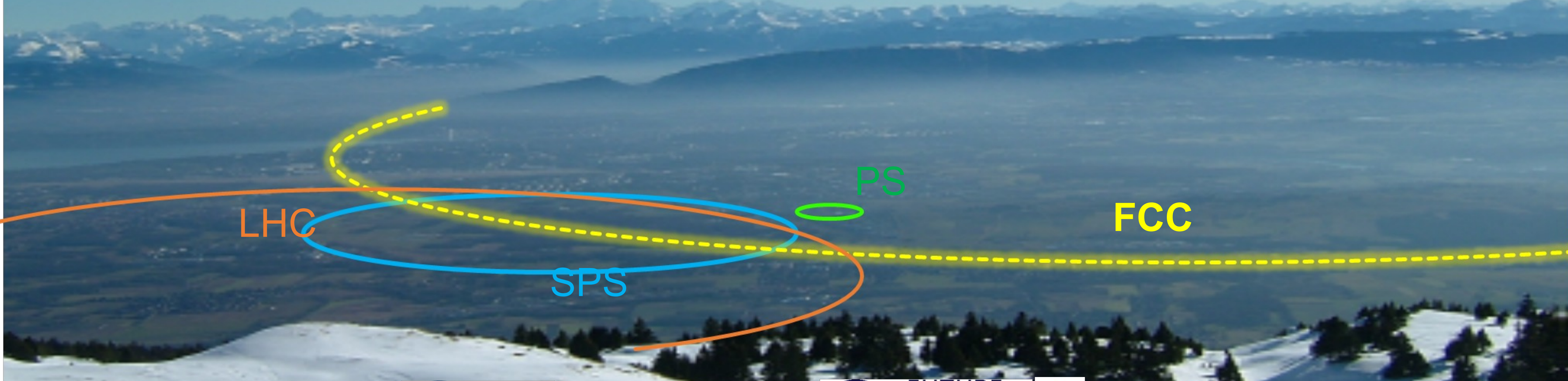
The FCC Feasibility Study and Global Collaboration

Andrey Abramov
CERN

On behalf of Emmanuel Tsesmelis and the FCC collaboration

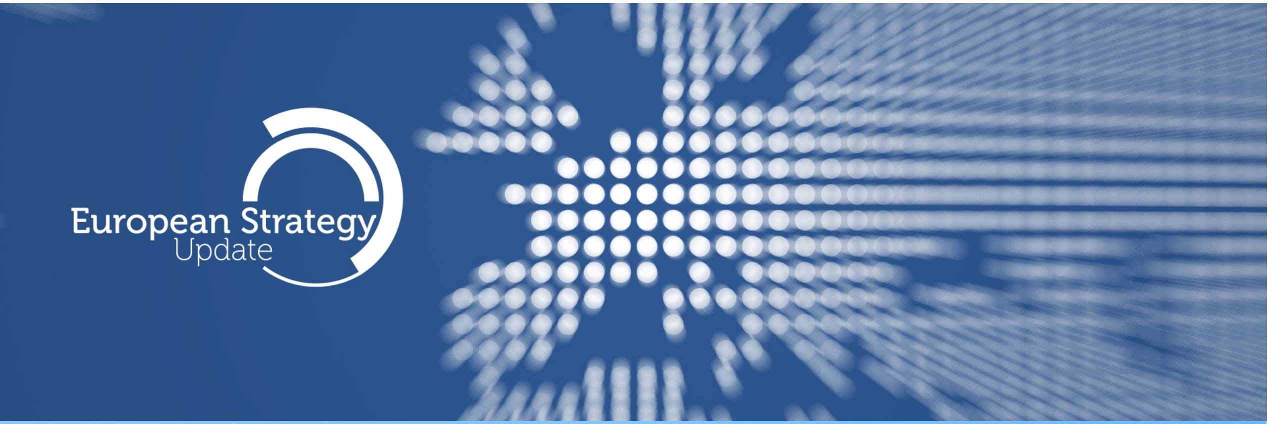


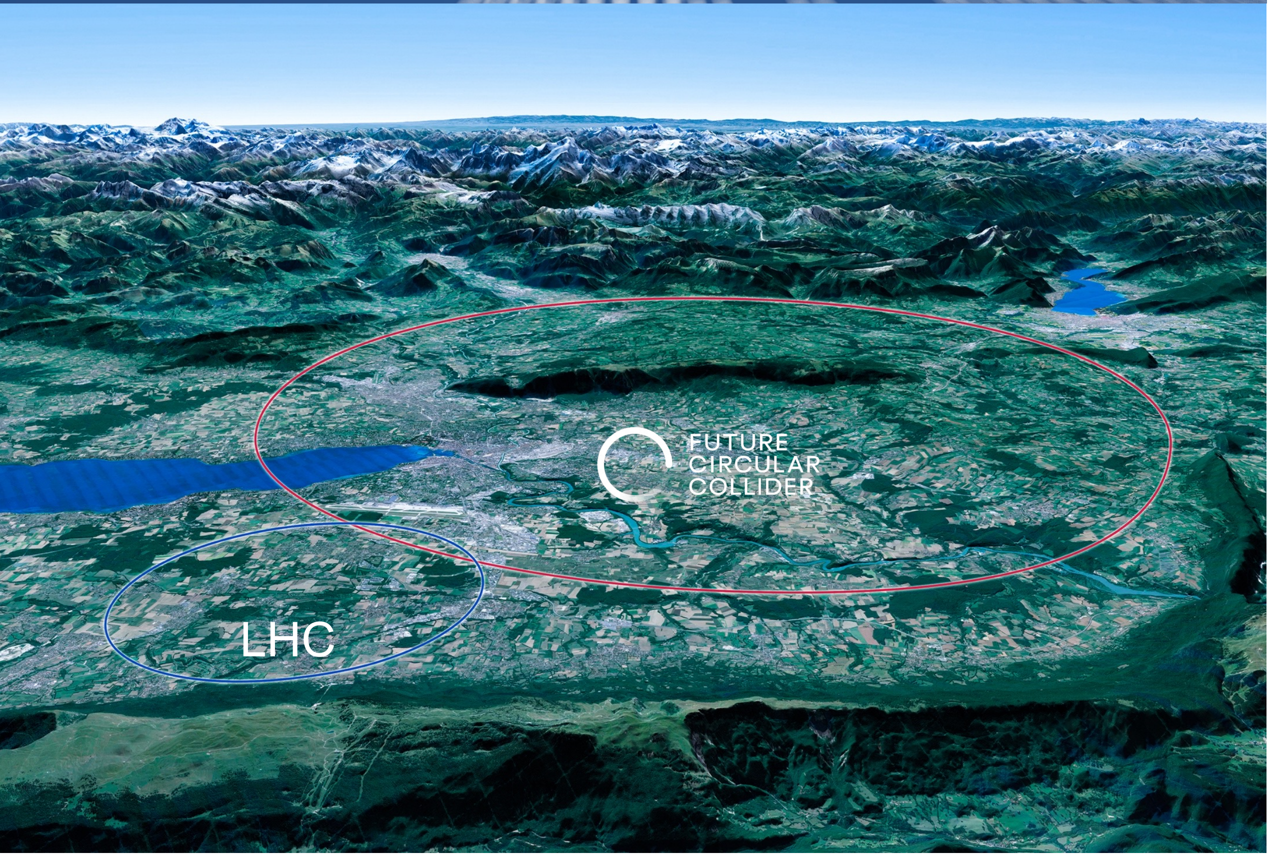
http://cern.ch/fcc

*Work supported by the **European Commission** under the **HORIZON 2020 projects EuroCirCol**, grant agreement 654305; **EASITrain,** grant agreement no. 764879; **ARIES**, grant agreement 730871, **FCCIS**, grant agreement 951754, and **E-JADE,** contract no. 645479*

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.

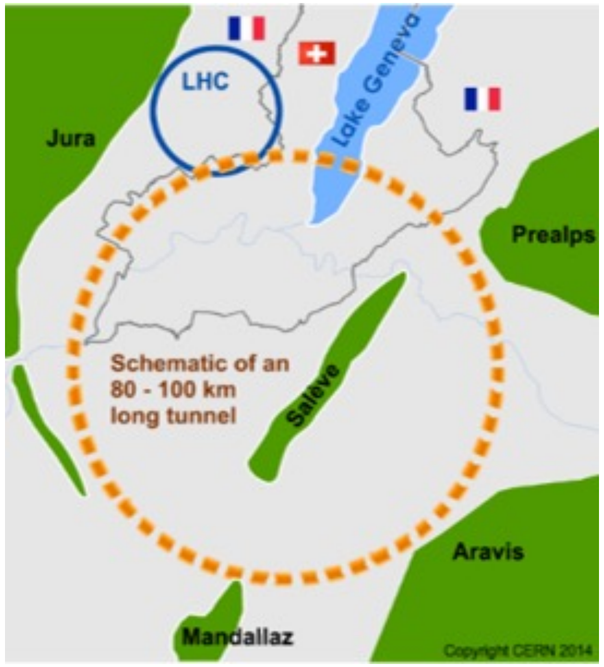
FUTURE CIRCULAR COLLIDER

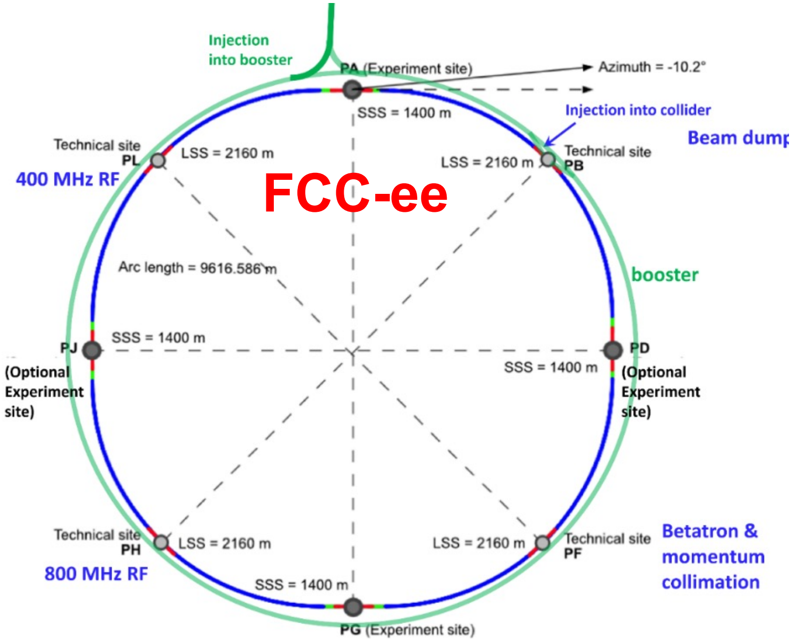
The FCC Integrated Programme

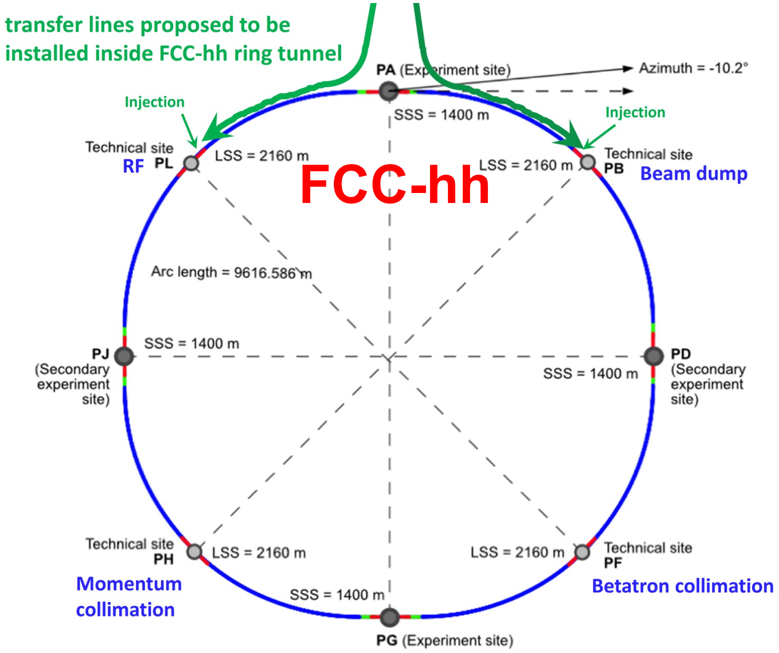
Inspired by Successful LEP – LHC Programmes at CERN

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**
- Complementary physics
- Common civil engineering and technical infrastructures, building on and reusing CERN's existing infrastructure
- FCC integrated project allows seamless continuation of HEP after completion of the HL-LHC programme



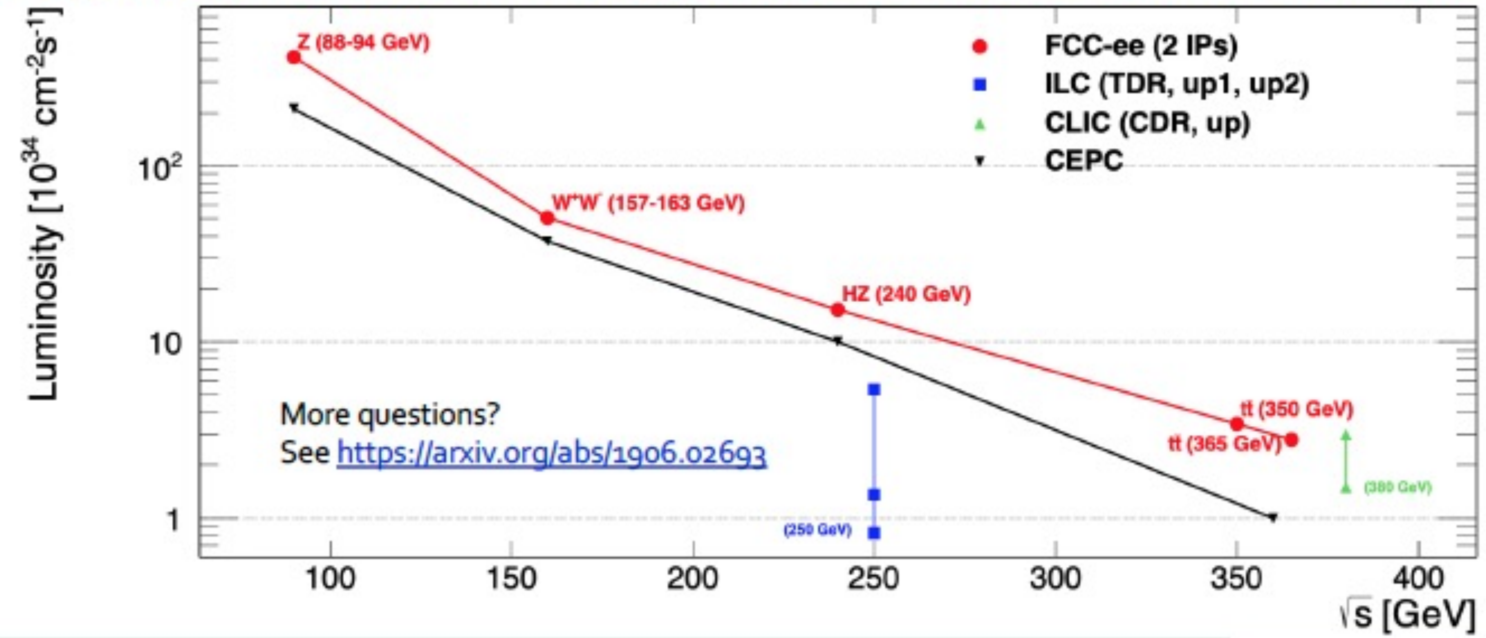




2020 - 2040 | **2045 - 2060** | **2070 - 2090++**

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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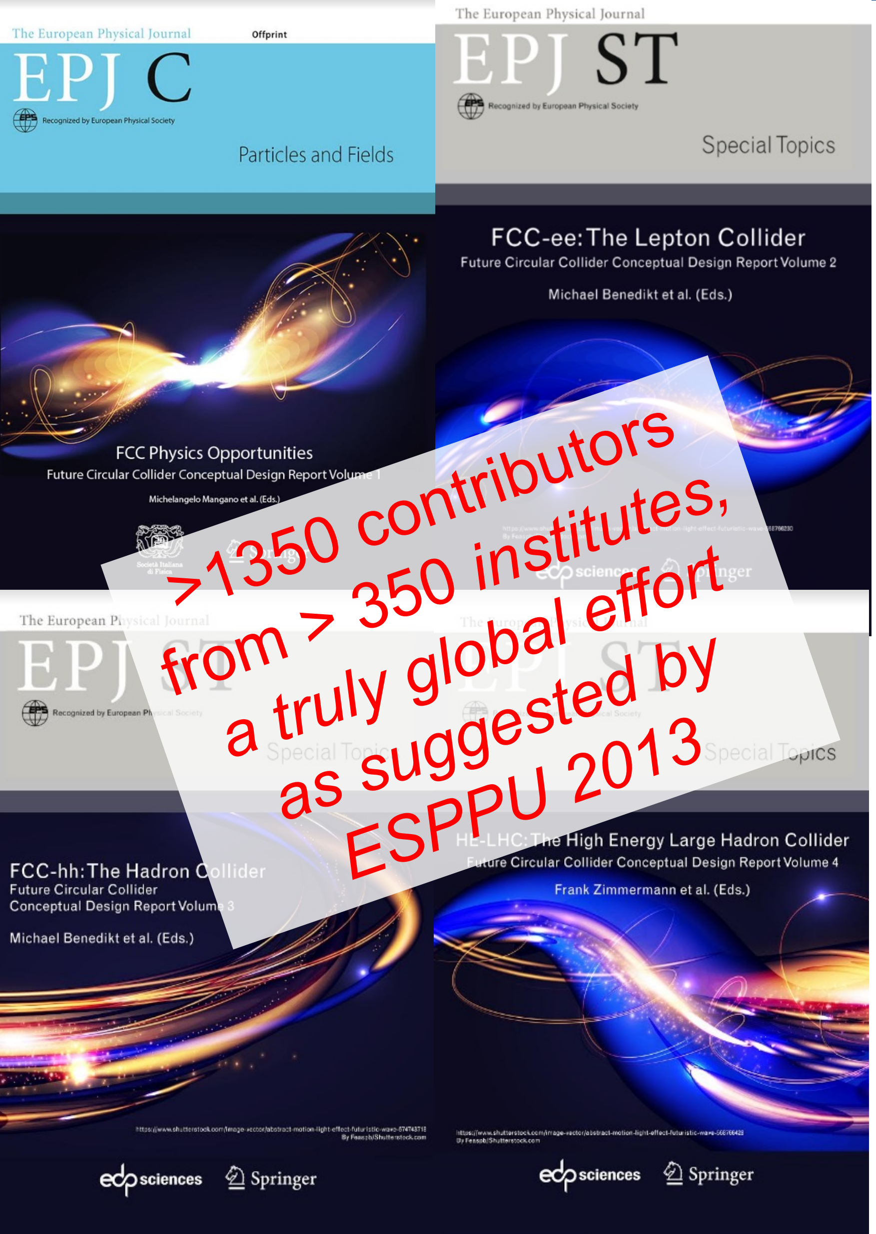
FCC Conceptual Design Report and Study Documentation



- **FCC-Conceptual Design Reports:**
  - **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

- **Summary documents provided to EPPSU SG**
  - **FCC-integral, FCC-ee, FCC-hh, HE-LHC**
  - Accessible on http://fcc-cdr.web.cern.ch/

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.

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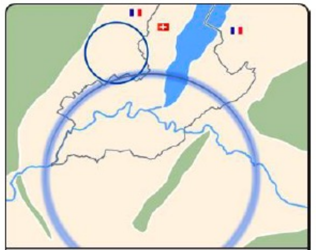
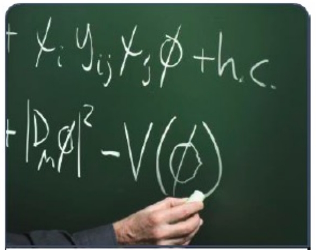
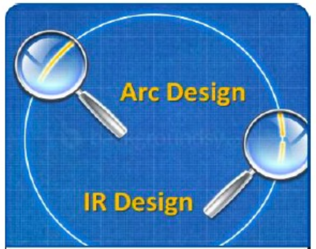
High-level Goals of Feasibility Study

High-level goals of Feasibility Study

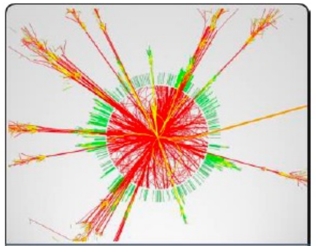
- optimisation of placement and layout of the ring and related infrastructure, and demonstration of the geological, technical, environmental and administrative feasibility of the tunnel and surface areas;
- pursuit, together with the Host States, of the preparatory administrative processes required for 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.

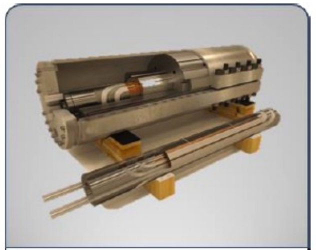

Infrastructures


Physics Cases



Collider Designs


Experiments


R&D Programs

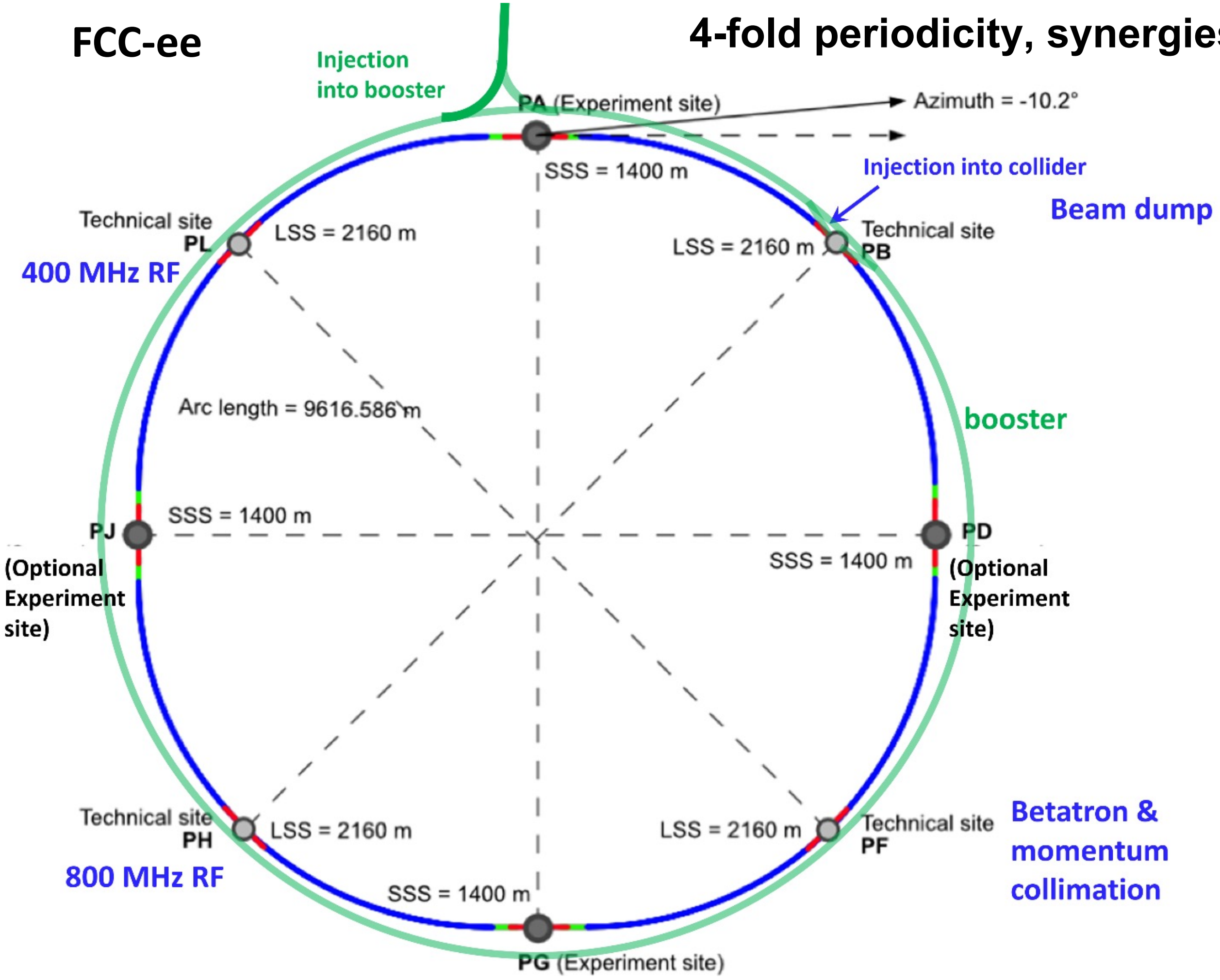
Cost Estimates

New Layouts & Preliminary Assignments of Straight Sections

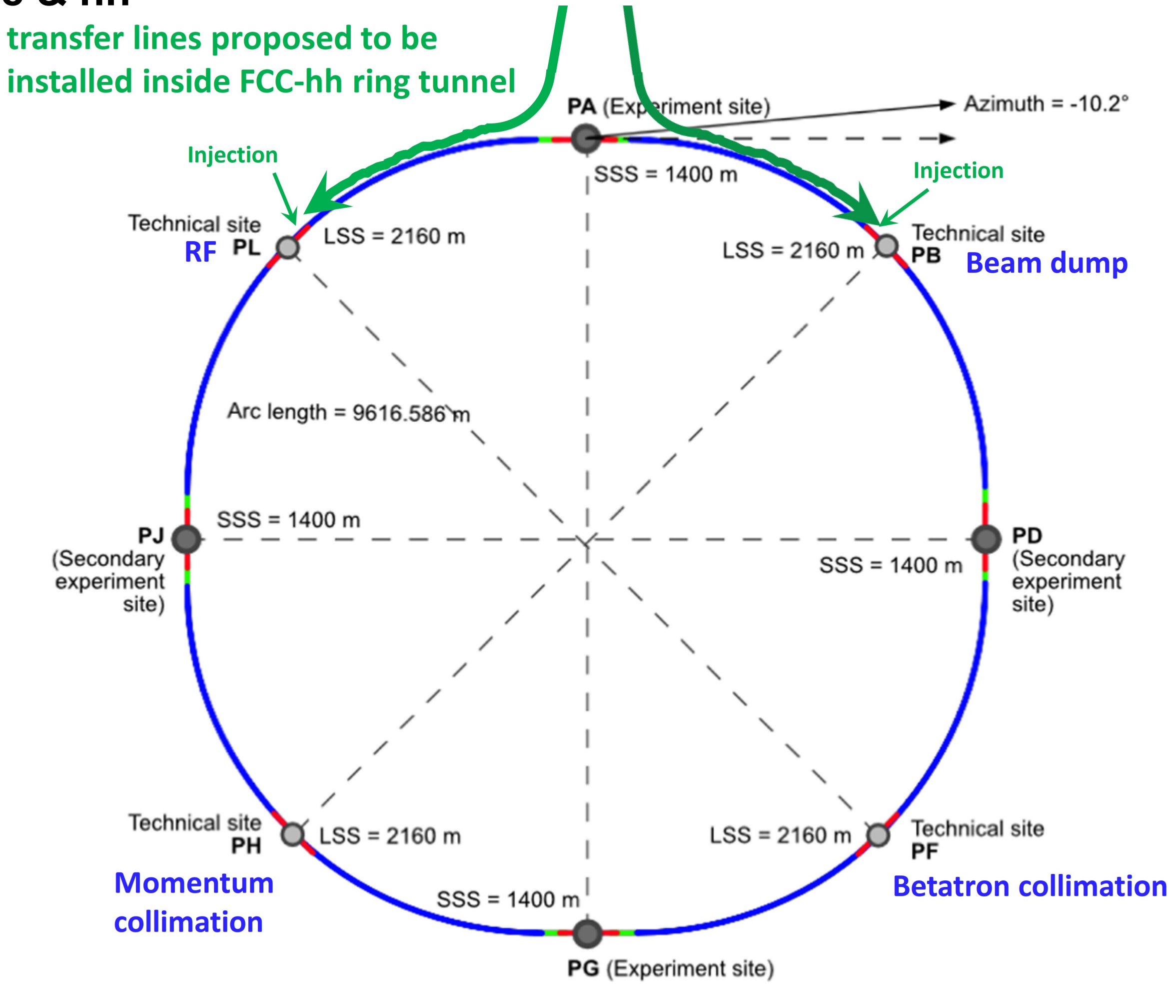
injection-tunnel near PA; 400 MHz RF in PL; 4 exp. caverns for both

4-fold periodicity, synergies ee & hh

FCC-ee



FCC-hh



FCC-ee in a Nutshell

- **High luminosity precision study of Z, W, H, and $t\bar{t}$** 2×10^{36} cm^{-2}s^{-1}/IP at Z (or total $\sim10^{37}$ cm^{-2}s^{-1} with 4 IPs), 7×10^{34} cm^{-2}s^{-1} at ZH, 1.3×10^{34} cm^{-2}s^{-1} at $t\bar{t}$, unprecedented energy resolution at Z (<100 keV) and W (<300 keV)
- **Low-risk technical solution** based on 60 years of e^+e^- circular colliders and particle detectors ; R&D on components for improved performance, but no need for "demonstration" facilities; LEP2, VEPP-4M, PEP-II, KEKB, DAΦNE, or SuperKEKB already used many of the key ingredients in routine operation
- Infrastructure will support a **century of physics**
  - FCC-ee → FCC-hh → FCC-eh and/or several other options (FCC-μμ, Gamma Factory ..)
- **Utility requirements** similar to CERN existing use
- **Strong support** from CERN, partners, and 2020 ESPPU
- **Detailed multi-domain feasibility study underway** for 2026 ESPPU

FUTURE CIRCULAR COLLIDER

Stage 1: Updated Parameters

K. Oide, D. Shatilov,

Parameter [4 IPs, 91.2 km, T_{rev}=0.3 ms]	Z	WW	H (ZH)	ttbar
beam energy [GeV]	45	80	120	182.5
beam current [mA]	1280	135	26.7	5.0
number bunches/beam	10000	880	248	36
bunch intensity [10^{11}]	2.43	2.91	2.04	2.64
SR energy loss / turn [GeV]	0.0391	0.37	1.869	10.0
total RF voltage 400/800 MHz [GV]	0.120/0	1.0/0	2.08/0	4.0/7.25
long. damping time [turns]	1170	216	64.5	18.5
horizontal beta* [m]	0.1	0.2	0.3	1
vertical beta* [mm]	0.8	1	1	1.6
horizontal geometric emittance [nm]	0.71	2.17	0.64	1.49
vertical geom. emittance [pm]	1.42	4.34	1.29	2.98
horizontal rms IP spot size [μm]	8	21	14	39
vertical rms IP spot size [nm]	34	66	36	69
beam-beam parameter ξ_x / ξ_y	0.004/ .159	0.011/0.111	0.0187/0.129	0.096/0.138
rms bunch length with SR / BS [mm]	4.38 / 14.5	3.55 / 8.01	3.34 / 6.0	2.02 / 2.95
luminosity per IP [10^{34} cm^{-2}s^{-1}]	182	19.4	7.3	1.33
total integrated luminosity / year [ab^{-1}/yr]	87	9.3	3.5	0.65
beam lifetime rad Bhabha + BS [min]	19	18	6	9

FCC-ee RF Staging Scenario

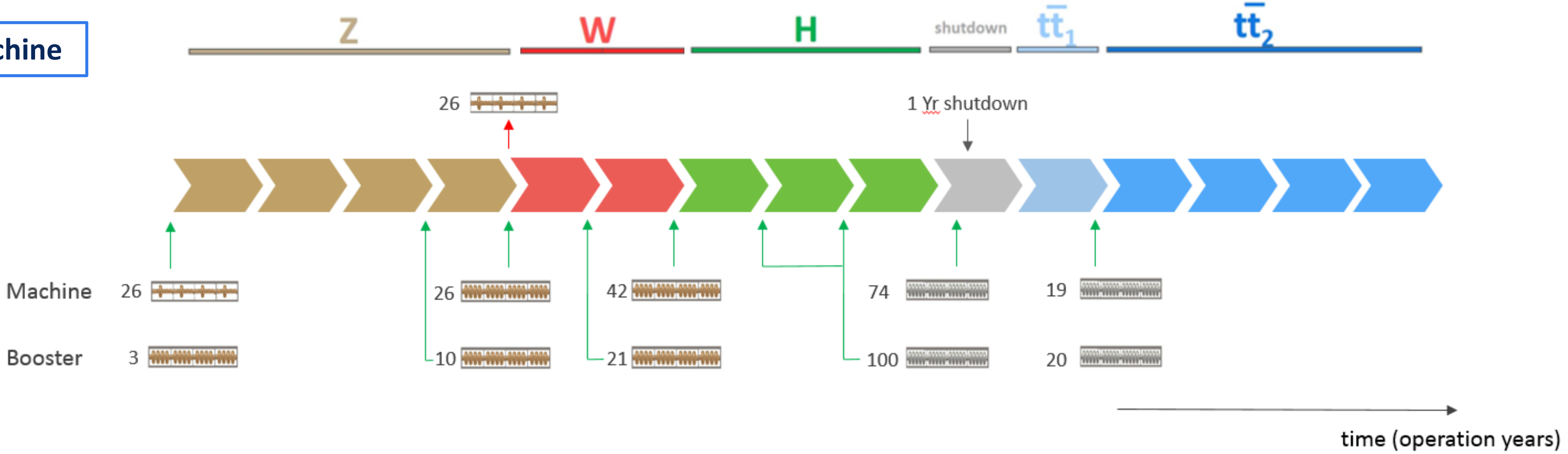
"Ampere-class" machine

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

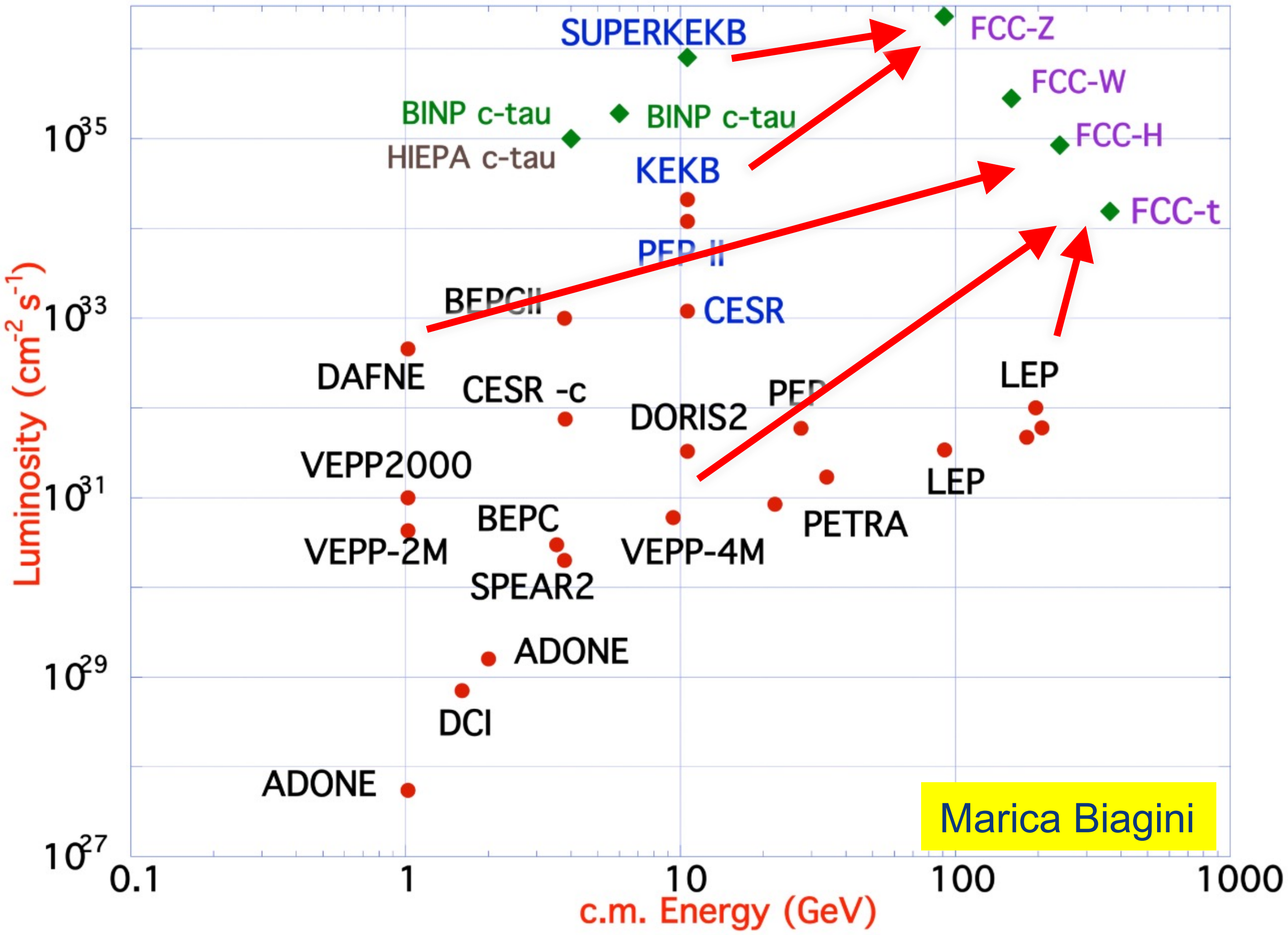
three sets of RF cavities to cover all options for FCC-ee & booster:

- **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)**



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

Electron Ion Collider (EIC)

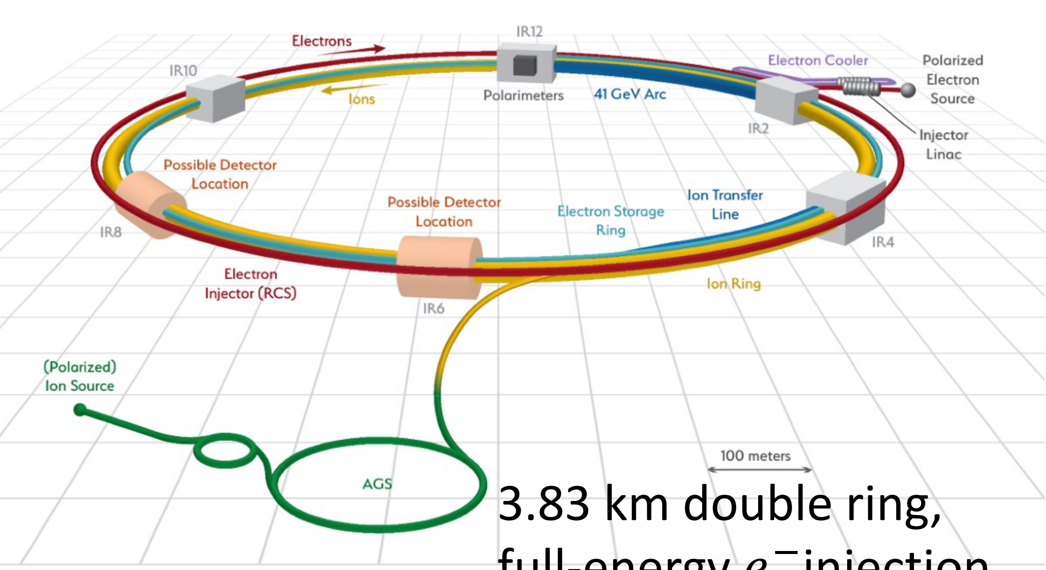
US EIC Electron Storage Ring similar to, but more challenging than, FCC-ee.

Beam parameters almost identical, but twice the maximum electron beam current, or half the bunch spacing, and lower beam energy.

~10 areas of common interest identified by the FCC and EIC design teams, addressed through joint EIC-FCC working groups.

EIC start beam operation around decade before FCC-ee

The EIC will provide another invaluable opportunity to train the next generation of accelerator physicists on an operating collider, to test hardware prototypes, beam control schemes, etc.



3.83 km double ring, full-energy e^{-}injection, injection rate 1 Hz, every 2 min into same bucket

	EIC	FCC-ee-Z
Beam energy [GeV]	10 (18)	45.6 (80)
Bunch population [10^{11}]	1.7	1.7
Bunch spacing [ns]	10	15, 17.5 or 20
Beam current [A]	2.5 (0.27)	1.39
SR power / beam /meter [W/m]	7000	600
Critical photon energy [keV]	9 (54)	19 (100)

FCC-ee Accelerator R&D Examples

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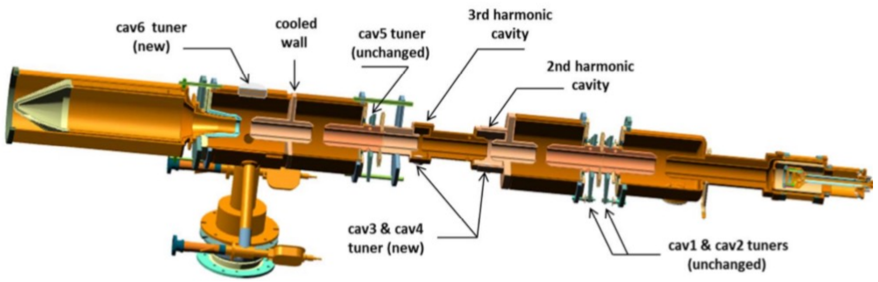
Efficient RF power sources
(400 & 800 MHz)

I. Syratchev

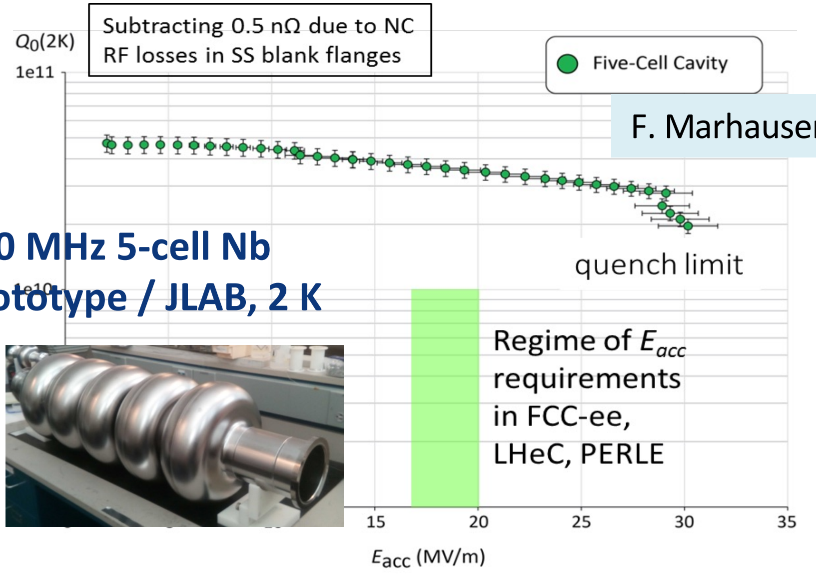


FPC & HOM coupler, cryomodule, thin-film coatings…

Efficient SC cavities

Jefferson Lab

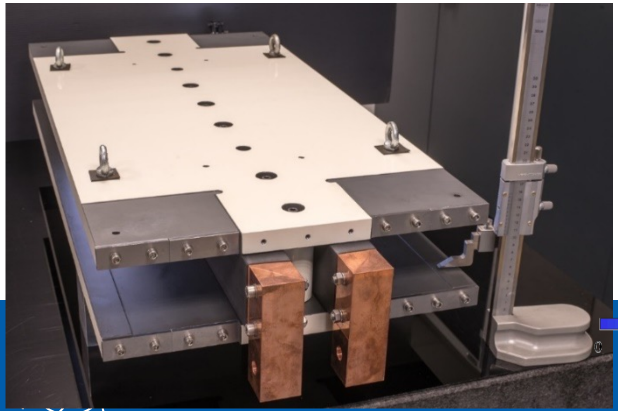
400 MHz
1-,2- & 4-cell
Nb/Cu ,
4.5 K

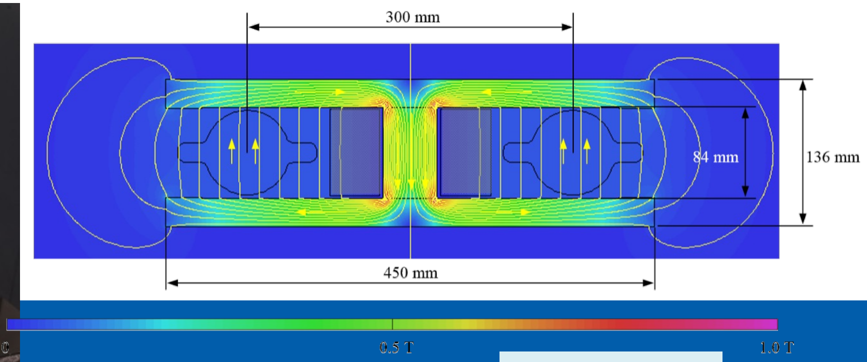


800 MHz 5-cell Nb prototype / JLAB, 2 K

F. Marhauser

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

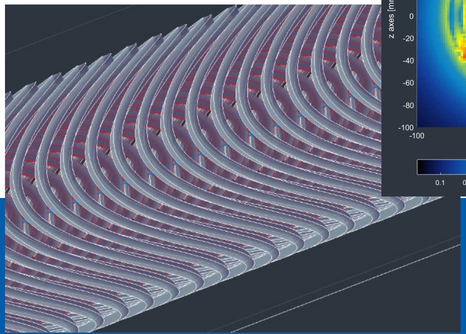


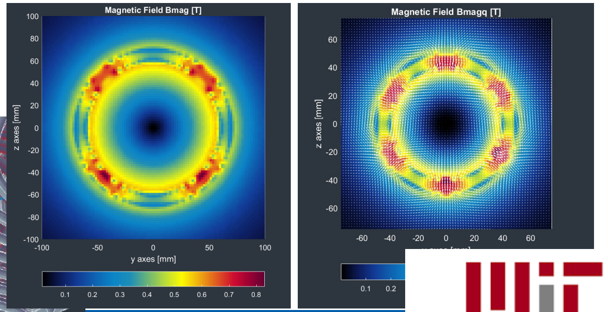


A. Milanese

Under study: **CCT HTS quad's & sext's for arcs**

PAUL SCHERRER INSTITUT PSI



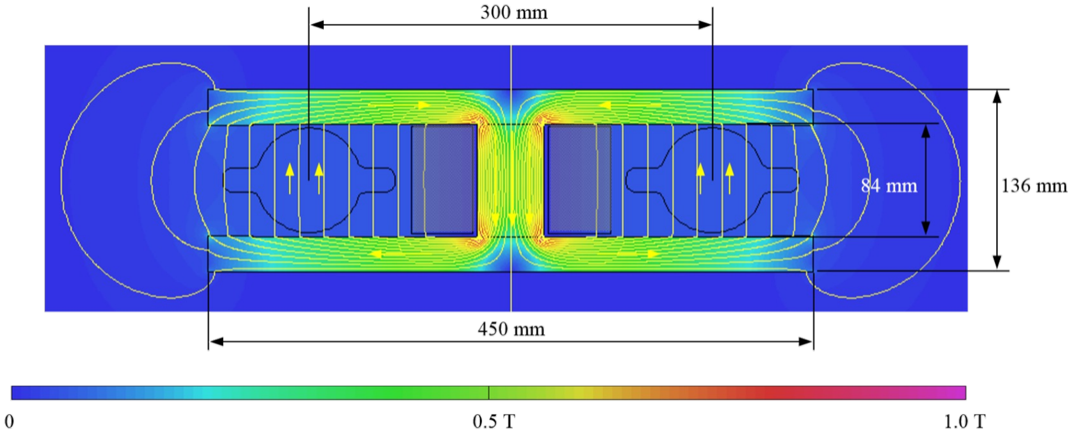


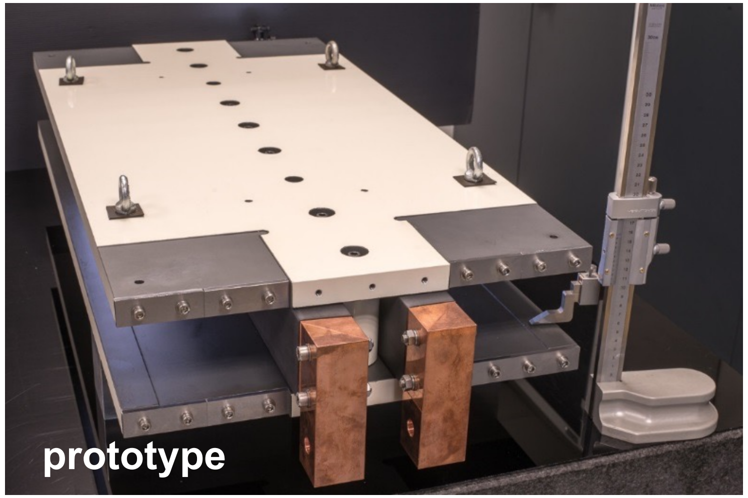
M. Koratzinos

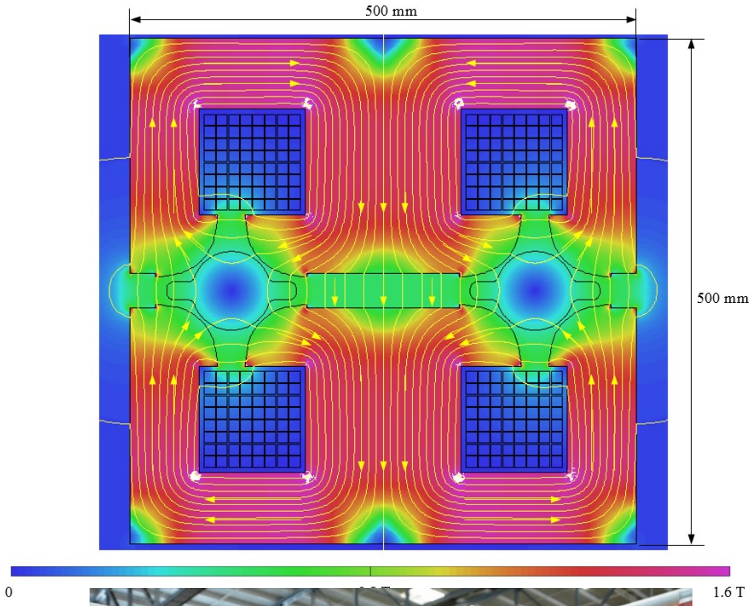
Massachusetts Institute of Technology

Prototypes of FCC-ee Low-power Magnets

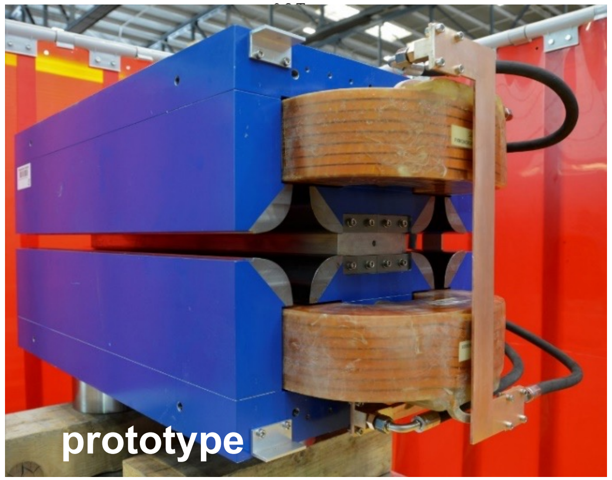
Twin-dipole design with 2× power saving 16 MW (at 175 GeV), with Al busbars







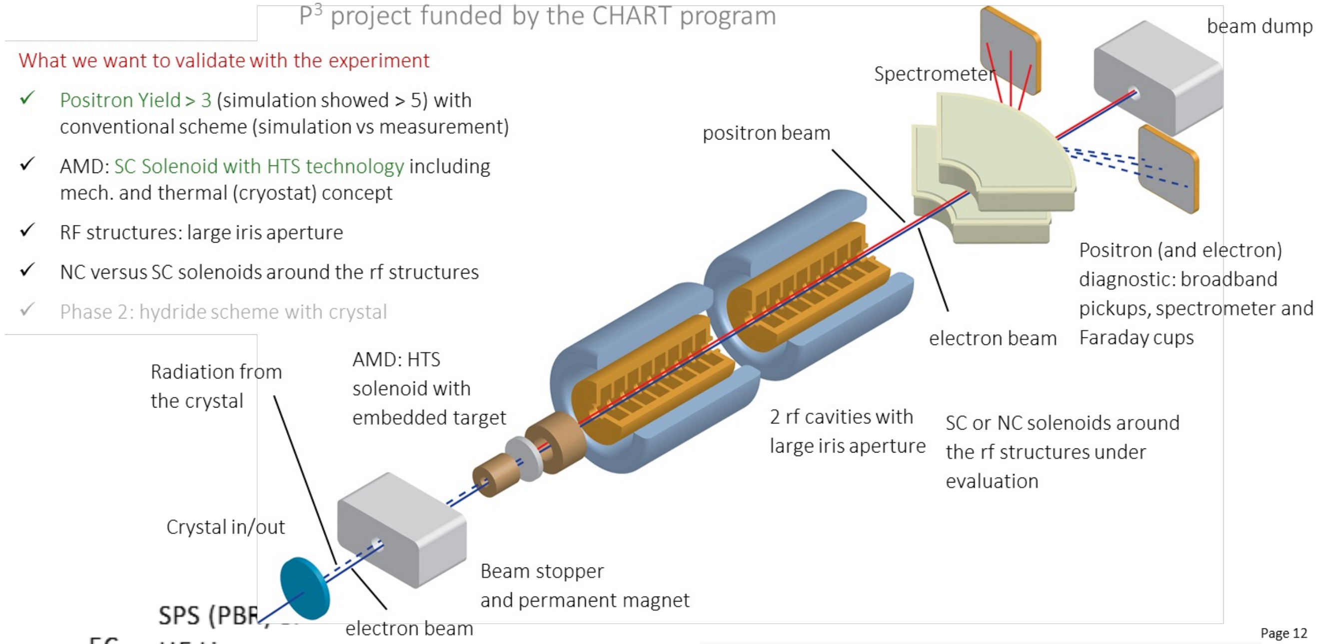
Twin F/D arc quad design with 2× power saving 25 MW (at 175 GeV), with Cu conductor



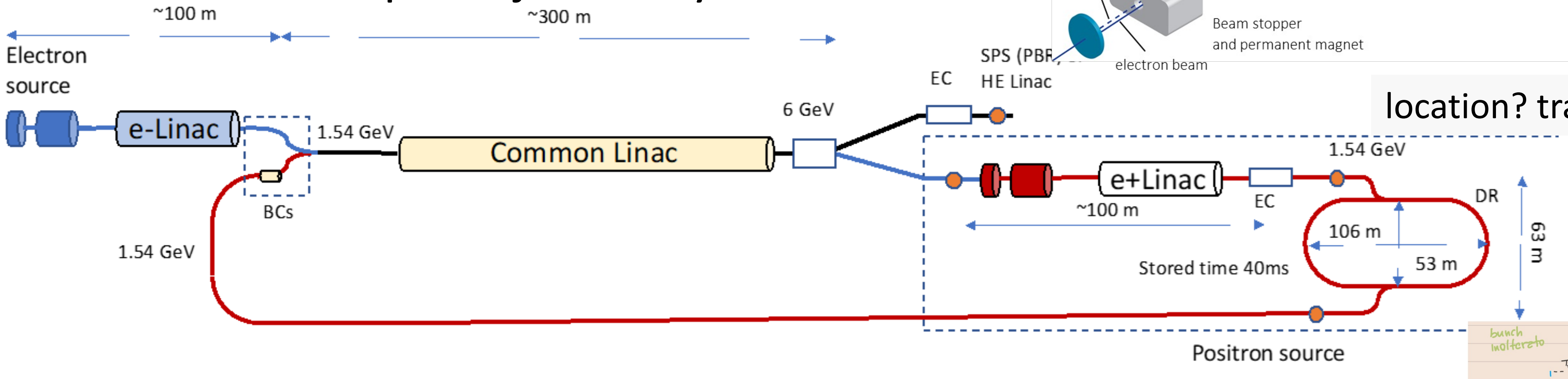
FCC-ee Pre-Injector - Swiss CHART 2 Programme

Collaboration between PSI and CERN with external partners: CNRS-IJCLab (Orsay), INFN-LNF (Frascati), KEK/SuperKEKB as observer, INFN-Ferrara – radiation from crystal

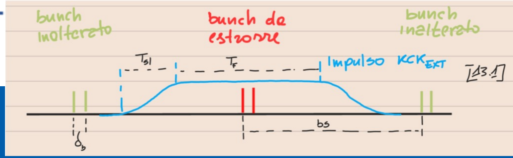
P^3: PSI e^+ production experiment with HTS solenoid at SwissFEL planned for 2024/25



Latest FCC-ee pre-injector layout



location? transfer lines?

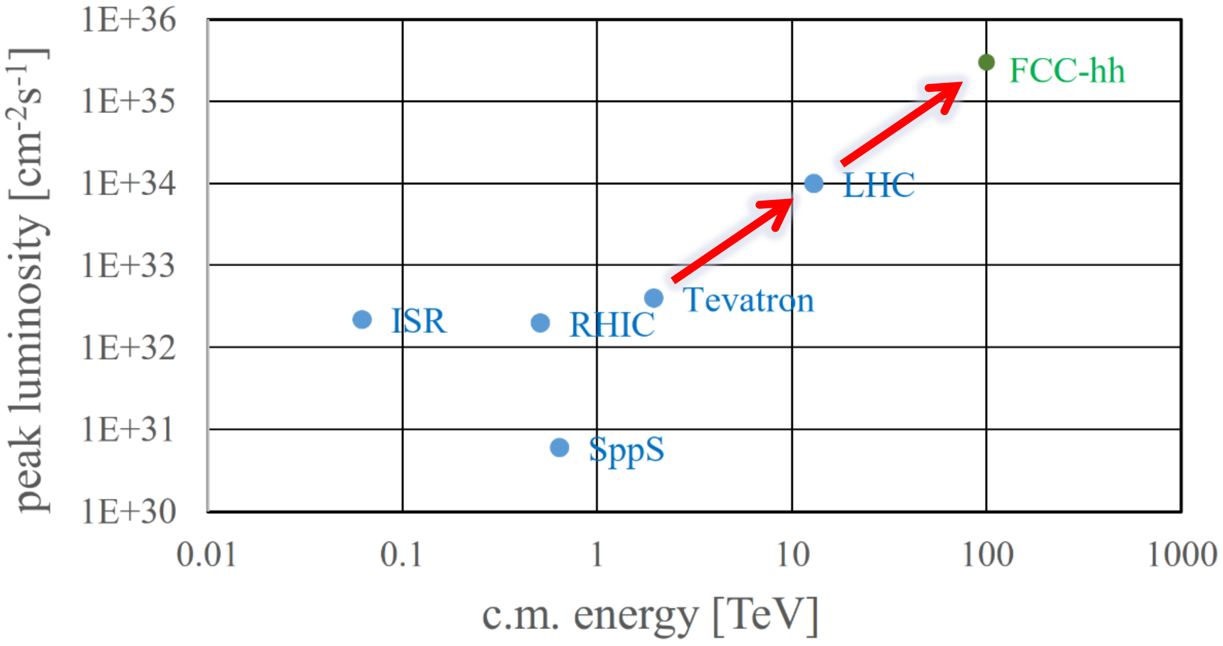


P. Craievich, A. Grudiev, C. Milardi, A. De Santis, et al.

Stage 2: FCC-hh (pp) Collider Parameters

parameter	FCC-hh		HL-LHC	LHC
collision energy cms [TeV]	100		14	14
dipole field [T]	~17 (~16 comb.function)		8.33	8.33
circumference [km]	91.2		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

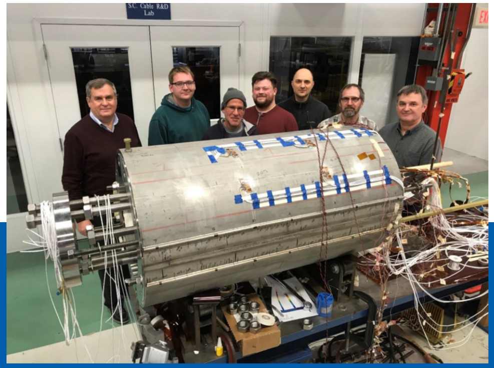
FCC-hh: Highest Collision Energies



- **Order of magnitude performance increase** in both **energy & luminosity**
- **100 TeV cm collision energy** (vs 14 TeV for LHC)
- **20 ab^{-1} per experiment collected 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

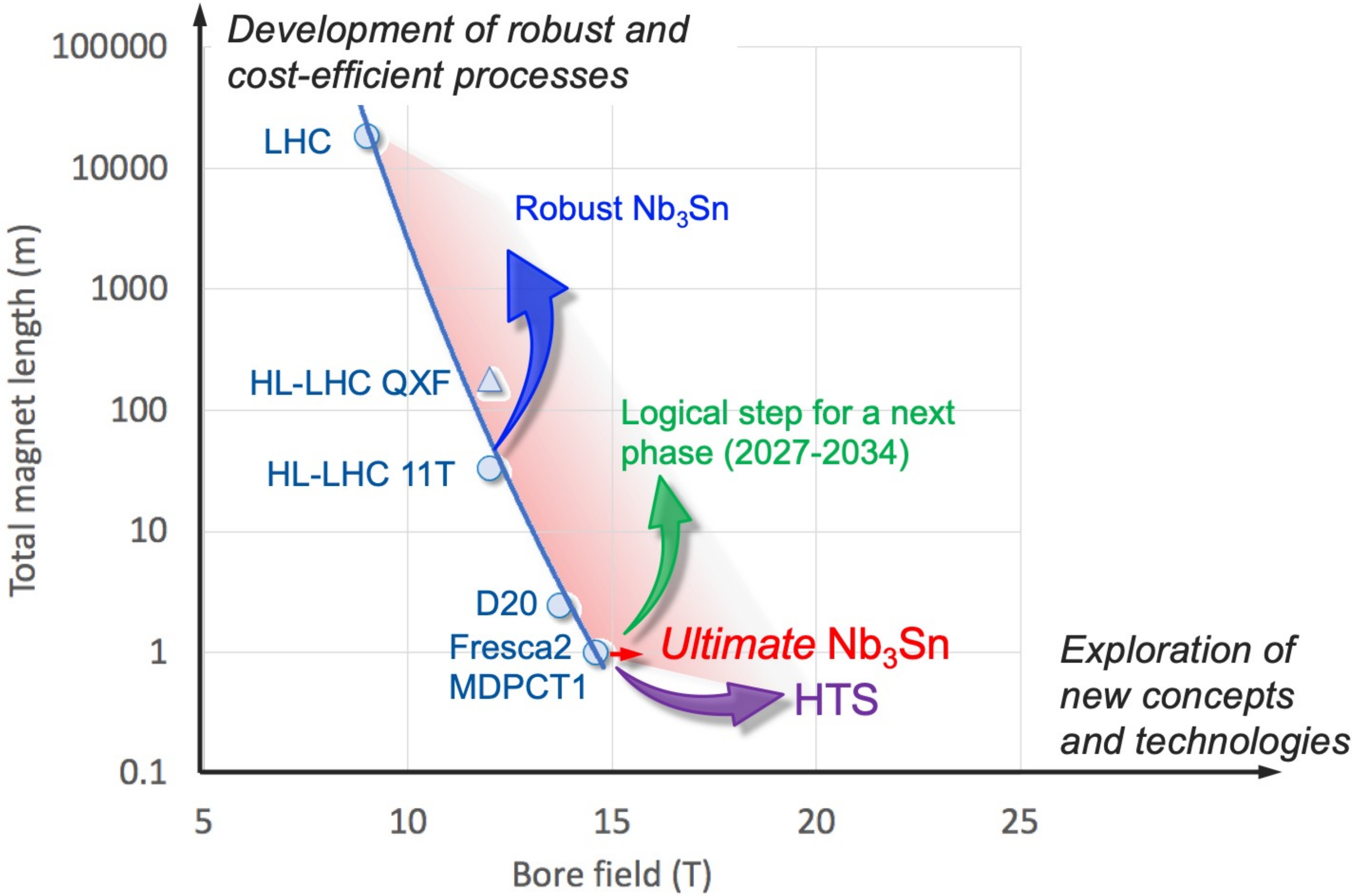
via
HL-LHC technology
12 T Nb_3Sn quadrupole



FNAL dipole demonstrator
14.5 T Nb_3Sn

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

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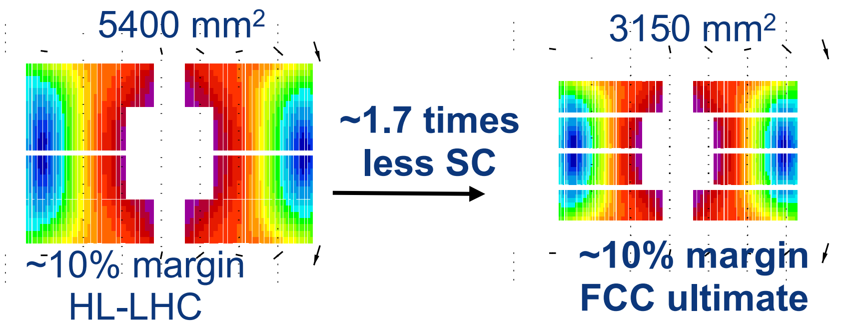
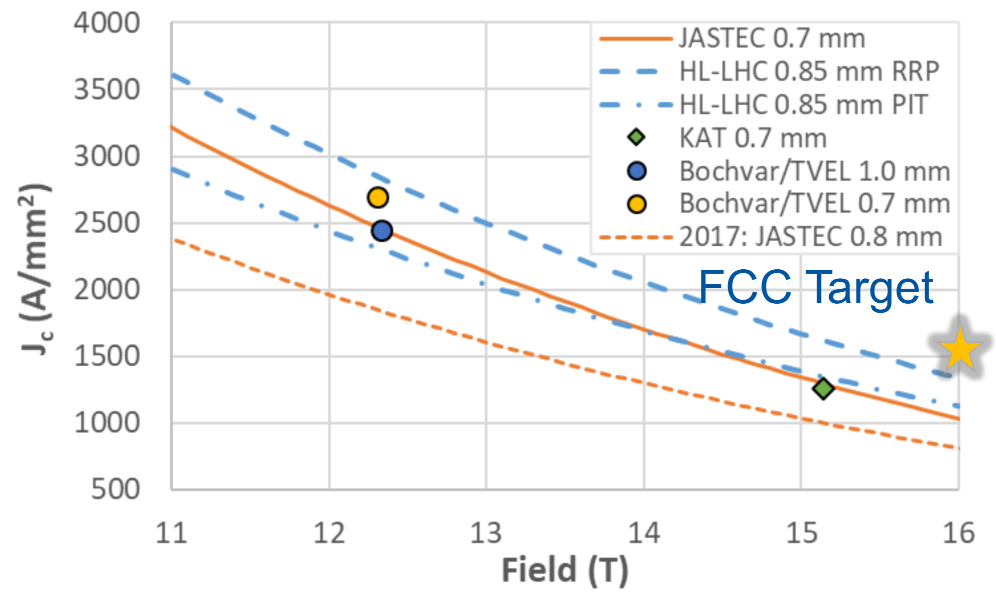
Main development goal is wire performance increase:

- **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.

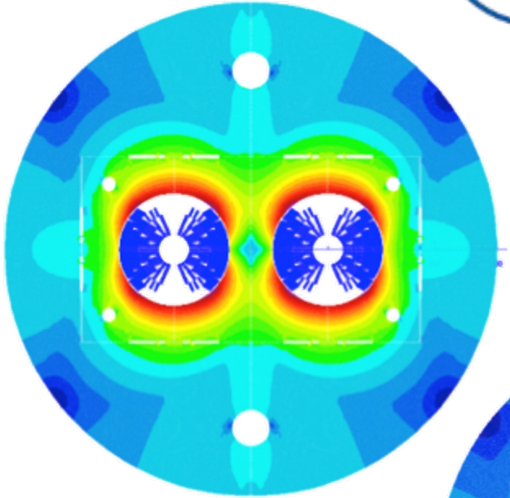
16 T Dipole Design Activities and Options

FUTURE CIRCULAR COLLIDER

H2020 EuroCirCol
A key to New Physics

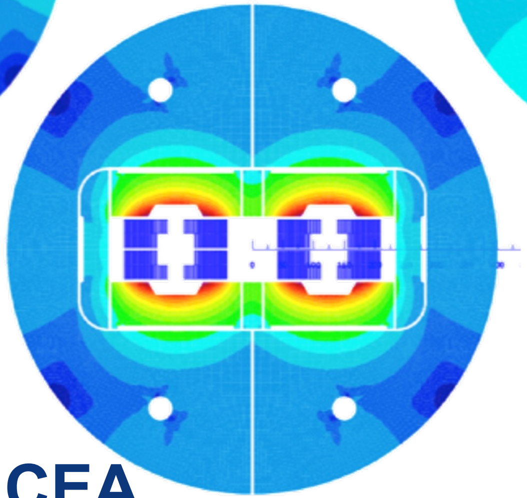
Swiss contribution

Cos-theta



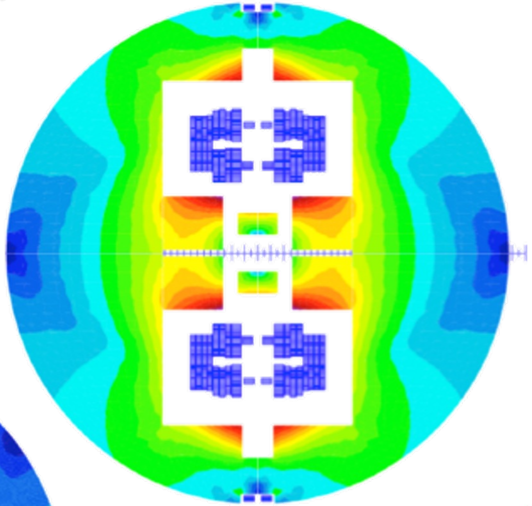
INFN

Blocks



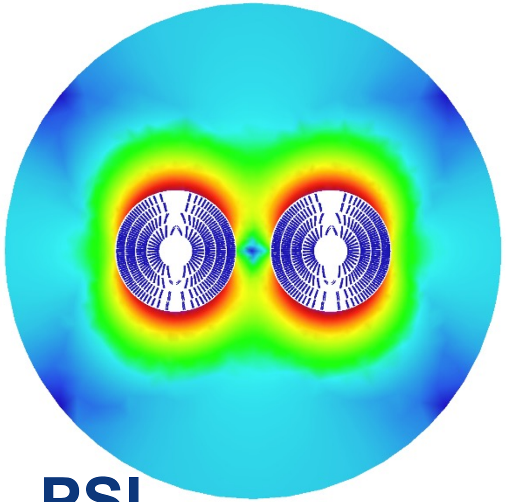
CEA

Common coils

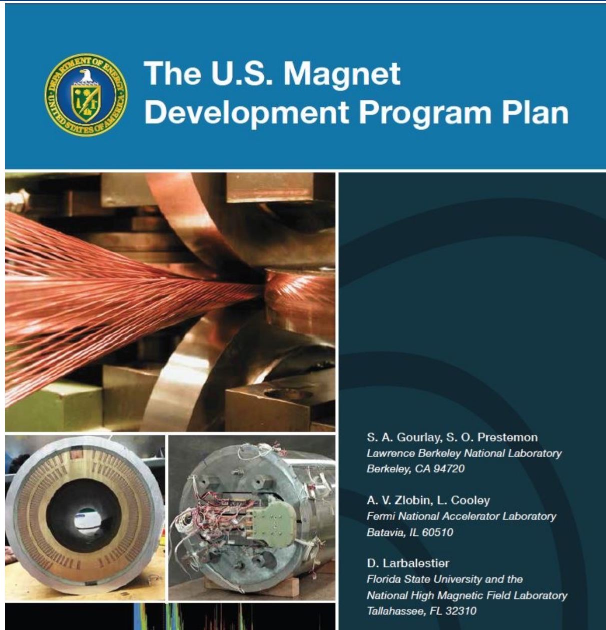


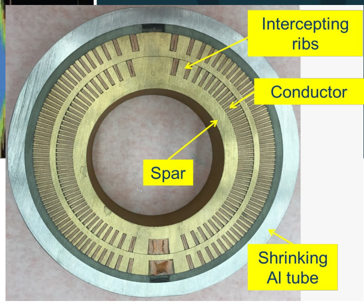
CIEMAT

Canted Cos-theta



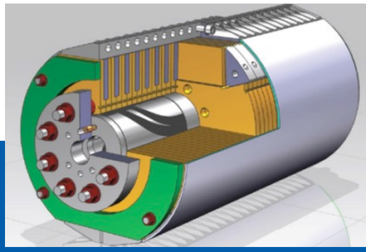
PSI





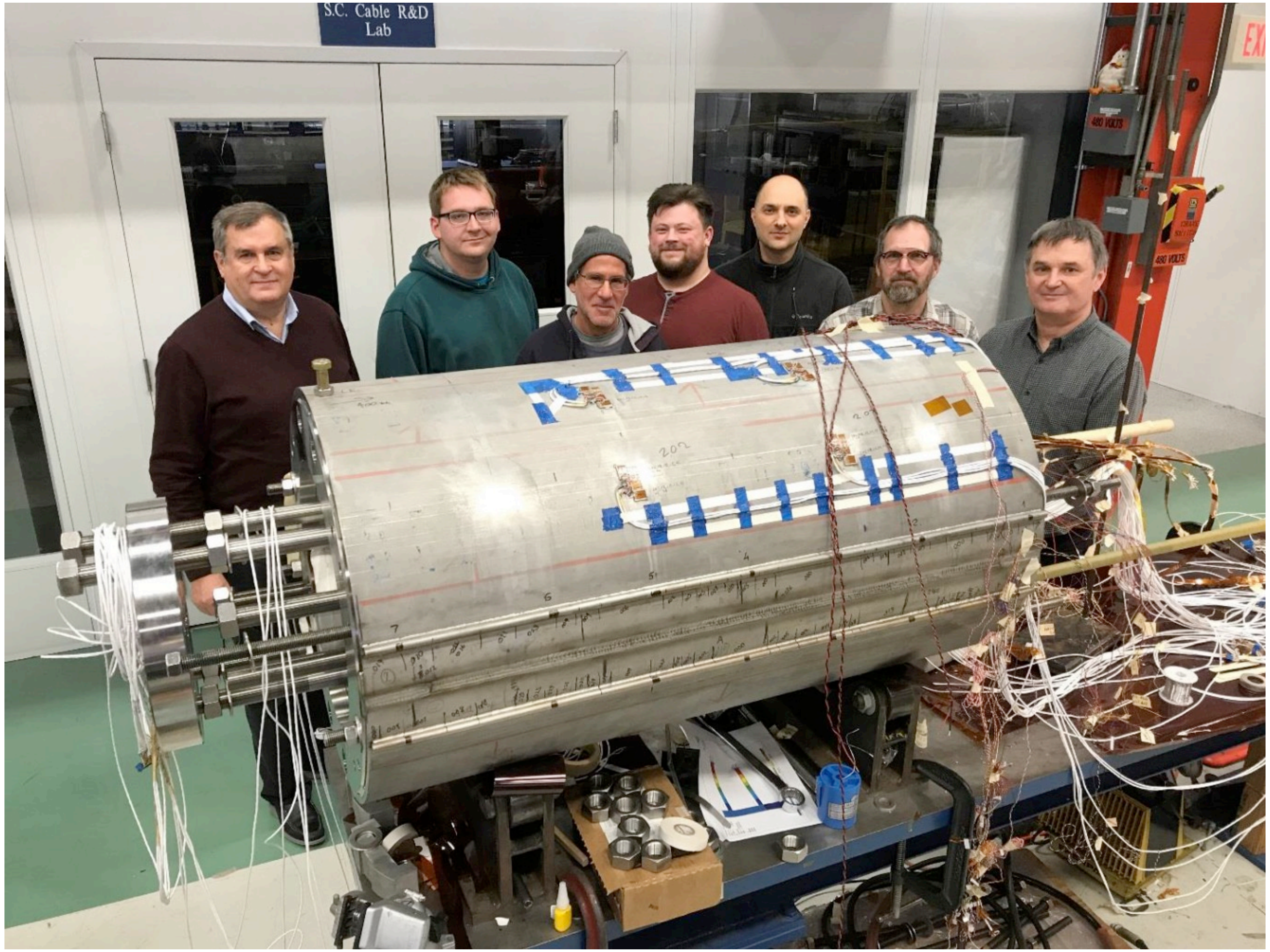
LBNL

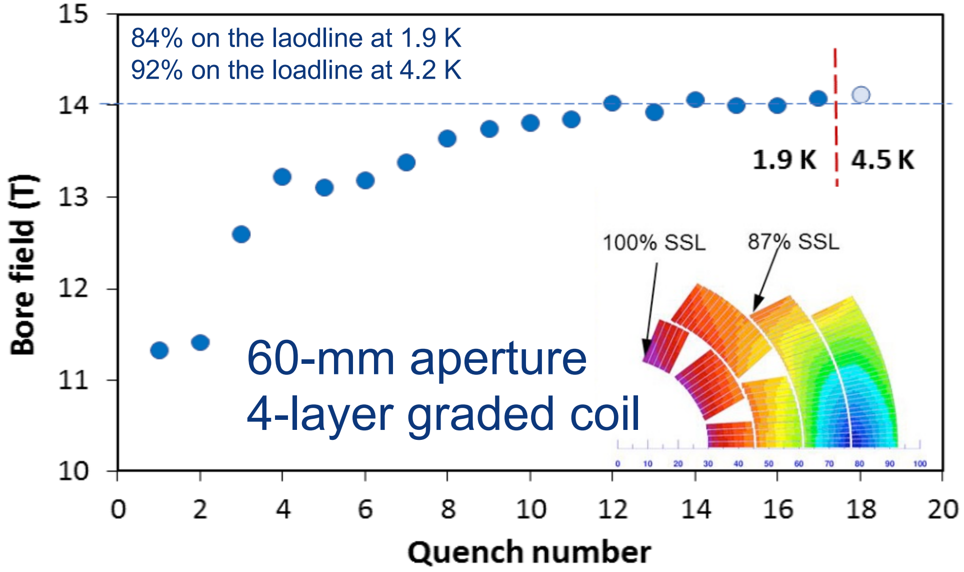
FNAL



Short model magnets (1.5 m lengths) will be built until 2025

US – MDP: 14.5 T Magnet Tested at FNAL

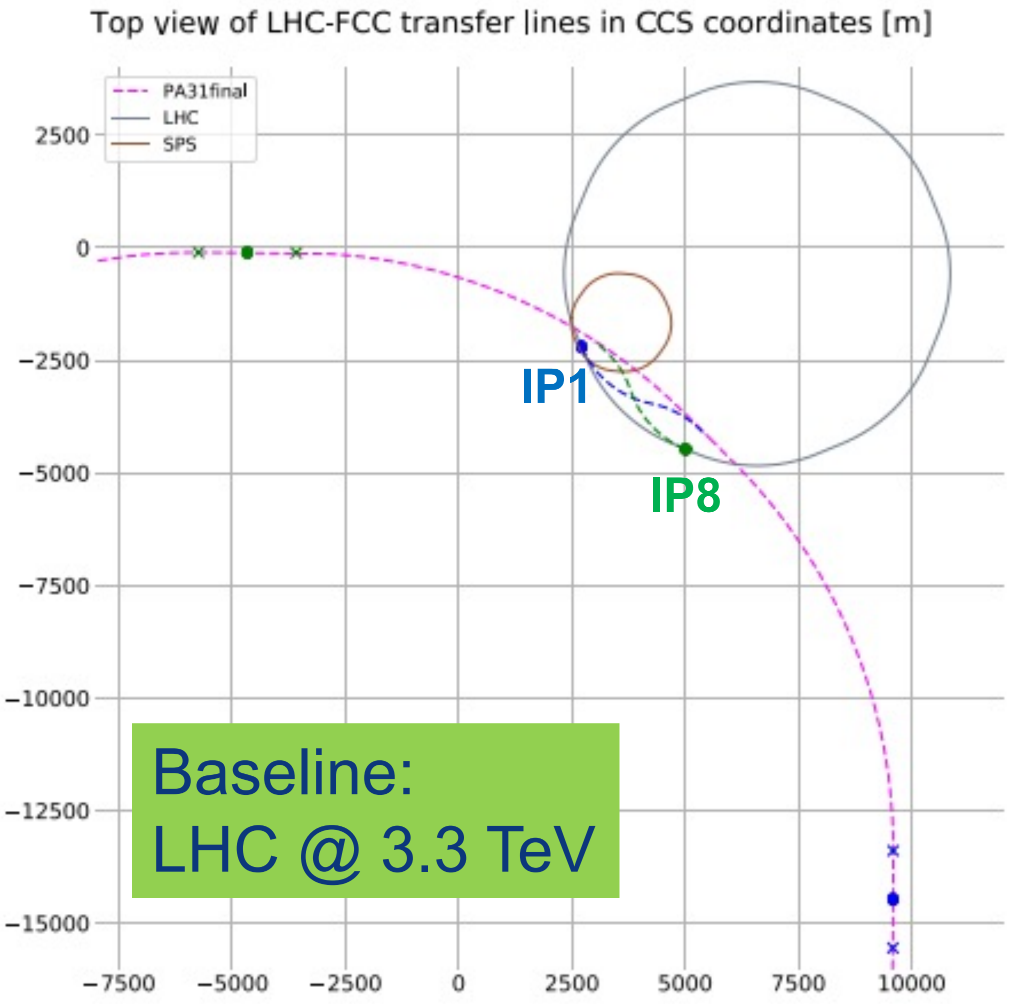


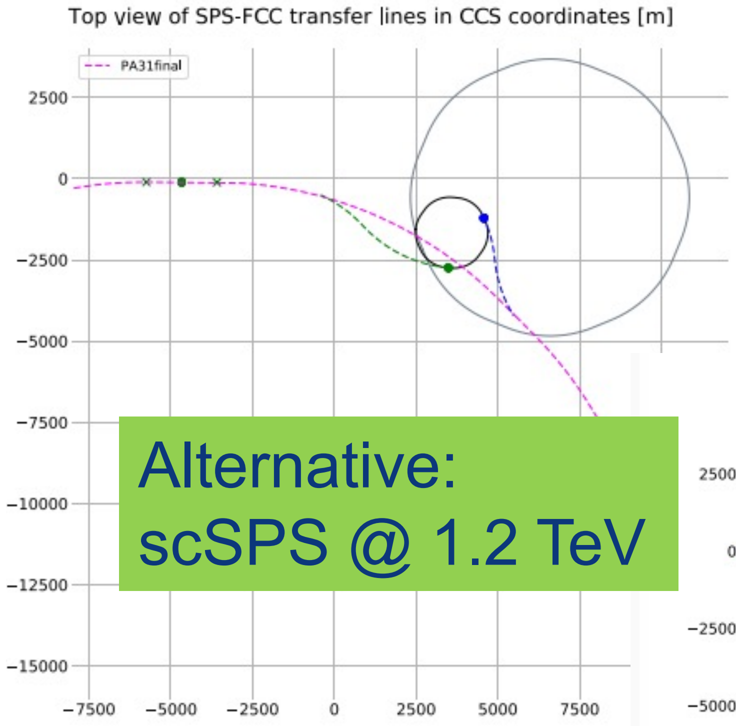


- 15 T dipole demonstrator
- Staged approach: In first step pre-stressed for 14 T
- Second test in June 2020 with additional pre-stress reached 14.5 T

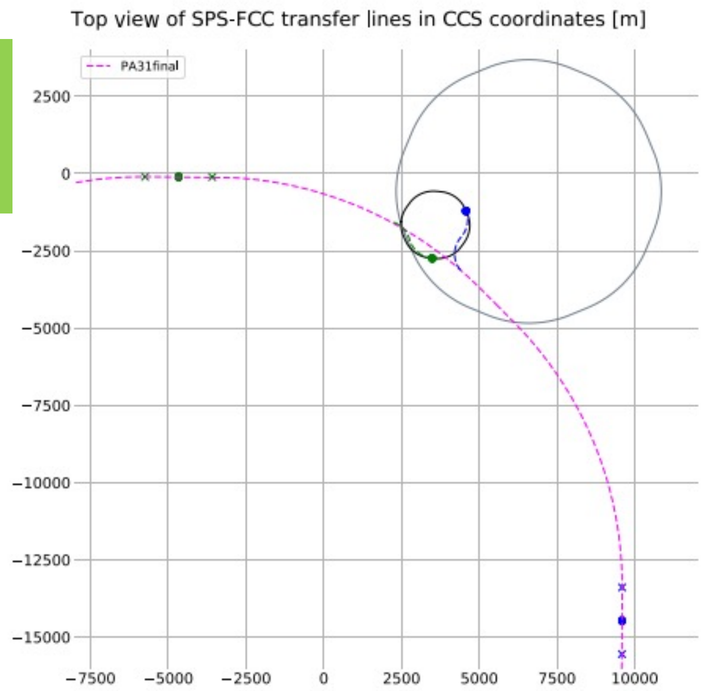
FCC-hh Hadron Injector Lines for New Layout

Injection from LHC





Injection from scSPS
NC (left) or
SC transfer lines (below)



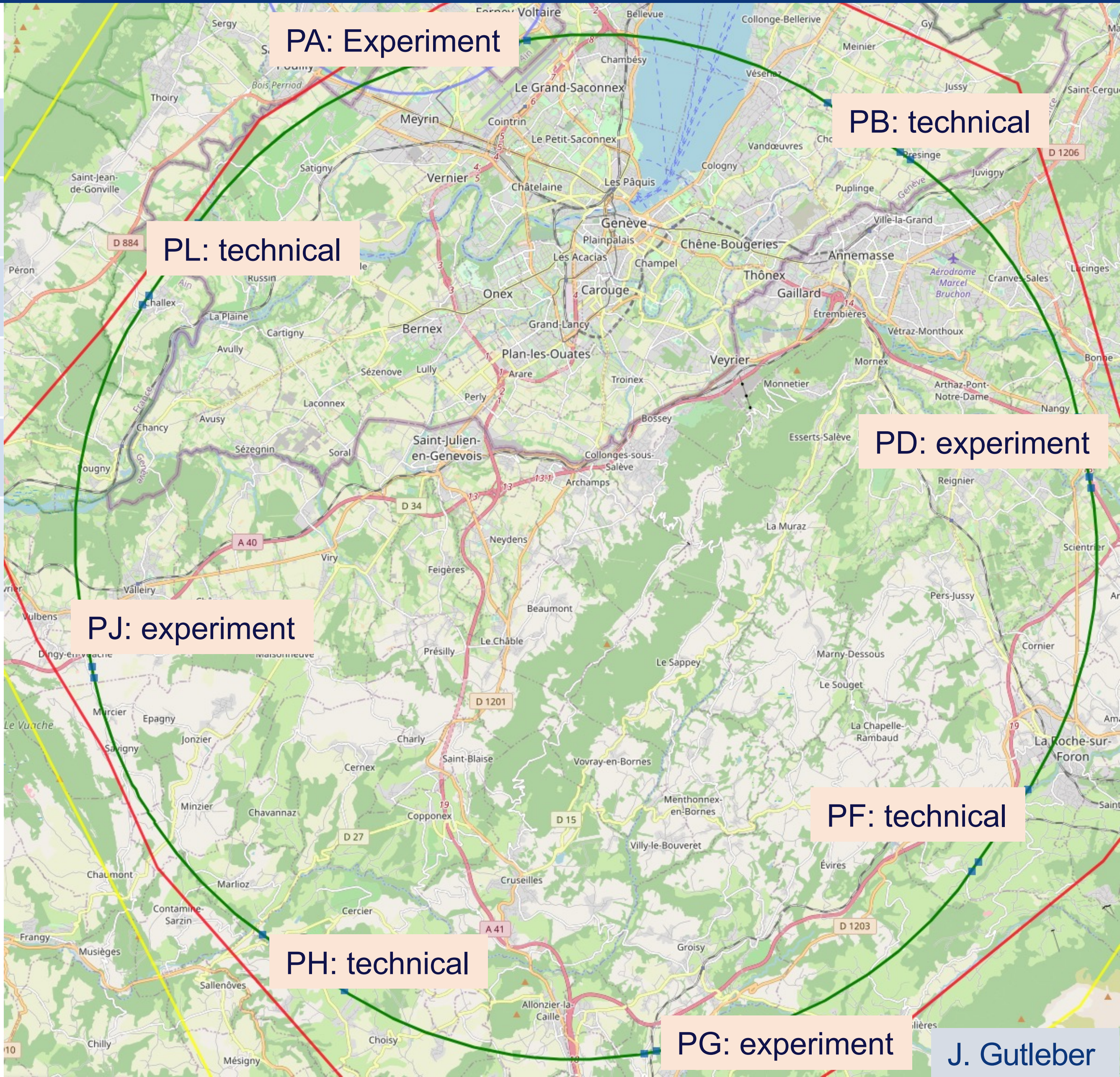
tunnel lengths:
- LHC, SC, 3.2/3.5 km
- SPS, NC, 4.6/3.2 km
- SPS, SC, 1.5/2.1 km

Optimised Placement and Layout

8-site baseline "PA31"

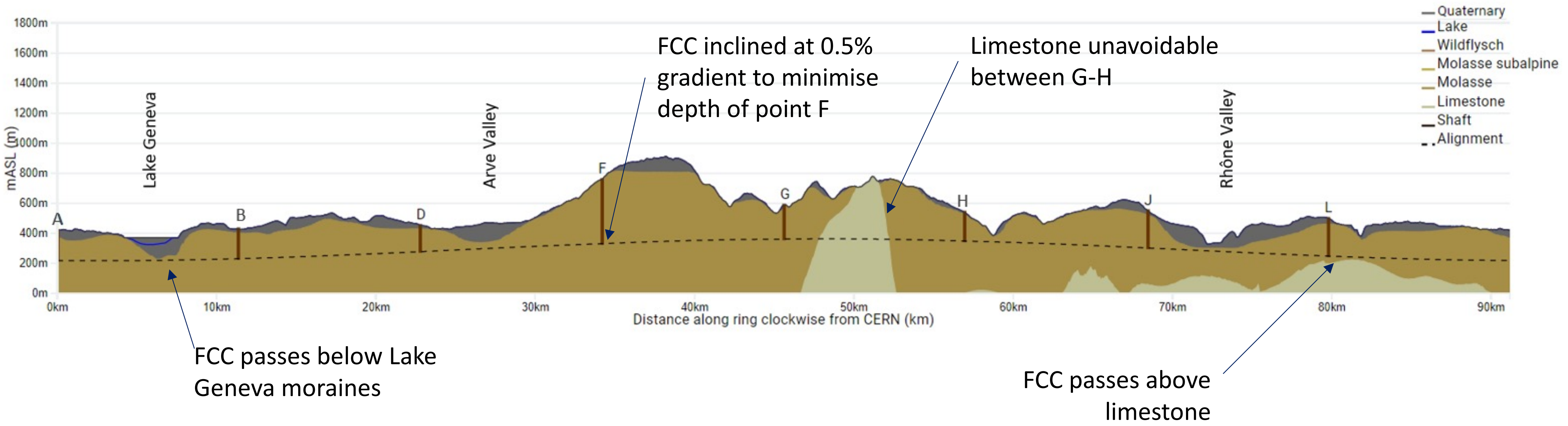
Number of surface sites	8
LSS@IP (PA, PD, PG, PJ)	1400 m
LSS@TECH (PB, PF, PH, PL)	2143 m
Arc length	9.6 km
Sum of arc lengths	76.9 m
Total length	**91.1 km**

- 8 sites – less use of land, <40 ha instead 62 ha
- Possibility for 4 experiment sites in FCC-ee
- All sites close to road infrastructures (< 5 km of new road constructions for all sites)
- Vicinity of several sites to 400 kV grid lines
- Good road connection of PD, PF, PG, PH suggest operation pole around Annecy/LAPP
- **Exchanges with ~40 local communes in preparation**



J. Gutleber

FCC Long Section – PA31-1.0

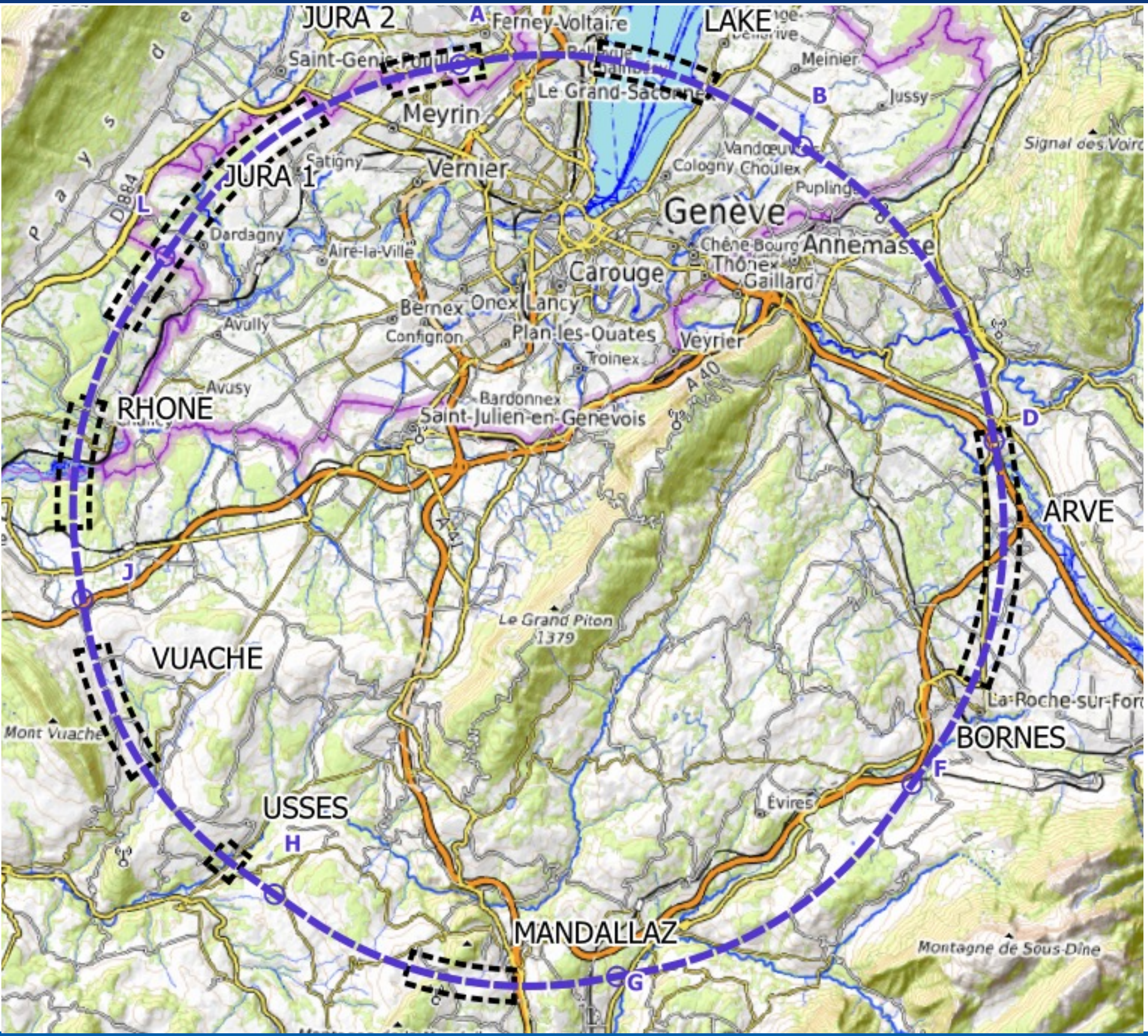


Shaft depth:

A: 202 m B: 200 m D: 177 m F: 399 m G: 228 m H: 139 m J: 251 m L: 253 m

John Osborne

Plans for High-risk Area Site Investigations



JURA, VUACHE (3 AREAS)
Top of limestone
Karstification and filling-in at the tunnel depth
Water pressure

LAKE, RHÔNE, ARVE AND USSES VALLEY (4 AREAS)
Top of the molasse
Quaternary soft grounds, water bearing layers

MANDALLAZ (1 AREA)
Water pressure at the tunnel level
Karstification

BORNES (1 AREA)
High overburden molasse properties
Thrust zones

Site investigations planned for 2024 – 2025:
~40-50 drillings, 100 km of seismic lines

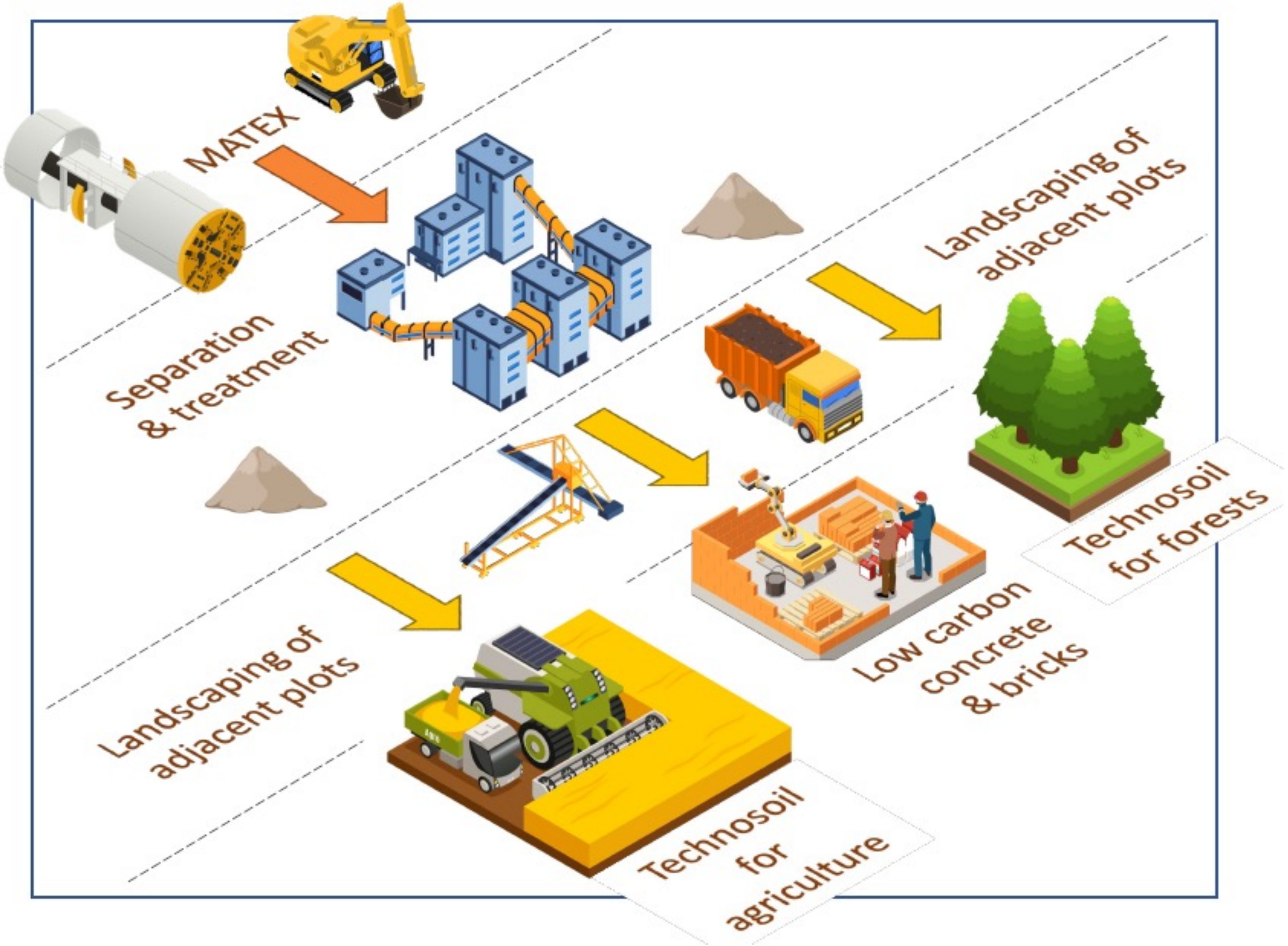
Mining the Future – Excavation Material Reuse

AMBERG Konsortium: In-situ characterisation (Crossbelt elemental analyzer) and preparation for use as construction material on site (Spritzbeton, Bindemittel aus Bio-Mineralstoffen). Production of construction elements without cement/concrete.

BG Konsortium: Online-analysis and preparation of Molasse for construction elements from sandstone, sand, filing material for concrete, low-carbon concrete, terracotta bricks, etc.

ARCADIS Konsortium: Molasse combined with some stabilisation material for production of construction bricks via high mechanical pressure. Replacing high-carbon construction materials. Mobile production plants directly on site.

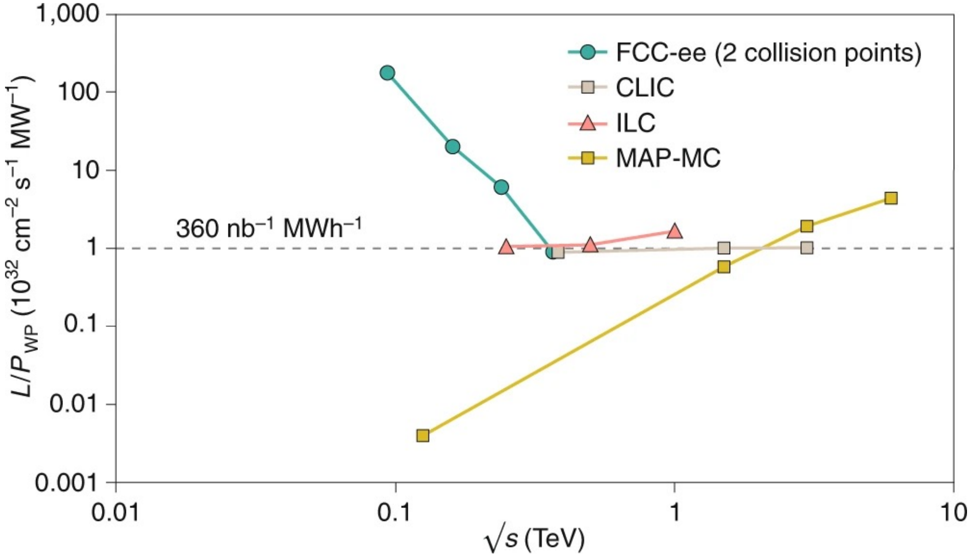
EDAPHOS Konsortium: Combining mineral (Molasse) material and organic material to produce fertile soil with on-site production plants by using microbiology to accelerate humus creation. Fertile soil as top layer for agricultural use, recultivation.



Sustainability and Carbon Footprint Studies

Highly-sustainable Higgs Factory

Luminosity vs. Electricity Consumption



Thanks to twin-aperture magnets, thin-film SRF, efficient RF power sources, top-up injection

Optimum usage of excavation material

int'l competition "mining the future®"

https://indico.cern.ch/event/1001465/

FCC-ee Annual Energy Consumption ~ LHC/HL-LHC

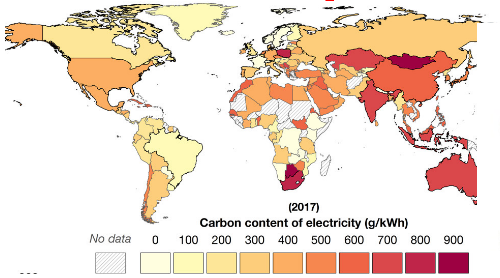
120 GeV	Days	Hours	Power OP	Power Com	Power MD	Power TS	Power Shutdown		
Beam operation	143	3432	293					1005644	MWh
Downtime operation	42	1008	109					110266	MWh
Hardware, Beam commissioning	30	720		139				100079	MWh
MD	20	480			177			85196	MWh
technical stop	10	240				87		20985	MWh
Shutdown	120	2880					69	199872	MWh
Energy consumption / year	365	8760						1.52	TWh
Average power								174	MW

J.-P. Burnet, FCC Week 2022

incl. CERN site & SPS

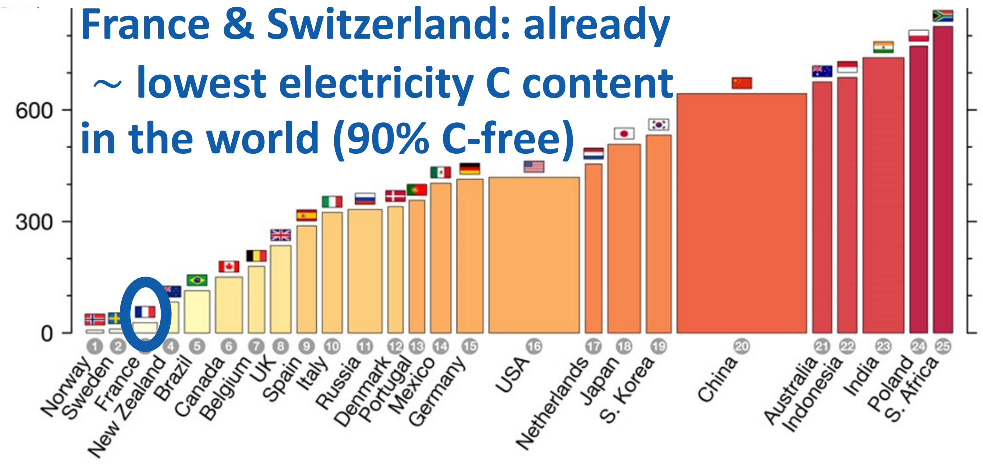
CERN Meyrin, SPS, FCC	Z	W	H	TT
Beam energy (GeV)	45.6	80	120	182.5
Energy consumption (TWh/y)	1.82	1.92	2.09	2.54

Powered by mix of renewable & other C-free sources



https://www.carbonbrief.org/

France & Switzerland: already ~ lowest electricity C content in the world (90% C-free)



FCC FS Council Documents, June 2021

FUTURE CIRCULAR COLLIDER

Organisational Structure of the FCC Feasibility Study

http://cds.cern.ch/record/2774006/files/English.pdf

CERN/SPC/1155/Rev.2
CERN/3566/Rev.2
Original: English
21 June 2021

ORGANISATION EUROPÉENNE POUR LA RECHERCHE NUCLÉAIRE
CERN EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

Action to be taken		*Voting Procedure*
For decision	**RESTRICTED COUNCIL** 203rd Session **17 June 2021**	Simple majority of Member States represented and voting

FUTURE CIRCULAR COLLIDER FEASIBILITY STUDY:

PROPOSED ORGANISATIONAL STRUCTURE

This document sets out the proposed organisational structure for the Feasibility Study of the Future Circular Collider, to be carried out in line with the recommendations of the European Strategy for Particle Physics updated by the CERN Council in June 2020. It reflects discussion at, and feedback received from, the Council in March 2021 and is now submitted for the latter's approval.

Main Deliverables and Timeline of the FCC Feasibility Study

http://cds.cern.ch/record/2774007/files/English.pdf

CERN/SPC/1161
CERN/3588
Original: English
21 June 2021

ORGANISATION EUROPÉENNE POUR LA RECHERCHE NUCLÉAIRE
CERN EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

Action to be taken		*Voting Procedure*
For information	**RESTRICTED COUNCIL** 203rd Session **17 June 2021**	-

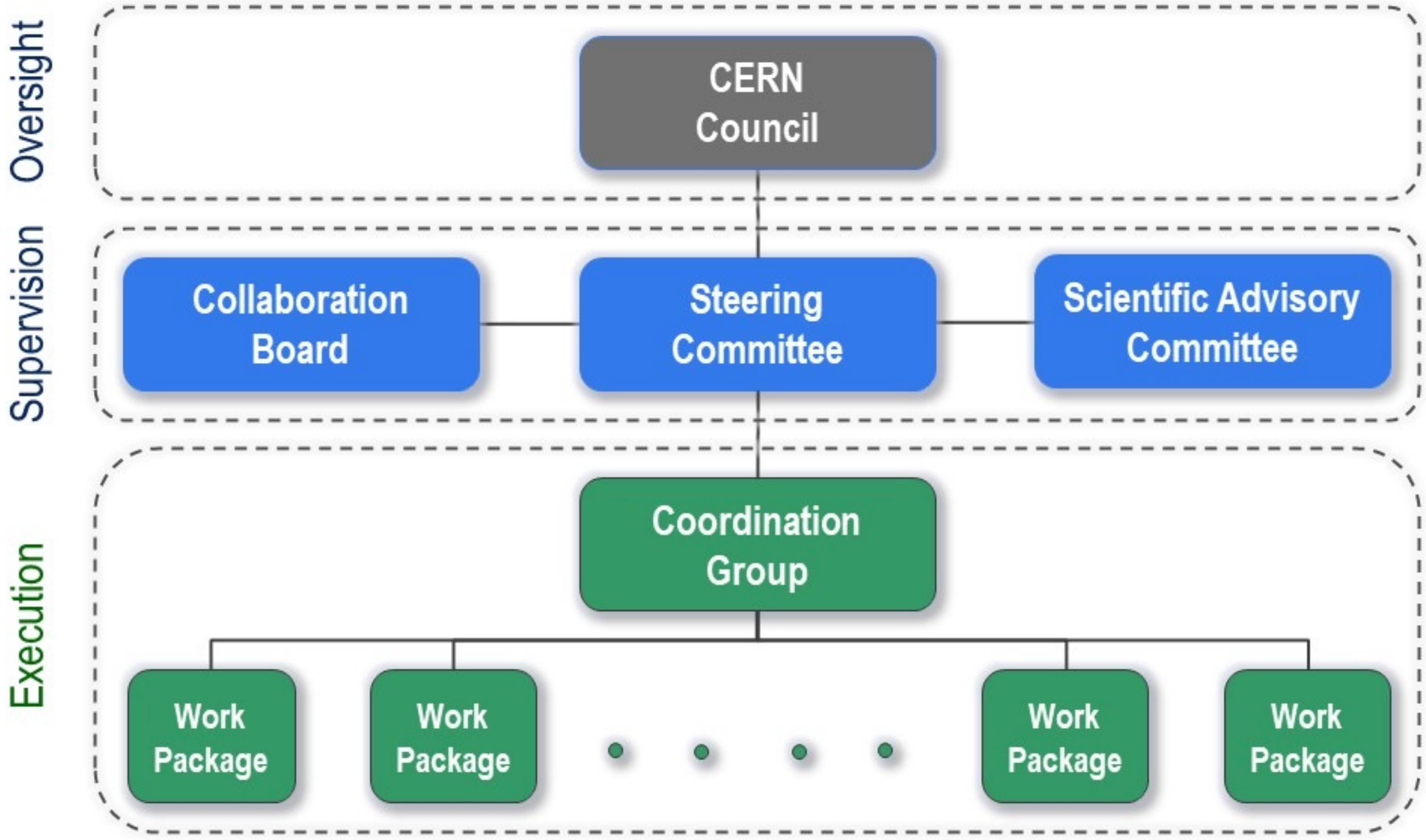
FUTURE CIRCULAR COLLIDER FEASIBILITY STUDY:

MAIN DELIVERABLES AND MILESTONES

This document describes the main deliverables and milestones of the study being carried out to assess the technical and financial feasibility of a Future Circular Collider at CERN. The results of this study will be summarised in a Feasibility Study Report to be completed by the end of 2025.

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.



FCC Feasibility Study

EU Projects
NN

Collaboration building
Emmanuel Tsesmelis

Communications
Panagiotis Charitos, James Gillies

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
- **Physics performance** — Patrizia Azzi, Emmanuel Perez
- **Software and computing** — Gerardo Ganis, Clément Helsens

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** — Alain Blondel, Jorg Wenninger
- **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

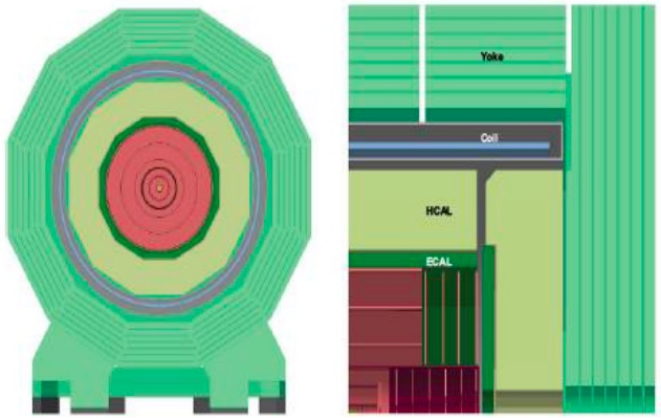
- **Administrative processes** — Friedemann Eder
- **Placement studies** — Johannes Gutleber, Volker Mertens
- **Environmental evaluation** — Johannes Gutleber
- **Tunnel, subsurface design** — John Osborne
- **Surface sites layout, access and building design** — LD opening

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

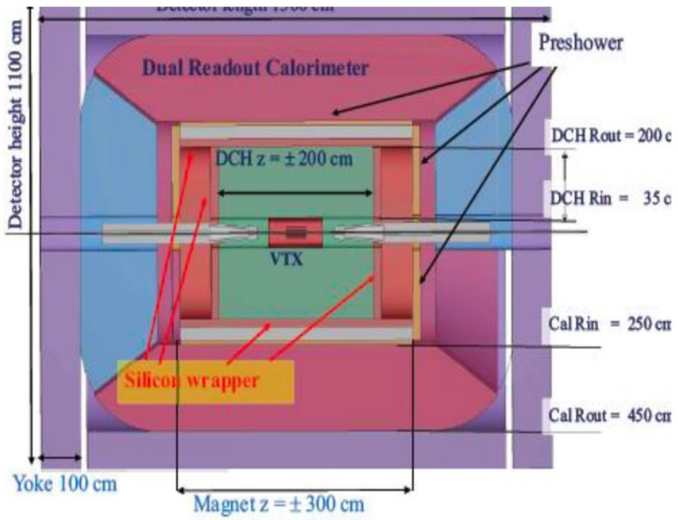
Detectors Under Study for FCC-ee

CLD



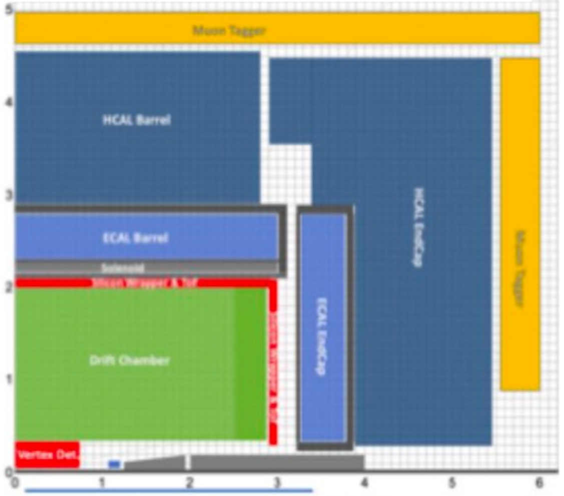
conceptually extended from the CLIC detector design
- full silicon tracker
- 2T magnetic field
- high granular silicon-tungsten ECAL
- high granular scintillator-steel HCAL
- instrumented steel-yoke with RPC for muon detection

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

Noble Liquid ECAL



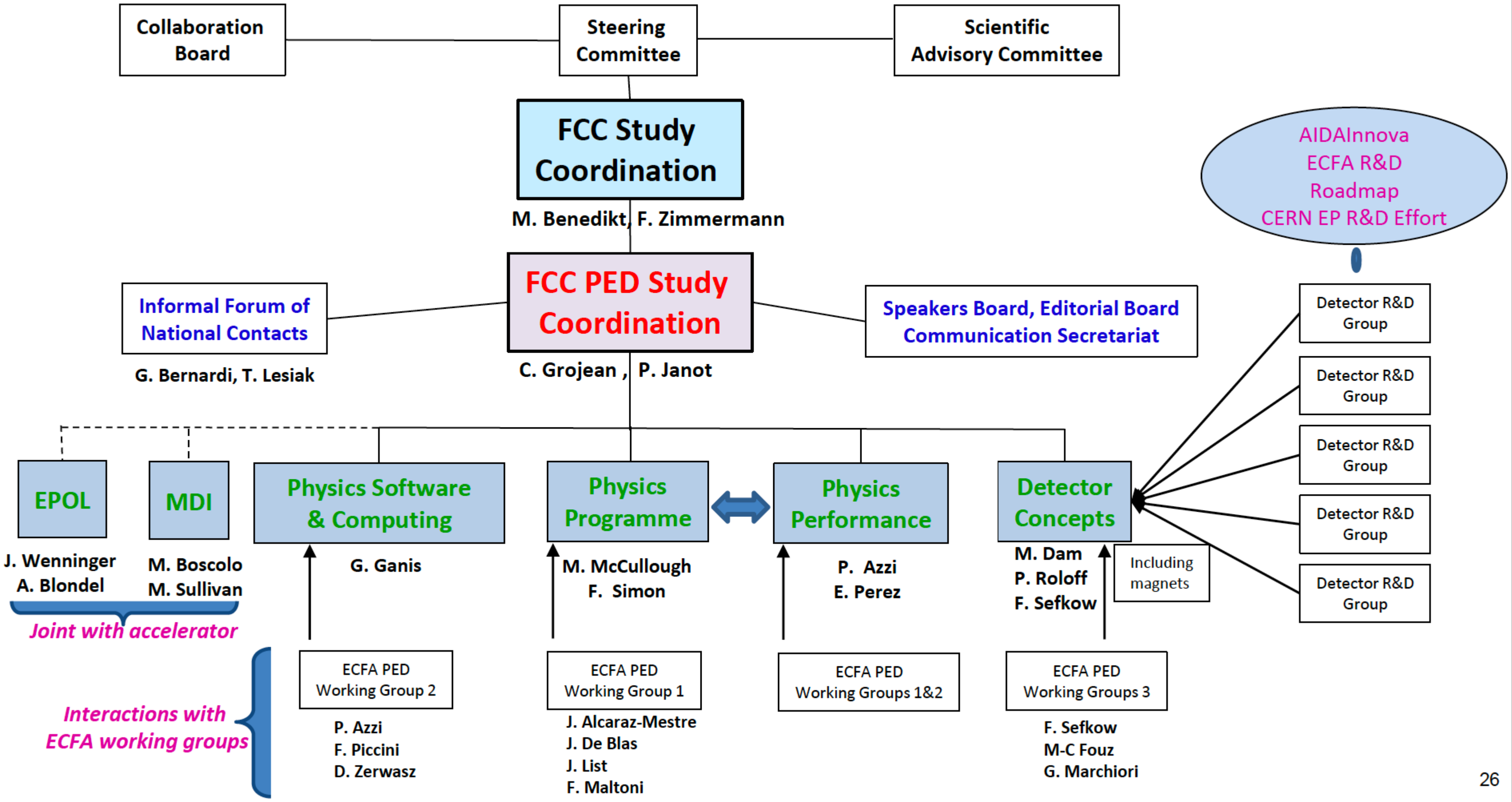
- explicitely designed for FCC-ee, recent concept, under development
- silicon vertex
- Low X_0 drift chamber
- Thin Solenoid before the Calorimeter
- High Granularity Liquid Argon Calorimetry

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

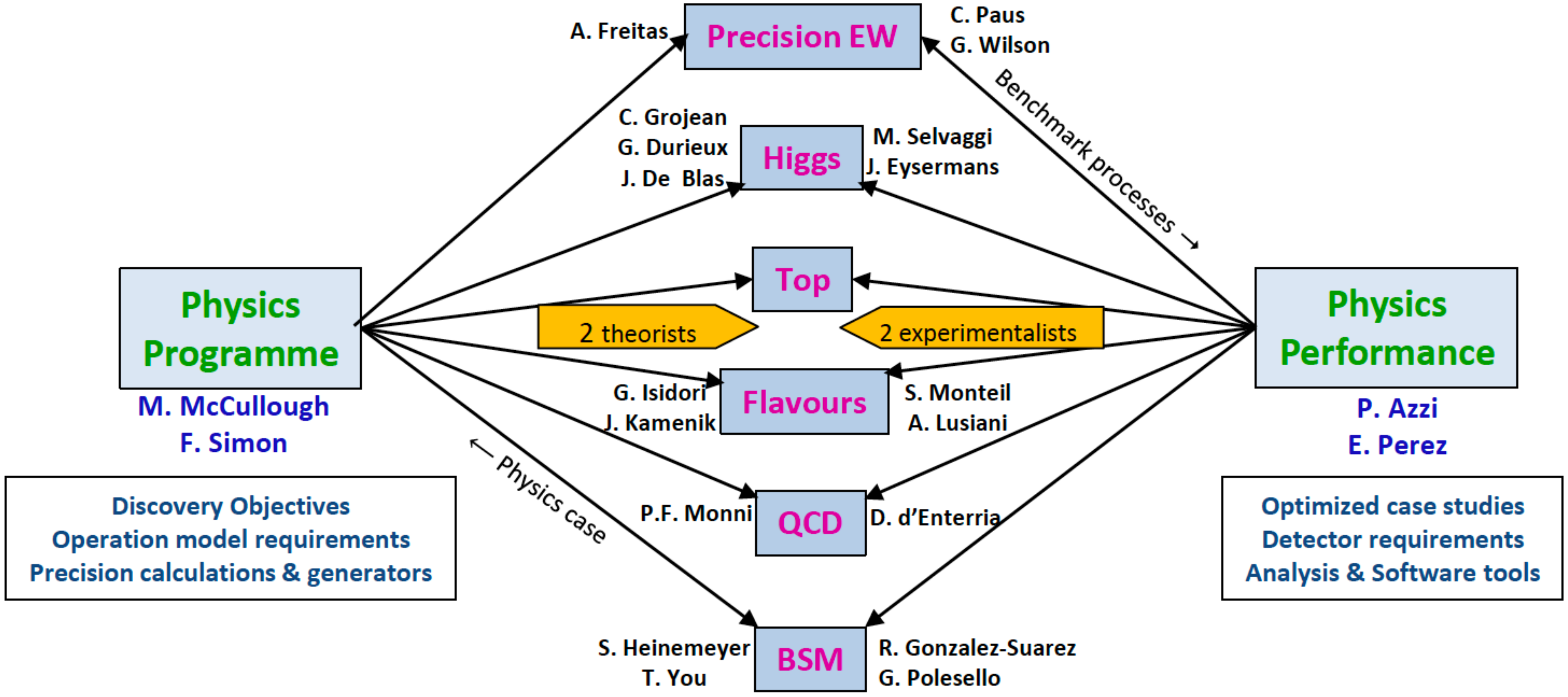
With potentially 4 experiments, many complementary options will be implemented, Definitely a place to contribute

PED Organisation and Convenors

PED = Physics, Experiments and Detectors



Joint Physics Groups



Timeline of the FCC Integrated Programme

FUTURE CIRCULAR COLLIDER

Technical schedule

1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | ………………… | 19 | 20 | FCC-ee ~ 15 years operation | 10 years | FCC-hh ~ 25 years operation | 70

- Feasibility Study
- ESPP
- Geological investigations, infrastructure detailed design and tendering preparation
- Tunnel, site and technical infrastructure construction
- FCC-ee dismantling, CE & infrastructure adaptations FCC-hh
- FCC-ee accelerator and detector R&D and technical design
- FCC-ee accelerator and detector construction, installation, commissioning
- Superconducting magnets R&D
- Long model magnets, prototypes, pre-series
- High-field magnet industrialization and series production
- FCC-hh accelerator and detector R&D and technical design
- FCC-hh accelerator and detector construction, installation, commissioning

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

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

F. Gianotti

FUTURE CIRCULAR COLLIDER

Feasibility Study Timeline

2021				2022				2023				2024				2025			
Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4

CDR baseline design adaptations for new implementation scenario

Status reports & study planning ,

FCC Week & Review : implementation, baseline design, organisation, communication

high-risk areas site investigations, territorial integration & environmental initial state studies with host states

FCCW followed by mid-term review: general coherency, cost update

detailed design towards FS report

FCC Week & Review: key technology R&D programs

FS Report

Release FSR
Project cost update

- **Total CERN funding for the Feasibility Study 2021 - 2025: 100 MCHF material & personnel**
- **H2020 FCCIS Design Study**
- **Swiss CHART programme**
- **FCC collaboration resources**

Mid-Term Review & Cost Review, Autumn '23

Mid-term review report, supported by additional documentation on each deliverable, will be submitted to review committees and to Council and its subordinate bodies, as input for the review.

Results of both general mid-term review and the cost review should indicate the main directions and areas of attention for the second part of the Feasibility Study

Infrastructure & placement

- Preferred placement and progress with host states (territorial matters, initial states, dialogue, etc.)
- Updated civil engineering design (layout, cost, excavation)
- Preparations for site investigations

Technical Infrastructure

- Requirements on large technical infrastructure systems
- System designs, layouts, resource needs, cost estimates

Accelerator design FCC-ee and FCC-hh

- FCC-ee overall layout with injector
- Impact of operation sequence: Z, W, ZH, $t\bar{t}$ vs start at ZH
- Comparison of the SPS as pre-booster with a 10-20 GeV linac
- Key technologies and status of technology R&D program
- FCC-hh overall layout & injection lines from LHC and SC-SPS

Physics, experiments, detectors:

- Documentation of FCC-ee and FCC-hh physics cases
- Plans for improved theoretical calculations to reduce theoretical uncertainties towards matching FCC-ee statistical precision for the most important measurements.
- First documentation of main detector requirements to fully exploit the FCC-ee physics opportunities

Organisation and financing:

- Overall cost estimate & spending profile for stage 1 project

Environmental impact, socio-economic impact:

- Initial state analysis, carbon footprint, management of excavated materials, etc.
- Socio-economic impact and sustainability studies

FCC Stage 1: Infrastructure and FCC-ee Project Cost Estimate and Spending Profile

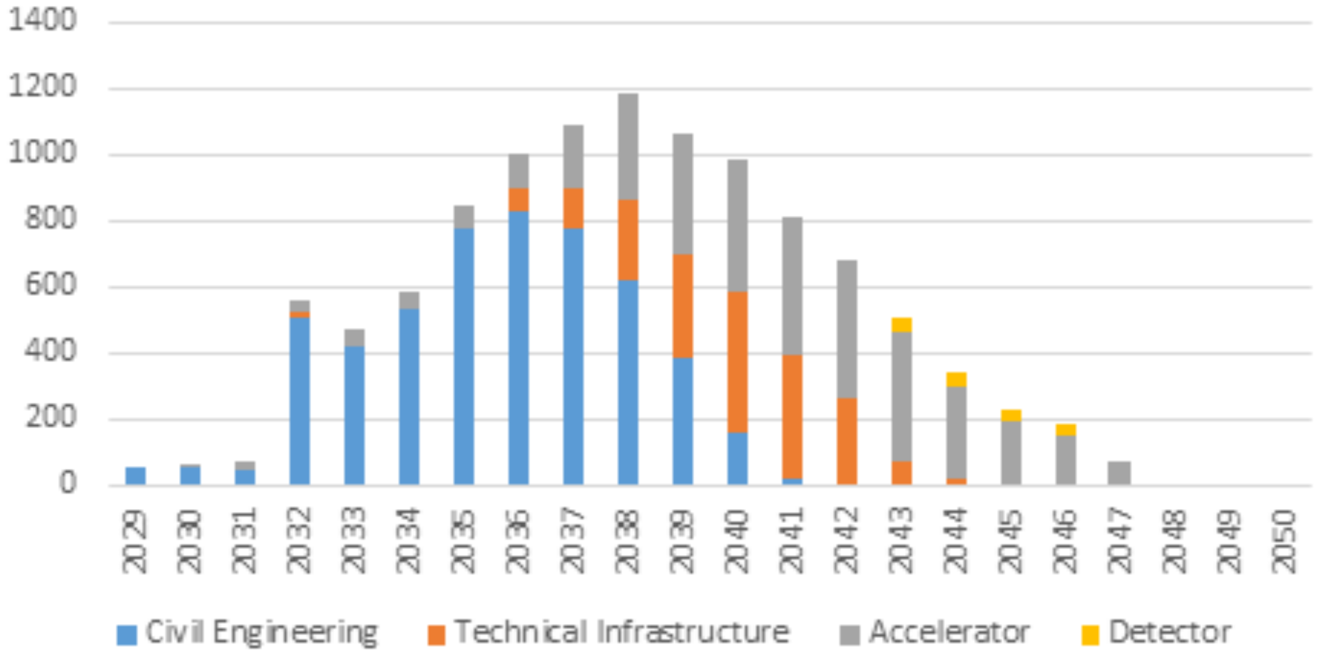
Construction cost estimate for FCC-ee

- Machine configurations for Z, W, H working points included
- Baseline configuration with 2 detectors
- CERN contribution to 2 experiments incl.

cost category	[MCHF]	%
civil engineering	5.400	50
technical infrastructure	2.000	18
accelerator	3.300	30
detector	200	2
total cost (2018 prices)	10.900	100

Spending profile for FCC-ee

- CE construction 2032 - 2040
- Technical infrastructure 2037 - 2043
- Accelerator and experiment 2032 – 2045
- Commissioning and operation start 2045 -2048.



Status of Global FCC Collaboration

Increasing international collaboration as a prerequisite for success:

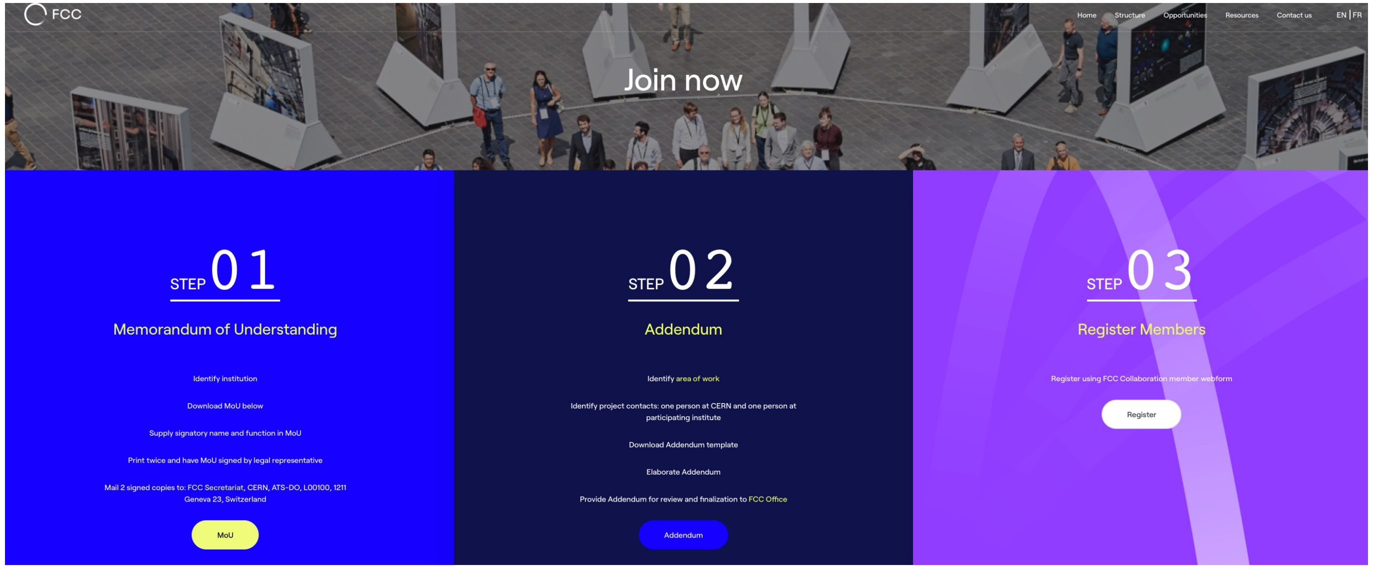
links with science, research & development and **high-tech industry** will be essential to further advance and prepare the implementation of FCC

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

FCC Week 2022, Sorbonne, Paris, 30 May – 3 June 2022

483 participants

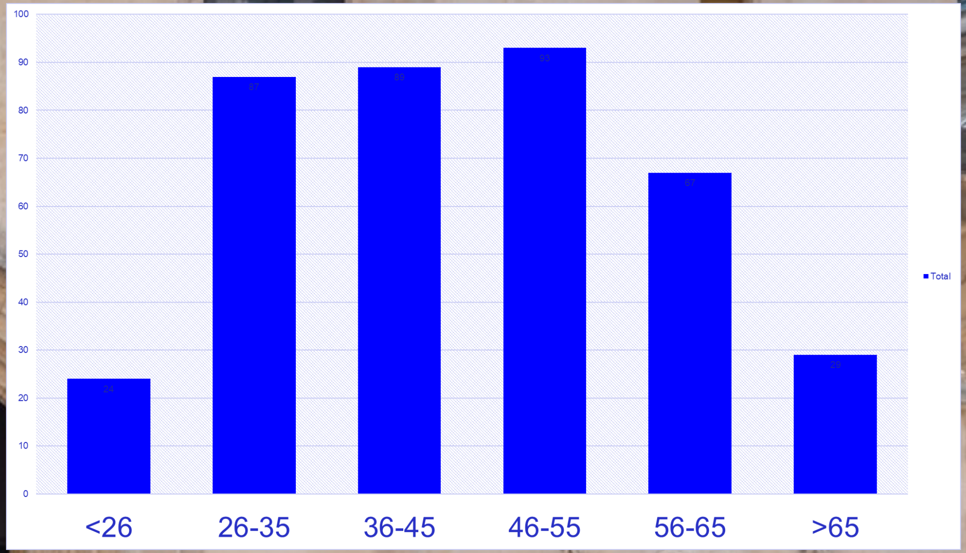
269 in person and 214 remote

45 sessions,

202 presentations,

+ 20 posters

Distribution of participants by age group




FCC WEEK
2023
5 – 9 June
STAY TUNED

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