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European Strategy for Particle Physics: input from the collider physics group at Uppsala University

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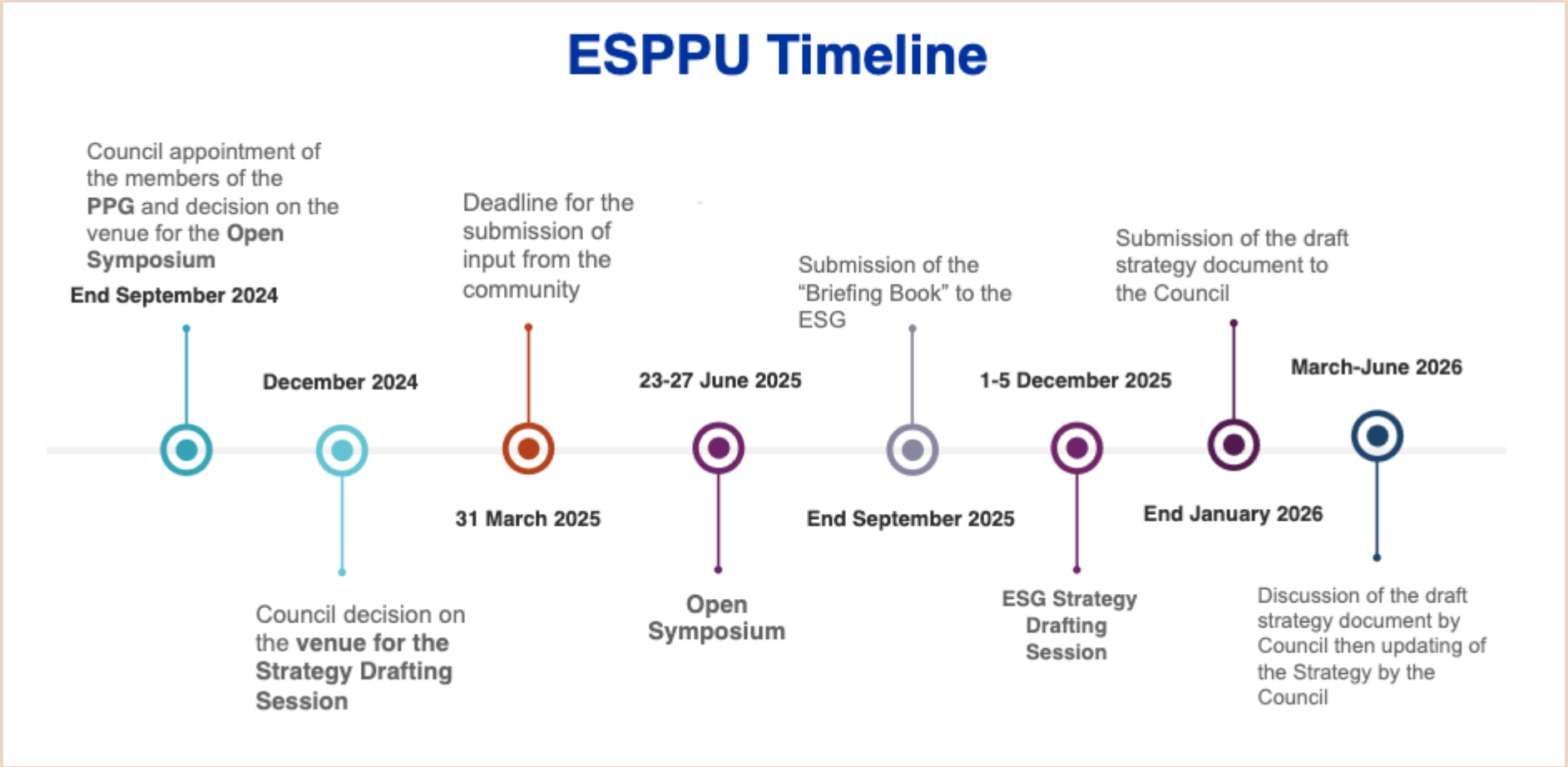
European Strategy for Particle Physics



ESPP – national inputs

- The community is asked to submit input by March 31, 2025. A major component is the "national inputs" that are expected to be collected individually by each country (or by regions).
- ECFA has a set of guidelines for the collection of the national inputs.
- Town-hall meeting to discuss the input from Sweden in Stockholm on January 9th, 2025: https://indico.fysik.su.se/event/8993/
  - Organisation committee: R. Brenner (ESG & UU), A. Ferrari (RECFA & UU), S. Stranberg (Stockholm), D. Silvermyr (Lund).
- Prior to this town-hall meeting, local meetings at Swedish institutes, as well as among the ECR community → gather a first set of inputs!
- More meetings should follow:
  - Mid-March: a Nordic ESPP meeting is being scheduled, stay tuned
  - Spring 2025: discuss ESPP inputs (deadline for comments on May 26),
  - Autumn 2025: after the release of the Briefing Book draft (deadline for comments on November 14).

ESPP input – UU collider physics group

Question 3a – Which is the preferred next major/flagship collider project for CERN?

We support the baseline scenario, i.e. an e^+e^- Higgs factory (FCC-ee) followed by a high-energy hadron collider (FCC-hh), as proposed at the previous ESPP update.

Question 3b – Most important elements in the response to 3a?

(i) Physics potential:

- Accurate electroweak measurements, close interplay with the Higgs sector.
- More precise measurements of the properties of the Higgs boson than those expected to be achieved from the legacy results of HL-LHC.
- Searches for new physics are also possible:
  - directly: e.g. low-mass states, feebly-interacting and long-lived particles, exotic Higgs boson decays, etc.
  - indirectly: EFTs with better accuracy than at HL-LHC thanks to a clean environment.

ESPP input – UU collider physics group

Some limitations of the FCC-ee physics potential though:

- Running a lepton collider at fixed energies (rather than scanning or having access to a full spectrum) limits the potential of direct BSM searches.
- The FCC-ee running baseline cannot reach the ttH threshold. Running at that energy would allow to probe the top-Higgs interaction with precision. At FCC-ee, the top Yukawa coupling will then be measured indirectly.
- Similarly, FCC-ee will remain below the 500 GeV threshold for direct HH production. Precision measurements of the Higgs self-coupling at FCC-ee can only proceed indirectly through accurately determining electroweak corrections to single-Higgs production.
  - Is the advertised predicted precision of 20-30% really competitive against HL-LHC (50% per experiment right now, will probably get better)?
  - What are the theoretical uncertainties on electroweak corrections and will they be a limiting factor in measuring the Higgs self-coupling?

ESPP input – UU collider physics group

Addendum from THEP on the physics potential:

A theoretical priority is presently the development of methods to account for insofar neglected soft colour and colour interference effects in both the initial and final state evolution and fragmentation, as well as assessing sub-leading colour effects in the hard scattering, as these will all become testable with the increased energies and/or luminosities of future colliders.

A sequence seeing an e^+e^- machine first (where to isolate the aforementioned effects in distributions and model these appropriately in a clean environment) followed by a hadron-hadron accelerator (where this colour dynamics would grossly manifest to affect cross sections too), thereby mirroring the historical LEP/LHC sequence, would represent the ideal way forward, thus aligning with the FCC priorities.

ESPP input – UU collider physics group

Question 3b – Most important elements in the response to 3a?

(ii) Long-term perspective:

We need to keep the field alive and ensure continuity, we do not want to risk sidelining a whole community like what happened in the USA once Tevatron was closed.

Hence we need a collider at CERN shortly after HL-LHC. Not building the FCC means that we will lose the expertise and we may even lose know-how for building linear colliders or muon colliders.

Going for ILC or CLIC instead of FCC-ee at CERN likely means that there is no immediate perspective for upgrading to a hadron machine in the 100 TeV range.

ESPP input – UU collider physics group

Question 3b – Most important elements in the response to 3a?

(iii) Financial and human resources: requirements and effect on other projects:

Going forward with FCC-ee should not jeopardise R&D for muon colliders. It is obvious that R&D for high-field magnets should be supported as part of the baseline towards FCC-hh.

Including forward physics and similar satellite programs in the FCC baseline is important to keep that community alive.

(iv) Timing:

We need a collider at CERN shortly after HL-LHC, and this needs to be approved within less than 5 years from now.

ESPP input – UU collider physics group

Question 3b – Most important elements in the response to 3a?

(v) Careers and training:

We want young people in the community to have long-term career prospects, hence a flagship project at CERN in order to guarantee faculty positions for our current and future PhD students. This is needed to revitalise the field.

(vi) Sustainability:

Obviously important and the FCC project should be planned with that in mind, nevertheless with the risk of increasing its cost. Still, sustainability principles should be in the guidelines and technical choices.

FCC-ee followed by FCC-hh in Europe is sustainable because only one tunnel is built, with respect to digging several tunnels in parallel. Also, sustainability is likely to be worse elsewhere.

ESPP input – UU collider physics group

Question 3c – Should CERN/Europe proceed with the preferred option set out in 3a or should alternative options be considered:
i) if Japan proceeds with the ILC in a timely way?
ii) if China proceeds with the CEPC on the announced timescale?
iii) if the US proceeds with a muon collider?
iv) if there are major new (unexpected) results from the HL-LHC or other HEP experiments?

- ILC in Japan is highly unlikely but the CEPC threat is real...
- FCC-ee would still win on the luminosity reach against any linear collider (also more experiments). However, if we want to reach higher energies (500 GeV and above), then CLIC is the best way to go, not ILC.
- We believe that FCC-ee has not lost the competition against e^+e^- colliders elsewhere yet, even if China wants to proceed with CEPC.

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- If there is an e^+e^- collider outside Europe, what about a hadron collider in the FCC tunnel (low-field magnets, new tunnel) or a high-energy LHC (high-field magnets, same tunnel)? One needs to understand how much time without colliding physics this would imply, the physics potential, etc.
- Energy recovery linacs would allow to have ep collisions right after HL-LHC and bridge the gap towards a higher-energy hadron collider. Weaker physics case and not a flagship project for CERN though.
- Regardless R&D on high-field magnets must continue in any scenario.

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- A muon collider in the US would be great, but no change of plan concerning FCC-ee followed by FCC-hh!
- R&D for muon colliders should be supported by CERN but happen elsewhere so that CERN can invest its resources on the FCC program (including high-field magnets).
- As for new physics results, this is very speculative. We would need to calibrate our program based on such new physics. Still, one should keep the (flexible) baseline of FCC and invest more on muon colliders if this helps address new physics.

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Question 3d – Beyond the preferred option in 3a, what other accelerator R&D topics should be pursued in parallel?

High-field magnets for sure, where CERN should be the leader. Other activities (plasma acceleration, muon colliders, etc) can be performed in laboratories elsewhere.

Question 3e – What is the prioritised list of alternative options if the preferred option set out in 3a) is not feasible?

No consensus on the prioritisation of other projects yet → to be discussed at national level.

Anything that is not FCC should come very soon after HL-LHC. A long gap before the next flagship project at CERN is likely to kill the field.