The Path Towards the Future Circular Collider at CERN

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KPS Pioneer Session - Present and Future of the LHC Programme at CERN
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Swiss Accelerator Research and Technology

http://cern.ch/fcc

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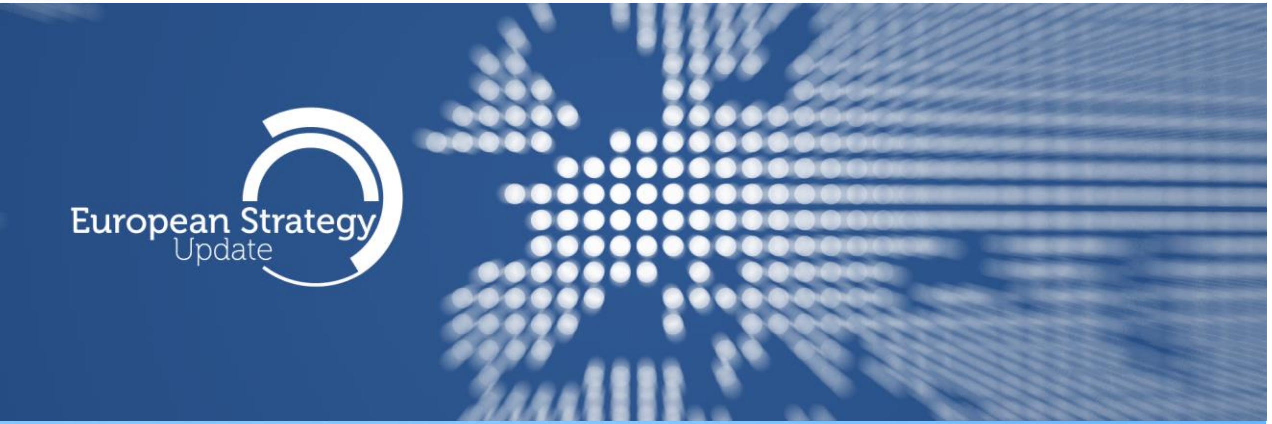
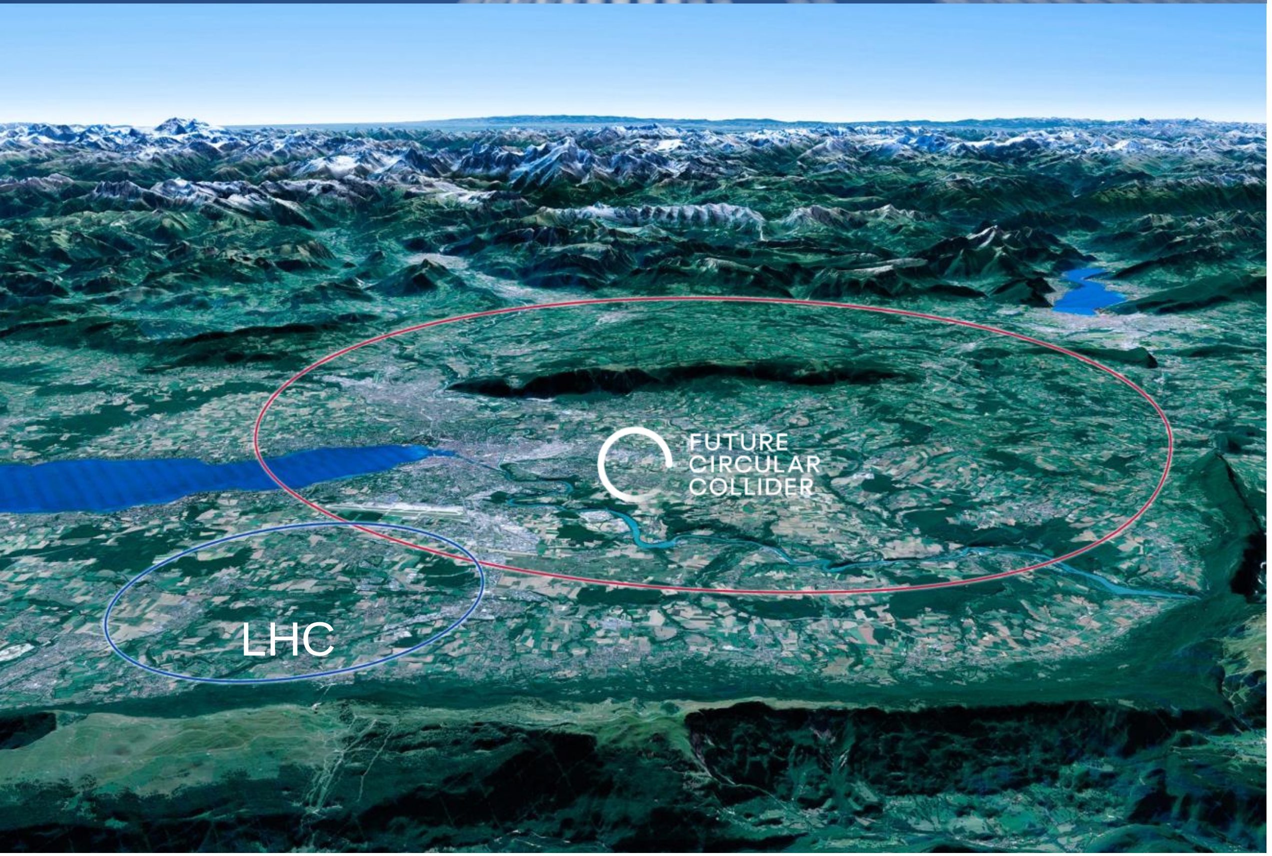
photo: J. Wenninger

FUTURE CIRCULAR COLLIDER





CERN Scientific Priorities for the Future

Implementation of the recommendations of the **2020 Update of the European Strategy for Particle Physics**:

- Fully exploit the LHC & HL-LHC.
- Build a Higgs factory to further understand this unique particle.
- Investigate the technical and financial feasibility of a future energy-frontier 100 km collider at CERN.
- Ramp up relevant R&D.
- Continue supporting other projects around the world.

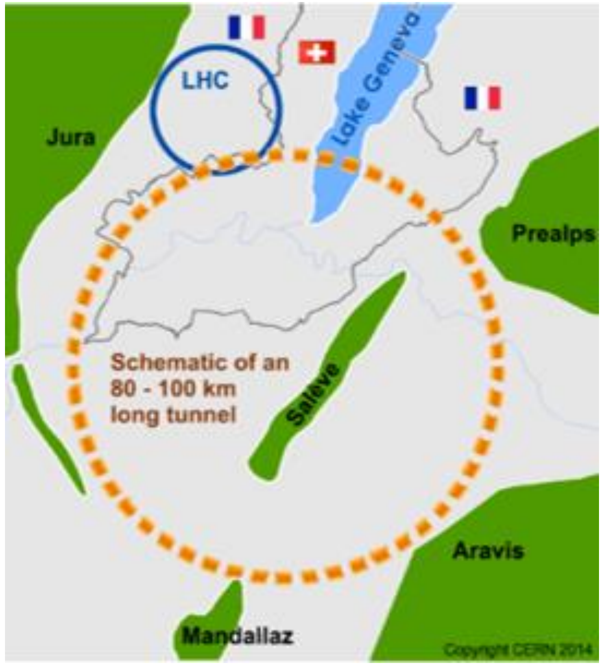
FUTURE CIRCULAR COLLIDER

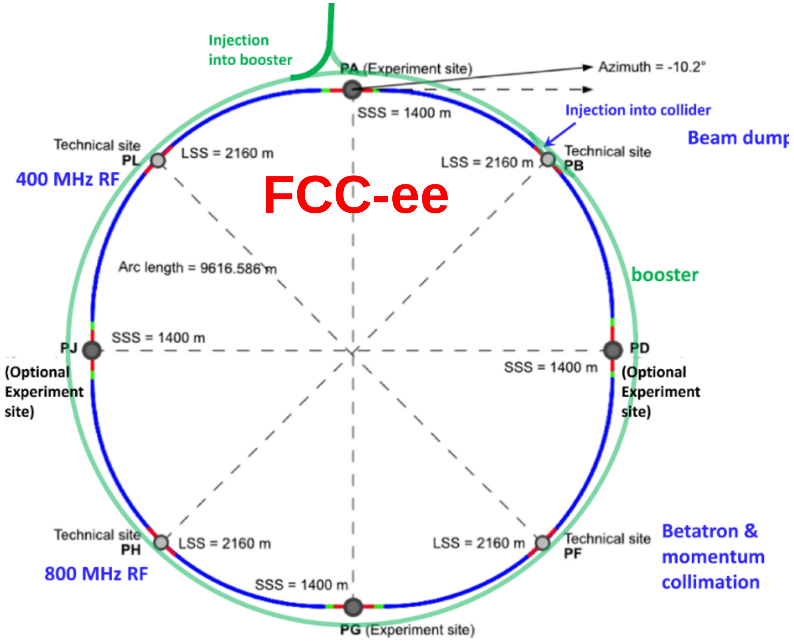
The FCC Integrated Programme

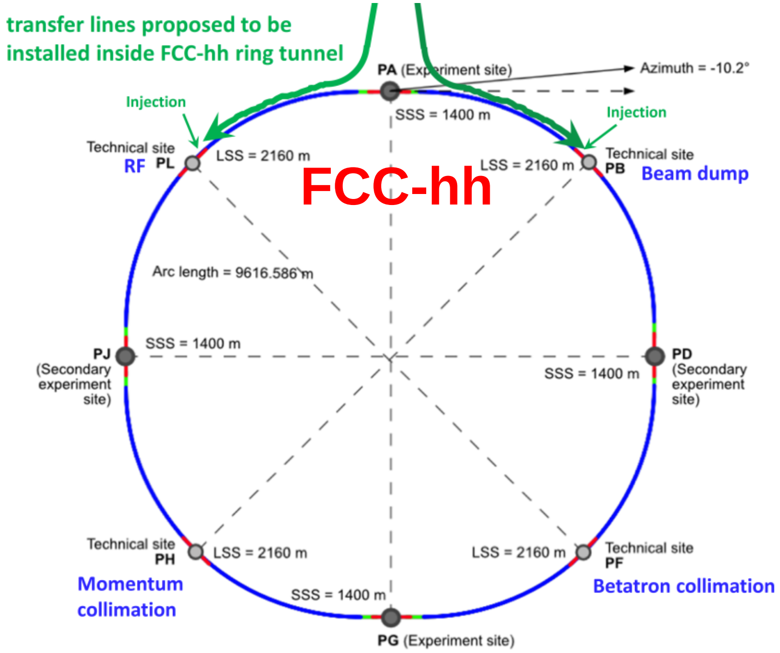
Inspired by Successful LEP – LHC Programmes at CERN

Comprehensive long-term programme maximising physics opportunities

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





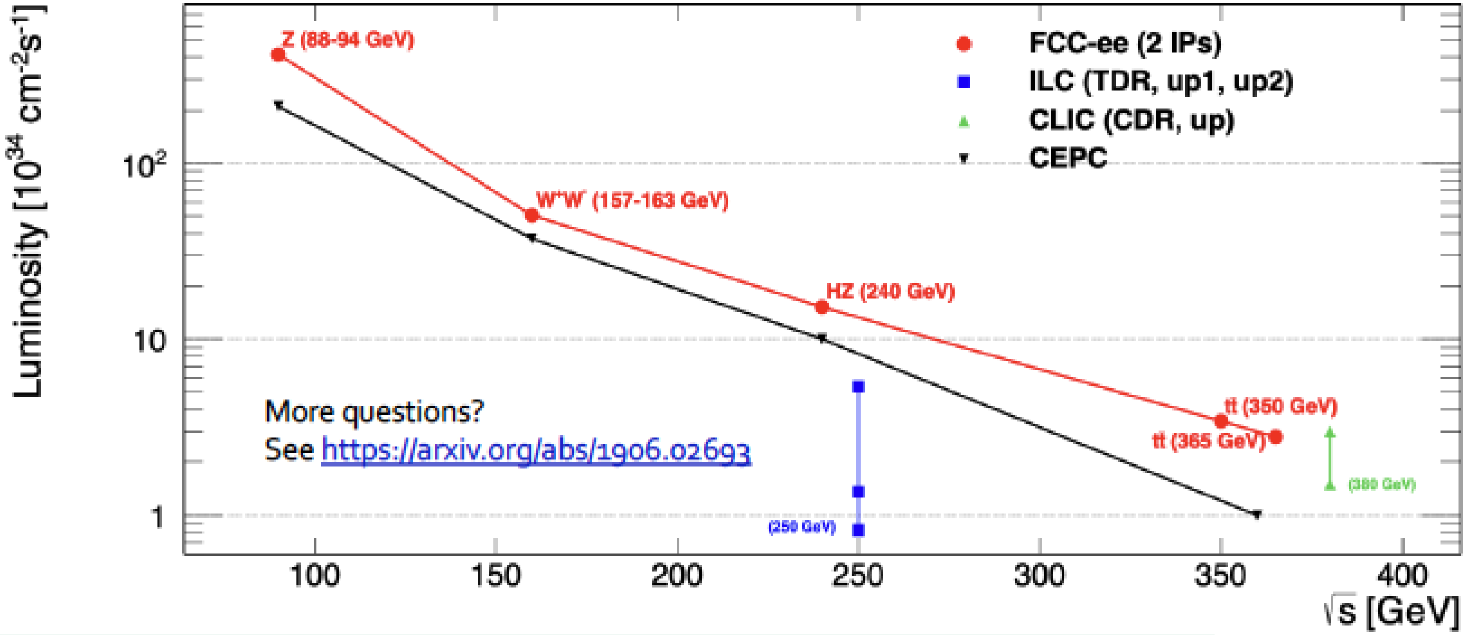


2020 - 2040 | **2045 - 2063** | **2070 - 2095**

A similar two-stage project CEPC/SppC is under study in China

FCC-ee Higgs and Electroweak Factory

- Great energy range for the SM heavy particles + highest luminosities + √s precision



				E_{CM} errors:
Z peak	E_{cm} ~ 91 GeV	5×10^{12} e+e- → Z	LEP x 10^5	<100 keV
WW threshold+	$E_{cm} \geq 161$ GeV	$> 10^8$ e+e- → WW	LEP x 10^3	<300 keV
ZH threshold	E_{cm} : 240 GeV	10^6 e+e- → ZH	Never done	2 MeV
$\bar{t}t$ threshold	E_{cm} ~ 350 GeV	10^6 e+e- → $\bar{t}t$	Never done	5 MeV

P. Janot

Physics Opportunities with FCC-hh

- **With 30 ab^{-1} @ 100 TeV in 25 years**
  - 2×10^{10} Higgs bosons (180 × HL-LHC)
    - 2×10^{7} Higgs pairs, 10^{8} ttH events
  - 10^{12} top pairs (300 × HL-LHC)
  - 5×10^{13} W, 10^{13} Z (70 × HL-LHC)
  - 10^{5} gluino pairs im m_{gluino} ~ 8 TeV
  - …

- **High precision study of H and top**
  - Exploration of EWSB in all details
    - Higgs self-coupling to 2-3%
  - Rare or BSM decays
    - BR(H → invisible) to 2.5×10^{-4} (DM!)
    - $g_{H\mu\mu}$, $g_{H\gamma\gamma}$, $g_{HZ\gamma}$ to 0.5%
      - → FCC-ee standard candle essential

- **Sensitivity to heavy new physics**
  - With indirect precision probes
    - e.g., with cross-section ratios
    - e.g., with high-p_T final states
  - Trade statistics for systematics
    - Further improved by FCC-ee synergies
  - High-energy phenomena (VBS, DY)

- **Direct particle observation**
  - Mass reach enhanced by ~5 wrt LHC
    - New gauge bosons up to 40 TeV
    - Strongly interacting particles up to 15 TeV
    - Natural SUSY up to 5-20 TeV
    - Dark matter up to 1.5-5 TeV
      - → Possibility to find or rule out thermal WIMPs as Dark Matter candidates

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FCC Feasibility Study

FCC Feasibility Study

FCC Feasibility Study (FS) will address a recommendation of the 2020 update of the European Strategy for Particle Physics (ESPP):

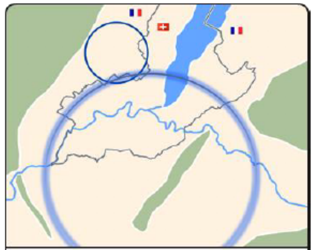
- "Europe, together with its international partners, should investigate the technical and financial feasibility of a future hadron collider at CERN with a centre-of-mass energy of at least 100 TeV and with an electron-positron Higgs and electroweak factory as a possible first stage.
- Such a feasibility 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."

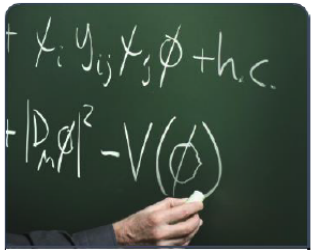
FCC FS is organised as an international collaboration.
The FCC FS and a possible future project will profit from CERN's decades-long experience with successful large international accelerator projects, e.g. the LHC and HL-LHC, and the associated global experiments, such as ATLAS and CMS.

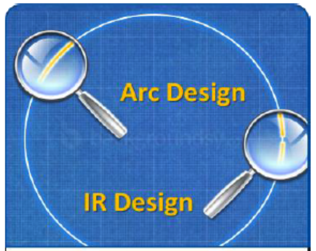
High-level Goals of Feasibility Study

High-level goals of Feasibility Study

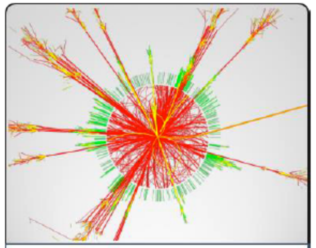
- optimisation of placement and layout of the ring and related infrastructure, and demonstration of the geological, technical, environmental and administrative feasibility of the tunnel and surface areas;
- pursuit, together with the Host States, of the preparatory administrative processes required for a potential project approval, with a focus on identifying and surmounting possible showstoppers;
- optimisation of the design of the colliders and their injector chains, supported by targeted R&D to develop the needed key technologies;
- development and documentation of the main components of the technical infrastructure;
- elaboration of a sustainable operational model for the colliders and experiments in terms of human and financial resource needs, environmental aspects and energy efficiency;
- identification of substantial resources from outside CERN's budget for the implementation of the first stage of a possible future project;
- consolidation of the physics case and detector concepts for both colliders.

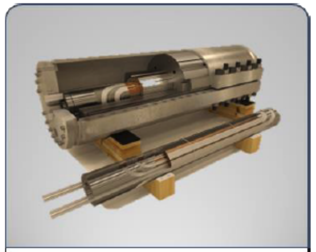

Infrastructures


Physics Cases



Collider Designs


Experiments


R&D Programs

Cost Estimates

Stage 1: FCC-ee Highest Luminosity Lepton Collider

Double ring e^+e^- collider, with full-energy booster

2 or 4 interaction points

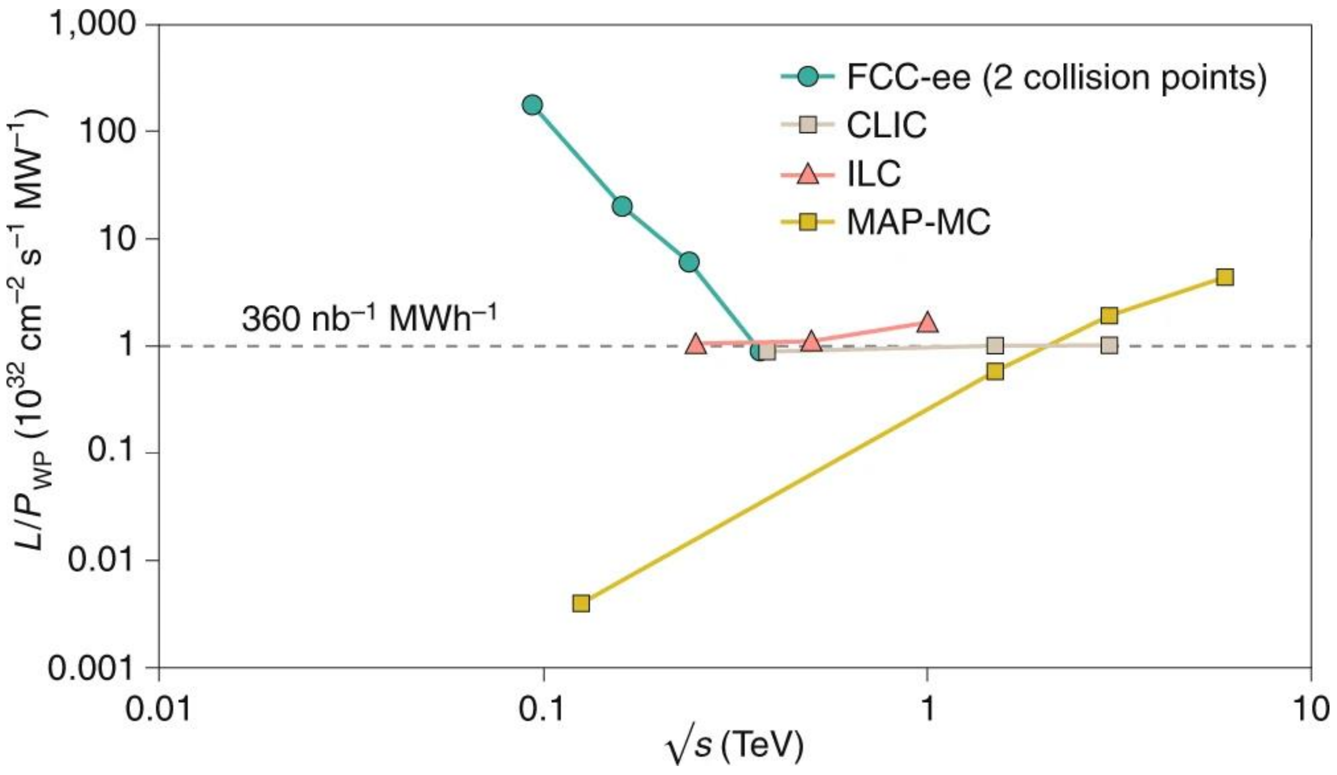
Efficient $\mathcal{L}$ from Z to $t\bar{t}$

thanks to twin-aperture magnets, high-Q SRF, efficient RF power sources, top-up injection, etc.

>2.5 ab^{-1} with ~0.5×10^6 H / IP (3y)

>75 ab^{-1} with ~2×10^{12} Z / IP (4y)

Luminosity vs. Electricity Consumption



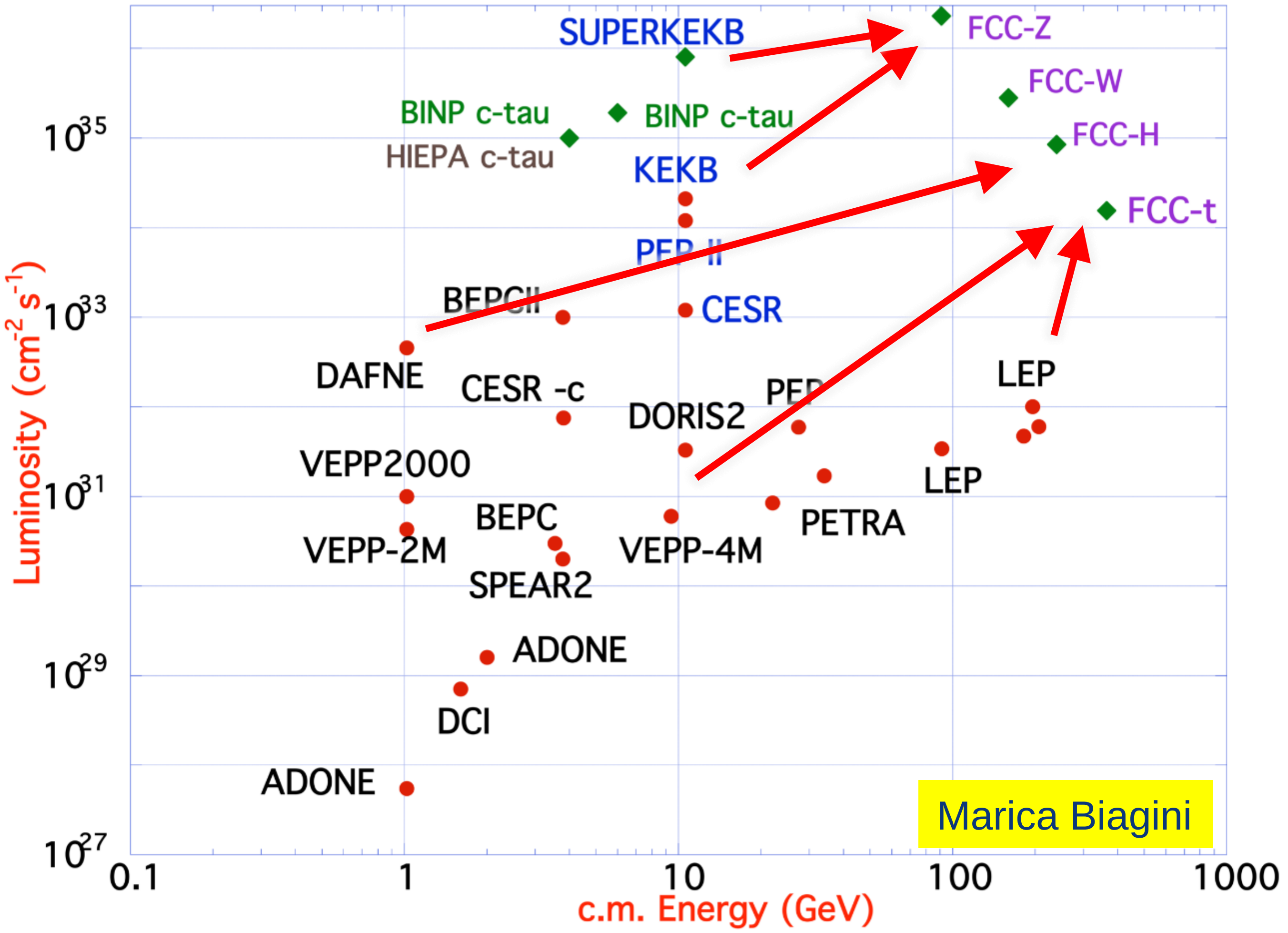
Enormous performance increase: collects LEP data statistics in few minutes

Highest lumi/power of all *H* fact. proposals

Nature Physics 16, 402–407 (2020)

FCC-ee Design Concept

Based on lessons and techniques from past colliders (last 40 years)



B-factories: **KEKB & PEP-II:**
- double-ring lepton colliders,
- high beam currents,
- top-up injection

DAFNE: crab waist, double ring

S-KEKB: low β_y^*, crab waist

LEP: high energy, SR effects

VEPP-4M, LEP: precision E calibration

KEKB: *e*$^+$ source

HERA, LEP, RHIC: spin gymnastics

combining successful ingredients of several recent colliders → highest luminosities & energies

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Stage 1: FCC-ee Collider 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

Currently assessing technical feasibility of changing operation sequences (e.g. starting at ZH energy)

- ❑ x10-50 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

FCC-ee RF Staging Scenario

Baseline Operational Sequence Starting from Z

"Ampere-class" machine

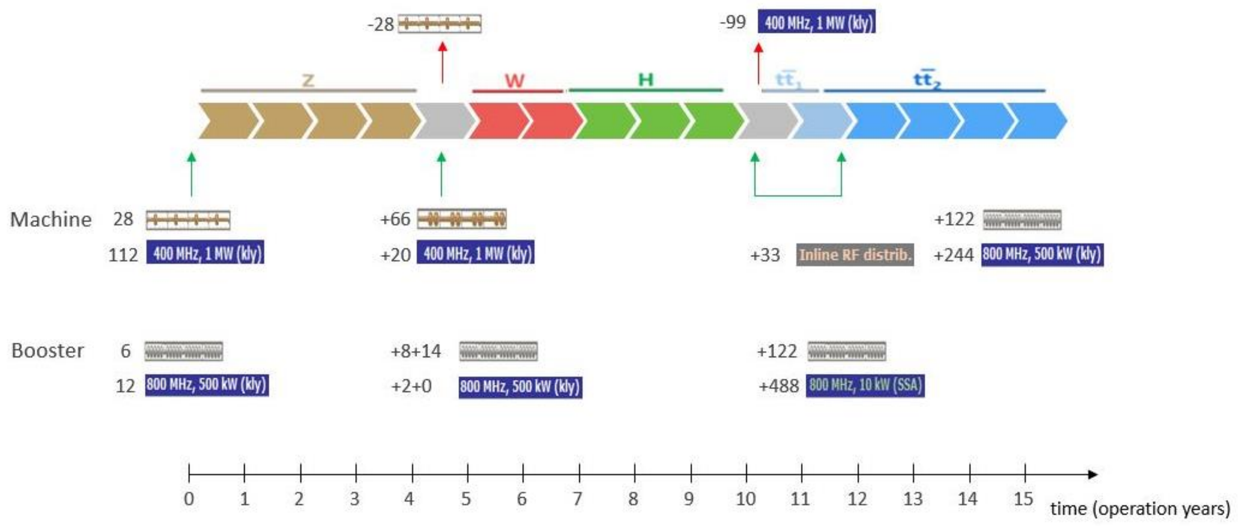
WP	V_{rf} [GV]	#bunches	I_{beam} [mA]
Z	0.1	16640	1390
W	0.44	2000	147
H	2.0	393	29
ttbar	10.9	48	5.4

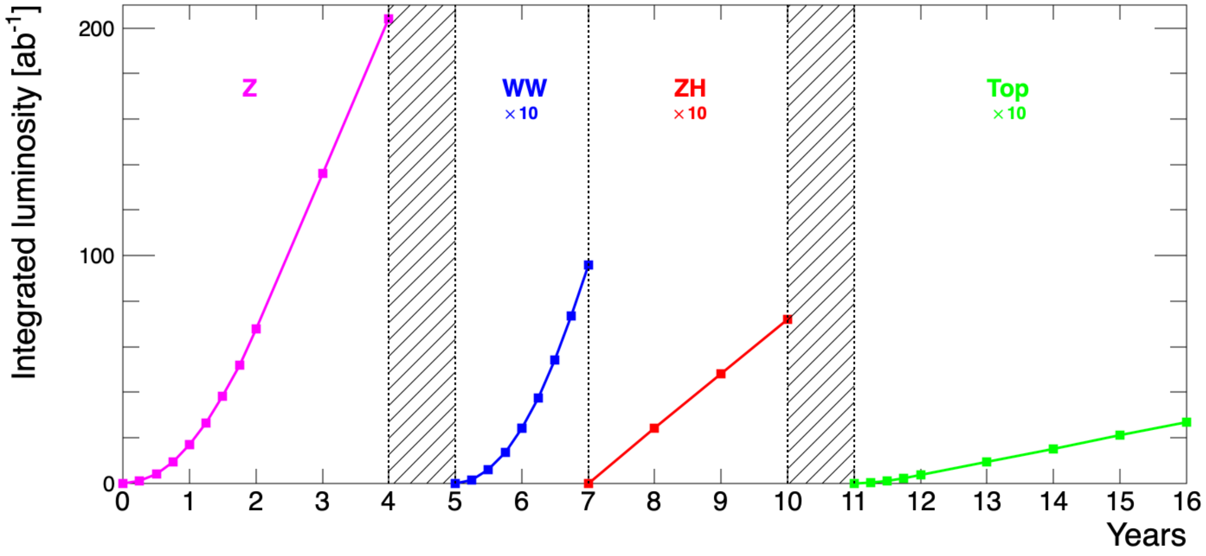
"high-gradient" machine

Three sets of RF cavities to cover all options for FCC-ee & booster:

- High intensity (Z, FCC-hh): 400 MHz mono-cell cavities (4/cryom.)
- Higher energy (W, H, t): 400 MHz four-cell cavities (4/cryomodule)
- ttbar machine complement: 800 MHz five-cell cavities (4/cryom.)
- Installation sequence comparable to LEP (≈ 30 CM/shutdown)

O. Brunner, F. Peauger

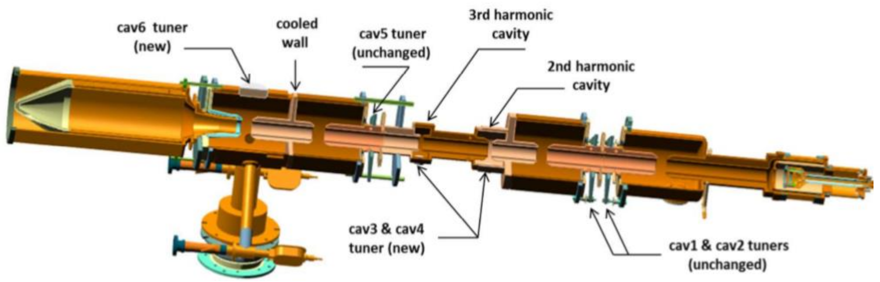




FCC-ee Accelerator R&D Examples

Efficient RF power sources (400 & 800 MHz)

I. Syratchev



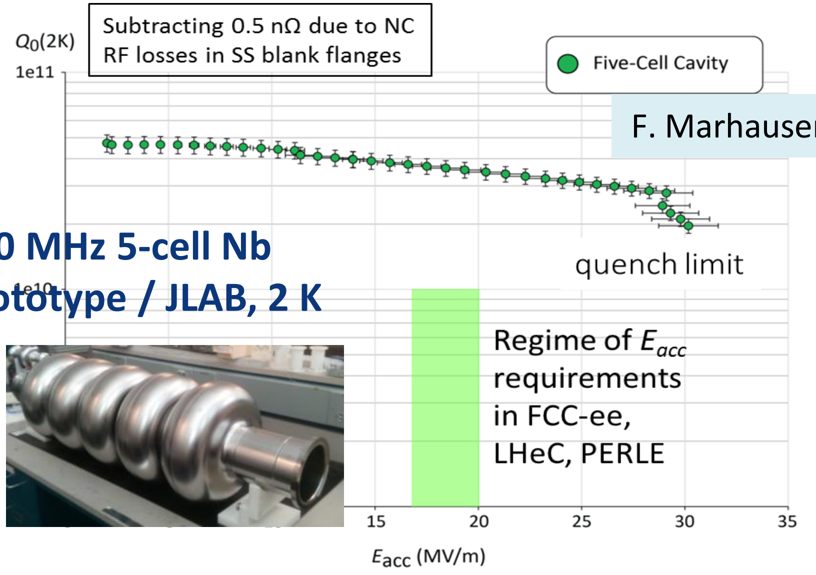
FPC & HOM coupler, cryomodule, thin-film coatings…

Efficient SC cavities

Jefferson Lab

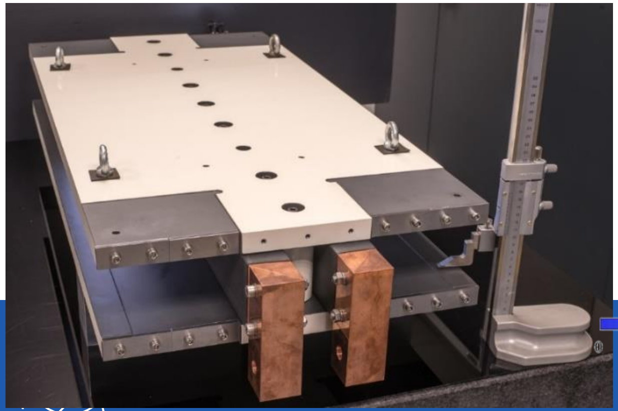
400 MHz 1-,2- & 4-cell Nb/Cu , 4.5 K

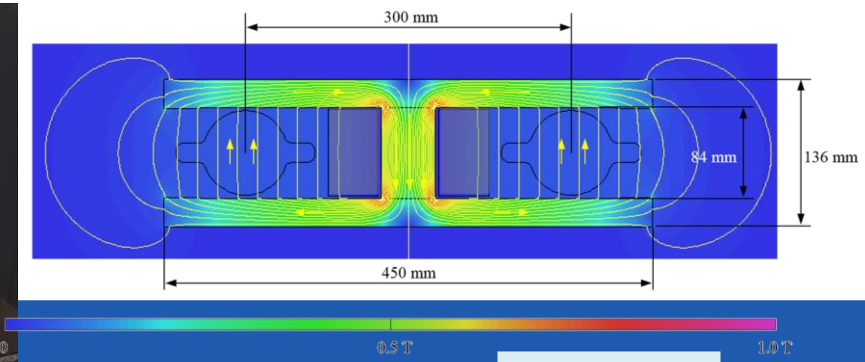
800 MHz 5-cell Nb prototype / JLAB, 2 K



F. Marhauser

Energy **efficient** twin aperture **arc dipoles**

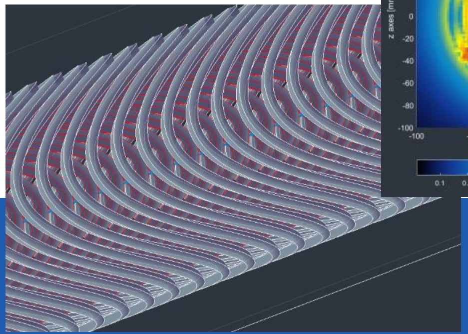


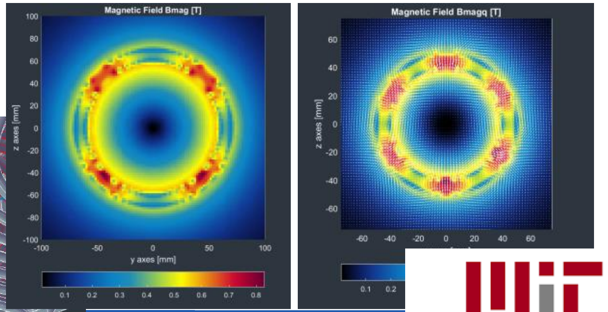


A. Milanese

Under study: **CCT HTS quads & sexts for arcs**

PAUL SCHERRER INSTITUT PSI

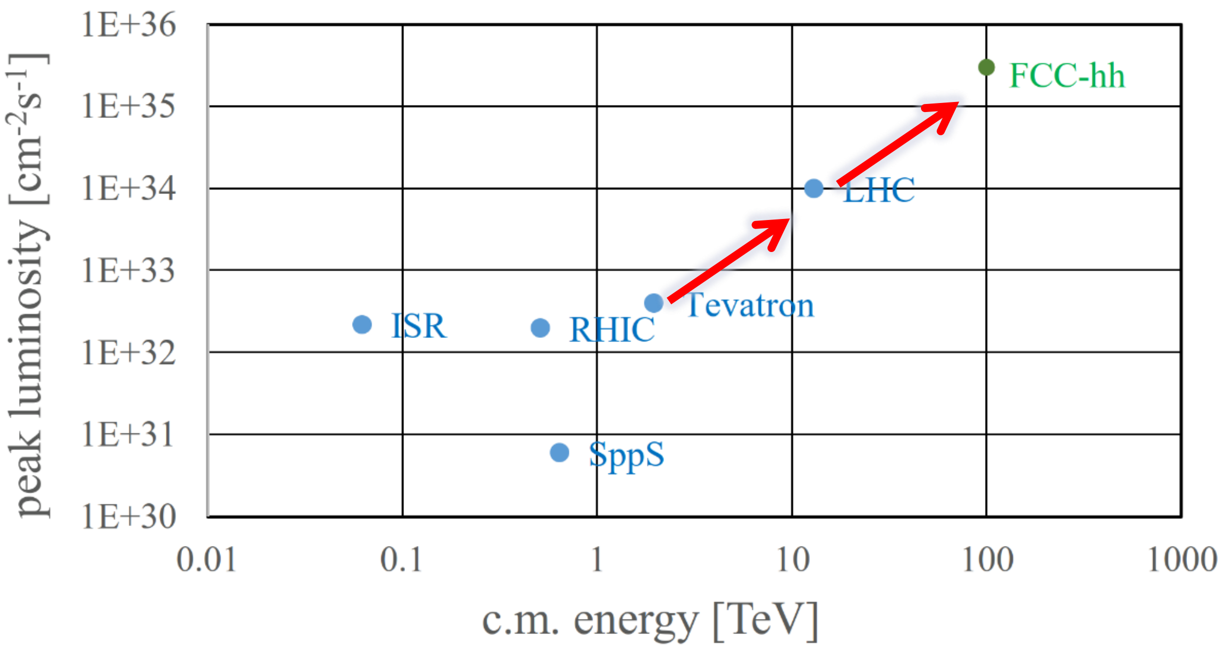




Massachusetts Institute of Technology

M. Koratzinos

Stage 2: FCC-hh Highest Collision Energies



~Order of magnitude performance increase in both energy & luminosity w.r.t. LHC

~100 TeV cm collision energy (vs 14 TeV for LHC)

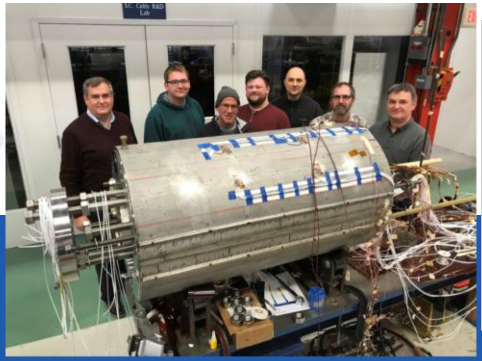
20 ab^{-1} per experiment over 25 years of operation (vs 3 ab^{-1} for LHC)

Similar performance increase as from Tevatron to LHC

Key technology: high-field magnets

from
LHC technology
8.3 T NbTi dipole

via
HL-LHC technology
12 T Nb_3Sn quadrupole



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

HTS technology

Hybrid Nb-Ti/HTS

FCC-hh: Main Machine Parameters

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Parameter	FCC-hh		HL-LHC	LHC
collision energy cms [TeV]	80-116		14	14
dipole field [T]	14 (Nb_3Sn) – 20 (HTS/Hybrid)		8.33	8.33
circumference [km]	90.7		26.7	26.7
beam current [A]	0.5		1.1	0.58
bunch intensity [10^{11}]	1	1	2.2	1.15
bunch spacing [ns]	25	25	25	25
synchr. rad. power / ring [kW]	2700		7.3	3.6
SR power / length [W/m/ap.]	32.1		0.33	0.17
long. emit. damping time [h]	0.45		12.9	12.9
beta* [m]	1.1	0.3	0.15 (min.)	0.55
normalized emittance [μm]	2.2		2.5	3.75
peak luminosity [10^{34} $cm^{-2}s^{-1}$]	5	30	5 (lev.)	1
events/bunch crossing	170	1000	132	27
stored energy/beam [GJ]	7.8		0.7	0.36

Formidable challenges:

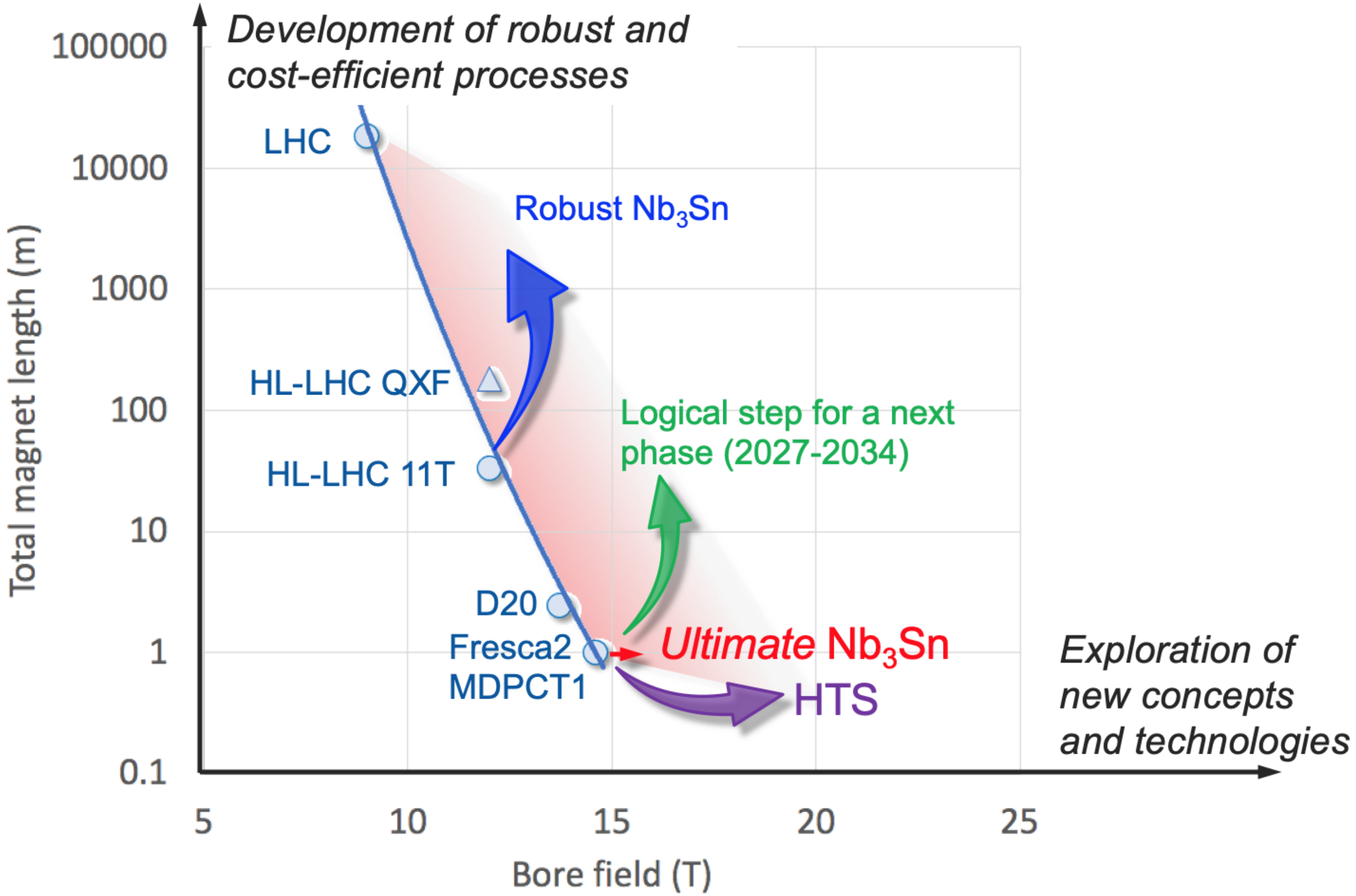
- ❑ High-field superconducting magnets: 14 - 20 T
- ❑ Power load in arcs from synchrotron radiation: 5 MW → cryogenics, vacuum
- ❑ Stored beam energy: 8 GJ → machine protection
- ❑ Pile-up in the detectors: ~1000 events/xing
- ❑ Energy consumption: 4 TWh/year → R&D on cryo, HTS, beam current, …

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

High-field Magnet R&D: First steps towards FCC-hh

In parallel to FCC Study, HFM development programme as long-term separate R&D project



Main R&D activities:

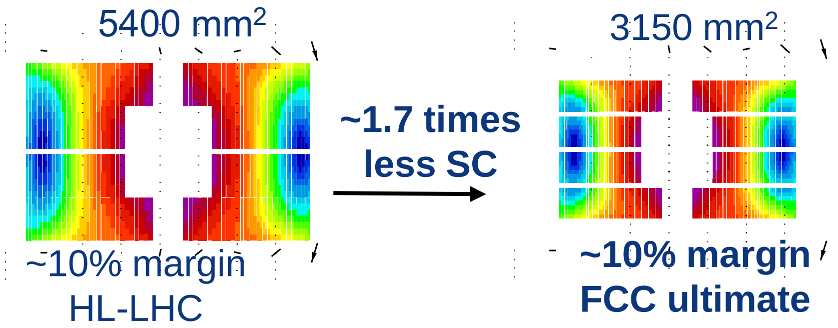
- ❑ materials: goal is ~16 T for Nb_3Sn, at least ~20 T for HTS inserts
- ❑ magnet technology: engineering, mechanical robustness, insulating materials, field quality
- ❑ production of models and prototypes: to demonstrate material, design and engineering choices, industrialisation and costs
- ❑ infrastructure and test stations: for tests up to ~ 20 T and 20-50 kA

Global collaborations already established during FCC CDR phase.

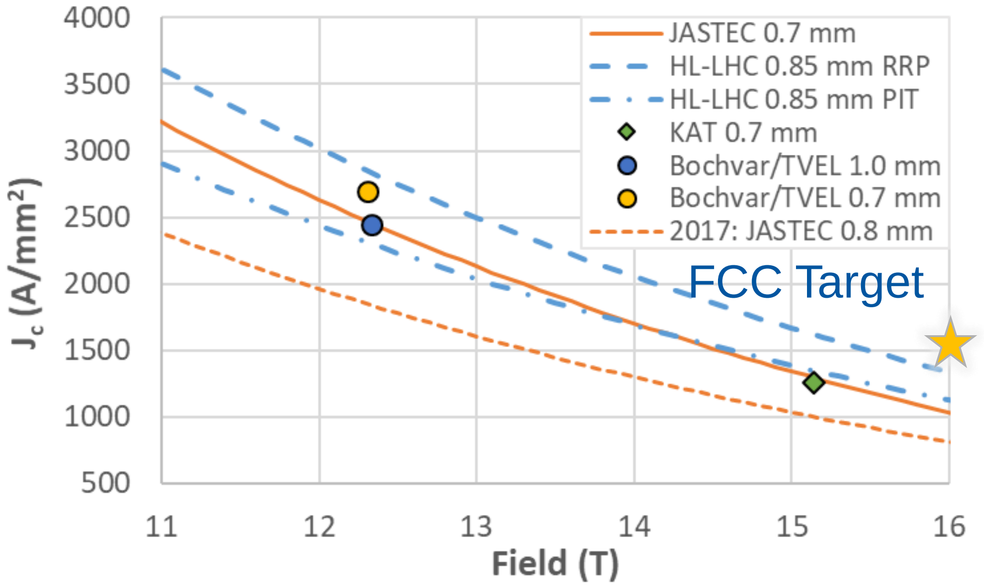
World-wide FCC Nb_3Sn Programme

Main development goal is wire performance increase:

- **J_c (16T, 4.2K) > 1500 A/mm² →50% increase wrt HL-LHC wire**
- **Reduction of coil & magnet cross-section**



After 1-2 years development, **prototype Nb_3Sn wires from several new industrial FCC partners already achieve HL-LHC J_c performance**



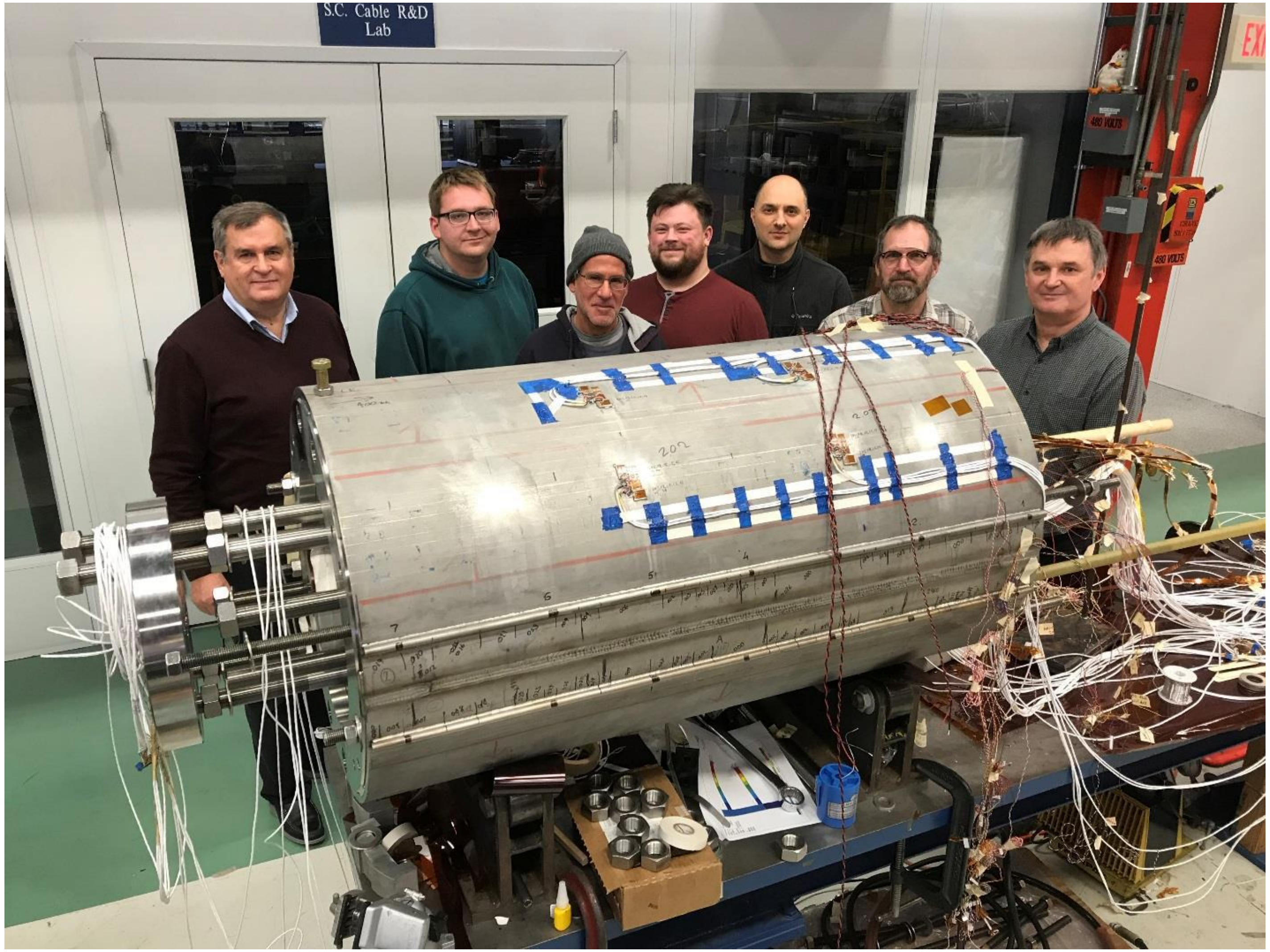
FCC conductor development collaboration:

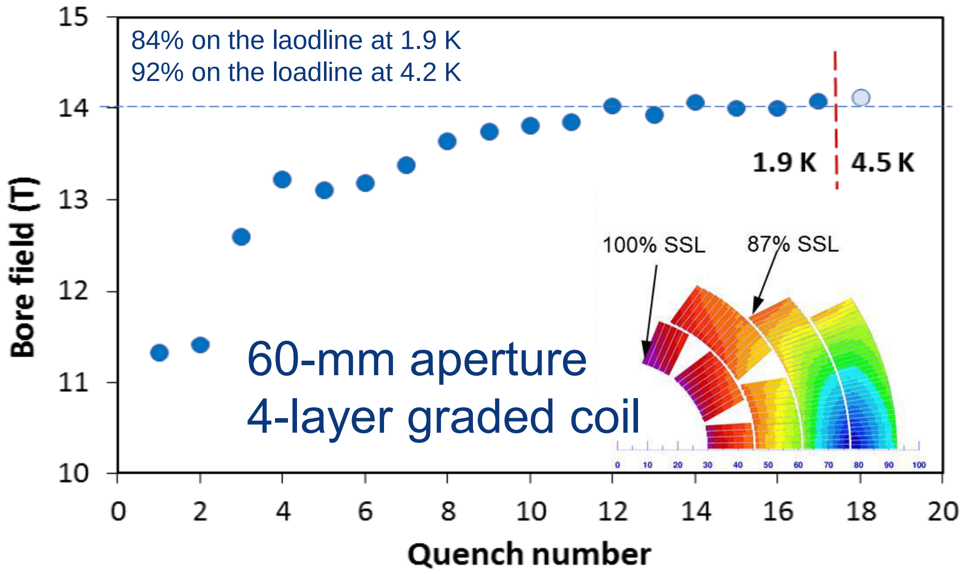
- **Bochvar Institute** (production at **TVEL**), **Russia**
- **Bruker, Germany, Luvata Pori, Finland**
- **KEK** (**Jastec** and **Furukawa**), **Japan**
- **KAT**, **Korea, Columbus, Italy**
- **University of Geneva**, **Switzerland**
- **Technical University of Vienna**, **Austria**
- **SPIN**, **Italy, University of Freiberg, Germany**

2019/20 results from US, meeting FCC J_c specs:

- **Florida State University:** high-J_c Nb_3Sn via Hf addition
- **Hyper Tech /Ohio SU/FNAL**: high-J_c Nb_3Sn via artificial pinning centres based on Zr oxide.

US – MDP: 14.5 T Magnet Tested at FNAL





- 15 T dipole demonstrator
- Staged approach: In first step pre-stressed for 14 T
- Second test in June 2020 with additional pre-stress reached 14.5 T

Optimised Placement and Layout

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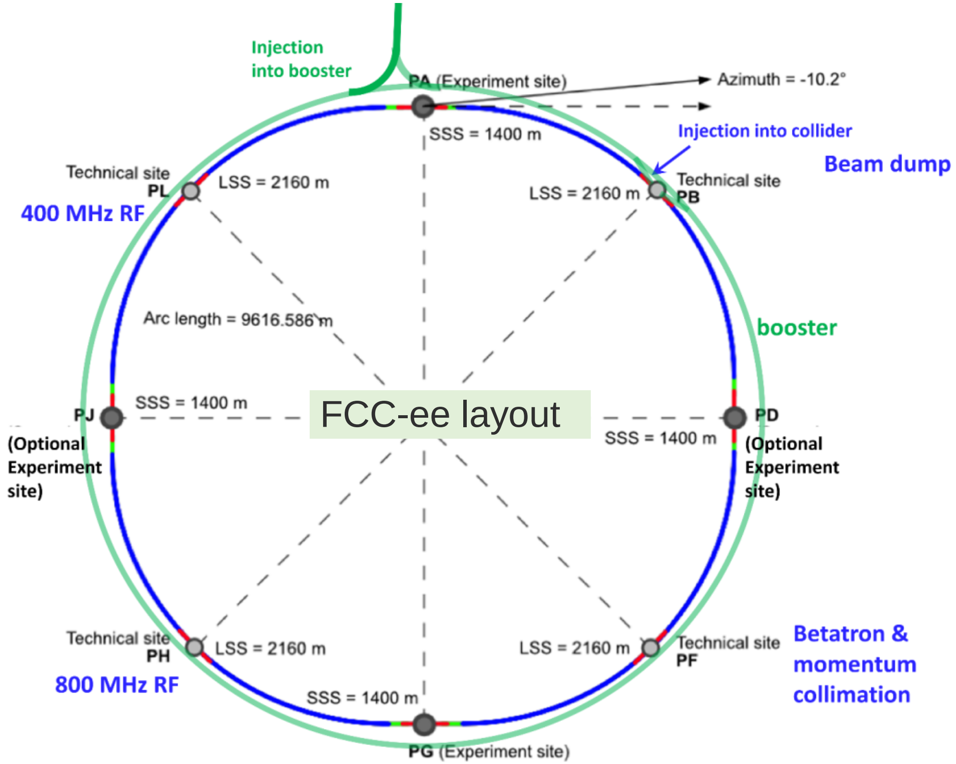
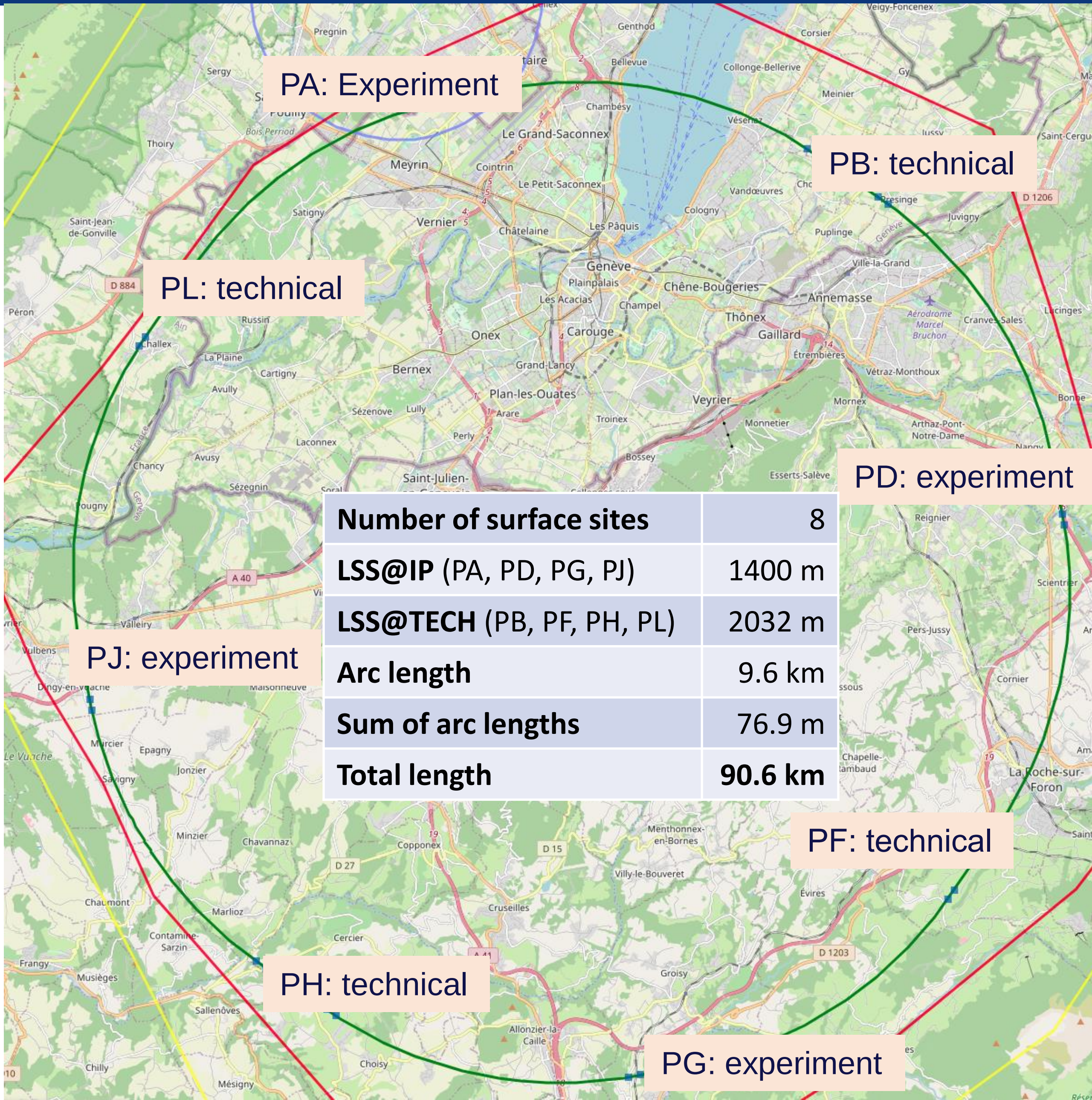
Major achievement: optimisation of the ring placement

Layout chosen out of ~ 50 initial variants, based on geology and surface constraints (land availability, access to roads, etc.), environment (protected zones), infrastructure (water, electricity, transport), etc.
"Éviter, reduire, compenser" principle of EU and French regulations

Baseline ring: 90.7 km ring, 8 surface points

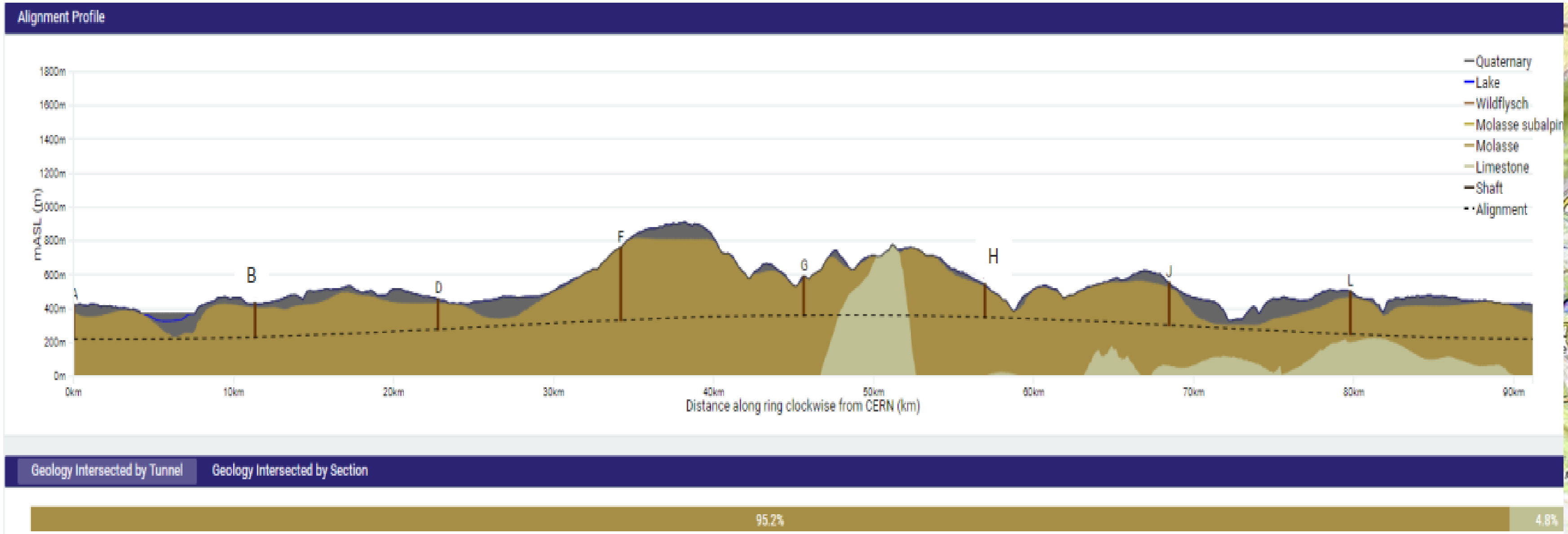
- ❑ Whole project now being adapted to this placement
- ❑ Site investigation: 9 areas with uncertain geological conditions to be further investigated (~40 drillings and 100 km of seismic lines)

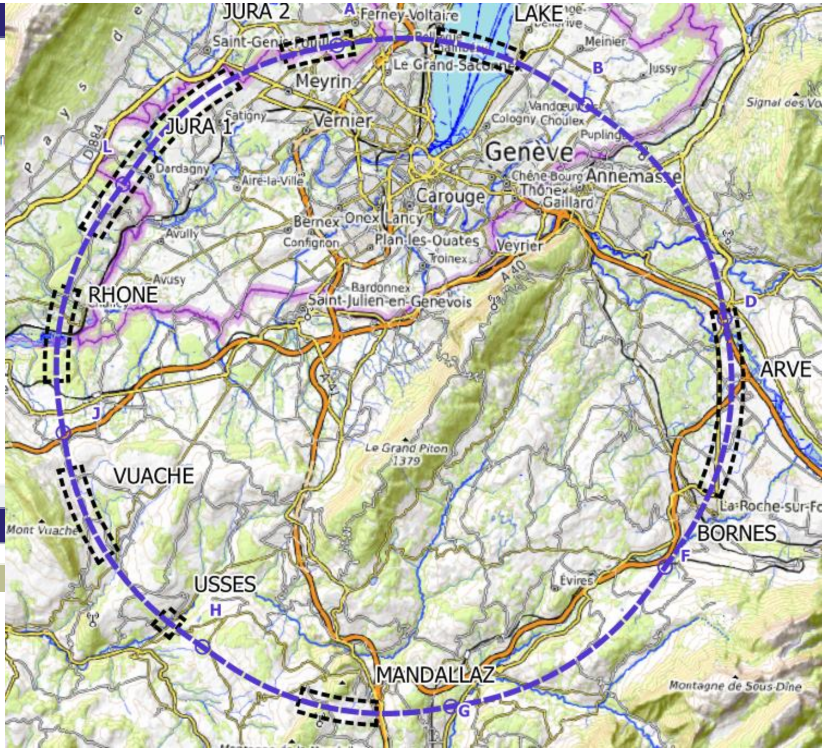




Number of surface sites	8
LSS@IP (PA, PD, PG, PJ)	1400 m
LSS@TECH (PB, PF, PH, PL)	2032 m
Arc length	9.6 km
Sum of arc lengths	76.9 m
Total length	**90.6 km**

FCC Implementation - Footprint Baseline





Present baseline implementation

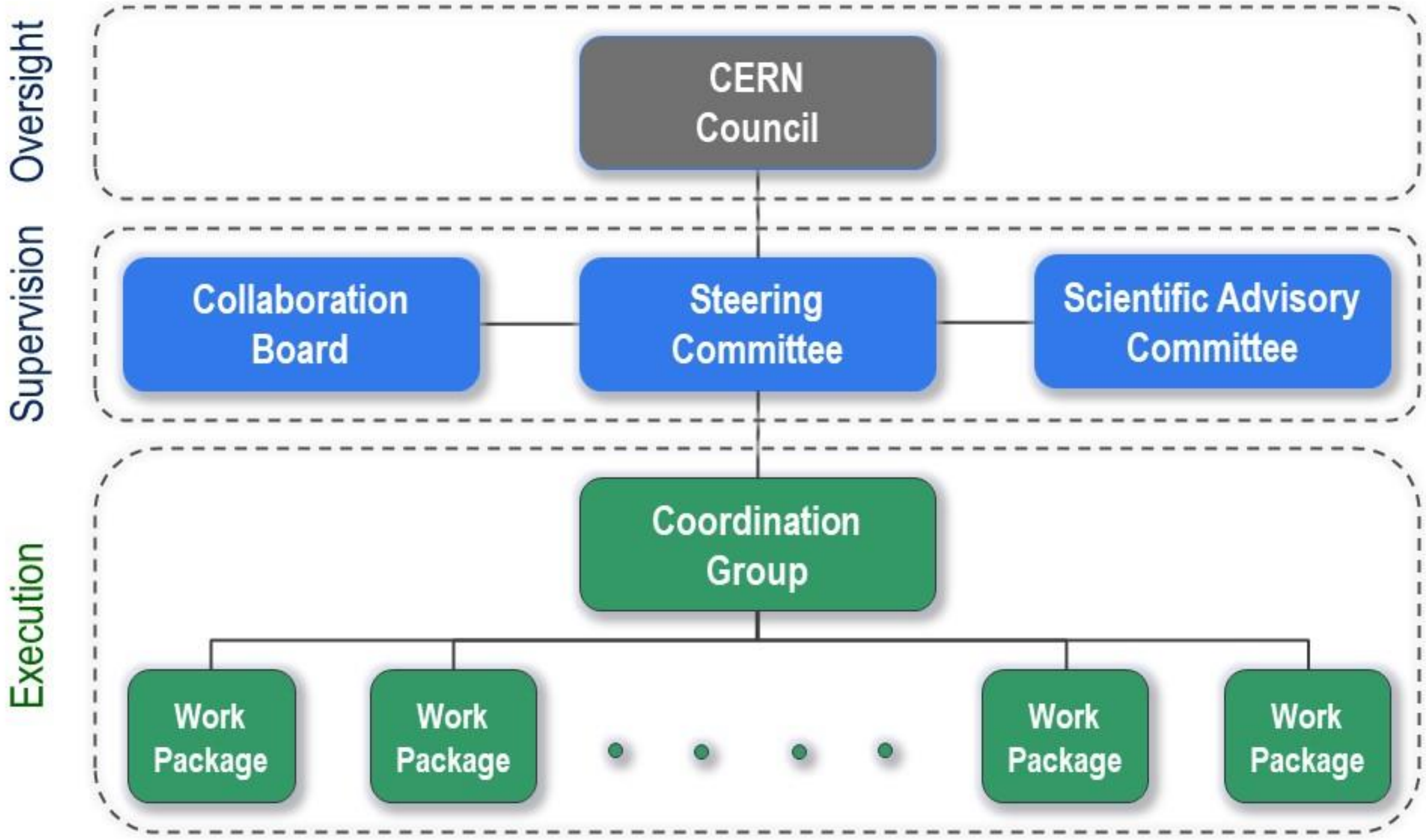
- 91 km circumference
- 95% in molasse geology for minimising tunnel construction risks
- 8 surface sites with ~5 ha area each.

Site investigations planned for 2024 and 2025 in areas with uncertain geological conditions:

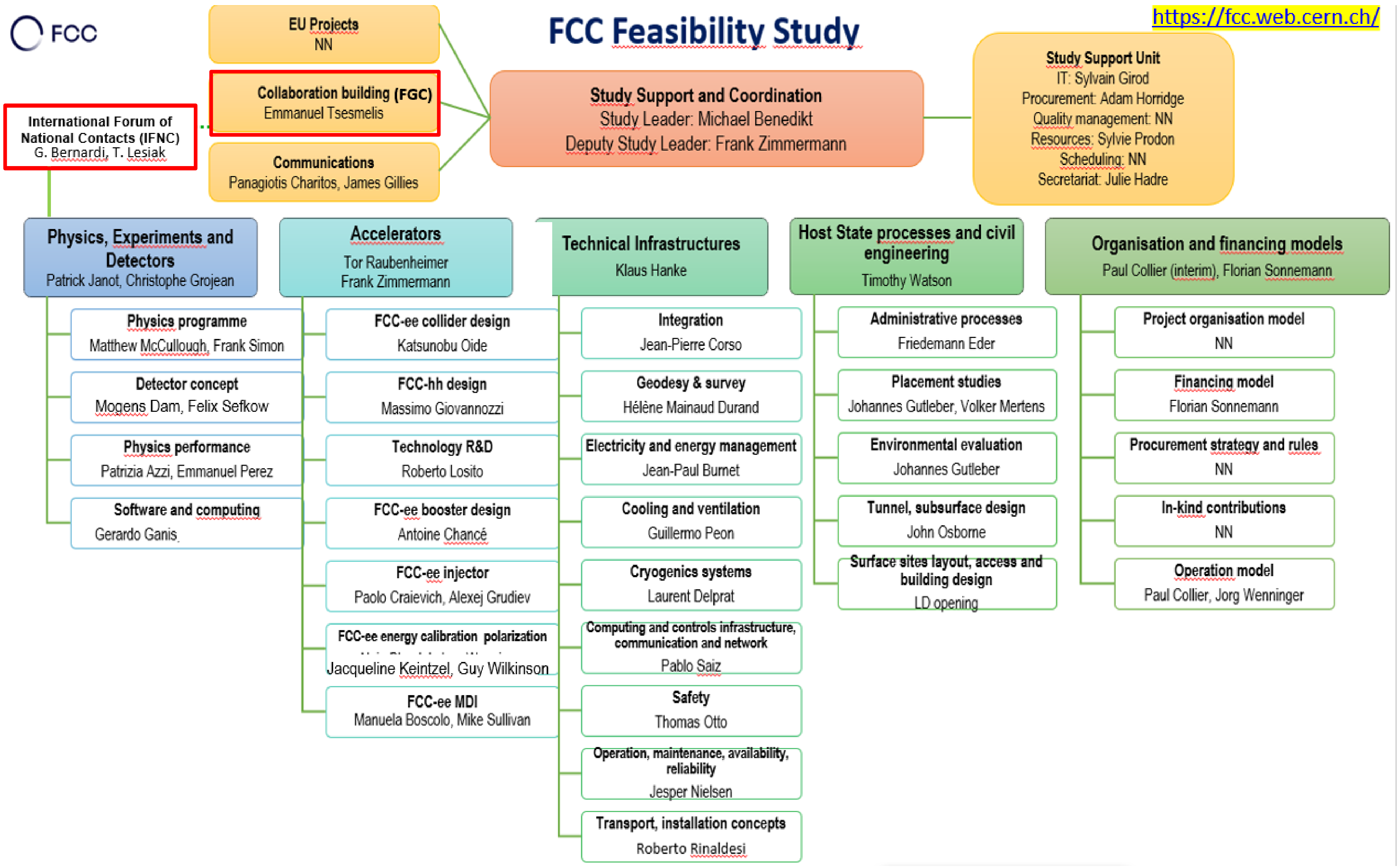
- Limestone-molasse border, karstification, water pressure, moraine properties, water bearing layers, etc.
- ~40-50 drillings, 100 km of seismic lines

FCC Feasibility Study Organisational Structure

- **Ownership** of the Feasibility Study by the Council.
- Effective and timely **supervision**.
- Integration of scientific and technical **advice**.
- **Participation of stakeholders** that can potentially make significant financial and technical contributions to a possible future project.
- **Execution** of Feasibility Study.



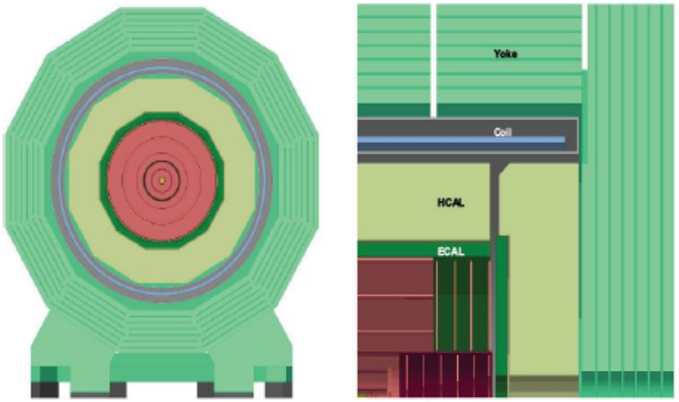
FGC and IFNC



FCC
FCC Feasibility Study
https://fcc.web.cern.ch/
EU Projects
NN
Collaboration building (FGC)
Emmanuel Tsesmelis
Communications
Panagiotis Charitos, James Gillies
International Forum of National Contacts (IFNC)
G. Bernardi, T. Lesiak
Study Support and Coordination
Study Leader: Michael Benedikt
Deputy Study Leader: Frank Zimmermann
Study Support Unit
IT: Sylvain Girod
Procurement: Adam Horridge
Quality management: NN
Resources: Sylvie Prodon
Scheduling: NN
Secretariat: Julie Hadre
Physics, Experiments and Detectors
Patrick Janot, Christophe Grojean
Physics programme
Matthew McCullough, Frank Simon
Detector concept
Mogens Dam, Felix Sefkow
Physics performance
Patrizia Azzi, Emmanuel Perez
Software and computing
Gerardo Ganis
Accelerators
Tor Raubenheimer
Frank Zimmermann
FCC-ee collider design
Katsunobu Oide
FCC-hh design
Massimo Giovannozzi
Technology R&D
Roberto Losito
FCC-ee booster design
Antoine Chancé
FCC-ee injector
Paolo Craievich, Alexej Grudiev
FCC-ee energy calibration polarization
Jacqueline Keintzel, Guy Wilkinson
FCC-ee MDI
Manuela Boscolo, Mike Sullivan
Technical Infrastructures
Klaus Hanke
Integration
Jean-Pierre Corso
Geodesy & survey
Hélène Mainaud Durand
Electricity and energy management
Jean-Paul Burnet
Cooling and ventilation
Guillermo Peon
Cryogenics systems
Laurent Delprat
Computing and controls infrastructure, communication and network
Pablo Saiz
Safety
Thomas Otto
Operation, maintenance, availability, reliability
Jesper Nielsen
Transport, installation concepts
Roberto Rinaldesi
Host State processes and civil engineering
Timothy Watson
Administrative processes
Friedemann Eder
Placement studies
Johannes Gutleber, Volker Mertens
Environmental evaluation
Johannes Gutleber
Tunnel, subsurface design
John Osborne
Surface sites layout, access and building design
LD opening
Organisation and financing models
Paul Collier (interim), Florian Sonnemann
Project organisation model
NN
Financing model
Florian Sonnemann
Procurement strategy and rules
NN
In-kind contributions
NN
Operation model
Paul Collier, Jorg Wenninger

Detectors Under Study for FCC-ee

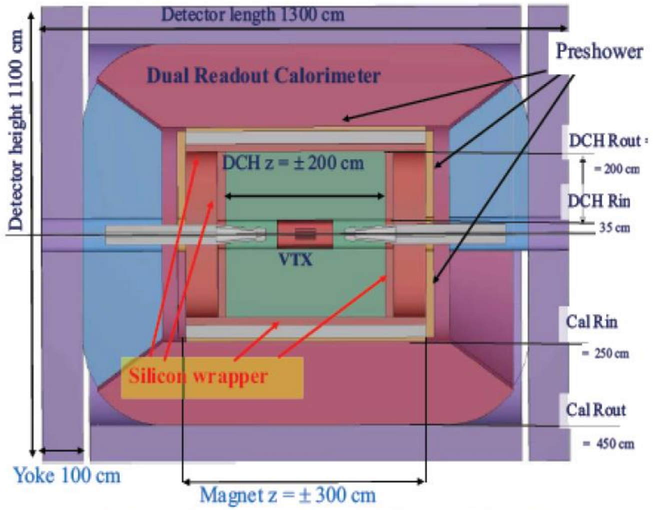
CLD



conceptually extended from the CLIC detector design

- full silicon tracker
- 2T magnetic field
- high granular silicon-tungsten ECAL
- high granular scintillator-steel HCAL
- instrumented steel-yoke with RPC for muon detection

IDEA



explicitly designed for FCC-ee/CepC

- silicon vertex
- low X_0 drift chamber
- drift-chamber silicon wrapper
- MPGD/magnet coil/lead preshower
- dual-readout calorimeter: lead-scintillating cerenkhov fibers

ALLEGRO

explicitely designed for FCC-ee, recent concept, under development

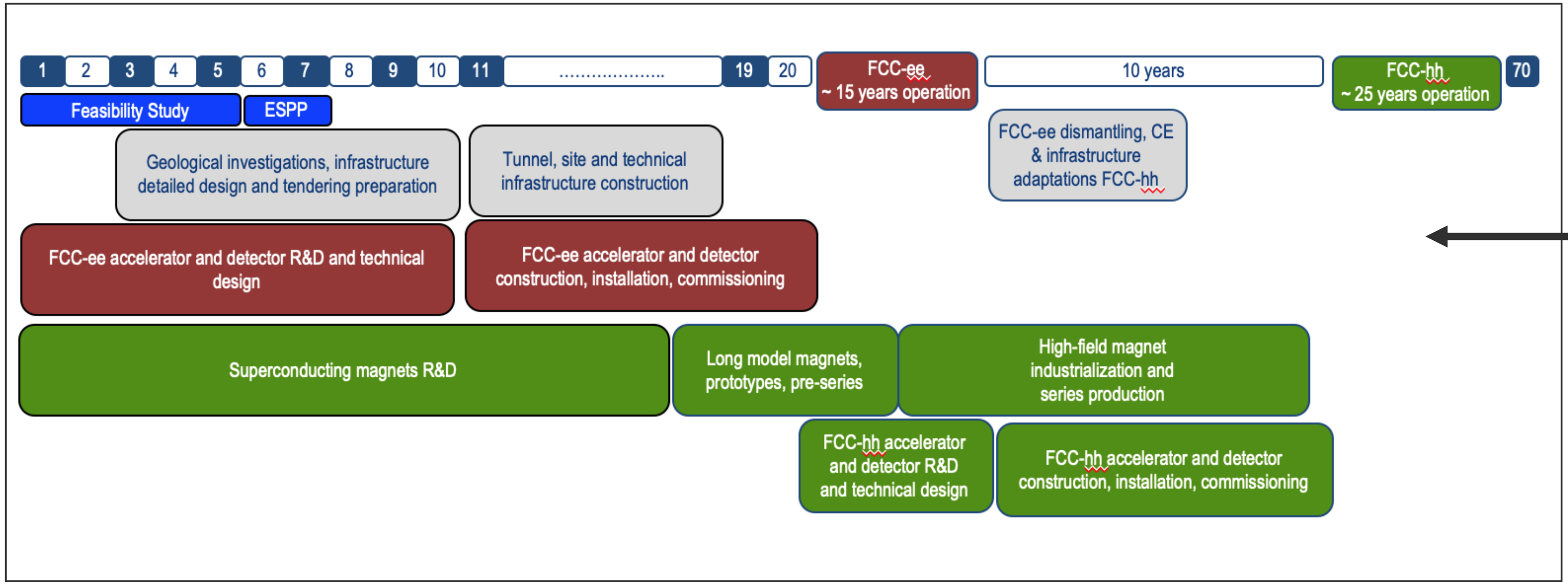
- silicon vertex
- low X_0 drift chamber + silicon wrapper
- Thin Solenoid before the Calorimeter
- High Granularity Liquid Argon Calorimetry

But several other options like Crystal Calorimetry (active in US, Italy), are under study (similarly for tracking, muons and particle ID)

With potentially 4 experiments, many complementary options will be implemented

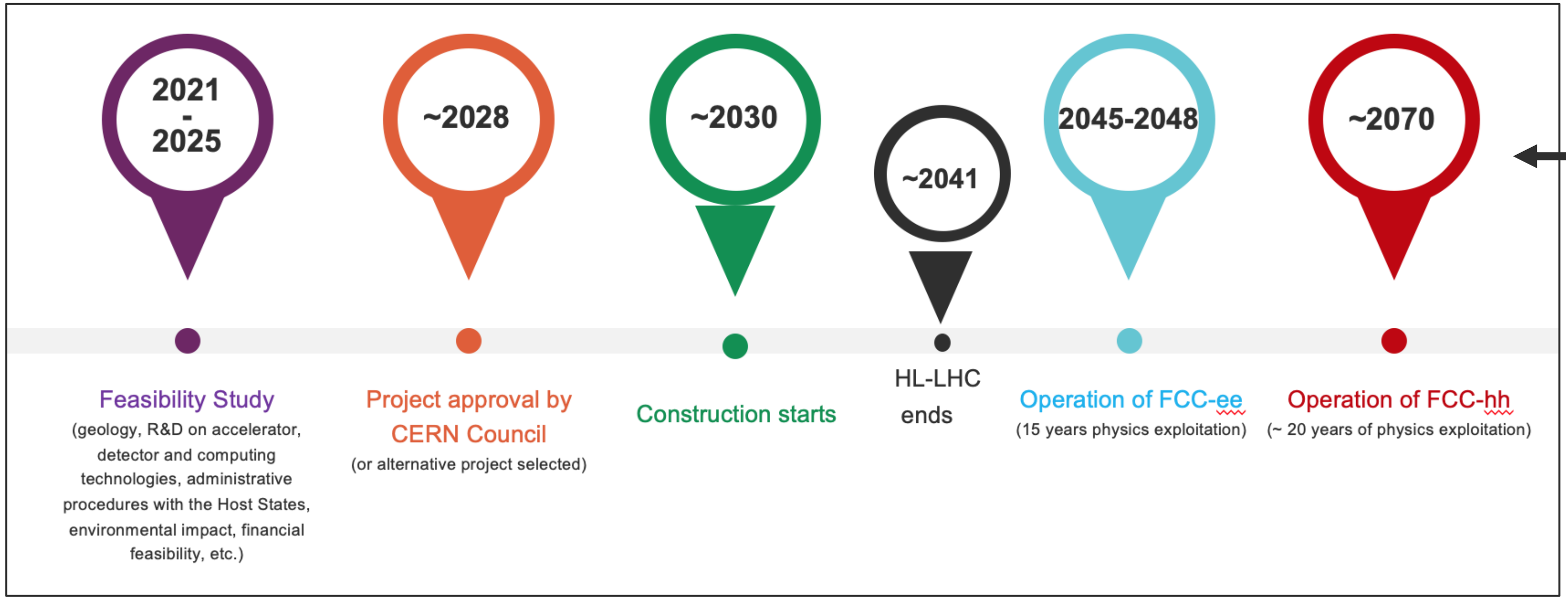
FCC Timeline

FUTURE CIRCULAR COLLIDER



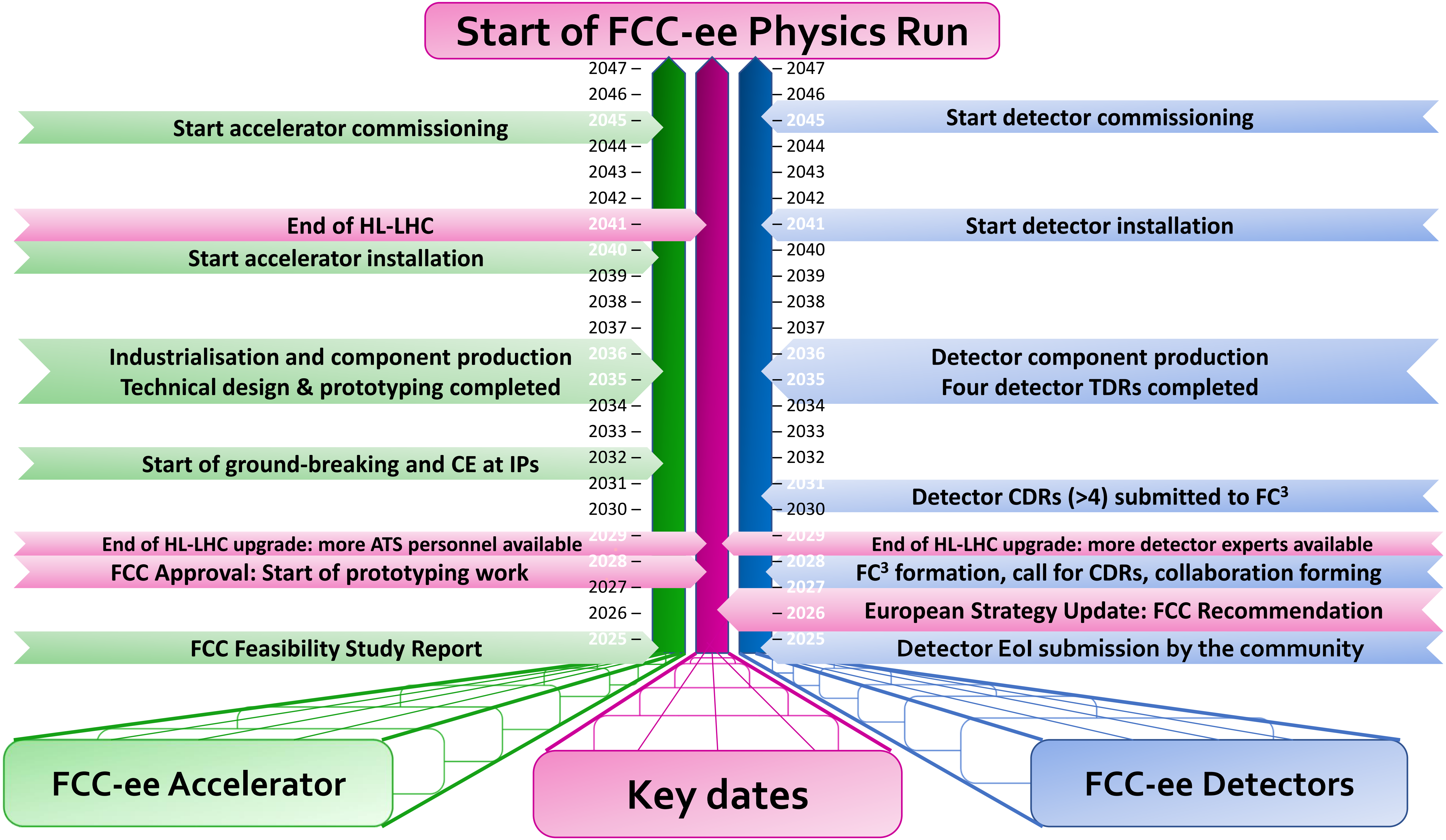
Note: FCC Conceptual Design Study started in 2014 leading to CDR in 2018

Technical schedule:
FCC-ee could start operation **in 2040 or earlier**



Realistic schedule takes into account:
- ❑ CERN Council approval timeline
- ❑ Past experience in building colliders at CERN
- ❑ HL-LHC will run until ~ 2041
- → **ANY future collider at CERN cannot start physics operation before 2045-2048** (but construction will proceed in parallel to HL-LHC operation)

F. Gianotti


Start of FCC-ee Physics Run
Start accelerator commissioning
End of HL-LHC
Start accelerator installation
Industrialisation and component production
Technical design & prototyping completed
Start of ground-breaking and CE at IPs
End of HL-LHC upgrade: more ATS personnel available
FCC Approval: Start of prototyping work
FCC Feasibility Study Report
Start detector commissioning
Start detector installation
Detector component production
Four detector TDRs completed
Detector CDRs (>4) submitted to FC3
End of HL-LHC upgrade: more detector experts available
FC3 formation, call for CDRs, collaboration forming
European Strategy Update: FCC Recommendation
Detector EoI submission by the community
2047
2046
2045
2044
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2036
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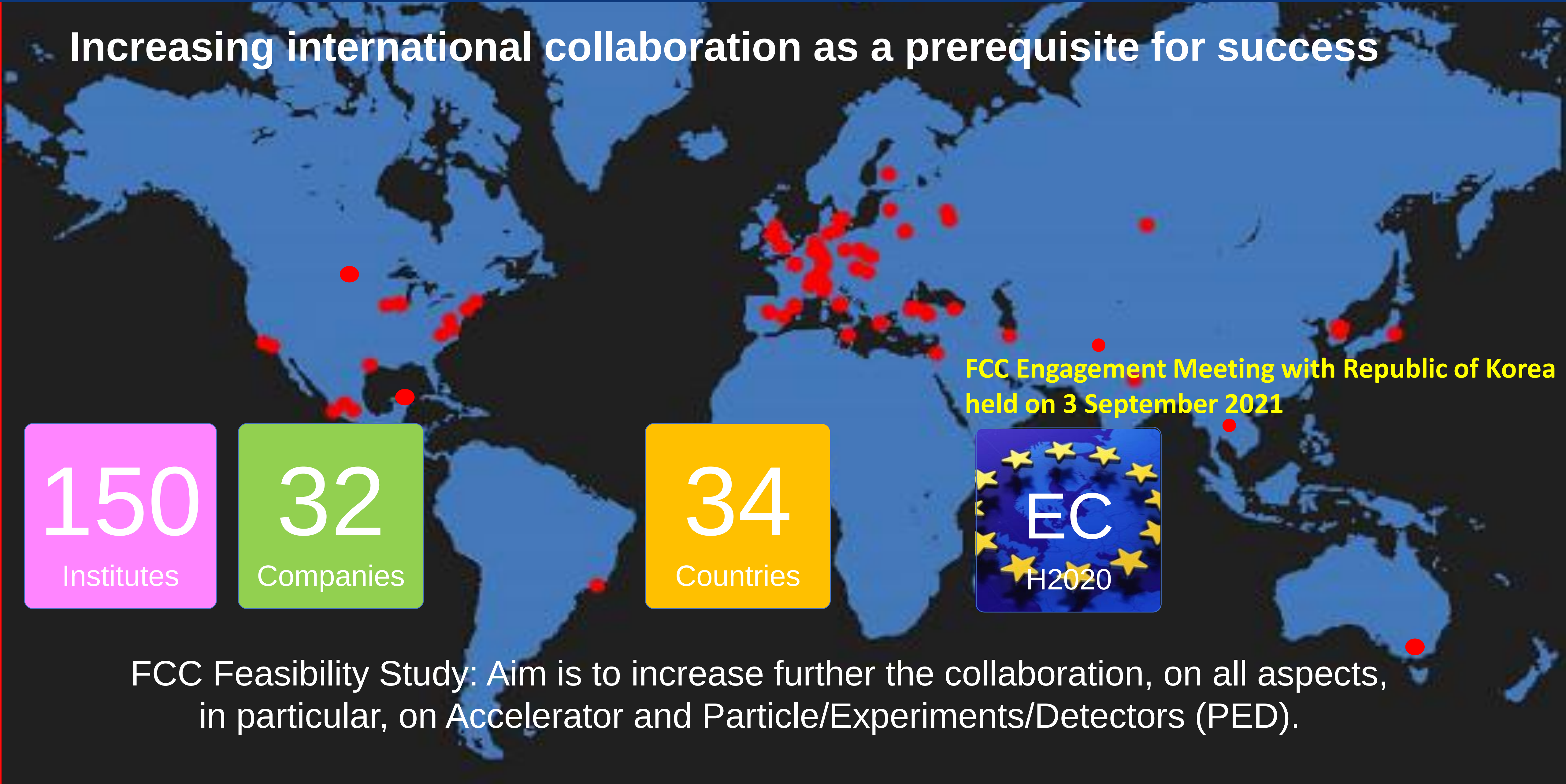
2034
2033
2032
2031
2030
2029
2028
2027
2026
2025
FCC-ee Accelerator
Key dates
FCC-ee Detectors

Status of FCC global collaboration

FUTURE CIRCULAR COLLIDER

Increasing international collaboration as a prerequisite for success



FCC Engagement Meeting with Republic of Korea held on 3 September 2021

150	32	34	EC
Institutes	Companies	Countries	H2020

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

FCC and the Republic of Korea

- Members of FCC Collaboration through MoU (& Addenda) from the Republic of Korea
  - Gangneung-Wonju National University (GWNU, Gangneung)
  - Korea Advanced Institute of Science and Technology (KAIST, Yuseong-gu)
  - Korea Institute for Advanced Study (KIAS, Seoul)
  - Korea University (KU, Seoul)
  - Korea University (KUS, Sejong)
  - Pohang Accelerator Laboratory (PAL, Pohang)
  - Yonsei University (YU, Seoul)
  - Kyungpook National University (KNU, Daegu)
  - University of Seoul (UOS, Seoul)
  - Pusan National University (PNU, Busan)
  - Sungkyunkwan University (SKKU, Seoul)
  - Hanyang University (HUY, Seoul)
  - Kyunghee University (KHU, Seoul)

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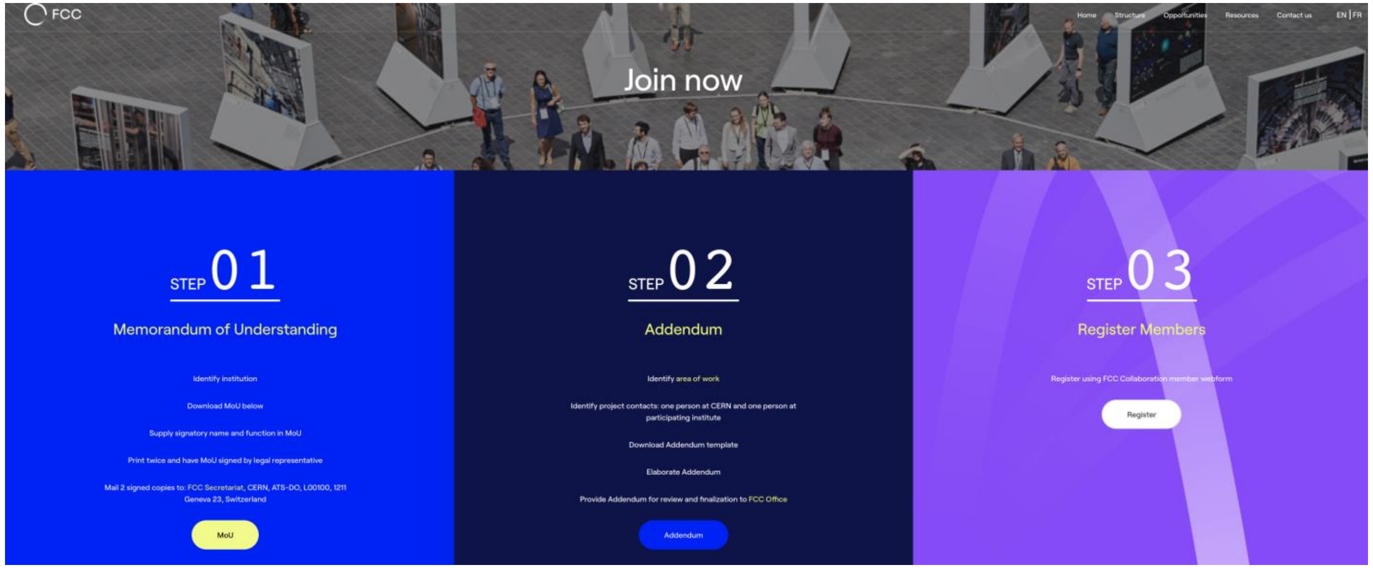
FCC Feasibility Study Collaboration Membership

Participation in FCC through **MoU and Addenda**.

The FCC MoU for the first phase of the study is being **updated to cover the Feasibility Study**.

The current participating institutes who wish to take part in the Feasibility Study can continue to participate on the basis of the previously signed MoU until the updated MoU is signed.



https://fccis.web.cern.ch/join-now

FUTURE CIRCULAR COLLIDER

FCC Week 2023
London, UK

473 participants

362 in person and
111 remote

Courtesy P. Charitos

Outlook

Comprehensive R&D programme and implementation preparation is presently being carried out in the frameworks of **FCC FS**, the EU co-financed **FCC Innovation Study**, the **Swiss CHART** programme, and the **CERN High-Field Magnet Programme**.
Goal: demonstrate FCC feasibility by 2025/26.

Plenty of opportunities for collaborations and for **joint innovative developments** with international partners !

The **first stage of FCC could be approved within a few years after the 2027 European Strategy Update**, if the latter is supportive. **Tunnel construction could then start in the early 2030s** and **FCC-ee physics programme could begin in the second half of the 2040s**, a few years after the completion of the HL-LHC physics runs, expected by 2041.

Long-term goal: **world-leading HEP infrastructure for 21st century** to push particle-physics **precision and energy frontiers** far beyond present limits.

FCC Summary

- The European Strategy Update in 2020 issued the **request for a feasibility study of the FCC integrated programme to be delivered by end 2025.**
- **The main activities of the FCC Feasibility Study are:**
  - **Local/regional implementation scenario** in collaboration **with Host State authorities.**
  - Accompanied by **machine optimisation, physics studies and technology R&D.**
  - Performed **via global collaboration** and supported by **EC H2020 Design Study FCCIS.**
  - In parallel **High-Field Magnet R&D programme** as separate line, to prepare for FCC-hh.
- Long term goal: **world-leading HEP infrastructure for 21st century** to push the particle-physics **precision and energy frontiers** far beyond present limits.

Success of FCC relies on strong global participation.
Everybody interested is warmly welcome to join the effort!

FUTURE
CIRCULAR
COLLIDER

Thank you