

# CSN1 INFN Activities 2022

Paolo SPAGNOLO  
INFN Pisa

**CSN1: 21 coordinators, 19 national managers**  
5 observers from other CSNs and CCR  
and **50 external referees**



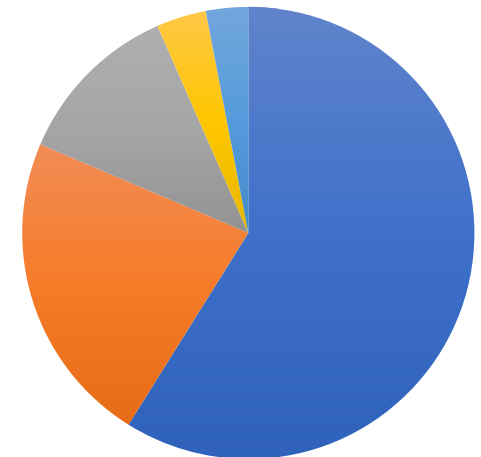
# This presentation →

- A bit of statistics
- LHC and its upgrades
- Other experiments
- Future accelerators

CSN1 FTE: **850 FTE**

CSN1 budget: **20 M€ + 3 M€ External funds**

CSN1 Sector in 2022	FTE (%)	Budget (%)
Physics at hadron colliders (LHC)	58,90	58,89
Flavor Physics (including LHCb)	25,97	22,52
Charged Lepton Physics	9,20	12,01
Proton Structure	3,15	3,56
R&D for Future Accelerators	2,79	3,02



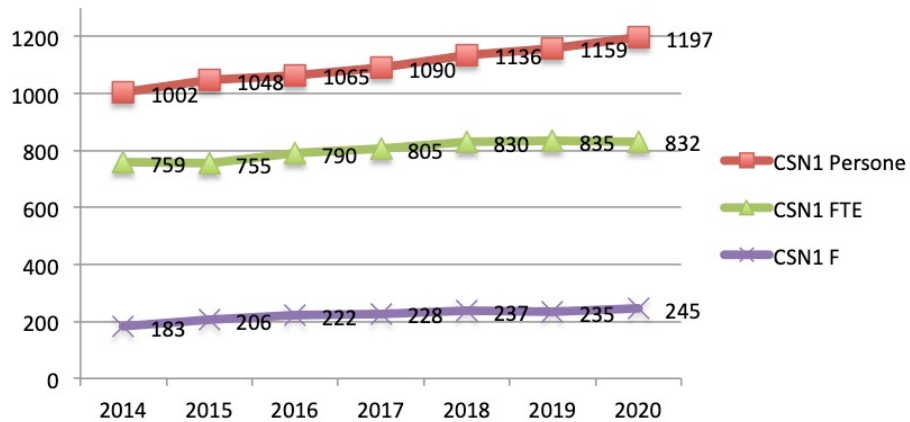
# CSN1

personnel

affiliation FTE fraction: 70-75 %

publications

CSN1 FTE e Persone



	2014	2015	2016	2017	2018	2019	2020
Number of publications (PUBS)	535	543	603	573	642	682	568
Average IF	5,03	4,7	4,4	4.5	5,2	4,14	4,1**
FTE	759	755	790	805	830	835	831,85
PUBS / FTE	0,71	0,72	0,76	0,71	0,77	0,81	0,71
% INFN authors	28	29	29	29	29	25	Not computed yet

# Physics @Hadron Colliders

# LHC getting ready for RUN 3

- 2021: progress of the 8 LHC sectors towards readiness



- Run3 → Physics from June 2022 to Nov 2025
- About  $100 \text{ fb}^{-1}/\text{year}$  ( $1.8 \times 10^{11}$  p/bunch)
- Final confirmation of Run 3 beam energy: **6.8 TeV**

- ATLAS New Small Wheels (NSW) were on critical path for RUN 3. Construction and tests had an impressive acceleration in 2021
- NSW-A and NSW-C completed and positioned in the pit in September and November 2021.

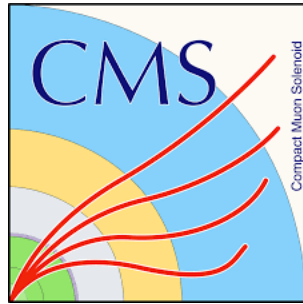
**INFN FTE: 207,3**

NSW-A



NSW-C

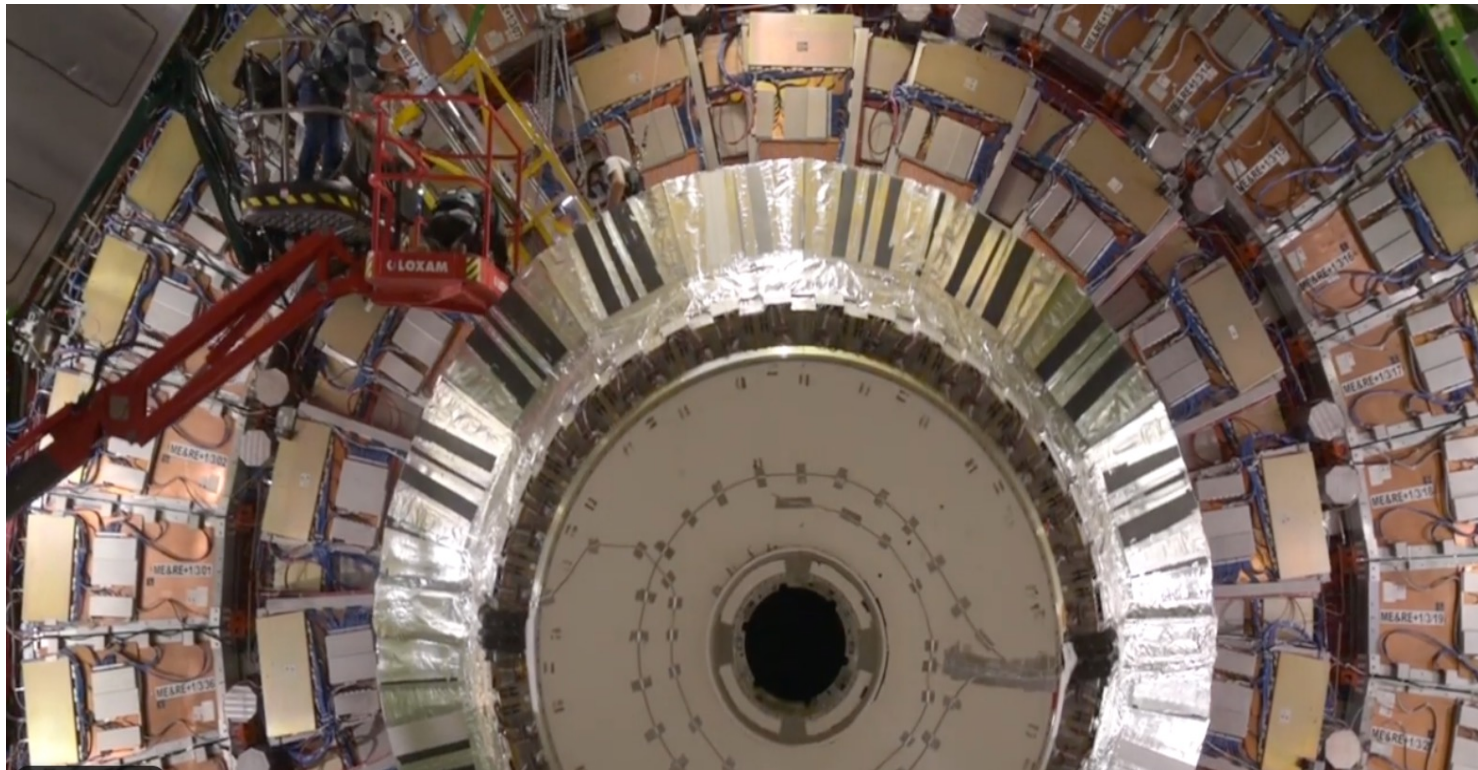




# and Run 3

**INFN FTE: 245,2**

- Upgrades (in particular the new layer 1 of the pixel detector and the new GEM chambers) all installed.







# – Phase 2 upgrades

- Highest priority project of the ESPP
  - Aim: tenfold increase in integrated luminosity and LHC's lifetime extension beyond the mid-2030s
- Progress made on accelerator & detector upgrades despite the difficult situation (pandemic)
- However **significant delays (1.5 years)** accumulated for the start

## > 100 New Magnets:

- Quadrupole Triplets ( $\text{Nb}_3\text{Sn}$ )
- 2 types of dipoles 
- 3 types of corrector magnets 

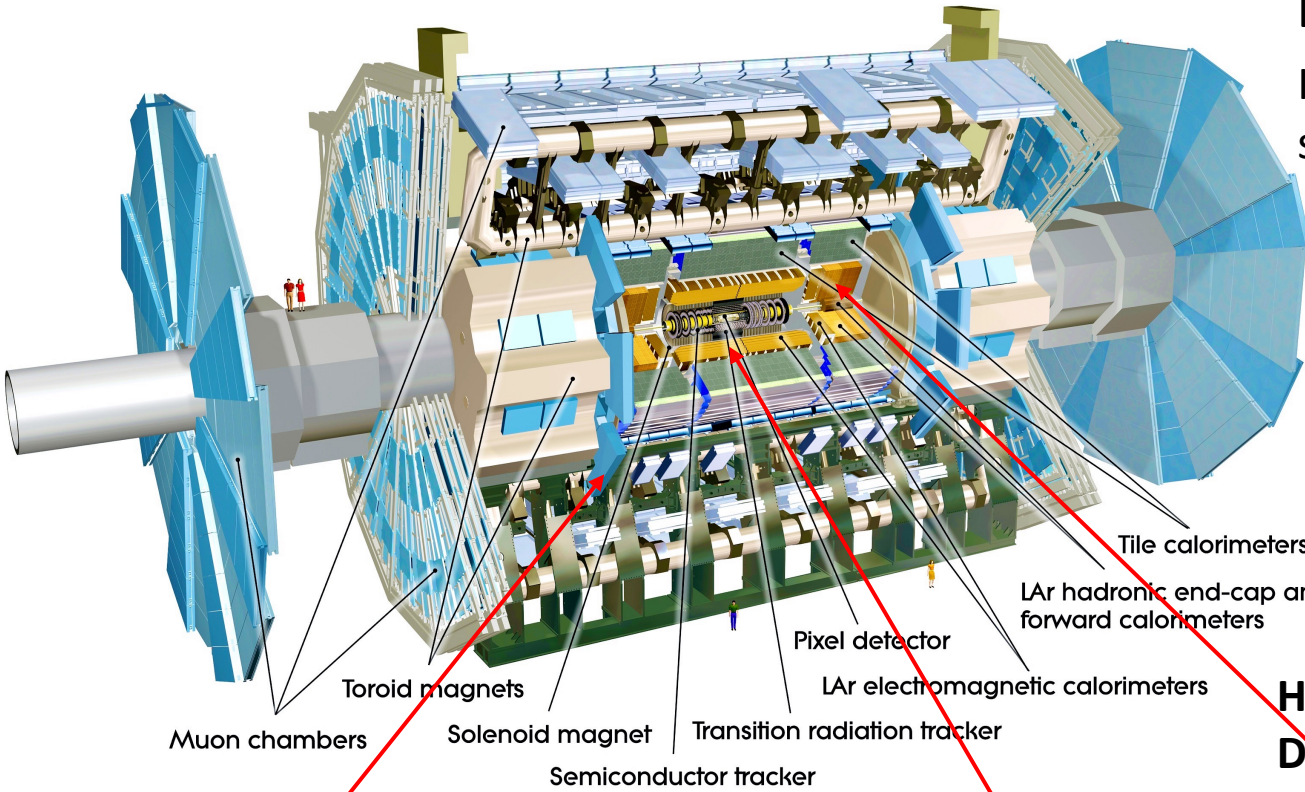
## • Main concerns:

- $\text{Nb}_3\text{Sn}$  quadrupoles (inner triplets): first full-sized magnets at CERN showed performance limitations.
- ATLAS: Inner Tracker
- CMS: Endcap Calorimeter




# ATLAS upgrade Phase 2

**Core Budget: 19M€**



## Upgraded Trigger & DAQ

LvL0 Trigger at 1 MHz 

Improved HLT (150 kHz full-scan tracking)

## Electronics Upgrades

LAr & Tile Calorimeter

Muon system

## High Granularity Timing Detector (HGTD)

Forward region ( $2.4 < |\eta| < 4.0$ )

Low-Gain Avalanche Detectors (30 ps track resolution)

## New Inner Tracking Detector (ITk)

All silicon, up to  $|\eta| = 4$  

## New Muon Chambers

Inner barrel region with new RPC and sMDT detectors

## small upgrades

Lumi.detectors (1% precision goal) HL-ZDC



A PISA l'attività si articola in: **Analisi dei dati** e **Sviluppo di rivelatori** per la calorimetria e il trigger

## Rivelatore:

- EF Tracking (NEW):
  - Studio degli algoritmi di pixel clustering (applicazione tecniche di Machine Learning al tracciamento)
  - Attività di system design e integrazione (accelerazione della ricostruzione di tracce con CPU, GPU, FPGA)
- Calorimetro adronico TileCal:
  - Manutenzione e *data quality check*
  - Test di fotomoltiplicatori (PMT) per la fase di "HL-LHC" e test di PMT multianodo
  - Progettazione nuova linea ottica per il sistema di calibrazione laser di TileCal

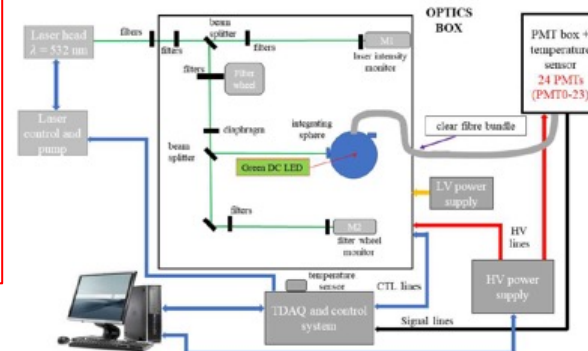


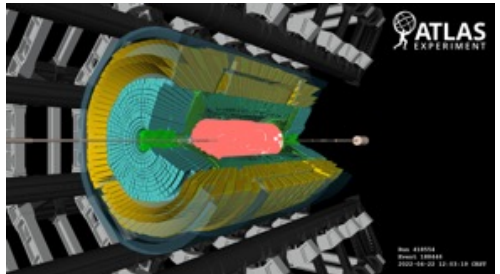
A. Annovi: responsabile nazionale TDAQ

P. Mastrandrea: responsabile System Design & Integration per EVTFLT

F. Scuri: TileCal P2U Deputy project leader

S. Leone: resp. nazionale TileCal

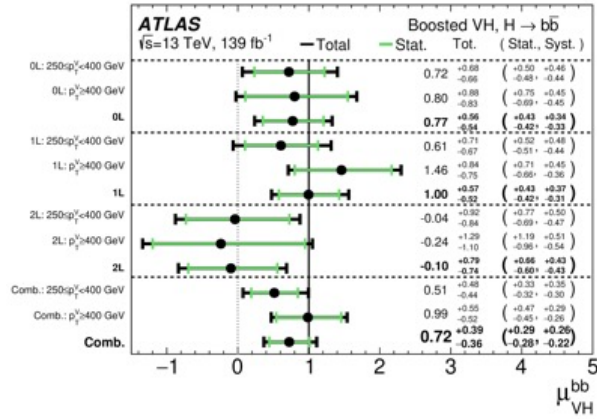
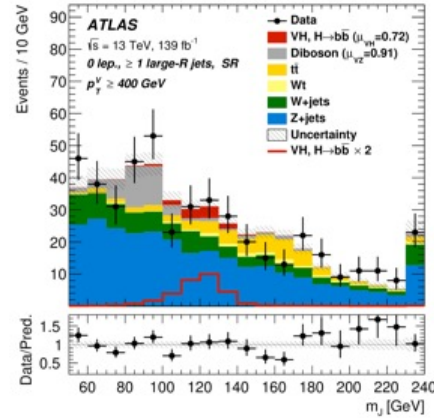
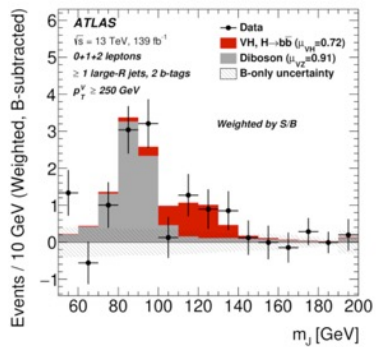




Analisi Dati a Pisa:

- Higgs -> b-jets: principali sviluppatori dell'analisi VHbb nella regione ad alto  $p_T$  (boosted)
  - Tesi M.Calvetti – premio migliore tesi di ATLAS 2021 / Premio Conversi 2021
  - Tesi G.Di Gregorio – premio migliore tesi di ATLAS 2022
- Higgs -> b-jets: sviluppo analisi WH( $\tau\nu bb$ ) e ZH( $\tau\tau bb$ ) + sinergia con HH( $\tau\tau bb$ ). Combinazione analisi Run 2
- Higgs - combinazione di tutte le analisi del Run2
- Misura g-2 del tau – collaborazione teorici Pisa (N.Vignaroli) / studio pdf fotoni /sezioni d'urto / modello BSM
- Ricerca di particelle esotiche, candidati per dark-matter, particelle a lunga vita media

P. Francavilla: convener H-combination group  
M. Verducci: convener DP – Non collision background group



# CMS upgrade Phase-2

## New Tracker

- Rad. tolerant, high granularity and light
- 40 MHz selective readout for hardware trigger
- Extend coverage to  $\eta \simeq 3.8$

## Barrel Electromagnetic calorimeter

- New electronics
- Lower operating temperature (8°)

## Muon systems

- New DT electronics
- Some CSC electronics
- Complete RPC coverage in region  $1.5 \lesssim \eta \lesssim 2.4$
- Adding GEM detectors
- Muon tagging  $2.4 \lesssim \eta \lesssim 3$

## New Endcap Calorimeters

- Rad. tolerant - high granularity
- 4D shower measurement capability

## New Luminosity and beam conditions monitoring

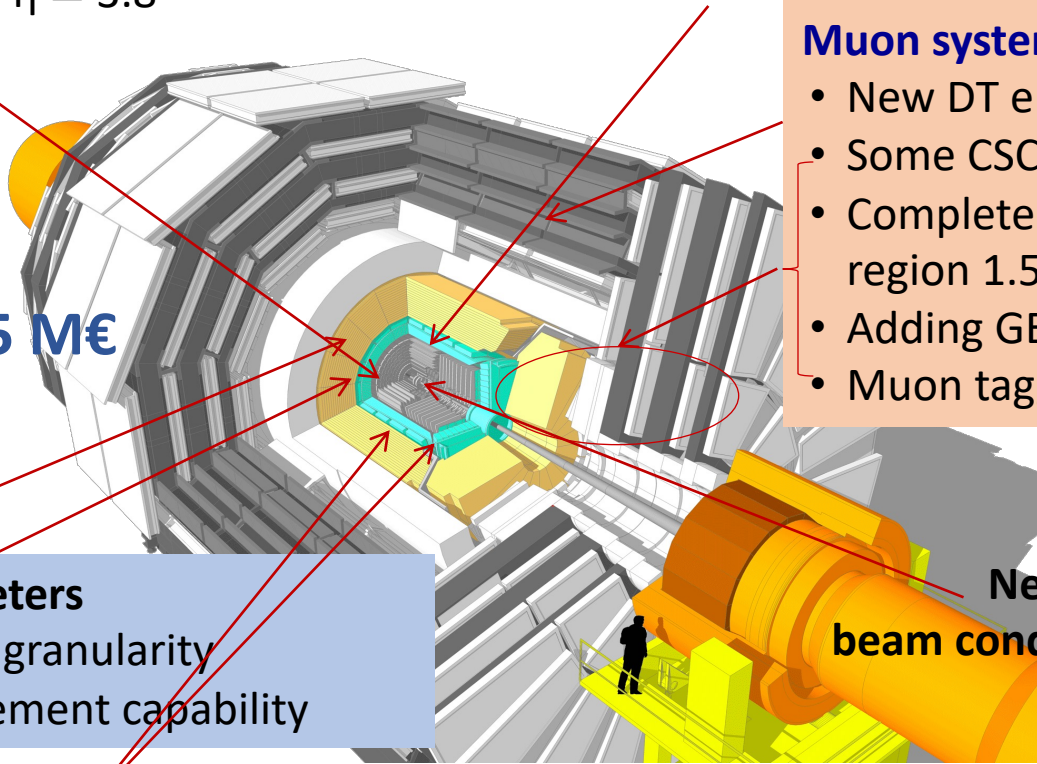
## New detector for MIP timing measurement

- Barrel layer: Lyso Crystals
- Endcap layer: silicon LGADs

## Trigger/DAQ

- Implement track information at 40 MHz
- Full readout at  $\simeq 750$  kHz after  $12.5 \mu\text{s}$
- Register  $\simeq 7.5$  kHz after computing selection

Core Budget: 25,5 M€



# CMS: Analisi e Run 3

## Analisi

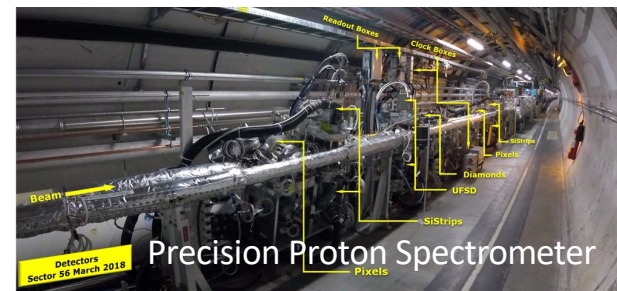
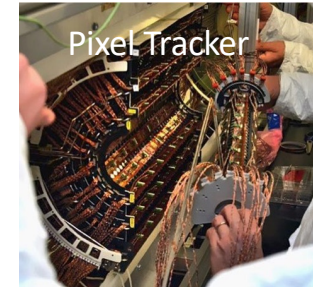
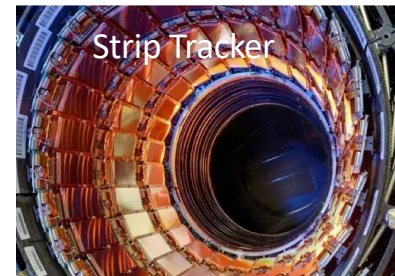
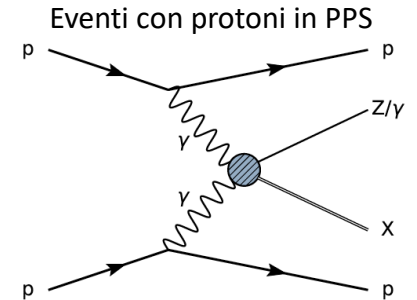
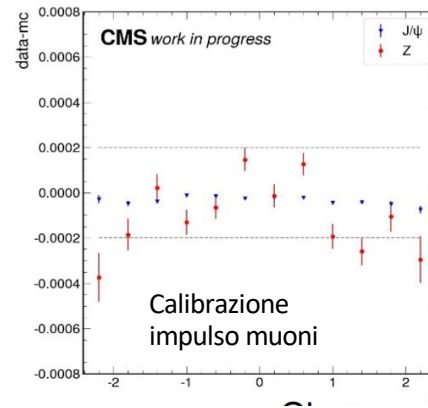
- Massa W (ERC)
- VBF con fotoni stato finale
- Ricerca produzione HH
- Studio canali  $H \rightarrow bb$  e  $H \rightarrow \mu\mu$
- LFV:  $B_c \rightarrow J/\psi l\nu$
- Ricerca  $Z(\ell\ell)+X$  e  $\gamma+X$  con PPS
- Coordinamento attività di fisica di CMS
- Tecniche di analisi con Machine Learning e AI

## Rivelatore

- Tracciatore
  - Sistema di controllo e sicurezza, DAQ, ricostruzione e calibrazione offline
- Precision Proton Spectrometer
  - Timing detector
  - Sviluppo fw e sw DAQ
  - Presa dati Totem
- Coordinamento attività Trigger di CMS

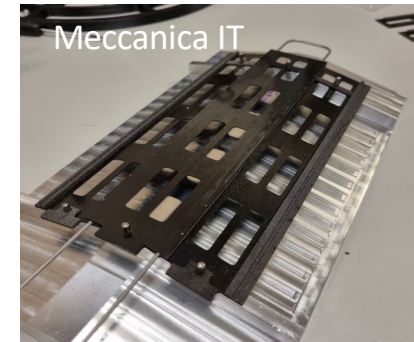
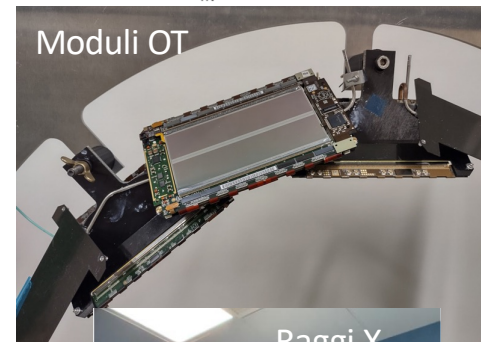
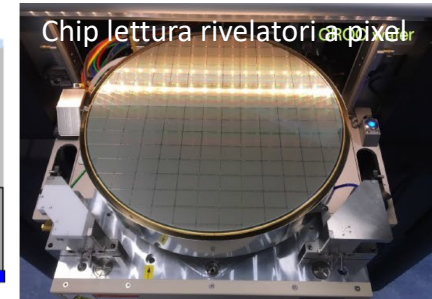
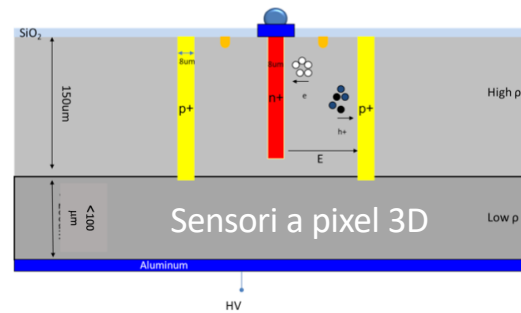
## Calcolo

- T2 a Pisa
- Coordinamento Servizi e Infrastrutture CMS



# Upgrade CMS Tracker

- Sviluppo e caratterizzazione sensori a pixel 3D
- Sviluppo ASIC lettura rivelatori a pixel (RD53-CROC)
- Disegno, sviluppo e costruzione meccanica barrel tracciatore interno (a pixel: IT) (fino a fine 2025)
- Test e integrazione su strutture meccaniche moduli tracciatore esterno (OT) (2023-2026)
- Progettazione, produzione e sviluppo fw schede ATCA per DAQ e Trigger
- Recenti acquisizioni in sezione:
  - Sistema di raffreddamento a CO<sub>2</sub> : 300W a -28C
  - Macchina radiogena per caratterizzazione rivelatori
- Criticamente dipendenti da completamento camere pulite e camera climatica



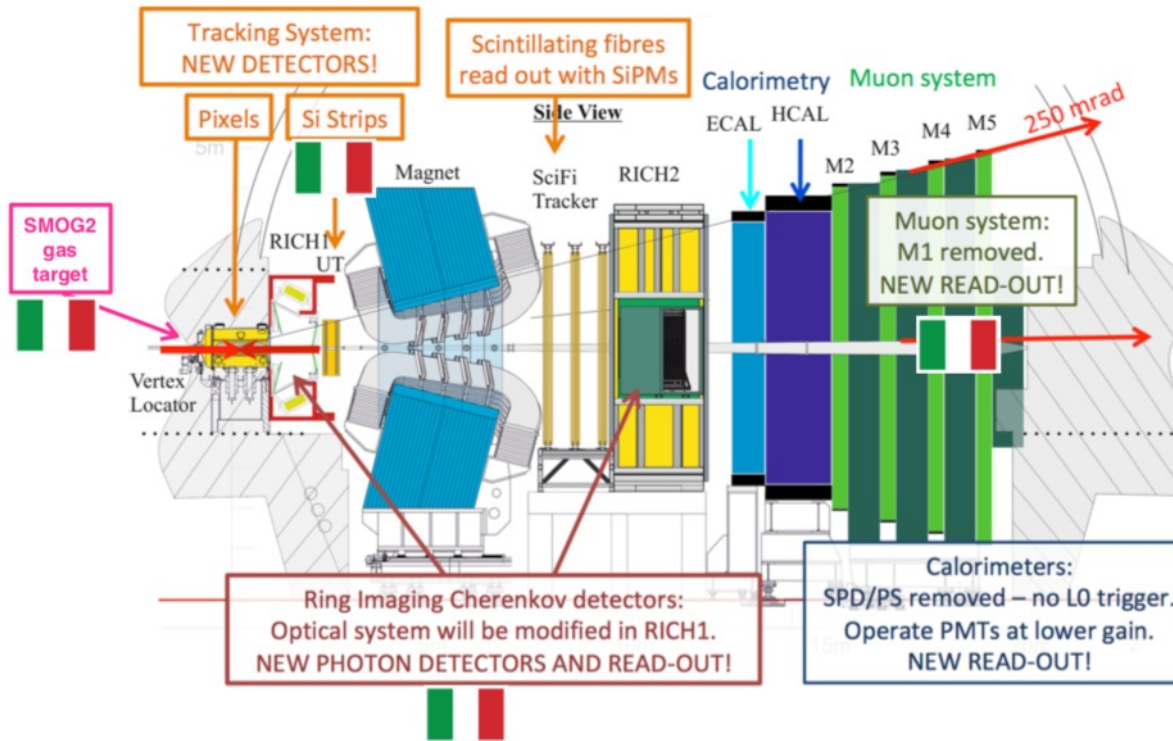
# Flavour Physics



# and Run 3

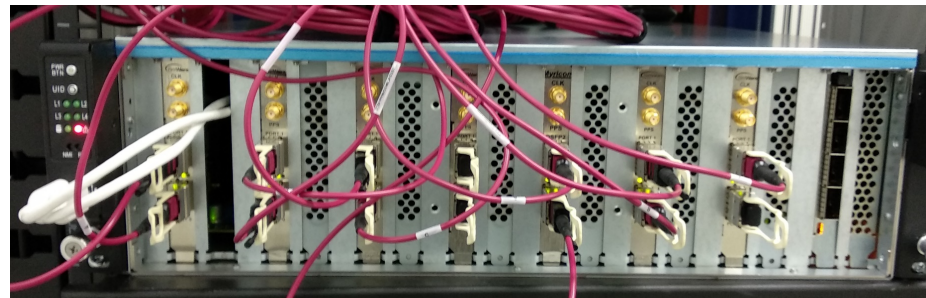
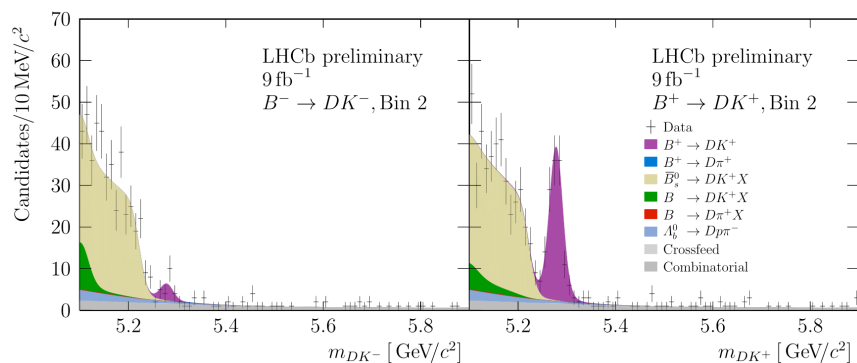
INFN FTE: 102,7

- LHCb: essentially rebuilt, elements on critical path: Upstream Tracker (UT), Vertex Locator (VELO) and Scintillator Fibers (SciFi)
  - UT, involving the INFN CSN1 groups, suffered delays for delivery of components. All UT modules now available and will be integrated into the experiment.





- 25/5: **Publication** of world-best  $D^0$  mixing parameter  $y_{CP}$
- LHCb22: **Largest observed CPV asymmetry** (85%)
- Commissioning new detector for Run-3 next year
- Preparing TDRs for Upgrade-II ( $L > 10^{34}$ )



PISA activities

- Responsabilita': Convener Charm WG + Convener RD WG + Chair Editorial Board
- Studenti 2022: 3 PhD Similfellows @ CERN, 6 studenti magistrali
- Premio Conversi (2nd time) (T. Pajero), miglior tesi LHCb e miglior tesi UNIPI (G. Tuci)
- Attivita':
  - Largest Italy group in Real Time Analysis
  - Leadership of Fast Simulation efforts, founders of 'Simulation Project'
- Commissioned FPGA-based hit-finding in LHCb vertex detector (VELO)
  - Increases DAQ throughput by 12%. Replaces raw VELO data on-the-fly with hit coordinates.
  - First real-life application of RETINA project: data reconstruction embedded in the readout
- New development: FPGA-based Luminosity measurement in real time & LHC feedback
- INFN prototype of FPGA tracker at Level-0 (30 MHz) getting ready for parasitic running in Run 3



It looks like the “old” Belle, but it is effectively a brand new detector

Only structure, magnet and calorimeter crystals are re-used

**Features:**  
 Energy-asymmetric  $e^+e^-$  collider  $\rightarrow$  low background.  
 Highest luminosity ( $3.1 \times 10^{34} \text{cm}^{-2}\text{s}^{-1}$ ) in the world.

**Vertex detector (VXD)**  
 Inner 2 layers: pixel detector (PXD)  
 Outer 4 layers: strip sensor (SVD)  
 Vertex resolution :  $15 \mu\text{m}$



**Particle Identification**

Barrel: Time-Of-Propagat counters (TOP)  
 Forward: Aerogel RICH (ARICH)



**Target:**  
 Collect more than  $50 \text{ab}^{-1}$  data;  
 700  $BB$  pairs/second  
**Currently:**  
 213.5  $\text{fb}^{-1}$  data are collected.

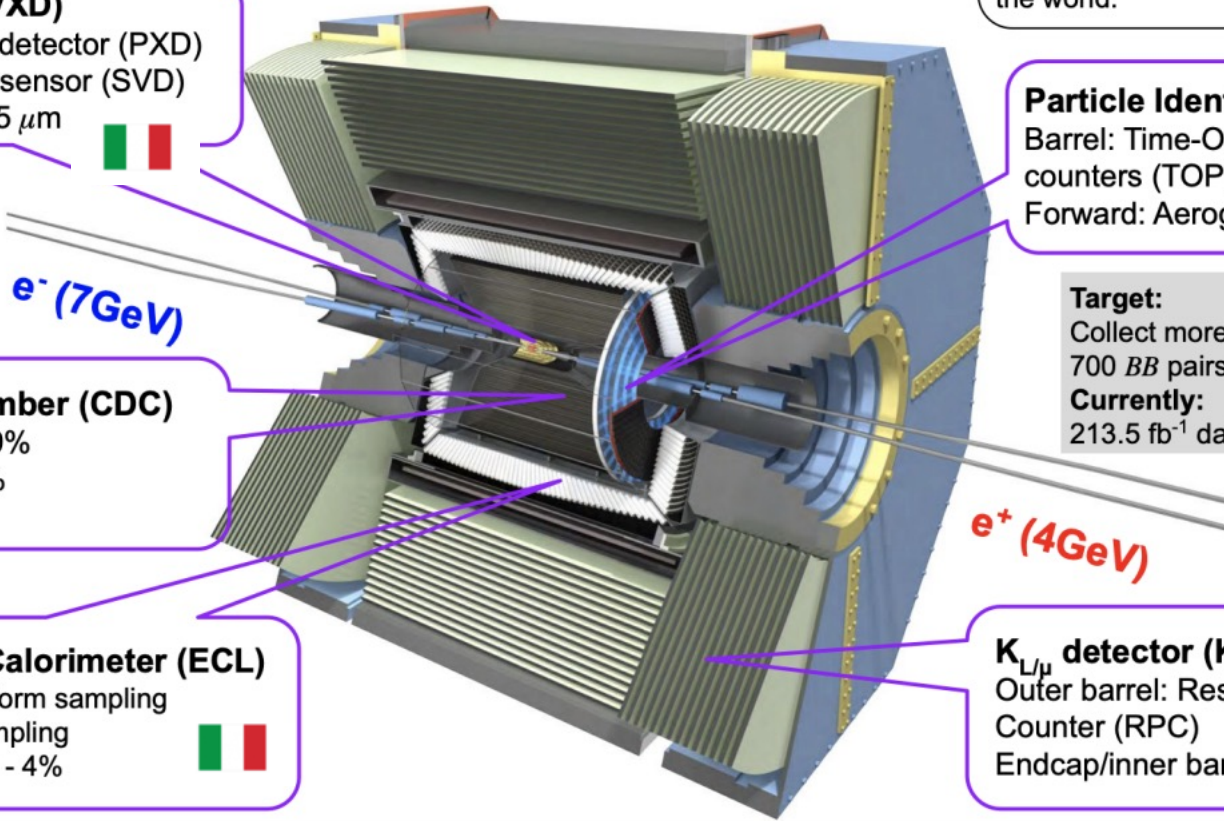
**Central Drift Chamber (CDC)**  
 Track efficiency  $\sim 99\%$   
 $dE/dx$  resolution : 5%  
 $p_T$  resolution : 0.4 %

**ElectroMagnetic Calorimeter (ECL)**  
 Barrel: CsI(Tl) + waveform sampling  
 Endcap: waveform sampling  
 Energy resolution : 1.6 - 4%



**$K_{L/\mu}$  detector (KLM)**

Outer barrel: Resistive Plate Counter (RPC)  
 Endcap/inner barrel: Scintillator





# $D^0$ & $D^+$ Lifetimes

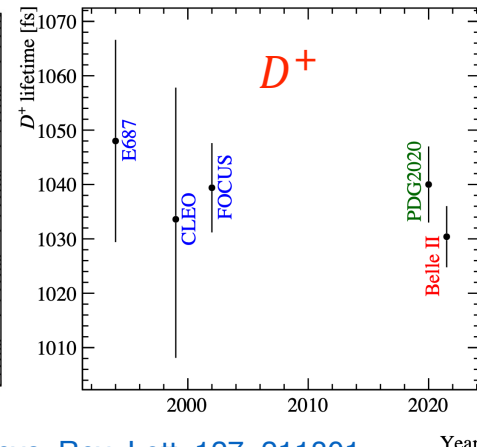
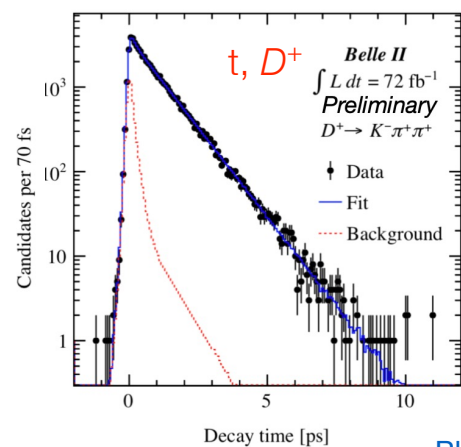
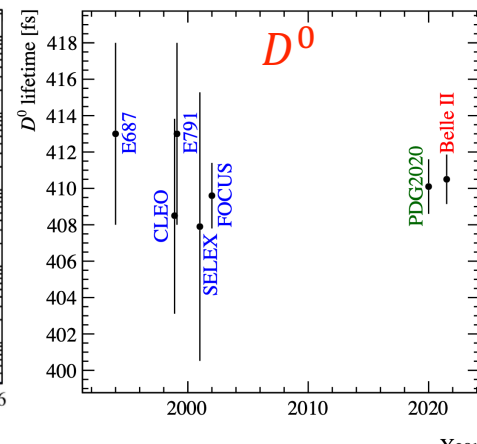
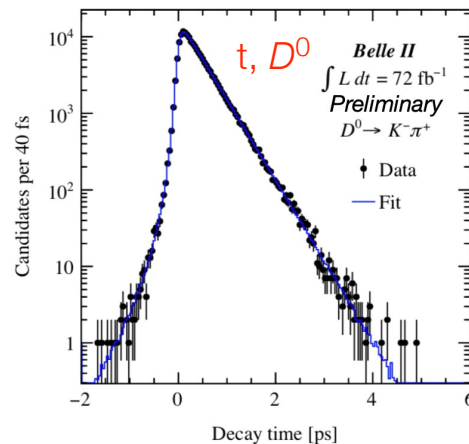
$$\begin{aligned}\tau(D^0) &= 410.5 \pm 1.1 \pm 0.8 \text{ fs} \\ \tau(D^+) &= 1030.4 \pm 4.7 \pm 3.1 \text{ fs} \\ \tau(D^+)/\tau(D^0) &= 2.510 \pm 0.015\end{aligned}$$

Few % accuracy establishes the excellent performance of vertex detector!

- Silicon Vertex Detector  $\rightarrow$  FW&BW modules built in INFN clean rooms

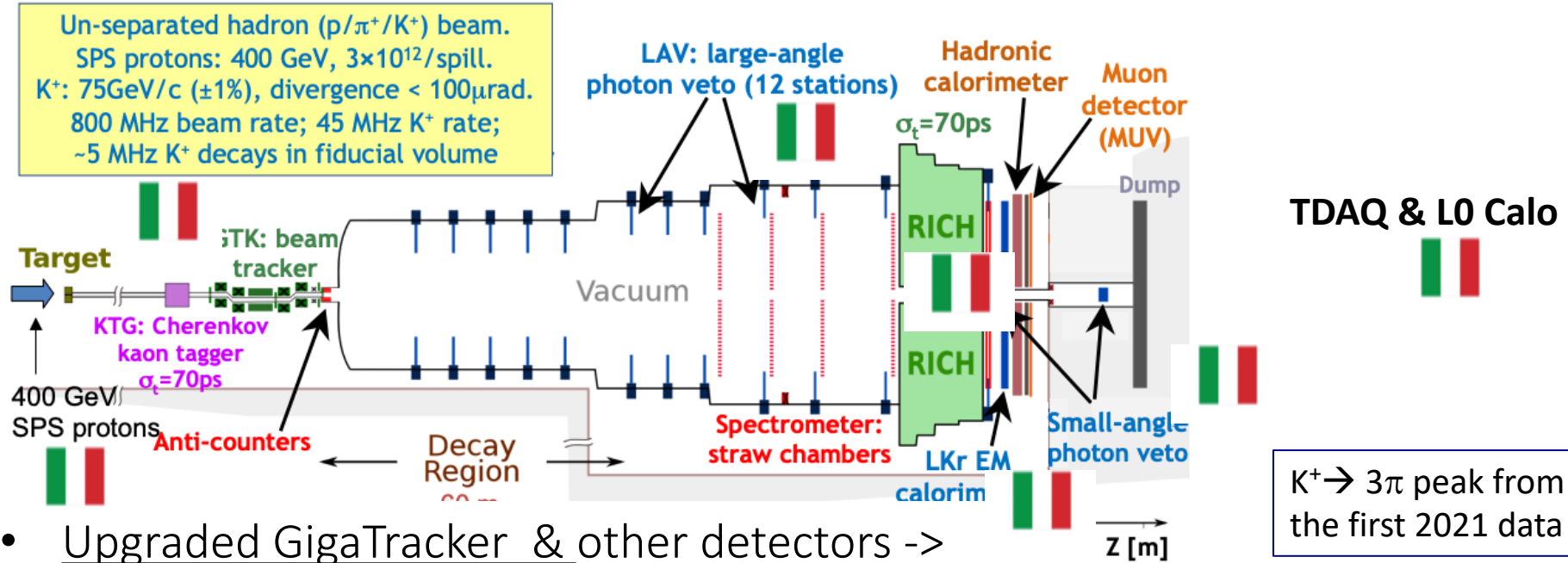


world's most precise measurements of  $D^0$  and  $D^+$  lifetimes

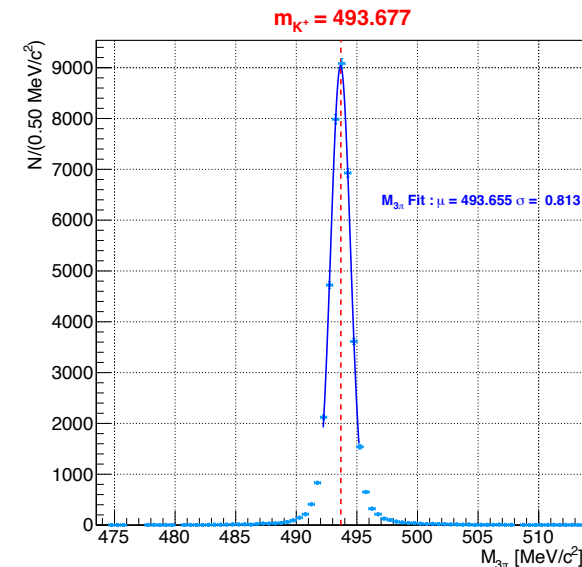


[Phys. Rev. Lett. 127, 211801](https://arxiv.org/abs/1801.07228)

Year



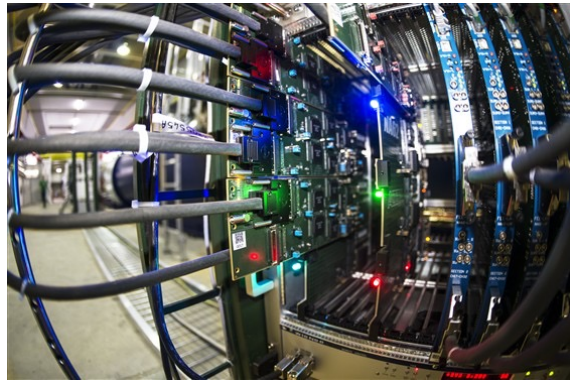
- Upgraded GigaTracker & other detectors -> reduce upstream pions by a factor 6
- Acceptance increased with new collimator.
- Goal: 80 signal evt with Run 3, with  $BR(K^+ \rightarrow \pi^+ \nu \nu)$  uncertainty closer to theoretical one.
- Dump mode run for the search of new physics





@PISA

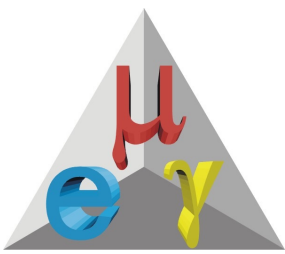
L'esperimento è attualmente nella sua seconda fase di presa dati, con intensità del fascio incrementata



- Attività di manutenzione per sistema TDAQ comune dell'esperimento  
Coordinamento TDAQ in NA62 M. Sozzi
- Contributo all'upgrade del processore centrale di trigger di livello 0  
Progetto coordinato in NA62 da J. Pinzino
- Attività di progettazione ed implementazione di trigger con l'uso di GPU a basso livello  
Progetto coordinato in NA62 da G. Lamanna
- Attività di analisi: studio di violazioni di lepton-flavour universality nei decadimenti  $K^+ \rightarrow \pi^+ \mu^+ \mu^-$  vs.  $K^+ \rightarrow \pi^+ e^+ e^-$  (J. Pinzino)
- Studio di implementazione di tecniche di deep-learning in trigger di basso livello
- Contributo all'hardware e al readout del sistema di veto upstream

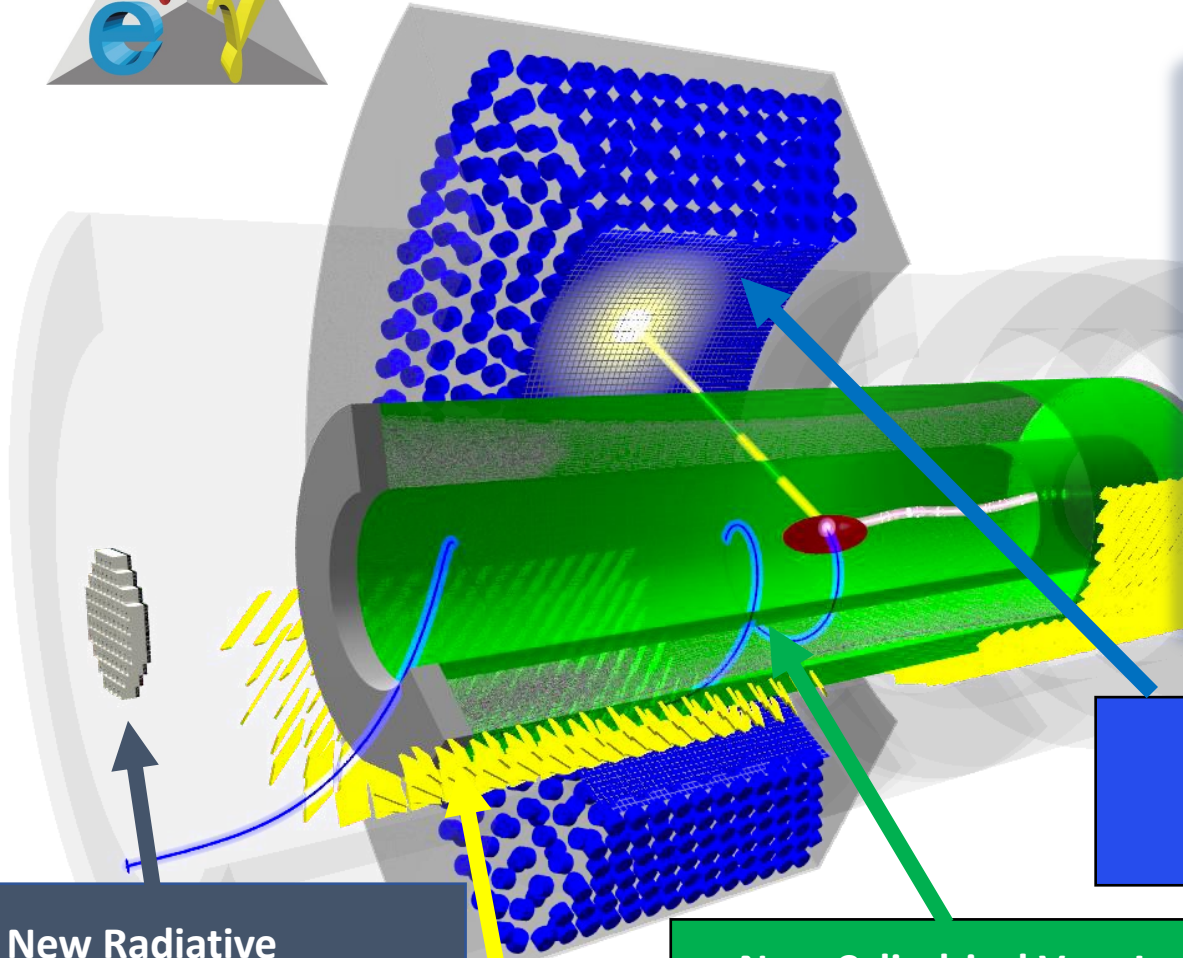


# Charged Leptons Physics



# MEG II @ PSI

- Search of  $\mu \rightarrow e\gamma$  at BR below  $10^{-13}$  with  $10^8 \mu/s$  @ PSI



- New Drift Chamber and its Front End Electronics
- Mechanics and Calibration System of the New Timing Counter
- New Trigger System



**New Radiative Decay Counter**

**New Cylindrical Very Low Mass Drift Chamber**

**New Timing Counter Pixelated**

**High density readout of the LXe  $\gamma$  detector by means of UV sensitive SiPM**



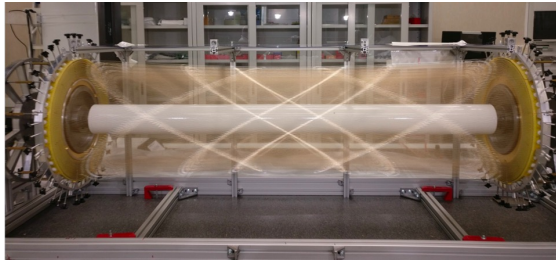
**INFN FTE: 17,8**

# Esperimento MEG II - latest highlights

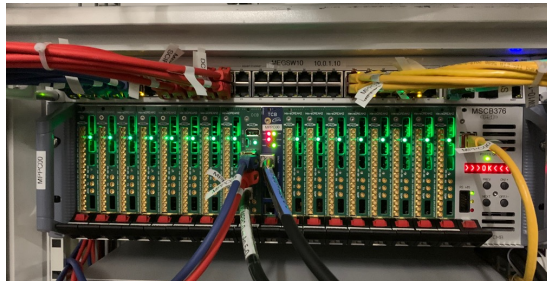
Misure di altissima precisione dei decadimenti del  $\mu$ :  $\mu \rightarrow e\gamma$  ma anche  $\mu \rightarrow eX$  e  $\mu \rightarrow eX\gamma$

Attività' in corso @PSI

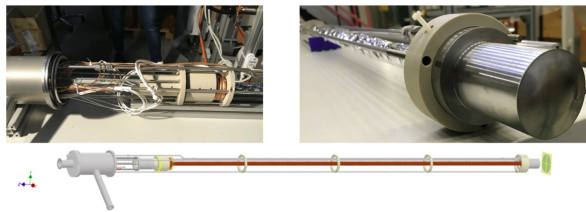
camera a drift



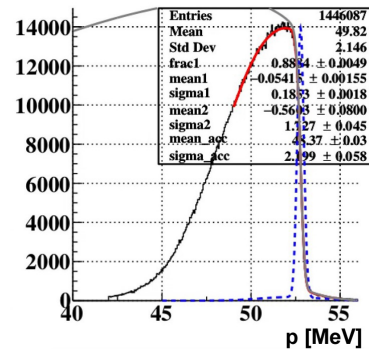
elettronica  
TDAQ



Fascio e Calibrazioni



primo spettro energia e+



Dal 2021 MEG e'  
in presa dati

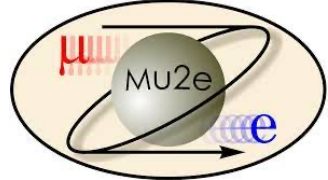
\*verifica anomalia X17  
possibile in MEG:  
prima presa dati di  
commissione lo scorso  
Febbraio

Attività' in corso @INFN



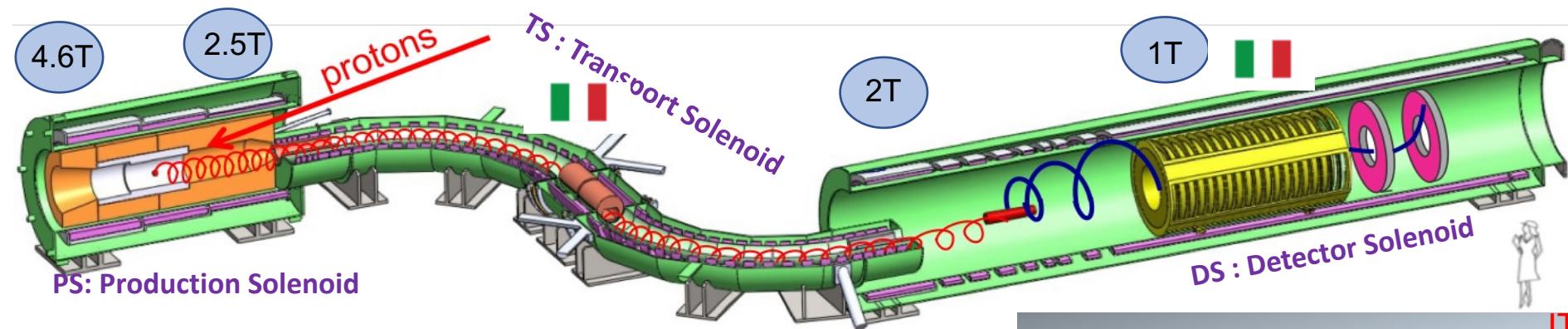
Costruzione camera  
seconda camera a  
drift per  
l'esperimento ,  
tempo per  
costruzione ~1.5y





# Mu2e @ Tevatron

- Goal: **x1000/x8000** (RunI/RunII) current SES on CLFV  $\mu \rightarrow e$  conversion
- Highest  $\mu$  beam intensity (10 GHz stop-rate) in the world  $\rightarrow 10^{18}$   $\mu$  stops
- Run-I data taking foreseen for 2025-2027



Prototyping/oversight of TS IT  
 Module Construction @ASG  
 Superconductors (Genoa) IT

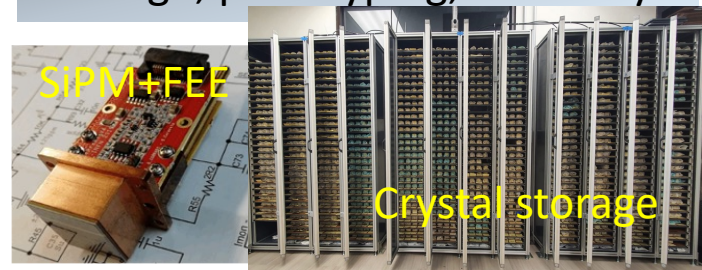


TS assembly @ FNAL



Calo Mechanical assembly @ INFN

CsI+SiPM calorimeter IT  
 Design, prototyping, assembly IT



SiPM+FEE

Crystal storage

TDAQ + DCS + reconstruction  
 Large participation

- $\rightarrow$  Data transfer @ 40 GBps (200 kB/ev)
- $\rightarrow$  SW trigger on disk @  $O(10\text{pB/y})$

# Mu2e

**Mu2e** search for the coherent, neutrinoless muon-to-electron conversion in the field of a nucleus.

$R_{\mu e} < 6 \times 10^{-17}$  (@ 90% C.L.).

**INFN** is in charge of e.m. calorimeter. **Pisa** responsible for the readout electronics, most of mechanics and thermal cooling

Important milestone: VST in May 2021. All mechanical components, crystals, FEE are already in FNAL.

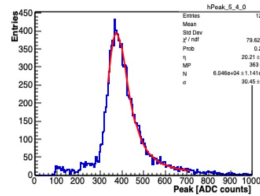
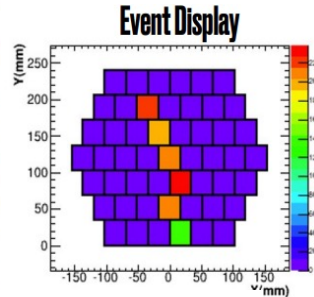
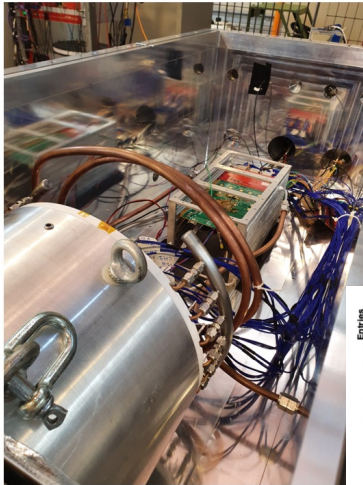
Assembly start: June-July 2022



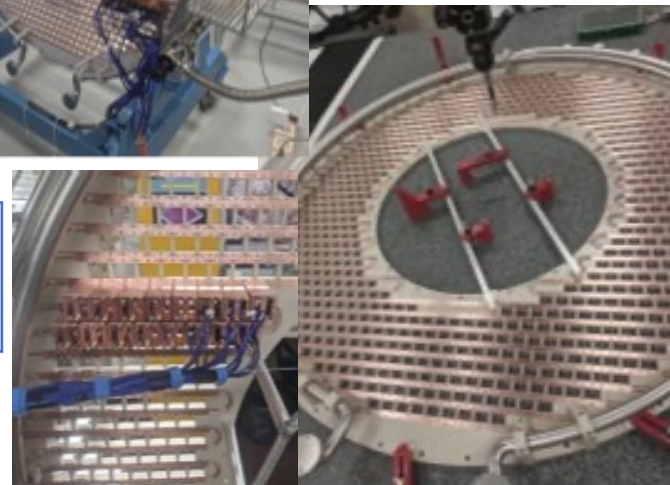
Manifolds and crates for electronics cooling: designed @ INFN Pisa and tested @ LNF



Carbon Fiber Inner Cylinder for CsI crystal support: designed @ INFN Pisa and tested @ LNF



ReadOut Units and cabling of Front-End Electronics: production ongoing

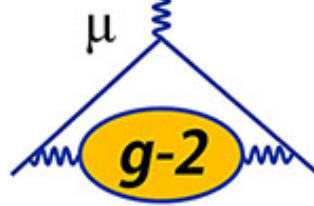


BackPlane for SiPM and ReadOut cooling: designed and tested @ INFN Pisa

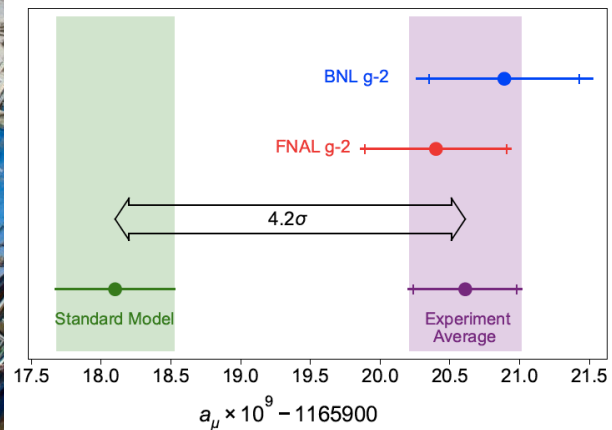
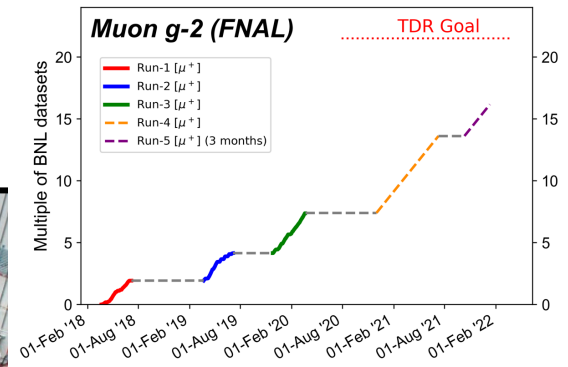
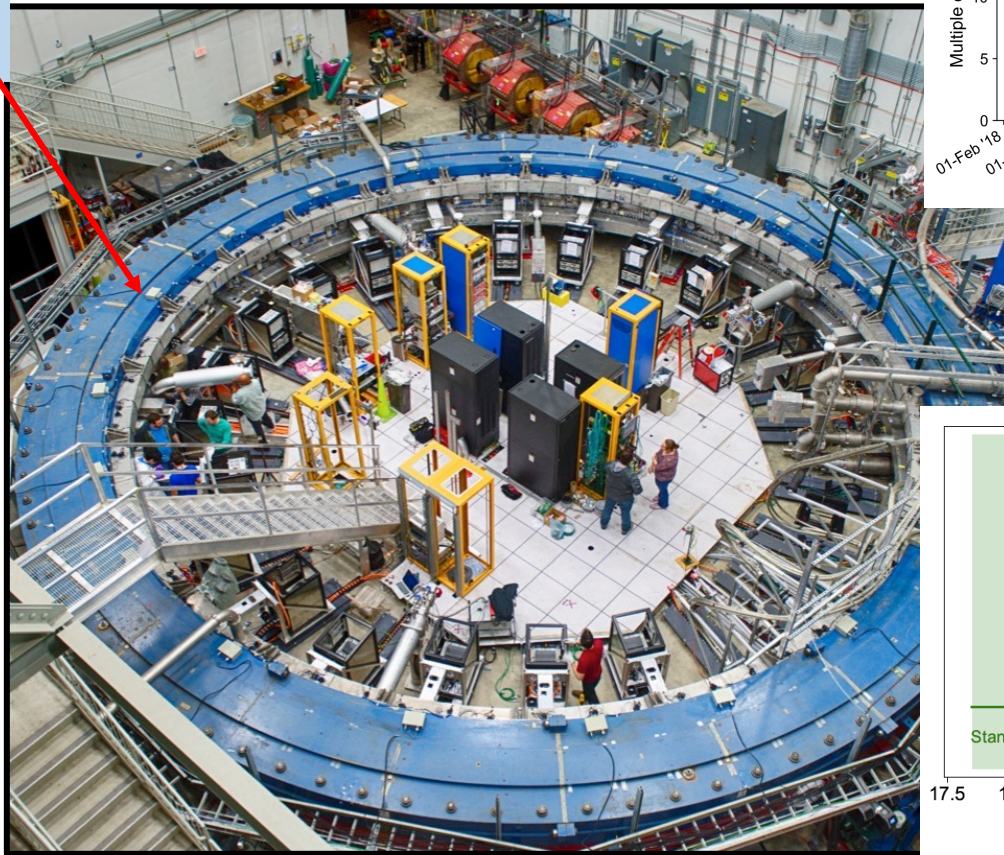
Vertical Slice Test @ Module 0

Energy distribution deposited by cosmic rays

laser control system  
for a precise  
calorimeter  
calibration



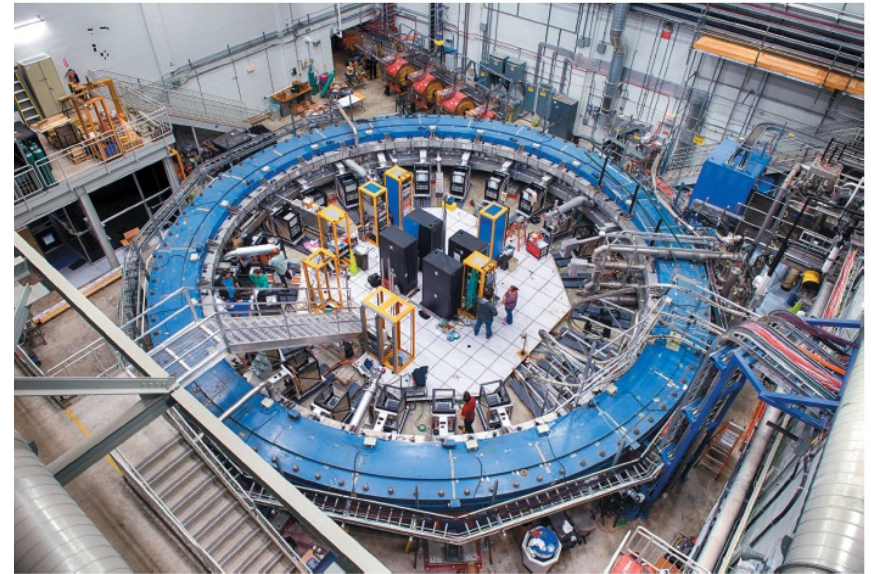
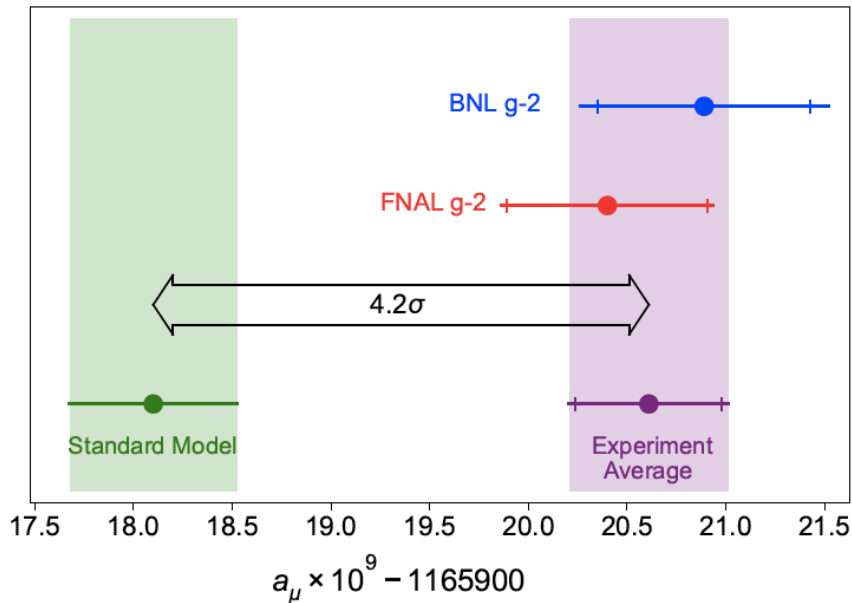
# status



- RUN 5 (Nov 2021-Jul 2022) -> reach project luminosity  $\sim 20 \times \text{BNL}$
- Aim: reducing by a factor of 3 the total uncertainty
- Analysis RUN2+3 ( $5 \times \text{BNL}$ ) under way

# Muon G-2@Fermilab

- Misura del momento magnetico anomalo del muone ad altissima precisione nell'esperimento Muon g-2 a Fermilab.
- La misura combinata di Fermilab e BNL si discosta di  $4.2 \sigma$  dalla predizione del Modello Standard  $\rightarrow$  Possibile evidenza di nuova fisica



The Muon g-2 experiment will look for deviations from the standard model by measuring how muons wobble in a magnetic field.

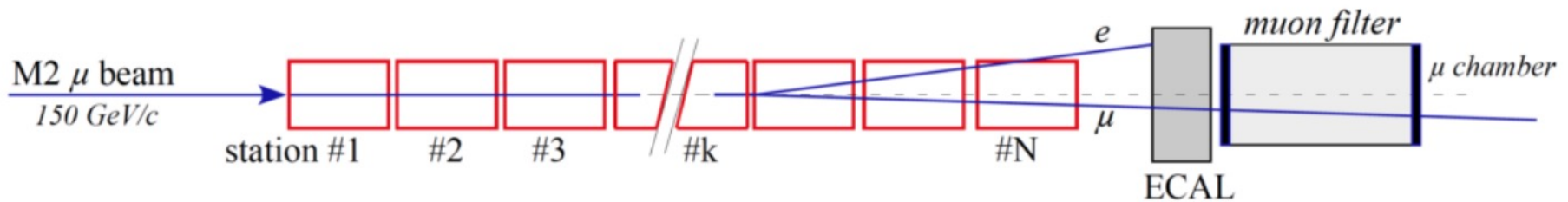
<https://web.infn.it/gminus2/>

- Attività INFN su calibrazione calorimetro con sistema laser, misura del campo magnetico residuo tramite rotazione di Faraday di raggio laser polarizzato, software di ricostruzione positroni, misura della frequenza di precessione del muone



# status

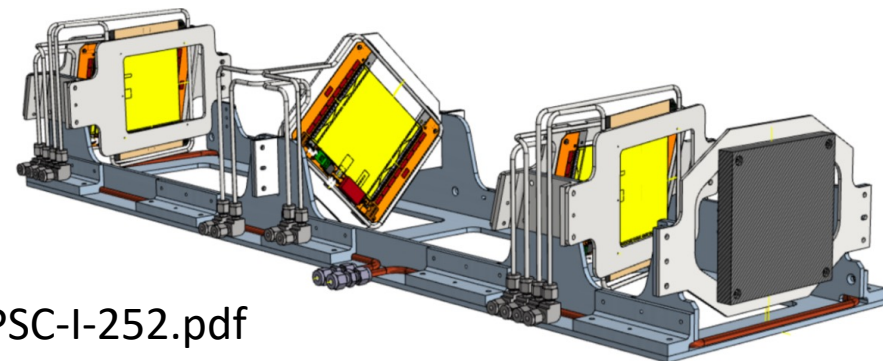
- Precise determination of the leading hadronic contribution to the muon magnetic moment
  - Measure the differential cross section shape of  $\mu e$  elastic scattering
- Test run for **MUonE** in 2022/2023
- Physics run with 2% accuracy before LS3 Final accuracy ( $<0.5\%$ ) after LS3
- Activities in Pisa in the laboratory and data analysis

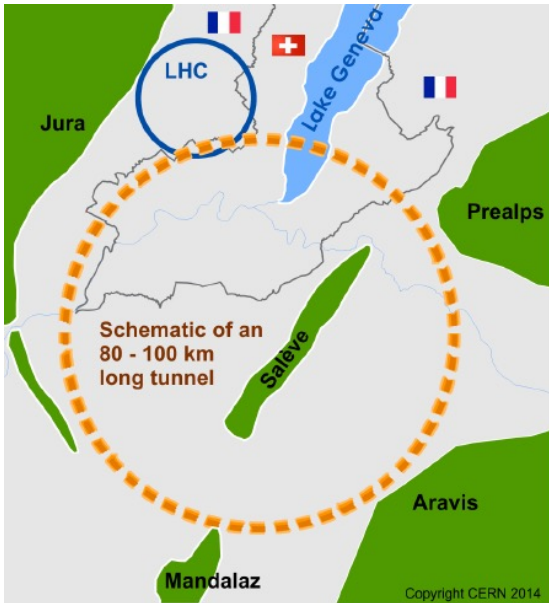


-C. M. Carloni Calame et al *PLB* 746 (2015) 325

-G. Abbiendi et al *Eur.Phys.J.C* 77 (2017) 3, 139

-LoI <https://cds.cern.ch/record/2677471/files/SPSC-I-252.pdf>



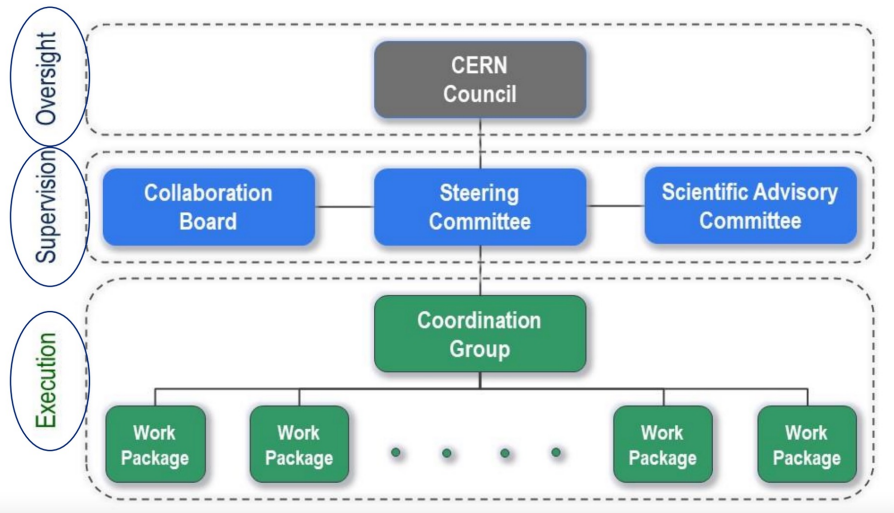


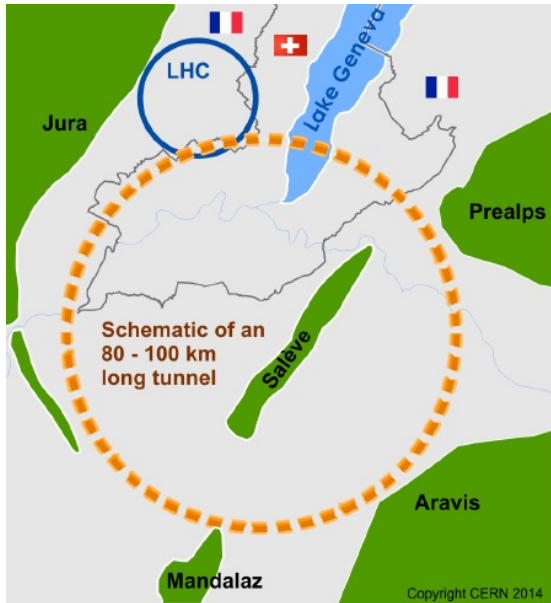
## Desired timeline\* for a future collider at CERN:

- recommendation by next ESPP ~ 2026
- approval by CERN's Council by end of the decade
- construction's in early-2030's
- operation's start mid 2040's.

## INFN Contribution:

- **In 2016:** RD-FCC activity started
  - CDR & ESPP preparation
  - IDEA detector concept proposed





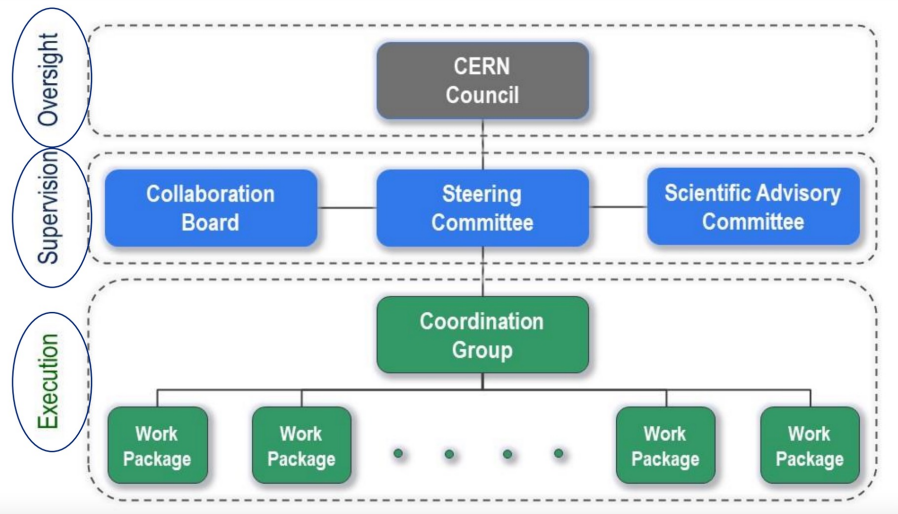
## Desired timeline\* for a future collider at CERN:

- recommendation by next ESPP ~ 2026
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- construction's in early-2030's
- operation's start mid 2040's.

## INFN Contribution:

### Nowadays:

- 91 scientists/16 FTE
- ~ 6-700 k€/yr (NFN & EU grants)
- 7 Italian institutions in the CB
- Several responsibilities
- Detector, MDI, software/physics





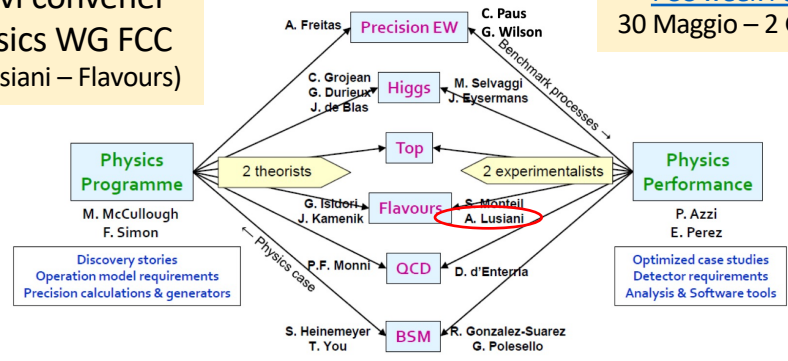
<https://agenda.infn.it/event/29752/>  
130 partecipanti - 9 da Pisa

Attività ECFA WG1 – precision  
(conveners A.Irles, A.Meyer, A.Freitas, P.Azzurri)  
<https://indico.cern.ch/event/1129966/>  
<https://indico.cern.ch/event/1131344/>  
Precision calculations for future e+e- colliders  
<https://indico.cern.ch/event/1140580/>

<https://fcc.web.cern.ch>  
<https://indico.cern.ch/category/15156/>

nuovi convener  
Physics WG FCC  
(A Lusiani – Flavours)

FCC week Parigi  
30 Maggio – 2 Giugno



composizione Gruppo Pisa

1	Annovi Alberto	CSN I	10
2	Azzurri Paolo	CSN I	30
3	Bedeschi Franco	CSN I	25
4	Bianchini Lorenzo	CSN I	5
5	Buttazzo Dario	CSN IV	10
6	Cavasinni Vincenzo	CSN I	0
7	Cervelli Franco	CSN I	0
8	Chiarelli Giorgio	CSN I	10
9	Ciocci Maria Agnese	CSN I	10
10	Francavilla Paolo	CSN I	10
11	Leone Sandra	CSN I	10
12	Ligabue Franco	CSN I	10
13	Messineo Alberto	CSN I	10
14	Palla Fabrizio	CSN I	5
15	Punzi Giovanni	CSN I	10
16	Roda Chiara Maria	CSN I	10
17	Rolandi Luigi	CSN I	15
18	Scuri Fabrizio	CSN I	10
19	Spagnolo Paolo	CSN I	5
20	Tenchini Roberto	CSN I	10
21	Tonelli Guido Emilio	CSN I	0
22	Trincherini Enrico	CSN IV	10
23	Verducci Monica	CSN I	20
FTE: 2.35			

Attività locale hardware / software ricostruzione

- Hidra2**: Realizzata stazione di test per fibre scintillanti.
  - Prime misure di attenuazione vs  $\lambda$  (C.Roda, F.Bedeschi)
- Vertexing** (in DELPHES) : fit di decadimenti in sequenza con impulsi ed errori delle particelle associate alla catena di decadimento. In arrivo vincoli in massa dei vertici. (F. Bedeschi)

<https://indico.desy.de/event/33640/>



# Conclusions

- Strong INFN involvement in HEP experiments at the intensity and energy frontiers
- At present most of the budget focused on projects at CERN
  - LHC experiments upgrade taking most of the effort, both from the personnel and financial point of view
- Efforts dedicated also to other activities:
  - Special focus on flavour and lepton sector
- Preparing the future which, in particular, means FCC