Implementing the P5 Recommendations: Report of the Subcommittee of the NSF MPS Advisory Committee

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Introduction

Particle physics explores the fundamental constituents of matter and energy. It reveals the deep connections underlying the smallest and the largest structures in the Universe. Past investments have been rewarded with profound discoveries as well as significant technological innovations. Upcoming opportunities will exploit these and other discoveries to push the frontiers of science into new territory at the highest energies and earliest times imaginable.[1] For all these reasons, research in particle physics inspires young people to engage with science. Particle physics is a global and highly collaborative discipline that brings together physicists from around the world to advance science, technology, and education.

In May 2014, the Particle Physics Project Prioritization Panel (P5), a subpanel of the High Energy Physics Advisory Panel (HEPAP), released its report, "Building for Discovery: Strategic Plan for U.S. Particle Physics in the Global Context".[1] A year-long community-wide study preceding the formation of P5 laid out scientific opportunities. P5, charged by the National Science Foundation's Directorate for Mathematical and Physical Sciences (MPS) and the Department of Energy's Office of Science, then carefully prioritized these opportunities, directly confronting numerous difficult choices to fashion executable programs under the tightly constrained budget scenarios. The P5 report presents a strategy that enables discovery and maintains the position of the U.S. as a global leader through specific investments by NSF's Directorate for MPS and DOE's Office of Science. The P5 report concludes that to address the most pressing scientific questions and maintain the nation's status as a global leader for the next decade and beyond, the U.S. must continue its high level of participation in the most impactful research opportunities in the field by both hosting a unique, world-class facility and being a partner on the highest priority facilities hosted elsewhere. The P5 report was unanimously accepted by HEPAP and overwhelmingly endorsed by the particle physics community. In September 2014, this subcommittee of the NSF MPS Advisory Committee was formed and charged to advise NSF on how best to implement the recommendations of P5. The charge to the subcommittee is shown in Appendix A, the science drivers identified by the particle physics community and P5 are presented in Appendix B, and the P5 recommendations are listed in Appendix C.

NSF has already been successfully executing a number of projects and programs that are aligned with the P5 recommendations. They include efforts towards completing the Large Hadron Collider phase-1 upgrades for the ATLAS, CMS and LHCb experiments [P5 Rec. 10], the Large Synoptic Survey Telescope [P5 Rec. 17], and the muon g-2 experiment [P5 Rec. 22]; proceeding immediately with a broad second-generation dark matter direct detection program [P5 Rec. 19]; supporting R&D for third-generation dark matter

[1]Report of the Particle Physics Project Prioritization Panel
http://science.energy.gov/~/media/hep/hepap/pdf/May%202014/FINAL_P5_Report_Interactive_060214.pdf

direct detection experiments [P5 Rec. 20]; investing in cosmic microwave background and dark energy experiments for which the multidisciplinary nature of the science warrants continued multiagency support [P5 Recs. 16 and 18]; supporting the discipline of accelerator science through funding for university programs [P5 Rec. 23]; strengthening global cooperation to address computing and scientific software needs [P5 Rec. 29]; and providing efficient training in next-generation hardware and data-science software [P5 Rec. 29]. NSF has made significant contributions to both accelerator-based and non-accelerator-based neutrino experiments, and university groups supported by NSF are playing leadership roles in developing and executing the neutrino program [P5 Recs. 9, 12, 13, and 15]. There has been timely communication among the NSF Division of Astronomical Sciences, the NSF Division of Physics, and the DOE Office of High Energy Physics on the Cerenkov Telescope Array [P5 Rec. 21]. Theory groups supported by NSF have been and will be critical to the success of the field.

In the following sections the subcommittee presents its response to the charge.

Process

A series of in-depth teleconference meetings and two face-to-face meetings were held over a period of several months. Input from the particle physics community was solicited and submitted to the subcommittee via a web portal.[2] The subcommittee solicited brief documents from the collaborations of future mid- and large-scale projects that were identified by P5, and received a thoughtful response from each of them. The subcommittee then considered models for the support of these projects in the form of one or more Mid-Scale Instrumentation Fund (MSIF) or Major Research Equipment and Facilities Construction (MREFC) projects under the two budget scenarios given in the charge.

As in the past, potential for major discovery in particle physics will depend both on mid- and large-scale projects and on scientists who perform their research on the resulting facilities. These scientists are a significant fraction of the PIs supported by NSF's particle physics program, consisting of the experimental Elementary Particle Physics (EPP) and Particle Astrophysics programs and the Elementary Particle Theory program. In addition to construction funding, these projects require investments of R&D and operating funds, which must be carefully balanced with the full range of PI-driven research awards. The subcommittee gave serious consideration to the opportunity costs for such investments in making our recommendations.

[2] In addition, the subcommittee received numerous email messages and phone calls from the community.

Addressing Charge 1

The major role of NSF is to support a broad range of first-class scientific research and to assist in the education of the next generation of scientific leaders. This should remain the top overall research priority of the Division of Physics.

Quality, breadth and flexibility are the hallmarks of the NSF particle physics program. Based on the science drivers and priorities identified in the P5 report, **NSF should invest broadly while also targeting a few specific resource-intensive projects.**

If NSF limits too severely the range of particle physics it supports, NSF will not provide the variety of opportunities in the future needed for a healthy, evolving field of research [P5 Rec. 6].

On the horizon, several specific project opportunities, in which NSF is already playing a visible role, should have a major scientific impact. Using the Major Research Instrumentation (MRI), MSIF, and MREFC funding processes for small-, mid-, and large-scale projects, respectively, it should be possible to support some of these projects if they meet the criteria described below on this page and on page 4. There is, however, a large gap between the maximum funding that can be expected for an MSIF project and the minimum threshold for an MREFC project. There are scientifically important projects with funding needs in this gap that are difficult to accommodate. **The MPS should continue to explore options to bridge this gap.**

Addressing Charge 3

The Physics Division has been doing an excellent job of coordinating its efforts with DOE. There has been effective and timely communication, and this should continue. There exist examples of unique roles for the Division in projects jointly funded by the two agencies. To the extent that the two agencies can cooperate in supporting, often in complementary ways, current and proposed projects of high scientific value, the community and the nation are winners [P5 Rec. 9].

NSF should contribute to areas of common interest with DOE when the NSF investment:

- **significantly enhances scientific value;**
- **enables NSF-supported groups to play distinctive and visible roles;**
- **results in the training of the next generation of scientists; and**
- **results in significant broader impacts.**

Addressing Charge 2, and part of Charges 4 and 5

The scenario described in Charges 4 and 5 corresponds to an investment in the LHC phase-2 upgrades, which could range from the mid scale to the MREFC level, and mid-scale investments in other high priority scientific areas identified by P5 in the two budget options. Maintaining an optimal balance between broad investment in the field and specific important opportunities will remain a challenge, but with appropriate advice from the community through processes such as P5 and the NSF peer review system the Physics Division can meet this challenge.

The health of the field depends ultimately on the strength of the base research program supported by PI-driven research awards: it provides important experimental and theoretical leadership and makes significant contributions to training the next generation of scientists. Facilities (projects) play a critical role for the strength of the base research program. The balance at NSF between facility investments and PI-driven research awards over the past several decades has been appropriate for particle physics. A mix of small-, mid-, and large-scale projects is important for the vitality of the field and for the continuity of scientific discoveries [P5 Rec. 4]. **To balance support among projects of different scales, the Physics Division should consider the following criteria:**

- **scientific impact;**
- **feasibility of project execution within the proposed budget;**
- **training of the next generation of scientists;**
- **visibility and importance of the NSF investment;**
- **broader impacts; and**
- **budgetary impact on PI-driven research awards.**

Required investments outside of the construction project could be significant for some of the mid- and large-scale projects that NSF considers undertaking in response to the P5 report. These include R&D before the construction project funding is available and operating costs after the completion of the construction. Careful consideration must be given to proceeding with these projects to ensure that they do not create an unacceptable negative impact on PI-driven research awards [P5 Rec. 7]. **The total investment in R&D for future projects and operations for ongoing facilities is currently about one third of the particle physics budget. This fraction, distributed among projects of different scales, is a reasonable level going forward.**

Addressing Charges 4 and 5 that concern the LHC phase-2 upgrades

The P5 report lists the LHC phase-2 upgrades as the highest priority near-term large project [P5 Recs. 1 and 10]. Starting with the original detector design and construction, NSF has supported the U.S. involvement in the LHC experiments for more than 15 years. More than 50% of the PIs currently supported by the EPP program do their research on the LHC experiments. NSF groups have been playing scientific and technical leadership roles. They have worked on cutting-edge detector development and significant new computing initiatives and have produced outstanding physics results including the Higgs discovery.

The potential for discovery of new physics with upgraded accelerators and detectors at the LHC is extraordinary. The upgrades represent a unique opportunity to enable research, innovation, education, and broader societal impacts, with potential to create new scientific understanding, engineering processes, and infrastructure technology. They provide excellent opportunities for educating the next generation of particle physicists, data scientists, and technology developers. The opportunities for public outreach are great. The U.S. LHC collaborators have well-defined and crucial tasks to carry out for the phase-2 upgrades. The full discovery and educational and societal benefit potential of the LHC will go unrealized without strong NSF participation.

The subcommittee considered the support of the LHC detector upgrades in the form of one or more mid-scale investments and found that they are insufficient to allow NSF to play significant and visible roles in these premier global experiments. Furthermore, even at that insufficient scale, they would compromise the broad balanced nature of the particle physics program. The subcommittee also considered an option of NSF groups not participating in the LHC detector upgrades and concluded that the opportunity cost of this option is too high.

Based on the above considerations, the proper funding mechanism for the NSF investment in the LHC phase-2 upgrades is through the MREFC process. The time scale could be appropriate as current MREFC projects approach completion, although there is a challenge to match the MREFC pre-construction planning and approval process to CERN's proposed LHC upgrade schedule. NSF has been supporting operating costs through sub-awards to university PIs under the Cooperative Agreements, "U.S. ATLAS Operations at the LHC" and "U.S. CMS Operations at the LHC". These operating costs support detector maintenance and operations, software and computing including Tier-2 centers at U.S. universities, and R&D for the phase-2 upgrades, much of which has been carried out at U.S. universities. The subcommittee believes that the potential R&D and operating costs for the LHC phase-2 upgrades are consistent with the budgetary criteria described on page 4. The project team is well positioned to undertake the work needed for the MREFC process.

Based on the criteria described on pages 3 and 4, the subcommittee strongly supports the NSF investment in the LHC phase-2 upgrades as a way to enable and participate in fundamental discoveries. Funding at the MREFC level is required for NSF to play significant and visible leadership roles. In addition current levels of support for operations and PI-driven research awards will be required throughout the data-taking and analysis period once phase-2 construction is complete. The particle physics community understands that acquiring support through the MREFC program is a very significant challenge. This subcommittee acknowledges that in order to be successful, it is critical for the LHC's extraordinary science case to be transmitted to the broader scientific community, and for the science case and an in-depth technical design, cost, schedule, and risk of the projects to be communicated to the Physics Division as soon as possible.

Addressing Charges 4 and 5 that concern other large projects

P5 identified the physics associated with neutrino mass as one of five science drivers for the field [P5 Rec. 2]. P5 recommended forming a new international collaboration to design and execute a Long-Baseline Neutrino Facility (LBNF) hosted by the U.S. as the highest-priority large project in its timeframe [P5 Rec. 5]. When the LBNF project is better defined and the shape of the international contribution begins to emerge, NSF should evaluate its participation in the LBNF following the criteria described on pages 3 and 4.

The role of NSF in support of an exploratory science program with a multidisciplinary nature is important for science in the U.S. There have been projects of this nature supported by multiple divisions and/or multiple programs at NSF that led to high-impact results. IceCube, supported by the Division of Polar Programs and the Division of Physics, is a great example. P5 encouraged further development of the PINGU portion of the IceCube upgrade since it addresses the neutrino mass hierarchy. The Division of Physics should evaluate its participation in the IceCube upgrade following the criteria described on page 4 if approached by the Division of Polar Programs.

Conclusions and Prospects

Particle physics addresses profound questions, inspires and invigorates scientists far beyond the field, and lays foundations for future technologies that we can only begin to imagine. Historic opportunities await us, enabled by decades of hard work and support. Many opportunities will go unrealized without strong NSF participation in a broad range of research programs including a few specific projects with mid- and large-scale investments identified in the P5 report. This subcommittee report provides criteria for the Physics Division to use to balance support among projects of different scales and to balance support between facility investments and PI-driven research awards.

The universities supported by NSF bring fresh ideas to the field and provide a crucial component in developing theories, in designing and realizing experiments, in exploiting facilities, in analyzing the resulting data, and in interpreting the results. They train graduate students – the next generation of scientists for the field of particle physics and for a wide range of professions that are key to future American competitiveness.

NSF's strong partnerships with the community and DOE are well appreciated and crucial for advancing the field.

Acknowledgement

The subcommittee appreciates the thoughtful input that it has received from the MPS Directorate and staff of the Division of Physics and from the community.

Appendix A: Charge to the subcommittee

National Science Foundation
Directorate for Mathematical and Physical Sciences
Charge to: MPSAC Subcommittee on NSF Response to Strategic Plan for Particle Physics Outlined in the May 2014 Particle Physics Project Prioritization Panel Report

The NSF has significant investments in accelerator-based elementary particle physics and in particle astrophysics in the Division of Physics (PHY). Particle physics is a highly collaborative discipline that brings together physicists from around the world and the nation to advance the science. The NSF focuses its support on high impact science carried out by the university community, and partners in support of the field with the DOE Office of High Energy Physics, which supports both laboratories and university groups. The MPS Directorate and the DOE Office of Science ("Agencies") jointly secure advice from the High Energy Physics Advisory Panel (HEPAP).

Informed by community input through the APS Division of Particles and Fields' 2013 Snowmass[1] process, the Agencies charged[2] HEPAP to form a subpanel to develop a strategic plan for US Particle Physics that could be executed over the next ten years within the context of a 20-year global vision for the field. In May 2014 that subpanel, the Particle Physics Project Prioritization Panel (P5), released its report[3] "Building for Discovery: Strategic Plan for U.S. Particle Physics in the Global Context". This report was unanimously accepted by the High Energy Physics Advisory Panel (HEPAP) and overwhelmingly endorsed[4] by the US Particle Physics community at large.

The P5 report identified five intertwined science drivers that encompass the most compelling scientific questions in the field for the coming decade. The report recommends a global program with projects at all scales, from the largest international projects to mid- and small-scale projects. It also lists as the highest near-term priority for large projects Phase 2 Upgrades to the LHC accelerator and the ATLAS and CMS detectors. In this context, this subcommittee is asked to address the following questions:

1. Based on the science drivers identified in the P5 report, how should the NSF target its investments in such a way that they maximize the NSF impact and visibility? Should the Physics Division target specific areas or should it invest broadly?
2. What criteria should the Physics Division use to balance support between small-scale, mid-scale and large projects?
3. How should the Division of Physics define a unique role in areas of common interest with DOE?

The committee is not expected to revisit the P5 charge, priorities, or conclusions. Rather, the committee is expected to focus on the balance of NSF investments in light of the P5 report.

In response to P5, the Division of Physics is considering the following scenario for major investments in the next 10 years:

> An investment in LHC Phase 2 Upgrades, which could range from the midscale to the MREFC level, and Midscale investments in other scientific priority areas identified by P5.

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[1] http://www.snowmass2013.org
[2] http://science.energy.gov/~/media/hep/pdf/files/COV/P5_Charge_2013.pdf
[3] http://science.energy.gov/~/media/hep/hepap/pdf/May%202014/FINAL_P5_Report_Interactive_060214.pdf
[4] https://dl.dropboxusercontent.com/u/24655052/P5_CommunityLetter_to_DOE_NSF_Final_2100_DNSF-4.pdf

In the context of P5 and NSF priorities as elaborated in its Strategic Plan[5], this subcommittee is asked to assess this scenario and how it contributes to and impacts the Physics Division mission. This analysis should be undertaken assuming both a budget that is flat at the FY 2014 level and a budget at constant FY 2014 dollars for particle physics funding over the 10-year period of FY 2015 through FY 2024.

For this scenario:

4. Would proposed investments of this type best capture the strengths of NSF and result in NSF funding having a significant and identifiable impact in the field? What criteria should be used to determine whether or not the Physics Division should pursue this scenario?
5. What are the opportunity costs of such an investment strategy? Would required investments[6] outside the MREFC budget line before, during, and after a construction project allow enough flexibility to respond to new, unforeseen particle physics opportunities? Is the balance between facility investments (pre-construction, construction, and operations & maintenance) and PI-driven research awards appropriate for particle physics at the NSF?

We would appreciate an interim report from the Subcommittee to the MPSAC at its November 2014 meeting, and a final report delivered to the MPSAC at its January 2015 meeting. The committee is expected, if necessary, to consult with the relevant communities and/or stakeholders. We recognize that this will be a challenging task; however your considerations on these issues will be essential input into planning at the NSF.

Timeline: Charge Delivered to Panel – September 2014
Interim Report Due to MPSAC: November 2014 MPSAC Meeting
Final Report Due to MPSAC: January 2015 MPSAC Meeting

These reports will detail progress and interim (draft) findings, and will bring to the attention of the MPSAC any major opportunities and challenges. The report can be delivered virtually, and will be coordinated by the MPSAC.

The Chair of the subcommittee should coordinate delivery of materials with the MPS AC Chair in advance of scheduled MPS AC meetings.

The final written report will be due no later than January 31, 2015, with a presentation to the MPSAC at its January 2015 meeting.

Presentations to the MPSAC may be delivered remotely or in person.

Resources
NSF will arrange for and host virtual meetings of the subcommittee as required by the Chair.

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5 http://www.nsf.gov/publications/pub_summ.jsp?ods_key=nsf14043

6 While midscale projects derive support during pre-construction, construction, and operations from the PHY research budget, funding for construction of MREFC projects is provided by a dedicated MREFC budget line external to the Physics Division. However, both pre-construction and operations support for MREFC-level projects is provided from the Physics Division research budget.

Appendix B: P5 Science Drivers

Snowmass, the yearlong community-wide study, preceded the formation of the P5. A vast number of scientific opportunities were investigated, discussed, and summarized in Snowmass reports. The P5 distilled those essential inputs into five intertwined science drivers for the field:

- Use the Higgs boson as a new tool for discovery
- Pursue the physics associated with neutrino mass
- Identify the new physics of dark matter
- Understand cosmic acceleration: dark energy and inflation
- Explore the unknown: new particles, interactions, and physical principles.

Appendix C: P5 Recommendations

1	Pursue the most important opportunities wherever they are, and host unique, world-class facilities that engage the global scientific community.
2	Pursue a program to address the five science Drivers.
3	Develop a mechanism to reassess the project priority at critical decision stages if costs and/or capabilities change substantively.
4	Maintain a program of projects of all scales, from the largest international projects to mid- and small-scale projects.
5	Increase the budget fraction invested in construction of projects to the 20%–25% range.
6	In addition to reaping timely science from projects, the research program should provide the flexibility to support new ideas and developments.
7	Any further reduction in level of effort for research should be planned with care, including assessment of potential damage in addition to alignment with the P5 vision.
8	As with the research program and construction projects, facility and laboratory operations budgets should be evaluated to ensure alignment with the P5 vision.
9	Funding for participation of U.S. particle physicists in experiments hosted by other agencies and other countries is appropriate and important but should be evaluated in the context of the Drivers and the P5 Criteria and should not compromise the success of prioritized and approved particle physics experiments

10	Complete the LHC phase-1 upgrades and continue the strong collaboration in the LHC with the phase-2 (HL-LHC) upgrades of the accelerator and both general-purpose experiments (ATLAS and CMS). The LHC upgrades constitute our highest-priority near-term large project.
11	Motivated by the strong scientific importance of the ILC and the recent initiative in Japan to host it, the U.S. should engage in modest and appropriate levels of ILC accelerator and detector design in areas where the U.S. can contribute critical expertise. Consider higher levels of collaboration if ILC proceeds.
12	In collaboration with international partners, develop a coherent short- and long-baseline neutrino program hosted at Fermilab.
13	Form a new international collaboration to design and execute a highly capable Long-Baseline Neutrino Facility (LBNF) hosted by the U.S. To proceed, a project plan and identified resources must exist to meet the minimum requirements in the text. LBNF is the highest-priority large project in its timeframe.
14	Upgrade the Fermilab proton accelerator complex to produce higher intensity beams. R&D for the Proton Improvement Plan II (PIP-II) should proceed immediately, followed by construction, to provide proton beams of >1MW by the time of first operation of the new long-baseline neutrino facility.
15	Select and perform in the short term a set of small-scale short-baseline experiments that can conclusively address experimental hints of physics beyond the three-neutrino paradigm. Some of these experiments should use liquid argon to advance the technology and build the international community for LBNF at Fermilab.
16	Build DESI as a major step forward in dark energy science, if funding permits.
17	Complete LSST as planned.
18	Support CMB experiments as part of the core particle physics program. The multidisciplinary nature of the science warrants continued multiagency support.
19	Proceed immediately with a broad second-generation (G2) dark matter direct detection program with capabilities described in the text. Invest in this program at a level significantly above that called for in the 2012 joint agency announcement of opportunity.
20	Support one or more third-generation (G3) direct detection experiments, guided by the results of the preceding searches. Seek a globally complementary program and increased international partnership in G3experiments.
21	Invest in CTA as part of the small projects portfolio if the critical NSF Astronomy funding can be obtained.

22	Complete the Mu2e and muon g-2 projects.
23	Support the discipline of accelerator science through advanced accelerator facilities and through funding for university programs. Strengthen national laboratory-university R&D partnerships, leveraging their diverse expertise and facilities.
24	Participate in global conceptual design studies and critical path R&D for future very high-energy proton-proton colliders. Continue to play a leadership role in superconducting magnet technology focused on the dual goals of increasing performance and decreasing costs.
25	Reassess the Muon Accelerator Program (MAP). Incorporate into the GARD program the MAP activities that are of general importance to accelerator R&D, and consult with international partners on the early termination of MICE
26	Pursue accelerator R&D with high priority at levels consistent with budget constraints. Align the present R&D program with the P5 priorities and long-term vision, with an appropriate balance among general R&D, directed R&D, and accelerator test facilities and among short-, medium-, and long-term efforts. Focus on outcomes and capabilities that will dramatically improve cost effectiveness for mid-term and far-term accelerators.
27	Focus resources toward directed instrumentation R&D in the near-term for high-priority projects. As the technical challenges of current high-priority projects are met, restore to the extent possible a balanced mix of short-term and long-term R&D.
28	Strengthen university-national laboratory partnerships in instrumentation R&D through investment in instrumentation at universities. Encourage graduate programs with a focus on instrumentation education at HEP supported universities and labs, and fully exploit the unique capabilities and facilities offered at each.
29	Strengthen the global cooperation among laboratories and universities to address computing and scientific software needs, and provide efficient training in next-generation hardware and data-science software relevant to particle physics. Investigate models for the development and maintenance of major software within and across research areas, including long-term data and software preservation.