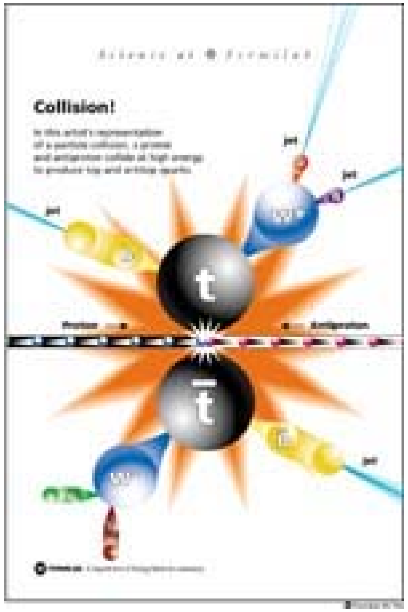
U.S. Department of Energy

Office of Science

The High Energy and Nuclear Physics Program

- 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

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:

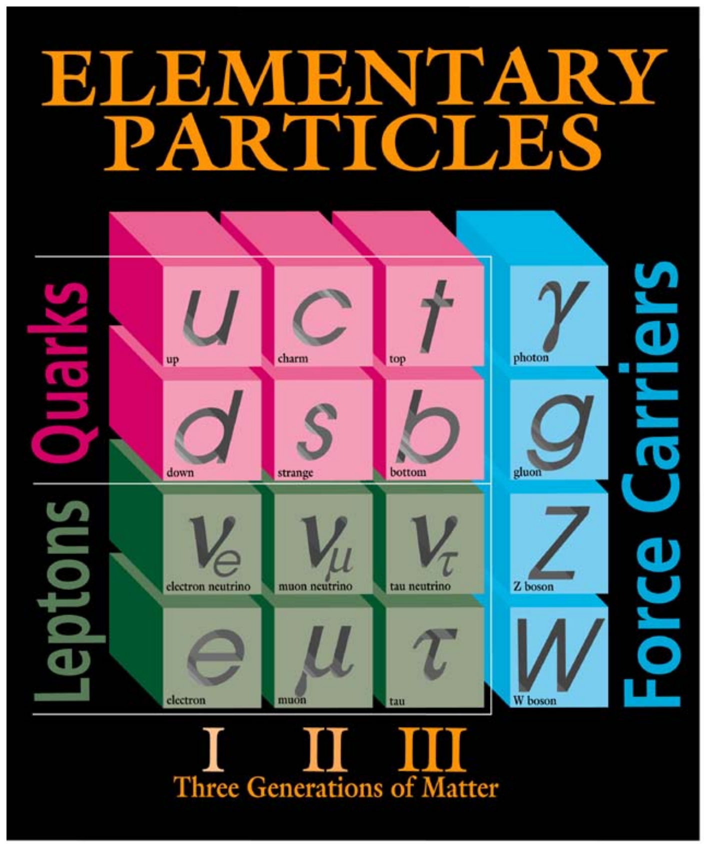
- Particle Accelerators – major part of our program
  "Atom Smashers" ± create particles and interactions
- The Universe
  Experiments underground, on the ground, and in space
  to study fundamental particles and forces

DOE High Energy & Nuclear Physics

Dark Matter

Quark Gluon Plasma

String Theory



Fermilab 95-759

Dark Energy

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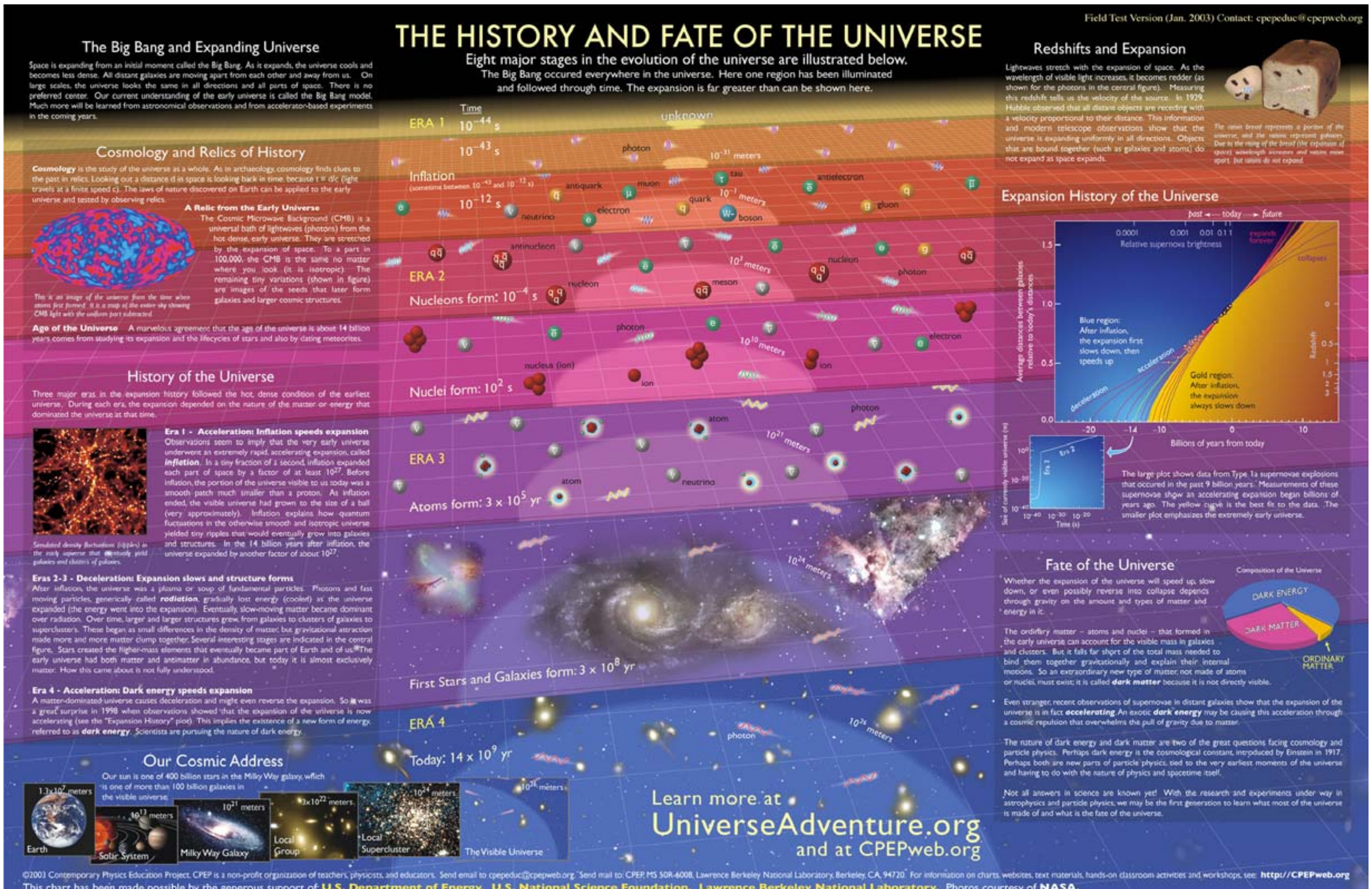
DOE High Energy and Nuclear Physics

Strong Overlaps with Astrophysics & Cosmology



DOE High Energy and Nuclear Physics

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

DOE-HENP þ

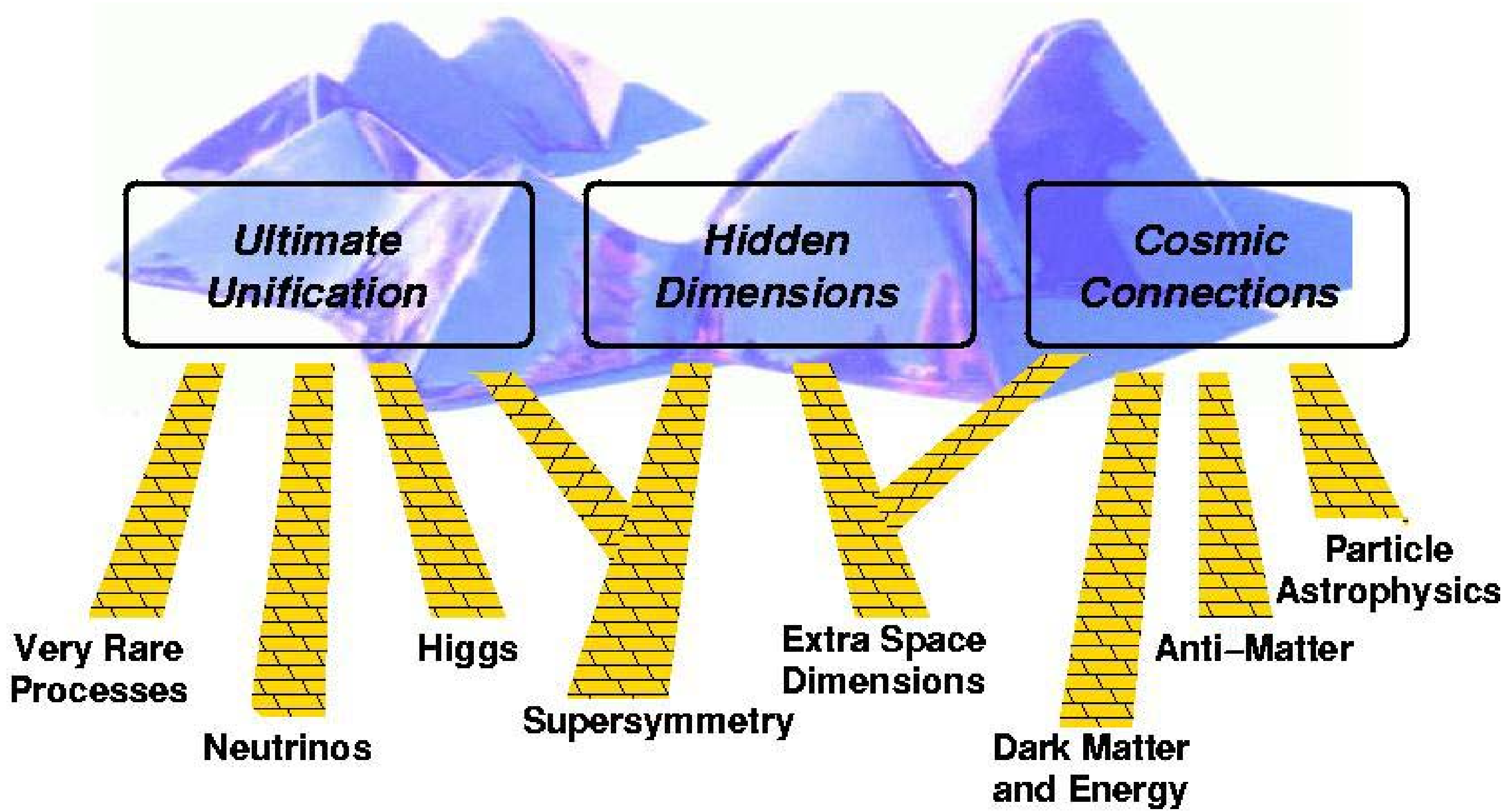
- Supports ~ 90% of the U.S. basic research on fundamental particles and forces and nuclear matter
- Constructs and operates major accelerator research facilities
  - We provide oversight for the labs and have annual peer reviews
  - Experiments undergo rigorous bi-annual independent reviews during construction

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

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

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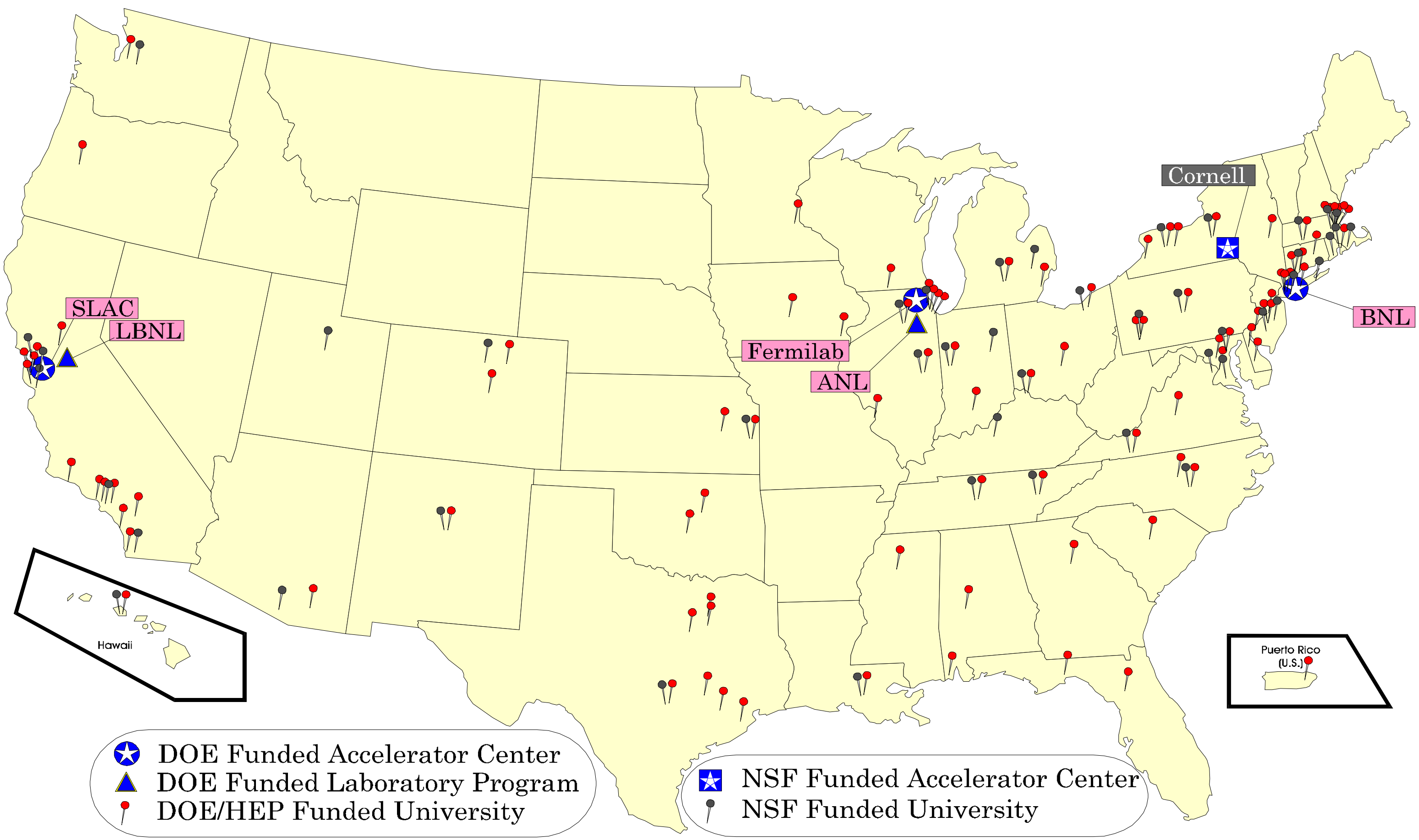
Quarks to Cosmos Recommendation #1

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



DOE High Energy Physics

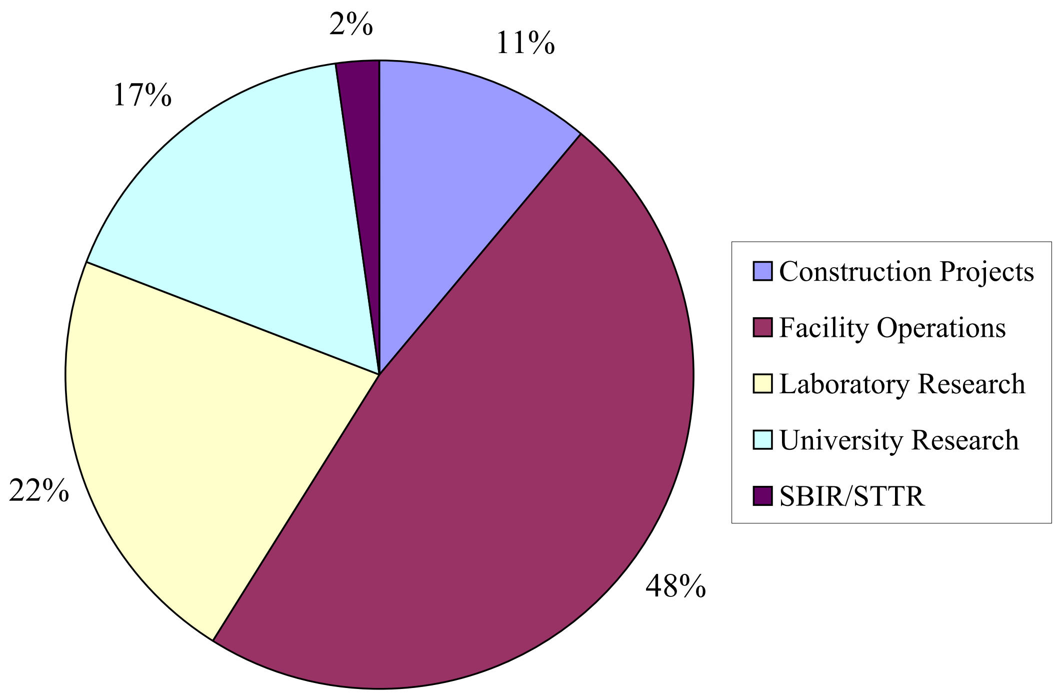
FY03 Funding Distribution

HEP budgets:

FY02 $697.4M

FY03 $717.9M

FY04 request: $738M



DOE High Energy Physics Program

- **Goal: Ultimate Unification & Hidden Dimensions**
  - **Tools: Higgs search, Supersymmetry, CP violation, υ 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

- **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

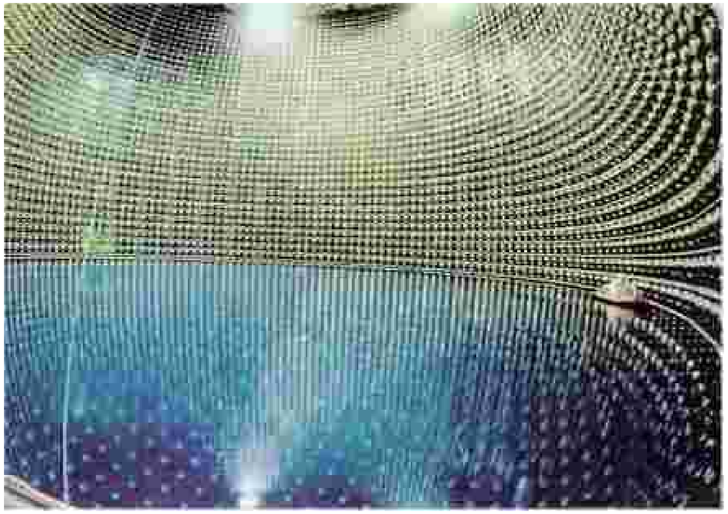
Pierre Auger high energy cosmic ray detector array – in Argentina

1600 ground stations being built over 3000 km^2 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

- 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

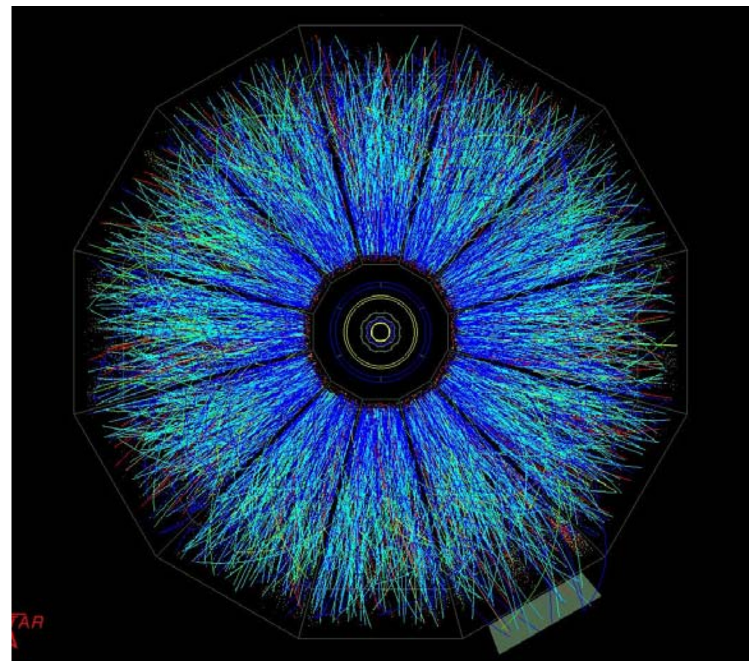
  KamLAND – neutrinos in Japan

  MiniBOONE at Fermilab

NP Particle Accelerators

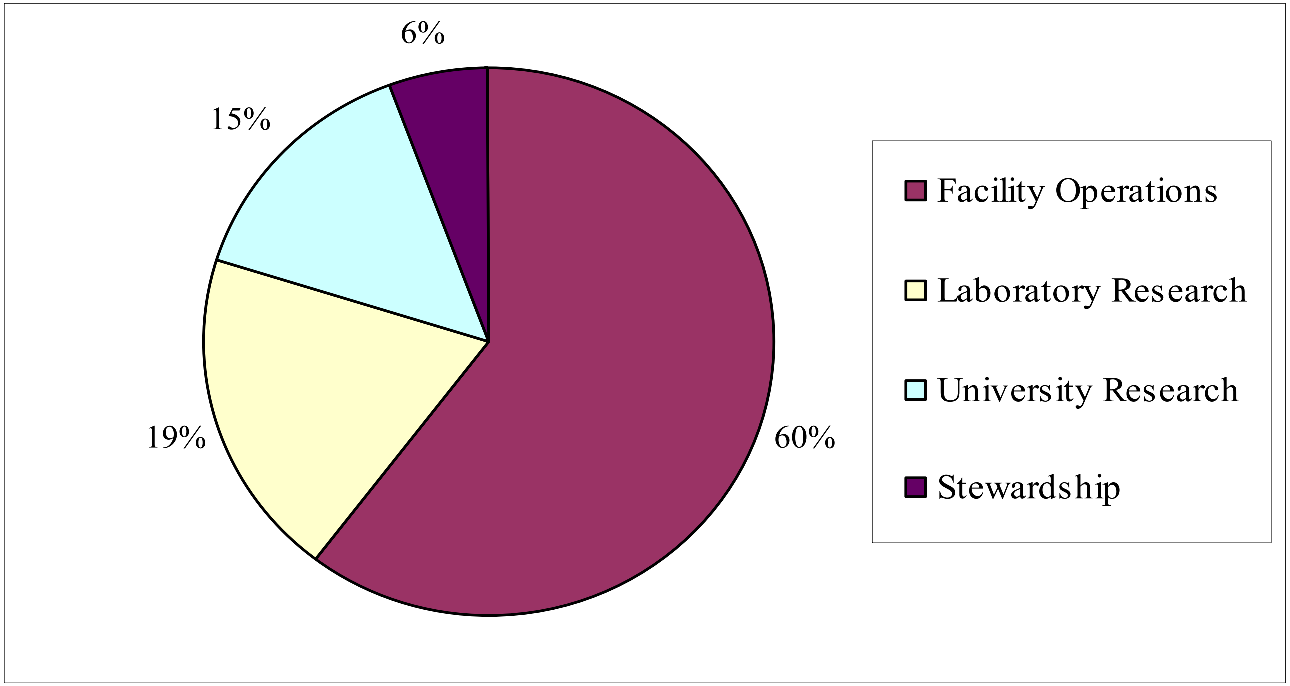
Relativistic Heavy Ion Collider

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

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:

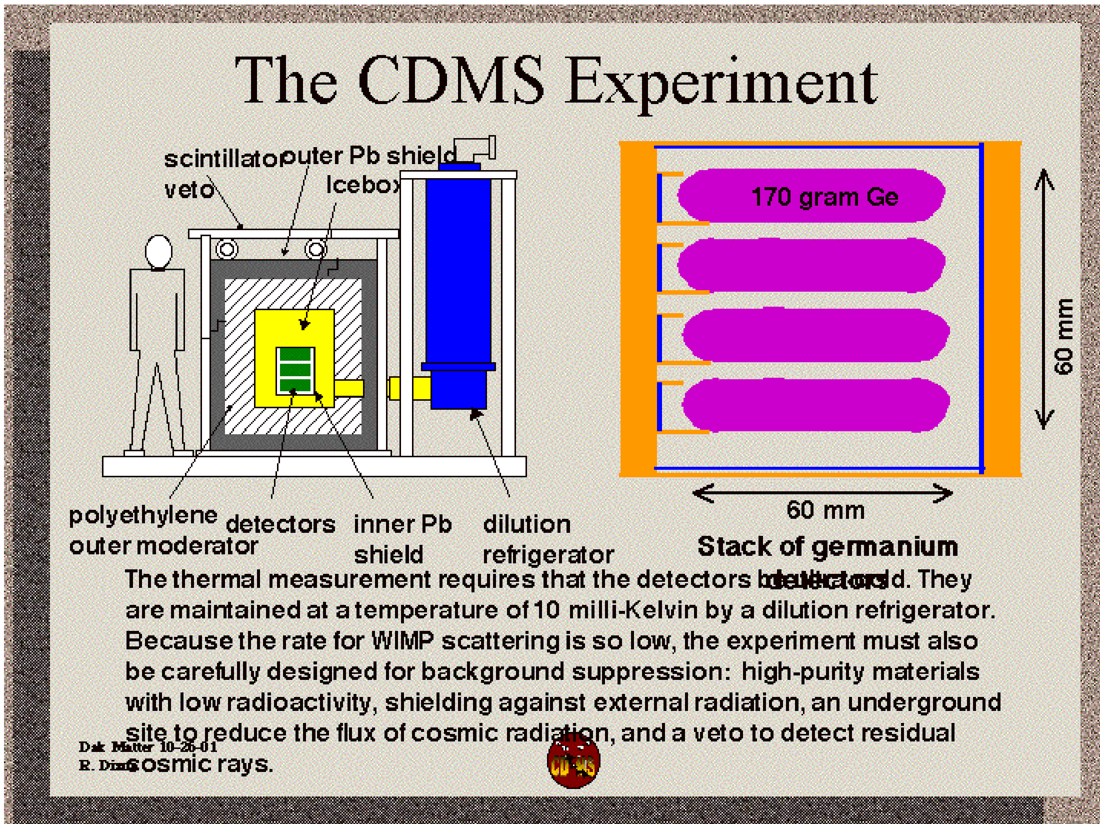
Under Construction:

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

Also have searches:

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

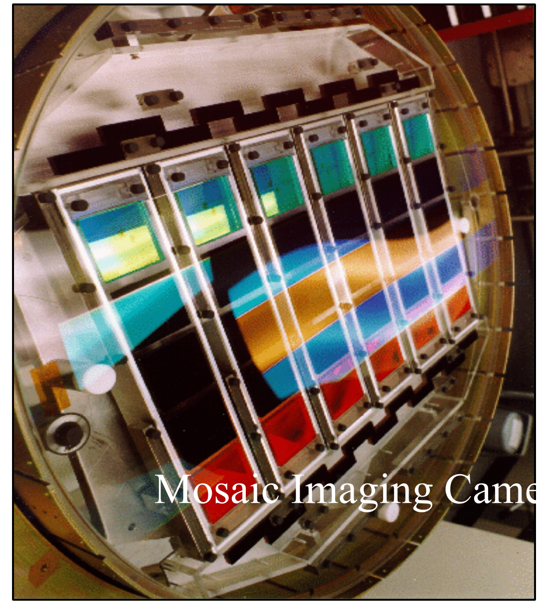
Cold Dark Matter Search - Detectors



Germanium disks

Sloan Digital Sky Survey - Detectors/Equipment

2.5 m Telescope

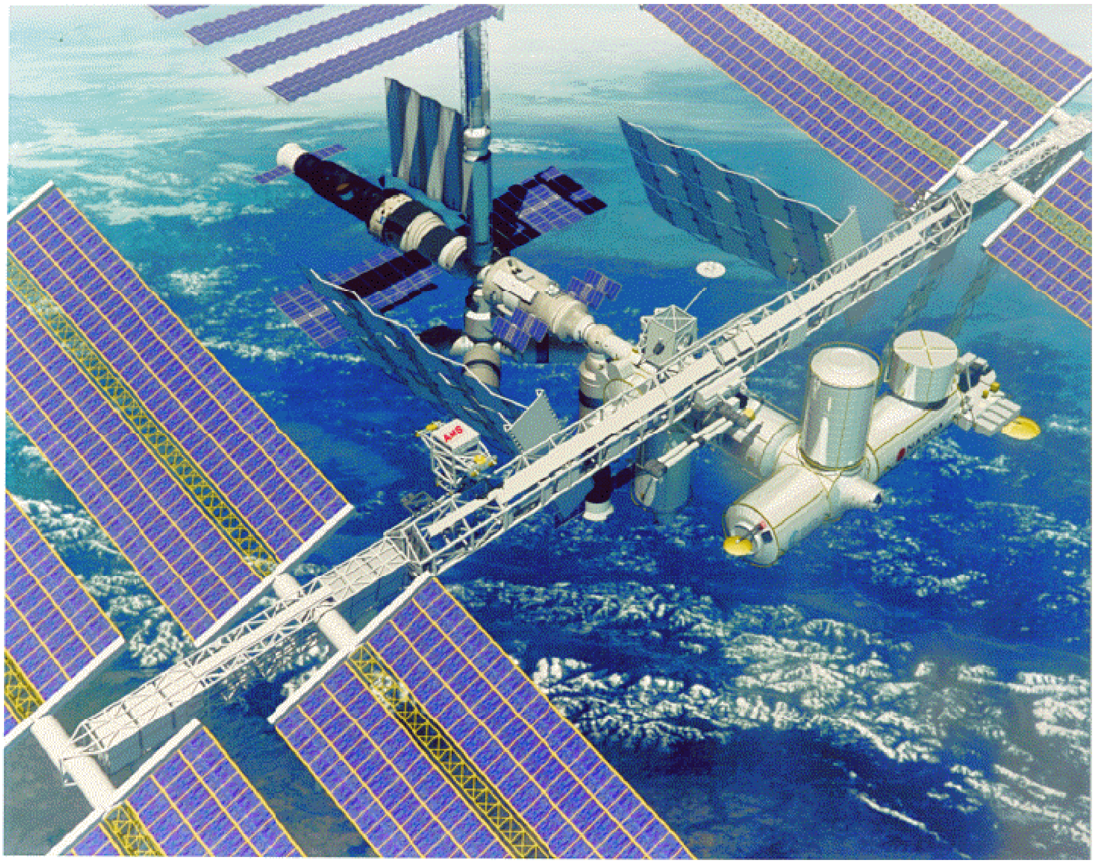


Mosaic Imaging Came

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

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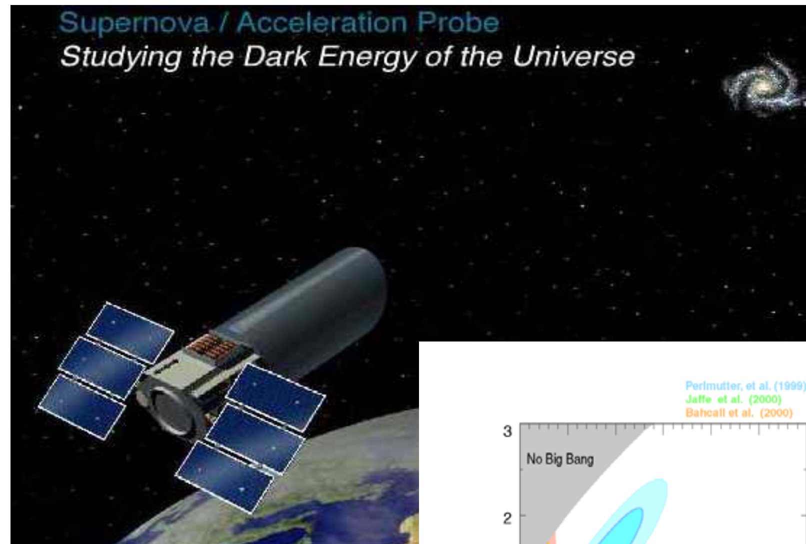
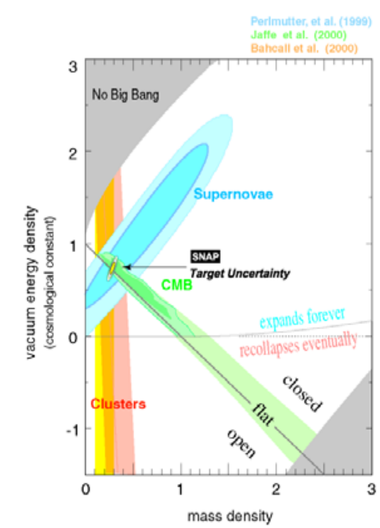
SuperNova/Acceleration Probe (SNAP)

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)

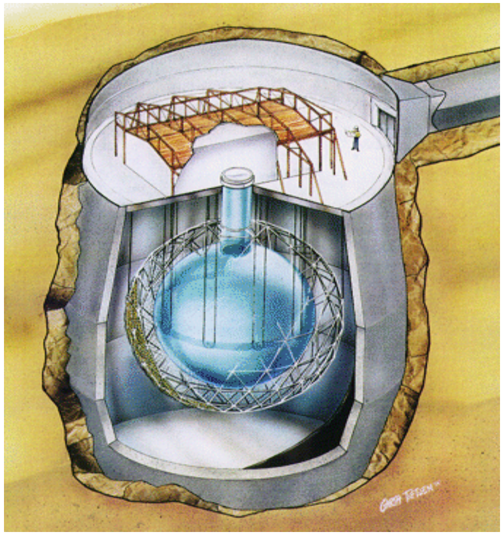
Future - scientific studies for future experiments:

JHFnu, Superbeams, UNO or HyperK, Solar Neutrinos, EXO (double beta decay)

Non Accelerator Experiments

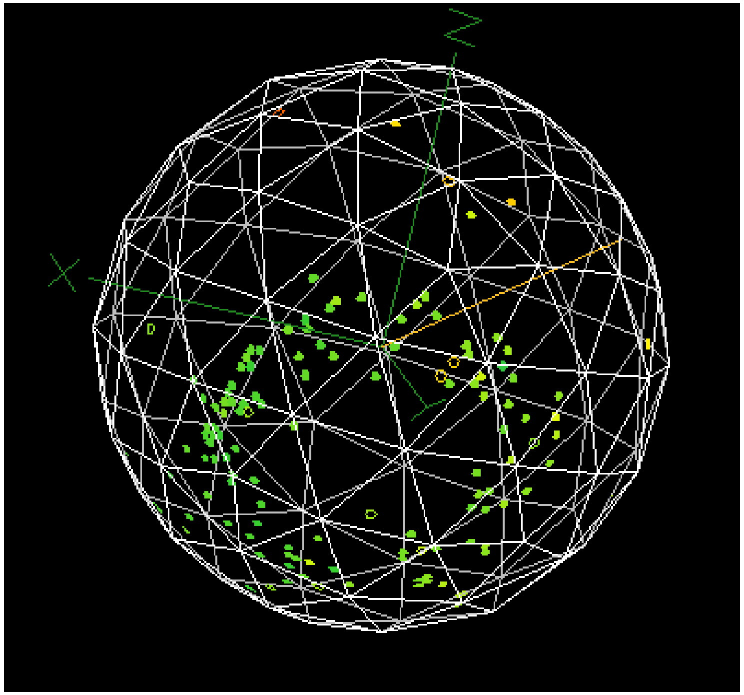
Sudbury Neutrino Observatory
Solar Neutrino Detector

Uses 1 kiloton of deuterated water

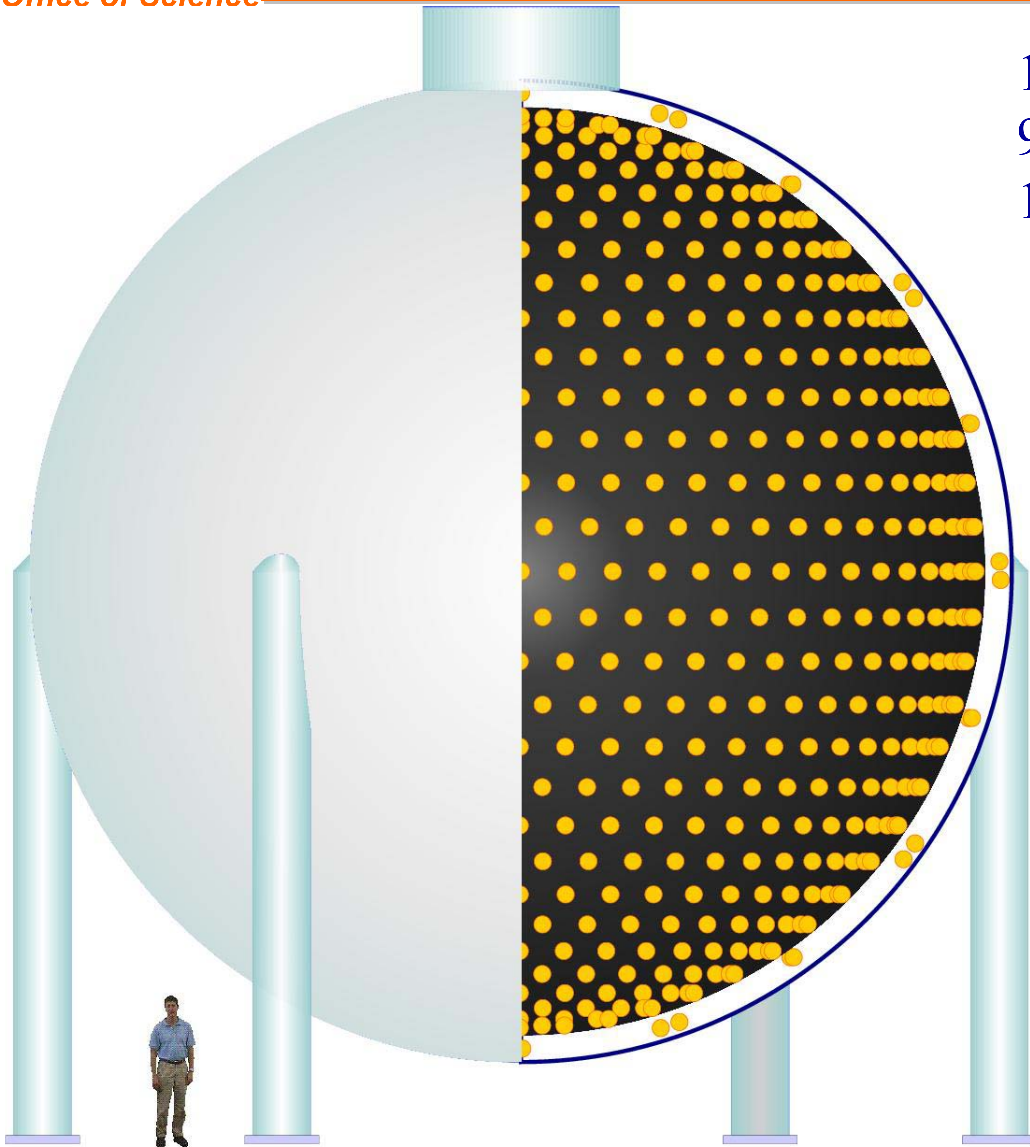


Sudbury Neutrino Observatory

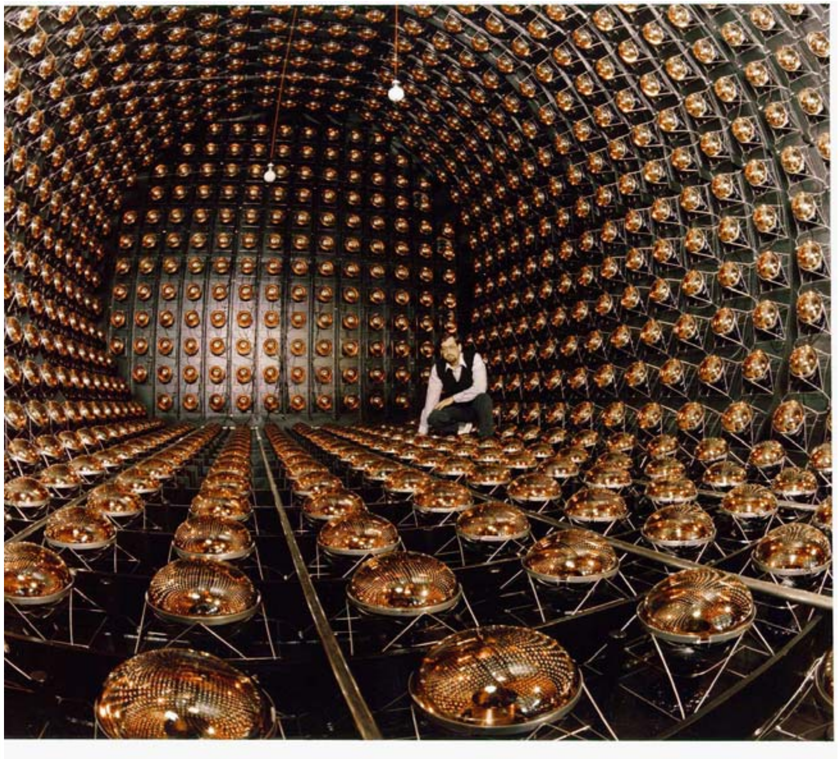
candidate solar neutrino event – Cherenkov light ring



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:

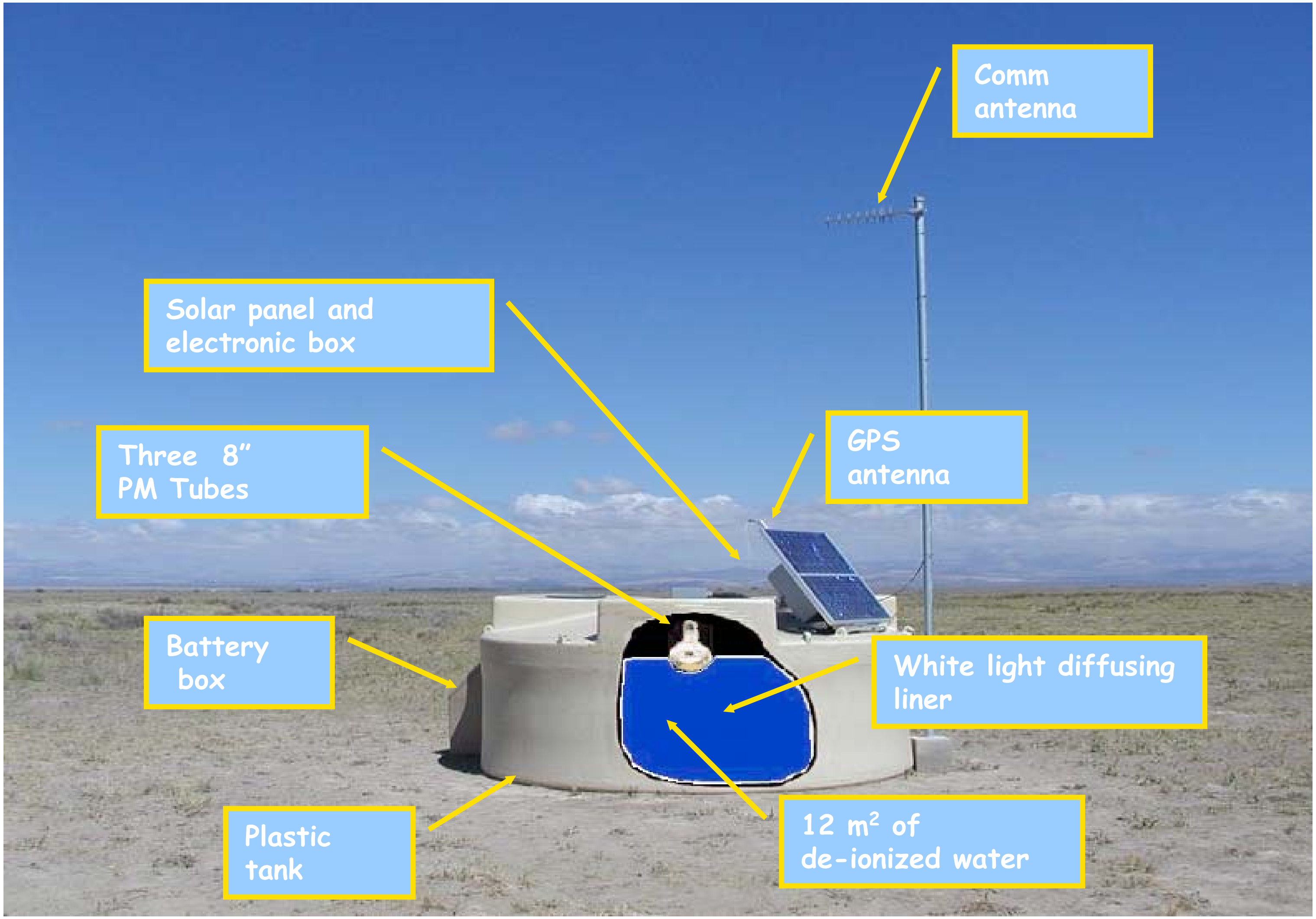
VERITAS – (with NSF, foreign)

GLAST

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

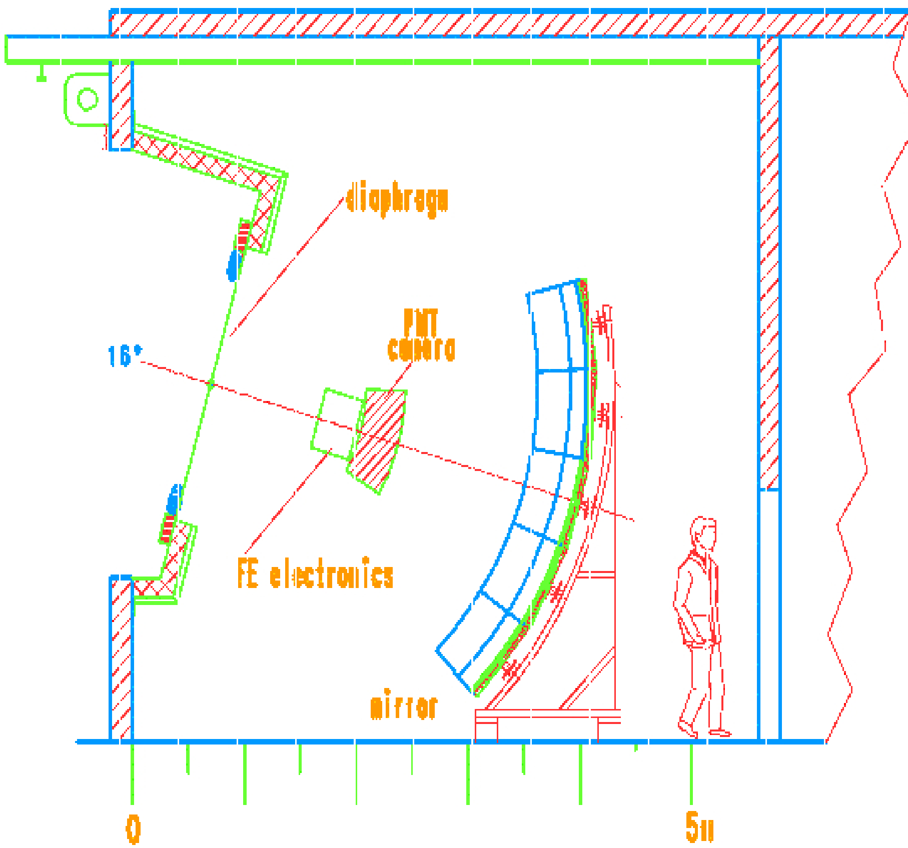
- Large Area Telescope **(LAT) –** primary instrument on GLAST
- **NASA/DOE partnership + 4 foreign partners**
- Managed out of SLAC
- Funding profile has been set from DOE-HEP – secure
- LAT project will undergo a **joint NASA/DOE Critical Design Review and CD3/Start of Construction review May 12-16,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

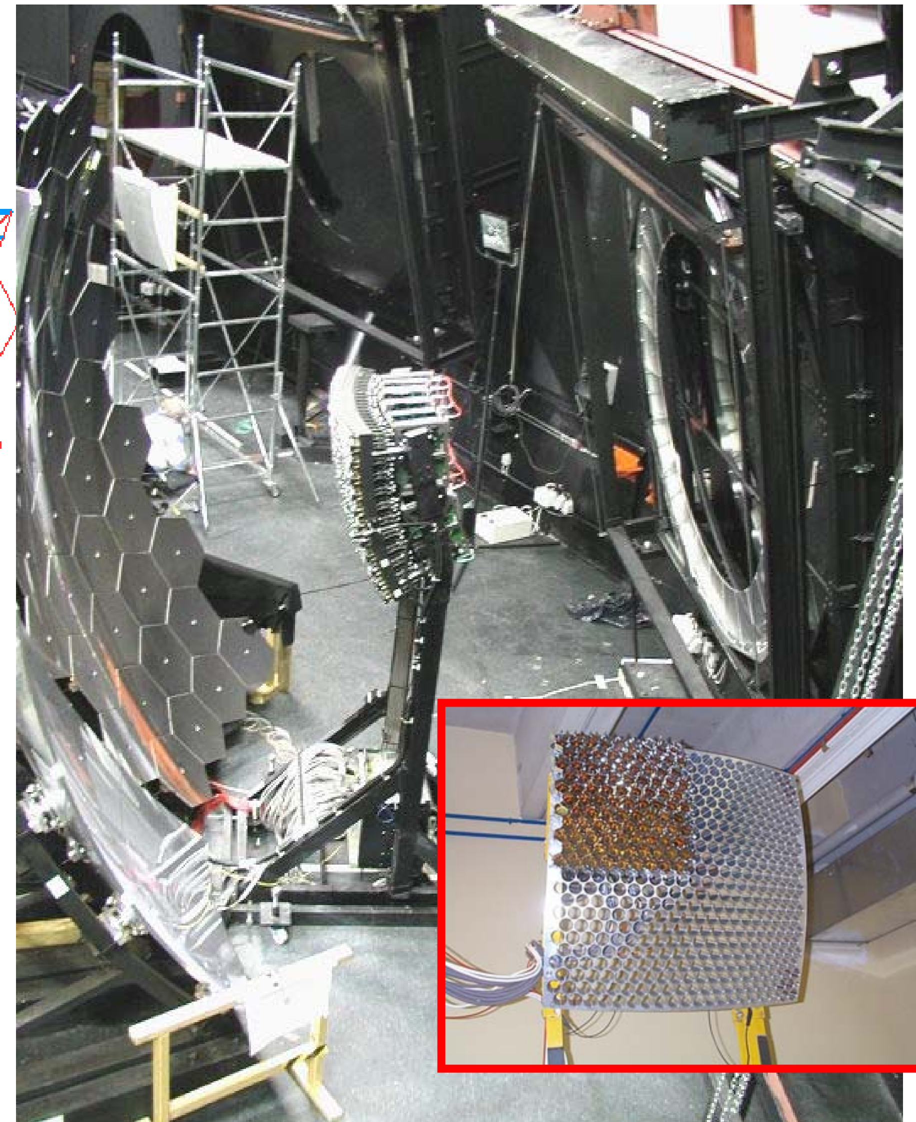
Pierre Auger - Surface Detector



Pierre Auger - Fluorescence Detector

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)