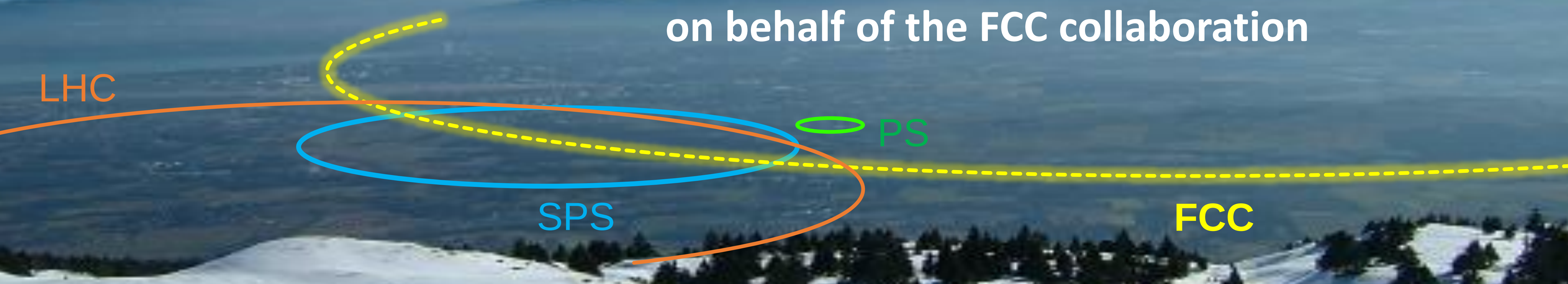
Future Circular Colliders

CERN Accelerator School, 20 May 2021

Michael Benedikt, CERN

on behalf of the FCC collaboration



http://cern.ch/fcc

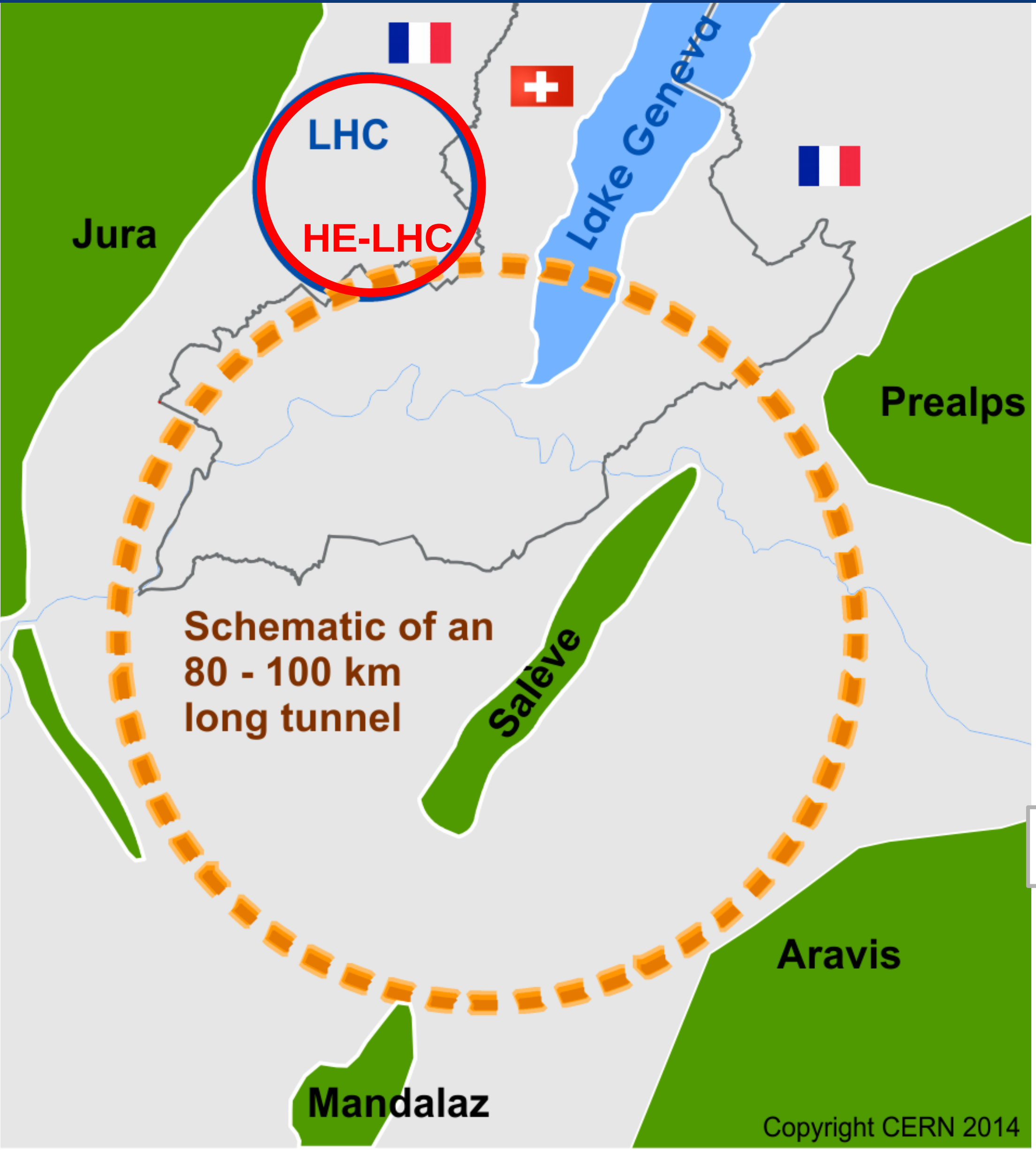
*Work supported by the **European Commission** under the **HORIZON 2020 projects EuroCirCol**, grant agreement 654305; **EASITrain,** grant agreement no. 764879; **ARIES**, grant agreement 730871, **FCCIS**, grant agreement 951754, and **E-JADE,** contract no. 645479*

European Commission

Horizon 2020
European Union funding
for Research & Innovation

photo: J. Wenninger

CERN Future Circular Collider Study

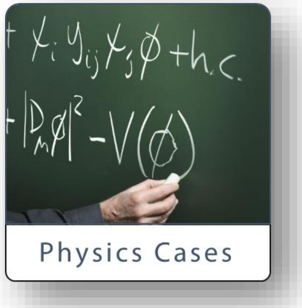


International FCC collaboration (CERN as host lab) to study:

- **~100 km tunnel infrastructure** in Geneva area, linked to CERN
- ***e^+e^-* collider (*FCC-ee*),** as potential first step
- ***pp*-collider (*FCC-hh*)** → long-term goal, defining infrastructure requirements

~16 T ⇒ 100 TeV *pp* in 100 km

- **lepton-hadron collisions** as options to FCC-hh

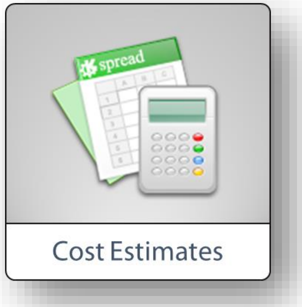

Physics Cases


Experiments

Collider Designs


R&D Programs

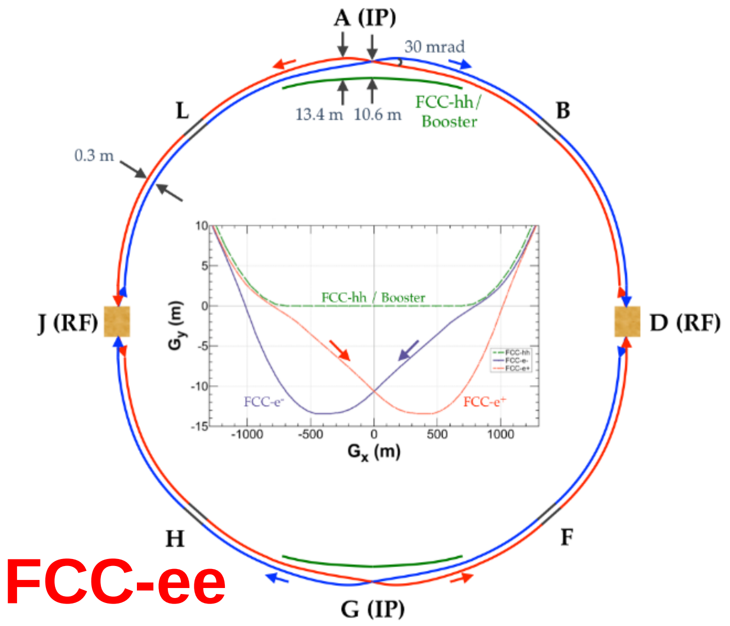

Infrastructures


Cost Estimates

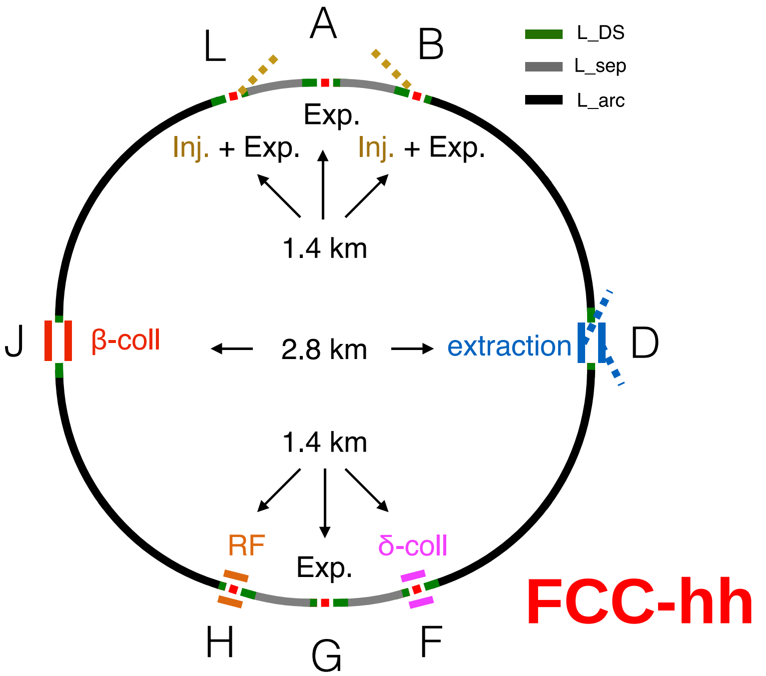
FCC integrated program
inspired by successful LEP – LHC programs at CERN

comprehensive cost-effective program maximizing physics opportunities

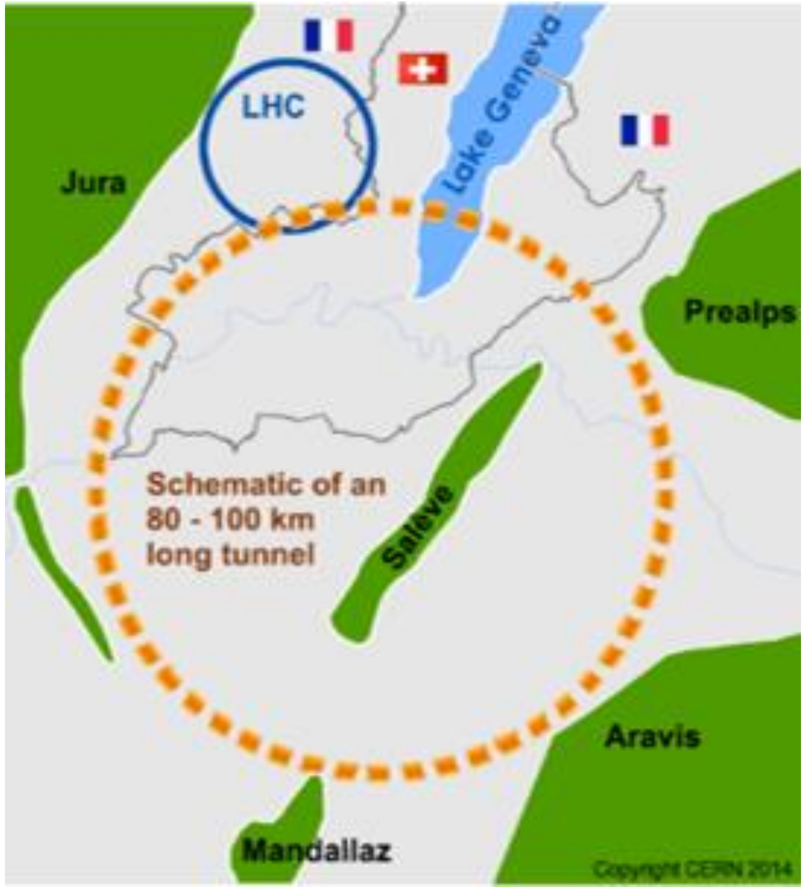
- **stage 1: FCC-ee (Z, W, H, $t\bar{t}$) as Higgs factory, electroweak & and top factory at highest luminosities**
- **stage 2: FCC-hh (~100 TeV) as natural continuation at energy frontier, with ion and eh options**
- complementary physics
- common civil engineering and technical infrastructures
- building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



FCC-ee



FCC-hh



FCC study: physics and performance targets

FCC-ee:

- **Exploration of 10 to 100 TeV energy scale via couplings with precision measurements**
- **~20-50 fold improved precision on many EW quantities (equiv. to factor 5-7 in mass)**

($m_{Z,}$ m_W, m_{top} , $\sin^2 \theta_w^{eff}$, R_b , α_{QED} (m_z) α_s (m_z m_W m_τ), Higgs and top quark couplings)

➢ **Machine design for highest possible luminosities at Z, WW, ZH and ttbar working points**

FCC-hh:

- **Highest center of mass energy for direct production up to 20 - 30 TeV**
- **Huge production rates for single and multiple production of SM bosons (H,W,Z) and quarks**

➢ **Machine design for ~100 TeV c.m. energy & integrated luminosity ~ $20 ab^{-1}$ within 25 years**

FCC-ee basic design choices

double ring e^+e^- collider ~100 km

follows footprint of FCC-hh, except around IPs

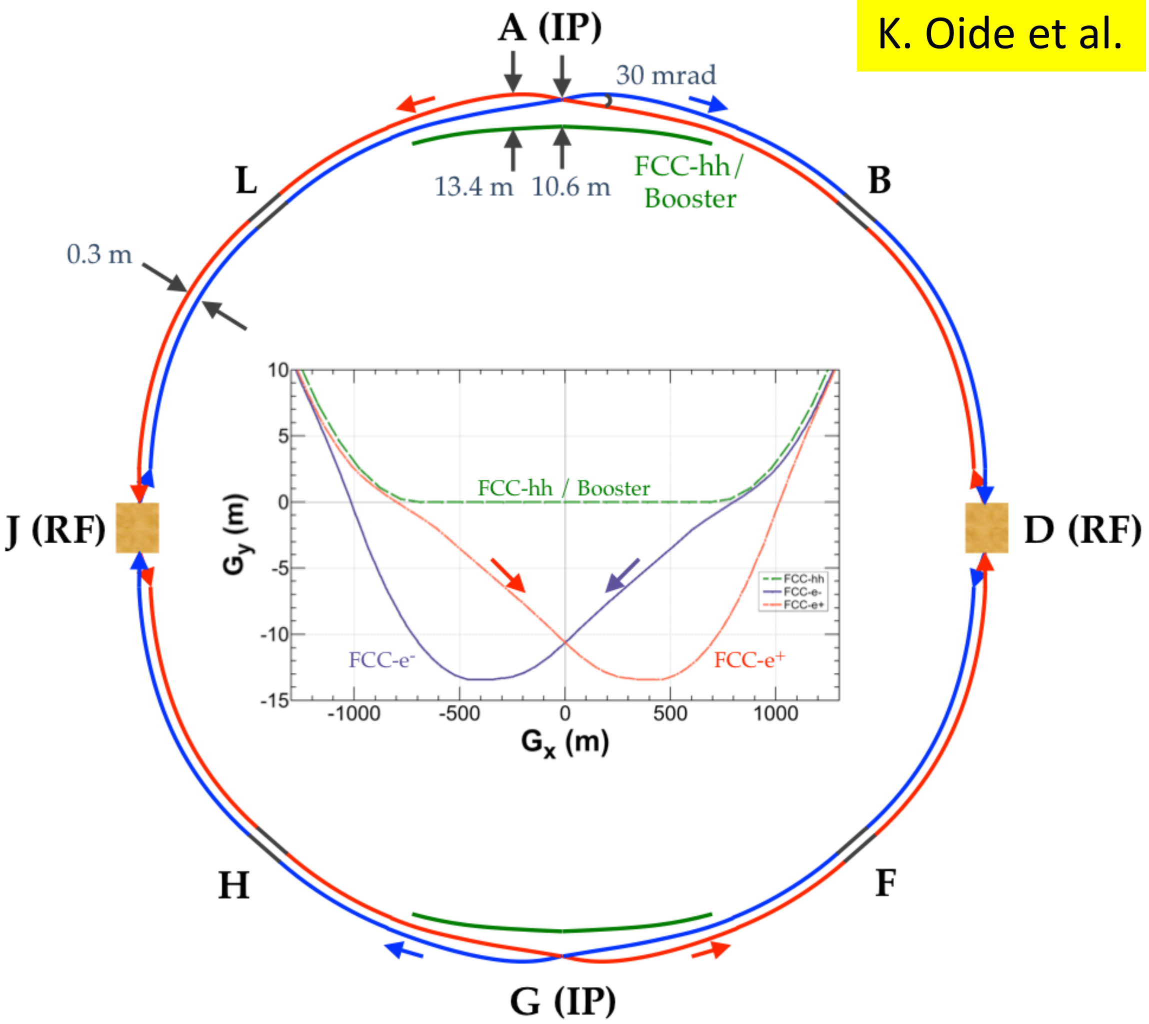
asymmetric IR layout & optics to limit synchrotron radiation towards the detector

presently 2 IPs (alternative layouts with 3 or 4 IPs under study), **large** horizontal crossing angle **30 mrad, crab-waist optics**

synchrotron radiation power 50 MW/beam at all beam energies; tapering of arc magnet strengths to match local energy

common RF for $t\bar{t}$ running

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



K. Oide et al.

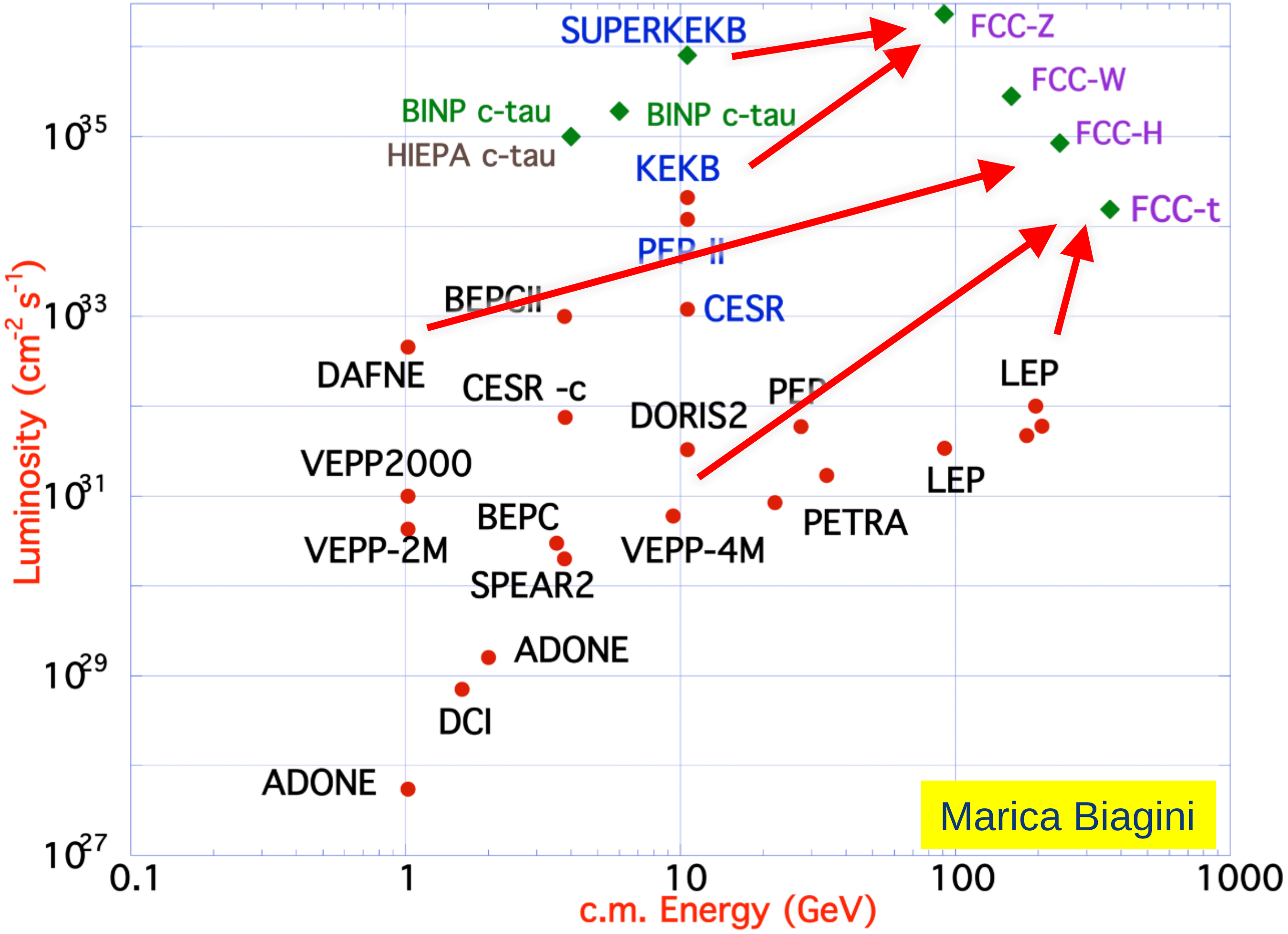
FCC-ee: The Lepton Collider, **Eur. Phys. J. Spec. Top. 228**, 261–623 (2019)
K. Oide et al., **Phys. Rev. Accel. Beams 19**, 111005 (2016)

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 design concept

based on lessons and techniques from past colliders (last 40 years)



Marica Biagini

B-factories: KEKB & PEP-II:
double-ring lepton colliders,
high beam currents,
top-up injection

DAFNE: crab waist, double ring

S-KEKB: low β_y*, crab waist

LEP: high energy, SR effects

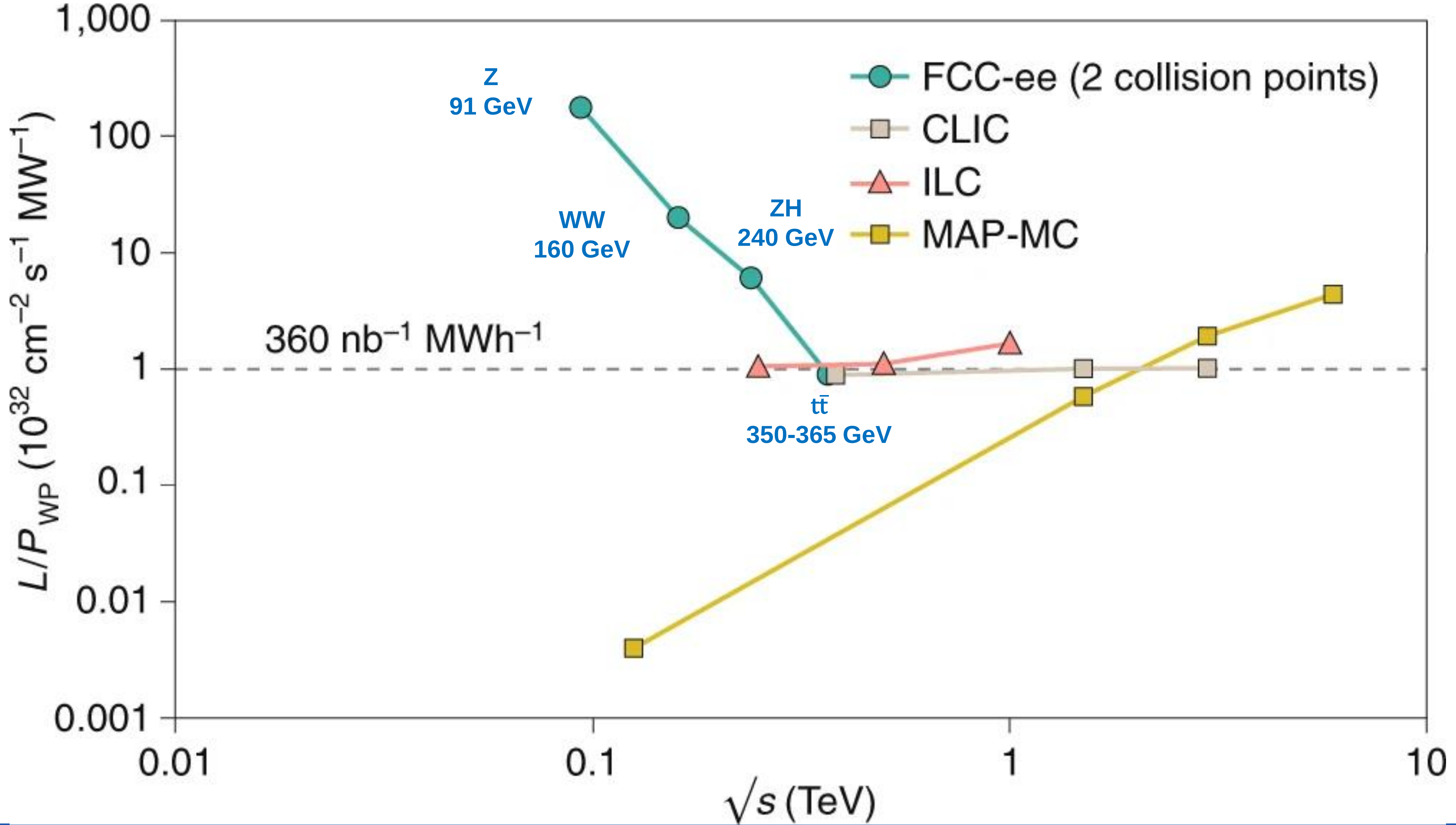
VEPP-4M, LEP: precision E calibration

KEKB: *e^+* source

HERA, LEP, RHIC: spin gymnastics

combining successful ingredients of several recent colliders → highest luminosities & energies

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

M. Benedikt, A. Blondel, P. Janot, et al., **Nat. Phys. 16**, 402-407 (2020), and
European Strategy for Particle Physics Preparatory Group, *Physics Briefing Book* (CERN, 2019)

FCC-ee figures of merit

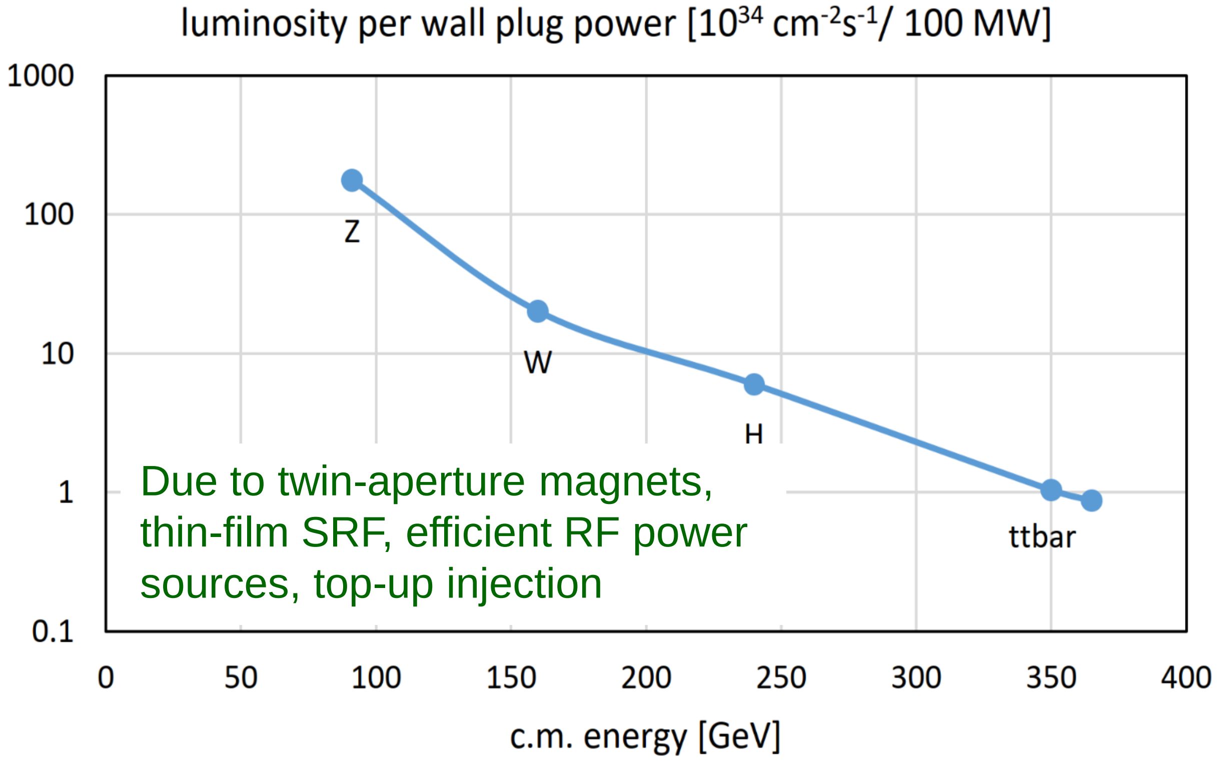
Luminosity vs. capital cost

- for the H running, **with 5 ab^{-1} accumulated over 3 years and 10^6 H produced**, the total investment cost (~10 BCHF) corresponds to
  → **10 kCHF per produced Higgs boson**
- for the Z running with **150 ab^{-1} accumulated over 4 years and $5x10^{12}$ Z produced,** the total investment cost corresponds to
  → **10 kCHF per $5×10^6$ Z bosons**

This it the number of Z bosons collected by each experiment during the entire LEP programme !

Capital cost per luminosity dramatically decreased compared with LEP !

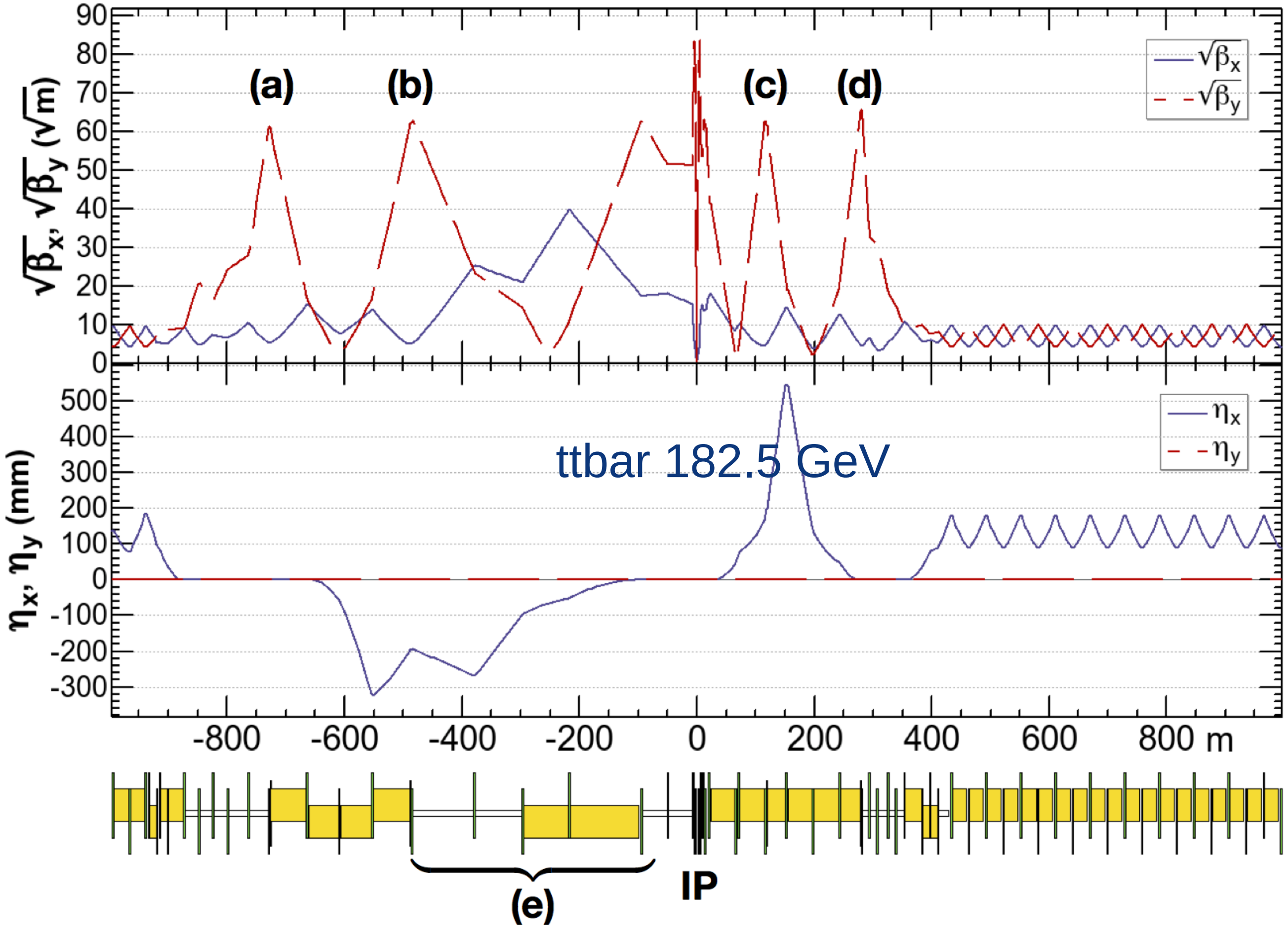
Luminosity vs. electricity consumption



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

Highest lumi/power of all H fact proposals
Electricity cost ~200 CHF per Higgs boson

FCC-ee asymmetric crab-waist IR optics



Novel asymmetric IR optics to suppress synchrotron radiation toward the IP, **$E_{critical}$ <100 keV from 450 m from IP (e)** **– lesson from LEP**

H. Burkhardt, A. Blondel, M. Koratzinos, K. Oide, et al.

only two sextupoles per final focus side:
minimum nonlinearity,
large dynamic aperture

yellow boxes: dipole magnets

4 sextupoles (a–d) for local vertical chromaticity correction combined w. crab waist, optimized for each working point – **novel "virtual crab waist", standard crab waist demonstrated at DAFNE**

K. Oide et al., **Phys. Rev. Accel. Beams 19**, 111005 (2016)

FCC-ee RF staging

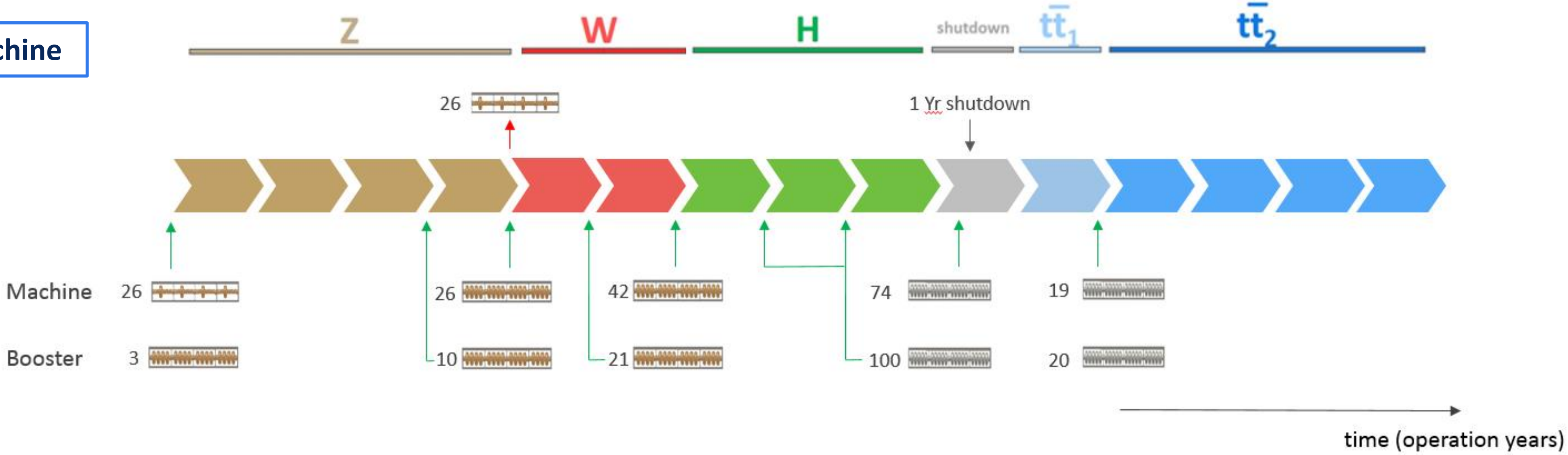
“Ampere-class” machine

WP	V_{rf} [GV]	#bunches	I_{beam} [mA]
Z	0.1	16640	1390
W	0.44	2000	147
H	2.0	393	29
ttbar	10.9	48	5.4

“high-gradient” machine

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

- **high intensity (Z, FCC-hh): 400 MHz mono-cell cavities (4/cryom.)**
- **higher energy (W, H, t): 400 MHz four-cell cavities (4/cryomodule)**
- **ttbar machine complement: 800 MHz five-cell cavities (4/cryom.)**
- **installation sequence comparable to LEP (≈ 30 CM/shutdown)**



FCC-ee physics program staging

working point	luminosity/IP [10^{34} cm^{-2}s^{-1}]	total luminosity (2 IPs)/ yr	physics goal	run time [years]
***Z* first 2 years**	100 (50% nominal)	26 ab^{-1}/year	**150 ab^{-1}**	**4**
***Z* later**	200	48 ab^{-1}/year		
W	25	6 ab^{-1}/year	**10 ab^{-1}**	**2**
H	7.0	1.7 ab^{-1}/year	**5 ab^{-1}**	**3**
machine modification for RF installation & rearrangement: **1 year**				
top 1st year (350 GeV)	0.8 (50% nominal)	0.2 ab^{-1}/year	**0.2 ab^{-1}**	**1**
top later (365 GeV)	1.4	0.34 ab^{-1}/year	**1.5 ab^{-1}**	**4**

total program duration: 15 years - ***including machine modifications***

phase 1 (*Z*, *W*, *H*): 9 years, phase 2 (top): 6 years

FCC-ee R&D: RF, cryo-modules, power sources

R&D aimed at improving performance & efficiency and reducing cost:

- improved Nb/Cu coating/sputtering, partner STFC (e.g. ECR fibre growth, HiPIMS)
- new cavity fabrication techniques, partner STFC (e.g. EHF, improved polishing, seamless)
- coating of A15 superconductors (e.g. Nb_3Sn), · cryo-module design optimisation
- bulk Nb cavity R&D at FNAL, Cornell, JLAB, also KEK and CEPC/IHEP
- MW-class fundamental power couplers for 400 MHz; · novel high-efficiency klystrons

Seamless 400 MHz single-cell cavity formed by spinning at INFN-LNL

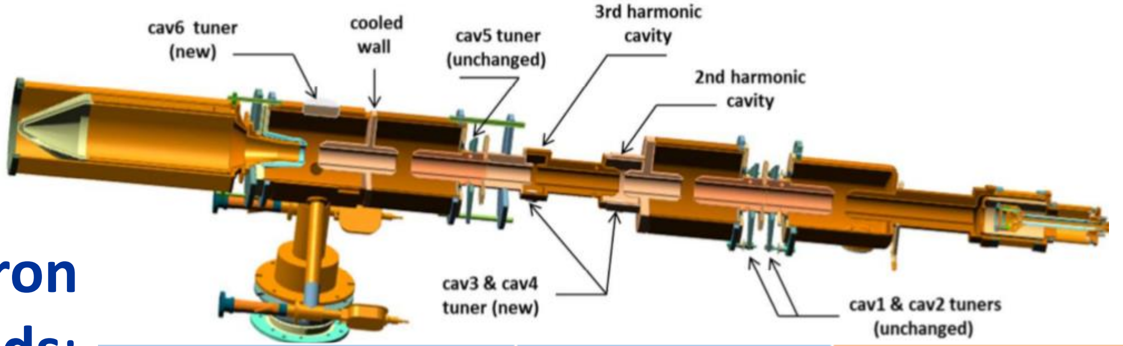
Legnaro, Feb 2018

V. Palmieri †

C. Pira

Tooling fabricated and successfully tested with an Aluminium cavity.

high-efficiency klystron at CERN



novel klystron bunching methods: LHC klystron retrofit as proof of principle for FCC

Parameter	present TH2167	CSM upgrade
Frequency [MHz]	400	
Beam voltage [kV]	54	
Saturated RF power [kW]	**300**	**350**
Efficiency [%]	**60**	**70**

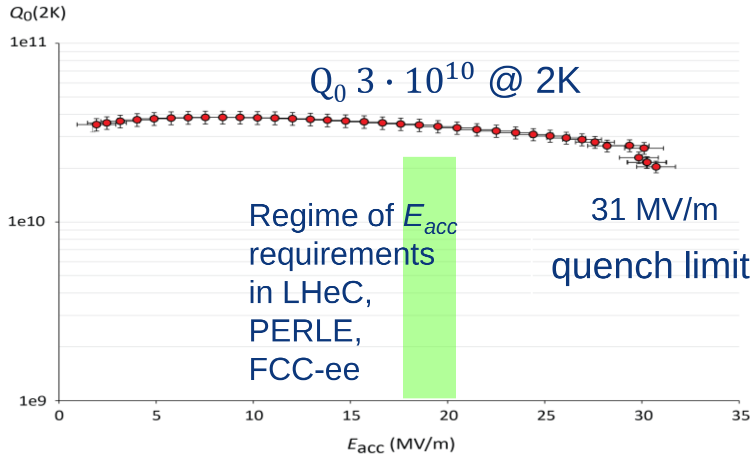
SRF R&D program, FCC-eh option and ERL


F. Marhauser et al

JLAB, October 25, 2017

5-cell 800 MHz cavity, JLAB prototype for FCC-ee (top mode) & FCC-eh; also single-cell cavities for all FCC's

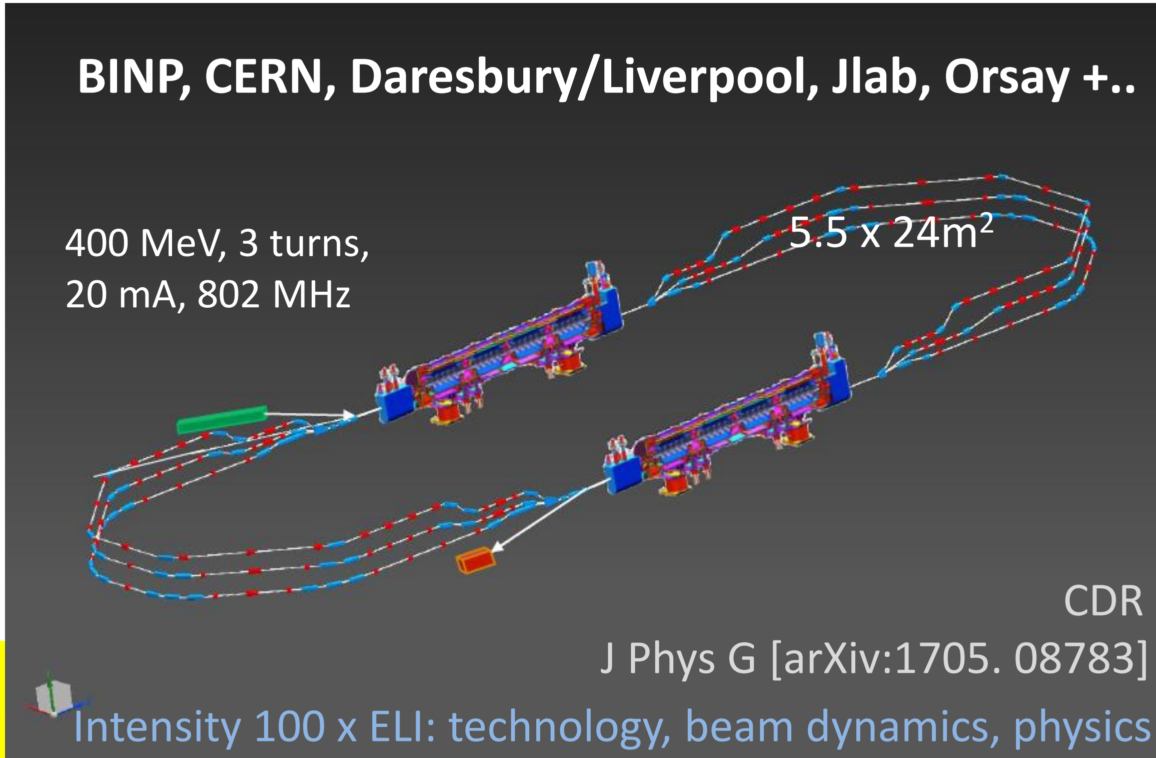
optimized for high current operation



FCC-eh: 60 GeV e^- from

Energy Recovery Linac (ERL)

PERLE@Orsay ERL test facility


BINP, CERN, Daresbury/Liverpool, Jlab, Orsay +..

400 MeV, 3 turns, 20 mA, 802 MHz

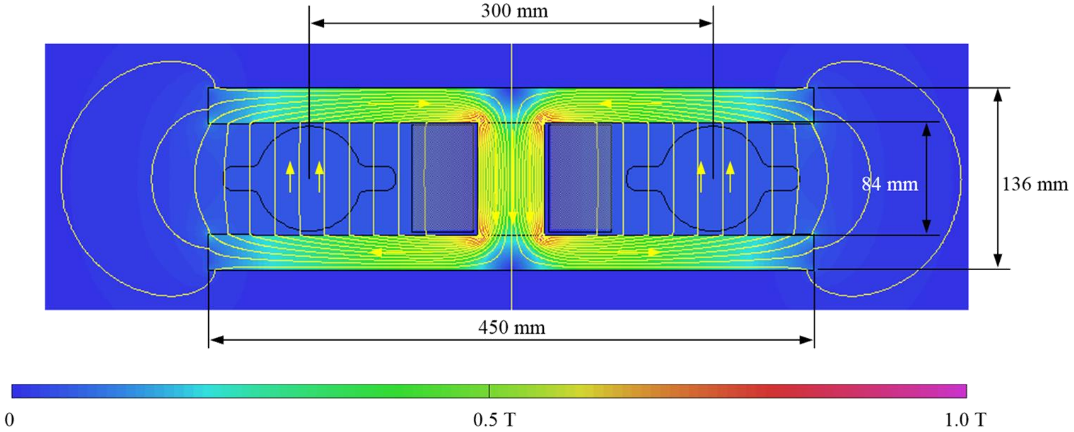
CDR

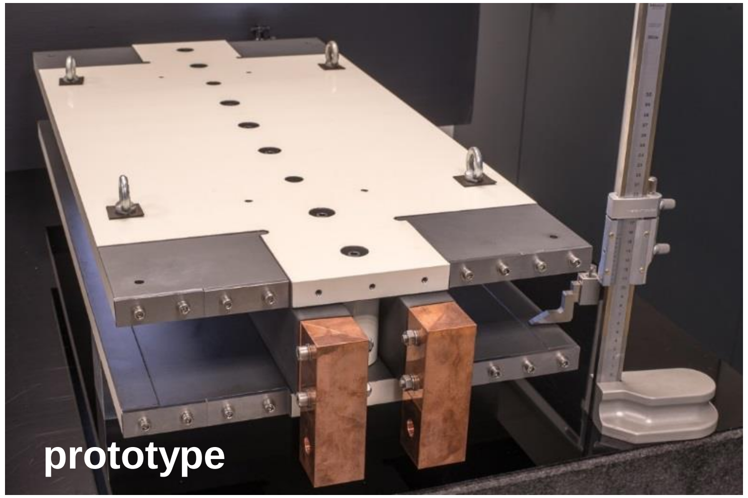
J Phys G [arXiv:1705. 08783]

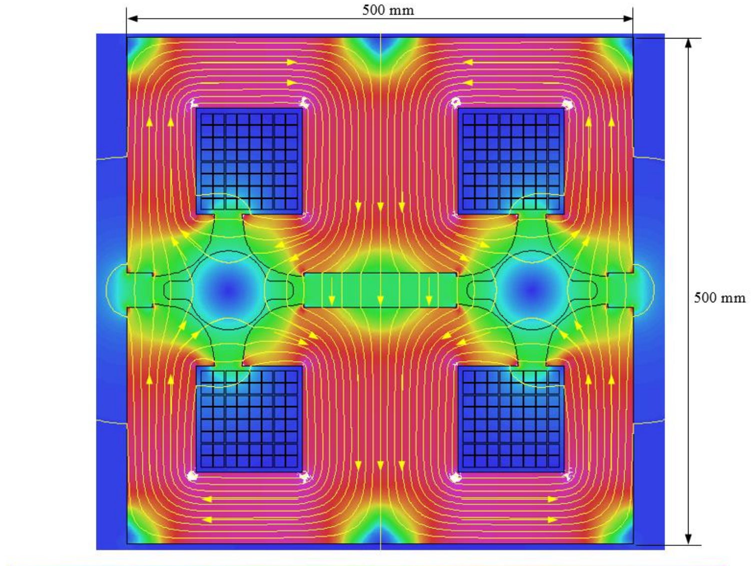
Intensity 100 x ELI: technology, beam dynamics, physics

Prototypes of FCC-ee low-power magnets

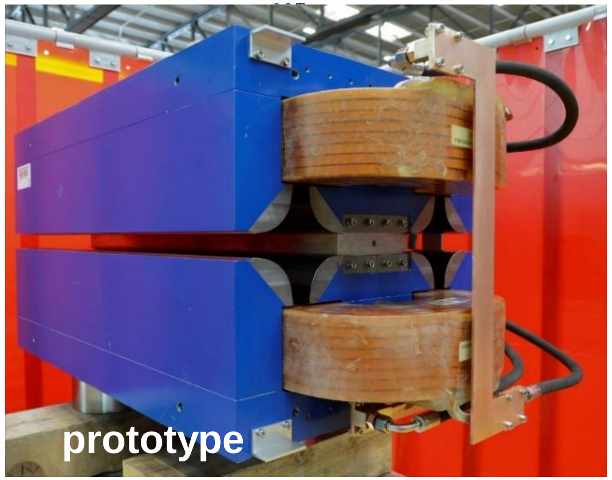
Twin-dipole design with 2× power saving 16 MW (at 175 GeV), with Al busbars



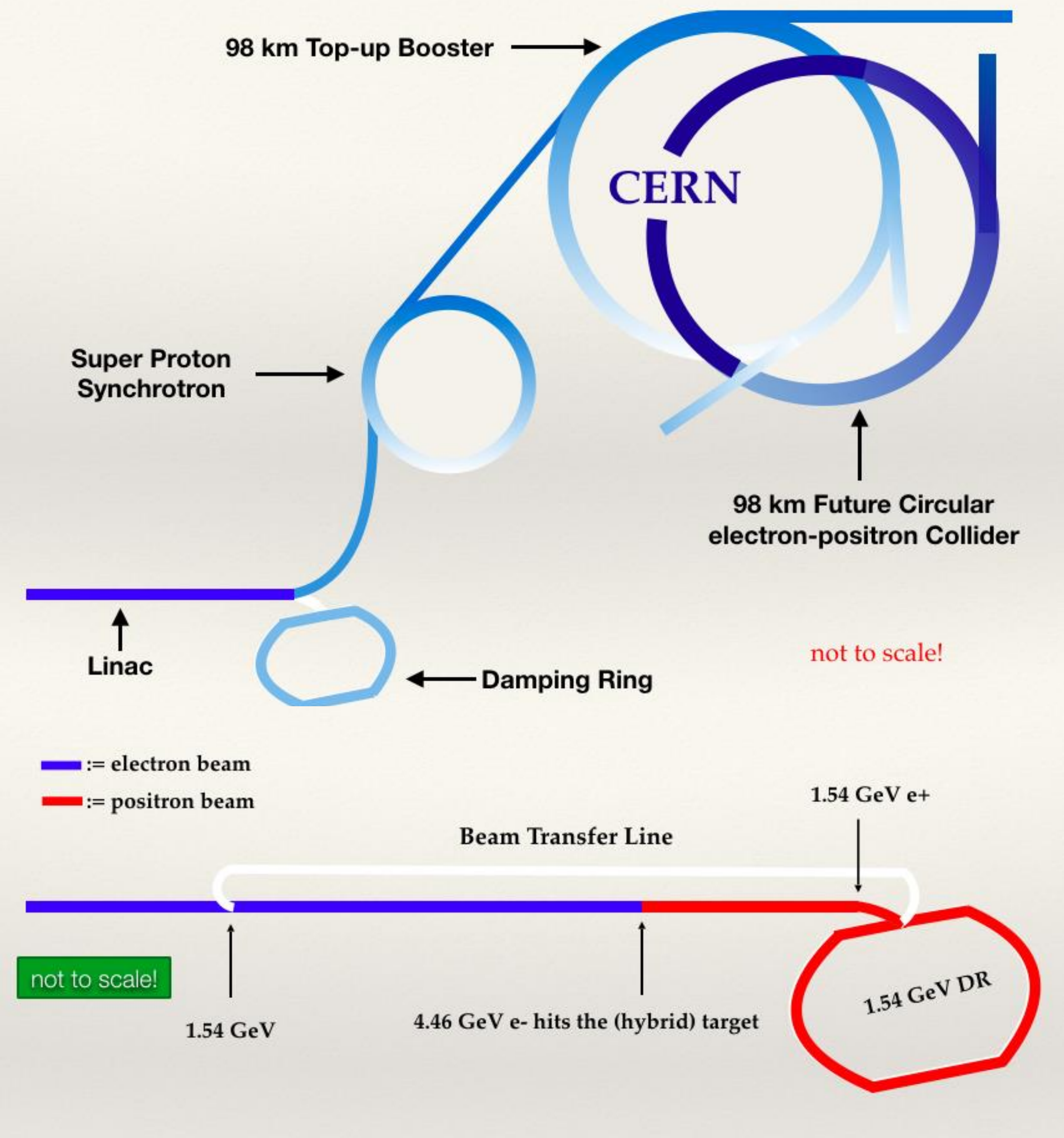




Twin F/D arc quad design with 2× power saving 25 MW (at 175 GeV), with Cu conductor



FCC-ee injector complex (baseline)



SLC/SuperKEKB-like 6 GeV S-band linac accelerating **1** or **2** bunches (2E10/b), with repetition rate **100-200 Hz**

Same linac used for e+ production @ **4.46 GeV** e+ beam emittances reduced in DR @ **1.54 GeV**

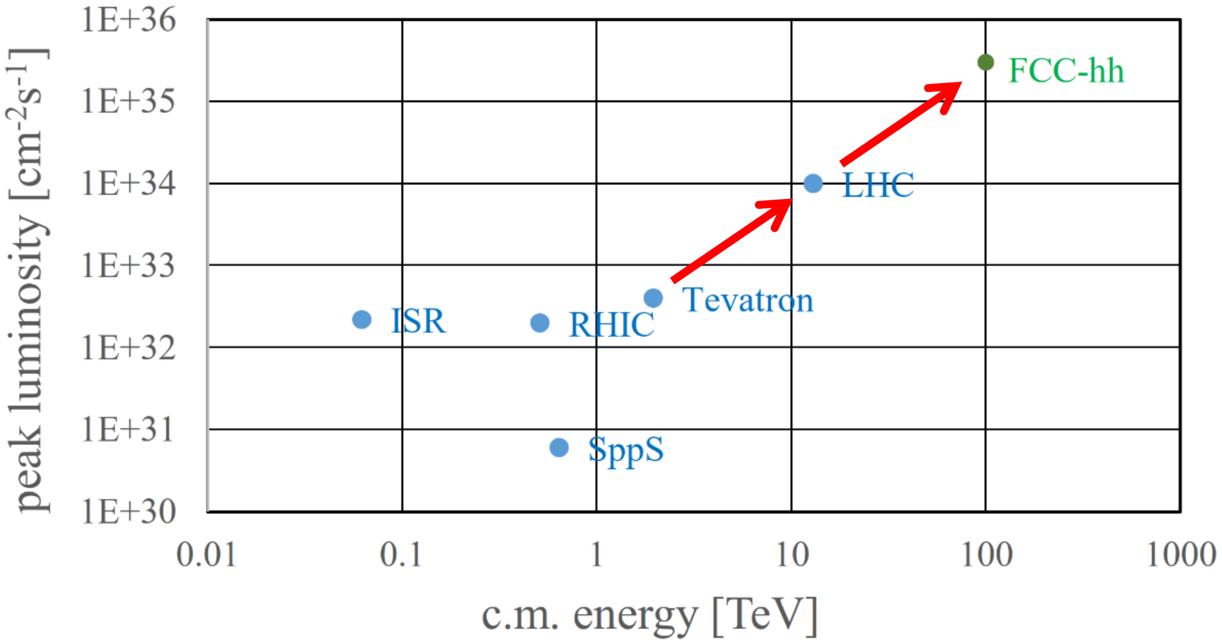
Injection @ **6 GeV** into pre-booster Ring (SPS or new ring) & accel. to 20 GeV, or 20 GeV linac

injection to main Booster @ **20 GeV** and interleaved filling of e+/e- (**<20 min for full filling**) and continuous top-up, typical rate 1/minute (Z) to 1/10s (tt)

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

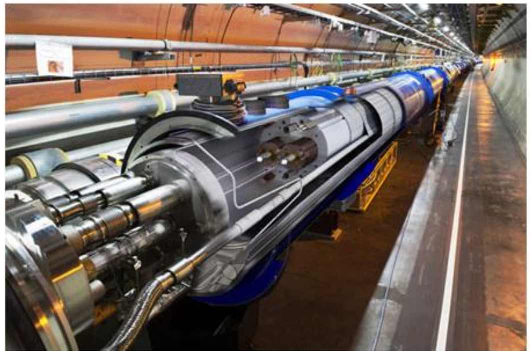
parameter	FCC-hh		HL-LHC	LHC
collision energy cms [TeV]	100		14	14
dipole field [T]	16		8.33	8.33
circumference [km]	97.75		26.7	26.7
beam current [A]	0.5		1.1	0.58
bunch intensity [10^{11}]	1	1	2.2	1.15
bunch spacing [ns]	25	25	25	25
synchr. rad. power / ring [kW]	2400		7.3	3.6
SR power / length [W/m/ap.]	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

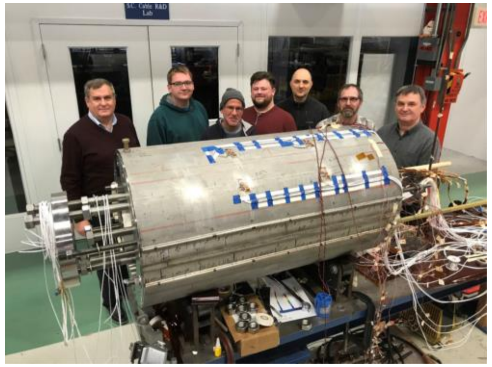


- **order of magnitude performance increase** in both **energy & luminosity**
- **100 TeV cm collision energy** (vs 14 TeV for LHC)
- **20 ab^{-1} per experiment collected over 25 years** of operation (vs 3 ab^{-1} for LHC)
- similar performance increase as from Tevatron to LHC
- **key technology: high-field magnets**

from
LHC technology
8.3 T NbTi dipole

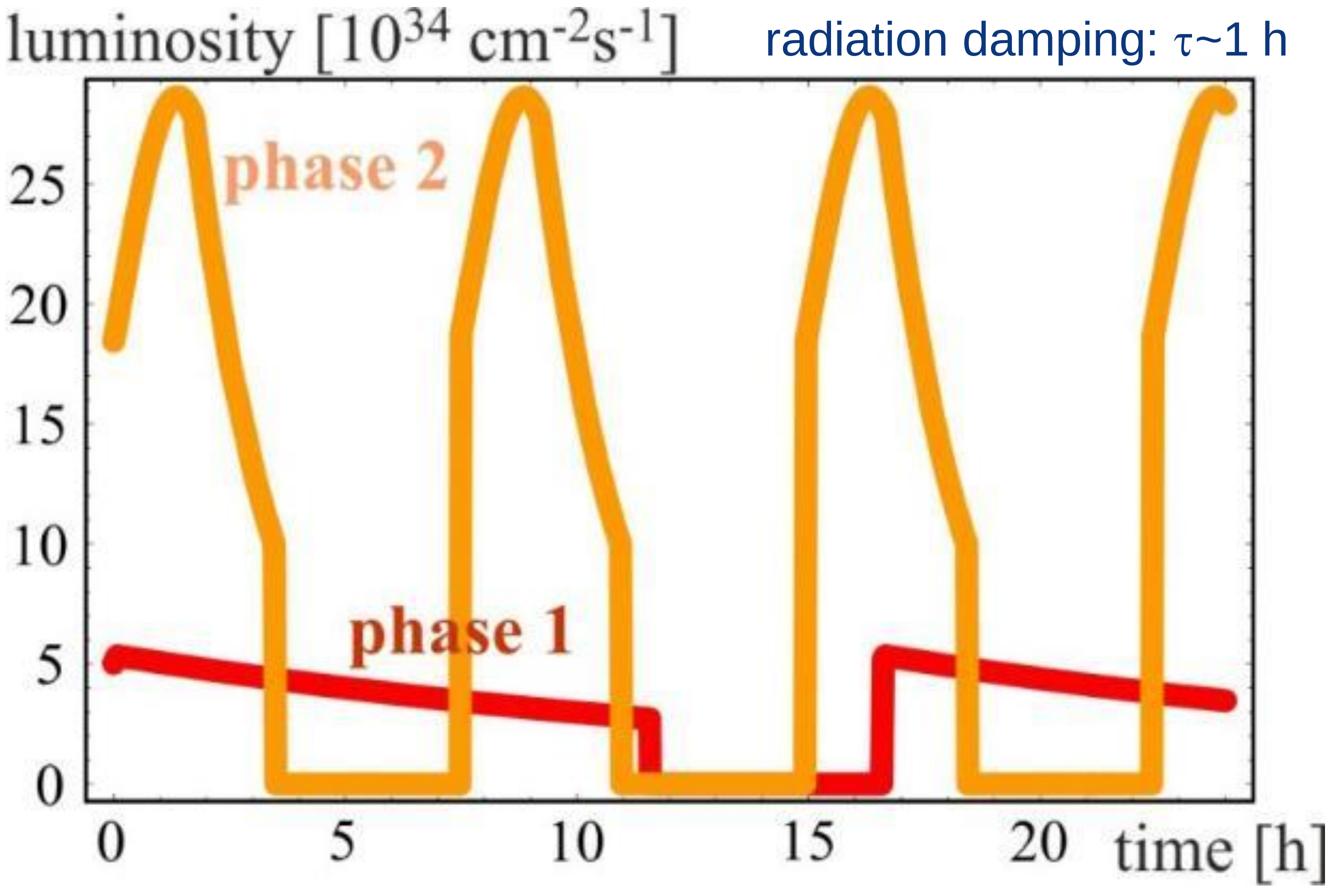


via
HL-LHC technology
12 T Nb$_3$Sn quadrupole



FNAL dipole
demonstrator
14.5 T Nb$_3$Sn

FCC-hh operation phases and luminosity



Phase 2: Interplay of radiation damping, luminosity burn-off, controlled transvers blow-up

phase 1:
β^*=1.1 m, $\Delta Q_{tot}=0.01$, t_{ta}=5 h
250 fb^{-1} / year

phase 2:
β^*=0.3 m, $\Delta Q_{tot}=0.03$, t_{ta}=4 h
1 ab^{-1} / year

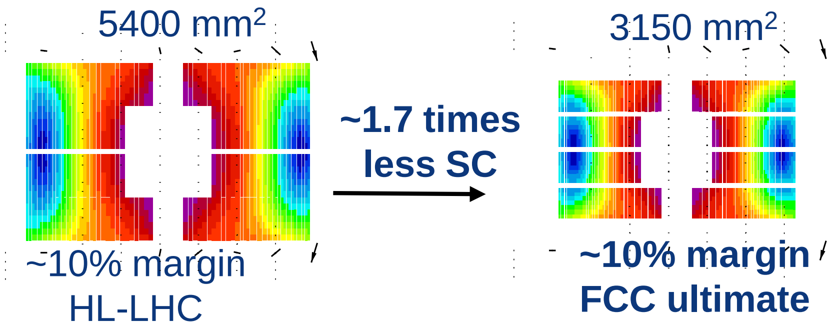
Transition via operation experience, no HW modification

Total integrated luminosity over 25 years operation:
O(20) ab^{-1}/experiment
consistent with physics goals

Worldwide FCC Nb_3Sn program

Main development goal is wire performance increase:

- **J_c (16T, 4.2K) > 1500 A/mm² →50% increase wrt HL-LHC wire**
- **Reduction of coil & magnet cross-section**


5400 mm²

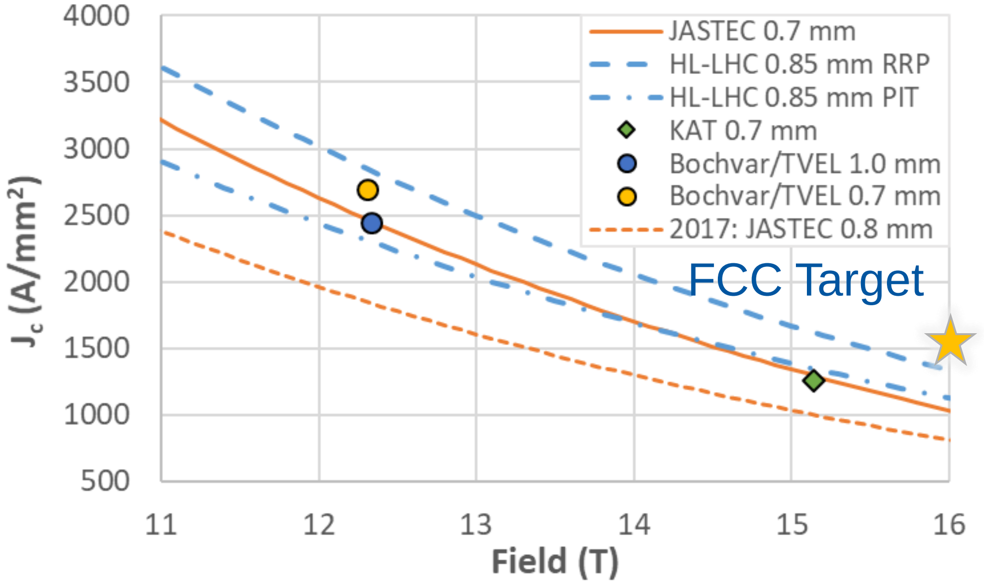
~10% margin
HL-LHC

~1.7 times
less SC

3150 mm²

~10% margin
FCC ultimate

After 1-2 years development, **prototype Nb_3Sn wires from several new industrial FCC partners already achieve HL-LHC J_c performance**



FCC conductor development collaboration:

- **Bochvar Institute** (production at **TVEL**), **Russia**
- **KEK** (**Jastec** and **Furukawa**), **Japan**
- **KAT**, **Korea, Columbus**, **Italy**
- **University of Geneva**, **Switzerland**
- **Technical University of Vienna**, **Austria**
- **SPIN**, **Italy, University of Freiberg**, **Germany**
- **Bruker**, **Germany, Luvata Pori**, **Finland**

2019/20 results from US, meeting FCC J_c specs:

- **Florida State University:** high-J_c Nb_3Sn via Hf addition
- **Hyper Tech /Ohio SU/FNAL**: high-J_c Nb_3Sn via artificial pinning centres based on Zr oxide.

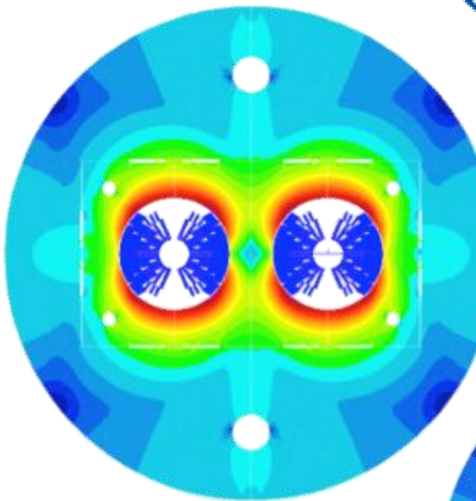
16 T dipole design activities and options

H2020

EuroCirCol

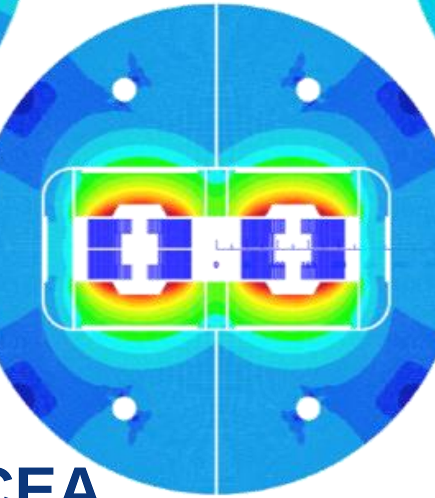
A key to New Physics

Cos-theta



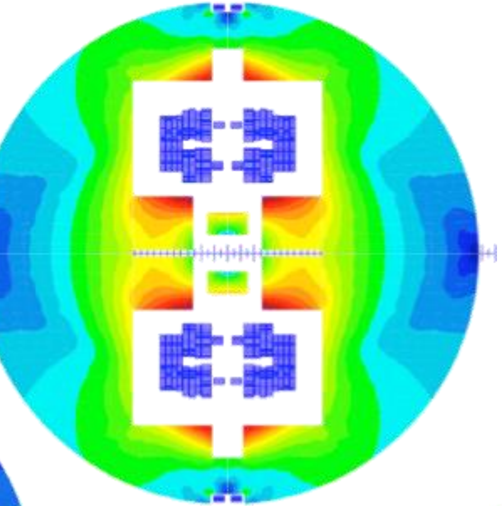
INFN

Blocks



CEA

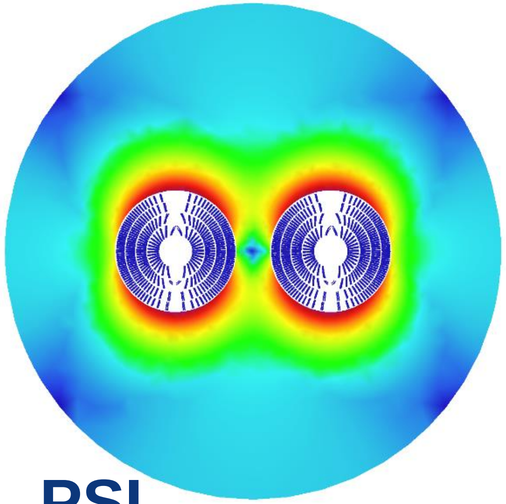
Common coils



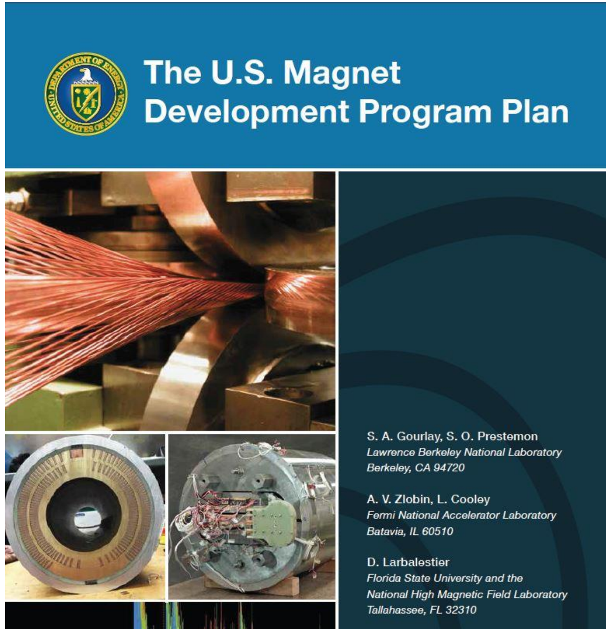
CIEMAT

Swiss contribution

Canted Cos-theta



PSI

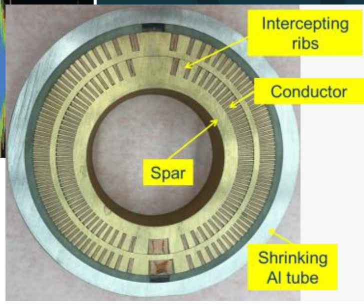


The U.S. Magnet Development Program Plan

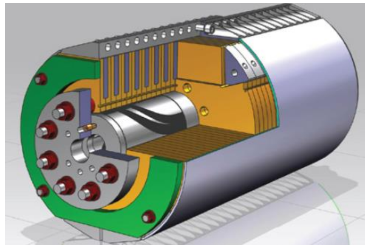
S. A. Gourlay, S. O. Prestemon
Lawrence Berkeley National Laboratory
Berkeley, CA 94720

A. V. Zlobin, L. Cooley
Fermi National Accelerator Laboratory
Batavia, IL 60510

D. Larbalestier
Florida State University and the
National High Magnetic Field Laboratory
Tallahassee, FL 32310



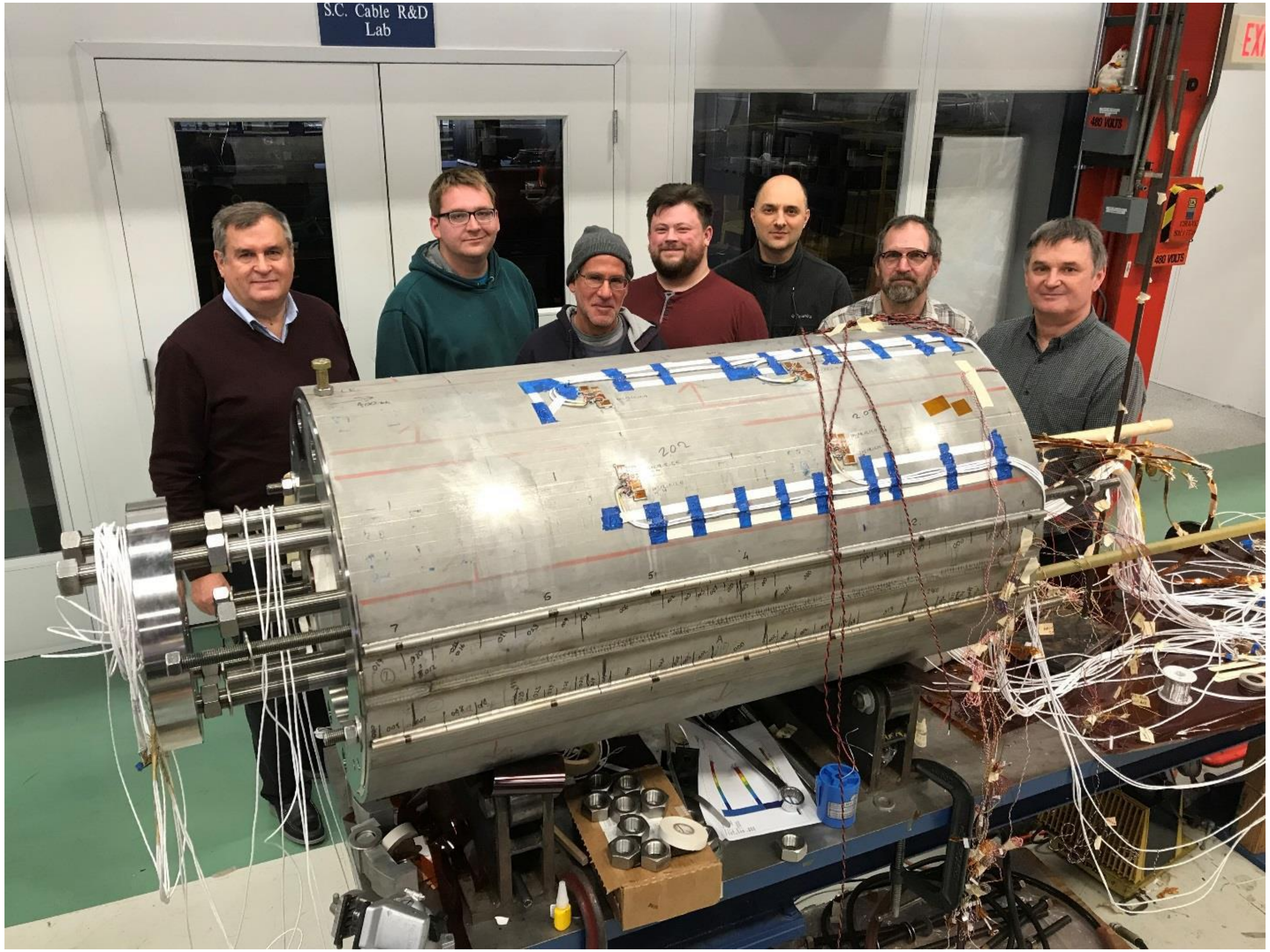
LBNL

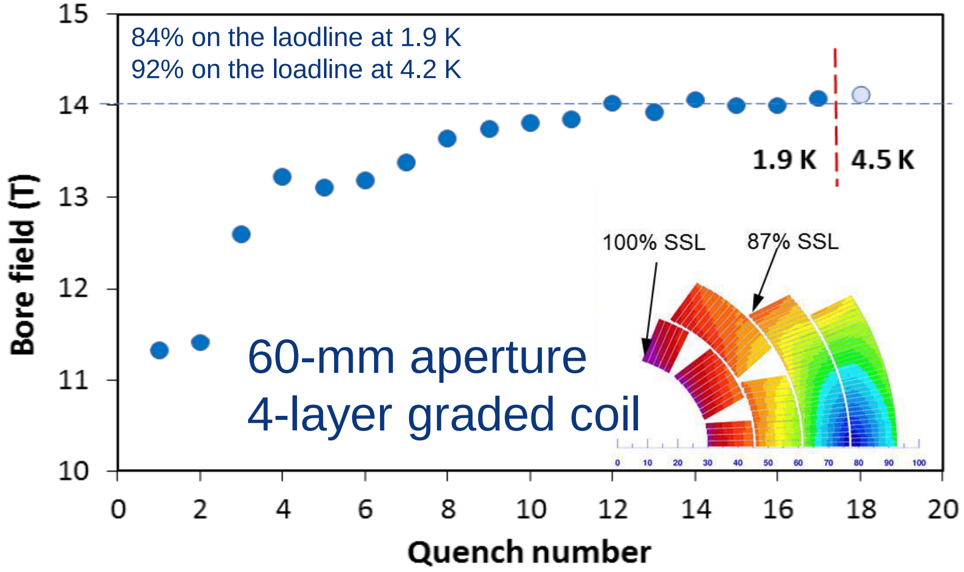


FNAL

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

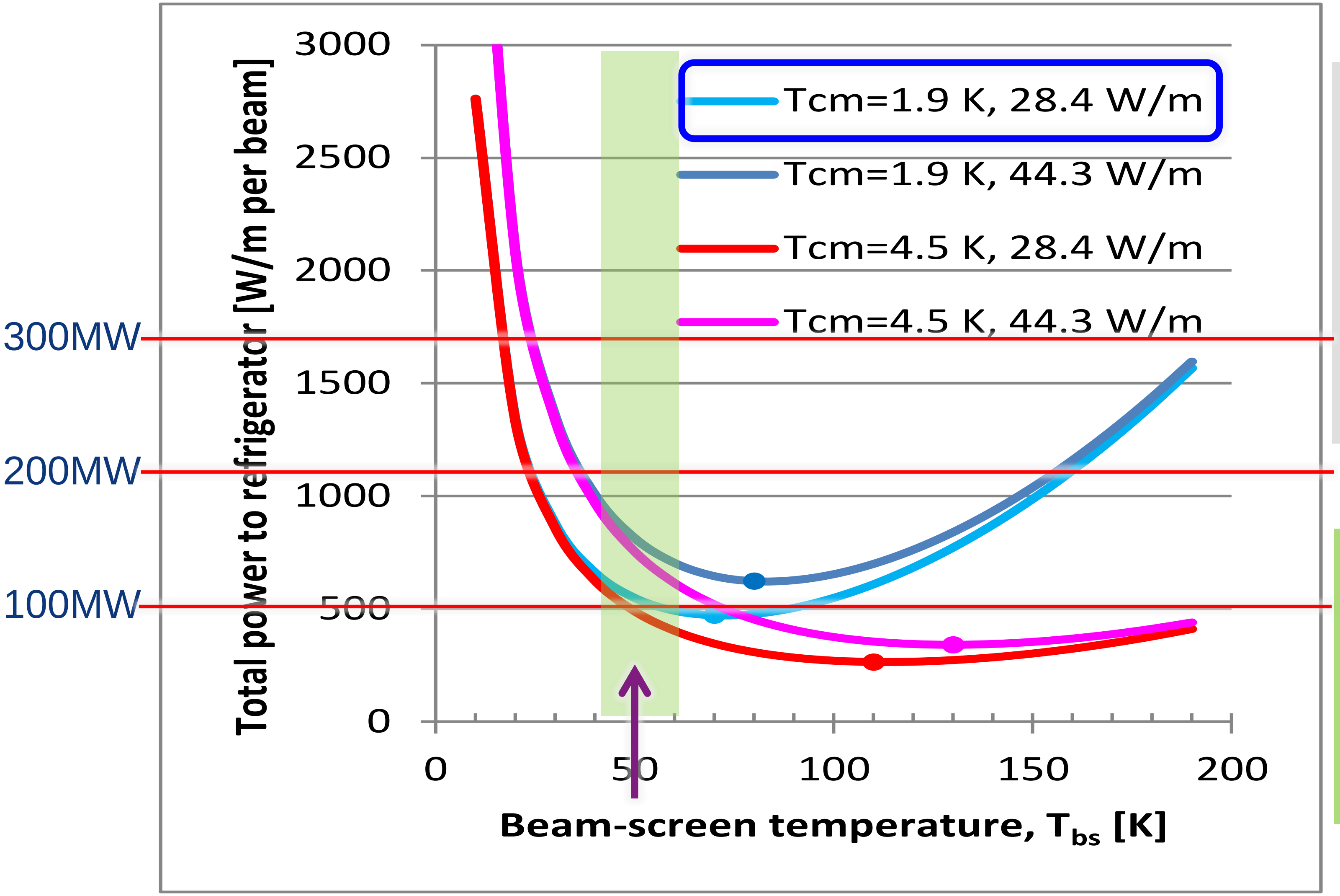
US – MDP: 14.5 T magnet tested at FNAL





- 15 T dipole demonstrator
- Staged approach: In first step pre-stressed for 14 T
- Second test in June 20209 with additional pre-stress reached 14.5 T

Cryoplants – energy efficiency



BS temperature choice is overall optimisation of:

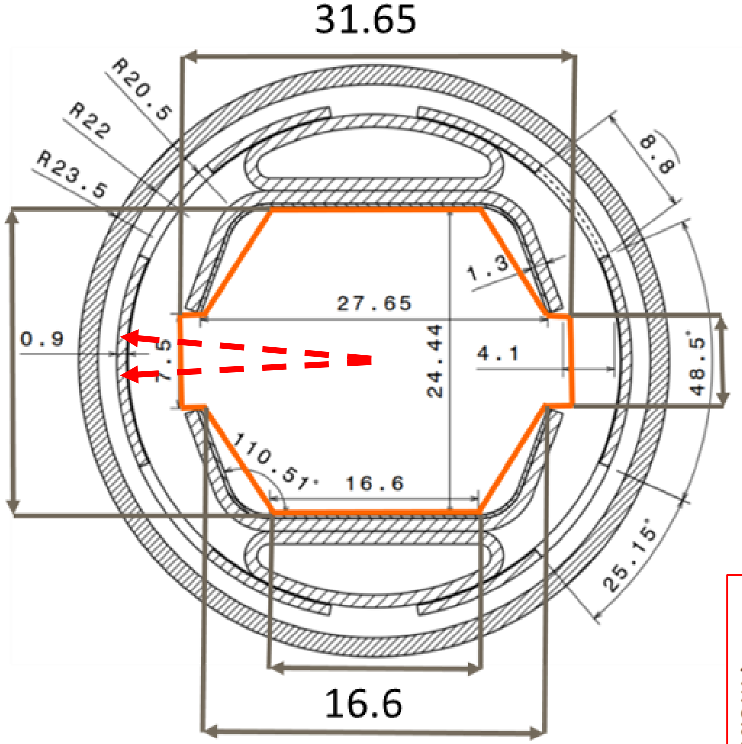
- **Cryoplant power consumption**
- **Vacuum system performance**
- **Impedance and beam stability**

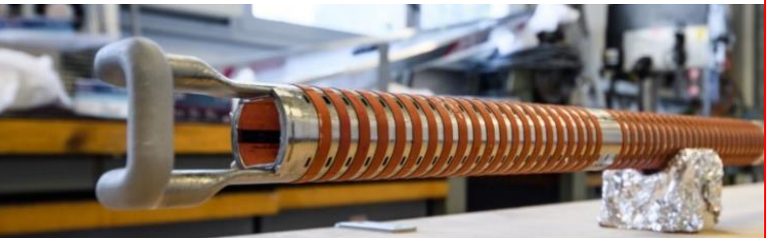
- **Optimum beam screen operation temperature 40 - 60 K**
- **Electrical power for beam screen cooling ~100 MW .**

Succesful test of FCC-hh beam screen

synchrotron radiation **(~ 30 W/m/beam (@16 T field)** (cf. LHC <0.2W/m) **~ 5 MW total load in arcs**

- **absorption of synchrotron radiation at higher temperature (> 1.8 K)** for cryogenic efficiency
- provision of beam vacuum, suppression of photo-electrons, electron cloud effect, impedance, etc.

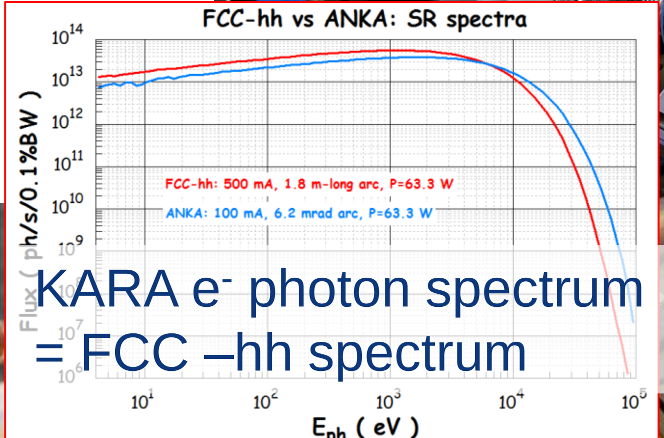




FCC-hh beam-screen test set-up at ANKA/Germany:

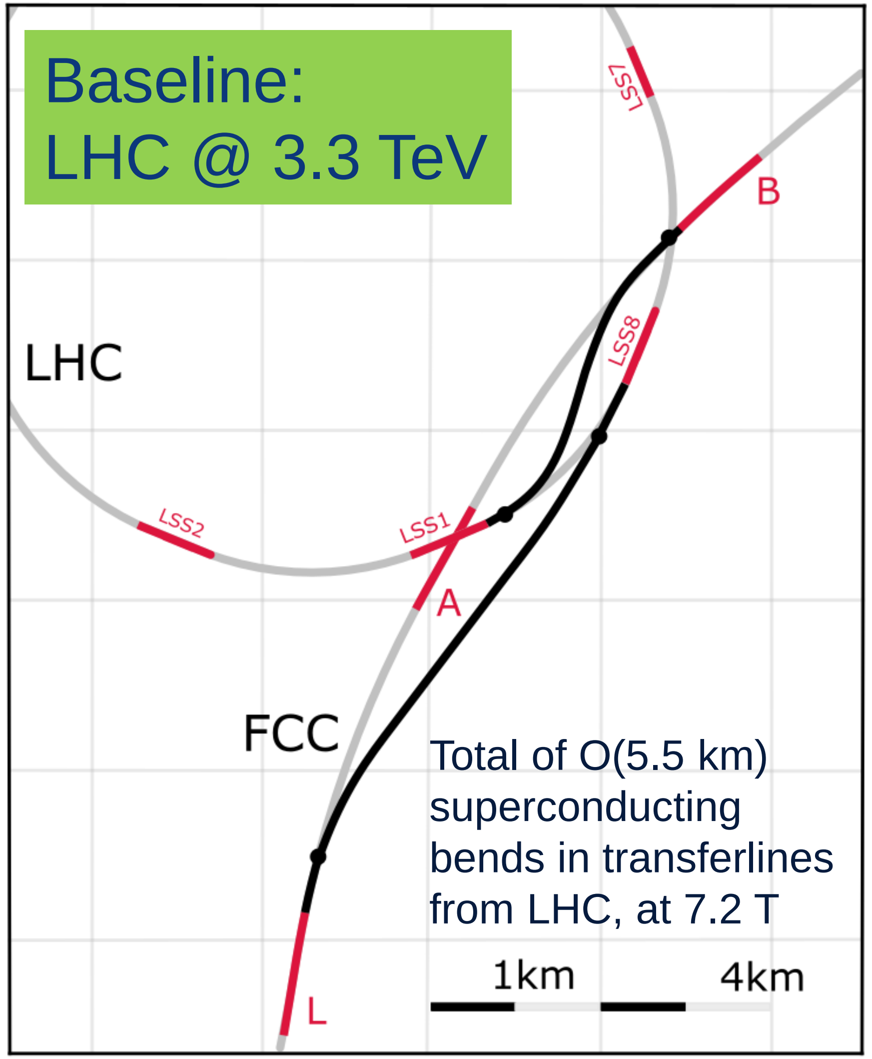
beam tests with three prototype beam screens, confirming vacuum design simulations

2.5 GeV ANKA/KIT
storage ring



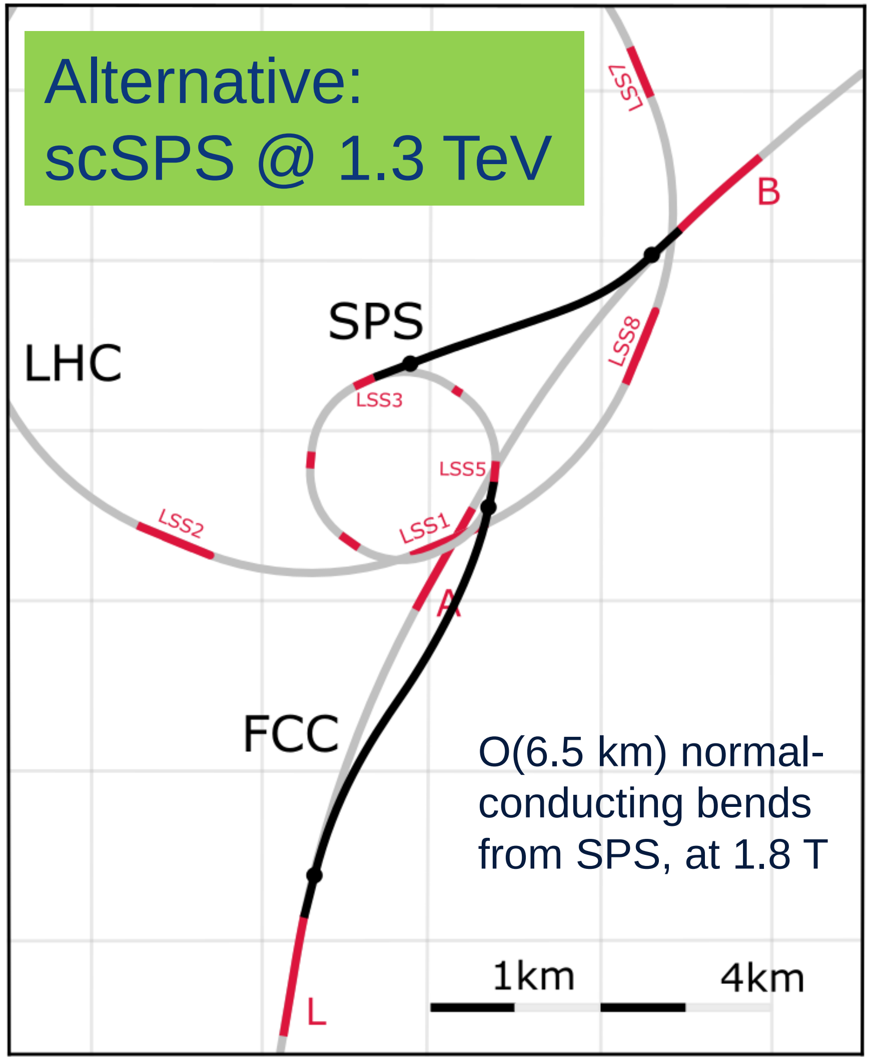
KARA e^- photon spectrum
= FCC –hh spectrum

FCC-hh injector options and transfer lines



Baseline:
LHC @ 3.3 TeV

Total of O(5.5 km) superconducting bends in transferlines from LHC, at 7.2 T



Alternative:
scSPS @ 1.3 TeV

O(6.5 km) normal-conducting bends from SPS, at 1.8 T

Current baseline:

- **Injection energy 3.3 TeV LHC**

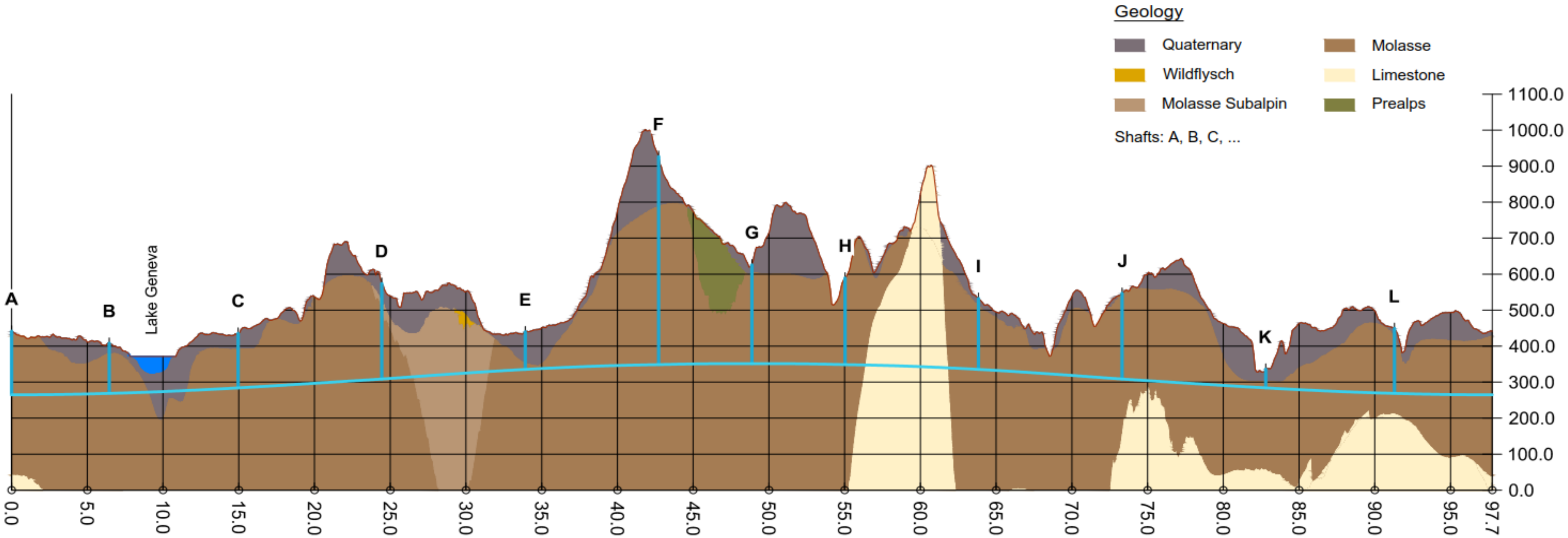
→ Field-swing FCC-hh like LHC

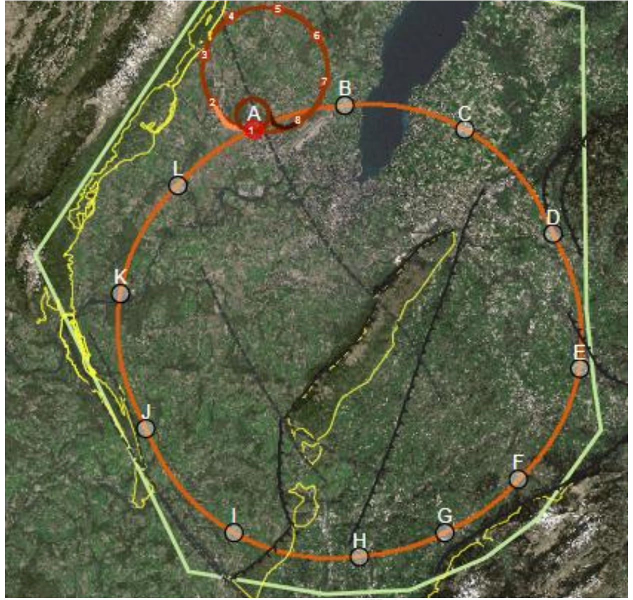
Alternative option:

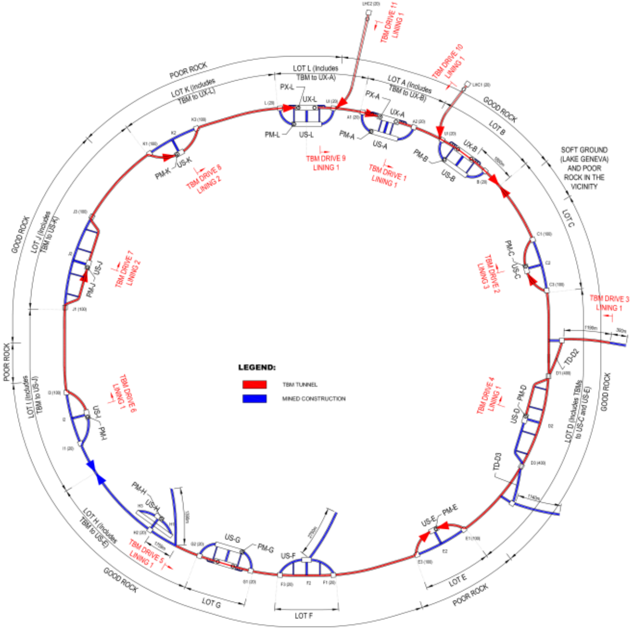
- **Injection from $\text{SPS}_{\text{upgrade}}$ around 1.3 TeV**

- **$\text{SPS}_{\text{upgrade}}$ could be based on fast-cycling SC magnets, 6-7T, ~ 1T/s ramp, cf. SIS 300 design**

FCC implementation - footprint baseline





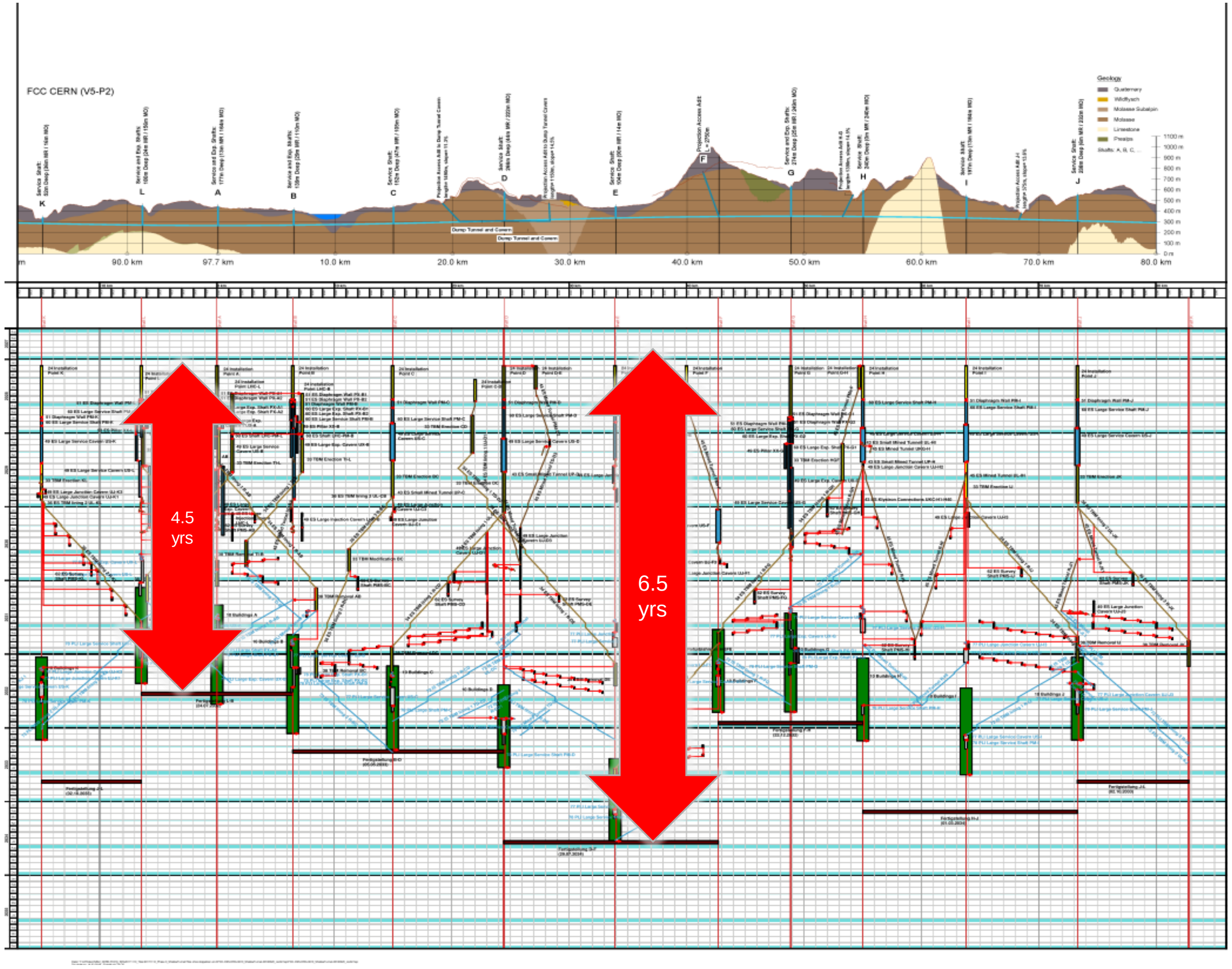


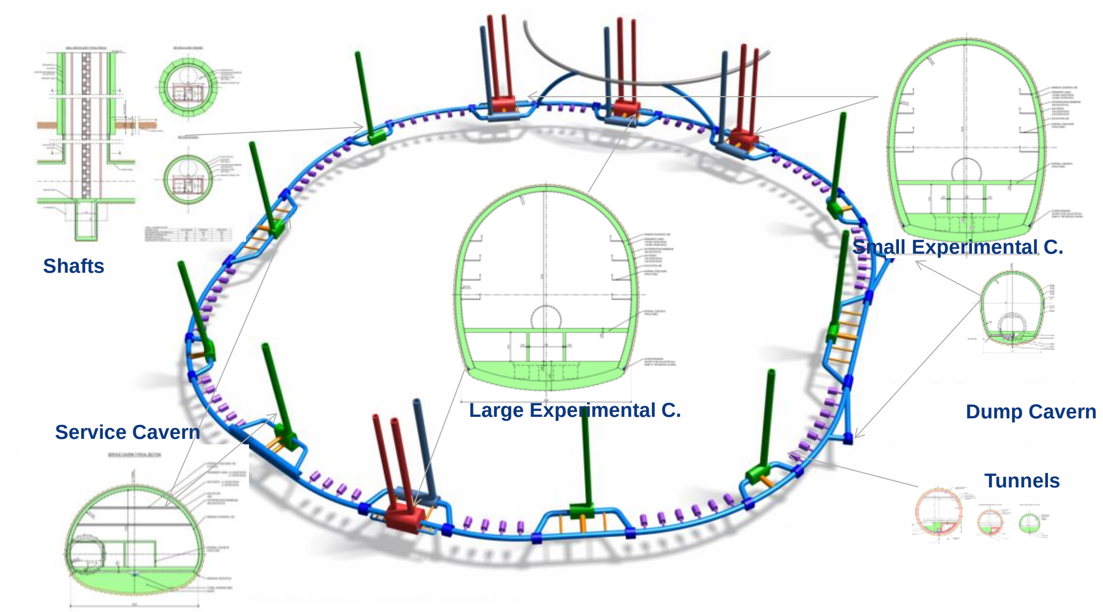
present baseline position was established considering:

- lowest risk for construction, fastest and cheapest construction
- feasible positions for large span caverns (most challenging structures)

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

civil engineering studies

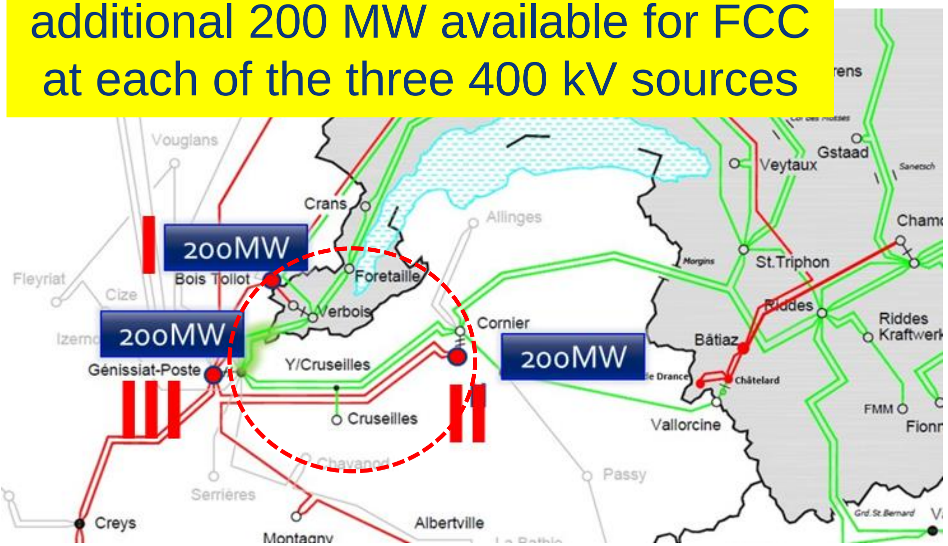




- **Total construction duration 7 years**
- **First sectors ready after 4.5 years**

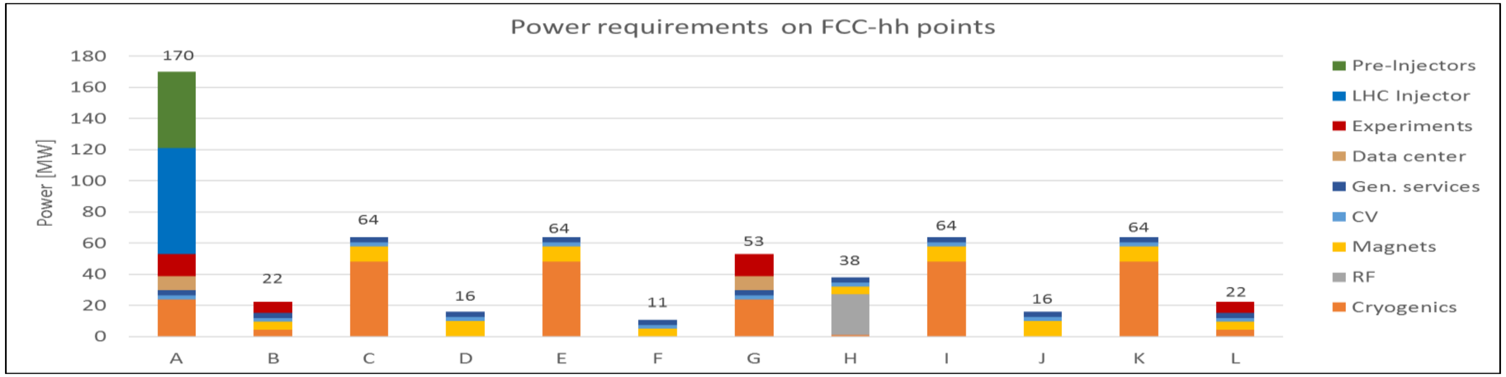
supply & distribution of electrical energy

additional 200 MW available for FCC
at each of the three 400 kV sources

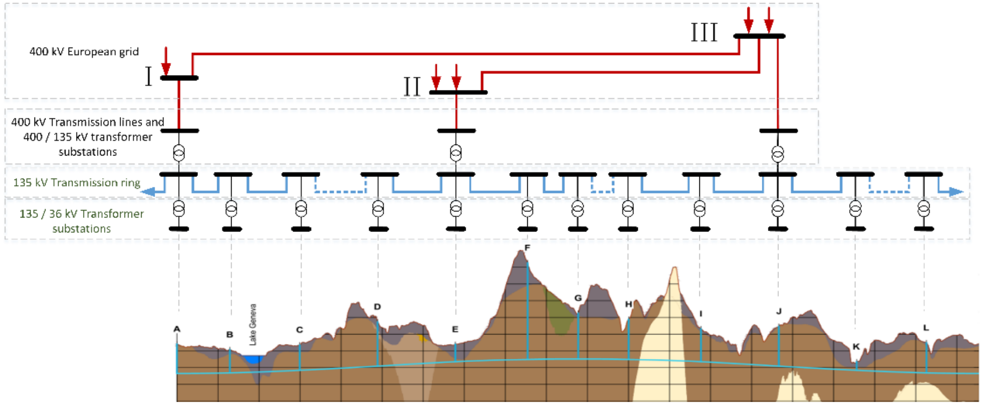


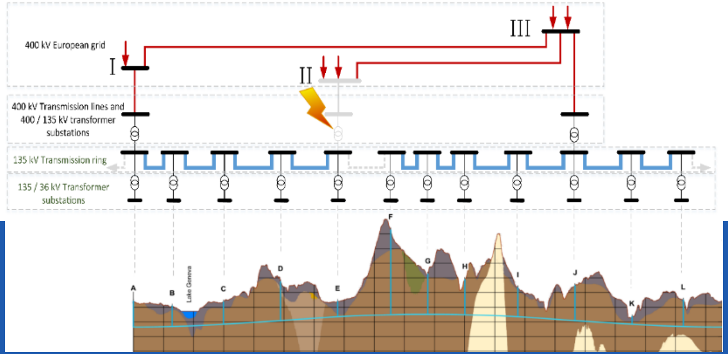
---- 400 kV ---- 230 kV

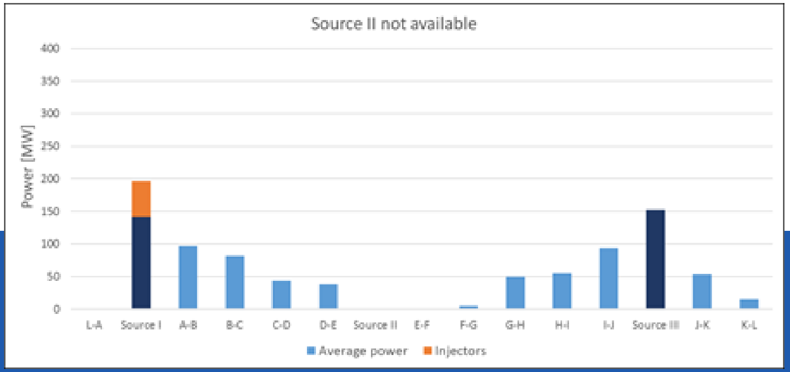
per-point power requirements as input for infrastructure-optimized conceptual design (peak FCC-ee: 260-340 MW, total FCC-hh: 550 MW)



If one power source goes down fall back to “degraded mode“: FCC remains cold, vacuum preserved, controls on, RF off, no beam (“standby”); all FCC points supplied from 2 other 400 kV points, through the power transmission line

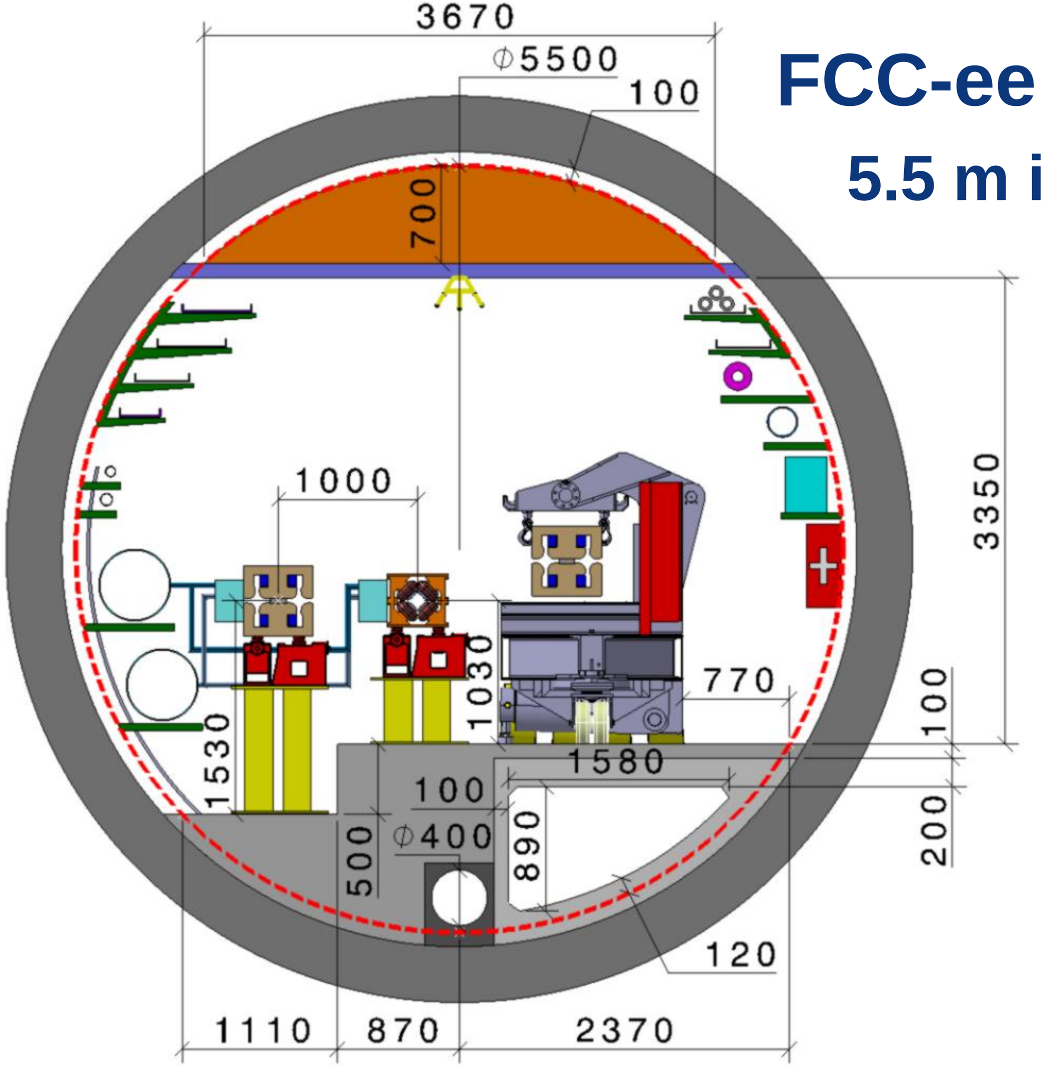






3 x 400 kV connections
+ 135 kV underground power distribution (NC)

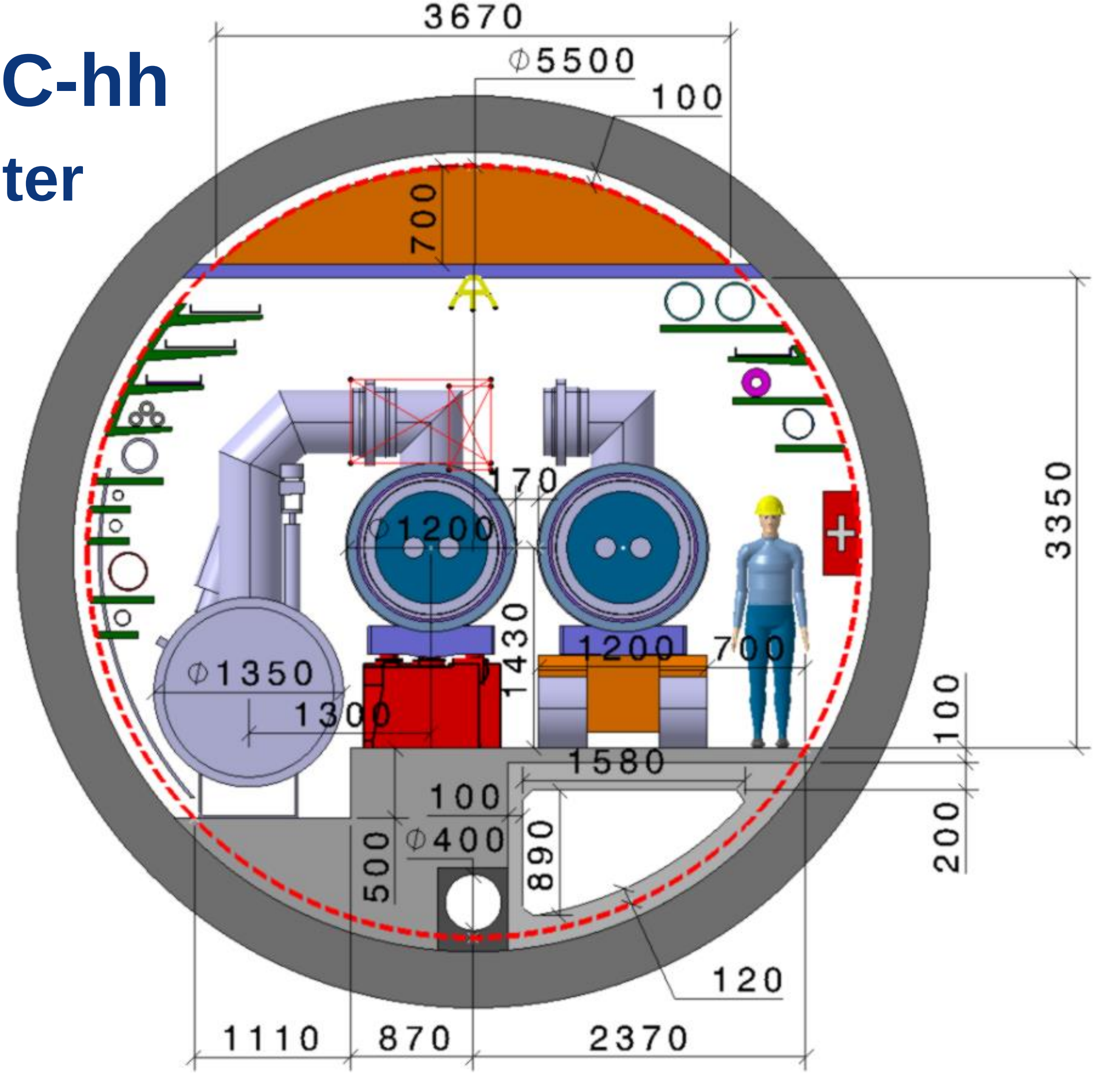
FCC-tunnel integration in the arcs



FCC-ee

FCC-hh

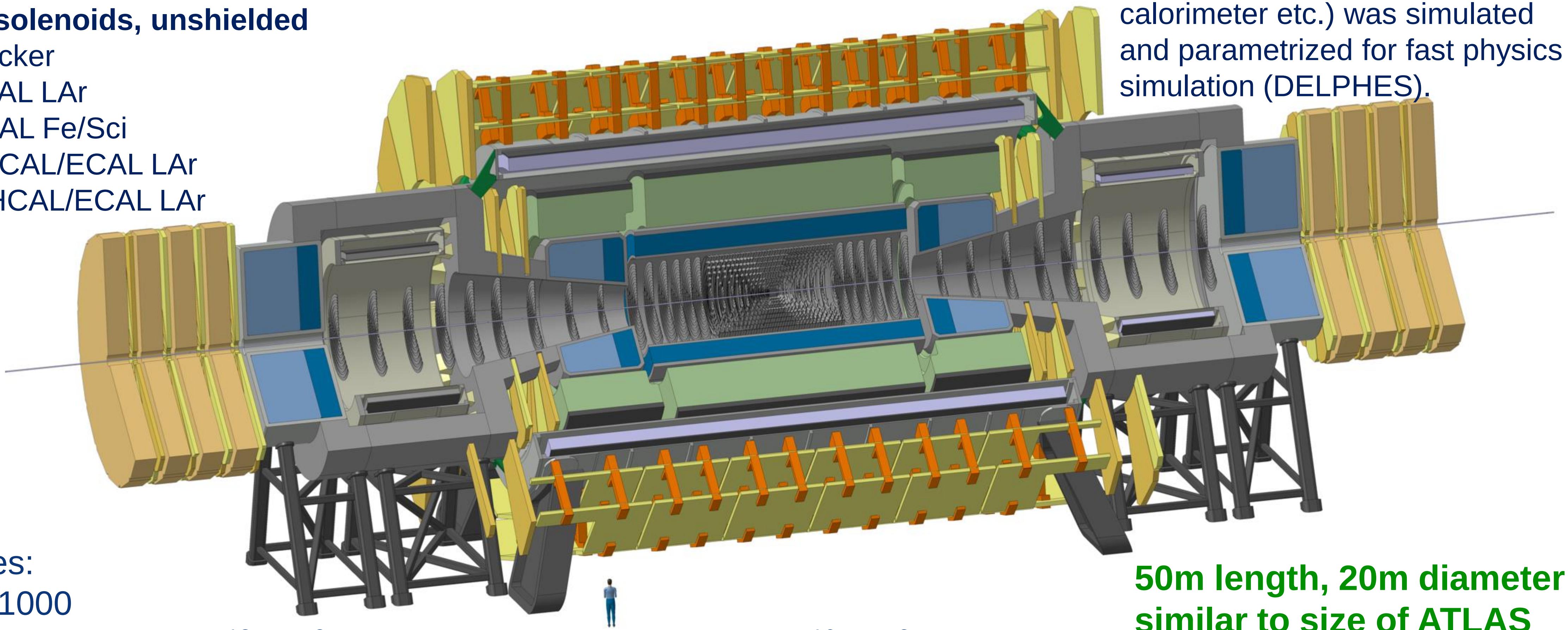
5.5 m inner diameter



FCC-hh reference detector

- **4T, 10m solenoid, unshielded**
- **Forward solenoids, unshielded**
- Silicon tracker
- Barrel ECAL LAr
- Barrel HCAL Fe/Sci
- Endcap HCAL/ECAL LAr
- Forward HCAL/ECAL LAr

Subdetector performance (tracker, calorimeter etc.) was simulated and parametrized for fast physics simulation (DELPHES).

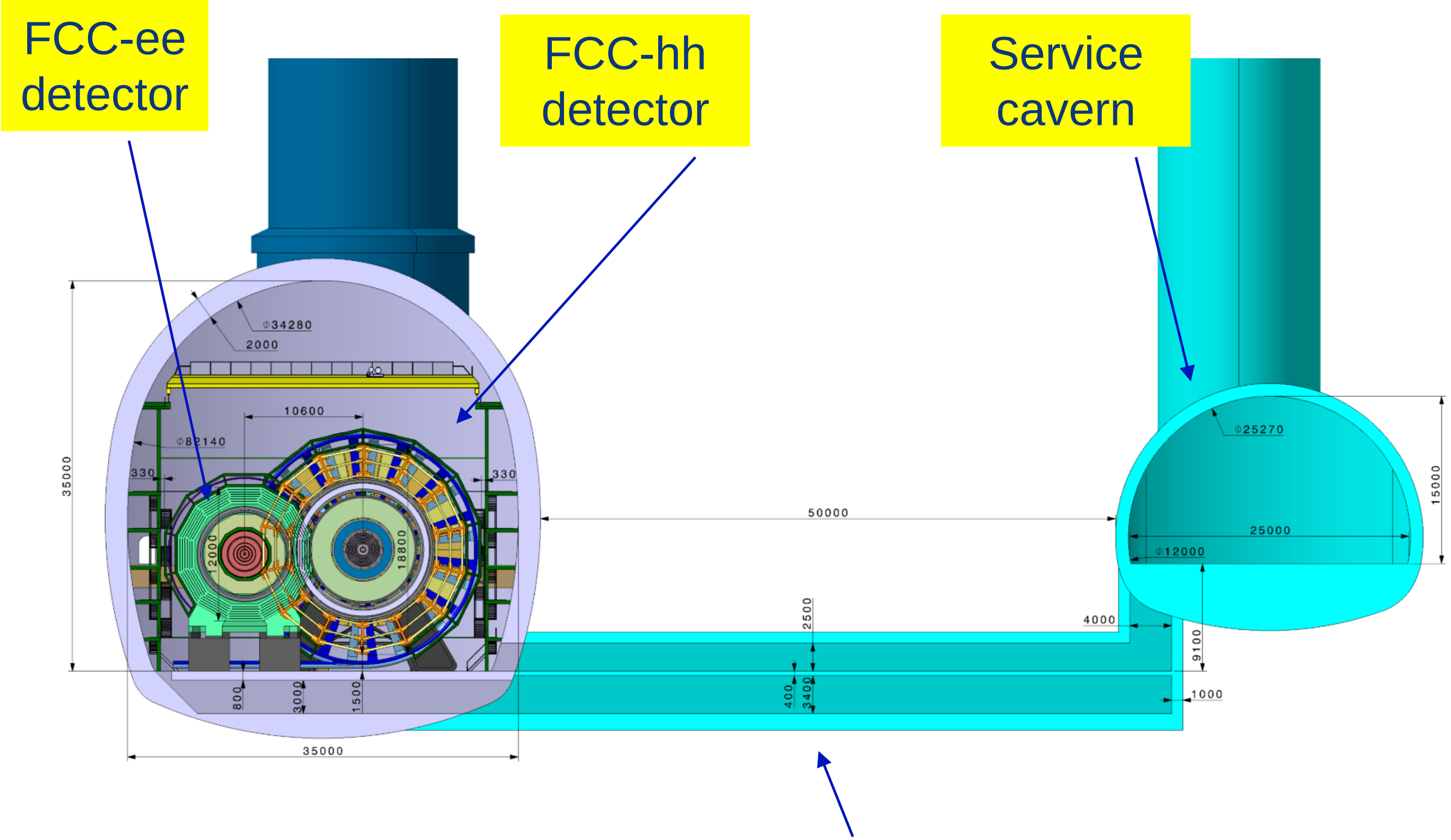


50m length, 20m diameter similar to size of ATLAS

- Challenges:
- Pileup of 1000
- Radiation levels up to 10^{18} cm^{-2} 1MeV neutron equivalent vs. 10^{16} cm^{-2} at HL-LHC
- Integration, opening and maintenance scenarios

Common experimental points (A, G)

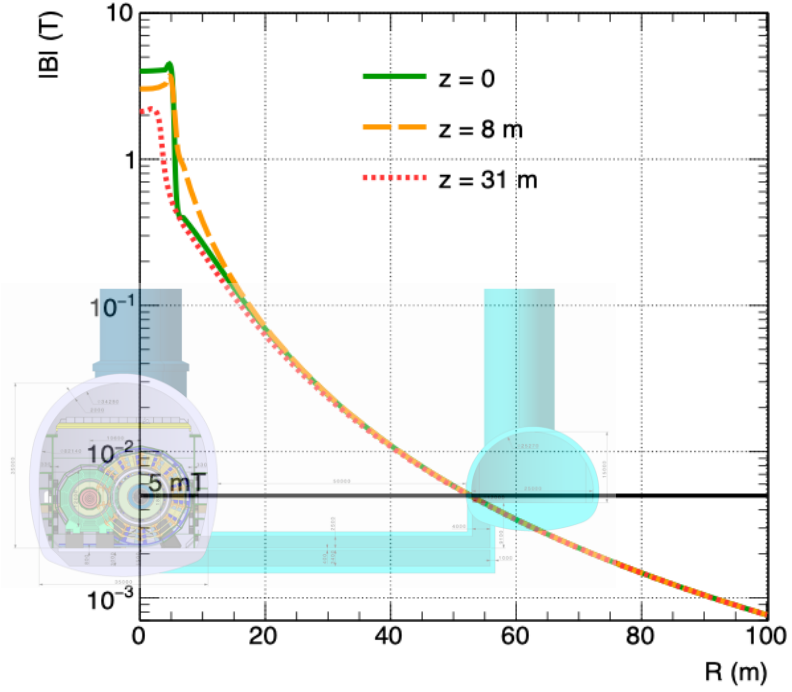
Distance between detector cavern and service cavern 50 m.
Strayfield of unshielded detector solenoid < 5mT.


FCC-ee detector

FCC-hh detector

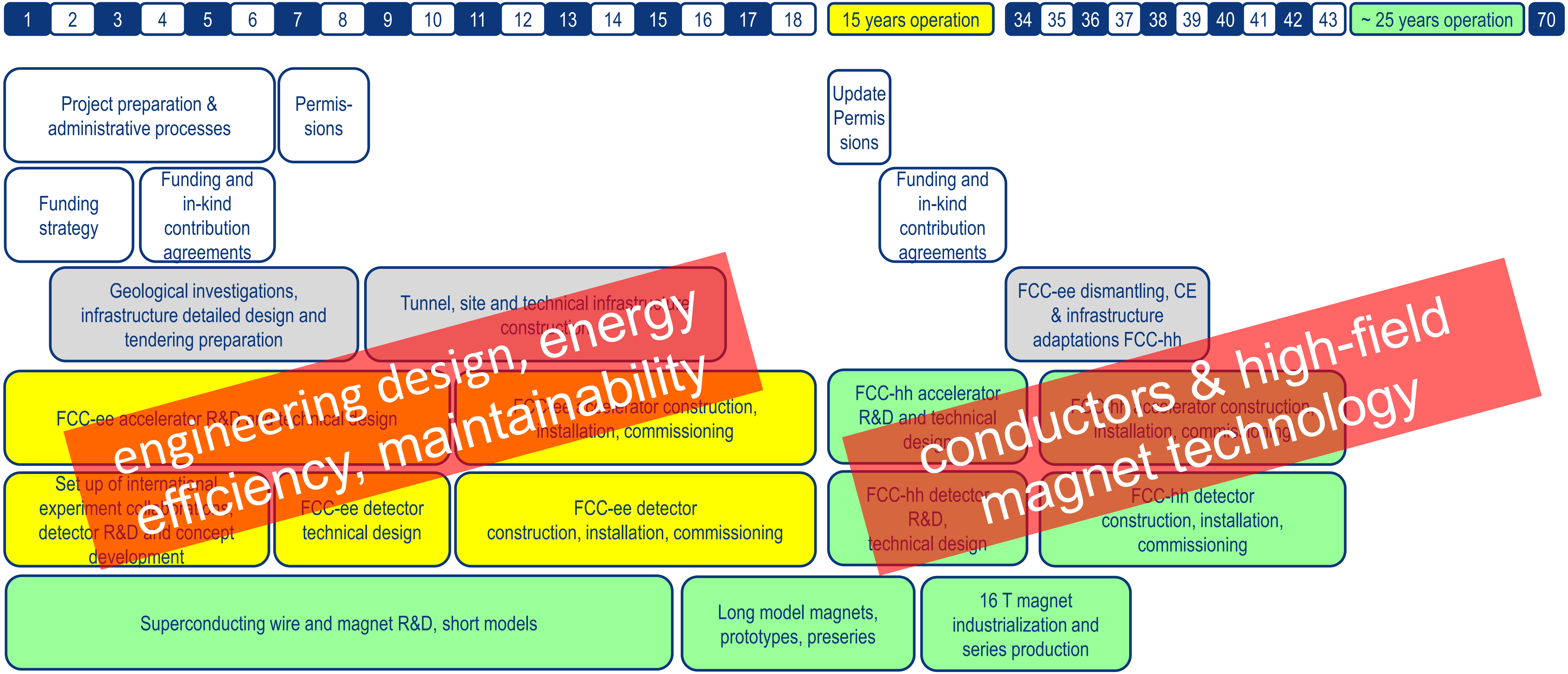
Service cavern

Preliminary design of access and cable paths



Less than 5mT in the Service Cavern,
200-300mT outside the detector.

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

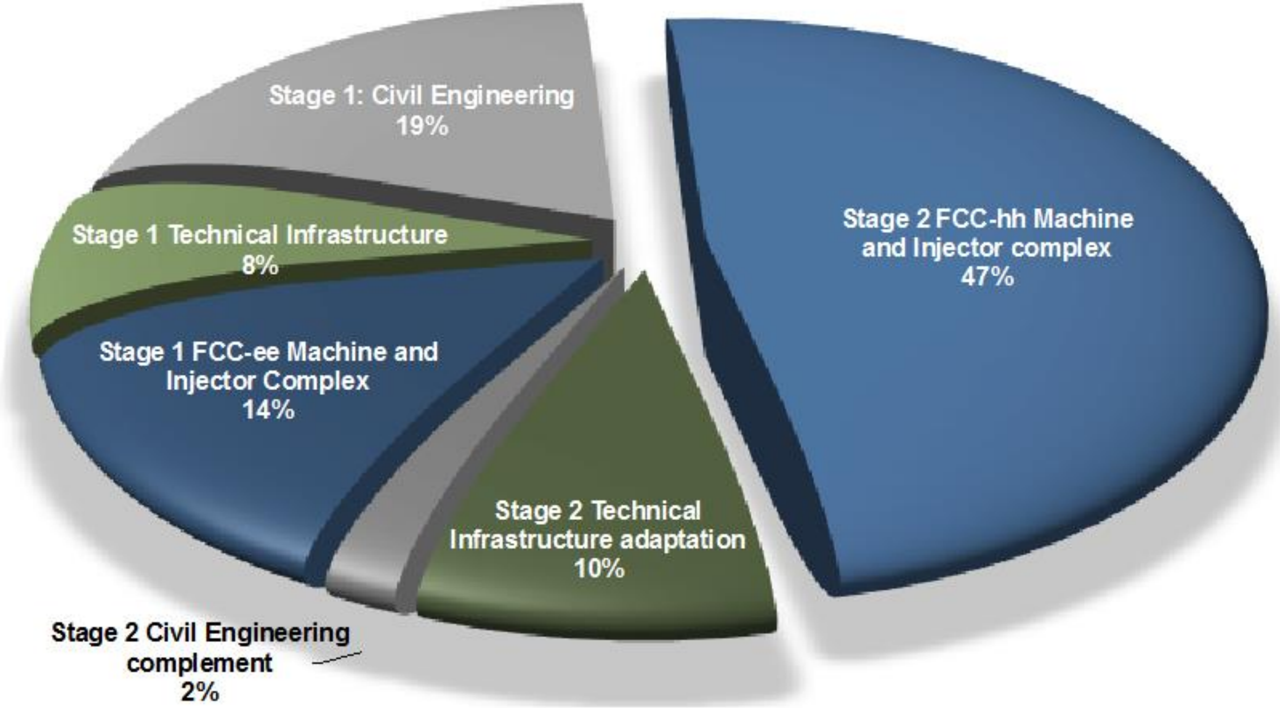
16 T magnet industrialization and series production

engineering design, energy efficiency, maintainability

conductors & high-field magnet technology

FCC-integrated project cost estimate

Domain	Cost in MCHF
Stage 1 - Civil Engineering	5,400
Stage 1 - Technical Infrastructure	2,200
Stage 1 - FCC-ee Machine and Injector Complex	4,000
Stage 2 - Civil Engineering complement	600
Stage 2 - Technical Infrastructure adaptation	2,800
Stage 2 - FCC-hh Machine and Injector complex	13,600
TOTAL construction cost for integral FCC project	**28,600**

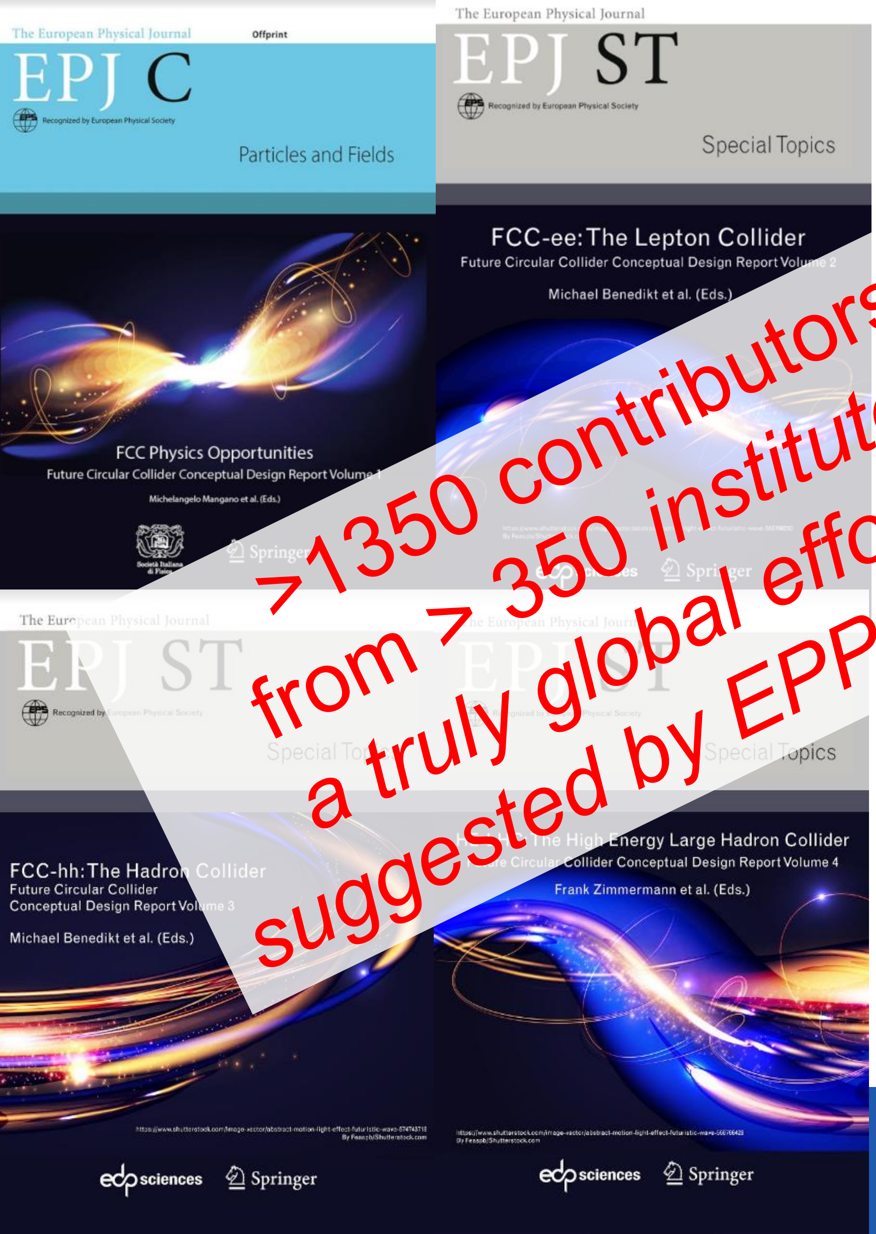


total construction cost FCC-ee (Z, W, H) : ~10,500 MCHF & 1,100 MCHF (tt)

total construction cost for subsequent FCC-hh: 17,000 MCHF.

(FCC-hh stand alone cost ~25 BCHF)

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":

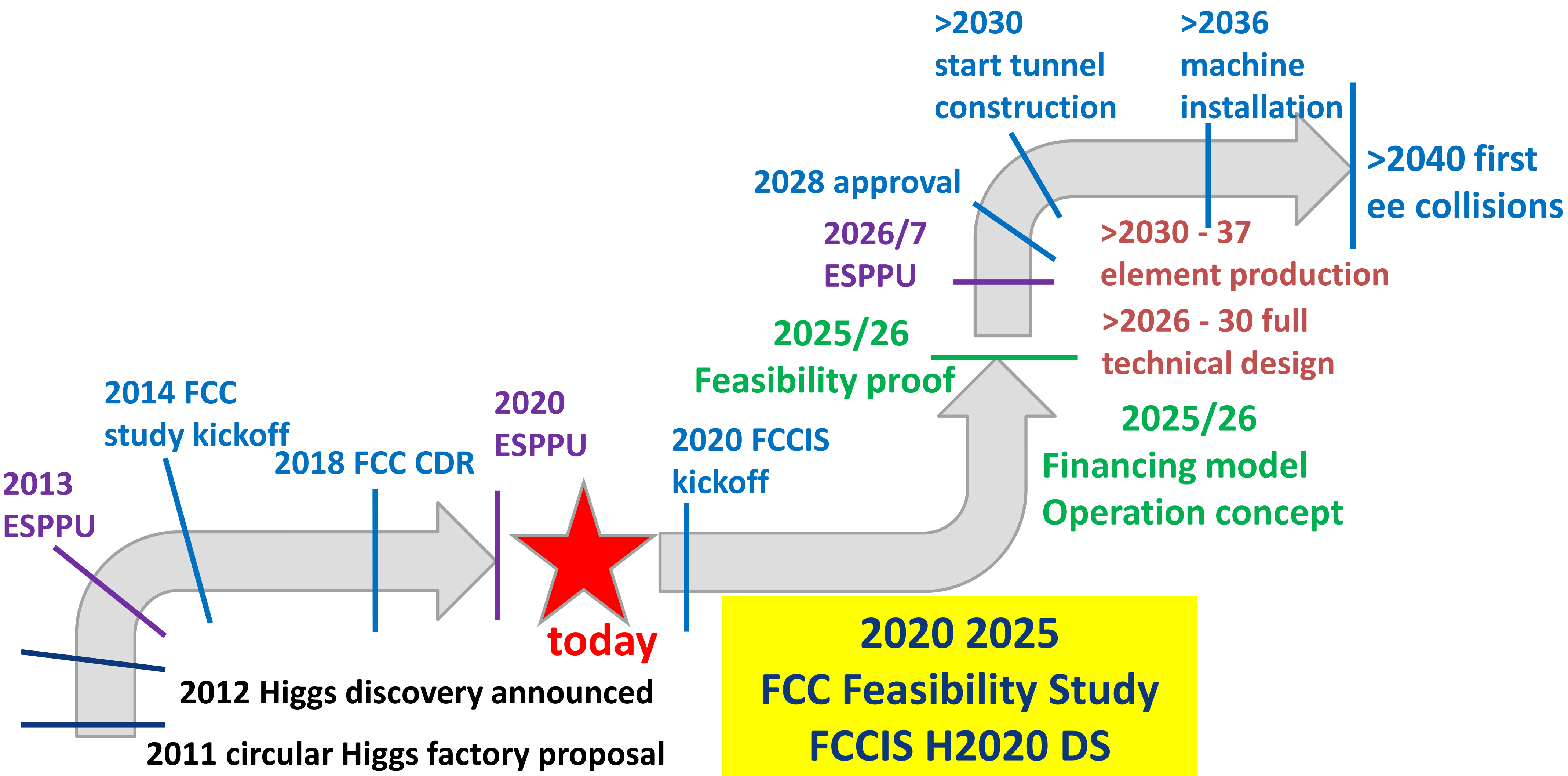
"Europe, together with its international partners, should investigate the technical and financial feasibility of a future hadron collider at CERN with a centre-of-mass energy of at least 100 TeV and with an electron-positron Higgs and electroweak factory as a possible first stage. Such a feasibility 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 next ESPP Update expected by 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 sequential nature of implementation and overall timeline need to be taken into account !

FCC roadmap towards stage 1



>2030
start tunnel
construction

>2036
machine
installation

>2040 first
ee collisions

2028 approval

2026/7
ESPPU

>2030 - 37
element production

>2026 - 30 full
technical design

2025/26
Feasibility proof

2025/26
Financing model
Operation concept

2014 FCC
study kickoff

2018 FCC CDR

2020
ESPPU

2020 FCCIS
kickoff

2013
ESPPU

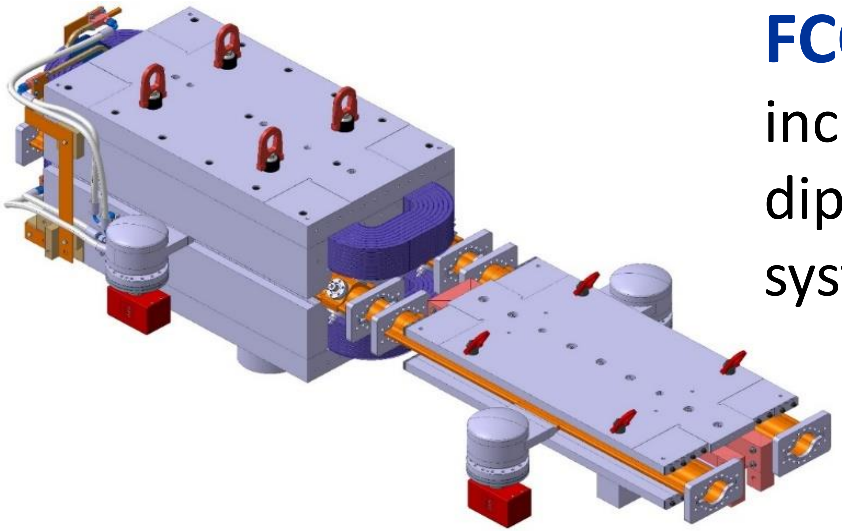
today

2012 Higgs discovery announced

2011 circular Higgs factory proposal

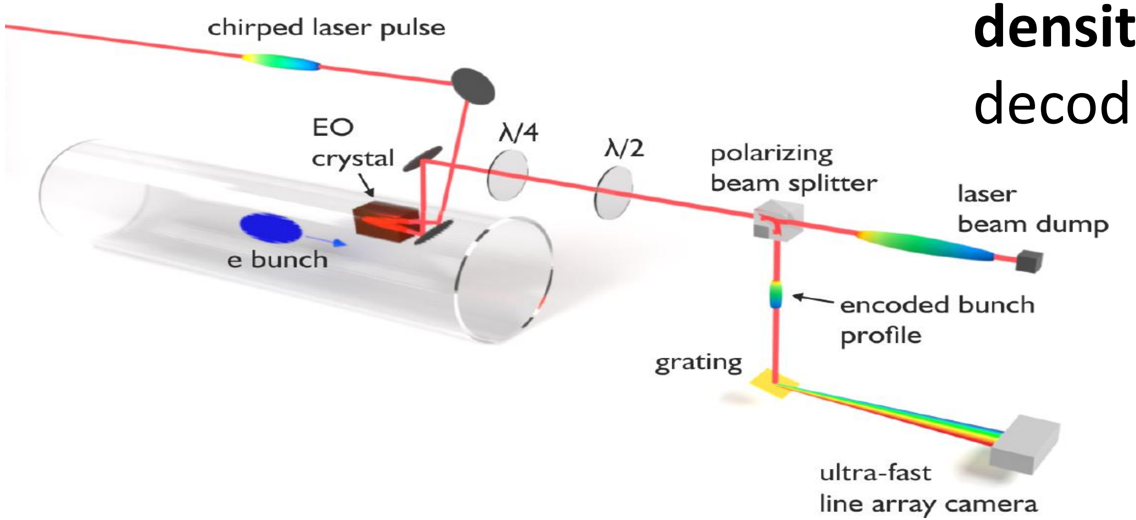
2020 2025
FCC Feasibility Study
FCCIS H2020 DS

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) ;

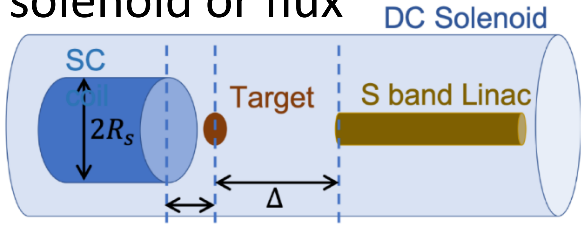
ultra-low emittance measurement (X-ray interferometer tests at SuperKEKB, ALBA) ;
beam-loss monitors (IJCLab/KEK?) ;
beamstrahlung monitor (KEK);
polarimeter ; **luminometer**

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

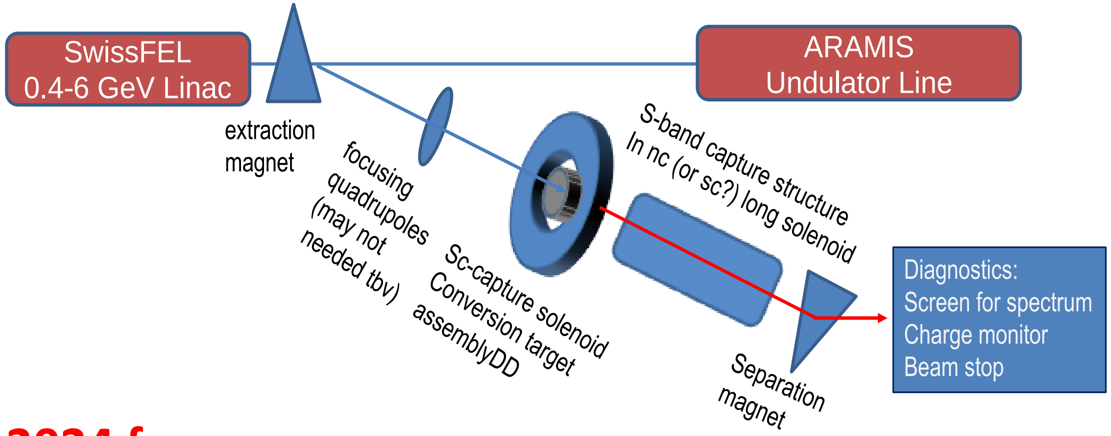


positron capture linac

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

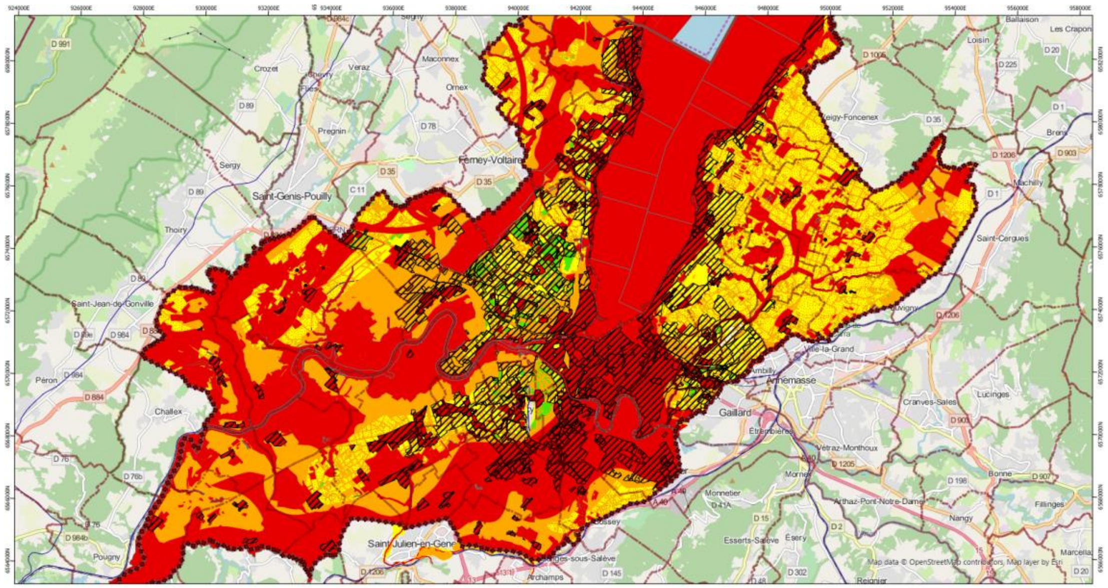


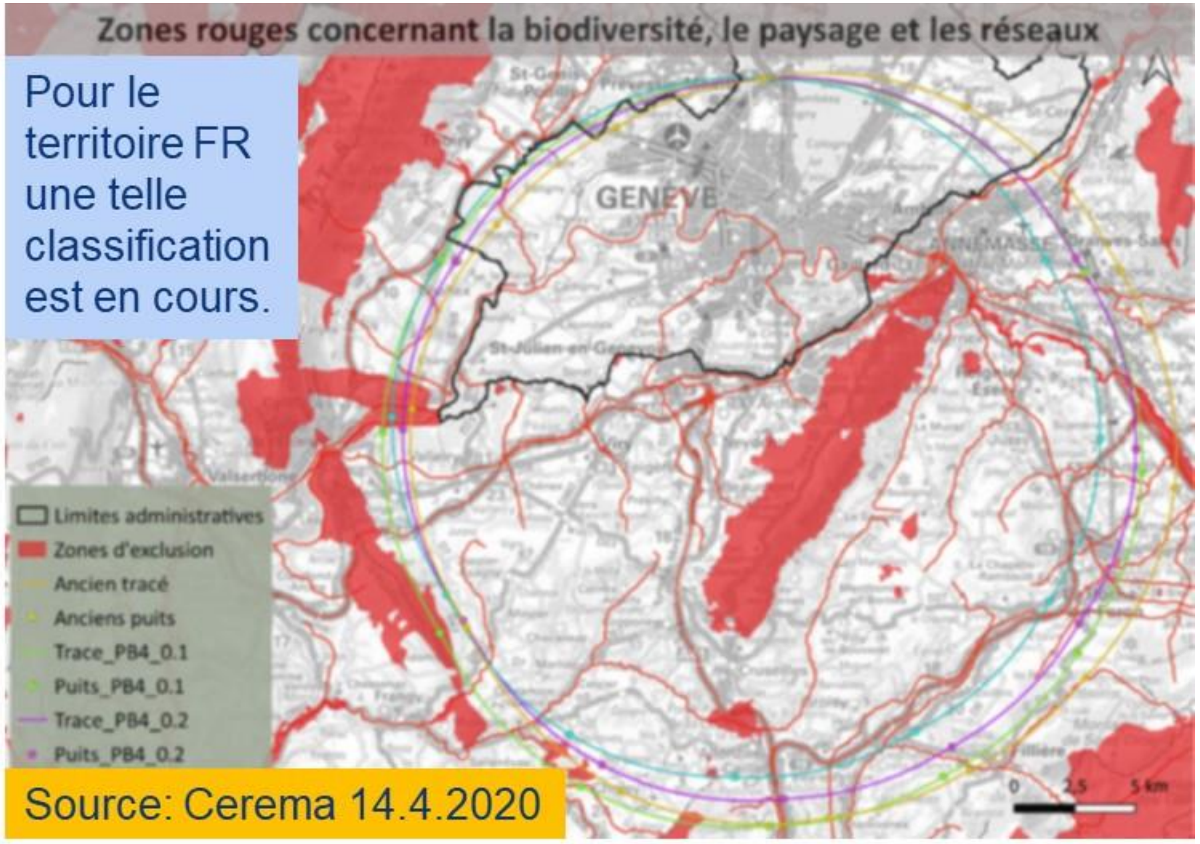
strong support from Switzerland via CHART II program 2019 – 2024 for FCC-ee injector, HFM, beam optics developments, geology and geodesy activities.

Implementation studies with host states

- Classification of zones along/around the perimeter of FCC according to „realisation risk levels“ defined with host states.
- Study of variants following the approach „Avoid – Reduce – Compensate“

Territorial constraints – Canton Geneva





Pour le territoire FR une telle classification est en cours.

Source: Cerema 14.4.2020

collider placement optimisation

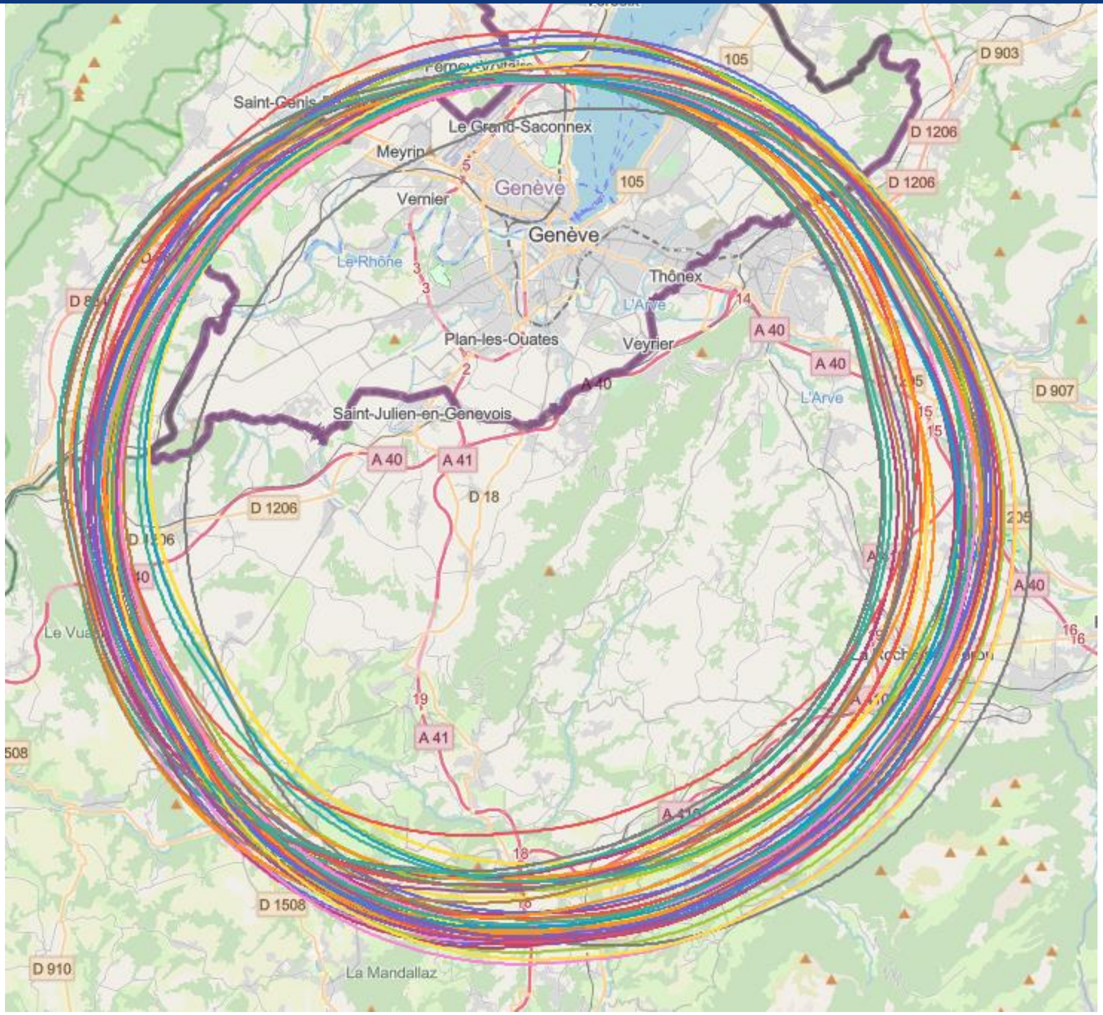
layout & placement optimisation across both host states (Switzerland and France) ;

following "avoid-reduce-compensate" directive of European & French regulatory frameworks ;

diverse requirements and constraints:

- permitting **world-leading scientific research**
- **technical feasibility of civil engineering** and subsurface constraints
- **territorial constraints on surface** and subsurface
- **nature, accessibility**, technical infrastructure, resource needs & constraints
- economic factors including benefits for, and synergies, with the **regional developments**
- ...

collaborative effort: CERN technical experts, consulting companies, government-notified bodies



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.
- **Success of FCC relies on strong global participation !**