

- DOE and NSF have requested an Editorial Board assume the responsibility of preparing the input to the ESG in consultation with the U.S. community.
 - This will be the U.S. HFCC input to ESG.
- Editorial Board:
 - Josh Bendavid, Viviana Cavaliere, Spencer Gessner, Kellen McGee
 - Marcel Demarteau, Sarah Eno, Ritchie Patterson, Srinu Rajagopalan*
 - Steven Gourlay, Matthias Liepe, Tor Raubenheimer*, Jean-Luc Vay
 - ex-officio: Anadi Canepa, Mike Tuts, Jinlong Zhang
- The Editorial Board have put together this slide deck to provide a starting point for wider discussions, incl. the HFCC-PED (SLAC) and HFCC-ACC (FNAL) community meetings.
- Comments from the broader audience is being sought.
- * Tor, Srinu (co-chairs of Editorial Board)

ECFA Guidelines for ESG input

- 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).

Context for the response

These DRAFT response are listed for discussion!

Intent of these slides is to provide a starting point for community discussion at SLAC/FNAL. It is meant to provide sufficient information to steer the discussion. These slides do not translate directly to a written report.

- It is critical to talk about what we say and different people have different opinions.
- Communication with U.S. MuC and DPF/DPB also in order to assure broad community buy in.

The white paper will include the process and acknowledge other US developments to date

The US is looking to collaborate with CERN on future large scientific projects.

P5 left a lot of room to develop a program that includes a timely off-shore HF.

The FCC-ee is CERN's first choice for a Higgs Factory.

- What could deviate from that program:
 - CEPC, ILC in Japan, Cost, Schedule, ...

ESG request (a)

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

- The Integrated FCC program is currently CERN's preferred option, with FCC-ee providing a natural path to FCC-hh.
- The proposed Integrated FCC program is within the scientific goals described by P5.
- The last ESPPU requested a feasibility study for the Integrated FCC program, which CERN and its member states have duly complied with. These will be reviewed by ESG.
 - Any other option will require a new feasibility study and will delay the decision of the next preferred project.
 - Different projects may have different timescales for realization of the physics all of which will follow the HL-LHC completion.
- A decade of investment in studying the feasibility of the FCC option appear to show no technical show-stoppers for the proposed initial phase (FCC-ee).
- The U.S. – CERN statement provides support for a U.S. contribution to the FCC-ee program at CERN.
- A viable financial model for the next Project at CERN is essential. However, funding models are outside the remit of the ESG and expected to be considered by CERN council following ESPPU.
- A viable U.S. financial model is also essential, A targeted panel, recommended by P5, will review the scope of U.S. participation – while maintaining a healthy domestic program.
- Given these points, there appears to be a broad US consensus, that the ESG recommend the FCC-ee program as the next major/flagship collider project at CERN.

ESG request (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
- All of the above are important elements to be considered. In decreasing order of priority:
 - **Physics** must be the driving priority for any program. It is the primary reason for constructing and operating research laboratories such as CERN.
 - A **timely** decision and the timely realization of physics from the next project are important. It is also important to maintain a seamless transition between the HL-LHC and the next flagship project.
 - **Financial and Human resources** are important considerations. In particular, we encourage CERN to build global partnerships and communities to seek the resources required to build and operate any mega-scale future project.
 - Timing is also correlated to **Careers and Training**, A large gap between two programs would erode the talent pool of engineers and physicists and derail the training of next generation scientists.
 - **Sustainable** solutions, especially when designing projects that go beyond our lifetimes is a responsibility to be addressed seriously.
 - Complementarity with **other projects** is essential and a global planning of complementary projects offers cost-effective strategies and maximizes the scientific output.

ESG request (c)

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

- **If US builds the muon collider.**

U.S. Muon Collider community is preparing an input to ESG. We are coordinating with them to ensure consistency in messaging. Our response will refer to their whitepaper.

The US is not planning to build a muon collider in the time scale of FCC-ee construction.

- A demonstrator is being planned in the 2030s, and the time scale for the launch of a U.S. based muon collider will likely follow the completion of the FCC-ee construction.
- P5 has suggested budget scenarios where both the MuC demonstrator and FCC-ee could be accommodated and we expect minimal conflicts although the budgets may be impacted.

Given this, a planned muon collider effort in the U.S. should not influence the decision to move forward with the FCC-ee program at CERN.

ESG request (c)

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

- **If ILC is built in Japan**
- ILC in Japan is consistent with the P5 report.
- ESPPU-2020 acknowledged that a timely realization of an ILC in Japan is compatible with an Integrated FCC program at CERN.
- In the event that ILC is successfully launched in Japan
 - CERN will need to reevaluate the complementarity of an FCC-ee along with ILC
 - Funding to operate two mega global projects will become a challenge.
- In such a situation, the U.S. community will need to re-evaluate its options

ESG request (c)

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

- **If China builds the CEPC**

- There is overlap in physics goals and reach between a CEPC and an FCC-ee. From a scientific viewpoint, it would not make sense to build two mega projects with the same goals assuming they are both open to the global scientific community.
- Geopolitical tensions will limit U.S. ability to participate in CEPC.
- If CERN chooses to pursue FCC-ee while CEPC moves forward, it should do so in an accelerated timescale to remain competitive.
- A CEPC inclusion in the next 5-year Plan of China should not immediately influence CERN's direction. Given the uncertainty in execution of the plan, this should not impact the ESG recommendation or Council decision.
- CERN and the US should carefully monitor the developments in China over next several years and develop an appropriate plan should CEPC construction move ahead.

ESG request (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?

- P5 recommended a Higgs Factory at CERN with a long-term vision for a 10 TeV pCM collider.
- Accelerator R&D on alternate Higgs Factories should be pursued including high gradient SRF and NCRF technologies to keep those options viable.
- A number of R&D topics should be pursued in parallel with the FCC-ee program which give CERN and the US flexibility in determining the future toward a 10 TeV pCM collider. The high-field magnet R&D program is critical to realizing the integrated FCC program and the Muon Collider Program. These include:
 - High field magnets including HTS and cost-effective implementation
 - Muon collider technologies
 - Advanced accelerator concepts toward a 10 TeV pCM e+/e- collider

ESG request (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)?

- The P5 report supports a program that would explore Higgs physics on the timescale of the 2040's at CERN.
- There are several possible alternatives to consider (not prioritized):
 - FCC-hh, Linear Collider, Extending HL-LHC, HE-LHC, Muon Collider, etc.
 - The prioritization depends on the challenges or concerns
- All of the alternatives have pros and cons and none provide the magical solution for any of the above-mentioned scenarios: cost, timing, international developments.
 - Lack of feasibility studies for an alternative program at CERN limits our ability to prioritize
- While there is no ideal alternative today, it is important for CERN to invest early in significant R&D and studies (see response to d), with global partnership, that could potentially provide a realizable alternative path should the preferred option be deemed not feasible down the road.
- Hence, while supporting a timely decision on the preferred option, ESG should recommend appropriate steps be taken soon that will lead to a realizable plan in the coming 3-5 years.

ESG request (f)

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

- The response offered in (b) is applicable here as well.

Backup Slides

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.:**

We reaffirm the previous P5 recommendations on major initiatives:

1. 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).

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.

P5 recommended targeted panel

Recommendation 6: Convene a targeted panel with broad membership across particle physics later this decade that makes decisions on the US accelerator-based program at the time when major decisions concerning an offshore Higgs factory are expected, and/or significant adjustments within the accelerator-based R&D portfolio are likely to be needed. A plan for the Fermilab accelerator complex consistent with the long-term vision in this report should also be reviewed.

The panel would consider the following:

1. *The level and nature of US contribution in a specific Higgs factory including an evaluation of the associated schedule, budget, and risks once crucial information becomes available.*
2. Mid- and large-scale test and demonstrator facilities in the accelerator and collider R&D portfolios.
3. A plan for the evolution of the Fermilab accelerator complex consistent with the long-term vision in this report, which may commence construction in the event of a more favorable budget situation