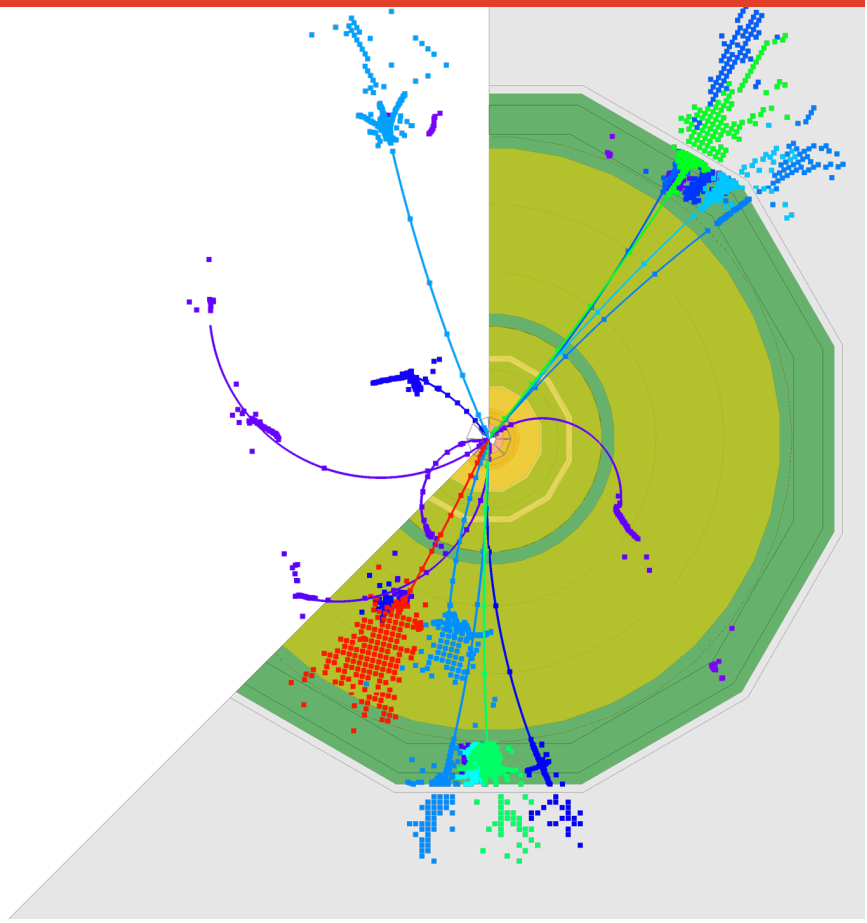
Future strategy for collider physics

Higgs–Maxwell Workshop, 19 February 2025

Aidan Robson, University of Glasgow

Context:

European Strategy for Particle Physics Update



European Strategy for Particle Physics Update

Remit of the European Strategy Group (ESG):

*"The aim of the Strategy update should be to 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 ESG should take into consideration:

- The **input of the particle physics community;**
- The **status of implementation of the 2020 Strategy update**;
- The **accomplishments over recent years**, including the results from the LHC and other experiments and facilities worldwide, the progress in the construction of the High-Luminosity LHC, the outcome of the Future Circular Collider Feasibility Study, and recent technological developments in accelerator, detector and computing;
- **The international landscape of 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 ESG is supported by the Physics Preparatory Group (PPG),
which has in turn appointed Working Groups to assemble the strategy Briefing Book

European Strategy for Particle Physics Update

Timeline:

More information:

https://europeanstrategyupdate.web.cern.ch/about

European Strategy for Particle Physics Update

UK community preparations:

Series of workshops and discussions organised by ECFA UK delegates and PPAP:

ECFA-UK Physics Workshop, IPPP Durham, 23–26 Sept 2024
https://conference.ippp.dur.ac.uk/event/1357/

Drafting days:
Daresbury, 4 Nov 2025 https://conference.ippp.dur.ac.uk/event/1391/
UCL, 9 Jan 2025 https://indico.stfc.ac.uk/event/1183/
RAL, 28 April 2025 https://indico.stfc.ac.uk/event/1430/

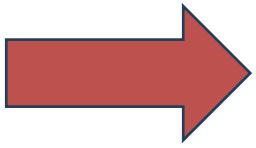
First draft of UK national strategy input available for comment:
https://indico.stfc.ac.uk/event/1434/

– can be commented on now, for initial submission by 31st March;
– will be updated in light of all project inputs, and the discussion on 28th April

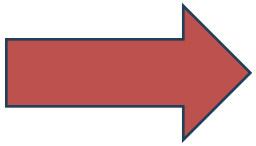
The big picture

The Higgs boson is a new window on the Universe;
what can it tell us about:

- Dark matter?
- Cosmic inflation?
- The mass pattern in the quark and lepton sectors?
- Origin of matter-antimatter asymmetry?
- The electroweak phase transition?

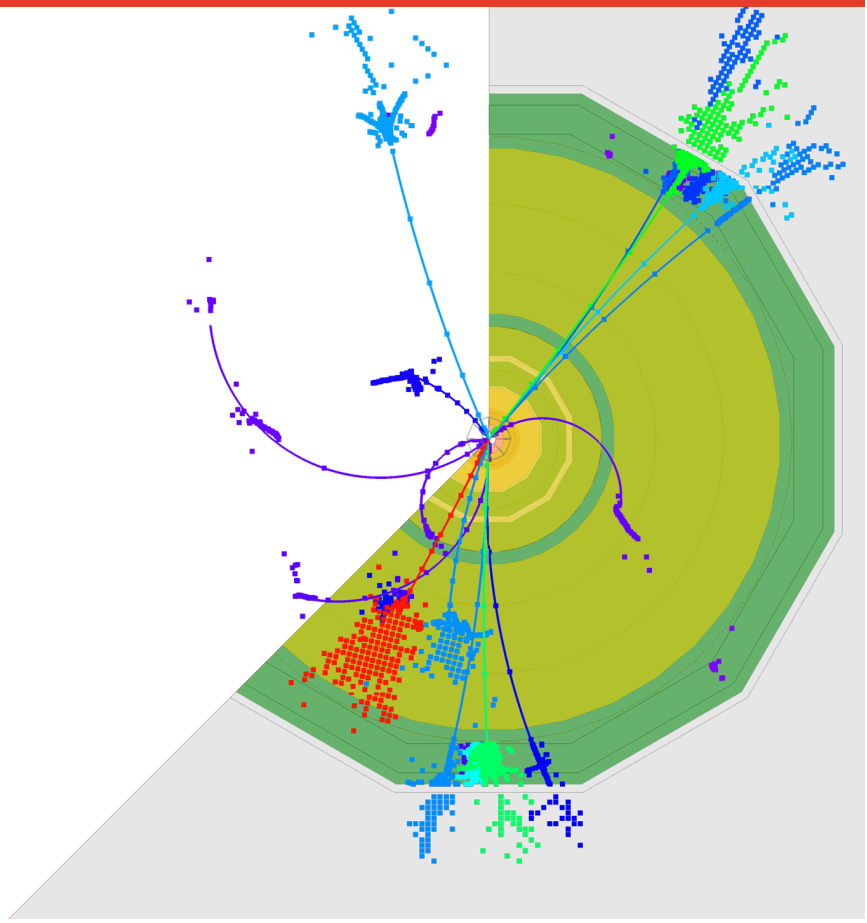


To fully exploit the Higgs sector, an ***e+e– Higgs factory***, which can go beyond the capabilities of the HL-LHC, is strongly motivated



If new physics is at the TeV scale, we would also like to ***keep pushing the energy frontier***, via a collider that comes after the Higgs factory

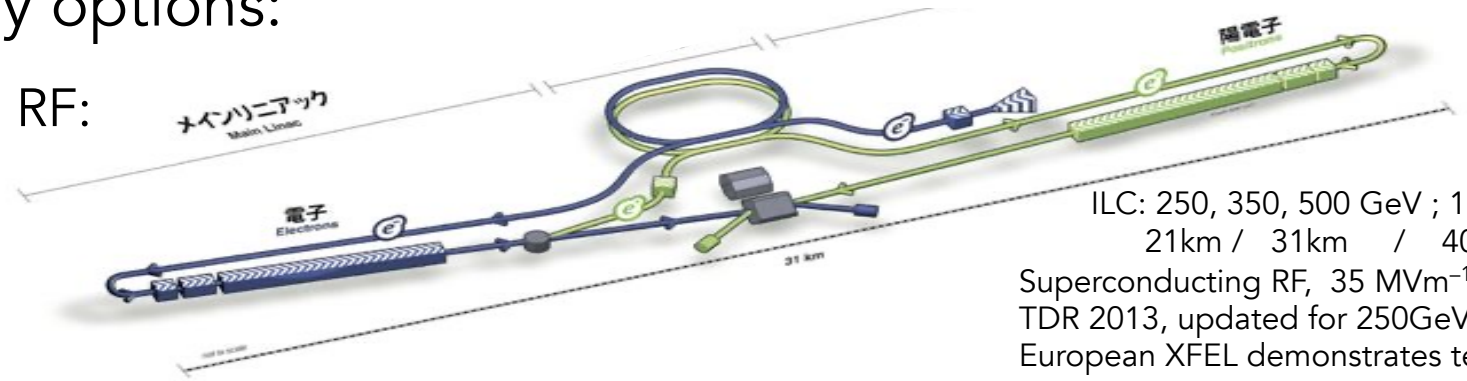
Linear colliders



Linear collider Higgs factory options

Two main technology options:

Superconducting RF:

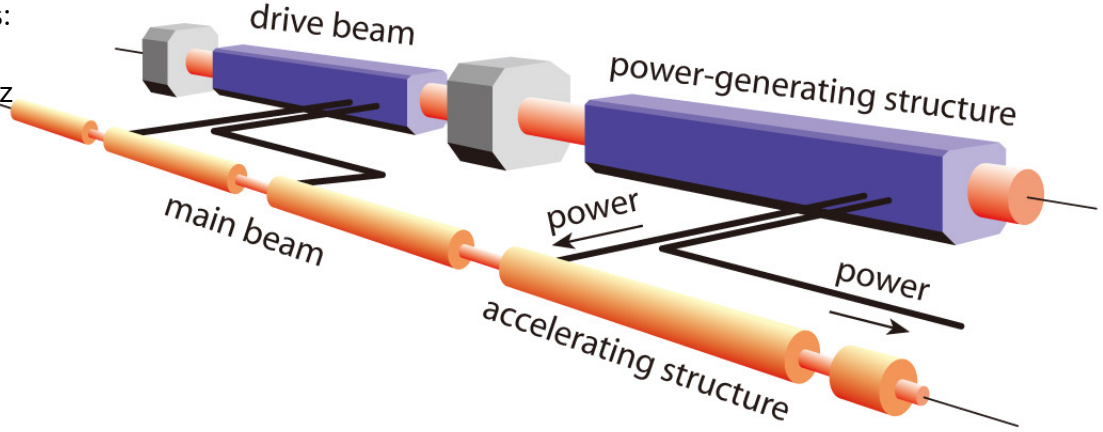


ILC: 250, 350, 500 GeV ; 1 TeV
21km / 31km / 40km
Superconducting RF, 35 MVm^{-1}
TDR 2013, updated for 250GeV
European XFEL demonstrates technology

Room temperature RF:

CLIC: 380 GeV ; 1.5 TeV 3 TeV
11km / 29km / 50km
Room temperature, 72–100 MVm^{-1}
CDR 2012, Updated Staging Baseline 2016,
Project Implementation Plan 2018
Similar structures used for Swiss FEL

Recently updated luminosities:
380 GeV : 2.2ab^{-1} at 50Hz
or 4.3ab^{-1} at 100Hz
1.5 TeV : 4ab^{-1}
3 TeV : 5ab^{-1}



– both options extensively studied for CERN

propose Linear Collider Facility @CERN

Footprints of superconducting (ILC-like) and normal-conducting (CLIC-like) machines have been made to be the same
–> either could be realised

Incorporates two interaction points (different from original ILC and CLIC proposals).

Cool Copper Collider (C^3)

C^3: 250, 550 GeV
8km / 8km
Operation temperature 77K, 70–120 MVm^{-1}

Hybrid Asymmetric Linear Higgs Factory (HALHF)

HALHF: 250 GeV (e^- 500GeV, e^+ 31GeV), 3.3km
25 MVm^{-1} conventional, 6.3GVm^{-1} plasma

Key physics deliverables

250 GeV (/380 GeV)

- precision Higgs mass and couplings; total ZH cross-section
- Higgs –> invisible (Dark Sector portal)
- two-fermion (ff) and WW programmes
- optional: WW threshold scan

  - several couplings at few-0.1% level: Z, W, g, b, tau
  - some more at ~1%: gamma, c

Z pole, few billion Z bosons

- EWPOs 10–100x better than today

  - benefit from beam polarization

350 GeV

- precision top mass from threshold scan

500–600 GeV

- Higgs self-coupling in ZHH

  - sensitive at ~15% to all values of self-coupling
- top-quark EW couplings

  - many not accessible at HL-LHC
- top Yukawa coupling including CP structure
- improved Higgs, WW and ff
- probe Higgsinos up to ~300GeV
- probe Heavy Neutral Leptons up to ~600GeV

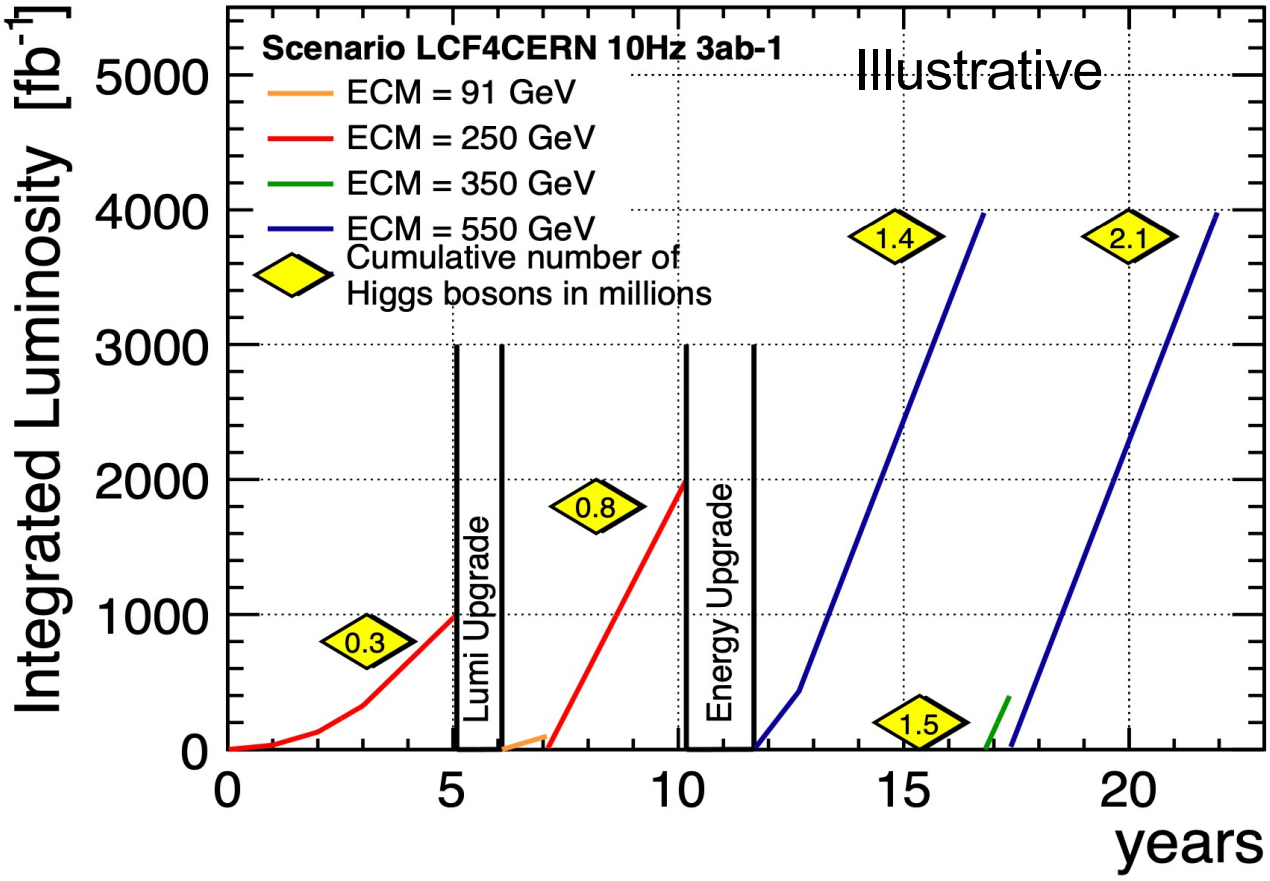
800–1000 GeV

- Higgs self-coupling in VBF
- further improvements in tt, ff, WW
- probe Higgsinos up to ~500GeV
- probe Heavy Neutral Leptons up to ~1000GeV
- searches…

≥500 GeV e+e– collisions are only achievable at a linear collider facility

Example timeline

several years approval period
5–7 year preparation period
10 year construction period



Why linear?

Maturity

- CLIC CDR 2012 followed by 2016, 2018, 2025 updates ; ILC TDR 2012 ;

both studied extensively for CERN site

Flexibility

- Intrinsically extensible / stageable: choice at each stage to increase energy in e+e–

(with same or new technology e.g. plasma), or to move to the next collider (pp / μμ / …)

Energy reach

- beyond opening up of more processes, also allows cross-check of core Higgs measurements

from ZH production, in VBF production

Longitudinal beam polarization

- for control of systematics / exploring structure of new interactions

Cost

- Linear Collider Facility Higgs factory is realisable with current CERN budget envelope

'Low' power consumption

- CLIC and ILC operate at around 110MW for their initial stages

Factorisability

- It's premature to decide on the next-to-next (i.e. energy frontier) collider

=> decouple the infrastructures, and pursue accelerator / magnet R&D in parallel

Speed

- Project can proceed quickly (quicker for SCRF than for room-temperature option), for

first collisions around end of HL-LHC

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–> a linear collider provides a realisable route to an e+e– Higgs factory at CERN, and attractive upgrade options

Circular colliders –> Guy