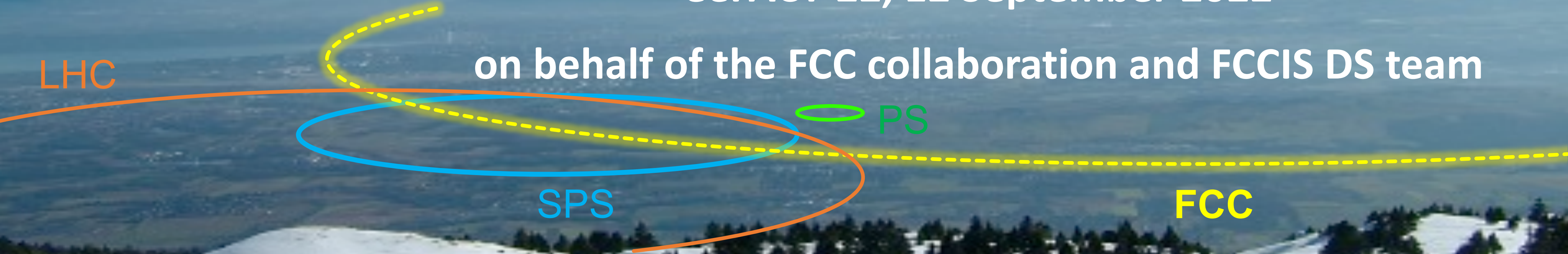
FCC-ee Feasibility Study Progress

Frank Zimmermann, CERN

Thanks to Andrey ABRAMOV, Alain BLONDEL, Manuela BOSCOLO, Michael BENEDIKT, Emanuela CARIDEO, Paolo CRAIEVICH, Massimo GIOVANNOZZI, Michael HOFER, Klaus Patrick JANOT, Jacqueline KEINTZEL, Mike KORATZINOS, Roberto LOSITO, Mauro MIGLIORATI, Katsunobu OIDE, Tor RAUBENHEIMER, Dmitry SHATILOV, Rogelio TOMAS, …

eeFACT'22, 12 September 2022

on behalf of the FCC collaboration and FCCIS DS team



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

http://cern.ch/fcc

CERN

*Work supported by the **European Commission** under the **HORIZON 2020 projects EuroCirCol**, grant agreement 654305; **EASITrain,** grant agreement no. 764879; **iFAST**, grant agreement no. 101004730, **FCCIS**, grant agreement 951754, and **E-JADE,** contract no. 645479*

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

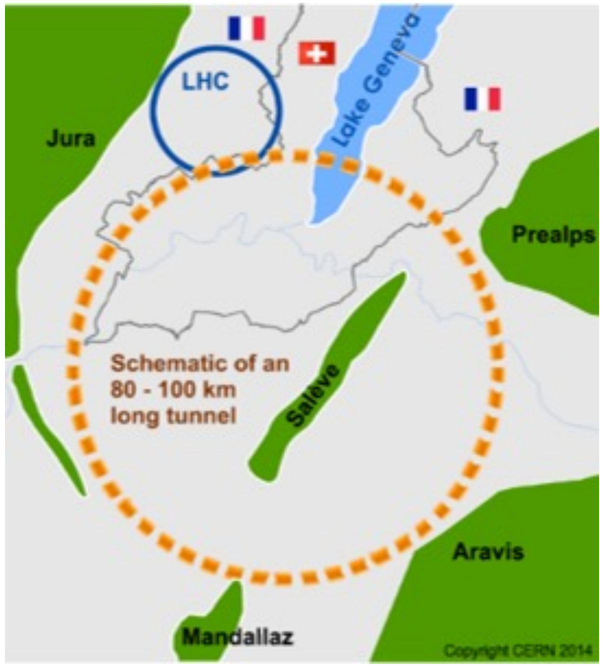
photo: J. Wenninger

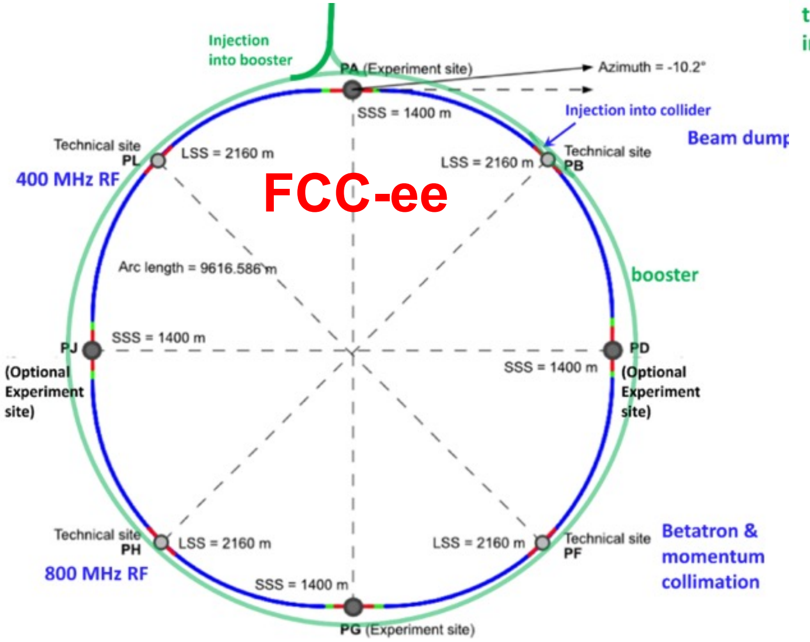
FUTURE CIRCULAR COLLIDER

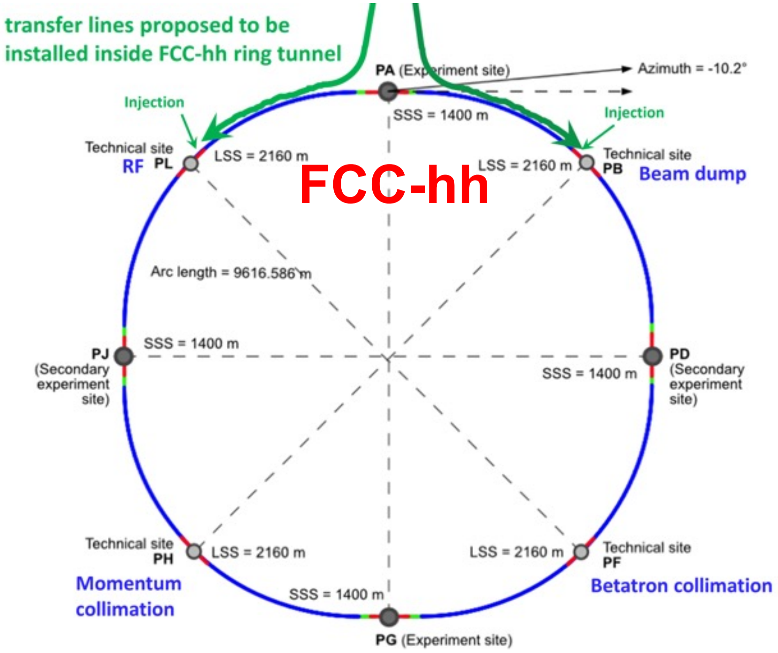
The FCC integrated program inspired by successful LEP – LHC programs at CERN

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



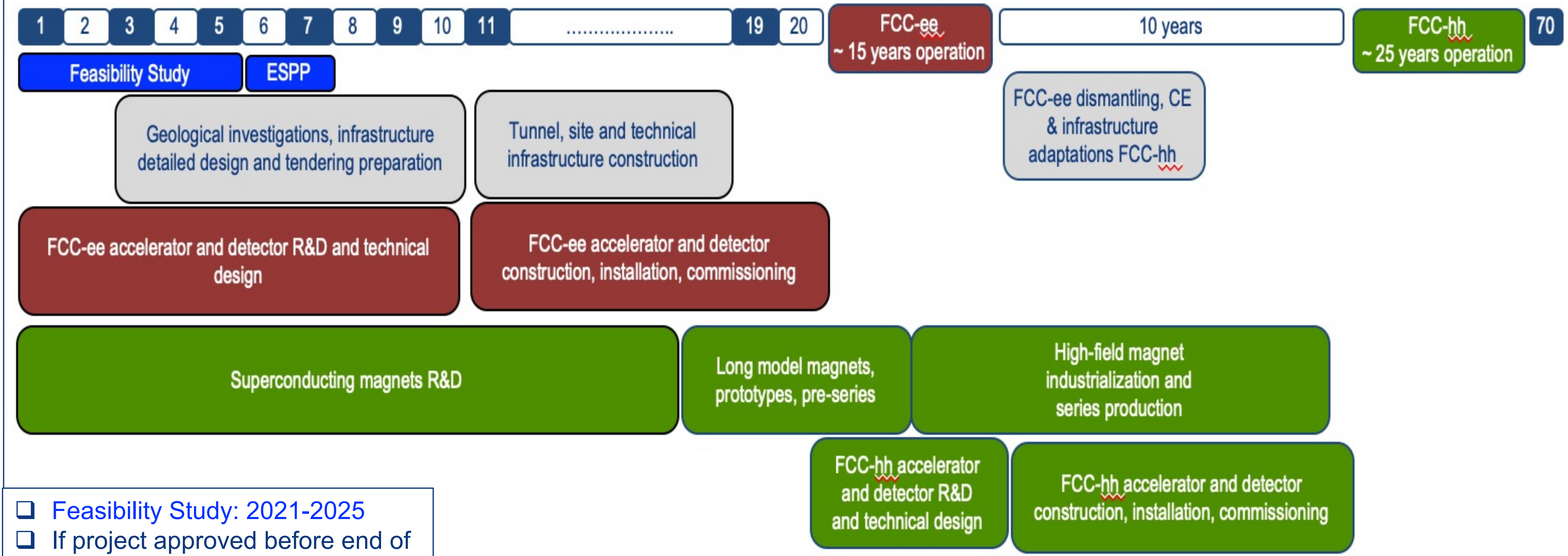




2020 - 2040	2045 - 2060	2065 - 2090

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

technical 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

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

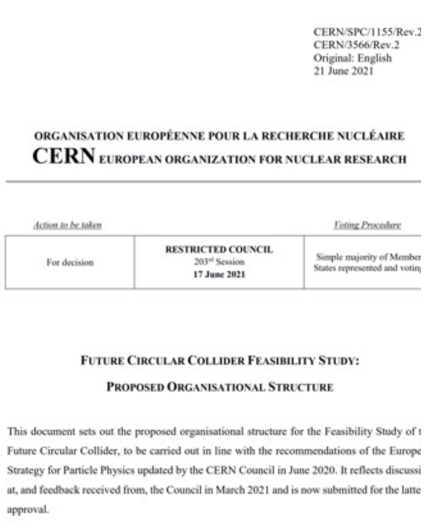
- Feasibility Study Report (FSR) expected by the end of 2025 , not only the technical design, but also numerous other key feasibility aspects, including tunnel construction, financing, and environment
- FSR will be an important input to the next ESPPU expected in 2026/27.

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

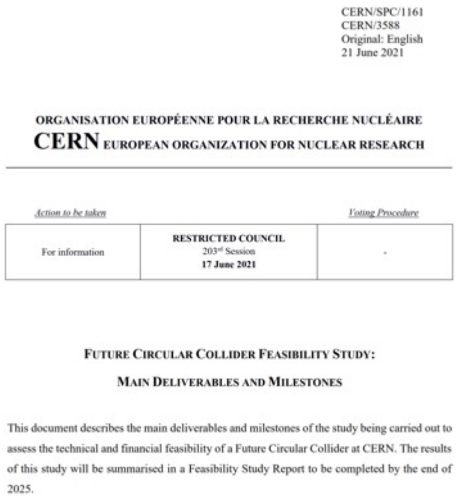

CERN/SPC/1155/Rev.2
CERN/3566/Rev.2
Original: English
21 June 2021

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 European 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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CERN/3588
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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.

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**

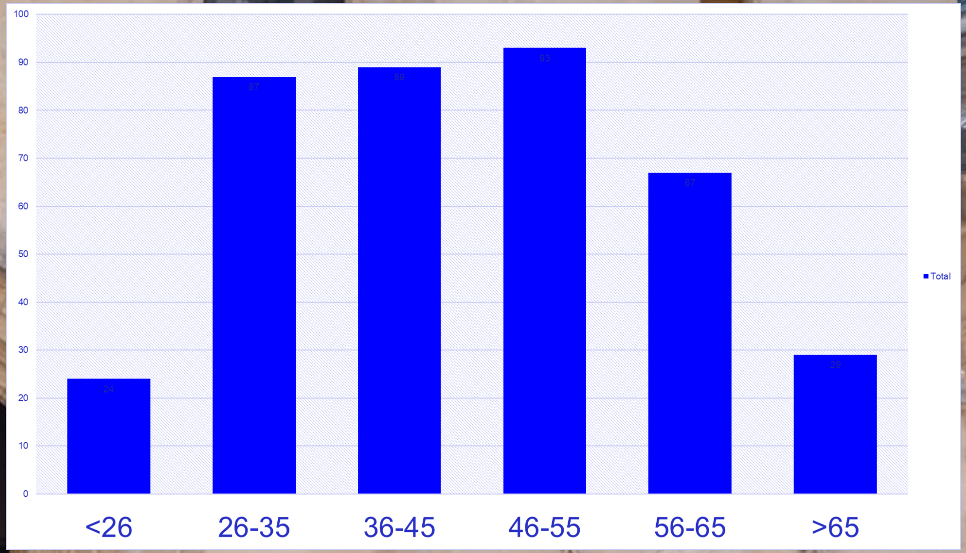
FCC Week 2022, Sorbonne, Paris, 30 May – 3 June 2022

483 participants

269 in person and 214 remote

45 sessions,
202 presentations,
+ 20 posters

Distribution of participants by age group



snapshots from FCC Week 2022 - ~25% women participants, speakers and chair persons

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

preliminary

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-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

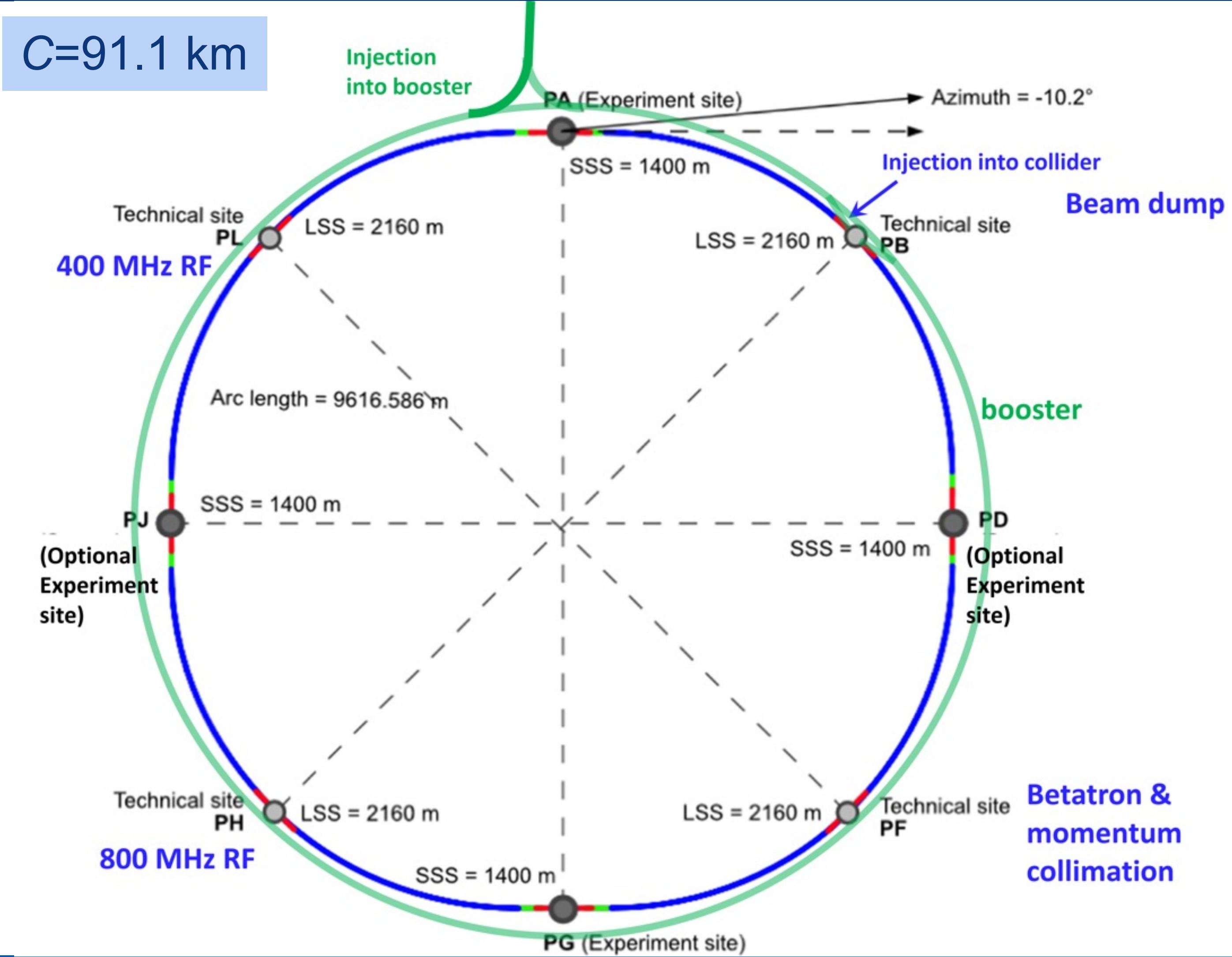
FCC-ee parameters

Parameter [4 IPs, 91.1 km, T_{rev}=0.3 ms]	Z	WW	H (ZH)	ttbar
beam energy [GeV]	45.6	80	120	182.5
beam current [mA]	1400	135	26.7	5.0
number bunches/beam	8800	1120	336	42
bunch intensity [10^{11}]	2.76	2.29	1.51	2.26
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	2.1/0	2.5/8.8
long. damping time [turns]	1170	216	64.5	18.5
horizontal beta* [m]	0.15	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]	10	21	14	39
vertical rms IP spot size [nm]	34	66	36	69
beam-beam parameter ξ_x / ξ_y	0.004/ 0.159	0.011/0.111	0.0187/0.129	0.096/0.138
rms bunch length with SR / BS [mm]	4.32 / 15.2	3.55 / 7.02	2.5 / 4.45	1.67 / 2.54
luminosity per IP [10^{34} cm^{-2}s^{-1}]	181	17.3	7.2	1.25
tot. integr. luminosity / yr [ab^{-1}/yr]	86	8	3.4	0.6
beam lifetime rad Bhabha / BS [min]	19 / ?	20 / ?	10 / 19	12 / 46

90° phase advance / cell with 2x cell length

shared RF at ZH and ttbar

FCC-ee Design Outline



Double ring e^+e^- collider

Common footprint with FCC-hh

Asymmetric IR layout and optics to limit SR towards the detector

Large crossing angle **30 mrad, "virtual" crab-waist collision, four-fold superperiodicity**: 2 or 4 IPs

SR power 50 MW/beam

Top-up injection requires **booster synchrotron in collider tunnel**

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

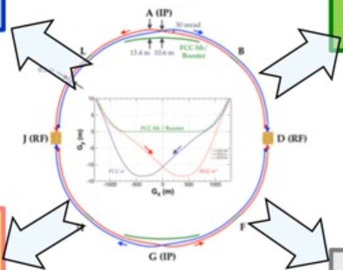
FCC-ee & hh would share the 4 experimental caverns

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

Detector Requirements in Brief

"Higgs Factory" Programme
- Momentum resolution of $\sigma_{p_T}/p_T^2 \simeq 2 \times 10^{-5}$ 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

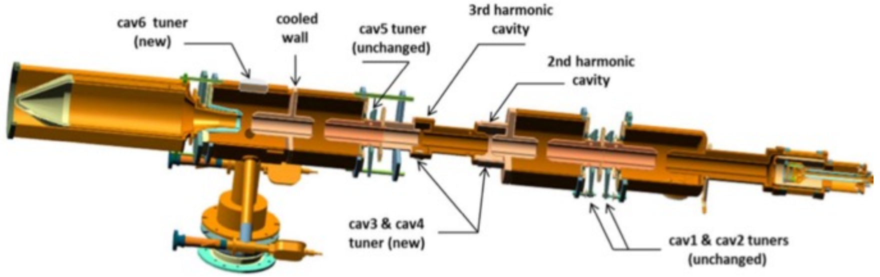
Feebly Coupled Particles - LLPs

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

accelerator R&D examples

efficient RF power sources (400 & 800 MHz)

I. Syratchev



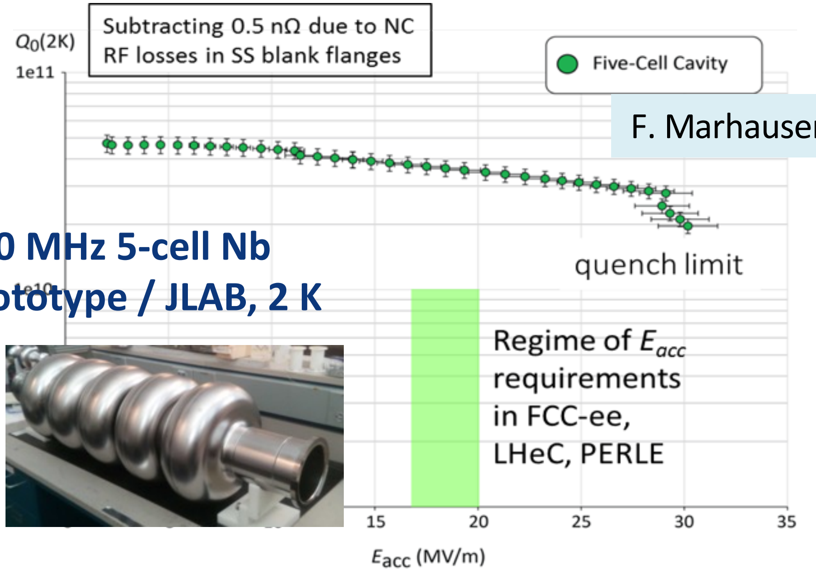
FPC & HOM coupler, cryomodule, thin-film coatings…

efficient SC cavities

Jefferson Lab

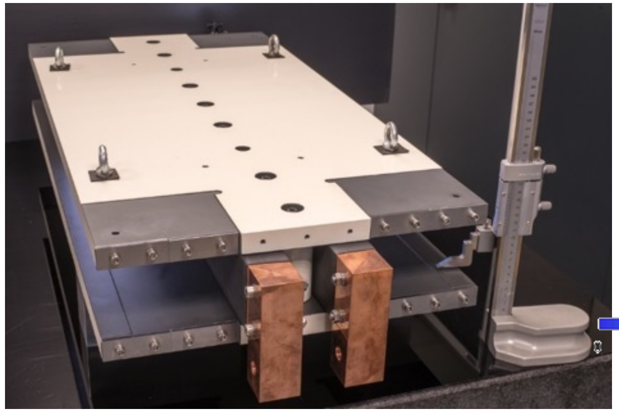
400 MHz 1-,2- & 4-cell Nb/Cu , 4.5 K

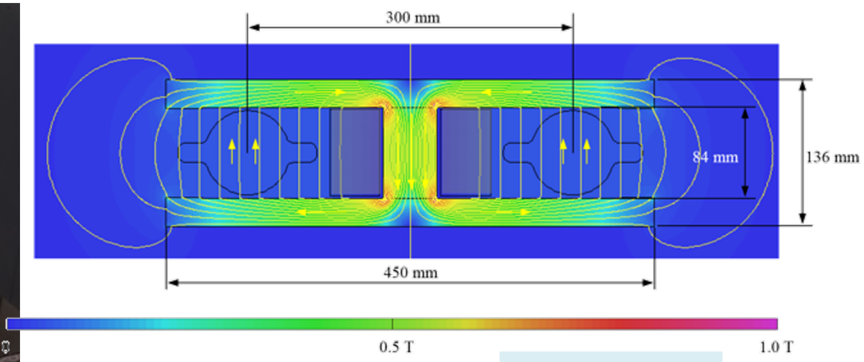
800 MHz 5-cell Nb prototype / JLAB, 2 K



F. Marhauser

energy efficient twin aperture arc dipoles

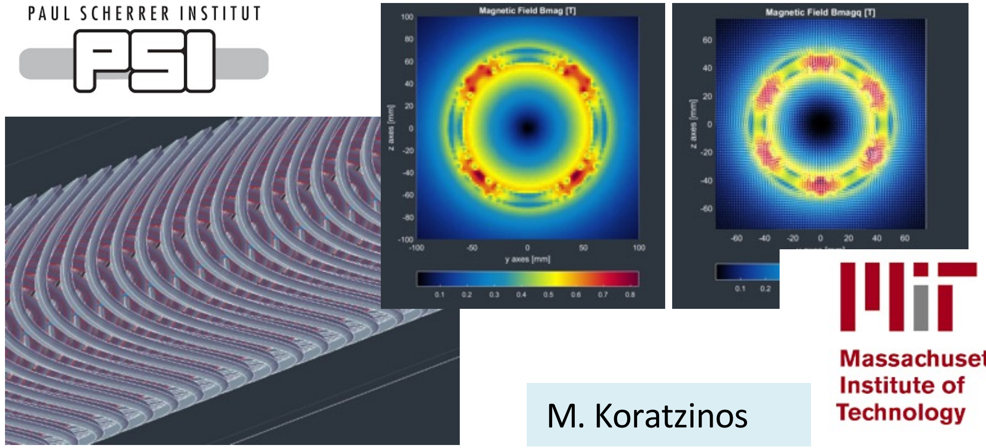




A. Milanese

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

PAUL SCHERRER INSTITUT PSI



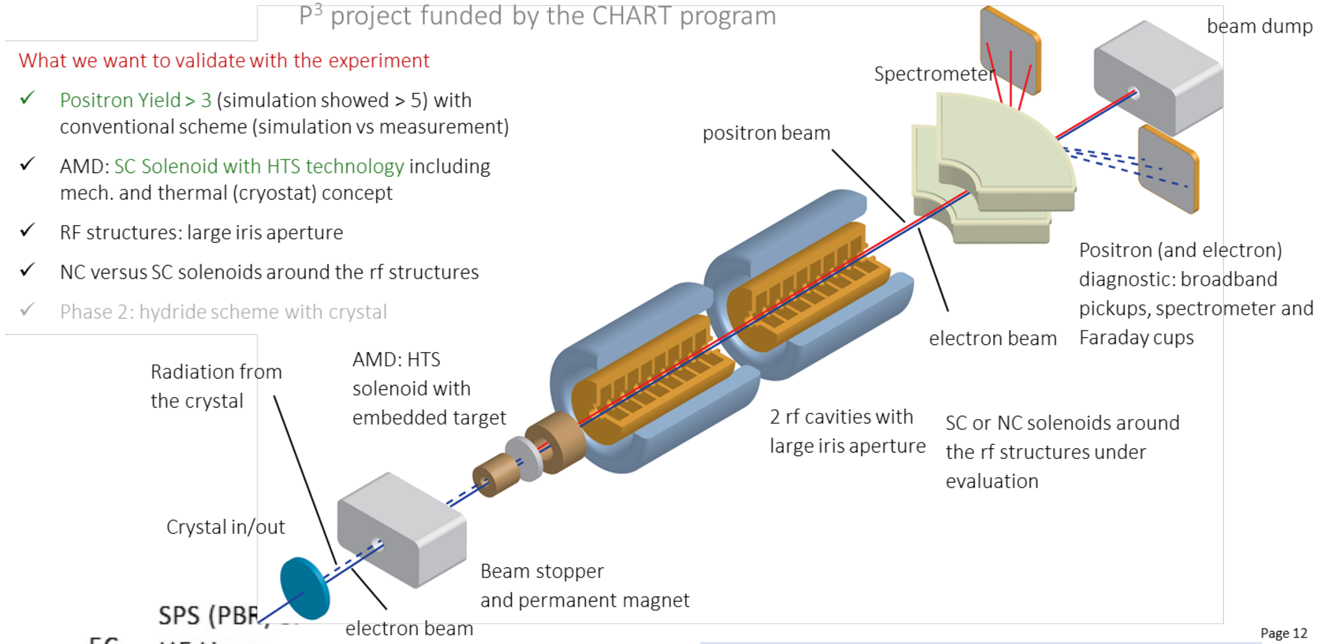
Massachusetts Institute of Technology

M. Koratzinos

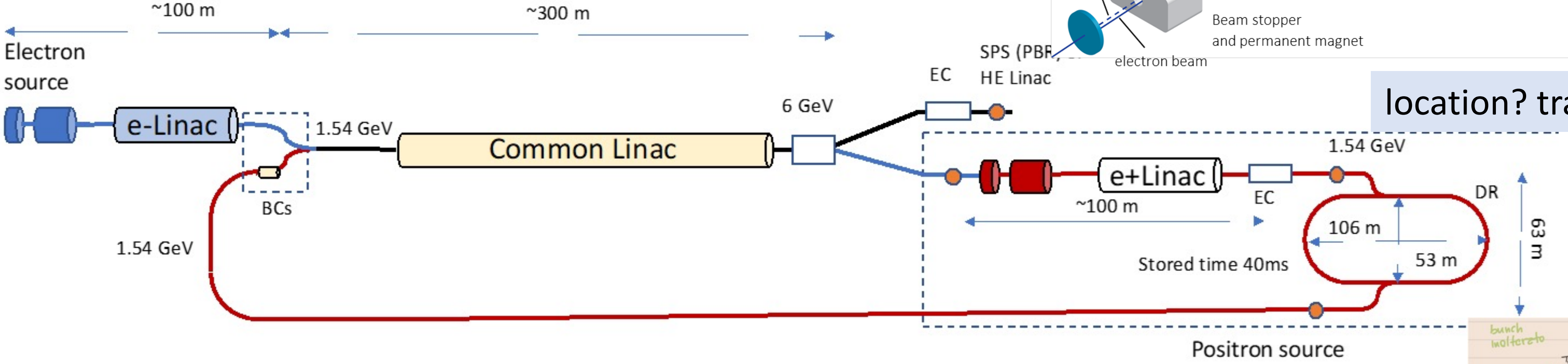
FCC-ee Pre-Injector - Swiss CHART 2 program

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

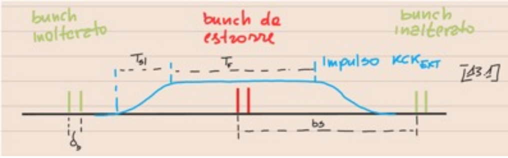
P^3: PSI e^+ production experiment with HTS solenoid at SwissFEL planned for 2024/25



Latest FCC-ee pre-injector layout



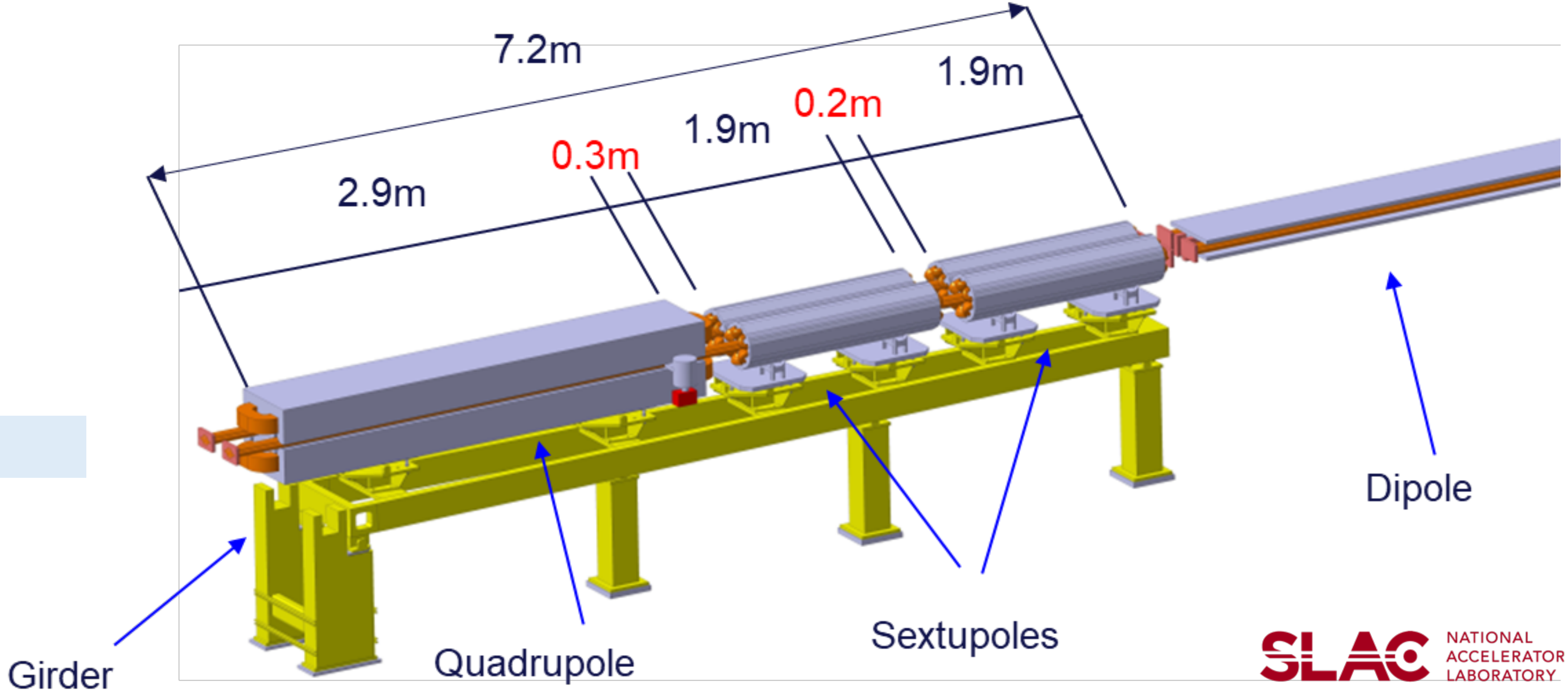
location? transfer lines?



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

FCC-ee Arc Mockup

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



F. Carra et al.

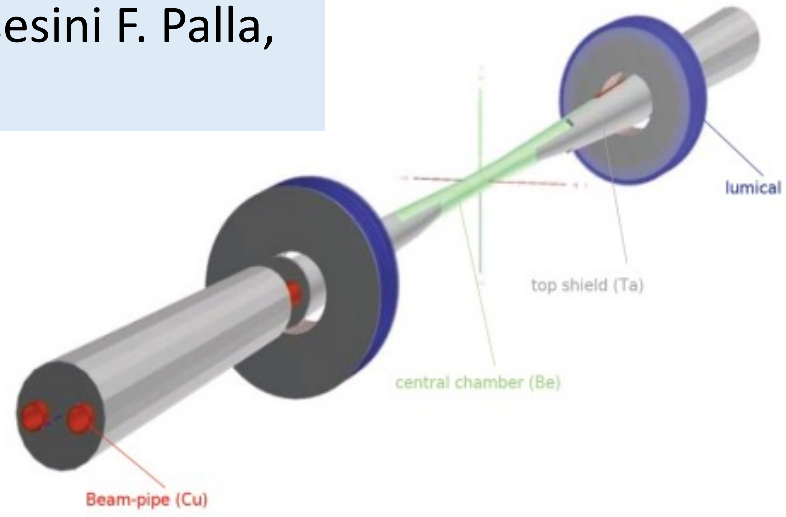
FCC-ee IR Mockup

IP chamber: critical for performance, MDI

Step 1: Central IP vacuum chamber (test cooling and vacuum systems), **AlBeMet162 & steel transition** (shape of transition, EBW process), **Bellows** (vacuum and thermal tests), **Welding** (EBW for elliptical geometry), **C-fibre support structure**

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, F. Fransesini F. Palla, et al.



SLAC NATIONAL ACCELERATOR LABORATORY

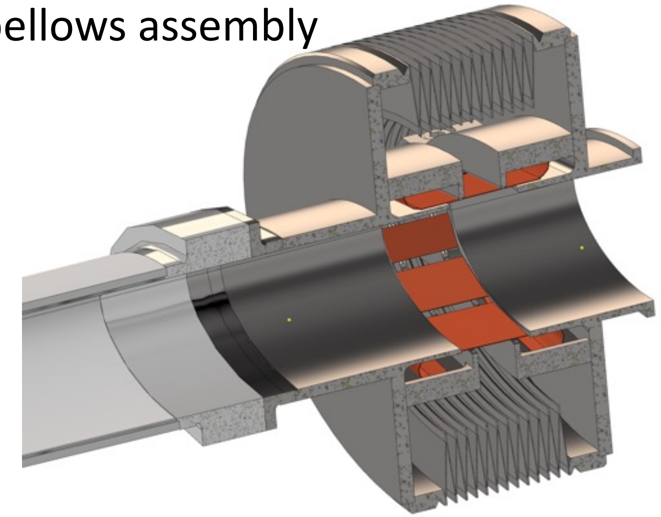
INFN LNF Istituto Nazionale di Fisica Nucleare

LAPP Laboratoire d'Annecy de Physique des Particules

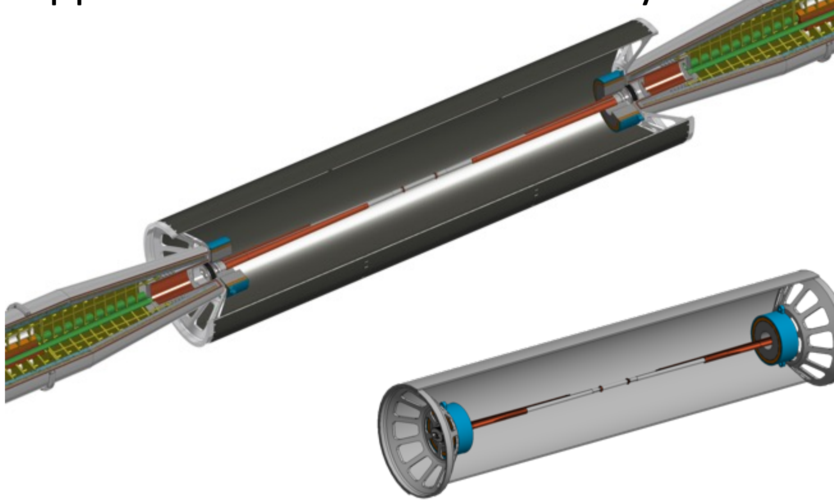
CERN

INFN Istituto Nazionale di Fisica Nucleare Sezione di PISA

bellows assembly

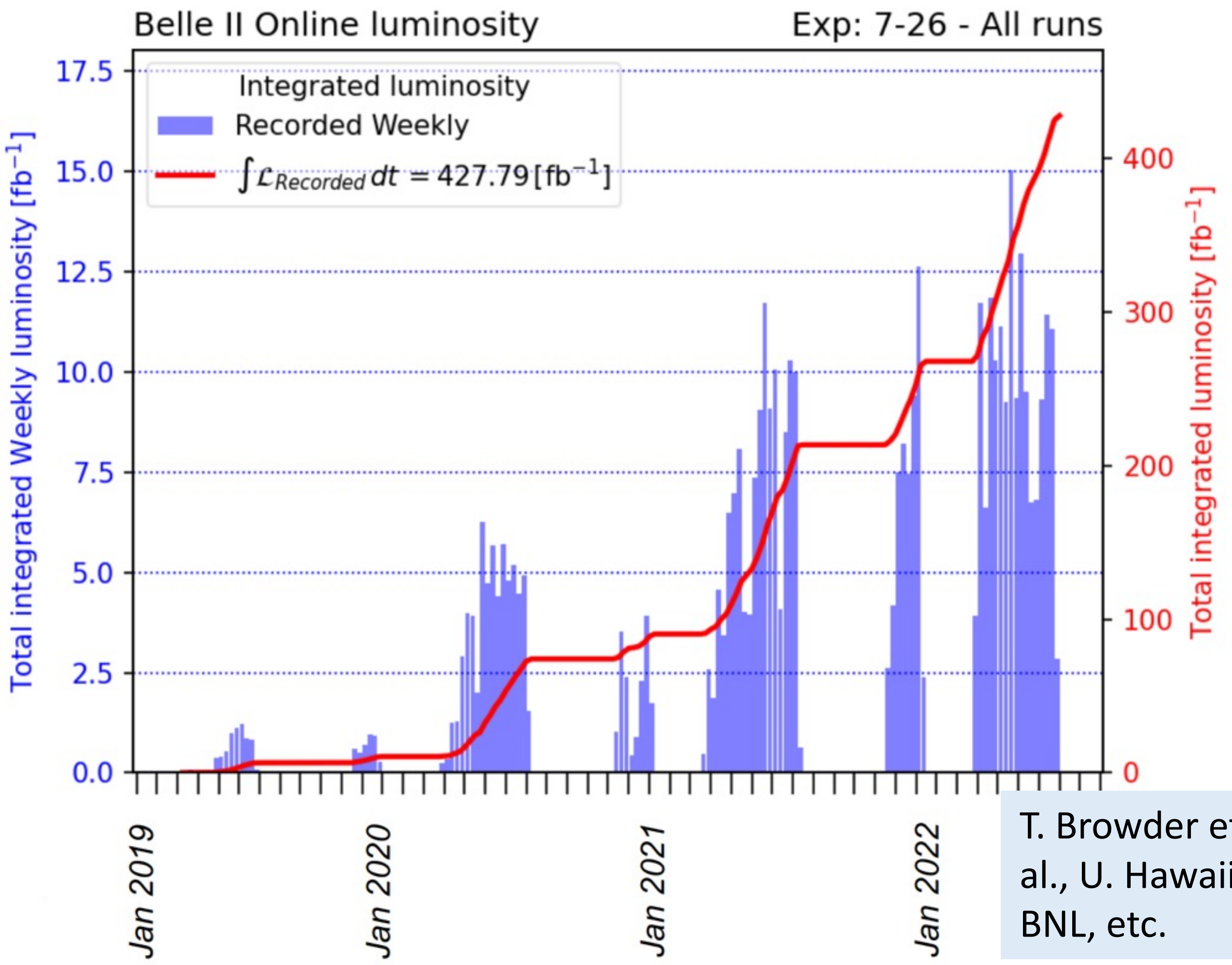


support tube with carbon fiber cylinder



SuperKEKB / Belle II

Design: double ring e^+e^- collider as *B*-factory at 7(e^-) & 4(e^+) GeV; target luminosity ~6 x 10^{35} $cm^{-2}s^{-1}$; β_y^* ~ 0.3 mm; beam lifetime ~5 min; top-up inj.; e^+ rate up to ~ 2.5 10^{12} /s ; under commissioning



T. Browder et al., U. Hawaii, BNL, etc.

$\mathcal{L}_{peak}$ = 4.7 x 10^{34}/cm²/sec
nanobeams: vertical beam spot size 300nm (design 50nm)

This is four-times PEP-II peak with much lower beam currents.

>2 x higher than KEKB

Not easy:
ran throughout the two years of the COVID-pandemic with social distancing.

Integrated a BaBar size data sample, 428 fb^{-1}. Need more running time.

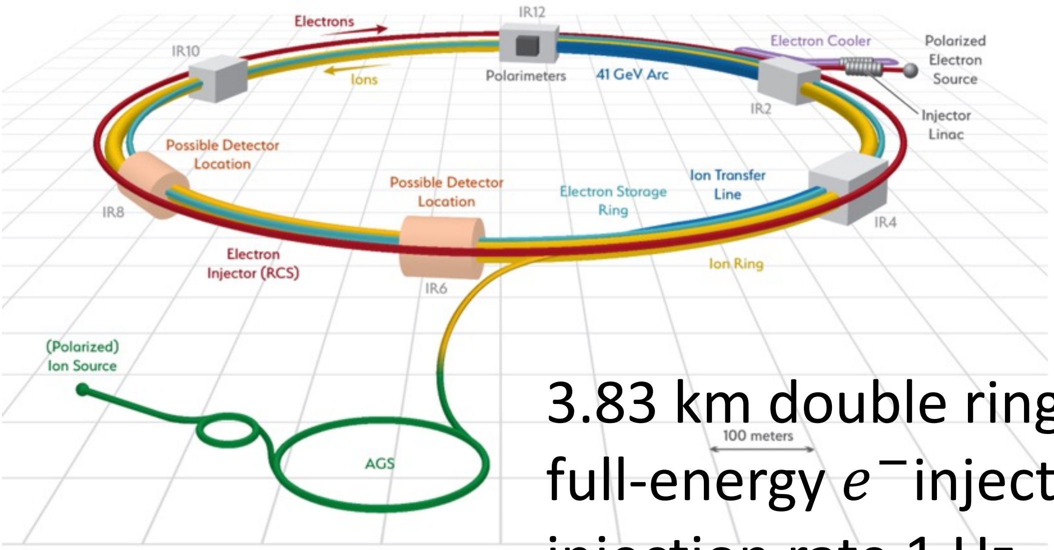
world record luminosity of 4.71×10^{34} $cm^{-2}s^{-1}$ on 22 June 2022, β_y^* = 1.0 mm in routine operation, also β_y^* = 0.8 mm demonstrated in both rings – with FCC-ee-style "virtual" crab-waist collision scheme originally developed for FCC-ee (K. Oide)

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.



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

EIC will start beam operation about a decade prior to 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.

	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)

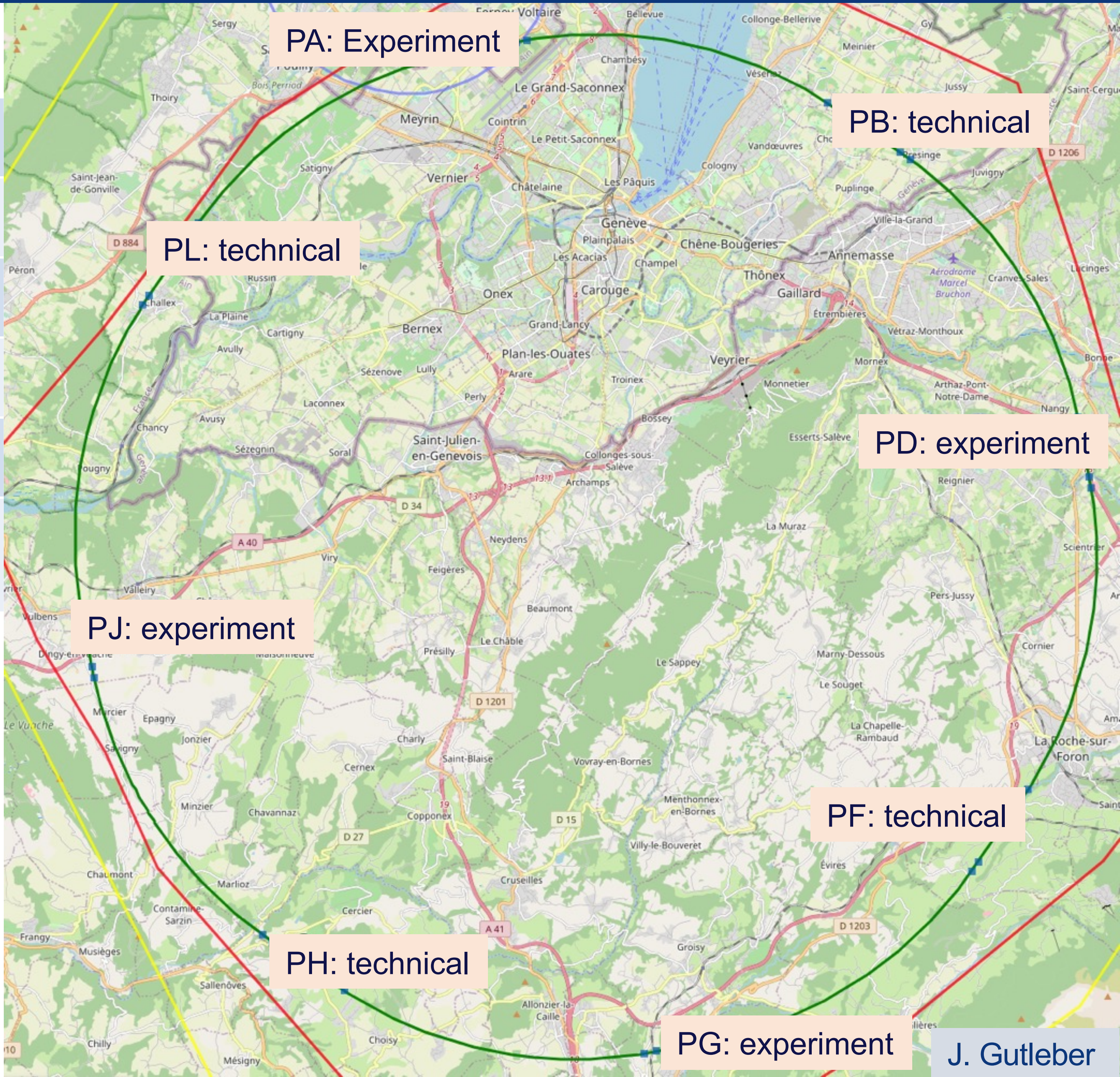
FUTURE CIRCULAR COLLIDER

optimized placement and layout

8-site baseline “PA31”

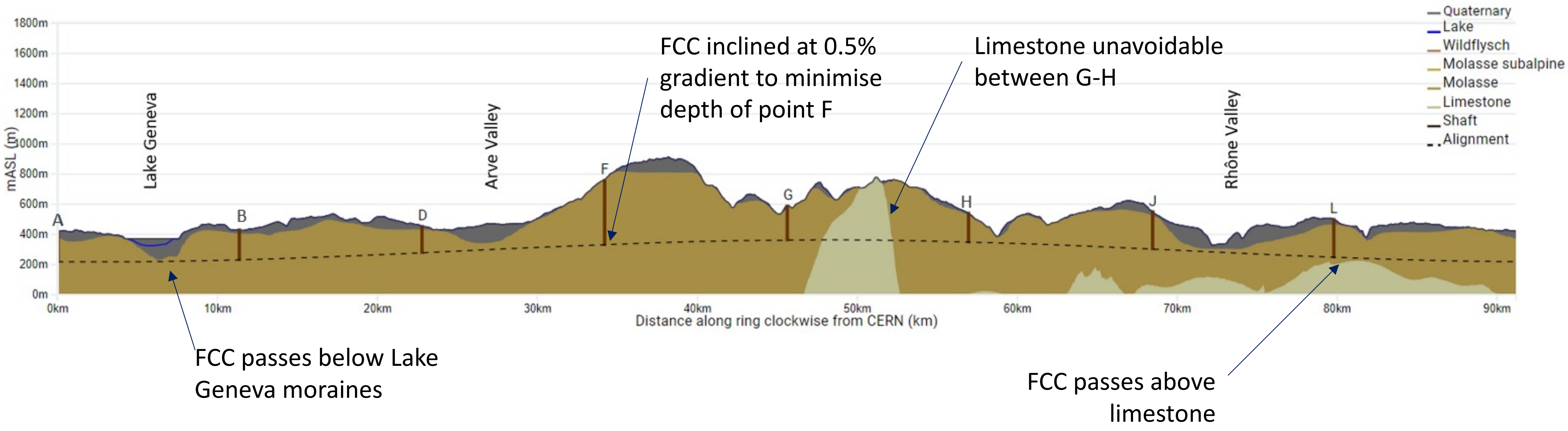
Number of surface sites	8
LSS@IP (PA, PD, PG, PJ)	1400 m
LSS@TECH (PB, PF, PH, PL)	2143 m
Arc length	9.6 km
Sum of arc lengths	76.9 m
Total length	**91.1 km**

- 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



J. Gutleber

FCC Long Section – PA31-1.0

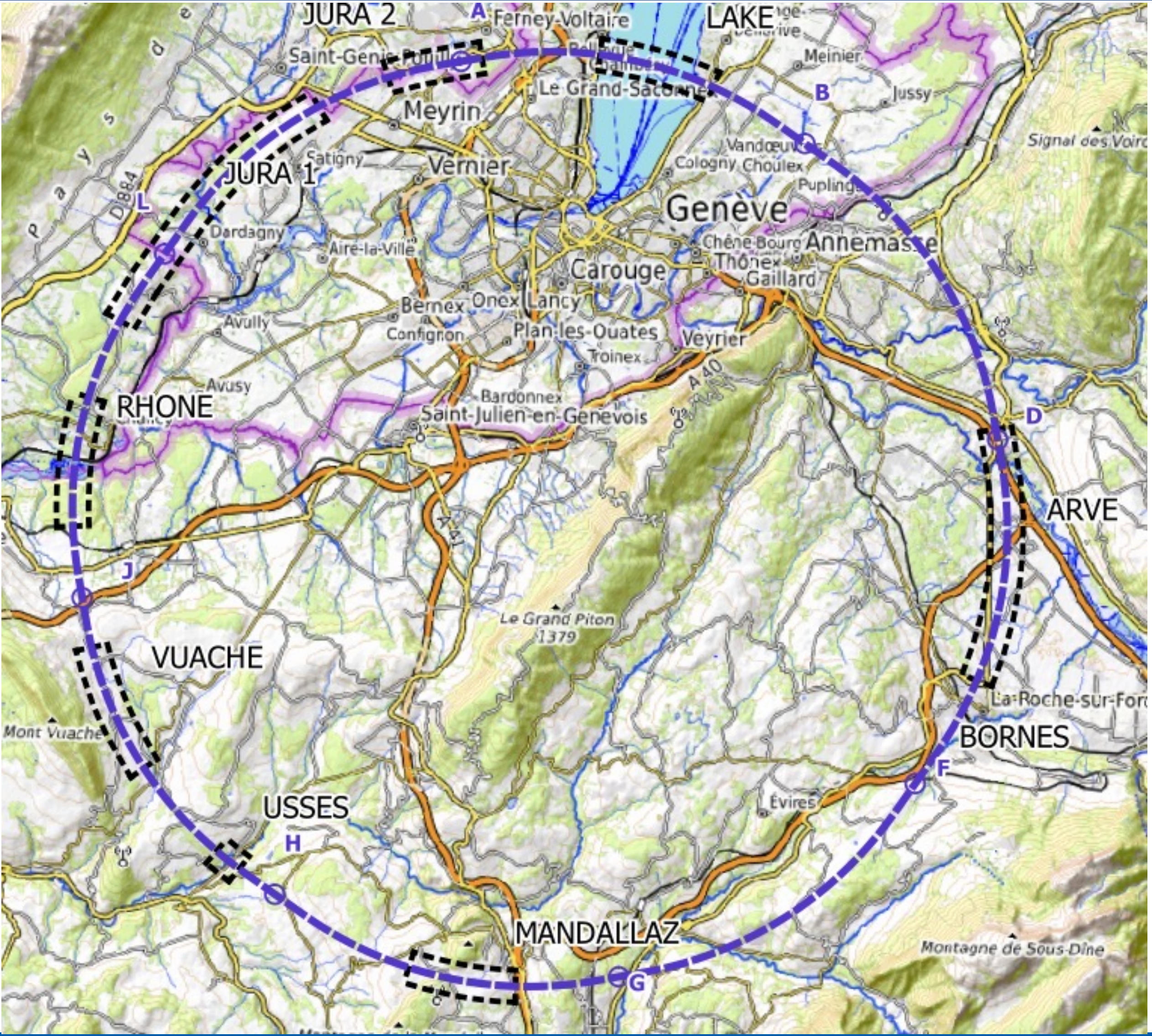


Shaft depth:

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 AREAS)
Water pressure at the tunnel level
Karstification

BORNES (1 AREA)
High overburden molasse properties
Thrust zones

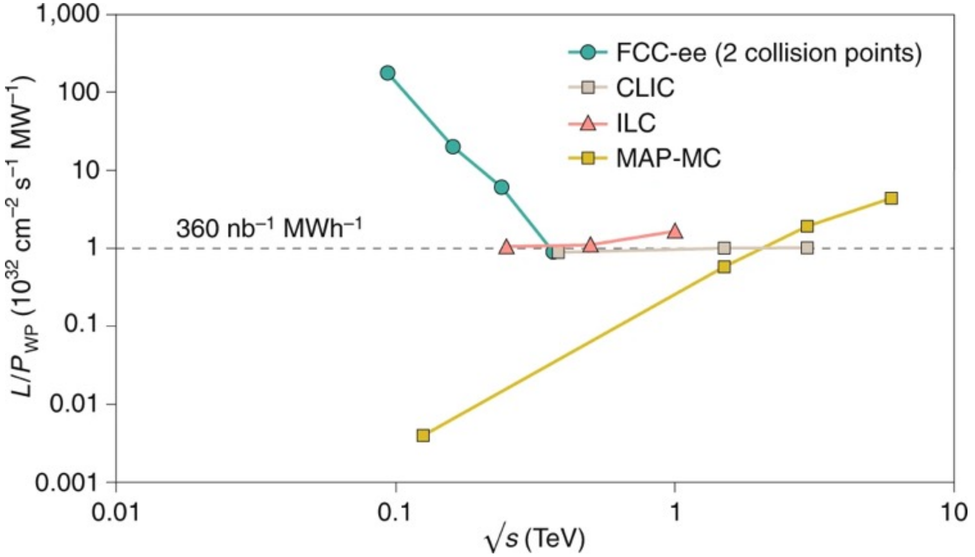
Site investigations planned for 2024 – 2025:
~40-50 drillings, some 100 km of seismic lines

sustainability and carbon footprint studies

FUTURE CIRCULAR COLLIDER

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

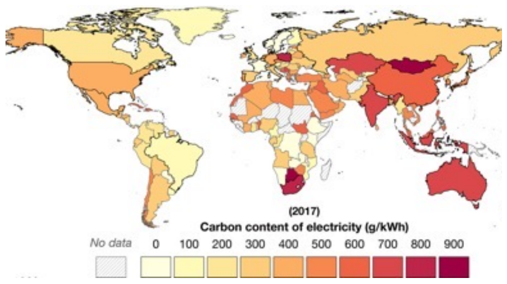
120 GeV	Days	Hours	Power OP	Power Com	Power MD	Power TS	Power Shutdown		
Beam operation	143	3432	293					1005644	MWh
Downtime operation	42	1008	109					110266	MWh
Hardware, Beam commissioning	30	720		139				100079	MWh
MD	20	480			177			85196	MWh
technical stop	10	240				87		20985	MWh
Shutdown	120	2880					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

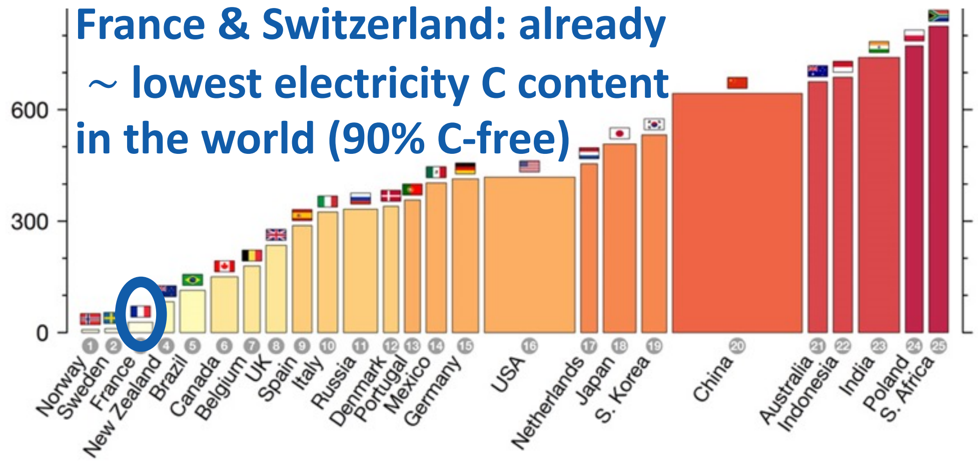
CERN Meyrin, SPS, FCC	Z	W	H	TT
Beam energy (GeV)	45.6	80	120	182.5
Energy consumption (TWh/y)	1.82	1.92	2.09	2.54

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)



FUTURE CIRCULAR COLLIDER

sustainability compared with other Higgs factories

TWh / year for the "Higgs factory" centre-of-mass energy

Patrick Janot

https://indico.cern.ch/event/1178975/

$\sqrt{s}$ = 240 GeV for CEPC/FCC-ee, 250 GeV for ILC/C3, 380 GeV for CLIC

CLIC	ILC	C3	FCC-ee	CEPC
0.8	0.9	0.9	1.1	2.0

P. Janot and A. Blondel, *Who is the greenest? - The environmental footprint of future Higgs boson studies*, arXiv 2208.10466 (2022); https://arxiv.org/abs/2208.10466

Energy consumption in MWh / Higgs

CLIC	ILC	C3	CEPC	FCC-ee
30	20	21	10	3.3

becomes 2 MWh / Higgs for FCC-ee with 4 IPs

Present carbon footprint for electrical energy in tons CO_2 / Higgs

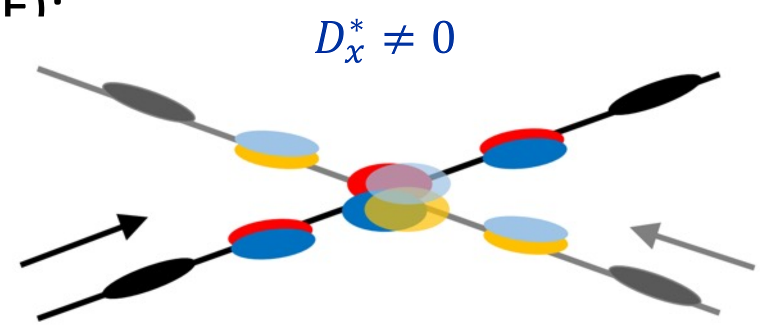
CLIC@CERN	ILC@KEK	C3@FNAL	CEPC@China	FCC-ee@CERN
2.1	7.8	8.5	6.1	0.24

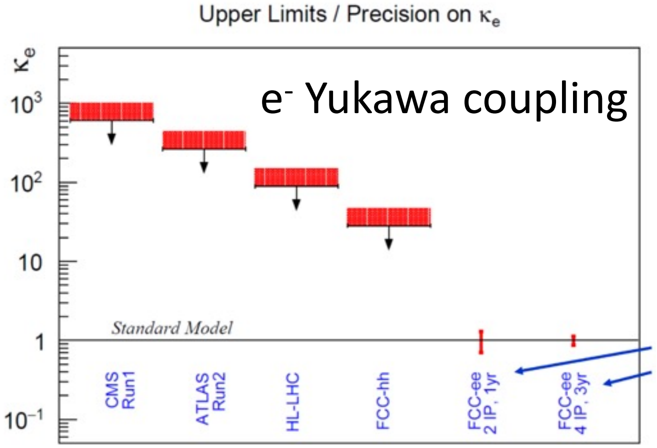
0.14 ton CO_2 / Higgs for FCC-ee with 4 IPs

future upgrades and uses

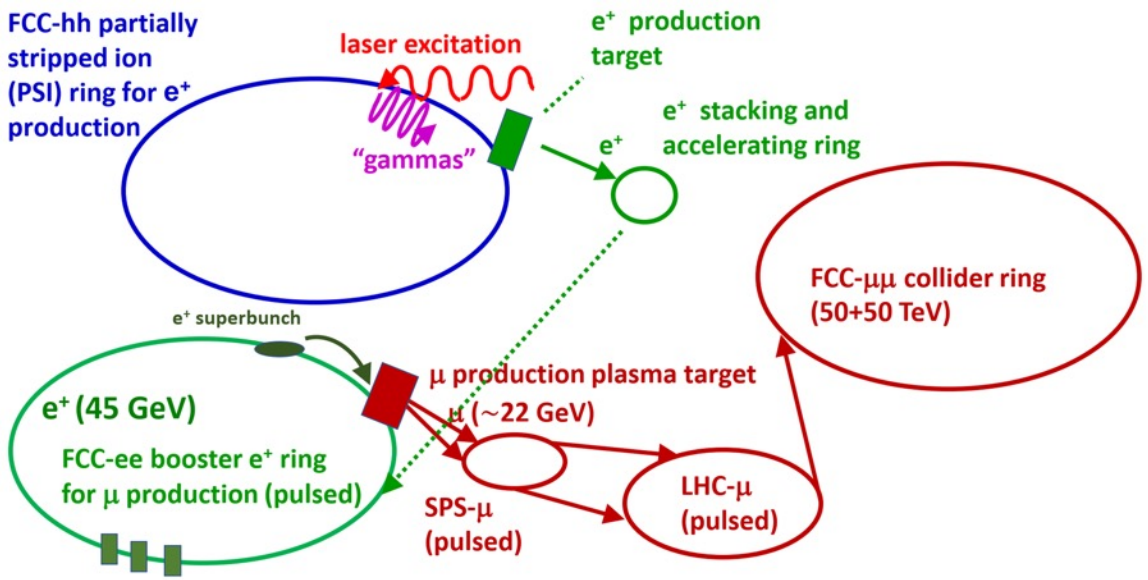
- FCC-ee: not only Higgs, but **Z and W factory** (TeraZ); **$t\bar{t}$ upgrade** (~1 BCHF);
- optional **direct *s*-channel Higgs production** at 125 GeV with **monochromatization**
- **civil construction & technical infrastructures shared with** [and prepare] 100 TeV **hadron collider FCC -hh – stage 2 of FCC integrated program** (next slide)
- numerous other possible extensions (ep/eA/AA, Gamma Factory, LEMMA-type μ collider FCC-μμ ? …, ERL upgrade ? …)

A. Faus-Golfe et al., Eur. Phys. J. Plus, 137 (2022) 31



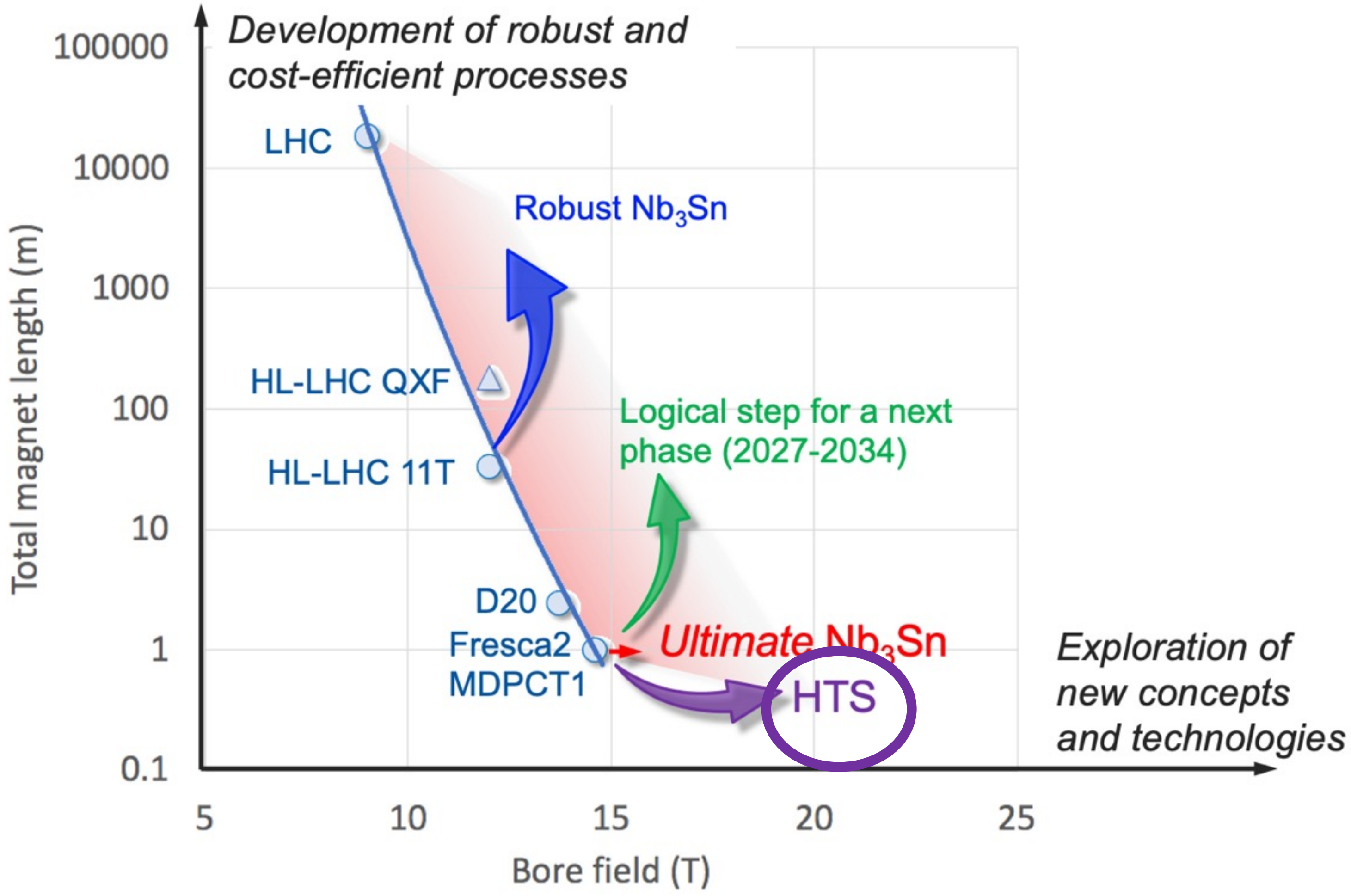


F. Zimmermann et al., PAC'22, Bangkok, WEPOST009



preparing for FCC stage 2 (FCC-hh)

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

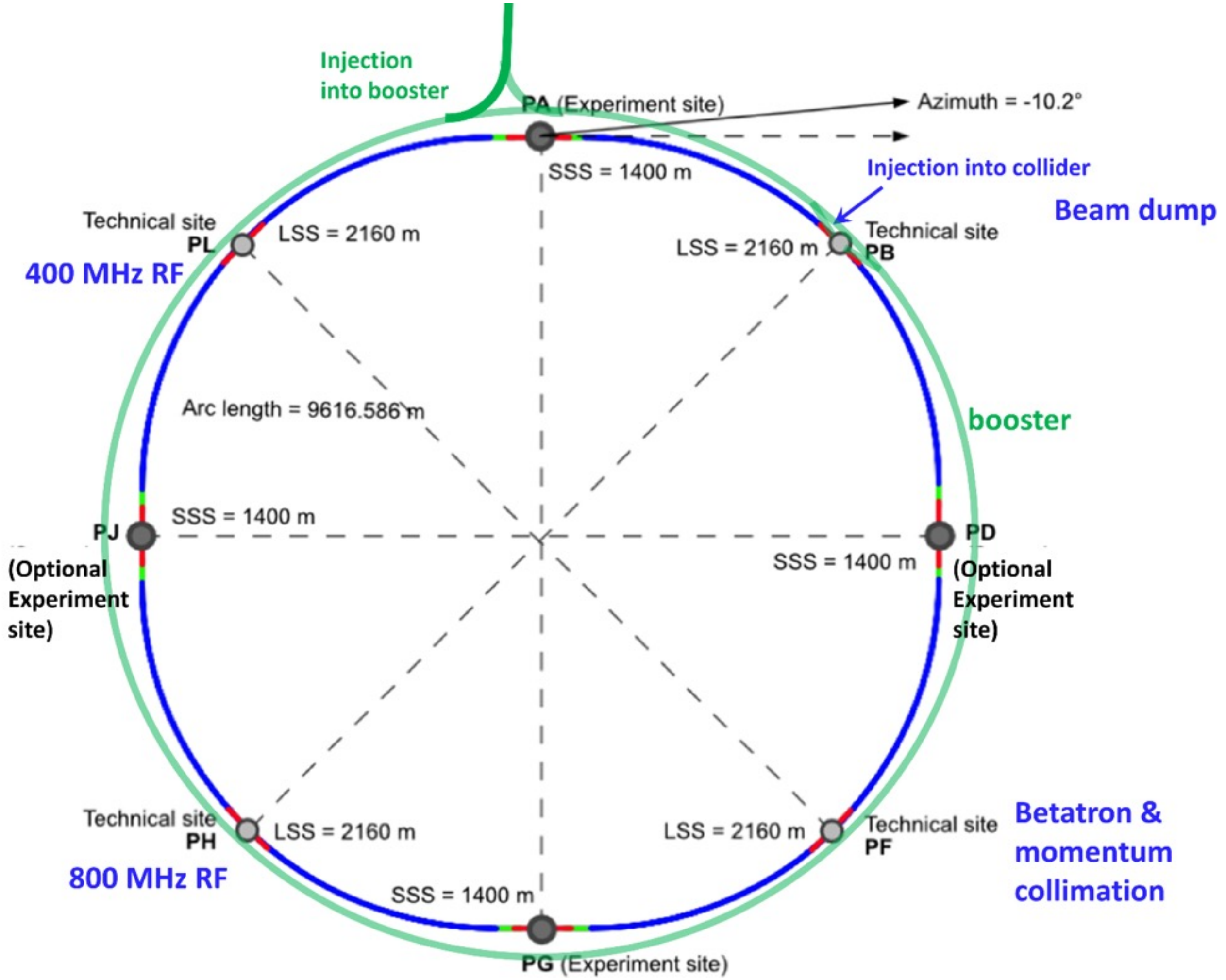
L. Bottura, F. Gianotti, A. Siemko

new layouts & preliminary assignments of straight sections

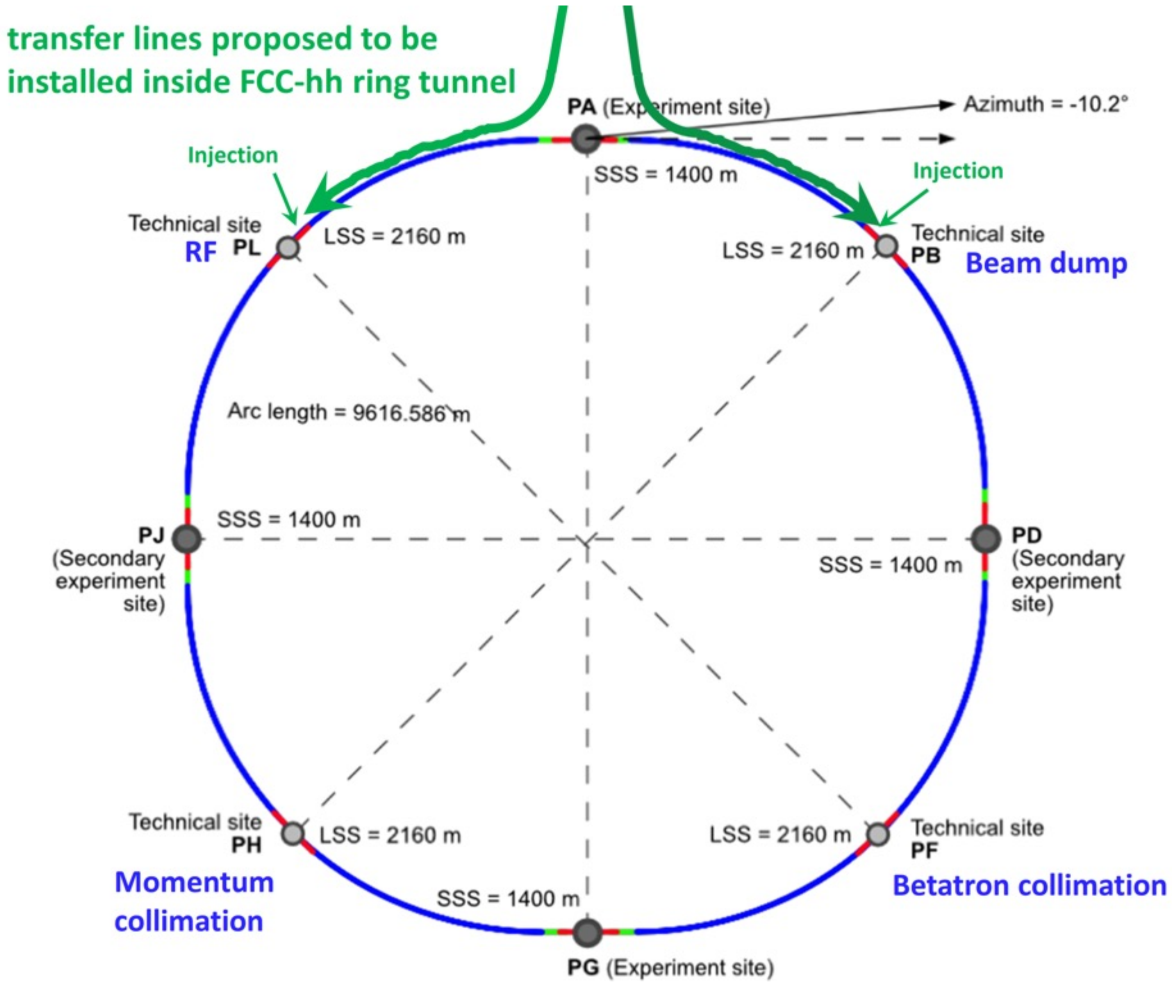
injection-tunnel near PA; 400 MHz RF in PL; 4 exp. caverns for both

4-fold periodicity, synergies ee & hh

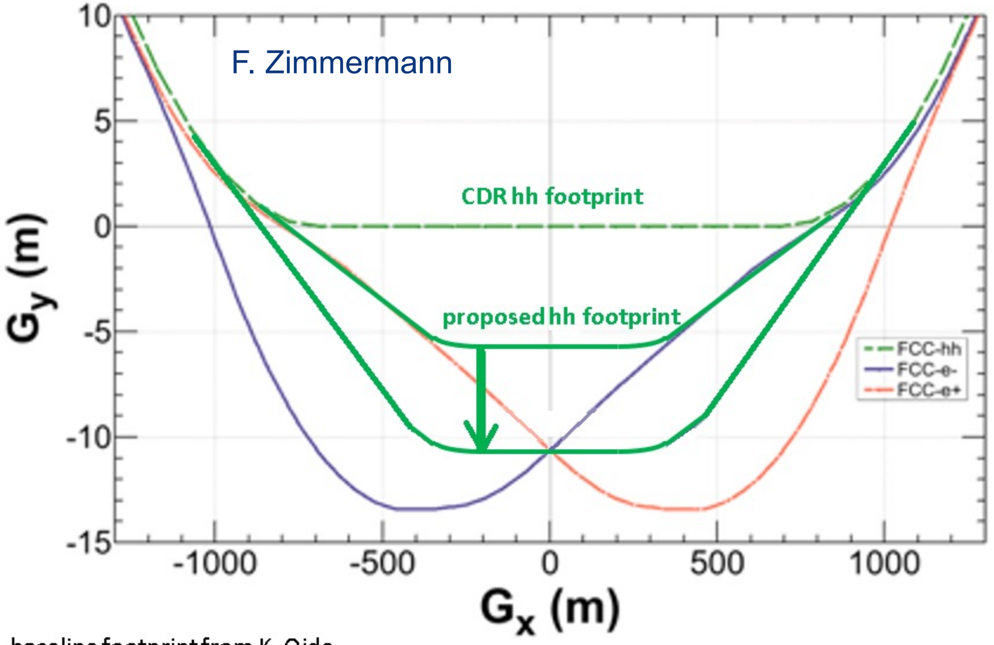
FCC-ee



FCC-hh



layout optimisation of high-luminosity insertions

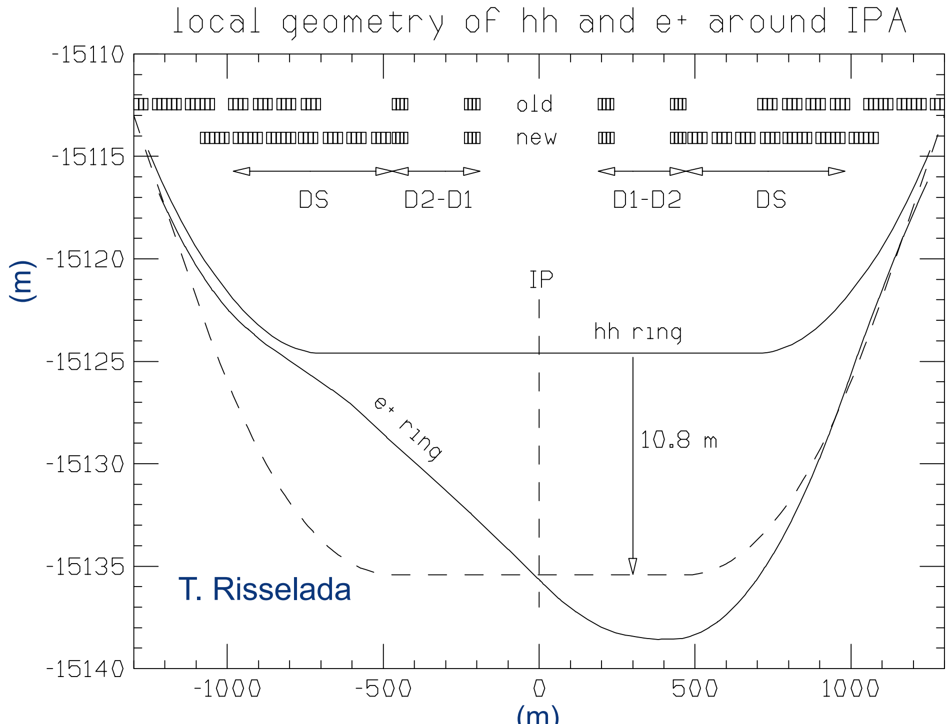


baseline footprint from K. Oide

In CDR:

- Due to FCC-ee asymmetric IR layout, transverse displacement of IPs for FCC-ee and FCC-hh.
- FCC-hh footprint compatible with FCC-ee injector

Massimo Giovannozzi & Thys Risselada



Implementation of an improved layout with FCC-ee & FCC-hh IPs with same transverse positions

Advantages:

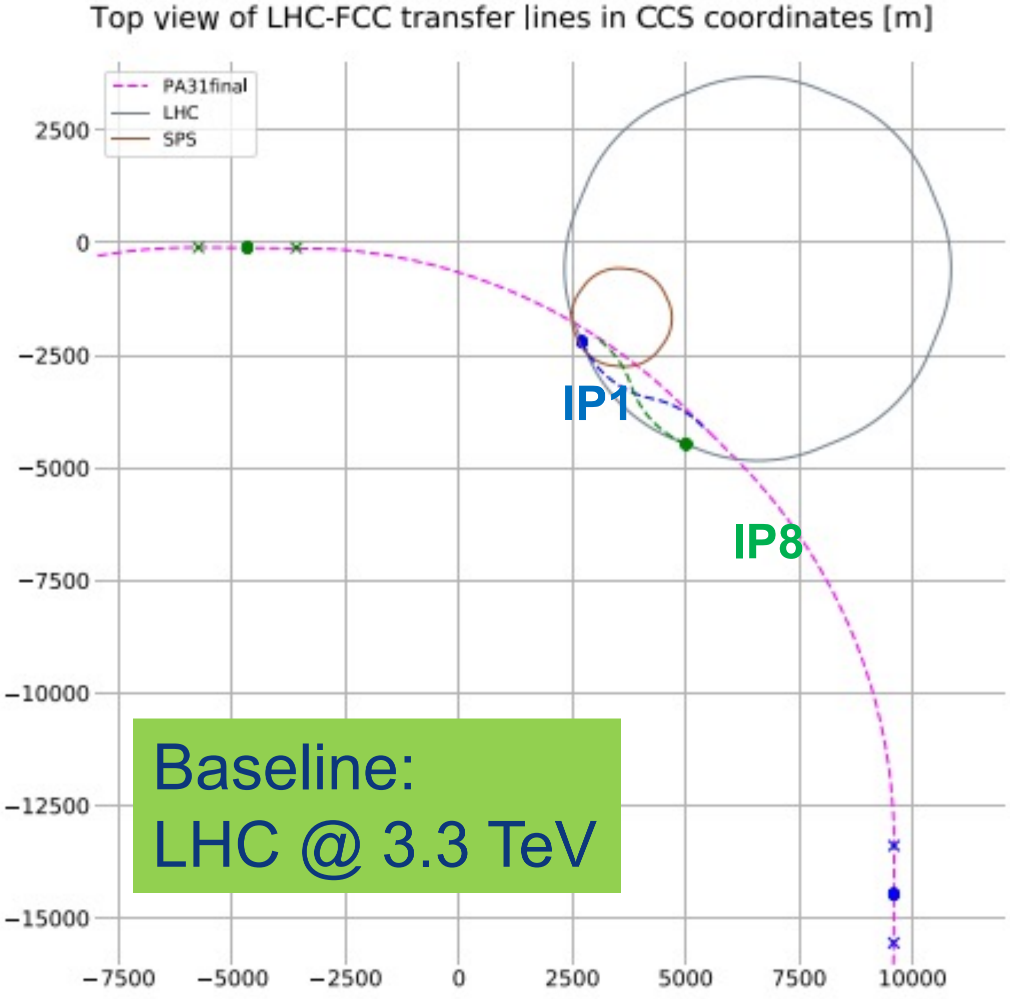
- **Transverse size of detector cavern reduced**
- **Tunnel width reduced over 2 x 500 m**
- **Potential re-use of FCC-ee detector magnets for FCC-hh**

Stage 2: FCC-hh (pp) collider parameters

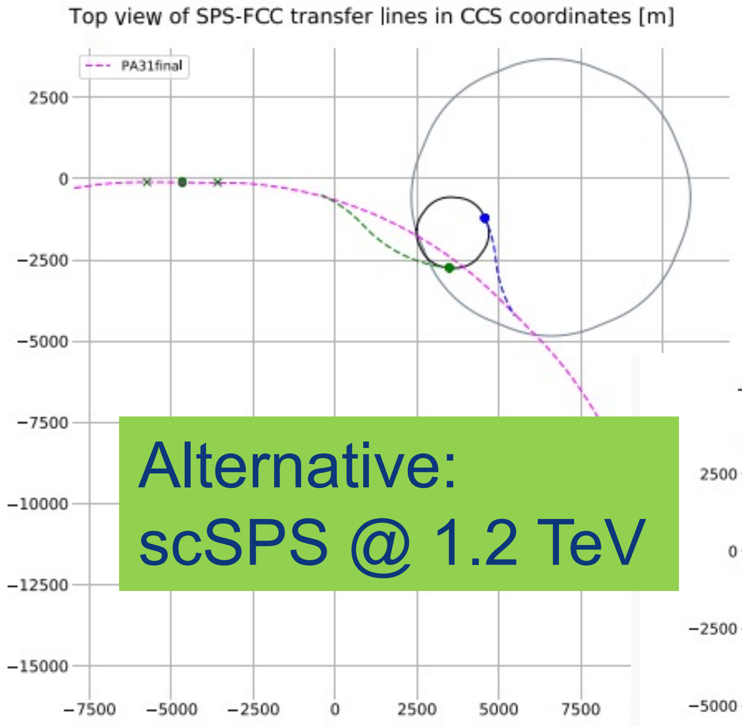
parameter	FCC-hh		HL-LHC	LHC
collision energy cms [TeV]	100		14	14
dipole field [T]	~17 (~16 comb.function)		8.33	8.33
circumference [km]	91.2		26.7	26.7
beam current [A]	0.5		1.1	0.58
bunch intensity [10^{11}]	1	1	2.2	1.15
bunch spacing [ns]	25	25	25	25
synchr. rad. power / ring [kW]	2700		7.3	3.6
SR 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 hadron injector lines for new layout

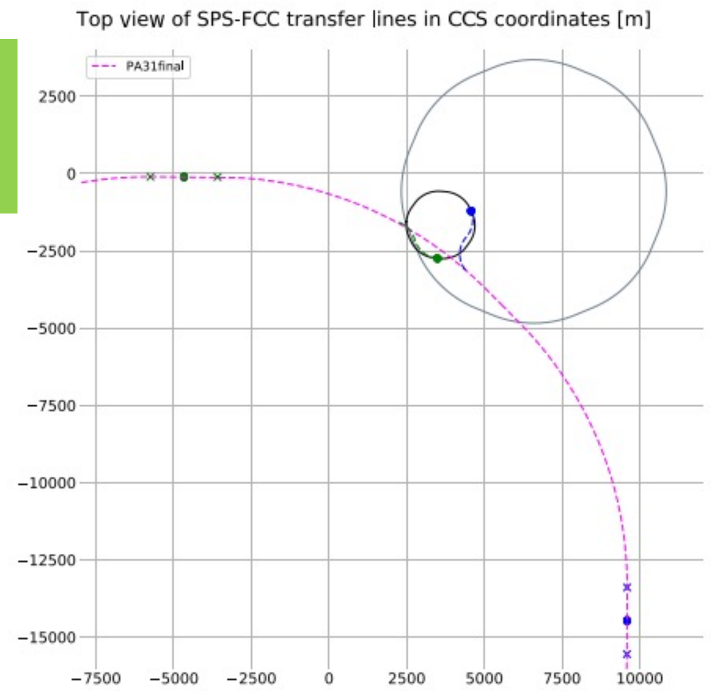
injection from LHC



Wolfgang Bartmann



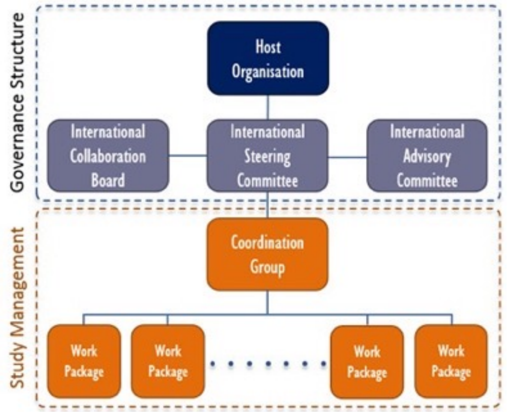
injection from scSPS
NC (left) or
SC transfer lines (below)



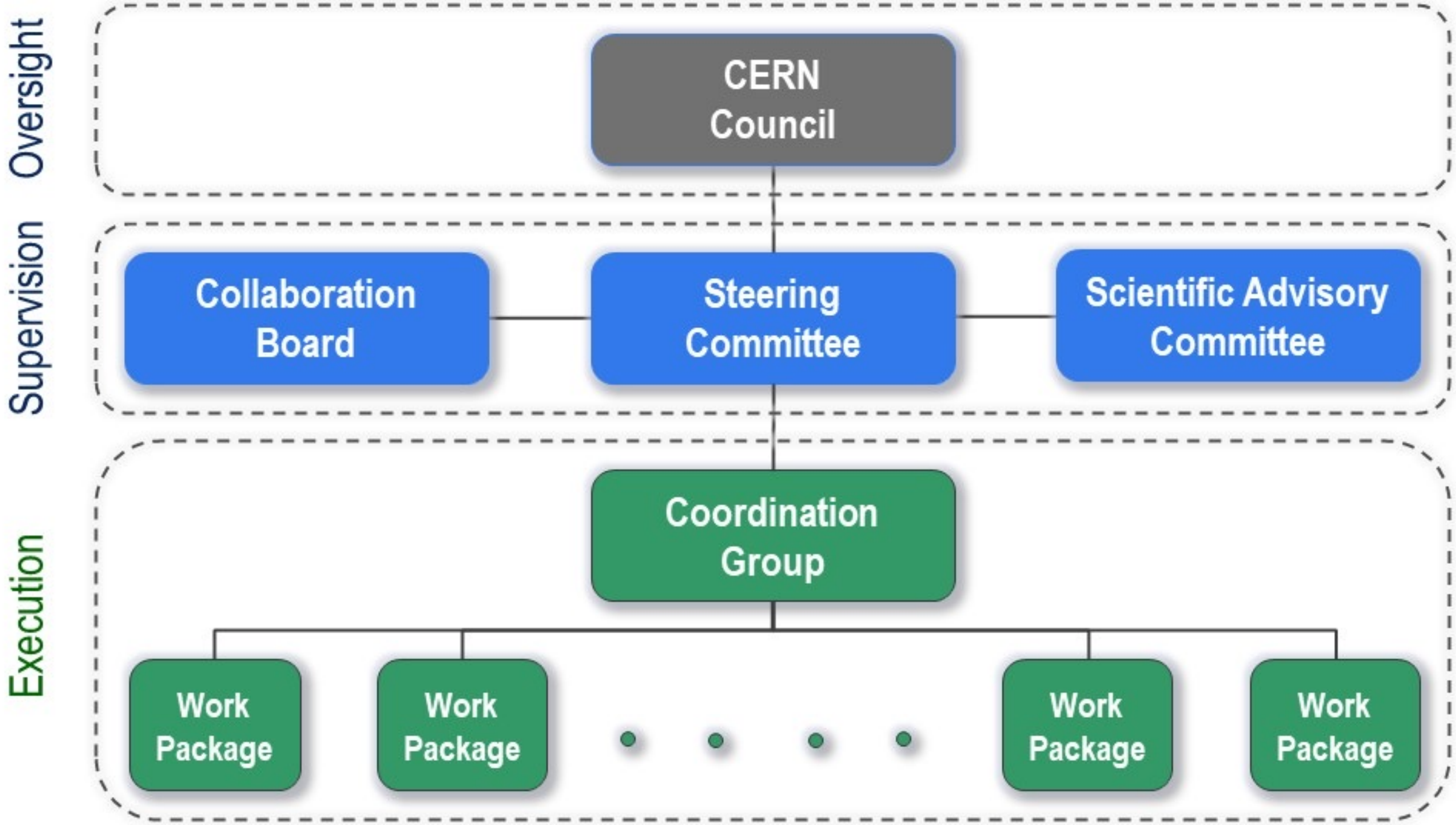
tunnel lengths:
- LHC, SC, 3.2/3.5 km
- SPS, NC, 4.6/3.2 km
- SPS, SC, 1.5/2.1 km

FCC Feasibility Study - organisational structure

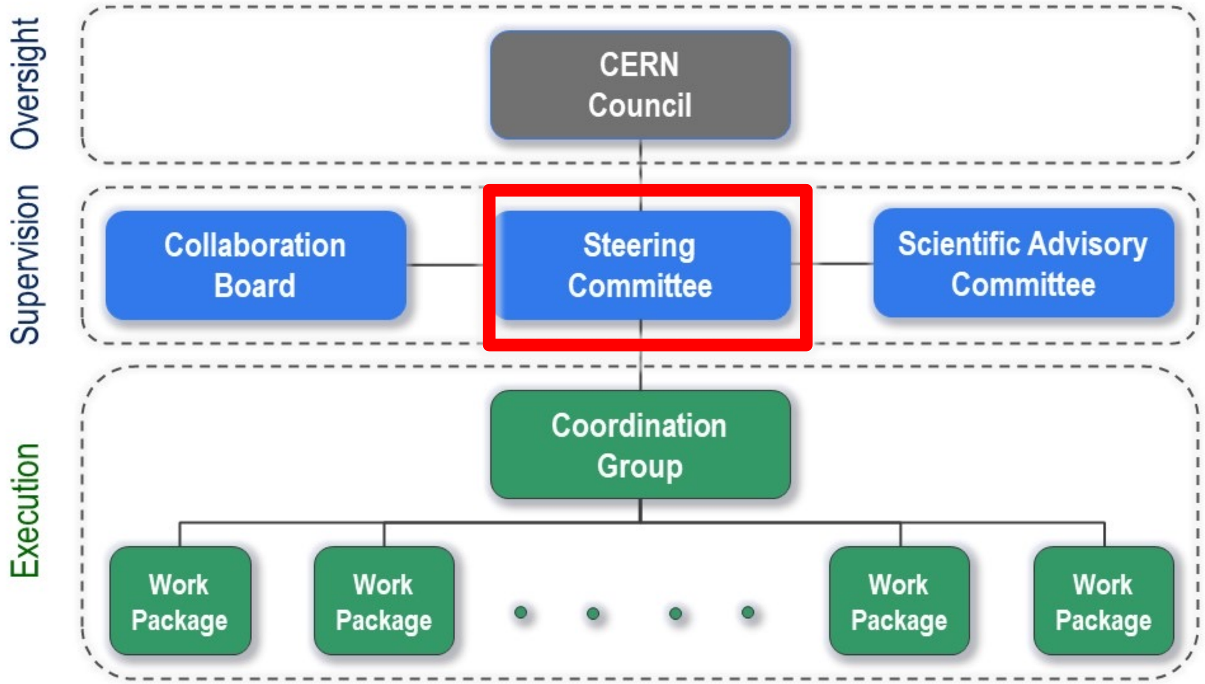
- New structure very similar to the first phase of the FCC Study (2014-2020), leading to the Conceptual Design Report as input to the ESPPU.



- Classical structure common to CERN projects.



FCC Steering Committee (SC)



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

Members:

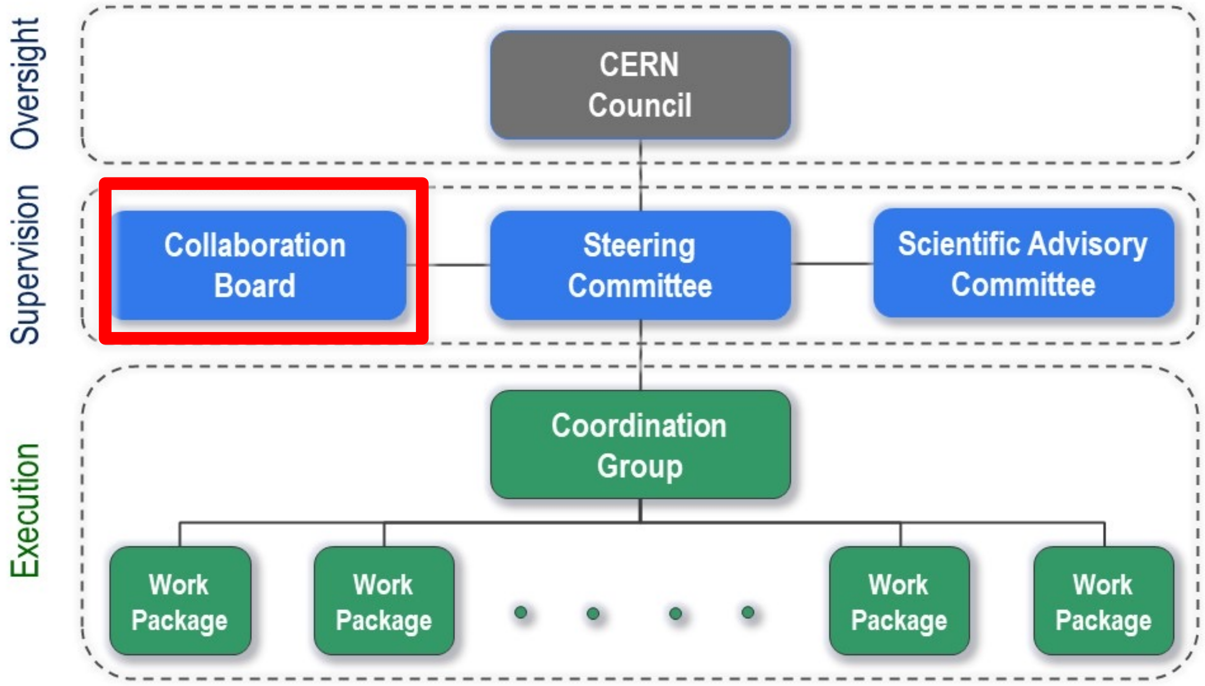
- CERN DG (SC Chair),
- The members of the CERN Directorate,
- the Chair of the CB,
- and up to 5 members nominated by the CB,
- the FCC Study Leader w/o voting rights
- the Council president as observer

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)

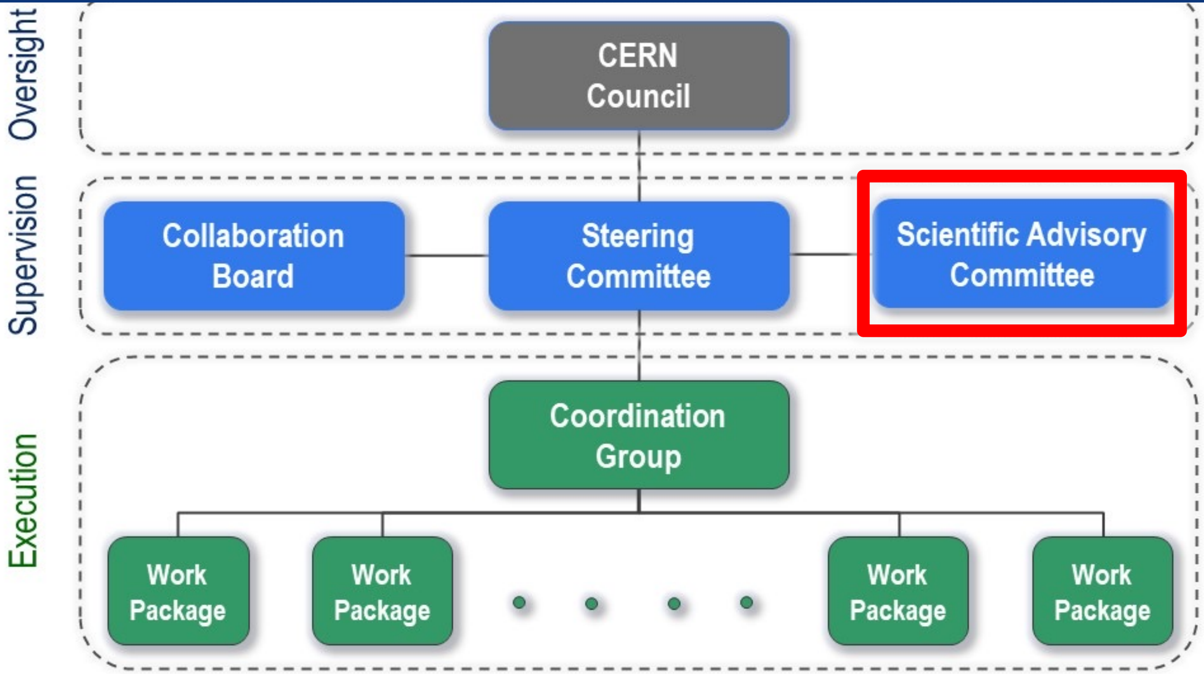


CB reviews the work needs and resource requirements and their sharing among the participating institutes; appoints up to five members of the Steering Committee from among the participating institutes.

<u>Members:</u>
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/India)

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 Feasibility Study

FCC

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

FUTURE CIRCULAR COLLIDER

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

147	30	34	EC
Institutes	Companies	Countries	H2020

FCC Feasibility Study: 58 fully-signed previous members, 17 new members , MoU renewal of remaining CDR participants in progress

FCC-ee Project Cost Profile - *preliminary*

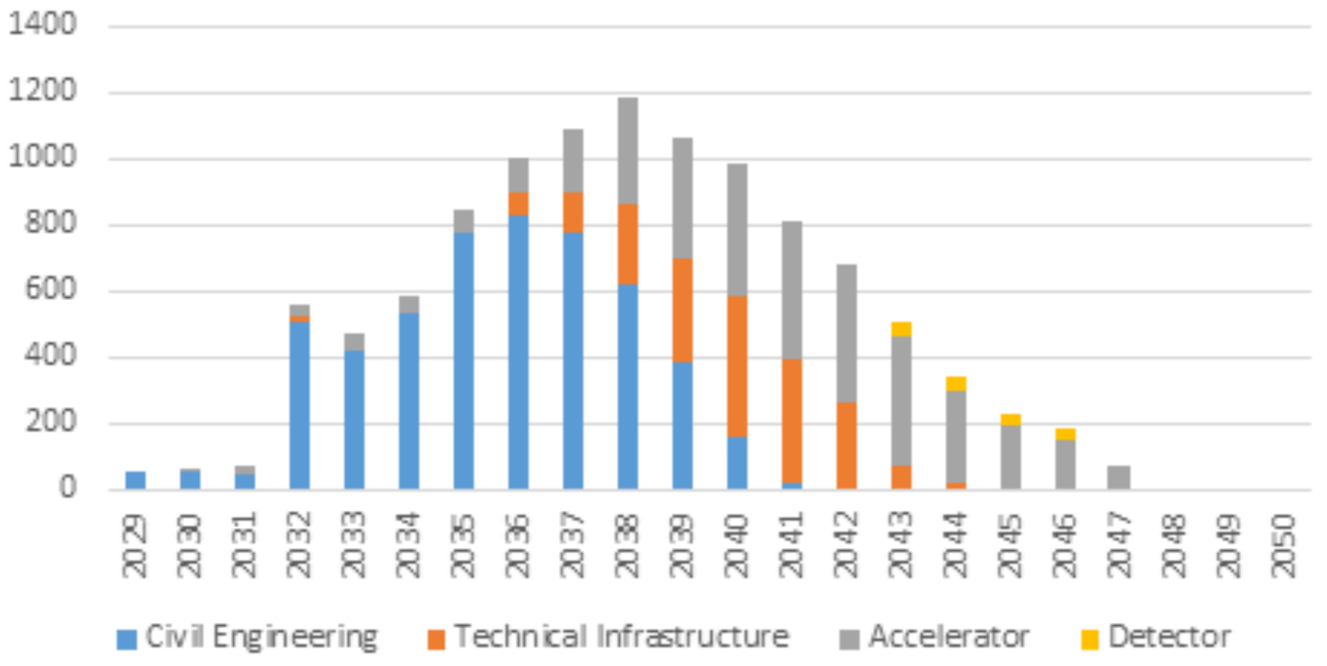
Construction cost estimate for FCC-ee (from CDR 2018, update in 2025)

- 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.



Outlook

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

Plenty of opportunities for collaborations (incl. DAFNE, EIC, SuperKEKB/Belle II,…) and for **joint innovative developments** with int’l 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 program 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 WEEK
2023
5 – 9 June
STAY TUNED