U.S. Input to ESPP on Higgs Factories

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Discussion

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U.S. input to ESPP

- The U.S. Higgs Factory Coordination Consortia (HFCC-PED & HFCC-A) has been mandated by DOE and NSF to prepare and provide our input to the ongoing European Strategy Update.
- Our goal is to build on the P5 recommendations and seek consensus within the U.S. community to deliver a coherent and focused input.
- The U.S. is by far the largest national partner in CERN based projects and it is critical that we engage in the ongoing process and provide our comments.
    - Other inputs may be forthcoming, including those from our colleagues in intensity and cosmic frontier as well as muon collider, but our input (based on the high priority future initiatives in the 2020 ESSPU) is by far the most relevant and critical for a next generation project planned at CERN.
- This meeting provides the first opportunity to discuss the framework of our input with principal stakeholders.
    - Additional meetings with the wider community, including a discussion at the upcoming HEPAP, is planned.
- There are two parts to our input: A strategic input requesting a response to the questions from ESG (slide 7) and a technical input highlighting the potential areas of U.S. contribution. This discussion focusses on our strategic input.

Quoting from the 2020 ESPPU

An **electron-positron Higgs factory is the highest-priority next collider**. For the longer term, the European particle physics community has the ambition to operate a proton-proton collider at the highest achievable energy. Accomplishing these compelling goals will require innovation and cutting-edge technology:

- the particle physics community should **ramp up its R&D effort focused on advanced accelerator technologies**, in particular that for high-field superconducting magnets, including high-temperature superconductors;
- Europe, together with its international partners, should **investigate** the technical and financial feasibility of a **future hadron collider at CERN** with a center-of-mass energy of at least **100 TeV** and with an **electron-positron Higgs and electroweak factory as a possible first stage**. Such a feasibility study of the colliders and related infrastructure should be established as a global endeavor and be completed on the timescale of the next Strategy update.
- The timely realization of the electron-positron International Linear Collider **(ILC) in Japan would be compatible with this strategy** and, in that case, the European particle physics community would wish to collaborate.

P5 on HL-LHC

- **“As the highest priority independent of the budget scenarios, complete construction projects and support operations of ongoing experiments and research to enable maximum science.:**
- ”HL-LHC (including the ATLAS and CMS detectors, as well as the Accelerator Upgrade Project) to start addressing why the Higgs boson condensed in the universe (*reveal the secrets of the Higgs boson*, section 3.2), to *search for direct evidence for new particles* (section 5.1), to *pursue quantum imprints of new phenomena* (section 5.2), and to *determine the nature of dark matter* (section 4.1).”

- Comment: We must re-emphasize the importance of successfully completing the HL-LHC construction and operations at the highest priority.
  - The physics realized at the LHC/HL-LHC could well shape the direction of particle physics globally.
  - However, given the timescales involved in the realization of next generation mega-projects, it is clear that we cannot afford to wait until the completion of HL-LHC to make a decision.
  - The community appears to agree, based on discussions at recent meetings, that a prompt decision should be made and a strong recommendation by ESG to CERN council would enable that.
  - Please comment if you agree and if we should stress this point in our report.

P5 on Future Colliders

- P5 20-year vision statement:
  - In 20 years, the HL-LHC program will be completed, a Higgs factory will be preparing to take data, and a vigorous R&D program will be paving the path to a 10 TeV pCM collider [FCC-hh, muon-collider, …]. Each of these projects will fill in the map of the Higgs boson's behavior in complementary ways: The HL-LHC will deliver the first draft, the Higgs factory will provide incredible detail in key areas of the landscape, and the 10 TeV pCM collider will reveal the challenging heights of the Higgs boson's interaction with itself.
- Recommendation 2c:
  - **Construct a portfolio of major projects that collectively study nearly all fundamental constituents of our universe and their interactions, as well as how those interactions determine both the cosmic past and future.**
  - An offshore Higgs factory, realized in collaboration with international partners, in order to reveal the secrets of the Higgs boson. The current designs of FCC-ee and ILC meet our scientific requirements. The US should actively engage in feasibility and design studies. Once a specific project is deemed feasible and well-defined, the US should aim for a contribution at funding levels commensurate to that of the US involvement in the LHC and HL-LHC, while maintaining a healthy US onshore program in particle physics.

- Comment: The P5 report discusses the Linear Collider (ILC) in the context of Japan as the host of a global project (sec 6.5), while FCC option is discussed in the context of CERN. A LC at CERN is not explicitly discussed in the report.

U.S. – CERN Statement of Intent

Acknowledged the importance of the European Strategy for Particle Physics Update and the U.S. P5 plan to guide the long-range strategies for Europe, CERN, and the United States; including the leading roles each have played in developing and executing one another's strategy.

The United States and CERN intend to:

- Enhance collaboration in future planning activities for large-scale, resource-intensive facilities.
- Continue to collaborate in the feasibility study of the Future Circular Collider Higgs Factory (FCC-ee), the proposed major research facility planned to be hosted in Europe by CERN
- Should the CERN Member States determine the FCC-ee is likely to be CERN's next world-leading research facility following the high-luminosity Large Hadron Collider, the United States intends to collaborate on its construction and physics exploitation, subject to appropriate domestic approvals.

ESG request

a) Which is the preferred next major/flagship collider project for CERN?

b) What are the most important elements in the response to (a)?
   - Physics potential; Long-term perspective; Financial and human resources; Requirements and effect on other projects; Timing; Careers and training; Sustainability

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

d) Beyond the preferred option in (a), what other accelerator R&D topics (e.g. high field magnets, RF technology, alternative accelerators/colliders) should be pursued in parallel?

e) What is the prioritized list of alternative options if the preferred option set out in (a) is not feasible (due to cost, timing, international developments, or for other reasons)?

f) What are the most important elements in the response to (e)? (The set of considerations in (b) should be used).

ESG request (a)

a) Which is the preferred next major/flagship collider project for CERN?

- Based on the discussions you have heard earlier today, should the U.S. support the Integrated FCC program as the next major/flagship project at CERN?
- Some points to consider:
  - The last ESPPU requested a feasibility study for the Integrated FCC program, which CERN and its member states have duly complied with.
  - A formal feasibility study would need to be launched should another option be pursued at CERN. This likely delays any decision for the next future project at CERN to the following ESPPU (~2030?).
    - A new feasibility study could be performed in a shorter time scale given the FCC experience.
  - A decade of investment in studying the feasibility of the FCC option has shown no technical show-stoppers for the proposed initial phase (FCC-ee).
  - FCC-ee provides a natural path to FCC-hh if a circular collider option is pursued.
  - The timely realization of physics and advantages of higher energies with a Linear Collider is still debated.
  - Financial model still under discussion and needs to be addressed prior to the next CERN Council. Funding consideration (not within the ESG remit) may have an impact on the proposed project timelines.
- Should the U.S. provide an even stronger support for a collider option at CERN, and acknowledge that a Linear Collider is not a preferred option for CERN?

ESG request (c)

c) Should CERN/Europe proceed with the preferred option set out in a) or should alternative options be considered?

- If Japan builds the ILC; or China builds the CEPC; or US builds the muon collider.

- Important to plan the next major project at CERN following the completion of the HL-LHC (~2041).
  - U.S. muon collider is not in the same time scale and should not influence the above decision.
  - Technical accelerator R&D incl. a demonstrator facility can likely proceed during this timescale.
- CEPC from China would almost certainly exclude a U.S. participation in that project.
  - The U.S. should strongly collaborate with CERN in enabling the next project where U.S. can engage and benefit from the science.
- An ILC in Japan is highly desirable; the Japanese community are committed to hosting it (see P5 report)
  - There has been little progress in the past decade to realize an ILC in Japan.
  - ESPPU-2020 clearly articulated that an ILC in Japan would be complementary and compatible with CERNs vision for an FCC program.
  - Supporting two mega projects is a challenge and requires a new level of international engagements.
  - Should the global community provide a renewed support for ILC? Should the U.S. encourage the ESG to provide strong recommendations to renew efforts to seek global support to build an ILC in Japan?

ESG request (e)

e) What is the prioritized list of alternative options if the preferred option set out in a) is not feasible (due to cost, timing, international developments, or for other reasons)?

- A document is being prepared by LC Vision to explore the possibility of a Linear Collider at CERN. This is an important input for the ESG. It would hopefully articulate if a Linear Collider would provide a cost-effective and timely alternative, but this would need to be debated again in the context of the (next) ESPPU.
  - Would a Linear Collider at CERN anyway have to be followed with an FCC-hh (?).
  - Unclear if Linear Collider is the right option for CERN's vision and future direction.
- If FCC is not feasible due to factors listed above, a plausible way forward that aligns with the 2020 ESPPU and the 2023 P5 reports would be to pursue an ILC in Japan in the shorter time scale as a global project followed by an FCC-hh at CERN on a slightly longer timescale (2050s?) allowing time for R&D on cost-effective high-field magnet technology.
  - ILC in Japan remains unrealistic.
  - Funding to construct an ILC while pursuing R&D for FCC-hh would remain a challenge.
  - Not an ideal option for CERN to introduce long gaps between HL-LHC and FCC.
- There appear to be no ideal alternative option that aligns with the 2020 ESPPU and 2023 P5 report.

U.S. input to ESG (questions for discussions)

1) Should the U.S. provide its strong support to the Integrated FCC program emphasizing the need for a timely decision?
2) Should the U.S. provide an even stronger support for a collider option at CERN, and acknowledge that a Linear Collider is not a preferred option for CERN?
3) Should the U.S. encourage the ESG to provide strong recommendations to renew efforts to seek global support to build an ILC in Japan?
4) What statements can the U.S. make in response to the alternative options if the preferred option were not to succeed?
5) What are the most important elements for the next project: Physics potential; Timing; Financial and human resources; Careers and training; Sustainability; Long-term perspective; Requirements and effect on other projects
   - Is the above listed in right priority? Which option serves to satisfy most elements?
6) Should the U.S. make a statement beyond the P5 narrative on its contribution to the off-shore program, namely “commensurate with our contributions to LHC/HL-LHC” and $1-$3B in U.S. accounting?
7) Other?