Status of ESPPU

- Where we are
- Short- and mid-term next steps
- Remaining milestones and a few suggestions

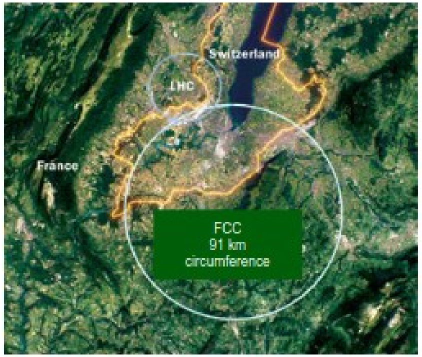
- Most slides borrowed from presentations in Venice, mostly
  - https://agenda.infn.it/event/44943/contributions/267517/attachments/137766/207161/ESPP_Venice_Summary_2025.06.27.pdf
  - https://agenda.infn.it/event/44943/contributions/263364/attachments/137571/206899/V14_DIACONU_SI_VENICE2025.pdf

Timeline for the update of the European Strategy for Particle Physics

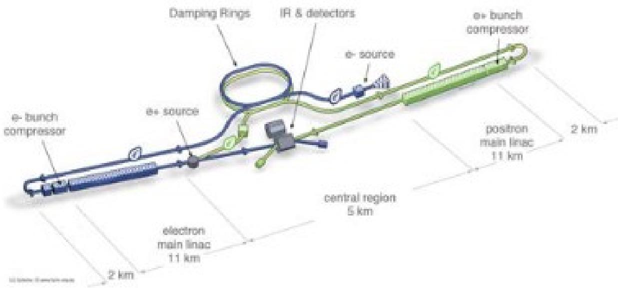
Major projects at CERN, ~2045

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

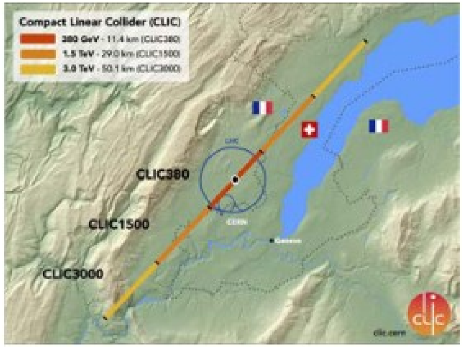
FCC-ee (e^+e^-, circular, 91 – 365 GeV)



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



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

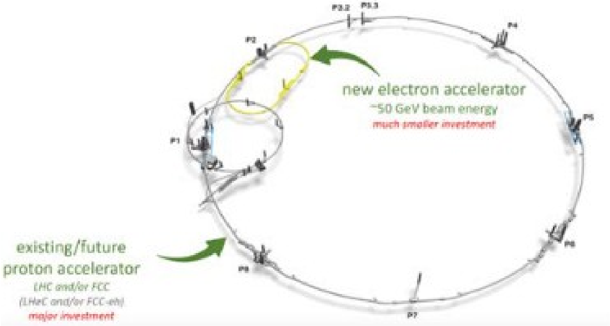


Intermediate projects

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

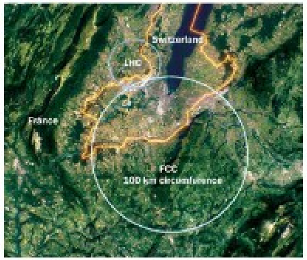
LEP3 (e^+e^-, circular, 91 – 230 GeV)

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



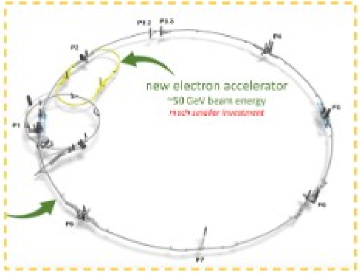
Potential for the more distant future

FCC-ee



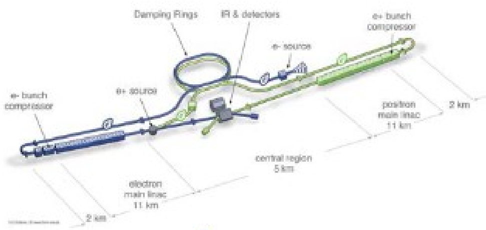
LEP3

LHeC

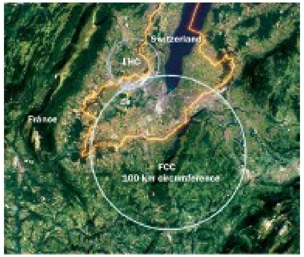


PERLE

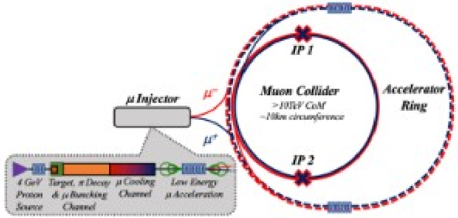
LCF, CLIC



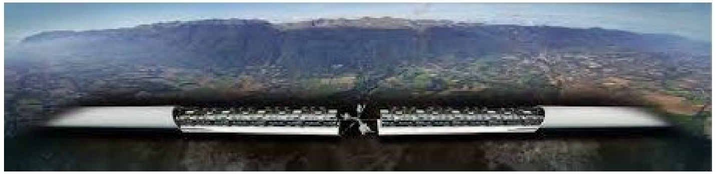
R&D



FCC-hh,
baseline 85 TeV (→ 120 TeV)



Muon Collider (3, 10 TeV)



e^+e^- with improved acceleration technologies
LCF, C³ (→ 1 TeV), CLIC (1.5 TeV), HALHF, …

Summary of inputs

The view of the national HEP communities

- **Completing the full HL-LHC programme** is essential and must remain a high priority for CERN;

  It is paramount to fully exploit the High-Luminosity LHC (HL-LHC) to maximise scientific returns

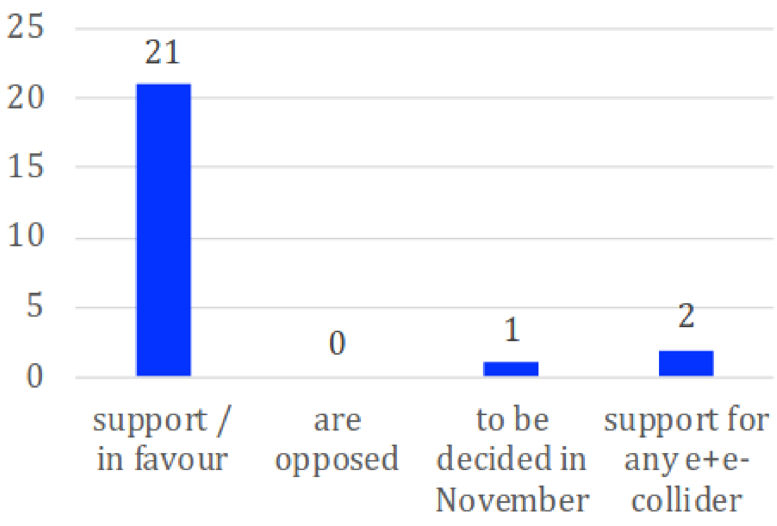
- It is important that the **next flagship collider supports a broad physics programme**, given that it is not clear where new physics will show up.

- Should a dedicated energy-frontier collider or a high-luminosity e^+e^- machine not prove feasible or face significant delays, **intermediate collider projects** such as LHeC and LEP3 are recognised as strategically valuable by some member-states HEP communities

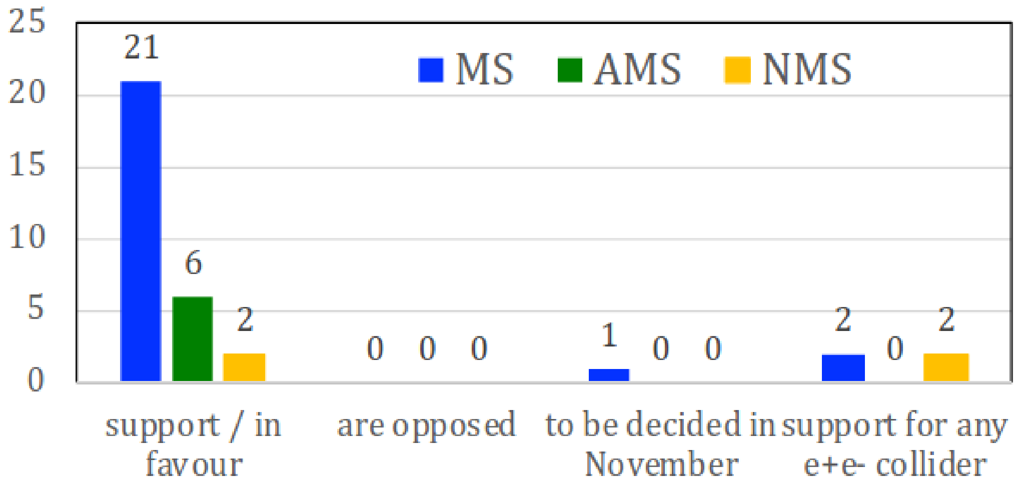
Summary of inputs

What is the preferred large-scale accelerator for CERN

CERN Member States (MS)



... incl. Associate- and Non-Member States (MS)

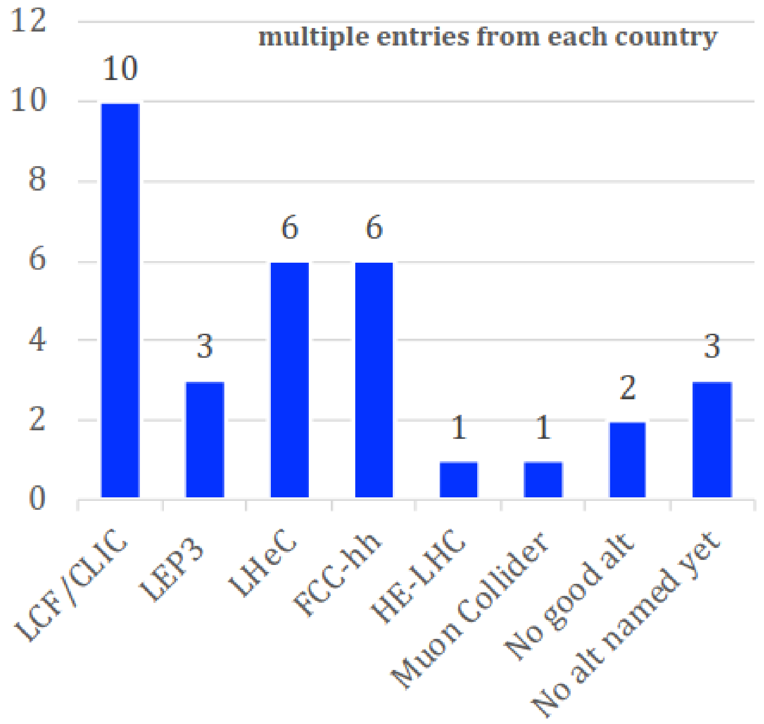


- Overwhelming support (21/24 CERN MS HEP communities) in favour of the integrated FCC-ee/hh programme

- Support as well from Associate Member states (AMS) and Non-member states (NMS)

Summary of inputs

What is the alternative if the preferred option is not feasible?



CERN Member States (MS) (multiple entries allowed)

- 10 MS HEP communities list a Linear Collider (LCF, CLIC) as second best choice
  (LCF is preferred to be realised with 550 GeV)
- 3 MS HEP mention LEP3 as a genuinely less costly alternative to FCC-ee
- 6 MS HEP communities support LHeC
- 6 MS HEP communities support a lower-energy hadron collider
- 2 MS HEP see no reason for another option, as they would be equally costly.

Cost estimates

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.

FCC-ee

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: Upgrade of SRF (800 MHz) & cryogenics for ttbar operation corresponds to additional cost of 1,260 MCHF

LCF CLIC

Unit: MCHF	LCF 250 (LP)	Δ LCF 550 (FP)	CLIC 380	Δ CLIC 1500
Collider	3864	4204	2471	4684
Main Beam inj./transfer	1181	86	1046	23
Drivebeam inj./transfer	-	-	1060	302
Civil Engineering	2338	0	1403	703
Technical Infrastructure	1109	1174	1361	1404
Sum	**8492**	**5464**	**7341**	**7116**

LEP3

Cost Element	2 new Xpts	2 Exist Xpts
Accelerator	2705	2705
Injectors and Transfer Lines	295	295
Technical Infrastructures	435	435
Experiments	130	60
Civil Engineering	165	165
LHC Removal/LEP3 Installation	140	140
Total CERN (MCHF)	**3870**	**3800**
Experiments non-CERN part	900	270

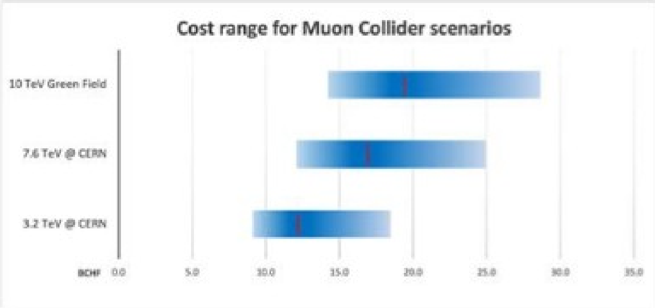
Cost summary table in 2024 MCHF for the construction of FCC-hh.

FCC-hh
(after FCC-ee)

Domain	FCC-hh Cost [MCHF]
FCC-ee dismantling	200
Collider*	13400
Injectors and transfer linear	1000
Civil Engineering	520
Technical infrastructures	3960
Experiments	N/A
Total	**19080**

*target price of 2.0 MCHF per 14.3 m long magnet with 1.0 MCHF of conductor, 0.5 MCHF for assembly, and 0.5 MCHF for components

Muon Collider



LHeC (cost estimate 2018, 60 GeV e-)

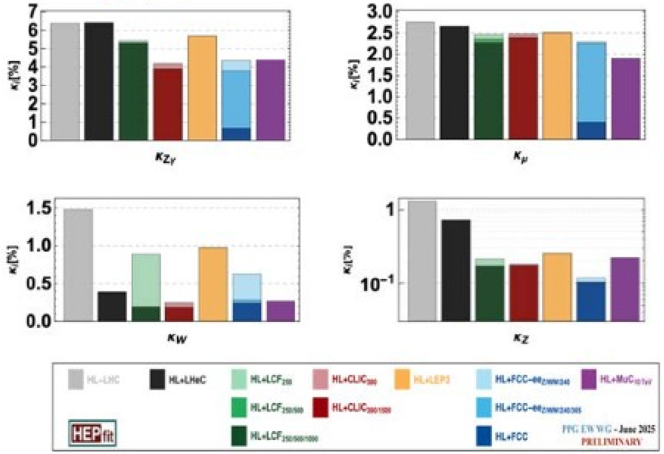
Budget Item	Cost
SRF System	805MCHF
SRF R&D and Proto Typing	31MCHF
Injector	40MCHF
Magnet and Vacuum System	215MCHF
SC IR magnets	105MCHF
Dump System and Source	5MCHF
Cryogenic Infrastructure	100MCHF
General Infrastructure and installation	69MCHF
Civil Engineering	386MCHF
Total	1756MCHF

→ ~2 BCHF (2025)

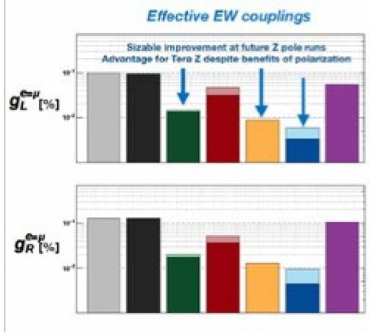
Scientific potential – Electroweak

- The **HL-LHC** will provide legacy measurements for top, ttH, λ_3 and rare decays until a top and high energy run
- **Multiple energy points in e^+e^- colliders** are important to Higgs precision (i.e. width, HWW, λ_3)
- **Tera-Z brings highest overall sensitivity to el.weak**
- Significantly improved high-precision tests of the el.weak sector are vital to guide future direct searches of new physics
- Precision and energy are strongly complementary
- A focus on both precision (→ smaller effects) and breadth (→ characterization of any eventual signal) is important in the search of the unknown.
- Fundamental advancements in theory techniques and tools needed

Higgs physics



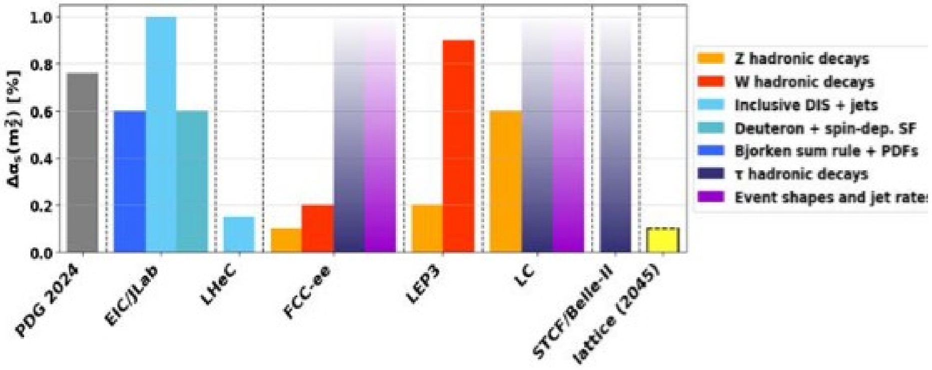
Z pole physics



Scientific potential - QCD

- The **strong coupling** is the least known amongst the four forces

  → Reaching 0.1% requires
  FCC-ee (10^{12} Z bosons), Lattice, LHeC, theory



- Significant progress in **higher order calculations** (N^nLO+N^nLL pQCQ) and in the understanding of non-perturbative QCD (hadronisation, colour reconnection) required

  → stress test of the SM (el.weak, Higgs, top, …)

- **Hadron structure** is of fundamental scientific interest;
  Uncertainties limit important Higgs and el.weak measurements at hadron colliders

  → significant improvements could / will be achieved at LHeC / EIC

Scientific potential - QCD

- **HL-LHC:** rich physics programme in non-perturbative QCD
  (full exploitation already encouraged in 2020 strategy, ongoing)

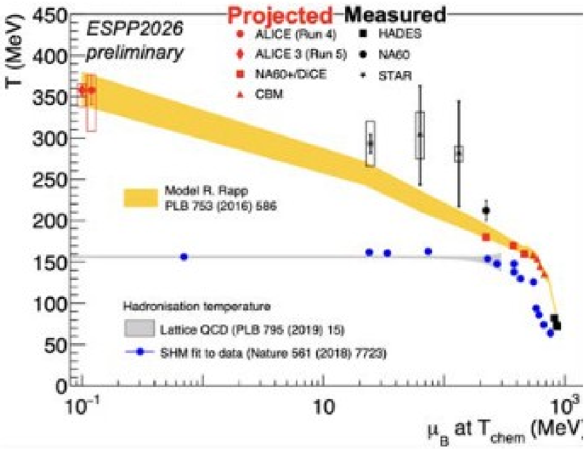
  - **High-temperature QCD**
    → quark-gluon plasma equilibration with heavy quarks,
    temperature and its time evolution

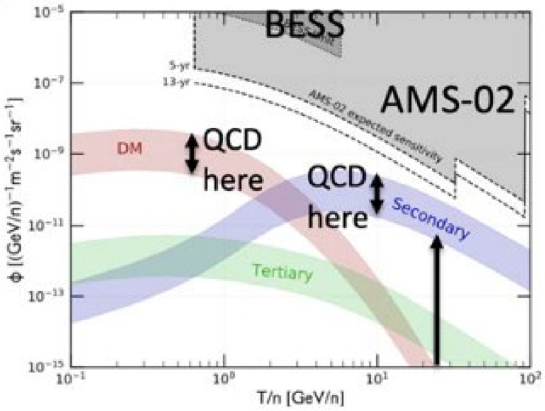
  - Hadron nature (exotica) and interactions
    (very relevant for astro(particle) physics)

- **Post-HL-LHC**: programme **at SPS** essential to keep HI activities ongoing at CERN, in addition to FAIR
  -complementary to LHC (high baryon-density)

  long-term goal: **continue HI-physics at FCC-hh**
  → allow for novel studies in high-*T* QCD

- Complementary possibilities: FPF, HIE-ISOLDE





Some semi-personal considerations after Venice

- Overwhelming community support for the FCC integrated program at CERN
  - An extremely detailed feasibility study has been completed
  - shared feeling that the project appears in a generally difficult context
- LCF presents an “entrée de gamme” version ($\sqrt{s}$=250 GeV only) at reduced cost, presenting itself as a viable “plan B”
- Overall strong support for hadron-oriented programs (pp, ep)
- “plan B” discussions are crucial, but difficult
  - Since all alternatives are less general than the FCC program, opinions often reflect one’s personal interests or taste
  - Often-heard statement that any mention of a plan B undermines plan A
  - Decisions external to EU (CEPC) potentially have major implications, but are considered out of scope

Next steps

Council appointment of the members of the PPG and decision on the venue for the Open Symposium
End September 2024
December 2024
Council decision on the venue for the ESG Strategy Drafting Session
Deadline for the submission of main input from the community
31 March 2025
26 May 2025
Deadline for the submission of additional national input in advance of the Open Symposium
Open Symposium
23-27 June 2025
End September 2025
Submission of the "Briefing Book" to the ESG
Deadline for the submission of final national input in advance of the ESG Strategy Drafting Session
14 November 2025
1-5 December 2025
ESG Strategy Drafting Session
Submission of the draft strategy document to the Council
End January 2026
March and June 2026
Discussion of the draft strategy document by the Council and updating of the Strategy

Physics Briefing Book

- Circulating ~now within the Physics Preparatory Group
- Expected to become public on September 30
- No community-wide circulation and feedback, but project leaders can semi-officially coordinate with the working-group conveners

Further French inputs?

- Mature and well-received community input last winter
- Support letter from our institutes (CEA, CNRS) wasn’t very compelling
  - HL-LHC as first priority
  - Acknowledgement of FCC as the community’s preference for the next project
  - Necessity to discuss alternatives
- Other countries’ lead institutes provided more advanced thoughts. could/should we push for more?

CEA/CNRS contribution

France CEA and CNRS wish to contribute to this ESPP session, by highlighting the following points:

- The immediate priority for CERN remains the HL-LHC program, whose scientific exploitation must be maximized once the experimental facility is operational
- The French particle physics community confirms the scientific interest of the FCC project, with its two phases — FCC-ee and FCC-hh — with FCC--ee offering a unique opportunity for high-precision electroweak and Higgs physics, while paving the way to the energy frontier. CERN is perfectly positioned to lead this ambitious project.
- The current R&D efforts on accelerator components, in particular on accelerating RF systems and on high-field superconducting magnet technology (underlined as a top priority in the previous ESPP session), must be reinforced, as they will benefit both the next flagship program and a wider range of scientific and technological fields. These developments should help to reduce CERN technologies environmental impact.
- Given the major uncertainties underlying the feasibility of the FCC project (environmental issues, financial sustainability in a particularly complex financial context, …), it is important to consider alternative scenarios to the FCC, so that CERN can be guaranteed to present a scientific program at the best level, if it were not ultimately decided by the CERN Council to launch the FCC project. The discussion on those alternative options, based at CERN, even if they present a reduced scientific potential and attractiveness, should be triggered and coordinated by CERN, with the active participation of the European scientific community, including of course representative from the French community.