CERN Programme & Plans

KfB-Verbundforschungsworkshop
"Teilchen 2027-2030"

13 Mai 2026

Frank Tecker

Material from Mark Thompson

and Oliver Brüning

Content

- CERN Strategy and Priorities 2026-2030
  - HL-LHC
  - FCC-ee
  - Long Shutdown LS3
- Some examples for technology R&D plans

CERN Strategy and Priorities for 2026-2030

Strongly based on European Strategy for Particle Physics

Five Pillars

The CERN strategy is structured around five strategic pillars

- Global leadership in **accelerator science and technology**
- Cutting-edge **research** at the forefront of knowledge
- Delivering **value for CERN's stakeholders**
- Wider societal **impact**
- **Organisational excellence**

The Scientific Strategy is dominated by HL-LHC (machine and detectors) and FCC-ee

- the clear priorities identified in the European Strategy for Particle Physics

ESG Main Recommendations

slide from Karl Jacobs

General Recommendations

i. *The **full exploitation of the physics potential of the LHC and the HL-LHC and the completion of the high-luminosity upgrade remain the highest priorities** of European particle physics.*
Every effort must be made to complete the HL-LHC upgrade within the current schedule.

CERN's new strategy is entirely aligned with Recommendation i)

- **HL-LHC machine and detectors are CERN's highest priorities**
- **Full exploitation of HL-LHC including LHCb and ALICE upgrades**
- **Importance of maintaining the current schedule**

The importance of the HL-LHC

The LHC has been an outstanding scientific success

- A unique machine that has outperformed all expectations!
- Higgs discovery
- Well over 4000 papers from ALICE + ATLAS + CMS + LHCb

We are now ready to take the next steps with the High-Luminosity LHC and the major upgrades of ATLAS and CMS

- Greater than a factor five more data than the LHC and almost a factor 10 more than has been currently analysed by ATLAS and CMS
- We will have much more capable detectors
- The particle physics community is doing a great job of improving analysis techniques using AI

This will be a massive step forward; we are just at the start of the LHC journey

- Much more data, better detectors, advances in analysis

HL-LHC will be incredibly exciting – with real discovery potential

HL-LHC: let us not forget

The construction of the HL-LHC and the ATLAS/CMS upgrades will dominate the next five years at CERN

- Long Shutdown 3 (LS3) for the LHC commences on 30 June 2026
- The plan and **clear intent** is to be commissioning the machine and detectors in 2030

This is a major task

- The HL-LHC installation will be the largest project undertaken by CERN in around 20 years
- The Phase 2 detector upgrades, are the largest projects undertaken by ATLAS and CMS since the construction of the original detectors

The HL-LHC *and* the detector upgrades represent *by far* the highest priority for CERN in the coming years

- Meeting the current schedule, which is our intention, will require **laser focus**
- Accordingly, CERN will prioritise resources to maximize the likelihood of success

HL-LHC and the Phase 2 upgrades are CERN’s highest priority

Recommendations on next collider at CERN

I. The *next CERN flagship collider project*

i. *The electron–positron Future Circular Collider (FCC-ee) is recommended as the preferred option for the next flagship collider at CERN.*

ii. *A descoped FCC-ee is the preferred alternative option for the next flagship collider at CERN*

At this stage, without knowing the reasons for which the FCC-ee would not be feasible, other alternative options are not ranked.

slide from Karl Jacobs

Strategy for FCC-ee

From the European Strategy Group (ESG) report:

- **Strong endorsement of the physics and strategic case for FCC-ee as CERN's next flagship collider**
  - Near consensus within the particle physics communities in CERN's Member States
- **A descoped/staged FCC-ee was considered as the best possible alternative**
  - The choice of a descoped/stage FCC-ee as the best alternative reflects the large scientific and strategic gap with respect to other options

The CERN Strategy 2026-2030 aims to deliver the ESPP main recommendations

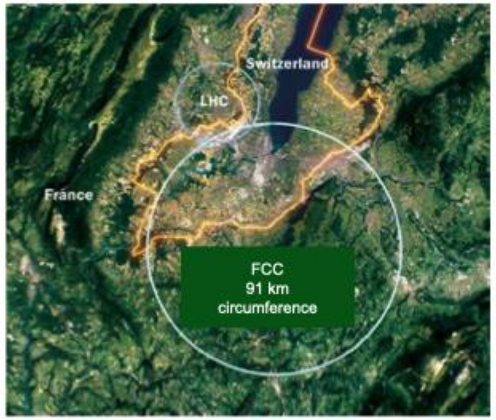
- **FCC-ee is the priority for CERN's next Flagship Collider**
  - It represents a remarkable scientific opportunity and would retain European scientific leadership in particle physics with the associated technological benefits
- We aim to be in a position for CERN Council to take a decision *from* June 2028
  - We will be looking for a "go" / "no-go" decision on FCC-ee

Proposed large-scale projects at CERN, ~ 2045

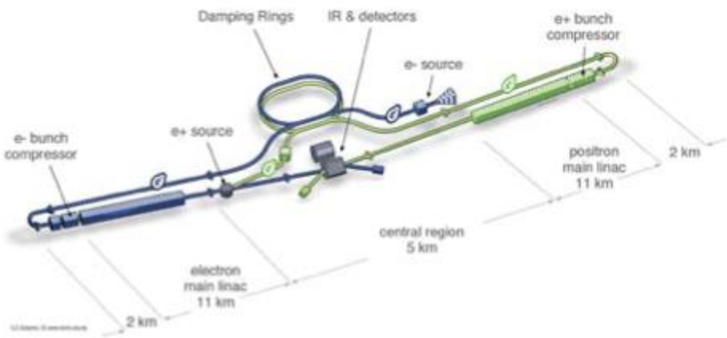
e^+e^- colliders
("Higgs factories")

FCC-ee clearly identified as THE preferred option in the ESPP update process!

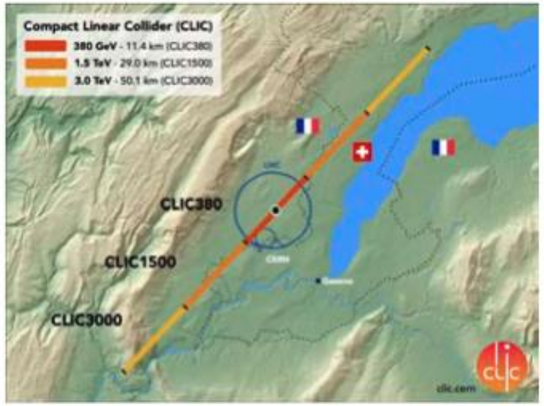
FCC-ee (e^+e^-, circular, 91 – 365 GeV)



LCF (e^+e^-, linear, 91 – 240, 550 GeV)



CLIC (e^+e^-, linear, 380 GeV, 1.5 TeV)



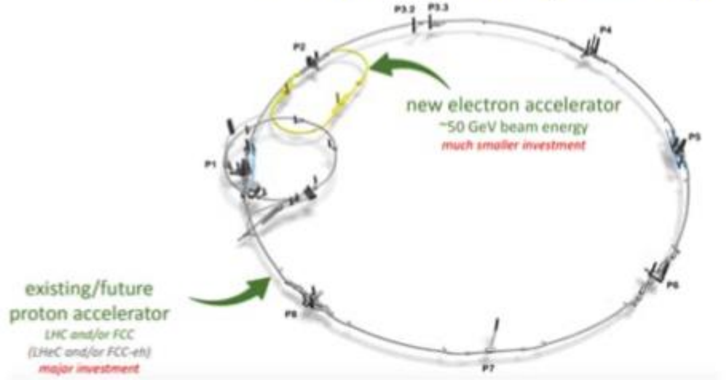
Intermediate projects

(Leave room (time, budget, resources) for further development of THE machine that can probe directly the energy frontier at the 10 TeV parton scale)

The focus is FCC, but some other projects should also be studied to prepare CERN for case that FCC timescale or cost turn out to be challanging

LEP3 (e^+e^-, circular, 91 – 230 GeV)

LHeC (ep, circular, electron ERL, 50 GeV e^-, > 1 TeV ep collisions)



K. Jakobs, EPS-HEP Conference, Marseille, 10th July 2025

Potential for development: future 10 TeV parton-scale collider options

FCC-ee

LEP3

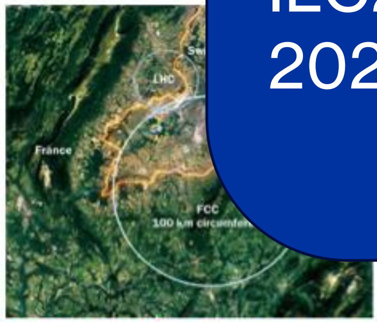
LHeC

LCF, CLIC

Next Steps:

Council discussion in June 2026

→ Likely for CERN to follow as Plan B studies LEP3 and ILC250 in preparation for an FCC-ee decision by 2028/2029



FCC-hh,
baseline 85 TeV (→ 120 TeV)
+ possibility for HI collisions

Muon Collider (3, 10 TeV)

R&D

e^+e^- with improved acceleration technologies
LCF, C^3 (→ 1 TeV), CLIC (1.5 TeV), HALHF, …
→ plasma acceleration for higher energies
(can $\mathcal{O}(10)$ TeV be reached? on what timesca

K. Jakobs, EPS-HEP Conference, Marseille, 10th July 2025

Pillar 1: Global leadership in accelerator science and technology

Main priorities

- **Completion of the HL-LHC with commissioning in 2030**
  - This is the top priority by far and this degree of priority is being reflected in our financial and personnel planning
  - Colleagues in ATS are developing a globally resource-loaded plan for all activities within LS3, with break points for non-HL-LHC activities that could be delayed to maintain the HL-LHC schedule
  - Given the commitment to complete the HL-LHC in 2030, the MTP will now include contingency for HL-LHC. **This will be needed to maintain the schedule**
- **Bringing the FCC-ee to a decision point in 2028**
  - **FCC-ee** is the highest long-term priority – some additional background in next few slides
- **Consolidation of CERN's injector complex**
  - With a view to the long-term PS and SPS based non-collider physics programmes, e.g. NA-CONS
  - Our aim is to complete the planned programme, but may need to adapt according to wider priorities

Pillar 2: Cutting-edge research

Main priorities

- **Completion of the ATLAS and CMS upgrades by 2030**
  - Alongside the HL-LHC, this is the top priority
  - CERN will strengthen the host-laboratory programme to maximise the likelihood of success, including the **creation of additional CERN "LS3 upgrade" project posts** in ATLAS and CMS Technical Coordination and dedicated engineering support for ATLAS and CMS
- **Fully exploit the HL-LHC**
  - Progress the TDRs of the LS4 ALICE and LHCb upgrades and associated funding model
  - Need a plan compatible with the current LS4 schedule (2034-2035) and available funding
- **Evolve the computing for the HL-LHC operation**
  - Working with the LHC collaborations and the WLCG to evolve the computing model for HL-LHC operation within the likely available resources
  - Increase adoption of next-generation computing technologies

Pillar 2: Cutting-edge research

The non-collider physics programme at CERN

- An essential part of the attractiveness of the laboratory and its scientific output
- Supports a large scientific user community of ~3,000 users
- The Physics Beyond Colliders programme has developed ideas for options for new projects, using CERN's unique infrastructure
- And potential future developments elsewhere: ISOLDE, AD/ELENA, AICE, …

Main priorities for non-collider physics at CERN

- **Develop a long-term roadmap for non-collider physics at CERN**
  - Embed a long-term view in the MTP
  - Prioritise potential new experimental activities taking a holistic view
    - **this work has already started**
  - SHiP remains a scientific priority, but we now need to have clarity on the scope, schedule and funding model

Pillar 3: Delivering value for CERN's stakeholders

Main priorities:

- **Improve the balance of return to CERN's Member States**
  - At a time when we will soon be seeking approval for FCC-ee, **this is absolutely essential, we will need the strong support from all of our Member States.** Aiming at better balance in both "industrial return" and "personnel return"
  - To this end, we have already strengthened the Member and Associate Member State Relations office at CERN
    - We need strong working partnerships with our Member States

What lies ahead of us:
Key Challenges for the Coming 5 years

- Finishing successfully the LHC Run3 in 2026

The LHC is running beautifully

Low pile-up runs for ATLAS (μ=3) and CMS (μ=5) are ahead of schedule – will benefit the precise measurement of W mass

And very long fills are good news for LHCb

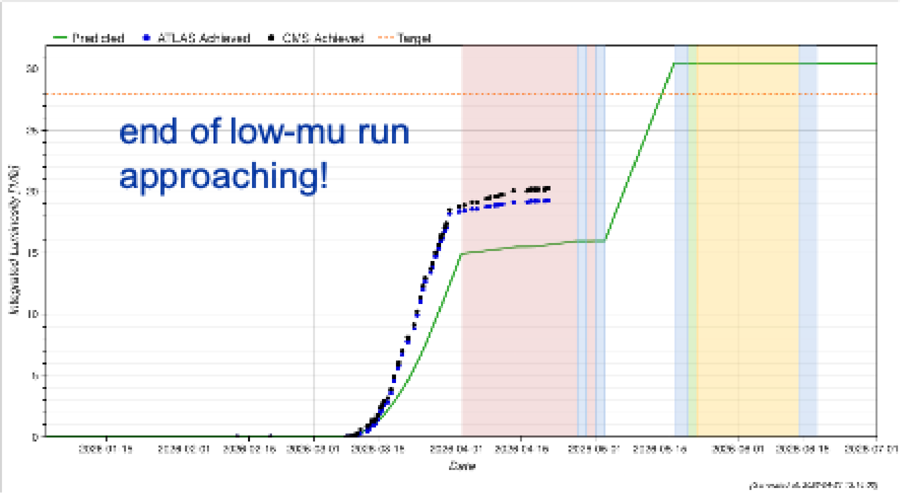
Performance targets (likely to be exceeded):

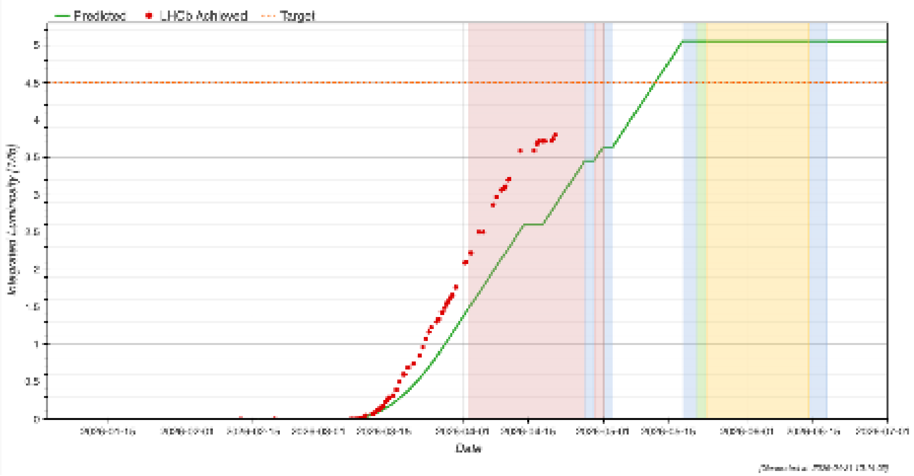
p-p

- ATLAS/CMS: 28 fb^{-1}
- LHCb: 4.5 fb^{-1}
- ALICE: 28 nb^{-1}

Pb-Pb

- ATLAS/CMS: 1.8 nb^{-1}
- LHCb: 0.6 nb^{-1}
- ALICE: 1.3 nb^{-1}

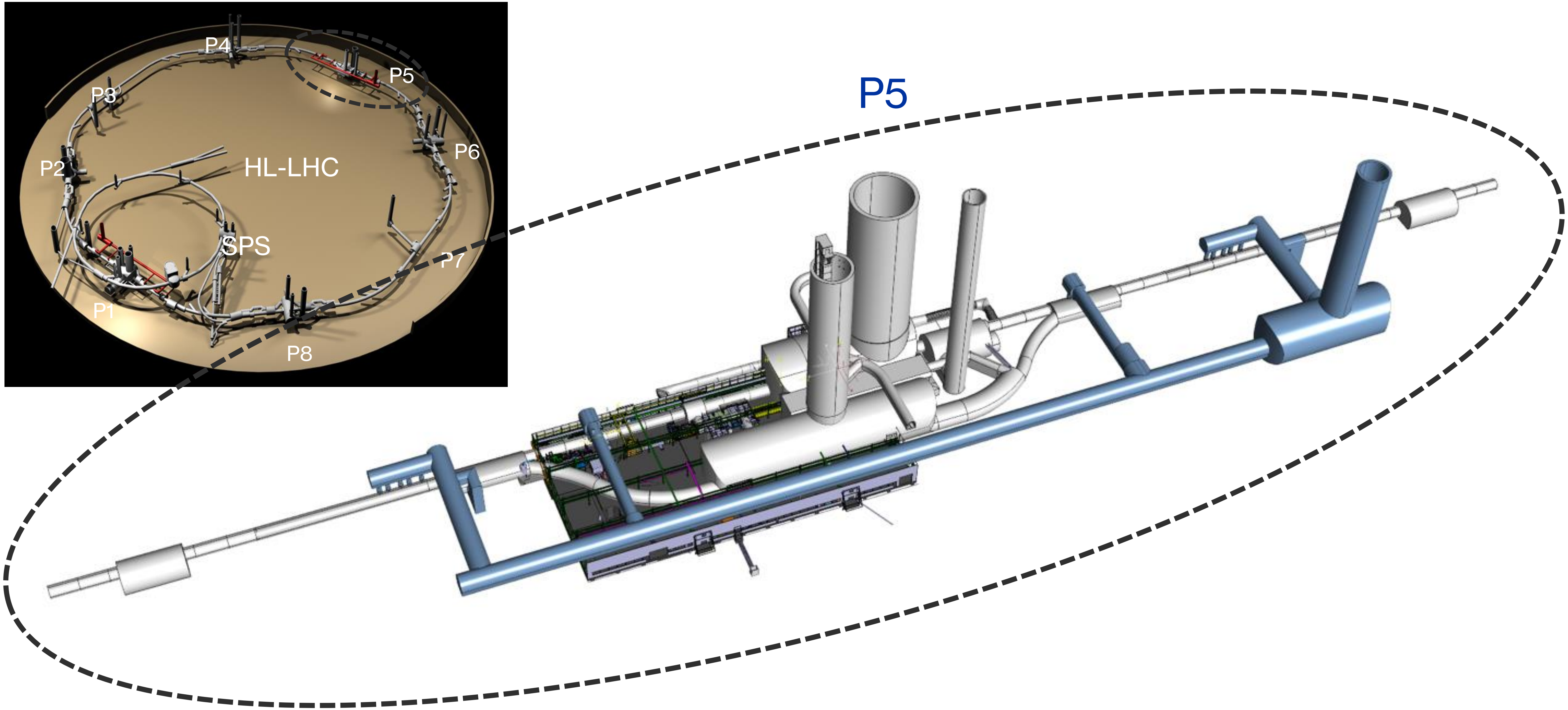




Key Challenges for the Coming Term

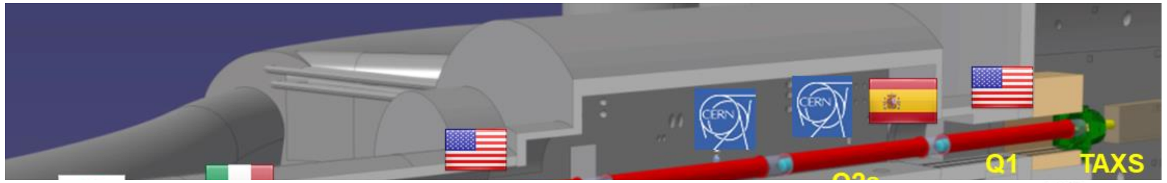
- Finishing successfully the LHC Run3 in 2026
- Complete the HL-LHC IT-String test in 2026

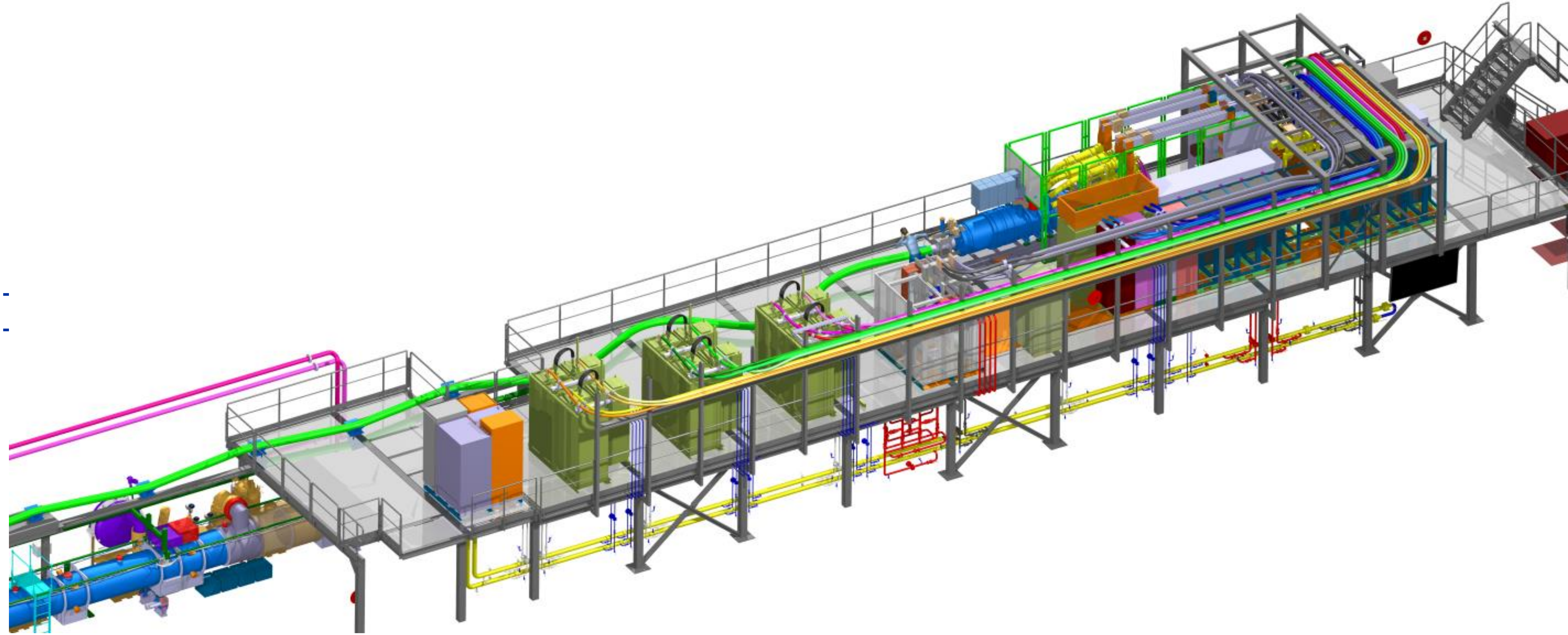
IT-String Update



IT-String Update

- Inner Triplet String installation was completed and preparation for cool down started in July 2025





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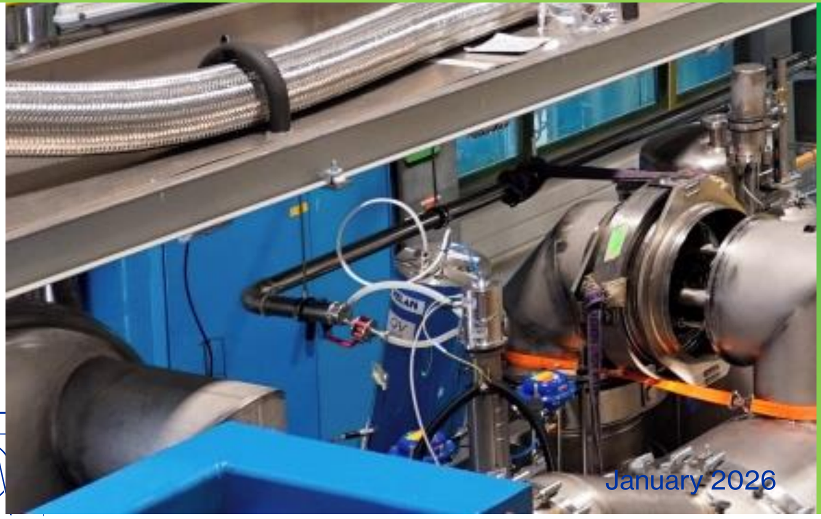
IT String repair completed by end 2025 – Cooldown completed and powering ongoing

Preparation for cooldown showed vacuum leaks at 2 locations in 2025

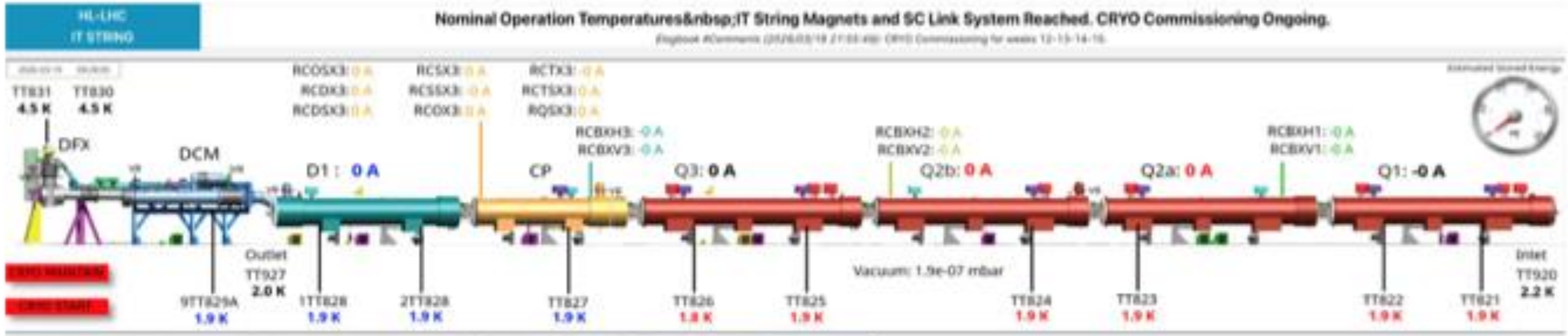
Cause of the leaks was swiftly identified, unveiling a conceptual problem of the N-Line system [power lines across the assembly] for the installation in the tunnel

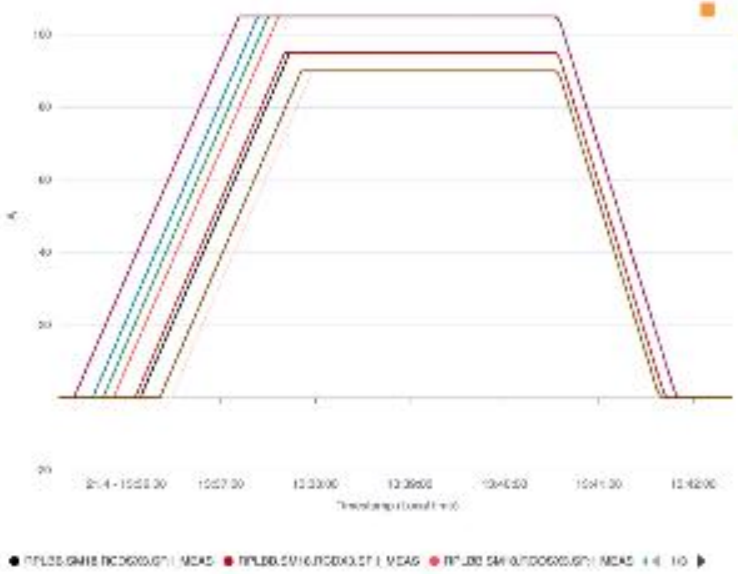
with time for developing design upgrades!!!



The IT-String will provide validation of the HL-LHC magnetic and powering concept and provide valuable operational experience before the start of LS3

HL-LHC: Great progress with the Inner Triplet String



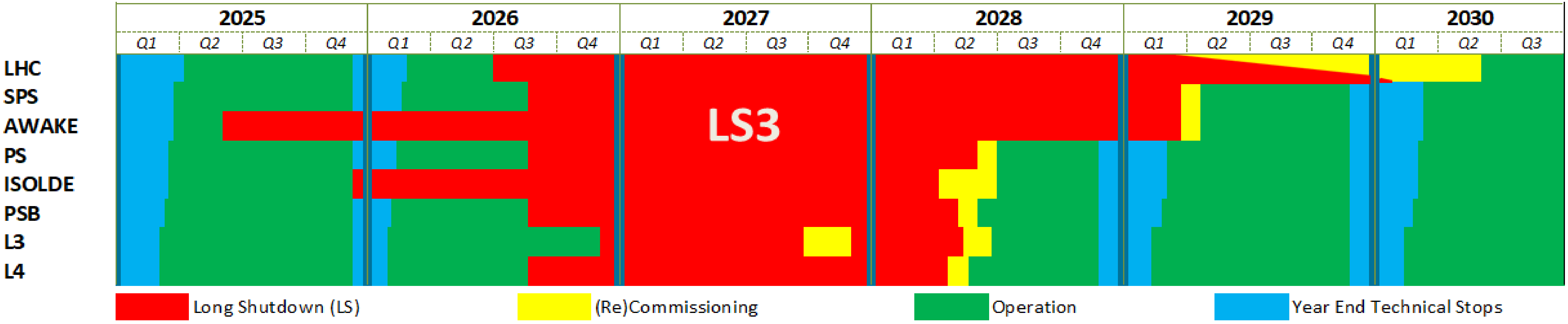


- No degradation in insulation vacuum
- IT-String Reached 1.9K on March 17th
- Corrector magnet powering tests have now started

Key Challenges for the Coming 5 years

- Finishing successfully the LHC Run3 in 2026
- Complete the HL-LHC IT-String test in 2026
- Launch and conduct the Long Shutdown 3 according to Schedule
  - Start of LS3 for the LHC end June 2026
  - Re-start of the accelerator complex [Linac3, Linac 4, PS, PSB, ISOLDE, LEIR and the anti-proton complex] in 2028
  - NA-Cons implementation
  - Restart of the SPS in 2029
  - Implement the HL-LHC project during LS3 and start HL-LHC operation in 2030

Long Shutdown (LS3)



LS3 start

- AWAKE: 02.06.2025
- ISOLDE: 08.12.2025
- LHC: 29.06.2026
- Injectors: 31.08.2026
- L3: 30.11.2026

Inj. Operation restart

- L4 : May 2028
- PSB : May 2028
- PS : July 2028 (*)
- SPS : April/May 2029 (*)

(*) To be optimised

LHC restart

- 1st sectors cooldown : Early 2029
- Final HW Com (P1&5) : January 2030
- Caverns closure : Mid May 2030
- Beam vac valves op : End May 2030

LS3 Schedule: Latest Version [October'25] fits into 47 months!

Q2
2026

LSS dismantling after cryo lockout

Cabling dismantling

Core excavation (LHC side)

Cabling installation

LSS installation

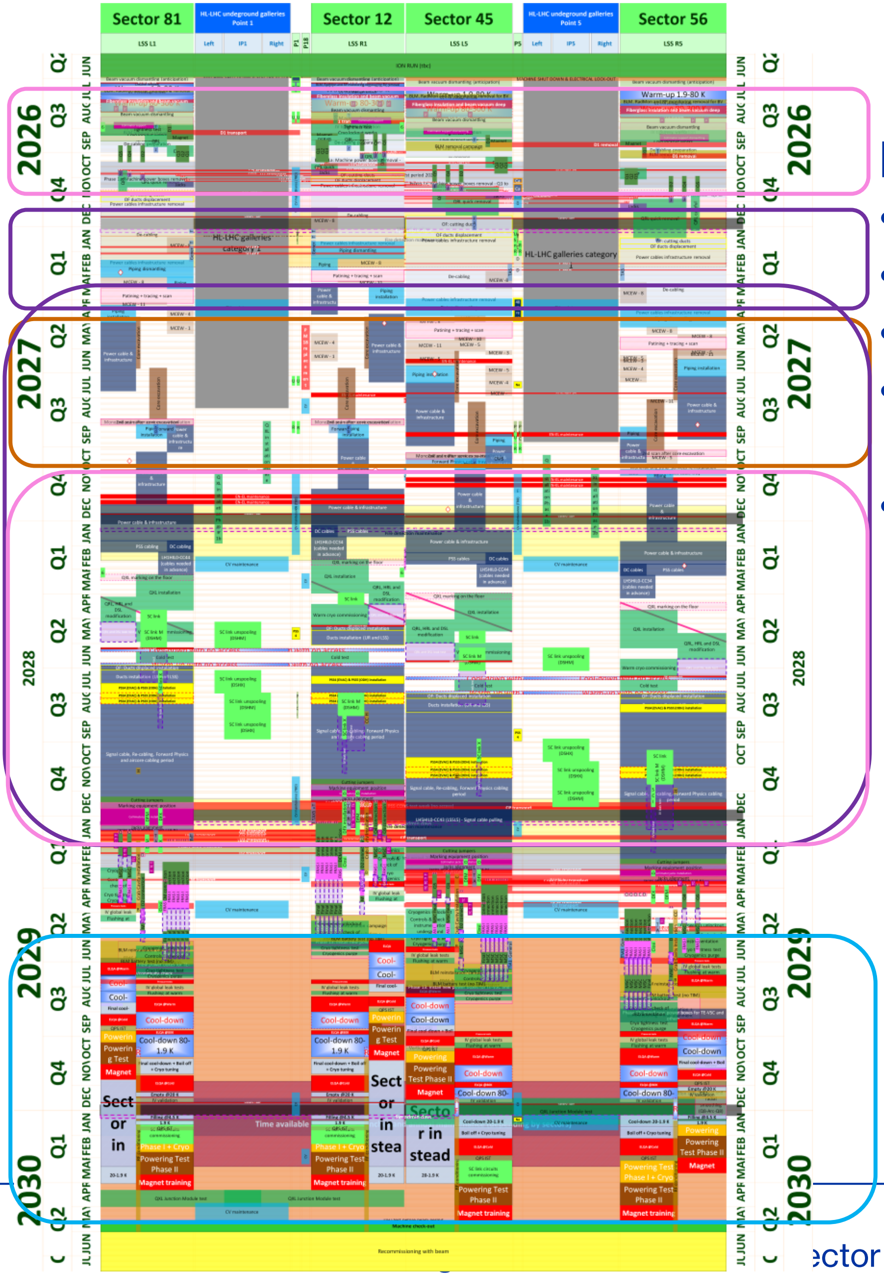
Triplet installation planned for Q1 to Q2 2029

CC installation planned for Q4 '28 to Q2 '29

Cool-down, related test and HWC

Long Shutdown 3 (LS3) is going to be very busy!

LS3 Schedule – TCC October 2025



Plus

- Injector Complex
- North Area Consolidation
- HI-ECN3
- Experiments (+CO2 cooling)
- ...

It fits, but with a success oriented planning

➔ We are working on options to provide additional flexibility

CERN Technology R&D Examples

Twin aperture FCC-ee main bending magnet

High-Temperature Superconducting Magnets:

- Final Focus FCC-ee quads
- Lattice combined function quad/sextupole
- Positron capture solenoid
- Short straight section quad/sextupole

SRF: synergetic technologies

- 400 MHz FCC 2-cell cavity cryomodule
- 800 MHz cryomodule

- Triston – High-Efficiency RF power source

High-Field Magnet Program

Sustainable main bending magnets are being proposed for FCC-ee, with a twin layout, a low current density and aluminum conductor

PHYSICAL REVIEW ACCELERATORS AND BEAMS 19, 112401 (2016)

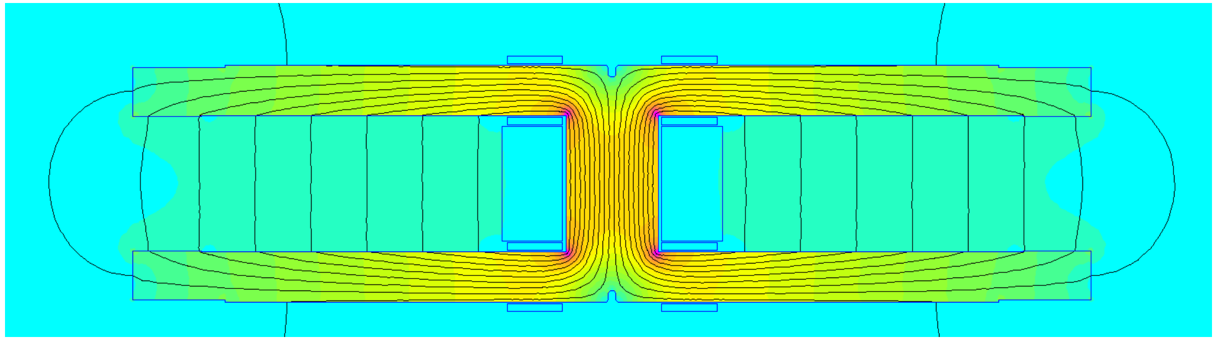
Efficient twin aperture magnets for the future circular e^+/e^- collider

A. Milanese
CERN-The European Organization for Nuclear Research, CH-1211 Geneva, Switzerland
(Received 29 June 2016; published 2 November 2016)

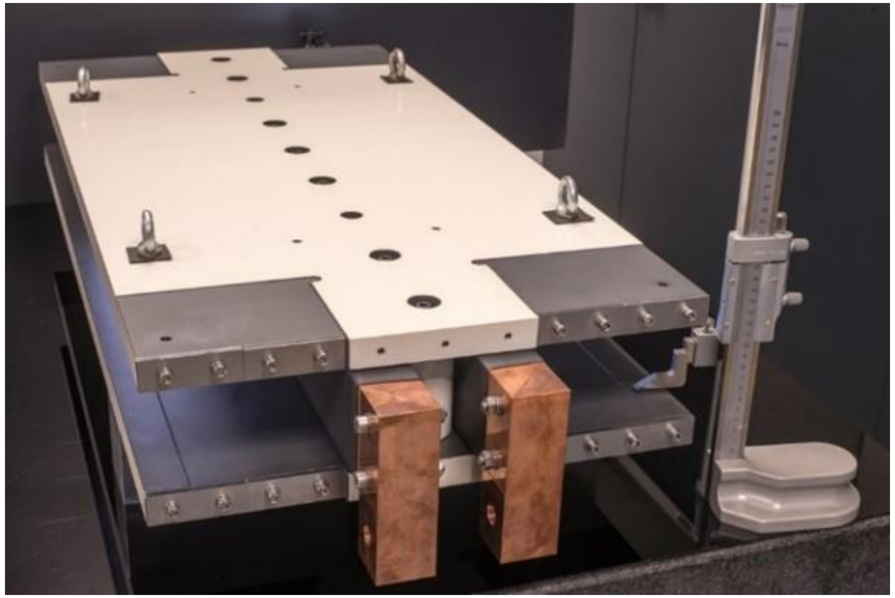
We report preliminary designs for the arc dipoles and quadrupoles of the FCC-ee double-ring collider. After recalling cross sections and parameters of warm magnets used in previous large accelerators, we focus on twin aperture layouts, with a magnetic coupling between the gaps, which minimizes construction cost and reduces the electrical power required for operation. We also indicate how the designs presented may be further optimized so as to optimally address any further constraints related to beam physics, vacuum system, and electric power consumption.

DOI: 10.1103/PhysRevAccelBeams.19.112401

First paper on efficient resistive magnets for FCC-ee



Cross section of FCC-ee bending magnet as of May 2025



First model of FCC-ee collider main dipole

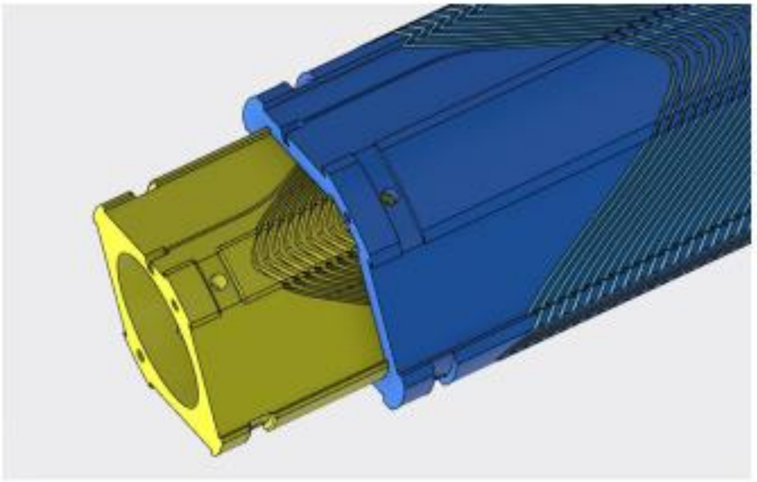
Twin layout allows 50% energy (and material) reduction with respect to separate magnets, as the Ampere turns are recycled in the second aperture

HTS REBCO Studies for FCC ee (1/2)

High-gradient applications (performance-driven)

Machine Detector Interface

Final Focus FCC-ee Quadrupoles
Baseline: Nb-Ti



Inner and outer layer of the CCT HTS FF quadrupole

REBCO CCT at ~ 30 K

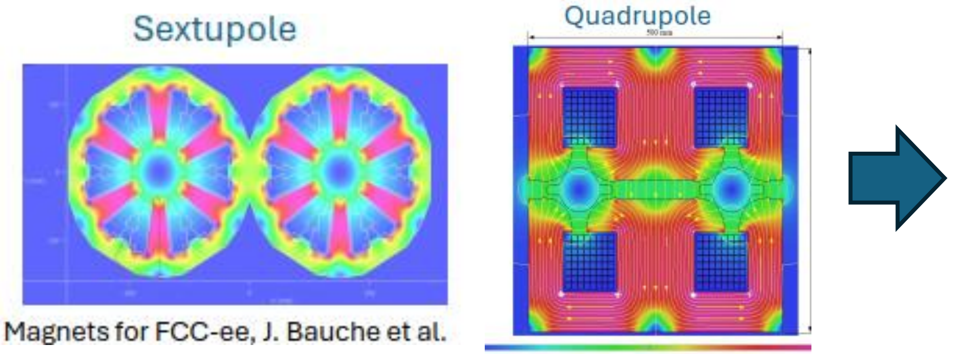
Two opposed solenoid fields
Superconductor in a groove

Matthieu Marchand, Laurent Brunetti et al (LAPP – IN2P3)
M.Koratzinos, F. Bardi (PSI – CERN)
F. Toussaint (SYMME – Univ Savoie Mont-Blanc)

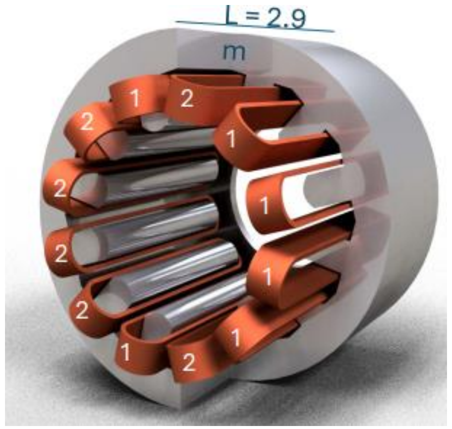
System-level energy-efficient lattice magnets

Collider Ring

Lattice combined function MQ/MS
Baseline: resistive iron dominated magnets



Magnets for FCC-ee, J. Bauche et al.



2900 quadrupoles and 4700 sextupoles in the 80 km arc cells

REBCO at ~ 20-50 K

Dodecapole structure allowing quadrupole, sextupole, and combined operation

INFN SAPIENZA UNIVERSITÀ DI ROMA

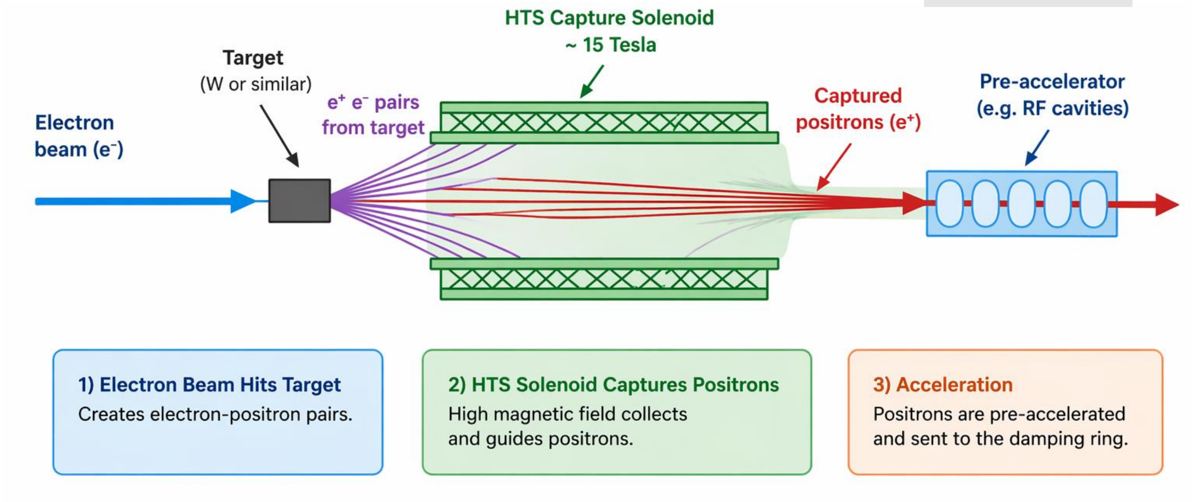
Simone Busatto
Samuele Mariotto
Lucio Rossi

HTS REBCO Studies for FCC ee (2/2)

HTS studies complementary to main lattice and final-focus systems

Positron capture solenoid

→ High-field **REBCO** (**~15 T, ~15 K**), compact source region



REBCO matching/capture solenoid at the target (one per positron source line). Demonstration in the P^3 experiment at PSI

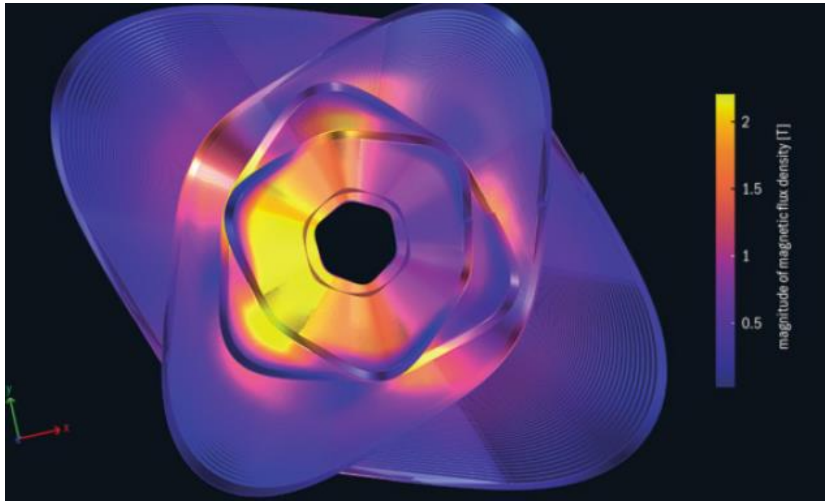
PAUL SCHERRER INSTITUT PSI

CHART Swiss Accelerator Research and Technology

Short Straight Sections (nested Q-S magnets)

→ Energy-efficient optics, increased filling factor

PAUL SCHERRER INSTITUT PSI HTS4



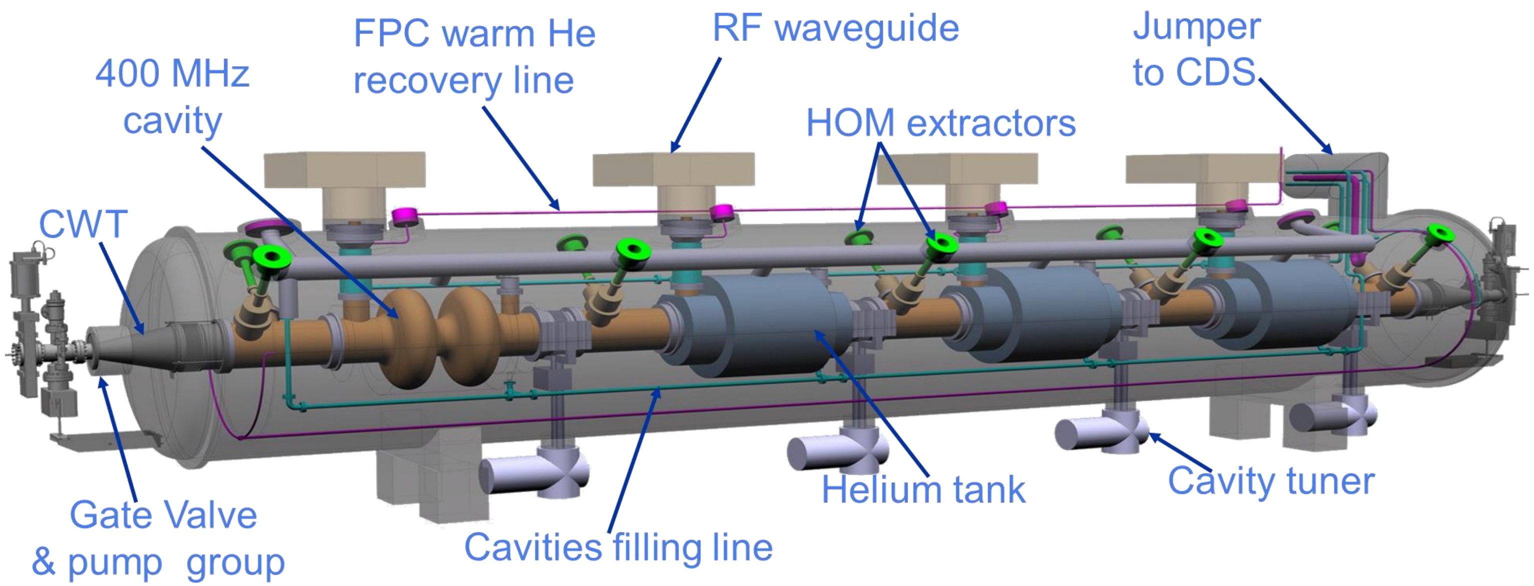
Resitive baseline:
~ 39 MW average power

REBCO (**~2T, ~40 K**)
Cooling < 11 MW

HTS in FCC-ee spans both traditional high-field applications and new energy-efficiency-driven concepts

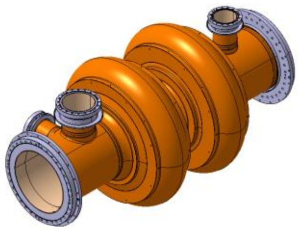
SRF R&D

Build 400 MHz Demo, an FCC 2-cell cavity full size cryomodule



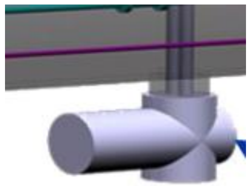
Parameter (machine installed)	Value
No. cryomodules	66
2-cell cavities per cryomodule	4
CM length (GV flange to flange)	~ 11 m
RF frequency (MHz)	400.79
Cavity voltage (MV)	7.95
Cavity gradient Eacc (MV/m)	10.6
Qo	2.7E+09
Dyn. HL (CW)/cavity at 4.5 K	129 W
Stat. HL/CM	197 W
Environ. Magnetic field	≤ 5 mG
RF power (kW, CW)	380
Q_L (optimum coupling)	9.2E+05
HOM power per CM: Z (W/H/ttbar)	62.3 kW (coax. Extractor for 15/20 kW peak!) (lower for W/H/ttbar)

Items to be designed, built and qualified (non exhaustive list!)

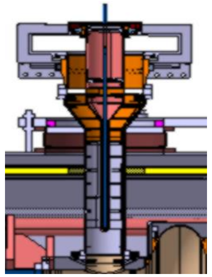


Cavity Nb sputtered

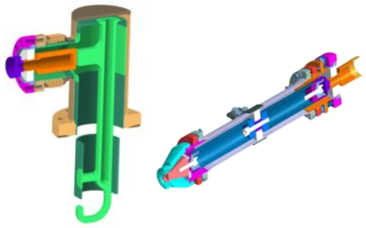
He tank



Tuning system



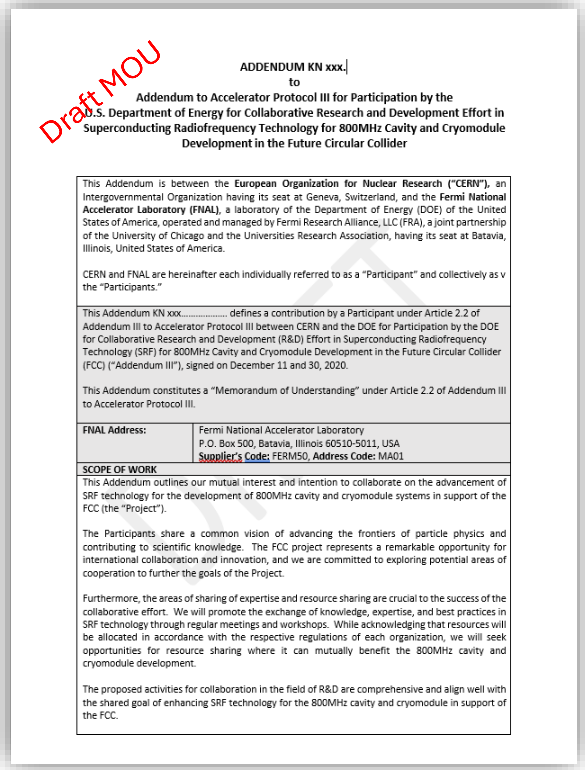
FPC



HOMs, RF extraction lines (LHC/Crab designs shown)

Derived from LHC SRF, but **final designs will be considerably different !**

800 MHz with collaborations: FNAL, DESY, HZB, IJCLAB, CEA



ADDENDUM KN xxx.
to
Addendum to Accelerator Protocol III for Participation by the U.S. Department of Energy for Collaborative Research and Development Effort in Superconducting Radiofrequency Technology for 800MHz Cavity and Cryomodule Development in the Future Circular Collider

This Addendum is between the **European Organization for Nuclear Research ("CERN")**, an Intergovernmental Organization having its seat at Geneva, Switzerland, and the **Fermi National Accelerator Laboratory (FNAL)**, a laboratory of the Department of Energy (DOE) of the United States of America, operated and managed by Fermi Research Alliance, LLC (FRA), a joint partnership of the University of Chicago and the Universities Research Association, having its seat at Batavia, Illinois, United States of America.

CERN and FNAL are hereinafter each individually referred to as a "Participant" and collectively as v the "Participants."

This Addendum KN xxx.................. defines a contribution by a Participant under Article 2.2 of Addendum III to Accelerator Protocol III between CERN and the DOE for Participation by the DOE for Collaborative Research and Development (R&D) Effort in Superconducting Radiofrequency Technology (SRF) for 800MHz Cavity and Cryomodule Development in the Future Circular Collider (FCC) ("Addendum III"), signed on December 11 and 30, 2020.

This Addendum constitutes a "Memorandum of Understanding" under Article 2.2 of Addendum III to Accelerator Protocol III.

FNAL Address:	Fermi National Accelerator Laboratory P.O. Box 500, Batavia, Illinois 60510-5011, USA **Supplier's Code:** FERM50, **Address Code:** MA01

SCOPE OF WORK

This Addendum outlines our mutual interest and intention to collaborate on the advancement of SRF technology for the development of 800MHz cavity and cryomodule systems in support of the FCC (the "Project").

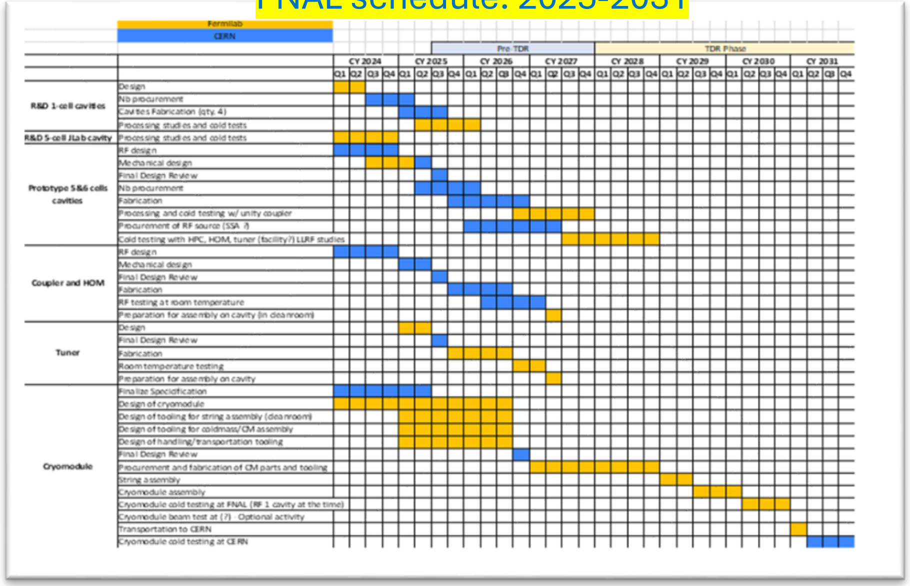
The Participants share a common vision of advancing the frontiers of particle physics and contributing to scientific knowledge. The FCC project represents a remarkable opportunity for international collaboration and innovation, and we are committed to exploring potential areas of cooperation to further the goals of the Project.

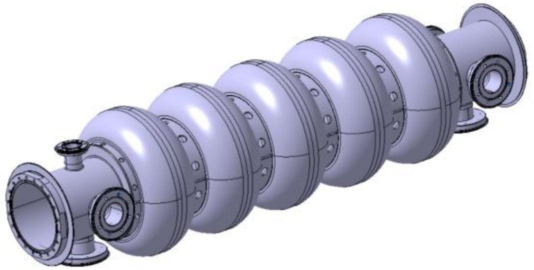
Furthermore, the areas of sharing of expertise and resource sharing are crucial to the success of the collaborative effort. We will promote the exchange of knowledge, expertise, and best practices in SRF technology through regular meetings and workshops. While acknowledging that resources will be allocated in accordance with the respective regulations of each organization, we will seek opportunities for resource sharing where it can mutually benefit the 800MHz cavity and cryomodule development.

The proposed activities for collaboration in the field of R&D are comprehensive and align well with the shared goal of enhancing SRF technology for the 800MHz cavity and cryomodule in support of the FCC.

Deliverables	
Identifier	**Title**
FNAL-CE-1.1	Design, Fabrication, Processing, and Cold Testing of 1-Cell 800MHz Cavities
FNAL-CE-1.2	Design, Fabrication, Processing, and Cold Testing of 6-Cell 800MHz Cavities
FNAL-CE-1.3	Design of the 800MHz Cavity subsystems: FPC, HOM, and Tuner
FNAL-CE-1.4	800 MHz Cryomodule design
FNAL-CE-1.5	Development, Assembly, and Cold Testing of 800MHz Cryomodules

FNAL schedule: 2025-2031



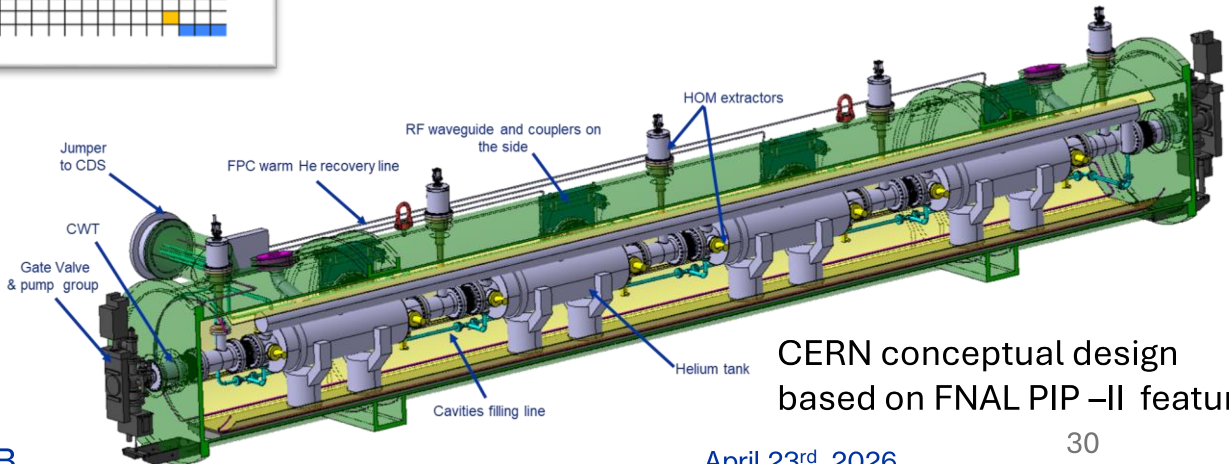


High Qo studies (under FCC project funding):

- 5 single cell cavities in fabrication at CERN (MME), 3 to be supplied to FNAL (June '25)
- FNAL improving EP process on a 5-cell cavity (cold testing now)
- Mid T baking and retesting of same cavity to follow
- Single cell processing to follow

800 MHz CM plan for assy & testing by 2031

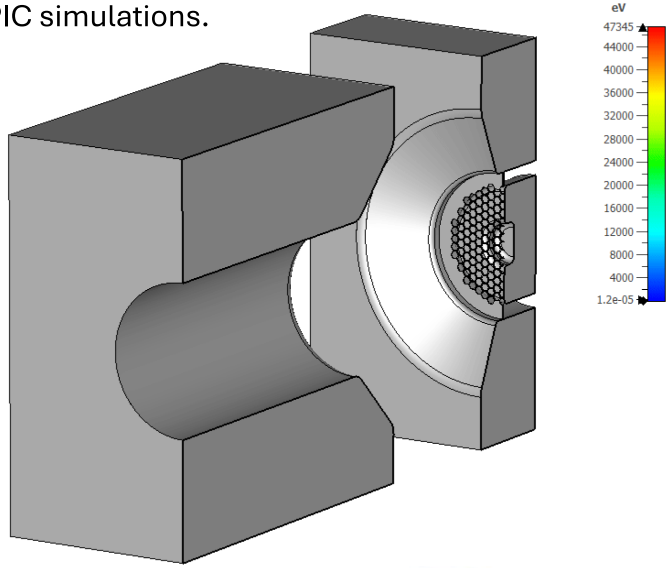
- Regular fruitful exchanges with FNAL (every 2 weeks)
- But funding still pending (FNAL made a cost estimate)
- FCC management agreed to fund 4 6-cell cavities through FCCee (but now funding is postponed)
- We have limited funding under SRD-D project (1.4 MCHF) → purchase of Nb

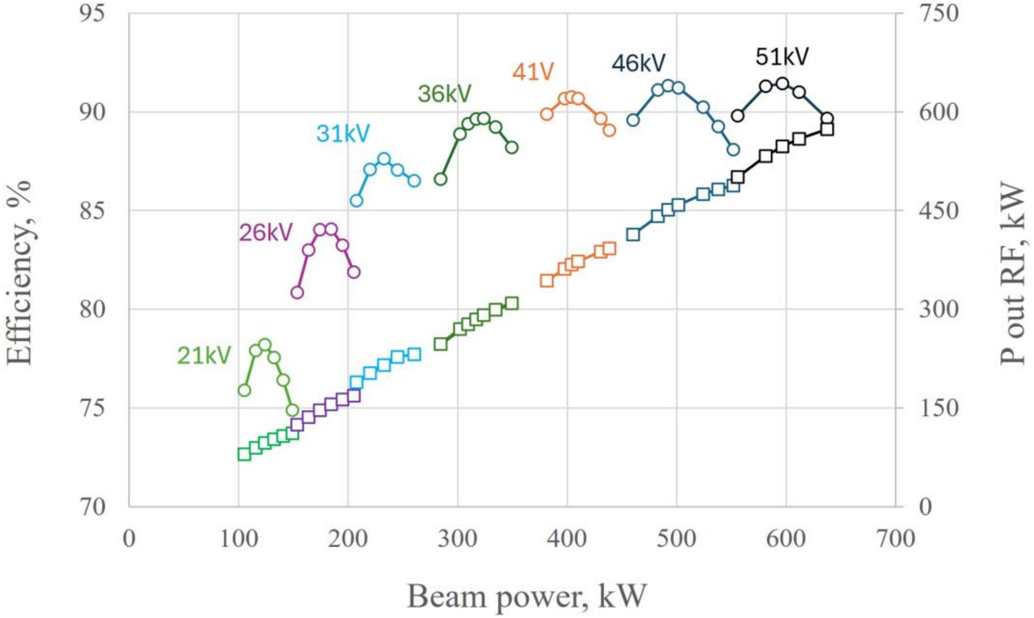


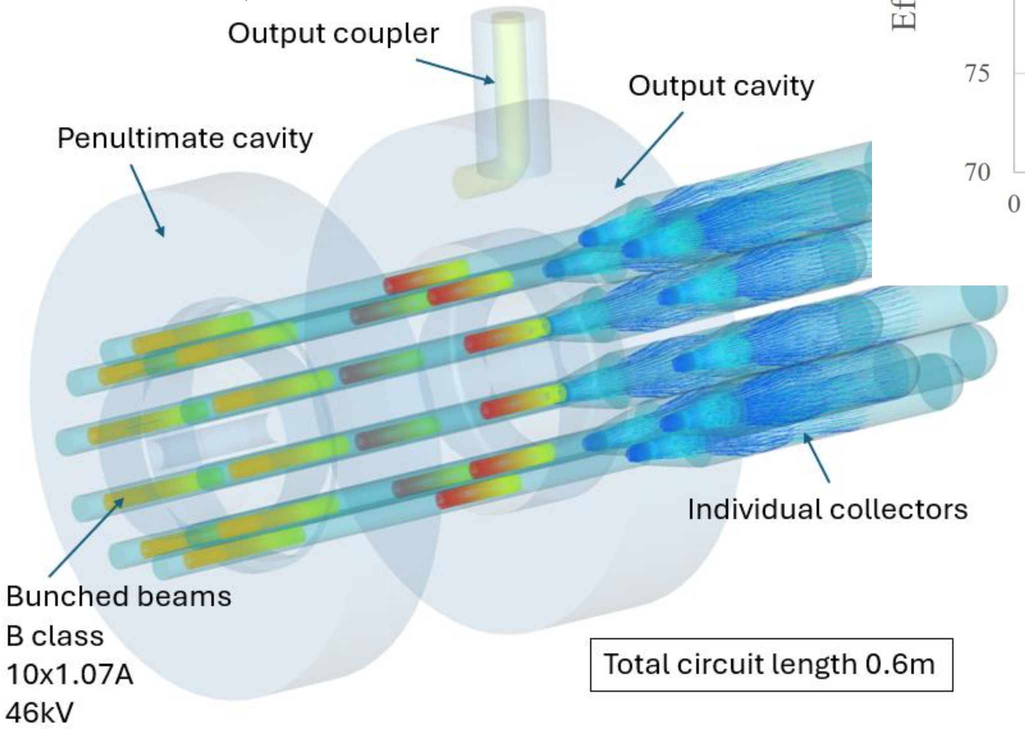
CERN conceptual design based on FNAL PIP –II features

FCC$_{ee}$ 400MHz, 0.5MW, CW MB
Tristron

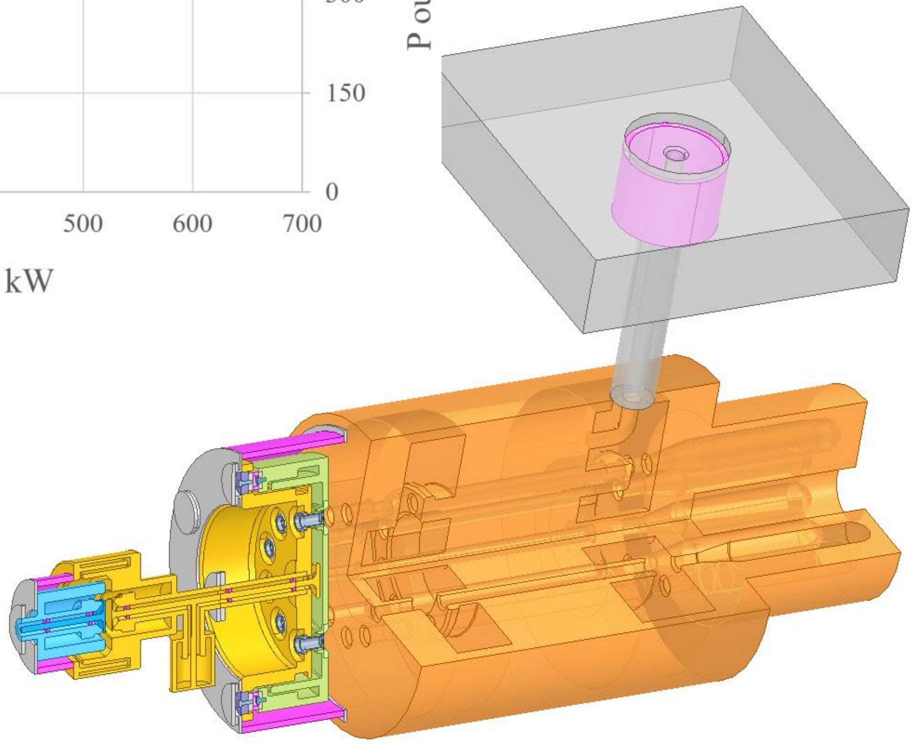
Tristron Gridded cathode
CST PIC simulations.





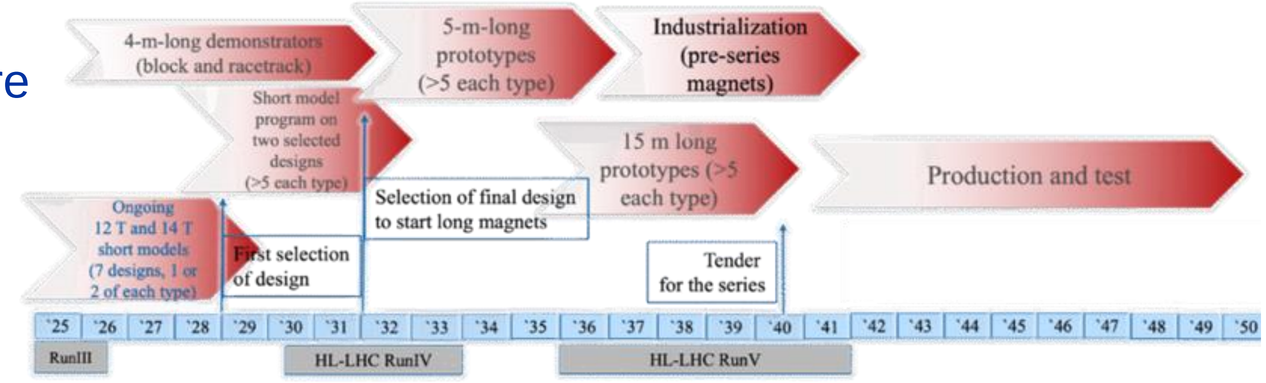


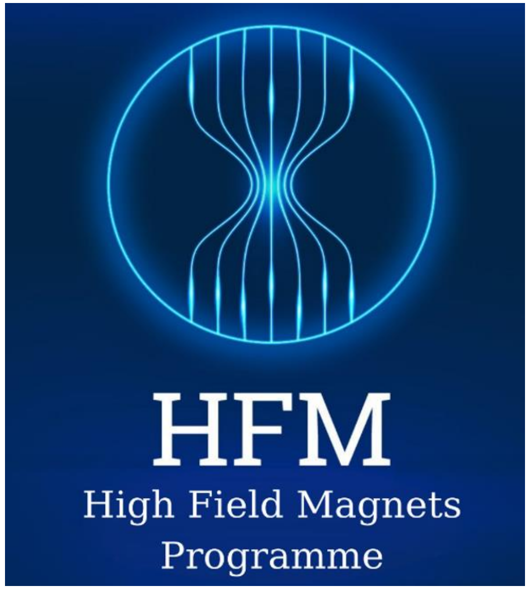
Total circuit length 0.6m



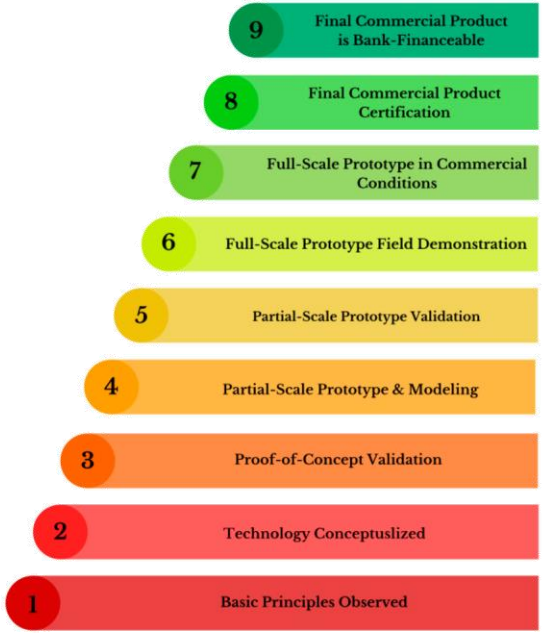
Preparing for the Future

- **The High Field Magnets Programme (HFM)**
  - An essential R&D activity that is relevant for all future accelerators
  - Developing long, 14 T accelerator dipole magnets capable of being industrialized by 2040 [Nb_3Sn]
  - Develop HTS magnet technology for accelerators





- **Targets for 2026-2030**
  - Bring the Technology Readiness Level for **14 T Nb_3Sn** magnets from yellow towards green through short models
    - Address costs by looking at hybrid options
  - Bring the Technology Readiness Level for **14 T HTS** High Temperature Superconductor magnets from red to yellow through various demonstrators
    - Short model foreseen for mid 2030's



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