Status of the FCC Feasibility Study

Manuela Boscolo, INFN-LNF
on behalf of FCC collaboration

TERZA GIORNATA ACCELERATORI
Frascati, 4 Aprile 2024

INFN ACCELERATORI
Terza Giornata Acceleratori

EuroCirCol A key to New Physics

FUTURE CIRCULAR COLLIDER Innovation Study

CERN

European Commission | Horizon 2020 European Union funding for Research & Innovation

*Work supported by the **European Commission** under the **HORIZON 2020 projects***
***EuroCirCol**, grant agreement 654305; **FCCIS**, grant agreement 951754*

http://cern.ch/fcc

photo: J. Wenninger

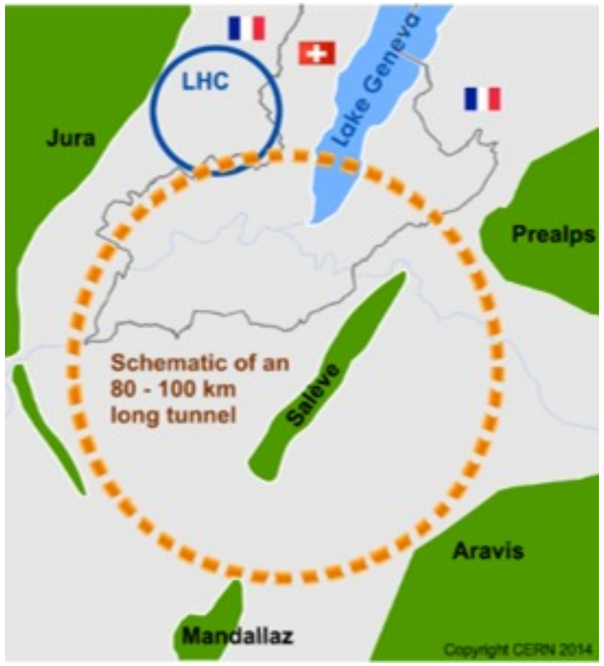
Outline

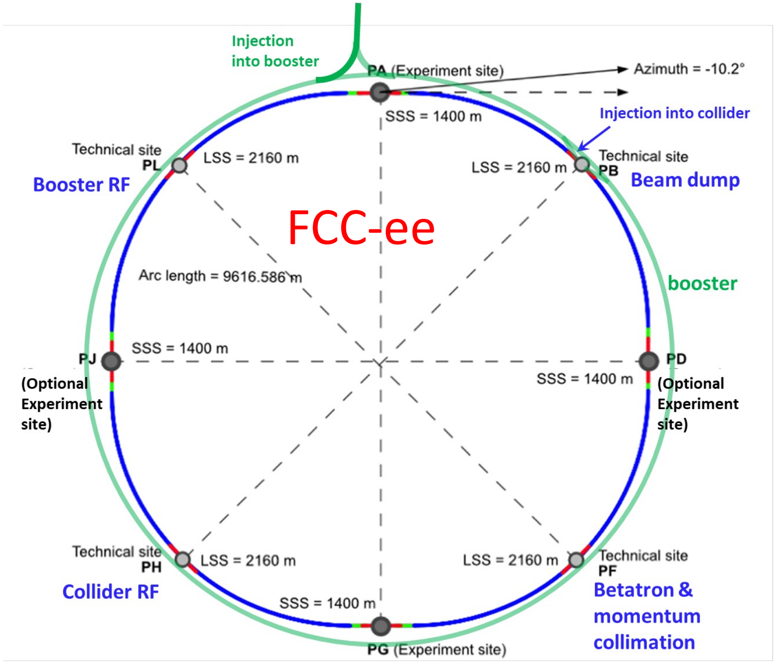
- Feasibility Study - New FCC Accelerated Schedule
- Accelerator Design
- FCC Italia activities and involvement

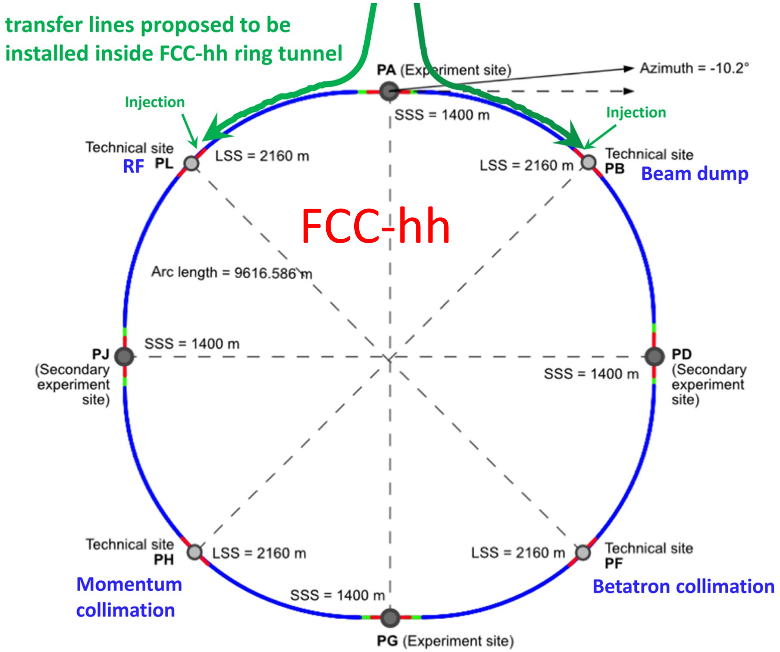
FCC integrated program

Comprehensive long-term program maximizing physics opportunities

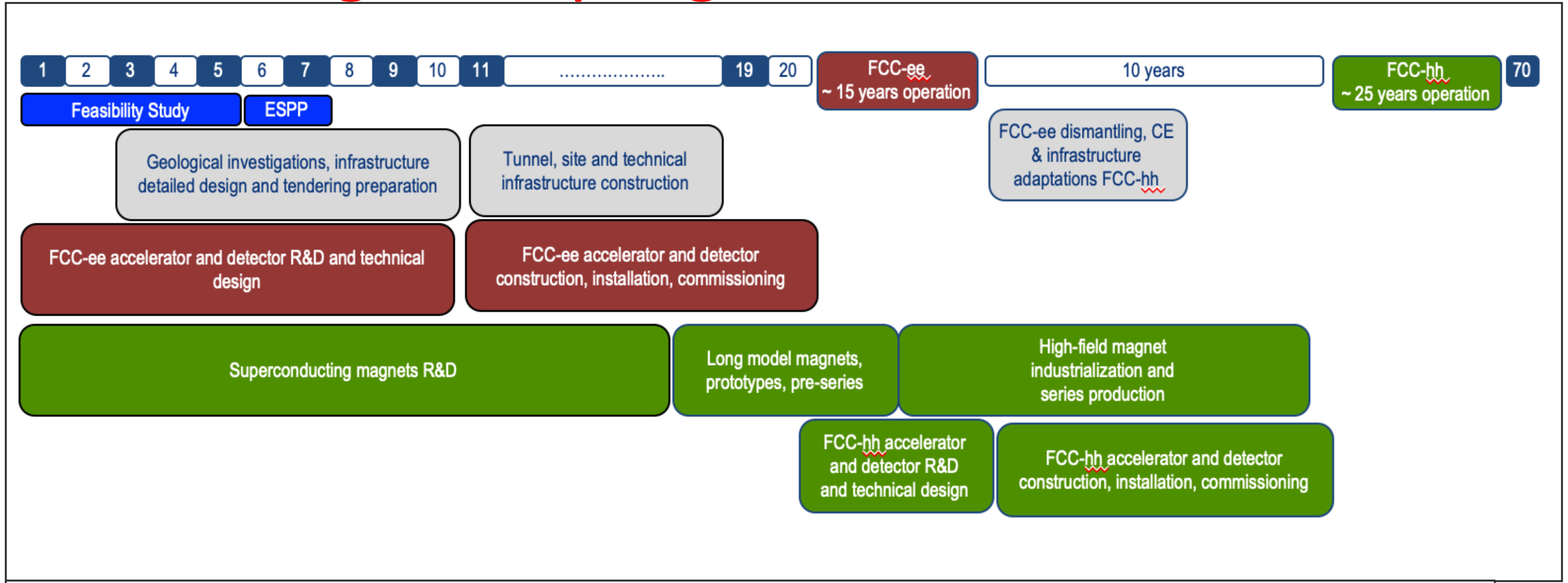
- **stage 1: FCC-ee (Z, W, H, $t\bar{t}$) as Higgs factory, electroweak & top factory at highest luminosities**
- **stage 2: FCC-hh (~100 TeV) as natural continuation at energy frontier, pp & AA collisions; e-h option**
- highly synergetic and complementary programme boosting the physics reach of both colliders
- common civil engineering and technical infrastructures, building on and reusing CERN's existing infrastructure
- FCC integrated project allows the start of a new, major facility at CERN within a few years of the end of HL-LHC

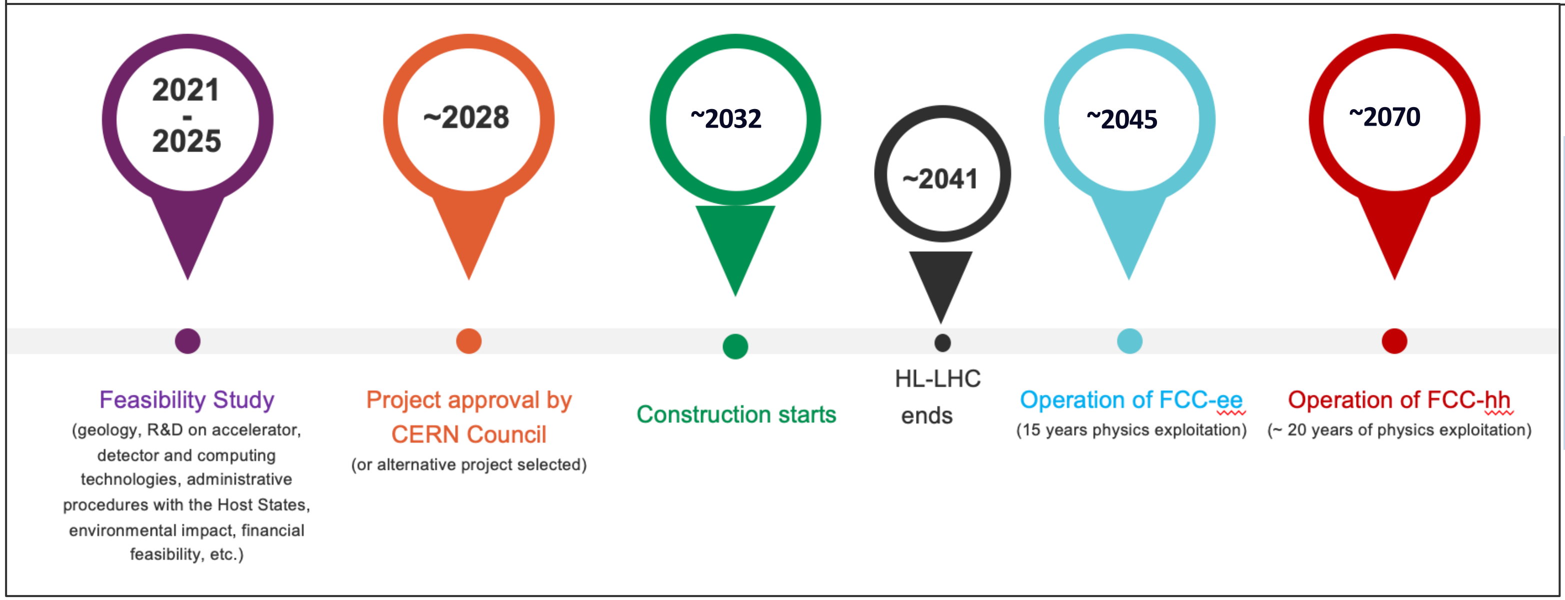






FCC integrated program - timeline





Note: FCC Conceptual Design Study started in 2014 leading to CDR in 2018

Ambitious schedule taking into account:
- ❑ past experience in building colliders at CERN
- ❑ approval timeline: ESPP, Council decision
- ❑ that HL-LHC will run until 2041
- ❑ **project preparatory phase with adequate resources immediately after Feasibility Study**

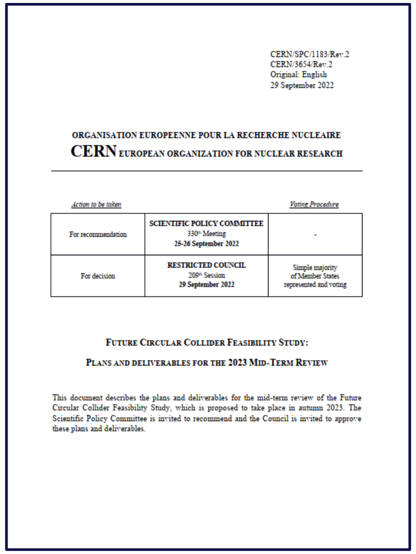
FCC FS mid-term review

The goal of the FCC FS mid-term review is to assess the progress of the Study towards the final report.
Deliverables approved by the Council in September 2022:

https://indico.cern.ch/event/1197445/contributions/5034859/attachments/2510649/4315140/spc-e-1183-Rev2-c-e-3654-Rev2_FCC_Mid_Term_Review.pdf

Deliverables:
- D1 : Definition of the baseline scenario
- D2 : Civil engineering
- D3 : Processes and implementation studies with the Host States
- D4 : Technical infrastructure
- D5 : FCC-ee accelerator
- D6: FCC-hh accelerator
- D7: Project cost and financial feasibility
- D8: Physics, experiments and detectors

← Many thanks to the Host States for their strong support!



CERN/SPC/1183/Rev.2
CERN/3654/Rev.2
Original: English
29 September 2022

ORGANISATION EUROPEENNE POUR LA RECHERCHE NUCLEAIRE
CERN EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

Action to be taken		*Voting Procedure*
For recommendation	**SCIENTIFIC POLICY COMMITTEE** 330th Meeting **25-26 September 2022**	-
For decision	**RESTRICTED COUNCIL** 209th Session **29 September 2022**	Simple majority of Member States represented and voting

FUTURE CIRCULAR COLLIDER FEASIBILITY STUDY:

PLANS AND DELIVERABLES FOR THE 2023 MID-TERM REVIEW

This document describes the plans and deliverables for the mid-term review of the Future Circular Collider Feasibility Study, which is proposed to take place in autumn 2023. The Scientific Policy Committee is invited to recommend and the Council is invited to approve these plans and deliverables.

Documents:
- ❑ Mid-term report (all deliverables except D7)
- ❑ Executive Summary of mid-term report
- ❑ Updated cost assessment (D7)
- ❑ Funding model (D7)

Review process:
- ❑ Oct 2023: Scientific Advisory Committee (scientific and technical aspects) and Cost Review Panel (ad hoc committee; cost and financial aspects)
- ❑ Nov 2023: SPC and FC
- ❑ 2 Feb 2024: Council

Many thanks to the SAC, CRP, SPC, FC and the Council for the very useful reviews!

FCC Feasibility Study mid-term report

Full Report
8 Chapters/Deliverables
~ 700pp document
~ 16 editors
~ 500 contributors

Executive Summary
8 Chapters/Deliverables
~ 45pp document
~ 16 editors

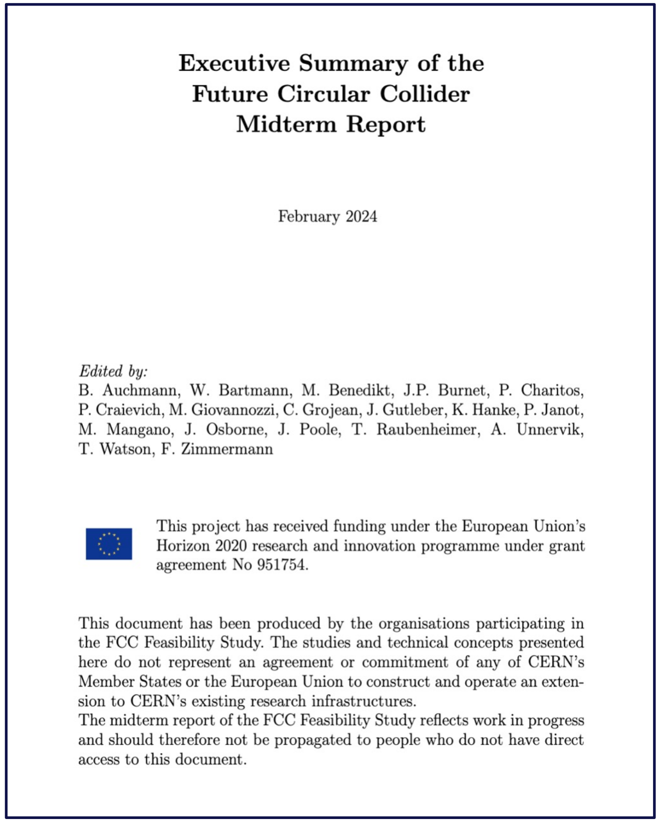
Future Circular Collider
Midterm Report

February 2024

Edited by:
B. Auchmann, W. Bartmann, M. Benedikt, J.P. Burnet, P. Craievich, M. Giovannozzi, C. Grojean, J. Gutleber, K. Hanke, P. Janot, M. Mangano, J. Osborne, J. Poole, T. Raubenheimer, T. Watson, F. Zimmermann

This project has received funding under the European Union's Horizon 2020 research and innovation programme under grant agreement No 951754.

This document has been produced by the organisations participating in the FCC feasibility study. The studies and technical concepts presented here do not represent an agreement or commitment of any of CERN's Member States or of the European Union for the construction and operation of an extension to CERN's existing research infrastructures.
The midterm report of the FCC Feasibility Study reflects work in progress and should therefore not be propagated to people who do not have direct access to this document.



Executive Summary of the
Future Circular Collider
Midterm Report

February 2024

Edited by:
B. Auchmann, W. Bartmann, M. Benedikt, J.P. Burnet, P. Charitos, P. Craievich, M. Giovannozzi, C. Grojean, J. Gutleber, K. Hanke, P. Janot, M. Mangano, J. Osborne, J. Poole, T. Raubenheimer, A. Unnervik, T. Watson, F. Zimmermann

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Both documents are available to the CERN community at:
https://doi.org/10.17181/mhas5-1f263

Please note that the midterm report of the FCC Feasibility Study reflects work in progress and should therefore not be propagated to people without direct access to this page.

You are kindly asked to treat the information with the appropriate level of confidentiality, as defined in the CERN Data Protection Policy.

For questions on access please contact the FCC Secretariat: fcc.secretariat@cern.ch

Summary of P5 Report for USFCC

December 2023

- Funding for an **offshore Higgs factory** such as FCC-ee is recommended is all studied budget scenarios. It is recommended to allocate investment in detector R&D to accelerate US leadership in this area.
- Now more than ever, particle physics is an **international, global endeavor**. Resources and cooperation are required at a global scale and experiments take more than a decade to design and build.
- **Strong participation from the US** on the milestones set by P5, **both helping CERN prepare the feasibility study, and showing the depth of support in the US for this project, is essential**.

FCC Events

25-27 March

Second Annual US FCC Workshop 2024

https://indico.mit.edu/event/876/

FCC Week 2024

10-14 June

https://indico.cern.ch/event/1298458/

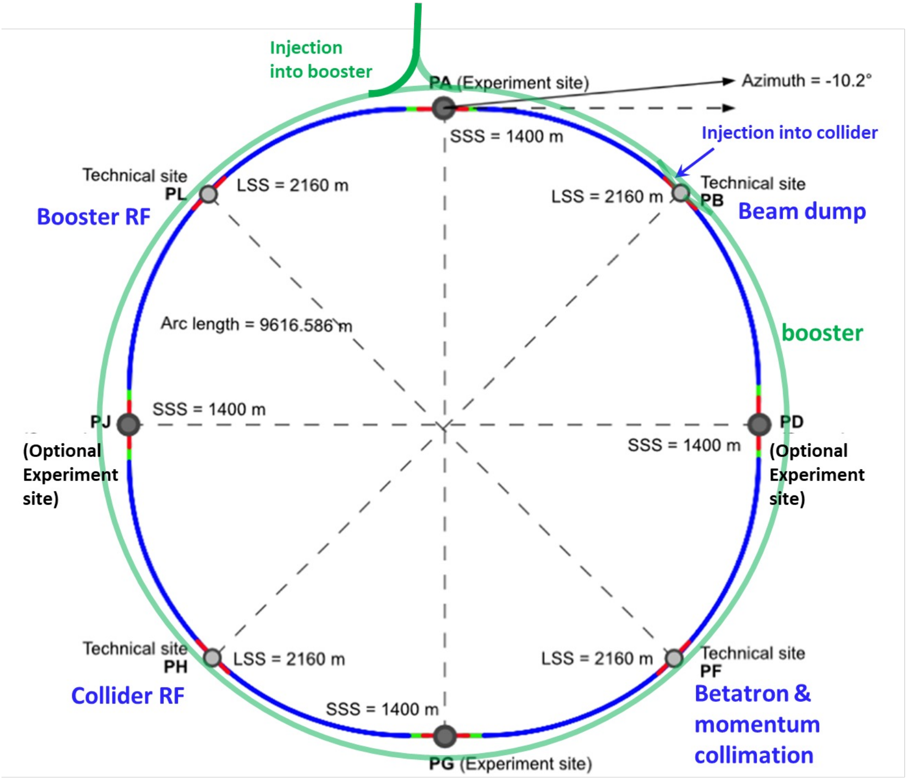
INFN well represented

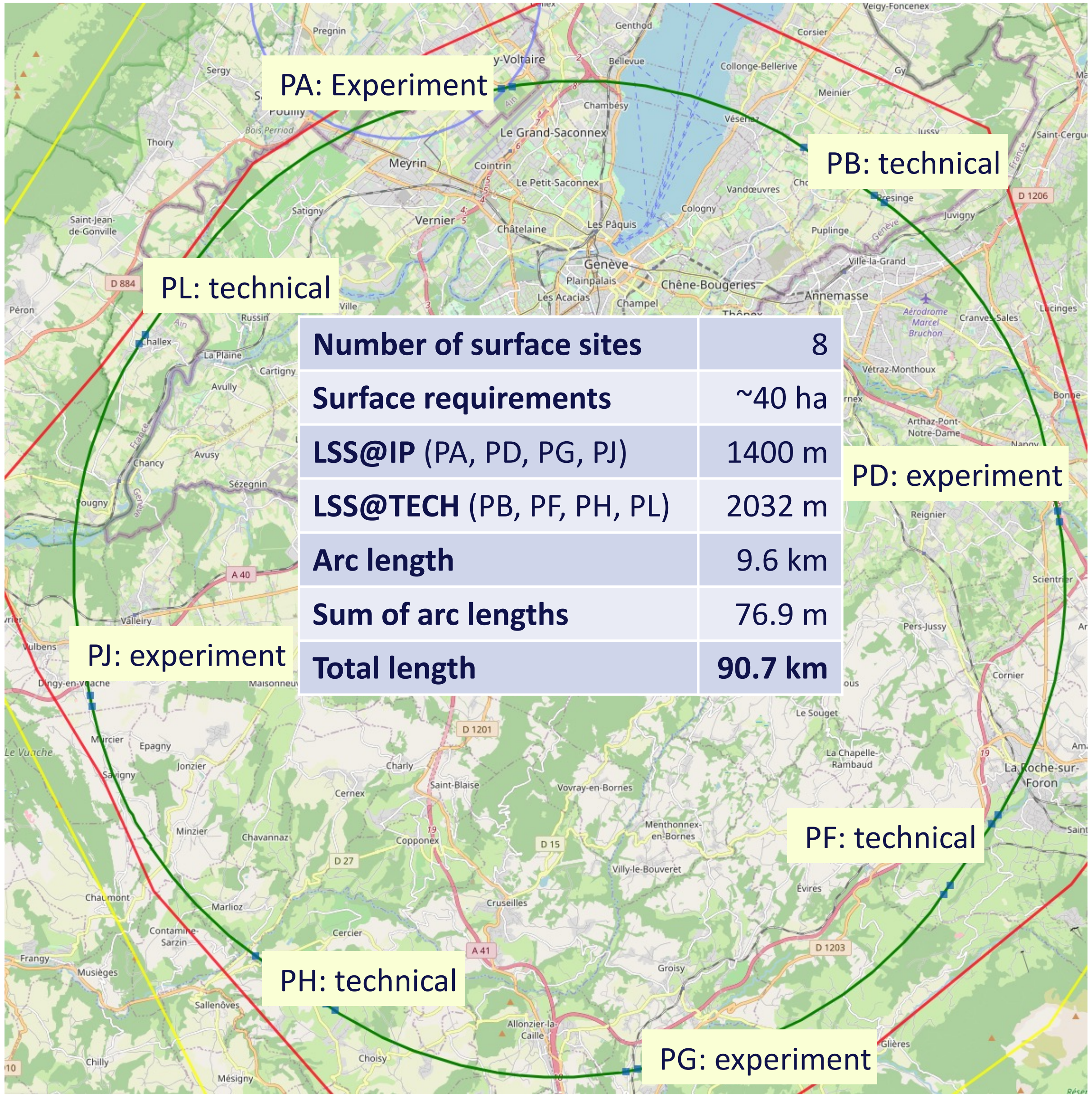
Optimized placement and layout for feasibility study

Layout chosen out of ~ 100 initial variants, based on **geology** and **surface constraints** (land availability, access to roads, etc.), **environment,** (protected zones), **infrastructure** (water, electricity, transport), **machine performance** etc.

“Avoid-reduce -compensate” principle of EU and French regulations

Overall lowest-risk baseline: 90.7 km ring, 8 surface points,
Whole project now adapted to this placement





Number of surface sites	8
Surface requirements	~40 ha
LSS@IP (PA, PD, PG, PJ)	1400 m
LSS@TECH (PB, PF, PH, PL)	2032 m
Arc length	9.6 km
Sum of arc lengths	76.9 m
Total length	**90.7 km**

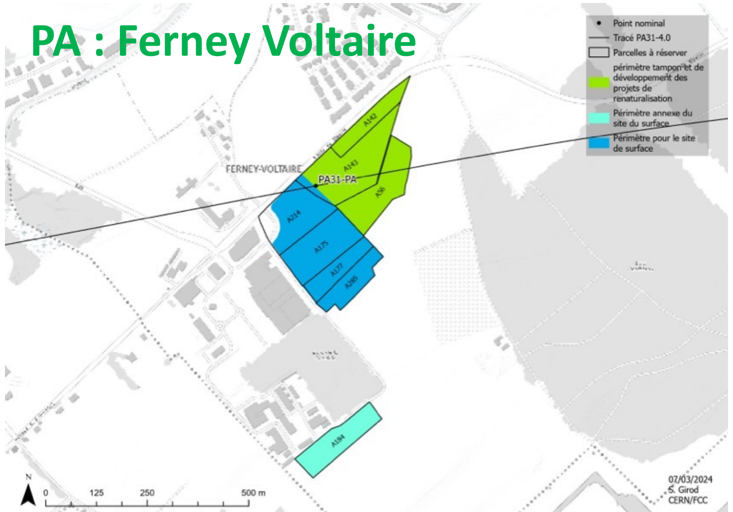
Surface sites development and reservation of land-plots

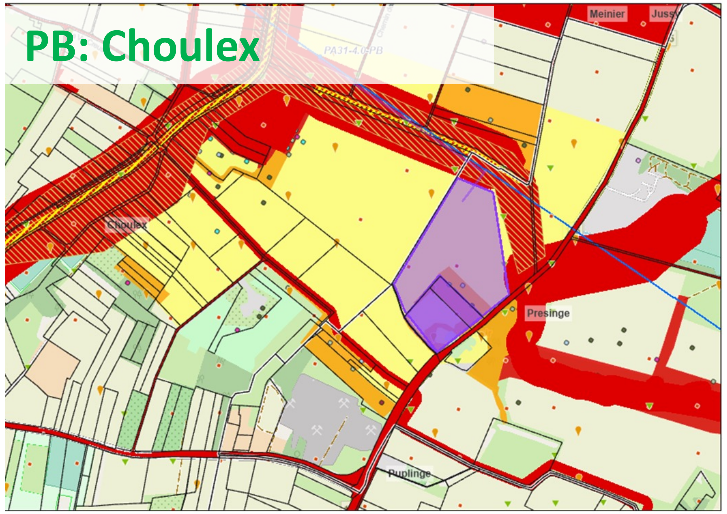
Meetings ongoing with all communes concerned by surface sites to identify individual land-plots for development of surface site layout and land reservation.

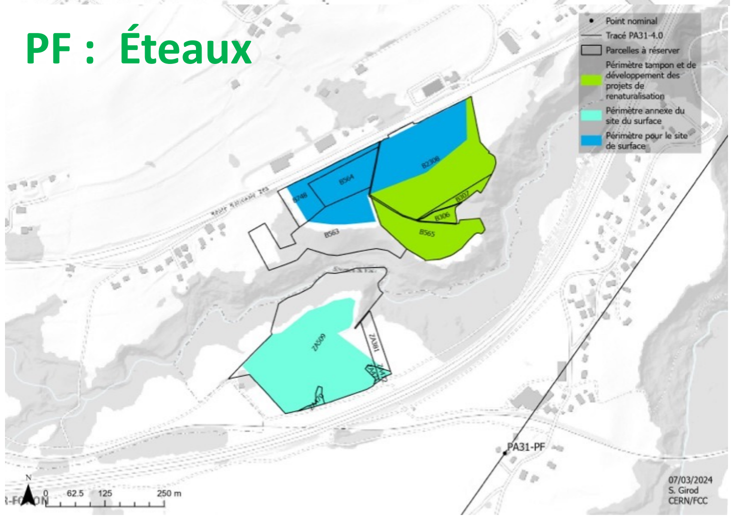
- **PA : Ferney Voltaire: 01/2024**
- **PB: Choulex : 12/2023**
- **PB: Presinge : 01/2024, plenary session with community council 04/2024**
- **PD : Nangy: 05/2024**
- **PF : Éteaux : 03/2024**
- **PG : Groisy / Charvonnex: 04/2024**
- **PH : Marlioz / Cercier : 02/2024**
- **PJ : Vulbens / Dingy en Vuache : 09/2023, 01/2024**
- **PL : Challex: 03/2024, further meetings in Q2/24 to identify best site location**

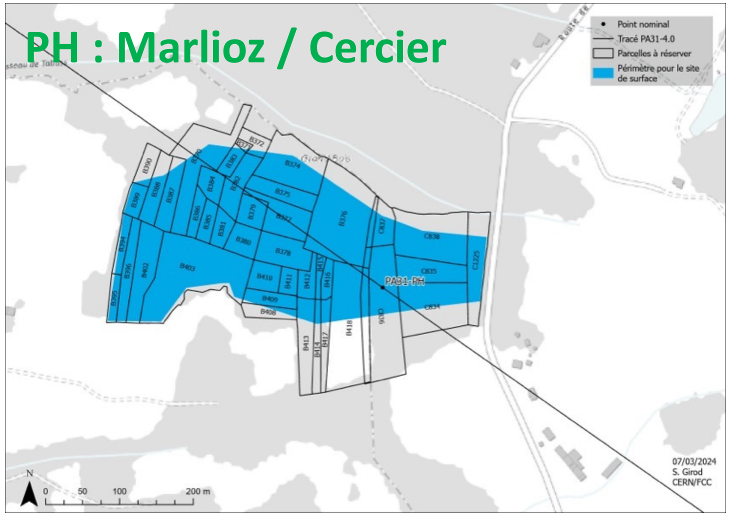
Green: parcelles identified and agreed

Blue: ongoing

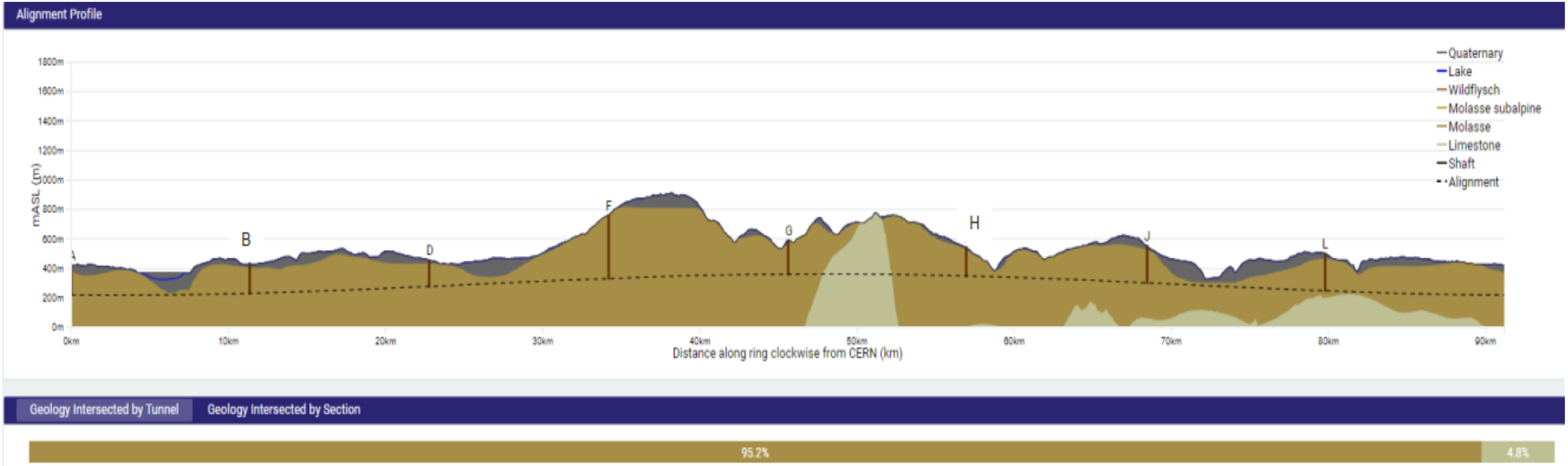








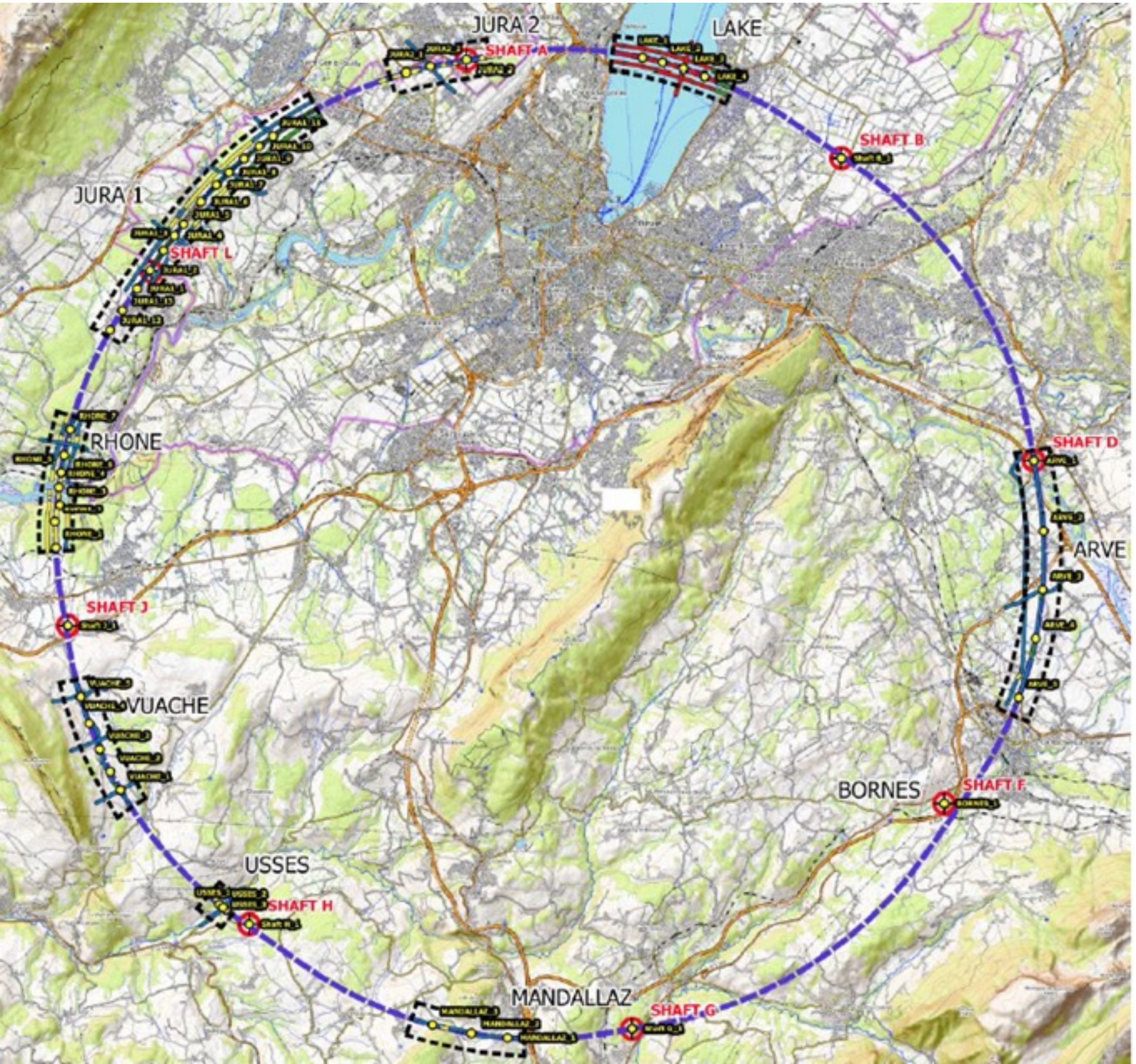
FCC tunnel implementation



Tunnel implementation summary

- 91 km circumference
- 95% in molasse geology for minimising tunnel construction risks
- Site investigations in zones where tunnel is close to geological interfaces: moraines-molasse-limestone

Status of site investigations



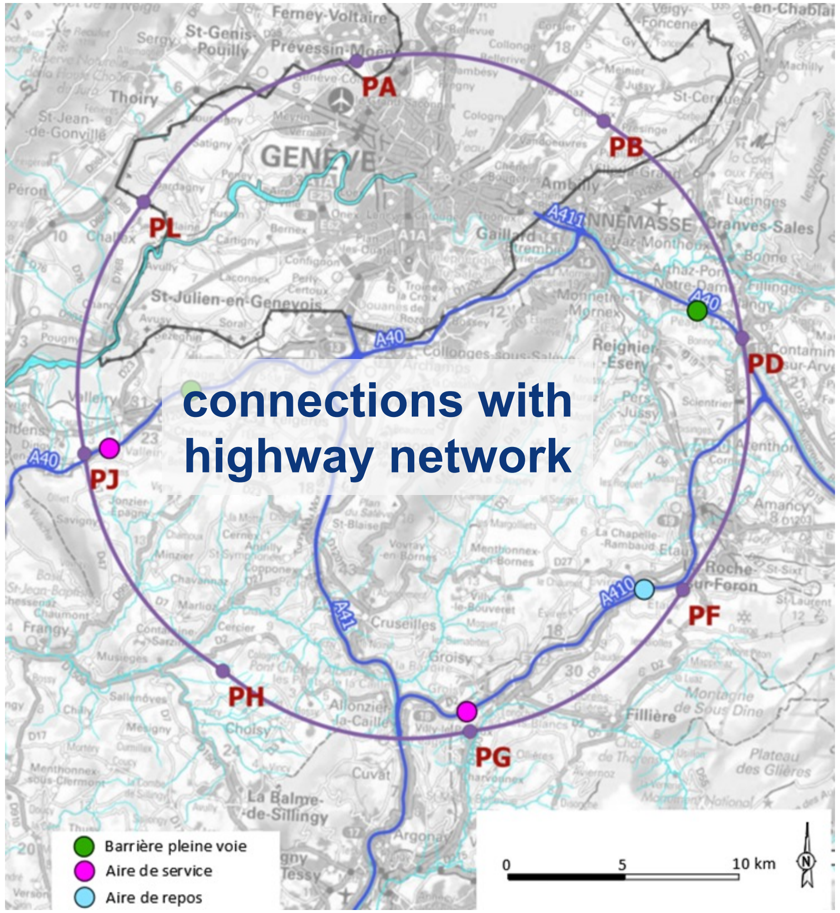
- **Site investigations in areas with uncertain geological conditions:**
  - Optimisation of localisation of drilling locations ongoing with site visits since end 2022.
- **Contracts Status:**
  - Contract for engineering services and role of Engineer during works, active since July 2022
  - Contracts for drillings and seismics in final negotiation round.
  - Start of work in Q2/2024.

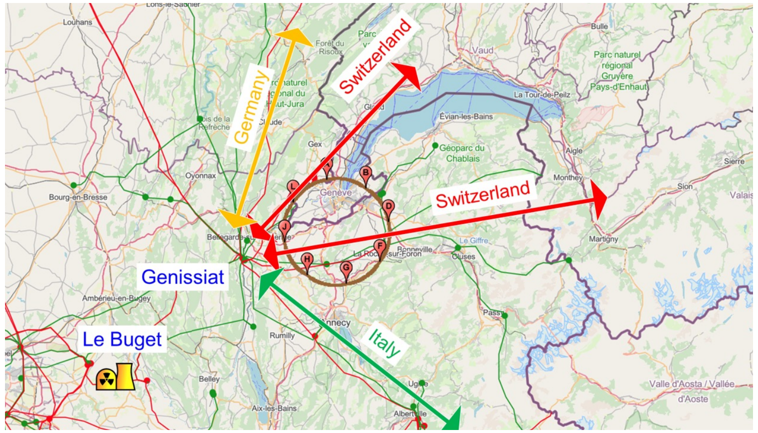
Sondage A89 (2007) incliné de 45° de 125 ml (surface plateforme estimée : 12 x 12 m soit environ 150 m²)

Drilling works on the lake

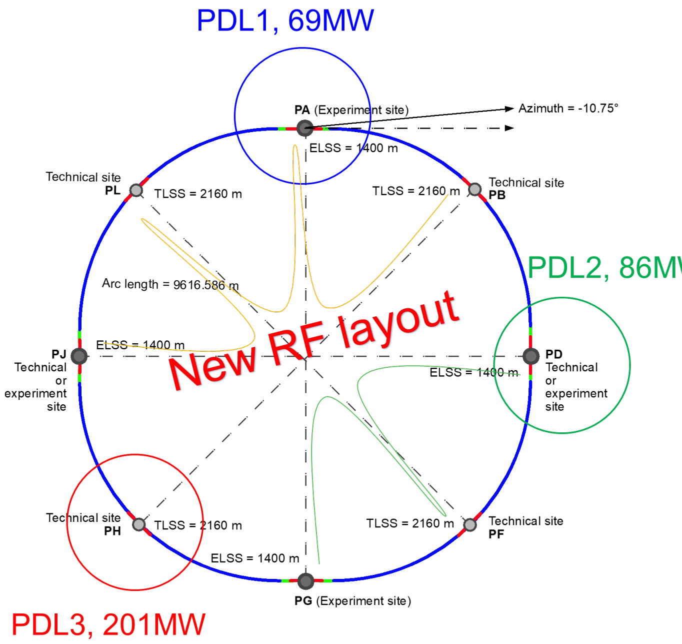
Connections with regional infrastructure

- Road accesses developed for all 8 surface sites
- Four possible highway connections defined
- Less than 4 km new departmental roads required





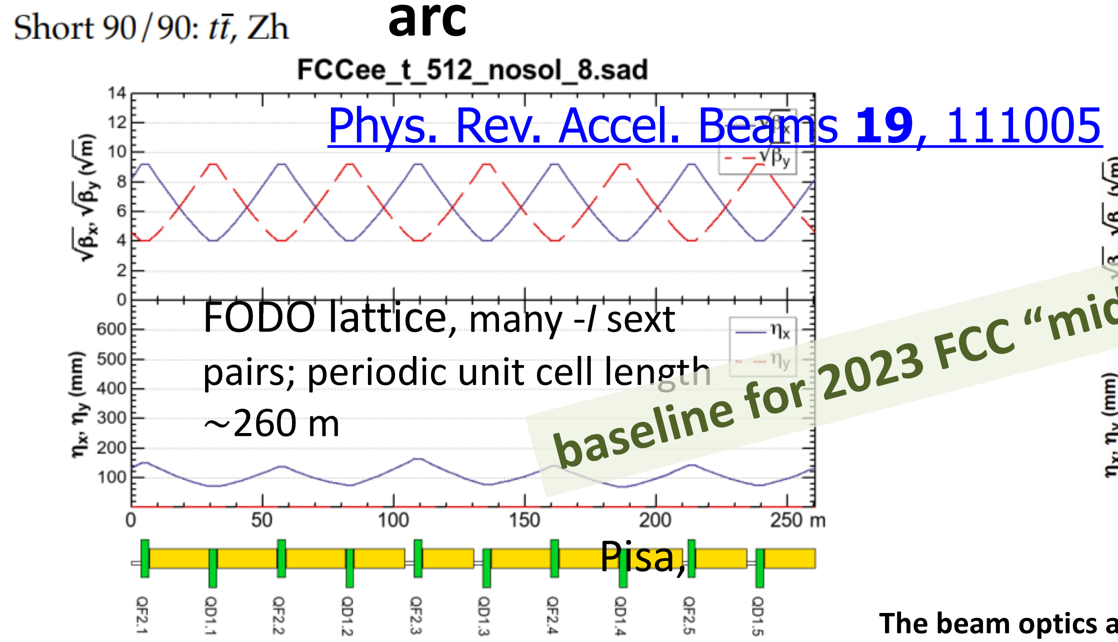
connections to French electrical grid



- **Electrical connection concept studied by RTE (French electrical grid operator) ➔ requested loads have no significant impact on grid**
- **Powering concept and power rating of the three sub-stations compatible with FCC-hh**
- **R&D efforts aiming at further reduction of the energy consumption of FCC-ee and FCC-hh**

FCC-ee collider optics development: 2 options

arc

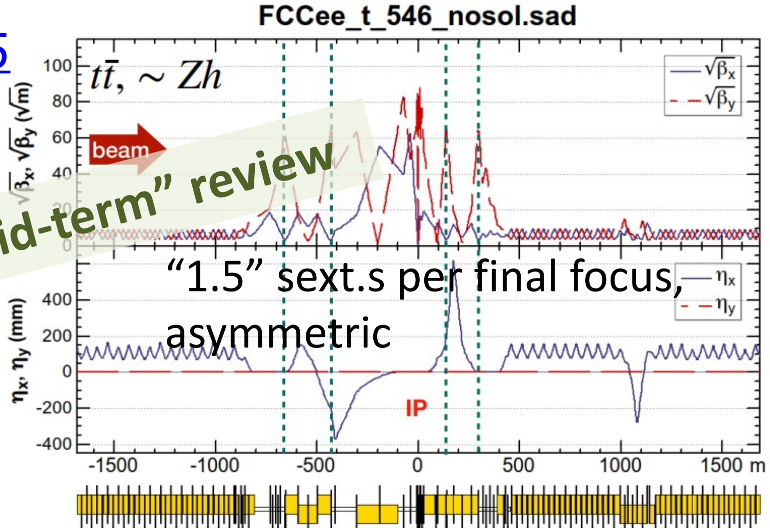


Phys. Rev. Accel. Beams **19**, 111005

FODO lattice, many -*I* sext pairs; periodic unit cell length ~260 m

Pisa,

interaction region

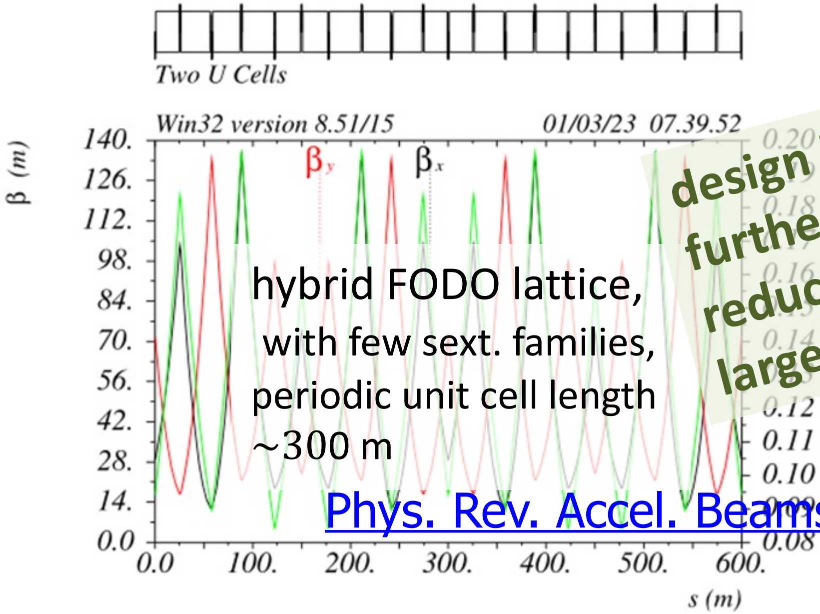


“1.5” sext.s per final focus, asymmetric

baseline for 2023 FCC “mid-term” review

The beam optics are asymmetric between upstream/downstream due to crossing angle & suppression of the SR upstream to the IP

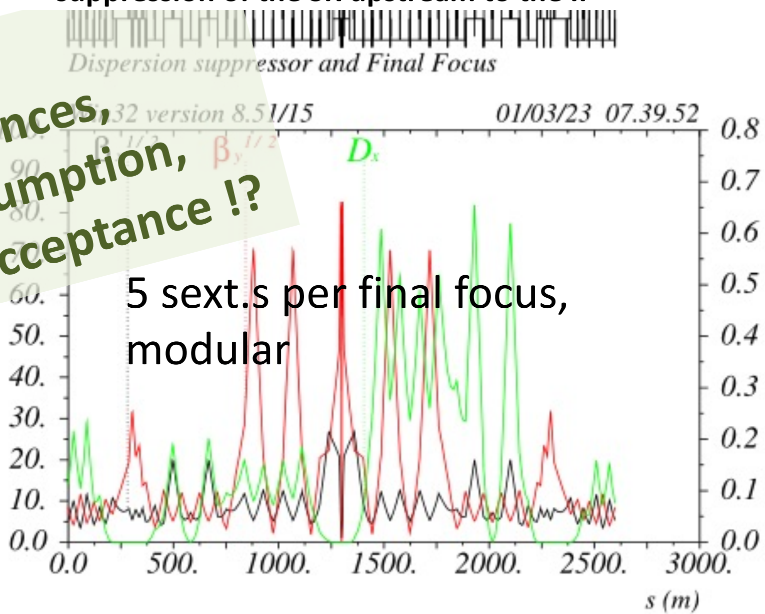
K. Oide, 2023 EPS
Rolf Wideroe award winner



hybrid FODO lattice, with few sext. families, periodic unit cell length ~300 m

Phys. Rev. Accel. Beams **26**, 021601

design in progress - further relaxed tolerances, reduced power consumption, larger momentum acceptance !?



5 sext.s per final focus, modular

P. Raimondi, 2017 EPS
Gersh Budker award winner

FCC-ee: main machine parameters

Parameter	Z	WW	H (ZH)	ttbar
beam energy [GeV]	45.6	80	120	182.5
beam current [mA]	1270	137	26.7	4.9
number bunches/beam	11200	1780	440	60
bunch intensity [10^{11}]	2.14	1.45	1.15	1.55
SR energy loss / turn [GeV]	0.0394	0.374	1.89	10.4
total RF voltage 400/800 MHz [GV]	0.120/0	1.0/0	2.1/0	2.1/9.4
long. damping time [turns]	1158	215	64	18
horizontal beta* [m]	0.11	0.2	0.24	1.0
vertical beta* [mm]	0.7	1.0	1.0	1.6
horizontal geometric emittance [nm]	0.71	2.17	0.71	1.59
vertical geom. emittance [pm]	1.9	2.2	1.4	1.6
horizontal rms IP spot size [μm]	9	21	13	40
vertical rms IP spot size [nm]	36	47	40	51
beam-beam parameter ξ_x / ξ_y	0.002/0.0973	0.013/0.128	0.010/0.088	0.073/0.134
rms bunch length with SR / BS [mm]	5.6 / 15.5	3.5 / 5.4	3.4 / 4.7	1.8 / 2.2
luminosity per IP [10^{34} $cm^{-2}s^{-1}$]	140	20	5.0	1.25
total integrated luminosity / IP / year [ab^{-1}/yr]	17	2.4	0.6	0.15
beam lifetime rad Bhabha + BS [min]	15	12	12	11
	4 years 5 x 10^{12} Z LEP x 10^5	2 years > 10^8 WW LEP x 10^4	3 years 2 x 10^6 H	5 years 2 x 10^6 tt pairs

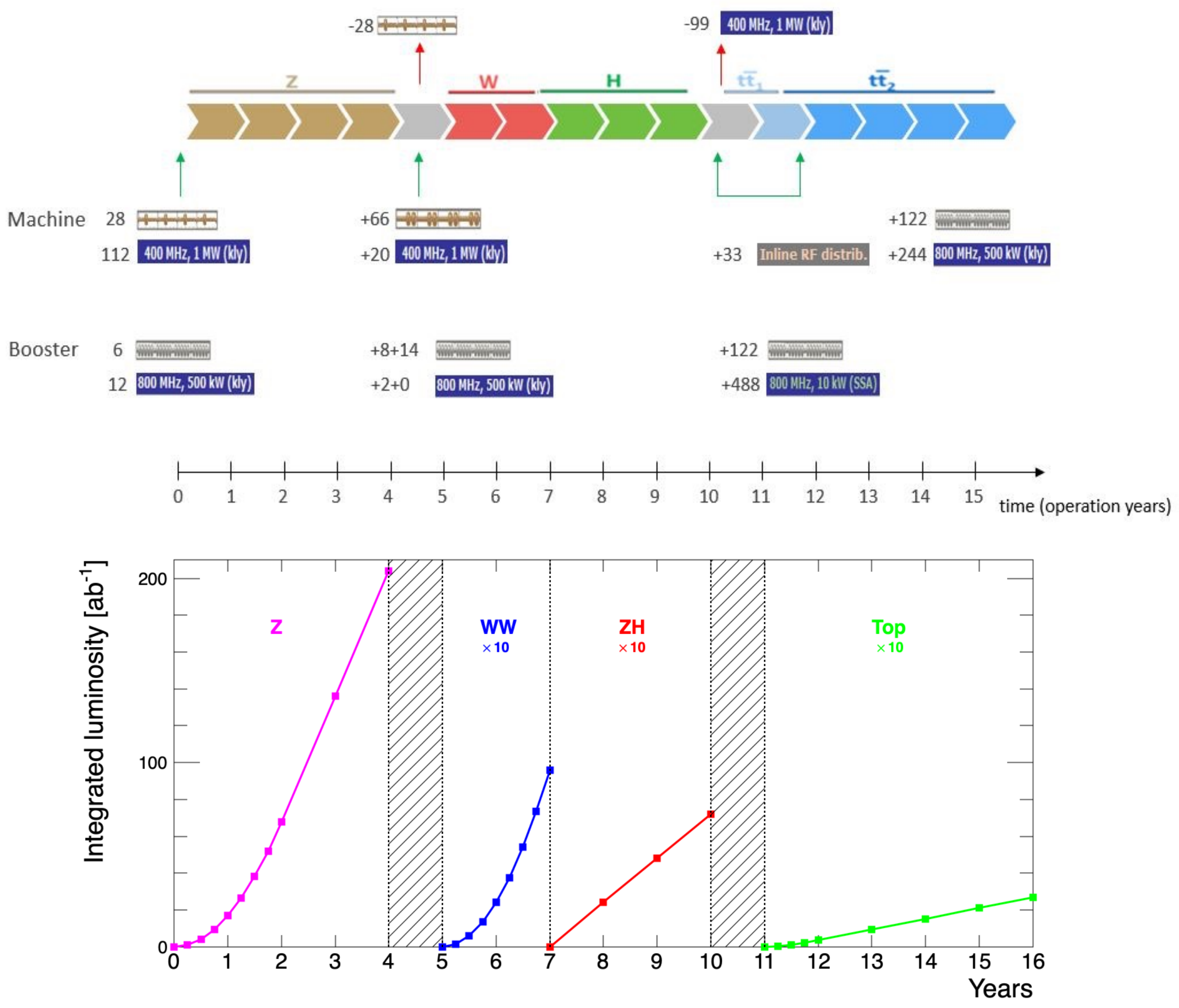
Design and parameters dominated by the choice to allow for 50 MW synchrotron radiation per beam.

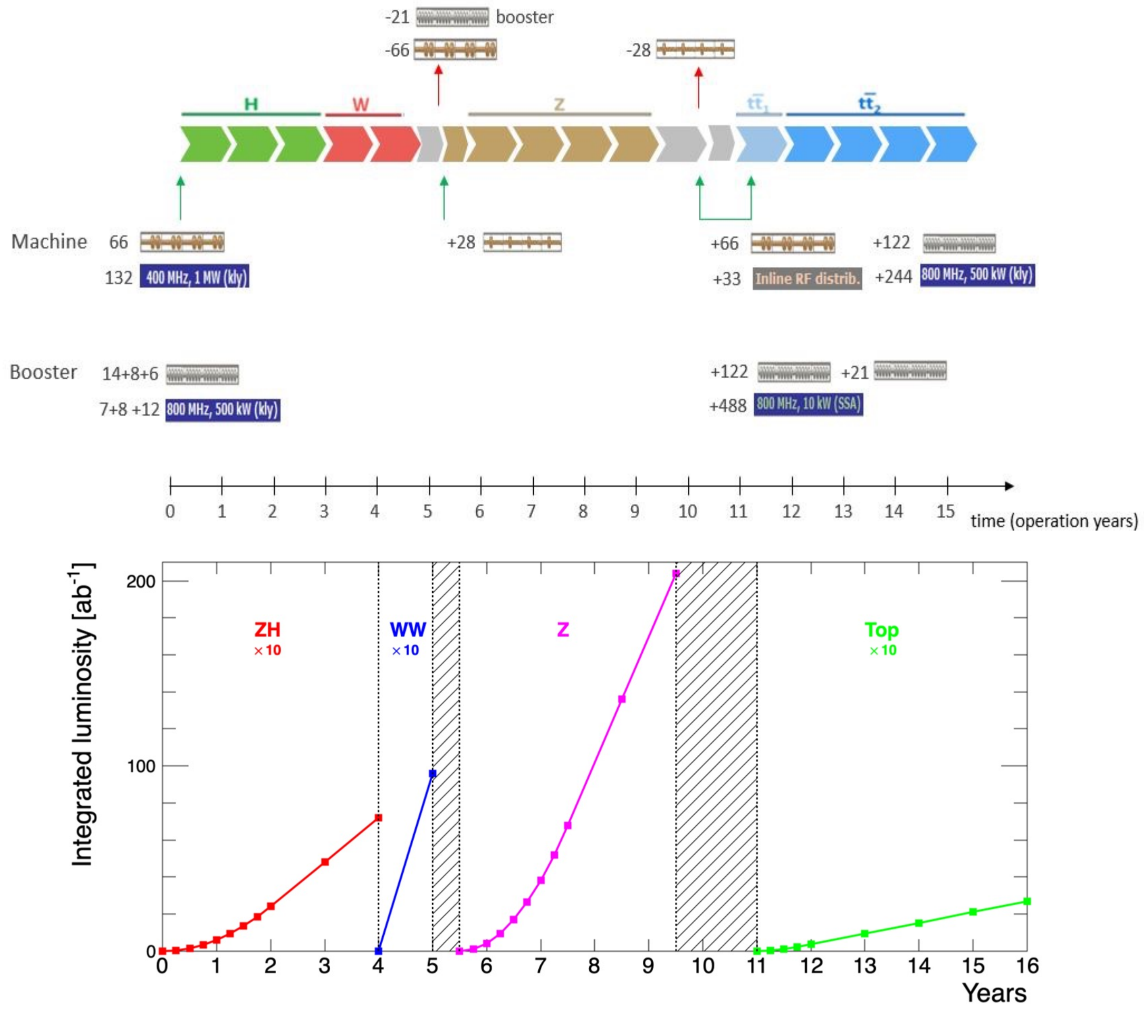
- x 10-50 improvements on all EW observables
- up to x 10 improvement on Higgs coupling (model-indep.) measurements over HL-LHC
- x10 Belle II statistics for b, c, τ
- indirect discovery potential up to ~ 70 TeV
- direct discovery potential for feebly-interacting particles over 5-100 GeV mass range

Up to 4 interaction points → robustness, statistics, possibility of specialised detectors to maximise physics output

F. Gianotti

Operational sequences for FCC-ee and RF configuration





- **Evolution of RF configuration of collider and booster with beam energies and physics operation points**
- **Long-term R&D for SRF, in particular for the 800 MHz system**

RF R&D activities

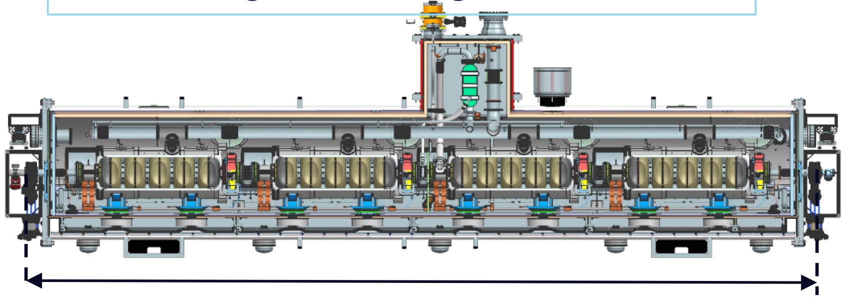
RF system R&D is key for increasing energy efficiency of FCC-ee

- Nb on Cu 400 MHz cavities, seamless cavity production, coating techniques
- Bulk Nb 800 MHz cavities, surface treatment techniques, cryomodule design
- RF power source R&D in synergy with HL-LHC.

800 MHz cavity and CM design

collaborations with **JLAB and FNAL**

800 MHz segmented design, based on PIP-II

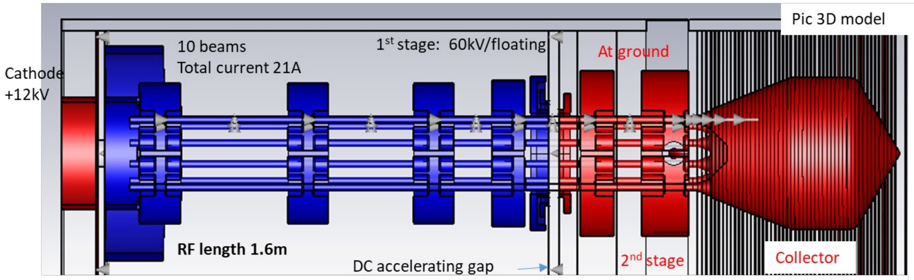


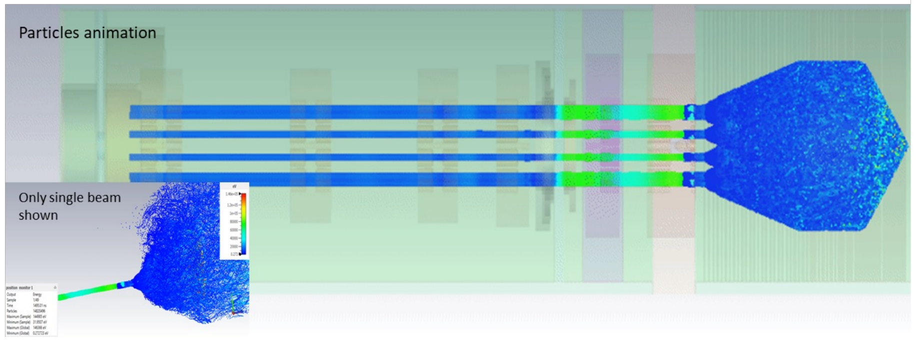
~7 m

high-efficiency klystron R&D

in collaborations with **THALES & CANON**

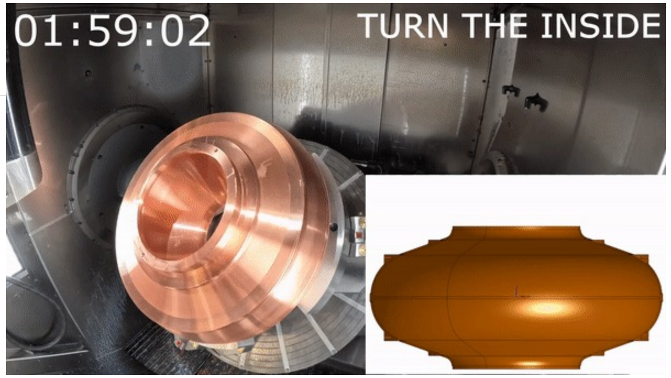
Novel two-stage MBK klystron: CW, 400MHz, 1.28MW.

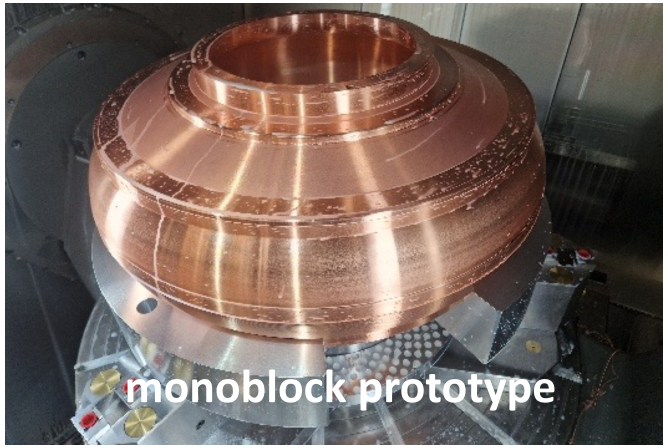




400 MHz cavity production

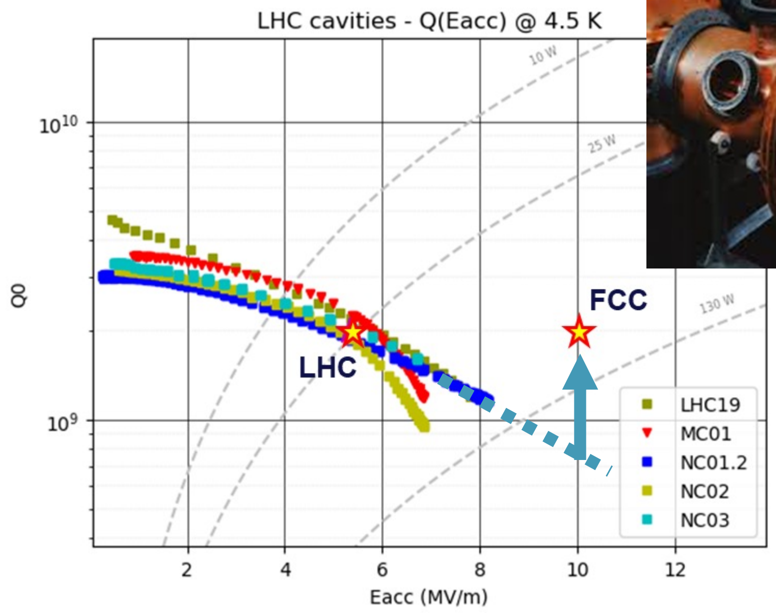
in collaboration with **KEK**





Thin film SRF cavities R&D @LNL

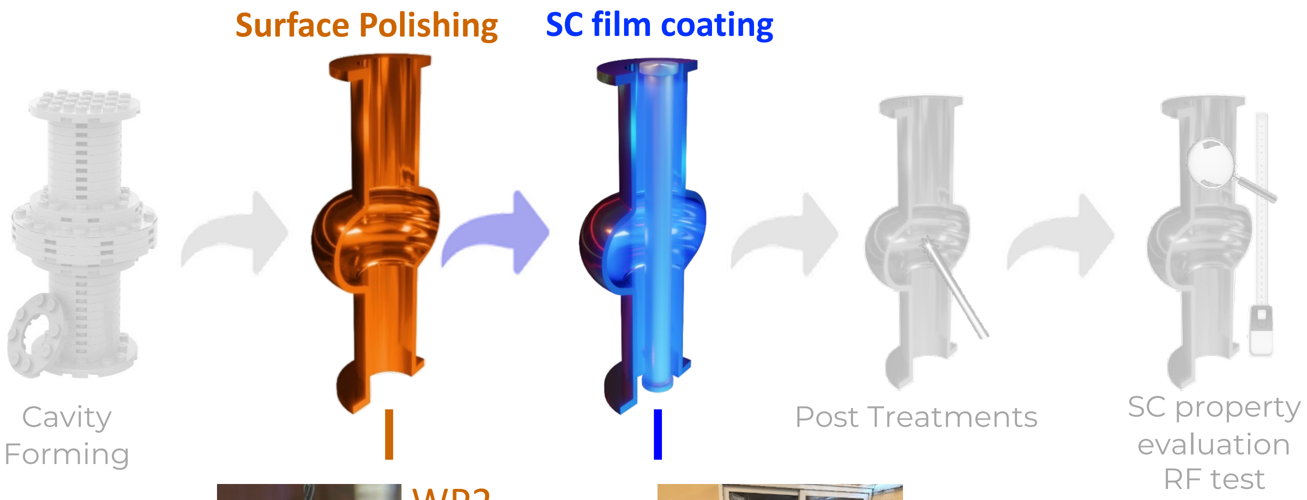
Cristian Pira (LNL)



FCC-ee requires
higher cavities performances rather than LHC

To increase Q at High Field

Mandatory improve all production steps



WP2
Plasma
Electrolytic
Polishing

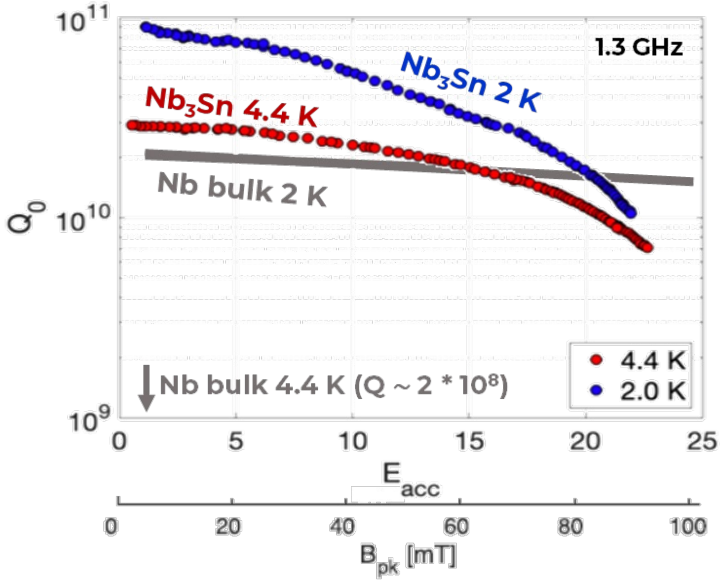
WP1
Nb_3Sn on Cu Coatings

SRF **R**&D for **F**CC-ee project funded by by INFN executive board (ESPPU special funds) for R&D on Nb_3Sn coatings and Cu surface polishing by PEP in collaboration with CERN (W. Venturini and G. Rosaz)

INFN-CERN MOU is in preparation

Thin film SRF cavities R&D @LNL – Nb_3Sn coatings

Cristian Pira (LNL)



S. Posen, SRF 2019 proceedings (elaborated)

Nb_3Sn on Nb

- Nb_3Sn has a Tc of about 18 K (Nb = 9.2 K)
- which allows maximizing Q values at 4.5 K (FCC operating Temperature)
- Q Nb_3Sn @ 4.5 K ~ Q Nb @ 2K
- Nb_3Sn on Nb by Vapor Tin Diffusion already tested successfully on 1.3 GHz at Fermilab, Cornell and JLab
- Technology not scalable to FCC 400 MHz cavities because of bulk Nb high cost

Nb_3Sn on Cu

R&D in progress on 1.3 GHz @LNL and CERN

ADVANTAGES:

- Cu Cheaper than Nb
- Higher thermal conductivity
- Higher mechanical stability
- Same PVD technology used for LHC

Nb_3Sn coating by Physical Vapor Deposition (PVD)

FIRST RESULTS by LNL (preliminary) on a Quadrupole Resonator:

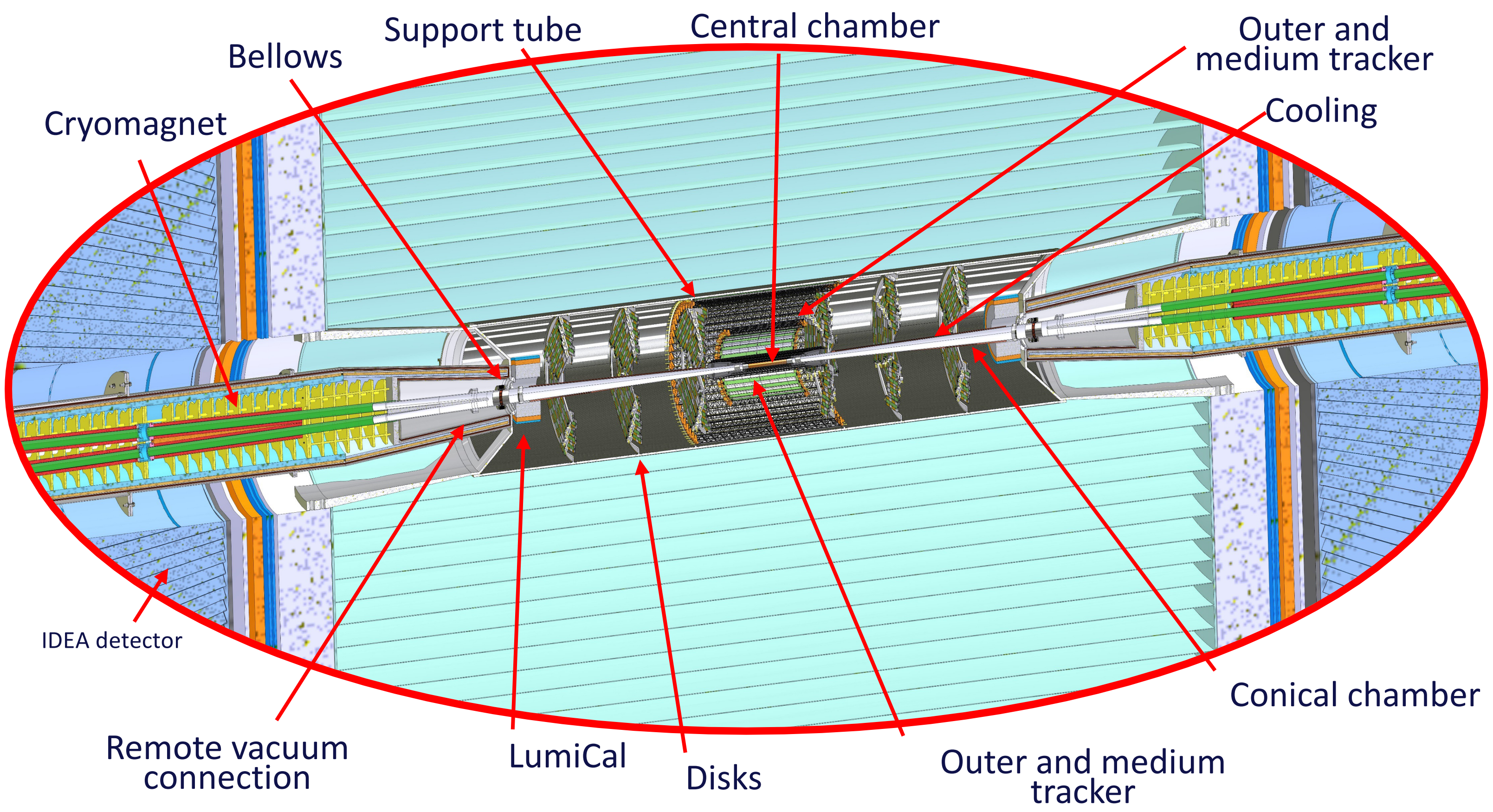
@20 mT @400 MHz @4.5K

Rs= 23 nΩ → Q = 1*10^{10}

1 order of magnitude better than LHC!

$Q_{LHC\ Nb\ on\ Cu}$= 2*10^9

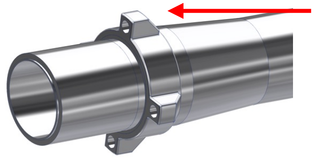
FCC-ee engineered Interaction Region



F. Fransesini

Design in continuous optimization:

- vacuum chamber copper cooling manifolds replaced by AlBeMet to minimize showers in the LumiCal

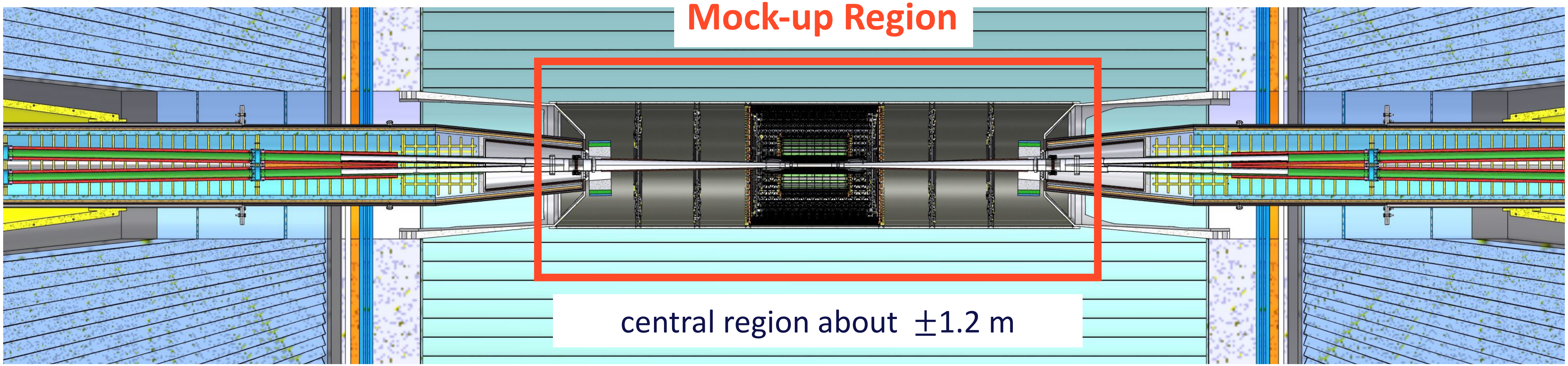


- More advanced and detailed studies on vertex detector integration
- IR magnet system to be integrated
- Remote vacuum connection to be designed

- Crucial area: a full-scale mockup assembly has started

Ref: M. Boscolo, F. Palla, et al., *Mechanical model for the FCC-ee MDI,* EPJ+ Techn. and Instr., https://doi.org/10.1140/epjti/s40485-023-00103-7

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:

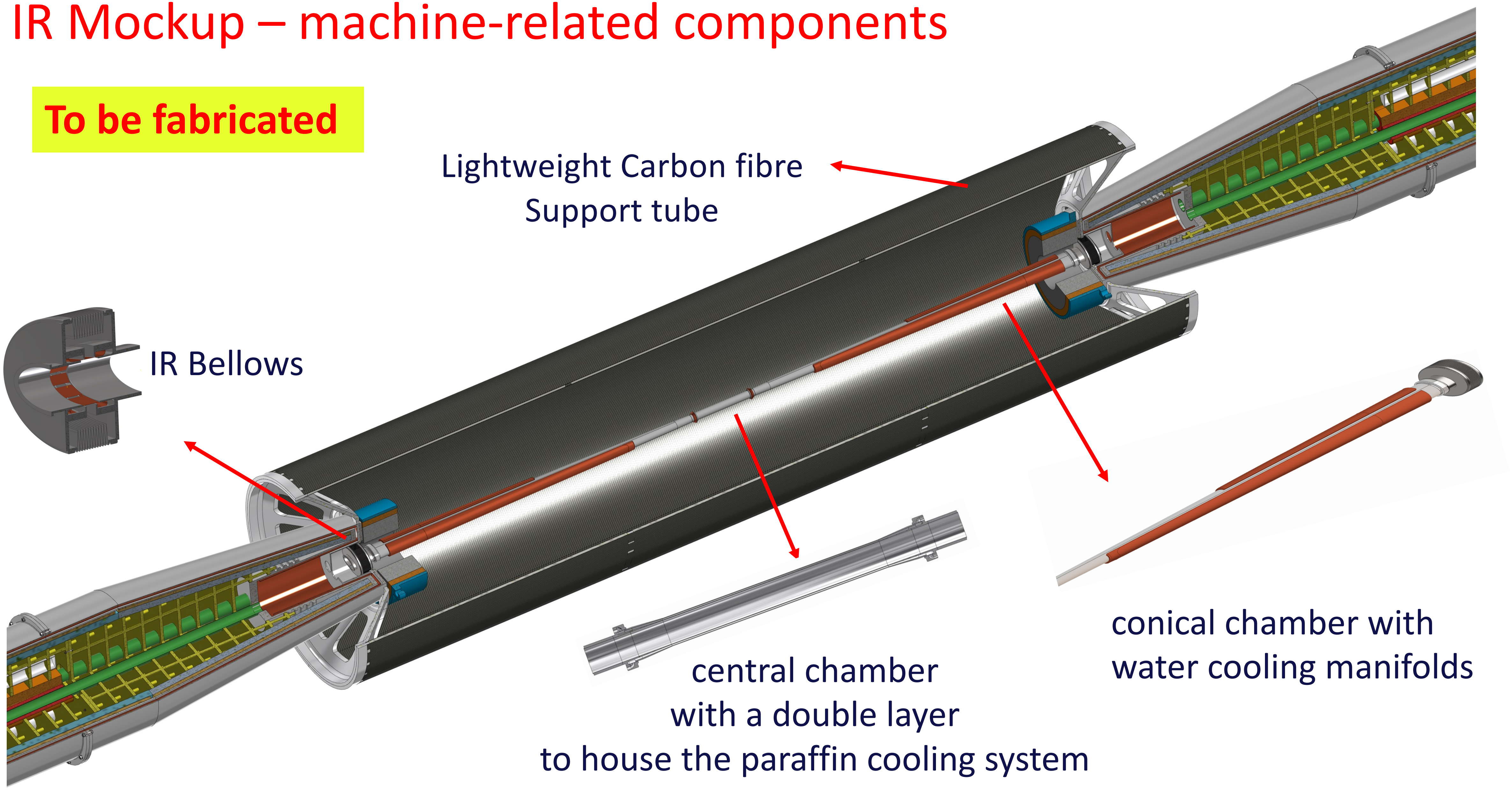
Starting date	1.11.2023
Delivery to INFN-LNF of the central vacuum chamber	30.11.2024
End date	31.12.2025

The mockup project has received a great deal of interest within the FCC community

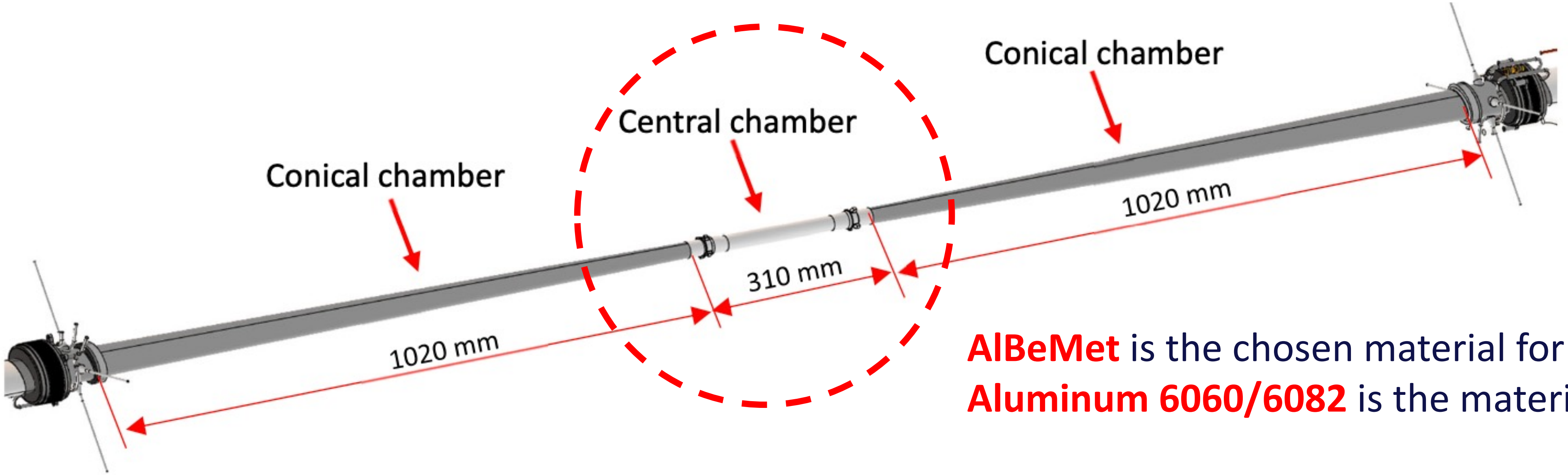
- primarily for technology validation of the MDI design for the Feasibility Study
- Integrating vertex and chambers "on paper" has been proven to be difficult, more surprises expected with a real mock-up!
- Global assembly sequence to be studied

IR Mockup – machine-related components

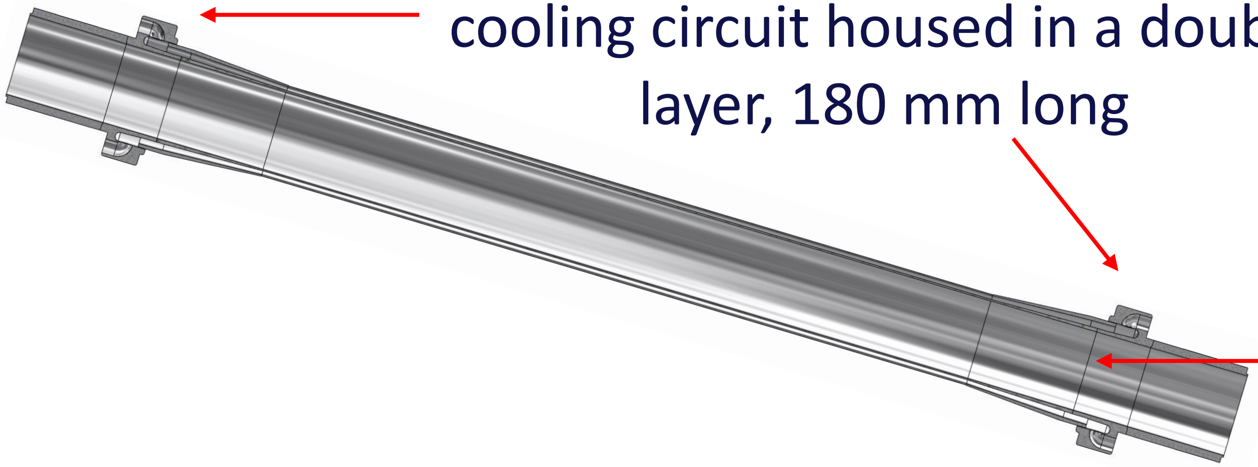
To be fabricated



Central Vacuum Chamber



AlBeMet is the chosen material for the FCC-ee IR
Aluminum 6060/6082 is the material for the mock-up



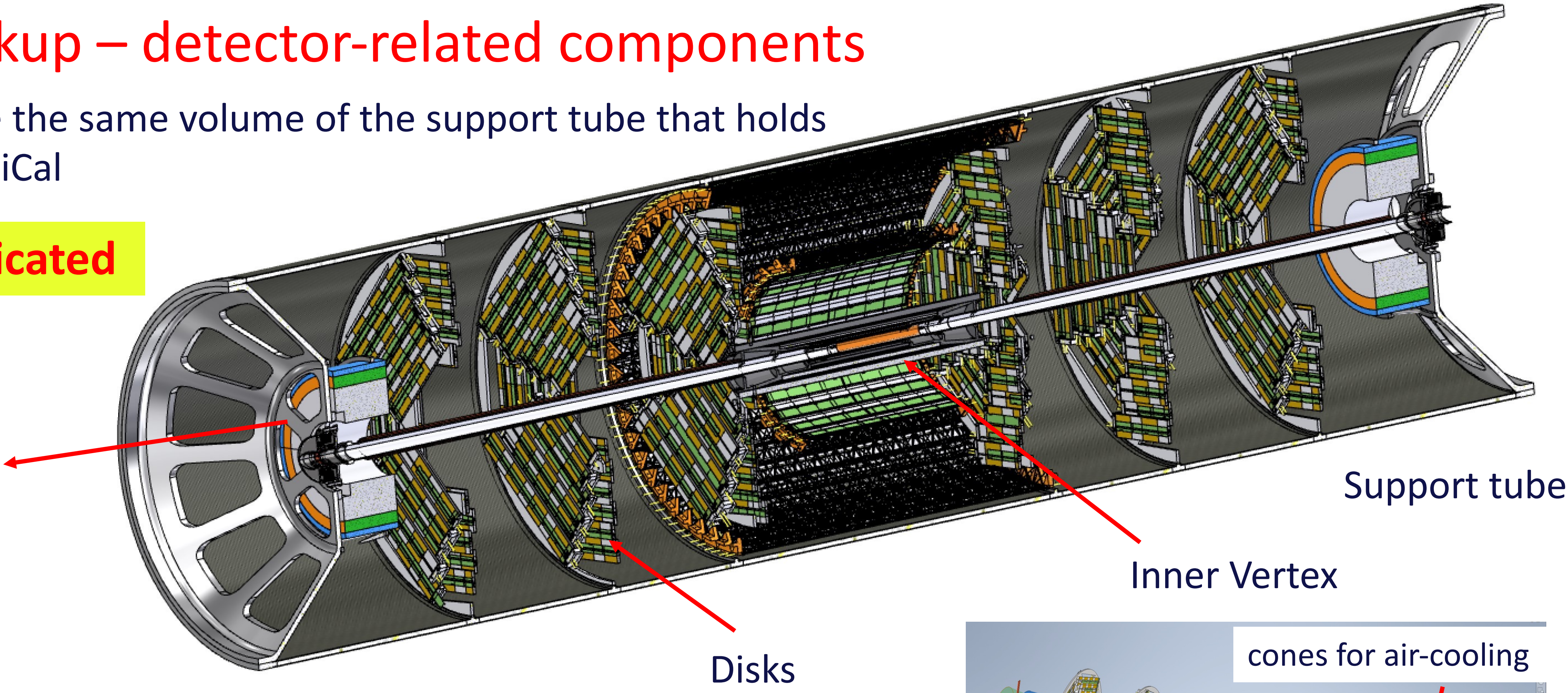
Inlets/outlets for the paraffin cooling circuit housed in a double layer, 180 mm long

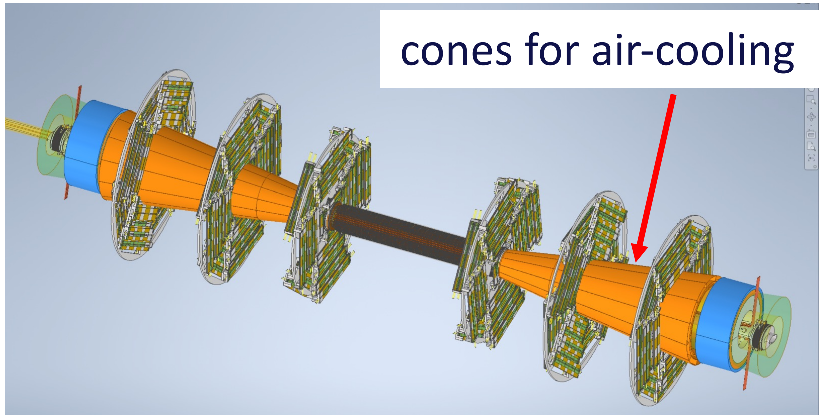
Circular to elliptical transition

IR Mockup – detector-related components

Vertex inside the same volume of the support tube that holds also the LumiCal

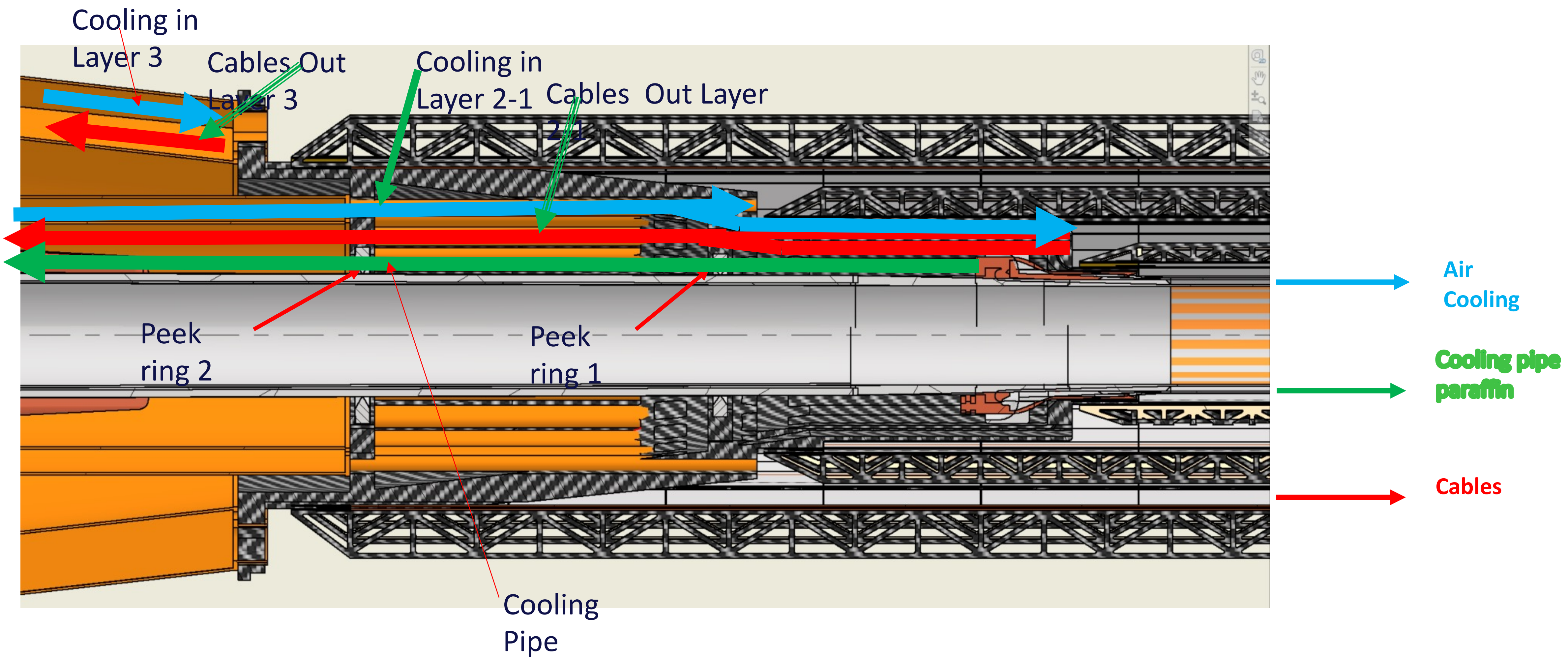
To be fabricated





Integration of the inner vertex with conical vacuum chamber

- cables and cooling pipes integration



FCC-ee MDI & IR Mock-up Workshop

16-17 November 2023, Frascati

FUTURE CIRCULAR COLLIDER

FCC-ee MDI & IR mockup Workshop

16–17 Nov 2023
Laboratori Nazionali di Frascati
Europe/Rome timezone

Enter your search term

Welcome to the FCCIS MDI and IR mockup workshop in Frascati!

The MDI and IR mockup workshop of FCC Innovation Study of WP2 and Task 3 will be held in Frascati, National Laboratories of INFN, from 16 to 17 November 2023.

This workshop will focus on Machine-Detector-Interface studies and on the IR mockup, covering topics such as:

- IR mockup critical concepts,
- Beam losses in the IR,
- Synchrotron radiation,
- IR HOM calculations,
- Vertex detector integration & cooling,
- Accelerator and detector constraints in the IR.

We are looking forward to seeing you in Frascati !

- Overview
- Timetable
- Registration
- Participant List
- Committees
- Hotel suggestions
- Privacy Policies
- Zoom Conference Room
- Wifi Internet Access

Contacts
fcc.secretariat@cern.ch
fcc.logistics@lists.lnf.infn.it

FCCIS – The Future Circular Collider Innovation Study. This INFRADEV Research and Innovation Action project receives funding from the European Union's H2020 Framework Programme under grant agreement no. 951754.

Starts 16 Nov 2023, 08:00
Ends 17 Nov 2023, 17:15
Europe/Rome

Laboratori Nazionali di Frascati
Aula Salvini
Via Enrico Fermi, 60, 00044 Frascati RM, Italie
Go to map

FRANK ZIMMERMANN
Manuela Boscolo

There are no materials yet.

https://agenda.infn.it/event/37720/

Scientific scope and motivation, technical details, and project timeline discussed at the workshop.

FCCIS 2023 Annual Workshop

13-15 November 2023, Rome

https://indico.cern.ch/event/1326738/

MDI Status & Plans, link

Part of the FCC-ee MDI activity is financed by FCCIS EU-H2020 project

News Link

INFN LNF Istituto Nazionale di Fisica Nucleare

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Home » In evidenza » Due workshop internazionali sul disegno del collisore FCC-ee a Roma e Frascati

DUE WORKSHOP INTERNAZIONALI SUL DISEGNO DEL COLLISORE FCC-EE A ROMA E FRASCATI

6 Dicembre 2023 In evidenza, News

I partecipanti all'MDI Workshop a Frascati di fronte all'edificio dell'acceleratore DAFNE

Due importanti workshop internazionali si sono svolti in area romana a metà novembre sul progetto del futuro collisore circolare di elettroni e positroni del CERN, FCC-ee.

Il primo dei due, "**FCCIS Collider Design Workshop**", si è svolto a Roma presso il centro congressi dell'**Angelicum**, ed ha raccolto fisici degli acceleratori dai laboratori più prestigiosi al mondo, tra i quali CERN, SLAC, BNL, DESY, KEK, LNF per discutere di questioni ancora aperte sul disegno di macchina e presentarne lo stato di avanzamento dei lavori. Il congresso che si è svolto è il quarto del progetto europeo finanziato da Horizon 2020 *Future Circular Collider Innovation Study*, FCCIS. L'agenda è disponibile al link: https://indico.cern.ch/event/1326738/.

Le discussioni avvenute si sono inserite perfettamente con la tempistica di valutazione dell'intero progetto FCC, che ha visto una prima valutazione intermedia (*mid-term review)* da parte di un comitato internazionale di esperti che ha valutato lo stato di avanzamento e la stima dei costi. Si sono gettate quindi le basi per la programmazione dello studio dei prossimi due anni, che saranno cruciali per la decisione da parte del CERN per l'approvazione finale di FCC.

Il grande interesse dei fisici italiani e il supporto dell'INFN per FCC sono stati espressi dal membro di Giunta Esecutiva INFN Pierluigi Campana e dal presidente della Commissione Scientifica Nazionale 1, Roberto Tenchini. Nel suo intervento Campana ha illustrato i piani di finanziamento dell'INFN sui progetti di ricerca e sviluppo previsti per la prossima European Particle Physics Strategy Update (EPPSU), di cui due su FCC-ee: uno sul mockup della regione di interazione, l'altro sulle cavità superconduttive a radiofrequenza. Nell'altro intervento Tenchini ha illustrato il forte interesse da parte della comunità sperimentale italiana per FCC-ee che permetterà di effettuare misure di precisione all'Higgs, alla Z, al ttbar, nonché la prospettiva di poter utilizzare l'infrastruttura del tunnel da 100 km per una macchina adronica che potrà raggiungere fino a 100 TeV di energia nel centro di massa.

Il secondo workshop si è svolto presso i laboratori nazionali di Frascati nei due giorni successivi della settimana, 16 e 17 novembre il "**FCC-ee MDI & IR Mockup Workshop**".

Il congresso è stato dedicato alla discussione del disegno della regione di interazione (IR) di FCC-ee con i punti ancora aperti come quello del sistema dei magneti superconduttori interni al rivelatore e al disegno del loro criostato, l'integrazione con il rivelatore ed in particolare con il vertex detector, oltre agli studi per i fondi. Sono stati discussi inoltre gli obiettivi e lo stato del progetto di R&D per un prototipo 1:1 della IR cofinanziato dal CERN e dall'INFN. L'agenda è disponibile al link: https://agenda.infn.it/event/37720/.

Le discussioni scientifiche, improntate ad uno spirito collaborativo, hanno identificato le soluzioni più innovative per la migliore regione di interazione per la prossima macchina leptonica da costruirsi in Europa.

Frank Zimmermann nella sua prolusione ha sottolineato l'importanza del laboratorio nella nascita dei collisori e+e- ed ha auspicato che DAFNE, fiore all'occhiello dei laboratori, possa diventare una "*Open Accelerator Test Facility*".

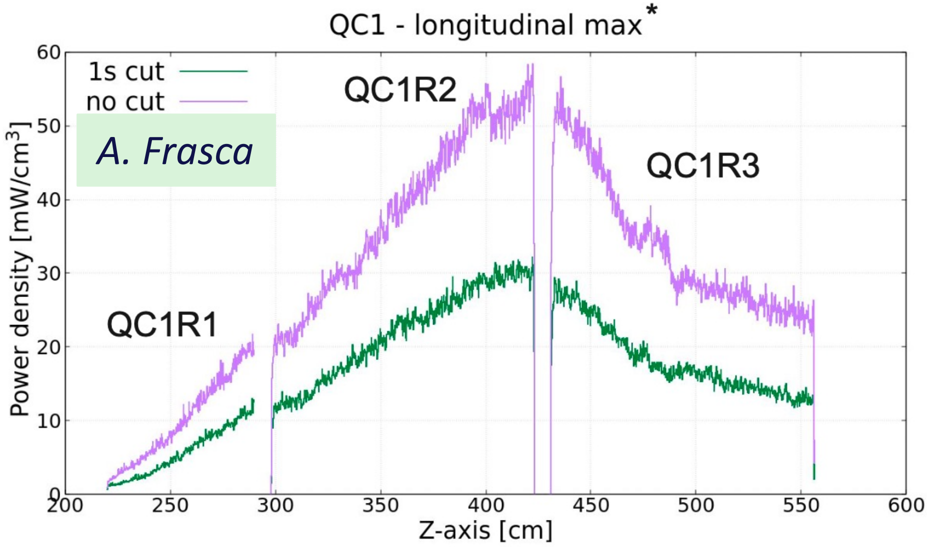
Entrambi gli eventi sono stati organizzati da Manuela Boscolo dei LNF, responsabile scientifica per l'INFN di FCCIS e convener delle attività di macchina per FCC, insieme al *deputy study leader* Frank Zimmermann del CERN. Essenziale è stato il supporto segreteria dell'INFN-Roma1 per l'evento all'Angelicum, e della segreteria della divisione acceleratori per quello ai LNF.

Share | Facebook | Twitter

Beam losses, Backgrounds & Radiation

Ongoing simulations on various background sources, few examples of recent updates below

Fluka studies of Radiative Bhabhas



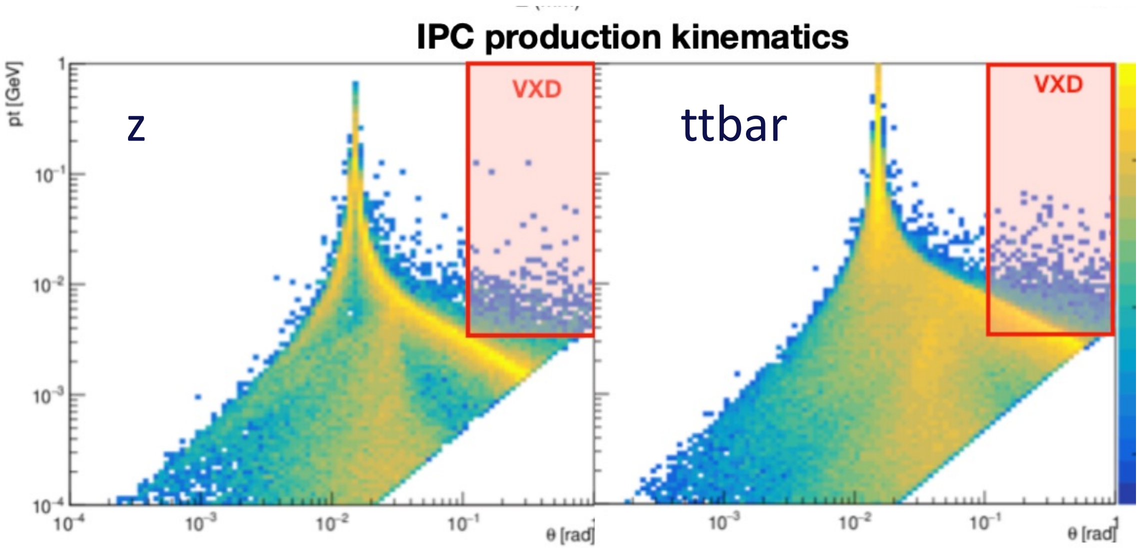
*rφz mesh: bins 0.5mm*2°*2mm

- Estimated power deposition **~10 mW/cm³**
- Estimated dose **~10 MGy/y** inside the superconducting FFQs
- **Internal shielding must be developed to avoid quenches**

Luminosity Backgrounds

A. Ciarma

Incoherent Pairs Creation (IPC)



	Z	WW	ZH	Top
Bunch spacing [ns]	30	345	1225	7598
Max VXD occ. 1us	2.33e-3	0.81e-3	0.047e-3	0.18e-3
Max VXD occ.10us	23.3e-3	8.12e-3	3.34e-3	1.51e-3
Max TRK occ. 1us	3.66e-3	0.43e-3	0.12e-3	0.13e-3
Max TRK occ.10us	36.6e-3	4.35e-3	1.88e-3	0.38e-6

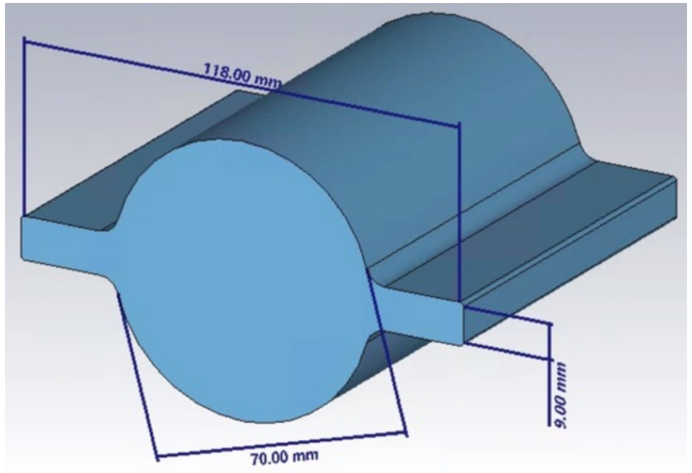
Collective effects for FCC-ee

M. Migliorati et al. (Sapienza & INFN)

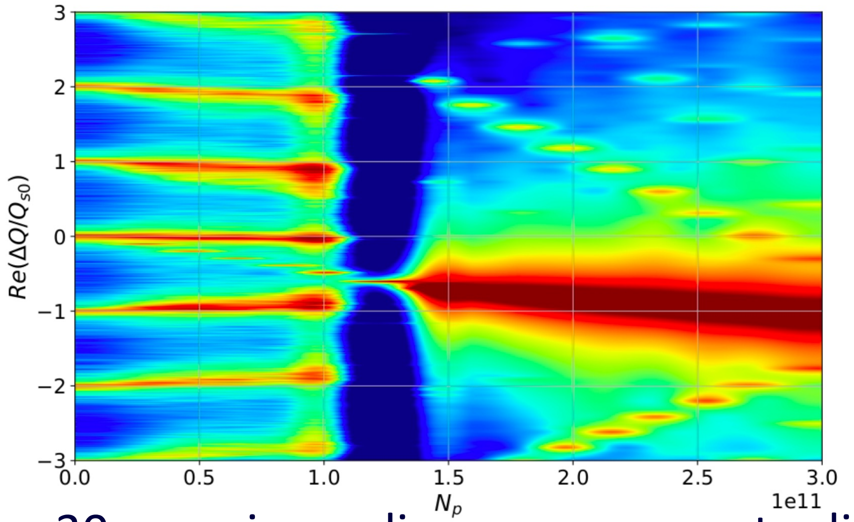
Resistive wall

It is the largest impedance source for FCC-ee evaluated so far. NEG coating is needed to mitigate the electron cloud build-up in the positron machine and for pumping reasons in both rings.

A beam pipe radius reduction (35 mm → 30 mm) is now requested to reduce power consumption in quads and sexts



This would increase the transverse dipolar impedance by 60%

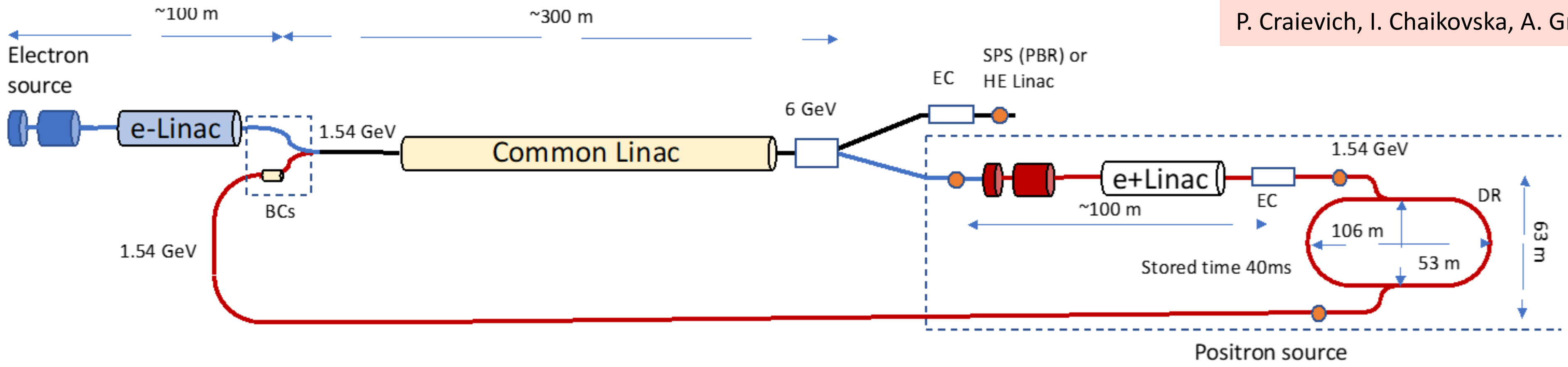


30 mm pipe radius, new parameter list

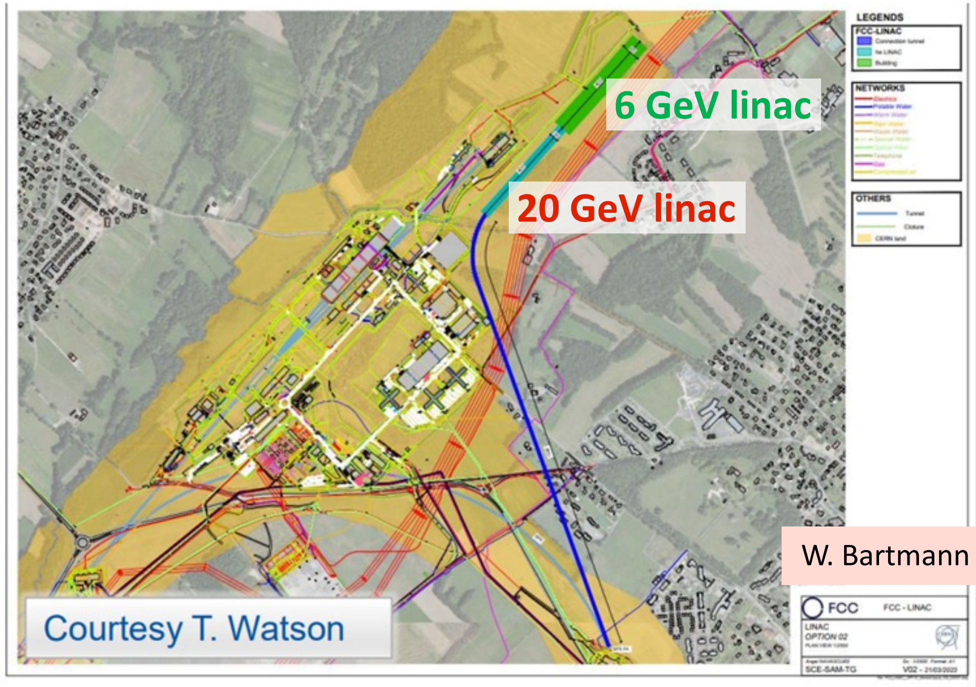
Due to the updated parameter list, the bunch population is higher and, even if the TMCI thresholds are similar, with the 30 mm radius the instability is much stronger.

FCC-ee injector layout & implementation

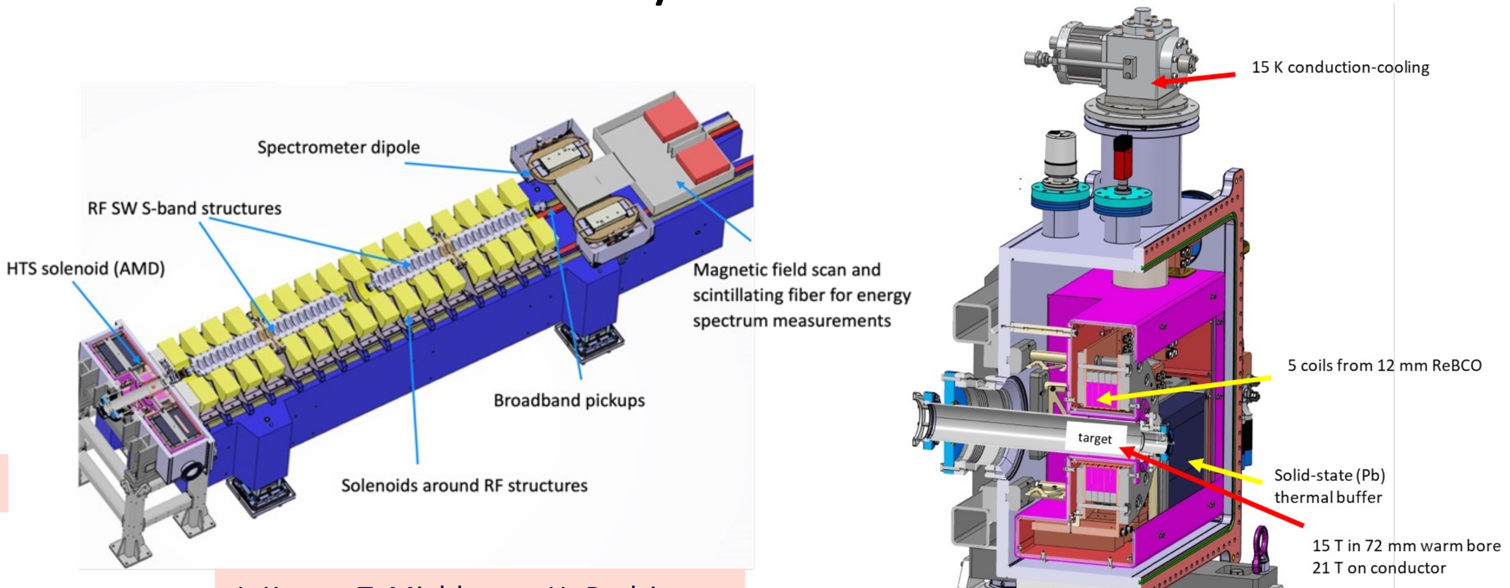
P. Craievich, I. Chaikovska, A. Grudiev, C. Milardi, et al



implementation study on Prevessin site



"Positron production experiment" at PSI's SwissFEL, beam tests from 2025/26



J. Kosse, T. Michlmayr, H. Rodrigues

FCC Italia

Activity funded by CSN1 within **RD_FCC**
National Responsible Paolo Giacomelli (Bologna) since this year 2024
Activity organized in WP:

- **WP1 Physics & software** — P. Azzi PD, N. De Filippis BA
- **WP2 Acceleratore** — M. Boscolo **LNF** — **Lab and sections: LNF, LNL, Roma-1, Pisa, Fe, Mi, Pg, Ge**
- **WP3 Silicon/Vertex detectors** — A. Andreazza MI, F. Palla PI
- **WP4 Drift chamber** — F. Grancagnolo LE
- **WP5 MPGD for muon/preshower** — M. Poli Lener LNF
- **WP6 Dual readout calorimetry** — R. Ferrari PV

Increase in manpower
2023: 19 units
- Researchers /Tecnologists: 151
- FTE: 30.70

2024: 19 units
- Researchers /Tecnologists: 170
- FTE: 38.20

INFN special funds to FCC for the ESPPU

Special funds have been allocated by INFN executive board to projects on future colliders, in preparation of the Next European Strategy for Particle Physics Update (ESPPU).

Two (out of five) funded projects are for FCC

- IR and MDI full-scale mockup **LNF** *Addendum CERN-INFN approved.*
- SRF cavities **LNL**

All of these funded projects are revised by the INFN MAC and approved by the INFN GE.
Activity is part of the CSN1.

FCC Feasibility Study – summary and outlook

- **The first half of the FCC Feasibility Study has been completed with the mid-term review**
  - placement & layout was defined, and entire project adapted to the new geometry
  - dialogue with local-regional actors and stakeholders for implementation established and ongoing
  - all deliverables met, list of recommendations from committees towards final Feasibility Study
- **Progress was made possible by a fruitful collaboration between scientific & technical actors, in close cooperation with the host state services concerned.**
- **Next milestone is completion of the FCC Feasibility Study by March 2025 to enable advancing project decision and project start date:**
  - Complete technical work for FCC FS by end 2024
  - Implementation of recommendations of the mid-term review with focus on “feasibility items” and items with important impact on cost/performance
  - Full design iteration in view of technical and cost optimisation of entire project.
  - Update of cost estimate
  - Further development of an affordable funding model and related governance implications (with Council).
  - Setup structure for preparatory phase

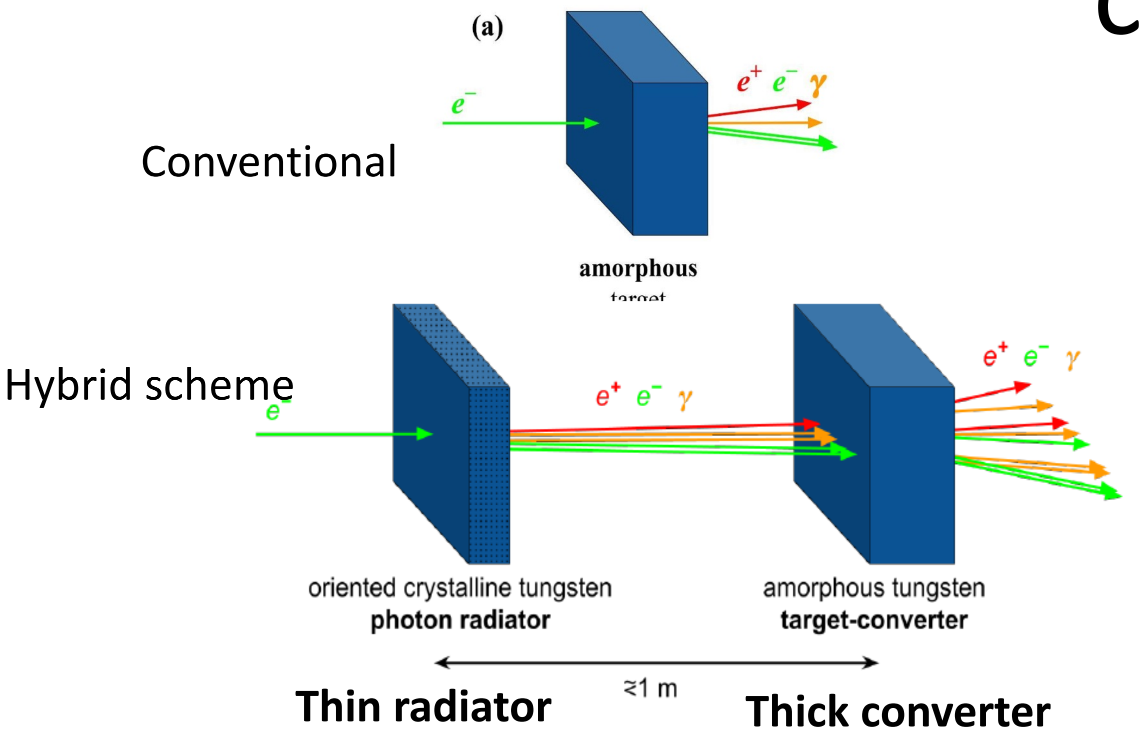
Main goals during preparatory phase until 2031/32

- **By 2027-2028, project approval, start of CE design contract:**
  - provision of requirements and specifications to enable CE tender design to start from 2028 (underground) and 2029 (surface)
  - requires overall integration study and designs based on technical pre-design of accelerators, technical infrastructure and detectors
  - refined input for environmental evaluation and project authorisation process.
- **By 2031-32, start of CE construction:**
  - CE groundbreaking
  - TDR to enable prototyping, industrialization towards component production

Thank you!

Additional

Intense positron source for based on oriented crystals



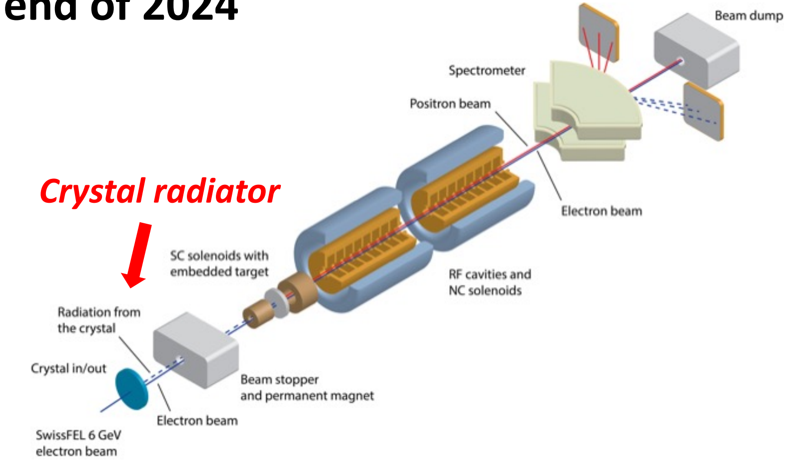
L. Bandiera et al., Eur. Phys. J. C 82 (2022) 699

Goals:

- include the design in the next FCC-ee CDR
- **Proposal for future upgrade of the CHART project on the full FCC-ee injector at PSI at the end of 2024**

PAUL SCHERRER INSTITUT PSI

CHART Swiss Accelerator Research and Technology



Hybrid vs Conventional: **higher photo-production in oriented W crystal-> possibiltity to use a shorter converter -> less deposited energy in the converter!**

INFN Units involved: Ferrara, LNL, Milano, MiB, Naple

Collaboration with the **FCC-ee Injector Studies Group** (I. Chaikovska, IJCLab)

MoU signed between in INFN Ferrara and IJLab in Sept. 2022

Funded by the European Union NextGenerationEU

Ministero dell'Università e della Ricerca — Bando PRIN 2022

e+BOOST (PI L. Bandiera) PRIN2022-2022Y87K7X

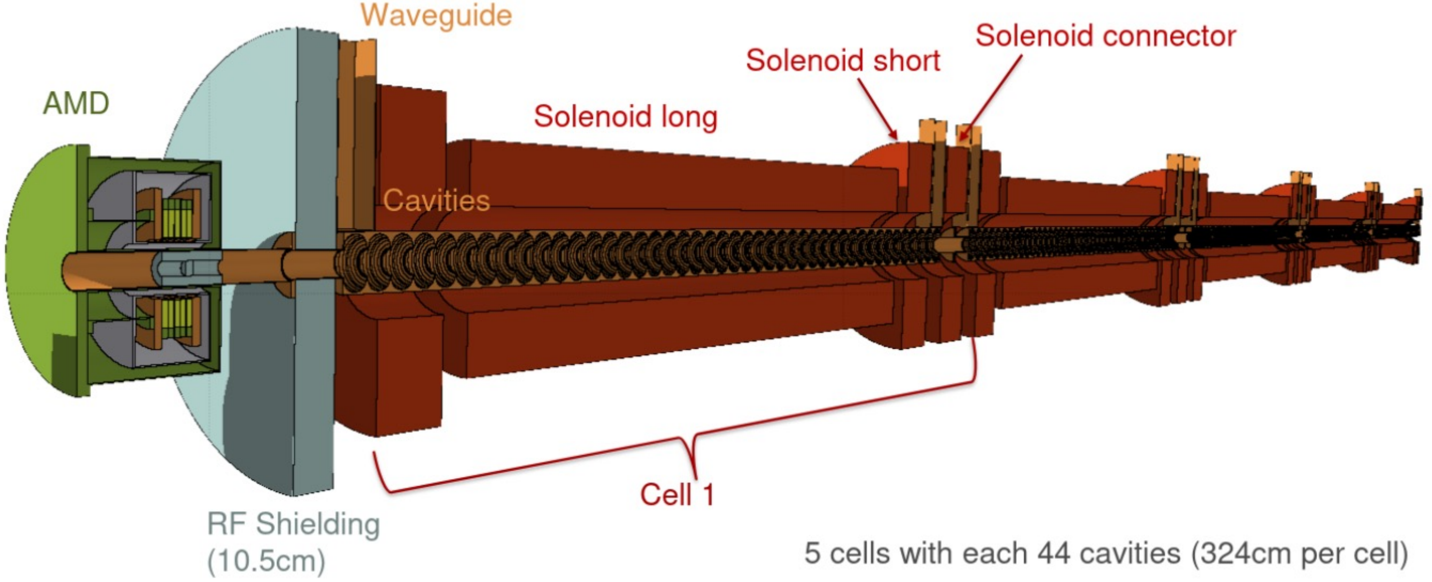
Activity born in the past CSN5 STORM project (2021-22) and CSN1 RD-MUCOL (for LEMMA), currently in CSN1 RD-FCC

FCC-ee injector preliminary simulation: e+ yield before the dumping ring

Ongoing optimization / very preliminary

case	Accepted yield e+/e-	Deposited Power [kW]
Conventional	**7,0**	**1,13**
W 9mm	7,22	0,65
W 12mm	**7,72**	**0,99**
W1.1mm + converter	**7,16**	**0,84**
W2.0mm + converter	7,51	0,96

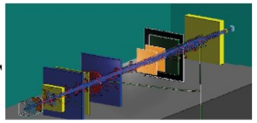
Curtesy of D. Boccanfuso (Naple)



Ongoing optimization, still not final but already showing interesting results:

With a bit higher e+ yield, the deposited power is decreased (being the total crystal+converter length shorter) -> crucial parameter for the injector design

GEANT



European Commission

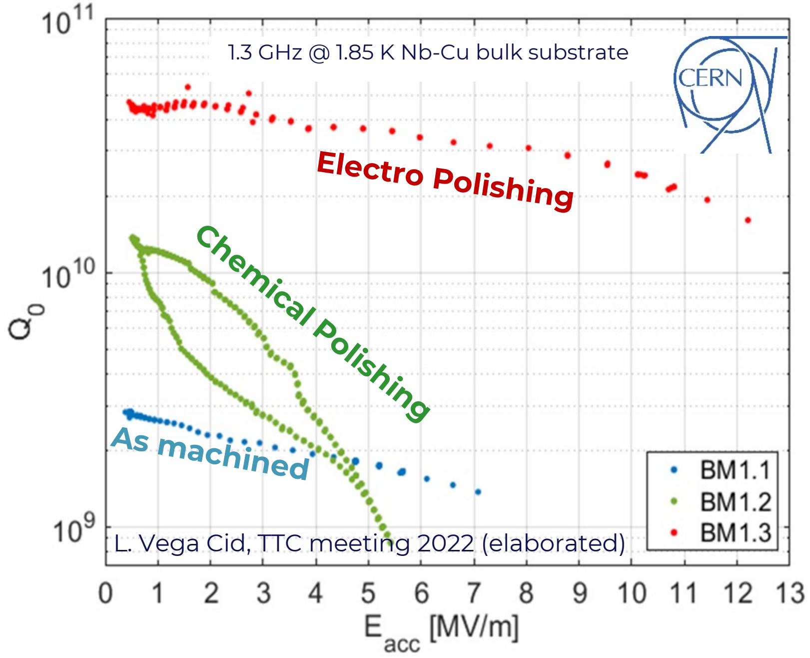
Trillion

Marie Curie Individual fellow
https://www.fe.infn.it/trillion/

Cristian Pira (LNL)

Thin film SRF cavities R&D @LNL – Plasma Electrolytic Polishing

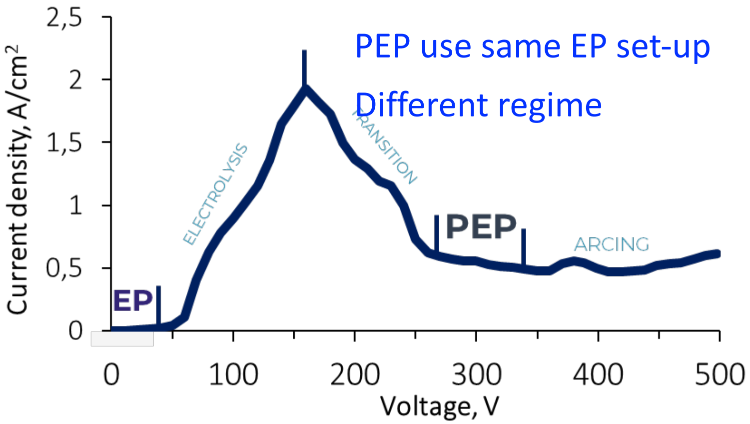
Cu substrate plays a fundamental role in SRF performances

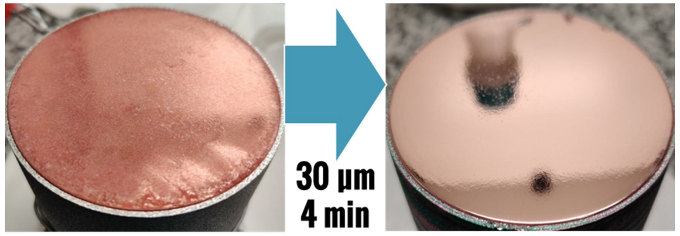


Roughness and defects reduction by **surface treatments are mandatory** for a good and uniform SRF coating

PEP technology provides advantages over EP that are fundamental to FCC cavities:

- Reduces polishing time by more than a factor of 10
- Reduces surface roughness by at least 30 percent-
- Less sensitive to cathode shape
  (higher uniformity for complex geometries such as elliptical)



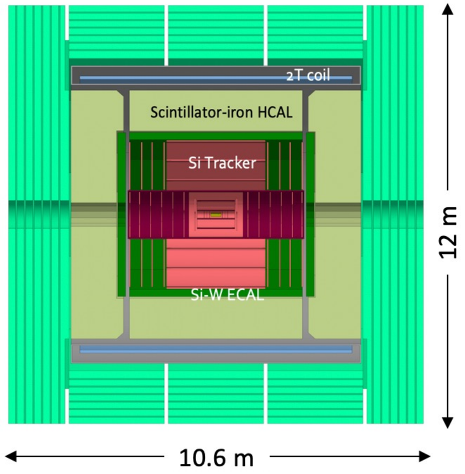


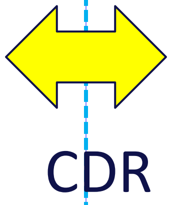
High quality substrate in a very short time

In collaboration with CERN, it will be investigated if PEP provides a reduction in surface resistance of SRF coatings and scalability to 1.3 GHz elliptical cavities.
Possible success would then open the way to FCC 400 MHz

FCC-ee Detector Concepts

CLD

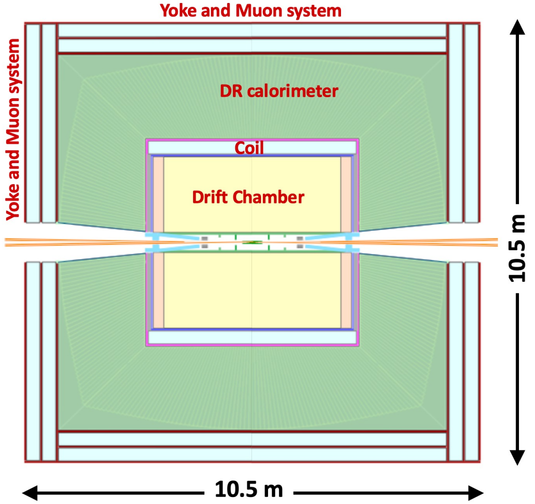




- Full Silicon vertex detector + tracker;
- Very high granularity, CALICE-like calorimetry;
- Muon system
- Large coil outside calorimeter system;

- Possible optimization for
  - Improved momentum and energy resolutions
  - PID capabilities

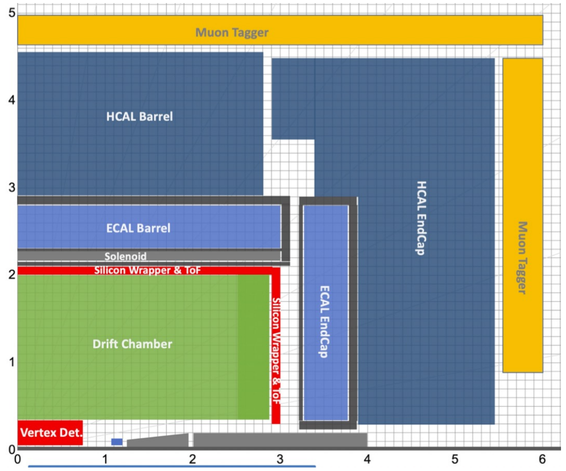
IDEA



- Si vertex detector;
- Ultra light drift chamber w. powerfull PID;
- Monolitic dual readout calorimeter;
- Muon system;
- Compact, light coil inside calorimeter;

- Possibly augmented by crystal ECAL in front of coil;

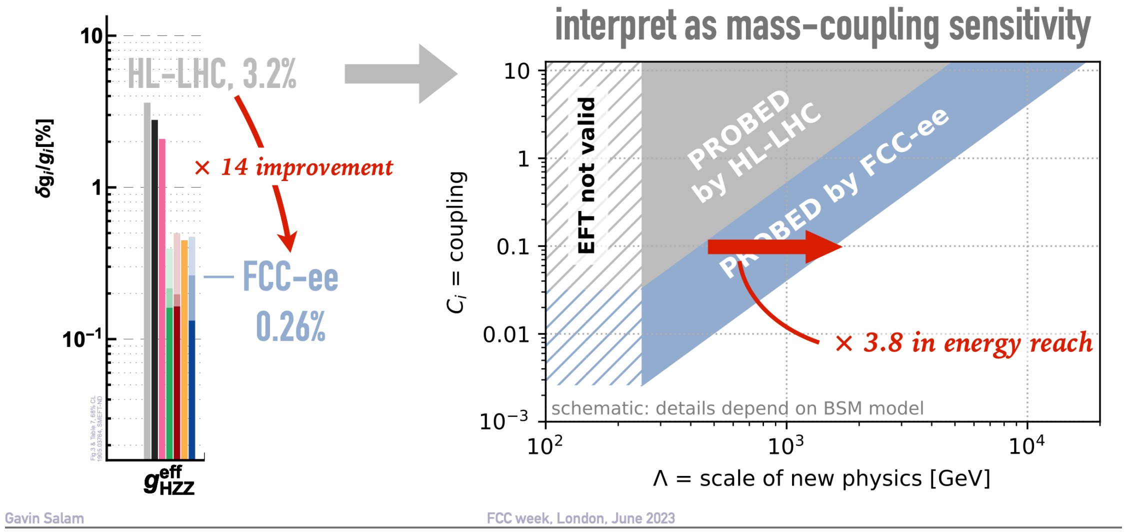
ALLEGRO

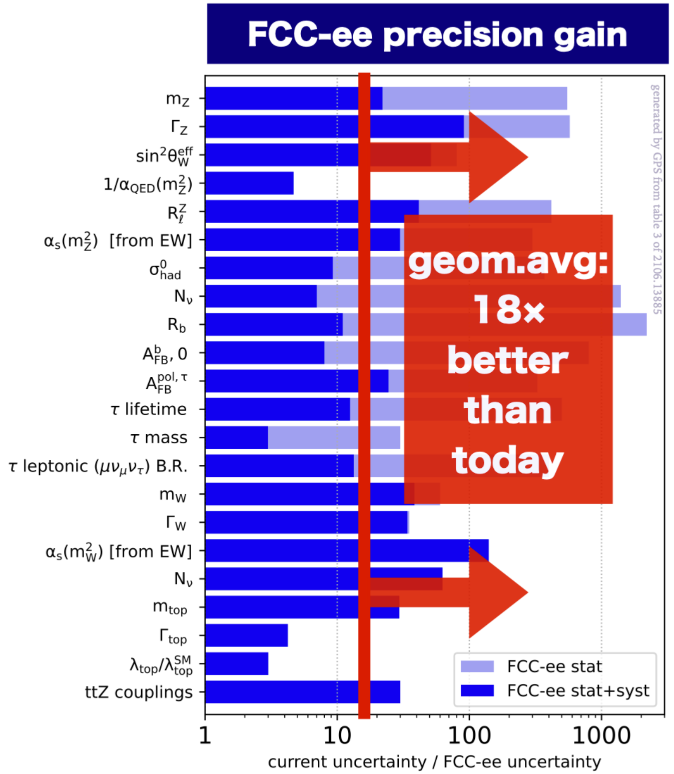


- Noble Liquid ECAL based
- High granularity Noble Liquid ECAL as core;
  - PB+LAr (or denser W+LCr)
- Drift chamber (or Si) tracking;
- CALICE-like HCAL;
- Muon system;
- Coil inside same cryostat as LAr, possibly outside ECAL.

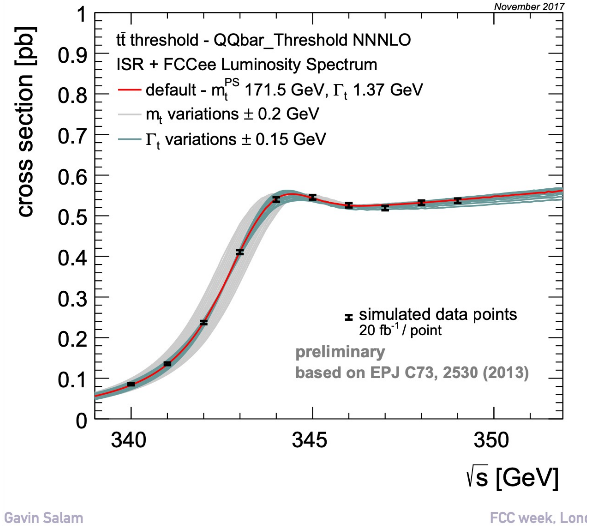
Physics Potential

Interpret higher precision as increase in indirect reach

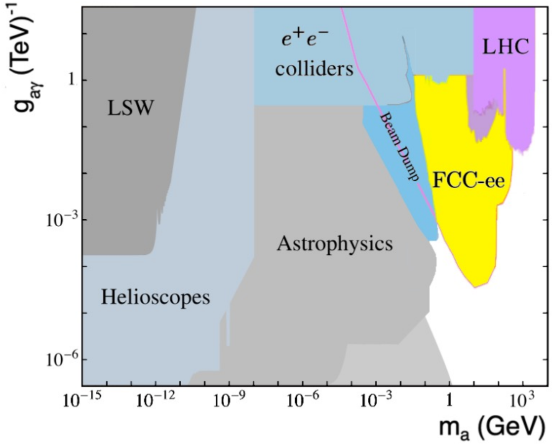




threshold scan for top mass



Axions



Flavour physics: 15× more b-pairs at FCC-ee than at Belle II

2106.01259

FCC-ee

Attribute	$\Upsilon(4S)$	pp	Z^0
All hadron species		✓	✓
High boost		✓	✓
Enormous production cross-section		✓	
Negligible trigger losses	✓		✓
Low backgrounds	✓		✓
Initial energy constraint	✓		(✓)

FCC-hh layout, optics work, geom. integration

parameter	FCC-hh	HL-LHC	LHC
collision energy cms [TeV]	81 - 115	14	
dipole field [T]	14 - 20	8.33	
circumference [km]	90.7	26.7	
arc length [km]	76.9	22.5	
beam current [A]	0.5	1.1	0.58
bunch intensity [10^{11}]	1	2.2	1.15
bunch spacing [ns]	25	25	
synchr. rad. power / ring [kW]	1020 - 4250	7.3	3.6
SR power / length [W/m/ap.]	13 - 54	0.33	0.17
long. emit. damping time [h]	0.77 – 0.26	12.9	
peak luminosity [10^{34} cm^{-2}s^{-1}]	~30	5 (lev.)	1
events/bunch crossing	~1000	132	27
stored energy/beam [GJ]	6.1 - 8.9	0.7	0.36

With FCC-hh after FCC-ee: significantly more time for high-field magnet R&D aiming at highest possible energies

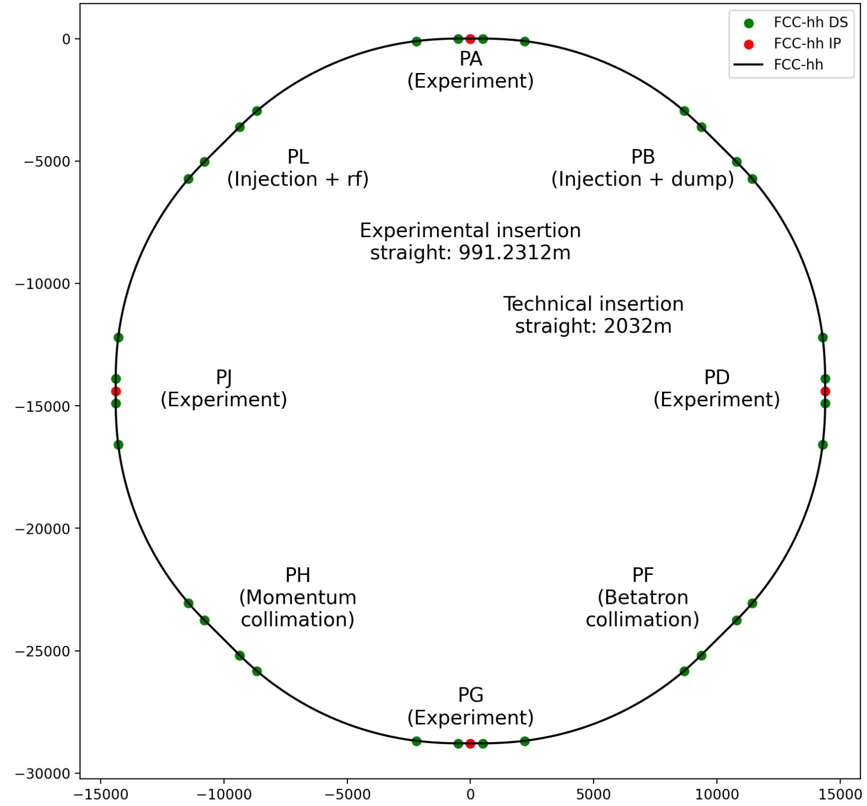
Formidable challenges:

- high-field superconducting magnets: 14 - 20 T
- power load in arcs from synchrotron radiation: 4 MW → cryogenics, vacuum
- stored beam energy: ~ 9 GJ → machine protection
- pile-up in the detectors: ~1000 events/xing
- energy consumption: 4 TWh/year → R&D on cryo, HTS, beam current, …

Formidable physics reach, including:

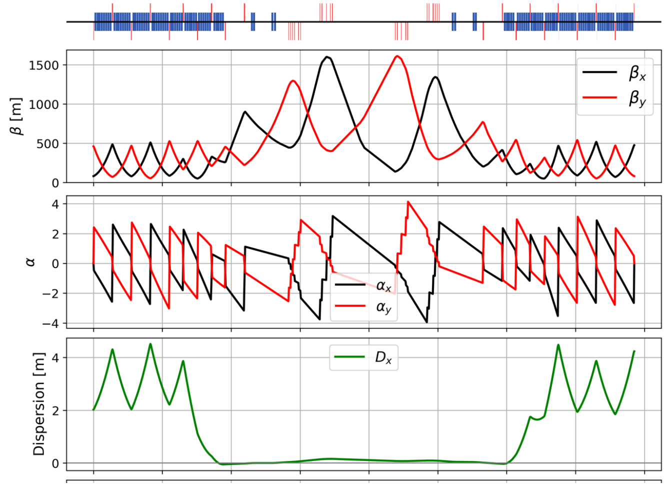
- Direct discovery potential up to ~ 40 TeV
- Measurement of Higgs self to ~ 5% and ttH to ~ 1%
- High-precision and model-indep (with FCC-ee input) measurements of rare Higgs decays ($\gamma\gamma$, Zγ, μμ)
- Final word about WIMP dark matter

FCC-hh layout, optics work, geom. integration

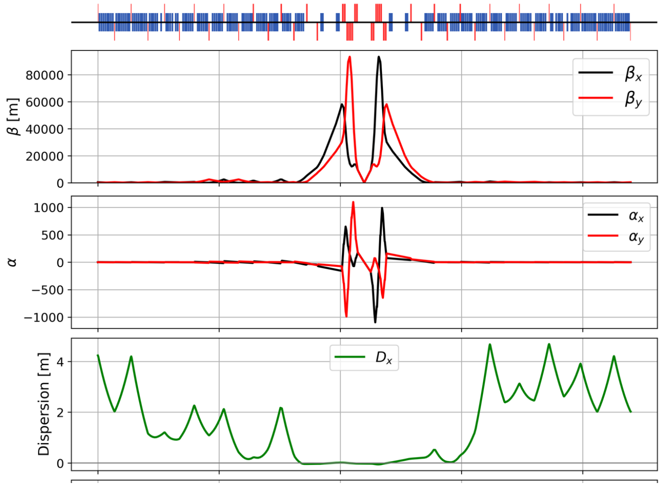


- adaptation to new layout and geometry
- shrink β collimation & extraction by ~30%
- optics optimisation (filling factor etc.)
- move hh IPs on top of ee IP to optimise tunnel and cavern widths.

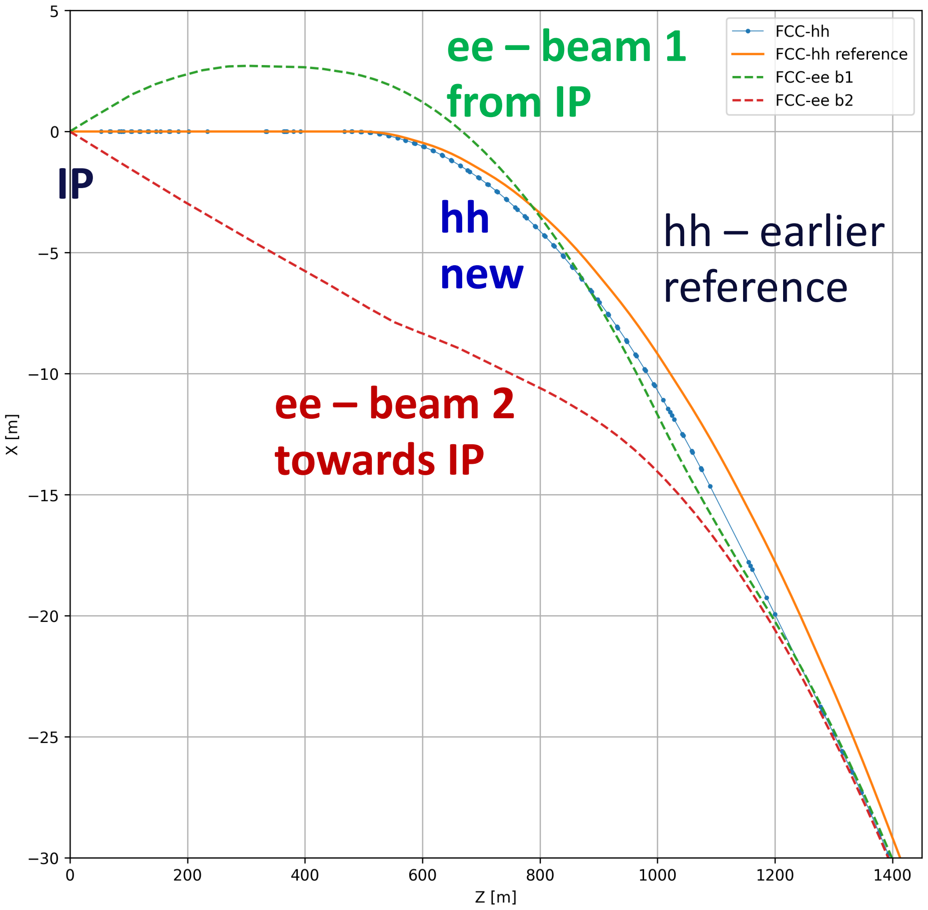
betatron collimation straight



experimental straight

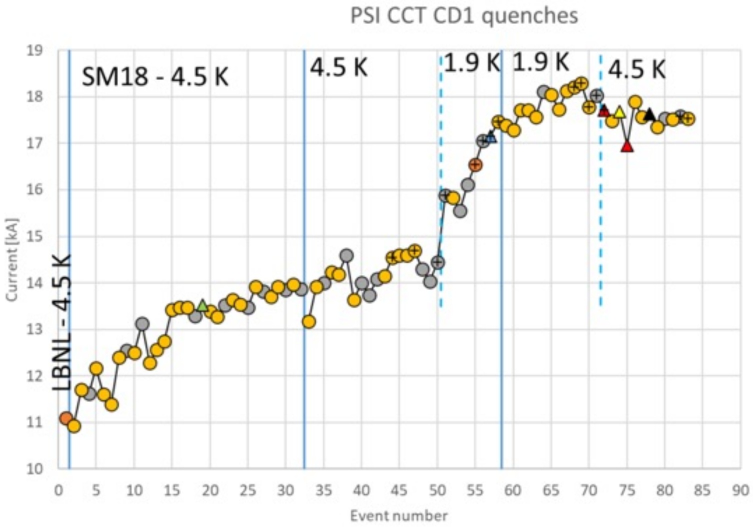


3 - beam footprint at interaction point



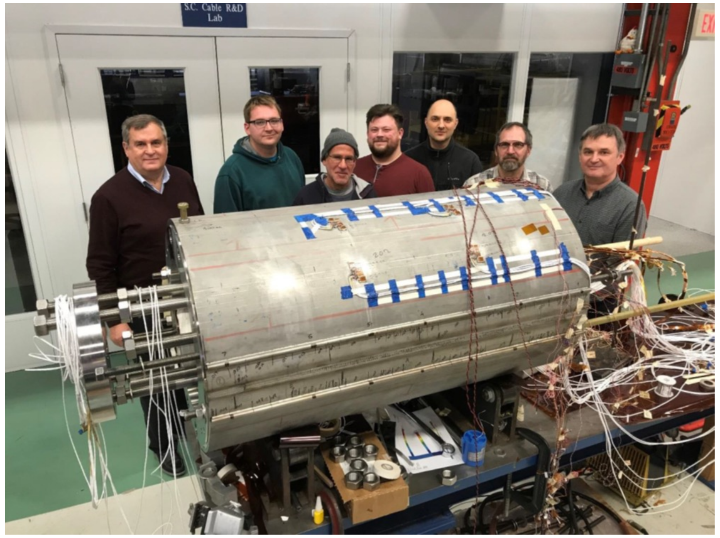
High-field magnets for FCC-hh: Nb_3Sn & HTS R&D

PSI Nb3Sn CCT «CD1» main test carried out in 2022/23

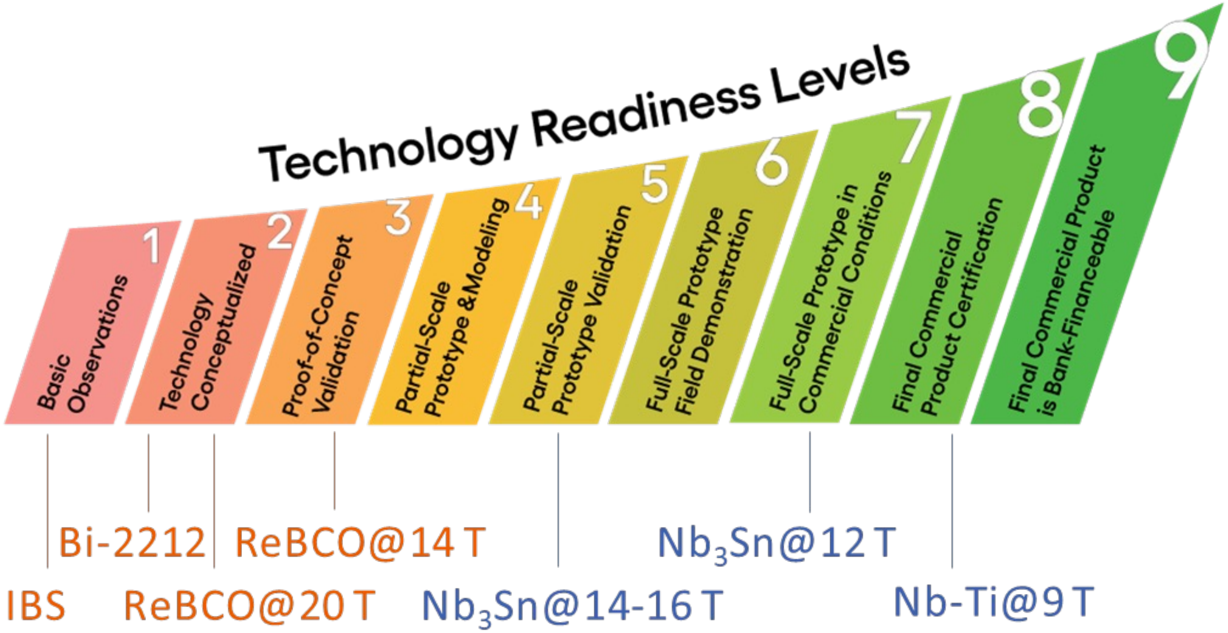


It trained A LOT. It reached 100% of maximum field at 4.5 K. No conductor degradation occurred from handling, assembly, powering, or thermal cycling.

Stress-management works, CD1 is a robust magnet.



FNAL dipole demonstrator
4-layer cosϑ
14.5 T Nb_3Sn
in 2019



Rough estimates

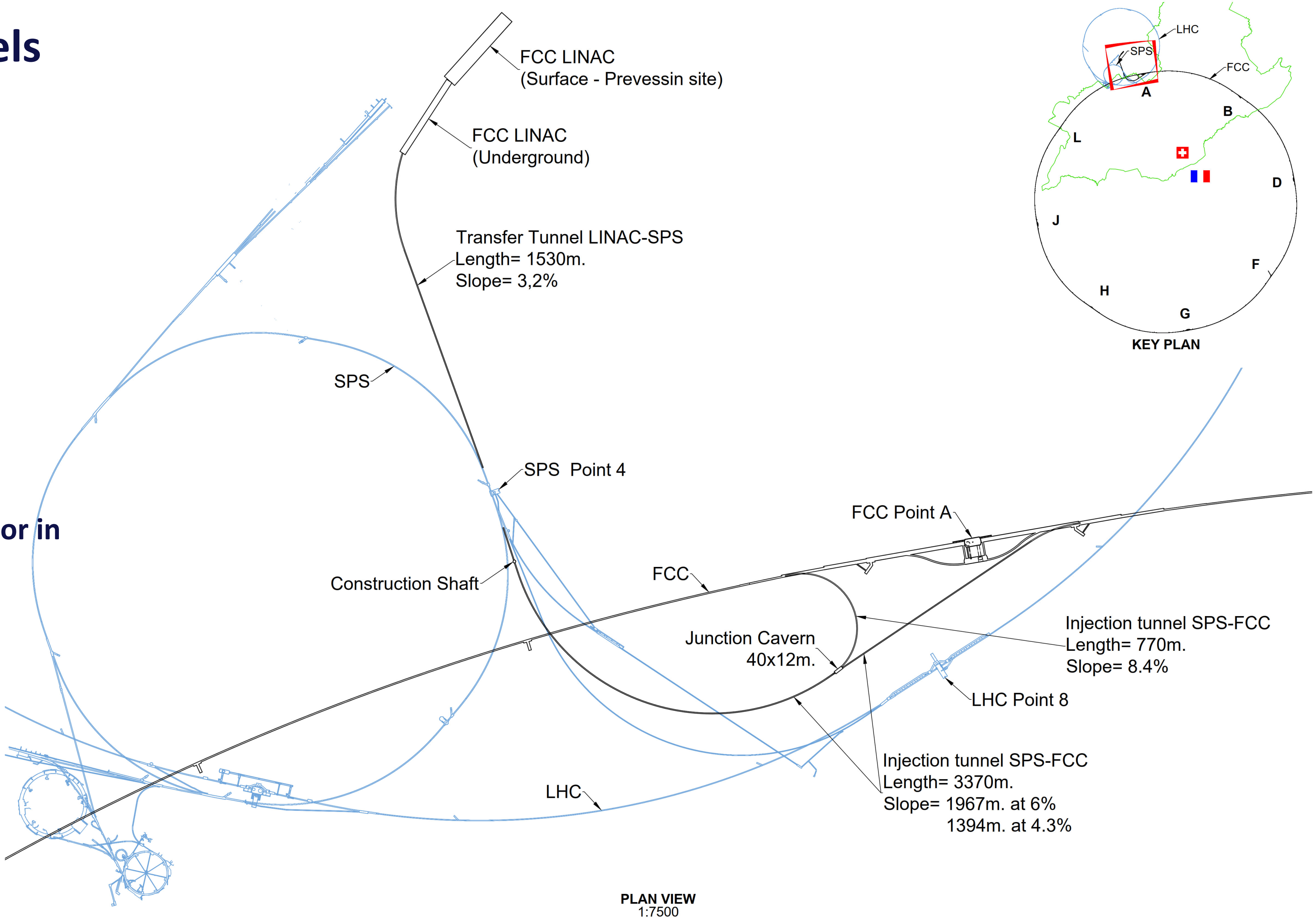
Bottom line: HTS technology must catch up over the coming 10 years in TRL to LTS

FUTURE CIRCULAR COLLIDER

Transfer line FCC-ee (option with SPS for FCC-hh)

LINAC and Injection Tunnels

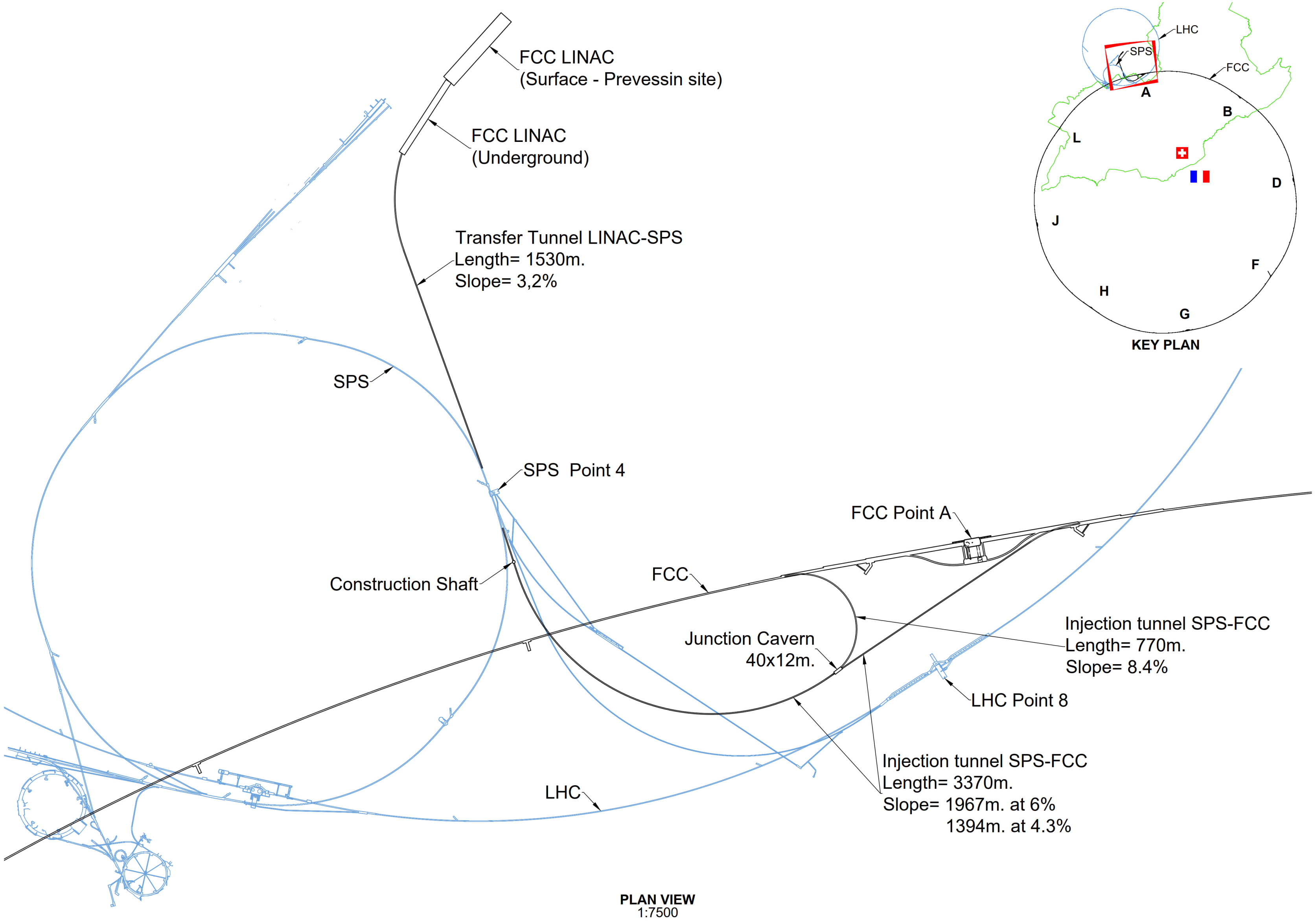
- **Injector with ~20 GeV HE Linac sited on surface at CERN-Prevessin**
- **Single transfer tunnel to FCC Booster with spur to enable anti-clockwise injection**
- **Design allows re-use for FCC-hh if injector in the SPS tunnel (SC-SPS option)**
  - **SPS Point 4 to FCC (clockwise)**
  - **SPS Point 6 to FCC (counter-c.w.)**



Transfer line FCC-ee (option with SPS for FCC-hh)

LINAC and Injection Tunnels

- Designed to enable injection either from the HE Linac sited at Prevessin of from the SPS as pre-booster
- Single tunnel with spur to enable anti-clockwise injection
- Design allows re-use for FCC-hh if injector in the SPS tunnel (SC-SPS option)
  - SPS Point 4 to FCC (clockwise)
  - SPS Point 6 to FCC (counter-c.w.)



SPS as alternative to high-energy linac as pre-booster

- Synchrotron radiation masks would need to be reinstalled at every SPS dipole magnet, or else a fully new vacuum chamber be constructed and installed
- LEP-era SR masks in the SPS used the same flange for installation as the impedance shields now installed for the SPS LHC hadron beam operation
- Masks were/are welded in place; difficult access ! SPS magnets are closed and not C-shaped
- Removal of impedance shields is incompatible with HL-LHC operation
- There were about 20 different variants of LEP masks; it is uncertain if these masks would cope with 100-400x higher radiation power levels for FCC-ee beams at 16 GeV (see table below)
- Time required for SPS modifications: several years of SPS shutdown for the installation, plus a lot of human resources
- Impact on p-physics operation: during Z-run period SPS blocked for ~85% for top-up operation.

Parameter	SPS for LEP	SPS for FCCee
Extraction energy [GeV]	20	16
SR - dipole magnets only [W/m]	1.85	198
Averaged SR- dipole magnets only [W/m]	0.024	8.1
SR - dipole and damping wiggler [W/m]	-	809
Averaged SR - dipole and damping wiggler [W/m]	-	107
Beam current [mA]	0.45	160

FUTURE CIRCULAR COLLIDER

Recently updated

FCC-ee RF parameter table

Number of 800 MHz cavities: 1088
Total number of cavities: 1456

20-Apr-23	Z		W		H		ttbar2		
	Collider per beam	booster	Collider per beam	booster	Collider 2 beams	booster	Collider 2 beams	Collider 2 beams	booster
RF Frequency [MHz]	400	800	400	800	400	800	400	800	800
RF voltage [MV]	120	140	1050	1050	2100	2100	2100	9200	11300
Eacc [MV/m]	5.93	6.23	10.78	20.76	10.78	20.76	10.78	20.12	20.10
# cell / cav	1	5	2	5	2	5	2	5	5
Vcavity [MV]	2.22	5.83	8.08	19.44	8.08	19.44	8.08	18.85	18.83
#cells	54	120	260	270	520	540	520	2440	3000
# cavities	54	24	130	54	260	108	260	488	600
# CM	13.5	6	32.5	13.5	65	27	65	122	150
T operation [K]	4.5	2	4.5	2	4.5	2	4.5	2	2
dyn losses/cav * [W]	23	0.3	158	4	158	4	158	23	3
stat losses/cav [W]	8	8	8	8	8	8	8	8	8
Qext	6.9E+04	3.2E+05	1.1E+06	8.0E+06	1.1E+06	1.6E+07	5.4E+06	4.2E+06	8.3E+07
Detuning [kHz]	8.620	4.393	0.479	0.136	0.096	0.014	0.007	0.056	0.003
Pcav [kW]	912	205	379	91	379	46	79	163	8
rhob [m]	9937	9937	9937	9937	9937	9937	9937	9937	9936
Energy [GeV]	45.6	45.6	80.0	80.0	120.0	120.0	182.5		182.5
energy loss [MV]	38.49	38.49	364.63	364.63	1845.94	1845.94	9875.14		9876.13
cos phi	0.32	0.27	0.35	0.35	0.88	0.88	0.98	0.86	0.87
Beam current [A]	1.280	0.128	0.135	0.0135	0.0534	0.003	0.010	0.010	0.0005

* heat loads from power coupler and HOM couplers not included

one RF system per beam

common RF system for both beams

Limiting parameters for RF

- Cavity performances: 20 % margin added on Eacc and Q0 between vertical test and operation
- In total: 364 cryomodules, 1456 cavities, 25% with Nb/Cu technology, 75% with bulk niobium technology

Synchrotron radiation in the tunnel

	LEP-II (1999-2000)	FCC-ee Z	FCC-ee W	FCC-ee ZH	FCC-ee ttbar
Beam energy	98-104.5 GeV	45.6 GeV	80 GeV	120 GeV	182.5 GeV
Bending radius	3.1 km	10 km			
Beam current	6.2 mA (@98 GeV)	2 x 1270 mA	2 x 137 mA	2 x 26.7 mA	2 x 4.86 mA
Energy loss/turn (arcs)	2.6 GeV (@98 GeV) 3.4 GeV (@104.5 GeV)	0.04 GeV	0.37 GeV	1.9 GeV	10.3 GeV
Power loss (arcs)	16 MW (@98 GeV)*	100 MW			
Total arc length	23 km	77 km			
Power loss/unit length (arcs)	0.7 kW/m (@98 GeV)*	1.3 kW/m			
Critical energy	0.7 MeV – 0.8 MeV	0.02 MeV	0.1 MeV	0.4 MeV	1.3 MeV

**Indicative value (beam current decreased from 98 GeV to 104.5 GeV)*

- **Source term comparable to LEP operation, higher critical energy for ttbar run.**
- **Baseline with distributed (water cooled) photon stops every ~6 m.**
- **Different shielding strategies for (Z, W, ZH) vs ttbar?**

OpenSky Laboratory: demonstrate molasse reuse cases

FUTURE CIRCULAR COLLIDER

GOAL: demonstrate the feasibility to transform Molasse (excavated material) into fertile soil.

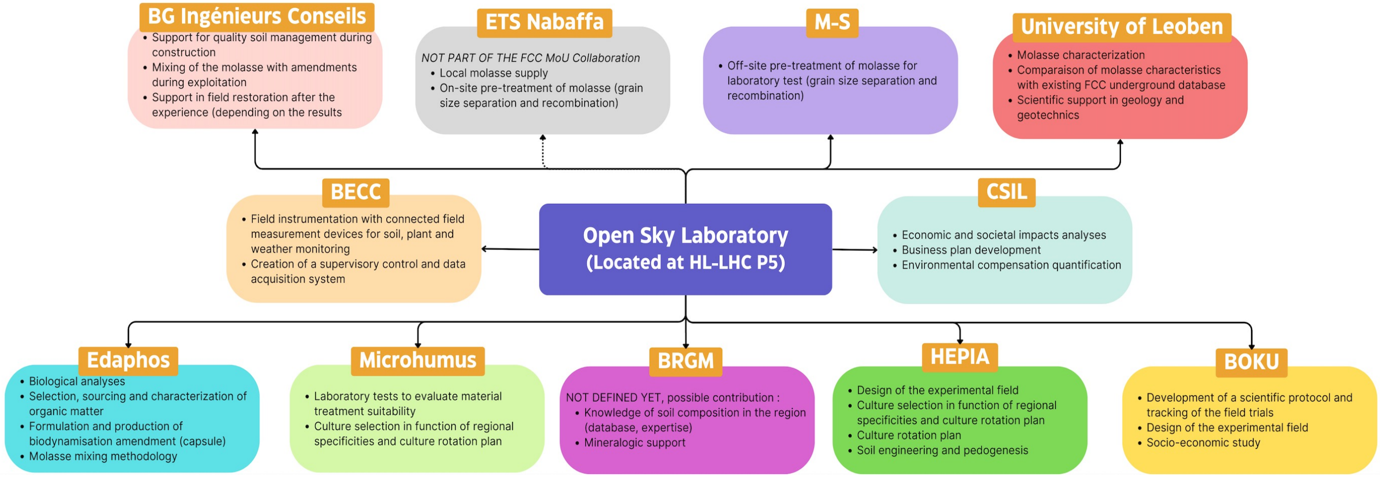
- **Project launched in January 2024**
- **10000 m^2 near LHC P5 in Cessy, France.**

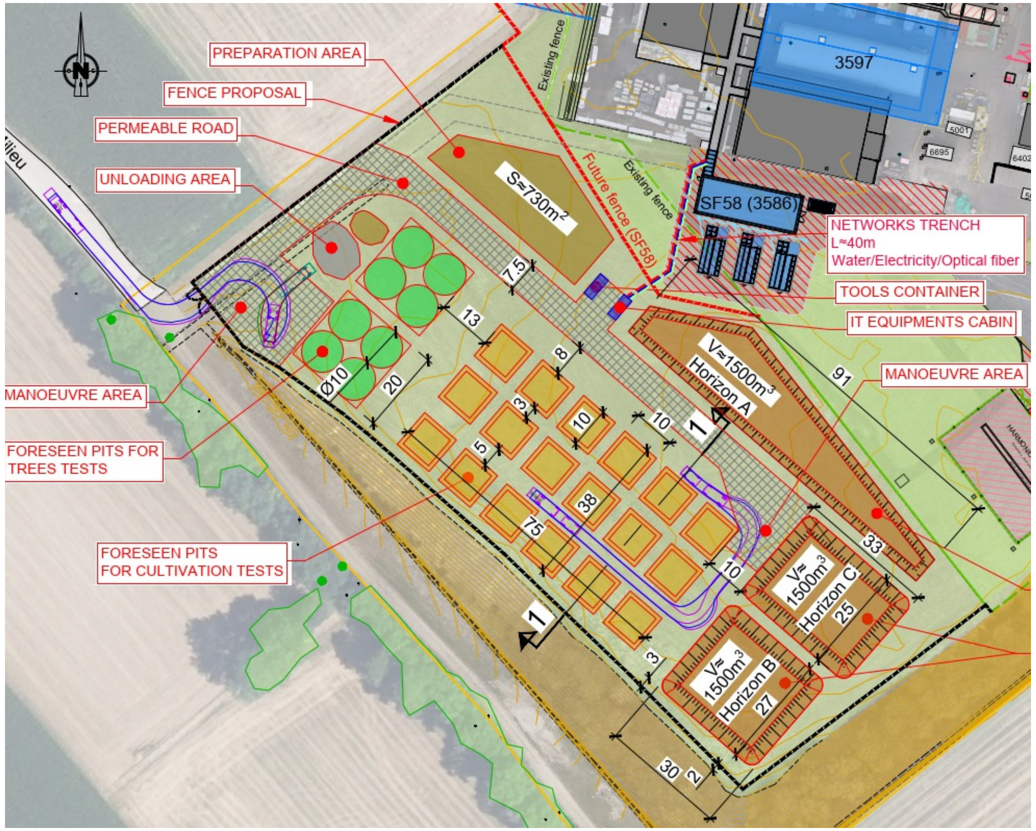
Project phases:

1) Laboratory tests to **identify** the **most suitable mix** of molasse and amendments.

2) **Field tests** in a **controlled environment** (plants selected in function of regional specificities and possible soil reuse cases)

International collaboration with partners from academia and industry specialised in agronomy, soil paedogenesis, phytoremediation





Status - March 2024:

- **Project approved at CERN level**
- **Collaboration agreements being signed**
- **Definition of the laboratory and field tests**

FCC Feasibility Study (2021-2025): high-level objectives

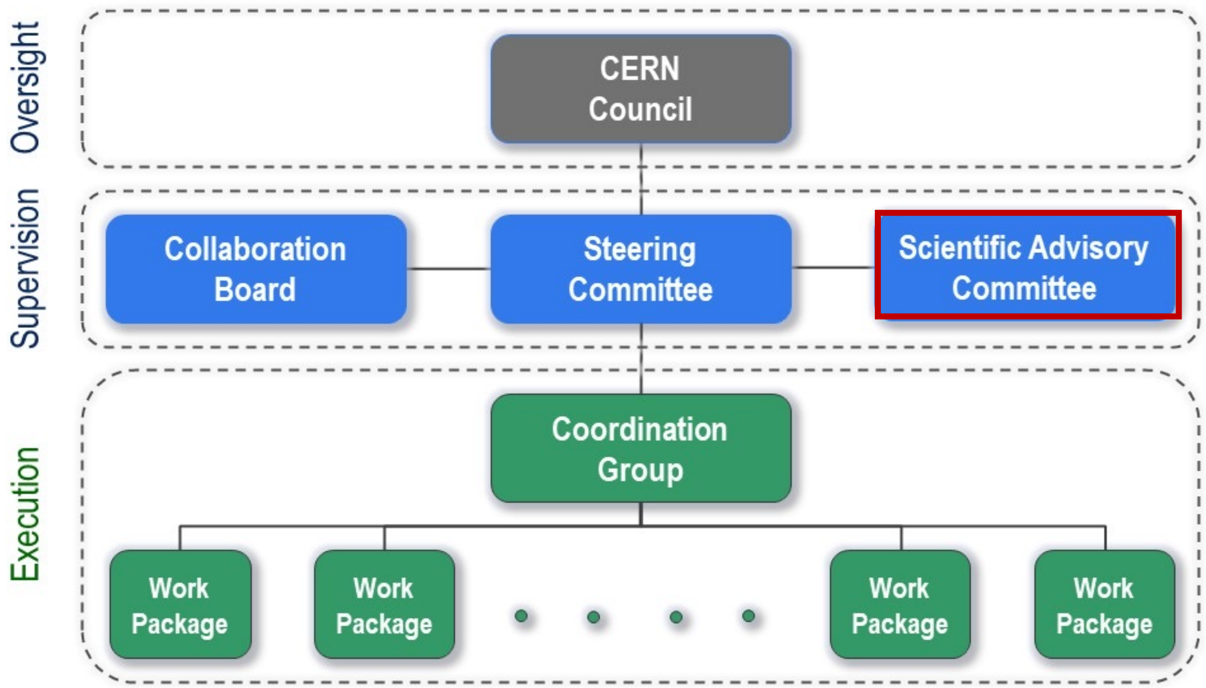
- demonstration of the geological, technical, environmental and administrative feasibility of the tunnel and surface areas and optimisation of placement and layout of the ring and related infrastructure;
- pursuit, together with the Host States, of the preparatory administrative processes required for a potential project approval to identify and remove any showstopper;
- optimisation of the design of the colliders and their injector chains, supported by R&D to develop the needed key technologies;
- elaboration of a sustainable operational model for the colliders and experiments in terms of human and financial resource needs, as well as environmental aspects and energy efficiency;
- development of a consolidated cost estimate, as well as the funding and organisational models needed to enable the project's technical design completion, implementation and operation;
- identification of substantial resources from outside CERN's budget for the implementation of the first stage of a possible future project (tunnel and FCC-ee);
- consolidation of the physics case and detector concepts for both colliders.

Results will be summarised in a Feasibility Study Report to be released at end 2025

Feasibility Study funded from CERN budget: 100 MCHF total over 5 years; in addition: ~20 MCHF/year for high-field magnet R&D
Additional funding from the European Commission and collaborating institutes (e.g. CHART collaboration with Switzerland)

Scientific Advisory Committee (SAC)

SAC follows and reviews the implementation of the Feasibility Study, giving scientific and technical advice to FCC Steering Committee and Coordination Group, and providing them with guidance to facilitate major technical decisions.



Composition: up to 16 international experts not directly involved in the Feasibility Study with renowned expertise in one or more scientific and technical domains relevant to the Study (accelerators, technical infrastructure, key technologies, physics, detectors, etc.). Members and Chair are appointed by the Steering Committee.

Riccardo Bartolini (DESY), Alain Chabert (Société Française du Tunnel Routier du Fréjus), Brigitte Fargevieille (Électricité de France), Belen Gavela Legazpi (UAM), Katri Huitu (Helsinki), Srinivas Krishnagopal (BARC), Peter Krizan (Ljubljana), Philippe Lebrun (CERN, retired), Peter McIntosh (STFC), Michiko Minty (BNL), **Andrew Parker** (**Chair**, Cambridge), Kyo Shibata (KEK), **Roberto Tenchini (Pisa)**

Cost Review Panel (CRP)

Ad-hoc committee established to review the updated cost assessment of the FCC project, which is one of the mid-term review deliverables.

CRP's mandate:

- Review the methodology and assumptions used in producing the cost estimates
- Identify inaccurate or missing cost information
- Check the consistency of the cost estimates with respect to applicable reference work, e.g., recent large-scale infrastructure and accelerator projects
- Review the uncertainty estimates
- Identify potential areas of savings and cost mitigation for future work
- Advise the FCC Feasibility Study team on matters of cost estimation with a view to the preparation of the final Feasibility Study Report by end 2025.

Composition: around 10 international experts, not directly involved in the Feasibility Study, with renowned expertise in costing and project management aspects related to the scientific and technical domains relevant to the Study (accelerators, technical infrastructure, civil engineering, detectors, etc.). Members and Chair are appointed by the Steering Committee.

Carlos Alejaldre (Fusion for Energy), Austin Ball (CERN, retired), Umberto Dosselli (INFN), Vincent Gorgues (CEA), **Norbert Holtkamp** (**Chair**, Stanford), Christa Laurila (National Audit Office, Finland), Ursula Weyrich (German Cancer Research Centre), Jim Yeck (BNL), Thomas Zurbuchen (ETH Zürich)