for next three years

***The period during which T2K can operate***



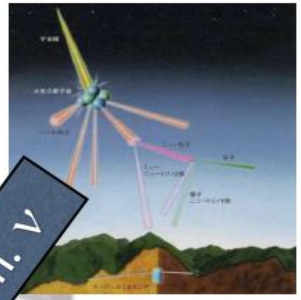

T2K to run 4 months of neutrino beam run per year until Hyper-K era will starts

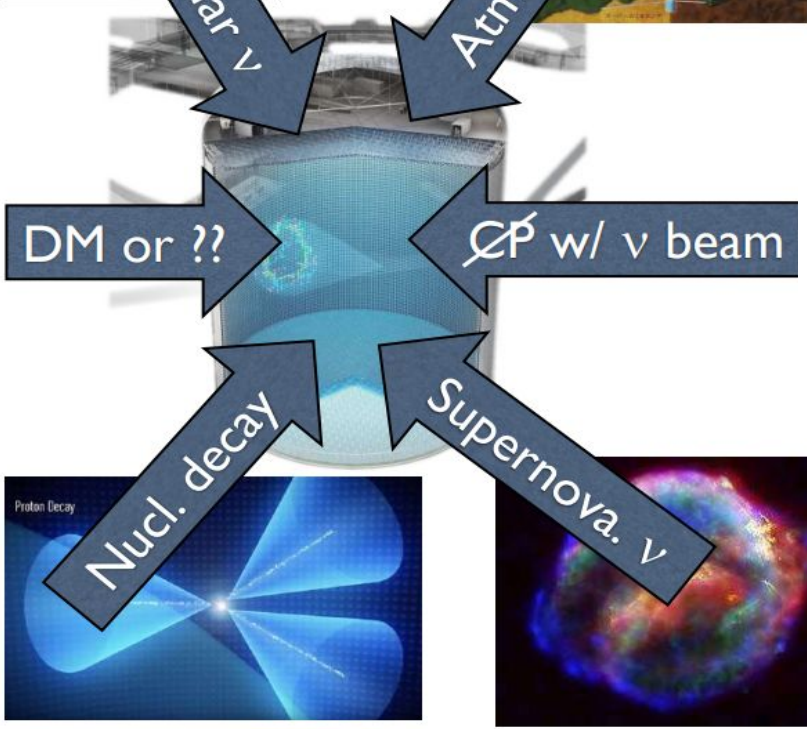
# Hyper-Kamiokande Project

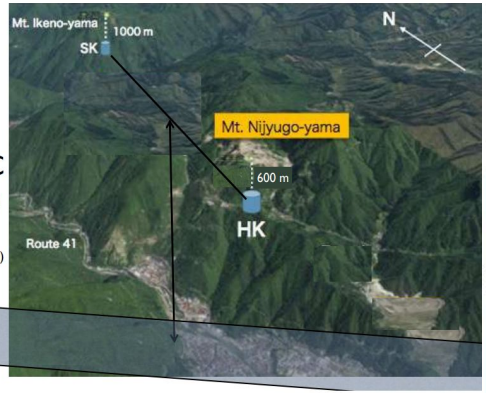
Rich physics & discovery potential

Construction started in 2020

Operation will start in 2027






J-PARC ν beam axis (depth ~1.3 km)

Hosts: UTokyo & KEK

75% non-Giapponese

Italia ~10% Collaborazione


## INFN contribution fixed 2023

| | Item | Cost (K€) | Cost (K€) |
|---|---|---|---|
| mPMTs | 300 mPMTs | 2940 | 2990 |
| | Electronic TestBench | 50 | |
| Electronics | 20" PMTs front-end | 2000 | 2287 |
| | Cables, feedthroughs (sharing) | (*) 215 | |
| | Timing distribution | 72 | |
| | Computing (2022-26) | 621 | 621 |

**5.3(+0.7M) capital costs**

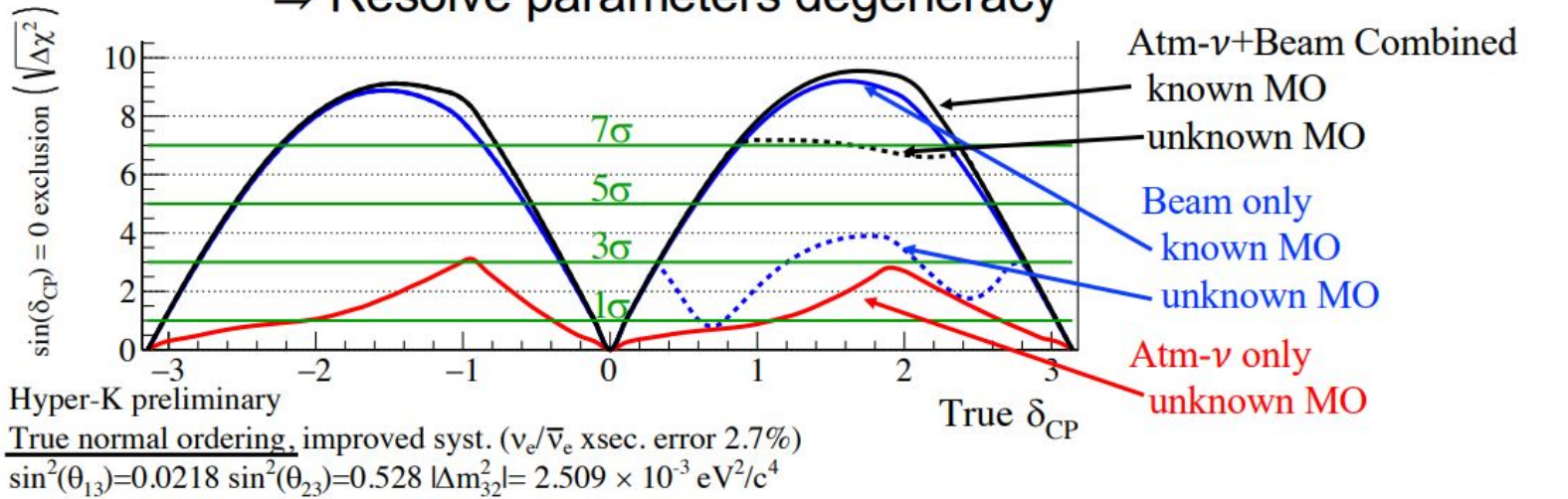
**+**

**0.6M computing**

# Strategy of oscillation measurement at Hyper-K

## Combination of long-baseline and atm. ν observations

## ⇒ Resolve parameters degeneracy

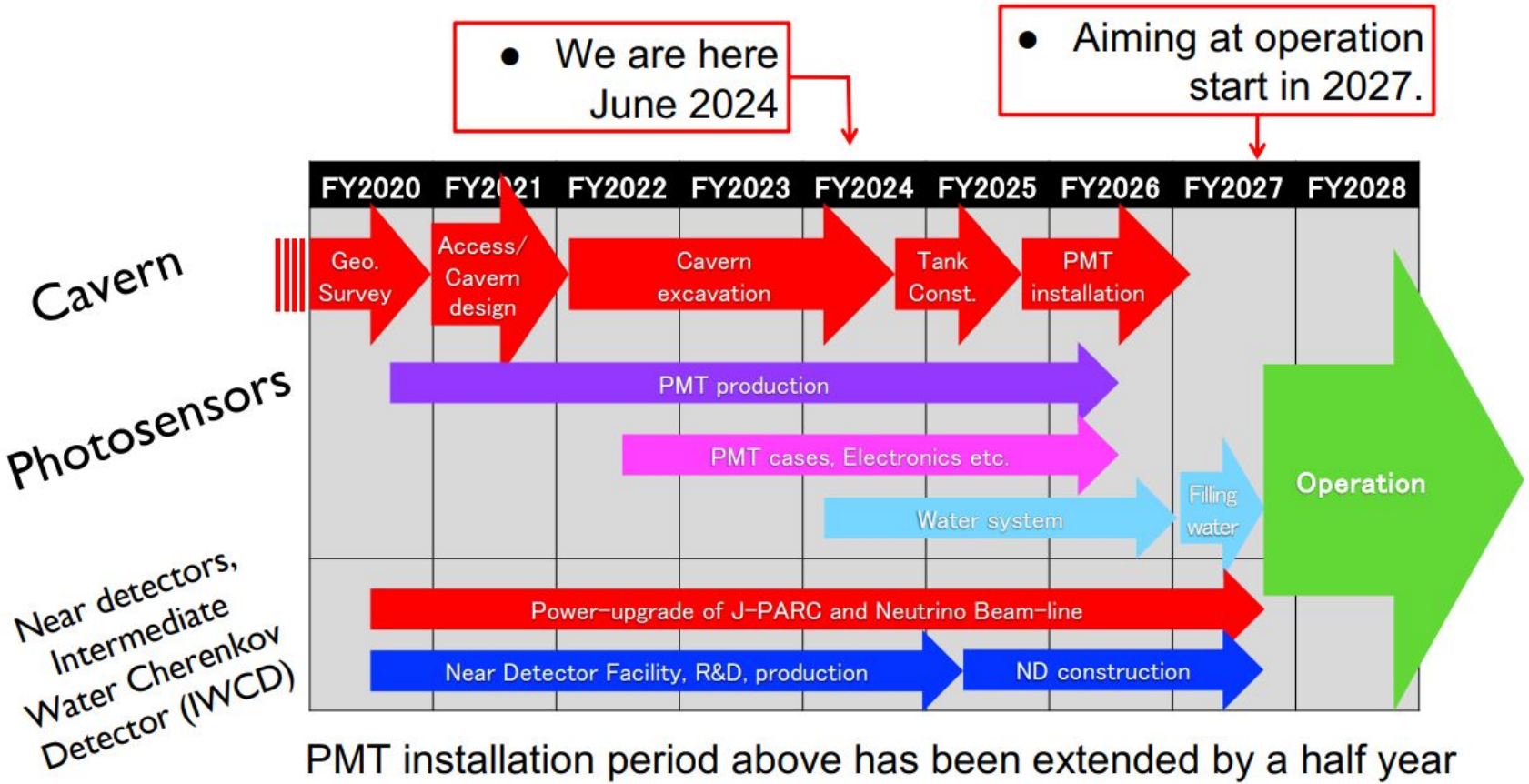



| | $\sin^2\theta_{23}$ | Atmospheric neutrino | Atm + Beam |
|---|---|---|---|
| Mass ordering | 0.40 | 2.2 σ | → 3.8 σ |
| | 0.60 | 4.9 σ | → 6.2 σ |
| $\theta_{23}$ octant | 0.45 | 2.2 σ | → 6.2 σ |
| | 0.55 | 1.6 σ | → 3.6 σ |

10 years with 1.3MW, normal mass ordering is assumed

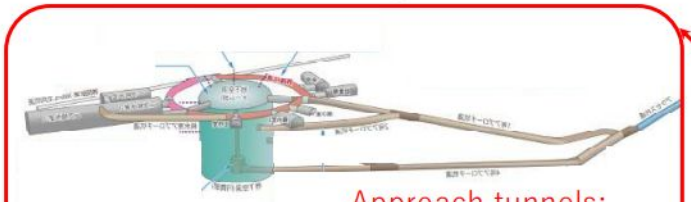
Atmospheric neutrino:
sensitive to mass ordering by Earth's matter effects
→ Constraints on mass ordering enhance sensitivity to CP violation by long-baseline

# Updated Construction Schedule




PMT installation period above has been extended by a half year due to a final design of a PMT support structure.

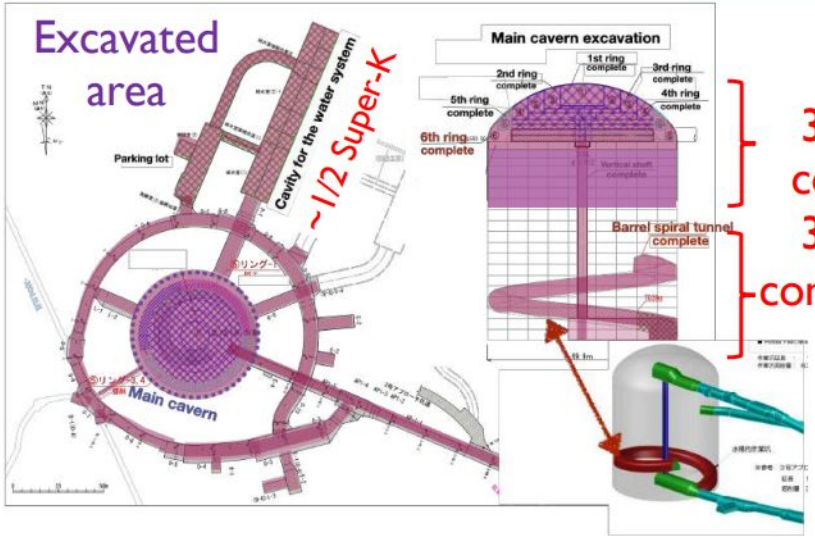
# Excavating the world's largest human-made cavern



Approach tunnels:
XXX completed

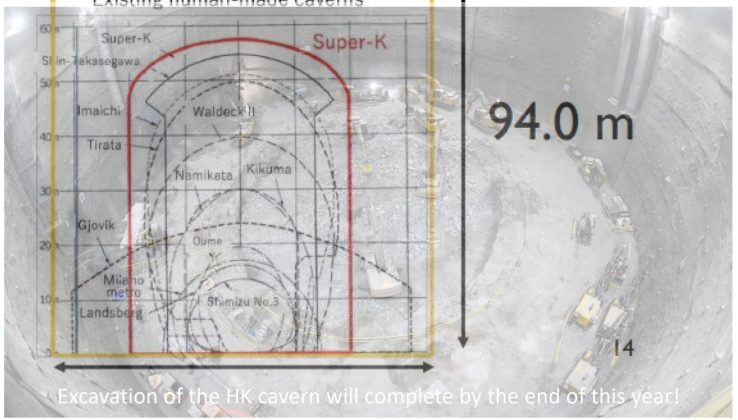






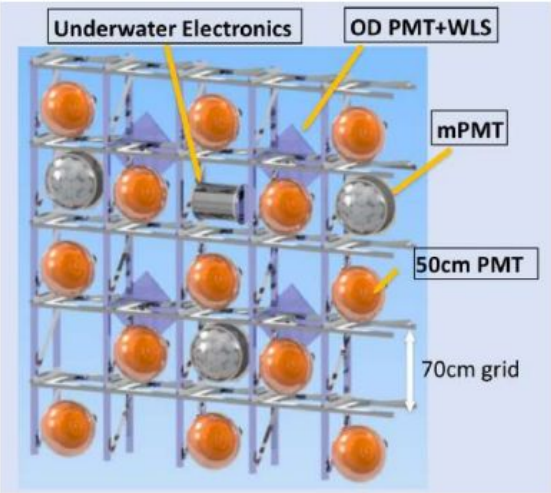

3 Super-K completed.
3 Super-K coming ~1/2yr

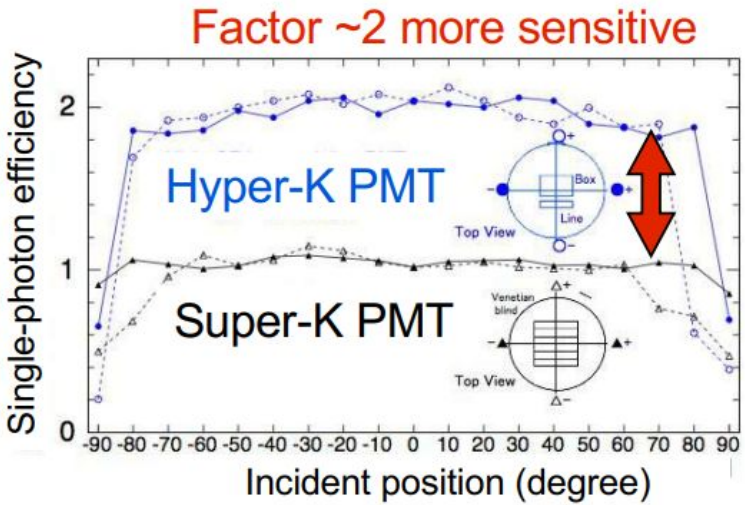
69.0 m



# Photo-detection system

- Detailed design of the tank lining and photosensor support structure completed.



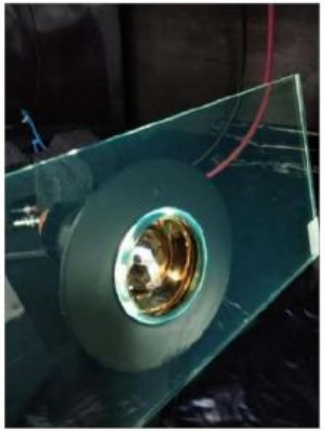




- New features on 50 cm PMT (B&L-dynode) include
  - High QE, T resolution, pressure tolerance (x2 better than Super-K)
  - dark rate reduction, low radioactivity, cover development
  - long-term performance evaluation already in Super-K

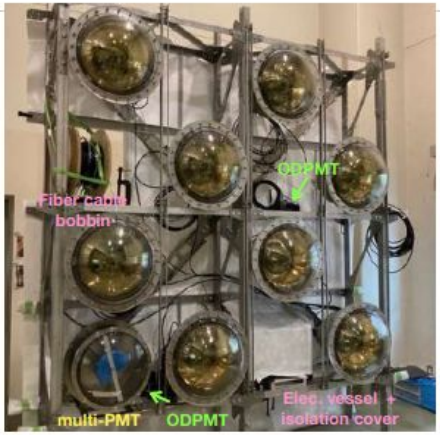
  ➔ 20 000 of 50 cm PMTs from Japan

# International contributions and preparation for production

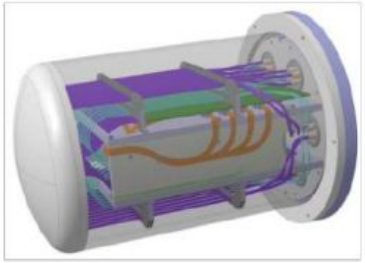
**Outer detector:** PMT+WLS plate

Photosensors/elec. mockup

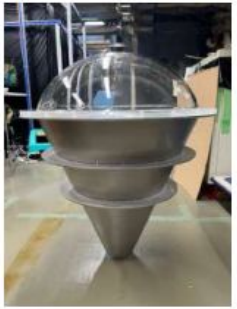


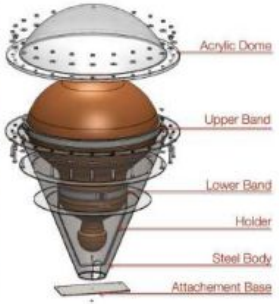

**Underwater electronics:**
Case design and feedthrough



**Multi-PMT module:**
(ref. KM3NeT)

**PMT cover**



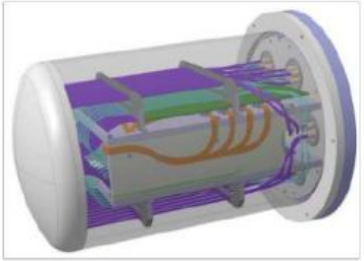


# Contributo INFN cruciale in HK

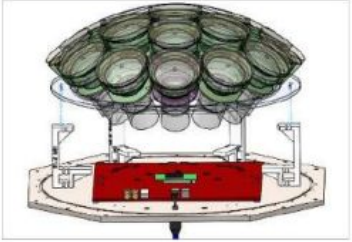
## Elettronica Inner Detector

- Disegno e produzione Elettronica in acqua (FE e digitizer)
- Test Bench Vessel elettronica (high pressure)
- Contributo a calibrazione e assembly al CERN

**Underwater electronics:**
Case design and feedthrough



**Multi-PMT module:**
(ref. KM3NeT)

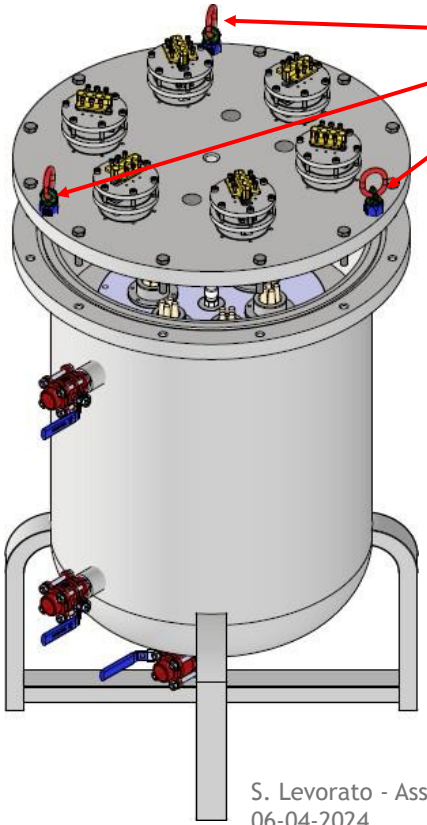


## Multi-PMT

- Disegno Multi-PMT
- Contributo ad assemblaggio e calibrazione ad INFN Napoli

# Pressure tank for Vessels  Stefano Levorato

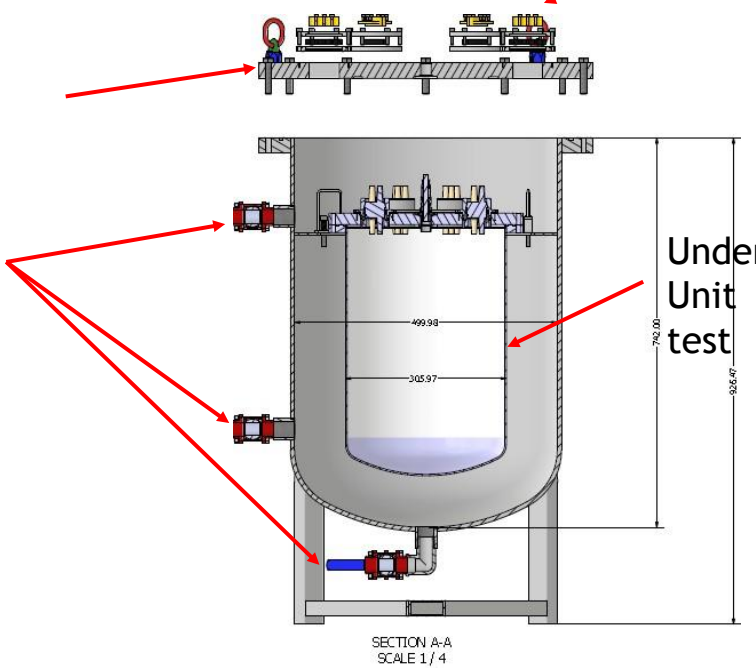
## for INFN PD



Lifting system for the main flange

main flange

Water filling and evacuation system (plus dedicated inlet/outlet on the main flange )



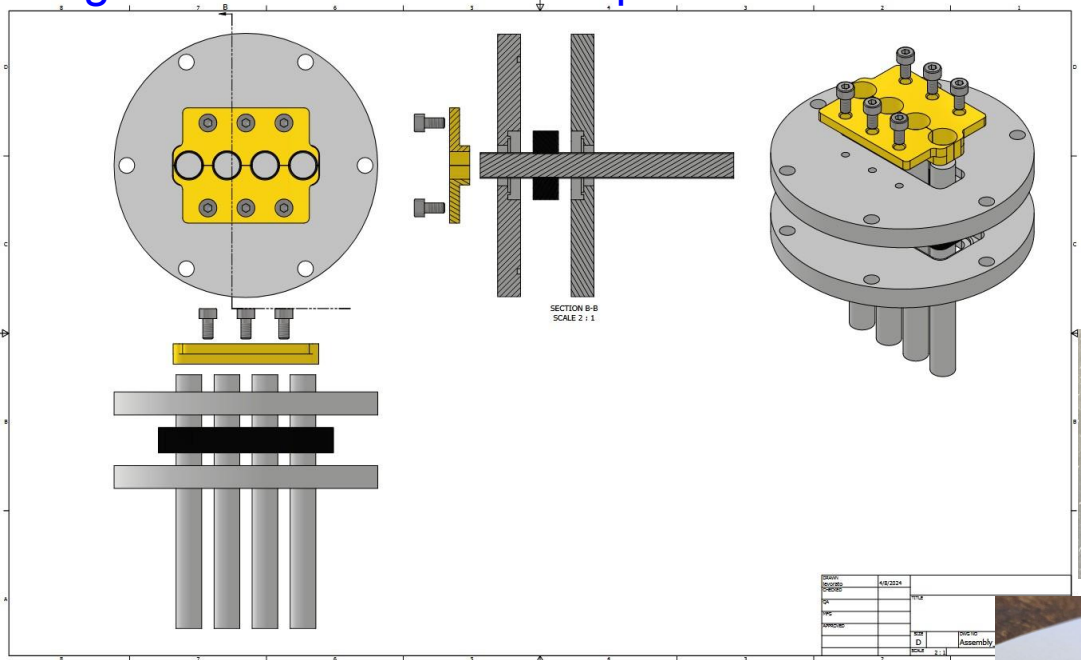

Feedthrough system

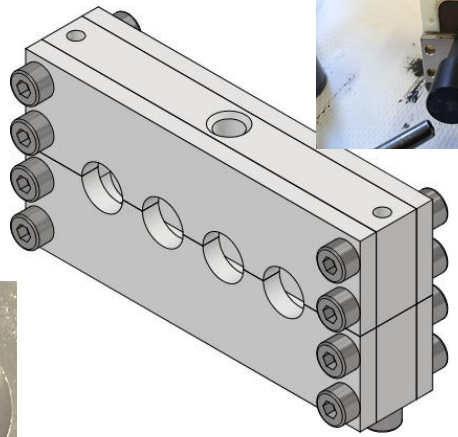
Underwater Unit under test

Approximatively: 1 meter h x 0.5 m w , 150 liters of water

# Pressure tank for Vessels  Stefano Levorato

## Progetto avanzato  fase di produzione del test bench



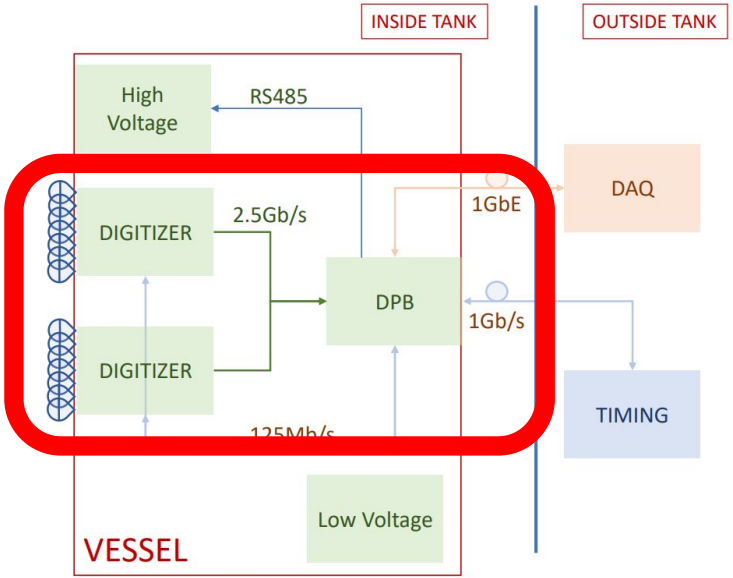
1 Dedicated molding and compression system

2 Dedicated choice of bicomponent sealing compressible material. Chemical inert and removable from the cables after the test

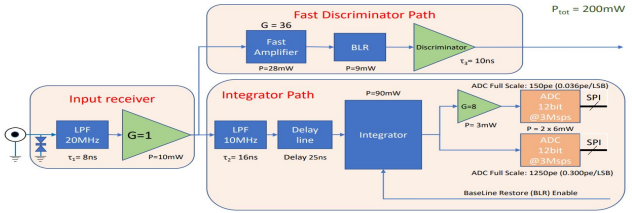
Grazie al Servizio di Officina Meccanica

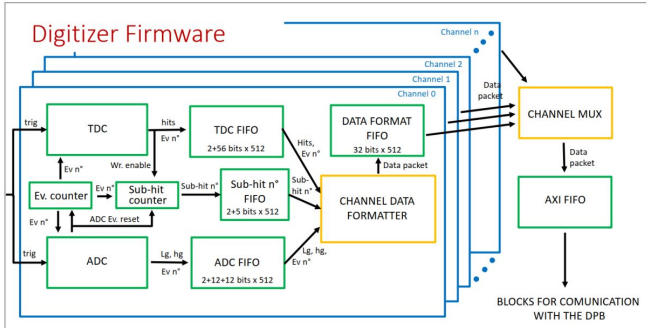
# Coinvolgimento INFN PD

## anche nella produzione (test bench) ed assemblaggio elettronica




- The circuit is based on discrete ICs
  - Developed by NA group
- PMT input signal feeds 2 paths:
  - Integrator for CHARGE measurement
  - Fast Discriminator for TIME STAMPING
- Design uses Baseline Restore Enable technique

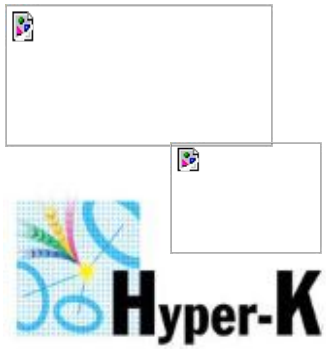


# Anagrafica 2025 - Hyper-K Padova

| Nome | Contratto | Qualifica | % | Esperimenti |
|---|---|---|---|---|
| G.Collazuol | Associato | PA | 70 | T2K + SK + HK |
| D.D'Ago | Associato | Assegnista | 70 | T2K + HK |
| S.Levorato | INFN | Primo Tecnologo | 40 | T2K + HK |
| M.Feltre | Associato | Dottorando | 40 | T2K + HK |
| M.Grassi | Associato | PA | 70 | T2K + HK |
| M.Laveder | Associato | RU | 80 | T2K + HK |
| A.Longhin | Associato | PA | 40 | T2K + HK |
| M.Mezzetto | INFN | DR | 78 | T2K + HK |
| M.Mattiazzi | Associato | Assegnista | 70 | T2K + SK + HK |
| D.Henaff | Associato | Assegnista | 70 | T2K + HK |
| F.Pupilli | INFN | RI | 40 | T2K + HK |
| | | Tot | 6.7 FTE | |

# Richieste Servizi Sezione 2024



## Servizi Tecnici ed Elettronici

- Test elettrici ed assemblaggio mPMT per HK – attivita` a Napoli ~ 2 m.p.

## Servizio Elettronica

- Test elettrici ed assemblaggio mPMT per HK – attivita` al CERN ~ 3 m.p.
- Test bench produzione elettronica digitale RO HK (supporto al gruppo PD) ~ 1 m.p.

## Servizio Progettazione Meccanica

- Disegno parti meccaniche per HK ~ 1 m.p.

## Servizio Officina Meccanica

- Officina Meccanica - realizzazione parti per attivita' T2K/HK ~ 1 m.p.

## Preventivi gruppo PD 2024

| | |
|---|---|
| Missioni ..... | 110 k€ |
| Apparati ..... | 15 k€ |
| Consumabile ..... | 10 k€ |
| Inventariabile ..... | 10 k€ |
| SP-Servizi ..... | 25 k€ |

DEEP UNDERGROUND
NEUTRINO EXPERIMENT

RL: Filippo Varanini

# Padova: DUNE

- Luca Stanco (Dir.Ric.) – Associato
- Filippo Varanini (Ric. INFN)
- Bagdat Baibussinov (Ric. INFN)
- Magda Cicerchia RTDA
- Meng Guang (Tecnologo)
- Judilka Bermudez (Tecnologo)
- Alberto Guglielmi (Dir.Ric.) - Associato

- Gruppo Icarus, iscritto in DUNE:
  - Alberto Guglielmi (Dir.Ric.) - Associato
  - Filippo Varanini (Ric. INFN)
  - Bagdat Baibussinov (Ric. INFN)
  - Christian Farnese (Ric. INFN)
  - Meng Guang (Tecnologo)
  - Sandro Ventura (Pr.Tec.)
  - Daniele Gibin (Prof. ass.)
  - Maria Artero Pons (post-doc)
  - Sandro Centro (Prof.Ord. – out)

**2.5 FTE**

Coinvolgimenti:
- SAND (management CL, STT, GRAIN at LNL)
- Purity Monitors per ProtoDUNE, FAR
- SBN (Icarus...)

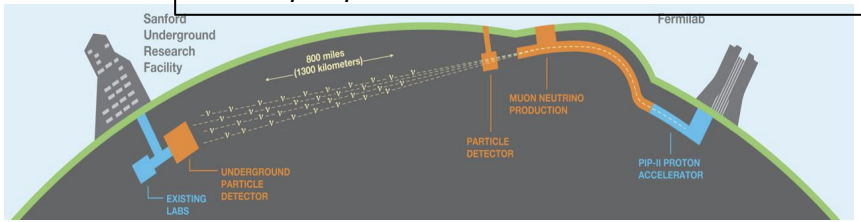
Prospettive:
- Possibili contributi dal Lab.Elettronica
- Meccanica ⟶ *2024*
- Eventuale sito di produzione STT/Tracker al capannone HEP di Legnaro

- Icarus group -> DUNE in the near future

*Luca Stanco ⟶ Filippo Varanini resp. Padova dal 1.5.24*

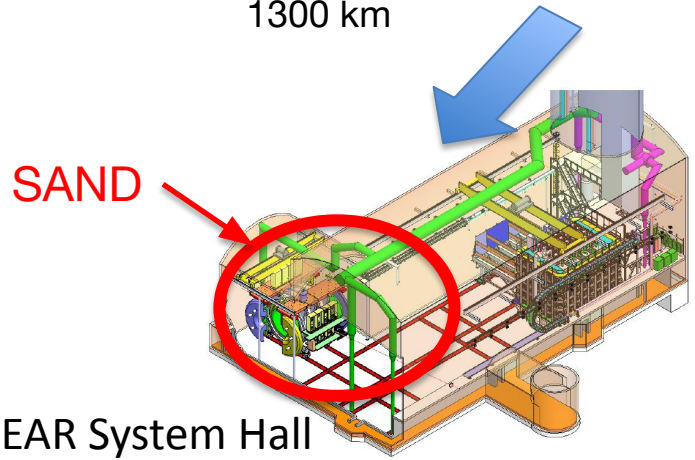
# DUNE context

*1400+ people, 200+ institutions w/ CERN, 34 countries*

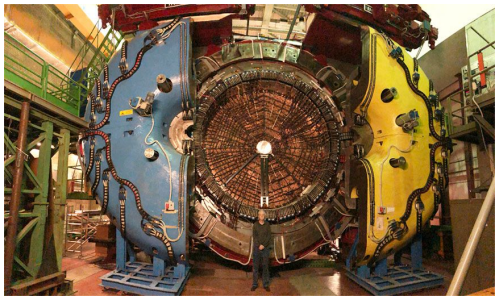


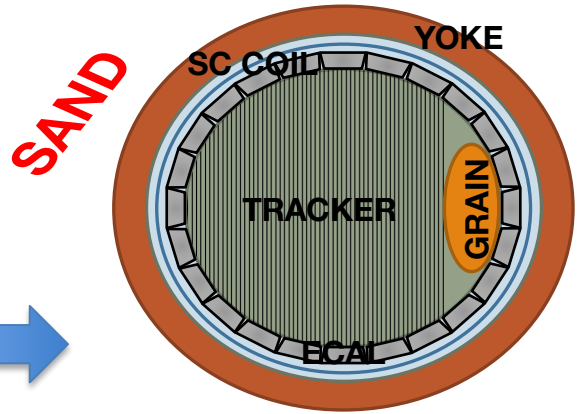

FAR ⟷ NEAR

1300 km




KLOE in Frascati

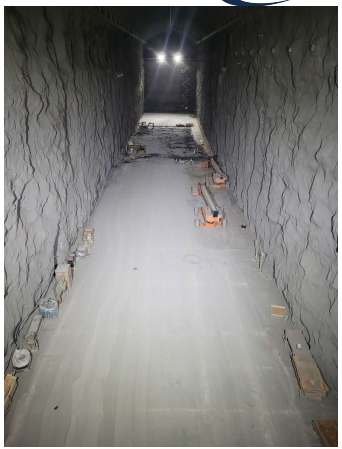




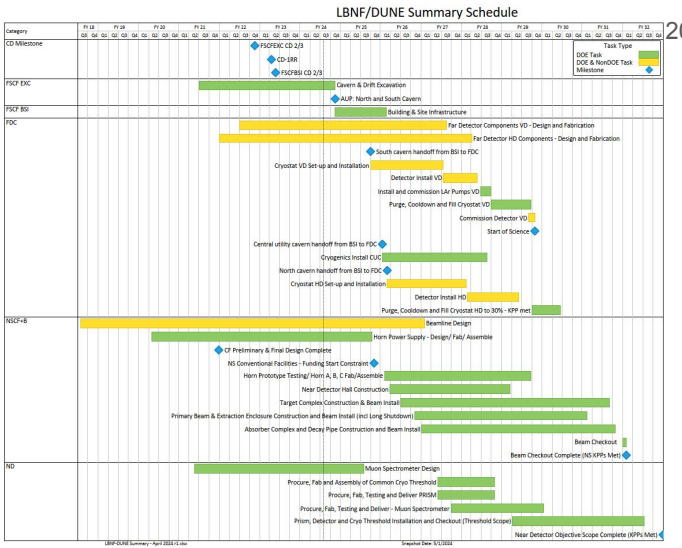
# DUNE update

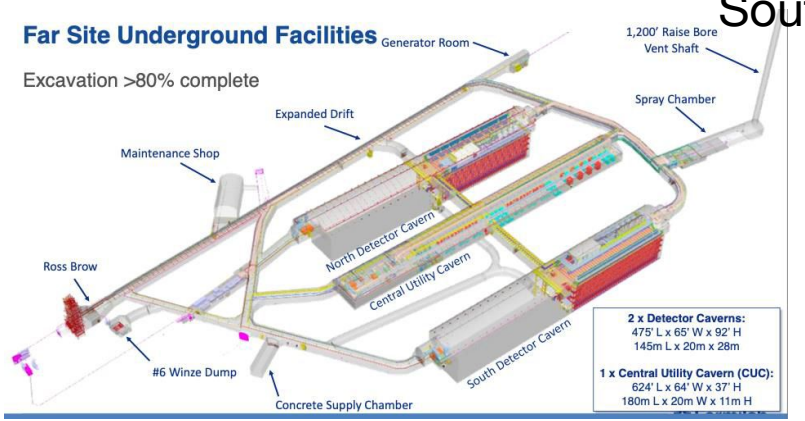
## FAR Excavation completed in Feb 2024!

- 800,000 tons of rock removed
- Cryostat installation begins in 2025
- Detector components begin arriving at far site in 2026
- **Near**-site construction begins in 2025

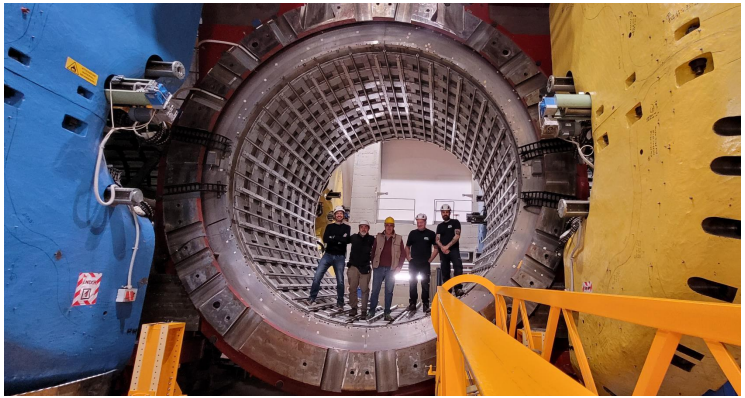


South cavern

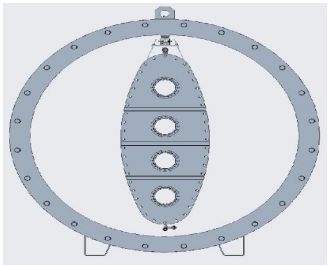


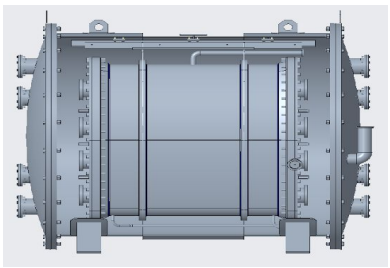



# SAND update



ECAL barrels extracted!





GRAIN: Facility at LNL under way

*MOU DOE-INFN signed on April 9th,2024*

DOE-Italian MUR MoU, signed in April, defines reciprocal responsibilities, taken respectively by Fermilab and INFN.
Among others, it ensures resources for construction and installation of most of SAND detector subcomponents, even though SAND is not part of the DUNE DOE Project.
Inner tracker is not covered, although INFN allocated resources to manage at least some of the associated risks.

Two options under investigation for the tracker:
- Straw Tube Tracker (STT)
- Drift Chambers (DCH)

**Icarus competence at DUNE: A new LAr purity monitor based on a Bi207 source.**

The deposited $e^-$ energy from Bi207 can be measured with the present LAr-TPC cryogenic front-end electronics with ~50 keV resolution at EDRIFT ~ 500 V/cm as used on most of LAr-TPCs.

We are preparing in Padova using the test facility of ICARUS at LNL lab/CERN, a new advanced prototype to be tested and inserted asap in the ProtoDUNE Vertical Drift.

DUNE- Padova: Richieste ai servizi

Supporto dell'OM per la test facility di Legnaro: 3 mesi

# Riassunto richieste servizi G1

**Unita': mese persona**

| Sigla\servizi | Prog. Meccanica (Benettoni) | Off. Meccanica (Ramina) | Elettronica (Bellato) | Tec. Avanzate (Pepato) | STG e elettronica (Nicoletto) | Calcolo e reti (Michelotto) |
|---|---|---|---|---|---|---|
| **Belle II** | | | 0.5 | | | |
| **CMS** | 3 | 1 | 52 | 6 | | 25 |
| **LHCb** | 2 | 1 | 3 | | | |
| **LUXE/ELBEX** | -/7 | 1/- | | | | |
| **MUONE** | | | | | 1 | |
| **TwoCryst** | 0.5 | 1 | | | | |
| **ENUBET** | | | 1 | | | |
| **ICARUS** | | 1 | | | 20 | 3 |
| **DUNE** | | 3 | | | | |
| **HYPER-K** | | 1 | 3 | | 2 | |