Perspectives from CSN1

3–4 Apr 2024 LNL
Quarta Giornata Acceleratori

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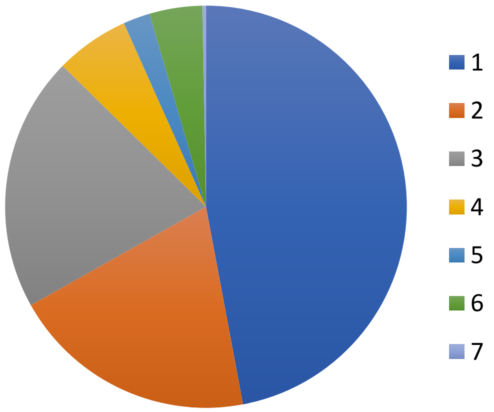
INFN
Istituto Nazionale di Fisica Nucleare
SEZIONE DI PISA

Linee di ricerca CSN1

- **ATLAS+CMS con upgrades HL-LHC**
- **Flavour physics**
- **Neutrino experiments**
- **Preparing the future**
- **Charged Lepton physics, Proton Structure, Dark Sector**

CSN1 Sector **2025**	FTE	Budget
Physics at hadron colliders (LHC)	48,20	47,05
Neutrino Physics	13,30	19,80
Flavor Physics (including LHCb)	24,40	20,50
Charged Lepton Physics	5,35	5,95
Proton Structure	2,15	2,16
R&D for Future Accelerators	5,77	4,26
Dark Sector	0,83	0,28

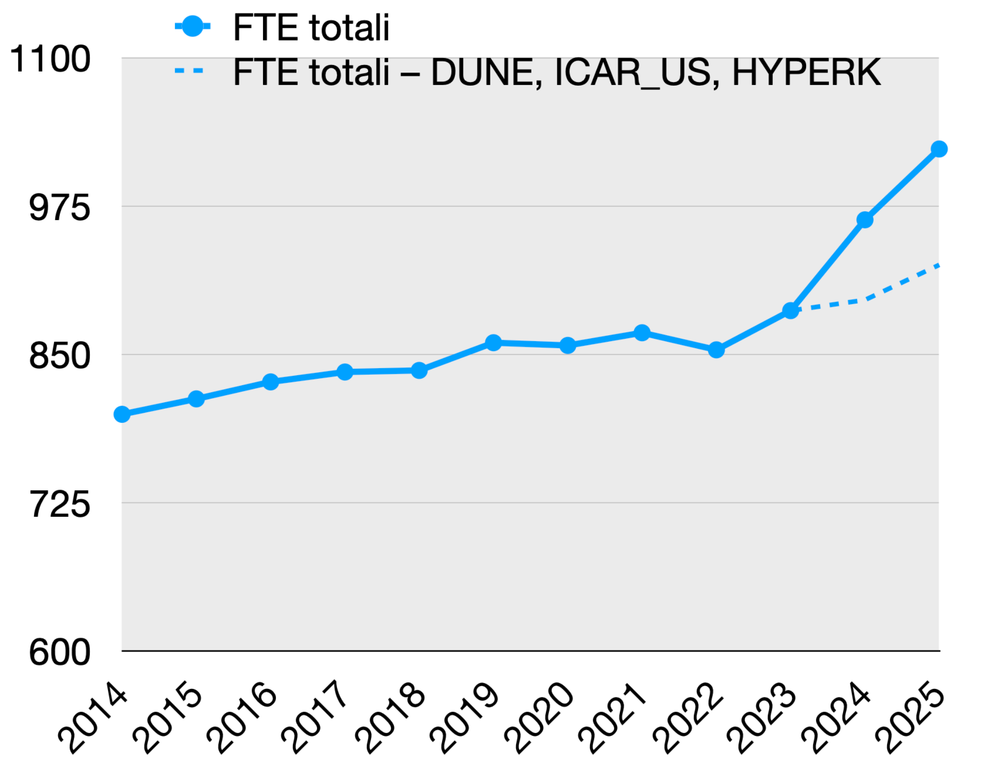


(*) 2025 CSN1 Budget 27 M€, does not include the external fund complementing HL-LHC and DUNE detector construction, Tier2 computing

CSN1 PERSONNEL

Frazione FTE con CSN1: ≈ 65-70% costante negli anni

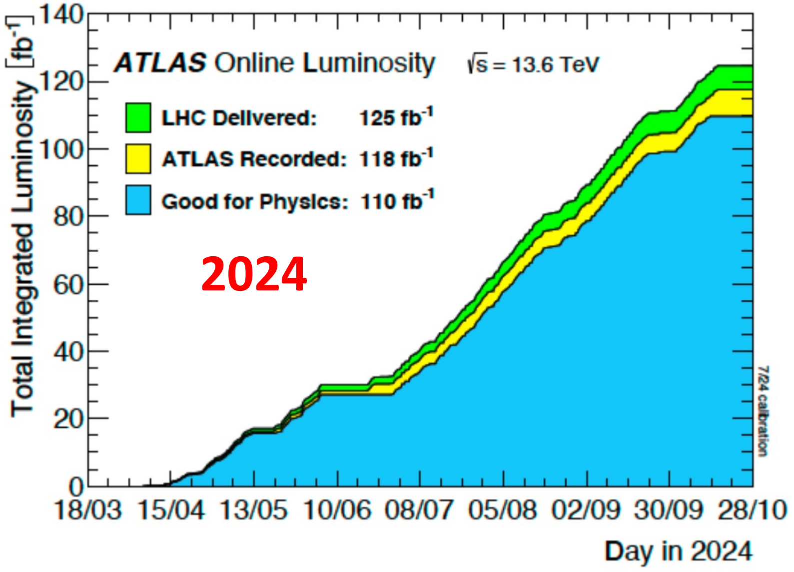
ANAGRAFICA ATTUALE (Aprile 2025) :
1019 FTE , 1531 Ricercatori + Tecnologi
1299 232

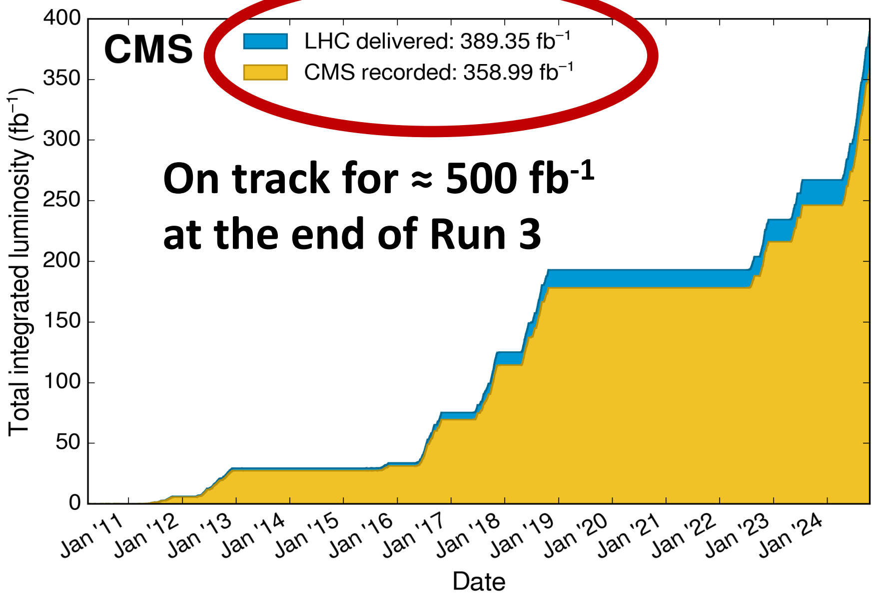


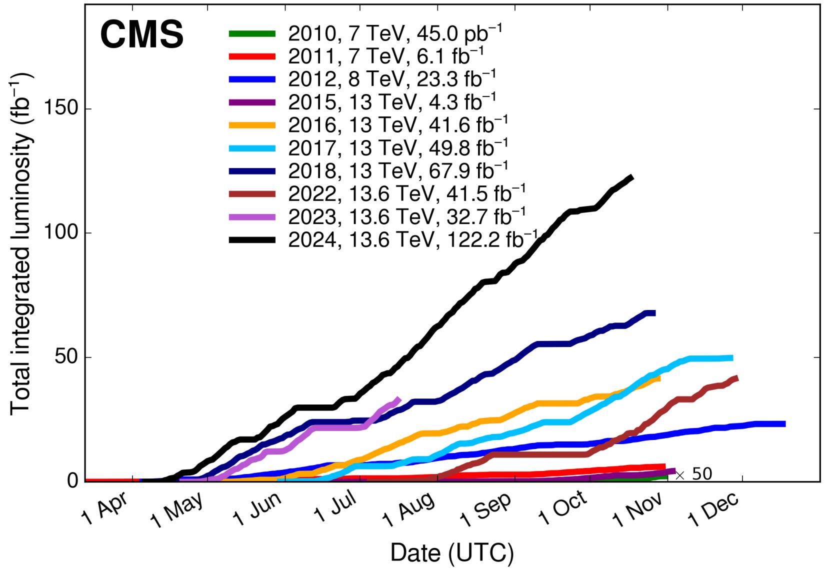
Produzione SCIENTIFICA CSN1

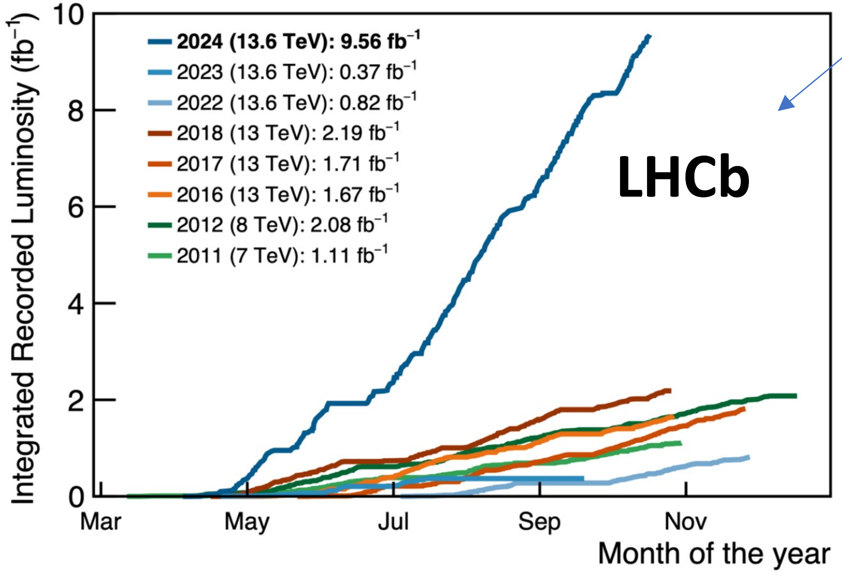
Pubblicazioni CSN1	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Numero pubblicazioni (PUBS)	535	543	603	573	642	682	568	454	322	637
IF Medio	5,03	4,7	4,4	4.5	5,2	4,14	4,33	5,49	5,55	4,46
FTE (*)	759,98	753,03	784,19	797,86	822,38	825,86	834,62	813,69	820,27	848,71
PUBS / FTE	0,71	0,72	0,76	0,71	0,77	0,81	0,71	0,56	0,39	0,75
% autori INFN	28	29	29	29	29	25	Non disponib	26,2	22,4	19,6

LHC 2024 Performance: Integrated Luminosity

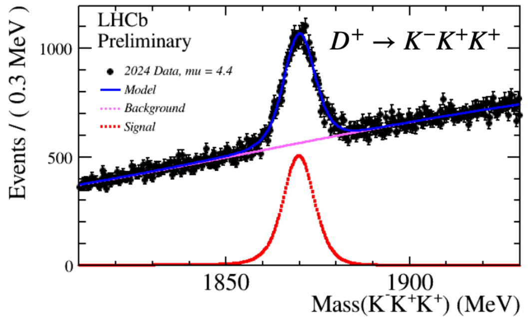








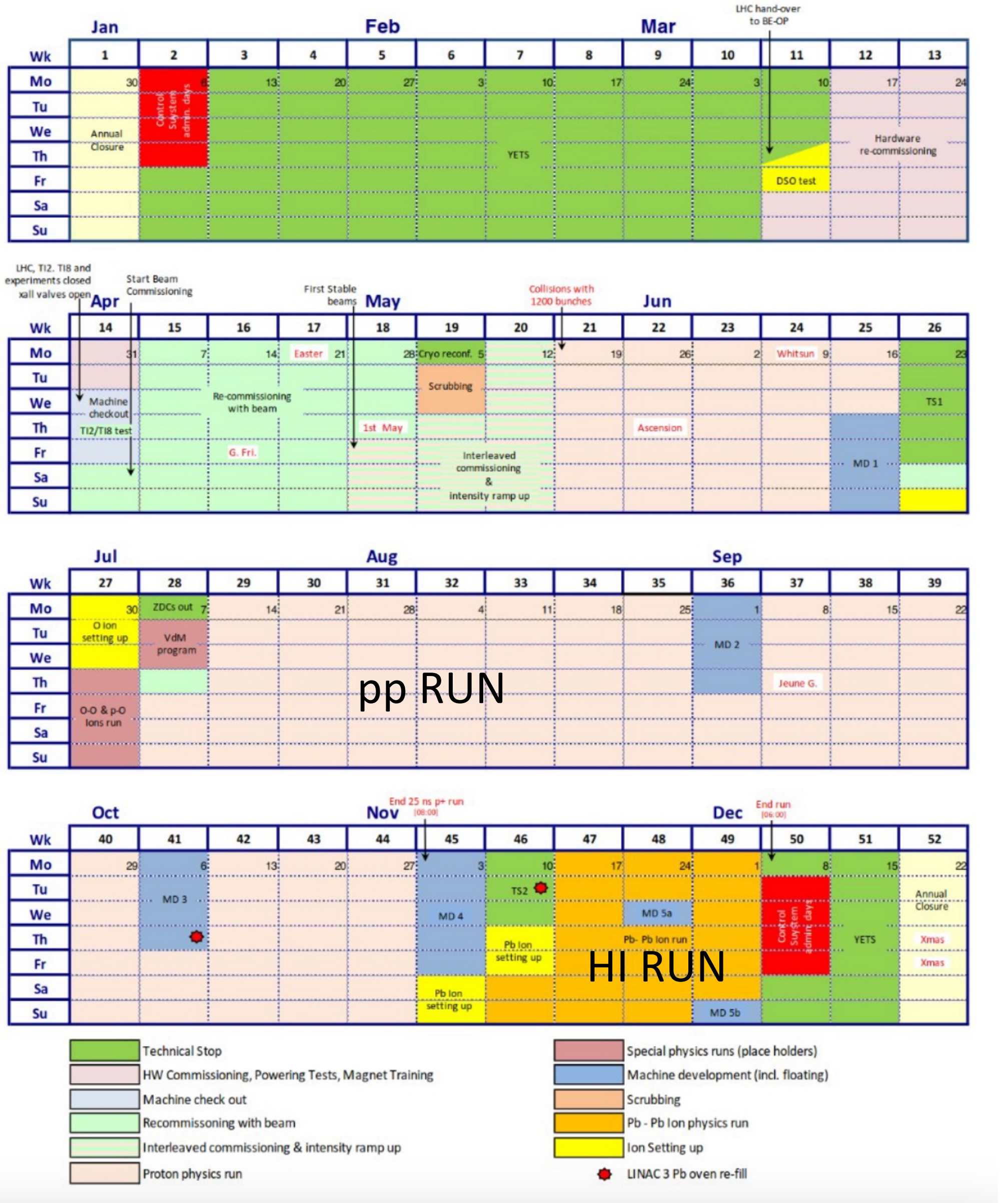
Excellent performance for LHCb Upgrade 1, too !

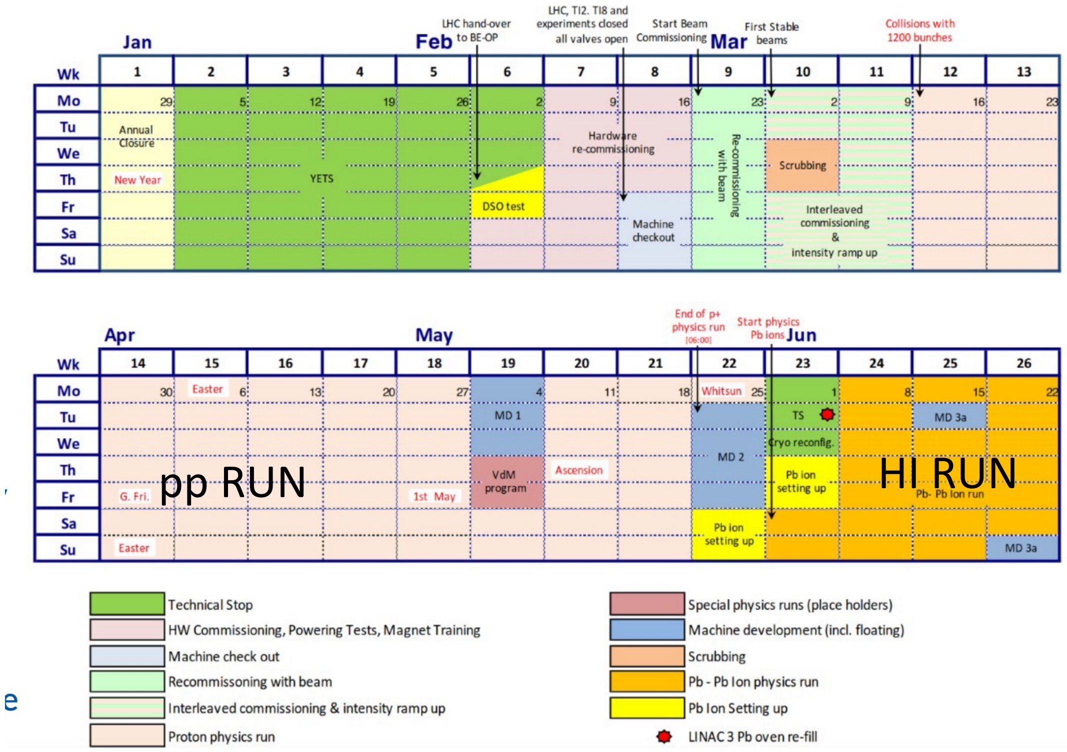


yield/pb^{-1}= 1.03×10^3

($\times$ 2.5 Run2)

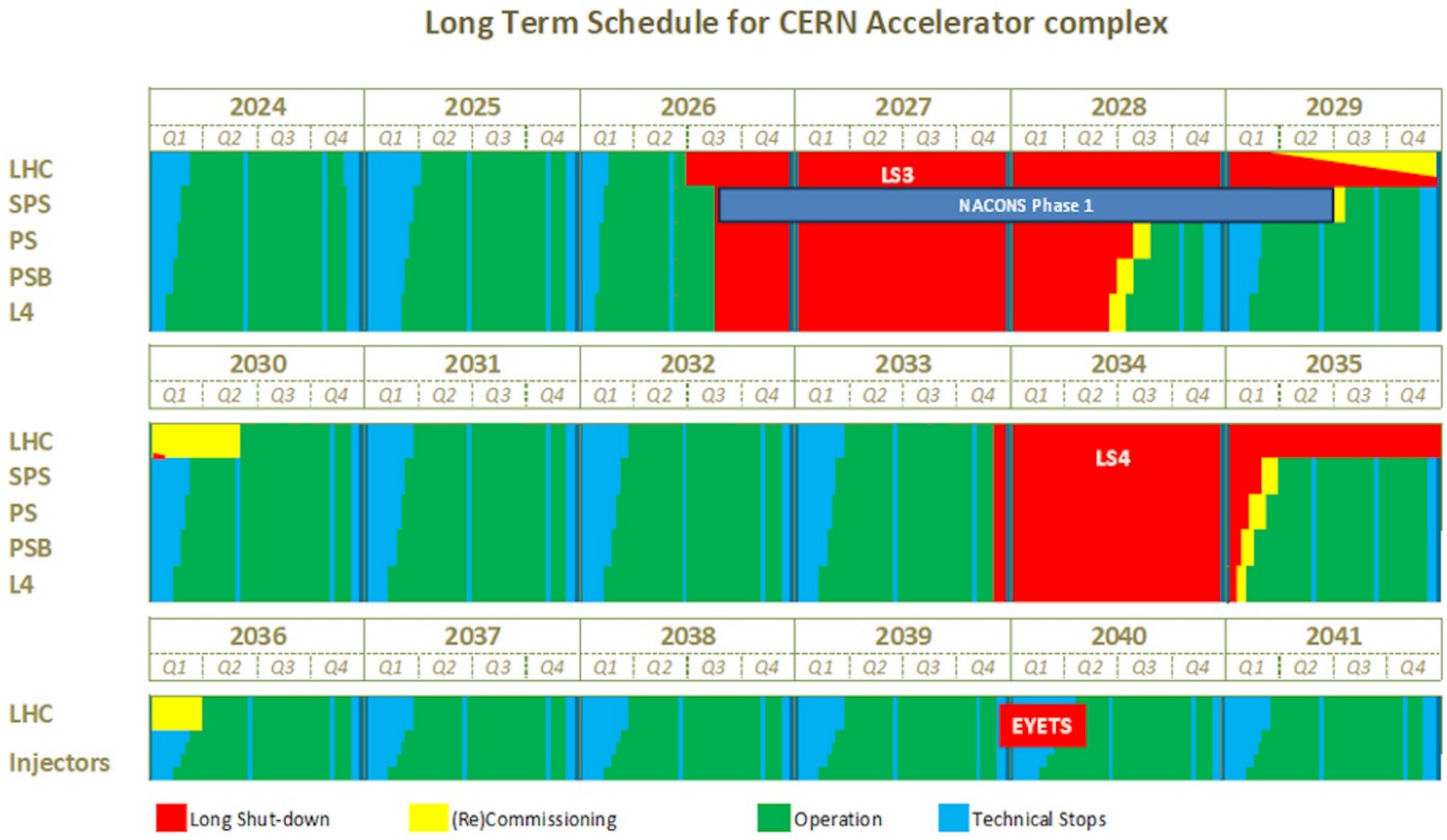
2025 and 2026 LHC schedule



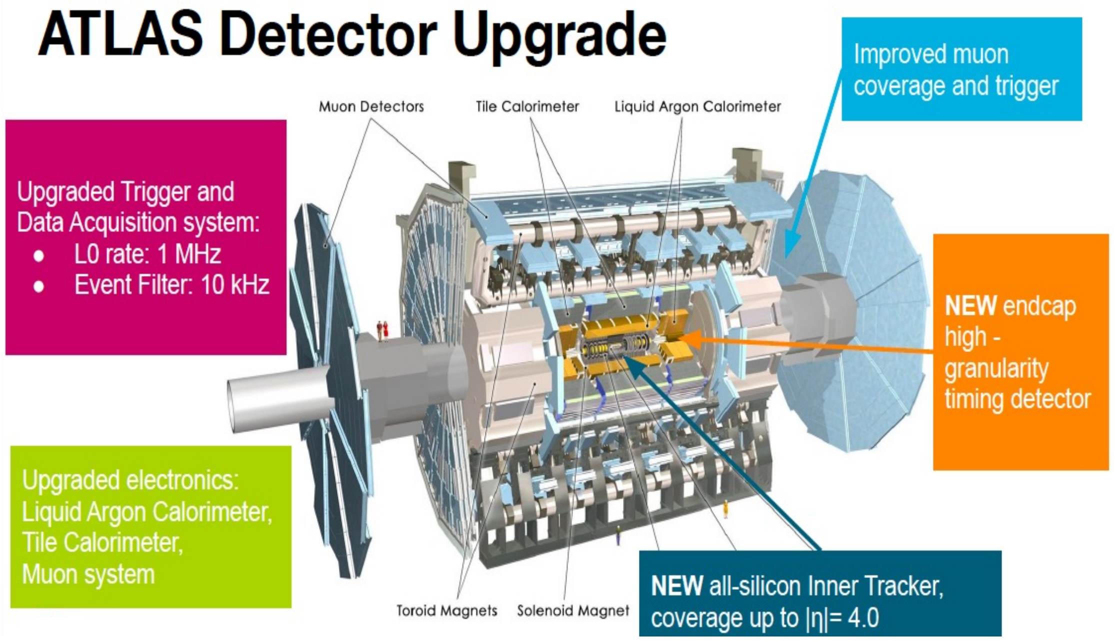


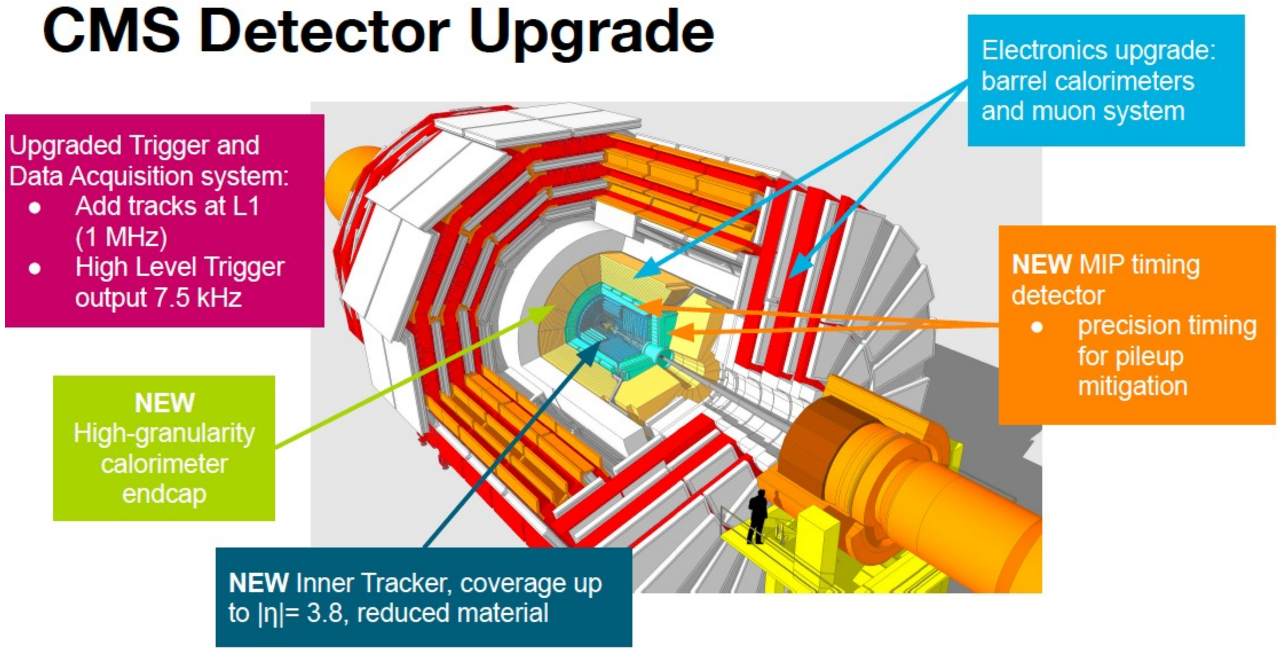
Oct 2024: revised schedule for LHC and the CERN accelerators complex

"The LHC will now enter LS3 in July 2026, seven and a half months later than planned, with the start of the High- Luminosity LHC (Run 4) beginning in June 2030. The injectors will run until the end of August 2026."



ATLAS and CMS upgraded detectors (phase 2)





Main INFN INVOLVEMENTS:
- Tracker (ITK)
- Liquid Argon Calorimeter
- Tile Calorimeter
- MUON
- TDAQ

NEW: neutron monitors, originally russian responsability

MAIN INFN INVOLVEMENTS:
- Tracker (inner and outer)
- MTD timing layer
- ECAL
- MUON
- BRIL

Nuove schedule di costruzione Fase 2 (esempio da ATLAS)

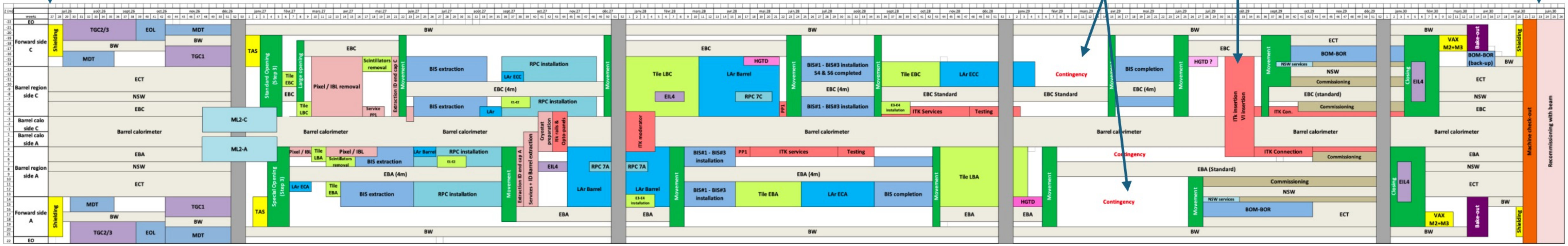
Schedule Installazione LS3

1/7/2026

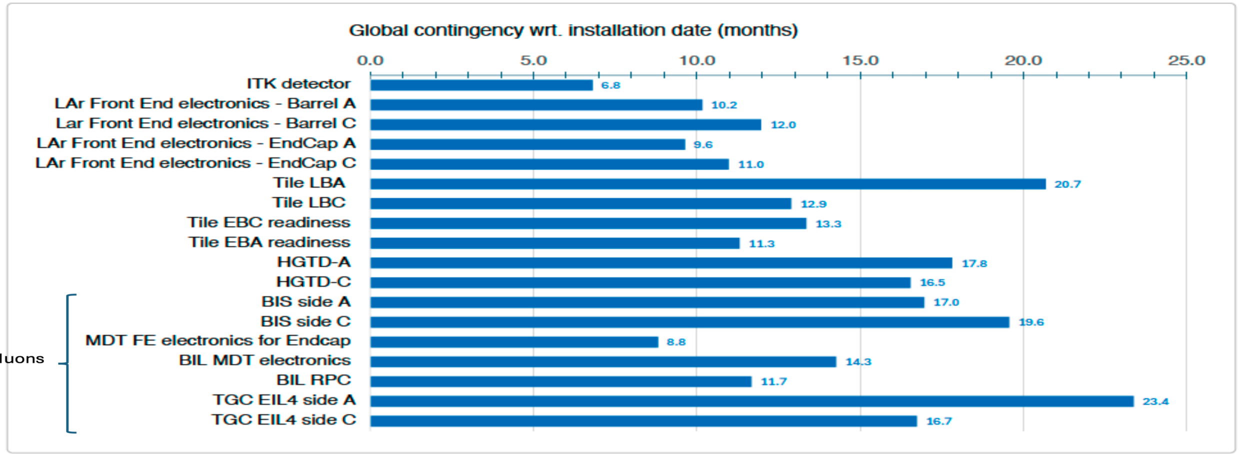
New: Contingency

ITk insertion 8/2029

31/5/2030

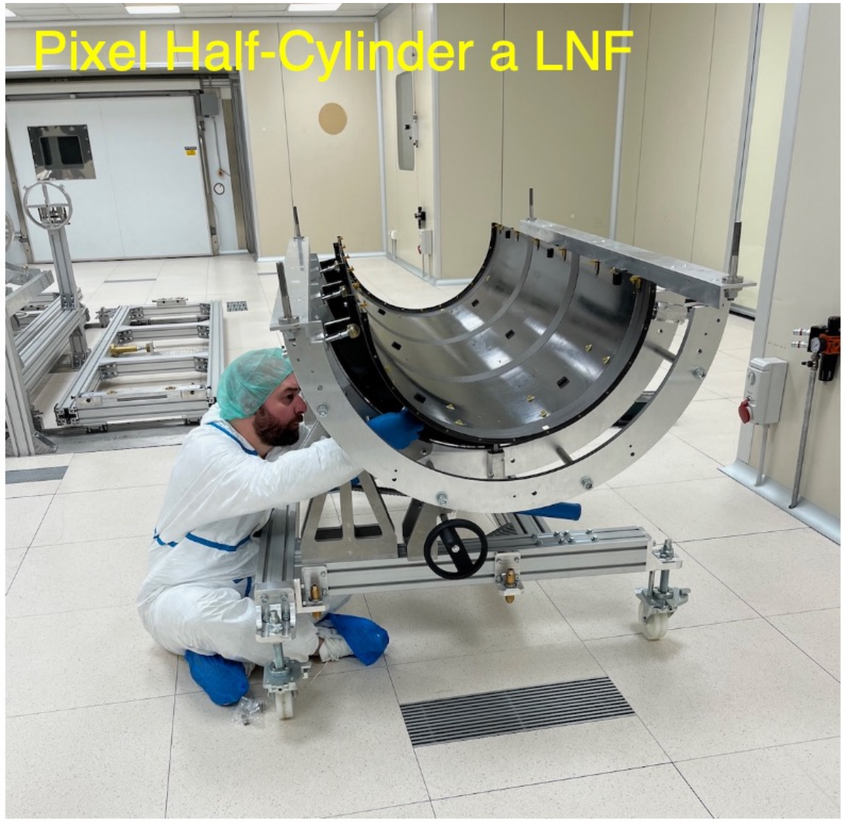


Shortest contingency for ITk, +6.8 months
Anyway schedules remain tight and

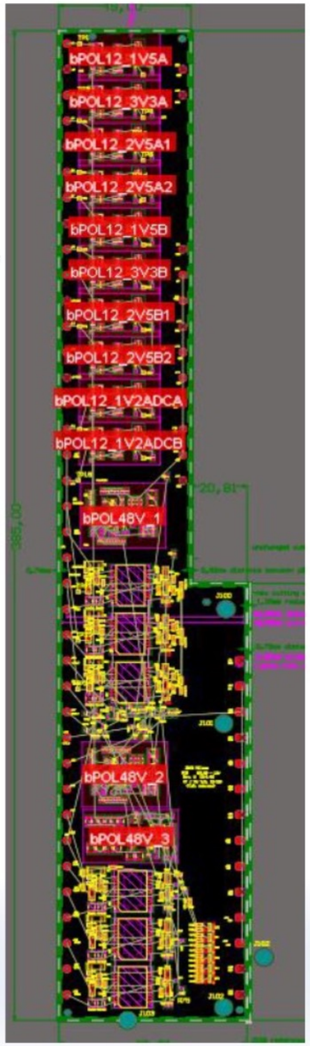


ATLAS Phase 2 at INFN

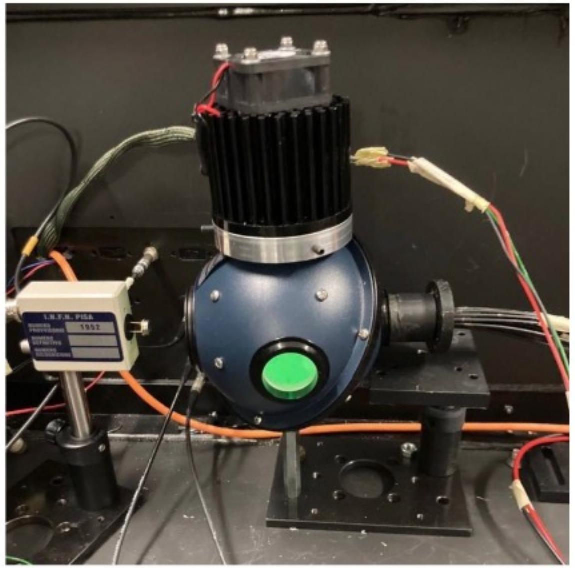
- ITK Pixel all components in pre-production
- Lar trigger electronic prototype ready
- Tilecal ready for preproduction
- RPC electronic testing prototypes



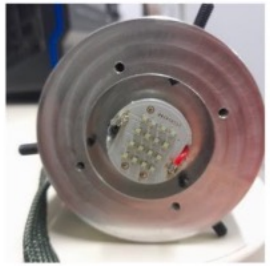
Electronics LAr, prototype



Tile Calorimeter: Integrating sphere + DC LED matrix in Pisa

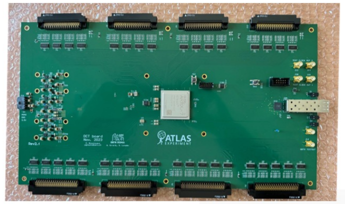


16 green LED array



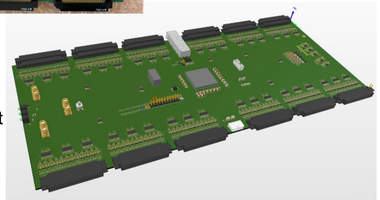
Cooling system with heat sink and fan

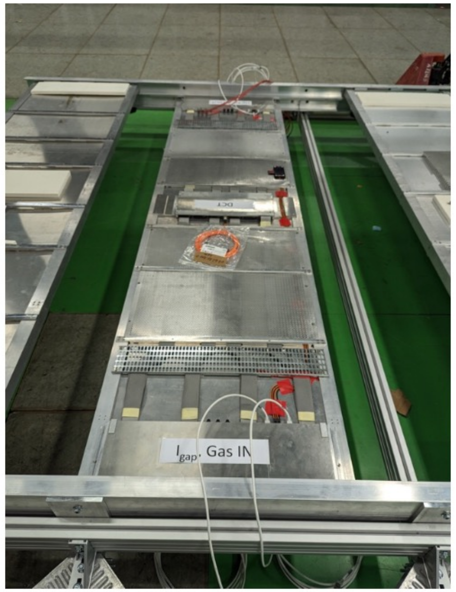
RPC electronics



BMBO DCT (2nd prototype)

BI DCT layout





Service integration test

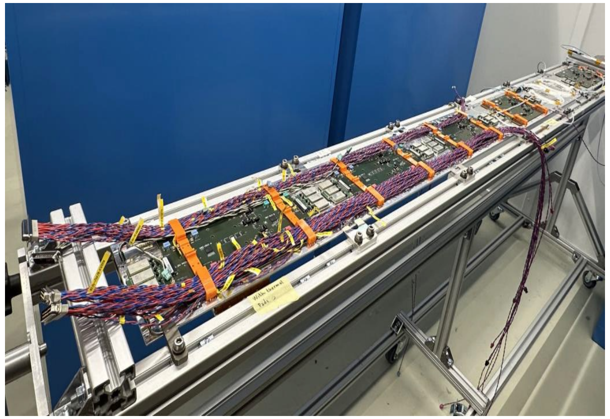
CMS Phase 2 at INFN

- Tracker OT sensors, ASIC produced, IT sensor, ASIC prod ongoing
- ECAL “enforneur” ready, chip production ongoing
- MTD BTL Lyso, SiPM, ASIC procured, testing assembly
- MUON DT electronic prod started, iRPC components procured

Tracker support tube

CROC Chip Readout Chip / Pixel Inner Tracker

Timing layer BTL tray



MUON GEM

Beam test tracker final modules

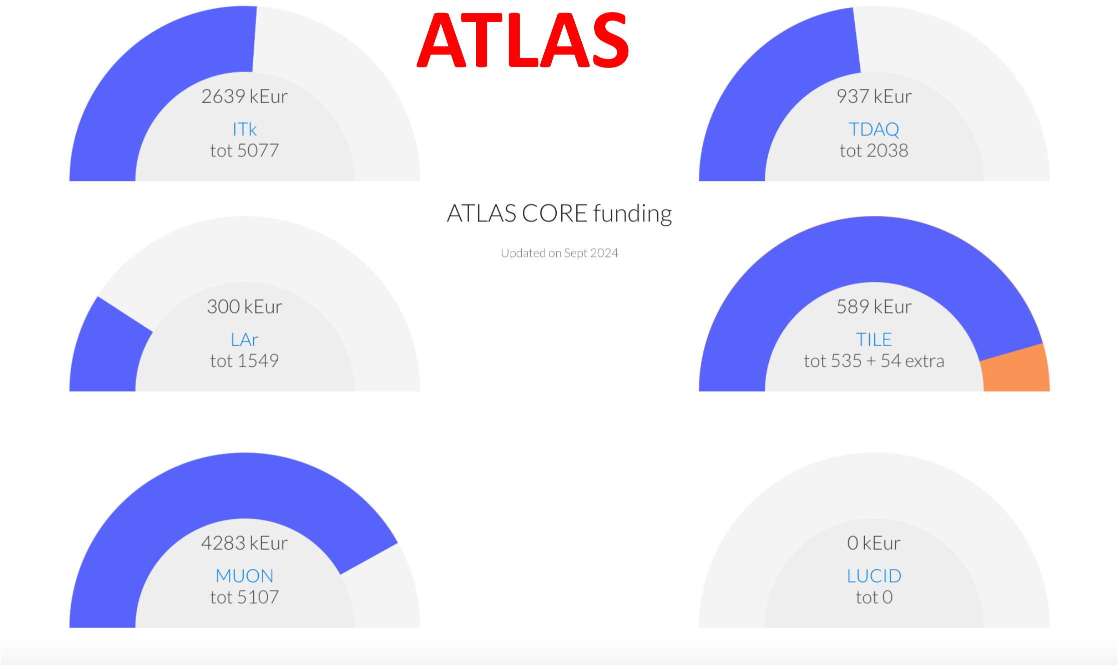
ECAL new “enforneur”

MUON GEM module test

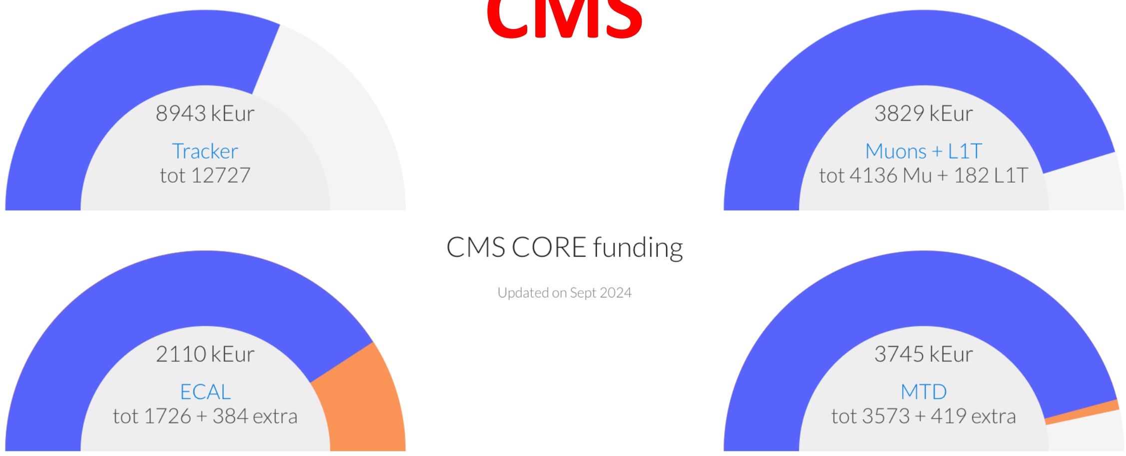
CORE funds for construction spent todate

(Extracosts in orange)

ATLAS



CMS



Final extra-costs still under evaluation by the experiments, expect ≈ 25% extracost

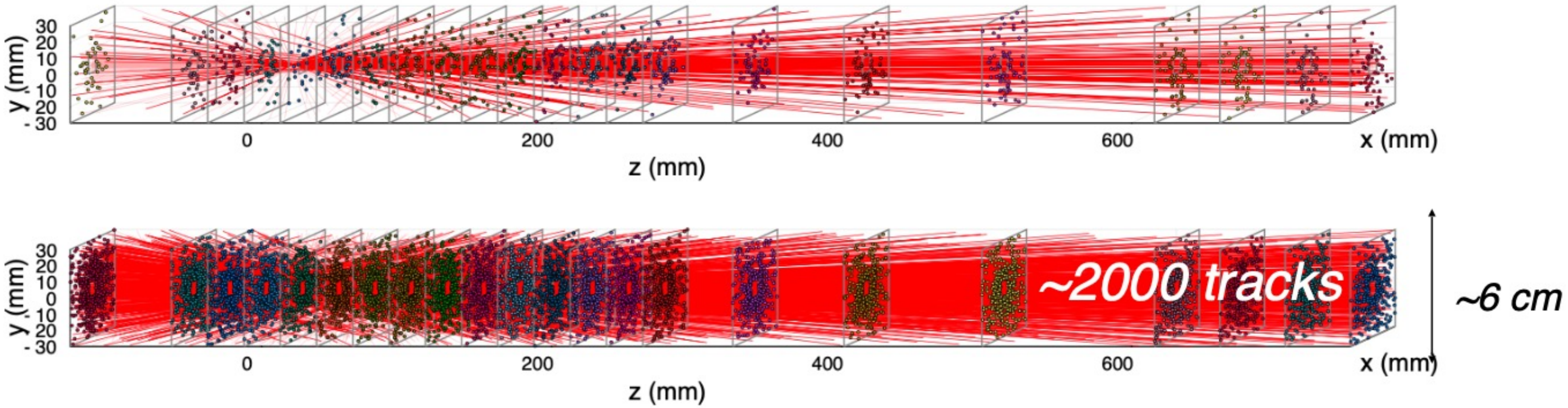
Notevole impatto sul budget CSN1 fino al 2028 (incluso)

LHCb proposing Upgrade 2

Run 3: pile-up ~6

Upgrade II: pile-up ~40

VErtex LOcator (VELO)



Timeline

2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041
Run 3		LS3				Run 4				LS4		Run 5					
TDR phase			Construction phase							Installation		Exploitation					

LHCb Upgrade 2

CSN1 review of possible INFN participation started

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH (CERN)

CERN-LHCC-2024-010
LHCb-TDR-026
September 2, 2024

LHCb Upgrade II Scoping Document

LHCb collaboration

Abstract

A second major upgrade of the LHCb detector is necessary to allow full exploitation of the LHC for flavour physics. The new detector will be installed during long shutdown 4 (LS4), and will operate at a maximum luminosity of $1.5 \times 10^{34}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$. By upgrading all subdetectors and adding new detection capability it will be possible to accumulate a sample of $300\,\mathrm{fb}^{-1}$ of high energy *pp* collision data, giving unprecedented and unique discovery potential in heavy flavour physics and other areas. The baseline LHCb Upgrade II detector has been presented in a Framework Technical Design Report that was approved in 2022. Here, updates are presented alongside scoping options with reduced detection capability and operational luminosity. The costs and physics performance of each scenario are discussed, and an overview of the project management plans is presented.

The U2 objective is to integrate≈300 fb-1 at Run 5 and 6

NEW :Scoping document ready
Simulazioni with three scenarios

ALSO NEW: Detector enhancement at LS3, anticipate some upgrades

	Baseline	Middle	Low
$\mathcal{L}_{\text{peak}}$ $(10^{34}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1})$	1.5	1.0	1.0
	(kCHF)	(kCHF)	(kCHF)
VELO	16672	15906	13753
UP	8077	7719	6887
Magnet Stations	2592	2234	0
Mighty-SciFi	21767	21273	17388
Mighty-Pixel	15994	11641	11061
RICH	21450	18415	14794
TORCH	12508	8756	0
PicoCal	27607	27607	21584
Muon	9785	8266	8266
RTA	18800	11700	9500
Online	11800	9467	8993
Infrastructure	14463	13284	12430
Total	181515	156268	124656

Two examples of scenarios for tracking and particle id

Baseline	Middle	Low
$1.5 \times 10^{34}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$	$1.0 \times 10^{34}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$	$1.0 \times 10^{34}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$
	VELO	
32 stations, $\eta < 4.8$	32 stations, $\eta < 4.8$	28 stations, $\eta < 4.7$
module 0.8% X_0	module 0.8% X_0	module 1.6% X_0
RF foil 75 µm	RF foil 75 µm	RF foil 150 µm
	TORCH	
18 quartz bars	12 quartz bars	removed
225,000 channels	158,000 channels	—

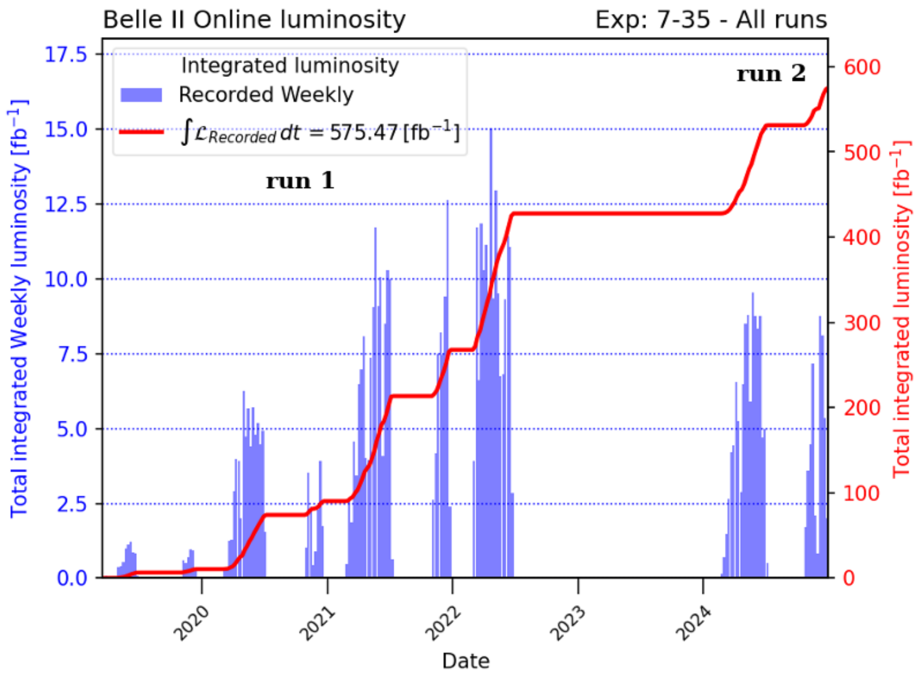
***MIDDLE :** 1.0x10^{34}cm^{-2}s^{-1} → 260 fb^{-1}, all sub-detectors included*

- *reduce granularity (to account for lower lumi), detector features as in Baseline*

***LOW:** 1.0x10^{34}cm^{-2}s^{-1} → 260 fb^{-1}, no TORCH and Magnet Stations*

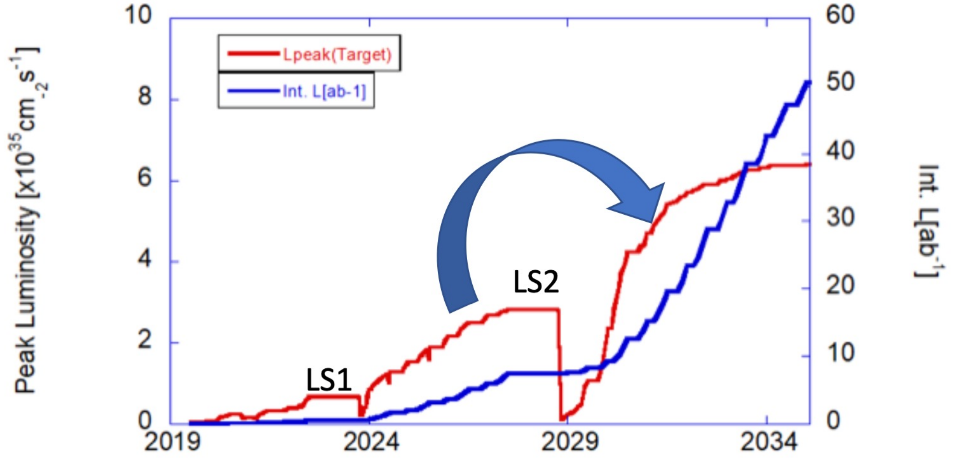
- *VELO: reduced acceptance, heavier sensors, Mighty Tracker: minimal area of pixels and reduced outer acceptance of fibers, PicoCal: no long. segmentation on outer part*

Belle 2 at Super KEKB : restarted after LS1

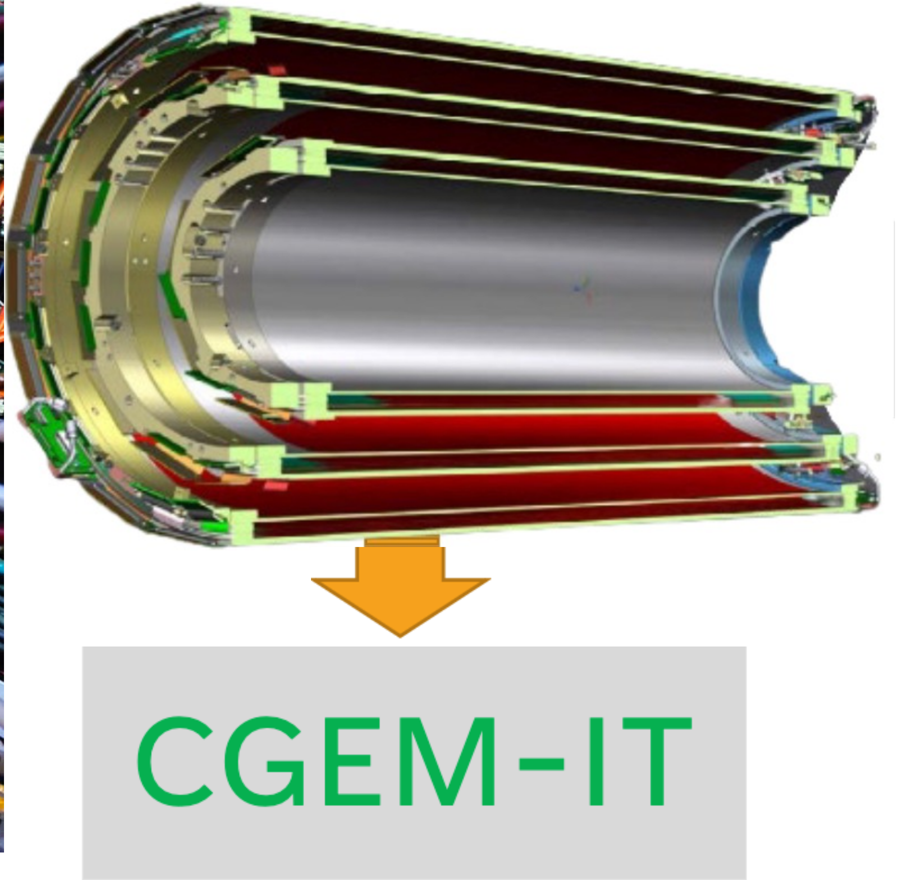


- Jan 29th operation resumed, Feb 20th first run collisions
- Unfortunately running plagued by sudden beam losses
- Pixel detector suffered (small) damaged, kept off for most of the 2024 run
- Injection problems, beam current limitations
- The Belle 2 apparatus is generally in good shape, in particular the detectors of INFN responsibility
- Published interesting papers with the current statistics
  - e.g. best UL for $B \rightarrow K^* \tau\tau$
- Proposal for detector upgrades during LS2
- CSN1 is going to review the proposal, for the moment funded limited R&D for tracking and PID

- Belle 2 completed Long Shutdown 1 (LS1)
- <u>Data taking restarted in February 2024, ended in December 2024, 10 months shutdown in 2025</u>
- Accelerator consolidation at LS1 should have allowed the machine to reach 2.5×10^{35} cm^{-2} s^{-1} luminosity
- More work and ideas needed to reach the design luminosity of 6×10^{35} cm^{-2} s^{-1}



Three layers of new BES III GEM tracker, designed and constructed in Italy, are now ready in Beijing. There were commissioned collecting cosmics, insertion in BES III took place in October 2024.

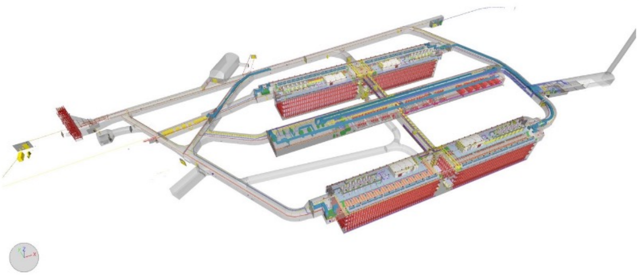


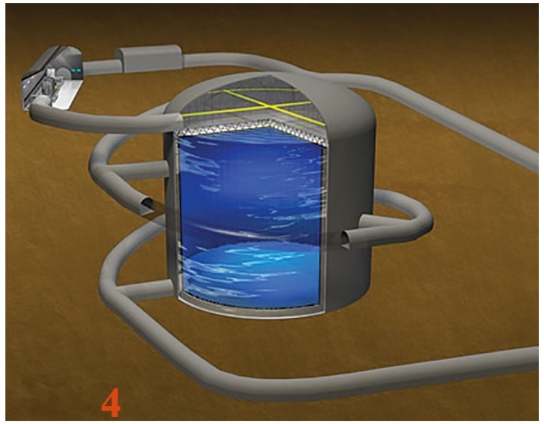
Neutrini in CSN1

- **SND@LHC (from 2021)**
- **DUNE (from 2024)**
- **Icarus (from 2024)**
- **Hyperk + T2K (from 2025)**
- **ENUBET (*) (from 2025)**

(*) measurement of the positrons produced in the decay tunnel of conventional neutrino beams: these particles signal uniquely the generation of an electron neutrino at source.

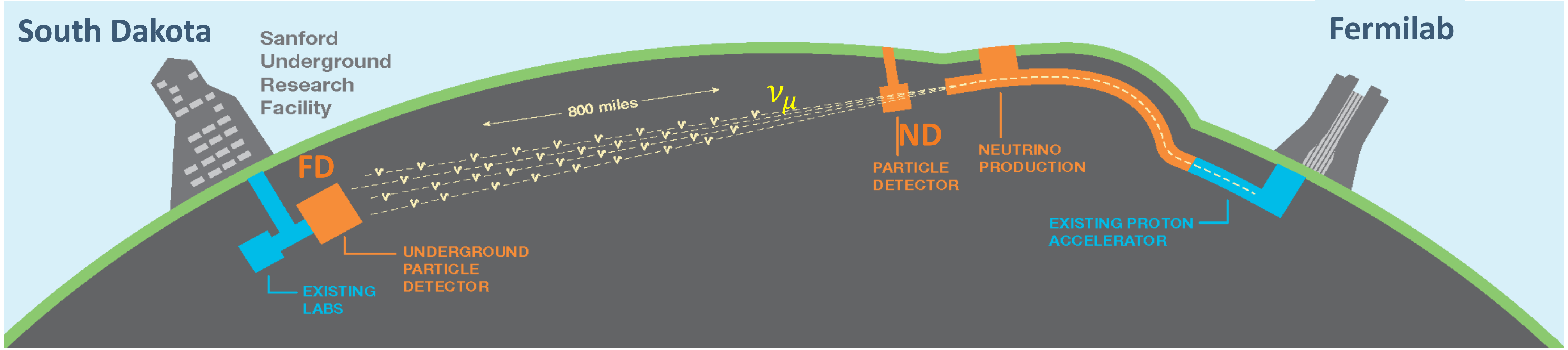
DUNE and Hyper-K: different detectors, different strategy





- DUNE:
  - Very long baseline → large matter effect
  - Broadband neutrino beam → high statistics over full oscillation period
  - LArTPC → imaging + calorimetry for ν-Ar interactions at ~2.5 GeV
  - Highly-capable near detector to constrain systematic uncertainties
- Hyper-K:
  - Shorter baseline → small matter effect
  - Off-axis location creates narrow beam → very, very high statistics at oscillation maximum, less feed-down
  - Water Cherenkov → kinematic measurement of E_ν from ν-O interactions at ~0.6 GeV
  - Highly-capable near detector to constrain systematic uncertainties

The Deep Underground Neutrino Experiment (DUNE)

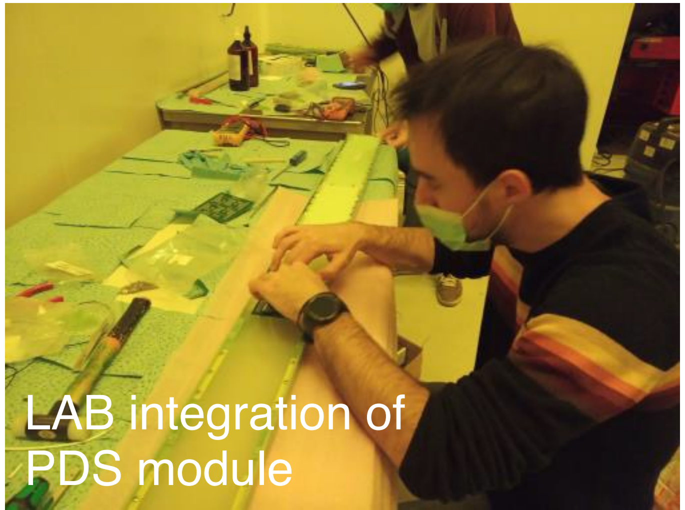


INFN plays a significant role in both the Far and Near Detectors

- FD: important commitments in the realisation of the Photon Detection System (PDS)
  - **the first two modules of the Far Detector passed the** Production Readiness Review and **are under construction, the PDS is the largest spending driver of DUNE-INFN in 2023-25.**
  - **on crytical path to start science end of 2028**
- ND: major responsibility in SAND, based on the KLOE MAGNET and ECAL, plus additional liquid argon target with imaging capabilities (GRAIN) and CH_2/C-target TRACKER (straw-tube or drift chamber)
  - **SAND aims at being in-line for first beam in 2031**

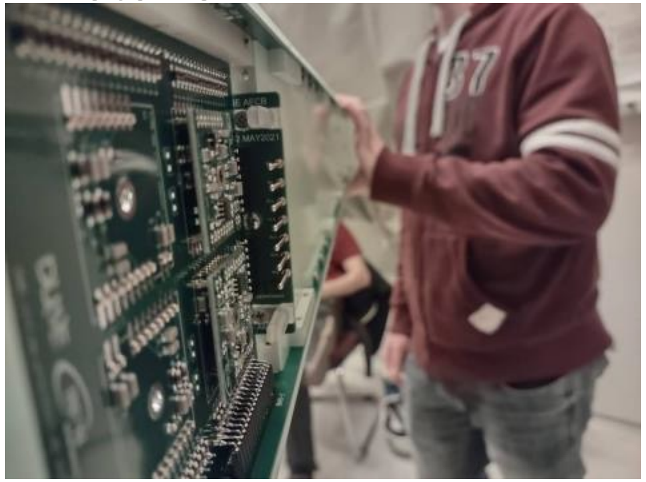
DUNE FD PDS (photon detection system) @ INFN

INFN postdoc installing a PDS module in ProtoDUNE-HD



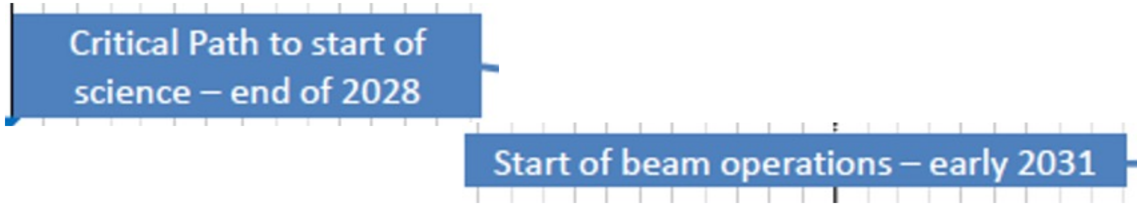
LAB integration of PDS module

PDS electronics installation at ProtoDUNE-HD

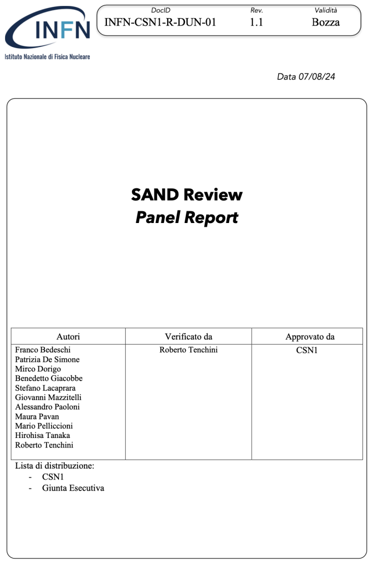


Vertical Drift: test of x-arapuca photon readout in Napoli

Caverna a Sanford in completamento, consegnata agli utenti a inizio 2026



DUNE
SAND


INFN
Istituto Nazionale di Fisica Nucleare

DocID	Rev.	Validità
INFN-CSN1-R-DUN-01	1.1	Bozza

Data 07/08/24

SAND Review
Panel Report

Autori	Verificato da	Approvato da
Franco Bedeschi Patrizia De Simone Mirco Dorigo Benedetto Giacobbe Stefano Lacaprara Giovanni Mazzitelli Alessandro Paoloni Maura Pavan Mario Pelliccioni Hirohisa Tanaka Roberto Tenchini	Roberto Tenchini	CSN1

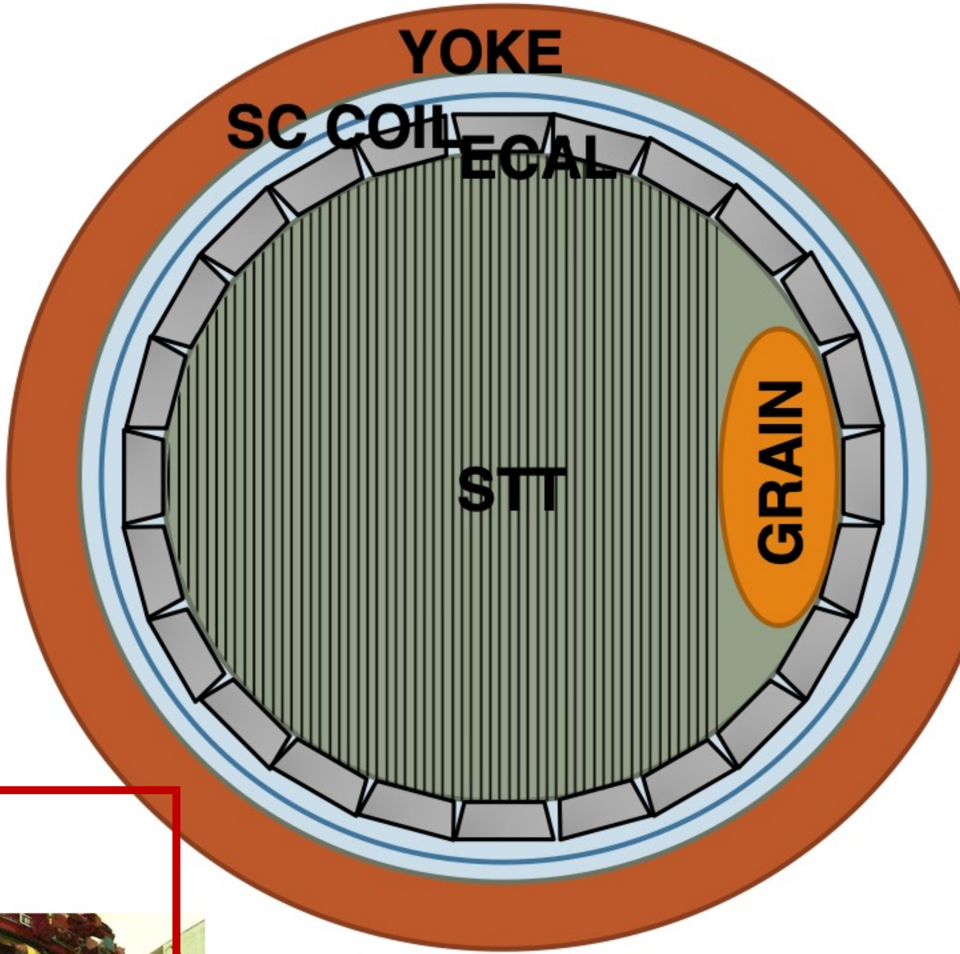
Lista di distribuzione:
- CSN1
- Giunta Esecutiva

MAGNET – KLOE 0.6T superconductive coil + Fe Yoke

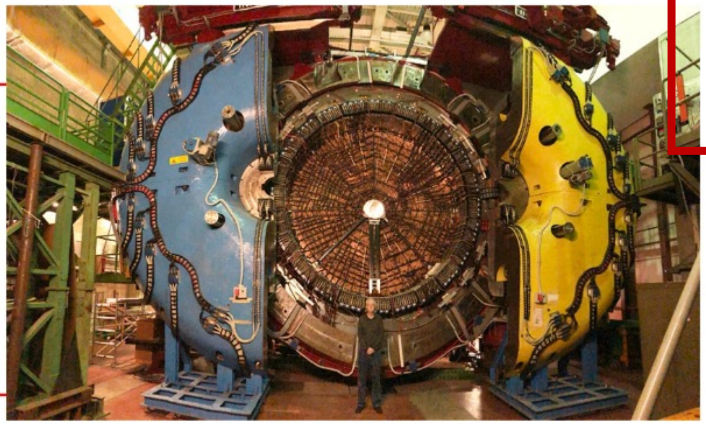
ECAL - KLOE Lead Scintillating Fibers calorimeter (Barrell-23 ton Pb- + EndCaps)

STT – 5 ton Straw-Tube tracker with “solid-H” target CH_2 and C interleaved slabs

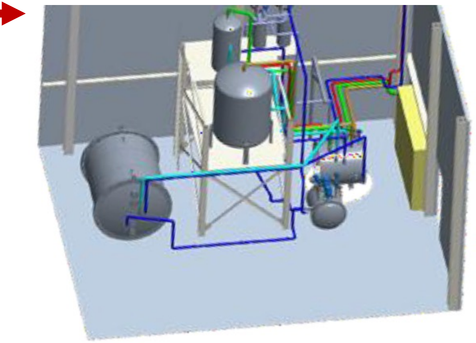
GRAIN – 1 ton liquid Argon target with VUV imaging system (fully optical read-out)



SAND, a multipurpose detector with an high-performant ECAL, light-targeted tracker, LAr target, <u>all of them in a magnetic field</u>



Test facility at Legnaro

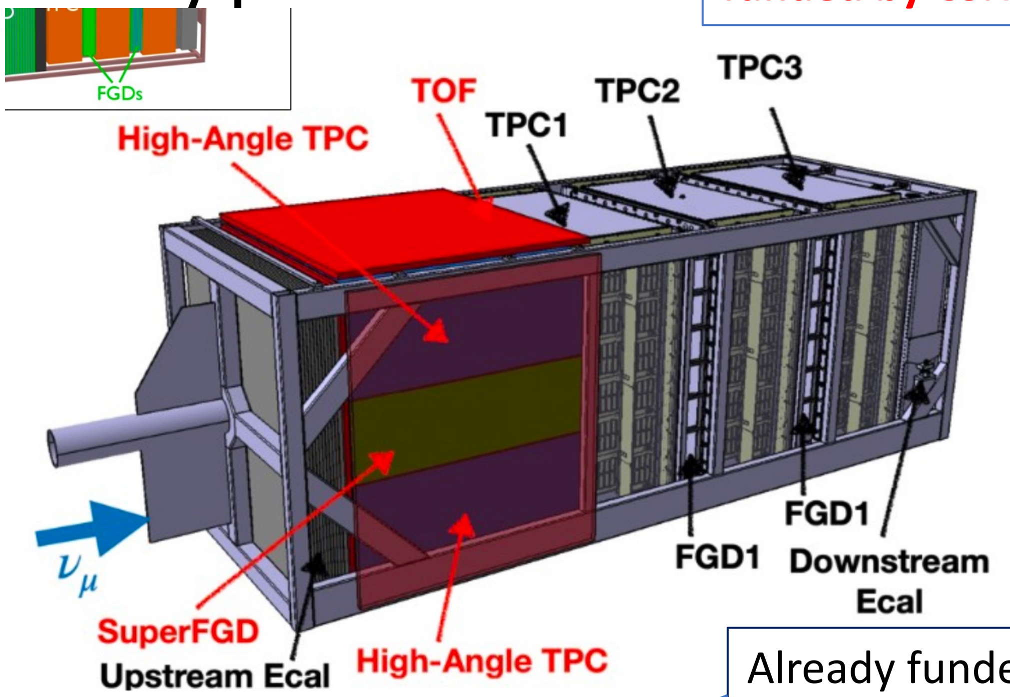


“Hyper-K”: Hyper-Kamiokande, T2K, Super-K

Run/Analysis	Upgrade	Construction
• **T2K/SK running experiments** – Analysis: OA, new samples, xsects – SK-GD: 0.03% Gd	• **T2K-II assembly and installation** – Beam upgrade – ND280 upgrade – Nuove HATPC	• **Hyper-K design and construction** – mPMTs – FEB 20“, timing – computing
Data taking Analysis Run until 2027	Upgrade May 2024	Final Design Review Excavation Procurement Run 2027-

INFN commitments in HyperK

Most of this already funded by CSN2 !

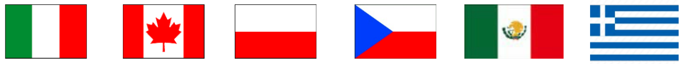


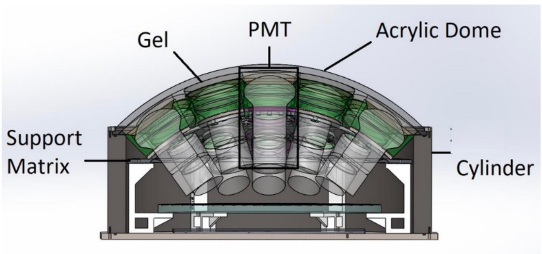
Already funded and produced

Table 2: Work package 2, High Angle TPCs detector deliverables in kCHF

TPC	Sum	Krakow	RWTH	CERN	INFN	IN2P3	Saclay	Warsaw	IFAE
Field Cage	555				549				6
Micromegas	278			248			30		
TPC mechanics	193	39				24	130		
Electronics	380					170	170	21	19
Gas system	276			276					
HV, LV	134		74			20	40		
GMC	34		34						
Shipment from CERN to J-PARC	50			50					
Total	**1900**	**39**	**108**	**574**	**549**	**214**	**370**	**21**	**25**

Italian contribution in Hyper-K

- Multi-PMT 
  - 300 mPMTs, out of 808 mPMTs in total. Initially proposed by the Italian group
- Elettronica
  - Front-end digitizer 20“ PMTs (+OD 3“ PMTs digitizer design, in collaboration with UK)
  - Timing distribution (in collaboration with LPNHE and IRFU/CEA)
- Computing
  - ~25% of Hyper-K computing 2023-27 at CNAF. Development of WAS, collaborative tools, database. Preparation of analysis tools
- Near Detector
  - Construction of two new TPCs for near detector upgrade di T2K (it will be part of the Hyper-K near detector). In collaboration with France, CERN, Spain, …



- **Hyper-K INFN funded 5.3 Meur + installation costs**
- **PMT 3” tender completed**
- **mPMT mechanics and other components (cables, connectors, etc.) currently in preparation**
- **FE electronic tender currently in preparation**
- <u>Mass production 2025-26</u>

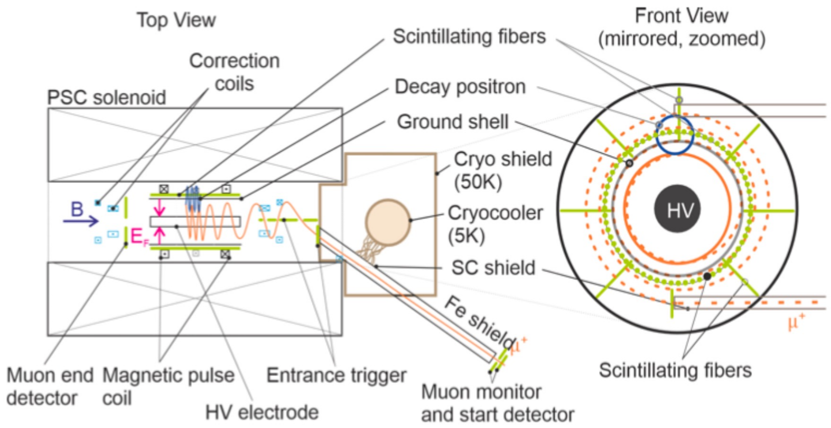
“Piccoli” esperimenti in CSN1

Vari esperimenti di “piccole dimensioni” sono stati finanziati o considerati per finanziamento in CSN1
Due esempi recenti :

The muEDM experiment at PSI

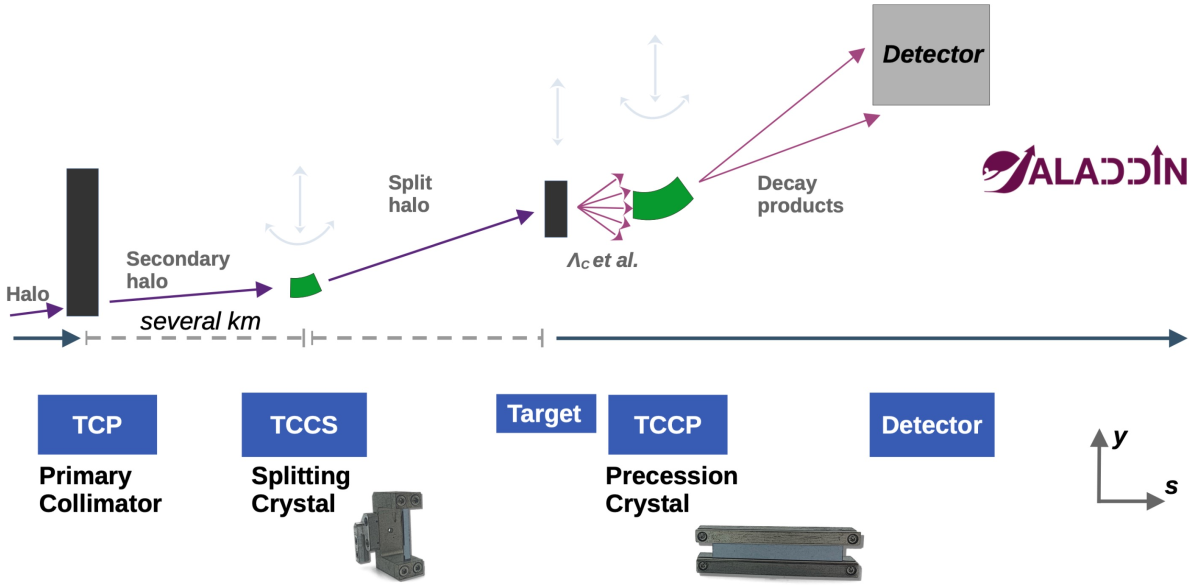
Sigla aperta Feb. 2025

- Muons enter the **uniform magnetic** field region via **SC injection lines. Correction coils** are used to increased the storage efficiency
- A **radial magnetic** field pulse stops them within **a weakly focusing** where they are **stored**
- **Radial electric** field **“freezes” the spin** so that the precession due to the magnetic dipole moment is cancelled



proposta in corso

LHC Double Crystal FT Experiment – (Proposed 2029+)

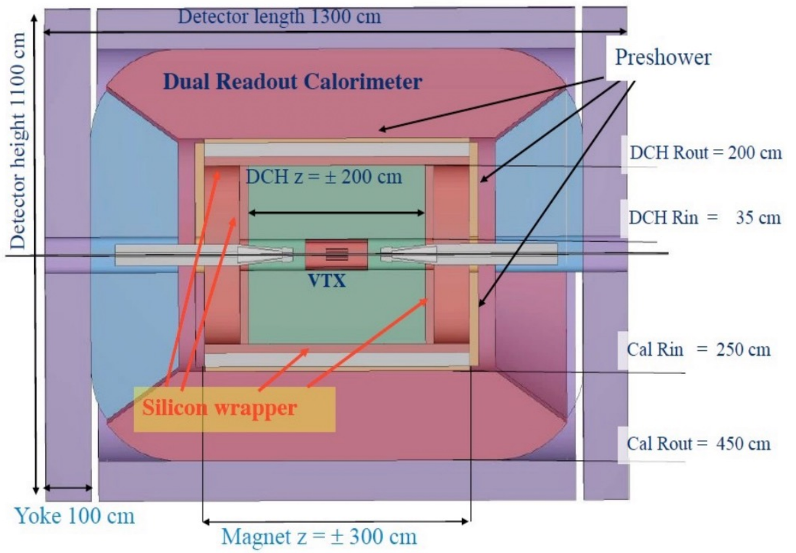


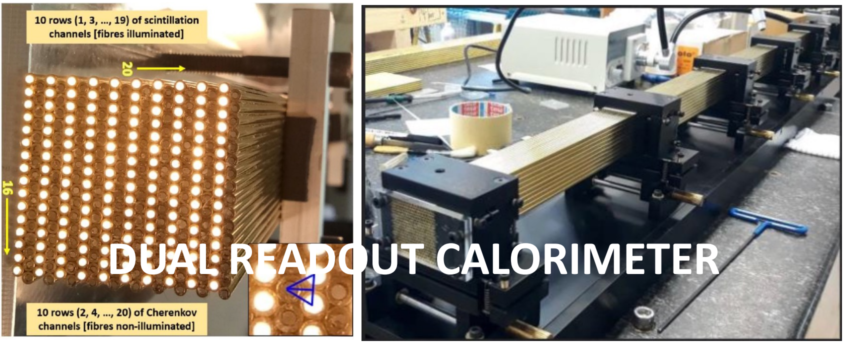
First direct measurements of Λ_c^+, Ξ_c^+ magnetic (**MDM, μ**) and electric (**EDM, δ**) **dipole moments.** No measurements to date

Vedi anche UA9 nelle slides addizionali

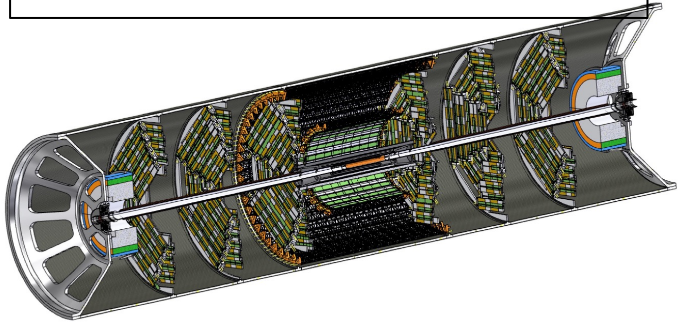
Preparing the future at CSN1: **FCC @ INFN, Detector R&D**

IDEA detector for FCC-ee

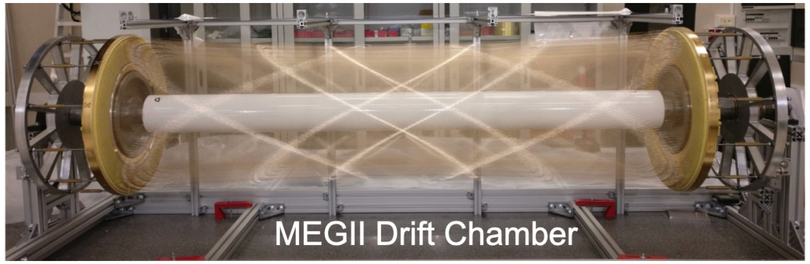




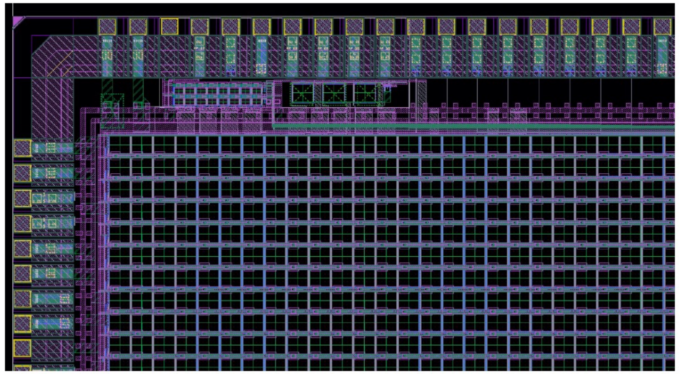
Example: developed a detailed design of the vertex detector region, with MAPs based silicon sensors. Integration takes into account crossing angle and other accelerator constraints



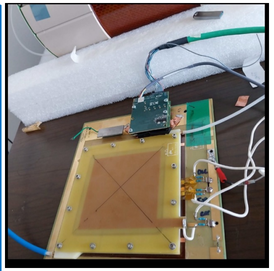
INFN MEG II Drift Chamber as a prototype for FCC Tracking



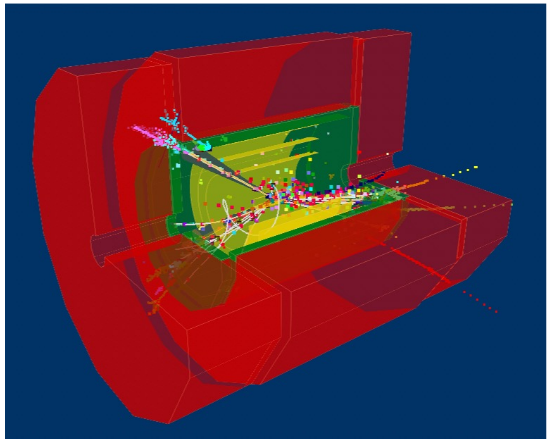
Collaboration with FBK for Digital SiPM CMOS dedicated to fiber calorimeter



Prototype of μRWELL detector for muon chambers , tested with new TIGER low noise electronics



Detector R&D towards a Mucol experiment @ 10 TeV

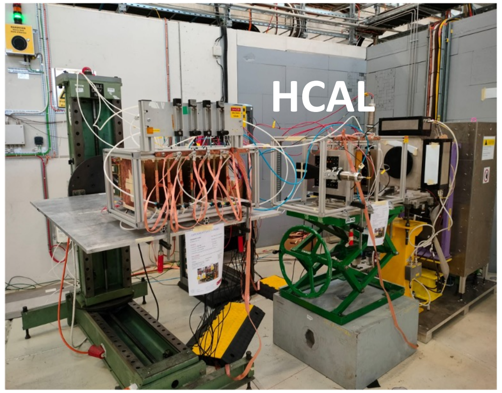


Tracker silicon sensors + electronics: DRD3/DRD7
LGAD-4D tracking new thin sensors – also ERC COMPLEX TO
MAPS to face higher occupancies @ vertex inner layers PD
e.m. calorimeter: DRD6/PRIN
CRILIN: crystal calorimeter with longitudinal information
Full size prototype: 5x5 crystals and 5 layers - 21 X_0 and 1 M_R
LNF + PD + RM3 + TO + ENEA + YALE
hadron calorimeter: DRD6/PRIN
MPGD-based HCAL: prototype with 20x20 cm^2 detectors – BA
timing muon layer: DRD1 - WP7 MPGD Timing Detectors
picosec – PV

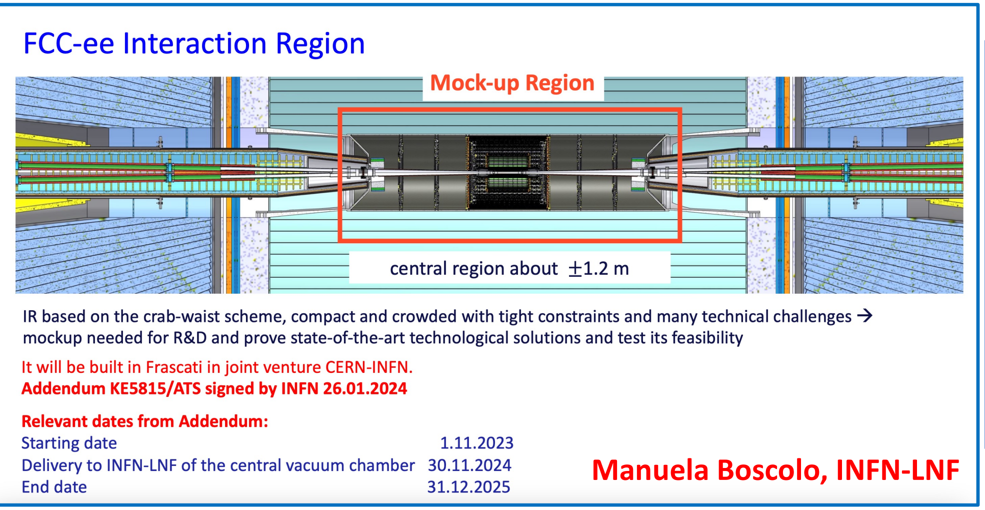
TPC atmospheric pressure @ demonstrator: DRD1
prototype detector – sinergy with neutrino physics – BA

Radiation damage in detector @ 10 TeV

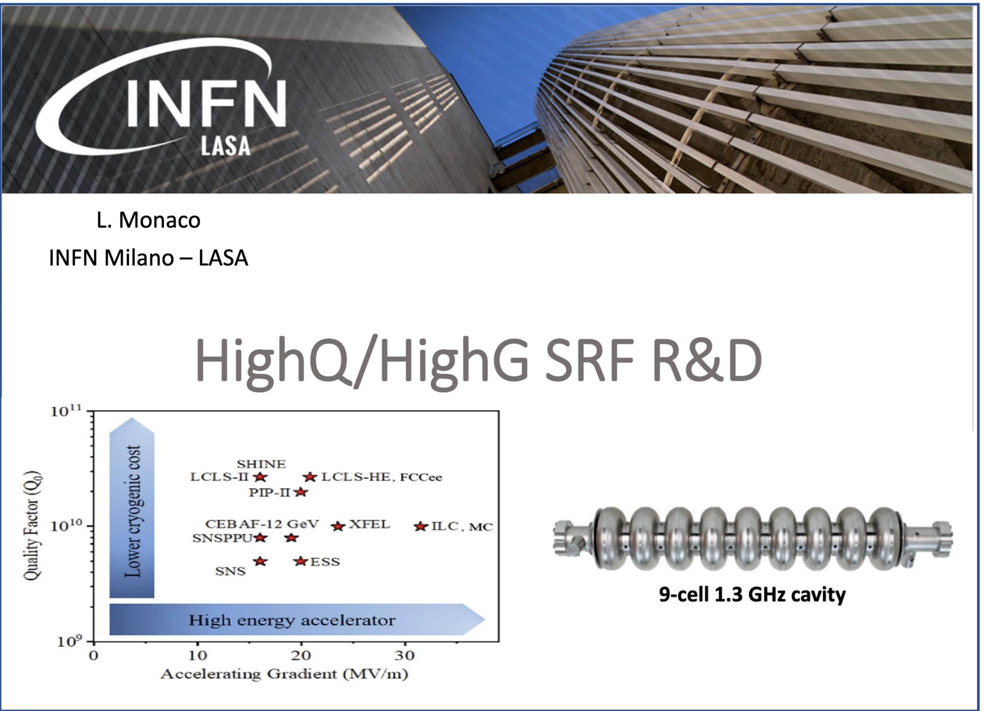
Per year of operation (140d)	Ionizing dose	Si 1 MeV neutron-equiv. fluence
Vertex detector	200 kGy	3×10^{14} n/cm^2
Inner tracker	10 kGy	1×10^{15} n/cm^2
ECAL	2 kGy	1×10^{14} n/cm^2



Accelerator projects for particle physics @ CSN1

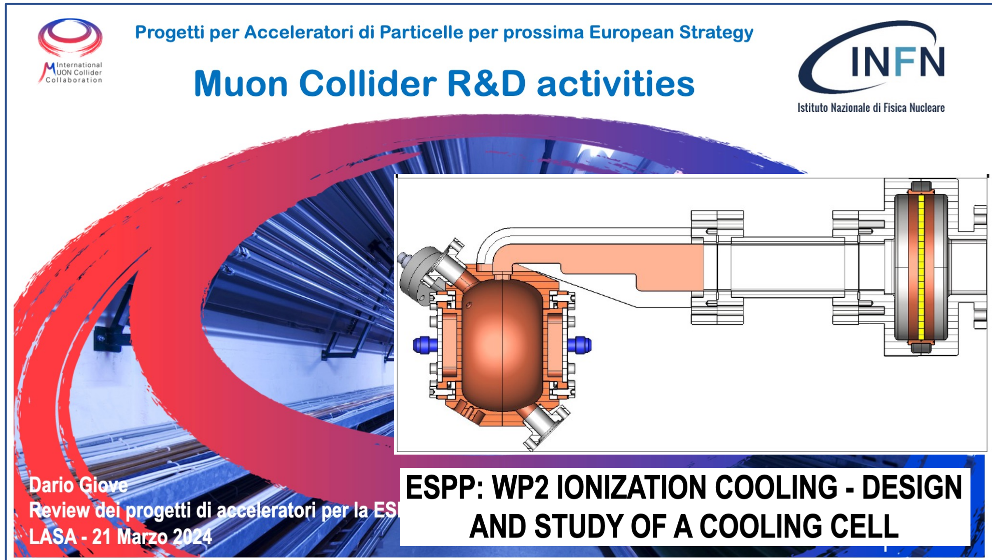


Coordinating the efforts to boost participation and include the INFN accelerator community, in synergy with other projects

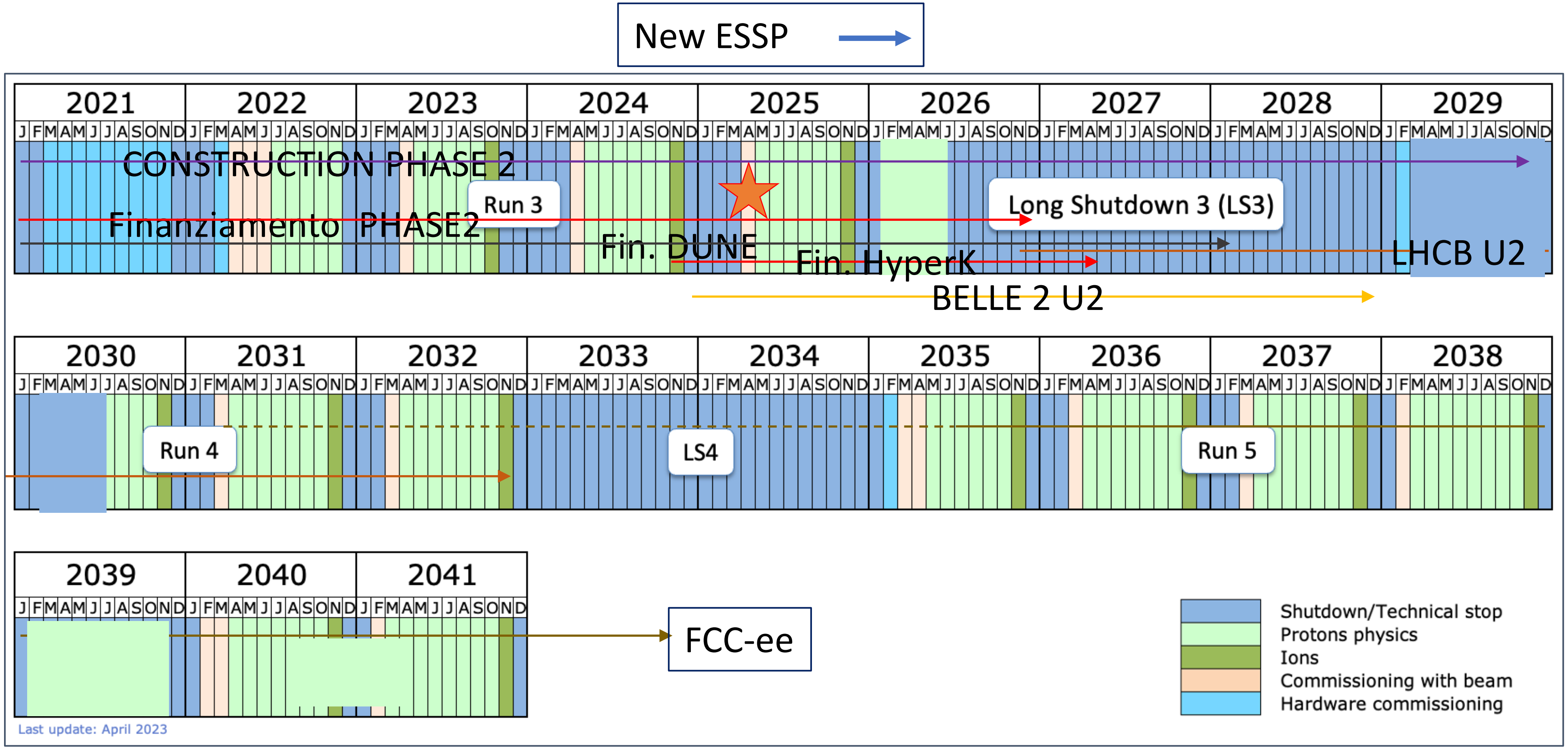


Four flagship projects with special INFN Funds (≈ 2 MEUR+personnel)

Common review by CSN1 and MAC committees



LHC long-term schedule and OTHER main CSN1 projects



HL-LHC : Run 4, Run 5, Run 6 at least 3000 fb-1 for ATLAS e CMS (*ultimate lumi* 4500 fb-1)

Upgrades LHCb [and ALICE] Fase 2 : Run 5 e Run 6

FCC-ee : start 204X dictated by CERN budget, anticipated start tecnically possible

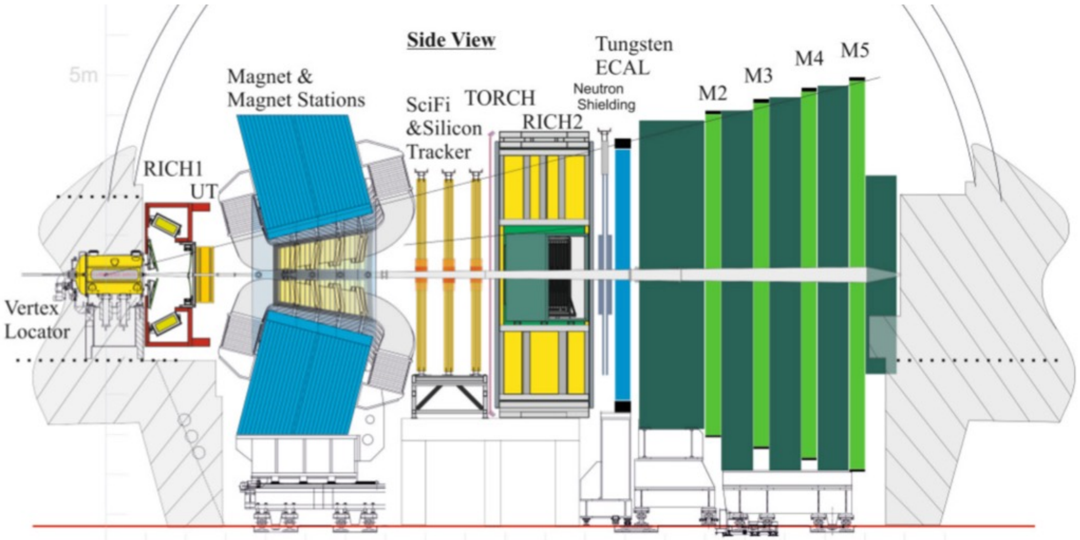
Considerazioni finali su CSN1 e comunità acceleratori

- La CSN1 e' passata dall'avere un **Laboratorio Nazionale di riferimento**
  - **LNF (ADONE, DAFNE, *SuperB*)** →
- a supporto/interazione con **almeno 3 laboratori legati alla comunità nazionale acceleratori**
  - **LNF, LNL, LASA** (e ora con DUNE anche LNS)
- Questo è legato soprattutto, ma non solo, a supporto e **R&D per futuri grandi progetti di fisica delle particelle (FCC, MuCol)**
- Abbiamo avuto una **prima esperienza di review congiunta (CSN1 – MAC)** di progetti legati a sviluppo di componenti per future macchine
  - <u>questo approccio va nella direzione giusta: la CSN1 puo' fornire la spinta motivazionale per i futuri progetti di acceleratori, ma non possiede tutta l'esperienza tecnologica necessaria per una review completa e puntuale</u>

ADDITIONAL INFORMATION

LHCb Upgrade II : The detector challenge

Targeting same performance as in Run 3, but with pile-up ~40!



Same spectrometer footprint, innovative technology for detector and data processing

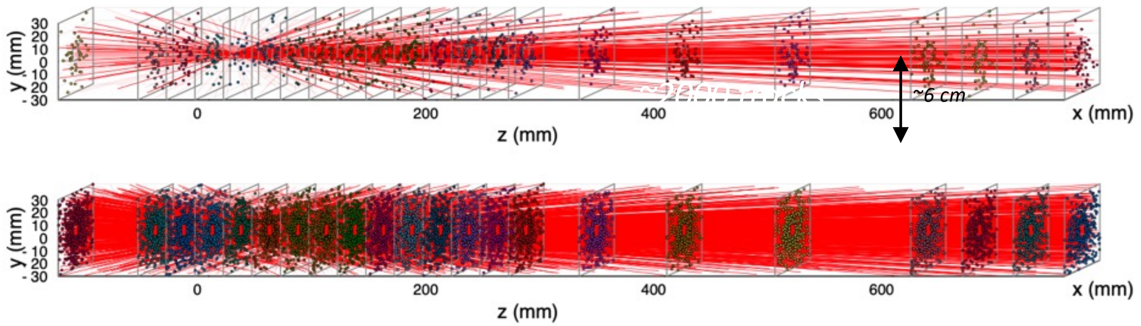
Key ingredients:

- granularity
- fast timing (few tens of ps)
- radiation hardness

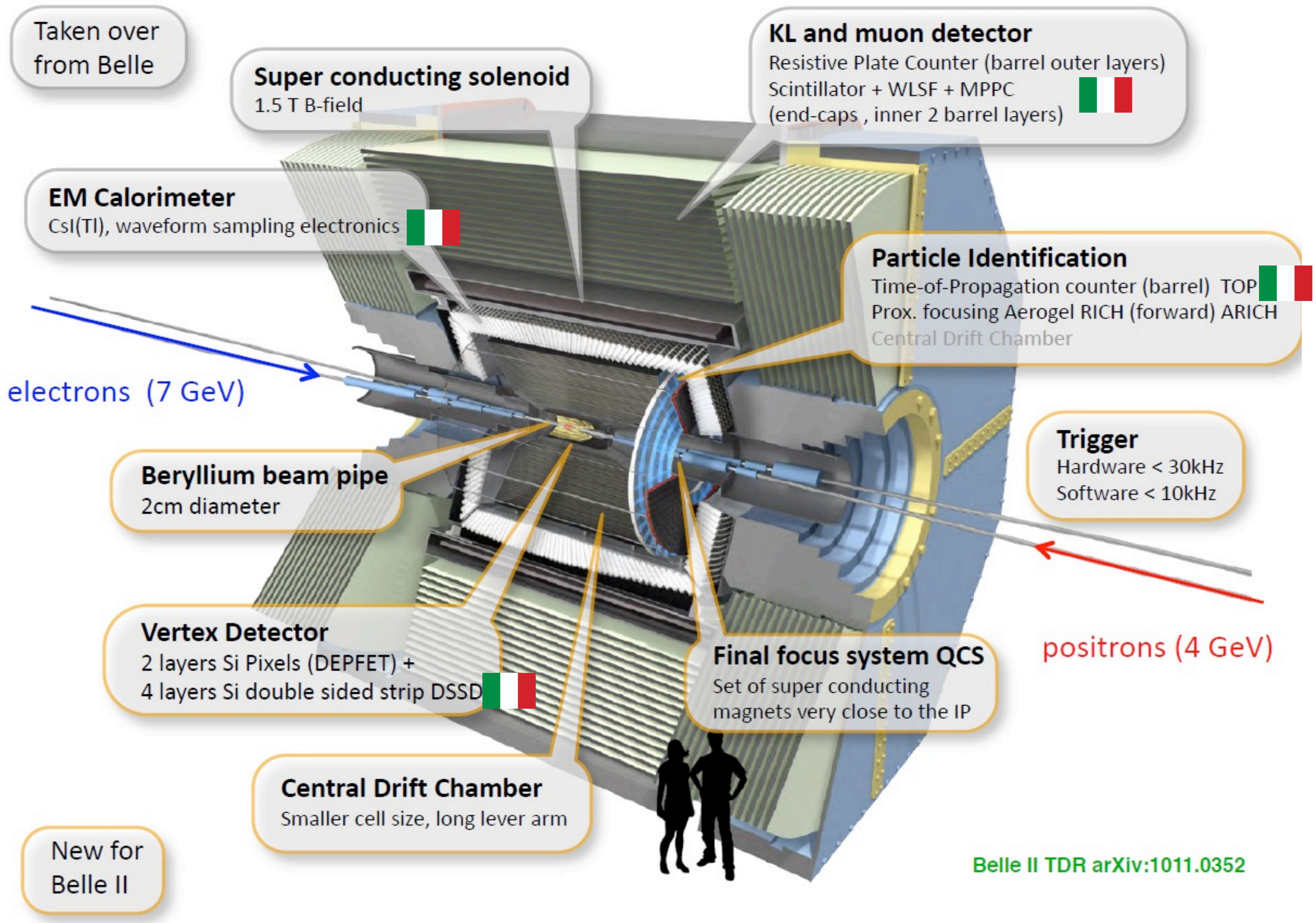
VErtex LOcator (VELO)

Run 3: pile-up ~6

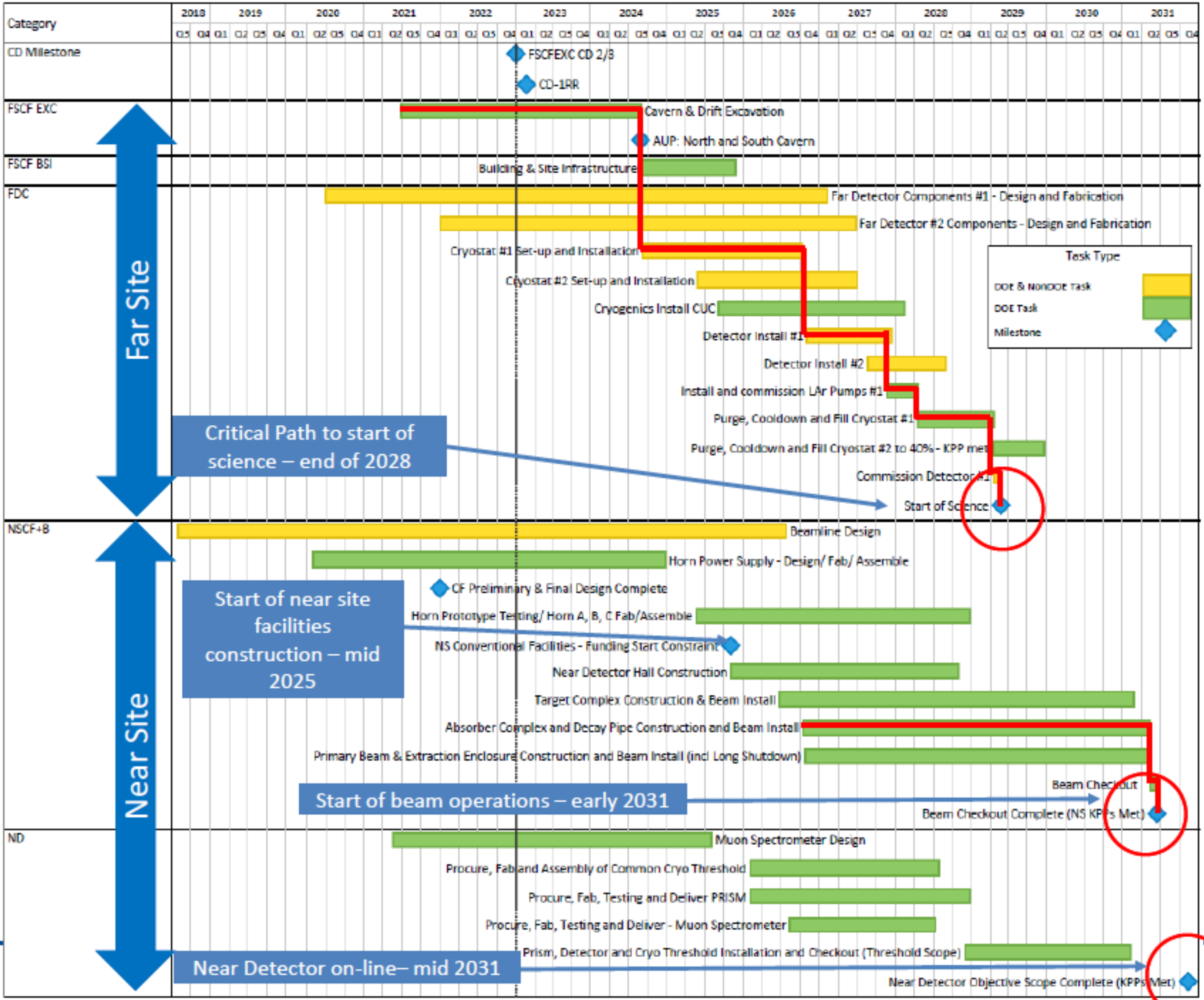
Upgrade II: pile-up ~42



The Belle II detector and INFN commitments



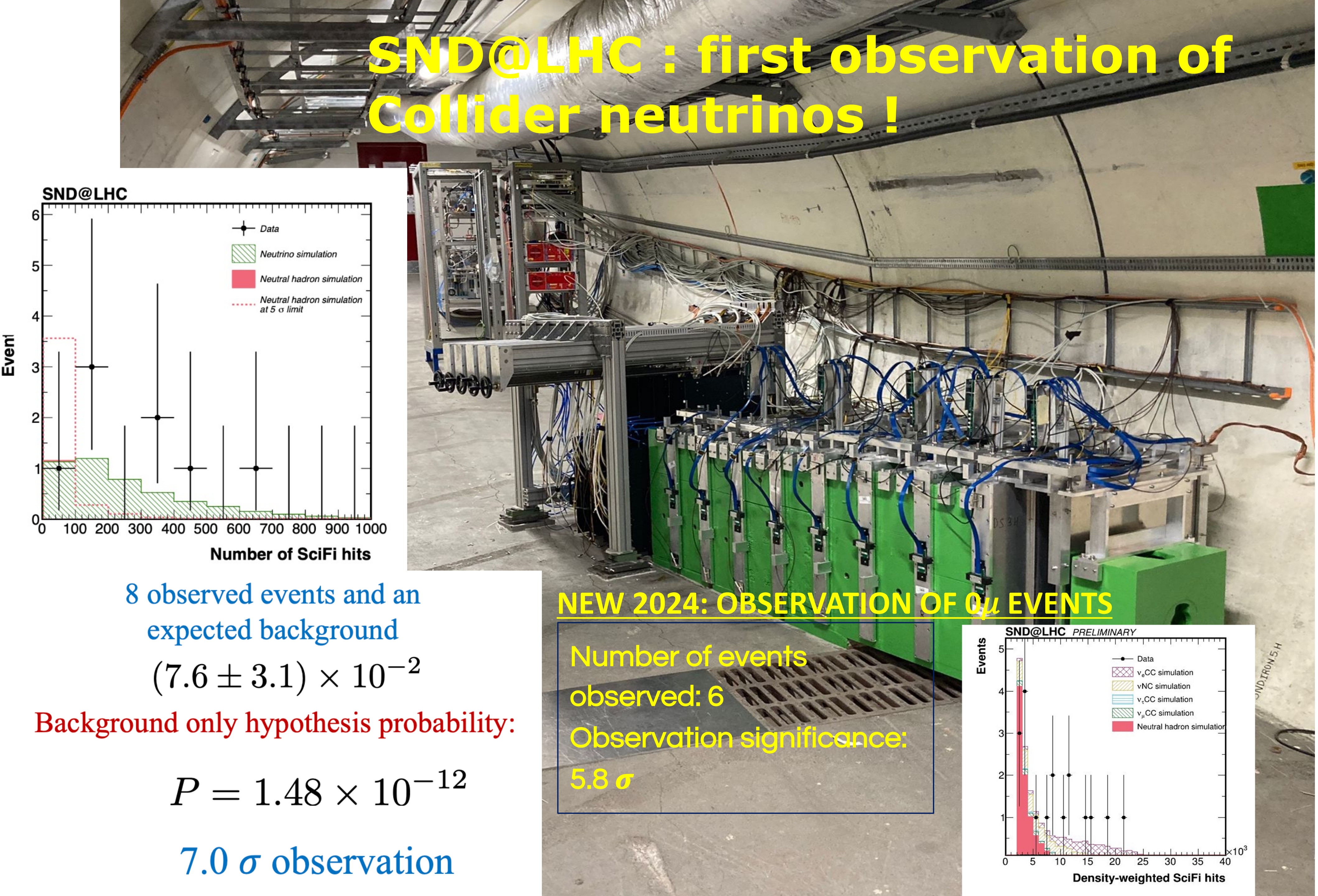
Summary Schedule with Critical Paths through Start of Science (FD1) and Beam-on



Favorable execution schedule enabled by new DOE funding profile in March 2022

Notes:
- Fiscal Year display
- Early completion dates shown

SND@LHC : first observation of Collider neutrinos !



8 observed events and an expected background

$$(7.6 \pm 3.1) \times 10^{-2}$$

Background only hypothesis probability:

$$P = 1.48 \times 10^{-12}$$

7.0 σ observation

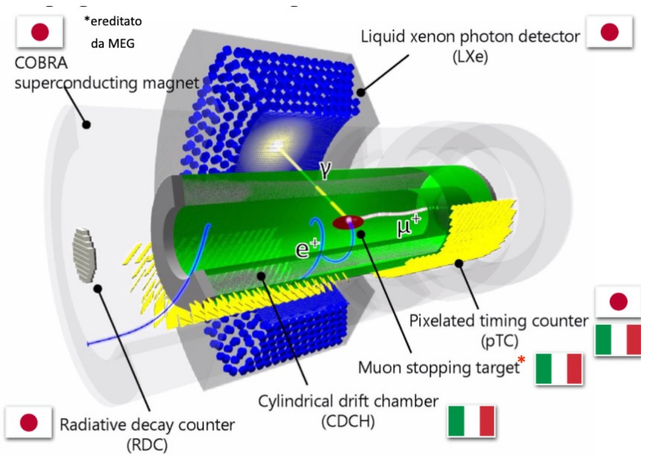
NEW 2024: OBSERVATION OF 0μ EVENTS

Number of events observed: 6

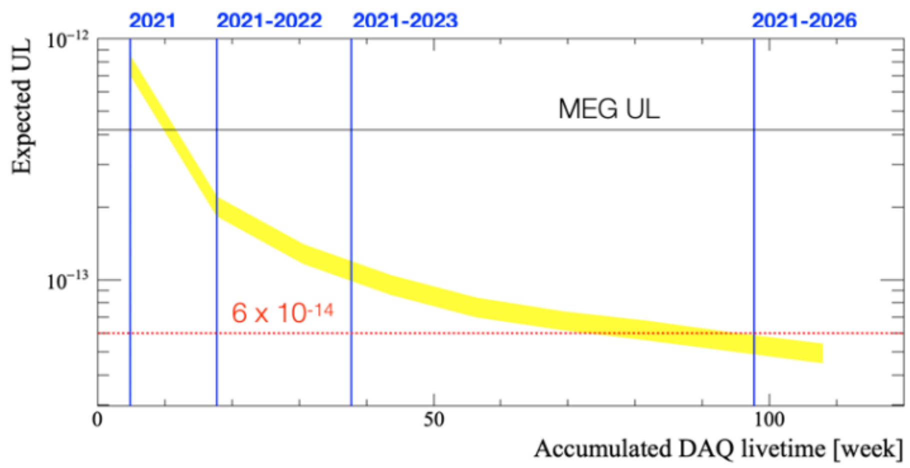
Observation significance: 5.8 σ

MEG 2 at PSI

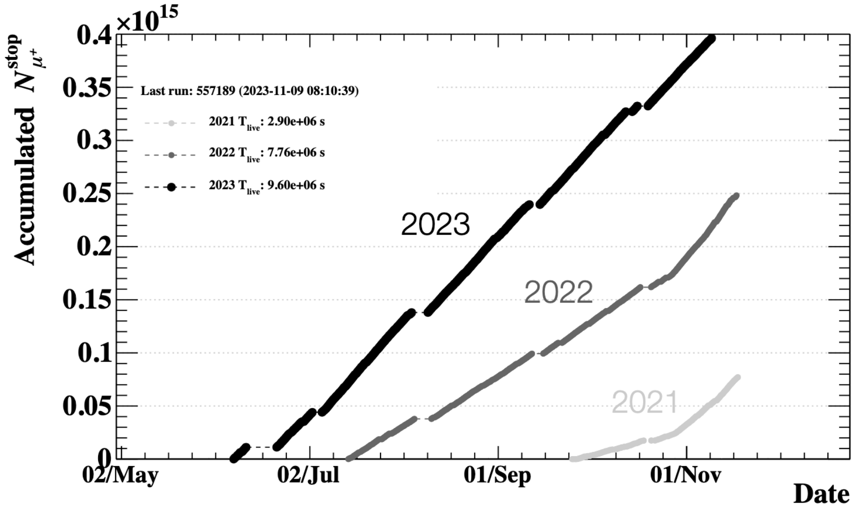
Taking data from 2021: number of muons on target steadily increasing
Unfortunately data taking in 2024 not started, yet, due to PSI Cryoplant problems

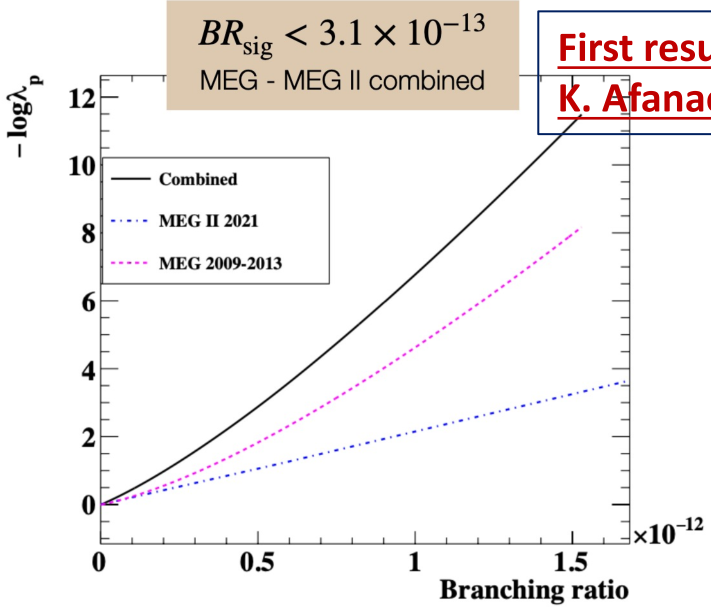


Foreseen sensitivity



The MEG II dataset (so far…)

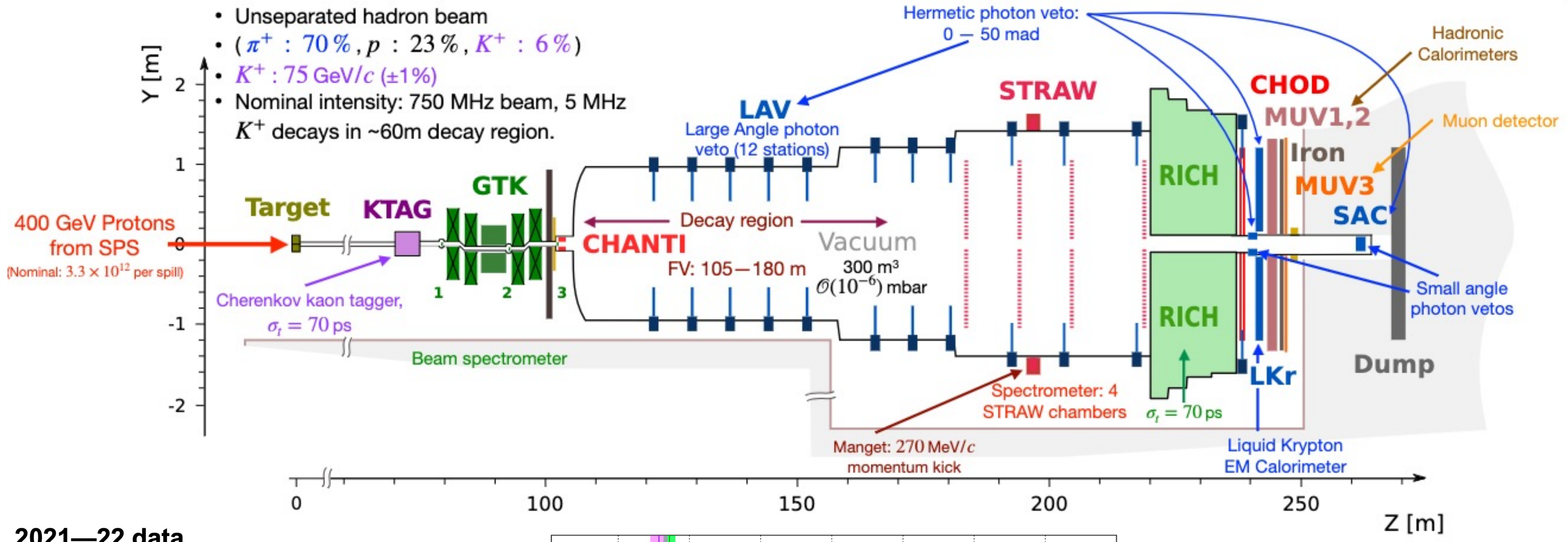


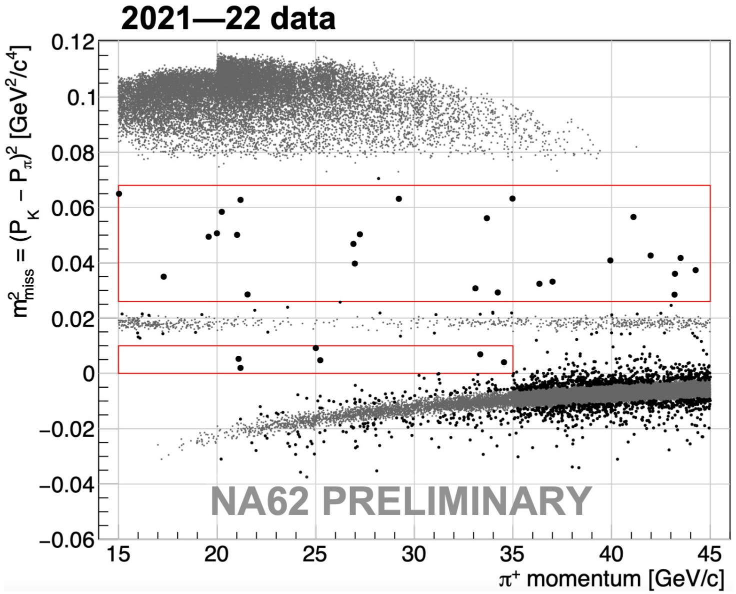


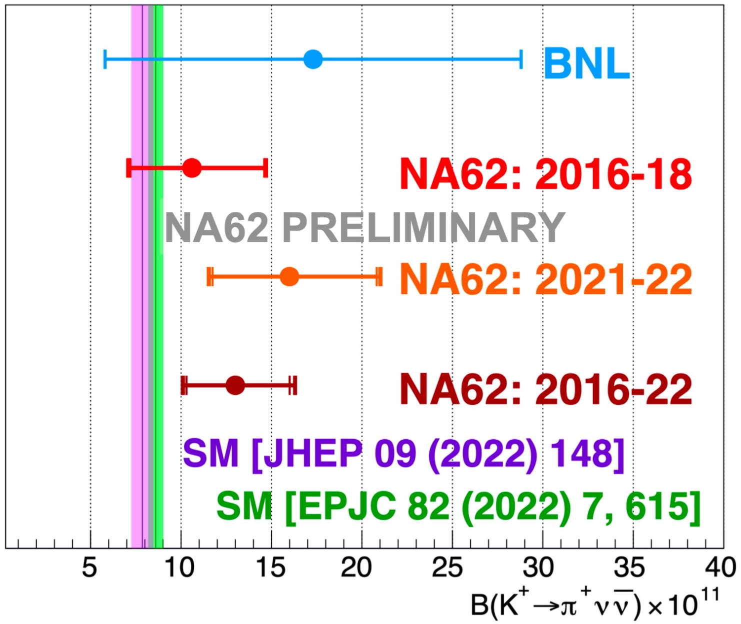
First result of MEG 2 on μ → eγ
K. Afanaciev et al., arXiv:2310.12614

NA62 Beamline & Detector

[JINST 12 (2017) 05, P05025]



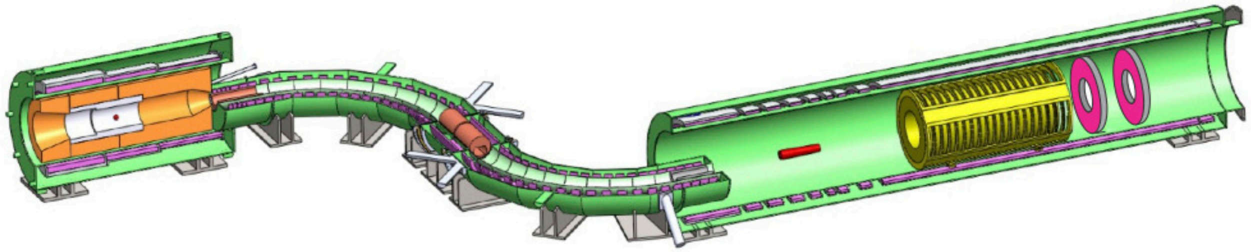


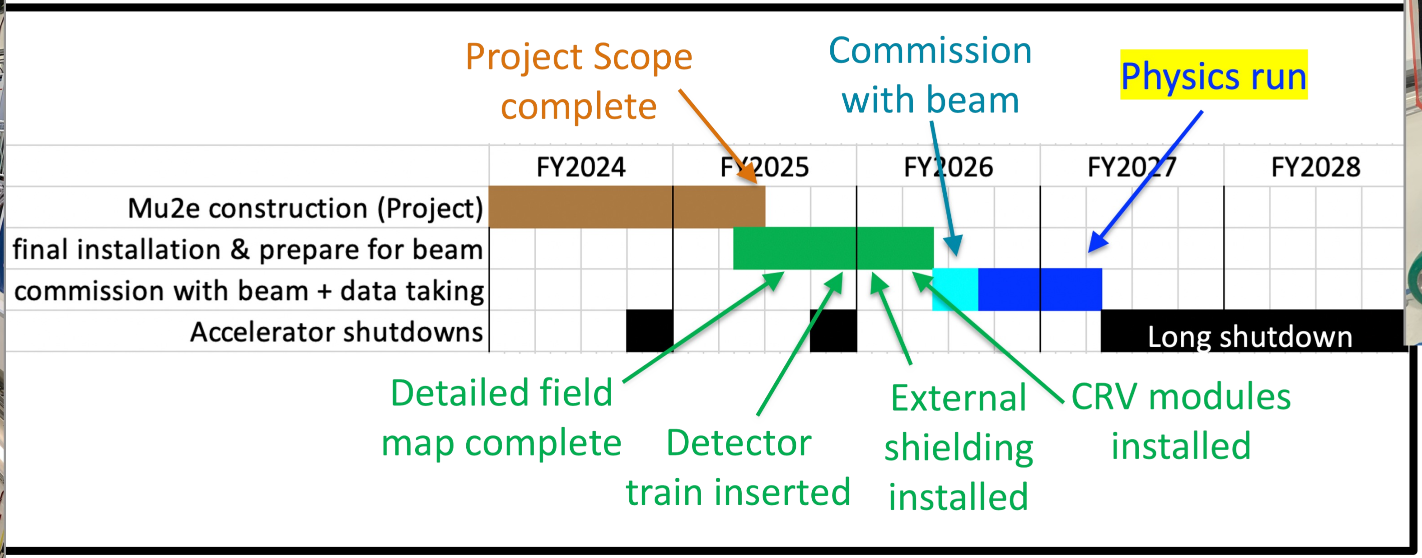


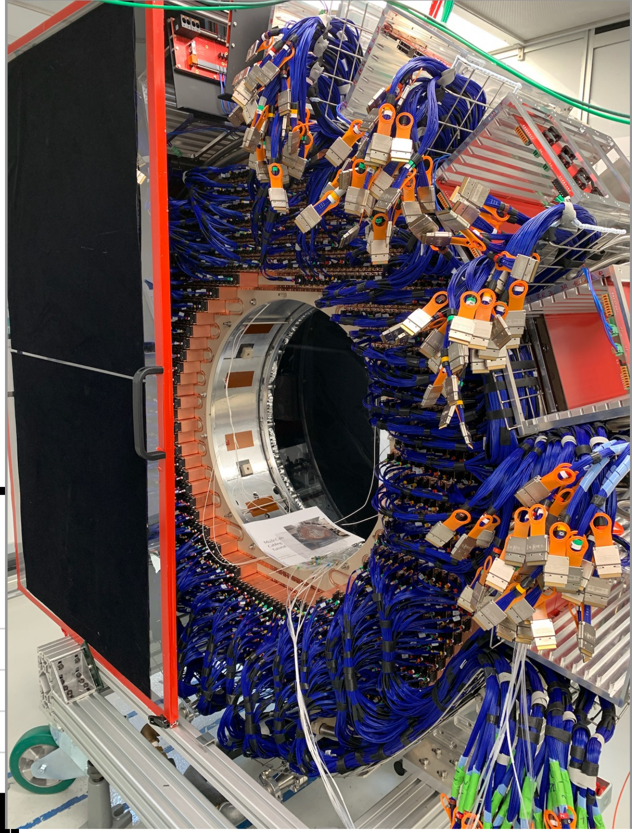
- Combining with 2016–18 data for full 2016–22 results:
  - $N_{bg} = 18^{+3}_{-2}$, $N_{obs} = 51$ (using 9+6 categories for BR extraction)
  - $\mathcal{B}_{16-22}(K^+ \to \pi^+ \nu\bar{\nu}) = (13.0^{+3.3}_{-2.9}) \times 10^{-11} = (13.0\ (^{+3.0}_{-2.7})_{stat}\ (^{+1.3}_{-1.2})_{syst}) \times 10^{-11}$
  - Background-only hypothesis rejected with significance $Z>5$.
- First observation of $K^+ \to \pi^+ \nu\bar{\nu}$ decay: BR consistent with SM prediction within 1.7σ
  - Need full NA62 data-set to clarify SM agreement or tension.

The Mu2e experiment at Fermilab

Searching for muon-to-electron conversion in a thin aluminum stopping target



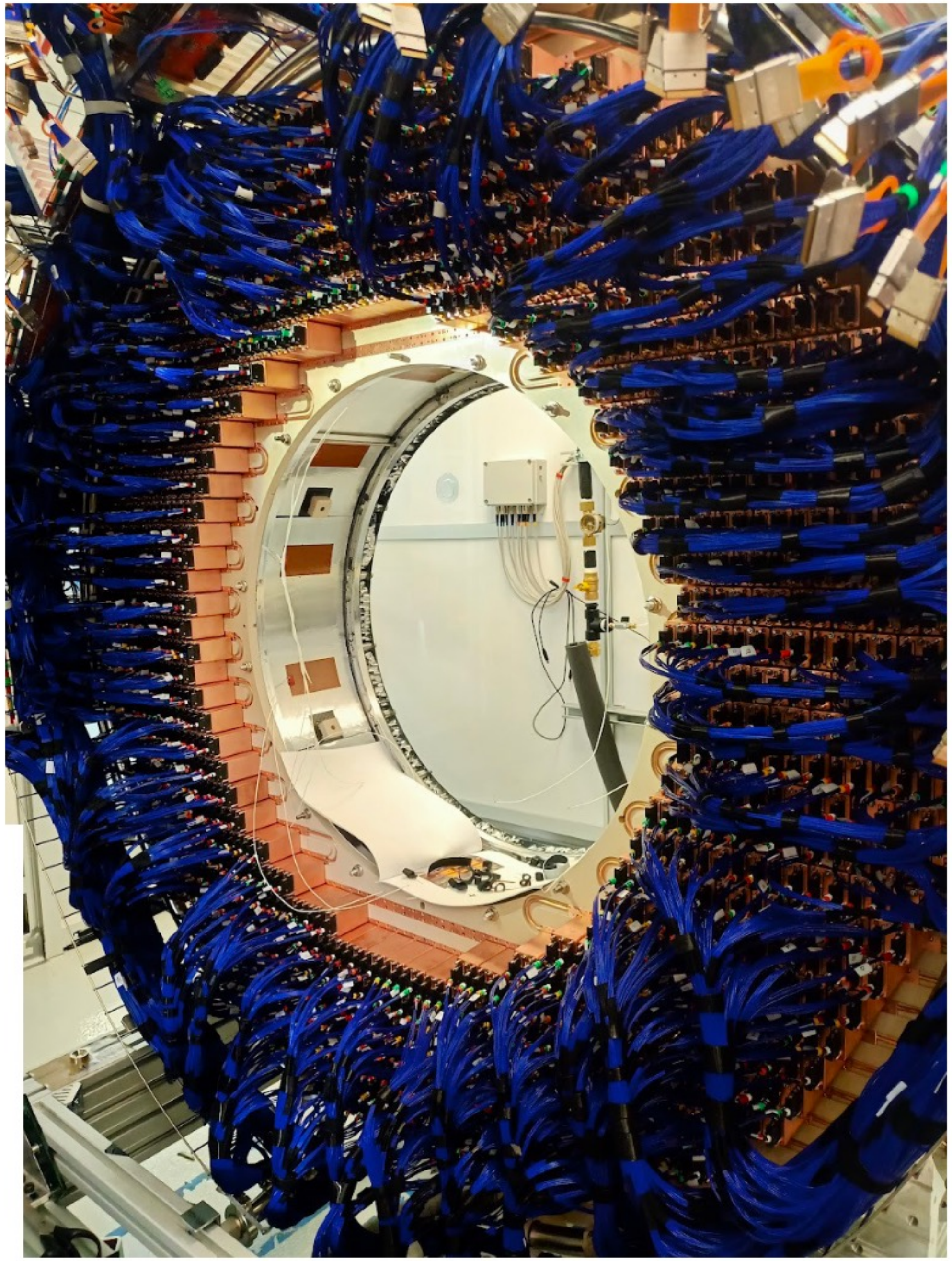


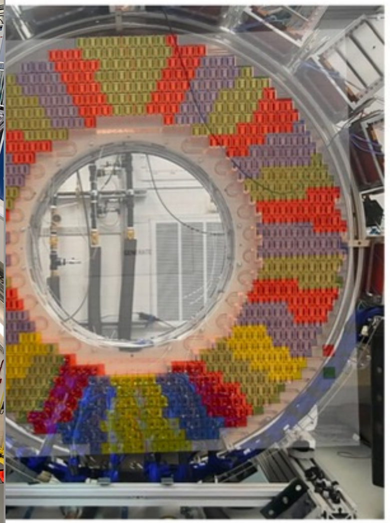


Calorimeter disk assembled with crystals (INFN responsibility)

The experimental hall with the recently installed Transport Solenoid (AGS Superconductors Genova)

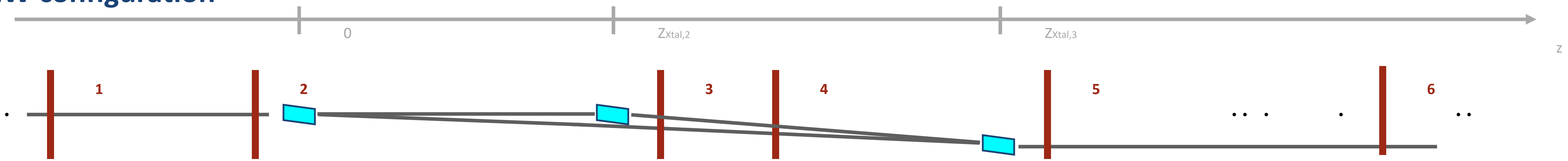
Other exp in backup slides, but cannot avoid mentioning the Significant progress for MU2E !!





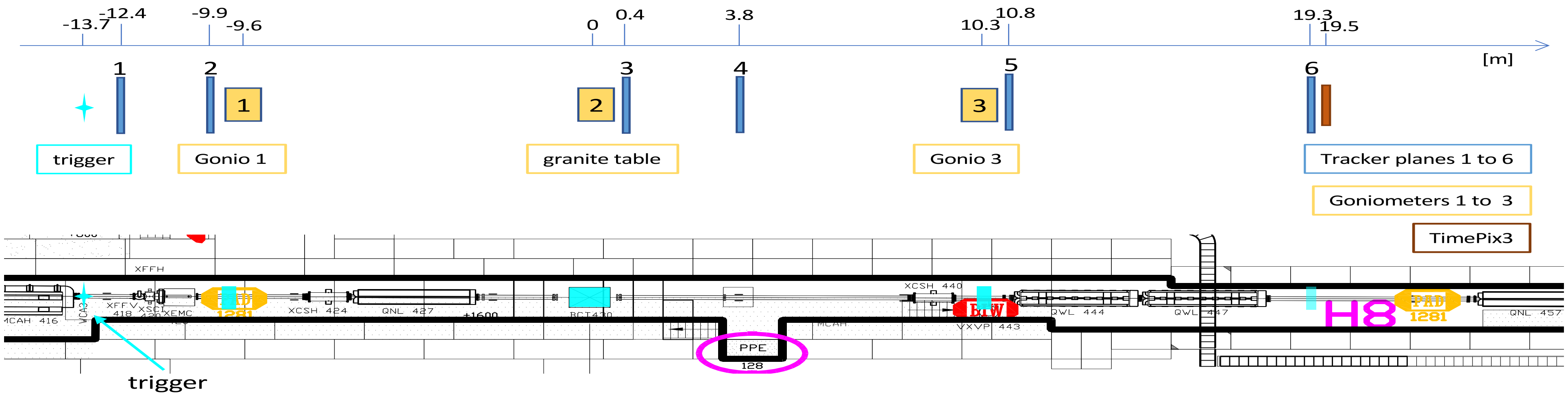
UA9, cristalli per manipolazione fasci

NEW configuration



incoming tracklet: 1 & 2

flexible track reconstruction with planes: 3, 4, 5, 6



Single station position might float by up to 0.5m

Beamline scintillator XSCI420 as trigger