INFN CSN1: stato e prospettive su programmi European Strategy

4–5 Apr 2024 LNF

Terza Giornata Acceleratori

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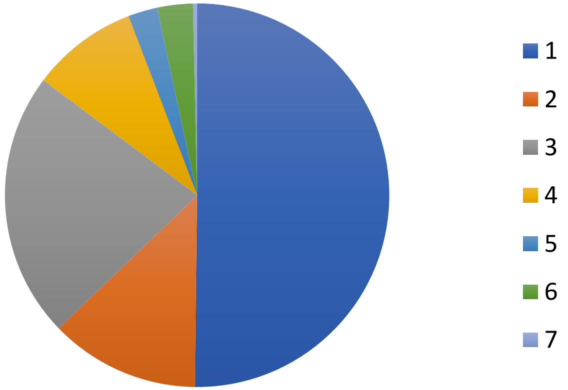
SEZIONE DI PISA

Outline

- Some statistics
- HL-LHC and its upgrades
- Flavour physics
- Neutrino experiments
- European Strategy, FCC, attività per futuri acceleratori

Research lines CSN1 2024	FTE (%)	Budget (%)
Physics at hadron colliders (LHC)	50,71	50,19
Neutrino Physics	9,10	12,6
Flavour Physics (with LHCb)	27,11	22,45
Charged Lepton Physics	5,73	8,95
Proton Structure	2,61	2,46
R&D for Future Accelerators	3,76	3,01
Dark Sector	0,99	0,34

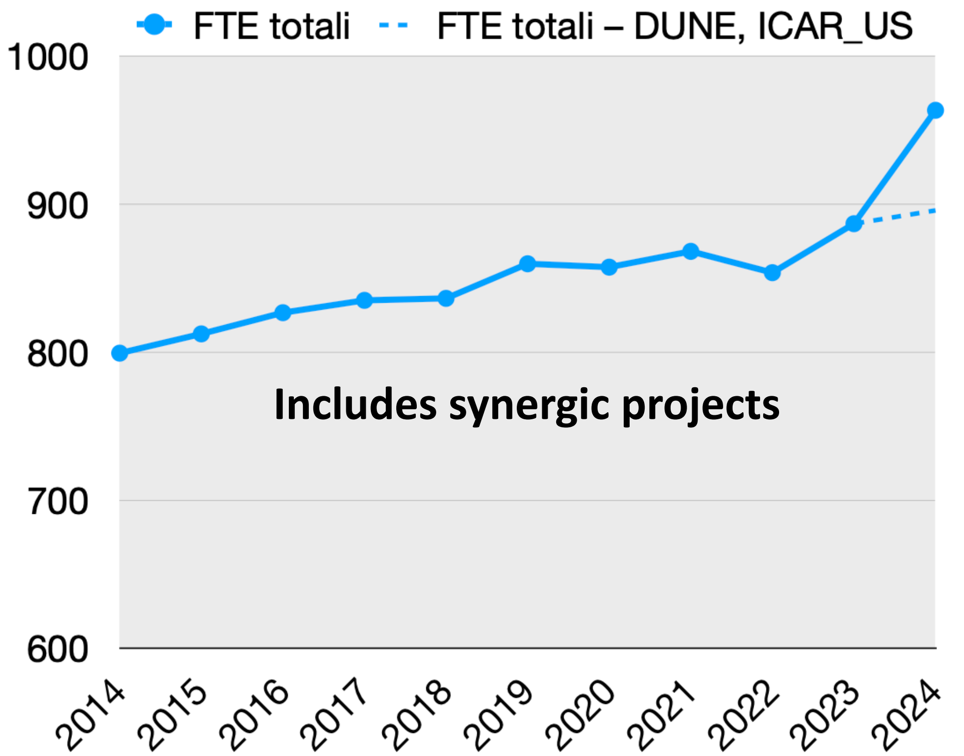


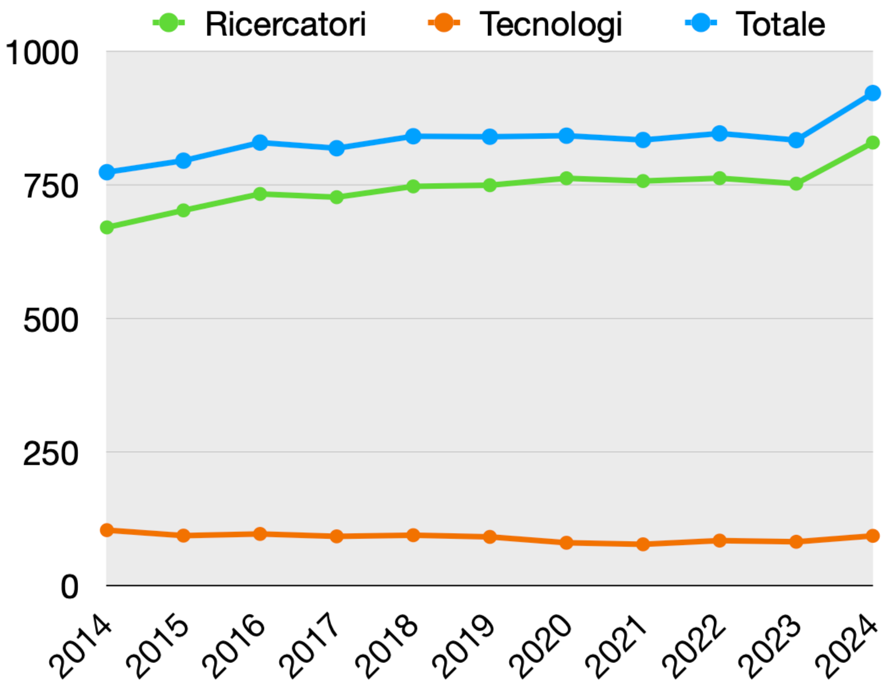
(*) 2024 CSN1 Budget 25 M€, does not include the external fund complementing HL-LHC and DUNE detector construction, Tier2 computing

CSN1 PERSONNEL

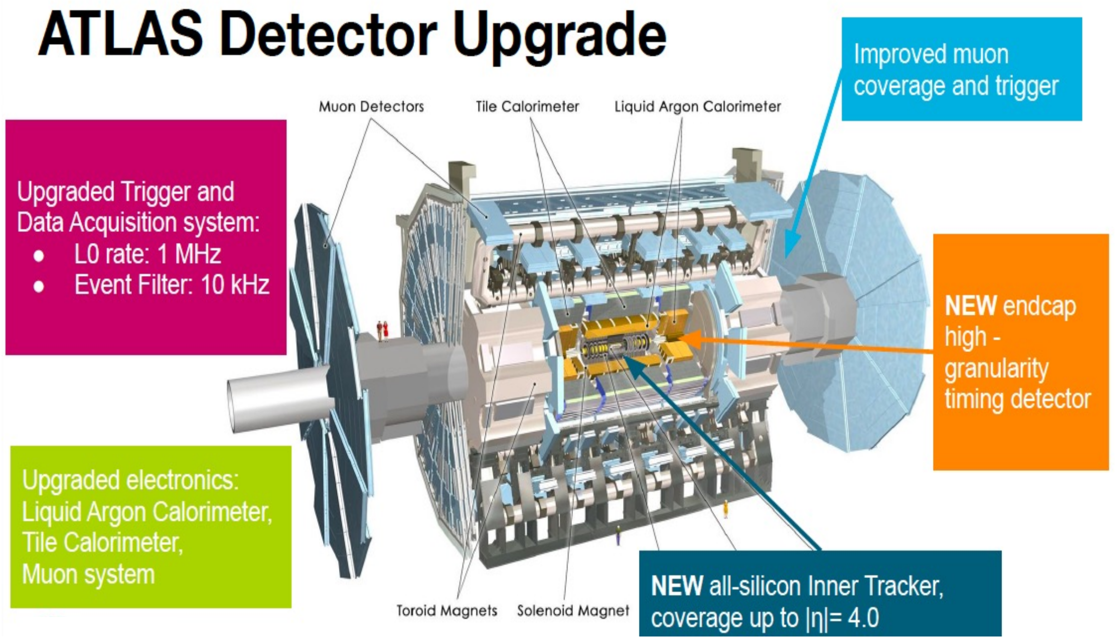
CSN1	2014	2015	2016	2017	2018	2019	2020	2021	2022
FTE	759,98	753,03	784,19	797,86	822,38	825,86	834,62	813,69	820,27
People	998	1043	1061	1084	1124	1151	1166	1185	1181
FTE/people	76,2%	72,2%	73,9%	73,6%	73,2%	71,8%	71,6%	68,7%	69,5%
Women	186	209	227	231	234	233	236	244	259
%Women	18,6%	20,0%	21,4%	21,3%	20,8%	20,2%	20,2%	20,6%	21,9%

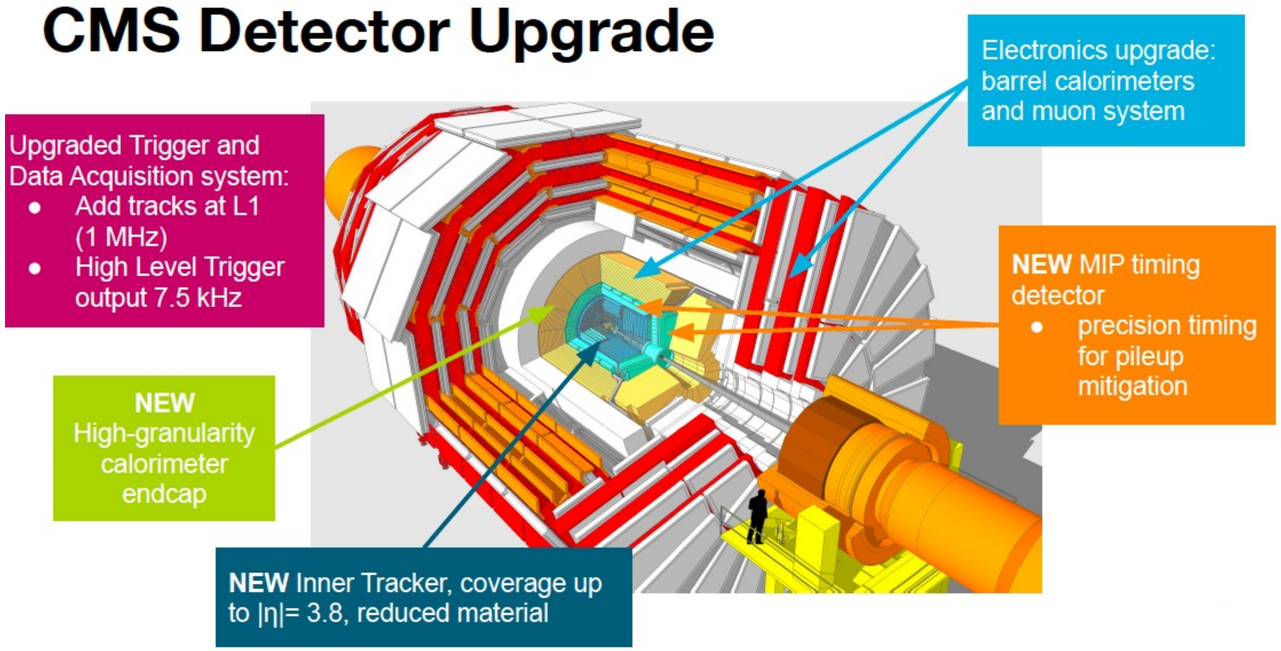
FTE fraction with CSN1: ~70% constant over the years





ATLAS and CMS upgraded detectors (phase 2)





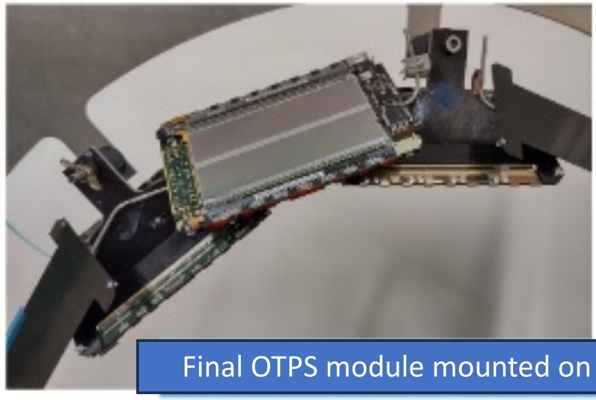
Main INFN INVOLVEMENTS:
- Tracker (ITK)
- Liquid Argon Calorimeter
- Tile Calorimeter
- MUON
- TDAQ

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

Progress in the PHASE 2 upgrade @ INFN

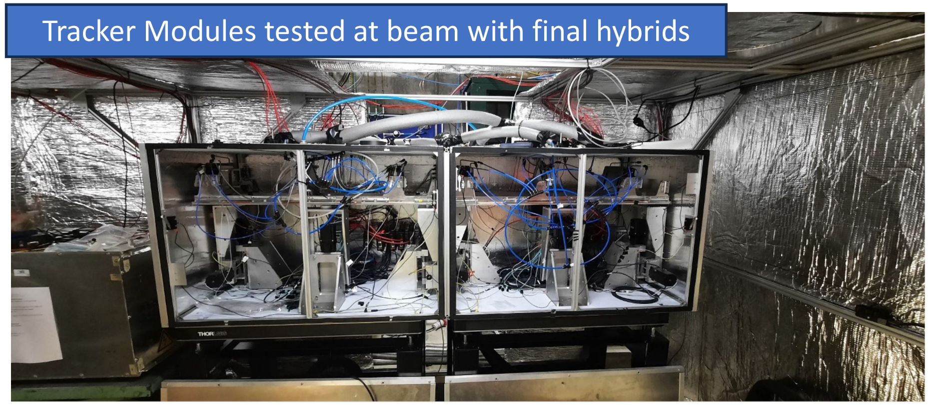
- Most projects of INFN interest close or at production phase
  - Final qualifications of prototypes in progress or close to completions **Some examples →**

CMS Tracker

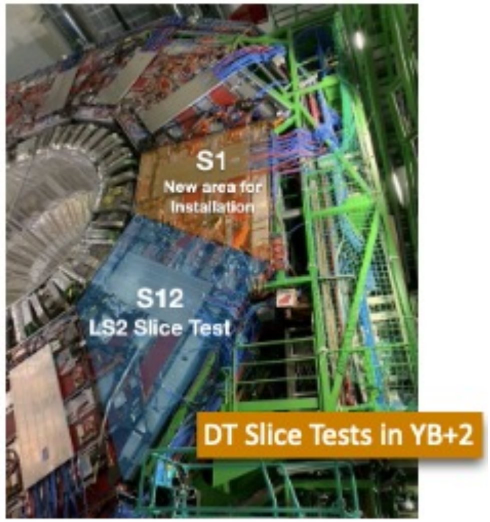


Final OTPS module mounted on ring at INFN PIsa

Tracker Modules tested at beam with final hybrids

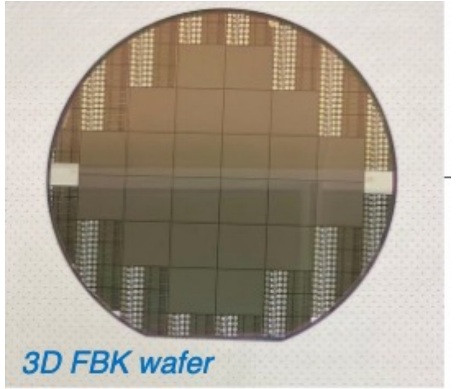


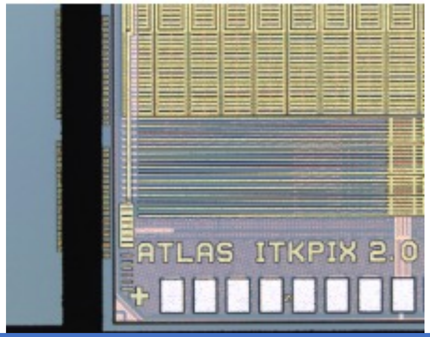
CMS Muons



Final DT electronics close to production, testbed for qualification of all modules being prepared in Legnaro

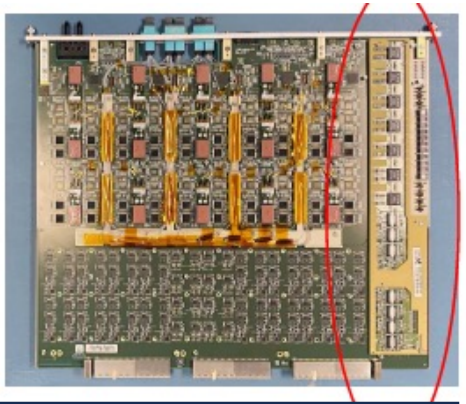
ATLAS ITK





Italian cluster Ge/Mi for assembly, Bo for Thermal cycles and Bo/Tn/Ud for cold testing is going through the Site Qualification. Few modules assembled

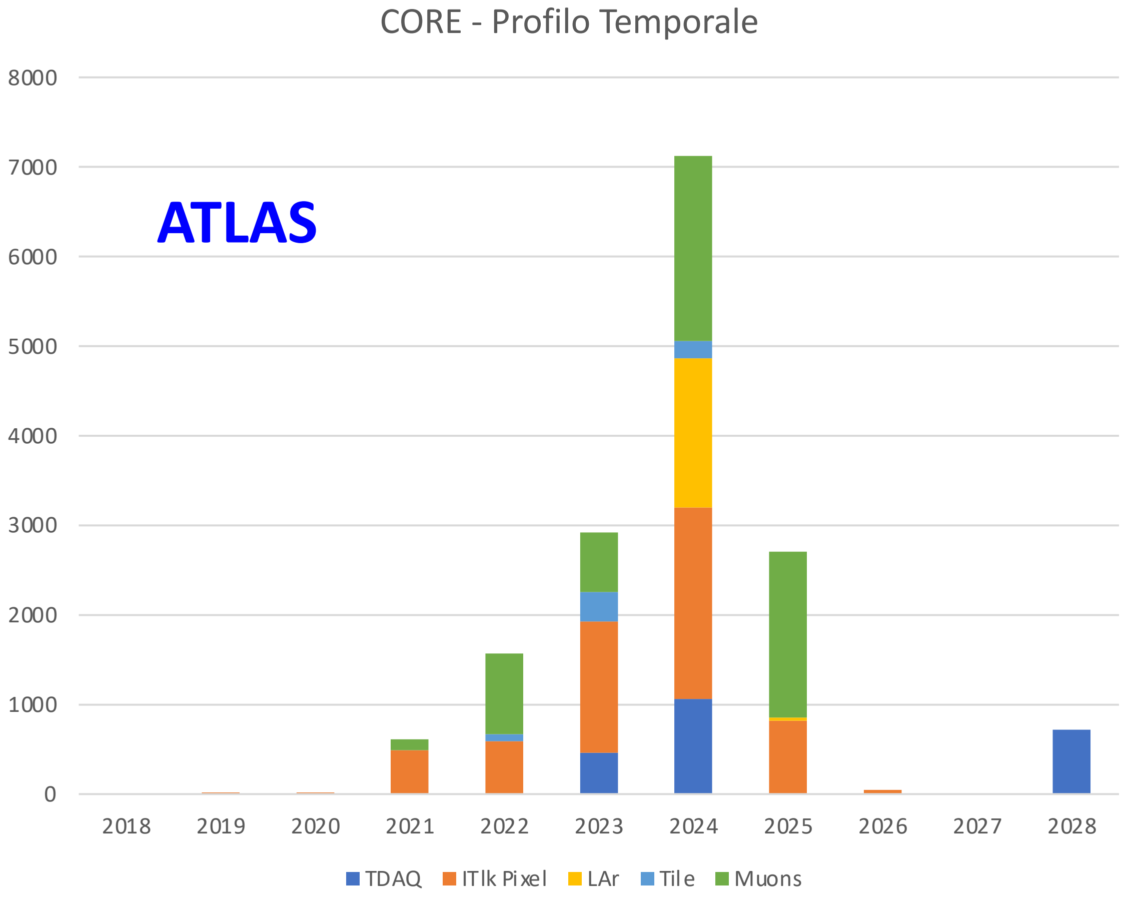
ATLAS LAr

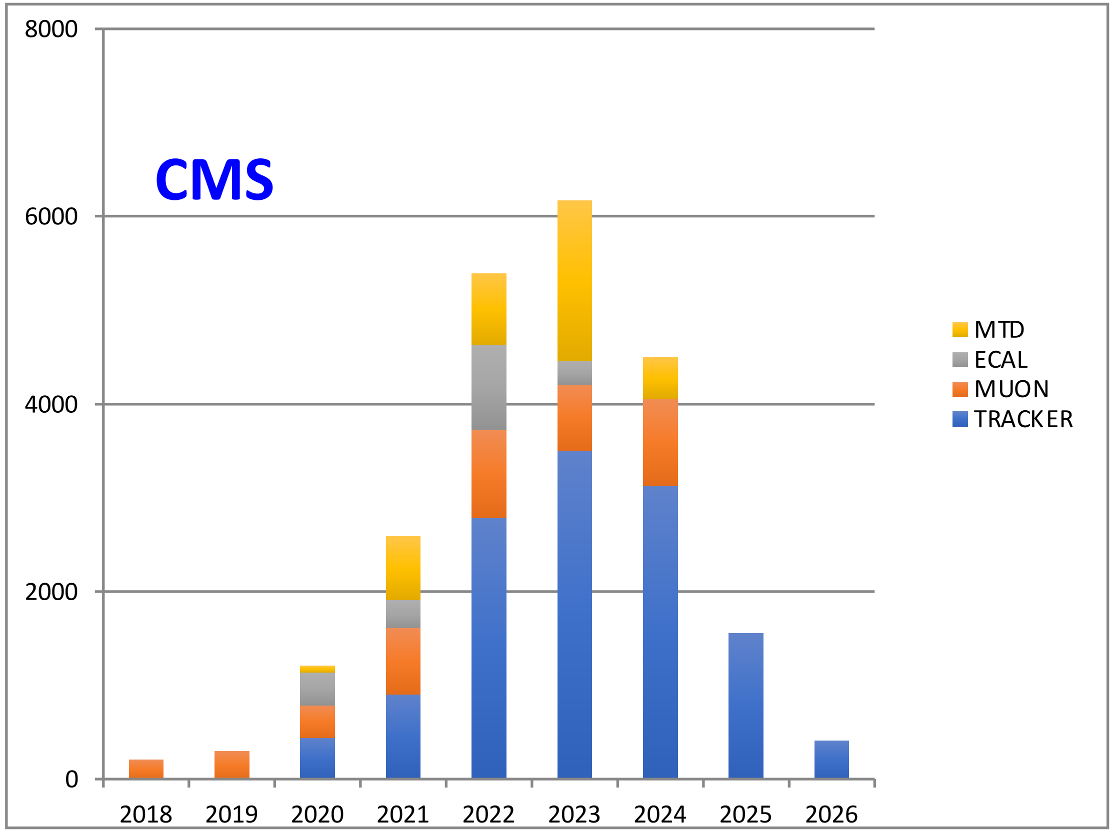


Advanced prototype of trigger electronics, integration tests foreseen next year

LHC Phase 2 CORE construction time profile

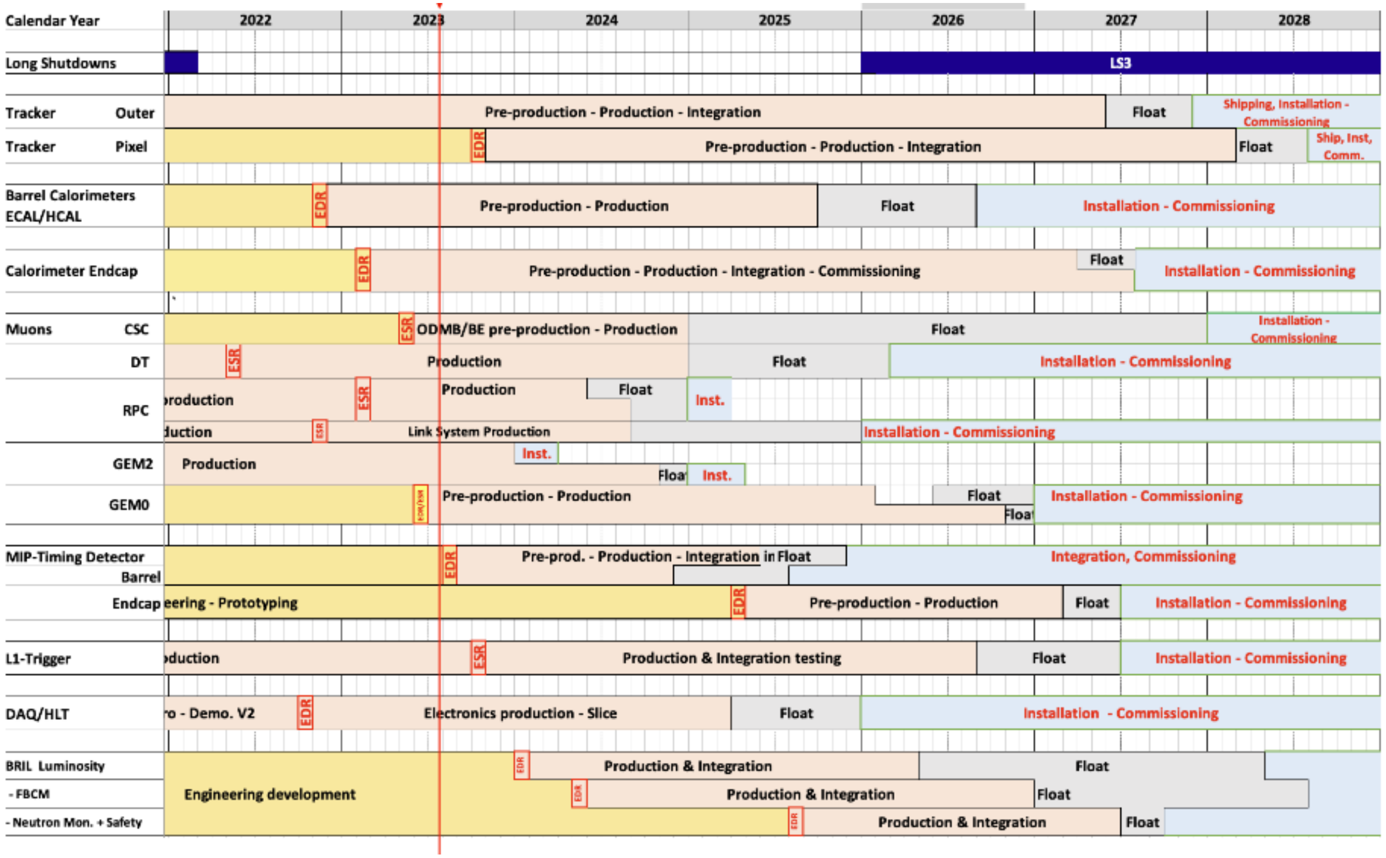
(extra-costs non included, yet, ≈ 20% total additional cost)



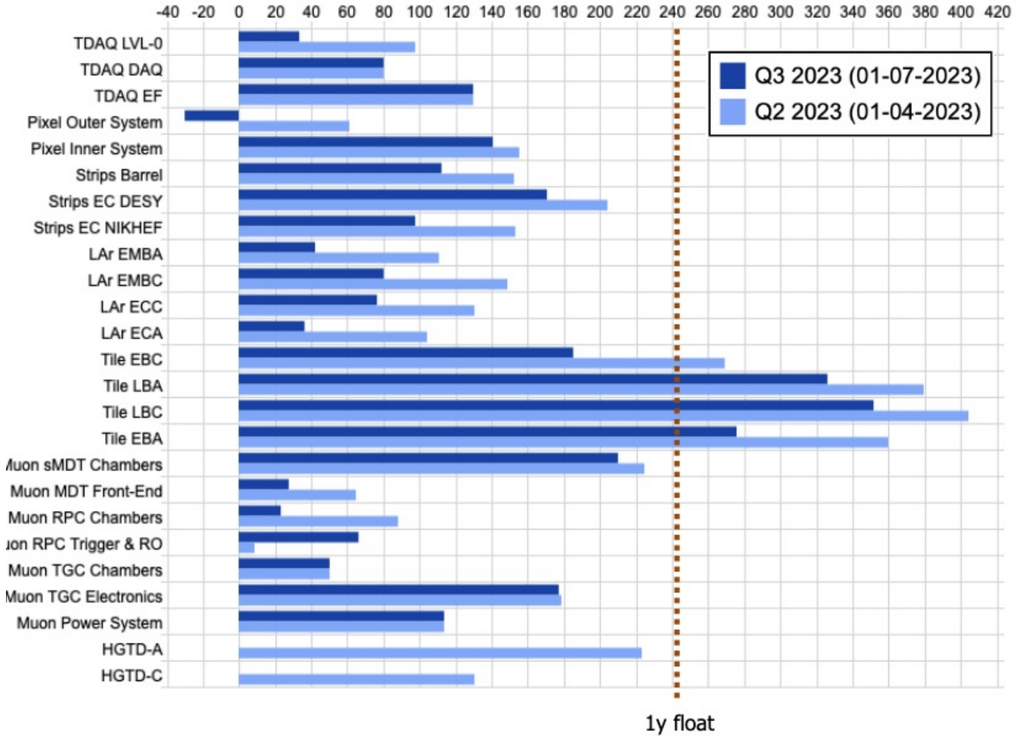


Concerns for the schedule, reduced contingency

CMS Construction schedule



ATLAS Time Contingency, typically less than 1 year



LHCb Upgrade 2

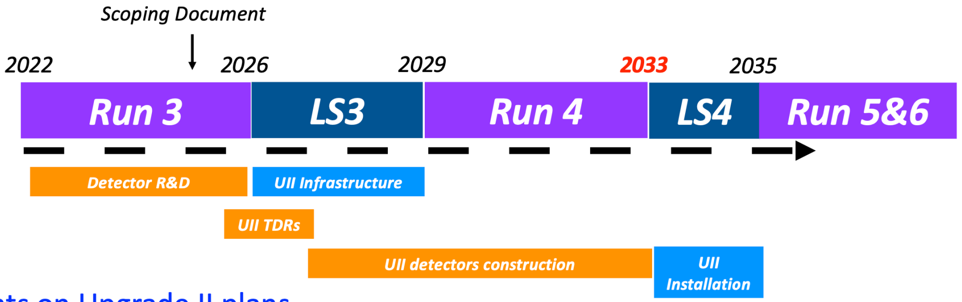
CSN1 review of possible INFN participation started

LHCC-2021-012

Approved March 2022

- Detector design and technology options
- R&D program and schedule
- Cost for baseline, options for descoping
- National interests

Constraints on timeline



Constraints on Upgrade II plans

- All detector components fully ready at beginning of LS4, in 2033
- LS4 duration of 2 years will be fully needed for Upgrade II installation

Mitigation strategy

- Start detector element construction during LS3
- Anticipate some detector & infrastructure work to LS3 as a part of consolidation work (ECAL, RICH, Magnet stations, RTA under discussion)

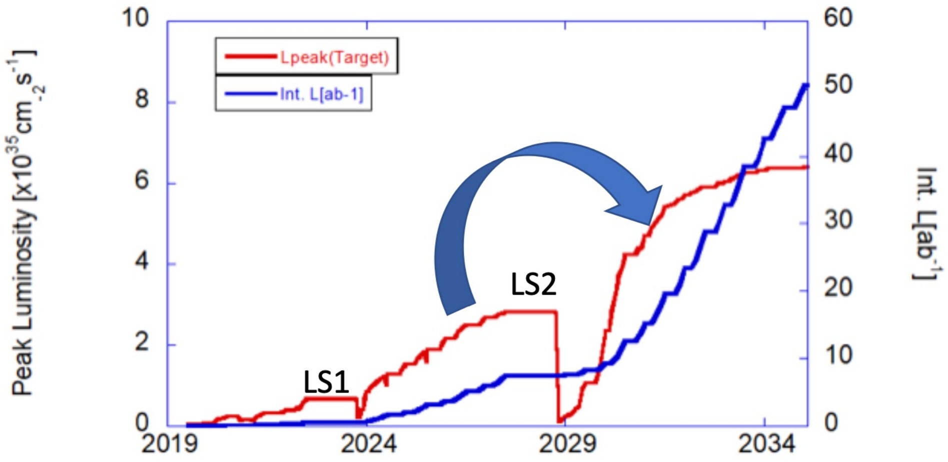
Detector	Baseline (kCHF)
VELO	14800
UT	8900
Magnet Stations	2300
MT-SciFi	22400
MT-CMOS	19500
RICH	15600
TORCH	9900
ECAL	34800
Muon	7100
RTA	17400
Online	8900
Infrastructure	13500
Total	175100

Scoping document in preparation →

- The project consists of a major change of the detector during LS4, in order to sustain an instantaneous luminosity of up to 1.5×10^{34} $cm^{-2}s^{-1}$ and integrate 50/fb per year during Run 5 and Run 6 of LHC (target ~300/fb)

- In the FTDR we indicated two main directions to explore: reduce peak luminosity (from 1.5×10^{34} $cm^{-2}s^{-1}$ down to 1.0×10^{34} $cm^{-2}s^{-1}$) and optimise and/or reduce detector features
- The FTDR has an ambitious baseline cost of 175 MCHF → we are now exploring descoping scenarios at the level of ~85% and ~70% of max envelope

Belle 2 and next detector upgrade (LS2)



Motivation and for Belle II upgrades

- Improve detector robustness against backgrounds
  - Provide larger safety factors for running at higher luminosity
  - Increase longer term subdetector radiation resistance
- Develop the technology to cope with different future paths
  - For instance if a major IR redesign is required to reach the target luminosity
- Improve physics performance: get more physics per ab-1.
- A number of ideas are being developed for the *different time scales*
  - *Now: LS1 and before LS2*
  - *Medium term: LS2 (2027)*
  - *Long term: future upgrades (203x)*

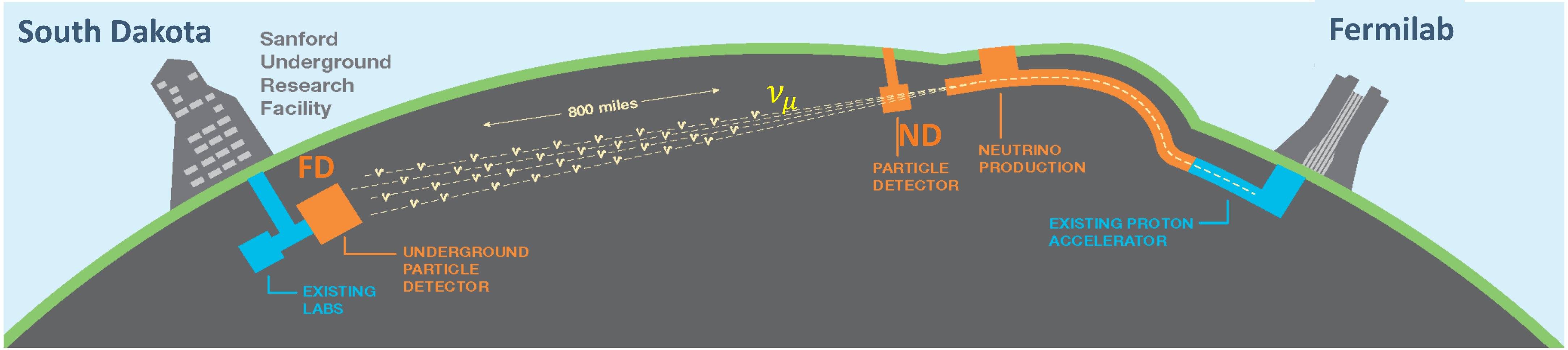
- Belle 2 completed Long Shutdown 1 (LS1)
- Data taking restarted in February
- Accelerator consolidation at LS1 should allow the machine to reach 2.5 X 10^{35} cm^{-2} s^{-1} luminosity
- More work and ideas needed to reach the design luminosity of 6 X 10^{35} cm^{-2} s^{-1}

Belle 2 detector upgrade in LS2 : consolidate and upgrade the detector to maximise physics reach at full luminosity.

CDR in preparation (ready end of 2023)

Expect relevant INFN participation in next detector upgrade

The Deep Underground Neutrino Experiment (DUNE)



A new generation Long Baseline – 1300 km – neutrino oscillation experiment based on

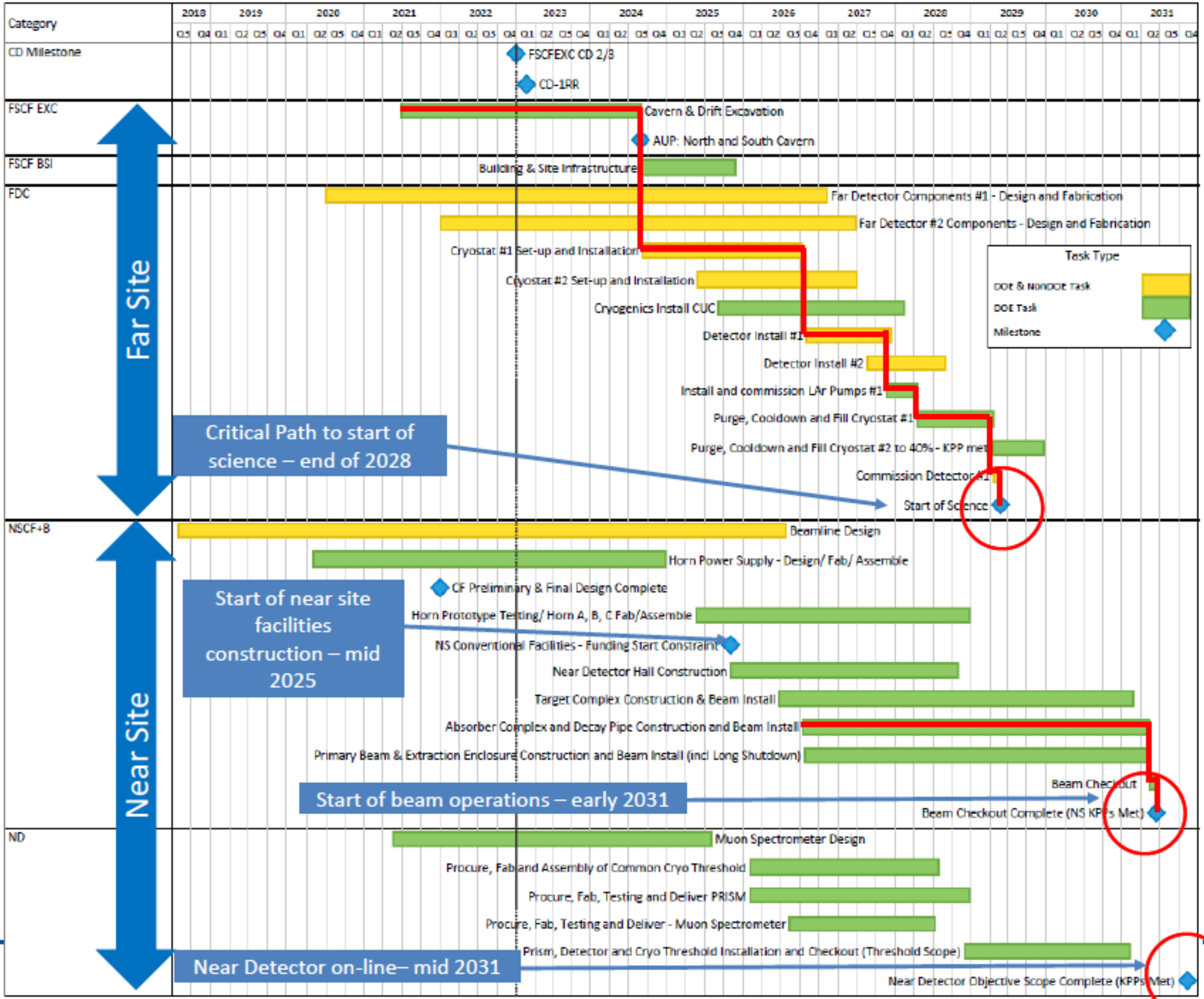
- a wide band high intensity (1.2 MW upgradable to 2.4 MW) $\nu/\bar{\nu}$ neutrino beam produced at Fermilab
- a large total mass (~70 kton) Far Detector at the Sanford Underground Neutrino Facility (SURF) 1.5 km underground exploiting the Liquid Argon Time Projection Chamber (LArTPC) technology
- a Near Detector complex (ND) at Fermilab providing control of systematic uncertainties, enabling a rich physics program

Some physics goals (phase 1)

Oscillation Physics:

- Definitive resolution of the mass ordering
- Sensitivity to maximal CP violation (δCP ~ ± π/2)
- World-leading measurement of mass splitting (Δm2atm)

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

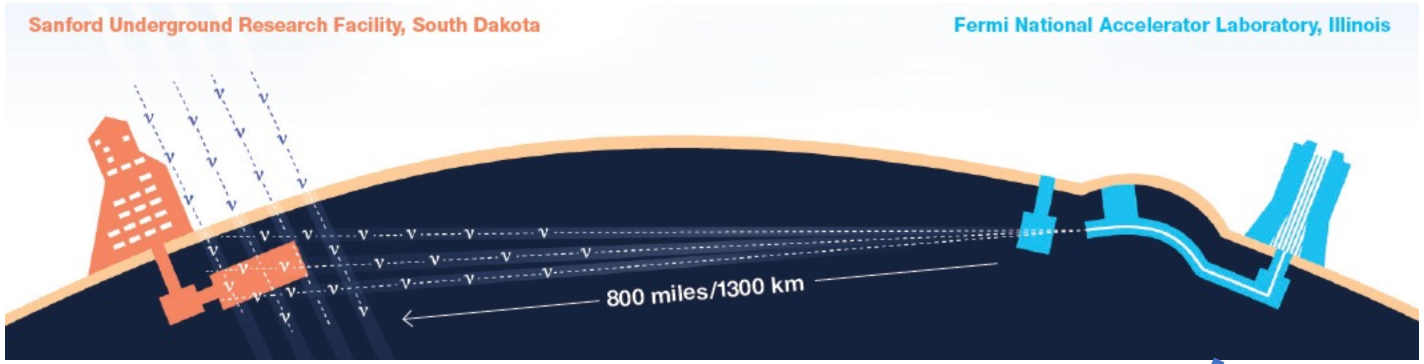


Favorable execution schedule enabled by new DOE funding profile in March 2022

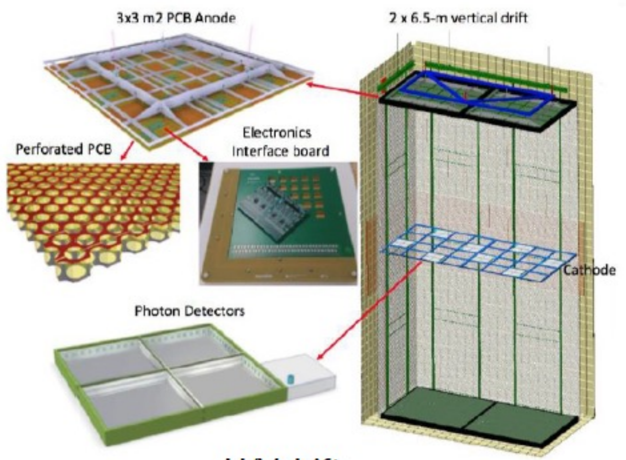
Notes:
- Fiscal Year display
- Early completion dates shown

LBNF/DUNE

INFN @ DUNE



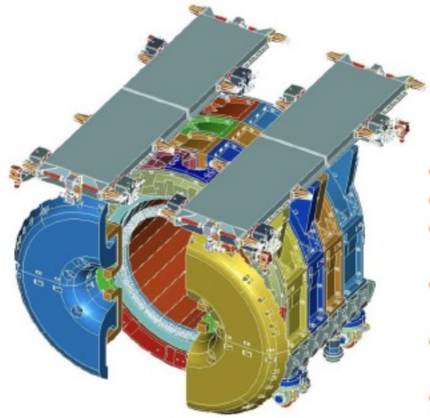
DUNE Far - Photon Detection System (PDS)



H/V drift

European site for WLS evaporation

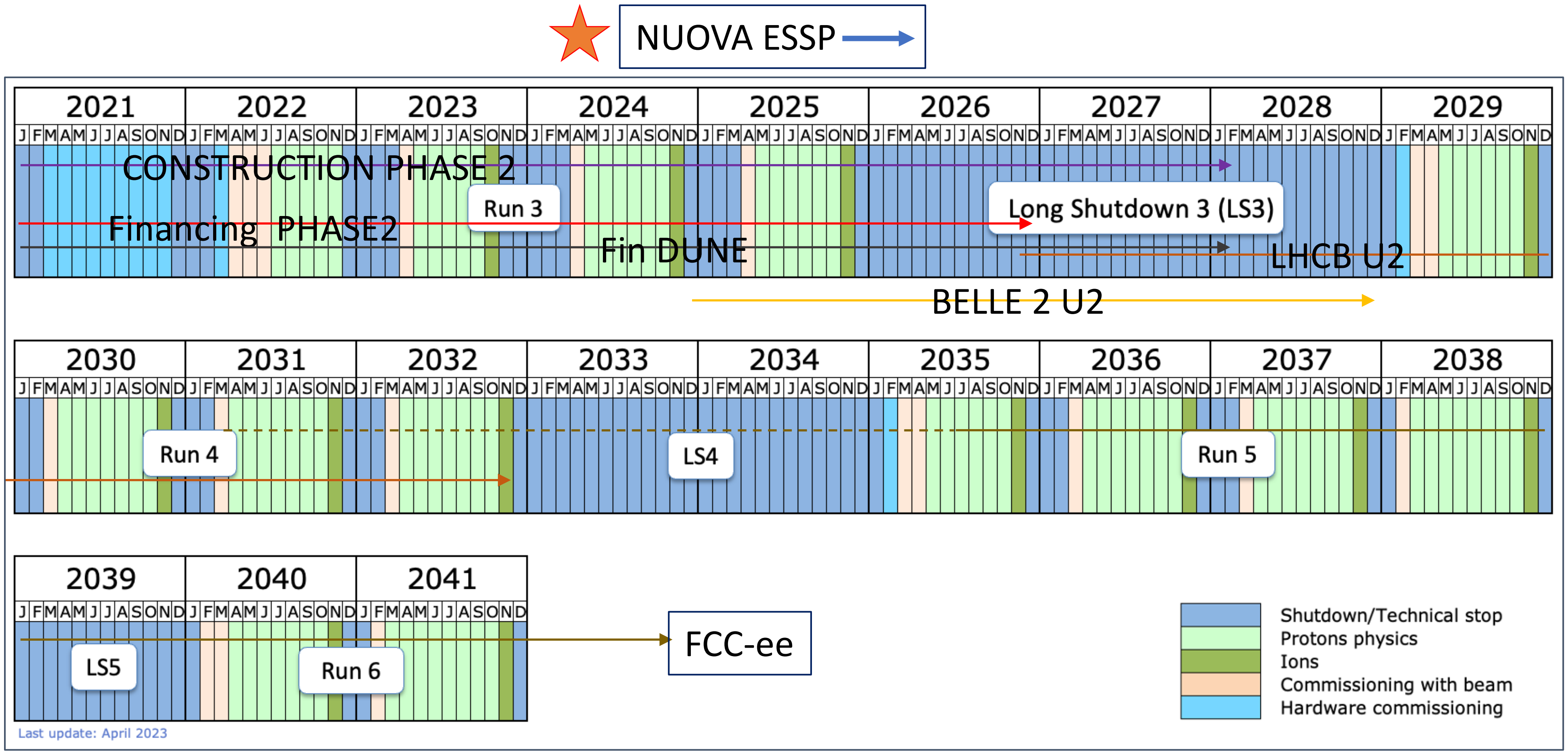
DUNE Near from KLOE→ SAND



Granular Argon for Interaction of Neutrinos (GRAIN)

- provide an independent measurement of the **flux**
- measure the **flavor** content of the neutrino beam
- contribute to remove **degeneracies** when the other components are off-axis
- add robustness to the ND complex to keep **systematics** under control
- provide a reasonable **control** of the systematics (SAND installed since Day-1 of data taking)
- exploit the high statistics to perform other **high precision neutrino physics** measurements and BSM searches without any ad-hoc modification

LHC long-term schedule and other projects

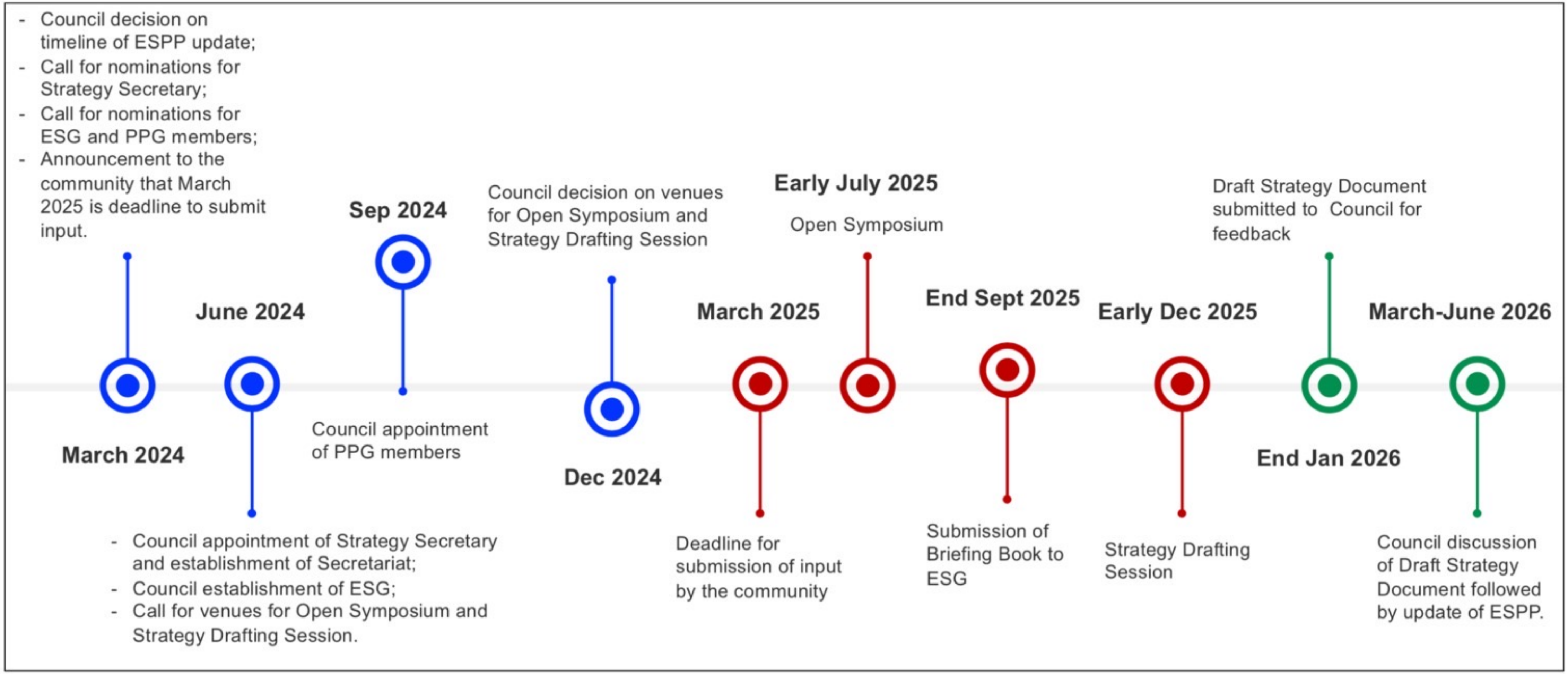


HL-LHC : Run 4, Run 5, Run 6 at least 3000 fb-1 for ATLAS e CMS (*ultimate lumi* 4500 fb-1)

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

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

Nuova European Strategy for Particle Physics



As last time, a more detailed timeline will be presented to Council by the Strategy Secretariat once established

L' INFN e la Strategia Europea per la Fisica delle Particelle

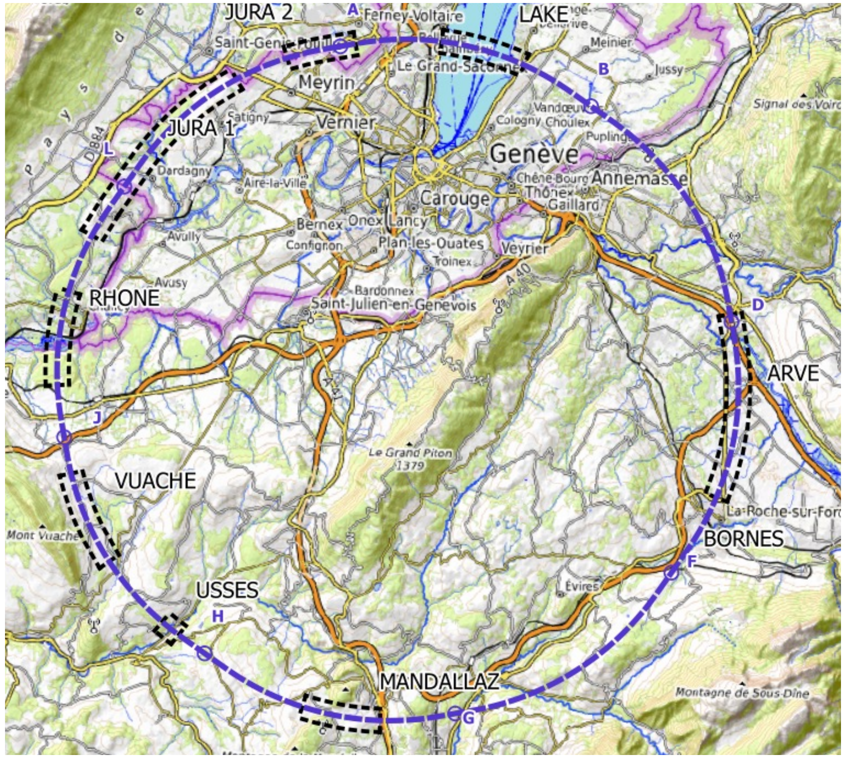
Le attività INFN per lo Studio di Fattibilità per il collider FCC, per le roadmap sugli acceleratori (High Field Magnets, Muon Collider, Cavità RF) e sui rivelatori.

- 6 e 7 Maggio a Roma, Centro Congresso Frentani (di fronte a Sapienza Università)
- Incontro che si colloca in modo ideale per la preparazione dell' Input da parte dell' INFN per la prossima European Strategy, fondamentale per la discussione del futuro della Fisica delle Alte Energie in Europa (CERN, e non solo) e quindi anche del nostro Istituto.
- **Le iscrizioni sono ancora aperte!**
- https://www.roma1.infn.it/conference/infn-espp-2024/

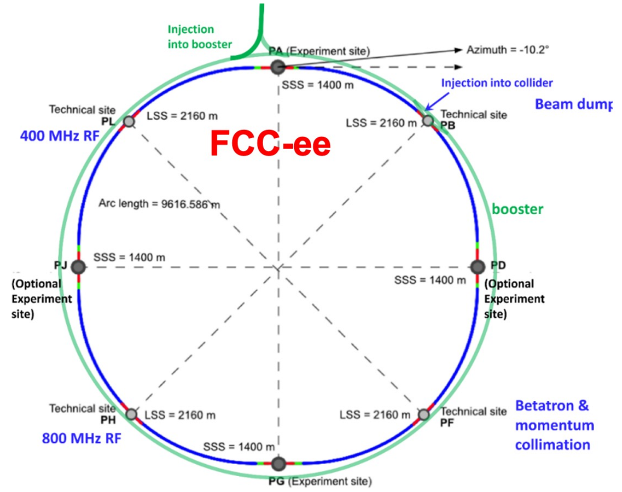
After HL-LHC: the FCC integrated project

Comprehensive long-term program maximizing physics opportunities

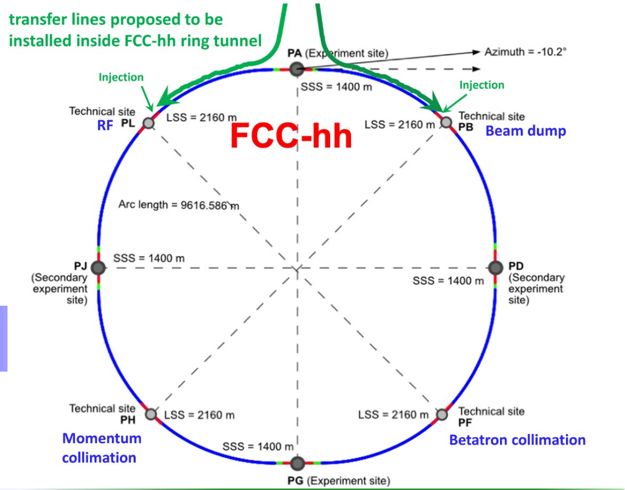
- **stage 1: FCC-ee (Z, W, H, $t\bar{t}$) as Higgs factory, electroweak & top factory at highest luminosities**
- **stage 2: FCC-hh (~100 TeV) as natural continuation at energy frontier, with ion and eh options**
- complementary physics
- common civil engineering and technical infrastructures, building on and reusing CERN's existing infrastructure
- FCC integrated project allows seamless continuation of HEP after completion of the HL-LHC program



Infrastructure preparation 2020 - 2040



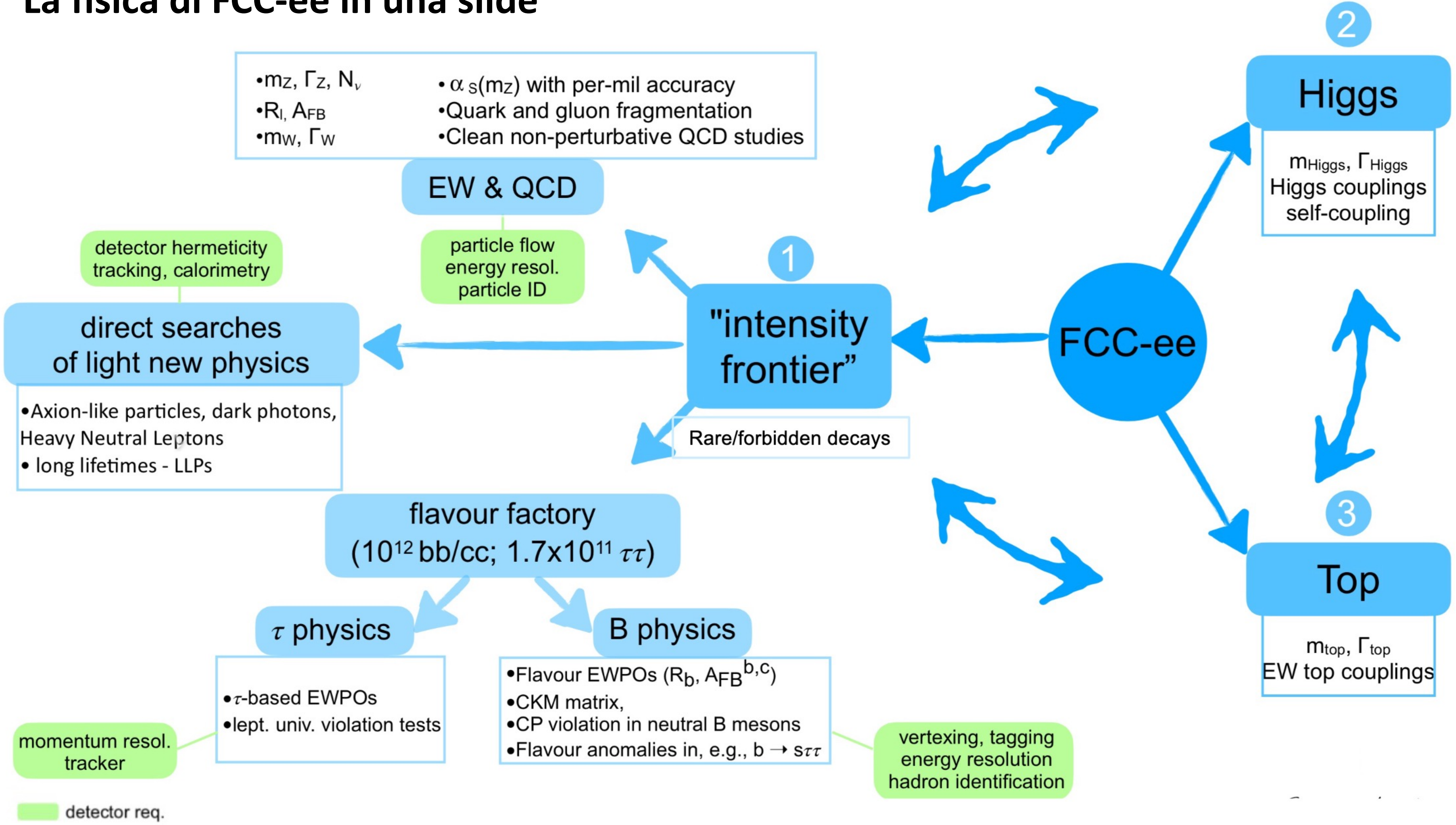
2045 - 2060



2065 - 2090

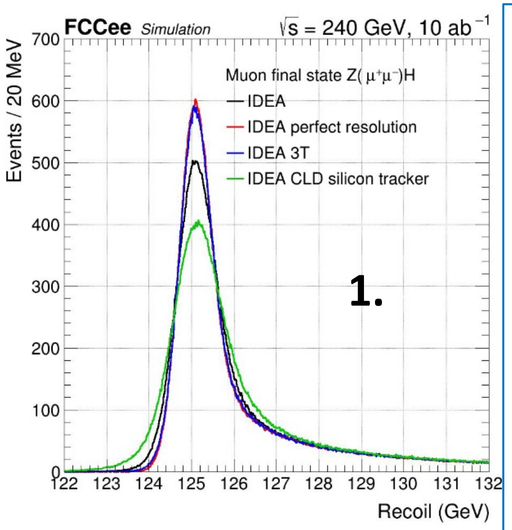
A first class infrastructure to maintain the leadership of European research in particle physics over the 21st century

La fisica di FCC-ee in una slide

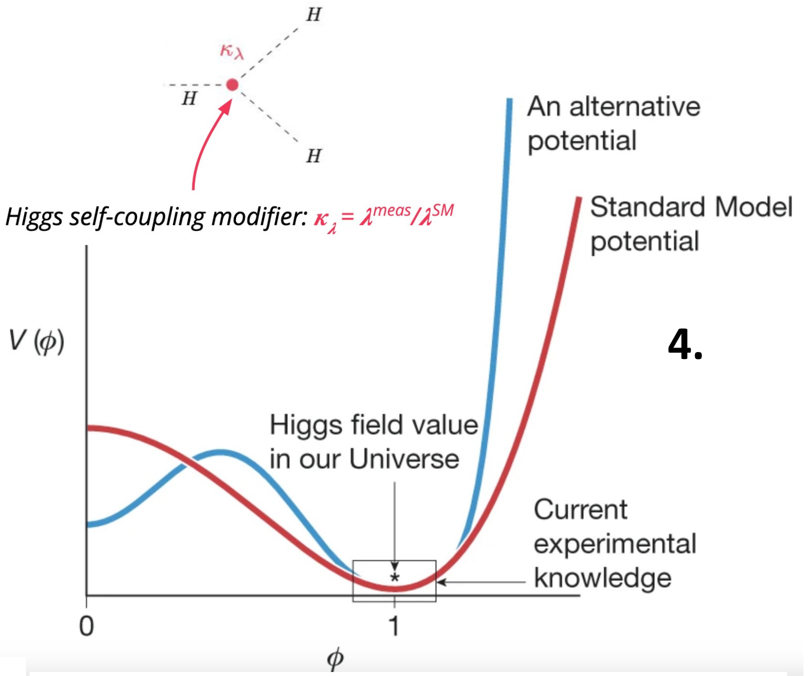


Slide from C. Grojean @ FCC Week'22

FCC unique project to unveal the Higgs

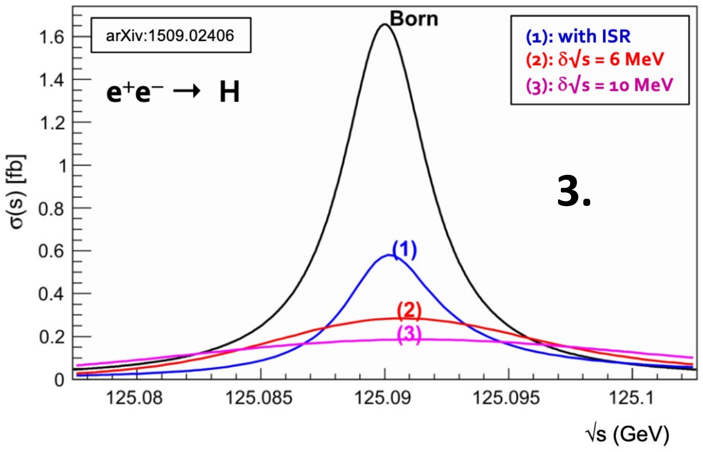


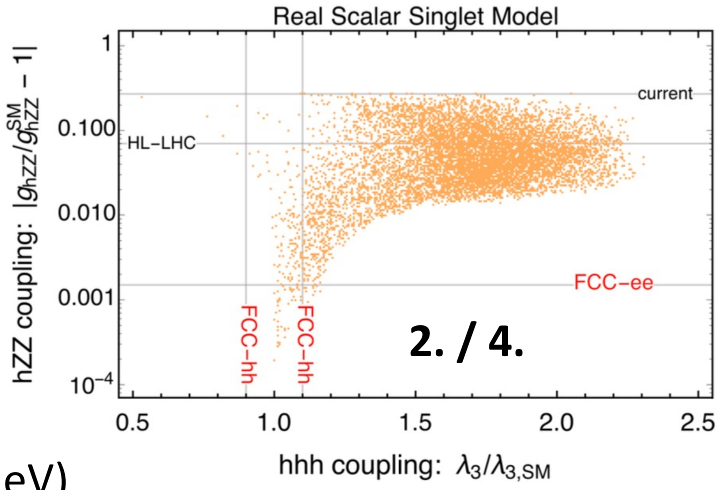
1. FCC-ee : Measurement of <u>absolute couplings</u> and <u>invisible width</u> with recoil in HZ
2. FCC-ee : precision couplings (permil for ZZ)
3. FCC-ee : potential to investigate 1st generation
4. FCC-hh : Higgs self-coupling at ≈ 5% (with FCC-ee ≈ 20% with single Higgs)
5. FCC-ee : precision top mass vs Higgs investigates stability of the Universe

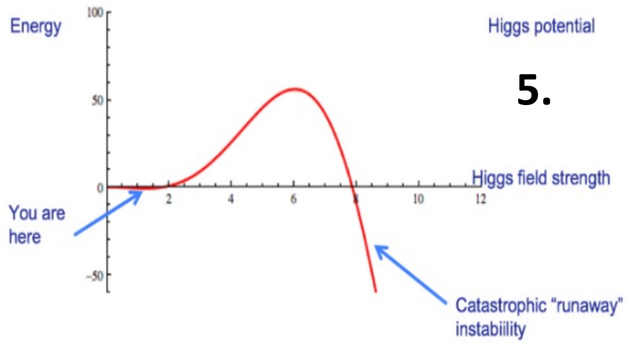


$$V(\Phi^+\Phi) = \mu^2\Phi^+\Phi + \lambda(\Phi^+\Phi)^2$$

Salam, G.P., Wang, LT. & Zanderighi, *Nature* **607** (2022)





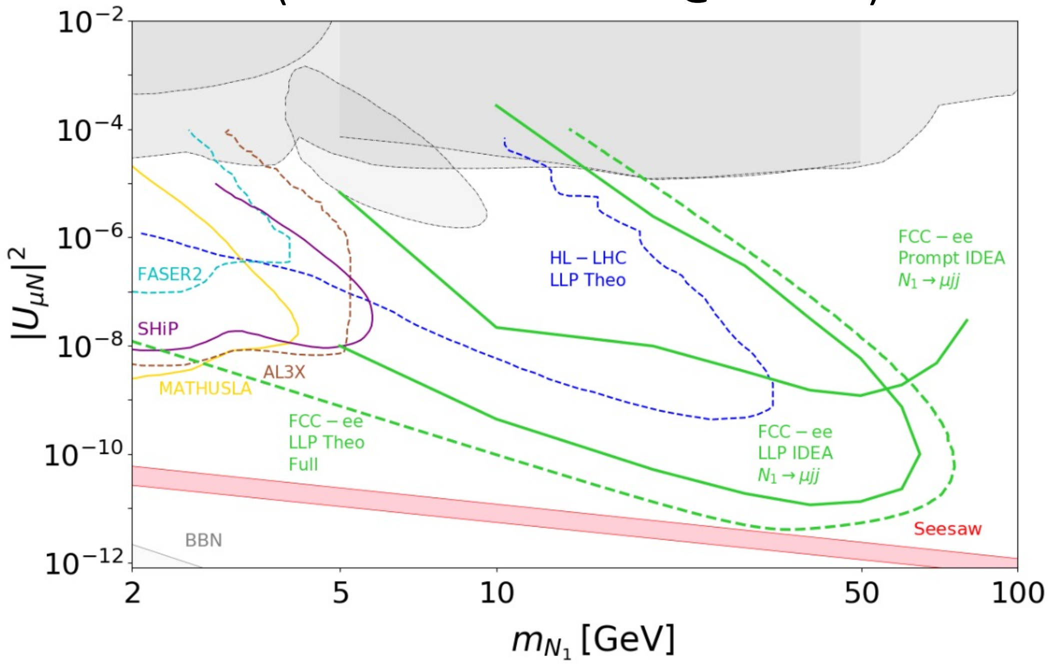


Need √s monochromatisation (Γ_H ≈ 4.2 MeV)

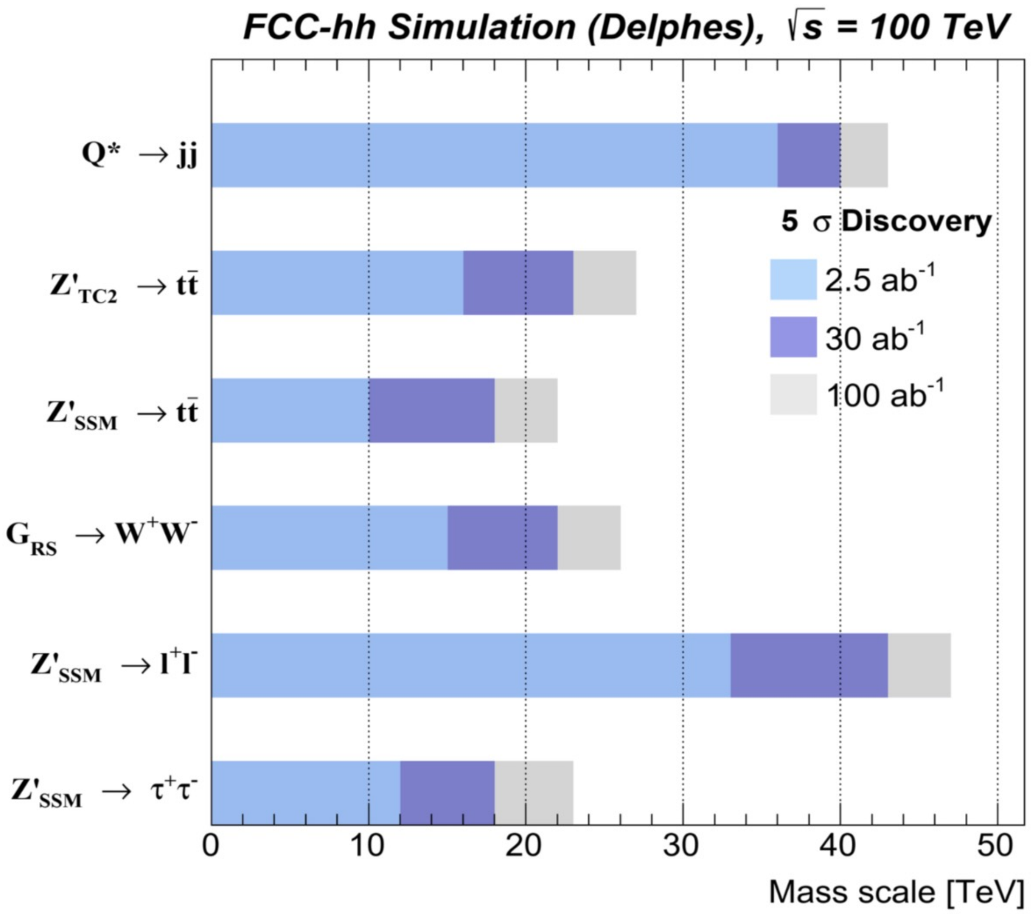
FCC exploring new territories for BSM

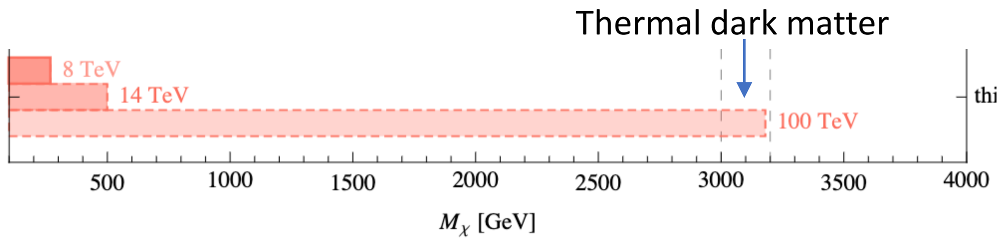
Heavy Neutral Leptons

(seesaw mechanism @ FCC-ee)



Strength of the sterile-active mixing vs HNL mass



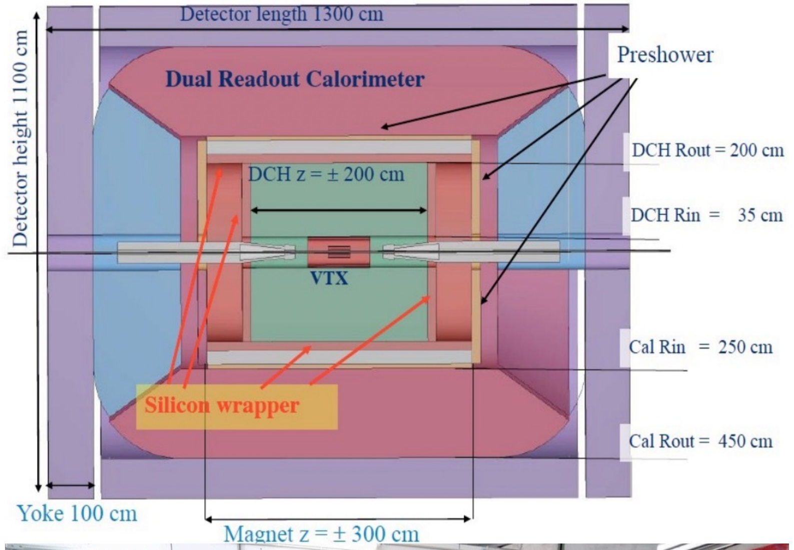


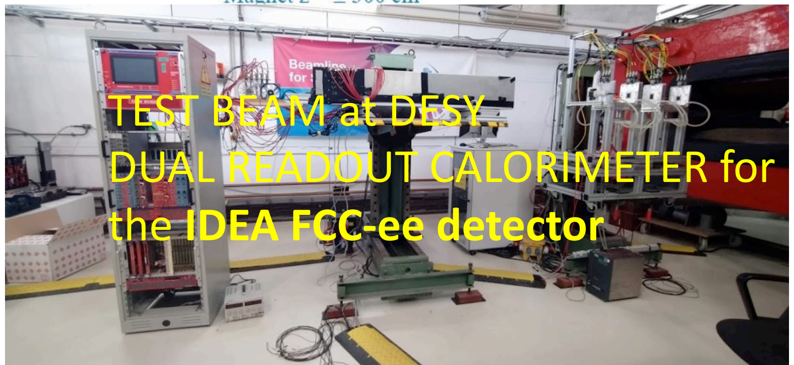
FCC-hh closing the window for WIMP dark matter

Preparing the future at CSN1:

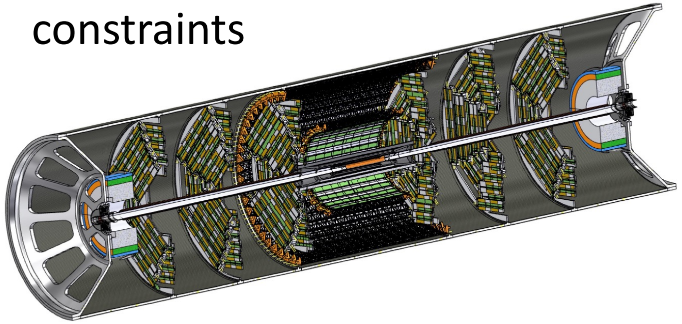
FCC @ INFN (talk of M. Boscolo)

IDEA detector for FCC-ee

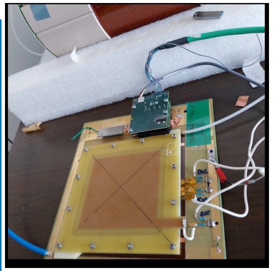




Example: developed a detailed design of the vertex detector region, with MAPs based silicon sensors. Integration takes into account crossing angle and other accelerator constraints



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



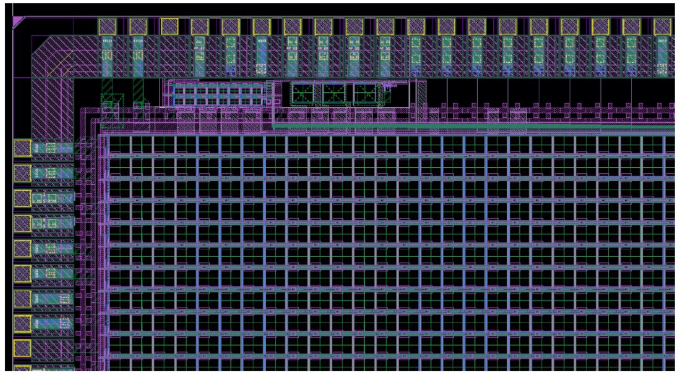
MUON Collider @ INFN (talk of N. Pastrone)

Key Challenge Areas

- **Physics potential** evaluation, including **detector concept and technologies**
- Impact on the environment
  - **Neutrino flux mitigation** and its impact on the site (first concept exists)
  - **Machine Induced Background** impact the detector, and might limit physics
- **High-energy systems** after the cooling (acceleration, collision, ...)
  - Fast-ramping magnet systems
  - High-field magnets (in particular for 10+ TeV)
- **High-quality muon beam production**
  - Special RF and high peak power
  - Superconducting solenoids
  - Cooling string demonstration (cell engineering design, demonstrator design)
- **Full accelerator chain**
  - e.g. proton complex with H- source, compressor ring ➔ test of target material

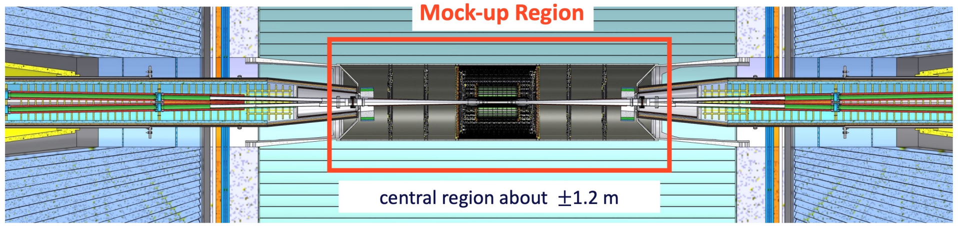
High energy complex requires known components
➔ synergies with other future colliders

Collaboration with FBK for Digital SiPM CMOS dedicated to fiber calorimeter



Accelerator projects for particle physics @ CSN1

FCC-ee Interaction Region



IR based on the crab-waist scheme, compact and crowded with tight constraints and many technical challenges → mockup needed for R&D and prove state-of-the-art technological solutions and test its feasibility

It will be built in Frascati in joint venture CERN-INFN.
Addendum KE5815/ATS signed by INFN 26.01.2024

Relevant dates from Addendum:

Starting date	1.11.2023
Delivery to INFN-LNF of the central vacuum chamber	30.11.2024
End date	31.12.2025

Manuela Boscolo, INFN-LNF

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

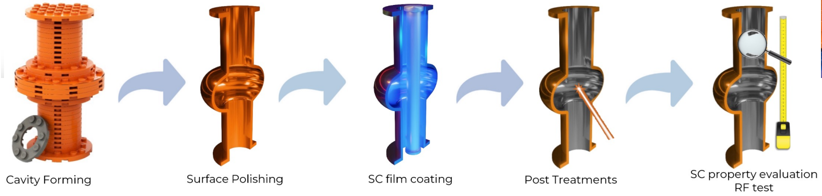
Cristian **Pira** INFN LNL

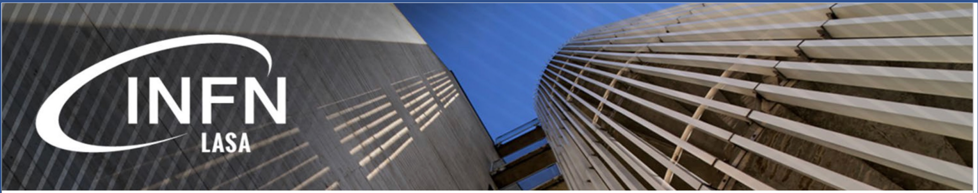
SRF cavities R&D for FCC-ee

INFN Accelerator European Strategy Program

WP1
Nb_3Sn on Cu Coatings

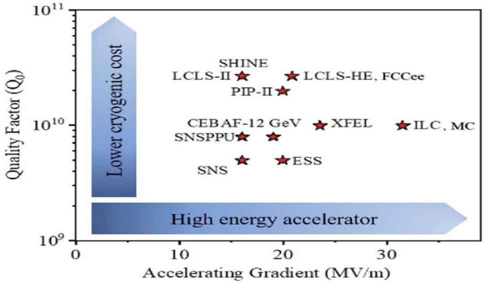
WP2
Surface Polishing via PEP





L. Monaco
INFN Milano – LASA

HighQ/HighG SRF R&D



9-cell 1.3 GHz cavity

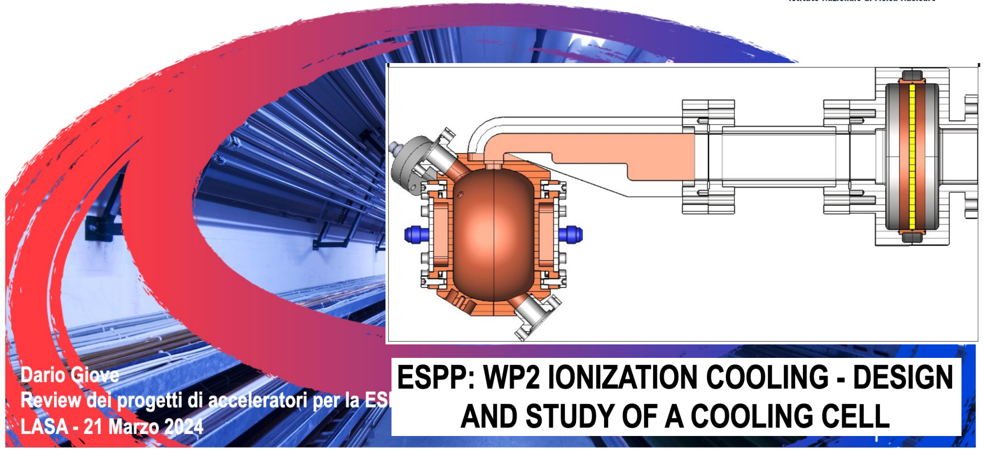
Four flagship projects with special INFN Funds (≈ 2 MEUR+personnel)

Common review by CSN1 and MAC committees

Progetti per Acceleratori di Particelle per prossima European Strategy

Muon Collider R&D activities

International MUON Collider Collaboration — INFN Istituto Nazionale di Fisica Nucleare



Dario Giove
Review dei progetti di acceleratori per la ESI
LASA - 21 Marzo 2024

ESPP: WP2 IONIZATION COOLING - DESIGN AND STUDY OF A COOLING CELL

CONCLUSIONI

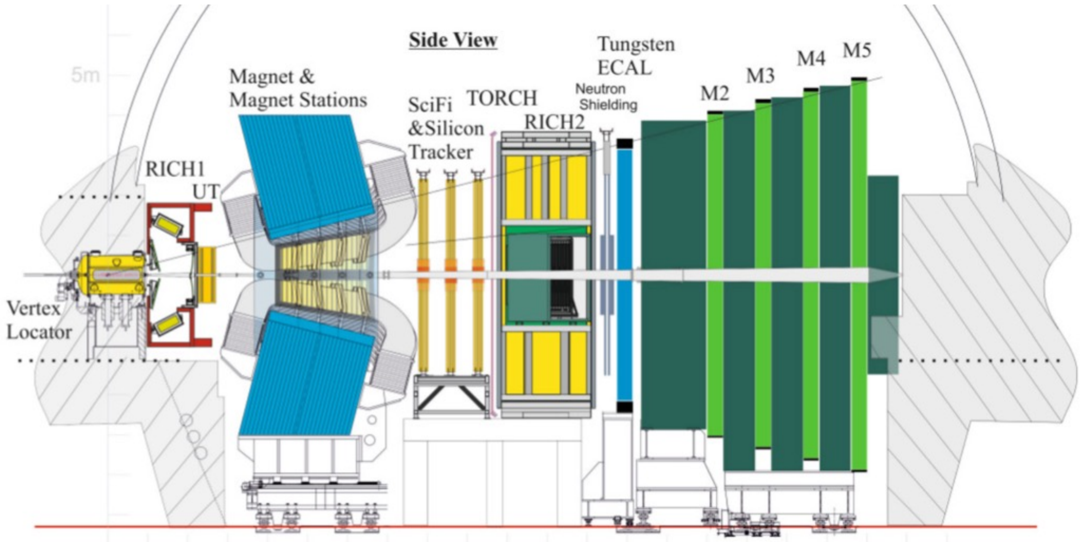
- Costruzione FASE 2 ATLAS e CMS per HL-LHC maggiore impegno della CSN1 nel presente – immediato futuro
- Importanti nuovi progetti per fisica del flavour (LHCb U2, Belle 2 upgr)
- Fisica dei neutrini ad acceleratori in CSN1 (Dune, Icarus, SND@LHC)
- Accelerazione (anticipazione) della European Strategy for Particle Physics e completamento Feasibility Study per FCC per 2025
- Notevole impegno CSN1 per progetti Futuri Acceleratori per HEP
- Altre attivita’ non discusse causa tempo limitato : NA62, MEG 2, MU2E, G-2, AMBER, UA9, PADME, MUonE, BES 3, KLOE, IGNITE

https://www.roma1.infn.it/conference/infn-espp-2024/

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

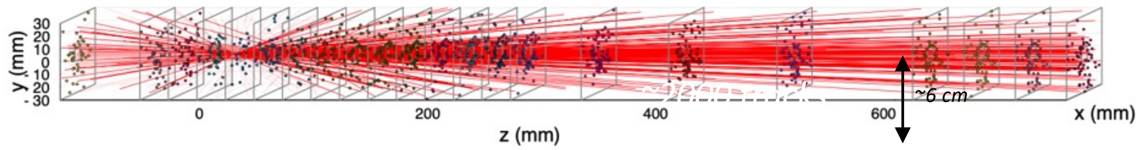
Key ingredients:

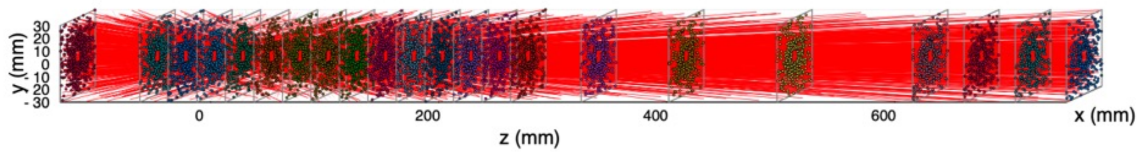
- granularity
- fast timing (few tens of ps)
- radiation hardness

VErtex LOcator (VELO)

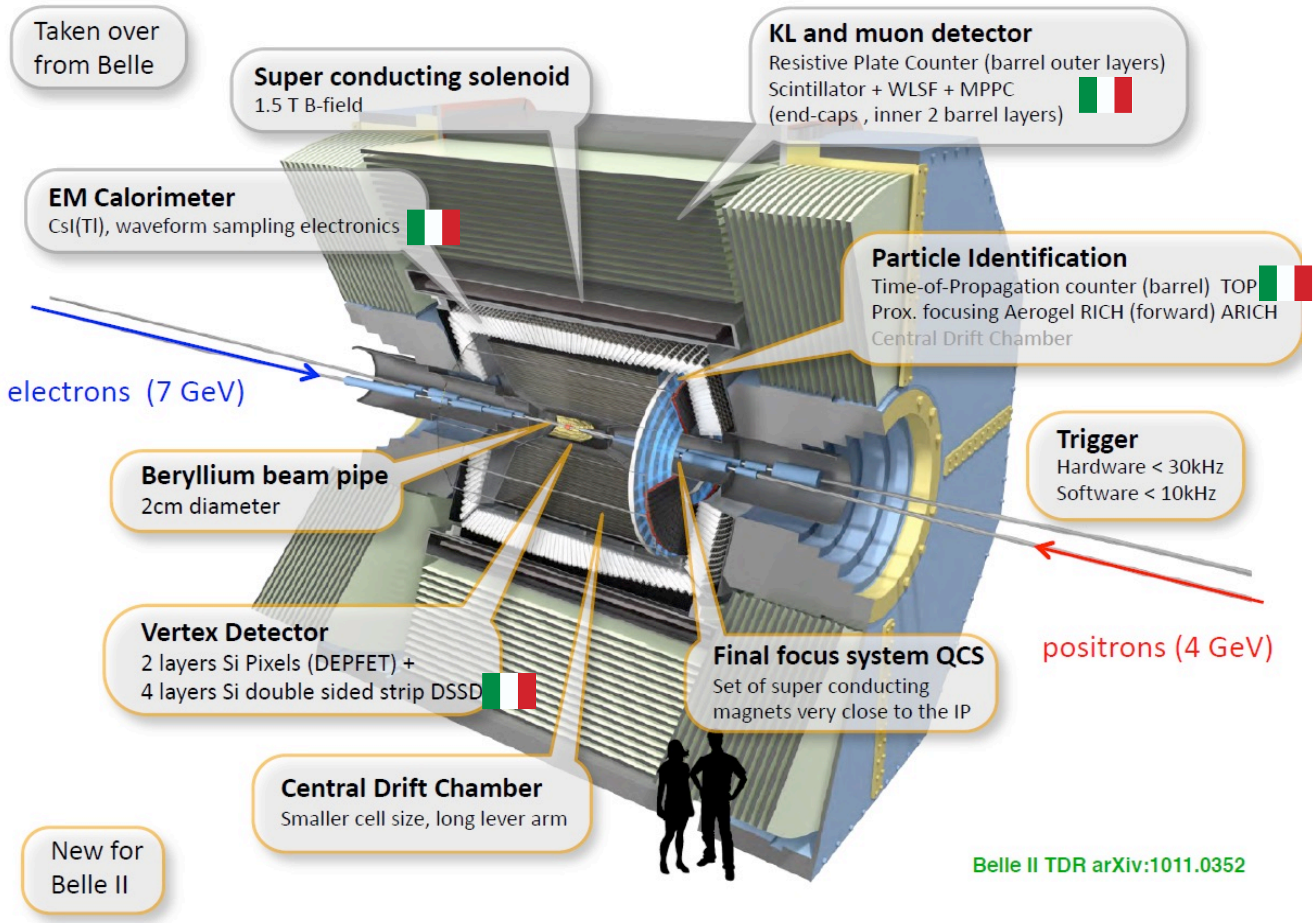
Run 3: pile-up ~6

Upgrade II: pile-up ~42



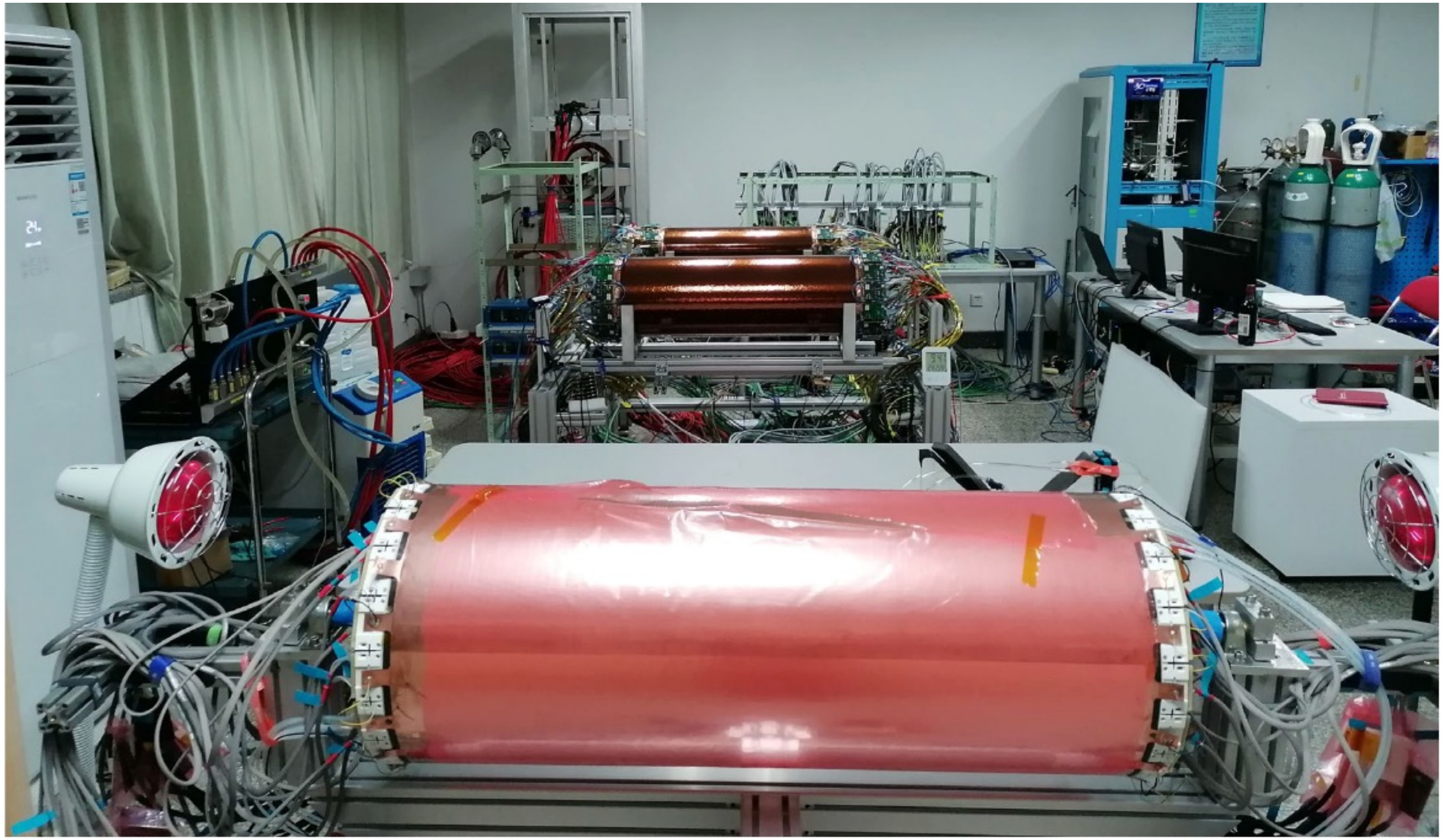


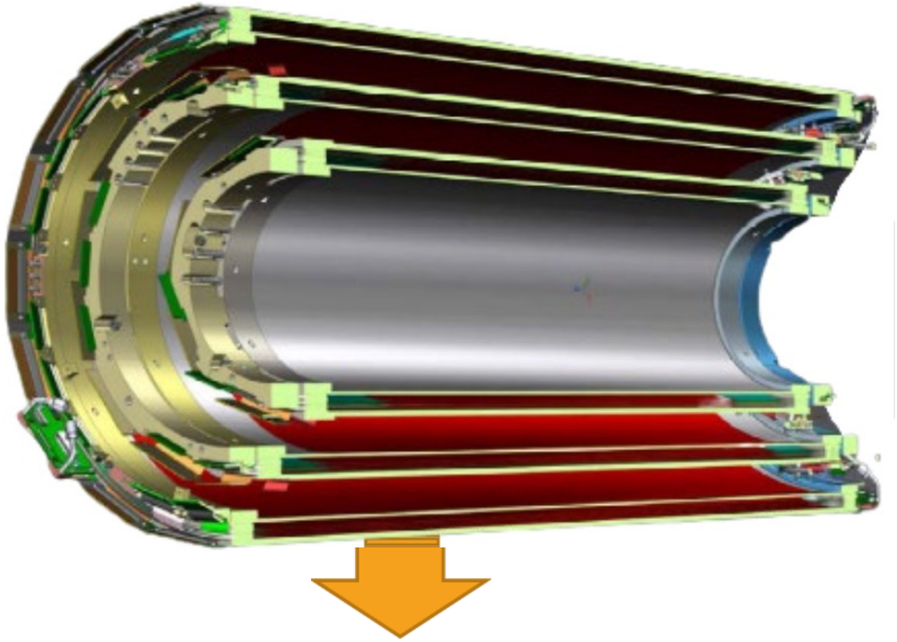
The Belle II detector and INFN commitments



BESIII

Three layers of new BES III GEM tracker, designed and constructed in Italy, are now ready in Beijing.
There are in commissioning collecting cosmics, insertion in BES III expected in 2024





CGEM-IT

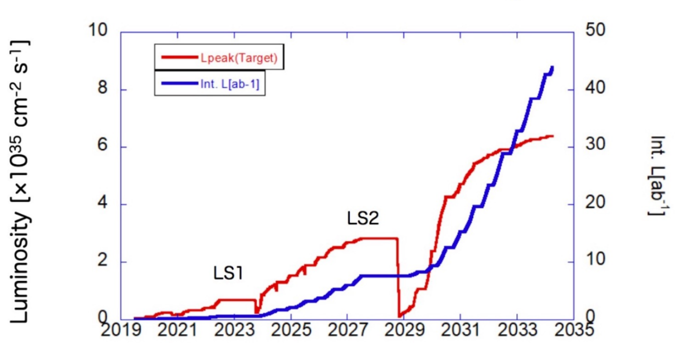
Belle 2 and future upgrades

Q1

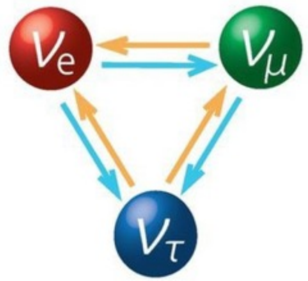
SuperKEKB ha una lunga lista di contromisure alle limitazioni di luminosità osservate: buona parte si stanno implementando durante LS1

	Aim	Possible countermeasures	Status
(1)	·Increase injection power (efficiency)	Linac upgrade to designed specification	
		Large physical aperture at electron injection point (HER)	During LS1
		Linac upgrade beyond designed specification	
(2)	·Relax beam-beam effect ·Expand dynamic aperture	Utilizing rotatable sextuplole magnets (LER)	Done before LS1
		"Perfect matching"	Under consideration (It was found that it is not easy.)
		QCS modification (Option#1): Move QC1RP to the far side of IP	Under consideration
		Larger scale QCS modification (Option #8)	
(3)	·Suppress BG ·Expand physical aperture	QCS cryostat front panel modification and additional shield to IP bellows	During LS1
		Optimization of collimator location	Done before LS1
		Enlargemen of QCSR beam pipe (Option#3)	Under consideration
(4)	·Relax TMCI limit	"Non-linear collimator"	During LS1
(5)	·Improve stability	Robust collimators	During LS1 (Partially)
		Upgrade of beam abort system and loss monitor system	During LS1 (Partially)
(6)	·Anti-aging measures	Preparation of standby machines and spares, repair of facilities, etc.	During LS1 (Partially)

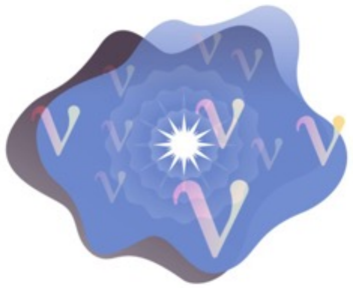
SuperKEKB Run Plans



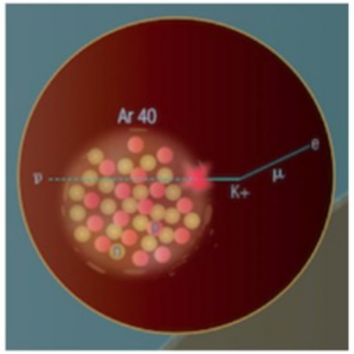
DUNE and its Physics Program in one slide



- **Long- baseline wide-band neutrino beam**
  - <u>Measurement of CP violation phase</u> and determination of the <u>neutrino mass ordering</u> in a single experiment using spectral information

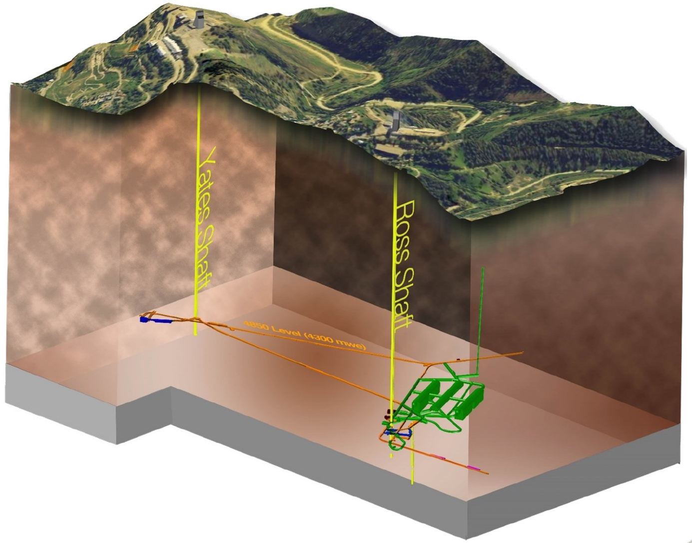


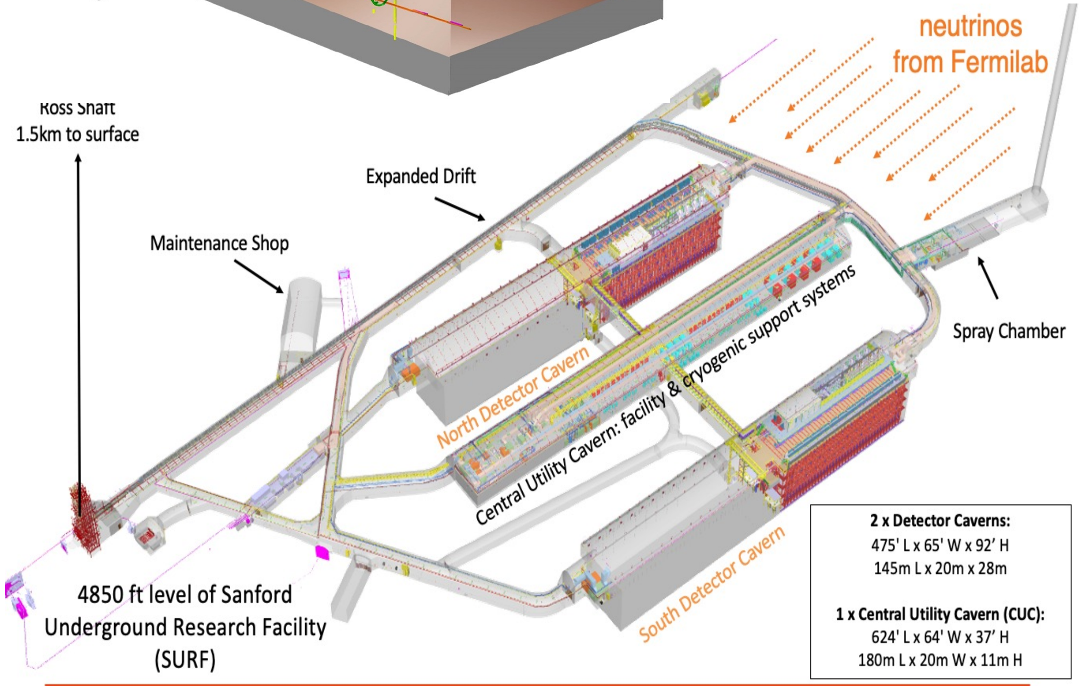
- **Underground location → access to astrophysical neutrinos**
  - Supernova neutrino burst detection – sensitive to the ν_e component
  - Atmospheric neutrino – capability of ν_τ identification
  - Solar neutrinos – potential for detection of hep flux
- **Massive detectors with tracking and calorimetric information**
  - Search for baryon number violating processes – $p \to \nu K^+$, $n\,\bar{n}$



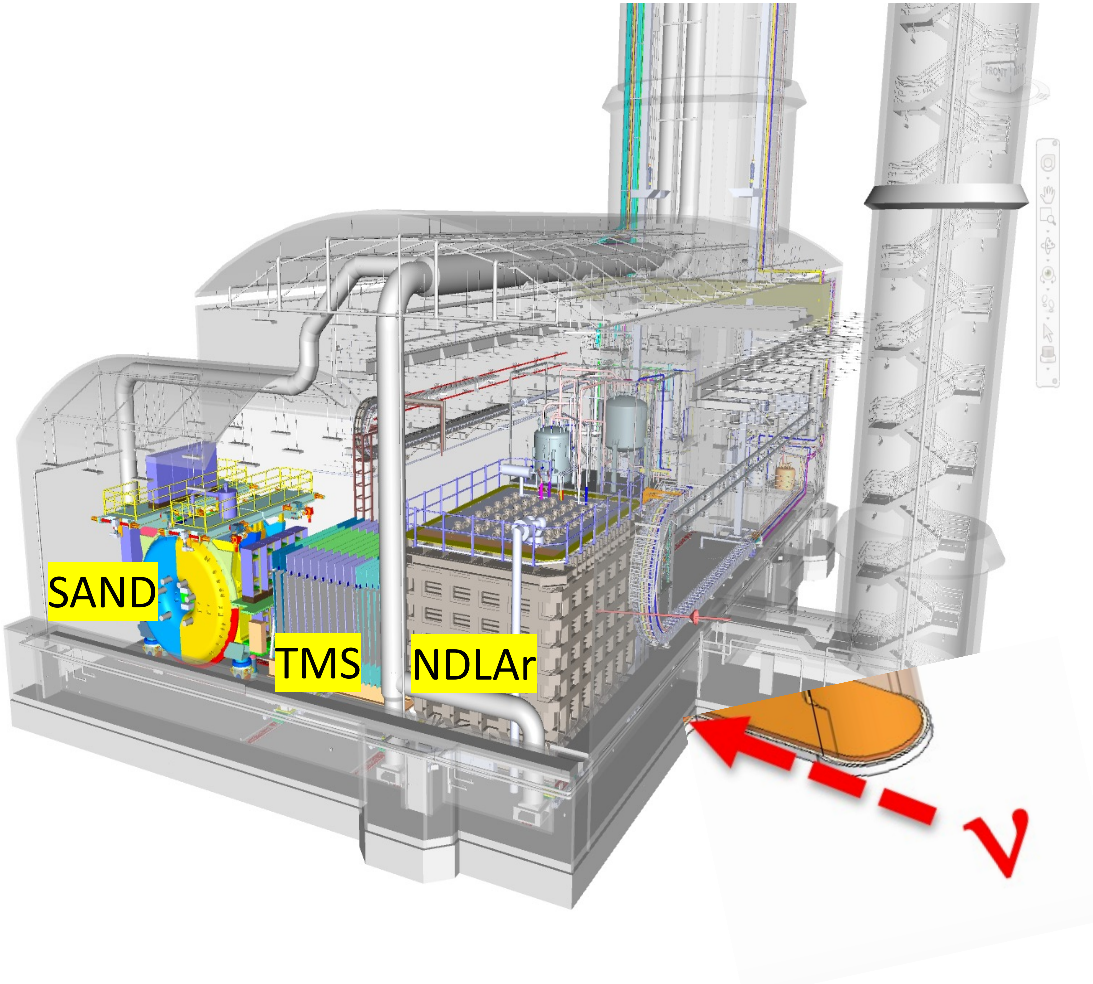
- **Long baseline + higher energy neutrino beam**
  - ν_τ appearance, NSI searches
- **Capable Near Detector Complex**
  - Precise neutrino physics (cross sections, nuclear effects)
  - BSM searches

Sanford Underground Research Facilities





Near Detector Complex



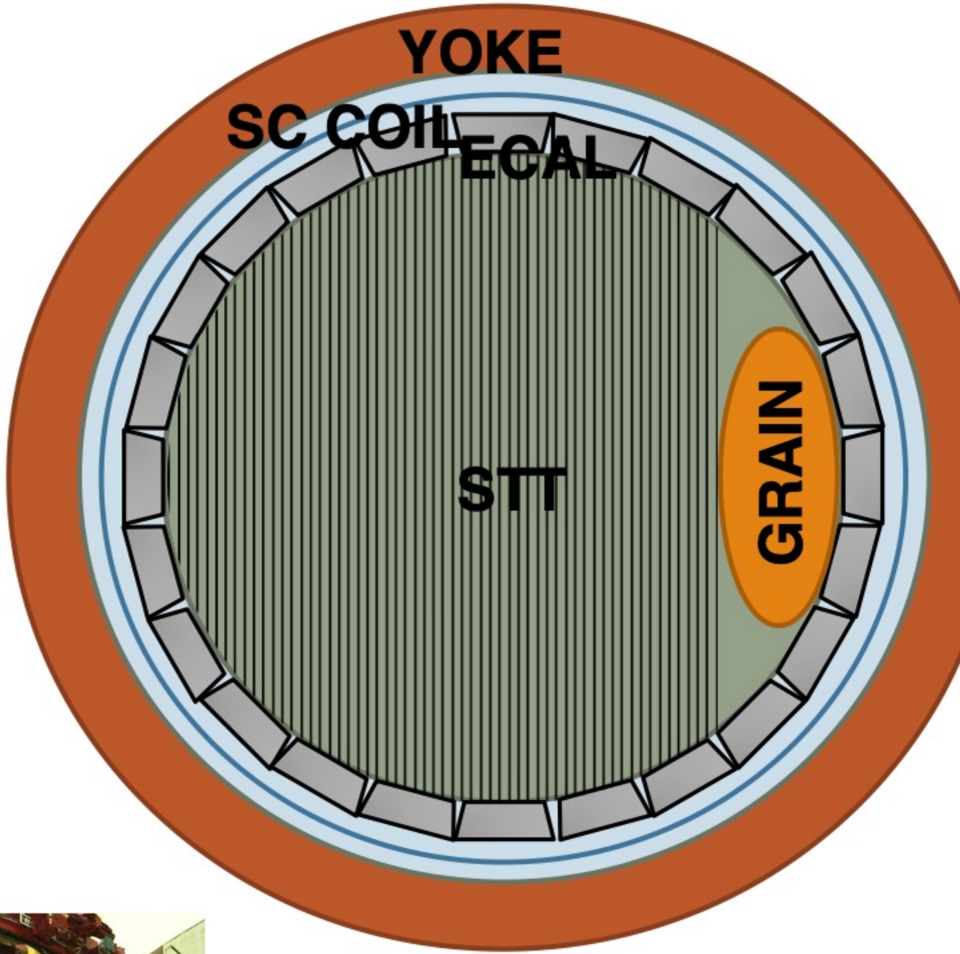
DUNE
SAND

MAGNET – KLOE 0.6T superconductive coil + Fe Yoke

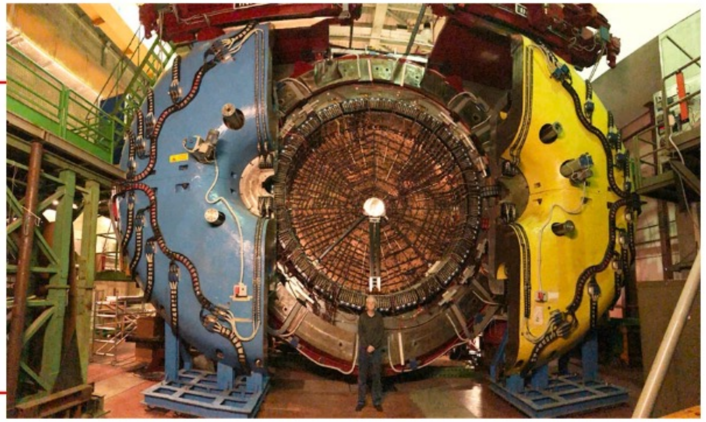
ECAL - KLOE Lead Scintillating Fibers calorimeter (Barrell-23 ton Pb- + EndCaps)

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>

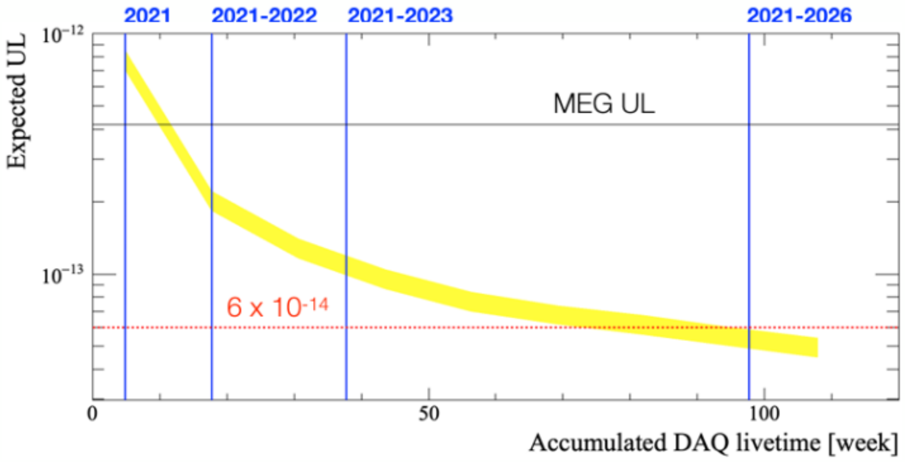


MEG 2 at PSI

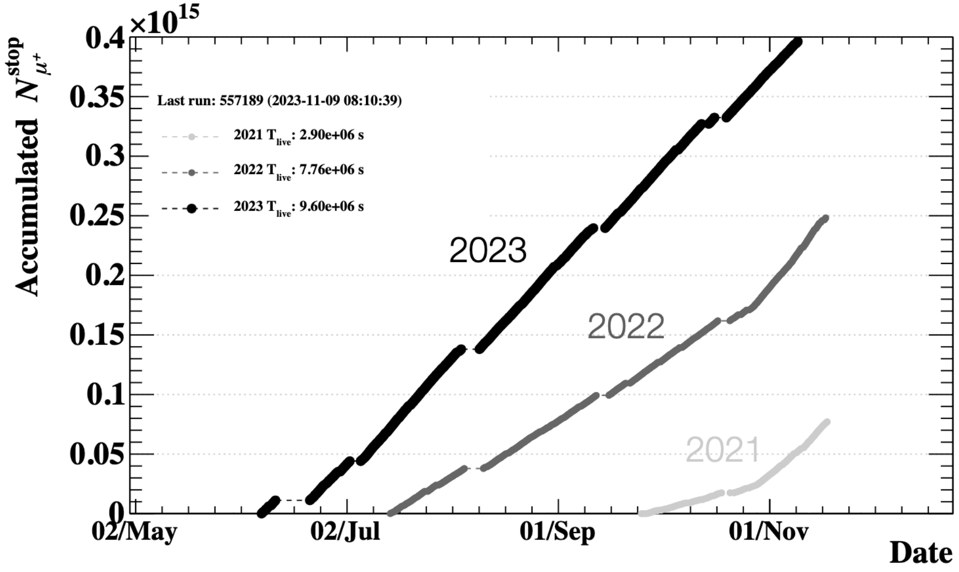
First result of MEG 2 on μ → eγ
K. Afanaciev et al., arXiv:2310.12614

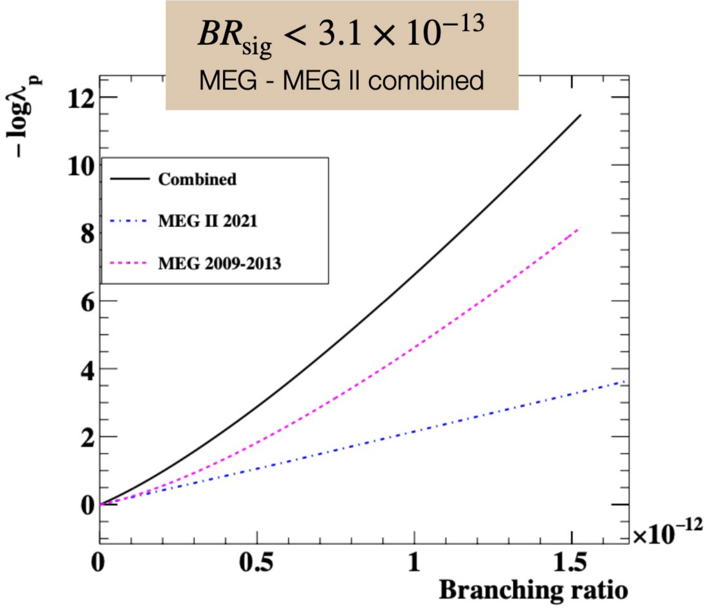
Taking data from 2021: number of muons on target steadily increasing

Foreseen sensitivity



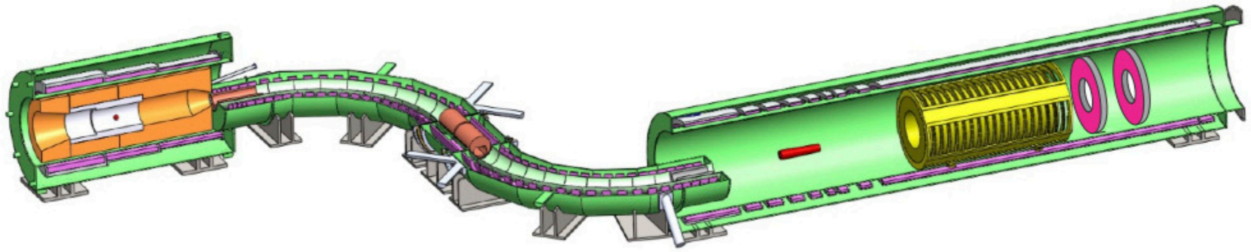
The MEG II dataset (so far…)

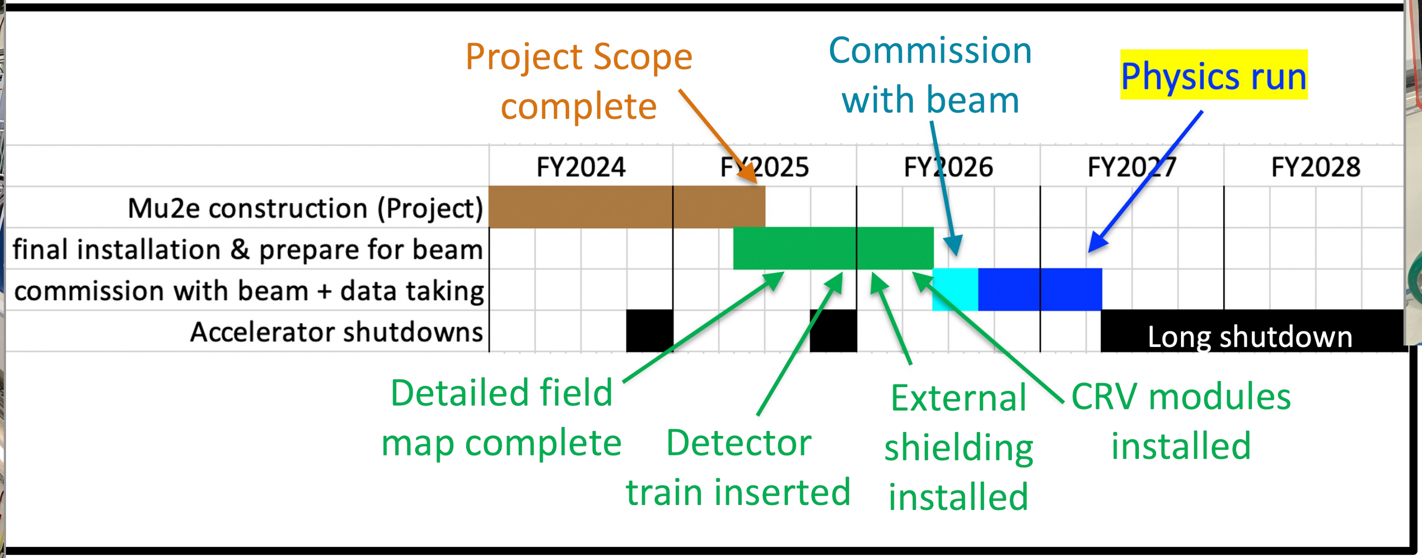


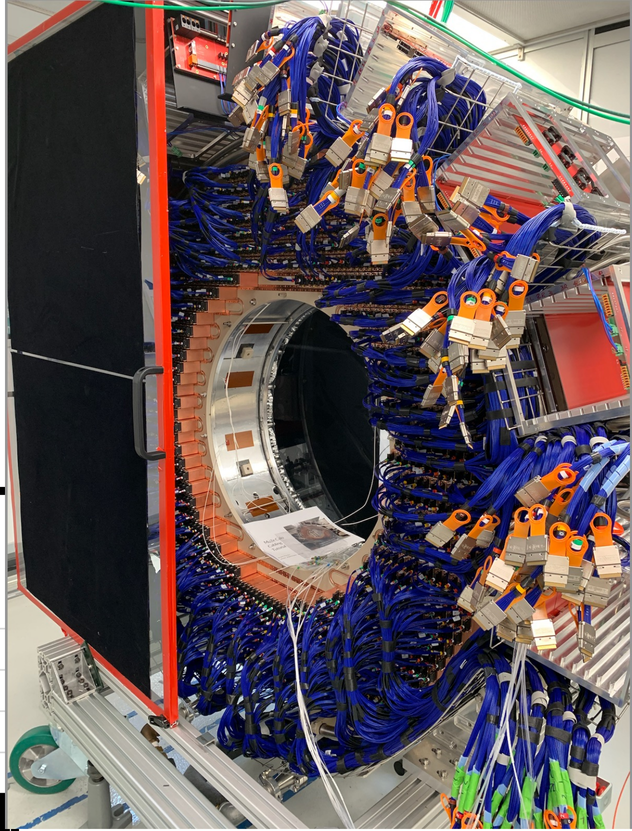


The Mu2e experiment at Fermilab

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



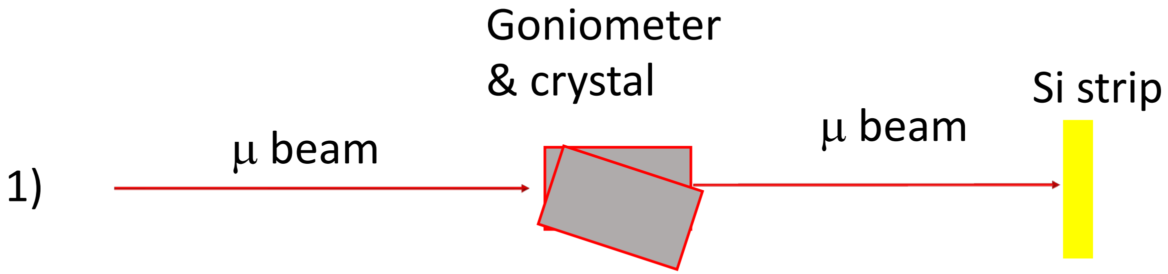


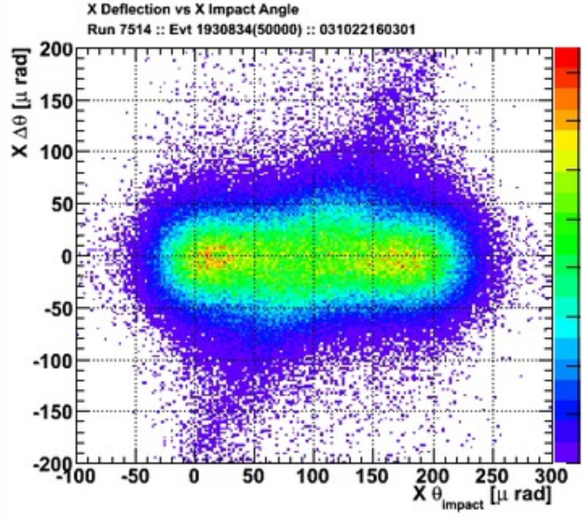


Calorimeter disk assembled with crystals (INFN responsibility)

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

UA9 : Cristalli per manipolazione e ricombinazione fasci



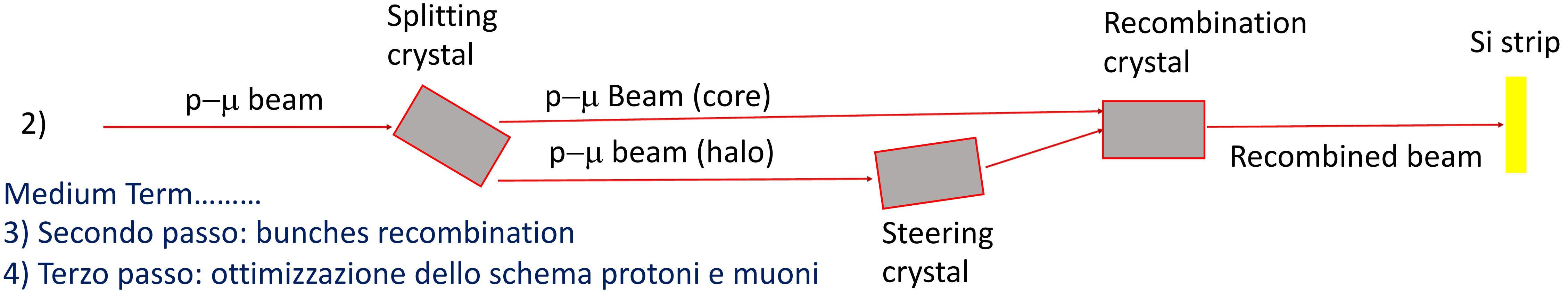


Primo scopo è quello di fornire due fasci sincronizzati da ricombinare

Short Term, 2023

1) Test dei cristalli Aplyx nel nuovo bender realizzato da Roma1

2) Primo passo: test di allineamento della configurazione a tre cristalli (de-bunched).



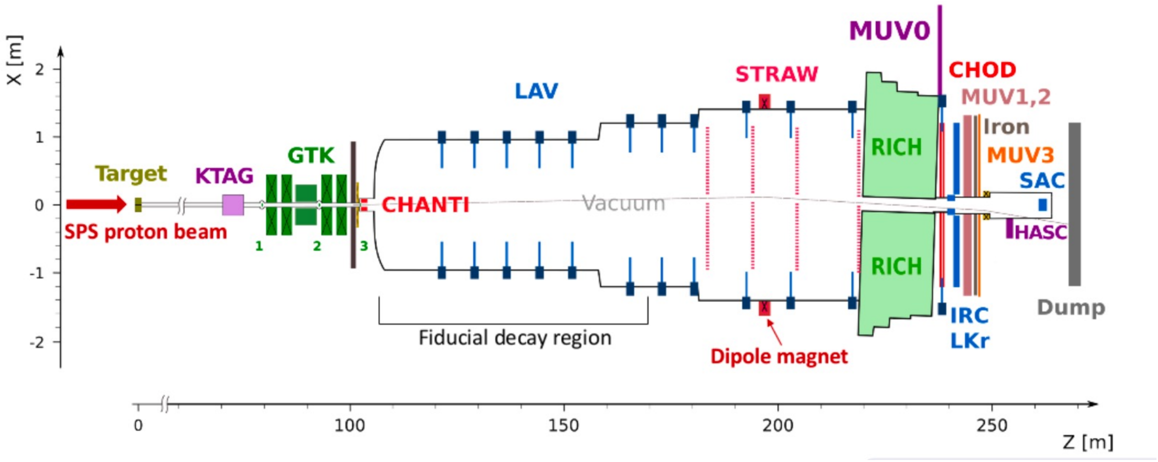
Medium Term………

3) Secondo passo: bunches recombination

4) Terzo passo: ottimizzazione dello schema protoni e muoni

NA62 and kaon physics

- NA62: measure the SM branching fraction of $K^+ \rightarrow \pi^+ \nu\nu$ with 15-20% precision

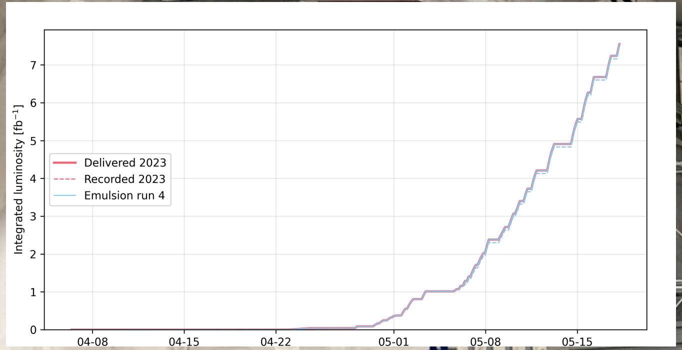


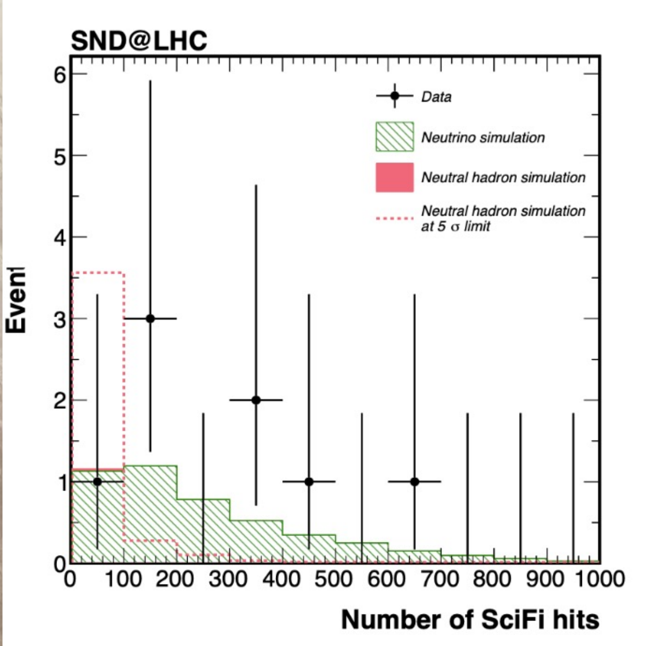
- Result from full Run 1 [JHEP 06 (2021) 093]:
  $B^{NA62}(K+ \rightarrow \pi+\nu\bar{\nu}) = (1.06+0.40 \pm 0.09 \text{ syst}) \times 10^{-10}$
- 3.4σ significance
- Data taking resumed in 2021, after CERN LS2, approved until CERN LS3

High Intensity Kaon Experiments

- LoI submitted in November 2022 [arXiv: 2211.16586]
- Proposal for Phases 1 and 2 submitted in August 2023 to SPSC, still not publicly available.
- Expected answer from SPSC expected by end of 2023 → March 2024 : not approved by CERN
- Current HIKE Phase 1 estimated start in 2031 (according to the latest beam upgrade schedule)
- **HIKE Phases 1 and 2 will cover a total of 15 standard years, including 4 standard years in dump mode and 11 standard years in kaon mode**

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:

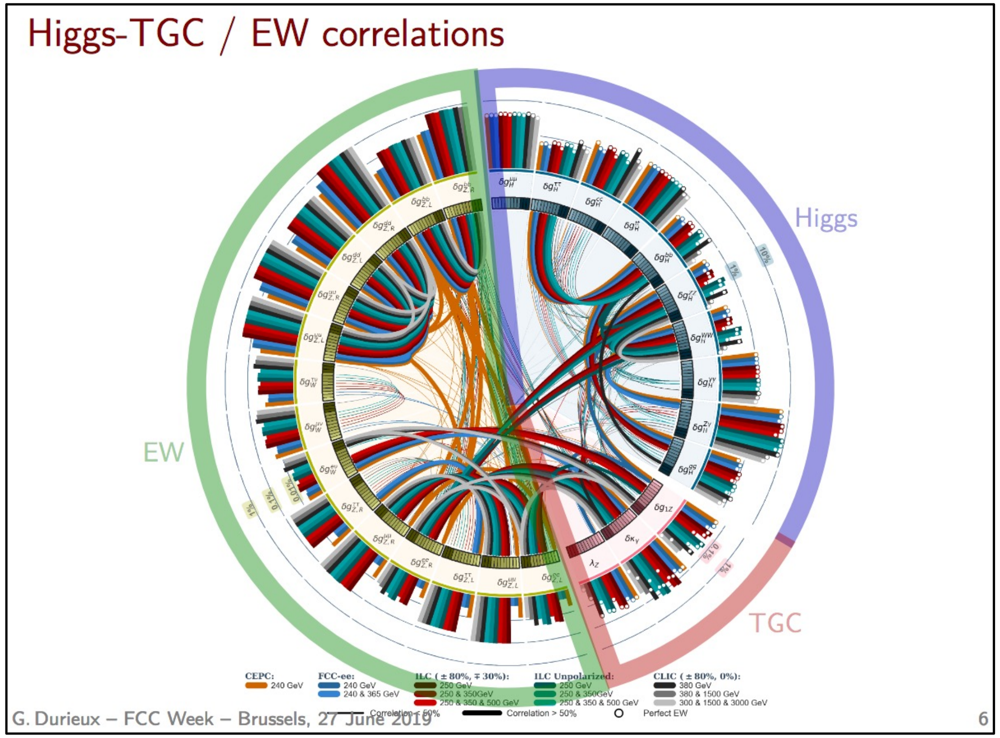
$$P = 1.48 \times 10^{-12}$$

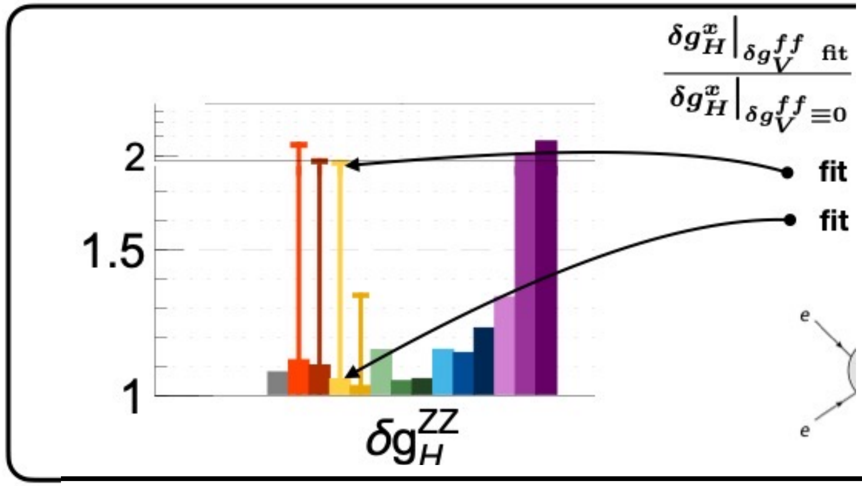
7.0 σ observation

Beyond Standard Model, Precision Measurements, Discoveries: un robusto programma di ricerca a medio/lungo termine deve affrontare gli aspetti e correlazioni delle misure di precisione e delle ricerche dirette.

Esempio: incertezze Higgs couplings senza e con nuove misure alla Z

Correlazioni tra osservabili Higgs, Z e W a futuri acceleratori



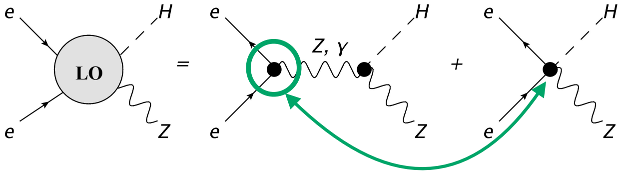


$$\frac{\delta g_H^x\big|_{\delta g_V^{ff}\ \text{fit}}}{\delta g_H^x\big|_{\delta g_V^{ff}\equiv 0}}$$

fit assuming LEP/SLD Z-pole measurements

fit including Future Z-pole measurements

EW-Higgs SMEFT correlations

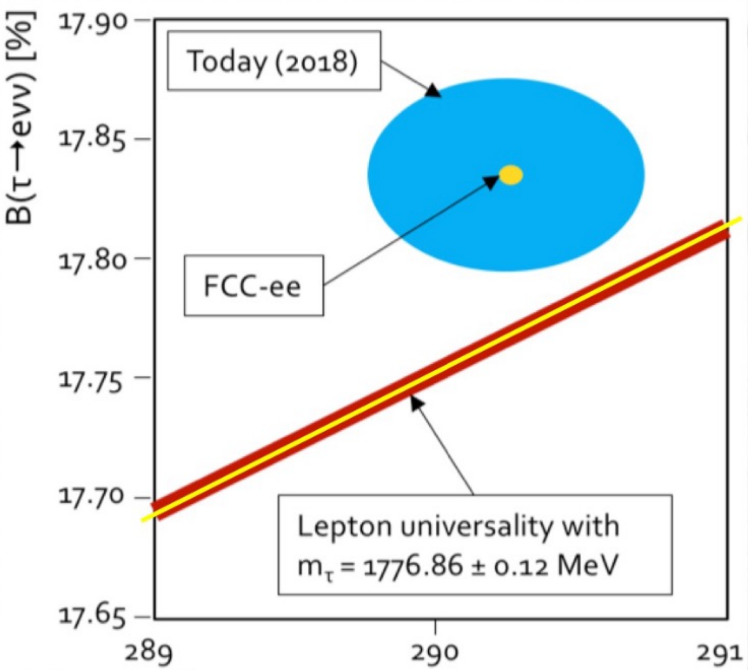


Flavour-Factory Physics

An unparalleled probe of flavour physics!

Particle production (10^9)	B^0 / $\overline{B}^0$	B^+ / B^-	B^0_s / $\overline{B}^0_s$	Λ_b / $\overline{\Lambda}_b$	$c\overline{c}$	τ^-/τ^+
Belle II	27.5	27.5	n/a	n/a	65	45
FCC-*ee*	300	300	80	80	600	150

For example...



Monteil