

# Experimental Particle Astrophysics at Fermilab

E881

Pierre Auger Observatory



E891  
CDMS-II

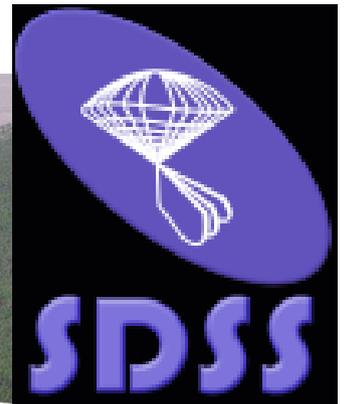
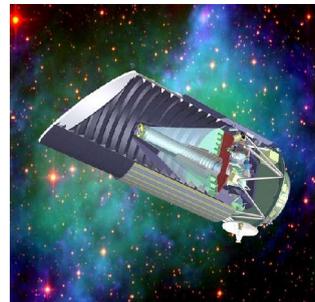


DARK ENERGY  
Survey

P939  
DES



R&D  
SNAP/JDEM



E949  
SDSS-II

# **Particle Astrophysics at Fermilab**

- **Fermilab mission statement:**
  - *".. advance the understanding of the fundamental nature of matter and energy ... at the frontiers of high energy physics and related disciplines."*
- **Experimental Particle Astrophysics Program - Understand the nature of ...**
  - **Nature's most energetic particles (Auger)**
    - *Standard model*
  - **Dark Matter (SDSS II, CDMS II)**
    - *Beyond the standard model*
  - **Dark Energy (SDSS-II, DES, SNAP)**
    - *Beyond the beyond the standard model*

# *Fermilab Center for Particle Astrophysics*

Celebrated its first year this past year

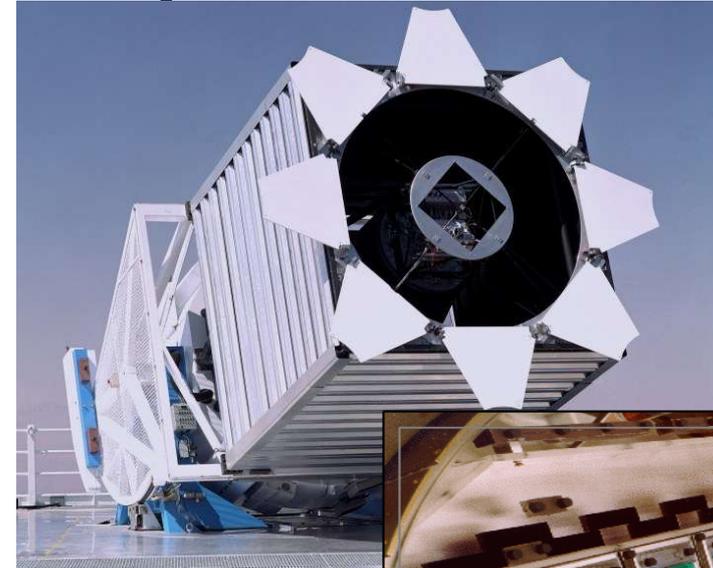
**Unifies 5 astroparticle experiments,  
scientists and theorists for exchange  
of ideas, results, and people.**



# Sloan Digital Sky Survey-II (E949)

**Collaboration: ~150 scientists from**

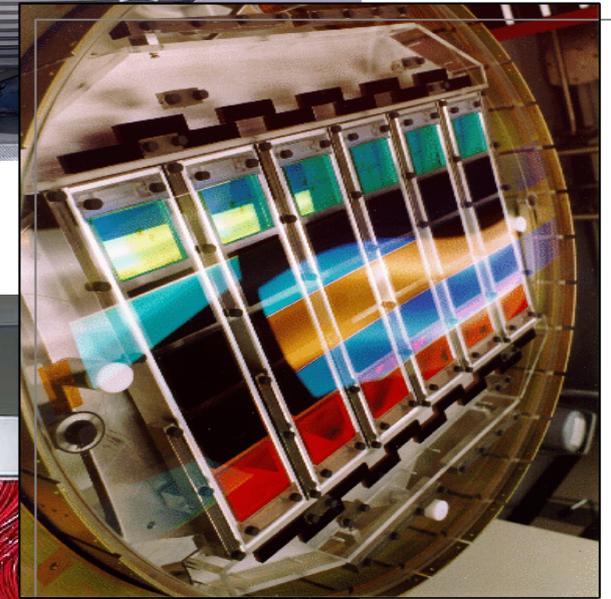
Am. Museum Nat. History  
Astrophysical Inst. Potsdam  
U. Basel  
Cambridge U.  
Case Western Reserve  
U. Chicago  
Drexel U.  
Fermilab  
Institute for Adv. Studies  
Japanese Participation Grp  
Johns Hopkins U.  
JINA  
Kavli Institute for Part. Astro.  
Korean Scientist Group  
LAMOST (China)  
Los Alamos Nat. Lab  
Max Planck Inst. Astron.  
Max Planck Inst. Astrophy.  
New Mexico State U.  
Ohio State U.  
U. Pittsburgh  
U. Portsmouth  
Princeton U.  
US Naval Obs.  
U. Washington



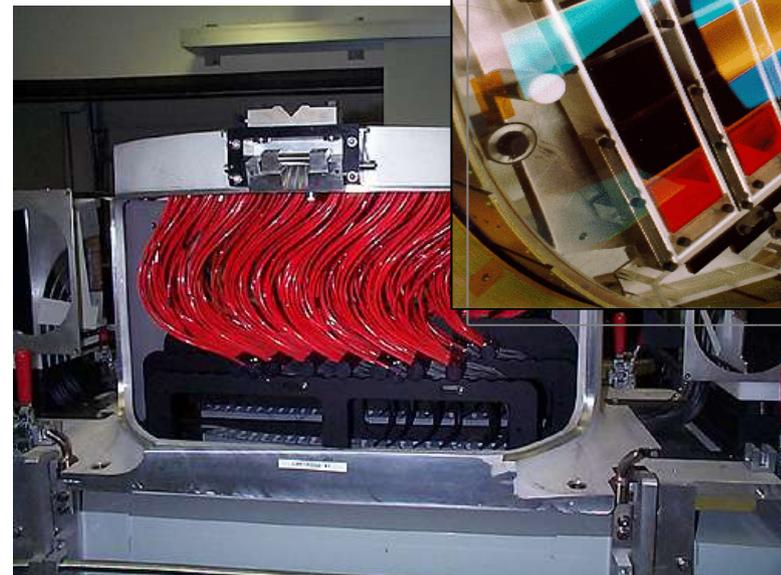
Beamline



Calorimeter



Massive Spectrometer





# *SDSS II - the sequel* *3 year mission (2005-2008)*

- **Legacy:**

- Complete SDSS program
- Imaging and Redshift survey - Large scale structure

- **SEGUE:**

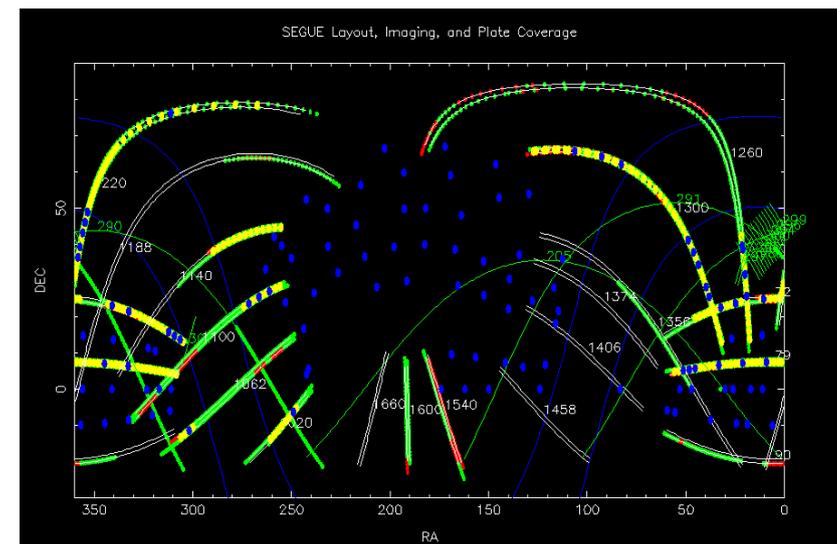
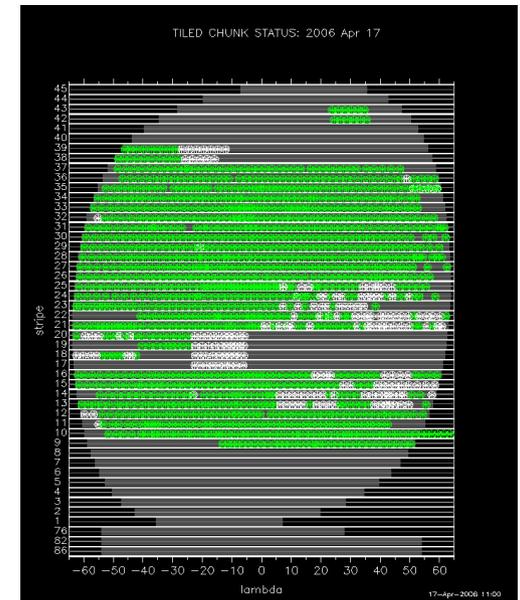
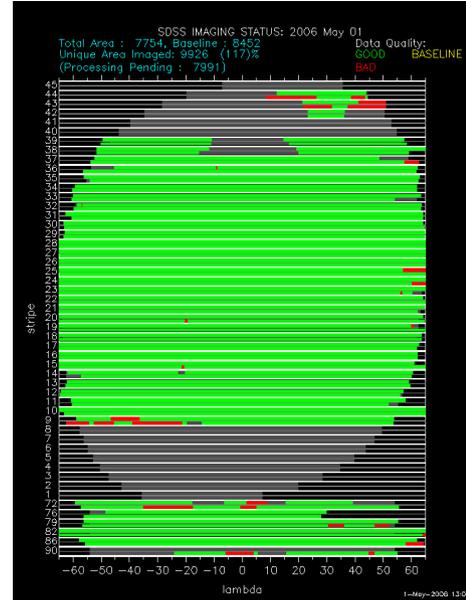
- Milky Way halo – Dark Matter probes

- **Supernovae**

- Low and intermediate redshift, Dark Energy probe

- **Funding:**

- Sloan, DOE, NSF, NASA, Japanese Mongbukagakusho, Max Planck Society, HEFCE





# ***FNAL tasks and resources*** ***in SDSS-II***

- **Fermilab Interests**

- 13 scientists (3 divisions)
  - **Kent co-leader of Legacy**
  - **Yanny co-leader of Segue**
  - **Frieman co-leader of Supernova Program**
- 1 current postdoc
- 2 joining soon

## **Tasks**

**DAQ upgrade  
Plugplate design**

**Data distribution  
APO Engineering/Technical support**

- **Required resources**

- 4 FTE scientist
- 10 FTE CP, admin, tech.
- \$300K M&S/yr
- \$300K DAQ upgrade

- **Funding**

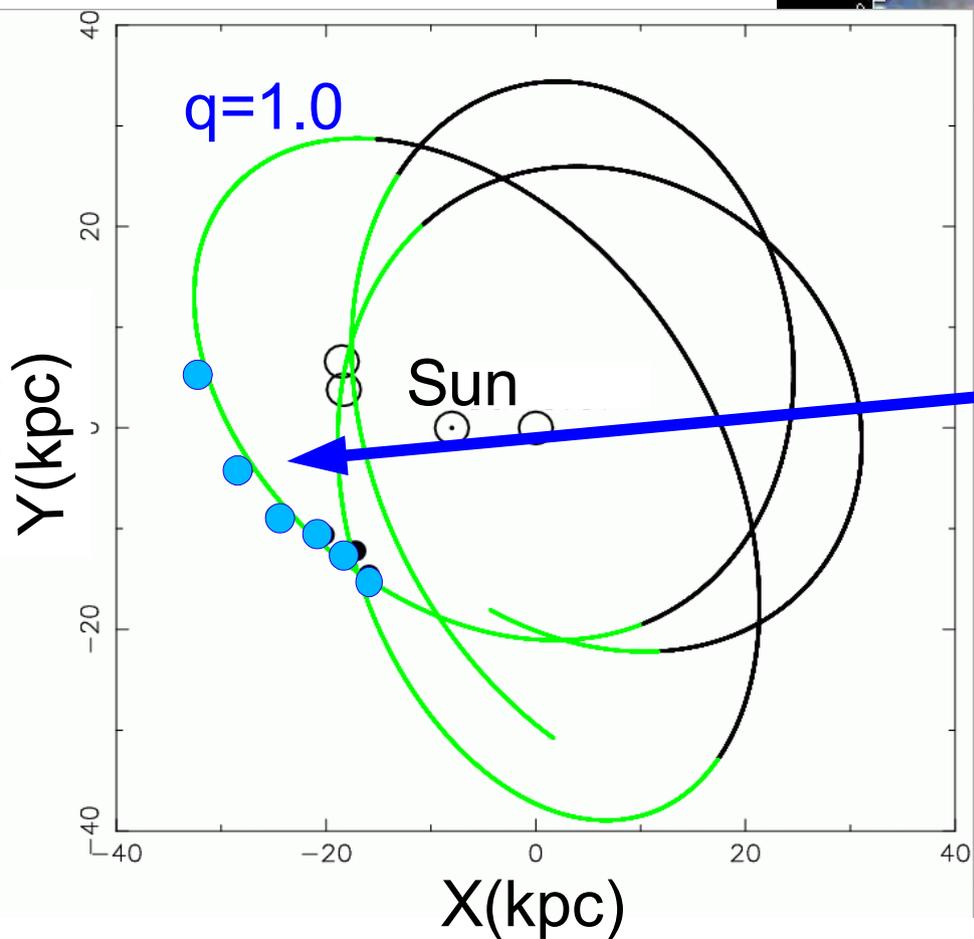
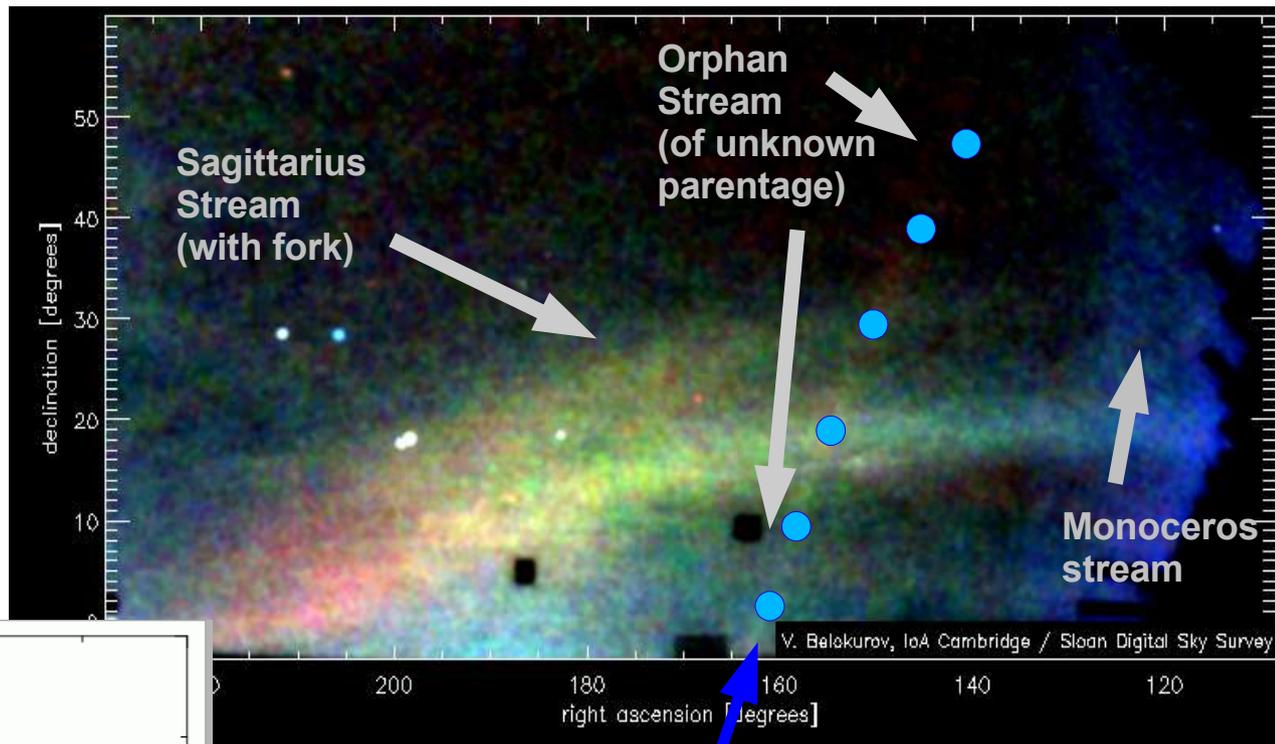
- **Significant cost sharing with SDSS project (\$1.2 million)**

**Survey planning  
Legacy, SEGUE, SNe  
data processing  
Project Mgmt.**



Star streams as probes of Dark Matter!

Example: Fit with  $q=1.0$  model implies consistency with Spherical halo.



Fitting the orbit of the 'Orphan stream' in 3-D can constrain the flattening of the Dark Matter Halo surrounding our Milky Way Galaxy.

**Recent SDSS Press Release!**

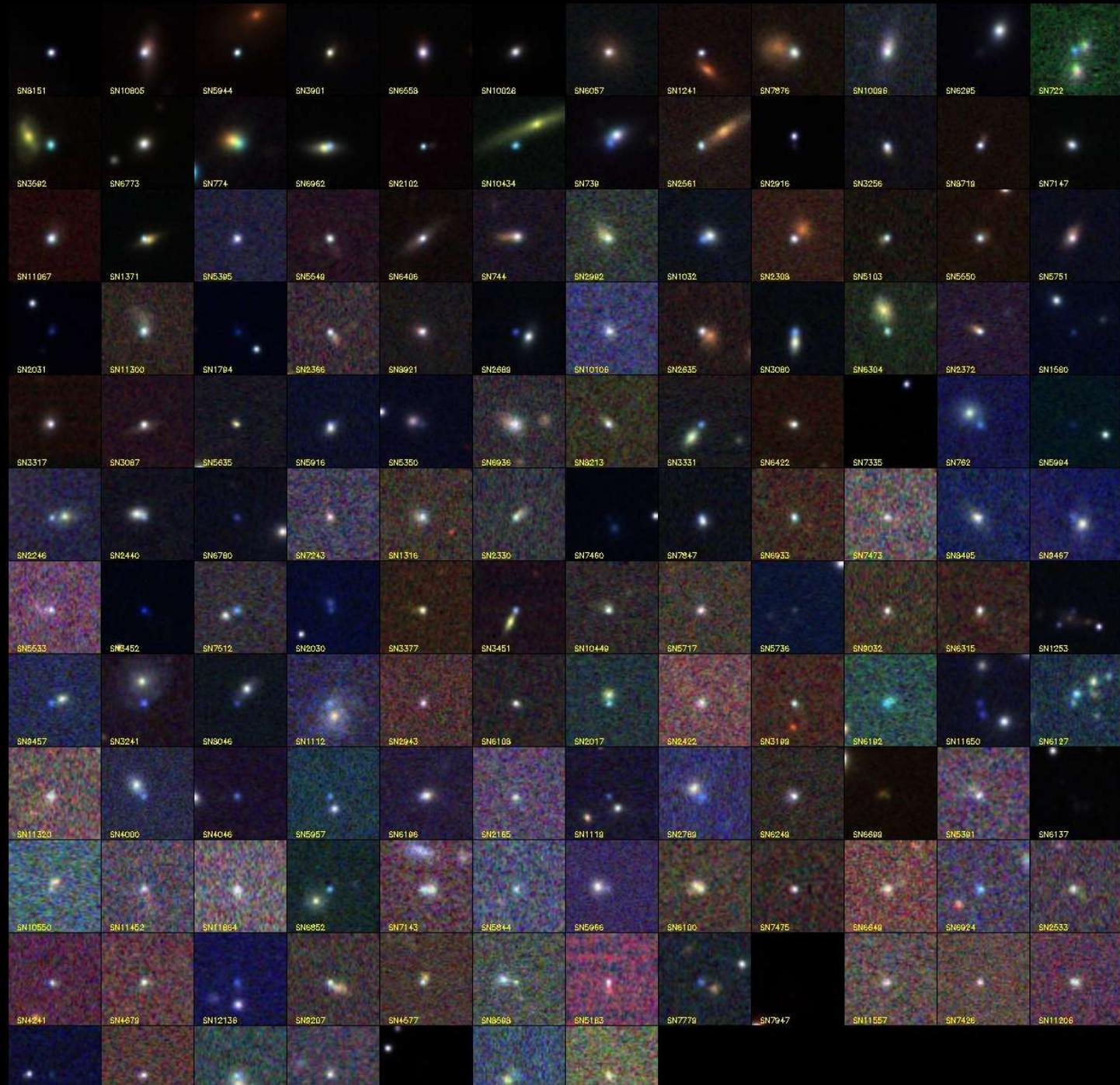
# SDSS-II 2005 Gallery of SN Ia!

Fall 2005:

130  
spectroscopically  
confirmed  
Type Ia's

14 spectroscopically  
likely/possible Ia  
11 confirmed SN II  
6 confirmed Ib/c  
~100's of  
unconfirmed Ia's  
based on light  
curves

Full results  
coming this  
summer





The SDSS is a remarkable resource for the astrophysics community worldwide.

### Scientific Impact:

As of May 2006, 1061 refereed, published papers mention SDSS, “Sloan Survey”, or make use of the SDSS dataset.

Over 30,000 citations of these papers in the literature.

21 papers with more than 200 citations.

### Universal Accessibility:

Fermilab is the host site for the SDSS/SDSS-II searchable databases which have served more than 60 Terabytes of images and object catalogs to scientists and the public worldwide.

About half the papers that use the SDSS data are by scientists who are NOT members of the SDSS collaboration.



# **The Pierre Auger Project** (E881)

**A new cosmic ray observatory to study**

**The Highest Energy Cosmic Rays**

**$>10^{19}$  eV**

**Energy Spectrum - Direction - Composition**

**Two Large Air Shower Detectors**

**Mendoza, Argentina (construction underway)**

**Colorado, USA (in planning)**



**Surface detector station**

**1600 total**

**\*\*\*\*\***

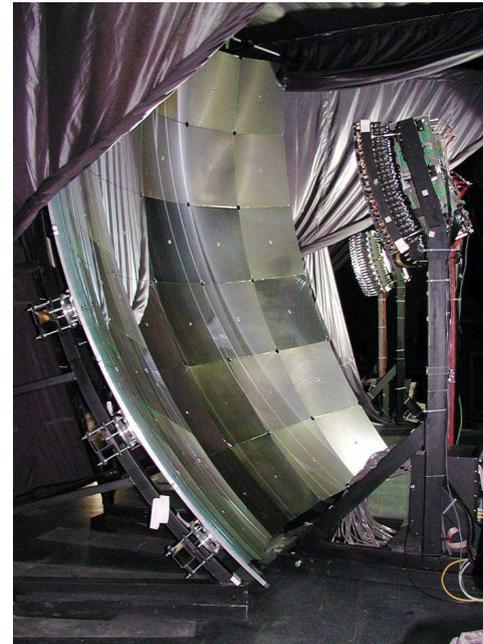
**Status**

**Construction**

**Commissioning**

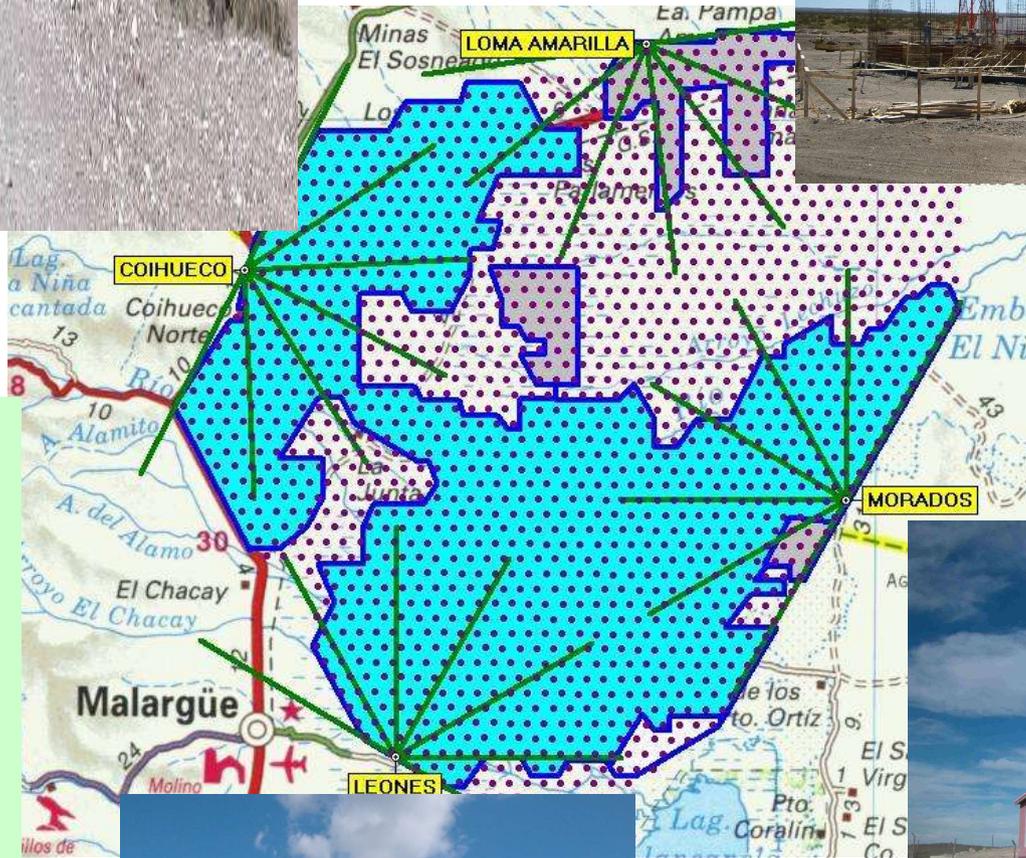
**Data taking**

**First Results in 2005**



**Fluorescence telescope**

**24 total**



## Auger Construction Status

- 1135 surface detector stations deployed, 932 sending data (blue). Always on, day/night.
- Three fluorescence buildings complete each with 6 telescopes – the fourth under construction. 10% duty cycle (cloudless nights).



PIERRE  
AUGER

# **The Auger Collaboration**

**Participating Countries - 63 Institutions, ~269 Scientists**

**Argentina**

**Australia**

**Bolivia\***

**Brazil**

**Czech Republic**

**France**

**Germany**

**Italy**

**Mexico**

**Netherlands\*\***

**Poland**

**Portugal\*\***

**Slovenia**

**Spain**

**United Kingdom**

**USA**

**Vietnam\***

***\*Associate countries***

***\*\*New countries***

**Support**

**DOE, NSF – Funding agencies in 15 other countries. US support about 25%.**

# **Fermilab Participation**

## • **Fermilab Participation**

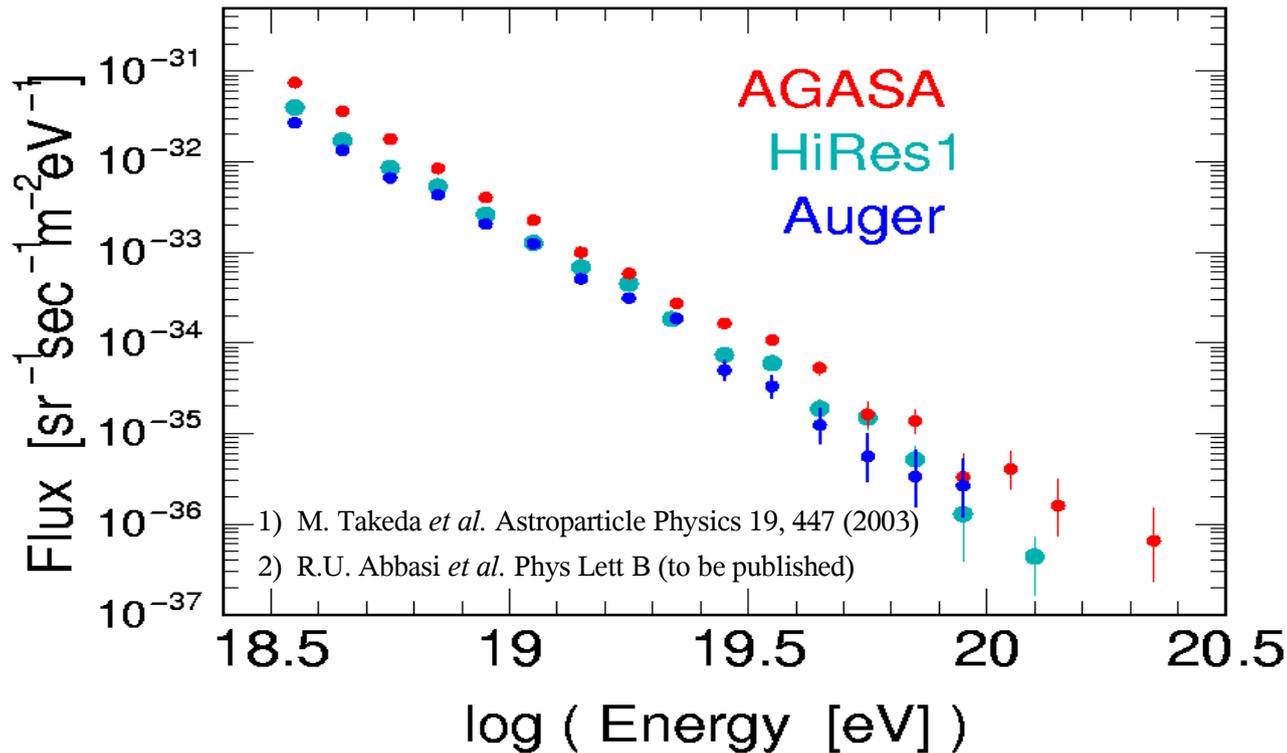
- **Scientists – 5 full time + 2 Part time+1 postdoc**
- **+ 1 Brinson Pre-doctoral Fellow**
- **Staff – 2 full time**
- **Activities**
  - **Project Management**
  - **Construction**
  - **Commissioning**
  - **Data analysis**
- **Group size – approximately constant; may grow slightly as Auger North evolves.**

## • **Funding**

- **~\$250K M&S/yr – mostly travel and project office support**

# Accomplishments

- Auger South Observatory now ~75% complete
- First physics results – Summer 2005 - Highlight talk + 38 papers – ICRC (August 05)



3-4 more years of data for definitive High-energy spectrum

# CDMS - Direct Detection of Dark Matter (E891)

CDMS Collaboration at Soudan



## CDMS Institutions

*DOE Laboratory*

**Fermilab**

LBNL

*DOE University*

Brown

Minnesota

Stanford

UC Santa Barbara

*NSF*

Case Western Reserve

Colorado (Denver)

Santa Clara

UC Berkeley

*Other*

Caltech

Florida

# CDMS Active Background Rejection

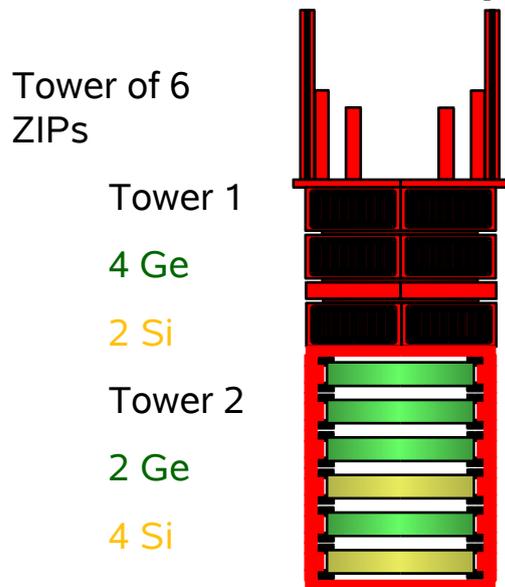
Detectors with excellent event-by-event background rejection

Measured background rejection:

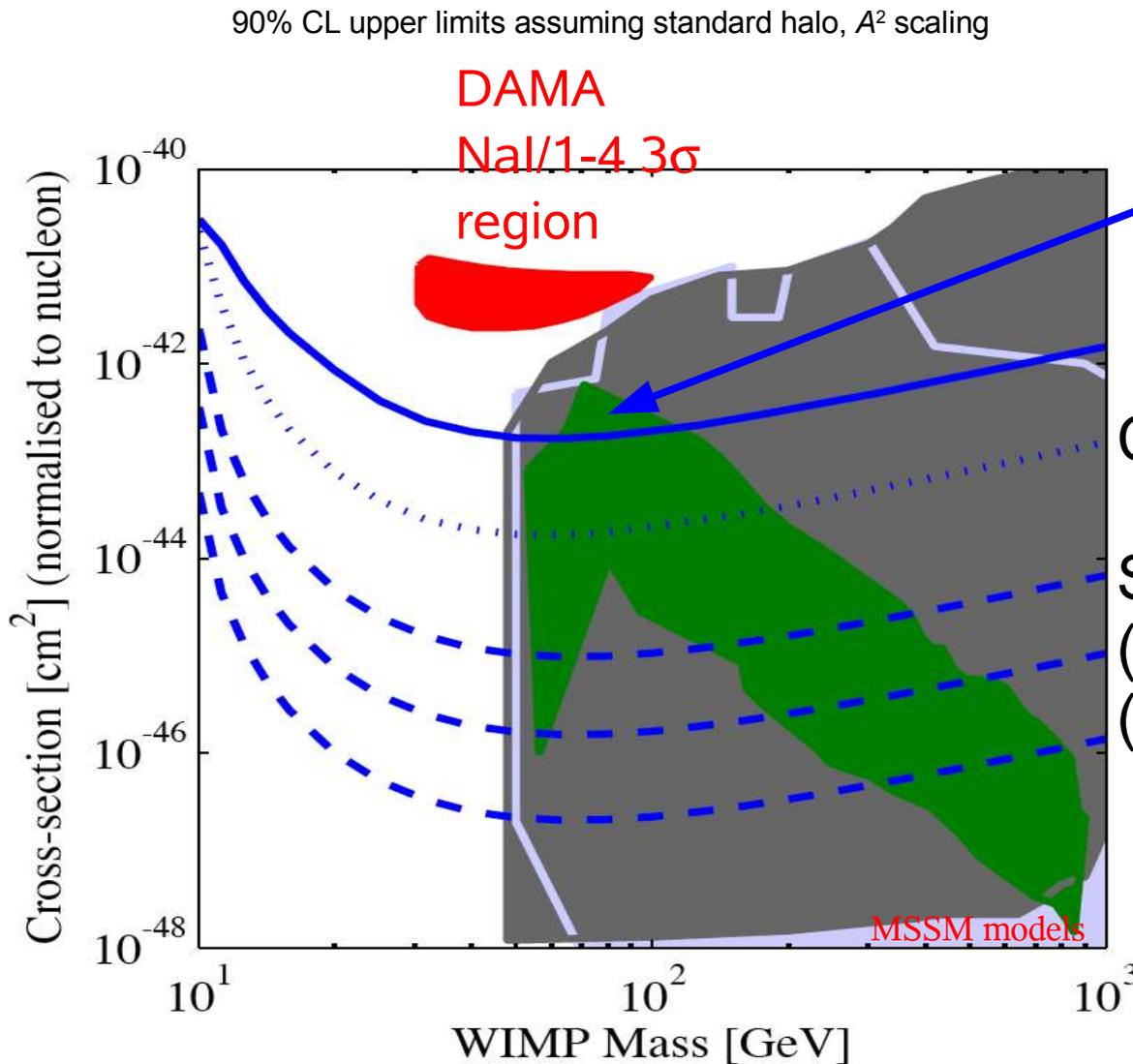
99.995% for EM backgrounds using charge/phonon ratio.

99.4% for  $\beta$ 's using pulse risetime as well

Much better than expected in CDMS II proposal!



# Current CDMS WIMP Limits



- Upper limits on the WIMP- nucleon cross section are  $1.7 \times 10^{-43} \text{ cm}^2$  for a WIMP with mass of  $60 \text{ GeV}/c^2$ 
  - Factor of 2.3 below CDMS Tower 1 limits
  - Factor 10 lower than any other experiment
- Expect x10 additional improvement with two more years of running at Soudan (through 2008)

# Fermilab role in CDMS

- **Scientific (3 FTE → 4 FTE)**
  - 3 Scientist + 1 postdoc
    - Project Manager, Soudan operations and infrastructure, cryogenics, electronics, analysis, electronics, analysis
  - Need another scientist/postdoc
    - Cryogenics/detector/electronics interface + analysis
- **Technical and Administrative (4 FTE → 7 FTE)**
  - Engineering/Technicians -> New cryogenics, electronics
  - 0.25 FTE administrative (need more project management help)
- **Budget (2006)**
  - \$0.5M M&S
  - \$1.3M Labor



DARK ENERGY  
SURVEY

# The Dark Energy Survey (DES)

## P939

### Program:

- 5000 sq. deg. survey of the Southern Galactic Cap
- Measure dark energy with 4 complementary techniques:
  - Clusters
  - Weak Lensing
  - Baryon Oscillations
  - Supernovae
- *Overlap with South Pole Telescope S-Z cluster survey*

### New Equipment:

- Fermilab lead: 2.2 Degree field 512 MPixel camera
- UIUC lead: Data Management, public archive

### Survey

- 5 year survey: 2010-2015



Use the Blanco 4M Telescope at the Cerro-Tololo Inter-american Observatory (CTIO)

# **Fermilab Dark Energy Program**

- **The Dark Energy Task Force\* defined 4 classes of dark energy projects**
  - **Stage I: already completed (2006)**
  - **Stage II: projects already taking data**
  - **Stage III: near-term, medium-cost, currently proposed projects**
  - **Stage IV: next generation projects (\$0.3-\$1 billion range)**
    - **Large Survey Telescope (LST), Square Kilometer Array (SKA), Joint Dark Energy Mission (JDEM)**
- **Fermilab has projects in each class**
  - **Stage I: SDSS-I large scale structure measurements**
  - **Stage II: SDSS-II Supernova Survey**
  - **Stage III: Dark Energy Survey**
  - **Stage IV: SNAP**

\*A DOE/NSF/NASA AAAC and  
DOE/NSF HEPAP joint subcommittee

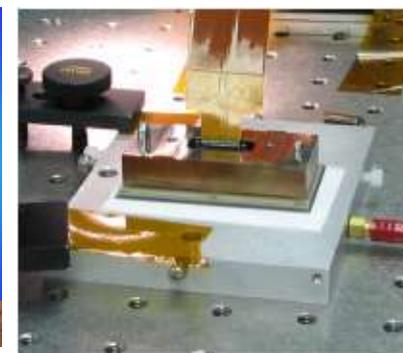
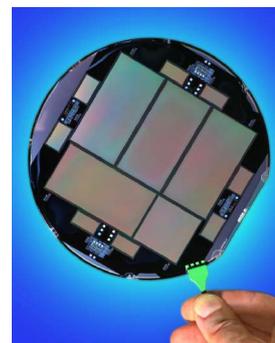
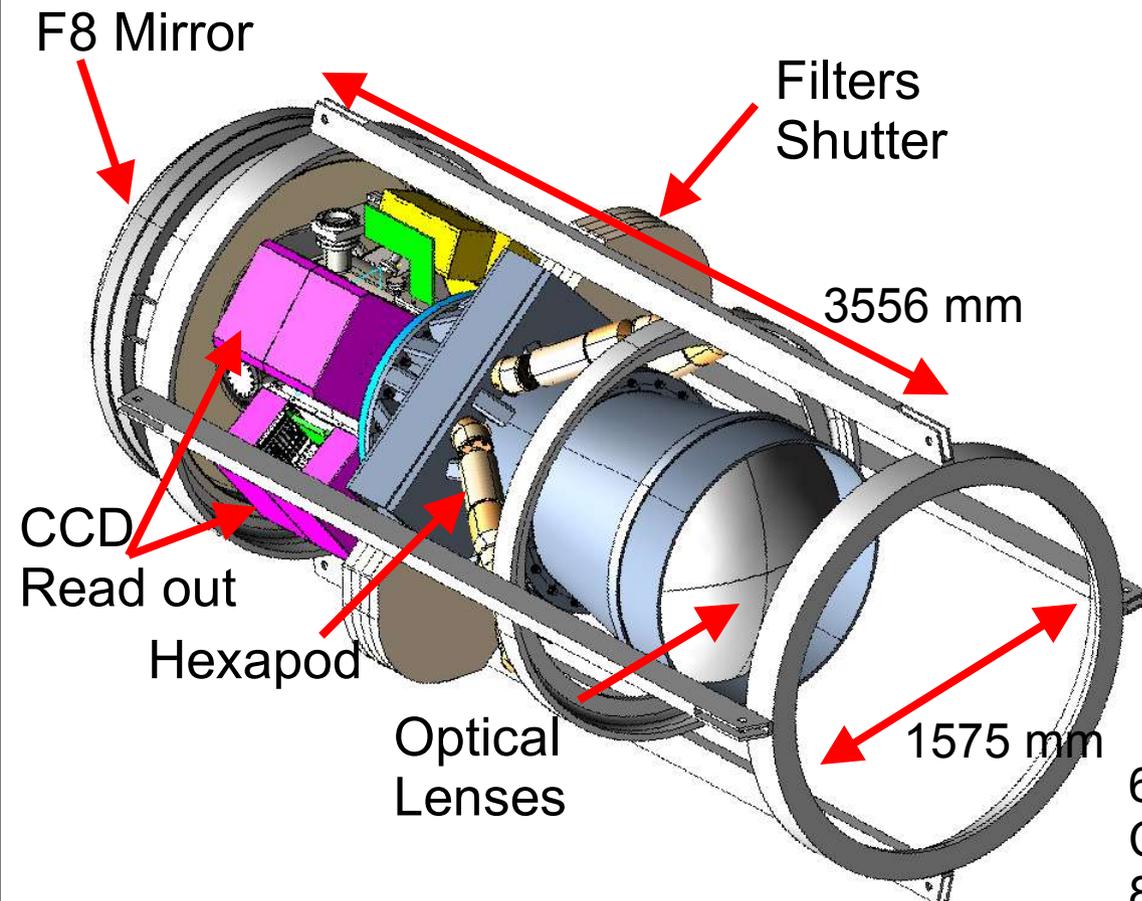


DARK ENERGY SURVEY

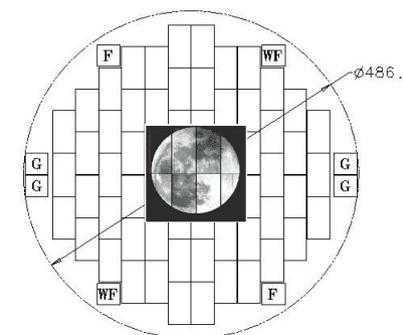
# The DES Instrument: DECam

DECam will be larger than any existing CCD camera

Fermilab Role:  
DECam project management  
CCD packaging  
CCD readout (lead)  
CCD Focal plane and vessel  
Optical Corrector barrel  
Cage and hexapod/alignment  
Simulations, Calibrations



62 2kx4k Image  
CCDs: **520 MPix**  
8 2kx2k Guide,  
focus, alignment



UK will provide optical elements  
Spain will provide production electronics



DARK ENERGY  
SURVEY

# **DES science: Four-fold path**

Dark Energy Task Force (DETF), DOE/NSF/NASA recommend proceeding with Stage III experiment, involving multiple ways of getting at nature of D.E.

## **LAMBDA**

Einstein's Legacy is the Cosmological Constant (CC). Is it really constant? DETF standardized parameterization of equation of state ( $w$ ) and its time derivative ( $w_a$ ).

$$w(z) = w_0 + w_a(1-a)$$

1. Baryon Oscillations
2. Galaxy Cluster Counts vs. redshift
3. Weak Lensing of Galaxies
4. Supernovae to  $z=0.8$

Pressure =  $w$  \* density  
Normal Matter has  $w > 0$ ,  
Dark Energy  $w < 0$ , C.C. has  $w = -1$ .

**DES can constrain  $w$ ,  $w_a$  to a factor of three better than existing constraints! DES meets DETF Stage III requirements.**



DARK ENERGY  
SURVEY

# DECam Funding Need Profile

(then yr \$, Overhead included)

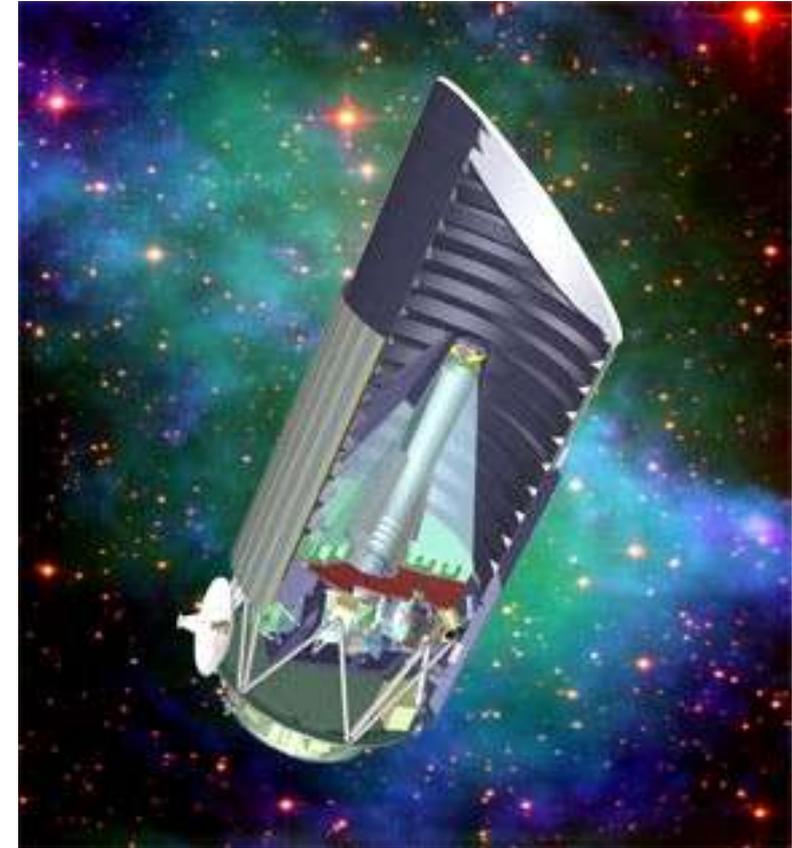
\$ M	FY07	FY08	FY09	FY10	TOTAL
ACTIVITY	R&D	CONST	CONST	CONST	
R&D FUNDS (DOE HEP)	4.1				4.1
DOE HEP MIE FUNDS		5.8	4.9	1.9	12.6
EXTERNAL (Foreign + Univ. Non DOE)	1.0	2.0	0.0	0.0	3.0*
TOTAL	5.1	7.8	4.9	1.9	19.7

\*Additional \$1M in External funds in FY06, Total External Funds = \$4M

- **Total Project Cost: (FY07-FY10) = \$19.7 M**
- **Total DOE Project cost: \$16.7 M**
- **DOE Major Item of Equipment (MIE) total of \$12.6 M includes M&S equipment (\$7M), technical labor (\$5.6M) and a total of ~35% contingency**
- **Scientists: ~ 6 FTEs now (11 Experimentalists + 3 Theorists)**
- **Technical: 13 FTEs (ME, EE, Drafters)**
- **CD1 review coming up: Sept. 2006**

# SNAP/JDEM

- **JDEM: Joint DOE/NASA Dark Energy Mission**
- **SNAP: DOE project proposed as the JDEM experiment.**
- **Science: Precision Dark Energy**
- **Techniques:**
  - **Supernovae redshifts out to  $z=2$**
  - **Wide area hi-res Weak lensing**
- **Strengths:**
  - **High statistical precision (2000 objects)**
  - **High systematic precision**
- **Timescale: launch beyond 5 year horizon**





# **SNAP - Tasks and Resources**

## **Tasks**

- **Wide angle science**
- **Software & Simulations**
- **Calibrations**
- **Radiation Shield**
- **Electronics**
  - **Mass Memory**
  - **ASICs**
- **CCD testing**

## **Resources**

- **FTEs**
  - **2.25 Scientist**
  - **3.75 Eng/CP/Tech**
- **M&S**
  - **\$68K per yr**
  - **\$75K from outside (MOUs)**

# *Summary*

**Fermilab Experimental Particle Astrophysics Program is vibrant, with multiple operating and planned experiments**

**Each operating experiment is a world-leader in its particular field**

**Vision for the future: precision experiments to investigate what the universe can tell us about dark matter, dark energy, and the most energetic particles**