Snowmass Reports
Summary
What we want to communicate to HEPAP

Nick Hadley
Vice-Chair, Division of Particles and Fields
American Physical Society

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Snowmass Summary

- As demonstrated in the preceding four talks, the Snowmass process has reconfirmed the vibrancy and great promise of our field.
- Particle physics inspires the young and the old, and opens wonders from the smallest distance scales to the cosmos to us all. It builds enduring partnerships that transcend national borders.
- The U.S. community is united and eager to engage in the next phase of a *global particle physics program* that will benefit all participants.
- The U.S. brings crucial leadership, design talent, technology, knowledge, and resources that are essential for progress in this field regardless of where each experiment is located.

Snowmass Summary

- **After many meetings, the Snowmass process is almost complete.**
- **The report of the Summer Study (due Nov. 1) is intended to be a key resource in setting priorities for particle physics.**
  - **The proponents of each facility and experiment have had time to explain why the are excited about the approach they have chosen to answer one (or more) of the big questions facing the field.**
  - **The importance of advances in theoretical particle physics has been shown as well.**
  - **The instrumentation, computing and accelerator communities have also documented their contributions and importance. The role Education and Outreach has been highlighted.**
    - The endeavor to advance the knowledge of particle physics also has practical value, since it helps drive technical innovation in instrumentation, computing, and accelerators. It demands new technological solutions and it trains a new generation of scientists and engineers. This development of new technology has continually improved human well-being.

Snowmass Process and P5

- Snowmass report is only part of the record of the Community Summer Study (Snowmass) process.
  - Many talks, papers in the archives.
  - The Working Group (Frontier) conveners are a resource that can:
    - answer detailed questions from P5 or
    - know who can answer those questions.

Snowmass Process and P5

- Snowmass has not only demonstrated the breadth and vitality of particle physics in the U.S. (and throughout the world), it has also brought a renewed appreciation of that breadth and vitality to the members of the particle physics community.
  - We are united by the science we wish to do.
- P5 now has the difficult task of prioritizing all of this science and all of these possible projects and making them fit in realistic budgetary scenarios.
  - In a world without resource constraints, we would want to pursue all of these ideas. Clearly, this will not be possible.

DPF and P5

- Some experiments and facilities are expensive.
  - The optimization should be global.

- Setting priorities will inevitably leave some in our community disappointed.
- The process by which P5 makes its decisions is important.
  - Snowmass was successful in bringing the community together as all of the community was included from the beginning.

- The DPF, as the group representing particle physics in the U.S., requests its role continue in the coming year and during the P5 process.

Conclusion

- P5 will have to make difficult choices.

- There is an outstanding array of exciting science from which to make these choices.
  - "Do not let what you cannot do interfere with what you can do." (John Wooden)

Backup

- **The eleven questions from my first talk today are repeated on the next slides as are the questions from the enabling frontiers.**

Unifying questions that emerged from the Snowmass Study

1. How do we understand the Higgs boson? What principle determines its couplings to quarks and leptons? Why does it condense and acquire a vacuum value throughout the universe? Is there one Higgs particle or many? Is the Higgs particle elementary or composite?

2. What principle determines the masses and mixings of quarks and leptons? Why is the mixing pattern apparently different for quarks and leptons? Why is the CKM CP phase nonzero? Is there CP violation in the lepton sector?

3. Why are neutrinos so light compared to other matter particles? Are neutrinos their own antiparticles? Are their small masses connected to the presence of a very high mass scale? Are there new interactions invisible except through their role in neutrino physics?

4. What mechanism produced the excess of matter over anti-matter that we see in the universe? Why are the interactions of particles and antiparticles not exactly mirror opposites?

Unifying questions that emerged from the Snowmass Study

5. Dark matter is the dominant component of mass in the universe. What is the dark matter made of? Is it composed of one type of new particle or several? What principle determined the current density of dark matter in the universe? Are the dark matter particles connected to the particles of the Standard Model, or are they part of an entirely new dark sector of particles?

6. What is dark energy? Is it a static energy per unit volume of the vacuum, or is it dynamical and evolving with the universe? What principle determines its value?

7. What did the universe look like in its earliest moments, and how did it evolve to contain the structures we observe today? The inflationary universe model requires new fields active in the early universe. Where did these come from, and how can we probe them today?

Unifying questions that emerged from the Snowmass Study

8. Are there additional forces that we have not yet observed? Are there additional quantum numbers associated with new fundamental symmetries? Are the four known forces unified at very short distances? What principles are involved in this unification?
9. Are there new particles at the TeV energy scale? Such particles are motivated by the problem of the Higgs boson, and by ideas about space-time symmetry such as supersymmetry and extra dimensions. If they exist, how do they acquire mass, and what is their mass spectrum? Do they carry new sources of quark and lepton mixing and CP violation.
10. Are there new particles that are light and extremely weakly interacting? Such particles are motivated by many issues, including the strong CP problem, dark matter, dark energy, inflation, and attempts to unify the microscopic forces with gravity. What experiments can be used to find evidence for these particles.
11. Are there extremely massive particles to which we can only couple indirectly at currently accessible energies? Examples of such particles are seesaw heavy neutrinos or GUT scale particles mediating proton decay.

Questions from Enabling Frontiers

1. As experiments continue to reach for rarer processes, more precise measurements, higher energies and luminosities, and more inclusive observations how do we achieve the finer granularity, larger volume, more radiation-hard, lower cost, and higher speed detectors that will in large part determine our experimental reach?
2. Paradigm-altering technology developments are occurring in electronics and materials design potentially offering breakthrough capabilities. How can these advances be incorporated into new detectors with improved overall performance? How do we make best use of the resources available in universities, national laboratories and industry to develop new detector systems?
3. What technologies will be needed to acquire, analyze and store the enormous amounts of data from future experiments? Can local intelligence be incorporated to manage data flow? How will we fully and efficiently utilize data stored in large databases?
4. Scaling of current accelerator designs to higher energy leads to machines of very large size, cost, and power demand. Can new technologies lead to more practical strategies? Is there an ultimate highest energy for colliders?
5. Proposed experiments both at low and at high energy call for particle beams of extreme brightness. Are there technologies to achieve high beam power in a better controlled and more cost-effective way?

Questions from Education and Outreach

1. How do we engage particle physicists in communication, education and outreach activities so as to convince policy makers and the public that particle physics is exciting and worth supporting?

2. How do we develop a talented and diverse group of students that enter particle physics and other STEM careers, including science teaching?

Goals that emerged from the Snowmass Study

- These questions lead naturally to a set of goals. (Order does not reflect prioritization!)

Goals that emerged from the Snowmass Study

1. Probe the highest possible energies and smallest distance scales with the existing and upgraded Large Hadron Collider and reach for even higher precision with a lepton collider; study the properties of the Higgs boson in full detail
2. Develop technologies for the long-term future to build multi-TeV lepton colliders and 100 TeV hadron colliders
3. Execute a program with the U.S. as host that provides precision tests of the neutrino sector with an underground detector; search for new physics in quark and lepton decays in conjunction with precision measurements of electric dipole and anomalous magnetic moments
4. Identify the particles that make up dark matter through complementary experiments deep underground, on the Earth's surface, and in space, and determine the properties of the dark sector

Goals that emerged from the Snowmass Study

5. Map the evolution of the universe to reveal the origin of cosmic inflation, unravel the mystery of dark energy, and determine the ultimate fate of the cosmos
6. Invest in the development of new, enabling instrumentation and accelerator technology
7. Invest in advanced computing technology and programming expertise essential to both experiment and theory
8. Carry on theoretical work in support of these projects and to explore new unifying frameworks
9. Invest in the training of physicists to develop the most creative minds to generate new ideas in theory and experiment that advance science and benefit the broader society
10. Increase our efforts to convey the excitement of our field to others