Snowmass Reports
Introduction and Overview

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Snowmass

- Particle physics research in the United States has been a vibrant field since the middle of the past century. In the past thirty years the particle physics community has gathered periodically at Snowmass, Colorado, to take stock of its progress and chart its future. The last such meeting was held in 2001.
- In 2011, with the expected discovery of the Higgs Boson and the likelihood of advances in neutrino physics, the Division of Particles and Fields of the American Physical Society decided that the time was ripe for another "Snowmass" gathering.
- Preparatory meetings during 2012 and 2013 were launched by a Community Planning Meeting at Fermilab, October 11--13, 2012.
- The Community Summer Study ("known as Snowmass") meeting was held on the campus of the University of Minnesota, July 29 -- August 6, 2013.
    - This meeting brought together nearly 700 physicists to identify the critical research directions for the United States particle physics program and was the culmination of intense work over the past year that defined the most important questions for this field and identified the most promising opportunities to address them.

Snowmass Process

- "Snowmass on the Mississippi" (the 2013 Community Summer Study) has been designed to address the questions the particle physics community wishes to answer over the next two decades, and how we plan to answer them.
- While we do not prioritize activities, our aim is to ask and answer hard questions. A subsequent prioritization panel with broad community representation will place these questions and answers within realistic budgetary scenarios.
- Our aim has been to produce a report, of length and emphasis similar to the Physics Briefing Book (2012) of the European Strategy Group, which such a panel will find useful in its deliberations.
- We also hope to convey the health and diversity of the U.S. program, in a global context, to our colleagues and fellow citizens.
- Although we found it convenient to retain the "frontier" categories of the previous P5 ("Particle Physics Project Prioritization Panel"), whose last report was issued in 2008, the division of the field into such categories should not obscure our focus on fundamental questions of physics, which, by their nature, cross such frontiers. These inter-frontier discussions have been a major component of the meeting in Minneapolis.

DPF Leadership

- Chair line
  - Past chair: Pierre Ramond (Chair in 2012)
  - Chair: Jonathan Rosner (2013)
  - Chair-elect: Ian Shipsey (Chair in 2014)
  - Vice-Chair: Nick Hadley (Chair in 2015)
- Secretary-Treasurer: Howie Haber (2013-2015)
- Councilor: Marjorie Corcoran (2010-2013)
- Executive Committee members:
  - Jonathan Feng (2011-2013)
  - Lynne Orr (2011-2013)
  - Yuri Gershtein (2012-2014)
  - Nikos Varelas (2012-2014)
  - Robert Bernstein (2013-2015)
  - Sally Seidel (2013-2015)
- Election of 2014 Vice-Chair, two new EC members to take place soon

Snowmass Working Groups

- Conveners of "Frontiers"
  - Energy: Chip Brock, Michael Peskin
  - Intensity: JoAnne Hewett, Harry Weerts
  - Cosmic: Jonathan Feng, Steve Ritz
  - Instrumentation: M. Demarteau, Ron Lipton, H. Nicholson
  - Facilities ("Capabilities"): Bill Barletta, Gil Gilchriese
  - Computation: Lothar Bauerdick, Steve Gottlieb
  - Education and Outreach: Marge Bardeen; Dan Cronin-Hennessy
  - Theory: Michael Dine

- Subgroups:
  - Each group has several subgroups;
    see http://www.snowmass2013.org for details

Snowmass Report

- The Snowmass Report will be presented in such a way that it can be read at various levels. An Executive Summary lays out the broad topics treated in more detail in a summary chapter. Each Frontier (Intensity, Energy, Cosmic, Theory, Capabilities, Instrumentation, Computing, and Communication) has its own chapter containing further details. Reference is made to submissions by each Frontier's subgroups, and to contributed White Papers.
  - Report to be ready November 1.
  - Provides a detailed resource to P5.
  - Following talks will present summaries from the Frontiers.
- Note that other parts of the world are engaged in a similar process
  - For example: the European Physics Briefing Book http://europeanstrategygroup.web.cern.ch/europeanstrategygroup

Intense Preparation

- **Snowmass was a process, not just one meeting.**
  - **"By failing to prepare, you are preparing to fail." Benjamin Franklin**
  - **There was a lot of preparation.**
  - **A sample of some of the working group meetings (Frontiers)**

Group	Date(s) in 2013	Location(s)	Subject(s)
Energy	Jan 14-15	Princeton	Higgs Working Group
	Jan 14-16	UC Irvine	New Particles Working Group
	Feb 18-20	Duke Univ.	Electroweak Working Group
	Apr 3-6	Brookhaven	General meeting
	May 13-15	Fla. State	QCD Group
	May 29-31	KITP, UCSB	Theory: Joint with IF, CF, KITP programs
	Jun 30 - Jul 3	Univ. Wash.	General meeting after Lepton-Photon
	See Energy Frontier Snowmass 2013 web page for other related workshops		
Intensity	February 13-15	Fermilab	Electric dipole moments
	March 6-7	SLAC	Neutrino (with Cosmic, DURA)
	April 25-27	ANL	General; with Project X
Cosmic	March 6-8	SLAC	With Capabilities, AARM (Mar. 4), DURA (Mar. 5)
	Mar 22-25	Snowbird	Non-WIMP dark matter
	May 29-31	KITP (UCSB)	Joint CF/EF/IF (see EF above)

Members of the Cosmic Frontier participated in other meetings in 2013 as well.

Preparation (cont.)

•	Instrumentation	Jan 9-11	Argonne	CPAD Meeting
		Mar. 20-21	Fermilab	LAr TPC R&D Workshop
		April 17-19	Boulder	Snowmass/CPAD
		May 30-Jun 1	LBNL	IC Design for HEP workshop
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•	Capabilities	Feb 21-22	CERN	High energy hadron colliders
		Feb 25-26	U of Chicago	Accelerator technology testbeds and test beams
		April 9-11	MIT	High energy lepton colliders
		April 17-19	BNL	High intensity proton beams
		May 24-27	Asilomar, CA	Underground Physics Opportunities
		June 24-28	UC Santa Cruz	Writers' meeting
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•	Computing	Jan-July	Various	With Energy/Intensity/Cosmic
		11/28/12	Washington	With NERSC (special hardware)
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•	E & O	March 16-17	Baltimore	Teachers and students
		April 12-13	Denver	Scientific community, policy makers, general community
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- **Snowmass report will reflect a huge amount of work over many months.**

Unifying questions that emerged from the Snowmass Study

- Vigorous investigation over the past decade has yielded significant insights into our understanding of the universe and the properties of neutrinos and other elementary particles.
- The discovery of the Higgs boson in 2012 completes the picture of the particle world called the Standard Model, a remarkable achievement made possible by decades of worldwide collaboration.
- However, many mysteries remain, both with the known elementary particles, and in their relation to the cosmos, where our knowledge fails to account for 95% of the mass and energy in the universe.
- One of the goals of Snowmass was to develop a framework of scientific questions that can form the basis for a future program in particle physics. To introduce a summary of the results of Snowmass, we propose a set of eleven Particle Physics Questions. The search for their answers will be carried out with a broad range of experimental methods, cutting across the "frontiers" around which the Snowmass study was organized.

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.

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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

Conclusion

- The next four talks will discuss a program of research to answer these questions.
  - Theory is an important part of our field. There will be a talk Friday by Sally Dawson on the DPF Panel on the Future of High Energy Theory.
  - Although the talks are organized by “Frontiers”, the division of the field into such categories should not obscure our focus on fundamental questions of physics, which, by their nature, cross such frontiers.