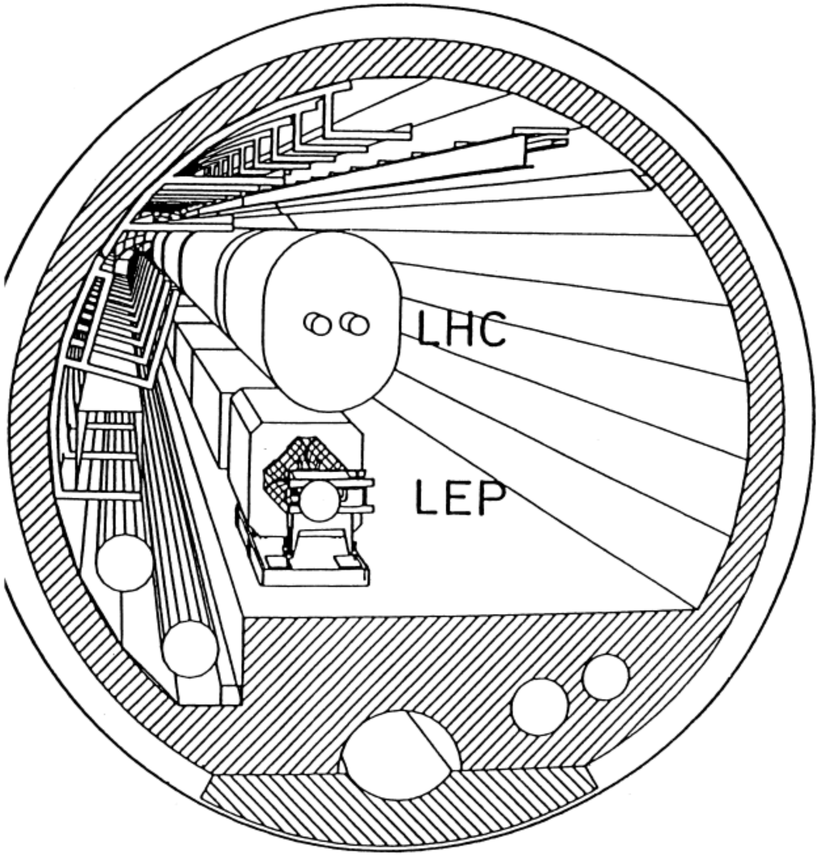
LEP3: Reusing the LEP/LHC Tunnel



Setting the Scene 1: 2019 ESPP

Recommendations 2019 ESPP

a. The **successful completion of the HL-LHC**

b. Neutrino Platform

c. An electron-positron Higgs factory is the highest-priority next collider.

d. R&D effort focused on advanced accelerator technologies, in particular that for high-field superconducting magnets, including high-temperature superconductors

e. investigate the technical and financial feasibility of a future hadron collider at CERN with $\sqrt{s}$ ~ 100 TeV and with an e^+e^- Higgs and electroweak factory as a possible first stage.

Point e. clearly points to the FCC project, which has been extensively discussed.

Setting the Scene 2: Request for Alternatives

We support CERN's preferred option for its future, namely the FCC

ESG Guidance

However, the ESG's remit explicitly states that "The Strategy update should include the preferred option for the next collider at CERN and prioritised alternative options to be pursued if the chosen preferred plan turns out not to be feasible or competitive".

It is imperative that the European HEP community should provide explicit feedback on both the preferred and alternative options for this "next collider at CERN", which will be the Laboratory's next flagship project, and an explanation of any specific prioritisation.

Setting the Scene 3

Any viable alternative should not have the same scale of difficulties associated with the FCC project.

One possibility is to **TRY to re-use**, as much as possible, the **existing infrastructure of CERN**, and **financing within the envelope of the current pluri-annual budget of CERN**. Several possibilities come to mind: HE-LHC, LHeC, LEP3, …..

Proposed alternatives to the preferred option, (FCC(ee) followed by FCC(hh)), include linear and muon colliders. We propose that another option, an electron-positron collider in the LHC tunnel, sometimes labeled LEP3, also should be considered as an alternative. Indeed, we argue that it is the best fall-back to the FCC. .
Several others have also discussed such a possibility in the past.

e.g. 2013 ESPP, a Higgs factory (LEP3) was proposed but not pursued any further. [https://cds.cern.ch/record/1471486].

LEP3: A High Luminosity e+ e- Collider in the LHC Tunnel to Study the Higgs Boson

A.P. Blondel (Geneva U.), F. Zimmermann (CERN), M. Koratzinos (CERN), M. Zanetti (MIT) (May, 2012)

Contribution to: IPAC 2012

LEP3: A High Luminosity e^+e^- Collider to Study the Higgs Boson

A. Blondel (Geneva U.), M. Koratzinos, R.W. Assmann (CERN), A. Butterworth (CERN), P. Janot (CERN) et al. (Aug, 2012)

e-Print: 1208.0504 [physics.acc-ph]

Setting the Scene 4

LEP3

Is inferior to FCC(ee), but with possibly adequate (?) accuracy for Higgs boson and EW physics parameters. Factor ~5 lower numbers of events.

Not possible to get to the tt threshold

Re-deploy (reuse components) detailed studies conducted/used for FCC(ee)

Several items are essentially radius-independent eg. A dedicated Linac as injector (as for FCCee) but at lower injection energy

Re-use existing CERN facilities

Parameters worked out under the assumption of 50 MW/beam with 66% RF efficiency →200 MW (same as FCCee and current facilities)

Affordable cost, reasonable timeline

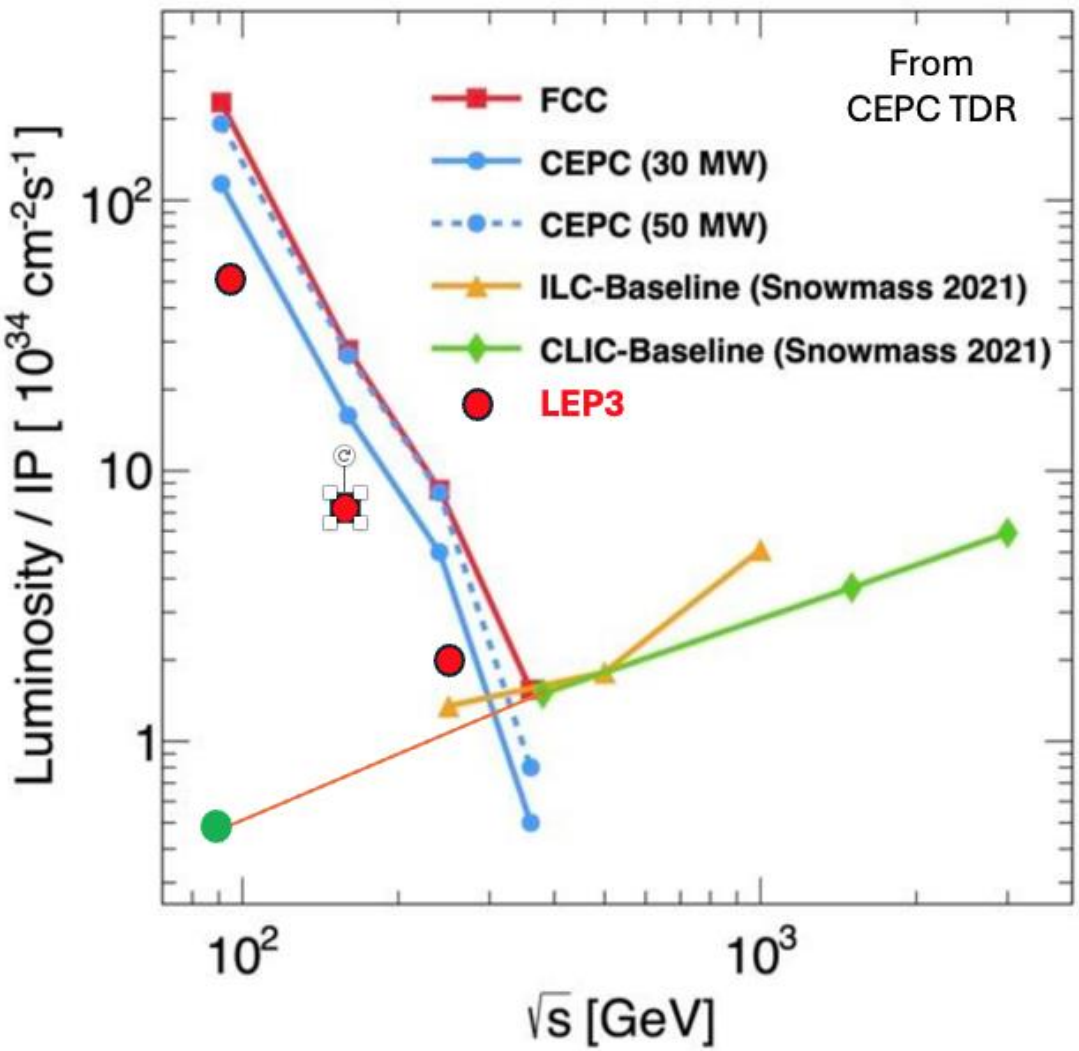
LEP3 Principal Parameters

No. of IPs	2
Highest c.o.m. energy	230 GeV
SR power loss	Fix at 50MW
SR energy loss/turn	~5 GeV
Total rf Voltage	~6 GV
Inst Luminosity	~1.5 10^{34} $cm^{-2}s^{-1}$
Running Scenario	~20 years programme e.g. 5 yrs at 230GeV, 4 years around WW, 5 years around Z
Est. total no. of Events	3.10^5 H, 4.10^7 WW at 163 GeV, $1.5.10^{12}$ Z at 91.2 GeV

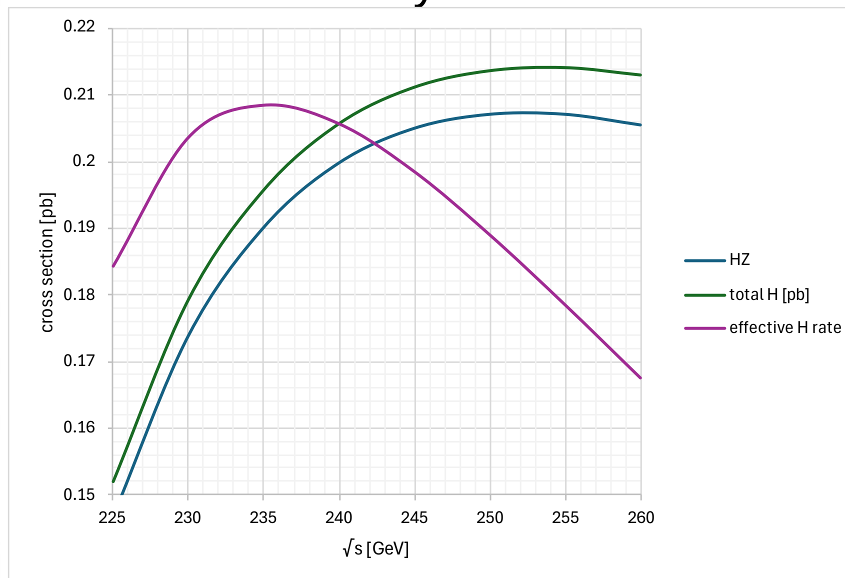
LEP3 can be competitive with FCC(ee) wrt Higgs and E-W physics

*For the integrated luminosity, 185 days of operation per year, and luminosity production
at 75% efficiency with respect to the ideal top-up running is assumed, giving 1.2.10E+7s effective.
** First year at 50% efficiency; Z running at 88, 91, 94 GeV in ratio 1:3:1 for 4 years; WW running at 158 and 163 GeV in ratio 1:1 for 2+ years;
*** Baseline [arXiV 2203.09186] +polariztion ; 2 ab-1 at √s=250 GeV ; 620 fb-1 at 163 GeV, 100 fb-1 at Z pole;

e^+e^- Colliders: Instantaneous Luminosity



In circular colliders, for the same synchrotron power loss, at a lower energy, more current can be put to increase luminosity.



LEP3: Run at √s =230 GeV

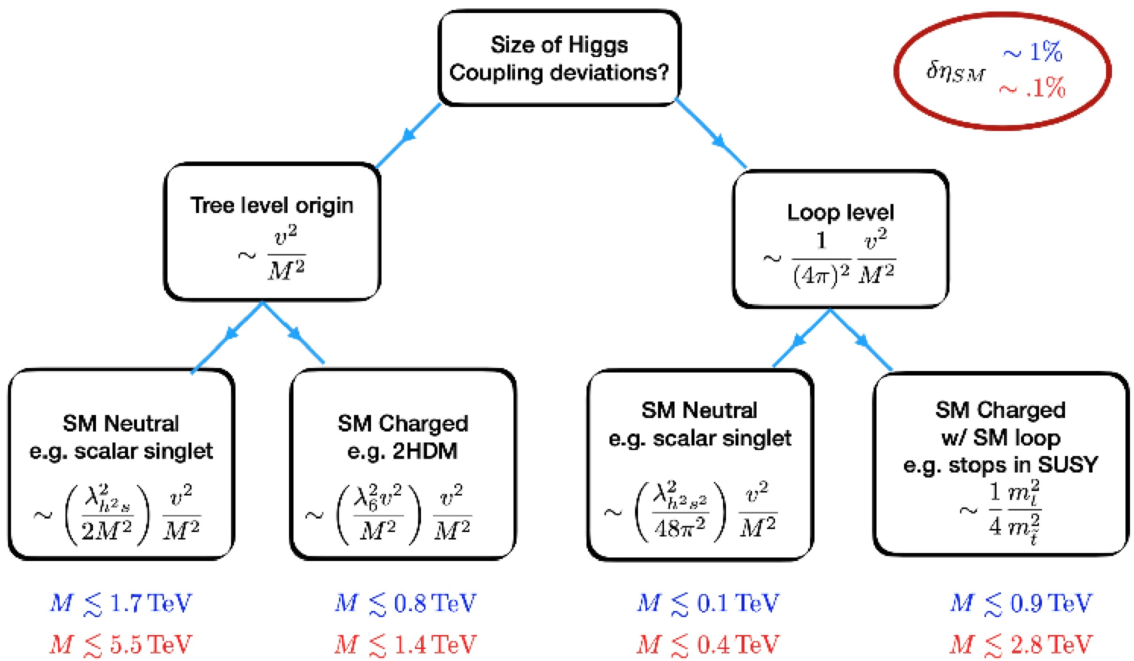
- Only 10% higher energy than LEP.
- 18% lower synchrtson power loss at √s=230 GeV compared with 240 GeV.

Higgs boson physics 1

The discovery of the Higgs boson has raised several questions.

- Is the Higgs sector SM-like
- Is the Higgs boson elementary or composite?
- Is the Higgs sector a portal to a hidden sector?

What is the needed precision for measurement of the properties of the Higgs boson, 0.5% or 0.1%.



Conservative Scaling for Upper Limit on Mass Scale Probed by Higgs Precision

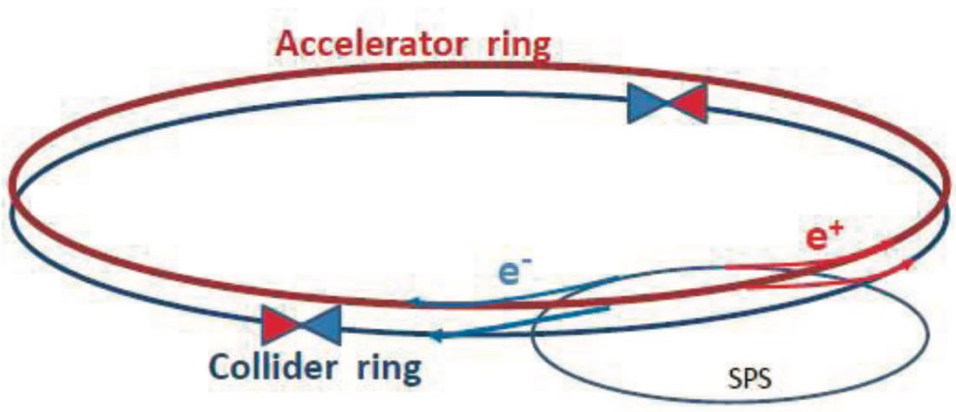
Follow ESPP2013 proposal & FCC(ee) Design

LEP3 installed in the existing LHC/LEP tunnel

Design of LEP3 could follow closely that outlined in FCC MTR and [ESPP 2013: https://cds.cern.ch/record/1471486].

- Separate full energy collider and accelerator (booster) rings, the latter for top-up injection. Electrons and positrons in the collider ring travel in separate beam pipes.
- With top-up - beam lifetime ~ 15 minutes (expected to be dominated by loss due radiative Bhabhas) top up ~ few 10^{10} electron/s

Earlier work (2013)



	LEP3	TLEP (LEP4)
circumference	26.7 km	80 km
max beam energy	120 GeV	175 GeV
max no. of IPs	4	4
luminosity at 350 GeV c.m.	-	0.7×10^{34} cm^{-2}s^{-1}
luminosity at 240 GeV c.m.	10^{34} cm^{-2}s^{-1}	5×10^{34} cm^{-2}s^{-1}
luminosity at 160 GeV c.m.	5×10^{34} cm^{-2}s^{-1}	2.5×10^{35} cm^{-2}s^{-1}
luminosity at 90 GeV c.m.	2×10^{35} cm^{-2}s^{-1}	10^{36} cm^{-2}s^{-1}

Note ratio of Lumi (1/5)

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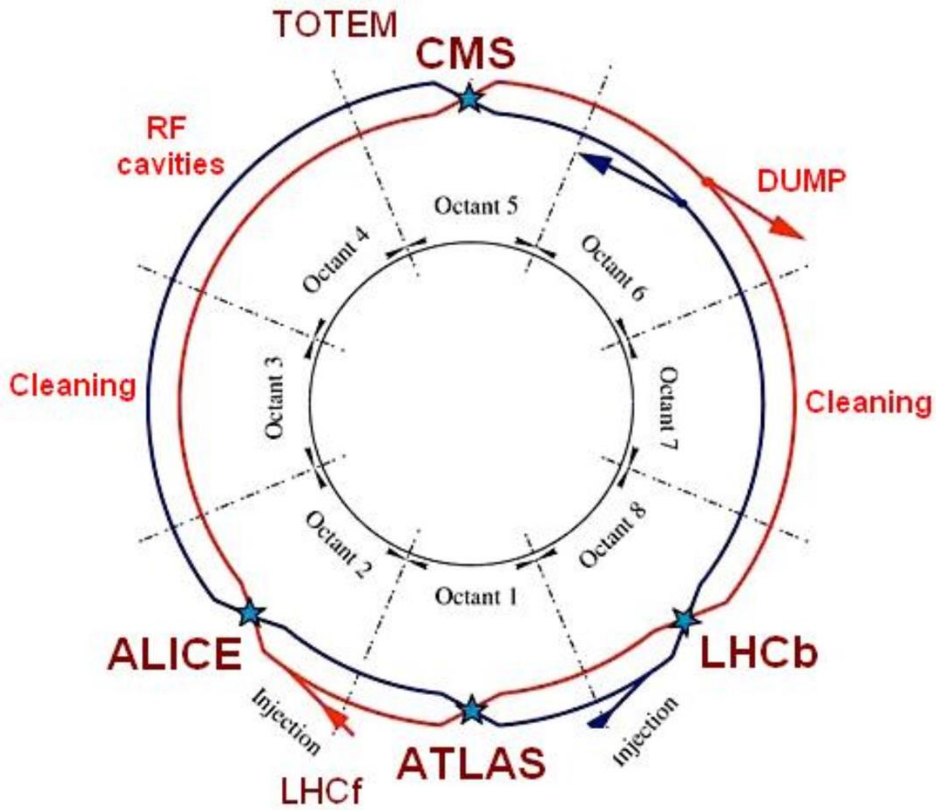
LEP3



The arcs are 2.45-km long, and the straight sections are 545-m long. The inner diameter of the tunnel varies between 3.8m in the arcs and ~ 4.4 m in the straight sections.

Deploy Re-purposed ATLAS and CMS experiments

Choice of Components: Magnets

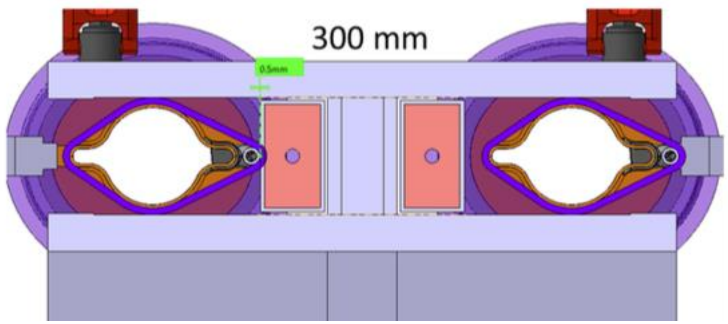
Follow FCC(ee) design

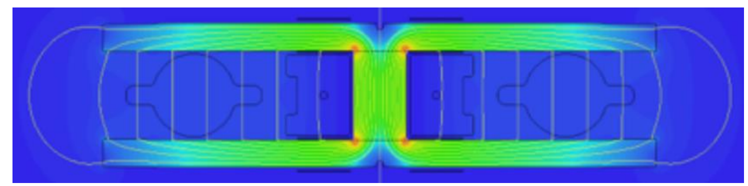
Instantaneous Luminosity [CEPC or FCC(ee) / LEP3] ~5; **~ 1.5×10^{34} cm^{-2}s^{-1} per IP**

2 Experiments; Reuse existing ATLAS and CMS experiments, suitably modified.

Use FCC designs for magnets

e.g. dipole shown





FCC MTR

- **Dedicated linac injector** on Prevessin site; Injection energy lowered from 20 to 10GeV.
- **RF**: 800 MHz, 0.5MW, 18.7 MV/m sc bulk niobium cavities run at 2K. Housed in two x two straight sections; one set for the accelerator and one set for the collider.
  The two colliding beams share RF.
- Operate with a 30 mrad **crossing angle** (15mrad half-angle).
- Using the FCCee cost methodology, estimate the **cost of LEP3** to be **~3 BCHF**.

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Choice of Components: RF System

Energy loss/turn @ √s=230 GeV: 5.1 GeV.

- A total 6.0 GV to be installed, with the same margin as FCCee

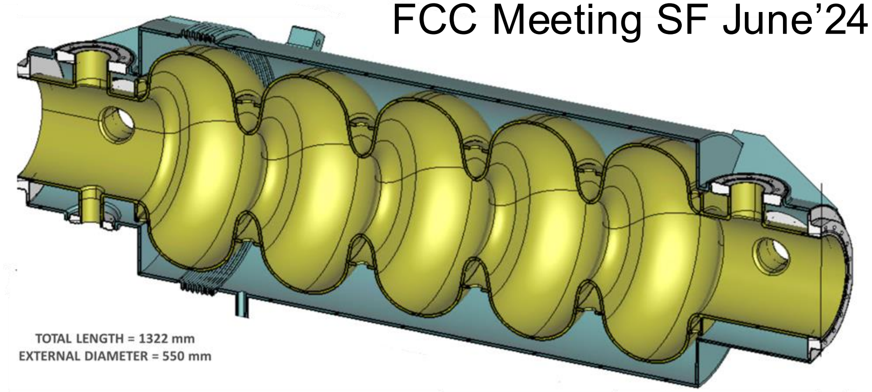
Deploy “tt” FCC(ee) cavities as possible baseline (for accelerator and collider)

- 800 MHz, 0.5MW, 5-cell 18.7 MV/m 7.5m long cavities
- External diameter ~55cm.

Use 4 LSSs; 2 for accelerator, 2 for booster

- Same cavities for e+ and e-

FCC Meeting SF June’24

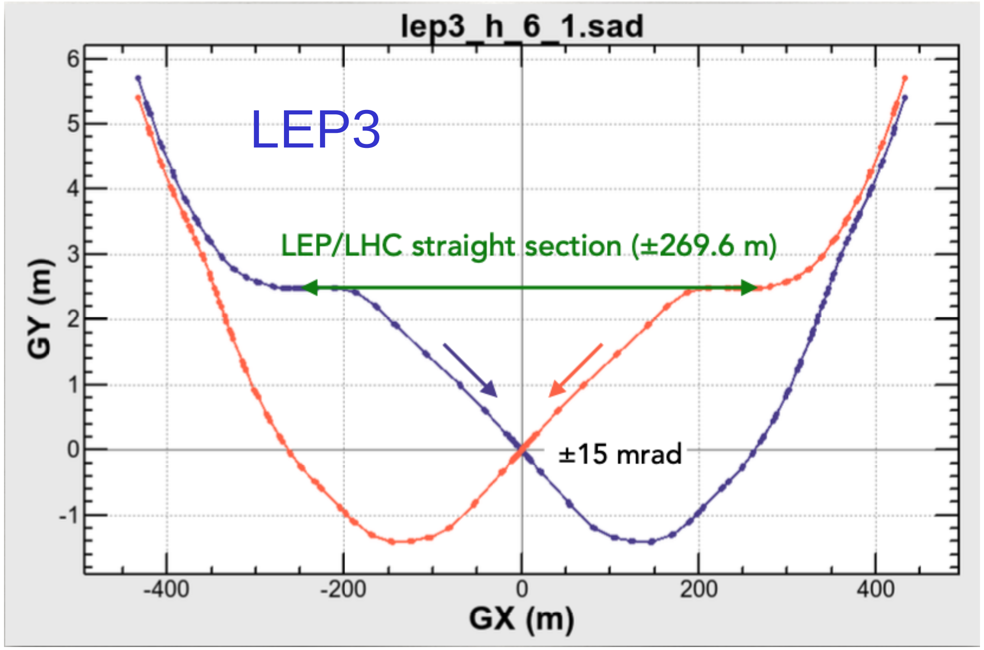


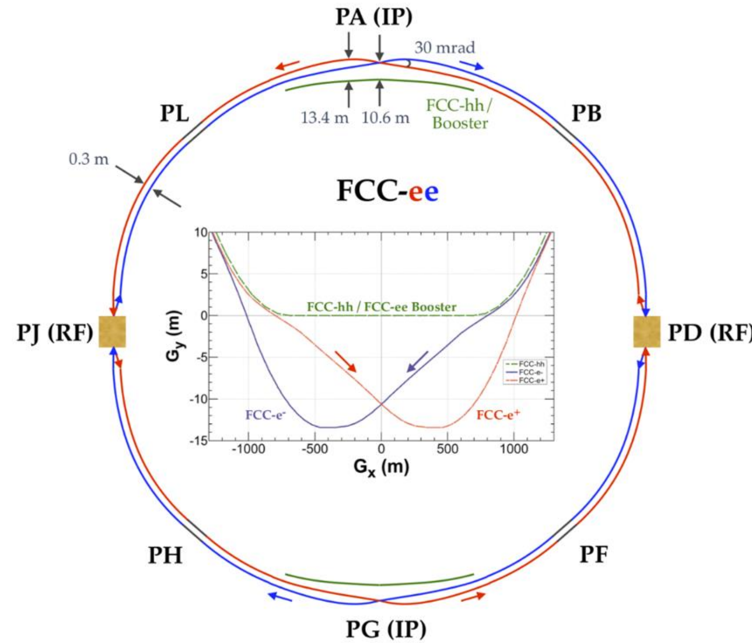
Is there room enough? To be checked carefully.

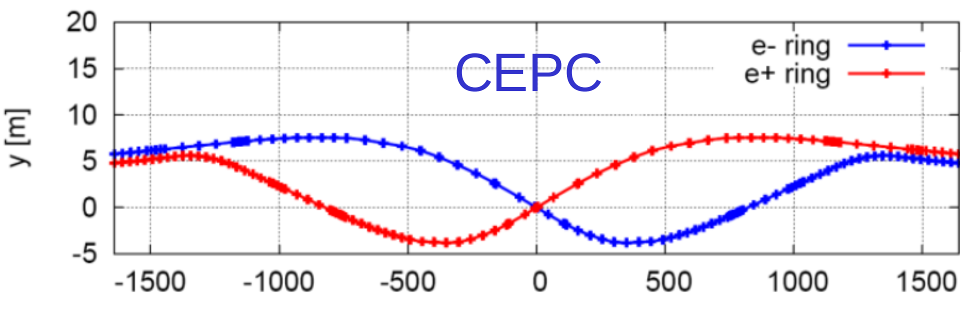
- Preliminary studies suggest use of ~ 40 6-cells made of 9.5 +0.5 m long cryomodules in each LSS
- Including enough (1 per cell) 4m-long quads → ~420 m, leaving enough room for separation and recombination

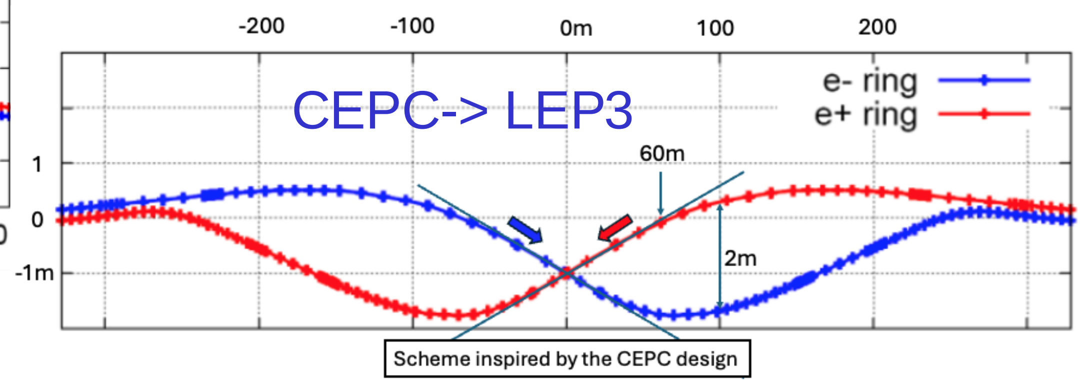
RF is the costliest item in the budget (~1 BCHF)

Issues: Crossing Angle









CEPC: No bending magnets placed in straight section within 70m of the collision points.

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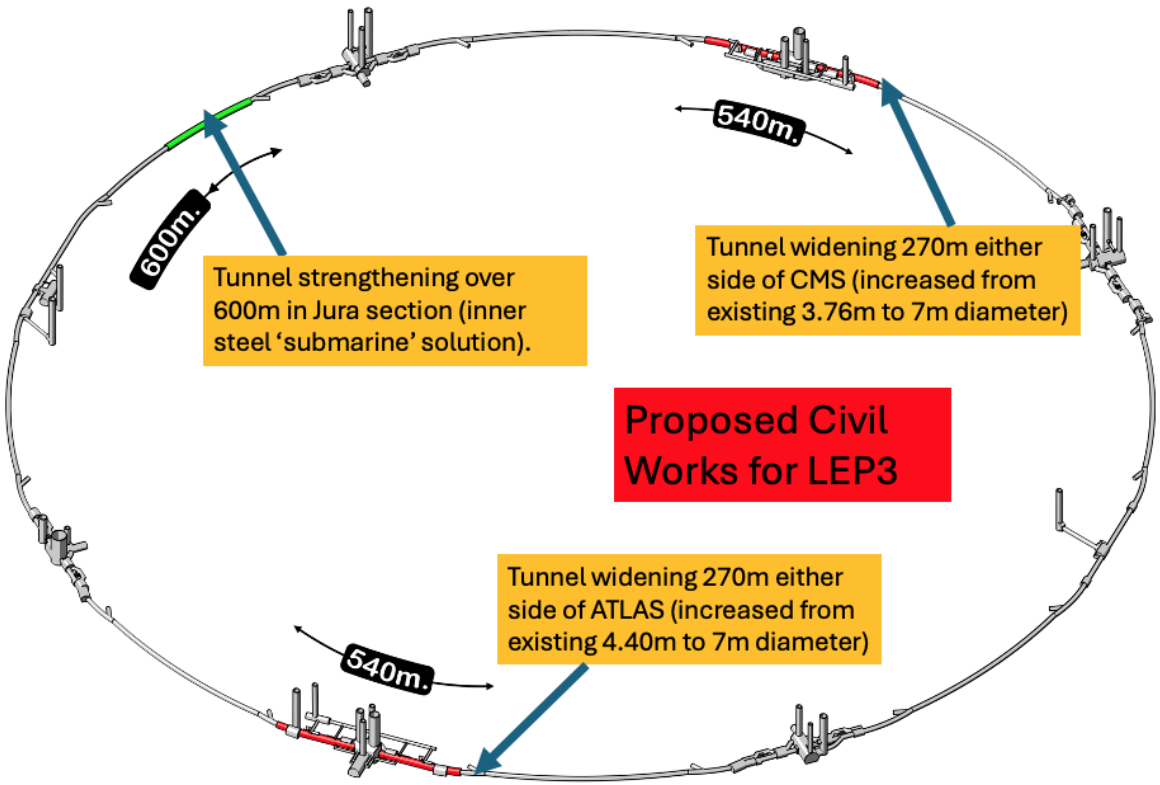
Cvil Engineering

- 40 years old infrastructure, some parts need maintainance
- High lumi acheived by crab-waist → large xing-angle → need to widen the LSS cross section on either side of the experiments
- possibly need of by-passes (avoidable possibly not needed)
- Overall civil engineering cost estimated: <200 MCHF



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Issues: Experiments-Machine Detector Interface

Assume that the ATLAS and CMS experiments can be re-used with **suitable modifcation or rebuilding of the inner trackers and the integration of focusing quadrupoles** some 2m from the IP. Same magnets but at lower fields. Trackers costing around MCHF 100/per experiment are assumed. (Should save the community >1BCHF)

Exploit all R&D done for ILC, CLIC and FCC(ee) detectors as well as LHC upgrades.

Baseline: Accelerator(booster) beam passes through tracker. If too much of perturbation then need bypasses.

All of the above need detailed studies.

From FCC MTR:
Integration of IR optics.
Independent beam pipes ~ 1-2m from IP.

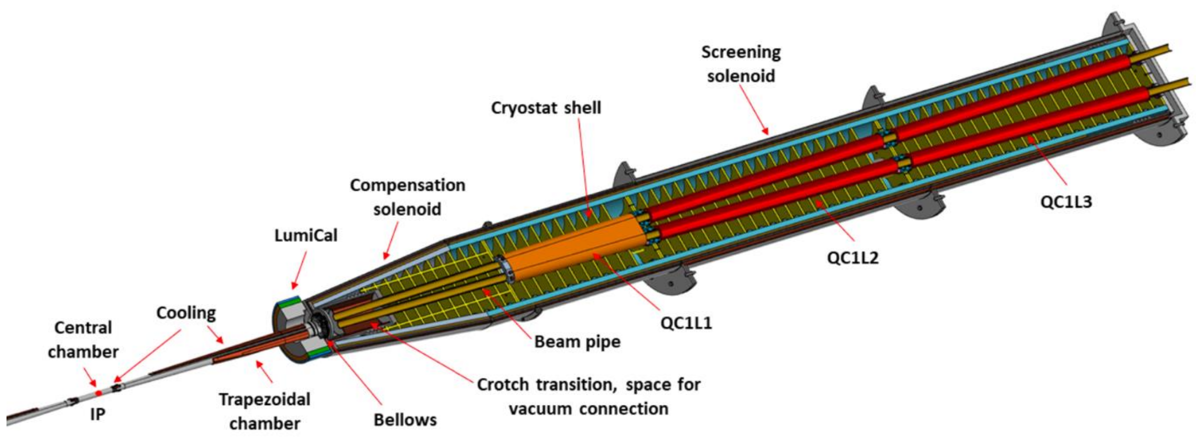
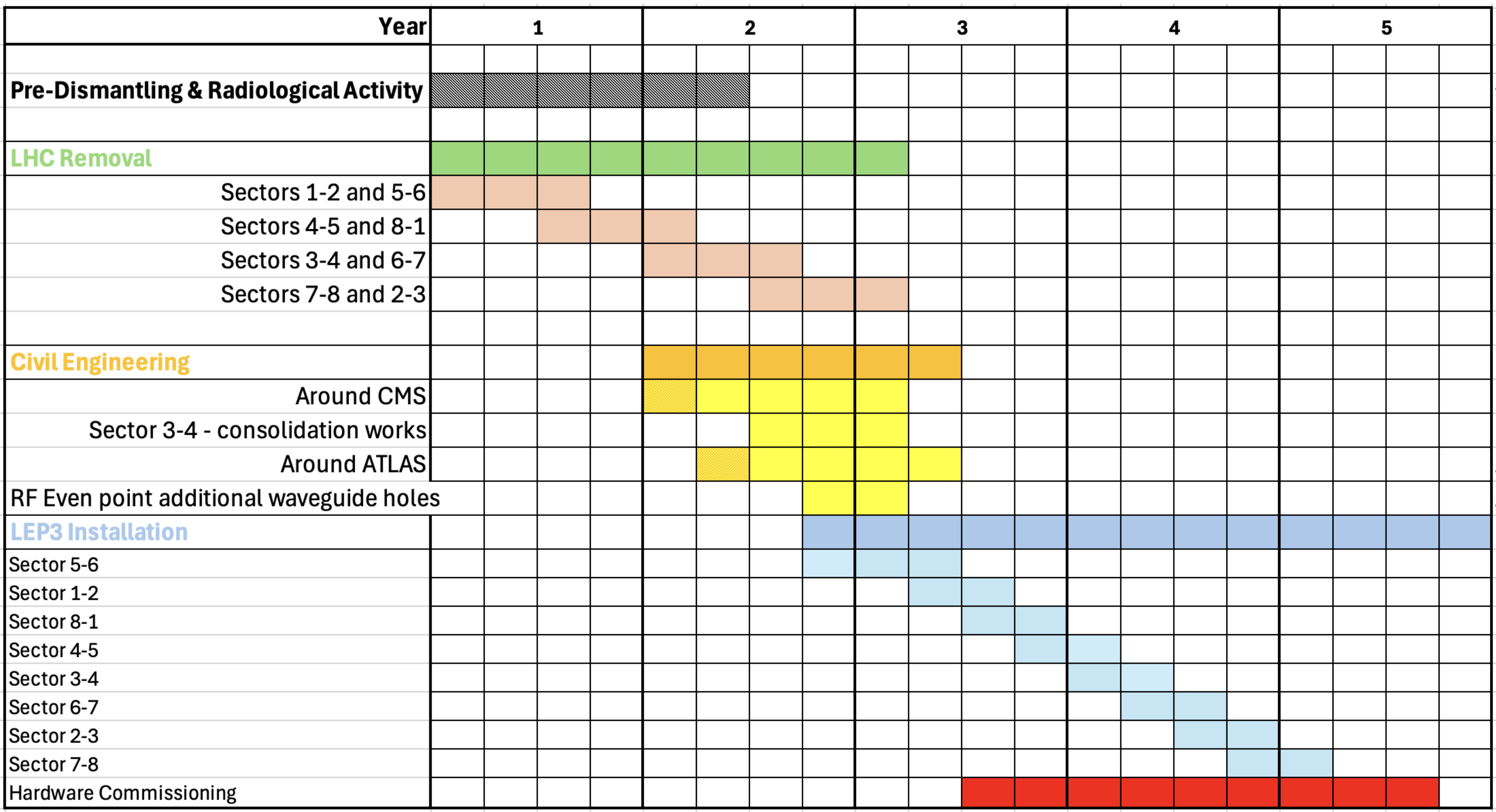


Fig. 217 Section view of the accelerator components from the IP to the end of the first final focus quadrupole (QC1), at about 8.4 m.

Example: Shutdown Schedule: After LHC stops



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Possibilities: The Future Beyond LEP3

Aim: an accelerator with constituent √s ~10 times higher than LHC (1-2 TeV).

If FCC(ee) or CEPC is built then a ~100 TeV hadron collider would be the obvious next step.
R&D Goal: Develop high field magnets - followed by the setting up for industrial production to provide solid cost estimates.

Muon colliders could provide another approach to reach constituent com energies of 10 TeV or above.
R&D Goal: on muon colliders with along-the-way milestones that still deliver physics as the R&D progresses - muon driven neutrino beams for experiments such as nuSTORM or those on neutrino/antineutrino factories.

After LEP3 (i.e. after around 30 years from today) perhaps via a worldwide strategy.

If R&D on high field magnets is successfiul and their construction cost and production capacity are known and appear affordable, then a decision could be made to go to a higher energy hadron machine such as FCC(hh) (~100 TeV).

If R&D on a muon collider is successful, then the option to go to a Muon Collider in the LEP/LHC tunnel could be available.

R&D Goal: increase gradient and efficiency of rf cavities and bring down their cost

Summary

Sustainability: important issue: use ideas/proposals from the other projects

ESPP requests an alternative/ backup option for the preferred one (we assume that is the FCC).

- LEP3 is a reasonable (perhaps the best) backup option
- Addresses many of the the potential FCC showstoppers
- Although suboptimal, it will yield good results for many of the same physics cases as FCC(ee)
- Leaves room (time, budget, resources) for further development of THE machine that can probe directly the energy frontier at a constituent $\sqrt{s}$ ~ 10 times LHC.

Although no show-stoppers have come to light, several issues have been raised which will need detailed studies and optimization before a LEP3-like project could proceed.

Questions 1: Physics

i) How well should the centre of mass (com) energy be known at Z, WW and ZH thresholds? What are its physics benefits? FCC wishes for 10^{-6} at Z, whilst LEP2 achieved 10^{-5} precision.

ii) What is the physics penalty for not being able to reach the ttbar threshold?

iii) What is the physics penalty for not having polarization?

iv) How much e-w and Higgs boson physics can be done at LEP3 in comparison with LHeC, CEPC or FCC(ee), over and above that at the HL_LHC?

v) How important is physics extracted from ttH reaction.

Questions. 2: Technical

i) What is the maximum achievable instantaneous luminosity?

ii) What beam optics studies are needed?

iii) What are the implications of a crossing angle of ~ 30 mrad. Does the tunnel need widening, and over what length, and can the interaction point be centred as in the current ATLAS and CMS experiments?

iv) What cavities are the most appropriate for LEP3? Can such cavities be easily integrated into the existing straight sections in the LEP/LHC tunnel?

v) If the tunnel needs enlargement or consolidation in some areas, how easily can it be done? How much time will be needed? Can the cost of civil engineering works be estimated?

vi) If two rings are necessary how does one deal with the placement of the accelerator ring through the interaction regions? Does it go through the experiments or do special bypasses need to be built?

vii) What procedures/derogations are required for the removal of LHC elements? Where will these components be stored?

viii) What is the optimal injector and injection energy for the LEP3 accelerator?

ix) Can the total cost of the whole LEP3 endeavour be kept below ~ 3BCHF?

x) How is the issue of sustainablility addressed?