Planning for Discoveries in Particle Physics

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This is a special time in particle physics.

J. Lykken, EPP2010,11/30/2004

- urgency: provocative discoveries lead to urgent questions
- connections: questions appear to be related in fundamental but mysterious ways $\rightarrow$ big ideas are in play
- tools: we have the experimental tools, technologies and strategies needed to tackle these questions

conclusion:

we are seeing a scientific revolution in the making

Particle Physics

Major themes:

the quantum vacuum

the particle zoo

unification

the origin of space and time

Major research areas:

collider physics

neutrino physics

particle astrophysics

quark physics

accelerator R&D

detector R&D

theoretical physics

Particle Physics

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- quark physics
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- theoretical physics

Opportunities for revolutionary discoveries

The biggest questions -- quantum vacuum, Higgs, supersymmetry, extra dimensions -- will be addressed with the flagship colliders:

- Large Hadron Collider
- International Linear Collider

Some landmark discoveries can't be made at colliders:

- Neutrino masses, mass hierarchy, CP violation
- New physics first appearing in quark decays
- Detection of dark matter
- Measuring the effects of dark energy

Planning U.S. particle physics within budget constraints

- In planning our field, especially with tight budgets, we need to optimize carefully
  - the currently operating program
  - the operating program 5 -10 years from now
  - developing the facilities needed 10 -20 years from now
- The currently operating program in the U.S. is outstanding science for the investment.
- The medium-term future and the long-term future are at risk.
  - The science opportunities are great.
  - We know what experimental facilties are needed.
  - But the only part of the U.S. future on stable ground is the LHC.

Colliders at the Energy Frontier

World Program of Particle Physics

1. **Tevatron**
2. **Large Hadron Collider**
3. **International Linear Collider**

U.S. program

1. Operating the Tevatron program and producing great physics
2. Building the ATLAS and CMS detectors and US-LHC accelerator components, doing LHC research
3. R&D and conceptual design

The Tevatron keeps particle physics at the energy frontier until the LHC physics program takes over.

The ILC is the facility needed beyond the LHC.

The special role of the LHC physics program

- Revolutionary discoveries about particle physics are sure to come from the Large Hadron Collider.
- Experimental results on dark matter, CP violation, and everything else will take on new significance when viewed in the light of what is seen or not seen at the LHC.
- A large luminosity upgrade to the LHC is very important, and it will be challenging.
  - Superconducting quadrupole magnets of new technology
  - New detector systems to operate successfully at higher luminosity

The U.S. role at the LHC

- U.S. research groups bring unique experience to the LHC program.
  - operating the Tevatron, CDF, and DZero
  - building high-gradient, superconducting quadrupoles
  - reconstructing and analyzing the data from the Tevatron program
- It is very important that U.S. scientists are able to take full advantage of the LHC research program.
  - For accelerator physicists, this means support for the LHC Accelerator Research Program (LARP).
  - For groups working on CMS and ATLAS, this means support for the CMS and ATLAS research programs and for the research groups at universities and laboratories.

The International Linear Collider

- The world community of particle physicists has identified two flagship facilities that are needed to study and understand the mysteries of the TeV energy scale:
  - The Large Hadron Collider
  - The International Linear Collider

- It has been clear for some years that the ILC will require a new model of international planning, funding, and management.
  - visas and lab access
- The ILC will take strong support from Europe, Asia, and North America.
- In addition, one country or region must make a special investment as the host of the ILC.

The U.S. role in the ILC

- The world of particle physics is in a transition from five large laboratories operating the largest accelerators for particle physics to two, if the ILC is built.
- For the U.S. to remain one of the leaders in worldwide particle physics, it will have to take on the host role for the ILC.
- Why should we do so, if the field is so international?
  - Accelerator physics and technology has contributed greatly to current state of light sources, neutron sources, and medical diagnosis and treatment. The U.S. needs to stay at the forefront.
  - The international compact for open use of particle physics facilities depends on the sharing of the responsibility for building these facilities, averaged over time.
  - The host country does have a special role. The great discoveries coming at the LHC will highlight the leadership Europe is showing in physical sciences.

Neutrino Physics

World Program

Present program

- long-baseline experiments
- solar, atmospheric, and reactor neutrino experiments

Future program

- long baseline (+ perhaps short baseline) @ Fermilab
- medium baseline @ J-PARC
- More intense proton sources
- neutrinoless double-β decay
- reactor experiment

U.S. program

Present program

- MiniBooNE and MINOS
- Participation in SNO, Kamland,... abroad

Future program

- NOνA and other expts. @ Fermilab
- R&D on proton driver
- Double-β decay experiment
- Reactor neutrino experiment in U.S. or abroad

Neutrino physics requires a distributed effort with very different types of experiments using different neutrino sources.

World neutrino program

We need to

- improve the measurements of known mixing parameters
- clarify the possibility of a short-baseline oscillation,
- measure the third mixing angle,
- understand the mass hierarchy and determine whether CP violation is in the measurable range,
- determine the mass scale for neutrinos, and
- measure several cross sections better.

Each step takes at least one dedicated experiment.

This is not like collider physics. The neutrino program must be distributed worldwide with several experiments of very different types.

The U.S. role in neutrino physics

- The U.S. should take a lead role for some of the critical experiments needed in the distributed program of neutrino physics.
  - The U.S. will have a unique role as home of the long-baseline accelerator neutrino facility.
    - To take full advantage of this will require a new experiment and a proton driver.
  - U.S. physicists will participate in
    - a reactor neutrino experiment &
    - a double beta decay experiment.

Particle Astrophysics

World program

- direct dark matter searches
- dark matter production at colliders
- sky surveys to measure dark matter and energy
- cosmic ray, gamma-ray, and neutrino observatories

U.S. program

- CDMS-II now,
  Super-CDMS, Xenon in the future
- Tevatron and U.S. part of LHC program
- SDSS now,
  DES, LSST, JDEM in the future
- Auger Cosmic Ray Observatory,
  GLAST for γs, Ice Cube for νs

The science at the interface of particle physics and cosmology requires several approaches, each of which gathers very different experimental information.

Quark Flavor Physics

World Program

Present program

- 2 B-factories and 2 charm factories
- Tevatron program

Future program

- LHC experiments
- possible K programs at J-PARC, BNL, CERN
- possible Super B-Factory at KEK

U.S. Program

Present program

- PEP-II B-factory @ SLAC
- Tevatron program @ Fermilab
- CLEO-C @ Cornell

Future program

- possible KOPIO at BNL
- Little other experimental emphasis in U.S.

U.S. has a leading role in quark flavor physics, with Japan, but is planning to ramp this down as a priority decision within expected budgets.

Major components of the U.S. program today

Quantum vacuum, Higgs, supersymmetry, extra dimensions

- The Tevatron program: CDF and DZero
- The LHC program in final stage of construction
- The ILC: R&D, advancing toward a conceptual design

Quarks and Leptons

- The neutrino program:
  - at accelerators: MiniBooNE and MINOS
  - underground: SNO and Kamland
- QCD and nucleon structure:
  - The HERA program
- Quark flavor physics
  - BaBar, CDF and DZero, CLEO-c

Particle Astrophysics

- Observing the cosmos: sky surveys
- Detecting dark matter in the laboratory
- Cosmic ray, gamma ray, neutrino observatories

Major components (definite & proposed) of the U.S. program in 2011-2019

Quantum vacuum, Higgs, supersymmetry, extra dimensions

- The LHC program: ATLAS and CMS, LARP, with upgrades
- The ILC

Quarks and Leptons

- Neutrinos and other leptons:
  - MINOS, NOνA, & smaller experiments, Proton Driver
  - Reactor neutrino and double beta decay experiments
  - muon to electron conversion MECO
  - R&D on ν factories
- Quark flavor physics
  - B physics at ATLAS and CMS
  - K physics with KOPIO

Particle Astrophysics

- Sky survey(s) to measure dark energy
- New, larger experiment(s) to study dark matter in the lab
- Cosmic ray observatories: Auger, Ice-Cube, Veritas, and follow-ups

Unification

- Proton Decay experiment

(Underlined: projects under consideration)

Maintaining expertise and infrastructure

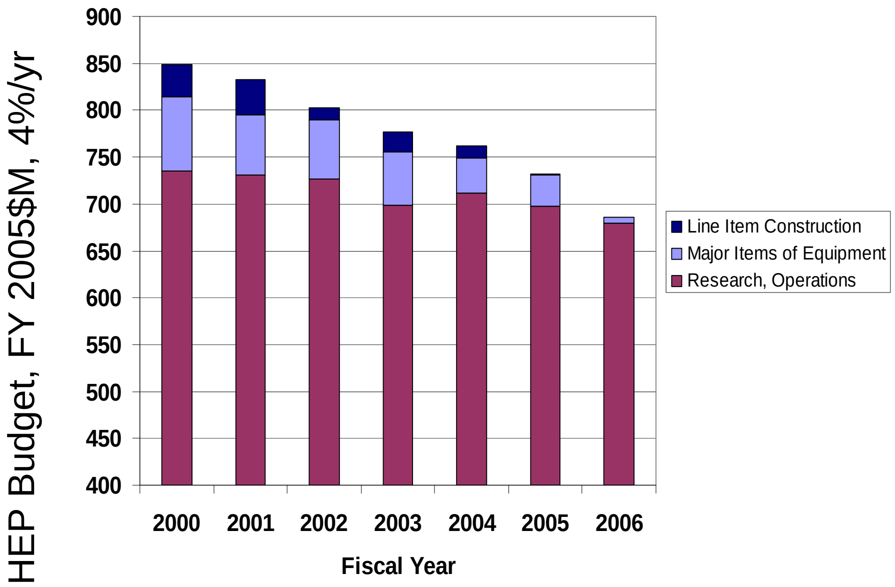
- The field of particle physics has benefited greatly from building on existing reservoirs of expertise and infrastructure at the laboratories.
- The operating role of laboratories is changing.
  - Fermilab, SLAC, BNL, Cornell operated accelerators primarily for particle physics in 2000. By 2010 only Fermilab will do so. (BNL for nuclear physics with some particle physics, SLAC & Cornell for light sources)
- We must maintain accelerator expertise and infrastructure in the laboratories if we are to maintain the ability to pursue particle physics in the future.

OHEP budget history

- The expected funding level dropped by ~$100-150M/yr over 4 years.
- Operation of newly built or upgraded facilities was given priority.

⇨ No projects funded

- Various midsize projects ($50-$500 M) are coming up for approval.
  - Each one represents ~1-10% of host country investment in ILC.
  - How do we balance these?



The Strategy

- The highest priority for a new project is the ILC.
- The road to the ILC has decision points.
- The critical approvals must come from the highest levels of several governments. The commitment of the particle physics community is not enough.

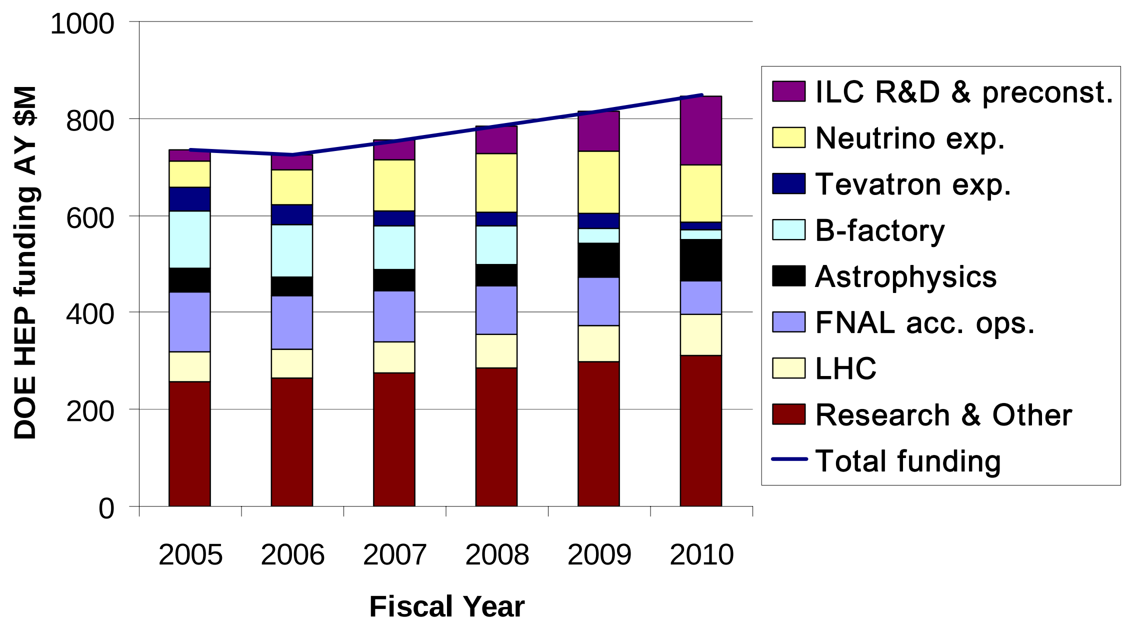
⇨ At each stage of committing increased resources to ILC, we need to review the scope of the rest of the particle physics program in the U.S.

- We need a decision on ILC in the U.S. by the end of the decade.
- We need to maintain strong programs in other select areas – LHC, neutrinos, particle astrophysics – matched to funding.
- We will pursue the neutrino path faster if ILC is delayed.

DOE OHEP Budget model
(NSF, NASA also play critical roles.)

This budget model represents **optimum ILC ramp-up**.

- ILC up to $140 M in 2010
  - 40%/yr to $80 M in 2009
  - $350 M 2006-10
- Other increases
  - $325 M for new neutrino facilities in 2006-10
  - astrophysics doubling from $40M/yr to $85 M/yr
  - LHC from $60 M to $85 M
- Steady support
  - Research support increases at 4%/yr
- Programs ending
  - B-factory in FY 2008
  - Tevatron in FY 2009



- Blue line represents total funding:
  - $736 M in FY 2005
  - $725 M in FY 2006
  - 4%/yr increase after FY 2006 for inflation

DOE OHEP Budget model
(NSF, NASA also play critical roles.)

This budget model represents **moderate ILC ramp-up** & **more aggressive neutrino program.**

- ILC up to $70 M in 2010
  - 1.5 year slower
  - $230 M 2006-10
- $450 M for new neutrino facilities in 2006-10
- Other increases
  - astrophysics doubling from $40M/yr to $85 M/yr
  - LHC from $60 M to $85 M
- Steady support
  - Research support increases at 4%/yr
- Programs ending
  - B-factory in FY 2008
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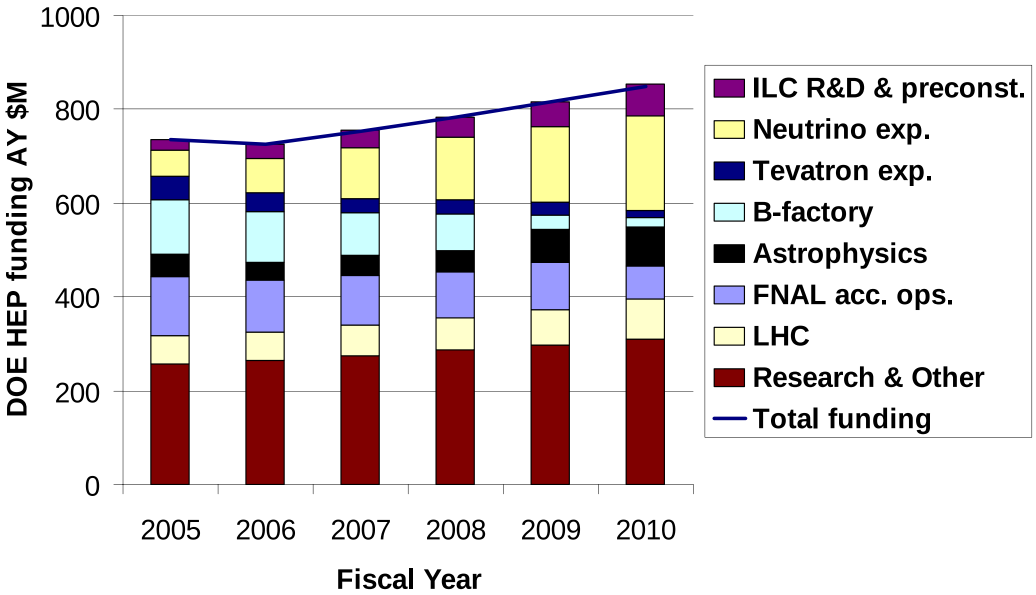

- There are many other options.
  - More increases around 2010 for astrophysics, flavor physics, or...
  - 2% instead of 4% on total funding

Strategic decisions

Strategic decisions must be made in a timely way, with good scientific and technical information, reliable project schedules, and realistic assumptions about expected funding profiles.

2007

- Is ILC cost compatible with possible U.S. funding?
  - If so, press toward construction start
  - If not, is more R&D called for?
    - keep investing in midterm program
- Which of the major neutrino experiments in the U.S.?
- Which major particle astrophysics projects in the U.S.?

2010

- Are we approaching an ILC construction start?
  - Has U.S. funding been ramping up?
  - Have the preproject milestones been met?
  - What is the nature of the new physics at the LHC?
- How is the neutrino story evolving?
  - How does the neutrino roadmap change?
- What are the funding and approval prospects?

Summary

- We are at the start of a revolutionary period in particle physics.
- The U.S. role in this revolution will depend on the funding level that will be available.
- The biggest question is whether the U.S. will assume the host role for the ILC.
- If the U.S. does not assume this role, it can still have a program that provides excellent science for the dollar, but it will not lead the world in particle physics.
- There needs to be a definite, public schedule for making decisions about the ILC.