Dark Matter Experiments at Fermilab

CDMS, COUPP, DarkSide

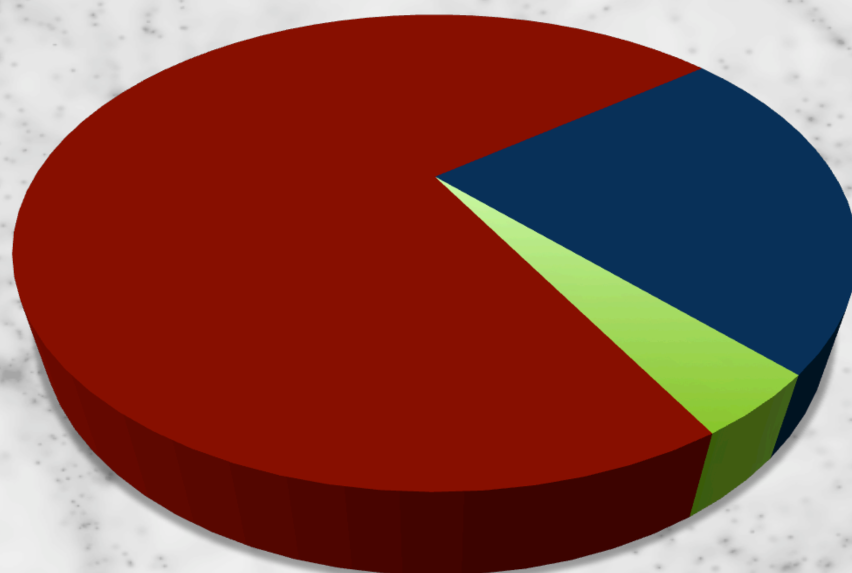
Jeter Hall

Fermilab Center for Particle Astrophysics

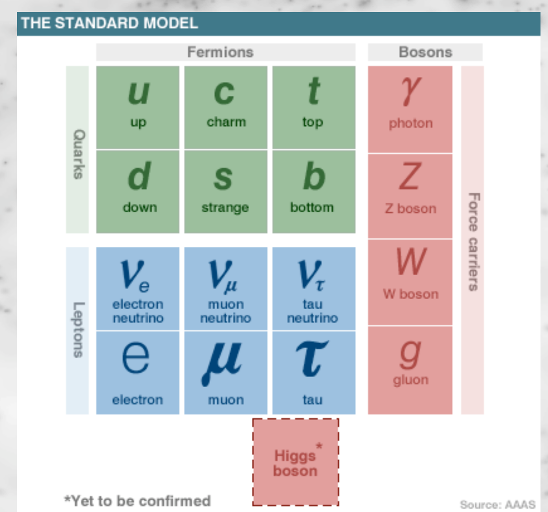
The Cosmic Frontier

Dark Matter
(Cold, Non-Baryonic)
~ 23%

Dark Energy
~ 73%

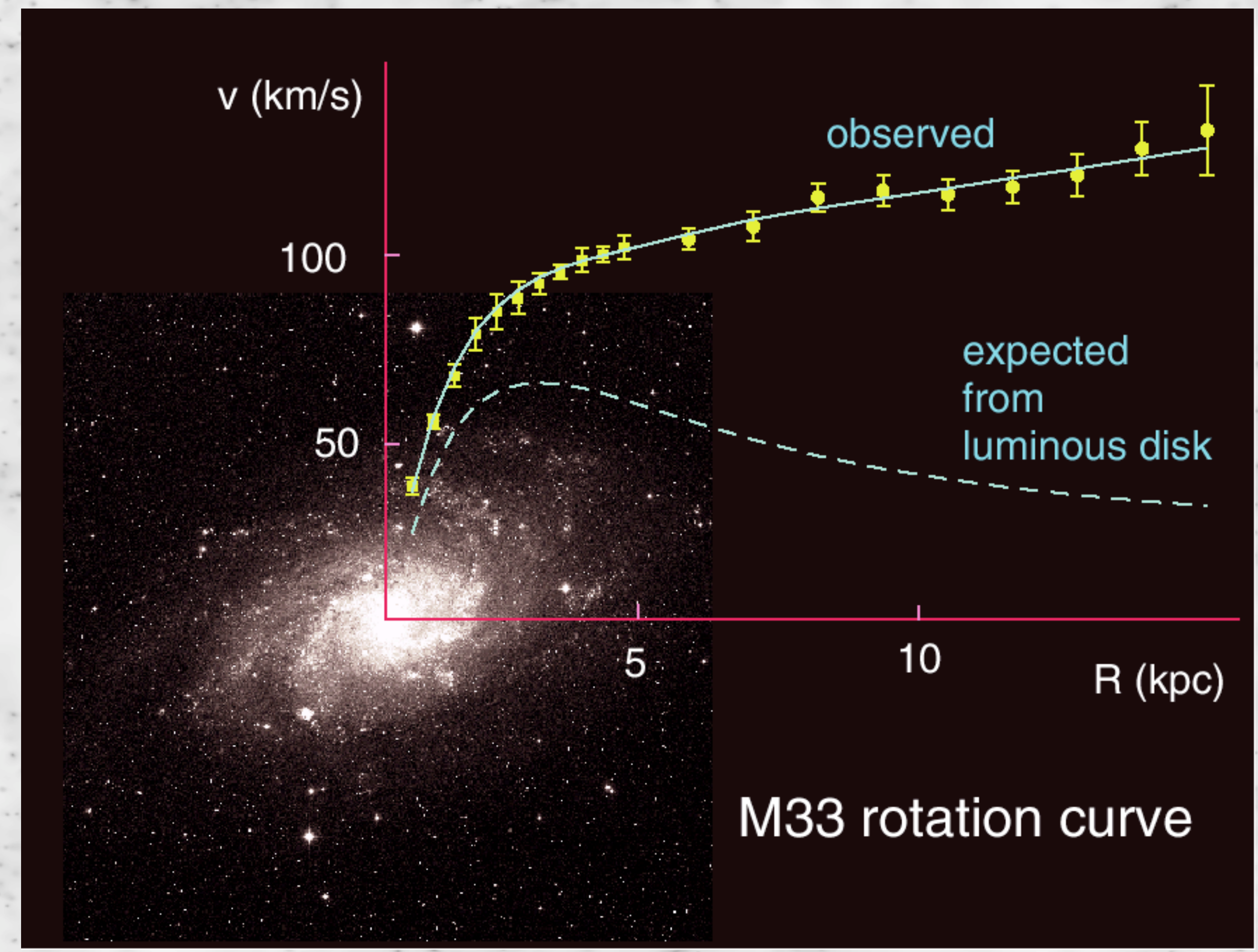


Standard Model
~ 4%



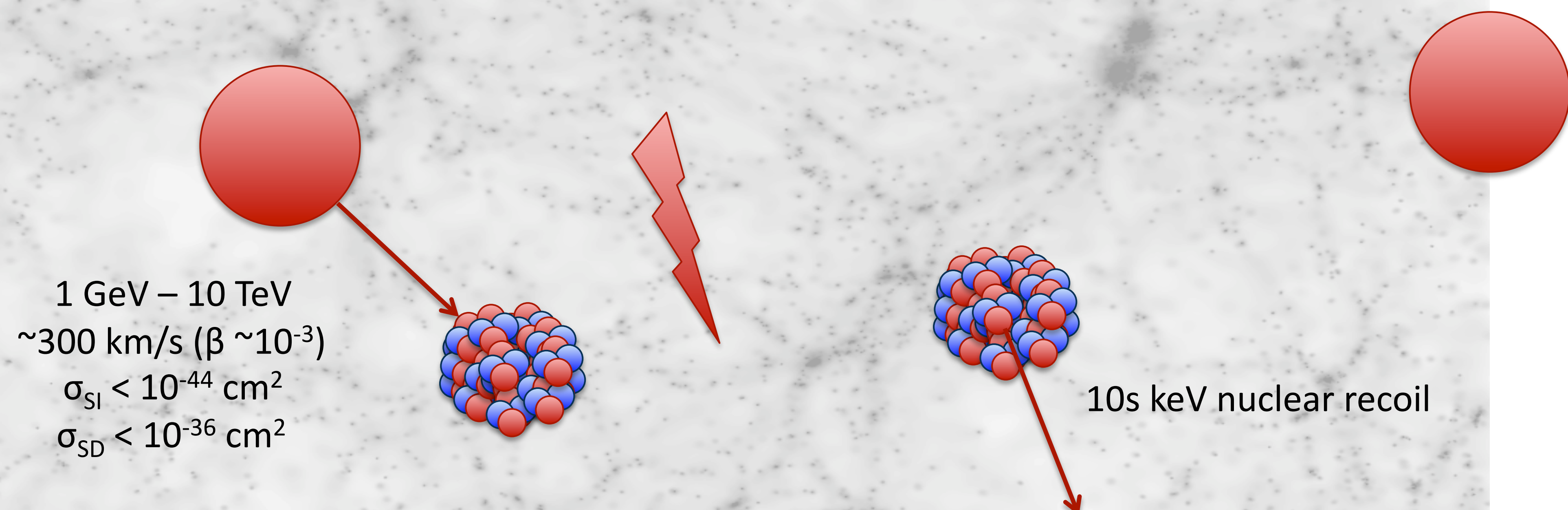
- Dark Energy
  - DES/JDEM (J. Estrada)
- Dark Matter
  - CDMS/COUPP/DarkSide

The Dark Matter Problem

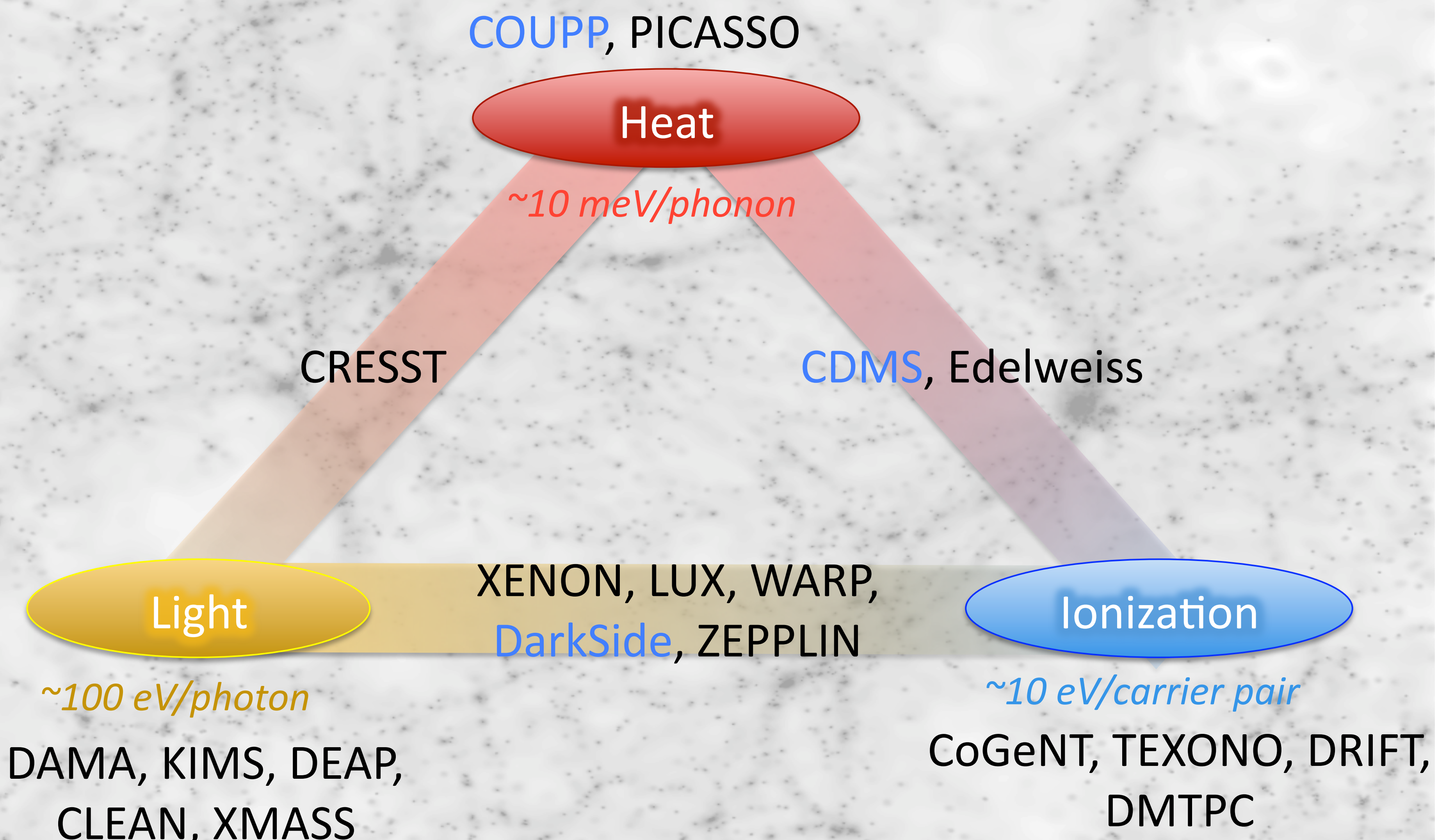


Direct Detection of Dark Matter

- Searching for WIMP-Nucleus elastic scattering
- In a sea of background radiation
  - Backgrounds, backgrounds, backgrounds…



Direct Detection Techniques



Dark Matter in PASAG

- SuperCDMS-Soudan is supported in order to prove the detector technology for SuperCDMS-SNOLAB
- The 100 kg SuperCDMS experiment in SNOLAB is specifically recommended in all budget scenarios
- The 500 kg COUPP bubble chamber construction is recommended in all budget scenarios
- An effort in depleted Argon is supported in all budget scenarios

The Cryogenic Dark Matter Search

California Institute of Technology
Z. Ahmed, J. Filippini, S.R. Golwala, D. Moore, R.W. Ogburn

Case Western Reserve University
D. Akerib, C.N. Bailey, M.R. Dragowsky,
D.R. Grant, R. Hennings-Yeomans

Fermi National Accelerator Laboratory
D. A. Bauer, F. DeJongh, J. Hall, D. Holmgren,
L. Hsu, E. Ramberg, R.L. Schmitt, J. Yoo

Massachusetts Institute of Technology
E. Figueroa-Feliciano, S. Hertel,
S.W. Leman, K.A. McCarthy, P. Wikus

NIST *
K. Irwin

Queen's University
P. Di Stefano *, N. Fatemighomi *, J. Fox *,
S. Liu *, P. Nadeau *, W. Rau

Santa Clara University
B. A. Young

Southern Methodist University
J. Cooley

SLAC/KIPAC *
E. do Couto e Silva, G.G. Godrey, J. Hasi,
C. J. Kenney, P. C. Kim, R. Resch, J.G. Weisend

Stanford University
P.L. Brink, B. Cabrera, M. Cherry *,
L. Novak, M. Pyle, A. Tomada, S. Yellin

Syracuse University
M. Kos, M. Kiveni, R. W. Schnee

Texas A&M
J. Erikson *, R. Mahapatra, M. Platt *

University of California, Berkeley
M. Daal, N. Mirabolfathi, A. Phipps, B. Sadoulet,
D. Seitz, B. Serfass, K.M. Sundqvist

University of California, Santa Barbara
R. Bunker, D.O. Caldwell, H. Nelson, J. Sander

University of Colorado Denver
B.A. Hines, M.E. Huber

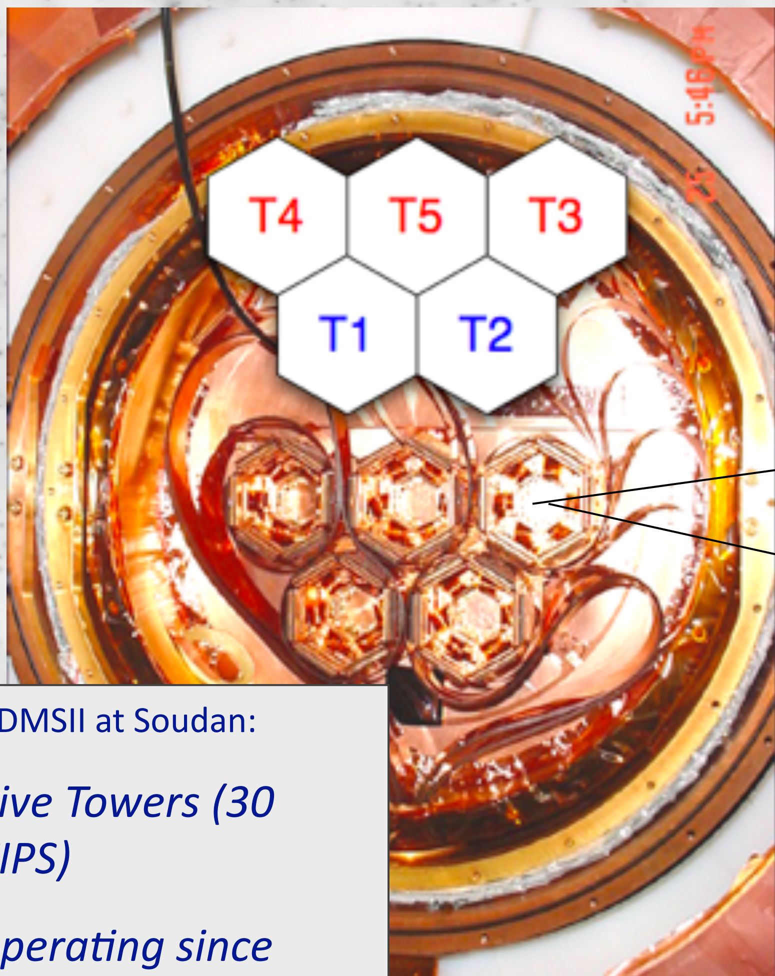
University of Florida
T. Saab, D. Balakishiyeva, B. Welliver *

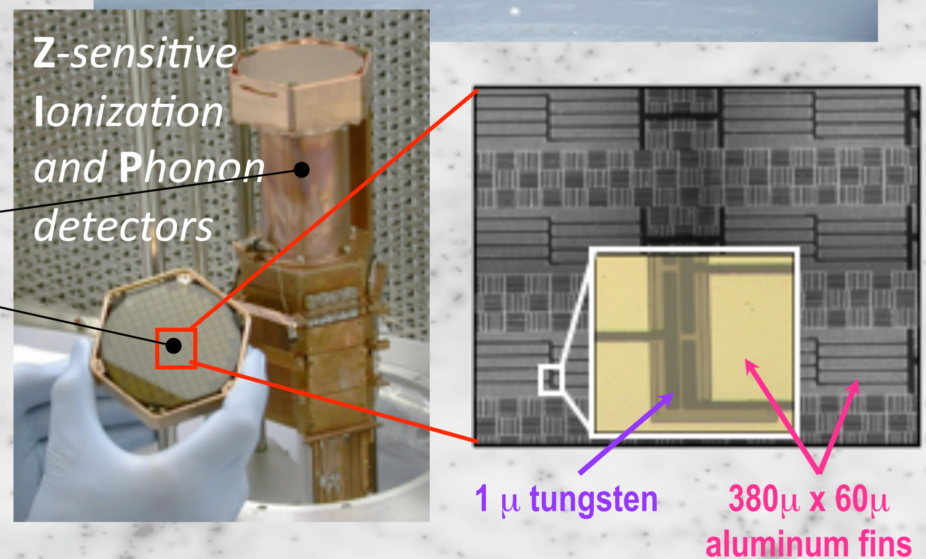
University of Minnesota
J. Beaty, P. Cushman, S. Fallows, M. Fritts,
O. Kamaev, V. Mandic, X. Qiu, A. Reisetter, J. Zhang

University of Zurich
S. Arrenberg, T. Bruch, L. Baudis, M. Tarka

** new collaborators or new institutions in SuperCDMS*

The CDMS-II Experiment





CDMSII at Soudan:

Five Towers (30 ZIPS)

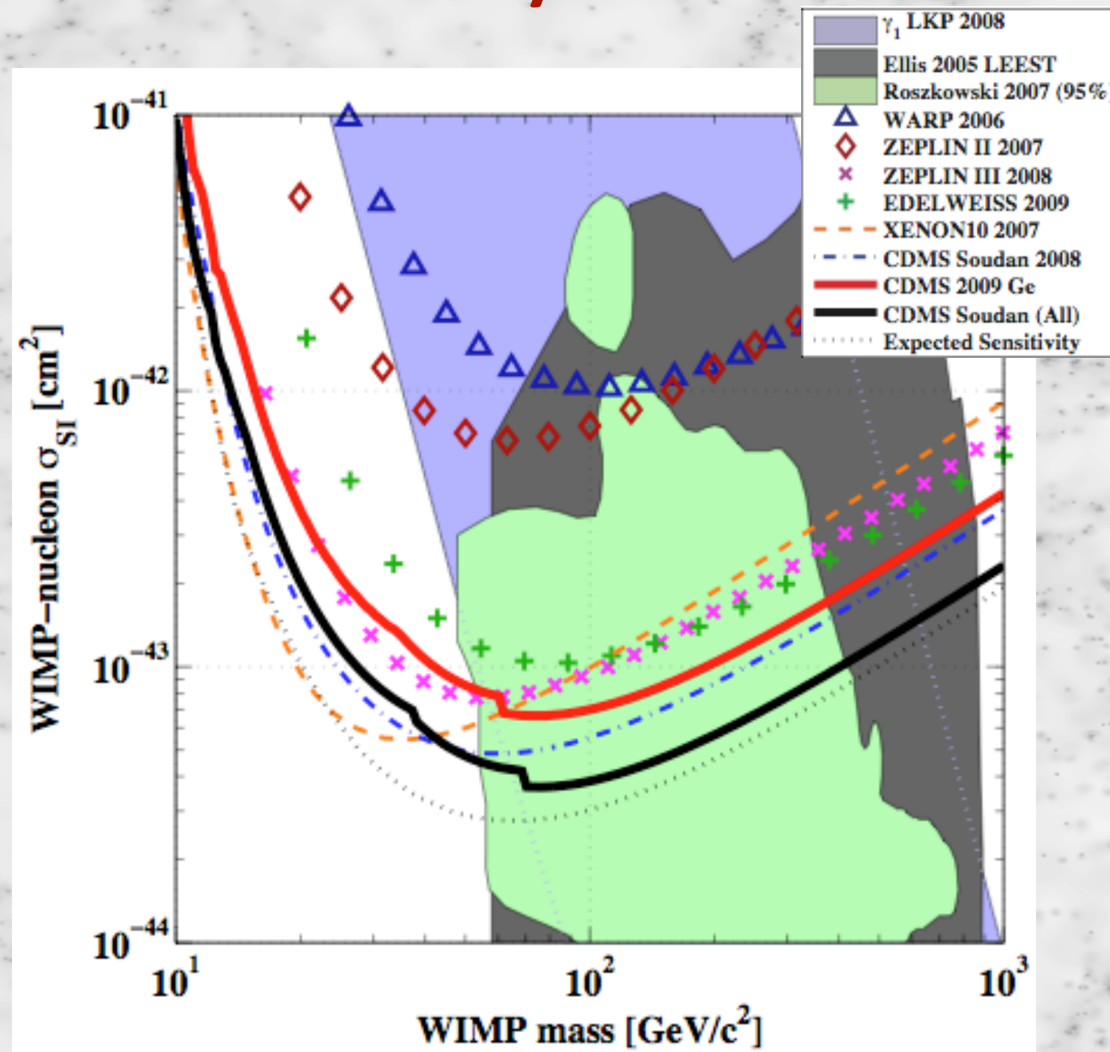
operating since June '06

Fermilab CDMS Group

- Leadership roles in
  - Cryogenics (D. Bauer, R. Schmitt, T. Tope)
  - Analysis (J.Hall, D. Holmgren, L. Hsu, J. Yoo)
  - Operations (D. Bauer)
  - Electronics (F. DeJongh, J. Hall, S. Hansen)

CDMS Sensitivity

- 2 events with an exposure of 200 kg days
- Low expected background of 0.9 events
- Leading the world in sensitivity to spin-independent WIMP-nucleus elastic scattering

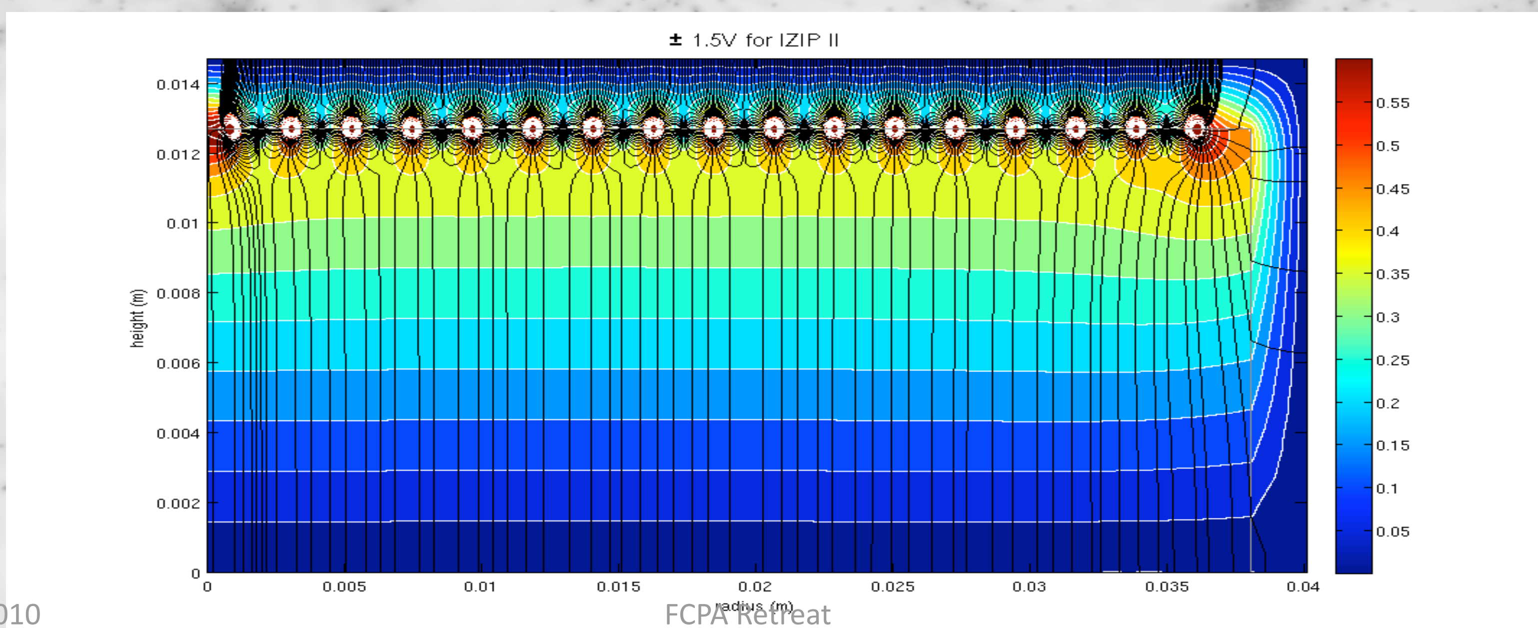


Recent CDMS Results

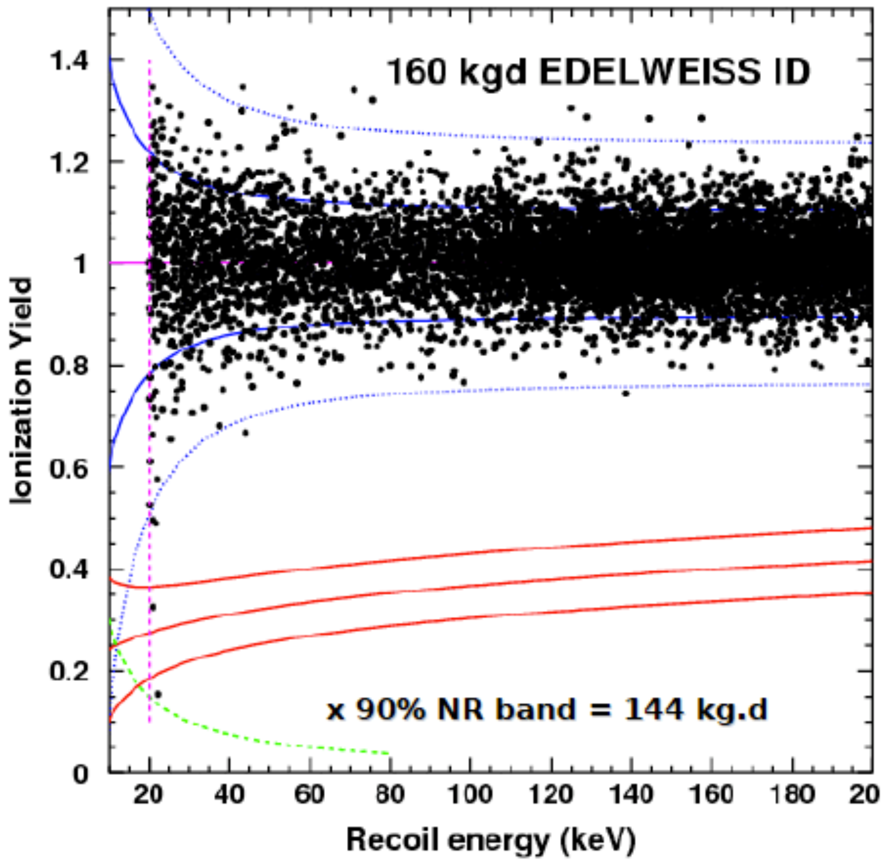
- Dark Matter Search Results from the CDMS II Experiment
  - *Science* 10.1126/science.1186112 (2010)
- Analysis of the Low-Energy Electron-Recoil Spectrum of the CDMS Experiment
  - *Physical Review D* **81**, 042002 (2010)
- Search for Axions with the CDMS Experiment
  - *Physical Review Letters* **103**, 141802 (2009)
- Search for Weakly Interacting Massive Particles with the First Five-Tower Data from the Cryogenic Dark Matter Search at the Soudan Underground Laboratory
  - *Physical Review Letters* **102**, 011301 (2009)

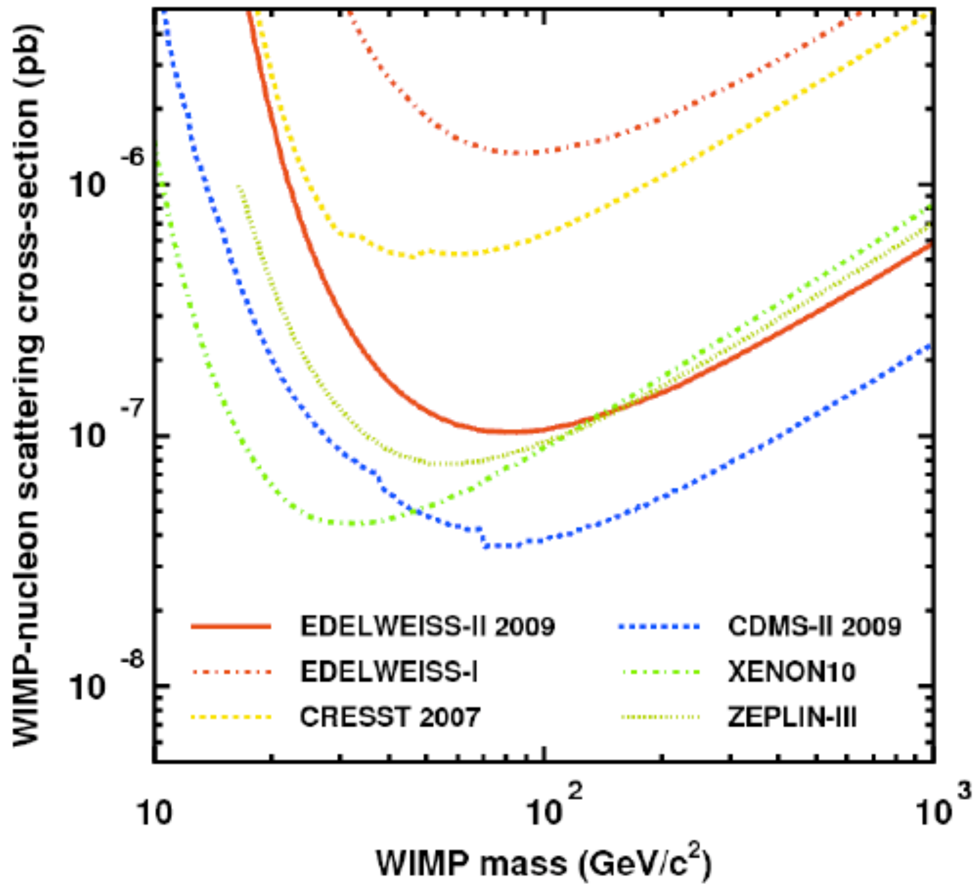
CDMS Technology Breakthrough

- New symmetric detectors (iZIP) have demonstrated a background rejection improvement of more than an order of magnitude (ton scale CDMS style experiment now feasible)
- First production of iZIPs now ongoing
- Trial run this summer in Soudan facility



CDMS Competition





- Edelweiss
- CRESST

COUPP

Kavli Institute
for Cosmological Physics
AT THE UNIVERSITY OF CHICAGO

University of Chicago

J. Collar, C.E. Dahl, D. Fustin, M. Szydagis

Indiana University South Bend

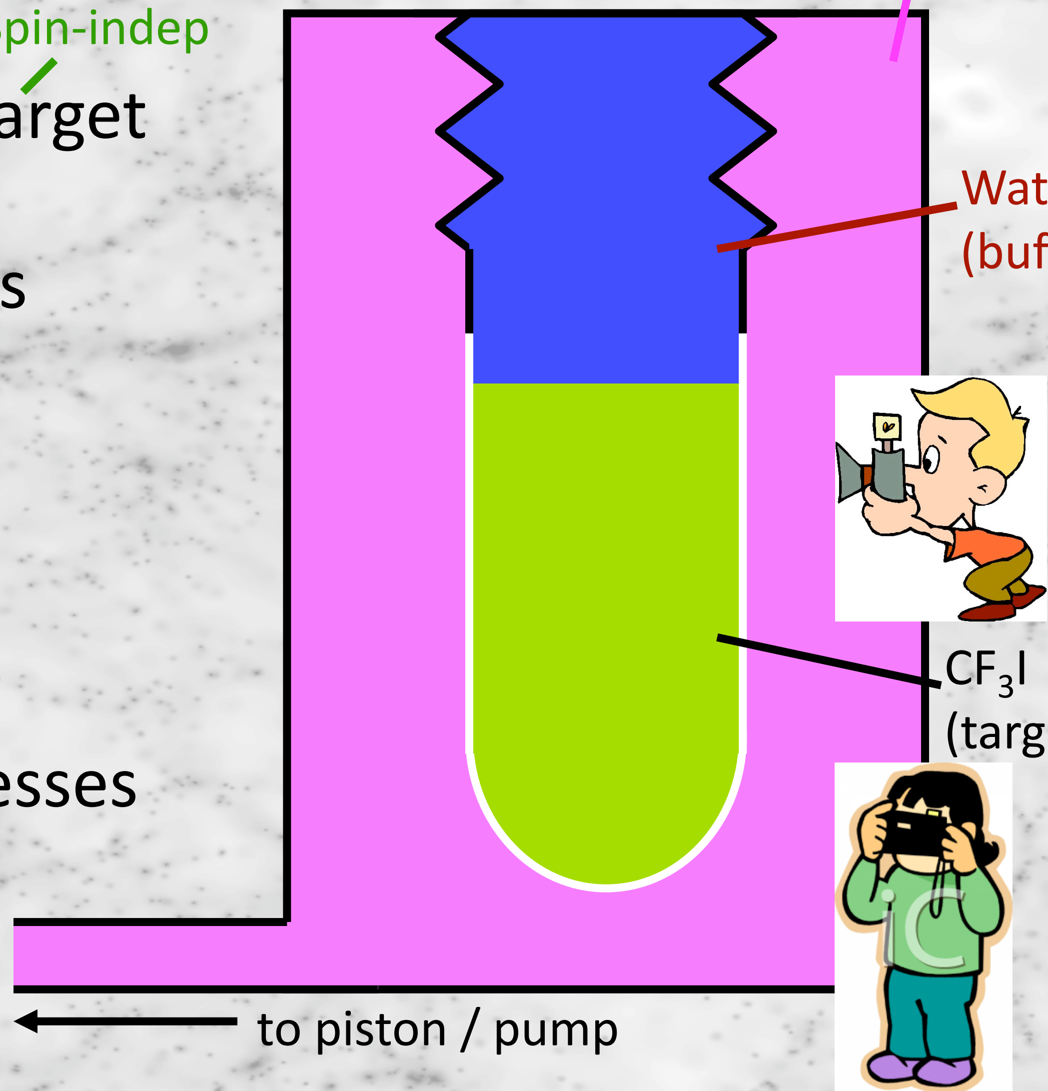
E. Behnke, J. Behnke, J.H. Hinnefeld, I. Levine, A. Palenchar, T. Shepard, B. Sweeney

Fermi National Accelerator Laboratory

S. Brice, D. Broemmelsiek, P. Cooper, M. Crisler, J. Hall, M. Hu, E. Ramberg, A. Sonnenschein

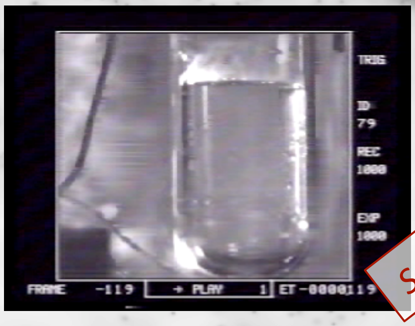
COUPP Technique

- Superheated CF_3I target (Spin-dep: F; Spin-indep: I)
- Particle interactions nucleate bubbles
- Cameras capture bubbles
- Chamber recompresses after each event



COUPP Bubble Chamber Program

- Take long runs with smaller chambers to understand backgrounds, operations, and for research and development while developing and commissioning an order of magnitude larger chamber



Test tube
(U Chicago)

COUPP 2kg

COUPP 4kg

COUPP 60kg

COUPP Bubble Chamber Program

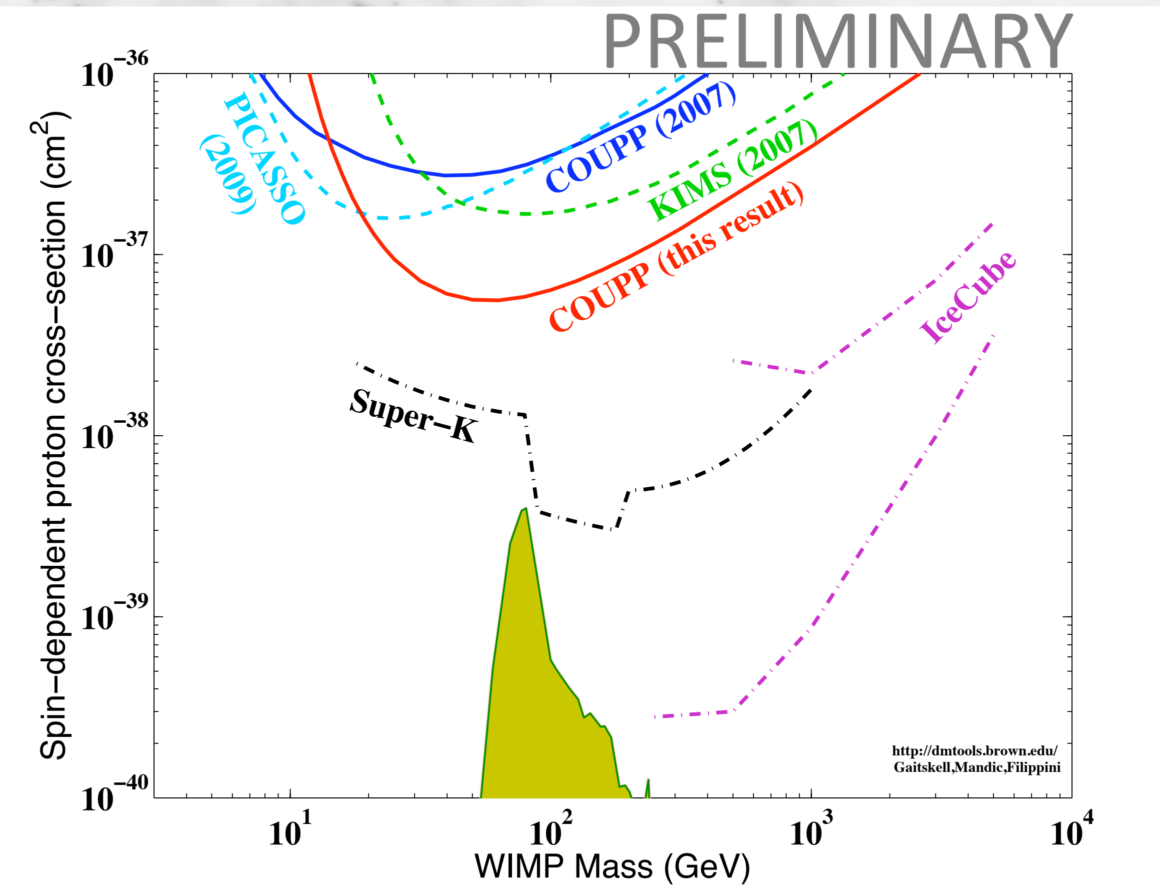
	2003	2005	2007	2009	2011
Mass	**18 grams**	**2-Kg**		**4-Kg**	**60-Kg**
Site	UChicago	NuMI Tunnel			SNOLAB
Depth	10 m.w.e.	300 m.w.e.			6000 m.w.e.
Backgrounds	7000 events/kg-day	77 events/kg-day	7 events/kg-day	0.7 events/kg-day	0.01 events/kg-day?
				0.1 events/kg-day after acoustic cut	
Physics		**World's best spin-dependent sensitivity (W-p)**			**Best spin-independent?**
Technical		10^{-10} gamma rejection	Metal seals	**Acoustic background discrimination**	
			Radon eliminated	Fused silica inner vessel	
				Wall events eliminated	
	Nearly continuously sensitive bubble chamber	Pressure balancing of inner/outer vessel		High purity fluid handling system	
				Retroreflective illumination, small angle stereo	
		Hydraulic pressure control	w/ automatic temperature compensation		

Fermilab Role in COUPP

- Operations (A. Sonnenschein)
- MINOS Near Hall Logistics (E. Ramberg)
- Analysis (S. Brice, J. Hall)
- DAQ (D. Broemmelsiek, P. Cooper)
- R&D (M. Crisler)

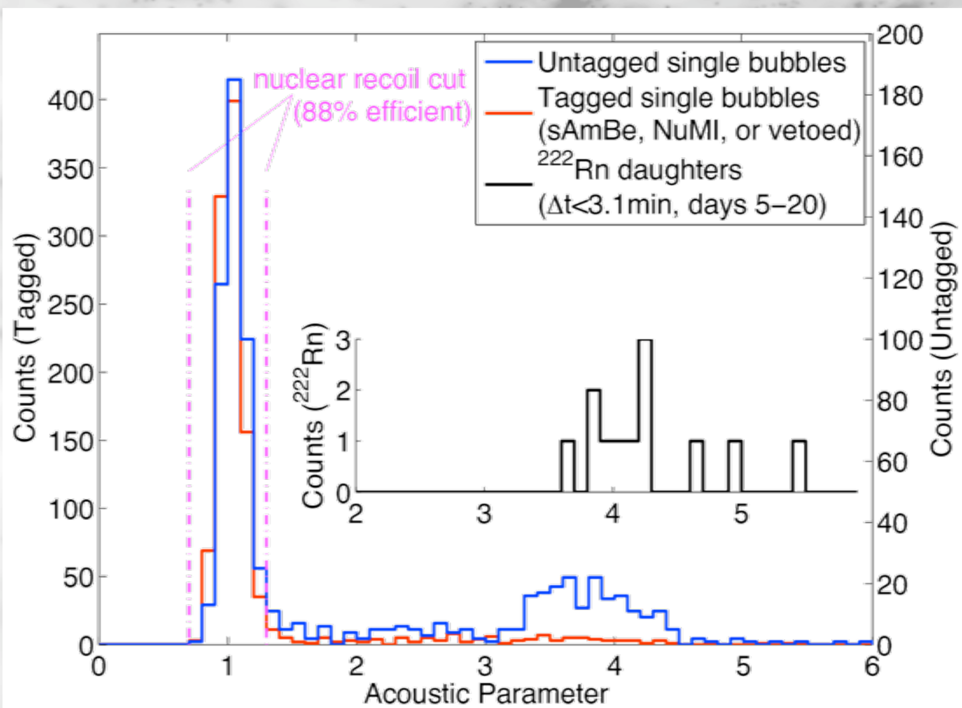
COUPP Results

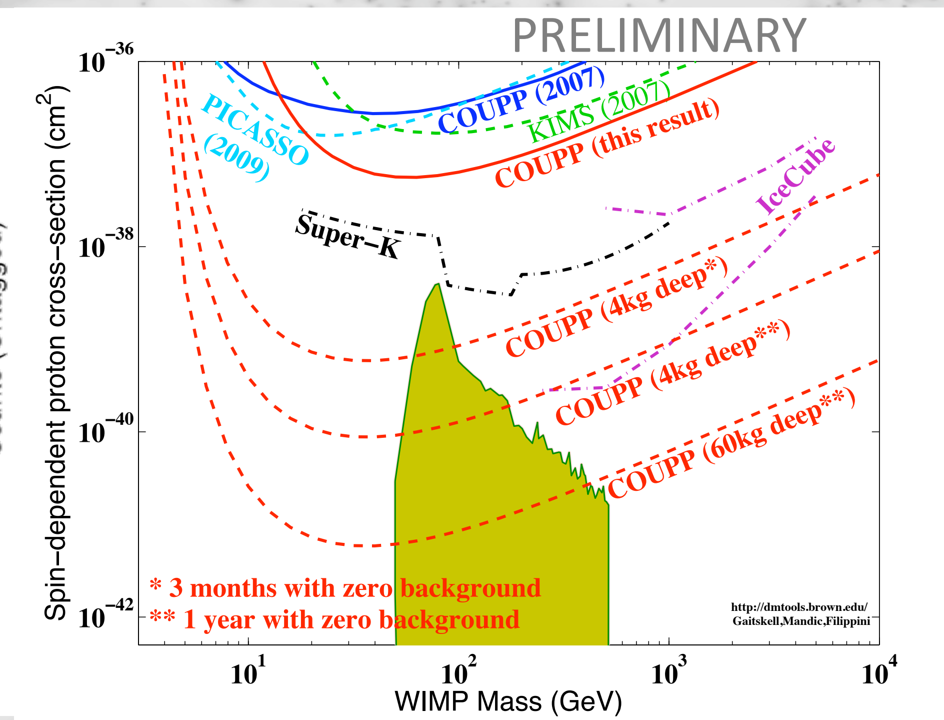
- Blue line –*Science* **319**:933-936 (2008)
- Red line – latest result see the Joint Experimental-Theoretical Seminar today at 4 pm
- Latest results limited by cosmic radiation in the MINOS near hall



COUPP Technological Advance

- Ultrasound transducers reduce the alpha decay backgrounds by 2-3 orders of magnitude





COUPP Competition

- PICASSO (C_4F_{10})
  - Using superheated droplets
- 1 kg / 1 m^3

DarkSide and MAX

DarkSide Collaboration : UMass Amherst, Arizona State, Augustana College, Black Hills State, Fermilab, Houston, Notre Dame, Princeton, Temple, UCLA

- DarkSide-50 (50 kg, 10^{-45} cm^2)

DarkSide + XENON = MAX Collaboration

UMass Amherst, Arizona State, Augustana, Black Hills State, Coimbra, Columbia University, Fermilab, Houston, INAF, LNGS, MIT, Münster, Notre Dame, Princeton, Rice, Shanghai Jiao Tong, Temple, UCLA, Virginia, Waseda, Zürich

- 5t Depleted Argon and 2.5t Xe TPCs (10^{-47} cm^2)
- S4 Funded Project
- Possible change in baseline (25t DAr, 10t Xe) if DUSEL delay to 2016-2017 confirmed

adapted from C.Galbiati PAC presentation 11/09

DarkSide-50

dual-phase TPC

50 kg active mass

background-free for 3 yrs

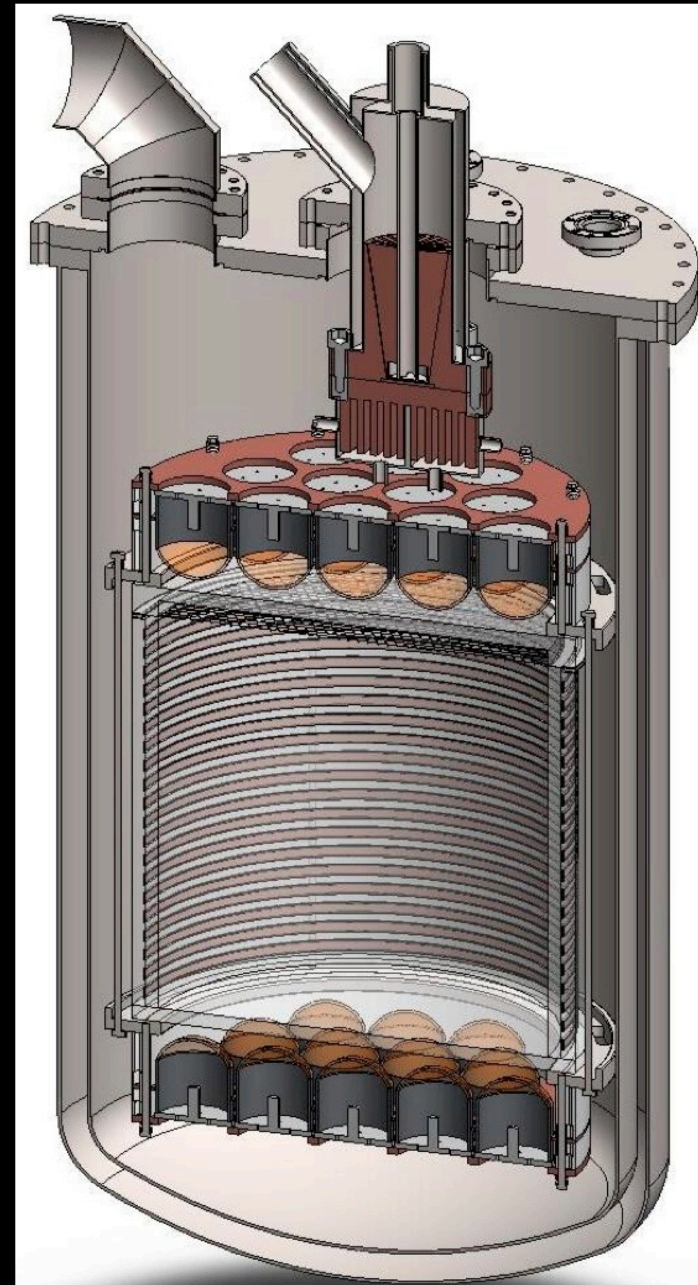
sensitivity 10^{-45} cm^2

Test for three advances crucial to achieve zero background:

1) depleted argon

2) QUPIDs at LAr temp

3) active liquid scintillator neutron veto



adapted from C.Galbiati PAC presentation 11/09

Why depleted argon?

- Atmospheric argon has specific activity 1 Bq/kg ($^{39}Ar/Ar$ ratio 8×10^{-16})

  Limits size (and sensitivity) of detectors using atmospheric Argon to 500-1000 kg due to ^{39}Ar events pile-up

- ^{39}Ar produced by cosmic rays in atmosphere (beta decays, Q = 565 keV, $t_{1/2}$ = 269 years)
- ^{39}Ar-depleted argon available via centrifugation or thermal diffusion, but expensive at the ton scale!
- ^{39}Ar production by cosmic rays strongly suppressed underground

adapted from C.Galbiati PAC presentation 11/09

Fermilab Responsibilities

- DarkSide-50:
  - Cryogenic Simulations
  - DAQ and Electronics (w Houston)
  - Purification (w Temple)
  - Shielding and Muon Veto
- MAX:
  - See WBS of MAX S4 proposal

from C.Galbiati PAC presentation 11/09

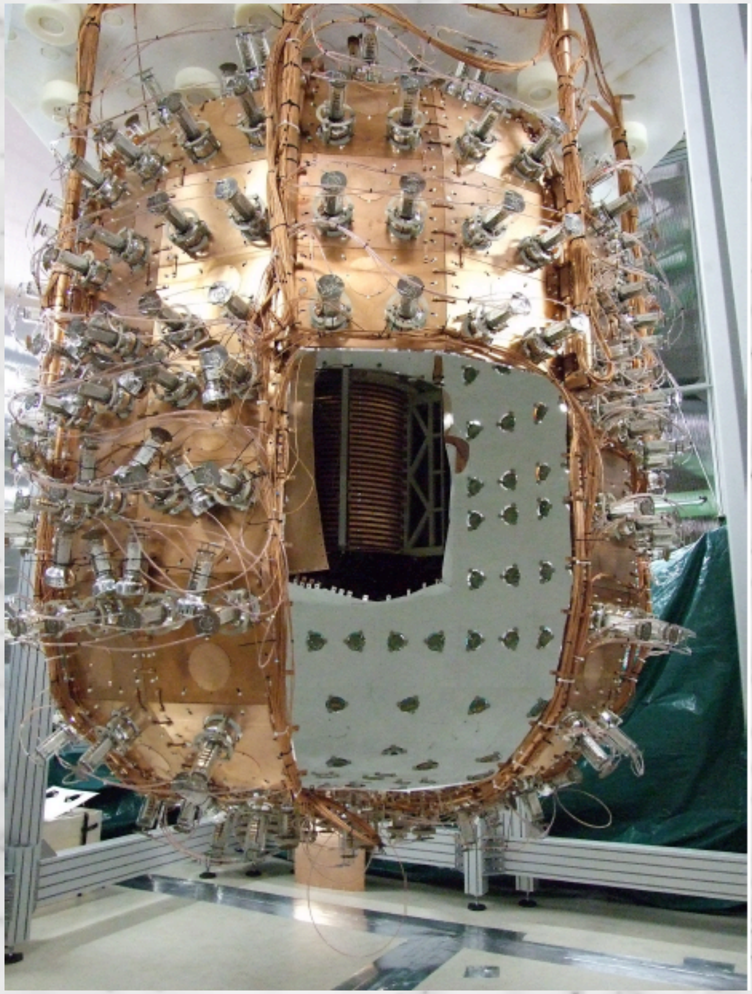
Synergies at FNAL

- LAr Neutrino Program (LBNE, MicroBoone, ArgoNeut)
  - Purification, DAQ, Electronics, Material Qualification, Wavelength Shifters, Optical Measurements and Simulations, Data Storage, Analysis, Electrostatics Design, HV Feedthroughs, Power and readout of QUPIDs and PMTs
- CDMS
  - Neutron Veto, Low Background Materials and Measurement, Cryogenics
- COUPP
  - Neutron Veto, Quartz Vessel

from C.Galbiati PAC presentation 11/09

DarkSide Competition

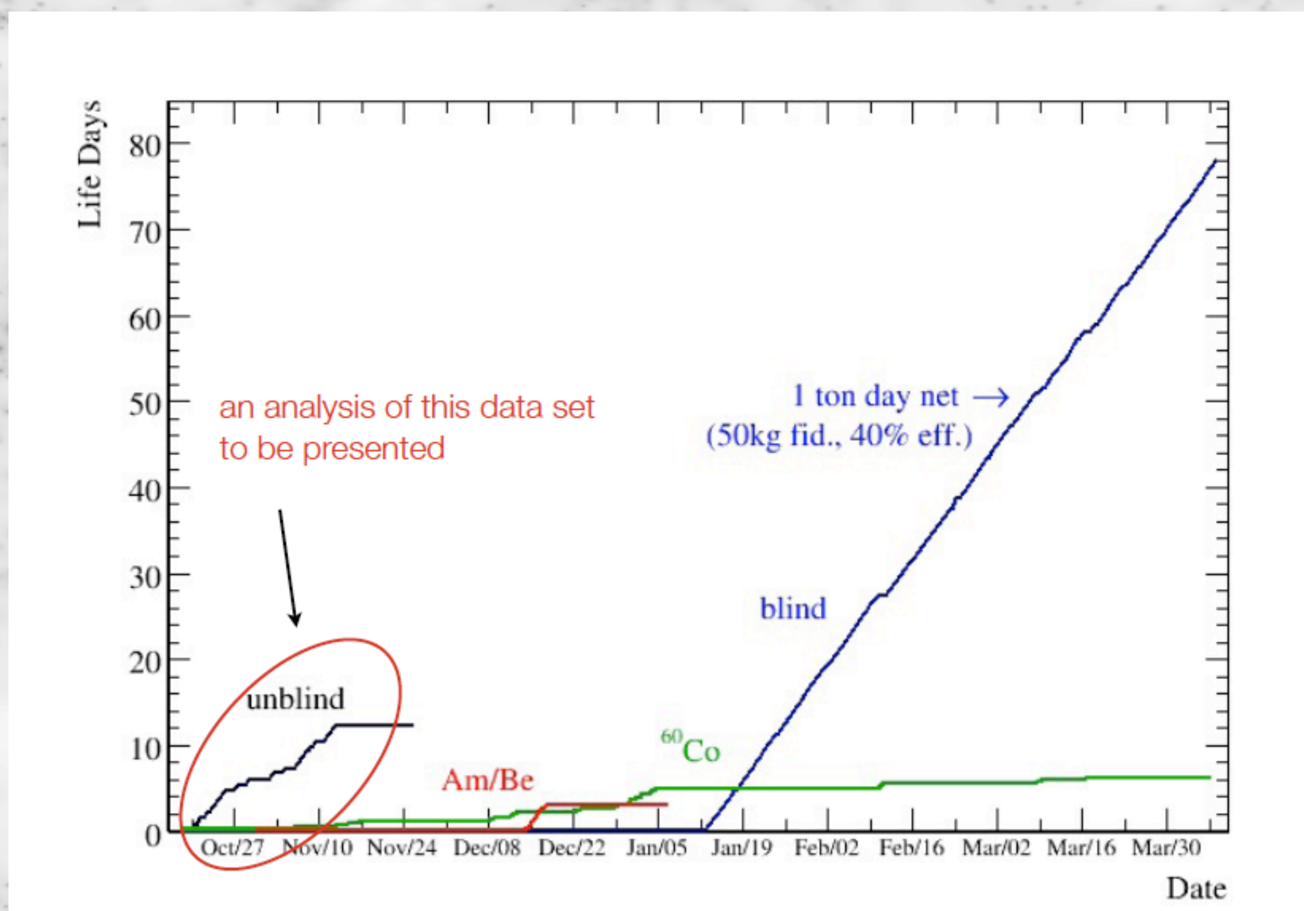
- WArP-100
- 100L lAr
- Surrounded by 6T lAr shield
- Currently running in Gran Sasso



DarkSide Competition

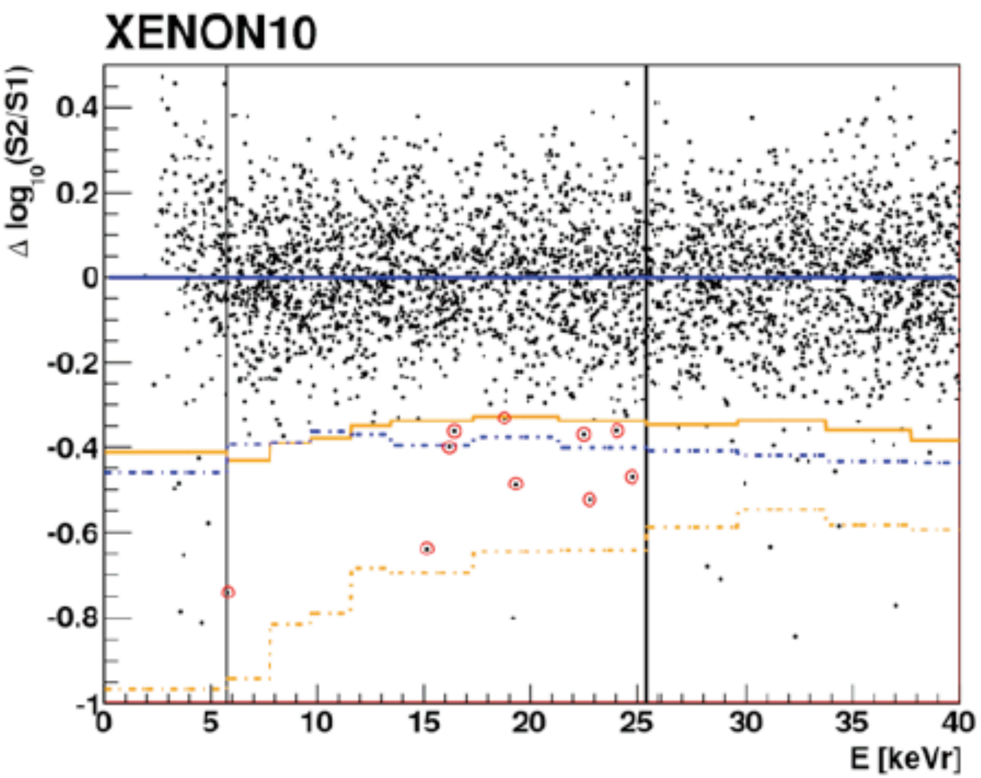
- MiniCLEAN
  - 360 kg Ar
  - 100 kg fiducial
  - Construction near completion
- DEAP-3600
  - 1T fiducial
  - “Funded and being engineered”

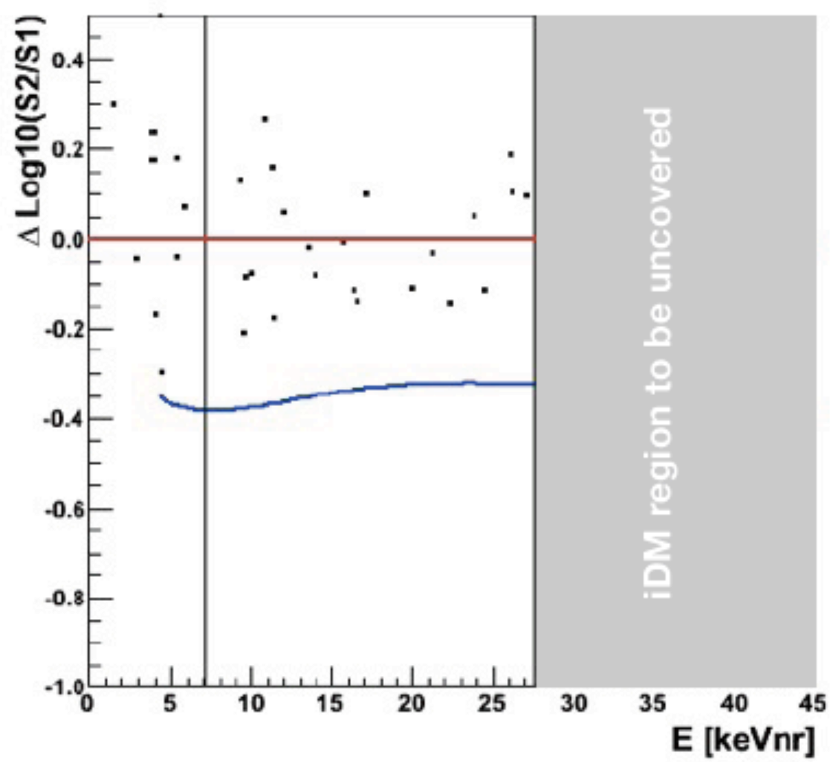
Competition from Other Technologies



- Xenon-100 is the most significant competition operating

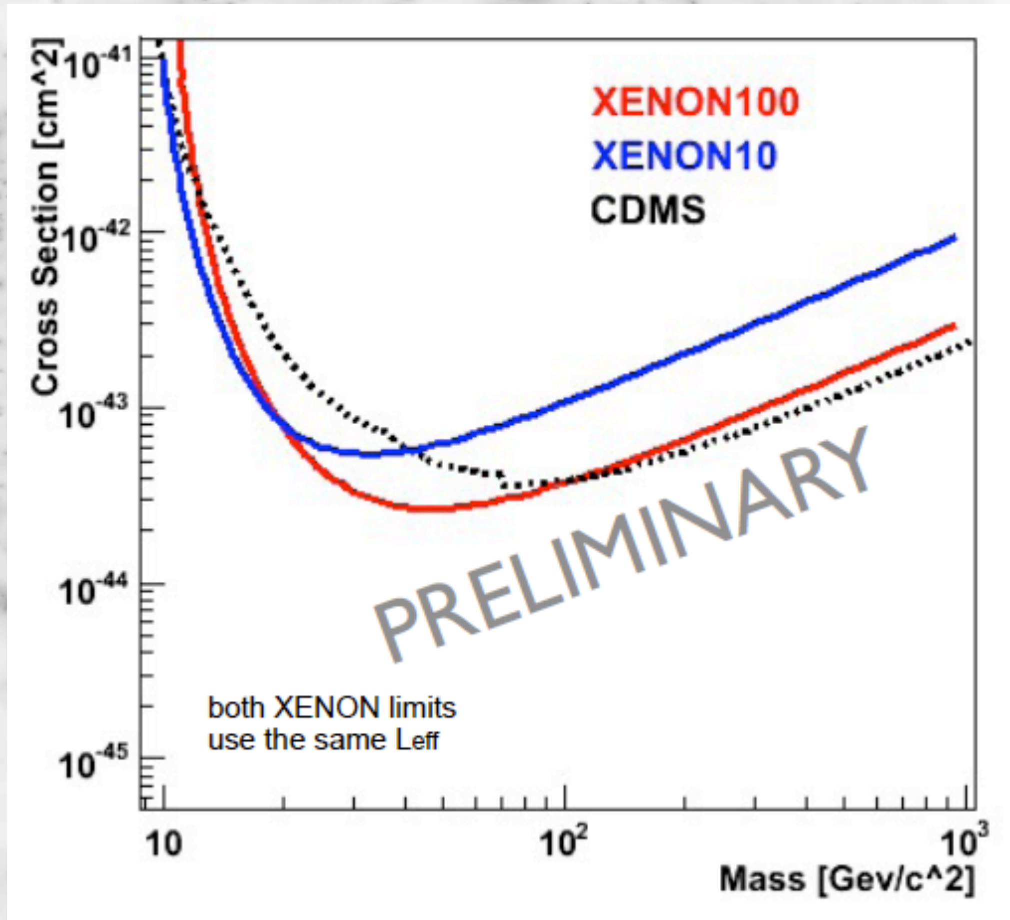
Competition from Other Technologies





- Xenon-100 is the most significant competition operating

Competition from Other Technologies



- Xenon-100 is the most significant competition operating

Competition from Other Technologies

- Xenon-100 is the most significant competition operating
- LUX is a similar design (Xe TPC) with X3 more active detector
  - Operating at surface of SUSEL
  - DUSEL future is unclear
- XMASS is a single phase 800 kg single phase device
  - Under construction in Kamioka mine
  - Expect results late this year
  - First demonstration of single phase xenon at a scale where self-shielding is important
- Xenon technology is interesting, but generally very little background rejection
  - Can be considered an additional physics reach because they probe low background electron scattering

Discussion Points

- Fermilab is the leading national laboratory in the direct detection of dark matter
  - CDMS is leading the field in spin-independent dark matter scattering sensitivity
  - COUPP is leading the field in spin-dependent dark matter scattering sensitivity
  - DarkSide and and the development of depleted Argon have the potential of changing the direction of the field
- Fermilab has developed a large scientific expertise applicable to any detector technology considered if down-selection is necessary
- Fermilab has a strong pool of skilled labor, techs and engineers

Discussion Points

- Will results from the LHC have a realistic chance of changing this program? In what time scale?
- We do not have significant experimental involvement in the indirect detection of dark matter (neutrinos, gamma rays)
- What to do about DAMA? Ignore? Repeat in the Southern Hemisphere?

Questions to address

1) Is the science compelling and within the DOE OHEP mission?

Direct detection of WIMP and/or axion dark matter seem to fit very well within the OHEP mission statement:

The mission of the High Energy Physics program is to understand how our universe works at its most fundamental level. We do this by discovering the most elementary constituents of matter and energy, exploring the basic nature of space and time itself, and probing the interactions between them.

and it has been judged compelling by national advisory panels such as PASAG:

The direct detection and understanding of dark matter remains one of the most important scientific priorities of particle physics.

Questions to address

2) Is our experimental program leading the field, or at least competitive?

CDMS has led the field for most of the last decade in terms of spin-independent WIMP-nucleon cross section limits. PASAG recommended proceeding with SuperCDMS Soudan (15 kg) and SNOLAB (100 kg) under all budget scenarios.

COUPP has recently taken the lead in spin-dependent limits and is exploiting a new acoustic sensor technique to extend sensitivity. PASAG was less clear about COUPP, but definitely recommended continued exploration of the bubble chamber technique.

DarkSide is a new initiative that is untested, but may be a leader at the ton-scale as noted by PASAG:

The liquid argon technique may be especially promising with the use of depleted argon and should also be explored in any of the funding scenarios.

Questions to address

3) Identify the FNAL roles (scientific, technical and management) in the experiments. Are they leading, or at least significant?

CDMS

- Scientific - Leading role in most analyses (Yoo, Hall, Hsu)
- Technical - Major responsibilities in Soudan operations, cryogenics, shielding, electronics, DAQ
- Management – Project and operations management

COUPP

- Scientific – Significant player in analysis
- Technical – Major responsibilities in operations, bubble chamber, veto, DAQ
- Management – Project and operations management

DarkSide

- Scientific – Not relevant yet
- Technical – Major responsibilities in distillation and measurement of depleted Argon
- Management – No role

Questions to address

4) What is the future role of FNAL in this area? Are we positioned to be a leader?

FNAL is pursuing three of the leading techniques in direct detection (cryogenic detectors, bubble chambers and depleted liquid argon). We are not involved in two other interesting technologies: liquid Xenon and directional detectors (low pressure gas TPCs). It is too early to tell which of these techniques will have sufficient control of backgrounds to advance to ton-scale sensitivities, but we certainly have the most diverse portfolio of anyone in this area.

Questions to address

5) What are the weaknesses of our program in this area? How should we address them?

- CDMS
  - Loss of scientists to other efforts; need to recruit more staff
  - Need to graduate from small project to CD-level project
- COUPP
  - Need to focus on a single dark matter experiment with 60 kg
  - Is there enough manpower and funding for R&D on 4 kg, 500 kg?
- DarkSide
  - FNAL is not the leader in this yet; our role needs to expand
  - Need to develop this prototype in a timely way to be competitive

Questions to address

6) How does Fermilab serve the broader national and international community? Are we valued contributors in our collaborations? Why is Fermilab participation needed for success?

In all three experiments, we are certainly valued contributions. FNAL contributes the following key elements to each:

- Technical personnel (engineers and technicians)
- Laboratory equipment and facilities that are unavailable at Universities
- Expertise in doing large experiments
- Strong scientific participation
- Project management