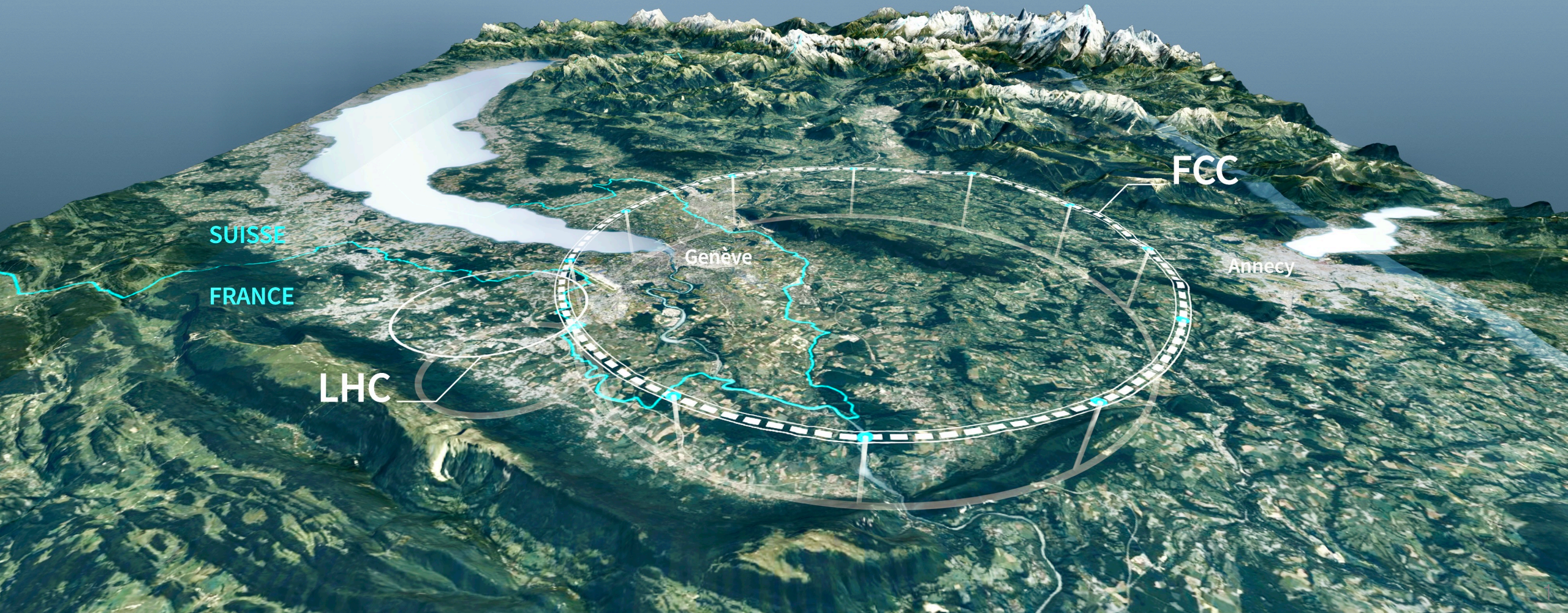


Future Circular Collider (FCC)

Europe's Next-Generation Flagship Particle Physics Project at CERN

Andreas Hoecker (CERN), Les Rencontres de Noirmoutier, 3 June 2026



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High-energy physics has an environmental footprint driven by high power demands, large-scale infrastructures, and specialised detector technologies

Unlike previous large-scale accelerator projects, sustainability considerations have been integrated into the FCC design from the outset

Sustainability involves *environmental impact*, *economic viability*, and *societal benefit*

In this talk, I will introduce the project and its scientific goals, while highlighting the associated environmental challenges along the way

The European Strategy for Particle Physics



Open Symposium, European Strategy of Particle Physics, 23–27 Jun 2025, Venice Lido [[Link](#)]

The European Strategy for Particle Physics

- Cornerstone of Europe's decision-making process for the long-term future of the field
- Mandated by CERN Council, the Strategy is formed through a broad consultation of the particle physics communities in Europe and worldwide (266 individual and national submissions, 2-year process)
- In the Strategy process, recommendations are developed which are submitted to the CERN Council for an update of the Strategy
- It is *not* a project approval process; projects are approved by the CERN Council through a separate decision process, taking the Strategy recommendations into account

Original Strategy (2006):	LHC, mooting of luminosity upgrade of LHC, R&D in accelerator technologies, coordination with a potential ILC project
1 st Update (2013):	High Luminosity LHC, need for a post-LHC programme
2 nd Update (2020):	FCC feasibility study
3 rd Update (2026):	Recommendation for the next large-scale accelerator project at CERN

The European Strategy for Particle Physics

Main recommendations of the 2026 strategy update

- **The full exploitation of the physics potential of the LHC and the HL-LHC and the completion of the high-luminosity upgrade remain the highest priorities of European particle physics.** Every effort must be made to complete the HL-LHC upgrade within the current schedule
- **The electron–positron Future Circular Collider (FCC-ee) is recommended as the preferred option for the next flagship collider at CERN**
- A descoped FCC-ee* is the preferred alternative option for the next flagship collider at CERN
*No ttbar run: –1.26 BCHF, drop 2 / 4 experiments: –0.80 BCHF, decrease RF power from 50 → 30 MW (–0.35 BCHF)
- **The particle physics community should continue and intensify its efforts to develop and adopt sustainable solutions**
- ...

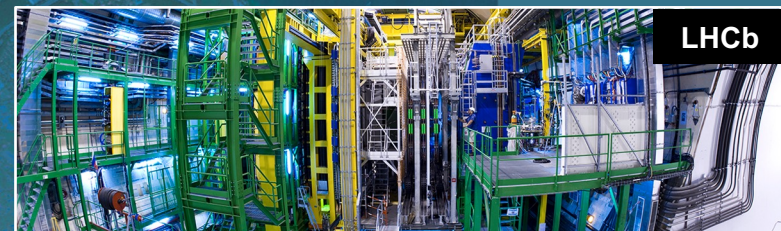
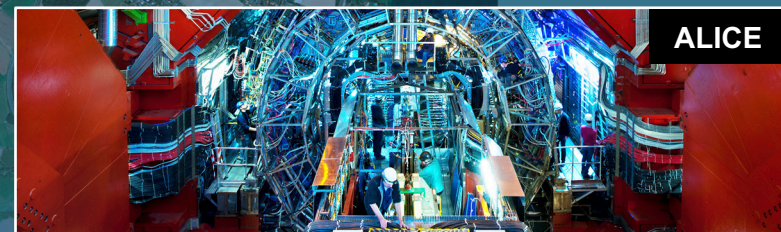
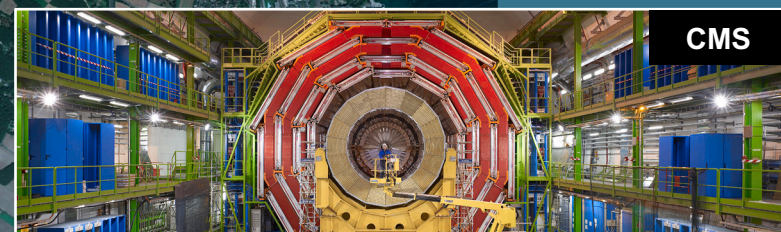
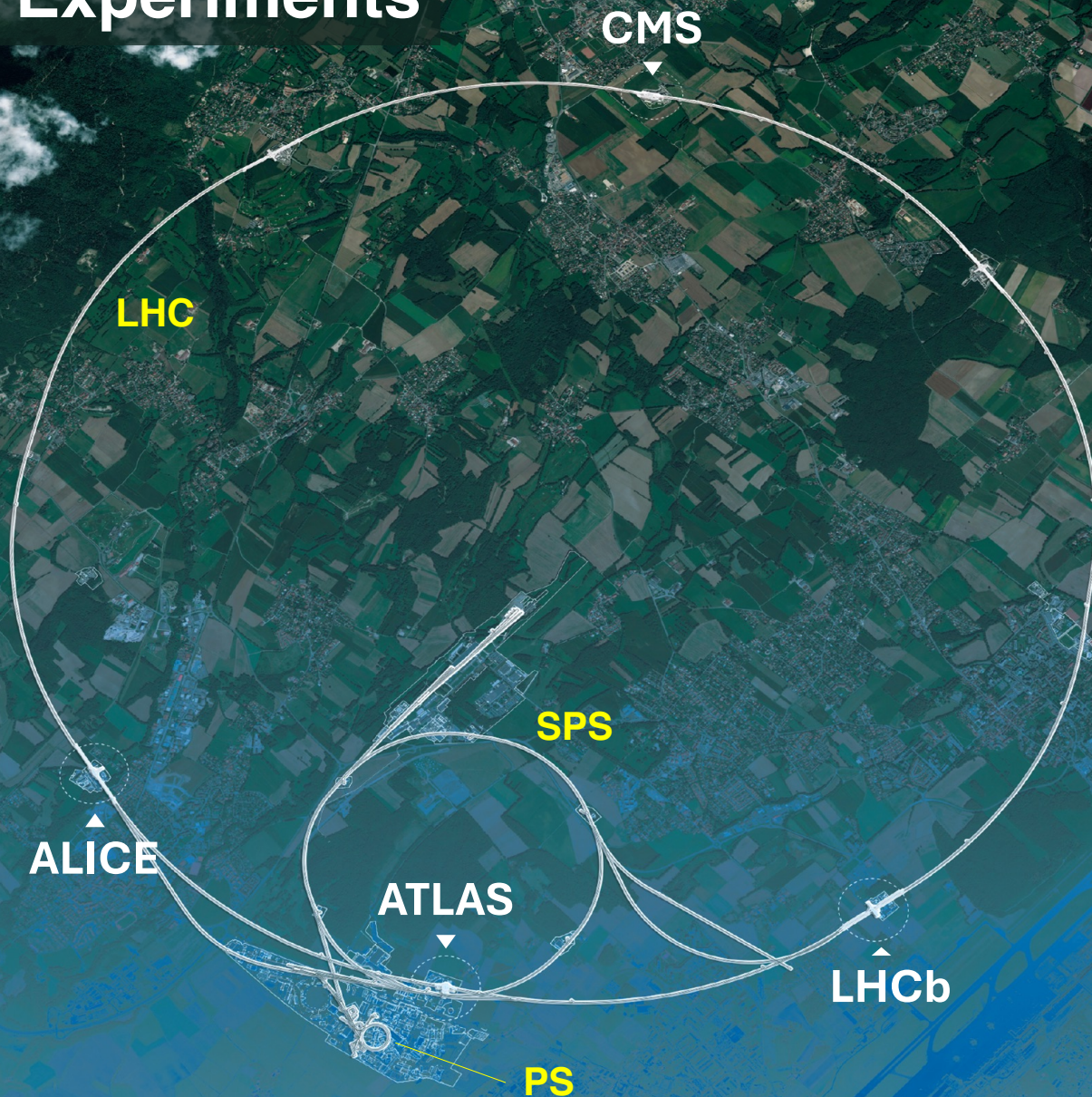
Links: [CERN Council resolution](#), [Recommendations](#), [Briefing book](#), [All documents](#), [More information](#), [CERN Colloquium by Karl Jakobs](#)

Large Hadron Collider (LHC) at CERN: the world's largest accelerator reaching unprecedented energy and intensity



- 27 km underground accelerator and collider
- Superconducting magnets ($1.9\text{ K} = -271.3\text{ }^{\circ}\text{C}$) steer the particles around the ring
- Proton and ions are accelerated to multi-TeV scale energies before they collide

LHC and Experiments



All experiments are global collaborations

Aerial view

LHC and Experiments

LHC

CMS
▼ MilliQan

SPS

ALICE

ATLAS

▼ LHCf

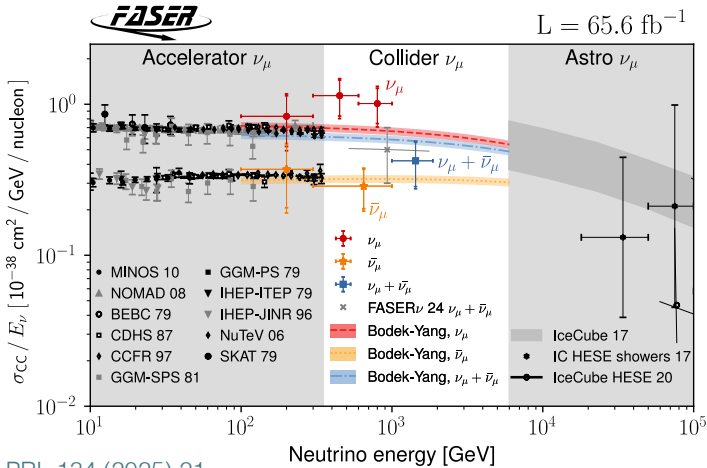
FASER

PS

LHCb
MoEDAL

FASER

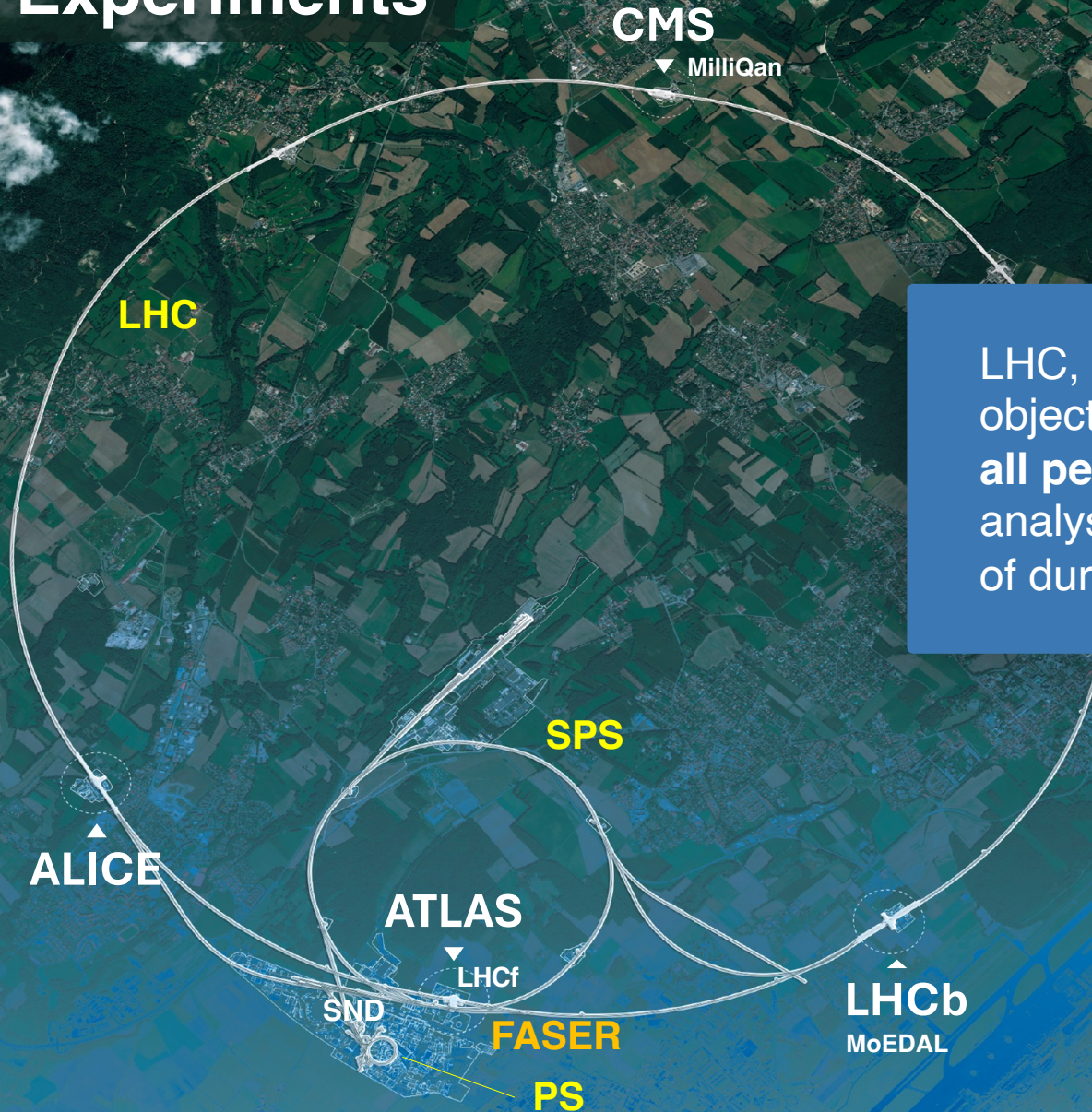
SND@LHC



PRL 134 (2025) 21

Aerial view

LHC and Experiments



LHC, experiments, software & computing, object reconstruction and physics analysis — **all perform beyond design**. Many new analyses ideas emerged that were not thought of during the design phase. ML now ubiquitous

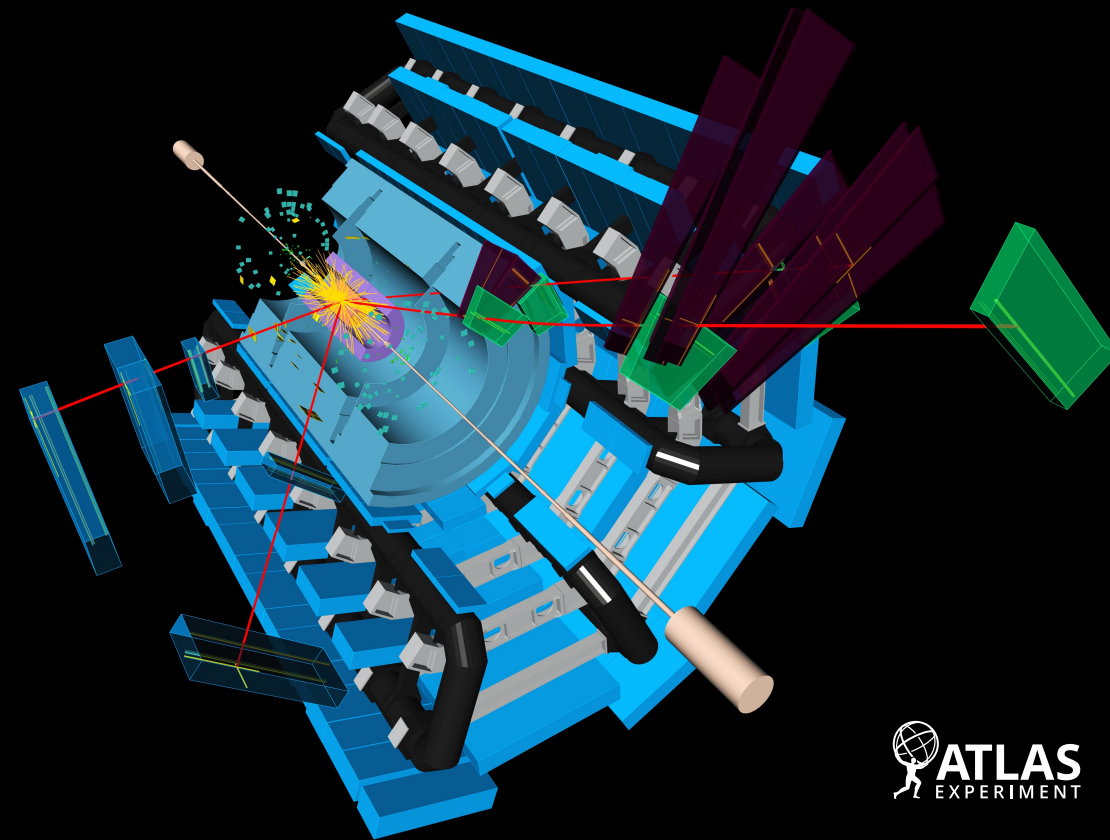
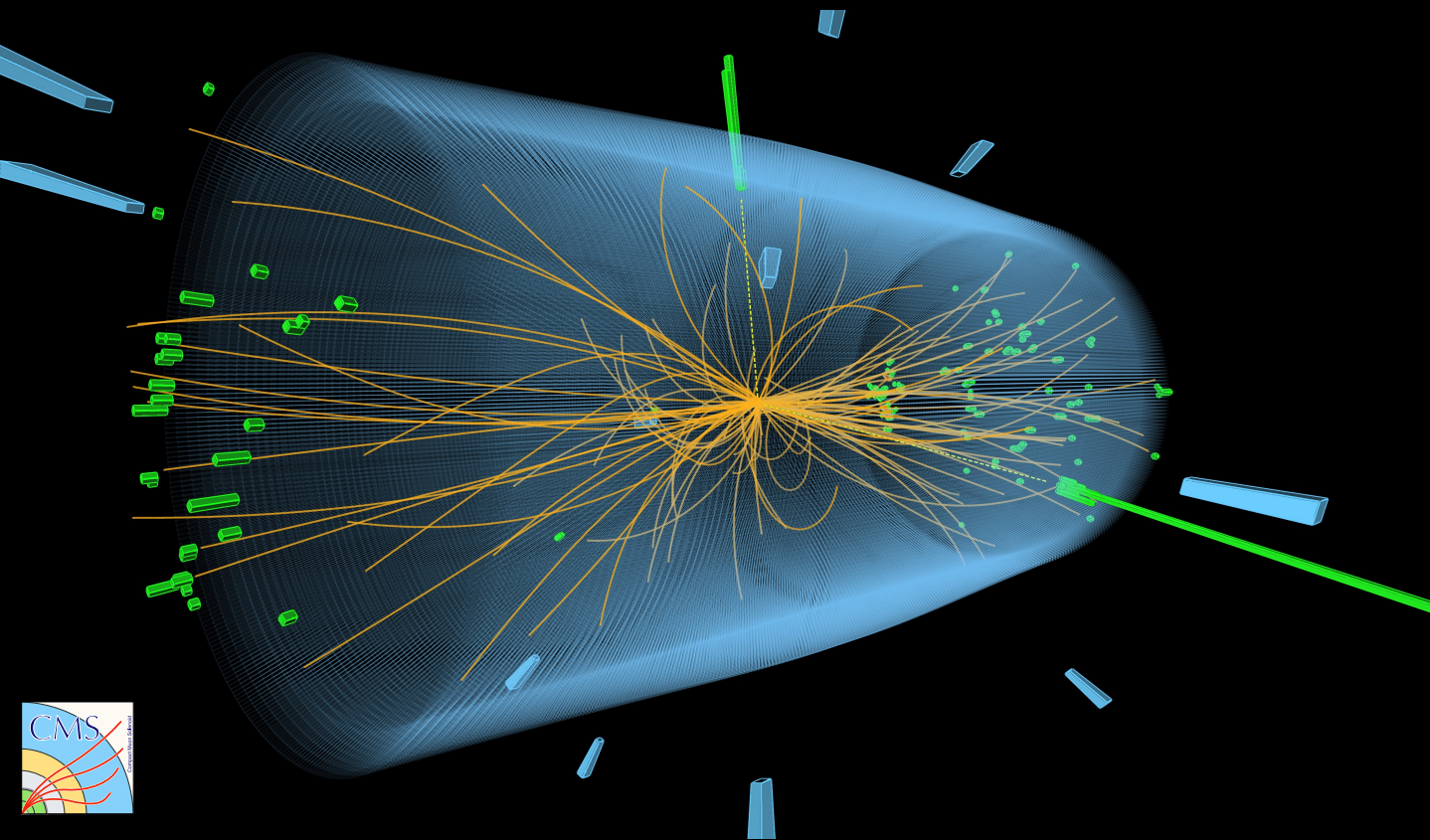
Aerial view

A monumental discovery



Presentation of Higgs boson discovery by ATLAS and CMS at CERN on 4 July 2012

A monumental discovery

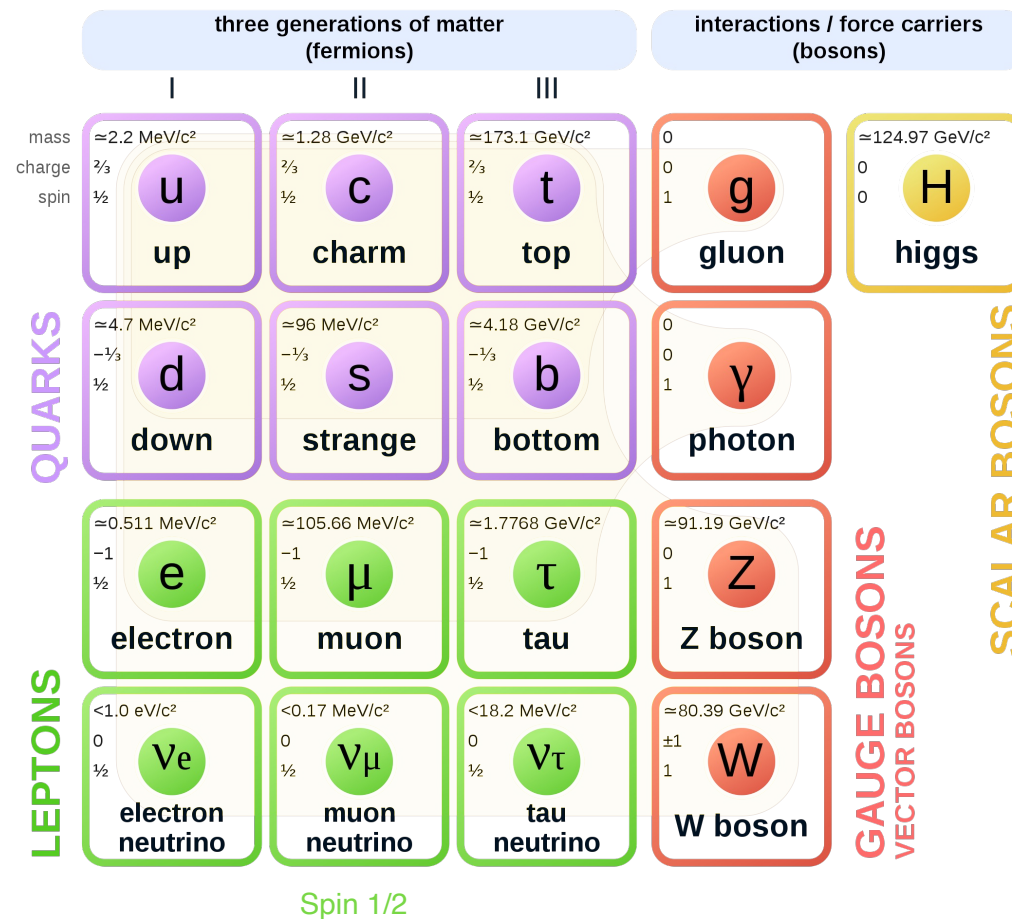


ATLAS
EXPERIMENT

The fundamental universe is profoundly strange

The sub-atomic structure of matter and its interactions is described by the [Standard Model \(SM\)](#)

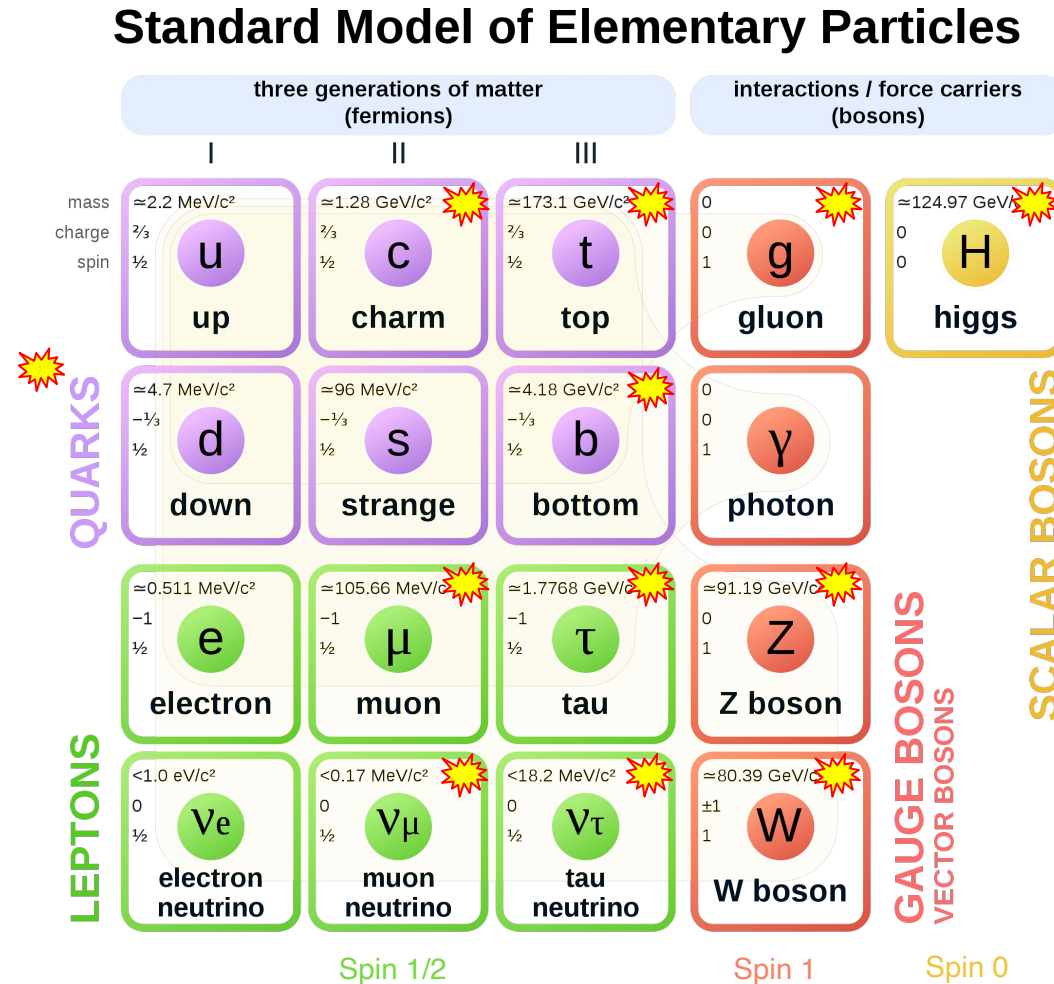
Standard Model of Elementary Particles



The fundamental universe is profoundly strange

The sub-atomic structure of matter and its interactions is described by the **Standard Model (SM)**

☀ Particles discovered through decades of **international, high-technology accelerator-based** research



The fundamental universe is profoundly strange

The sub-atomic structure of matter and its interactions is described by the **Standard Model (SM)**

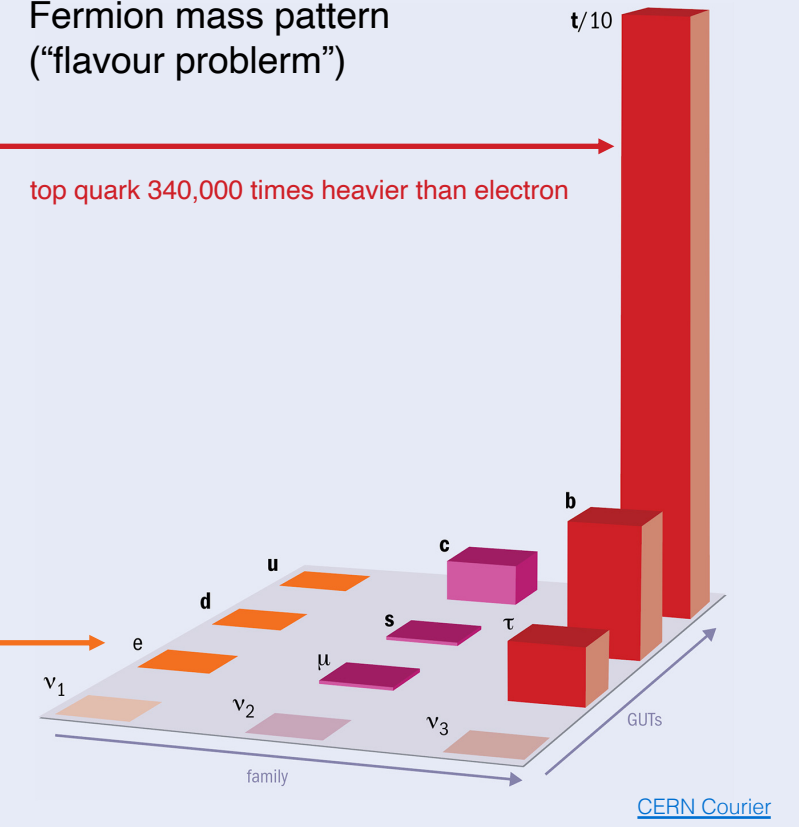
Standard Model of Elementary Particles

three generations of matter (fermions)			
	I	II	III
QUARKS	mass charge spin $\approx 2.2 \text{ MeV}/c^2$ $\frac{2}{3}$ $\frac{1}{2}$ u up	$\approx 1.28 \text{ GeV}/c^2$ $\frac{2}{3}$ $\frac{1}{2}$ c charm	$\approx 173.1 \text{ GeV}/c^2$ $\frac{2}{3}$ $\frac{1}{2}$ t top
	$\approx 4.7 \text{ MeV}/c^2$ $-\frac{1}{3}$ $\frac{1}{2}$ d down	$\approx 96 \text{ MeV}/c^2$ $-\frac{1}{3}$ $\frac{1}{2}$ s strange	$\approx 4.18 \text{ GeV}/c^2$ $-\frac{1}{3}$ $\frac{1}{2}$ b bottom
	$\approx 0.511 \text{ MeV}/c^2$ -1 $\frac{1}{2}$ e electron	$\approx 105.66 \text{ MeV}/c^2$ -1 $\frac{1}{2}$ μ muon	$\approx 1.7768 \text{ GeV}/c^2$ -1 $\frac{1}{2}$ τ tau
LEPTONS	$< 1.0 \text{ eV}/c^2$ 0 $\frac{1}{2}$ ν_e electron neutrino	$< 0.17 \text{ MeV}/c^2$ 0 $\frac{1}{2}$ ν_μ muon neutrino	$< 18.2 \text{ MeV}/c^2$ 0 $\frac{1}{2}$ ν_τ tau neutrino

Spin 1/2

Fermion mass pattern
("flavour problem")

top quark 340,000 times heavier than electron

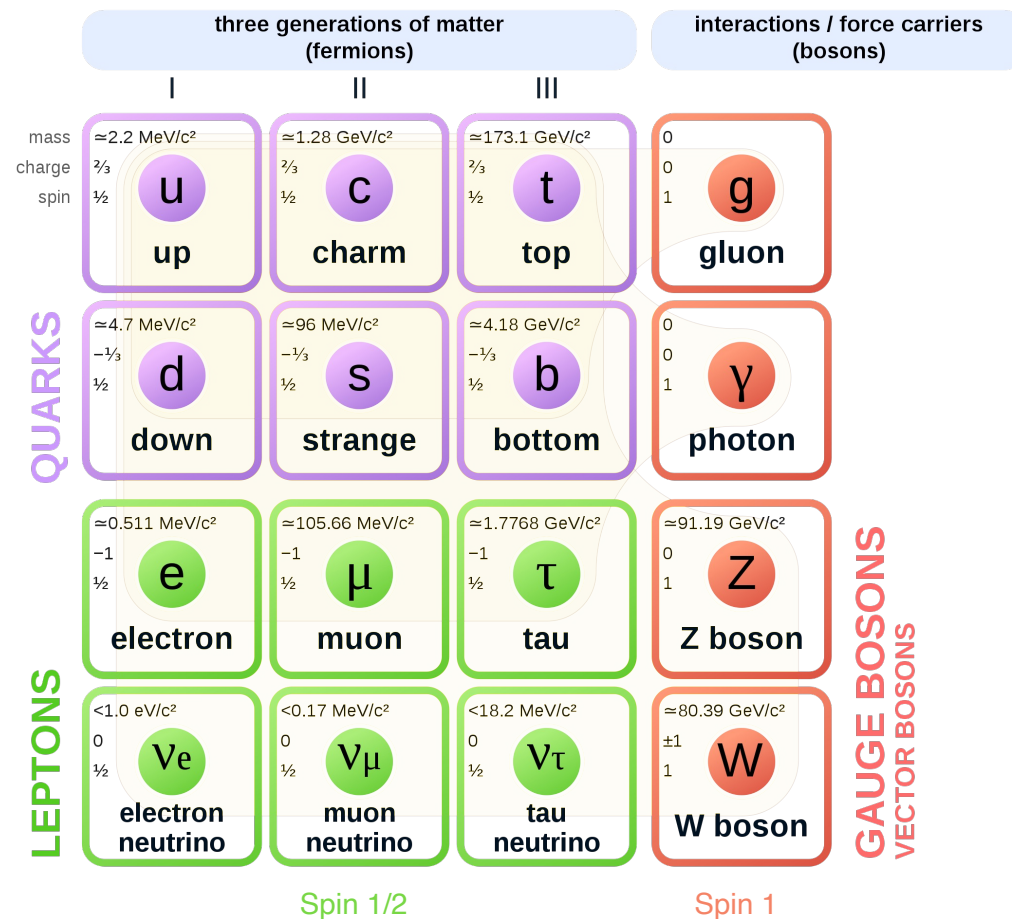


CERN Courier

The fundamental universe is profoundly strange

The sub-atomic structure of matter and its interactions is described by the [Standard Model \(SM\)](#)

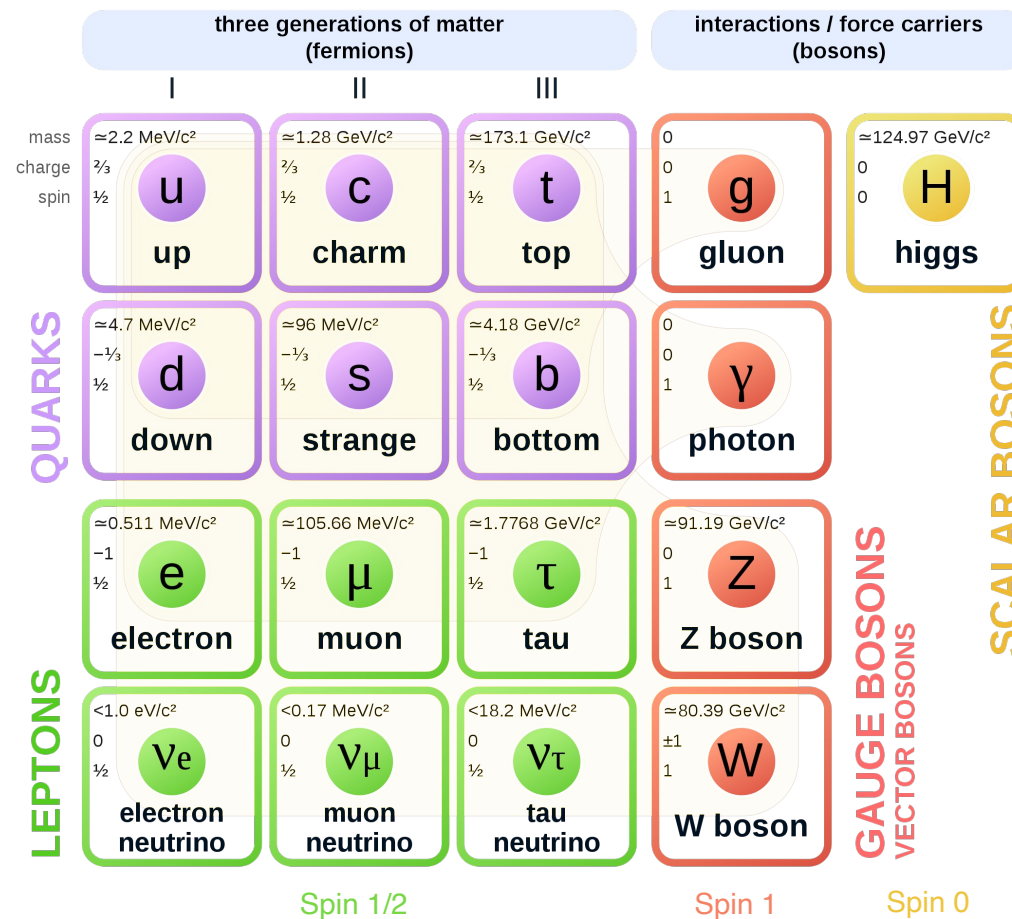
Standard Model of Elementary Particles



The fundamental universe is profoundly strange

The sub-atomic structure of matter and its interactions is described by the **Standard Model (SM)**

Standard Model of Elementary Particles



New kind of interactions, unlike any known force

A manifestation of a vacuum field that gives elementary particles mass according to their coupling strength

The core conceptual challenges of the SM are tied to the Higgs sector (unstable mass)

The Higgs may also hold clues to dark matter, matter–antimatter asymmetry, and physics beyond the SM (eg, is the Higgs boson elementary? Does it have brothers and sisters? ...)

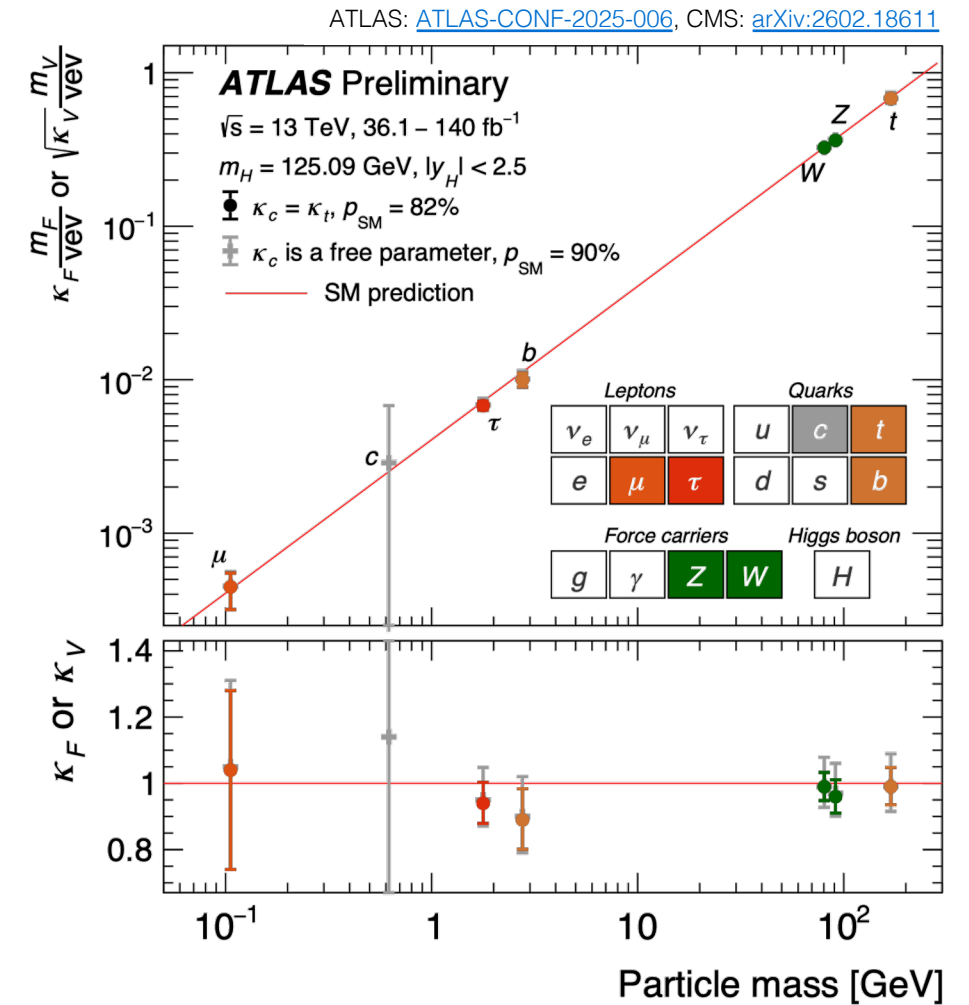
The LHC showed that the Brout-Englert-Higgs mechanism is real

Discovery of Higgs boson enables the direct study of electroweak symmetry breaking and the process of mass generation

$\mathcal{L} = -\frac{1}{4} F_{\mu\nu} F^{\mu\nu} + i\bar{\psi}\not{D}\psi + h.c. + \chi_i y_{ij} \chi_j \phi + h.c. + |D_\mu \phi|^2 - V(\phi) + \dots$

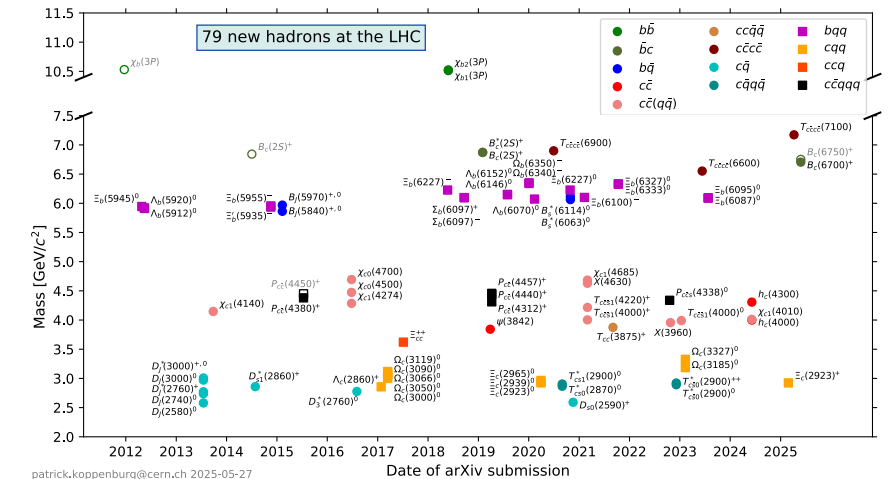
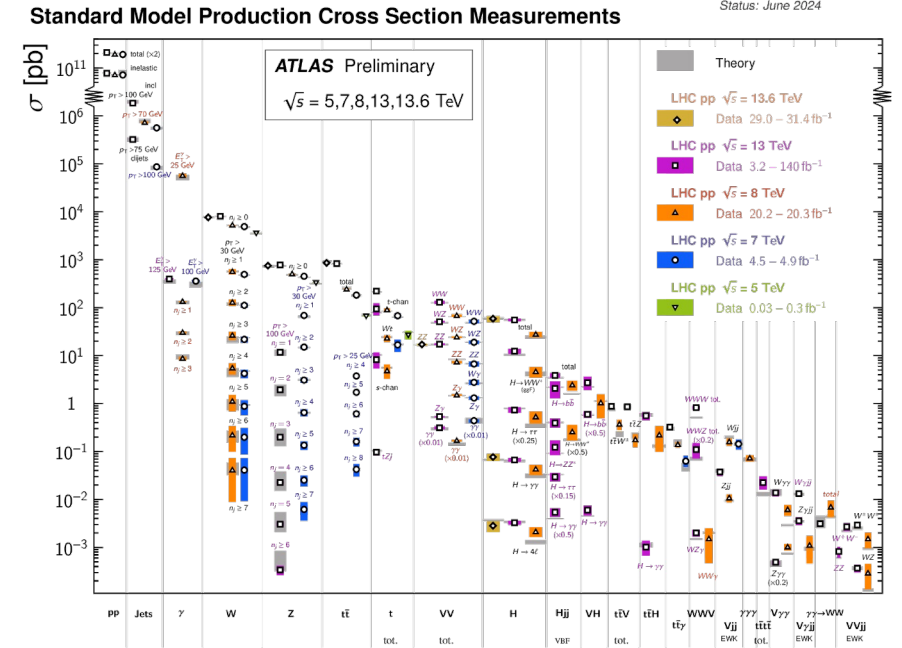
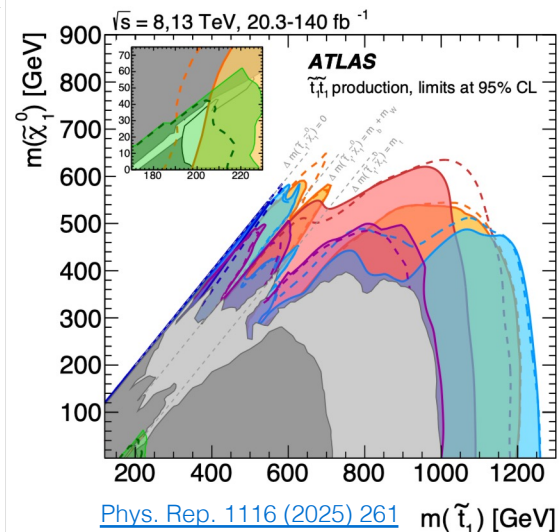
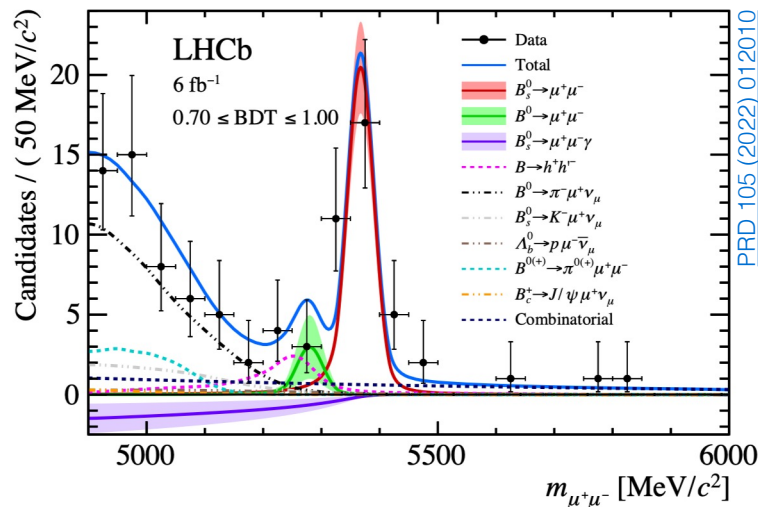
Unpleasant scalar sector (23 parameters, large hierarchy) — key to many mysteries

Coupling strength modifiers: $\kappa_i = \kappa_i^{\text{obs}} / \kappa_i^{\text{SM}}$



We have learned so much more at the LHC ...

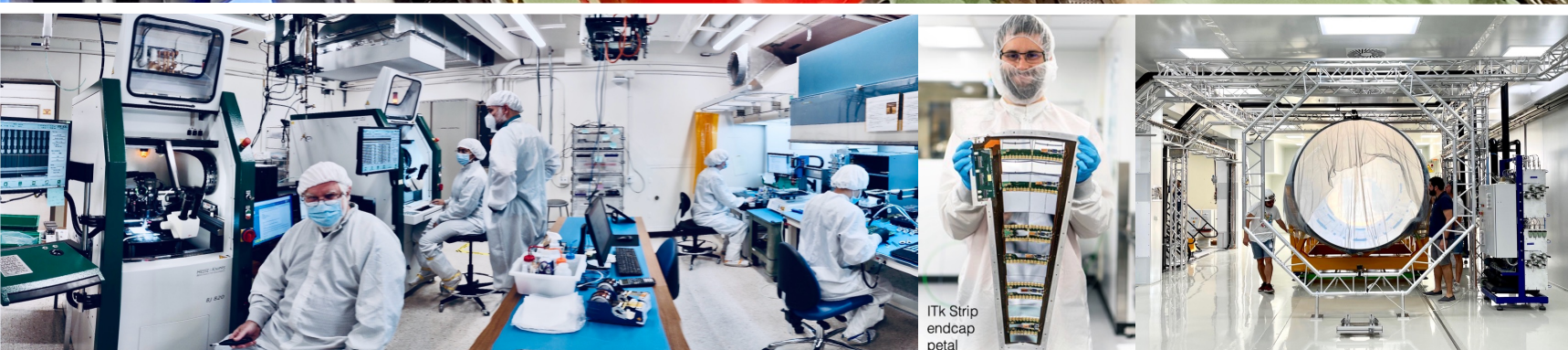
- A plethora of measurements, some involving extremely rare and sensitive processes, others reaching very high precision, confirm the predictive power of the SM and deepen our understanding
- 82 new hadronic bound states discovered so far, 28 of which exotic, the heaviest being toponium
- Heavy-ion collisions enabled unprecedented insights into the quark-gluon plasma
- Searches for new phenomena have set tight constraints on some of the most popular SM extensions, thus completely changing the field of beyond the SM physics





Upgrade to the High-Luminosity LHC is under way

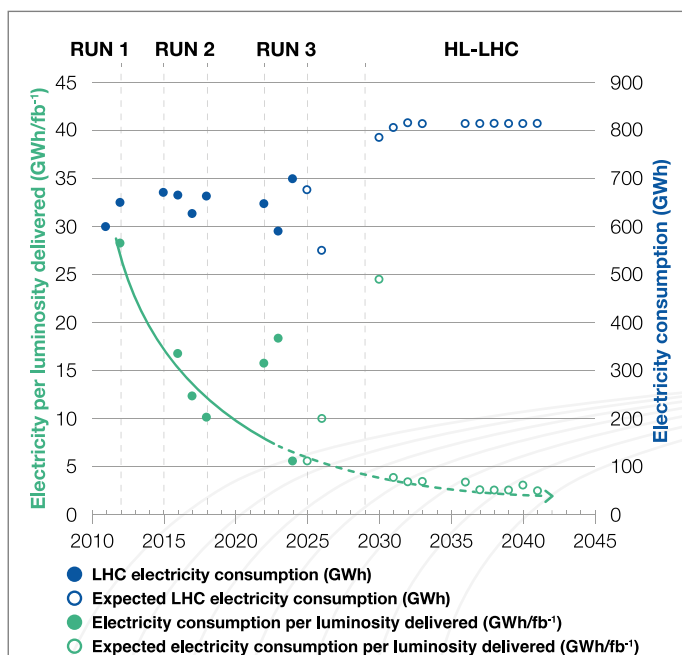
- The HL-LHC will use new technologies to provide 6 times more collisions than the LHC
- Intensities require large-scale detector upgrades
- Access to rare phenomena, greater precision and new discovery potential (350M H, 240k HH, 13B top, 720M WW, ...)
- It will start operating in 2030 and run until 2041
- **Complementary in many ways to the FCC-ee**



Environmental impact of LHC / HL-LHC operation

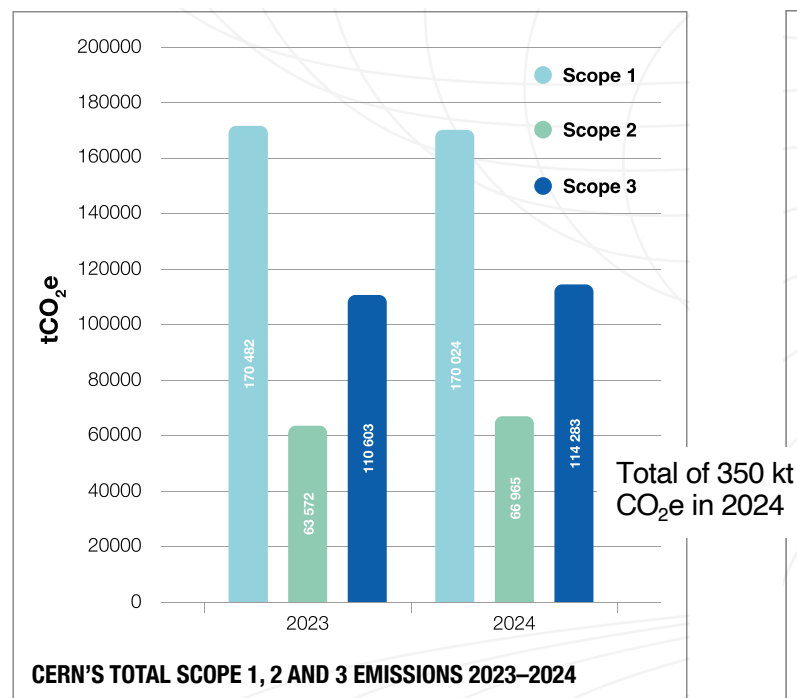
Source: [CERN Environmental Report 2023–2024](#)

CERN's total annual power consumption is ~1.3 TWh dropping to ~0.4 TWh when LHC is not operating



ELECTRICITY INTENSITY OF THE LHC

Quantity of electricity used to run the LHC per unit of luminosity delivered, showing that less and less electricity has been needed over time to produce the same amount of data and, hence, scientific output. During the year after each Long Shutdown (LS), while the accelerator is being brought back online and progressively ramped up, the luminosity delivered is not at its maximum – as seen in 2022 and expected for 2030. The outliers in 2023 are due to the technical issue that led to the stop of the LHC machine for one month, with an impact on electricity consumption. The outliers forecast for 2026 are due to the partial operation of the machine (LS starting mid-year).

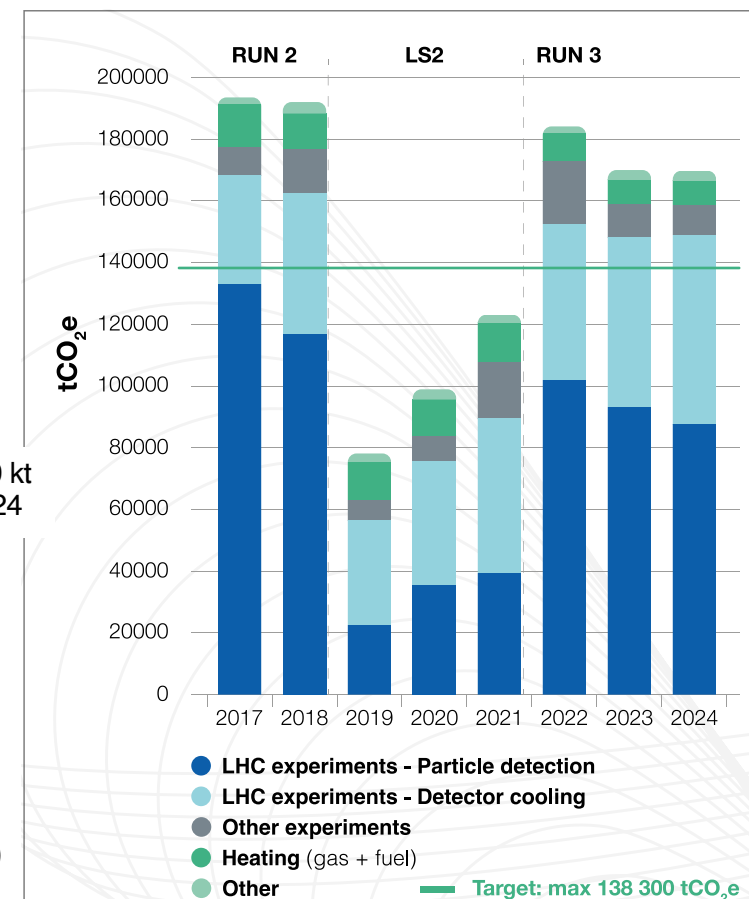


Scope 1: direct emission of greenhouse gases*

Scope 2: indirect emission via purchased electricity

Scope 3: all other indirect emission (procurement, ...)

*F-gas impact mainly from RPC losses and detector cooling; HL-LHC reductions from leak repairs, gas dilution, and new CO₂ cooling plants



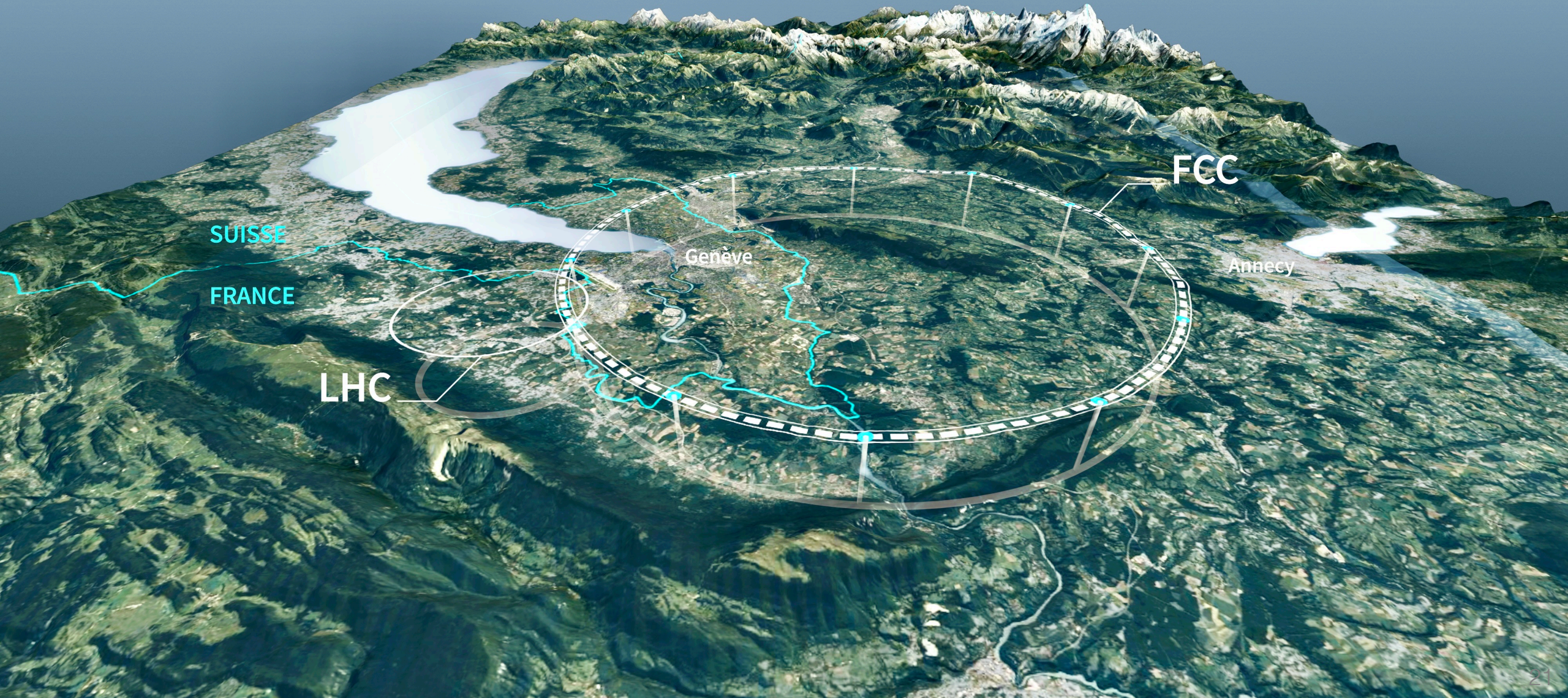
CERN SCOPE 1 EMISSIONS FOR 2017–2024 BY CATEGORY

"Other" includes air conditioning, electrical insulation, emergency generators and the fuel consumption of the CERN vehicle fleet.

Future Circular Collider

90.7 km circumference tunnel facility to host an e^+e^- and a hadron collider

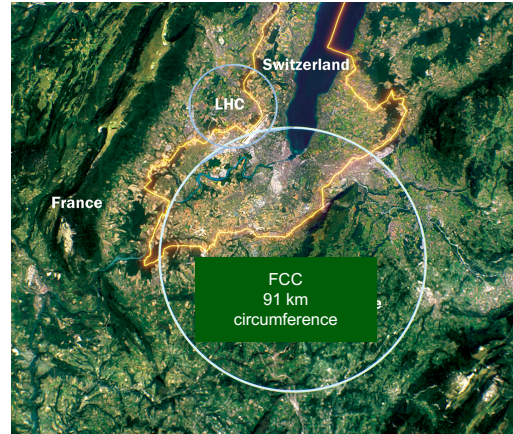
Feasibility study: 3 volumes (physics & experiments, accelerator, civil engineering & sustainability) (March 2025), [All documents](#)



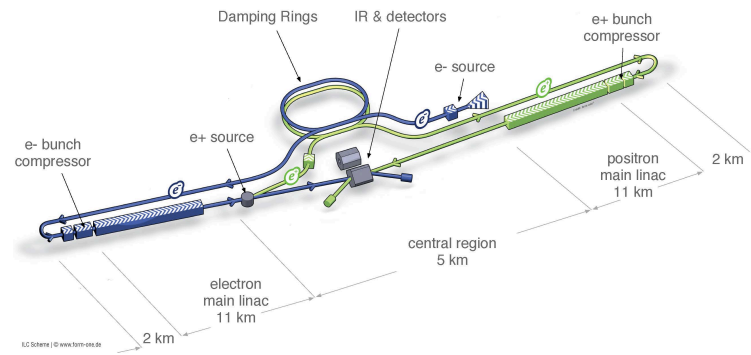
Proposed large-scale projects at CERN, ~ 2045

e^+e^- colliders
("Higgs factories")

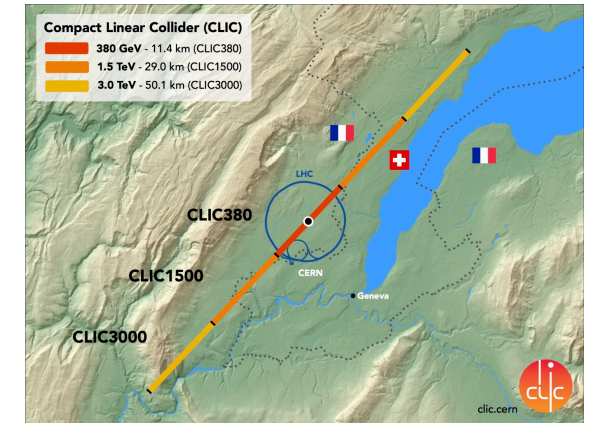
FCC- ee (e^+e^- , circular, 91 – 365 GeV)



LCF (e^+e^- , linear, 91 – 240, 550 GeV)



CLIC (e^+e^- , linear, 380 GeV, 1.5 TeV)



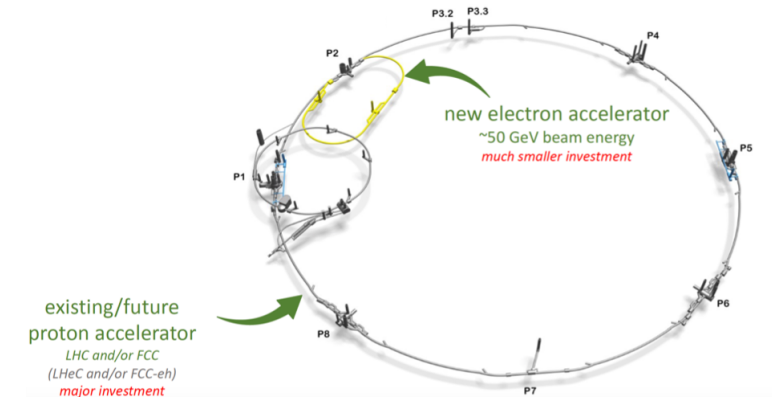
Intermediate projects

(Leave room (time, budget, resources) for further development of THE machine that can probe directly the energy frontier at the 10 TeV parton scale)

LEP3 (e^+e^- , circular, 91 – 230 GeV)



LHeC (ep, circular, electron ERL, 50 GeV e^- , > 1 TeV ep collisions)



Assessment of proposed colliders by expert group

[\[Link to ESG WG2a report\]](#)

Project	Scope	TRL (1–9)	R&D	Test facilities	Performance	Site preparation	Schedule	Cost	Risk
CLIC 380 GeV, 1.5 TeV		4 - 6 / 5.2							
FCC-ee 91-365 GeV		4 - 7 / 6.0							
FCC-hh 85 TeV		4 - 7 (Nb ₃ Sn) / 4.3							
		2 - 7 (HTS) / 3.2							
FCC-hh - SA 85 TeV		4 - 7 (Nb ₃ Sn) / 5					Nb ₃ Sn		
LCF 250 - 550 GeV		5 - 7 / 5.5							
LEP3 91 - 230 GeV		3 - 6 / 4.0							
LHeC: HL-LHC + 50 GeV ERL		3 - 6 / 4.5							
MC 3.2 TeV, 7.6 TeV		3.2 TeV: 3 - 5 7.6 TeV: 2 - 5							

Muon Collider: Technologies in early phases of exploration, large R&D programme defined (300 MCHF, 1800 FTEy), demonstrator required

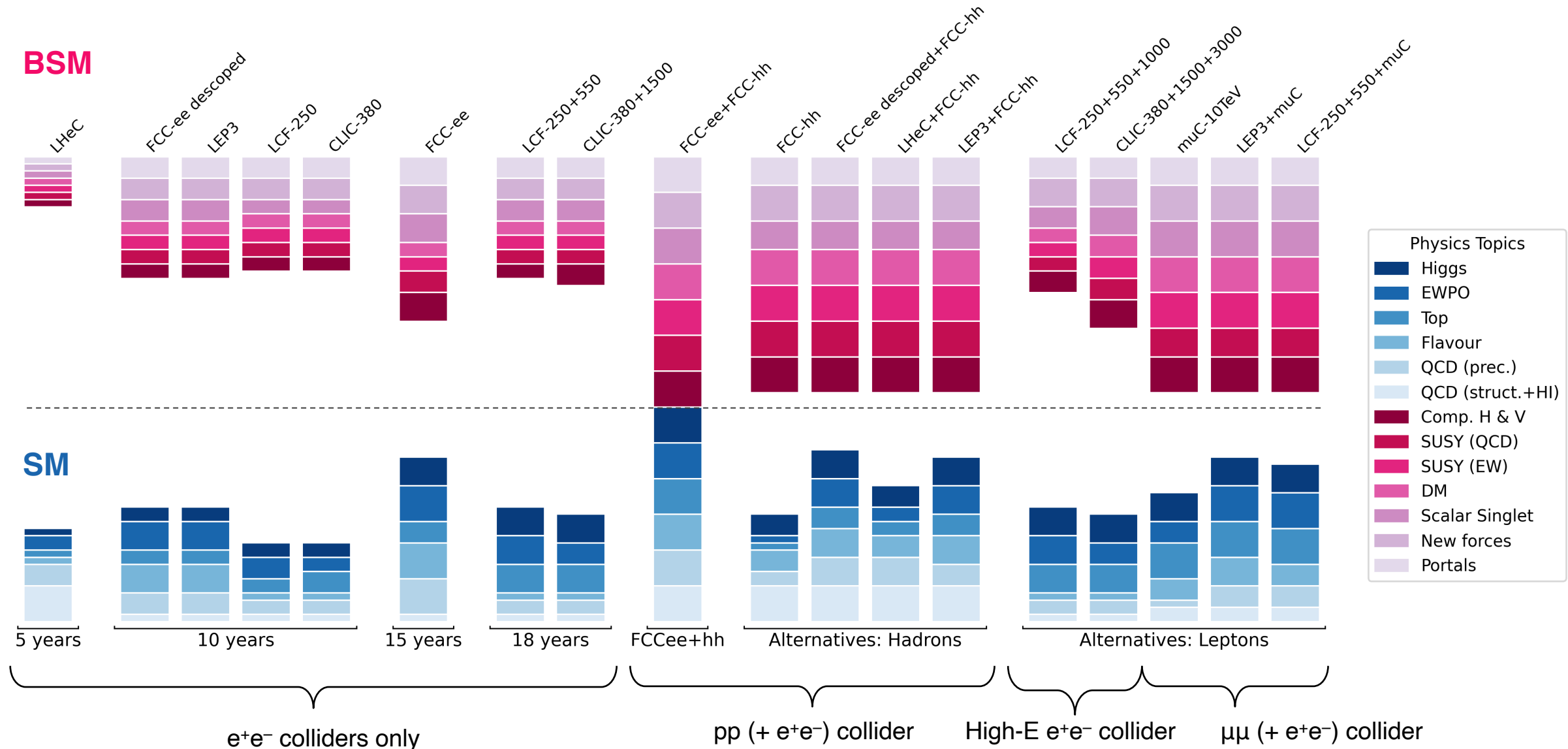
FCC-hh: Further R&D and industrialisation with cost reduction of high-field magnets (Nb₃Sn 15–20 y, HTS ?)

LEP3: No detailed lattice design & full-scale simulation, proposed baseline HTS nested quadrupoles/sextupoles has lowest TRL

LHeC: Performance relies on very high current Energy-Recovery Linac (ERL), large luminosity uncertainty, PERLE @ IJCLab required

Assessment of physics reach

[\[Link to ESG WG2b report\]](#)



A remark on CEPC

Total cost 4.6B USD

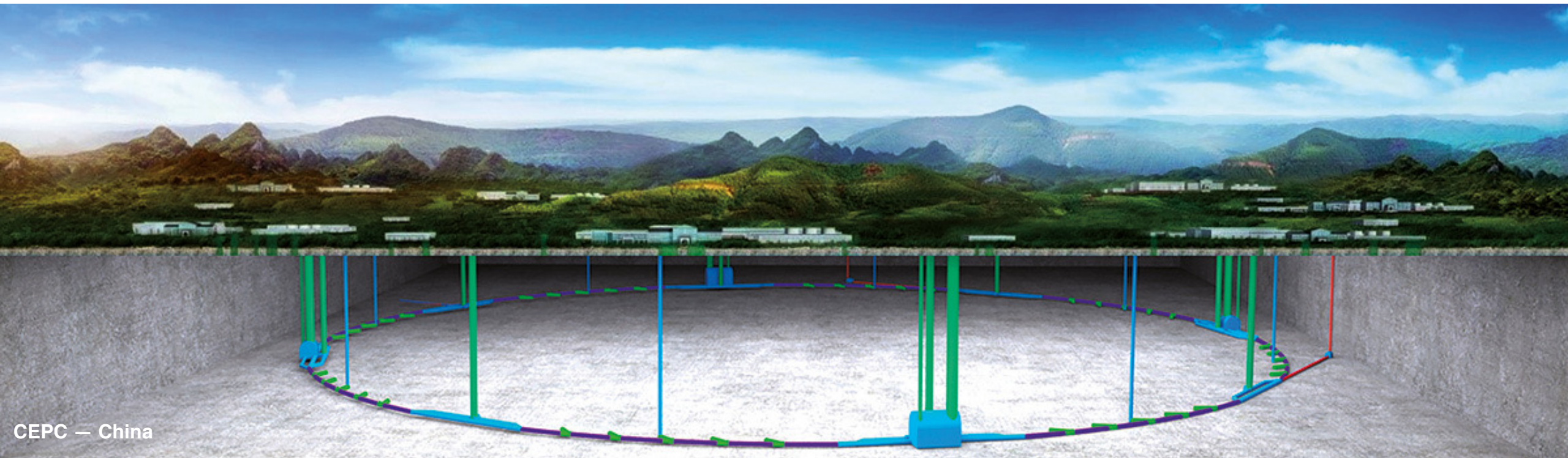
CEPC TDR: [arXiv:2312.14363](https://arxiv.org/abs/2312.14363)
Detector TDR: [arXiv:2510.05260](https://arxiv.org/abs/2510.05260)

CEPC — Circular (not *Chinese*!) Electron Positron Collider

Very similar to FCC-ee: baseline is 100 km tunnel, top-up, 30 MW / beam, 2 IPs, option for subsequent hadron collider

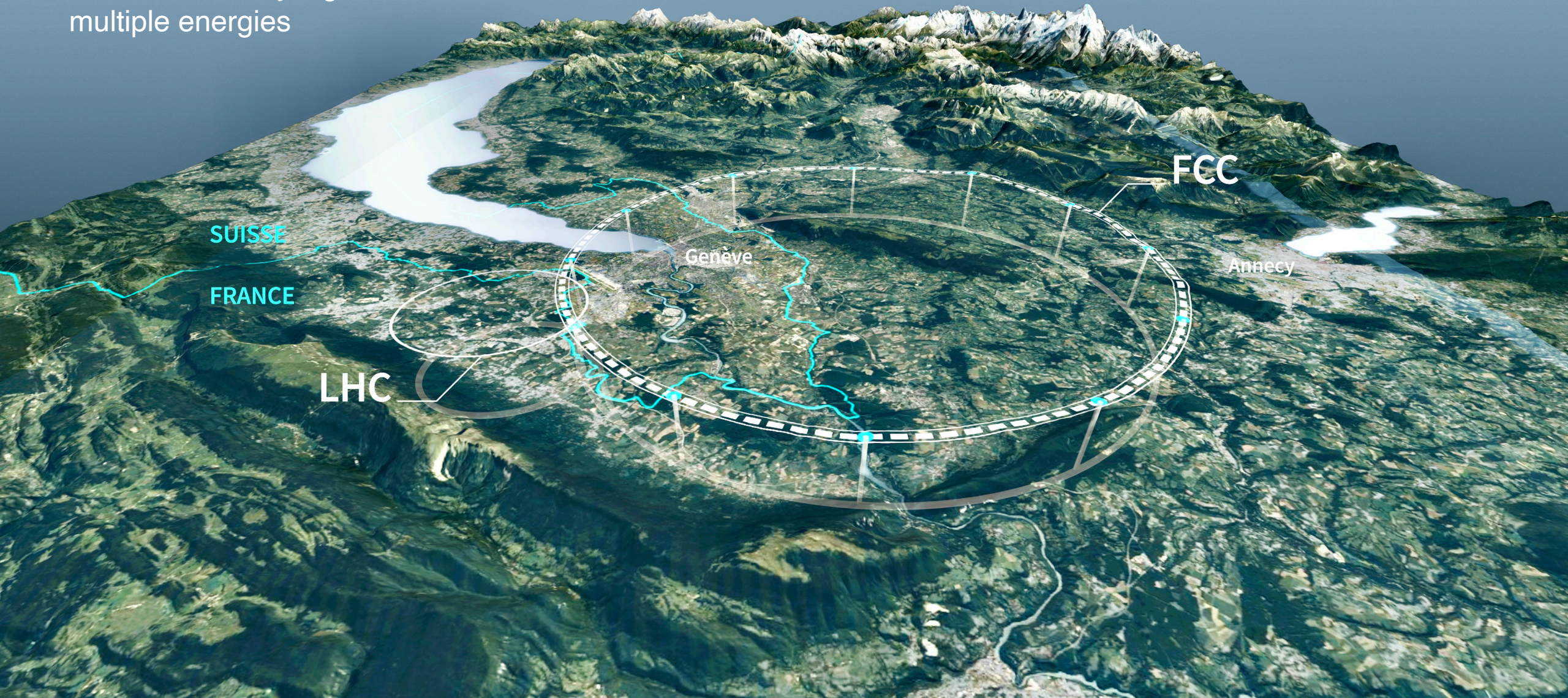
CEPC proposal was submitted to Chinese Academy of Science for inclusion in 15th 5-year plan in 2025, but not retained (STCF preliminarily yes)

CEPC plan: hope to retain funding, seek collaboration with FCC-ee, resubmit in 2030 if FCC-ee not approved by then



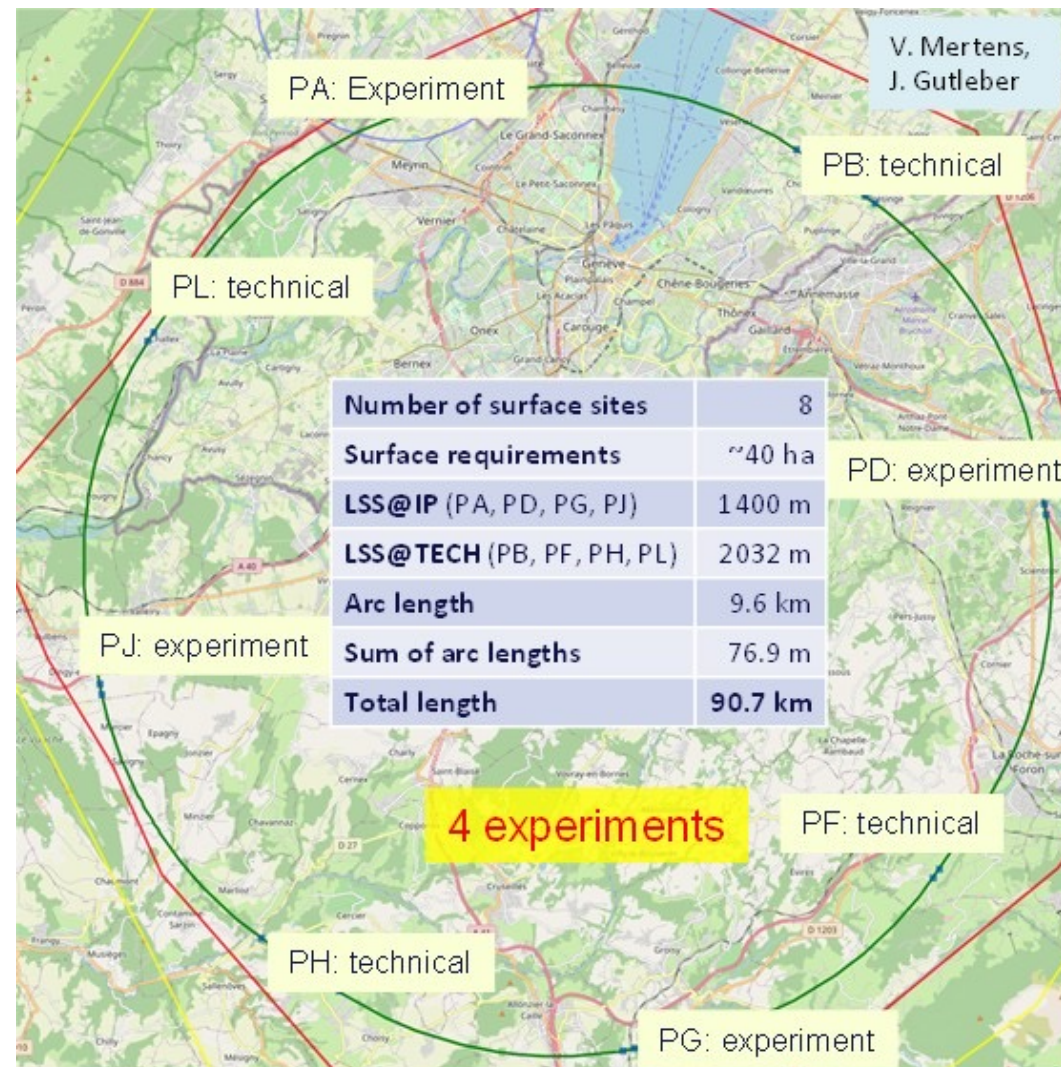
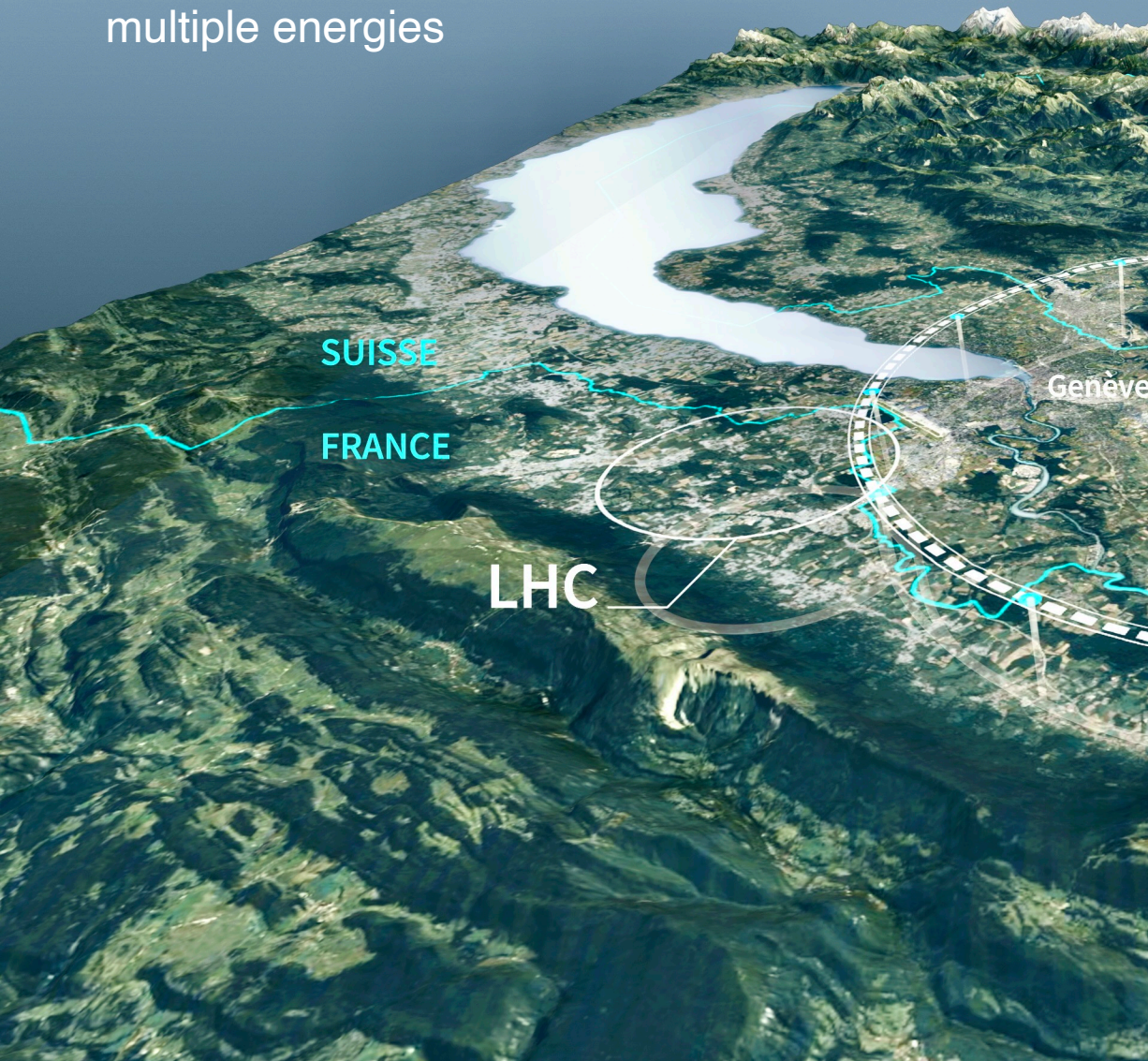
FCC-ee

Next-generation circular e^+e^- collider to deliver extremely high luminosities across multiple energies



FCC-ee

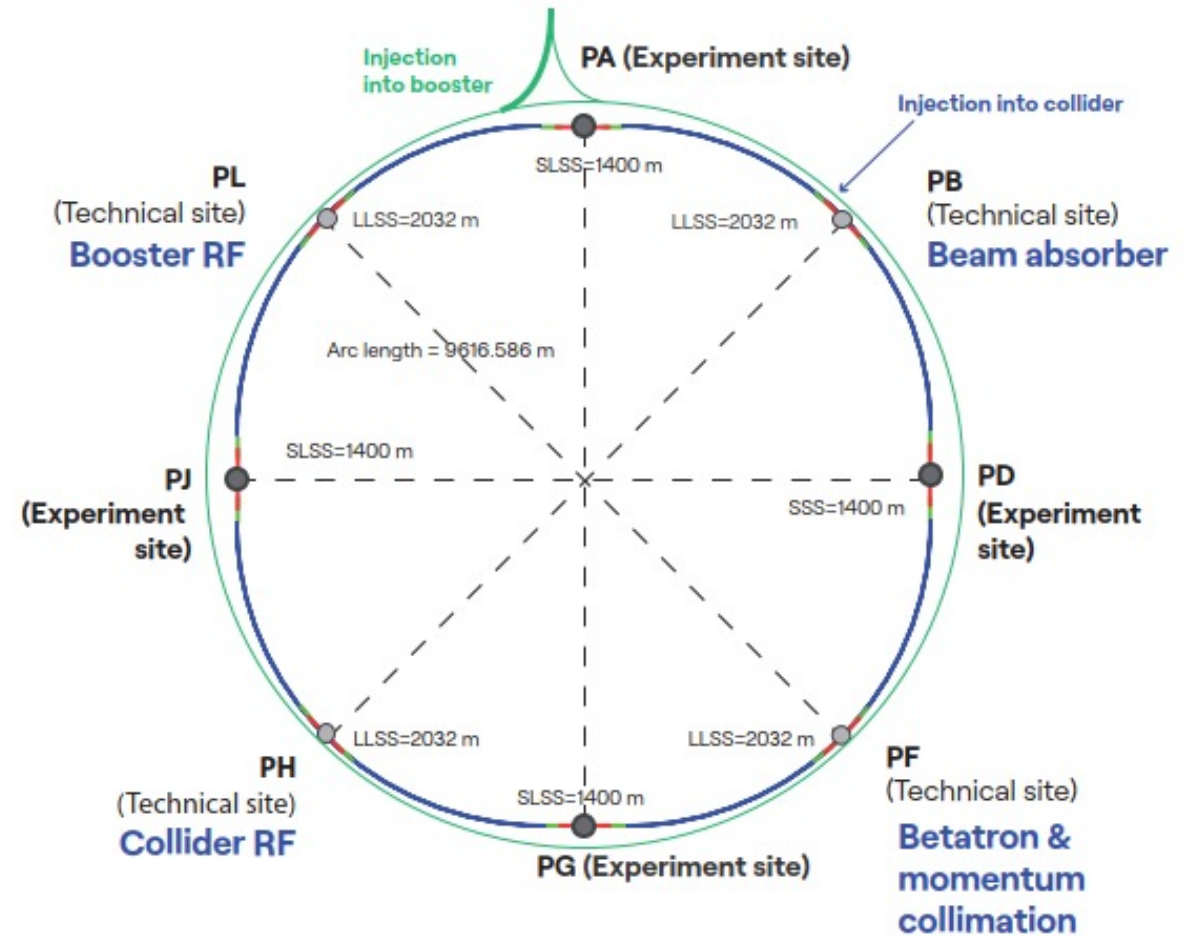
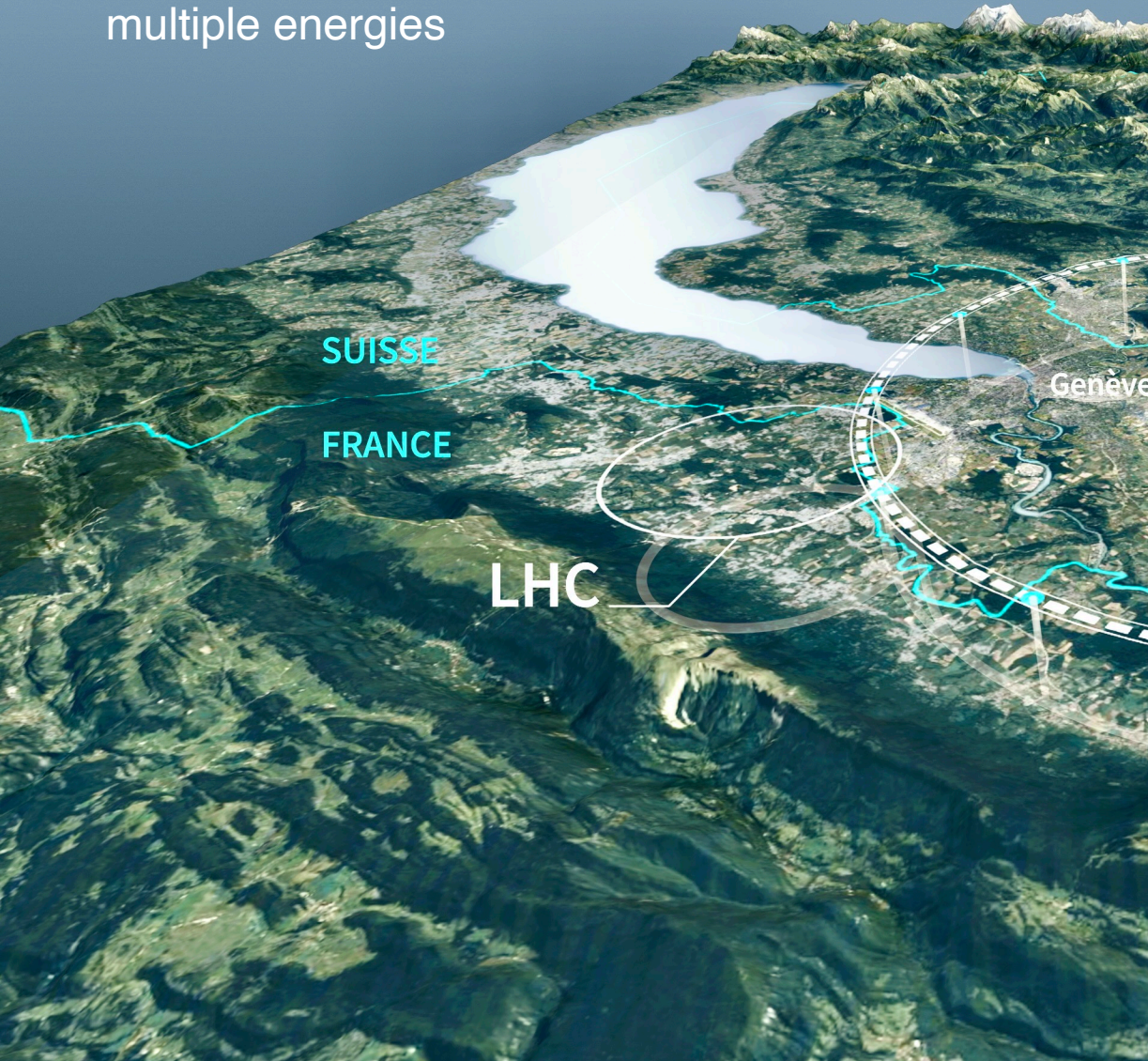
Next-generation circular e^+e^- collider to deliver extremely high luminosities across multiple energies



Detailed feasibility study: layout selected from ~100 variants following the EU “Avoid–Reduce–Compensate” principle — 90.7 km ring, 8 surface sites (7 FR, 1 CH), 5.5 m tunnel diameter, 50–560 m depth

FCC-ee

Next-generation circular e^+e^- collider to deliver extremely high luminosities across multiple energies



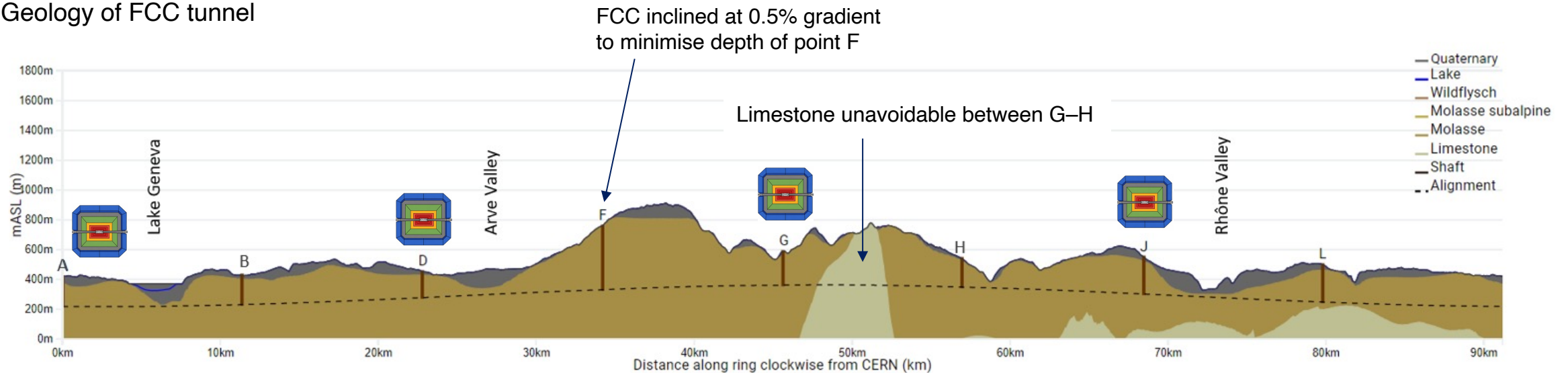
Ring structure: 4 experiments, 1 RF-section / beam,
1 collimation section, 1 section for injection and dump

Booster is single-beam synchrotron which cycles within a few seconds between accelerating and top-up injecting e^+ and e^-

FCC-ee

Next-generation circular e^+e^- collider to deliver extremely high luminosities across multiple energies

Geology of FCC tunnel



Tunneling mainly in molasse layer (soft rock), well suited for fast, low-risk construction, **6 million m³ excavated volume**
→ **8.5 million m³ excavation material on surface (OpenSkyLab R&D project to study reuse)**, average shaft depths ~240 m

265'000 m³ concrete/year over 8 years (0.075% of annual EU production), use of low-carbon concrete under study

Total civil engineering construction carbon footprint estimate: 530,000 – 1,184,000 tCO₂(eq)

= 1.5 – 3.4 × CERN with LHC operation per year

Assessed according to European Norms (EN 17472, EN15804+A2)

FCC-ee — territorial dialogue & public participation

Public information and
discussion meetings

First cycle of public information meetings between April 2024 – March 2025

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

During 2025: Second cycle of public information meetings

- Workshops with residents in municipalities potentially affected by surface sites; meetings with stakeholders of the territory

May/June – October 2026: Formal public participation process in France (Débat Public) and Switzerland (public concertation)

- Workshops with residents in municipalities potentially affected by surface sites; meetings with stakeholders of the territory



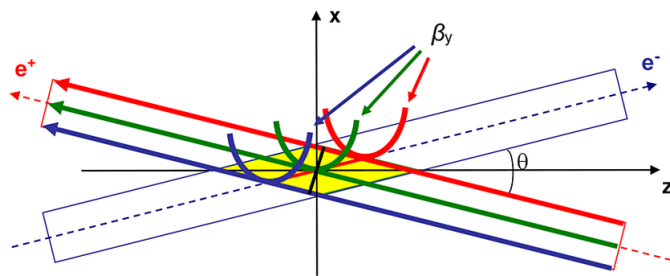
Dialogue website:



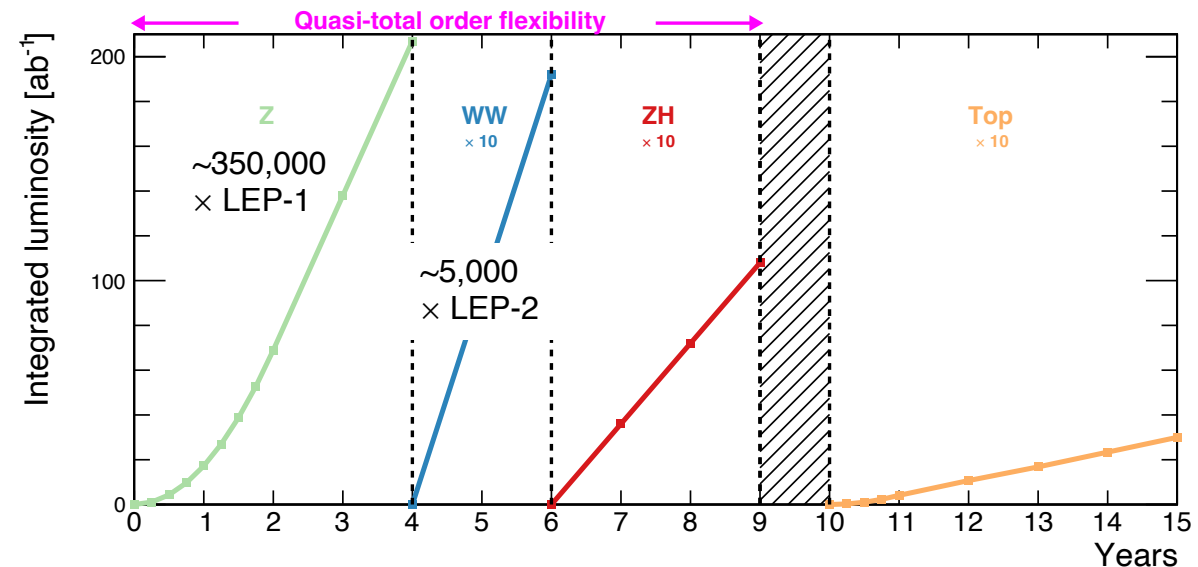
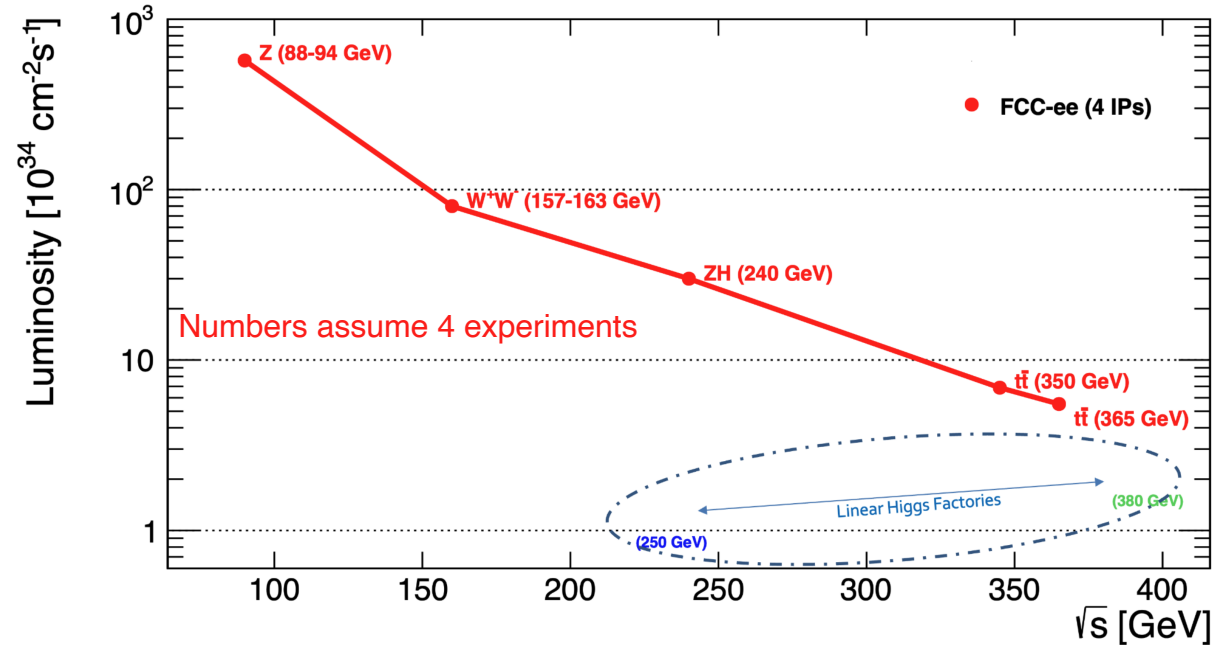
FCC-ee — maximum luminosity

FCC-ee collider concept for maximum luminosity

- **Double ring collider:** many bunches, high current, like LHC and B factories, different from LEP (CERN)
- **Top-up injection (requiring booster) during collisions:** needed due to short luminosity lifetime (~ 10 – 20 min, radiative Bhabhas), standard at light sources and used at PEP-II, KEKB, BEPCII. Booster intensity $\sim 1\%$ of collider; full RF voltage as in collider
- **Superconducting RF:** LEP-proven Nb/Cu 400 MHz cavities; bulk Nb 800 MHz cavities as in ESS/EuXFEL; efficient RF sources and simplified energy-switching scheme
- **Crab-waist collisions:** successfully demonstrated at DAΦNE and SuperKEKB



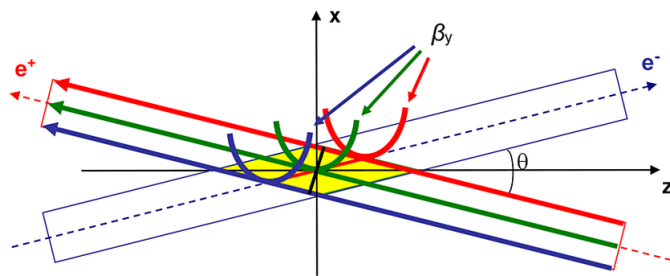
Crab waist scheme: sextupoles near IP rotate vertical waist along the opposing beam's path (and suppresses beam-beam resonances)



FCC-ee — maximum luminosity

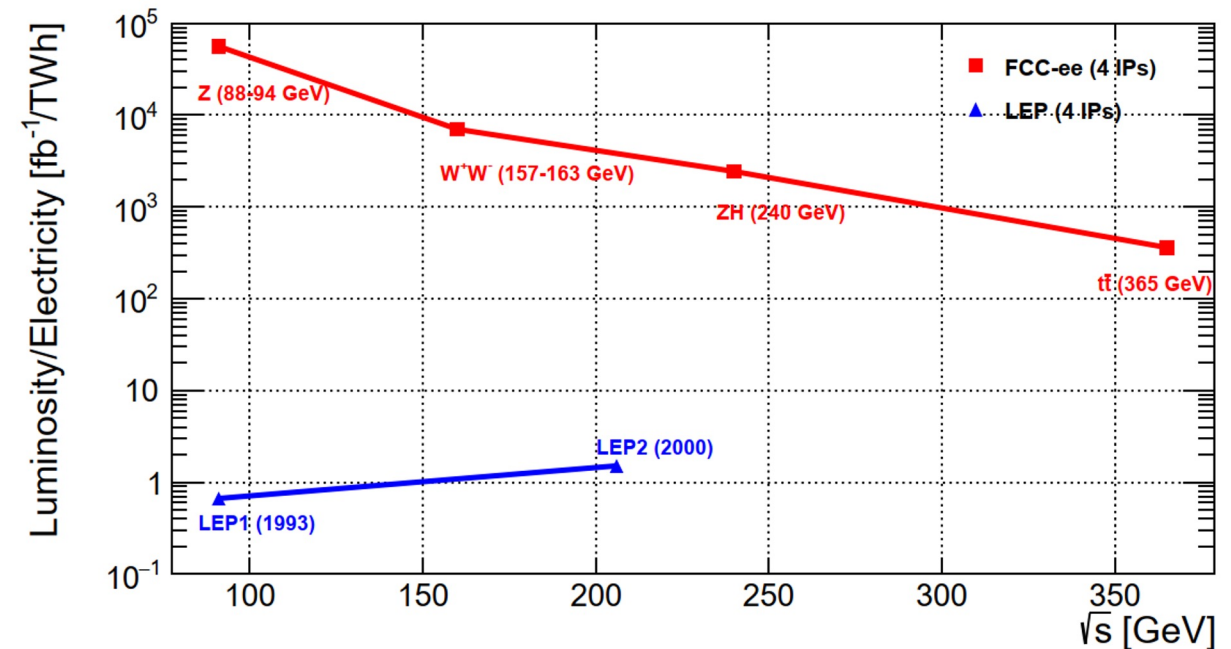
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Crab waist scheme: sextupoles near IP rotate vertical waist along the opposing beam's path (and suppresses beam-beam resonances)

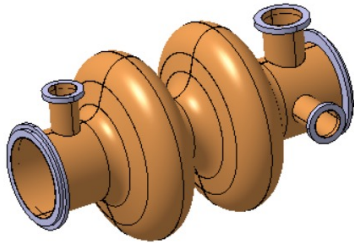
Combining all these concepts results in a giant efficiency step: $10^4 - 10^5 \times$ luminosity / electrical power of LEP



$$*\eta = \frac{P_{\text{RF out}}}{P_{\text{beam}}}$$

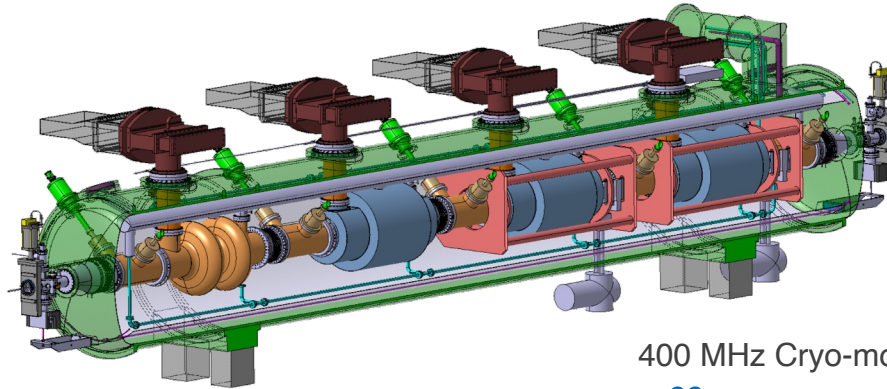
Superconducting RF system — key technology

- 2-cell* 400 MHz SRF system for Z, W and ZH



400 MHz superconducting cavity (6~10 MV/m), copper Nb coated, 1.5 m long

× 264



400 MHz Cryo-module

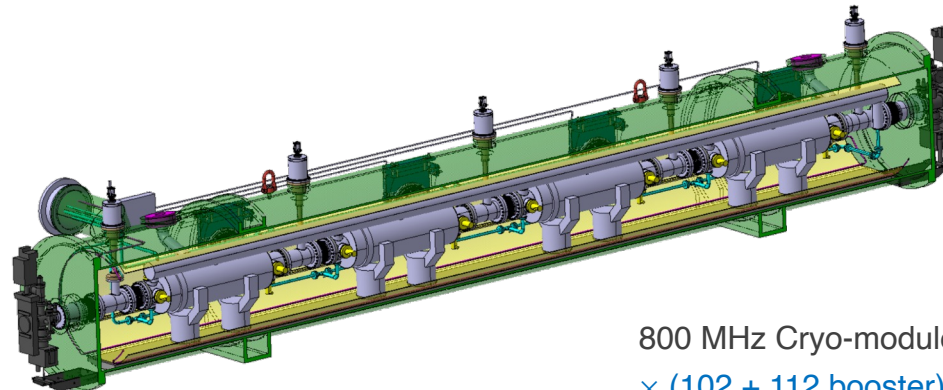
× 66

- Higher gradient 6-cell 800 MHz SRF system for tt collider operation and booster at all energies



Compact 800 MHz cavity (~20 MV/m), 6-cell, bulk Nb, Nb₃Sn if R&D is successful

× (408 + 448 booster)

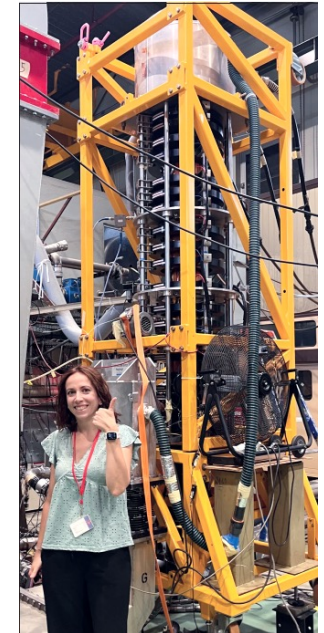


800 MHz Cryo-module

× (102 + 112 booster)

Power source: 380 kW Klystron prototype built (HL-LHC) $\eta^* = 70\%$
 → two-stage Klystrons $\eta = 86\%$
 → multibeam Tristrons $\eta > 90\%$ (R&D)

× 264



Klystron prototype

× 204 Tristons +
 448 × 10 kW SSA booster

FCC-ee — parameters

$$\Delta E_{\text{SR-loss}} \propto E_{\text{beam}}^4 / (m_e^4 \cdot \varrho), \quad P_{\text{SR}} = U_0 I, U_0 \propto E^4$$

FCC-ee main parameters (assuming 4 IPs / experiments)

Ref: [arXiv:2505.00274](https://arxiv.org/abs/2505.00274)

Parameter	Z	WW	H (ZH)	t $\bar{t}$	
Collision energy $\sqrt{s}$ [GeV]	88, 91, 94	157, 163	240	340–350	365
SR energy loss / turn [GeV]	0.036	0.08	1.7	7.8	9.2
Total RF voltage 400 / 800 MHz [GV]	0.08 / 0	1.0 / 0	2.1 / 0	2.1 / 7.4	2.1 / 9.2
Synchrotron radiation/beam [MW]	50	50	50	50	50
Beam current [mA]	1294	135	26.8	6.0	5.1
Number bunches / beam	11200	1852	300	70	64
Luminosity / IP [$10^{34} \text{ cm}^{-2}\text{s}^{-1}$]	144	20	7.5	1.8	1.4
Luminosity / year [ab^{-1}]	68	9.6	3.6	0.83	0.67
Run time (including lumi ramp-up) [years]	4	2	3	1	4
Total integrated luminosity [ab^{-1}]	205	19.2	10.8	0.4	2.7
Total number of events	$6 \cdot 10^{12} \text{ Z}$	$2.4 \cdot 10^8 \text{ WW}$ (incl. WW at higher $\sqrt{s}$)	$2.2 \cdot 10^6 \text{ ZH}$ 65k WW $\rightarrow$ H	$2 \cdot 10^6 \text{ t}\bar{\text{t}}$ + 370k ZH + 92k WW $\rightarrow$ H	

$\sim 350,000 \times \text{LEP-1}$ (~ 6 years)
 $\sim 26 \times \text{HL-LHC}$ (~ 9 years)

$\sim 5,000 \times \text{LEP-2}$
(~ 5 years)

0.5% of HL-LHC
(~ 9 years)

0.01% of HL-LHC (tt)
(~ 9 years)

$$\Delta E_{\text{SR-loss}} \propto E_{\text{beam}}^4 / (m_e^4 \cdot \varrho), \quad P_{\text{SR}} = U_0 I, U_0 \propto E^4$$

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Total RF voltage 400 / 800 MHz [GV]	0.08 / 0	1.0 / 0	2.1 / 0	2.1 / 7.4	2.1 / 9.2
Synchrotron radiation/beam [MW]	50	50	50	50	50

Despite the constant synchrotron power, due to the larger RF voltage and system size (increased cryogenic system), RF efficiency losses, and other increasing accelerator demands, the electrical power consumption increases with CM energy:

FCC-ee electrcital energy consumption	Z	W	H	top
Beam energy [GeV]	45.6	80	120	182.5
Peak power during beam operation [MW]	250	275	297	381
Total FCC-ee yearly consumption [TWh]	1.2	1.3	1.4	1.85

LHC + injectors: ~ 200 MW peak power
Today CERN with LHC operating: ~1.3 TWh

Various R&D towards further reduction of electrical energy consumption

FCC-ee — detectors

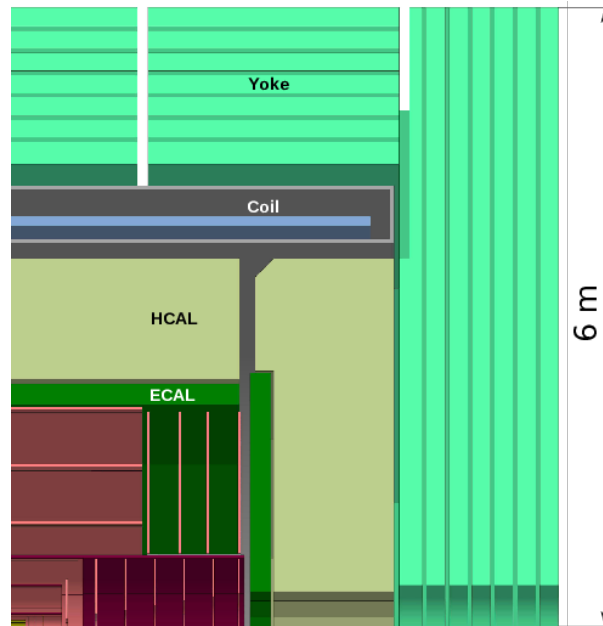
*A too-strong detector solenoid (≥ 4 T) would distort the beam trajectories, induce transverse coupling, and blow up the vertical emittance — drastically reducing luminosity

Event rates and radiation are modest compared with HL-LHC, but Tera-Z precision imposes unprecedented stability and resolution demands: luminosity at 10^{-5} relative and 10^{-4} absolute precision, acceptance definition at 10^{-5} , etc. Ultimately, most measurements will be systematics- and theory-limited

Detector concepts are built around high-granularity particle-flow calorimetry, close-to-beam MAPS vertex detectors, large low-material central trackers, PID, a ~ 2 T solenoid, and muon tagging, with fields up to 3 T possible above the Z pole.



ALLEGRO detector concept around noble-liquid EM calorimeter [Ref]



CLD detector concept silicon-tungsten EM calorimeter and tracker [Ref]

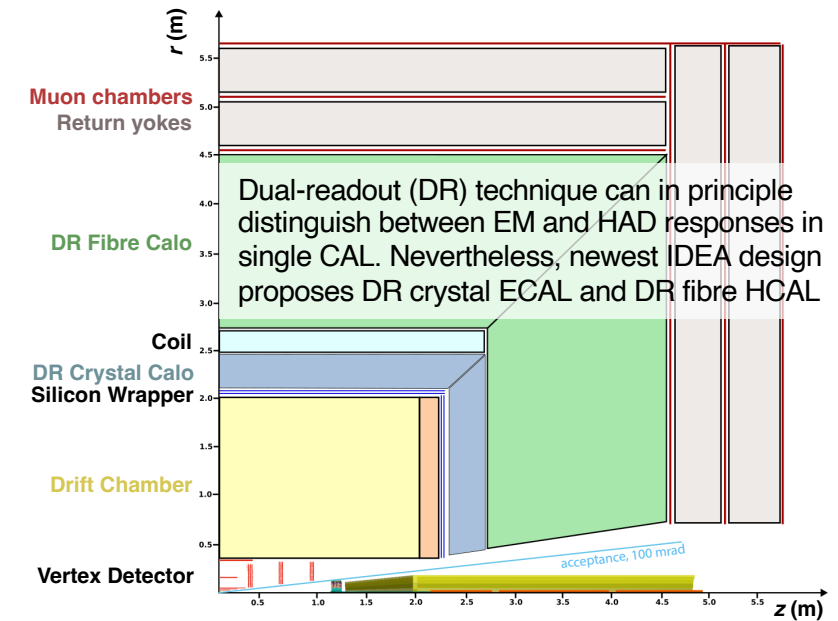
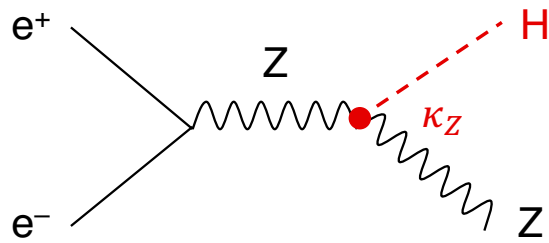


Figure 3: Overview of the IDEA detector layout.

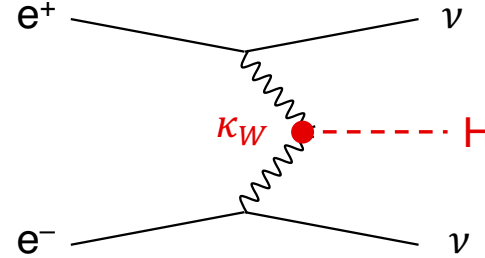
IDEA detector concept around dual-readout (scintillation (all) & Cherenkov (relativistic – e/γ) light) fiber/Cu calorimeters [Ref]

FCC-ee — Higgs Factory

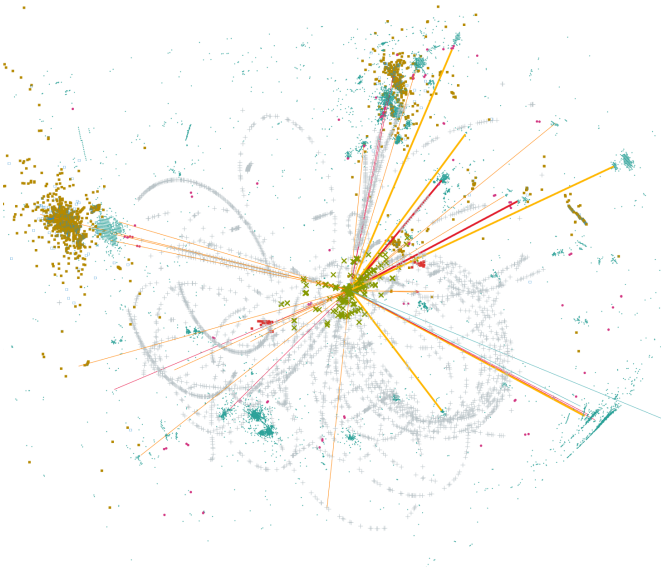
Primary goal: Higgs precision measurements



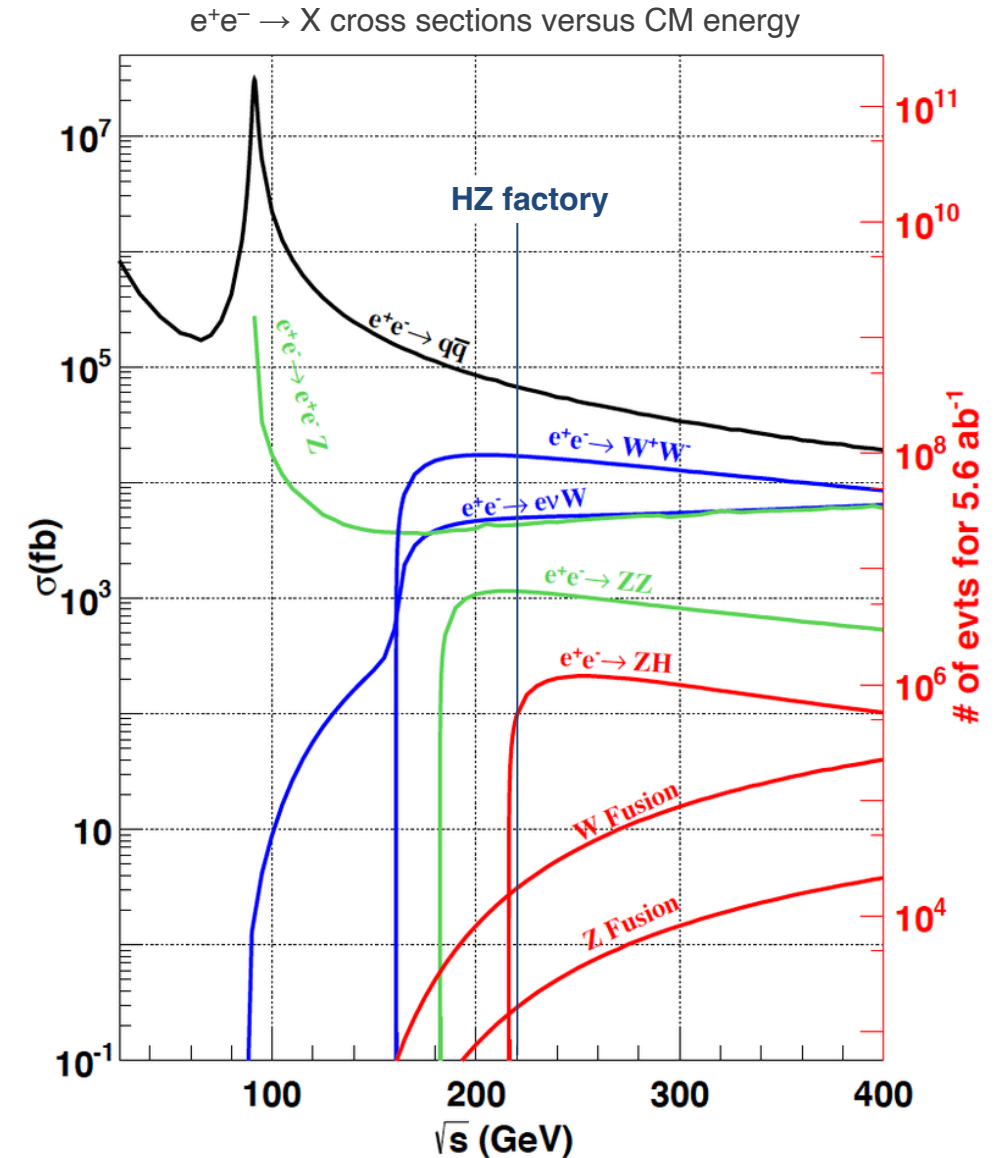
Higgsstrahlung ($\sigma = 232 \text{ fb}$ at $\sqrt{s} = 240 \text{ GeV}$)
 s-channel: $\sigma \propto 1/s$ — falling off a resonance



W-boson fusion (6.7 fb)
 (Z-boson fusion 0.63 fb)
 WBF: $\sigma \propto \ln^2(s/m_W^2)$ — e^+/e^- radiate
 W/Z, which increases with energy

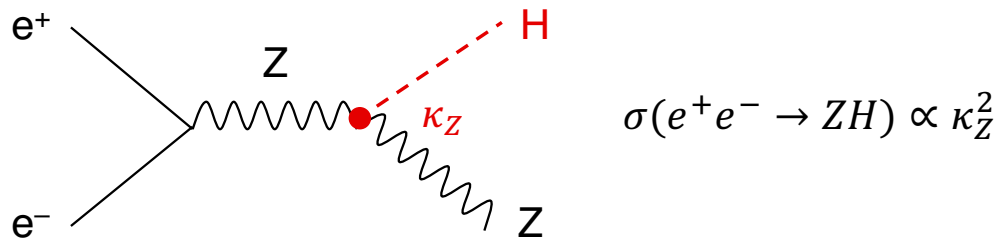


Simulated $e^+e^- \rightarrow ZH$ event at
 $\sqrt{s} = 240 \text{ GeV}$ in IDEA detector



FCC-ee — Higgs Factory

Absolute coupling strengths — difficult at LHC due to weak constraint on Γ_H (current precision $\sim 50\%$, HL-LHC $< 25\%$)

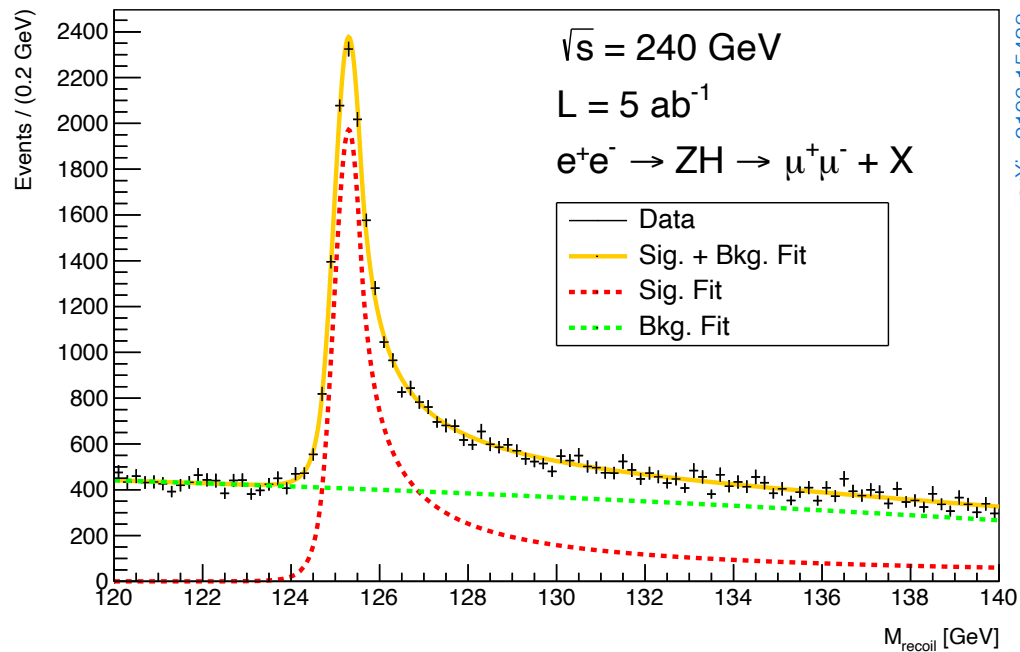


Can measure total HZ cross section and hence κ_Z (0.1% precision) independently of Higgs decays via recoil mass (M_{recoil}) by counting events with an identified $Z \rightarrow \ell\ell$

$$M_{\text{recoil}}^2 = (\sqrt{s} - E_{\ell^+} - E_{\ell^-})^2 - |\mathbf{p}_{\ell^+} + \mathbf{p}_{\ell^-}|^2$$

Standard reference to be used by all other Higgs coupling measurements

Higgsstrahlung ($\sigma = 232 \text{ fb}$ at $\sqrt{s} = 240 \text{ GeV}$)



Combination with measurement of $\sigma(e^+e^- \rightarrow ZH(\rightarrow ZZ^*)) \propto \frac{\kappa_Z^4}{\Gamma_H}$ allows to determine Γ_H to 0.8% precision ($30 \times \text{HL-LHC}$)

FCC-ee – the Higgs factory

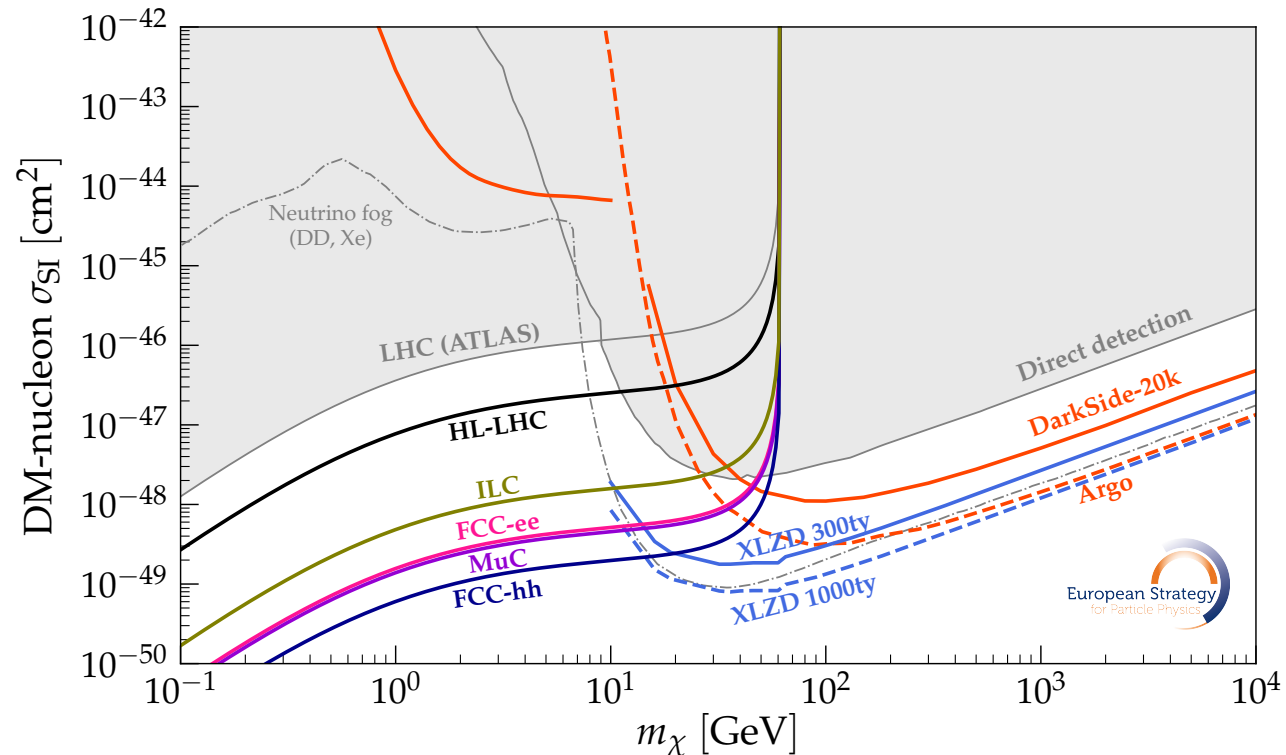
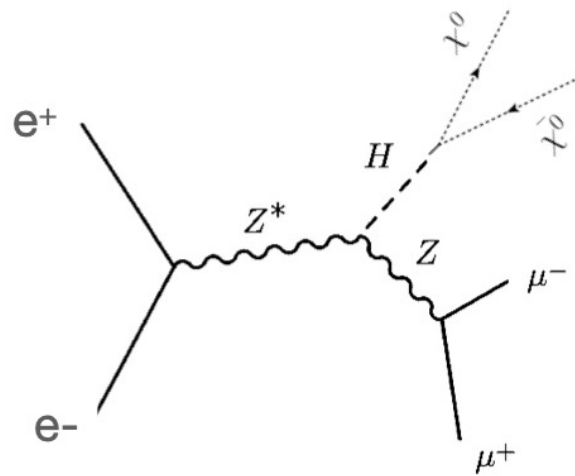
Why “factory”? 2.2M Higgs (FCC-ee) vs 350M (HL-LHC), production through Higgsstrahlung rather than s-channel
→ **e^+e^- collisions offer exceptionally clean Higgs reconstruction, unmatched precision on decays with large branching ratios**

FCC-ee feasibility study (Vol 1): [arXiv:2505.00272](https://arxiv.org/abs/2505.00272)

		Coupling	HL-LHC	FCC-ee	FCC-ee + FCC-hh	Uncertainty HL-LHC / FCC-ee	
*Incl. SM parametric uncertainties		κ_Z (%)	1.6	0.10	0.10	16	Most precise coupling, probes $f_H \sim 8$ TeV
		κ_W (%)	1.6	0.29	0.25	5.5	
		κ_b (%)	3.6	0.38 / 0.49*	0.33 / 0.45	7.3	
		κ_g (%)	2.4	0.49 / 0.54	0.41 / 0.44	4.4	Particularly large improvement over HL-LHC
		κ_τ (%)	1.9	0.46	0.40	4.1	
Note: current uncertainties on Higgs branching fraction predictions O(1.5%)		κ_c (%)	~ 40	0.70 / 0.87	0.68 / 0.85	~ 44	
		κ_γ (%)	1.8	1.1	0.30	1.6	
		$\kappa_{Z\gamma}$ (%)	6.8	4.3	0.67	1.6	
		κ_t (%)	3.4	3.1	0.75	1.1	
		κ_μ (%)	3.0	3.3	0.42	0.9	
		$ \kappa_s $ (%)	—	+29 −67	+29 −67	—	BR($H \rightarrow 4\nu$) = $10.6 \cdot 10^{-4}$
		Γ_H (%)	< 25	0.78	0.69	< 32	
		$\mathcal{B}_{\text{inv}} (<, 95\% \text{ CL})$	0.025	5×10^{-4}	2.3×10^{-4}	50	
		$\mathcal{B}_{\text{unt}} (<, 95\% \text{ CL})$	0.04	6.8×10^{-3}	6.7×10^{-3}	5.9	

FCC-ee – the Higgs factory

Why “factory”? 2.2M Higgs (FCC-ee) vs 350M (HL-LHC), production through Higgsstrahlung rather than s-channel
 → e^+e^- collisions offer exceptionally clean Higgs reconstruction, unmatched precision on decays with large BR



Collider limits overlaid onto direct detection (Higgs portal assuming Majorana DM)

$\mathcal{B}_{\text{inv}} (<, 95\% \text{ CL})$	0.025	5×10^{-4}	2.3×10^{-4}	50
	HL-LHC	FCC-ee	FCC-ee + FCC-hh	

$\text{BR}(H \rightarrow 4\nu) = 10.6 \cdot 10^{-4}$

FCC-ee – also a Tera-Z, W and top factory

Extreme luminosity on Z pole: $140 \cdot 10^{34} \text{ cm}^{-2}\text{s}^{-1}$ / IP, 205 ab^{-1} & $6 \cdot 10^{12} \text{ Z}$ (4 IPs) — ultimate EW precision data

[arXiv:2505.00272](https://arxiv.org/abs/2505.00272)

Observable	value	present ±	uncertainty	FCC-ee Stat.	FCC-ee Syst.	Comment and leading uncertainty
m_Z (keV)	91 187 600	±	2000	4	100	From Z line shape scan Beam energy calibration
Γ_Z (keV)	2 495 500	±	2300	4	12	From Z line shape scan Beam energy calibration
$\sin^2 \theta_W^{\text{eff}} (\times 10^6)$	231,480	±	160	1.2	1.2	From $A_{\text{FB}}^{\mu\mu}$ at Z peak Beam energy calibration
$1/\alpha_{\text{QED}}(m_Z^2) (\times 10^3)$	128 952	±	14	3.9 0.8	small tbc	From $A_{\text{FB}}^{\mu\mu}$ off peak From $A_{\text{FB}}^{\mu\mu}$ on peak QED&EW uncert. dominate
$R_\ell^Z (\times 10^3)$	20 767	±	25	0.05	0.05	Ratio of hadrons to leptons Acceptance for leptons
$\alpha_S(m_Z^2) (\times 10^4)$	1 196	±	30	0.1	1	Combined R_ℓ^Z , Γ_{tot}^Z , σ_{had}^0 fit
$\sigma_{\text{had}}^0 (\times 10^3) \text{ (nb)}$	41 480.2	±	32.5	0.03	0.8	Peak hadronic cross section Luminosity measurement
$N_\nu (\times 10^3)$	2 996.3	±	7.4	0.09	0.12	Z peak cross sections Luminosity measurement
$R_b (\times 10^6)$	216 290	±	660	0.25	0.3	Ratio of $b\bar{b}$ to hadrons
$A_{\text{FB}}^{b,0} (\times 10^4)$	992	±	16	0.04	0.04	b-quark asymmetry at Z pole From jet charge
$A_{\text{FB}}^{\text{pol},\tau} (\times 10^4)$	1 498	±	49	0.07	0.2	τ polarisation asymmetry τ decay physics

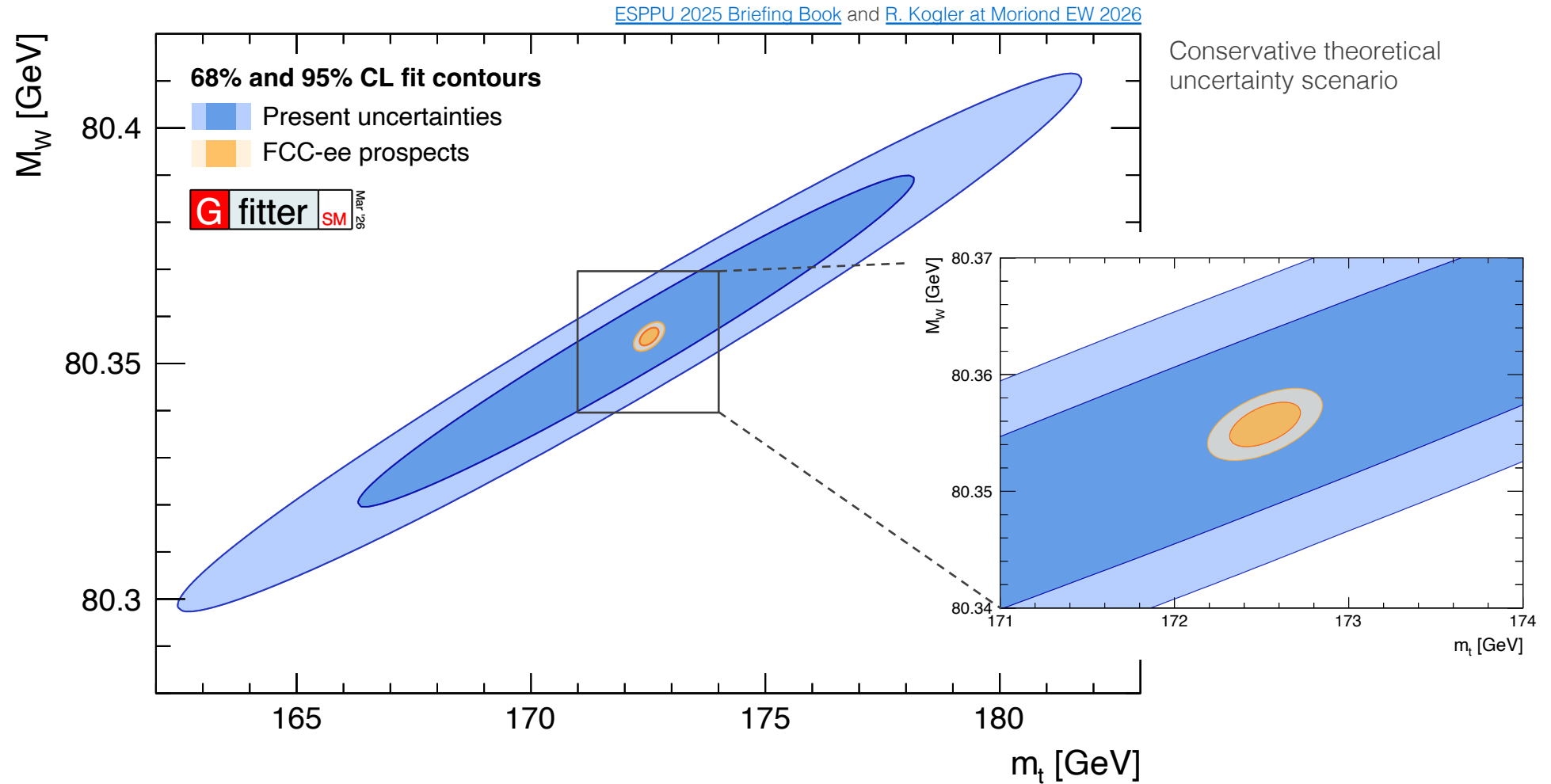
Observable	value	present ±	uncertainty	FCC-ee Stat.	FCC-ee Syst.	Comment and leading uncertainty
τ lifetime (fs)	290.3	±	0.5	0.001	0.005	ISR, τ mass
τ mass (MeV)	1 776.93	±	0.09	0.002	0.02	estimator bias, ISR, FSR
τ leptonic ($\mu\nu_\mu\nu_\tau$) BR (%)	17.38	±	0.04	0.00007	0.003	PID, π^0 efficiency
m_W (MeV)	80 360.2	±	9.9	0.18	0.16	From WW threshold scan Beam energy calibration
Γ_W (MeV)	2 085	±	42	0.27	0.2	From WW threshold scan Beam energy calibration
$\alpha_S(m_W^2) (\times 10^4)$	1 010	±	270	2	2	Combined R_ℓ^W , Γ_{tot}^W fit
$N_\nu (\times 10^3)$	2 920	±	50	0.5	small	Ratio of invis. to leptonic in radiative Z returns
m_{top} (MeV)	172 570	±	290	4.2	4.9	From $t\bar{t}$ threshold scan QCD uncert. dominate
Γ_{top} (MeV)	1 420	±	190	10	6	From $t\bar{t}$ threshold scan QCD uncert. dominate
$\lambda_{\text{top}}/\lambda_{\text{top}}^{\text{SM}}$	1.2	±	0.3	0.015	0.015	From $t\bar{t}$ threshold scan QCD uncert. dominate
$t\bar{t}Z$ couplings		±	30%	0.5–1.5 %	small	From $\sqrt{s} = 365 \text{ GeV}$ run

Improvements up to $\times 500$ over current knowledge

Input to global electroweak fit: requires significant improvements in theoretical predictions

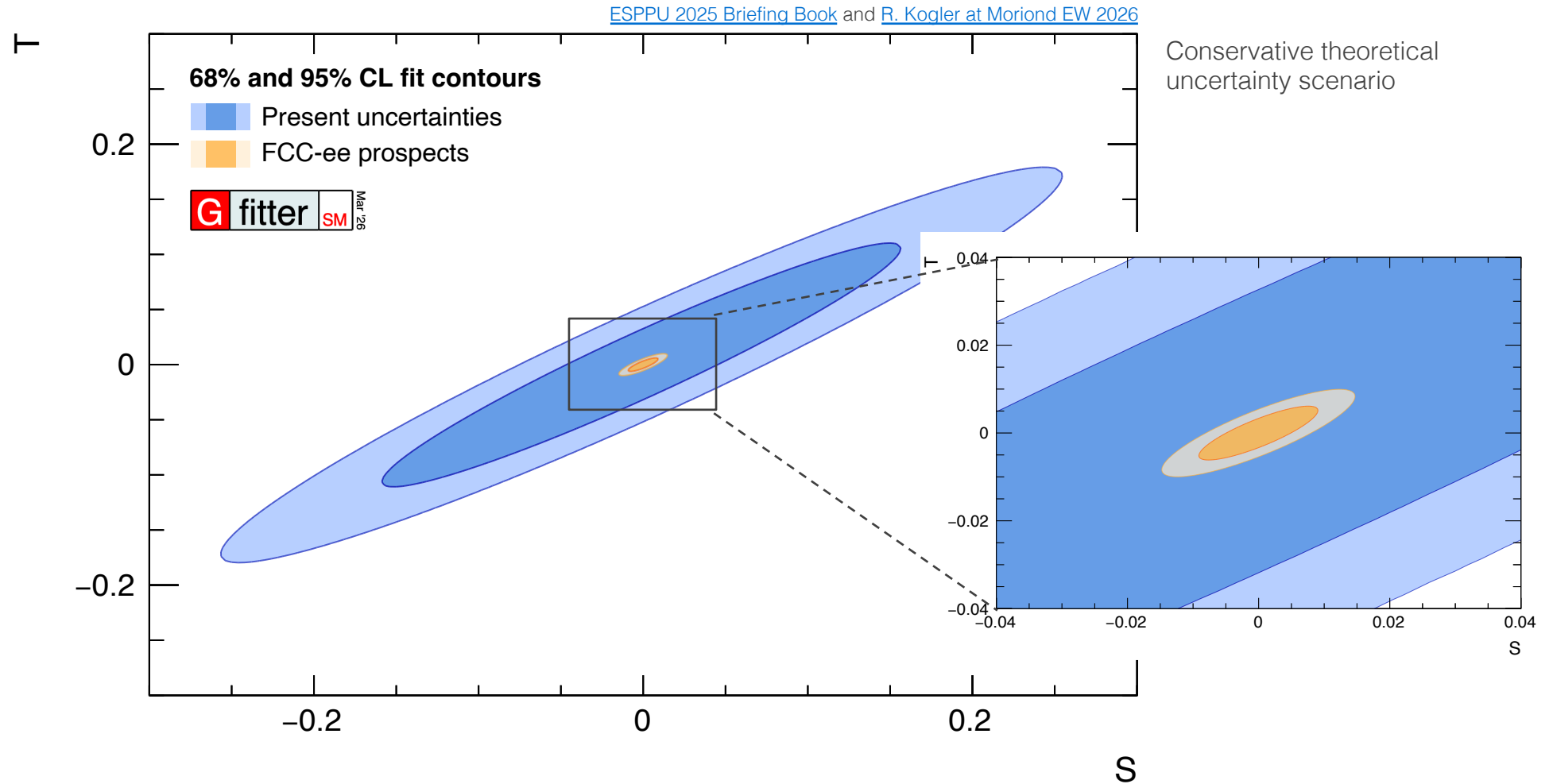
FCC-ee – also a Tera-Z, W and top factory

Global electroweak fit expressed on top versus W mass



FCC-ee – also a Tera-Z, W and top factory

Global electroweak fit: indirect constraints on new physics via “oblique parameters”



FCC-ee – also a flavour factory (on Z pole)

$$BR(Z \rightarrow bb / cc) = 15\% / 12\%$$

$$\Gamma(Z \rightarrow qq) \propto (g_V^2 + g_A^2)$$

Large c and b-hadron statistics — combines strengths of Belle-II ($e^+e^- \rightarrow \Upsilon(4S) \rightarrow B\bar{B}$) and LHCb ($pp \rightarrow b\bar{b} + X$)

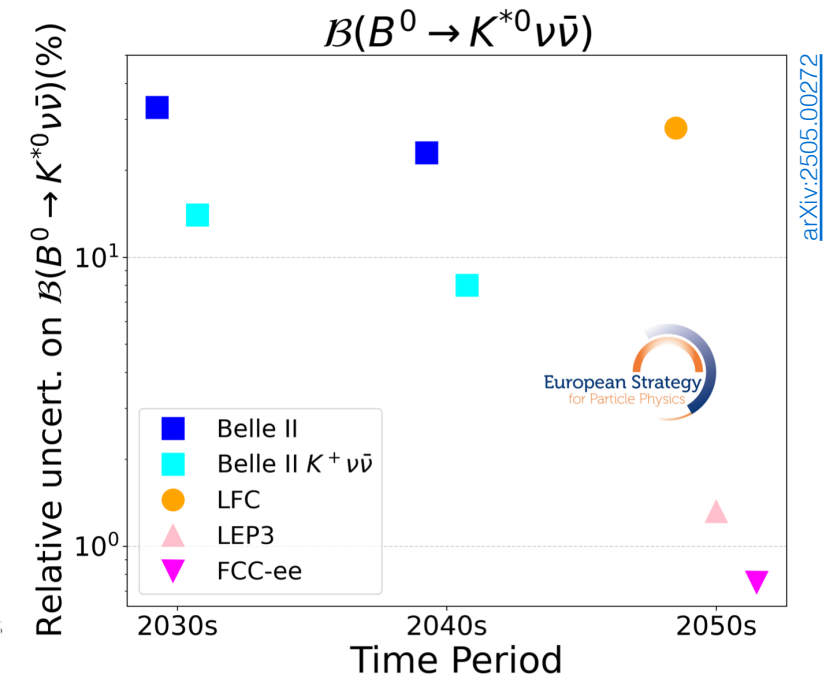
Attribute	$\Upsilon(4S)$	pp	Z
All hadron species		✓	✓
High boost		✓	✓
Enormous production cross-section		✓	
Negligible trigger losses	✓		✓
High geometrical acceptance	✓		✓
Low backgrounds	✓		✓
Flavour-tagging power	✓		✓
Initial-energy constraint	✓		(✓)

Particle species	B^0	B^+	B_s^0	Λ_b	B_c^+	$c\bar{c}$	$\tau^-\tau^+$
FCC-ee ($\times 10^9$)	370	370	90	80	2	720	200
Belle-II ($\times 10^9$)	28	28	—	—	—	33	46

Yields for
 $6 \cdot 10^{12}$ Z

Yields for
 50 ab^{-1}

The larger yield of B mesons than Belle II allows unmatched precision on B decays with neutrinos



Clean reconstruction due to boost and flavour tagging ($> \text{LHCb}$), excellent charm / τ separation (challenging at $\Upsilon(4S)$)

Ultimate CKM angle precision (similar to LHCb)

Ultimate τ factory

$B \rightarrow \tau \nu$ allows 1% measurement of $|V_{ub}|$ and running above WW threshold allows *on-shell* measurement of $|V_{cb}|$ to $\sim 1\%$

Current precision $3.5_{V_{ub}} / 1.1_{V_{cb}}\%$, but discrepancies between exclusive and inclusive results of $17_{V_{ub}} / 5_{V_{cb}}\%$, respectively

FCC-ee — projected construction cost

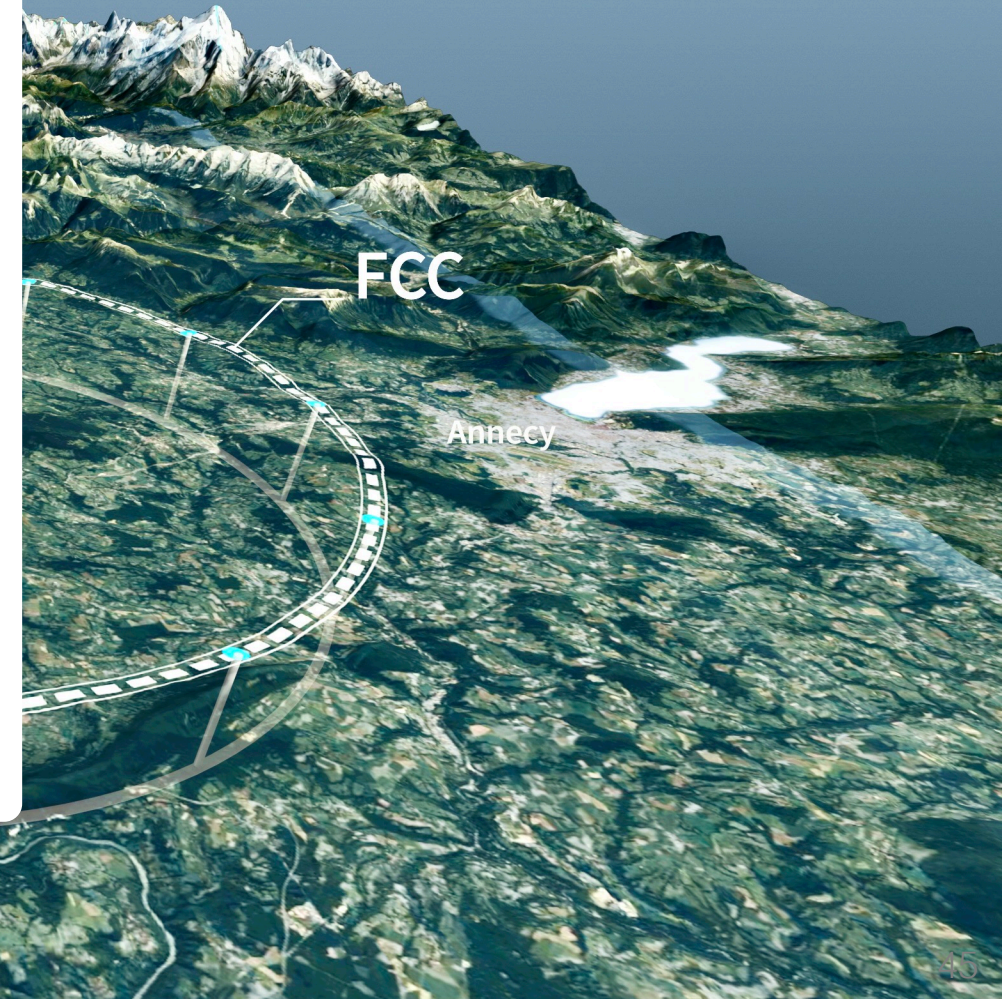
First stage incl. Z, WW and ZH working points. Upgrade to ttbar adds 1,260 MCHF

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
FCC-ee total	14,020
+ four experiments (non-CERN part)	1,300
FCC-ee total incl. four experiments	15,320

Note: First FCC-ee stage (up to ZH)

Over a period of 15 years

- Human resources for construction estimated to 15,000 FTE-years



FCC-ee — projected construction cost

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Over a period of 15 years

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Socio-economic impact analysis (incl. investment, personnel, external effects, dismantling, ...) estimates benefit–cost factor of 1.2 (net: 4.1 MCHF)

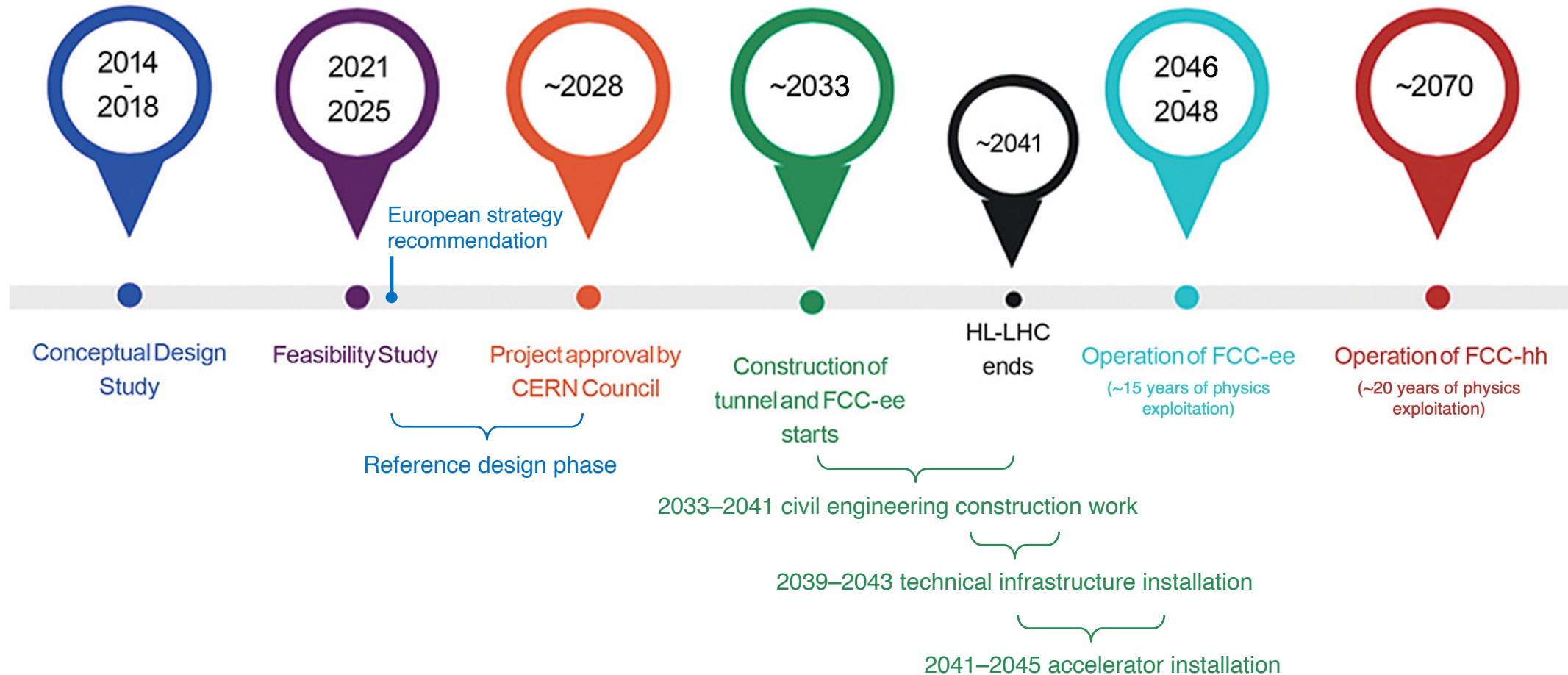
TOTAL COSTS (MCHF) 20,020		TOTAL BENEFITS 24,092	
INVESTMENTS (CAPEX)	10,8%	SCIENTIFIC PRODUCTIO	11,7%
OPERATION COSTS	9,42%	EARLY CAREER TRAINING	20,7%
Personnel	7,544	INDUSTRIAL BENEFITS (SUPPLIERS)	39,7%
Other Ops	1,879	OPEN SOFTWARE	18,2%
NEGATIVE EXTERNALITIES	1,7%	CULTURAL BENEFITS	9,7%
Shadow Cost of Carbon	341	Onsite Visitors	2,242
Other (Radiation, Noise, Air Pollution, etc.)	13	Online Visitors	102
DECOMMISSIONING	72		
NET PRESENT VALUE 4,071 MCHF		BENEFIT-COST RATIO 1.20	

90% CL lower limit

<https://doi.org/10.5281/zenodo.10653395>

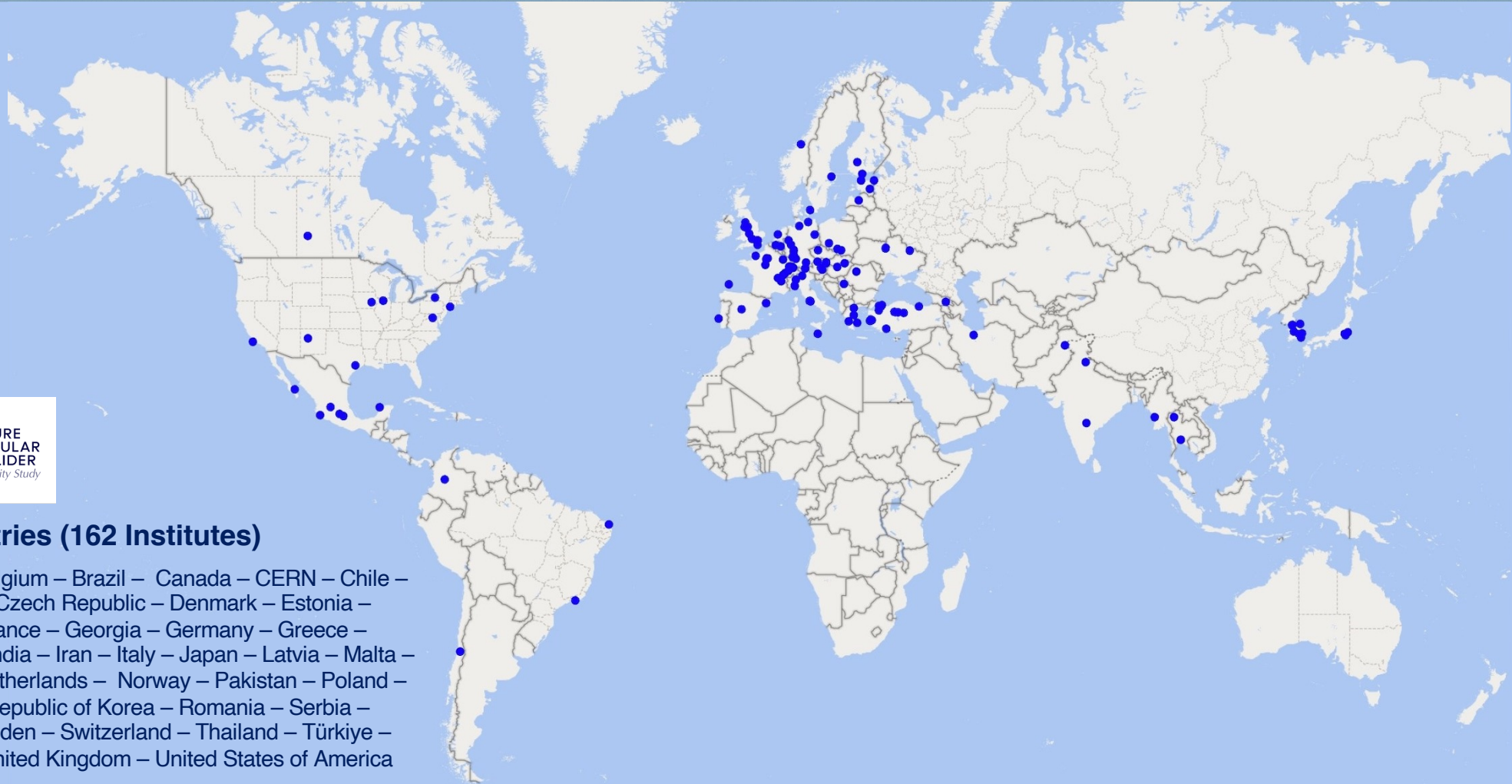
FCC — timeline of integrated programme

FCC-ee followed by FCC-hh



FCC-ee — global collaboration

Increasing international collaboration is a prerequisite for success. Links with science, R&D, and high-tech industry will be essential to further advance and prepare the implementation of the FCC



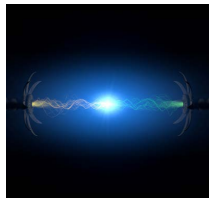
38 Countries (162 Institutes)

Austria – Belgium – Brazil – Canada – CERN – 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

European Commission — moonshots

Recognition by the European Commission highlights the strategic value of the FCC, not only for fundamental research but also as a project fostering high-level collaboration in Europe

[Link to document](#)



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.



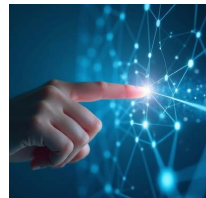
Clean Aviation

What: Lead the world in developing the next generation of CO₂-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.



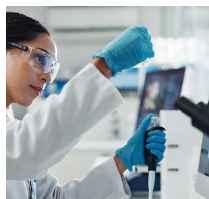
Data Sovereignty

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.



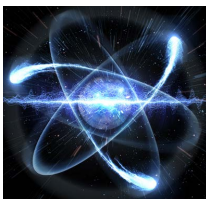
Automated Transport and Mobility

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.



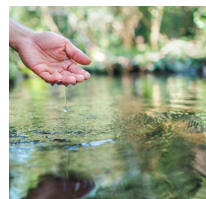
Fusion Energy

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.



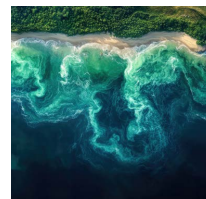
Space Economy

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

Conclusions

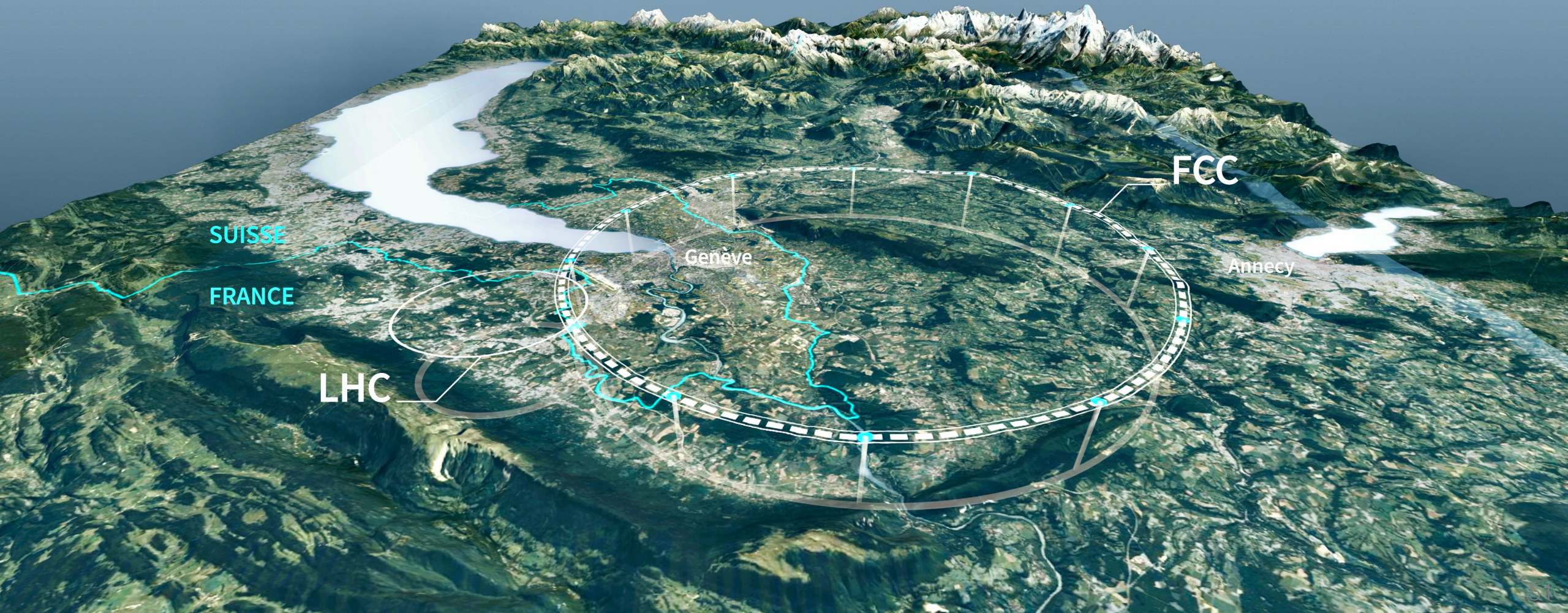
FCC-ee is Europe's priority for CERN's next collider project: a transformative instrument for exploring the Higgs boson, the electroweak sector, and the quantum structure of fundamental interactions with unprecedented precision

A detailed feasibility study has been released, and the project is now moving toward the next design phase, with a possible CERN Council decision around 2028

FCC-ee is also the foundation for the future energy frontier, enabling a subsequent hadron collider in the same infrastructure — a highly synergistic and complementary programme that maximises the long-term physics reach

Sustainability is a design principle, not an afterthought, embedded in the FCC-ee study from the outset

Extra slides ...



FCC-ee — projected acceptance

Does the average taxpayer in CERN's member states support a new accelerator at CERN?

A public perception study assessed quantitative indicators for drivers as basis for evidence-based actions

Country	Respondents aware of CERN	Respondents with WTP > 0	WTP per person (all responders)		WTP per person (only respondents with WTP>0)		Average tax contribution per person in 2021
			Mean	Median	Mean	Median	
	%	%	CHF	CHF	CHF	CHF	CHF
CERN member states							
Switzerland	80	73	55	20	67	50	6
UK	44	77	30	14	39	19	4
Italy	65	76	29	13	38	22	2
Germany	39	69	20	11	29	22	3
Israel	28	68	16	6	23	15	3
France	46	52	4 to 14	2	28	11	3
Poland	38	77	9	6	12	10	1
Non-member states							
USA	27	73	44	24	61	48	zero
Japan	13	29	10	0	35	18	zero

How much of their taxes would citizens be willing to allocate to a new collider project at CERN?

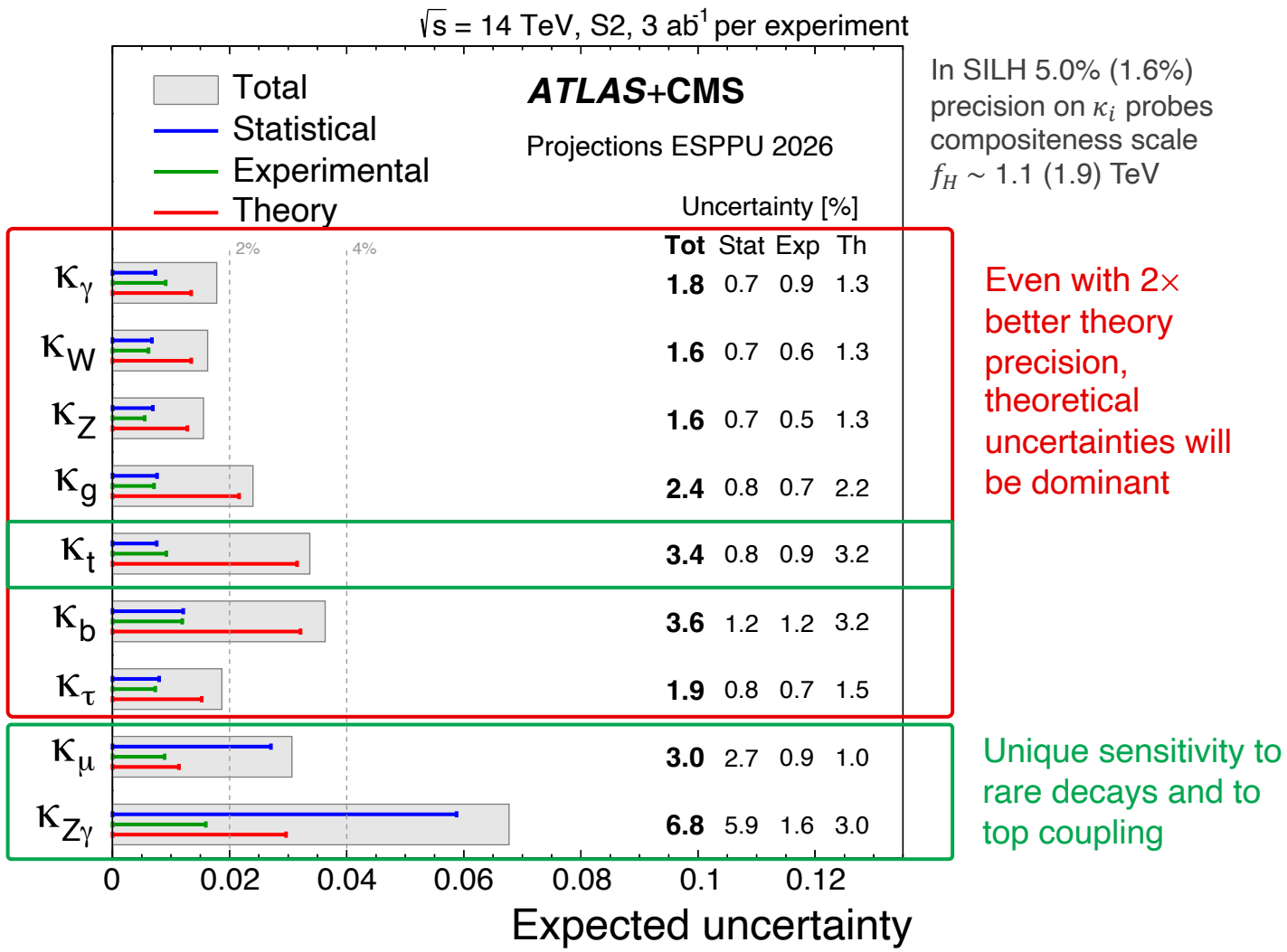
Study based on accredited methodology, passed through an ethics committee and carried out with an independent, domain specific quality management certified support company.

Link to article: <https://inspirehep.net/literature/3155013>

- In general, the offered amounts exceed significantly the actual contribution of a taxpayer to CERN
- 66% of respondents expressed their willingness to financially support a new collider at CERN with their annual taxes. 34% reported zero willingness to support
- Positive opinions raised from 58% to 78%, negative fell from 18% to 2% after receiving specific CERN related information

HL-LHC Physics prospects — Higgs

Higgs coupling prospects | Coupling strength modifiers ($\kappa_i^2 \equiv \sigma_i/\sigma_i^{SM}$, assuming SM Γ_H)

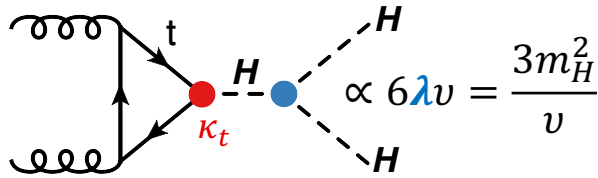


Prospects for Higgs width from off-shell measurement, invisible Higgs decays, Higgs sector extensions (2HDM)

- Γ_H via $\mu_{\text{off-shell}} / \mu_{\text{on-shell}}$ in $H \rightarrow 4\ell$ & $2\ell 2\nu$ with $< 20\%$ uncertainty
- $\text{BR}(H \rightarrow \text{invisible}) < 2.5\%$
- Discover or exclude MSSM two Higgs doublets scenario deep into TeV scale for $\tan\beta > 6$

HL-LHC Physics prospects — Higgs

Higgs self-coupling via Higgs pair production: complex final states, eldorado for ML enthusiasts, strongest channels: $HH \rightarrow b\bar{b}\gamma\gamma, b\bar{b}\tau\tau, b\bar{b}b\bar{b}$. Best sensitivity to λ at low $m(HH)$

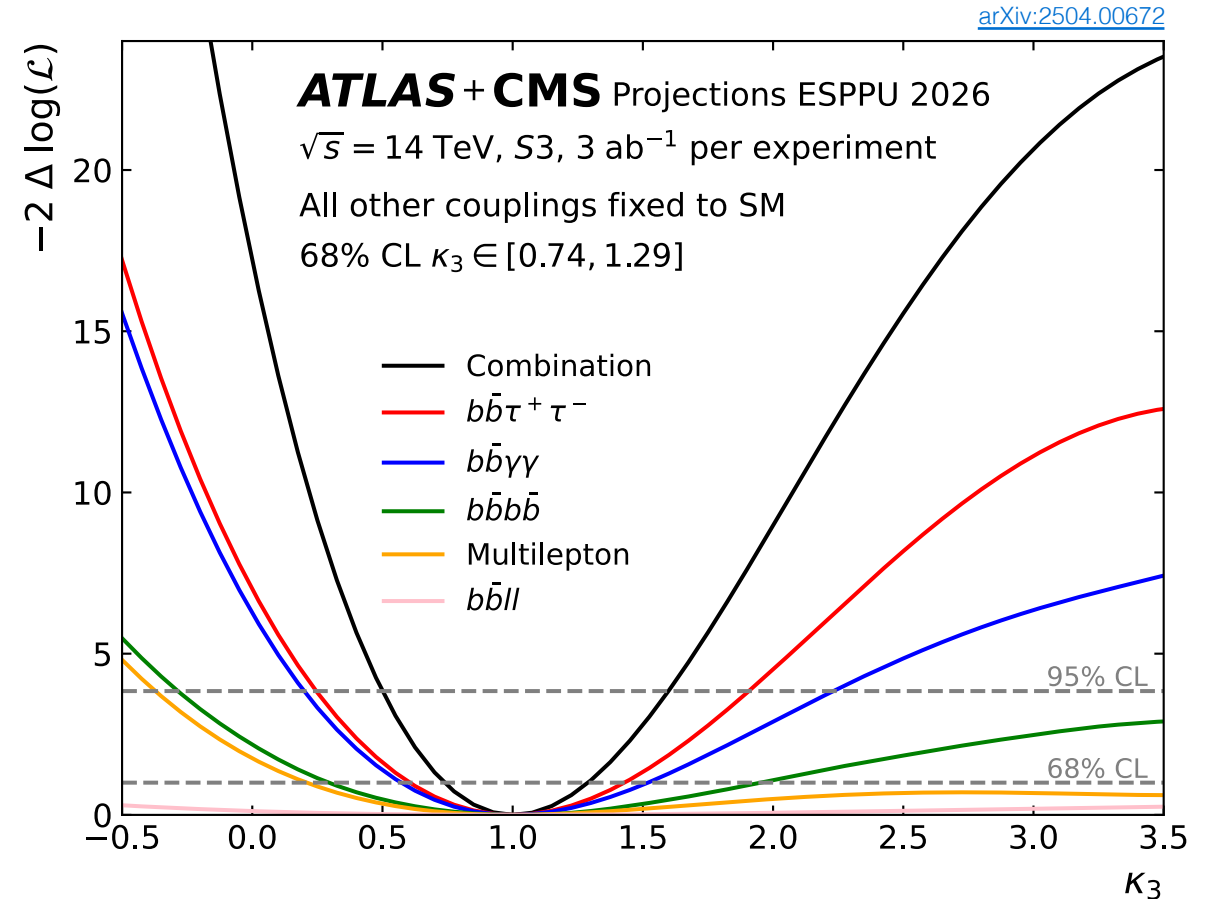


$$V(\phi) = -\mu^2|\phi|^2 + \lambda|\phi|^4$$

$$\kappa_\lambda \equiv \lambda_3^{\text{obs}} / \lambda^{\text{SM}}$$

For SM:

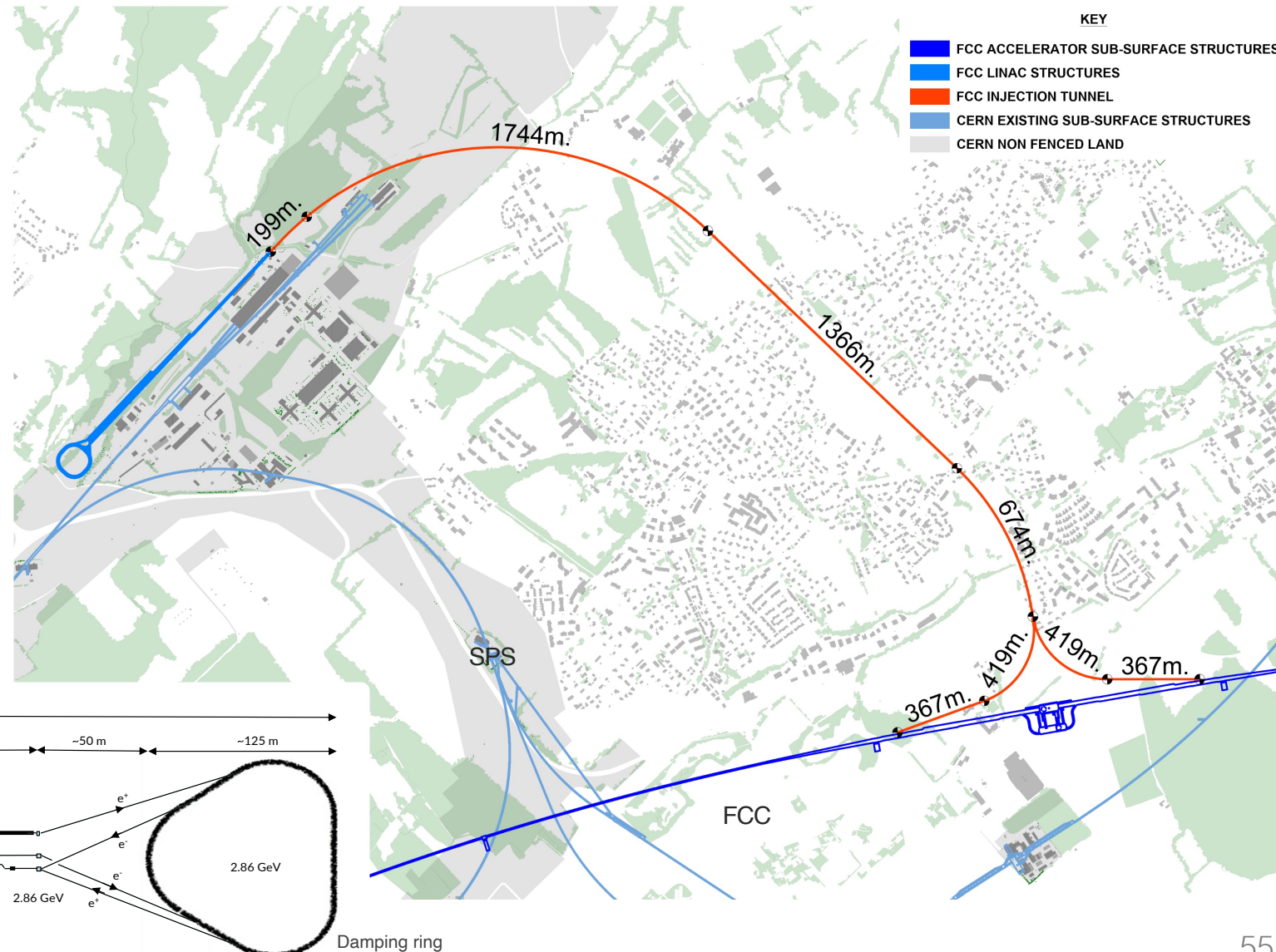
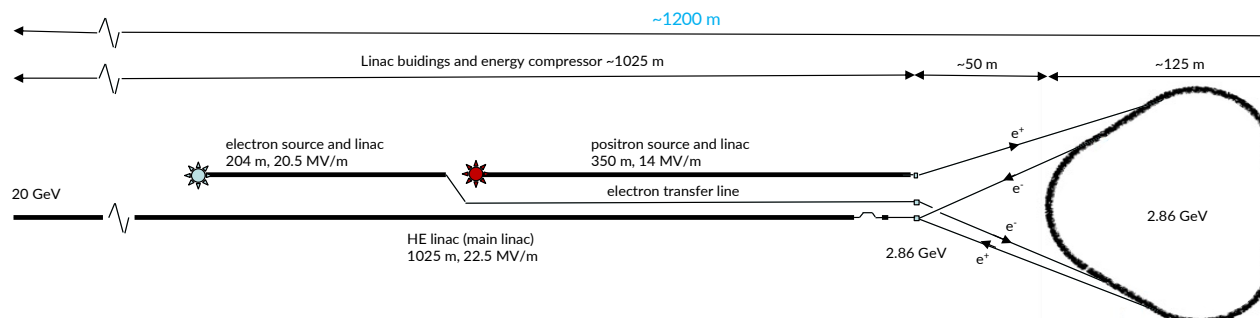
- **Expect HH observation $> 7\sigma$**
- κ_λ **precision better than 30%**



FCC-ee – Injector

FCC-ee injector with high-energy linac

- Located on CERN Préveessin site
- Transfer line to FCC PA (LHC P8, LHCb), “cut and cover” construction
- Conventional positron source using tungsten target + capture linac, need: $1.1 \times 10^{13} \text{ e}^+/\text{s}$ (SLC: $\sim 6 \times 10^{12} \text{ e}^+/\text{s}$)
- 2.9 GeV damping ring with wigglers (small synchrotron to reduce transverse and longitudinal beam emittance)
- Main linac $\sim 1 \text{ km}$ with 22.5 MV/m to accelerate e^+ and e^- to 20 GeV for injection into booster
- Total length about 1.2 km



FCC-ee — parameters

Global data-centre electricity use is projected to rise from 460 TWh in 2024 (1.5% of total electricity consumption) to 1,000 TWh ($\pm 25\%$) by 2030 and 1,300 ($\pm 40\%$) TWh by 2035 ($\sim 15\%$ annual raise), driven mainly by the US and China. The AI share may grow from 10~20% today to 30~50% in 2035.

Reference: [International Energy Agency](#),
see also [this critical review](#) of the modelling



Aerial view of Microsoft's new AI datacenter in Mt Pleasant, Wisconsin, Sep 2025 [\[Link\]](#)

Despite the constant synchrotron power ($U_0 \propto E^4/\rho$, $P_{SR} = U_0 I$), due to the larger RF voltage and system size (increased cryogenic system), RF efficiency losses, and other increasing accelerator demands, **the electrical power consumption increases with CM energy:**

FCC-ee electrical energy consumption	Z	W	H	top
Beam energy [GeV]	45.6	80	120	182.5
Peak power during beam operation [MW]	250	275	297	381
Total FCC-ee yearly consumption [TWh]	1.2	1.3	1.4	1.85

LHC + injectors: ~ 200 MW peak power

Today with LHC operating: ~ 1.3 TWh

Various R&D towards further reduction of electrical energy consumption

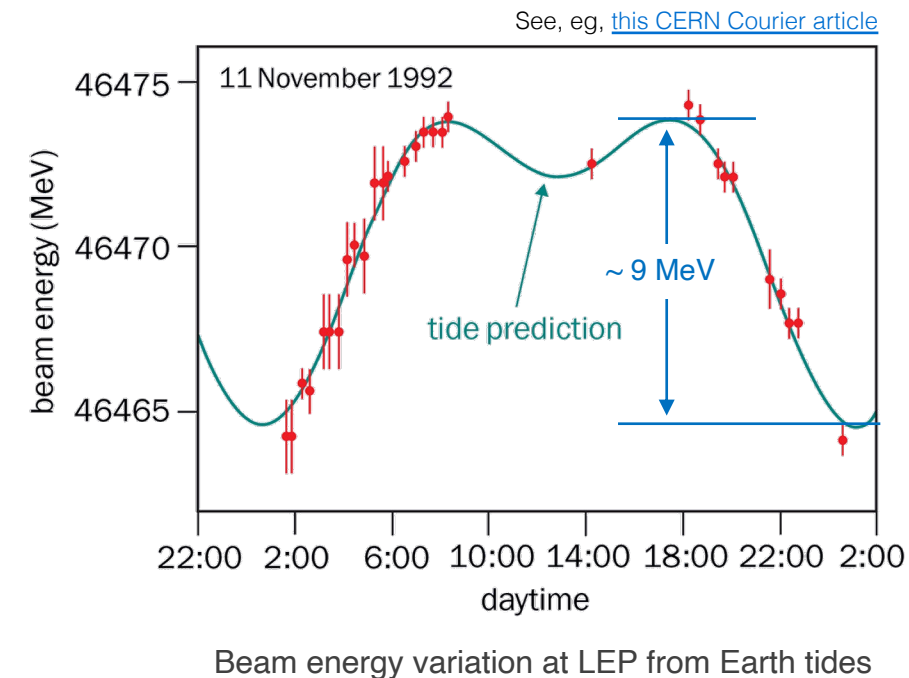
FCC-ee — beam energy

Precise knowledge of beam energy at Z pole crucial, meticulous work done at LEP to achieve

	m_Z	Γ_Z
LEP E_{CM} related syst. uncertainty:	1.7 MeV (1.9×10^{-5})	1.2 MeV
FCC-ee statistical uncertainty:	4 keV ($\ll 10^{-6}$)	4 keV

Precise beam energy calibration ($\Delta E/E < 10^{-6}$) through resonant depolarisation (RDP) as previously done at VEPP-2M (Novosibirsk) and LEP

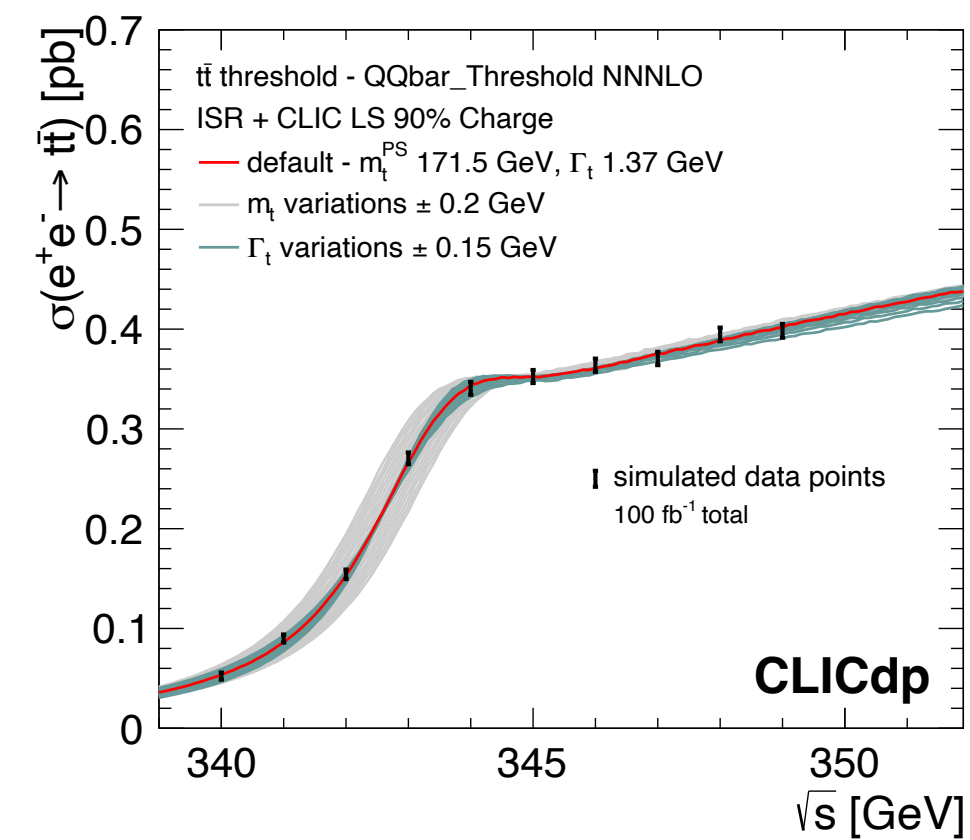
- Due to synchrotron radiation, $e^\pm$ in storage ring become transversely polarised with a spin tune (number of spin precessions per turn in the bending field): $\nu_e = a_e \gamma = a_e E_e / m_e$. By applying an external RF field tuned to ν_e , which depolarises the beam, E_e can be measured with extraordinary precision
- At LEP, RDP could only be performed in a few fills, before or after collisions. E_{CM} knowledge limited by modelling of time evolution between measurements. E_{CM} calibration must be a central consideration in FCC-ee design & operational strategy: quasi-continuous RDP using non-colliding (unpaired) bunches
- Expect that E_{CM} systematics can be limited to 100 keV on m_Z and 25 keV on Γ_Z



FCC-ee – also a Tera-Z, W and top factory

Extreme luminosity on Z pole: $140 \cdot 10^{34} \text{ cm}^{-2}\text{s}^{-1}$ / IP, 205 ab^{-1} & $6 \cdot 10^{12} \text{ Z}$ (4 IPs) — ultimate EW precision data

[arXiv:2505.00272](https://arxiv.org/abs/2505.00272)



Simulation of tt threshold scan with CLIC [\[arXiv:2503.24168\]](https://arxiv.org/abs/2503.24168)

Observable	value	present ±	uncertainty	FCC-ee Stat.	FCC-ee Syst.	Comment and leading uncertainty
τ lifetime (fs)	290.3	±	0.5	0.001	0.005	ISR, τ mass
τ mass (MeV)	1 776.93	±	0.09	0.002	0.02	estimator bias, ISR, FSR
τ leptonic ($\mu\nu_\mu\nu_\tau$) BR (%)	17.38	±	0.04	0.00007	0.003	PID, π^0 efficiency
m_W (MeV)	80 360.2	±	9.9	0.18	0.16	From WW threshold scan Beam energy calibration
Γ_W (MeV)	2 085	±	42	0.27	0.2	From WW threshold scan Beam energy calibration
$\alpha_S(m_W^2) (\times 10^4)$	1 010	±	270	2	2	Combined R_ℓ^W , Γ_{tot}^W fit
$N_\nu (\times 10^3)$	2 920	±	50	0.5	small	Ratio of invis. to leptonic in radiative Z returns
m_{top} (MeV)	172 570	±	290	4.2	4.9	From $t\bar{t}$ threshold scan QCD uncert. dominate
Γ_{top} (MeV)	1 420	±	190	10	6	From $t\bar{t}$ threshold scan QCD uncert. dominate
$\lambda_{\text{top}}/\lambda_{\text{top}}^{\text{SM}}$	1.2	±	0.3	0.015	0.015	From $t\bar{t}$ threshold scan QCD uncert. dominate
ttZ couplings		±	30%	0.5–1.5 %	small	From $\sqrt{s} = 365 \text{ GeV}$ run

Improvements up to $\times 2000$ over current knowledge

FCC-ee – the Higgs factory

Extremely challenging — cornering the electron Yukawa coupling: $g_e = \sqrt{2}m_e/v \approx 2.9 \cdot 10^{-6}$

Can we measure the decay? (recall: $\Gamma_H = 4.1 \text{ MeV}$)

$$\text{BR}(H \rightarrow e^+e^-) \simeq \frac{1}{\Gamma_H} \cdot \frac{G_F m_H m_e^2}{4\pi\sqrt{2}} \approx 5.2 \cdot 10^{-9}$$

The entire HL-LHC may produce 2 such events!

At the FCC-ee, BW s-channel resonance:

$$\sigma(e^+e^- \rightarrow H) \simeq \frac{4\pi\Gamma_H\Gamma(H \rightarrow e^+e^-)}{(s - m_H^2)^2 + m_H^2\Gamma_H^2} \xrightarrow{s=m_H^2} \frac{4\pi}{m_H^2} \text{BR}(H \rightarrow e^+e^-) \approx 1.6 \text{ fb}$$

but ISR and $\sqrt{s}$ spread will lead to smearing of BW peak, so that effective cross section is 0.3 fb (remember: $L_{ZH} = 10.8 \text{ ab}^{-1}$). **Can it be done?**

three generations of matter (fermions)			interactions / force carriers (bosons)	
I	II	III		
mass charge spin $\approx 2.2 \text{ MeV}/c^2$ $\frac{2}{3}$ $\frac{1}{2}$ u up	$\approx 1.28 \text{ GeV}/c^2$ $\frac{2}{3}$ $\frac{1}{2}$ c charm	$\approx 173.1 \text{ GeV}/c^2$ $\frac{2}{3}$ $\frac{1}{2}$ t top	0 0 1 g gluon	$\approx 124.97 \text{ GeV}$ 0 0 H higgs
$\approx 4.7 \text{ MeV}/c^2$ $-\frac{1}{3}$ $\frac{1}{2}$ d down	$\approx 96 \text{ MeV}/c^2$ $-\frac{1}{3}$ $\frac{1}{2}$ s strange	$\approx 4.18 \text{ GeV}/c^2$ $-\frac{1}{3}$ $\frac{1}{2}$ b bottom	0 0 1 γ photon	
$\approx 0.511 \text{ MeV}/c^2$ -1 $\frac{1}{2}$ e electron	$\approx 105.66 \text{ MeV}/c^2$ -1 $\frac{1}{2}$ μ muon	$\approx 1.7768 \text{ GeV}/c^2$ -1 $\frac{1}{2}$ τ tau	$\approx 91.19 \text{ GeV}/c^2$ 0 1 Z Z boson	
$< 1.0 \text{ eV}/c^2$ 0 $\frac{1}{2}$ ν_e electron neutrino	$< 0.17 \text{ MeV}/c^2$ 0 $\frac{1}{2}$ ν_μ muon neutrino	$< 18.2 \text{ MeV}/c^2$ 0 $\frac{1}{2}$ ν_τ tau neutrino	$\approx 80.39 \text{ GeV}/c^2$ ± 1 1 W W boson	

Almost all Higgs couplings to SM particles will have been measured at HL-LHC & FCC-ee

FCC-ee – the Higgs factory

Extremely challenging — cornering the electron Yukawa coupling: $g_e = \sqrt{2}m_e/v \approx 2.9 \cdot 10^{-6}$

Can we measure the decay? (recall: $\Gamma_H = 4.1$ MeV)

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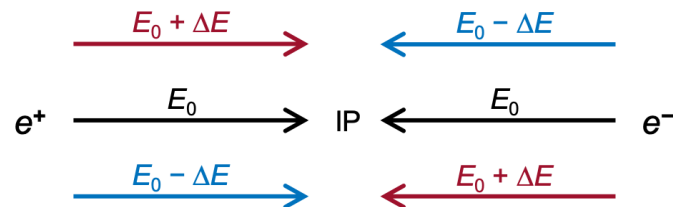
The entire HL-LHC may produce 2 such events!

At the FCC-ee, BW s-channel resonance:

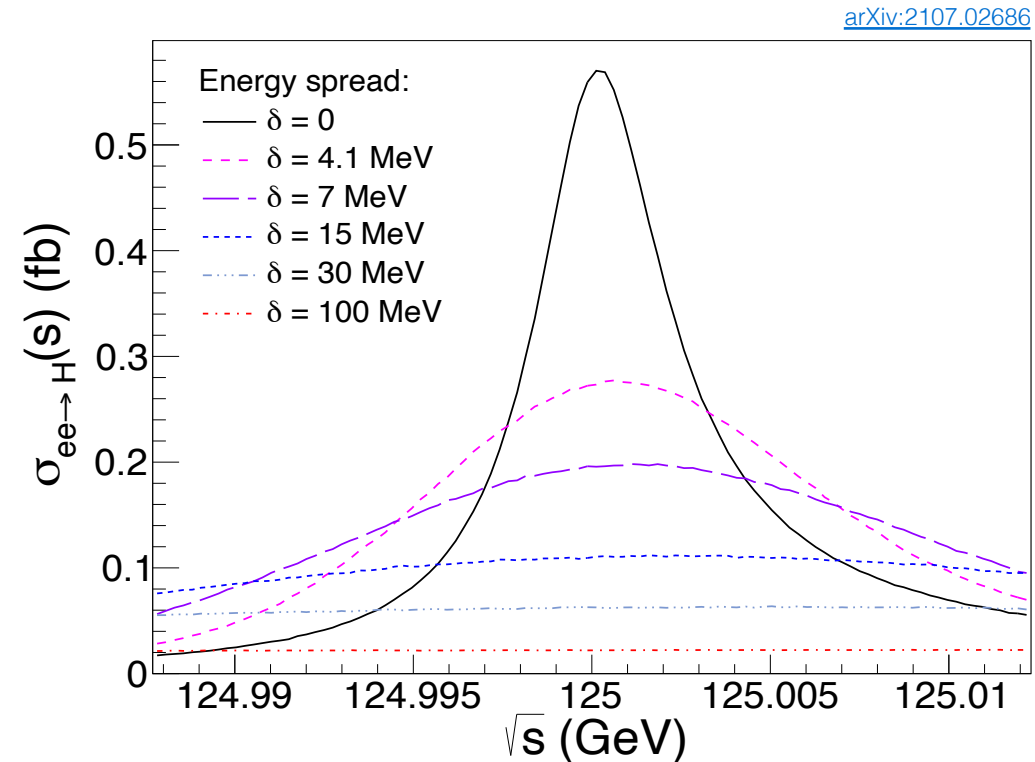
$$\sigma(e^+e^- \rightarrow H) \simeq \frac{4\pi\Gamma_H\Gamma(H \rightarrow e^+e^-)}{(s - m_H^2)^2 + m_H^2\Gamma_H^2} \xrightarrow{s=m_H^2} \frac{4\pi}{m_H^2} \text{BR}(H \rightarrow e^+e^-) \approx 1.6 \text{ fb}$$

but ISR and $\sqrt{s}$ spread will lead to smearing of BW peak, so that effective cross section is 0.3 fb (remember: $\mathcal{L}_{ZH} = 10.8 \text{ ab}^{-1}$). **Can it be done?**

- Requires precise knowledge of Higgs mass to few MeV
- Beam must be monochromatized to match narrow Γ_H [arXiv: 2411.04210]



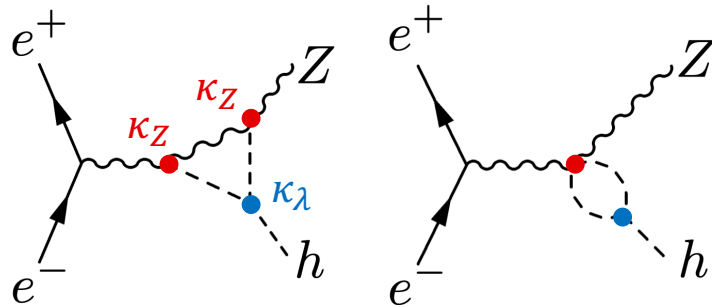
Correlate energy and transverse position so high-energy particles collide with low-energy ones (opposite beam dispersions at IP) — requires dedicated instruments: proposed for many e^+e^- colliders, but never implemented



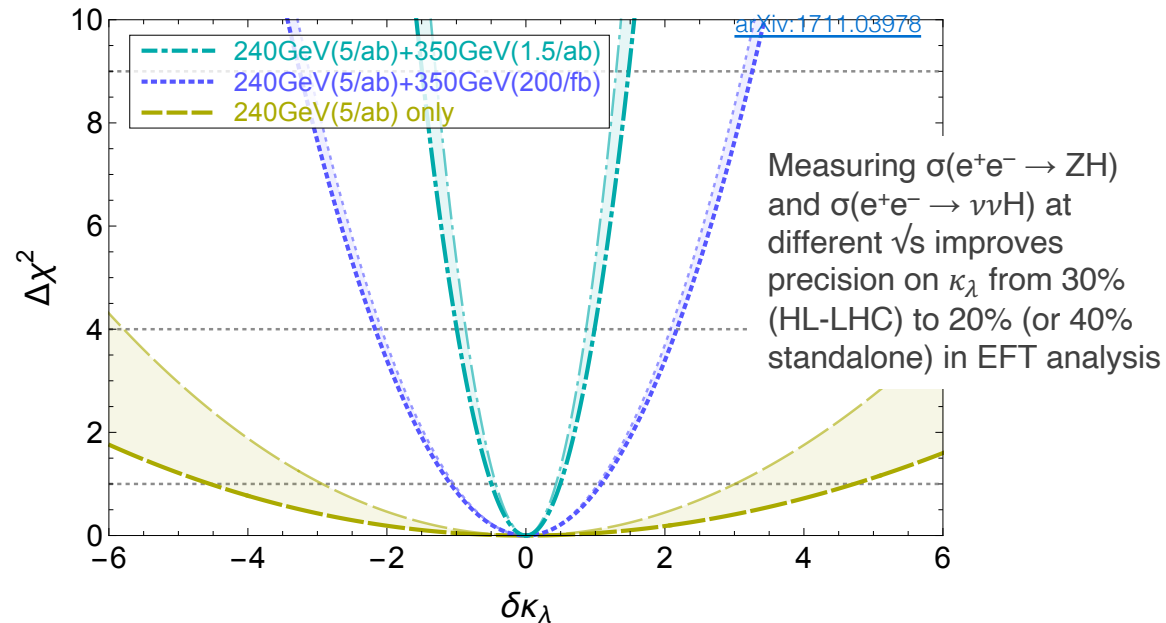
Possible sensitivity to g_e of $\sim 0.5\sigma$ per year and IP

FCC-ee – the Higgs factory

Higgs self-coupling — no HH production at FCC-ee, sensitivity through H–H–H loops

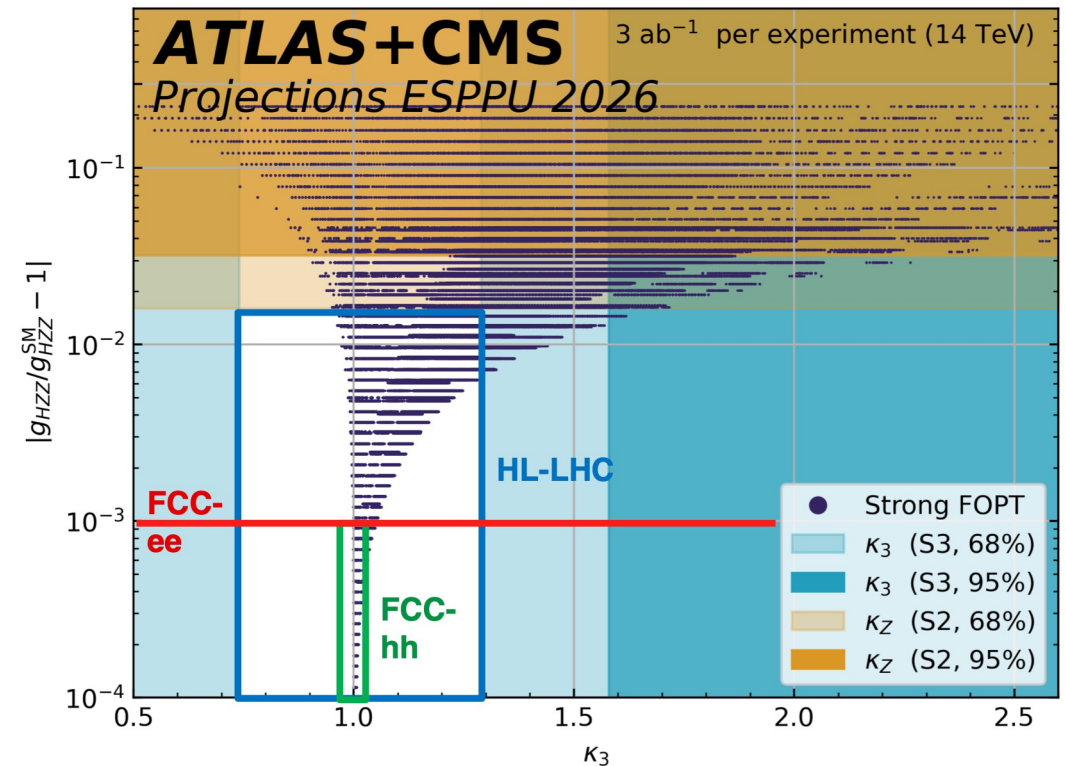


NLO vertex corrections to Higgsstrahlung (similar for W-boson fusion)



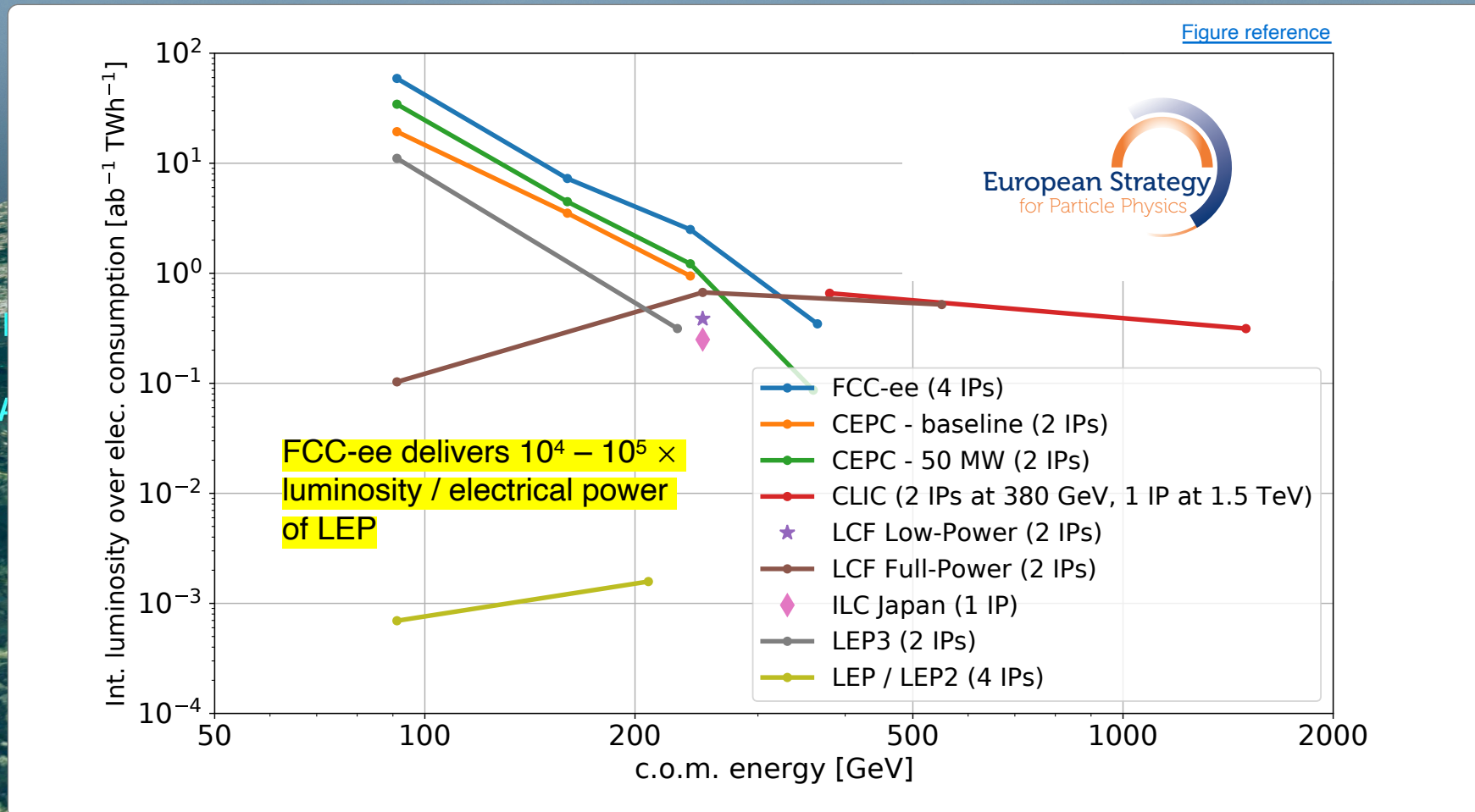
FCC-ee+hh tightly constrains BSM models with 1st order EW phase transition

[arXiv:2504.00672](https://arxiv.org/abs/2504.00672)



Power efficiency: next-generation e^+e^- collider

FCC-ee vs LEP: larger bending radius, more efficient superconducting RF, improved beam optics (higher beam-beam performance limits), ultra-low emittance magnet lattices, crab waist scheme, continuous top-up injection via booster (always near optimal luminosity), **power-optimised from the start**



The big picture: next-generation collider projects for CERN

Project	Construction start	First beams	Peak lumi at Z per IP [$10^{34} \text{ cm}^{-2} \text{ s}^{-1}$]	Peak lumi at HZ per IP [$10^{34} \text{ cm}^{-2} \text{ s}^{-1}$]	Years of operation	Construction cost* [BCHF]	Next stage collider	Start of operation	Total construction cost* [BCHF]
FCC-ee	2033	2046	144	7.5	14	15.3	FCC-hh	2079	34.7
LEP3	2037	2047	40	1.6	15	4.1	FCC-hh	2074	32.5
LCF 250 → 550 GeV	2035	2045	0.28	1.4 – 2.7	19	9.4 + 5.4 = 14.8	> 1 TeV collider?	–	–
CLIC 380 → 1500 GeV	2035	2045	–	1.2 _{380 GeV}	20	7.5 + 7.1 = 14.6	3 TeV collider?	–	–
LHeC	2037	2044	–	2.3	7	2.1	FCC-hh	2064	30.5

Similar start dates driven by HL-LHC running until 2041

*Construction costs include experiments

Intermediate conclusions by ESG

[\[Link to document\]](#)

FCC-ee is technically feasible and would deliver the broadest high-precision particle physics programme. It would also pave the way towards a hadron collider reusing the tunnel and much of the infrastructure

LEP3 and LHeC as alternative options with significantly lower construction cost (but no new tunnel for a possible hadron collider): not competitive with FCC-ee on breadth of physics programme, not flagship colliders

CLIC and LCF as alternative options: operation at 550 GeV or higher would offer competitive programmes in Higgs and top-quark physics, however, overall not competitive with FCC-ee. Both require a new tunnel of about 33 km to reach their ultimate energies. Path to 10 TeV pCM requires plasma wakefield acceleration, which is not yet a proven technology

Descoped FCC-ee to reduce cost by 15% (no ttbar run: −1.26 BCHF, drop 2 / 4 experiments: −0.80 BCHF, decrease RF power from 50 → 30 MW (−0.35 BCHF) significantly impacts breadth of the physics programme and precision, but still stronger than other options. Scenarios would be reversible

[$L(\text{FCC-ee}) \times 3/5 \times 2/4 \times 1.2 = L(\text{FCC-ee}) \times 0.36 \rightarrow$ need to run 2.8 × longer for equivalent physics]

General Recommendations

- i. The **full exploitation of the physics potential of the LHC and the HL-LHC and the completion of the high-luminosity upgrade remain the highest priorities** of European particle physics. Every effort must be made to complete the HL-LHC upgrade within the current schedule.*
- ii. The unique ecosystem of particle physics research centres and universities in Europe should be further strengthened in order to address the objectives set out in this Strategy.*
- iii. The implementation of the Strategy should be pursued in strong collaboration with global partners and neighbouring fields.*
- iv. The relationship between the particle physics community and the European Commission should be further strengthened, exploring funding opportunities for the realisation of infrastructure projects and R&D programmes in cooperation with other fields of science and industry.*

The next CERN flagship collider project

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

At this stage, without knowing the reasons for which the FCC-ee would not be feasible, other alternative options are not ranked.

Technology

To ensure that Europe remains at the forefront of technologies for particle physics, R&D in collaboration with international partners and industry must continue to be supported with high priority, thereby enhancing sustainability and societal impact.

Accelerator Technology:

- i. *In order to realise the visionary plan presented, the **highest priority** must be the **development and industrialisation of key technologies: advanced superconducting and normal-conducting RF structures, efficient RF power sources and accelerator-quality magnets in the 14 - 20 T range**, including those based on **high-temperature superconductors**.*
- ii. *Demonstration of **high-current multi-turn energy recovery** in linacs constitutes an important step towards power-efficient lepton accelerators for a broad range of applications and should be pursued.*
- iii. *The **longer-term** development of advanced technologies, such as **high-gradient wakefield acceleration and those underpinning bright muon beams**, should be supported at an appropriate level. Synergies with the US initiative on muon collider R&D should be exploited.*

The European Strategy for Particle Physics – Update (ESPPU)

[From Karl's talk](#)

- Strategy update process was initiated by the CERN Council in 2024

Motivation:

- Large progress towards future colliders at CERN (FCC feasibility study) and beyond
- International landscape of the field (CEPC, ILC, P5 in the US)
- Accomplishments in physics (LHC, HL-LHC and elsewhere)
- Long timescales (community engagement)



- Aim: develop a **visionary and concrete plan** that greatly advances human knowledge in fundamental physics through the **realisation of the next flagship project at CERN**. This plan should attract and value **international collaboration** and should **allow Europe to continue to play a leading role in the field**.
- 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 Strategy update should also **indicate areas of priority for exploration complementary to colliders** and for other experiments to be considered at CERN and at other laboratories in Europe, as well as for participation in projects outside Europe.

Overall summary

[From Karl's talk]

Machine	Precision Physics	BSM physics	Phys vs CEPC	Tech readiness	Const. cost (GCHF)	Path to ≥ 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	

Physics: from WG2b: sum of precision/BSM physics

Phys vs CEPC: competitiveness, assuming CEPC is running in parallel

Tech readiness: from WG2a

Construction cost: from proponents + exp. (CERN part)

LEP3 — a Higgs and EW factory in the LHC tunnel

Backup if (preferred) FCC-ee cannot be realised with long-term goal of an energy-frontier hadron or muon collider:
similar to FCC-ee with booster and collider rings, 2 beampipes, 50 MW / beam, 2 IPs

LEP3	Parameter	Z	WW	H (ZH)		$t\bar{t}$	Construction:
	Inst. luminosity / IP [$10^{34} \text{ cm}^{-2}\text{s}^{-1}$]	40	6.2 (160 GeV)	1.6 (230 GeV)		—	Total cost 3.7B CHF ESPPU input: arXiv:2504.00541
	SR energy loss / turn [GeV]	0.13	1.3	5.4		(~25 GeV)	
	Integrated luminosity / year / IP [ab^{-1}]	4.8	0.7	0.19		—	
	Run time [years]	5	4	6		—	
	Total integrated luminosity [ab^{-1} , 2 IPs]	48	6.0	2.3		—	
	Total number of events [2 IPs]	$1.4 \cdot 10^{12}$	$0.36 \cdot 10^8$	$0.42 \cdot 10^6$		—	
FCC-ee	Inst. luminosity / IP [$10^{34} \text{ cm}^{-2}\text{s}^{-1}$]	144	20 (157, 163 GeV)	7.5 (240 GeV)	1.8 (~350 GeV)	1.4 (365 GeV)	Total cost 13.7B + 1.3B $_{t\bar{t}}$ CHF
	SR energy loss / turn [GeV]	0.036	0.08	1.7	7.8	9.2	
	Integrated luminosity / year / IP [ab^{-1}]	17	2.4	0.9	0.21	0.17	
	Run time (including lumi ramp-up) [years]	4	2	3	1	4	FCC-ee SR loss reference
	Total integrated luminosity [ab^{-1} , 4 IPs]	205	19.2	10.8	0.4	2.7	
	Total number of events [4 IPs]	$6 \cdot 10^{12}$	$2.4 \cdot 10^8$	$2.2 \cdot 10^6$	$2 \cdot 10^6$		

Challenges for LEP3 include design of IRs, large E-loss, need 6.0 GV RF power installed in 4 long straight sections (2 booster, 2 collider), crab-waist scheme requires large crossing angle and widening tunnel on either side of the experiments from ~4m to 7m diameter along 270 m

Linear Collider Facility (LCF) at CERN

Very similar to ILC: baseline is 33.5 km tunnel, SRF cavities with an accelerating gradient of 31.5 MV m^{-1} , $\sqrt{s} = 250 \text{ GeV}$ upgradable to 550 GeV, longitudinal polarisation ($\pm 80/30\%$ for e^-/e^+ , $\sim 20\%$ higher $\sigma(\text{ZH})$), 2 IPs (sharing luminosity)

LCF	Parameter	Z	WW	H (ZH)	above $t\bar{t}$	
	Inst. luminosity / IP [$10^{34} \text{ cm}^{-2}\text{s}^{-1}$]	0.28	—	$1.4_{\text{LP}} / 2.7_{\text{FP}}$ (250 GeV)	3.9 (550 GeV)	
	Integrated luminosity / year / IP [ab^{-1}]	30	—	$0.19_{\text{LP}} + 0.64_{\text{FP}}$	2.3	
	Run time [years]	1	—	$5_{\text{LP}} + 3_{\text{FP}}$	10	
	Total integrated luminosity [ab^{-1} , 2 IPs*]	0.07	—	$1.0_{\text{LP}} + 1.9_{\text{FP}}$	8.3	
	Total number of events [2 IPs*]	$0.002 \cdot 10^{12}$	—	$0.8 \cdot 10^6$	$\sim 1.6 \text{ (H)} / 3.9 \text{ (tt)} \cdot 10^6$	
FCC-ee	Inst. luminosity / IP [$10^{34} \text{ cm}^{-2}\text{s}^{-1}$]	144	20 (157, 163 GeV)	7.5 (240 GeV)	1.8 ($\sim 350 \text{ GeV}$)	1.4 (365 GeV)
	Integrated luminosity / year / IP [ab^{-1}]	17	2.4	0.9	0.21	0.17
	Run time (including lumi ramp-up) [years]	4	2	3	1	4
	Total integrated luminosity [ab^{-1} , 4 IPs]	205	19.2	10.8	0.4	2.7
	Total number of events [4 IPs]	$6 \cdot 10^{12}$	$2.4 \cdot 10^8$	$2.2 \cdot 10^6$	$2 \cdot 10^6$	

Construction:

Total cost:

- 8.5B CHF (250 GeV, LP)
- 9.3B CHF (250 GeV, FP)
- 14.8B CHF (550 GeV)

ESPPU input: [arXiv:2503.19983](https://arxiv.org/abs/2503.19983)

Total cost 15.3B CHF

*LCF proposes to share luminosity among two interaction regions, ie, same integrated luminosity as for single IP

Challenges for for LCF include the positron source, final focus and nano-beam stability ($\sigma_y^* \sim 6\text{--}8 \text{ nm}$, FCC-ee: 40 nm)

Options to increase energy beyond 550 GeV with development and installation of higher gradient accelerating technologies (see [here](#) for a discussion of options)