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How high-energy physics plans its future

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Past and present chairs of the Division of Particles and Fields of the American Physical Society explain how the high-energy physics community in the US decides the priorities for research through regular planning exercises that started 40 years ago at Snowmass, Colorado.

Progress in high-energy physics (HEP) requires complex accelerators to create very high-energy collisions to uncover evidence for new particles and forces, as well as very intense lower-energy beams for precision measurements that can reveal subtle inconsistencies between theory and experiment. By the late 1960s, these accelerators and the associated experiments had already become very expensive. Today a new accelerator, or a colliding beam facility, and its experiments can cost several billion US dollars, require more than a decade to construct and involve thousands of scientists and technicians. Over the past decades, the application of particle theory and detector technology to fundamental questions in areas such as cosmology has expanded the range of projects under the HEP umbrella. Resource limitations mean that the research community needs to periodically identify the best, most efficient, and cost-effective projects. Here we explain how this is done.

History of planning exercises

For four decades, every seven to ten years the US HEP community has been undertaking a year-long Community Planning Exercise, or community study, sponsored by the Division of Particles and Fields (DPF) of the American Physical Society (APS)[1]. The goal is to identify the most important scientific questions in the field for the next two decades and the facilities, infrastructure, and R&D needed to pursue them. For many years these studies concluded with a few-week-long workshop in the summer at Snowmass, Colorado. The DPF chair of the first meetings, Charles Baltay, of Yale University, said: "The 1982 DPF Summer Study was the first attempt in recent years to bring together physicists from the whole country to consider the future of our field from the point of view of the best overall national programme. The DPF Executive Committee felt that the exercise had been sufficiently useful to repeat it in the years to come[2]."

Snowmass 2013

For the most recent community study in 2013, we moved the workshop to a location other than Snowmass and made it shorter. The 2013 edition, Snowmass on the Mississippi, was held at the University of Minnesota and lasted ten days. About 800 people attended. International participation was encouraged and many scientists from outside the US joined us. We retained the name Snowmass to commemorate the open and expansive spirit of the previous meetings.

In 2013, the planning exercise focussed on scientific issues without taking into account budget constraints. The output of the Snowmass process was a report[3] that provided input to a subsequent panel, the Particle Physics Project Prioritization Panel, known as P5, whose task was to set the priorities for the various projects under specific budget scenarios provided by the Department of Energy. P5 began its work in the fall of 2013 and produced a report[4] with its recommendations the next spring. The combination of the Snowmass and P5 processes led to a broad acceptance of the P5 report, which identified five main physics drivers for HEP (BOX 1) and made 29 recommendations concerning the future programme. The outcome received widespread support in the HEP community and resulted in the suite of new projects we have been undertaking since 2015, including the two assigned the highest priority: participation in the High Luminosity Upgrade of the Large Hadron Collider programme, including the ATLAS and CMS experiments at CERN; and the construction of the LBNF/DUNE long baseline neutrino experiment, which will detect neutrinos produced at Fermilab interacting in massive underground detectors 1,300 kilometres away in the Homestake Mine in South Dakota. Among several other recommended projects were an upgrade of the proton source at Fermilab to provide more intense beams (PIP-II); the Vera C. Rubin Observatory and its LSST Camera; investigations into dark matter (LZ, ADMX-Gen2, and SuperCDMS) and dark energy (DESI); preparation for the next generation investigation of the cosmic microwave background (CMB-S4); and investment in R&D for future accelerators. Some projects were not assigned high priority by P5 and were not able to move forward.

Snowmass 2021

More than two years ago, with the projects supported by the 2013/2014 planning process underway, the High Energy Physics Advisory Panel (HEPAP), asked DPF to

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Box 1 | **Science questions and science drivers**

In 2014 the Particle Physics Project Prioritization Panel (P5) identified five compelling lines of inquiry, listed below, that show great promise for discovery over the next 10 to 20 years.

Use the Higgs boson as a new tool for discovery
What principles determine its effects on other particles? How does it interact with neutrinos or with dark matter? Is there one or many Higgs particle(s)? Is the new particle really fundamental, or is it composed of others?

Pursue the physics associated with neutrino mass
What is the origin of neutrino mass? How are the masses ordered? What are the masses? Do neutrinos and antineutrinos oscillate differently? Are there additional neutrino types or interactions? Are neutrinos their own antiparticles?

Identify the new physics of dark matter
What is dark matter made of? Is it composed of one type of 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?

Understand cosmic acceleration: dark energy and inflation
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? What did the Universe look like at its earliest moments, and how did it evolve to contain the structure that we observe today?

Explore the unknown: new particles, interactions, and physical principles
Are there additional forces that we have not yet observed? Are there new particles at the TeV energy scale? Are there new particles that are light and extremely weakly interacting? Are there extremely massive particles to which we can only couple to indirectly at currently accessible energies?

undertake a new community study to develop the initiatives that would be needed in the next decade and beyond. This study, which should have concluded in July of 2021, was named Snowmass 2021. The new study is organized into ten working groups, called Frontiers. These are Accelerators, Cosmic, Community Engagement, Computing, Energy, Instrumentation, Neutrinos, Rare Processes and Precision Measurements, Theory, and Underground Facilities and Infrastructure. Each Frontier represents a broad array of ground-breaking scientific research topics and the underlying technology and infrastructure needed to execute them. Young-Kee Kim, DPF Chair in 2020 reminded our community that "DPF aims for everyone's voice to be heard. Your contributions and participation are critical for the success of Snowmass". Each of the Frontiers divides its work into several topical groups which encourage their members to produce white papers describing their ideas.

Multidisciplinary and international involvement

There are important connections among all the Frontiers, and we have implemented a strong team of cross-frontier liaisons to make sure that these connections are considered. Because numerous challenges, professional and social, face our youngest members, a Snowmass Early Career (SEC) organization has been formed to assist young physicists in contributing to the Snowmass process and to bring their issues into the community study. Finally, the whole process is overseen by a steering group, which includes the four members of the DPF chair line and two past chairs. HEP now has much in common with other scientific disciplines with whom we now collaborate on hardware, including accelerators, detectors, and telescopes, and software development. Increasingly, we address the same or related topics, such as dark matter, neutrino physics, proton structure, and precision tests of theory, but from different perspectives and in different parts of the parameter space. We therefore have included in the steering group one representative from each of the four closely associated divisions in the APS: Physics of Beams, Nuclear Physics, Astrophysics, and Gravitational Physics. The international community is represented by an advisory group that includes members chosen by national and regional physics societies. Taken together, this governance structure ensures that we will consider the activities elsewhere in the world and in other fields as we develop our new ideas.

Challenges

The COVID-19 pandemic severely disrupted our plans and forced us to slow down or even, in some areas, pause our work between January and September of 2021 to lighten the burden on our younger scientists who do many of the key calculations. With childcare centres and schools closed, many of them had to devote much of the workday to looking after and teaching young children at home. We resumed work in September of 2021 and, despite the lingering pandemic and the need to adapt to a world interconnected by online meetings with very little in-person interaction, we accomplished an amazing amount of work.

We are currently summarizing the over 500 white papers that have been produced under the guidance of the Frontier and Topical Group conveners. Snowmass 2021 will conclude at the Community Summer Study and Workshop (CSS) in Seattle from July 17–26 2022. We are looking forward a hybrid meeting, with an expected in-person attendance of over 600 people and a large audience connecting remotely. Another result of the delay is that we can begin to assess at the CSS the impact of the pandemic on our ability to execute our current, approved programme. Although data analysis, which was being done remotely even before the pandemic, continued and accelerator and experiment operations were maintained, R&D for upgrades to existing facilities and future projects slowed down because they especially benefit from intense personal interaction. Moreover, we already are seeing the impact of supply chain problems and inflation that is sure to slow our research.

Next steps

The identified scientific questions and proposed facilities in the white papers are summarized in Topical Group reports that will contribute to Frontier summaries which in turn will be combined into an executive summary. These will be modified by discussions at the CSS and new results from the summer conferences. By the end of CSS, we will have draft Frontier reports and the main conclusions from the study. Then we will spend a few weeks finalizing the report and assembling the Snowmass 2021 book. The book will be submitted in the autumn of 2022 as input to the new P5.

The CSS will be intense: frontier and cross-frontier parallel meetings in the mornings, plenary sessions in the afternoons followed by questions and answers. We expect to reach some conclusions about the scientific investigations we should pursue, but we often disagree on which approaches, experiments, and facilities are best to achieve them. This is to be expected in a community of many ideas and many creative and passionate researchers. We encourage an open discussion and the presentation of all scientifically credible points of view. Finally, there will be a series of panels and discussions from national and international leaders to provide the broad context in which P5 will consider the plans and proposals emerging from Snowmass.

We hope that the CSS participants will leave with an appreciation of the great opportunities present in each Frontier, the interconnections between the Frontiers, and the connections to programmes in the rest of the world and that our report will help P5 produce recommendations that the community can unite behind, as it did in 2014. This is a proven effective step in convincing the public and government policy makers that we have conducted a rigorous process and achieved a consensus that is worthy of their support.

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Competing interests

The authors declare no competing interests.