HEP P5 Response and Impacts

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Outline

- **HEP General Comments on P5**
  - Elevator Speech
  - Executive Summary
  - Timeline
- **HEP Action Items**
  - General recommendations and Major Changes
  - Other recommendations
  - Project-specific recommendations
- **Budget Impacts**
- **Open Issues**
- **Broader Impacts**

Praise for P5 Report

- **HEPAP unanimously approved the P5 report on May 22nd.**
  - Initial reaction to the report has been positive in every interaction between Steve or HEP with DOE, OMB, OSTP, and Congress
- **The community did a huge amount of work in the Snowmass process, establishing the scientific groundwork that P5 built on and initiating the discussions and debates that would lead to a fully participatory process.**
- **The committee did a huge amount of work understanding details, assessing impacts of various decisions, and seriously considering many alternative choices. It shows.**
- **DOE is extremely grateful to P5 and the community for developing a consensus vision**

HEP P5 RESPONSES

Our P5 Elevator Speech

- **This report represents a consensus vision developed bottom-up by the physics community with extensive consultation to identify the most exciting and productive areas of research and how we pursue them.**

- **The report recognizes the reality of a challenging funding landscape, where choices have to be made and resources stewarded carefully, and confronts those challenges head on.**

- **The promise/potential of high energy physics has never been greater – far from "settling" the big questions in high energy physics, the discovery of the Higgs boson and other recent milestones in physics have opened many more doors to exploring and understanding our universe.**

- **Even given funding challenges, much important fundamental work can be accomplished and many tremendous scientific opportunities pursued, if we make the right strategic choices as a community.**

- **This is a time of excitement and intellectual fervor that can engage young scientists and provide direction for a rewarding and fulfilling career.**

P5: Executive Summary

- ***We recommend a limited, prioritized and time-ordered list of experiments to optimally address these science drivers, with pieces covering small, medium and large investment scales that will produce results continuously throughout a twenty-year timeframe.***
  - **These derive directly from 5 Drivers**
  - **US contribution to big offshore projects (LHC, ILC) to be decided after consultations with international partners.**
  - **LBNE reconfigured as fully international project to achieve science goals.**
  - **Time-ordering makes it feasible in ~flat budget scenarios (see timeline)**
  - **Some additional project-specific details on following slides**

Construction and Physics Timeline

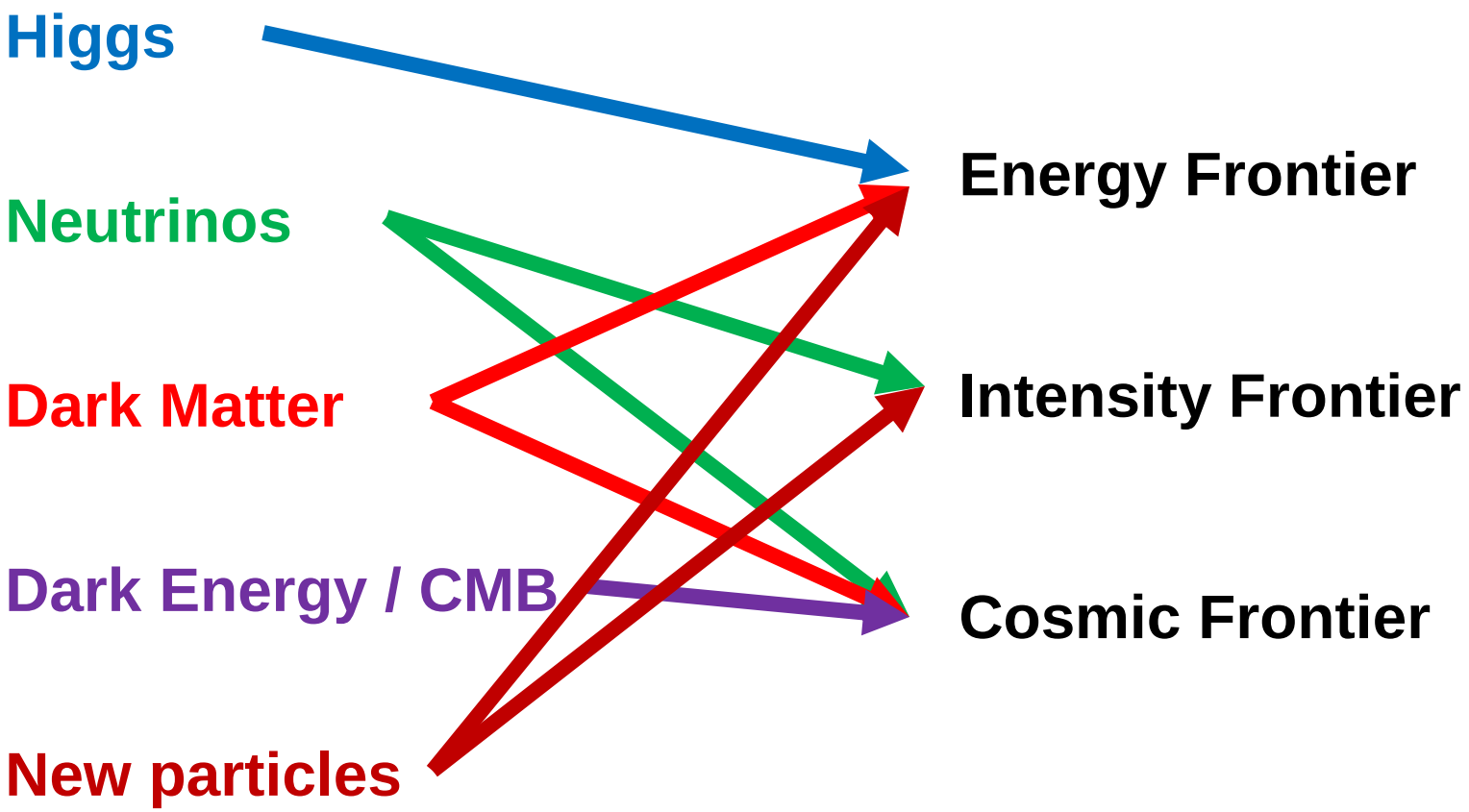
HEP P5 ACTION ITEMS

Near-Term Action Items : Big Picture

- **"Particle Physics is Global" [R1]***
  - Already have full-time program manager dedicated to International issues (+ a growing fraction of HEP management time).
    - This will require much work. International partners are interested but cautious given US history. We will engage DOE leadership to support the P5 plan and vigorously make the case with the rest of the Administration and Congress.
  - Many discussions with partners, SC international, State…
    - New/Updated int'l agreements in preparation (CERN, Italy, India)
      - Note formal agreements require State approval
      - Informal agreements (e.g. MOUs) require SC approval
    - Working on alignment and improving bi-directional nature of continuing int'l agreements (China, Japan)
    - Exploring possible options with other interested parties (Korea, UK)
- **The Five Drivers [R2]***
  - Can incorporate this concept fairly easily into HEP narrative justifications and other communications
  - We are not abandoning "Frontiers" basis for budget or internal program management

***Relevant P5 Recommendations referenced throughout with [R#]**

The Science Drivers & The Frontiers



Near-Term Action Items II : Major Changes

- *Increase new project construction to 20—25% of the program while university and laboratory research funding should not reduce below 40%.* **[We will use this guidance in budget formulation] [R5]**
- *The long baseline neutrino program should be reformulated to be internationally coordinated and funded, with Fermilab as the host.***[Initial discussions with FNAL and partners have started] [R12, 13]**
- *Invest in the Fermilab proton accelerator complex with the aim to provide substantial intensity beam (> 1 MW) at first operation of the new long baseline neutrino facility.* **[We concur. This is the current plan] [R14]**
- *Increase investment in and immediately proceed with the next generation Dark Matter direct detection program.* **[Challenging w/current budgets. We are using this as a key argument to increase HEP budget] [R19, 20]**
- *Substantially increase particle physics funding as part of the multiagency partnerships that support cosmic microwave background (CMB) research.* **[will convene the CMB community to (re)define the "S4" science plan] [R18]**
- *Re-align accelerator R&D to focus on the latest assessment of our long-term needs, moving away from muon accelerator activities and towards capabilities that could dramatically improve the cost effectiveness of future accelerators.* **[charging new HEPAP subpanel to recommend plan][R24, 25, 26]**

Other P5 Recommendations

- **[R3]** ***Develop a mechanism to reassess the project priority at critical decision stages if costs and/or capabilities change substantively***
  - Developing parameters for "National PAC" w/agency gatekeeper
  - Will also address new projects post-P5
- **[R24]** ***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.***
  - Small R&D efforts for near-term
  - Will be prioritized as part of HEPAP accelerator R&D subpanel (other P5 Recommendations [R23, 25, 26] reference this as well)
- ***Several recommendations on "balance", diversity of program, and improving university-lab partnerships*** **[R4, 6, 7, 28]**
  - Note there is no specific "small project portfolio" in HEP
  - Discussion items for HEPAP

Other P5 Recommendations Continued

- **[R29]** ***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.***
  - Set up Forum for Computational Excellence to work with HEP to address this Recommendation
  - A Pilot Forum has been set up by DOE led by Rob Roser (FNAL) and Salman Habib (ANL) to follow up on these issues among other topics
    - Contact Rob or Salman if you are interested in this

Project-Specific Comments

- **We note that the P5 recommendations, taken together, constitute a coherent HEP program, so one should not read too much into individual recommendations without context**
- **That said, on the next few slides we address some DOE responses to recommendations concerning specific projects**

Project Recommendations

- **[R10] *Complete the LHC phase-I upgrades and collaborate in the high-luminosity upgrades of the accelerator and both general-purpose experiments (ATLAS and CMS). The LHC upgrades constitute our highest-priority near-term large project.***
  - We concur. Phase-I accelerator upgrades underway (via LARP). Initial funding for Phase-I detector upgrades in FY15 Request.
  - The State Department is currently evaluating a DOE/NSF request to begin negotiations with CERN on an updated agreement between the US and CERN to provide the framework for the next stage
    - This agreement will be needed to seek approval of CD-0 for the HL-LHC projects.
    - High-luminosity (Phase-II) accelerator upgrades in advanced discussion stages with CERN
    - Phase-II detector upgrades in early discussion stage with international partners. Full scope of Phase-II detectors and US share will require an iterative process with CERN management and "scrutiny group"
      - Close DOE-NSF partnership will be necessary for success
      - We are working to better understand near-term R&D needs to prepare for the Phase-II detector projects.

Project Recommendations Continued

- **[R11]** ***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.***
  - The meaning of "modest" will depend on the HEP budget
    - Initial support will be by redirection of effort
  - The meaning of "appropriate" will depend on the areas where Japan would like us to help
    - We believe the current priority is for site-specific accelerator R&D and design efforts
  - We await further discussions with the Japanese government

Project Recommendations Continued

- ***Short Baseline Neutrino Program* [R12, 15]*:***
  - The Fermilab director has appointed a coordinator of the Short-Baseline Neutrino (SBN) program. The SBN coordinator has been charged with forging a plan to get a multi-detector SBN program at Fermilab operational by 2018 with two primary goals:
    - Make definitive measurements of the Liquid Scintillator Neutrino Detector (LSND) anomaly and the MiniBooNE low energy excess.
    - Further research and development of Liquid Argon Time Projection Chambers (LAr TPCs) and associated support systems to further the Long-Baseline Neutrino (LBN) program.
  - Various organizational efforts have already started. The intent is for a joint proposal to be reviewed at the July 2014 Fermilab PAC meeting.
    - Based on the Fermilab PAC report, and the Fermilab director's recommendation, DOE will determine if the projects are ready to be considered for next-stage review and approval (eg CD-0).

LBNF Internationalization [Recommendation 13]

- **In order to attract foreign support, work needs to be done on two levels: (1) since funding agencies support the work of their PIs, we need PIs to be attracted to LBNF, and (2) we need to work out 'rules of engagement' between DOE and the other funding agencies**
  1. FNAL Director has to take the lead in attracting PIs to LBNF. A 'summit' meeting is planned for end of July for this purpose. We think the P5 plan should be quite attractive with PIP2 increasing power to >1MW and SURF and LBNE project development well along.
  2. DOE, working with FNAL Director, has to take the lead in attracting foreign funding agencies to work with the US. The LHC management model will be followed as closely as possible. DOE SC project rules have the flexibility needed to do this. Proper oversight of the construction is important to SC; initial discussions with some foreign funding agency representatives indicate that a uniform (Lehman-style) review process may be desirable for all partners.
- **There is also much physics work to do! *(see ICFA neutrino panel report:* http://www.fnal.gov/directorate/icfa/files/ICFA-Neutrino-Panel-Rpt-1.pdf) . DOE (NP, HEP) and NSF (EPP, PA) are discussing modes of cooperation to support the neutrino program**

Some Concerns Expressed on LBNF and DOE Response

- **"The P5 version of LBNF is delayed relative to LBNE plans"**
  - LBNE CD1 featured 10kt on the surface. LBNF is at 4850' with a minimum target mass defined by P5. LBNF as planned by P5 can be afforded by both the US program and its partners by phasing the peak of spending relative to LHC. It is up to the LBNF collaboration, working with funding agencies, to collect resources globally to move as fast as it can.
  - This is an *opportunity* to enable the science the community wants to do
- **Other regions have their own plans, why would they participate?**
  - P5 felt the impact of LBNF underground with a larger detector and more powerful beam was much more scientifically compelling than the DOE CD-1 version. Initial discussions with several potential European partners concur. We note the 2013 European HEP strategy explicitly called out the possibility of offshore collaboration on neutrino projects. Other (non-European) potential partners have also shown interest.

More LBNF FAQ

- **Does DOE plan to "re-open" LBNE CD-1?**
  - No. We are re-evaluating total project cost for the revised LBNF plan (as required by CD process rules) but do not expect to re-open CD-1. That said, international negotiations may impact some of the design choices.
- **Is there any possibility for "early physics" before ~2025?**
  - Yes. How much can be done depends on overall budget levels and readiness at the SURF site to begin construction of the far detector halls. It will be a high priority to get this going as fast as we can.
- **This is a long-term program. Is DOE committed to it, even in the face of possible delays, difficult negotiations, international competition, changing physics landscape?**
  - Yes. HEP is committed now to try to make the full-scale LBNF happen, following the P5 plan. Note that DOE will have stuck with LHC for 20+ years if the upgrades happen as P5 envisions. No reason to believe the same cannot be done for LBNF. But the community must also maintain their commitment.

Other Recommended Projects

Project	P5 Recommendation	HEP action/comment
Mu2e	[R22] Yes in all scenarios. Reprofile?	In current budget plan. May adjust at CD-2.
LSST	[R17] Yes in all scenarios.	In current budget plan.
Dark Matter G2	[R19] Yes in all scenarios. Joint DOE-NSF. Expand number of funded expt's.	Expanded program challenging in current budget. No MIE in FY15 Request. Downselect announced asap.
Dark Matter G3	[R20] Support one or more depending on G2 DM outcome.	Launching G2 DM is near-term priority. Scope TBD.
CMB S4	[R18] Yes in all scenarios. DOE should get involved in next-gen large-scale expt's.	Will discuss DOE role with other agencies (NSF, NASA) and CMB community
DESI	[R16] Yes in Scenario B, C. No in Scenario A.	Not in FY15 Request. Using DESI as argument for Scen. B CD-1 review by end FY2014.
g-2	[R22] Yes in all scenarios	In current budget plan

Cosmic Frontier – Cherenkov Telescope Array (CTA)
(P5 Recommendations, OHEP Response)

- **[R21]** ***Invest in CTA as part of the small projects portfolio if the critical NSF Astronomy funding can be obtained.***
  - CTA has a broad science reach that transcends fields, with the dark matter detection capabilities of direct importance to particle physics
  - Using P5 Criteria, a de-scoped US component should be shared by NSF-AST, NSF-PHY and DOE.

NSF-AST has said publicly that its budget is unable to accommodate this project as a strategic initiative; Only possibility is the competed mid-scale program.

➔HEP doesn't plan to continue support of research or R&D efforts on CTA.
  - This could be re-considered if NSF moves forward on the project and requests a partnership with DOE, based on priorities, funding etc.

HEP Budget Impacts : FY15

- **Note HEP FY15 Request was developed before P5 Plan was announced, so there was little ammunition available to argue for higher budget levels**
  - FY15 Request is slightly below P5 Scenario A level.
  - FY14 Appropriation is above Scenario B.
  - It is impossible at this stage to know which Scenario we are working in
- **But since we have already been working in this budget framework, only relatively small adjustments are needed for FY15 Request to "fit" P5 plans**
  - We have communicated these adjustments to Congress at their request
  - We have also made the arguments for Scenario B funding levels
  - We expect House and Senate mark-ups to be released soon
- **We hope P5 plan + positive community reaction will help support more robust HEP budget generally**
  - Users groups and DPF have been very active in supporting the plan
  - How much of the near-term plan can be achieved will depend largely on FY15 Appropriation

Open Issues

- **Advanced Technology R&D [R23, 24, 26, 27]**
  - P5 suggested significant reduction/redirection here, as well as improving lab/university collaboration
  - How to do this and stay competitive in global program?
  - Impact of paradigm shifts? (e.g., "the end of Moore's Law"?)
- **MAP/GARD redirection and transition [R25]**
  - Need to understand core competencies that need to be preserved
  - Many details still to be worked out
- **HEP Computing R&D (including Trigger/DAQ) [R29]**
  - US has been a world leader here but cost model may be breaking
  - P5 suggested exploring new partnerships and R&D modes
  - Impact of paradigm shifts? (as above)

P5 Rollout Timeline

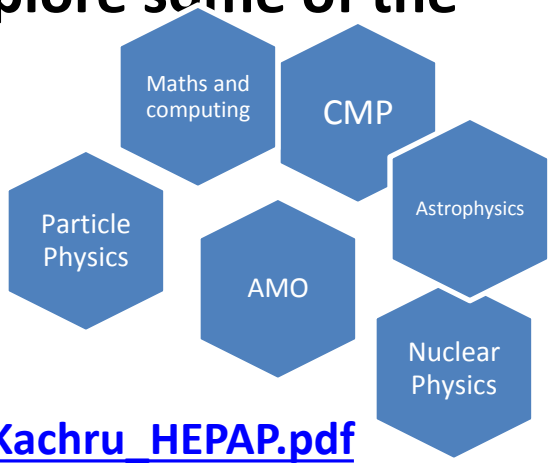
Date	DOE/HEPAP effort	Date	Other effort
May 22-23	HEPAP Meeting (incl press briefing, auxiliary mtgs)		Press releases; emails to community
Late May	Key stakeholder briefings	Late May	Letters from DPF exec, CERN
	Request lab P5 responses	June 2	Ritz community presentation
Early June	Lab SC briefings	June 4-6	DPF Congressional visits, Senate Energy briefing
		June 10	House Science hearing
June 11-12	FNAL User Meeting		
June 16-17	HEP PI Meeting (Rockville) *(you are here)*	June 18	PI Congressional visits
June 23-24	Funding Agency Mtg (Paris)		
Mid-July	HEP lab meeting (DC)		Neutrino PI & agency meetings
August	FY15 initial fin plan		Congressional visits (in home districts)

HEP Science & Technology Connections

- **The strength of the US S&T enterprise in which US HEP is embedded is a significant technical advantage for US HEP relative to competing regions**
  - Only relevant if HEP community systematically takes advantage of the technical opportunities presented by our sister sciences
  - Need to identify and develop community support around those connections areas with largest promise for impact either in HEP or the allied field.
  - Important to remember that Connections are cyclic
  - Innovations developed in particle physics move outwards and evolve – while science and technology advances elsewhere help us
  - Better planning, cooperation, and organizing may help strengthen connections and accelerate S&T gains
- **P5 has also noted the importance of our Benefits and Connections to Society**

Particle Physics Connections with Other Disciplines

- **Science Connections - to other Science Disciplines via synergies in the underlying physical systems and/or theoretical, mathematical, or computational frameworks that describe their behavior.**
- **Technology Connections - via similar tools and techniques useful in pursuing science priorities of individual programs.**
- **HEP recently charged Two Task Forces to explore some of the connections of Particle Physics with other basic sciences and beyond, and identify science opportunities at the interfaces.**



http://science.energy.gov/hep/news-and-resources/reports/

http://science.energy.gov/~/media/hep/hepap/pdf/201403/Kachru_HEPAP.pdf

- **This follows a prior 1998 NAS report on such intersections.**

Paths Forward

- **HEP invites nominations for a Connections Core Working Group**
  - Nominees : expected to be leaders in our field with established interdisciplinary credentials and contacts.
  - Connections Core Group will work with HEP and the Community to identify opportunities and move forward along the most promising ones.
- **The Core Working Group may suggest additional studies in consultation with DOE and potential partner disciplines**
  - Please send your Nominations to Lali Chatterjee at HEP lali.chatterjee@science.doe.gov
- **In the meantime, HEP is contacting potential partner programs and agencies**
  - Suggestions welcome…

Take-Away Messages

- **Recall Snowmass message from Moniz: "Get a plan. Get behind it."**
  - We have a plan. HEP supports the plan.
  - Community (and broader) reaction has been positive so far
  - Continued effort is needed to build support for the plan
- **We have several action items in progress to implement the P5 recommendations**
  - Some can be done quickly, but many will take time
- **We will not know which budget scenario we are in until after the fact**
  - We are using the excellent P5 plan and impact statements to argue for more robust budgets
  - Near-term appropriations (FY15, FY16) will be very important in setting the course for the future
- **There is a lot of work to do, on many fronts**
  - Let's get going!

BACKUP

Prioritization for Large Projects

Project/Activity	Scenarios			Science Drivers					Technique (Frontier)
	Scenario A	Scenario B	Scenario C	Higgs	Neutrinos	Dark Matter	Cosm. Accel.	The Unknown	
Large Projects									
Muon program: Mu2e, Muon g-2	Y, Mu2e small reprofile needed	Y	Y					✓	I
HL-LHC	Y	Y	Y	✓		✓		✓	E
LBNF + PIP-II	Y, LBNF components delayed relative to Scenario B.	Y	Y, enhanced		✓			✓	I,C
ILC	R&D only	R&D, possibly small hardware contri-butions. See text.	Y	✓		✓		✓	E
NuSTORM	N	N	N		✓				I
RADAR	N	N	N		✓				I

Prioritization for Medium and Small Projects

Project/Activity	Scenarios			Science Drivers					Technique (Frontier)
	Scenario A	Scenario B	Scenario C	Higgs	Neutrinos	Dark Matter	Cosm. Accel.	The Unknown	
Medium Projects									
LSST	Y	Y	Y		✓		✓		C
DM G2	Y	Y	Y			✓			C
Small Projects Portfolio	Y	Y	Y		✓	✓	✓	✓	All
Accelerator R&D and Test Facilities	Y, reduced	Y, some reductions with redirection to PIP-II development	Y, enhanced	✓	✓	✓		✓	E,I
CMB-S4	Y	Y	Y		✓		✓		C
DM G3	Y, reduced	Y	Y			✓			C
PINGU	Further development of concept encouraged				✓	✓			C
ORKA	N	N	N					✓	I
MAP	N	N	N	✓	✓	✓		✓	E,I
CHIPS	N	N	N		✓				I
LAr1	N	N	N		✓				I
Additional Small Projects (beyond the Small Projects Portfolio above)									
DESI	N	Y	Y		✓		✓		C
Short Baseline Neutrino Portfolio	Y	Y	Y		✓				I

P5: Executive Summary

- *Particle physics is a discovery-driven science. Investments have rewarded us with fundamental discoveries and current opportunities will push into new territory.*
- ***Particle physics is global.*** ***Successfully addressing urgent scientific questions requires the U.S. to both host world-class facilities and act as reliable international partner with the worldwide community.***
- **This will require much work. International partners are interested but cautious given US history. We will engage DOE leadership to support the P5 plan and vigorously make the case with the rest of the Administration and Congress.**

- ***Five intertwined scientific drivers*** ***were distilled from the results of a yearlong community-wide study:***
  - *Use the* ***Higgs boson*** *as a new tool for discovery* **[→ LHC + upgrades; ILC]**
  - *Pursue the physics associated with* ***neutrino mass*** **[→ FNAL nu program]**
  - *Identify the new physics of* ***Dark Matter*** **[→ direct detection + LHC, ILC]**
  - *Understand cosmic acceleration:* ***Dark Energy*** *and Inflation* **[→ LSST, DESI, CMB next-gen expt's]**
  - *Explore the* ***unknown****: new particles, interactions, and physical principles.* **[→ Mu2e + LHC, ILC and most other recommended IF projects]**

Funding Stability and Investment Opportunities

- *Small changes in yearly budgets have large impacts on the timeline and capability of the U.S. particle physics program.* ***Opportunities are identified where small limited-time funding increments would yield substantial returns.*** **[→ This is the core of the argument "why HEP budget should be ~Scenario B"]**
- *The lowest budget scenario is detrimental to the long-term health of particle physics: the U.S. would lose its position as a global leader in this field, and highly productive international relationships would be fundamentally altered*.**[→ This is the core of the impact statement for "what if you are stuck in Scenario A budgets"]**
- ***Three high-priority activities are identified for additional investments beyond our constrained scenarios:*** **[ie, Scenario C. These will need additional development to become compelling arguments]**
  - ***Expansion of accelerator R&D*** *that would enable very high-energy future machines and likely provide benefits beyond particle physics*. **[New HEPAP accelerator R&D subpanel will address the case for such an expansion, and what investments would be recommended]**
  - ***Play world-leading roles in the ILC*** *detector and accelerator programs.*
  - ***Host a large water-based neutrino detector*** *to unify the global long-baseline neutrino community around the world's highest intensity neutrino beam provided by Fermilab.*

Project Recommendations Continued

- ***General Observations on Recommended Neutrino Program:***
  - There will need to be action on multiple levels to implement this plan.
  - Interested neutrino physicists from around the world will need develop a concept for the best neutrino program possible within fiscal constraints.
  - Funding agencies will need to develop appropriate arrangements to provide contributions to the US neutrino program to support the participation of their scientists
  - There will be high level meeting of interested funding agencies in Paris in late June to discuss cooperating on global program.
  - Fermilab is planning to invite prominent neutrino physicists from around the world this summer to meet and discuss how to bring together the needed collaboration(s)

Recommendations

Global recommendations

- **Recommendation 1: Pursue the most important opportunities wherever they are, and host unique, world-class facilities that engage the global scientific community.**
- **Recommendation 2: Pursue a program to address the five science Drivers.**
- **Recommendation 3: Develop a mechanism to reassess the project priority at critical decision stages if costs and/or capabilities change substantively.**
- **Recommendation 4: Maintain a program of projects of all scales, from the largest international projects to mid- and small-scale projects.**

Recommendations

Program budget allocation

- **Recommendation 5: Increase the budget fraction invested in construction of projects to the 20%–25% range.**
- **Recommendation 6: In the research program, a balance should be found between providing enough resources to reap the full and timely science benefits from major projects and maintaining the flexibility to support, at a reasonable level, new ideas and developments outside approved projects.**
- **Recommendation 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.**
- **Recommendation 8: As with the research program and construction projects, facility and laboratory operations budgets should be evaluated to ensure alignment with the P5 vision.**

Recommendations

Project prioritization (part 1)

- **Recommendation 9: Funding for participation of U.S. particle physicists in experiments hosted by other fields 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.**
- **Recommendation 10: Complete the LHC phase-I upgrades and collaborate in the high-luminosity upgrades of the accelerator and both general-purpose experiments (ATLAS and CMS). The LHC upgrades constitute our highest-priority near-term large project.**
- **Recommendation 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.**

Recommendations

Project prioritization (part 2)

- **Recommendation 12: In collaboration with international partners, develop a coherent short- and long-baseline neutrino program hosted at Fermilab.**
  - The minimum requirements to proceed are the identified capability to reach an exposure of at least 120 kt*MW*yr by the 2035 timeframe, the far detector situated underground with cavern space for expansion to at least 40kt LAr fiducial, and >1.2MW beam upgradable to higher beam power. The experiment should have the demonstrated capability to search for SN bursts and proton decay, providing a significant improvement in discovery sensitivity over current experiments for the proton lifetime.
  - To address even the minimum requirements specified above, the expertise and resources of the international neutrino community are needed. A change in approach is therefore required.
- **Recommendation 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.**
- **Recommendation 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 >1 MW by the time of first operation of the new long-baseline neutrino facility.**
- **Recommendation 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.**

Recommendations

Project prioritization (part 3)

- **Recommendation 16: Build DESI as a major step forward in dark energy science, if funding permits (see Scenarios discussion below).**
- **Recommendation 17: Complete LSST as planned.**
- **Recommendation 18: Support CMB experiments as part of the core particle physics program. The multidisciplinary nature of the science warrants continued multiagency support.**
- **Recommendation 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.**
- **Recommendation 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 G3 experiments.**
- **Recommendation 21: Invest in CTA as part of the small projects portfolio if the critical NSF Astronomy funding can be obtained.**
- **Recommendation 22: Complete the Mu2e and muon g-2 projects.**

Recommendations

Advanced technology R&D and computing (part 1)

- **Recommendation 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.**
- **Recommendation 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.**
- **Recommendation 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.**
- **Recommendation 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 longterm efforts. Focus on outcomes and capabilities that will dramatically improve cost effectiveness for mid-term and far-term accelerators.**

Recommendations

Advanced technology R&D and computing (part 2)

- **Recommendation 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 shortterm and long-term R&D.**
- **Recommendation 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 laboratories, and fully exploit the unique capabilities and facilities offered at each.**
- **Recommendation 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.**

Changes in Direction

Several of these recommendations represent significant changes in direction, which we highlight here:

- **Increase to 20%–25% the fraction of the budget devoted to construction, and plan with care any further reductions in real funding levels for research. In our budget exercises, we adopted an internal guideline of >40% for research.**
- **A change in approach is required for the long-baseline neutrino program. The activity should be reformulated as an internationally coordinated and internationally funded program, with Fermilab as the host, to reach the science driver goals specified in the text. A new international collaboration should be formed.**
- **Upgrade the Fermilab proton accelerator complex to produce higher intensity beams, redirecting some of the existing accelerator R&D and former Project-X activities at Fermilab toward this effort. R&D for PIP-II should proceed immediately, followed by construction, to provide proton beams of >1 MW by the time of first operation of the new long-baseline neutrino facility.**
- **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.**
- **Provide substantially increased particle physics funding of CMB research and projects, as part of the core particle physics program, in the context of continued multiagency partnerships.**
- **Re-align activities in accelerator R&D, which is critical to our future, based on new physics information and long-term needs. Specifically, reassess the Muon Accelerator Program (MAP), incorporating into the general accelerator R&D program those activities that are of broad importance to accelerator R&D, and consult with our international partners on the early termination of MICE. In addition, in the general accelerator R&D program, focus on outcomes and capabilities that will dramatically improve cost effectiveness for mid- and far-term accelerators.**

Scenario A and Scenario B

Scenario A is much more challenging [than Scenario B].

- **The reduction relative to Scenario B, which is approximately $30M per year until FY2018 and then grows over time to $95M in 2024, would have very large impacts:**
  - DESI would not be possible
  - Accelerator R&D and advanced detector R&D would be reduced substantially
  - Extension of flat-flat research program funding would result in further personnel reductions and loss of research capability
  - Ramp up of funding for LBNF would be delayed relative to Scenario B (preliminary work would proceed immediately in both scenarios)
  - A small change in the funding profile of Mu2e may be required.
- **DESI should be the last project to be cut if moving from Scenario B toward Scenario A. A small, limited-time increment above Scenario A would make this very important small project possible.**
- **Scenario A is precarious.**
  - It is close to the point beyond which hosting a large project (>$0.5B) in the U.S. would not be possible while maintaining the other elements necessary for mission success, particularly a minimal research program and our strong leadership position in a small number of core, near-term projects, which produce a steady stream of important new physics results. Without the capability to host a large project, the U.S. would lose its position as a global leader in this field, and the international relationships that have been so productive would be fundamentally altered.
- **The return on the investment of the relatively small increment from Scenario A to Scenario B is large.**

Scenario C

Our vision for Scenario C is not a long list of projects. Instead, we focus on a few high-priority opportunities:

- **The U.S. could move boldly toward development of transformational accelerator R&D.**
  - A detailed vision and roadmap should be articulated by the upcoming HEPAP sub-panel on accelerator research.
  - As work proceeds worldwide on far-future vision accelerator concepts, the U.S. should be counted among the potential host nations.
  - Experience suggests this effort will also have large, positive impacts beyond particle physics.
- **The interest expressed in Japan of hosting the International Linear Collider (ILC), a 500 GeV e^+e^- accelerator upgradable to 1 TeV, is an exciting development.**
  - Should the ILC go forward, Scenario C would enable the U.S. to play world-leading roles in the detector program as well as provide critical accelerator components.
- **It could be possible for the U.S. to offer to host a large water Cherenkov experiment, unifying the global long-baseline neutrino community to take full advantage of the world's highest intensity neutrino beam.**
  - The placement of the water and LAr detectors would be optimized for complementarity. This approach would be an excellent example of global cooperation and planning.