

# 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 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



# Sloan Digital Sky Survey-II (E949)

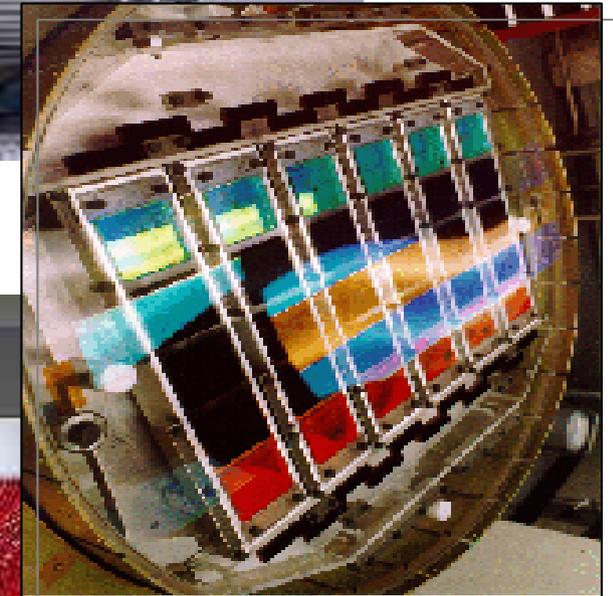
**Collaboration: ~150 scientists from**

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

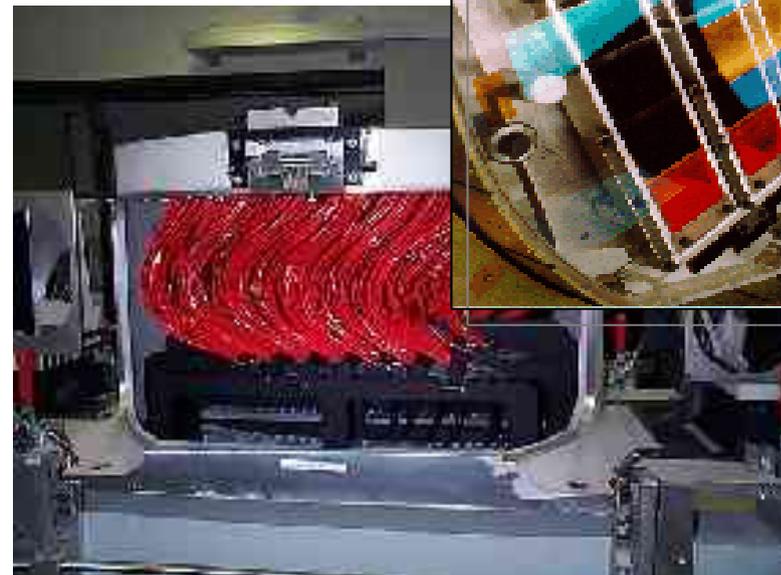


Beamline

Calorimeter



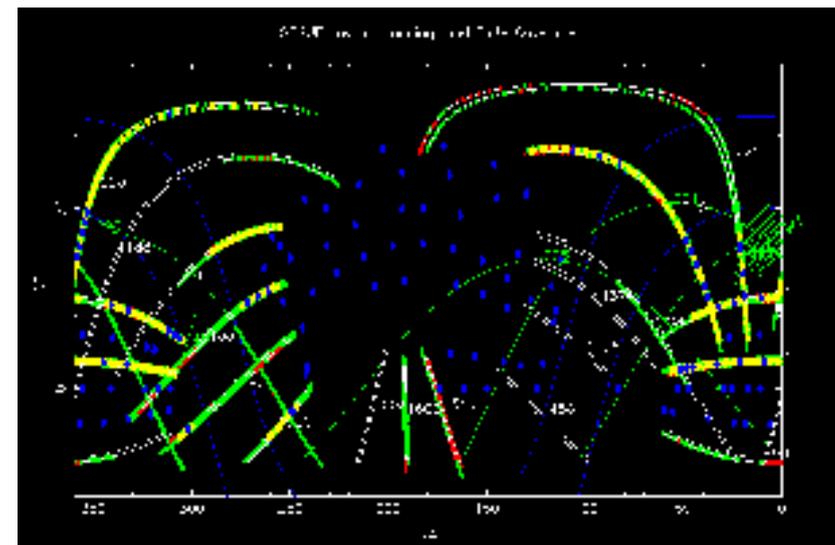
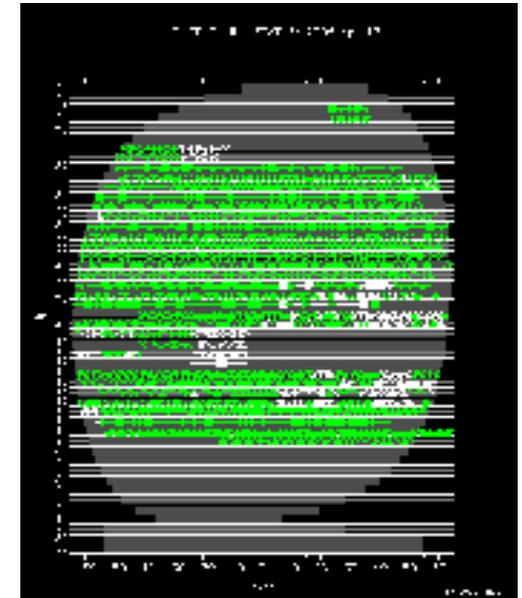
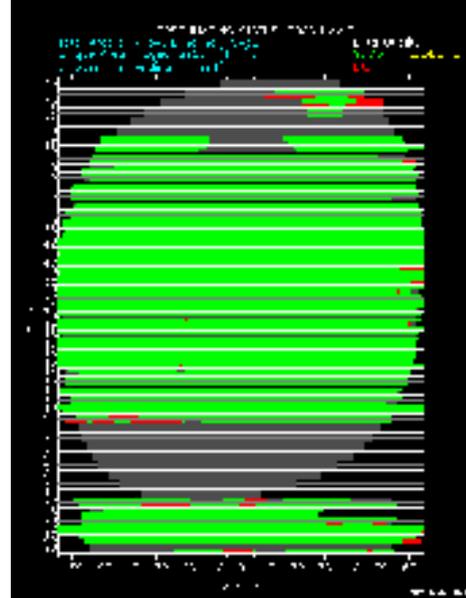
Massive Spectrometer





# *SDSS-II: 3 year mission*

- **Legacy:**
  - Imaging and Redshift survey - Large scale structure
- **SEGUE:**
  - Milky Way halo - mergers
- **Supernovae**
  - Low and intermediate redshift
- **Funding:**
  - NSF, Sloan, DOE, NASA, Japanese  
Mongbukagakusho, Max  
Planck Society, HEFCE





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

- **Fermilab Interests**

- **14 scientists (3 divisions)**

- **Kent co-leader of Legacy**
- **Yanny co-leader of Segue**
- **Frieman co-leader of Supernove**

## **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**
- **\$1.3 million SWF**

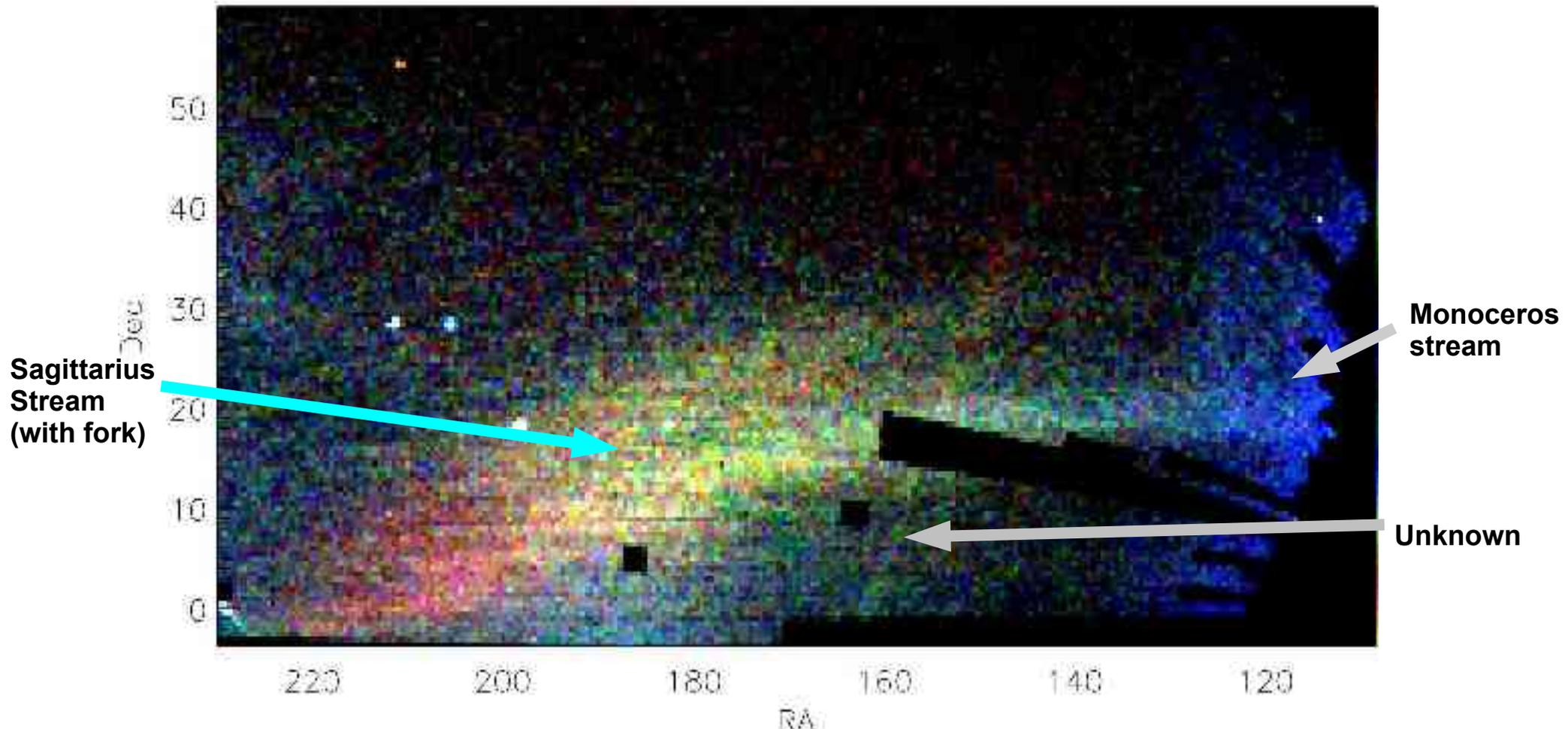
- **Funding**

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

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



# *SDSS-II Hot results*



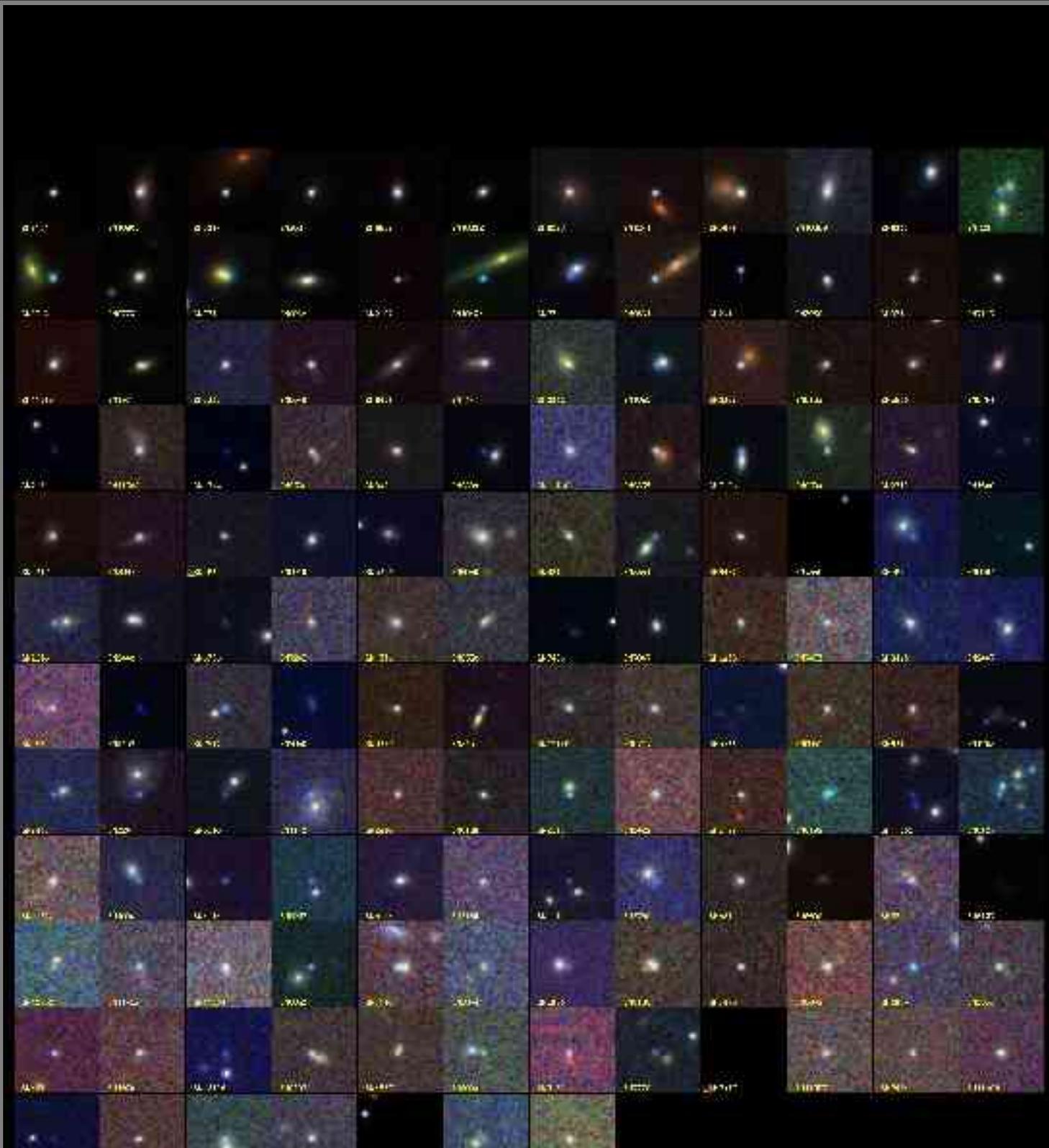
**"Field of Streams" - mergers in Galactic Halo  
(Beam to CDMS II)**

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 Dark Energy Survey (DES)*

## Proposal:

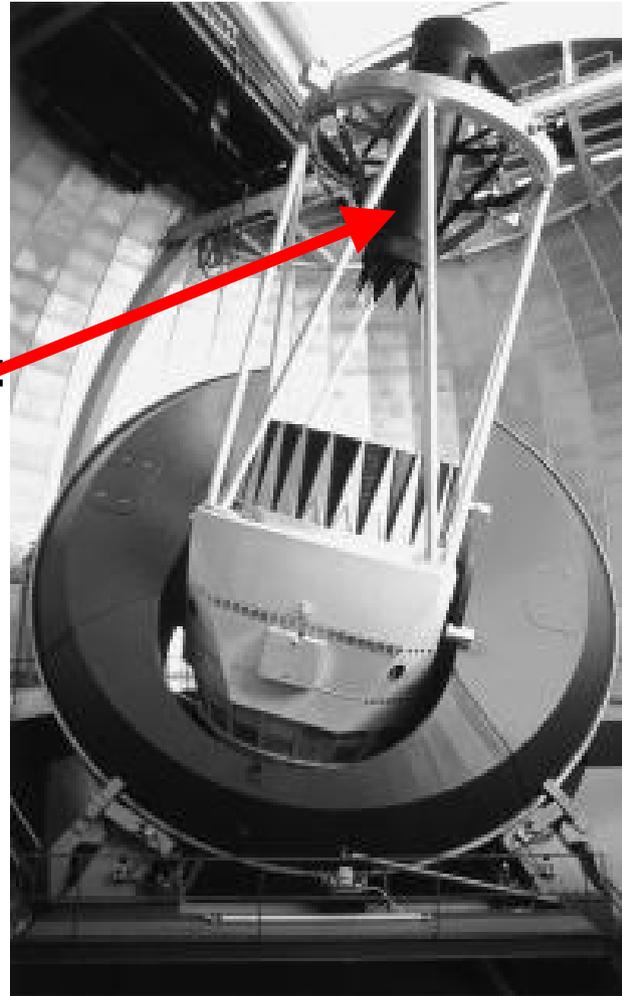
- Perform a 5000 sq. deg. survey of the southern galactic cap (overlap w SPT)
- measure  $w$  with 4 complementary techniques: Clusters, Weak Lensing, BAO, SNIa

## New Equipment:

- Fermilab lead: Replace the PF cage with a new 2.2 FOV, 520 Mega pixel optical CCD camera
- UIUC lead: Data Management, public archive

## Survey

- 5 year survey: 2010-2015
- 105 nights/yr when S.Gal.Cap is visible (Sept-Feb)



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

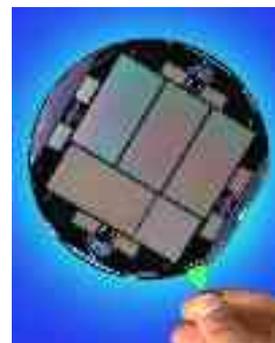
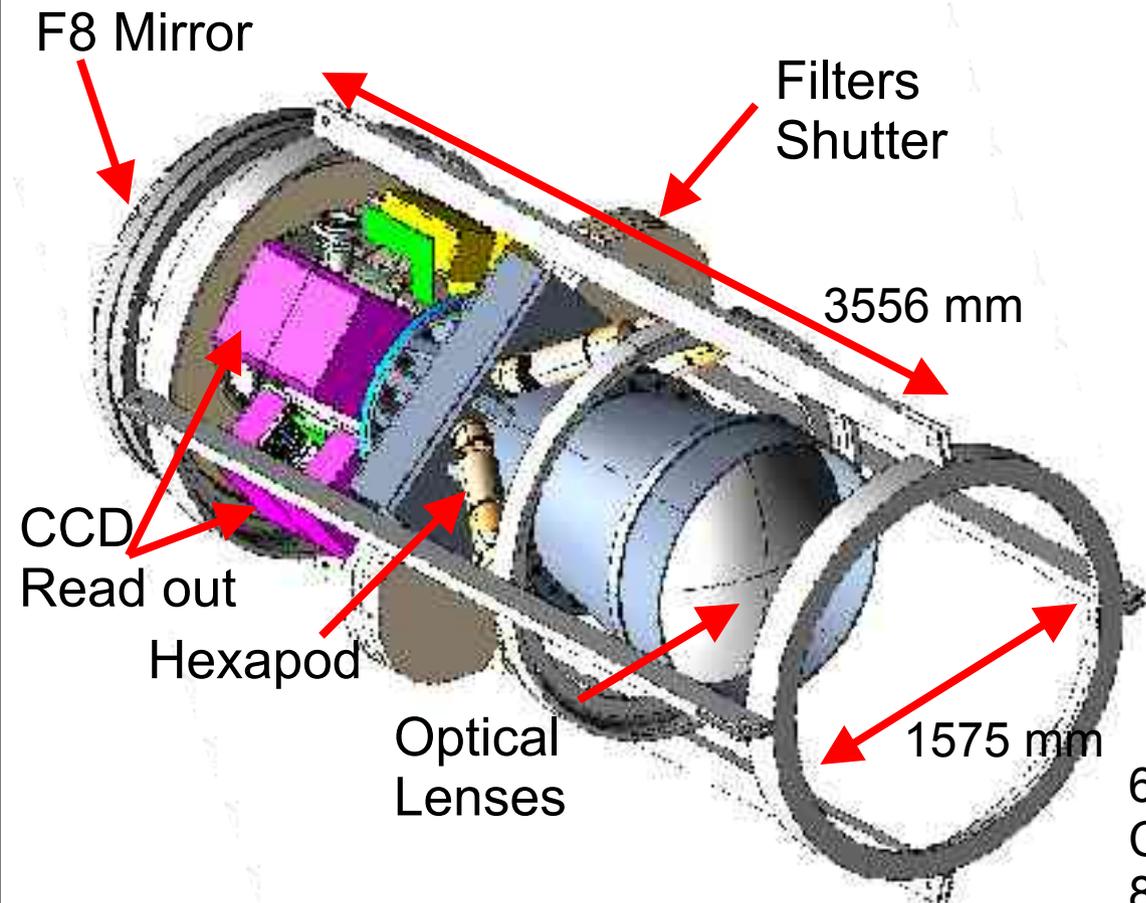


DARK ENERGY SURVEY

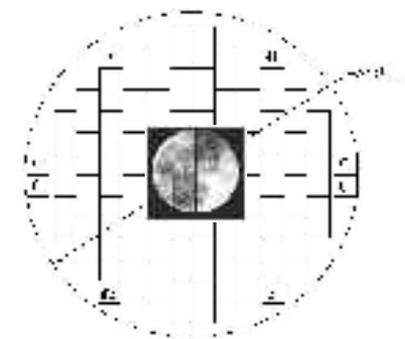
# The DES Instrument: DECam

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



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



UK will provide optical elements  
Spain will provide production electronics



# DES Forecasts: Power of Multiple Techniques

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

68% CL

Four individual measurements of  $w$  at 5-10% statistical precision assuming constant  $w$ .

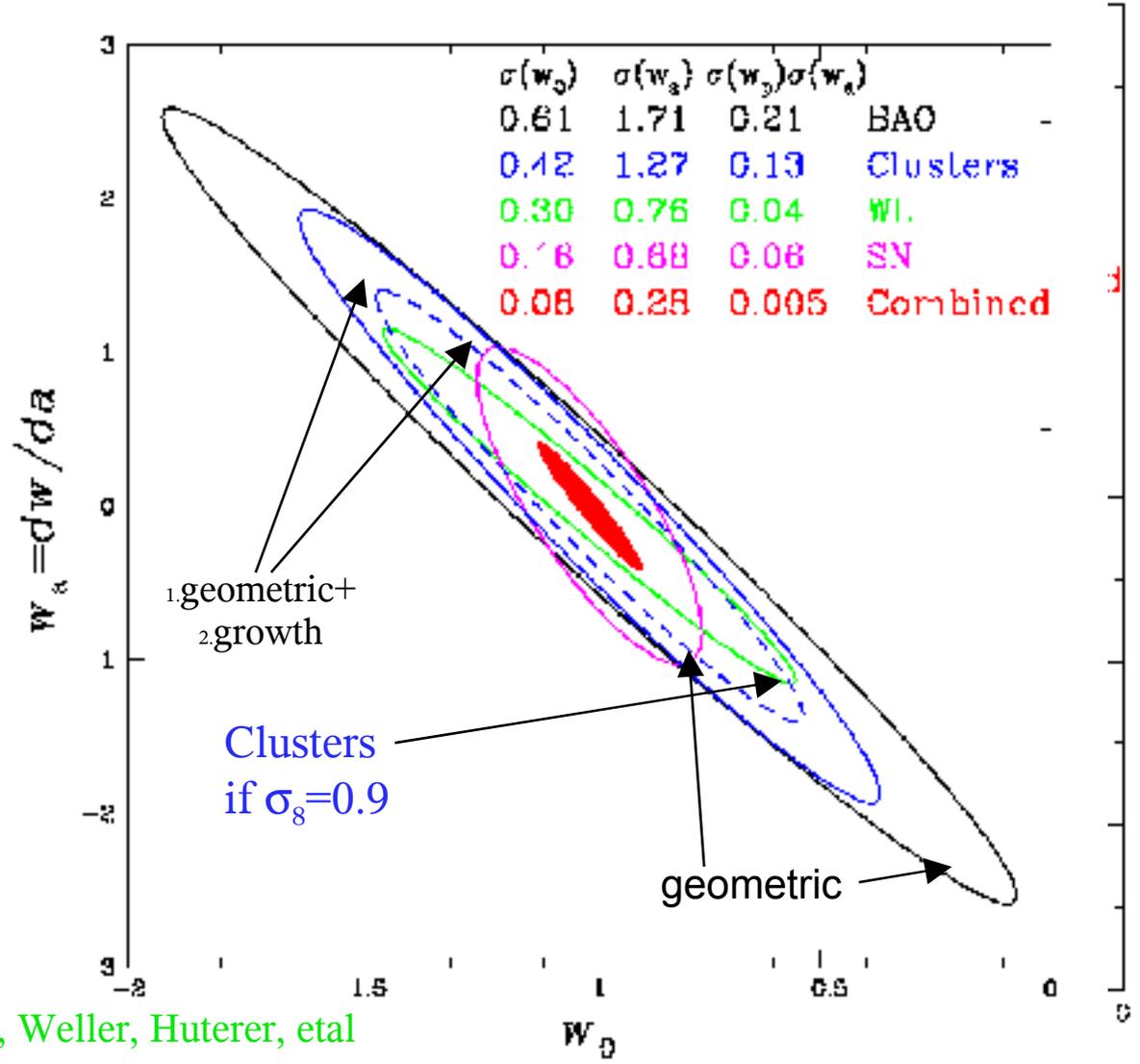
Combined power allows investigation into evolution of  $w$

## Assumptions:

- Clusters:**  $\sigma_8=0.75, z_{\max}=1.5$ , WL mass calibration (no clustering)
- BAO:**  $z_{\max}=300$
- WL:**  $z_{\max}=1000$  (no bispectrum)

Statistical+photo-z systematic errors only

Spatial curvature, galaxy bias marginalized  
Planck CMB prior





# **Fermilab Personnel and costs**

- ~ 5 FTE Scientists, Associate Scientist
  - 5 PPD/HEP (Flaugher, Merritt, Diehl, Estrada, Grunendahl, Wester)
  - 5 CD/EAG (Annis, Lin, Kent, Stoughton, Tucker)
  - 1 AD (Scarpine)
- ~ 0.5 FTE Theorists (Frieman, Dodelson, Stebbins)
- ~ 3 FTE: Mechanical Engineers
- ~ 2 FTE ME and EE design and drafting
- ~ 4 FTE Electrical Engineers
- ~4 FTE ME and EE Technicians
- Total PPD Labor cost est for FY06 is about the same as 05 ~ \$1.6M w/o Overhead, Steve could add EAG costs – Mont will have the fully loaded numbers and not count the theorists
- M&S in FY05 was ~ \$1M, of this 700k went to starting the CCD R&D – good thing too, these are long leadtime items, Req that went in Sept. 05 will result CCDs delivered to FNAL in Oct. 06! Establishing the CCD processing and yield is difficult!
- M&S In FY06 allocation is \$0.4M so far



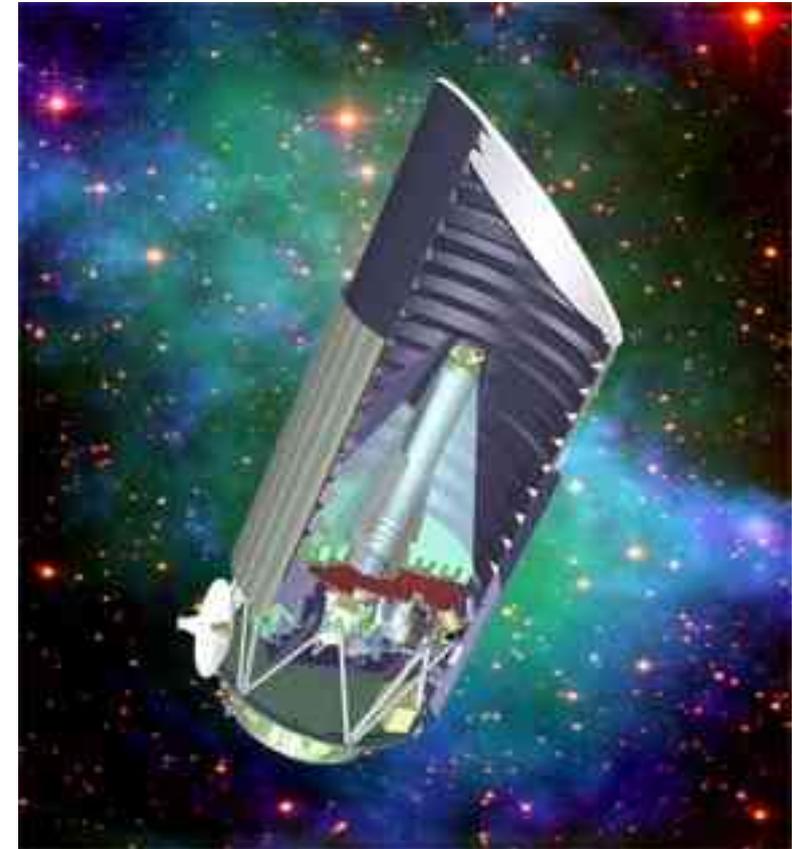
**Table for basis of fully loaded costs in the funding profile table These numbers have no overhead!**

COSTs (then yr M\$, no O/H)	FY05	FY06	FY07	FY08	FY09	FY10	Total
M&S, then yr \$, no O/H	1.06	1.97	2.56	3.68	0.88	0.27	10.42
M&S Contingency	0.00	0.00	0.00	1.00	1.70	0.30	3.00
Total	1.06	1.97	2.56	4.68	2.58	0.57	13.42
Funding from outside sources	0.10	0.90	1.00	2.00	0.00		4.00
<b>Total M&amp;S Needed from FNAL</b>	<b>0.96</b>	<b>1.07</b>	<b>1.56</b>	<b>2.68</b>	<b>2.58</b>	<b>0.57</b>	<b>9.42</b>
UIUC and FNAL Technical Labor	1.49	1.53	1.12	1.32	0.51	0.28	6.25
uiuc labor, esc, no oh	0.06	0.06	0.04	0.04	0.03	0.03	0.27
<b>FNAL technical labor cost</b>	<b>1.44</b>	<b>1.47</b>	<b>1.08</b>	<b>1.28</b>	<b>0.47</b>	<b>0.25</b>	<b>5.98</b>
FNAL Labor Contingency	0.00	0.00	0.00	0.80	1.00	0.50	2.30
<b>Total FNAL Labor Cost</b>	<b>1.44</b>	<b>1.47</b>	<b>1.08</b>	<b>2.08</b>	<b>1.47</b>	<b>0.75</b>	<b>8.28</b>
<b>Scientists</b>		<b>0.65</b>					
<b>FNAL R&amp;D (M&amp;S + Labor)</b>	<b>2.39</b>	<b>2.53</b>	<b>2.64</b>				<b>7.56</b>
<b>FNAL Equipment (M&amp;S + Labor)</b>				<b>4.75</b>	<b>4.06</b>	<b>1.32</b>	<b>10.13</b>



# **SNAP/JDEM**

- **JDEM: joint DOE/NASA mission**
- **SNAP: DOE project proposed as the JDEM experiment.**
- **Science: Precision Dark Energy**
- **Techniques:**
  - **Supernovae  $z=1.7$**
  - **Weak lensing**
- **Strengths:**
  - **High statistical precision (2000 objects)**
  - **High systematic precision**



# SNAP Simulation

Optical PSF



+

Extended Object



=

Convolved Object

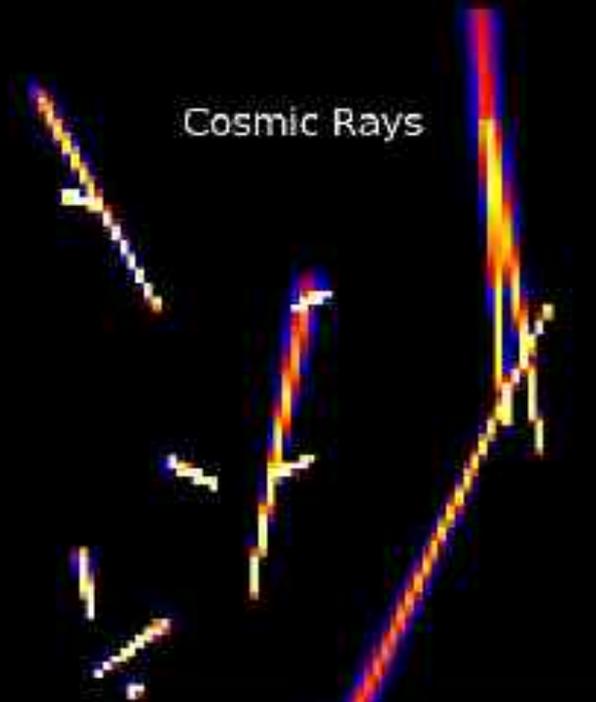


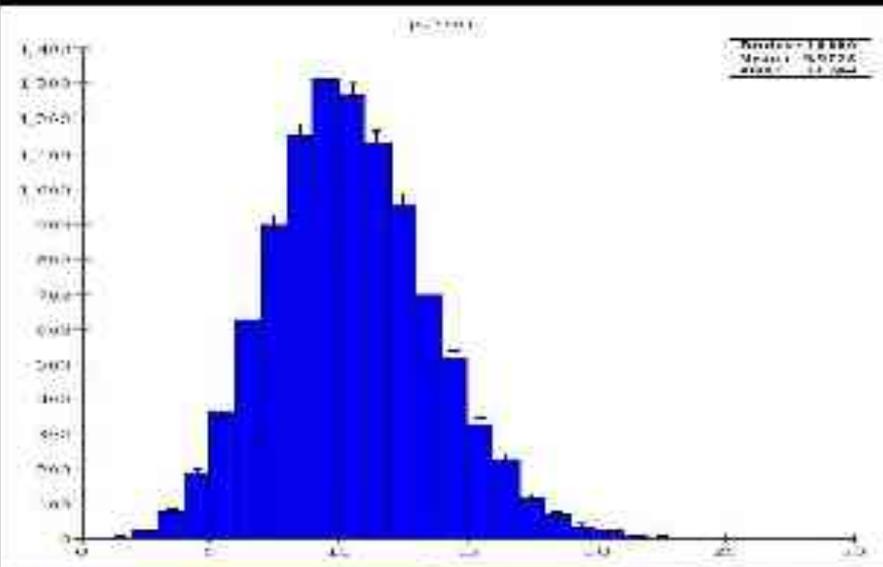
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Rotation



Cosmic Rays





Number	18880
Mean	16.0726
Std	11.064

SNAPSim December 2, 2005



18



# ***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)**



# **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**

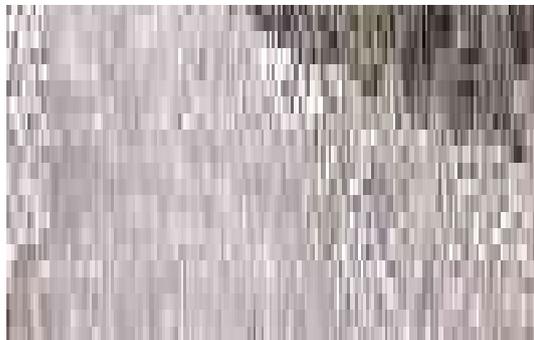


**Fluorescence telescope**

**24 total**



PIERRE  
AUGER



## Auger Construction Status

- 1135 surface detector stations deployed, 932 sending data (blue).
- Three fluorescence buildings complete each with 6 telescopes – the fourth under construction.





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*

**Participating US institutions – 60 Scientists**

**UCLA**

**Case Western**

**Chicago**

**Colorado**

**Colorado State**

**Columbia**

**Fermilab (and ANL)**

**Louisiana State**

**Michigan Tech**

**Minnesota**

**Nebraska**

**New Mexico**

**Northeastern**

**Ohio State**

**Utah**

**Support**

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



# **Fermilab Participation**

## • **Fermilab Participation**

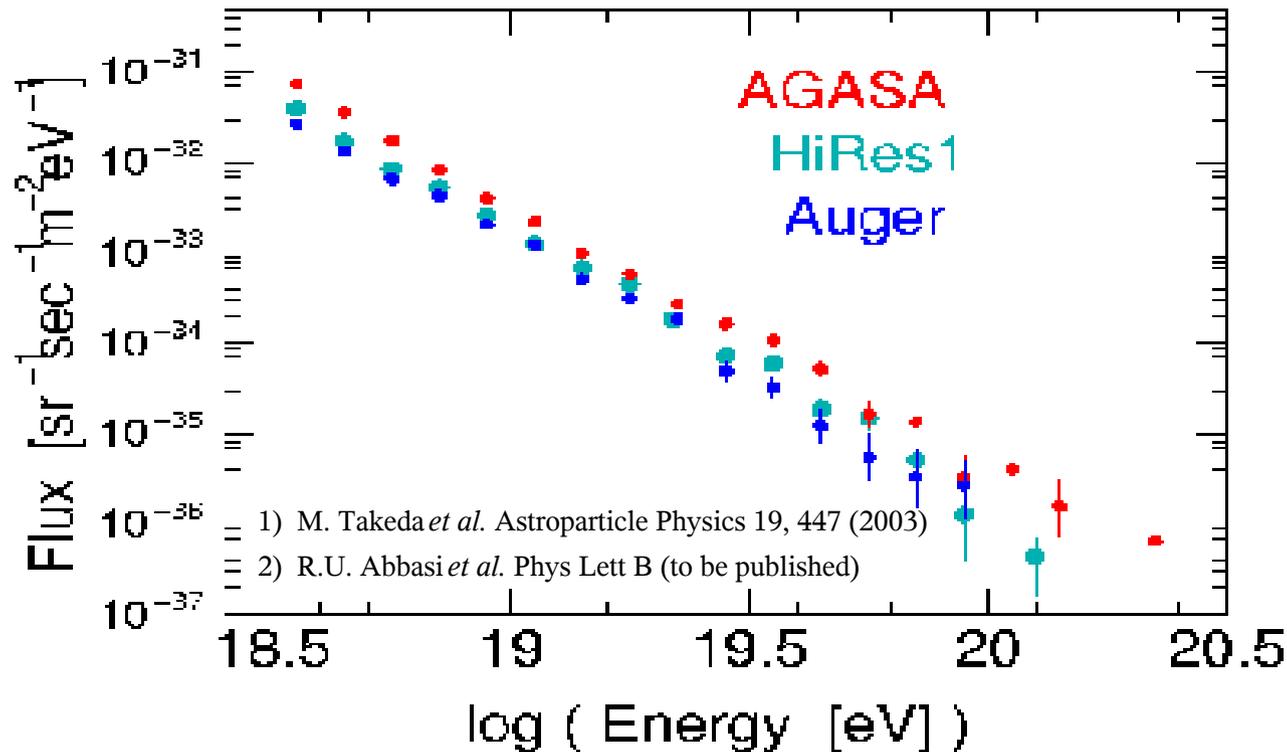
- **Scientists – 5 full time + 2 Part time+1 postdoc**
- **+ 1 Brinson Pre-doctoral Fellow**
- **Staff – 2 full time**
- **Activities**
  - **Project Management**
  - **Construction**
  - **Commissioning**
  - **Data analysis**
- **Group size – approximately constant; may grow slightly as Auger North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



# CDMS - Direct Detection of Dark Matter

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/heat**  
**99.4% for  $\beta$ 's using pulse risetime as well**  
**Much better than expected in CDMS II proposal!**



Tower of 6 ZIPs

Tower 1

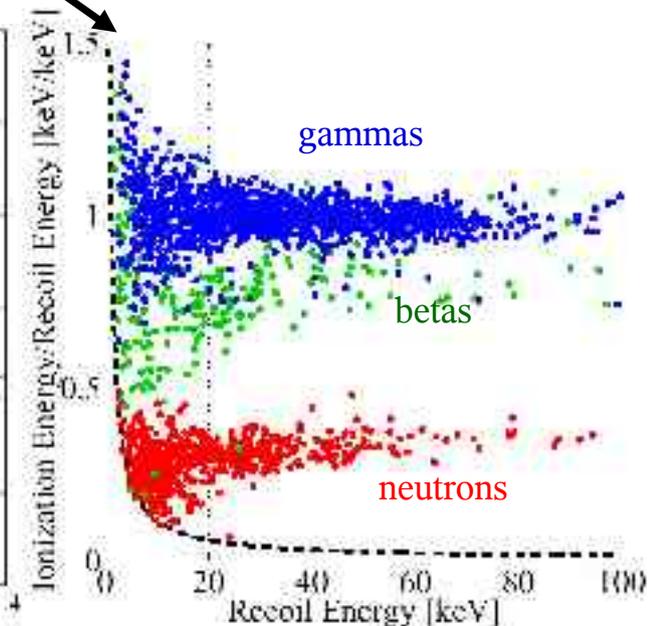
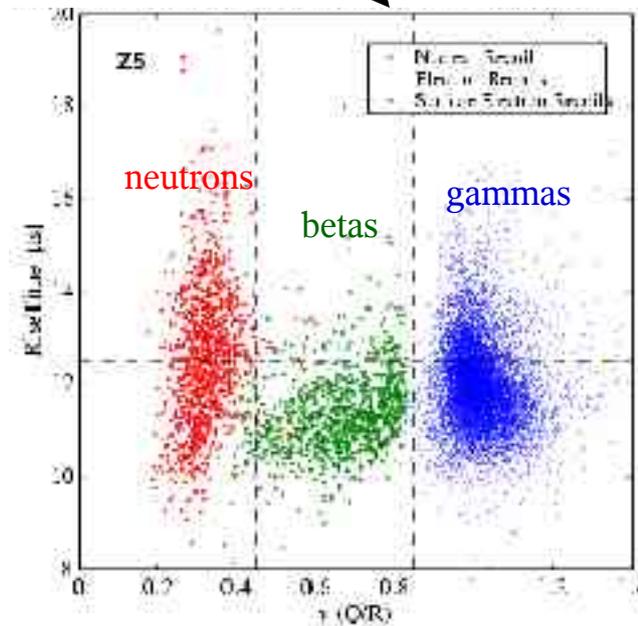
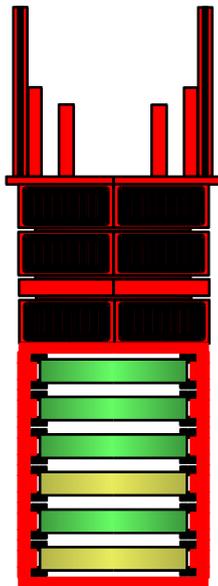
4 Ge

2 Si

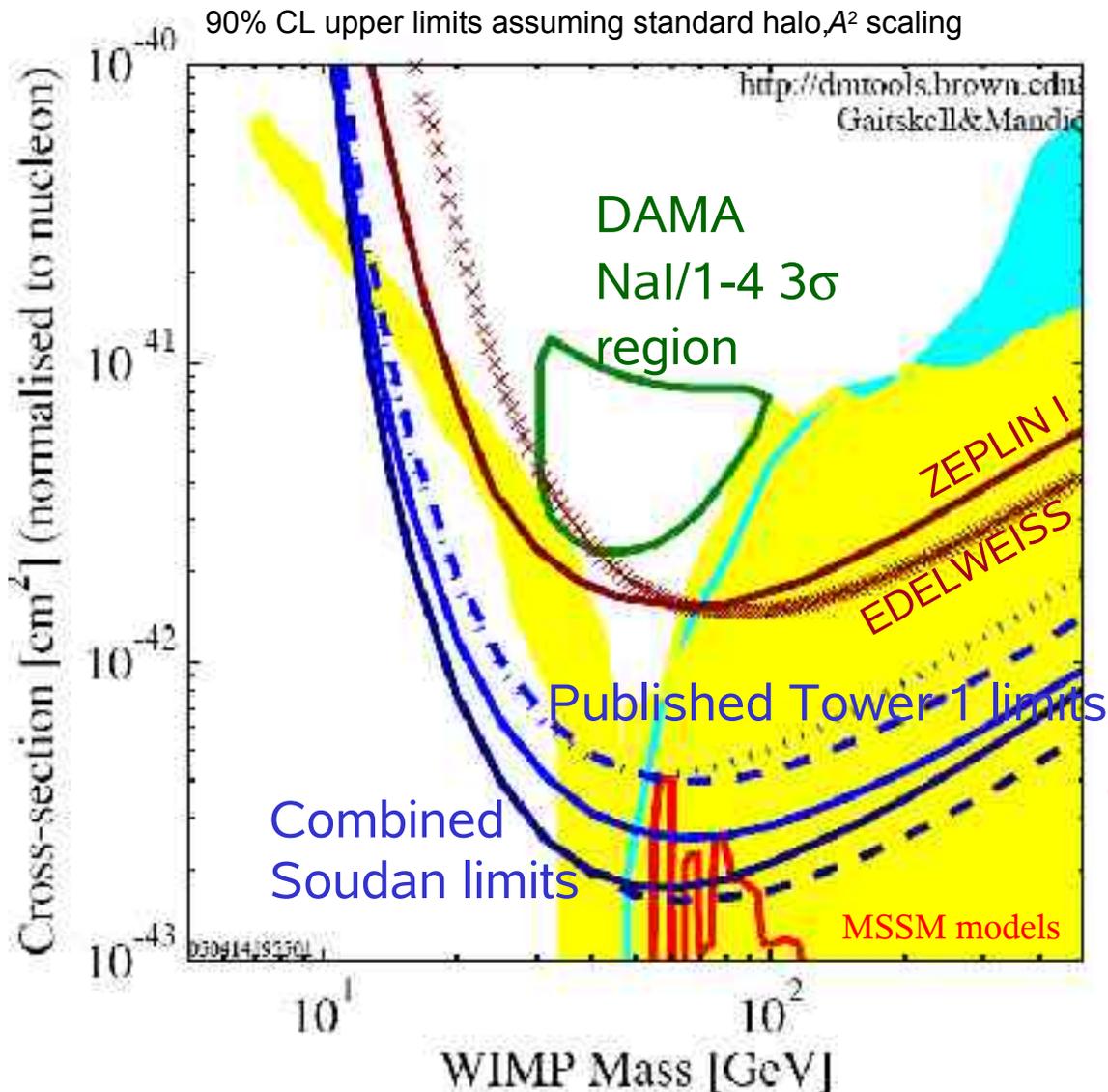
Tower 2

2 Ge

4 Si



# 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

## **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 Engineering/Technician -> ~7 FTE (new cryogenics, electronics)**
  - **0.25 FTE administrative (need more project management help)**

# **CDMS Fermilab Budget**

Type of Funds	2005	2006	2007	2008	2009	2010
M&S	435	460	471	483	495	507
Labor	848	1283	1341	1405	1462	1520
Total	1283	1743	1812	1888	1956	2027

Years are fiscal; amounts in k\$

# **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**