Future Circular Collider and CERN Plans

Türkiye-CERN Relationships, 9 May 2024

Frank Zimmermann, CERN

with many warm thanks to Orhan Cakir, Abbas Kenan Ciftci, Haluk Denizli, Ozgur Etisken, Sehban Kartal, Salim Ogur, Saleh Sultansoy, Ilkay Turk Cakir, and Ömer Yavas

FUTURE CIRCULAR COLLIDER Innovation Study · EuroCirCol A key to New Physics · EASITrain · iFAST · E-JADE · EAJADE · CHART Swiss Accelerator Research and Technology · http://cern.ch/fcc · CERN

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

photo: J. Wenninger

European Strategy for Particle Physics 2020 Update

"The successful completion of the high-luminosity upgrade of the machine and detectors should remain the focal point of European particle physics, together with continued innovation in experimental techniques."

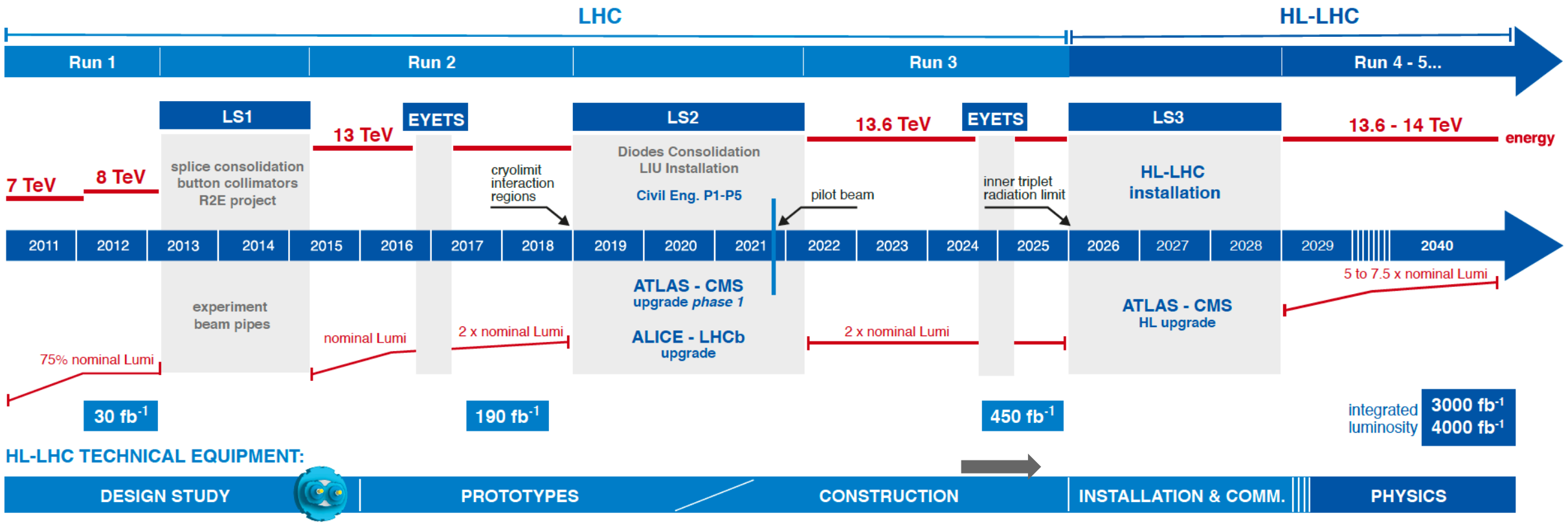
"The full physics potential of the LHC and the HL-LHC, including the study of flavour physics and the quark-gluon plasma, should be exploited."

2022 Snowmass Energy Frontier Summary:

"Our highest immediate priority accelerator and project is the HL-LHC, the successful completion of the detector upgrades, operations of the detectors at the HL-LHC, data taking and analysis, including the construction of auxiliary experiments that extend the reach of HL-LHC in kinematic regions uncovered by the detector upgrades."

HL-LHC – the medium-term future

LHC / HL-LHC Plan

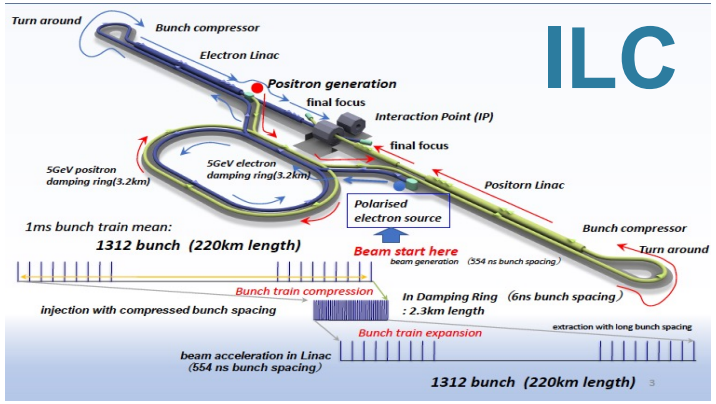


HL-LHC TECHNICAL EQUIPMENT:

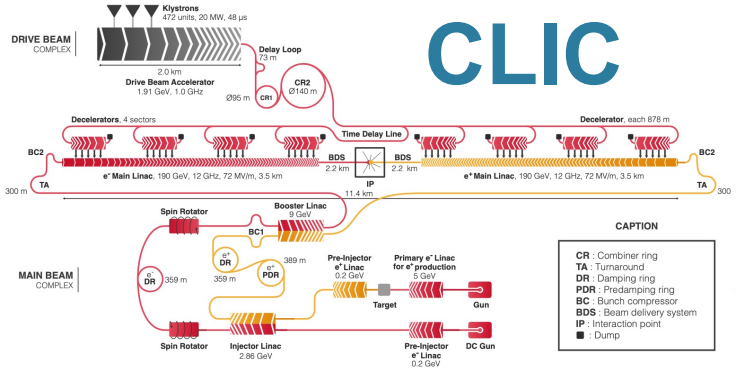
HL-LHC CIVIL ENGINEERING:

some future collider options

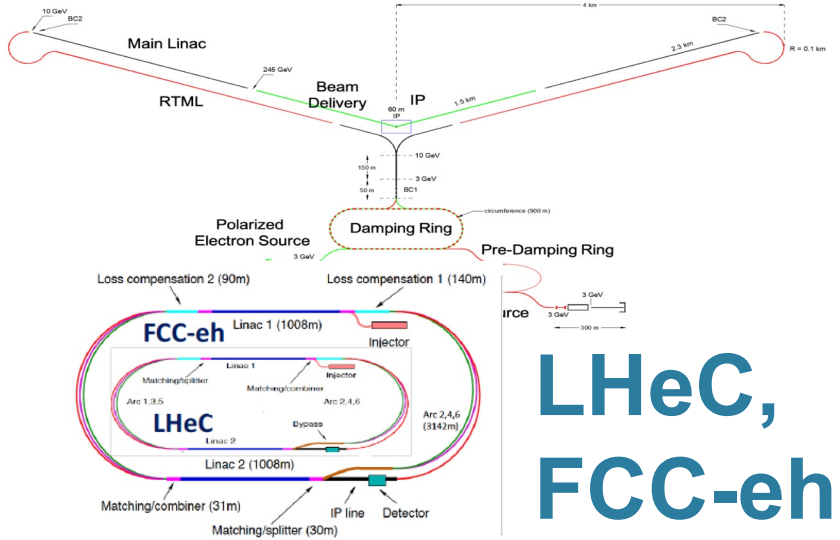
ILC



CLIC

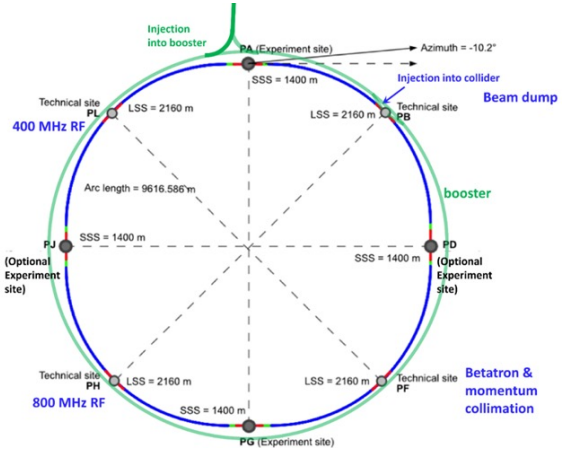


C³

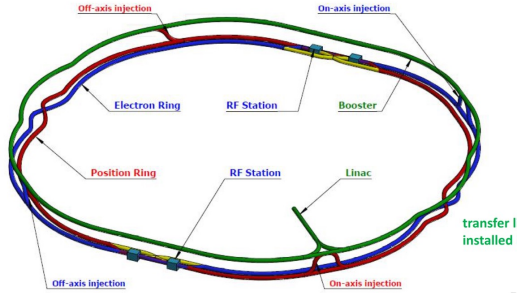


LHeC, FCC-eh

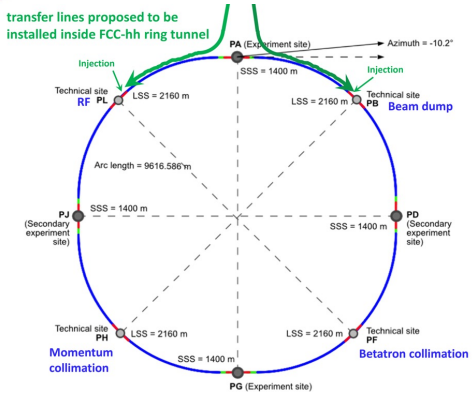
FCC-ee



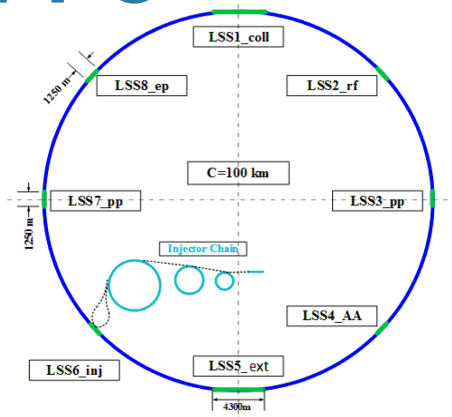
CEPC



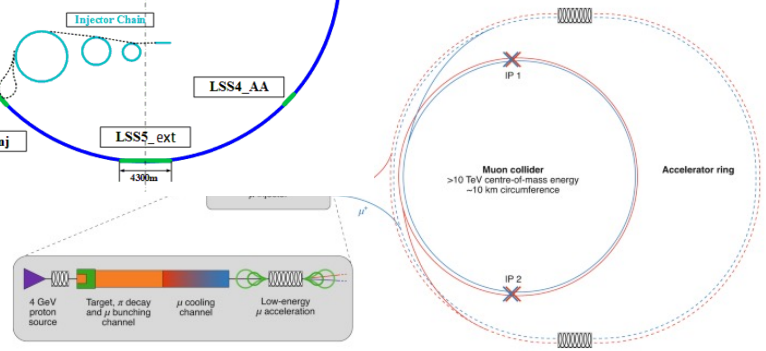
FCC-hh



SPPC



MC



ESPPU2020 also said…

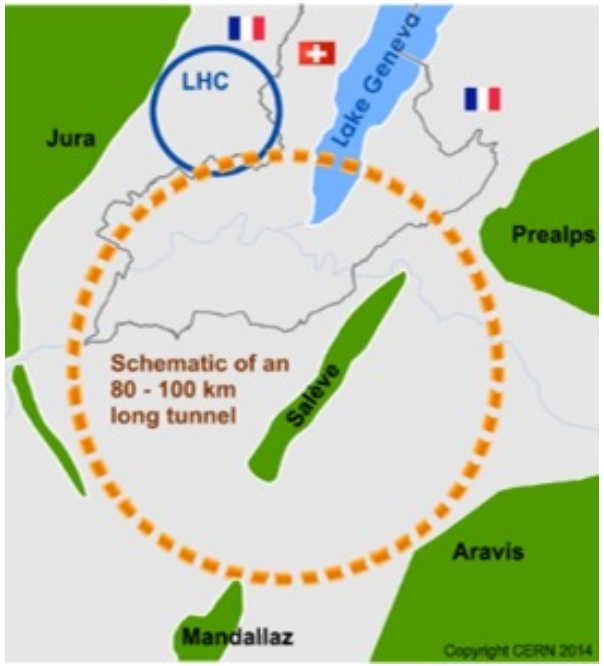
- "*An **electron-positron Higgs factory is the highest-priority next collider**.*"
- *For the longer term, the European particle physics community has the ambition to operate a **proton-proton collider at the highest achievable energy**.*"
- ***"Europe, together with its international partners, should investigate the technical and financial feasibility of a future hadron collider at CERN with a centre-of-mass energy of at least 100 TeV and with an electron-positron Higgs and electroweak factory as a possible first stage**."*
- *"Such a feasibility study of the colliders and related infrastructure should be **established as a global endeavour and be completed on the timescale of the next Strategy update**."*

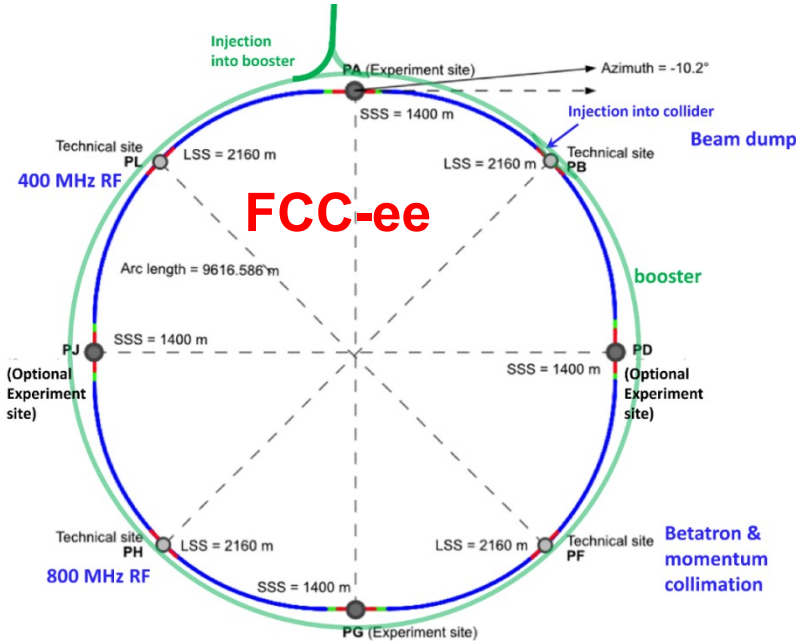
→ **2021 Launch of FCC Feasibility Study (FCC FS) by CERN Council**

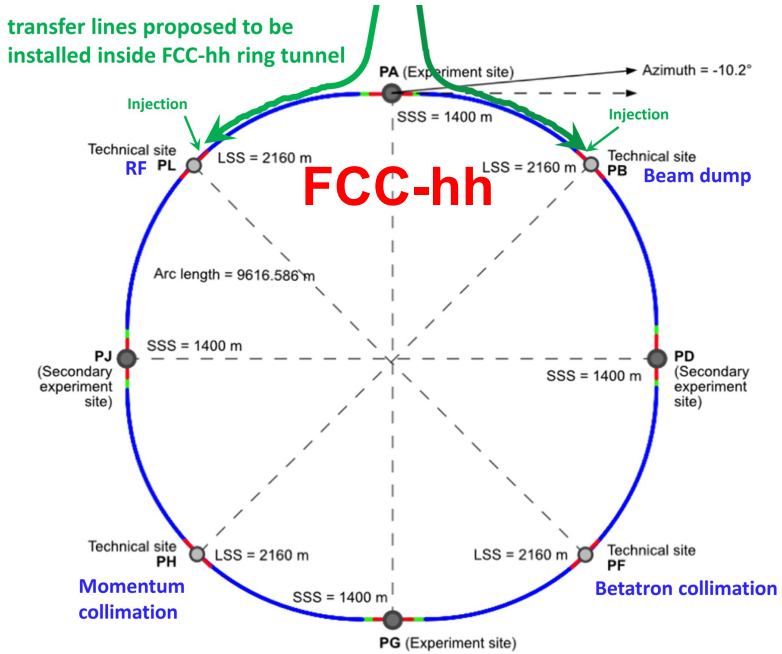
FCC integrated program

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



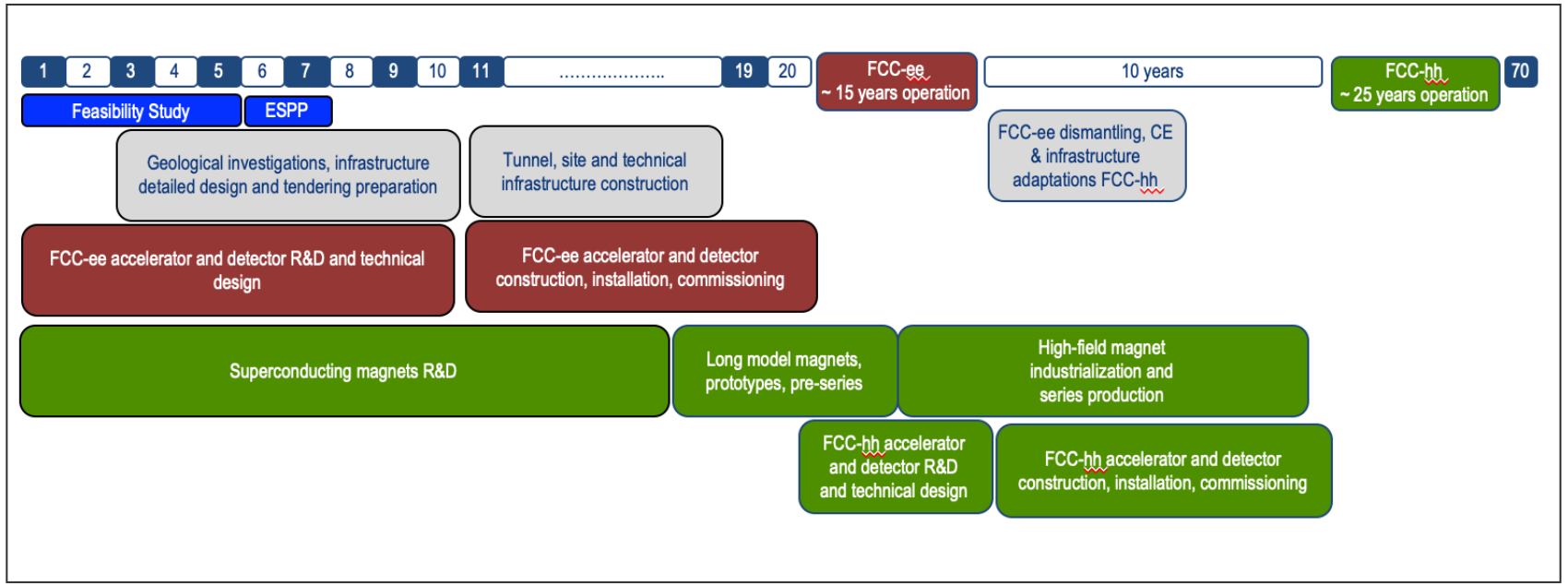




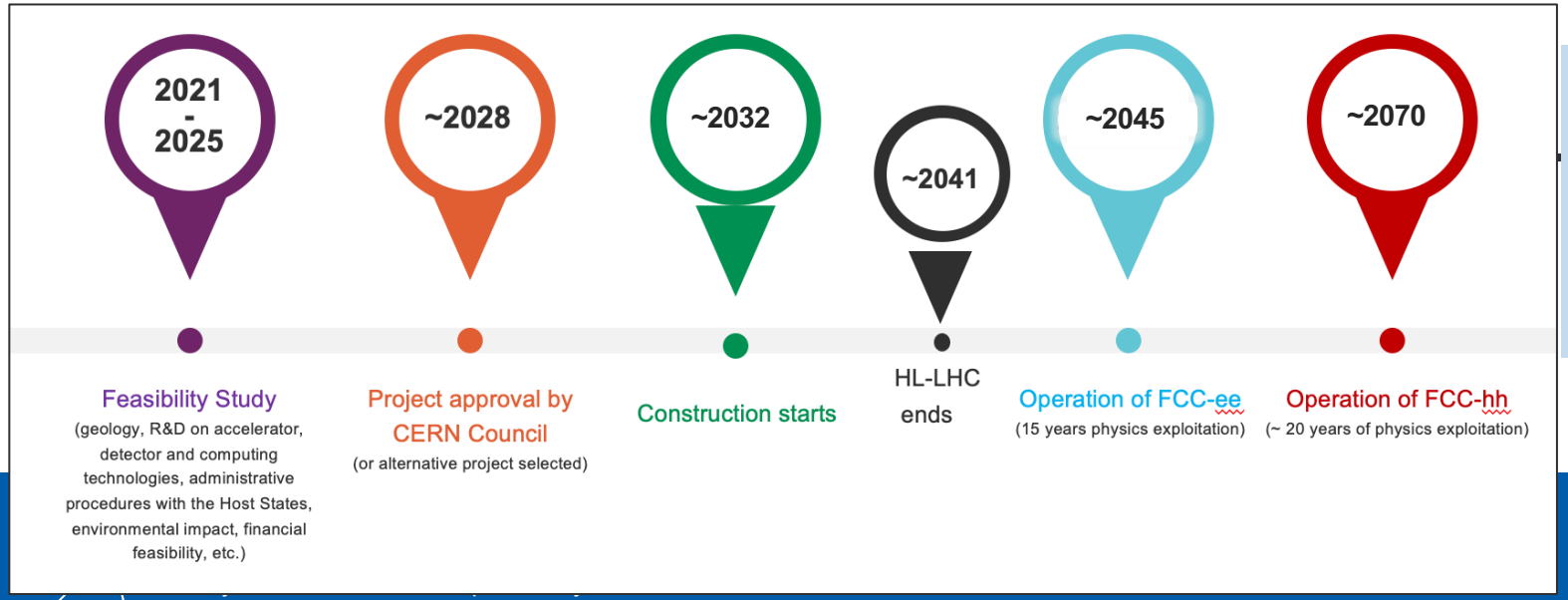
2020 - 2040 | **2045 - 2060** | **2065 - 2090**

a similar two-stage project CEPC/SPPC is under study in China

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 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 by March 2025

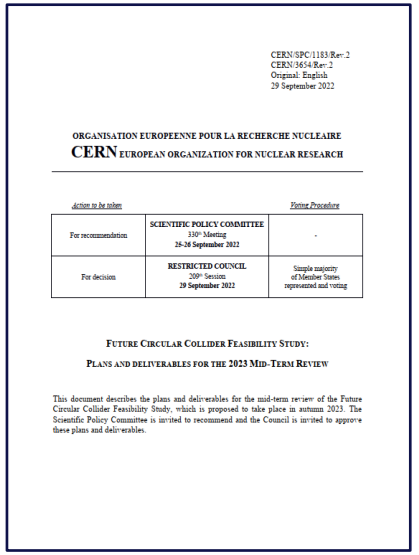
FCC FS Mid-Term Review concluded in February 2024

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 130th Meeting 28-30 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

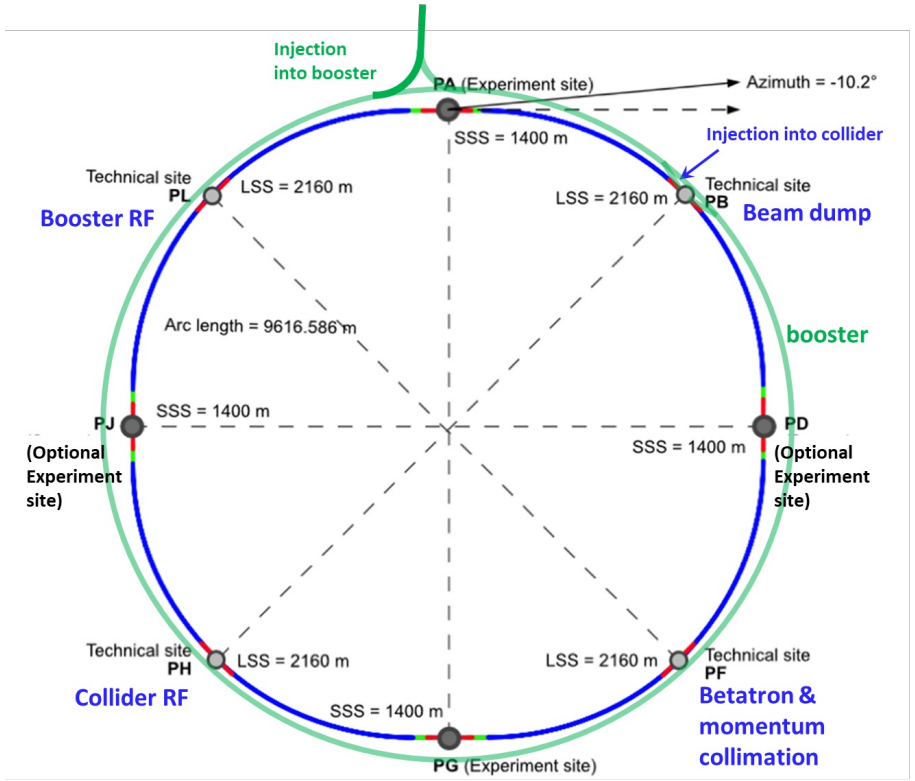
Many thanks to the SAC, CRP, SPC, FC and the Council for the very useful reviews!

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



V. Mertens, J. Gutleber

PA: Experiment

PB: technical

PL: technical

PD: experiment

PJ: experiment

PF: technical

PH: technical

PG: experiment

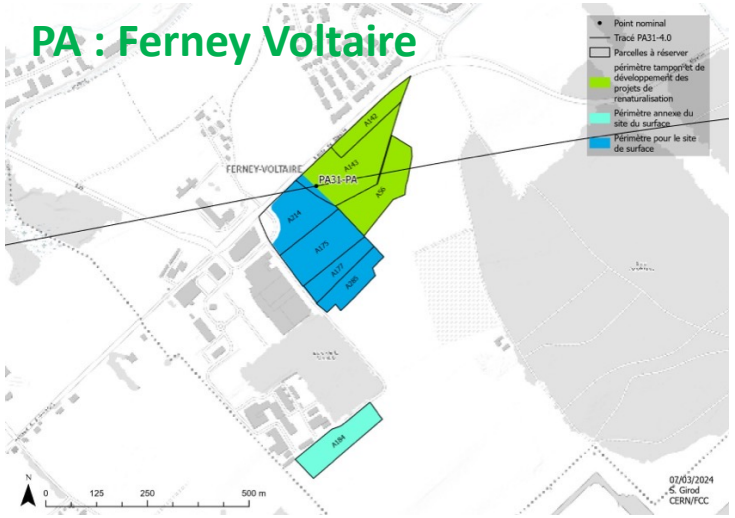
Number of surface sites	8
Surface requirements	~40 ha
LSS@IP (PA, PD, PG, PJ)	1400 m
LSS@TECH (PB, PF, PH, PL)	2032 m
Arc length	9.6 km
Sum of arc lengths	76.9 m
Total length	**90.7 km**

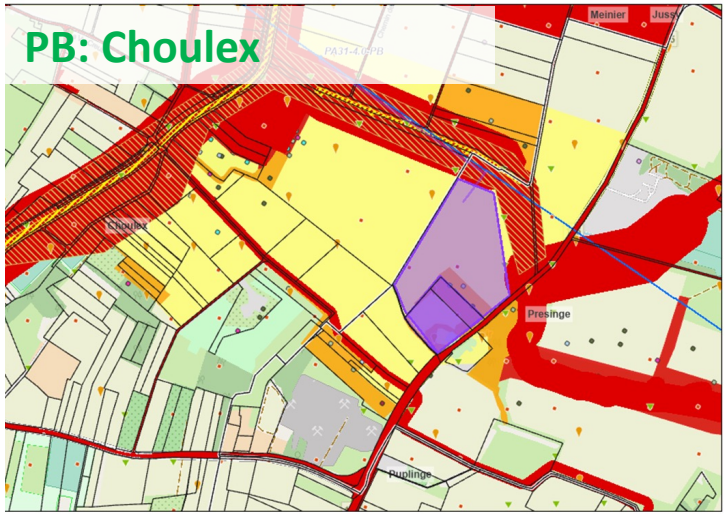
Surface sites development and reservation of land-plots

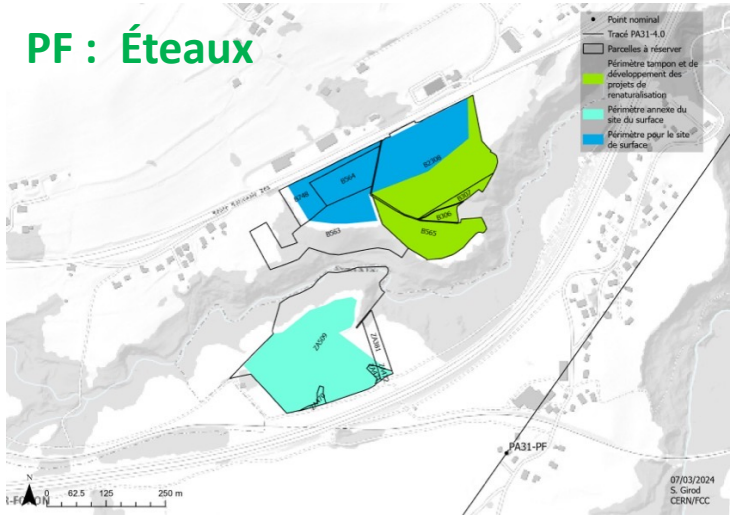
Meetings ongoing with all communes concerned by surface sites to identify individual land-plots for development of surface site layout and land reservation.

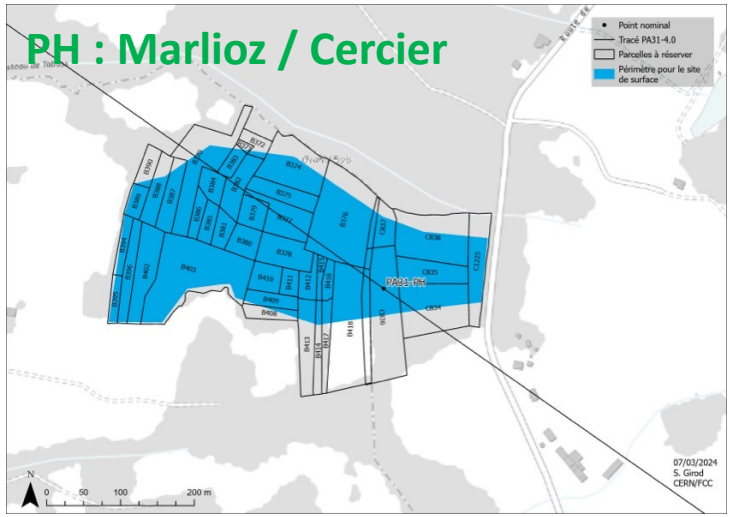
- PA : Ferney Voltaire: 01/2024
- PB: Choulex : 12/2023
- PB: Presinge : 01/2024, plenary session with community council 04/2024
- PD : Nangy: 05/2024
- PF : Éteaux : 03/2024
- PG : Groisy / Charvonnex: 04/2024
- PH : Marlioz / Cercier : 02/2024
- PJ : Vulbens / Dingy en Vuache : 09/2023, 01/2024
- PL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

Green: parcelles identified and agreed
Blue: ongoing



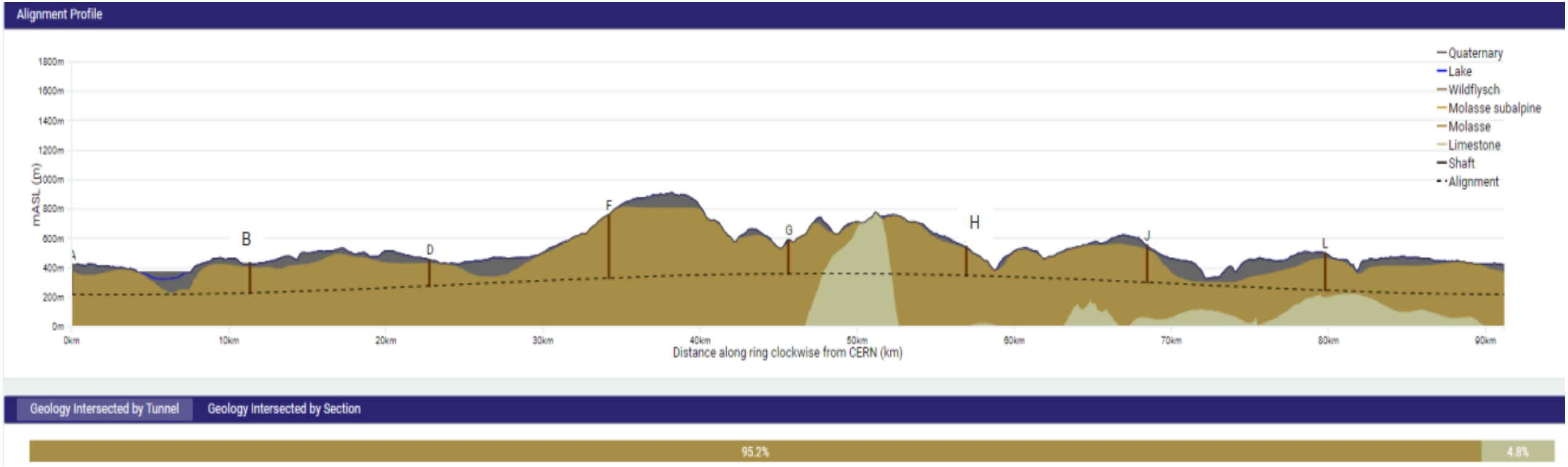






FUTURE CIRCULAR COLLIDER

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

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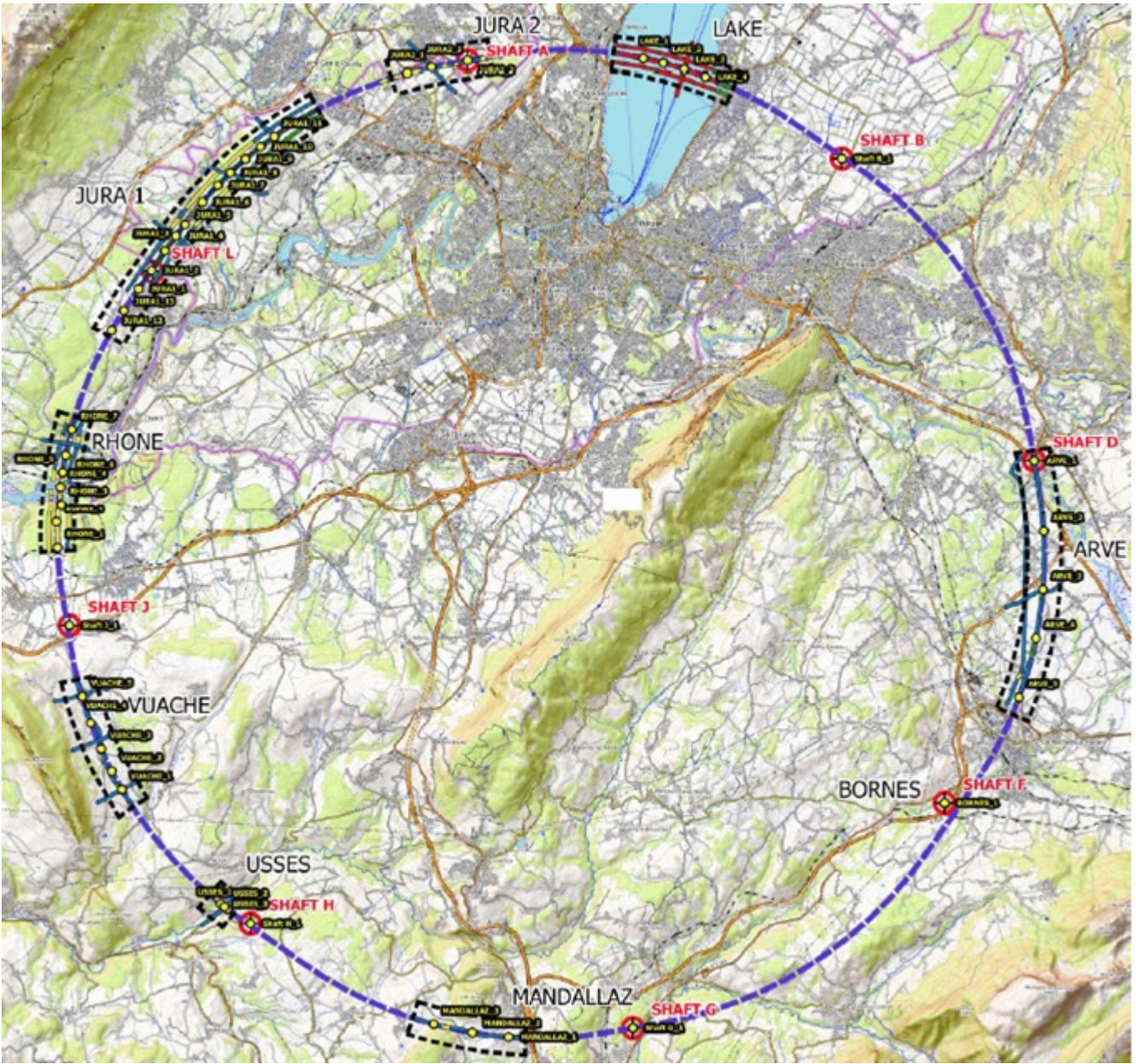
Status site investigations



- **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 June 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

OpenSky Laboratory: demonstrate molasse reuse cases

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

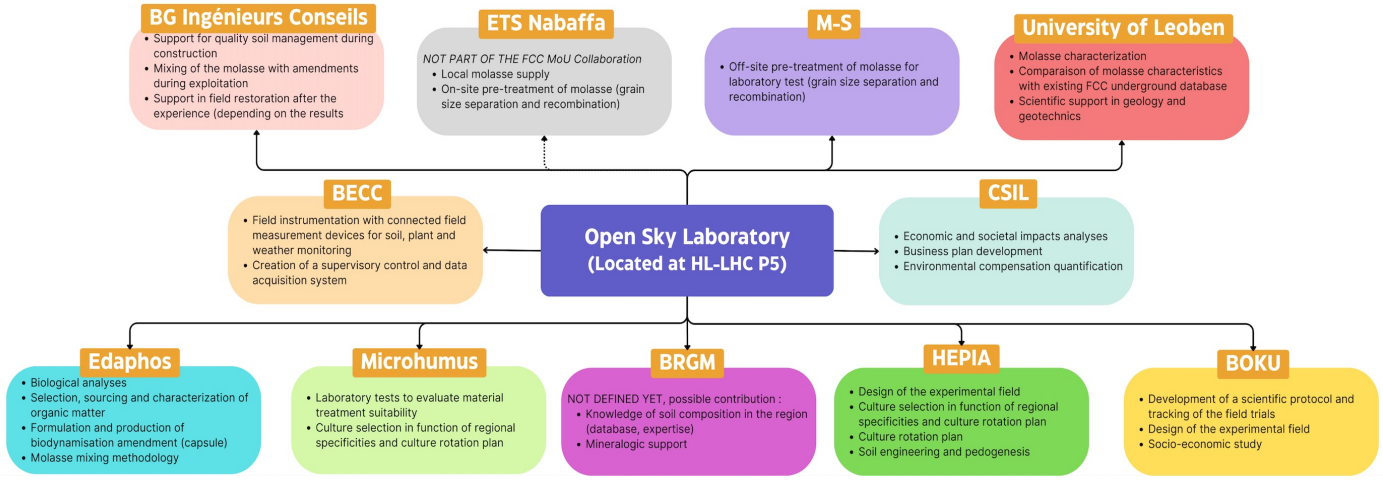
- **Project launched in January 2024**
- **10000 m² near LHC P5 in Cessy, France.**

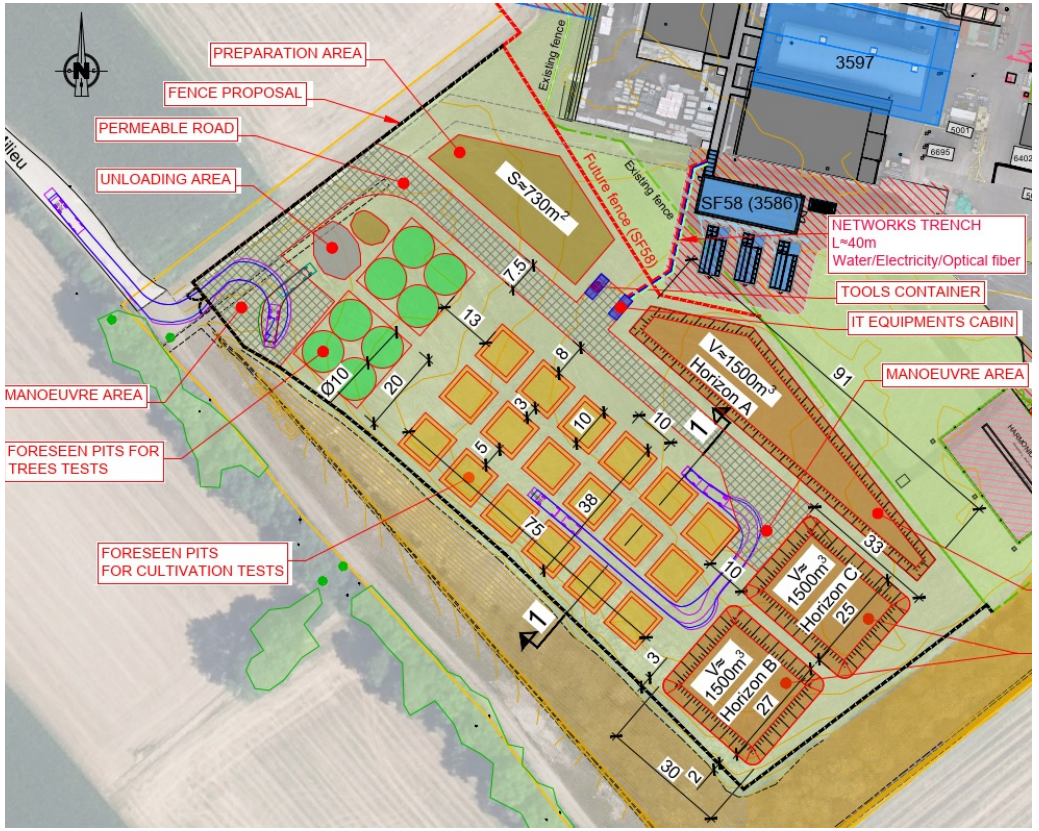
Project phases:

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



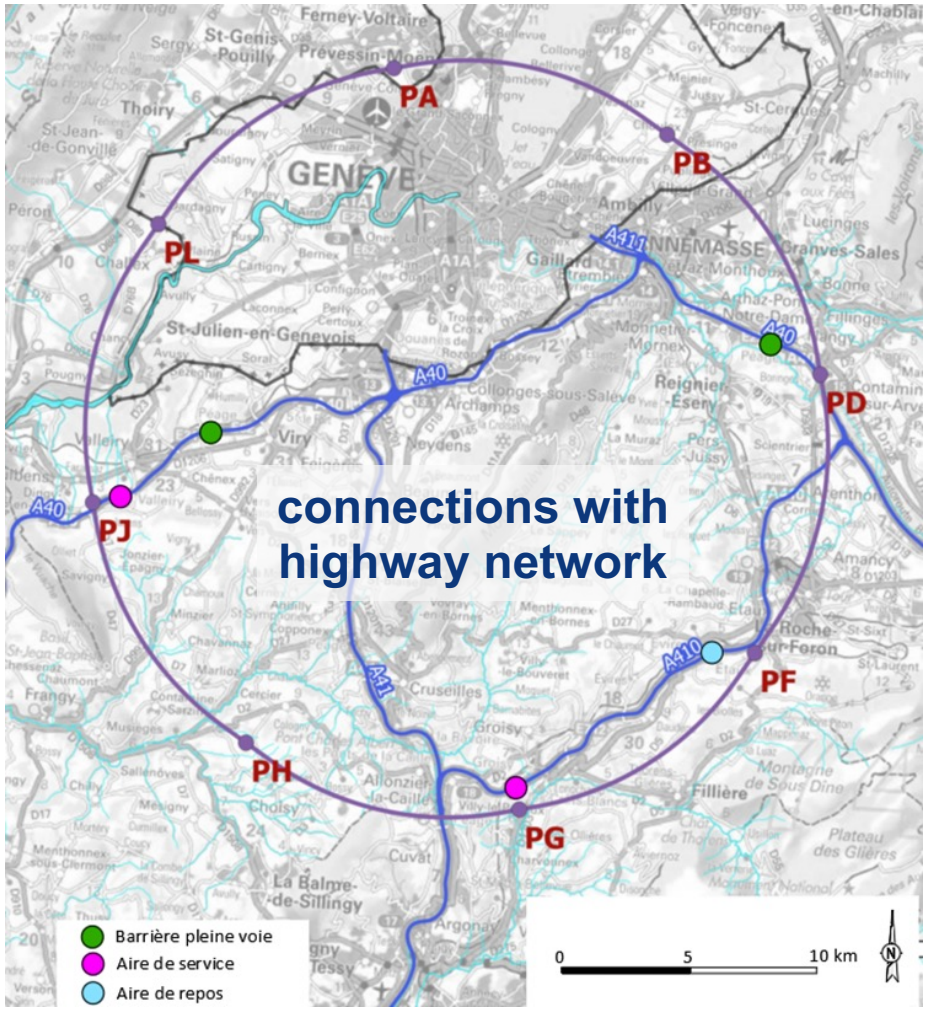


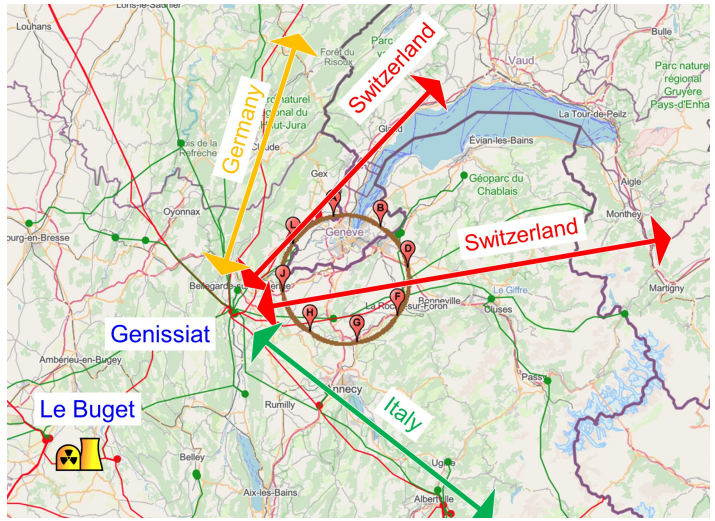
Status - March 2024:

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

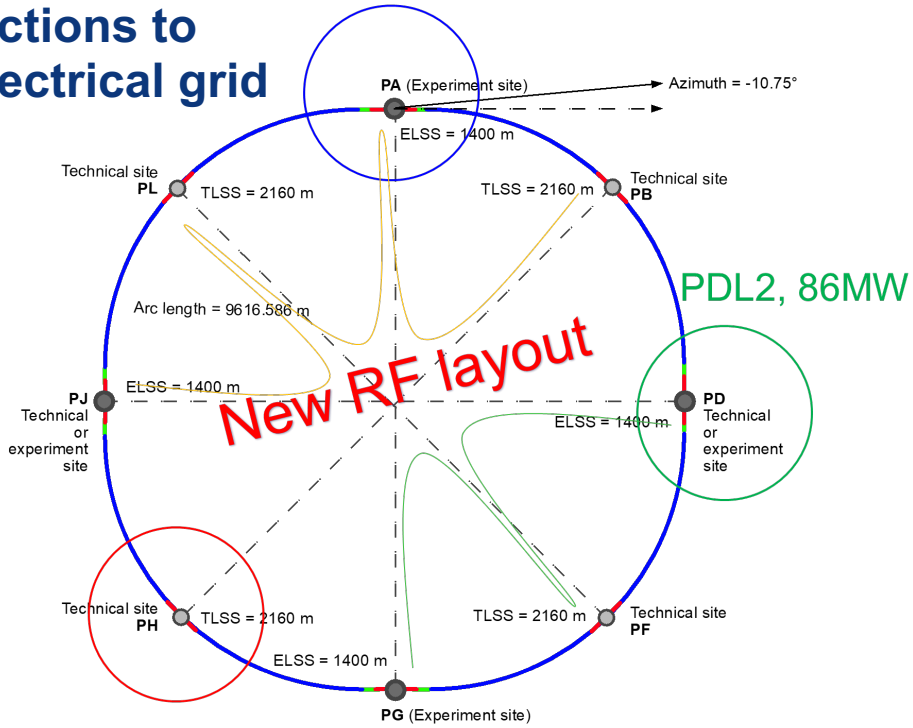
Connections with regional infrastructure

- 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

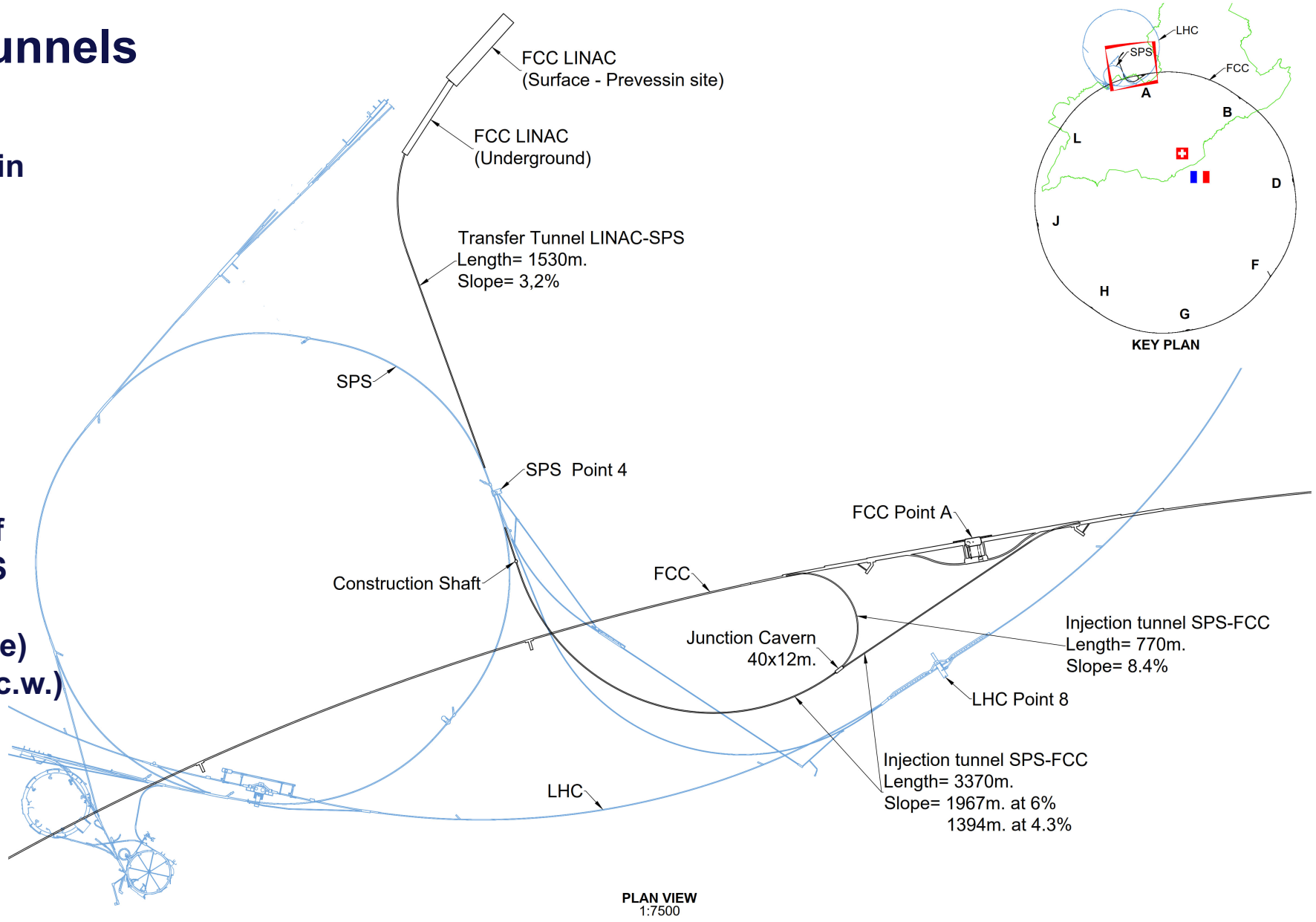


- Electrical connection concept studied by RTE (French electrical grid operator) ➔ requested loads have no significant impact on grid
- Powering concept and power rating of the three sub-stations compatible with FCC-hh
- R&D efforts aiming at further reduction of the energy consumption of FCC-ee and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

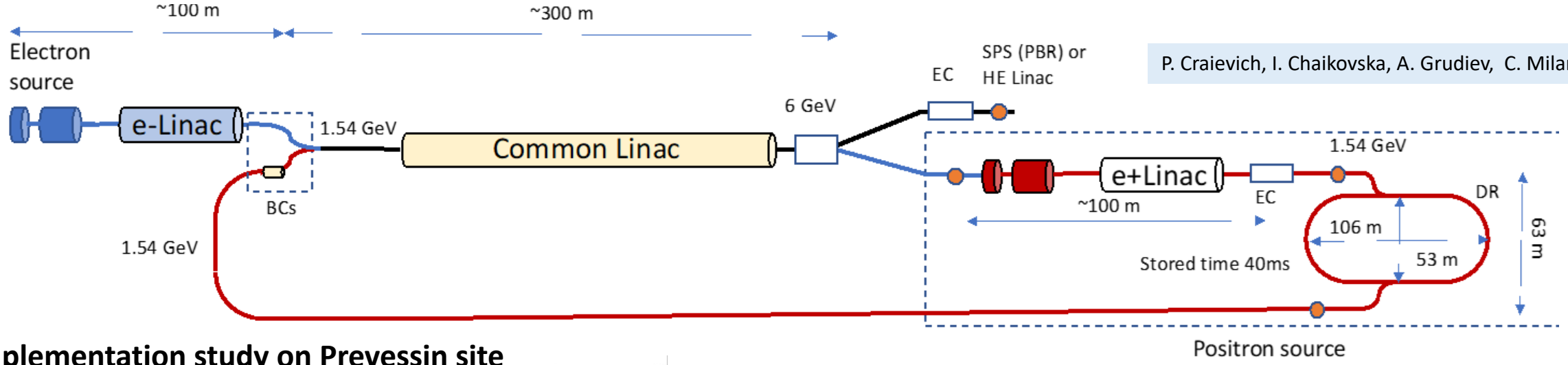
Transfer line FCC-ee (option with SPS for FCC-hh)

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.)

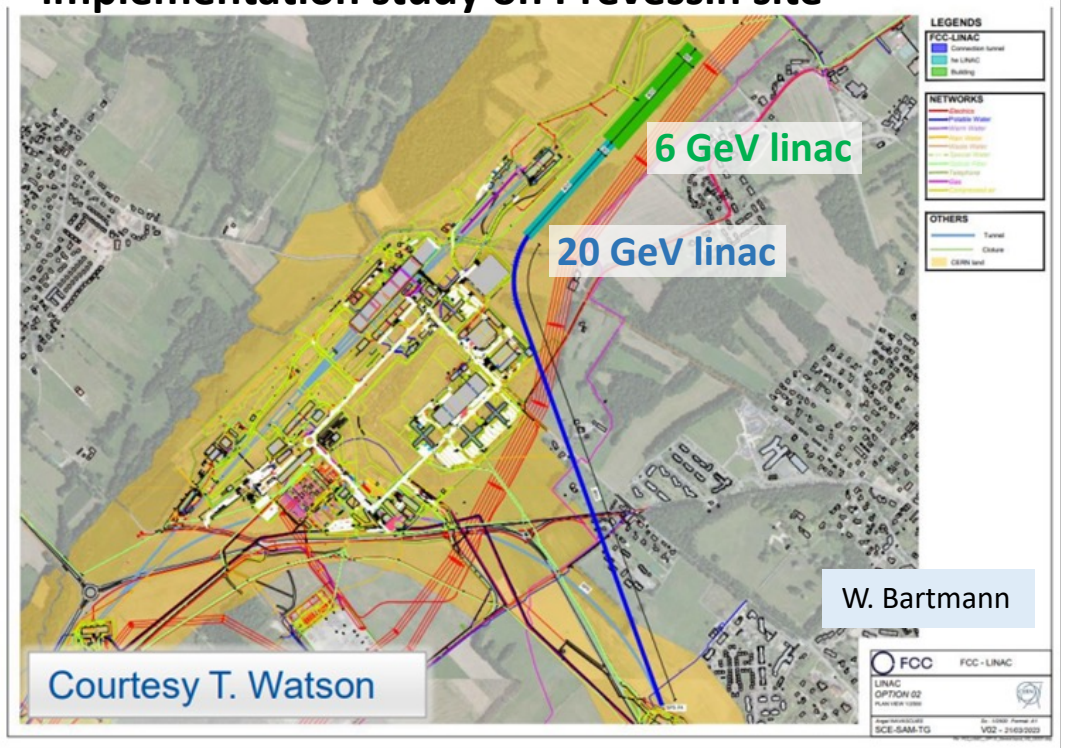


FCC-ee injector layout & implementation

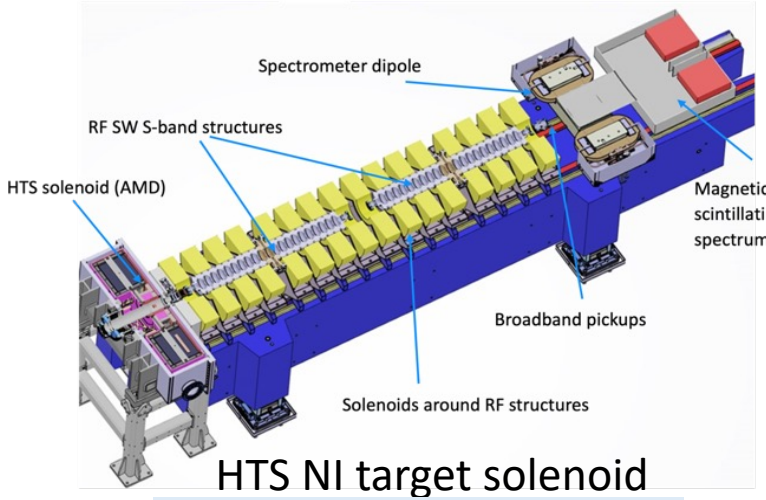


P. Craievich, I. Chaikovska, A. Grudiev, C. Milardi, et al

implementation study on Prevessin site

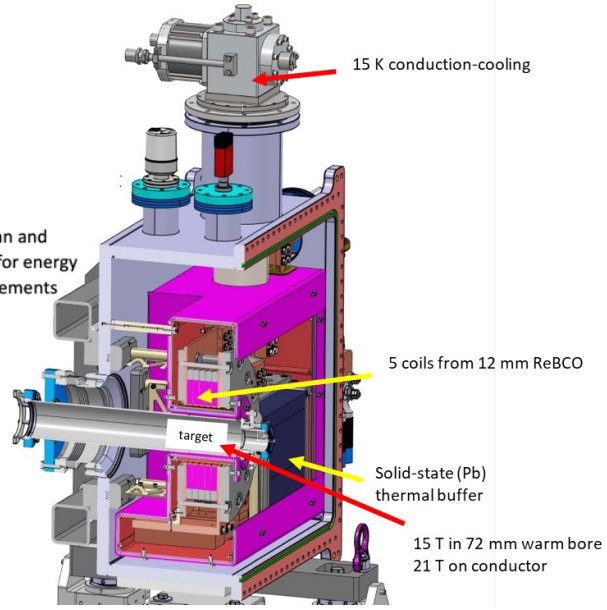


"Positron production experiment" at PSI's SwissFEL, beam tests from 2025/26



HTS NI target solenoid

J. Kosse, T. Michlmayr, H. Rodrigues



FUTURE CIRCULAR COLLIDER

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

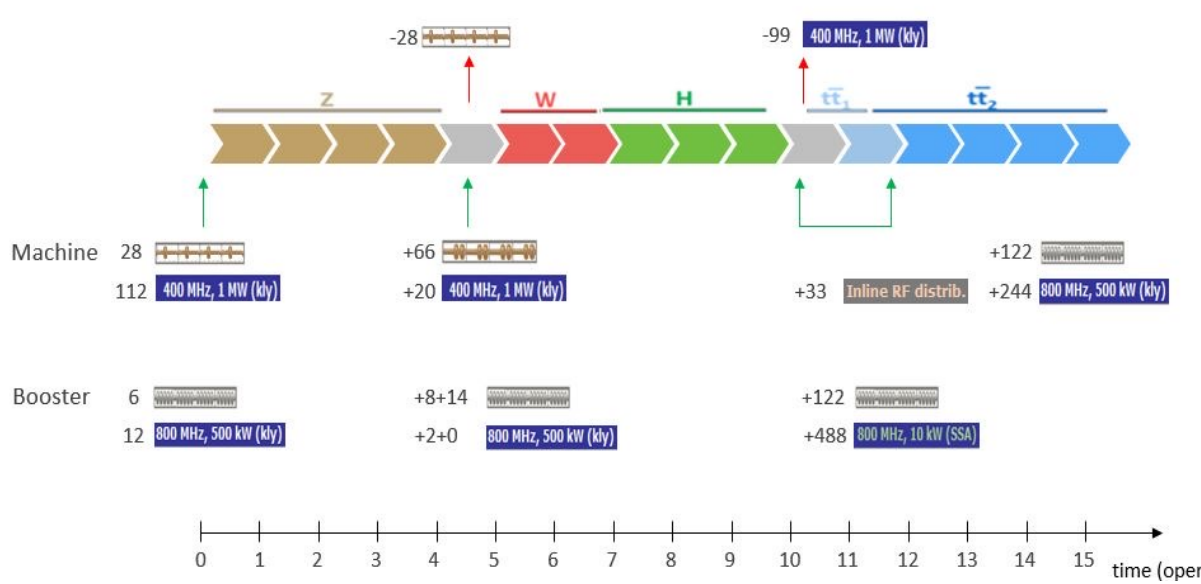
Design and parameters dominated by the choice to allow for 50 MW synchrotron radiation per beam.

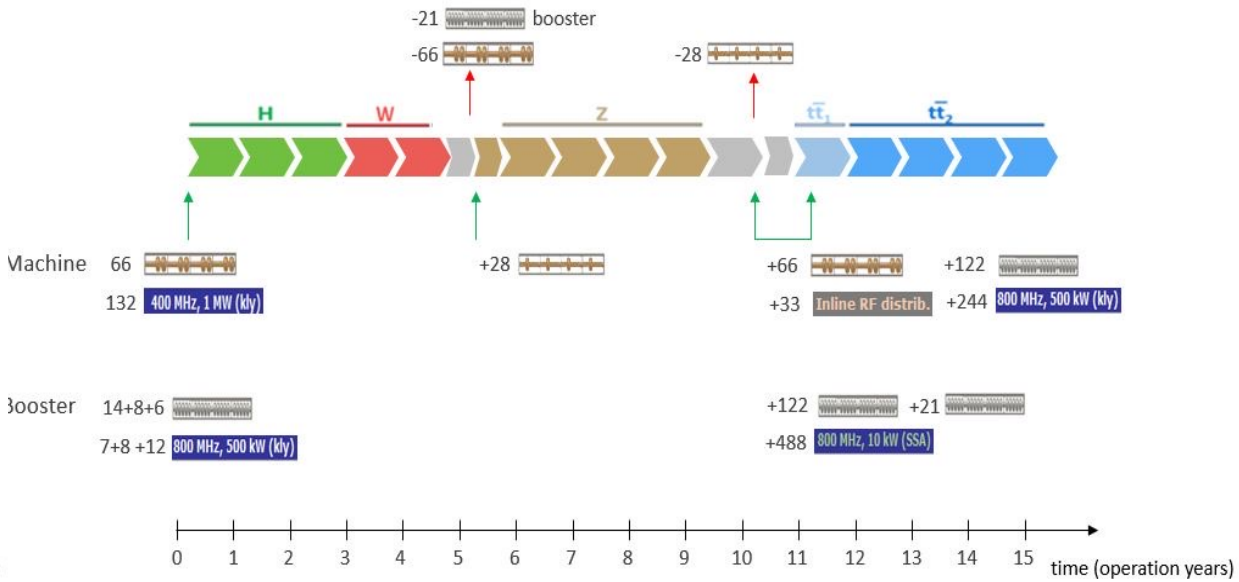
- x 10-50 improvements on all EW observables
- up to x 10 improvement on Higgs coupling (model-indep.) measurements over HL-LHC
- x10 Belle II statistics for b, c, τ
- indirect discovery potential up to ~ 70 TeV
- direct discovery potential for feebly-interacting particles over 5-100 GeV mass range

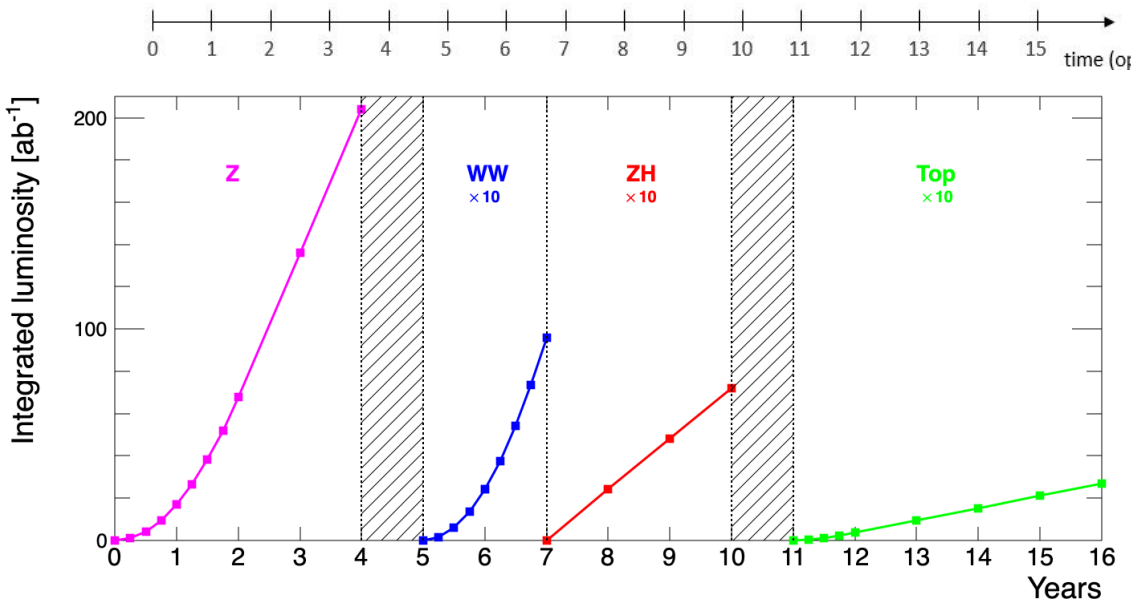
Up to 4 interaction points → robustness, statistics, possibility of specialised detectors to maximise physics output

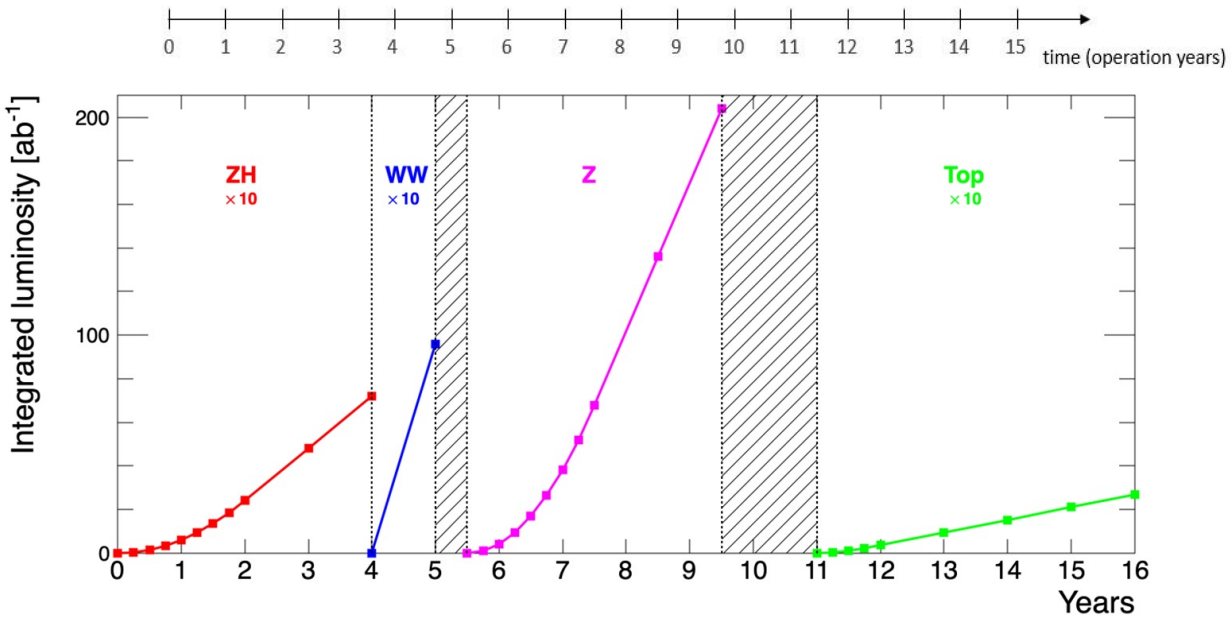
F. Gianotti

Operation sequences for FCC-ee and RF configuration









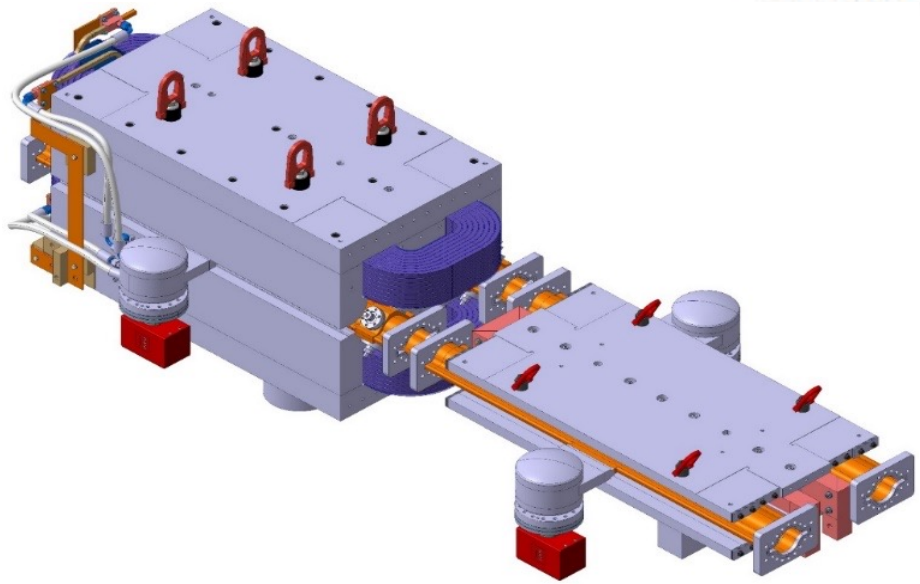
- **Evolution of RF configuration of collider and booster with beam energies and physics operation points**
- **Long-term R&D for SRF, in particular for the 800 MHz system**

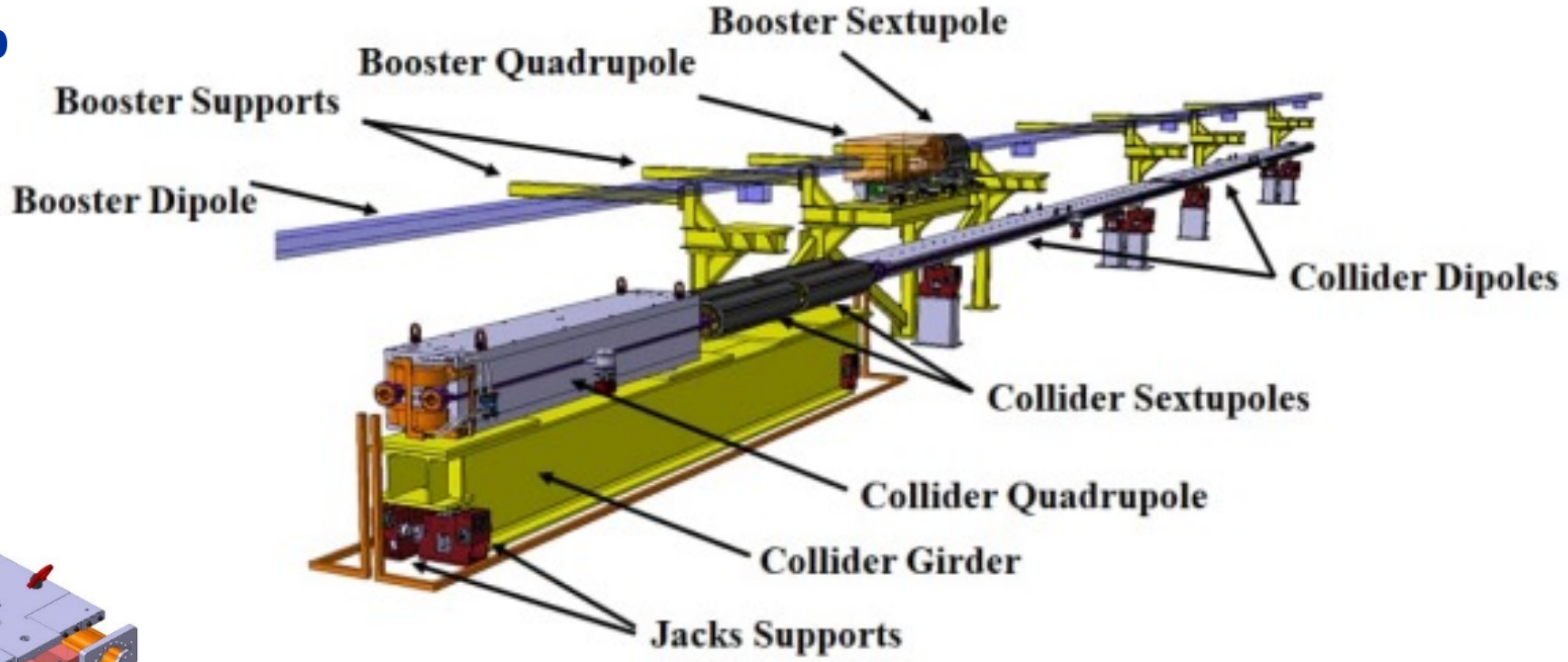
Arc layout and integration optimisation

Arc cell optimisation – 80 km total system length, dedicated working group active.

- including support, girder and alignment systems, shielding systems
- vacuum system with antechamber + pumps, dipole, quadrupole + sext. magnets, BPMs,
- cabling, cooling & technical infrastructure interfaces.
- safety aspects, access and transport concept,

FCC-ee arc half-cell mock up





FUTURE CIRCULAR COLLIDER

FCC-hh parameters

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
Integrated luminosity/main IP [fb^{-1}]	20000	3000	300

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 ($\gamma\gamma$, $Z\gamma$, $\mu\mu$)
- ❑ Final word about WIMP dark matter

FUTURE CIRCULAR COLLIDER

Status of FCC global collaboration

The CERN Council reviewed the work undertaken in a fruitful meeting on 2 February 2024.
It congratulated and thanked all the teams involved in the study for the excellent and significant work done so far and for the impressive progress, and looks forward to receiving the final report in 2025.

From Türkiye 15 FCC Collaboration members: **Giresun** University, **IYTE** Urla Izmir, **Izmir University of Economics**, **Istanbul University**, **TOBB** University of Economics and Technology Ankara, **Istanbul Aydin** U., **Piri Reis** Üniversitesi Tuzla/Istanbul, Izmir University Bakırcay (**IBU**), **Isik** University Sile/Istanbul, **Bursa Uludağ** University Nilüfer, **Ege** University Bornova-Izmir, **Ankara U** Tandogan/Ankara, **İstinye** University Istanbul, **Kirikkale** University, Kirikkale, **AIBU** Bolu

150 Institutes

32 Companies

33 Countries

EC H2020

FCC Feasibility Study: Aim is to increase further the collaboration, on all aspects, in particular, on Accelerator and Particle/Experiments/Detectors (PED).

FCC workshops organized by Turkish FCC community

İ. ÖZ (TAEK)
E. RECEPOĞLU (TAEK)
S. ŞAHİN (Akdeniz U.)
K. TAŞDÖVEN (Akdeniz U.)
Z.Ş. TURHAN IRAK (Igdir U.)
E. YILDIZ (Kırıkkale U.)
A. YÜKSEL (TAEK)

A. ŞENOL (BAİB U.)
G. ÜNEL (UCI & CERN)
Y. ÖNEL (Iowa U.)
E .V. ÖZCAN (Bogazici U.)
M. SELVAGGI (CERN)
F. ZIMMERMANN (CERN)

http://aknam.akdeniz.edu.tr/fcc-workshop/
aknam@akdeniz.edu.tr

FUTURE CIRCULAR COLLIDER

Conceptual Design Report 2018

2013 Update of European Strategy for Particle Physics:

"CERN should undertake design studies for accelerator projects in a global context, with emphasis on proton-proton and electron-positron high-energy frontier machines."

→ FCC Conceptual Design Reports (2018/19)

Vol 1 Physics, Vol 2 FCC-ee, Vol 3 FCC-hh, Vol 4 HE-LHC

CDRs published in **European Physical Journal C (Vol 1) and ST (Vol 2 – 4)**

EPJ C 79, 6 (2019) 474 , EPJ ST 228, 2 (2019) 261-623 , EPJ ST 228, 4 (2019) 755-1107 , EPJ ST 228, 5 (2019) 1109-1382

>1350 contributors (***41 from Türkiye!***) and
>350 *institutes* (***19 institutes from Türkiye!***)

Physics Publications by FCC groups in Turkey (to be updated !)

1) The 28 GeV Dimuon Excess in Lepton Specific 2HDM, A. Cici, S. Khalil, B. Niş, C. S. Un, arXiv:1909.02588v1 [hep-ph]

2) Study on Anomalous Neutral Triple Gauge Boson Couplings from Dimension-eight Operators at the HL-LHC, A. Senol, H. Denizli, A. Yilmaz, I. Turk Cakir, O. Cakir., arXiv:1906.04589 [hep-ph].

3) Sensitivity on Anomalous Neutral Triple Gauge Couplings via ZZ Production at FCC-hh, A. Yilmaz, A. Senol, H. Denizli, I. Turk Cakir, O. Cakir., arXiv:1906.03911 [hep-ph].

4) Top quark anomalous FCNC production via tqg couplings at FCC-hh, K.Y. Oyulmaz, A. Senol, H. Denizli, O. Cakir, Phys.Rev. D99 (2019) no.11, 115023. 10.1103/PhysRevD.99.115023.

5) Testing for observability of Higgs effective couplings in triphoton production at FCC-hh, H. Denizli, K.Y. Oyulmaz, A. Senol., arXiv:1901.04784 [hep-ph]

6) Linac and Damping Ring Designs for the FCC-ee, S. Ogur et al., Proceedings of International Particle Accelerator Conference (IPAC 2019), pp. 420-423, 2019

7) FCC-ee: The Lepton Collider : Future Circular Collider Conceptual Design Report Volume 2, FCC Collaboration (A. Abada et al.)., Eur.Phys.J.ST 228 (2019) no.2, 261-623, 10.1140/epjst/e2019-900045-4.

8) FCC-hh: The Hadron Collider : Future Circular Collider Conceptual Design Report Volume 3, FCC Collaboration (A. Abada et al.)., Eur.Phys.J.ST 228 (2019) no.4, 755-1107, 10.1140/epjst/e2019-900087-0.

9) HE-LHC: The High-Energy Large Hadron Collider, FCC Collaboration (A. Abada et al.)., Eur.Phys.J.ST 228 (2019) no.5, 1109-1382. 10.1140/epjst/e2019-900088-6.

10) FCC Physics Opportunities : Future Circular Collider Conceptual Design Report Volume 1, FCC Collaboration (A. Abada et al.)., Eur.Phys.J. C79 (2019) no.6, 474. 10.1140/epjc/s10052-019-6904-3.

11) Probing anomalous tq\gamma and tqg couplings via single top production in association with photon at FCC-hh, K.Y. Oyulmaz, A. Senol, H. Denizli, A. Yilmaz, I. Turk Cakir, O. Cakir, Eur.Phys.J. C79 (2019) no.1, 83. 10.1140/epjc/s10052-019-6593-y.

12) Probing top quark FCNC tq\gamma and tqZ couplings at future electron-proton colliders, O. Cakir, A. Yilmaz, I. Turk Cakir, A. Senol, H. Denizli, Nucl.Phys. B944 (2019) 114640. ,10.1016/j.nuclphysb.2019.114640.

13) Probing the Effects of Dimension-eight Operators Describing Anomalous Neutral Triple Gauge Boson Interactions at FCC-hh, A. Senol, H. Denizli, A. Yilmaz, I. Turk Cakir, K.Y. Oyulmaz, O. Karadeniz, O. Cakir., Nucl.Phys. B935 (2018) 365-376, 10.1016/j.nuclphysb.2018.08.018.

14) Light stops and fine-tuning in MSSM, A. Çiçi, Z. Kırca, C. S. Ün; , Eur. Phys. J. C (2018) 78: 60. https://doi.org/10.1140/epjc/s10052-018-5549-y

15) Probing the Anomalous FCNC Couplings at Large Hadron Electron Collider , I. Turk Cakir, A. Yilmaz, H. Denizli, A. Senol, H. Karadeniz, O. Cakir. Adv.High Energy Phys. 2017 (2017) 1572053.

15) Top quark FCNC couplings at future circular hadron electron colliders , H. Denizli, A. Senol, A. Yilmaz, I. Turk Cakir, H. Karadeniz, O. Cakir. Phys.Rev. D96 (2017) no.1, 015024.

16) Probing Charged Higgs Boson Couplings at the FCC-hh Collider , I.T. Cakir, S. Kuday, H. Saygin, A. Senol, O. Cakir. , Phys.Rev. D94 (2016) 015024.

17) Single production of the excited electrons in the future FCC-based lepton–hadron colliders, Abdullatif Caliskan, Seyit Okan Kara., Int.J.Mod.Phys. A33 (2018) no.24, 1850141.

18) Layout and Performance of the FCC-ee Pre-Injector Chain, Salim Ogur et al., DOI: 10.18429/JACoW-IPAC2018-MOPMF034.

19) Pre-Booster Ring Considerations for the FCC e^+e^- Injector, Ozgur Etisken, Fanouria Antoniou, Abbas Çiftçi, Yannis Papaphilippou, DOI: 10.18429/JACoW-IPAC2018-MOPMF002.

20) Bunch Schedules for the FCC-ee Pre-injector, Salim Ogur, Katsunobu Oide, Yannis Papaphilippou, Dmitry Shatilov, Frank Zimmermann. DOI: 10.18429/JACoW-IPAC2018-MOPMF001.

21) First Look at the Physics Case of TLEP , TLEP Design Study Working Group (M. Bicer et al.). , JHEP 1401 (2014) 164.

22) Excited muon searches at the FCC based muon-hadron colliders , A. Caliskan, S.O. Kara, A. Ozansoy. arXiv:1701.03426 [hep-ph]. Adv.High Energy Phys. 2017 (2017) 1540243.

23) Azimuthal Angular Decorrelation at Future High Energy Colliders , I. Hos, H. Saygin, S. Kuday. arXiv:1809.01505 [hep-ph].

24) Projections for Neutral Di-Boson and Di-Higgs Interactions at FCC-he Collider , S. Kuday, H. Saygın, İ. Hoş, F. Çetin., Nucl.Phys. B932 (2018) 1-14. 10.1016/j.nuclphysb.2018.05.002.

25) FCC Based Lepton-Hadron and Proton-Electron Colliders: Luminosity and Physics, Y. C. Acar, A. N. Akay, S. Beser, H. Karadeniz, U. Kaya, B. B. Oner, S. Sultansoy, Nucl.Instrum.Meth. A871 (2017) 47-53

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27) Excited neutrino search potential of the FCC-based electron-hadron colliders, A. Caliskan, Adv.High Energy Phys. 2017 (2017) 4726050

28) Excited muon searches at the FCC based muon-hadron colliders, A. Caliskan, S.O. Kara, A. Ozansoy, Adv.High Energy Phys. 2017 (2017) 1540243

29) Resonant production of leptogluons at the FCC based lepton-hadron colliders, Y. C. Acar, U. Kaya, B. B. Oner, S. Sultansoy, Acta Phys.Polon. B49 (2018) 1763

30) I Probing Anomalous WW γ and WWZ Couplings with Polarized Electron Beam at the LHeC and FCC-ep Collider, . Turk Cakir, A. Şenol, A. T. Tasci and O. Cakir. World Academy of Science, Engineering and Technology International Journal of Chemical, Molecular, Nuclear, Materials and Metallurgical Engineering (2015) Vol:9, No:1.

31) Search for Flavour Changing Neutral Current Couplings of Higgs-up Sector Quarks at Future Circular Collider (FCC-eh), I. Turk Cakir, B. Hacisahinoglu, S. Kartal, A. Yilmaz, A. Yilmaz, Z. Uysal, O. Cakir, World Academy of Science, Engineering and Technology, Open Science Index 132, International Journal of Physical and Mathematical Sciences (2017), 11(12), 525-529.

32) The Search of Anomalous Higgs Boson Couplings at the Large Hadron Electron Collider and Future Circular Electron Hadron Collider, I. Turk Cakir, M. Altinli, Z. Uysal, A. Senol, O. Yalcinkaya, A. Yilmaz, World Academy of Science, Engineering and Technology, Open Science Index 132, International Journal of Physical and Mathematical Sciences (2017), 11(12), 519-524.

FCC-Turkey team extremely active and productive

FCC PhD theses by students from Turkish universities

PhD theses

Salim OGUR, Bogazici University, "Linac and Damping Ring Designs of the future Circular e+e- Collider of CERN", CERN/Bogazici PhD April 2019 – later CERN fellow, now JLAB

Umit KAYA, Ankara U / TOBB, "Search for Color Octet Electron (e8) at TeV Energy Scale Colliders", PhD 2019

Ozgur ETISKEN, Ankara University, "Pre-Booster Ring Design for FCC-e^+e^- Injector complex", CERN/Ankara PhD 2021, now Kirikkale U.

Kaan Yuksel OYULMAZ, Bolu Abant Izzet Baysal University, "Upgrade and performance studies of CMOS sensors for future colliders," PhD 2022, now U. of Edinburgh

Özgün Mustafa ÖZŞİMŞEK, Hacettepe Üniversitesi, "Investigation of flavor changing neutral current interactions of top quark through scalar boson," PhD 2022

FCC Master of Science (MSc) theses by students from Turkish universities

Rokia Omar Ali ALAMIN, 2017, "Anomalous heavy down type b' quark production at the future circular collider", Kastamonu University

Burak HACIŞAHİNOĞLU, 2017, "Search for flavour changing neutral current couplings of higgs-up sector quarks at electron-proton colliders", Istanbul U.

Murat ALTINLI, 2017, "Investigation of gauge boson anomalous couplings with higgs particle at electron-proton colliders", Istanbul U.

Alev Ezgi DEMİRCİ, 2017, "Production and decay channels of charged higgs boson at high energy hadron colliders", Ankara U.

Yunus Emre OKYAYLI, 2018, "Search for R-parity violation interactions of scalar leptons at future circular collider", Istanbul U.

Gökhan HALİMOĞLU, 2018, "Measurement of lepton + jets at 100 TeV at future circular collider", Istanbul U.

Çağla ÇAĞLAR, 2019, "Search for quarkonium consists of E6 model predicted isosinglet quark at future colliders", Ege University

Leyla ADYIN, 2021, "A search for spin-1/2 excited quark with dijet final state at high-luminosity and high-energy large hadron colliders", Kahramanmaraş Sütçü İmam Üniversitesi

Ali TOSUN, 2022, "FCC-hh deneyinde çoklu parton etkileşimlerinin jet özellikleri üzerindeki katkısı", Tokat Gaziosmanpaşa Üniversitesi

Nur DAIF, 2022, "Investigation of compositeness scale with contact interactions in electron-proton collisions based on the future circular collider," Hatay Mustafa Kemal Üniversitesi

Shahad Ahmed AL YOUSIF, 2022, "Investigation of neutral triple gauge coupling via pp→ZZ production with anomalous coupling approach for future hadron colliders," Bolu Abant İzzet Baysal Üniversitesi

Safwa HAITHAM JAMEEL, 2022, "A study on DIM-8 neutral triple gauge couplings via ZZ production at future hadron colliders," Bolu Abant İzzet Baysal Üniversitesi

Haneen YOUSIF, 2022, "A study on investigation of FCNC tqZ couplings via vZp production at future electron-proton colliders," Bolu Abant İzzet Baysal Üniversitesi

Şeyma BİÇER, 2022, "Pair production of exotic vektor like Y quark at the FCC-hh", Kütahya Dumlupınar Üniversitesi

Osman EMRE DELİALİOĞLU, 2022, "Search potential of FCC-pp collider for vector like leptons", Search potential of FCC-pp collider for vector like leptons, TOBB Ekonomi ve Teknoloji Üniversitesi

Ali TOSUN, 2022, "FCC-hh deneyinde çoklu parton etkileşimlerinin jet özellikleri üzerindeki katkısı", Tokat Gaziosmanpaşa Üniversitesi

Ceren HELVECİ, 2023, "Using machine learning method to search the anomalous quartic gauge couplings via tri-photon production at future hadron colliders," Bolu Abant İzzet Baysal Üniversitesi

Zakira HASHIMI, 2023, "Electromagnetic calorimeter design study for the future circular electron-hadron collider (FCC-eh) detector", Bursa Uludağ Üniversitesi

Mehmet DURGUT, 2023, "Resonance production of second generation vector leptokuark sat FCC based lepton hadron colliders," Bursa Uludağ Ünivers.

Ahmed NAJIB ALİ AL-SOUDI, 2023, "Production of vector leptoquarks at fcc based photon proton colliders," Bursa Uludağ Üniversitesi

numerous FCC graduates

FUTURE CIRCULAR COLLIDER

Progress on international collaboration

★ ★ ★

Joint Statement of Intent between The United States of America and The European Organization for Nuclear Research concerning Future Planning for Large Research Infrastructure Facilities, Advanced Scientific Computing, and Open Science

The United States and CERN intend to:

- Enhance collaboration in future planning activities for large-scale, resource-intensive facilities with the goal of providing a sustainable and responsible pathway for the peaceful use of future accelerator technologies;
- Continue to collaborate in the feasibility study of the Future Circular Collider Higgs Factory (FCC-ee), the proposed major research facility planned to be hosted in Europe by CERN with international participation, with the intent of strengthening the global scientific enterprise and providing a clear pathway for future activities in open and trusted research environments; and
- Discuss potential collaboration on pilot projects on incorporating new analytics techniques and tools such as artificial intelligence (AI) into particle physics research at scale.

Should the CERN Member States determine the FCC-ee is likely to be CERN's next world-leading research facility following the high-luminosity Large Hadron Collider, the United States intends to collaborate on its construction and physics exploitation, subject to appropriate domestic approvals.

26 April 2024

White House Office of Science and Technology Policy Principal Deputy U.S. Chief Technology Officer Deirdre Mulligan signed for the United States while Director-General Fabiola Gianotti signed for CERN.

FUTURE CIRCULAR COLLIDER

Why FCC ?

F. Gianotti

1) Physics : best overall physics potential of all proposed future colliders

- ❑ FCC-ee : **ultra-precise** measurements of the Higgs boson, indirect exploration of next energy scale (~ x10 LHC)
- ❑ FCC-hh : **only** machine able to explore next **energy frontier** directly (~ x10 LHC)
- ❑ Heavy-ion collisions and, possibly, ep/e-ion collisions
- ❑ **4 collision points** → robustness; increased dataset for same machine power; specialized experiments for maximum physics outpu

2) **Timeline**

- ❑ **FCC-ee technology is mature** → construction can proceed in parallel to HL-LHC operation and physics can start few years after end of HL-LHC operation → This would keep the community, in particular the young people, engaged and motivated.
- ❑ **FCC-ee before FCC-hh** would also allow:
  - cost of the (more expensive) FCC-hh machine to be spread over more years
  - **20 years of R&D work towards affordable magnets providing the highest achievable field (HTS)**
  - **optimization of overall investment** : FCC-hh will reuse same civil engineering and large part of FCC-ee technical infrastructure

3) It's the **only facility commensurate with the size of the CERN community** (4 major experiments)

Is it feasible? Isn't it too ambitious?

-- The mid-term review will show the status of the Feasibility Study, including the funding model.

-- **FCC is big and audacious project, but so were LEP and LHC when first conceived** → they were successfully built and performed far beyond expectation → demonstration of capability of our community to deliver on very ambitious projects with < 20% cost overrun

FUTURE CIRCULAR COLLIDER

Conclusions and main for coming years

- **HL-LHC well underway, exciting physics till ~2040**
- **CERN now prepares for post-LHC era, full focus on FCC, a lot of efforts**
- **By 2027-2028, expect FCC project approval, start of CE design contract:**
  - specifications to enable CE tender design by 2028 (underground) and 2029 (surface)
  - requires overall integration study and designs based on technical predesign 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
- **Strong collaborations with Türkiye important for the success of the Feasibility Study and even more so for the FCC project to go ahead. Thank you for your contributions and looking forward to further collaboration !**

teşekkür ederim

FUTURE CIRCULAR COLLIDER

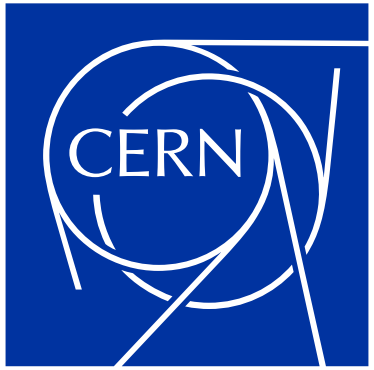
FCC Week 2024

Future Circular Collider (FCC) Week 2024, at the **Westin St. Francis in San Francisco.**

From **Monday 10 June to Friday 14 June 2024**. **Registration is open !**

https://fccweek2024.web.cern.ch/

We look forward to welcoming you in San Francisco for what promises to be an exciting and informative event!

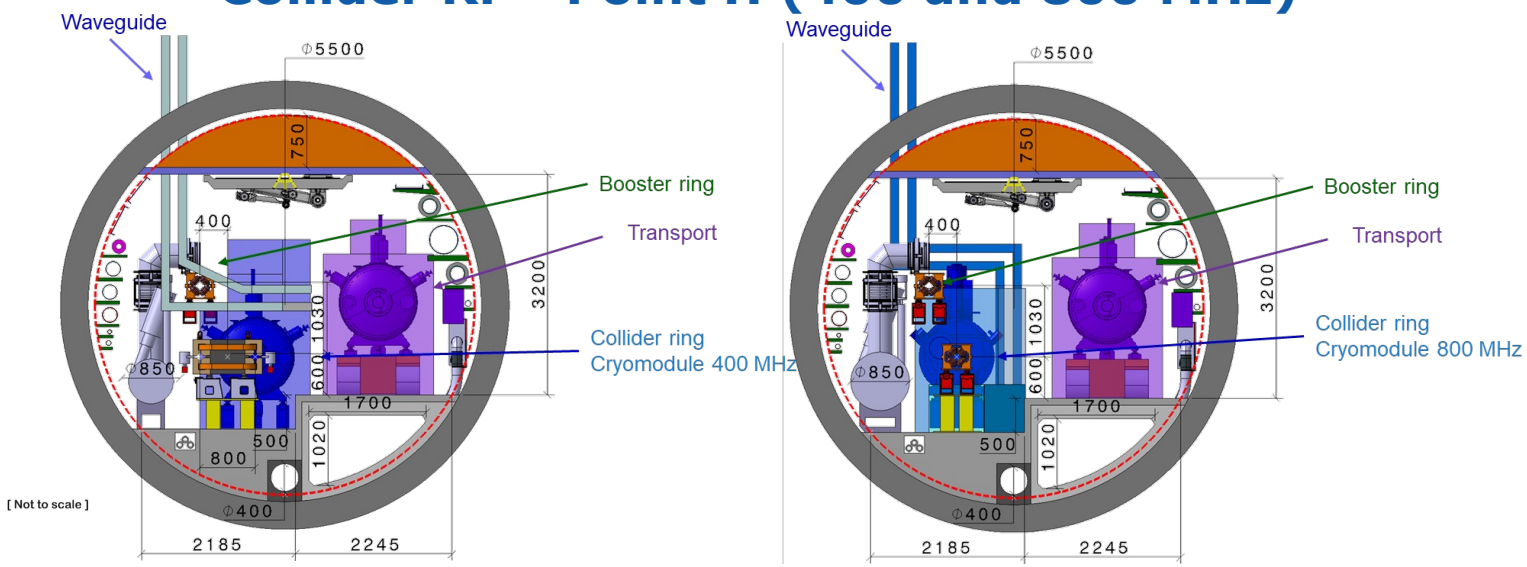


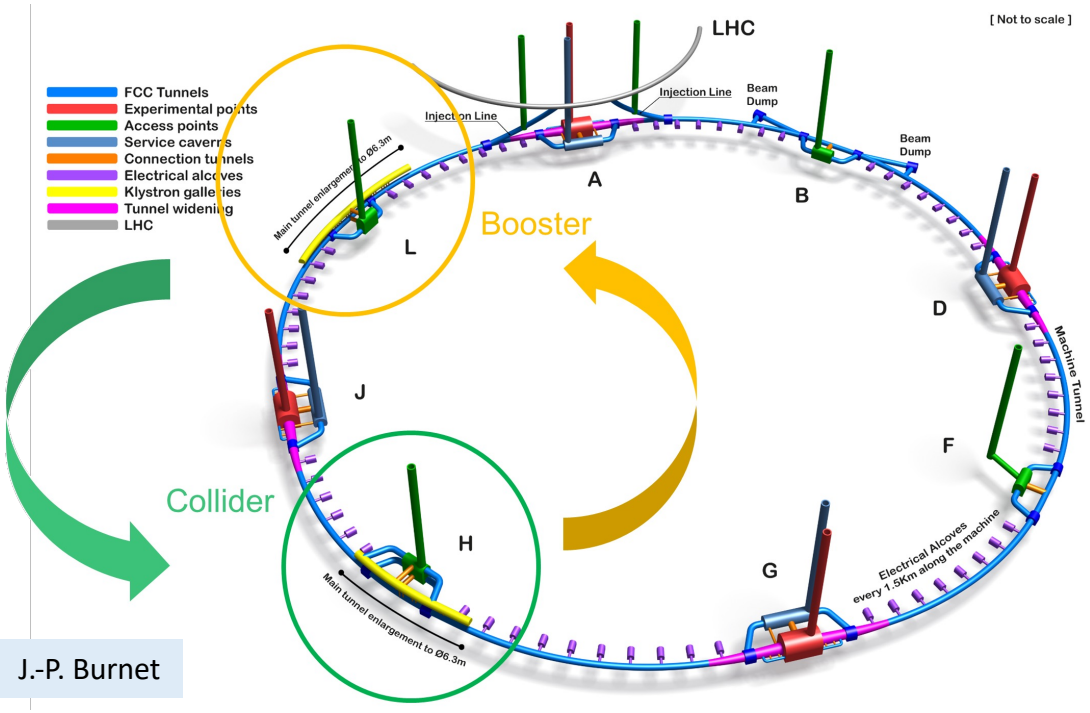
home.cern

FCC-ee RF layout

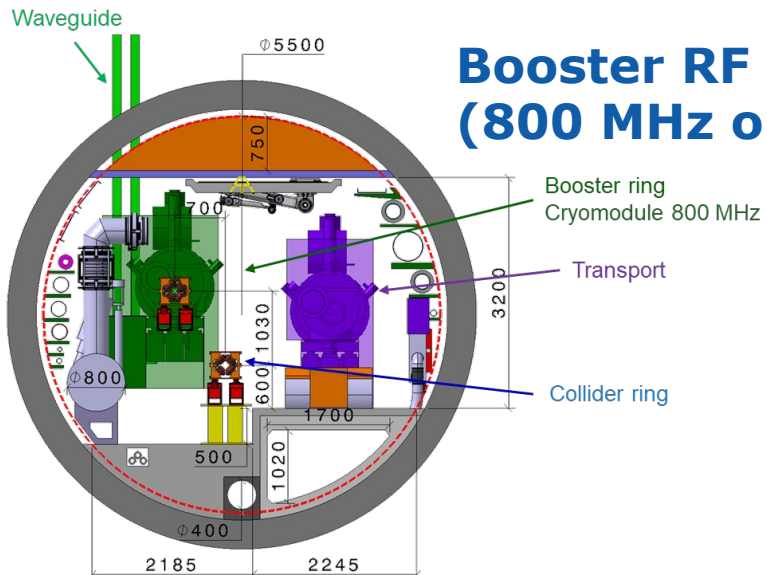
- RF for collider and booster in separate straight sections H and L.
- fully separated technical infrastructure systems (cryogenics)
- collider RF (highest power demand) in point H with optimum connection to existing 400 kV grid line and better suited surface site

Collider RF - Point H (400 and 800 MHz)





Booster RF - Point L (800 MHz only)



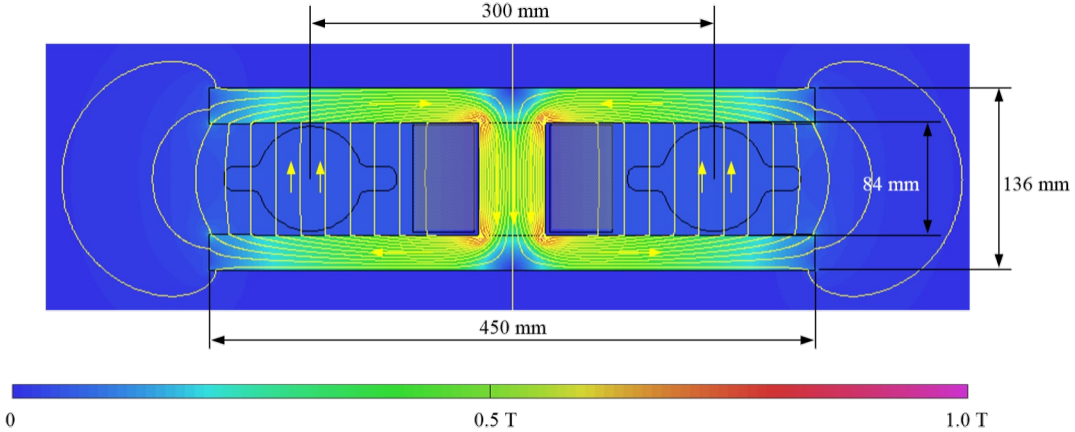
J.-P. Burnet

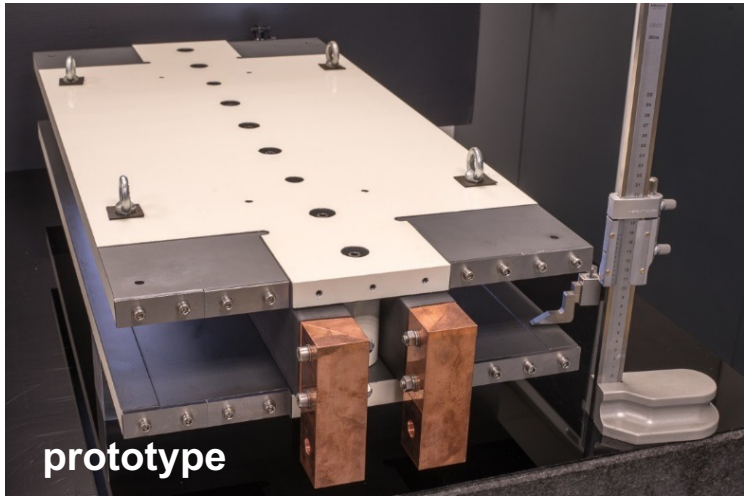
F. Valchova, F. Peauger

FUTURE CIRCULAR COLLIDER

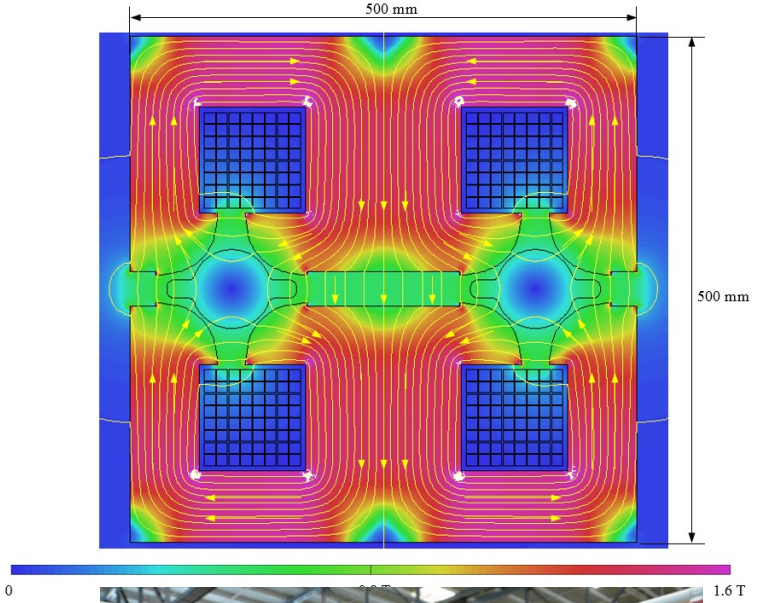
prototypes of FCC-ee low-power magnets

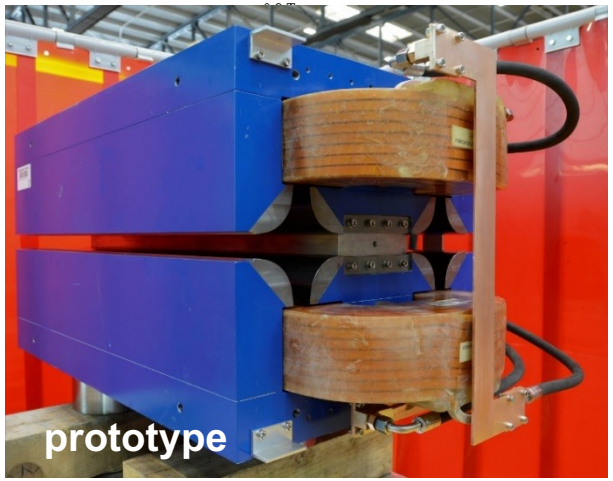
Twin-dipole design with 2× power saving
16 MW (at 175 GeV), with Al busbars





Twin F/D arc quad design with 2× power saving 25 MW (at 175 GeV), with Cu conductor





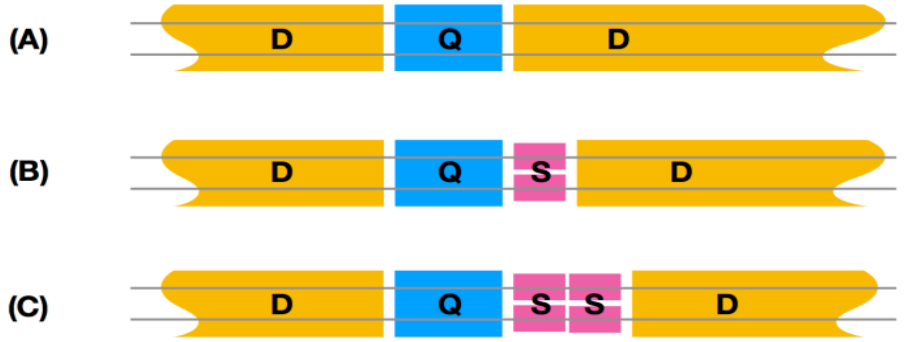
even more efficient alternative magnet designs are being explored

HTS option for FCC-ee arc quads and sextupoles

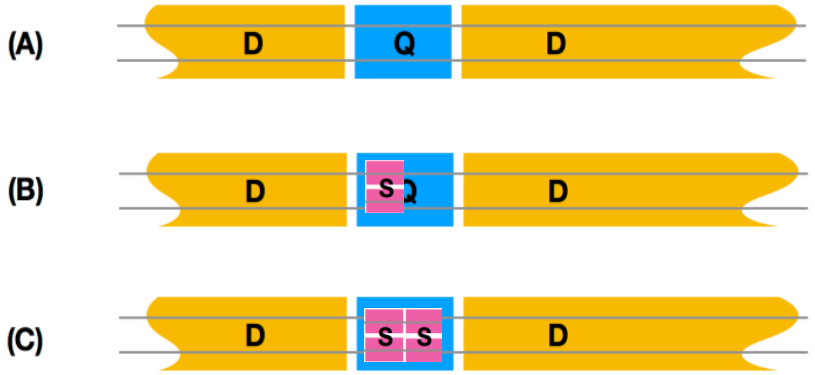
CDR: 2900 quads & 4700 sextupoles

- Normal conducting, ~50 MW @ ttbar
- 3 different types of short straight sections

CDR arc lattice



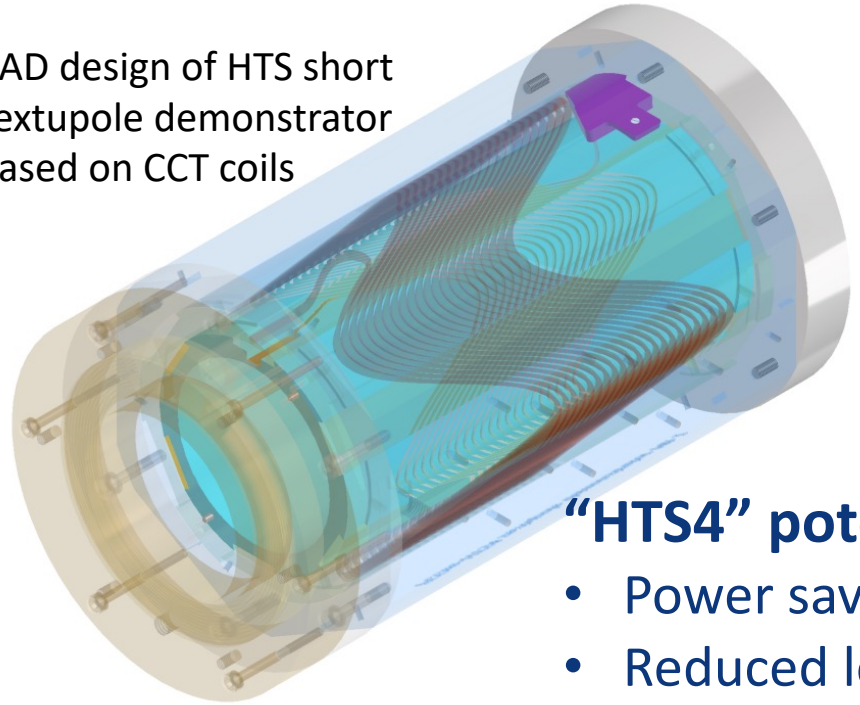
HTS option

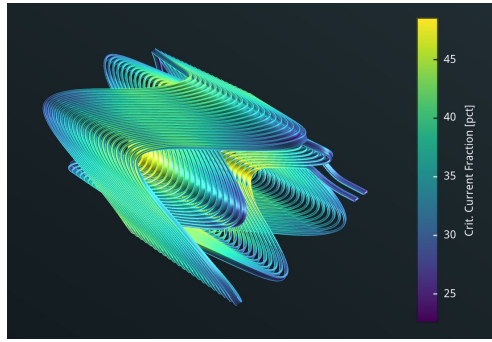


"HTS4" project within CHART collaboration

- Nested SC sextupole and quadrupole.
- HTS conductors operating at around 40K.
- Cryo-cooler supplied cryostat
- Produce a ~1m prototype by 2026

CAD design of HTS short sextupole demonstrator based on CCT coils





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"HTS4" potential

- Power saving
- Reduced length and increased dipole filling factor
- Optics flexibility