Future INFN projects in particle physics at accelerators

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SEZIONE DI PISA

Vulcano Workshop 2022 - Frontier Objects in Astrophysics and Particle Physics

25 September 2022 to 1 October 2022
Elba Island (Tuscany, Italy)

Future High Energy Physics projects with INFN involvement

- **High Luminosity LHC**
  - **ATLAS and CMS phase 2 upgrades**
  - **LHCb phase 2 upgrade**
  - **ALICE phase 2 upgrade**
- **The Future Circular Collider (FCC)**
  - **FCC-ee**
  - **FCC-hh**

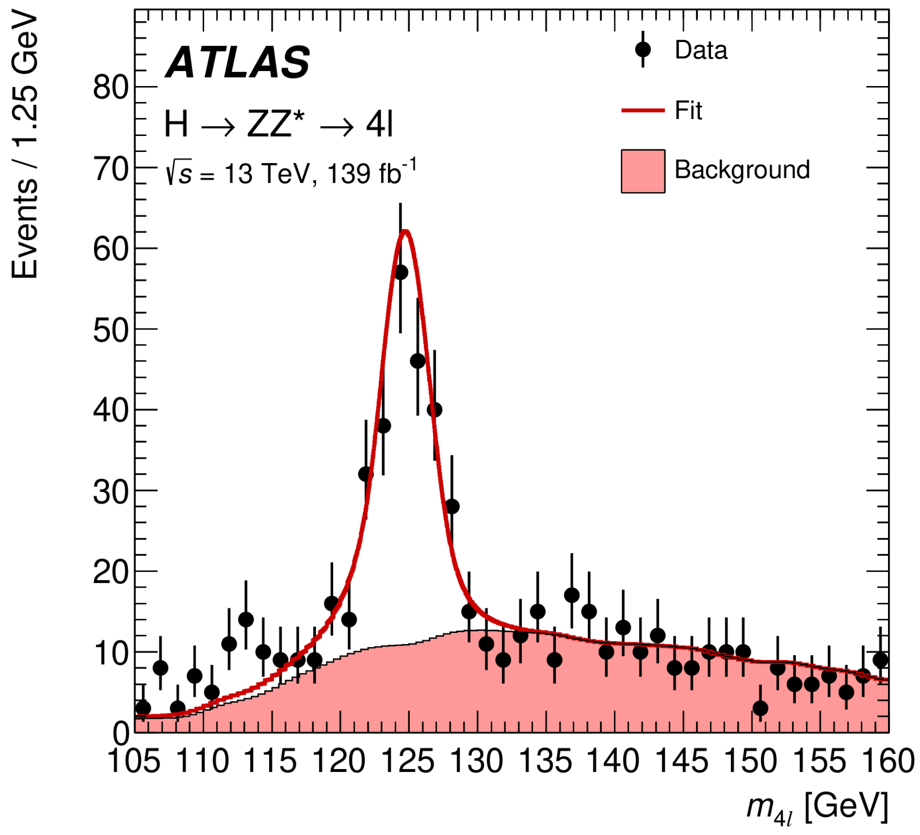
- **The Muon Collider**
- **Electron Ion Collider**
- **The neutrino platform at FNAL**
  - **Short neutrino Baseline (SNB)**
  - **Long neutrino Baseline (LNB)**
- **Hyper Kamiokande (HK)**

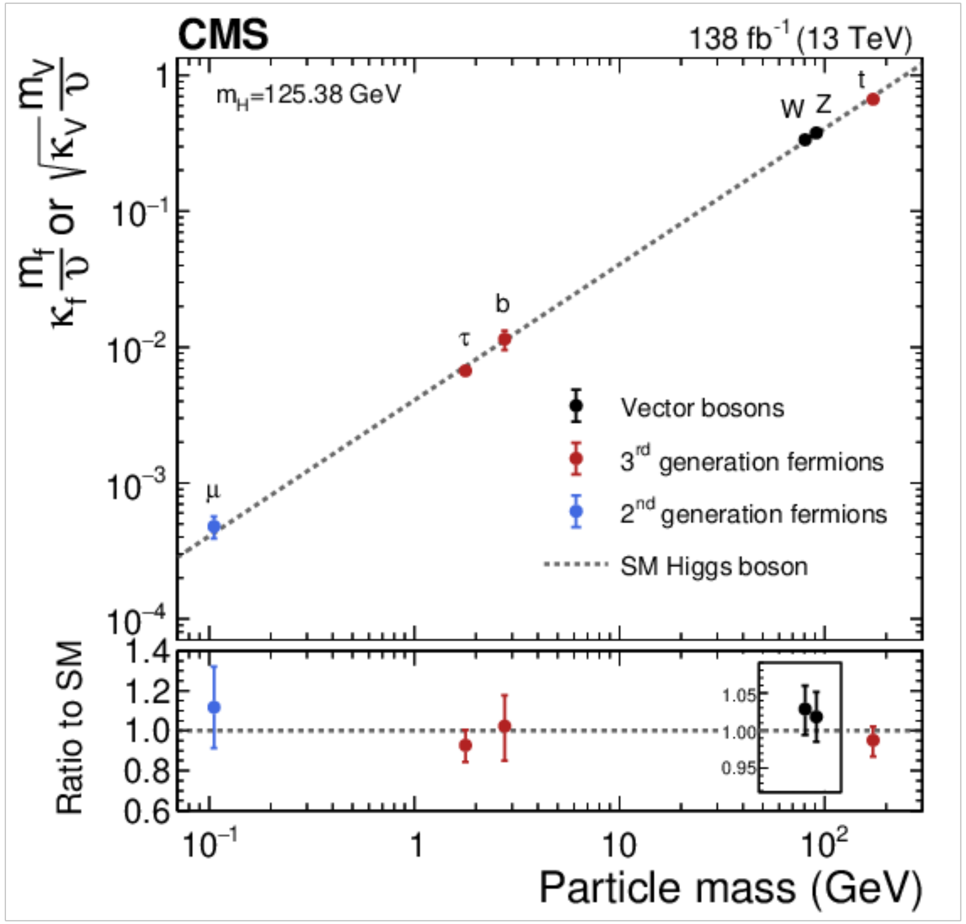
Smaller scale projects: **AMBER, BELLE 2 upgrade, HIKE, LUXE, MEG2, MU2E, NA60+**, etc.

(approved, under discussion)

- **From the European Strategy for Particle Physics:**

The full physics potential of the LHC and the HL-LHC, including the study of flavour physics and the quark-gluon plasma, should be exploited.





HL-LHC: the near future

>10x the statistics of the LHC still to be collected!

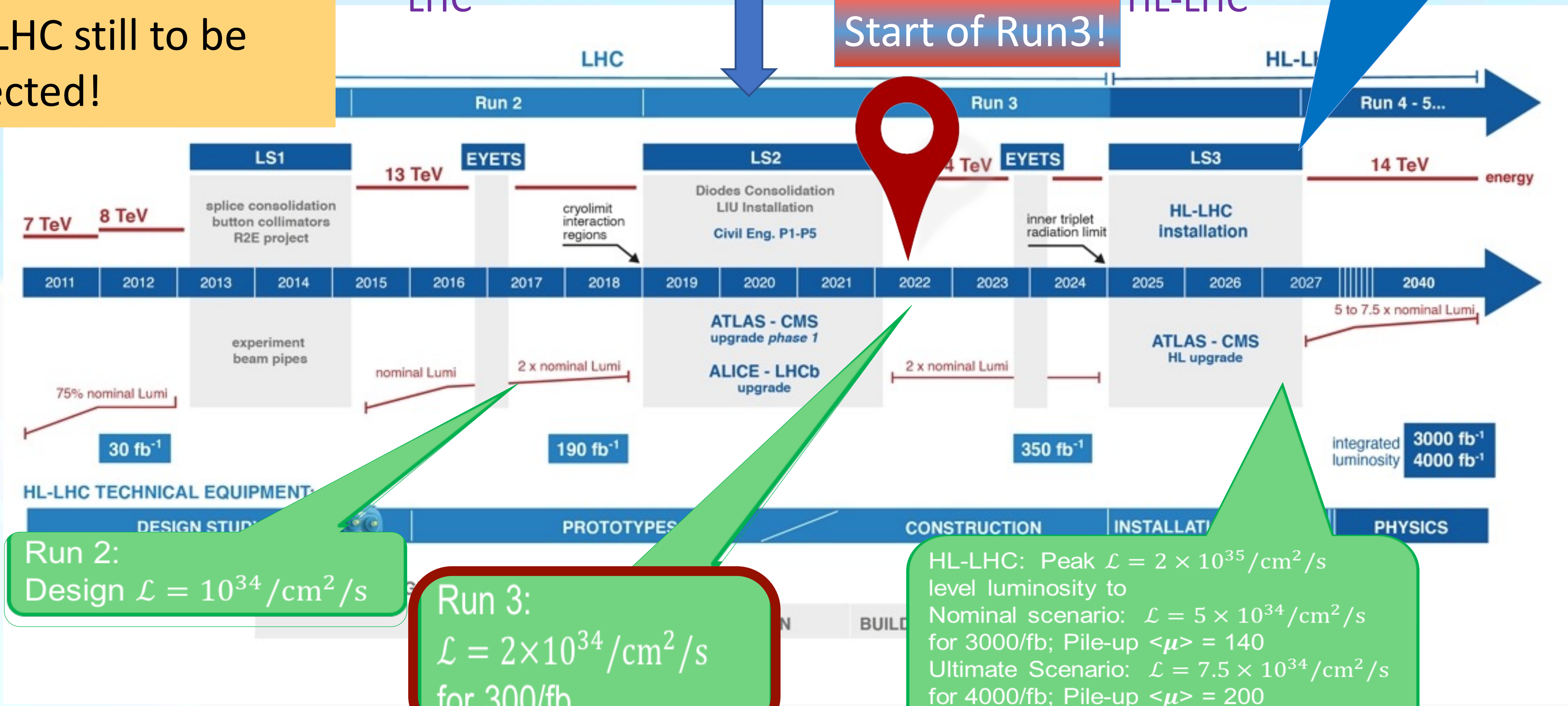
upgrade of injector chain to deliver brighter bunches

new interaction region layout and crab cavity

LHC

HL-LHC

Start of Run3!



Run 2:
Design $\mathcal{L} = 10^{34}/\mathrm{cm}^2/\mathrm{s}$

Run 3:
$\mathcal{L} = 2\times10^{34}/\mathrm{cm}^2/\mathrm{s}$
for 300/fb

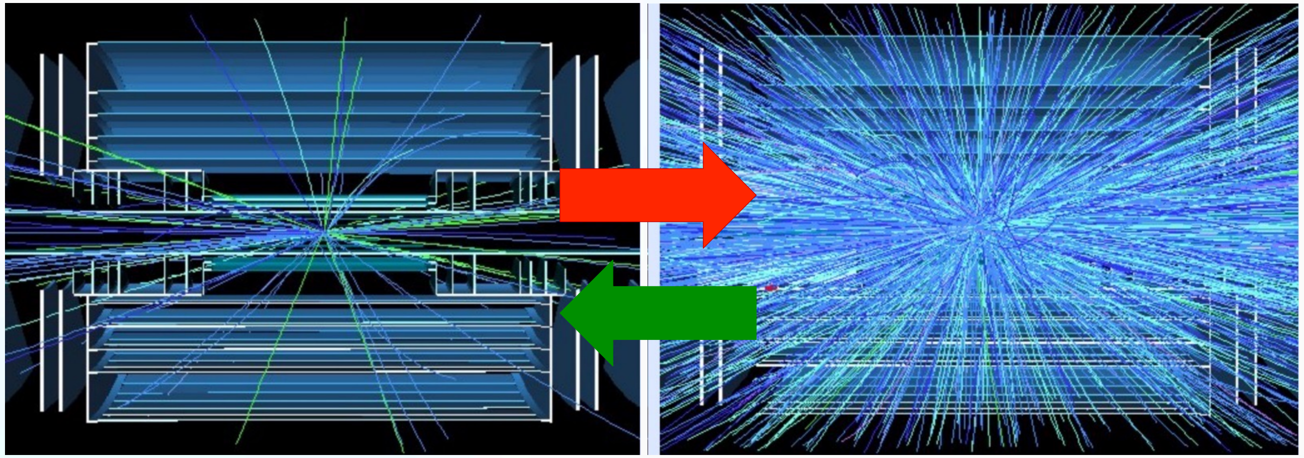
HL-LHC: Peak $\mathcal{L} = 2\times10^{35}/\mathrm{cm}^2/\mathrm{s}$
level luminosity to
Nominal scenario: $\mathcal{L} = 5\times10^{34}/\mathrm{cm}^2/\mathrm{s}$
for 3000/fb; Pile-up $\langle\mu\rangle = 140$
Ultimate Scenario: $\mathcal{L} = 7.5\times10^{34}/\mathrm{cm}^2/\mathrm{s}$
for 4000/fb; Pile-up $\langle\mu\rangle = 200$
$\Rightarrow$25% increase in integrated lum.

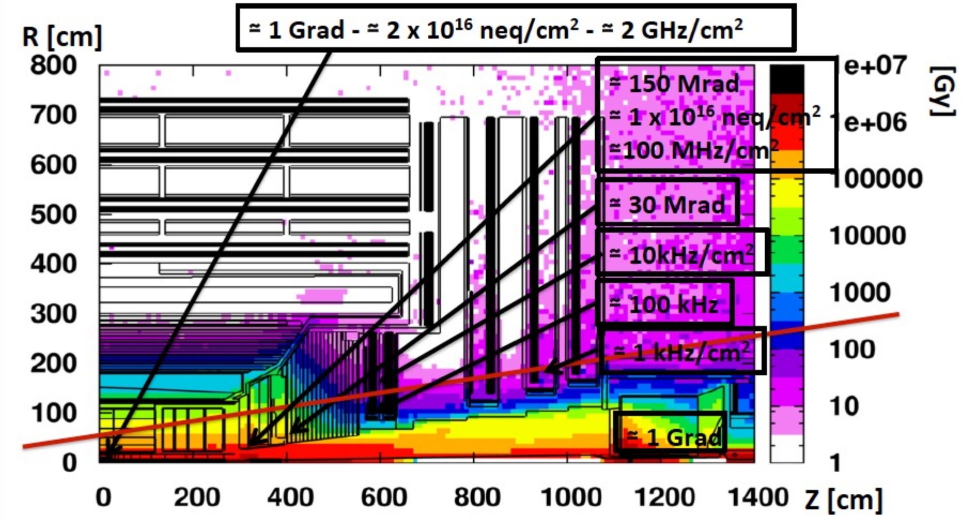
HL-LHC experimental challenges

- **High luminosity ➔ 200 soft pp interactions per crossing**
  - Increased combinatorial complexity, rate of fake tracks, spurious energy in calorimeters, increased data volume to be read out in each event
- **Detector elements and electronics are exposed to high radiation dose : requires new tracker, endcap calorimeters, forward muons, replacing readout systems**
- **Planned detectors shown to be able to successfully operate at the HL-LHC**

25 pileup

200 pileup

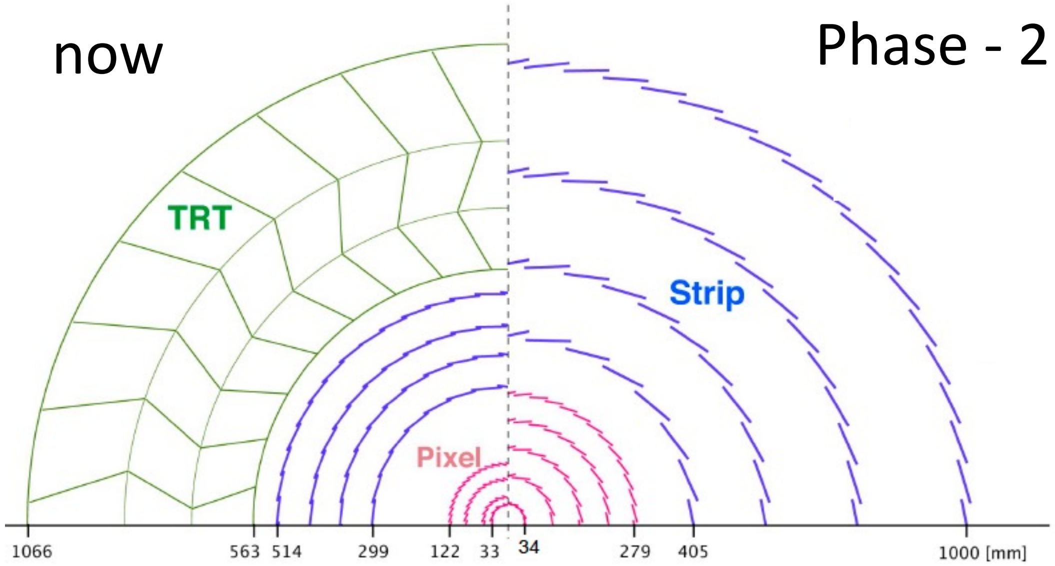




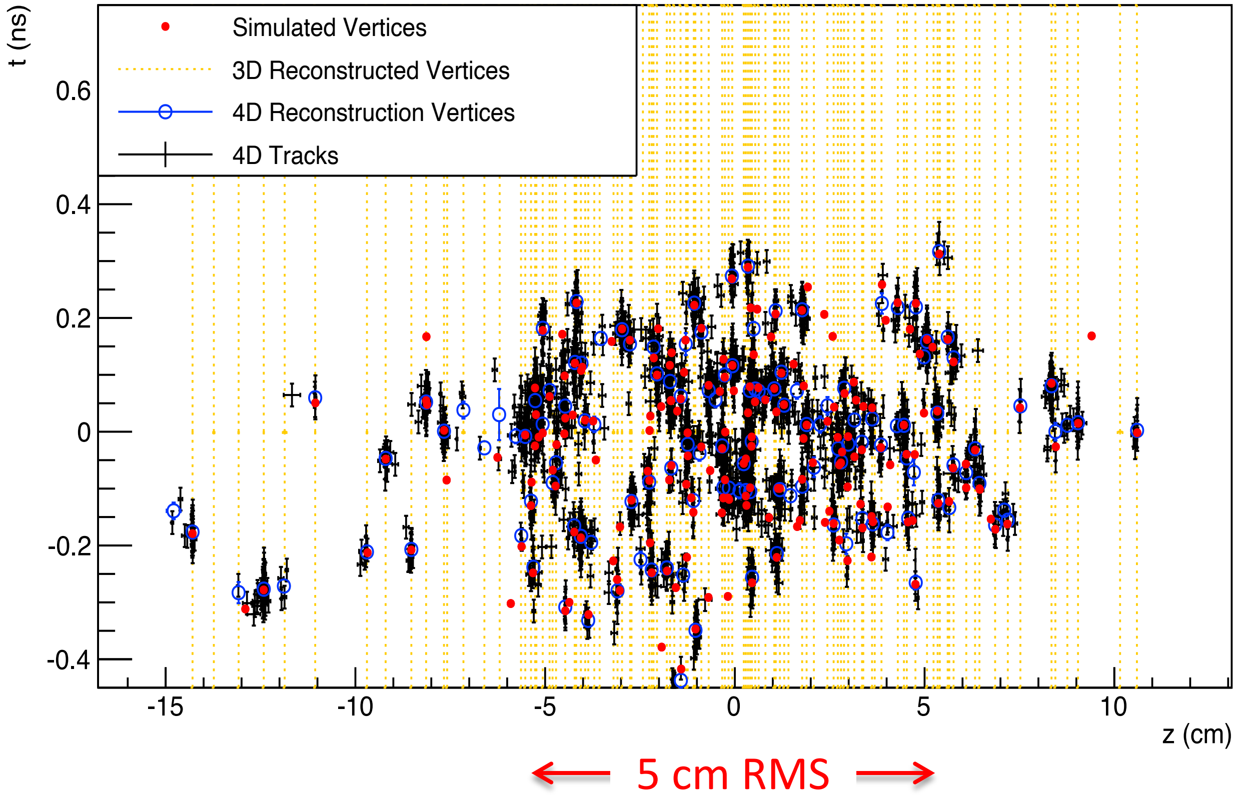
Roughly reaching limits of current techniques in several systems

Detector answers to the HL-LHC challenge

Example: ATLAS Tracker



Example: CMS Timing layer concept

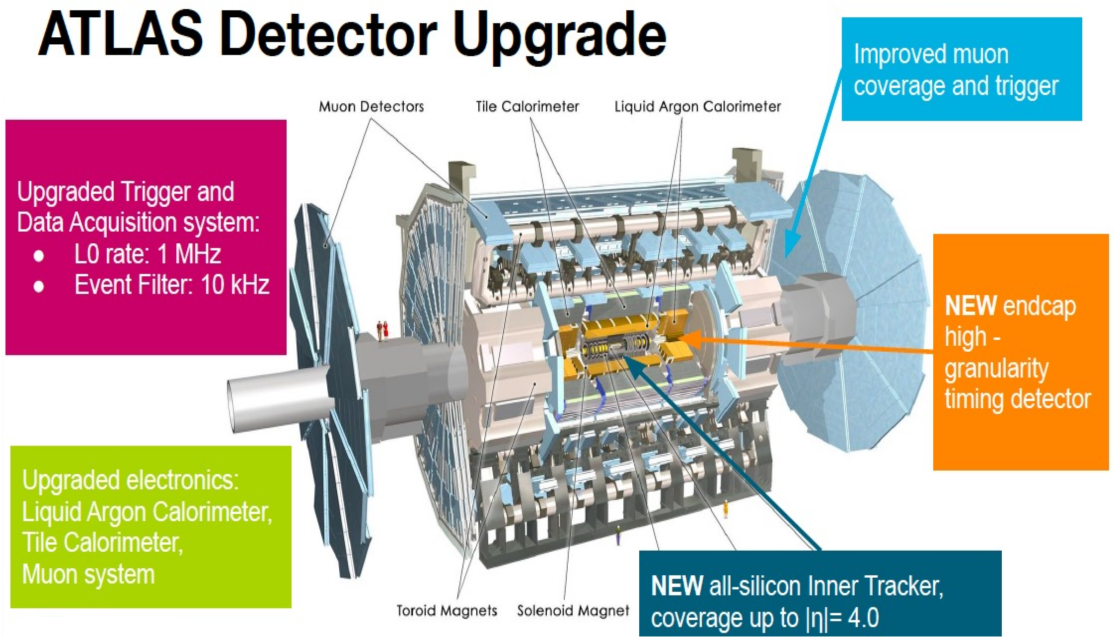


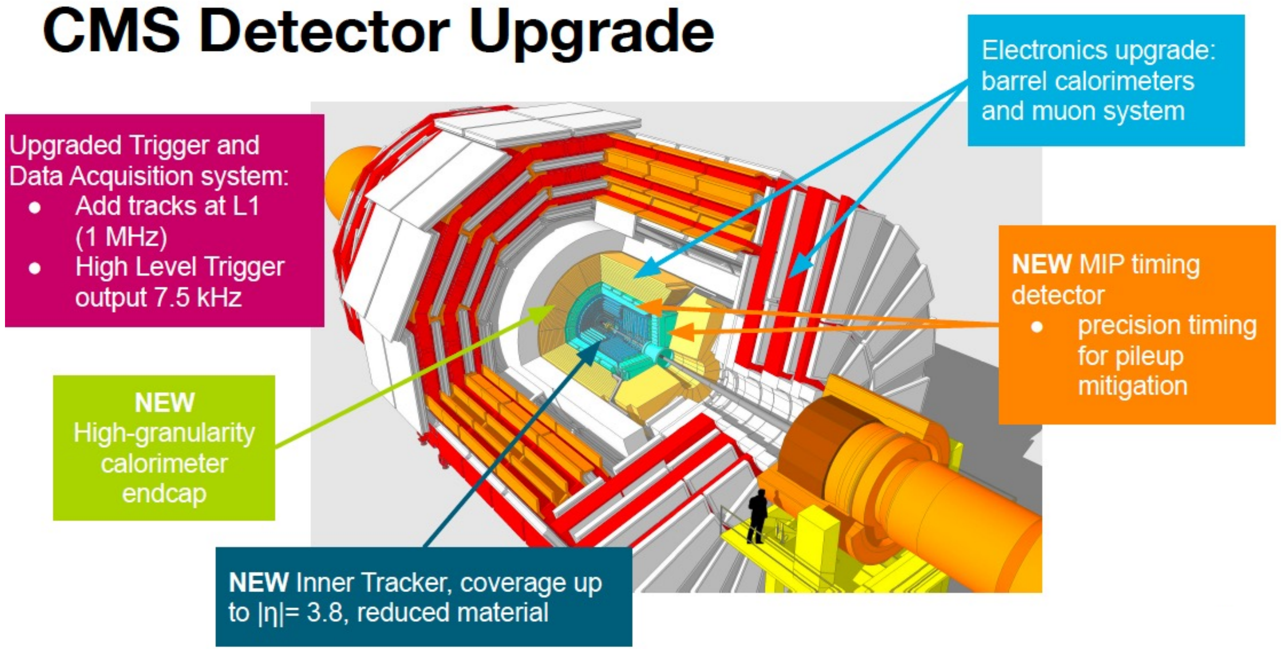
Improve granularity

+ radiation hardness

Add timing information

ATLAS and CMS upgraded detectors (phase 2)

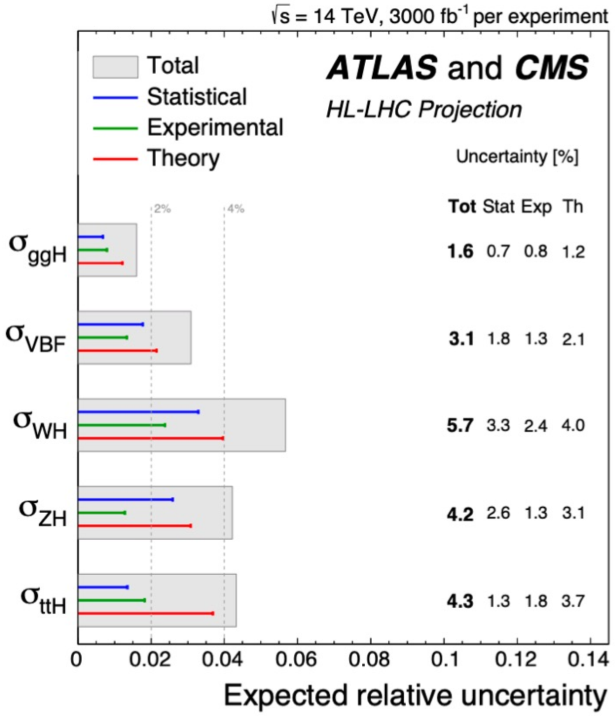


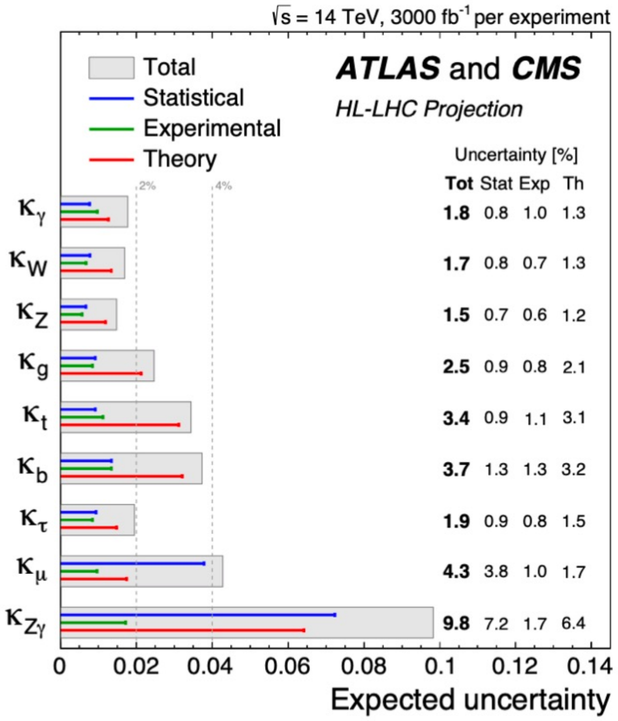


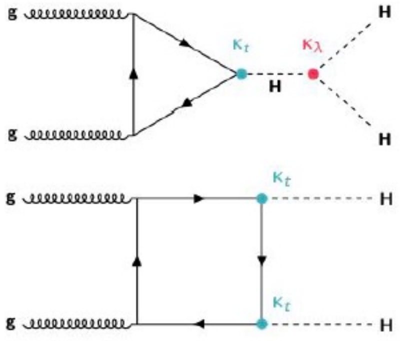
Main INFN INVOLVEMENTS:
- Tracker (ITK)
- Liquid Argon Calorimeter
- Tile Calorimeter
- MUON
- TDAQ

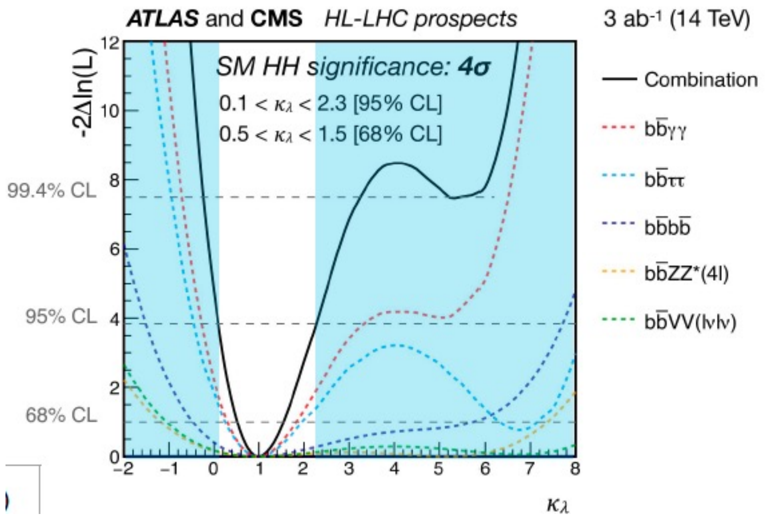
MAIN INFN INVOLVEMENTS:
- Tracker (inner and outer)
- MTD timing layer
- ECAL
- MUON

Examples of physics reach at HL-LHC







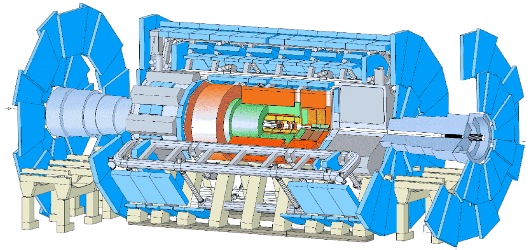


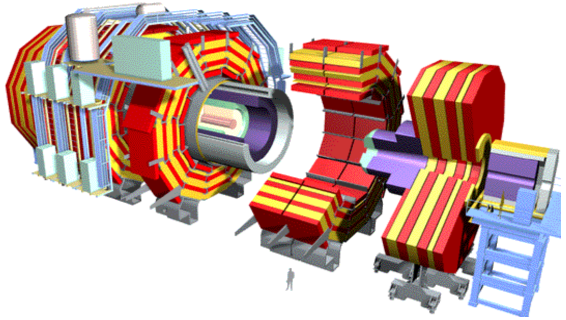
Typical deviation to SM
(depends on the new physics model)
$\Delta\kappa/\kappa \sim 5\%/\Lambda^2_{NP}$ (Λ_{NP} in TeV)

Double Higgs production and Higgs self-coupling
Recent RUN 2 results indicates that 5σ observation for HH production is in reach at HL-LHC

Main players in quark-flavour physics

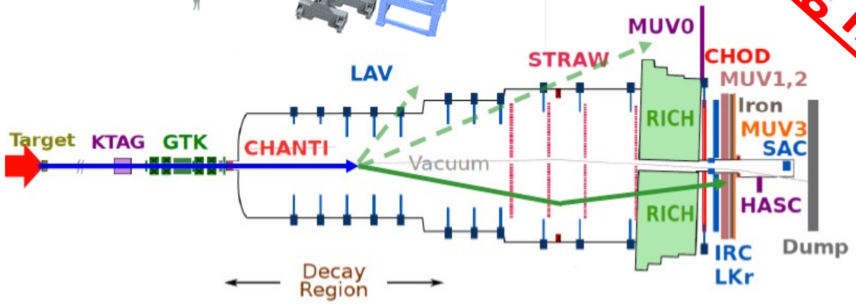
- ATLAS and CMS : measure some relevant B-physics channels, mainly with muons in the final state → but also new prospects eagerly awaited with parked data

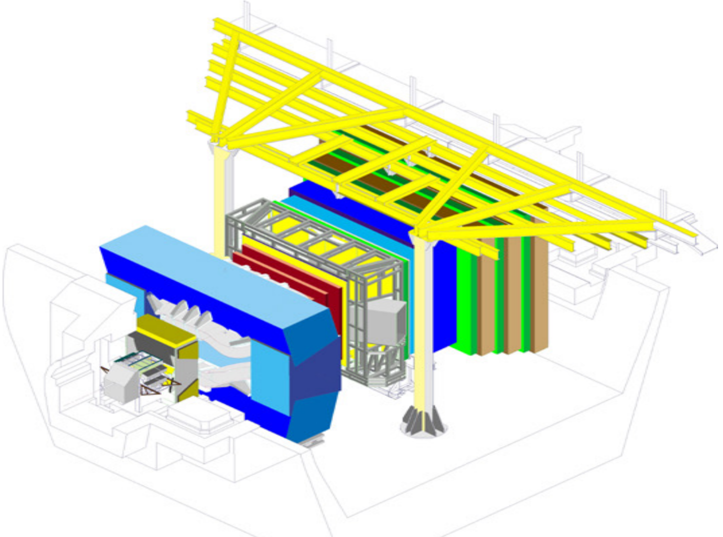




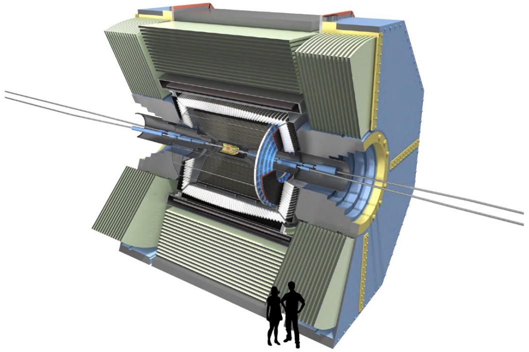
For all of them strong INFN involvement

- NA62: measure the SM branching fraction of $K^+ \rightarrow \pi^+ \nu\nu$ with 10% precision → future upgrades involve K^+ and K^0 rare decays (HIKE)



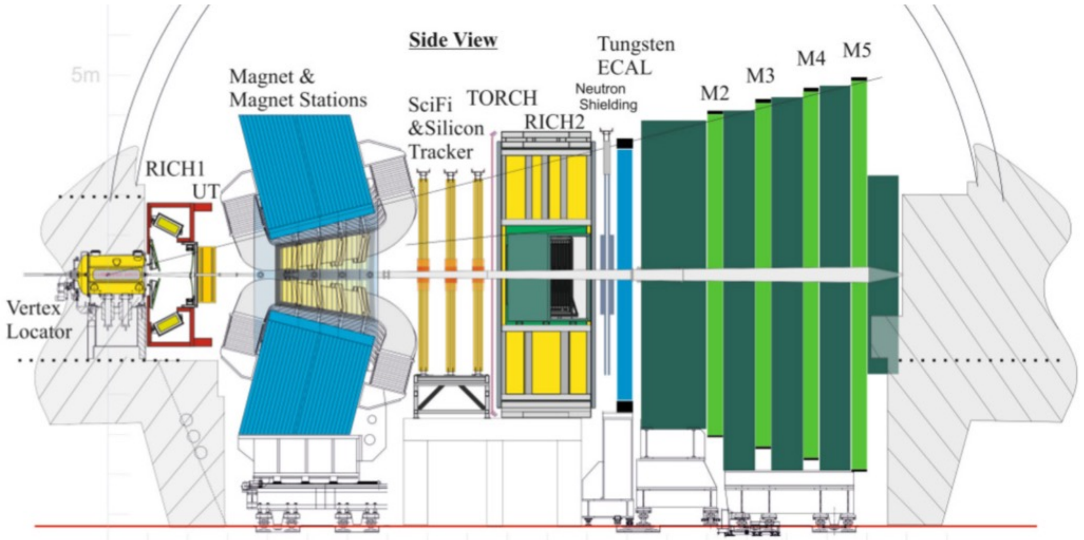


- LHCb and Belle II: dedicated detectors for flavour physics with wide range of measurements



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

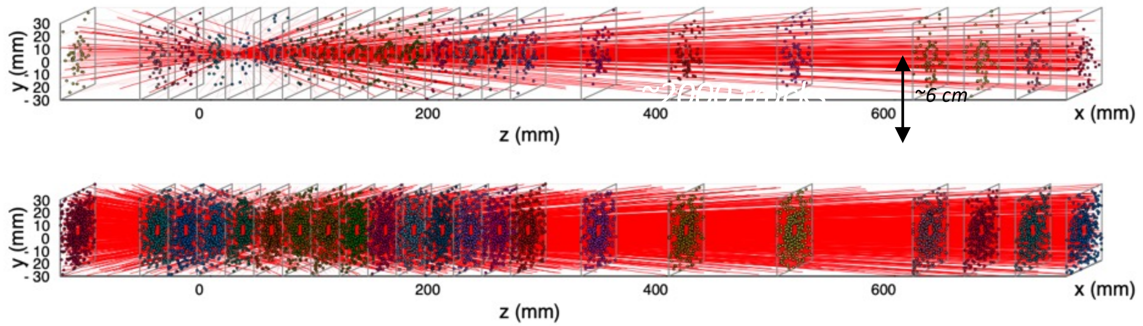
Key ingredients:

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

VErtex LOcator (VELO)

Run 3: pile-up ~6

Upgrade II: pile-up ~42

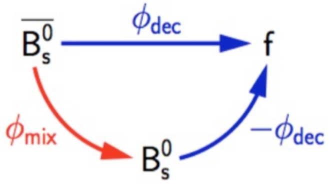


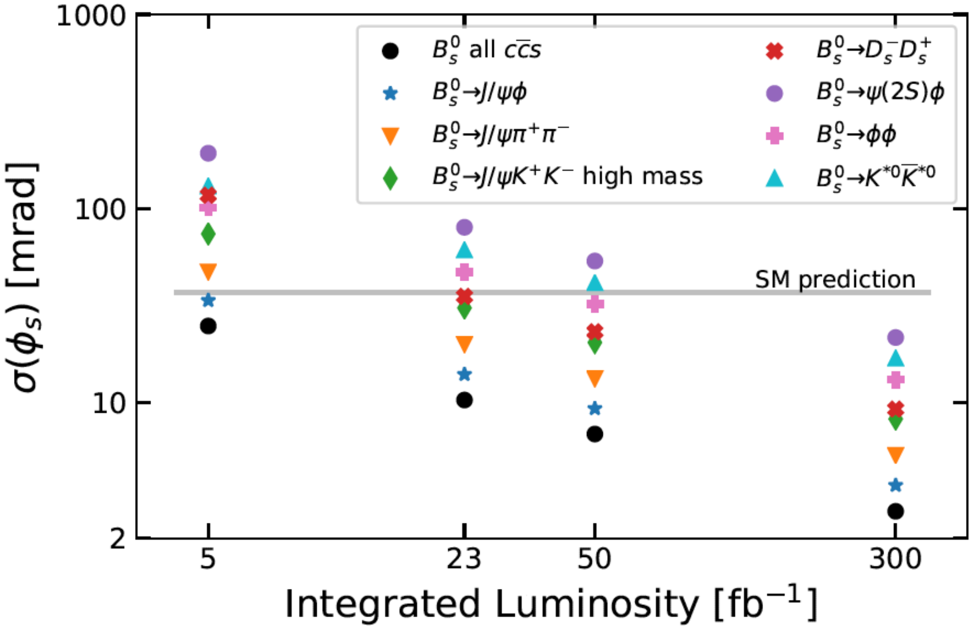
LHCb Upgrade 2: examples of reach and goals

	LHC era			HL-LHC era	
	Run 1 (2010-12)	Run 2 (2015-18)	Run 3 (2021-24)	Run 4 (2027-30)	Run 5+ (2031+)
LHCb $\int \mathcal{L}dt$	3 fb^{-1}	9 fb^{-1}	23 fb^{-1}	50 fb^{-1}	300 fb^{-1}

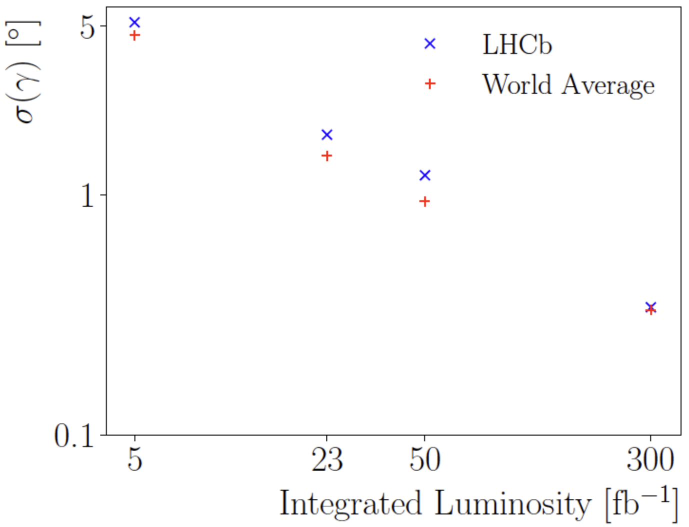
ϕ_s sensitivity in LHCb upgrades

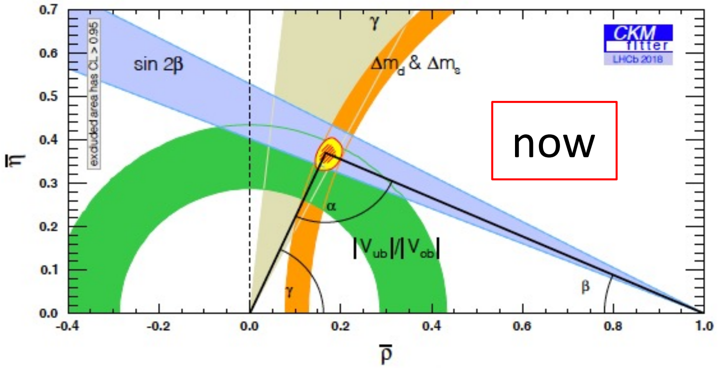
phase-difference between B_s mix and decay diagrams

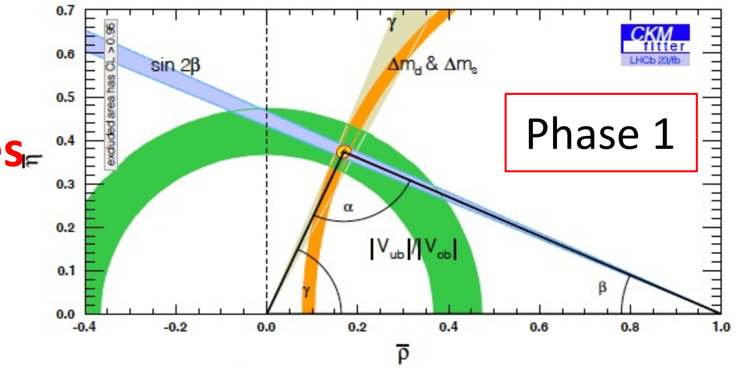


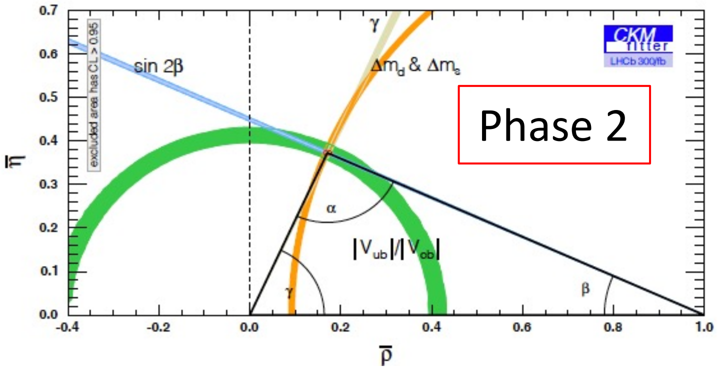


γ sensitivity in LHCb upgrades





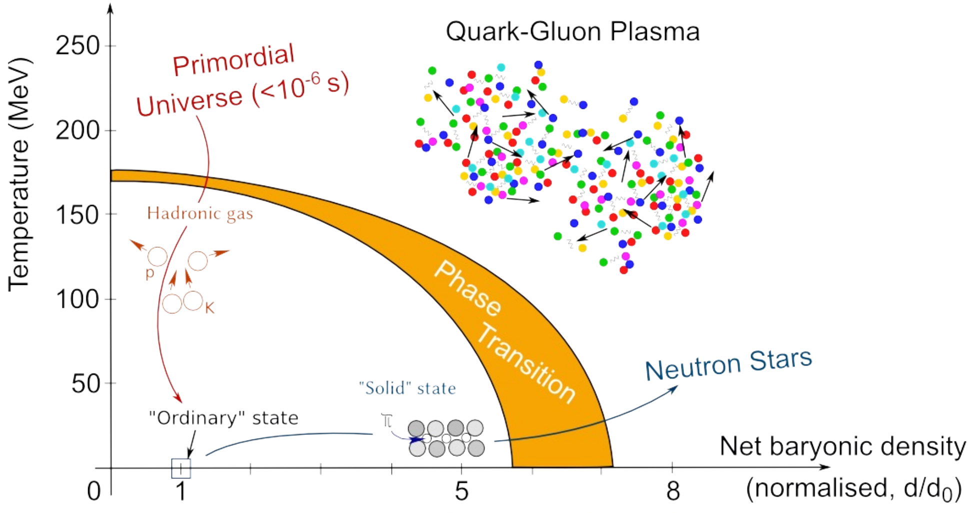


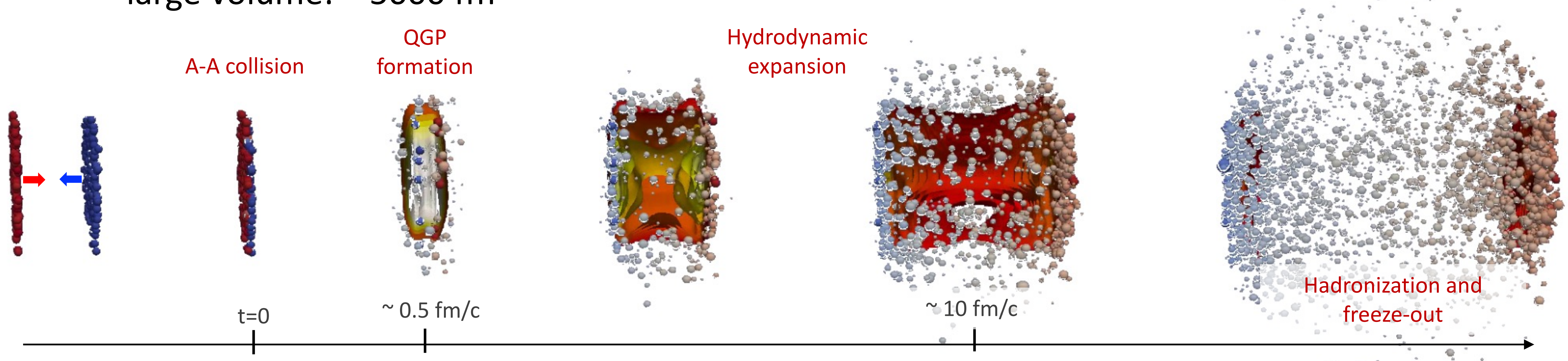


ALICE physics

- ALICE main goal: explore the deconfined phase of QCD matter
  - Quark-gluon plasma (QGP)
- Pb-Pb collisions at the LHC
  - large energy density: > 15 GeV/fm^3
  - large volume: ~ 5000 fm^3

https://cds.cern.ch/record/2025215

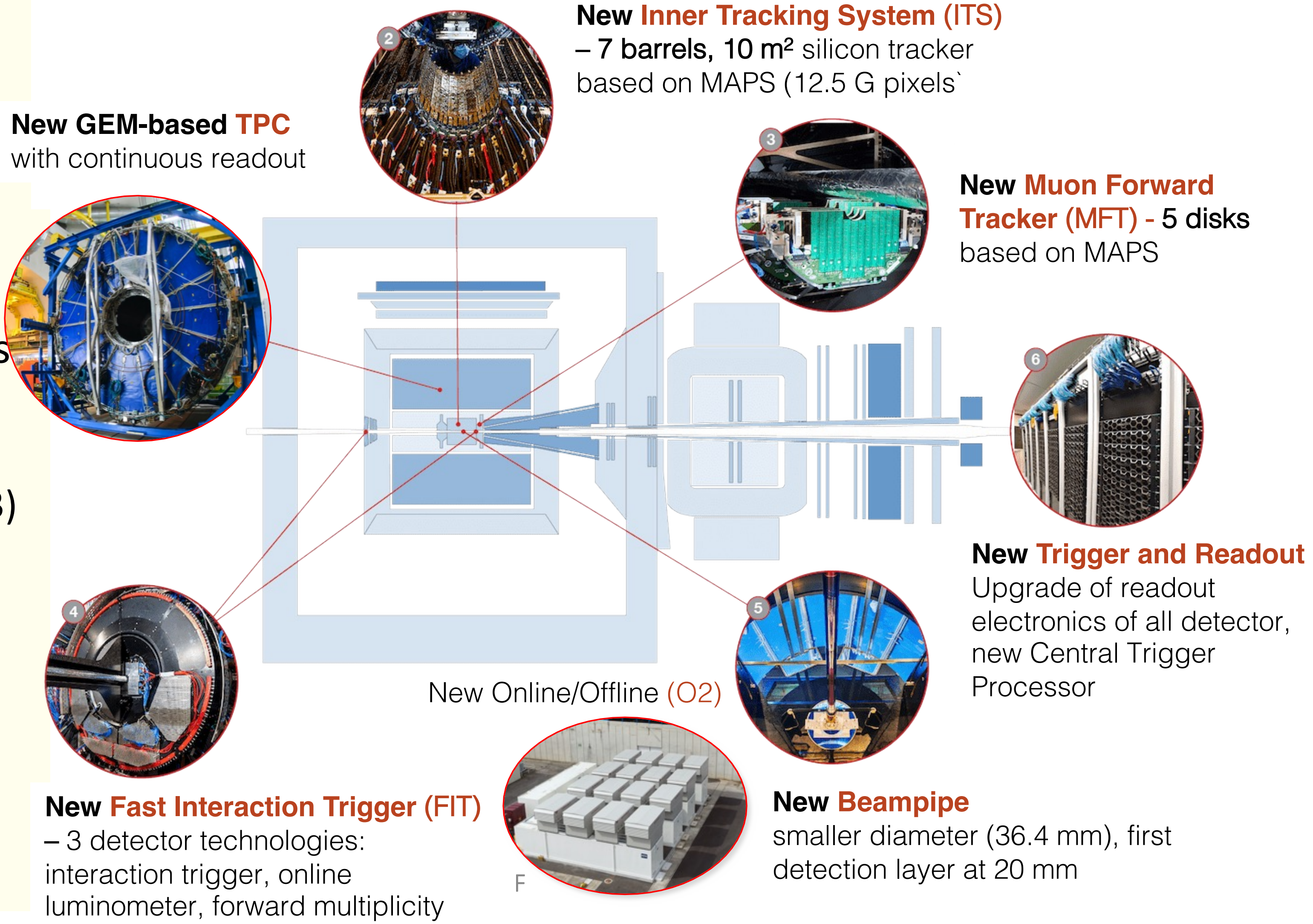




Visualization: J.E. Bernard arxiv:1804.04469

ALICE 2 Upgrade

- Pb-Pb rate: 50 kHz.
- pp rate: 1 MHz
- Continuous readout to sustain the expected rate
- A true minimum bias experiment: the goal is to process all the Pb-Pb collisions
- Expected statistics in Runs 3+4
  - ✓ Pb-Pb: 13 nb^{-1}
  - ✓ pp @13.6 Tev 200 pb^{-1} inspected (Run3) – 3 pb^{-1} stored MB
  - ✓ pp @ 5 TeV MB 6 pb^{-1}
  - ✓ p-Pb @ 8.8 TeV 0.6 pb^{-1}
- Tracking precision increase: ×3
- **Installation and commissioning during LS2: done!**



ALICE 3 detector

Compact, ultra-lightweight all-silicon tracker

→ $\sigma_{p_T}/p_T \approx$ 1-2%

Large acceptance

→ statistics, correlations, rapidity dependence

Vertex detector with unprecedented pointing resolution

→ $\sigma_{DCA} \approx 10\mu m$ (p_T = 200 MeV)

excellent electron and hadron identification (TOF + RICH)

→ π/K/p separation up to a few GeV/c,

→ electron ID up to ≈ 3 GeV/c with x10^3 pion rejection

muon identification (Muon absorber + Muon chambers)

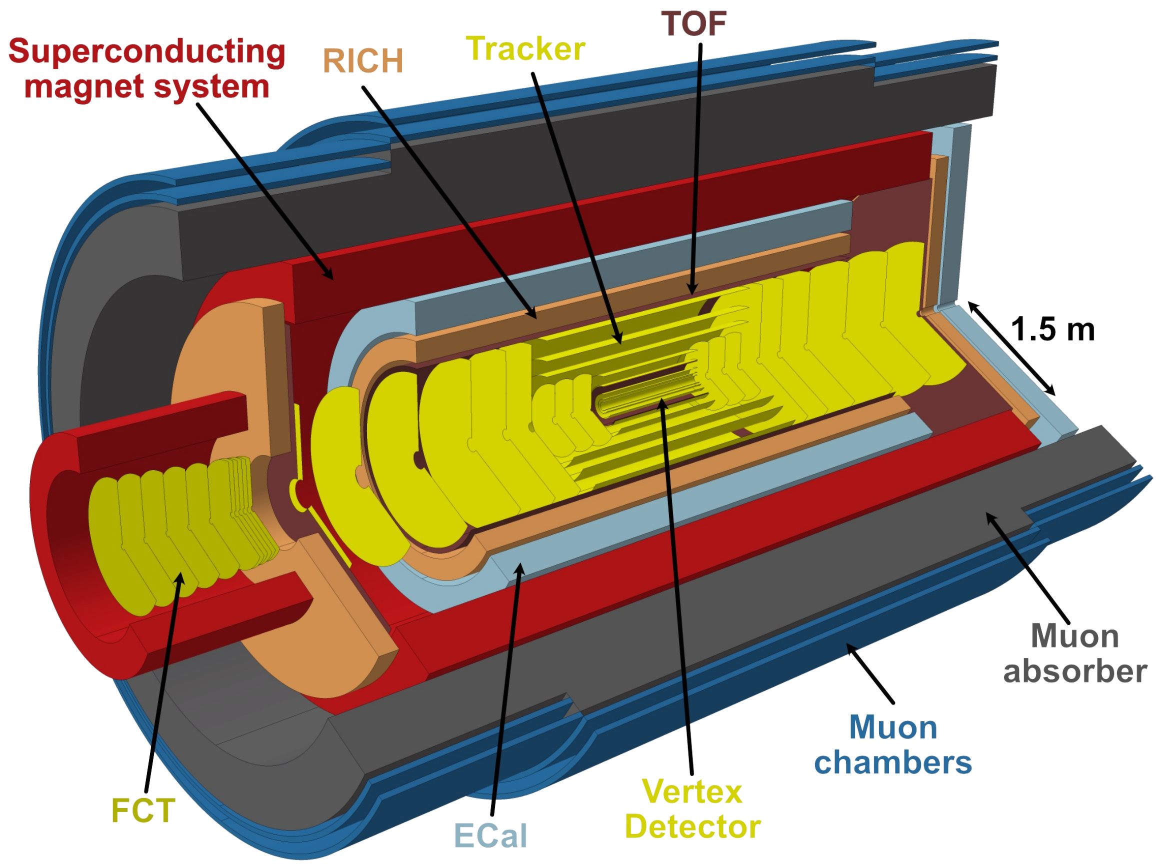
→ muon ID down to $p_T \approx$ 1.5GeV/c

ECal (Muon absorber + Muon chambers)

→ photons/jets over large η, high-resolution central segment

Superconducting magnet system (2T)

Continuous read-out and online processing



⇨ detector with unique and unprecedented features at the LHC

ALICE 3: a next-generation heavy-ion detector for LHC Run 5 & 6

Key physics questions and drivers

I. Nature of **interactions with the QGP** of highly energetic quarks and gluons

II. To what extent do quarks of different mass reach **thermal equilibrium** ?

III. What are the **mechanisms of hadron formation** in QCD?

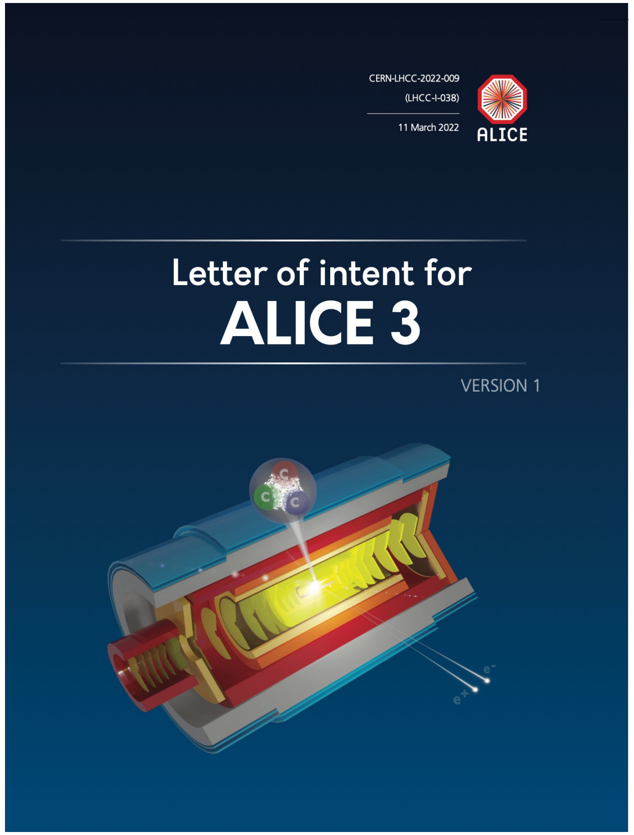
➪ Systematic measurement of (multi-)charm and beauty hadrons

QGP **temperature** throughout its space-time evolution

IV. What are the mechanisms of **chiral symmetry restoration** in the QGP?

➪ Precision measurements of dileptons

- QCD chiral phase structure (➪ fluctuations of conserved charges)
- Hadron interaction potential (➪ hadron-hadron correlations)
- ….

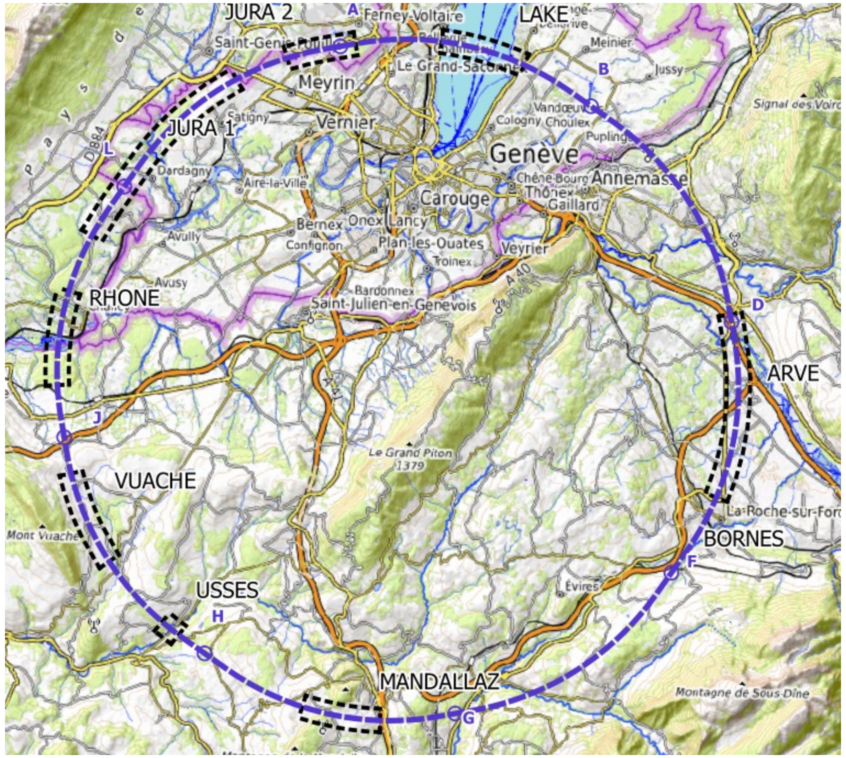


CERN-LHCC-2022-009

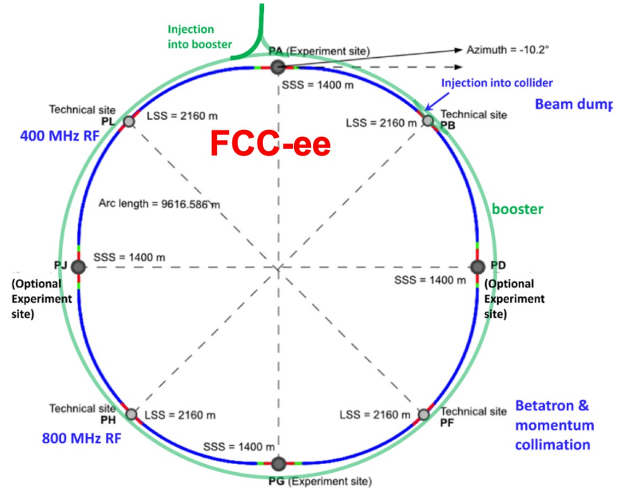
After HL-LHC: the FCC integrated project

Comprehensive long-term program maximizing physics opportunities

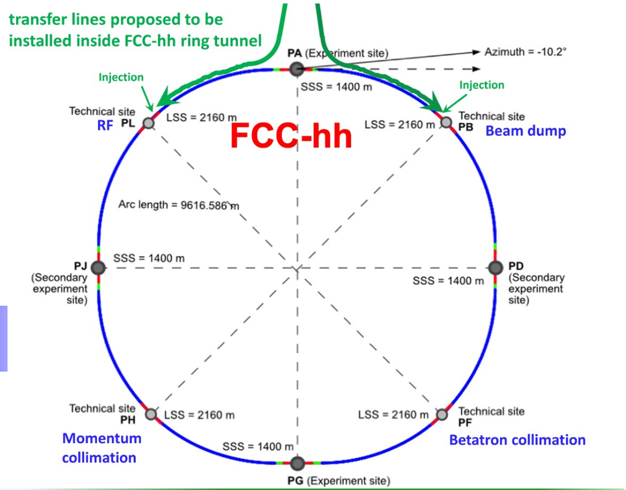
- **stage 1: FCC-ee (Z, W, H, $t\bar{t}$) as Higgs factory, electroweak & top factory at highest luminosities**
- **stage 2: FCC-hh (~100 TeV) as natural continuation at energy frontier, with ion and eh options**
- complementary physics
- common civil engineering and technical infrastructures, building 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

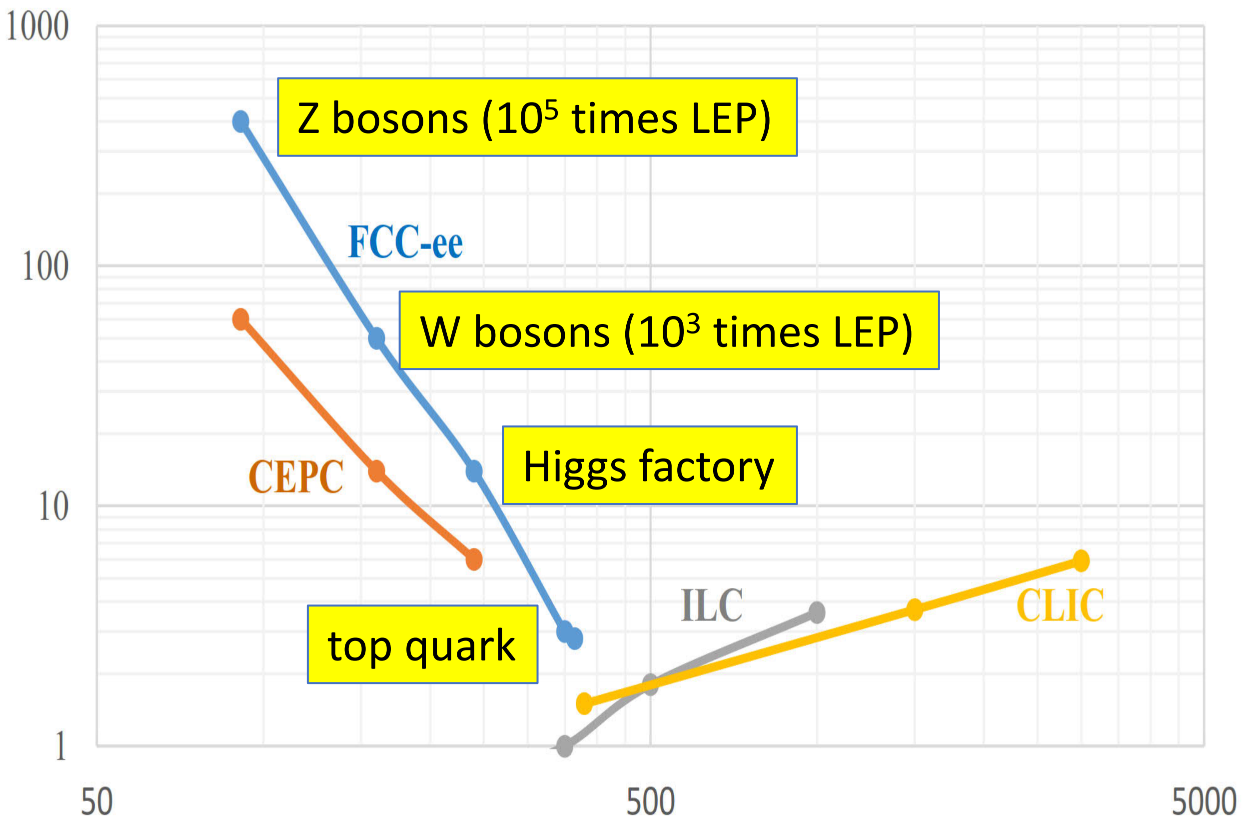


2065 - 2090

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

Where nature decided to put stuff (the electroweak playground)

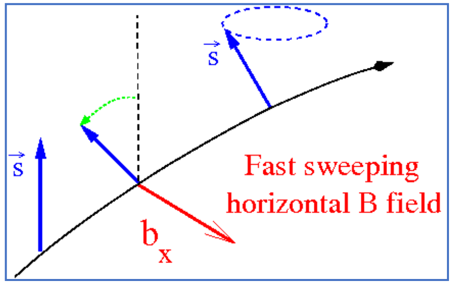
total luminosity [10^{34} cm^{-2}s^{-1}]

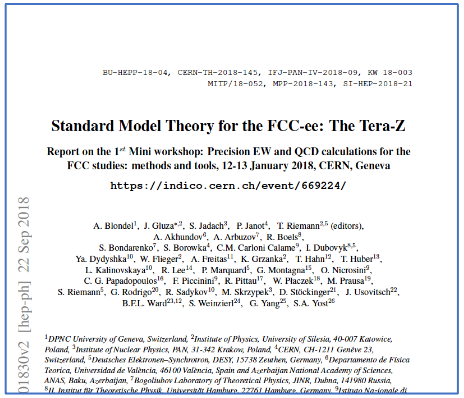


c.m. energy [GeV]

Some key points about FCC

- **FCC-ee is not just about brute-force luminosity**
  - Continuous calibration of centre-of-mass energy (e.g. 100 keV at the Z) with resonant depolarization
  - Direct measurement of parameters, which were computed until now (e.g. direct measurement of α_{QED} running)
- **There is a well-defined theory effort, to successfully use data in a meaningful way (e.g. 3-loop calculations)**
- **It has been shown in various ways (e.g. EFT analyses) that a jump in precision in Z, W, H, top measurements is required for a comprehensive interpretation of the electroweak sector**
  - A deviation of a single coupling or operator will not provide the full picture
- **FCC-hh is eventually required to precisely investigate the Higgs self-coupling, to close important chapters (e.g. WIMP interpretation of Dark Matter) and to significantly extend direct searches**




BU-HEPP-18-04, CERN-TH-2018-145, IFJ-PAN-IV-2018-09, KW 18-003
MITP/18-052, MPP-2018-143, SI-HEP-2018-21

Standard Model Theory for the FCC-ee: The Tera-Z

Report on the 1st Mini workshop: Precision EW and QCD calculations for the FCC studies: methods and tools, 12-13 January 2018, CERN, Geneva

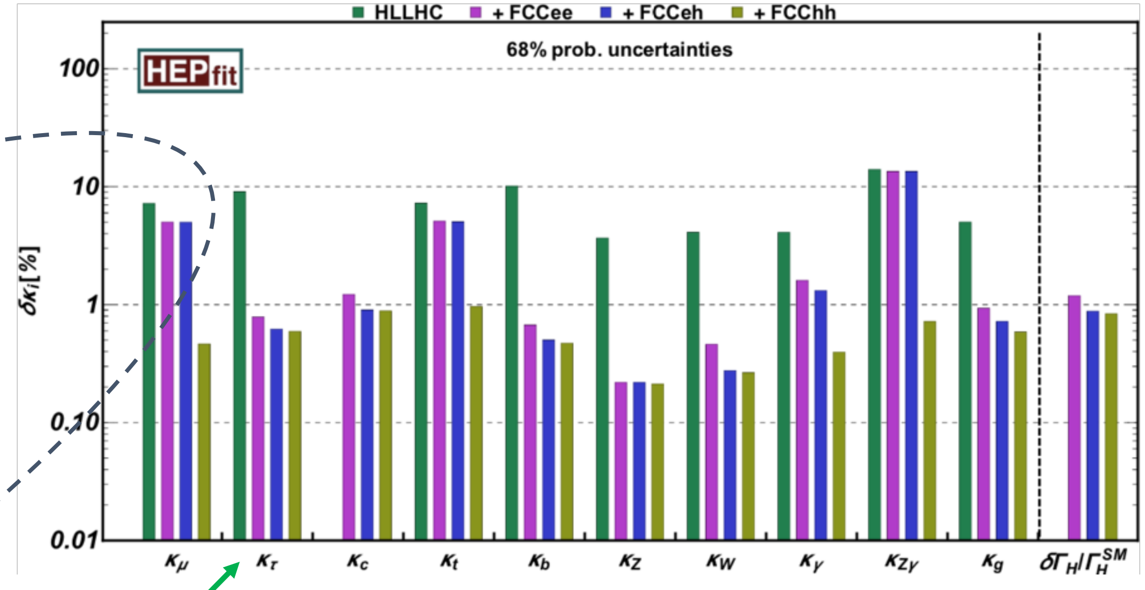
https://indico.cern.ch/event/669224/

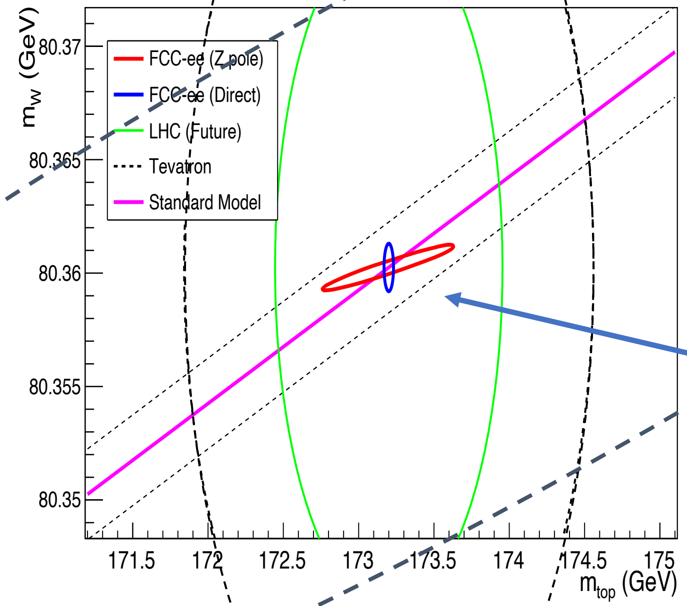
[hep-ph] 22 Sep 2018

	# Higgs pairs to bbγγ
LHC: 14TeV 300fb^{-1}	36
HL-LHC: 14TeV 3ab^{-1}	360
FCC: 100TeV 20ab^{-1}	92 x 10^3

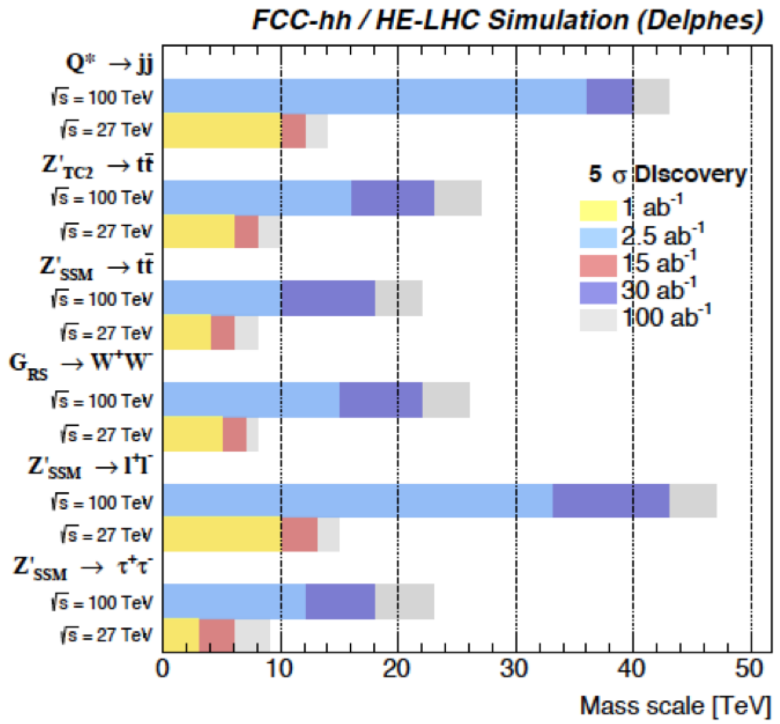
percent precision physics

A glimpse of FCC physics



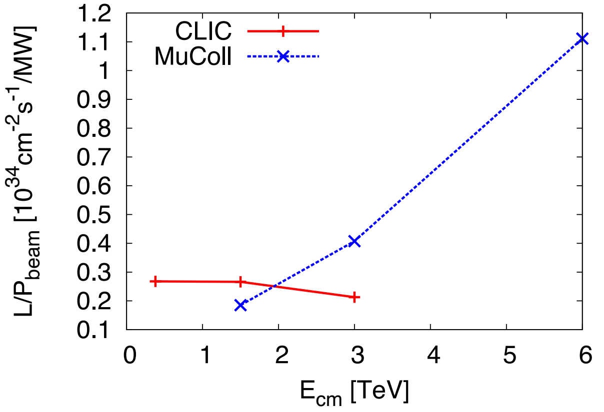


- One-two orders of magnitudes jump for **electroweak observables**
- **Higgs couplings** well below 1%
- FCC-hh explores the **20 - 50 TeV territory**



Muon Collider

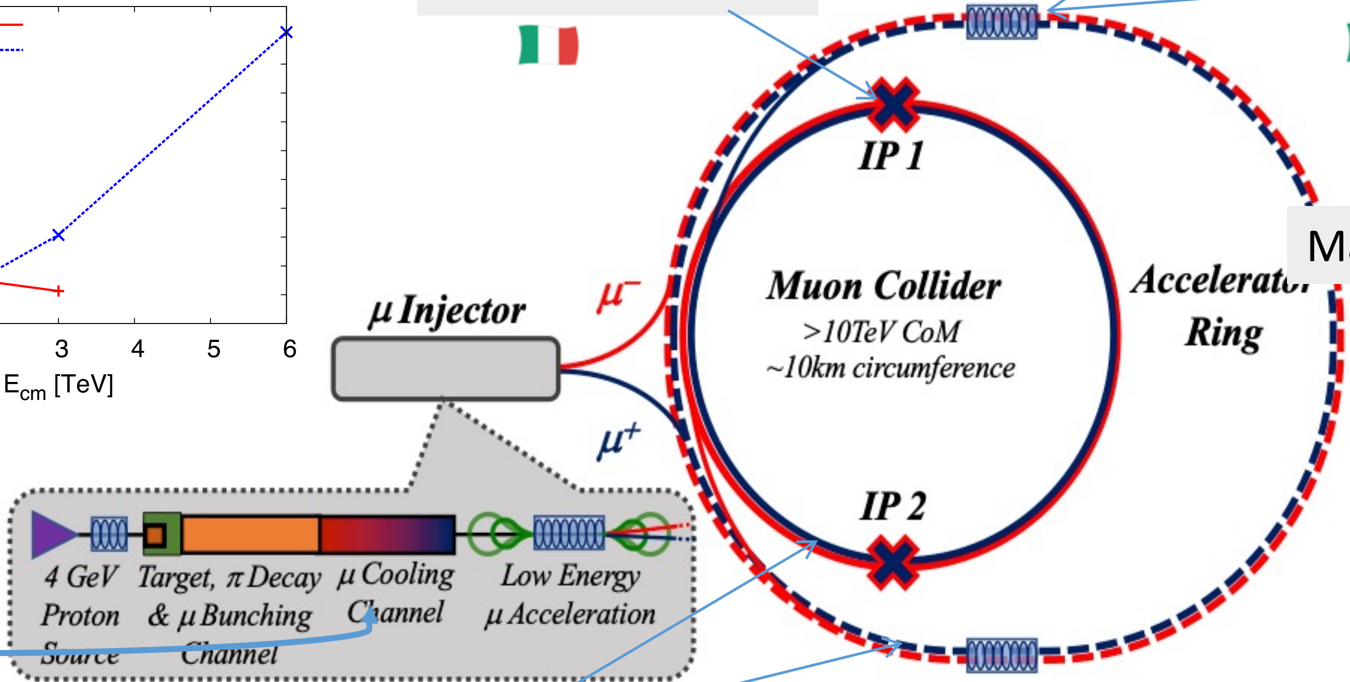
International MUON Collider Collaboration



Beam induced background

MDI and Detector design

Magnets &RF



Cooling cell prototyping

Cost and **power** consumption drivers, limit energy reach e.g. 30 km accelerator for 10/14 TeV, 10/14 km collider ring

ASSUMPTION/IP

$\mathcal{L} = (E_{CM}/10\text{TeV})^2 \times 10\ \text{ab}^{-1}$

@ 3 TeV 1 ab^{-1}/5 years

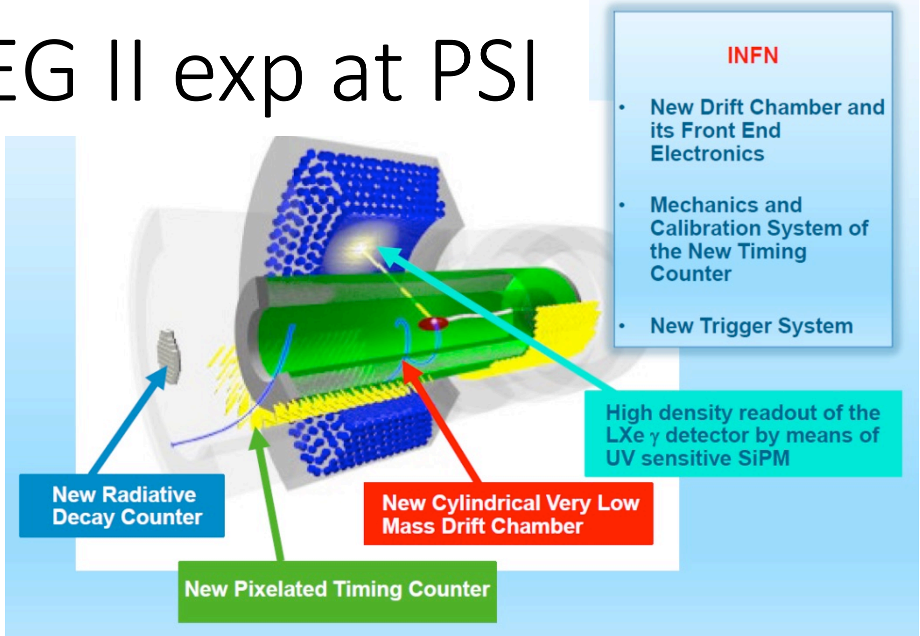
@ 10 TeV 10 ab^{-1}/5 y

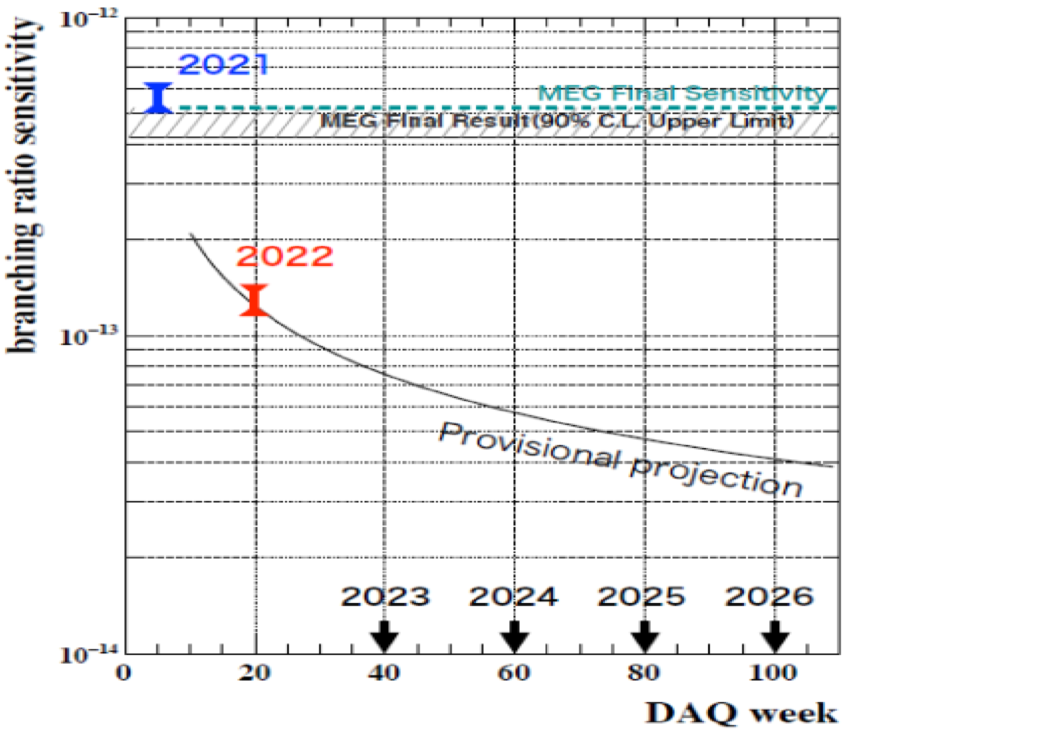
@ 14 TeV 20 ab^{-1}/5 y

1st stage a muon cooling demonstrator to be built in 2030+

The MEG II exp at PSI

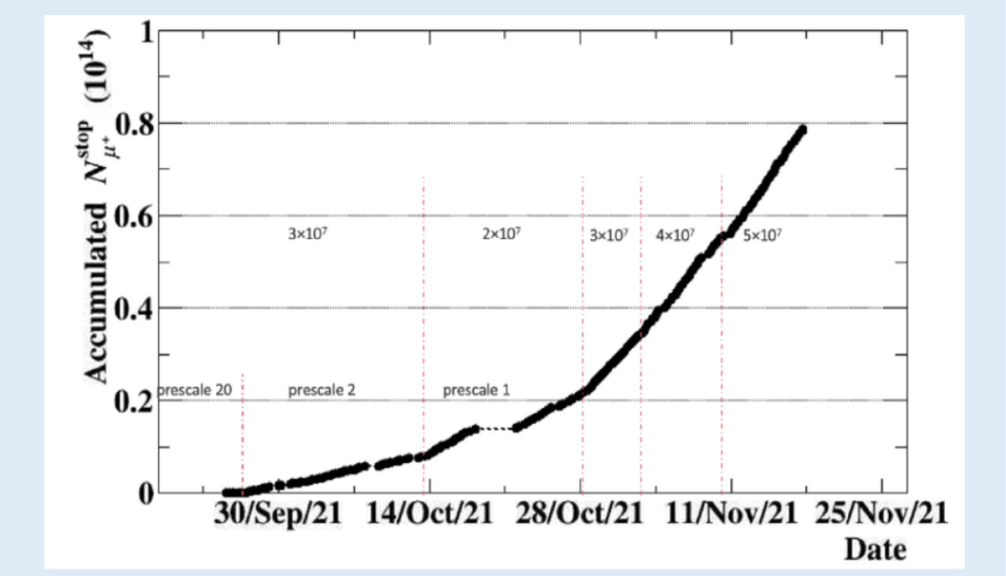
Search for
μ → eγ
decays



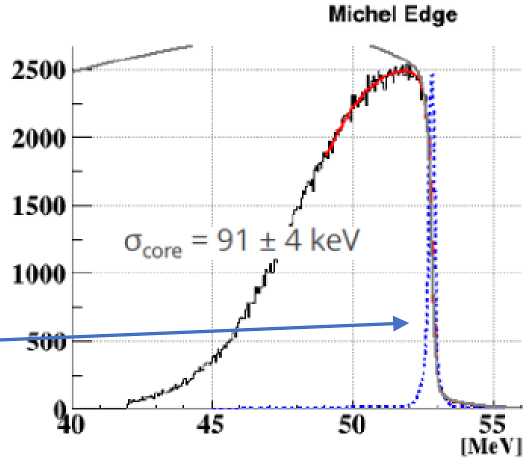


- Provisional projection curve based on expected detector performance ("Updated(2021)" in summary table)
- (20 DAQ weeks for 6 month beam time) per year
- DAQ time 2021 with correction for fraction of physics run

"Luminosity" accumulated during first physics run

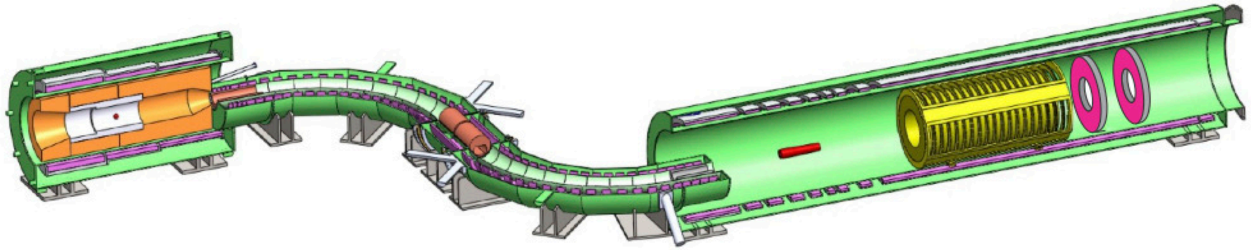


Performance of drift chamber is very good, already with initial alignement momentum resolution improved by a factor of 4 w.r.t. MEG I

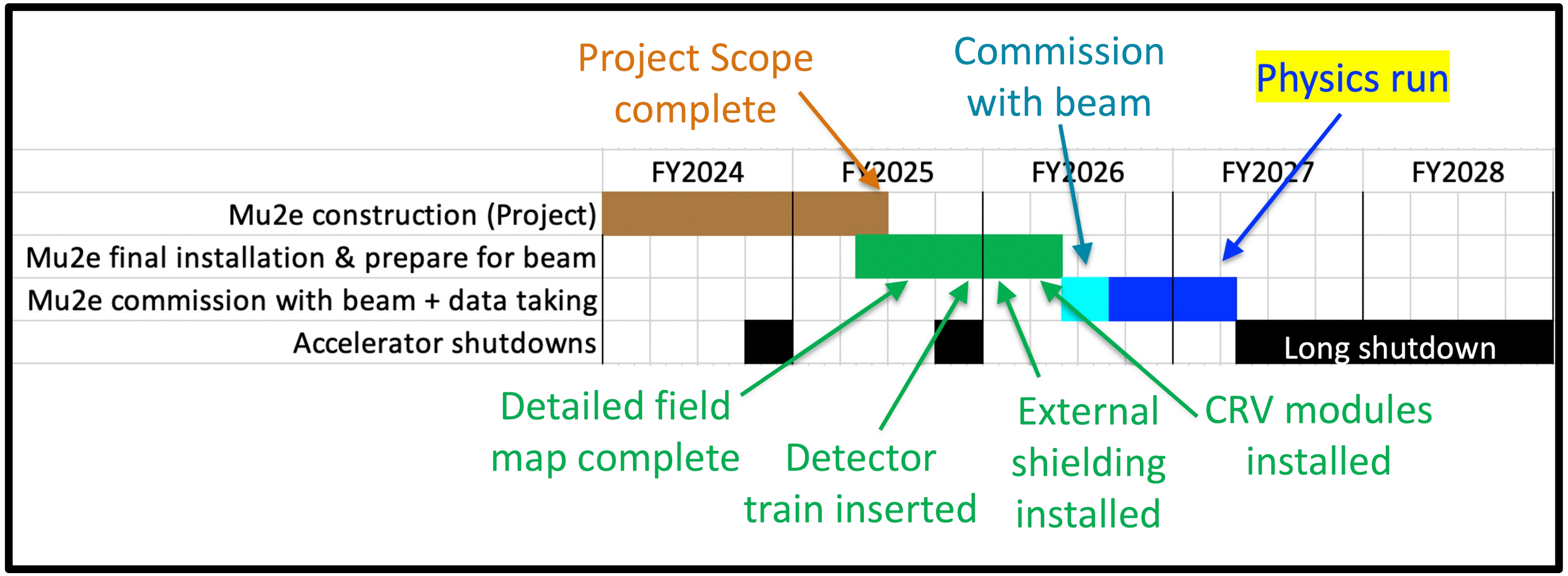


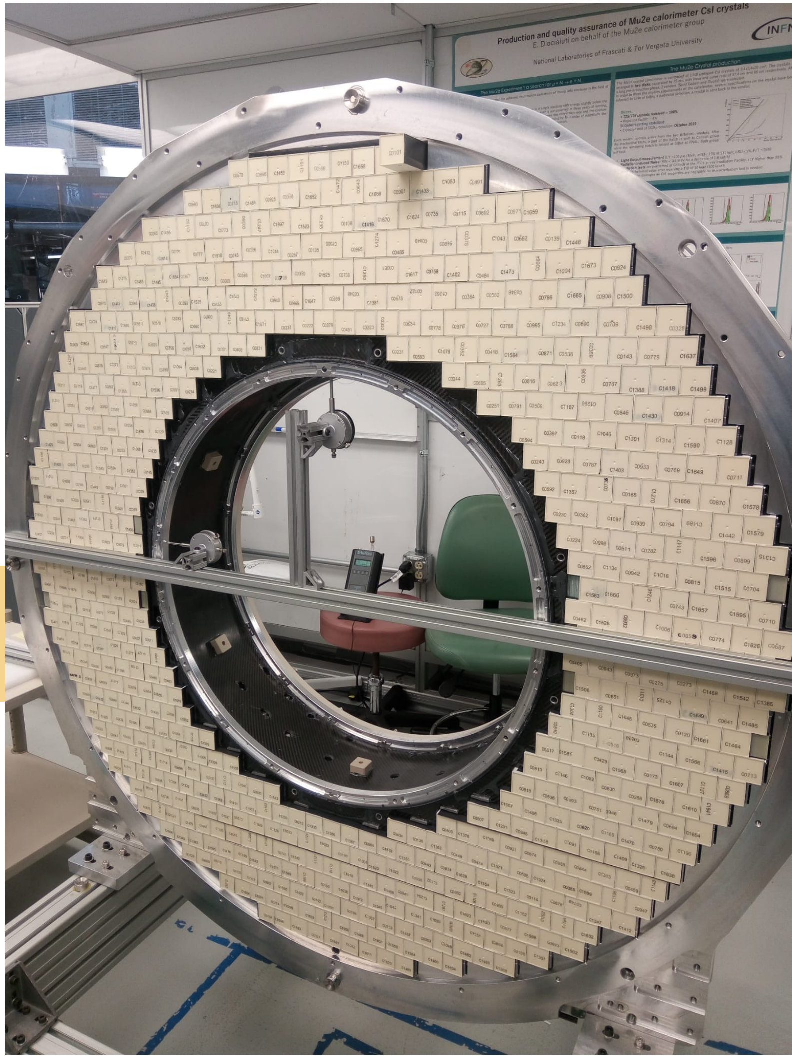
The Mu2e experiment at Fermilab

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



Mu2e progresses 2022: Critical path still driven by Solenoids +1.5 year Delay due to Covid → REBASELINED by DOE in Sept 2022.

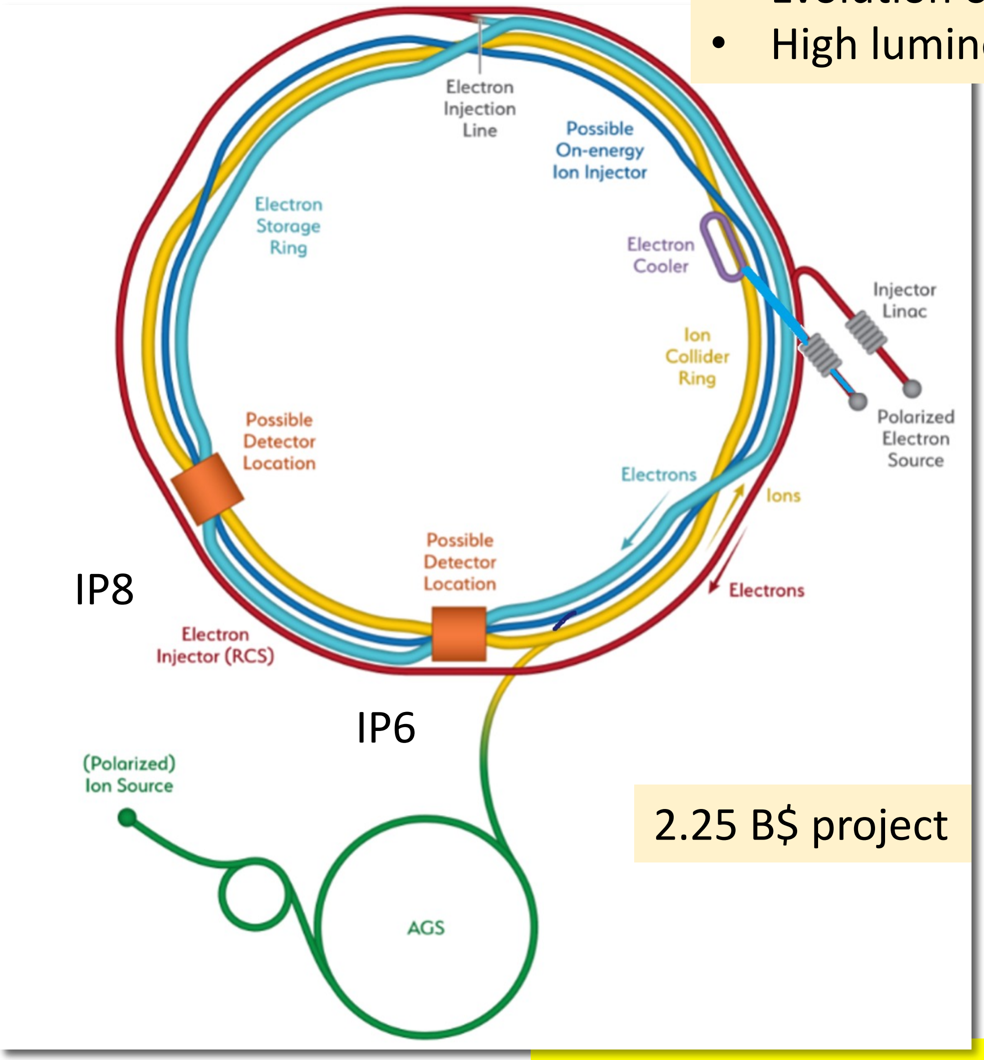




Calorimeter disk assembled with crystals (INFN responsibility)

EIC: Electron Ion Collider: the next QCD machine

- Evolution of RHIC facility (pp/pA/AA) at BNL → electron ring (E_e = 5-18 GeV)
- High luminosity ($10^{33} – 10^{34}$ $cm^{-2}s^{-1}$), polarized beams of e/p/ions at $\sqrt{s_{ep}}$ = 28 – 140 GeV



2.25 B$ project

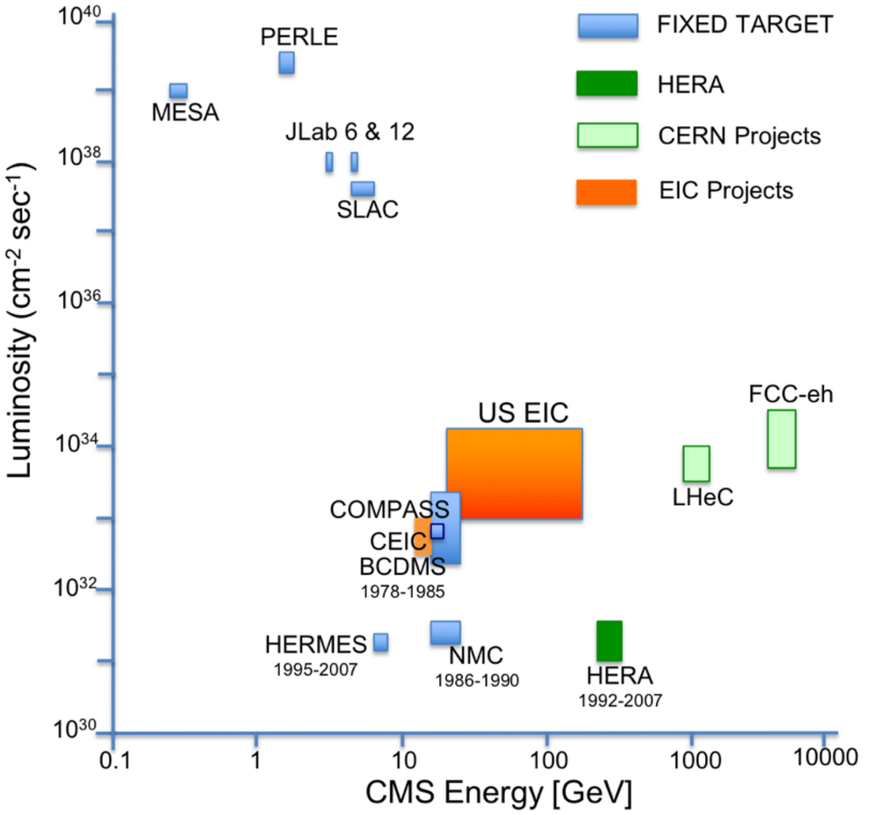
EIC key points:

<u>With respect to HERA:</u>

- x100 /x1000 higher luminosity
- (p, d, ^{3}He) and e polarized
- Nuclear beams (from d to U)

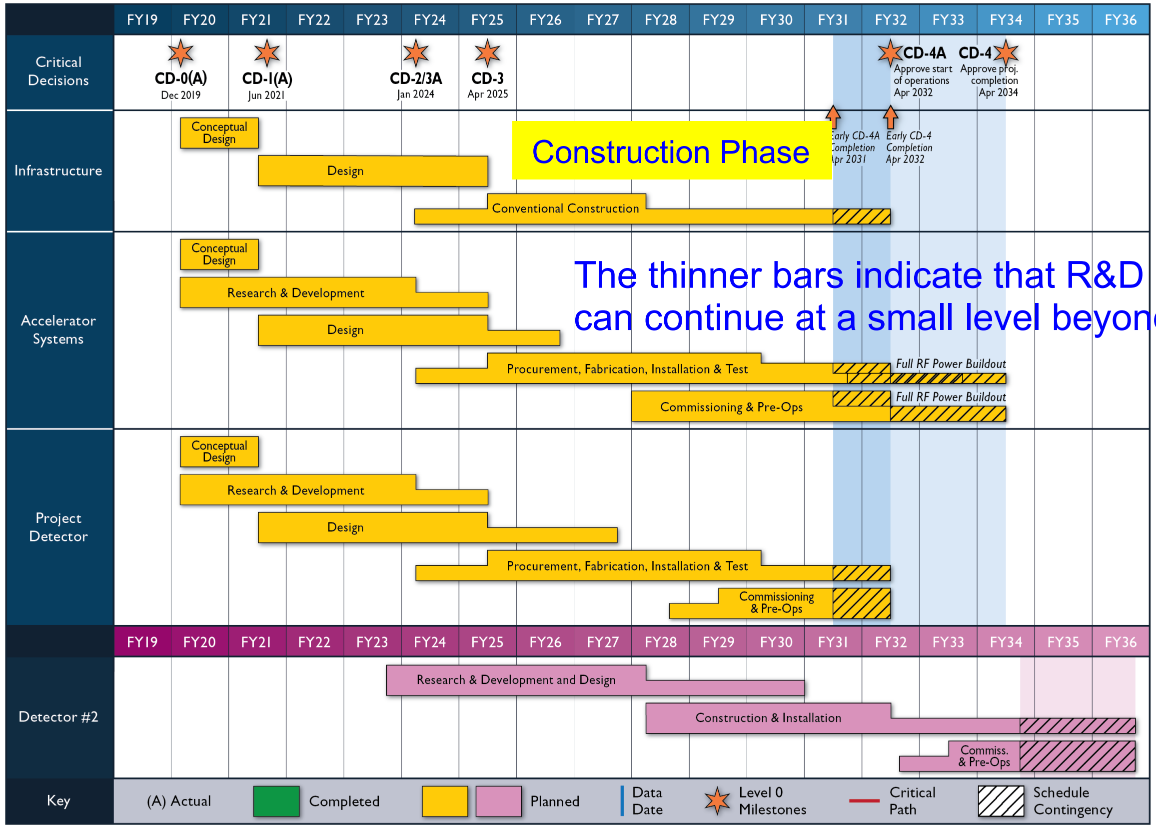
<u>With respect to fixed target facilities:</u>

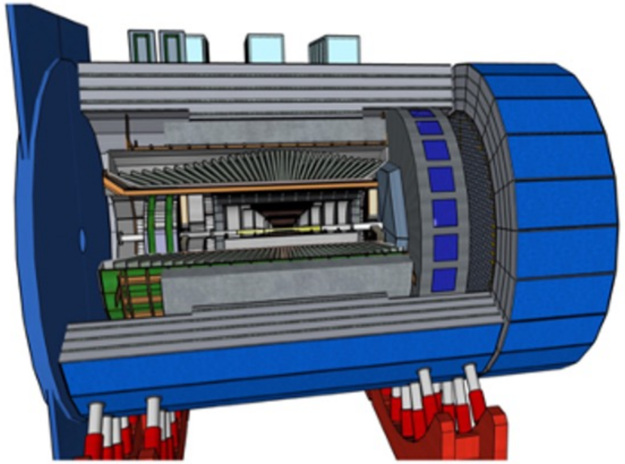
- Two orders of magnitude increase in (x, Q^2) kinematic space



- DoE supports the project including one detector at IP6 but design for two interaction regions
- INFN in-kind contribution to the accelerator under discussion (mitigation of secondary electron yields in hadron storage ring)

EIC timescale and the ePIC detector





1.7 T magnet

Italian R&D in ePIC detector (under sigla "EIC_NET", currently 85 researchers 20 FTE)

PID – forward dual RICH	Prototype and optics	FE
	Aerogel studies	BA FE
	SiPM and electronics	BO FE TO CS SA CT
	LAPPD for Cerenkov app.	GE TS
	Pressurized vessel	LNS TS
Vertex	Development of MAPS 65 nm	BA PD TS
Streaming readout	DAQ and AI algorithms	GE RM2
Physics, software and simulations	SIDIS	PV
	Parton imaging and diffraction	CS TO
	Simulation	TS BA LNS SA

- **ePIC** Collaboration (arising from detector proposals "ATHENA" and "ECCE") formed in July 2022
  → detector 1 at IP6
- 160 institutions (41% US, 27% from Europe)
- Pre-TDR to be finalized by October 2023
- Detector TDR by end of 2024!

Neutrini, their oscillations and masses

$$U = \begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix} \begin{pmatrix} c_{13} & 0 & s_{13}e^{-i\delta_{\rm CP}} \\ 0 & 1 & 0 \\ -s_{13}e^{i\delta_{\rm CP}} & 0 & c_{13} \end{pmatrix} \begin{pmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} e^{i\alpha_1} & 0 & 0 \\ 0 & e^{i\alpha_2} & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

θ_{23} & ΔM^2_{32}

Accel. LBL ($\nu\mu, \bar{\nu}\mu$) disapp. (K2K, MINOS, T2K, NOvA)
Accel. LBL ($\nu e, \bar{\nu}e$) appearance (MINOS, T2K, NOvA)
Atmospheric Experiments (SK, IC-DC)

CP phase δ & θ_{13}

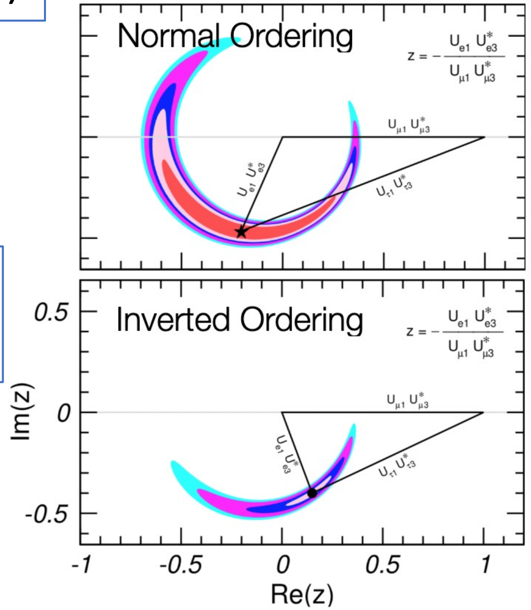
Reactor LBL (KamLAND)
Reactor MBL (Daya Bay, RENO, Double Chooz)
Accel. LBL ($\nu e, \bar{\nu}e$) appearance (MINOS, T2K, NOvA)

θ_{12} & ΔM^2_{21}

Solar Experiments
Reactor LBL (KamLAND)

Majorana phase

Double beta decays

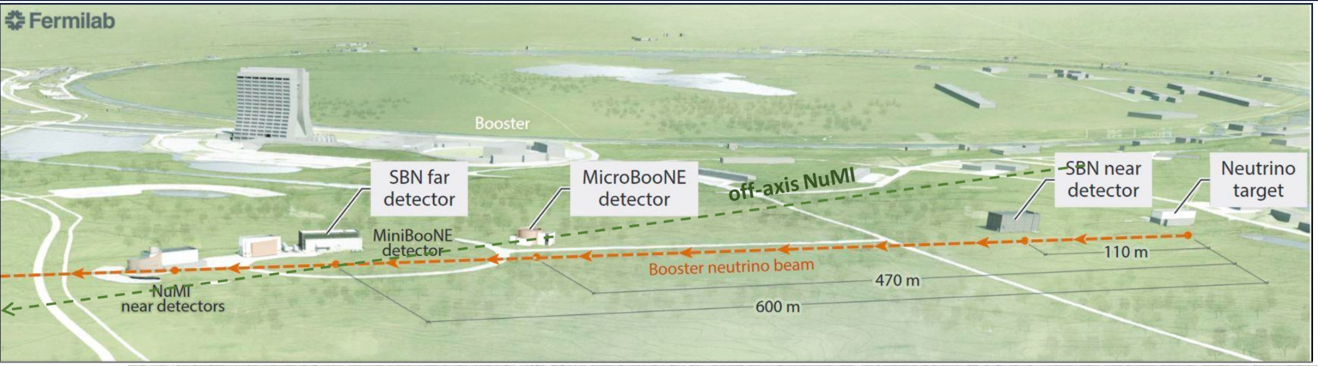


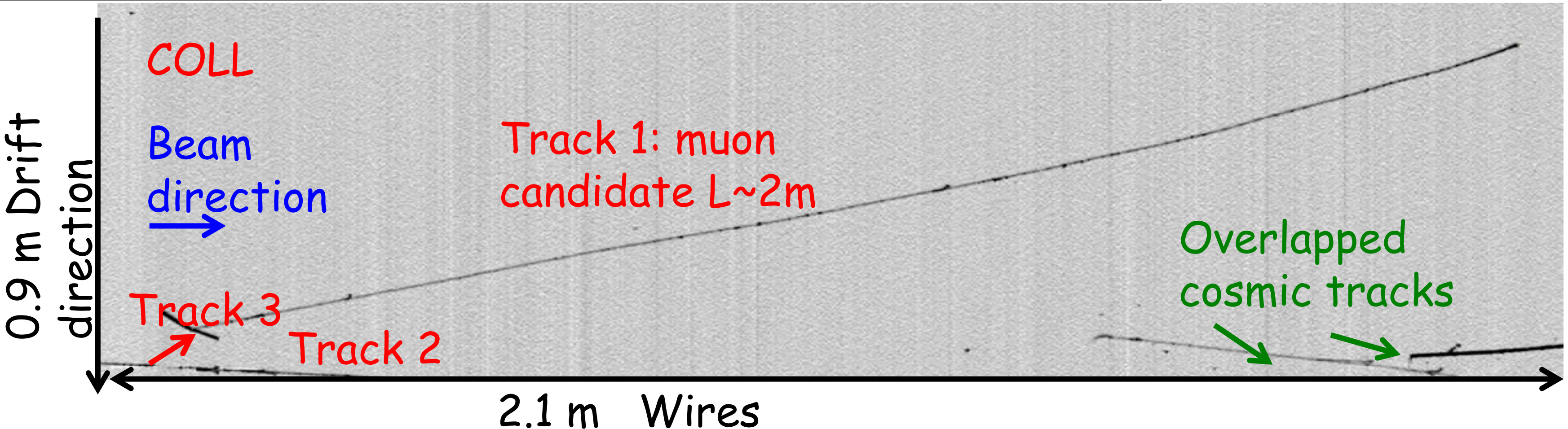
Important projects in preparation:
e.g., DUNE, HyperK, JUNO, KM3net, SBN Program
→ Status reports at this conference

Leptonic mixing matrix (PNMS matrix) still poorly known including mass ordering

A project recently completed : Icarus 600 T @ SBN

August 2018	August 2020	March 2021	June 2021	December 2021	May 2022	June 2022
start of installation at FNAL	detector activation	First BNB and NuMI detected neutrinos	Run-0 taking data 24/7 with beam	Installation of CRT system completed	End of overburden installation	Beginning of Run-1



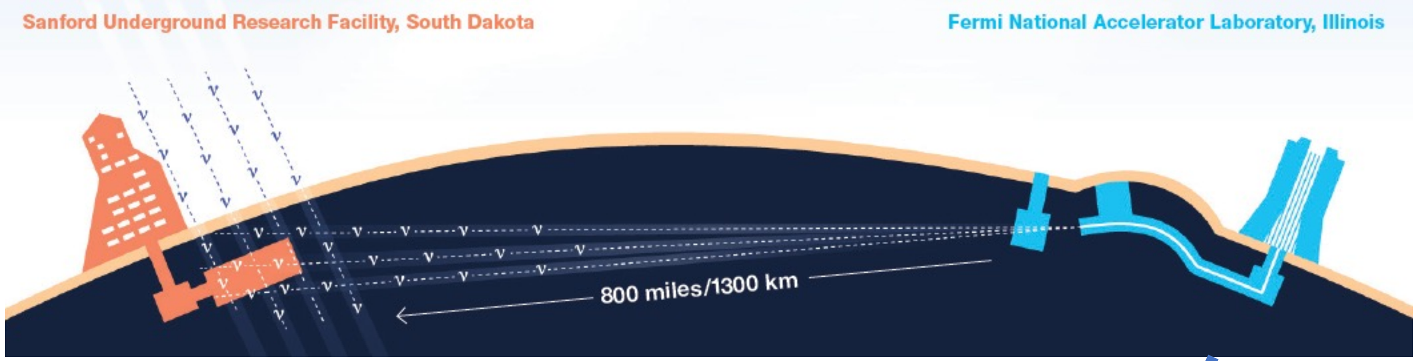


NU@FNAL: DUNE

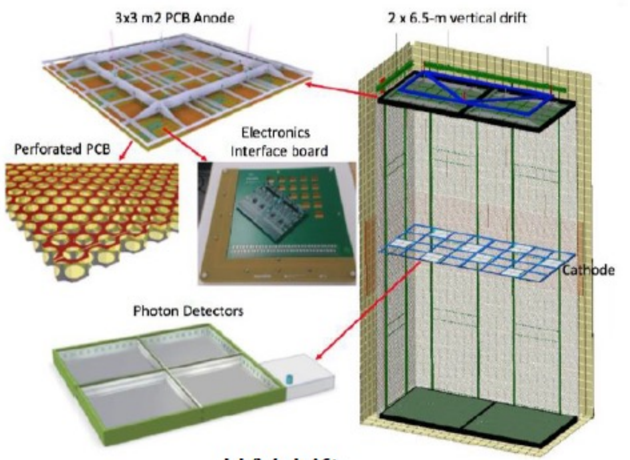
Some physics goals (phase 1)

Oscillation Physics:

- Definitive resolution of the mass ordering
- Sensitivity to maximal CP violation ($\delta CP \sim \pm \pi/2$)
- World-leading measurement of mass splitting ($\Delta m2atm$)



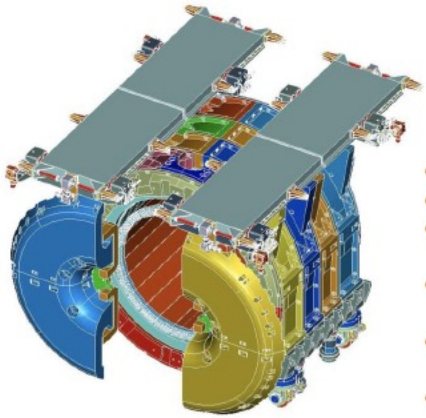
DUNE Far - Photon Detection System (PDS)



H/V drift

European site for WLS evaporation

DUNE Near from KLOE→ SAND

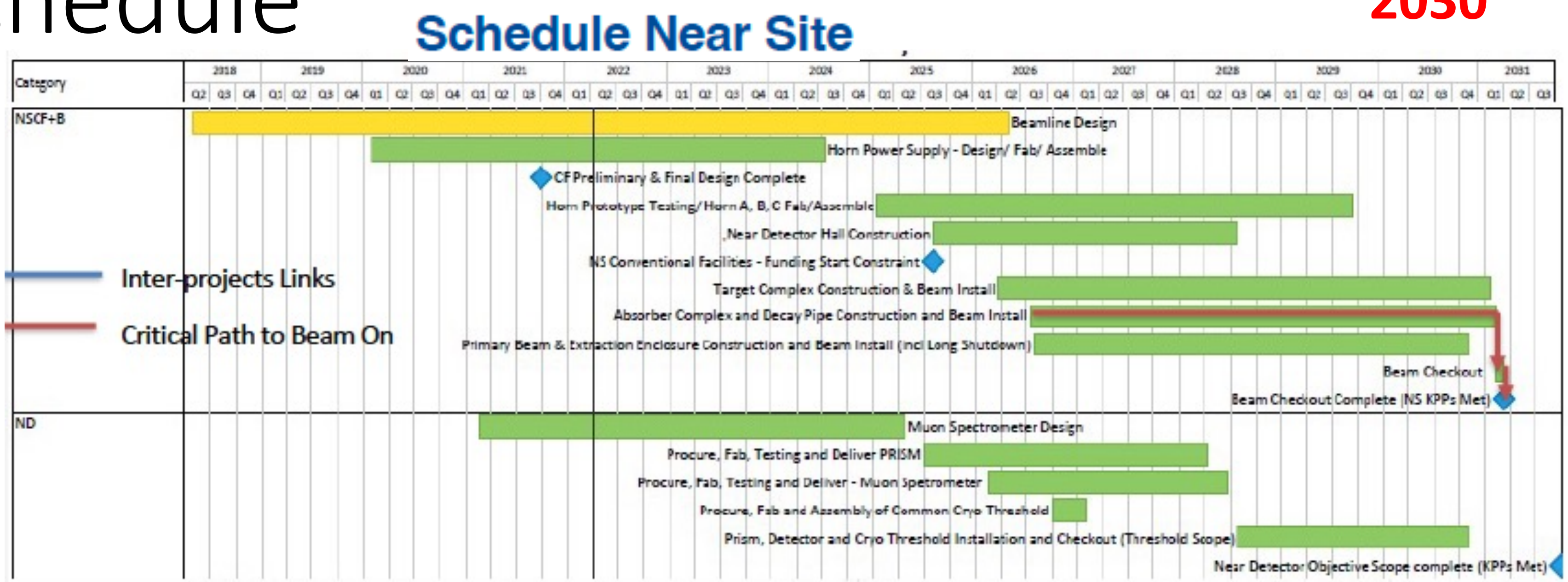


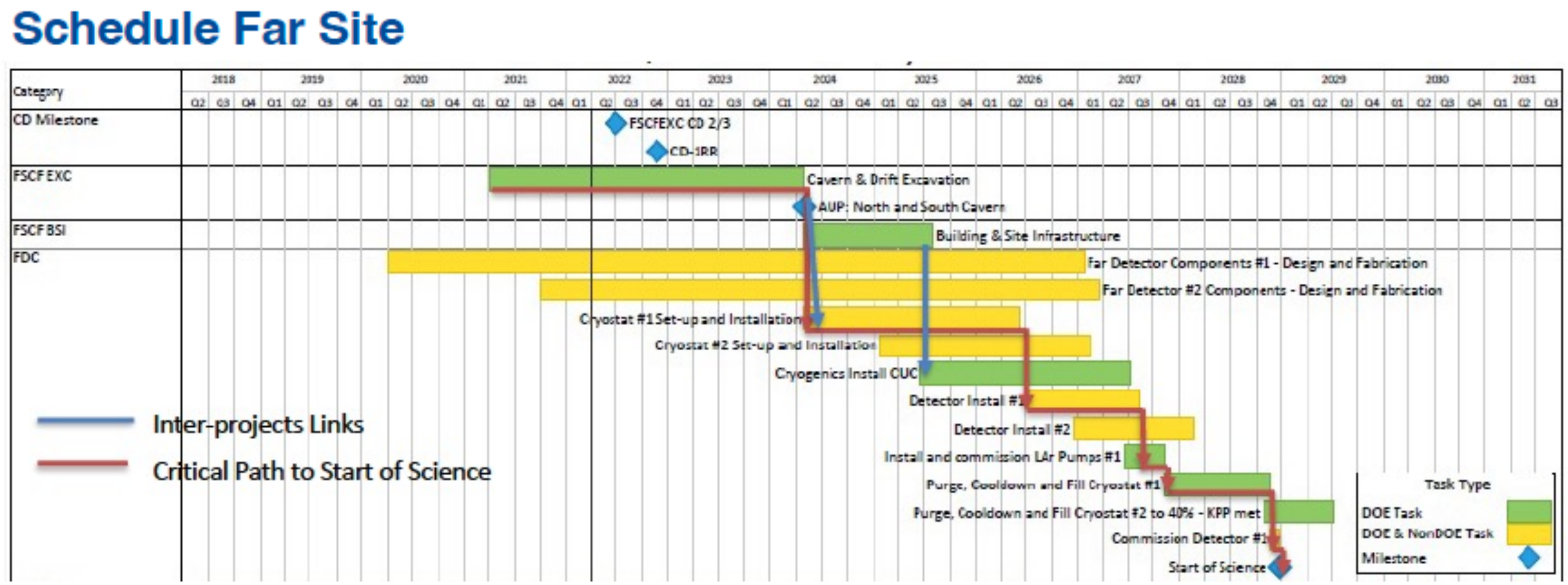
Granular Argon for Interaction of Neutrinos (GRAIN)

- 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

DUNE schedule

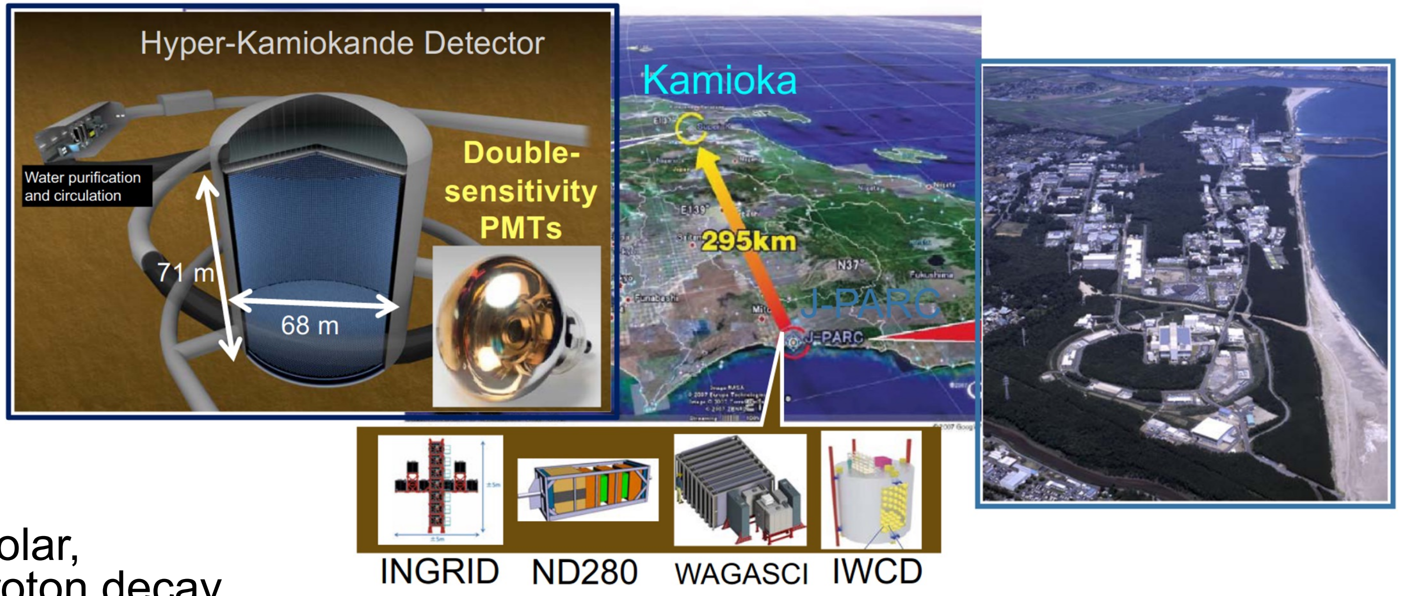
2030





Hyper-Kamiokande in a nutshell

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

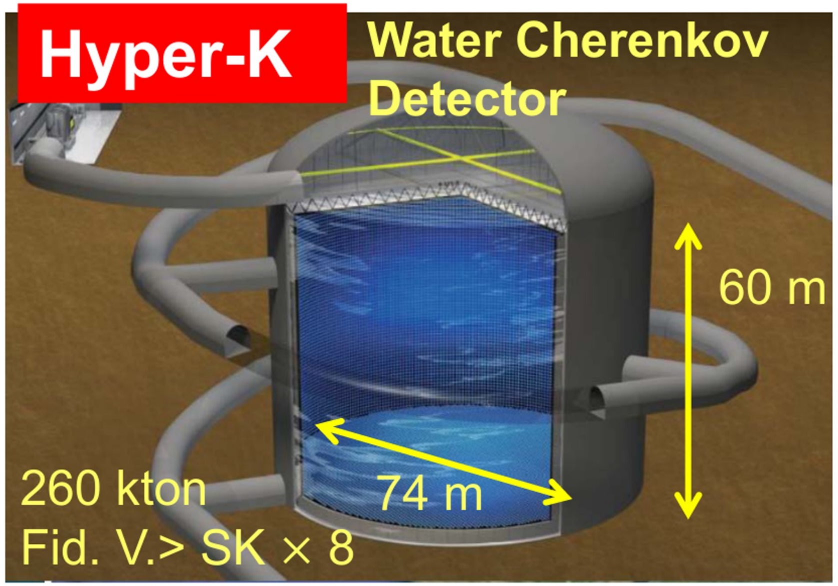


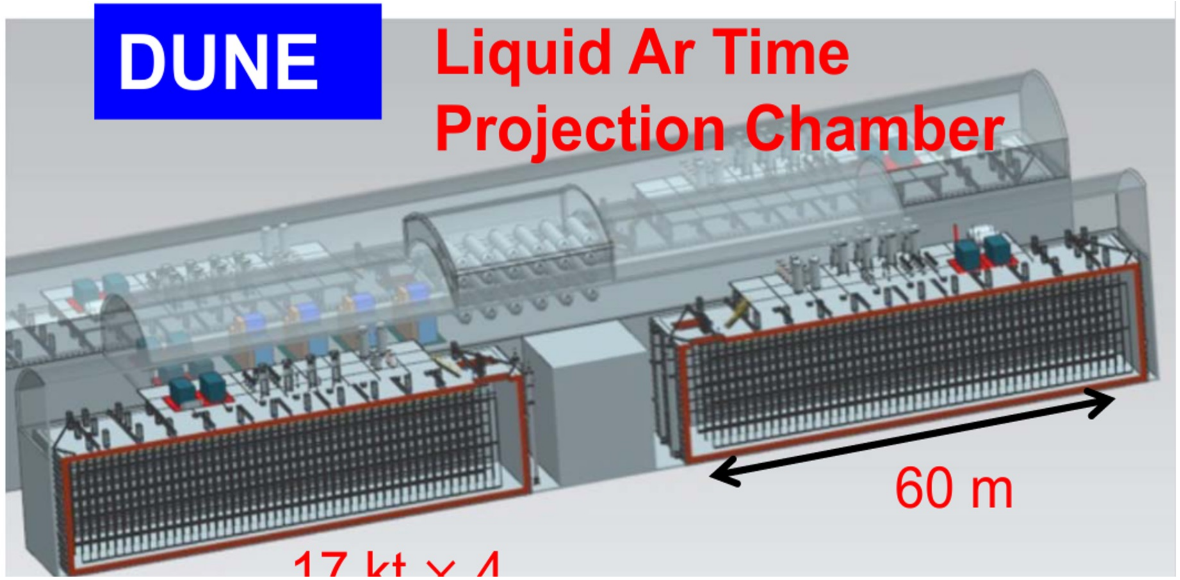
High intensity proton beam at JPARC (host KEK)

Accelerator, atmospheric, solar, supernova neutrinos and proton decay

1. **World largest detector for nucleon decay and neutrino experiment**
2. 8.4 times larger fiducial mass (190 kt) than Super-K with new photosensors: twice-as-sensitive 20'' PMTs and multi-PMTs
3. **World most intense neutrino beam**
4. 2.6 higher JPARC beam intensity (1.3 MW) than T2K
5. **New and upgraded near detectors to control systematics errors**

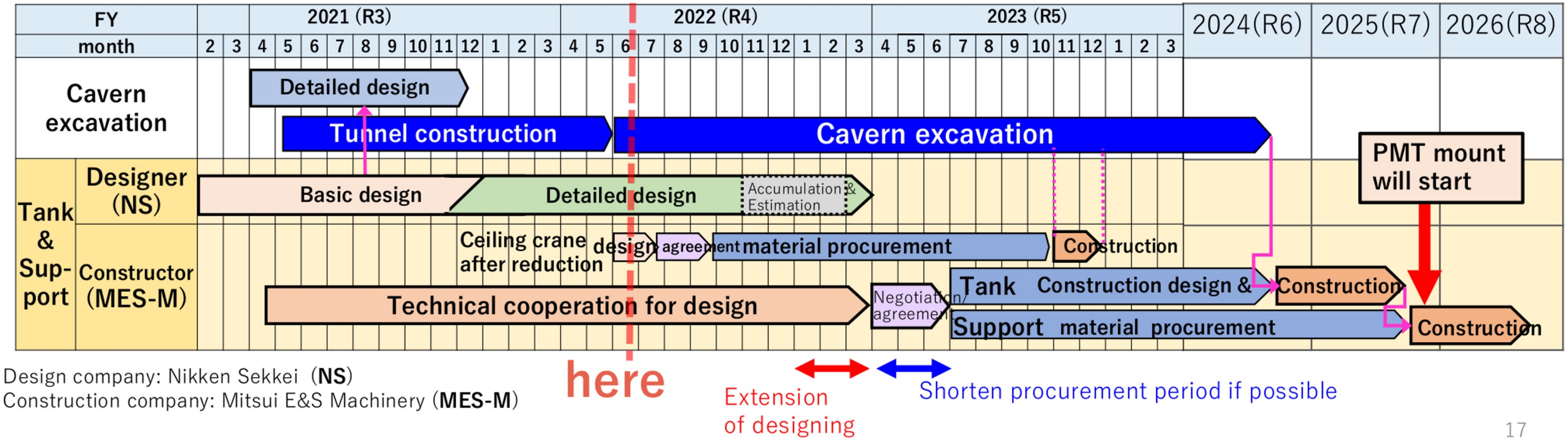
Hyper-Kamiokande vs DUNE





- Multipurpose experiments, similar goals, a different,complementary approach:
- Baselines and energy ranges: narrow band beam vs wide band beam
- Detector masses: fiducial 190 kton vs 20 (40) kton
- Detection process: at 10 MeV mainly IBD (antinue) vs CC (nue)
- Detector technology: water Cherenkov vs liquid Argon TPC

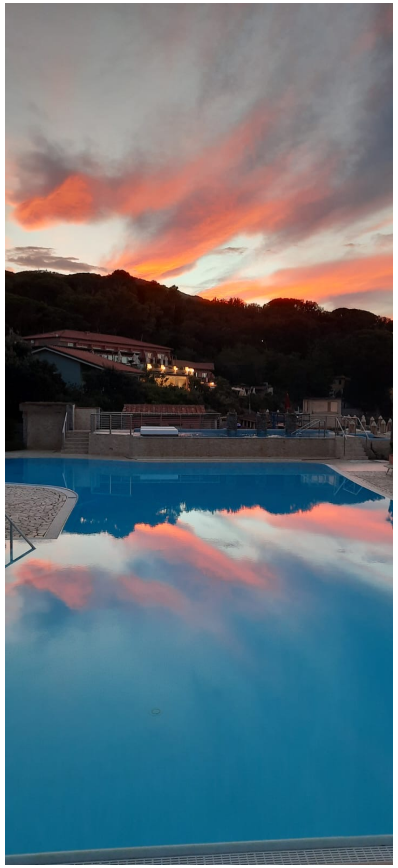
Hyper-Kamiokande timeline and INFN



- mPMT assembly start 04/2024
- Front-end prod. start 11/2024
- Installation start 11/2025
- Detector operation Q3/2027

- **Multi-PMT**
  - **Italy (project leader), Canada, Czech Rep., Messico, Polonia**
- **Electronics**
  - **Front-end 20'' (with France and Japan)**
  - **timing distribution (with LPNHE and IRFU/CEA)**
- **Near Detector**
  - **Construction (under way) of new TPC for T2K near detector upgrade (part of the near detector of Hyper-K)**

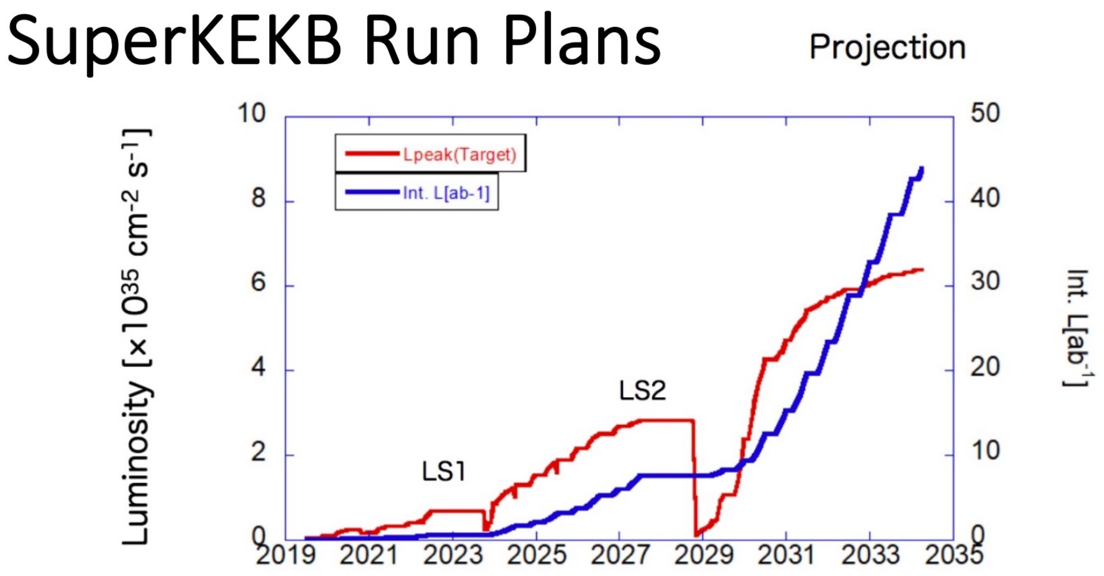
There is no summary … but a BIG THANKS to the Organizers for the excellent Workshop !!!



Additional Information

Belle 2 future upgrades

- SuperKEKB: new record of instantaneous luminosity (June '22): Lpeak = 4.7 1034 cm^{-2}s^{-1} 'crab waist scheme': 1300 mA (LER), 1040 mA (HER)
- Excellent performance of the detector, several publications and new results at ICHEP 2022
- Machine far from the target luminosity, long shutdown foreseen in 2026-7 (LS2) to upgrade final focus and for other interventions
- **LS2 in 2026-7 is an important opportunity for a detector upgrade that improves robustness (vs BKG) and performance**




Submitted to the Proceedings of the US Community Study on the Future of Particle Physics (Snowmass 2021)

Snowmass Whitepaper:
The Belle II Detector Upgrade Program

Belle II Collaboration

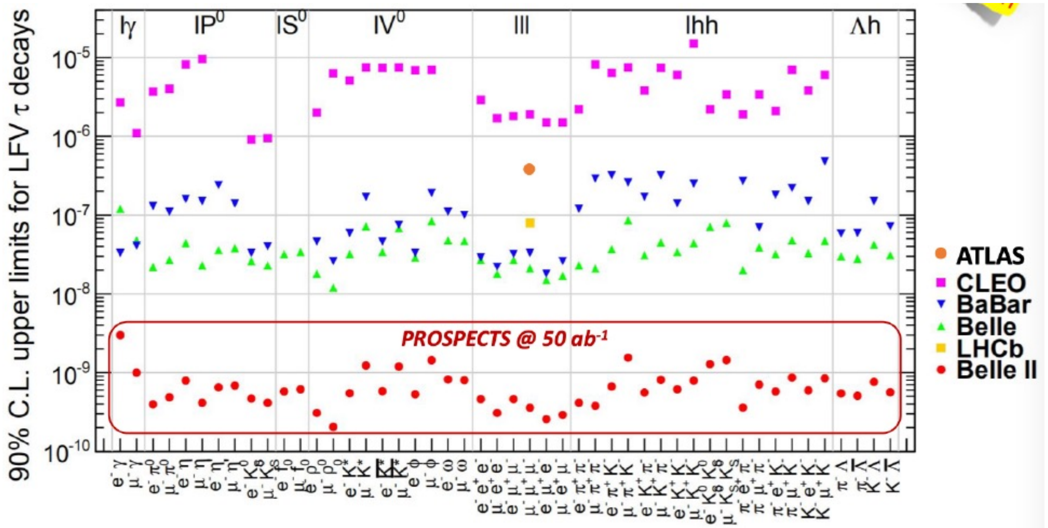
March 23, 2022

Abstract

We describe the planned near-term and potential longer-term upgrades of the Belle II detector at the SuperKEKB electron-positron collider in Tsukuba, Japan. These upgrades will allow increasingly sensitive searches for possible new physics beyond the Standard Model in flavor, tau, electroweak and dark sector physics that are both complementary to and competitive with the LHC and other experiments. We encourage the instrumentation-frontier community to contribute and study upgrade ideas as part of the Snowmass process.

arxiv:2203.11349

Example of physics case for tau physics



Belle 2 complementarity vs LHCb

	relevance	limitations	timeline	wrt LHCb
$\lvert V_{ub}\rvert$ and $\lvert V_{cb}\rvert$	Limits UT fit precision Help sorting out incl-vs-excl	Sistematics Lattice	pre-/post-LS1	Dominated by Belle II
R(D) and R(D*)	Anomaly	Sistematics	pre-/post-LS1	Dominated by Belle II
$B\to K^{(*)}\nu\nu$, $B\to K^{(*)}\tau\tau$, $B\to K^{(*)}\tau\nu$, $B\to\pi\pi$, $B\to\tau\ell$, $B\to\tau\nu$.	Sensitive to BSM related to $b\to s\,\ell\ell$	Sample size	pre-/post-LS1	Unique to Belle II
$B^0\to K^0\pi^0$: $B^0\to\pi^0\pi^0$, $B\to\rho\rho/\rho\pi$, $D^+\to\pi^+\pi^0$	Sensitive to BSM, CKM angle α check CPV in charm	Sample size	pre-/post-LS1	Unique to Belle II
Radiative	Sensitive to BSM	Sample size	pre-/post-LS1	Dominated by Belle II
Precision τ	Fundamental SM parameters Sensitive to BSM	Systematics/trigger	pre-/post-LS1	Unique to Belle II
Low-mass dark sector	Sensitive to BSM Related to muon g-2	Systematics/trigger	pre-/post-LS1	Unique to Belle II
$e^+e^-\to\pi^+\pi^-(\gamma)$	Key input to muon g-2	Systematics/trigger	pre-/post-LS1	Unique to Belle II
Spectroscopy/quarkonia	QCD and test LFU	Sample size Special runs	pre-/post-LS1	Unique to Belle II
Rare τ	Sensitive to BSM	Sample size	post-LS1	Dominated by Belle II
$B^0\to\eta' K^0$, $B^0\to\phi K^0_S$, $B^0\to K^0_S\pi^0\gamma$, $B^0\to\rho^0\gamma$	Sensitive to BSM	Sample size/syst	post-LS1	Unique to Belle II
R(K) and R(K*)	Anomaly	Sample size	post-LS1	Healthy redundancy
Angle γ	Fundamental SM parameter	Sample size	post-LS1	Healthy redundancy
Chiral Belle II	Fundamental SM parameter probe BSM	Sample size SKEKB upgrade	post-LS1	Unique to Belle II

NA62 and the future: HIKE

SPSC approved the extension of run NA62 until the end of LS3 (2021-2024)

- **BR($K^+ \rightarrow \pi^+ \nu\bar{\nu}$) with an error comparable to the theoretical one (O 10%)**
- Improvement of LNF and LNV decay limits
- Run in dump mode: 10^{17}, 10^{18} Proton On Target (10gg, 3mesi)

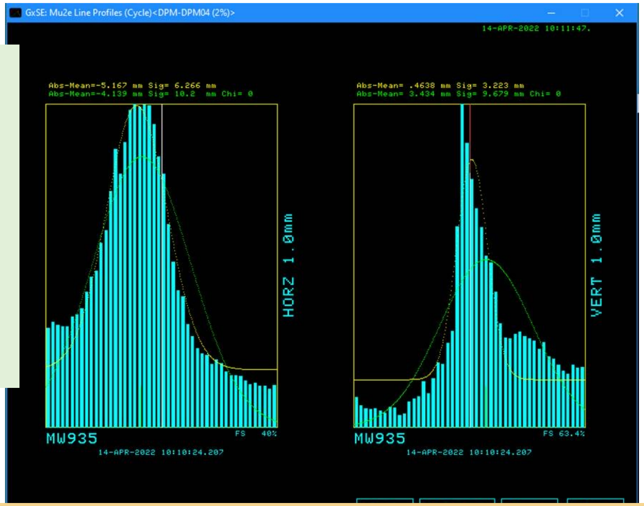
NP searches for MeV-GeV mass hidden-sector candidates: dark photons, heavy neutral leptons, Axions/ALP's, etc

HIKE, extensive multi-stage programme :

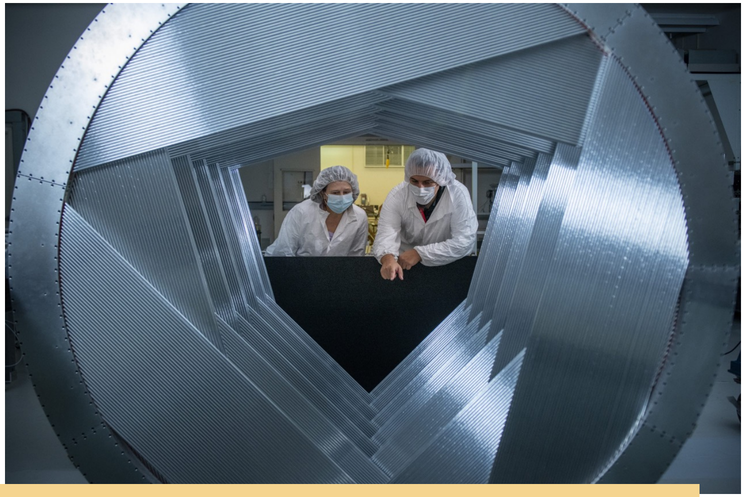
- K^+ with beam intensity 4x NA62 : 500 $K+ \rightarrow \pi+\nu\nu$ decays
- K_L with beam intensity 6x NA62: 60 $K_L \rightarrow \pi^0\nu\nu$ decays
- Intermediate phase : K_L beam, detector with tracking & PID, rare decays, Lepton-flavor violation, $K_L \rightarrow \pi^0 e^+ e^-$ .....
- Frequent runs in dump mode for exotics

Mu2e status 2022

Test of beam in **M4 delivery** beamline



Tracker planes

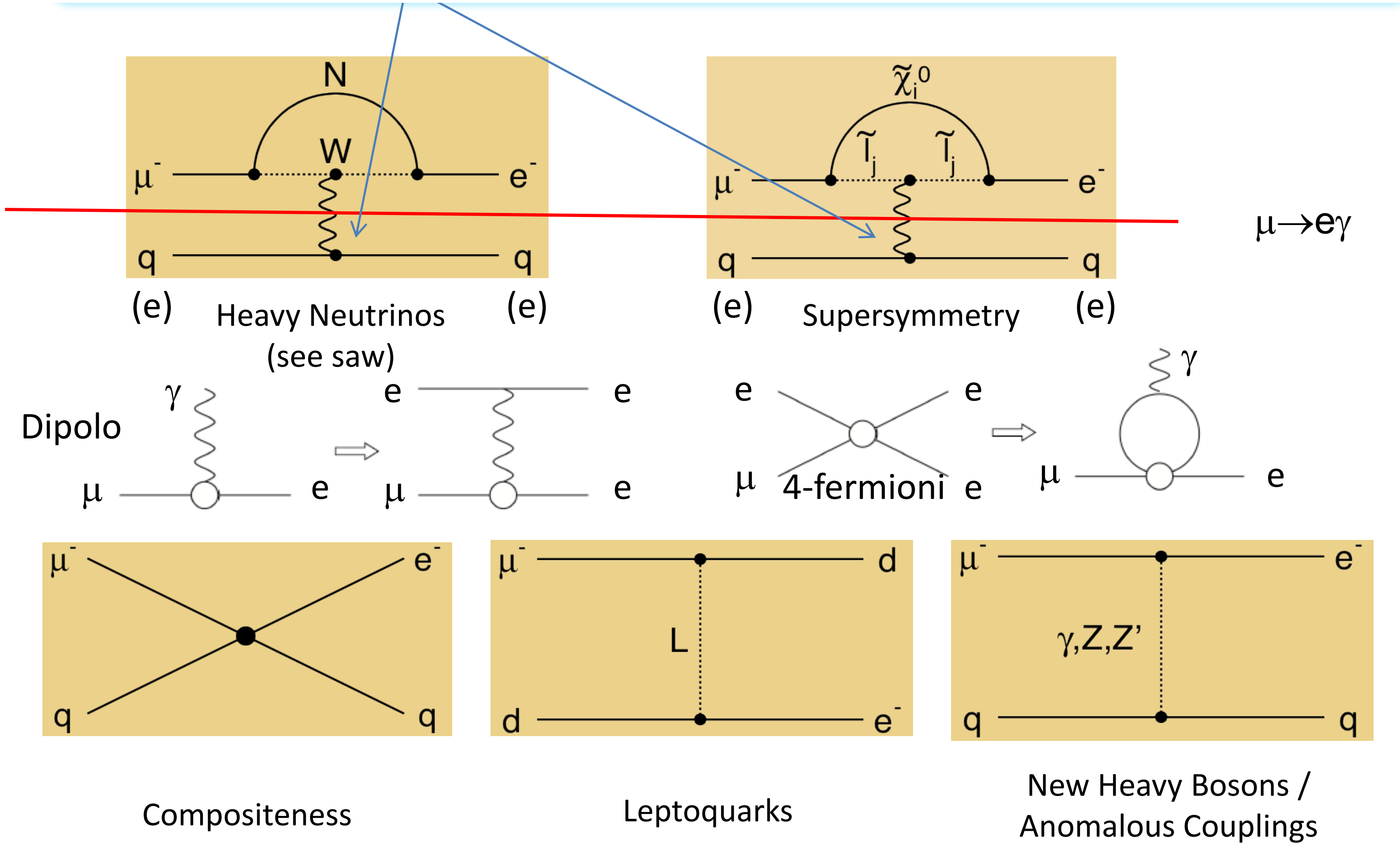


Mu2e progresses 2022: Critical path still driven by Solenoids +1.5 year Delay due to Covid → REBASELINED (Sept 2022)

- **Solenoids:** (GA) Winding of PS completed, DS is well progressed (ASG) - **TS-U + TS-D done**
- **Accelerator: first beam in M4 beamline, ESS under way, Production Target: done**
- **Tracker:** Panel assembly ~ completed in Minnesota. 220/240. **Plane construction underway O(50%)**
- **CRV:** Scintillators and SiPMs done. Module production reached 80%. FEE OK, readout in progress
- **Calorimeter:** Prod of 1500 CsI, 4000 SiPMs, 3500 FEE boards done. 2500 FEE tested, **800 at DUBNA**
  → Production of large mechanical parts completed, **Calorimeter assembly started at FNAL**
  → Digital boards well progressed. MB production started. DIRAC delayed to FPGA shortage in market
- **6 months of commissioning in the PIT end 2023 with calorimeter. Tracker and part of CRV end 2024**
- **2024-2025 is transition to operation. Commissioning inside the DS with magnet ON, Cooling at 0 °C**

$\mu \rightarrow e$ transitions, complementarity between MEG II / Mu2e

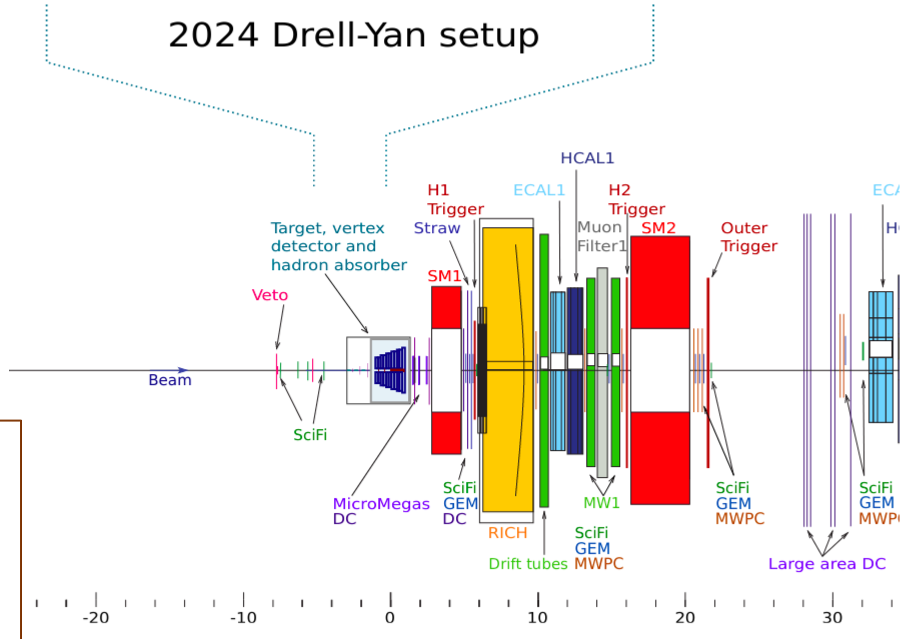
If dipole operators are involved MEG is better by $1/\alpha$, in other cases it's the other way around

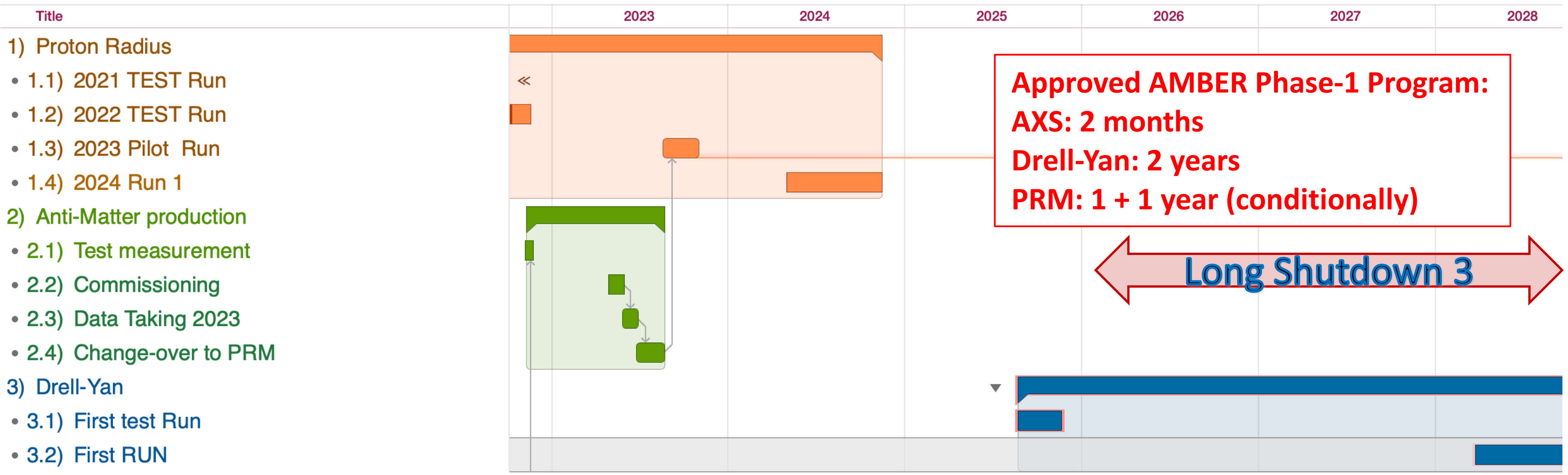


AMBER

Apparatus for Meson and Baryon Experimental Research

- Phase 1 (approved by SPSC)
  - Measurement of the proton radius
  - Production of antiprotons, antideuterion, antihelium
  - Measurement of pion structure using Drell-Yan as a probe
- Phase 2 (not approved, yet)
  - dedicated to negative kaon beams and high-intensity antiprotons



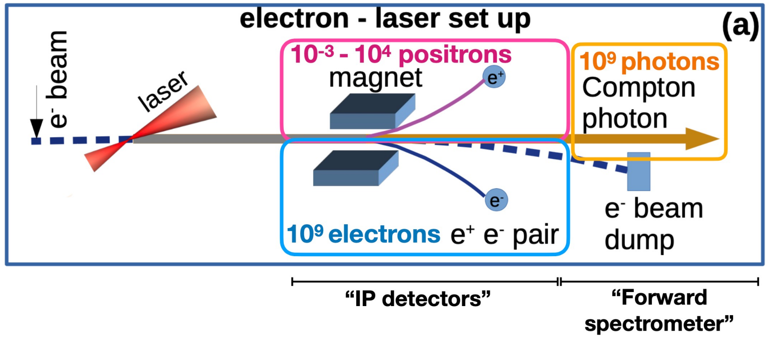


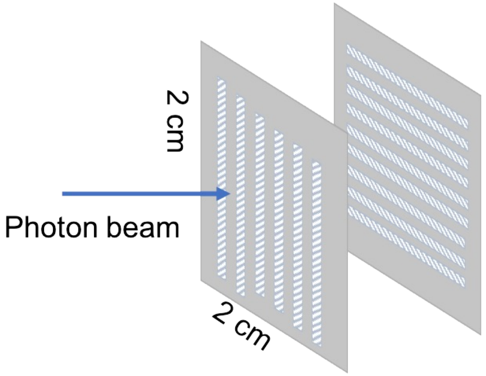
Drell-Yan process is a low cross-section process:

- High intensity hadron beam
- Hadron absorber to protect Spectrometer from a very high secondary flux
- Vertex Detector to compensate loses in resolution because of the absorber in order to improve mass and space resolution

Luxe at the DESY Eu.XFEL

- XFEL and high-power LASER electron beam collisions
  - Investigating QED in regimes beyond the Schwinger limit by XFEL electron scattering on photons from a very high power laser (100 TW)..
- Collabotion 90 members (26 institutes)
- INFN grups: Bologna, Padova
- INFN proposed contribution : beam profile measurement with a detector made with strips on sapphire

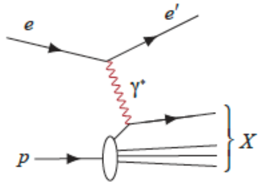


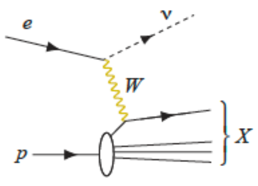


Thickness: 0.1 mm
Pitch: 0.1 mm
200+200 Readout channels

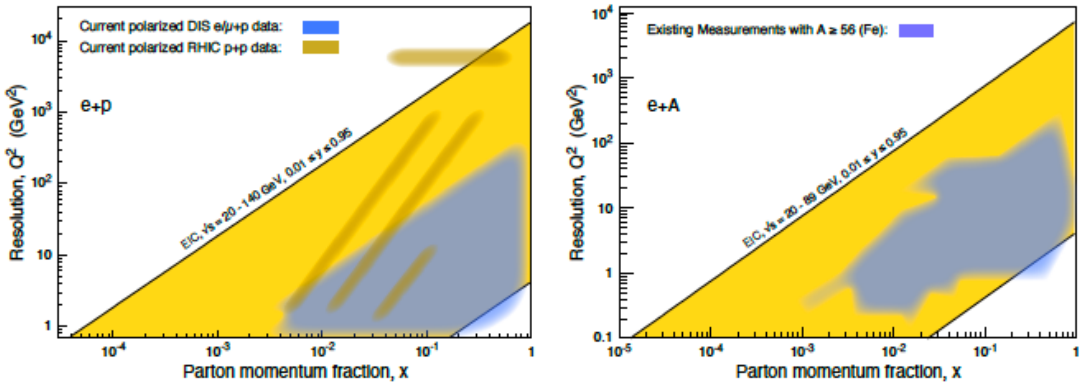
		2021				2022				2023				2024				2025				2026			
		Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Photon Profiler	Procure detector prototypes and test																								
	Test beam at ELBE/FRASCATI/XFEL																								
	LUBPRO design, production																								
	Movable support mechanics design, production																								
	Detector installation/commissioning																								
	Detector ready for data-taking																								

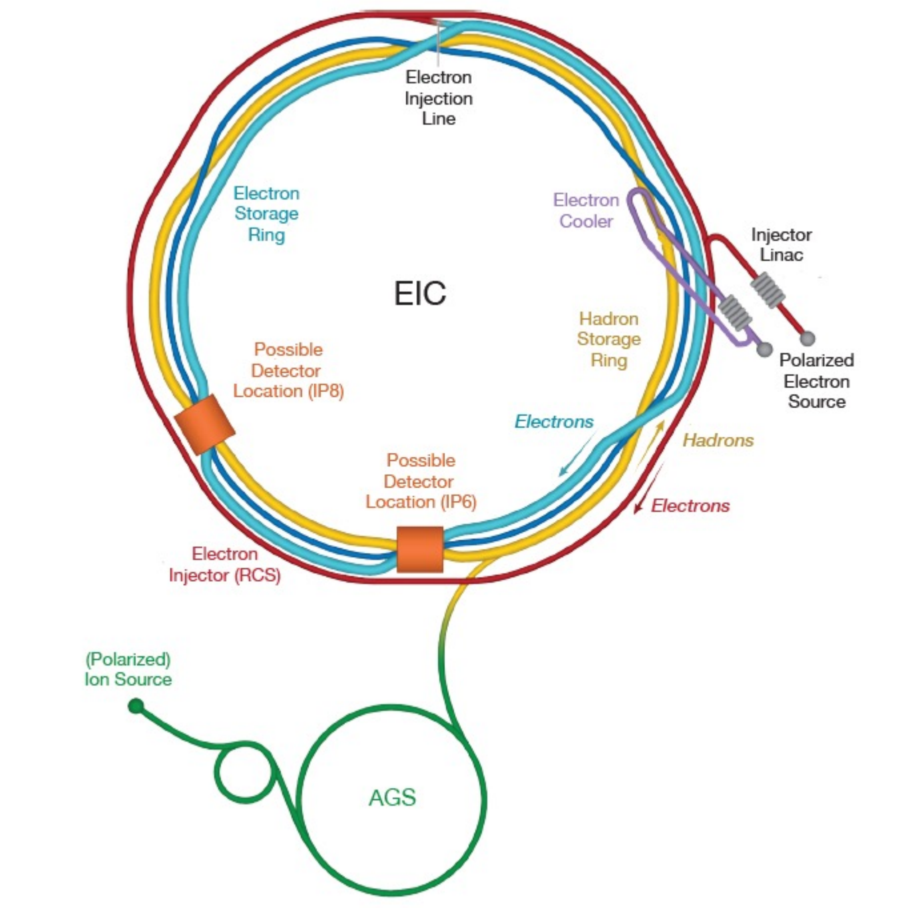
EIC: Electron Ion Collider





- Highly polarized electron (~70%) and proton (~70%) beams
- Ion beams from deuterons to heavy nuclei such as gold, lead, or uranium
- Variable $e+p$ center-of-mass energies from 20–100 GeV, upgradable to 140 GeV
- High collision electron-nucleon luminosity 10^{33}–10^{34} $\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$





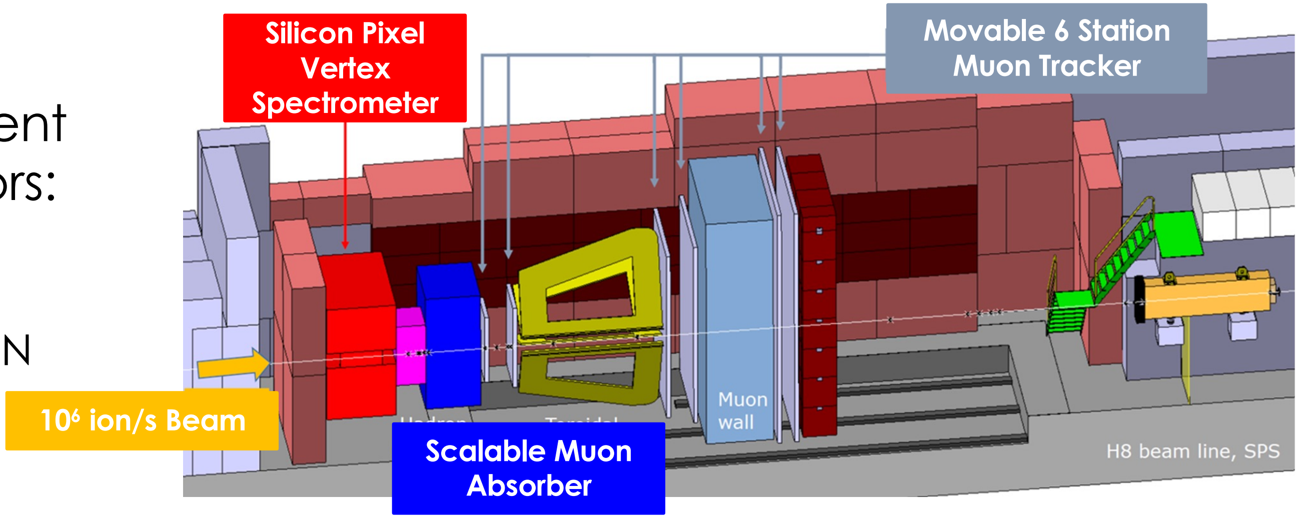
NA60+: current status and timeline

Schematic detector layout for $\sqrt{s_{NN}}=6\ \mathrm{GeV}$ at North hall H8 beamline

Letter of Intent Collaborators:

CERN
Italy – Uni./INFN
  Cagliari
  Padova
  Torino
US
  Rice
  Stony Brook
  TAMU
Israel
  Weizmann Inst.

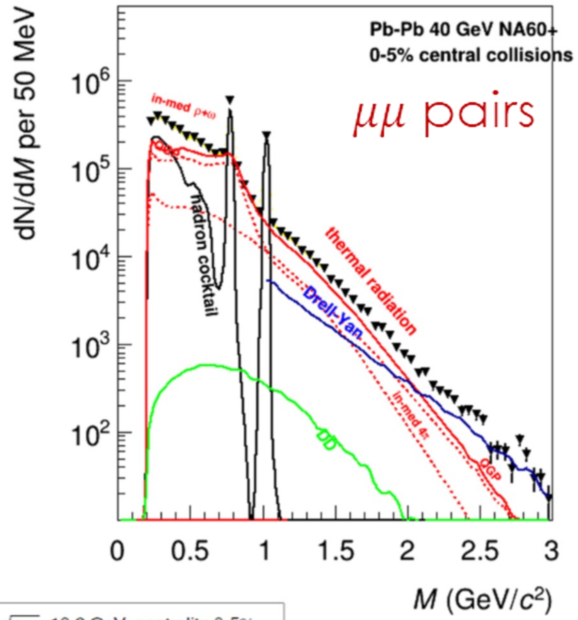
Additional interested Institutions in France, Germany, and India

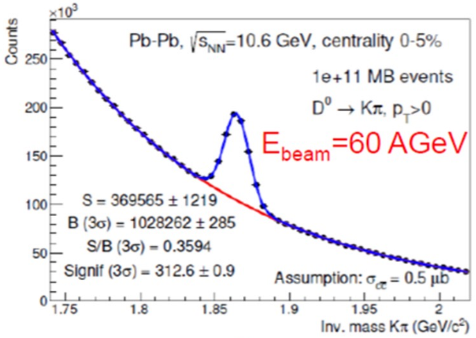


Timeline

- Expression of Interest 2019
  - Technical support from CERN
  - Location identified
- Letter of Intent 2022 (in preparation)
- Planned data taking starting 2029
  - 1 month/year
  - 5-6 years

Advanced performance studies

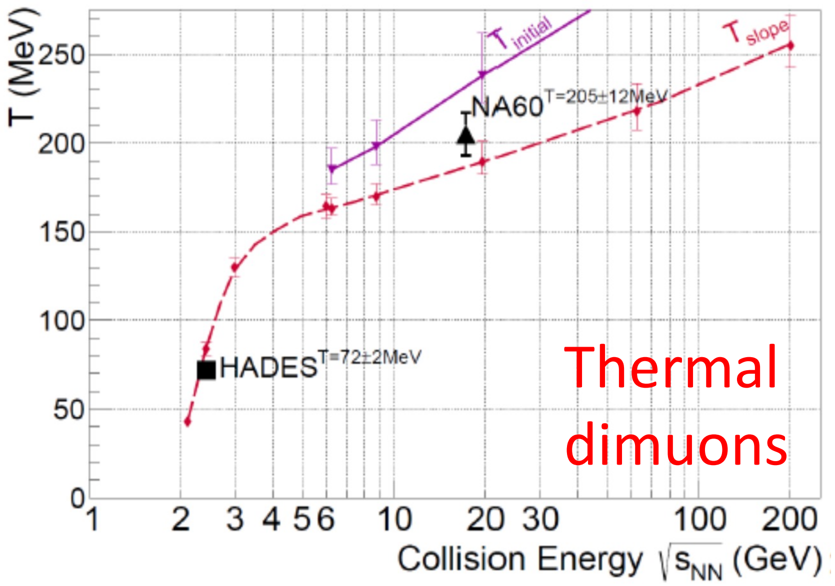


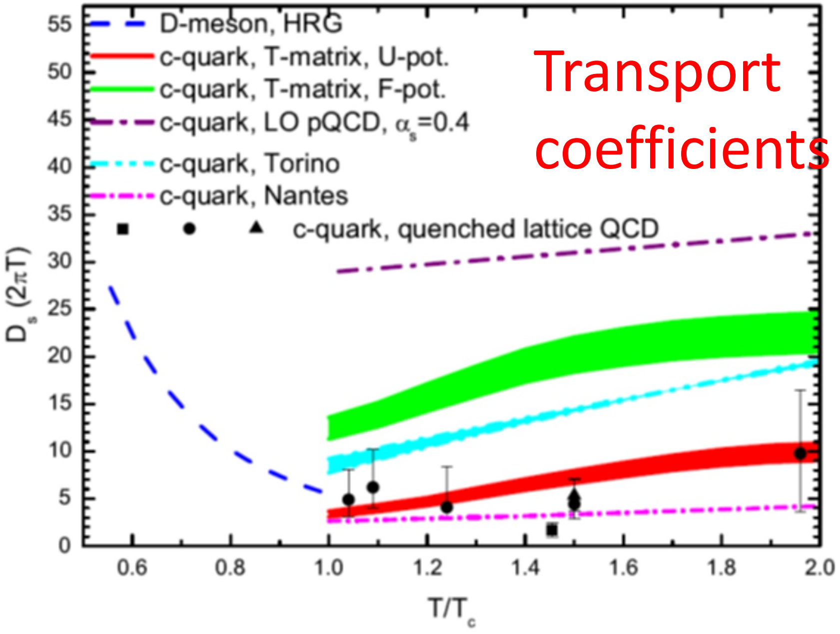


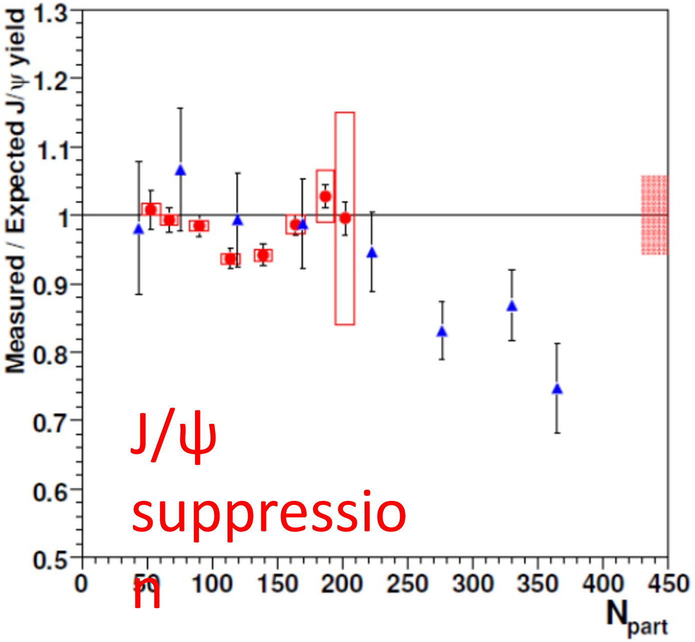
$D^0 \to K\pi$

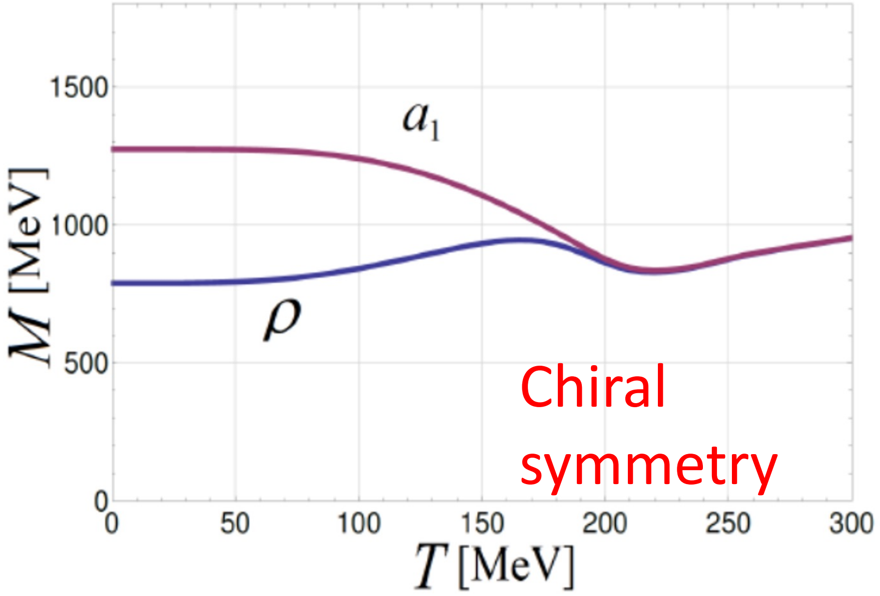
NA60+: physics case

- Four main “pillars”
  - Thermal dimuons from QGP/hadronic phase: caloric curve
  - ρ-a_1 modifications: chiral symmetry restoration
  - Quarkonium suppression: signal of deconfinement
  - Open charm mesons/baryons: QGP transport coefficients





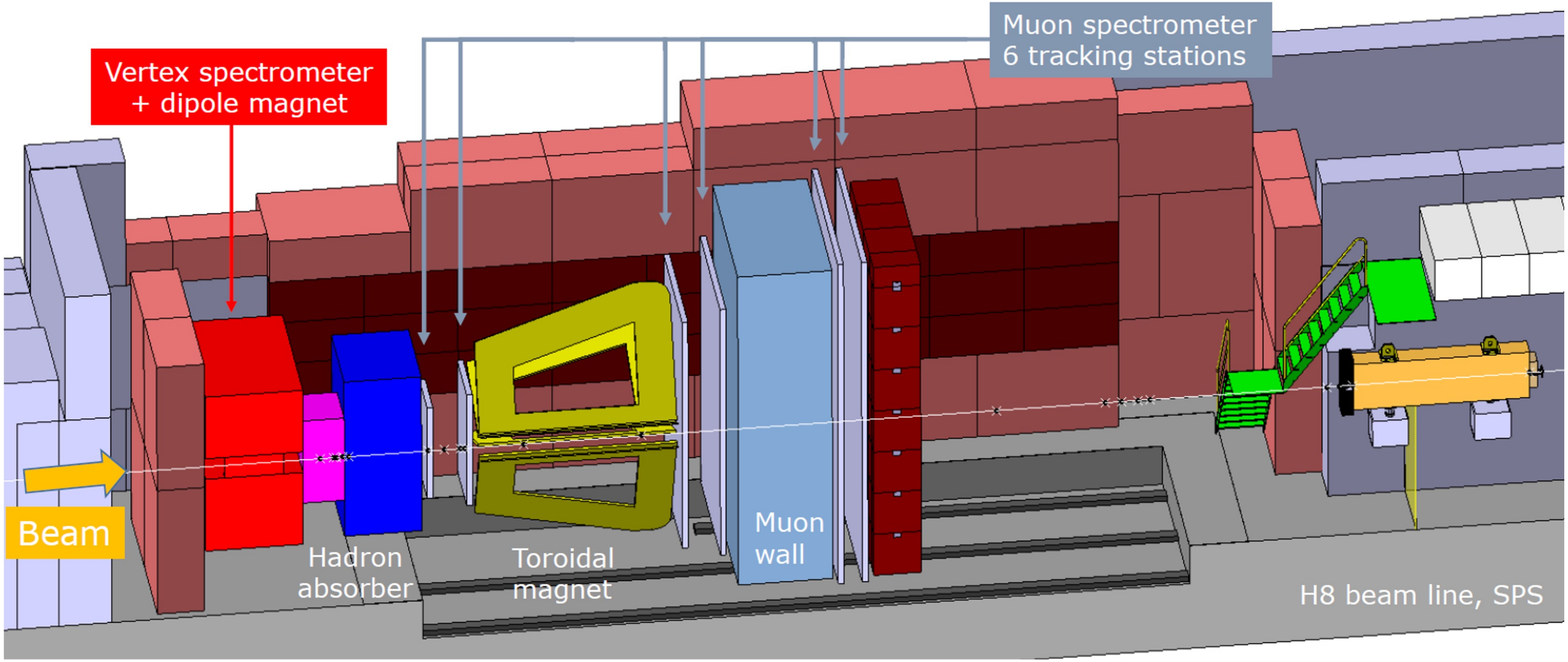




No accurate data exist for any of these observables below top SPS energy

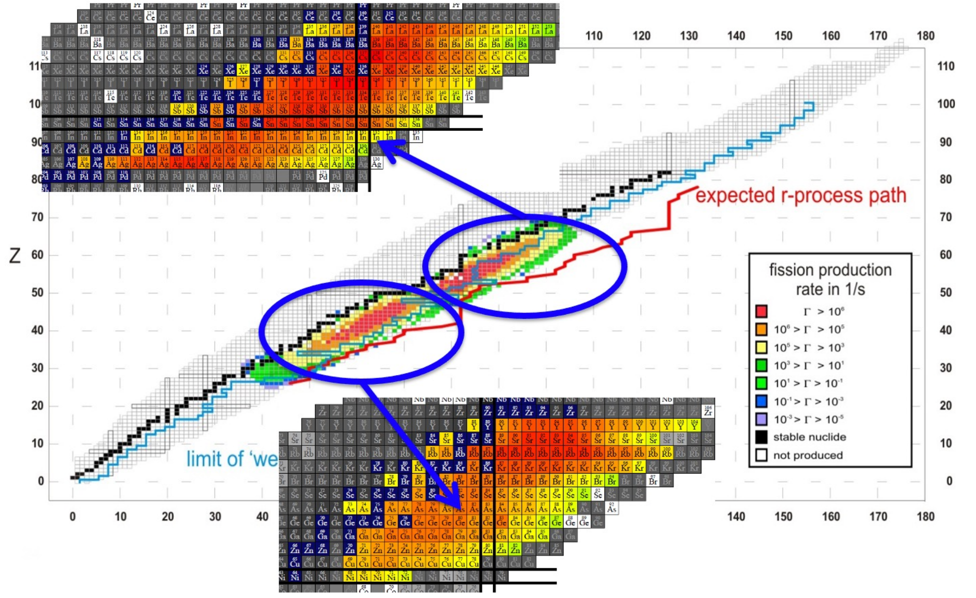
NA60+: overview

- Aim: perform accurate measurements of the dimuon spectrum from threshold up to the charmonium mass region, and of hadronic decays of charm and strange hadrons
- Energy scan with a Pb beam from top SPS energy ($\sqrt{s_{NN}}$=17 GeV) down to $\sqrt{s_{NN}}$~ 6 GeV (E_{lab}~20 A GeV)
- Based on a muon spectrometer (toroid field) coupled to a vertex spectrometer (dipole field)
- High luminosity is an essential requirement →10^6 s^{-1} Pb ions/s

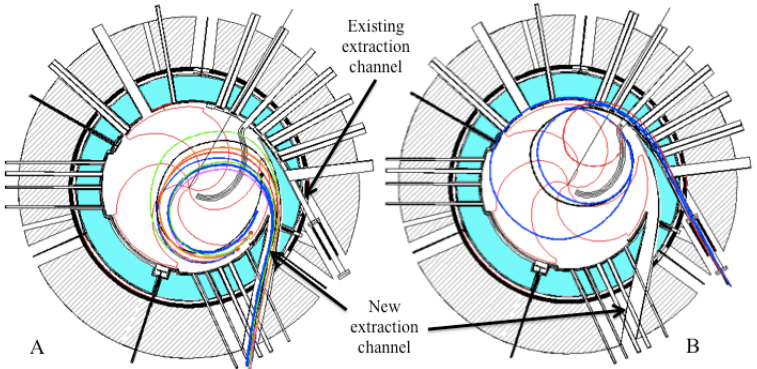


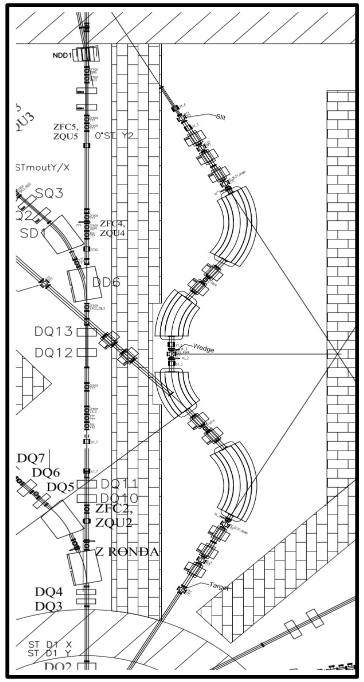
LNL and LNS upgrades open new perspectives

40 MeV - 200 µA of protons → production of re-accelerated neutron-rich exotic beams **10^{13} fission/s in-target production, and re-acceleration at 10*A MeV (A=132)**



Superconductive cyclotron: new extraction channel by stripping. For light ions up to A~40 intensities up to ~10^{14}pps (5 - 10 kW on target) → new physics cases





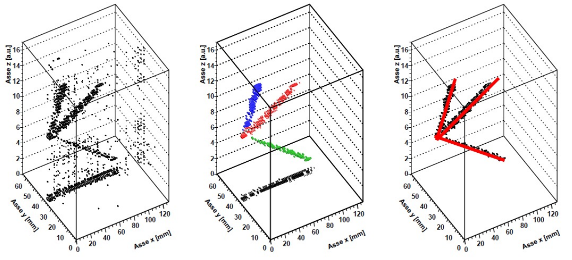
High-intensity RIBS with FRAISE

Production in-flight → complementarity with SPES in terms of energies, species and lifetimes

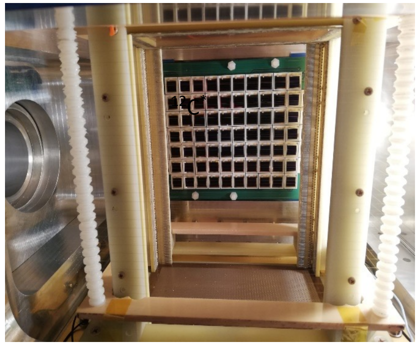
Intensities up to 10^8 pps with high purity

… and will host new and upgrades facilities for new physics

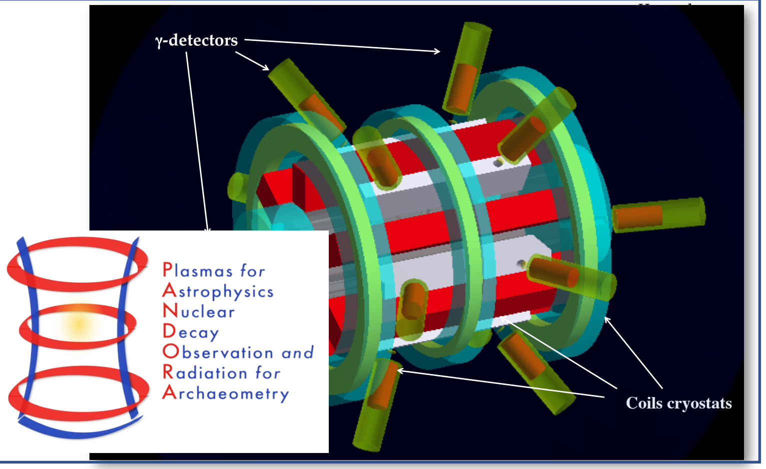
Active Target (ATS): aims at building a gas detector to measure transfer reactions. The ATS is at the same time the target and the detector and will be used with SPES beams



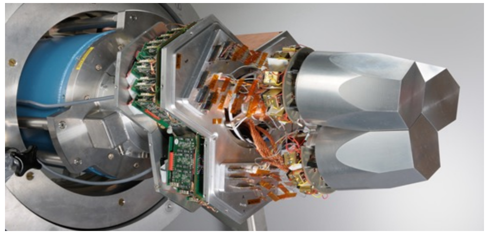
$^{11}B+iC_4H_{10}$ at 32 MeV
3 particles emitted and stopped in the gas.



PANDORA aims at building an innovative magnetic plasma trap, for interdisciplinary and fundamental research, the study of β-decays under astrophysical conditions



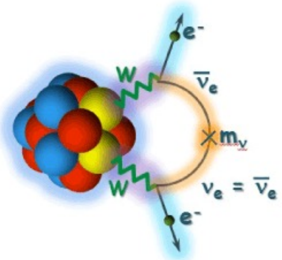
AGATA: highly segmented germanium gamma-ray tracking array. Currently the most advanced gamma-array in Europe at LNL for a campaign with stable and SPES beams. Ongoing development to produce p-type detectors (call N3G).



AGATA coupled to the magnetic spectrometer PRISMA

MAGNEX is under upgrade for allowing the extraction of *"data-driven"* information on Nuclear Matrix Elements for all the systems candidate for 0νββ. For the use with high intensity beams a new focal plane detector, a new gas tracker and a LaBr3 calorimeter will be installed

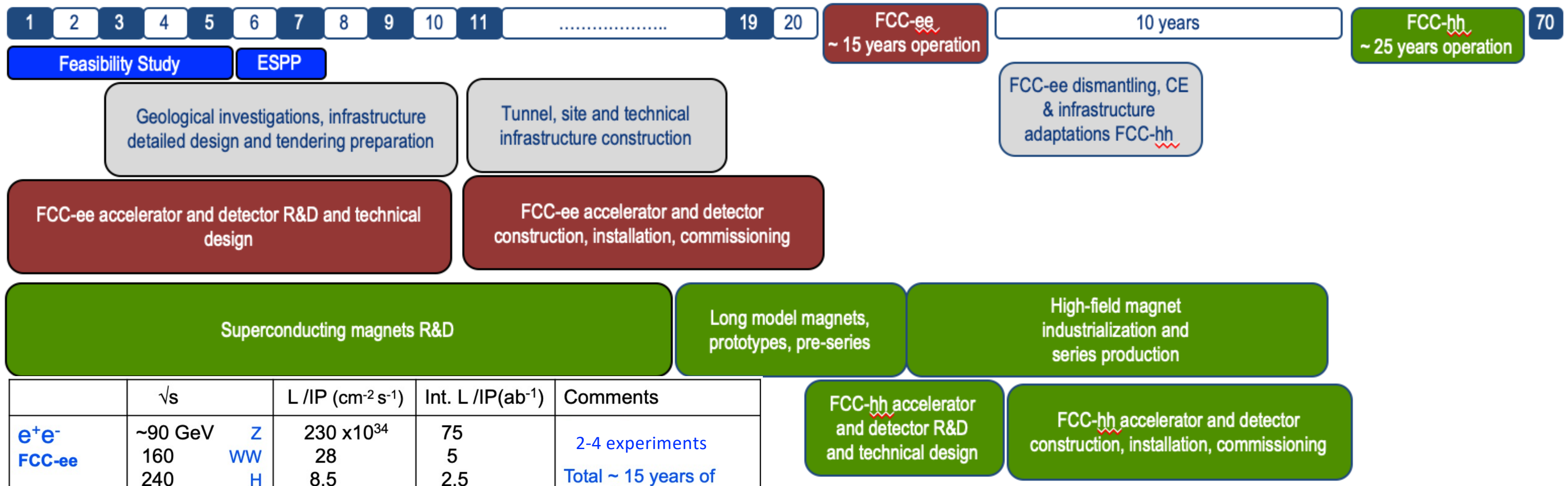
NUMEN



Timeline of the FCC integrated programme

FUTURE CIRCULAR COLLIDER

Technical schedule



	$\sqrt{s}$	L /IP ($cm^{-2} s^{-1}$)	Int. L /IP(ab^{-1})	Comments
e^+e^- FCC-ee	~90 GeV Z 160 WW 240 H ~365 top	230 $\times 10^{34}$ 28 8.5 1.5	75 5 2.5 0.8	2-4 experiments Total ~ 15 years of operation
pp FCC-hh	100 TeV	5 $\times 10^{34}$ 30	20-30	2+2 experiments Total ~ 25 years of operation
PbPb FCC-hh	$\sqrt{s_{NN}}$ = 39TeV	3 x 10^{29}	100 nb^{-1}/run	1 run = 1 month operation
ep Fcc-eh	3.5 TeV	1.5 10^{34}	2 ab^{-1}	60 GeV e- from ERL Concurrent operation with pp for ~ 20 years
e-Pb Fcc-eh	$\sqrt{s_{eN}}$ = 2.2 TeV	0.5 10^{34}	1 fb^{-1}	60 GeV e- from ERL Concurrent operation with PbPb

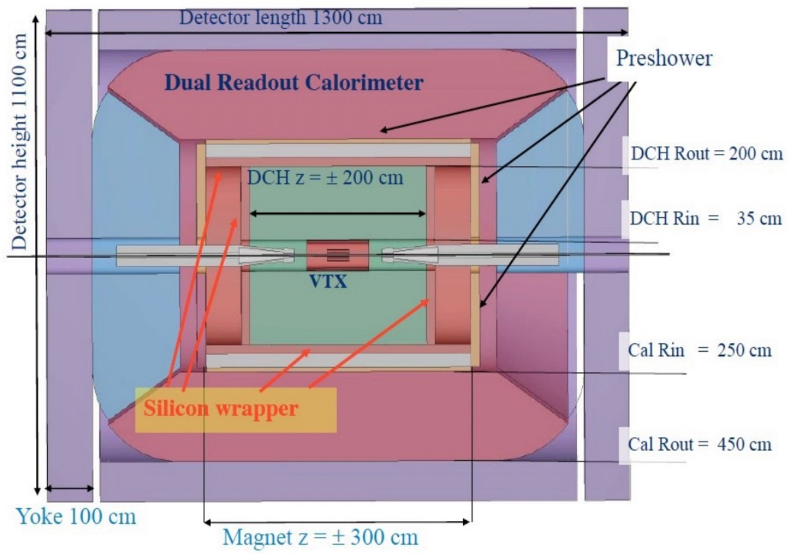
F. Gianotti

- ❑ Feasibility Study: 2021-2025
- ❑ If project approved before end of decade → construction can start beginning 2030s
- ❑ FCC-ee operation ~2045-2060
- ❑ FCC-hh operation 2070-2090++

CSN1: RD_FCC

105 scientists/15.3 FTE

- IDEA detector: light tracker (Drift Chamber) , a dual-readout calorimeter, and a light-weight magnet.
  - Baseline for physics/performance studies and technology exploration.
  - Test-beams in progress
- Machine-Detector-Interface
- Activities in simulation/software
  - Algorithm development:jet flavour tagging, Particle ID, tau reconstruction
  - Physics studies: Higgs Recoil, Flavor, A_{FB}(bb,cc), ALPS, Top



https://agenda.infn.it/e/FCC-Italy