

# Key Results of the FCC Feasibility Study and Steps Towards Implementation

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on behalf of the FCC collaboration*

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Swiss Accelerator  
Research and  
Technology

<http://cern.ch/fcc>



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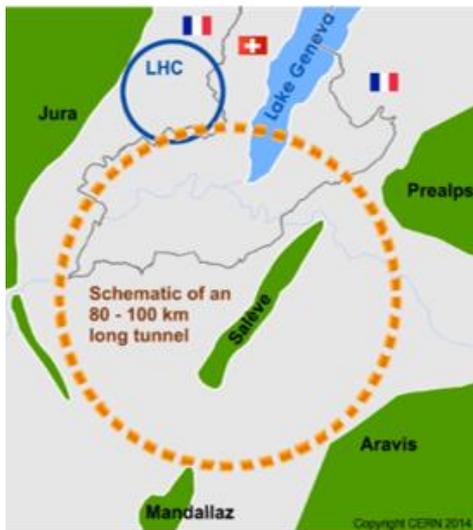
European  
Commission

Horizon 2020  
European Union funding  
for Research & Innovation

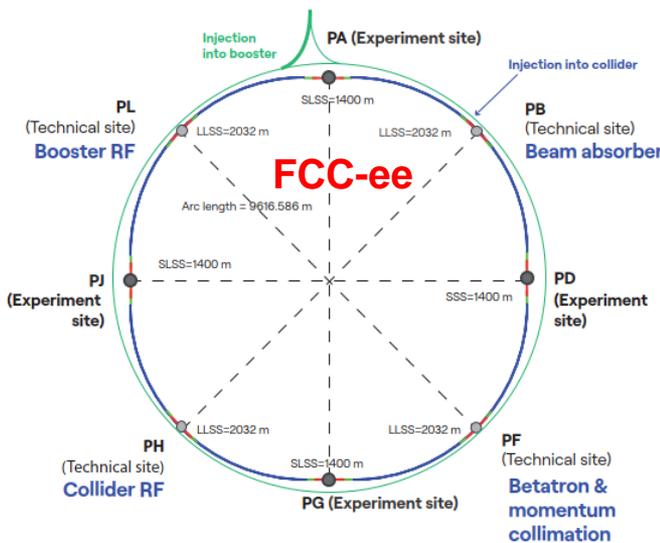
photo: J. Wenninger

# Future Circular Collider integrated program – scope

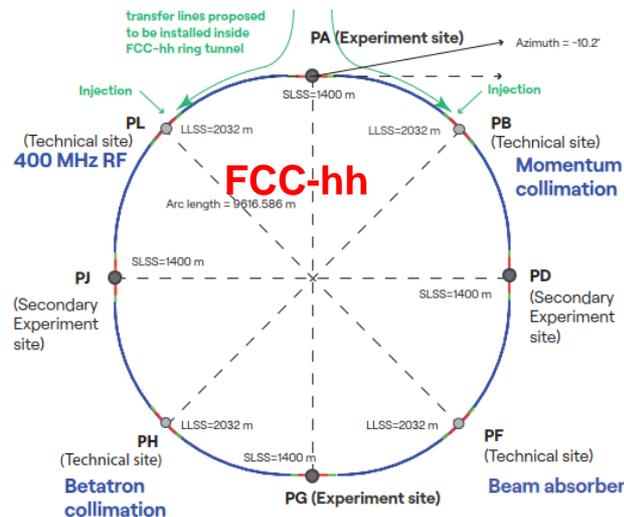
- stage 1: FCC-ee (Z, W, H,  $t\bar{t}$ ) as Higgs factory, electroweak & top factory at highest luminosities
- stage 2: FCC-hh (~100 TeV) as natural continuation at energy frontier, pp & AA collisions; e-h option
- highly synergetic and complementary programme maximising the physics opportunities
- common civil engineering and technical infrastructures, building on and reusing CERN's existing infrastructure
- FCC integrated project allows the start of a new, major facility at CERN within a few years of the end of HL-LHC



2020 - 2045

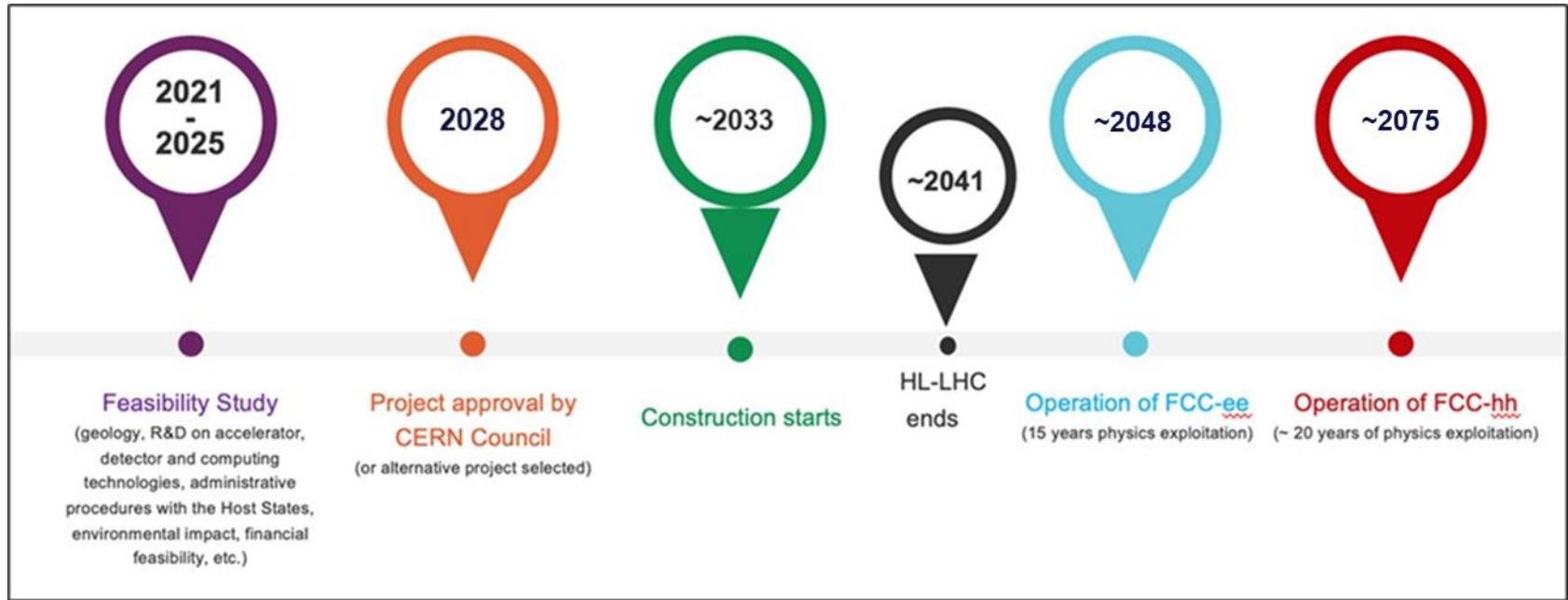


2048 - 2062



~2075 - ~2100

# FCC integrated program – timeline



## **Ambitious schedule** taking into account:

- past experience in building colliders at CERN
- approval timeline: European Strategy for Particle Physics Update, CERN Council decision
- that HL-LHC will run until 2041
- constraints imposed by present assumptions in funding model**
- project preparatory phase with adequate resources immediately after Feasibility Study**



## 2013 Update of European Strategy for Particle Physics:

*“CERN should undertake design studies for accelerator projects in a global context, with emphasis on proton-proton and electron-positron high-energy frontier machines.”*

## FCC Collaboration delivered 4 volumes Conceptual Design Reports as input to ESPPU 2019/20



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

## 2020 Update of European Strategy for Particle Physics:

*“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.”*

➔ **Launch of the FCC Feasibility Study mid 2021 by CERN Council**



# Feasibility Study Report completed on 31 March 2025

**Vol. 1: Physics, Experiments & Detectors**

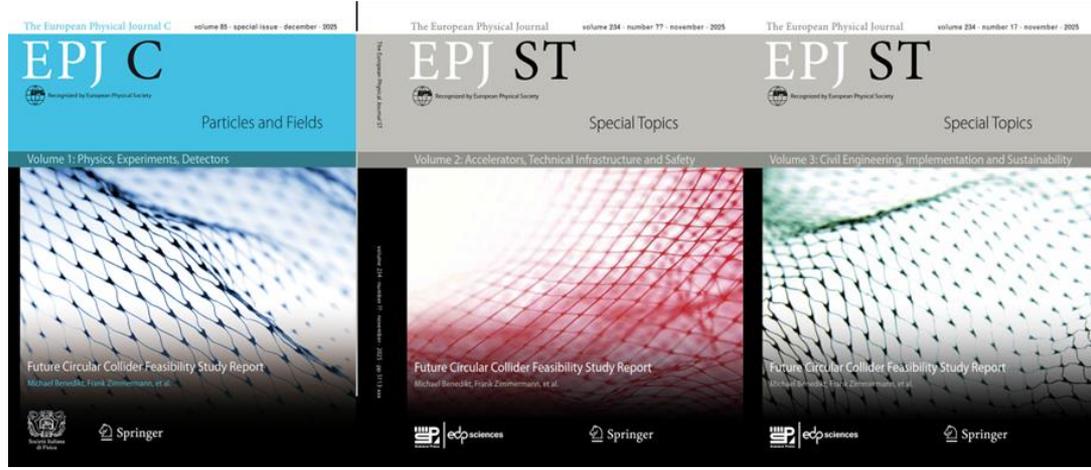
<https://doi.org/10.1140/epjc/s10052-025-15077-x>

**Vol. 2: Accelerators, Technical Infrastructures, Safety Concepts**

<https://doi.org/10.1140/epjs/s11734-025-01967-4>

**Vol. 3: Civil Engineering, Implementation & Sustainability**

<https://doi.org/10.1140/epjs/s11734-025-01958-5>



These+other FCC input to '25/26 ESPPU posted at <https://indico.cern.ch/event/1534205/>

## Input for 2025/26 Update of European Strategy for Particle Physics

prepared with Overleaf & published by EPJ (Springer-Nature) – FCCIS members



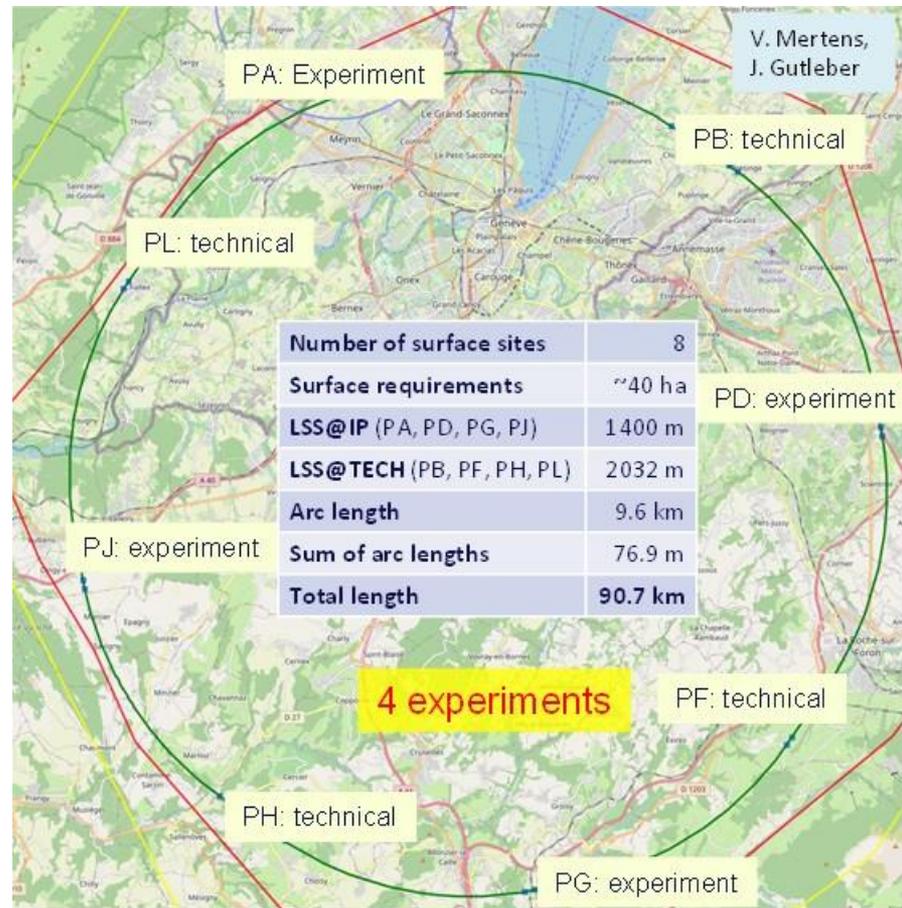
# Reference layout and implementation: PA31 - 90.7 km

Layout chosen out of ~ 100 initial variants, based on several criterias:

- **geology**,
- **surface constraints** (land availability, urbanistic, etc.),
- **environment** (protected zones),
- **infrastructure** (electricity, transport),
- **machine performance**

“**Avoid-reduce-compensate**” principle of EU and French regulations.

**Overall lowest-risk baseline:  
90.7 km ring, 8 surface points,  
4-fold superperiodicity & symmetry**





# Surface site locations 7 in France and 1 in Switzerland

Optimisation done together with municipalities and region

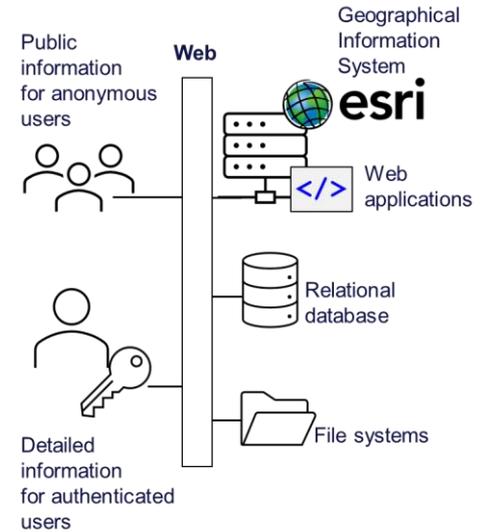


- land plot needs communicated to Host States in view of protecting the required areas
- process in FR: «prise en consideration», landplot in CH owned by Canton of Geneva

# Environmental initial state analysis



## Environmental information system



- The environmental **initial state analysis** at the eight surface site locations (~600 ha covered) **did not reveal principal showstoppers** for the project.
- **Basis for detailed optimisation of surface sites.**
- **Reference for the environmental impact assessment.**

# Territorial dialogue and public participation

**First cycle of public information meetings completed** (April 2024 – March 2025)

**11 sessions reached over 1,500 people** in France & Switzerland



**During 2025:**

Second cycle of **public information meetings**.

**Presence days** in municipalities affected by surface sites to enable discussion with habitants. Meetings with stakeholders of the territory.



• *First dialogue and exchange meeting with local environmental associations, 5 may, 2025*

**Dialogue Website**



**During 2026:**

**Formal public participation** process planned in France (Debat Public) and Switzerland (public concertation).

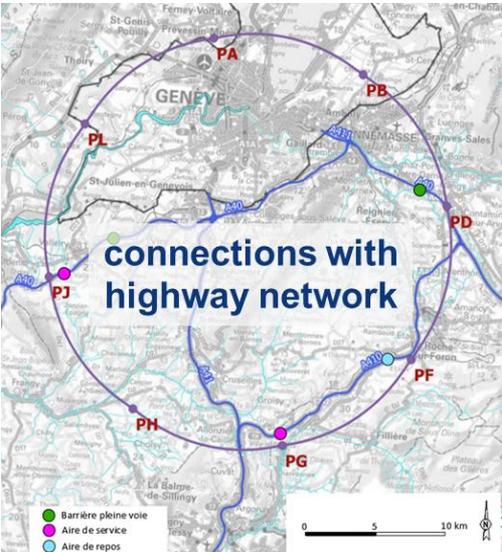
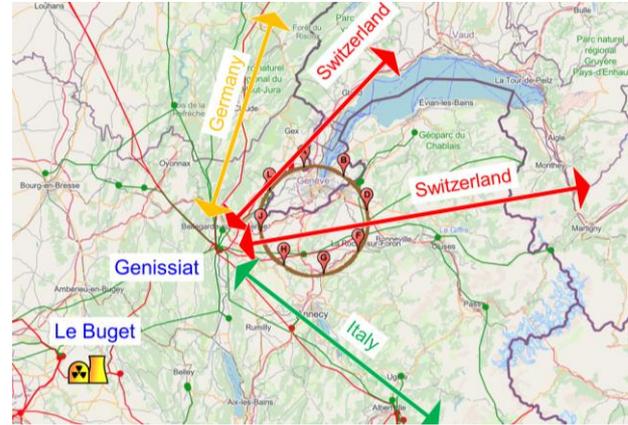
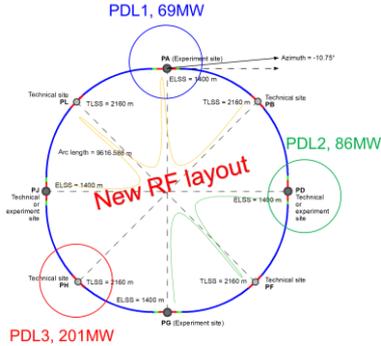
# Resource needs & connections to regional infrastructure

**Electricity consumption 1.1 – 1.8 TWh/year**

Three supply points, also for redundancy

- Two new substations from existing HV grid
- Reuse of present CERN station

Feasibility confirmed with RTE (FR operator)



## Road access

developed for all 8 surface sites

Four highway connections to existing access areas

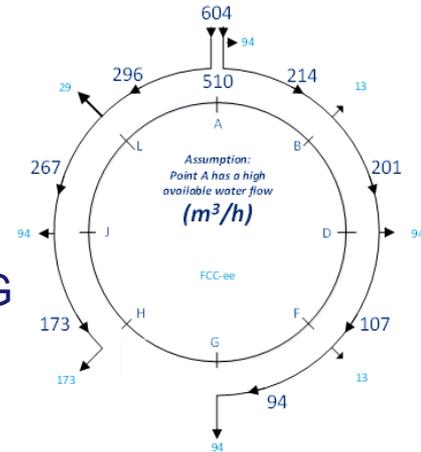
Less than 4 km of new roads required

## Raw water need:

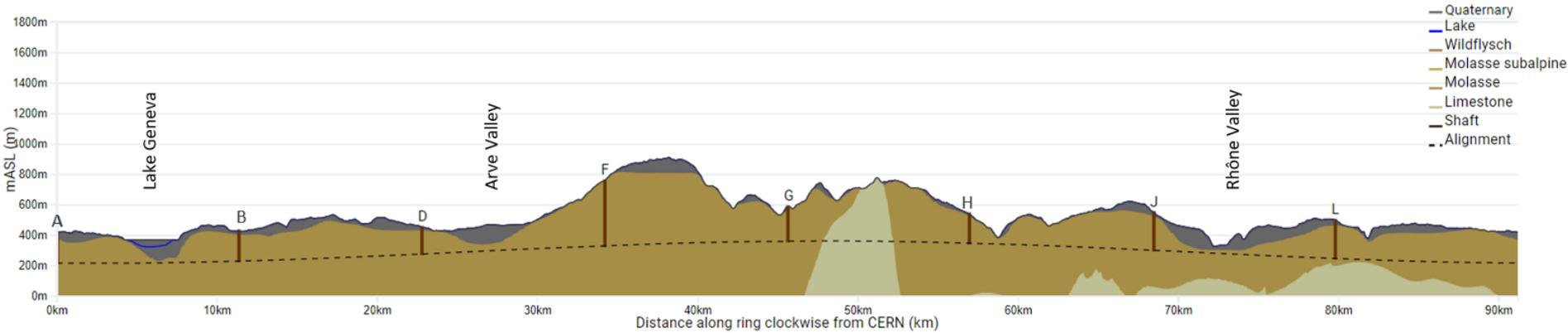
1 – 3 million m<sup>3</sup>/year

Water supply from lake Geneva via existing SIG supply to CERN

Distribution via tunnel



# Optimum placement of FCC tunnel and geology



**Tunneling mainly in molasse layer (soft rock), well suited for fast, low-risk TBM construction.**

**6,25 million m<sup>3</sup> excavated volume → ~8.5 million m<sup>3</sup> excavation material on surface (expanded)**

**CE Designs of all underground structures developed**

**Average shaft depths ~240 m**

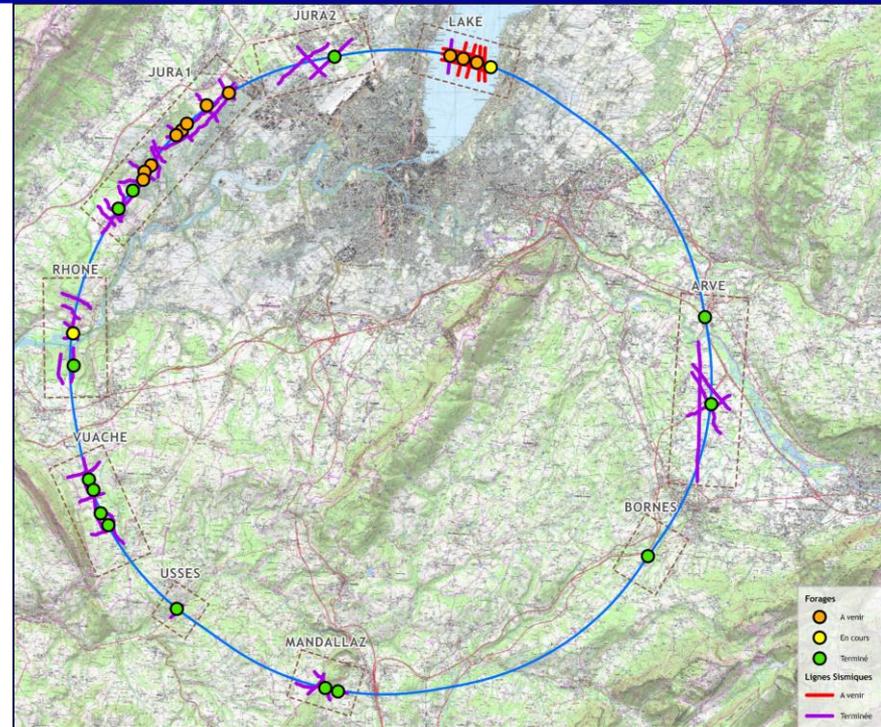
**To fix the vertical position of the tunnel, interfaces between geological layers have to be known**

# Geological investigations

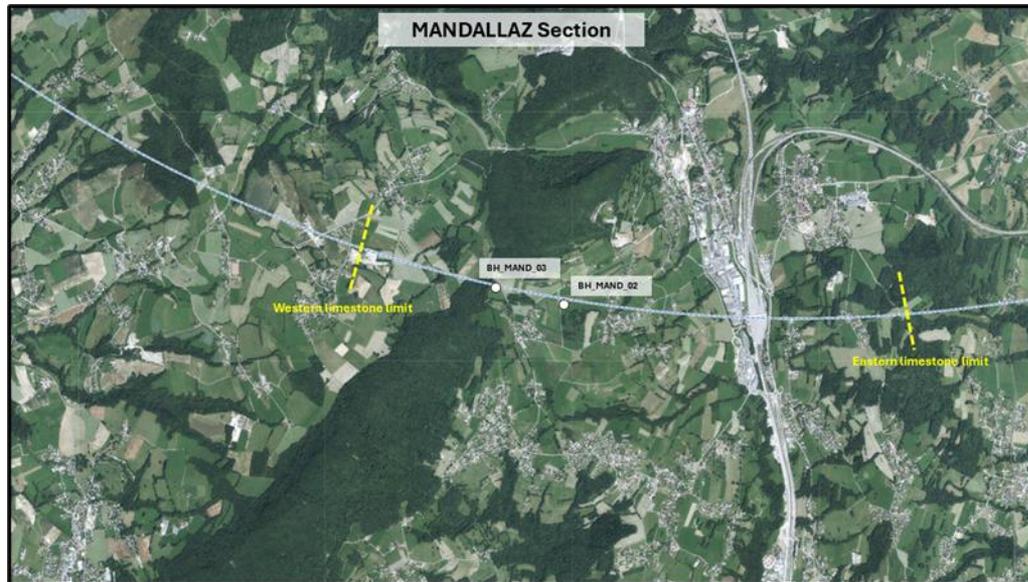
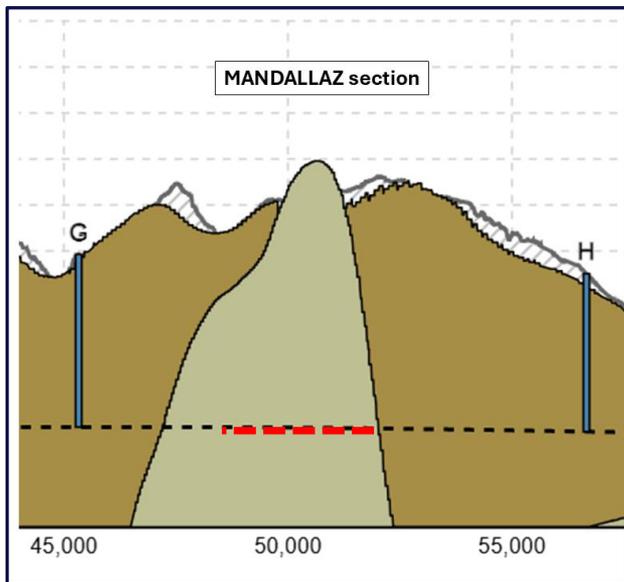
Focused on 8 zones to improve précision of geological model and identify the intercased moraine – molasse and molasse – limestone.

- **86 km of seismic investigations completed**
- **15 of 27 bore holes completed**
- **1st lake bore hole completed**
- **Completion of all bore holes ~June 2026**

Results so far confirm geological model

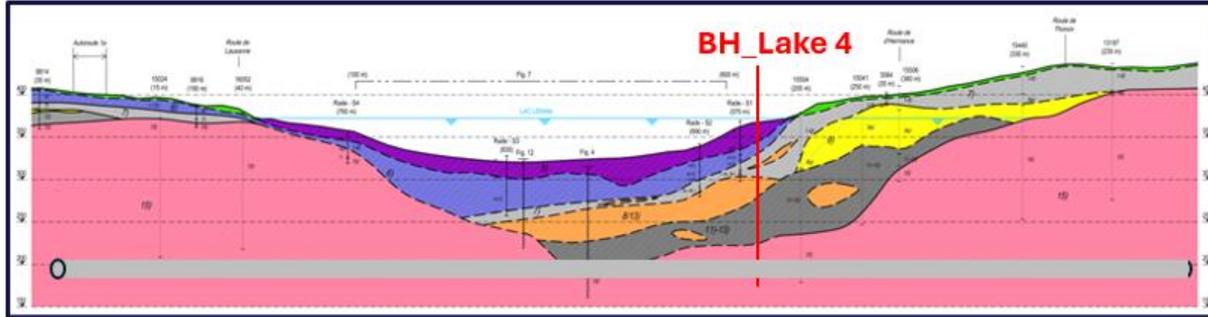


## MANDALLAZ Boreholes

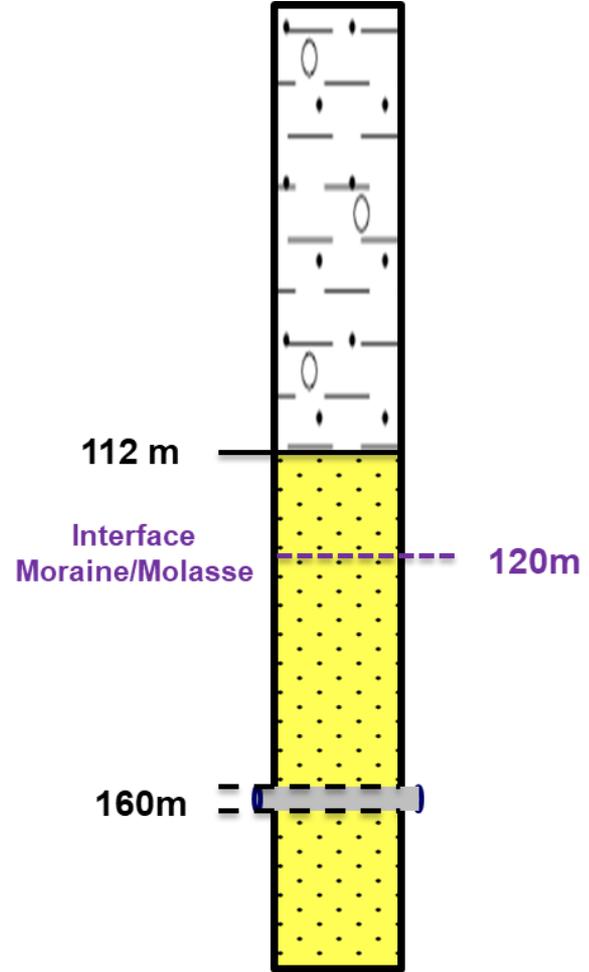


- Two boreholes in the Mandallaz region have enabled a more accurate assessment of the limestone profile in this area.
- It is now considered the limestone interface is steeper than originally thought thus reducing the estimate length of tunnelling from 4.7 km (black trace) down to less than 3km (red trace).

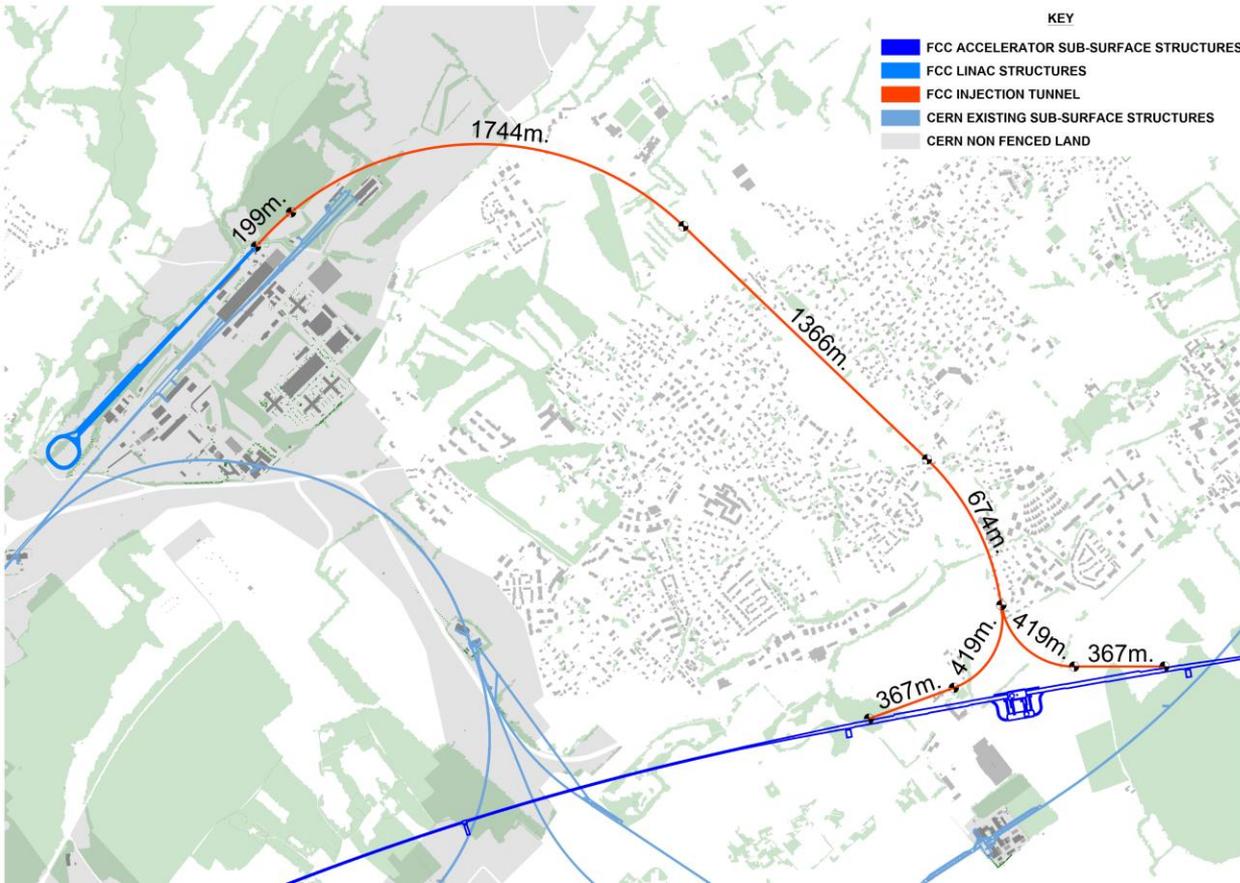
# Bore Hole Lake\_04



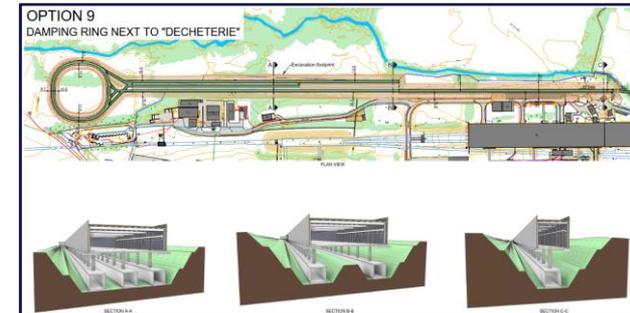
- First lake borehole is positive with molasse commencing at a slightly shallower depth than assumed in baseline.
- If this is also the case for the other boreholes, it may be possible to make the tunnel shallower by several metres under the lake.
- It will also mean the Tunnel Boring Machine will remain in the molasse rock rather than going into the overlying moraine thus avoiding a more complex machine.



# FCC-ee injector implementation



- Located on CERN Prévessin site
- possible connection to North Area to enable non-collider physics
- transfer line to FCC PA (LHC P8)
- “cut and cover” construction



# FCC-ee basic design choices and performance

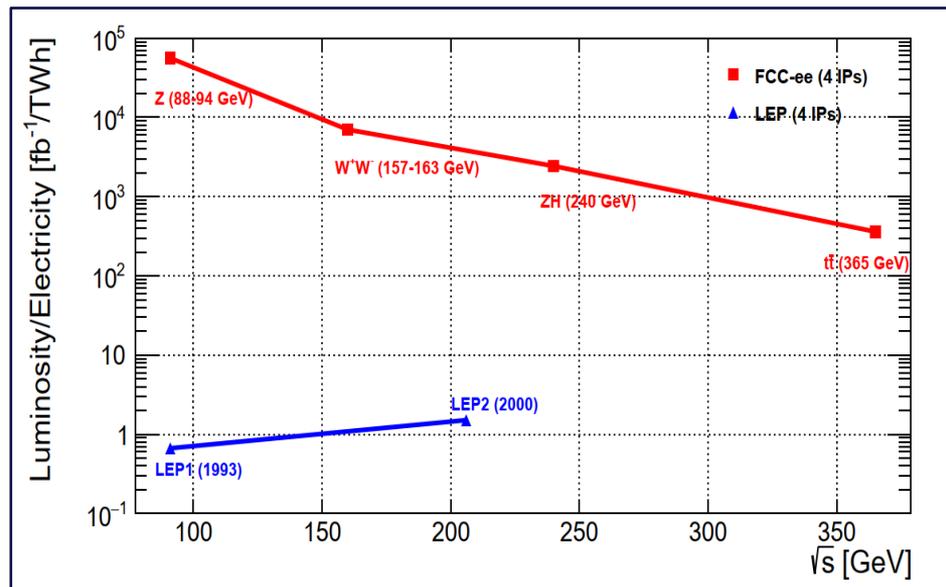
- **Double ring**  $e^+e^-$  collider, allowing many bunches, high current, like LHC and B factories, different from LEP
- **Synchrotron radiation power 50 MW/beam** at all beam energies. Energy loss  $\Delta E$  per turn:

$$\Delta E \sim \gamma^4/\rho = (E/m_0)^4/\rho$$

- **Asymmetric IR layout** and optics to **limit synchrotron radiation towards the detector** and to provide **large** horizontal crossing angle **30 mrad for crab-waist collision optics**, demonstrated at DAFNE (Italy) and SuperKEKB (Japan)
- **Top-up injection** scheme as at modern light sources (APS, SLS,...) and as at recent  $e^+e^-$  colliders, PEP-II (USA), KEKB & SuperKEKB (Japan), BEPCII (China), requires **booster synchrotron in collider tunnel**

Combining concepts from past and present lepton colliders and using high-efficiency SRF system results in a giant step in efficiency:

→  $10^4$ – $10^5$ x luminosity/el.energy of LEP  
 → sustainable physics



# Stage 1: $e^+e^-$ collider FCC-ee

## Consolidated main parameters

## FCC-ee functional layout

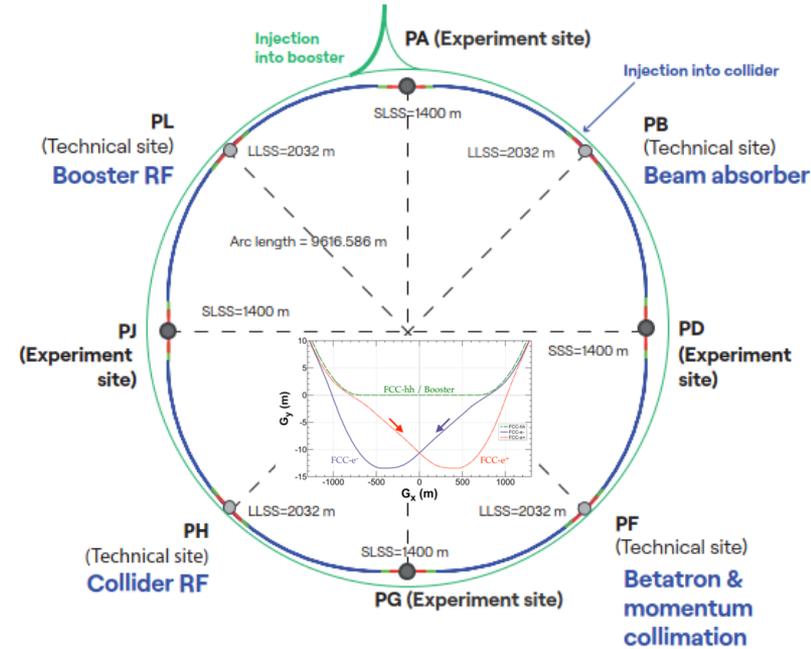
parameter	Z	WW	H (ZH)	$t\bar{t}$
beam energy [GeV]	45.6	80	120	182.5
synchrotron radiation/beam [MW]	50	50	50	50
beam current [mA]	1294	135	26.8	5.1
number bunches / beam	11200	1852	300	64
total RF voltage 400/800 MHz [GV]	0.08 / 0	1.0 / 0	2.09 / 0	2.1 / 9.2
luminosity / IP [ $10^{34} \text{ cm}^{-2}\text{s}^{-1}$ ]	145	20	7.5	1.4
total integrated luminosity / IP / year [ $\text{ab}^{-1} / \text{yr}$ ]	17	2.4	0.9	0.17
beam lifetime [min]	21	13	9	10

4 years  
 $6 \times 10^{12} \text{ Z}$   
LEP  $\times 10^5$

2 years  
 $> 10^8 \text{ WW}$   
LEP  $\times 10^4$

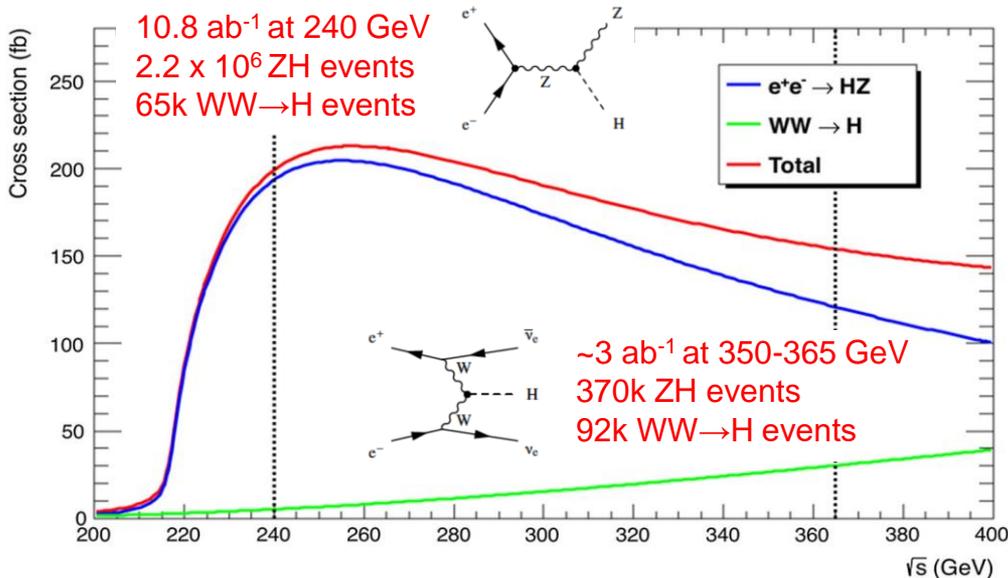
3 years  
 $> 2 \times 10^6 \text{ H}$

5 years  
 $2 \times 10^6 \text{ tt pairs}$



# Higgs physics at FCC-ee (and -hh)

FCC-ee provides model-independent and precise measurement of many Higgs properties, far beyond HL-LHC's reach  
 Achieved through operation at two energy points: 240 GeV and 350-365 GeV



Precision on  $\kappa$  parameters (ratio of measured / SM couplings)

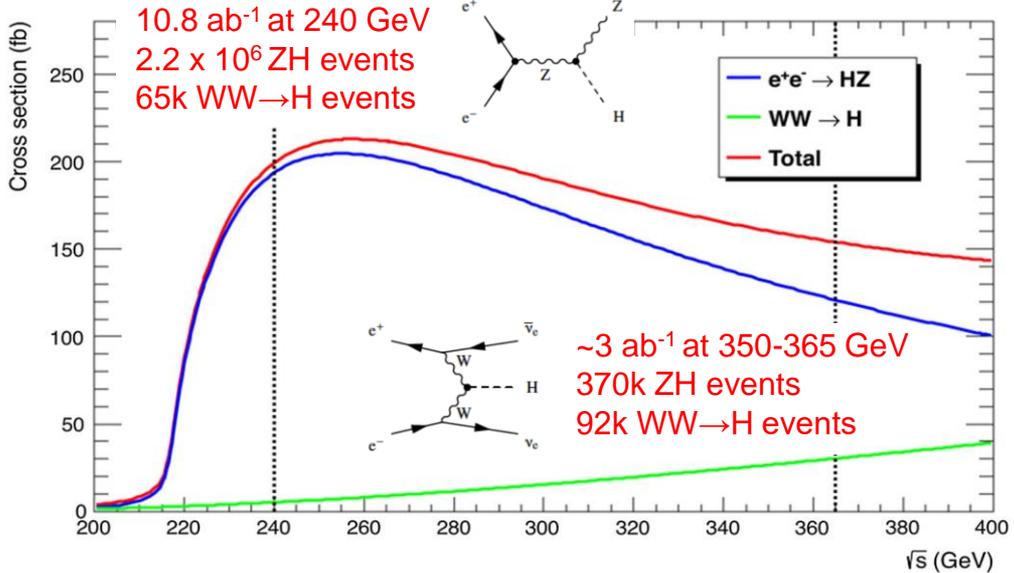
Coupling	HL-LHC	FCC-ee	FCC-ee + FCC-hh
$\kappa_Z$ (%)	1.3*	0.10	0.10
$\kappa_W$ (%)	1.5*	0.29	0.25
$\kappa_b$ (%)	2.5*	0.49	0.49
$\kappa_g$ (%)	2*	0.54	0.54
$\kappa_\tau$ (%)	1.6*	0.46	0.40
$\kappa_c$ (%)	-	0.87	0.87
$\kappa_\gamma$ (%)	1.6*	1.1	0.30
$\kappa_{Z\gamma}$ (%)	10*	4.3	0.67
$\kappa_t$ (%)	3.2*	3.1	0.75
$\kappa_\mu$ (%)	4.4*	3.3	0.42
$ \kappa_s $ (%)	-	+29 -67	+29 -67
$\Gamma_H$ (%)	-	0.78	0.69
$\mathcal{B}_{inv} (<, 95\% \text{ CL})$	$1.9 \times 10^{-2} *$	$5 \times 10^{-4}$	$2.3 \times 10^{-4}$
$\mathcal{B}_{unt} (<, 95\% \text{ CL})$	$4 \times 10^{-2} *$	$6.8 \times 10^{-3}$	$6.7 \times 10^{-3}$

\* next to HL-LHC numbers → not model independent

- FCC-ee permits *model-independent measurement* of Higgs width ( $\Gamma_H$ ), not possible at HL-LHC...
- ...and *sub-percent precision* on many of the most interesting coupling modifiers, e.g. HZZ ( $\kappa_Z$ ) to 0.1% ...
- ...and probes for the *first time* coupling to second generation quarks, e.g. charm, with Hcc ( $\kappa_c$ ) to 0.9%
- Extensions to baseline plan, e.g. H-pole run at 125 GeV, to measure Higgs coupling to electrons, under evaluation

# Higgs physics at FCC-ee (and -hh)

FCC-ee provides model-independent and precise measurement of many Higgs properties, far beyond HL-LHC's reach  
 Achieved through operation at two energy points: 240 GeV and 350-365 GeV



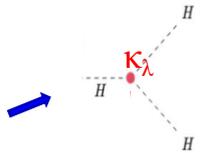
Precision on κ parameters (ratio of measured / SM couplings)

Coupling	HL-LHC	FCC-ee	FCC-ee + FCC-hh
κ <sub>Z</sub> (%)	1.3*	0.10	0.10
κ <sub>W</sub> (%)	1.5*	0.29	0.25
κ <sub>b</sub> (%)	2.5*	0.49	0.49
κ <sub>g</sub> (%)	2*	0.54	0.54
κ <sub>τ</sub> (%)	1.6*	0.46	0.40
κ <sub>c</sub> (%)	-	0.87	0.87
κ <sub>γ</sub> (%)	1.6*	1.1	0.30
κ <sub>Zγ</sub> (%)	10*	4.3	0.67
κ <sub>t</sub> (%)	3.2*	3.1	0.75
κ <sub>μ</sub> (%)	4.4*	3.3	0.42
κ <sub>s</sub>   (%)	-	+29 -67	+29 -67
Γ <sub>H</sub> (%)	-	0.78	0.69
B <sub>inv</sub> (<, 95% CL)	1.9 × 10 <sup>-2</sup> *	5 × 10 <sup>-4</sup>	2.3 × 10 <sup>-4</sup>
B <sub>unt</sub> (<, 95% CL)	4 × 10 <sup>-2</sup> *	6.8 × 10 <sup>-3</sup>	6.7 × 10 <sup>-3</sup>

\* next to HL-LHC numbers → not model independent

## FCC-hh completes the job !

- Dataset of 20 billion Higgs bosons allows for precise measurement of rare decay modes
- Great synergy and complementarity between -ee and -hh
- Dataset of 30 million Higgs pairs allows critical self-coupling parameter κ<sub>λ</sub> to be measured to ~3%

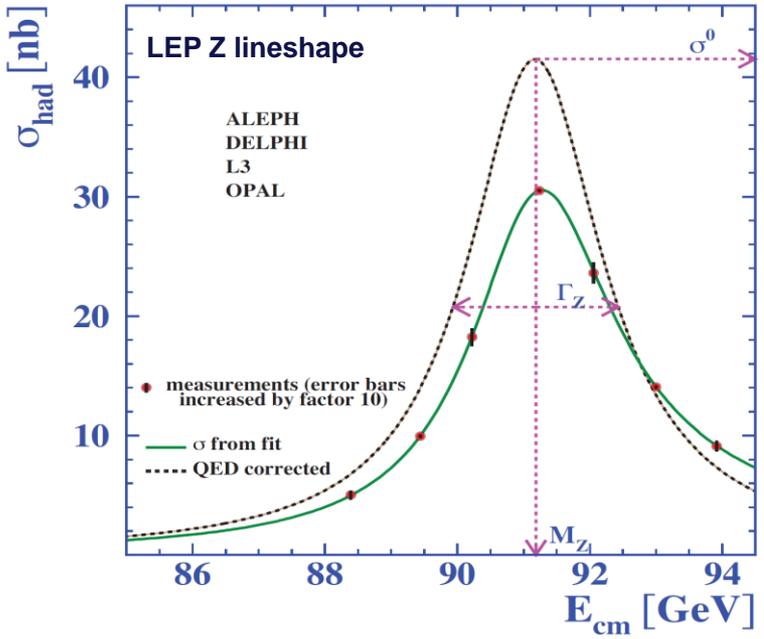


# Precision electroweak physics at FCC-ee

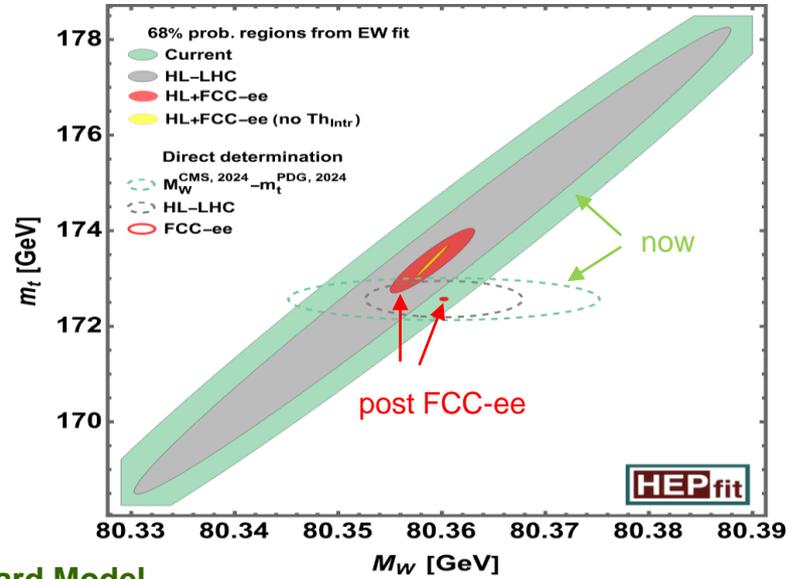
FCC-ee allows for ultra-precise studies of electroweak sector → highly sensitive indirect probe of New Physics !

Tera-Z:  $6 \times 10^{12}$  Z from  $205 \text{ ab}^{-1}$  taken on-peak and off

Execute LEP-style measurements, e.g. Z scan to determine mass and width, but with  $10^5$  increase in sample size



Similarly big improvements at higher energies from W mass and top-quark mass measurements



Standard Model  
'closure test'

Compare direct measurements with expectations from Standard Model deriving from measurements at Z peak

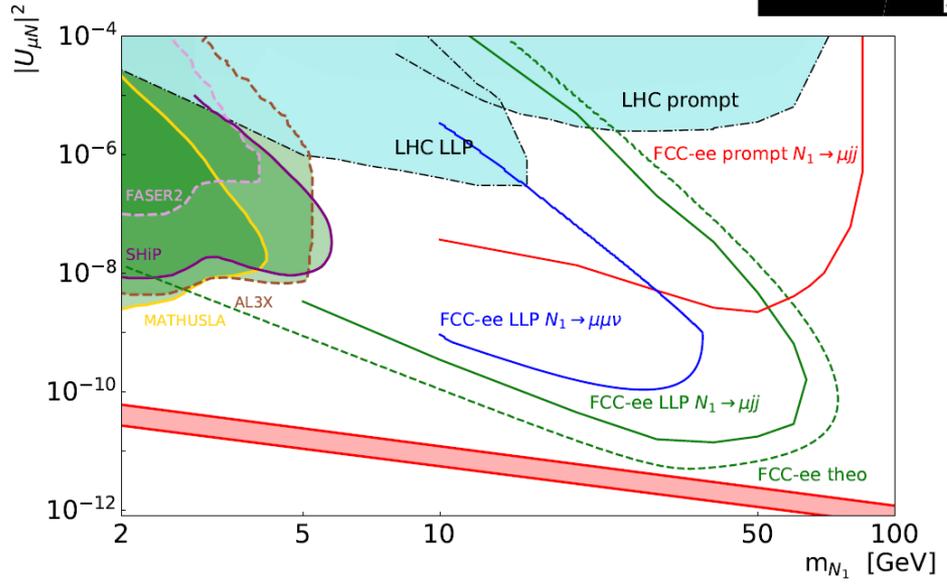
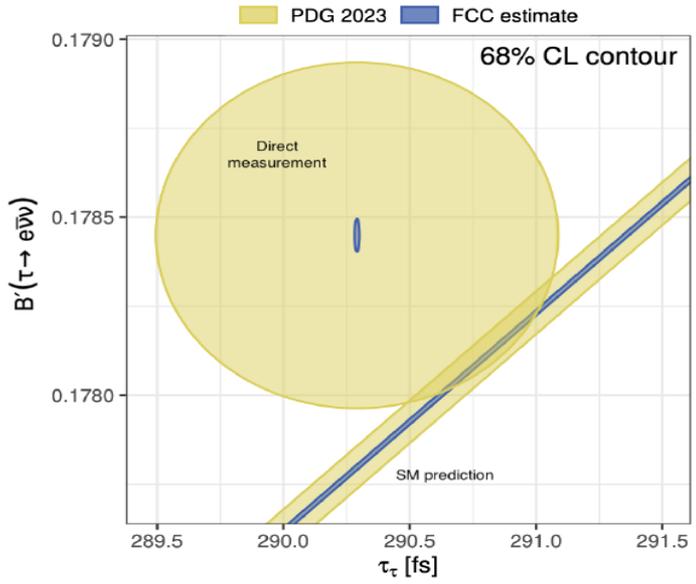
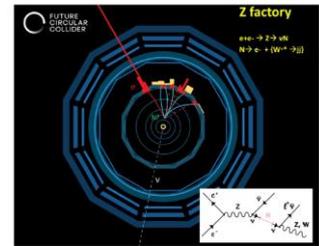
# Heavy flavour and direct search physics at FCC-ee

Huge sample of  $6 \times 10^{12}$  Z provide excellent opportunities in heavy flavour and search physics

**Flavour:** FCC-ee matches the key advantages of HL-LHC (very large samples of b, c and  $\tau$  decays) with those of Belle II (very clean environment)

e.g. lepton universality tests with taus

Searches for new feebly-coupled particles, e.g. heavy neutral leptons: sensitivity in key regions of parameter space inaccessible by SHiP and LHC

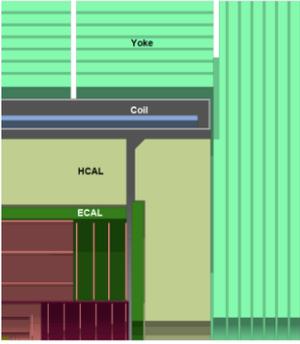


# Detector developments

Work progressing to understand detector requirements for *full* programme (not just Higgs!).

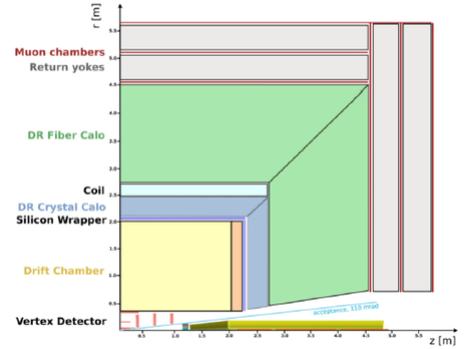
Four 'detector concepts' have already emerged, as test beds for possible solutions.

CLD



Full Si tracker  
CALICE-like calorimeter

IDEA



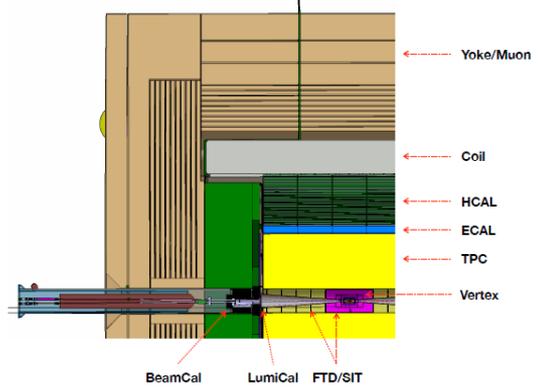
Ultra-light drift chamber  
Crystal ECAL  
Dual readout fibre calo

ALLEGRO



In early design phase  
Noble liquid (Ar) ECAL

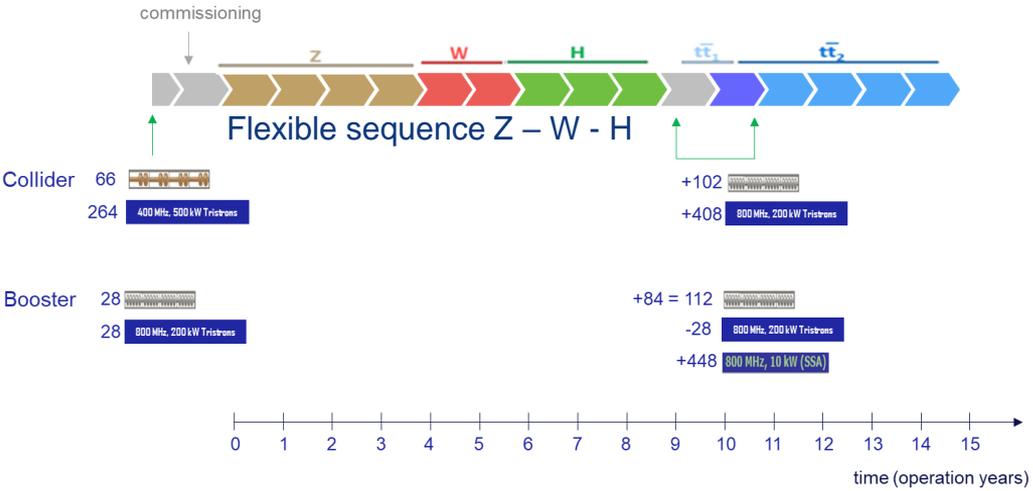
ILD



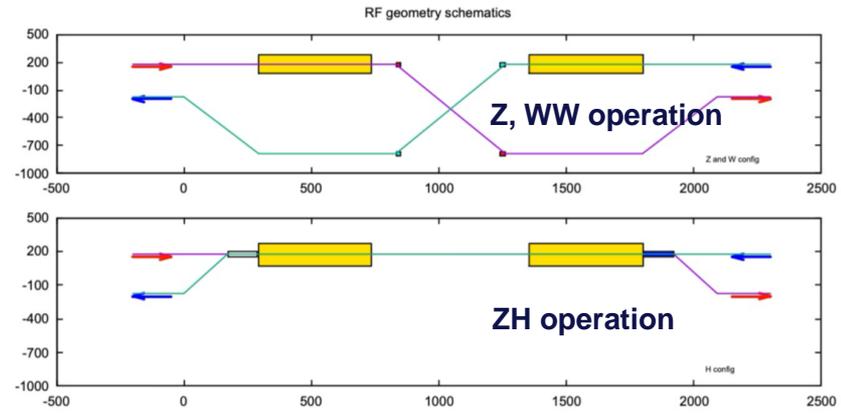
Ported from ILC  
Large volume TPC

...these are NOT yet collaborations or locked-in designs. Full participation of community, and close collaboration with DRD collaborations, needed to progress in next phase.

# FCC-ee operation sequence and SRF concept



## 400 MHz RF layout and beam switching



- **2-cell 400 MHz SRF system for Z, W and ZH**, entire system installed at operation start
  - flexibility for switching between Z, WW, ZH operation
  - reverse phase operation at Z allows constant cavity coupling
  - suppression of the single-cell 400 MHz system
  - reduced R&D, installation, commissioning, etc...
- **6-cell 800 MHz SRF system for collider ttbar operation and booster at all energies**

# FCC-ee different running modes

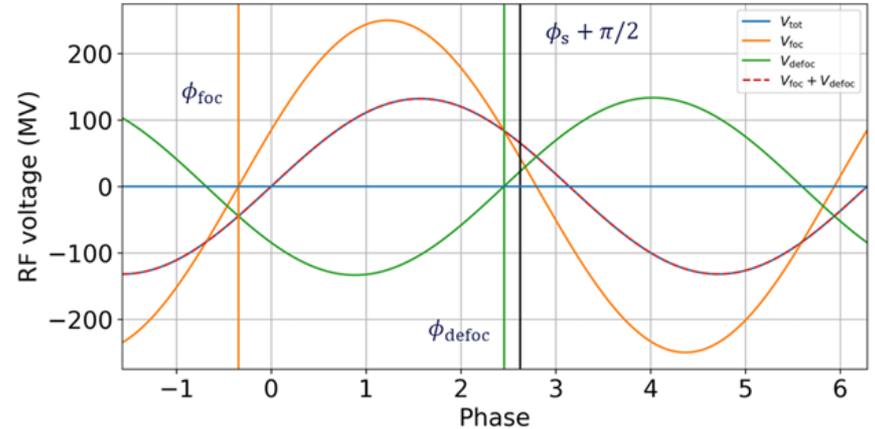
	Energy (GeV)	Current (mA)	RF voltage (GV)
Z	45.6	1294	0.079
W	80	135	1.05
H	120	26.7	2.1
t $\bar{t}$	182.5	5	11.3

## RF reverse phase operation



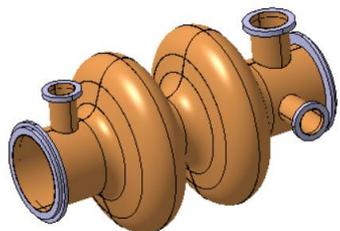
Reverse phase operation (RPO) mode allows increasing RF cavity voltage (Y. Morita et al., SRF, 2009)

- Experimentally verified with high beam loading in **KEKB** (Y. Morita et al., IPAC, 2010)
- Baseline solution for **EIC ESR** (e.g., J. Guo et al., IPAC, 2022)



at the Z pole  $\rightarrow$  enables one RF system from Z to ZH

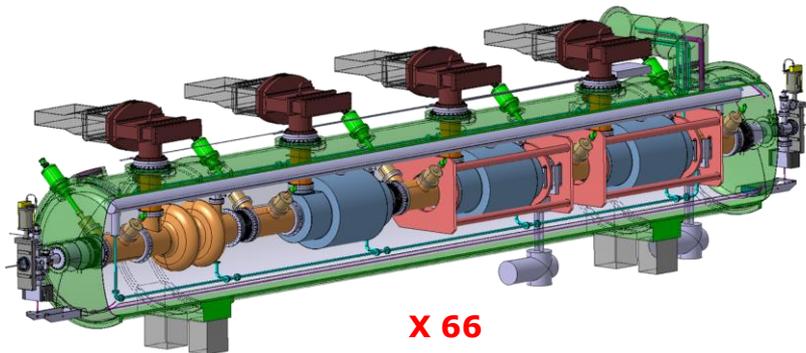
# 400 MHz system – collider Z, W, ZH



X 264

## Superconducting elliptical cavity

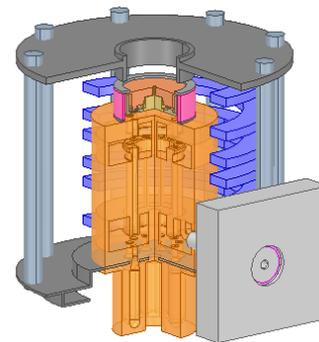
- 400 MHz, 2-cell
- 1.5 m. long
- Electropolished and seamless RF surface
- Niobium thin film with HiPIMS



X 66

## Cryomodule

- Segmented design, 4 cavities
- Vertical FPC, HOM damping and extraction
- Frequency tuning system
- Thermal and magnetic shielding



X 264

## Multibeam Tristron

- **400 MHz**
- 46 kV
- 500 kW, CW
- ~ 90% efficiency

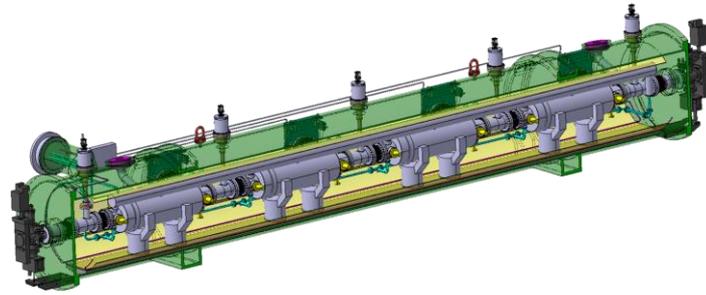
# 800 MHz system – for $t\bar{t}$ collider and booster



**X (408 + 448)**

## Superconducting elliptical cavity

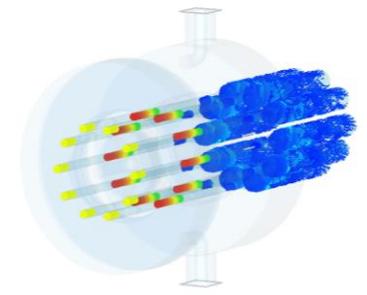
- 800 MHz, 6-cell
- Nb<sub>3</sub>Sn if R&D is successful



**X (102 + 112)**

## Cryomodule

- Segmented design, 4 cavities, 2 K
- Operation at 4.5 K if R&D successful



## Multibeam Tristron

- 800 MHz
- 250 kW, CW **X 408**

## Solid State Amplifier (SSA)

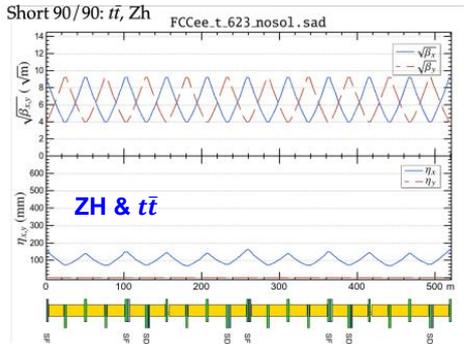
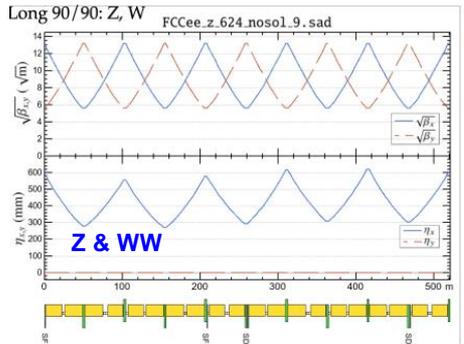
- 800 MHz **X 448**
- 10-15 kW pulsed



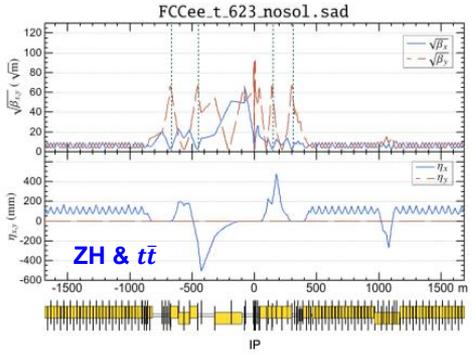
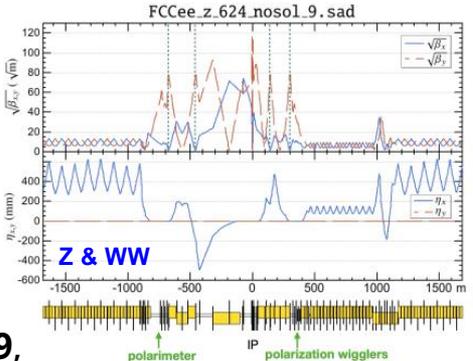
# FCC-ee optics baseline GHC

K. Oide et al.

arc



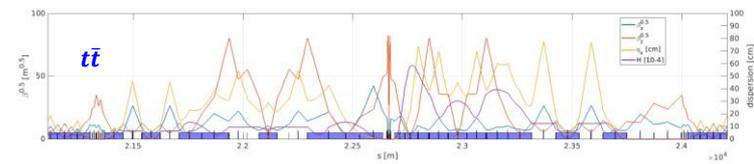
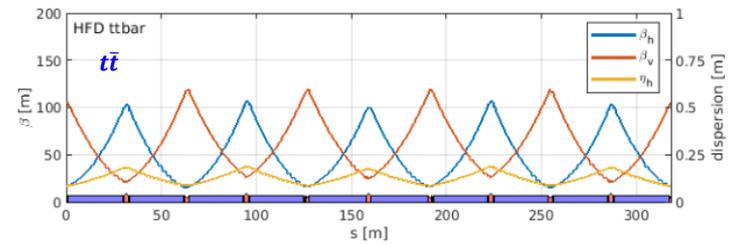
experimental straight



PRAB 19, 111005 (2016)

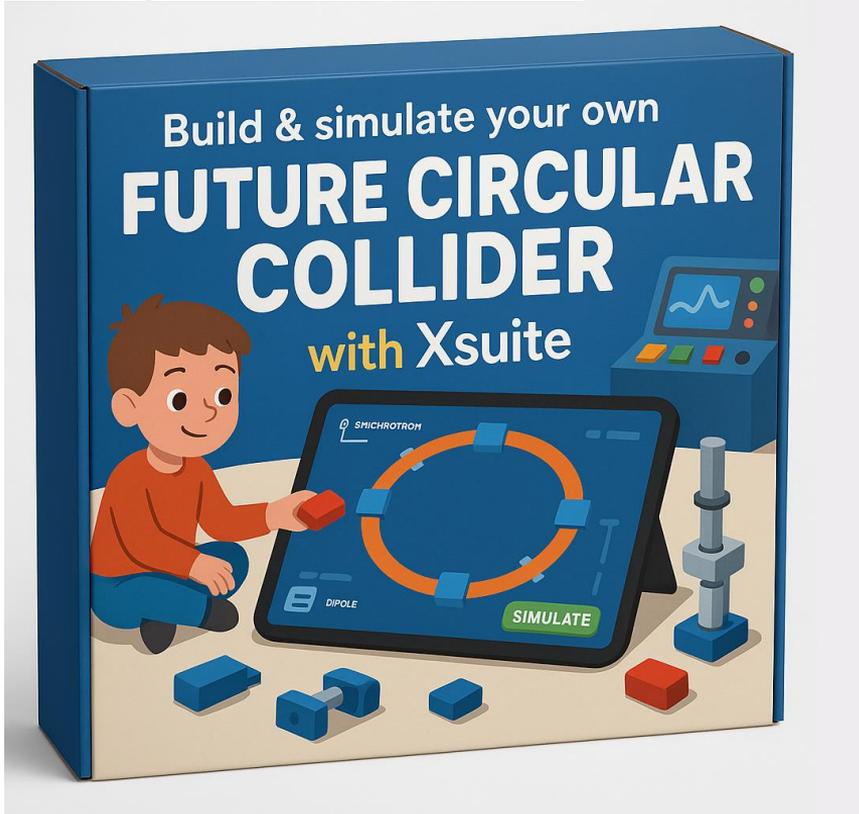
# alternative LCC

P. Raimondi, S. Liuzzo, et al.



PRAB 28, 021002 (2025)

# FCC design with Xsuite



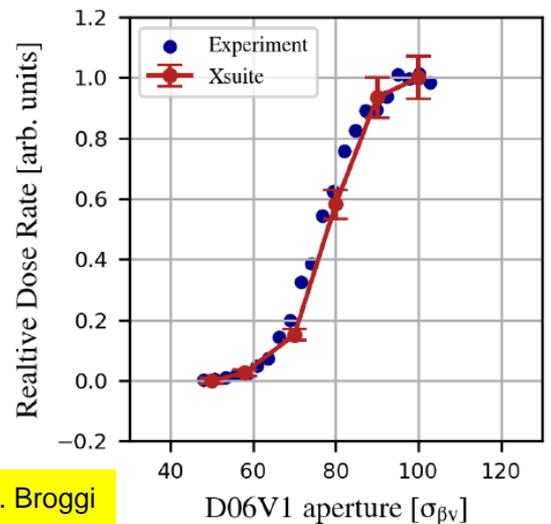
G. Iadarola

tutorials in form of Jupyter notebooks

# + SuperKEKB benchmarks

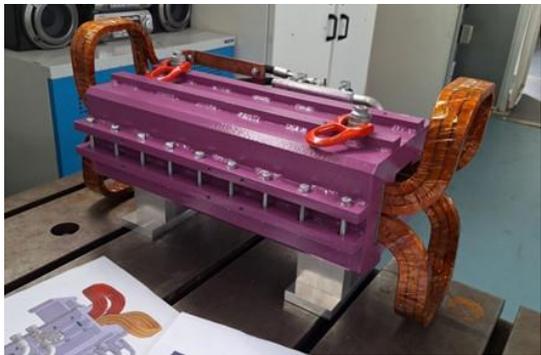
G. Broggi, J. Salvesen, G. Iadarola, H. Sugimoto, K. Oide

Touschek & beam-gas scattering for different collimator settings, including collimator-matter interaction



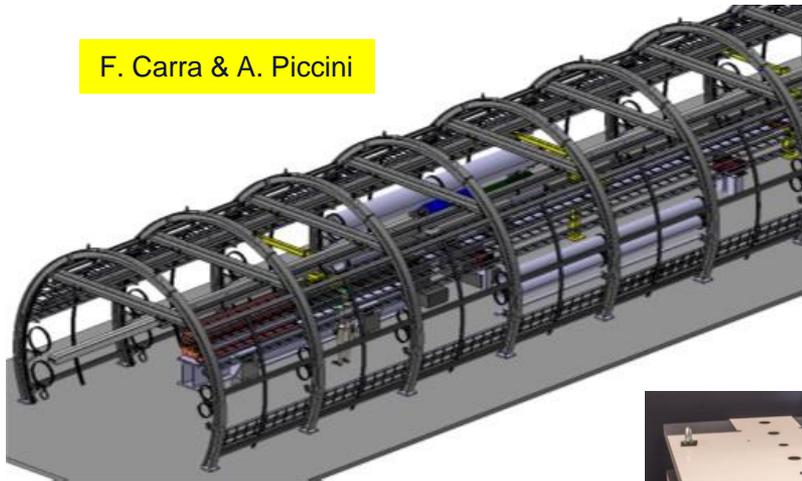
G. Broggi

# Design of arc magnets, girders, cavities, prototypes, mock-ups



Booster dipole  
low-field  
cycling  
magnet

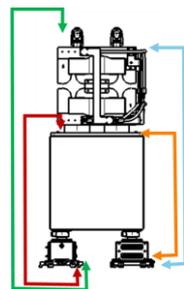
F. Carra & A. Piccini



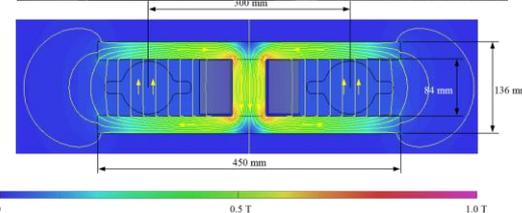
Arc half-cell =  
the most repeated  
region of  
mechanical  
hardware in the  
tunnel: → 77 km  
over 90 km are  
arc cells

A. Milanese

800 MHz bulk Nb 5-cell cavity  
Prototype fulfilling FCC specs  
JLAB, F. Marhauser



Twin-dipole  
design with 2x  
power saving  
16 MW  
(at 175 GeV)



Vibration studies with girder on PSI jacks

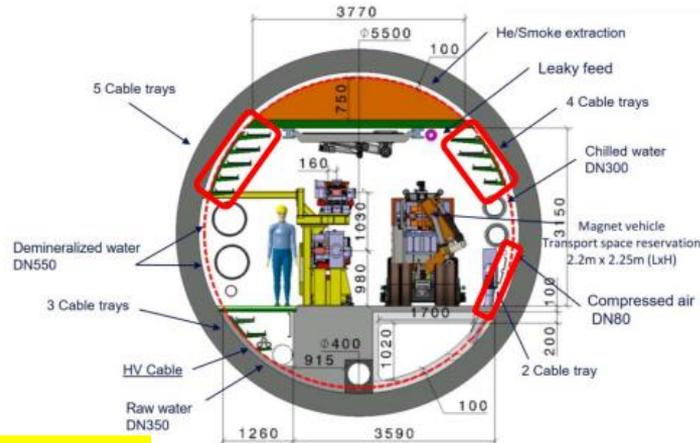
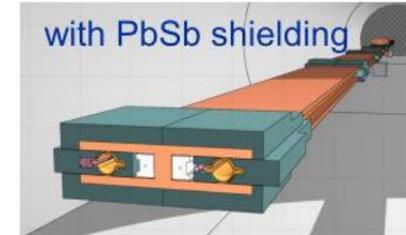
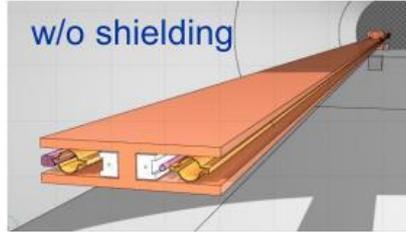
# Shielding concept: limiting cumulative dose ( $t\bar{t}$ )

Synchrotron radiations absorbers and additional shielding aiming factor  $\sim 100$  dose reduction in arcs

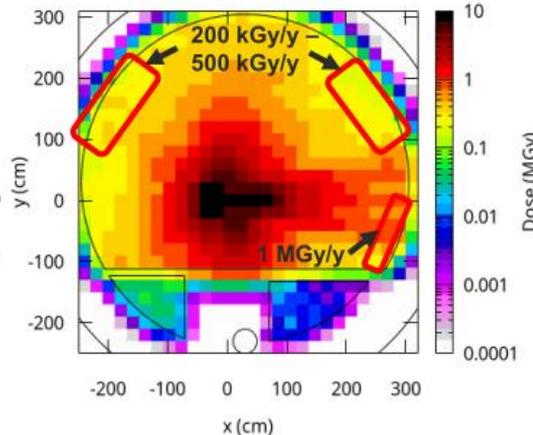
## Shielding material for full ring

Dipoles	2580
Photon stoppers	10
Shielding weight per stopper	400 kg
Total weight	10320 tons

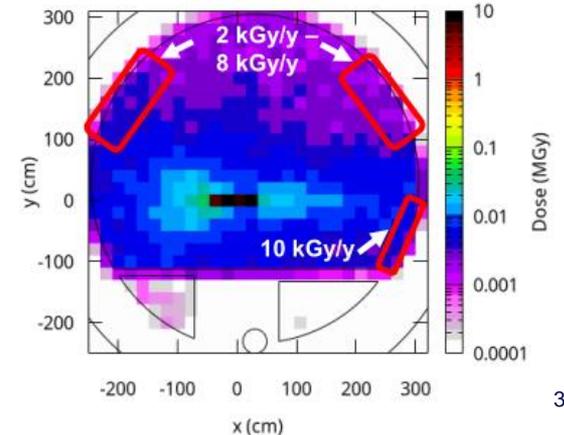
Photon stoppers include W-alloy layer in both cases



Annual dose (182.5 GeV, ttbar)



Annual dose (182.5 GeV, ttbar)



# Machine-Detector Interface

## Key topics:

SC IR magnet system & cryostat design

3D integration

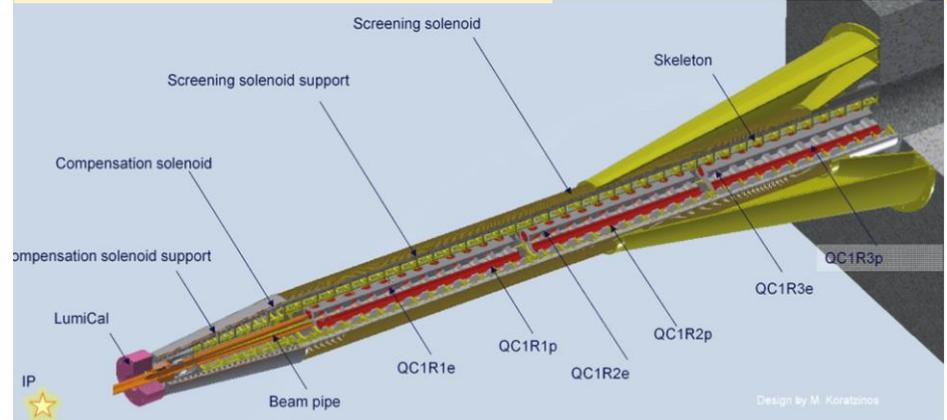
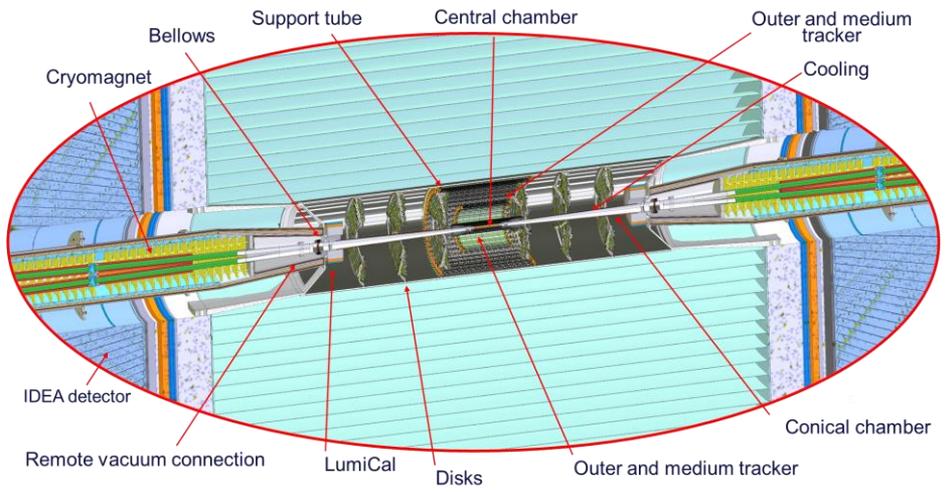
IR mock-up at INFN-LNF

Machine		FCCee	CEPC	ILC	SuperKEKB
Crossing-angle	mrad	30	33	14	83
L*	m	2.2	1.9	3.5	0.935
Vertical $\beta_y^*$ at IP	mm	0.7-1.6	0.9-2.7	0.4	0.3
Detector soln field	T	2/3	3	3.5/5	1.5
Detector stay clear	mrad	100	118/141	90	350/436
Two beam $\Delta X$ at L*	mm	66	62.7	49	77.6
He temperature	K	1.9	4.2	4.5	4.5



J. Seeman, A. Novokhatski, SLAC  
 B. Parker, Vikas Teotia, BNL  
 P. Tavares, CERN

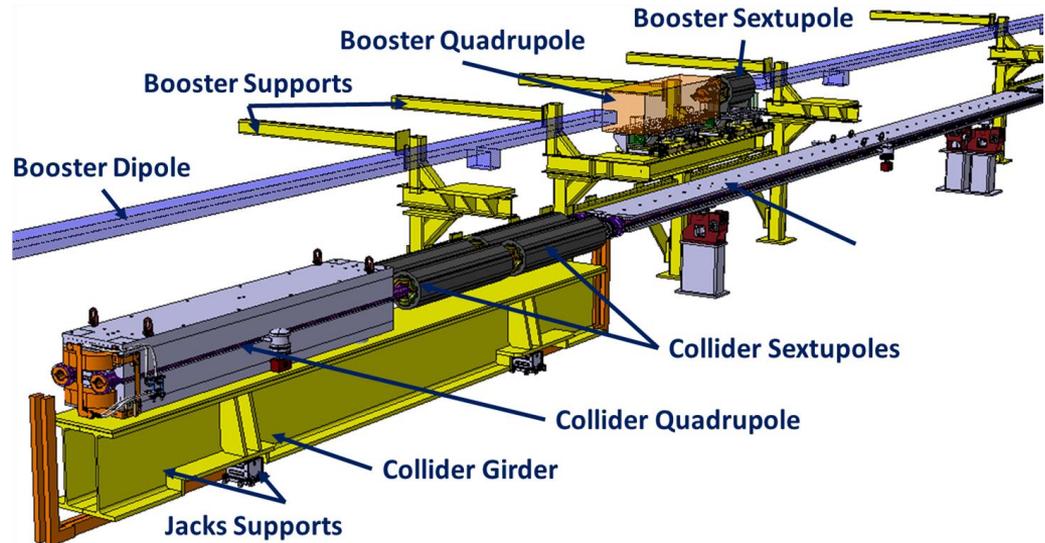
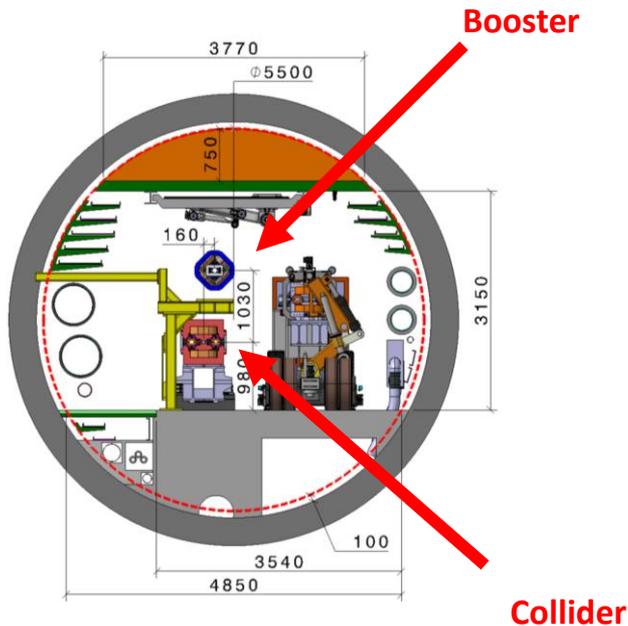
M. Koratzinos, PSI



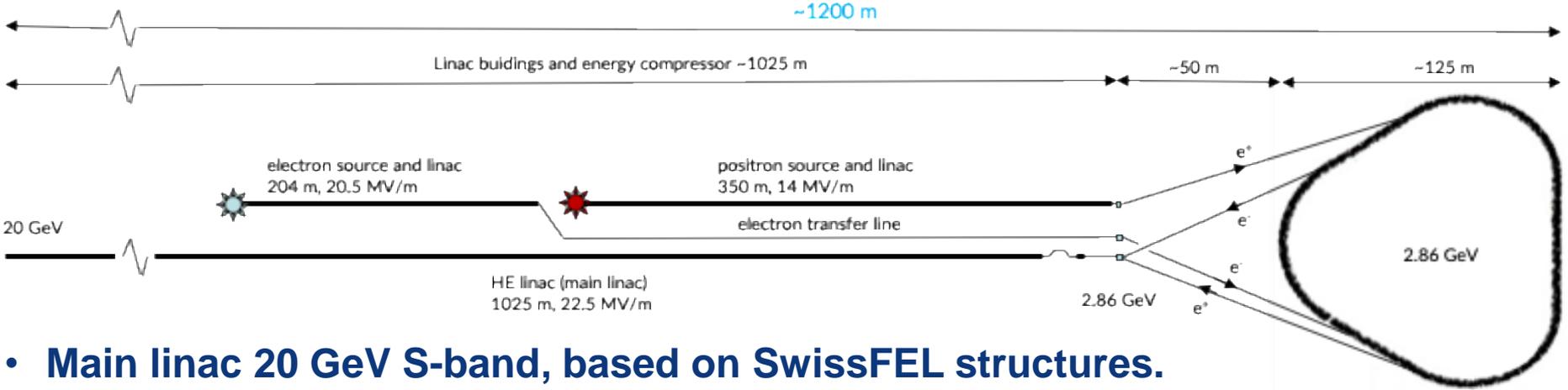
M. Boscolo, F. Palla, INFN

# FCC-ee booster

**full energy booster**, ramping from 20 GeV to 46 GeV – 182.5 GeV;  
 injection ~several times per minute to keep collider beam currents constant;  
 booster intensity ~1% of collider; full RF voltage as in collider



# FCC-ee injector design



- **Main linac 20 GeV S-band, based on SwissFEL structures.**

- new accelerating structures with higher shunt impedance;
- gradient 22.5/20.5 MV/m; repetition rate 100 Hz
- 80 MW S-band klystron, great interest in **KEK R&D**

- **Novel positron source**

- HTS solenoid (15 T on axis, tested 18 T @ 12 K)
- proof-of-principle beam tests at PSI SwissFEL from 2026



# other FCC-ee science opportunities

large circumference, high energy, abundant positron production, low-emittance beams, high-power beamstrahlung, injector complex → FCC-ee offers unique opportunities for various other fields of physics and science

## Examples:

- production of **true muonium**
- creation of a **Bose-Einstein condensate of positronium**
- **high(est)-energy photons**, Compton imaging, nuclear research etc.
- **spatially coherent photon beams**, possibly **down to 0.1 Å wavelengths**
- **higher average and peak brightness** than any existing or planned light source
- **radioactive isotope production**
- **neutron source**

## Other Science Opportunities at the FCC-ee

I. Agapov<sup>1</sup>, E.E. Alp<sup>2</sup>, K. Andre<sup>3</sup>, S. Antipov<sup>1</sup>, A. Apyan<sup>4</sup>, G. Arduini<sup>3</sup>, L. Bandiera<sup>5</sup>, H. Bartmann<sup>3</sup>, H. Bartosik<sup>3</sup>, M. Benedikt<sup>3</sup>, S. Bettoni<sup>7</sup>, J.M. Byrd<sup>2</sup>, M. Calviani<sup>3</sup>, A. Camper<sup>8</sup>, C. Carli<sup>3</sup>, S. Casalbuoni<sup>9</sup>, A. Chance<sup>10</sup>, P. Craievich<sup>7</sup>, P. Crivelli<sup>11</sup>, B. Dalena<sup>10</sup>, M. Dickmann<sup>12</sup>, M. Doser<sup>3</sup>, I. Drebot<sup>13</sup>, C. Duchemin<sup>3</sup>, K. Dupraz<sup>14</sup>, S.J. Freeman<sup>3,15</sup>, A. Frasca<sup>3,16</sup>, F. Günsing<sup>11,17</sup>, J. Jäckel<sup>18</sup>, B. King<sup>19</sup>, M.W. Krasny<sup>20</sup>, A. Lechner<sup>3</sup>, C.A. Lindström<sup>8</sup>, A. Mazzolari<sup>5,6</sup>, C. Milardi<sup>21</sup>, E. Musa<sup>1</sup>, R. Negrello<sup>5,6</sup>, F. Nguyen<sup>22</sup>, K. Oide<sup>23</sup>, Y. Papaphilippou<sup>3</sup>, G. Paternò<sup>5</sup>, V. Petrillo<sup>24</sup>, K. Piotrkowski<sup>25</sup>, B. Rienäcker<sup>16</sup>, G. Schnell<sup>26,27</sup>, C. Schroer<sup>1</sup>, I. Schulthess<sup>1</sup>, L. Serafini<sup>13</sup>, V. Shiltsev<sup>28</sup>, M. Stampanoni<sup>7,11</sup>, A. Variola<sup>29</sup>, T. Watson<sup>3</sup>, H.-U. Wienands<sup>2</sup>, M. Wing<sup>30</sup>, and F. Zimmermann<sup>\*3</sup>

<sup>1</sup>Deutsches Elektronen-Synchrotron DESY, Hamburg, Germany

<sup>2</sup>Argonne National Laboratory, Lemont, Illinois, United States of America

<sup>3</sup>European Organization for Nuclear Research (CERN), Geneva, Switzerland

<sup>4</sup>A.I. Alikhanyan National Laboratory, Yerevan, Armenia

<sup>5</sup>INFN Ferrara, Ferrara, Italy

<sup>6</sup>University of Ferrara, Ferrara, Italy

<sup>7</sup>PSI, Villigen, Switzerland

<sup>8</sup>University of Oslo, Oslo, Norway

<sup>9</sup>European XFEL, Hamburg, Germany

<sup>10</sup>CEA, Saclay, France

<sup>11</sup>ETH Zürich, Zürich, Switzerland

<sup>12</sup>University of the Bundeswehr Munich, Neubiberg, Germany

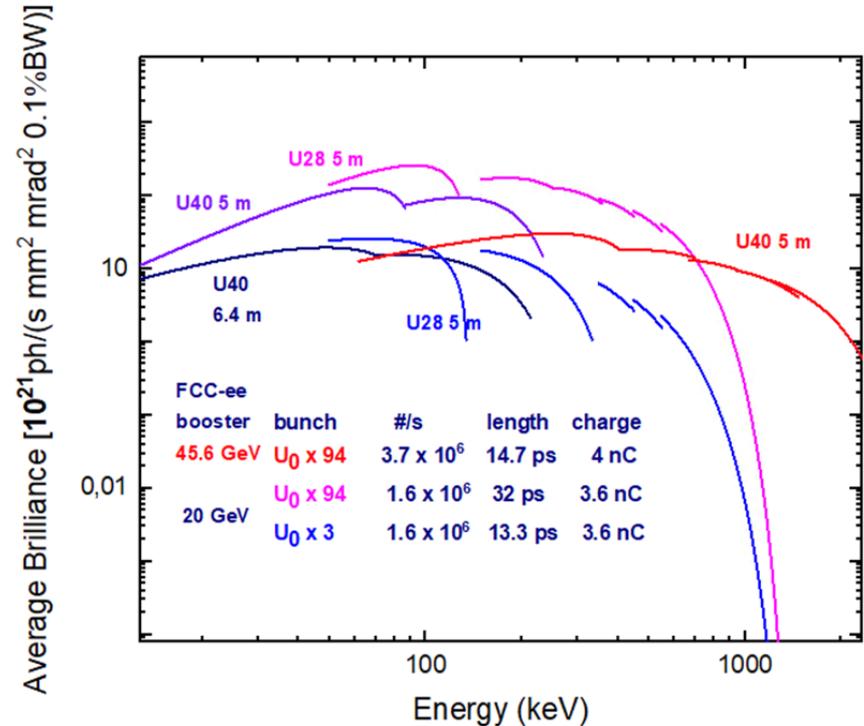
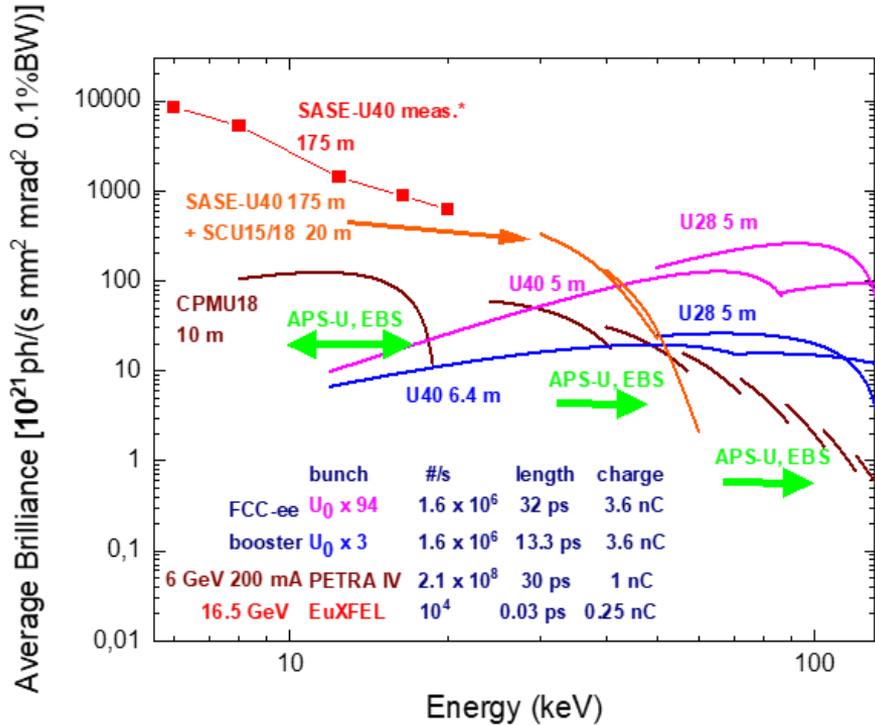
<sup>13</sup>INFN Milano, Milano, Italy

<sup>14</sup>IJCLab, Orsay, France

..

CERN-FCC-ACC-2025-0005,  
doi: [10.17181/CERN.BSP4.H8ED](https://doi.org/10.17181/CERN.BSP4.H8ED)  
submitted to EPJ Plus

# FCC-ee booster as unique ultimate photon source



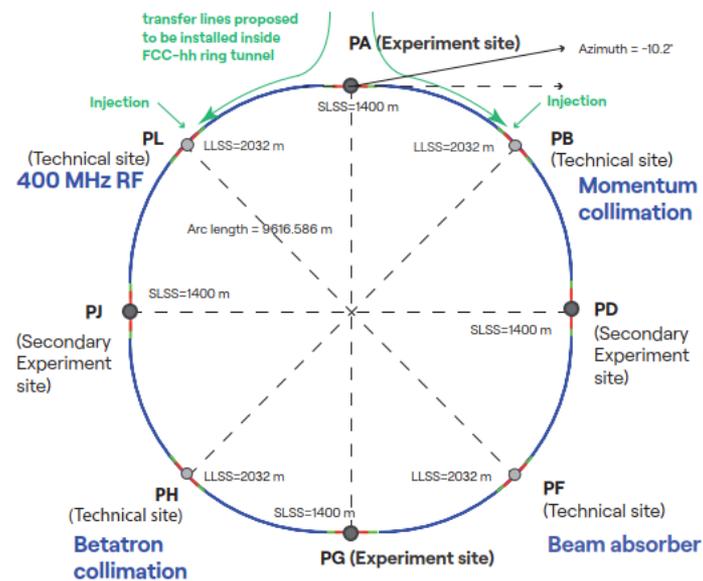
# Stage 2: hadron collider FCC-hh

- Parameter optimization to lower electricity consumption (~max. consumption of FCC-ee)
- Magnetic field considered realistic with today's technologies ( $Nb_3Sn$ , ~14T, 1.9 K)

## Main parameters FSR 2025

parameter	FCC-hh	FCC-hh CDR	HL-LHC
collision energy cms [TeV]	85	100	14
dipole field [T]	14	16	8.33
circumference [km]	90.7	97.8	26.7
beam current [A]	0.5	0.5	1.1
synchr. rad. per ring [kW]	1200	2400	7.3
peak luminos. [ $10^{34} \text{ cm}^{-2}\text{s}^{-1}$ ]	30	30	5 (lev.)
integr. luminosity / IP [ $\text{fb}^{-1}$ ]	20000	20000	3000

## FCC-hh functional layout

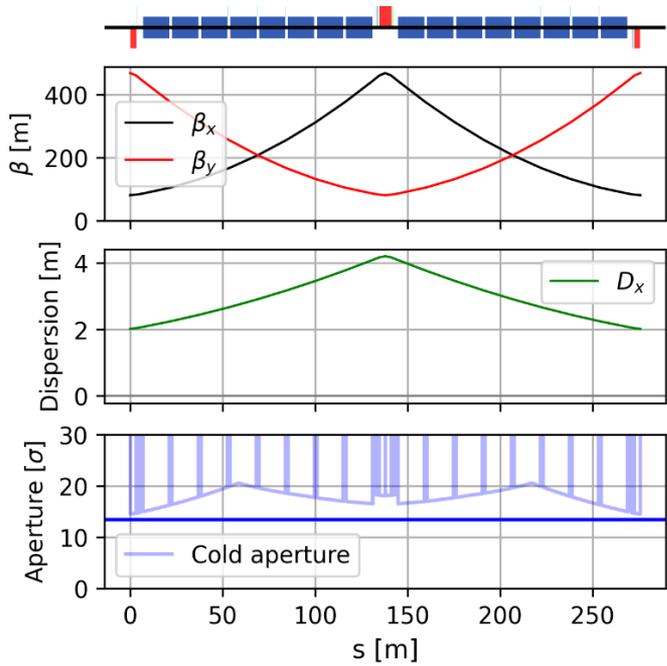


- For  $Nb_3Sn$  @ 1.9 K: 355 MW el, consumption and 2.3 TWh/y
- For  $Nb_3Sn$  @ 4.5 K potential to reduce to ~1.8 TWh/y as for FCC-ee.

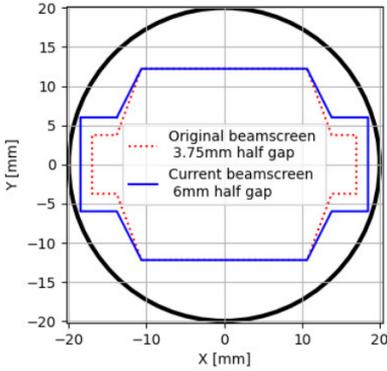
# FCC-hh beam optics perfectionated for highest energy !

regular arc cell

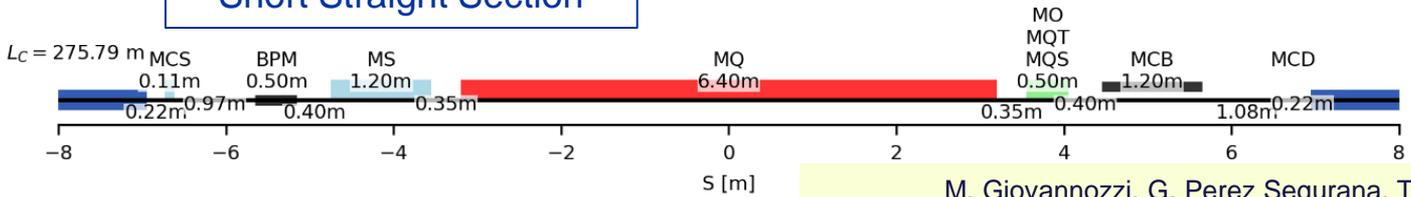
	CDR cell		
	12-dipole	12-dipole	16-dipole
# dipoles	4668	4288	4464
Cell length [m]	213.030	213.030	<b>275.792</b>
Circumference [km]	97.75	<b>90.657</b>	<b>90.657</b>
CM energy @14T [TeV]	88.477	81.275	<b>84.611</b>



~275m



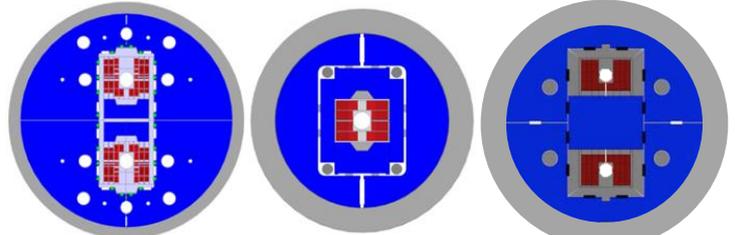
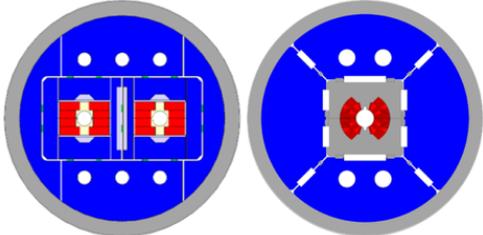
Short Straight Section



# FCC-hh High-Field Magnet Nb<sub>3</sub>Sn and HTS R&D

## Nb<sub>3</sub>Sn:

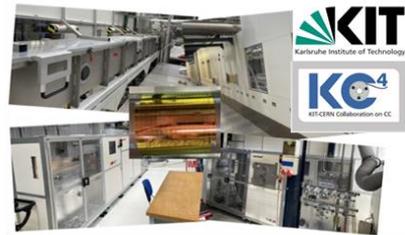
- 12- and 14-T short demonstrators
- Different coil geometries
- tests scheduled for 2026



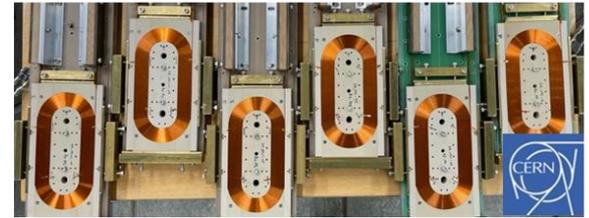
## HTS R&D in various domains:

- REBCO and IBS Conductor R&D
- Racetrack coil developments

B. Auchmann, E. Todesco



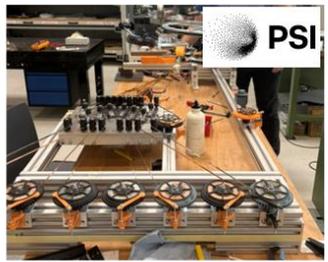
REBCO coated-conductor R&D line at KIT.



Insulated tape-stack coils for assembly in common-coil config at CERN.



Iron-based SC powder synthesis and R&D tape fabrication at CNR SPIN



Fabrication of racetrack from solder-impregnated tape-stack cable at PSI.



CL winding      CL winding + 100 turns of Dumomag      CL winding + 120 turns MI

CEA process development for metal-insulated racetrack coils.

**Down selection of technology by 2035-2040**

# Status of the FCC Global Collaboration

**Increasing international collaboration is a prerequisite for success:**

→ links with science, research & development and **high-tech industry** will be essential to further advance and prepare the implementation of the FCC

→ Next step is preparation of a plan with national laboratories for in-kind contributions to the project

## 38 Participating Countries

Austria – Belgium – Brazil – Canada – Chile –  
Colombia – Czech Republic – Denmark – Estonia –  
Finland – France – Georgia – Germany – Greece –  
Hungary – India – Iran – Italy – Japan – Latvia – Malta –  
Mexico – Netherlands – Norway – Pakistan – Poland –  
Portugal – Republic of Korea – Romania – Serbia –  
Spain – Sweden – Switzerland – Thailand – Türkiye –  
Ukraine – United Kingdom – United States of America

162  
Institutes

38  
Countries  
+  
CERN



FUTURE  
CIRCULAR  
COLLIDER  
*Feasibility Study*



8-12 June  
**FCC  
WEEK**  
2026

Helsinki  
Finland  
Venue: Fabianinkatu 33  
University of Helsinki  
Main Building

**Next FCC collaboration meeting  
is the FCC WEEK 2026,  
8 – 12 June in Helsinki, Finland**

**Entire community is invited  
and welcome to participate!**

# Progress and support towards funding

Statements of intent to collaborate with CERN on construction and exploitation of FCC-ee, signed with US and with Canada.



26 April 2024

White House Office of Science and Technology Policy Principal Deputy U.S. Chief Technology Officer Deirdre Mulligan signed for the United States while Director-General Fabiola Gianotti signed for CERN.



9 April 2025

CERN Director-General, Fabiola Gianotti, and His Excellency Mr Patrick Wittmann, Ambassador of Canada to Switzerland and Liechtenstein, exchanging signed copies of the joint Statement of Intent between CERN and Canada.

Strong support from European Union expressed in the recent EU Competitiveness Report stating inter alia that

*“One of CERN’s most promising current projects, with significant scientific potential, is the construction of the Future Circular Collider... ..Refinancing CERN and ensuring its continued global leadership in frontier research should be regarded as a top EU priority”*



*“I am proud that we have financed the feasibility study for CERN’s Future Circular Collider (FCC)...”*

Ursula von der Leyen, President of the European Commission, during CERN 70 anniversary celebrations

**For 2028-2034 budget plan, a 3 BEuro budget line for FCC is proposed by the European Commission, to be approved by European Parliament in 2027.**

**Objective:** ambitious technology driven projects that boost the EU's strategic autonomy through research, development and deployment.

## Moonshots



### Future Circular Collider

**What:** Sustain Europe's leadership in particle physics by investing in CERN's next-generation collider.

**How:** Co-invest with other CERN countries, leveraging Horizon Europe funding.



### Clean Aviation

**What:** Lead the world in developing the next generation of CO<sub>2</sub>-free aircraft.

**How:** Bring together industry and scientific capacities to achieve breakthroughs in clean aviation.



### Quantum Computing

**What:** Make Europe the first continent with fully integrated quantum computing in daily life.

**How:** Develop applications from medicine to climate, solving previously impossible problems for 450 million citizens.



### Next Generation AI

**What:** Model the new AI on the laws of nature and grounded in physics and biology.

**How:** AI developed by, with, and for European scientists and industry, drawing to Europe the world's best minds.



### Data Sovereignty

**What:** Make Europe the global leader and safest hub for critical research data.

**How:** Provide access to critical data for researchers, universities and companies, offering competitive advantage in tackling global challenges.



### Automated Transport and Mobility

**What:** Advance safe, inclusive, and emission-reducing automated transport and mobility in Europe.

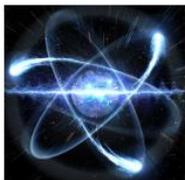
**How:** Invest in smart transport systems to improve traffic, reduce emissions, and enhance access.



### Regenerative Therapies

**What:** Deliver breakthrough therapies to improve people's health and lives.

**How:** Harness Europe's scientific strengths to treat incurable diseases and personalise medicine.



### Fusion Energy

**What:** The first commercial nuclear fusion power plant, generating safe, consistent, and reliable electricity.

**How:** Overcome the scientific and technological challenges necessary to put fusion on the grid in Europe by 2034.



### Space Economy

**What:** Make Europe the leader in the space economy.

**How:** Develop the next generation launch vehicles such as reusable rockets, able to deploy massive cargo by 2040.



### Zero Water Pollution

**What:** Move towards zero pollution of water in the EU.

**How:** Stimulate innovation to build a true water-smart economy which secures sufficient, clean and affordable water and sanitation to all at all times.



### Ocean Observation

**What:** Achieving strategic autonomy in ocean observation infrastructure, data and information services.

**How:** Developing, connecting, governing and securing the next generation of European ocean observing technologies

# ESG recommendation for preferred option for next flagship collider at CERN

The electron–positron Future Circular Collider (FCC-ee) is recommended as the preferred option for the next flagship collider at CERN.

## Motivation:

- ❑ it would deliver the world's broadest high-precision particle physics programme; outstanding discovery potential through Higgs, electroweak, flavour and top sectors, as well as advances in QCD → it's the most competitive of all options
- ❑ technical feasibility demonstrated by comprehensive FCC Feasibility Study
- ❑ scope and cost are well defined
- ❑ plausible funding scenarios have been developed
- ❑ its schedule enables first beams within 5-7 years after the end of HL-LHC operation
- ❑ it would pave the way towards a hadron collider reusing the tunnel and much of the infrastructure, providing direct discovery reach well beyond the 10++ TeV parton energy scale, in line with the community's ambition for exploration at the highest achievable energy.

A descoped FCC-ee is the preferred alternative option for the next flagship collider at CERN.

*“Although this would have a significant impact on the breadth of the physics programme and the precision achieved, the descoped FCC-ee would still provide a very strong physics programme and a viable path towards high energies, compared to the alternative collider options. Should additional resources become available, these descoping scenarios would be reversible.”*

*“Several other alternative options, listed here in alphabetical order, were also assessed. They offer substantially reduced precision physics programmes and would not be competitive with a collider like the FCC-ee. Moreover, in themselves, they currently lack a viable path towards energies of 10 TeV. At this stage, without knowing the reasons for which the FCC-ee would not be feasible, the other alternative options are not ranked.”*

# CERN Council review of the FCC Feasibility Study

- **7-9 July 2025:** Final reviews by the FCC Feasibility Study **Scientific Advisory Committee (SAC)**, chaired by A. Parker (Cambridge U.), and by the **FCC Cost Review Panel (CRP)**, chaired by N. Holtkamp (Stanford)
- **8-10 September 2025:** Reviews by CERN **Finance Committee (FC)** and **Scientific Policy Committee (SPC)**
- **6-7 November 2025:** **CERN Council** dedicated session on FCC Feasibility Study, **Conclusions:**

The Council, being committed to maintaining CERN as a world leader in science and technology:

.... congratulates the CERN Management and all the personnel involved in the FCC Feasibility Study....

.... considers that the FCC would provide the platform for a visionary physics programme addressing many of the open questions in particle physics,... and concludes that:

**a. the FCC Feasibility Study provides the basis for the FCC studies to continue and**

**b. the funding scenarios presented and the financial pledges obtained so far provide the basis for the continuation ...towards securing the full financial commitments required for approval of the FCC project.**

# Recent CERN press releases

## **The European Strategy for Particle Physics reaches an important milestone**

Geneva, 12 December 2025. At its 225th session, the CERN Council received the recommendations for the update of the European Strategy for Particle Physics, the aim of which is to develop a common vision for the future of the field. The recommendations will be reviewed by the Council in the coming months. A final decision is expected at a dedicated Council Session in Budapest in May 2026.

For the 2026 update of the ESPP, the CERN Council requested that the Strategy update should include the preferred option for the next collider at CERN and prioritised alternative options to be pursued if the chosen preferred plan turns out not to be feasible or competitive. ....

The electron–positron Future Circular Collider (FCC-ee) is recommended as the preferred option for the next flagship collider at CERN....

The ESG presents a descoped FCC-ee as the preferred alternative option for the next flagship collider at CERN.

A decision by the CERN Council on the possible construction of the FCC is expected around 2028.

## **Private donors pledge 860 million euros for CERN's Future Circular Collider**

Geneva, 18 December 2025. For the first time in CERN's history, private donors (individuals and philanthropic foundations) have agreed to support a CERN flagship research project. Recently, a group of friends of CERN, including the Breakthrough Prize Foundation, The Eric and Wendy Schmidt Fund for Strategic Innovation, and the entrepreneurs John Elkann and Xavier Niel, have pledged significant funds towards the construction of the Future Circular Collider (FCC), the potential successor of the Large Hadron Collider (LHC). These potential contributions, totalling some 860 million euros and corresponding to 1 billion US dollars, would represent a major private sector investment in the advancement of research in fundamental physics.

# FCC considerations on organisation

## The key points from the European Strategy Group report regarding FCC:

- Strong endorsement of the physics and strategic case for FCC-ee as the next flagship collider for CERN
  - Near consensus on this point within the particle physics communities in CERN's Member States
- A descoped/staged FCC is preferred to other options as an alternative

## The further development of FCC-ee will be CERN's **clear second highest scientific priority for 2026-2030 after HL-LHC**

- The goal remains to take FCC-ee to CERN Council in 2028, hopefully for a positive decision

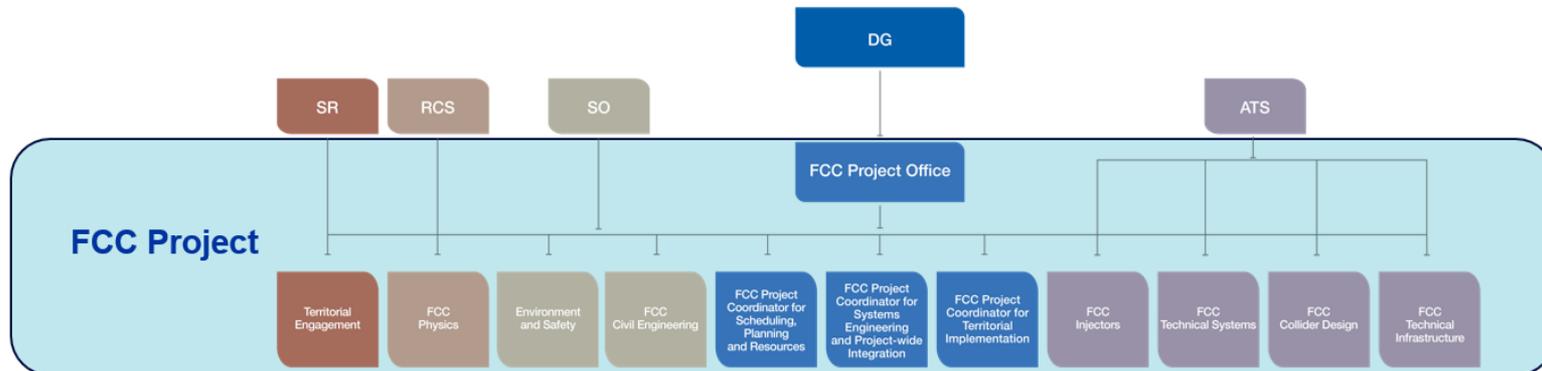
## FCC Organisation 2026-2030

- We will establish a new compact FCC Project Office to coordinate the FCC-ee activities
- Reporting directly to the D-G
- The delivery of the FCC activities within CERN will be embedded in CERN's sectors in a *traditional* "CERN matrixed" project structure
- With the overall project being defined and coordinated through the FCC Project Office

# FCC project structure

## How this might look in practice *(to be confirmed)*

Mark Thomson



**This change is a significant step that I believe is essential for the next phase in progressing FCC as CERN's next flagship project**

- There is a lot to do, but I am confident the PO team and colleagues across CERN can deliver
- We will also need to continue to develop international partnerships
- Again I would like to thank colleagues for their patience during this transitional period

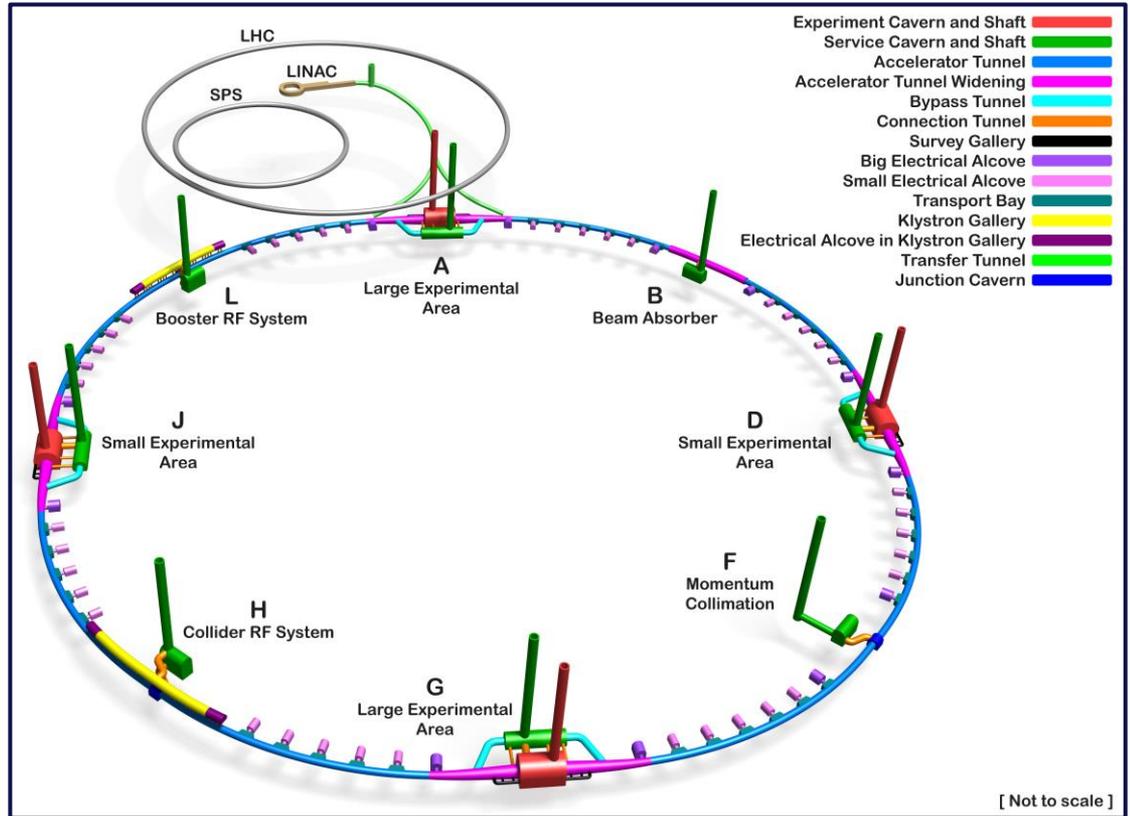
# Conclusions

- The technical part of the FCC Feasibility Study has been concluded with the submission of the **Feasibility Study Report** to the ESPP **end March 2025**
- A coherent baseline design for the FCC integrated programme has been developed, including a **well-advanced territorial implementation scenario**, in line with desired CE construction start by 2033.
- In December 2025, FCC FS successfully passed CERN Council review, and **ESG recommended FCC-ee** as the preferred option for the next flagship collider at CERN.
- FCC-ee design level enables moving towards technical design and prototyping phase, well aligned with overall schedule and towards preparing **input for potential project decision by 2028**.

***spare slides***

# Key features of the Underground Civil Engineering Baseline

- Tunnel Circumference: 90.7 km
- Excavated volume: 6.25 Mm<sup>3</sup> (*in-situ*)
- Access shafts: 12
- Construction shafts: 1
- Large experiment sites: 2
- Small experiment sites: 2
- Technical sites: 4
- Deepest shaft: 400m
- Average shaft depth: 243m
- Total concrete volume: 2 M m<sup>3</sup>



Schematic of FCC-ee Baseline Underground Civil Engineering

# Preliminary Results SSI1 Campaign Results

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- Section JURA** → Top of the limestone has not been encountered in 3 of the 11 boreholes that have so far been completed. Remaining boreholes will be completed by September 2026.
- Section MANDALLAZ** → Characterisation of the limestone on and above the tunnel alignment in the Mandallaz area. A few karsts were found but none where very large nor water-bearing.
- Section USSES** }  
**Section RHONE** } → Top of molasse found slightly higher than originally modelled in zones where tunnel is closest to the surface
- Section LAKE** → Top of the molasse in first borehole found at around the modelled depth. Results pending other 3 boreholes in 2026
- Section ARVE** → Top of the molasse found slightly higher the modelled depth
- Section VUACHE** → Limestone was not encountered and the molasse extends deeper than originally modelled

It is expected that it will be possible to maintain the tunnel in the Molasse other than in the Mandallaz area. However last Lake and Jura boreholes needed to confirm this and to allow a final refinement of the tunnel elevation and tilt.

# FCC-ee: detailed machine parameters

F. Gianotti

Parameter	Z	WW	H (ZH)	ttbar
beam energy [GeV]	45.6	80	120	182.5
beam current [mA]	1270	137	26.7	4.9
number bunches/beam	11200	1780	440	60
bunch intensity [ $10^{11}$ ]	2.14	1.45	1.15	1.55
SR energy loss / turn [GeV]	0.0394	0.374	1.89	10.4
total RF voltage 400/800 MHz [GV]	0.120/0	1.0/0	2.1/0	2.1/9.4
long. damping time [turns]	1158	215	64	18
horizontal beta* [m]	0.11	0.2	0.24	1.0
vertical beta* [mm]	0.7	1.0	1.0	1.6
horizontal geometric emittance [nm]	0.71	2.17	0.71	1.59
vertical geom. emittance [pm]	1.9	2.2	1.4	1.6
horizontal rms IP spot size [ $\mu\text{m}$ ]	9	21	13	40
vertical rms IP spot size [nm]	36	47	40	51
beam-beam parameter $\xi_x / \xi_y$	0.002/0.0973	0.013/0.128	0.010/0.088	0.073/0.134
rms bunch length with SR / BS [mm]	5.6 / 15.5	3.5 / 5.4	3.4 / 4.7	1.8 / 2.2
luminosity per IP [ $10^{34} \text{ cm}^{-2}\text{s}^{-1}$ ]	140	20	5.0	1.25
total integrated luminosity / IP / year [ $\text{ab}^{-1}/\text{yr}$ ]	17	2.4	0.6	0.15
beam lifetime rad Bhabha + BS [min]	15	12	12	11

4 years  
 $5 \times 10^{12}$  Z  
 $\text{LEP} \times 10^5$

2 years  
 $> 10^8$  WW  
 $\text{LEP} \times 10^4$

3 years  
 $2 \times 10^6$  H

5 years  
 $2 \times 10^6$  tt pairs

- x 10-50 improvements on all EW observables
- up to x 10 improvement on Higgs coupling (model-indep.) measurements over HL-LHC
- x10 Belle II statistics for b, c,  $\tau$
- indirect discovery potential up to ~ 70 TeV
- direct discovery potential for feebly-interacting particles over 5-100 GeV mass range

Up to 4 interaction points  $\rightarrow$  robustness, statistics, possibility of specialised detectors to maximise physics output

# FCC-hh injector options

- 1) superconducting machine in the SPS tunnel (scSPS)
- 2) modified faster-ramping LHC
- 3) new 4 T machine in the LHC tunnel
- 4) 2 T superferric machine in the LHC tunnel (1.75 TeV, not shown in the table)

	unit	scSPS	modif. LHC	4 T LHC
circumference	km	6.8	26.7	26.7
#apertures		1	2	1
injection energy	GeV	26	450	450
extraction energy	TeV	1.3	3.3	3.3
injection field	T	0.12	0.6	0.6
maximum field	T	6	6	6
energy/field swing		50	7	7
#dipoles		372	1232	1232
#bunches		640	2600	2600
stored energy	MJ	15	167	167
collider filling time	min	37	46	39

# ESG Summary Table, Dec 2026

Machine	Precision Physics	BSM physics	Phys vs CEPC	Tech readiness	Const. cost (GCHF)	Path to $\geq 10$ TeV
FCC-ee	22	23			15.3	
LCF250/ LCF550	15	17			14.8	
CLIC380/ CLIC1500	14	18			14.6	
LCF250	10	16			9.4	
CLIC380	10	16			7.5	
LEP3	14	17			4.1	
LHeC	8	7			2.1	

# FCC-ee construction schedule

Activity	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62		
Environmental evaluation & project authorisation processes	█	█	█	█	█	█																																	
Technical design accelerator			█	█	█	█	█																																
Civil engineering design and tendering			█	█	█	█	█																																
<b>Project decision</b>			📍																																				
Injector construction							█	█	█	█	█	█	█	█	█	█																							
<b>Start of subsurface constructions</b>							📍																																
Subsurface civil construction							█	█	█	█	█	█	█	█	█	█																							
Technical infrastructures installation													█	█	█	█	█	█																					
Accelerator installation																	█	█	█	█	█																		
Hardware commissioning																		█	█	█	█	█																	
Beam commissioning																																							
Lower intensity beam operation (Z pole)																																							
Z pole operation																																							
WW operation																																							
HZ operation																																							
Upgrade for ttbar																																							
ttbar operation																																							

- **2028** assumed project approval by CERN Council
- **01/2033 – 06/2041** CE construction work
- **07/2039 – 12/2043** technical infrastructure installation
- **07/2041 – 06/2045** accelerator installation
- **07/2046** start of beam commissioning and operation
- **01/2048** nominal beam operation

# Operation modes for RF

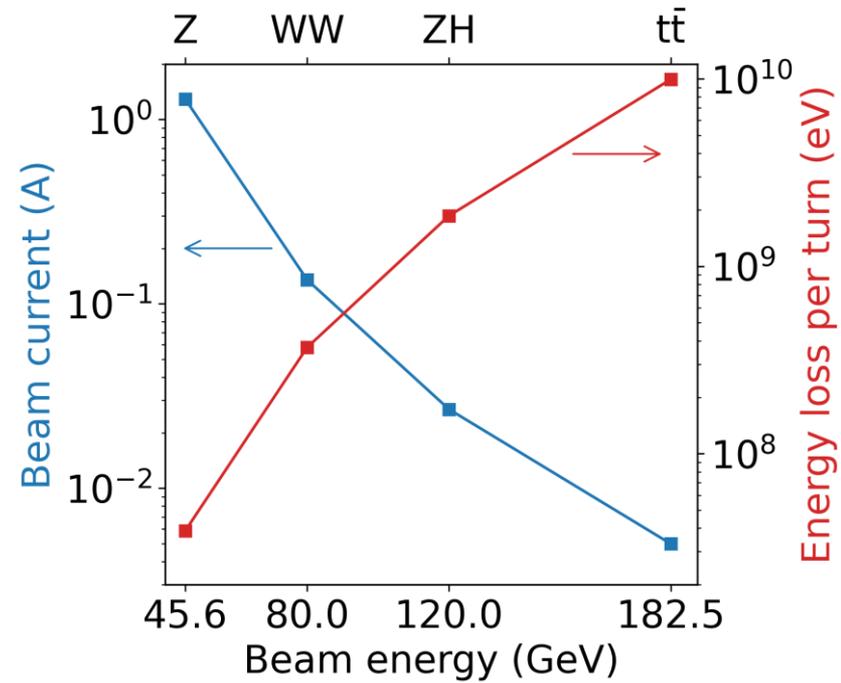
- Physics at 4 different energy points:  
 $Z^0$ ,  $W^+W^-$ , Higgs (ZH), t-tbar production
- Same SR power for all 4 modes  
 $P_{SR} = 50 \text{ MW}$  per beam

## Lowest energy:

- Low RF voltage
  - High beam current
- ↓
- Few cavities
  - Low voltage per cavity
  - **High power** per cavity
  - Significant HOM power
  - Instabilities
- ↓
- 1- or 2-cell cavities at low RF frequency (400MHz)

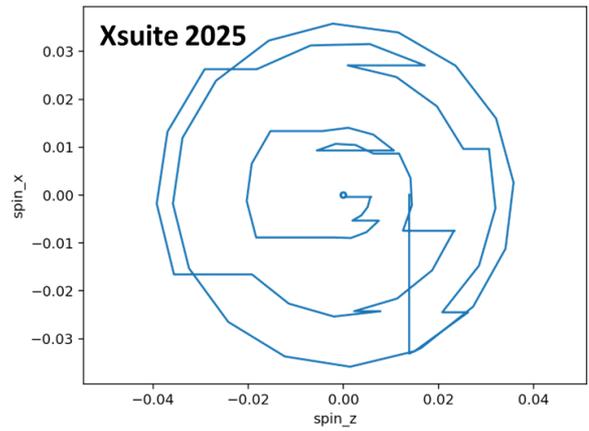
## Highest energy:

- High RF voltage
  - Low beam current
- ↓
- Many cavities
  - **High voltage** per cavity
  - Low power per cavity
  - Low HOM power
  - High SR damping
- ↓
- Multi-cell cavities at higher RF frequency (800MHz)

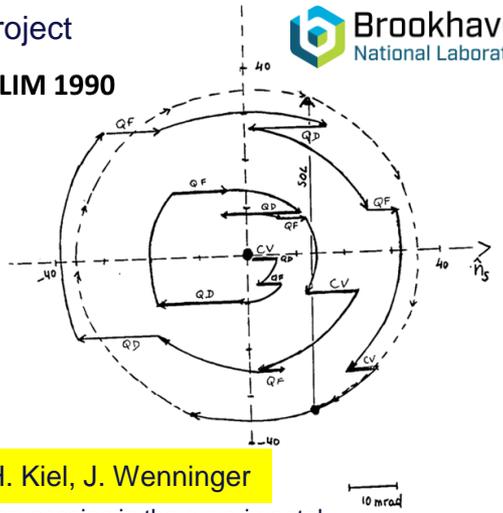


# examples of other FCC-ee optics and beam dynamics activities

spin tracking collaboration with BNL EIC project

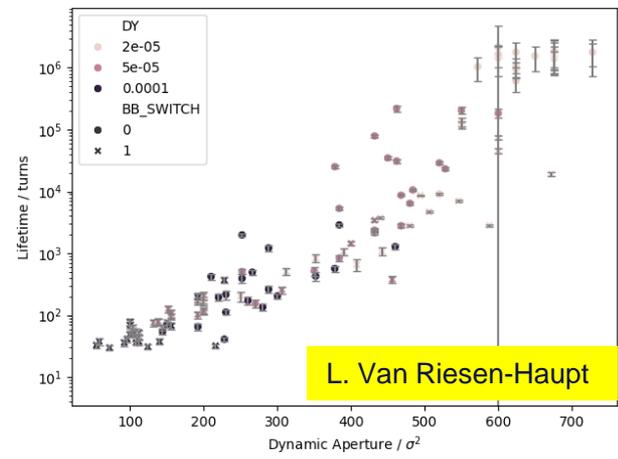


SLIM 1990



H. Kiel, J. Wenninger

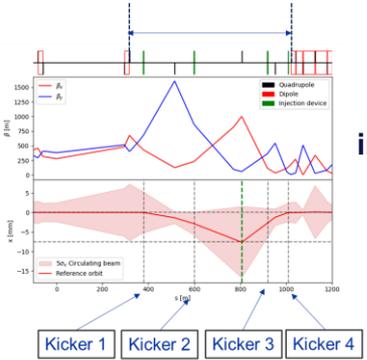
beam-beam interaction & sextupole alignment → dynamic aperture and beam lifetime - correlation



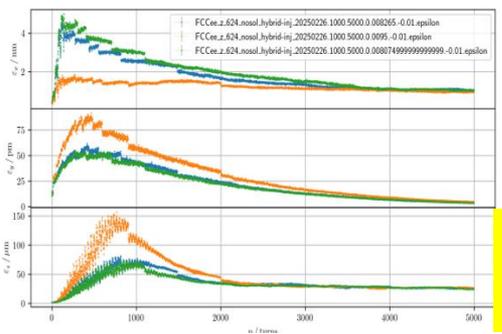
L. Van Riesen-Haupt

benchmarking case of LEP1 with orbit bumps to compensate precession in the experimental solenoids; good agreement with classical SLIM simulations

top-up on-axis & off-axis injection studies

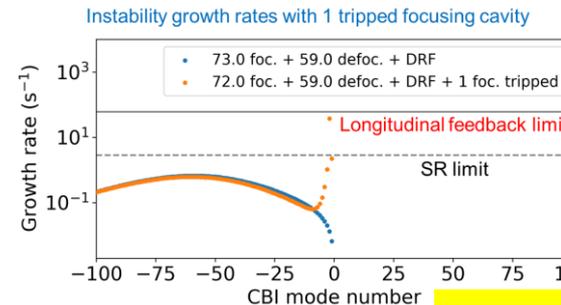


top-up hybrid injection studies



Y. Duteuil, S. Yue, T. Mori

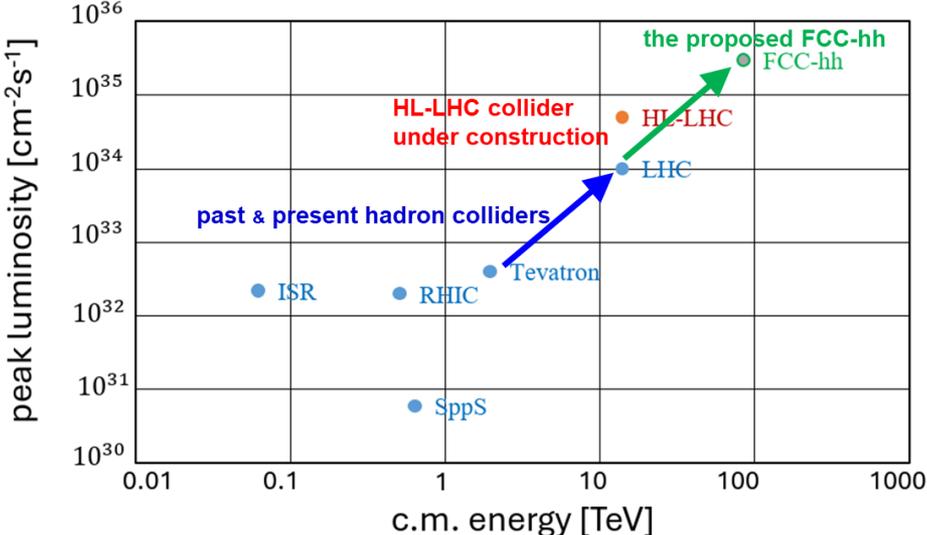
cavity trip in RPO scheme



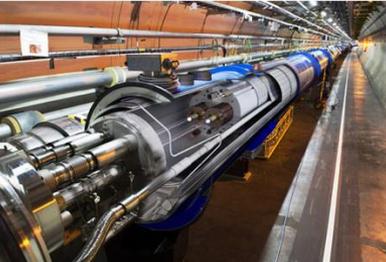
I. Karpov

# FCC-hh: highest collision energies

- order of magnitude performance increase in both energy & luminosity
- 20 ab<sup>-1</sup> per experiment collected over 25 years of operation (vs 3 ab<sup>-1</sup> 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<sub>3</sub>Sn quadrupole



FNAL dipole demonstrator 4-layer cos $\theta$  14.5 T Nb<sub>3</sub>Sn in 2019

# SuperKEKB as FCC-ee demonstrator

- an ultralow  $\beta_y^* \sim 0.8\text{--}1.0\text{ mm}^\dagger$ ,
- the virtual crab waist collision scheme,
- electron and positron beam currents exceeding 1.3 A

## challenges encountered:

- sudden beam loss (being addressed)
- stored beam vertical emittance ( $\sim 10x$  design)
- **injected vertical beam emittance ( $\sim 1000x$  the design stored beam emittance)**
- injection efficiency (large inj. emittance & physical+dynamics aperture)
- interaction region (highly complex source of IP aberrations)
- IP beta  $\beta_y^*$  (limited by injected beam emittance, IR aperture, DA)
- specific luminosity (linear & chromatic coupling, design lattice, optics errors, space charge, impedance, feedback/noise,...)
- limited number of experts



# SuperKEKB injected beam emittance

N. Iida

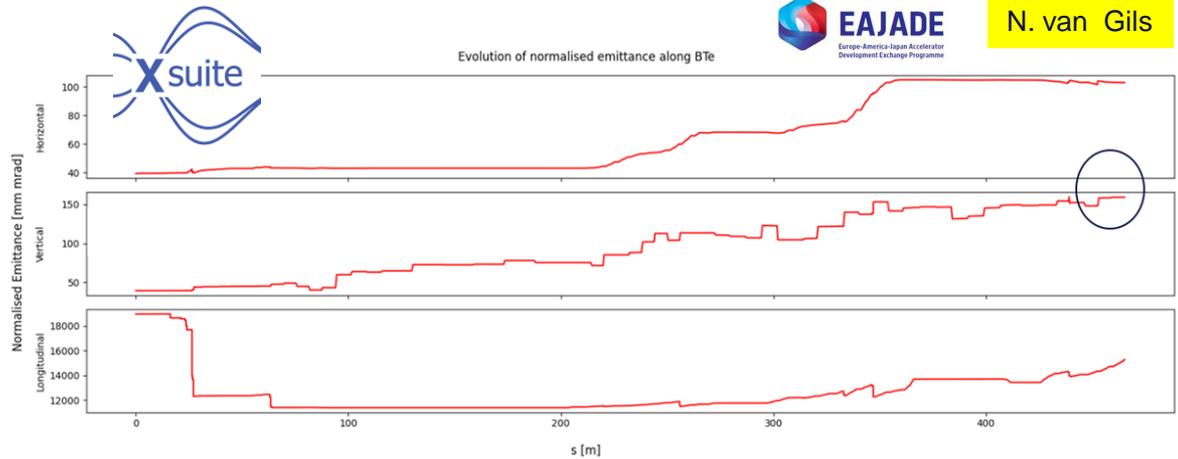
$e^+$	BT1	BT2	$e^-$	BT1	BT2
$\gamma\epsilon_x$	$110 \pm 10 \mu\text{m}$	$169 \pm 16 \mu\text{m}$	$\gamma\epsilon_x$	$39.2 \pm 9.6 \mu\text{m}$	$142 \pm 37 \mu\text{m}$
$\gamma\epsilon_y$	$10.5 \pm 4.0 \mu\text{m}$	$81 \pm 20 \mu\text{m}$	$\gamma\epsilon_y$	$42.5 \pm 7.7 \mu\text{m}$	$136 \pm 22 \mu\text{m}$

$\gamma\epsilon = 100 \mu\text{m} \leftrightarrow \epsilon = 13 \text{ nm}$

$\gamma\epsilon = 100 \mu\text{m} \leftrightarrow \epsilon = 7 \text{ nm}$

emittance growth in the beam transport lines of the SuperKEKB injector measured in 2024

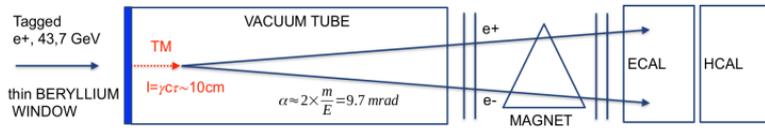
both **horizontal and vertical emittance growth** in BTe reproduced in **Xsuite** simulations with  $100 \mu\text{m}$  rms random quad misalignments



possible mitigations? → survey & realignment, dispersion-free steering

# producing true muonium – a world’s first !?!

assuming  $\Delta E \sim 44$  MeV, one can expect to produce around 1 TM atom per  $4.4 \times 10^{13}$  positrons.

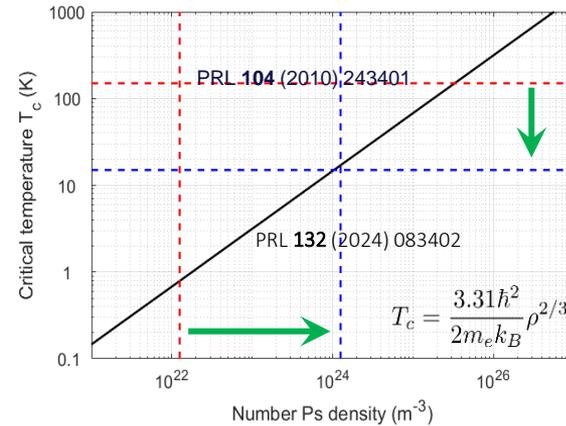


Simplified layout of the experimental set-up

with estimated rates the properties of the bound state could be studied

# Bose-Einstein condensate of Ps – also world’s first

A positronium density of  $10^{15} \text{mm}^{-3}$  is necessary for forming a BEC. Current  $e^+$  sources cannot reach that !



When a Ps-BEC annihilates, a coherent burst of gamma rays is emitted.

A proposed way to build a 511 keV gamma ray laser!

# FCC-ee cost estimate (FSR 2025)

Capital cost (2024 CHF) for construction of the FCC-ee is summarised below. This cost includes construction of the entire new infrastructure and all equipment for operation at the Z, WW and ZH working points.

Domain	Cost [MCHF]
Civil engineering	6,160
Technical infrastructures	2,840
Injectors and transfer lines	590
Booster and collider	4,140
CERN contribution to four experiments	290
<b>FCC-ee total</b>	<b>14,020</b>
+ four experiments (non-CERN part)	1,300
<b>FCC-ee total incl. four experiments</b>	<b>15,320</b>

Note: Upgrade of SRF (800 MHz) & cryogenics for  $t\bar{t}$  operation corresponds to additional cost of 1,260 MCHF.