

Physics @ FCC-ee

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*presentation largely based on K. Jacobs,
Cern Colloquium, 26 Feb 2026



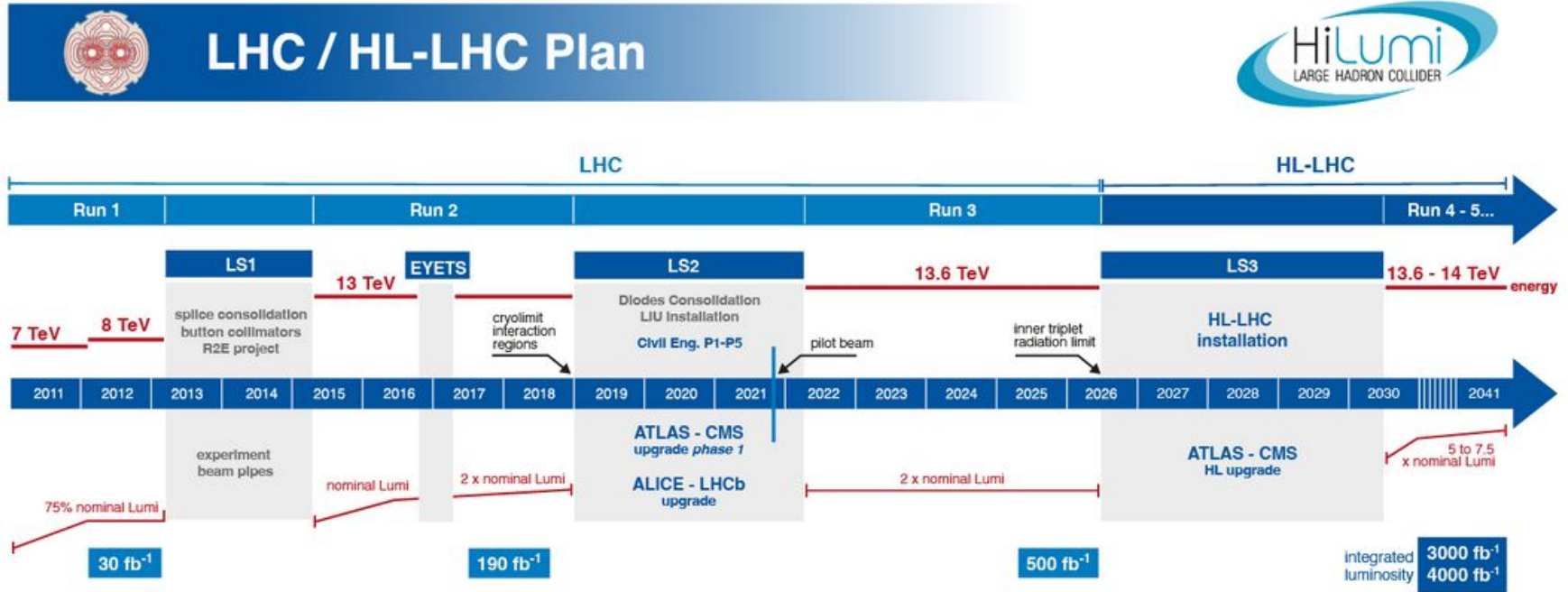
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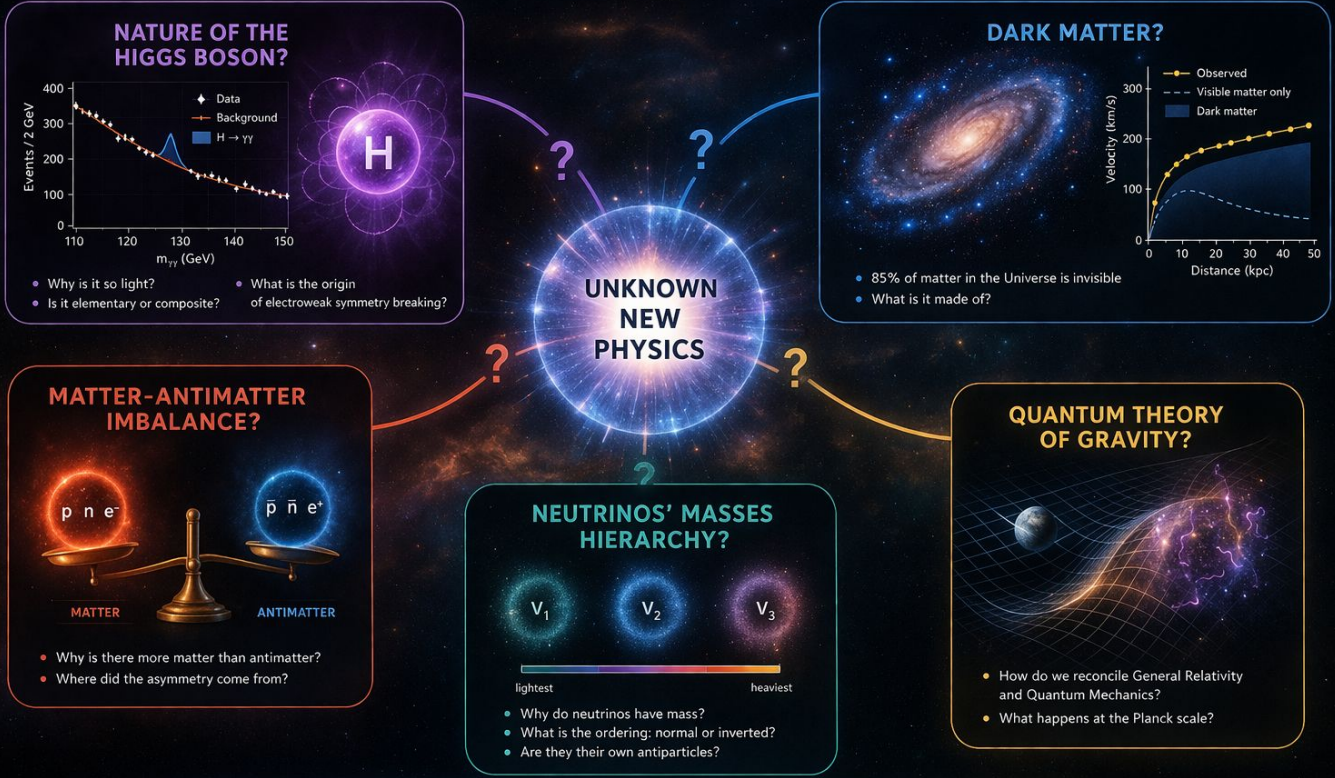


Where we are now



Open questions

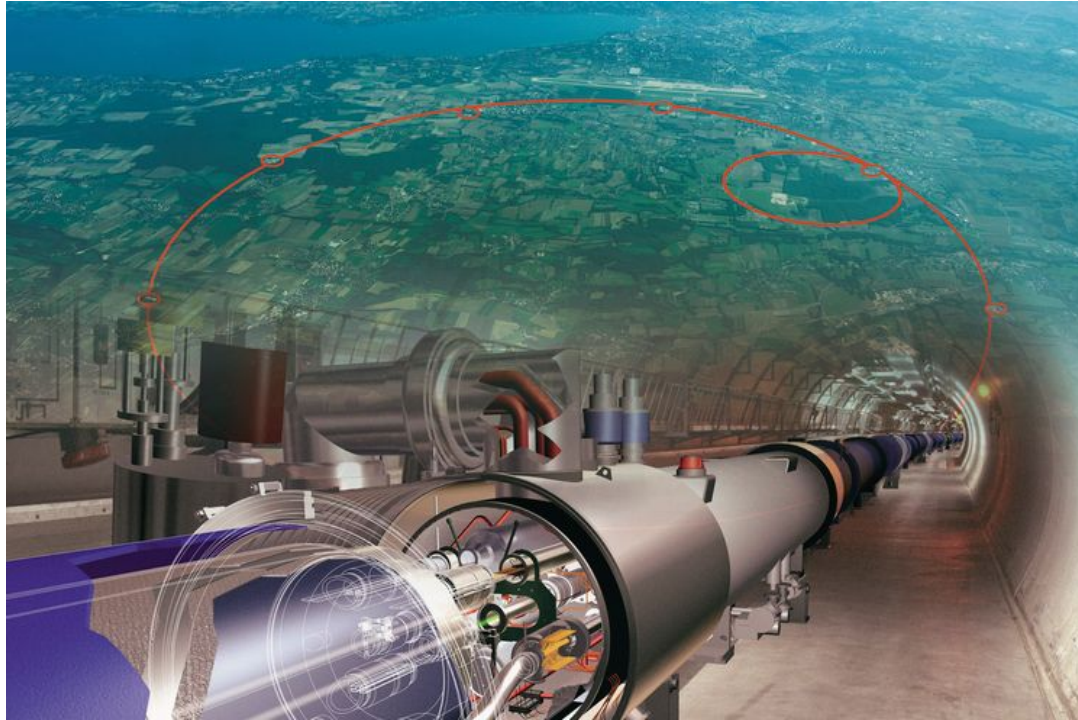
BIG QUESTIONS WE STILL DON'T KNOW



THE STANDARD MODEL IS INCREDIBLY SUCCESSFUL... BUT INCOMPLETE. WE NEED NEW IDEAS, NEW TOOLS, AND NEW DISCOVERIES.

What comes the next

What will be the next flagship project at CERN after the HL-LHC?



The European Strategy for Particle Physics (ESPP) 2026



<https://europeanstrategyupdate.web.cern.ch/>

Recommendations from ESPP 2026

The next CERN flagship collider project

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

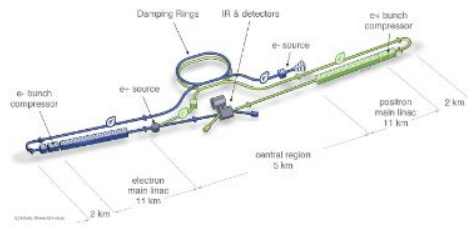
Proposed large scale projects @ CERN (2040s)

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

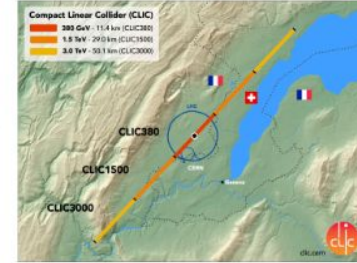
FCC-ee (e^+e^- , circular, 91 – 365 GeV)



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



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



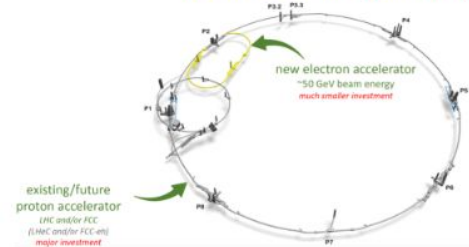
Intermediate projects

(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)

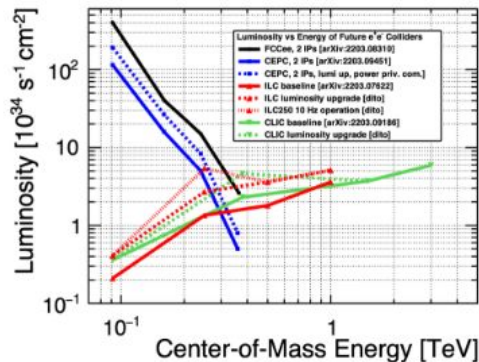


Circular or linear?

Circular e^+e^- colliders

- FCC-ee, CEPC
- Circumference: 90 - 100 km
- High luminosity & power efficiency at **low energies**;
→ huge rates at Z pole (table below)
- Less luminosity at higher E_{CM}
(synchrotron radiation)
- Multiple interaction regions
- Very clean: little beamstrahlung

per detector in e^+e^-	# Z	# B	# t	# charm	# WW
LEP	4×10^6	1×10^6	3×10^5	1×10^6	2×10^4
SuperKEKB	-	10^{11}	10^{11}	10^{11}	-
FCC-ee	2.5×10^{12}	7.5×10^{11}	2×10^{11}	6×10^{11}	1.5×10^8



Linear e^+e^- colliders

- LCF, CLIC
- Length
LCF: 250 – 550 GeV: → 33 km
CLIC: 380 GeV – 1.5 TeV: 29 km
- High luminosity & power efficiency at **high energies**;
- **Longitudinally spin-polarised beams**
- Long-term energy upgrades possible
 - longer tunnel, same technology and/or
 - replacing accelerating structure with advanced technologies (RF cavities with higher gradients, plasma acceleration?)



Towards more far future

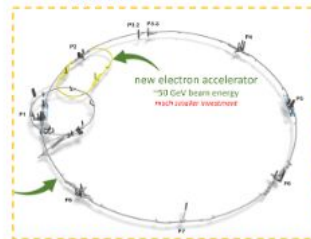
FCC-ee



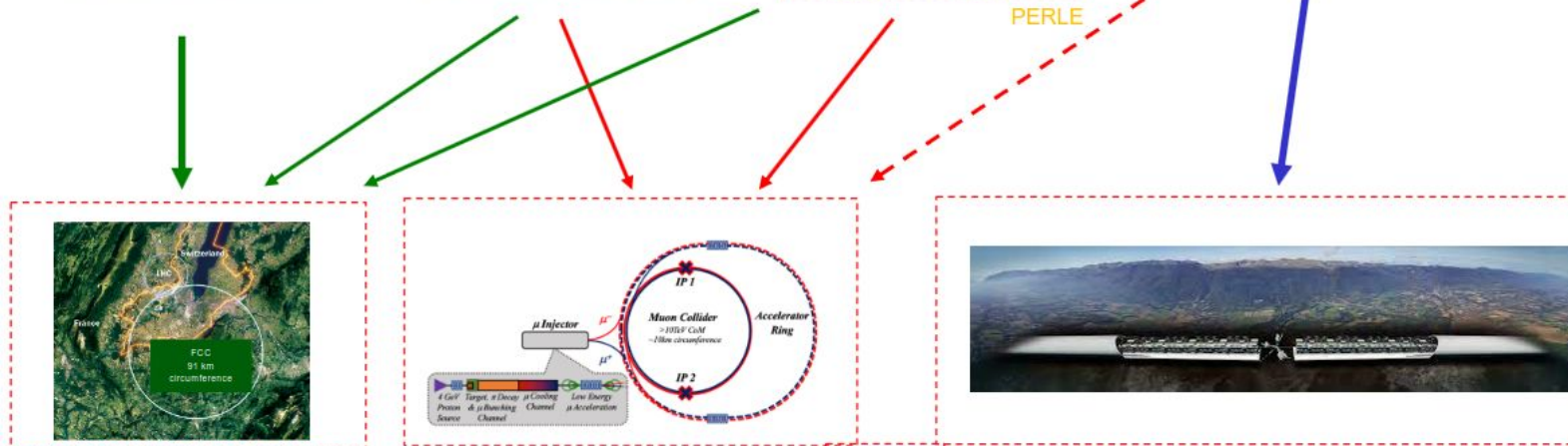
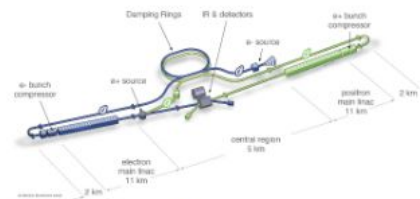
LEP3



LHeC



LCF, CLIC



FCC-hh,
baseline 85 TeV (\rightarrow 120 TeV)
+ possibility for HI collisions

Muon Collider (3, 10 TeV)

R&D

e^+e^- with improved acceleration technologies
LCF, C³ (\rightarrow 1 TeV), CLIC (1.5 TeV), HALHF, ...
 \rightarrow plasma acceleration for higher energies
(can $\mathcal{O}(10)$ TeV be reached? on what timescale?)



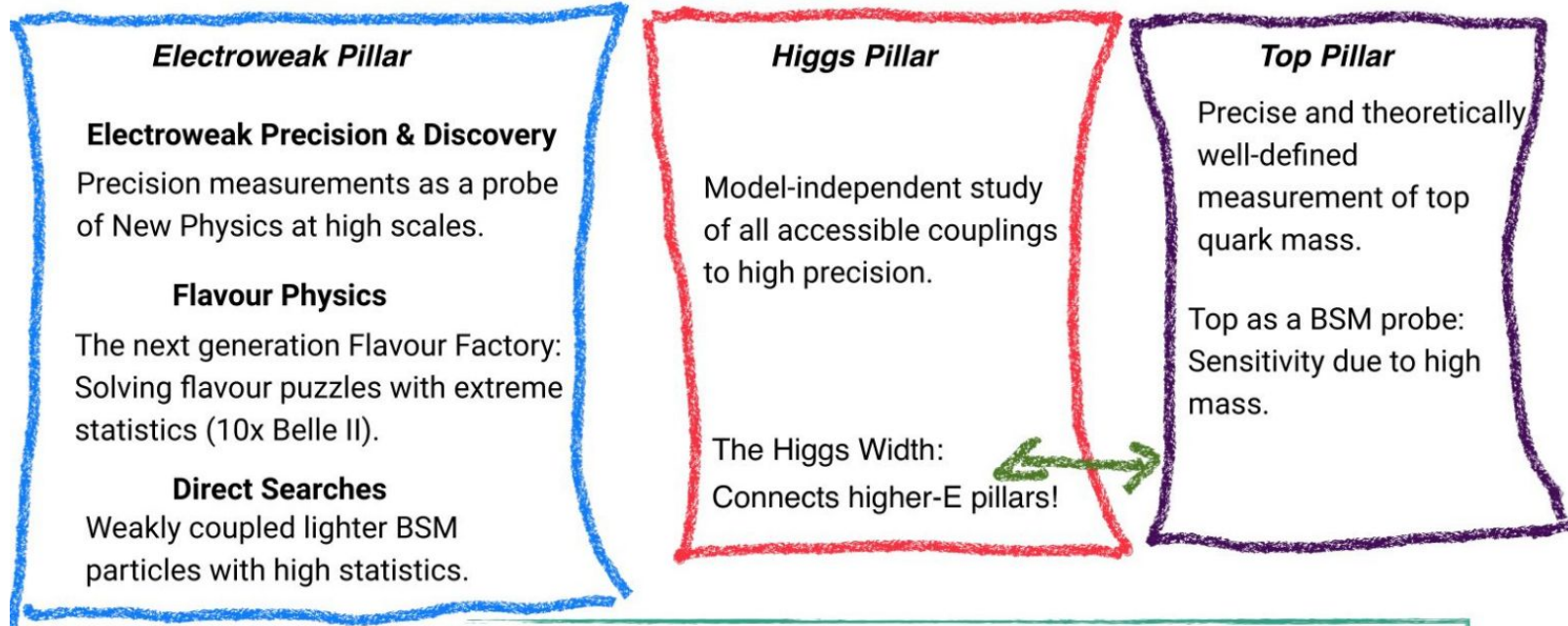
Evaluation of the proposed projects

Project	Scope	TRL	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							

Physics: the Driver

FCC-ee physics programme

[Frank Simon, 7th FCC
Physics Workshop](#)



The combination of all three pillars provides compelling discovery potential - and you need all three to cover the broadest possible range.

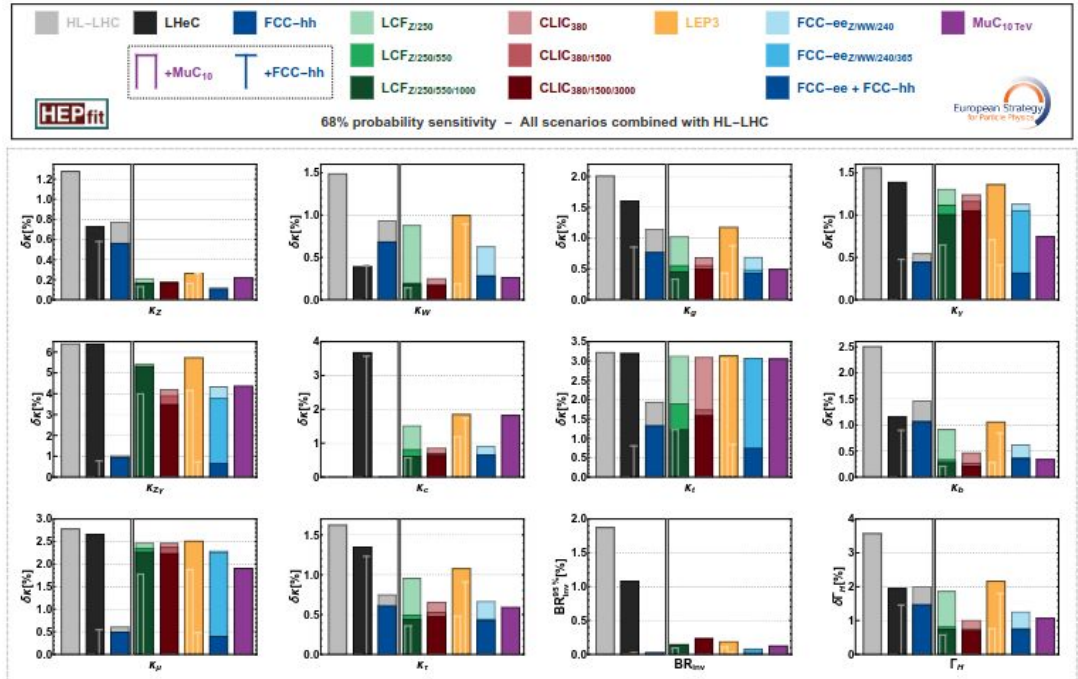
Higgs physics: Couplings

Model independent measurements at e+e- colliders

Sub-percent precision of κ modifiers in many channels

- Performance similar for centre of mass energies up to 240 GeV
- ttH, ZHH and vvHH contributes at higher energies (> 550 GeV)

Hadron colliders for improvements in rare decays ($H \rightarrow \mu\mu$, $H \rightarrow Z\gamma$)



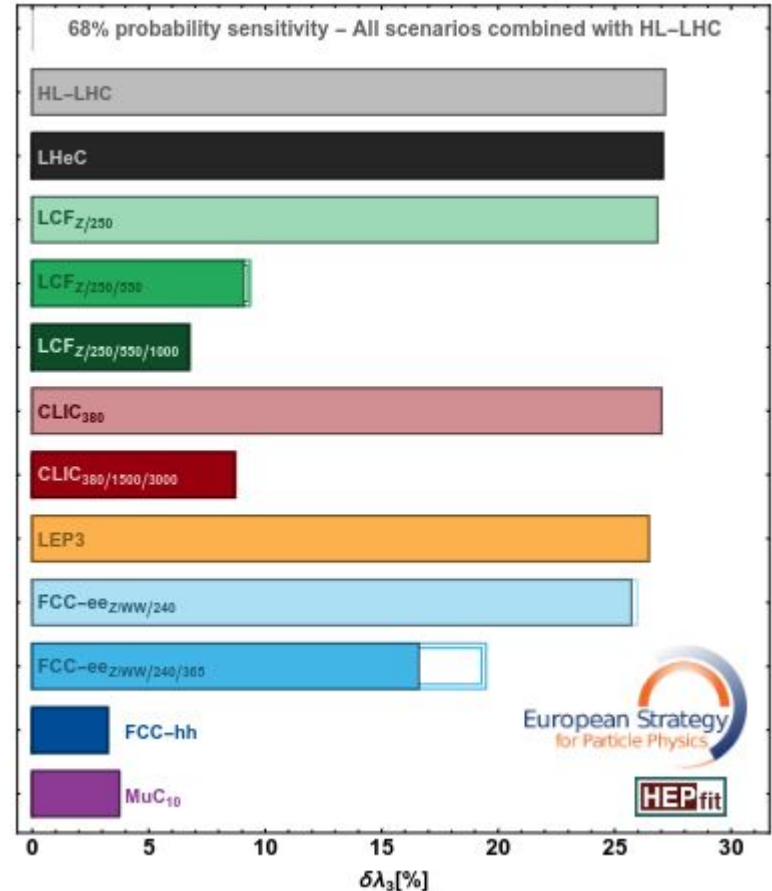
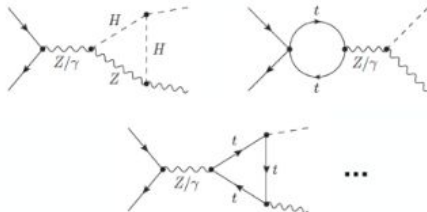
Higgs self-coupling

- (i) Determination via di-Higgs production
HL-LHC estimate: $\pm 27\%$



- (ii) Determination from single Higgs boson production
(sensitivity via loop effects)

- Two e^+e^- energies
- Constraining other contributions in the loops
(sizeable contributions from top operators)



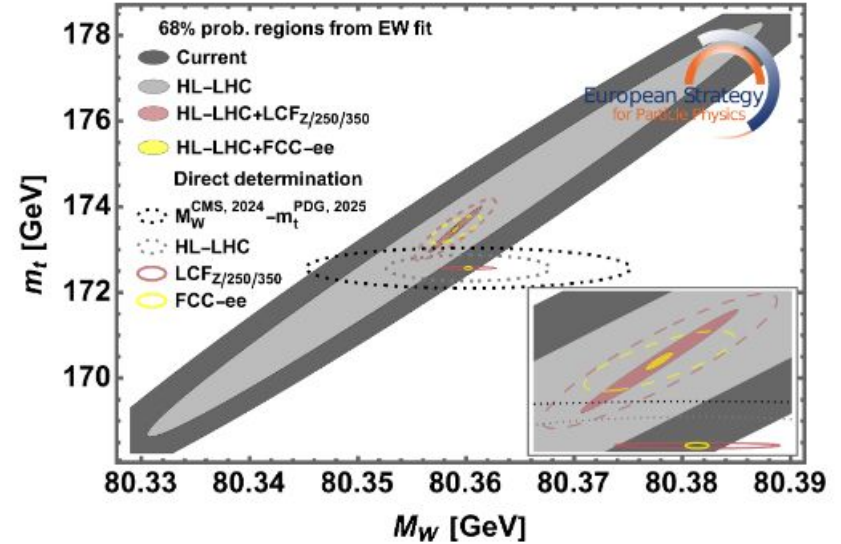
Electroweak precision observables (EWPO)

Best performance of the circular colliders (FCC-ee, LEP3) due to large samples

- 10 – 100x better precision compared to current limits

Linear colliders profit from polarised beams, but not reaching FCC-ee precision

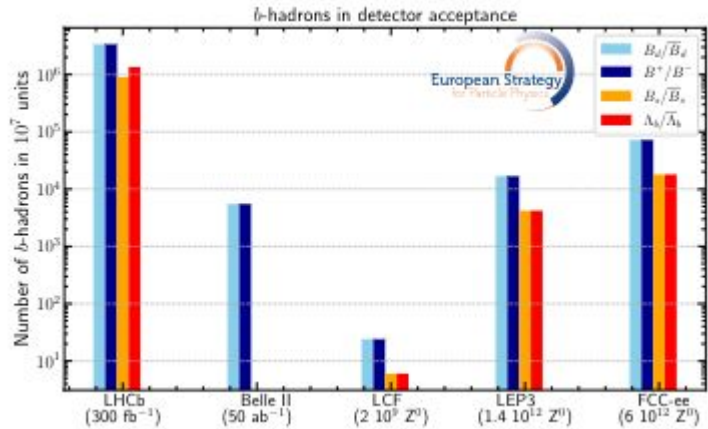
Observable	Current	FCC-ee	LCF	LEP3
Δm_Z (keV)	2000	4 (100)	200	7.5 (100)
$\Delta \Gamma_Z$ (keV)	2300	4 (12)	125	7.5 (23)
δR_μ ($\times 10^{-6}$) $R_\mu \equiv \frac{\Gamma_{\text{had}}}{\Gamma_\mu}$	1600	2.4 (2.3)	90 (90)	4.5 (2.3)
δR_b ($\times 10^{-6}$) $R_b \equiv \frac{\Gamma_b}{\Gamma_{\text{had}}}$	3300	1.2 (1.6)	70 (60)	2.2 (3.0)
$\Delta \sin^2 \theta_W$ ($\times 10^6$)	130	0.4 (0.5)	2.7 (2.3)	0.75 (0.95)
$\Delta \alpha(m_Z)^{-1}$ ($\times 10^3$)	14	0.8, 3.8	–	1.4, 7.3
Δm_W (keV)	9900	180 (160)	500 (1600)	430 (700)
$\Delta \Gamma_W$ (keV)	42000	270 (200)	2000	650 (500)



Flavour physics

LHCb and Belle-II will increase significantly its potential until 2045

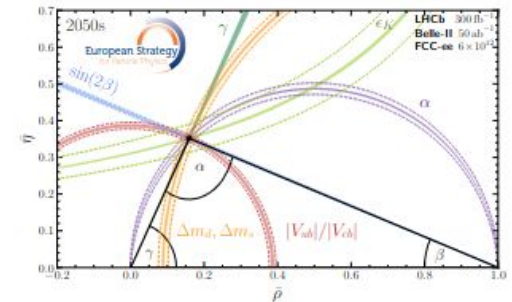
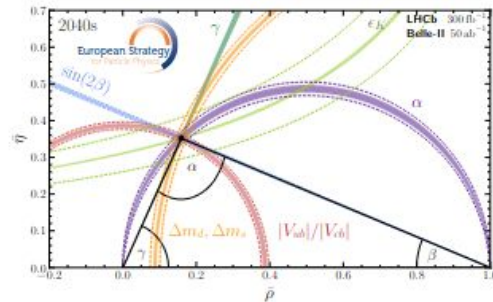
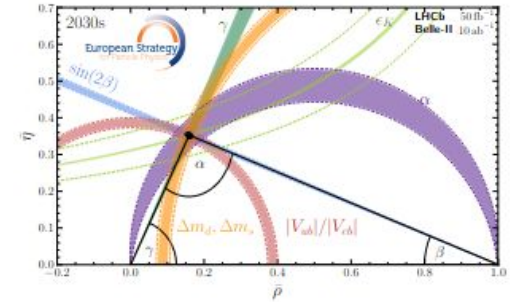
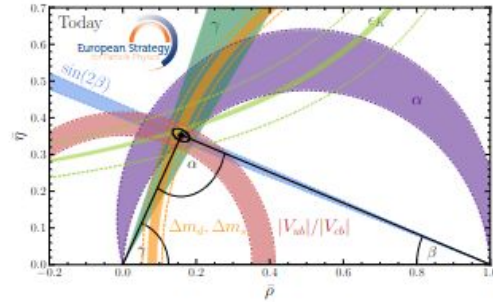
Reduced possibilities in linear colliders ($10^3 \times$ lower sample compared to circular colliders)



2030s
Belle II 10 ab⁻¹
LHCb 50 fb⁻¹

2040s
Belle II 50 ab⁻¹
LHCb 300 fb⁻¹

2050s
LCF 2 10⁹ Z⁰
LEP3 1.4 10¹² Z⁰
FCC-ee 6 10¹² Z⁰



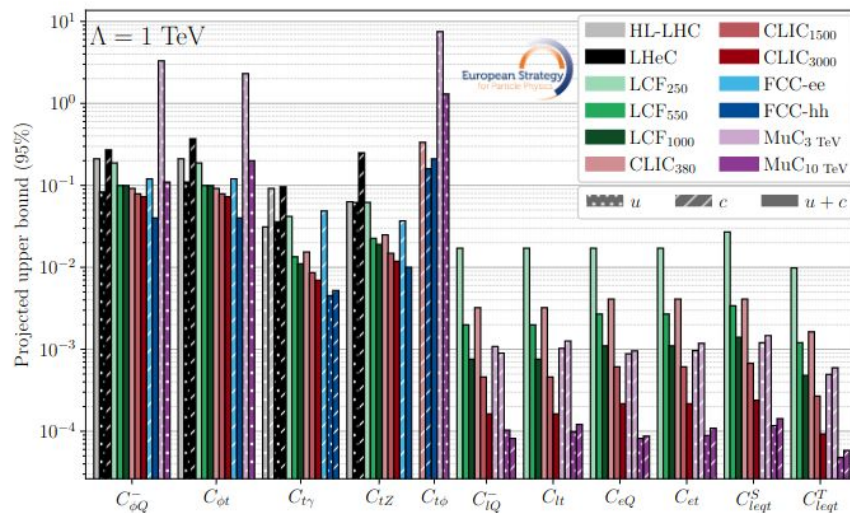
Top physics

Linear Colliders at higher energies significantly improve the sensitivity to EFT operators in the top-physics area

Highest sensitivity with 10 TeV muon collider, followed by 3 TeV (CLIC), 1 TeV LCF

Hadron colliders complementary

Sensitivity of SMEFT operators to FCNCs in the top-quark sector



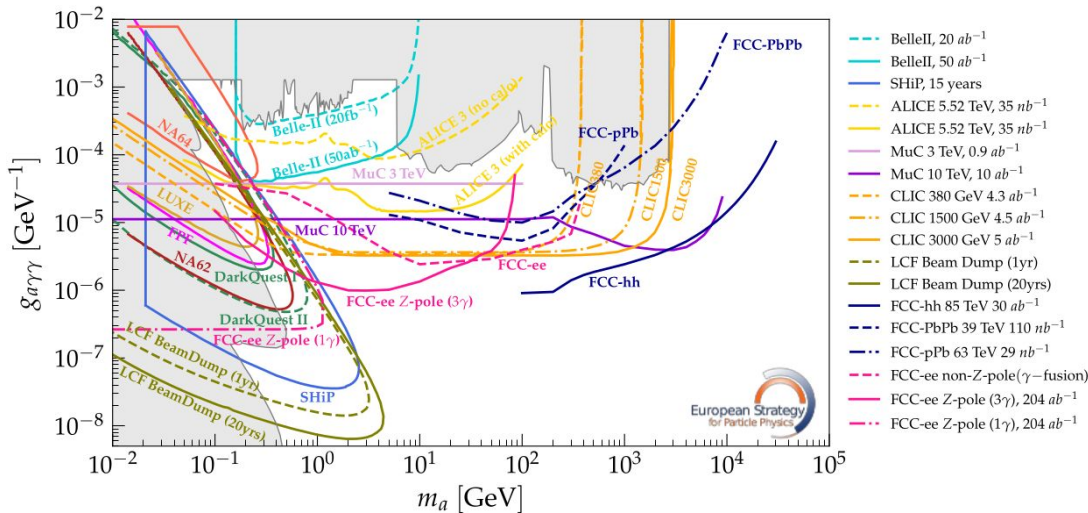
Beyond Standard Model at e⁺e⁻ colliders

Indirect searches by deviation from SM predictions

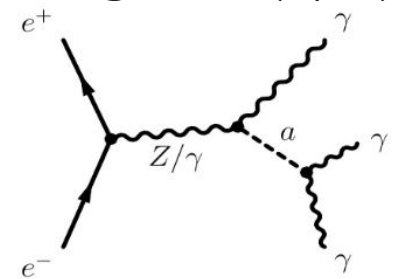
Direct searches for BSM particles – feebly interacting particles of low masses

- Strong requirements on the detector performance

Axion-Like Particles (ALPs)



ALP @ FCC-ee (Z pole)



FCC-ee and other options

FCC-ee

- Broadest high-precision particle physics programme
- Technical feasibility is demonstrated in the FCC feasibility study
- Straightforward path towards 10 TeV parton energy at FCC-hh

LEP3 and LHeC

- Proposed as intermediate colliders
- Reduced physics programme at lower cost
- Not competitive with an FCC-ee-like collider
- Need to be complemented by another machine leading to 10 TeV collisions

Linear Colliders

- Reduced physics programme
- Not competitive with an FCC-ee-like collider
- Currently no path exists to 10 TeV collisions

Descoped FCC-ee

Aim: to improve financial feasibility of FCC-ee, but to keep as wide range of physics programme as possible to keep

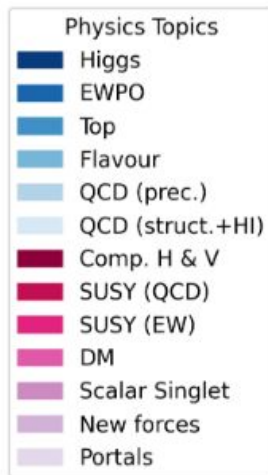
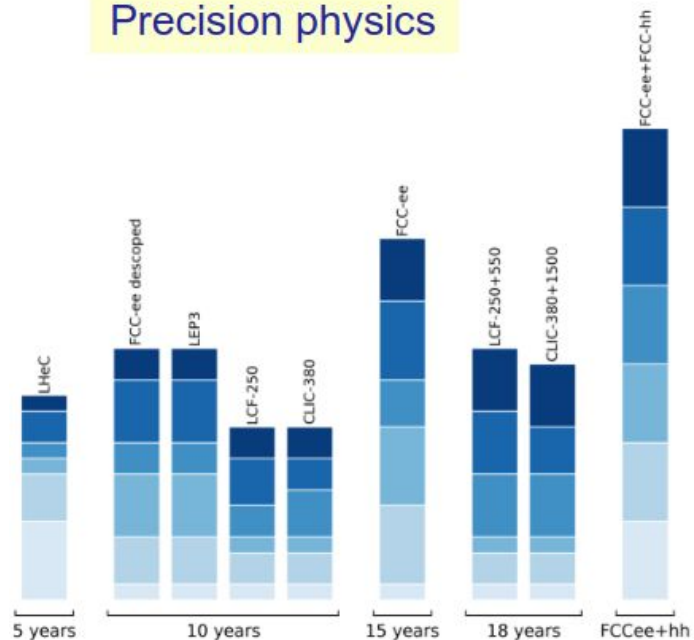
Descoping means

- removing top quark run (-1.26 BCHF)
- two instead of four experiments (0.8 BCHF)
- decreasing RF system power from 50 MW to 30 MW (-0.35 BCHF)

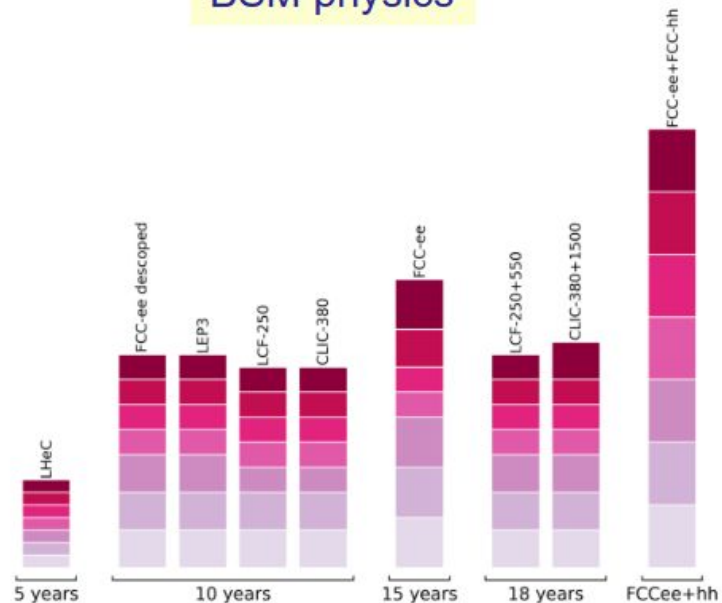
Reduction of the cost by ~15%

Physics reach

Precision physics



BSM physics



Comparison between the options

Machine	Precision Physics	BSM physics	Physics vs CEPC	Technical readiness	Constr. cost (BCHF)	Time scale	Path to ≥ 10 TeV
FCC-ee	22	23			15.3	2046-2060	
Descoped FCC-ee	15	17			12.9	2046-2055	
LCF550	15	17			14.8	2045-2065	
CLIC1500	14	18			14.6	2045-2066	
LCF250	10	16			9.4	2045-2053	
CLIC380	10	16			7.5	2045-2054	
LEP3	15	17			4.1	2047-2062	
LHeC	8	7			2.1	2044-2051	

Recommendations from ESPP 2026

The next CERN flagship collider project

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

Recommendations from ESPP 2026

The next CERN flagship collider project

1. The **electron–positron Future Circular Collider (FCC-ee)** is recommended as the preferred option for the next flagship collider at CERN.
→ Flagship project at CERN, which will allow Europe to play a leading role in the field
2. A descoped FCC-ee is the preferred alternative option for the next flagship collider at CERN.
→ Other projects not competitive with FCC-ee like machine, or currently no path exists to 10 TeV collisions in the future

More recommendations

LHC and HL-LHC programme as a highest priority

- Complete upgrades for HL-LHC is a must

R&D in collaboration with international partners and industry

- Accelerator technology
e.g. magnets up to 20 T; high-gradient wakefield acceleration
- Development of detectors

Requirements on the detectors

Physics at FCC-ee

- Electroweak precision measurements
- Higgs physics
- Flavour physics, top physics
- Searches for new physics

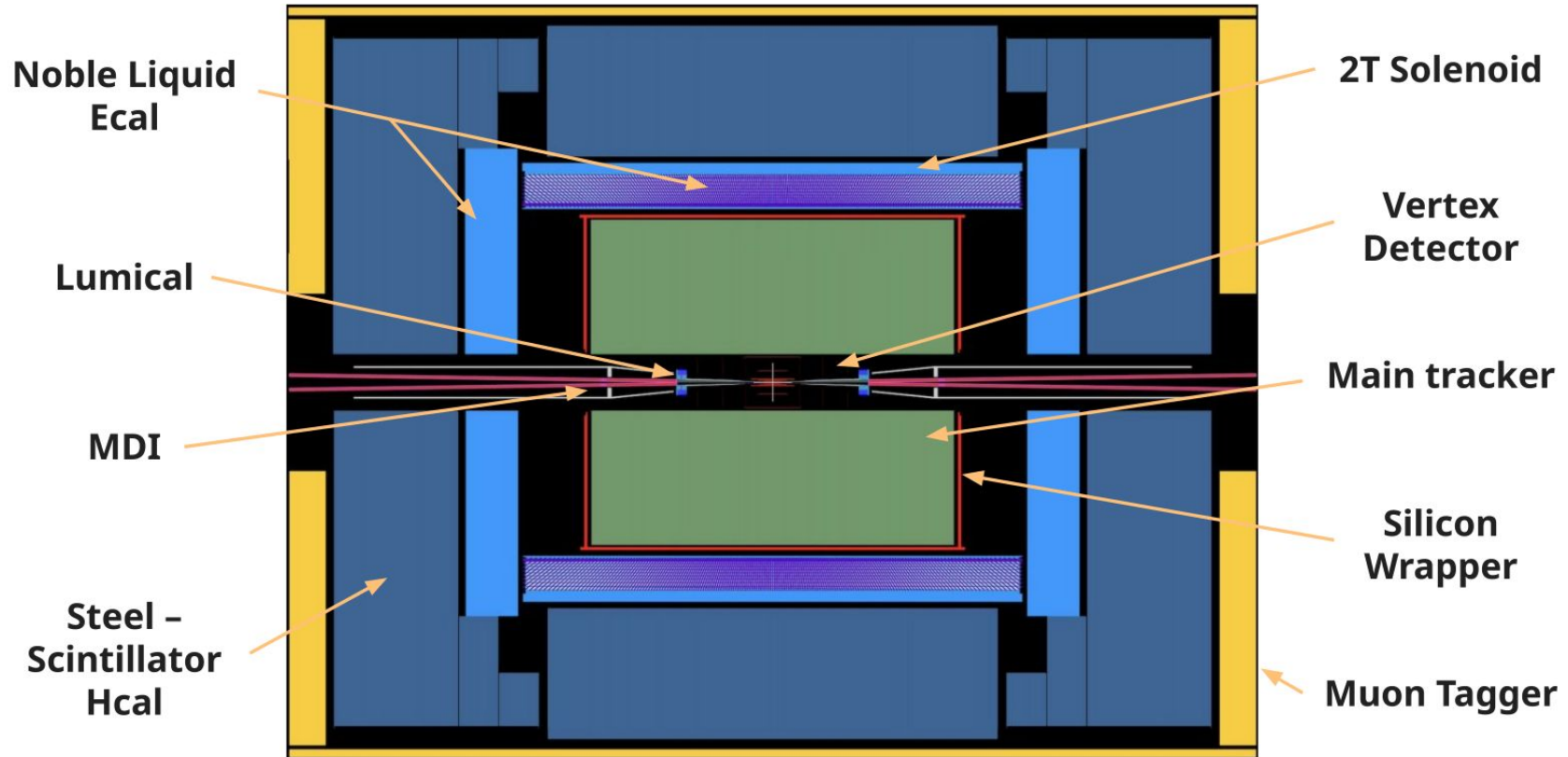


Detectors

- Small systematics on the measurements
- Perfect tracking, energy resolution
- Perfect tracking, energy resolution, particle identification
- Sensitivity to small signals, low noise, displaced vertex reconstruction

ALLEGRO detector concept

A Lepton-Lepton collider Experiment with Granular Read-Out



Conclusions

CERN Council: Update of the European Strategy for Particle Physics
(Budapest, 21-22 May 2026)

- Official Release of all Strategy Update Documents

Decision to build or not to build FCC-ee to be taken in 2028



References

1. European Strategy Update web
<https://europeanstrategyupdate.web.cern.ch/>
2. K. Jacobs, Cern Colloquium, 26 Feb 2026
<https://indico.cern.ch/event/1650119/>
3. Physics Briefing Book
<https://arxiv.org/abs/2511.03883>
4. Deliberation Document
<https://cds.cern.ch/record/2957411/>

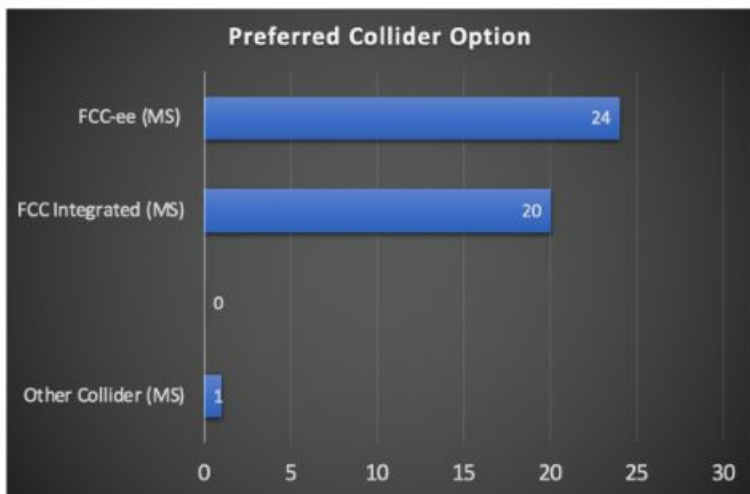
Backup

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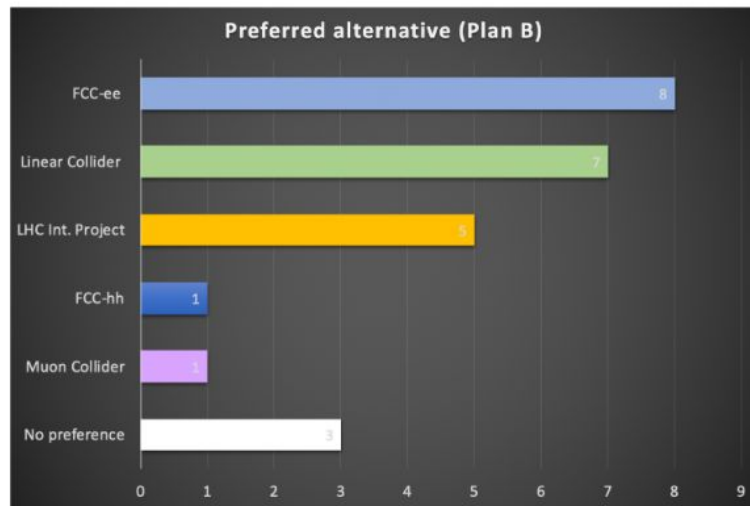
- Muon Collider: The technologies underpinning the MC design are in the early phases of exploration; Comprehensive R&D programme defined (300 MCHF, 1800 FTEy); Demonstrator need to be built.
- FCC-hh: Further R&D and industrialisation of high-field magnets (Nb₃Sn 15 - 20 y); Costs of HFM, further developments of high-temperature superconducting (HTS) magnets
- LEP3: Absence of a detailed lattice design and full-scale simulation → uncertainties on projected luminosity; Proposed baseline HTS nested quadrupoles/sextupoles represent the lowest TRL (luminosity, power)
- LHeC: Performance critically depends on a very high-current Energy-Recovery Linac (ERL); Uncertainty on luminosity of an order of magnitude; Successful demonstration of the PERLE programme at IJCLab is vital



National inputs



- 24/25 CERN Member States HEP communities in favour of the **FCC-ee programme**
- 20/24 CERN Member States HEP communities in favour of the **integrated FCC-ee / FCC-hh programme**



- No consensus
- Three main axes: - FCC (stretched in time, descoped, ...)
- Linear Collider
- Intermediate project in LHC tunnel as bridge towards FCC-hh (10++ TeV scale)