Answers to Questions from Steve Ritz to the Energy Frontier Conveners

Raymond Brock, Michael E. Peskin

October 31, 2013

Question 1:
What are the main messages of Snowmass from the Energy Frontier?

1. "The Higgs changes everything." The discovery of the Higgs boson sets in relief a number of questions that require exploration of the TeV energy scale. We see this as the biggest question in particle physics: How do we test the hypotheses of new physics at the TeV scale explaining the Higgs potential and dark matter?

   Exploring these issues requires a three-prong program at colliders:

   - Study the Higgs boson in as much detail as possible.
   - Search for the imprint of the Higgs on W, Z, and top.
   - Search for new particles with TeV-scale masses.

2. There is a compelling case for physics at the LHC up to 300 fb^{-1} with the Phase 1 upgraded detectors. This program gives a factor of 2 increase in discovery reach for new particles across a wide range. These searches already will give incisive tests of the hypotheses that require new particles at the TeV scale. Important precision measurements of Standard Model particles may shed more light on hints that continue to exist for small deviations from the Standard Model. A more precise W mass measurement is a prime example. This puts a focus back on precision pdf determination and continued development of QCD calculational tools.

   We cannot count on the discovery of new particles in this step, but we should be prepared for such a discovery, and we should be thinking about facilities that could exploit it. The detectors planned for the HL-LHC and for e^+e^- colliders are well-optimized to unravel the details of any of the extensions of the SM that have been explored theoretically, and they should also be capable of studying scenarios that are surprises.

3. There is a compelling case for the High-Luminosity LHC. There is a commonly expressed opinion that the HL-LHC is only an incremental improvement over the capabilities of the LHC at 300 fb^{-1}. We believe that this is a misperception. The extra factor 10 in luminosity has great benefit to many searches, in particular, for BSM vector bosons, Higgs sector resonances, electroweak SUSY particles, and dark matter. The high luminosity also opens windows to precision Higgs physics, rare top quark physics (10^9 top quarks) and other indirect searches using the heaviest particles of the Standard Model.

4. There is a compelling case for a lepton collider beyond LHC. Though there is great opportunity for discovering deviations from the SM in precision measurements at the LHC, many theoretical models predict deviations of the Higgs boson, top quark, and W boson couplings at the few-percent level, requiring a sub-percent level of precision for discovery. This level of precision can be achieved in lepton collider experiments. Likewise, precision study of new physics discovered at LHC will likely only be possible at a lepton collider. Given the long time scale for the realization of Energy Frontier accelerators, we need to consider this possibility in 2013. ILC, on the table now, will meet these goals.

5. It is important to maintain the vision of future high energy colliders. Any discovery from the LHC (or ILC) programs will raise physics questions that require higher energy colliders. We need to reinvigorate the development of technology for higher energy colliders. Our study emphasized the importance of studying a 100 TeV *pp* collider (VLHC) for a proposal and technical design a decade from now. This is a long program for which R&D has stalled. It is time to reinvigorate it at a measured pace, looking ahead two decades.

6. We will realize these goals through global collaboration. Our community is experienced with global collaboration. The LHC collaborations advance the model. We are fortunate that other regions of the world agree with our goals and are providing high-energy colliders with impressive capabilities. It is important the US physicists can participate in these programs.

7. While a 33 TeV hadron collider was included initially in the suite of facilities studied for Snowmass — and many groups did indeed include it in their calculations — we found little excitement generated towards this more modest increase in *pp* collision energy.

8. While an electron-hadron collider was included in the suite of facilities for consideration, there was little community effort expended in studying the scientific benefits of such a machine.

Question 2:
What, if anything, did Snowmass miss in the Energy Frontier study ?

1. The allocation of resources to large projects such as global collider collaborations is complex. For LHC, the timeline of machine and detector upgrades has been set by CERN and the collaborations. The scope of the Phase 1 LHC detector upgrades is well defined. But the more expensive Phase 2 upgrades are still being finalized. The Energy Frontier study at Snowmass did not critically evaluate the ATLAS and CMS plans for the Phase 2 upgrades. The participants in the study did express strong arguments that the US must participate in both ATLAS and CMS in the HL-LHC period.

Similarly, for ILC, the question of US participation must be asked because of interest in Japan to host the ILC accelerator. But, there is no decision to host as of now, and a complex international negotiation on cost sharing is needed. There are also questions of scope and available resources: Will the US support collaboration in 1 or 2 detectors?

These issues are relevant because the US physicists and engineers who would participate in the LHC and ILC experiments are largely the same people. Broadly, our study assumed a smooth transition from LHC to ILC through the 2020's. In the period after 2030, the ILC, if it is indeed constructed in Japan, would be the only Energy Frontier accelerator in the world. However, we have not tried to analyze this transition or the profile of US contributions to it.

The other colliders we have studied are still in the R&D phase. It is too early to ask comparable questions for them.

2. We had ambitious plans to understand the impact on the US of participation in accelerator projects abroad. We believe that priority decisions between projects hosted here in the US and abroad should be made on the physics rather than on perceived economic benefit to the US. It is obvious that, since most contributions to global projects are negotiated for in-kind contributions, almost all of the money spent by the US for LHC was actually spent in the US, much of it to develop US technologies. We wrote a paper elaborating on this and listing various benefits to the US from the LHC program. However, we were not able to pull together the statistics to support these ideas in time for the conclusion of Snowmass.

3. We began serious study of physics at energies greater than 14 TeV, developing suitable detector models and representative Standard Model background samples for 33 and 100 TeV pp colliders. However, this is just the beginning of a study that will continue for many years into the future.

4. It would have been enlightening to study a fictional path that would wind its way through a prescribed LHC future and into a follow-on lepton collider future. There are too many alternatives to have studied them all and there was little appetite for choosing only a small set to study. We did highlight and sketch out two specific scenarios at the end of our report. While the physics cases in a handful of futures would be fictional, the capabilities of existing and planned detectors would be highlighted and stumbling blocks might be uncovered. To that end, P5 might consider commissioning named, specific scenarios for study. The need to be totally ecumenical is less acute for P5 than it was for a completely community-based study.

5. The overlaps with the Intensity Frontier were not sufficiently explored. The narrative that the Energy Frontier tried to create about the importance of the Higgs mechanism surely has a thread that includes the mystery of neutrino masses. In addition, we believe that the primary motivation for rare process experiments is not to make a blind search for new physics at high scales but rather to access flavor couplings of new

particles associated with the TeV scale. However, we were not able to launch serious work on this connection. The distributed nature of Snowmass made this impossible. Follow-on workshops are planned now to try to remedy that loss.

Question 3:
What do you see as the main issues and decisions emerging from Snowmass that you anticipate P5 addressing?

1. Energy Frontier projects are large and have a major impact on the overall budget for particle physics. We would like to see P5 formally give significant priority to the main program elements listed in Question 1.

2. As we have stated already in the answer to Question 2, the provision of US resources to the HL-LHC program and the later transition of personnel and resources from LHC to ILC or other projects should be addressed by P5 to provide a vision for Energy Frontier experiments into the 2030's.

3. We hope that P5 will support the still longer-term visions of particle physicists by giving significant priority to R&D programs for higher-energy collider technologies.

4. We believe that it is time that detector R&D be adopted formally as a part of the planning of our scientific future.