U.S. Department of Energy

Office of Science

The High Energy Physics Program at the U.S. Dept of Energy

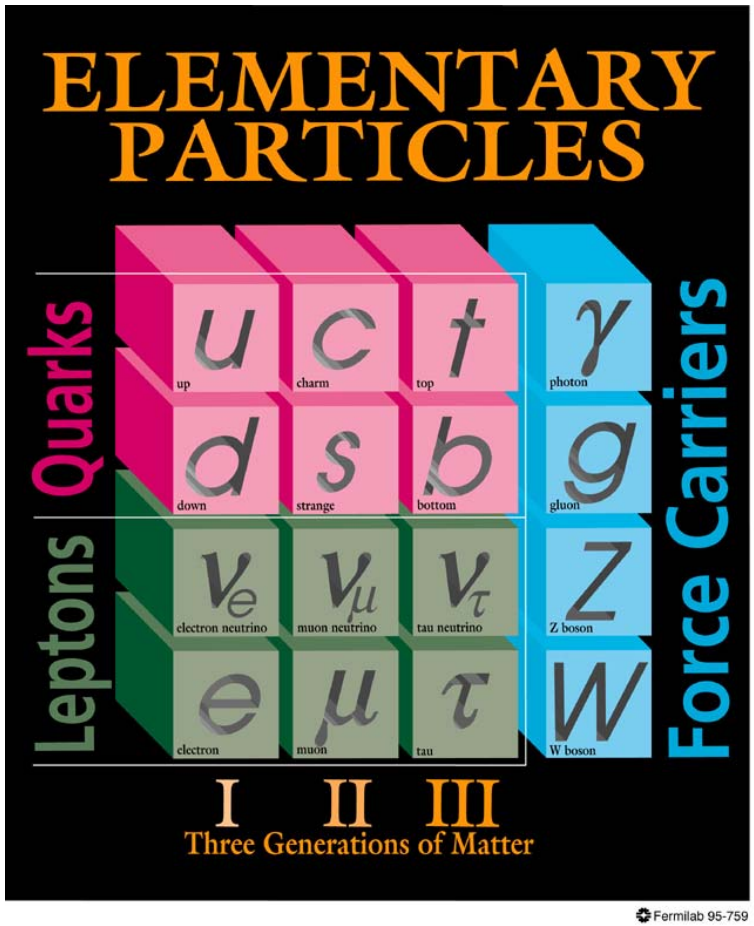
Our Mission:

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.

Dr. Kathleen Turner
Program Manager
Office of High Energy Physics,
Office of Science, U.S. Dept of Energy

University of Virginia
19 March 2004

High Energy Physics (HEP)



The Standard Model of Particle Physics

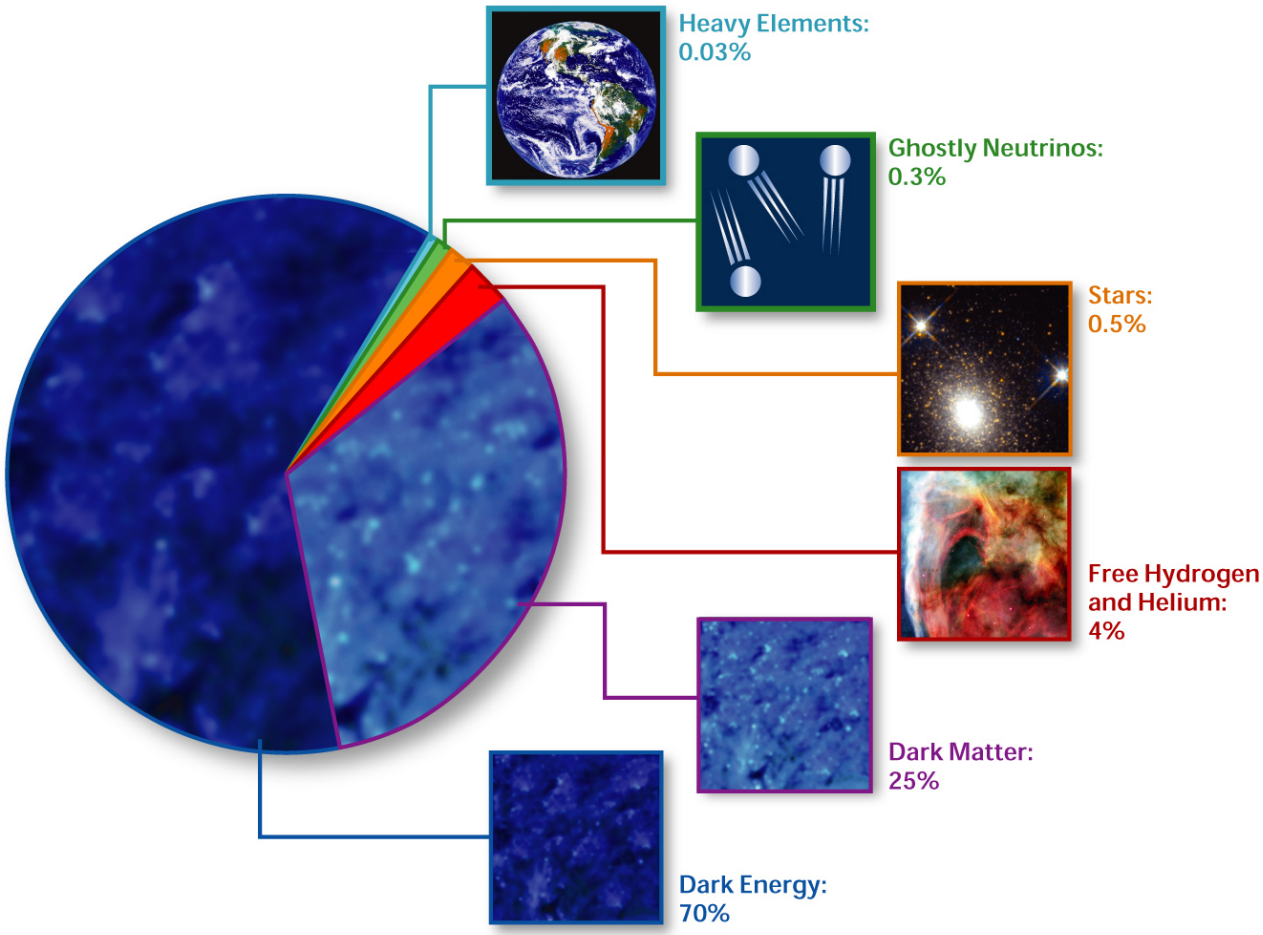
Model of fundamental particles – quarks and leptons – and how they interact through the electromagnetic, weak and strong forces.

- **Has held up to 3 decades of experimental and theoretical work**
- **Still missing: The Higgs boson which gives mass to the fundamental particles**
- **Discovery outside the Standard Model: neutrinos have mass!**

How does gravity relate to matter on the quantum scale?

High Energy Physics & the Universe

Meanwhile… we don't even know what ~ 95% of the Universe is made of!



Threshold of Discovery

- Over the next decade, we may discover a Universe very different from our current understanding.

- HEP program addresses key scientific questions about the Universe at its two extremes – the very large and the very small
  - **What is the path to unification ("Einstein's Dream")?**
  - **What is the fundamental particle that gives all other particles their mass?**
  - **Are there additional or hidden dimensions of space-time?**
  - **What are the masses of neutrinos and what can they tell us about the Universe?**
  - **Why is there more matter than antimatter in the Universe?**
  - **What is the nature of Dark Matter and Dark Energy?**

Where we get our data:

- Particle Accelerators – major part of our program

  "Atom Smashers" ± create particles and study their interactions

- The Universe

  Experiments underground, on the ground, and in space to study fundamental particles and forces

High Energy Physics – How We Work

Research conducted at over 100 universities and 5 national labs in U.S.
-- also at laboratories abroad

- experimental and theoretical research
- computing plays an important role - large data acquisition & crunching needs
- R&D for accelerator and detector technologies

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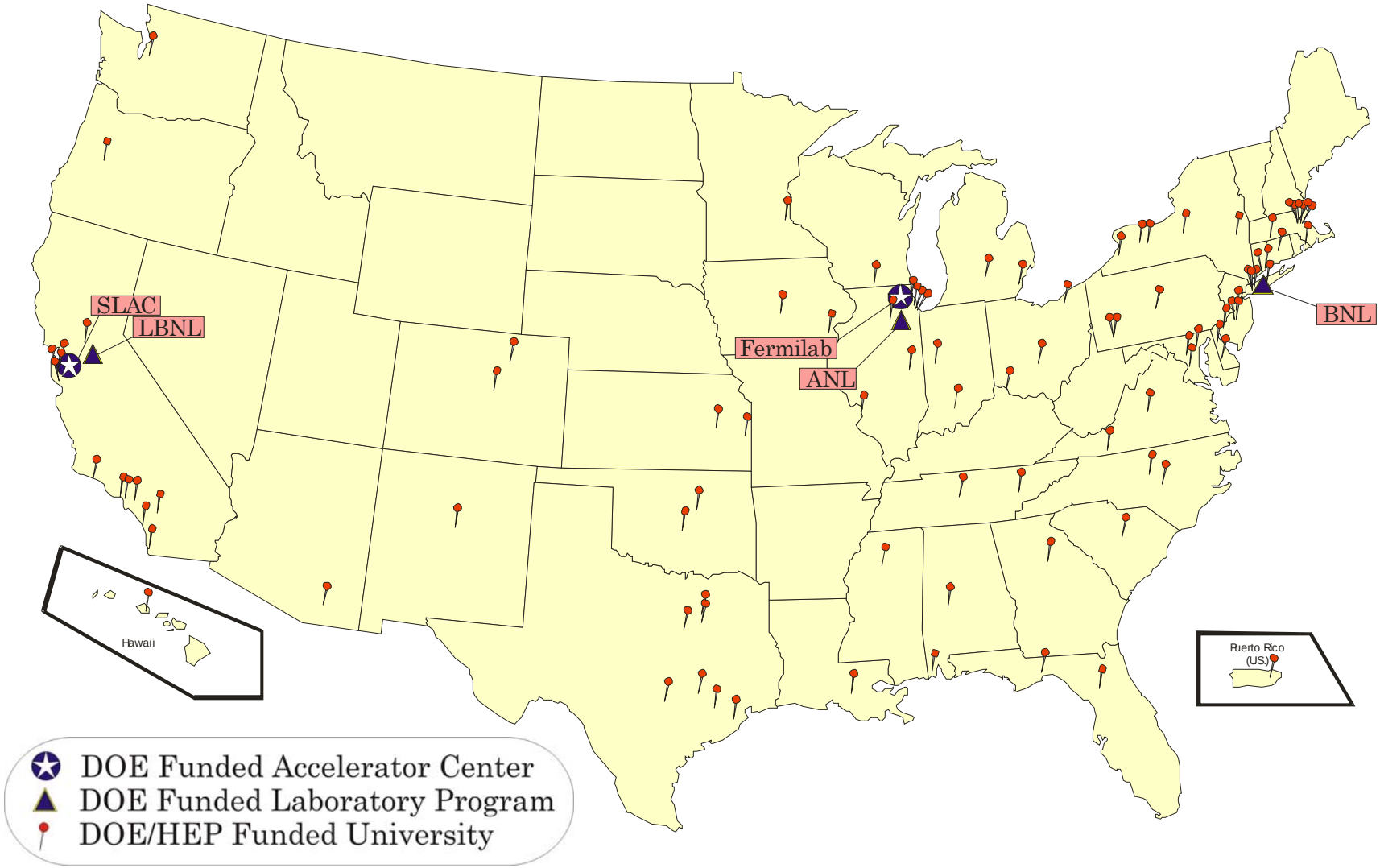
High Energy Physics Research conducted by scientists and students from over 100 universities and 7 laboratories nationwide



High Energy Physics – How We Work

This is a community-driven field!

Process:

Receive proposals from the scientific community and peer review them for their significance to:

- Scientific and Technical relevance to the program

Program Direction:

DOE/NSF High Energy Physics Advisory Panel (HEPAP) is a federally chartered scientific community panel that provides advice to the government

+ Lab advisory committees, National Academy of Science reports, subpanels, etc.

High Energy Physics Program Planning

This is a community-led field

- Scientists are involved in all phases and at all levels of a project: Conception, design, construction, operations, analysis
- We fund & follow this community and their expertise in pursuing the goals of our program.

Steps:

- Proposed projects come up via grass roots effort – labs have discretionary funds to start up new ideas
- Lab Program Advisory Committees (PAC) and the Scientific Assessment Group for Experiments in Non-Accelerator Physics (SAGENAP) panels review and assess new proposed projects
- HEPAP & it's subpanels make recommendations on our program

Theorists involved in all these activities too.

High Energy Physics Program

- **Goal: Ultimate Unification, Origin of Mass, Hidden Dimensions, Matter vs. Anti-Matter**
  - **Tools: Higgs search, Supersymmetry, CP violation, ElectroWeak unification, search for Extra Dimensions**

Operating:

CDF and DZero experiments using the Tevatron at Fermilab
BaBar at the PEP-II B-factory accelerator at SLAC

Under Construction:

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

Future Planning:

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

BTeV experiment for the Tevatron collider at Fermilab

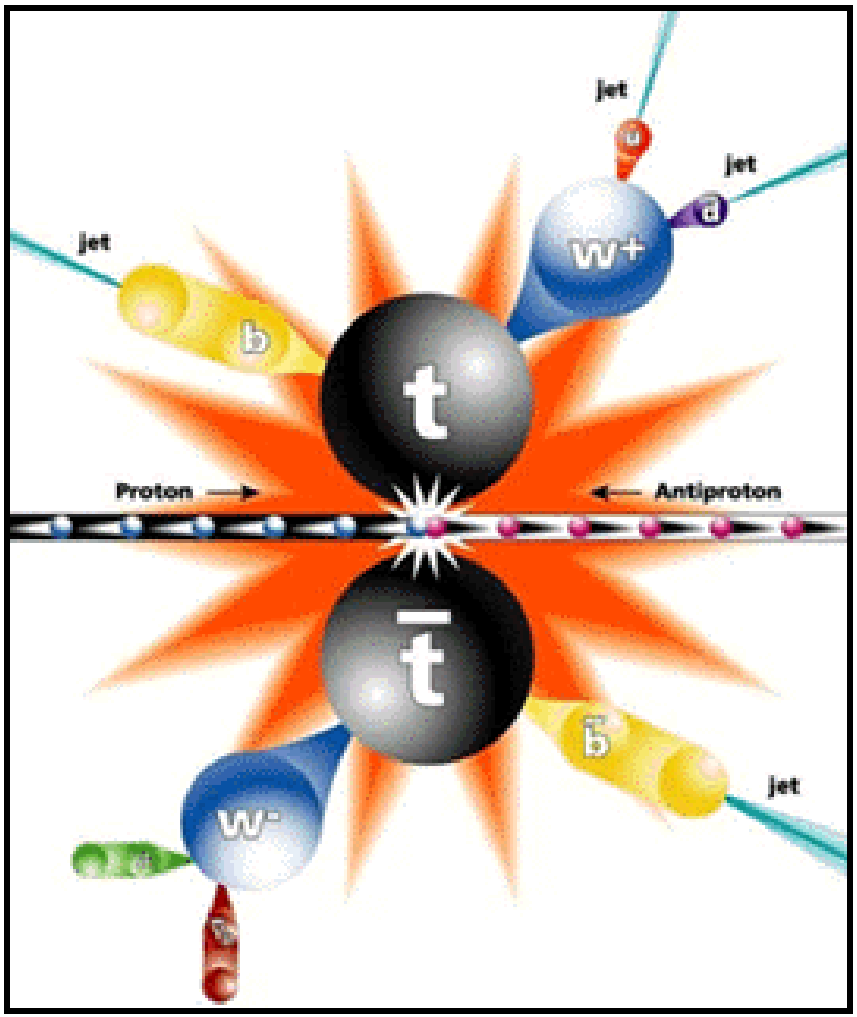
Particle Accelerators

Fermilab Tevatron Collider

2 TeV protons on 2 TeV anti-protons

Inside the tunnel

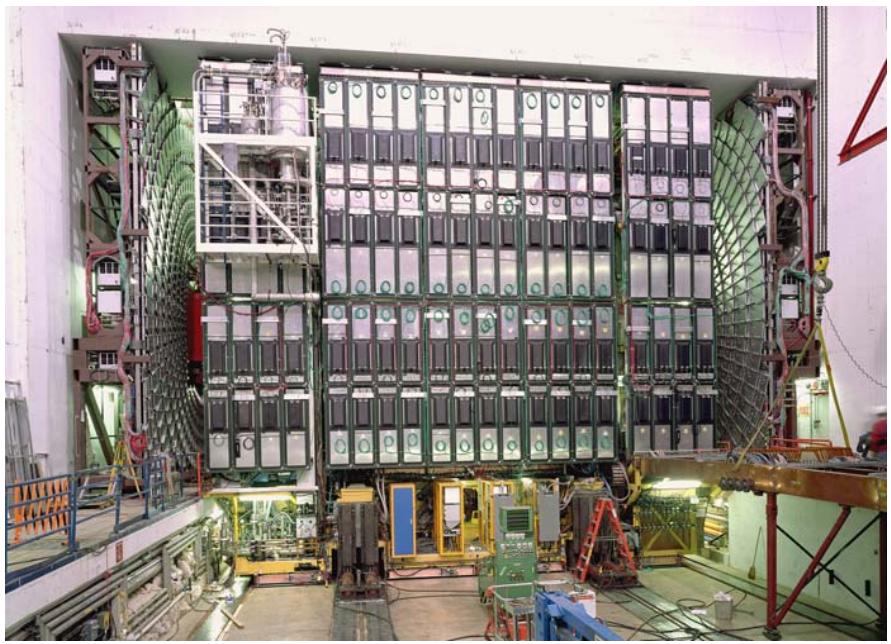
Dzero and CDF collaborations discovered the Top Quark in 1995!



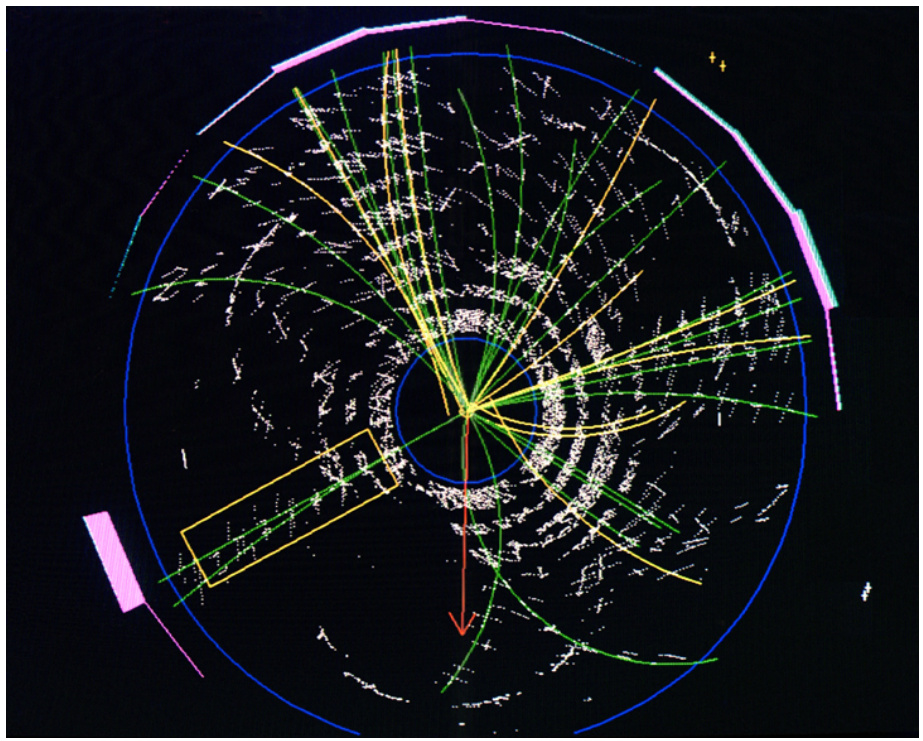
Dzero collaboration - Feb 2001

DZero & CDF Experiments – currently taking data

Physics: Top and B quark properties, searches for Higgs and supersymmetry, extra dimensions



Dzero detector

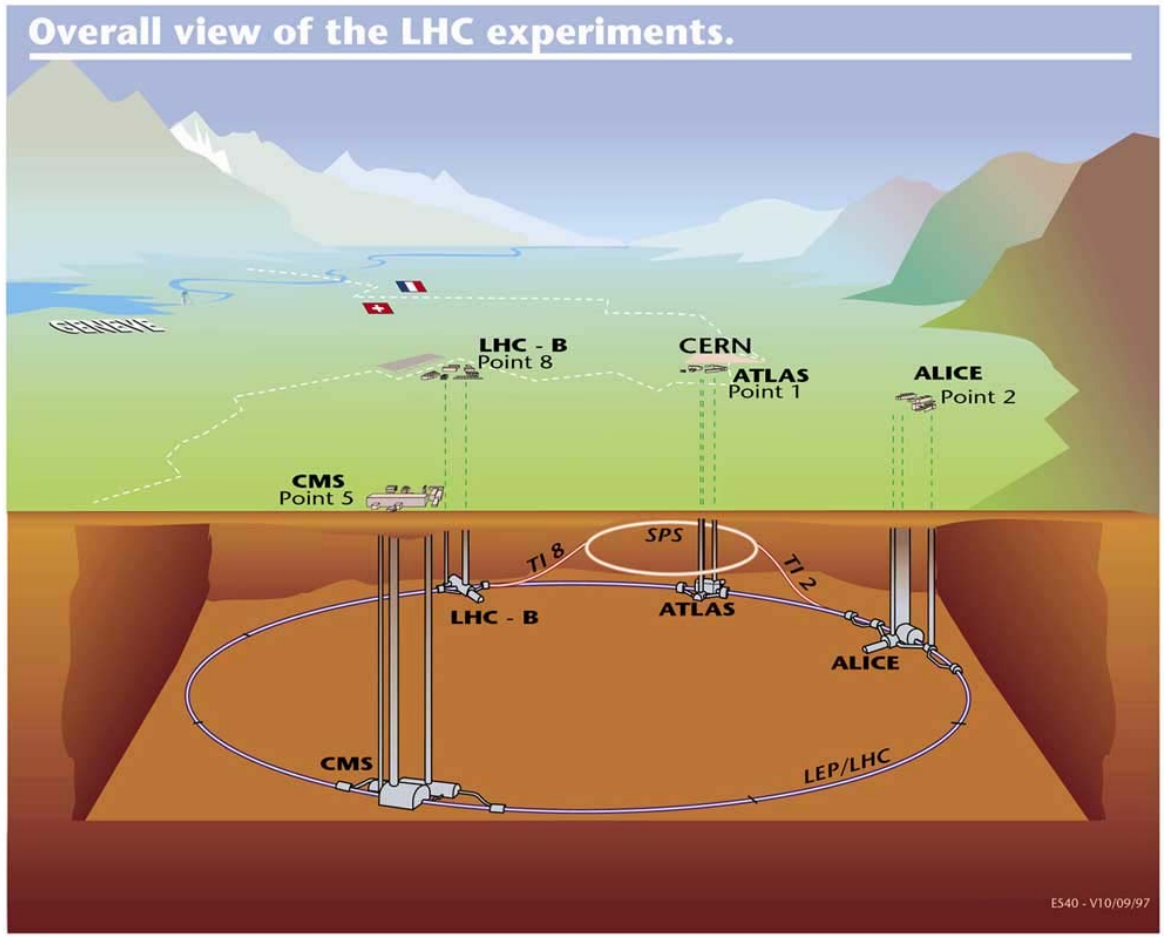


CDF – event display

ATLAS & CMS

-Detectors and Accelerator are currently under construction

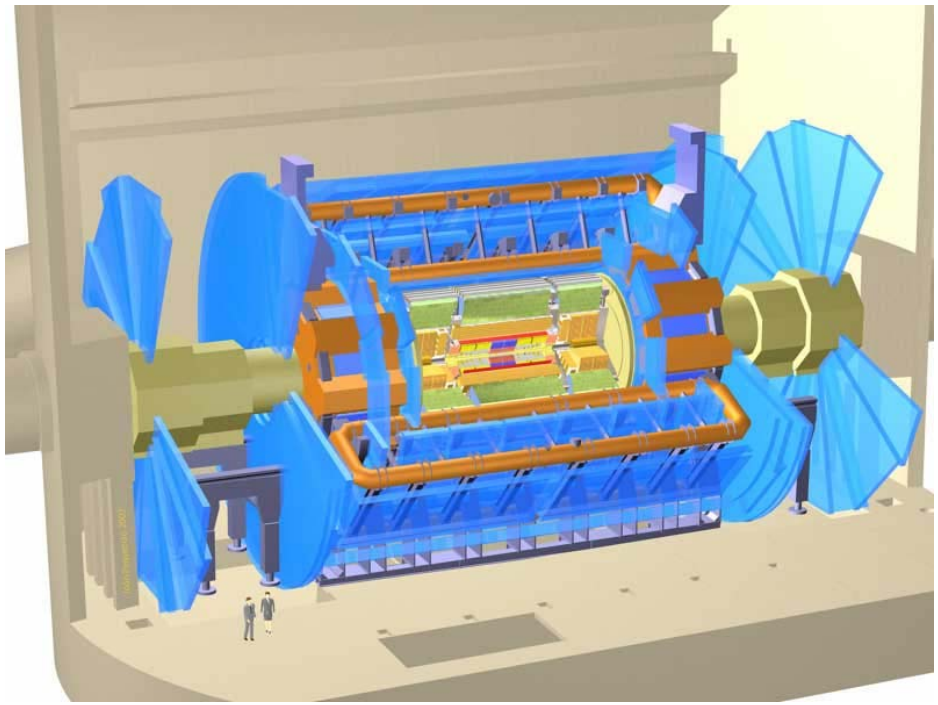
- 7 TeV protons on 7 TeV protons



ATLAS & CMS

searches for Higgs, supersymmetry, extra dimensions, physics beyond the Standard Model

To study in detail, will need a next-generation machine



ATLAS detector

CMS cavern

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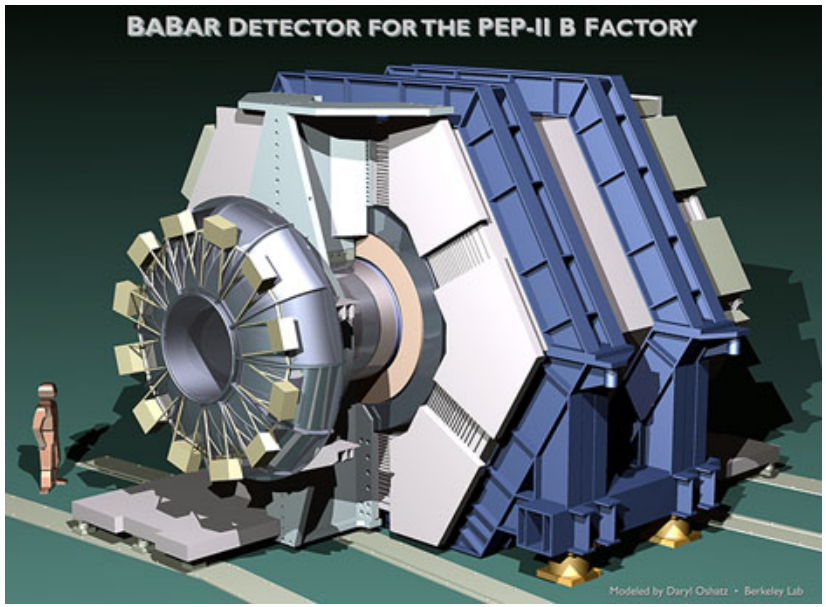
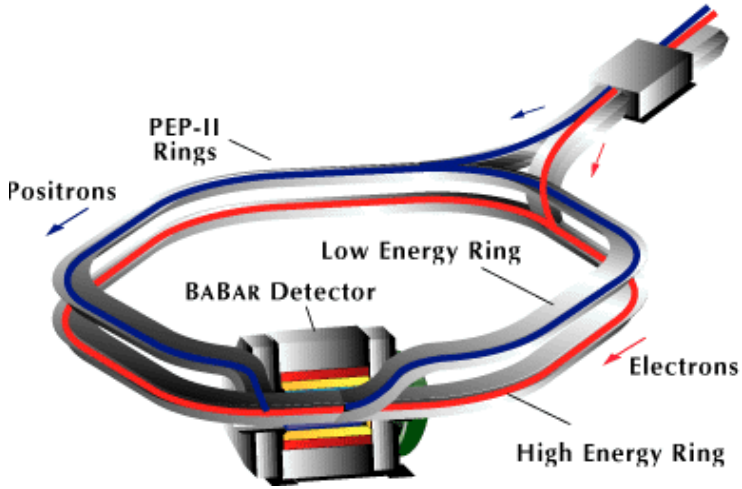
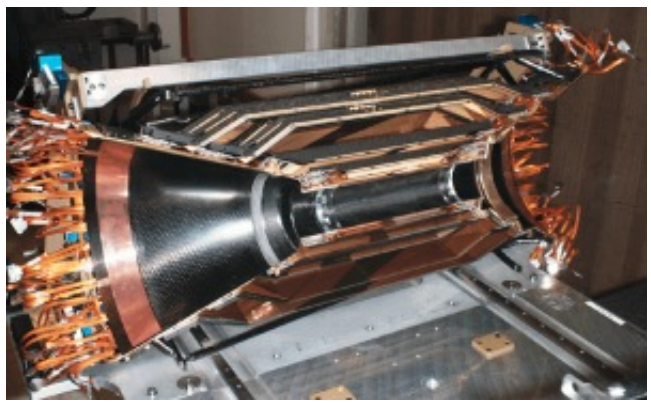
BaBar experiment
- at **Stanford Linear Accelerator Center (SLAC)**

Study B mesons produced by PEP-II Electron Positron Collider

Investigate matter-antimatter asymmetry in the Universe by studying CP violation
- occurs in weak interaction where quarks change flavor







Silicon vertex detector

High Energy Physics Program

- **Goal: What can neutrinos tell us?**
  - **Tools: study υ mass & mixing using accelerators, reactors and solar/atmospheric neutrinos**

Operating:

MiniBooNE - accelerator neutrino oscillation measurement at Fermilab
SNO (Canada) – underground detector for solar neutrinos

In Japan
SuperK – underground detector solar/atmospheric neutrinos, proton decay
K2K – neutrino beam from the KEK 12 GeV accelerator in Tsukuba, Japan to the SuperK detector (250km away)
KamLAND – measuring the anti-neutrino flux from reactors in Japan and Korea

Under Construction:

NUMI/MINOS – long baseline neutrino oscillation measurement

Future Planning:

Many proposals being prepared and a study to roadmap the future is taking place

SuperK experiment

SuperKamiokande detector

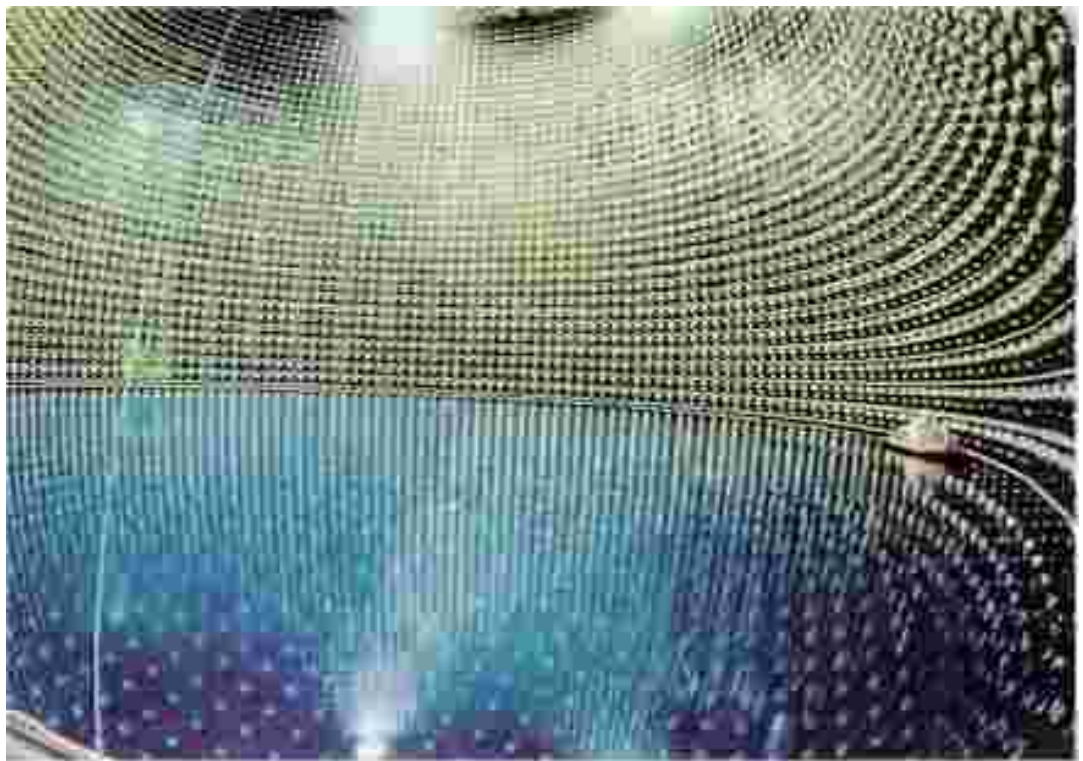
– water Cherenkov detector underground in the Kamioka mine in Japan

- Search for proton decay search and study neutrino interactions measurements

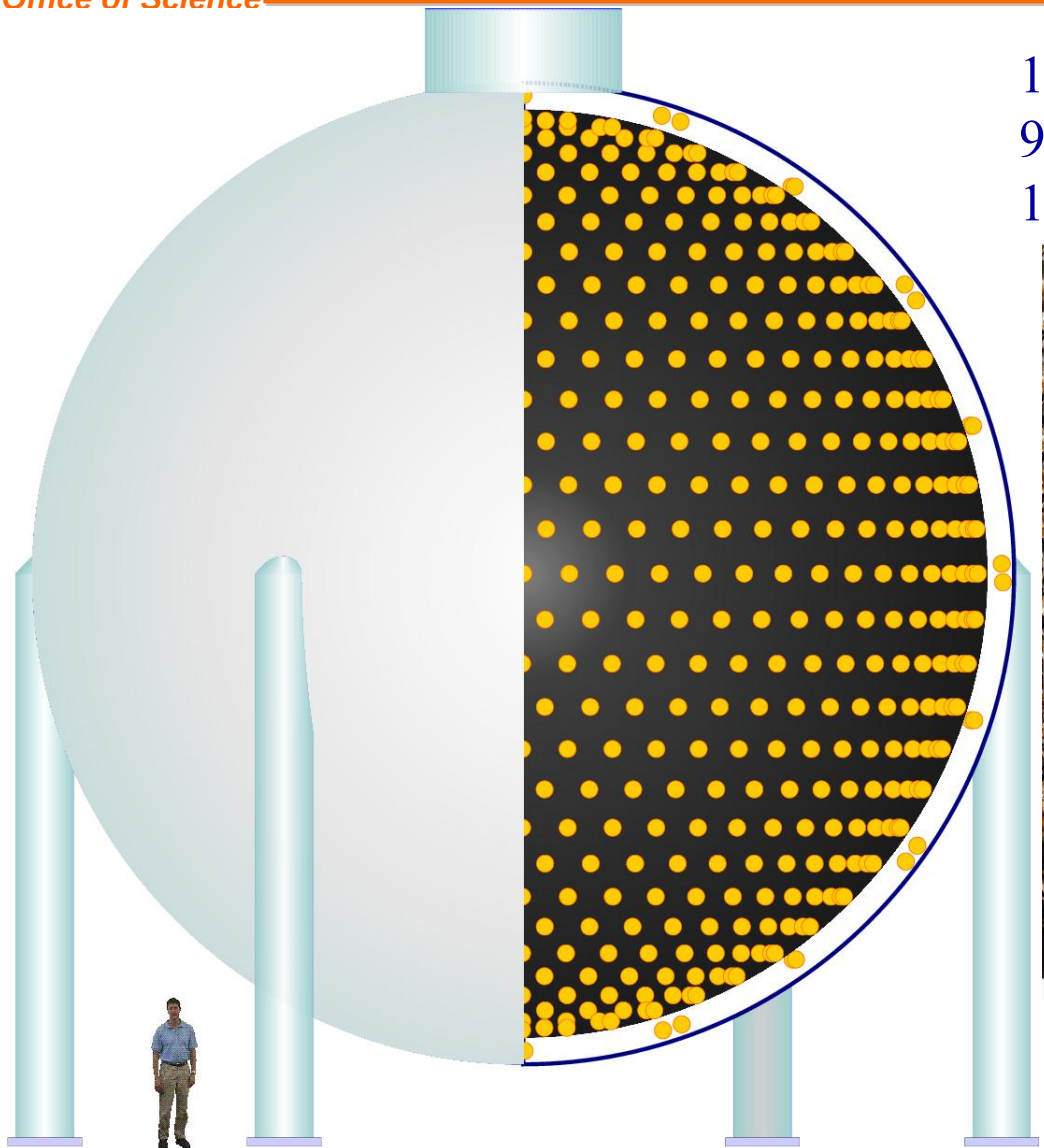
- In 1998, found the first evidence for neutrino oscillations (changing type, which means they have mass)

- Data taking & analysis continues

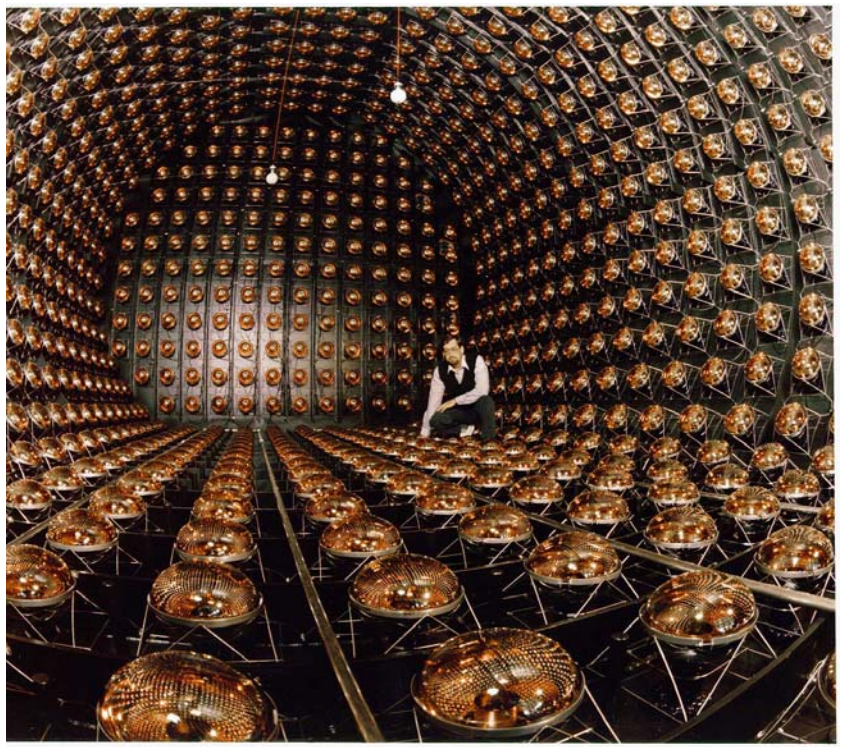
Uses 50,000 metric tons of pure water



MiniBooNE Detector – neutrinos from the Fermilab Booster accelerator



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



PMT's in the sphere

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NUMI-MINOS

Neutrinos at the Main Injector – Main Injector Neutrino Oscillation Search

Study neutrinos as they oscillate between types from Fermilab to the Soudan Mine in Minnesota

In the Soudan Mine

High Energy Physics Program

- **Goal: Cosmology and Particle Astrophysics**
  - **Tools: Cosmic ray and gamma-ray studies of Nature's acceleration mechanisms, nature of Dark Matter, Dark Energy making up most of the Universe**

Operating:

Sloan Digital Sky Survey – all sky map, dark matter distributions and dark energy
Supernova Cosmology Project & Nearby Supernova Factory – dark energy using supernovae

Under Construction:

Cold Dark Matter Search (CDMS-II) – underground in Soudan Mine, Minnesota
Large Area Telescope (LAT) – high energy gamma rays on NASA GLAST Mission
Pierre Auger – cosmic ray ground array in Argentina
AMS – Alpha Magnetic Spectrometer on International Space Station
VERITAS – high energy gamma rays, telescope in Arizona

Future Planning:

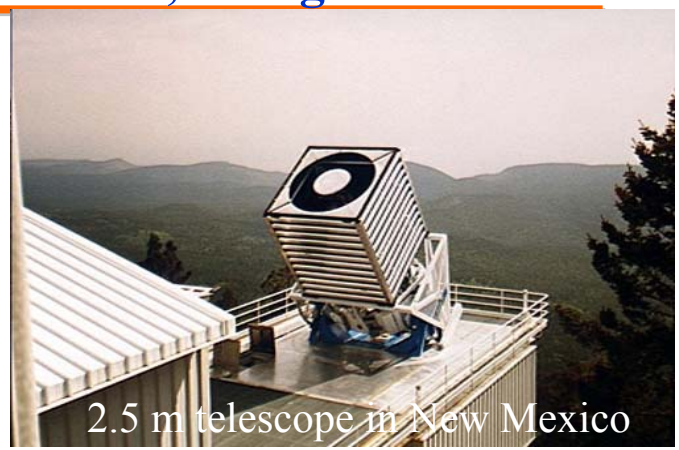
Joint Dark Energy Mission (JDEM) with NASA – precision dark energy measurement from space
(currently doing R&D on a mission concept)
LSST – ground telescope for dark matter, dark energy studies
AXION – dark matter search

Sloan Digital Sky Survey (SDSS)

- DOE, NASA, NSF, Sloan Foundation, foreign

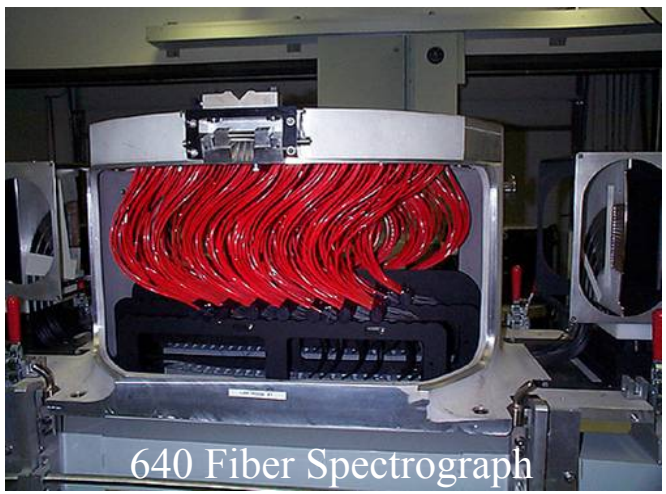
Scientific purpose: fundamental cosmology, dark matter distribution, formation & evolution of galaxies and large scale structure, uses 2.5m telescope with CCD camera and spectrograph

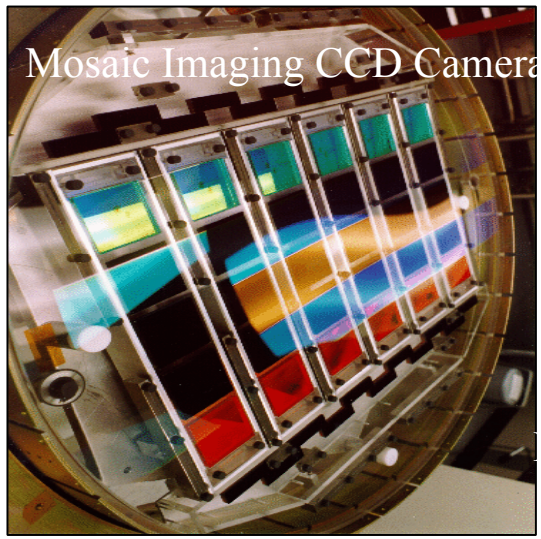
- digitally maps ¼ of the sky
- has data on ~135 million objects

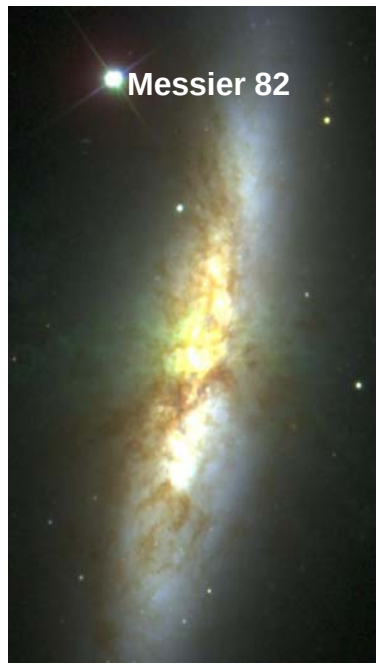

2.5 m telescope in New Mexico

Status:

- Science Magazine's 2003 Breakthrough of the Year: SDSS and WMAP confirm dark energy!
- Data-taking is 83% complete for imaging, 55% for spectroscopy (March'04)

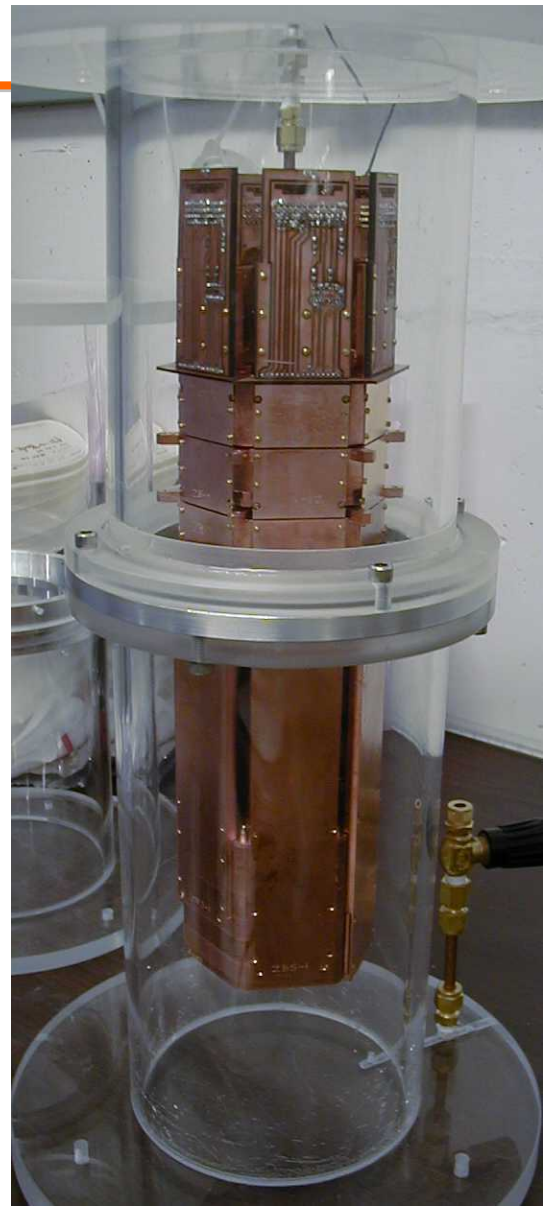

640 Fiber Spectrograph


Mosaic Imaging CCD Camera



CDMS II

- Scientific purpose: search for Weakly Interacting Massive Particle (WIMPS) - cold dark matter
- Located deep underground in the Soudan mine in Minnesota
- Cryogenic germanium and silicon detectors – detect the phonon signals generated within the crystal by elastic collisions between nuclei and WIMPS



Pierre Auger (Auger) - High Energy Cosmic Ray detector array in Argentina

Scientific purpose: Study origin and nature of highest energy particles in nature (> 10^{18} eV)

- prove existence of extraordinarily energetic cosmic rays
- study flux, arrival directions and other properties

Two types of detectors:

Cherenkov ground stations being built over 3000 km^2 site -- 300 currently installed out of 1600 -- each are 4 ft high & hold 3000 gallons pure water

Fluorescence stations – 2 out of 4 installed -- each with 6 telescopes to track showers through UV light emitted in atmosphere – on moonless nights

Very Energetic Radiation Imaging Telescope Array System - VERITAS

- Study of celestial sources of very high energy gamma-rays in the energy range of 50GeV-50TeV -- study extreme acceleration mechanisms
  - 4 telescope array is under construction at Kitt Peak in Arizona
  - Telescopes observe Cherenkov radiation produced by gamma-ray air showers in the atmosphere
  - Each 12-m telescope has 350 mirror segments plus a 500 phototube detector

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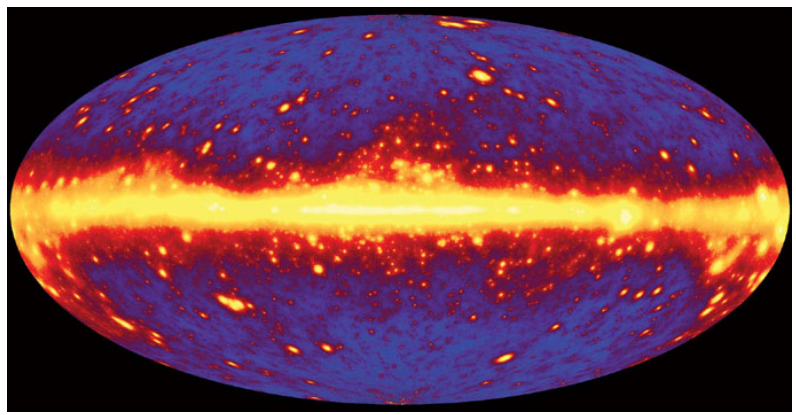
NASA's Gamma Ray Large Area Space Telescope (GLAST) Mission - under construction, Feb. '07 launch

Measurement of high energy gamma rays from space
- Energy and direction of gamma rays from 20 MeV to 300 GeV over wide field of view

- DOE/NASA partner on the primary instrument: Large Area Telescope (LAT) - Silicon tracker and calorimeter
- **study mechanism of particle acceleration from astrophysical sources**
- **determine high energy behavior of gamma ray bursts, active galactic nuclei, transient sources, etc.**
- **search for dark matter candidates**



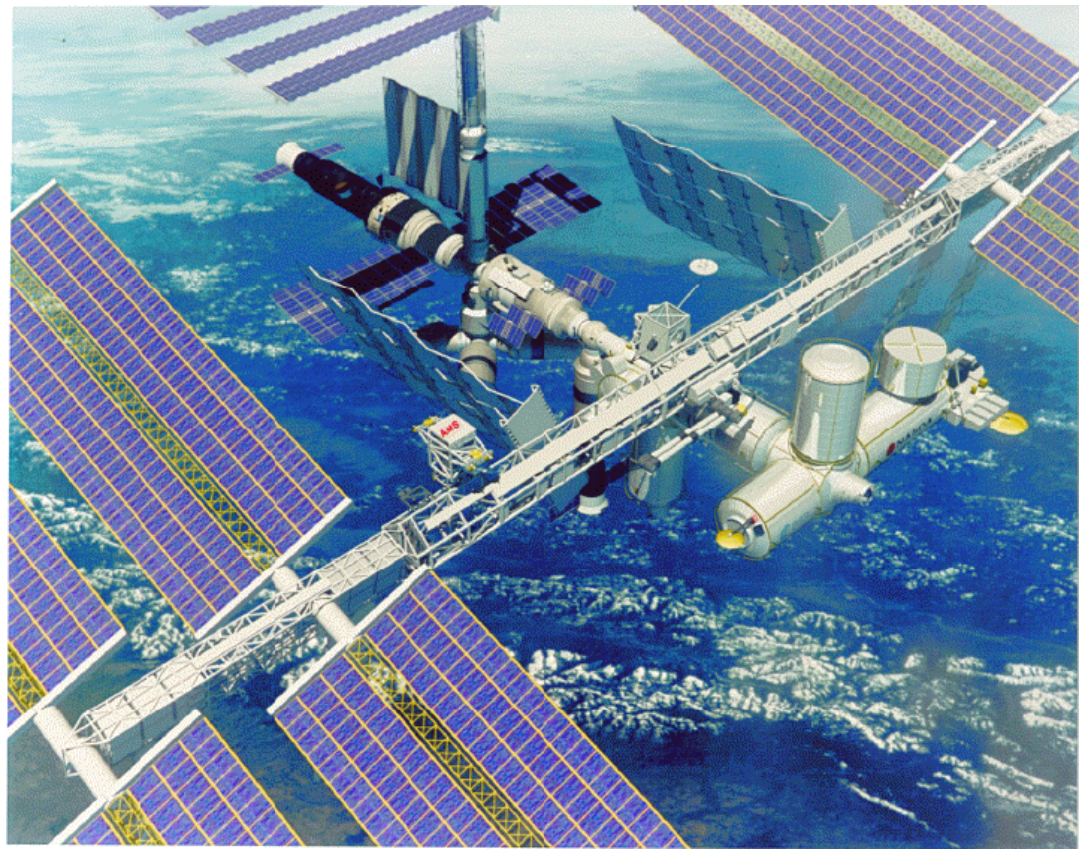
AMS - Alpha Magnetic Spectrometer

An experiment to search in space for dark matter, missing matter & antimatter on the International Space Station

High quality magnetic spectrometer to measure cosmic rays outside the atmosphere

Prototype took data on 10-day Space Shuttle flight in 1998

- Schedule:
  - >80% detector fabrication completed
  - Expected launch : Apr 2007



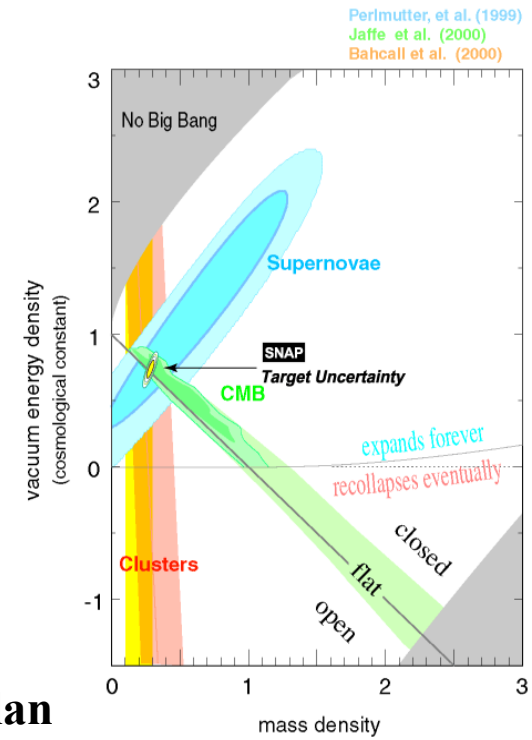
Dark Energy

Discovery that the expansion of the Universe is accelerating
- Science Magazine's 1998 Breakthrough of the Year

What is it? Is it Einstein's cosmological constant? Extra Dimensions? Is General Relativity wrong? Is it a field?

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 & decelerations of the Universe

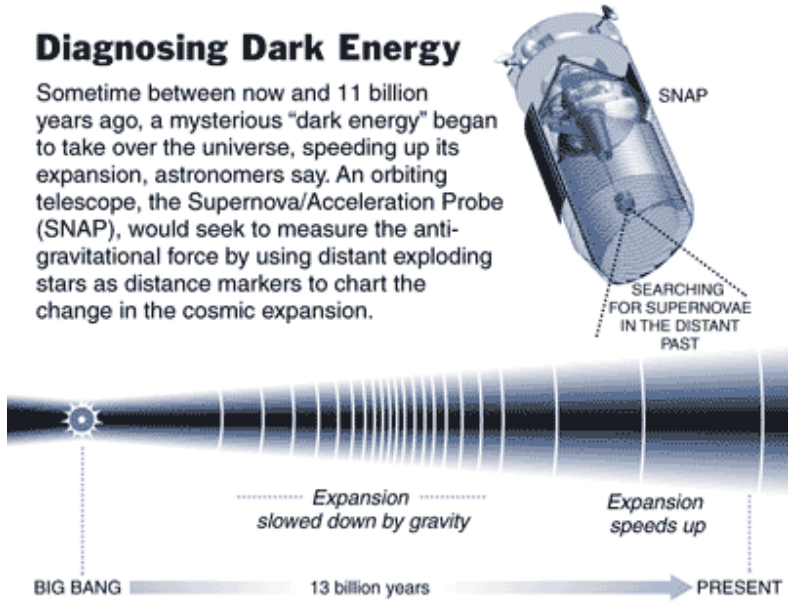


- **DOE/NASA Joint Dark Energy Mission (JDEM) plan**
- **JDEM is high priority on DOE's facilities for the future plan**

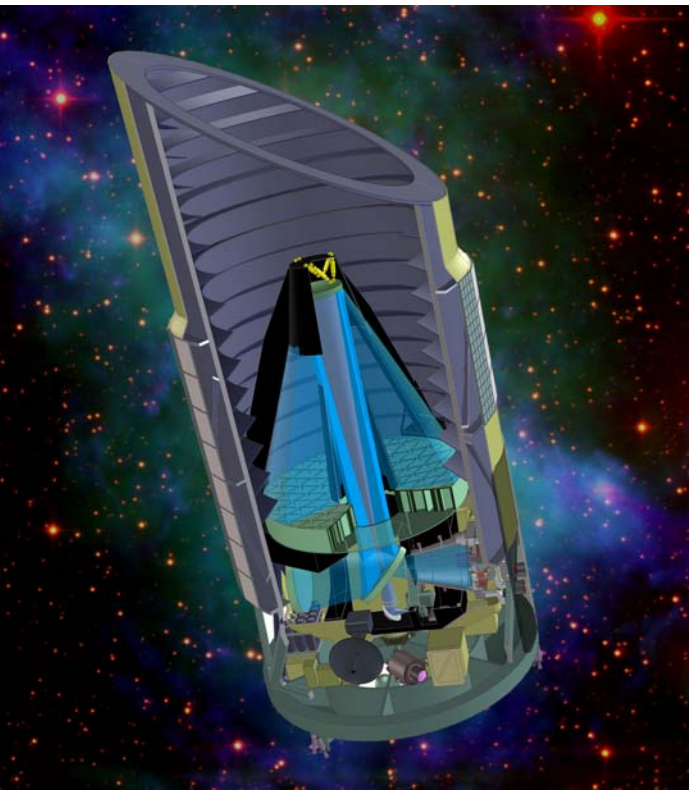
SuperNova/Acceleration Probe

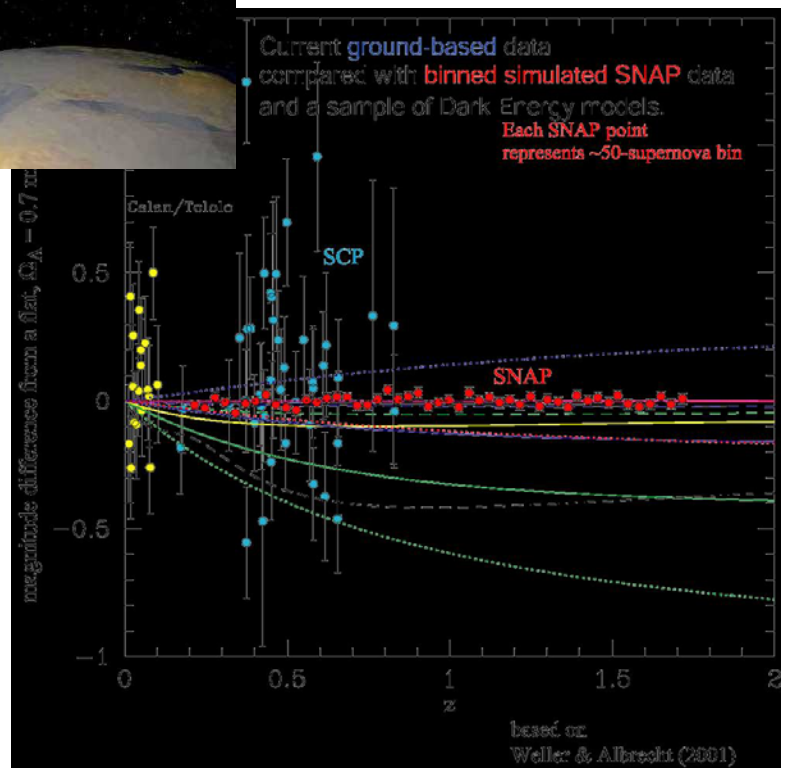
Dark Energy — causing the acceleration of the expansion of the universe — of central importance to HEP program

- **DOE is funding R&D for the SuperNova Acceleration Probe (SNAP) – a concept for JDEM**
- **SNAP would use supernova & weak lensing measurements to precisely measure the nature of dark energy over a large redshift range**



SuperNova/Acceleration Probe





High Energy Physics Program

DOE Office of Science: Facilities for the Future of Science
– a 20 Year Outlook

A strategic plan w/ 5 HEP projects

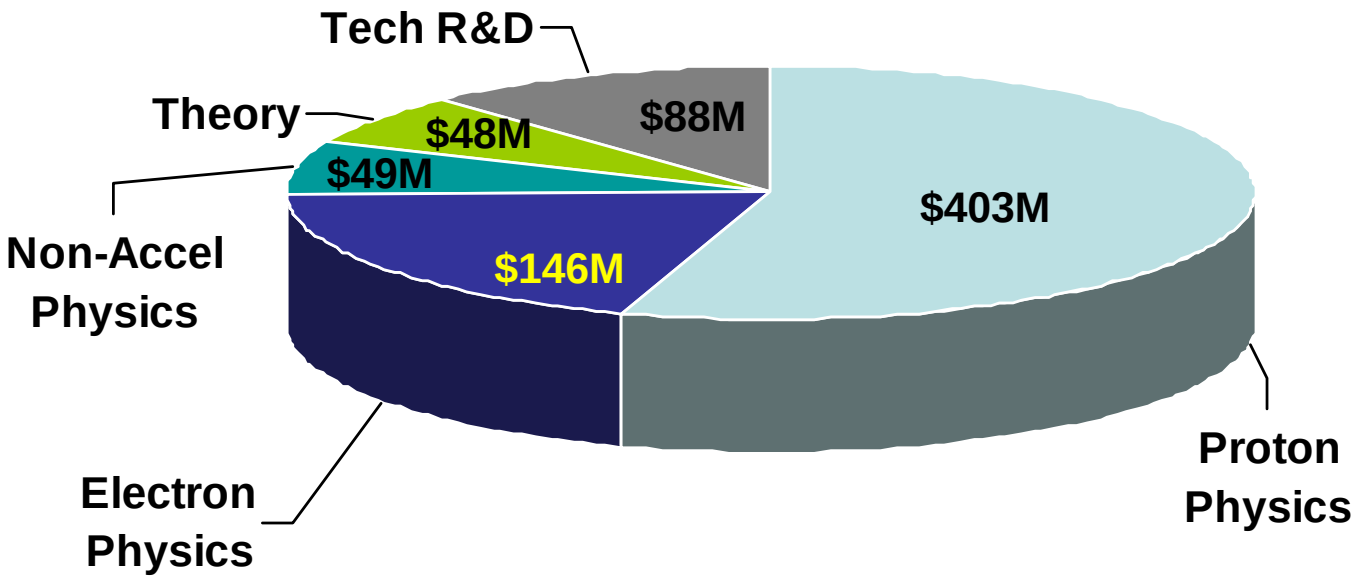
o TeV scale: Unification, origin of mass, hidden dimensions
- o Neutrinos: What are they? How do they relate to the Universe?
- o CP Violation: Where's all the anti-matter?
- o Dark Matter and Energy: What is the other 96% of the Universe?

We are on the threshold of discovery
- exciting new discoveries in the next decade

BACKUP

FY 2004 Funding Allocation

- Accelerator based physics (proton & electron) ~75%
- Non-Accelerator physics ~7%
- Theory ~7%
- Technology R&D ~12%



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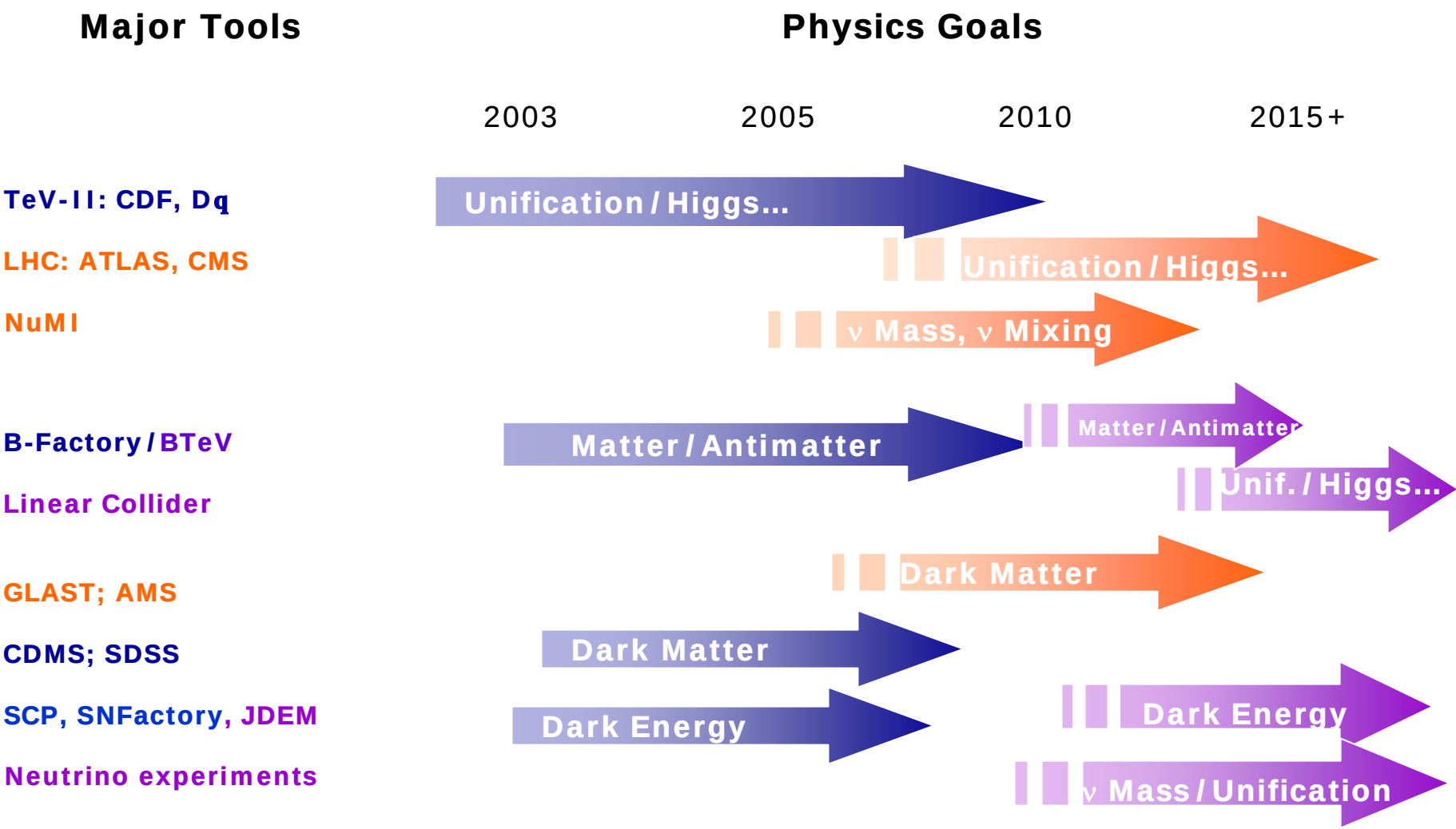
Major Program Thrusts



Blue = In operation Orange = Construction Purple = Future Possibilities

DOE-HEP Annual Budget
(in Millions)

DOE provides ~ 90% of funding for HEP in U.S.

FY 2003	FY 2004	FY 2005 Presidential Request
$718M	$734M	$737M

High Energy Physics - Funding

We provide support for high energy physicists at our (contractor operated) national labs (5) & universities (~110) with HEP research programs

We support scientists to work **on all phases of a project – funding is rather stable**

- **to develop new ideas and to build up areas of expertise**

University grants:

- **funded based on peer review (program run through HQ office)**
- **experimental, theoretical, accelerator and advanced detector research**
- **support faculty members (~ 500) and their groups**
- **our support "buys" their full-time research on our projects throughout the year**

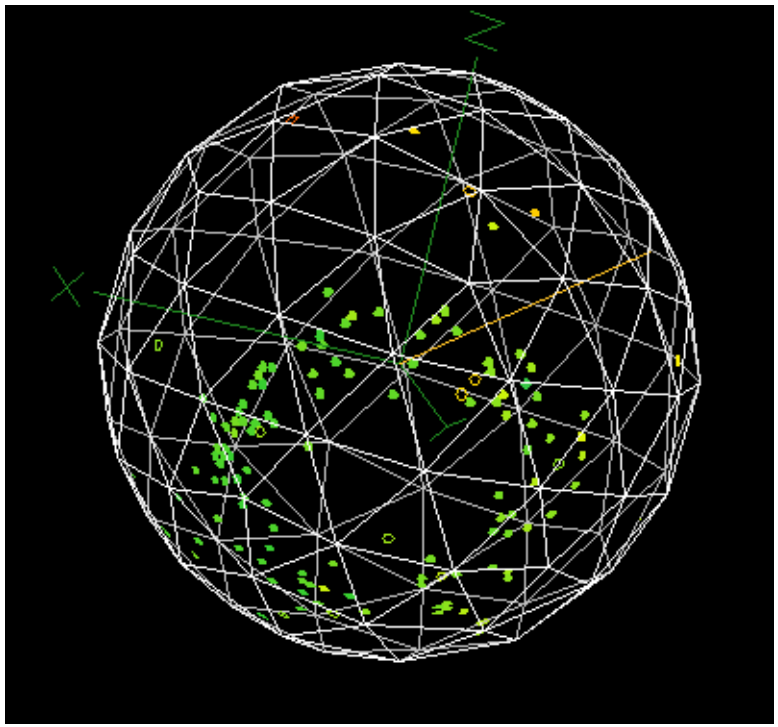
Laboratory funding:

- We provide operating funds to run the facility, build and run accelerators & experiments and to support scientific, technical and managerial staff
- Scientists work on the lab's program
- Our office provides oversight for the labs and independent reviews during project construction

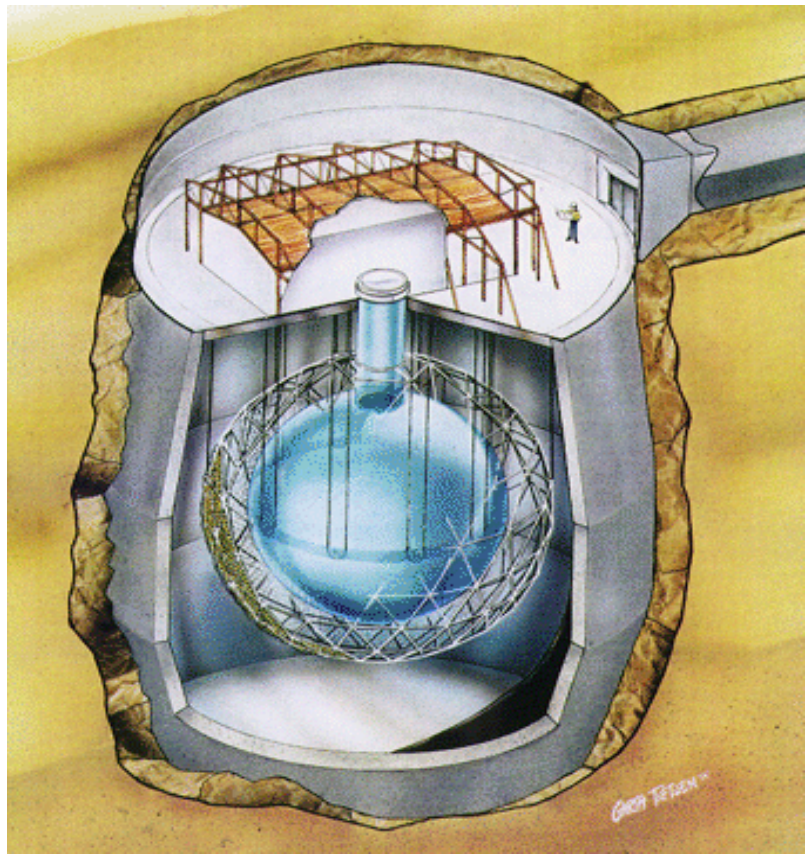
Sudbury Neutrino Observatory (SNO) – underground detector in Canada

Detects neutrinos produced by fusion reactions in the Sun; detects ~ 10 ν's per day

2001 results: solved 30-yr old mystery of missing solar neutrinos – found that they oscillated!



Detector - size of 10-story building with 9600 photomultiplier tubes in 1 kiloton of heavy water



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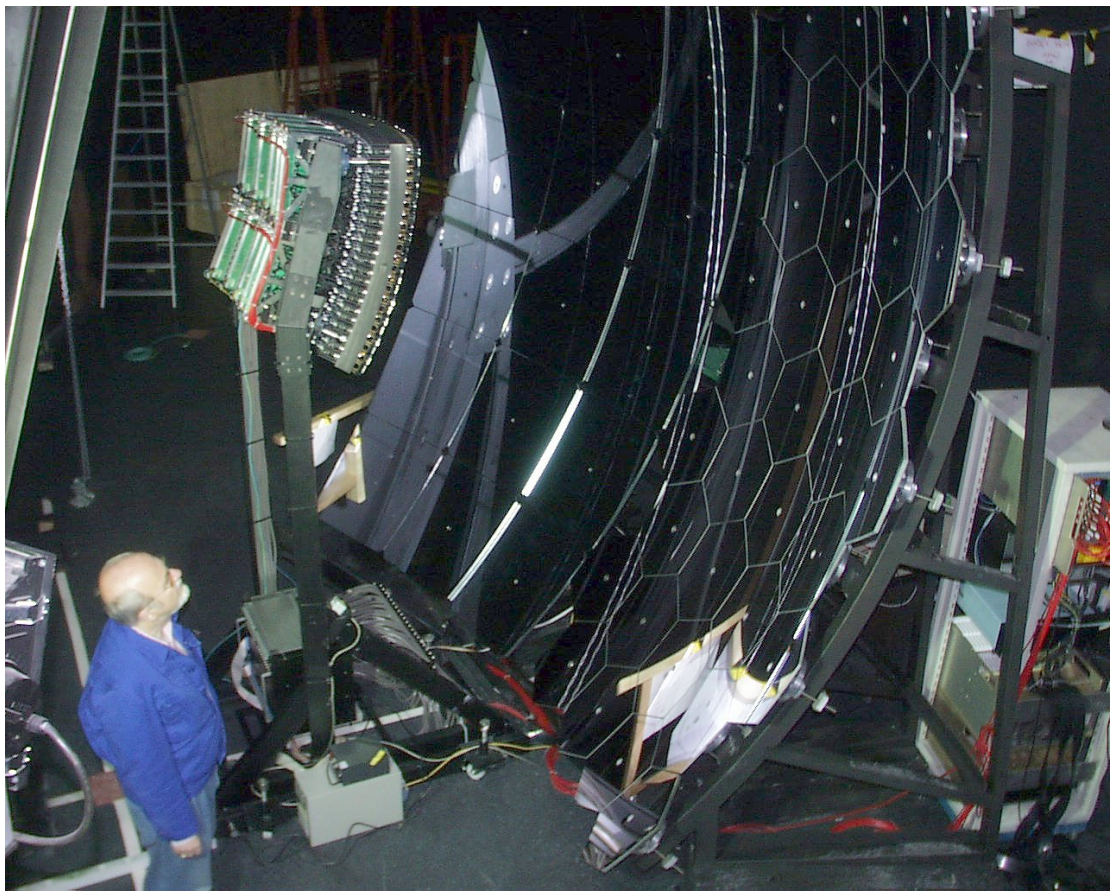
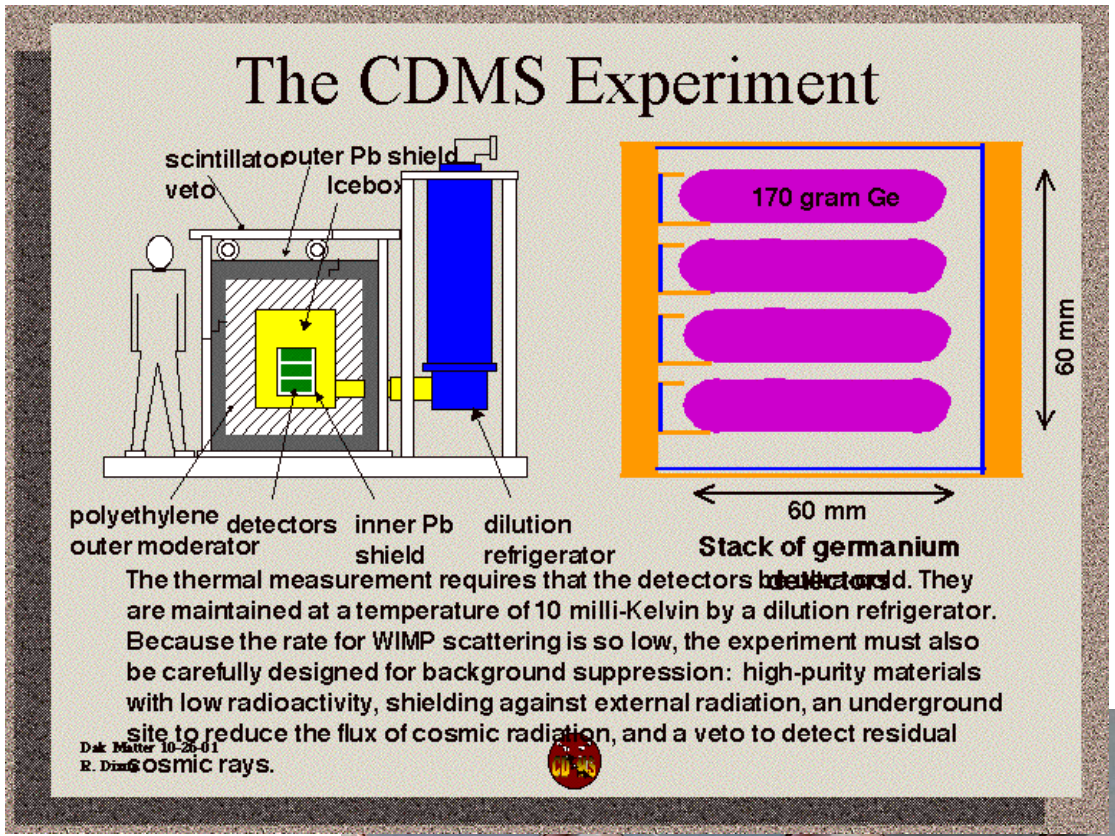
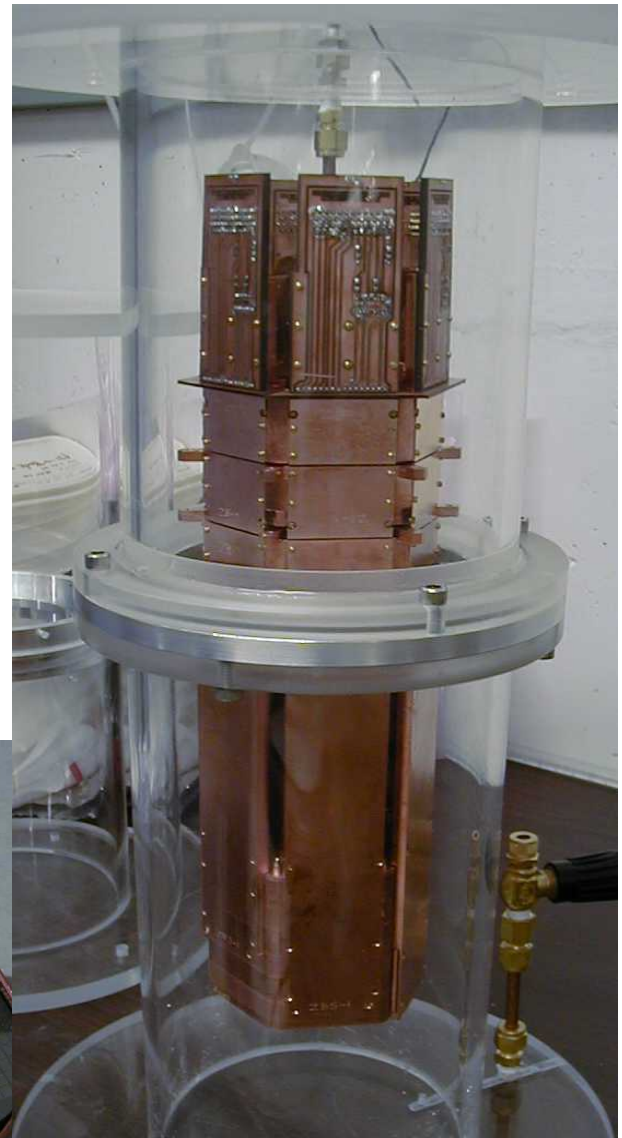


Telescope in Fluorescence station

Cold Dark Matter Search - Detectors





Germanium disks