FCC Feasibility Study & FCCIS Project

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on behalf of the FCC collaboration and FCCIS DS team

http://cern.ch/fcc

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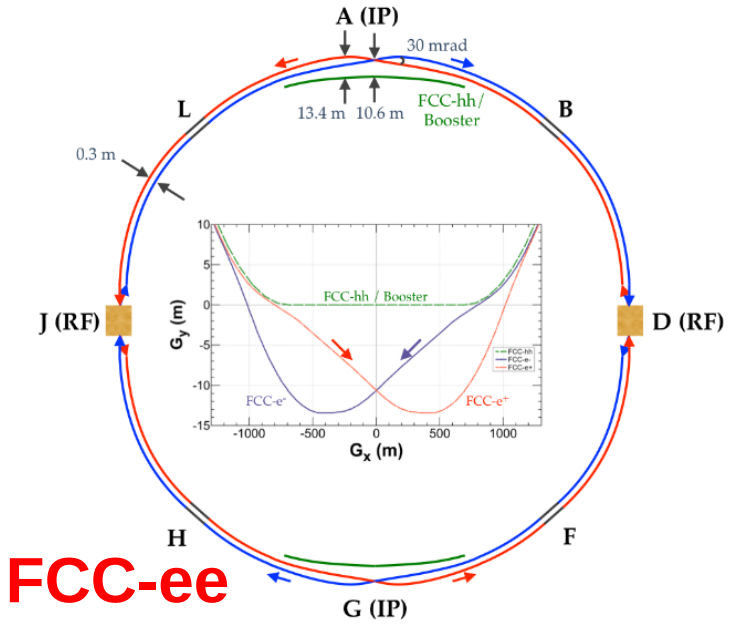
European Commission | Horizon 2020 European Union funding for Research & Innovation

photo: J. Wenninger

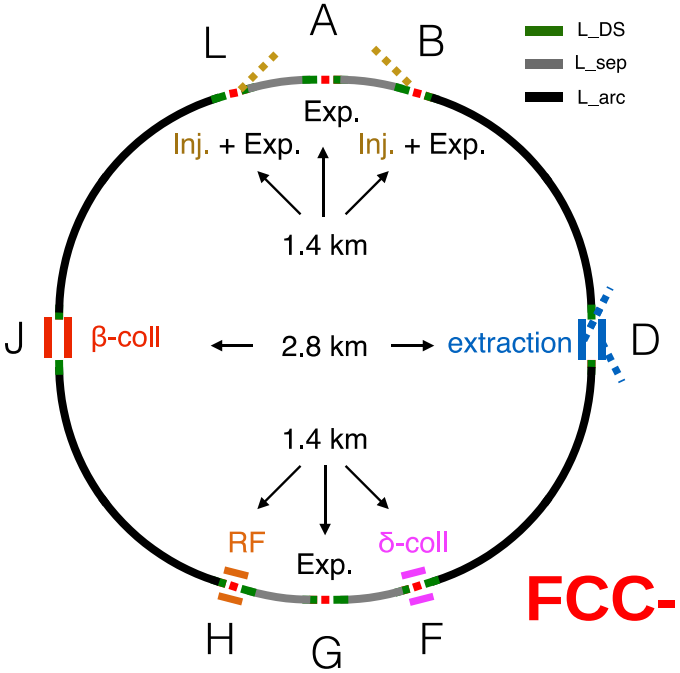
The FCC integrated program inspired by successful LEP – LHC programs at CERN

Comprehensive cost-effective program maximizing physics opportunities

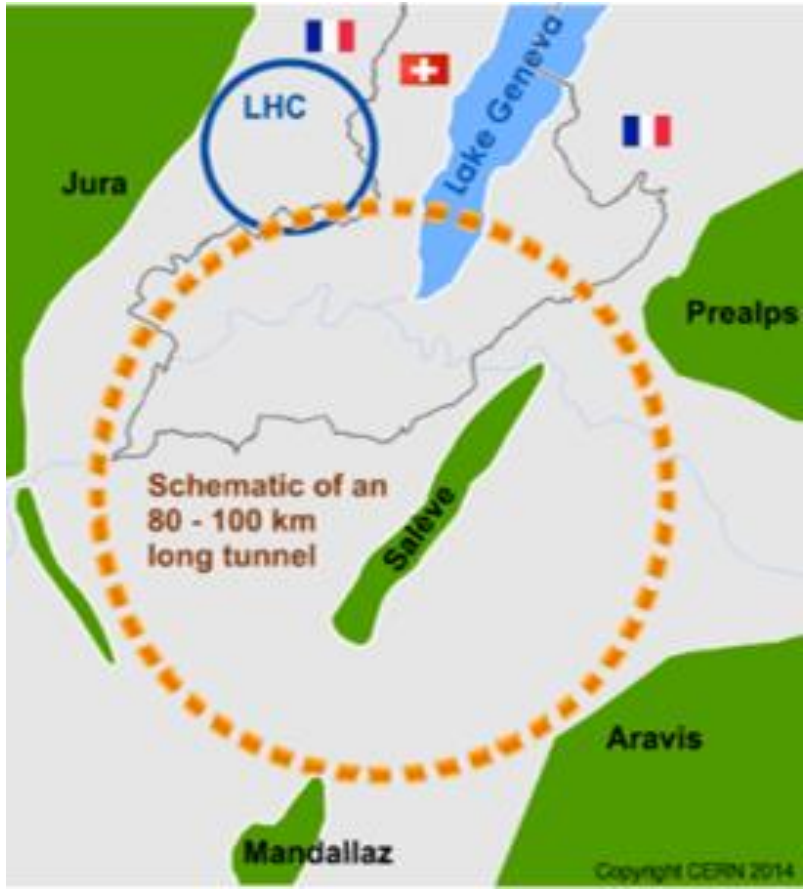
- **Stage 1: FCC-ee (Z, W, H, $t\bar{t}$) as Higgs factory, electroweak & and top factory at highest luminosities**
- **Stage 2: FCC-hh (~100 TeV) as natural continuation at energy frontier, with ion and eh options**
- Complementary physics
- Common civil engineering and technical infrastructures
- Building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



FCC-ee



FCC-hh

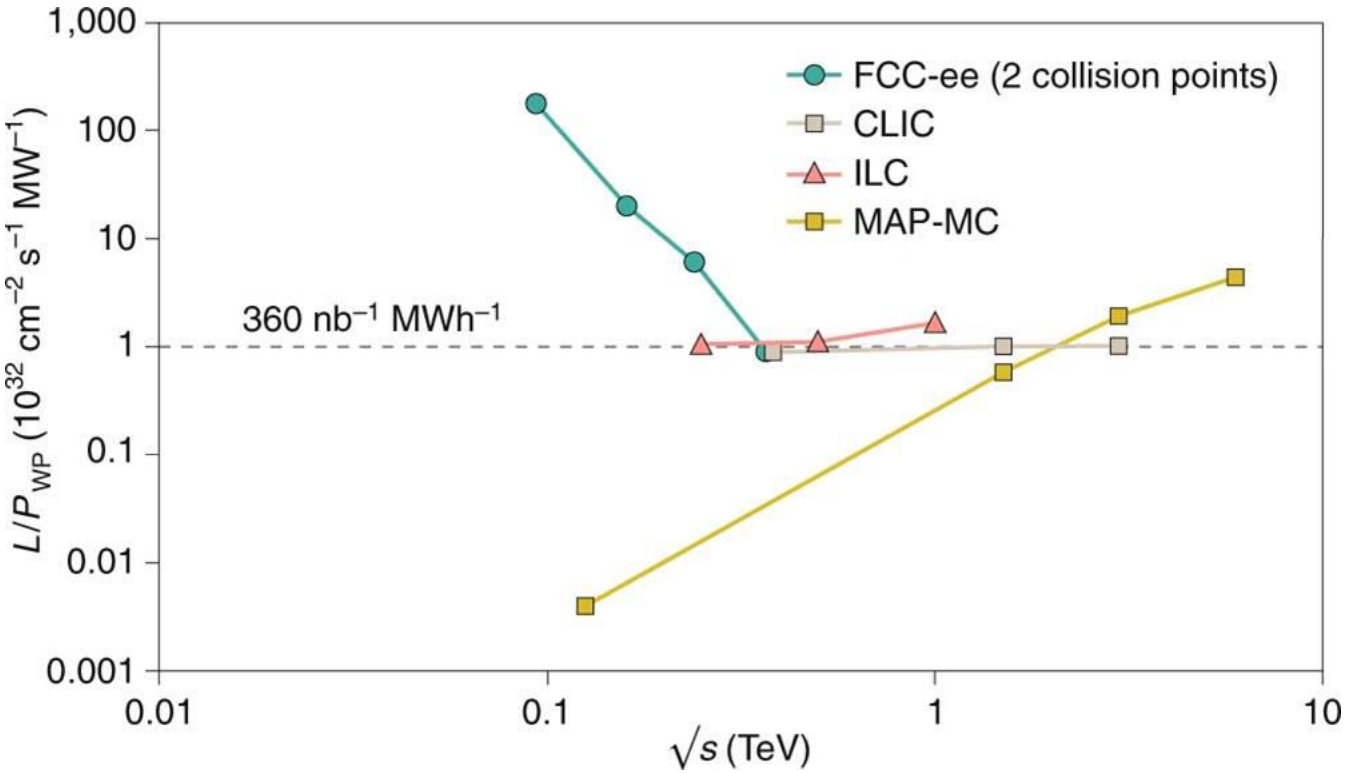


FCC-ee collider parameters (stage 1)

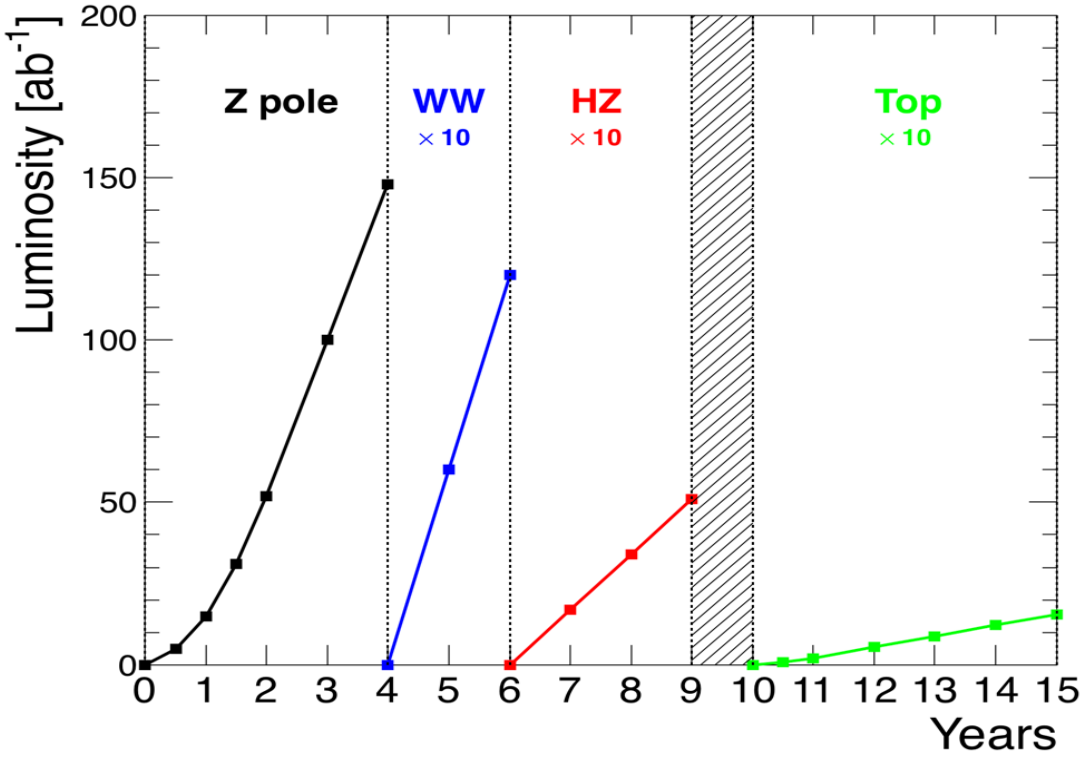
parameter	Z	WW	H (ZH)	ttbar
beam energy [GeV]	45	80	120	182.5
beam current [mA]	1390	147	29	5.4
no. bunches/beam	16640	2000	393	48
bunch intensity [10^{11}]	1.7	1.5	1.5	2.3
SR energy loss / turn [GeV]	0.036	0.34	1.72	9.21
total RF voltage [GV]	0.1	0.44	2.0	10.9
long. damping time [turns]	1281	235	70	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.



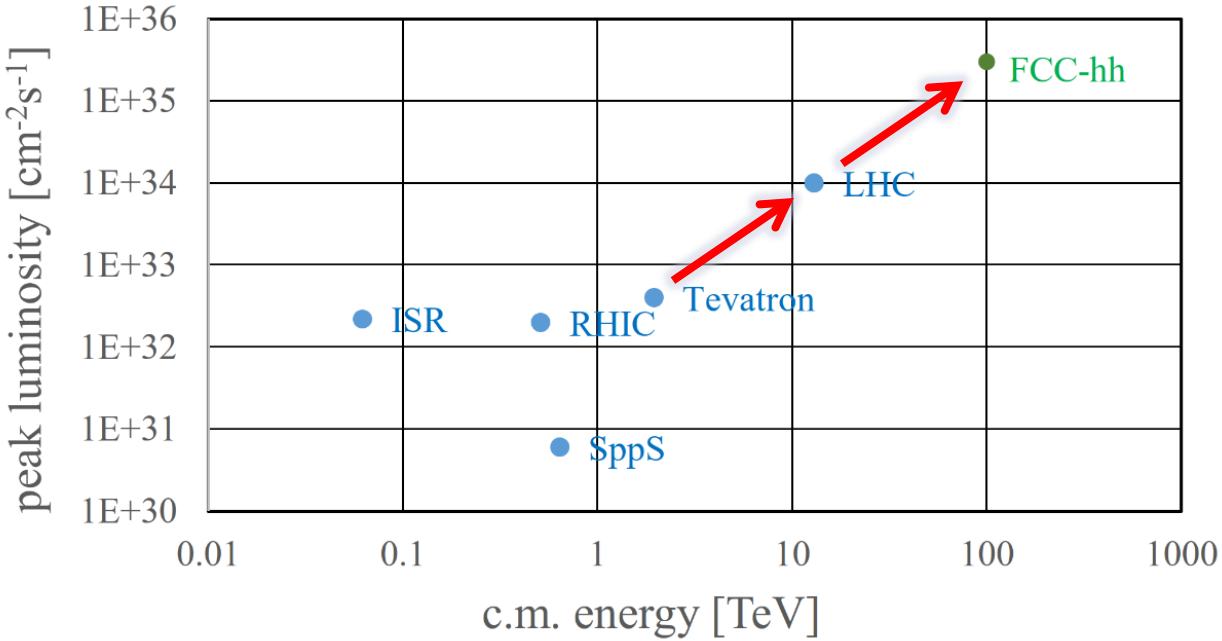
Operation plan and integrated luminosity compliant with physics requirements at the four working points Z, WW, ZH, tt.



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

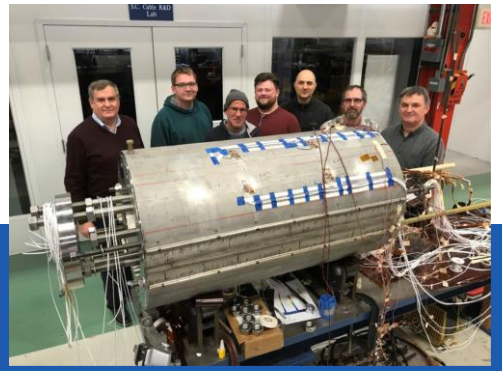
FCC-hh: highest collision energies



- **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**

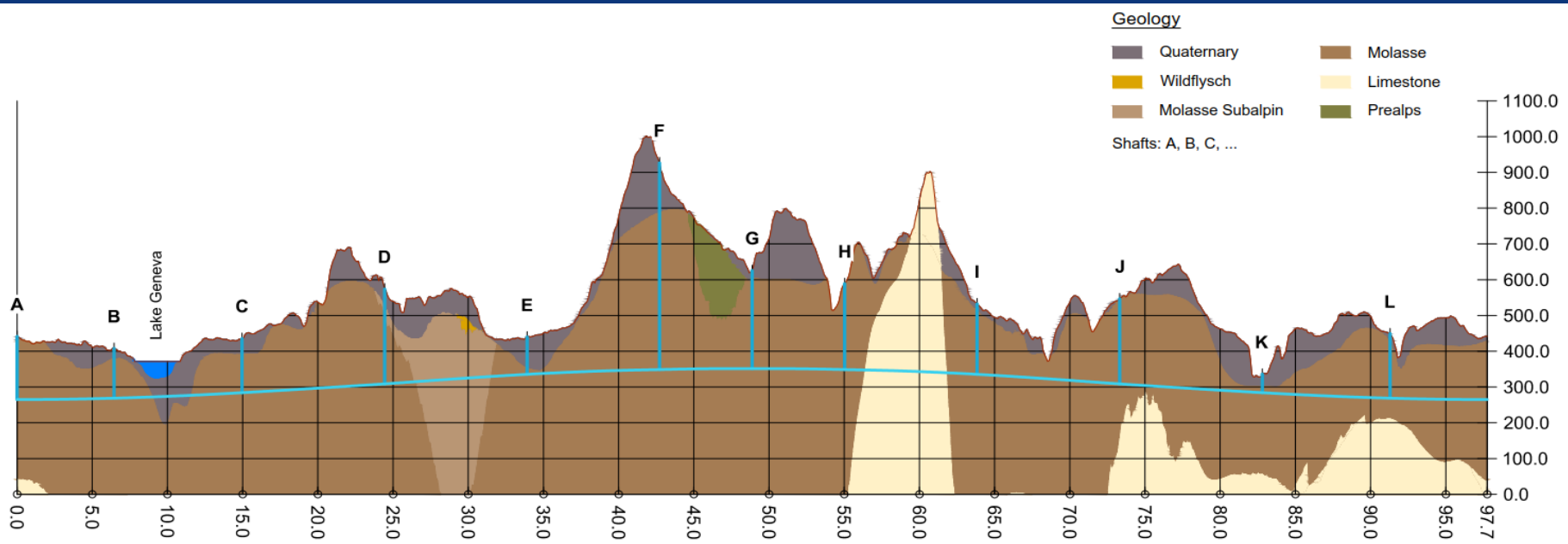
from
LHC technology
8.3 T NbTi dipole

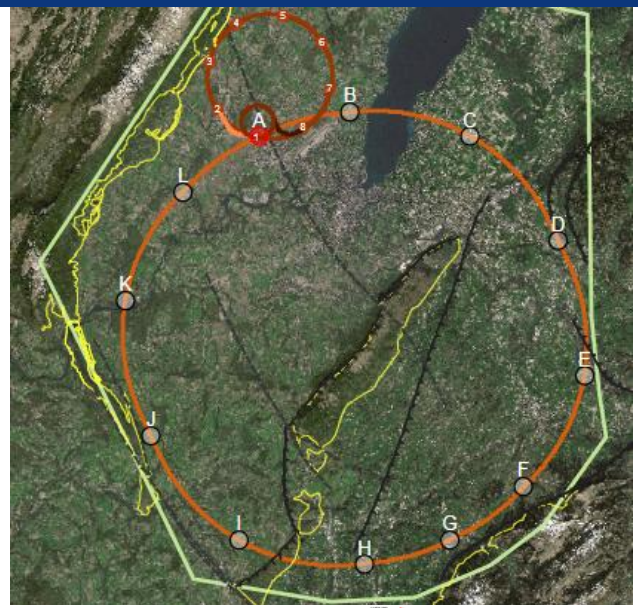
via
HL-LHC technology
12 T Nb_3Sn quadrupole

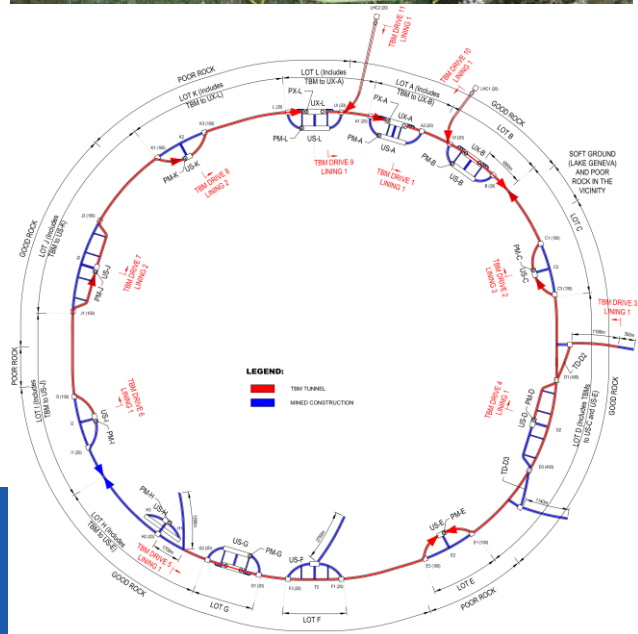


FNAL dipole demonstrator
14.5 T Nb_3Sn

FCC implementation - footprint baseline



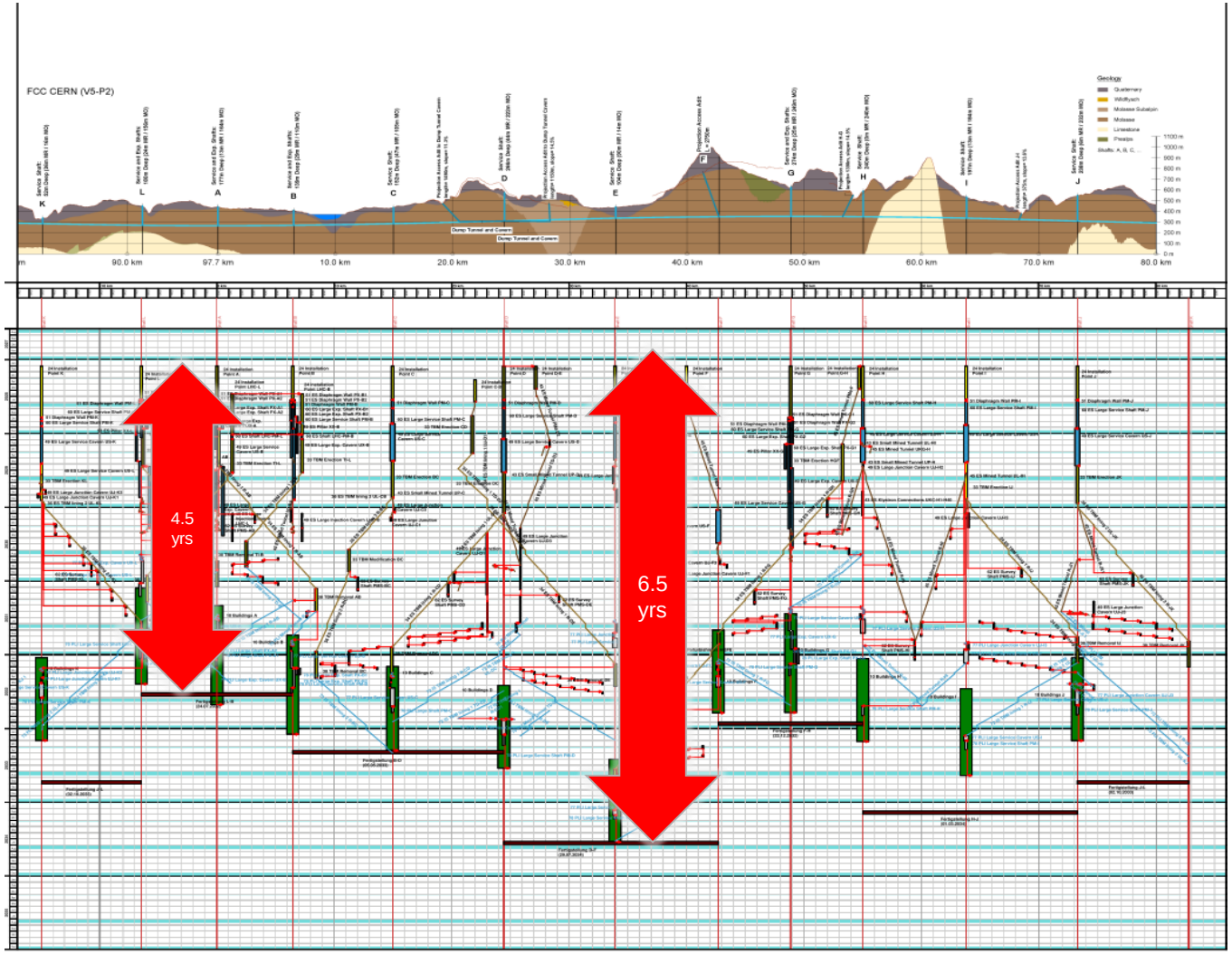


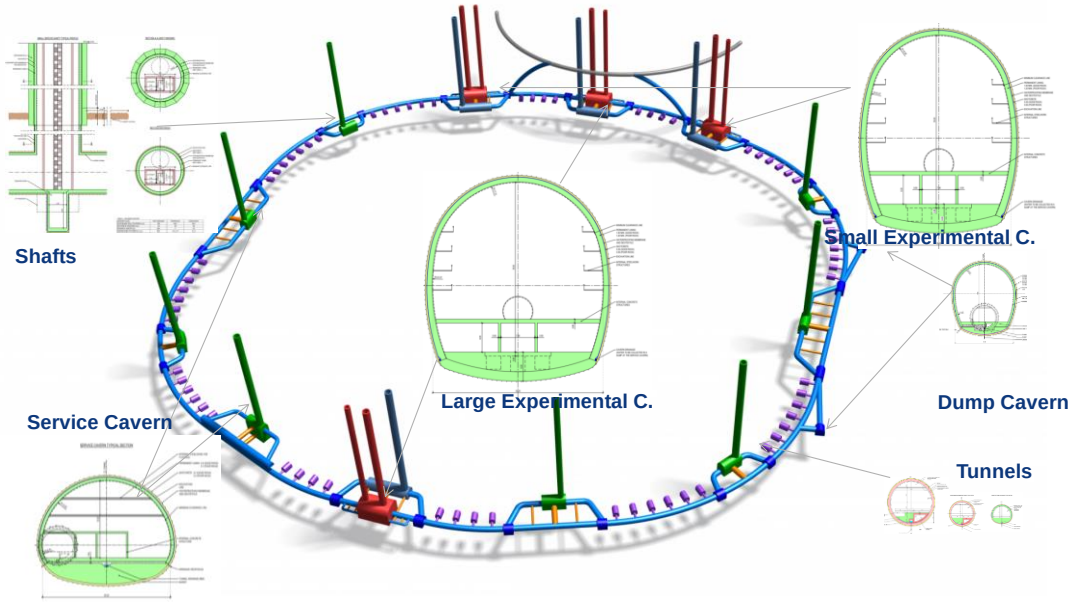


- **Present baseline position was established considering:**
- lowest risk for construction, fastest and cheapest construction
- Molasse rock preferred for tunnelling, avoid limestone with karstic structures

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

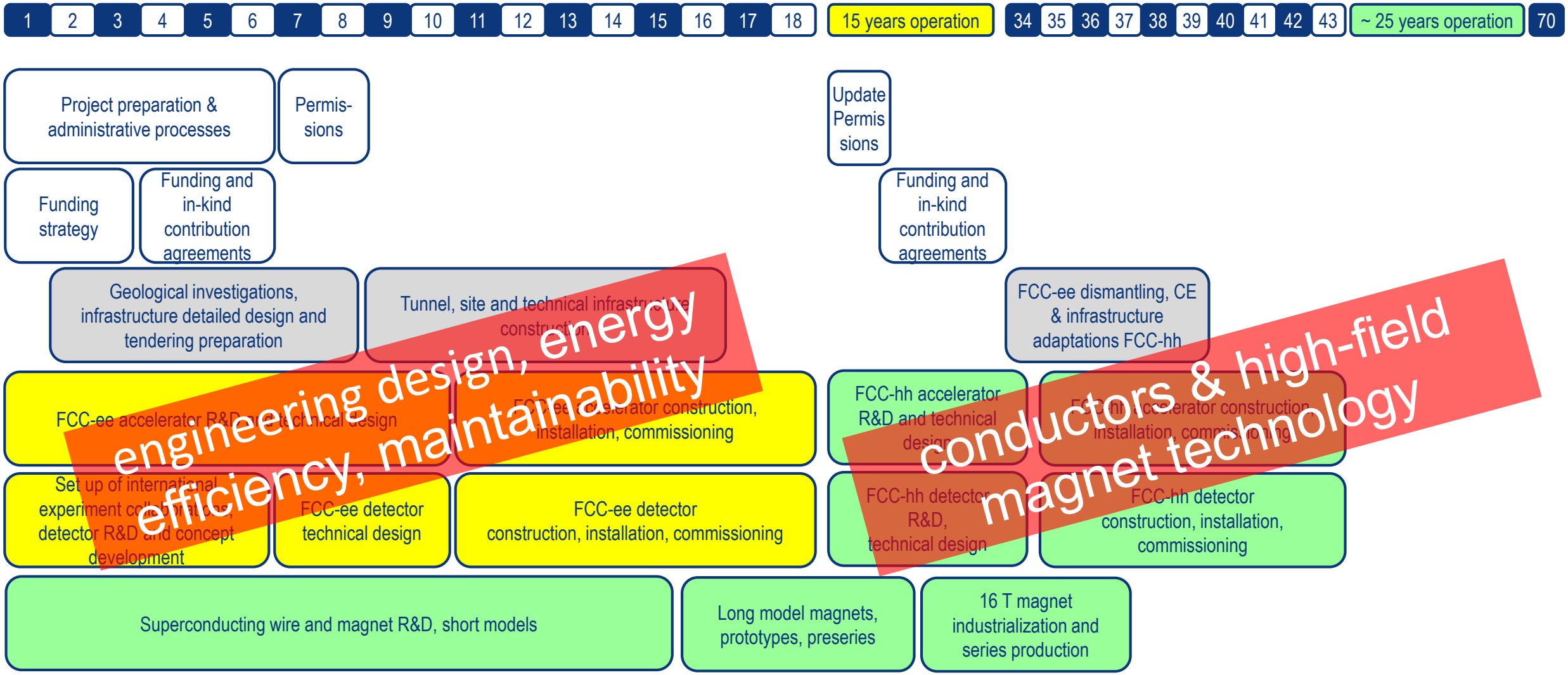
Civil Engineering construction schedule



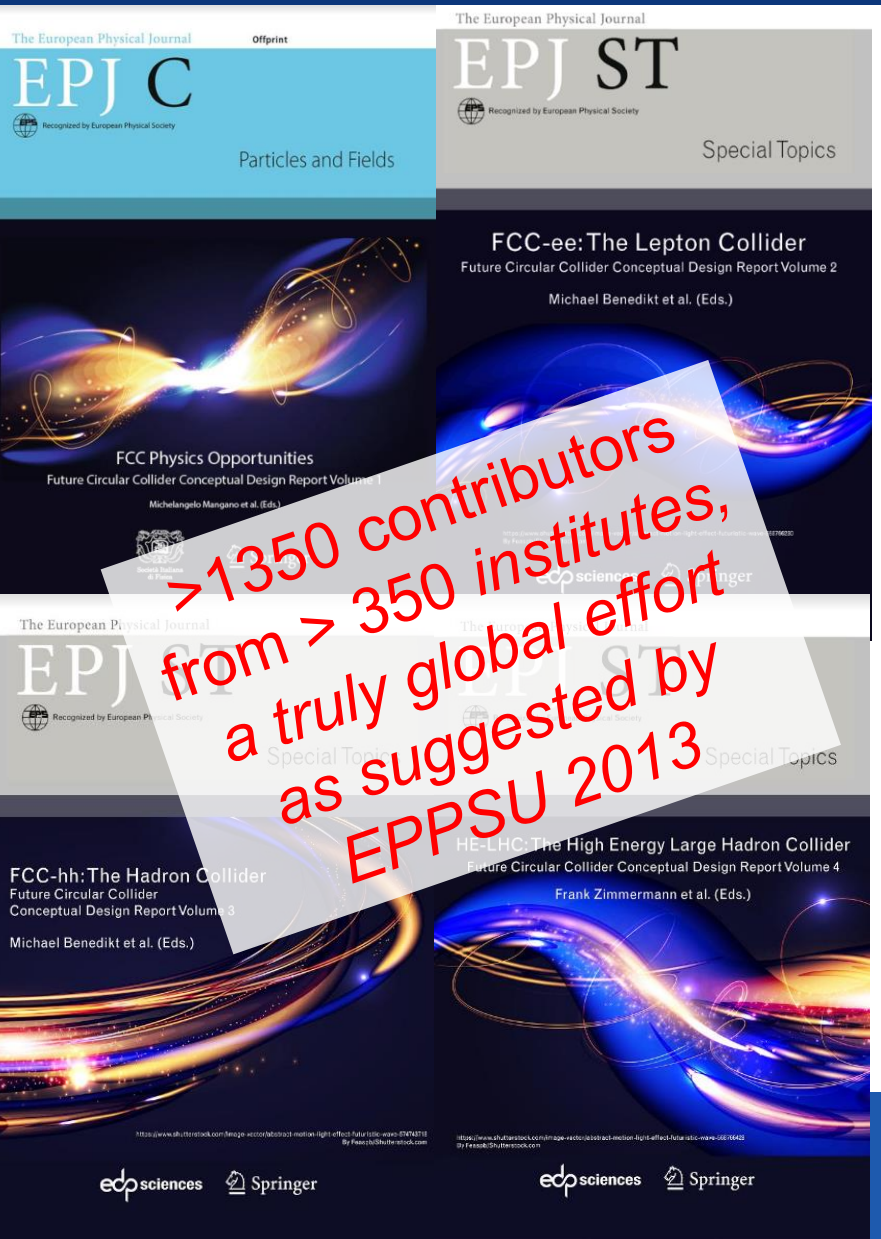


- **Total construction duration 7 years**
- **First sectors ready after 4.5 years**

FCC integrated project technical schedule



FCC CDR and Study Documentation



>1350 contributors
from > 350 institutes,
a truly global effort
as suggested by
EPPSU 2013

- **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/

From ESPPU 2020 document

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

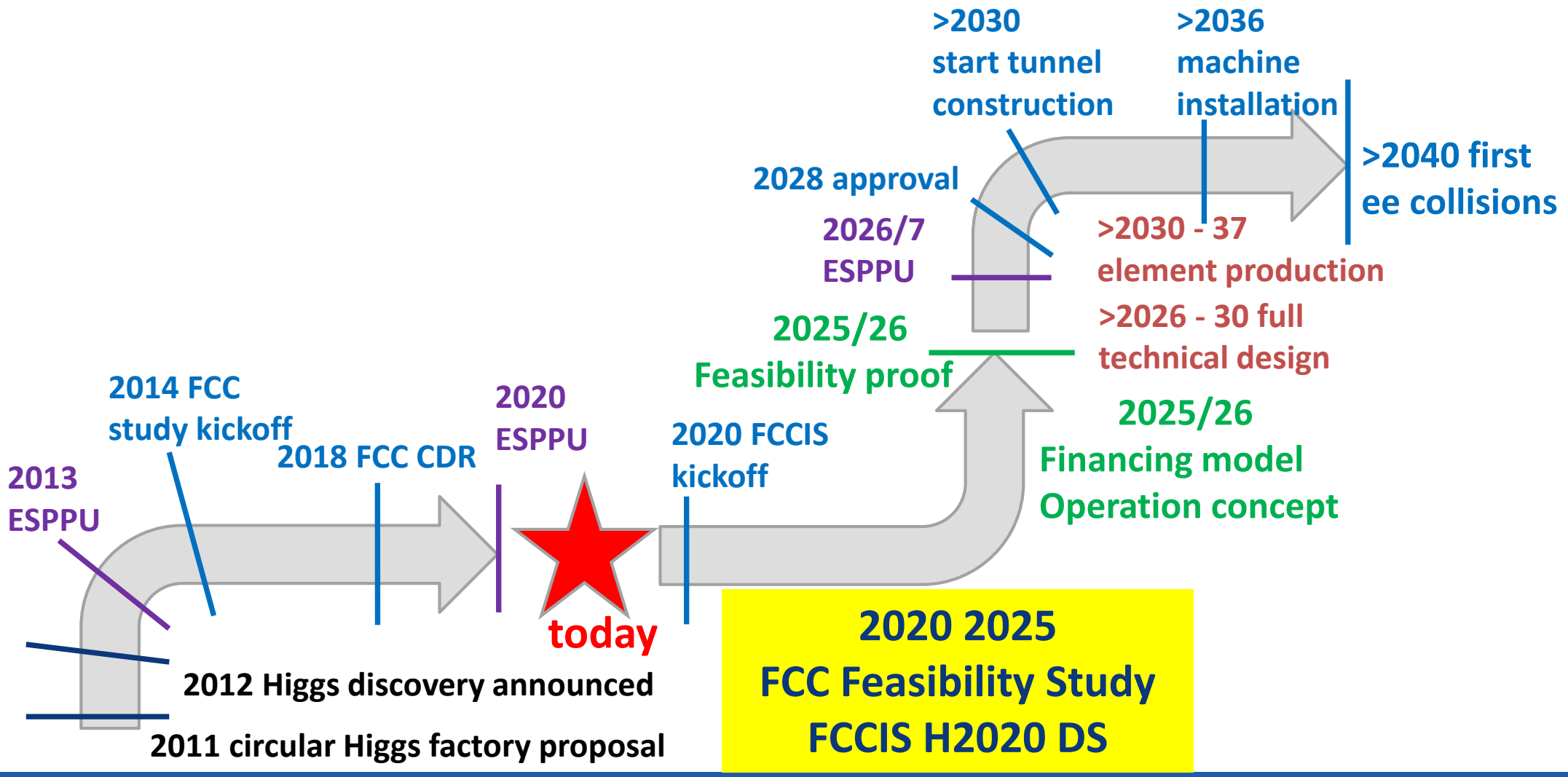
"Europe, together with its international partners, should investigate the technical and financial feasibility of a future hadron collider at CERN with a centre-of-mass energy of at least 100 TeV and with an electron-positron Higgs and electroweak factory as a possible first stage. Such a feasibility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

Feasibility Study of FCC integrated project

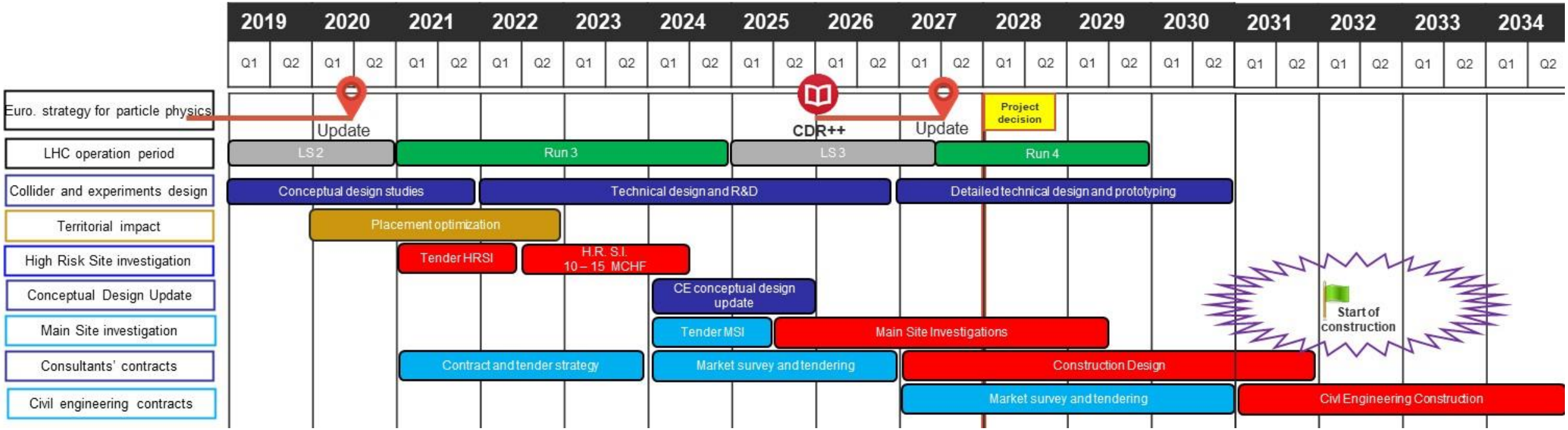
Feasibility study to be delivered end 2025 as **input for ESPP Update expected for 2026/2027, to enable a project decision**:

- ***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

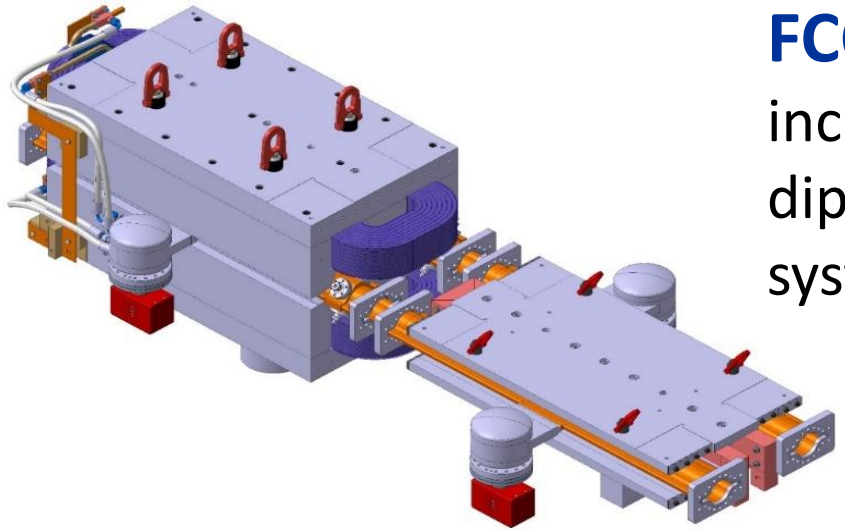


CE preparatory activities 2020 - 2030



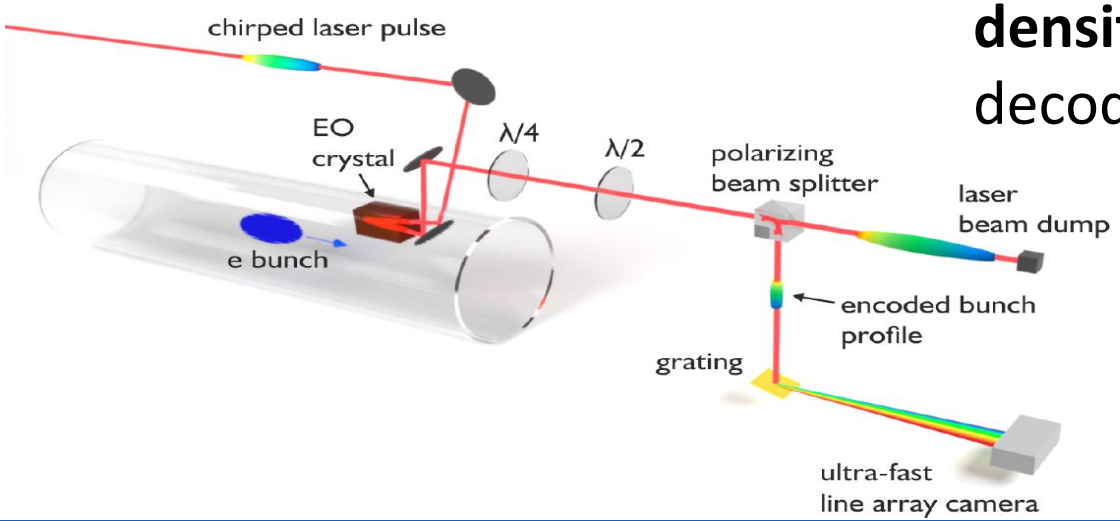
- Technical schedule of main processes leading to start of construction begin 2030ies
- For proof of principle feasibility: High risk area site investigations, 2022 – 2024
- Followed by update of civil engineering conceptual design and CE cost estimate 2025

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);

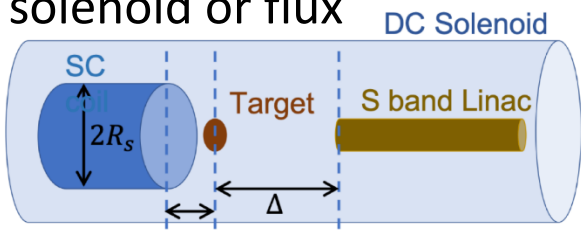
polarimeter ; **luminometer**

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

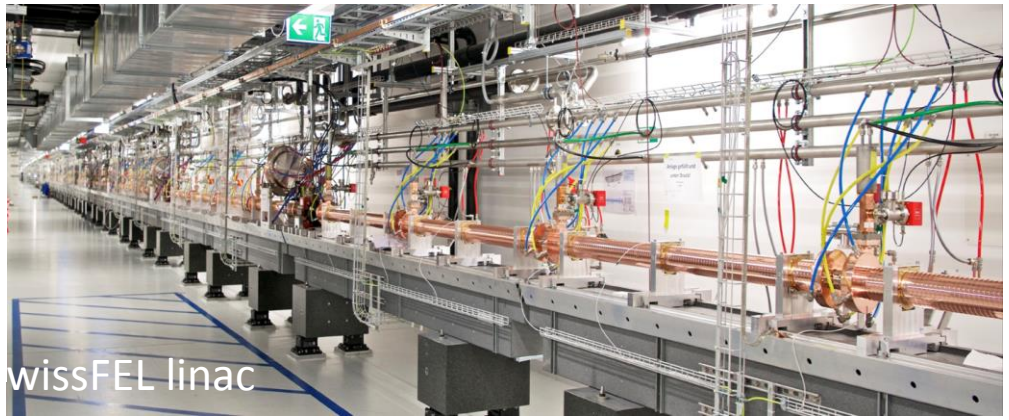
target with DC SC solenoid or flux concentrator



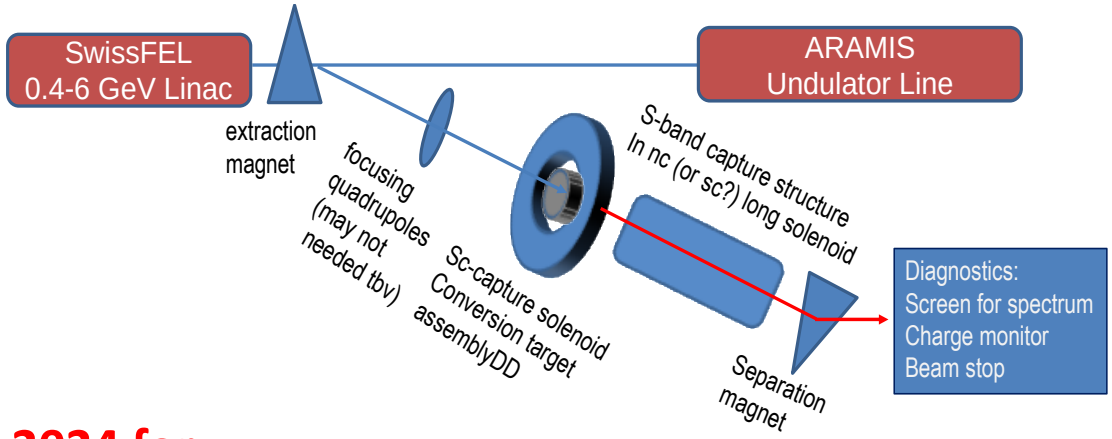
positron capture linac

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



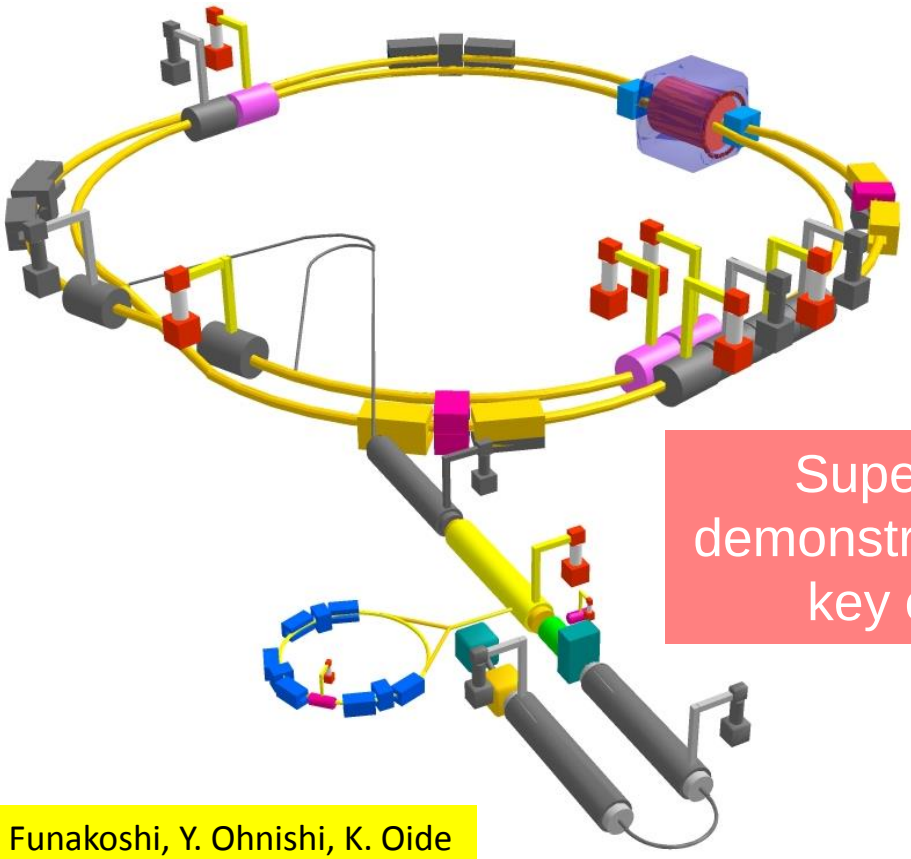
beam test of e⁺ source & capture linac at SwissFEL – yield measurement



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

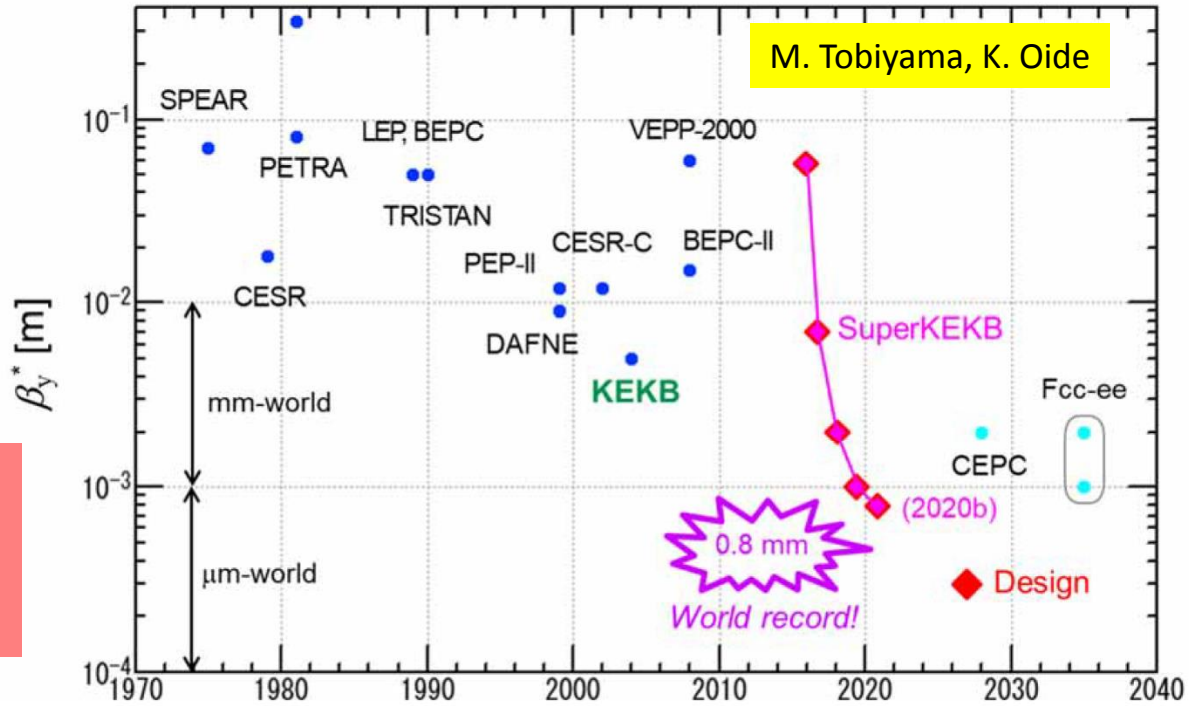
SuperKEKB – pushing luminosity and β*

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

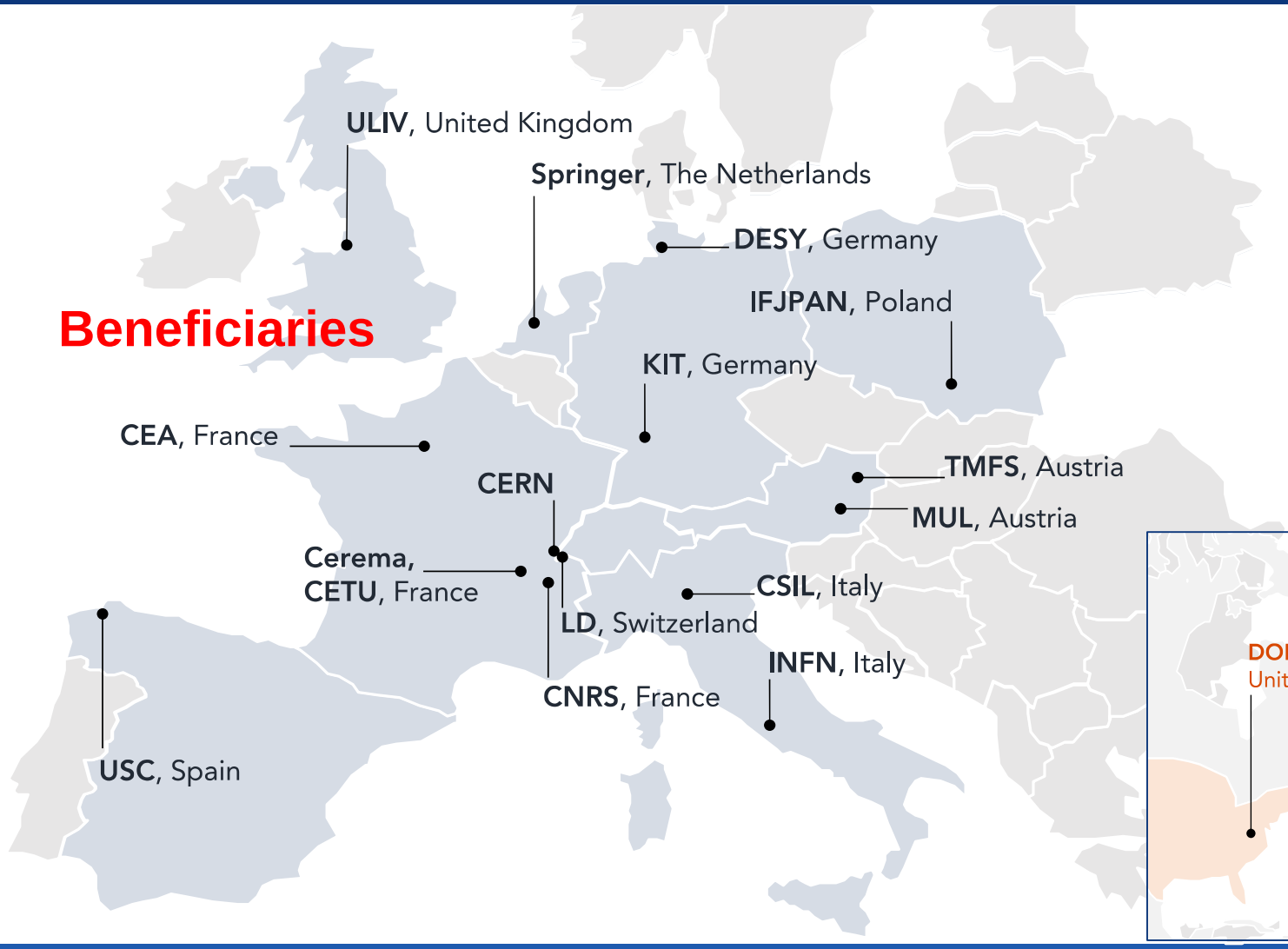
NSLS-II, EIC & FCC-ee beam parameters

	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 Thursday afternoon, towards EIC-FCC collaboration.

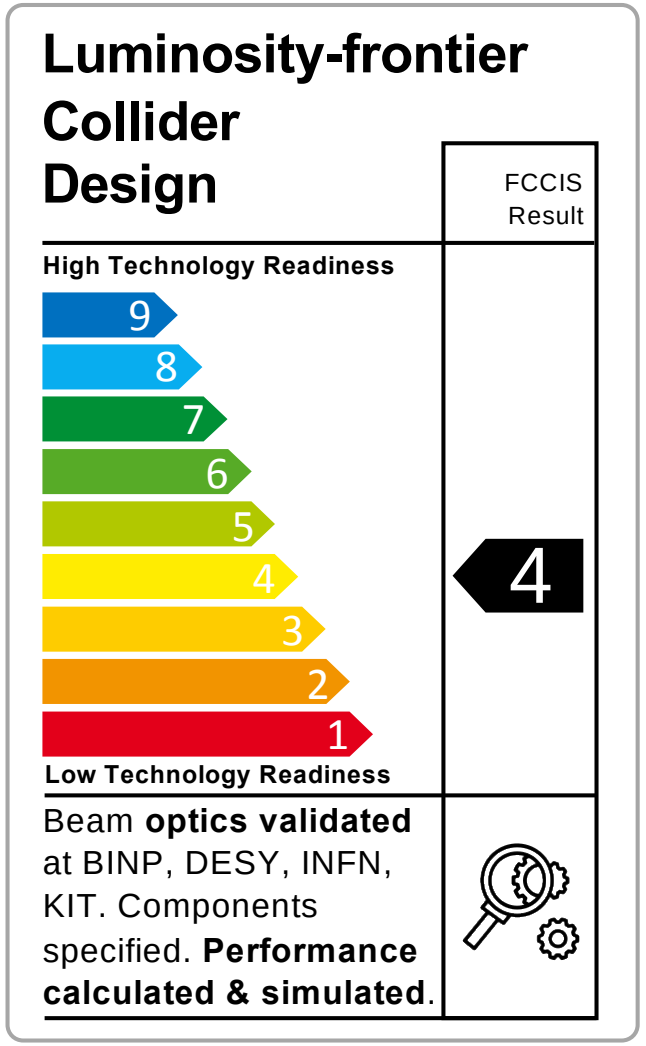
H2020 DS FCC Innovation Study 2020-24

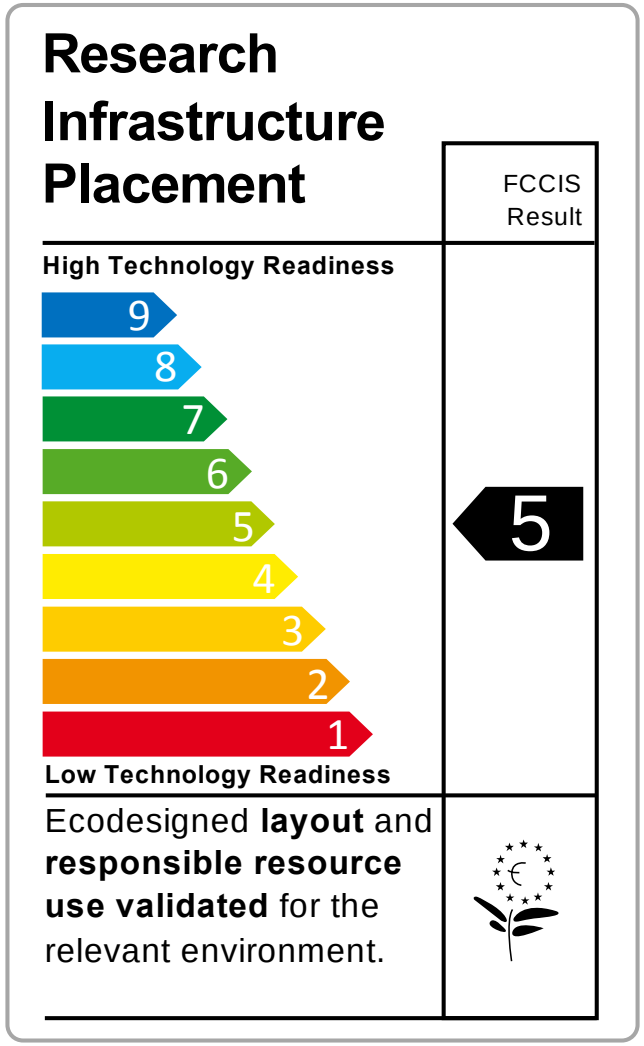


Topic	INFRADEV-01-2019-2020
Grant Agreement	FCCIS 951754
Duration	48 months
From-to	2 Nov 2020 – 1 Nov 2024
Project cost	7 435 865 €
EU contribution	2 999 850 €
Beneficiaries	16
Partners	6

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





FCCIS Work Packages

WP1: study management

WP2: collider design

Deliver a performance optimised machine design, integrated with the territorial requirements and constraints, considering cost, long-term sustainability, operational efficiency and design-for- socio-economic impact generation.

WP3: integrate Europe

Develop a feasible project scenario compatible with local – territorial constraints while guaranteeing the required physic performance.

WP4: impact & sustainability

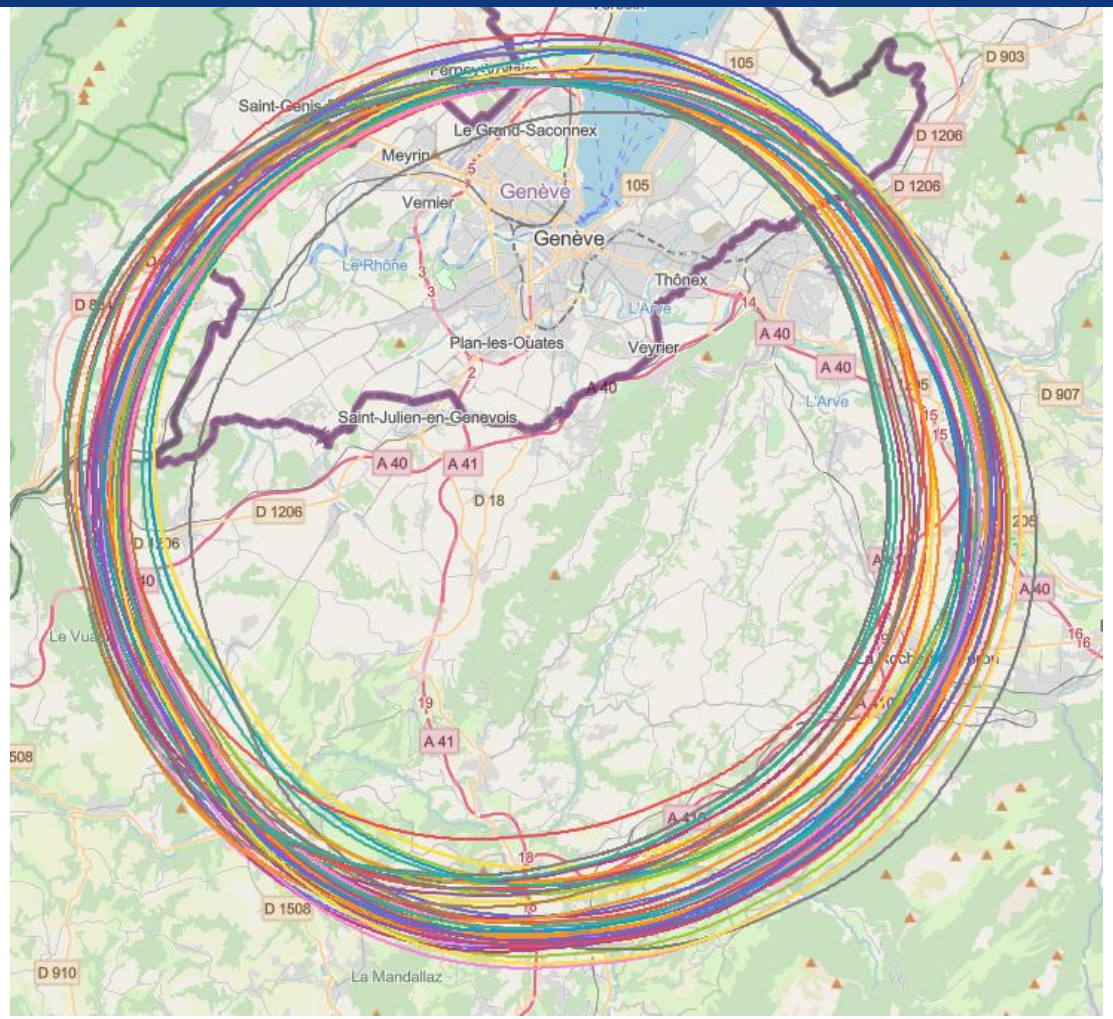
Develop the financial roadmap of the infrastructure project, including the analysis of socio-economic impacts.

WP5: leverage & engage

Engage stakeholders in the preparation of a new research infrastructure. Communicate the project rationale, objectives and progress. Create lasting impact by building theoretical and experimental physics communities, creating awareness of the technical feasibility and financial sustainability, forging a project preparation plan with the host states (France, Switzerland).

Collider placement optimisation

- An overall layout and placement optimisation process across both host states that follows the "avoid-reduce-compensate" directive according to European and French regulatory frameworks.
- Process integrates a diverse set of requirements and constraints, such as
  - performance for the scientific research to be competitive at international scale
  - civil engineering technical feasibility and subsurface constraints
  - territorial constraints at surface and subsurface
  - nature, accessibility, technical infrastructure and resource needs and constraints
  - economic factors including the development of benefits for and synergies with the regional developments
- Work takes place as a collaborative effort by 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

Status and Outlook

- **1st phase** of FCC design study **completed** → **baseline machine designs,** performance matching physics requirements, in **4 CDRs**
- **Integrated FCC programme** was submitted to the 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: a **world-leading HEP infrastructure for the 21st century** to push the particle-physics **precision and energy frontiers** far beyond present limits.
- Welcome all new participants to the FCC feasibility study phase and FCCIS project.