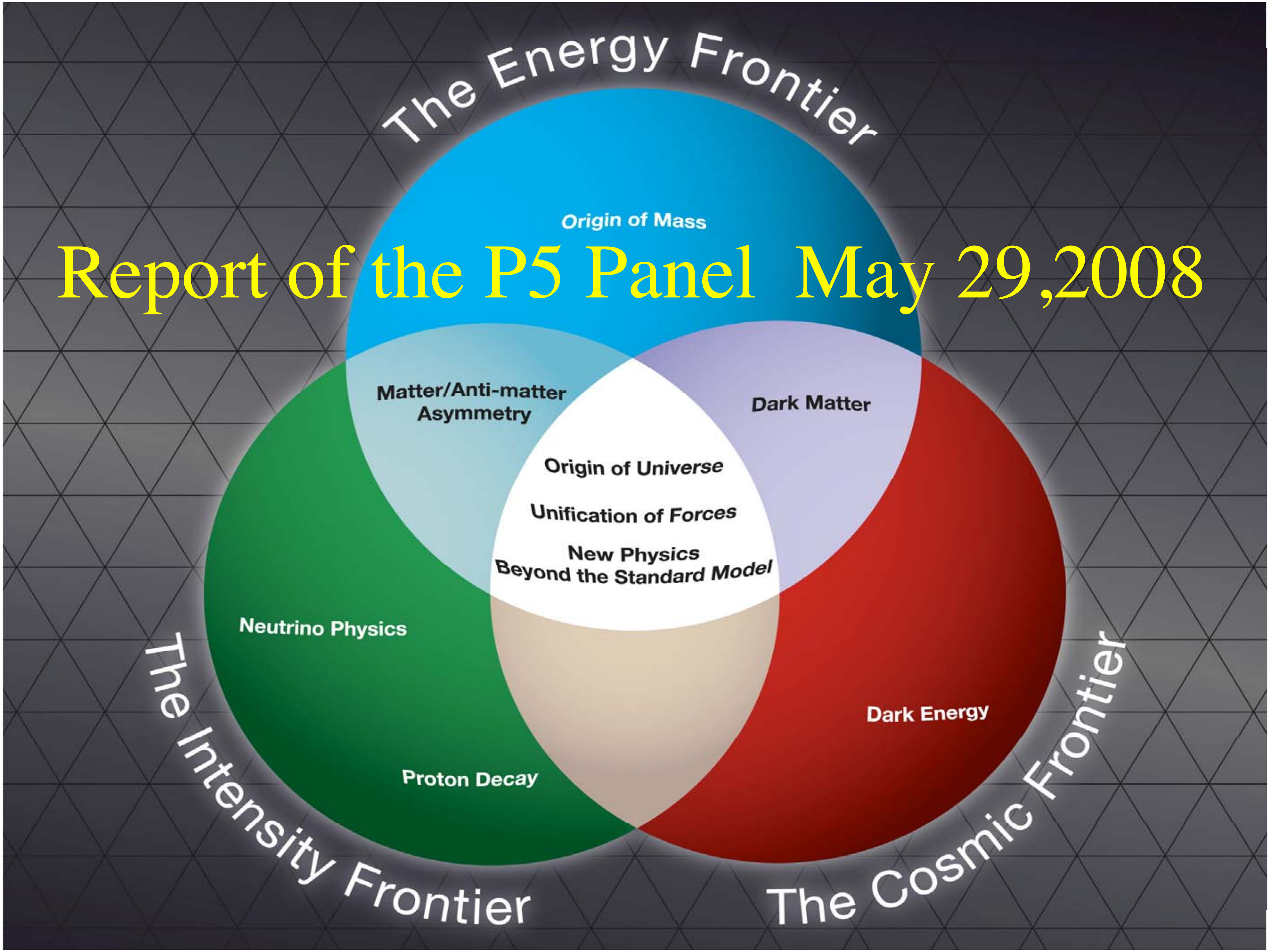
Report of the P5 Panel May 29,2008



US Particle Physics: Scientific Opportunities

A Strategic Plan for the Next Ten Years

Report of the
Particle Physics Project Prioritization Panel

May 29, 2008

Charge to the Panel

- In November of 2007 the DOE and the NSF asked HEPAP to reconvene the P5 panel
- Charge to the Panel: Develop a 10 year plan for US Particle Physics under various DOE funding scenarios:

  A. Constant effort at the FY2008 level(688 FY08 M$ DOE)

  B. Constant effort at the FY2007 level(752 FY07 M$ DOE)

  C. Doubling of budget over 10 years starting with FY2007

  D. Additional funding above the previous level, associated with specific activities needed to mount a leadership program

  The Panel was also briefed on the status of NSF fiscal planning. The plan described here assumes approval of the DUSEL MREFC proposal and continued funding of the NSF university program.

The First Three budget Scenarios Considered

	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
2008 Base Then Yr $	752	688	712	737	763	789	817	846	875	906	938	971
2007 Base Then Yr $	752	688	806	834	863	893	924	957	990	1025	1061	1098
2007 DoublThen Yr $	752	688	853	908	967	1030	1097	1169	1245	1325	1412	1503
2008 Base 2008$	752	688	688	688	688	688	688	688	688	688	688	688
2007 Base 2008$	752	688	778	778	778	778	778	778	778	778	778	778
2007 Doubl 2008$	752	688	824	848	874	901	928	955	984	1013	1044	1075

P5 Membership

Charles Baltay (Yale University), Chair

Hiroaki Aihara (University of Tokyo)

James Alexander (Cornell University)

Daniela Bortoletto (Purdue University)

James Brau (University of Oregon)

Peter Fisher (M I T)

Josh Frieman (Fermilab)

Fabiola Gianotti (CERN)

Donald Hartill (Cornell University)

Tor Raubenheimer (SLAC)

Andrew Lankford (U C Irvine)

Joseph Lykken (Fermilab)

William Marciano (Brookhaven)

Jay Marx (California Institute of Technology)

Steve Ritz (NASA GSFC)

Marjorie Shapiro (Berkeley)

Henry Sobel (U C Irvine)

Robert Tschirhart (Fermilab)

Carlos Wagner (Argonne)

Stanley Wojcicki (Stanford University)

Mel Shochet (University of Chicago) (Ex-Officio)

Report Translated into English by Judy Jackson

Particle Physics Project Priorization Panel

HEPAP,Following a request from the DOE and the NSF,constituted a new P5 Panel to develop a Long Range Plan for particle Physics in the US for the Coming decade.The purpose of this website is to keep the community informed of these proceedings.

Charge to the Panel
Panel Membership
Schedule of Meetings
The Fermilab Mtg
The SLAC Mtg
The Brookhaven Mtg

http://hepwww.physics.yale.edu/P5

P5 Meetings

- Fermilab — Jan 31 to Feb 2, 2008
- SLAC — Feb 21 to 23, 2008
- Brookhaven — March 6 to 8, 2008

These meetings included talks by selected experts in the field as well as a Town Meeting each to hear views from the community. The Panel also invited letters from the community.

- Washington — April 3 to 5, 2008
  to draft report

March 6, 2008

Dr. Charles Baltay
Yale University
Physics Department
217 Prospect Street
New Haven, CT 06511-3712

Dear Charlie:

The current P5 process to develop a plan for the U.S. particle physics community is critical for the future of the field. In making recommendations to the agencies within the difficult budget scenarios you have been presented with, you will need to make difficult and painful choices. We urge you to make the difficult choices that, in your collective wisdom, will result in the best possible path forward for the field.

Once P5 has set forth its recommendations for the field under the various budget scenarios, we are committed to supporting the P5 recommendations and working to align the HEP programs at our labs to make the plan successful. We recognize that unless the University and the lab communities unify in support of a common path forward, we will not be successful.

We will only move forward successfully if we move forward together.

Sincerely,

Samuel Aronson, BNL

Pierre Oddone, FNAL

Persis Drell, SLAC

Steven Chu, LBNL

Robert Rosner, ANL

Maury Tigner, Cornell

Argonne NATIONAL LABORATORY

BROOKHAVEN NATIONAL LABORATORY

Cornell University
Lloyd R. Newman Laboratory for
Elementary-Particle Physics

Fermilab

SLAC

The Changing context of Particle Physics

- Recent reports, including the National Research Council's "Revealing the Hidden Nature of Space and Time" (the EPP2010 report) and earlier P5 reports, have discussed the outlook for the field of particle physics in the United States.
- The scientific priorities have not changed since those reports appeared, but the context for the scientific opportunities they describe has altered.

The Changing context of Particle Physics

- Particle physics in the United States is in transition:
- Two of the three high-energy physics colliders in the US have now permanently ceased operation. The third, Fermilab's Tevatron, will turn off in the next few years.
- The energy frontier, defined for decades by Fermilab's Tevatron, will move to Europe when CERN's Large Hadron Collider begins operating. American high-energy physicists have played a leadership role in developing and building the LHC program, and they constitute a significant fraction of the LHC collaborations—the largest group from any single nation. About half of all US particle physicists participate in LHC experiments.

The Changing context of Particle Physics

- The US high-energy physics program faces serious fiscal challenges that change the particle-physics landscape as this transition occurs.
- The large cost estimate for the International Linear Collider, a centerpiece of previous plans, has delayed plans for a possible construction start and has led the particle physics community to take a fresh look at the scientific opportunities in the decade ahead.
- The severe funding reduction in the Omnibus Bill of December 2007 stopped work on several projects and had damaging impacts for the entire field.
- The present P5 panel has developed a strategic plan that takes these new realities into account.

Long Term Value of Research in Fundamental Sciences

- To quote from the Rising Above the Gathering Storm Report
    - "The growth of economies throughout the world has been driven largely by the pursuit of scientific understanding, the application of engineering solutions, and the continual technological innovation. Today, much of everyday life in the United States and other industrialized nations, as evidenced in transportation, communication, agriculture, education, health, defense, and jobs, is the product of investments in research and in the education of scientists and engineers. One need only think about how different our daily lives would be without the technological innovations of the last century or so."
- The Gathering Storm report makes the following recommendation:
    - "Sustain and strengthen the nation's traditional commitment to long-term basic research that has the potential to be transformational to maintain the flow of new ideas that fuel the economy, provide security, and enhance the quality of life"

Long Term Value of Research in Fundamental Sciences

- To quote from another National Academies report, "Charting the Course for Elementary Particle Physics," the work of a panel including leaders from both science and industry and chaired by economist Harold Shapiro:
  - "A strong role in particle physics is necessary if the United States is to sustain its leadership in science and technology over the long term. "
- That report continues:
  - "The committee affirms the intrinsic value of elementary particle physics as part of the broader scientific and technological enterprise and identifies it as a key priority within the physical sciences."
- Besides its long-term scientific importance, particle physics generates technological innovations with profound benefits for the sciences and society as a whole. Many examples of this are discussed in the P5 Report.

The Excitement in Particle Physics

- Particle Physics has been very successful in creating a major synthesis, the Standard Model, that explains to a high accuracy almost all experimental observations so far
- However recent results show that there is new physics Beyond the Standard Model
  - —Neutrino Oscillations: Neutrinos have mass, neutrino mixing
  - —Accelerating Universe: Dark Energy
  - —Missing mass in the Universe:Dark Matter
- Tevatron, LEP, SLD experiments strongly point to new physics at the Terascale

These discoveries make Particle Physics richer and more exciting then ever before.Over the past decade the field has developed new cutting edge instruments to address these new physics questions. We expect fundamental new discoveries in the coming decade.

A set of interrelated questions define the field

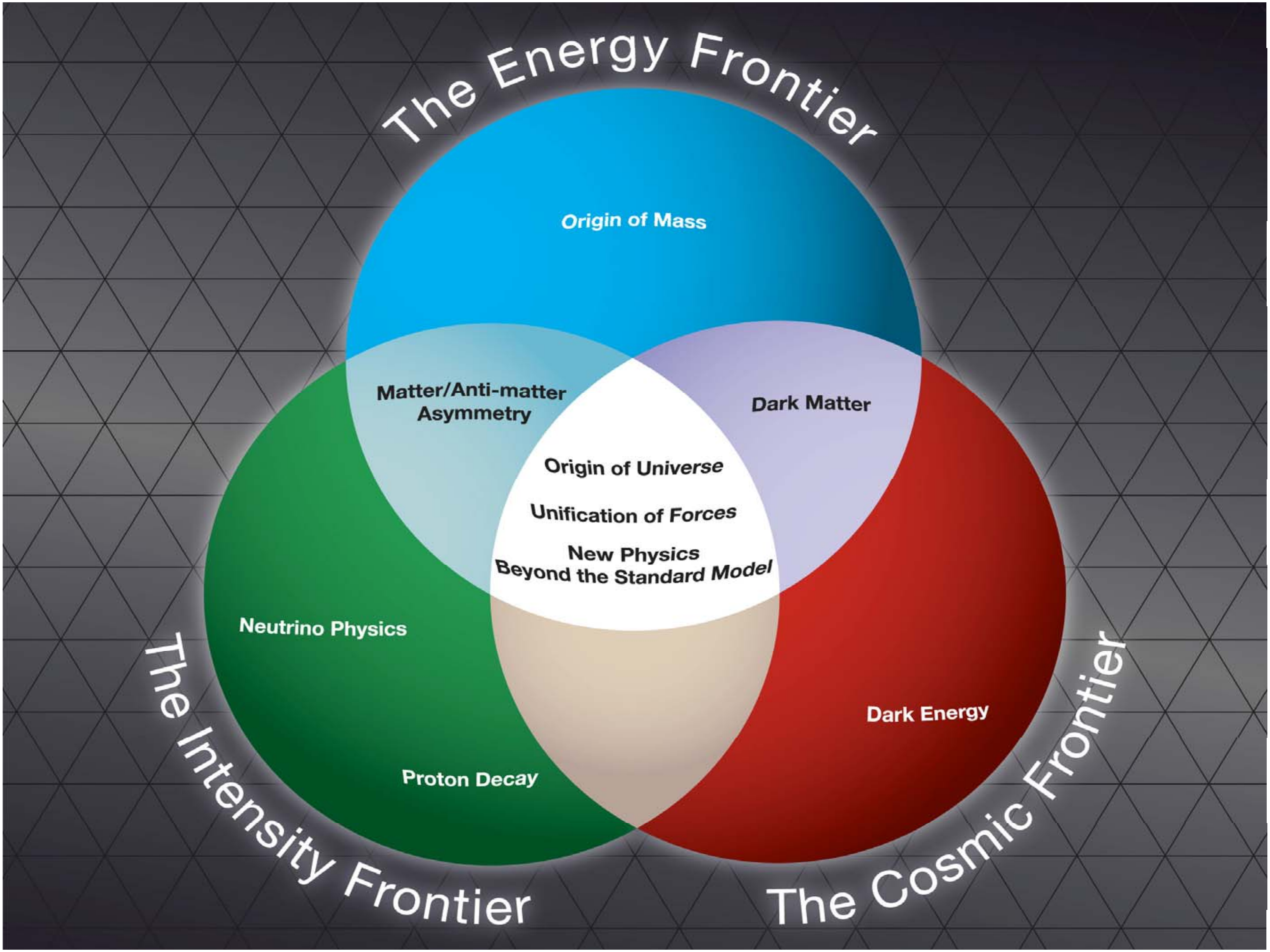
1. How do particles acquire mass? Does the Higgs boson exist, or are new laws of physics required?
2. What is the nature of new particles and new principles beyond the Standard Model?
3. What is the dark matter that makes up about one quarter of the contents of the universe?
4. What is the nature of the dark energy that makes up almost three quarters of the universe?
5. Do all the forces of nature become one? How does gravity fit in? Is there a quantum theory of gravity?
6. Why is the universe as we know it made of matter, with no antimatter present? What is the origin of this matter-antimatter asymmetry?
7. What are the masses and properties of neutrinos and what role did they play in the evolution of the universe? How are they connected to matter-antimatter asymmetry?
8. Is the building block of the stuff we are made of, the proton, unstable?
9. How did the universe form?

The Three Frontiers of Particle Physics

Addressing the central questions of the field requires a broad program of research using a variety of tools and techniques that we broadly classify into three interrelated frontiers:

- The Energy Frontier, using high-energy colliders to discover new particles and directly probe the properties of nature.
- The Intensity Frontier, using intense beams to uncover the elusive properties of neutrinos and observe rare processes that probe physics beyond the Standard Model.
- The Cosmic Frontier, revealing the natures of dark matter and dark energy and using high-energy particles from space to probe the architecture of the universe.

These three frontiers form an interlocking framework that addresses fundamental questions about the laws of nature and the cosmos.



The Energy Frontier
Origin of Mass
Matter/Anti-matter Asymmetry
Dark Matter
Origin of Universe
Unification of Forces
New Physics Beyond the Standard Model
Neutrino Physics
Proton Decay
Dark Energy
The Intensity Frontier
The Cosmic Frontier

Overall Recommendation of the Panel

- The panel recommends that the US maintain a leadership role in world-wide particle physics.

- The panel recommends a strong, integrated research program for US particle physics at three frontiers: the Energy Frontier, using both hadron colliders and lepton colliders to discover and illuminate the physics of the Terascale; the Intensity Frontier, comprising neutrino physics and high-sensitivity experiments on rare processes; and the Cosmic Frontier, probing the nature of dark matter and dark energy and other topics in particle astrophysics.

The Energy Frontier

Accelerators and experiments at the Energy Frontier are expected to make major discoveries leading to an ultimate understanding of the theory of particles and their interactions. They will address key questions about the physical nature of the universe: the origin of particle masses, the existence of new symmetries of nature, extra dimensions of space, and the nature of dark matter.

The Tevatron Collider

The Tevatron at Fermilab is currently the highest-energy collider in the world.

The panel recommends continuing support for the Tevatron Collider program for the next one to two years, to exploit its potential for discoveries.

The Large Hadron Collider

In the near future, the Large Hadron Collider at CERN in Geneva, Switzerland will achieve the highest collision energies. The LHC is an international project with significant US investment and major US involvement: Americans constitute the largest group of LHC scientists from any single nation. Significant US participation in the full exploitation of the LHC has the highest priority in the US particle physics program.

The panel recommends support for the US LHC program, including US involvement in the planned detector and accelerator upgrades, under any of the funding scenarios considered by the panel.

Lepton Colliders

- The international particle physics community has reached consensus that a full understanding of the physics of the Terascale will require a lepton collider as well as the LHC. The panel reiterates the importance of such a collider.
- In the next few years, results from the LHC will indicate the required energy for such a lepton collider.
- If the optimum initial energy proves to be at or below approximately 500 GeV, then the International Linear Collider is the most mature option with a construction start possible in the next decade.
  - The cost and scale of a lepton collider mean that it would be an international project, with the cost shared by many nations.
  - International negotiations will determine the siting; the host will be assured of scientific leadership at the energy frontier.
- A requirement for initial energy much higher than the ILC's 500 GeV will mean considering other collider technologies.
- Whatever the technology of a future lepton collider, and wherever it is located, the US should plan to play a major role.

Lepton Collider R&D Program

- For the next few years, the US should continue to participate in the international R&D program for the ILC to preserve the option of an important role for the US should the ILC be the choice of the international community. The US should also participate in coordinated R&D for the alternative accelerator technologies that a lepton collider of higher energy would require.
- The panel recommends for the near future a broad accelerator and detector R&D program for lepton colliders that includes continued R&D on ILC at roughly the proposed FY2009 level in support of the international effort. This will ensure a significant role for the US even if the ILC is built overseas. The panel also recommends R&D for alternative accelerator technologies, to permit an informed choice when the lepton collider energy is established.
- The panel also recommends an R&D program for detector technologies to support a major US role in preparing for physics at a lepton collider.

The Intensity Frontier

The accelerator-based neutrino program

- Measurements of the mass and other properties of neutrinos are fundamental to understanding physics beyond the Standard Model and have profound consequences for understanding the evolution of the universe. The US can build on the unique capabilities and infrastructure at Fermilab, together with the proposed DUSEL, the Deep Underground Science and Engineering Laboratory proposed for the Homestake Mine, to develop a world-leading program in neutrino science. Such a program will require a multi-megawatt proton source at Fermilab.

- The panel recommends a world-class neutrino program as a core component of the US program, with the long-term vision of a large detector in the proposed DUSEL laboratory and a high-intensity neutrino source at Fermilab.

Neutrino Program (cont)

- The panel recommends proceeding now with an R&D program to design a multi-megawatt proton source at Fermilab and a neutrino beamline to DUSEL and recommends carrying out R&D on the technology for a large detector at DUSEL.

- Construction of these facilities could start within the period considered by this report.

- A neutrino program with a multi-megawatt proton source would be a stepping stone toward a future neutrino source, such as a neutrino factory based on a muon storage ring, if the science eventually requires a more powerful neutrino source. This in turn could position the US program to develop a muon collider as a long-term means to return to the energy frontier in the US

Neutrino Program (cont)

- The panel further recommends that in any funding scenario considered by the panel, Fermilab proceed with the upgrade of the present proton source by about a factor of two, to 700 kilowatts, to allow a timely start for the neutrino program in the Homestake Mine with the 700-kilowatt source.

These accelerator-based neutrino measurements are extremely challenging and have ambiguities in the interpretation of results. The proposed U.S. and Japanese programs take complementary approaches that together would greatly enhance the understanding of the underlying science. One particular advantage of the envisioned US program is the long baseline available from Fermilab to the Homestake site.

Neutrino Program (cont)

When they become available by about 2012, the results of θ_{13} measurements and the results of accelerator and detector R&D efforts should be used to optimize the design of the long-baseline neutrino physics program. At that point construction of the beamline and the first stage of a detector should proceed as rapidly as possible. If the decision is made to proceed with the multi–megawatt proton source, construction should start as soon as possible after the completion of the R&D program under all but the lowest funding scenarios. The lowest funding scenario would delay the construction start of a multi–megawatt proton source.

Neutrino Program (cont)

- The panel recommends support for R&D on the technology for a large detector at DUSEL. The nature of such a large detector is not yet clear. The two contending technologies are water Cerenkov and liquid argon. Large-scale water Cerenkov detectors are a mature technology, although at a smaller scale than is envisioned for DUSEL.

- The panel recommends support for a vigorous R&D program on liquid argon detectors and water Cerenkov detectors in any funding scenario considered by the panel. The panel recommends designing the detector in a fashion that allows an evolving capability to measure neutrino oscillations and to search for proton decays and supernovae neutrinos.

Intermediate Neutrino Program

- The panel realizes that such an ambitious neutrino program must proceed in stages. The NOvA experiment has received approval by previous committees, has undergone detailed design and multiple reviews, and is ready for construction.

- In all but the lowest funding scenario, the panel recommends a rapid NOvA construction start. However, the lowest funding scenario would further delay the experiment's construction start, and the costs of NOvA construction and operation would displace other programs of higher priority. The panel therefore recommends that Fermilab not proceed with the NOvA experiment under the lowest funding scenario.

Nonaccelerator Neutrino Experiments

- The reactor experiments, Double Chooz and Daya Bay, are designed to carry out measurements of the mixing angle θ_{13}, an important physics parameter. The panel recommends support for these experiments under any of the funding scenarios considered by the panel.

- Nonaccelerator experiments searching for neutrinoless double beta decay have the potential to make discoveries of major importance about the fundamental nature of neutrinos. The panel recommends support for these experiments, in coordination with other agencies, under any funding scenario considered by the panel.

High-sensitivity Measurements

- The latest developments in accelerator and detector technology make possible promising new scientific opportunities through measurement of rare processes. Incisive experiments, complementary to experiments at the LHC, would probe the Terascale and possibly much higher energies.
- The panel recommends pursuing the muon-to-electron conversion experiment, subject to approval by the Fermilab PAC, under all budget scenarios considered by the panel.
- The intermediate budget scenario would allow in addition pursuing significant participation in one overseas next-generation B factory.
- The more favorable funding scenario, scenario C, would allow for pursuing a program in rare K decay experiments at Fermilab as well.

The DUSEL Facility

- The physics program of the Deep Underground Science and Engineering Laboratory is of central importance to particle physics. Experiments at DUSEL would address many issues, including neutrino physics, proton decay, dark matter, and neutrinoless double beta decay. DOE and NSF should define clearly the stewardship responsibilities for such an experimental program.

- The panel endorses the importance of a deep underground laboratory to particle physics and urges NSF to make this facility a reality as rapidly as possible.
- Furthermore the panel recommends that DOE and NSF work together to realize the experimental particle physics program at DUSEL.

The Cosmic Frontier

- Although ninety five percent of the universe appears to consist of dark matter and dark energy, we know little about them. The quest to elucidate the nature of dark matter and dark energy is at the heart of particle physics—the study of the basic constituents of nature, their properties and interactions. The US is presently a leader in the exploration of the Cosmic Frontier. The field has identified compelling opportunities for dark matter search experiments, and for both ground-based and space-based dark energy investigations.

- The panel recommends support for the study of dark matter and dark energy as an integral part of the US particle physics program.

Dark Matter Search Experiments

- The observation of dark matter particles from the galaxy would be an epochal discovery. In consonance with experiments at the LHC, dark matter detection experiments could help unravel the identity and properties of dark matter.

- The panel recommends that NSF and DOE jointly support direct dark matter detection experiments under any of the funding scenarios considered by the panel. The choice of which of these experiments to support in the longer term should be made after completion of the ongoing experiments and the R&D on the next generation of detectors.
  -

Experiments to Study the nature of Dark Energy

- The cause of the accelerated expansion of the universe is a mystery. It could signal the existence of a new form of energy, dark energy, or a breakdown of Einstein general relativity. For the near term, the panel reiterates the recommendation by the previous P5 panel for a construction start of the Dark Energy Survey. The panel recommends consideration of other selected ground-based experiments. For the longer term, the space-based Joint Dark Energy Mission and the ground-based Large Synoptic Survey Telescope offer major, complementary advances in probing the nature of dark energy.

The panel recommends that DOE support JDEM, at an appropriate level negotiated with NASA, under all budget scenarios considered by the panel.

The panel recommends DOE support for the ground-based LSST program, in coordination with NSF, in all funding scenarios considered by the panel, at a level that depends on the overall program budget.

High Energy Particles from Space

- The study of high-energy particles from space—ultra-high energy cosmic rays, gamma rays, and neutrinos—is a vibrant, rapidly developing area of science at the boundary between particle physics and astrophysics. These projects bring important diversity to particle physics, so relatively small investments are a high priority, even in the leanest budget scenarios. Due to extreme budget pressures, very large investments at this time are only possible in the higher budget scenarios. Multiagency, international cooperation is particularly important for the support of this exciting science.
- The panel recommends limited R&D funding for these other particle astrophysics projects under all budget scenarios considered by the panel, but support for any possible large construction projects should be considered only under funding scenarios C and D.
- The panel recommends that the funding agencies establish a Particle Astrophysics Science Advisory Group to advise DOE and NSF on the relative merits of the various proposals anticipated in this area.

Advanced Accelerator and Detector R&D

- Advances in accelerator and detector R&D are critical for the United States to maintain leadership at the Energy, Intensity and Cosmic Frontiers of particle physics; to allow the possibility of hosting a future energy-frontier accelerator in the United States; and to develop applications for the benefit of society.

- The panel recommends a broad strategic program in accelerator R&D, including work on ILC technologies, superconducting rf, high-gradient normal-conducting accelerators, neutrino factories and muon colliders, plasma and laser acceleration, and other enabling technologies, along with support of basic accelerator science.

Advanced Accelerator and Detector R&D

- The panel recommends creation of a HEPAP subpanel to develop a strategic plan for accelerator R&D. This panel should be followed by an advisory group to monitor the progress and effectiveness of this program.

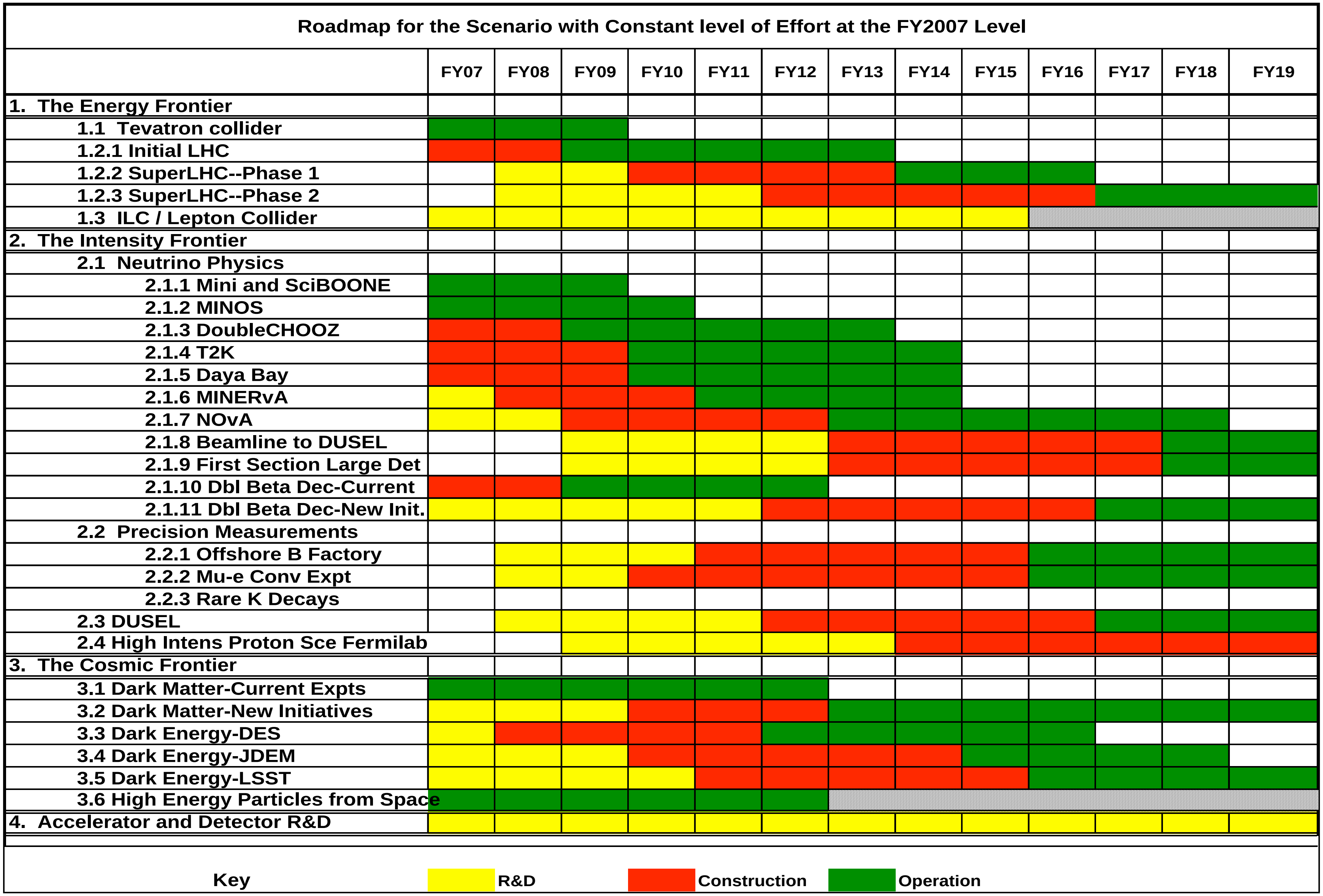
- The panel recommends support for a program of detector R&D on technologies strategically chosen to enable future experiments to advance the field, as an essential part of the program.

The University Program

- The US particle physics program is built on a strong partnership between the national laboratories and universities that combines human resources and facilities to advance the science, with a high level of interdependence. The universities bring fresh ideas to the field, provide a crucial component in designing and realizing experiments and their subsequent data analysis, and train graduate students. Graduate studies train scientists for the field of particle physics as well as for a variety of professions that are key to future American competitiveness.

- The panel recommends preserving the funding for the university program even under the lowest funding scenario, and increasing it by close to 10 percent, as recommended by the HEPAP subpanel on the University program, at the more favorable funding scenarios.

Roadmap for Funding Scenario B



Scenario A: Constant level of effort at FY2008

- Budget Scenario A would significantly reduce the scientific opportunities at each of the three frontiers compared to Scenario B and stretch out progress over a longer time scale.
- Scenario A would most profoundly limit studies at the Intensity Frontier, with a negative impact on both neutrino physics and high-sensitivity measurements.
- It would require cancellation of two neutrino experiments, NOvA and MINERvA, that are ready for construction, due to the lack of funds for construction of the experiments as well as the cost of operating the Fermilab accelerator complex. Consequently, a first look at the neutrino mass hierarchy would be unlikely during the next decade, and experimenters could not measure neutrino cross sections, including those important to future long-baseline neutrino oscillation experiments.

Scenario A: Constant level of effort at FY2008

- Furthermore, this budget scenario would delay the construction of a high-intensity proton source at Fermilab by at least three to five years. This delay would in turn severely compromise the program of neutrino physics and of high-sensitivity searches for rare decays at the Intensity Frontier in the subsequent decade.It would also postpone the development of a foundation for a possible future muon collider.
- The US could not contribute significantly to the next-generation overseas B factories that will carry out unprecedented studies of matter-antimatter asymmetry and searches for new processes in the quark sector.
- For dark-energy studies at the Cosmic Frontier, Budget Scenario A would delay DOE funding for the ground-based LSST telescope.
- This budget scenario could not support the investment in new facilities for advanced accelerator R&D, important for future accelerators both at the energy frontier and for other sciences.

Scenario A: Constant level of effort at FY2008

- Scenario A would require an additional reduction of approximately 10 percent beyond the FY2008 cuts in the number of scientists over the 10-year period. It would lead to a significant drop in the number of graduate students and postdoctoral fellows.
- Scenario A's drought in R&D coupled with delays in facility construction imposed during this decade would limit scientific opportunities in the subsequent decade.

- Overall, while this funding level could deliver significant science, there would be outstanding scientific opportunities that could not be pursued. It would sharply diminish the US capability in particle physics from its present leadership role.

Scenario C: Budget doubling over 10 years

- At the Energy Frontier, this budget scenario would extend the discovery potential of the Fermilab Tevatron Collider by supporting operation in FY2010.
- Progress toward a future lepton collider is a very high priority of the field worldwide. Should results from the LHC show that the ILC is the lepton collider of choice, funding in this scenario would support R&D and enable the start of construction of an ILC abroad.
- If another lepton collider technology is found to be preferable, its R&D would be advanced.

Scenario C: Budget doubling over 10 years

- Scenario C would significantly advance the exploration of physics at the Intensity Frontier.
- Construction of a new high-intensity proton source, which would support both neutrino physics and precision searches for rare decays, would be complete.
- Operation of the neutrino experiments would begin, using the beamline to DUSEL and a very sensitive neutrino detector, providing great sensitivity to matter-antimatter asymmetry in neutrinos.
- Scenario C would enable new rare K-decay experiments highly sensitive to new physics.

Scenario C: Budget doubling over 10 years

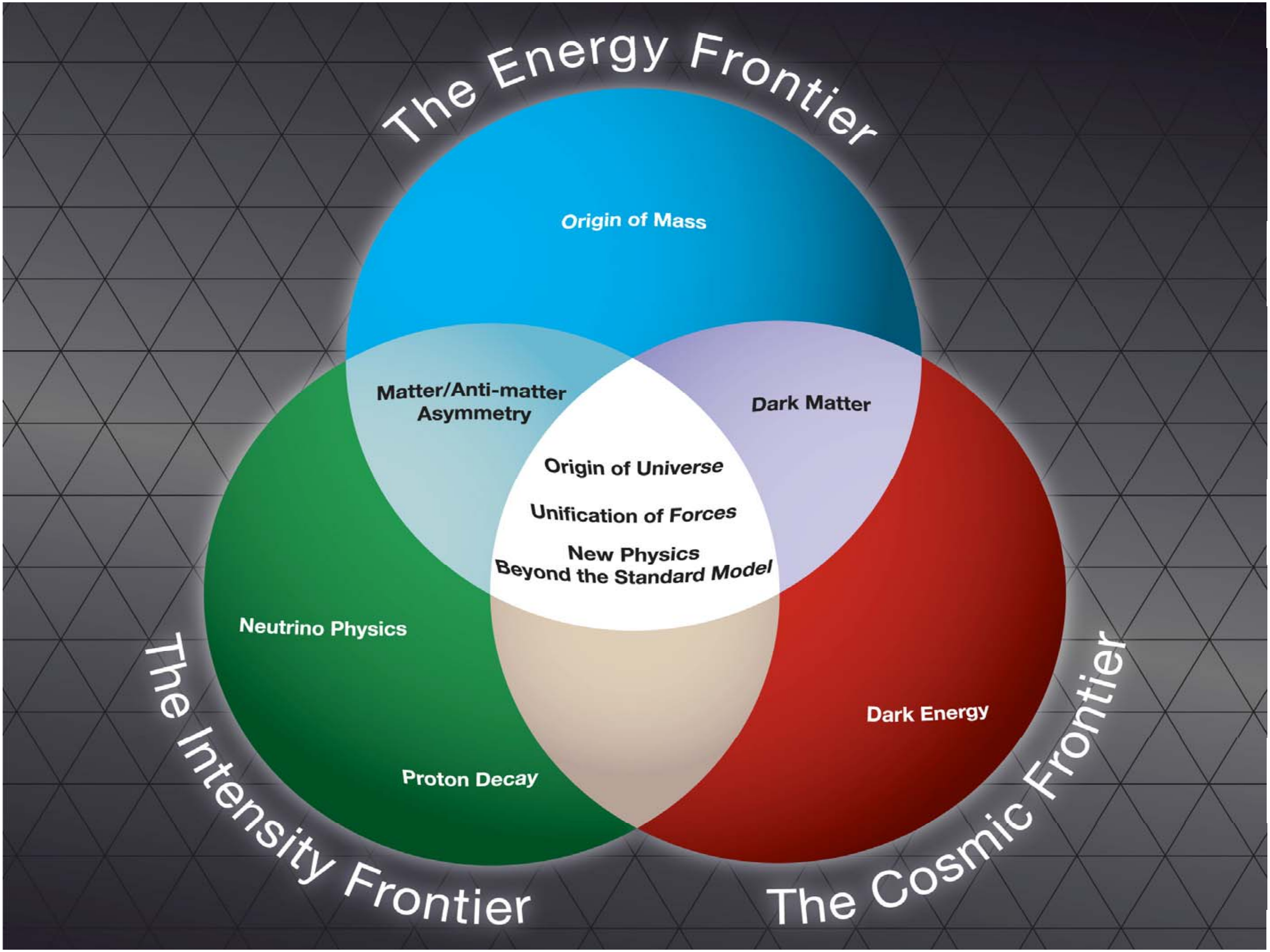
- At the Cosmic Frontier, Scenario C would advance the exploration of dark energy by enabling the timely completion of the two most sensitive detectors of dark energy, the JDEM space mission and the ground-based LSST telescope.
- Scenario C enables strategic, large-scale investments in exciting projects at the boundary between particle physics and astrophysics, the study of high-energy particles from space. Without these investments, the US will likely lose leadership in this rapidly developing area.

Scenario C: Budget doubling over 10 years

- Budget Scenario C would support a world-class program of scientific discovery at all three frontiers in the decade ahead. It would provide strong support for the development of future research capabilities and of the scientific workforce.
- This budget scenario would provide additional support for university groups, further addressing the pressing needs enunciated in several recent reports, among them the National Academy's "Rising above the Gathering Storm."
- It would obviate the need to cut the scientific work force at the national laboratories, as lower budget scenarios would require.

Scenario D: A Bump of Funding

- The following scientific opportunities would justify additional funding above the level of the funding scenarios discussed above.
- A lepton collider will be essential for the in-depth understanding of new physics discovered at the LHC: the source of the masses of the elementary particles, new laws of nature, additional dimensions of space, the creation of dark matter in the laboratory, or something not yet imagined. Major participation by the US in constructing such a facility would require additional funding beyond that available in the previous funding scenarios.
- The study of dark energy is central to the field of particle physics. DOE is currently engaged with NASA in negotiations concerning the space-based Joint Dark Energy Mission. If the scale of JDEM requires significantly more funding than is currently being discussed, an increase in the budget beyond the previous funding scenarios would be justified.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The Cosmic Frontier

Response to Questions from Members of HEPAP

C. Baltay

May 29, 2008

Response to Questions by HEPAP Members

- We received many thoughtful comments from HEPAP members in the last two weeks suggesting useful corrections and raising interesting issues.
- There were many emails and phone conversations but the full panel did not have time to meet since.
- We made most of the suggested changes and corrections as best as we could.
  - Rearranged order of sections for more logical flow and to put science up front Exec Summ--->Discussion of Science--->Summary of Recs
  - Added Boxes on Std Model, Hadron Colliders etc
  - Many smaller changes
- Some issues raised did not result in changes to the report and will be discussed in this presentation.

Interesting Questions Raised

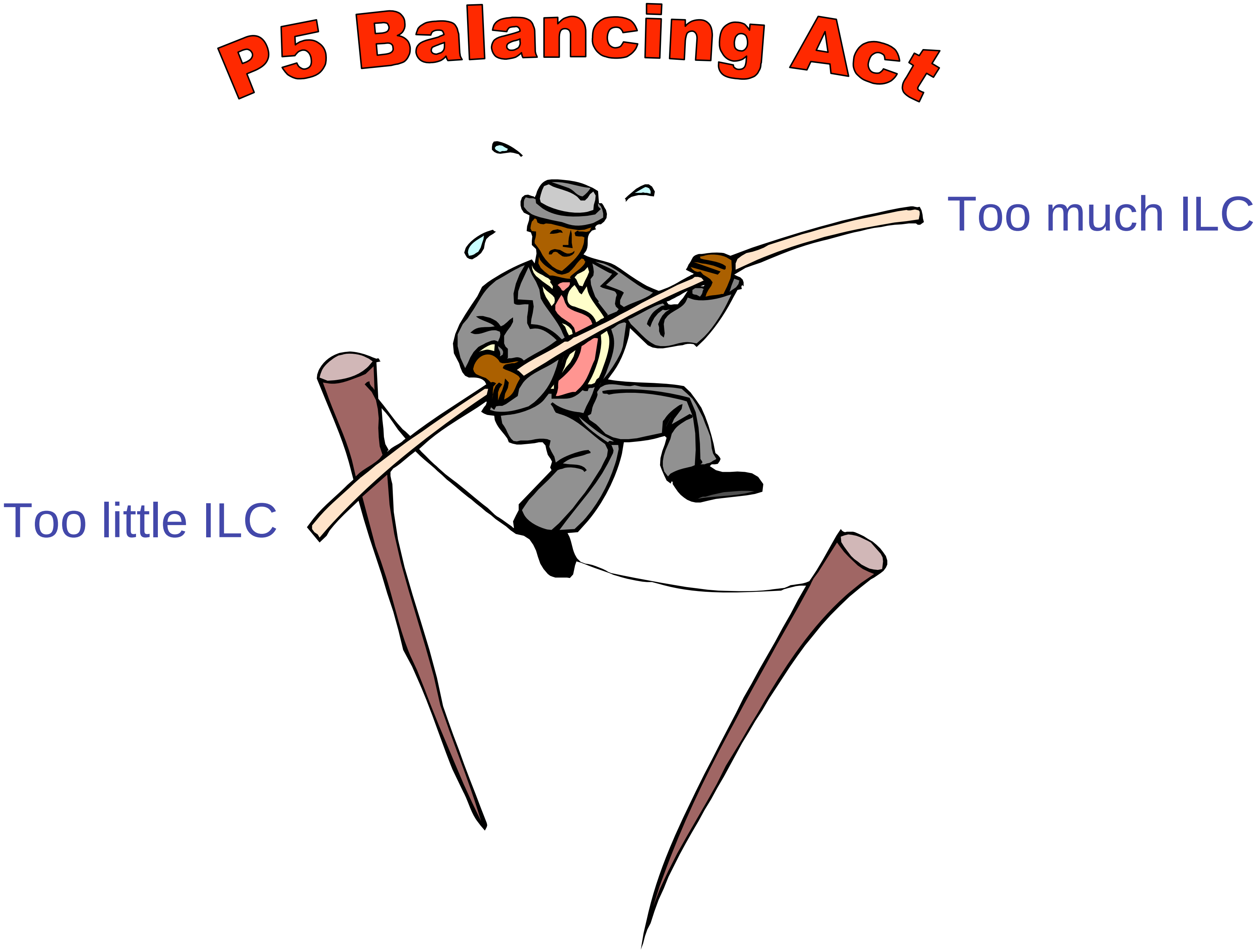
- Role of ILC in the Ten Year Plan
- More detail on reach of Neutrino Experiments
- Reliance on DUSEL
- Budget Detail

Interesting Questions Raised

- Role of ILC in the Ten Year Plan
- More detail on reach of Neutrino Experiments
- Reliance on DUSEL
- Budget Detail

Several people urged us to write like Shakespeare--
just urging was not quite enough…..

The Role of ILC in the Ten Year Plan



The Role of ILC in the Ten Year Plan

- There is a wide spread of opinion on this in the Community
- There was a wide spread of opinion on this in the P5 Panel
  - Long and thoughtful discussions
  - Arrived at a middle of the road plan that in the judgment of the panel promises a balanced overall particle physics program as well as the best shot at a future lepton collider
- There is a wide spread of opinion on this in HEPAP

Both P5 and HEPAP are to some approximation representative of the US particle physics community

Lepton Colliders

- The international particle physics community has reached consensus that a full understanding of the physics of the Terascale will require a lepton collider as well as the LHC. The panel reiterates the importance of such a collider.
- In the next few years, results from the LHC will indicate the required energy for such a lepton collider.
- If the optimum initial energy proves to be at or below approximately 500 GeV, then the International Linear Collider is the most mature and ready-to-build option with a construction start possible in the next decade..
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  - International negotiations will determine the siting; the host will be assured of scientific leadership at the energy frontier.
- A requirement for initial energy much higher than the ILC's 500 GeV will mean considering other collider technologies.
- Whatever the technology of a future lepton collider, and wherever it is located, the US should plan to play a major role.

Lepton Collider R&D Program

- For the next few years, the US should continue to participate in the international R&D program for the ILC to preserve the option of an important role for the US should the ILC be the choice of the international community. The US should also participate in coordinated R&D for the alternative accelerator technologies that a lepton collider of higher energy would require.
- The panel recommends for the near future a broad accelerator and detector R&D program for lepton colliders that includes continued R&D on ILC at roughly the proposed FY2009 level in support of the international effort. This will ensure a significant role for the US even if the ILC is built overseas. The panel also recommends R&D for alternative accelerator technologies, to permit an informed choice when the lepton collider energy is established.
- The panel also recommends an R&D program for detector technologies to support a major US role in preparing for physics at a lepton collider.

Vision for the Neutrino Program

- A vision for the long range US neutrino program:
  - Intense neutrino beam from Fermilab needs multi-megawatt proton source
  - Long baseline with large detector at DUSEL
  - May later need improved neutrino beam Neutrino factory using muon storage ring
- Such an ambitious program needs to proceed in steps
  - NOvA with 700 kW source
  - Phase 1 detector in Homestake Mine with 700 kW source
  - Full size detector in Homestake Mine with 2 MW source
  - Beam from Neutrino Factory if needed later

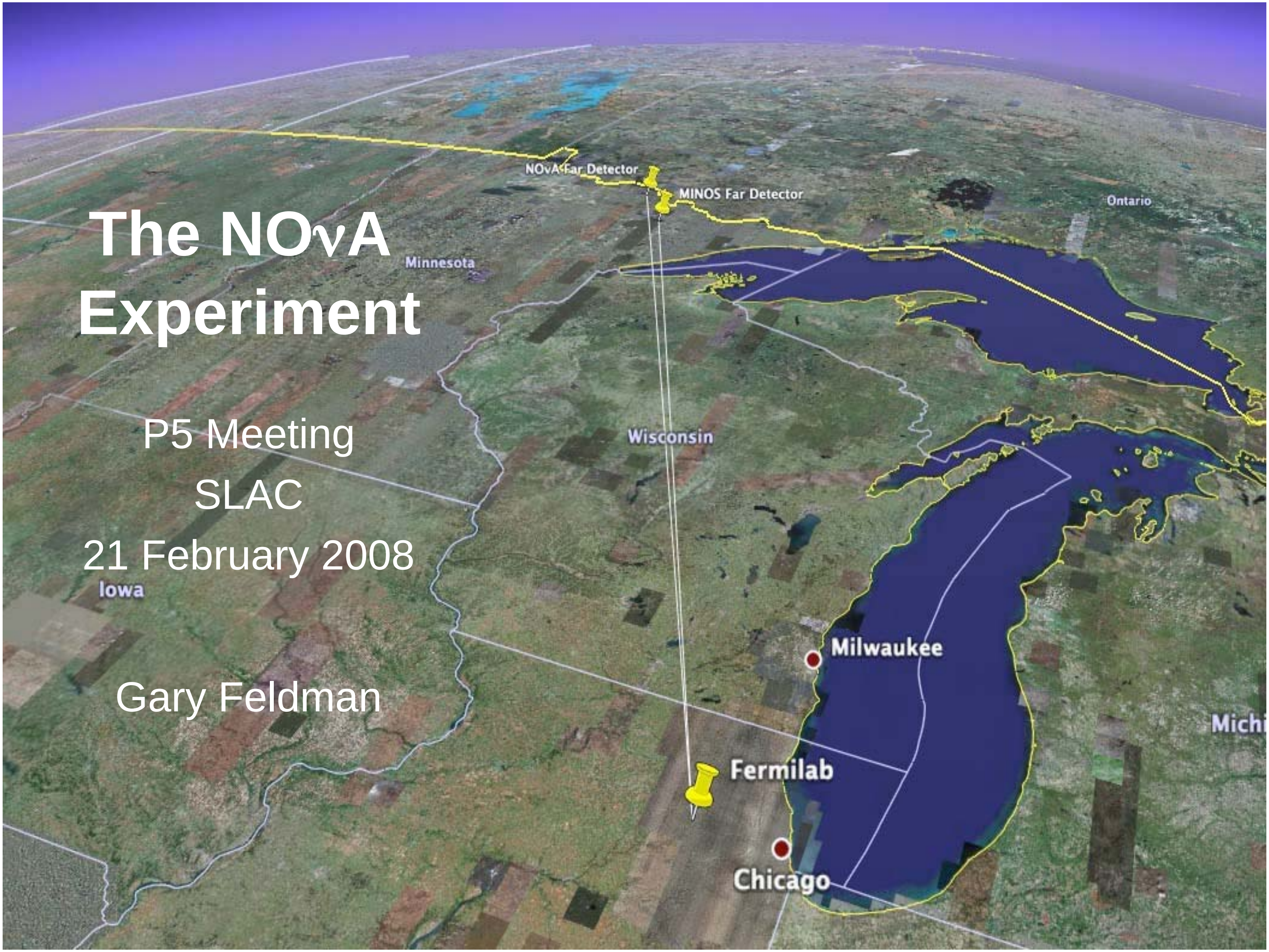
The NOνA Experiment

P5 Meeting

SLAC

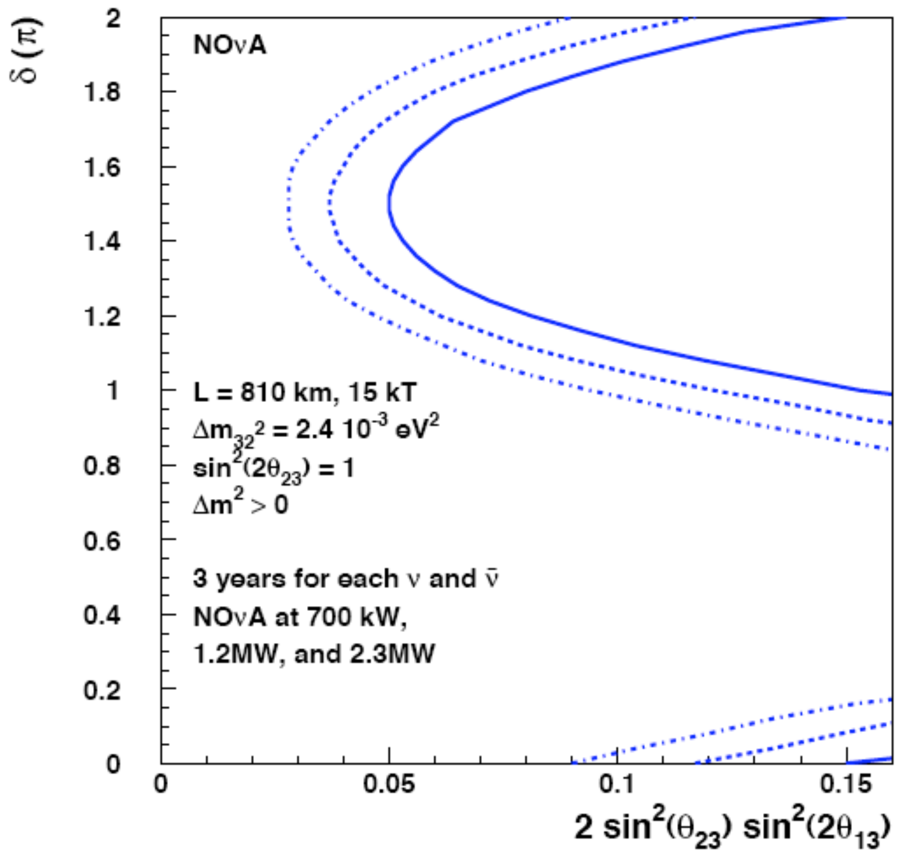
21 February 2008

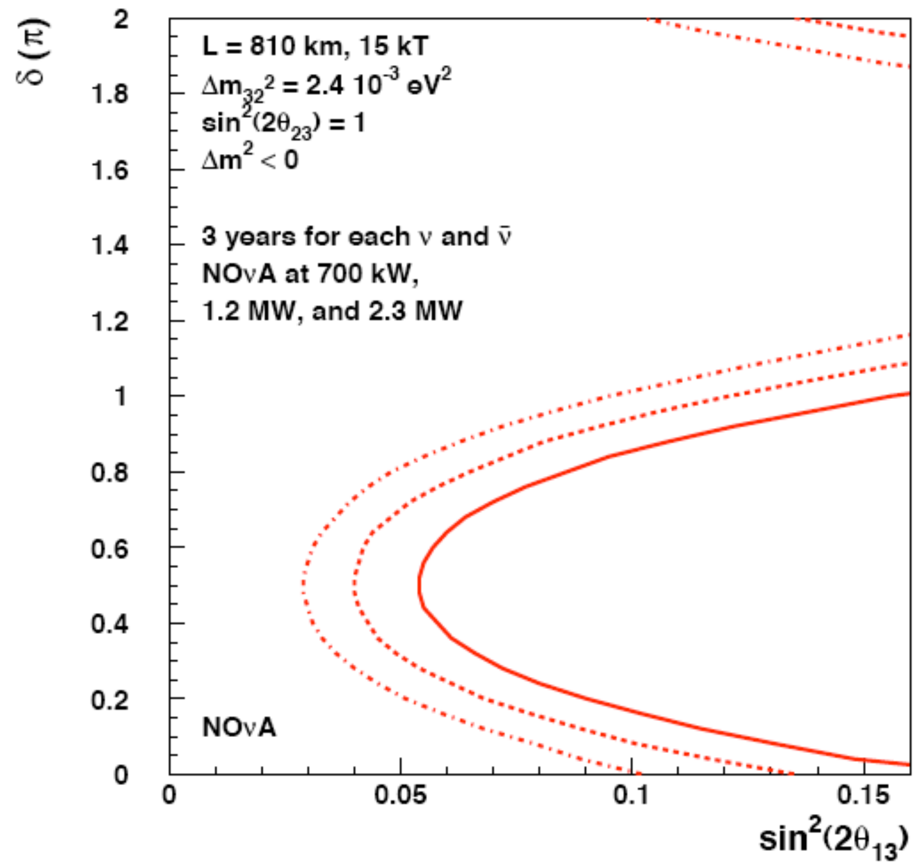
Gary Feldman



95% CL Resolution of the Mass Ordering NOνA Alone

Gary Feldman Presentation

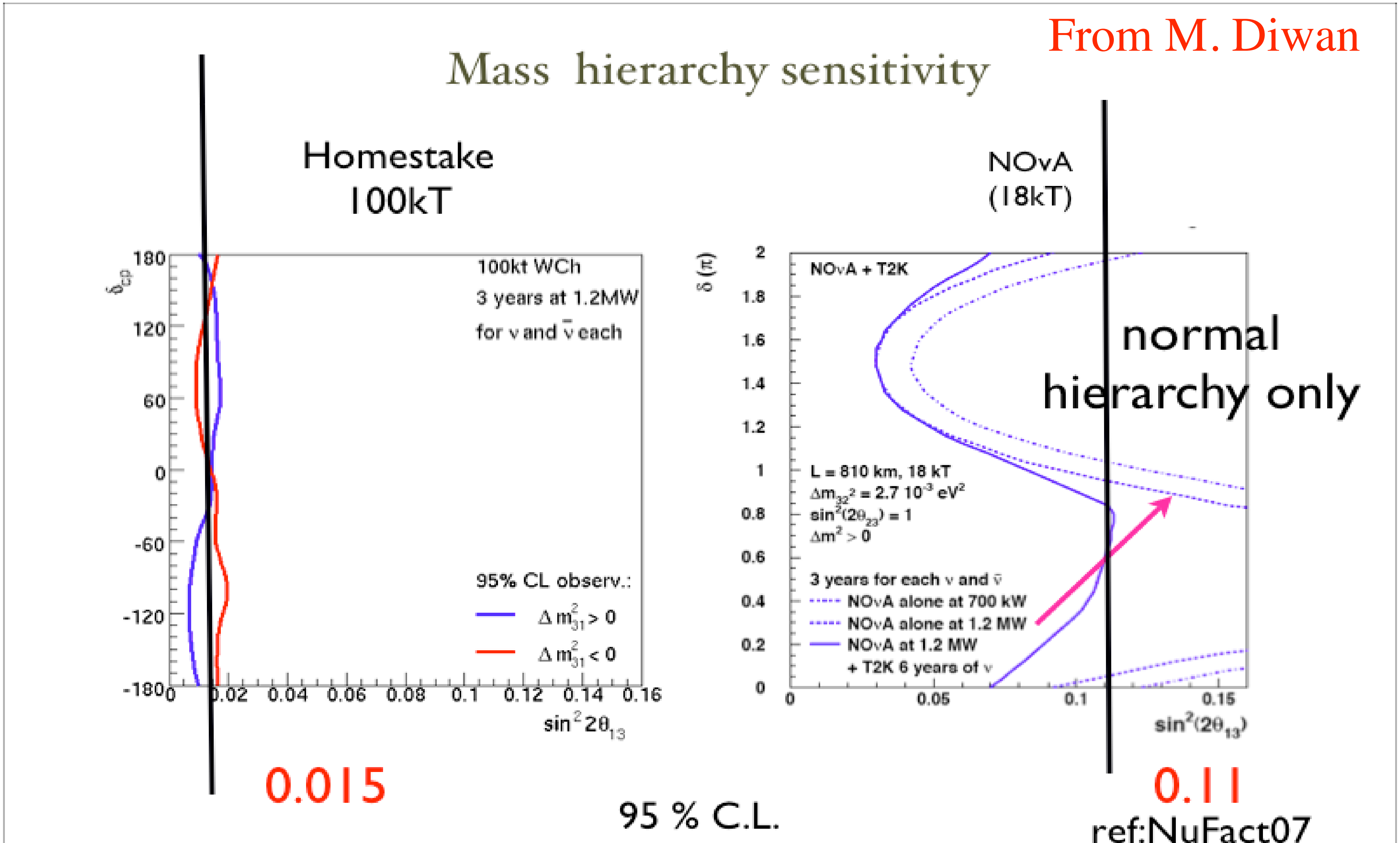




Normal Ordering — Inverted Ordering

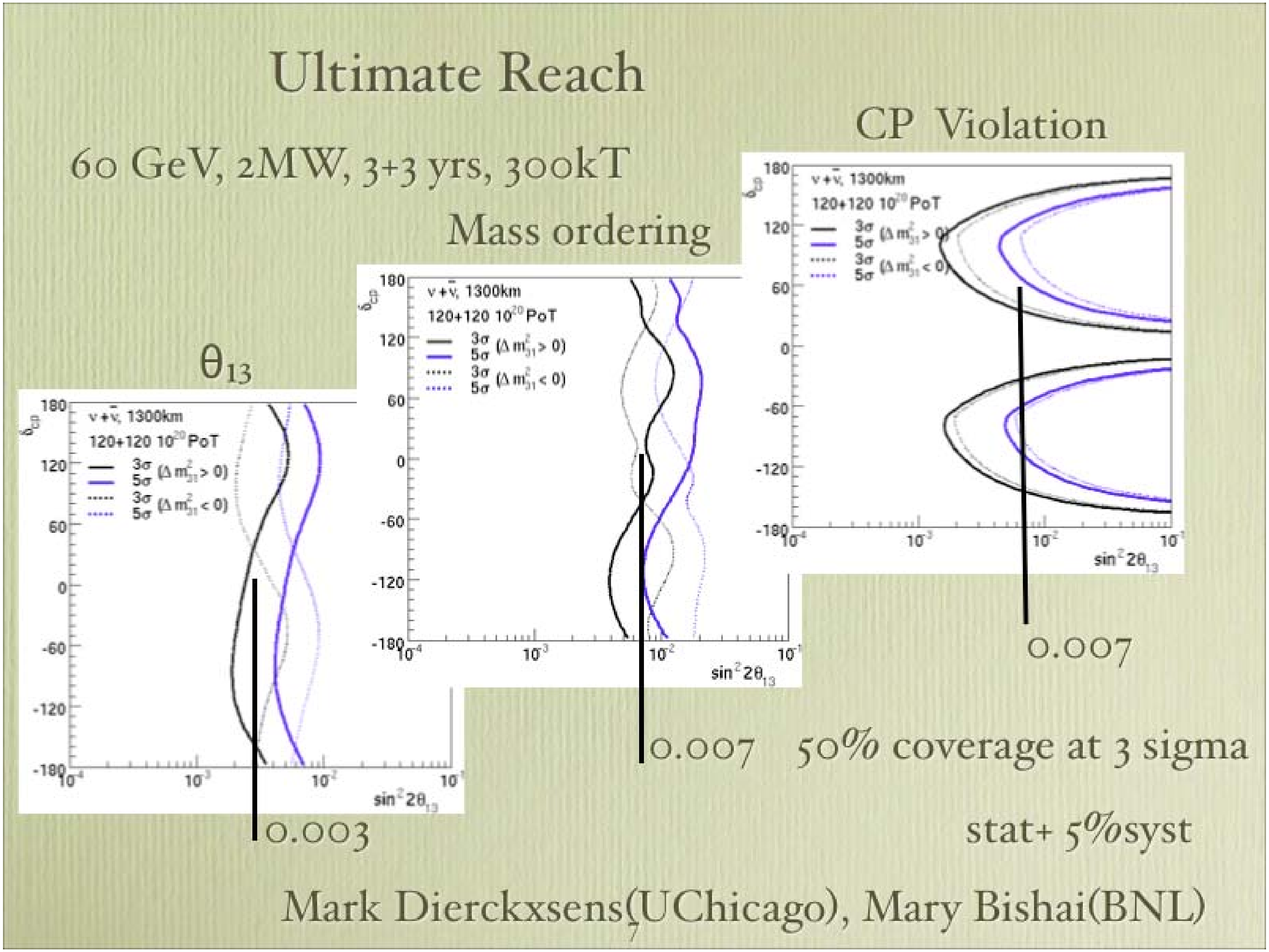
More recent calculations show improved sensitivity using energy spectrum

First Expt in DUSEL with 100kton detector



The homestake project is almost an order of magnitude better for mass hierarchy determination for same running

300 kton Detector in DUSEL with 2 MWatt Source at Fermilab



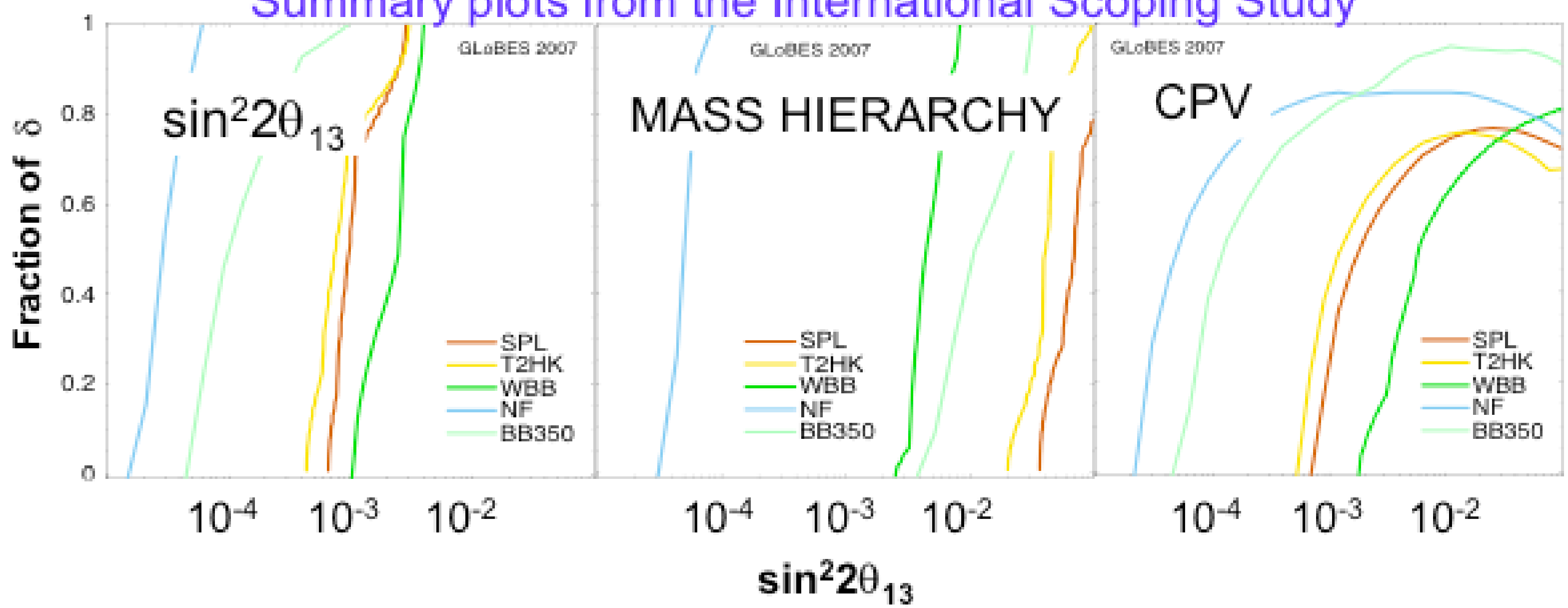
Sensitivity with a Neutrino Factory Beam

Steve Geer Presentation

APPENDIX: Discovery Reach for 25 GeV NF

- **Physics reach for 25 GeV NF looks great & if θ_{13} is small may be the only option.**

Summary plots from the International Scoping Study



- All of these (WBB, BB, NF, T2HK) next-but-one generation neutrino experiment options are necessarily ambitious.

- The NF is the most sensitive option for very small θ_{13}.

Reliance on DUSEL

- DUSEL, planned for the Homestake Mine in South Dakota, is important for the Particle Physics Program in many ways
  - The long baseline from Fermilab to Homestake enables the most sensitive neutrino experiments
  - DUSEL enables dark matter searches and experiments on proton decay and double beta decay that require a deep underground location

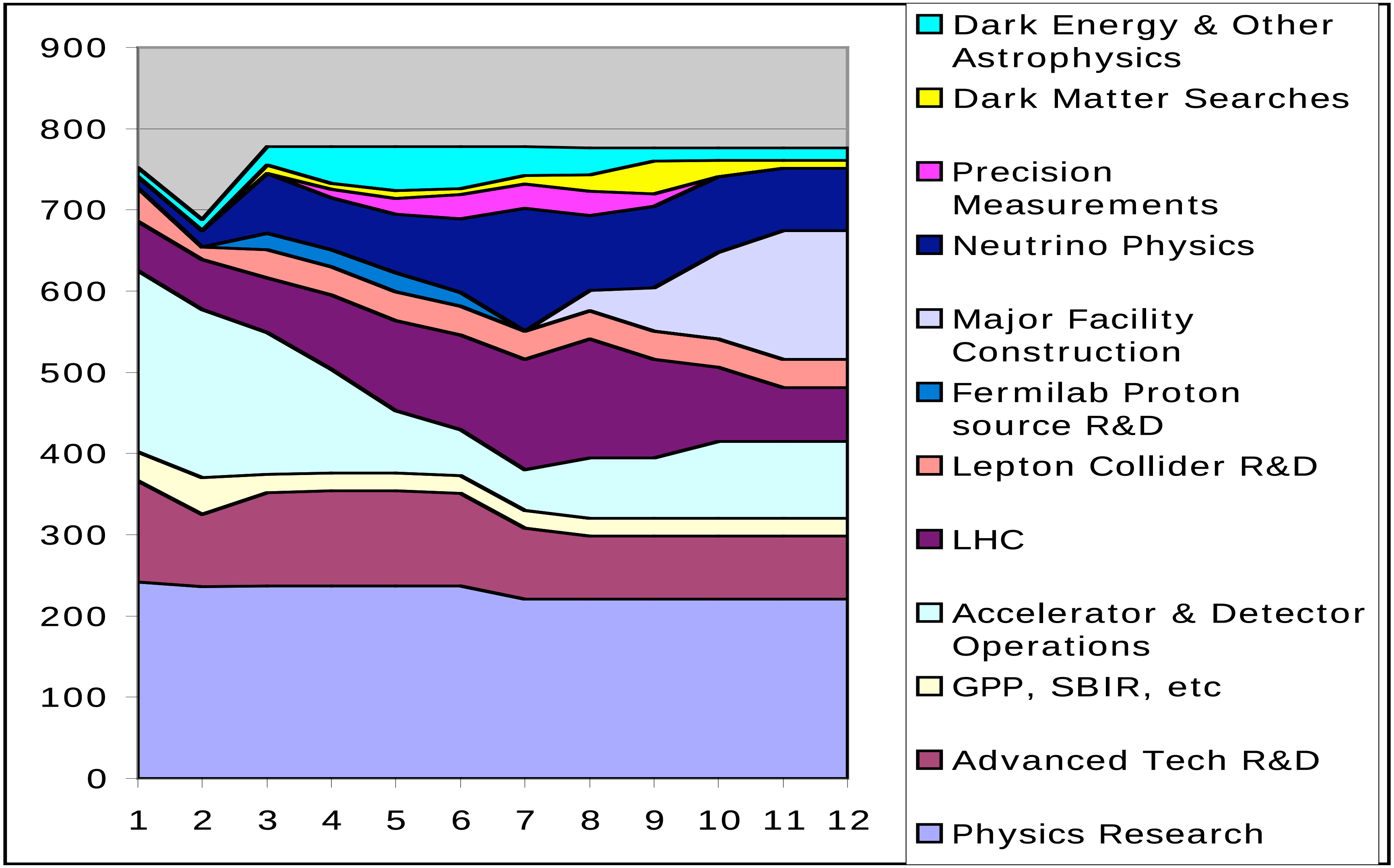
Reliance on DUSEL

- What if DUSEL is delayed or not approved?
  - Homestake Mine does exist and is being refurbished right now with substantial non-federal funding--the Sanford Lab
  - In any case it will continue to exist as a deep underground lab
- The panel is articulating a vision for a strong particle physics program
  - Many other components of this program are uncertain at this point
  - The agencies are doing their best to realize as much of this program as possible

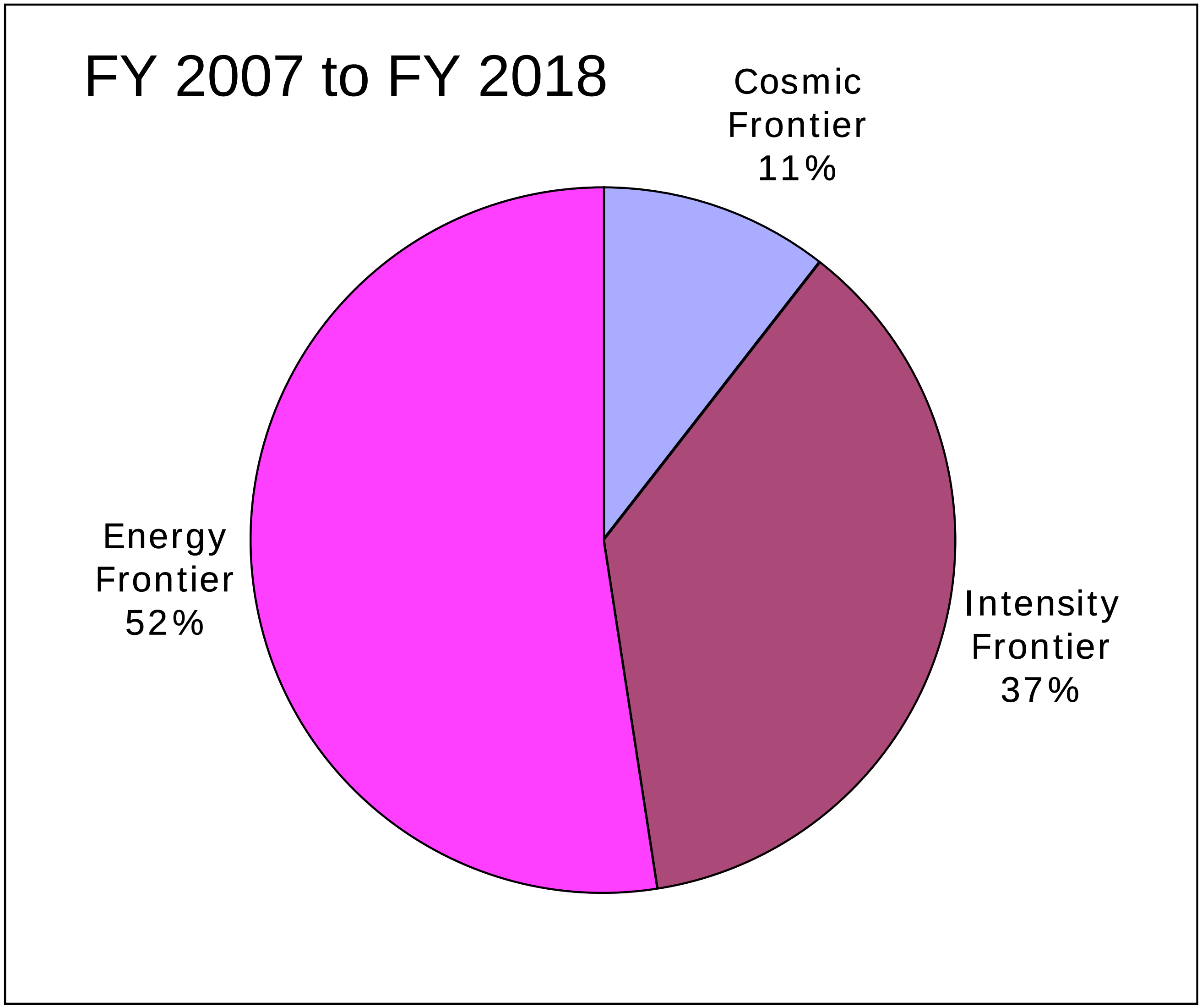
Budgetary Considerations

- The Panel spent considerable time and effort to collect and digest budgetary information. Estimates were provided by
  - The agencies, DOE and NSF
  - The National Labs
  - Proponents of projects
- All of this information suffers from uncertainties to various degrees.
- The Panel did its best to draw on their experience and expertise to formulate plans taking these uncertainties into account.

DOE Budget Scenario B FY 2007 to 2018

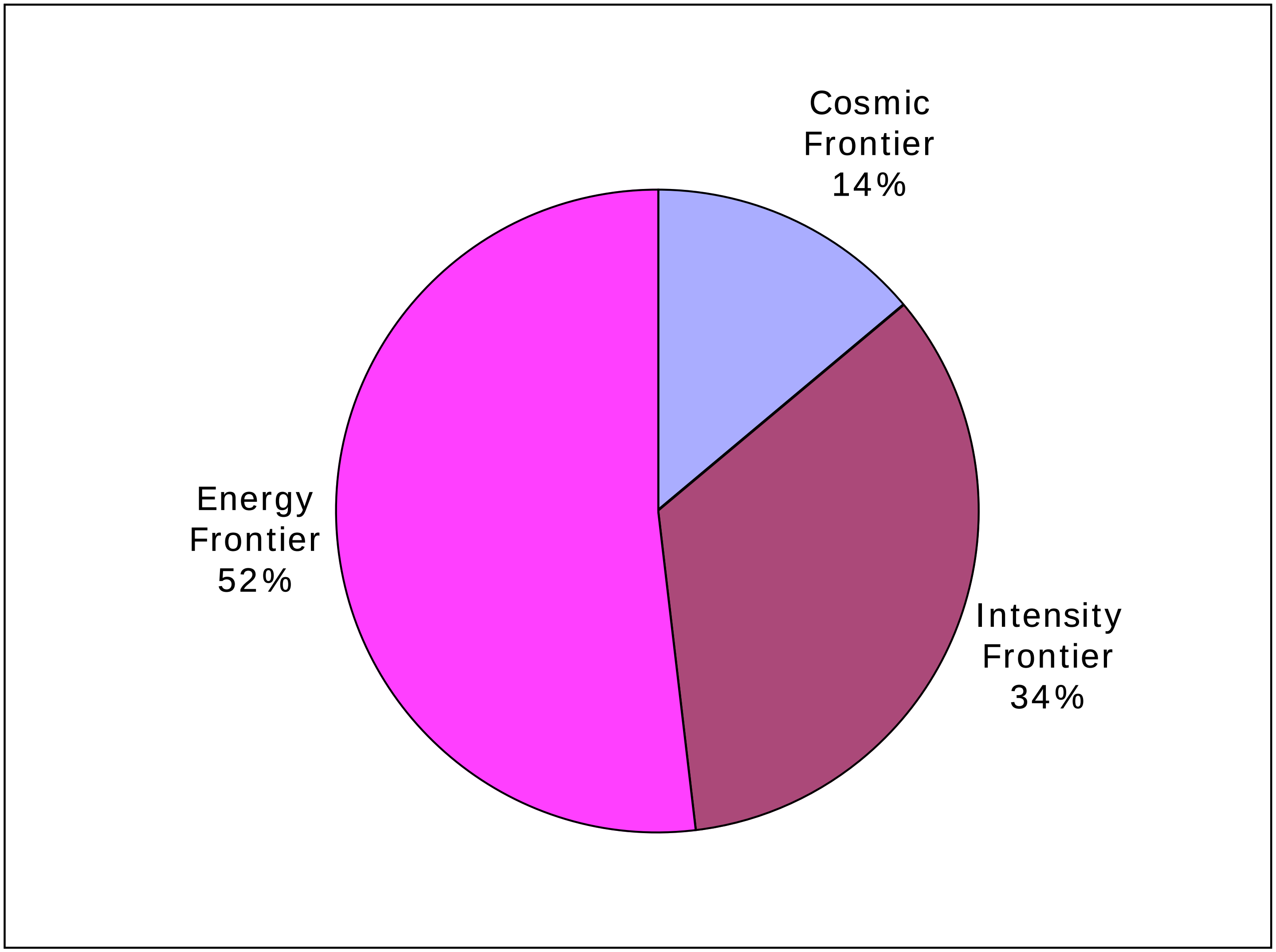


12 Year DOE Budget B by Frontier

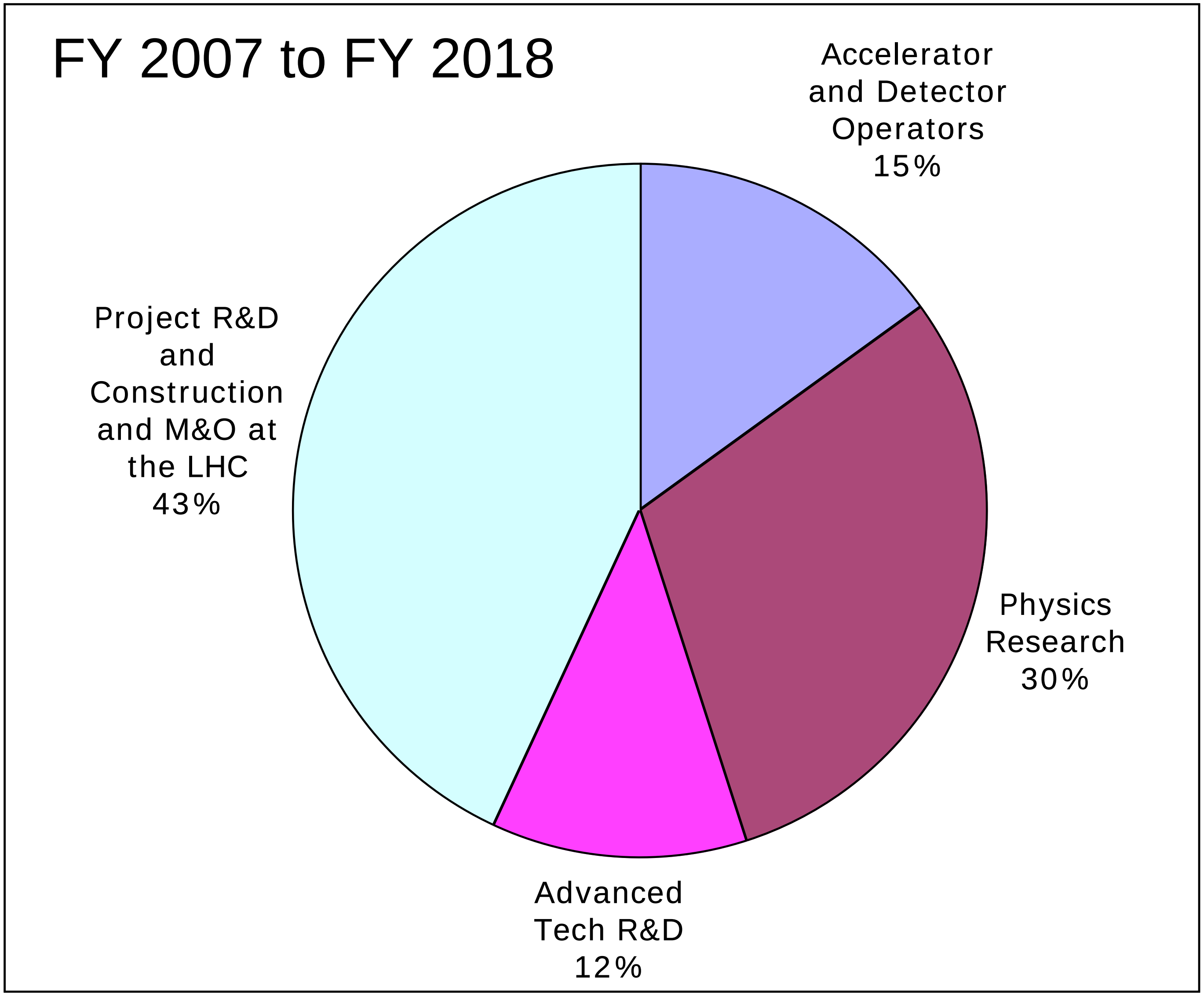


Research Interest of the DOE Univ PI's

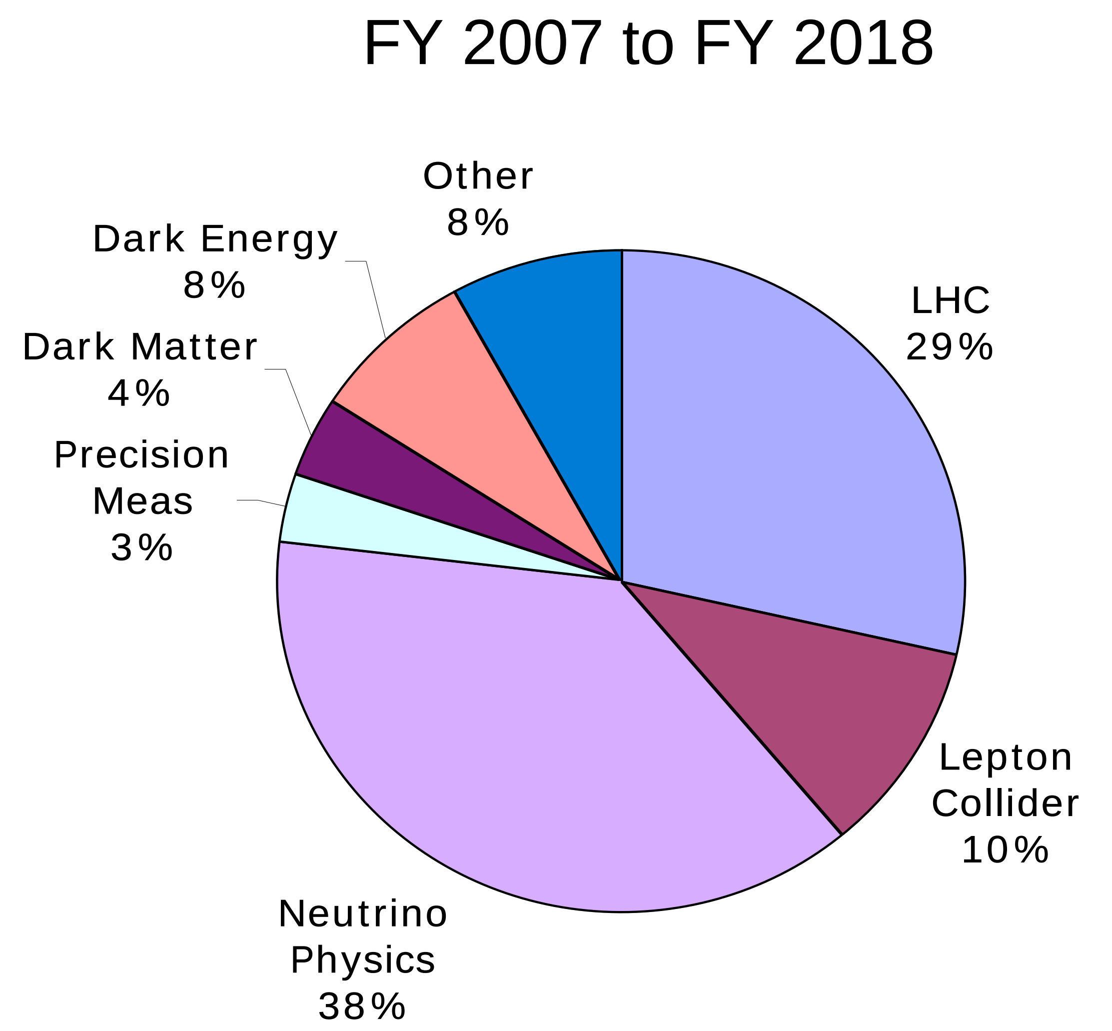
from Kathy Turner



12 Year DOE Budget B by Category

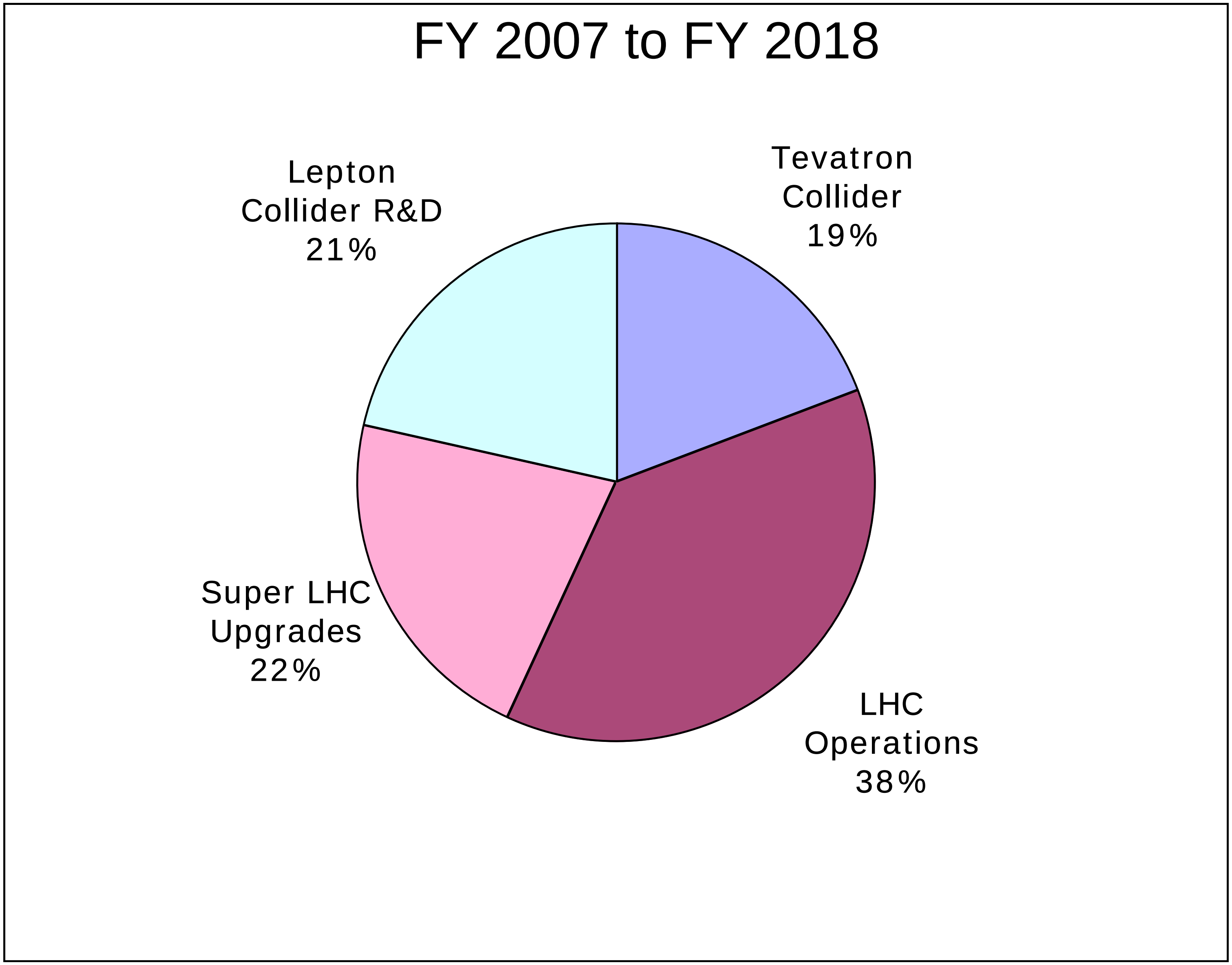


12 Year DOE Budget B by Project

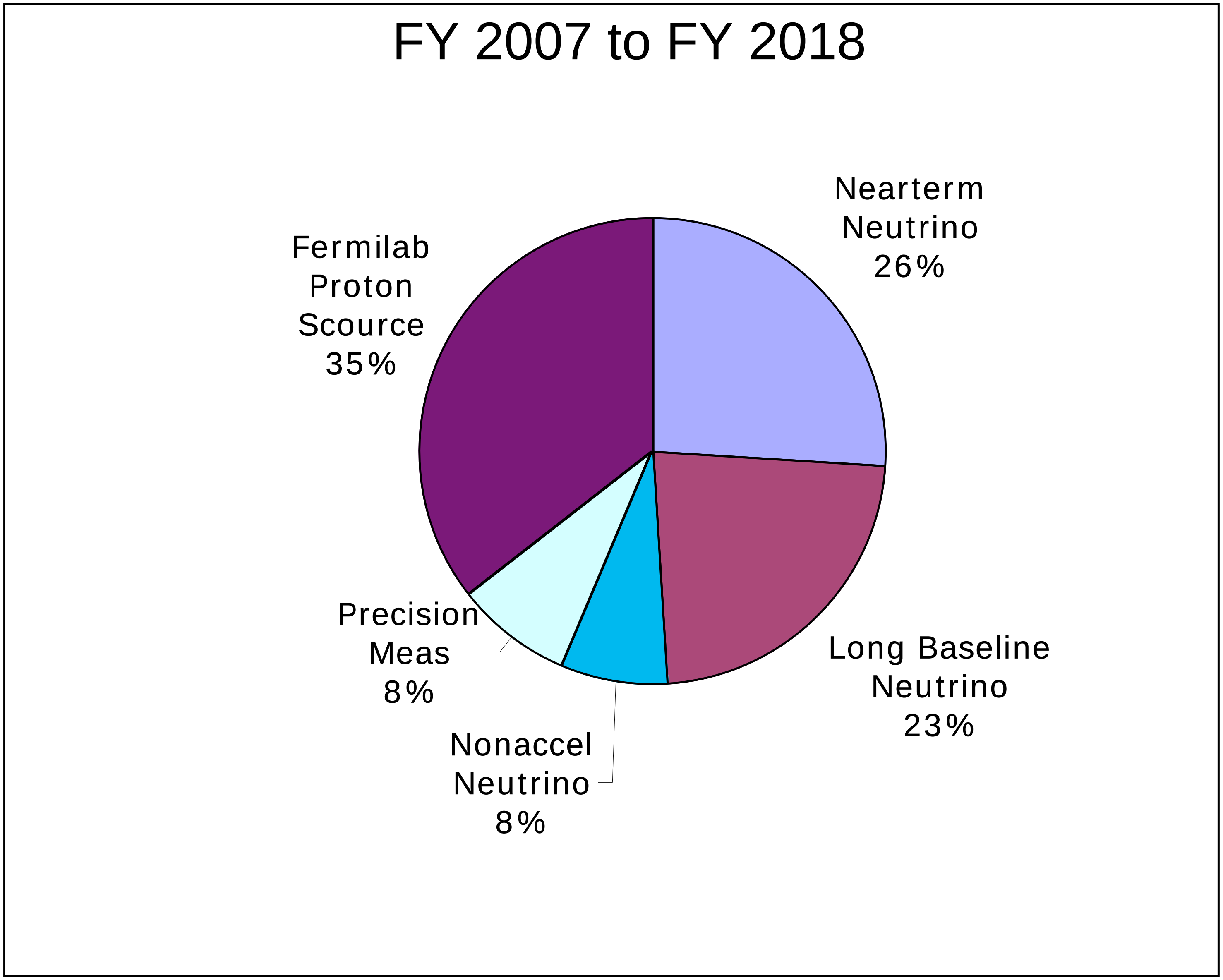


Project R&D and Construction and M&O at the LHC

Energy Frontier 12 Yr DOE Budget B



Intensity Frontier 12 Yr DOE Budget B



Cosmic Frontier 12 Yr DOE Budget B