

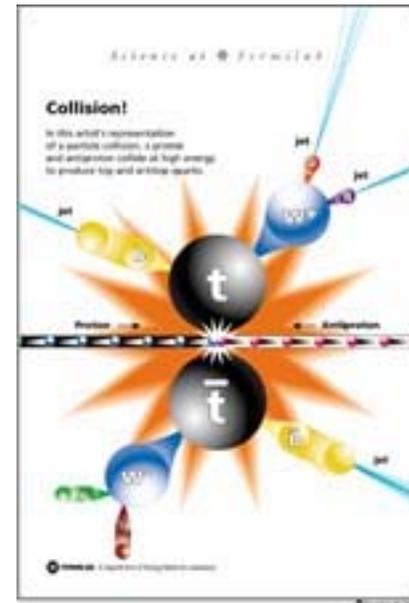


The High Energy and Nuclear Physics Program

Office of Science

- Our Science Mission and Goals
- Our Program
- Our Program that Relates to the 2002 NRC Quarks to the Cosmos Report's Questions & Recommendations
- Interagency Partnerships and Coordination

Kathleen Turner
Division of High Energy Physics,
Office of Science, DOE
Talk at the National Academy of Science,
Committee on Astronomy & Astrophysics
April 29, 2003 Meeting





DOE High Energy and Nuclear Physics

Office of Science

Our Mission:

- To understand the nature of matter at its most fundamental level and explore the evolution of the universe through the fundamental interactions of matter, energy, space & time.
- **Strong overlaps with astrophysics and cosmology**

Where we do our science:

- Particle Accelerators – major part of our program
“Atom Smashers” ± create particles and interactions
- The Universe
Experiments underground, on the ground, and in space
to study fundamental particles and forces

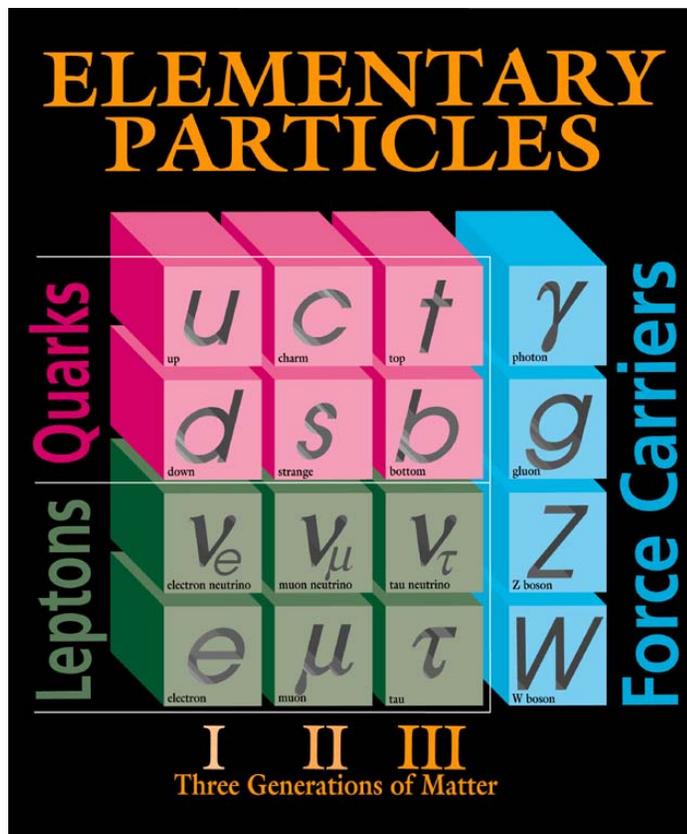
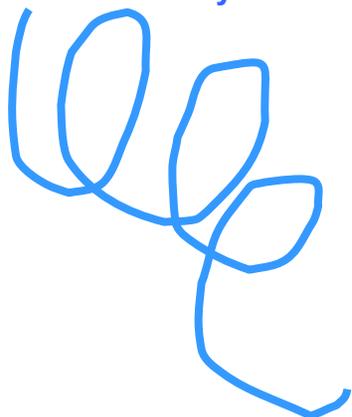


DOE High Energy & Nuclear Physics



Dark Matter

String Theory



Quark Gluon Plasma



Dark Energy



DOE High Energy and Nuclear Physics

Strong Overlaps with Astrophysics & Cosmology

The Big Bang and Expanding Universe

Space is expanding from an initial moment called the Big Bang. As it expands, the universe cools and becomes less dense. All distant galaxies are moving apart from each other and away from us. On large scales, the universe looks the same in all directions and all parts of space. There is no preferred center. Our current understanding of the early universe is called the Big Bang model. Much more will be learned from astronomical observations and from acceleration-based experiments in the coming years.

THE HISTORY AND FATE OF THE UNIVERSE

Eight major stages in the evolution of the universe are illustrated below. The Big Bang occurred everywhere in the universe. Here one region has been illuminated and followed through time. The expansion is far greater than can be shown here.

Redshifts and Expansion

Lightwaves stretch with the expansion of space. As the wavelength of visible light increases, it becomes redder (as shown for the photons in the central figure). Measuring this redshift tells us the velocity of the source. In 1929, Hubble observed that all distant objects are receding with a velocity proportional to their distance. This information and modern telescope observations show that the universe is expanding uniformly in all directions. Objects that are bound together (such as galaxies and stars) do not expand as space expands.

Cosmology and Relics of History

Cosmology is the study of the universe as a whole. As in archaeology, cosmology finds clues to the past in relics. Looking out a distance d in space is looking back in time because $t = d/c$ (right travels at a finite speed c). The laws of nature discovered on Earth can be applied to the early universe and tested by observing relics.

A Relic from the Early Universe
The Cosmic Microwave Background (CMB) is a universal bath of lightwaves (photons) from the hot dense early universe. They are stretched by the expansion of space. To a part in 100,000, the CMB is the same no matter where you look (it is isotropic). The remaining tiny variations (shown in figure) are images of the seeds that later form galaxies and larger cosmic structures.

The left image of the universe from the time when atoms first formed. It is a map of the entire sky showing CMB light with the uniform part subtracted.

Age of the Universe A marvelous agreement that the age of the universe is about 14 billion years comes from studying the expansion and the赫兹es of stars and also by dating meteorites.

ERA 1 Time: 10^{-44} s to 10^{-33} s. unknown

ERA 2 Time: 10^{-12} s to 10^{-4} s. Nucleons form

ERA 3 Time: 10^2 s to 3×10^5 yr. Atoms form

ERA 4 Time: 10^8 yr to 14×10^9 yr. Today

Expansion History of the Universe

The large plot shows data from Type Ia supernovae explosions that occurred in the past 9 billion years. Measurements of these supernovae show an accelerating expansion began billions of years ago. The yellow circle is the best fit to the data. The smaller plot emphasizes the extremely early universe.

History of the Universe

Three major eras in the expansion history followed the hot dense conditions of the earliest universe. During each era, the expansion depended on the nature of the matter or energy that dominated the universe at that time.

Era 1 - Acceleration: Inflation speeds expansion
Observations seem to imply that the very early universe underwent an extremely rapid accelerating expansion, called **inflation**. In a few fractions of a second, inflation expanded each part of space by a factor of at least 10^{27} . Before inflation, the portion of the universe visible to us today was a smooth patch much smaller than a proton. As inflation ended, the visible universe had grown to the size of a ball (very approximately). Inflation explains how quantum fluctuations in the otherwise smooth and isotropic universe yielded tiny ripples that would eventually grow into galaxies and structures. In the 14 billion years after inflation, the universe expanded by another factor of about 10^{27} .

Era 2 - Deceleration: Expansion slows and structure forms
After inflation, the universe was a plasma or soup of fundamental particles. Photons and fast moving particles, generically called **radiation**, gradually lost energy (cooled) as the universe expanded (the energy went into the expansion). Eventually, slow-moving matter became dominant over radiation. Over time, larger and larger structures grew from galaxies to clusters of galaxies to superclusters. These began as small differences in the density of matter, but gravitational attraction made more and more matter clump together. Several interesting stages are indicated in the central figure. Stars created the higher-mass elements that eventually became part of Earth and us. The early universe had both matter and antimatter in abundance, but today it is almost exclusively matter. How this came about is not fully understood.

Era 3 - Acceleration: Dark energy speeds expansion
A matter-dominated universe causes deceleration and might even reverse the expansion. So it was a great surprise in 1998 when observations showed that the expansion of the universe is now accelerating (see the "Expansion History" plot). This implies the existence of a new form of energy, referred to as **dark energy**. Scientists are pursuing the nature of dark energy.

Fate of the Universe

Whether the expansion of the universe will speed up, slow down, or even possibly reverse into collapse depends through gravity on the amount and types of matter and energy in it.

The ordinary universe - atoms and nuclei - that formed in the early universe can account for the visible mass in galaxies and clusters. But it falls far short of the total mass needed to bind them together gravitationally and explain their internal motions. So an extraordinary new type of matter, not made of atoms or nuclei, must exist: it is called **dark matter** because it is not directly visible.

Even stranger, recent observations of supernovae in distant galaxies show that the expansion of the universe is in fact **accelerating**. An exotic **dark energy** may be causing this acceleration through a cosmic repulsion that overwhelms the pull of gravity due to matter.

The nature of dark energy and dark matter are two of the great questions facing cosmology and particle physics. Perhaps dark energy is the cosmological constant, introduced by Einstein in 1917. Perhaps both are new parts of particle physics, tied to the very earliest moments of the universe and having to do with the nature of physics and spacetime itself.

Not all answers in science are known yet! With the research and experiments under way in astrophysics and particle physics, we may be the first generation to learn what most of the universe is made of and what is the fate of the universe.

Our Cosmic Address

Our sun is one of 400 billion stars in the Milky Way galaxy, which is one of more than 100 billion galaxies in the visible universe.

Learn more at UniverseAdventure.org and at CPEPweb.org

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DOE High Energy and Nuclear Physics

Office of Science

Program Direction:

Our FACA panels & subpanels provide advice to both DOE & NSF

- o High Energy Physics Advisory Panel (HEPAP)

- o Nuclear Science Advisory Panel (NSAC)

- Programs are also responding to the NRC “Quarks to the Cosmos” report chartered by DOE/NSF/NASA NRC

- **We are part of the OSTP’s Interagency Working Group**



DOE High Energy and Nuclear Physics

Office of Science

DOE-HENP

- Supports ~ 90% of the U.S. basic research on fundamental particles and forces and nuclear matter
- Constructs and operates major accelerator research facilities
 - We provide oversight for the labs and have annual peer reviews
 - Experiments undergo rigorous bi-annual independent reviews during construction

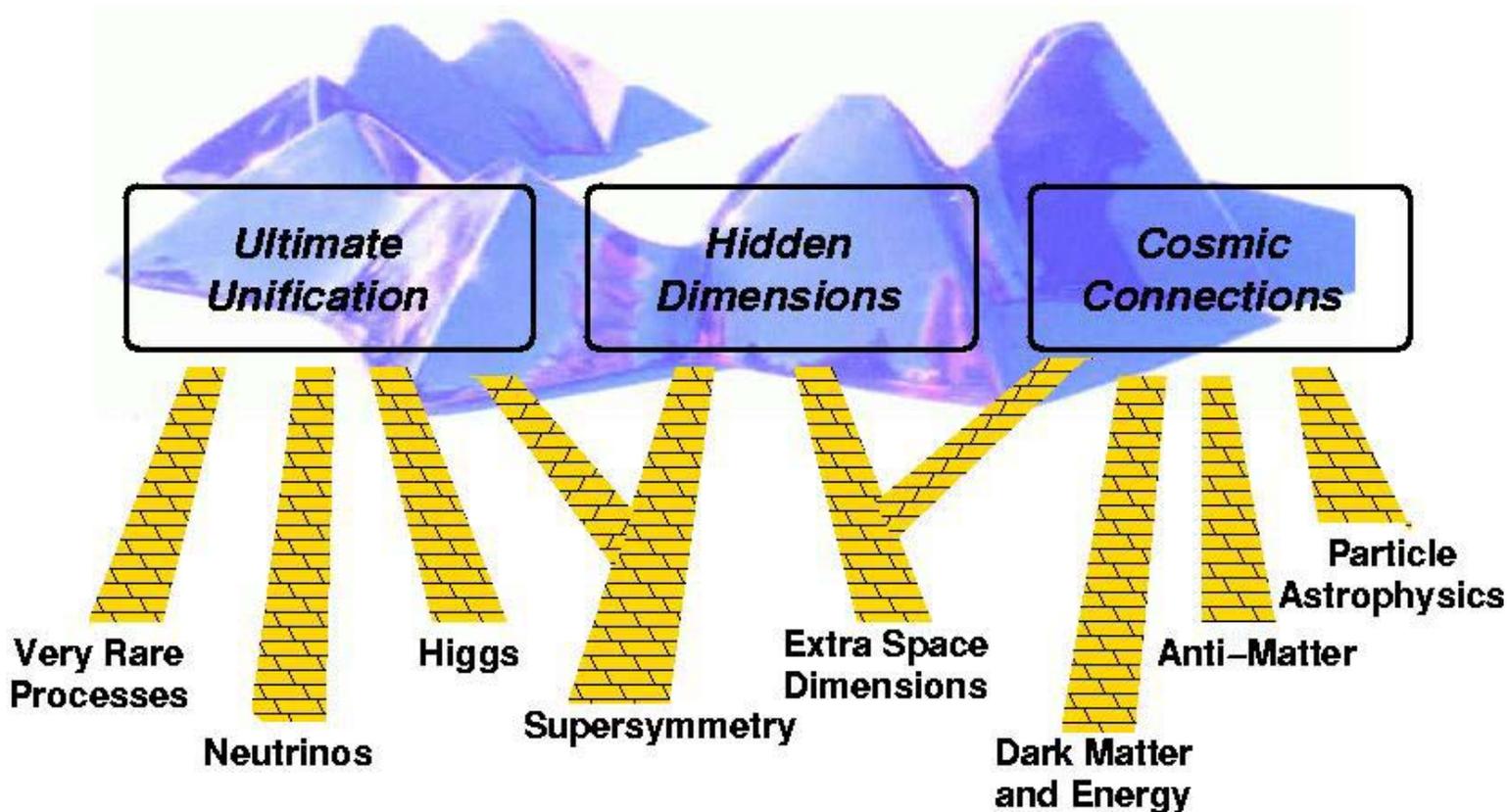
Scientists:

- We support about 3,000 scientists and 1,000 graduate students from more than 130 universities and 10 national laboratories.
 - University program is run thru our office – funding is according to peer review



High Energy Physics Program

HEPAP 2001 Long Range Planning Subpanel → Our Program Goals





DOE High Energy Physics Program

Office of Science

Our experimental projects:

Scientists are involved in all phases from conception, design, construction, operations, and data analysis

The large scientific collaborations have scientists involved at every level of the project →

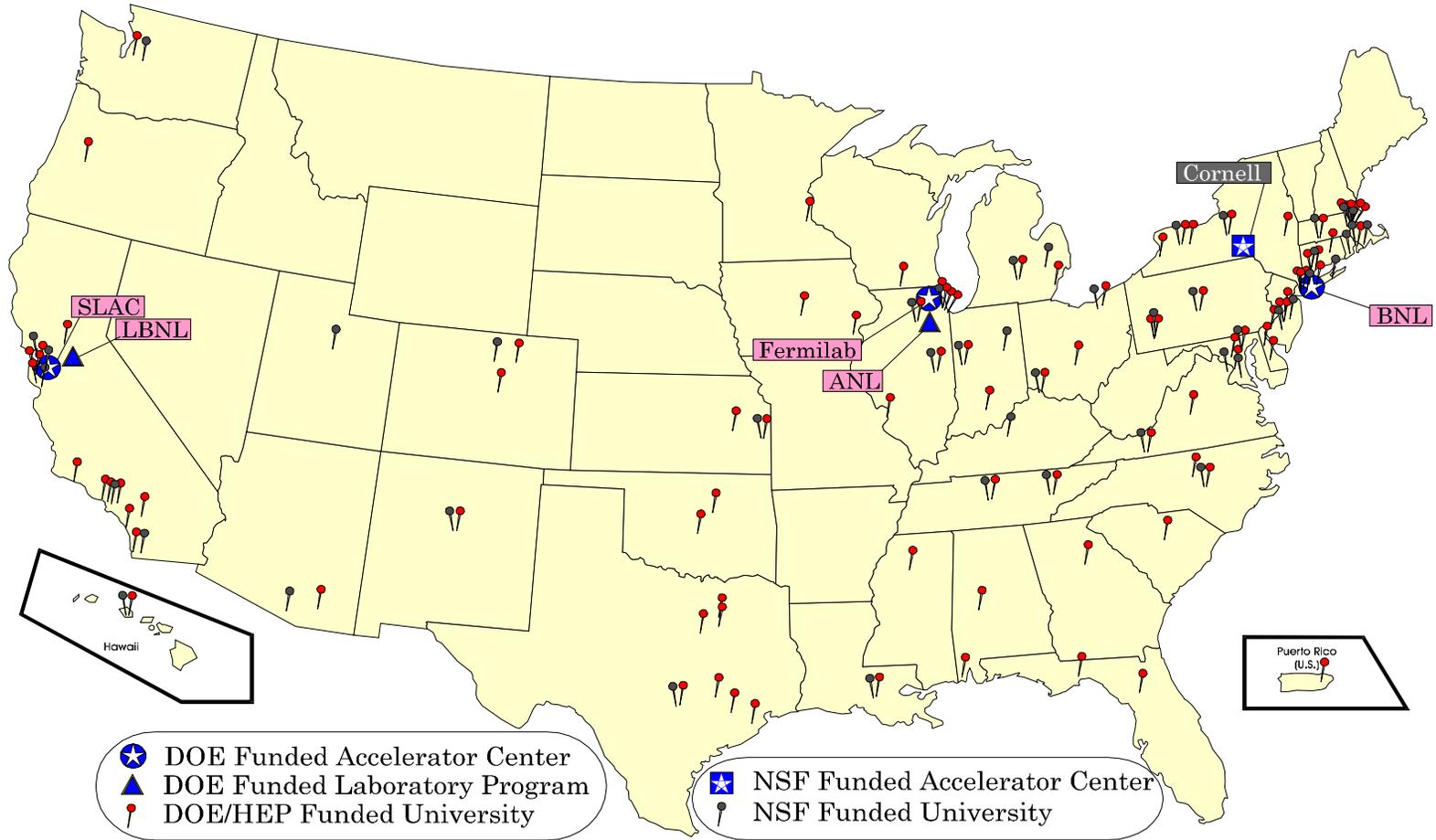
- **Intimate knowledge of the detector, data acquisition, science, etc.**
- **Many postdocs and students are trained**
- ❖ **Computing plays an important role in our program: simulations, data acquisition, data crunching, distributed analysis and storage.**
- ❖ **Theoretical & Advanced Technology work is spread throughout the program.**

Our experiments all have NSF collaborators & most have Foreign partners



Quarks to Cosmos Recommendation #1

High Energy Physics Research conducted by over 100 universities
and 9 labs nationwide





DOE High Energy Physics

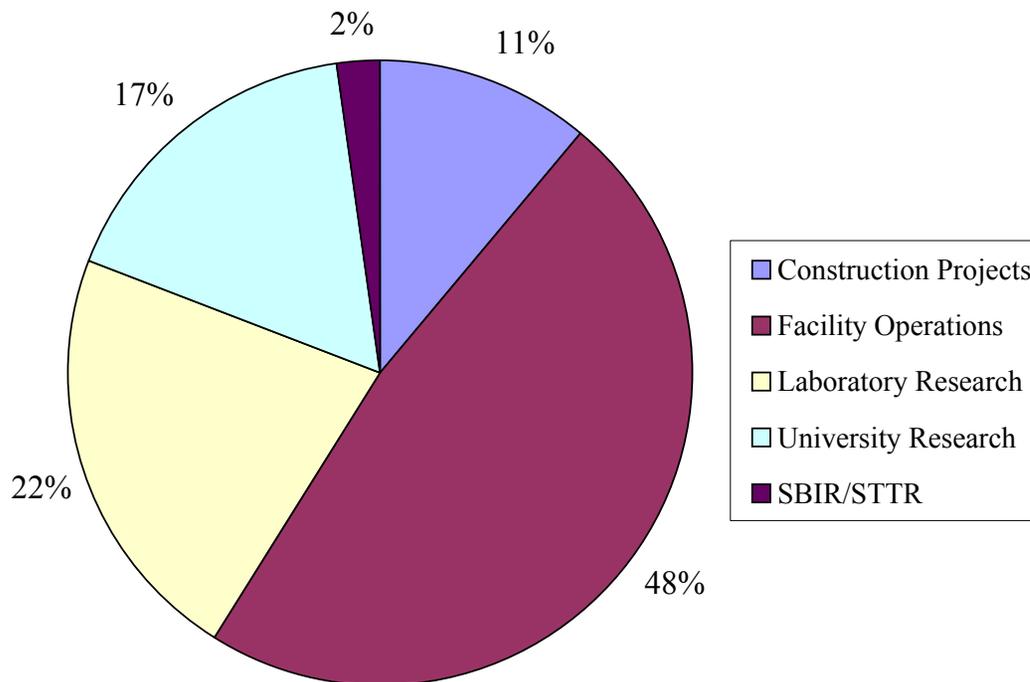
FY03 Funding Distribution

HEP budgets:

FY02 \$697.4M

FY03 \$717.9M

FY04 request: \$738M





DOE High Energy Physics Program

Office of Science

➤ Goal: Ultimate Unification & Hidden Dimensions

- **Tools: Higgs search, Supersymmetry, CP violation, ν mass & mixing, ElectroWeak unification, Extra Dimensions**

Operating:

CDF and DZero experiments at the Fermilab Tevatron accelerator

BaBar at the SLAC PEP-II B-factory accelerator

MiniBooNE - accelerator neutrino oscillation measurement at Fermilab

Super-Kamiokande & K2K – proton decay & neutrinos (Japan)

Construction:

ATLAS & CMS for the Large Hadron Collider (LHC) at CERN

NUMI/MINOS – long baseline neutrino oscillation measurement - Fermilab to Soudan Mine, MN

Future Planning:

Accelerator and Detector R&D for a possible World-community **Linear Collider**

Laser and Plasma driven acceleration and other acceleration studies - ongoing



Particle Accelerators

Fermilab Tevatron Collider



Inside the tunnel





DOE High Energy Physics Program

Office of Science

➤ Goal: Cosmology and Particle Astrophysics

- **Tools: Cosmic ray and gamma-ray studies, Sky maps, Dark Matter searches, Dark Energy studies, Cosmic Microwave Background studies, solar & atmospheric neutrinos**

Operating/Analysis:

Sloan Digital Sky Survey – all sky map, dark matter (DOE, NASA, NSF, foreign)

Supernova Cosmology Project & Nearby Supernova Factory – dark energy (w/NASA)

Construction:

Cold Dark Matter Search (CDMS) – underground in Soudan Mine, Minnesota (w/NSF)

Large Area Telescope (LAT) – on GLAST Mission, launch in 2006 (NASA, foreign)

Pierre Auger – cosmic ray ground array in Argentina (w/NSF, foreign)

AMS – Alpha Magnetic Spectrometer on International Space Station (NASA, international)

Future Planning:

VERITAS – high energy gamma rays, telescope in Arizona (w/NSF, SAO)

SuperNova/Acceleration Probe (SNAP) – precision dark energy measurement from space –
(partnership with NASA)



Particle Accelerators

Pierre Auger high energy cosmic ray detector array – in Argentina

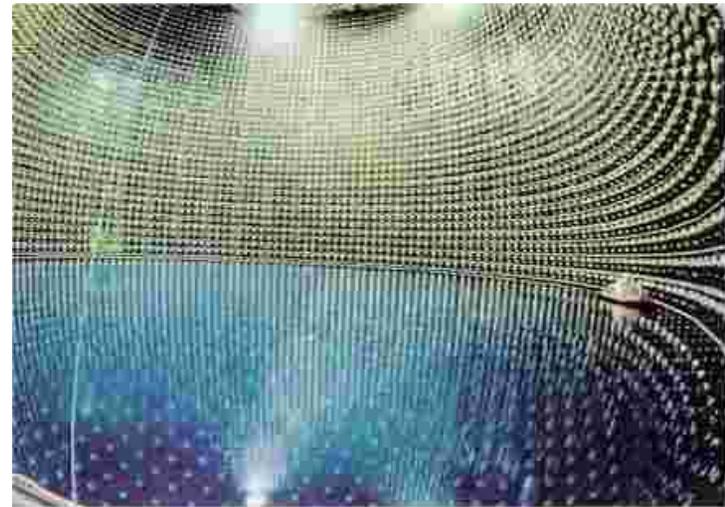
1600 ground stations being built over 3000 km² site



SuperKamiokande – in Japan

Proton Decay search and Neutrino measurements

Uses 50,000 metric tons of pure water





Nuclear Physics Program Goals

– from NSAC 2002 Long Range Plan

Office of Science

- What is the structure of the nucleon?
 - **Quark and gluon structure of the nucleon,**
JLAB and MIT/Bates experiments + RHIC spin program
FUTURE: JLAB Upgrade -
- What are the properties of hot nuclear matter?
 - **Hot nuclear matter in relativistic heavy ion collisions**
BRAHMS, PHENIX, PHOBOS, STAR
- at the Relativistic Heavy Ion Collider (RHIC) at BNL – Quark Gluon Plasma (QGP)
FUTURE: RHIC upgrade - increase in luminosity for further study of the QGP
- What is the structure of nucleonic matter?
 - **Nuclei at the limits of isospin and angular momentum**
Experiments with ATLAS, HRIBF, 88” Cyclotron accelerators
- What is the nuclear microphysics of the universe?
 - **Nuclear reactions important for nucleosynthesis**
Sudbury Neutrino Observatory (SNO) – neutrinos in Canada
HRIBF at Oak Ridge National Lab & ATLAS at Argonne National Lab - radioactive beams
FUTURE: Rare Isotope Accelerator – nuclear astrophysics using an accelerator
- What is the new Standard Model?
 - **Fundamental symmetry properties of neutron and neutrino**
Cold/Ultracold neutrons at LANSCE & SNS
Sudbury Neutrino Observatory (SNO) – neutrinos in Canada
KamLAND – neutrinos in Japan
MiniBOONE at Fermilab

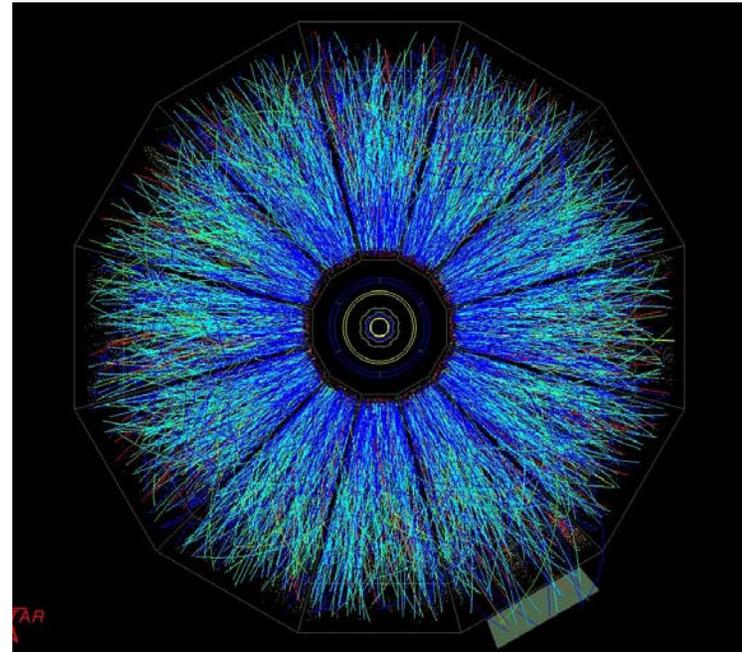


NP Particle Accelerators

Relativistic Heavy Ion Collider



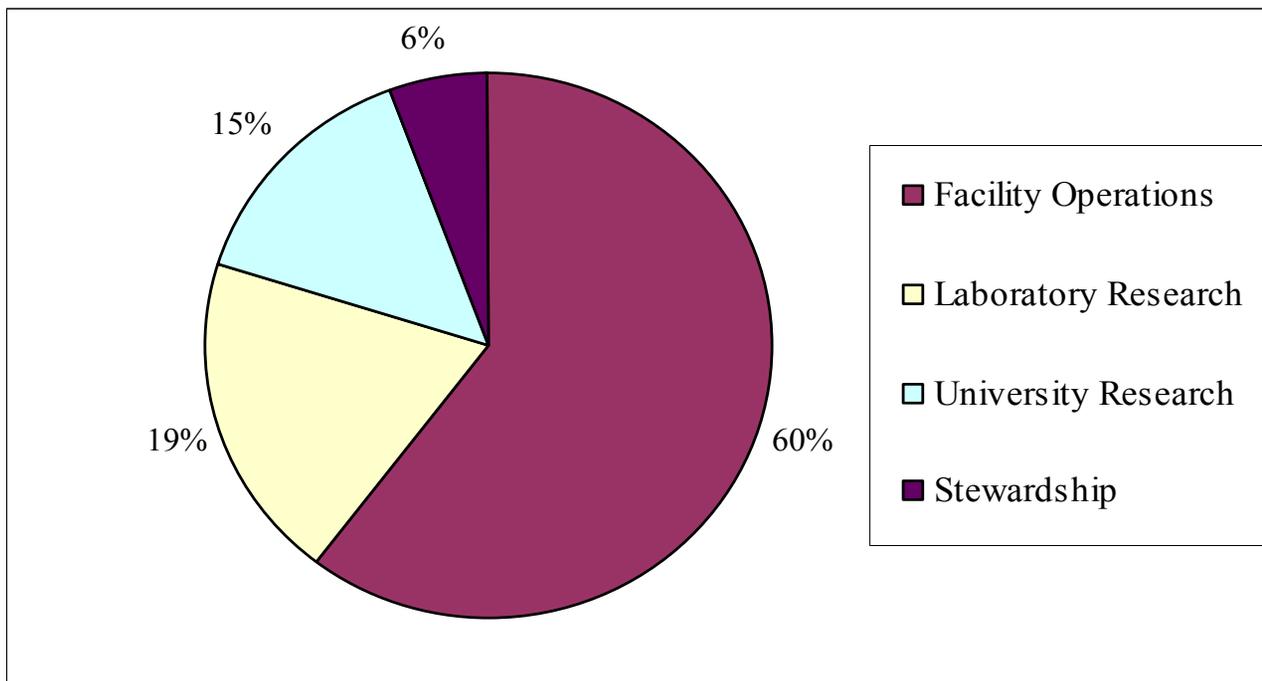
Central gold-gold collision detected by STAR detector at one of the collision areas





DOE Nuclear Physics

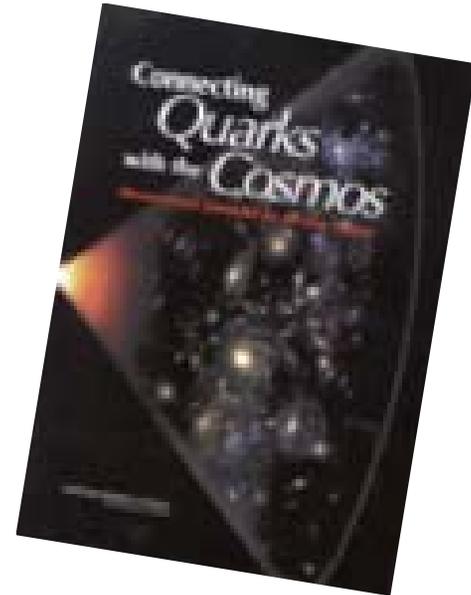
FY03 Funding Distribution





Quarks to the Cosmos

- The NRC report on Connecting Quarks to the Cosmos (Turner Panel) was released in 2002. This study was funded by DOE, NSF & NASA. The resulting report plays an integral part of our program planning process.



Report contains: 11 Questions with 7 resulting Recommendations



Quarks to the Cosmos

Office of Science

Question 1: What is Dark Matter?

Recommendation 3: Explore Unification of Forces from Underground

- ☆ New generation of experiments for neutrinos, dark matter, & proton lifetime (New DOE/NSF Initiative)
- ☆ Recommend that an underground lab w/sufficient depth and infrastructure should be built to house the experiments

Our Program:

Under Construction:

CDMS-II in Minnesota (with NSF) – dark matter

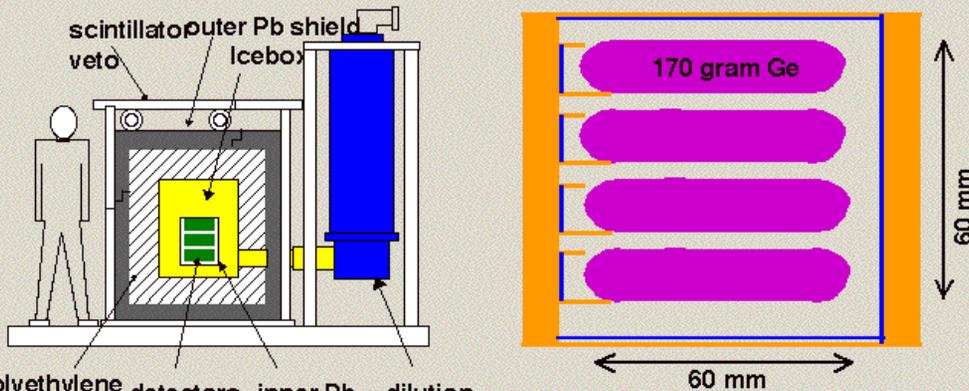
Also have searches:

Tevatron experiments, sky surveys (SDSS), GLAST/LAT

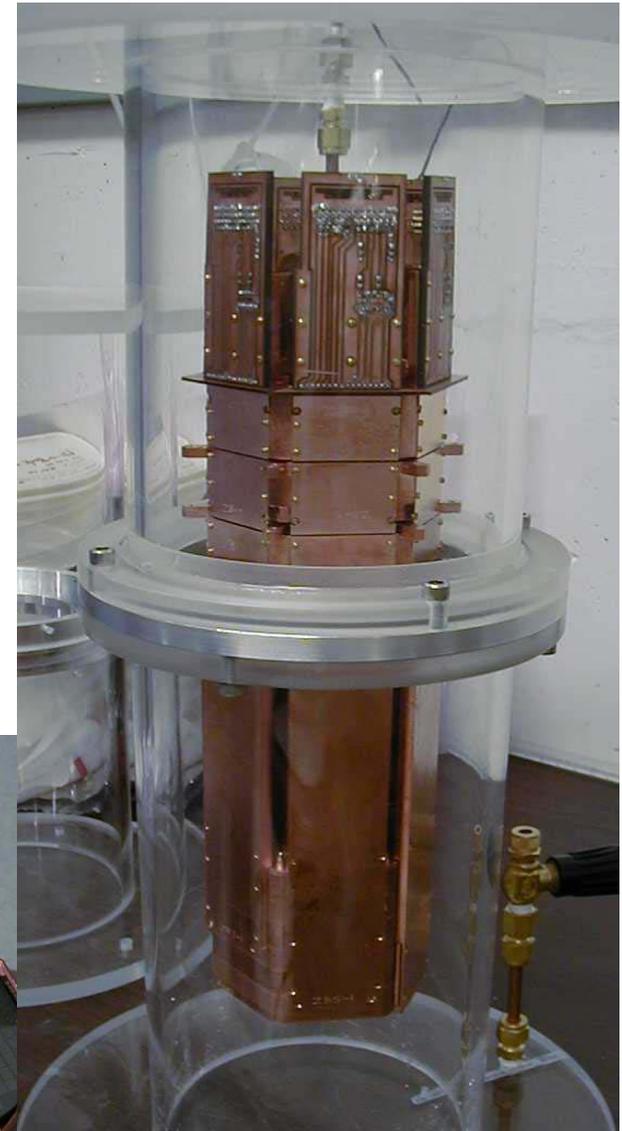


Cold Dark Matter Search - Detectors

The CDMS Experiment



polyethylene detectors inner Pb dilution
 outer moderator detectors shield refrigerator
 The thermal measurement requires that the detectors be cooled. They are maintained at a temperature of 10 milli-Kelvin by a dilution refrigerator. Because the rate for WIMP scattering is so low, the experiment must also be carefully designed for background suppression: high-purity materials with low radioactivity, shielding against external radiation, an underground site to reduce the flux of cosmic radiation, and a veto to detect residual cosmic rays.



Germanium disks





Sloan Digital Sky Survey - Detectors/Equipment



2.5 m Telescope



Mosaic Imaging Camera



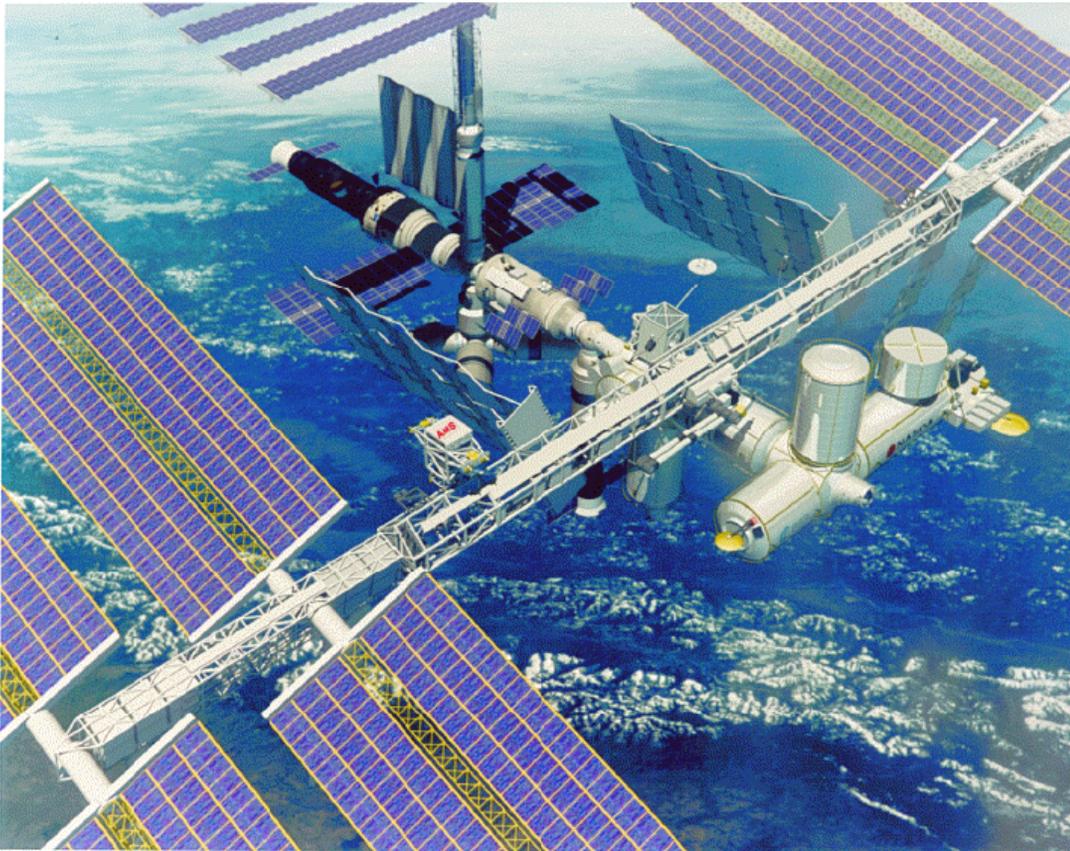
640 Fiber Spectrograph



"Photometric" telescope



AMS - Alpha Magnetic Spectrometer



- An experiment to search in space for dark matter, missing matter & antimatter on the International Space Station
- Still scheduled for Shuttle launch in 2005



Quarks to the Cosmos

Question 2: What is the Nature of Dark Energy?

Recommendation 2: Understanding the Destiny of the Universe

- ★ Large Synoptic Survey Telescope (LSST) – has promise for shedding light on dark energy (Support of Decadal Survey)
- ★ Construct a wide field telescope in space to use supernovae to fully probe the expansion history & the nature of the dark energy (New DOE/NASA Initiative)

Our Program:

Operating:

- Supernova Cosmology Project (SCP) at LBNL
 - continue using ground-based & Hubble space telescope
- Nearby Supernova Factory (SNFactory) at LBNL
 - started recently for ground-based local supernova measurements

Future:

- SNAP (investigating partnership w/NASA)
 - at LBNL, doing R&D now

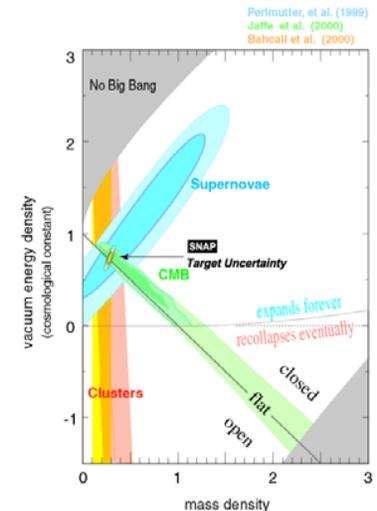
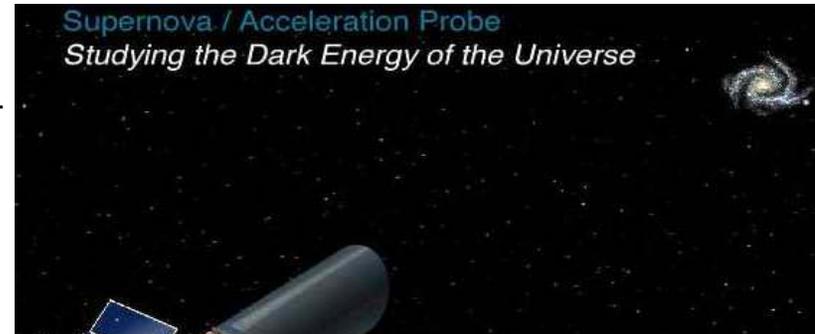


SuperNova/Acceleration Probe (SNAP)

Dark Energy — causing the acceleration of the expansion of the universe
— of central importance to HEP program

Current work:

- **Supernova Cosmology Project (SCP)** – continuing ground and HST measurements to collect statistics over redshift range with Dark Energy effects
- **SNFactory** – large sample of nearby supernovae to study properties in detail
- **Next Step:** precision measurements in space over full redshift range to determine nature of dark energy and history of accelerations and decelerations of the universe
- **HEPAP** facilities and long-range planning subpanels **have endorsed** the proposed SNAP R&D and science
- **DOE is funding R&D**
- **Investigating partnership with NASA**
- SNAP will propose to **NASA's Mission Concept announcement**





Quarks to the Cosmos

Question 3: How did the universe begin and how did its present large-scale structure come to be?

Recommendation 1: Understanding the Birth of the Universe

- ★ Measuring the polarization of the CMB to detect the gravity-wave signature of inflation
(Panel recommends: New DOE/NASA/NSF Initiative)

Our Program:

We are providing support for small group of scientists at universities and labs doing simulations, software algorithms, theoretical studies, hardware R&D and participating in CMB experimental collaborations:

Construction/Operations:

MAXIPOL(NASA,DOE,NSF)

Future:

Planck Surveyor (NASA,ESA)



Quarks to the Cosmos

Question 4: Did Einstein Have the Last Word on Gravity?

Recommendation 4: Explore Basic Laws of Physics from Space

- ★ Support for Constellation-X (Con-X) to probe event horizon of black holes (Support of Decadal Survey)
- ★ Support for Laser Interferometer Space Antenna (LISA) to detect gravity waves from colliding massive black holes (Support of Decadal Survey)

Our Program:

Scientific Discovery via Advanced Computing (SciDAC) program available to apply to for supercomputing time. The Office of Science is working to make our supercomputing facilities more open for use by everybody.



Quarks to the Cosmos

Question 5: What is the mass of the Neutrino and how have Neutrinos shaped the evolution of the Universe?

Recommendation 3: Explore Unification of Forces from Underground

- ☆ **New generation of experiments for neutrinos, dark matter, & proton lifetime (New DOE/NSF Initiative)**
- ☆ **Recommend that an underground lab w/sufficient depth and infrastructure should be built to house the experiments**

Our Program:

Operating:

SuperK, K2K, KamLAND (Japan) – (HEP, NP & NSF)

MiniBoone (Fermilab) – (HEP, NP & NSF)

SNO (Canada) – (NP)

Construction:

NUMI/MINOS (Fermilab/Minnesota)

Future - scientific studies for future experiments:

JHFnu, Superbeams, UNO or HyperK, Solar Neutrinos,

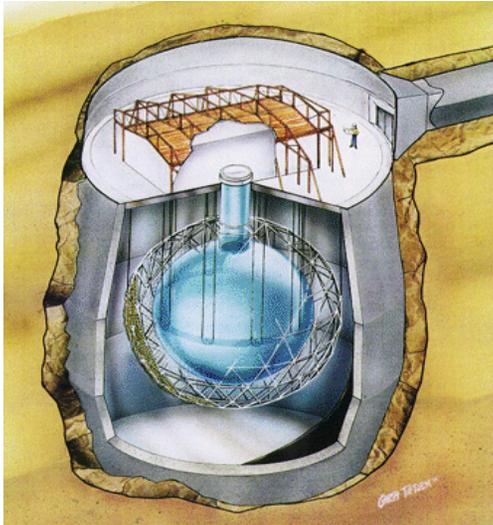
EXO (double beta decay)



Non Accelerator Experiments

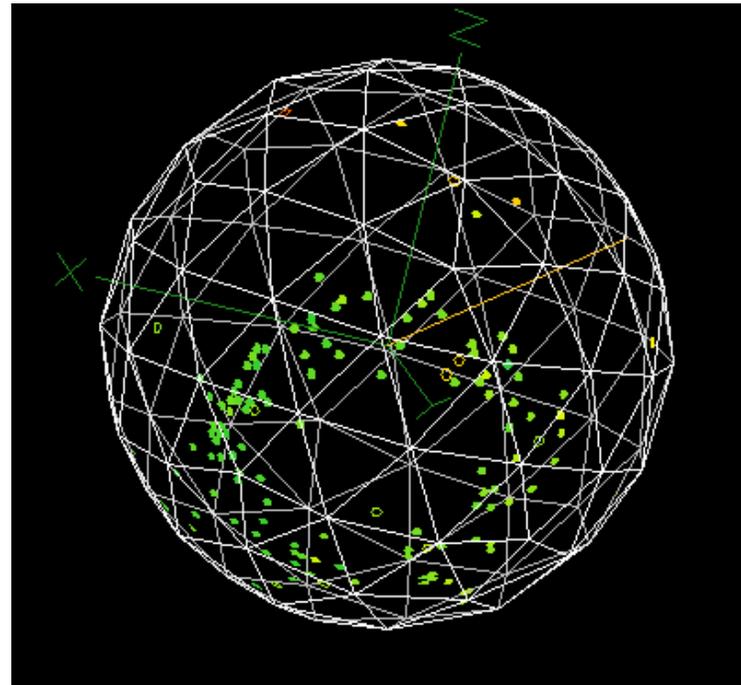
Sudbury Neutrino Observatory Solar Neutrino Detector

Uses 1 kiloton of deuterated water



Sudbury Neutrino Observatory

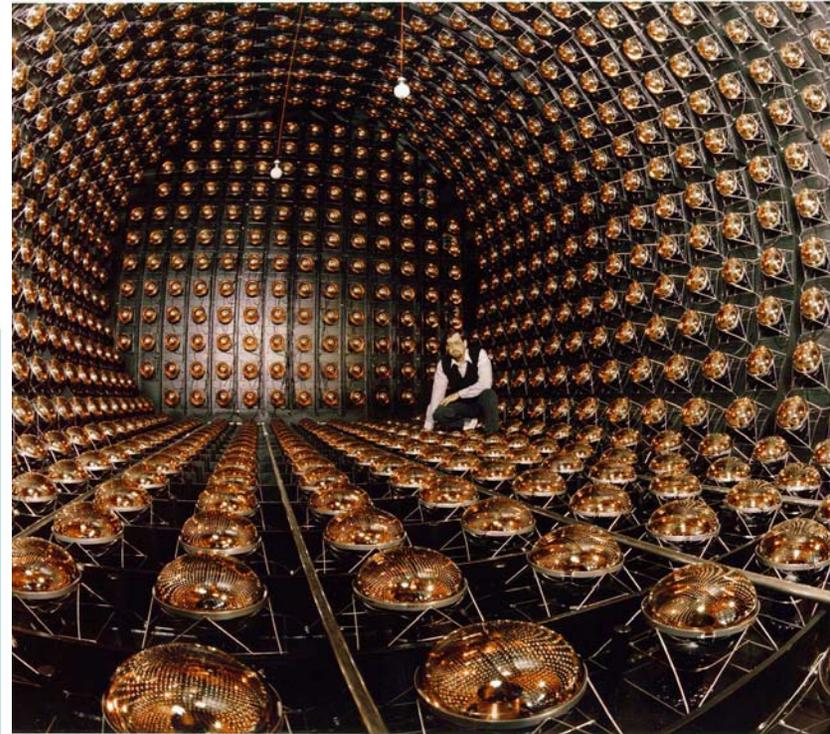
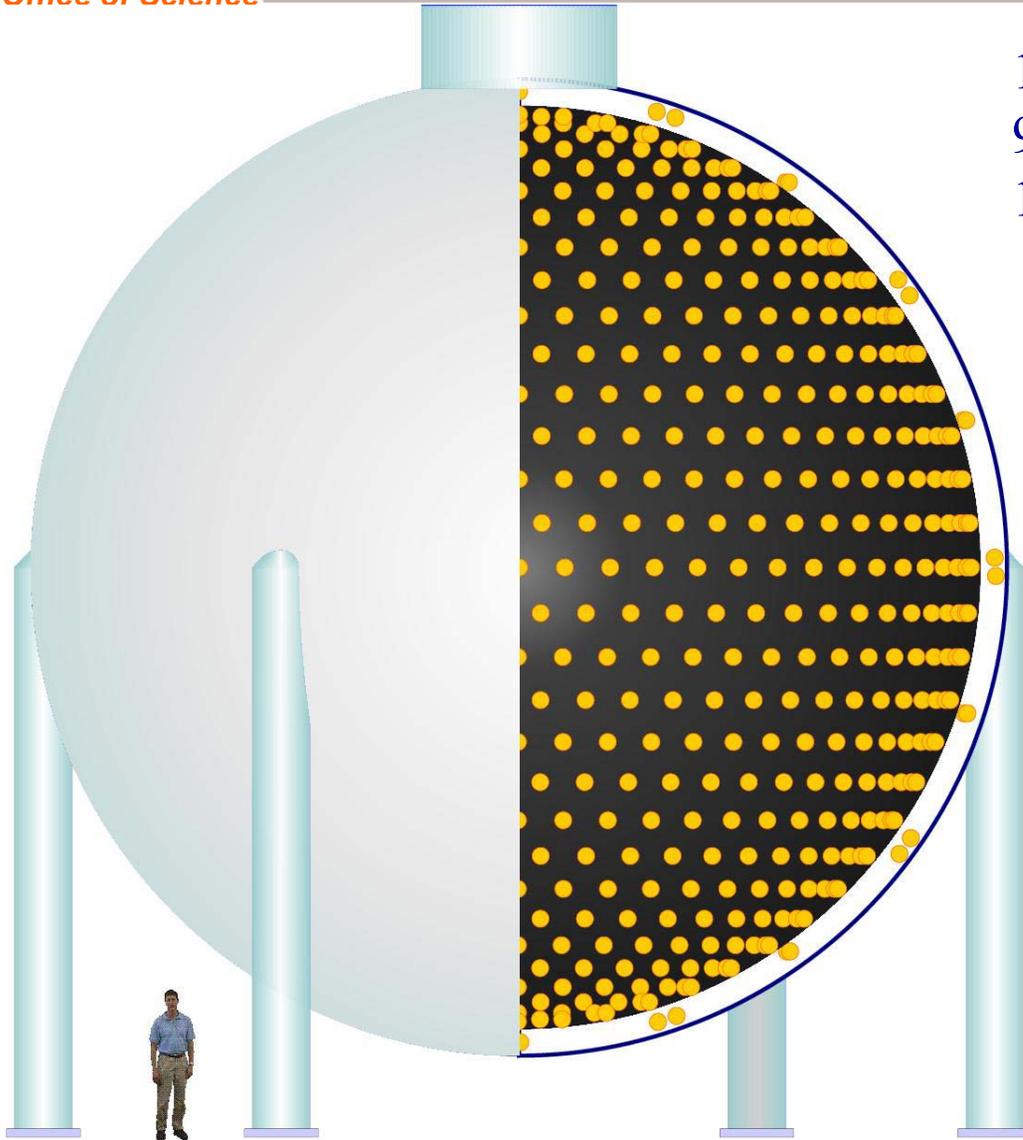
candidate solar neutrino event – Cherenkov light ring





MiniBooNE Detector

12 meter diameter sphere, filled with 950,000 liters of pure mineral oil and 1280 photomultiplier tubes



PMT's in the sphere



Quarks to the Cosmos

Question 6: How do cosmic accelerators work and what are they accelerating?

Recommendation 5: Understanding Nature's Highest Energy Particles

★ Support for current program in measurements of high energy gamma rays, cosmic rays & neutrinos – ensure completion & operation of Southern Auger array

Our Program:

Construction:

GLAST/LAT – (with NASA, foreign)

Pierre Auger (southern) – (with NSF, foreign)

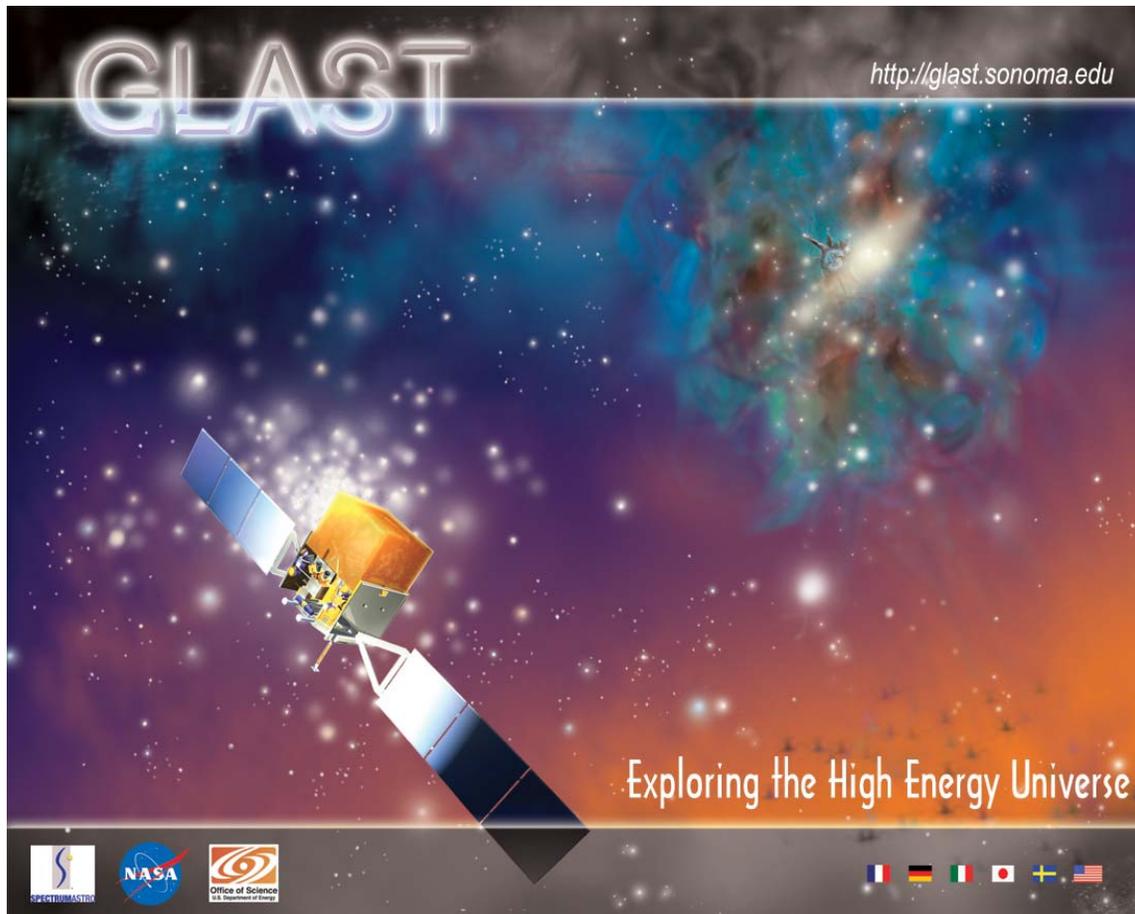
Future:

VERITAS – (with NSF, foreign)



GLAST

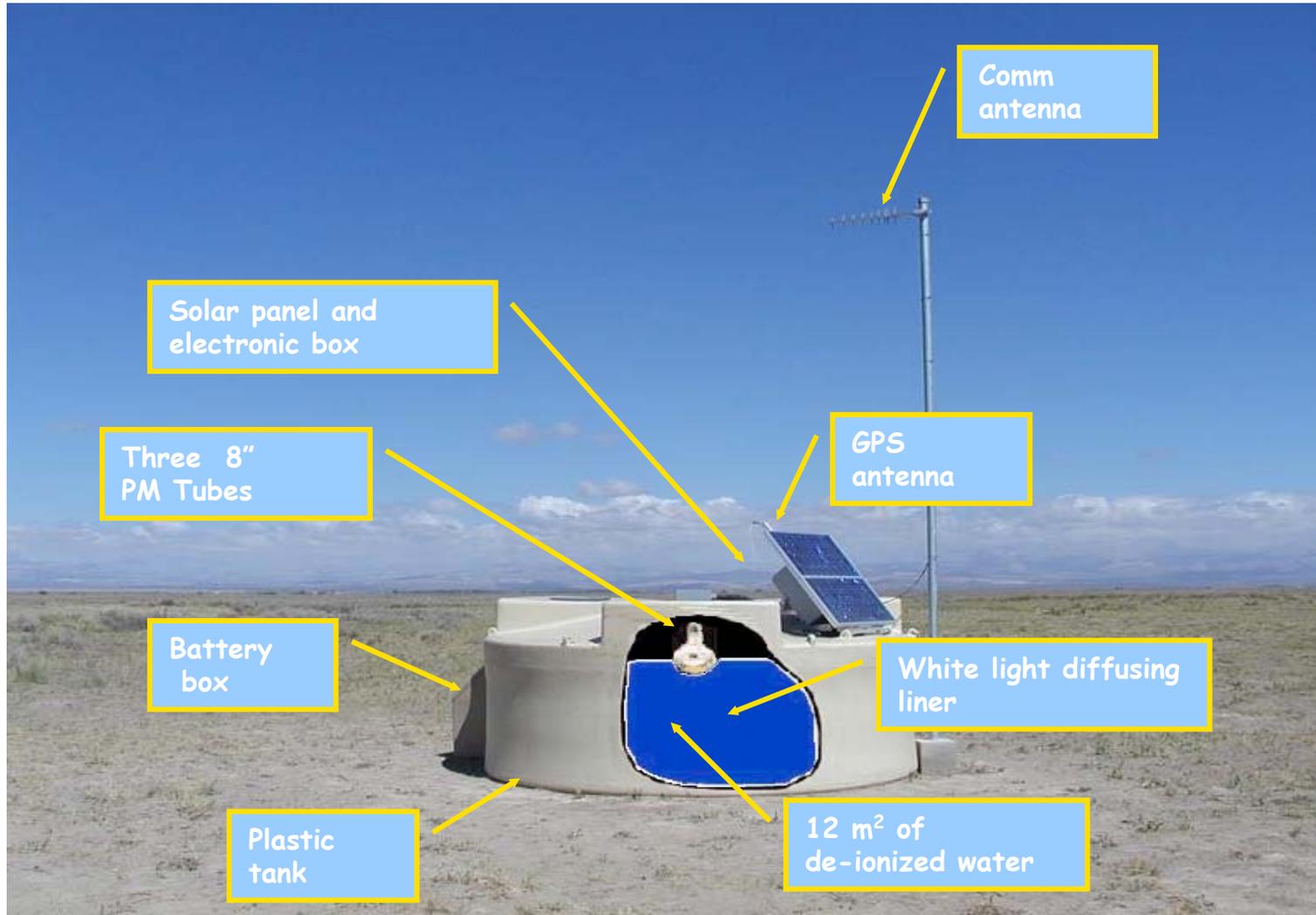
NASA's Gamma Ray Large Area Space Telescope (GLAST) Mission – Measurement of high energy gamma rays from space



- Large Area Telescope (**LAT**) – primary instrument on GLAST
- **NASA/DOE partnership + 4 foreign partners**
- Managed out of SLAC
- Funding profile has been set from DOE-HEP – secure
- LAT project will undergo a **joint NASA/DOE Critical Design Review and CD3/Start of Construction review May 12-16, 2003**
- **Launch** planned for **September 2006**



Pierre Auger - Surface Detector

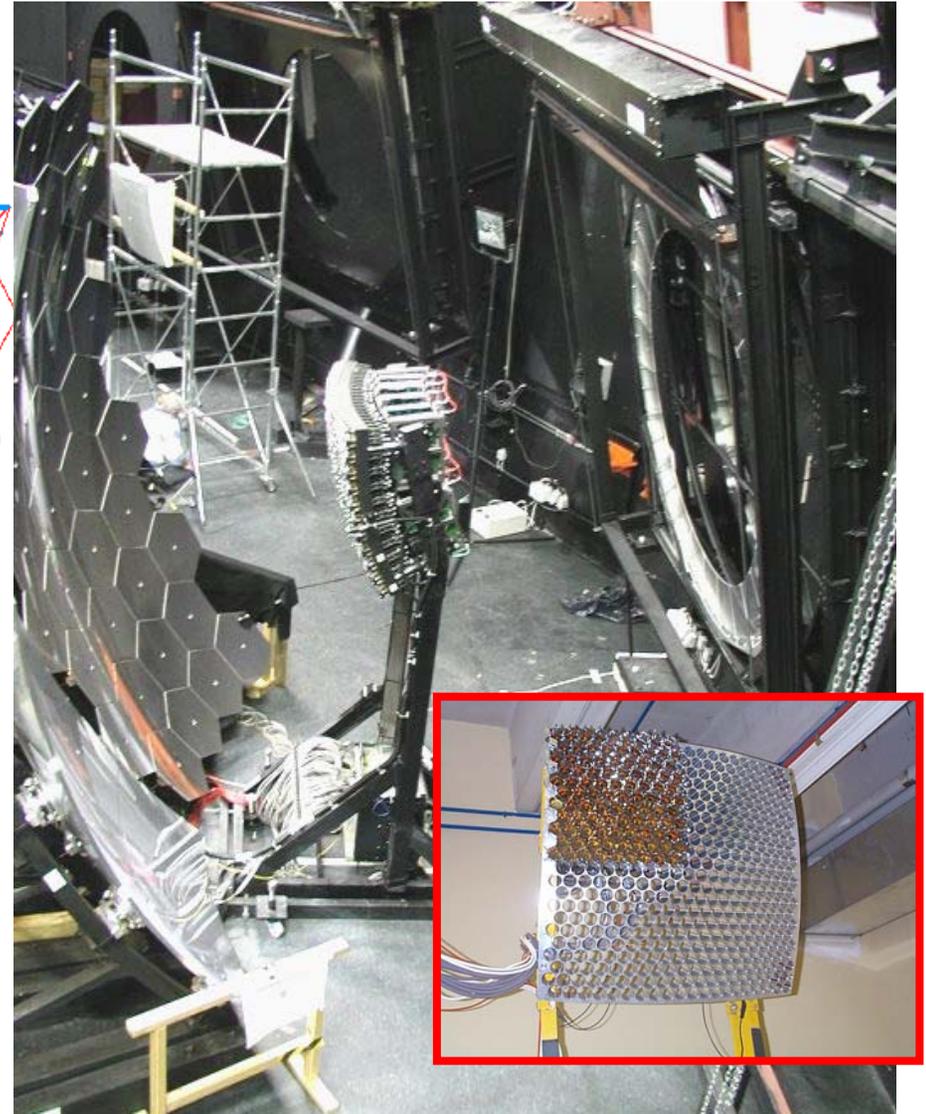
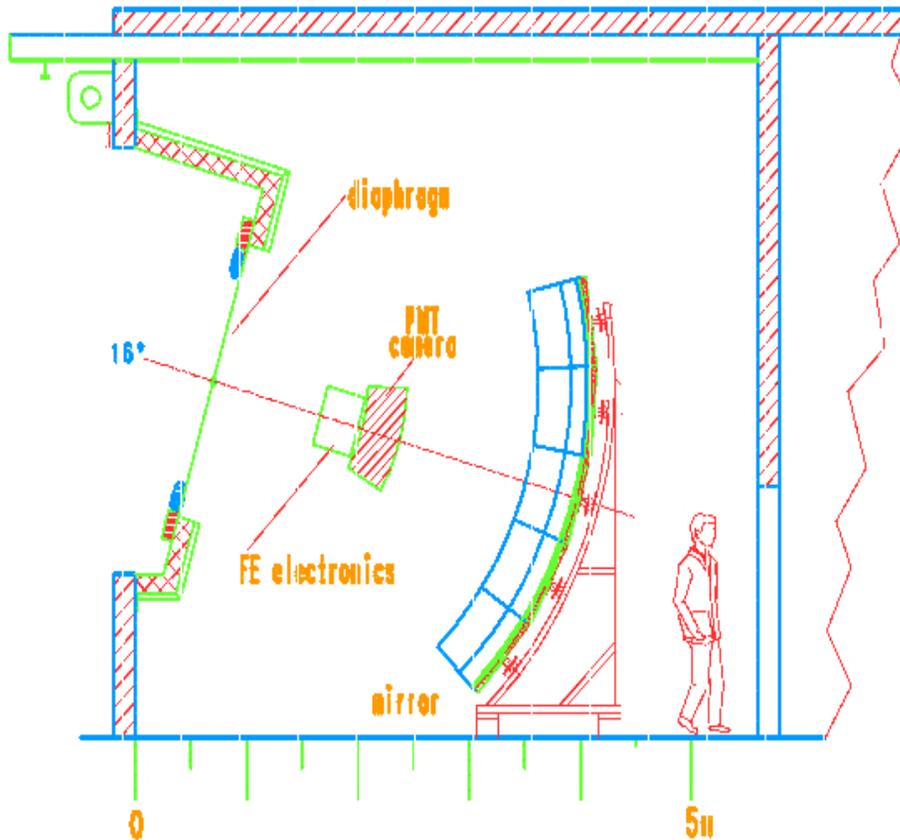




Pierre Auger - Fluorescence Detector

Office of Science

33 telescope units
3.4 meter diameter Mirrors
440 PMTs per camera





Quarks to the Cosmos

Question 7: Are Protons Unstable?

Recommendation 3: Explore Unification of Forces from Underground

- ☆ **New generation of experiments for neutrinos, dark matter, & proton lifetime (New DOE/NSF Initiative)**
- ☆ **Recommend that an underground lab w/sufficient depth and infrastructure should be built to house the experiments**

Our Program:

-- same detectors/experiments as in Question 5, Recommendation

3



Quarks to the Cosmos

Question 8: Are there new states of matter at exceedingly high density and temperature?

Recommendation 3: Explore Unification of Forces from Underground

- ☆ **New generation of experiments for neutrinos, dark matter, & proton lifetime**
(New DOE/NSF Initiative)
- ☆ **Recommend that an underground lab w/sufficient depth and infrastructure should be built to house the experiments**

Our Program:

Operating:

Relativistic Heavy Ion Collider (RHIC) at Brookhaven Lab, along with 4 associated detectors for discovery & study of Quark Gluon Plasma

Future:

RHIC x10 luminosity upgrade - will allow a study of the Quark Gluon Plasma through rare particle probes, thus completing a comprehensive characterization of this new state of matter and gaining new insight



Quarks to the Cosmos

Question 9: Are there additional spacetime dimensions?

Our Program:

Operating:

Tevatron Experiments

Construction:

Experiments at the Large Hadron Collider (LHC) at

CERN

Future:

World-community Linear Accelerator



Quarks to the Cosmos

Question 10: How were the elements from iron to uranium made?

Our Program:

Operating:

HRIBF at Oak Ridge National Lab

ATLAS at Argonne National Lab

Future:

Rare Isotope Accelerator – nuclear astrophysics using an accelerator

Question 11: Is a new theory of matter and light needed at the highest energies and electromagnetic fields?



Quarks to the Cosmos

Recommendation 7:

→ **Interagency Initiative on the Physics of the Universe**

- ★ **Joint planning & implementation of cross-agency projects to realize the scientific opportunities at the intersection of physics and astronomy (Interagency Initiative)**

DOE is part of the Interagency Working Group, spearheaded by OSTP, that is developing joint agency responses to the report.



Other DOE projects with NASA

NASA Space Radiation Laboratory at Brookhaven Lab

- NASA funding, DOE (nuclear physics) construction and operations
- Purpose: radiation simulator for human exploration
- Construction almost complete, commissioning soon

Also - Nuclear Propulsion (not in Office of Science)