Elementary Particle Physics: One View from Washington

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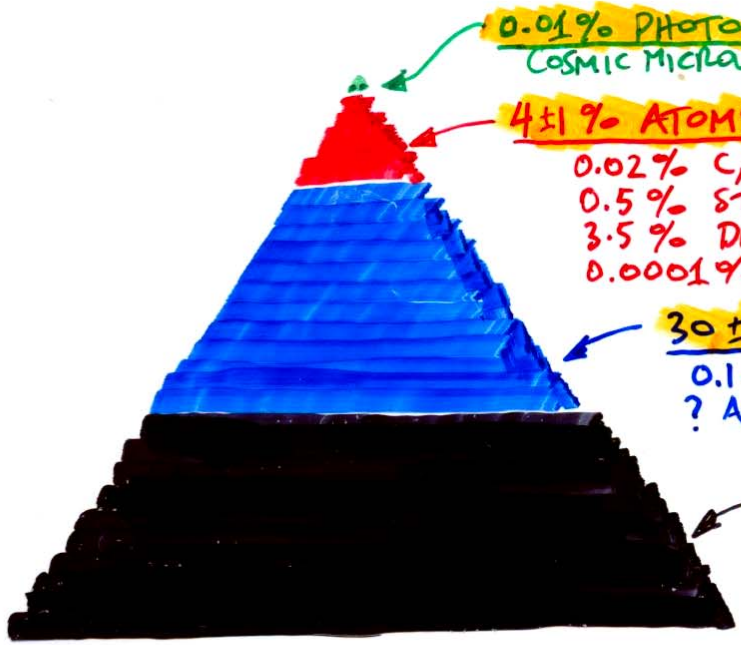
The Realm of Elementary Particle Physics Today is Grand and Expansive

- What is the Nature of the Universe and What is It Made Of?
- What Are Matter, Energy, Space And Time?
- How Did We Get Here and Where Are We Going?

– P. Drell et al, *The Quantum Universe*

COSMIC STUFF

0.5% STARS + 33% DARK MATTER + 66% DARK ENERGY



0.01% PHOTONS
COSMIC MICROWAVE BACKGROUND

4±1% ATOMS
0.02% C, N, O, ... Fe, ... U
0.5% STARS
3.5% DIFFUSE GAS
0.0001% BHs

30±4% EXOTIC DARK MATTER
0.1-5% NEUTRINOS
? AXIONS ? NEUTRALINOS

66±4% DARK ENERGY
? VACUUM ENERGY
? QUINTESSENCE
? ? ?

→ 96% IN NEW FORMS OF MATTER & ENERGY

Greatest Set of Intellectual Opportunities in 50 Years or More

- Are There Undiscovered Principles Of Nature, New Symmetries, or New Physical Laws?
- How Can We Solve The Mystery Of Dark Energy?
- Are There Extra Dimensions of Space?
- Do All The Forces Become One?
- Why Are There So Many Kinds of Particles?
- What Is Dark Matter? Can We Make It In The Laboratory?
- What Are Neutrinos Telling Us?
- How Did The Universe Come To Be?
- What Happened to Antimatter?

The Big Questions
from The Quantum Universe,
P. Drell et al

QUANTUM UNIVERSE

THE REVOLUTION IN 21ST CENTURY PARTICLE PHYSICS

DOE / NSF

HIGH ENERGY PHYSICS ADVISORY PANEL

QUANTUM UNIVERSE COMMITTEE

QUANTUM UNIVERSE

THE REVOLUTION IN 21ST CENTURY PARTICLE PHYSICS

What does “Quantum Universe” mean?

To discover what the universe is made of and how it works is the challenge of particle physics. Quantum Universe presents the quest to explain the universe in terms of quantum physics, which governs the behavior of the microscopic, subatomic world. It describes a revolution in particle physics and a quantum leap in our understanding of the mystery and beauty of the universe.

DOE / NSF
HIGH ENERGY PHYSICS ADVISORY PANEL
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EINSTEIN'S DREAM OF UNIFIED FORCES

1

ARE THERE UNDISCOVERED PRINCIPLES OF NATURE : NEW SYMMETRIES, NEW PHYSICAL LAWS?

The quantum ideas that so successfully describe familiar matter fail when applied to cosmic physics. Solving the problem requires the appearance of new forces and new particles signaling the discovery of new symmetries–undiscovered principles of nature's behavior.

2

HOW CAN WE SOLVE THE MYSTERY OF DARK ENERGY?

The dark energy that permeates empty space and accelerates the expansion of the universe must have a quantum explanation. Dark energy might be related to the Higgs field, a force that fills space and gives particles mass.

3

ARE THERE EXTRA DIMENSIONS OF SPACE?

String theory predicts seven undiscovered dimensions of space that give rise to much of the apparent complexity of particle physics. The discovery of extra dimensions would be an epochal event in human history; it would change our understanding of the birth and evolution of the universe. String theory could reshape our concept of gravity.

4

DO ALL THE FORCES BECOME ONE?

At the most fundamental level all forces and particles in the universe may be related, and all the forces might be manifestations of a single grand unified force, realizing Einstein's dream.

THE PARTICLE WORLD

5

WHY ARE THERE SO MANY KINDS OF PARTICLES?

Why do three families of particles exist, and why do their masses differ so dramatically? Patterns and variations in the families of elementary particles suggest undiscovered underlying principles that tie together the quarks and leptons of the Standard Model.

6

WHAT IS DARK MATTER? HOW CAN WE MAKE IT IN THE LABORATORY?

Most of the matter in the universe is unknown dark matter, probably heavy particles produced in the big bang. While most of these particles annihilated into pure energy, some remained. These remaining particles should have a small enough mass to be produced and studied at accelerators.

7

WHAT ARE NEUTRINOS TELLING US?

Of all the known particles, neutrinos are the most mysterious. They played an essential role in the evolution of the universe, and their tiny nonzero mass may signal new physics at very high energies.

THE BIRTH OF THE UNIVERSE

8

HOW DID THE UNIVERSE COME TO BE?

According to cosmic theory, the universe began with a singular explosion followed by a burst of inflationary expansion. Following inflation, the universe cooled, passing through a series of phase transitions and allowing the formation of stars, galaxies and life on earth. Understanding inflation requires breakthroughs in quantum physics and quantum gravity.

9

WHAT HAPPENED TO THE ANTIMATTER?

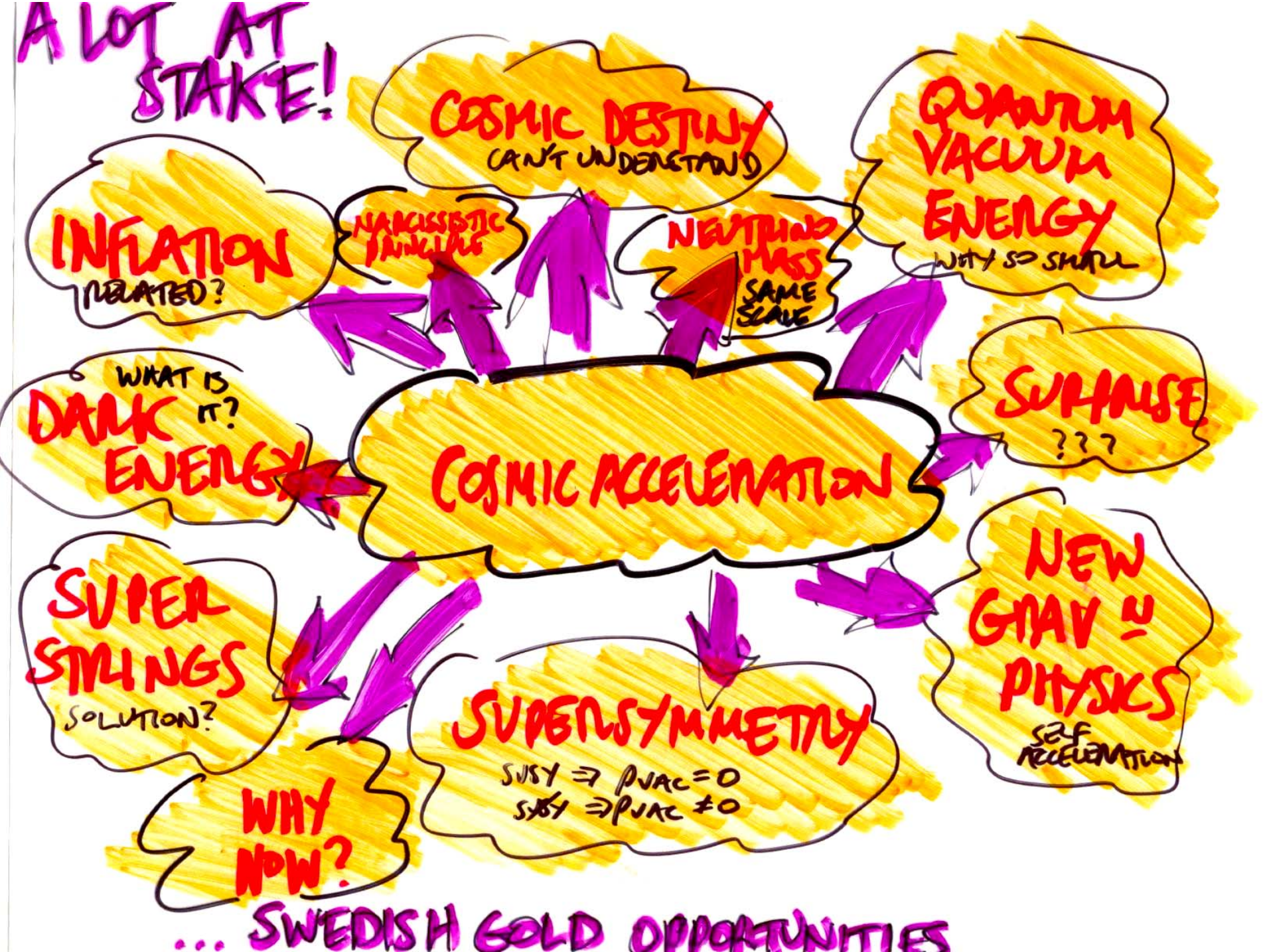
The big bang almost certainly produced equal amounts of matter and antimatter, yet the universe seems to contain no antimatter. How did the asymmetry arise?

OPPORTUNITIES FOR DISCOVERY

We live in an age when the exploration of great questions is leading toward a revolutionary new understanding of the universe.

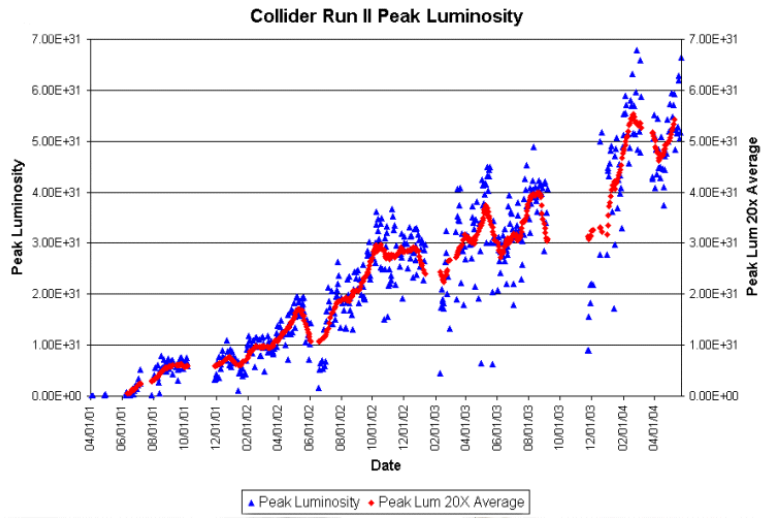
"Opportunities have emerged for discovery about the fundamental nature of the universe that we never expected," Presidential Science Advisor John Marburger said recently. "Technology places these discoveries within our reach, but we need to focus efforts across widely separated disciplines to realize the new opportunities."

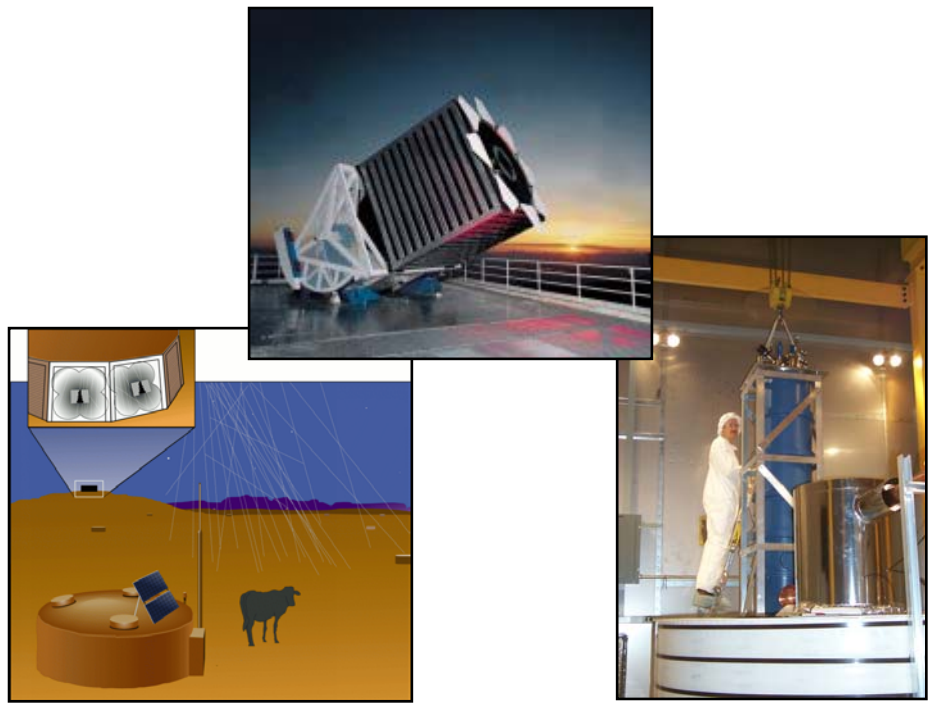
Quantum Universe is a response to that challenge. It serves as a guide to where the search for understanding has taken us so far, and to where it is going. The chapters that follow articulate how existing and planned particle physics experiments at accelerators and underground laboratories, together with space probes and ground-based telescopes, bring within reach new opportunities for discovery about the fundamental nature of the universe.


A LOT AT STAKE!
COSMIC DESTINY
CAN'T UNDERSTAND
QUANTUM VACUUM ENERGY
WHY SO SMALL
INFLATION
RELATED?
NARCISSISTIC FANCIFUL
NEUTRINO MASS
SAME SCALE
WHAT IS IT?
DARK ENERGY
COSMIC ACCELERATION
SURPRISE
???
SUPER STRINGS
SOLUTION?
NEW GRAV ≠ PHYSICS
SELF ACCELERATION
SUPERSYMMETRY
SUSY ⇒ ρVAC = 0
SUSY ⇒ ρVAC ≠ 0
WHY NOW?
... SWEDISH GOLD OPPORTUNITIES

Strong, Well-Supported Program In Place

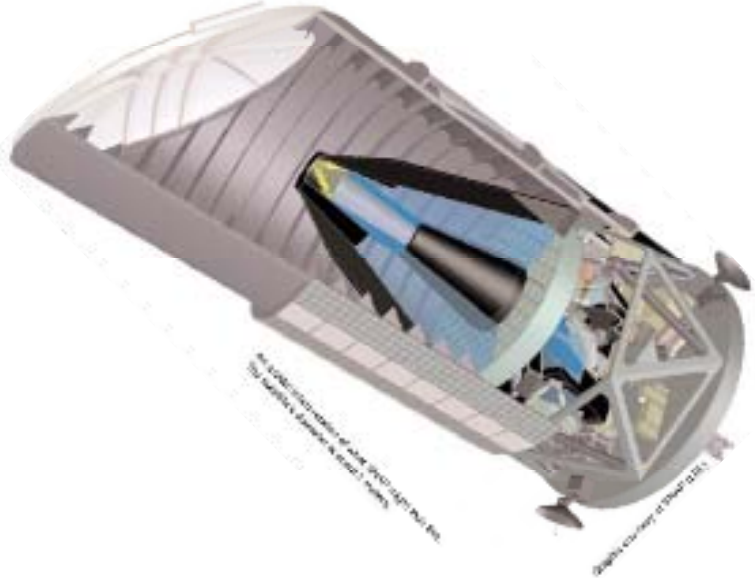
- Energy Frontier
  - Run II at Fermilab
- Sensitivity Frontier
  - SLAC B-Factory, CLEO
- Neutrino Physics
  - MiniBoone, MINOS, Kamland, K2K, …
- Particle Astrophysics
  - KIPAC at SLAC
  - Astrophysics Center at Fermilab
    - CDMSII, SDSS, Auger, Theoretical Astrophysics





Exciting Things on the Horizon

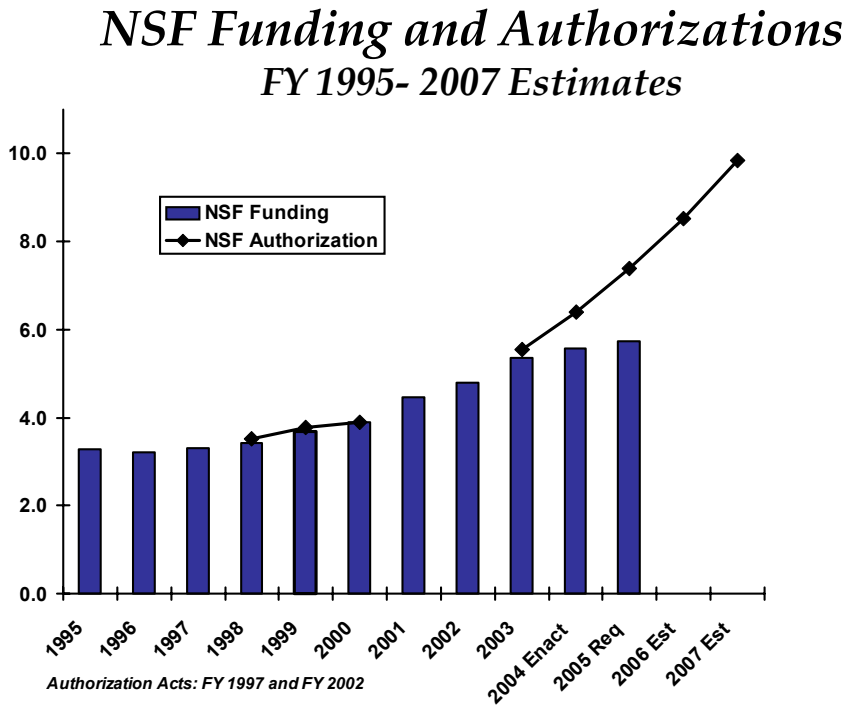
- Energy Frontier
  - LHC (Atlas and CMS)
- Sensitivity Frontier
  - RSVP, B-TeV
- Neutrinos
  - MINOS
- Particle Astrophysics
  - JDEM, UG Laboratory, LSST

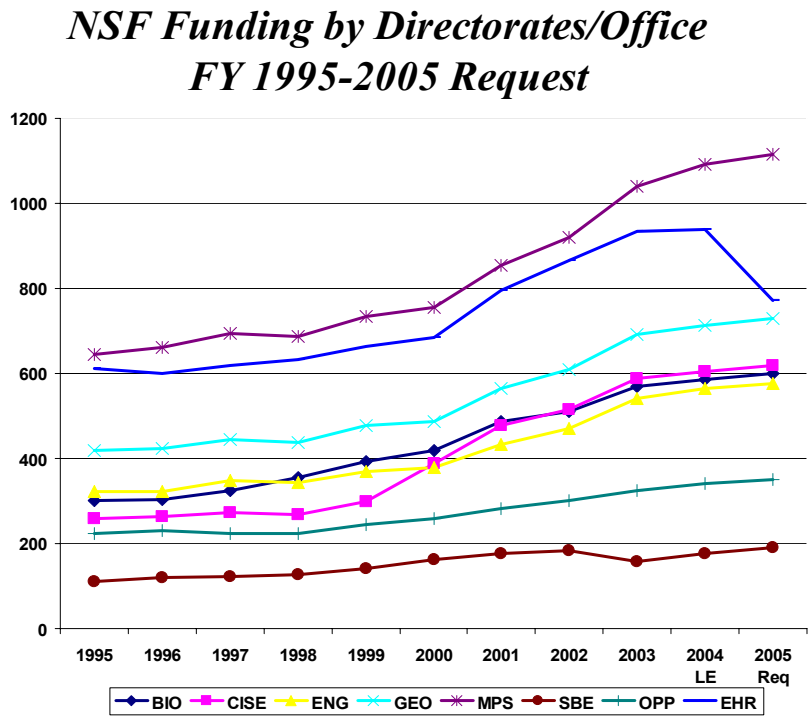


Challenges

- Tight Budgets Ahead
  - 500B$ Deficit
  - Higher National Priorities: War on Terrorism, Homeland Security and the Economy
- Expensive Science With Long Lead Times
  - Multi-billion-dollar Linear Collider
  - Billion-dollar JDEM
  - Billion-dollar Proton Decay/Neutrino Oscillation
- Other Very Exciting Science, especially biological sciences and astrophysics, that is more understandable
- No Longer Have A Special Relationship With National Leaders
- Workforce: White-male Priesthood Looking Dated

NSF Funding





+68% since 1998, but leveling (out years from FY05 budget)

2005	2006	2007	2008	2009
5.77B$	5.666B$	5.674B$	5.723B$	5.749B$
vs FY05:	-1.8%	-1.6%	-0.8%	-0.4%

Domestic S&E Workforce Diversity: Survival not Political Correctness

UC Physics Faculty, 2000

Face of the America, 2004

Chemistry Research Group

The number of bright foreigners in science & engineering coming to the US is dropping (visa problems, less welcoming atmosphere, good opportunities elsewhere)

Realizing The Grand Opportunities

- Communicate The Science Goals
  - The Quantum Universe
  - National Academy Decadal Study of Elementary Particle Physics
- Set National Priorities In a World Context
  - National Academy Study
- New Strategies and Tactics – Need Both Accelerators and Telescopes
- Fermilab Needs To Be A Truly National Laboratory

NRC Study: Elementary Particle Physics in the 21st Century

- Charge
  - Articulate and Prioritize the Scientific Opportunities
  - Prioritized Implementation Plan In a World Context
- Committee Will Involve the Larger Scientific Community
  - Broad Representation Across Physics (~50% HEP)
  - Validation of Goals and Plans of the Field
- Engage the Particle Physics Community
  - Town Meetings, “Snowmass-like” Activity
- Build upon and integrate important work already done
  - DOE Facilities Plan
  - Quarks to the Cosmos
  - Bagger-Barish Report
  - P. Drell Report
  - APS Neutrino Study
  - International Technology Committee (Barish Committee)
  - International activities and plans
  - P5 roadmap

THIS ACTIVITY IS IMPORTANT FOR THE FUTURE OF EPP

The Road to the Linear Collider

- Fully Realize the Investment in the Current Program
  - Run II, Neutrinos, LHC, …
- Prioritize and Make Hard Decisions
- Three Things Must Be In Place
  - Killer Physics Case (LHC Results Will Really Strengthen the Case)
  - Technology in Place and Demonstrated
  - World Participation

I am confident that there will be a Linear Collider – the science demands it – the road maybe a little bit longer and a little bit bumpier than expected.

Bright Future Ahead

Elementary Particle Physics Has the One Thing No Amount of Money Can Buy

THE GREATEST SET OF INTELLECTUAL OPPORTUNITIES IN 50 YEARS

Just Imagine, in 25 Years We Could Know

HOW THE FORCES ARE UNIFIED

WHAT THE DARK MATTER IS

COMPLETE LIST OF NATURE'S BUILDING BLOCKS

WHY THE UNIVERSE IS ACCELERATING

WHAT SPACE AND TIME REALLY ARE

HOW THE UNIVERSE BEGAN