Future Circular Colliders (FCC) – Status

Future Colliders Seminar Series, 14 March 2023

Frank Zimmermann, CERN

on behalf of the FCC collaboration and FCCIS DS team,
particular thanks to Michael Benedikt, Alain Blondel, Patrick Janot, Katsunobu Oide, Pantaleo Raimondi, Tor Raubenheimer, Dmitry Shatilov

FCC hh ee he | EuroCirCol A key to New Physics | EASITrain | iFAST | FUTURE CIRCULAR COLLIDER Innovation Study | 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

Recommendations of the 2020 update of the European Strategy for Particle Physics (ESPP):

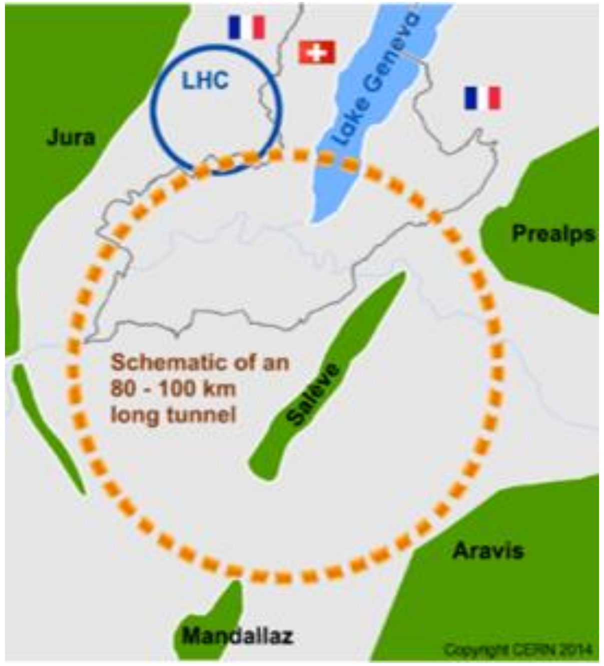
- Full exploitation of the high-luminosity LHC upgrade
- An **electron-positron Higgs factory is the highest-priority next collider**. For the longer term, the European particle physics community has the ambition to operate a **proton-proton collider at the highest achievable energy.**
- Europe, together 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.**

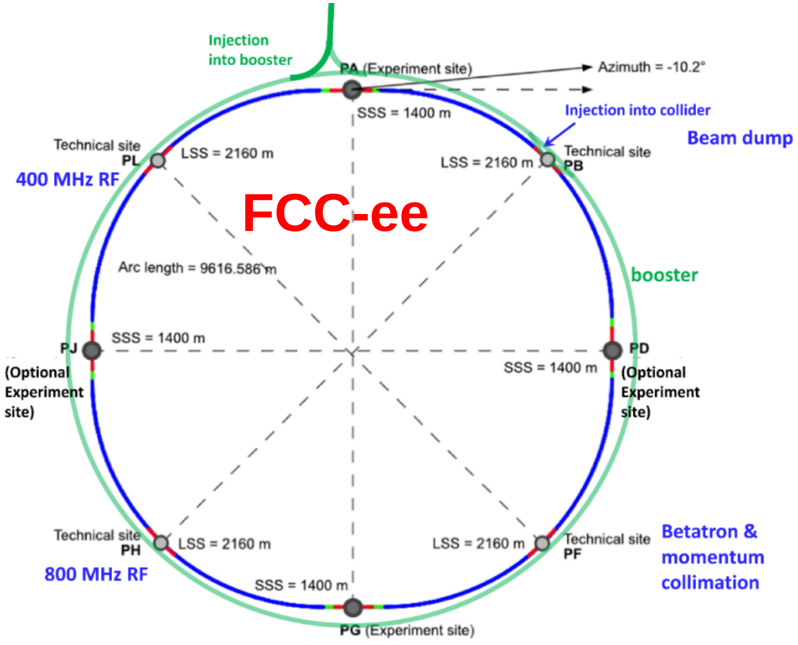
- **FCC Feasibility Study is one of the main recommendations of the 2020 update of the European Strategy for Particle Physics**

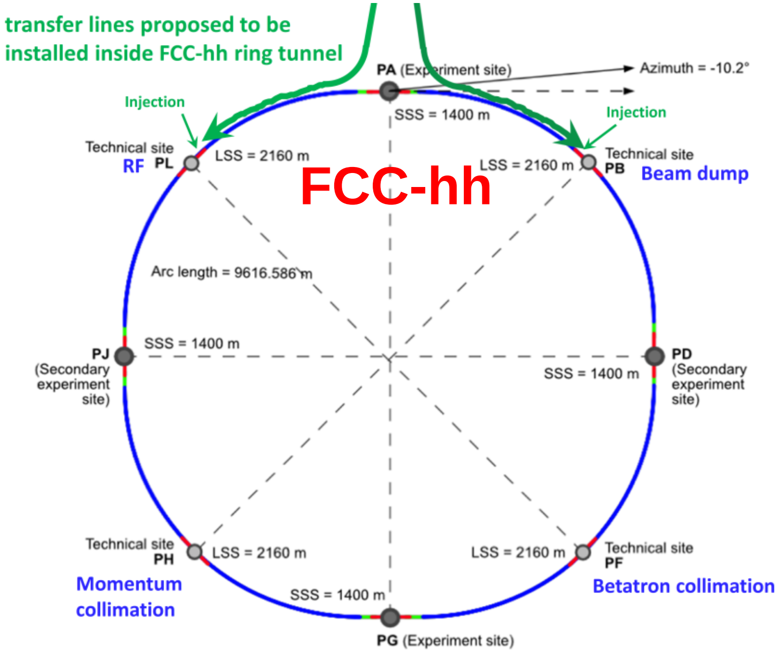
FCC integrated program
inspired by successful LEP – LHC programs at CERN

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, 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 program

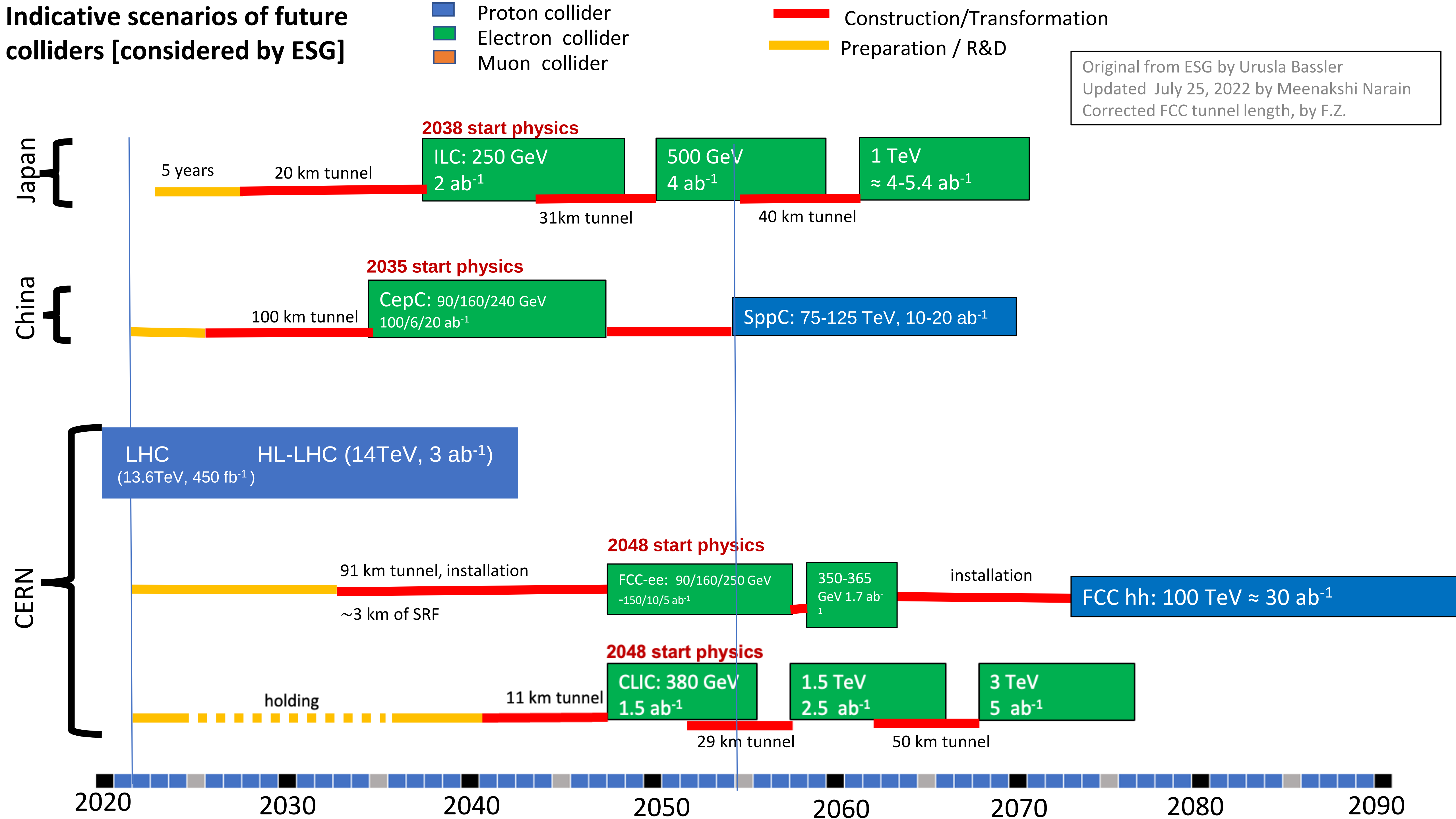






2020 - 2040 | **2045 - 2060** | **2065 - 2090**

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



Indicative scenarios of future colliders [considered by ESG]
Proton collider
Electron collider
Muon collider
Construction/Transformation
Preparation / R&D
Original from ESG by Urusla Bassler
Updated July 25, 2022 by Meenakshi Narain
Corrected FCC tunnel length, by F.Z.
Japan
2038 start physics
5 years
20 km tunnel
ILC: 250 GeV
2 ab-1
31km tunnel
500 GeV
4 ab-1
40 km tunnel
1 TeV
≈ 4-5.4 ab-1
China
2035 start physics
100 km tunnel
CepC: 90/160/240 GeV
100/6/20 ab-1
SppC: 75-125 TeV, 10-20 ab-1
CERN
LHC
(13.6TeV, 450 fb-1)
HL-LHC (14TeV, 3 ab-1)
2048 start physics
91 km tunnel, installation
~3 km of SRF
FCC-ee: 90/160/250 GeV
-150/10/5 ab-1
350-365
GeV 1.7 ab-1
installation
FCC hh: 100 TeV ≈ 30 ab-1
2048 start physics
holding
11 km tunnel
CLIC: 380 GeV
1.5 ab-1
29 km tunnel
1.5 TeV
2.5 ab-1
50 km tunnel
3 TeV
5 ab-1
2020
2030
2040
2050
2060
2070
2080
2090

2018 cost estimate for stage 1: infrastructure and FCC-ee

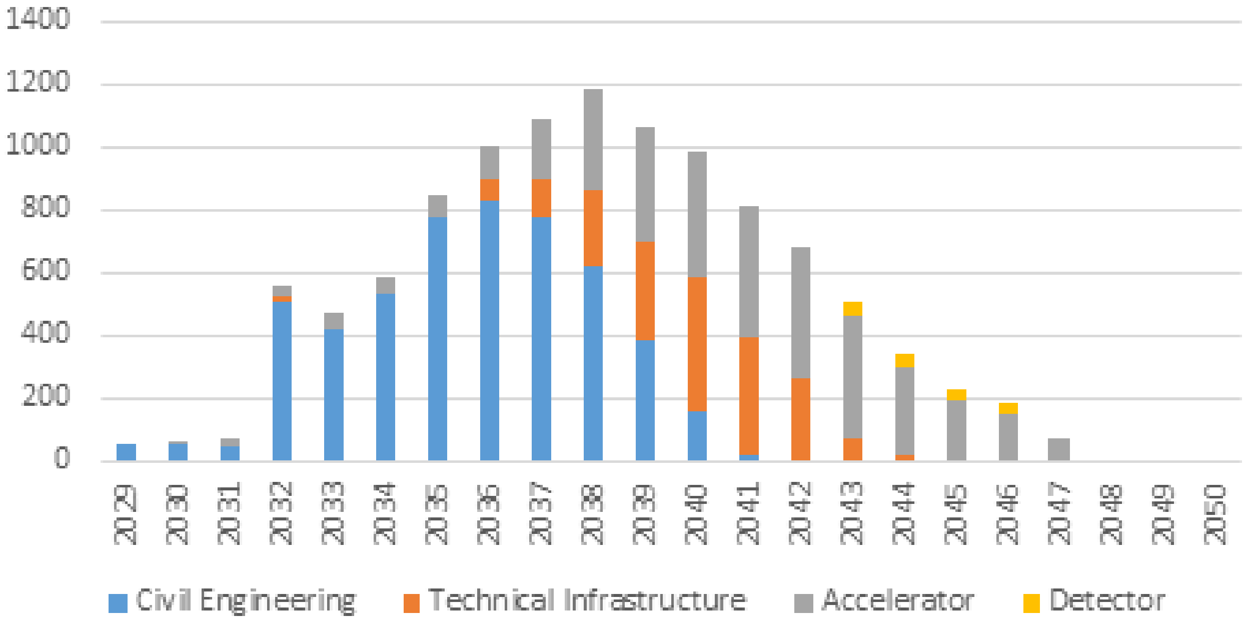
Construction cost estimate for FCC-ee

- 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



Stage 1: FCC-ee – highest luminosity lepton collider

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

2 or 4 interaction points

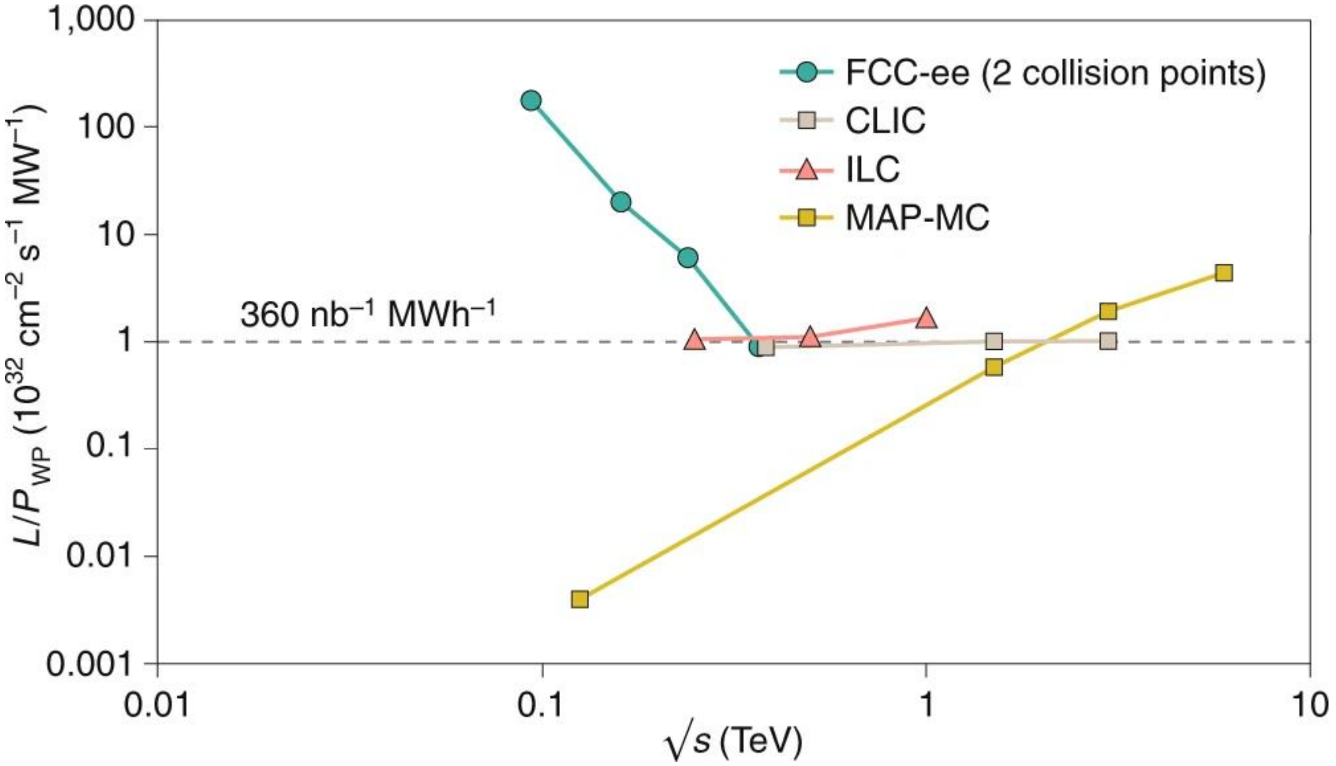
efficient $\mathcal{L}$ from Z to $t\bar{t}$

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)

a case for four IPs & experiments

Four different FCC-ee detectors to optimally address:

(1) Higgs factory program; (2) Ultraprecise electroweak & QCD physics; (3) Heavy Flavour physics; (4) Search for feebly coupled particles

For FCC-hh, two high-luminosity general-purpose experiments and two specialized experiments are foreseen, similar to present LHC detectors

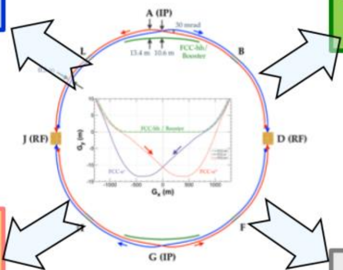
FCC-ee & hh would share the 4 experimental caverns

M. Dam, ECFA Det. R&D Roadmap, 2021, https://indico.cern.ch/event/994685/

Detector Requirements in Brief

"Higgs Factory" Programme
- Momentum resolution of $\sigma_{p_T}/p_T^2 \simeq 2 \times 10^{-5}\,\text{GeV}^{-1}$ commensurate with $\mathcal{O}(10^{-3})$ beam energy spread
- Jet energy resolution of 30%/√E in multi-jet environment for Z/W separation
- Superior impact parameter resolution for c, b tagging

Ultra Precise EW Programme
- Absolute normalisation (luminosity) to 10^{-4}
- Relative normalisation (e.g. $\Gamma_{had}/\Gamma_{\ell}$) to 10^{-5}
- Momentum resolution "as good as we can get it"
  - Multiple scattering limited
- Track angular resolution < 0.1 mrad (BES from μμ)
- Stability of B-field to 10^{-6} : stability of √s meast.



Heavy Flavour Programme
- Superior impact parameter resolution: secondary vertices, tagging, identification, life-time measts.
- ECAL resolution at the few %/ √E level for inv. mass of final states with π^0s or γs
- Excellent π^0/γ separation and measurement for tau physics
- PID: K/π separation over wide momentum range for b and τ physics

Feebly Coupled Particles - LLPs

Benchmark signature: Z → νN, with N decaying late
- Sensitivity to far detached vertices (mm → m)
  - Tracking: more layers, continous tracking
  - Calorimetry: granularity, tracking capability
- Large decay lengths ⇒ extended detector volume
- Hermeticity

FCC-ee accelerator R&D examples

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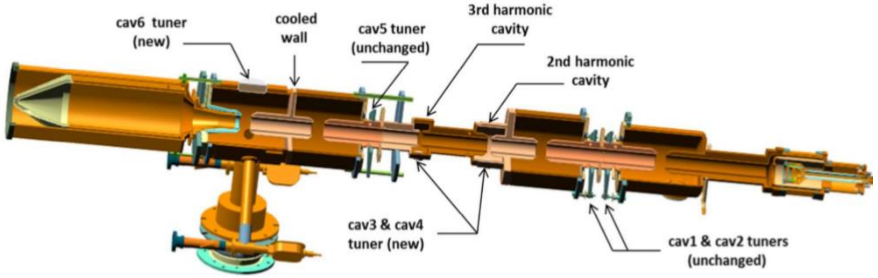
efficient RF power sources (400 & 800 MHz)

I. Syratchev



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

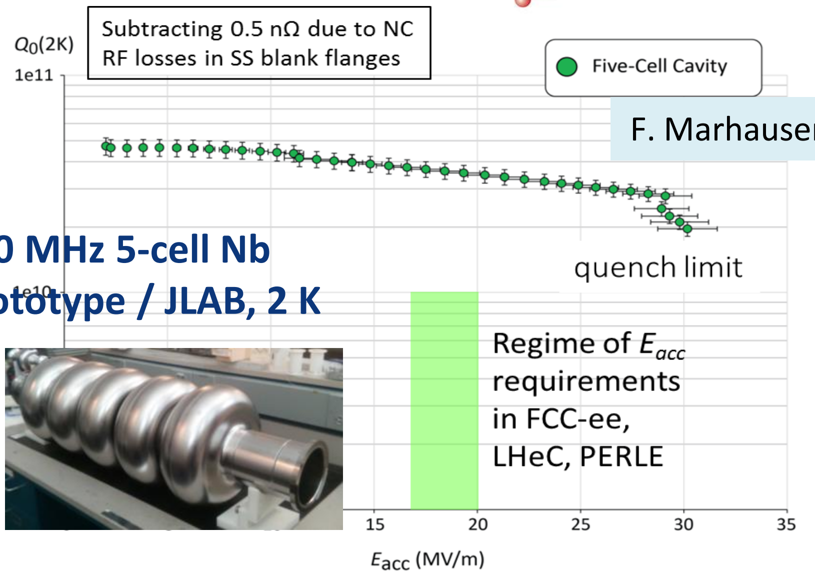
efficient SC cavities

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

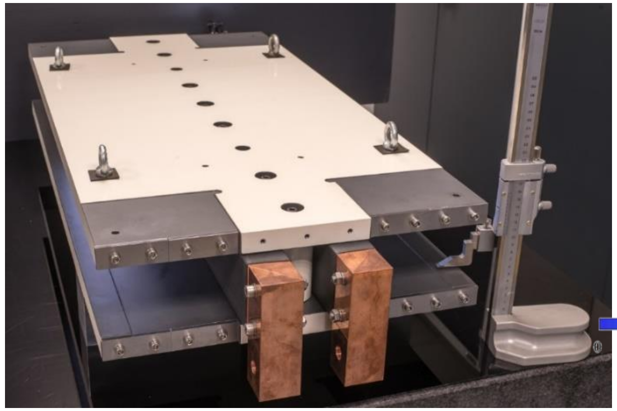
Jefferson Lab

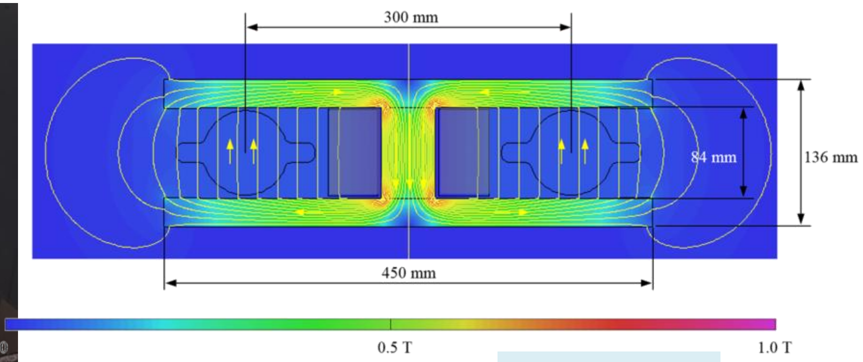
800 MHz 5-cell Nb prototype / JLAB, 2 K

F. Marhauser



energy **efficient** twin aperture **arc dipoles**

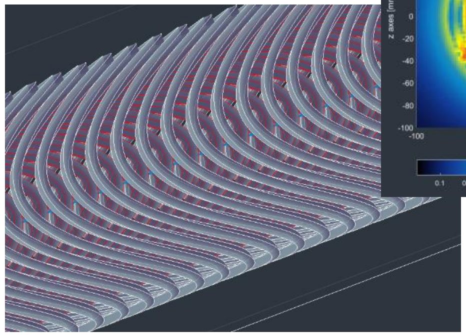


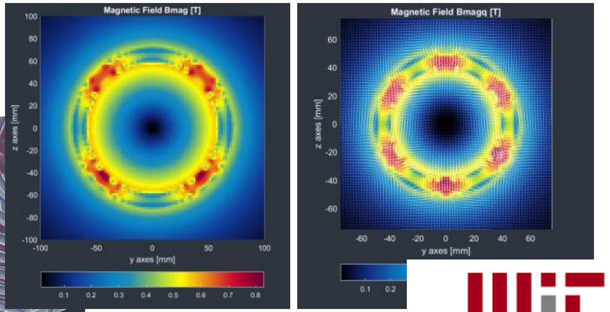


A. Milanese

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

PAUL SCHERRER INSTITUT PSI





M. Koratzinos

Massachusetts Institute of Technology

FUTURE CIRCULAR COLLIDER

Recently updated

FCC-ee RF parameter table

Number of 800 MHz cavities: 1088
Total number of cavities: 1460

F. Peauger

	Bare cavity in vertical test stand		Jacketed cav w HOM in vert test		Cryomodule (with FPC) in hor. test		Operation in the machine	
	Eacc (MV/m)	Q0	Eacc (MV/m)	Q0	Eacc (MV/m)	Q0	Eacc (MV/m)	Q0
1-cell 400 MHz	6.9	3.3E+09	6.6	3.15E+09	6.3	3.0E+09	5.7	2.7E+09
2-cell 400 MHz	13.2	3.3E+09	12.6	3.15E+09	12	3.0E+09	10.8	2.7E+09
5-cell 800 MHz	24.5	3.8E+10	23.3	3.64E+10	22.2	3.5E+10	20.0	3.0E+10

15-Feb-23	Z		W		H		ttbar2		
	per beam	booster	per beam	booster	2 beams	booster	2 beams	2 beams	booster
RF Frequency [MHz]	400	800	400	800	400	800	400	800	800
RF voltage [MV]	120	140	1050	1050	2100	2100	2100	9200	11300
Eacc [MV/m]	5.72	5.34	10.95	20.01	10.78	20.01	10.78	20.12	20.10
# cell / cav	1	5	2	5	2	5	2	5	5
Vcavity [MV]	2.14	5.00	8.20	18.75	8.08	18.75	8.08	18.85	18.83
#cells	56	140	256	280	520	560	520	2440	3000
# cavities	56	28	128	56	260	112	260	488	600
# CM	14	7	32	14	65	28	65	122	150
T operation [K]	4.5	2	4.5	2	4.5	2	4.5	2	2
dyn losses/cav [W]	22	0.2	163	3	158	3	158	23	3
stat losses/cav [W]	8	8	8	8	8	8	8	8	8
Qext	6.6E+04	2.7E+05	1.1E+06	7.7E+06	1.1E+06	1.5E+07	9.4E+06	3.8E+06	8.3E+07
Detuning [kHz]	8.939	5.126	0.412	0.141	0.096	0.014	0.031	0.032	0.003
rhob [m]	9937	9937	9937	9937	9937	9937	9937	9937	9937
Energy [GeV]	45.6	45.6	80.0	80.0	120.0	120.0	182.5		182.5
energy loss [MV]	38.49	38.49	364.63	364.63	1845.94	1845.94	9875.14		9875.14
cos phi	0.32	0.27	0.35	0.35	0.88	0.88	0.56	0.96	0.87
Beam current [A]	1.280	0.128	0.135	0.0135	0.0534	0.003	0.010	0.010	0.0005

RF source type	400 MHz - 1 MW klystron	800 MHz - 400 kW klystron	400 MHz - 1 MW klystron	800 MHz - 400 kW klystron	400 MHz - 1 MW klystron	800 MHz - 50 kW SSA	400 MHz - 50 kW SSA	800 MHz - 400 kW klystron	800 MHz - 50 kW SSA
Frequency [MHz]	400	800	400	800	400	800	400	800	800
Pcav [kW]	880	176	385	88	379	44	45	181	8
Prf conditioning [kW]	220	44	96	22	95	11	11	45	2
# cavities / RF sources	1	2	2	4	2	1	1	2	4
# RF sources	112	14	128	14	130	112	260	244	150

detailed specification, close to state of the art

FCC-ee mock-ups for arcs and IR

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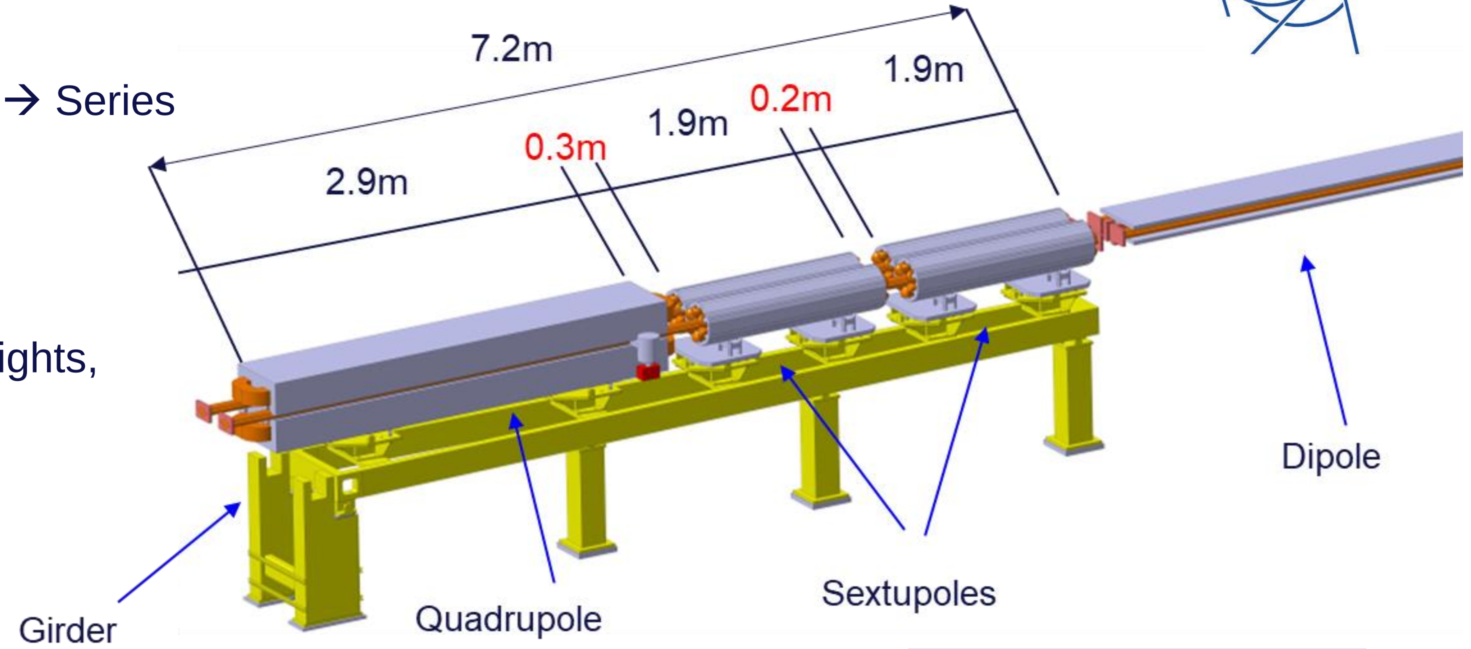
F. Carra et

Arc half-cell mock-up

- **Arc half-cell**: most recurrent assembly of mechanical hardware in the accelerator (~1500 similar FODO)
- **Mock-up** → Functional prototype(s) → Pre-series → Series
- Building a mock-up allows optimizing and testing **fabrication, integration, installation, assembly, transport, maintenance**
- Working with structures of equivalent volumes, weights, stiffness

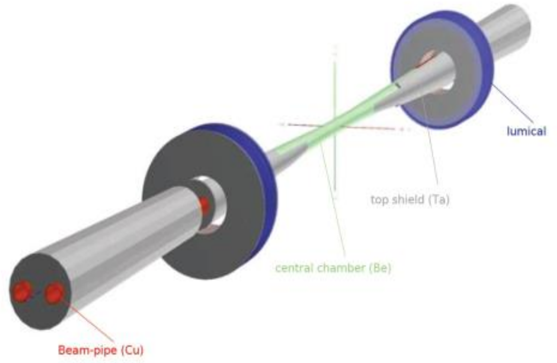


IR mock-up

Step 1: Central IP vacuum chamber (test the cooling system and the vacuum system), **AlBeMet162 & steel transition** (study the shape of the transition, EBW process), **Bellows** (vacuum and thermal tests), **Welding** (EBW for elliptical geometry)

Step 2: Trapezoidal vacuum chamber with remote vacuum connection, **first quadrupole QC1, cryostat,** beam pipe and quadrupole and **cryostat support**, **vibration & alignment sensors**

M. Boscolo et al.



SLAC NATIONAL ACCELERATOR LABORATORY

INFN LNF Istituto Nazionale di Fisica Nucleare

LAPP Laboratoire d'Annecy de Physique des Particules

FCC-ee collider optics development: 2 options

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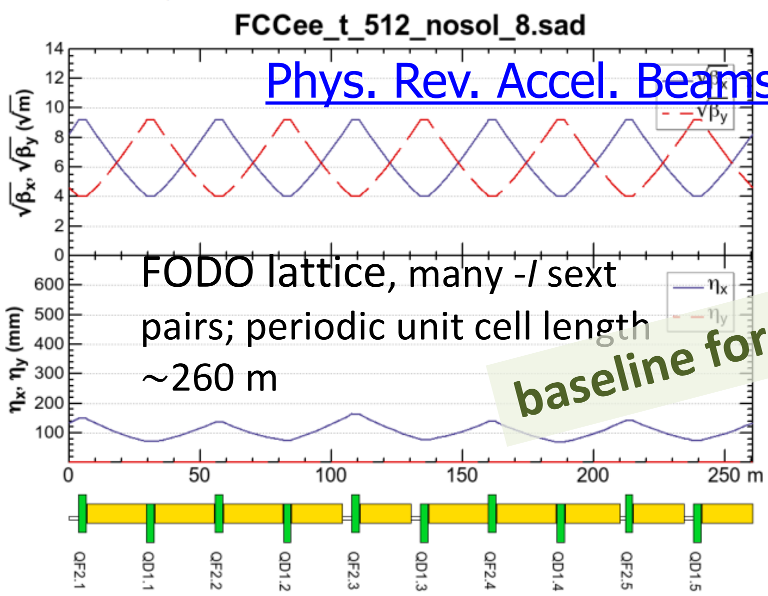
Short 90/90: $t\bar{t}$, Zh

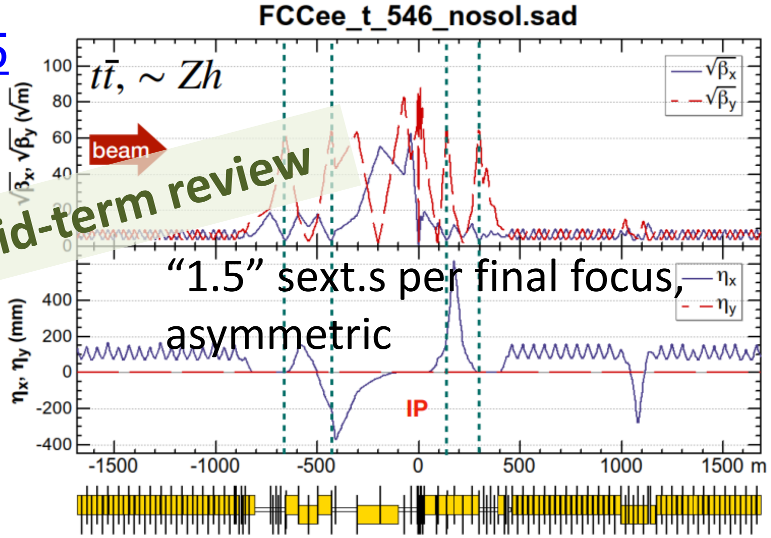
arc



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

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

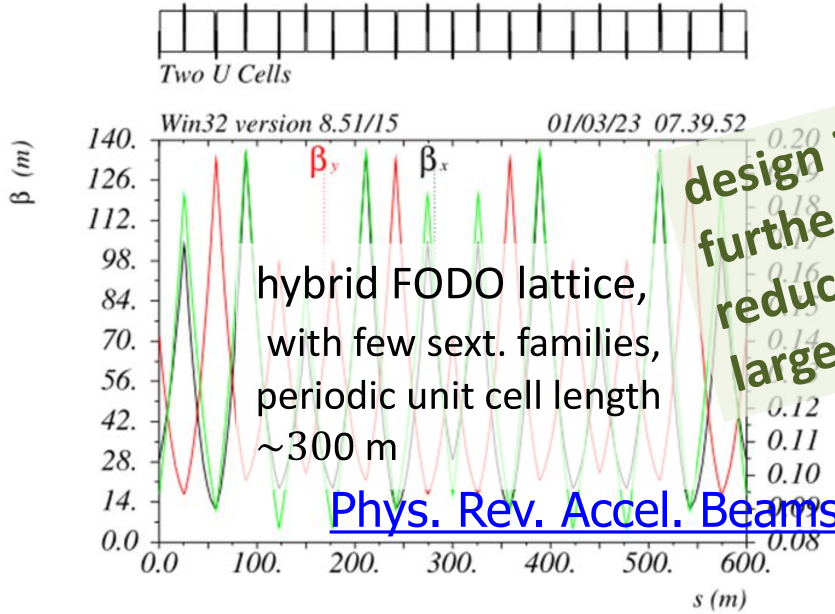
interaction region



"1.5" sext.s per final focus, asymmetric

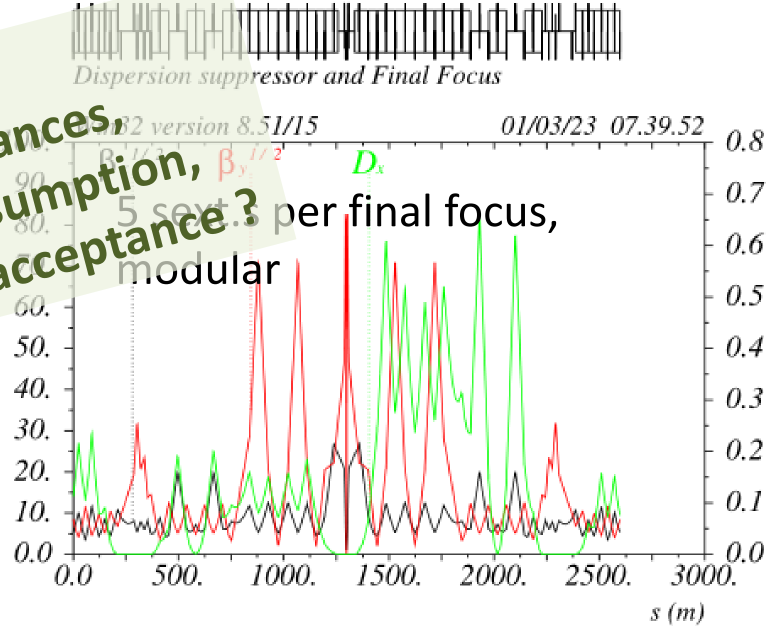
baseline for 2023 FCC mid-term review

K. Oide, 2023 EPS Rolf Wideroe award winner



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

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



5 sext.s per final focus, modular

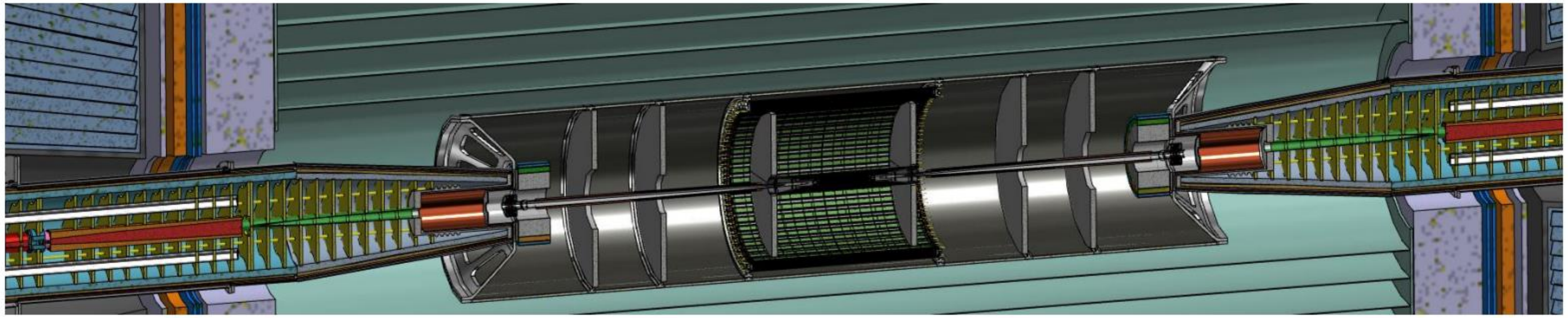
design in progress - further relaxed tolerances, reduced power consumption, larger momentum acceptance?

P. Raimondi, 2017 EPS Gersh Budker award winner

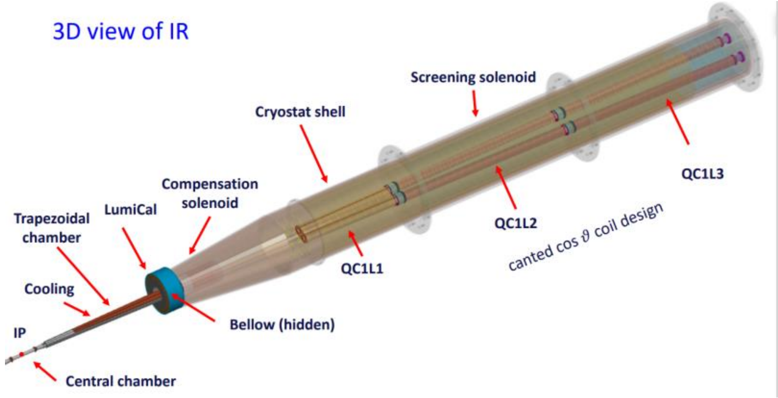
FCC-ee MDI developments - examples

Novel outer support tube for central beam pipe and vertex detector

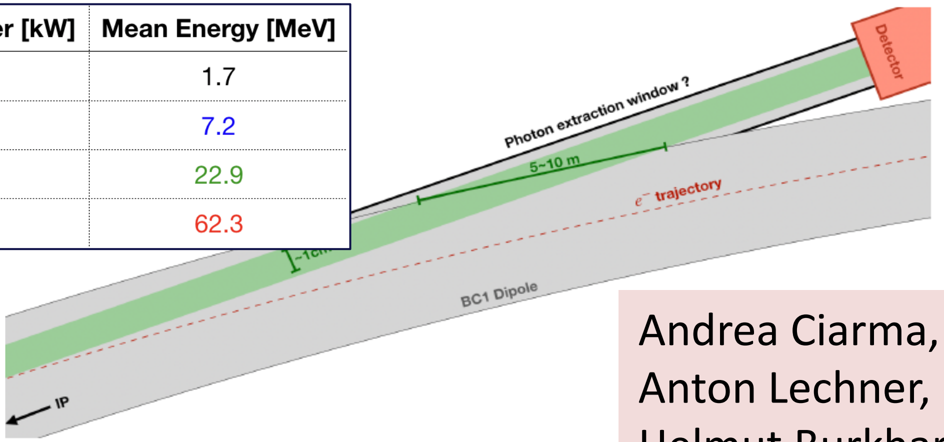
Manuela Boscolo, Fabrizio Palla, Filippo Bosi



- Inside the same volume of the support tube that holds also the LumiCal
  - Vertex detector supported by the beam pipe
  - Outer Tracker (1 barrel and 6 disks) fixed to the support tube



	Total Power [kW]	Mean Energy [MeV]
Z	370	1.7
WW	236	7.2
ZH	147	22.9
Top	77	62.3

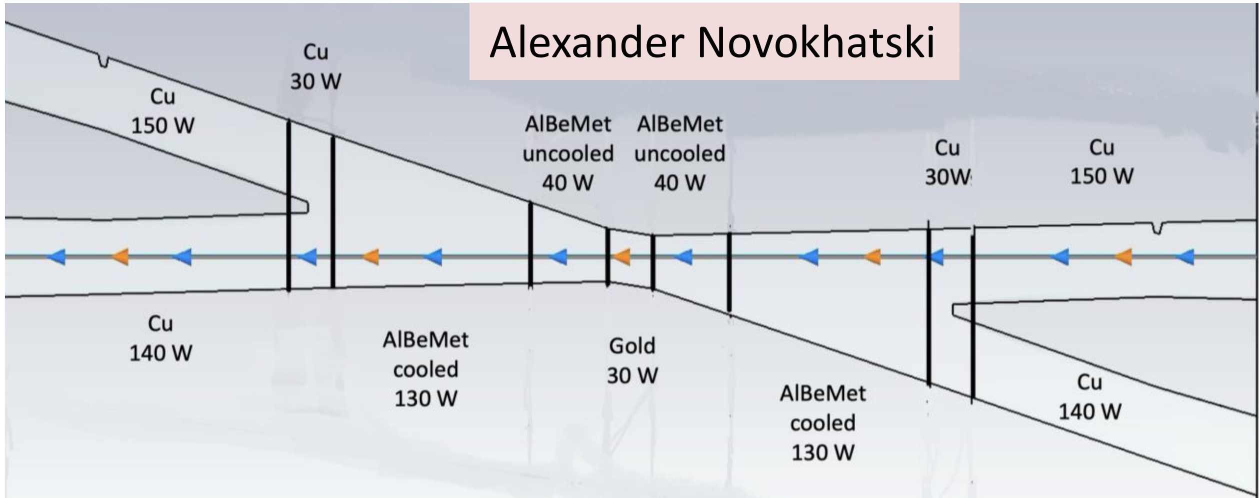


Beamstrahlung dump

Andrea Ciarma, Anton Lechner, Helmut Burkhardt, Manuela Boscolo

IR heat load distribution

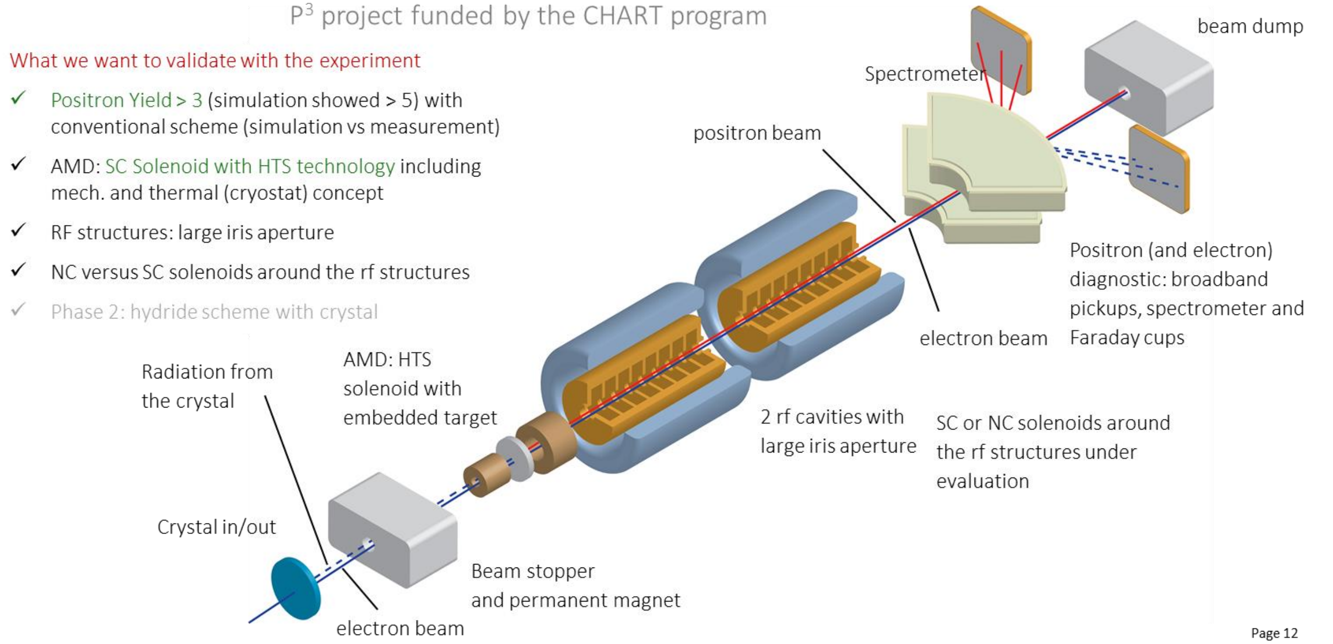
Alexander Novokhatski



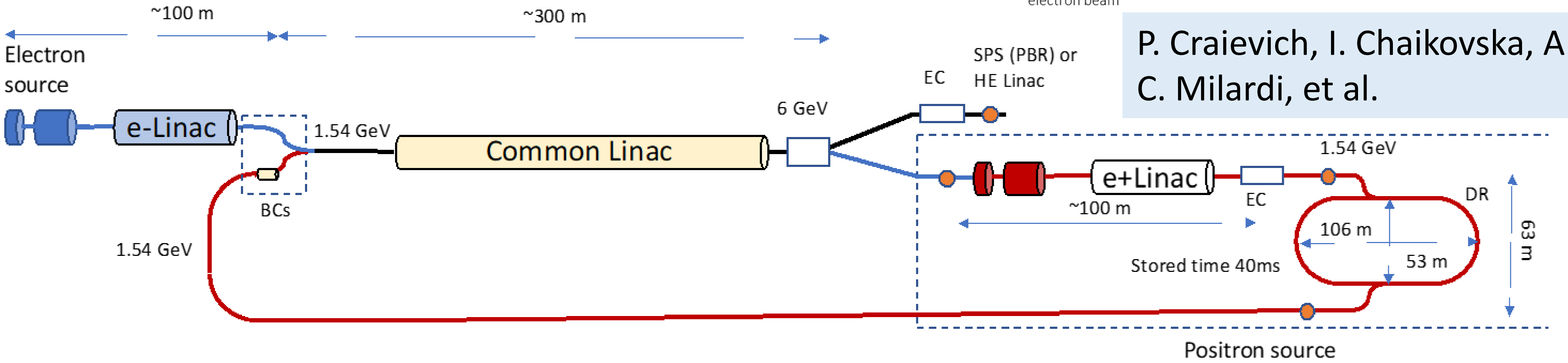
FCC-ee Injector Design – PSI, INFN, IJCLab, CEA, CERN

CHART collaboration PSI & CERN with partners CNRS-IJCLab (Orsay), INFN-LNF (Frascati), KEK/SuperKEKB as observer, INFN-Ferrara – radiation from crystal, CEA (FCCIS – booster design)

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

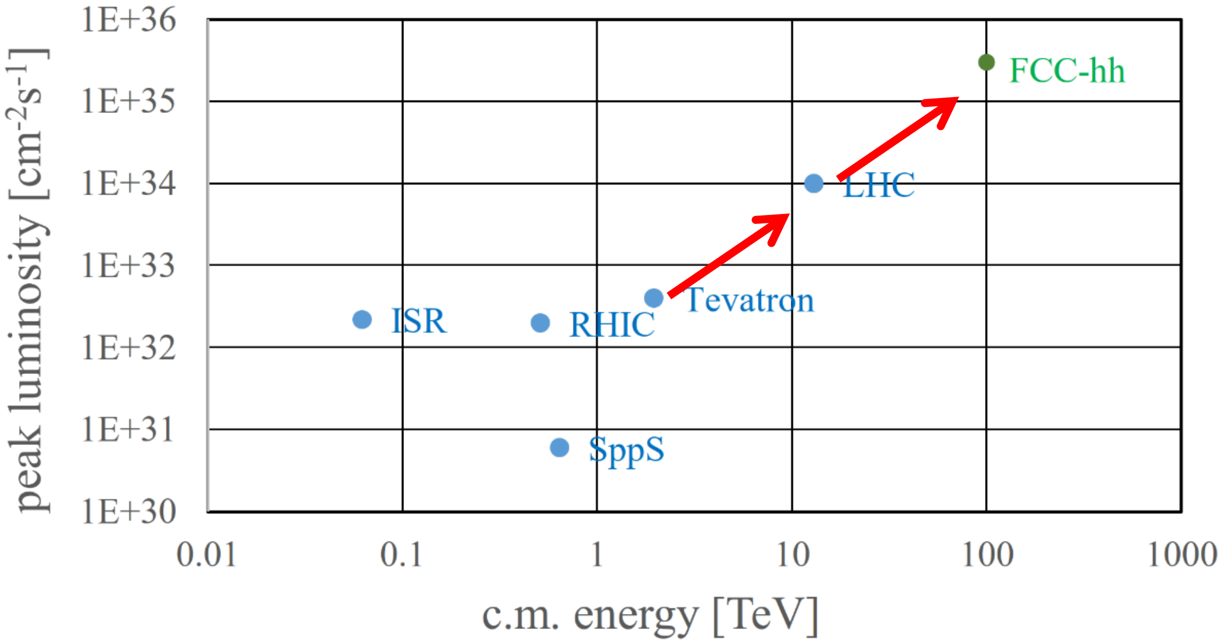


FCC-ee pre-injector layout



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

Stage 2: FCC-hh: highest collision energies



~order of magnitude performance increase in both energy & luminosity wrt LHC

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

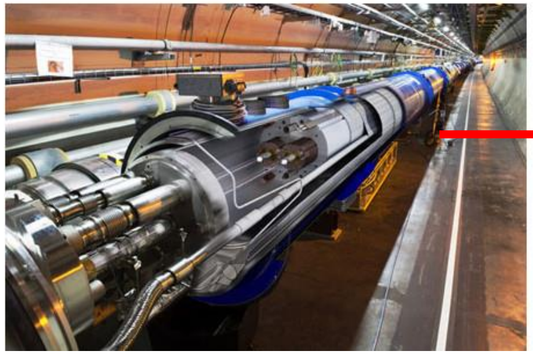
20 ab^{-1} per experiment over 25 years of operation (vs 3 ab^{-1} for LHC)

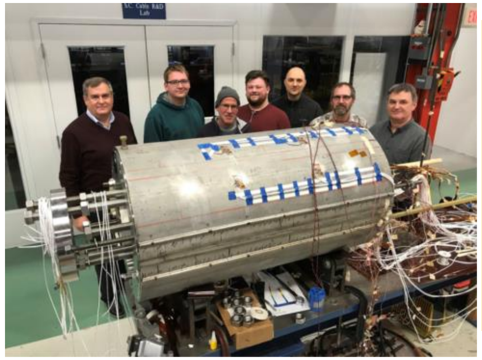
similar performance increase as from Tevatron to LHC

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

HFM: preparing for FCC stage 2 (FCC-hh)

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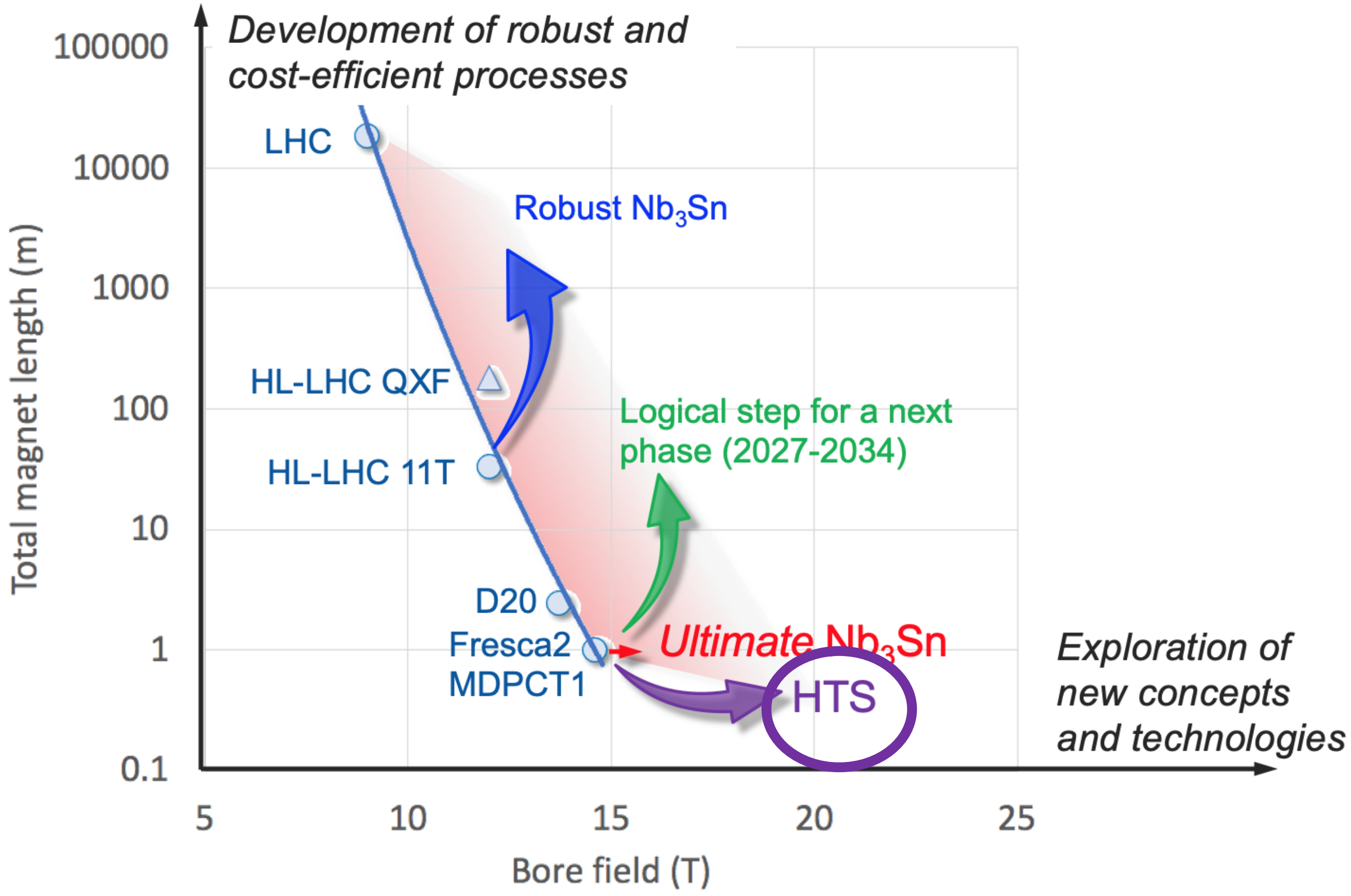
In parallel to FCC studies,
High Field Magnet development program as long-term separate R&D project



CERN budget for high-field magnets doubled in 2020 Medium-Term Plan (~ 200 MCHF over ten years)

Main R&D activities:

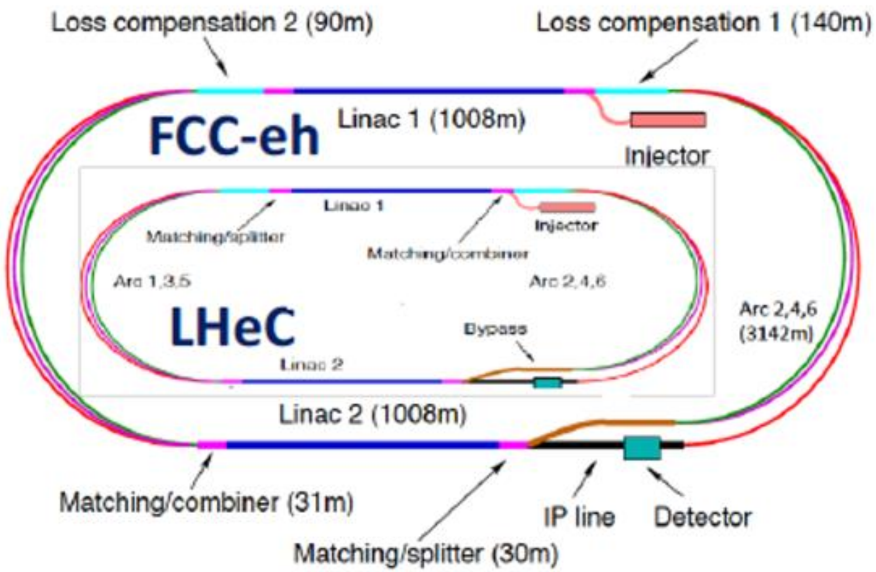
- ❑ materials: goal is ~16 T for Nb_3Sn, at least ~20 T for HTS inserts
- ❑ magnet technology: engineering, mechanical robustness, insulating materials, field quality
- ❑ production of models and prototypes: to demonstrate material, design and engineering choices,
  industrialisation and costs
- ❑ infrastructure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

Detailed deliverables and timescale being defined through Accelerator R&D roadmap under development

L. Bottura, F. Gianotti, A. Siemko

"stage 2b or stage 3" (FCC-eh, ERL-based)

LHeC and FCC-eh: twin machines



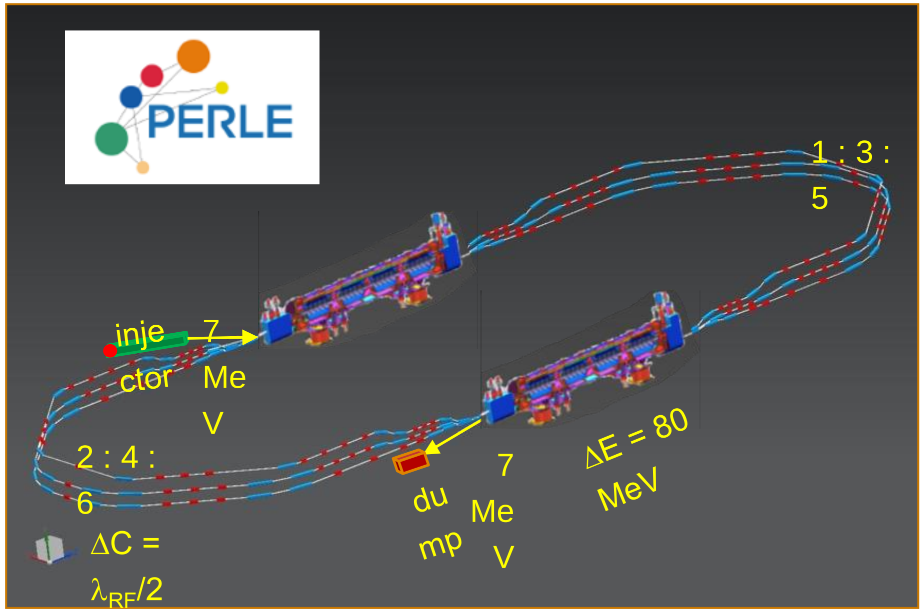
$\sqrt{s_{ep}}$ = 1-4 TeV

L(HERA) x 1000
(ERL and LHC)

1206.2913, JPhysG
2007.14491, JPhysG

f=802Mz,
3+3 passes: 20mA x 6
20 MV/m, $Q_0 > 10^{10}$

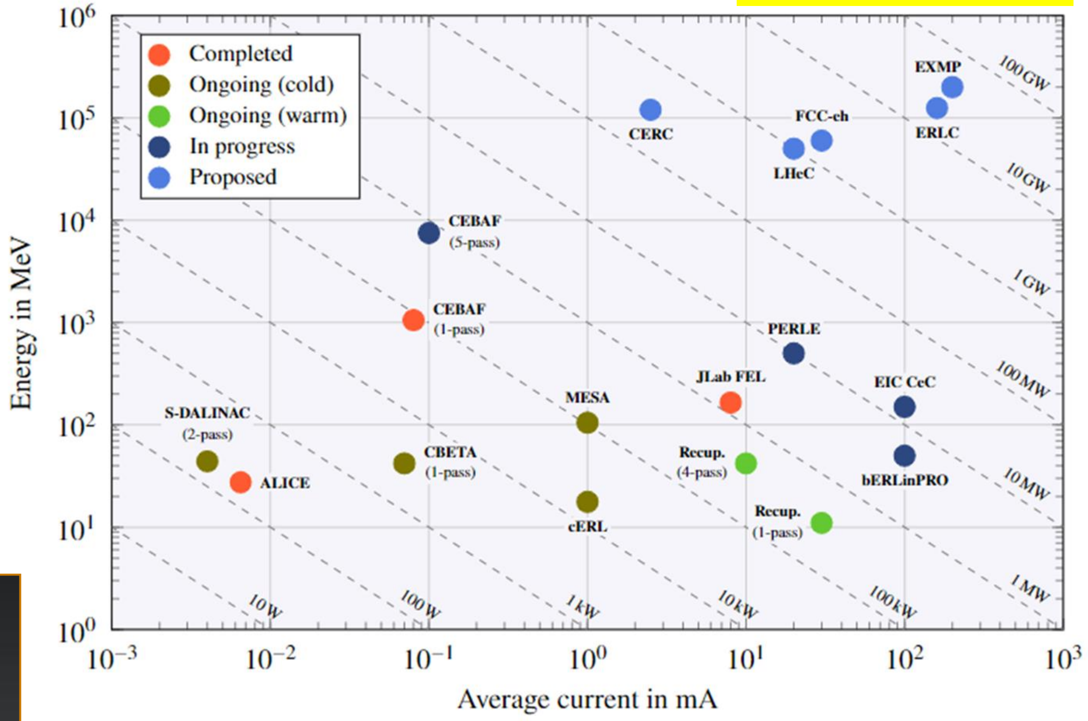
W. Kaabi,
A. Bogacz,
O. Bruning,
M. Klein



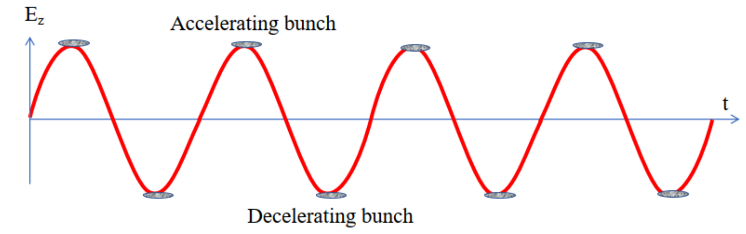
arXiv:1705.08783

ERL landscape

LDG ERL report



Principle of Energy Recovery Linac (ERL)



V. Litvinenko et al.

FUTURE CIRCULAR COLLIDER

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;

- optimising design of colliders and their injector chains, supported by R&D to develop the needed key technologies;

- elaboration of a sustainable operational model for the colliders and experiments in terms of human and financial resource needs, as well as environmental aspects and energy efficiency;

- development of a consolidated cost estimate, as well as the funding and organisational models needed to enable the project's technical design completion, implementation and operation;

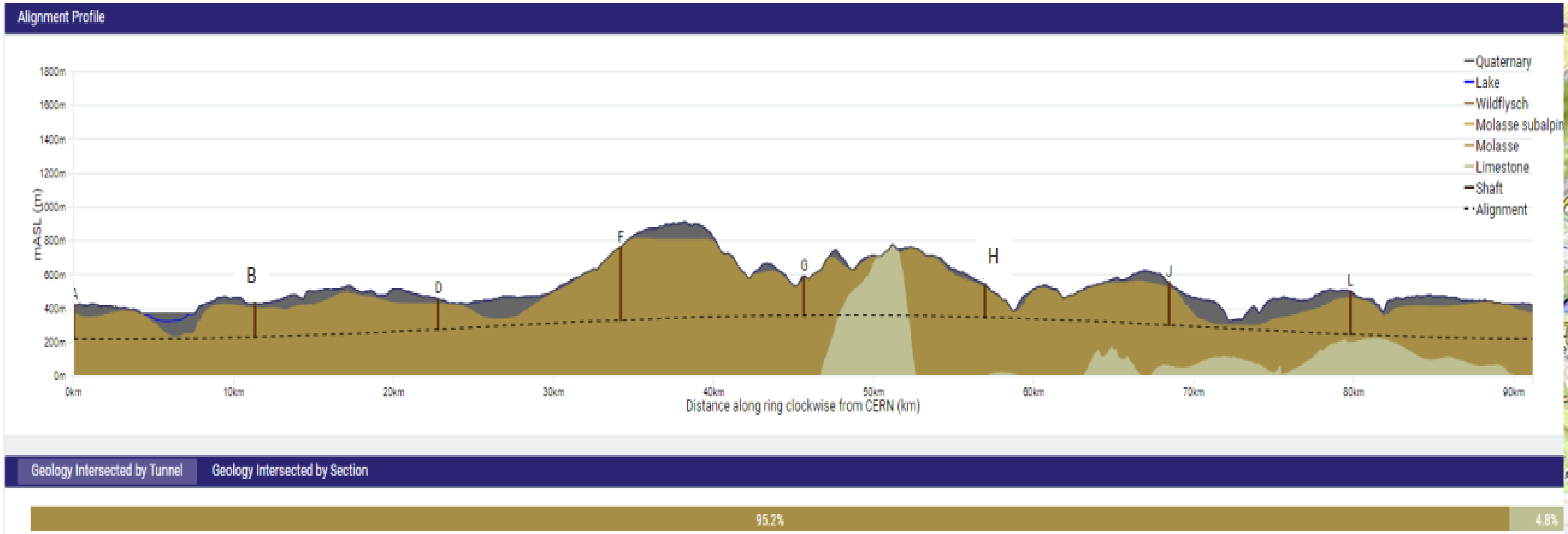
- identification of substantial resources from outside CERN's budget for the implementation of the first stage of a possible future project (tunnel and FCC-ee);

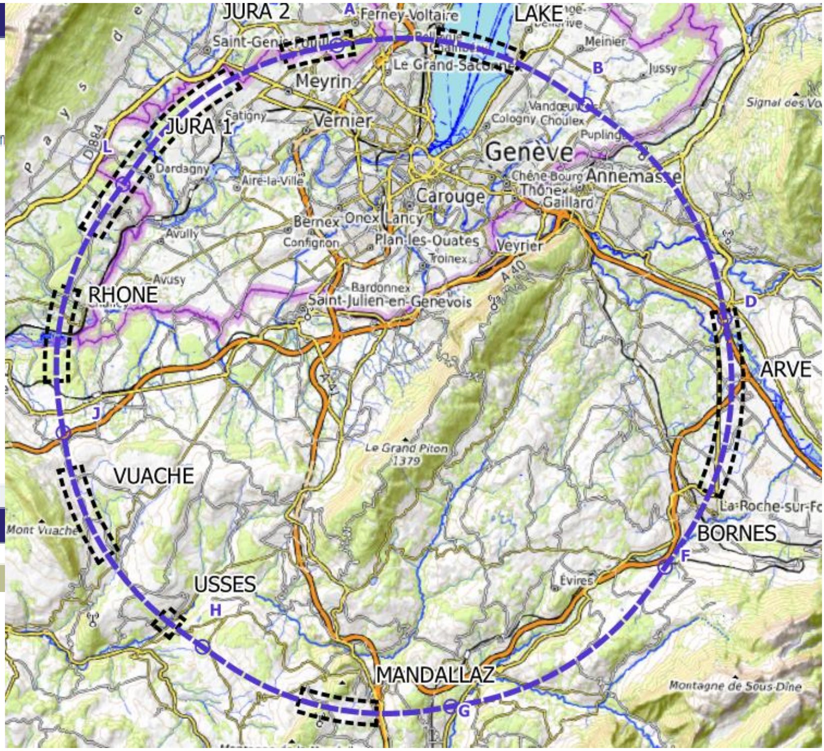
- consolidation of the physics case and detector concepts for both colliders.

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

F. Gianotti

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

FUTURE CIRCULAR COLLIDER

Implementation baseline PA31-3.0 91 km

1. **PA – Ferney Voltaire** (FR) – experimental site
2. **PB – Présinge/Choulex** (CH) – technical site
3. **PD – Nangy** (FR) – technical/experimental site
4. **PF – Etaux** (FR) – technical site
5. **PG – Charvonnex/Groisy** (FR) – experimental site
6. **PH – Cercier** (FR) – technical site
7. **PJ – Vulbens/Dingy en Vuache** (FR)

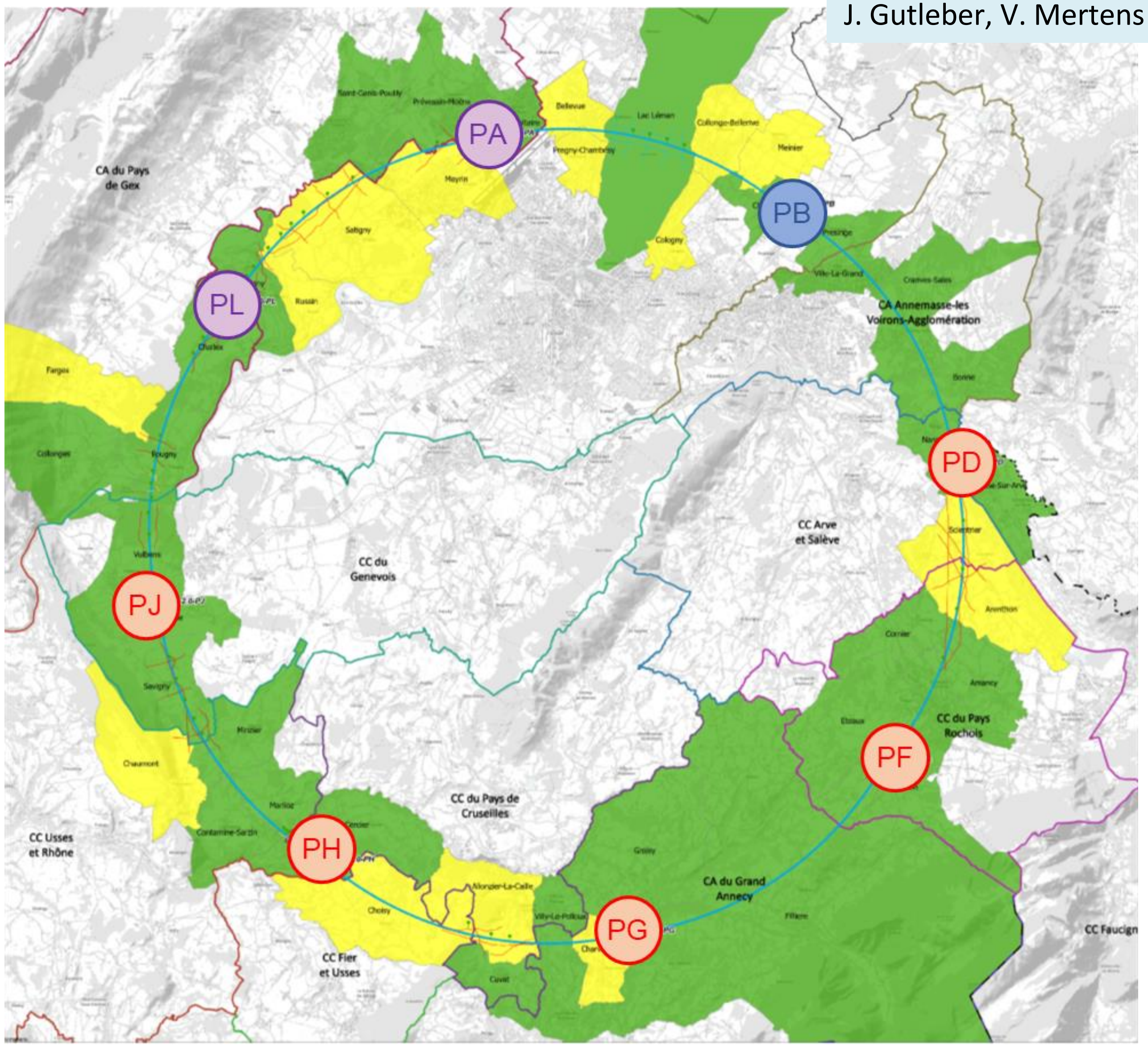
   – technical/experimental site
8. **PL – Challex** (FR) – technical site

First meetings with communes concerned in France (31) and Switzerland (10)

Rencontrée

Rendez-vous proposé / programmé

J. Gutleber, V. Mertens



US Electron Ion Collider (EIC)

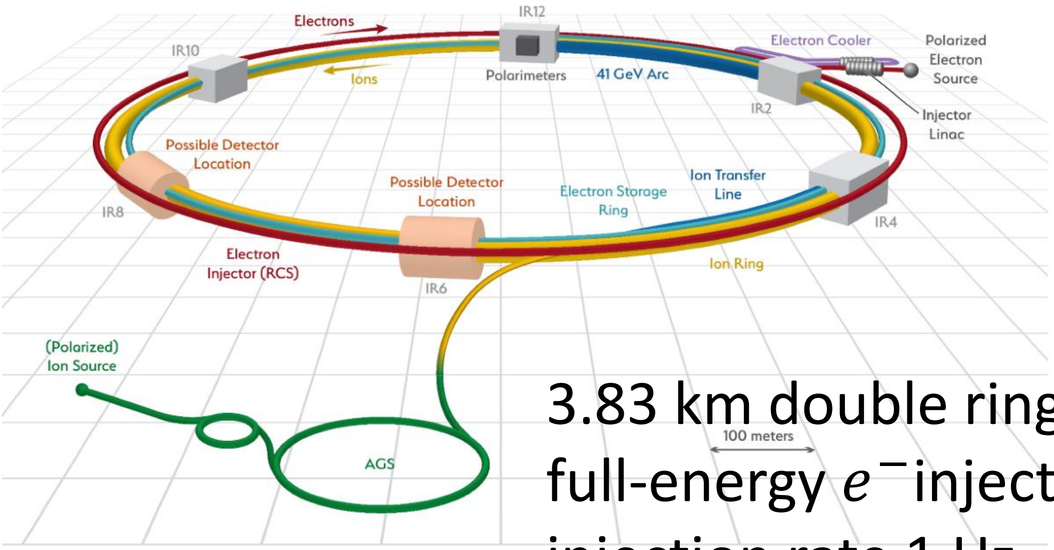
US EIC Electron Storage Ring similar to, but more challenging than, FCC-ee

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**, still evolving

EIC will start beam operation about a decade prior to FCC-ee

The EIC will provide another invaluable opportunity to train 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)

SuperKEKB

FUTURE CIRCULAR COLLIDER

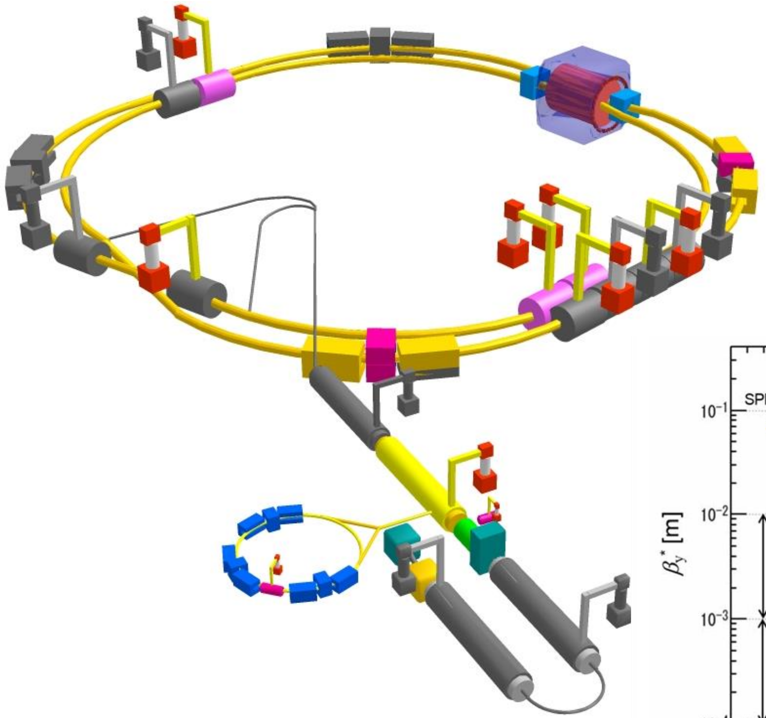
E-JADE

EAJADE

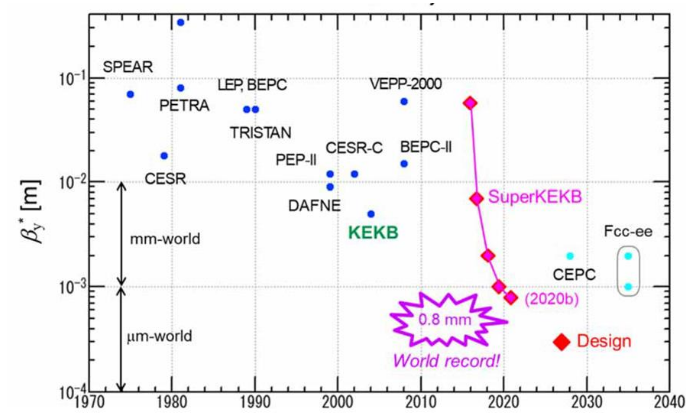
Belle II

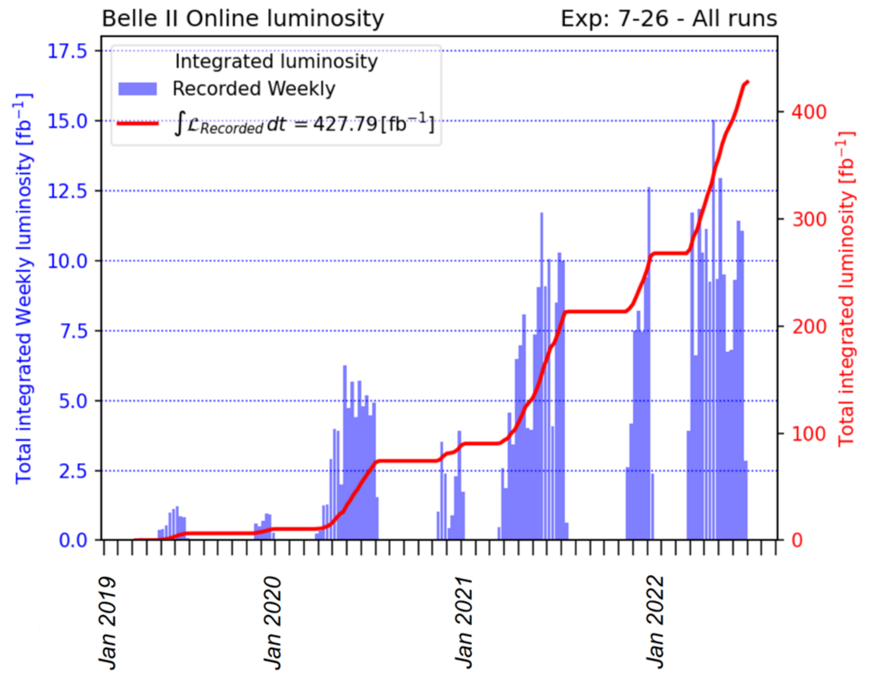
Super KEKB

circumference 3 km

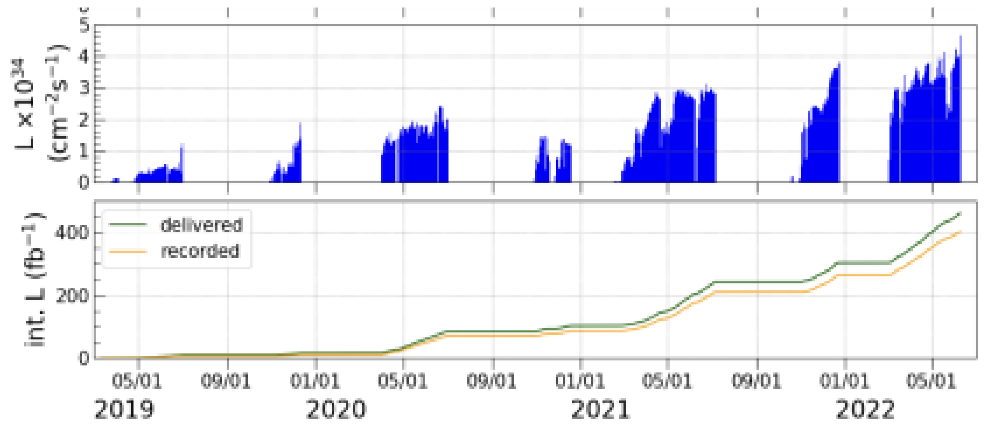


world's highest luminosity & lowest β^* e^+e^- collider





total integrated luminosity so far ~430 fb^{-1} over ~3 years



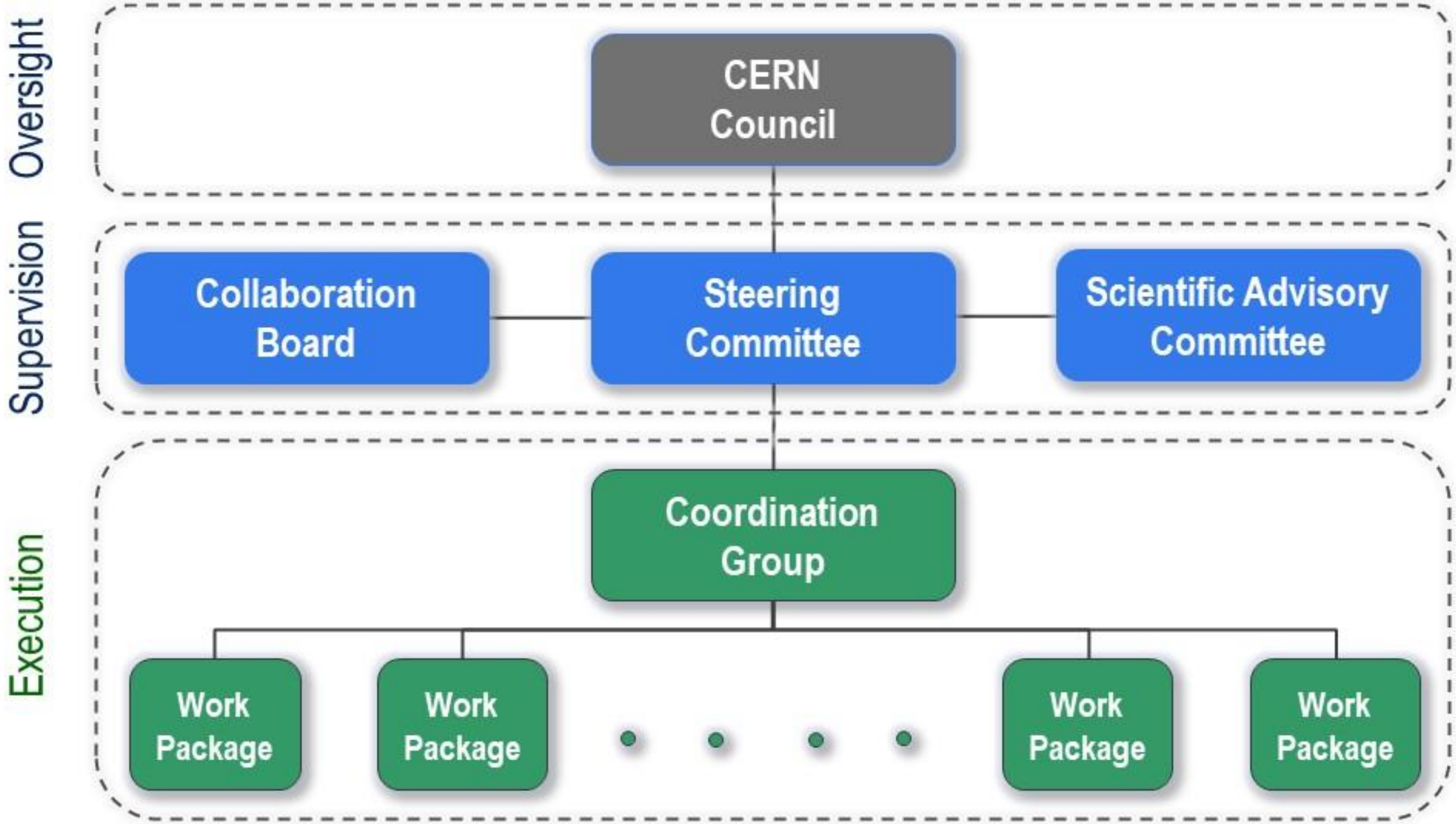
world record luminosity of 4.7x10^{34} cm^{-2}s^{-1}, β_y^* = 1.0 mm routinely, also β_y^* = 0.8 mm shown – with "virtual" crab-waist collision scheme originally developed for FCC-ee (K. Oide)

FUTURE CIRCULAR COLLIDER

Global FCC Collaboration

further increasing international collaboration is essential for preparing the FCC implementation

FCC Feasibility Study - organisational structure

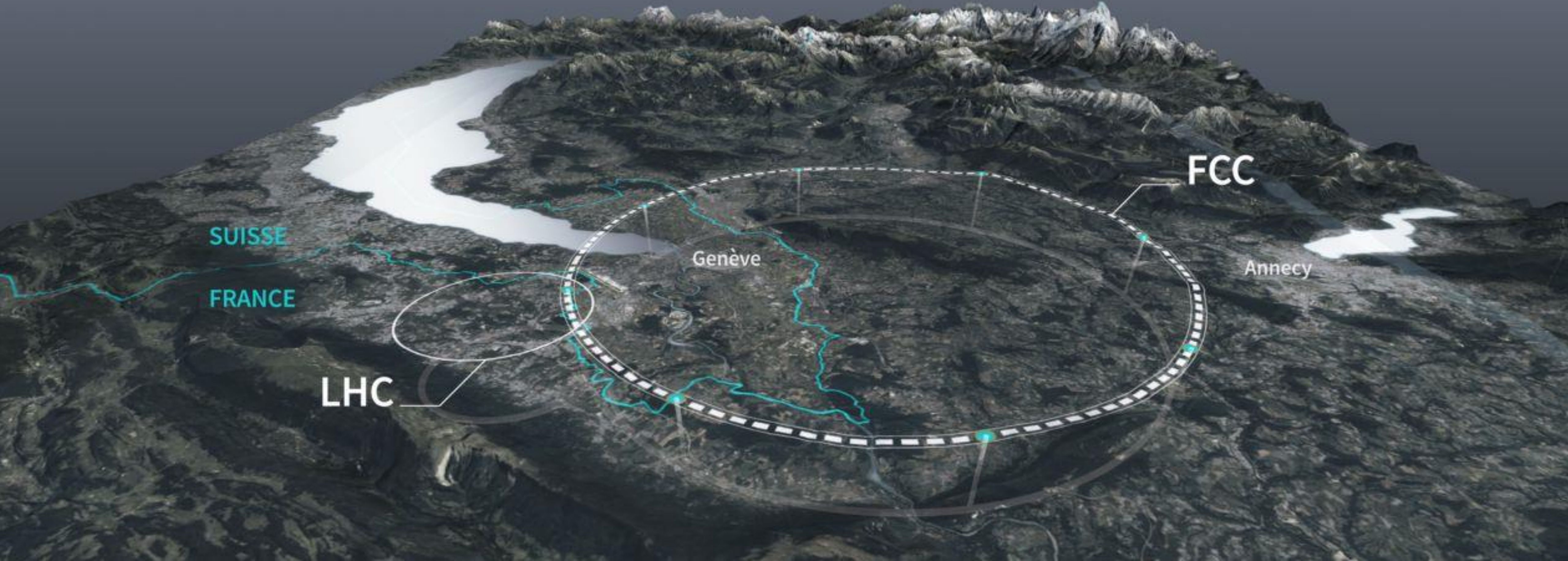


FCC key points

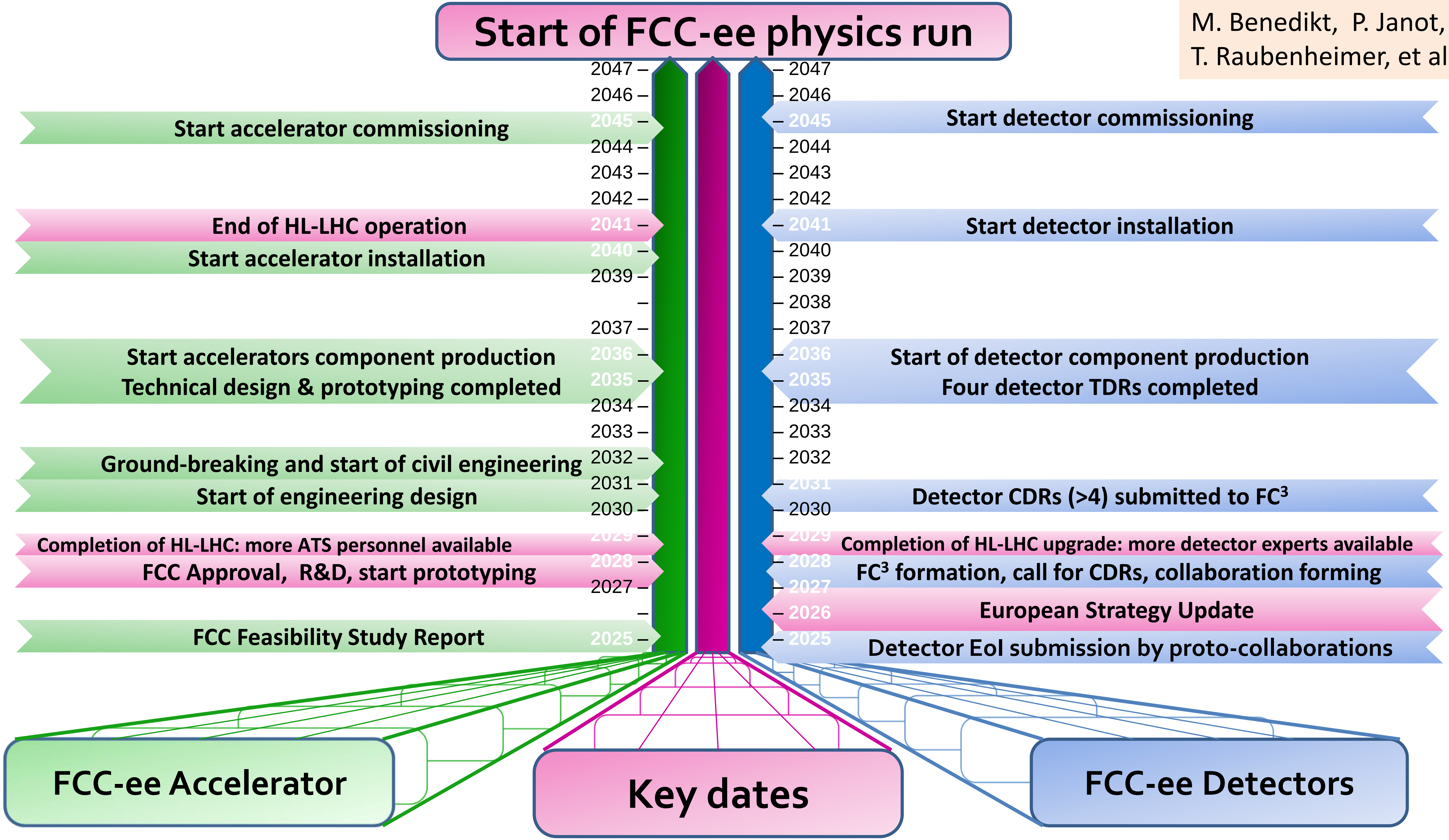
- **FCC-ee fills the need for a highest precision EW/Higgs factory**
- **Provides highest luminosity at Z, W and H@240 GeV of all proposed factories**
- **“Low-risk” solution** based on 60 years of e^+e^- circular colliders and particle detectors
  - R&D on components focused on improved performance, increased efficiency, industrialization and cost aspects, but no need for large scale “demonstration” facilities
- **Utility requirements** similar to CERN existing use
- **Most economic path to a next generation energy frontier hadron collider FCC-hh**
- **FCC integrated programme provides a long-term vision for global HEP at precision and energy frontiers, interlinked with large-scale advanced technology R&D programmes**
  - FCC-ee, FCC-hh hadron collider (100 TeV pp, AA), FCC-eh,…
- **Strong support from around the world is crucial for success of the Feasibility Study and for the FCC project to go ahead**

FCC research infrastructure for the 21st century

A new 91 km tunnel to host multiple colliders
100 – 300 m under ground, 8 surface sites
FCC-ee: electron-positron @ 91, 160, 240, 365 GeV
FCC-hh: proton-proton @ 100 TeV, and heavy-ions (Pb) @39 TeV
FCC-eh: electron-proton@ 3.5 TeV



M. Benedikt, P. Janot,
T. Raubenheimer, et al.



FCC Week 2023

FUTURE CIRCULAR COLLIDER

Future Circular Collider (FCC) Week 2023, at the **Millennium Conference Centre in London**, United Kingdom from **Monday 5 June to Friday 9 June 2023**.

- Organised with the **support** of the UK Research and Innovation Science and Technologies Facilities Council (STFC) and the EU-funded Horizon 2020 FCCIS project
- **Local partners** : STFC, the University of Cambridge, Imperial College London, King's College London, the University of Manchester, the University of Oxford, Queen Mary University of London, Royal Holloway University of London and University College London

Registration is open !

https://cern.ch/fccweek2023

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

thank you ! merci !

spare slides

FUTURE CIRCULAR COLLIDER

Stage 1: updated parameters

K. Oide, D. Shatilov,

Parameter [4 IPs, 90.7 km, T_{rev}=0.3 ms]	Z	WW	H (ZH)	ttbar
beam energy [GeV]	45.6	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+lattice)	8	18	6	10

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]	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

KEKB, SuperKEKB ’22, SuperKEKB design

parameter	KEKB w Belle		SuperKEKB 2022 w Belle II β_y^* = 1.0 mm CW		SuperKEKB Design	
	LER	HER	LER	HER	LER	HER
E [GeV]	3.5	8	4	7	4	7
β_x^* (mm)	1200	1200	**80**	**60**	**32**	**25**
β_y^* (mm)	5.9	5.9	**1.0**	**1.0**	**0.27**	**0.30**
ε_x (nm)	18	24	**4.0**	**4.6**	3.2	4.6
ε_y (pm)	150	150	**~45**	**~45**	**8.6**	**12.9**
I (mA)	**1640**	**1190**	**1321**	**1099**	**3600**	**2600**
n_b	1584		**2249**		2500	
I_b (mA)	1.04	0.75	**0.587**	**0.489**	1.44	1.04
ξ_y *	**0.098**	**0.059**	**0.041**	**0.028**	0.069	0.060
L_{sp} (10^{30}cm^{-2}s^{-1} mA^{-2})	17.1		72.1		214	
L (10^{34}cm^{-2}s^{-1})	2.11		4.65		80	

FCC Feasibility Study (FS)

2013 ESPPU requested FCC Conceptual Design four-volume report → 4 volumes delivered in 2018/19,
describing the physics cases, the design of the lepton and hadron colliders, and the underpinning technologies and infrastructures. Fol-

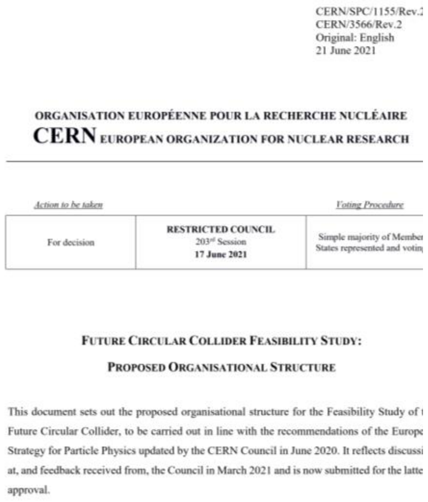
2020 ESPPU→ 2021 Launch of FCC Feasibility Study (FCC FS) by CERN Council

- Feasibility Study Report (FSR) expected by the end of 2025 , not only the technical design, but also numerous other key feasibility aspects, including tunnel construction, financing, and environment
- FSR will be an important input to the next ESPPU expected in 2026/27.

FCC FS is organized as an international collaboration.
The FCC FS and a possible future project will profit from CERN's decade-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.

Organisational Structure of the FCC Feasibility Study
http://cds.cern.ch/record/2774006/files/English.pdf

Main Deliverables and Timeline of the FCC Feasibility Study
http://cds.cern.ch/record/2774007/files/English.pdf

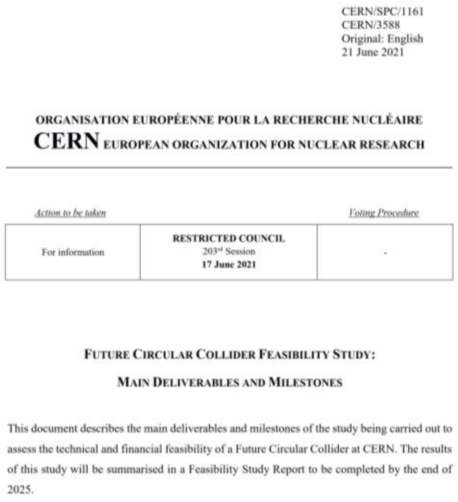

CERN/SPC/1155/Rev.2
CERN/3566/Rev.2
Original: English
21 June 2021

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 Europe Strategy for Particle Physics updated by the CERN Council in June 2020. It reflects discussi at, and feedback received from, the Council in March 2021 and is now submitted for the latte approval.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Original: English
21 June 2021

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

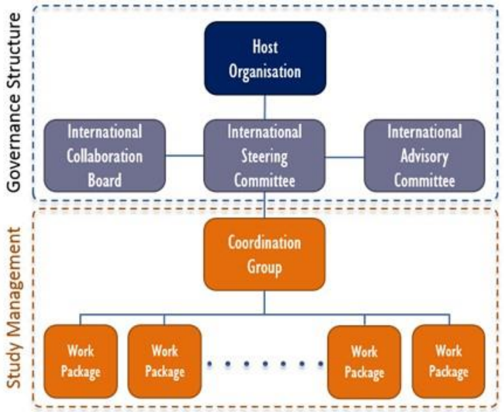
Action to be taken		Voting Procedure
For information	RESTRICTED COUNCIL 203rd Session 17 June 2021	-

FUTURE CIRCULAR COLLIDER FEASIBILITY STUDY:
MAIN DELIVERABLES AND MILESTONES

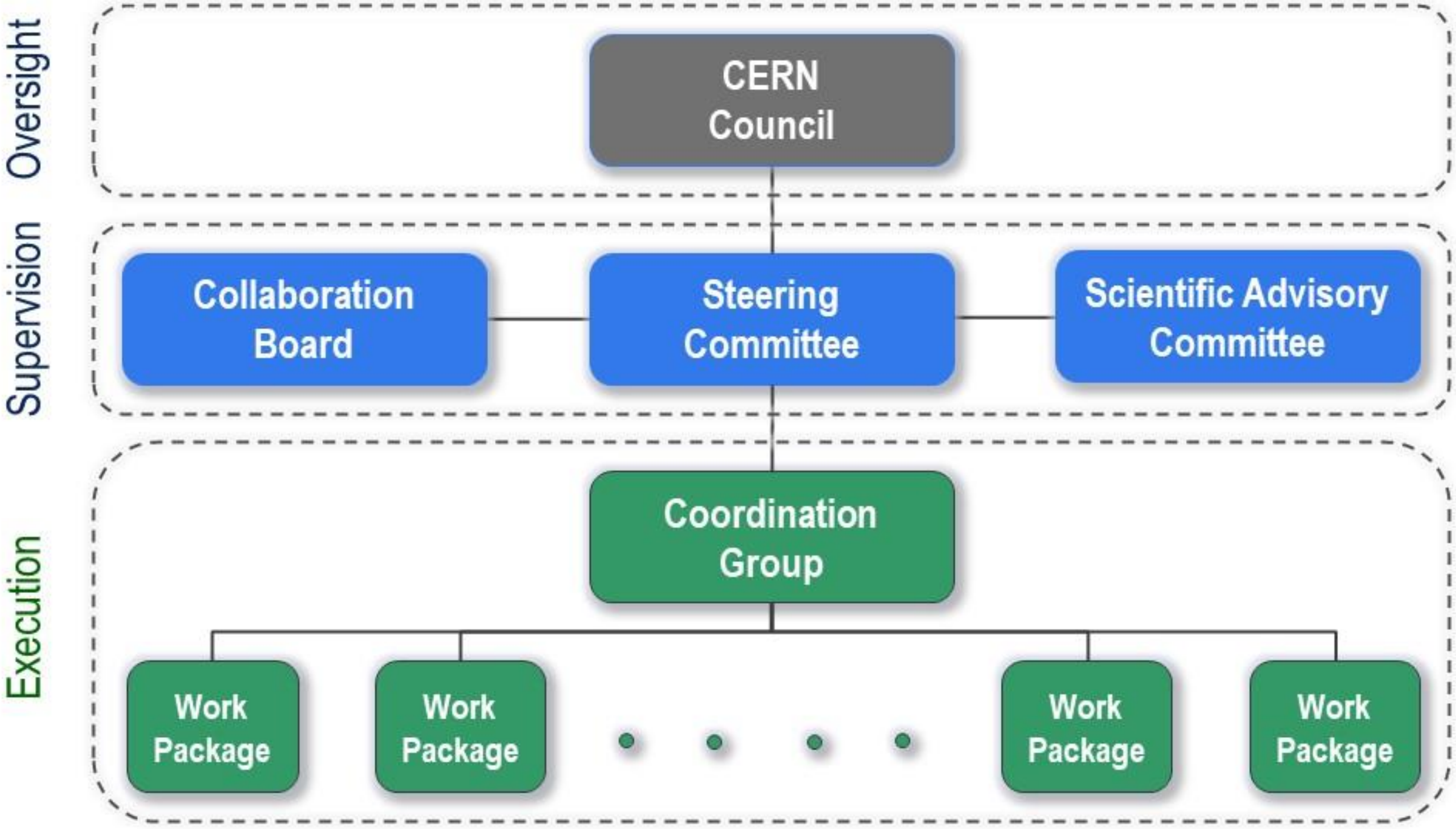
This document describes the main deliverables and milestones of the study being carried out to assess the technical and financial feasibility of a Future Circular Collider at CERN. The results of this study will be summarised in a Feasibility Study Report to be completed by the end of 2025.

FCC Feasibility Study - organisational structure

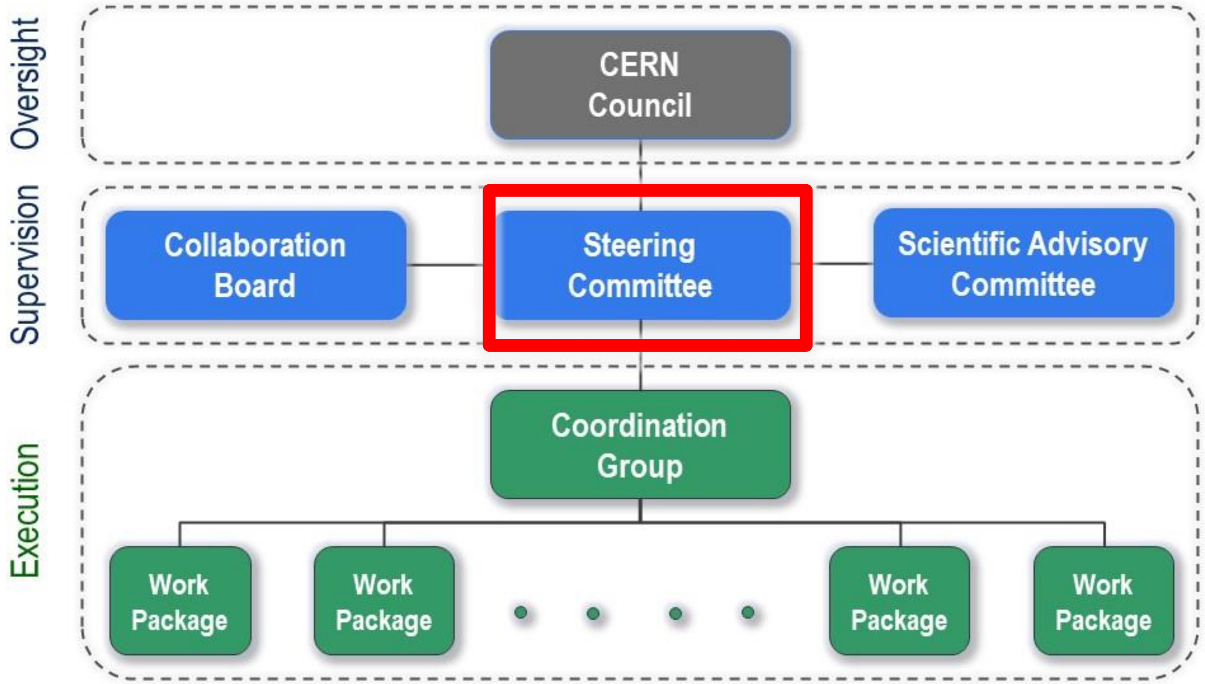
- New structure very similar to the first phase of the FCC Study (2014-2020), leading to the Conceptual Design Report as input to the ESPPU.



- Classical structure common to CERN projects.



FCC Steering Committee (SC)



SC provides organisational & technical supervision for execution of the Feasibility Study

Members:

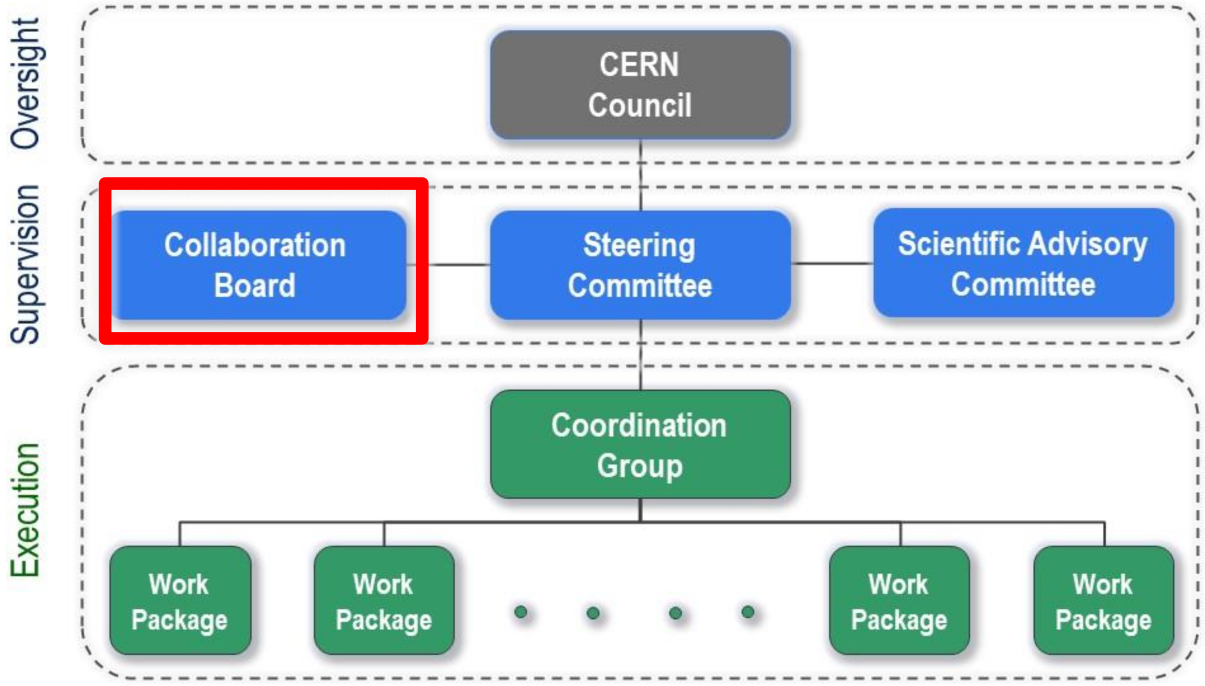
- CERN DG (SC Chair),
- The members of the CERN Directorate,
- the Chair of the CB,
- and up to 5 members nominated by the CB,
- the FCC Study Leader w/o voting rights
- the Council president as observer

Fabiola Gianotti (CERN, Chair), Raphaël Bello (CERN), Mike Lamont (CERN), Joachim Mnich (CERN), Charlotte Warakaulle (CERN)

Philippe Chomaz (CEA), Marina Cobal (INFN), Beate Heinemann (DESY), Tadashi Koseki (KEK), Lia Merminga (FNAL), Mike Seidel (PSI)

Michael Benedikt (CERN) Eliezer Rabinovici (Hebrew U.)

Collaboration Board (CB)

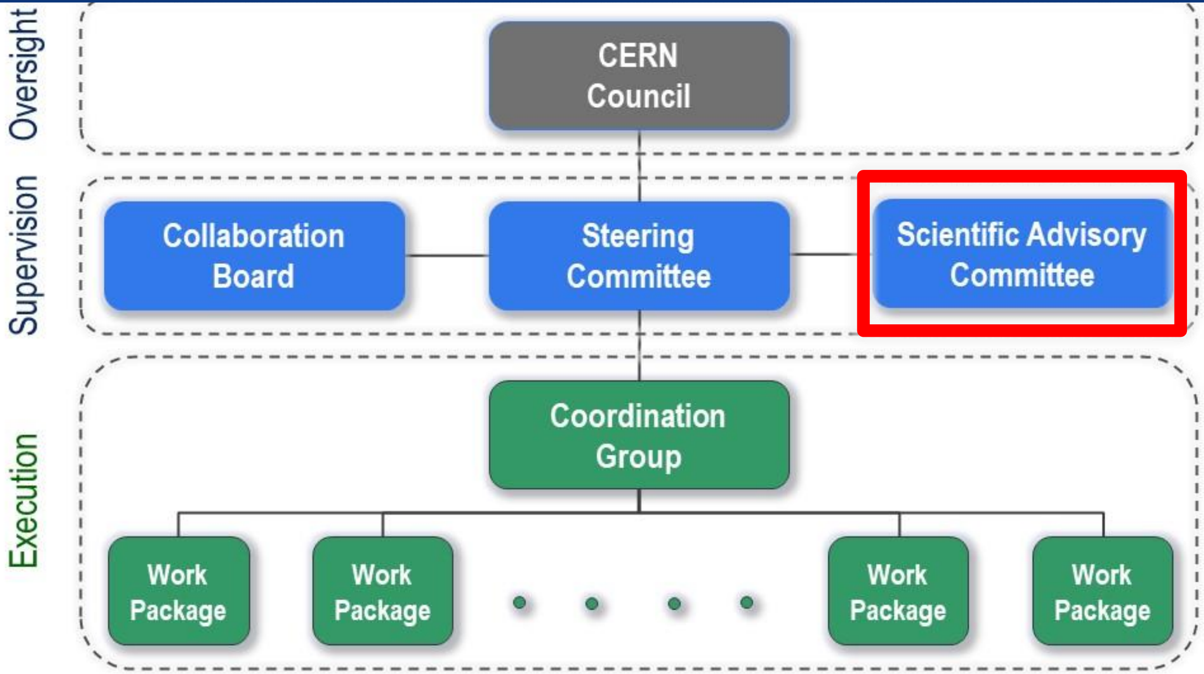


CB reviews the work needs and resource requirements and their sharing among the participating institutes; appoints up to five members of the Steering Committee from among the participating institutes.

Members:
one representative per institute contributing to the Feasibility Study, having signed the FCC MoU and whose participation has been approved by the Collaboration Board;

Elected Chair: Philippe Chomaz (CEA)
CB executive committee: Manuela Boscolo (INFN), Andy Lankford (UCI)

Scientific Advisory Committee (SAC)



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

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

Physics, experiments, detectors

- Andrew Parker (U. Cambridge) CHAIR
- Katri Huitu (U. Helsinki)
- Belen Gavela Legazpi (UAM Madrid)
- Peter Krizan (U. Ljubljana)
- Roberto Tenchini (INFN, Pisa)

Accelerator

- Michiko Minty (BNL)
- Riccardo Bartolini (DESY)
- Peter McIntosh (STFC)
- Kyo Shibata (KEK)
- Srinivas Krishnagopal (BARC)

Civil engineering, environment

- Alain Chabert (France)
- Brigitte Fargevieille (EDF, France)
- *NN CE expert, CH – tbc*

Technical infrastructure & large projects

- Philippe Lebrun (former CERN, former JUAS)
- NN, Tunnel techn. infrastructure, tunnel safety

FCC

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** – Guy Wilkinson, Jorg Wenninger
- **FCC-ee transfer lines** – Wolfgang Bartmann
- **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

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:

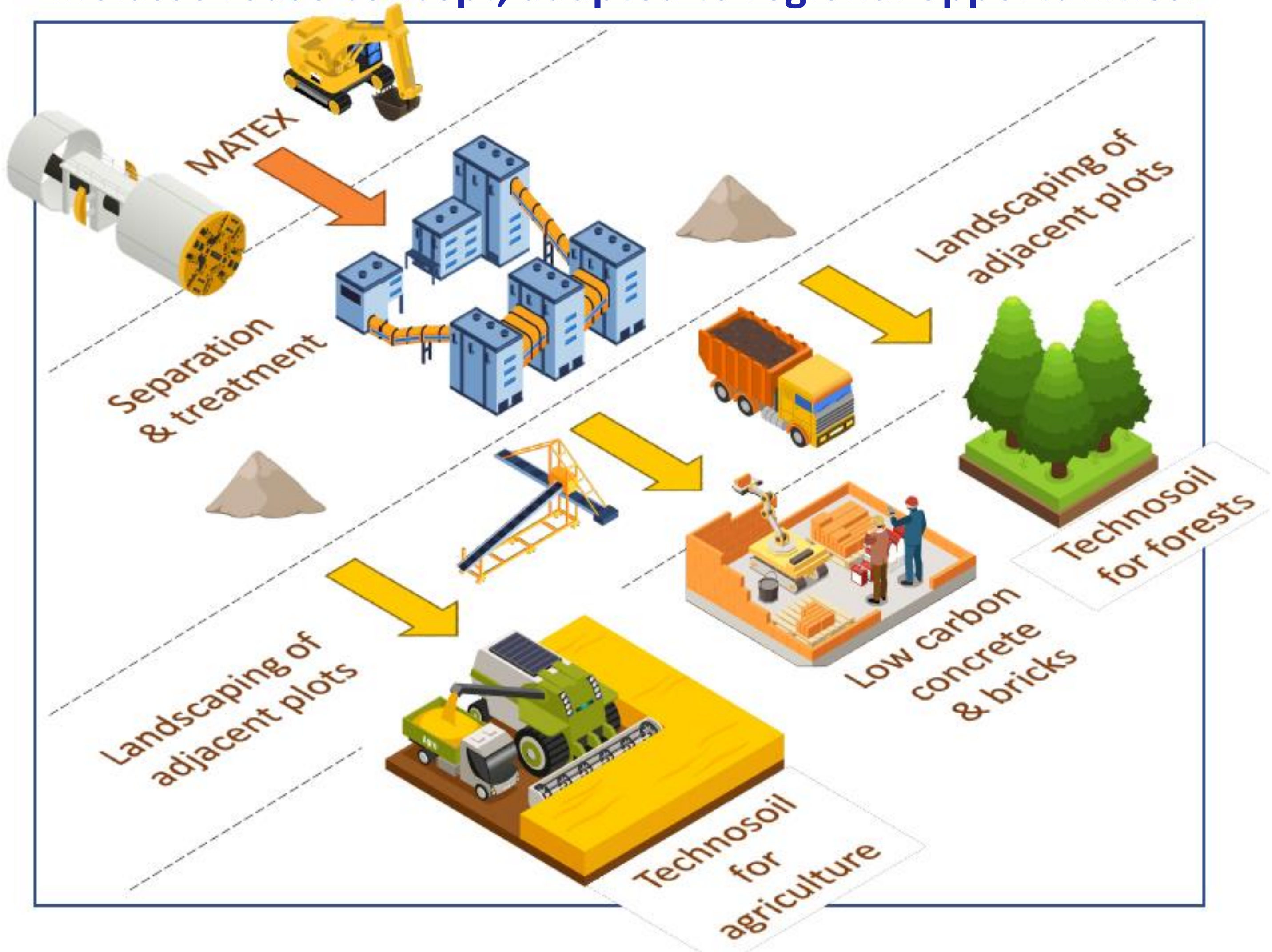
- Overall cost estimate & spending profile for stage 1 project

Environmental impact, socio-economic impact:

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

FCCIS – H2020 Mining the future competition results

- **Four consortia were qualified for the second stage.**
- **All four proposals could contribute to an integrated molasse reuse concept, adapted to regional opportunities.**



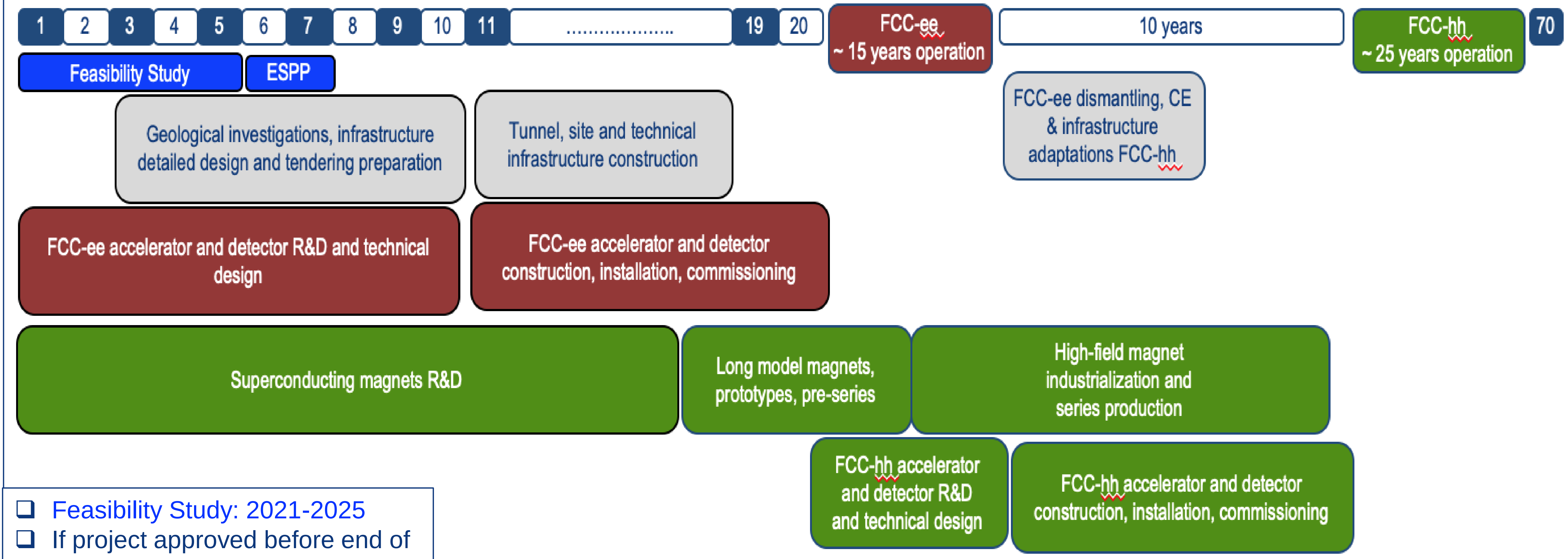
- **AMBERG consortium:** In-situ characterisation (Crossbelt elemental analyzer) and preparation for use as construction material on site (spray-concrete with binder from bio-mineral materials), Production of construction elements withouth cement/concrete.

  BG consortium: online-analysis and preparation of Molasse for construction elements from sandstone, sabd, filing material for concrete, low-carbon concrete, terra cotta bricks, etc.

  ARCADIS consortium: usage of clay and sand materials enriched with limestone as stabiliser for production of bricks by pressurizing, mobile plants for on-site production of bricks, replacement of construction materials with high CO2 bilan during production;

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

timeline of FCC integrated programme



- 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