

Gruppo 1 Padova

Stato Esperimenti, Anagrafica e Preventivi

CdS

5/7/2024

Stefano Lacaprara

INFN Padova

Slides by Tommaso, Ezio, Ale, Alessndro, Patrizia, Donatella, Piero, Enrico, Filippo,
Fabio, Gianmaria

Segreteria: **E. Colombo**, (R. Chiaratti)

con aiuto di Marina Andreazzo e Laura Zanovello: grazie!

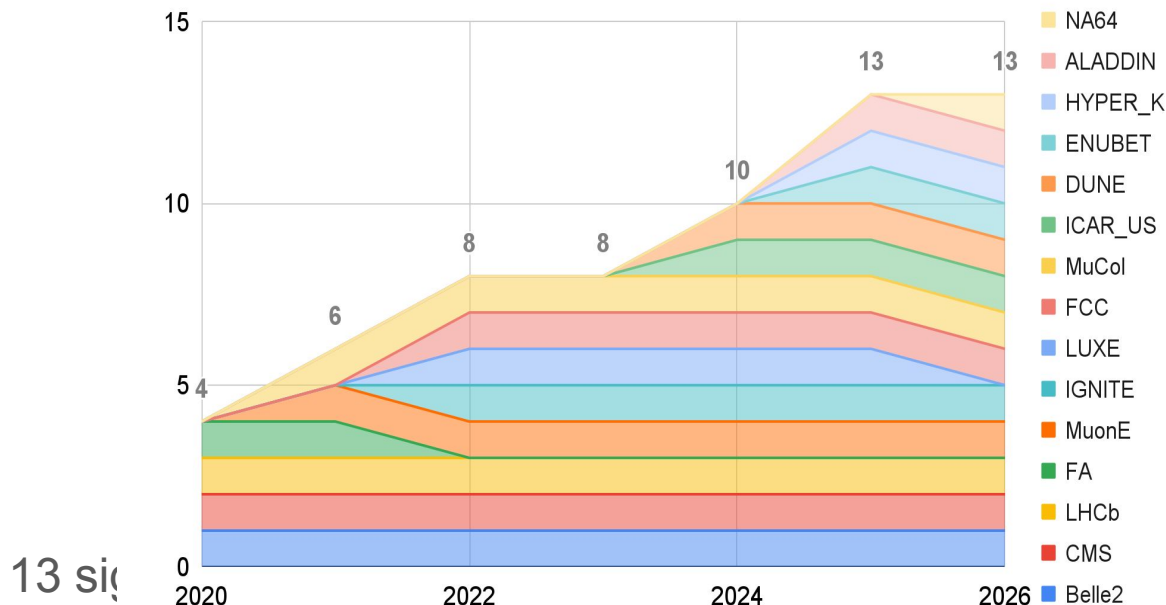
Outline

- General Summary
- Sigle (in ordine alfabetico)

- ALADDIN (was TwoCryst)
- Belle II
- CMS / Fase2_CMS
- DUNE
- ENUBET_NP06
- HYPER-K
- ICAR_US
- IGNITE
- LHCb
- MuonE
- **NA64** ← new
- RD FCC
- RD MuColl

- Da 2024 ICAR_US e Dune in CSN1
- Dal 2025 anche T2K ⇒ HYPER-K e ENUBET
- LUXE finisce come proto-sigla
 - Continua come progetto G5 SLBP
- NA64 nuova sigla (Donatella)

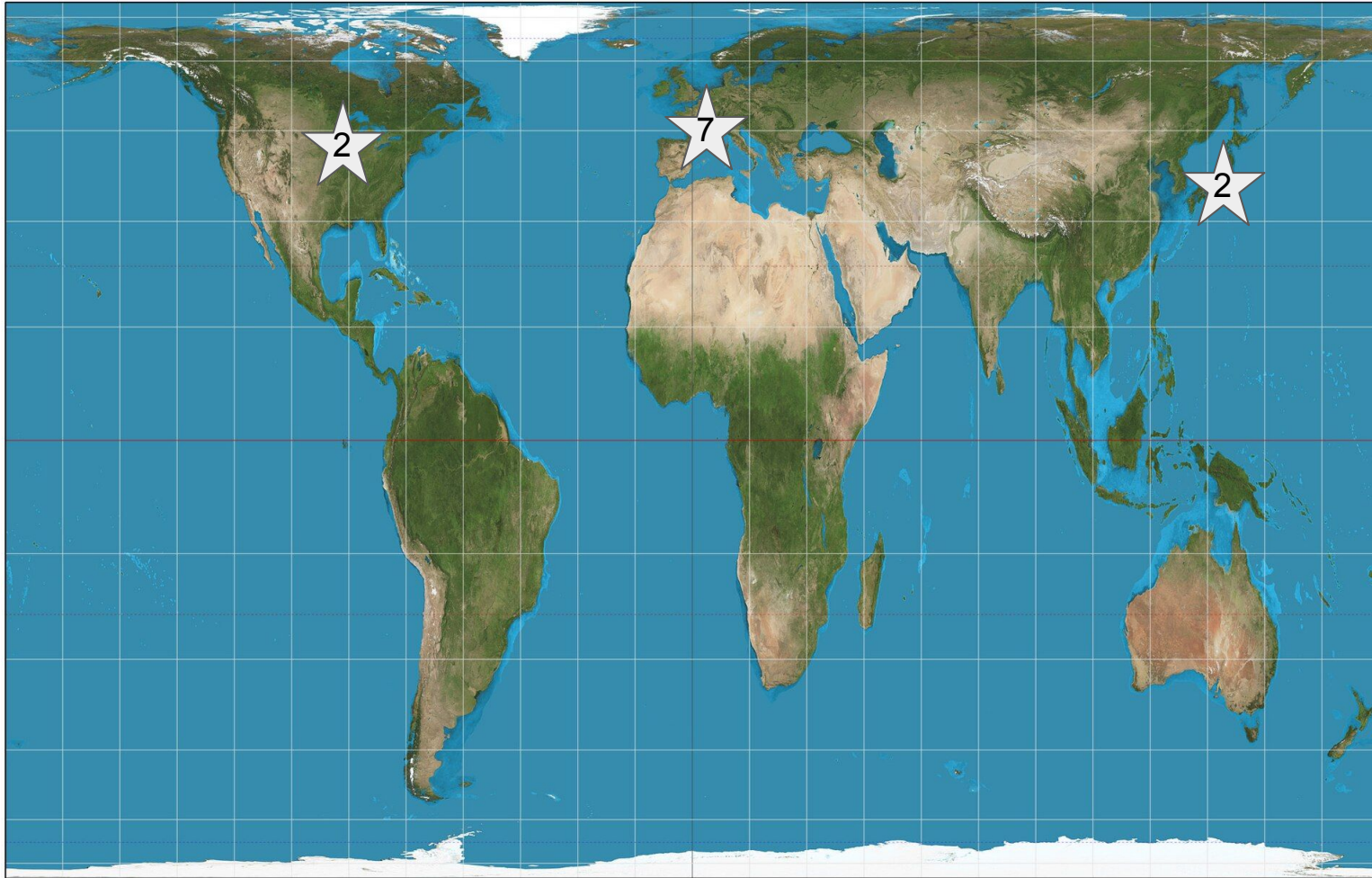
Sigle vs Anno



Outline

AuthaGraph projection

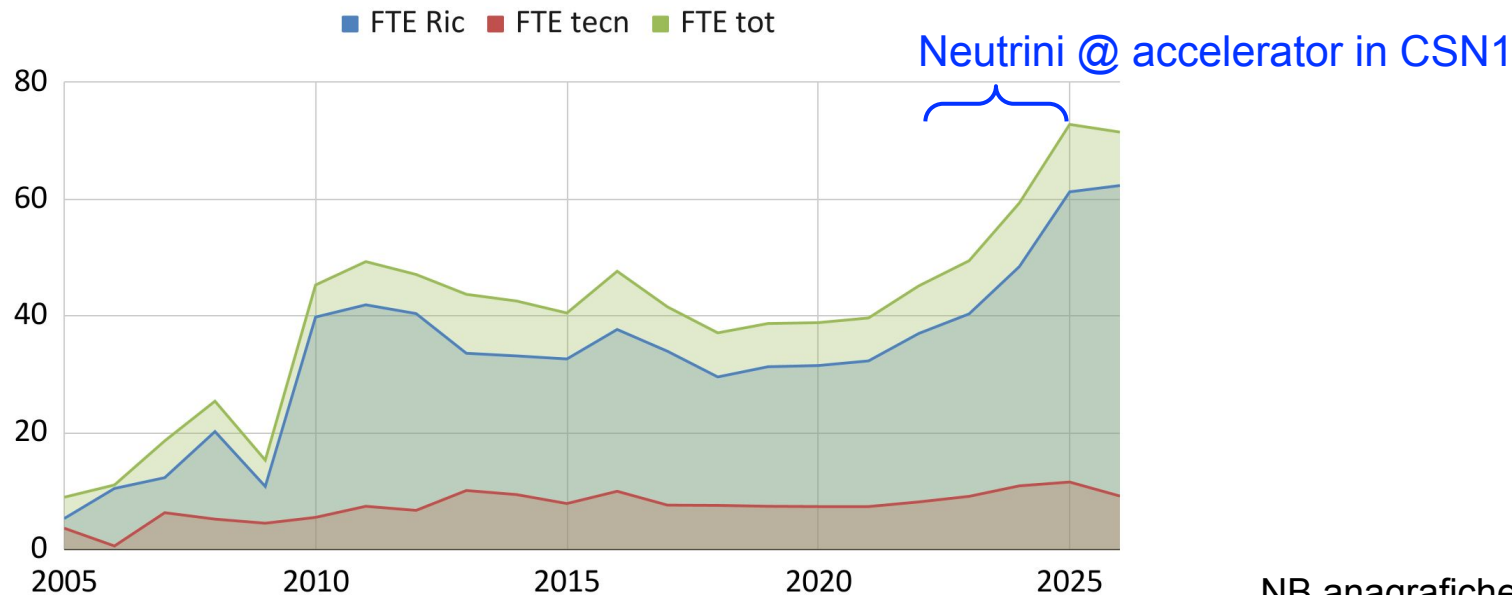




FTE e persone Gruppo1

Totale:	Ricercatori+Tecnologi:	71.48 FTE (109 px)
2025		72.8 FTE (102 px)
2024		59.35 FTE
2023		49.45 FTE

Gruppo 1 Padova FTE



NB anagrafiche da confermare

FTE e %

● High energy

- ~30% *

● Neutrini

- ~27%

● Flavour

- ~27% *

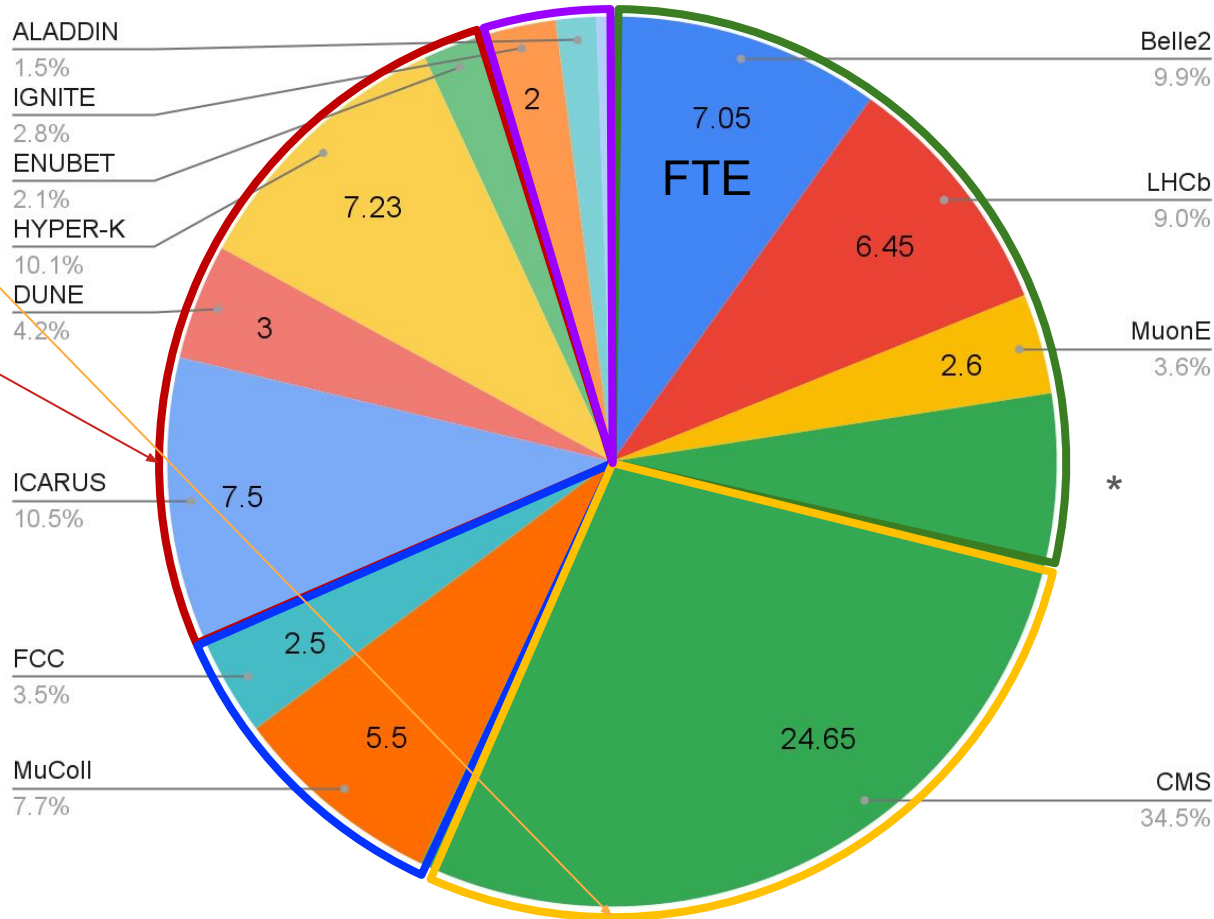
● Future

- 12%

● Other

- 5%

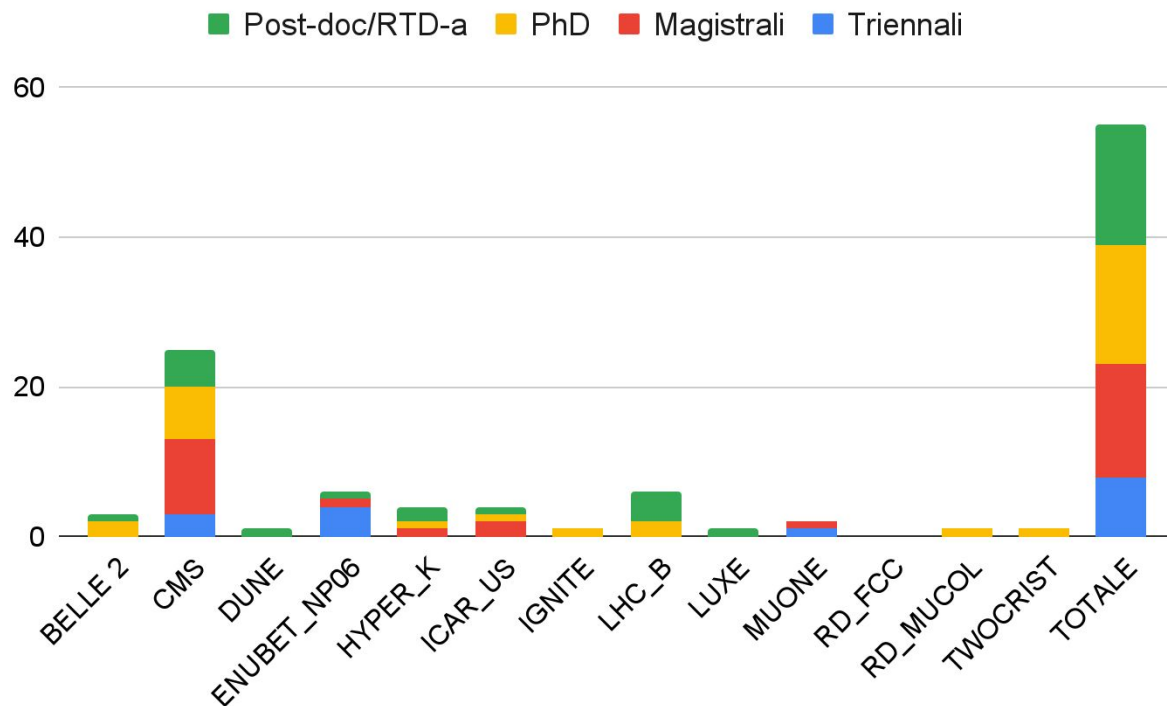
*ho messo (arbitrariamente)
parte di CMS in flavour



Survey giovani

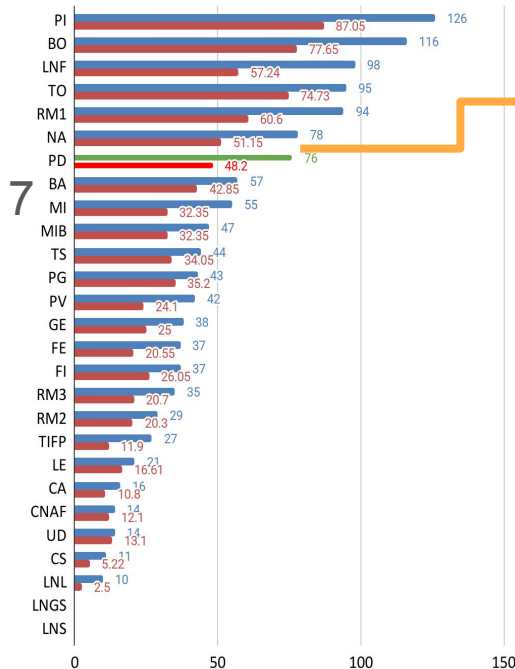
- Survey tesi triennali, magistrali, PhD, post-doc/RTD-a
 - Grande aiuto di Elena Colombo
- Idea e' di tenerlo aggiornato nel tempo

Triennali, Magistrali, PhD and Post-doc/RTD-a



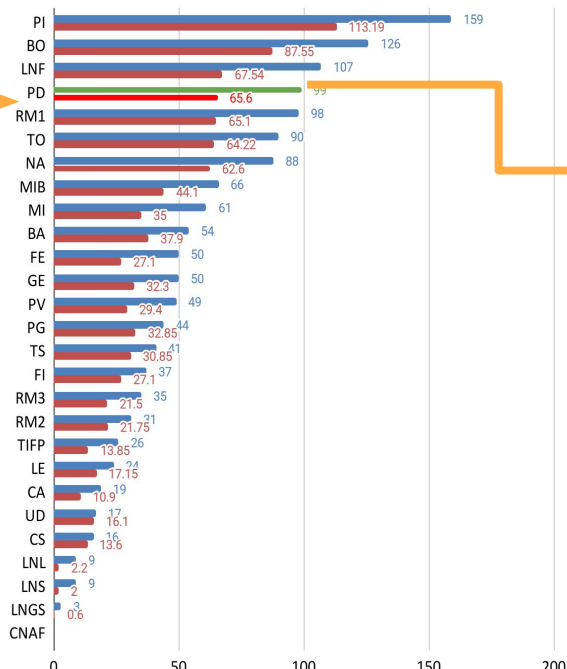
2023

■ Persone ■ FTE



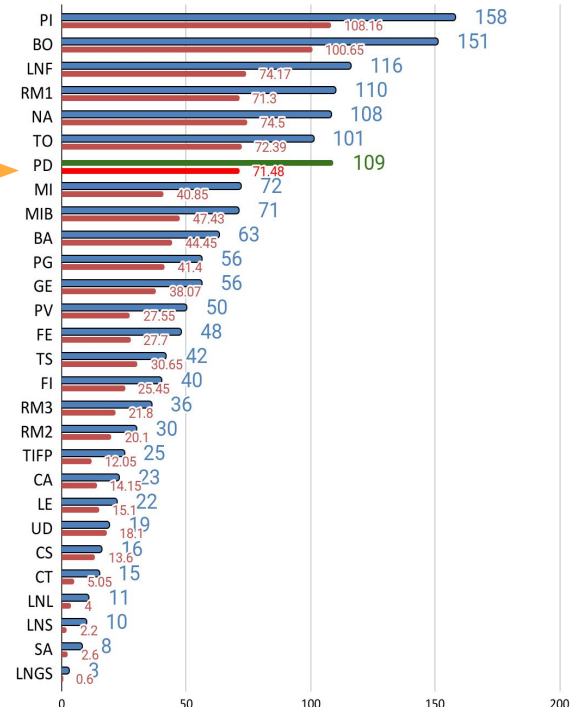
2024

■ Persone ■ FTE



2025

■ Persone ■ FTE



Frazione FTE/Persone

INFN: $1021.94/1547 = 0.66$ PD: $71.48/109 = 0.66$

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

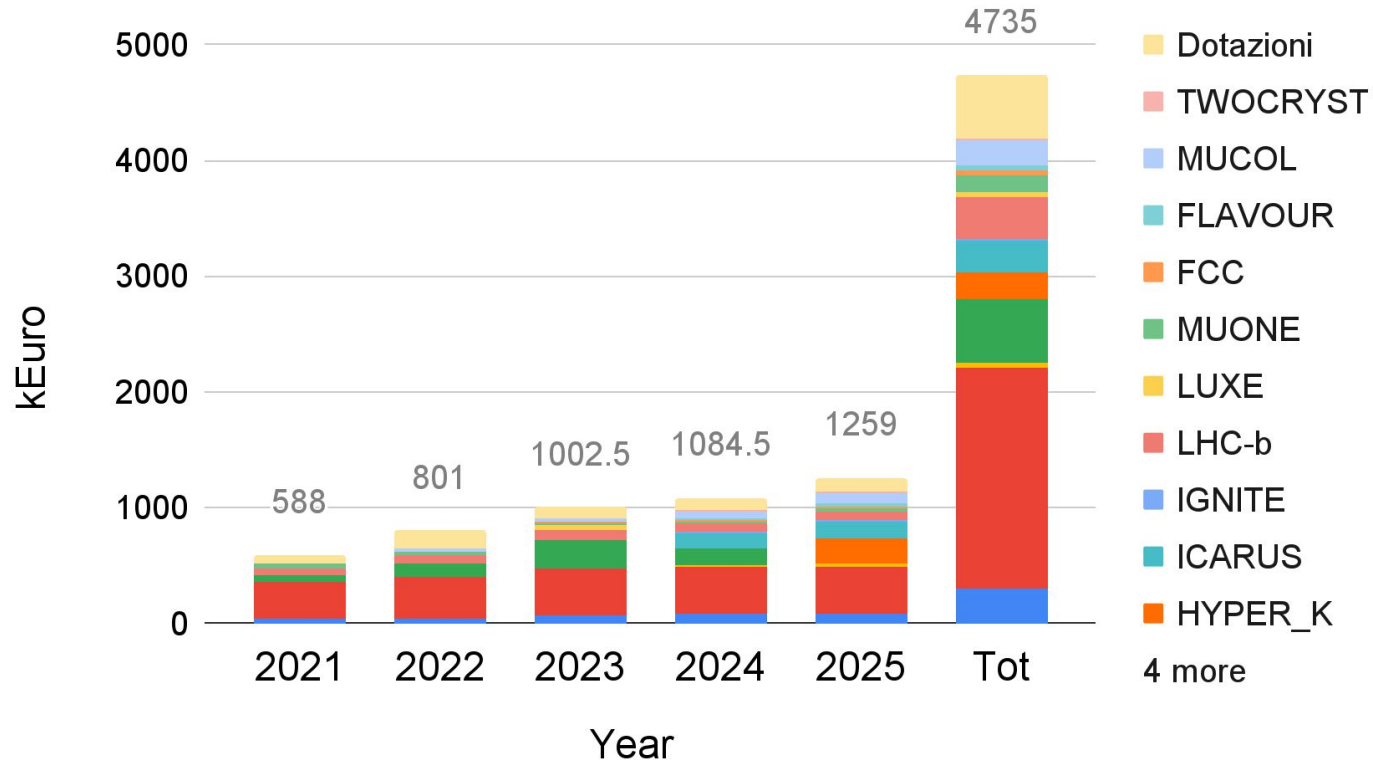
NB: anagrafica non e' completamente aggiornata

Finanziamenti da CSN1

Inclusi:



Stanziamanti CSN1 Padova



- common-fund (MoU-A/B)
 - Con qualche incertezza
- Finanziamenti diretti per CMS-FASE2 (fondi LHC-FOE)

Finanziamenti 2025

2025

Dotazioni

10.1%

MUCOL

7.3%

FLAVOUR

1.7%

FCC

1.5%

MUONE

2.5%

LHC-b

5.8%

ICARUS

11.6%

Belle2

6.6%

CMS

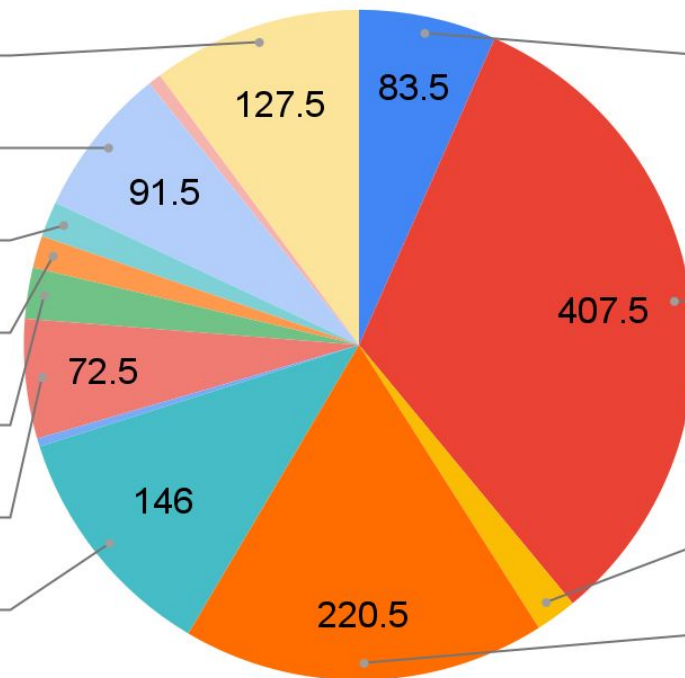
32.4%

DUNE

2.0%

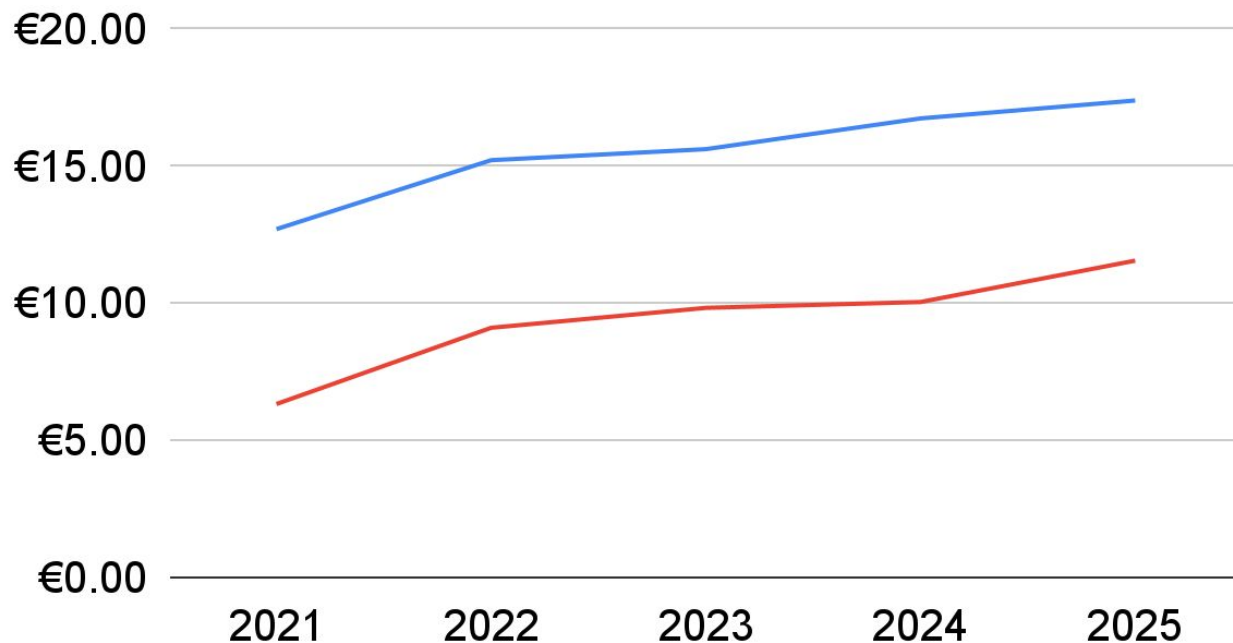
HYPER_K

17.5%



Finanziamenti per FTE/px

— kE/Fte — kE/Px



- 2025:
- 19.4k /FTE
- 11.5kE/Px

Presentazione sigle

- Sigle

- ENUBET_NP06
 - ICAR_US
 - DUNE
 - HYPER-K
 - Belle II
 - LHCb
 - MuonE
 - ALADDIN (was TwoCryst)
 - IGNITE
 - **NA64** ⇐ Donatella
 - CMS / Fase2_CMS
 - RD FCC
 - RD MuColl
- Neutrini
- Flavour
- Altro
- High Energy and Future

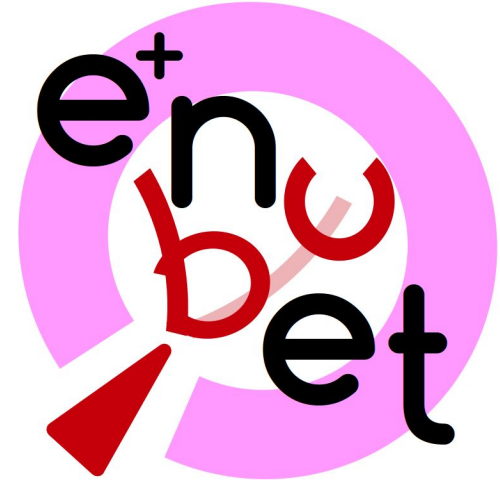
Disclaimer:

Ho di gran lunga troppe slides. Mi scuso se salterò attività' o le racconterò in modo approssimativo.

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

ENUBET_NP06

RL F. Pupilli



ENUBET/NP06: motivation and principle

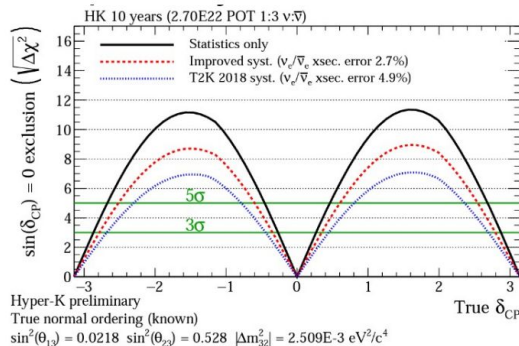
Full exploitation of data from future oscillation programs (DUNE, Hyper-K) strongly dependent on the control of **systematics**

Current systematic uncertainties

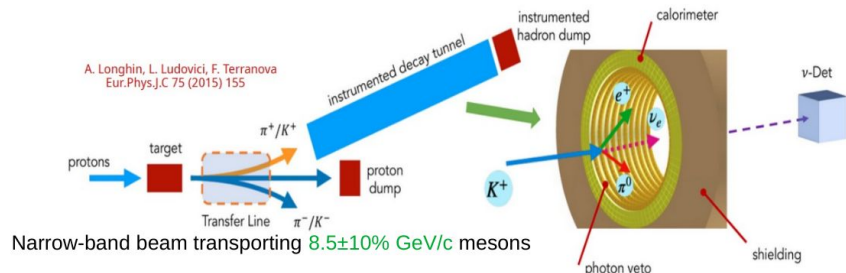
Uncertainty on N_e^{rec}	T2K	Hyper-K
Cross Sections	~4%	~3.5%
All Syst.	~5%	~3.5%

Fundamental a better knowledge of $\sigma_{\nu\mu}$ and $\sigma_{\nu e}$

→ **Main limitation:** uncertainties on ν flux, generally known with a precision worse than **O(5-10%)**



ENUBET: a monitored neutrino beam → measure rate of charged leptons ↔ **monitor ν flux at 1% level**



- Measure large angle **positrons** from K_{e3} in instrumented decay tunnel ⇒ ν_e flux meas.
- Measure large angle **muons** from $K_{\mu\mu}$ in instrumented decay tunnel ⇒ ν_μ flux meas.
- Measure forward **muons** from n in instrumented h-dump ⇒ ν_μ flux meas.

ERC funded project (2016-2022) – P.I. A. Longhin → Idea born in Padova!!!

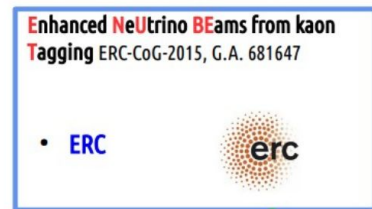
Same principle being studied for application at lower energies (1 GeV/c mesons), exploiting the **ESS linac** as proton driver

Development

2015 conceptual paper

EPJ C75 (2015) 155

The ENUBET ERC project 6/2016- 12/2022



ENUBET/NP06

- CERN Neutrino Platform

With SPSC:

- support of test beams of the tagger instrumentation at the PS
- monitoring of all neutrino flavors, including ν_μ from π and K decays

arXiv:2401.17068

nuTAG

Proposal for a tagged neutrino beam

Short baseline neutrinos @ PBC

- Physics Beyond Colliders

ENUBET

2025: “ENUBET + nuTAG” =
→ (SBN@CERN) →

nuSCOPE

neutrino SPS COMplex for Precision Experiments

nuSCOPE intended as the definitive facility for cross section measurements at the GeV scale, combining neutrino monitoring (ENUBET) and tagging (NuTag) techniques:

- Flux known at 1% (monitoring)
- Energy on event-by-event basis known at 1% level

Merging the two collaborations + X-sec experts from CERN

Detailed input document submitted to the 2026 ESPPU

27 Mar 2025

A short-baseline neutrino beam at CERN
for high-precision cross-section measurements

F. Acerbi^{a,b}, C. Andreopoulos^{c,e}, I. Angelis^a, A. Baratto Roldan^f, L. Bomben^{a,g}, M. Bonesini^h, F. Bramati^{i,j}, A. Branca^{k,l}, C. Brizzolari^{m,n}, G. Brunetti^o, M. Buizza Avanzini^p, S. Capelli^{q,r}, M. Capitani^{s,t}, S. Carturan^{u,v}, M.G. Catanesi^b, S. Cecchiniⁱ, N. Charitonidis^f, F. Cindolo^o, J. Cogan^{aa}, G. Cogo^o, G. Collazuol^{o,d}, D. D'Ago^o, F. Dal Corso^o, G. De Rosa^{h,k}, S. Dolan^o, A. Falcone^{o,i}, M. Feltré^{o,d}, A. Gola^o, D. Guffanti^{o,d}, L. Halić^{em}, F. Jacob^{o,d}, M.A. Jebramcik^o, C. Jollet^o, A. Kallitsopoulou^o, B. Klíčekⁿⁿ, A. Lai^o, Ch. Lampoudis^h, F. Lamm^o, M. Laveder^{o,d}, P. Legou^o, S. Levorato^o, A. Longhin^{o,d}, L. Ludovici^o, L. Magaletti^{h,q}, G. Mandrioli^o, A. Margotti^o, V. Mascagna^{h,x}, M. Mattiazzi^{o,d}, N. Mauri^o, J. McElwee^o, L. Meazza^{o,d}, A. Mereghia^o, M. Mezzetto^o, L. Munteanu^o, A. Paoloni^o, M. Paris^o, T. Papaevangelou^o, E.G. Parozzi^{o,f,z}, L. Pasqualini^{o,a}, G. Paternoster^o, L. Patrizzi^o, M. Perrin-Terrin^{aa}, L. Petit^{aa,ab}, M. Pozzato^o, M. Preste^{o,p}, F. Pupilli^o, E. Radicioni^h, F. Resnati^o, A.C. Ruggeri^{h,k}, A. Roueff^h, G. Saibene^{o,p}, D. Sampsonidis^h, A. Scam^{o,i}, C. Scian^{o,d}, G. Sirri^o, R. Speziali^{o,d}, M. Stipčevićⁿⁿ, M. Tenti^o, F. Terranova^{o,d}, M. Torti^{o,d}, S. E. Tzamarias^o, E. Vallazza^o, C. Vallée^{aa}, and L. Votano^o

<https://arxiv.org/abs/2503.21589>

2

Achievements of 2024-2025

Re-optimization of the original ENUBET beamline

- same physics performance but less eager of protons, compatible with CERN fixed target program (including SHiP)
- adapted to host the NuTag instrumentation

Analysis of test beam data on the Demonstrator of the instr. decay tunnel

- almost completed, publication within this year

Instrumentation of the hadron dump

- TB in October 2025 @ CERN-PS (first small prototype tested in August 2024)

Detailing the Physics Reach of the facility for X-sec measurements

- vast "menu" of possible measurements described in the ESPPU document

Studies done with a 4x4x22.3 m³, 500 t Lar detector placed # 25 m from the h-dump
Plans to have also Water Cherenkov/WBLS detector

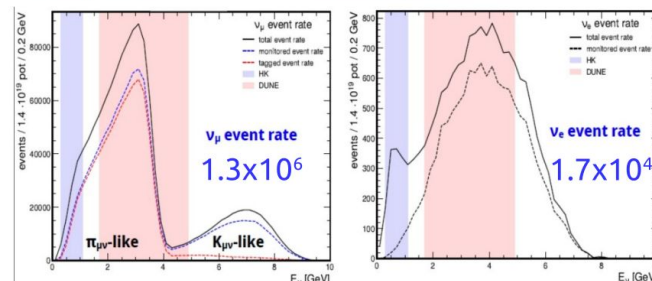


Figure 1 is a line graph showing the ratio $\sigma(E_\nu)/E$ in percent on the y-axis (ranging from 0 to 2.5) against the neutrino energy E_ν in GeV on the x-axis (ranging from 0 to 8). Two curves are plotted: a blue line for '0.5% X_0 per tracking plane' and an orange line for '1% X_0 per tracking plane'. Both curves start at high values (around 2.2% and 2.0% respectively) at low energies and decrease rapidly, approaching zero as energy increases. The orange curve is consistently above the blue curve.

E_ν [GeV]	$\sigma(E_\nu)/E$ [%] (0.5% X_0)	$\sigma(E_\nu)/E$ [%] (1% X_0)
0.5	2.2	2.0
1.0	0.8	0.7
2.0	0.3	0.3
4.0	0.1	0.1
6.0	0.05	0.05
8.0	0.02	0.02

- North Area, with a new experimental building on surface
- Existing tunnels near LSS6 at SPS, close to HighRadMat

- **Static focusing** (no horn needed) → **Slow extraction** mode (10^{13} pot/9.6 s)
- Annual proton intensity: $2.1\text{--}3.2 \times 10^{18}$ pot/year
- **Total proton requirement**: 1.4×10^{19} pot (for 1% stat. err on v_e x-sec)



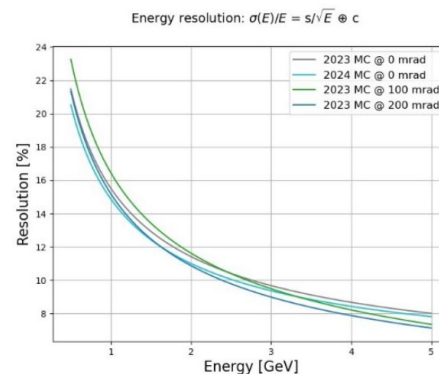
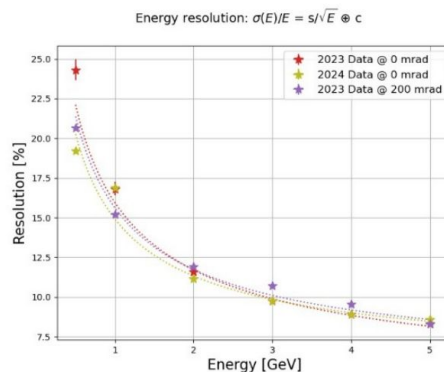
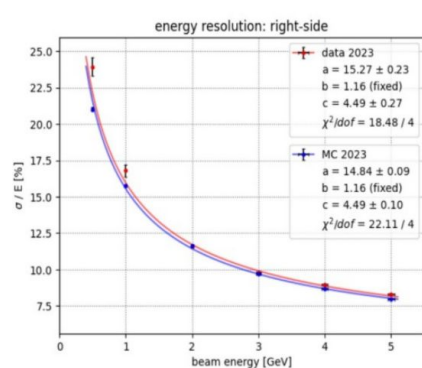
The Calorimeter Demonstrator



- Large scale prototype (3.5 ton, 1.65 m long) of the tunnel instrumentation (tagger) assembled in LNL
- 1275 active channels readout with SiPMs through 22 CAEN A5202 boards
- Tested at T9 beamline on CERN-PS in 2022, 2023 and 2024
- Evaluate the capabilities of $\pi/\mu/e$ discrimination and the e.m. energy resolution

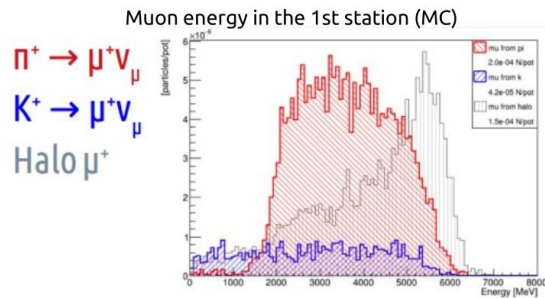
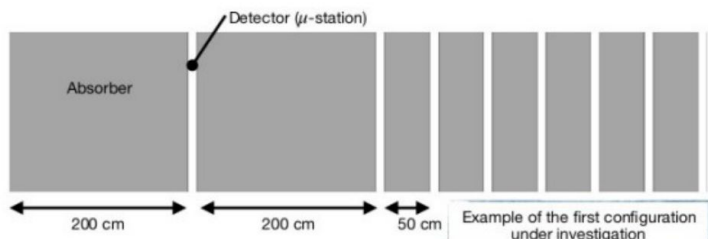
Full data analysis being finalized with results to be published within the year

- Good data/MC agreement
- Checked also inclined runs with no indication for a significant deterioration of the resolution in data or MC
- In progress: increase MC statistics, evaluate errors on the parameters of the fitting model and make a comparison at that level



Instrumented hadron dump

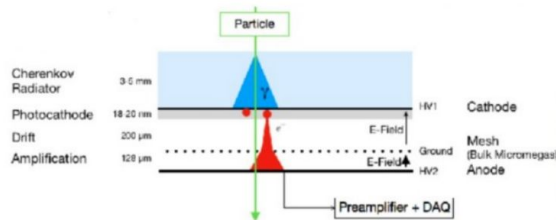
Range meter after the hadron dump. Extends the tagger acceptance in the forward region to **constrain $n_{\mu\nu}$ decays** contributing to the low- E_{ν_μ}



Candidate technology: **PICOSEC micromegas**

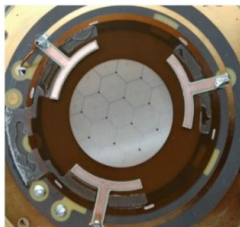
- Cherenkov radiator + thin drift gap
- Cutting edge timing ($O(10 \text{ ps})$)

PIMENT (Picosecond **M**icrom**E**gas for **e**Nube**T**) ANR project (Athens, CNRS, INFN, Thessaloniki, Zagreb) for studying their performance

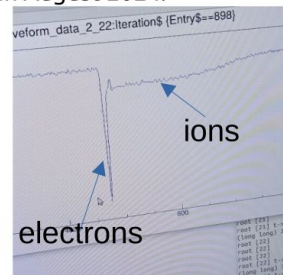
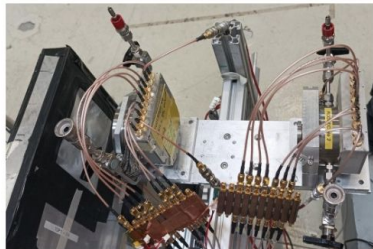


Test beam @ CERN-PS (T9 beamline) in October 2025: we will expose some modules with iron in between and evaluate the response to “busy” events (showers)

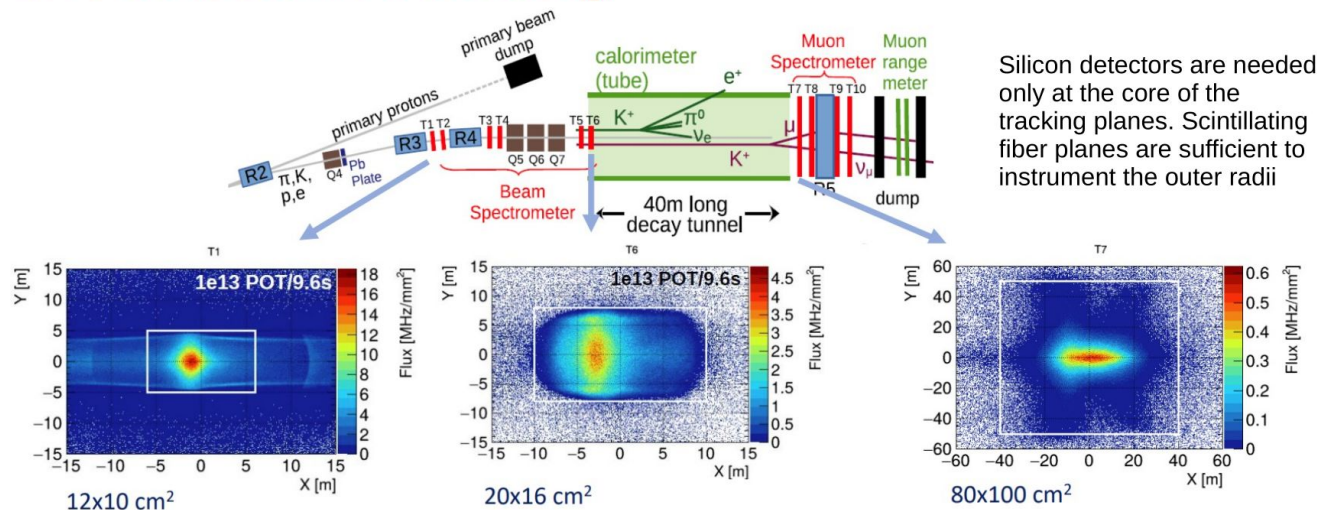
A preliminary test with tagger demonstrator+single plane was already achieved in August 2024.



19 channel anode $\square 1 \text{ cm}$



Meson and muon tracking



Silicon detectors are needed only at the core of the tracking planes. Scintillating fiber planes are sufficient to instrument the outer radii

- Particle rates in the hottest (central) planes: **20 MHz/mm² for 10¹³ pot in 9.6 s.**
- Peak fluence (non-ionizing dose): **10¹⁶ MeVn_{eq}/cm²** Requires s_t **O(100 ps)** and a detector granularity of **300 μ m**.
- We thus benefit from the technology currently being developed for the **LHCb velo upgrade**, pioneered @ 2 MHz/mm² rate and 4.5x10¹⁴ fluence level by **NA62**

GigaTracker - NA62



Three **ongoing developments** should meet the requirement for the first (hottest plane):
 TimeSpot and IGNITE by INFN
 PicoPix by CERN, Nikhef

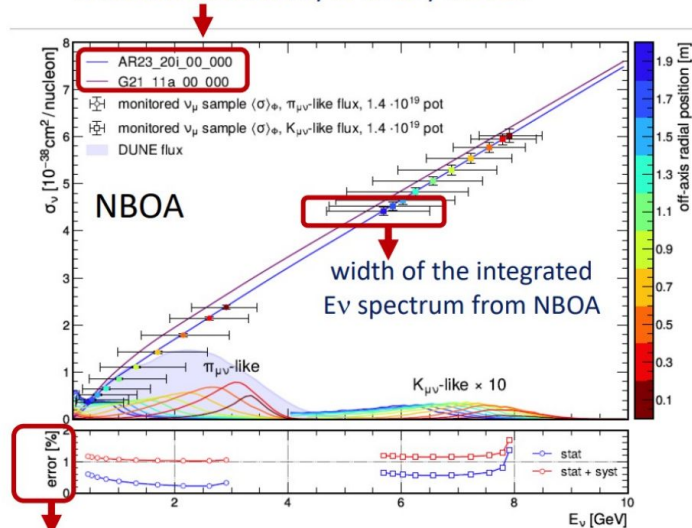
Addendum: PRIN (GigaNU, PRINS2022BZ2ABA) – A. Longhin, M. Mezzetto, F. Pupilli [2024-2026]

→ funded to study tracking and tagging of mesons in the context of ENUBET, synergic with these activities

What we can measure (not exhaustive) [1]

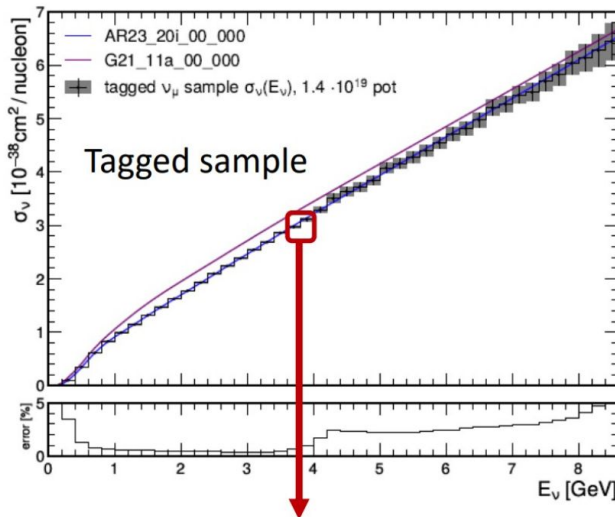
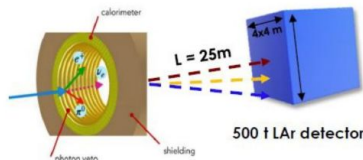
Energy dependence of the ν_μ cross section

it illustrates sensitivity to theory models

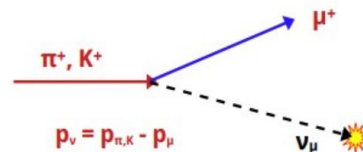


stat.+syst. error

NBOA: narrow-band off-axis technique (just monitoring)
exploits the small spread in momentum of parent mesons
and the correlation among neutrino energy and distance
from the beam axis at the detector of the interaction vertex



in the golden **tagged sample**, the integration
width is no more driven by the energy uncertainty
(<1% !!) but just by statistics

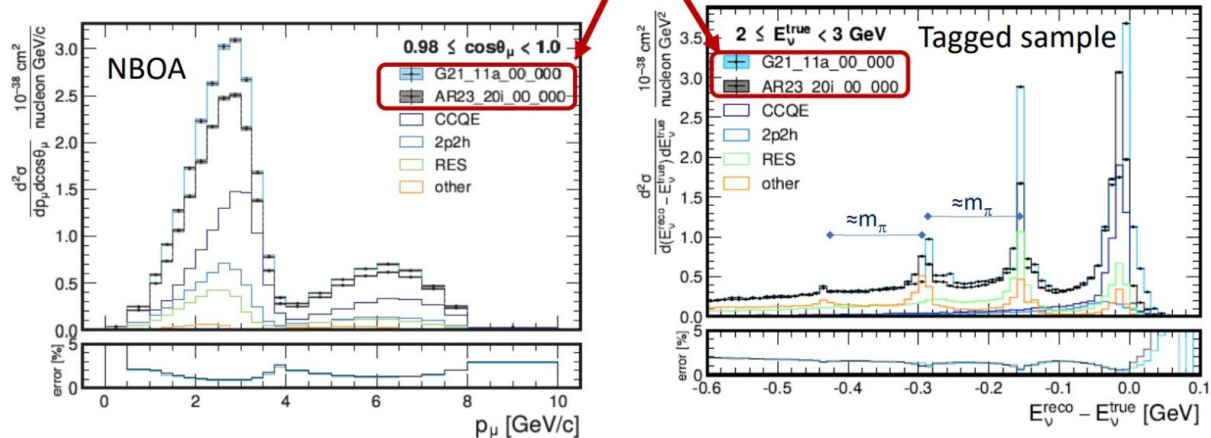


What we can measure (not exhaustive) [II]

Smearing of E_{ν}^{reco}

This key issue can be addressed by performing high-precision measurements of double differential cross sections using the NBOA technique or by directly measuring the energy bias from the tagged neutrino sample.

it illustrates sensitivity to theory models



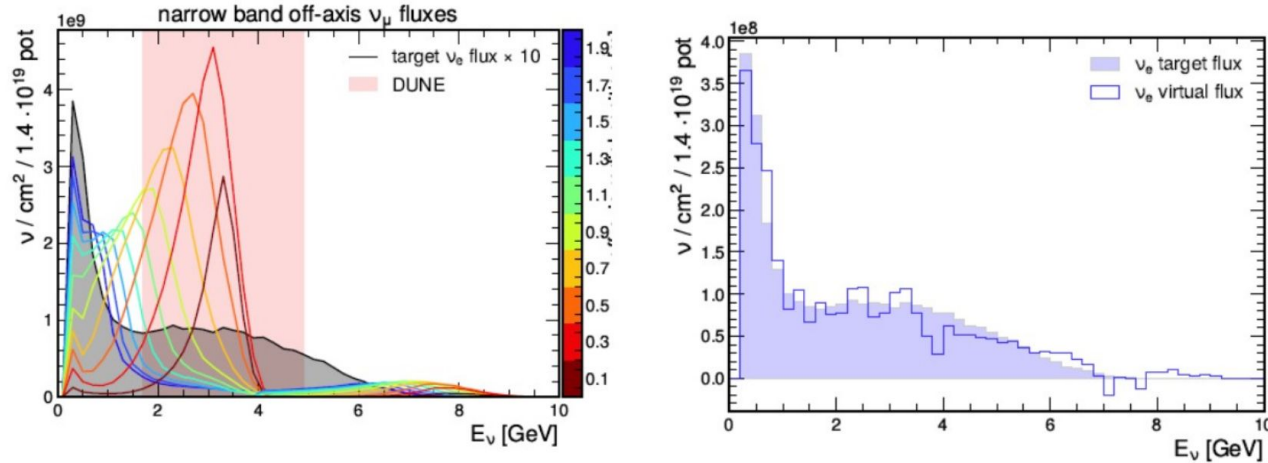
Without monitoring, the double differential cross section for “quasi elastic” (CC0p) would be systematic limited

The tagged sample employs the knowledge of the “true” neutrino energy to directly measure the energy bias in bins of E_{ν}^{true}

What we can measure (not exhaustive) [III]

ν_e cross sections and ν_e/ν_μ ratio

Oscillation experiments cannot fully rely on lepton universality to account for the ν_e cross sections due to phase-space-induced effects. Electron neutrino cross sections are therefore particularly valuable and, in nuSCOPE, mainly originate from kaon decays. These can be monitored with a precision at the 1% level. Additionally, a 2% level measurement of the ν_e/ν_μ ratio can be performed using the “PRISM technique”.



Since we cannot use either NBOA or tagging for ν_e , we measure the flux integrated ν_e cross section and compare it with the corresponding ν_μ cross section, which is built from linear combinations narrow-width ν_μ fluxes obtained from the NBOA or tagged sample.

Activities and requests for 2026

The technology for **neutrino monitoring and tagging** has reached maturity, thanks to the efforts of the ENUBET and NuTAG collaborations from 2016 to 2024, that are now merged in **nuSCOPE**

- Continue studies for a **proposal** of a **new facility at CERN** to tackle cross section measurements with percent-level precision:

- Siting at CERN (slow extraction in LSS6 of SPS, radioprotection)
- Detector technology for beamline instrumentation (silicon trackers, h-dump)
- Design of the neutrino detectors

Dedicated **workshop at CERN** on October 13-14, open to the community
(<https://indico.cern.ch/event/1548855/>)

- **Testbeam** at CERN-PS for **hadron dump instrumentation** with Picosec micromegas with a larger number of planes and channels wrt to the 2025 test

Overall requests: essentially only for travel and some instrumentation for the testbeam

FTE:

	ENUBET_NP06	ESSnuSB+	PRINS2022BZZABA
D. D'Ago	0	0.85	0
F. Dal Corso	0.2	0	0
M. Laveder	0.2	0	0
A. Longhin	0.4	0	0
M. Mezzetto	0.2	0	0
F. Pupilli	0.49	0.05	0.06
TOT	1.49	0.9	0.06



Tot: 2.45

Responsibilities:

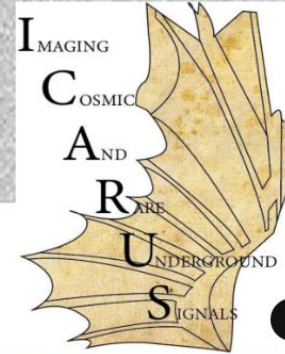
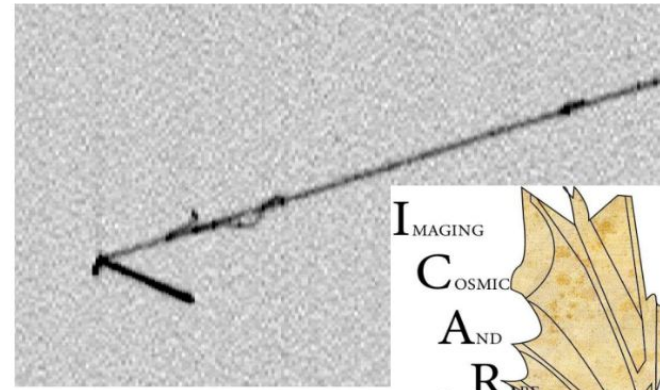
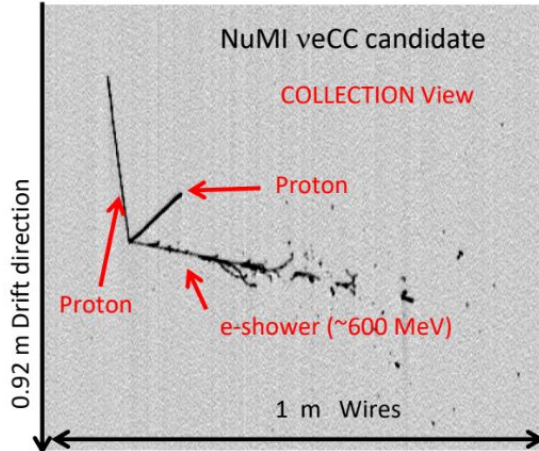
ENUBET_NP06: F. Pupilli (RL, nuSCOPE EC), A. Longhin (nuSCOPE EC)

ESSnuSB+: F. Pupilli (RN, Governing Board), A. Longhin (WP6 co-coordinator)

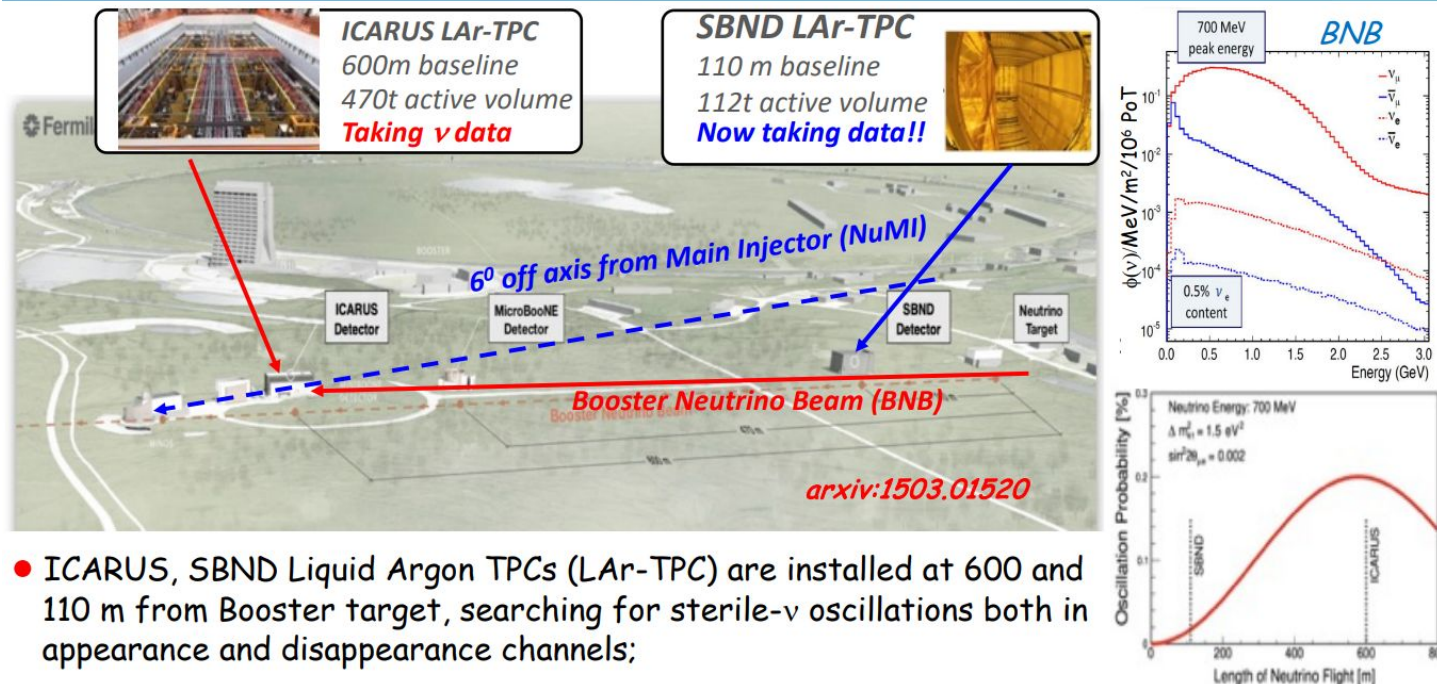
ICARUS at the Short-Baseline Neutrino Program

Responsabile locale INFN Padova
Christian Farnese
farnese@pd.infn.it

< **ICARUS** collaboration >

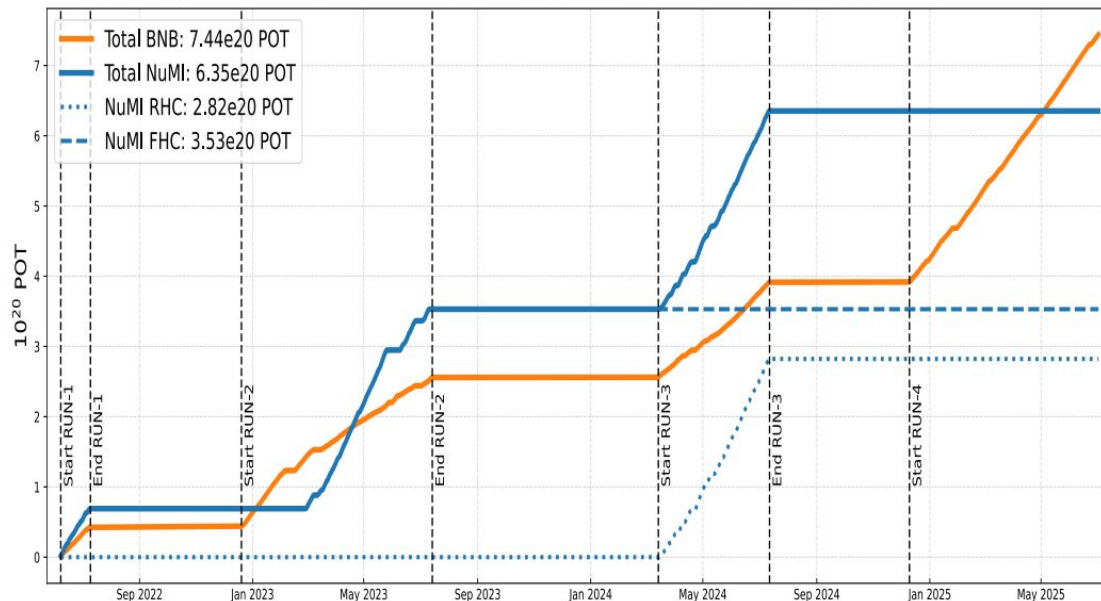


Short Baseline Neutrino (SBN) at FNAL BNB and NuMI beams



- ICARUS, SBND Liquid Argon TPCs (LAr-TPC) are installed at 600 and 110 m from Booster target, searching for sterile- ν oscillations both in appearance and disappearance channels;
- In addition: high-statistics ν -Ar cross-section measurements and event identification/reconstruction studies in view of DUNE
 - $\sim 10^6$ events/y in SBND < 1 GeV from Booster
 - $\sim 10^5$ events/y in ICARUS > 1 GeV from off-axis NuMI beam, allowing also for a rich Beyond the Standard Model search program.

- ICARUS data taking for physics started on June 9th 2022, after the concrete overburden installation completion, with TPC, PMT and CRT systems 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 $E_{\text{dep}} > 200$ MeV;
- Steady data taking with excellent stability at BNB rate > 4 Hz, >90% lifetime: 3 physics runs completed + fourth run ongoing since December 2024.



* No NUMI beam during RUN-4, plot updated on July 2nd

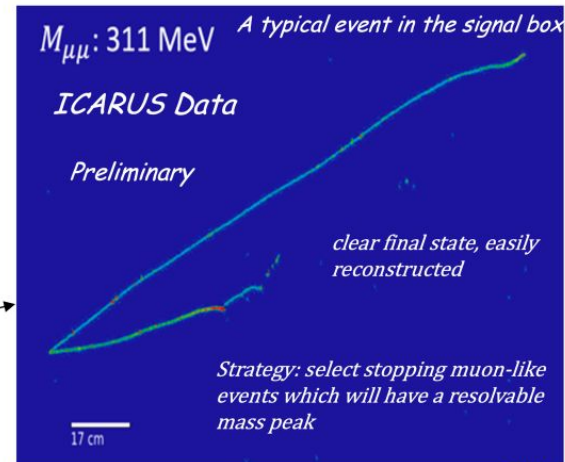
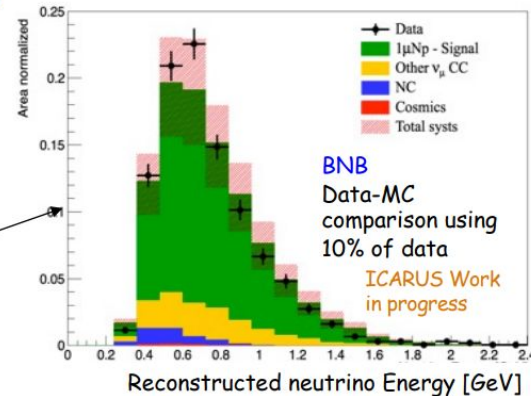
Slide# : 3

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

Investigation of ν_μ disappearance with BNB ν beam: focus on fully contained ν_μ CC events with a muon $L_\mu > 50$ cm and at least one proton with $E_K > 50$ MeV ($L_p > 2.3$ cm); *Padova group strongly involved in this analysis*

Study of ν_e, ν_μ events from off-axis NuMI beam, to measure ν -Ar interaction cross sections and optimize ν 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. *A first search for new particle decaying into di-muon has been completed. No new physics signal was observed, result published in PHYSICAL REVIEW LETTERS 134, 151801 (2025)*



- ICARUS Pd: 12 physicists/engineers, total 7.5 FTE inseriti nei RISE SENSE e PROBES;
- Grosso impegno del Gruppo Padovano nella gestione/manutenzione hardware/software dell'elettronica di read-out della TPC e del trigger dell'esperimento.
- Il Gruppo Padovano è fortemente impegnato nel software di ricostruzione degli eventi e analisi dati: esprime anche uno dei Software/Analysis Coordinator per tutto il programma SBN al FNAL, ~ 250 fisici impegnati in ICARUS e nel rivelatore Near SBND.
- Componenti del Gruppo Padovano coordinano le attività nei Working Groups di TPC, Trigger, Detector Calibration, Neutrino Identification e Neutrino Oscillations.
- Al Gruppo di Padova è sempre stato riconosciuto un ruolo di preminenza con il diritto di esprimere uno dei due Deputy della Collaborazione.
- Sinergia con gruppo DUNE:
 - B. Baibussinov, A. Guglielmi, G. Meng, F. Pietropaolo, F. Varanini: R&D per DUNE con realizzazione/test a Legnaro di purity monitors!
 - 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 2026: upgrades, maintenance, missions

PADOVA		Request (k€)
APPARATI	Substitution of 5 HP servers (out of warranty)	19.0
	5 new A5818 cards to replace the obsolete A3818	19.0
MANUTENZIONI	TPC read-out CAEN board maintenance (80 % out of warranty)	7.0
TRASPORTI	Transports of electronic boards, to CERN/FNAL	10.0
CONSUMO + ALTRI CONSUMI	Electronics Service/custom electronics repairs	6.0
	LAr procurements for LAr-TPC test facility at LNL	5.0
SP SERVIZI	Mechanics workshop (Mini-crates recovery)	3.0

Richieste Servizi Padova 2026:

- 6-7 MU Servizi Tecnici Generali/Elettronica: manutenzione/test elettronica TPC a Padova/FNAL (**Fondamentale la presenza a FNAL di una persona per 1 settimana ogni 2 mesi**) + sviluppo, costruzione e test di alimentatori HV low noise
- 1 MU Servizio Off. Meccanica
- 1 MU Calcolo e Reti.

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

The DUNE logo, featuring the letters "DUNE" in a blue sans-serif font. The letter "V" is stylized with an orange-to-yellow gradient and a white swoosh that extends from the "D" and "E".

DEEP UNDERGROUND NEUTRINO EXPERIMENT

RL: Filippo Varanini

Gruppo DUNE di Padova

- Luca Stanco (Dir.Ric. - associato) 40%
- Filippo Varanini (Primo Ric.) 30%
- Bagdat Baibussinov (Ric.) 60%
- Magda Cicerchia (RTDA) 80%
- Guang Meng (Tecnologa) 10%
- Judilka Bermudez (Tecnologa) 10%
- Francesco Pietropaolo (Primo Ric.) 50%
- Alberto Guglielmi (Dir.Ric. - associato) 20%

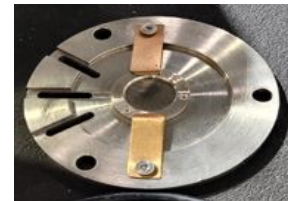
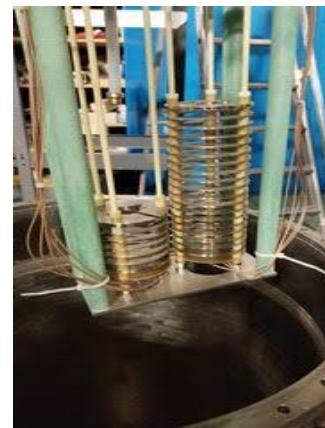
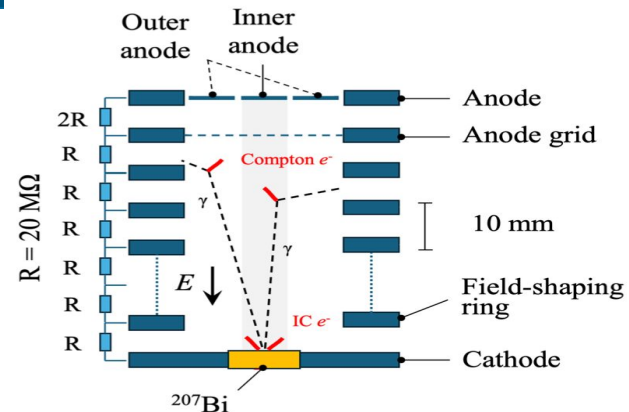
Attività:

- SAND (management CL, STT, GRAIN at LNL)
- Purity Monitors per DUNE-FD

8 partecipanti, 2.9 FTE, Ricercatori: 2.7 FTE, Tecnologi: 0.2 FTE

New Bi-207 based LAr purity monitor

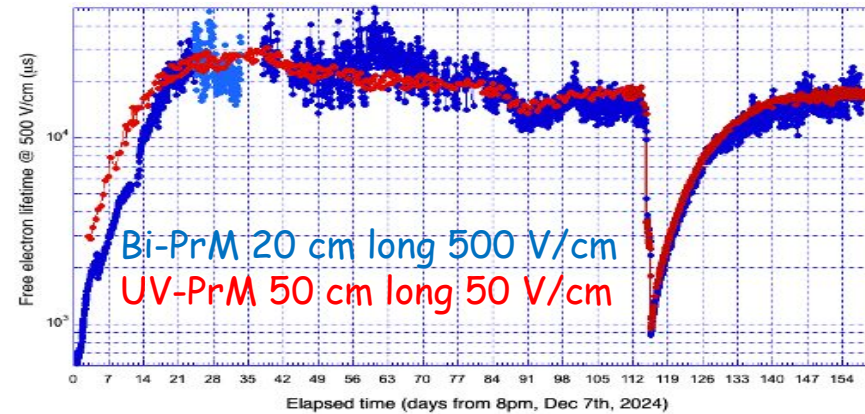
- Purity monitor PrM is crucial to measure the argon purity and the related attenuation of the ionization e^- signal produced by charged particles in LArTPCs.
- A new concept Bi-PrM with a ^{207}Bi radioactive source is proposed, based on collection of ~ 1 MeV IC e^- emitted by the source at cathode and drifted in 500 V/cm to anode.
- The anode is divided into an inner ring reading the IC e^- signal and Compton background, and an outer ring reading only the Comptons. The genuine IC e^- are determined by subtracting the external ring signal from the inner one.
- 2 Bi-PRMs of different drift length can be used to avoid absolute electronic gain calibration with a sensitivity exceeding 10 ms free e^- lifetime in LAr.
- Several advantages wrt traditional UV-based monitors
 - Can be operated continuously and without interfering with photon detectors
 - Can be operated at the same electric drift field as the TPC and with a similar readout electronics, allowing a more direct measurement of LAr purity.



PrM prototype:
 $L_{\text{DRIFT}} = 6, 18 \text{ cm}$

Purity monitor tests

- Bi-PrM developed in two phases:
 - R&D tests at Padova and CERN, focused on DAQ, electronics and mechanics. Proof-of-concept results in [JINST, 2025-02, Vol.20 \(2\), p. P02011](#).
 - Operation of a quasi-final version Bi-PrM composed by two detector $L_{\text{DRIFT}} = 6, 20$ cm in ProtoDUNE NP02, for long-term validation and comparison with UV-based monitor:
 - ✓ Continuous operation at ProtoDUNE since December '24
 - ✓ Results in good agreement with classic UV-based PrM
 - ✓ Fast response time. In case of LAr purity rapid drop, alarm is raised quickly
- Final optimization of the L_{DRIFT} is under way with a 3-detectors prototype $L_{\text{DRIFT}} \sim 6, 18, 50$ cm to maximize the sensitivity on the LAr purity measurements with a double Bi-PrM



Planned optimal layout of the PrM in DUNE

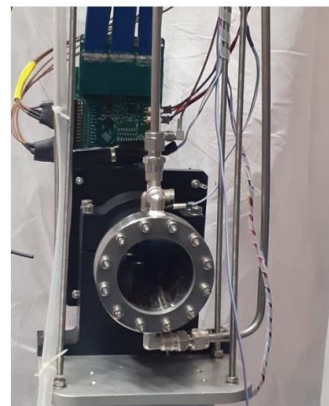
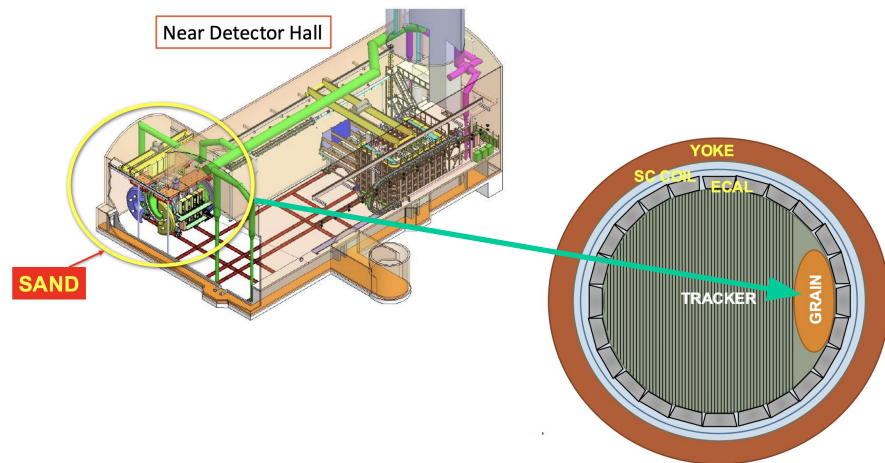
- Based on the present Bi-PrM performance which will be further validated with 3-detectors prototype, each Bi-PrM should be composed by either 1 or 2 detectors of different L_{DRIFT} .
- 6 Bi-PrMs would be installed in each of 2 DUNE Far modules:
 - ✓ 1 Bi-PrM with 1 single detector inline with the ultrapure LAr injection;
 - ✓ 3 Bi-PrM double detectors on the cryostat floor distributed along the 60 m length
 - ✓ 2 Bi-PrM single detector on two opposite cryostat corner coupled to UV Light-PrM
- Proposed sharing of deliverable between US-DOE and INFN (1 Far Site DUNE Module):
 - IRVINE Group with DOE funding contributes with:
 - ✓ 2 UV light complete PrMs; 3 single-detector Bi-PrM without electronics and HV FT
 - ✓ Bi sources for all Bi-PrMs
 - INFN would contribute with:
 - ✓ 3 double detectors PrMs but without the source procurement
 - ✓ Full electronic chains for the additional 3 US-built single detector Bi-PrM and HV feed-through

Financial plan submitted to INFN

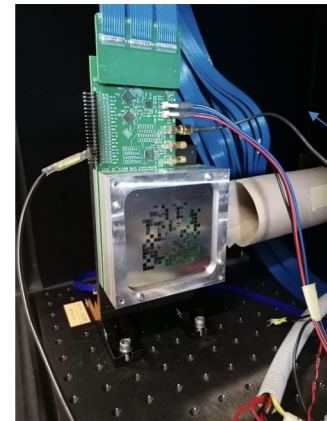
- R&D and first Bi-PrM prototype have been successfully performed with the available material from ICARUS and CERN, without additional funding from INFN:
 - Full electronic chain including cryo preAmp, feedthroughs, warm buffer and DAQ: designed, prototypized in Padova with support of Elettronics and Meccanics Services.
- The proposed plan, foresees a INFN funding for construction of PrM for each DUNE Far detector module would require ~ 81 k euro (NO TVA: delivering at CERN)
 - ✓ 3 double detectors Bi-PrMs but without the source procurement ~ 65 k euro
 - ✓ Full electronic chains + feed-troughs for the 3 single detector Bi-PrM ~ 16 k euro
- ~160 k euro are requested in total for equipping both DUNE Far Detector modules with 6 Bi-PrM each, to be shared in 4 fiscal years, 2026-2029.
- 2026: production and test of 2 double Bi-PrMs and electronics for 2 US single Bi-PrM:
 - 42 k euro for:
 - Bi-PrM mechanics: 9 k euro
 - Front-end electronics: 10 k euro
 - Cryogenic cables and feedthrough: 14 k euro
 - HV cables and Power Supplies: 9 k euro
 - 10 k euro for consumable for the test (LAr, 1 test-pulse generator, storage ...)
 - 15 k euro for mission/tests at CERN
 - Globally we need **4 MU (Electronics Service)** and **4 MU (Mechanics Service)**.

GRAIN

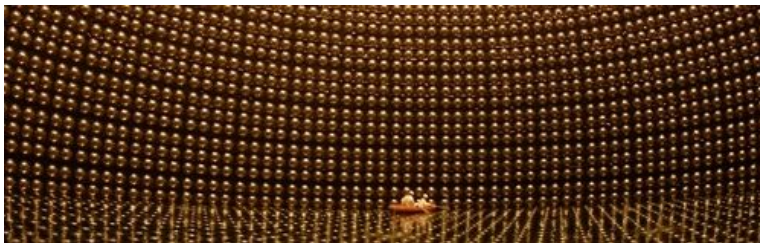
- SAND is magnetized on-axis detector in the Near Detector complex, to measure neutrino cross-sections and reduce systematics
- GRAIN is a 1-ton LAr-TPC with novel optical read-out
- Two technologies are being considered: lenses and coded masks
- Both will be tested in the GRAIN test facility at LNL before making a decision
- GRAIN building is being refurbished. Cryogenics has been simplified with significant cost saving
- Vacuum tank will be delivered at LNL in the fall
- Mockup test will be performed to estimate bubble formation in LAr
- Lens tests are ongoing in Genova



Lens readout



Coded mask readout 3



T2K

RL. Gianmaria Collazuol



Sigla INFN Hyper-K

Esperimenti



Intensa attivita` **neutrini in Giappone** con prospettiva di **nuovi dati per 20+ anni** e **nuovi rivelatori**

- **Hyper-K in fase di costruzione**
 - ☐ 2026 assemblaggi CERN / Japan
 - ☐ 2027 installazione a Kamioka
- **T2K Near Detector upgraded**
 - ☐ installate nuove TPC (Padova) un anno fa
 - ☐ nuovi dati neutrini con piena accettazione
 - ☐ R&D per nuovo upgrade (2030)

Dal 1° Luglio
Andrea e` nuovo
Rappresentante
Nazionale Hyper-K

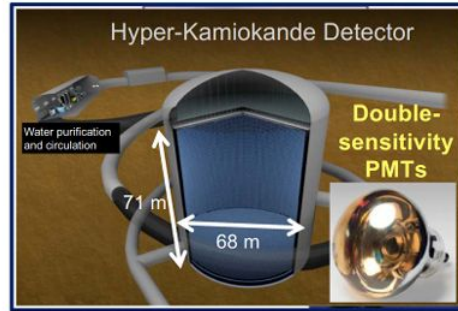
Gruppo locale in costante espansione

Staff: G.Collazuol, M.Grassi, M.Laveder, M.Mezzetto, F.Pupilli, A.Patelli, S.Levorato, A.Longhin

Post-Doc: D.D'Ago, M.Feltre, M.Mattiazzi **Dottorandi:** C.Forza **Laureandi (LM):** L.Mareso, D.Marchesini

Hyper-K in a nutshell

Hyper-K water
Cherenkov at
Kamioka
(host U-Tokyo)



High intensity
proton beam at
JPARC
(host KEK)

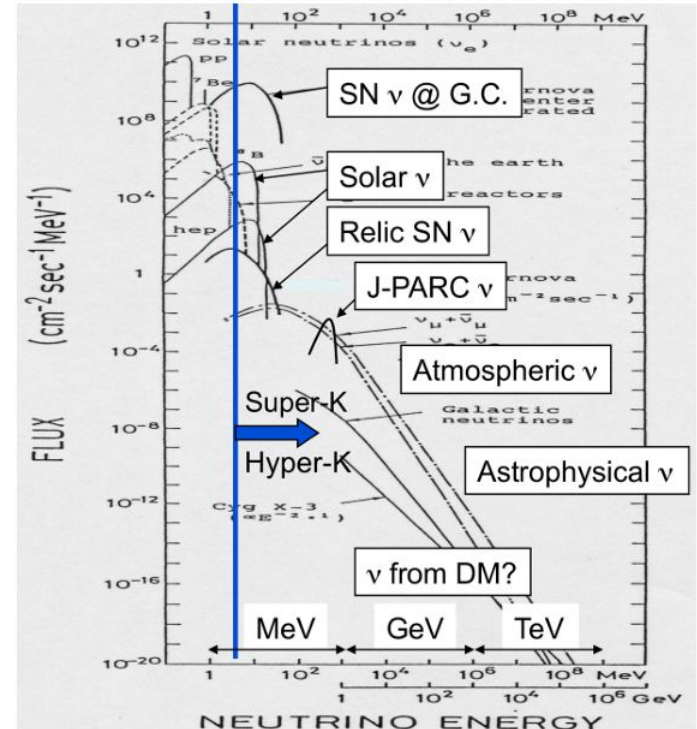
Accelerator, atmospheric, solar,
supernova neutrinos and proton decay



- **World largest detector for nucleon decay and neutrino experiment**
 - 8.4 times larger fiducial mass (188kt) than Super-K, with new photo-sensors: twice-as-sensitive 20" PMTs and new multi-PMTs
- **World most intense neutrino beam**
 - 2.6 higher JPARC beam intensity (1.3MW) than T2K 2020 (~500kW); T2K 06/2024: 800kW
- **New (IWCD) and upgraded (ND280) near detectors to control systematic errors**

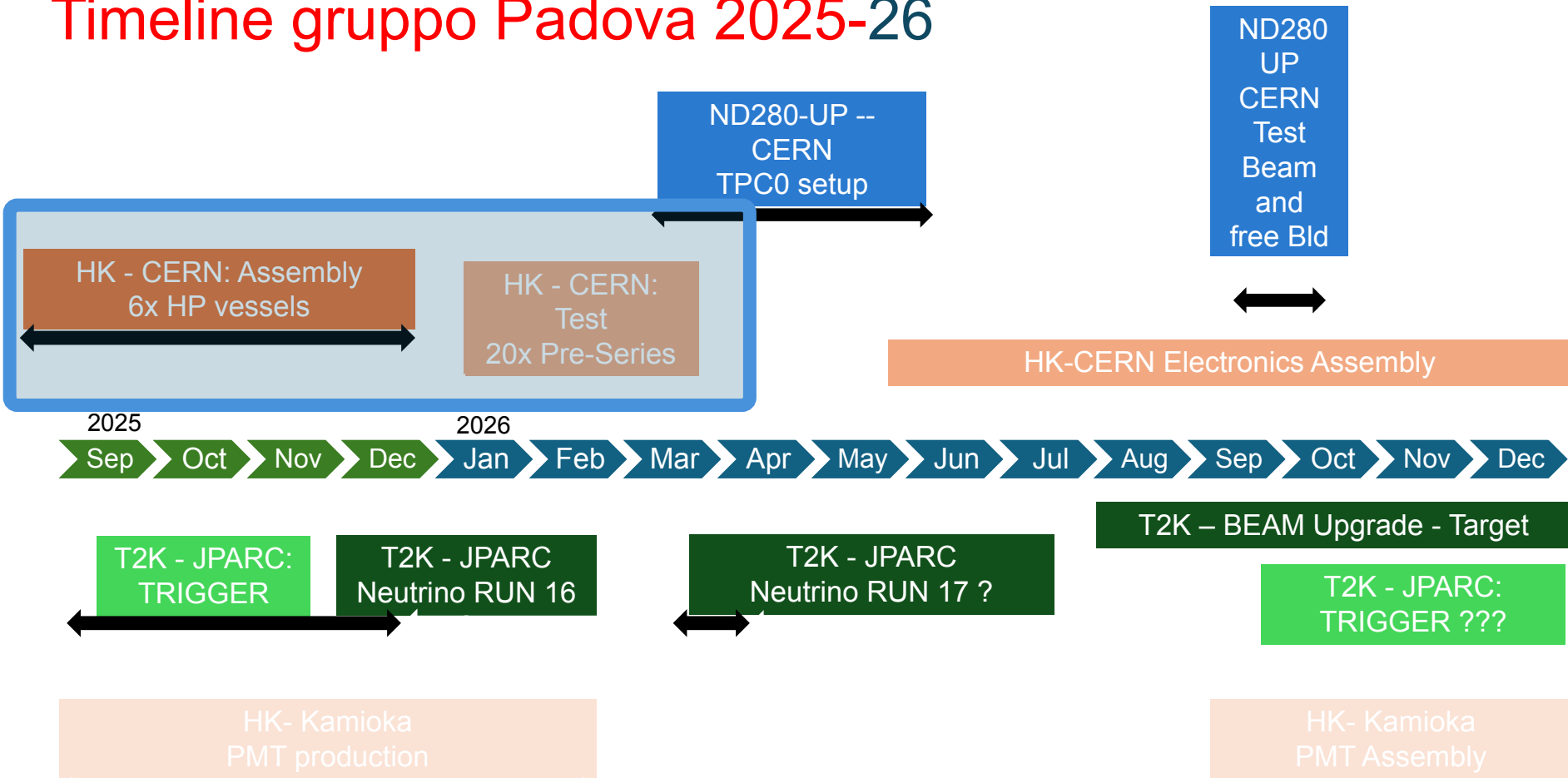
Hyper-K Physics manifesto

- **Neutrino Physics**
 - Accelerator & atmospheric oscillation: CPV & mass ordering
- **Astrophysics**
 - Supernovae, Sun, astrophysics sources
- **Physics BSM**
 - Nucleon decay, dark matter, non-standard interactions



A rich and ambitious scientific programme

Timeline gruppo Padova 2025-26



Richieste Servizi Sezione Padova

Richiesta **Servizio Officina Meccanica**

- Produzione parti x5 HP Tanks (3mp)

HK - CERN: Assembly
6x HP vessels

HK - CERN:
Test
20x Pre-Series
vessels

HK-CERN Electronics Assembly

2025

2026



Richiesta **Servizio Elettronica**

- per turni calibrazione elettronica CERN (1mp)

Richiesta **Servizi Generali**

- per assemblaggio HP Tanks e Vessels elettronica UnderW CERN (1.5 mp)
- per turni assemblaggio mPMT a Napoli (1.5mp)

INFN “Hyper-K” = T2K, T2K-II, SK e HK

Main items coinvolgimento INFN ed in particolare

INFN Padova

Run/Analysis → Legacy

- **T2K/SK running experiments**

- Analysis: OA, new samples, xsects
- SK-GD: 0.03% Gd

Data taking
Analysis
Run until 2027

Upgrade → Legacy

- **T2K-II assembly and installation**

- Beam upgrade
- ND280 upgrade
- Nuove HATPC

Commissioned, data
taking, preparing
reco&analysis

Procurement/
Construction

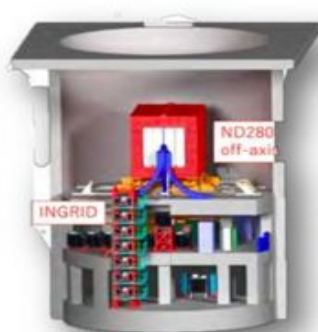
- **Hyper-K construction**

- mPMTs
- Underwater electronics of 20” PMTs

Production Readiness
Review → Procurement
Excavation finished
Run May 2028

Stato Upgraded Near Detector ND280

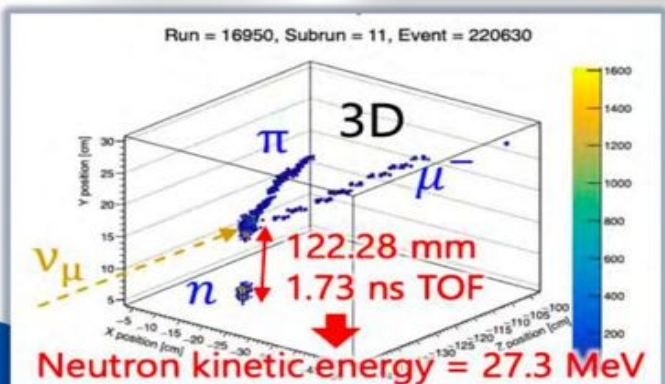
- Upgraded detectors are fully installed in May 2024
- Recorded 96.1% of data taking efficiency in June run



Event display (Side view)

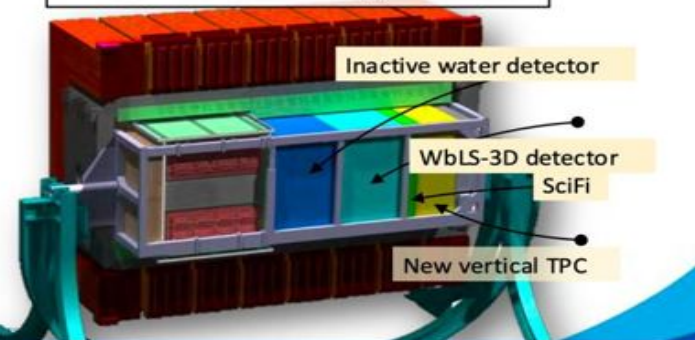


- Detector papers are going to be submitted soon.
- Analyses for the first physics result with the upgraded detector in progress (T2K)



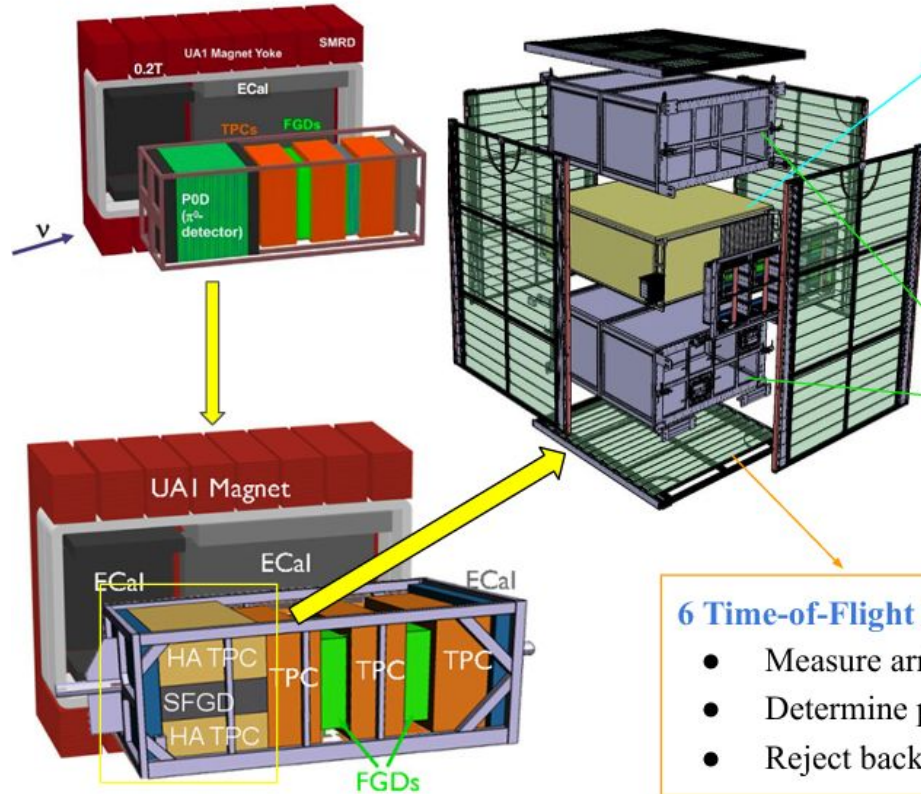
estimated with the time-of-flight technique.

ND280++ Reference design for ~2030



in view of the high-statistics phase, after 2030.

Upgraded ND280 e nuove TPC



Super Fine-Grained Detector (SFGD) [arXiv:1707.01785](https://arxiv.org/abs/1707.01785)

- Active neutrino target
- 3D grid of 2 million plastic scintillator cubes of 1 cm^3 .
- Excellent resolution to reconstruct proton & Neutrons will be reconstructed

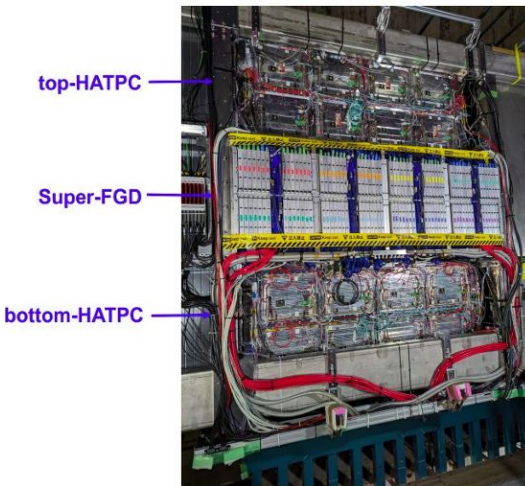
2 High-Angle TPC (HA-TPC) [arXiv:1907.07060](https://arxiv.org/abs/1907.07060)

- Novel lightweight composite field cage
- Readout using resistive micromegas
- 4π acceptance of charged particles & enhanced particle tracking

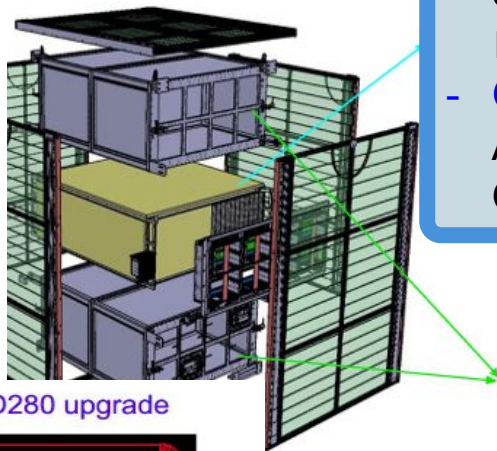
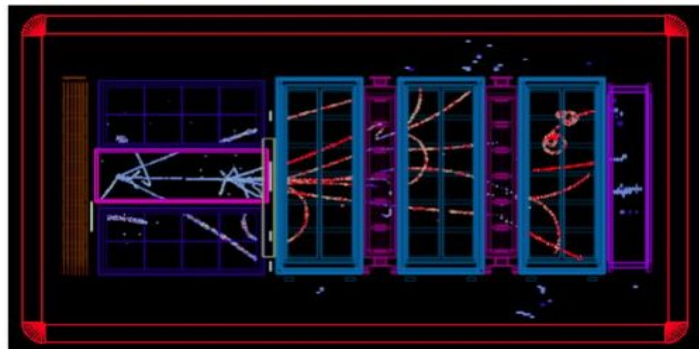
6 Time-of-Flight Detector (ToF) [arXiv:2109.03078](https://arxiv.org/abs/2109.03078)

- Measure arrival time of particles with a precision of $\sim 150 \text{ ps}$
- Determine particle direction – whether it's incoming or outgoing
- Reject backward background (particles entering from outside)

ND280 - attivita` 2026 “Rivelatore”



First neutrino interactions with full ND280 upgrade



- **Contributo INFN cruciale in HATPC**
- **Gruppo di Padova ruolo primario** in costruzione e installazione
 - G.Collazuol - P.Leader costruzione TPC
- **Grazie a Sezione di Padova** Direttore, Amministrazione e Servizi Generali ed Officina Meccanica

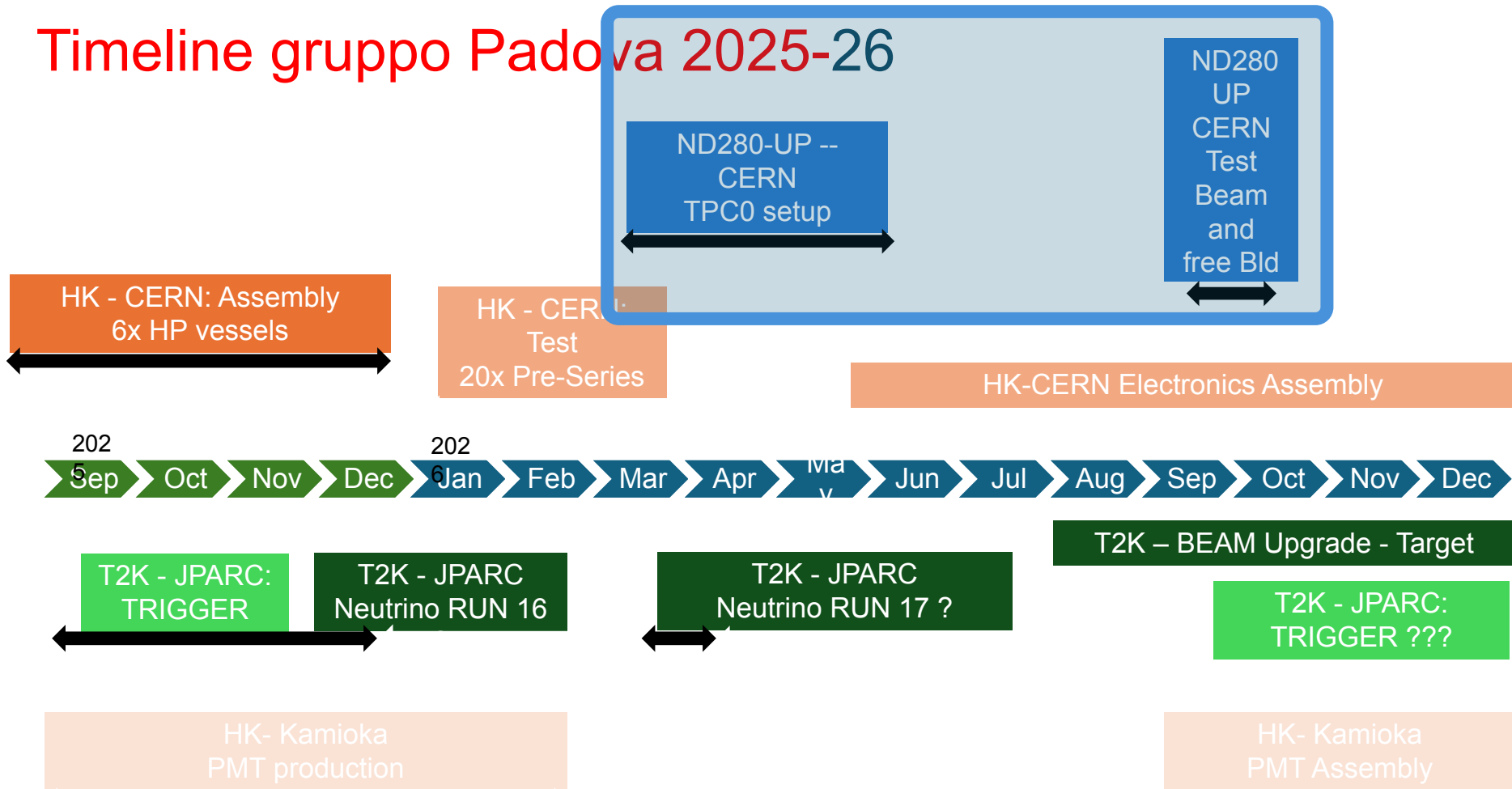
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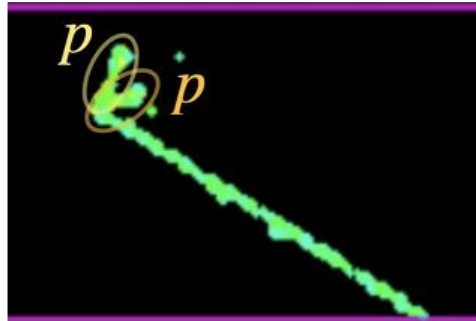
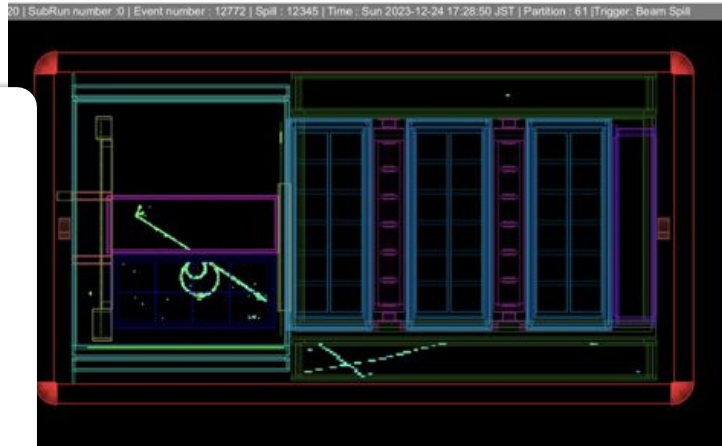
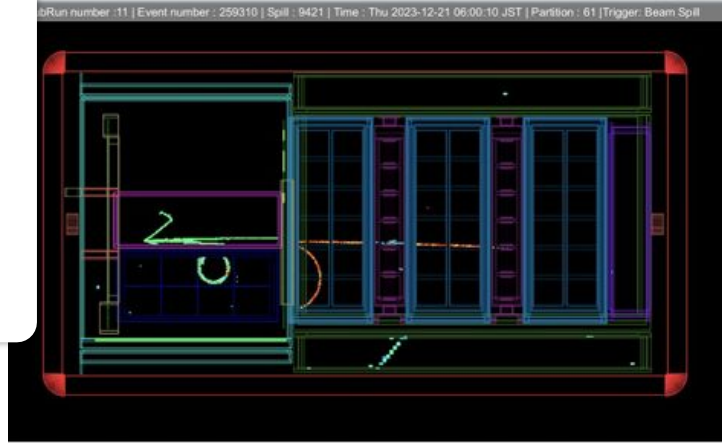
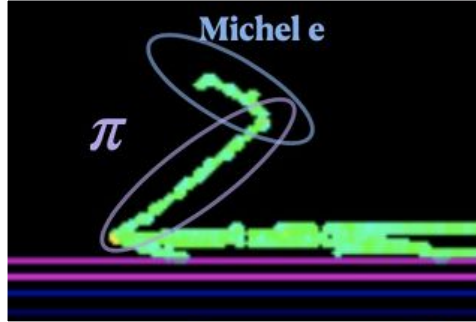
Attivita` “Rivelatore” 2026 - Padova

- Studio sistematiche risposta del Rivelatore con **Laser e Test Beam CERN**
- Nuova **simulazione e ricostruzione**

Timeline gruppo Padova 2025-26



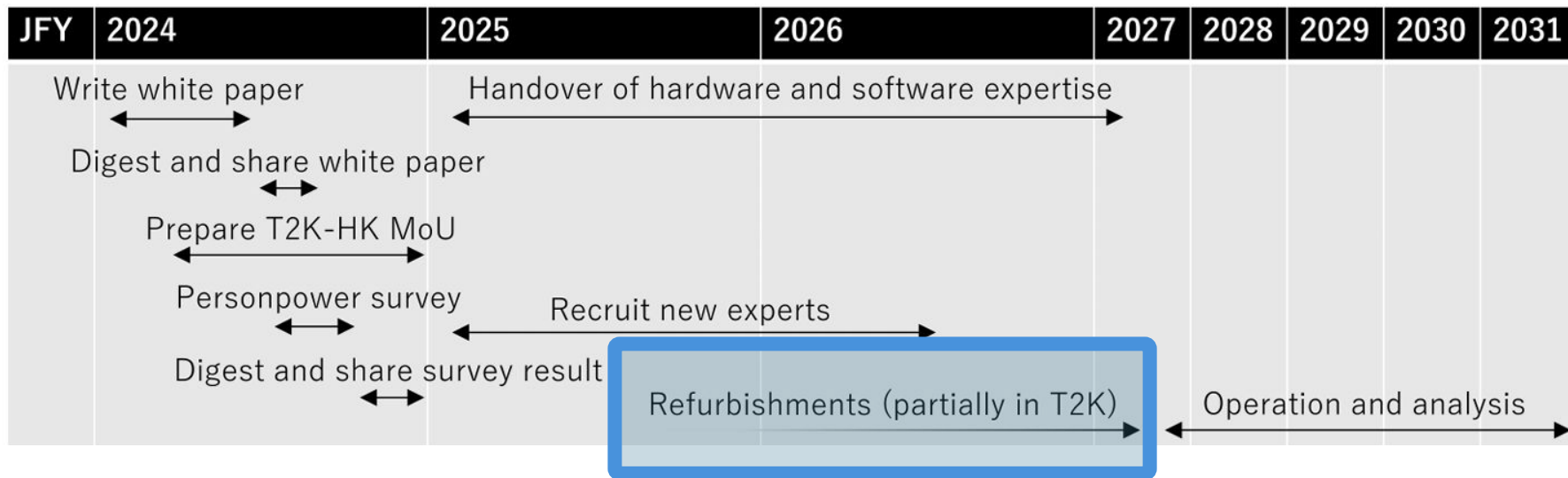
ND280 - attivita` 2026 “Analisi”



Attivita` di Analisi Padova

- Analisi Oscillazioni
A.Longhin - Convener
- Sezioni d'urto
neutrino dell'elettrone
M.Feltre
- Studi TPC e Calibrazioni
D.D'Ago

ND280 - Refurbishment & New Upgrade



ND280 - Refurbishment TDAQ Hardware

1) “patch” to Master Clock Board for improved trigger HATPC
(G.Collazuol - 2025)

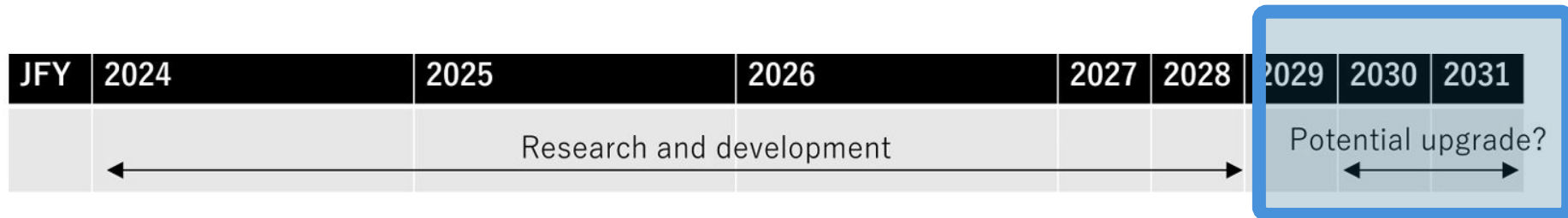
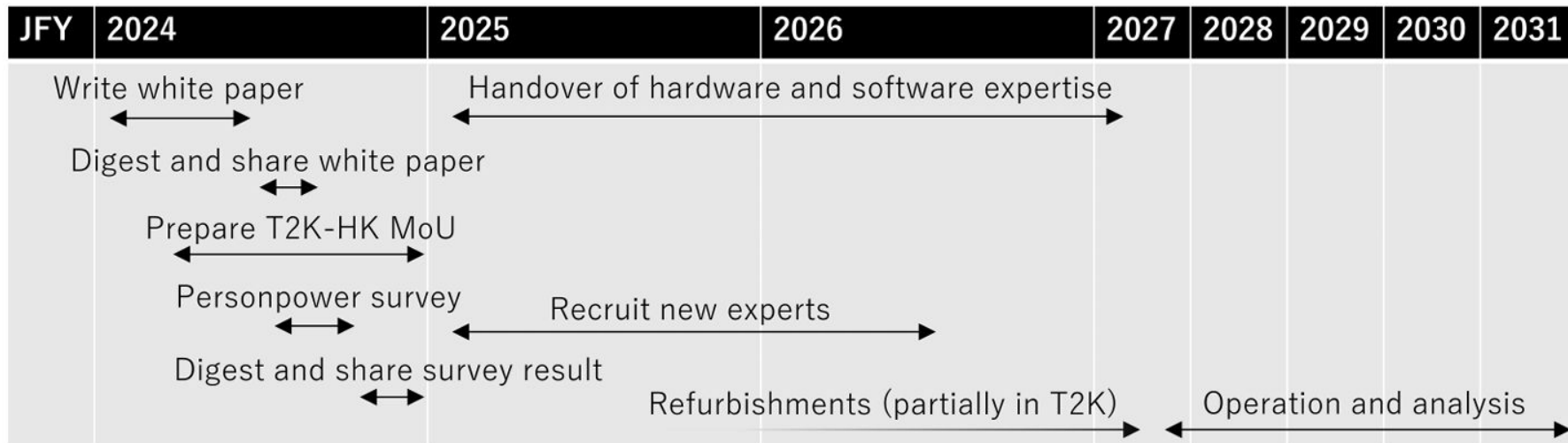
2) Clone / Refurbish old TPCs Readout boards

☐ Richiesta Servizio Elettronica ~ 2 mp
collaborazione con CEA-IRFU

3) New Trigger and Clock Distribution System (from scratch)

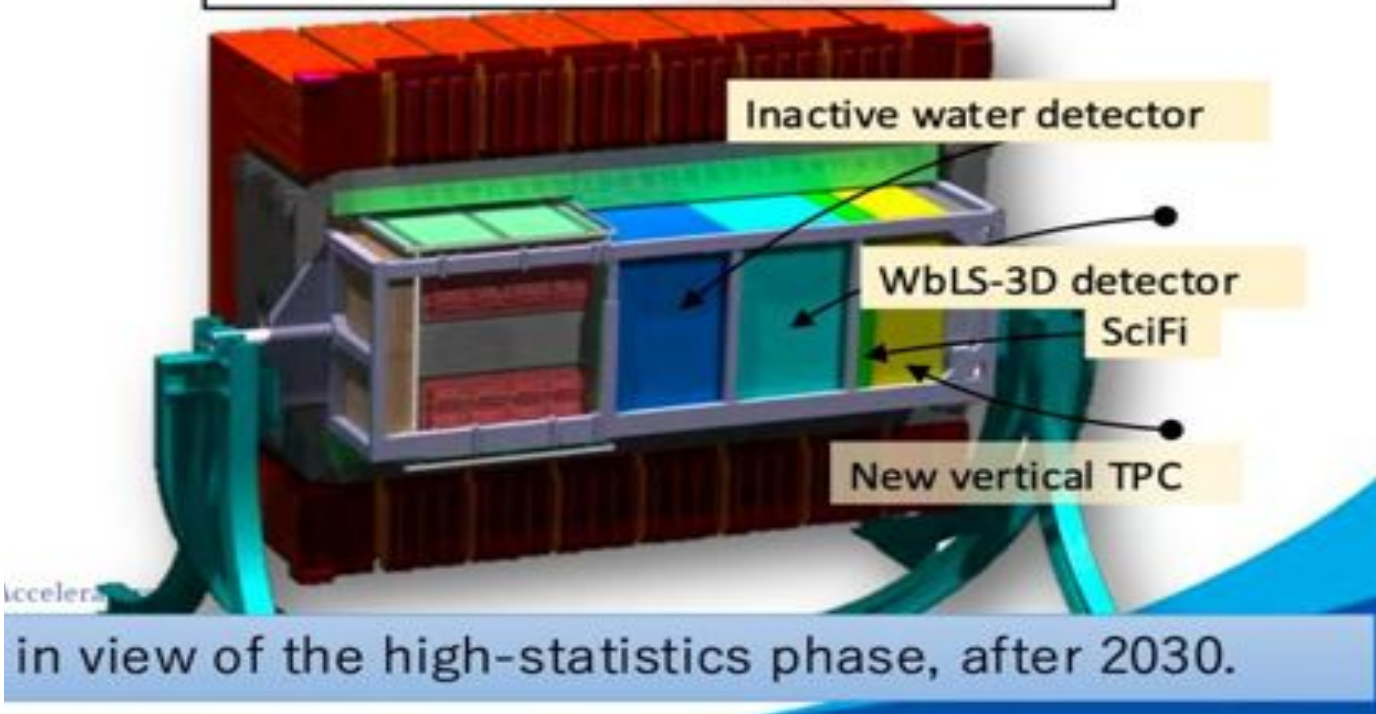
☐ Richiesta Servizio Elettronica ~ 1mp
collaborazione con INFN Pisa

ND280 - Refurbishment & New Upgrade



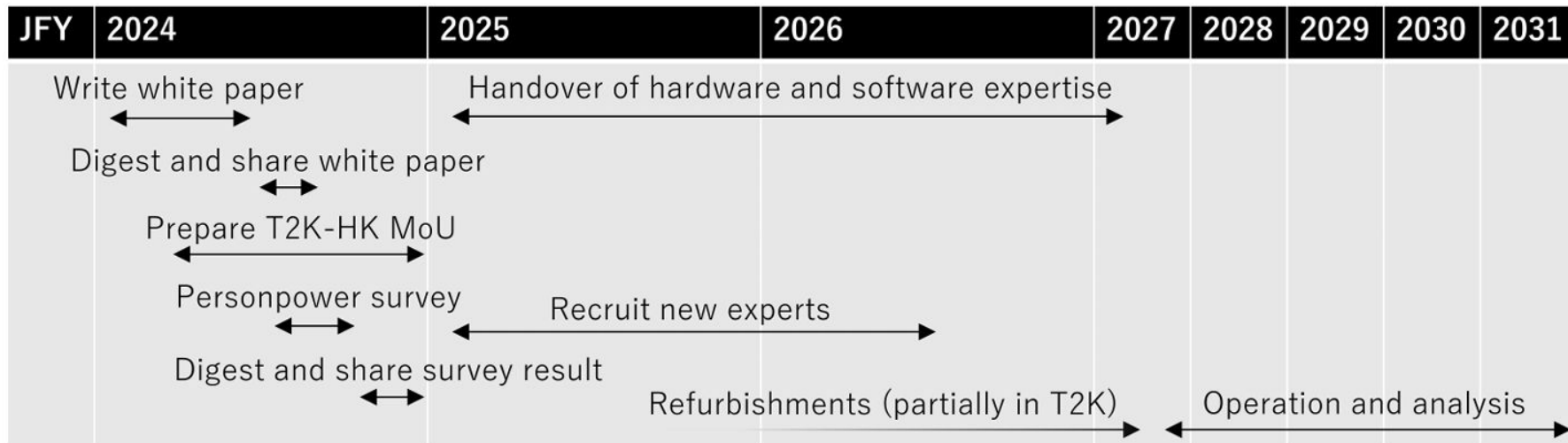
ND280 - Nuovo Upgrade per il 2030

ND280++ Reference design for ~2030

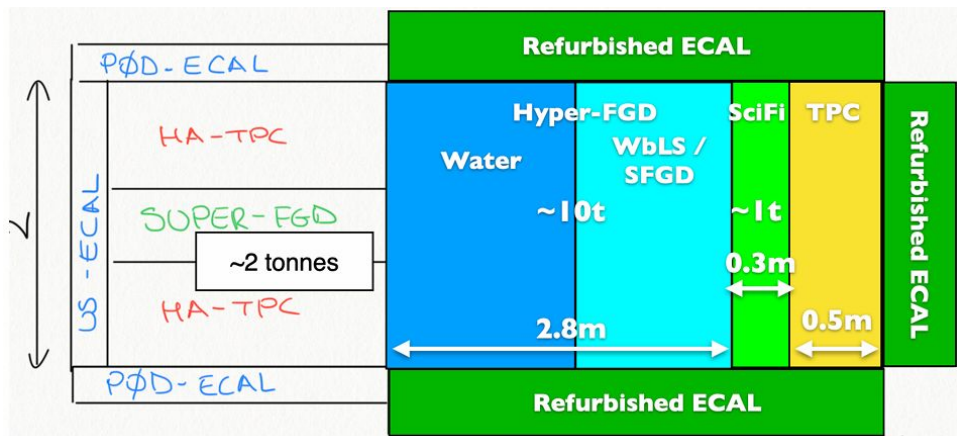


- Active water target
- High precision cross sections ν - μ and ν - e in water
- High precision Neutral Currents in water

ND280 - Refurbishment & New Upgrade



R&D per nuovo Upgrade -- Padova

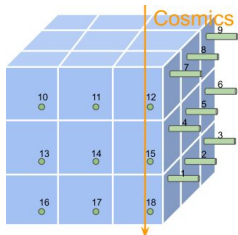


Development **TPC Optical Readout**
 SINERGIA □ DRD1/4 / INFN Gr5
 TIMEPIX4

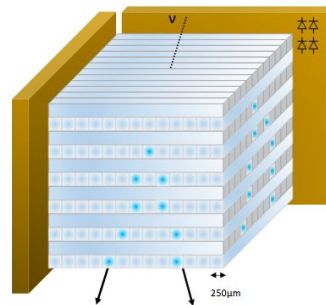
- Optical and Charge readout of avalanche gas multiplication
- Extended drift regions
 - Transparent conductive anodes
 - Advanced timing solutions

Development new **Digital-SiPM**
 SINERGIA □ DRD4 / INFN Gr5
 ASPIDES

Development new **Back Side illuminated SiPM**
 DRD4 / INFN Gr5 IBIS-Next / C.Forza PhD Tecn.



- Readout of
 - Water-based liquid scintillator
- SiPM => low noise & high PDE
 - Back Illuminated SiPM



- Readout of very fine grained sci-fi detector

Anagrafica 2026 - Hyper-K Padova



Nome	Contratto	Qualifica	%	Esperimenti
G.Collazuol	Ass. Ric. Sci.	PA	70	T2K + SK + HK
D.D'Ago	Ass. Ric. Sci.	Assegnista	15	T2K + HK
S.Levorato	INFN	Primo Tec.	40	T2K + HK
M.Feltre	Ass. Ric. Sci.	Assegnista	60	T2K + HK
M.Grassi	Ass. Ric. Sci.	PA	70	T2K + HK
M.Laveder	Ass. Ric. Sci.	RU	80	T2K + HK
A.Longhin	Ass. Ric. Sci.	PA	60	T2K + HK
M.Mezzetto	INFN	DR	78	T2K + HK
M.Mattiazzi	Ass. Ric. Sci.	Assegnista	30	T2K + SK + HK
C. Forza	Ass. Ric. Sci.	Dottoranda	90	T2K + HK
F.Pupilli	INFN	Primo Ric.	40	T2K + HK
A.Patelli	Ass. Ric. Sci.	PA	90	T2K
		Tot	7.2 FTE	

Riassunto Richieste Servizi Sezione 2026



Servizi Tecnici Generali □ 3 mp

- Assemblaggio meccanica ed elettronica mPMT per HK – **attività` a Napoli** ~ 1.5 m.p.
- Assemblaggio e calibrazione elettronica ID per HK – **attività` al CERN** ~ 1.5 m.p.

Servizio Elettronica □ 4 mp

- Turni calibrazione elettronica underwater @ CERN ~ 1 m.p.
- Rinnovo elettronica Readout TPC verticali ND280 (con INFN Pisa) ~ 2 m.p.
- Disegno nuova distribuzione Trigger e Clock ND280 (con INFN Pisa) ~ 1 m.p.

Servizio Officina Meccanica □ 3 mp

- Realizzazione parti per attività` HK High Pressure vessels ~ 3 m.p.

Preventivi gruppo PD 2026	Missioni	90 k€
	Apparati	50 k€
	Consumabile	15 k€
	Inventariabile	25 k€
	SP-Servizi	10 k€

Belle II

RL: Stefano L.



Bellell intro

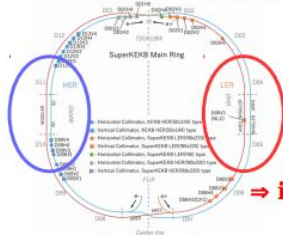


- Stato esperimento e presa data
- Attivita' Padovane
 - Analis
 - Studi performance
 - Studi upgrade
- Anagrafica, reponsabilita', richieste

Objectives in 2024c

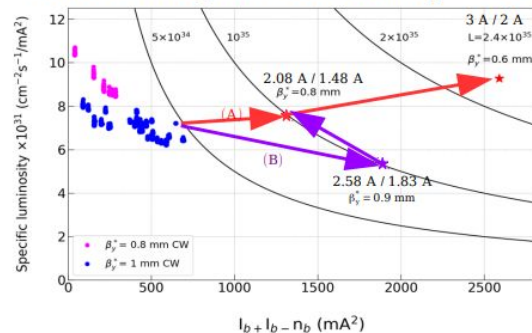
- Confirm that countermeasures against SBL works

- Flipped beam pipes with electron clearing electrodes (D04, D05) during summer 2024
- Check the frequency of SBL

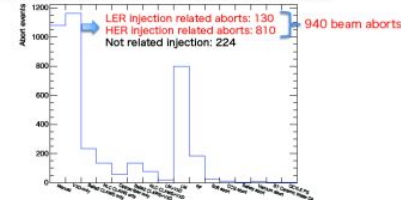


⇒ if we confirm that it works, we will consider to flip the remaining pipes
(5 beam pipes at D04/D05 + 30 beam pipes at D10/D11)

- Achieve higher luminosity → $10^{35} \text{ cm}^{-2} \text{ s}^{-1}$



3930 beam aborts in 2024ab in total

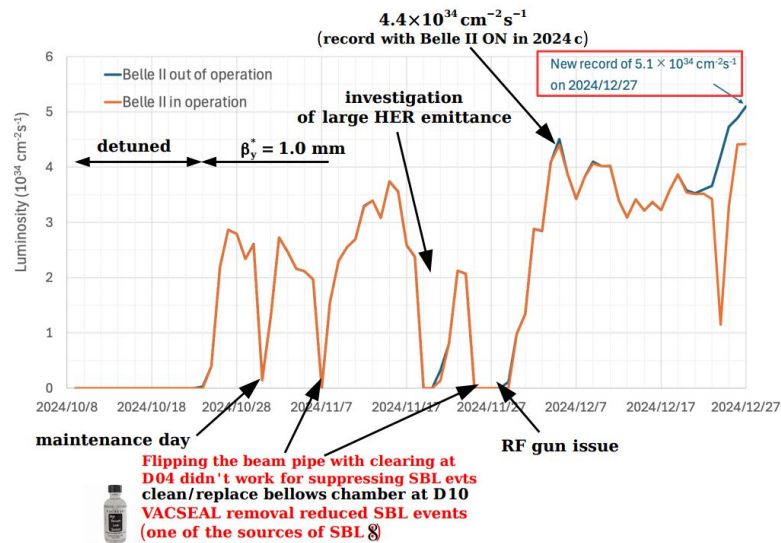


- New diamond threshold: outside/inside inj.

- Low threshold: 8/8/8 mRad outside inj
 - High threshold: 50/40/12/12 mRad during inj
- ⇒ suppress harmless inj. aborts during 2024 c

- Keep PXD off during 2024c
- Priority to machine studies to achieve higher luminosity
- Permission to turn off Belle II any time

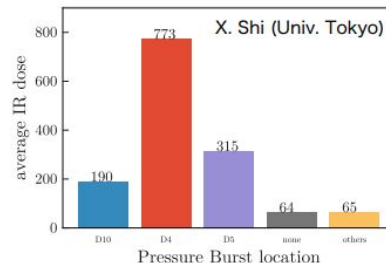
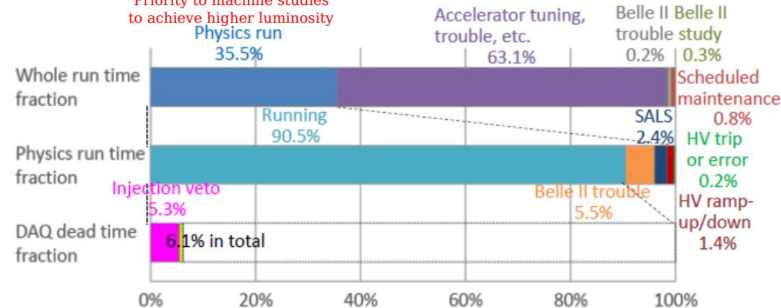
Data Taking 2024c



- Still no stable beam (frequent Beam Loss)
- Issue with vertical emittance
- Issue with RadioFrequency Gun
- But we learned something (hopefully) important:
the VacSeal saga

Data taking efficiency in 2024c

Priority to machine studies
to achieve higher luminosity



Recorded luminosity

426 fb^{-1} + 147 fb^{-1} = 573 fb^{-1}

Run1 Run2 (online)

- 495 fb^{-1} at Y(4S)
- 59 fb^{-1} at Y(4S) - 60 MeV
- 19 fb^{-1} around 10.75 GeV

c.f. BaBar: 424 fb^{-1} at Y(4S)

c.f. Belle: 711 fb^{-1} at Y(4S)

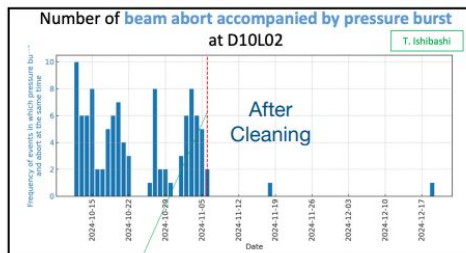
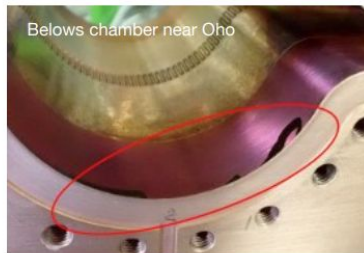


Plan for 2025c data taking

2

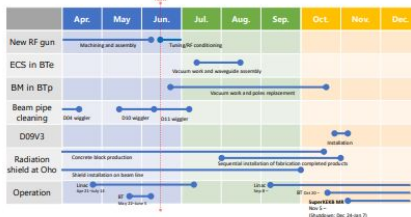
We have many reasons to be (cautiously) optimistic

We have identified, **for the first time**, a physical mechanism that can explain sudden beam losses in LER



Much work being done over summer shutdown:

- **Removal of stains from vacuum sealant**
- New electron gun
- New enhanced shielding near non-linear collimator @ Oho



We will embark on a long **7 month run** in fall (November - End of May)

→ Reaching **stable run conditions** in 2025c will be priority

The next run has **two goals** :

Push our recorded dataset to **1/ab**



Will keep close communication with SuperKEKB team to balance this; **physics will be priority** ← 80% of running time dedicated to physics runs

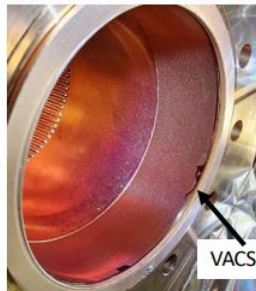
Show that there is path to reach luminosities of **$\sim 10^{35} \text{ cm}^{-2} \text{ s}^{-1}$**

Decisione di fare un medium shutdown e ripulire VacSeal (piu' altre attivita') e saltare presa dati primavera 2025

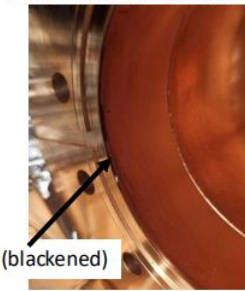
The VacSeal saga

Work on LER & HER progress:

LER D01 Bellows Chamber



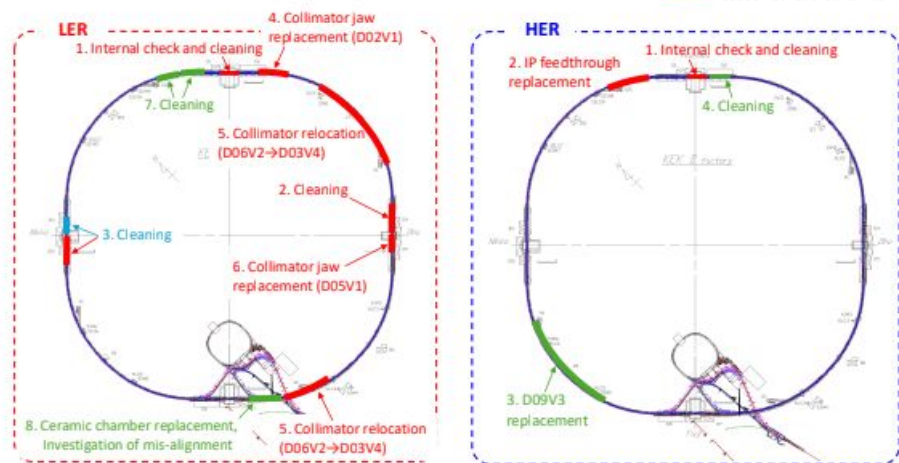
HER D01 Bellows Chamber



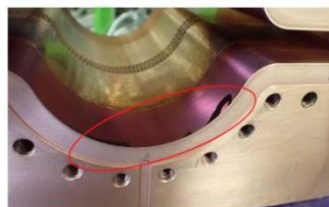
LER D02 beam pipe



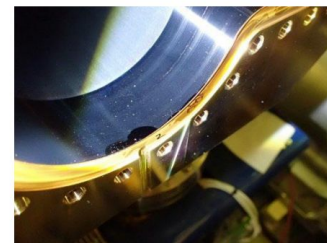
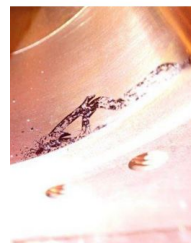
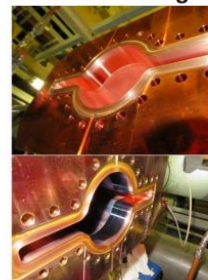
HER D02 Bellows Chamber



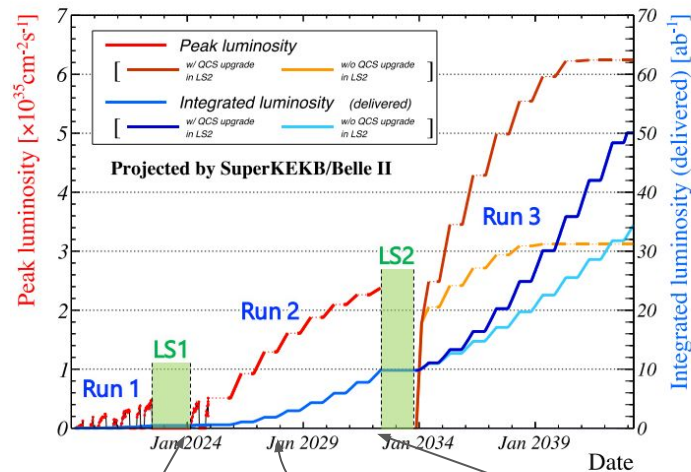
Inside of bellows chamber and beam pipe in the Oho Wiggler Section



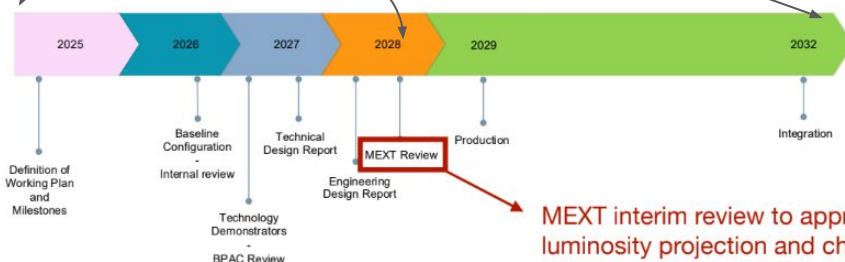
After cleaning



Luminosity profile update



Milestones:



MEXT interim review to approve recently updated luminosity projection and change LS2 timing to 2032

Plot of “delivered” integrated luminosity

- This projection does not take into account the presence of the detector performance degradation over long-term operation.
- The impact of such degradation on the recorded statistics and physics quality is to be assessed.

Key to realizing the upgrade and achieving the final goal

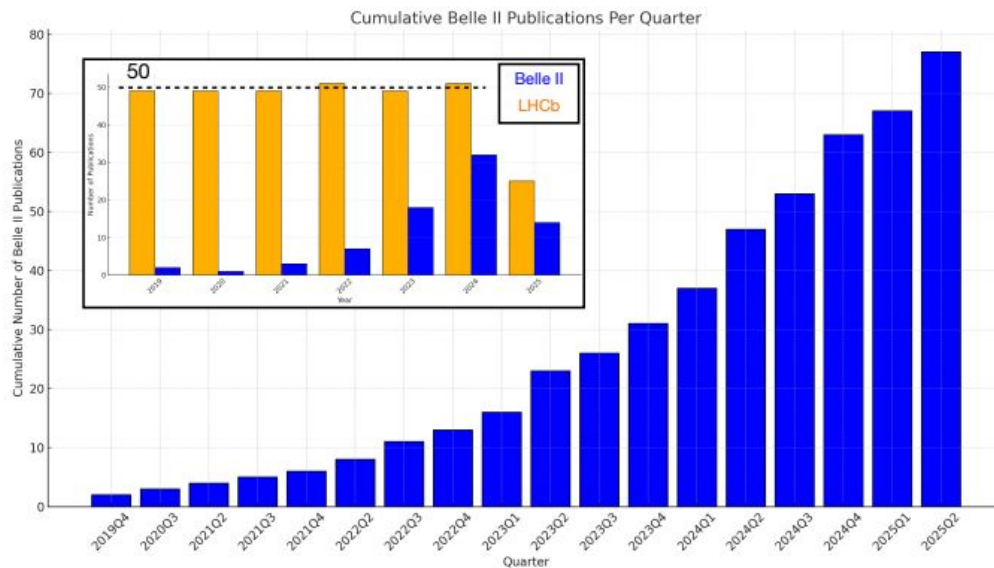
- Improvements in the machine performance and demonstration of the projection in the next few years are crucial for ensuring the reliability of the profile and securing approval for future upgrade projects.



Physics publications

- Total 77 submitted
 - 66 accepted
 - 11 preliminary results
- ~30 papers submitted in the last year
- Expected others $O(10)$ for summer conferences EPS, LP, CKM

77 paper submitted (66 accepted as of June 30th) :



Goal: 40-45 papers / year

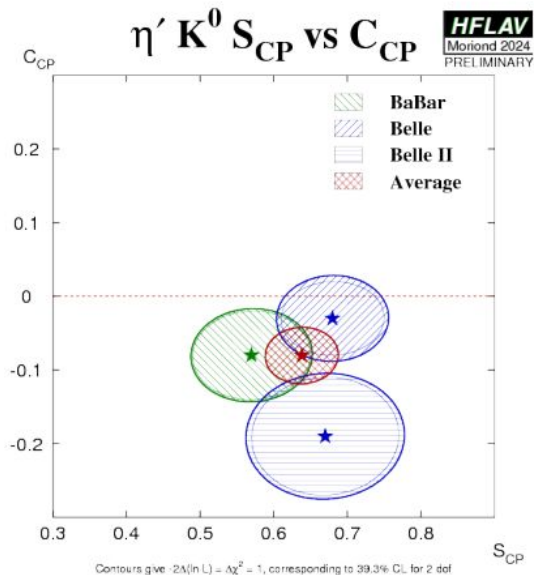
Attivita' Padovane

$B^0 \rightarrow \eta' K^0$

S. Lacaprara, J. Kandra, N. Brenny, C. Chen, M. Veronesi, S. Cuccuini, G. Finocchiaro, A. Passeri

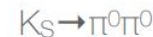


- Most sensitive analysis of $\sin 2\phi_1^{\text{eff}}$ in $b \rightarrow sq\bar{q}$ loops
- Dataset: Run1+2 (proc16+prompt)
 - Superseding Run1 analysis, using $\eta' \rightarrow \eta \gamma \pi^+ \pi^-$ and $\eta' \rightarrow \rho \gamma$ with $K_S \rightarrow \pi^+ \pi^-$
 - Adding $\eta' \rightarrow \eta 3\pi^+ \pi^-$, $K_S \rightarrow \pi^0 \pi^0$ and K_L
 - Improved flavor tagging (31% $\rightarrow$ 37%), skim and selection efficiencies across all channels
- Expecting $\text{stat}(S, R1+2) \sim \sqrt{2} * \text{stat}(S, R1)$
 - Sensitivity similar to Belle (world's best)



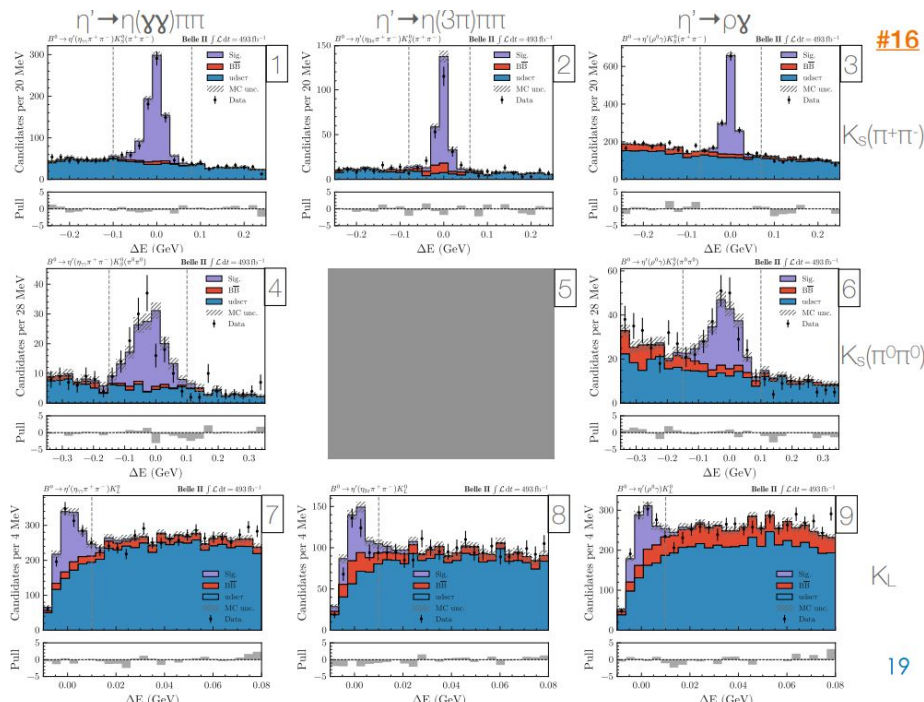
Mode	Experiment	$\sin(2\beta^{\text{eff}}) = \sin(2\phi_1^{\text{eff}})$	C_{CP}	Correlation
$\eta' K^0$	BaBar N(BB)=467M	$0.57 \pm 0.08 \pm 0.02$	$-0.08 \pm 0.06 \pm 0.02$	0.03 (stat)
	Belle N(BB)=772M	$0.68 \pm 0.07 \pm 0.03$	$-0.03 \pm 0.05 \pm 0.03$	0.03 (stat)
	Belle II N(BB)=387M	$0.67 \pm 0.10 \pm 0.03$	$-0.19 \pm 0.08 \pm 0.03$	0.03 (stat)
	Average	0.64 ± 0.05	-0.08 ± 0.04	0.02

1

Improvement in $K_S \rightarrow \pi^+ \pi^-$ selection

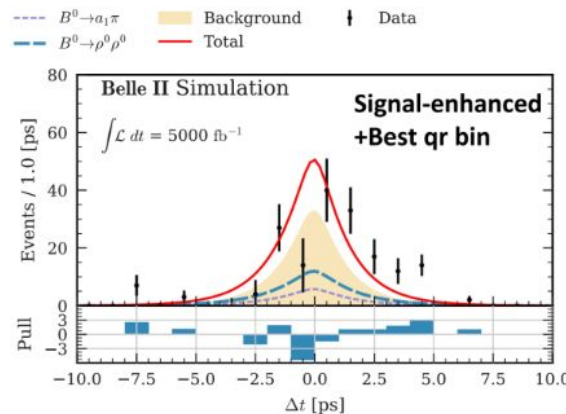
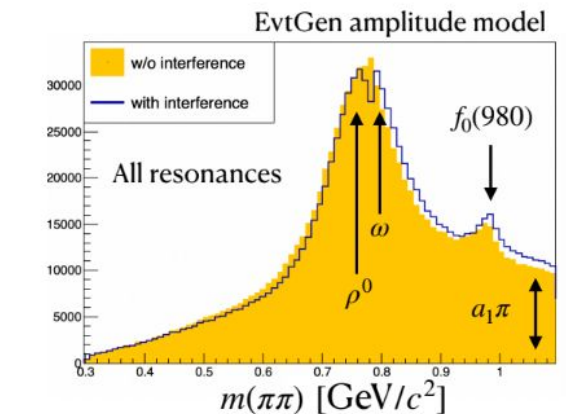
3k (B1) vs. 3.5k (B2) yields

- ✓ better signal purity
- ✓ better flavor tagging
- ✓ x1.8 yields [ch1-3]
- ✓ x3.5 yields [run1]
- ✗ PXD OFF in run2



$$B^0 \rightarrow \rho^0(\rightarrow \pi^+\pi^-) \rho^0(\rightarrow \pi^+\pi^-)$$

- **Goal:** Belle + Belle II time-dependent CP asymmetries
- **Motivation:** improve precision of $\phi_2 = \arg(-V_{td}V_{tb}^*/V_{ud}V_{ub}^*)$, which has the largest uncertainty
- **Challenges:** low branching fraction, large background, interference, large ρ width, angular analysis needed
- Developed amplitude model for $B^0 \rightarrow (\pi^+\pi^-)(\pi^+\pi^-)$ decays
- Working selection identified, optimisation ongoing
- Dedicated MVA's to suppress $e^+e^- \rightarrow q\bar{q}$ background and $B^0 \rightarrow a_1^\pm \pi^\mp$ peaking background
- Fit strategy: extract the CP asymmetries from a fit to ΔE , CSMVA, $m(\pi\pi)$, $\cos \theta_\rho$, Δt , qr
- Ongoing study of interference effect for the fit strategy



TOP PID using ML

Cecilia Antonioli,
Ale Gaz

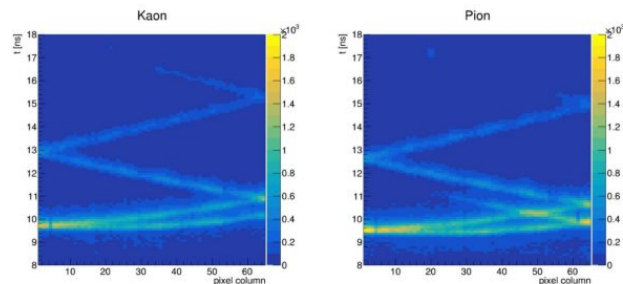


- TOP measures the arrival time and hit position of the Cherenkov photons produced by a charged particle traversing a TOP module
- TOP PID currently relies on matching these measurements to analytical PDFs, which depend on the particle hypothesis and track parameters
- The analytical PDF-based approach requires detailed knowledge of geometry and optical properties of all TOP components

New approach : Machine Learning-based pattern recognition

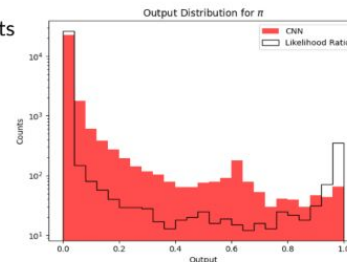
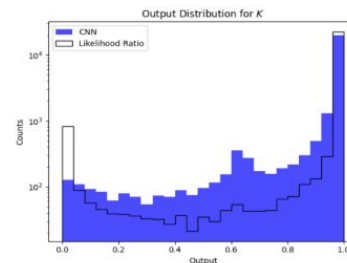
- Expected to achieve better performance compared to the analytical PDF-based method
- Less sensitive to residual mismodeling in the detector components

Current project : CNN for K and π separation



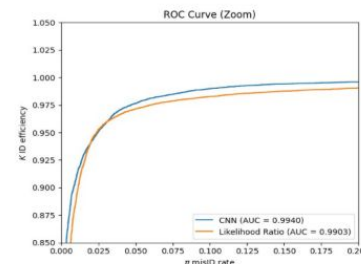
Measured patterns for thousands of photons (Cherenkov + background), for simulated K^+ or π^+ from the interaction point, with fixed momentum and direction ($p = 2.0$ GeV/c, $\theta = 90^\circ$, $\phi = 41.25^\circ$)

Training on ~80k events



Network output:
1 for K, 0 for π

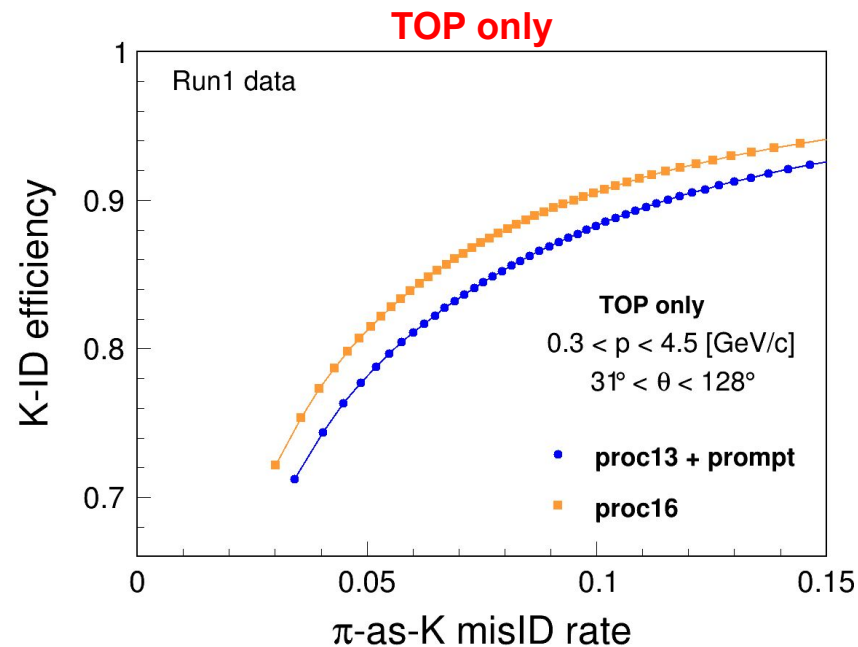
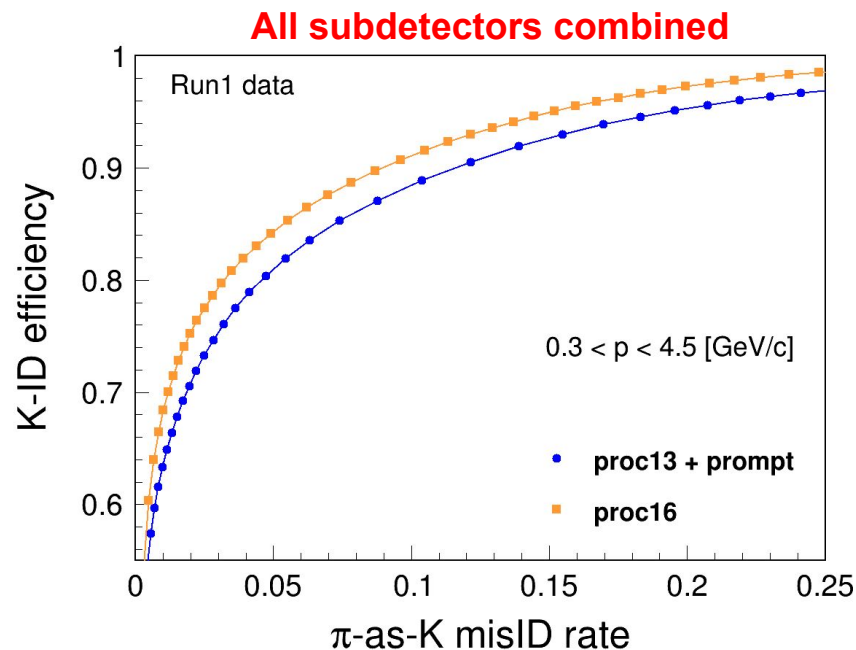
Test on ~50k events



PID performance monitoring

Ale Gaz

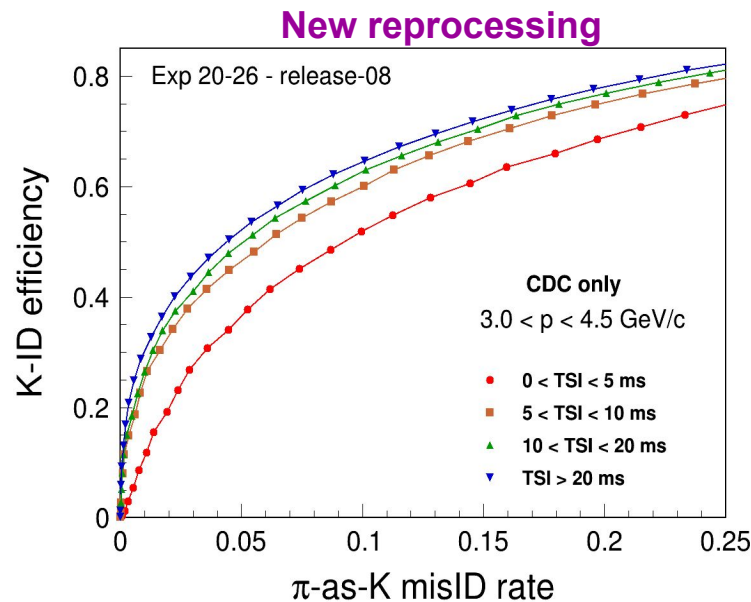
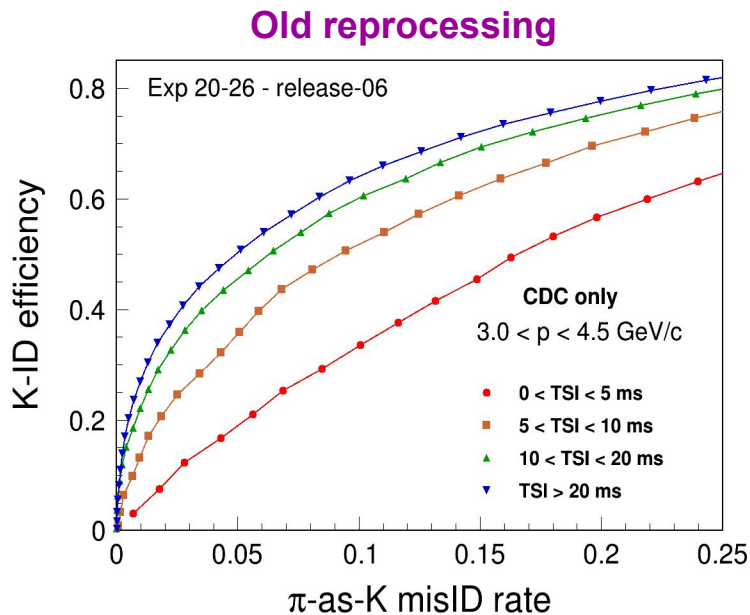
- Better PID performance on the **new** reprocessing versus the **old** one, thanks to several improvements in the calibrations and the reconstruction software;
- Significant gain particularly in the TOP-only likelihood;



PID performance monitoring

Ale Gaz

- The new CDC calibration procedure recovers part of the performance that we would lose due to the spike of background that follows a bunch injection:

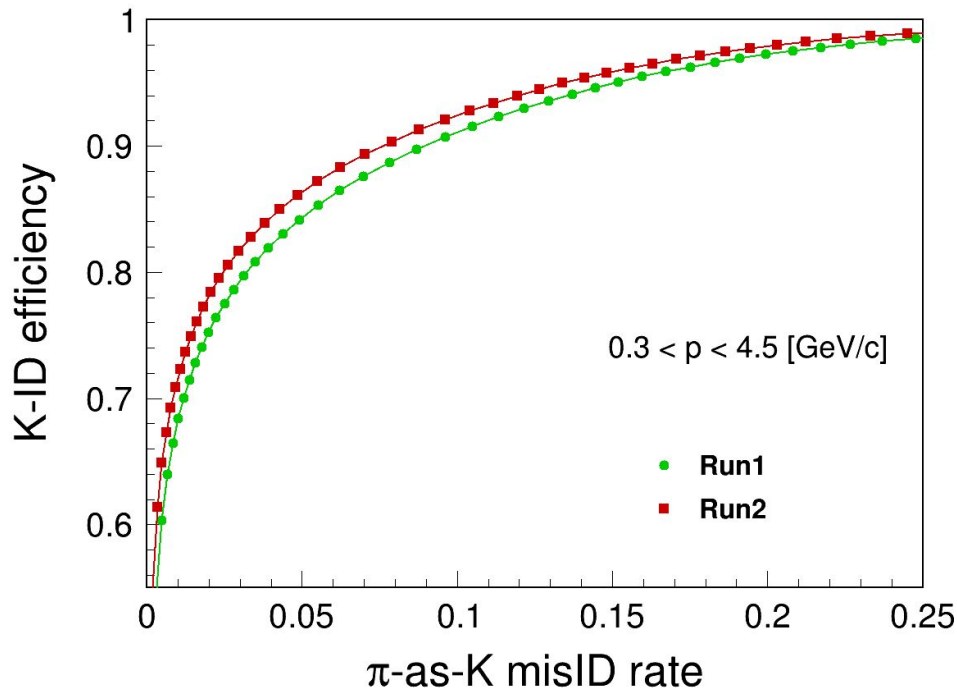


TSI = “time since last bunch injection”

PID performance monitoring

Ale Gaz

- Overall, better PID performance in Run2 vs Run1, thanks to hardware improvements implemented during the Long Shutdown 1 and better control of the running conditions (particularly for the CDC);
- Now using Neural Network based identification strategies for all particles;
- The Hadron ID (Run1) performance paper is now available on [arXiv](#) and has been submitted to EPJ-C.



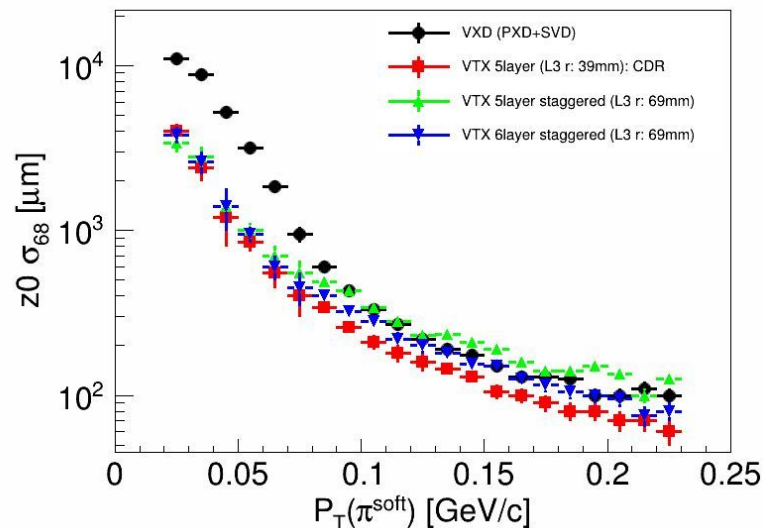
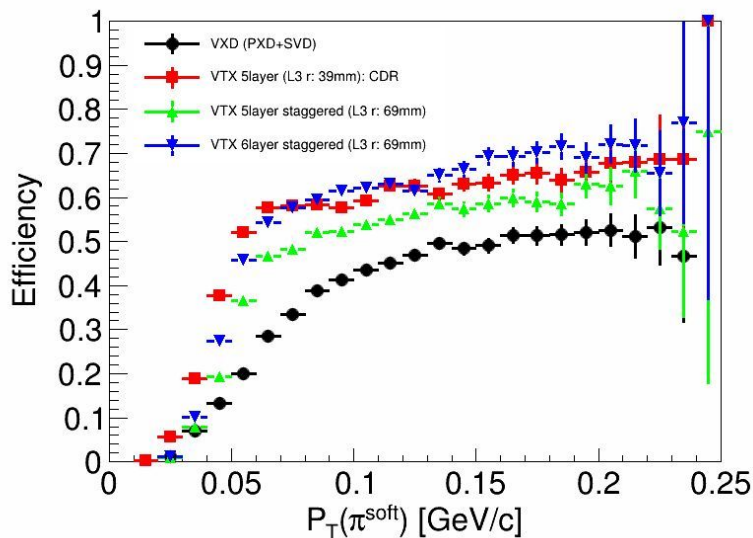
Belle II Upgrade

- After the submission of the [Framework CDR](#), we are continuing to prepare for a major upgrade during the next Long Shutdown (~2032);
- We are concentrating on the tracking system, as there is a general consensus that the current CDC will not survive LS2. We plan to replace it with another one with larger (e.g. from 14 to 36 cm) inner radius, and put new silicon layers in the gap: **Inner Tracking and Timing (ITT)**;
- Considering the following two scenarios:
 - 1) VTX + ITT with timing (30 ps, 100x100 mm², 3% X/X_0 per layer)
 - LGAD technology being considered. Not great in terms of material budget, but TOF measurement will help PID at low momentum;
 - 2) VTX + ITT with 'fast' CMOS (1 ns, 50x50 mm², 1% X/X_0 per layer)
 - Less material, but will ~lose PID for tracks that do not reach at least the inner layers of the upgraded CDC.

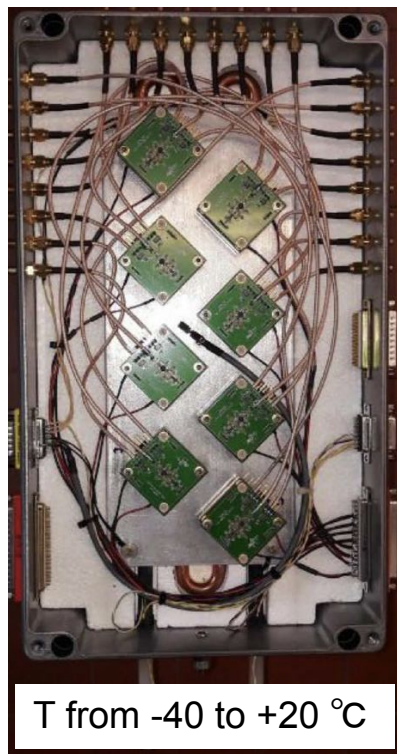
Belle II Upgrade

Ale Gaz

- Replacement plans for the silicon vertex detectors already quite consolidated;
- We plan to replace the current VXD with a new 6-layer pixel detector (VTX), designed to be more robust against beam backgrounds:



Compared to current detector (black markers) we expect much better reconstruction efficiency and resolution for low momentum tracks.



set	ID	model	set	ID	model
H1	0	Hamamatsu S13360-1350PE	MIX1	16	Ketek PM3315-WL
	1	Hamamatsu S13360-1350PE		17	Ketek PM3315-WL
	2	Hamamatsu S13360-1350PE		18	Ketek PM3335-WL
	3	Hamamatsu S13360-1350PE		19	Ketek PM3335-WL
	4	Hamamatsu S13360-1350PE		20	OnSemi 10035
	5	Hamamatsu S13360-1350PE		21	OnSemi 10035
	6	Hamamatsu S13360-1350PE		22	OnSemi 30035
	7	Hamamatsu S13360-1350PE		23	OnSemi 30035
FBK1	8	FBK NUV-HD-RH-3015	H2	24	Hamamatsu S13360-3025PE
	9	FBK NUV-HD-RH-3015		25	Hamamatsu S13360-3025PE
	10	FBK NUV-HD-RH-3015		26	Hamamatsu S13360-3050PE
	11	FBK NUV-HD-RH-1015		27	Hamamatsu S13360-3050PE
	12	FBK NUV-HD-RH-1015		28	Hamamatsu S14160-3015PS
	13	FBK NUV-HD-RH-1015		29	Hamamatsu S14160-3015PS
	14	FBK NUV-HD-RH-1015		30	Hamamatsu S14160-3050HS
	15	Hamamatsu S14160-3050HS		31	Hamamatsu S14160-3050HS

We tested 32 SiPMs with different dimensions and pixel sizes from different producers.
The goal is to identify current limits and provide guidance for future developments.

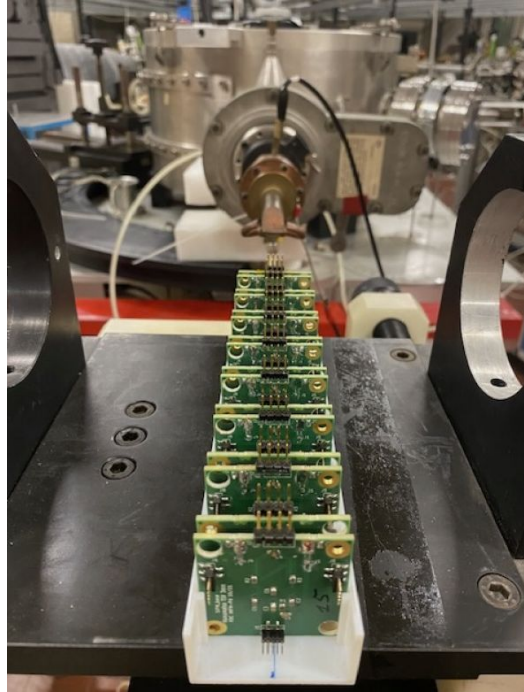
Set H1 (Hamamatsu 1.3 X 1.3 mm², 50 μm cells) **Single Photon**

SiPM ID	1 st irradiation
0	$5.07 \cdot 10^{11}$
1	$2.03 \cdot 10^{11}$
2	$1.01 \cdot 10^{11}$
3	$5.07 \cdot 10^{10}$
4	$2.45 \cdot 10^{10}$
5	$1.02 \cdot 10^{10}$
6	$5.06 \cdot 10^9$
7	$1.03 \cdot 10^9$

1st annealing 150°C for 8 weeks

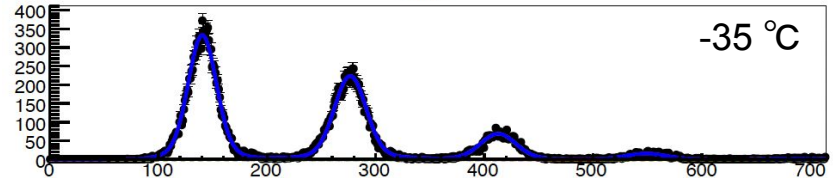
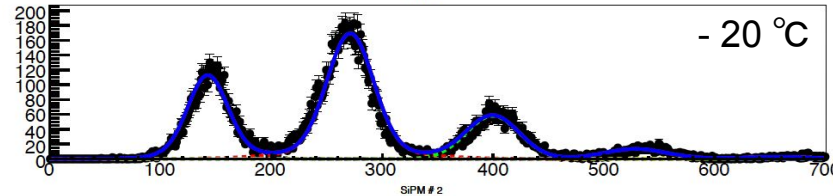
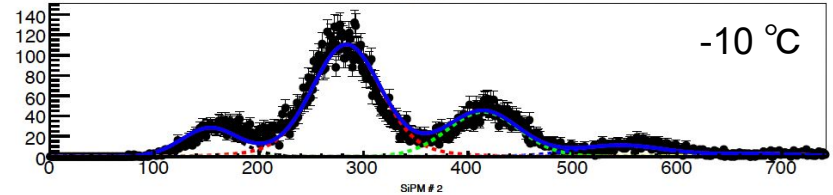
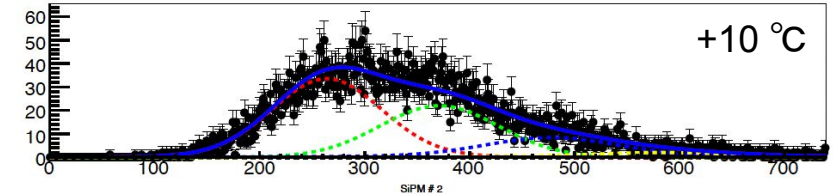
SiPM ID	2 nd irradiation
0	$9.97 \cdot 10^9$
1	$1.01 \cdot 10^{10}$
2	$1.00 \cdot 10^{10}$
3	$9.99 \cdot 10^9$
4	$9.99 \cdot 10^9$
5	$9.99 \cdot 10^9$
6	$1.00 \cdot 10^{10}$
7	$1.00 \cdot 10^{10}$

2nd irradiation 80°C for 1 day

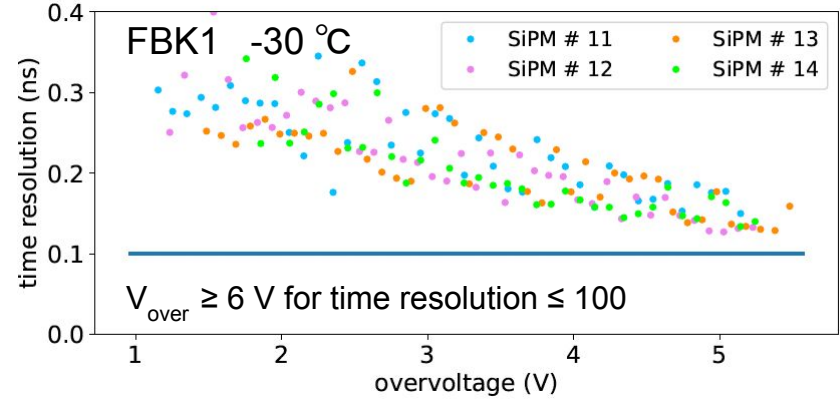
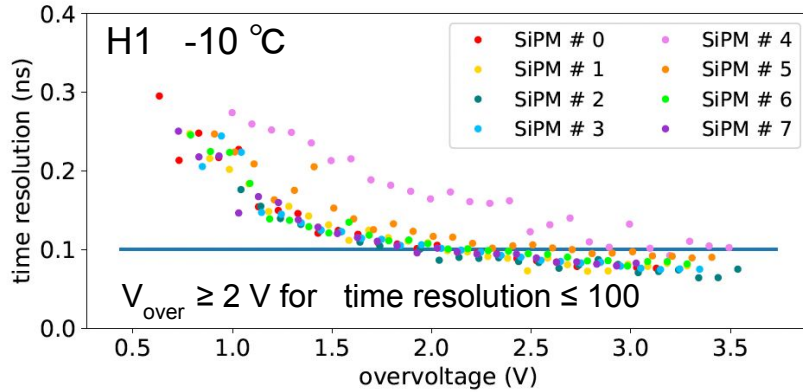


CN accelerator at LNL-INFN
4 MeV deuterium beam
Beryllium target 50 μm thick

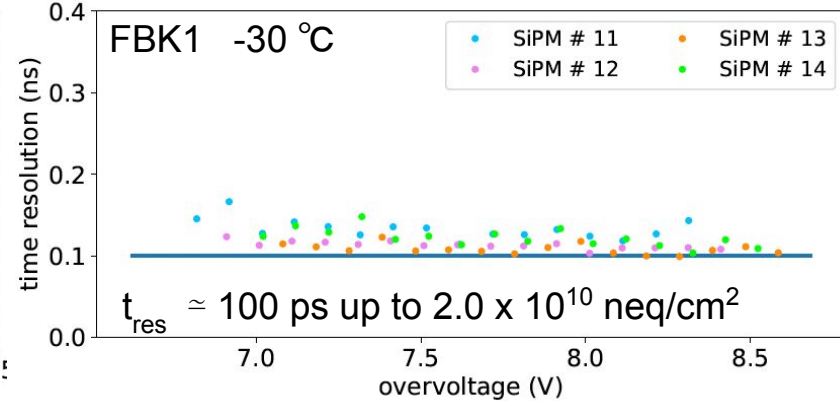
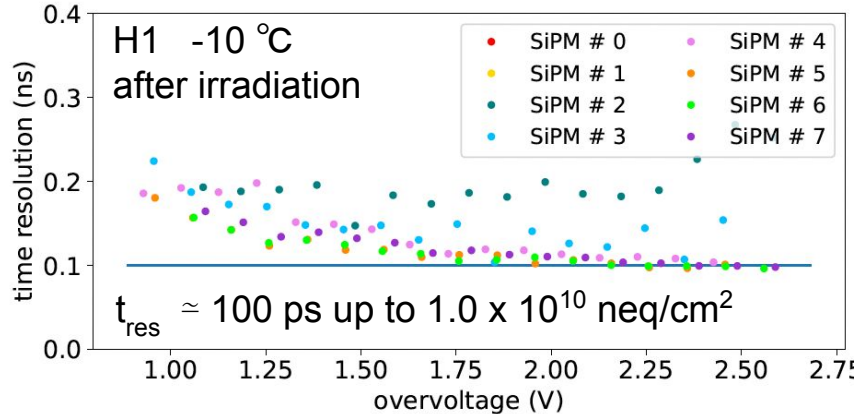
SiPM #2 : 1×10^{11} neq/cm²



Sets H1 and FBK1 Time Resolution



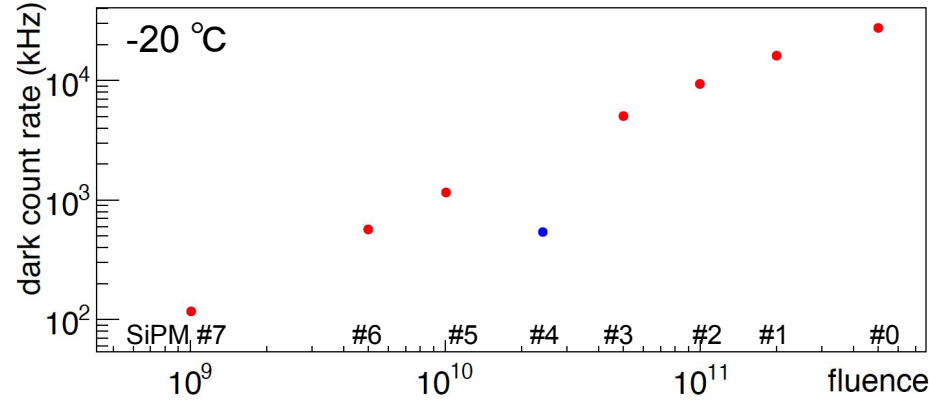
before irradiation



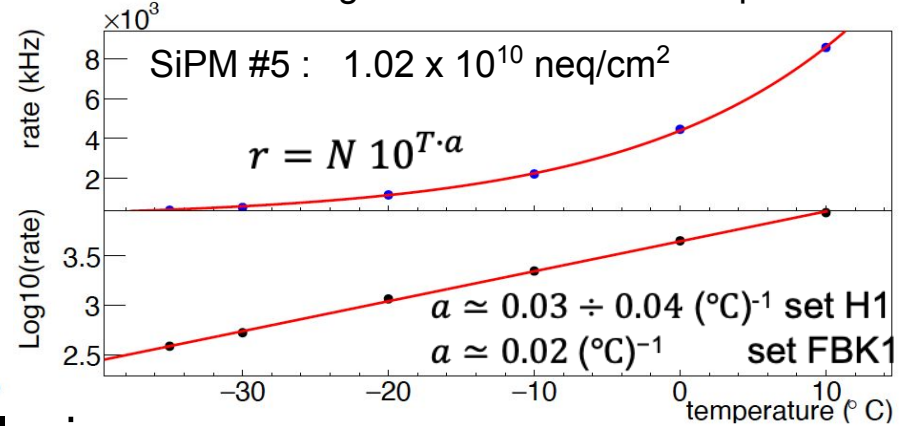
after irradiation

Sets H1 and FBK1 **Dark count rate**

Exponential increase of DCR with fluence



Reduction in log scale of DCR with temperature



Conclusions

SiPMs HPK1.3x1.3 mm² and FBK 1x1 mm²:

- single photons can be identified when irradiated up to 1.0×10^{11} neq/cm² and cooled down to -20 °C / -30 °C;
- time resolution ≈ 100 ps for irradiation up to $1-2 \times 10^{10}$ neq/cm², no degradation after annealing.

SiPMs 3x3 mm² any producers:

- too noisy to identify single photons at least down to -40 °C

Anagrafica, Responsabilita' e Richieste

- Antonioli 100% PhD
- Dal Corso 40%
- Gaz 100%
 - EB member, HadronID conv. (L2)
- Lacaprara 100%
 - Data Production coordinator (L1), EB/IB member
- Lin 100% PhD
- Kandra 100% postDoc
 - AdR contract will end in October
- Stroili 70%
- Torassa 95%
 - Shifter manager

○ **Totale 7.05**

Richieste servizi:

- None

Richieste in CSN1

- Missioni: 68k
- Metabolismo: 11k
- CAEN DT5204 10k (sj)

LHCb status update

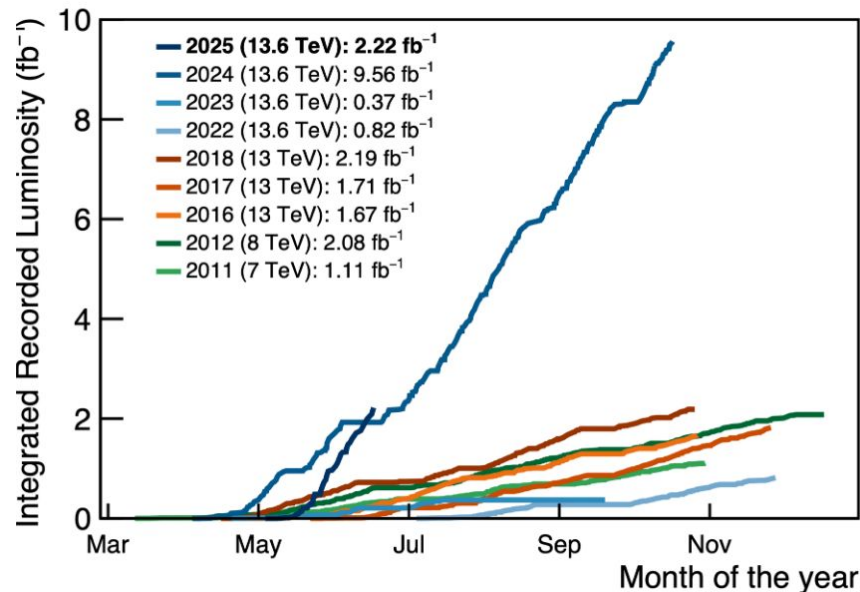
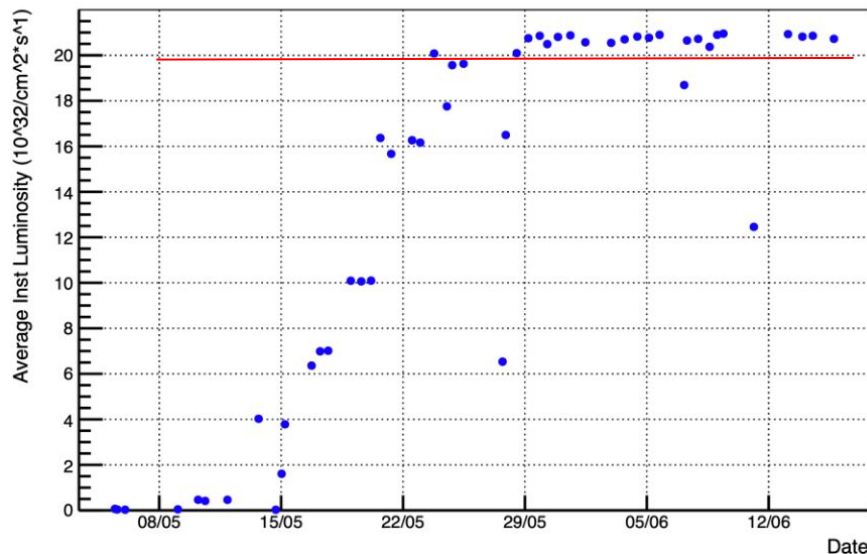
Riunione preventivi 2026

A Bertolin
per il gruppo LHCb-Padova
9 luglio 2025



Presa dati 2025

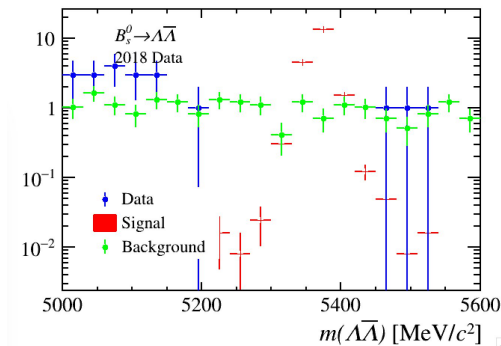
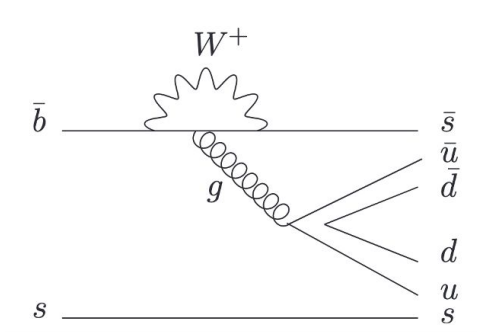
LHCb Average Instantaneous Lumi in p-p in 2025



- superato la luminosità istantanea attesa ($20 \times 10^{32} / \text{cm}^2 \cdot \text{s}$)
- la luminosità integrata segue le attese per il 2025 e dovrebbe superare il risultato del 2024

Analisi Padovane: BnoC (Search for $B_s \rightarrow \Lambda^0 \Lambda^0$)

- The $B_s \rightarrow \Lambda^0 \Lambda^0$ is dominated by $b \rightarrow s$ loop transitions, and sensitive to New Physics.
 - The upper limit of branching fraction of $B_0 \rightarrow \Lambda^0 \Lambda^0$ is determined to $< 3.2 \cdot 10^{-7}$ in Belle Collaboration, and the theoretical prediction for BR of $B_0 \rightarrow \Lambda^0 \Lambda^0 \sim 4 \cdot 10^{-9}$ and $B_s \rightarrow \Lambda^0 \Lambda^0 \sim 2.6 \cdot 10^{-7}$.
 - We used Run1+Run2 data to search for $B_s \rightarrow \Lambda^0 \Lambda^0$ at LHCb
 - The preliminary results is ready and analysis note will completed



Analisi Padovane: QEE

Ricerca di $H \rightarrow b\bar{b}$ e $H \rightarrow c\bar{c}$ con tecniche di ML

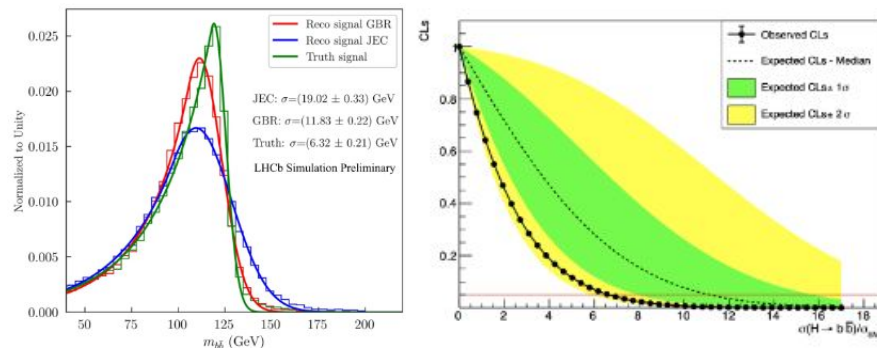
A. Gianelle, D. Lucchesi, L. Sestini (INFN FI), D. Zuliani

- Vengono richiesti solo 2 jet (@ trigger), nessuna richiesta su altri oggetti
 - Ricerca indipendente dal meccanismo di produzione
- Rispetto a misure passate, due miglioramenti
 - GBR per correggere energia dei jet
 - DNN per taggare i jet
- Fit alla massa invariante dei dijet per mettere upper limit
- Estrapolazione risultati a HL-LHC

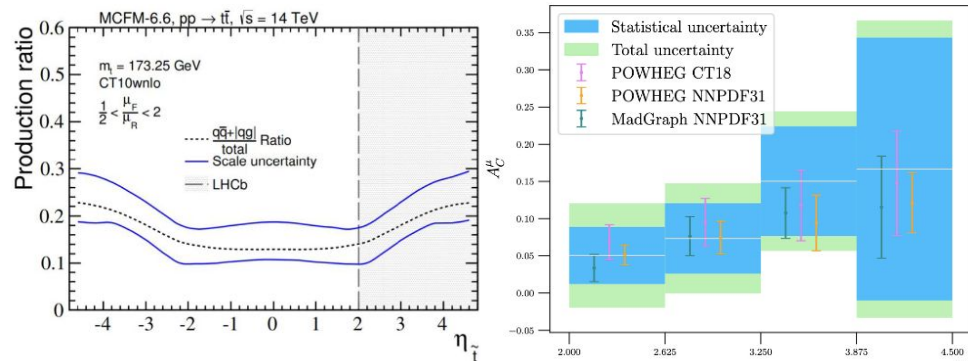
Misura della cross section e asimmetria $t\bar{t}$

L. Sestini (INFN FI), D. Zuliani

- Possibilità di testare SM, pQCD e ridurre incertezza sulla PDF del gluone
 - LHCb può sfruttare la regione in avanti dove c'è un maggior contributo qq
- Prima misura usando tutti i dati del Run 2
- Stato finale: $\mu + b$ -jet
- DNN per taggare jet da b quark
- Misura statisticamente limitata
 - proof-of-principle per analisi con dati Run 3



Analisi in First Circulation nella Collaborazione, risultati da presentare a EPS!

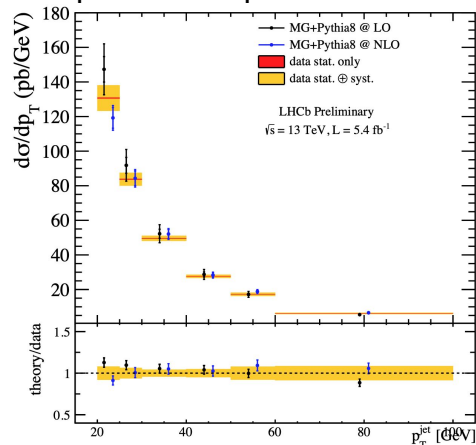


Analisi in Review Committee, risultati da presentare a prossime conferenze invernali!

Misura di W+jets con dati del Run 2

D. Lucchesi, L. Sestini (INFN FI), D. Zuliani

- Sensibili alle Parton Distribution Functions in una regione complementare rispetto ad ATLAS e CMS
- Prime misure a 13 TeV nella forward region
- Sono considerati stati finali con 1 μ e 1 o 2 jets
- Sezioni d'urto misurate in modo differenziale in funzione della cinematica
- Risultati compatibili con predizioni a NLO

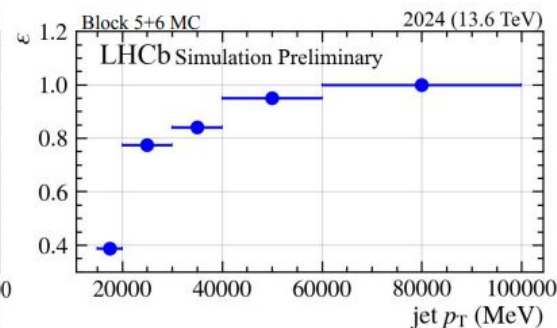
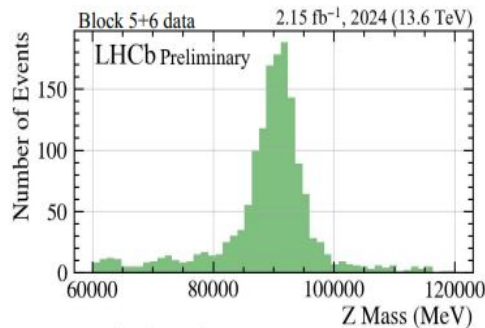


Analisi in WG review, risultati da presentare a prossime conferenze invernali!

First measurement of Z+jets with Run 3 data

D. Zuliani

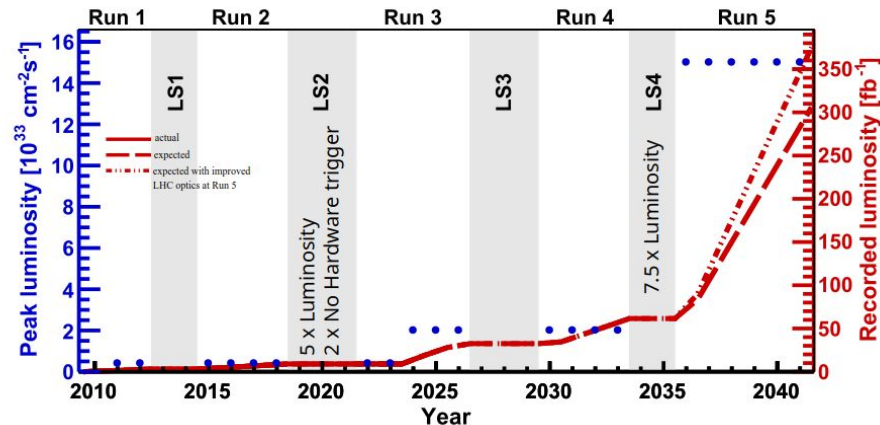
- Prima misura con i jet del Run 3
 - stato finale con 2 μ e almeno 1 jet (no bckg!)
- Misura fondamentale per calibrare la ricostruzione dei jet, in particolare:
 - valutare l'efficienza di ricostruzione
 - valutare la purezza
 - valutare JEC, JER e JES
- Misura limitata da sistematiche, importante tenerle sotto controllo!



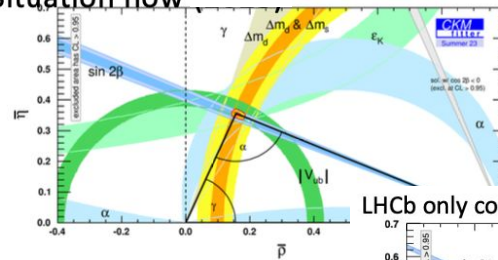
Analisi cominciata da poco, idealmente da finire entro l'anno

LHCb Upgrade II

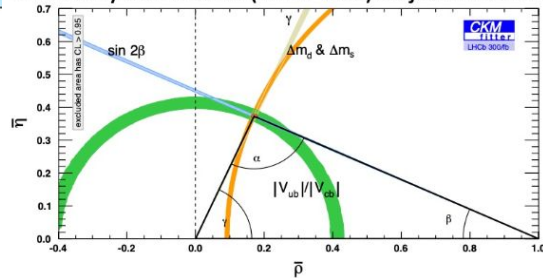
- During LS4: (2033 – 2034) 2035, a major upgrade (HL-LHC, Lumi $\sim 150 \cdot 10^{32}$);
- Motivation
 - UNIQUE PHYSICS programme with BSM discovery potential
 - Unprecedented sensitivity for B and D physics
 - Broad (general purpose) programme
 - Unique forward acceptance
 - Spectroscopy, EW precision 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

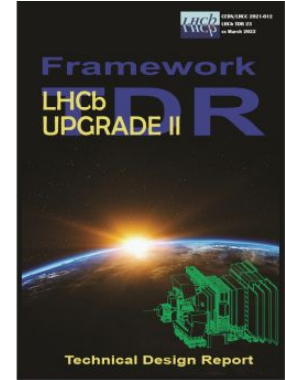
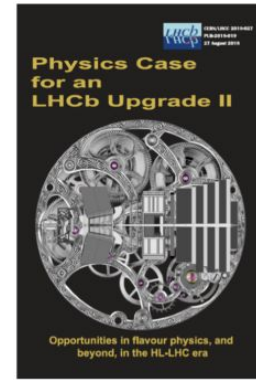


LHCb only constraints (CKMFitter) Projected 300 fb



LHCb Upgrade II

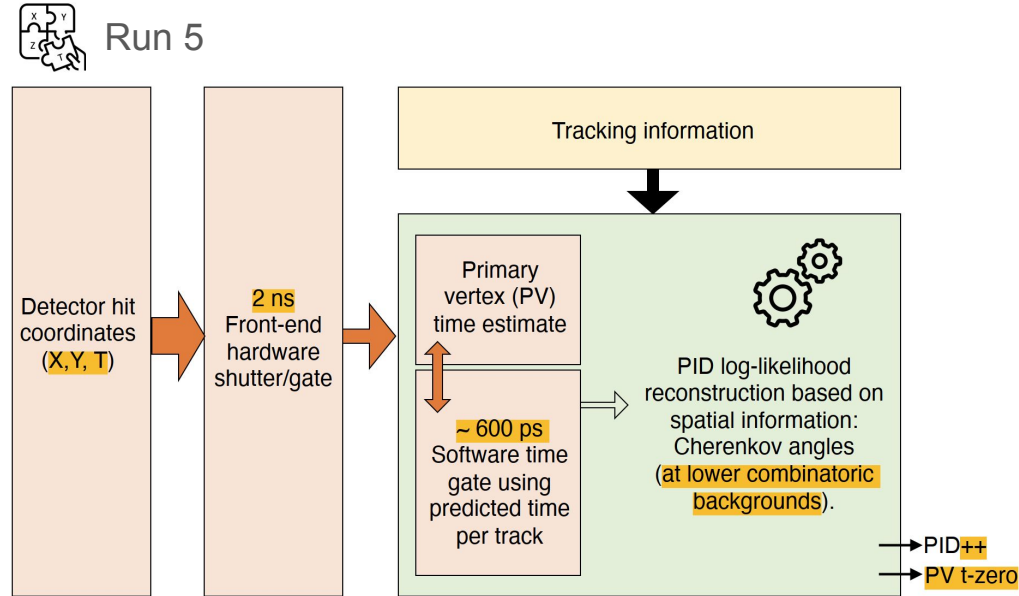
- 2017: Expression of interest
- 2018: Physics case
- 2022: Framework Technical design report
- 2021-2025: Initial R&D phase
- 2025: Scoping TDR
 - Costo significativo + disponibilità risorse
-> in discussione diversi scenari per ridurre i costi con minor impatto possibile sulle performance di fisica
 - sottomesso a fine 2024
 - 3 scenari di luminosità
- 2026: Technical design reports
- 2029-2033: (R&D+) Production phase
- 2035: LHCb Upgrade II / Start of Run 5



- RICH Upgrade II in breve
 - Front end electronics: riutilizzo del fast RICH da LS3Enhancements
 - Nuovi Sensori rad hard
 - Criostato o Cooling -80
 - Nuovo sistema termomeccanico
 - Nuova geometria degli specchi

LHCb RICH Upgrade II: Elettronica

- Re-use FastRICH time resolved electronics, time gating to $\sim 600\text{ps}$
- Change photon detectors to **improve time resolution**
 - **Use of time information in reconstruction**
 - **Reconstructed time resolution $< 100\text{ps}$**
- Improve **Optics** and **segmentation** to reduce **occupancy**

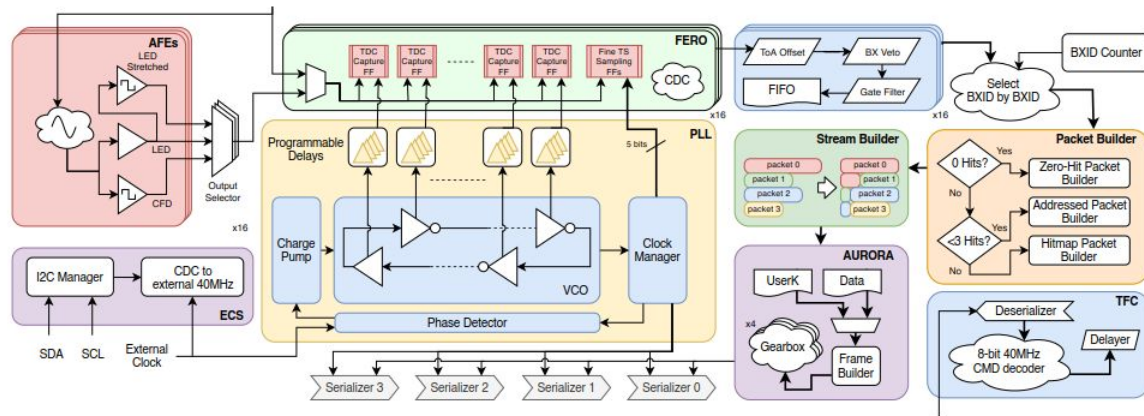


The FastRICH ASIC

Stato del Nuovo ASIC

The FastRICH ASIC is being designed in **65-nm CMOS** by the **CERN EP-ESE department** and the **University of Barcelona** with strong input in the specifications from our group and the LHCb RICH collaboration.

- **16-channel** design.
- Integrated TDC with **25 ps** bins.
- Constant Fraction Discrimination (**CFD**).
- Input signal dynamic range **30 μ A - 2 mA** for coupling MAPMT / SiPM / MCP sensors.
- Radiation hardness using **triplication**.
- **Compressed** data-driven format (40 MHz) and configurable output serialisers.
- Close integration with **IpGBT**.



More information on <https://fastrich.docs.cern.ch>

Il nuovo ASIC e' stato prodotto, ricevuto al CERN, e una intensa campagna di caratterizzazione e' in corso. Coinvolgimento Padovano

- S. Paniskaki (PhD): Caratterizzazione ASIC,
- F. Borgato (Post Doc): test su fascio ASIC + sensori

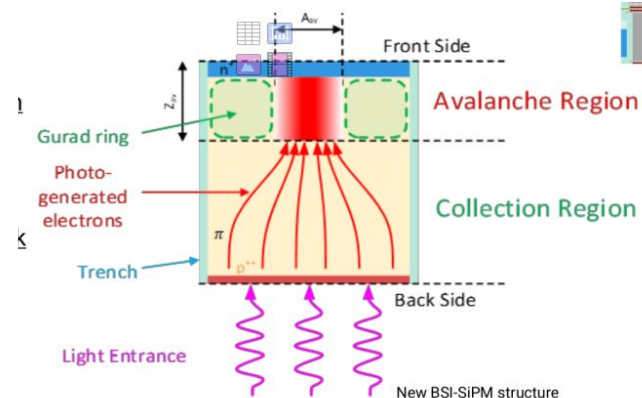
LHCb Upgrade II: sensori

Requirements:

- sensibilità singolo fotone
- risoluzione angolo Cherenkov 0.4/0.2 mrad (RICH1/RICH2)
- numero di fotoni rivelati $\sim 40/30$ (RICH1/RICH2)
- Alti rate (10Mhz/mm², bunch crossing 25ns)
- Alta granularità (1mm²) per mantenere bassa la occupancy
- risoluzione temporale $< 100\text{ps}$ per fotoni singoli
- Occupancy di dark rate $< 1/1000$
- Rad hard: 2Mrad TID, 3×10^{13} 1MeV neq/cm², 1×10^{13} HEH/cm²

R&D @ Padova

- Sviluppo con FBK di sensori SiPM illuminati da backside, sinergia con IBIS_NEXT in CSN5: tempistica molto stretta
- Sviluppo di SiPM low dark count con Hamamatsu

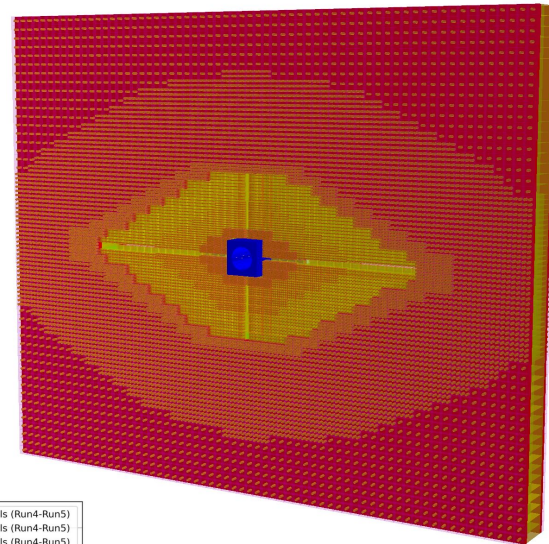


Upgrade 2 a Padova: ECAL

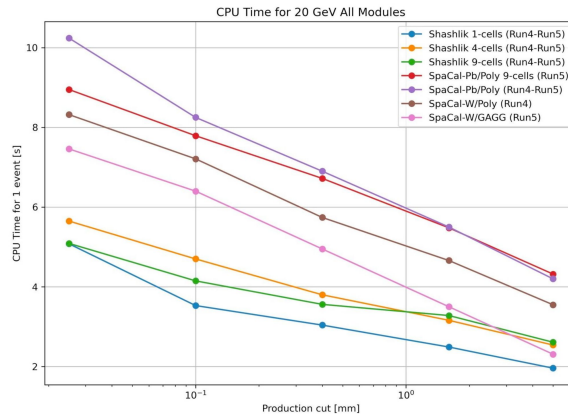
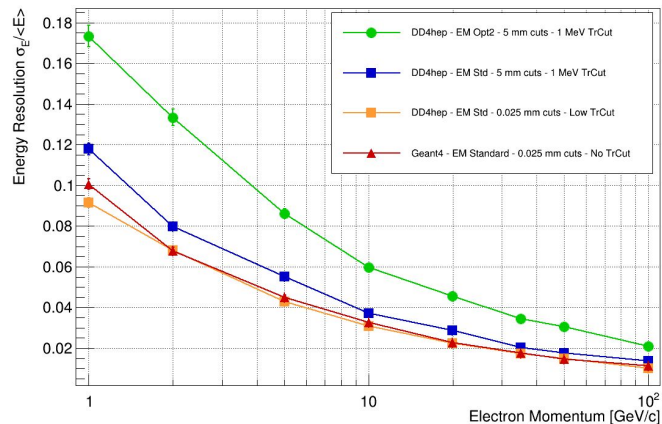
P. Andreetto, A. Gianelle, D. Zuliani



- Importante effort da parte del gruppo sul software di simulazione per l'upgrade di ECAL
- In particolare, si è lavorato all'implementazione della geometria
- Attualmente:
 - preparazione del software di simulazione per Run 4 e Run 5
 - studi di ottimizzazione per ridurre CPU time e mantenere efficienza
- In futuro:
 - implementazione della digitalizzazione (con aggiunta di info temporale)



SpaCal PbPoly



LHCb Padova: anagrafica

Anagrafica 2026

Le percentuali degli FTE in progetti sinergici a LHCb sono contate in "altro", riportate in "note" e incluse nella quota totale FTE

Sezione	Cognome	Nome	Ricercatore	Tecnologo	MOF A	Autore	FTE Ricercatori			FTE Tecnologi			Persone	FTE/Pers.	Job	Qualifica
							LHCb	Altro	Totale	LHCb	Altro	Totale				
	Andreotto	Paolo	0	1	0	0				25		25			tecn	Tecn
	Benettoni	Massimo	0	1	0	0				10		10			tecn	I Tecn
	Bertolin	Alessandro	1	0	1	1	70		70						staff	Ric
	Borgato	Federica	1	0	1	1	80		80						pdoc	Ass Ric
	Collazuol	Gianmaria	1	0	0	0	0		0						staff	PA
	Gianelle	Alessio	0	1	0	0				30	5	35			tecn	Tecn
	Han	Qundong	1	0	1	1	70	0	70						pdoc	Ass Ric
	Lucchesi	Donatella	1	0	1	1	50		50						staff	PO
	Lupato	Anna	1	0	1	1	70		70						staff	RTDB
	Paniskaki	Styliani	1	0	1	1	100		100						dott	Dott
	Simi	Gabriele	1	0	1	1	70		70						staff	PA
	Zuliani	Davide	1	0	1	1	70		70						pdoc	Ass Ric
PD			9	3	8	8	5.80	0.00	5.80	0.65	0.05	0.70	12	0.54		

LHCb Padova: responsabilità

A. Bertolin: Data Processing and Analysis Work Package 1 (Spruce) coordinator

D. Zuliani: sub-convenor del trigger, online processing and jets del gruppo di fisica QEE (jets and electroweak)

G. Simi: RICH General Quality Assurance for LS3 Enhancement

LHCb Padova: richieste

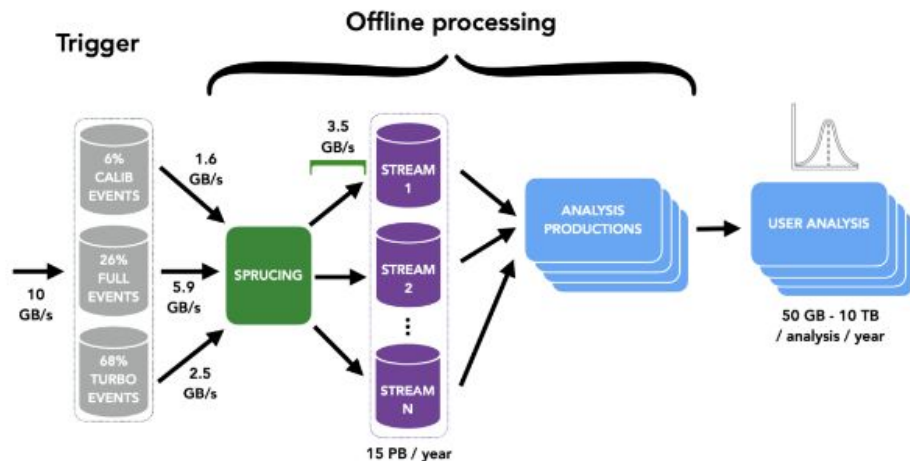
richieste finanziarie:

- missioni: secondo le formule standard
- materiale per RICH U1 / Run 3
 - 7 keuro per la costruzione di un mockup meccanico del sistema di calibrazione con fibra ottica e scattering Rayleigh
- materiale per RICH U2
 - 150k per infrastruttura termomeccanica delle colonne di RICH2
- materiale per PicoCal U2:
 - 100k CHF per acquisto fibre scintillanti (ordine fatto dal CERN in ottobre)

richieste servizi sezione di Padova:

- progettazione meccanica: **2 m.p.** x RICH Upgrade
- officina meccanica: **2 m.p.** x RICH Upgrade
- Servizio tecnici generali (Nicoletto): **1 m.p.** x RICH Upgrade

Coinvolgimento Padovano nel Run 3: Sprucing



The LHCb Sprucing and Analysis Productions

Ahmed Abdelmotteleb¹, Alessandro Bertolin², Chris Burr³, Ben Couturier³, Ellinor Eckstein⁴, Davide Fazzini⁵, Nathan Grieser⁶, Christophe Haen³, Ryunosuke O'Neil³, Eduardo Rodrigues⁷, Nicole Skidmore¹, Mark Smith⁸, Aidan R. Wiederhold⁹, Shunan Zhang¹⁰.

¹Department of Physics, University of Warwick, Coventry, United Kingdom,

²INFN Sezione di Padova, Padova, Italy,

³European Organization for Nuclear Research (CERN), Geneva, Switzerland,

⁴Universität Bonn - Helmholtz-Institut für Strahlen und Kernphysik, Bonn, Germany,

⁵INFN Sezione di Milano-Bicocca, Milano, Italy, ⁶University of Cincinnati, Cincinnati, USA,

⁷Oliver Lodge Laboratory, University of Liverpool, Liverpool, United Kingdom,

⁸Imperial College London, London, United Kingdom,

⁹Department of Physics and Astronomy, University of Manchester, Manchester, United Kingdom,

¹⁰Department of Physics, University of Oxford, Oxford, United Kingdom,

<https://arxiv.org/abs/2506.20309>

submitted to:

Computing and Software for Big Science

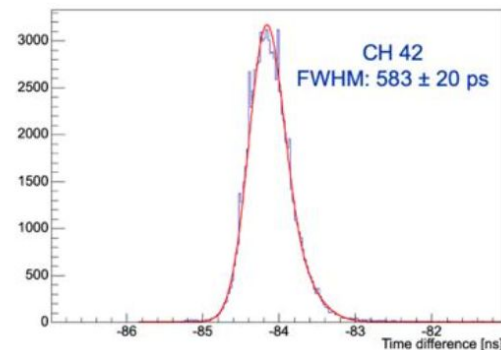
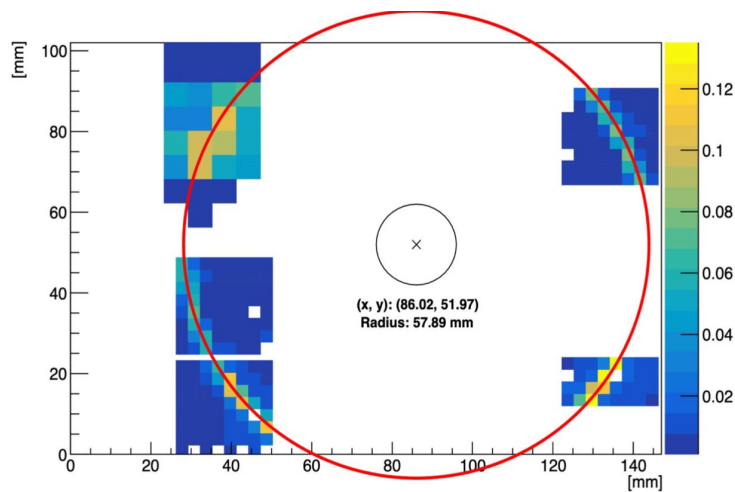
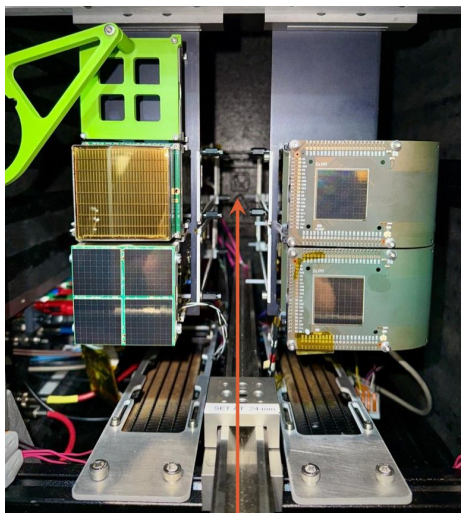
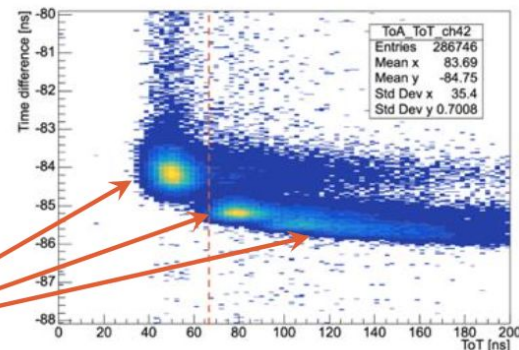
A. Bertolin: Data Processing and Analysis Work Package 1 (**== SPRUCING**) coordinator

Coinvolgimento Padovano per i Long Shutdown 3 Enhancements del RICH

Testbeam a CERN@SPS per testare la risoluzione temporale delle varie opzioni di sensori per LHCb Upgrade 2 (**F. Borgato, G. Simi, S. Paniskaki**):

- Sensori utilizzati: SiPMs, LAPPD
- Sensori accoppiati ad una catena elettronica che include FastIC e il picoTDC (bins~10ps), per ottenere informazioni tempo di arrivo dei fotoni Cherenkov.

il
sul
picchi di singolo,
doppio e triplo fotone
sui SiPM

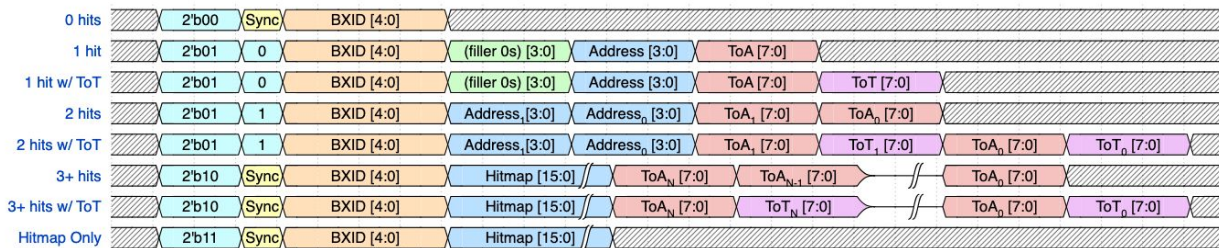
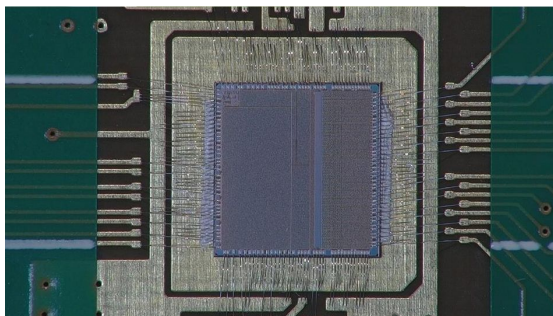


Coinvolgimento Padovano per i Long Shutdown 3 Enhancements del RICH

Caratterizzazione del FastRICH (F. Borgato, G. Simi, S. Paniskaki):

- FastRICH: ASIC progettata nell'ambito dei LS3 enhancements del RICH
- Milestone per gli LS3 enhancements
- FastRICH permette di essere accoppiato a vari sensori (come foto-moltiplicatori multi anodo e SiPM) e estrarne l'informazione temporale con grande precisione grazie al TDC integrato con bin di 25 ps.
- A maggio 2025 è arrivato il primo batch di FastRICH e i risultati preliminari sono molto promettenti.

FastRICH ASIC wire-bonded on PCB:



2025 LHCb Thesis awardees



Federica Borgato (Università di Padova)

Advisors: G.Simi, A.Lupato

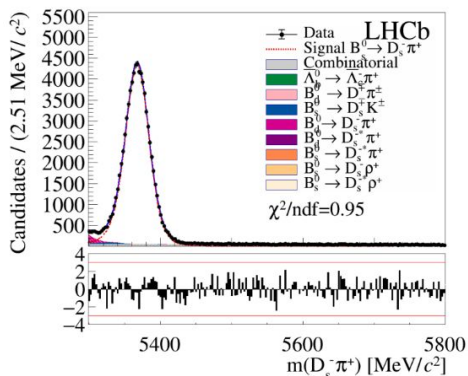
“LHCb RICH and VELO upgrade studies and measurement of the ratio of branching fractions $B(\Lambda_b^0 \rightarrow \Lambda_c(2625,2595)^\pm D_s^{()\mp}) / B(\Lambda_b^0 \rightarrow \Lambda_c^\pm D_s^{(*)\mp})$ ”*

The committee acknowledges her numerous and important contributions to the upgrade and the commissioning of the RICH photo-detector, the evaluation of the potential of a new RICH read-electronics using fast-timing and the characterization of an innovative trenched 3D pixel sensor for the VELO upgrade, together with the first measurement of the branching ratio of Λ_b^0 decays into $\Lambda_c^{*\pm} D_s^{(*)\mp}$.

Analisi Padovane: B2OC (b to open charm)

- Dati 2024 ([A. Bertolin](#))

- misura del rapporto di funzioni di frammentazione in funzione di PT ed ETA per adroni con beauty, Lambda_b e B_d
- una misura di oscillazione di mesoni con beauty (B_s) che necessita di Flavour Tagging

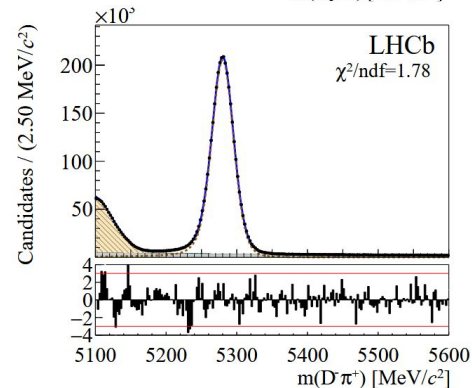
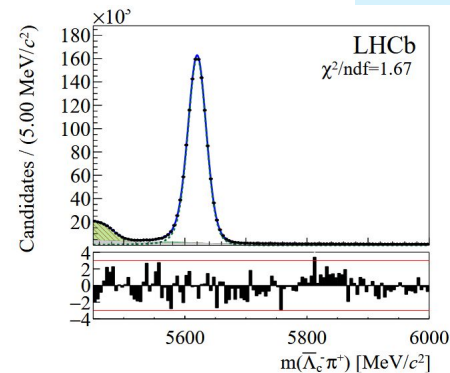


si riescono ad ottenere segnali molto puliti malgrado la luminosità' istantanea record

- entrambe da pubblicare su rivista sperabilmente entro l'anno solare 2025

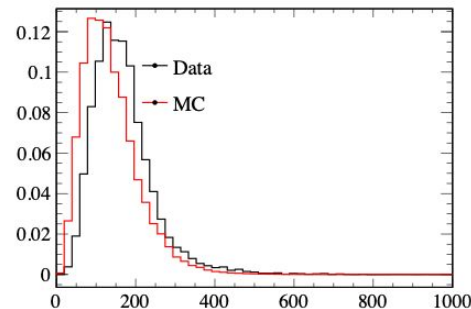
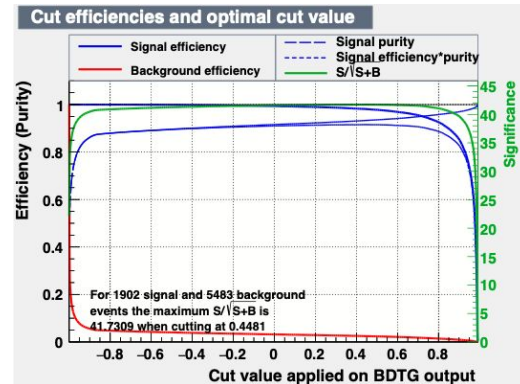
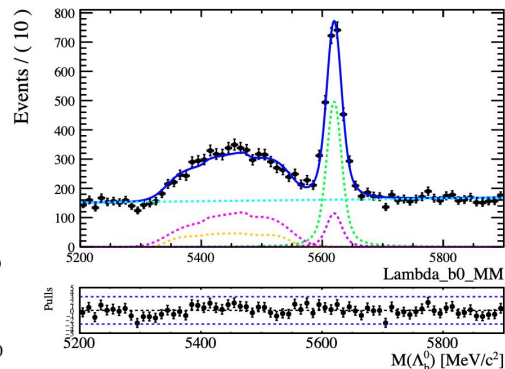
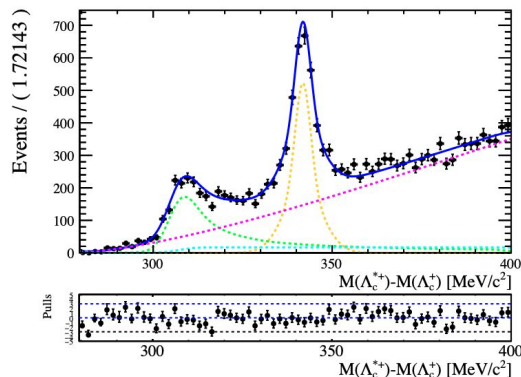
- Altre analisi in corso con i dati del Run 2:

- CP asymmetry from $B \rightarrow D \pi$ ([A. Lupato](#) et al)

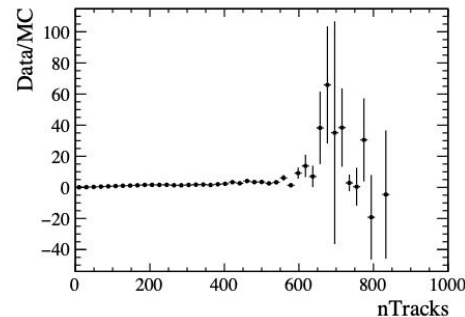


Misura di $\frac{BR(\Lambda_b^0 \rightarrow \Lambda_c^{*+} D_s^{(*)-})}{BR(\Lambda_b^0 \rightarrow \Lambda_c^+ D_s^{(*)-})}$

- **Tesi di dottorato di Federica Borgato**
- **Analisi: Osservazione e Misura del**
 - Prima osservazione del decadimento
 - Principale fondo per $R(\Lambda_c^*)$
 - Persone Coinvolte: **F. Borgato, A. Lupato, G. Simi**
 - analisi prossima all'entrata in wg review
 - **goal: conferenze invernali**



Prima della correzione



Dopo la correzione

Analisi Padovane: Decadimenti semileptonici



F. Borgato, A. Lupato, G. Simi

- Per la misura dell'universalità leptonica nei b-barioni Λ_b con i dati del Run 2 è necessario ridurre l'errore sistematico (A. Lupato, G. Simi LHCb-ANA-2018-026) dominato da

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

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

- **Analisi: Fattori di Forma**

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

- **Analisi: Analisi Angolare di $\Lambda_b^0 \rightarrow \Lambda_c \mu^- \bar{\nu}_\mu$**

- Misura dei coefficienti di Wilson e delle variabili sensibili a NP
- Analisi completata, in review
- Timescale: conferenze autunnali
- Persone coinvolte: **A. Lupato**

- **Analisi: Branching Ratio Ratios**

- $B_1 = B(\Lambda_b \rightarrow \Lambda_c (2565) \mu \nu) \cdot B(\Lambda_c (2595) \rightarrow \Lambda_c \pi^+ \pi^-)$
- $B_2 = B(\Lambda_b \rightarrow \Lambda_c (2625) \mu \nu) \cdot B(\Lambda_c (2625) \rightarrow \Lambda_c \pi^+ \pi^-)$
- Persone coinvolte: **A. Lupato, G. Simi**



MUONE

E. Conti

Activity 2025: beam tests

- **MiniMUONE** proposal approved by SPSC.
Assigned ~2 months total beam time (June-July 2025) in M2 beamline as main user
- All MUONE activities in 2025 were finalized to that important run.

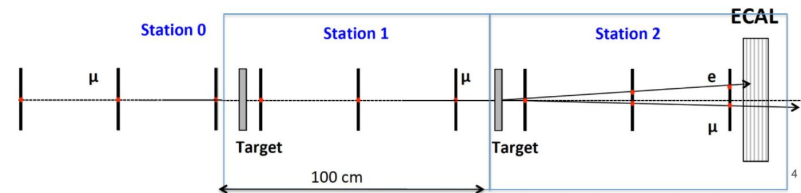


Fig. 4: (Not to scale) A schematic of three tracking stations, the configuration which will be used in the 2025 running (there will be 40 such stations in the final apparatus). As explained in the text, in each station the position measurement utilises two sensor layers, so there are 12 sensor layers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

- For ECAL (Padova):
 - improvement of FC7 firmware with lower latency
 - measurement of ECAL latency
 - intervention of ECAL to improve APD optical coupling
- Data taking in M2 beamline now in progress, till end of July. Maybe short extension in August (TBC).
Anyhow, run in parasitic mode w/o ECAL possible till end of beam activities.
Dismounting in late November

- P. Ronchese
 - 1 triennale, in laurea autunno
- F. Simonetto
 - 3 triennali , laurea in 2024
 - 1 magistrale, end 2025
 - 1 introduction to research activities, 2025

- MUONE collaboration:
Data analysis of MiniMUONE data 2025
 - goal: $\Delta\alpha_{\text{lep}}$ to $\sim 0.2\%$ precision
 $\Delta\alpha_{\text{had}}$ with $O(20\%)$ precision
- Assessment of Tracker and ECAL joint system
Evaluating possible new tracker devices
- Padova:
data analysis of MiniMUONE data 2025;
Evaluation of final ECAL design: size, energy resolution, timing properties;
 - resources, costs
- Possible test beam in summer 2026 for ECAL studies:
 - with $g-2$ crystals (PbF₂)? APD + SiPM readout ? new FE electronics?

Name	% 2026
Conti	100
Mastrolia	10
Montecassiano	50
Passera	10
Ronchese	30
Simonetto	30
Lusiani	10
Rossin	20
TOTALE FTE	2.6

(2.4 FTE in 2025)

Risorse sezione:

Uff. tecn. = 1 mese/uomo

Off. Mecc. = 1 mese/uomo

Off. Elett. = 1 mese/uomo

per sviluppo prototipo per test su fascio

Richieste finanziarie:

Missioni: 2 settimane x 3 persone @CERN per test beam + riunione di collab □ 15 kEu

Consumo/computing: 7 kEu

Twocryst - Aladdin

G. Simi - Università di Padova & INFN

for the Padova group (M. Benettoni, F. Borgato, A. Lupato, C. Maccani, J. Pazzini, A. Triossi, G. Simi, M. Zanetti)

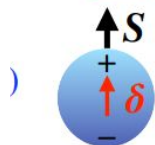


Obiettivi di fisica: MDM e EDM

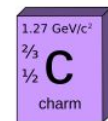
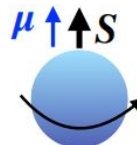
- Misura **preliminare** (Twocryst) per un **esperimento** (Aladdin) dedicato alla misura del momento di **dipolo elettrico (EDM)** e **magnetico (MDM)** di barioni charmati Ξ_c^+ e Λ_c^+ . **Prima misura sperimentale.**
 - Semplice modello a quark legati prevede **MDM** $= \mu_c$
 - Previsioni per MDM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

δ = electric dipole moment (EDM)
 μ = magnetic dipole moment (MDM)

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



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



Hamiltonian

$$H = -\mu \cdot B - \delta \cdot E$$

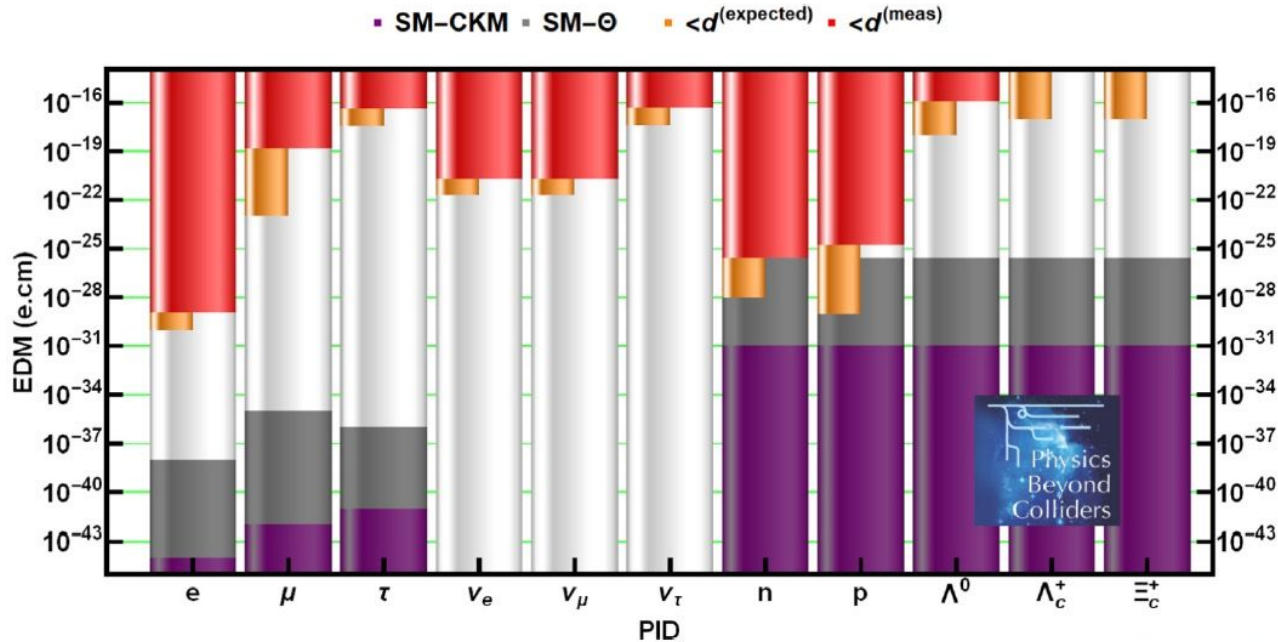
Time reversal, Parity:

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

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

Stato dell'arte

Non esistono misure dirette del dipolo elettrico dei barioni a causa della breve vita media



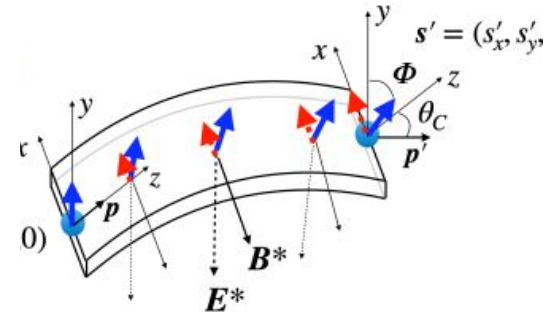
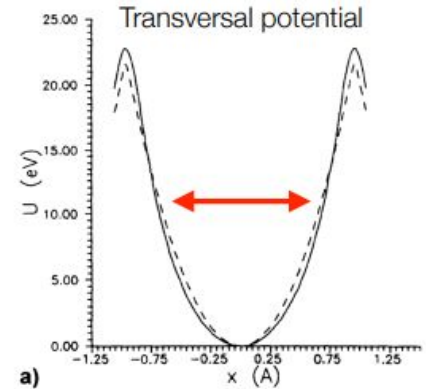
Tecnica sperimentale: precessione in cristallo curvo

- 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
- Particelle cariche con momento parallelo al piano del cristallo (entro qualche microrad) possono rimanere intrappolate
 - Campo elettrico $E \sim 1$ GV/m
 - Campo magnetico efficace $B \sim 500$ T

Il campo elettro-magnetico

- guida le particelle ad un certo angolo
- Induce la precessione dello spin su piccole distanze

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

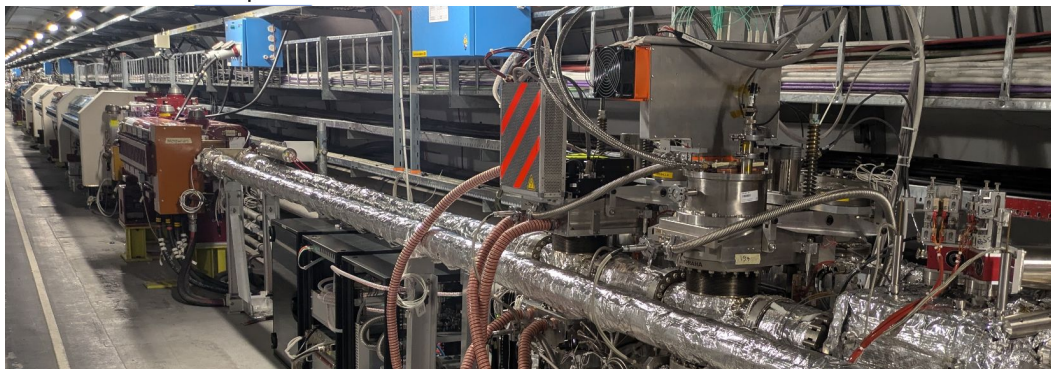
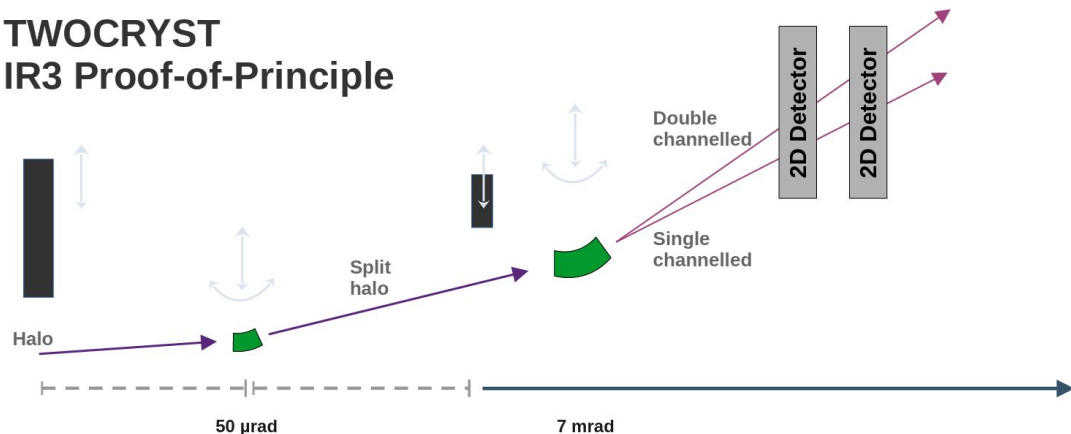


Misura preliminare: estrazione del fascio di LHC con 2 cristalli curvi $\Rightarrow$ sigla Twocryst 2024-2025

Obiettivo: prova di principio dell'estrazione con due cristalli

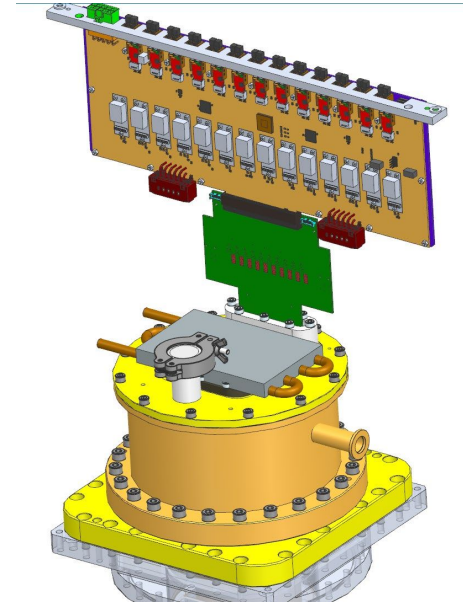
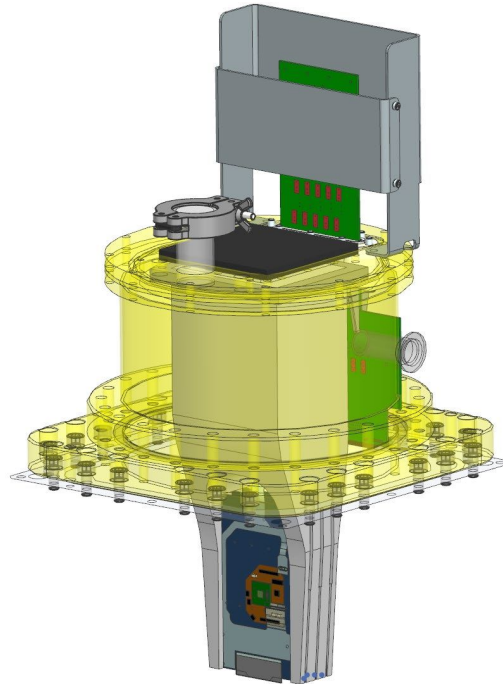
- Dimostrare la fattibilità delle operazioni di LHC a 7 TeV
 - Confermare il rate di protoni realizzabile
 - Misurare l'efficienza di estrazione a energie del TeV
 - Studiare i fondi
-
- Installato con successo nel 2025: Roman-pots con due tracciatori , due cristalli curvi, bersaglio di tungsteno

TWOCRIST IR3 Proof-of-Principle



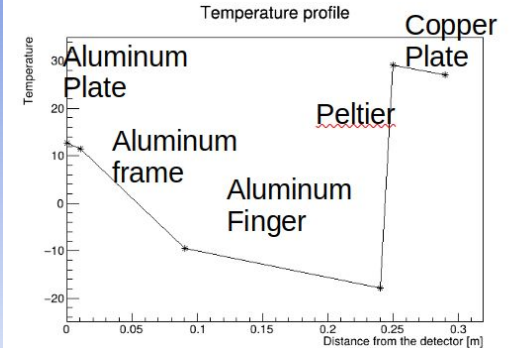
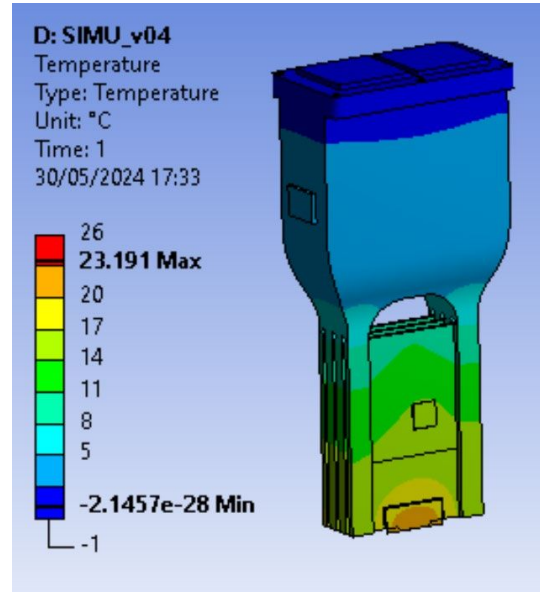
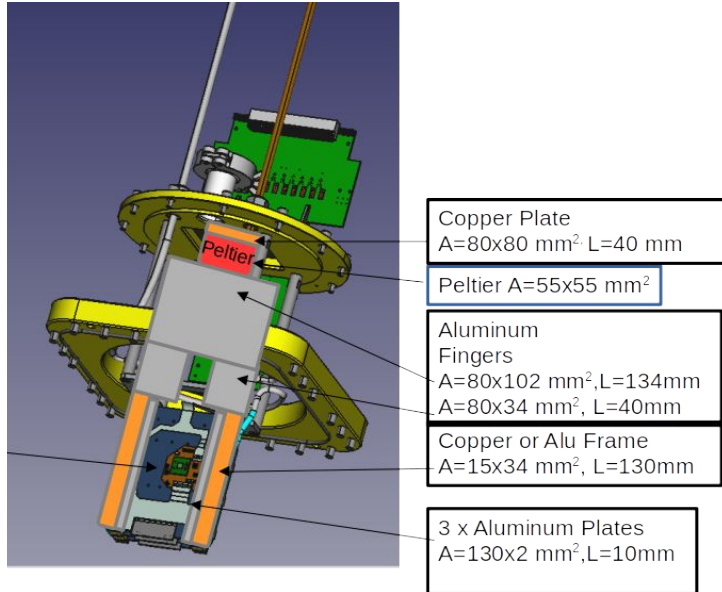
Twocryst attività a Padova '24-'25: VELO Pixel Tracker

- Integrazione Meccanica del rivelatore nelle Roman Pots
 - basate su design di Totem, rivelatore in vuoto secondario



Twocryst attività a Padova '24-'25: VELO Pixel Tracker

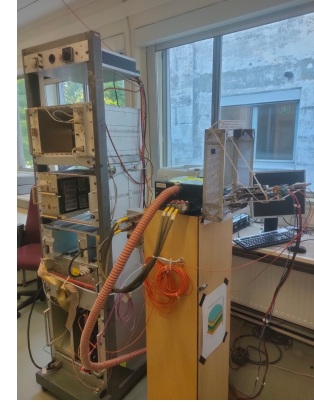
- Integrazione Meccanica del rivelatore nelle Roman Pots
 - basate su design di Totem, rivelatore in vuoto secondario
- Sistema di Raffreddamento: 45W, temperatura rivelatore 20C



Twocryst attività a Padova '24-'25: fiber tracker e validazione cristallo

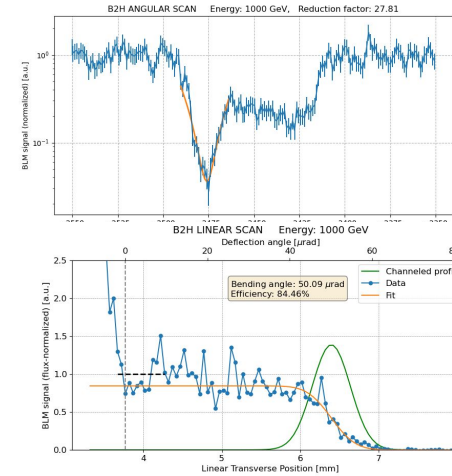
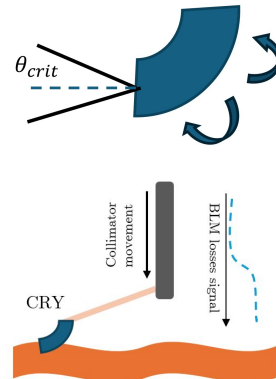
Fiber Tracker

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



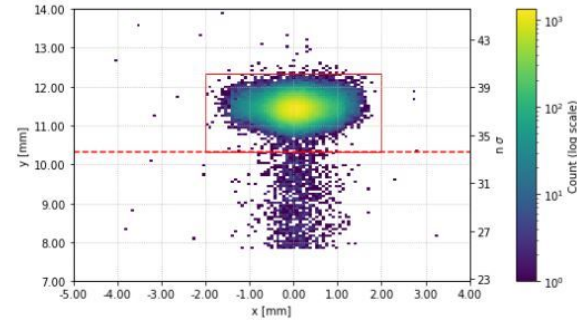
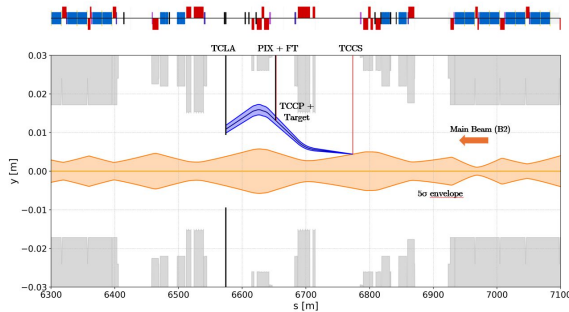
Validazione cristallo a LHC

- Scan angolare
- Scan Lineare

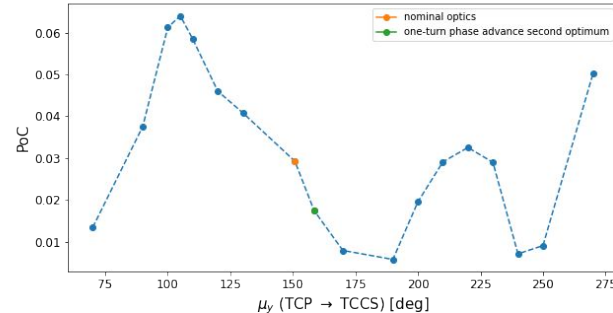
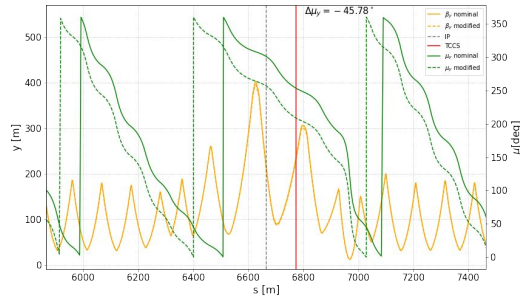


Attività a Padova '24-'25: MD Program e Simulazioni

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



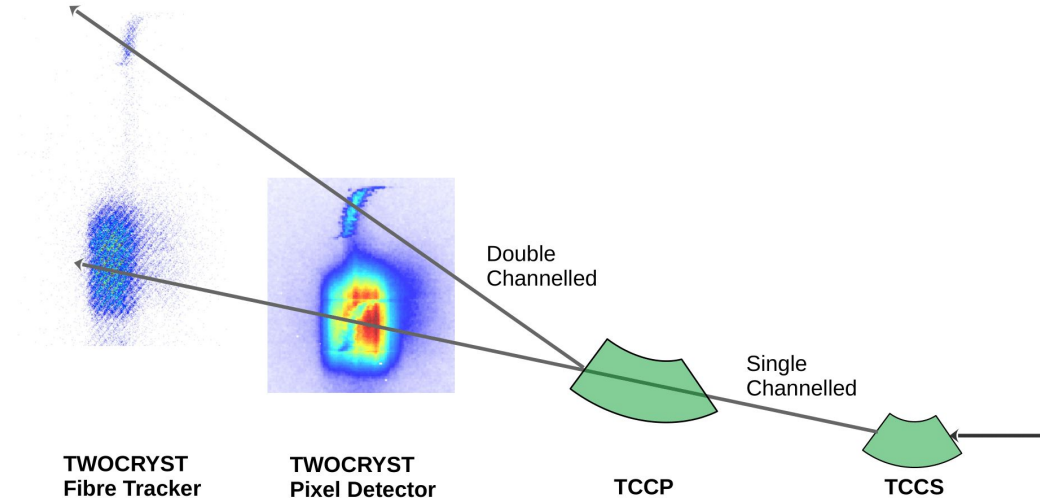
- Optics studies to optimize proton on crystal (PoC) and proton on target (PoT)



Primi risultati: test con fascio durante il MD 2025

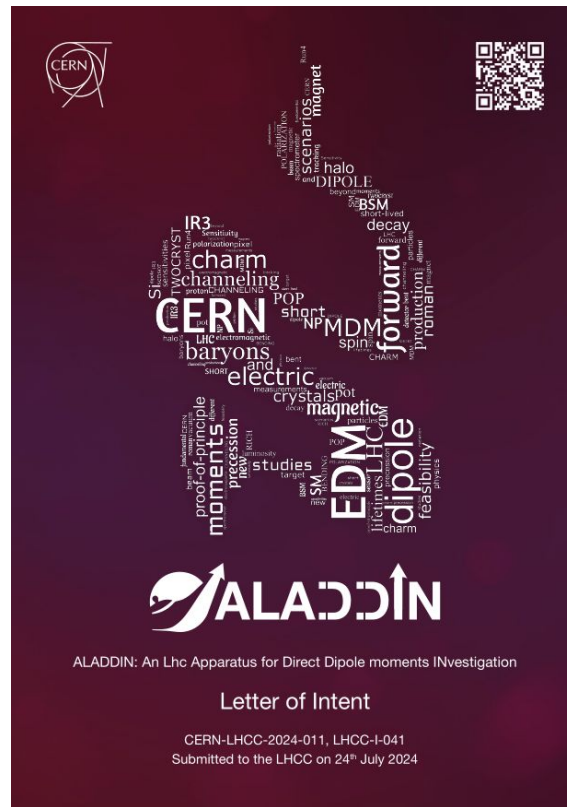
Prima osservazione del channelling con due cristalli in LHC

- Test operazioni di LHC positivo
 - Allineamento e misura efficienza di entrambi i cristalli
 - Tracking particelle con VELO Pixel
- Pixel



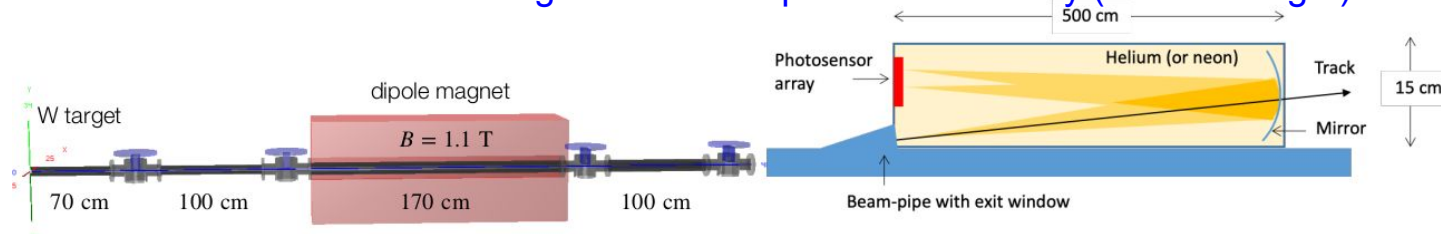
Futuro: esperimento Aladdin (An LHC Apparatus for Direct Dipole Moment INvestigation)

- LOI scritto e sottomesso a LHCC
 - **LHCC: procedere con scrittura di technical proposal entro 2025**
 - **Menzionato al simposio per l'update dell'ESPP**
- Proto collaborazione formata, eletti CB chair, spokesperson e phys-coordinator
- Esperimento con 10^{13} PoT
- Physics reach: First measurements of charm baryon dipole moments in 2 years data taking assuming 10^6 p/s
 - Sensitività su $MDM=2 \cdot 10^{-2} \mu_N$, su $EDM=3 \cdot 10^{-16} \text{ e cm}$ con $1.4 \cdot 10^{13}$ PoT
 - Exploration of τ (tau) 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 $\eta > 5^\circ$



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

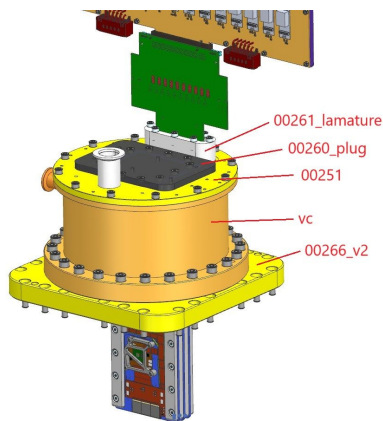
- Formata proto-collaborazione per misura di MDM e EDM
- LOI sottomesso a LHCC: raccomandato proseguire con un TDR entro la fine del 2025
- Zona sperimentale di twocryst (IR3) adatta per l'esperimento
 - Spectrometer: pixel detectors in 4 Roman Pot stations (440 cm length)
 - RICH: Helium radiator gas with SiPM photosensor array (500 cm length)



- Tracker: Risoluzione $Dp/p=2\%$ @ 500GeV, $\sigma_{\theta}=10\mu\text{rad}$, $\sigma_{xy}=20\mu\text{m}$
- RICH: $\sigma_{\theta} = 42 \mu\text{rad}$

R&D per Aladdin

- Nuova meccanica e cooling per VELOPIX
 - VELOPIX tracker con tre layers di pixels
 - Re-design del sistema di raffreddamento compatibilità con TOTEM Roman pot system
 - Multistage Peltier
 - CO₂ cooling (ispirato al raffreddamento in LHCb)



M. Benettoni

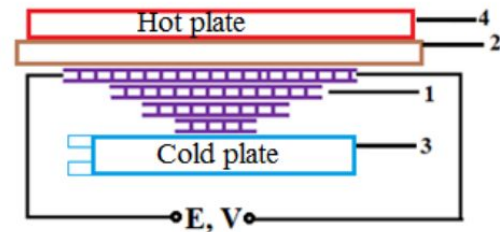
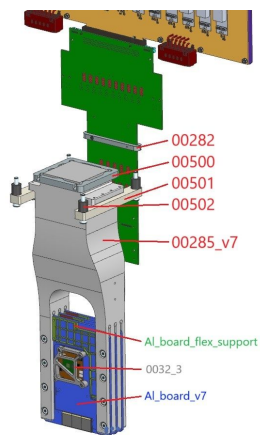
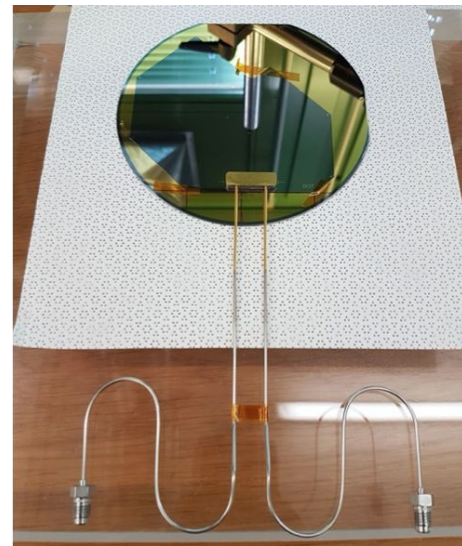


Fig. 2. Schematic diagram of the experimental layout.

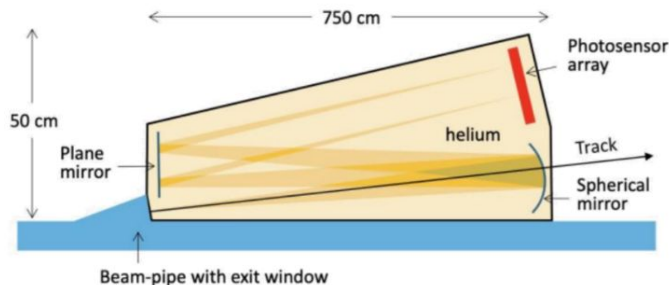


R&D per Aladdin

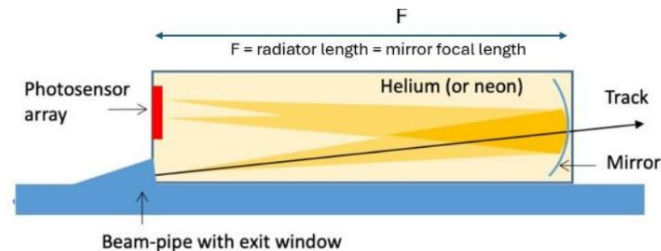
G. Simi, F. Borgato, A. Lupato,
A. Triossi, J. Pazzini

- studio di un RICH cilindrico con Neon
 - Studio del Vessel cilindrico
 - Ottimizzazione Vessel: 7.5m -12m => risoluzione ok con pixel 1mm²
 - Possibile utilizzare MCPMT o matrici di SiPM commerciali
 - 2 differenti gas (Neon, Elio)
 - Limitazioni spazio nel tunnel <(20m - spazio per servizi)
 - risoluzione 50-60 μ rad
 - [Todo] Simulazione: separazione p-pi, full sim, pattern reco, bkg simulation
 - [Todo] Elettronica di front-end: R&D Padova

Different geometries and gas options are under investigation:



a **7.5 m** radiator with **double reflection**

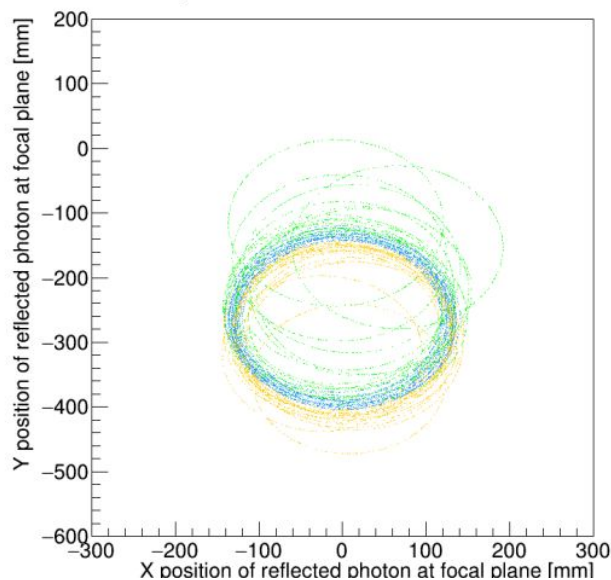


a **12 m** radiator with **single reflection**

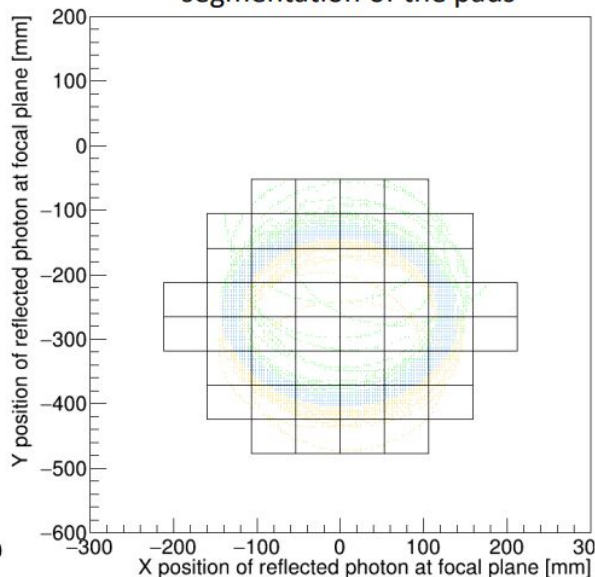
Preliminary segmentation study (I)

- Sensors array implemented but without pixels
- Preliminary study of pixel granularity ongoing using the true position of the reflected photon at the focal plane
- Two possible solutions with MCPs:
 - 16×16 channels per pad (~ 3.3 mm pitch)
 - 32×32 channels per pad (~ 1.6 mm pitch)

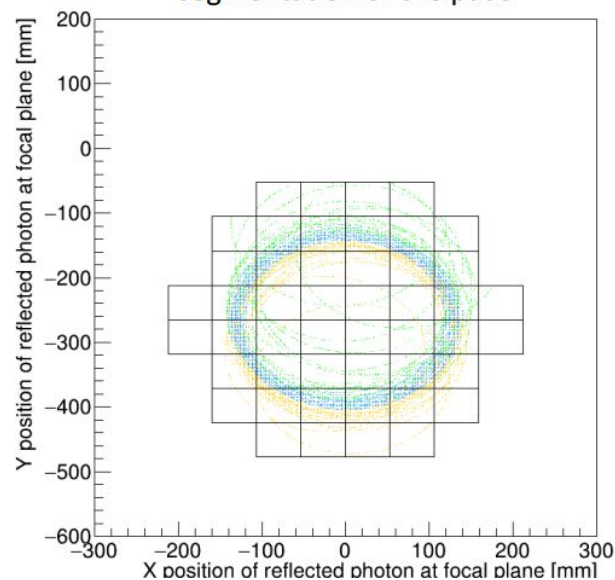
Focal plane illumination – 20 events



Focal plane illumination with 16×16 segmentation of the pads



Focal plane illumination with 32×32 segmentation of the pads



Attività in sezione/anagrafica

- Sigla
 - rimane sigla tecnica sotto dotazione fino all'approvazione dell'esperimento
- Servizi
 - finalizzazione integrazione modulo VELO nelle roman pot
 - 1 m.u. disegnatore meccanico
 - 2 m.u. officina meccanica
 - Design schede per protipo front-end
 - 2 m.u. servizi tecnici generali (Nicoletto)
- Richieste
 - Missioni
 - 1 m.u. per installazione
 - 1 m.u. per presa dati, workshop, test-beam
 - R&D VELOPIX ~ 5kE
 - cooling , meccanica
 - R&D RICH ~ 15kE
 - Acquisto FastRICH+, FPGA
 - Acquisto front-end del TORHC basata sul chip Nino,

● Anagrafica

- F. Borgato 10%
- A. Lupato 15%
- C. Maccani 100%
- J. Pazzini 15%
- G. Simi 15%
- M. Zanetti 15%
- A. Triossi 15%
- M. Benettoni 10%



RL. P. Giubilato

INFN **G**round-up **iNIT**iative for
μElectronics **d**evelopment

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

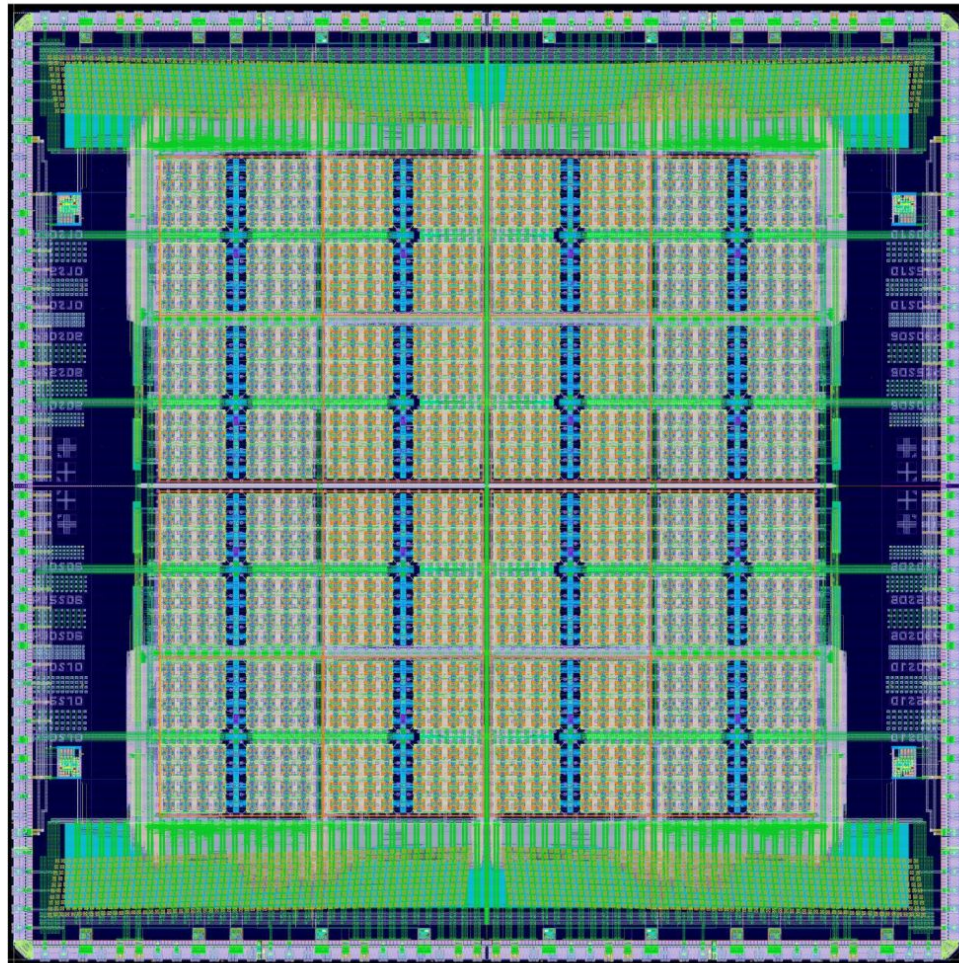
PV - Gianluca Traversi

TIFP - Philippe Velha

TO - Luca Pacher

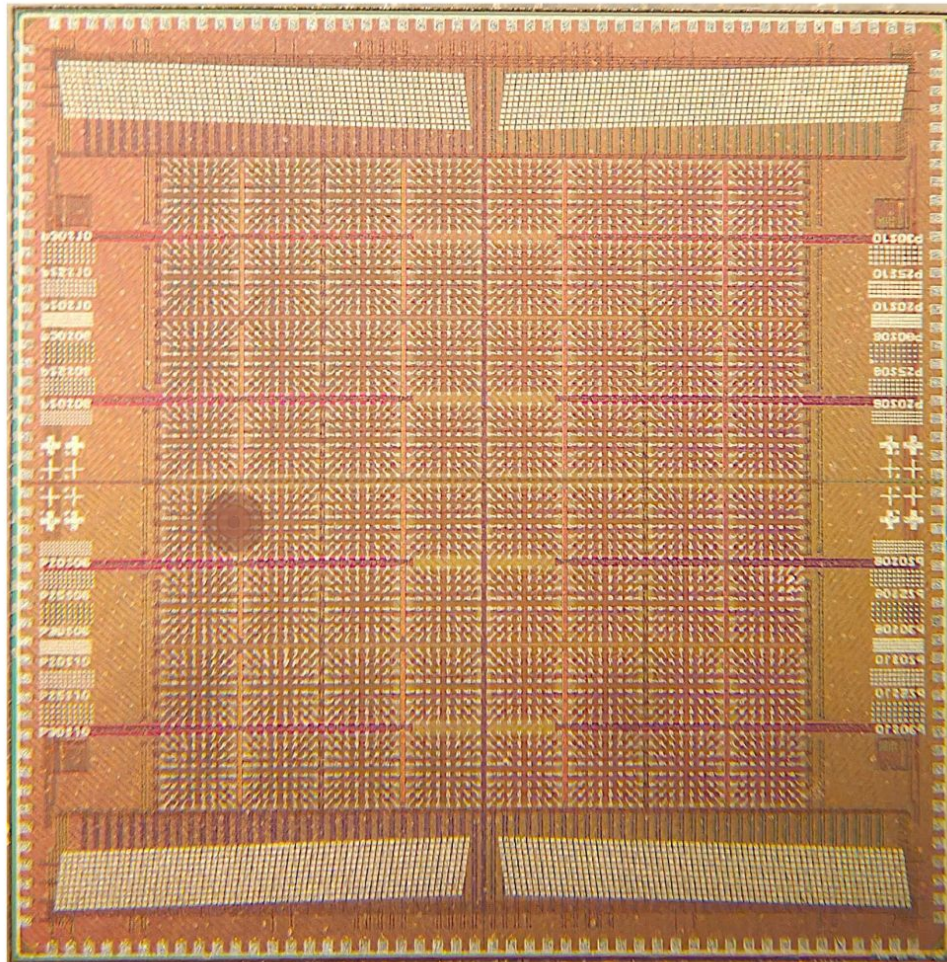
IGNITE_{μd} News 2025

- Fully functional ASIC **Ignite64**
- **5x5 mm²** (active area $\approx 3.5 \times 3.5$ mm²)
- 16 A-Blocks, 64 Mattonellas
- Purpose:
 - **front-end characterization**
 - Mattonella and A-Block (bias) test
 - Hybridization and timing sensor characterization onto AIDA-Innova sensors (FBK 3D-Trench and TI-LGAD, CNM 3D-DS columns, CNM I-LGAD)
- **Slow read-out** (4×1.28 Gbps), a lab/testbeam device
- Test of DBI structures



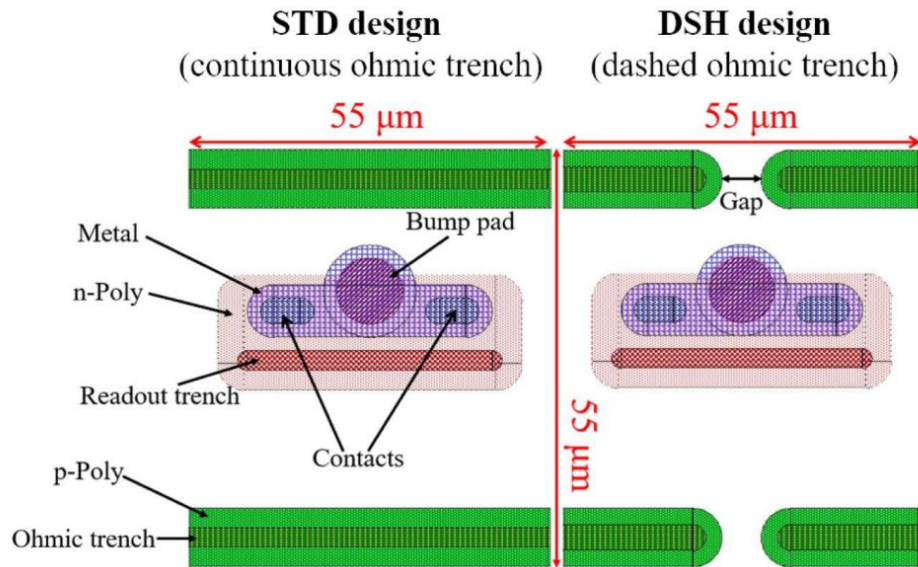
IGNITE_{pd} News 2025

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- **Slow read-out** (4×1.28 Gbps), a lab/testbeam device
- Test of DBI structures



IGNITE_{pd} News 2025

3D-trench TimeSPOT-AIDAInnova by FBK soon under test on Ignite32/64



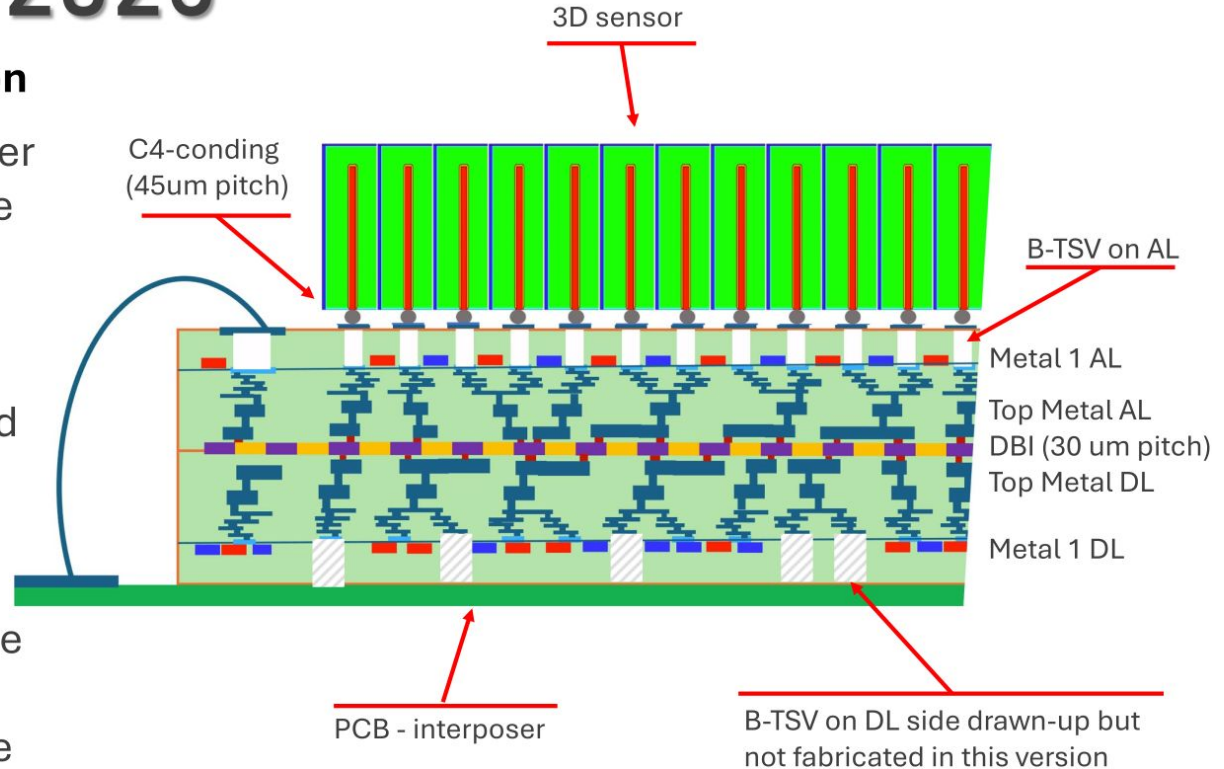
- Possible test beam at SPS in October 25
- 55 μm pitch Trench-based (à la TimeSPOT)
- 45 μm sensors being produced (ready end 2025)

IGNITE News 2025

3D heterogenous integration

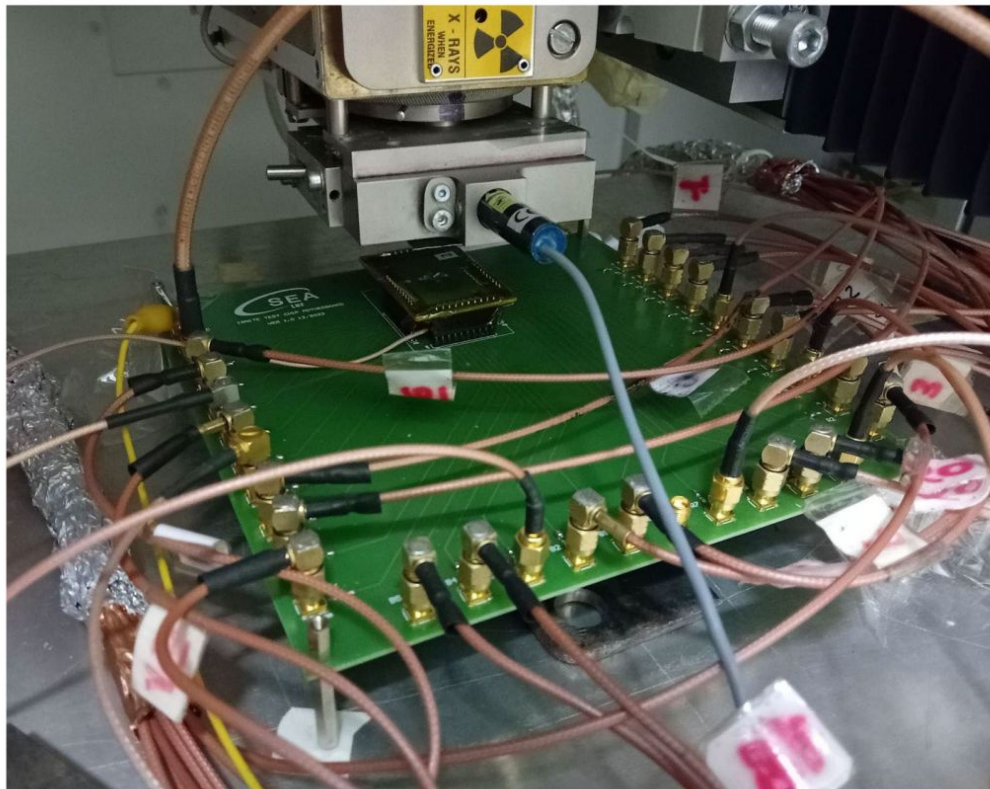
We chose this option for lower costs, shorter execution time and lower risk as well.

- The “full option”, having TSVs also on the DL back, could be possibly explored in a future version.
- The ASIC in itself is being prepared to implement such TSVs, which would be exploited for power distribution, allowing large extension of the matrix area in both directions



IGNITE_{Ed} News 2025

Experimental TID measurements in Padova



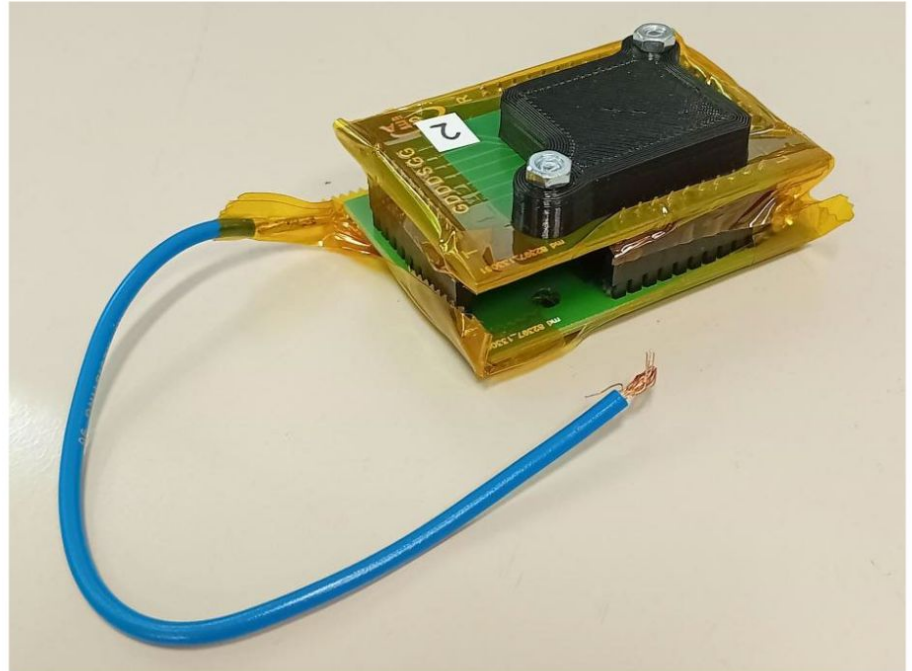
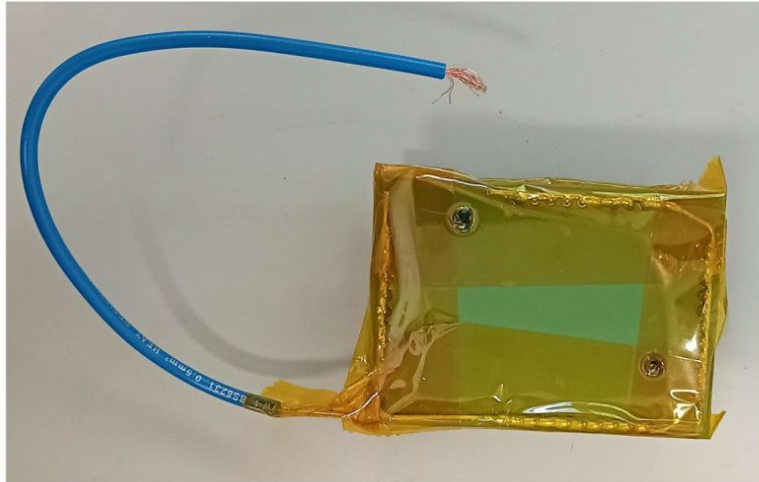
- Radiation source: 10 keV X-ray
- Dose rate: 4.3 Mrad/h
- Total dose: 500 Mrad (SiO₂)
- Required time to test one sample: ~6 days of irradiation + 2 days of annealing (24h@RT and 24h@100°C)
- Start of the tests: summer 2024
- Many problems with survival rate of pristine chips and the X-ray irradiator (now solved)
- Start of the test of new batch: May 2025

IGNITE_μ News 2025

Developments to keep the chips safe and alive

Before improvements, the survival rate was ~30% (failure rate ~70%), **now is 78%**

- Pin soldering before the chip bonding
- Pin grounding
- Transport on anti-static bags
- Covering with Kapton tape the chip pins



IGNITE Padova 2026

ANAGRAFICA (PD) 2026 → 2 FTE tot

People	FTE
Andreetta G. (PhD)	30% (new entry)
Bagatin M.	20%
Bonaldo S.	10%
Borgato F.	10%
Candelori A.	20%
Gerardin	20% (era 10%)
Giubilato P.	10%
Mattiazzo S.	10%
Paccagnella A.	15%
Vogrig D.	10%
Wyss J.	40% (era 50%)
Zingaretti A. (PhD)	15% (era 40%)

PREVENTIVI (PD) 2026

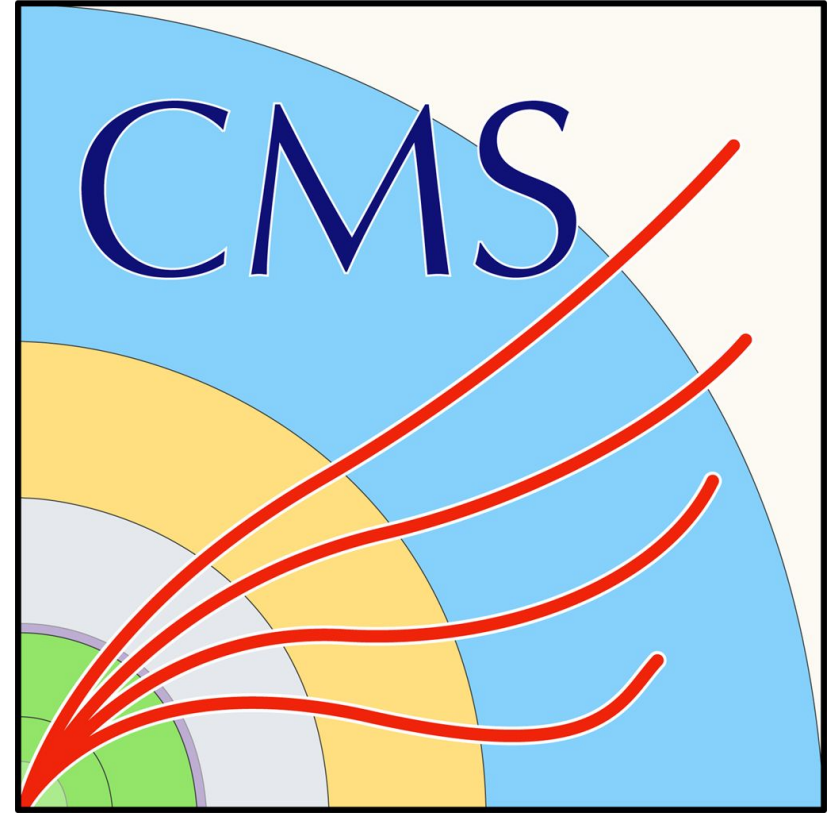
Activity	funding
X-Ray tube	4000
Methabolism	0
Missions	0

SERVIZI (PD) 2026

Activity	funding
Lab. Elettronica	1 m.u.

CMS

RL: Patrizia Azzi



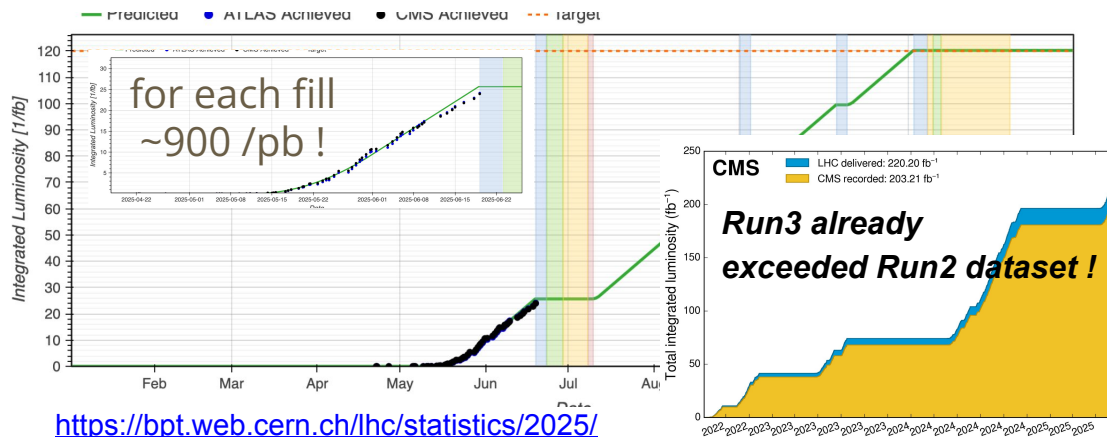
Sommario

- Highlights da CMS
- Attività a Padova
 - Detector
 - Analisi & Preparazione Run3
 - Outreach
- Anagrafica 2025 → 2026
- Responsabilità
- Richieste 2026

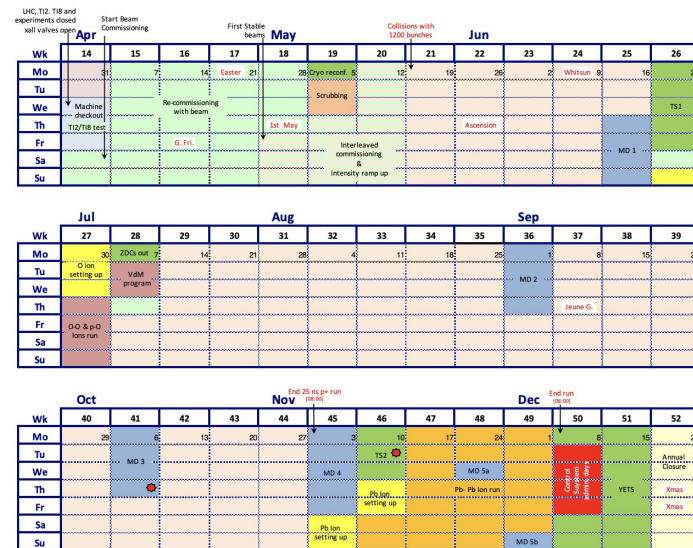
CMS operations .. so far

- “full machine” (2448b) since May-24
- LHC operations are proceeding well, slightly behind the pre MD target
 - integrated luminosity up to now: **~24.8 (23.4) /fb delivered (recorded)** ([2025 summary](#))
beam intensity is still 1.6e11 ppb till September, then up to 1.8e11 ppb in few steps

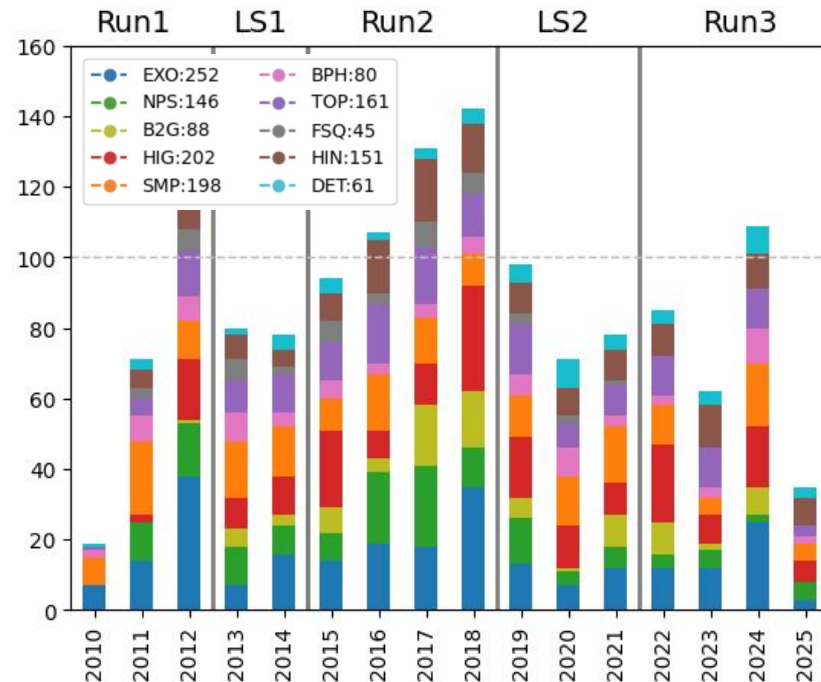
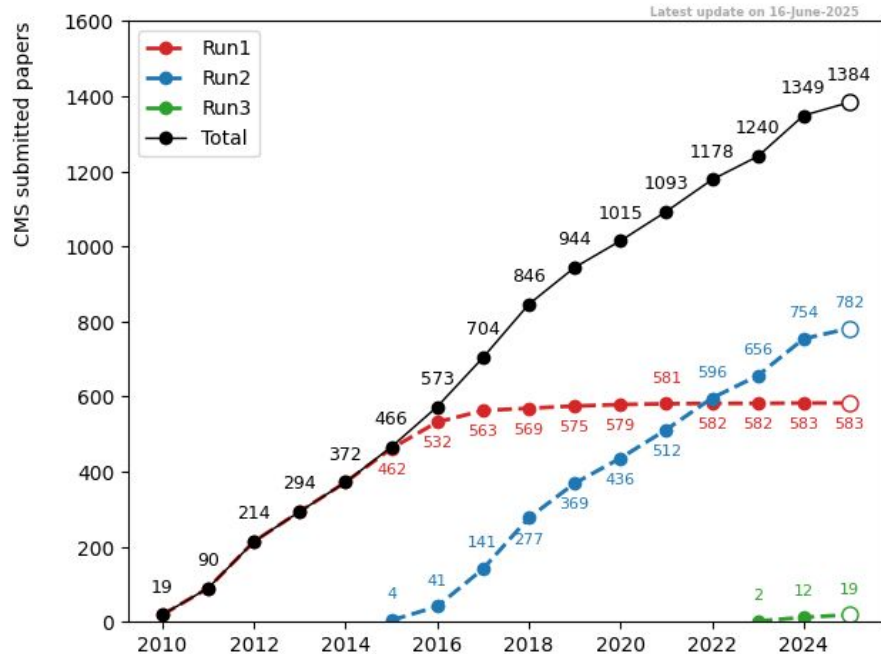
→ **typically, very smooth operations : 1 single run per fill !**



<https://bpt.web.cern.ch/lhc/statistics/2025/>



CMS e' arrivato a quasi 1400 pubblicazioni con dati LHC



still driven by innovative and challenging use of the large data set collected in Run2,
but Run3 sample is starting to become competitive

CMS Physics Highlights

Higgs

- $H(\gamma\gamma)$ [HIG-24-013] and $H(ZZ)$ [HIG-23-014] cross section @13.6 TeV

Standard Model

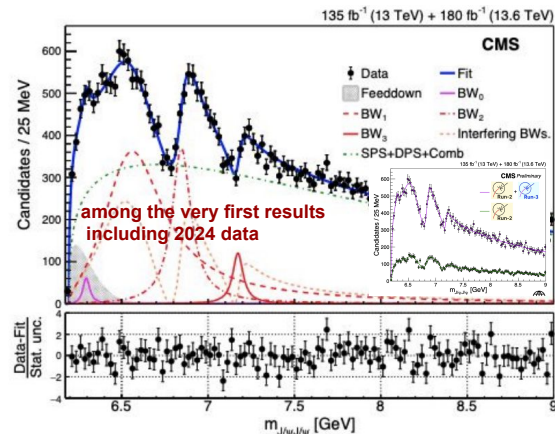
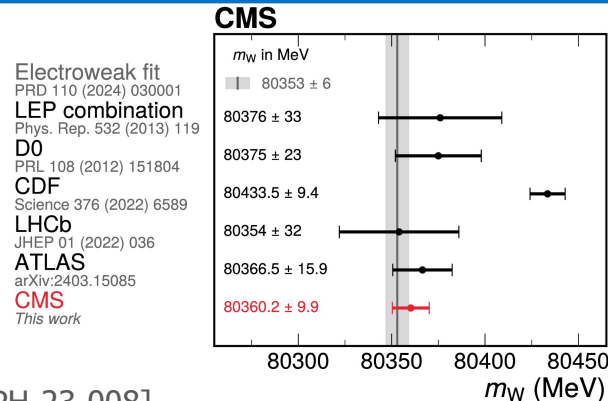
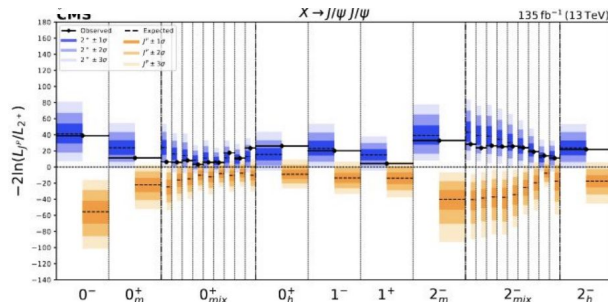
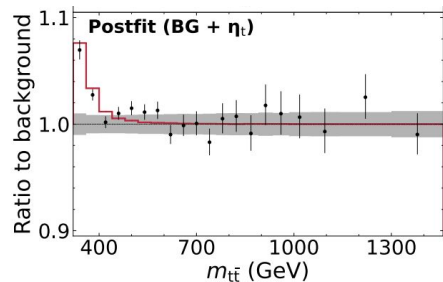
- W mass : the most precise measurement at LHC [SMP-23-002]
- α_S : the most precise measurement from jet cross sections [SMP-24-007]
- inclusive WZ [SMP-24-004] cross section @13.6 TeV
- Global EFT : first combination across PAGs [SMP-24-003]
→ probe energy scales >100 TeV depending on the Wilson coefficient

Flavour physics

- most sensitive search for the rare decay $D^0 \rightarrow \mu\mu$ (using Run3 parking dataset) [BPH-23-008]
- $J/\psi J/\psi$ spin and parity analysis [BPH-24-003] and BPH-24-002]

Top

- Observation of an excess at the threshold [TOP-24-007]



HIGGS

- $H \rightarrow \mu\mu$
- H/Z rare decays

TOP

- tWZ in multileptons
- $t\bar{t}H$ in multileptons

EXO

- NPLM
- Scouting

STANDARD MODEL

- VBF W production*
- VBS Semileptonico + EFT Run2
- Combination of VBS Run2
- VBS VV adronico (pol)**

FLAVOR

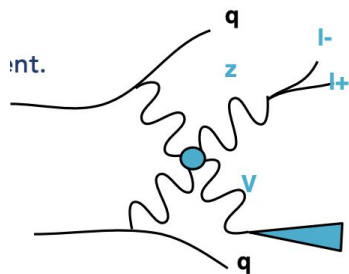
- Misura della violazione della simmetria CP nel canale $B_s \rightarrow J/\psi\Phi$ e $B^0 \rightarrow J/\psi K_s$
- Misura della violazione della simmetria CP nel mixing di mesoni B in eventi $t\bar{t}$
- Misura del mixing dei mesoni B usando eventi con tag di $B^+ \rightarrow J/\psi K^+$

*co-supervisione PhD Università di Cagliari

**co-supervisione PhD Università di Perugia

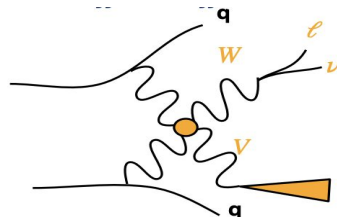
STANDARD MODEL - VBS ZVjj + EFT Dim8[SMP-22-011]

8

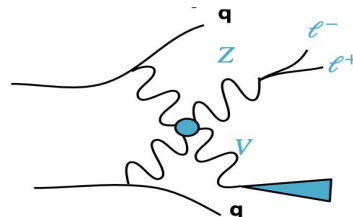


EWK ZV VBS sensitivity
never measured before.

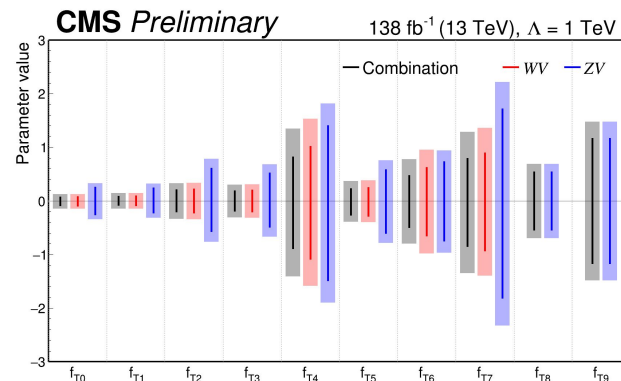
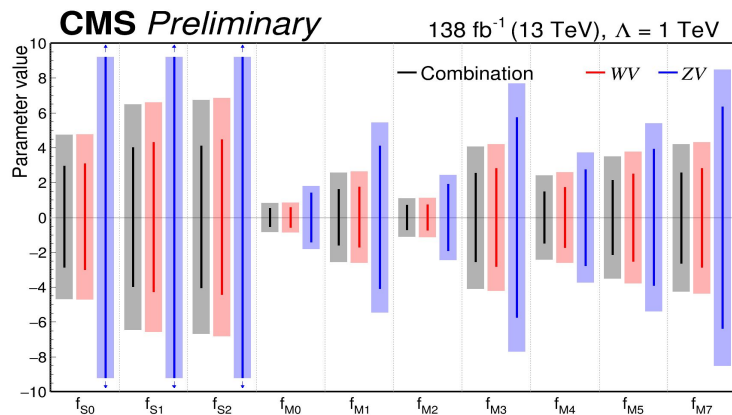
- VBS ZV analysis SMP-22-011 (P. Azzi(PD), KIT+FNAL) Final Reading this week!
- WV more sensitivity in general, but ZV helps with the Transverse operators



+

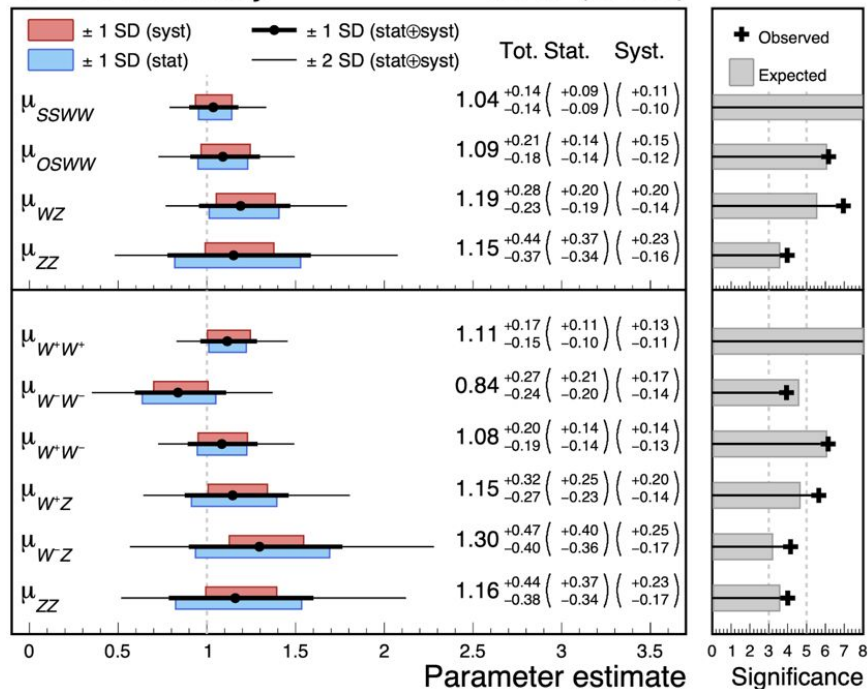


Anomalous QGC



SMP - VBS Run2 combination and EFT [SMP-24-013,SMP-25-002]

9

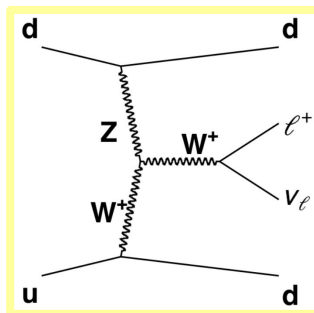
CMS Preliminary138 fb⁻¹ (13 TeV)

- **CMS combination of Run2 VBS results**
- involving several Italian contributions and including the ZVjj semileptonic analysis as one of the inputs. (P. Azzi, M. Presilla(KIT), C. Carrivale(PG), D.Ceballos(Lyon))
- **CERN Courier article appearing soon**
- **EFT interpretation with Dim6 in progress (SMP-25-002)**

STANDARD MODEL - VBF W Run2 [SMP-24-003]

Motivation:

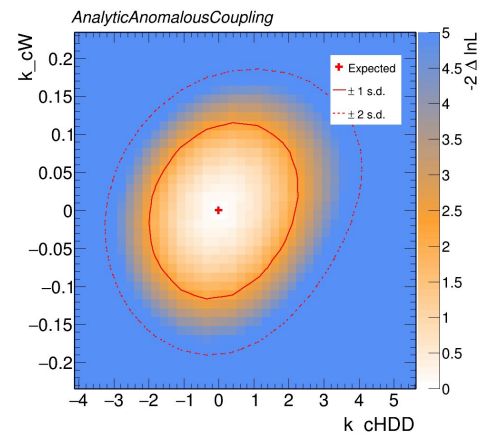
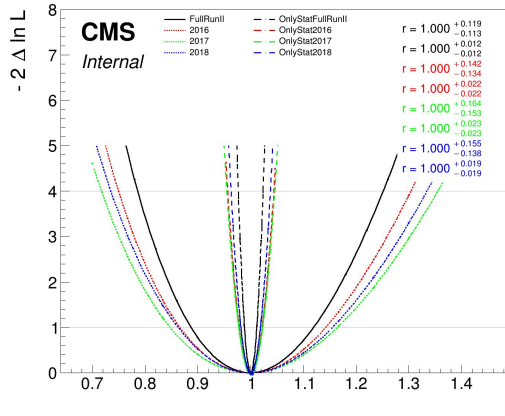
- Test of the SM gauge sector, **complementary** to Higgs Boson measurements
- Sensitive to new (BSM) physics: **aTGC, EFT**



Signature:

- 2 highly energetic jets (“tagging” jets):
 - large gap in η ($|\Delta\eta_{jj}|$)
 - high jet invariant mass (m_{jj})
- 1 charged lepton and neutrino $p_{T\text{miss}}$
 - central wrt the VBF jets

- **Statistical Method:** Combined binned maximum likelihood fit of the DNN output using signal and background templates.
- Expected 10% precision on the **signal cross section**
- **Direct** EFT injection and reinterpretation w/ high sensitivity to bosonic dimension-6 operators



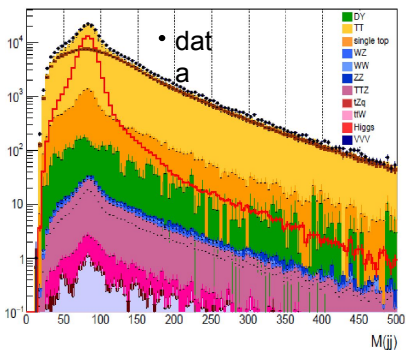
TOP - Study of tWZ production

CMS paper Phys.Lett.B(2024), DOI 10.1016/j.physletb.2024.138815 (multi isolated leptons + b-jets topologies) shows evidence of the production of single top in the tWZ channel, with a μ strength $\gg$ SM prediction: $\mu = 2.6 \pm 0.4 \pm 0.7$

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

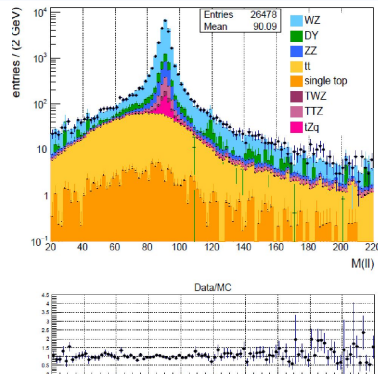
A complementary approach based on **exclusive reconstruction** of $W \rightarrow jj$ and $t \rightarrow bjj$ decays accompanying $Z \rightarrow ll$ and $W \rightarrow lv$ decays is being developed to understand better the origin of the discrepancy

$W \rightarrow jj$ reconstruction in tt single-lepton control region:

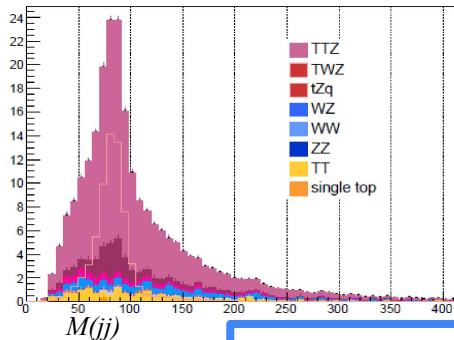


- true $W \rightarrow jj$
- comb. backg

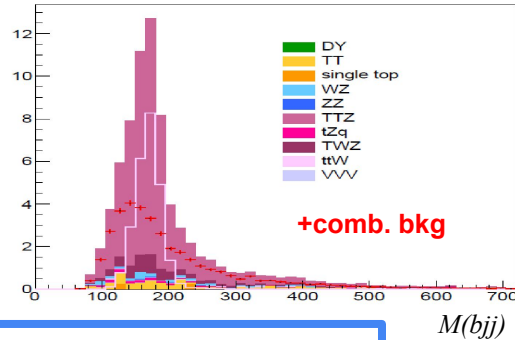
$Z \rightarrow ll$ reconstruction in WZ 3 isolated leptons control region:



$\int L = 137 \text{ fb}^{-1}$



- expected $ttZ + tWZ$ signal (WIP)



$W \rightarrow jj$ and $t \rightarrow bjj$ reconstruction in 3-leptons + b-jets signal region (MC data):

$M(bjj)$

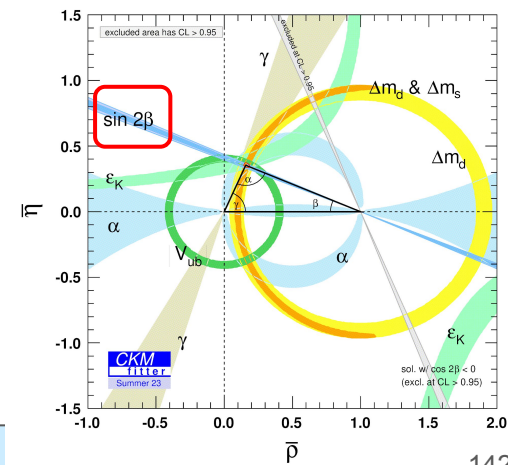
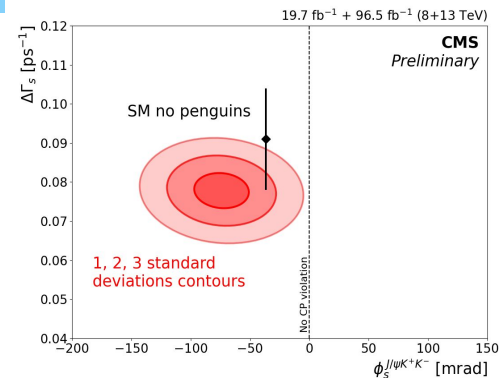
BPH - Time dependent measurements of CPV in neutral B mesons

- CP violation measurement in the $B_s \rightarrow J/\psi \phi(1020)$ channel with Run2 data**

- Precise characterization of the B_s meson system with a **time-** and **flavour-dependent angular** analysis of the final state
- Target parameters: ϕ_s (CPV in decay/mixing interference), $|\lambda|$ (CPV in decay), $\Delta\Gamma_s$, Γ_s , Δm_s of the $B_s/B_{\bar{s}}$ -bar system
- Comprehensive test of the physics of CPV and flavour mixing, with room for **New Physics**
- First evidence of CPV** in the $B_s \rightarrow J/\psi K^+ K^-$ decay
- Article **submitted to PRL**, working now on the last comments for the review

- CP violation measurement in the $B_{(s)} \rightarrow J/\psi K_S$ channel with Run3 data**

- Simultaneous** measurement for B^0 and B_s
- Target parameter: **$\sin 2\beta$** (CKM matrix parameter)
- Ongoing work on the NLL fit for the parameter extraction and on the flavour tagging



BPH - Mixing and CPV for neutral B mesons

Measurement of time-integrated mixing probability

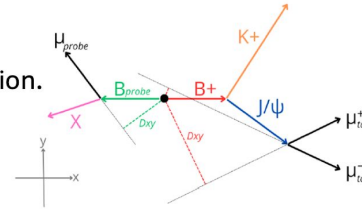
$$\bar{\chi} = \frac{Prob(B^0 \rightarrow \bar{B}^0) + Prob(\bar{B}^0 \rightarrow B^0)}{2}$$

$$\bar{\chi} = \frac{\#B^\pm \mu^\pm}{\#B^\pm \mu^\pm + \#B^\pm \mu^\mp}$$

Topology of the events: quark – antiquark produced in pairs to preserve flavor.

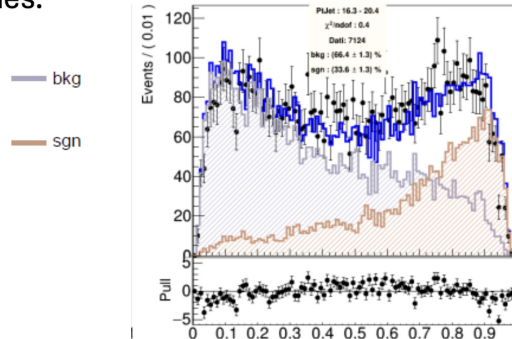
Tag side: $B^\pm \rightarrow J/\Psi K^\pm \rightarrow \mu\mu K^\pm$, used to constrain the flavor of the other b at the production.

Probe side: $b \rightarrow \mu$, flavor of the b at decay inferred from the sign of μ .

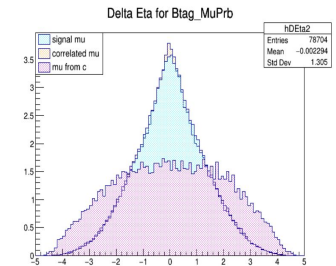


Charge correlation of $B^\pm$ and μ used to identify **oscillated events**.

Multidimensional fit to obtain the number of direct muons; a **multivariate discriminator** separates signal muons from background ones.

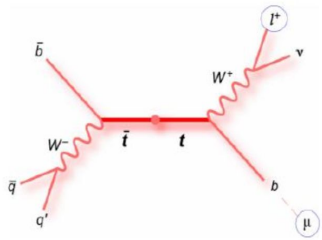


Background muons from cascade events ($b \rightarrow c \rightarrow \mu$) and uncorrelated muons (as DGS events) are separated exploiting the angular variable $\Delta\eta = \eta_{B\text{tag}} - \eta_\mu$



BPH- Semileptonic asymmetry in $t\bar{t}$ events

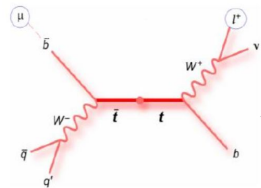
$$A_{SL} = \frac{Prob(B^0 \rightarrow \bar{B}^0) - Prob(\bar{B}^0 \rightarrow B^0)}{Prob(B^0 \rightarrow \bar{B}^0) + Prob(\bar{B}^0 \rightarrow B^0)}$$



Topology of the events: $t\bar{t}$ pair produced, both t decaying in b, l, ν , we select b decaying in μ . The sign of l tags the flavor of the t and of the b at production, the flavor of the b at decay is inferred by the sign of μ .

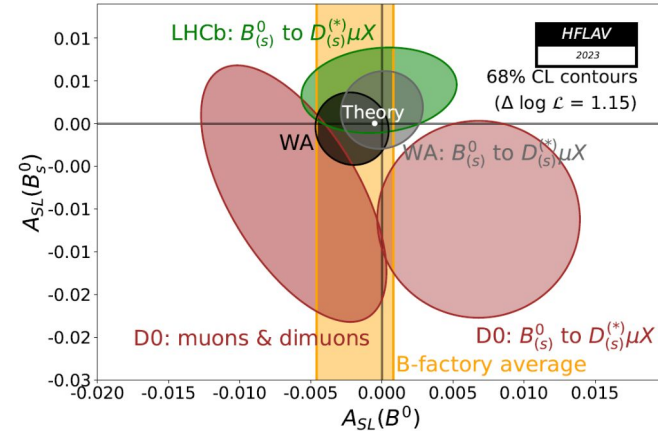
Charge correlation between hard lepton and soft muon used to compute

$$A_{SL} = \frac{l^+\mu^+ - l^-\mu^-}{l^+\mu^+ + l^-\mu^-}$$



Data sample not affected by **production asymmetries**.

Reconstruction asymmetries can be accounted for within the dataset itself.

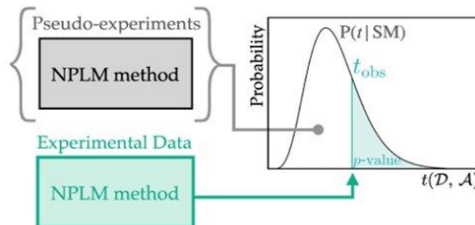
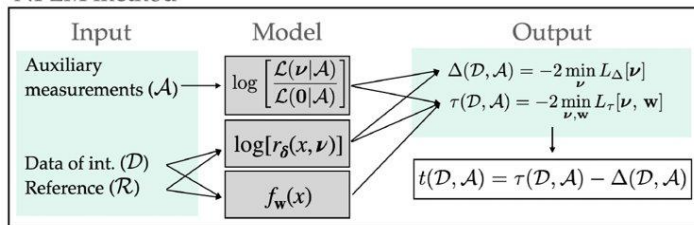


Knowledge about the soft μ sample acquired from mixing studies will be used in this analysis. Estimates of f_d and f_s are needed to calculate the asymmetry separately for the two mesons B_d^0 and B_s^0 .

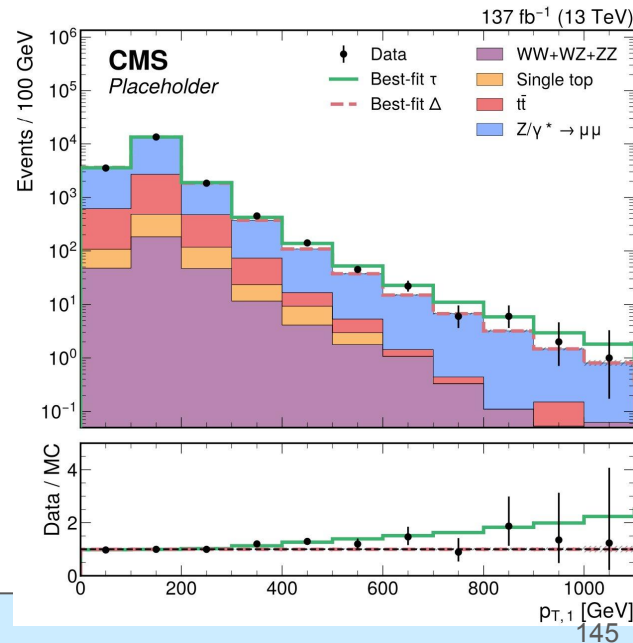
BSM - Anomaly detection in the di-muon final state

- Searches for physics Beyond the Standard Model (BSM) usually test a SM-only hypothesis optimizing the analysis against a specific SM+Signal hypothesis
- **New Physics Learning Machine (NPLM) [1,2] is a complementary (and innovative!!) analysis strategy to avoid specifying any BSM scenario**
 - **NPLM heavily relies on machine learning to compare data with the SM prediction**

NPLM method



- Final stages of the first-ever application of a signal-agnostic search focusing on a $\mu^+ \mu^-$ final state
- The goal is to compute the global discovery p-value related to the likelihood-ratio hypothesis test
 - **The alternative hypothesis is not specified a priori**
 - Parametrized using a neural network and fitted to the data

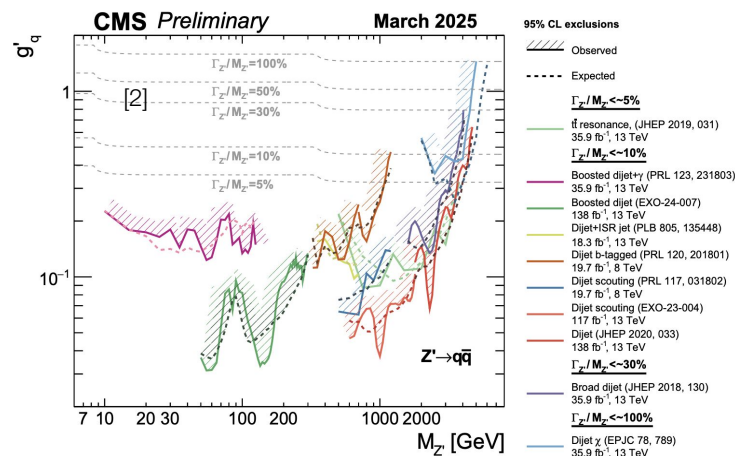
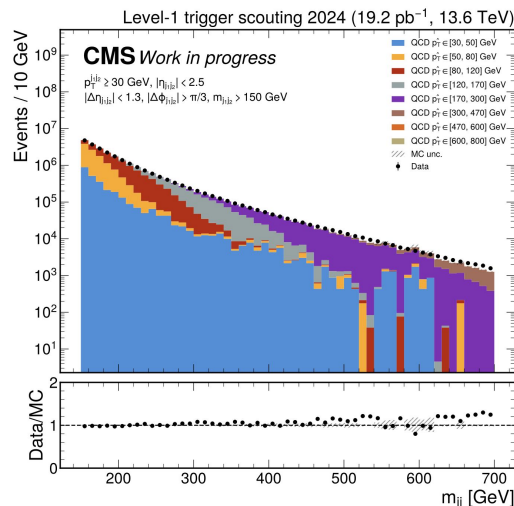


BSM - Level-1 Scouting analysis in Run 3

- The L1 Data Scouting (L1DS) demonstrator collects L1 objects at the bunch crossing (BX) rate of 40MHz. Operational since the start of Run 3 [1].
- The L1 Data Scouting recovers phase space and enable new physics searches: access low-pT, exotic or constrained by current triggers signatures, access correlations between BXs.**
- On-going analyses:
 - Search for Dijet Resonances with L1 Data Scouting (L1DS)*
 - Search for heavy stable charged particles (HSCPs) with L1 Scouting barrel muons stubs.

Dijet Search

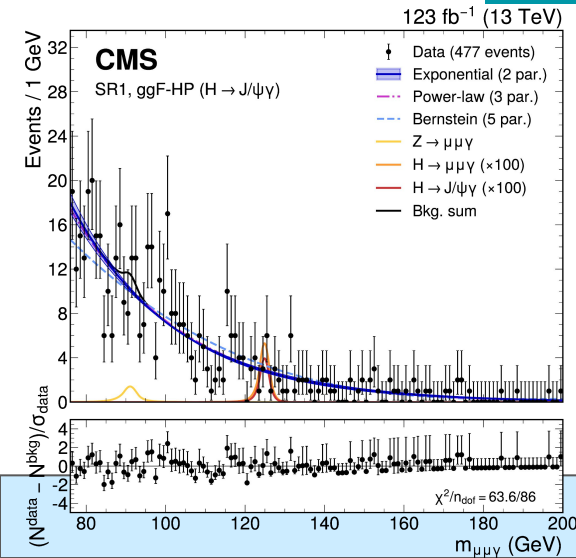
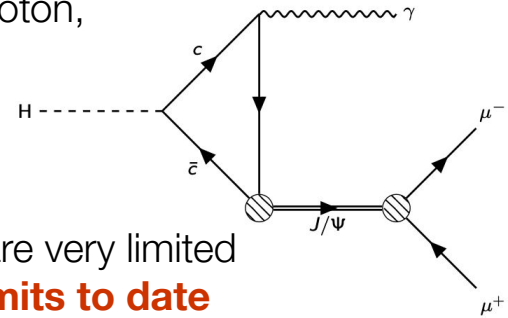
- Search for a leptophobic Z' boson decaying to $q\bar{q}$ pair.
- Inclusive dijet resonances search in the 200 – 700 GeV low mass range.
- Use L1DS dedicated dijet stream: select two jets with $p_{T>30}$ GeV and $|\eta| < 2.5$.



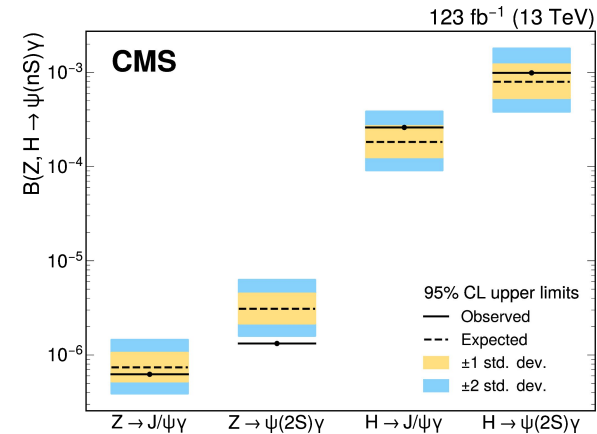
References: [1] [CMS DP -2024/056](#) [2] [Dijet summary plot](#)

HIGGS - Rare SM Higgs and Z decays

- The **Higgs** and **Z** bosons are expected to decay to a J/Ψ meson and a photon, also through the Higgs coupling to the c quark
- Never observed before, because branching ratios are small:
 - $B(Z \rightarrow J/\Psi \gamma) = 9 \times 10^{-8}$
 - $B(H \rightarrow J/\Psi \gamma) = 3 \times 10^{-6}$
- With the J/Ψ decaying to $\mu\mu$, the final state is clean and the backgrounds are very limited
- **Paper published with Run 2 data [1], providing the most stringent limits to date**
- Check out the official [CMS Physics Briefing](#)



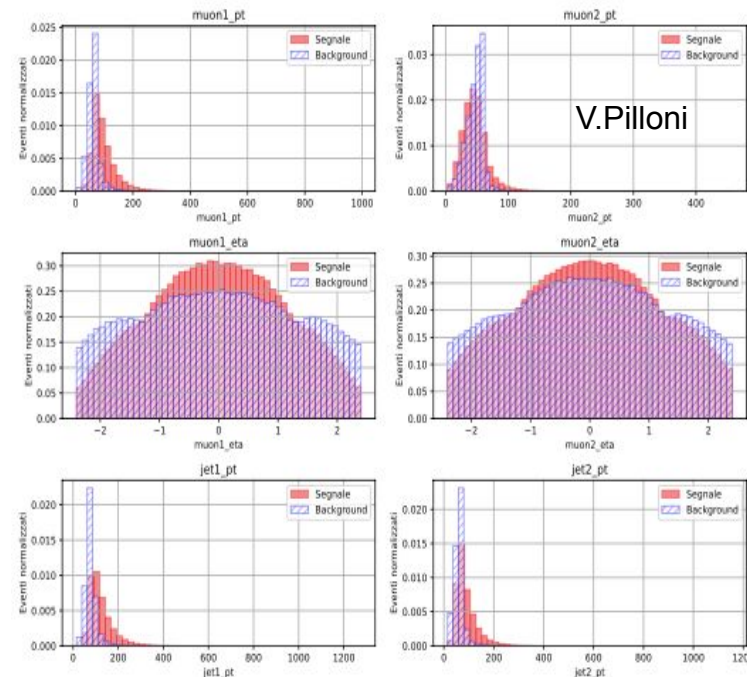
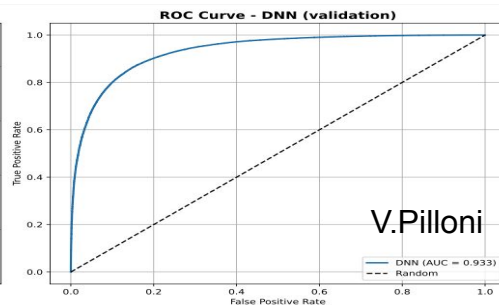
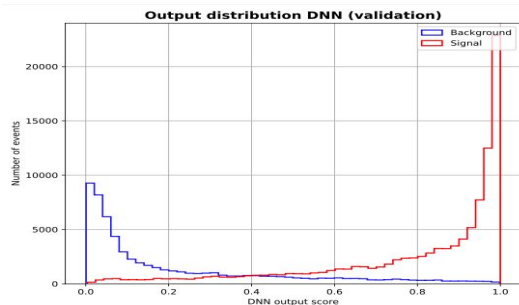
- Close to observe the decay of the $Z \rightarrow J/\Psi \gamma$: upper limit at 7.2 times the SM
- Higgs boson excluded up to 88 times the SM: this is a possible target for HL-LHC
- Able to constrain the Higgs-charm quark coupling: in the k -coupling modifier framework, $-157 < k_c/k_\gamma < 199$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



- **Currently improving the analysis for full Run-3 result**

HIGGS - $H \rightarrow \mu\mu$ (Run3)

- HMuMu working group coordination
- Run3 MC validation of signals (ggF, VBF) and main backgrounds (DYJets, ttbar) using NanoAOD
- Bachelor theses:
 - Veronica Pilloni - Exp.07/2025 - UniCa
 - Development of DNN for ggF and VBF classification using Run3 MC
 - Nicola Lavarda - UniPD
 - Filippo Dorigo - UniPD
 - Tommaso Zamboni - UniPD



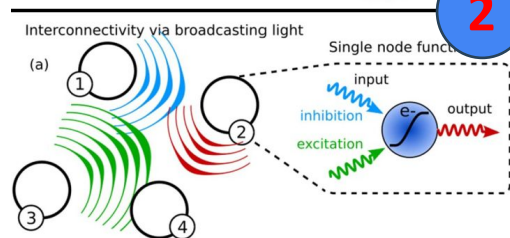
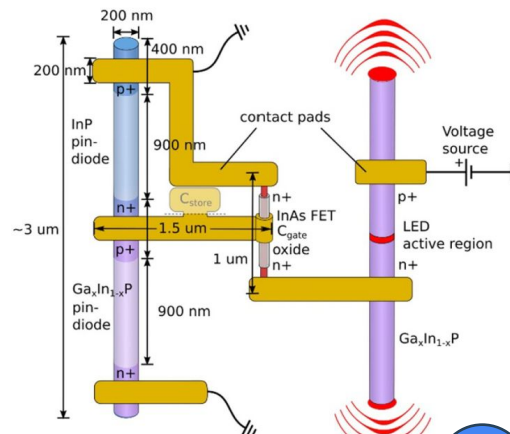
Innovative calorimetry with AI, neuromorphic computing (NC), and nanophotonics

- 1 Can we do particle ID in a highly-granular calorimeter?
- What is the largest cell size that retains relevant information?
- 2 Can we overcome granularity using photon time series-sensing nanowires, a NC readout, and local preprocessing using nanophotonics?
- 3 Can we hybridize a tracker and a calorimeter, learning the optimal layout?

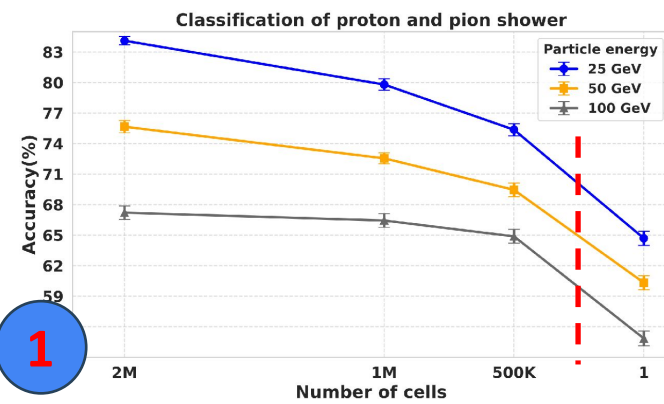
Studies within group INFN / UOV / LTU / KIT / RPTU / Lund:

Abhishek, M. Awais, M. Aehle, L. Chen, Abhijit Das, A. de Vita, T. Dorigo (PI), N. Gauger, R. Keidel, J. Kieseler, E. Lupi, A. Mikkelsen, XT. Nguyen, K. Schmidt, J. Wilmore, F. Sandin, P. Vischia

- 1 [MDPI Particles, 8 \(2\) \(2025\) p. 58](#)
- 2 [MDPI Particles, 8 \(2\) \(2025\) p. 52](#)
- 3 [MDPI Particles, 8 \(2\) \(2025\) p. 47](#)

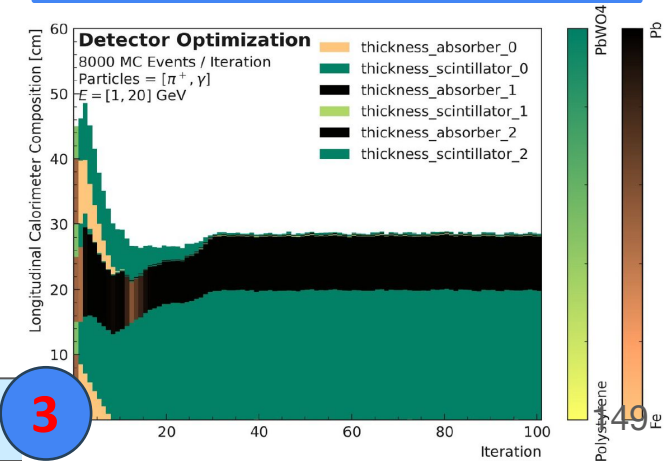


- 2 Above: light-activated and emitting nanowires can be used as elements of reservoir computing in a NC system



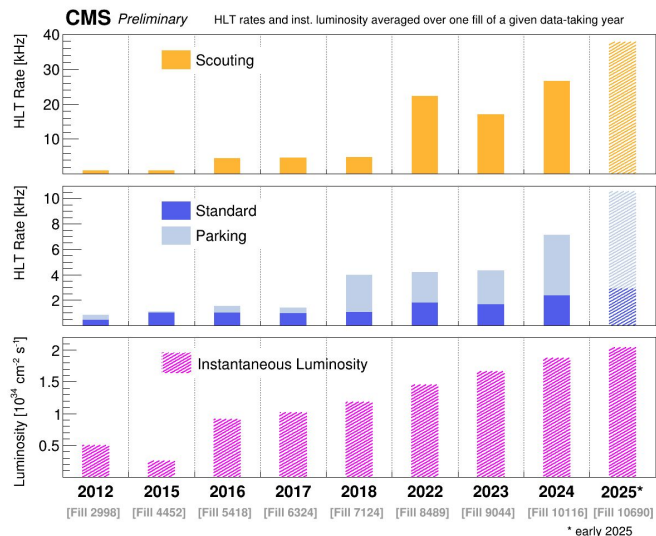
- 1 Above: p/ π discrimination of tailored GNN as a function of number of cells in homogeneous hadron calorimeter

- 3 Below: end-to-end optimization of a sampling calorimeter w/diffusion model



- 3

Trigger and Tracking @HLT Activities

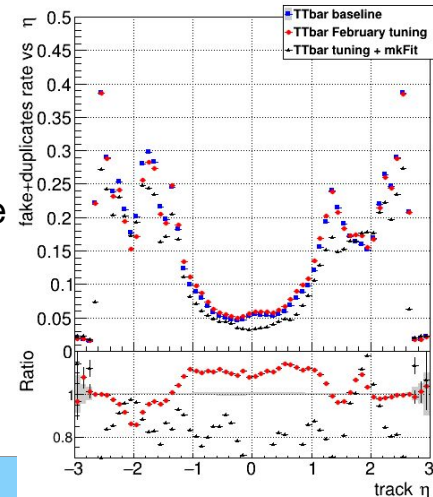


The 2025 pp trigger strategy continues to focus on improving acceptance in key physics channels:

- looser impact parameter req. in the **SingleMuon** trigger to boost efficiency for **displaced muons**
- **lower-threshold single and double photon/electron triggers** in the **barrel region**, for low mass **electroweak** and **exotic**
- **updated anomaly detection triggers** in **parking** and **scouting** streams

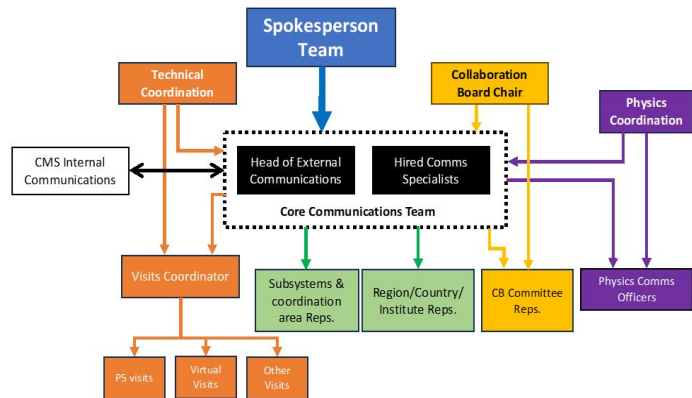
PD involved in crucial developments for Tracking at the HLT:

- Tuning of the Pixel Tracks reconstruction: **reduction in fake tracks** while maintaining the **reconstruction efficiency unchanged**
- **Porting the strip detector unpacking and clustering to GPU: significant timing improvement**
- Extension of Pixel Tracks to the first layers of strips → more resilient against degradation of pixel detector performance



Communication and Outreach

CMS Communications organization & information flow



- **Attivita' HEPSCAPE,**
adesso Sigla CC3M con
M. Tosi RL, con eventi a
PD e in Italia

The Core Team

Head of External Communications

David Barney

Deputy Head of External Communications

Marina Passaseo

Comms & Outreach

Sofia Hurst
Nefeli Stathaki
Thomas McCauley

Physics Communication

Ansar Iqbal
Andrés Delannoy

**Nuova struttura
per la
comunicazione a
CMS: M Passaseo
Deputy**



Breakthrough Prize 2024

The Collaboration taking ownership of the Breakthrough Prize



Photos & Design by Michael.Hoch@cern.ch/ CMS - KIT / 2025

On Saturday 5th April Patty McBride, former CMS Spokesperson, received the 2025 Breakthrough Prize in Fundamental Physics **on behalf of the CMS Collaboration** (joint award, along with ATLAS, LHCb and ALICE) for "*detailed measurements of Higgs boson properties confirming the symmetry-breaking mechanism of mass generation, the discovery of new strongly interacting particles, the study of rare processes and matter/antimatter asymmetry, and the exploration of nature at the shortest distances and most extreme conditions at CERN's Large Hadron Collider*".

Run3 e preparazione a HL-LHC

PD

Barrel Calorimeters

- crystal granularity readout at 40 MHz
- precise timing for $e/\gamma > 30$ GeV
- ECAL operation at low temperature (10°)
- upgraded laser monitoring system

A MIP Timing Detector (MTD)

- precision timing on single charged tracks (30 to 40 ps resolution)
- Barrel (BTL): LYSO crystals + SiPMs
- Endcaps (ETL): Low Gain Avalanche Diodes

PD

Tracker

- all silicon (strips and pixels)
- higher granularity ($>2B$ channels)
- less material
- coverage extended to $|\eta| = 4$

Endcap Calorimeter (HGCAL)

- silicon pixels (EM) and scintillators + SiPMs (HAD)
- 3D shower reconstruction with precise timing

Muon Detectors

- DTs & CSCs: new FE/BE readout electronics
- RPCs: new electronics
- new GEM chambers
- extended coverage to $|\eta| = 4$

PD

Beam pipe

- new version Phase-II design

CT-PPS

- upgrade of RP and moving system

Beam Radiation Instrumentation and Luminosity (BRIL)

- BCM/PLT refit
- new T2 tracker

L1-Trigger

- track trigger at L1 (40 MHz)
- latency up to $12.5 \mu s$
- triggers on displaced muons and long-lived particles

DAQ/HLT

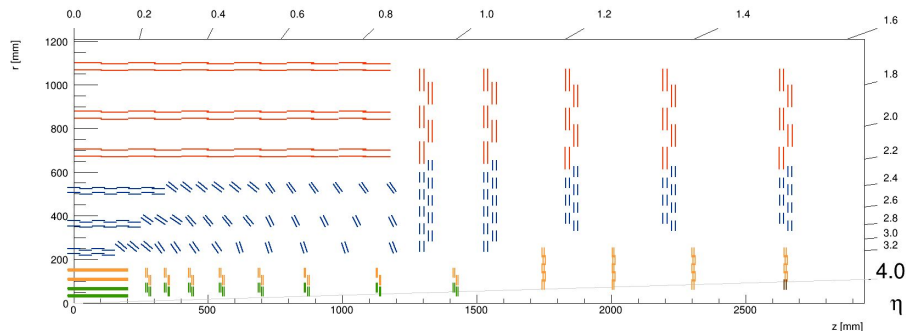
- HLT output at 7.5 kHz

PD

- Phase2 DT electronics
- Phase2 Tracker: MaPSA Testing
- Phase2: Barrel Timing Layer
- 40 Mhz L1-Scouting

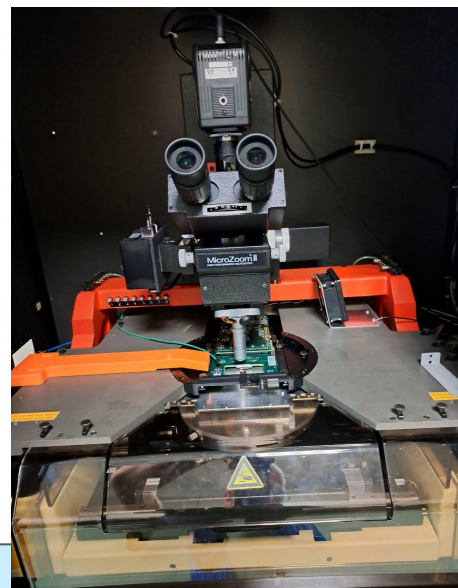
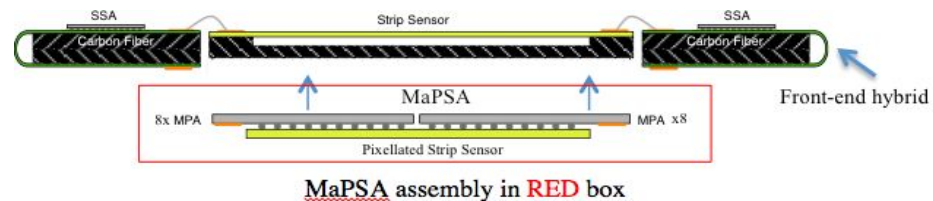
Phase II Tracker Upgrade: MaPSA testing in Padova

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



- MaPSAs are a section of the Phase2 Outer Tracker modules
 - Over 5000 modules need to be built, tested and assembled
- **Padova performs MaPSA testing: 10 modules/week during production phase (starting summer 2025)**
- Current status:
 - ~1h / test, thanks to test automation and error recovery improvements
 - Setup tested on over 60 pre-production modules

PS module cross-section.

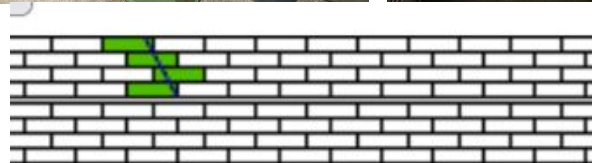
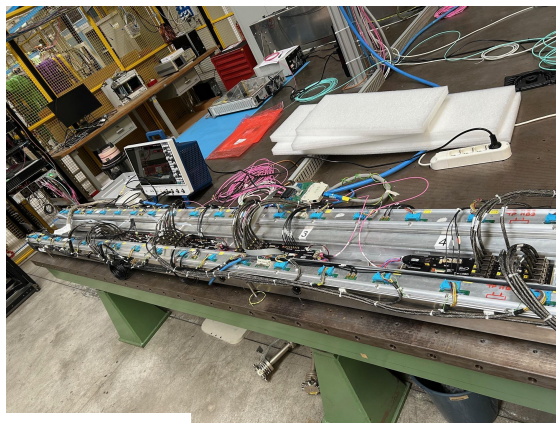


DT Fase II Upgrade - Elettronica

- **900 schede OBDT-PHY (readout) in produzione**
 - test e qualifica in corso a LNL
 - fine qualifica prevista per Ottobre 2025
- **Produzione e qualifica di 66 minicrate a seguire**
 - Fine qualifica prevista per Dicembre 2025
- **270 schede PSB (alimentazione) prodotte**
 - in fase di collaudo e taratura a LNL
 - fine qualifica prevista per Ottobre 2025
- **9200 cavi Front-end prodotti e collaudati**
- **750 cavi slow-control in produzione**
 - fine produzione : Agosto 2025
- **Sistema di Timing & Slow Control**
 - Manca l'HW definitivo (fornito dalla collaborazione CMS)
 - Consegna prototipi prevista per fine 2025

DT PHASE2 - Qualifica Minicrates

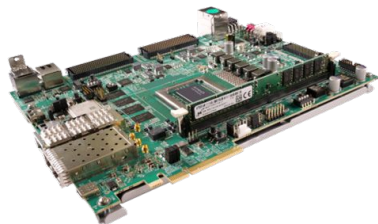
- Fatta prima a LNL
- HW di qualifica poi trasportato al CERN
- da rifare al CERN nel 2026



More Hardware Activities

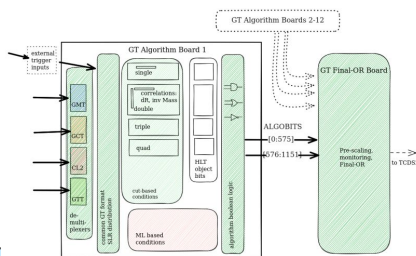
Quantum ML for online classification

- Hw inference of **Tree Tensor Network** binary classifiers for physics
- Model implementation at RTL and **HLS** level
- Comparison **TTN** vs **DNN** in terms of resources, latency and performance
- Extension to other topologies (like **Matrix Product State**)



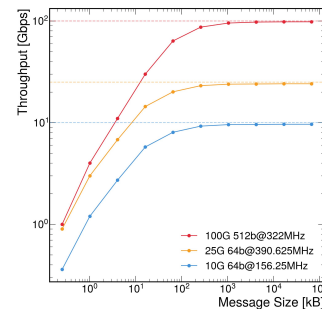
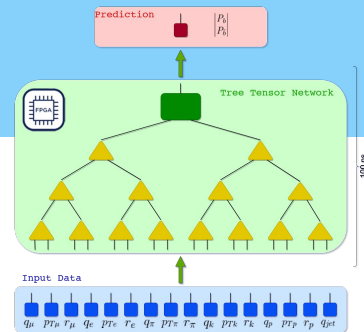
40MHz firmware developments

- 10/25/100Gbps **RDMA** based link (from FEROCe GrV)
 - Porting to Versal MRMAC 100G and DCMAC 200/400G
- $W \rightarrow 3\pi$ Online selection algorithm implementation in AIE



AI Engine benchmarking

- Implementation of highly parallelized **Gated Recurrent Unit** in **Versal** AI Engine processors with μs inference
- First implementation of CMS Particle Flow in AIE
- Comparison **AIE** vs **FPGA**



Phase-2 Global Trigger

- Firmware for ML-based conditions
- Trained and evaluated models for 5 different signatures
- Comparison **BDT** vs **DNN** in terms of resources and latency

BTL cold trays production finished

75 BTL trays assembled, 4 mm thick with 3mm I.D. evaporative CO2 cooling loops.

Production of parts mostly done by external suppliers:

- ✓ 450 machined Cold Plates
- ✓ 3600 laminas
- ✓ 80 cooling loops
- ✓ hundreds of support frames profiles and brackets

Masks for Cooling plates QC designed and produced @ PD
Swagelok glands custom machined @ PD workshop

Each cooling loop received at Cern qualified by:

- ✓ X-ray of orbital weldings @ supplier
- ✓ He Leak test to 10⁻⁸ mbar/l/1' @Cern
- ✓ CO2 leak test to 40 bar @Cern
- ✓ Pressure test at 160 bar in bunker facility @Cern

Spare trays production still in progress, waiting for missing parts

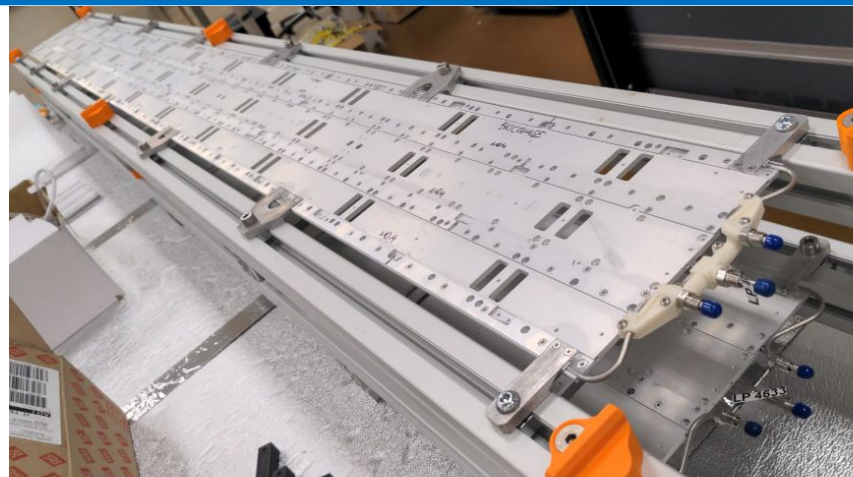
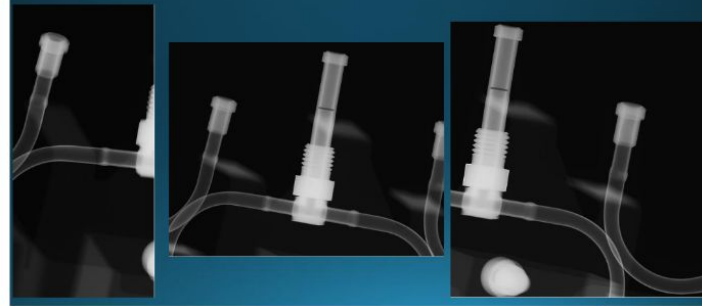


Immagine Sn 3
Piping Part

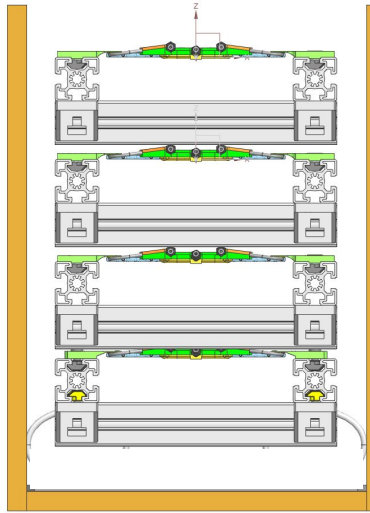
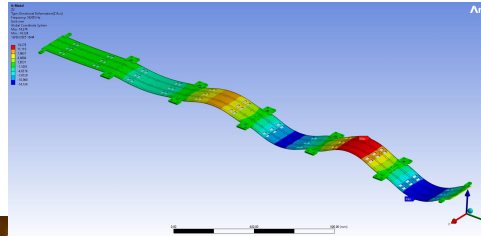
120Kv 500 µA
Filtro 2 Ben Leggero



BTL cold trays shipping

The BTL production model requires the shipments of the trays to the Assembly Centers for the dressing (Caltech, University of Virginia, Peking University, Milano Bicocca). The shipments are under our responsibility.

- Very first shipment of a wooden crate marked “FRAGILE” w/ 4 trays to PKU (Peking University) recorded a **>37g** acceleration (despite 6 cm of damping foam).
- Acceleration compatible with fall from a few tens of cm or resonance onset

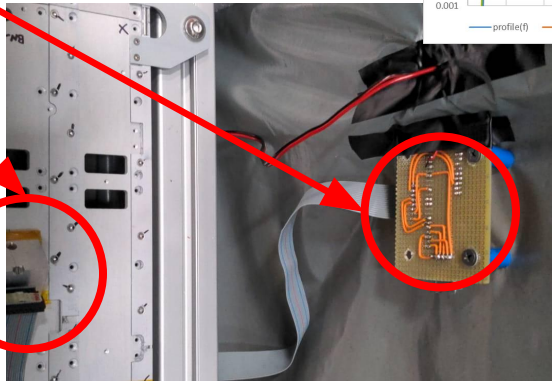


MTD - Barrel Timing Layer cold trays shipping

Upgraded version with wire rope dampers to limit shocks and avoid resonances (natural frequencies: ~ 35 -40 Hz and ~ 80 Hz up)

- wire rope dampers (characterized on a vibrating platform)
 - Cutoff frequency < 15 Hz and 10-fold attenuation every 15-30 Hz
- developed a 3-axis acceleration logging system based on Raspberry-Pi Pico capable of deadtimeless recording data @ 800 Hz for ~ 1 month (thx to Michele Giorato).

First shipments w/ the upgraded configuration to Caltech, University of Virginia, Peking University ongoing.



Anagrafica 2026 (confronto ~approx)

RUOLO	PERS25	FTE25	PERS26	FTE26
RICERCATORI&STUD.	28	20.9	33	19.6
TECNOLOGI	11	5.2	11	5.1
TOTALE	39	26.1	44	24.7(ARCO)

- Out:
 - PHDs: Ardino, Awais, Migliorini
 - Assegn.: Nguyen
 - Bacchetta: congedo
- Change: Bellato 40%->30%
- In: Grutta(Ass), Primavera(Ric), Zago (ass)
- NOTA: nel DB mancano
 - Grutta(100%) - (SL) c'e' al 80% (resto in SLPB - G5)
 - Primavera(70%) - (SL) in congedo RTD-A non risulta ancora associata a INFN-PD

RESPONSABILITÀ

[illegible]

Missioni

– Metabolismo+shifts/services:	189 keu
– Responsabilità:	39.5 keu
– Specifiche (dagli RA):	
DT(man +integrazione OBDT)	23keu (6mp)
MTD(integr./install.)*	11.5 keu

Consumi

– Metabolismo+camera pulita:	37+4=41.0 keu
------------------------------	---------------

*Discussione ancora in corso con RA Muoni.

Richieste in Sezione

Officina elettronica		Mesi uomo		Ufficio tecnico		Mesi uomo	
Tracker	Test Mapsa in camera pulita	3		BTL	Produzione disegni e documentazione	1	
Totale		3			Benettoni	2	
				Totale		3	
				Officina Meccanica		Mesi uomo	
				BTL	Lavorazione assemblaggio e installazione	1	
				Totale		1	
SPE		Mesi uomo					
DT	Installazione, test e commissioning al CERN (1 Tecnico+1 Tecnologo)	24		Calcolo		Mesi uomo	
	Timing	12			Supporto cluster locale, cloud	3	
Totale		36			Supporto produzione locale dati	3	
					Connessione, operazione, mant. TIER2 PD-LNL	18	
				Tracker	Supporto Computing & Networking	1	
				Totale		25	

Ridotta la richiesta del Tracker, aumento per DT per installazione e commissioning elettronica



FUTURE CIRCULAR COLLIDER



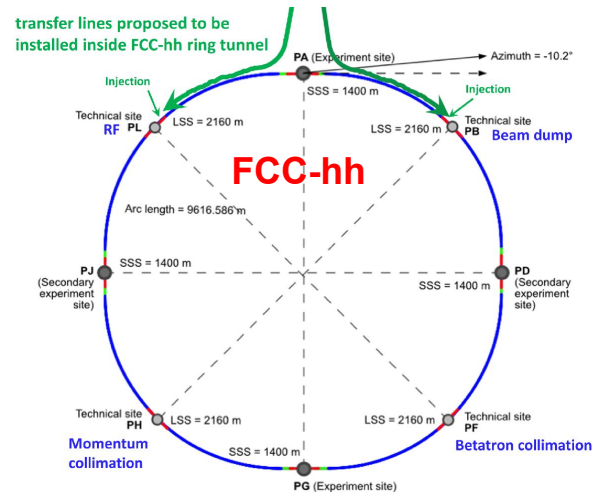
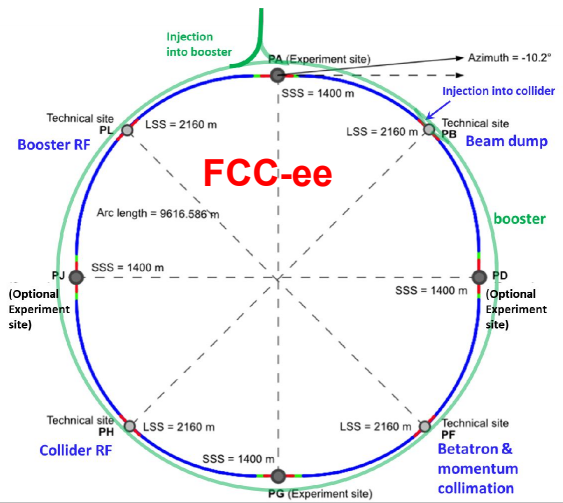
RD-FCC @PD

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
- SYMPOSIUM European Strategy in Venice Lido June 2024 molto positivo su FCC come "PianoA"



2020 - 2040

2045 - 2063

2070 - 2095

New National RD-FCC web Page

author: Anna Dalla Bona

https://web.infn.it/RD_FCC/



NEWS

Anagrafica RD-FCC

- **Riduzione FTE per ALICE e EPIC + congedo Bacchetta**
- **Chiaramente questi progetti risentono della poca disponibilita' di FTE di chi e' in Esperimenti di LHC.**
- Molti progressi e ottima attivita' sui MAPS (sinergia con IGNITE e ALICE)
- Nuovo lavoro anche su software di ricostruzione per FCC:
 - 1 Master Student ,1 stagista , 1 Doctoral Student
- **Responsabilita'**
 - P. Azzi :
 - Coordinatore RD-FCC WG1 "Software e Fisica" per CSN1 RD-FCC
 - **Coordinatore "Physics Performance" di "FCC Physics Experiment and Detector" (CERN)***
 - Convener del ECFA-WG2 per attività Higgs/EWK/Top Factories (terminated March 2025)

Table 1-2-1				
ANAGRAFICA 2026	FTE %	Sinergia	Sinergia	TOTAL
Azzi Patrizia	30			EXP
Bacchetta Nicola	0		CONGEDO	HW
Carlin Roberto	10			EXP
De Vita Andrea	100			SW
Barbara Anna Erdely	10			TH
Fanzago Federica	10			SW
Piero Giubilato	0	10	IGNITE	HW
Ramona Gröber	10			TH
Margoni Martino	10			EXP
Mattiazzo Serena	0	10	PHALAFEL/IGNITE	HW
Alejo Nahuel Rossia	10			TH
Rossin Roberto	10			EXP
Tosi Mia	20			EXP
Wyss Jeffery	30	40	IGNITE	HW
Zingaretti Alessandra	0	15	IGNITE	HW
TOTALE	250	75		325

Richieste 2025

		Richieste	SJ			Richieste	SJ
missioni	Responsabilita' (P. Azzi) : Coordinatore "Physics Performance" FCC-ee PED (https://fcc-ped.web.cern.ch/content/ped-study-coordination)	2.50	0.00			21.5	0
	Metabolismo per 3.25FTE (3.25FTE*1.2kE)	4.00	0.00				
	Conferenze/Workshop/Meetings(3.25FTE*4.5)=15	15.00	0.00				
inventario	WP3 - Contributo per acquisto cofinanziato DOE/CSN1/CSN3/Sez.PD - ANTICIPABILE (se anticipato anche da CSN1) macchina bondatrice per attivita' di R&D comuni a FCC, MuC ed esperimenti di CSN3. (DRD3-WP1 e DRD7-WP6)	10.00	0.00			10	0
Totale						31.5	0

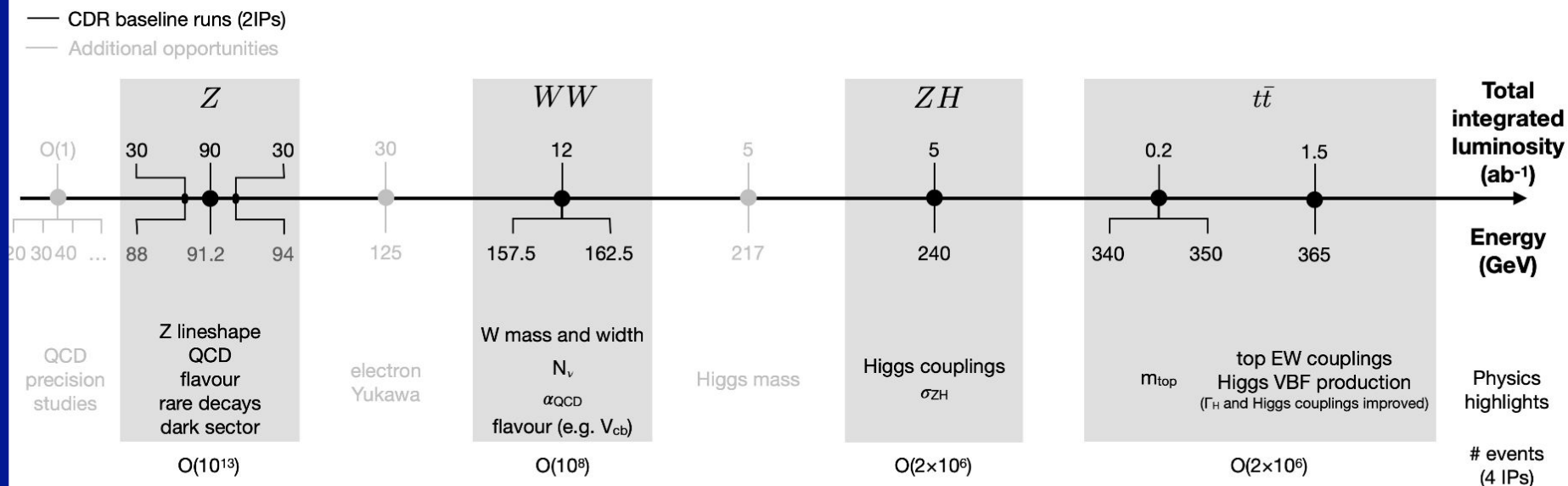
- Non ci sono richieste ai servizi specifiche.

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

E' stata identificata (vedi EPIC) una macchina finalmente compatibile con le necessita' e con un prezzo <100K. Richiesta inserita nel DB per 10K.

Flexible collider program



- **Opportunities** beyond the baseline plan ($\sqrt{s}$ below Z, 125GeV, 217GeV; larger integrated lumi...)
- **Opportunities** to exploit FCC facility differently (to be studied more carefully):
 - using the electrons from the injectors for beam-dump experiments,
 - extracting electron beams from the booster,
 - reusing the synchrotron radiation photons.

Published! Feasibility Study Reports

And a YellowReport on Future HTE factories

Future Circular Collider
Feasibility Study Report

Volume 1
Physics, Experiments, Detectors

April 1, 2025

Submitted to the European Physics Journal ST, a joint publication of EDP Sciences,
Springer Science+Business Media, and the Società Italiana di Fisica.

Future Circular Collider
Feasibility Study Report

Volume 2
Accelerators, Technical Infrastructure
and Safety

March 31, 2025

Submitted to the European Physics Journal ST, a joint publication of EDP Sciences,
Springer Science+Business Media, and the Società Italiana di Fisica.

Future Circular Collider
Feasibility Study Report

Volume 3
Civil Engineering, Implementation
and Sustainability

March 31, 2025

Submitted to the European Physics Journal ST, a joint publication of EDP Sciences,
Springer Science+Business Media, and the Società Italiana di Fisica.

CERN Yellow Reports, Monographs

CERN-2025-005

arXiv:2506.15390v1 [hep-ex] 18 Jun 2025

**ECFA Higgs, electroweak,
and top factory study**

Editors: Aidan Robson, Christos Leonidopoulos

ECFA Higgs, electroweak, and top factory study

The ECFA Higgs, electroweak, and top factory study ran between 2021 and 2025 as a broad effort across the experimental and theoretical particle physics communities, bringing together participants from many different proposed future collider projects. Activities across three main working groups advanced the joint development of tools and analysis techniques, tailored new considerations of detector design and optimisation, and led to a new set of studies resulting in improved projected sensitivities across a wide physics programme. This report demonstrates the significant expansion in the state-of-the-art understanding of the physics potential of future e^+e^- Higgs, electroweak, and top factories, and has been submitted as input to the 2025 European Strategy for Particle Physics Update.

Study Coordinators:

WG1 Physics Performance
Patrik Asai (INFN Padova)
Patrik Koppenburg (Rutherford)
Jenny Liu (CERN)
Fabio Maltoni (UCLouvain / Edinburg)
Former coordinator:
Juan Alcázar Maestro (CEMAT Madrid)

Chief Editors
Christos Leonidopoulos (Edinburgh)
Aidan Robson (Glasgow)

WG2 Physics Analysis Methods
Patrik Asai (INFN Padova)
Fulvio Piccini (INFN Pavia)
Dirk Zeppenfeld (UCLA/DMT)
Mary G. Zou (CERN/MTA) (Marseille)
Giovanni Marchiori (APC Paris)
Felix Sefkow (DESY)

<https://cds.cern.ch/record/2928193>

<https://cds.cern.ch/record/2928194>

<https://cds.cern.ch/record/2928793>

<https://arxiv.org/pdf/2506.15390>

Attività a Padova

Molteplici fronti

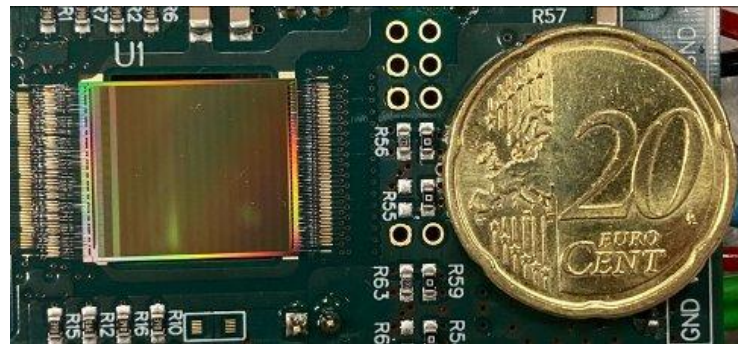
- **Hardware:** studio sensori monolitici (sinergie con ex-Arcadia/IGNITE, ALICE, EPIC)
 - Partecipazione a DRD7 (P. Giubilato RL)
- **Software:** ricostruzione di tracce con ML, e validazione per rivelatore IDEA
- **Fisica:**
 - **EXP:** interesse di studi di ricerca di particelle FIP (HNL) (Ajmal, S., Azzi, P., Giappichini, S. *et al.* Searching for type I seesaw mechanism in a two heavy neutral leptons scenario at FCC-ee. *J. High Energ. Phys.* 2025, 54 (2025).
[https://doi.org/10.1007/JHEP05\(2025\)054](https://doi.org/10.1007/JHEP05(2025)054))
 - **TH:** Probing Higgs light quark Yukawa couplings:
<https://arxiv.org/abs/2501.07628>, <https://arxiv.org/abs/2410.08272>, and more...

Arcadia MD3



The ARCADIA collaboration (2019-2022) has developed a full-chip prototype targeting requirements for different applications (future colliders, space, medical)

- Sensors for application at vertex detector at FCC-ee
- Low power $\rightarrow O(20 \text{ mW cm}^{-2})$ in high-rate mode
- Scale down to $O(10 \text{ mW cm}^{-2})$ in low-rate mode for space applications
- Small pixel pitch $\rightarrow 25 \times 25 \mu\text{m}^2$
- Thickness $\rightarrow 200 \mu\text{m}$ fully depleted (with backside bias HV = -90 V)
- Scalability to large area $\rightarrow$ up to $4 \times 4 \text{ cm}^2$
- High particle rate $\rightarrow$ up to 100 MHz cm^{-2}
- Timing resolution $\rightarrow O(1 \mu\text{s})$
- Investigating more advanced solutions for $O(10 \text{ ns})$ timing
- Digital readout and data-push architecture



Activities in 2024/2025

- Lab characterization:
 - Threshold and noise characterization with monochromatic sources, e.g. Fe55 and fluorescence X-rays, and with test pulse injection
 - Study of the rate capability with X-ray tube
- Commissioning of the telescope setup for test beam
- In-beam characterization: test beam measurements at Fermilab Test Beam Facility (June-July 2024)
- **Ongoing activity: paper preparation**

Activities in 2025/2026

- Lab characterization:
 - Study of the sensor performances for low energy X-ray and visible radiation
- **Testbeam with low energy protons (Trento) and electrons (BTF Frascati)**

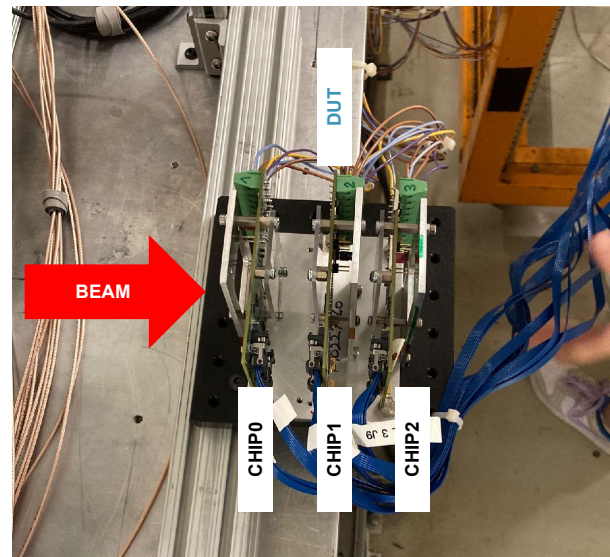
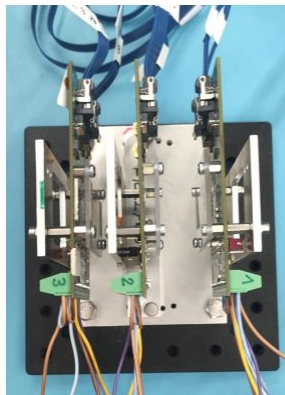
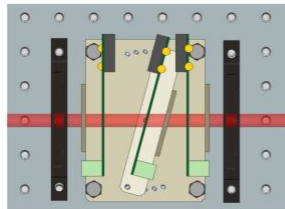
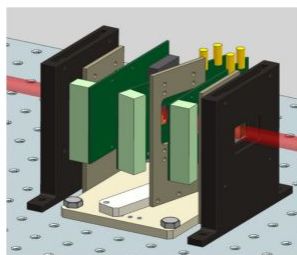
Involved people:

Sabrina Ciarlantini, Caterina Pantouvakis, Michele Rignanese, Alessandra Zingaretti, Davide Chiappara, Chiara Bonini, Patrizia Azzi, Piero Giubilato, Serena Mattiazzo, Devis Pantano, Jeffery Wyss, Nicola Bacchetta, Patrizia Azzi

Test Beam measurements @ FNAL

120 GeV proton beam

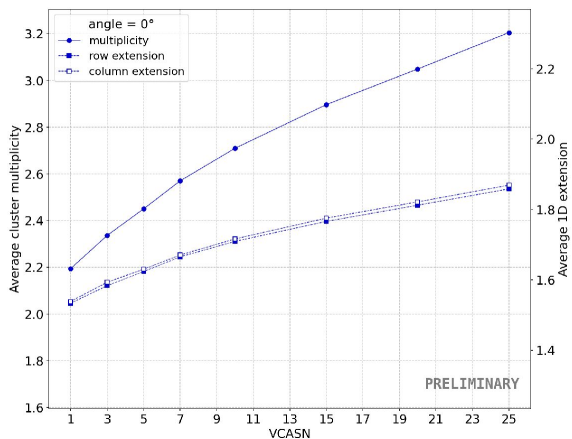
- Telescope with 3 ARCADIA-MD3 chips (one DUT, two tracking planes)
- Threshold, sensor HV, Front End circuit parameter and incidence angle parametrization: study of cluster size, tracking efficiency, spatial resolution



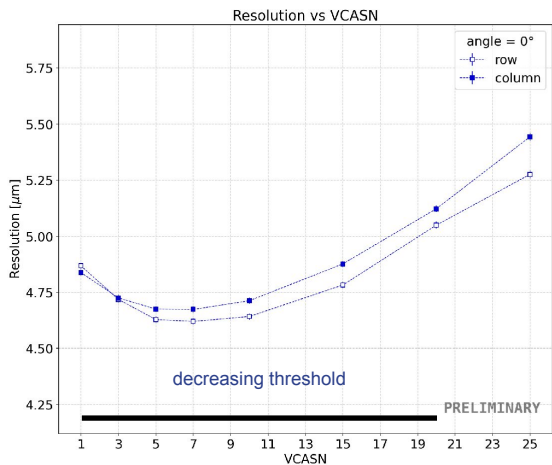
Test Beam @FNAL

Results with DUT orthogonal to the beam

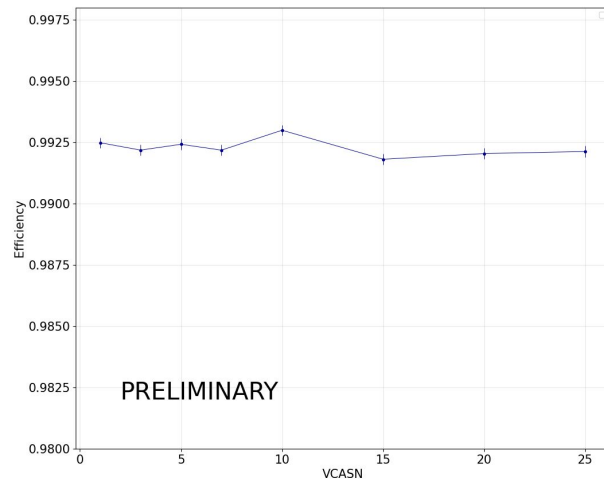
Cluster size



Resolution



Detection efficiency
Average efficiency over threshold scan
range: 99.23 %



VCASN is the DAC parameter
controlling pixel threshold
The two parameters are inversely
proportional

Software - Tracking with GNN

A. De Vita

Essential step for moving to FullSimulation& Reconstruction

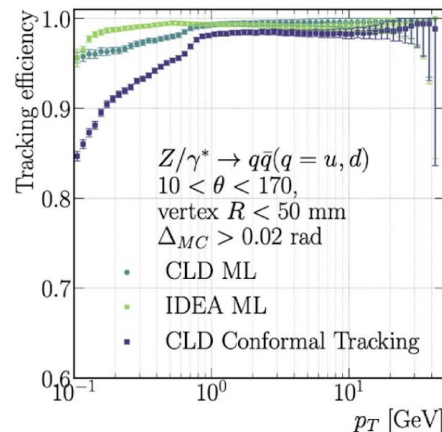
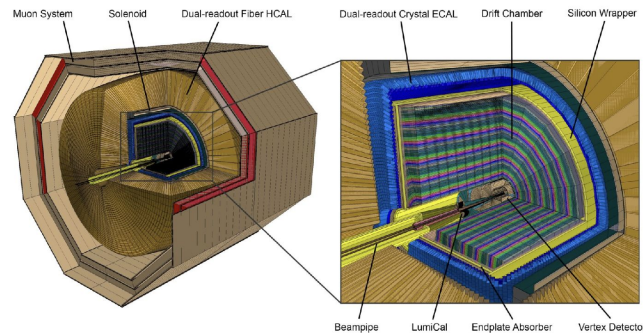
Track Reconstruction for the IDEA Detector (FCC)

The IDEA tracking system consists of three subdetectors: **a silicon pixel vertex detector, a central drift chamber, and a silicon strip wrapper.**

Track reconstruction is performed in two main steps: **track finding and track fitting.**

Track Finding is performed using a **Graph Neural Network** based model.

Track Fitting is implemented using Genfit2. It introduces the **Deterministic Annealing Filter**, which is capable of resolving the left-right ambiguity of IDEA drift chamber.



RD MuColl

D. Lucchesi



IMCC constituted by about 90 institutions, keep increasing.

Strong scientific support in US, but not investments so far:

P5 report

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.

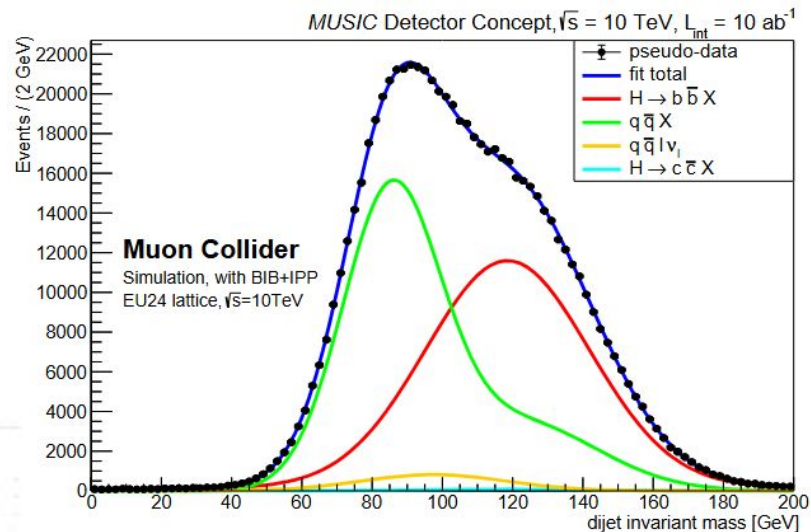
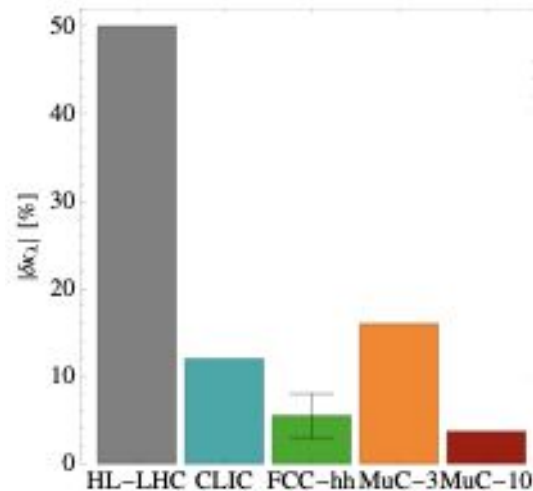
National Academy of Science report: Elementary Particle Physics

A collider with approximately 10 times the energy of the Large Hadron Collider (LHC) is crucial for addressing the big questions of particle physics and making discoveries.

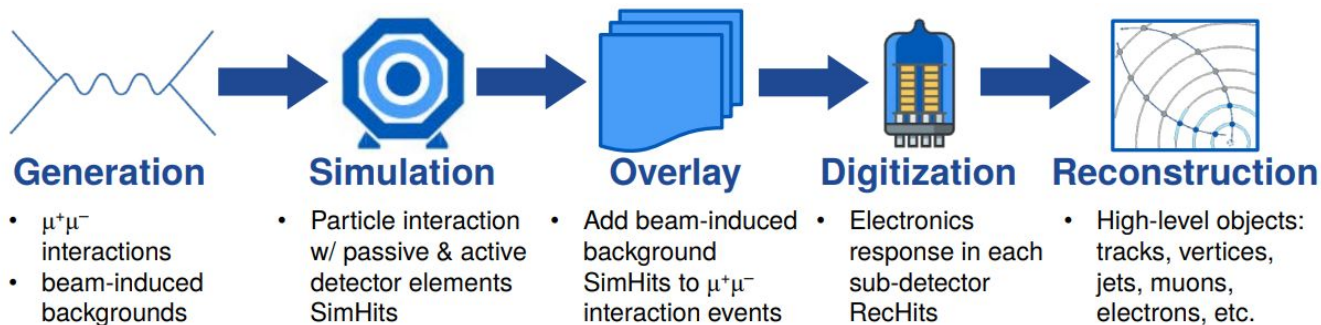
A 10-TeV muon collider on the Fermi National Accelerator Laboratory (Fermilab) site would have similar discovery reach as a 100-TeV proton collider. A muon collider combines the physics advantages of an electron-positron and a proton-proton collider, with a much smaller size.

Activities in Padova: Higgs reaches

- Full simulation studies $\rightarrow$ a Muon Collider can effectively study Higgs Physics
- Results obtained for $H \rightarrow b\bar{b}$, $H \rightarrow WW^*$ and $HH \rightarrow bbbb$ XS and trilinear self-coupling
- Results used by PPG for ESPPU



Activities in Padova: Software development and maintenance



- Muon Collider software based on Key4hep framework
- Legacy reconstruction algorithms (Marlin) gradually migrated to Gaudi
 - first migration of ACTS is nearly completion

Anagrafica

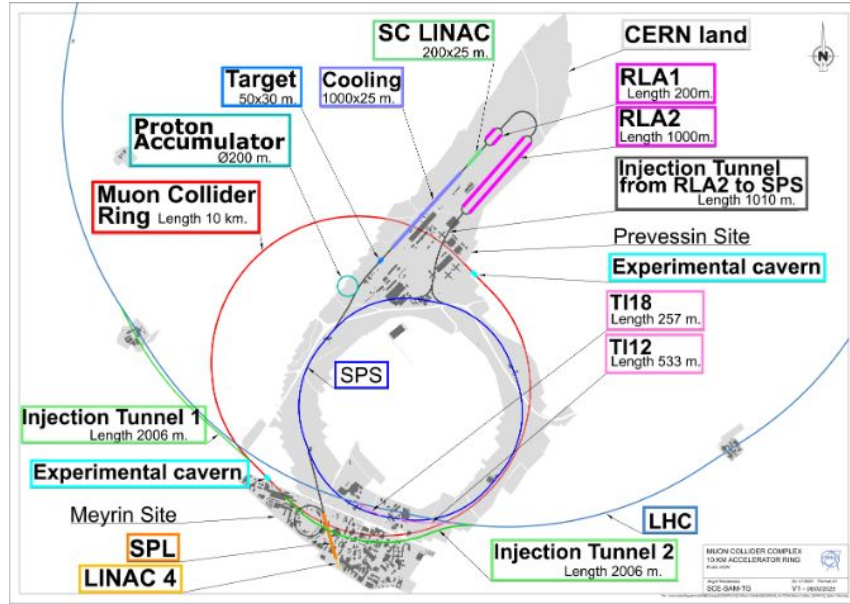
Number of people: 16

FTE: 5.65

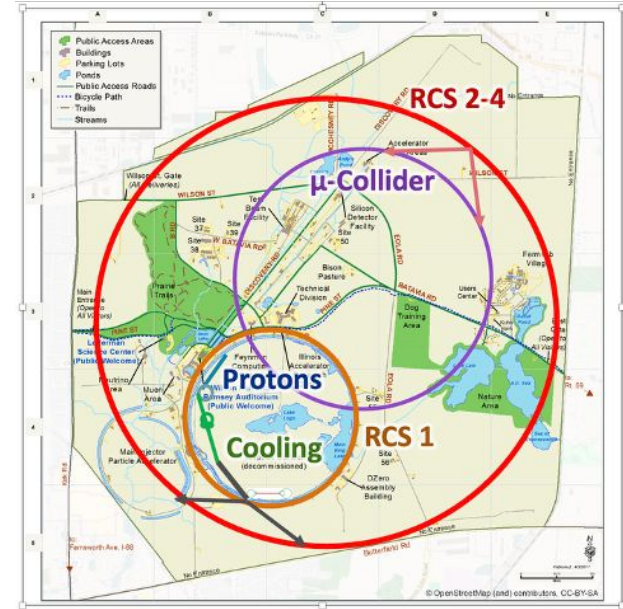
Andreetto Paolo	25
Awais Muhammad	50
Bertolin Alessandro	30
Calzolari Daniele	100
Ciarlantini Sabrina	30
Dorigo Tommaso	10
Dosselli Umberto	15
Gianelle Alessio	35
Lucchesi Donatella	30
Lupato Anna	30
Nardi Federico	0
Nguyen Xuan Tung	50
Palombini Leonardo	100
Qundomg Han	30
Zingaretti Alessandra	10
Zuliani Davide	20
Tot. FTE	5.65

Project status: accelerator facility

CERN



Fermilab

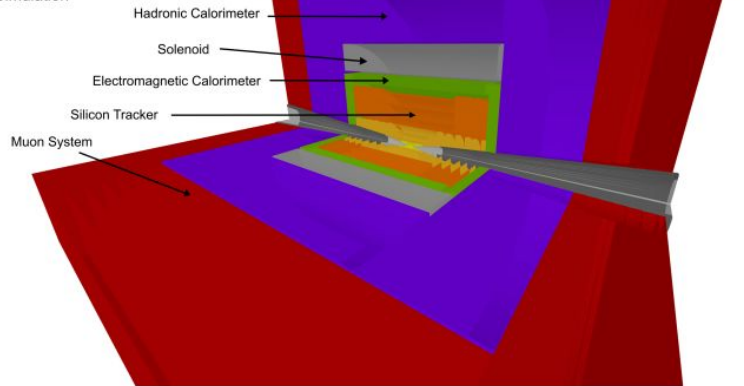


- Simulation of the single facility constituents available
- Start to end simulation to be done
- No showstoppers so far

Project status: Physics and Detector

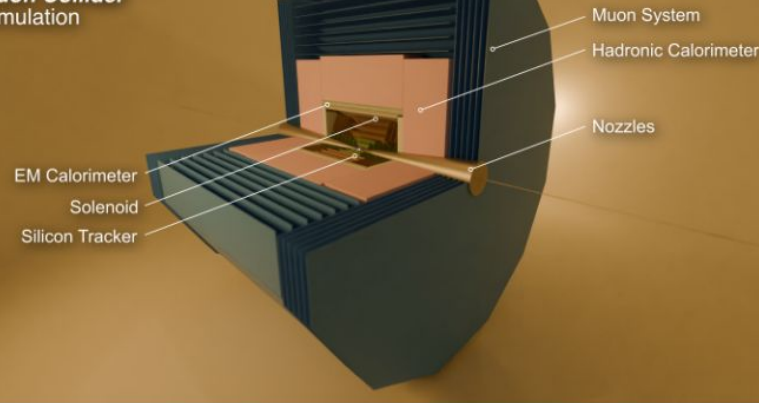
MUSIC Detector Concept

Muon Collider
Simulation



MAIA Detector Concept

Muon Collider
Simulation



- Developed detector for 3 TeV
- Developed 2 detector concepts for 10 TeV
 - + Delphes card for fast sim
- Optimized MDI for both 3 and 10 TeV cases

Requirement	Baseline	Aspirational
Angular acceptance $\eta = -\log(\tan(\theta/2))$	$ \eta < 2.5$	$ \eta < 4$
Minimum tracking distance [cm]	~ 3	< 3
Forward muons ($\eta > 5$)	tag	$\sigma_p/p \sim 10\%$
Track σ_{p_T}/p_T^2 [GeV^{-1}]	4×10^{-5}	1×10^{-5}
Photon energy resolution	$0.2/\sqrt{E}$	$0.1/\sqrt{E}$
Neutral hadron energy resolution	$0.4/\sqrt{E}$	$0.2/\sqrt{E}$
Timing resolution (tracker) [ps]	$\sim 30 - 60$	$\sim 10 - 30$
Timing resolution (calorimeters) [ps]	100	10
Timing resolution (muon system) [ps]	~ 50 for $ \eta > 2.5$	< 50 for $ \eta > 2.5$
Flavour tagging	b vs c	b vs c , s -tagging
Boosted hadronic resonance identification	h vs W/Z	W vs Z

Project status: Physics and Detector - 1

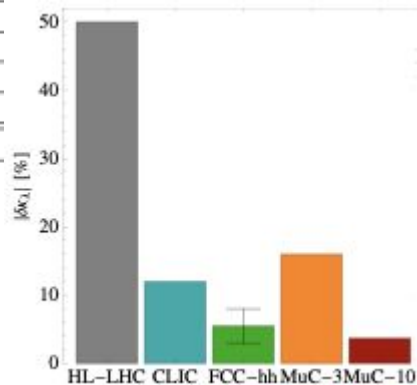
MuC at 10 TeV offers unique physics reach

Higgs fermions couplings

	HL-LHC	HL-LHC +10 TeV	HL-LHC +10 TeV + ee
κ_W	1.7	0.1	0.1
κ_Z	1.5	0.2	0.1
κ_g	2.3	0.5	0.5
κ_γ	1.9	0.7	0.7
$\kappa_{Z\gamma}$	10	5.2	3.9
κ_c	-	1.9	0.9
κ_b	3.6	0.4	0.4
κ_μ	4.6	2.4	2.2
κ_τ	1.9	0.5	0.3
κ_t^*	3.3	3.0	3.0

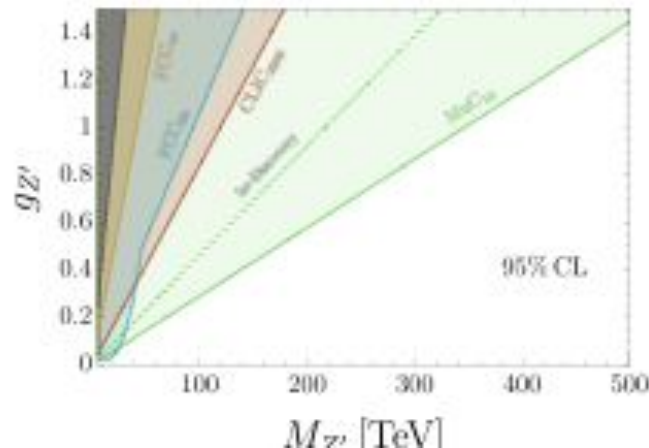
* No input used for the MuC

Higgs self coupling



Combination of high energy and high precision enhances sensitivity to new physics, to scales not reachable by pp collisions due to the composite nature of proton.

Discovery up to 100 TeV SM-like EW gauge couplings.
Exclusion up to 500 TeV for maximal value of the $g_{Z'}$ coupling.



IMCC paper submitted to the ESPPU

- [The muon collider](#): 10 pages document and 406 pages with all the relevant information on the current status and R&D proposals.
- [P. Andreetto et al., “Performance study of the MUSIC detector in \$\sqrt{s} = 10\$ TeV muon collisions”](#): paper dedicated to the description of MUSIC detector performance obtained with detailed detector simulation including machine induced background.
- [P. Andreetto et al., “Sensitivity study on \$H \rightarrow b\bar{b}\$, \$H \rightarrow W W^*\$, and \$HH \rightarrow b\bar{b}b\bar{b}\$ cross sections and trilinear Higgs self-coupling with the MUSIC detector in \$\sqrt{s} = 10\$ TeV muon collision”](#): paper dedicated to the expected precision on the most important Higgs measurements, including detailed detector simulation and all backgrounds.

Main requests to the ESPPU: support for the R&D!

Accelerator design

- Complete **start-to-end design** to validate and optimize performance, cost, power and risk

Muon cooling technology

- **Need hardware and test infrastructure**, in particular RF test stands
- **New detector technologies** for new generation of beam monitoring instrumentation

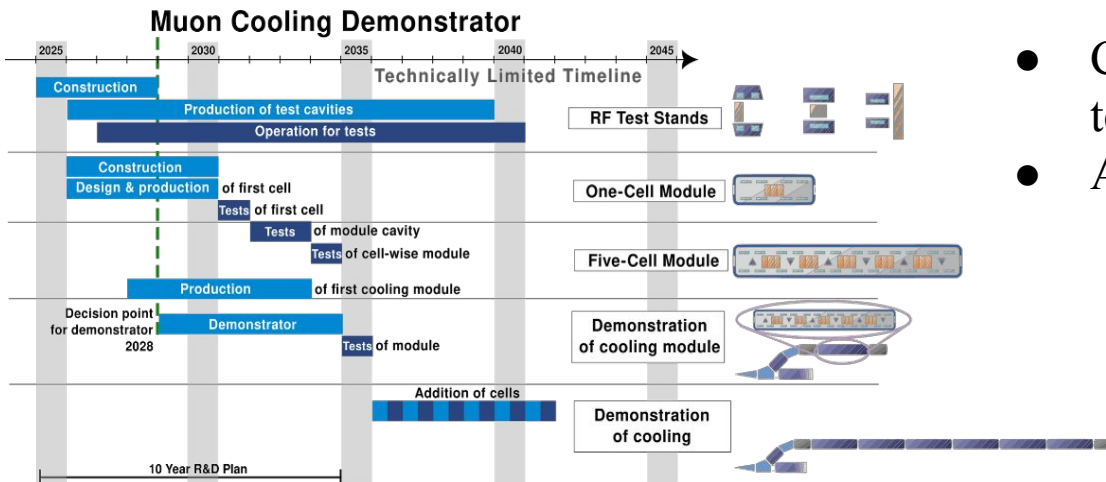
Detector

- Novel devices or innovative combinations of existing technologies to nullify the machine-induced background effects

Magnet programme

- Conceptual designs ready, need hardware
- HTS solenoids have important **synergy with society** and **industry** is ready to invest

The so called demonstrator



- Challenge: demonstrate muon cooling technology in stages
- Achieved so far:
 - Defined scope and concept, initial cost estimate
 - Staged timeline to implement demonstrator

- Two promising demonstrator site studies at CERN
- Budget for Fermilab site study approved

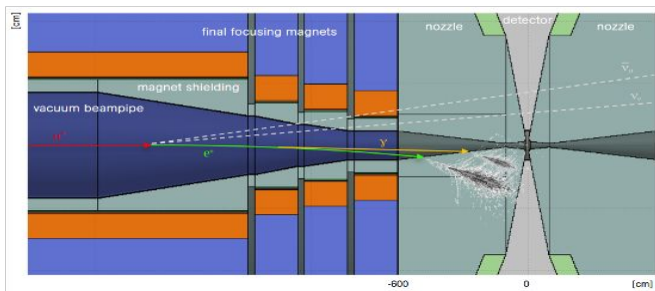
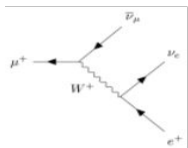


Activities in Padova: machine detector interface studies

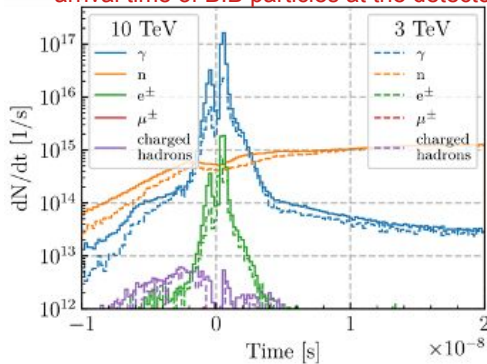
Optimization of shielding structure and absorber materials

background from muon decay (BIB)

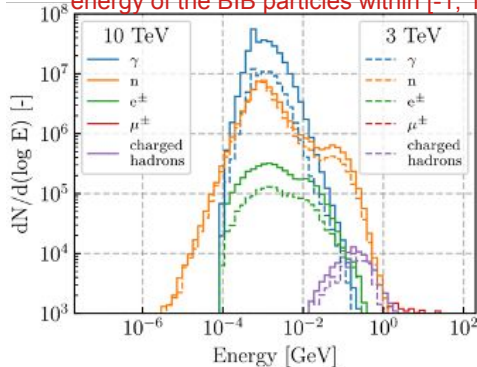
($\sim 10^8$ $\bar{\nu}_\mu$, $\sim 10^7$ n , and $\sim 10^5$ $e^\pm$ in the time window [-1, 15] ns)



arrival time of BIB particles at the detector

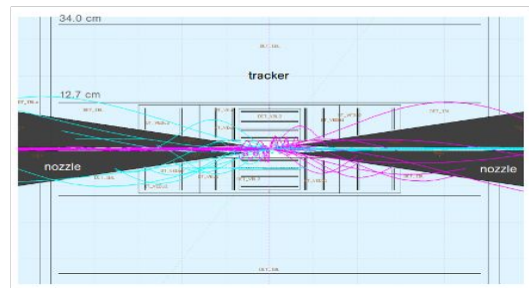
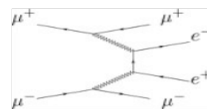


energy of the BIB particles within [-1, 15] ns

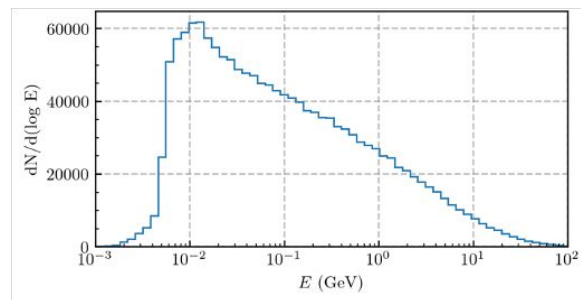


background from incoherent e^+e^- pair production

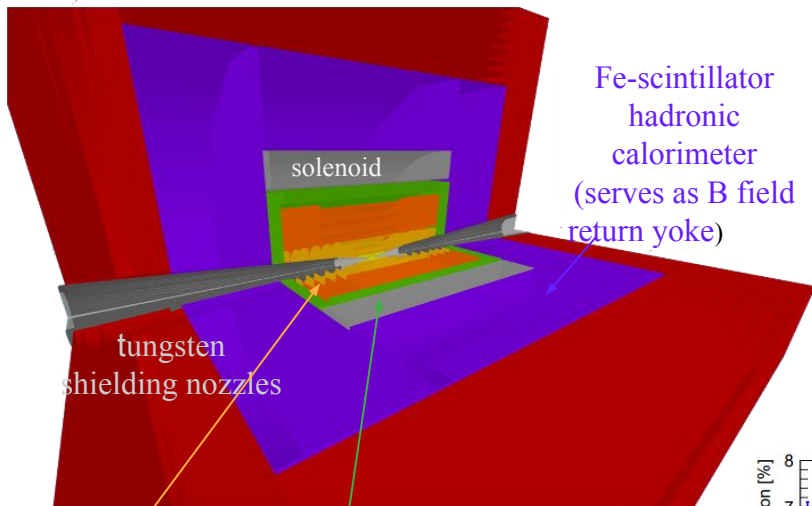
($\sim 10^6$ $\bar{\nu}_\mu$, $\sim 10^5$ n , and $\sim 10^5$ $e^\pm$)



$e^\pm$ energy



Activities in Padova: Detector concepts



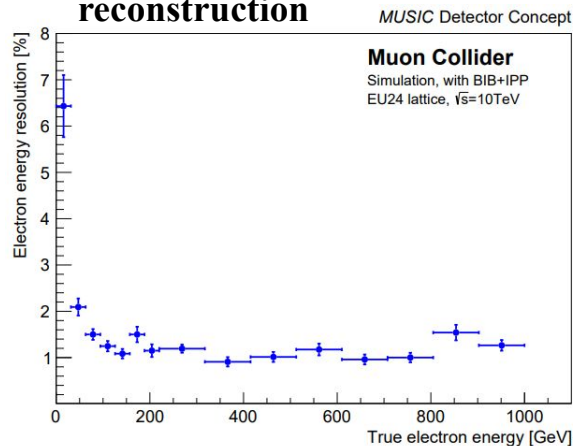
Fe-scintillator
hadronic
calorimeter
(serves as B field
return yoke)

tungsten
shielding nozzles

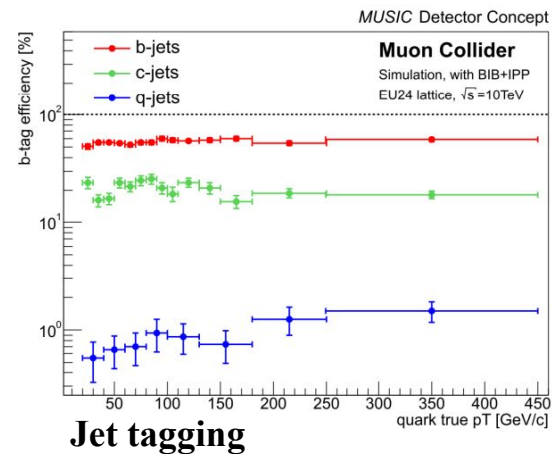
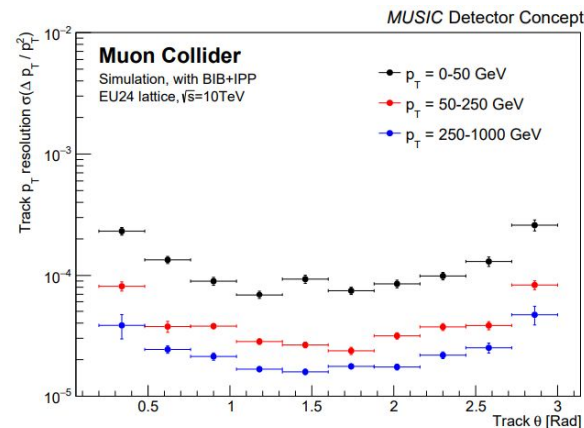
all-silicon
tracking system

PbF₂-crystal
electromagnetic
calorimeter (inside the
solenoid, 5T)

Calorimeter reconstruction



Track reconstruction



Riassunto richieste servizi G1

Unita': mese persona



Sigla servizi	Prog. Meccanica (Benettoni)	Off. Meccanica (Ramina)	Elettronica (Bellato)	Tec. Avanzate (Pepato)	STG (Nicoletto)	Calcolo e reti (Michelotto)
CMS	3	1	36	6	3	25
LHCb	2	2			1	
IGNITE					1	
MUONE	1	1			1	
Aladdin	1	2			2	
ICARUS		1			7	1
DUNE		4			4	
HYPER-K		3	4		3	