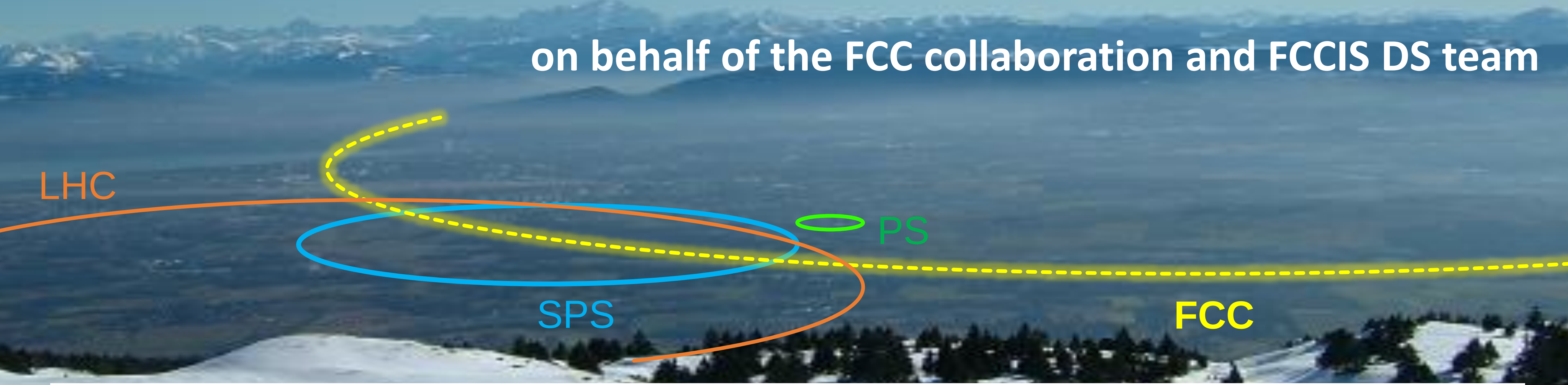
FCC Status and Plans

Michael Benedikt, CERN

on behalf of the FCC collaboration and FCCIS DS team



FUTURE CIRCULAR COLLIDER Innovation Study

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*

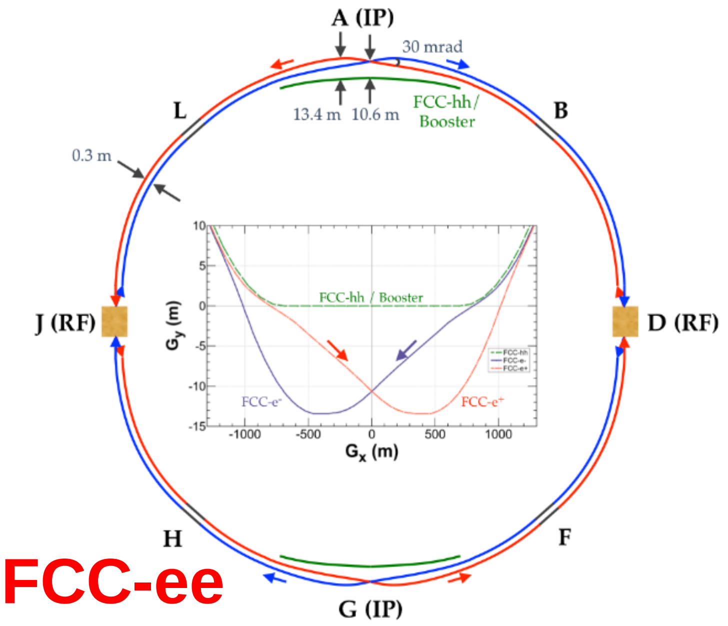
European Commission | Horizon 2020 European Union funding for Research & Innovation

photo: J. Wenninger

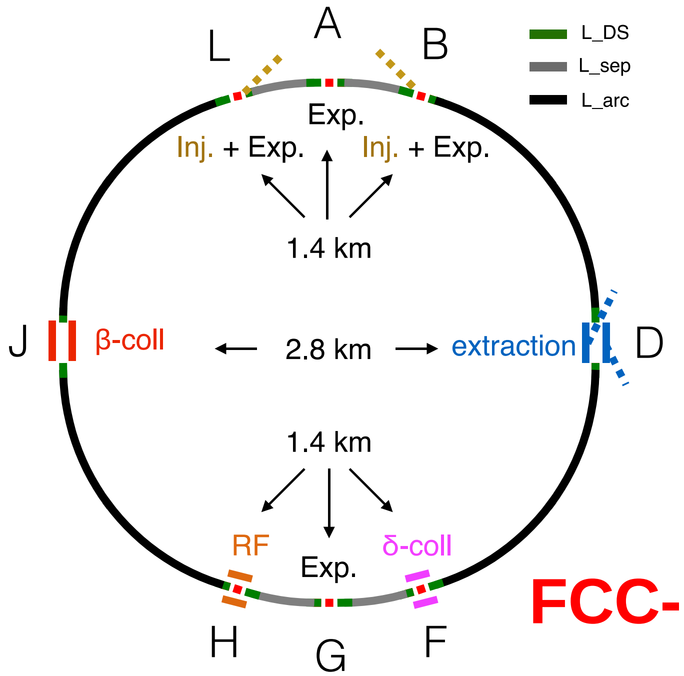
The FCC integrated program inspired by successful LEP – LHC programs at CERN

Comprehensive cost-effective program maximizing physics opportunities

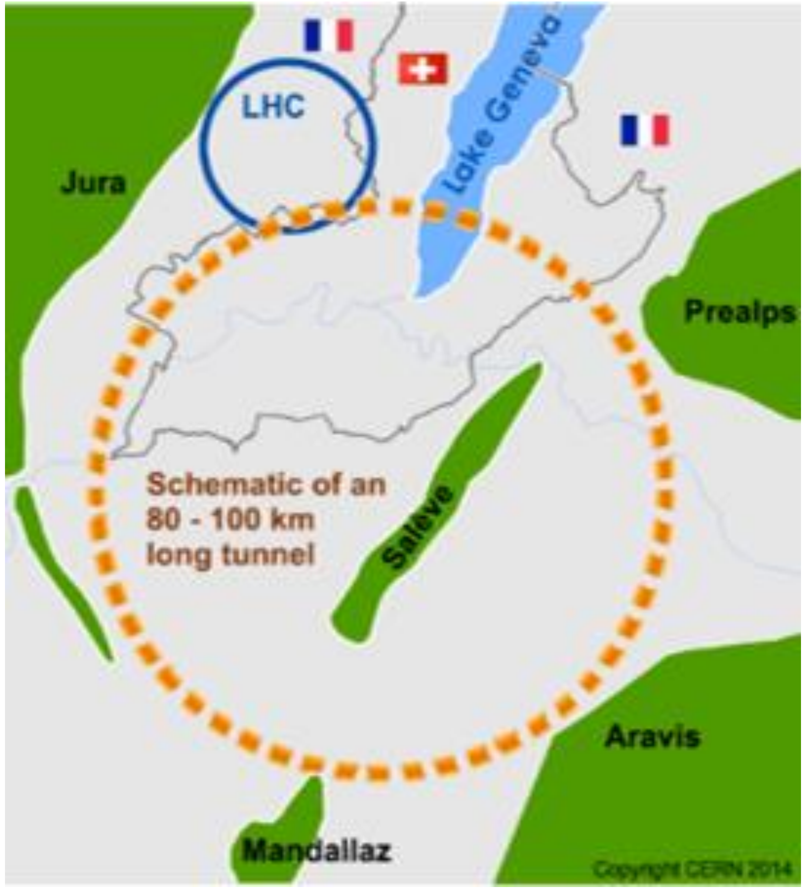
- **Stage 1: FCC-ee (Z, W, H, $t\bar{t}$) as Higgs factory, electroweak & and top factory at highest luminosities**
- **Stage 2: FCC-hh (~100 TeV) as natural continuation at energy frontier, with ion and eh options**
- Complementary physics
- Common civil engineering and technical infrastructures
- Building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



FCC-ee



FCC-hh



FCC integrated project technical schedule

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	15 years operation	34	35	36	37	38	39	40	41	42	43	~ 25 years operation	70

Project preparation & administrative processes

Permis-sions

Update Permis sions

Funding strategy

Funding and in-kind contribution agreements

Funding and in-kind contribution agreements

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 R&D and technical design

FCC-ee accelerator construction, installation, commissioning

FCC-hh accelerator R&D and technical design

FCC-hh accelerator construction, installation, commissioning

Set up of international experiment collaborations, detector R&D and concept development

FCC-ee detector technical design

FCC-ee detector construction, installation, commissioning

FCC-hh detector R&D, technical design

FCC-hh detector construction, installation, commissioning

Superconducting wire and magnet R&D, short models

Long model magnets, prototypes, preseries

16 T magnet industrialization and series production

engineering design, energy efficiency, maintainability

conductors & high-field magnet technology

From ESPPU 2020 document

Core sentence and main request "order of the further FCC study":

"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 feasibility study: main challenges

Fabiola Gianotti:
"CERN vision and goals until next strategy update"
FCCIS Kick-Off, 9 Nov. 2020

Financial feasibility

Cost of tunnel: ~5.5 BCHF; FCC-ee: ~5-6 BCHF; FCC-hh: ~17 BCHF (if after FCC-ee)

→ cannot be funded only from CERN's (constant) budget + "one-off" contributions from non-Member States → need new mechanisms (global project funding model; EC? private?)

First priority of feasibility study: find ~ 5 BCHF for the tunnel from outside CERN's budget

Technical and administrative feasibility of tunnel

- ❑ highly-populated area; two countries with different legislative frameworks
- ❑ land expropriation and reclassification
- ❑ high-risk zones
- ❑ environmental aspects

First priority of feasibility study: no show-stopper for ~100 km tunnel in Geneva region

Technologies of machine and experiments

- ❑ huge challenges, but under control of our scientific community
- ❑ pressing environmental aspects: energy, cooling, gases, etc.

First priority of feasibility study: magnets; minimise environmental impact; energy efficiency and recovery

Gathering scientific, political, societal and other support

→ requires "political work" and communication campaign for "consensus building" with governments and other authorities, scientists from other fields, industry, general public, etc.

→ can FCC be a facility also for other disciplines (nuclear science, photon science, etc.)?

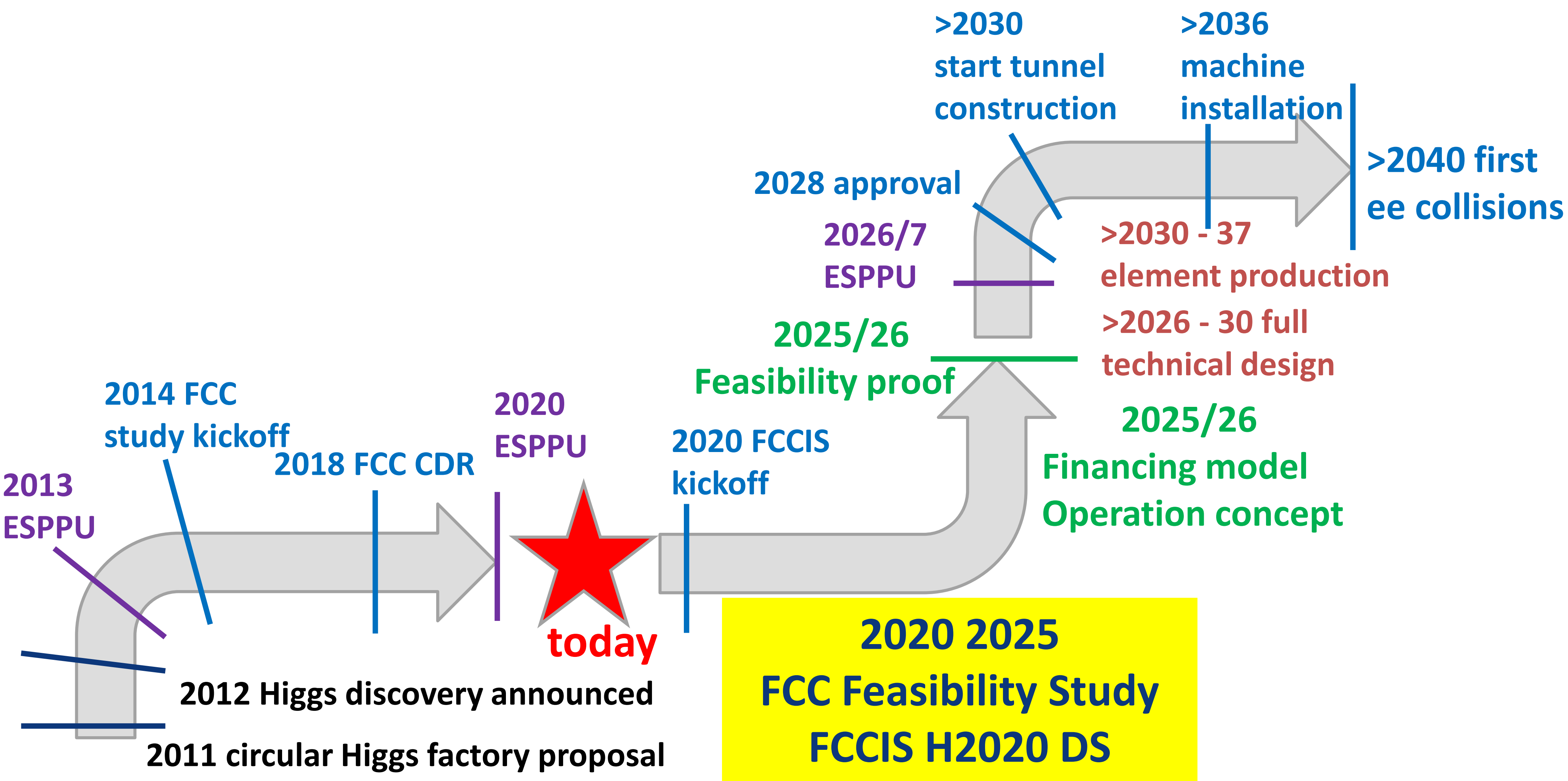
→ creative and proactive ideas for technology transfer from FCC to society

Feasibility Study of FCC integrated project

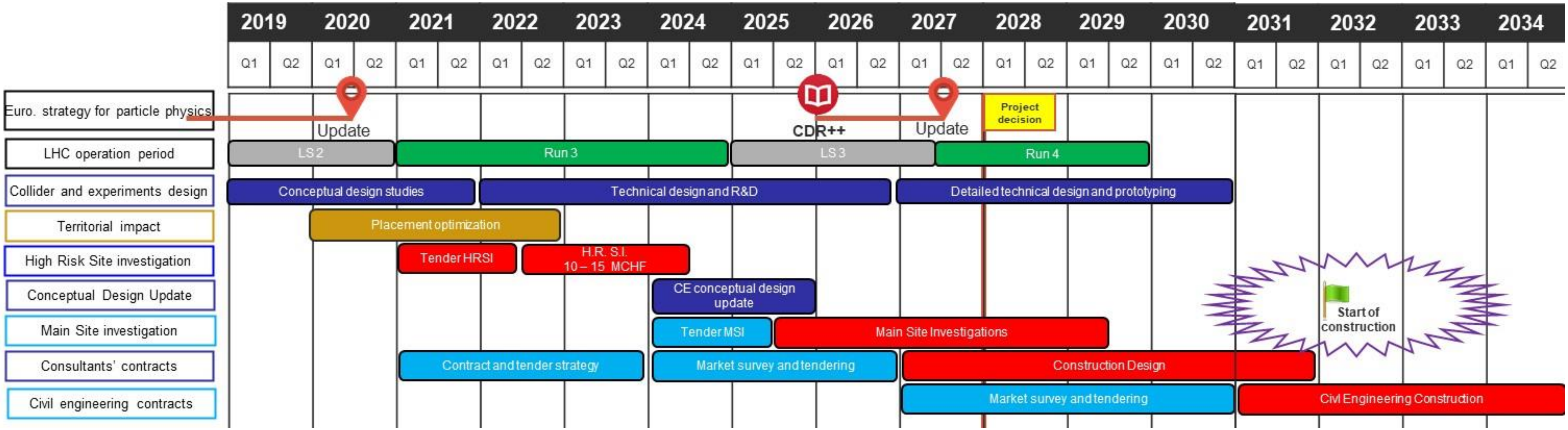
Feasibility study to be delivered end 2025 as **input for ESPP Update expected for 2026/2027, to enable a project decision**:

- ***Feasibility study of the 100 km tunnel*** *(infrastructure aspects, administrative aspects, local authorities, environment, energy, etc.)*
- ***High-risk areas site investigations included****, to confirm principle feasibility*
- ***Host-state related processes,*** *to* ***allow start of construction early 2030ies****.*
- ***CDR+ for colliders and injectors, including key technology proofs.***
- ***HFM program intermediate milestones,*** *in line with long-term R&D plan.*
- ***Physics and experiments CDR + for FCC integrated project.***
- ***Financing concept & organization model for project and operation phases.***
- For all these activities the sequential nature of implementation of the colliders and the overall timeline needs to be taken into account!

FCC roadmap towards stage 1

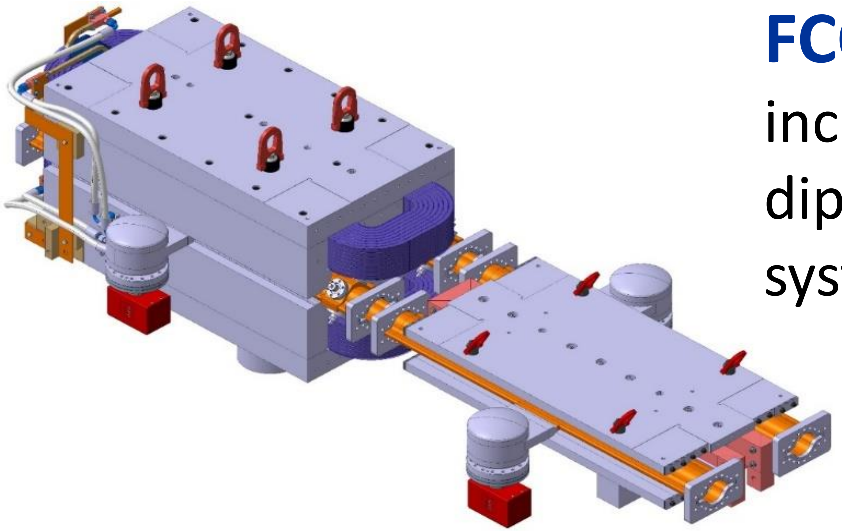


CE preparatory activities 2020 - 2030



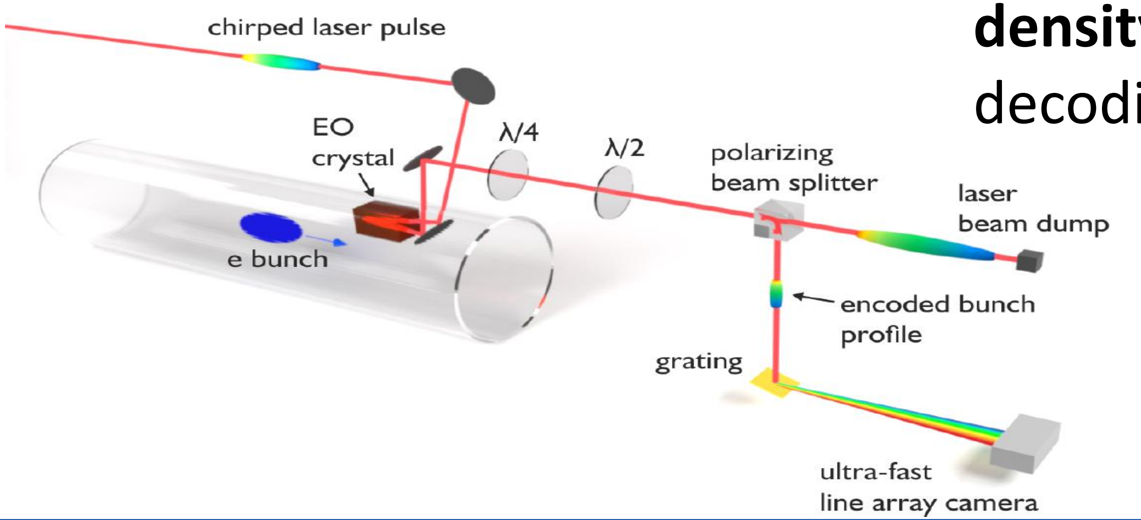
- Technical schedule of main processes leading to start of construction begin 2030ies
- For proof of principle feasibility: High risk area site investigations, 2022 – 2024
- Followed by update of civil engineering conceptual design and CE cost estimate 2025

FCC key deliverables: prototypes by 2025



FCC-ee complete arc half-cell mock up

including girder, vacuum system with antechamber + pumps, dipole, quadrupole + sext. magnets, BPMs, cooling + alignment systems, technical infrastructure interfaces.



key beam diagnostics elements

bunch-by-bunch turn-by-turn **longitudinal charge density profiles** based on electro-optical spectral decoding (beam tests at KIT/KARA) ;

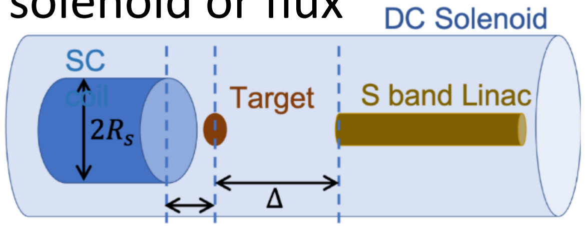
ultra-low emittance measurement (X-ray interferometer tests at SuperKEKB, ALBA) ;
beam-loss monitors (IJCLab/KEK?) ;
beamstrahlung monitor (KEK);
polarimeter ; **luminometer**

FCC key deliverables: prototypes by 2025

400 MHz SRF cryomodule,
+ prototype multi-cell cavities for FCC ZH operation
High-efficiency RF power sources

high-yield positron source

target with DC SC solenoid or flux concentrator

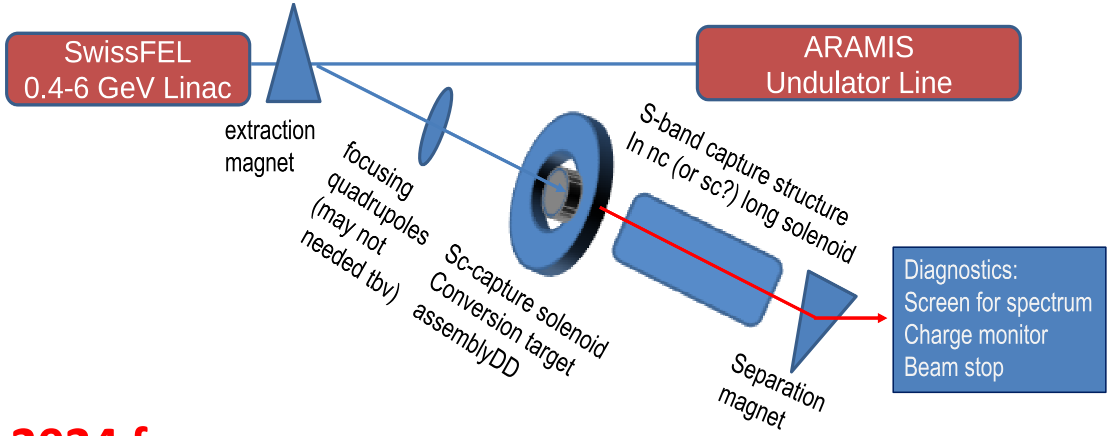


positron capture linac

large aperture S-band linac

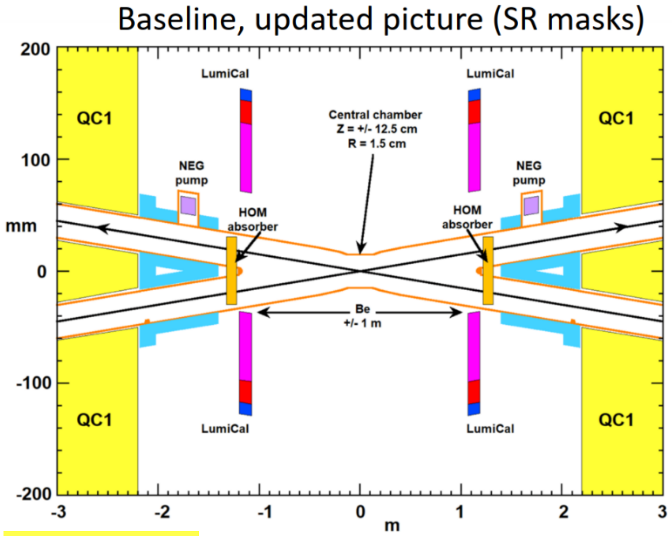
- Freq : 2.856 GHz
- 90 cells per structure
- Length: 3.254 m
- Distance between two TWs: 45 cm
- Gradient: 20 MV/m
- Aperture: 30 mm

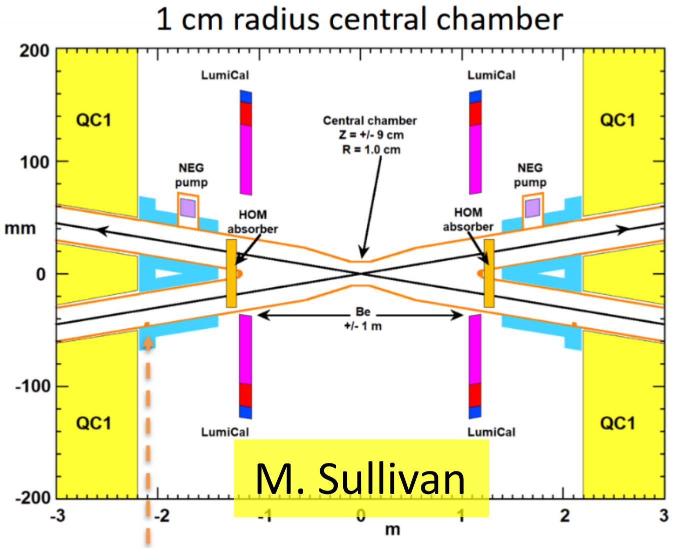
beam test of e^+ source & capture linac at SwissFEL – yield measurement



Strong support from Switzerland via CHART II program 2019 – 2024 for FCC-ee injector, HFM, beam optics developments, geology and geodesy activities.

FCC-ee Machine Detector Interface





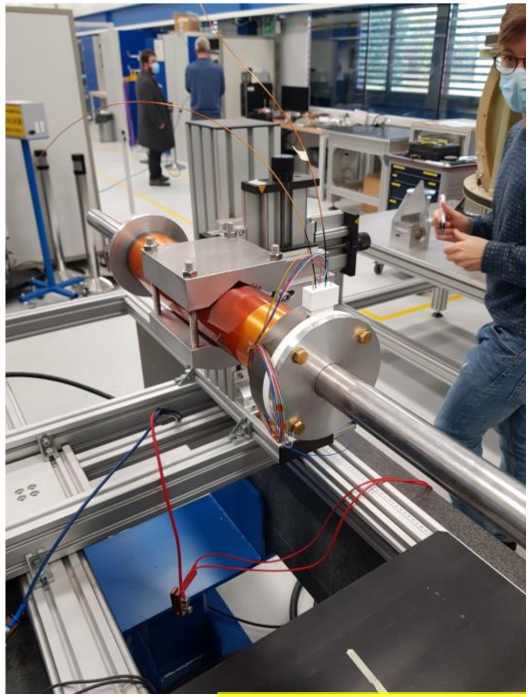
M. Sullivan

M. Boscolo

smaller IR chamber,
no longer trapped HOM

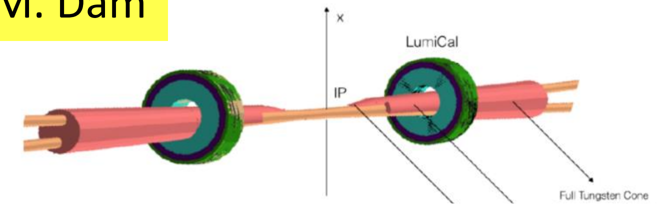
start of 3D mechanical
design & integration

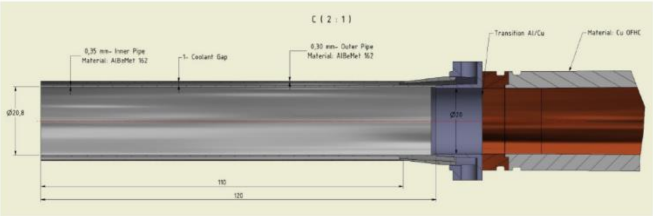
Q1 prototype, measured
multipoles very small,
confirming
design approach

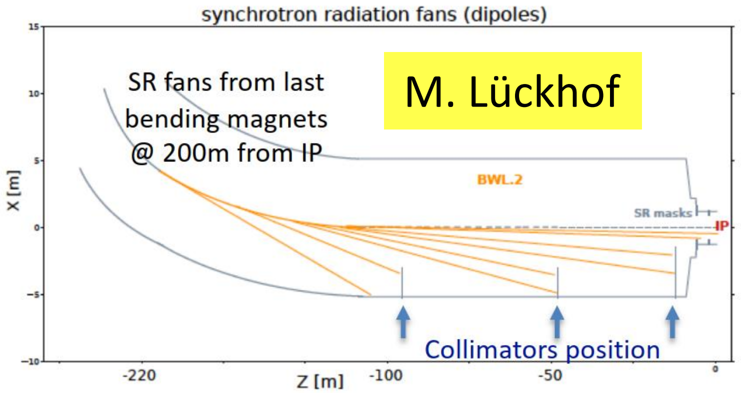


M. Koratzinos

M. Dam

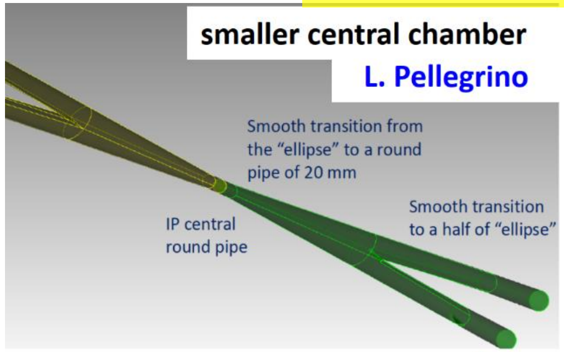


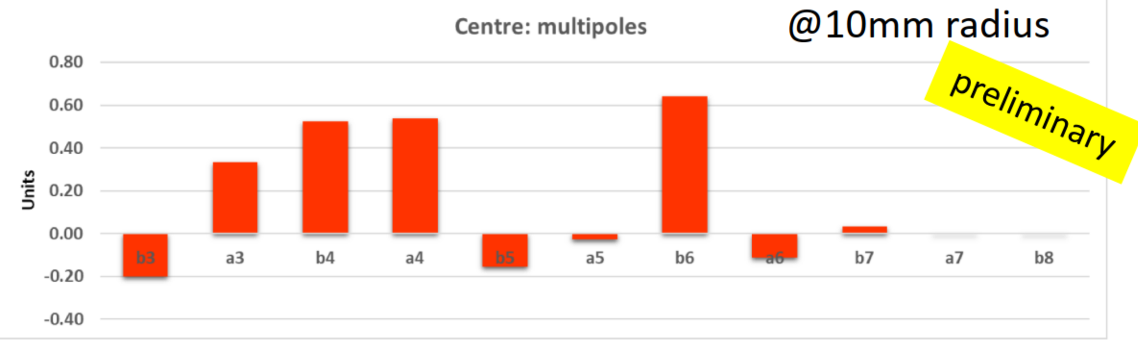




M. Lückhof

L. Pellegrino



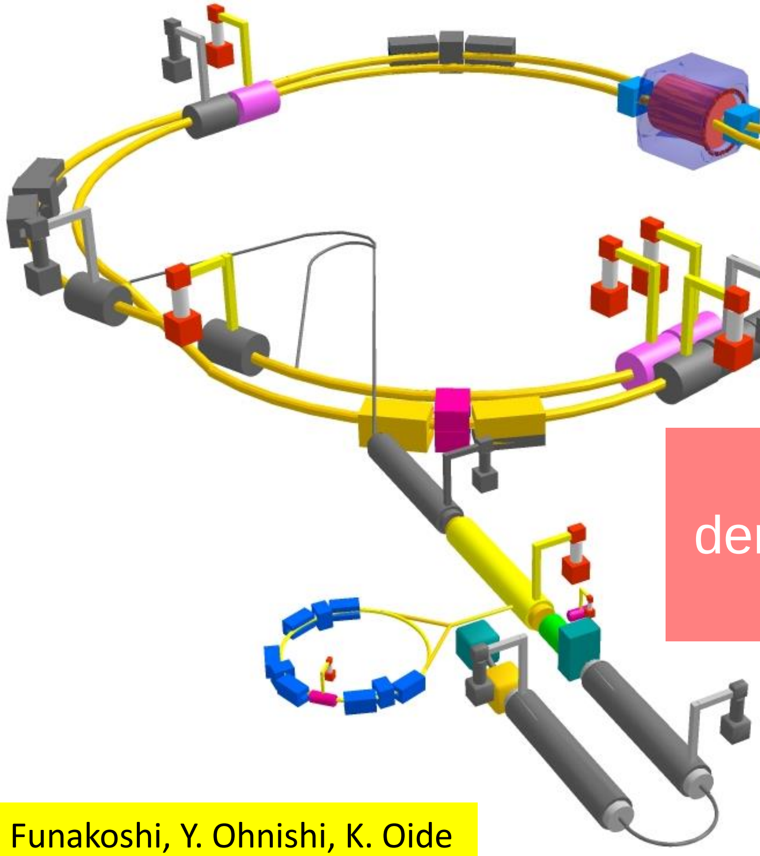


Carlo Petrone

Multipoles calculated up to B15, A15, but are all zero

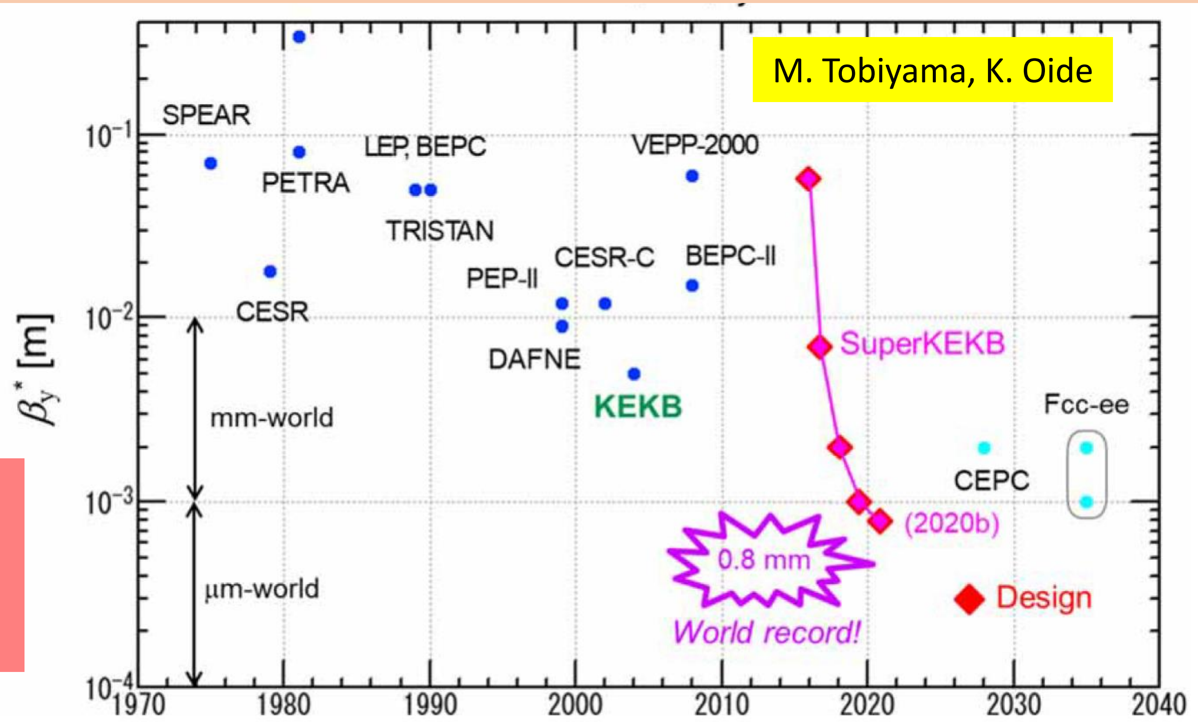
SuperKEKB – pushing luminosity and β*

Design: double ring e^+e^- collider as *B*-factory at 7(e^-) & 4(e^+) GeV; design luminosity ~8 x 10^{35} $cm^{-2}s^{-1}$; β_y^* ~ 0.3 mm; nano-beam – large crossing angle collision scheme (crab waist w/o sextupoles); beam lifetime ~5 minutes; top-up injection; e^+ rate up to ~ 2.5 10^{12} /s ; under commissioning



SuperKEKB is demonstrating FCC-ee key concepts

Y. Funakoshi, Y. Ohnishi, K. Oide



β_y^* = 0.8 mm achieved in both rings – using the FCC-ee-style "virtual" crab-waist collision scheme

Potential EIC – FCC collaboration

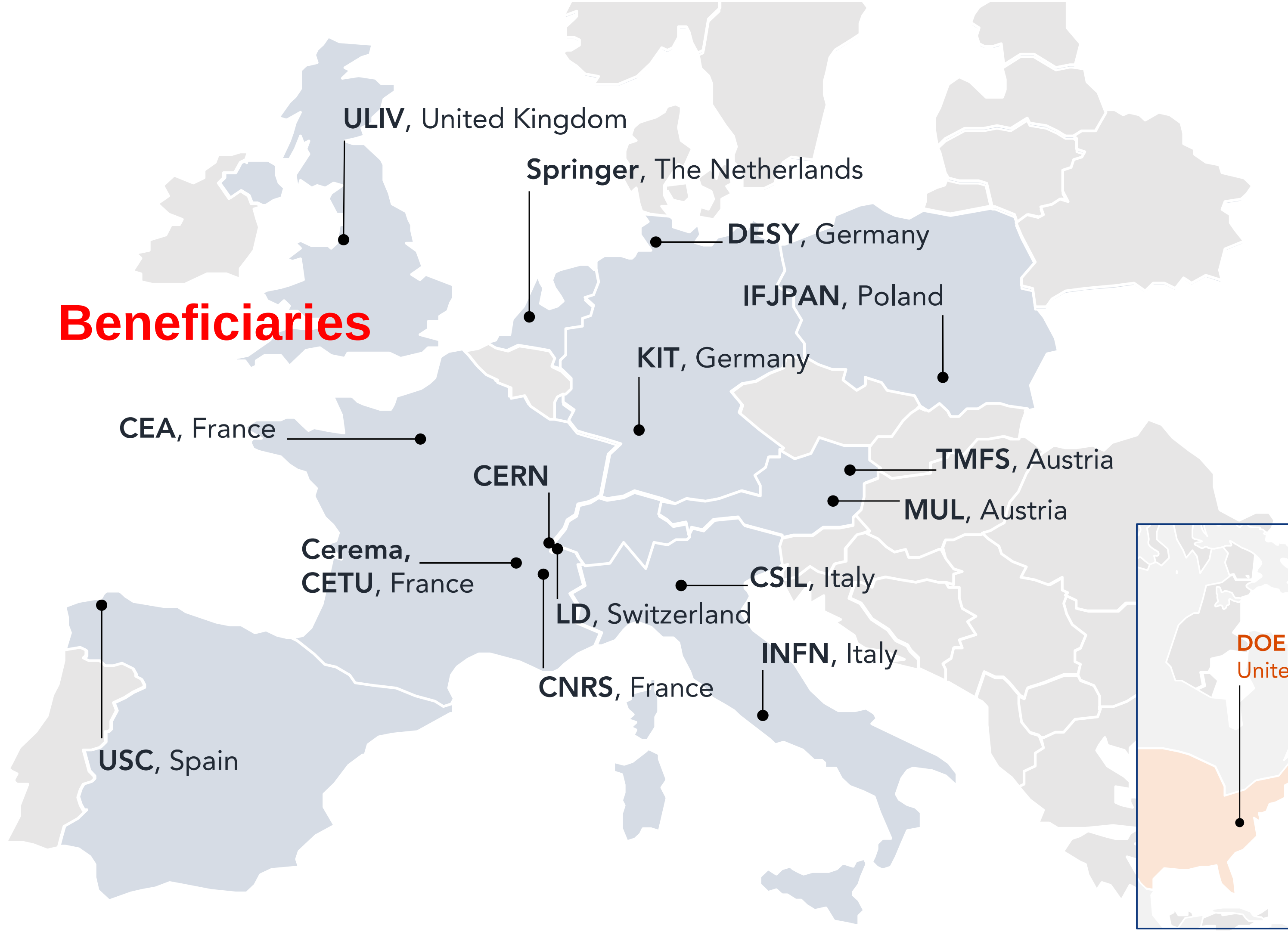
NSLS-II, EIC & FCC-ee beam parameters

	NSLS-II	EIC	FCC-ee-Z
Beam energy [GeV]	3	10 (20)	45.6
Bunch population [10^{11}]	0.08	1.7	1.7
Bunch spacing [ns]	2	10	15, 17.5 or 20
Rms bunch length [mm]	4.5 - 9	2	3.5 (SR)
Beam current [A]	0.5	2.5 (0.27)	1.39
RF frequency [MHz]	500	591	400

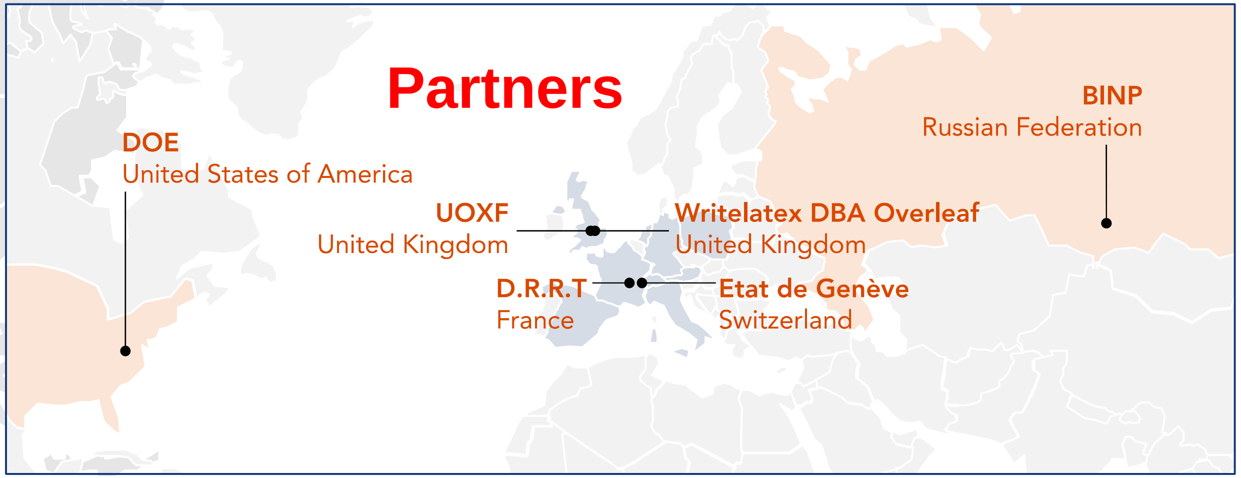
Similarity of several parameters strongly suggests collaboration to exploit synergies in areas such as beam instrumentation, SRF, vacuum system with SR handling, etc.

→ Two dedicated sessions at FCC-IS kick-off meeting towards EIC-FCC collaboration.

H2020 DS FCC Innovation Study 2020-24

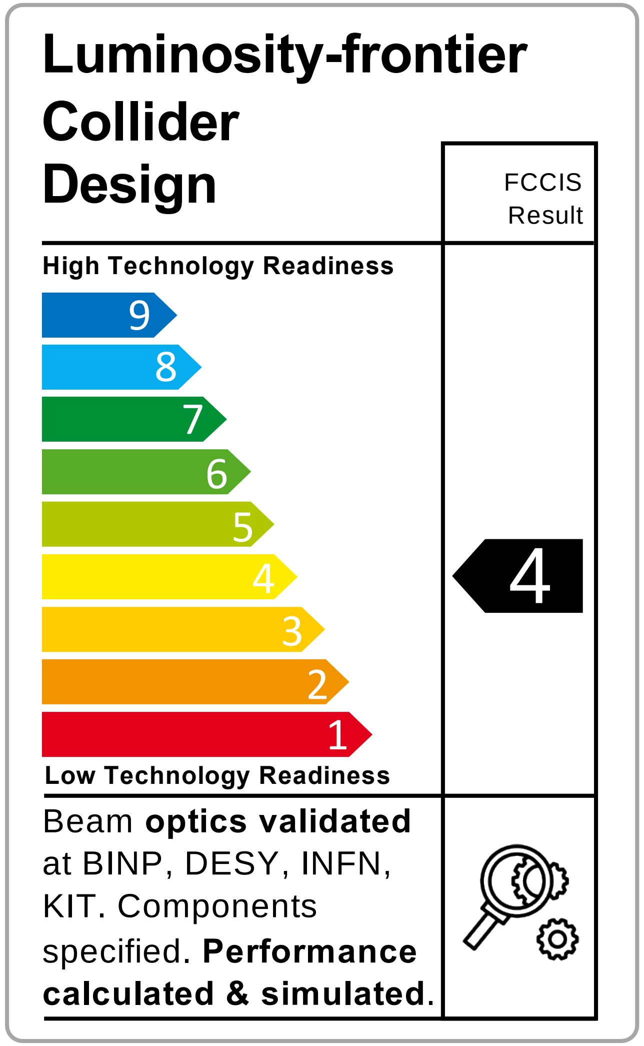


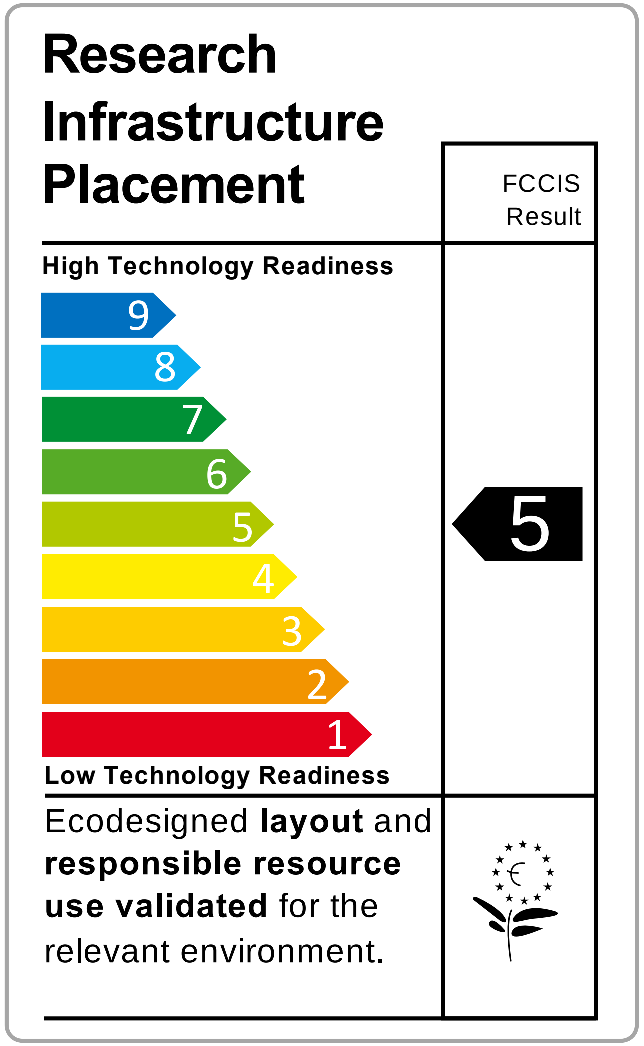
Topic	INFRADEV-01-2019-2020
Grant Agreement	FCCIS 951754
Duration	48 months
From-to	2 Nov 2020 – 1 Nov 2024
Project cost	7 435 865 €
EU contribution	2 999 850 €
Beneficiaries	16
Partners	6



Objectives of FCCIS (Description of Action)

- O1: **Design a circular luminosity frontier particle collider** with a research programme to remain at the forefront of research
- O2: **Demonstrate the technical and organizational feasibility** of a 100 km long, circular particle collider
- O3: **Develop an innovation plan for a long-term sustainable research infrastructure** that is seamlessly integrated in the European research landscape
- O4: **Engage stakeholders** from different sectors of the society
- O5: **Demonstrate the role and impact of the research infrastructure in the innovation chain**, focusing on responsible resource use and managing environmental impacts





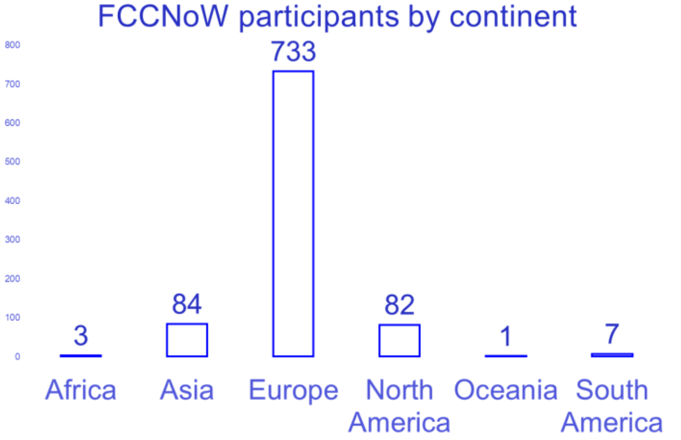
FCC November Week

- Kick-Off FCC Innovation Study

  (organisers M. Benedikt, J. Gutleber, F. Zimmermann)

  FCC-ee Collider Design (WP2)
  Integrate Europe (WP3)
  Impact & Sustainability (WP4)
  Leverage & Engage (WP5)

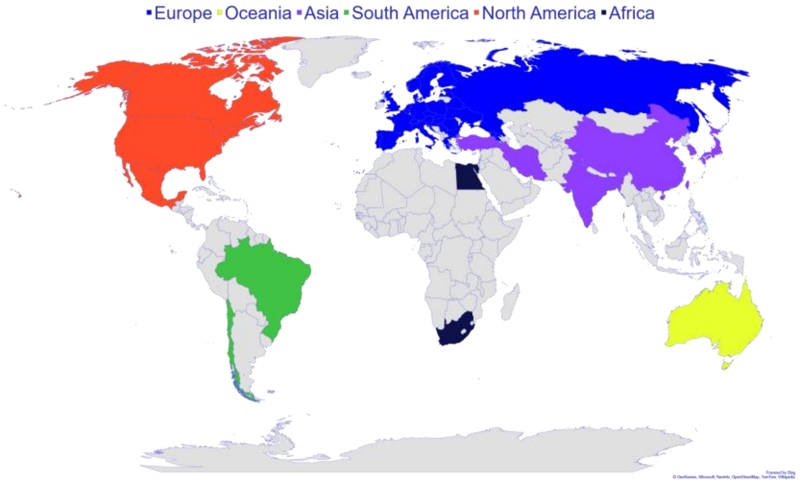
910 registered participants



- 4th FCC Physics & Experiments Workshop

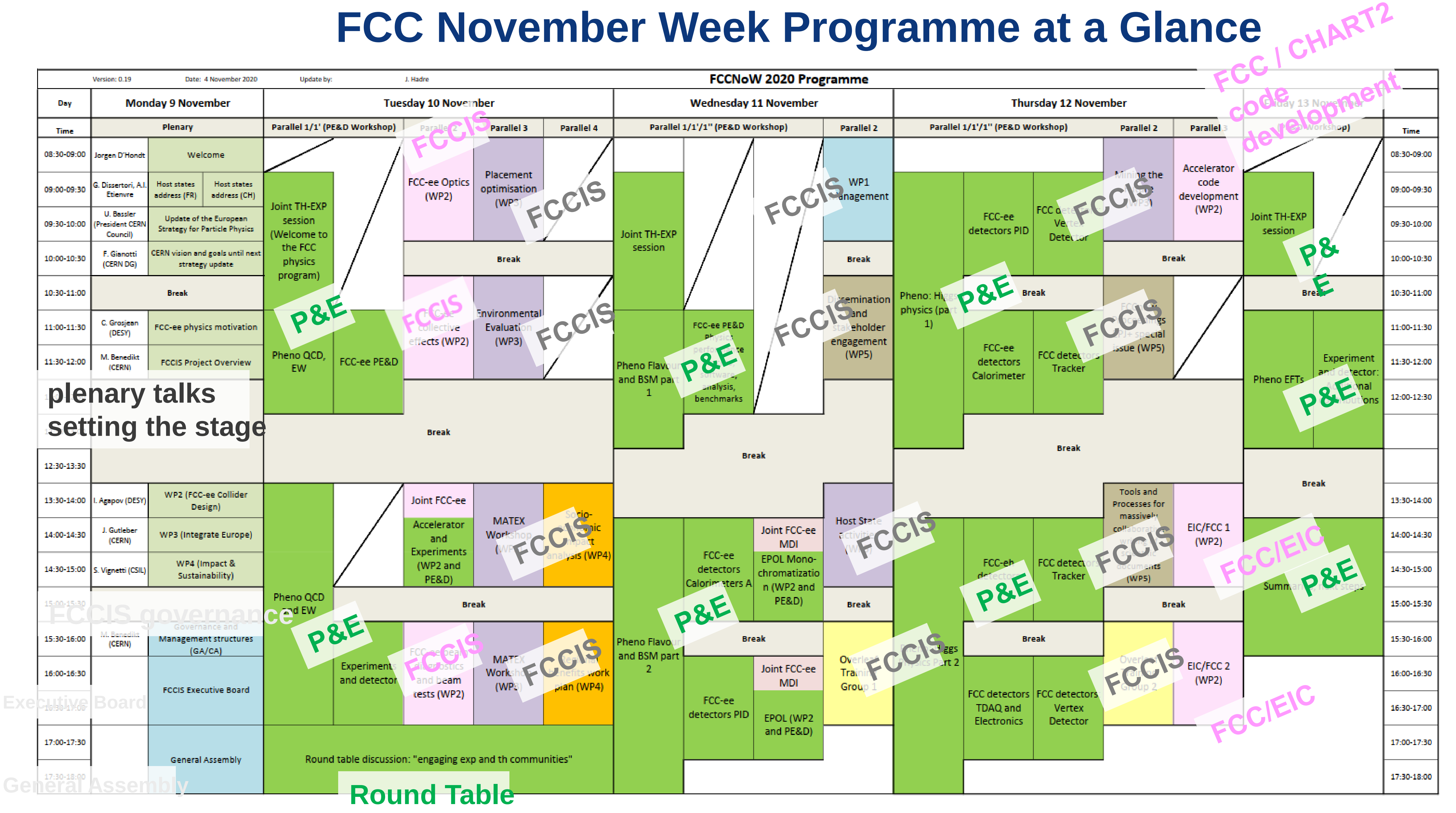
  (organisers A. Blondel, M. Mangano, M. Dam, P. Janot)

  Physics Prospects, Detector development, Collaboration Forming, Physics Benchmark Measurements, New Ideas and Challenges, Detector Technologies, Experimental Environment, and Machine-Detector Interface.



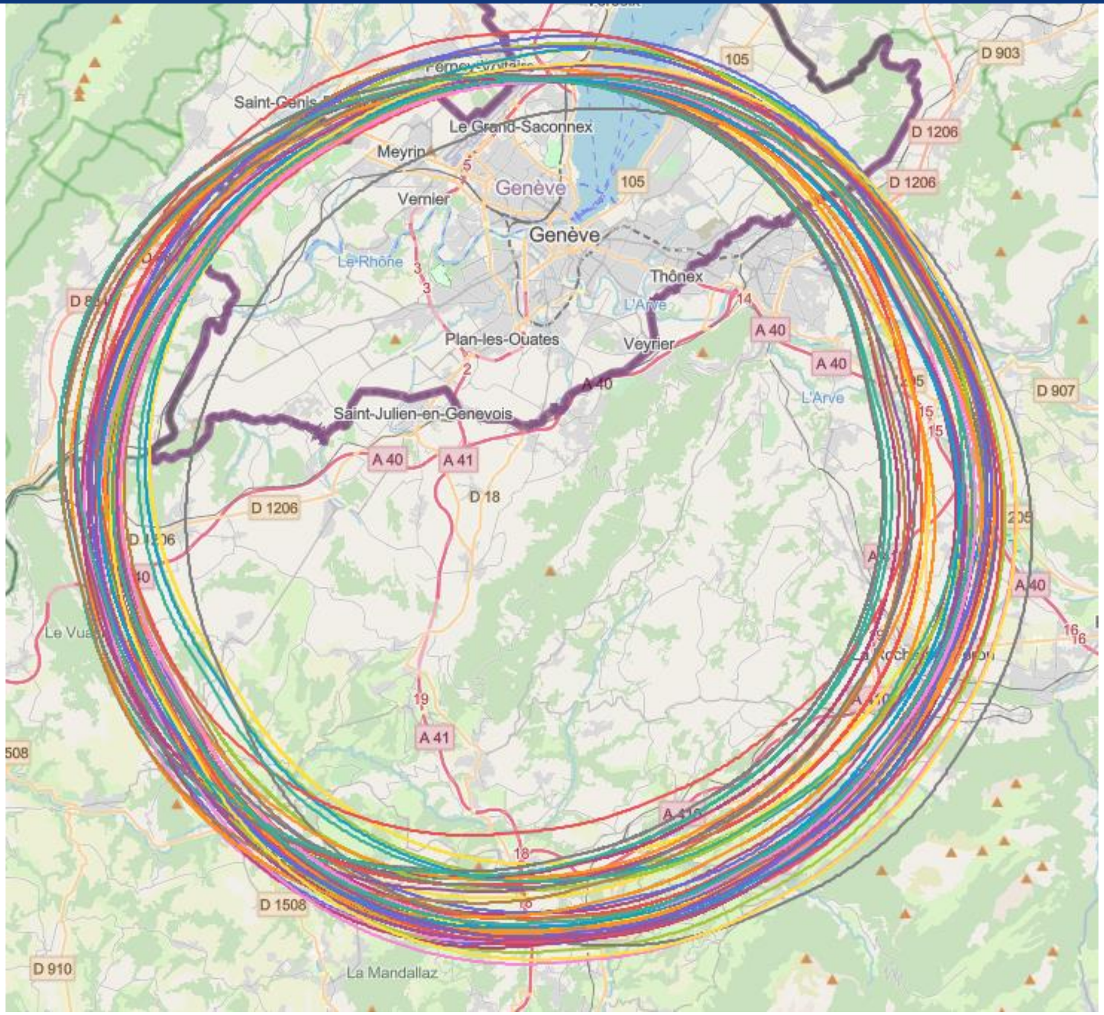
http://cern.ch/FCCNoW2020

FCC November Week Programme at a Glance



Collider placement optimisation

- Overall layout and placement optimisation process across both host states
- Following the "avoid-reduce-compensate" directive of European and French regulatory frameworks
- Process integrates diverse requirements and constraints:
  - performance permitting world-leading scientific research
  - technical feasibility of civil engineering and subsurface constraints
  - territorial constraints on surface and subsurface
  - nature, accessibility, technical infrastructure, and resource needs & constraints
  - economic factors including development of benefits for, and synergies, with the regional developments
  - …
- Collaborative effort of technical experts at CERN, consultancy companies and government notified bodies



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

141 Institutes

30 Companies

34 Countries

EC H2020

Status and Outlook

- **1st phase** of FCC design study **completed → baseline machine designs,** performance matching physics requirements, in **4 CDRs**
- **Integrated FCC programme** submitted to European Strategy Update 2019/20 **→ Request for feasibility study as basis for project decision by 2026/27**
- **Next steps: concrete local/regional implementation scenario** in collaboration **with host state authorities**, accompanied by **machine optimization, physics studies and technology R&D**, performed **via global collaboration** and supported by **EC H2020 Design Study FCCIS, to prove feasibility by 2025/26**
- Long term goal: **world-leading HEP infrastructure for 21st century** to push the particle-physics **precision and energy frontiers** far beyond present limits.

Spare Slides on

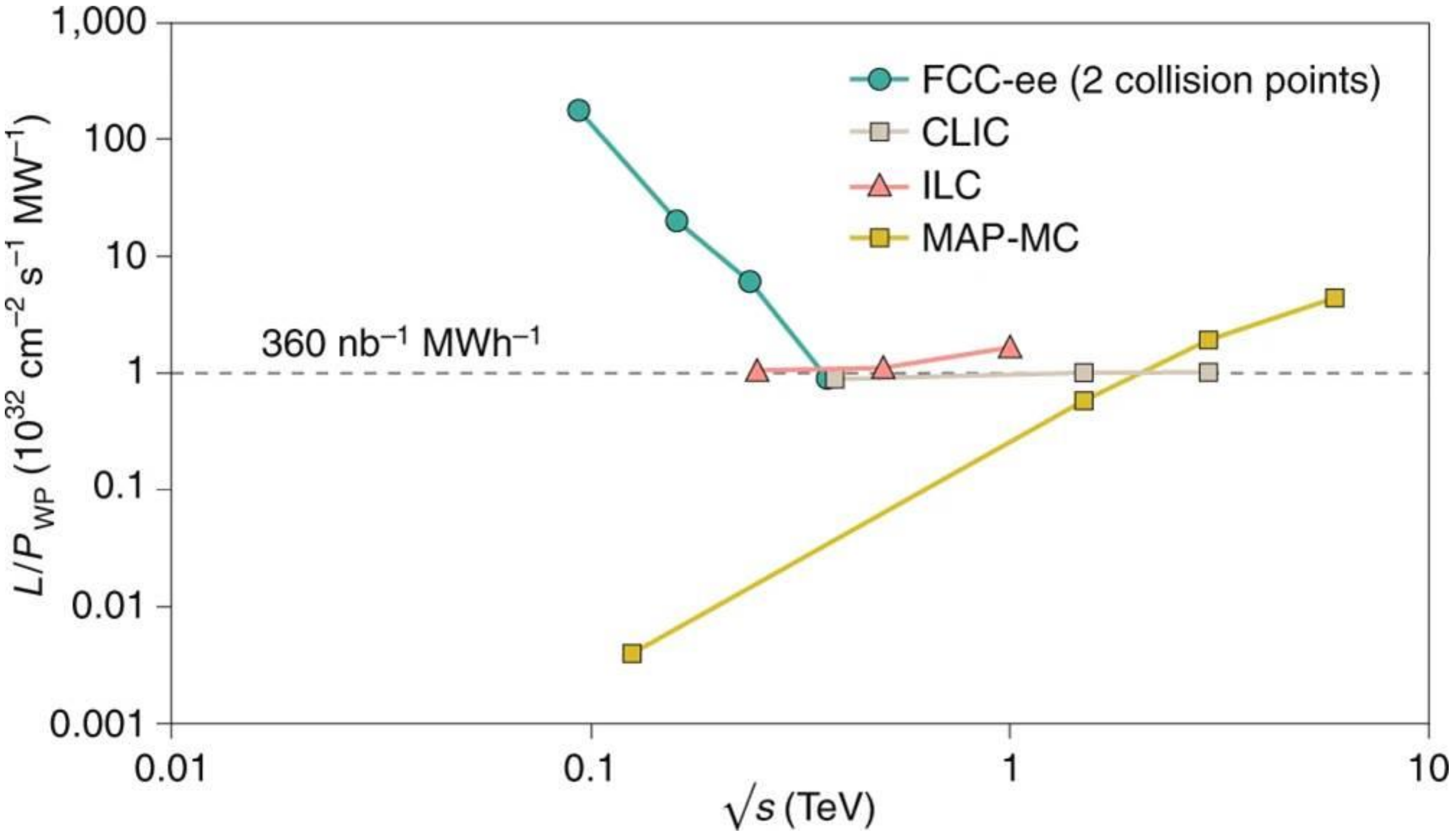
FCC CDR Status

FCC-ee collider parameters (stage 1)

parameter	Z	WW	H (ZH)	ttbar
beam energy [GeV]	45	80	120	182.5
beam current [mA]	1390	147	29	5.4
no. bunches/beam	16640	2000	393	48
bunch intensity [10^{11}]	1.7	1.5	1.5	2.3
SR energy loss / turn [GeV]	0.036	0.34	1.72	9.21
total RF voltage [GV]	0.1	0.44	2.0	10.9
long. damping time [turns]	1281	235	70	20
horizontal beta* [m]	0.15	0.2	0.3	1
vertical beta* [mm]	0.8	1	1	1.6
horiz. geometric emittance [nm]	0.27	0.28	0.63	1.46
vert. geom. emittance [pm]	1.0	1.7	1.3	2.9
bunch length with SR / BS [mm]	3.5 / 12.1	3.0 / 6.0	3.3 / 5.3	2.0 / 2.5
luminosity per IP [10^{34} cm^{-2}s^{-1}]	230	28	8.5	1.55
beam lifetime rad Bhabha / BS [min]	68 / >200	49 / >1000	38 / 18	40 / 18

FCC-ee: efficient Higgs/electroweak factory

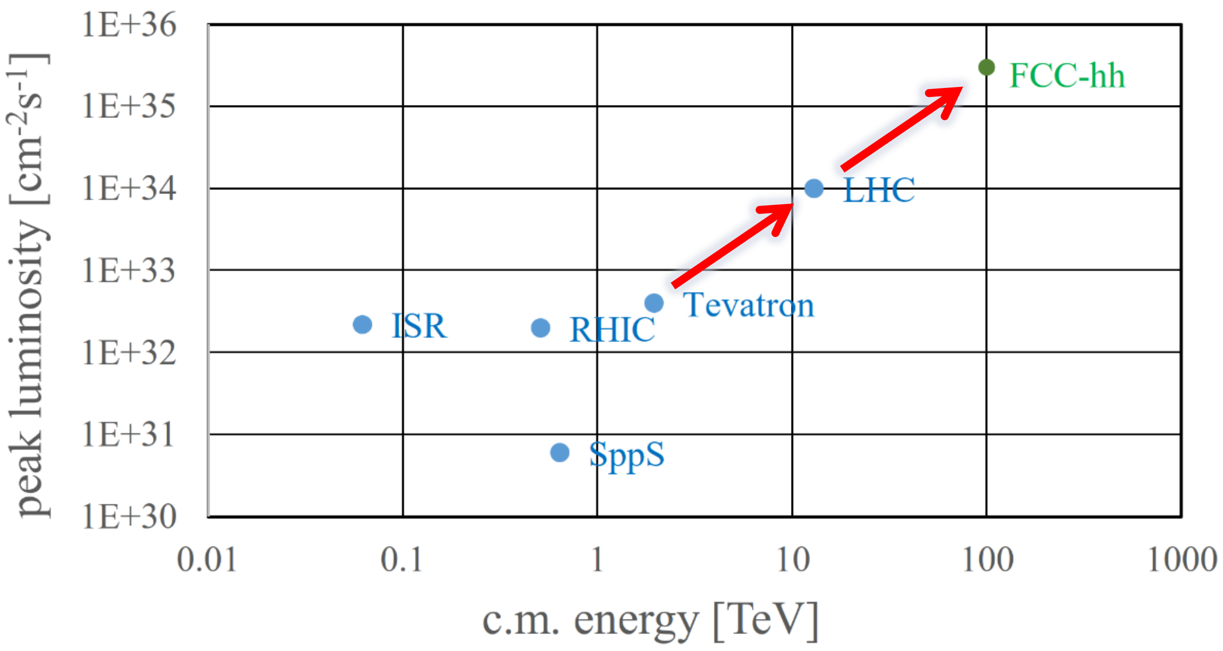
Luminosity L per supplied electrical wall-plug power P_{WP} is shown as a function of centre-of-mass energy for several proposed future lepton colliders.



FCC-hh (pp) collider parameters (stage 2)

parameter	FCC-hh		HL-LHC	LHC
collision energy cms [TeV]	100		14	14
dipole field [T]	16		8.33	8.33
circumference [km]	97.75		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]	2400		7.3	3.6
SR power / length [W/m/ap.]	28.4		0.33	0.17
long. emit. damping time [h]	0.54		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]	8.4		0.7	0.36

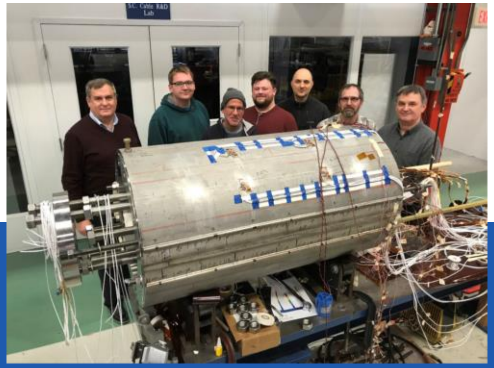
FCC-hh: highest collision energies



- **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**

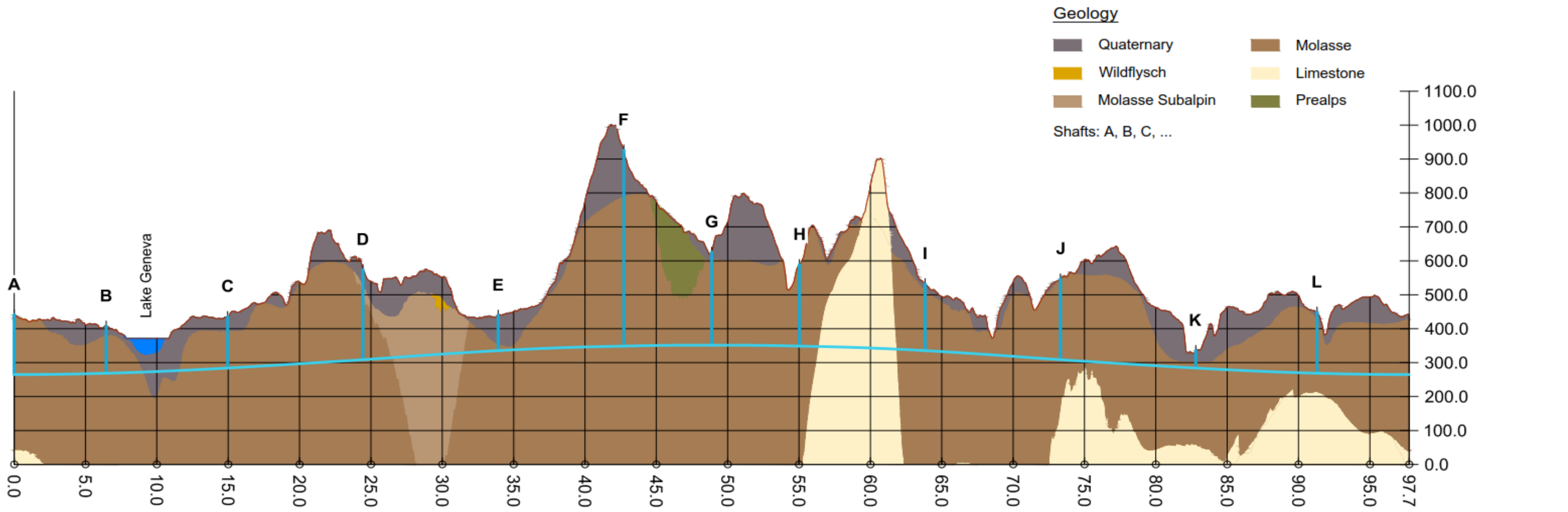
from
LHC technology
8.3 T NbTi dipole

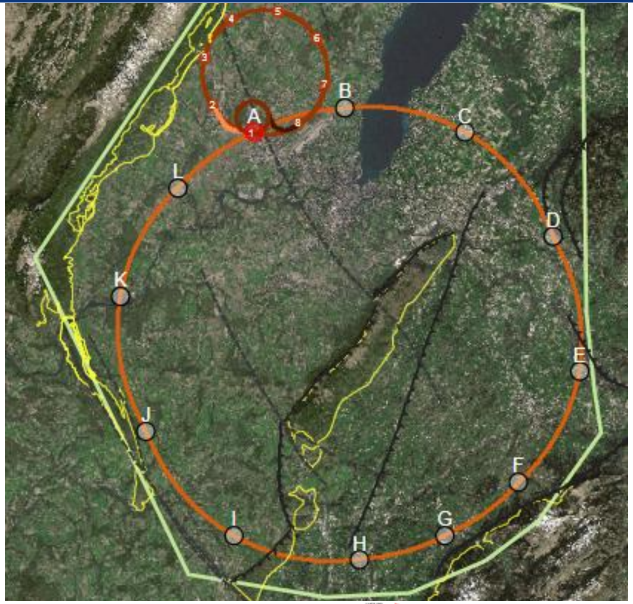
via
HL-LHC technology
12 T Nb_3Sn quadrupole

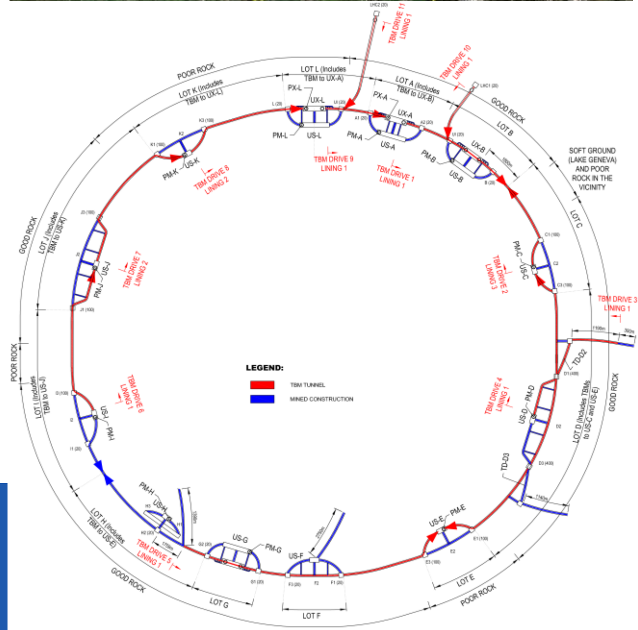


FNAL dipole demonstrator
14.5 T Nb_3Sn

FCC implementation - footprint baseline



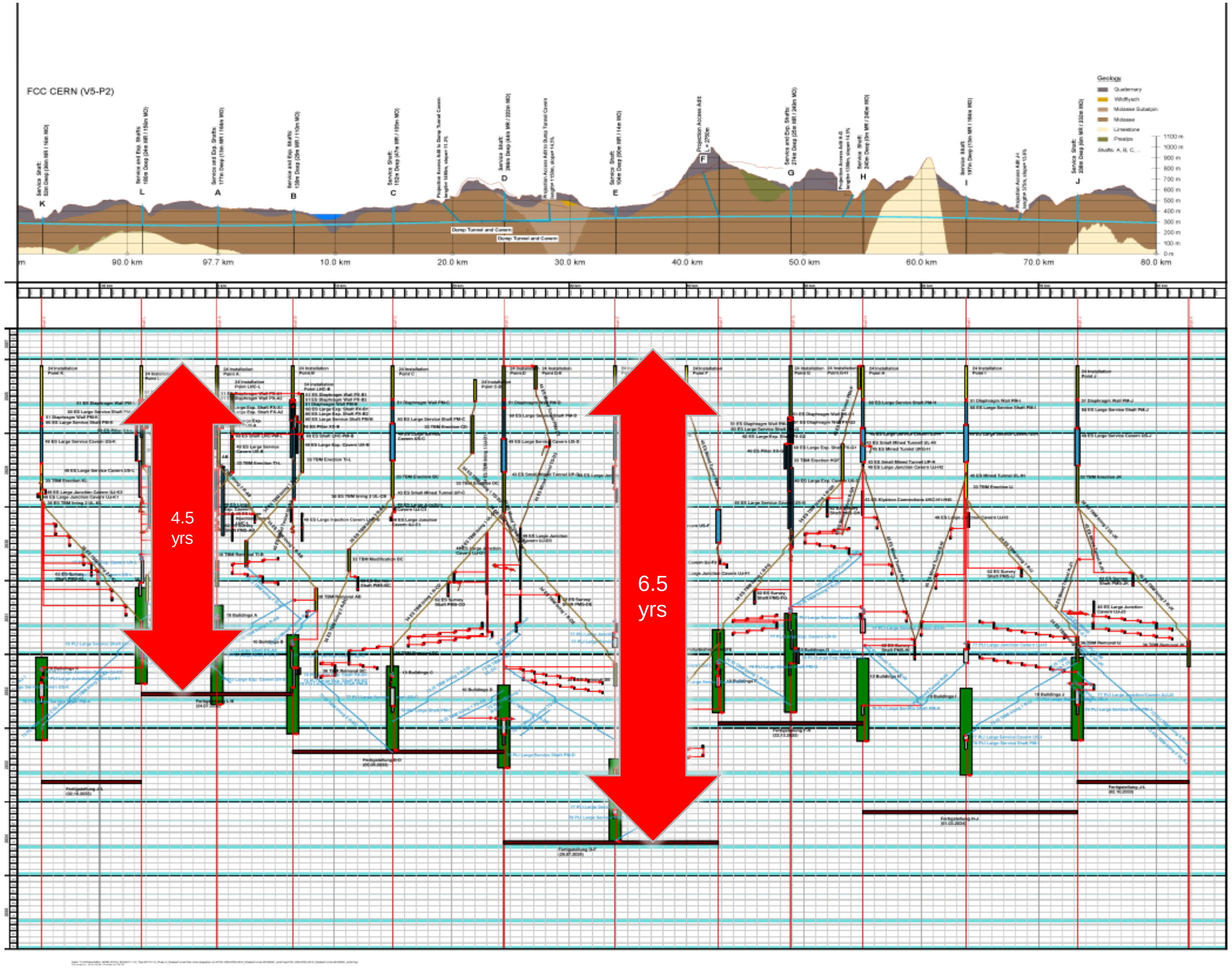


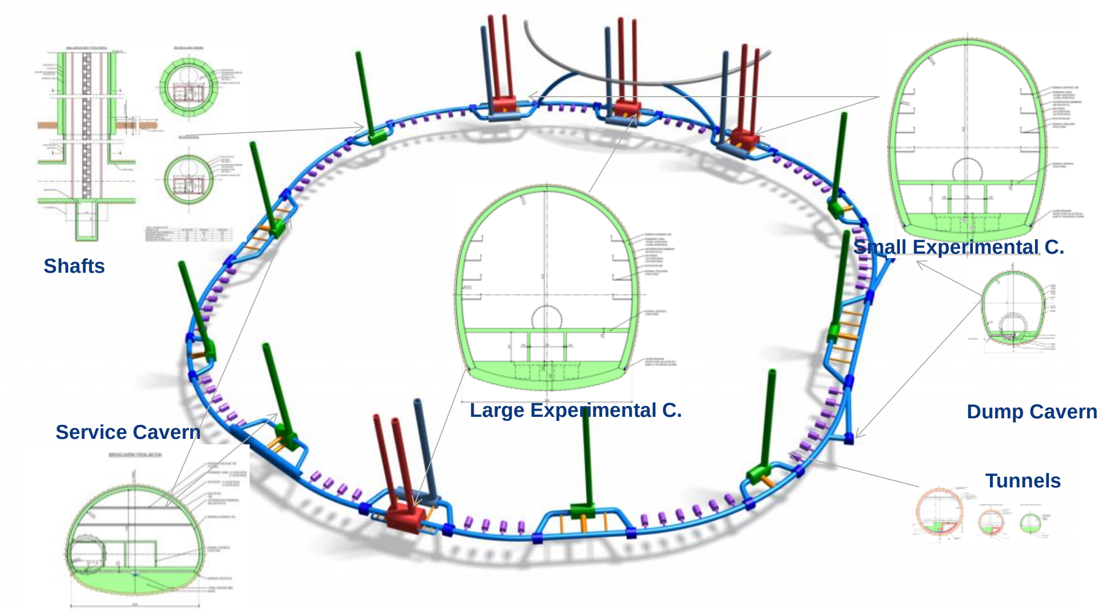


- **Present baseline position was established considering:**
- lowest risk for construction, fastest and cheapest construction
- Molasse rock preferred for tunnelling, avoid limestone with karstic structures

- **90 – 100 km circumference**
- **12 surface sites with few ha area each**

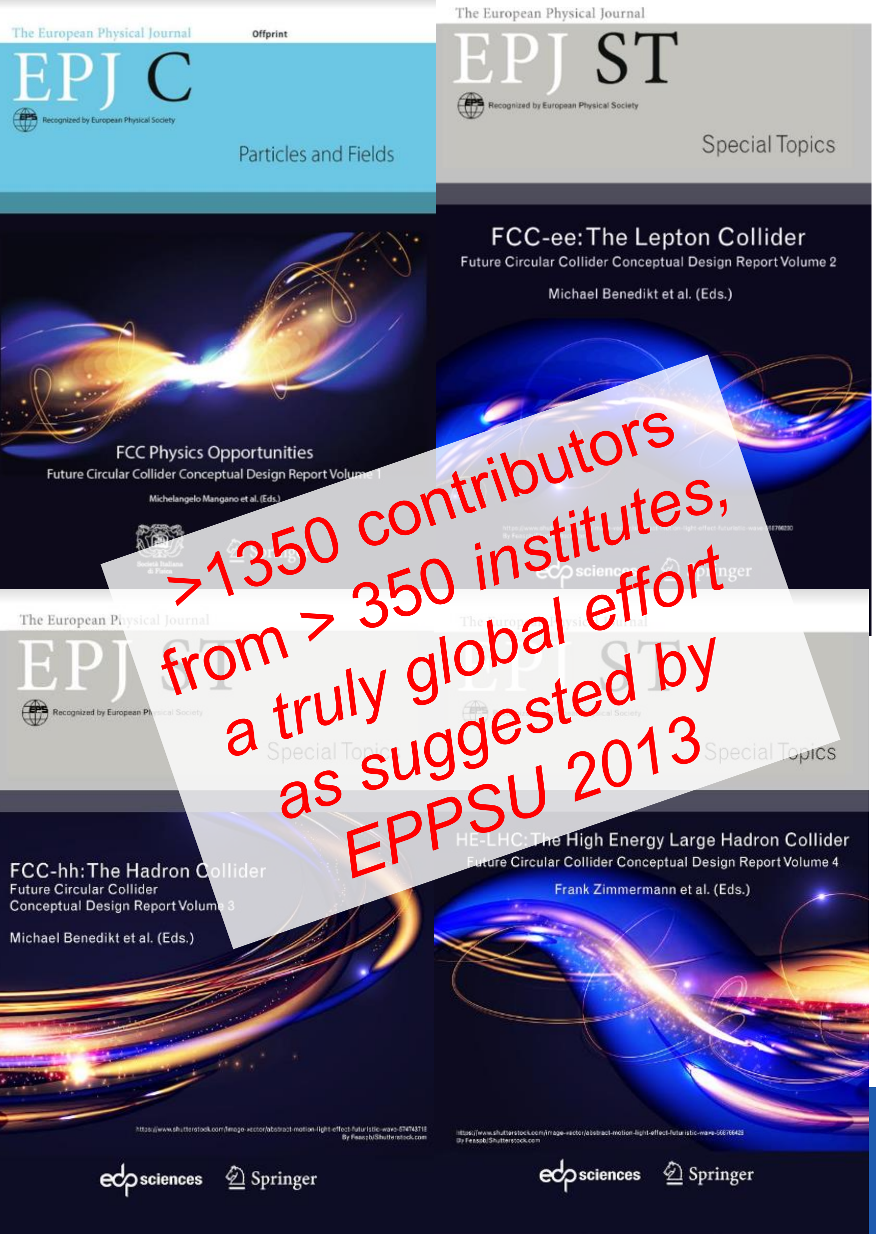
Civil Engineering construction schedule





- **Total construction duration 7 years**
- **First sectors ready after 4.5 years**

FCC CDR 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/