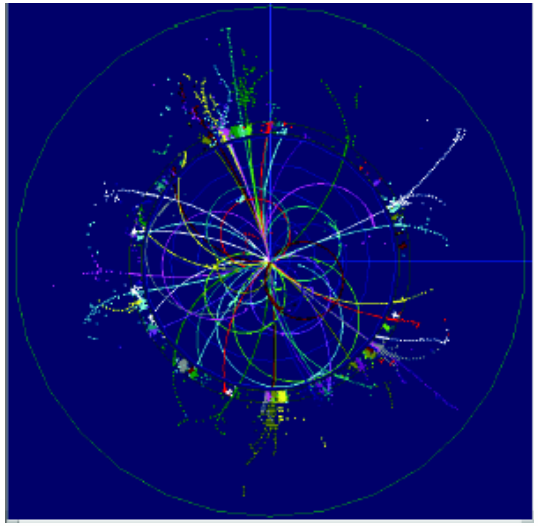
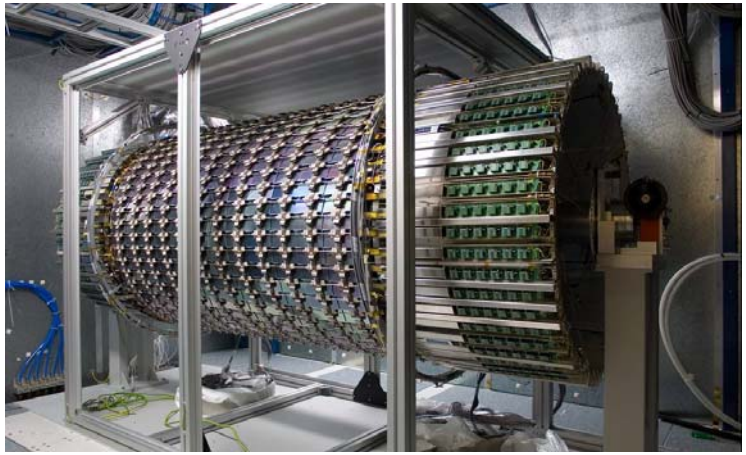
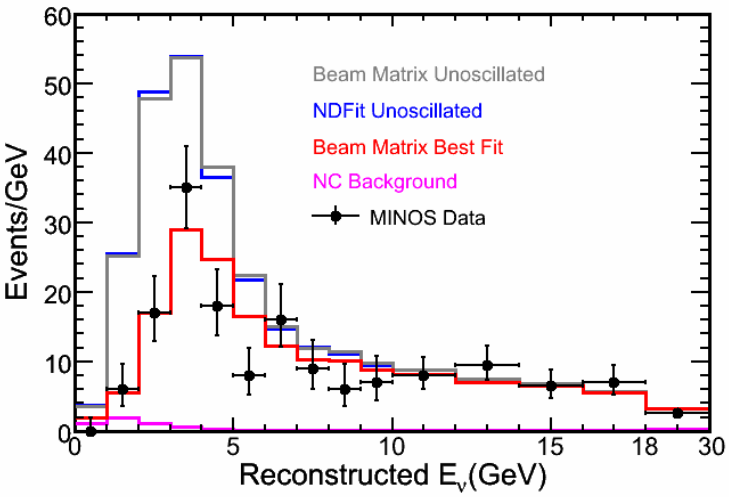
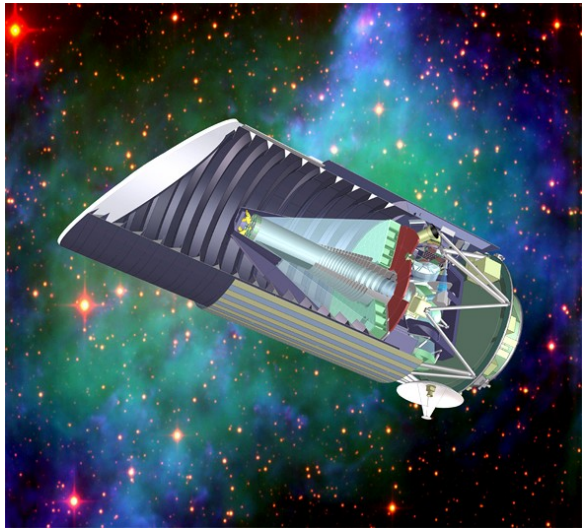
# P5 Report: The Particle Physics Roadmap







# Science Questions

- The question of mass:
  How do elementary particles acquire their mass?
  How is the electroweak symmetry broken?
  Does the Higgs boson –postulated within the Standard Model- exist?
- The question of undiscovered principles of nature:
  Are there new quantum dimensions corresponding to Supersymmetry?
  Are there hidden additional dimensions of space and time?
  Are there new forces of nature?
- The question of the dark universe:
  What is the dark matter in the universe?
  What is the nature of dark energy?
- The question of unification:
  Is there a universal interaction from which all known fundamental forces, including gravity, can be derived?
- The question of flavor:
  Why are there three families of matter?
  Why are the neutrino masses so small?
  What is the origin of CP violation?

# Science Opportunities

We have grouped the major science opportunities into five categories:

1) The energy frontier projects: LHC-ILC.
2) A program to study Dark Matter. This is complementary to the work in astrophysics.
3) A program to study the nature of Dark Energy. This is collaborative with the work in astrophysics.
4) A number of projects in neutrino science.
5) Precision measurements involving charged leptons or quarks.

# Budget Assumptions

To arrive at a roadmap we need to make assumptions about budgets. In the case of the DOE, a five year funding profile in the document called "Office of Science 5-year Budget Plan: FY2007-FY2011" submitted by the DOE to Congress in early March of 2006 as part of the FY07 budget submission gives us a concrete budget plan to work with. The numbers in this plan were as follows:

| FY07 | FY08 | FY09 | FY10 | FY11 |
|---|---|---|---|---|
| $775M | $785M | $810M | $890M | $975M |

In addition, the closing of PEP-II at the end of FY08 and the Tevatron around the end of FY09 (P5 to make a more explicit recommendation in about 6 months), as foreseen in the most recent P5 planning, should allow funds to flow to exciting new projects. The recuperation of funds presently used for these programs is a crucial assumption in our planning. We assume that budgets grow by 3% per year after FY11, a roughly "flat" budget in then year dollars assuming an annual inflation rate of 3%. We use these numbers in planning our roadmap. We call this our base budget plan.

We have also looked at an alternative budget that would double funding over 10 years as might be appropriate for a renewed emphasis on the physical sciences and their importance to the country's economic health. This plan would have about $50 million more available for investment each year as compared to the base budget.

# Planning Guidelines

In order to arrive at recommendations, we have articulated a number of planning guidelines. We summarize the key points here. They have been developed with the recent recommendations of the EPP2010 committee in mind, the goal of capitalizing on the major science opportunities before us, and the specific numbers in our base budget plan.

1) The LHC program is our most important near term project given its broad science agenda and potential for discovery. It will be important to support the physics analysis, computing, maintenance and operations, upgrade R&D and necessary travel to make the U.S. LHC program a success. The level of support for this program should not be allowed to erode through inflation.

2) Our highest priority for investments toward the future is the ILC based on our present understanding of its potential for breakthrough science. We need to participate vigorously in the international R&D program for this machine as well as accomplish the preparatory work required if the U.S. is to bid to host this accelerator.

# Planning Guidelines

3) Investments in a phased program to study dark matter, dark energy, and neutrino interactions are essential for answering some of the most interesting science questions. This will allow complementary discoveries to those expected at the LHC or the ILC. A phased program will allow time for progress in our understanding of the physics as well as the development of additional techniques for making the key measurements.

4) In making a plan, we have arrived at a budget split for new investments of about 60% toward the ILC and 40% toward the new projects in dark matter, dark energy, and neutrinos through 2012. The budget plan expresses our priority for developing the ILC but also allows significant progress in the other areas. We feel that the investments in dark matter, dark energy, and neutrino science in our plan are the minimum for a healthy program.

5) Recommendations for construction starts on the longer-term elements of the Roadmap should be made toward the end of this decade by a new P5 panel, after thorough review of new physics results from the LHC and other experiments.

# Recommendations for Construction and Reviews

To provide recommendations for major construction and R&D activities we have grouped the projects under consideration into several broad categories, with different degrees of priority for each group. We list groupings below in priority order. They are based on our set of planning guidelines. The activities are meant to mainly fit into a five-year timeline.

# Recommended for Construction or R&D Within Base Budget Plan

1. The highest priority group involves the investigations at the energy frontier. These are the full range of activities for the LHC program and the R&D for the ILC.
2. The second group includes the near-term program in dark matter and dark energy, as well as measurement of the third neutrino-mixing angle. This grouping includes the three small experiments: DES, the 25 kg CDMS experiment, and the Daya Bay reactor experiment. Also in this group is the support for the LSST and SNAP, to bring these to the "Preliminary Design Review Stage" in the case of the NSF and "CD2 Stage" in the case of the DOE over a two to three year time frame. We recommend that the DOE work with NASA to ensure that a dark energy space mission can be carried out and that the three potential approaches to the mission have been properly evaluated. The final item in this group is the R&D funding for DUSEL, along with support by the NSF and the DOE for R&D for both a large dark matter and neutrino-less double beta decay experiment.
3. The next item is the construction of the NO$\nu$A experiment at Fermilab along with a program of modest machine improvements.

# Recommendations for Reviews

We recommend a review by P5 toward the end of this decade to look at projects that could start construction early in the next decade. The base budget plan would allow a significant number of these to move forward to construction. The review should take into account new physics results, especially those from the LHC, results on R&D for new projects, budget and cost projections at the time, and the status of interagency agreements and MREFC plans. We list some of the areas to be examined.

1. The ILC, including a possible U.S. bid to host, and the steps needed at the governmental level for internationalization.
2. The LHC Upgrades, required for an order of magnitude luminosity increase at the LHC.
3. DUSEL and the large experiments to search for dark matter and neutrino-less double beta decay.
4. The Stage IV dark energy experiments, a large survey telescope and a dark energy space mission. Interagency agreements are crucial to these projects, which could start construction soon after review.
5. An evaluation of the status of flavor physics and the importance of further experiments across a number of possibilities such as the muon g-2, μ to e conversion, a very high luminosity B experiment, and rare K decays.

# Recommendations for Reviews

We anticipate that a separate review by P5 will be required to look at the best directions for further experiments in neutrino physics. Much work is ongoing internationally in this area with an optimum program dependent on measurements to be made by the next generation of neutrino experiments as well as results from ongoing R&D. A second important physics area that might be included in this review would be an ambitious proton decay experiment. These two projects could be the major second phase of experiments for DUSEL. The physics results over the next five to ten years will determine the best date and best set of areas to look at in such a review.

# P5 Roadmap - 2006, US Program