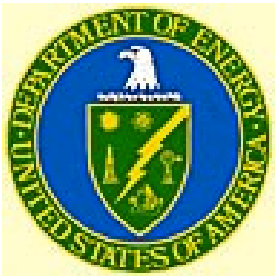
HEPAP Subpanel on Long Range Planning



Jon Bagger, Barry Barish, Fred Gilman
Briefing for OMB and OSTP
October 16, 2002

The Goal of the Subpanel

Create a Vision for the Field for the Next 20 Years

We started by asking questions

- What is our role in society and education?
- How have we been doing?
- What is particle physics?
- What are our scientific goals and how can we reach them?
- What do we expect in the near term?
- What opportunities do we identify for the longer term?
- How do our goals mesh with our international partners?
- What are the essential elements of a realistic program?
- How can we set priorities and make the best choices?
- How do we prepare for the far future?

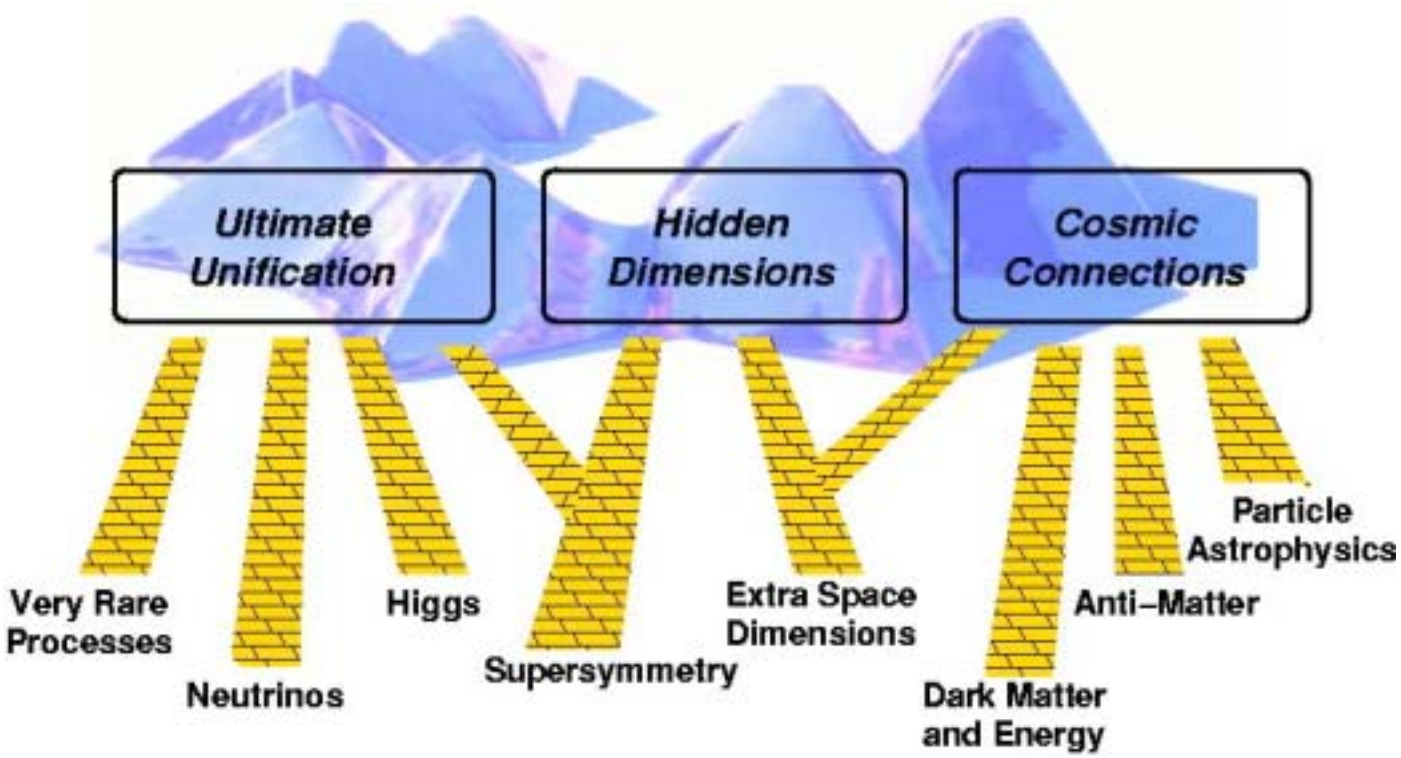
Particle Physics

Burning Questions that Drive the Science

- **What is the universe made of?**
  - What is the dark matter and dark energy?
  - What is the state of the vacuum?
  - What are the properties of neutrinos?
  - Are protons forever?
- **How does it work?**
  - Are there new forces, beyond gravity?
  - How do particle get their mass?
  - Are there new spacetime dimensions?
  - Do constants of nature change with time?
- **Where did it come from?**
  - What powered the Big Bang?
  - What happened to antimatter?
  - What is the ultimate fate of the universe?

Particle Physics

The Science of Matter, Energy, Space and Time



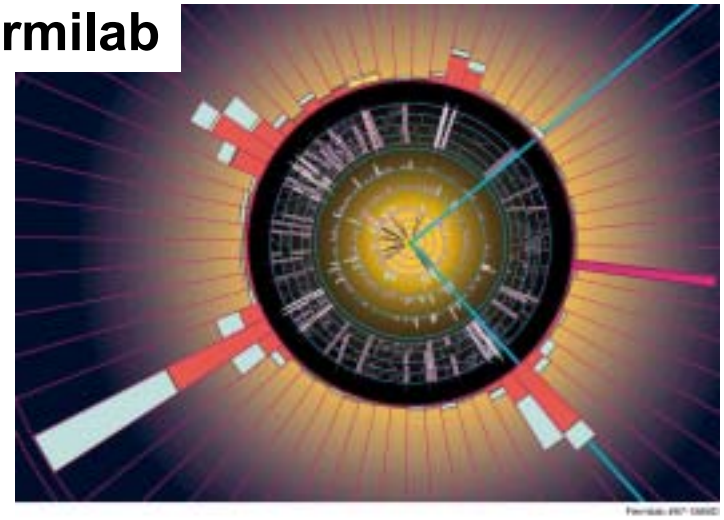
These goals can be attained through a diverse research program carried out in partnership with colleagues across the globe.

Particle Physics

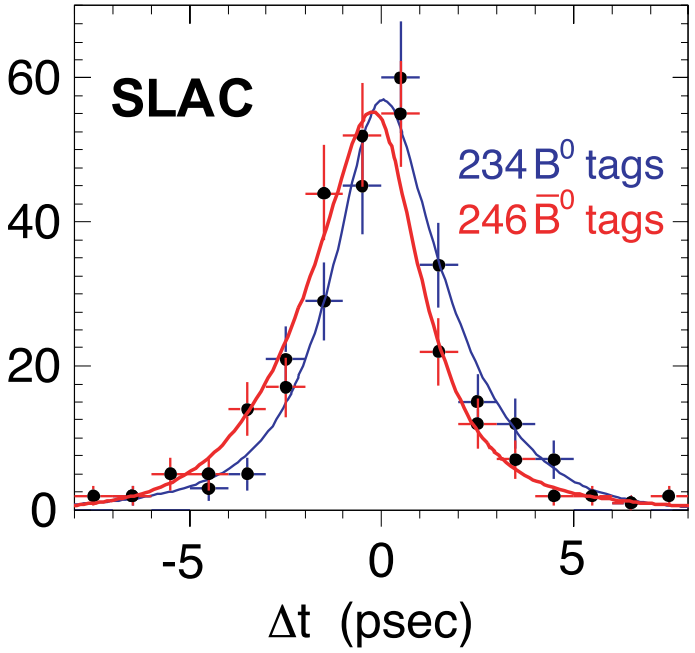
Recent Accomplishments

Top Quark Event

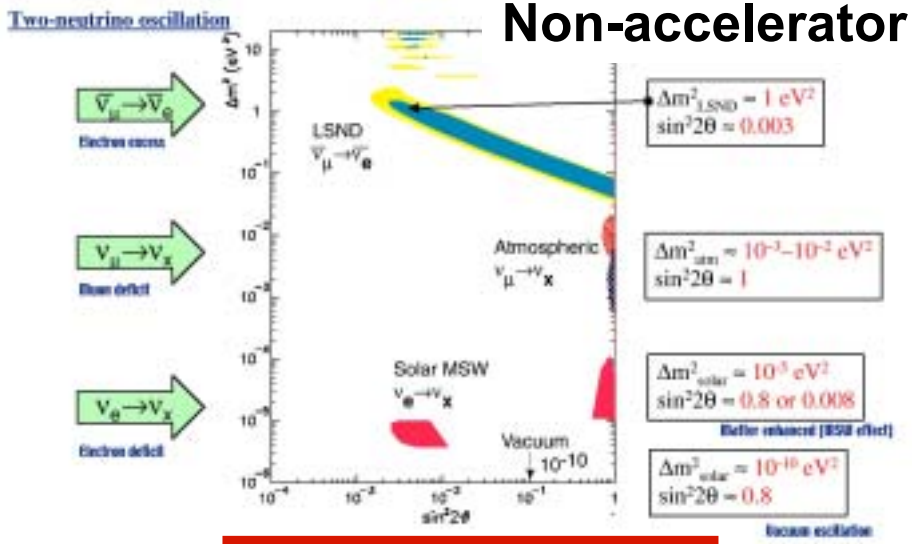
Fermilab



Anti-Matter Asymmetry



Non-accelerator

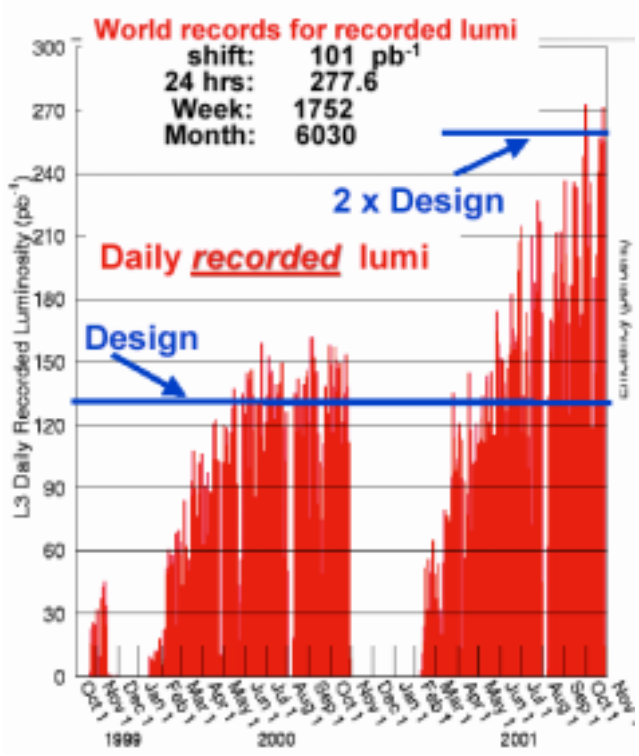


Neutrino Mass

Particle Physics

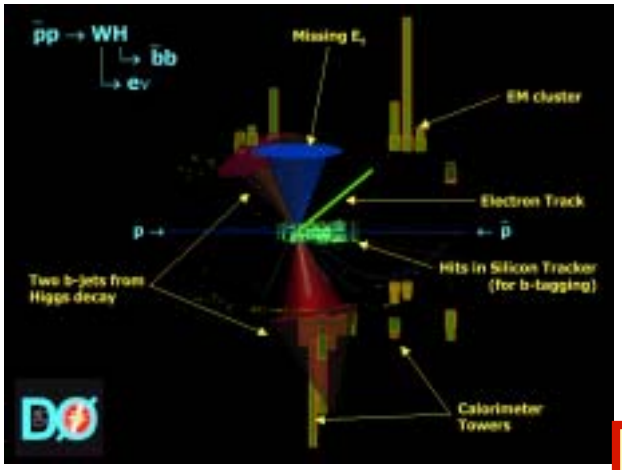
Near-Term Program

SLAC BaBar



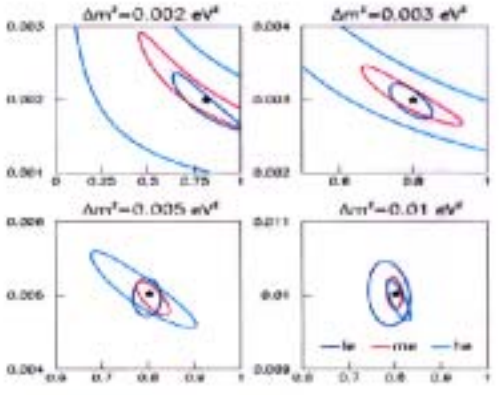
Precision Measurements Next 5 Years ~ 500 fb^{-1}

Fermilab Run 2



Pursuit of the Higgs

Fermilab MINOS



Neutrino Oscillation Parameters

Science Education and Society

- **Public education is a responsibility and privilege of our field**
  - **Current program is very successful**

Activity on education and outreach should be doubled to ensure a viable, effective and sustainable program.

- **National Security**
  - **U.S. Commission on National Security/21st Century (Hart-Rudman Report)**

National security rests on the strength of our scientific and technological base. The entire portfolio must be maintained to ensure the health, welfare and security of the nation in years to come.

Our Conclusions and Recommendations

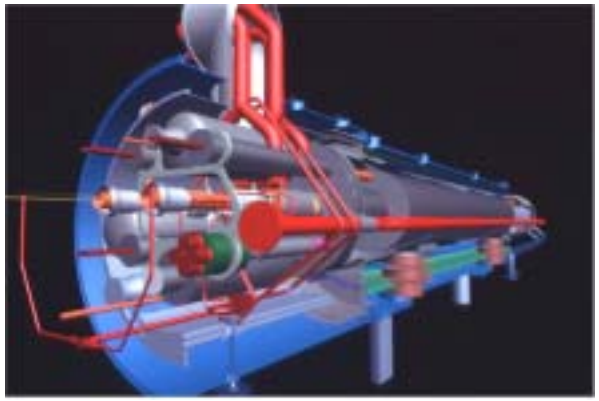
A long range plan and mechanisms for implementation

We offer much to society and national security, ranging from training to technology to scientific advances. Particle physics has made important discoveries in the recent past and has tremendous prospects for the future. The success of the Standard Model is allowing us to ask whole new questions about matter, energy, space and time.

- ***We recommend that the U.S. take steps to remain a world leader in particle physics, and that we renew and reaffirm our efforts toward the health, wealth and security of our nation and society at large.***

The Particle Physics Roadmap

- **In particle physics, we use many tools to access our science, ranging from forefront accelerators to satellites in space to experiments deep underground.**



Accelerator
LHC Magnet

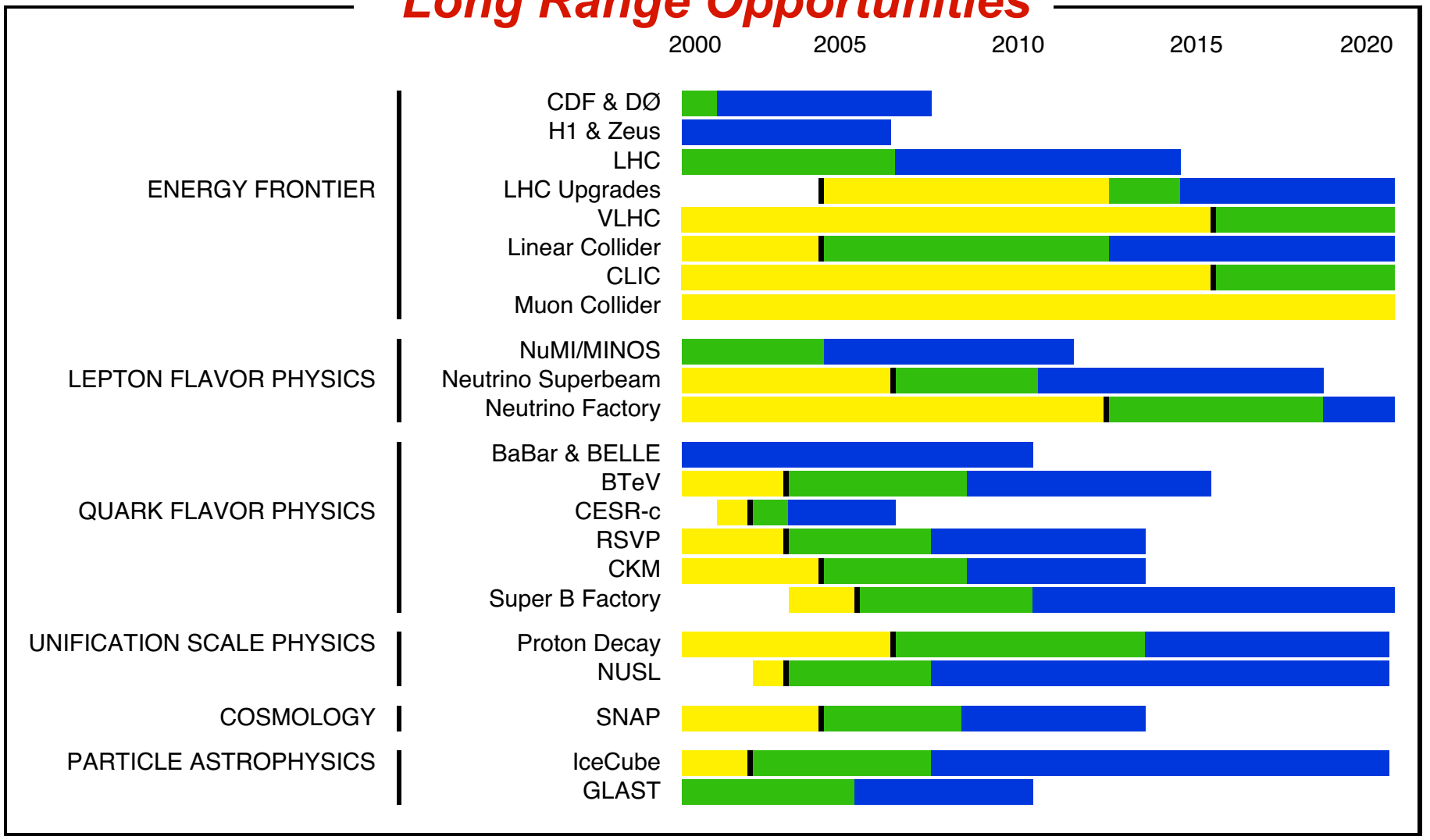
Space

The Soudan Mine
MINOS

We define our field by the questions we ask, and not by the tools we use.

The Particle Physics Roadmap

Long Range Opportunities



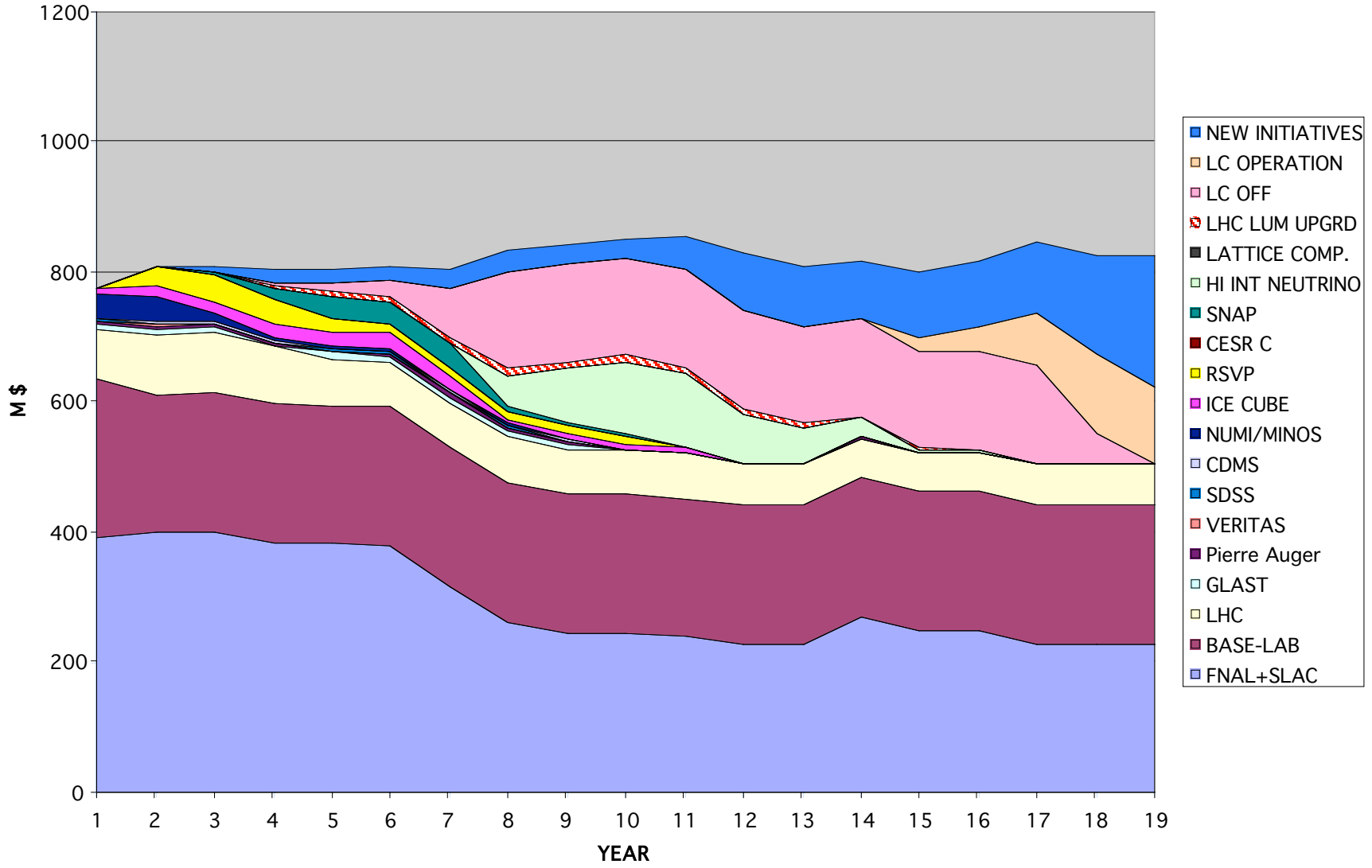
Not all projects illustrated on the roadmap can be pursued.

Setting Priorities and Making Choices

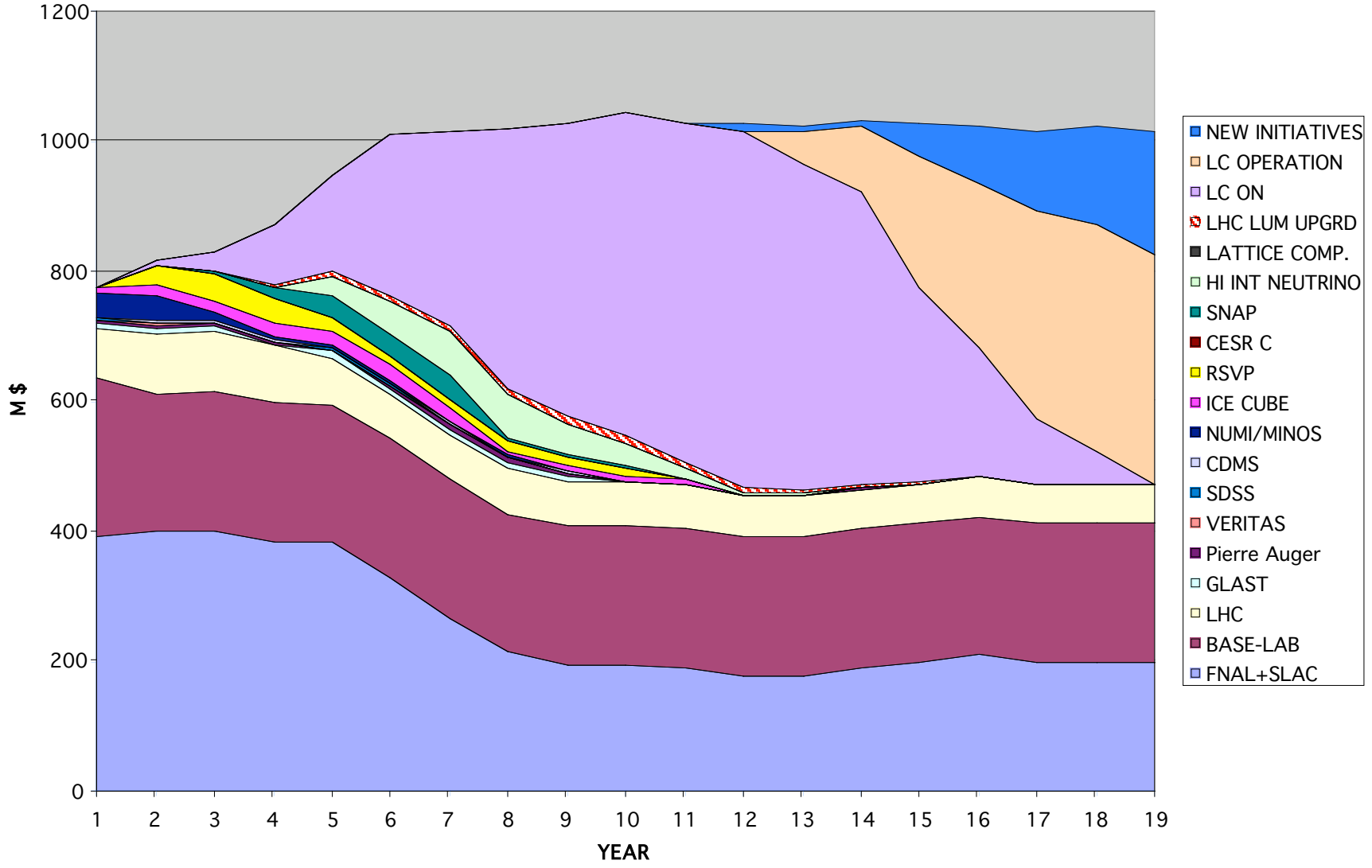
- **We recommend the creation of a Prioritization Panel for mid-scale projects.**
  - **Medium scale projects (total costs between $50M and $500M) make up a major part of the U.S. program and must be evaluated in competition with each other.**

We believe that prioritization is central to our plan for a diverse, aggressive program of particle physics, and to an optimal program of scientific investigation.

Scenario with off-shore linear collider



Scenario with on-shore linear collider



Our Conclusions and Recommendations

A long range plan and mechanisms for implementation

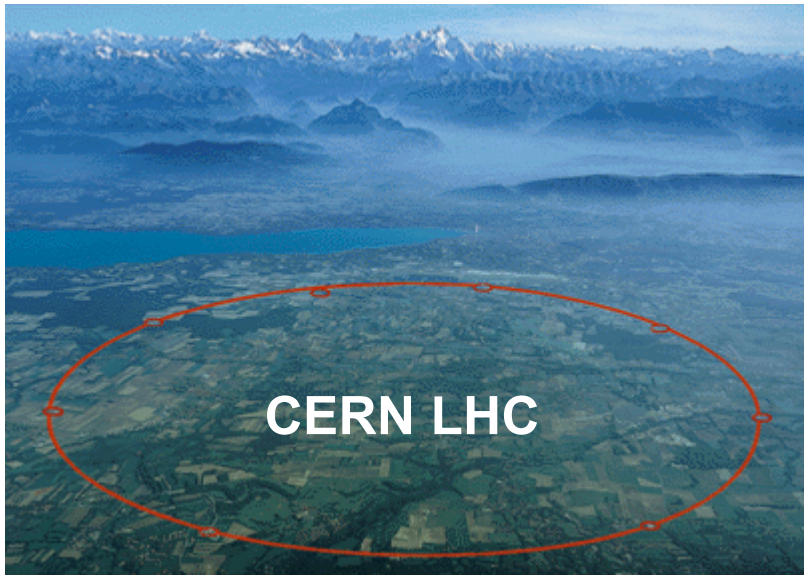
We define particle physics as the science of matter, energy, space and time. A wide variety of scientific and technical approaches will be used to achieve our goals.

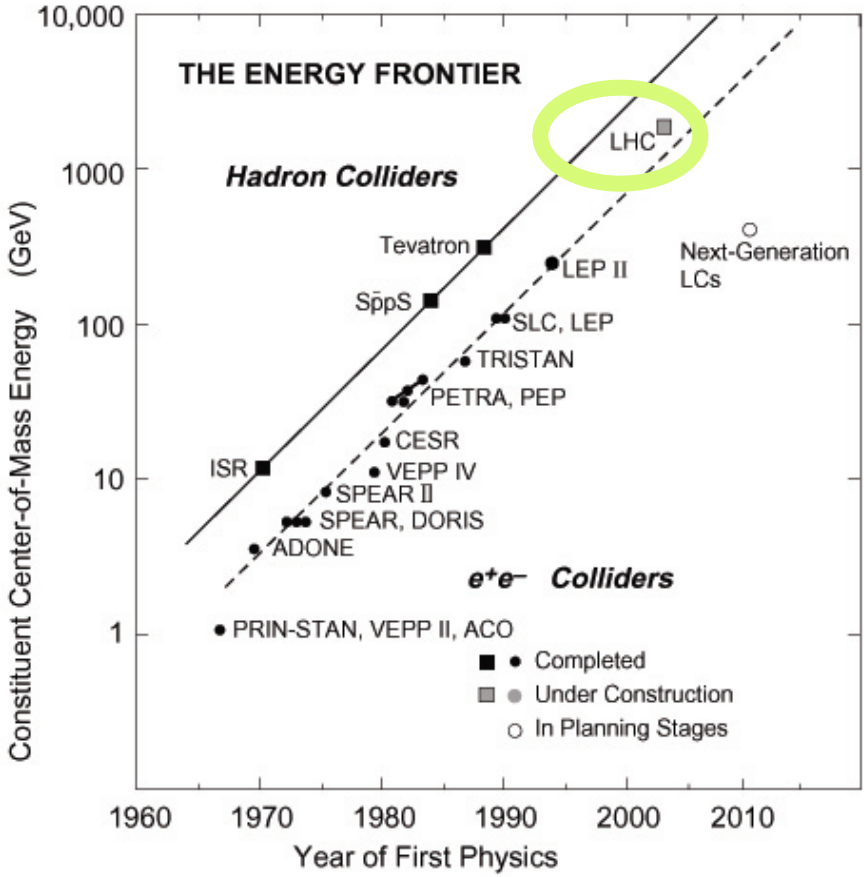
- ***We recommend a twenty-year roadmap for our field to chart our steps and allow us to craft a balanced program to maximize scientific opportunity. We propose a new mechanism for setting priorities and making decisions.***

The Particle Physics Roadmap

The Energy Frontier

- Higgs
- Supersymmetry
- Extra Dimensions
- New Phenomena





The energy frontier is a central element of the roadmap.

The TeV Scale

- **The scientific questions point to major new discoveries at the TeV scale.**
- **Exploration of that scale will begin, but not end, with the CERN LHC.**
- **There is now a worldwide consensus that the LHC and a linear collider are both essential to understand the TeV scale.**

The TeV scale is not an end in itself. It is a frontier for discovery, linking particle physics to cosmology and the early universe.

Why a Linear Collider?

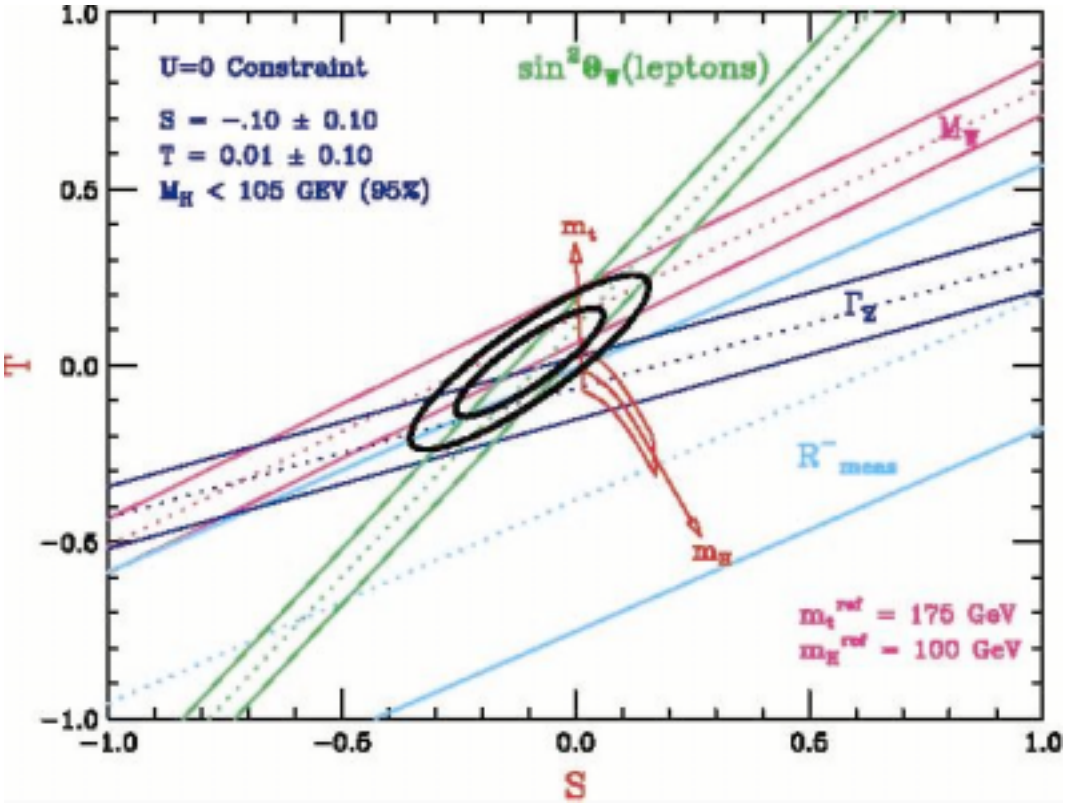
- **The initial state contains electrons and positrons, structureless particles that interact through precisely calculable weak and electromagnetic interactions.**

- **A linear collider can:**
  - **Determine the spins and quantum numbers**
  - **Measure cross sections and branching ratios**
  - **Carry out precision measurements**

Physics program endorsed by the Asian and European Committees for Future Accelerators, by the 2001 Snowmass Workshop, and by the HEPAP subpanel.

The Linear Collider

Precision Data



The present precision data were collected at hadron and electron machines.

The two probes provide complementary views – much like infrared and ultraviolet astronomy complement the optical.

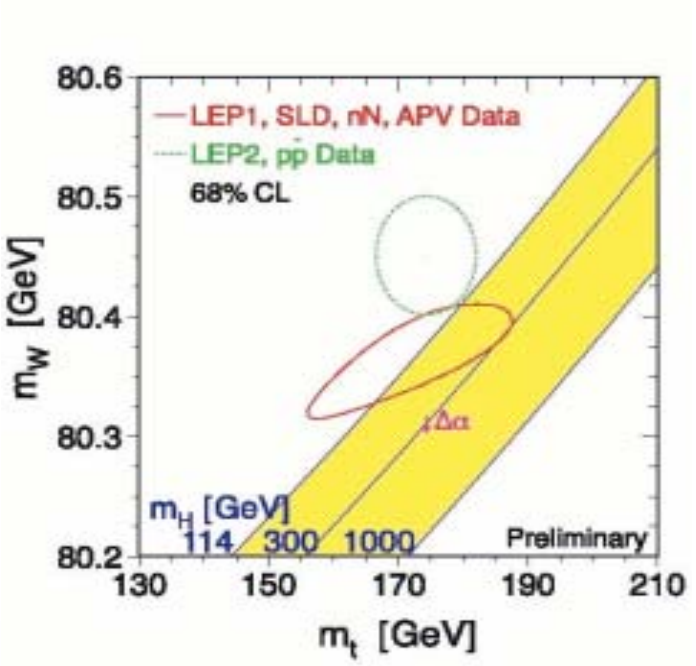
We fully expect this theme to continue into the future.

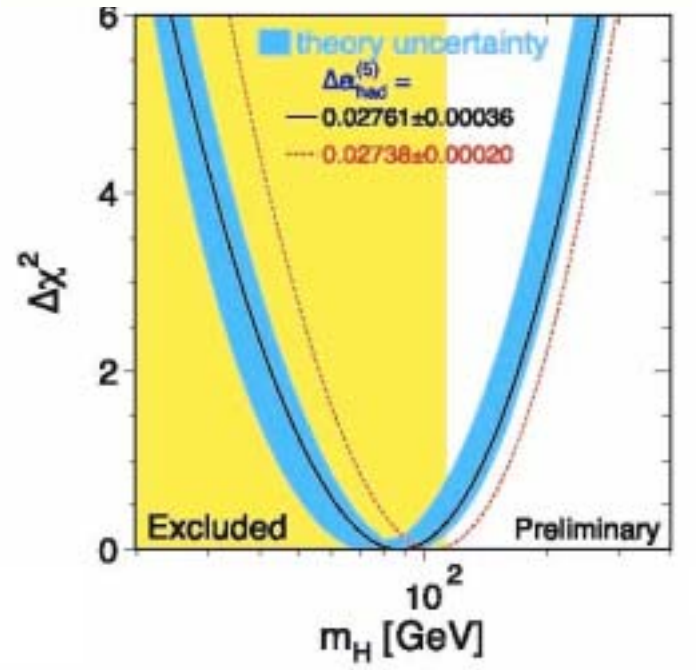
The Linear Collider

Standard Model Fit

Fits to the Standard Model prefer a Higgs boson mass of less than 200 GeV.

Such a light Higgs boson is well within reach of a linear collider.



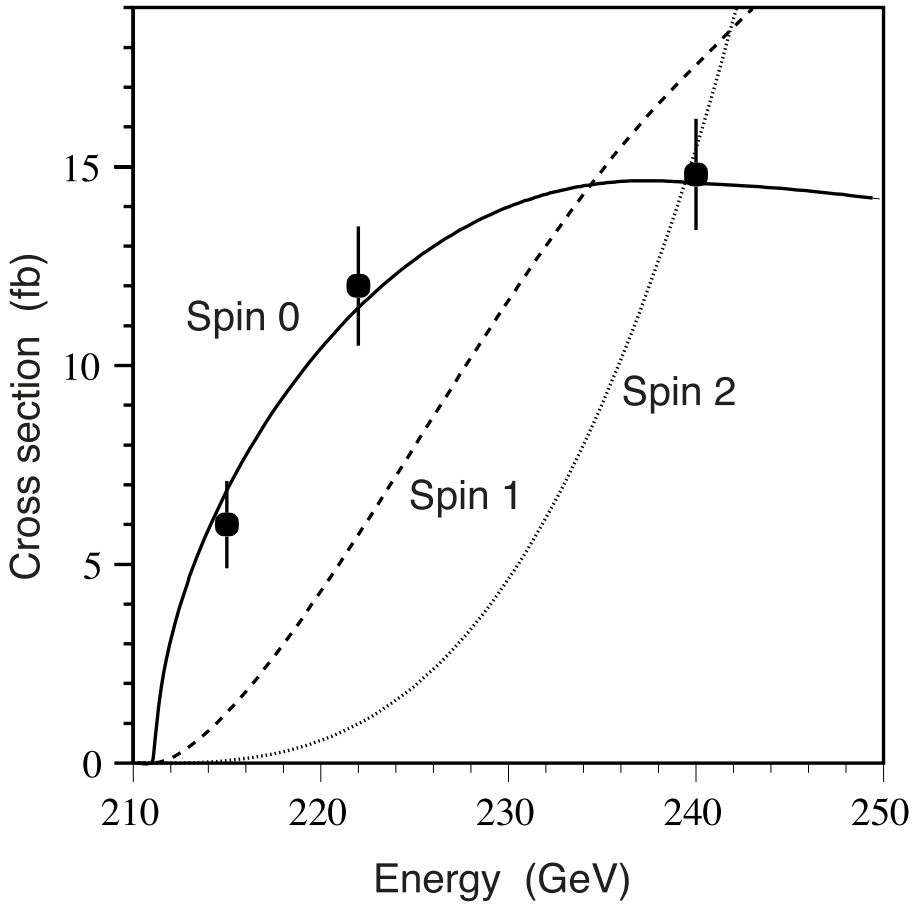


The Linear Collider

Higgs Spin Measurement

The LHC can determine the spin of a Higgs if its decay into *ZZ* has sufficient rate. But the linear collider can measure the spin of any Higgs it can produce.

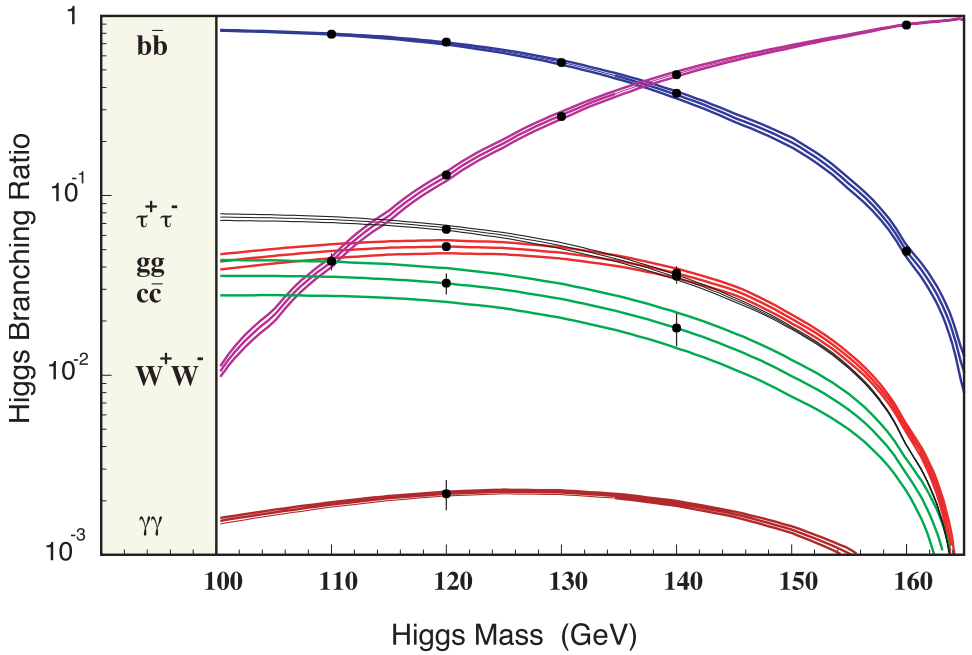
The process $e^+e^- \rightarrow HZ$ can be used to measure the spin of a 120 GeV Higgs particle.



The Linear Collider

Branching Fraction Measurement

The LHC will measure *ratios* of Higgs couplings. The linear collider, working with the LHC, can determine the *magnitudes* of these couplings very precisely.

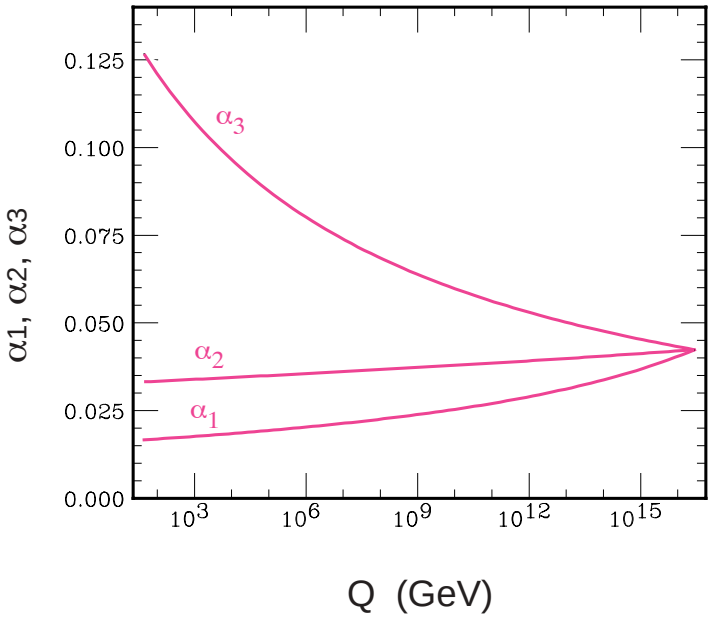


The figure shows estimated measurements of the Higgs branching fractions, assuming a 120 GeV Higgs.

The Linear Collider

New Quantum Dimensions

- **There are already hints that quantum dimensions permit the electroweak force to unify with the strong nuclear force.**
  - **A linear collider can test whether new particles are the signal of quantum dimensions.**
- **Supersymmetry unifies matter with forces.**
  - **Protons are unstable and eventually decay.**

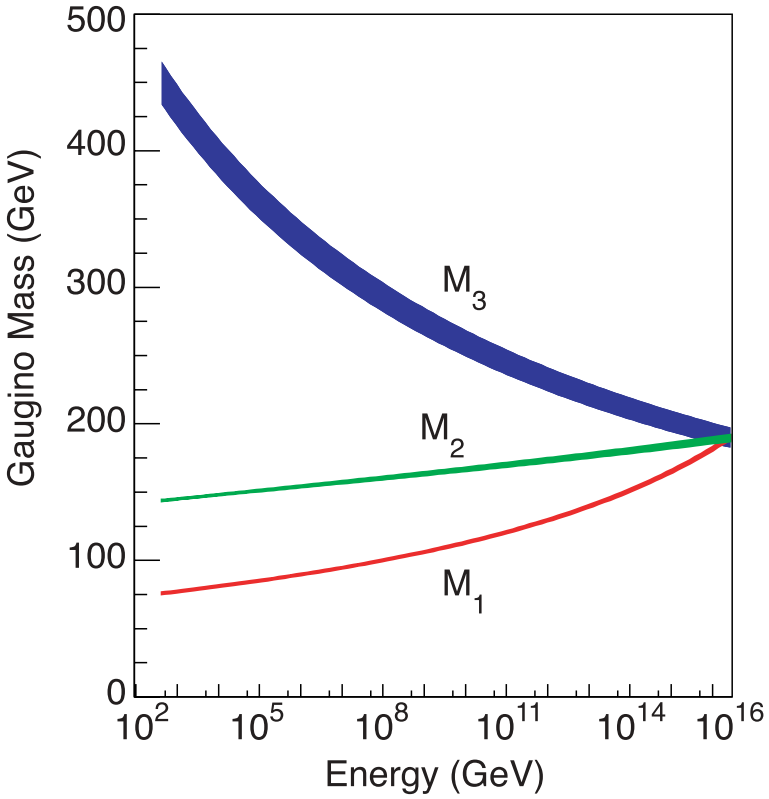


The Linear Collider

Gaugino Mass Unification

Do gaugino masses unify at the same scale as the gauge couplings?

The LHC will measure the gluino mass; the linear collider will provide precision mass determination for the superpartners of electroweak gauge and Higgs bosons.

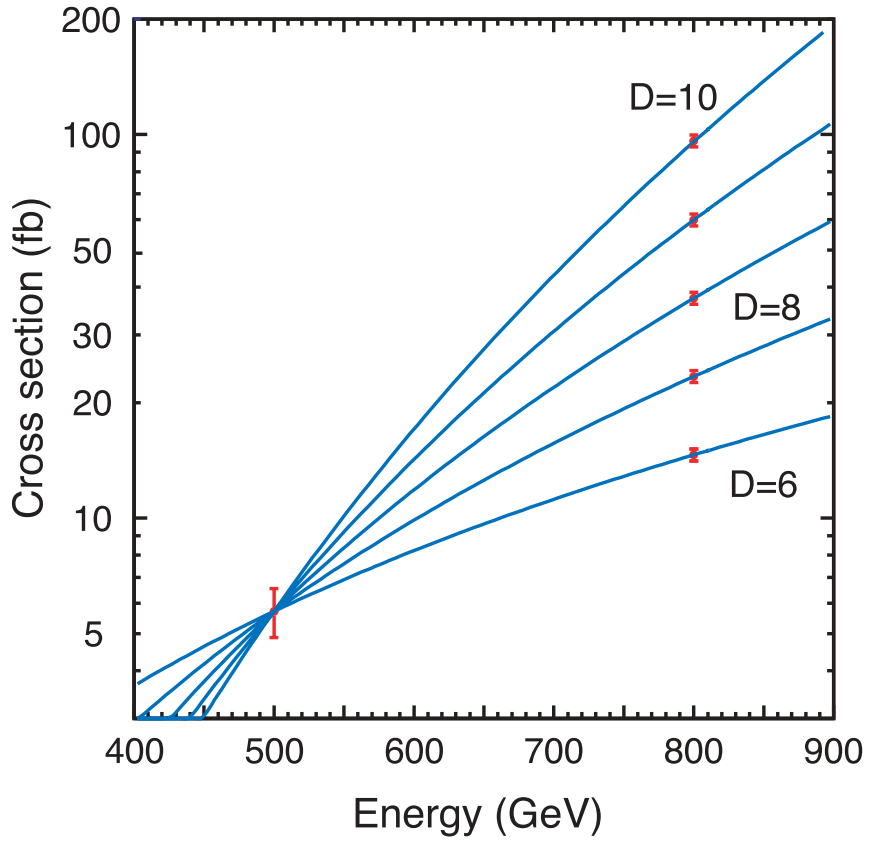


The Linear Collider

Measuring The Number of Dimensions

New spacetime dimensions are a generic prediction of string theory.

Their shapes and sizes can be mapped by a linear collider.



The Linear Collider

Finding Dark Matter

- **What is the dark matter?**
  - **Many models of TeV physics contain new particles that could fit the bill.**
  - **The dark matter might be neutralinos, stable neutral superparticles predicted by supersymmetry.**
- **Measurements at the linear collider will allow us to develop a predictive theory of this dark matter.**
  - **These measurements will push our detailed knowledge of the early universe back to a trillionth of a second after the Big Bang.**

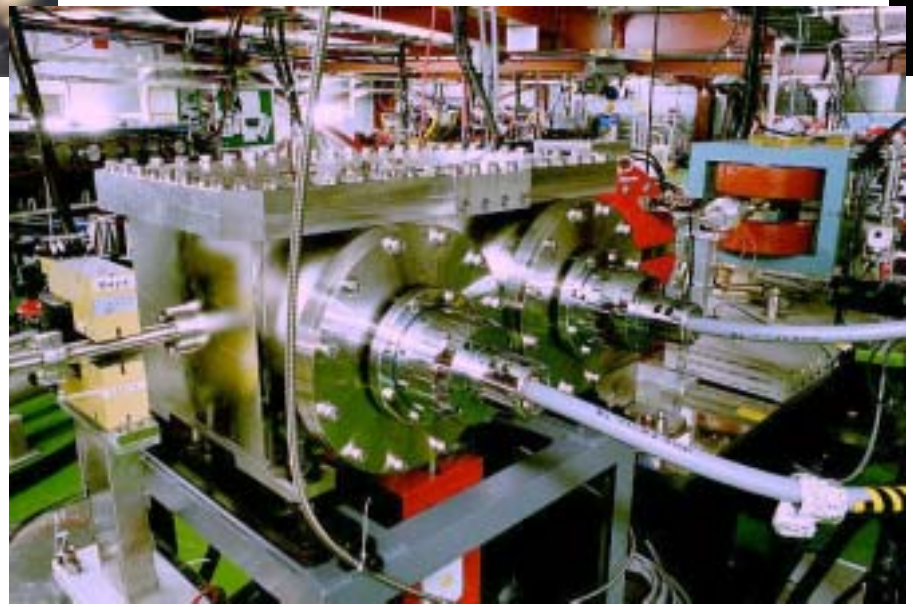
Linear Collider Technologies

- **The international accelerator community now firmly believes that a TeV-scale linear collider can be built at an acceptable cost with the correct science-driven capabilities.**

- **There has been formal collaboration between laboratories around the world on R&D and discussion of direct collaboration in the construction of a TeV-scale linear collider.**

TESLA
Superconducting Cavity

NLC
High Power
Klystron



JLC
Accelerator
Test Facility

Our Conclusions and Recommendations

A long range plan and mechanisms for implementation

Thorough exploration of the TeV scale is at the center of the particle physics roadmap. The LHC and a linear collider are both necessary to discover and understand the new physics that will be found.

- ***We recommend that the highest priority of the U.S. program be a high-energy, high-luminosity, electron-positron linear collider, wherever it is built in the world. We also urge the immediate creation of a steering group to coordinate all U.S. efforts.***

The Case for Hosting in the U.S.

- **The linear collider promises to be one of the greatest scientific projects of our time.**
  - **It will be at the frontier of basic science, advanced technological development, international cooperation, and educational innovation.**
  - **It will attract many of the top scientists in the world to participate in its scientific and technical opportunities.**

We believe that hosting the linear collider is a rare and timely opportunity, and one that should be seized by the U.S.

The Case for Hosting in the U.S.

- **A healthy worldwide physics program requires a distribution of major facilities around the globe.**
  - **The LHC is being constructed in Europe, and the JHF is underway in Japan.**
- **Past investments in accelerator facilities have enormously enriched our society.**
  - **History shows that accelerator facilities provide important platforms for major advances in physics and technology.**

The Case for Hosting in the U.S.

- Developing a truly international project would enable the U.S. to take the lead in forging a new approach to planning, collaboration and management in science on a global scale.

- Locating the facility in the United States would allow a greater portion of our economic investment to be recaptured through jobs and technological benefits.

Financing the Linear Collider

- A significant fraction of the linear collider must be financed from the existing U.S. high-energy physics program.
  - If a linear collider is built in the U.S, the site should be at or near an existing high-energy physics laboratory, to take full advantage of existing resources.
- International investment is essential for a project of this scale.
  - Steps toward internationalization should begin immediately, independent of the final location of the facility.
- We believe that a bold new initiative like the linear collider merits new funding from the U.S. government.

Our Conclusions and Recommendations

A long range plan and mechanisms for implementation

The linear collider promises to be one of the greatest scientific projects of our time.

- ***We recommend that the U.S. prepare to bid to host the linear collider. We envision financing the linear collider through a combination of international partnerships, existing resources, and incremental project support.***

Investing for the Future

- A healthy and strong university-based program is at the heart of how we do particle physics in the U.S., both now and in the future.

- Our subpanel gives very high priority to accelerator R&D because it is crucial to the long term future of our field.

- In order to enable a productive U.S. community for future international collaborations and facilities, significant resources will be needed for data acquisition, processing, storage and networking.

Accelerator R&D

- **Making the technology choice for the linear collider**
  - **There are now at least two technologies that could be used to build a linear collider.**
  - **Making the choice, optimizing the design and reducing the cost all require significant R&D.**

During the next few years, we need increased R&D to enable the technology choice.

Our Conclusions and Recommendations

A long range plan and mechanisms for implementation

Advances in particle physics depend on developing more powerful particle accelerators.

- ***We recommend vigorous long-term R&D aimed toward future high-energy accelerators.***