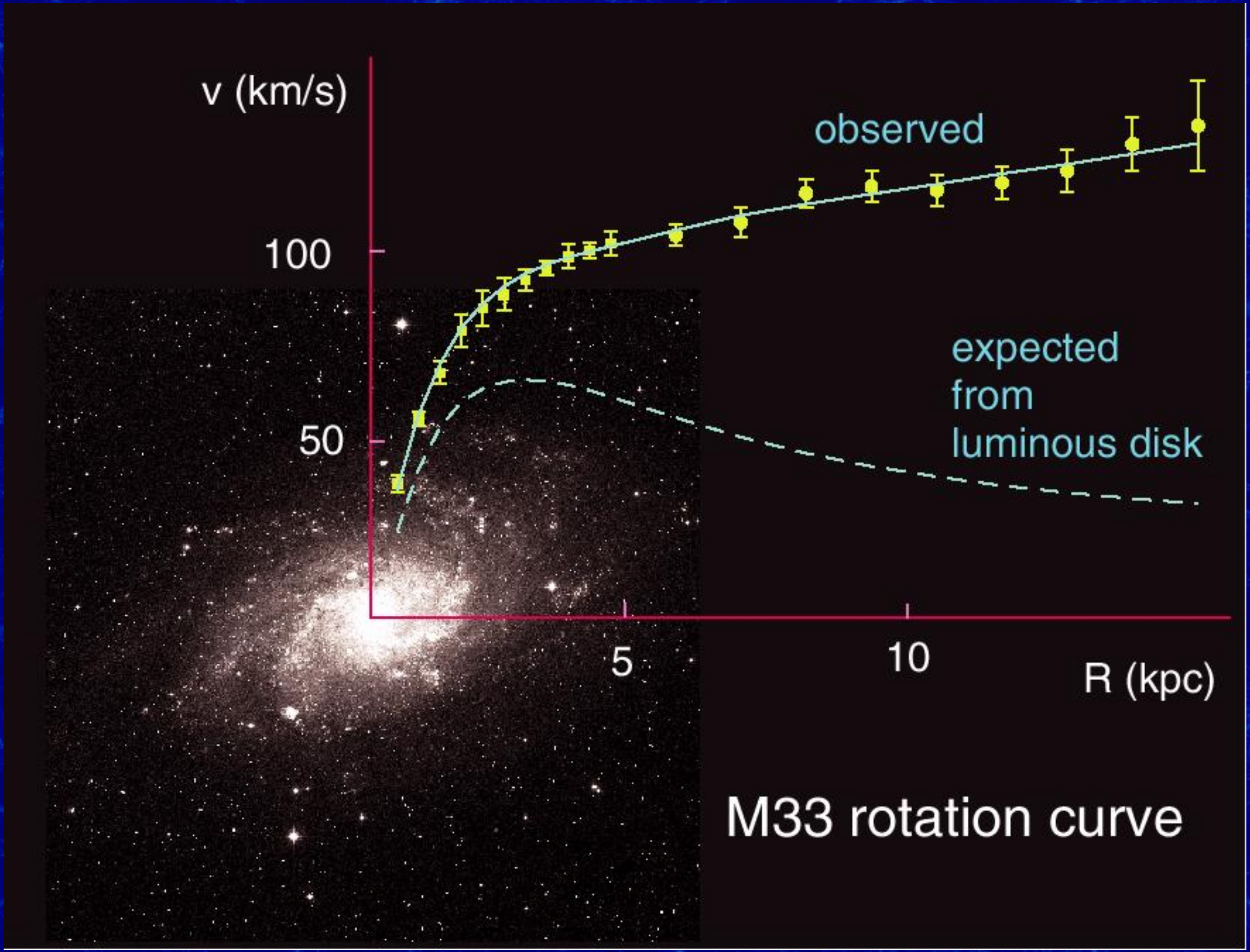
The Cryogenic Dark Matter Search

Jeter Hall

Fermi National Accelerator Laboratory

The Dark Matter Problem

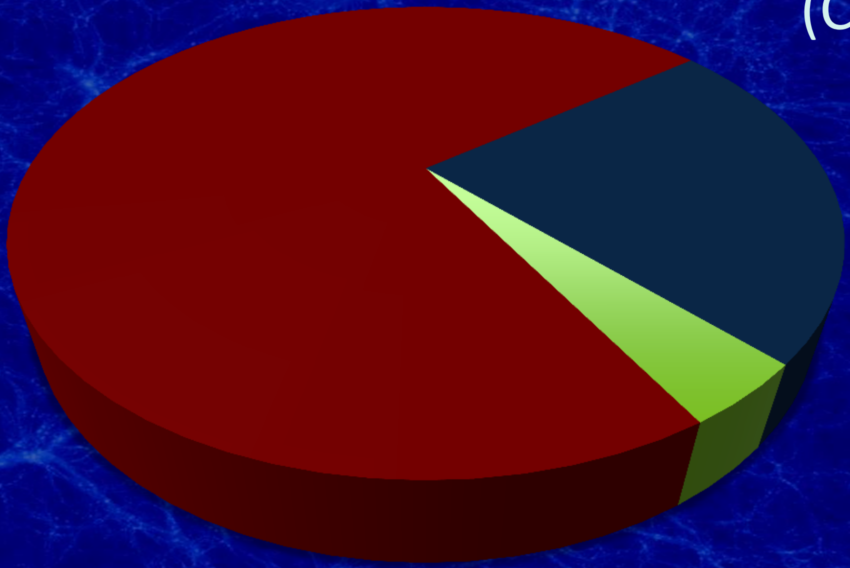


L. Bergstrom Rept.Prog.Phys. 63, 793 (2000)

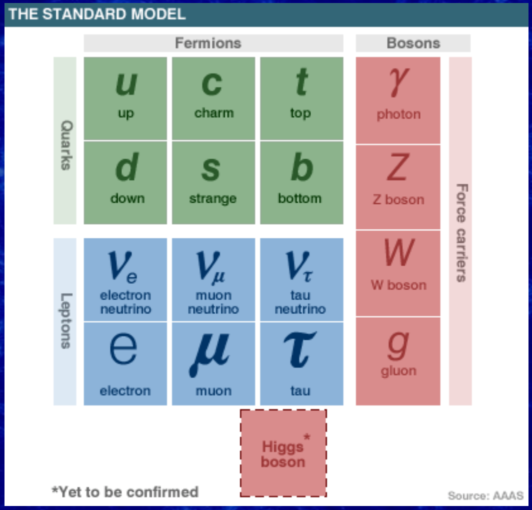
Composition of the Universe

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

Dark Energy
~ 73%



Standard Model
~ 4%
Top Quarks $\sim e^{-10^{42}}$
Neutrinos $\sim 10^{-4}$

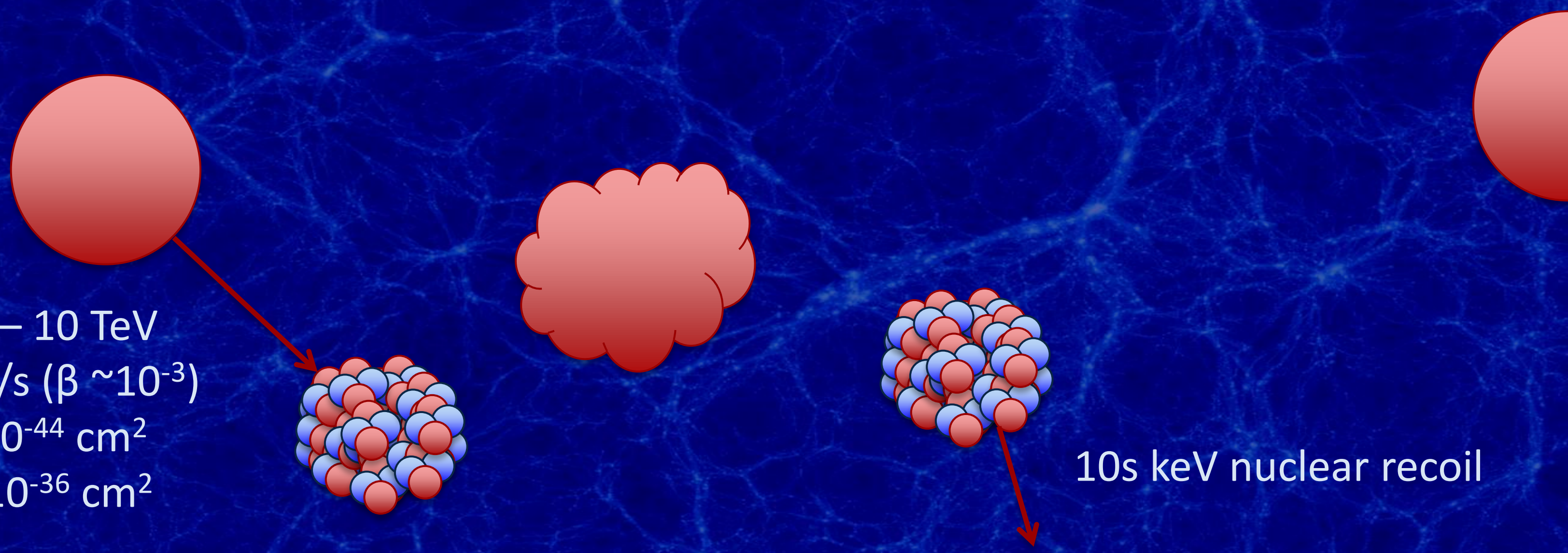


- There are many mysteries in this era of precision cosmology

Direct Detection of Dark Matter

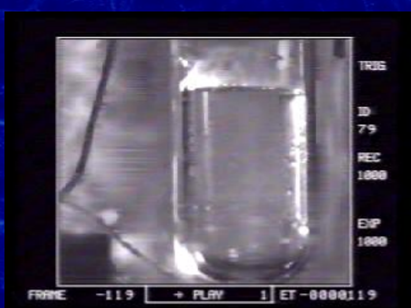
- Searching for WIMP-Nucleus elastic scattering
- In a sea of background radiation
  - Low background frontier

1 GeV – 10 TeV
~300 km/s (β ~10^{-3})
$\sigma_{SI} < 10^{-44}$ cm^2
$\sigma_{SD} < 10^{-36}$ cm^2



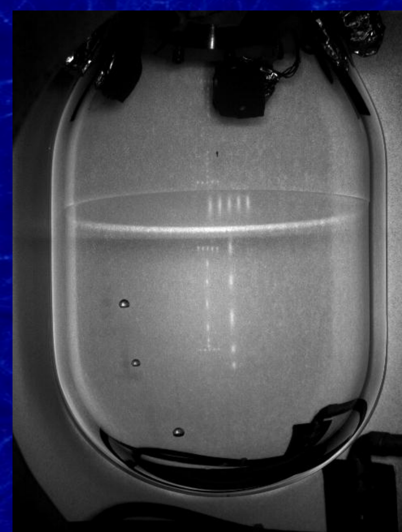
COUPP Bubble Chamber Program

- 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

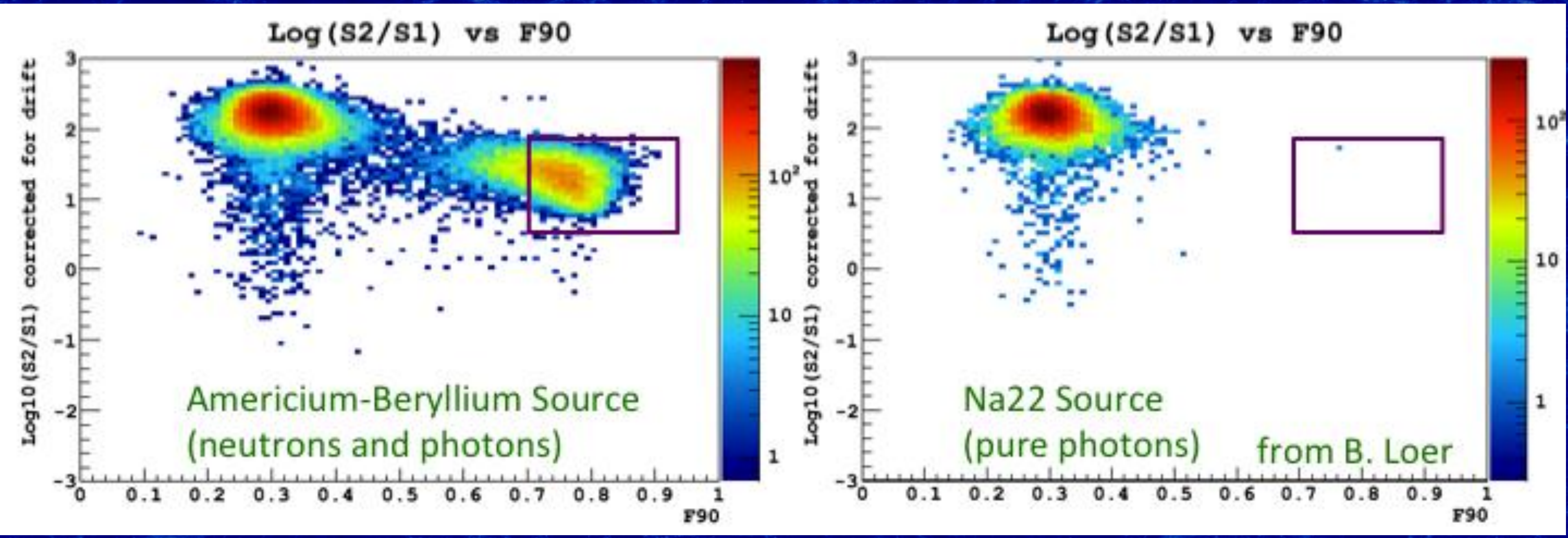
University of Chicago

Indiana University South Bend

Fermi National Accelerator Laboratory

SNOLAB

Darkside-50

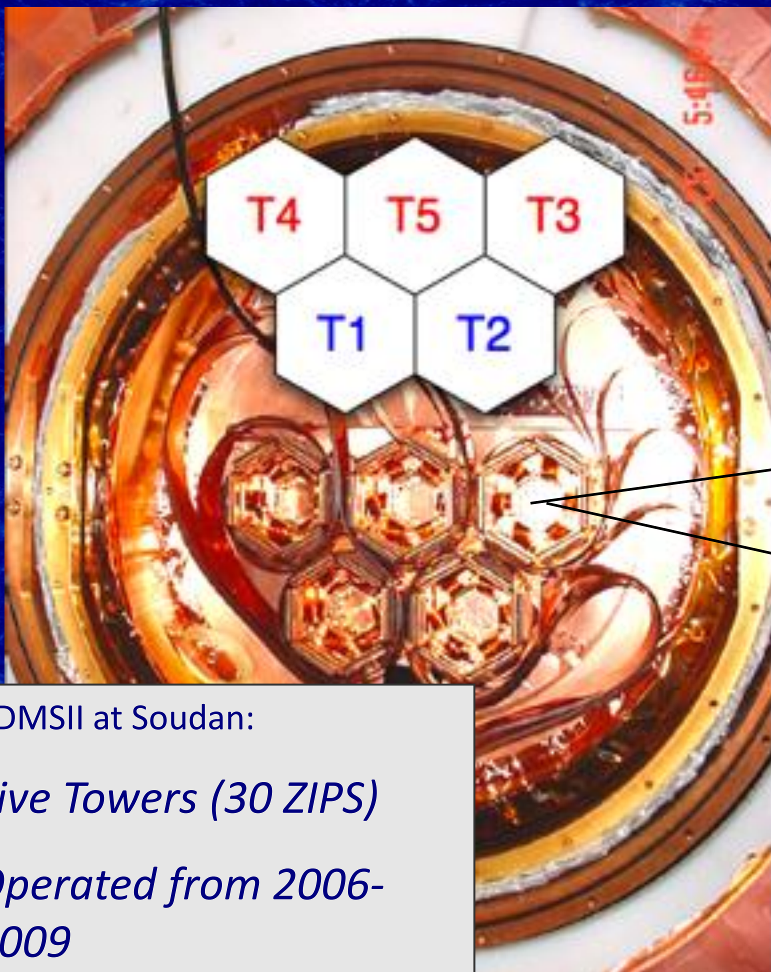


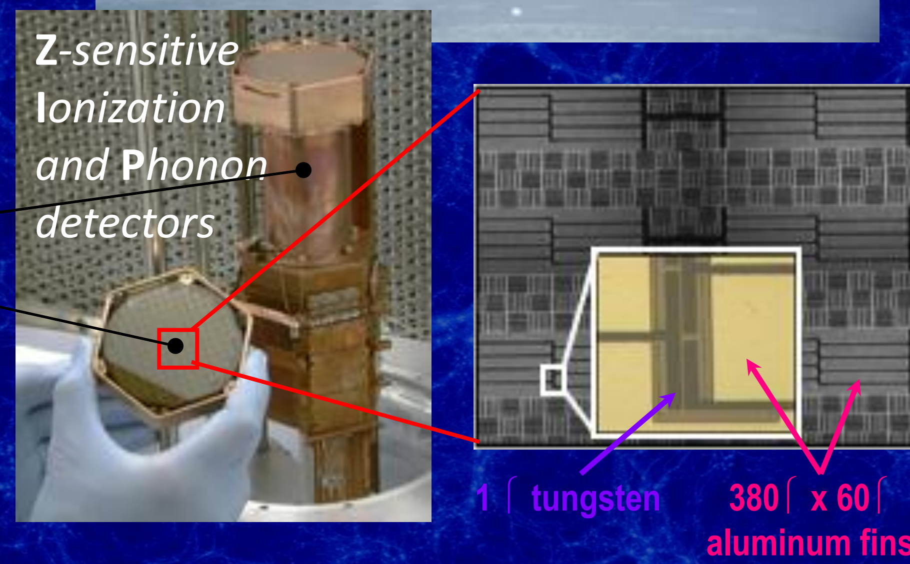
- Succesful operation of 10 kg prototype
- Prototype shipping to Laboratori Nazionali del Gran Sasso

Darkside-50

Augustana College
IHEP Beijing
Black Hills State University
University of California, Los Angeles
JINR Dubna
Fermilab
INFN and Università degli Studi Genova
INFN Laboratori Nazionali del Gran Sasso
University of Houston
RRC Kurchatov Institute
University of Massachusetts at Amherst
INFN and Università degli Studi Milano
INFN and Università degli Studi Napoli
INFN and Università degli Studi Perugia
Princeton University
St. Petersburg Nuclear Physics Institute
Temple University

CDMS





CDMSII at Soudan:

Five Towers (30 ZIPS)

Operated from 2006-2009

The Cryogenic Dark Matter Search

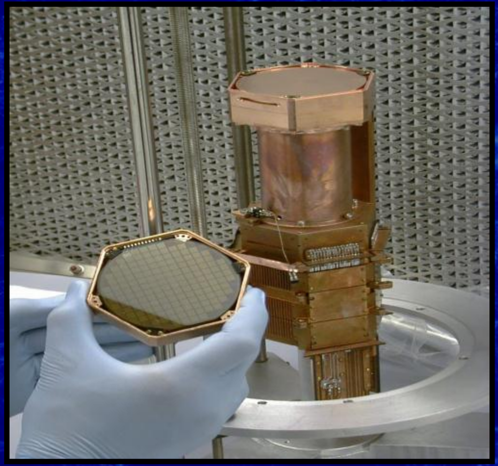
California Institute of Technology
Case Western Reserve University
Fermi National Accelerator Laboratory
Massachusetts Institute of Technology
NIST *
Queen's University*
Santa Clara University
Southern Methodist University*
SLAC/KIPAC *

Stanford University
Syracuse University
Texas A&M
University of California, Berkeley
University of California, Santa Barbara
University of Colorado Denver
University of Florida
University of Minnesota
University of Zurich

20 institutions, 35 Faculty, Scientists and Engineers, 70 Students and Postdocs

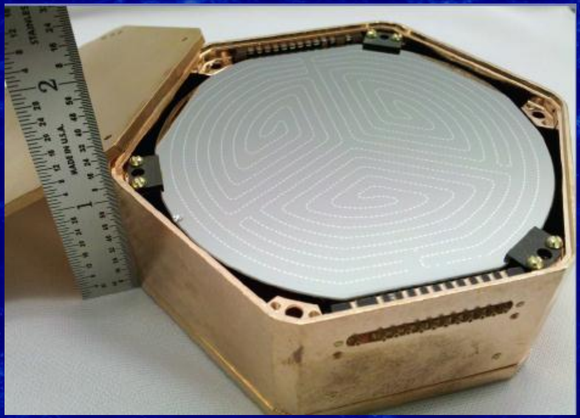
** new collaborators or new institutions in SuperCDMS*

ZIP Detectors



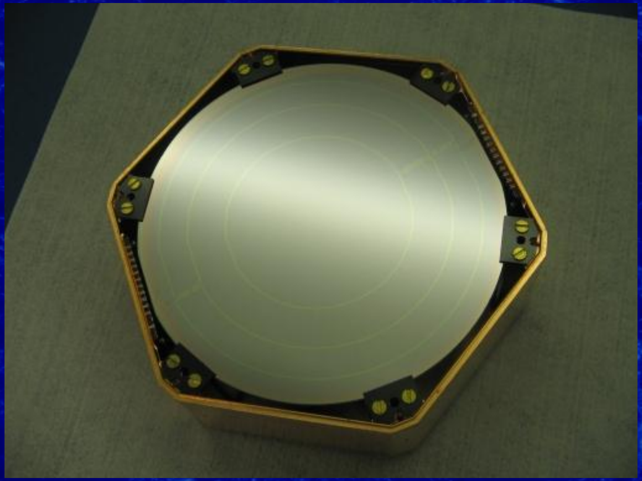
oZIP
3” diameter x
0.4” thick

CDMS-II



iZIP
3” diameter x
1” thick

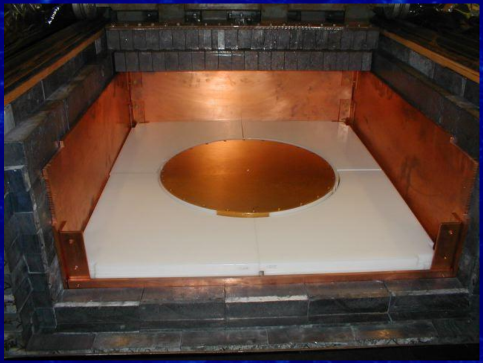
SuperCDMS
Soudan

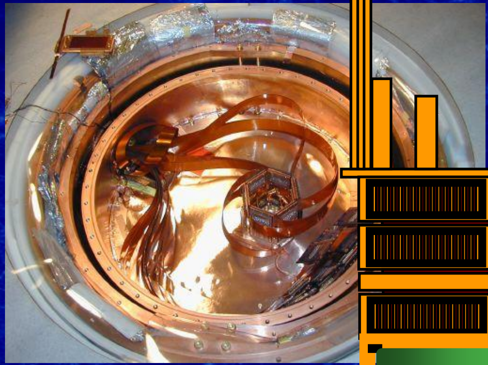


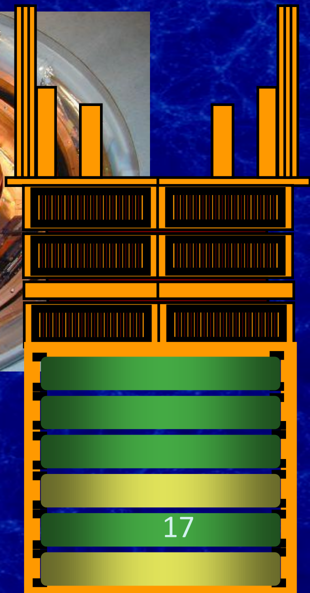
R&D
4” diameter x
1.3” thick

SuperCDMS
SNOLAB

Shielding/Radiopurity

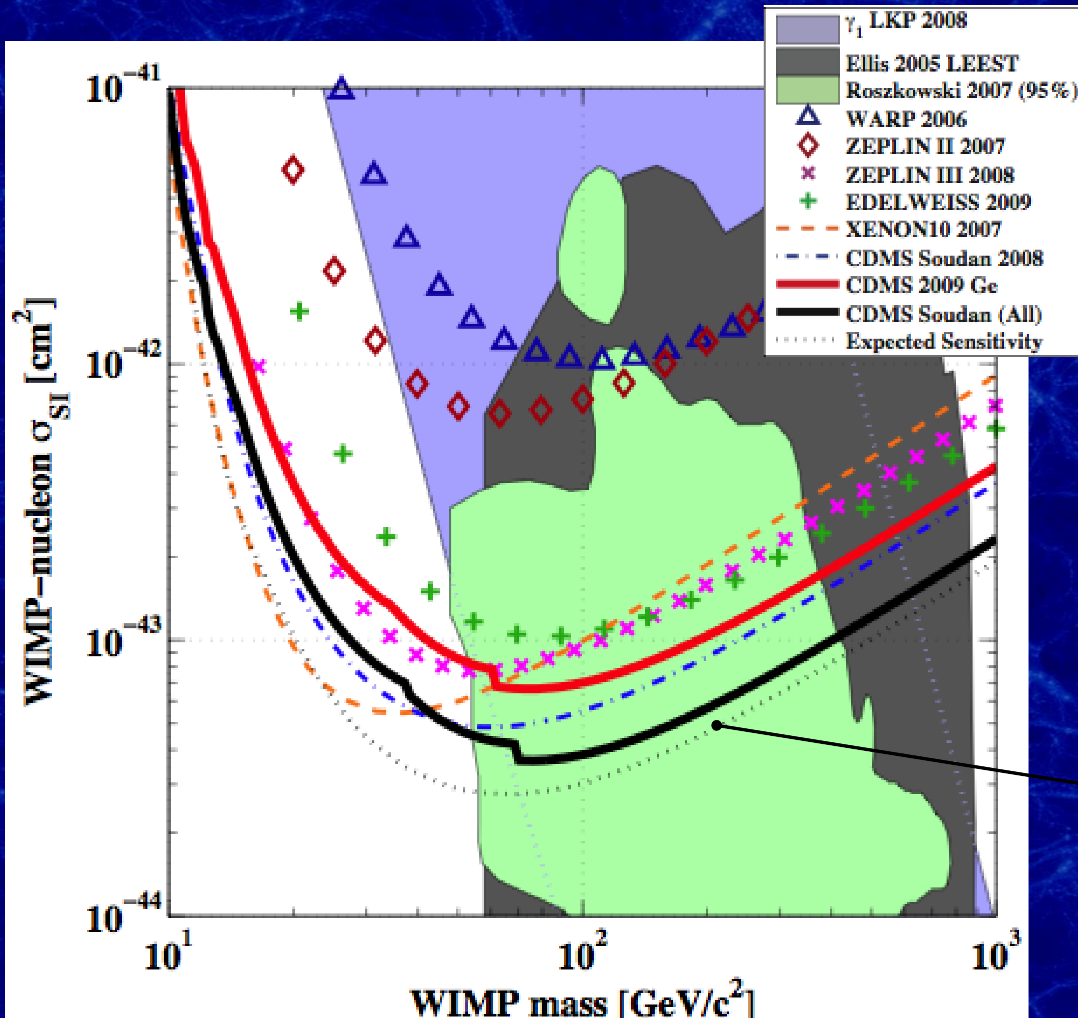






- 2000 m.w.e. (0.5 mile) rock overburden
- Plastic scintillator active veto
- 20 cm lead
- 50 cm polyethylene
- Copper cryostat
- 1 mm silicon endcaps
- Gaps between detectors minimized
- Rigorous cleanliness

CDMS-II WIMP Limits



Ahmed et al. Science 327, 1619 (2010)

CDMS-II Combined Soudan Data
@WIMP mass 70 GeV
$\sigma < 3.8 \times 10^{-44}$ cm^2 (90% C.L.)

Sensitivity curve based on revised bg estimate:

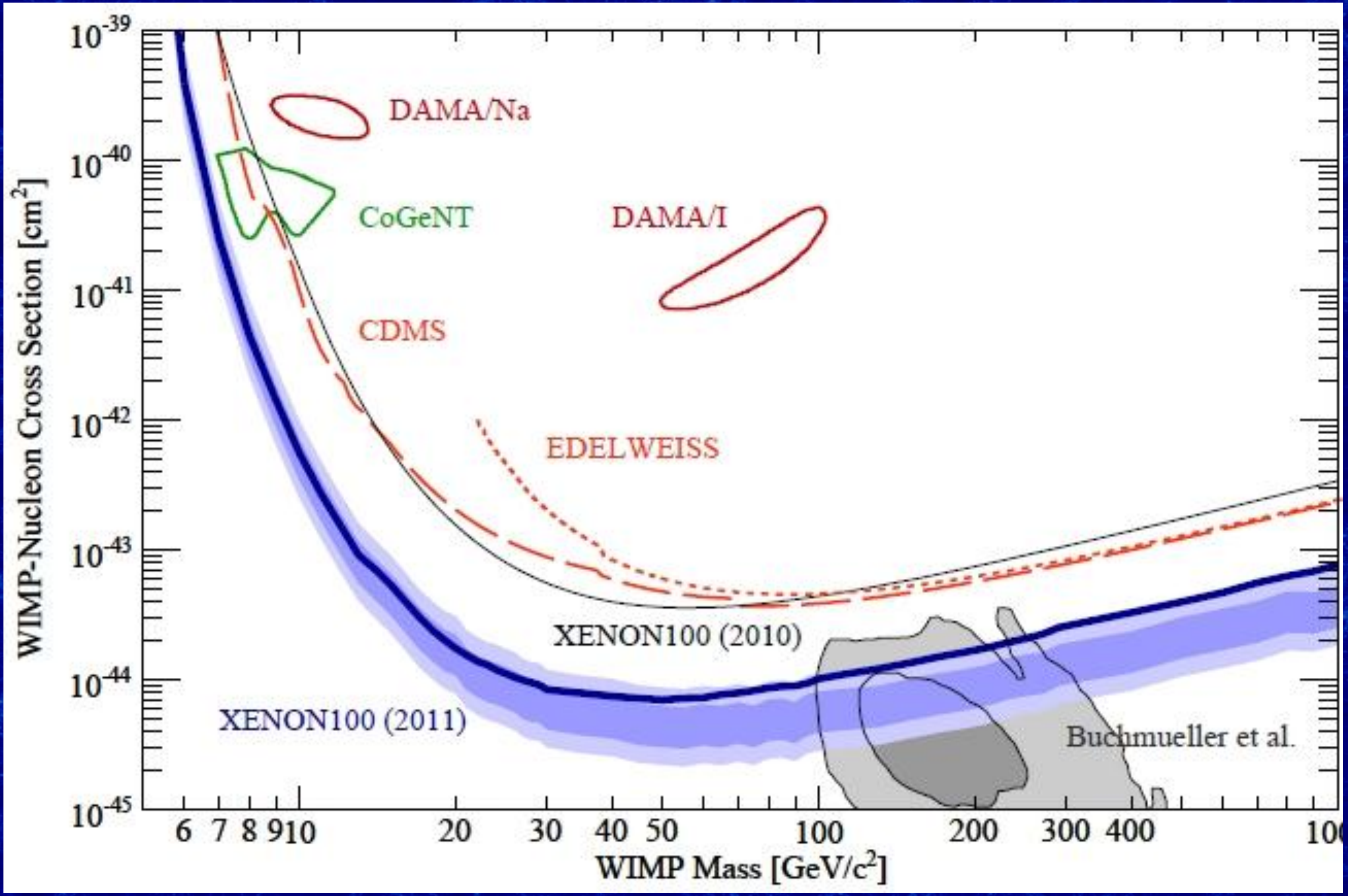
0.8±0.1(stat.)±0.2(sys.) surface events

$0.04^{+0.04}_{-0.03}$ cosmogenic neutrons

0.04 – 0.06 radiogenic neutrons

2 observed events consistent with total background expectation of 0.9 events

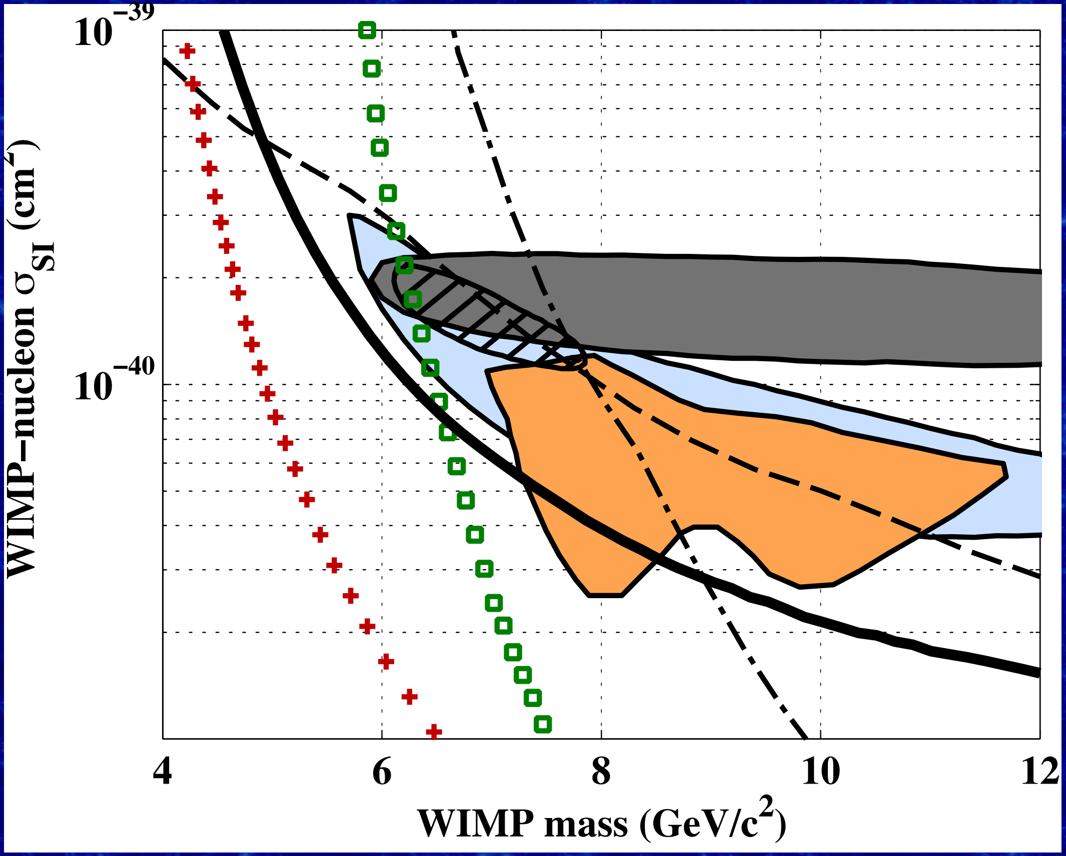
Current State of the Hunt



Aprile et al., arXiv:1104.2549

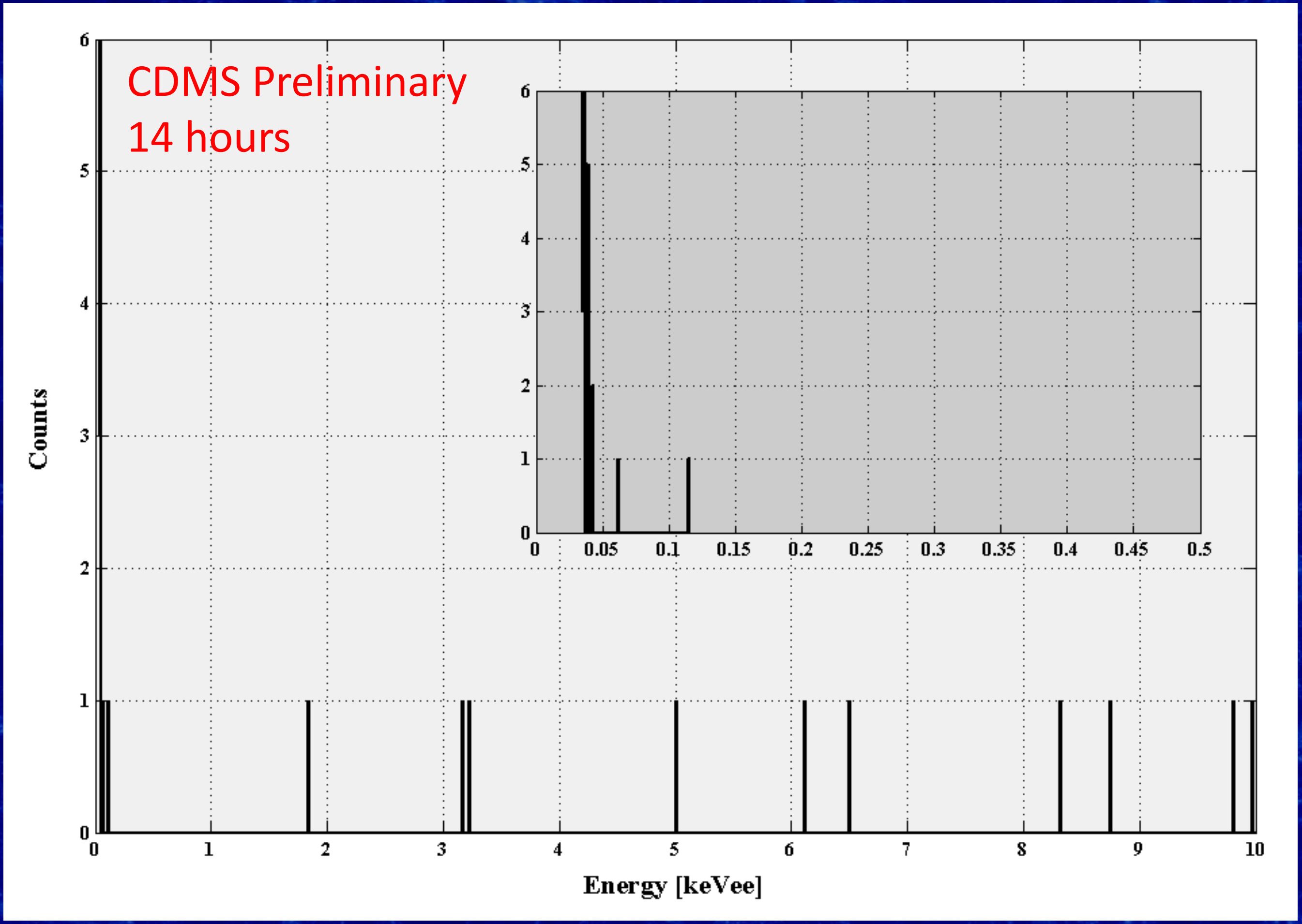
Light Dark Matter

- Recent results from DAMA/LIBRA, CoGeNT and others have been interpreted as possible evidence for elastic scatters from WIMPs with m_x~7 GeV and σ_{SI}~1x10^{-40} cm^2
- Previous CDMS Ge results not sensitive to these models since thresholds were ~10 keV (to maintain expected backgrounds <1 event)
- New analysis strongly constrains a WIMP interpretation of the CoGeNT spectrum



Ahmed et al., PRL **106**, 131302 (2011), *arXiv:1011.2482*
Akerib et al., PRD **82**, 122004 (2010), *arXiv:1010.4290*

CDMS Luke amplification



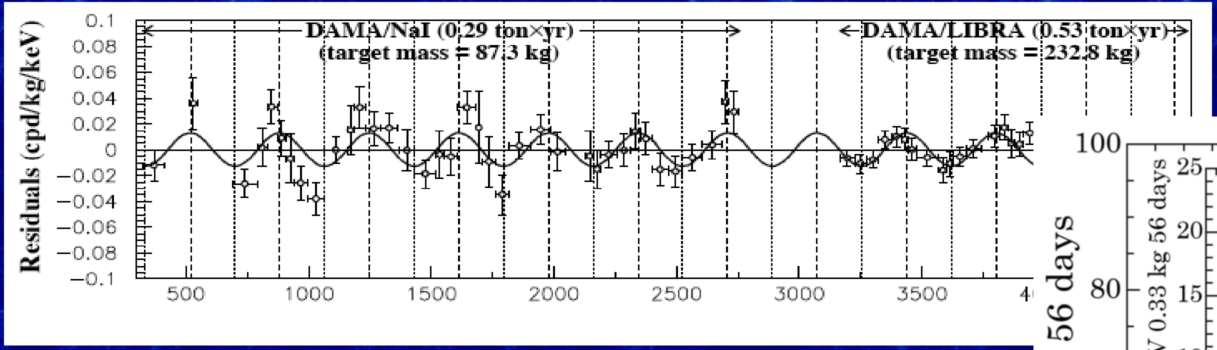
- Signal gain of 22 with ~50% increase in noise
- 50 eV threshold in Soudan (12 eh pairs)

Summary

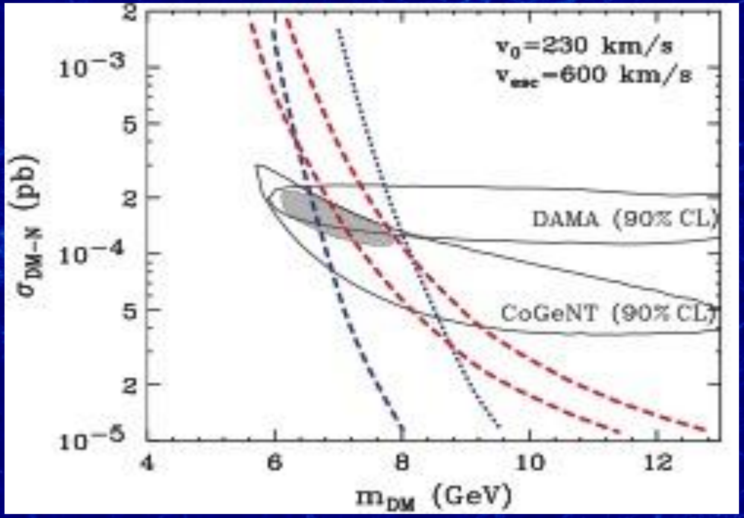
- Fermilab and its users are involved in the search for WIMP dark matter
- Sensitivity to weakly interacting massive particles is rapidly increasing (~order of magnitude every 3 years) with a variety of experimental techniques
- CDMS is a leader in the search for WIMPs
- We could be on the verge of discovering the nature of the dark matter

Backup

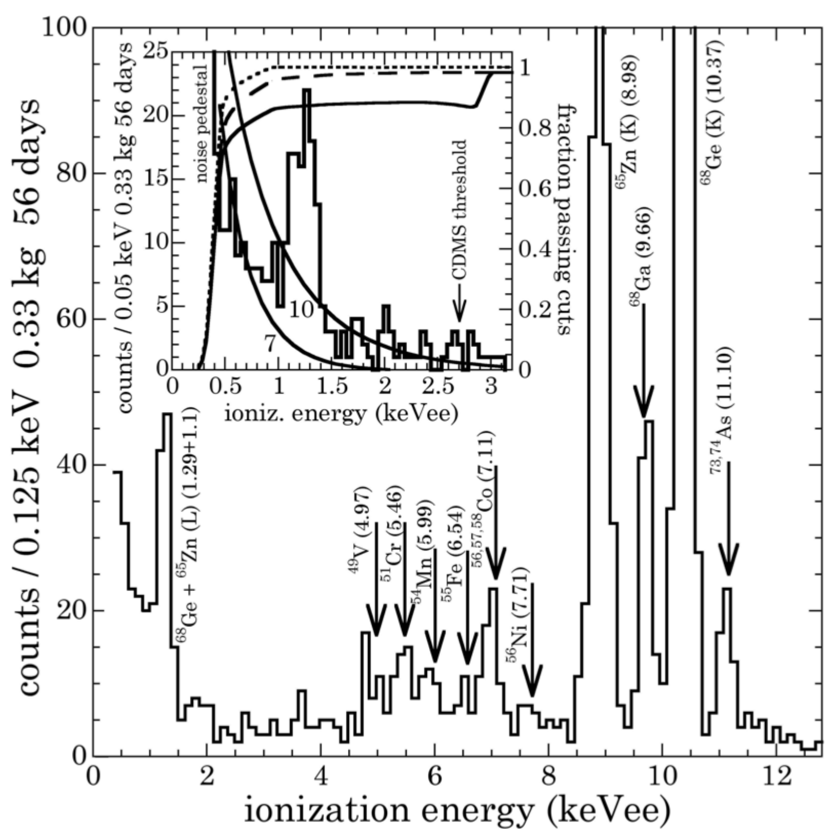
Light Dark Matter



Bernabei et al., Eur. Phys. J. C ***56*** *333 (2008)*



Hooper et al., Phys. Rev. D ***82****, 123509 (2010)*



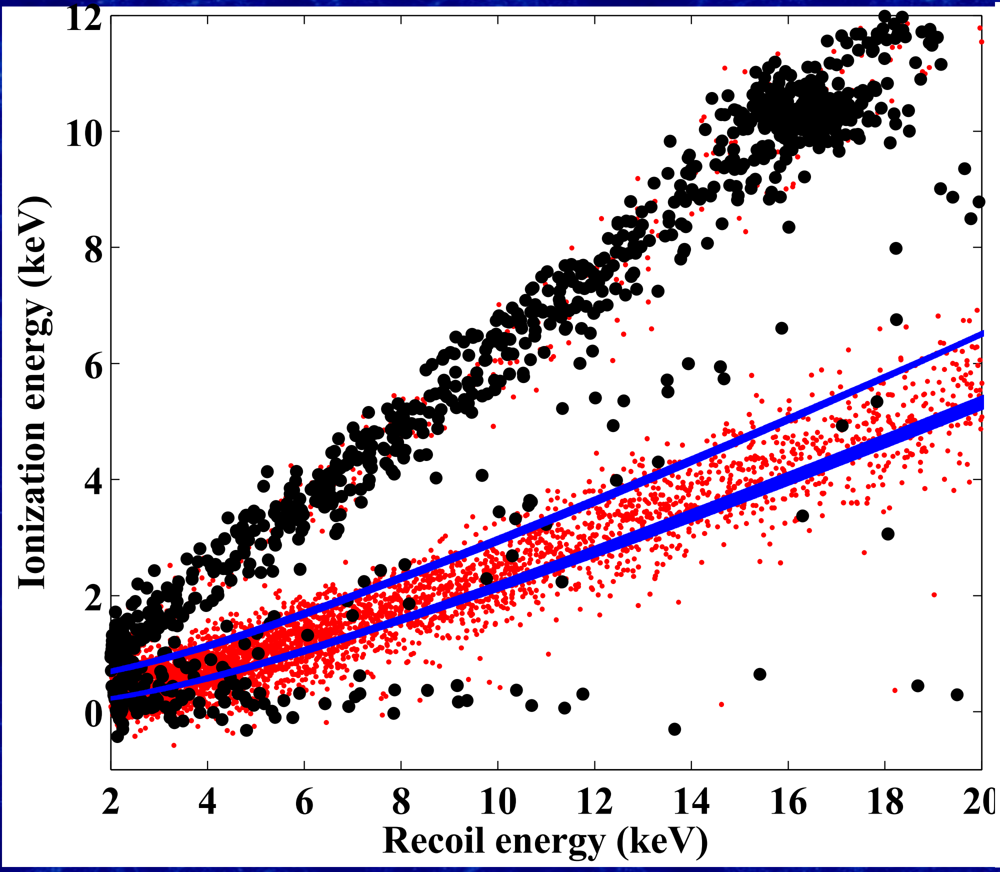
Aalseth et al., arXiv:1002.4703

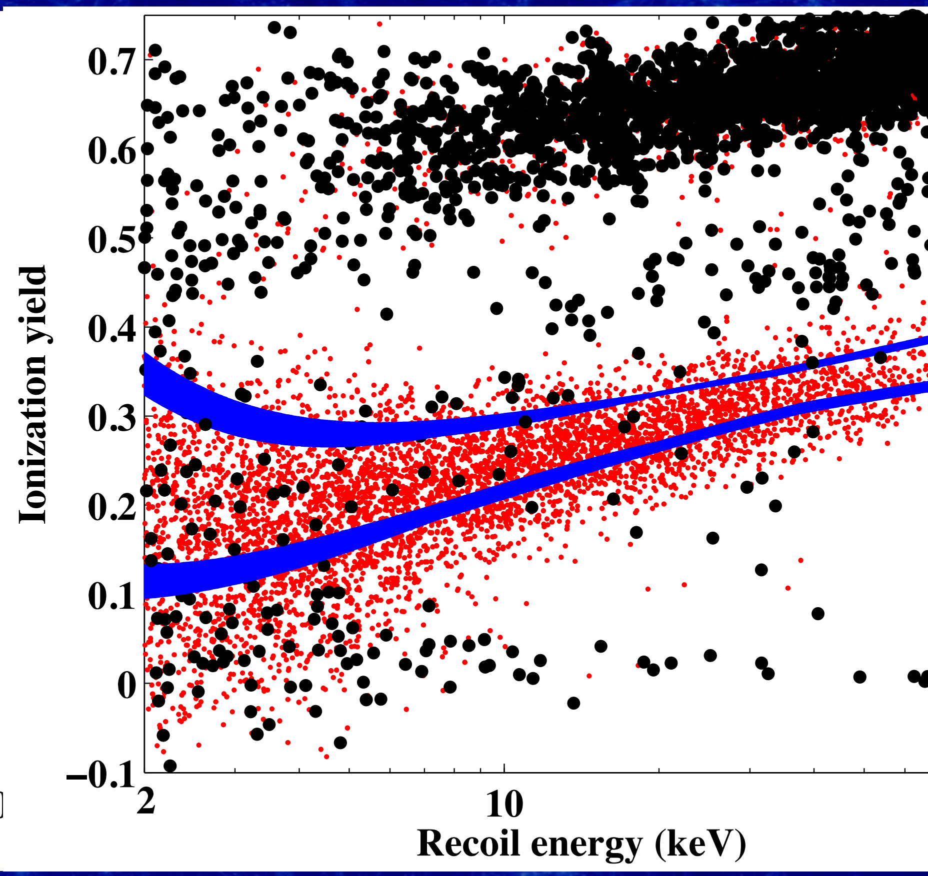
Light Dark Matter

- Recent results from DAMA/LIBRA, CoGeNT and others have been interpreted as possible evidence for elastic scatters from WIMPs with m_x~7 GeV and σ_{SI}~1x10^{-40} cm^2
- Previous CDMS Ge results not sensitive to these models since thresholds were ~10 keV (to maintain expected backgrounds <1 event)
- Can lower thresholds significantly at cost of higher backgrounds

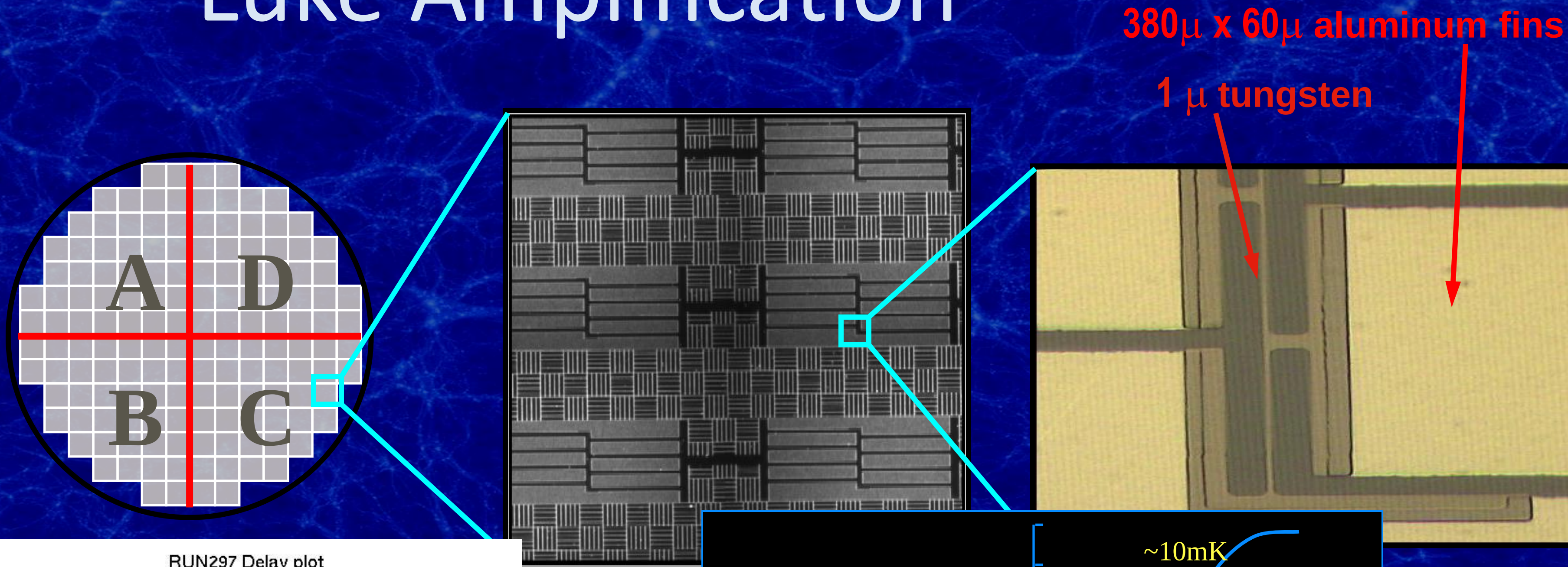
Low Energy Events in CDMS

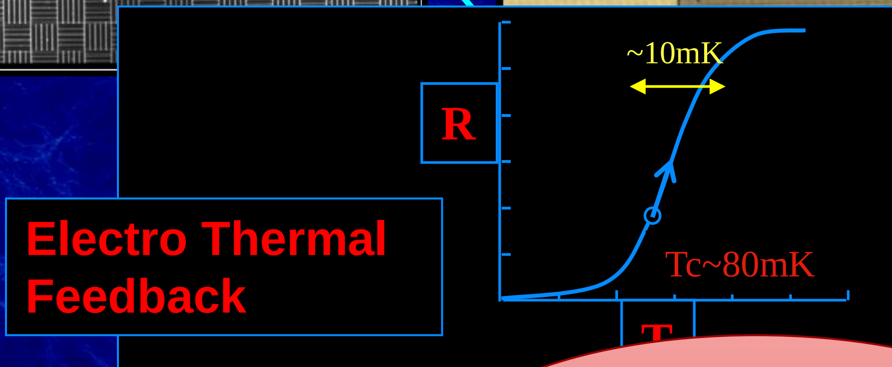
- At low energies the discrimination between nuclear and electron recoil worsens

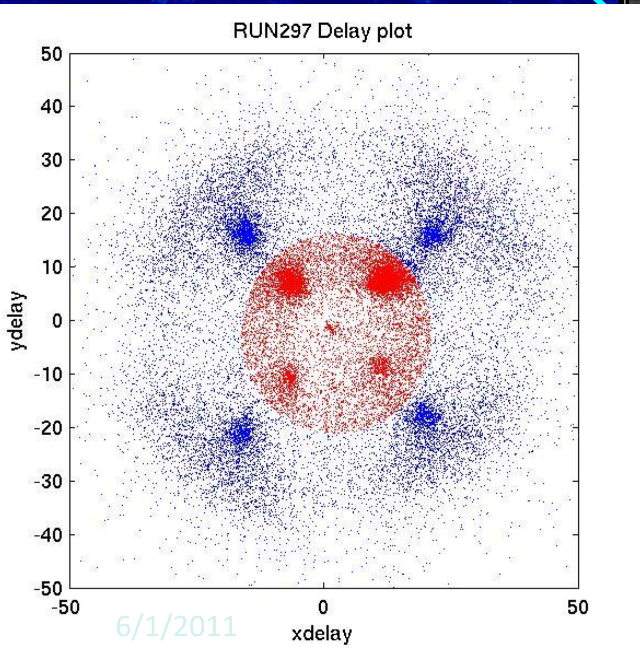




Luke Amplification





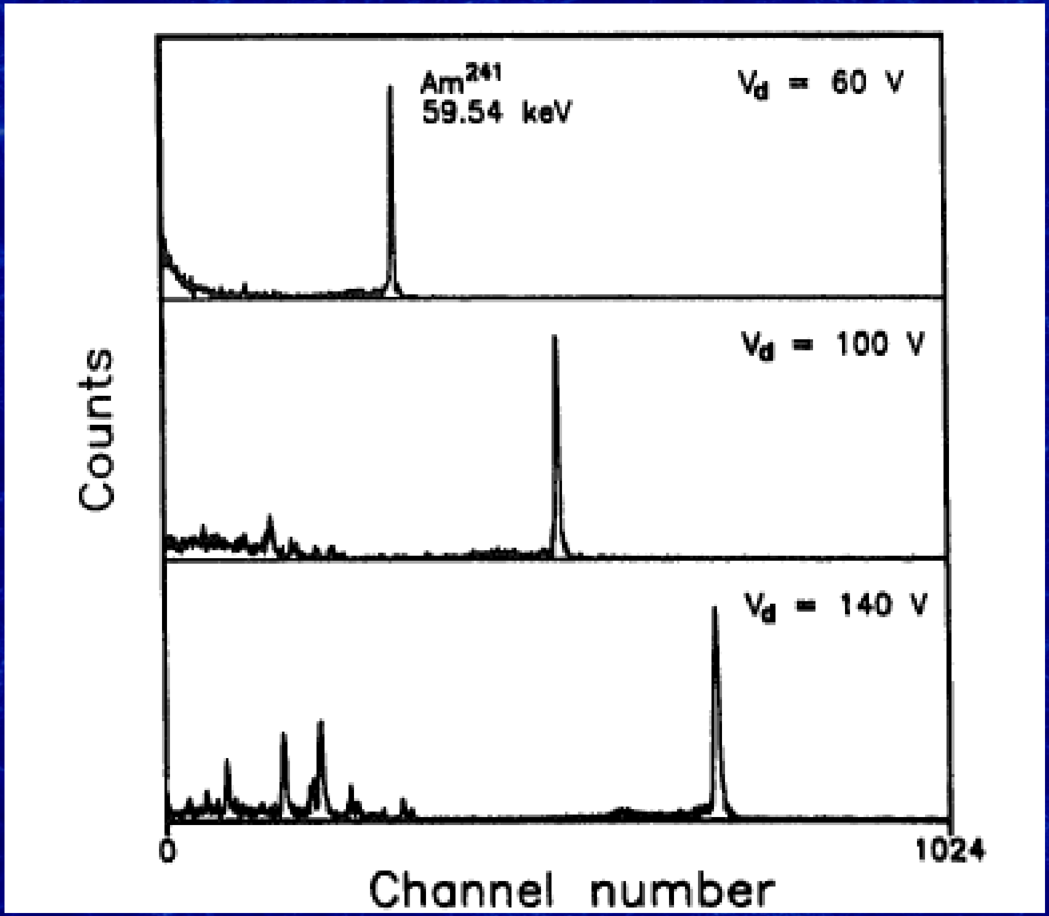


$$E_{phonon} = E_{rec\ldots} + V \times E_{ionization}/\varepsilon$$

Luke Amplification

Exponential is the most generic spectrum, especially near the electronic noise of detectors

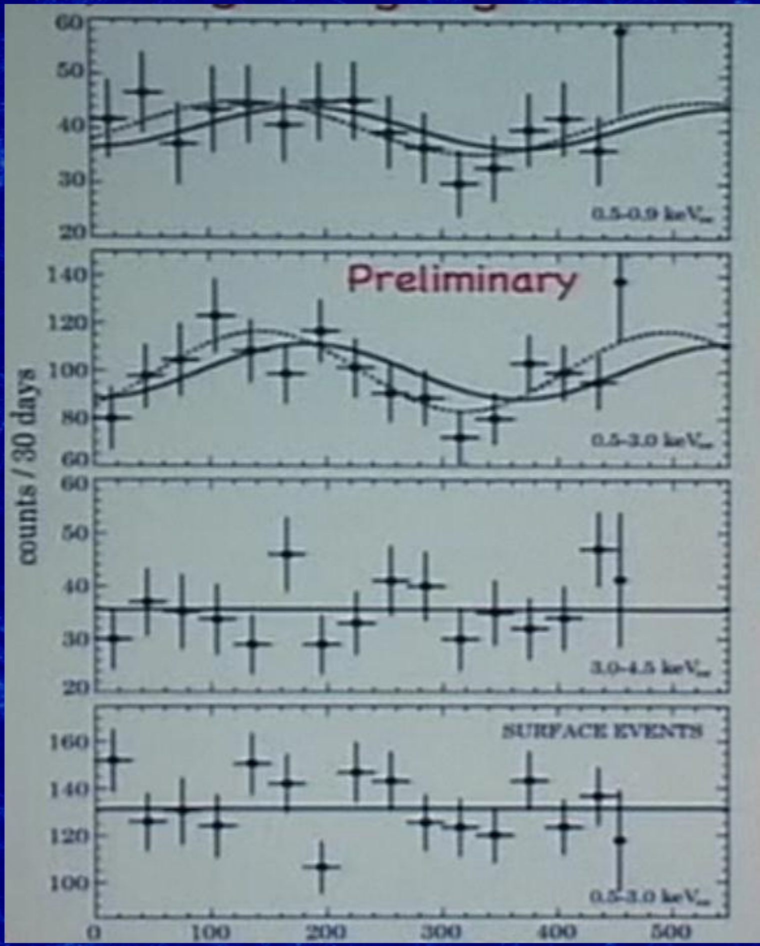
Good signal to noise is an important ingredient for understanding a dark matter signal



P.N. Luke et al., NIM A289, 406 (1990)

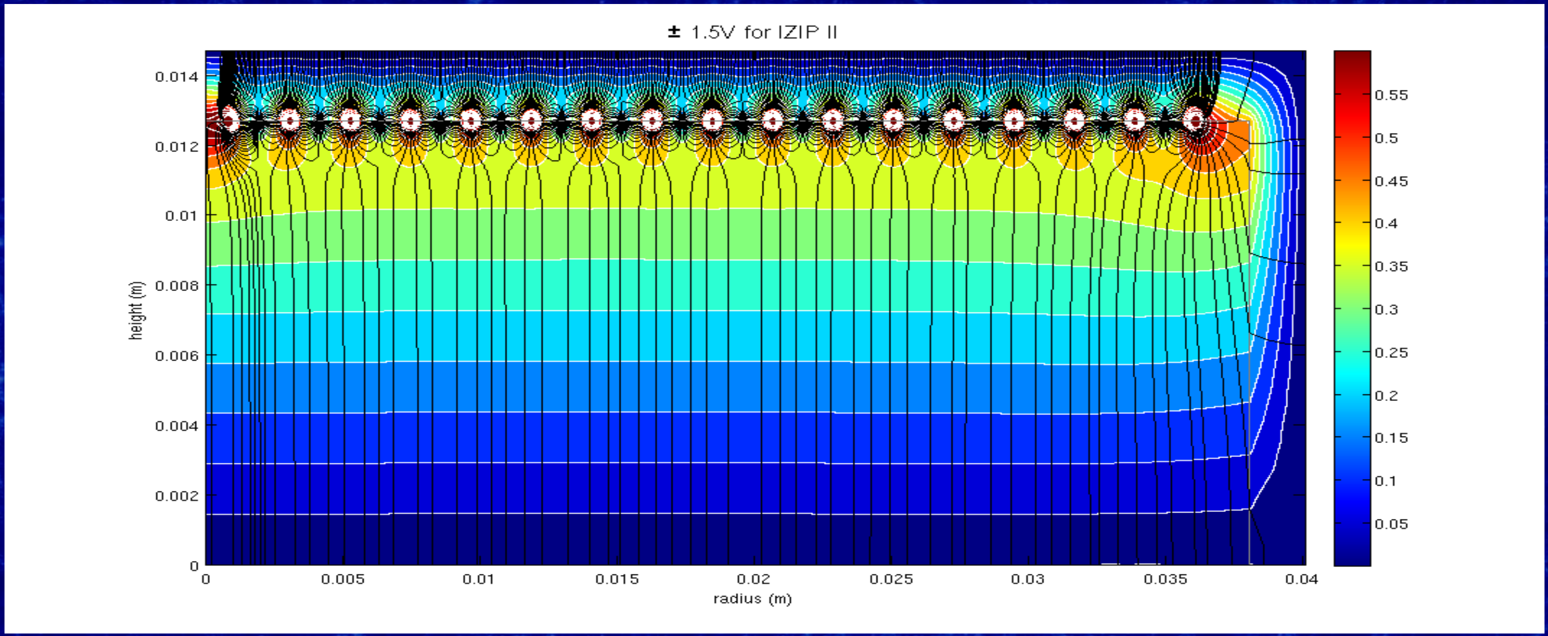
CoGeNT Annual Modulation

- The situation has become even more interesting
- The CoGeNT collaboration reported a posible annual modulation signal at the April APS meeting
- 2.8 sigma significance



SuperCDMS 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)
- Trial run in Soudan facility with a 10 kg payload (X5 sensitivity)



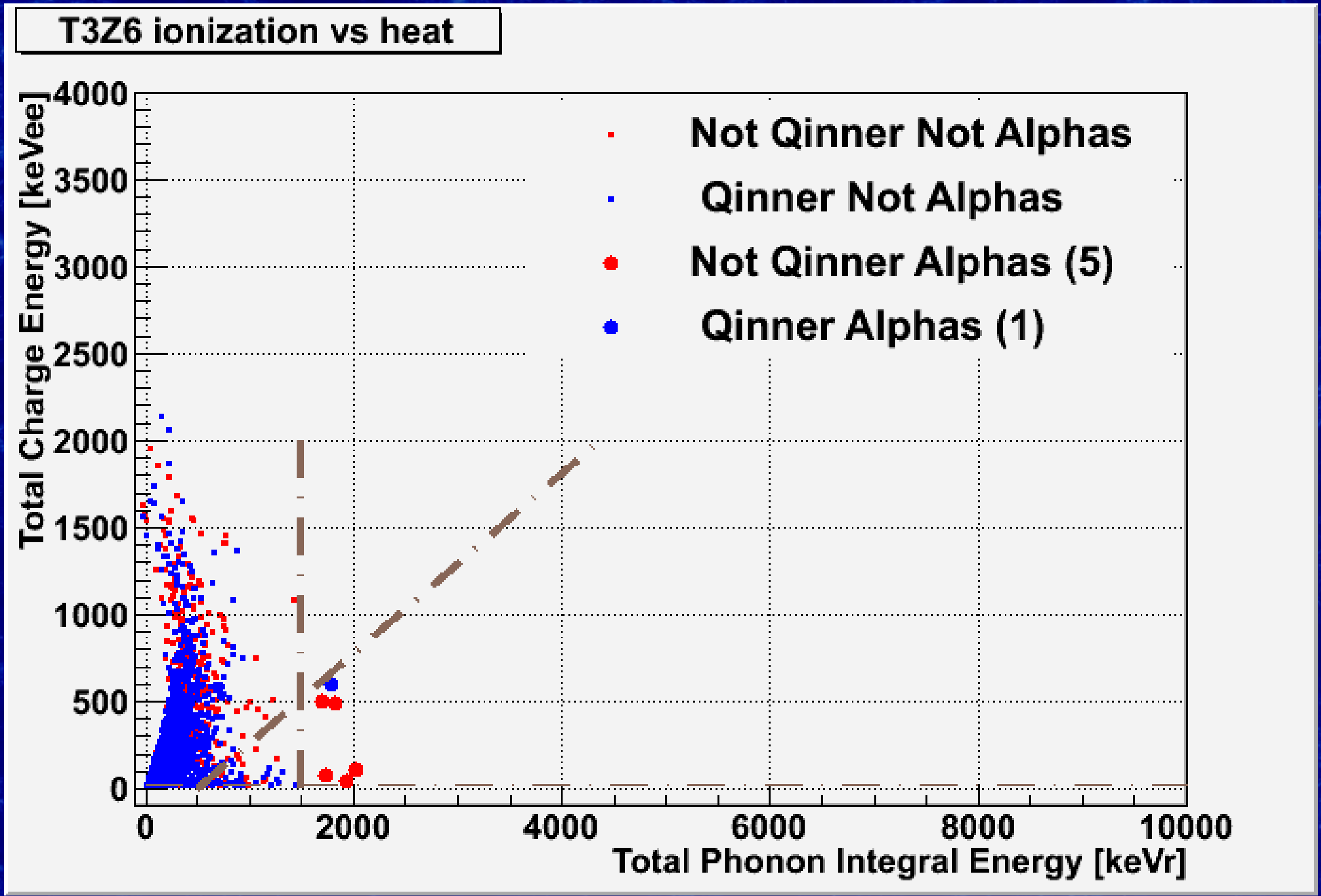
SuperCDMS Delay

- 10 kg experiment starts August
- Impact minimal but some enginering work delayed

Low threshold sensitivity

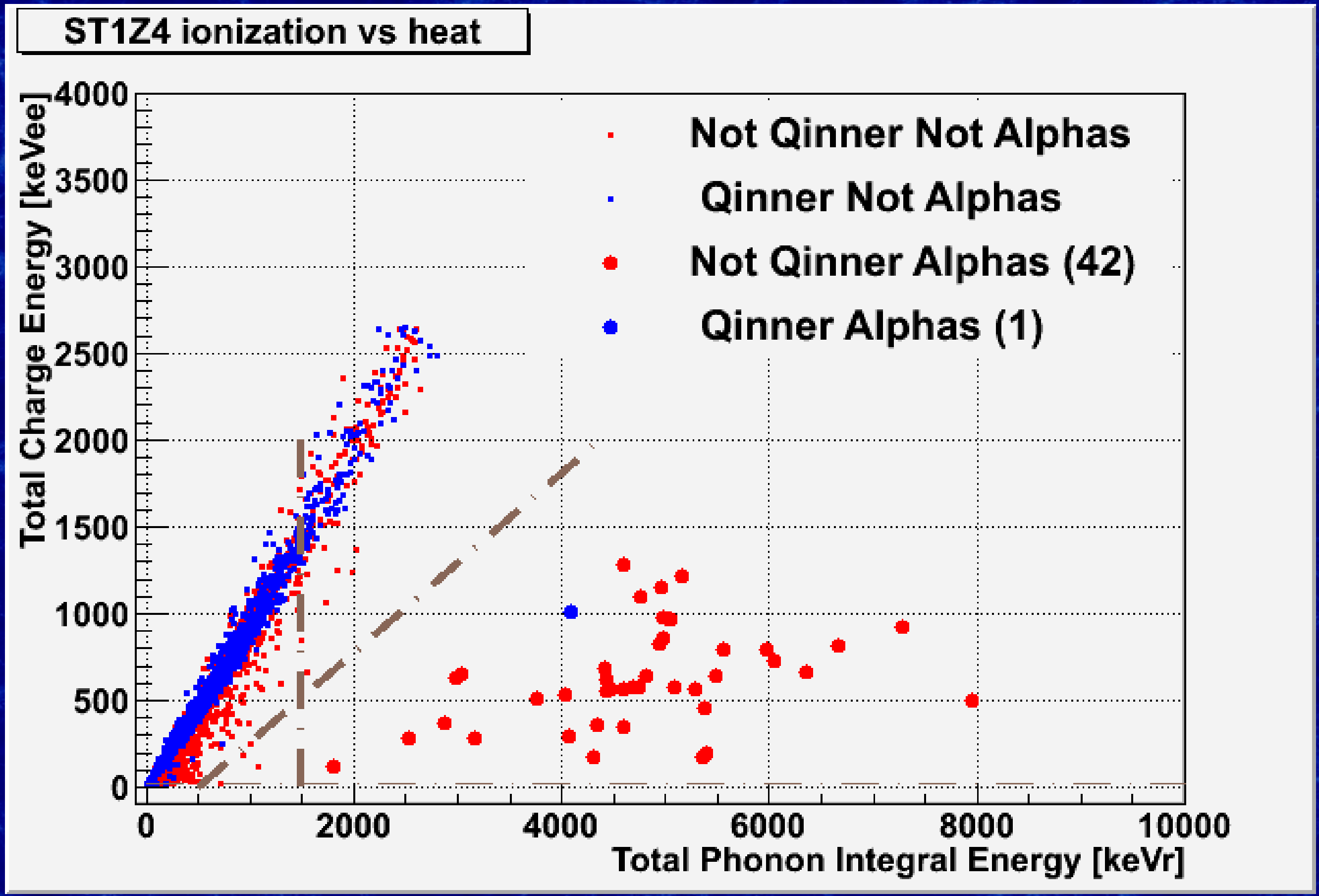
- Low threshold sensitivity is limited by backgrounds
- Understanding the backgrounds is now the way to make progress with CDMS
- ~2 months of data taken with high voltage (14 hours shown here)
- Few days of Germanium data taken

CDMS Phonon Non-Linearity



- CDMS-II Detectors can have strong non-linearity above ~few 100s keV

SuperCDMS Phonon Linearity

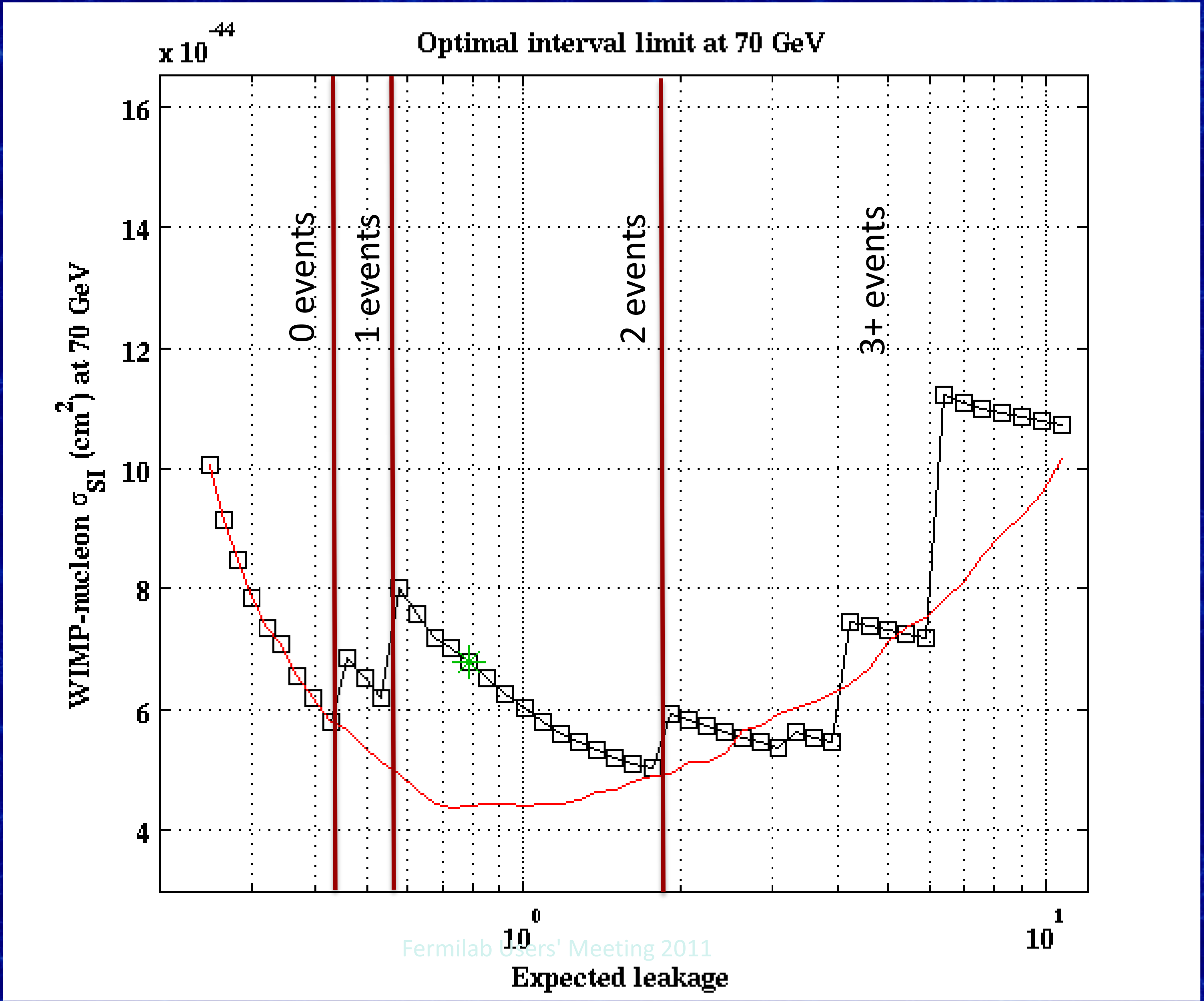


- New SuperCDMS detectors exhibit much better linearity

SuperCDMS Luke Amplification Advantages

- Better linearity
- Germanium has low energy lines for calibration
- 2.5X Thicker = 2.5X less E
  - Field emission at higher V
  - Breakdown at higher V

Cut Position



Likelihood Analysis

- Comparing nuclear scatters from neutron calibrations to surface electron scatters from gamma calibrations
- Likelihoods constructed only for the detectors that recorded the candidate events
- 3 independent methods constructing the likelihood distributions
  - Use of variety of methods helps check technique dependent systematic errors
  - Binned/Unbinned
  - Distribution fitting/no fitting
  - 2D (yield, timing) / 3D (yield, timing, energy)

Likelihood Results (over entire distribution)

- What is the probability of observing one surface electron event with a nuclear scattering likelihood greater than the candidate events in these detectors?

Event	Unbinned 3D	2D with fit	2D no fits
1	24 +/- 5 %	12 +/- 2 %	12 +/- 2 %
2	4 +/- 2 %	5 +/- 1 %	5 +/- 1 %

Likelihood Results (in the acceptance region)

- What is the probability that a true nuclear recoil in the acceptance region is as close to the cut boundaries as the observed events in these detectors?

Event	Unbinned 3D	2D with fit	Unbinned 2D no fit
1	1 %	3 %	4 %
2	12 %	2 %	19 %

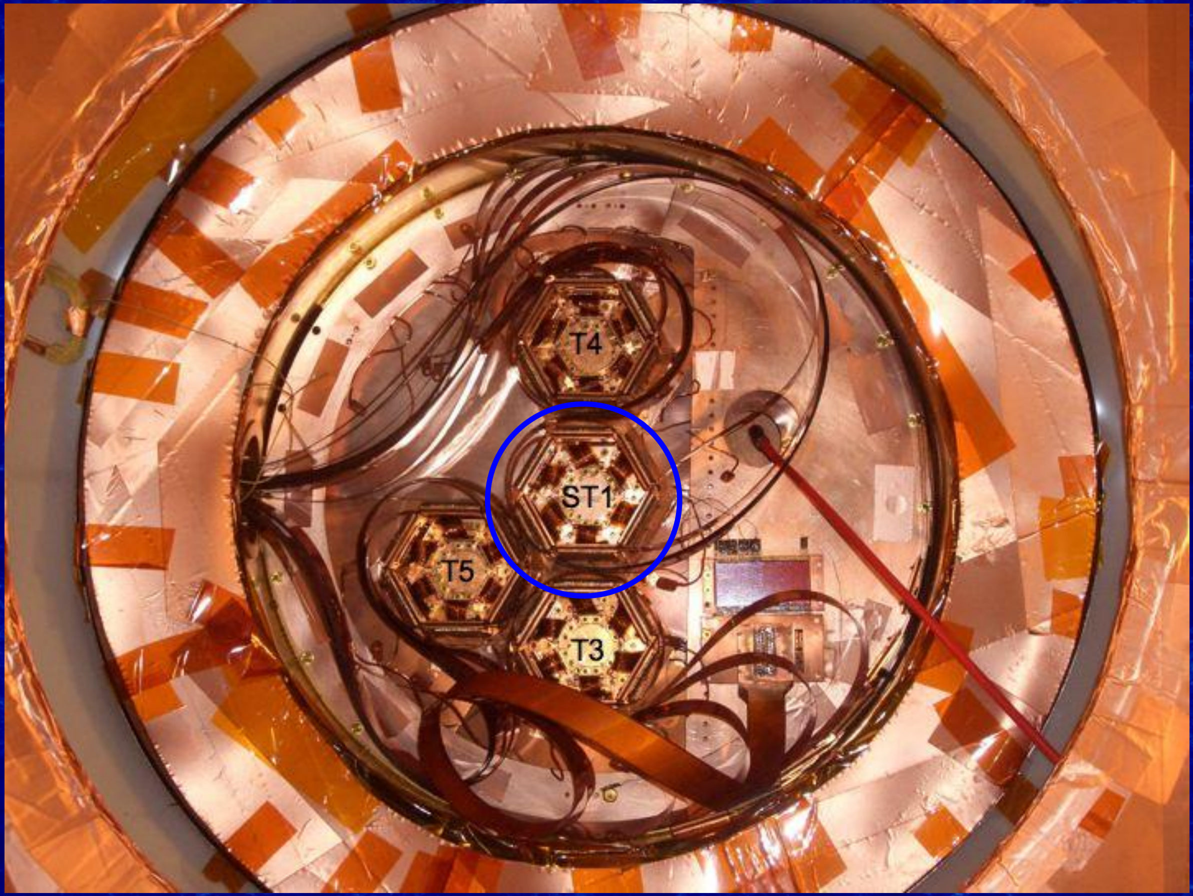
- What is the probability of an electron recoil in the acceptance region appearing to look more like nuclear recoils in the acceptance region in these detectors?

Event	Unbinned 3D	2D with fit
1	83 %	28 %
2	54 %	34 %

Likelihood Summary

- The results verify the initial calculation that the probability of observing two surface backgrounds appearing as nuclear recoil like is low, but not significantly low
- The results encourage suspicion that the observed events are due to surface electron scatters, especially event 1

SuperCDMS Soudan



CDMS II data-taking ended March 2009

First SuperTower data run complete (five 0.65 kg Ge detectors)

Detector background based on α rates below goal in all detectors

Currently analyzing data for surface background characterization

See afternoon talk by P. Brink for detector details and developments!

CDMS Conclusions

- CDMS-II operations complete
  - Limits on direct WIMP-nucleon scattering at the level of 7 x 10^{-44} cm^2 at 70 GeV WIMP mass
- Two events observed
  - Consistent with 0.9 ± 0.2 events expected from known backgrounds
  - Neither are golden events
    - Likelihood encourages suspicion about one event
    - Event reconstruction encourages suspicion about the other event
  - No obvious errors to exclude either event
- The search continues with more massive detectors

The Collaboration

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

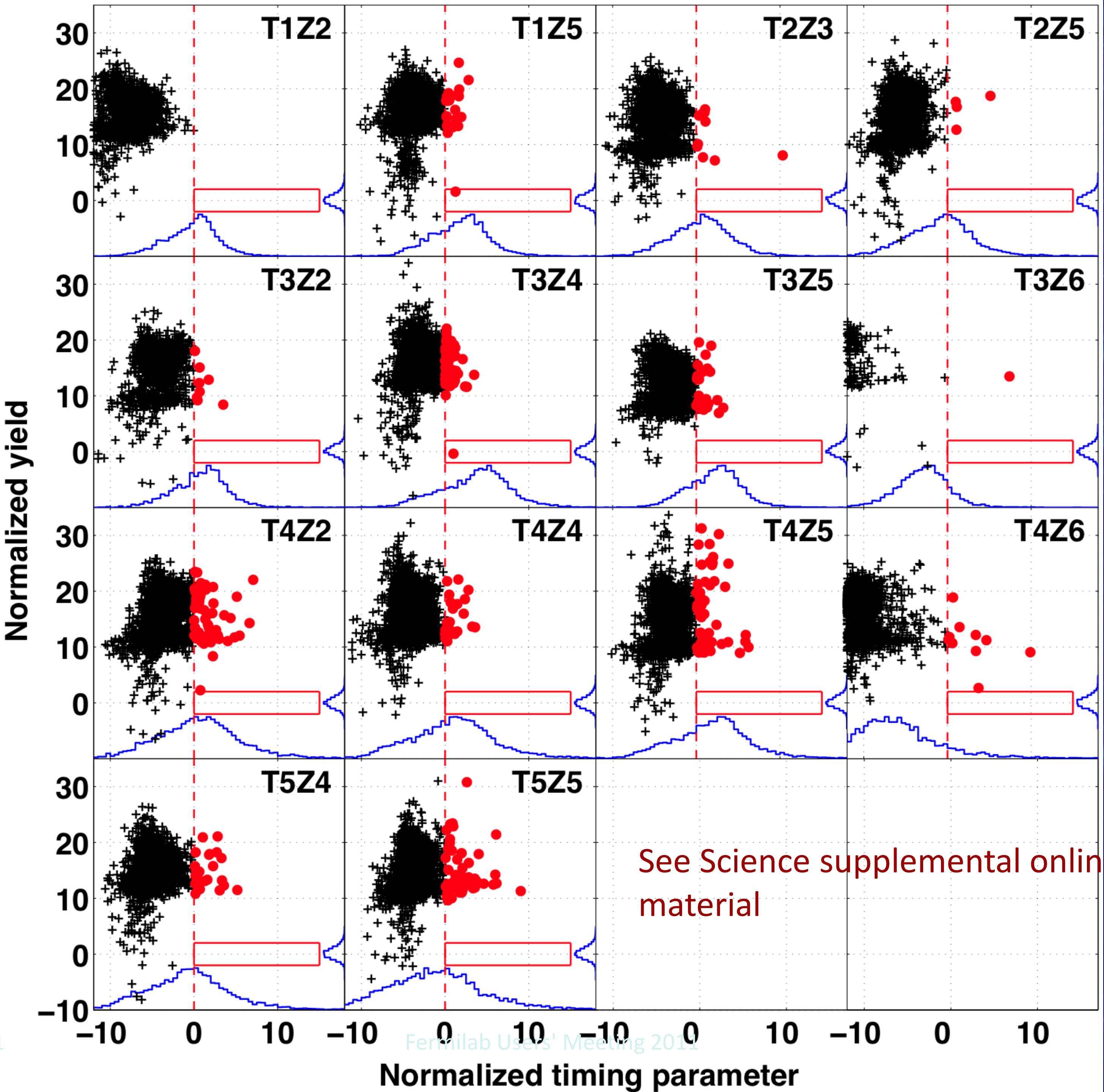
University of Colorado Denver
B.A. Hines, M.E. Huber

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*



See Science supplemental online material