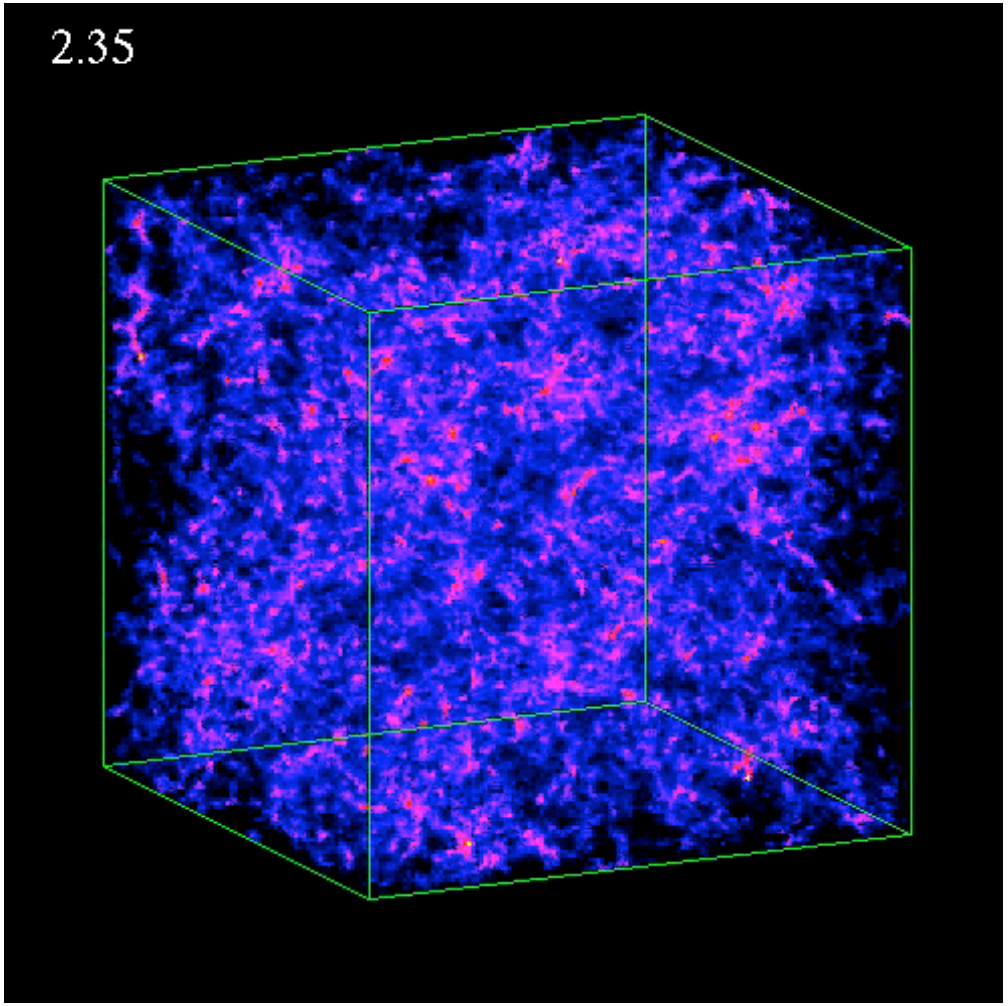
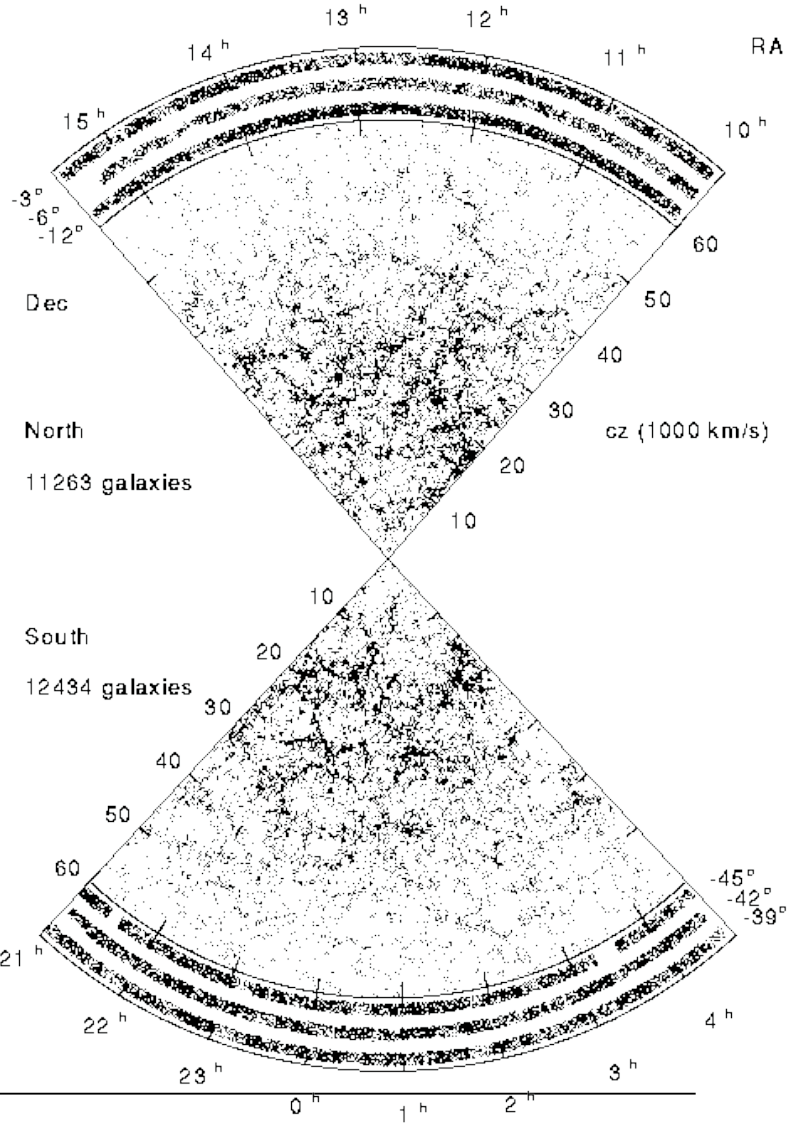
Large Area TES X-Ray Detectors

- Figure of merit is etendue given by: $A\Omega = 0.012\ d^2$ cm^2-sr, where the detector diameter d is in cm.
- Square detecter 25 mm on an edge with 1 mm square pixels and with an energy resolution of 4 eV FWHM would enable:
  - Search for missing baryons in warm-hot interstellar medium (WHIM) using oxygen x-ray lines (0.5 keV)
  - Surveys of clusters and groups of galaxies as a probe of the growth of structure
- A number of efforts to multiplex large numbers of single pixels - time domain and frequency domain schemes
- We are developing macropixel to cover large areas

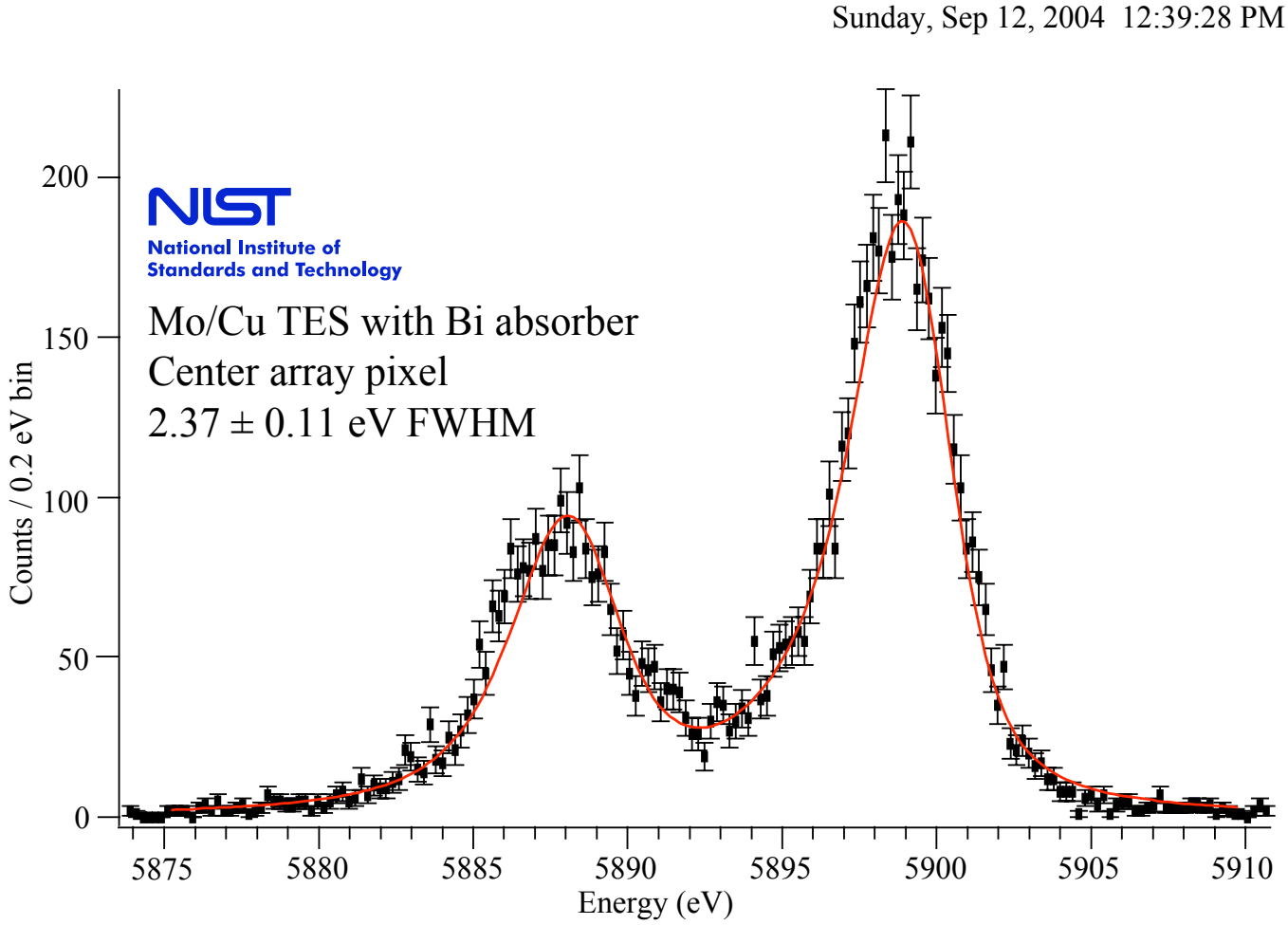
Expanding universe - simulations and data





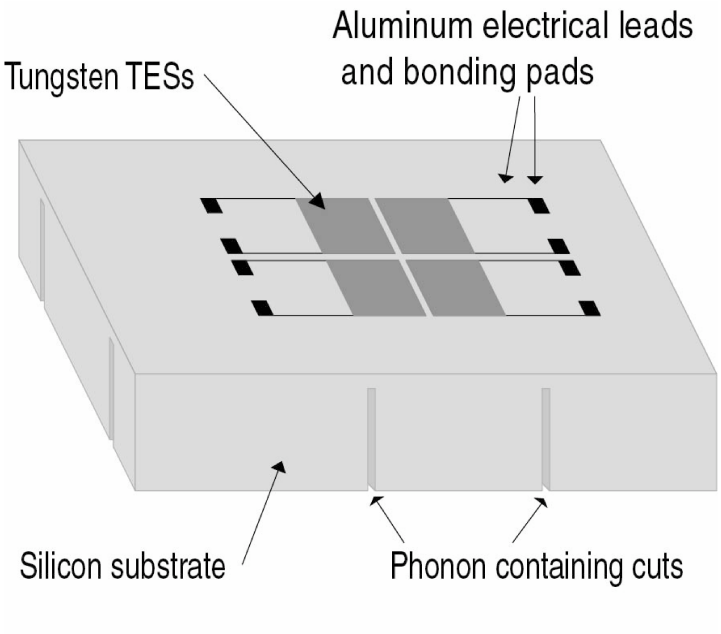
Best Single Pixel X-Ray Resolution

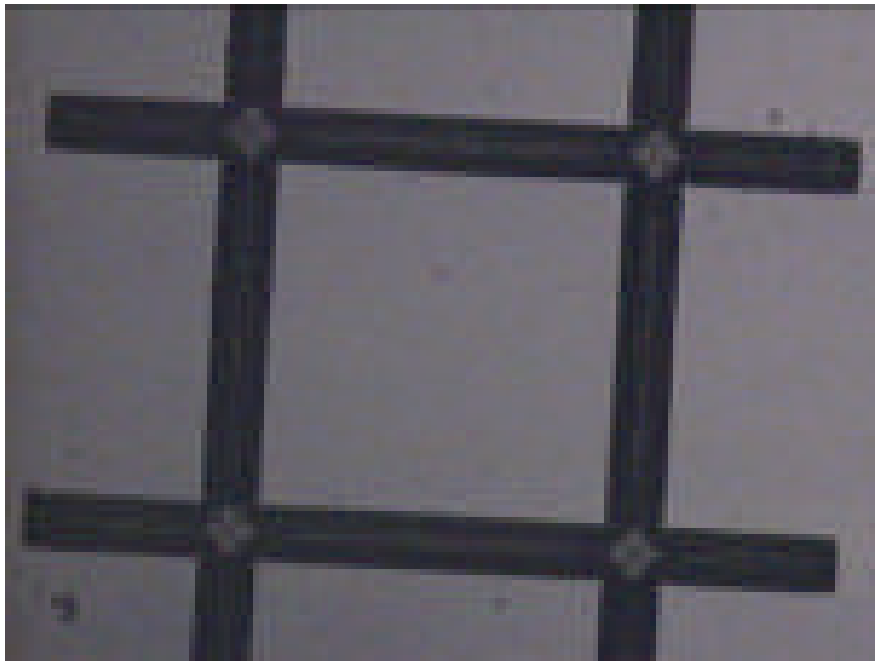
- R = E/ΔE = 2,490



Macropixel Concept

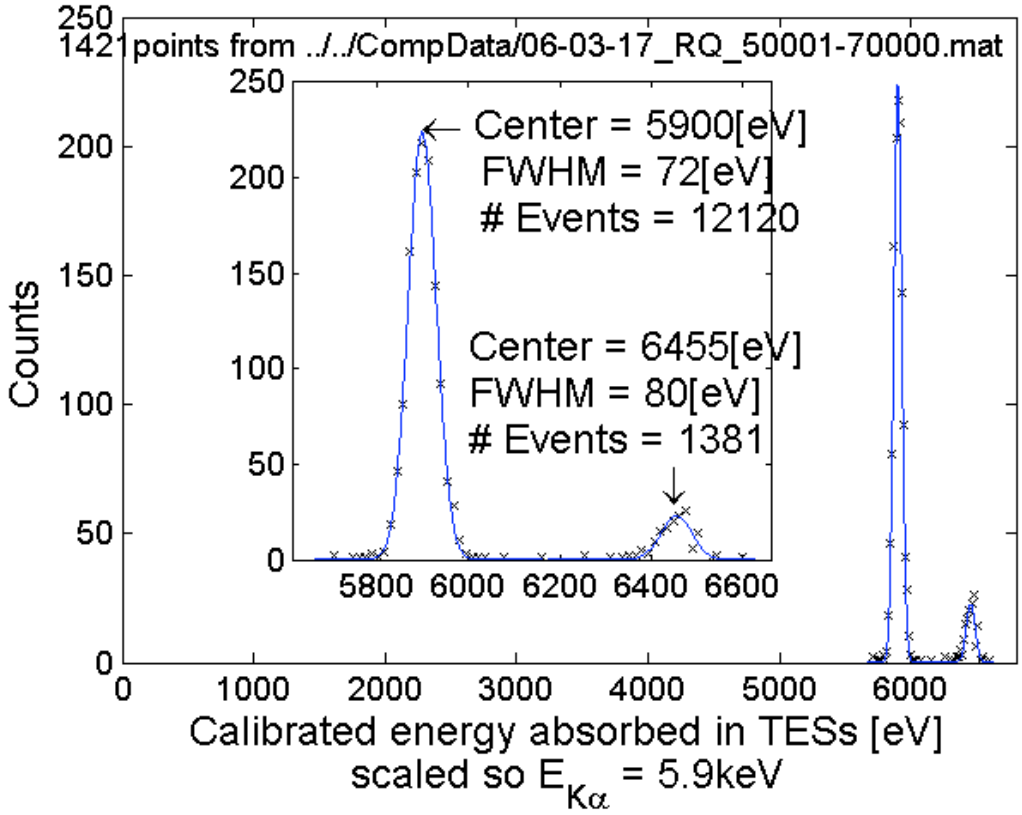
- Demonstration with 300 μm thick Si wafer
- X-rays incident on backside converting to phonons
- Phonon absorbed by TES sensors on front side





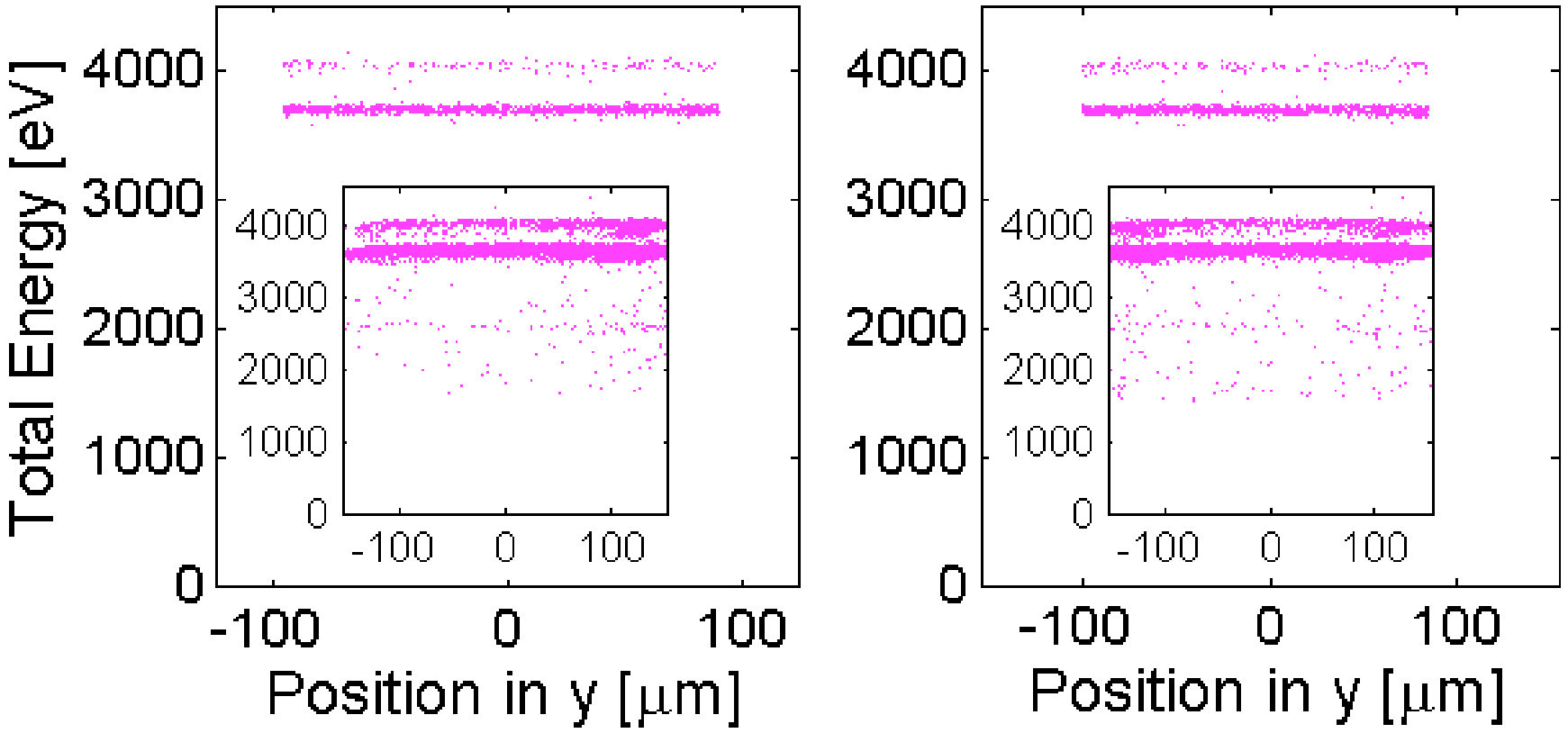
Macropixel Sensitivity

- Response from ^{55}Fe x-rays across macropixel
- Will improve using intrinsic Ge



Macropixel Concept

- Simultaneous energy and position resolution
- Inset is raw data and plot after position



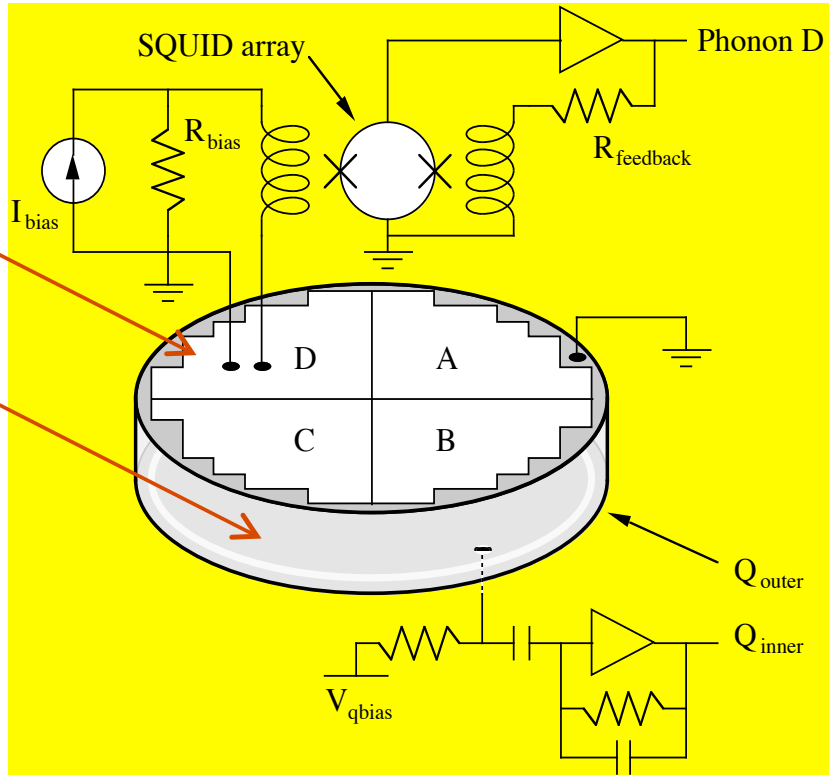
Dark Matter CDMS ZIP Detectors

Phonon sensors (4) (TES)

Ionization Electrodes (2)

x-y-z imaging:

from timing, sharing

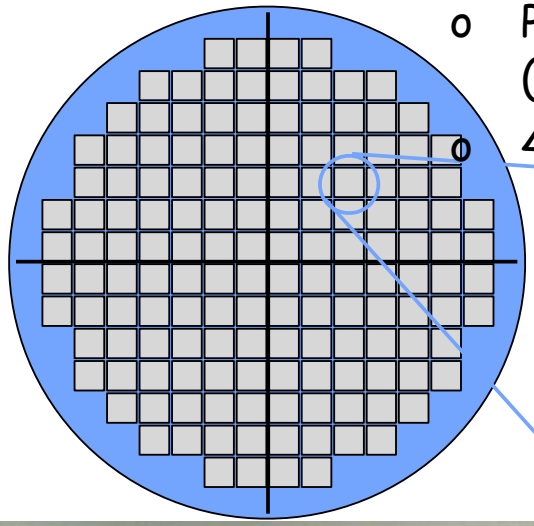


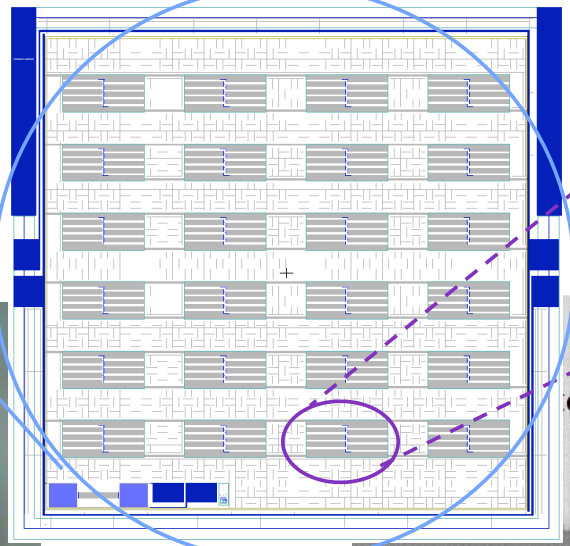
WIMPs: σ(Ge) >> σ(Si)

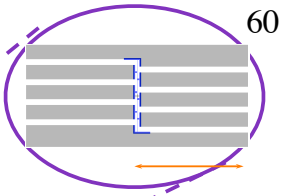
Neutrons: σ(Ge) ~ σ(Si)

ZIP detector phonon sensor technology

- TES's patterned on the surface measure the full recoil energy of the interaction
- Phonon pulse shape allows for rejection of surface recoils (with suppressed charge)
- 4 phonon channels allow for event position reconstruction

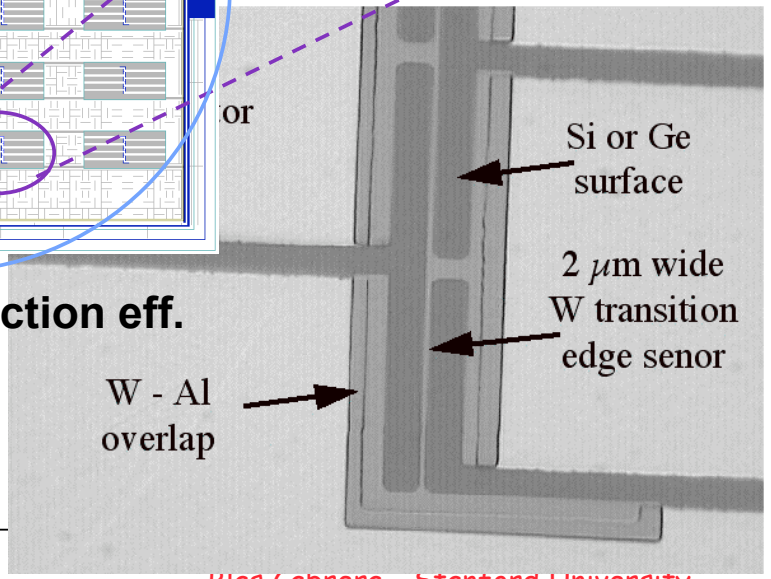






380 μm Al fins

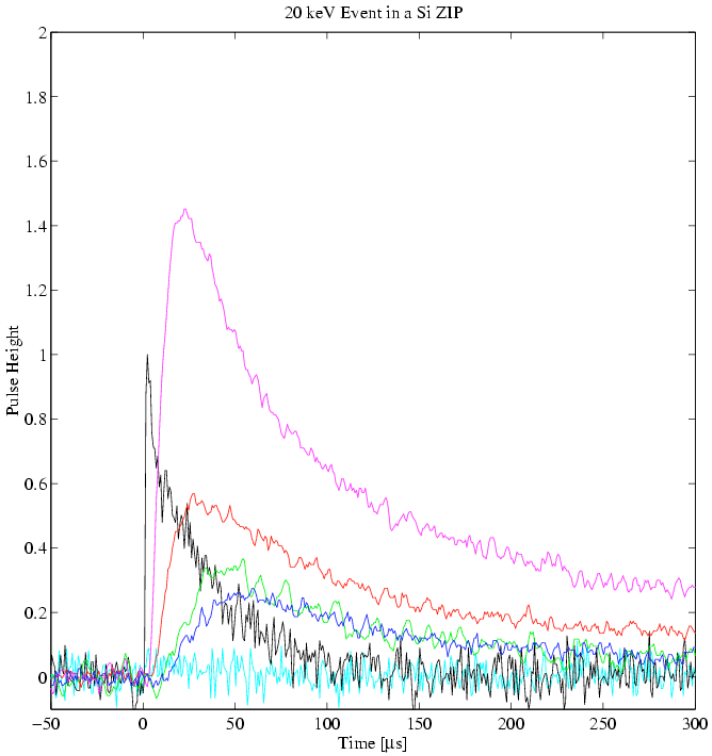
~25% QP collection eff.



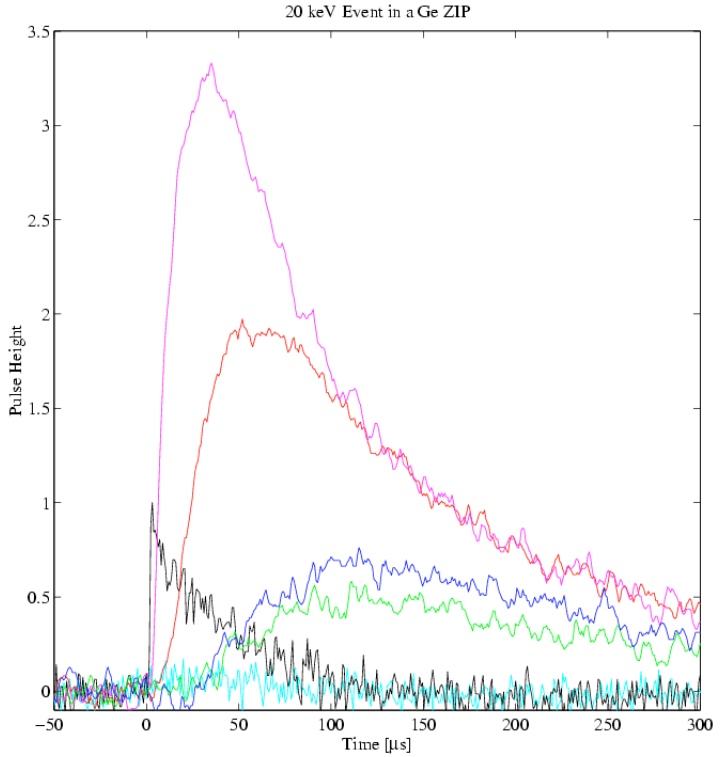
The ZIP Detector Signal

- Charge & Phonon signals occur on a similar timescale
- Phonon pulse time of arrival allows for event position reconstruction
- 20 keV event in a Si & Ge ZIP

Si ZIP

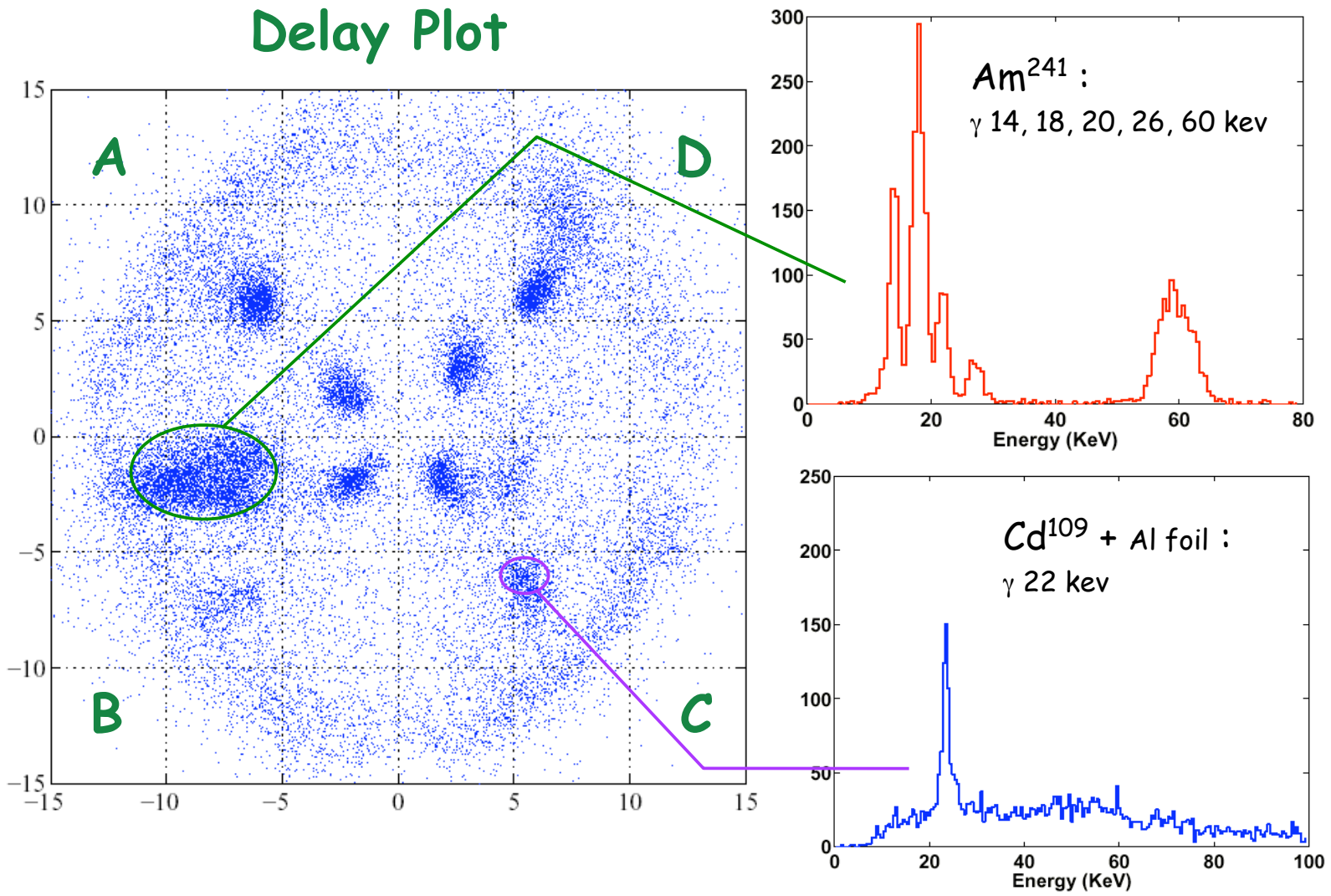


Ge



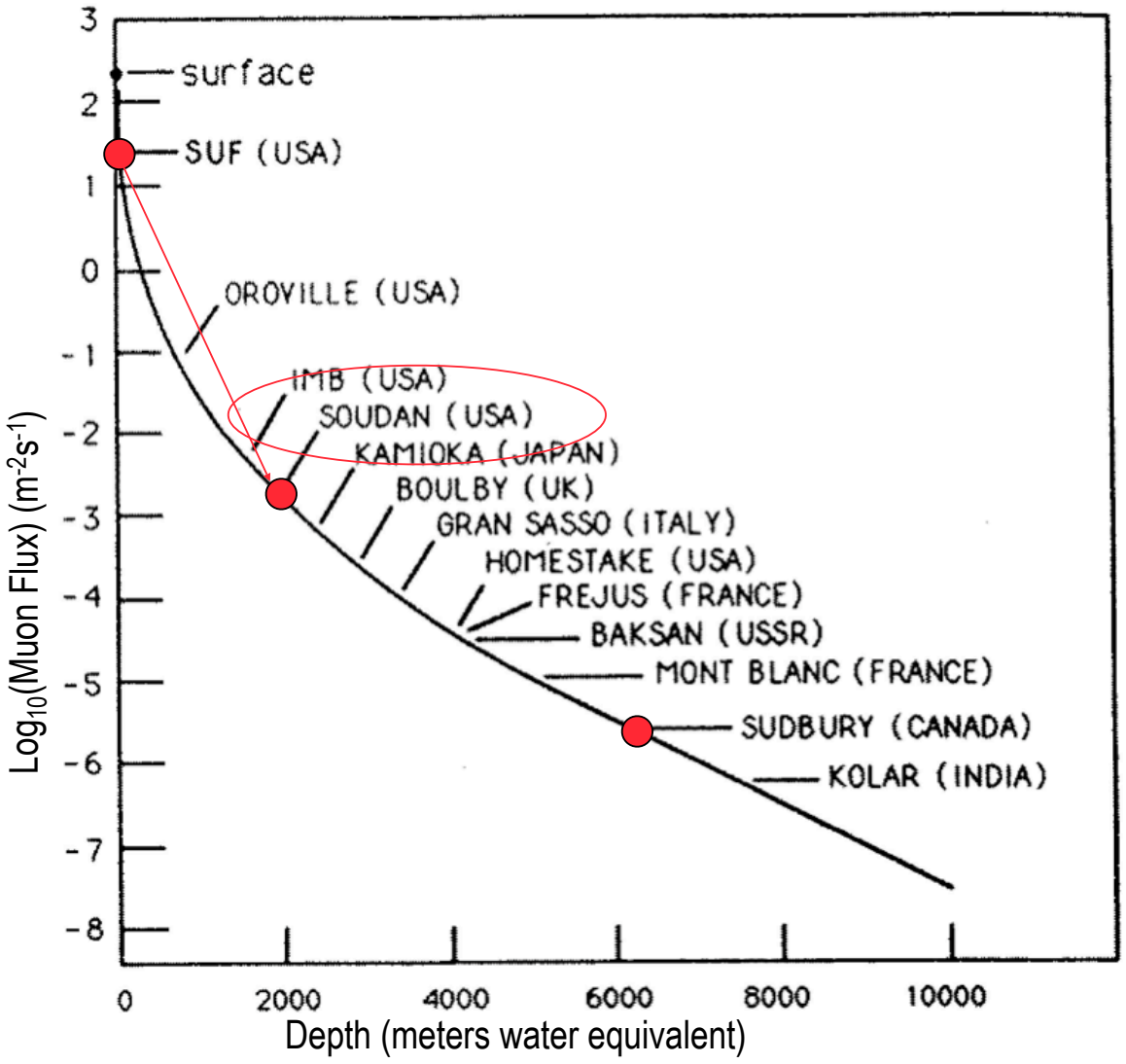
(EXCELLENT S/N FOR 20 KeV TRUE RECOIL ENERGY)

ZIP Phonon Position Sensitivity

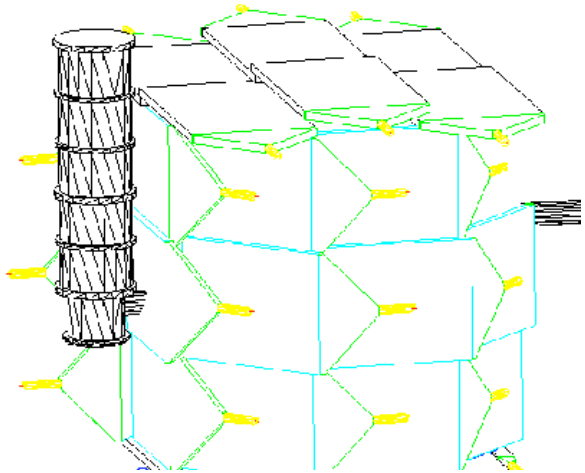


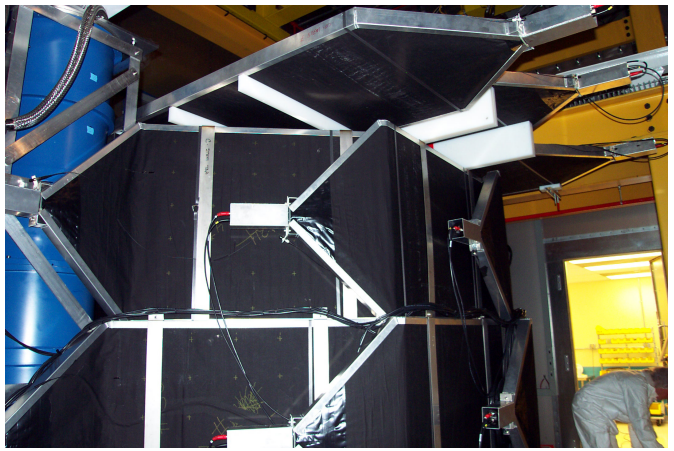
CDMS-II at Soudan (2090 mwe)

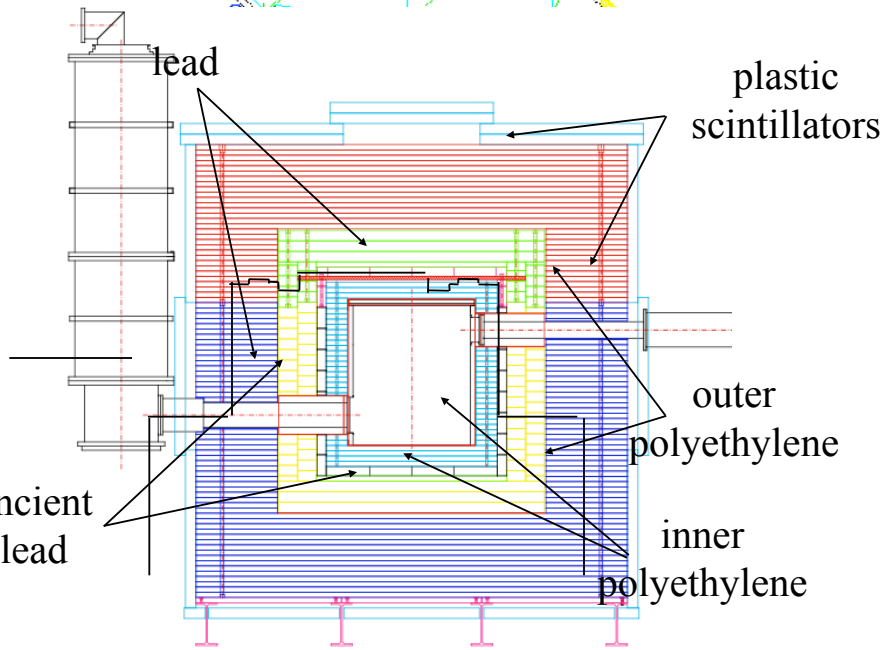
- At SUF
  - 17 mwe
  - 0.5 n/d/kg
- At Soudan
  - 2090 mwe
  - 0.6 n/y/kg
- At SNOLab
  - 6060 mwe
  - 1 n/y/ton



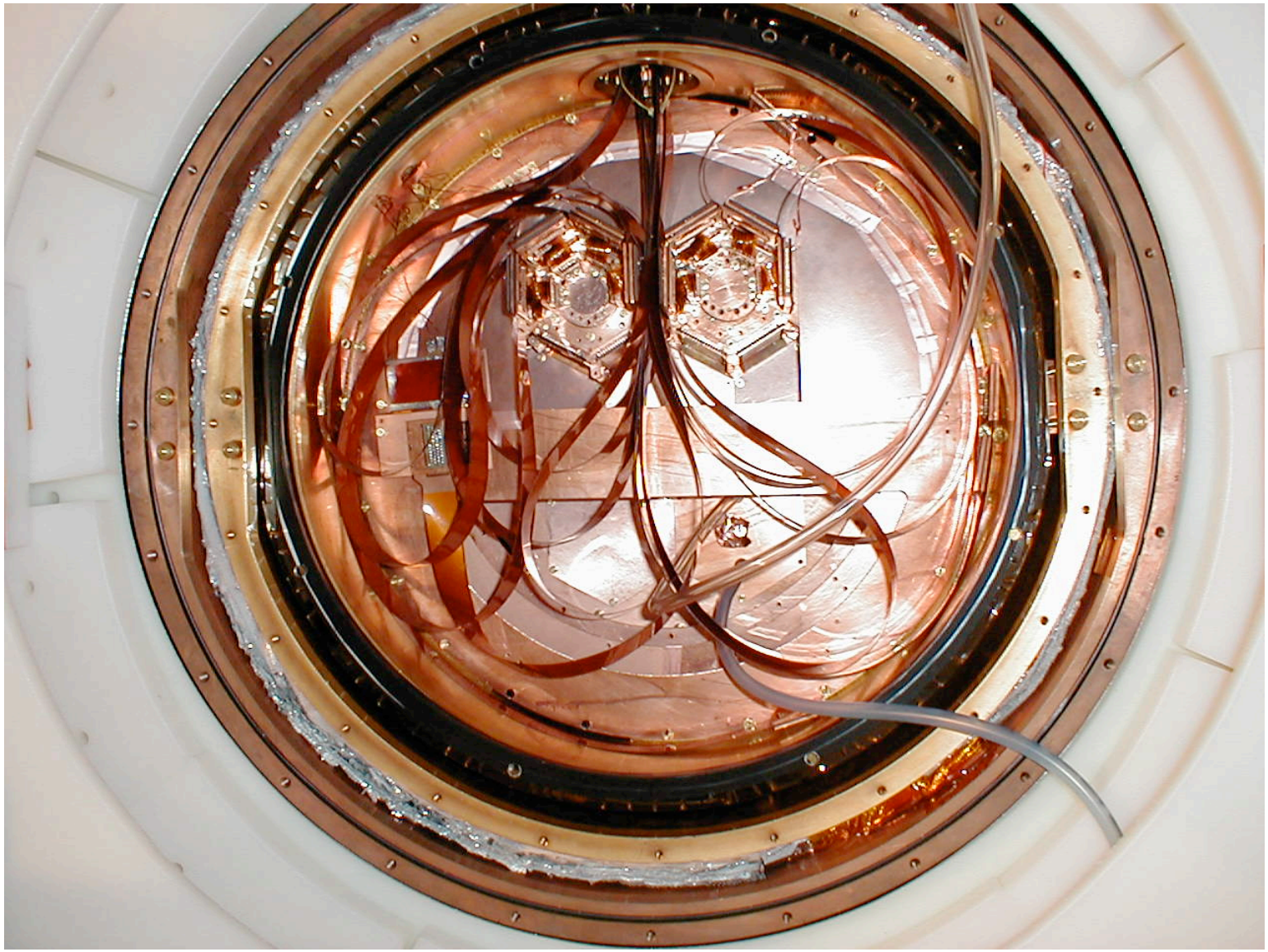
CDMS-II Soudan facility







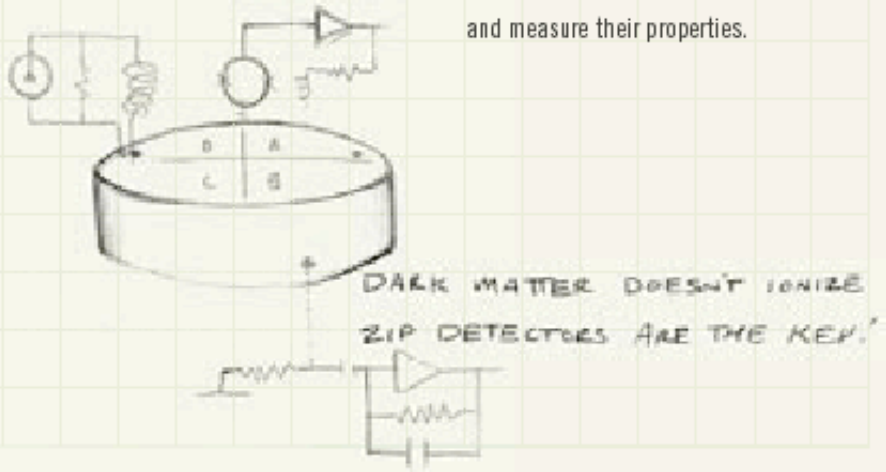
Run 118 (1T) & Run 119 (2T) in Soudan



Quantum Universe - CDMS!

From a vantage point a half-mile below ground, physicists of the Cryogenic Dark Matter Search have launched a quest to detect the dark matter that pervades the universe. Scientists of CDMS II, an experiment in the Soudan Iron Mine in northeastern Minnesota, hope to discover the weakly interacting massive particles that are leading candidates for the constituents of dark matter. The WIMPs are thought to be particles more massive than protons but interacting so rarely that thousands would pass through us undetected each second. Only occasionally would a WIMP hit a terrestrial atom, leaving a signal in the CDMS II detector.

In the kind of convergence that gets physicists' attention, the characteristics of WIMPs appear to match those of a particle predicted by supersymmetry, the neutralino. While CDMS II watches for WIMPs, accelerator experiments seek to create neutralinos in particle collisions and measure their properties.



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 β's using pulse risetime as well
- Much better than expected in CDMS II proposal!

Tower of 6 ZIPs

Tower 1

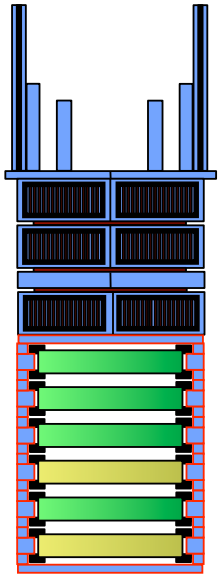
4 Ge

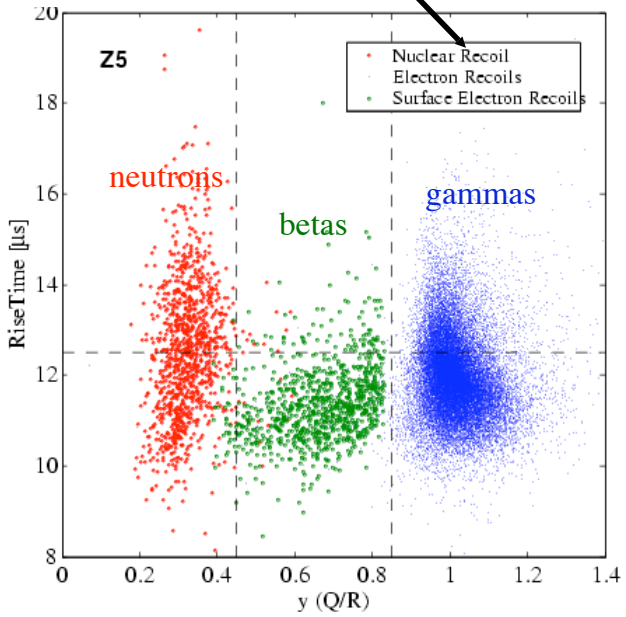
2 Si

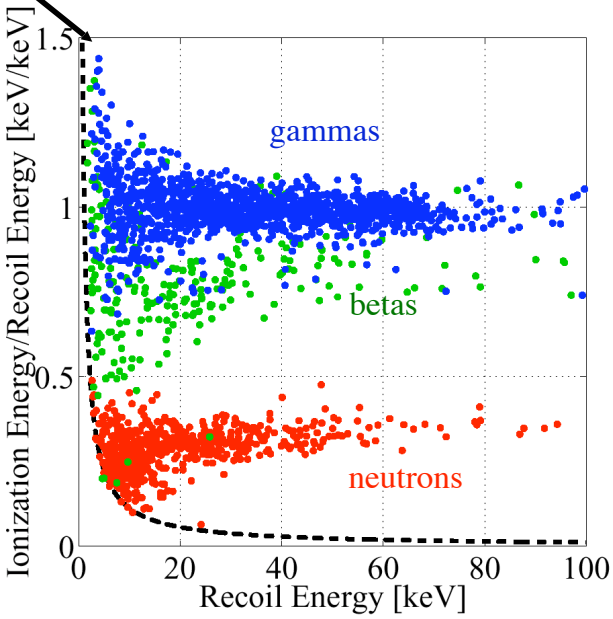
Tower 2

2 Ge

4 Si

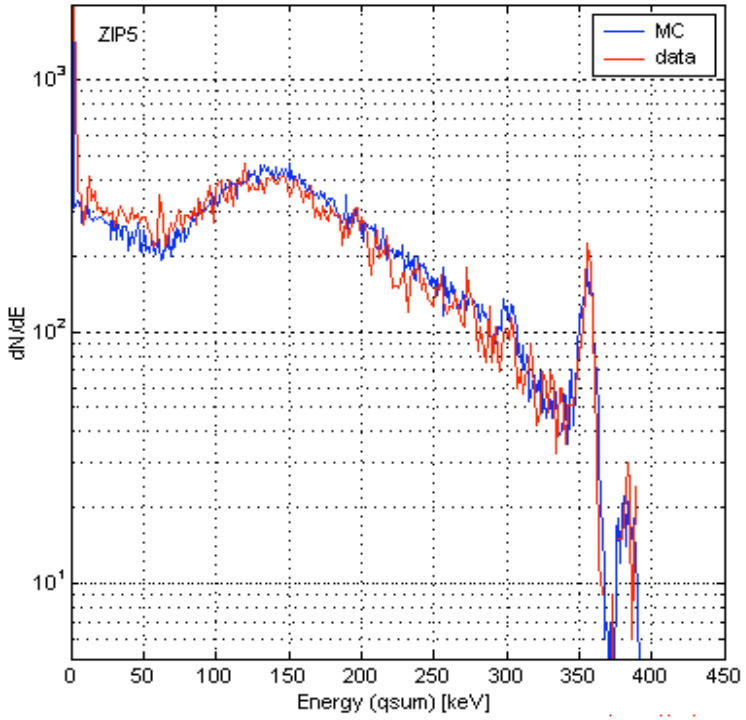




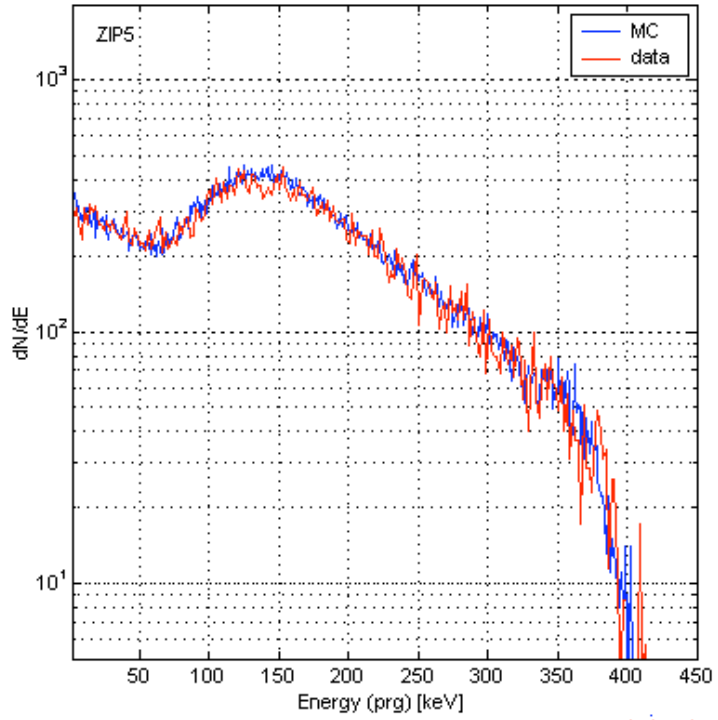


Energy calibration of Ge ZIP with ^{133}Ba source

Ionization energy in keV



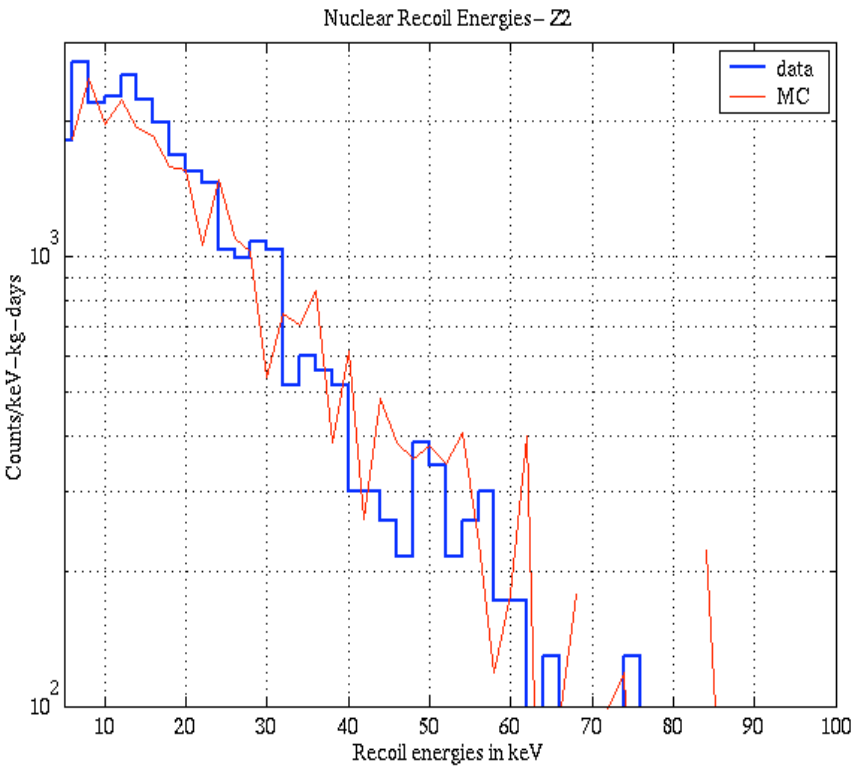
Phonon energy (prg) in keV



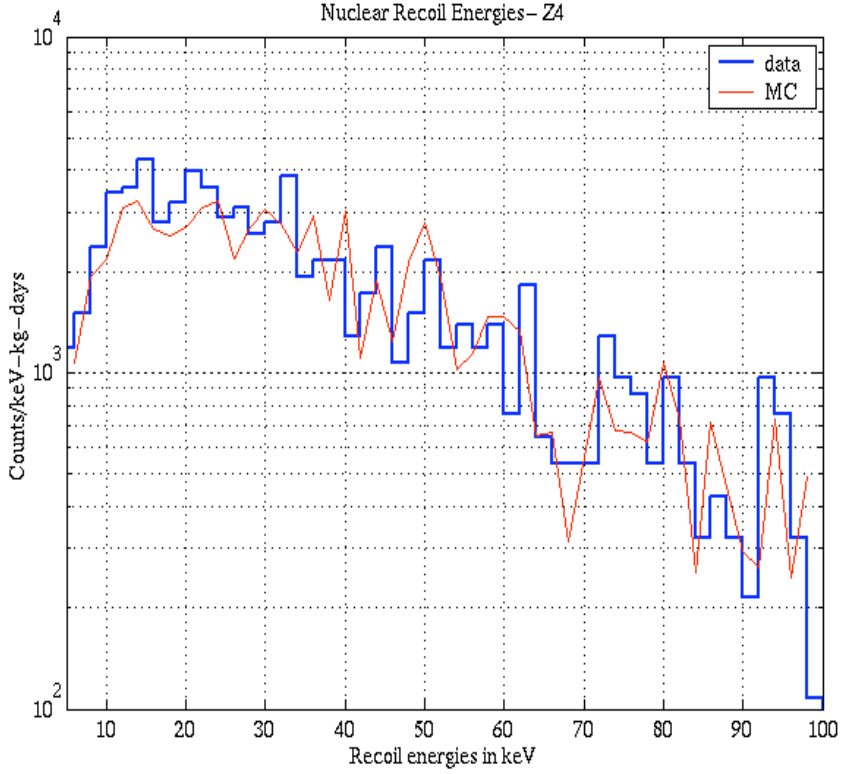
Excellent agreement between data and Monte Carlo

Nuclear recoil calibration: Ge&Si ZIPs w/ ^{252}Cf

Nuclear recoils in Ge ZIP



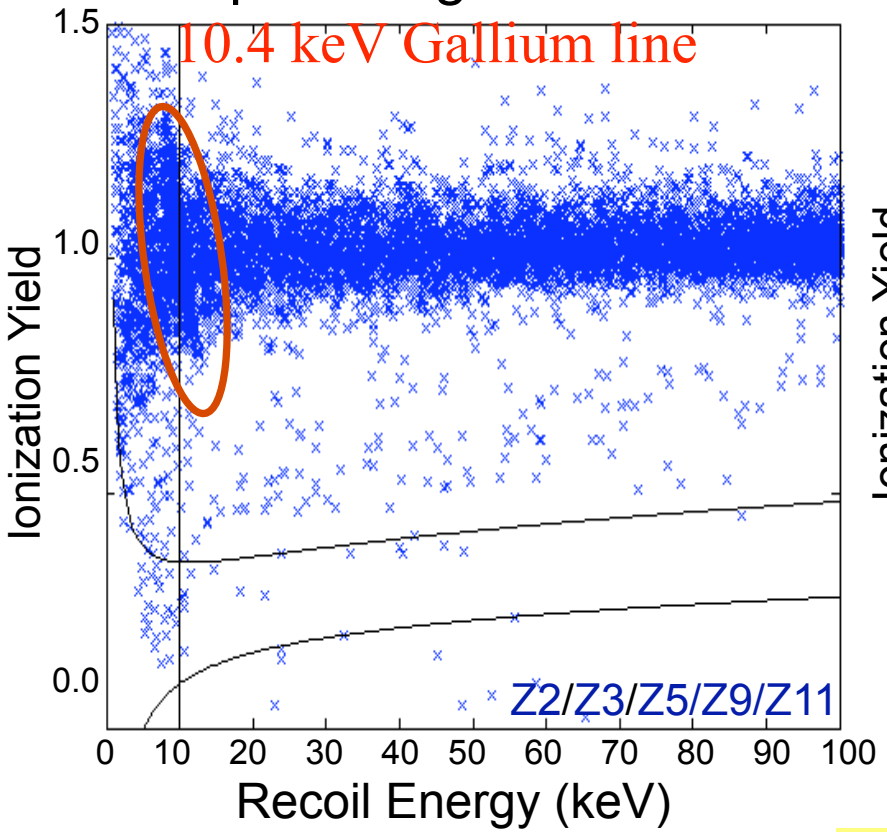
Nuclear recoils in Si ZIP



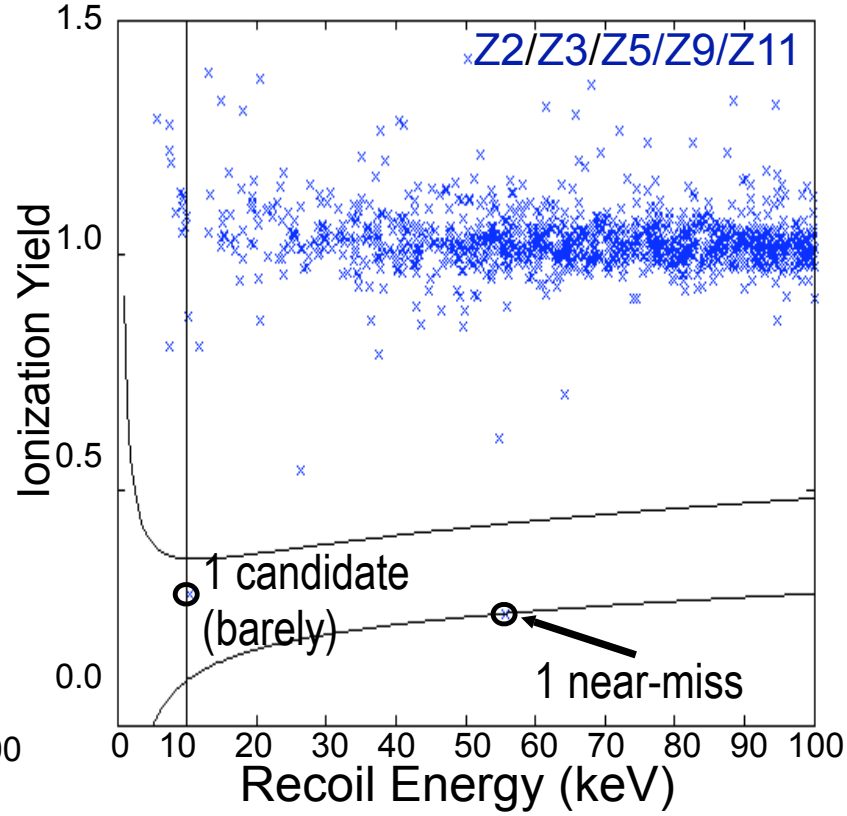
Excellent agreement between data and Monte Carlo

WIMP search data (5 Ge ZIPs ~53 kg-d)

Prior to phonon pulse shape timing cuts



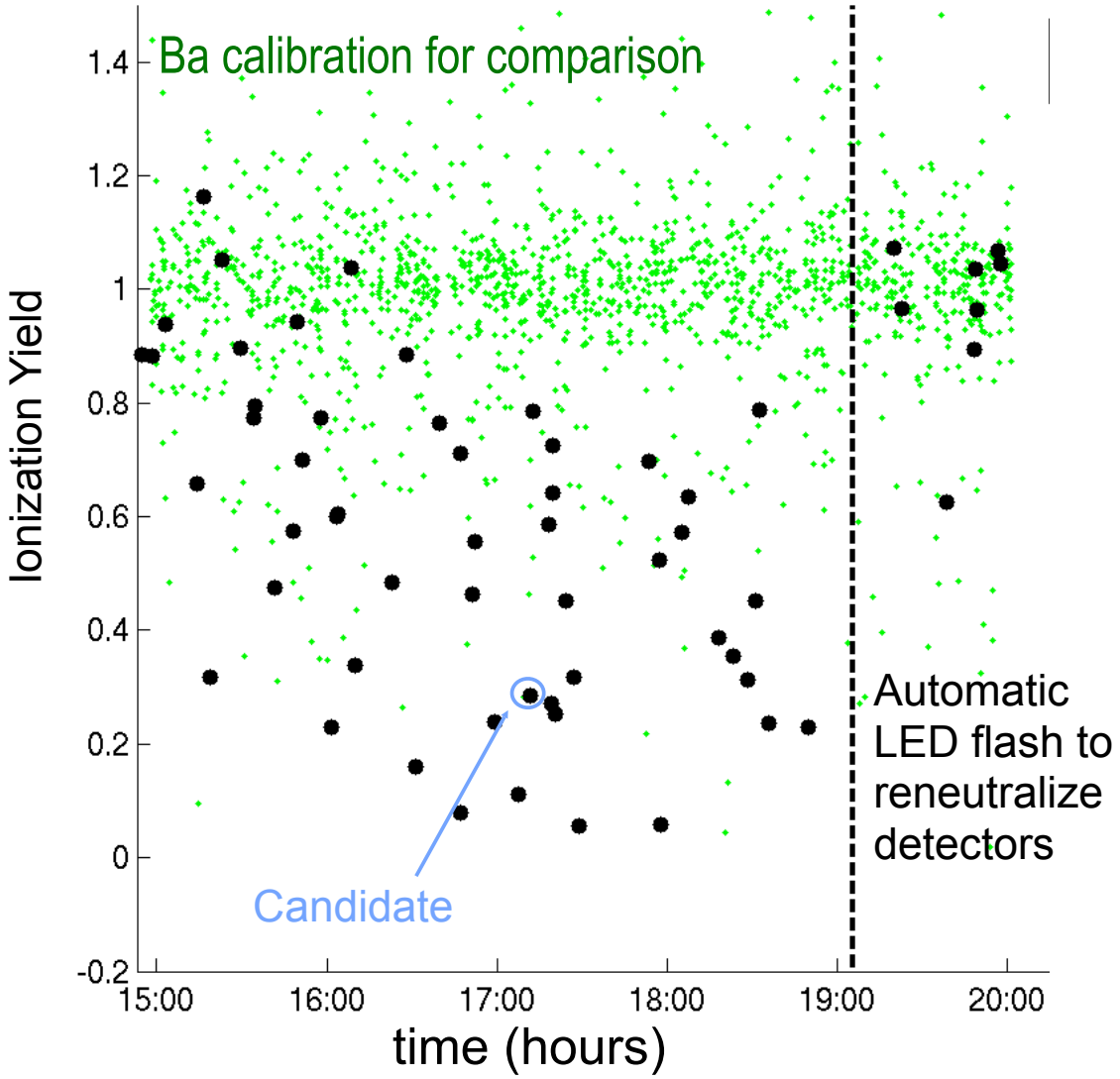
After timing cuts, which reject most electron recoils



Background ESTIMATE: 0.37 ± 0.20 (sys.) ± 0.15 (stat.) electron recoils, 0.05 recoils from neutrons expected

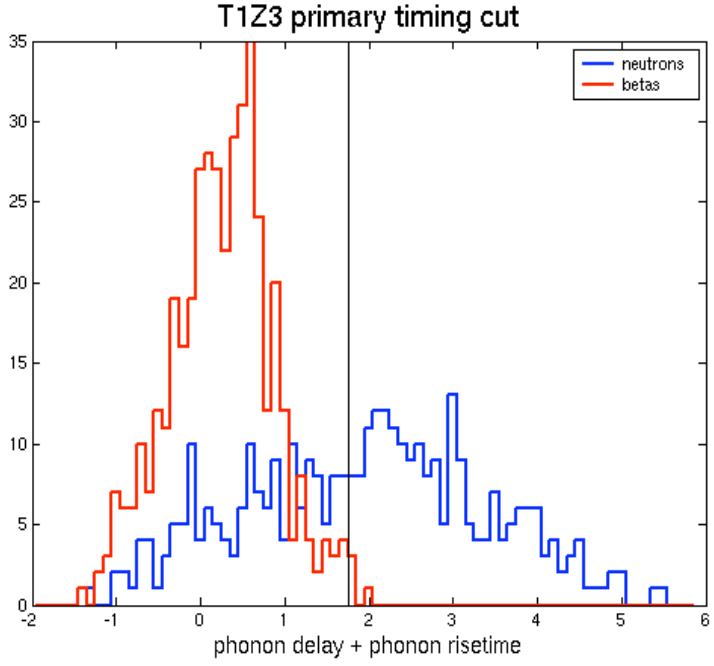
Is the Candidate Event Just Background?

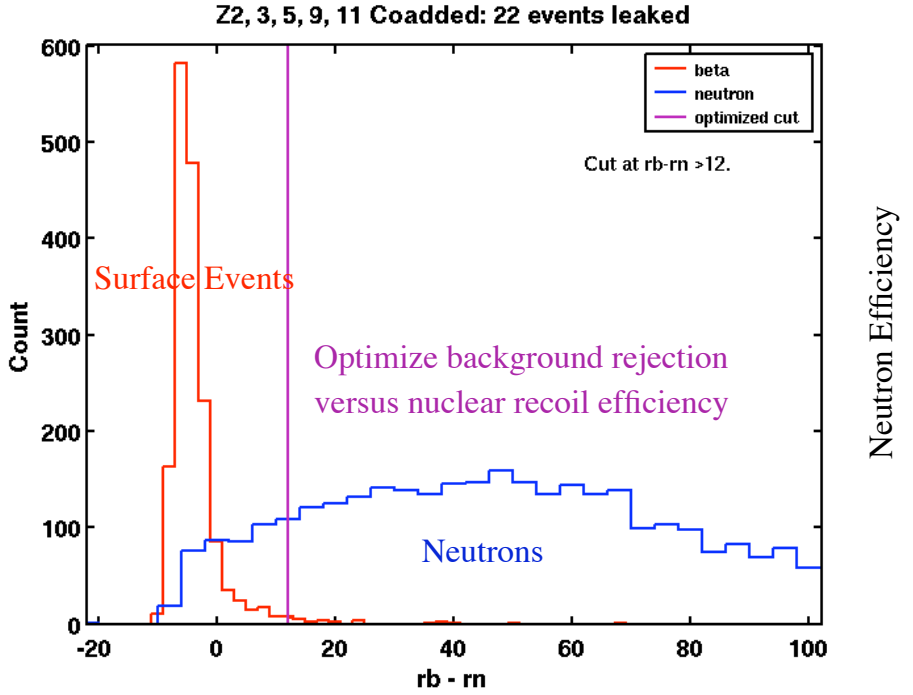
- Very likely so!
- Event occurred during run when its detector, Z11, suffered reduced ionization yield
  - Worst run for this detector
- In hindsight, our cuts on bad data periods for single detectors weren't strict enough
  - Some other detectors, without candidates, had similarly bad periods
- Will improve data quality screening for next run



Improvements in Surface Event Rejection

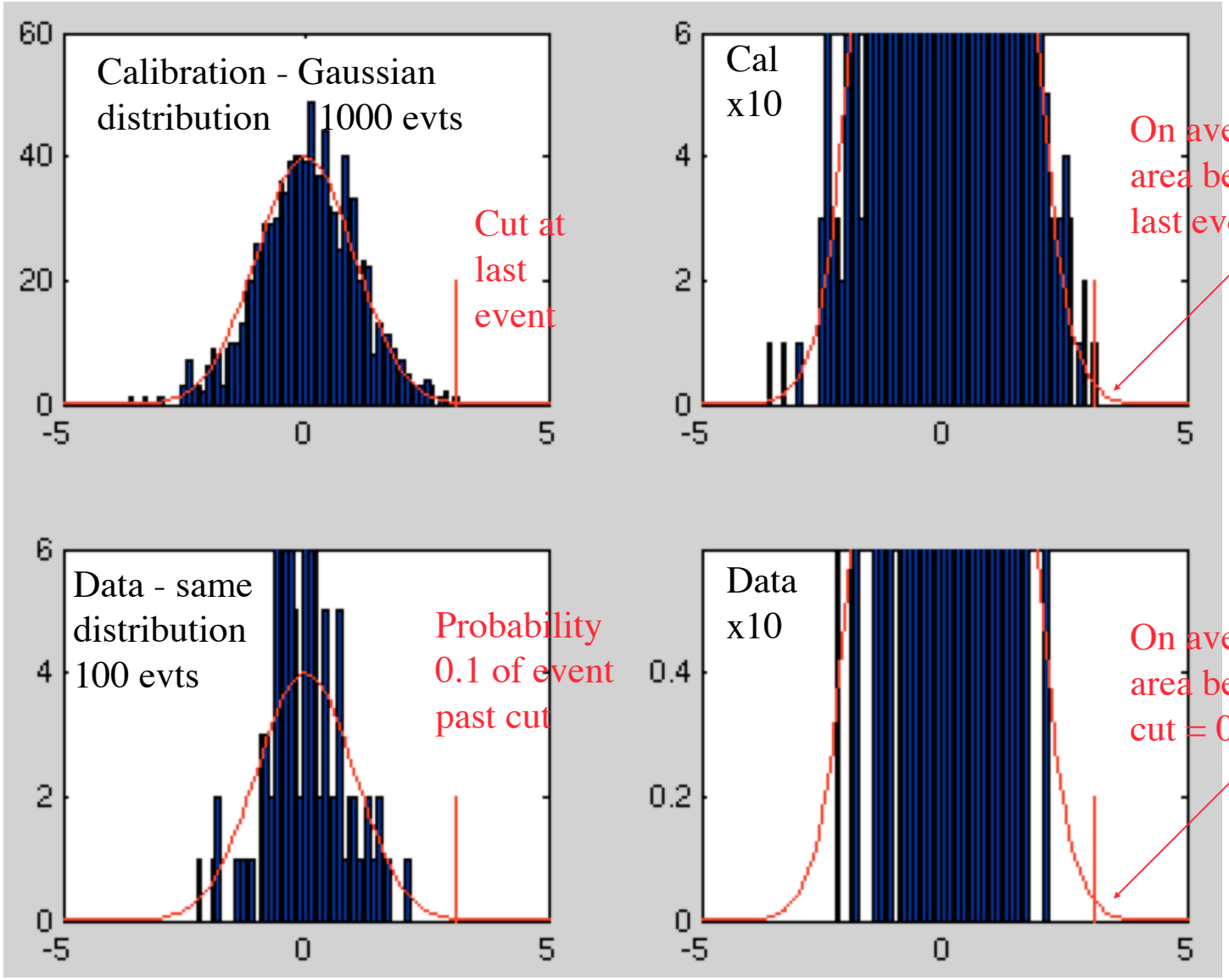
- Significant improvements in our analysis of phonon timing information
  - Surface event rejection improved by x3; kept pace with exposure increase!
  - Cuts are set from calibration data (blind analysis)
- We still have more discrimination power available as needed
  - Can continue to keep backgrounds < 1 event as more data accumulates
  - This is the real strength of CDMS detectors!





Chi-square (background pulse shape) - Chi-squared (neutron pulse shape)

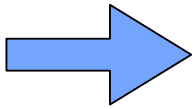
Simulation setting cut with calibration

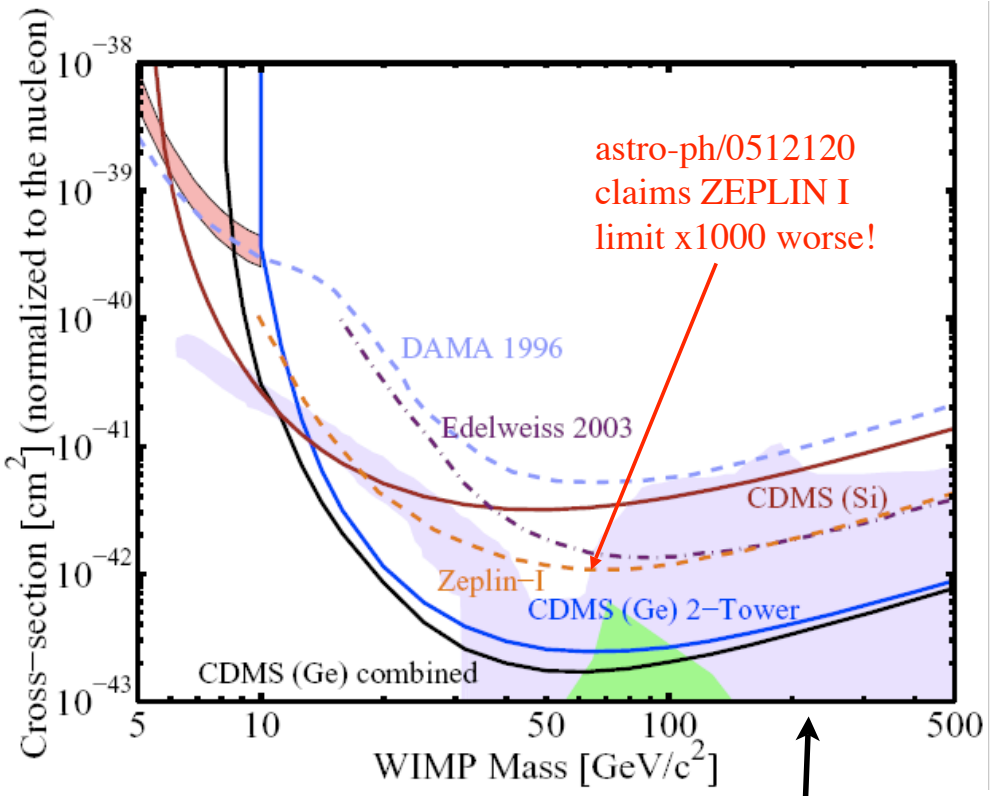


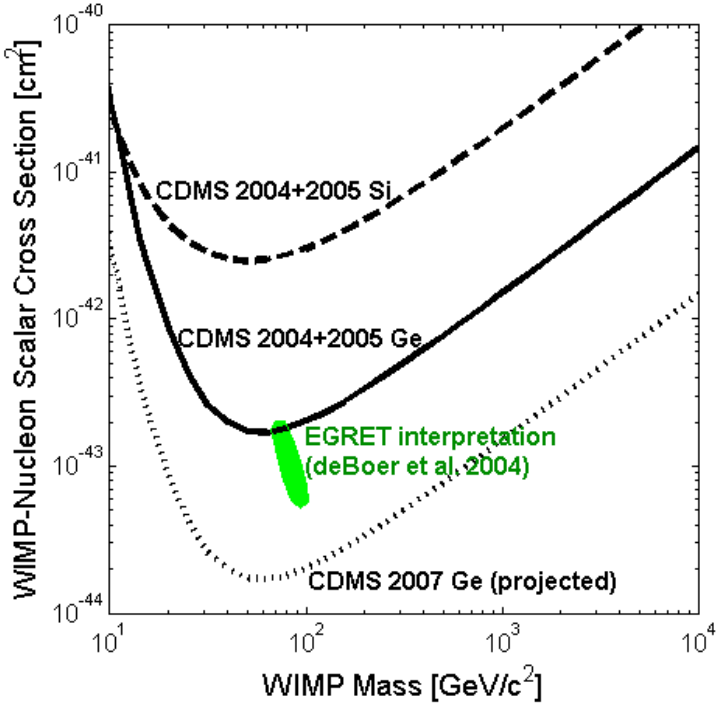
CDMS-II SI Results & Reach with 5 Towers

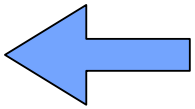
Experimental Motivations

DAMA/NaI
Bernabei et al.,
astro-ph/0307403









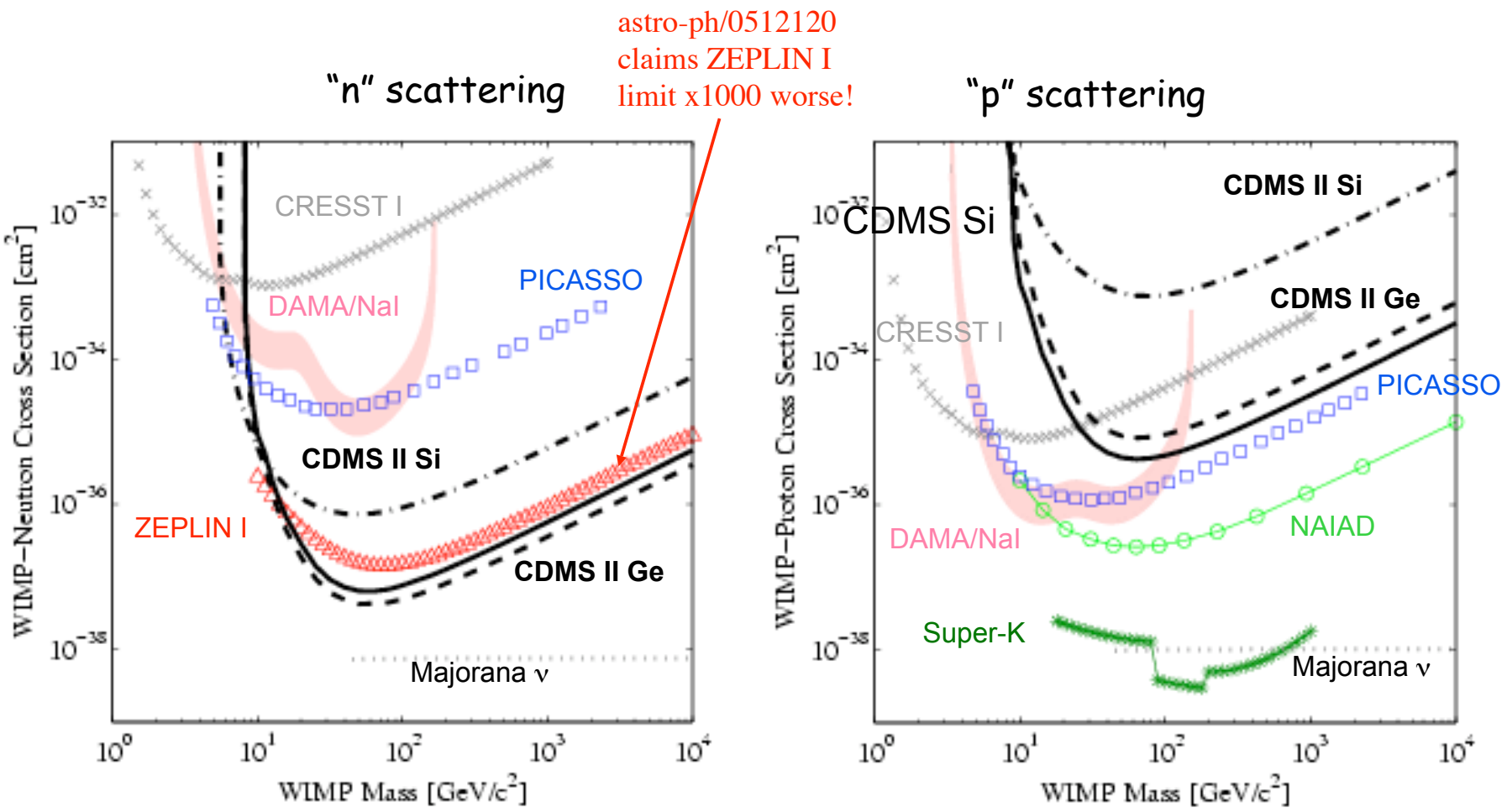
EGRET
de Boer et al., astro-ph/0412620

•Interpret EGRET gamma ray excess as DM annihilation

For further details see PRL 96, 011302 (2006)

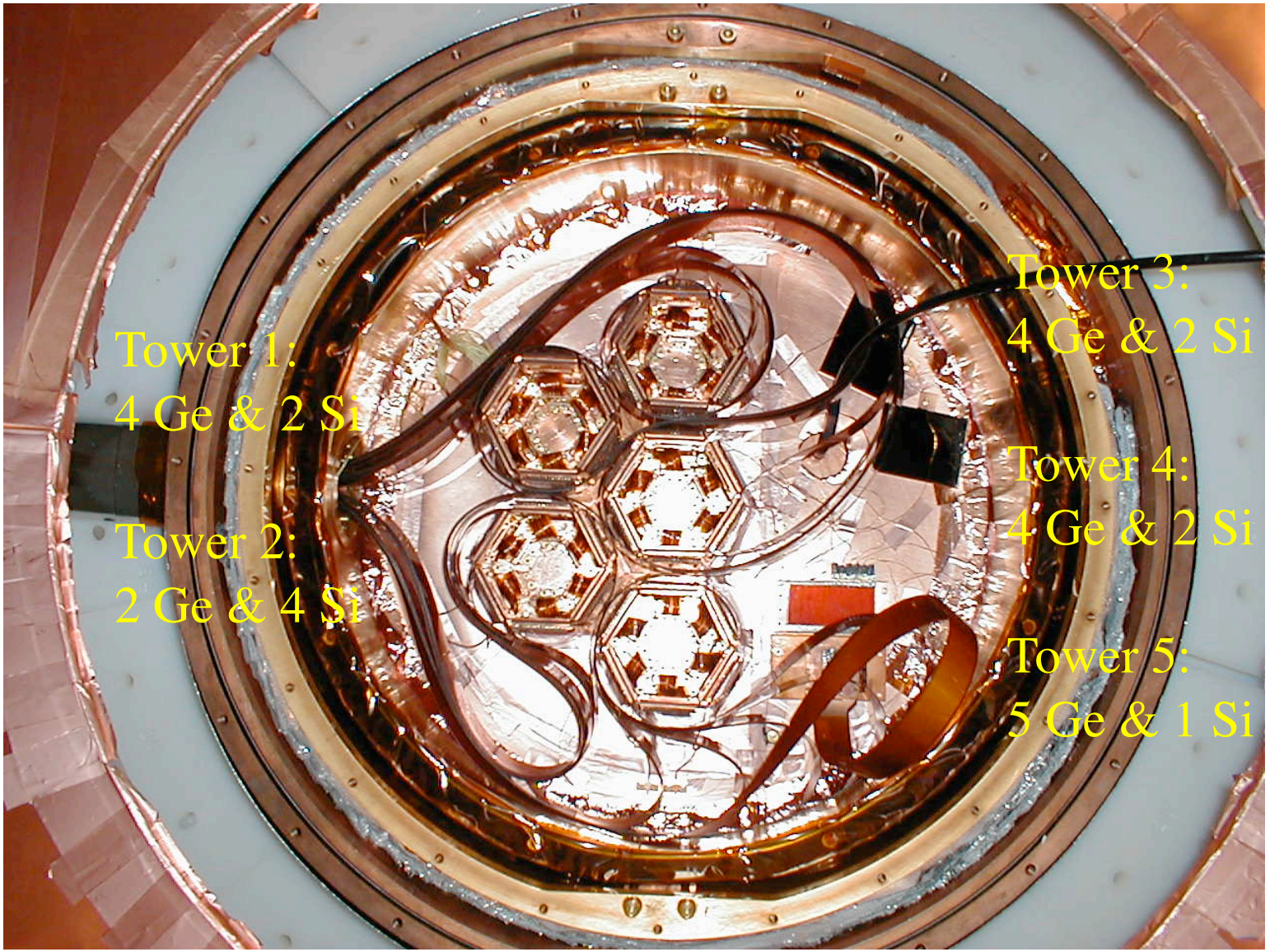
Spin Dependent WIMP limits

Spin-sensitivity from ^{73}**Ge** (J=9/2, 7.7%) and ^{29}**Si** (J=1/2, 4.7%)



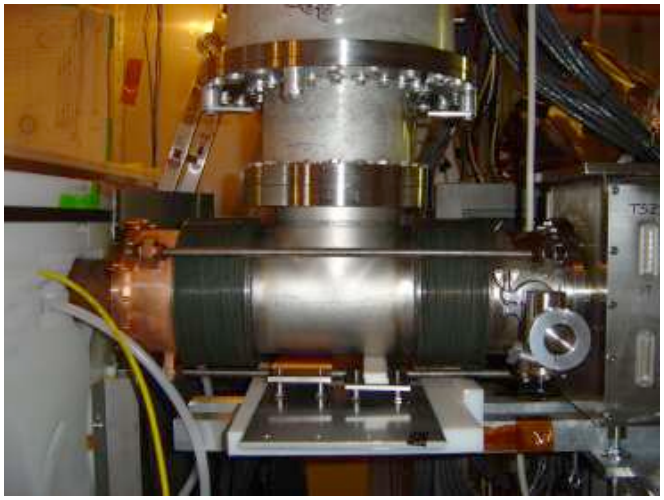
For further details see PRD D73, 011102 (2006)

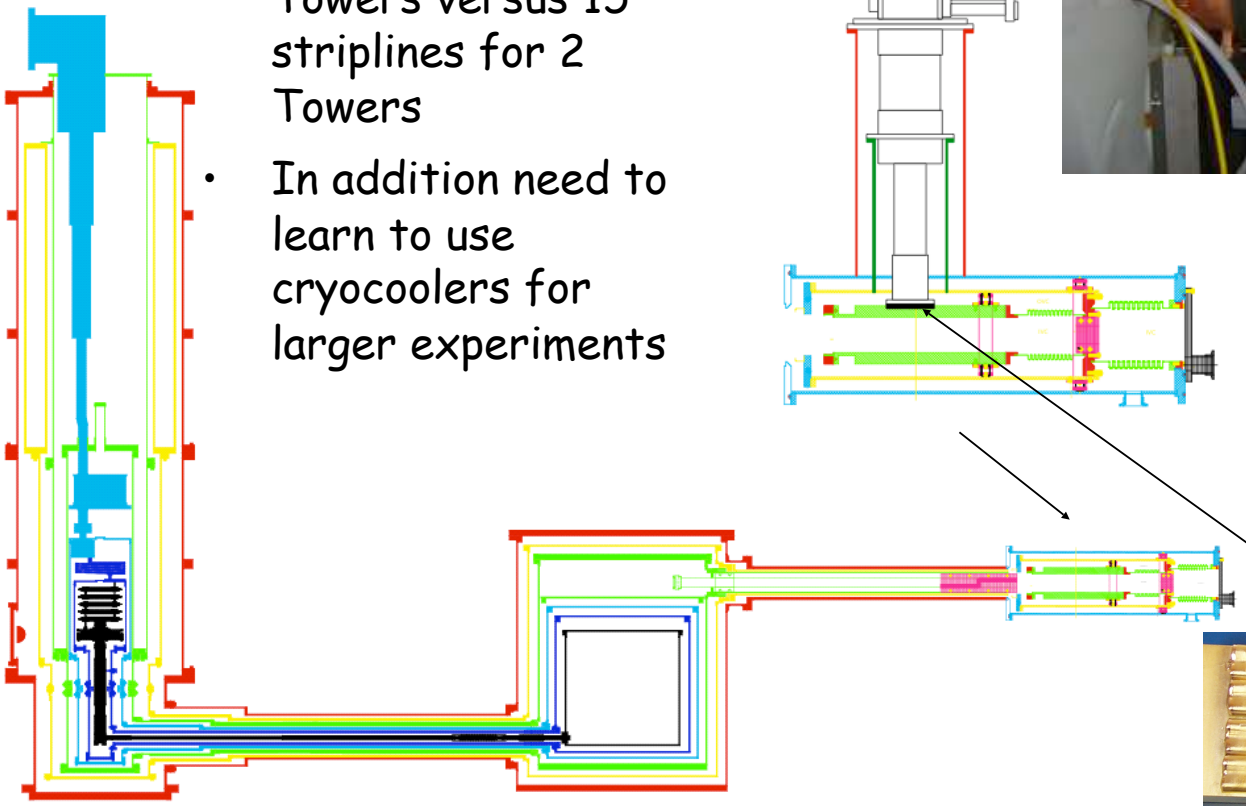
Five Towers now in Soudan



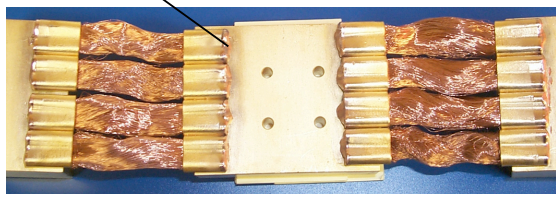
Added Cryocooler w/ Vibration Isolation

- We added cryocooler to estem to reduce additional heat load from 33 striplines for 5 Towers versus 15 striplines for 2 Towers
- In addition need to learn to use cryocoolers for larger experiments





• Add vibration isolation straps from Janis between 4K and cryocooler
• Tested successfully reduce vibrations by x100 during last run at Soudan



Current Status in Soudan Mine

- Just completed run demonstrating successful operation of cryocooler with vibration isolation.
- Vacuum system better than ever and dilution refrigerator reached base temperature < 20 mK.
- **But detectors remained at 170-200 mK** (spec < 50 mK).
- We have identified the likely cause to be increased heat through graphite thermal isolators, together with decreased conductance through Cu connections to DR.
- Thermal model consistent with all observations, and we are confirming with tests at UCB and Case facilities.
- **We have low-risk plans for completing CDMS-II science goals by end of calendar 2007 - standard cryogenic engineering.**

Proposal to DOE and NSF - May 06

SuperCDMS 25 kg Experiment

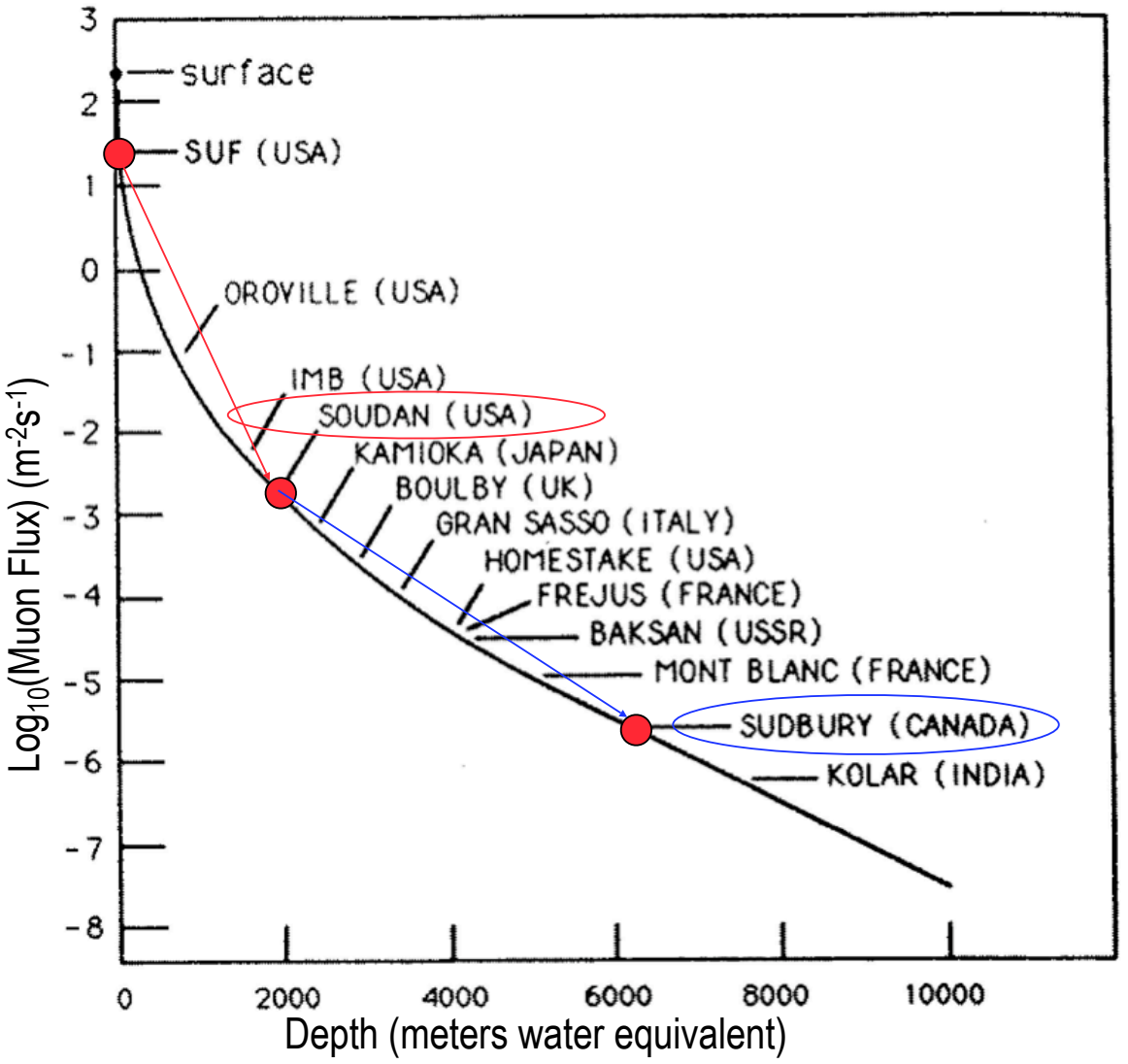
The SuperCDMS Collaboration

California Institute of Technology
Case Western Reserve University
Fermi National Accelerator Laboratory
Lawrence Berkeley National Laboratory
National Institute of Standards and Technology, Boulder
Queen's University, Canada
Santa Clara University
Stanford University
University of California at Berkeley
University of California at Santa Barbara
University of Colorado at Denver and Health Sciences Center
University of Florida
University of Minnesota

- Spokesperson: Blas Cabrera
  Co-spokesperon: Dan Akerib
  Project Manager: Dan Bauer
  Chair of Board: Bernard Sadoulet

SUF (17 mwe), Soudan (2090 mwe), & SNOLab (6060 mwe)

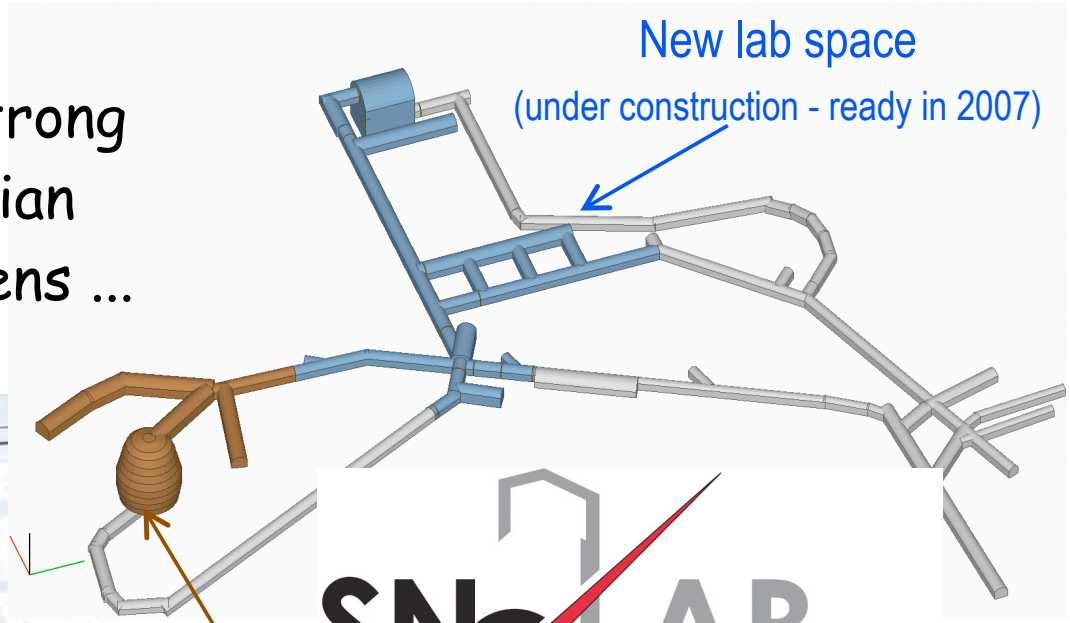
- At SUF
  - 17 mwe
  - 0.5 n/d/kg
- At Soudan
  - 2090 mwe
  - 0.6 n/y/kg
- At SNOLab
  - 6060 mwe
  - 1 n/y/ton



SuperCDMS at SNOLab

★ SuperCDMS is approved to be sited at SNOLab

★ We have received strong interest from Canadian collaborators - Queens ...

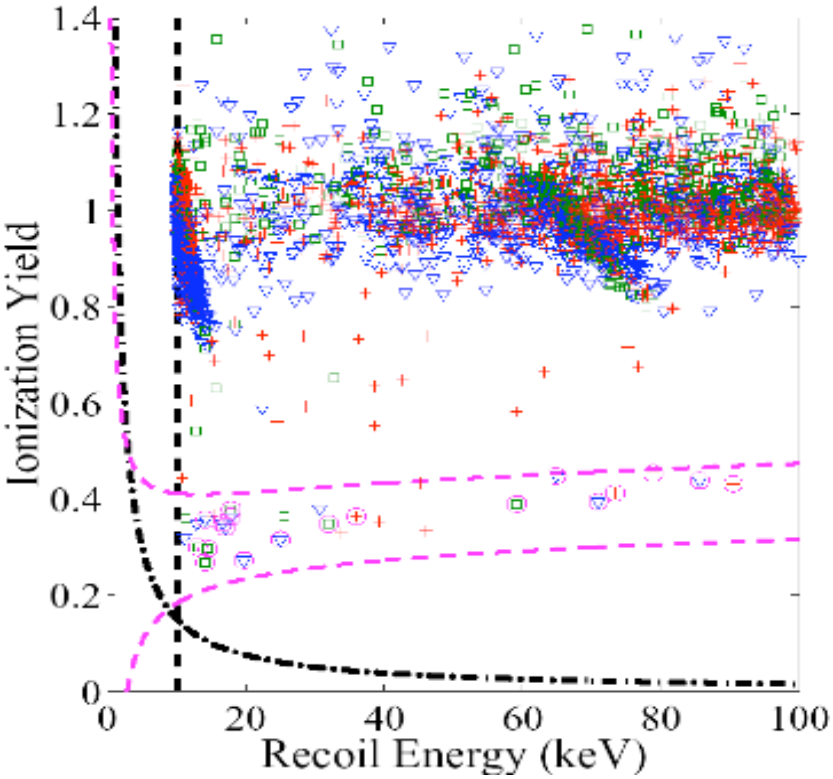


SNOLAB
MINING FOR KNOWLEDGE
CREUSER POUR TROUVER... L'EXCELLENCE
Sudbury, Ont. CA

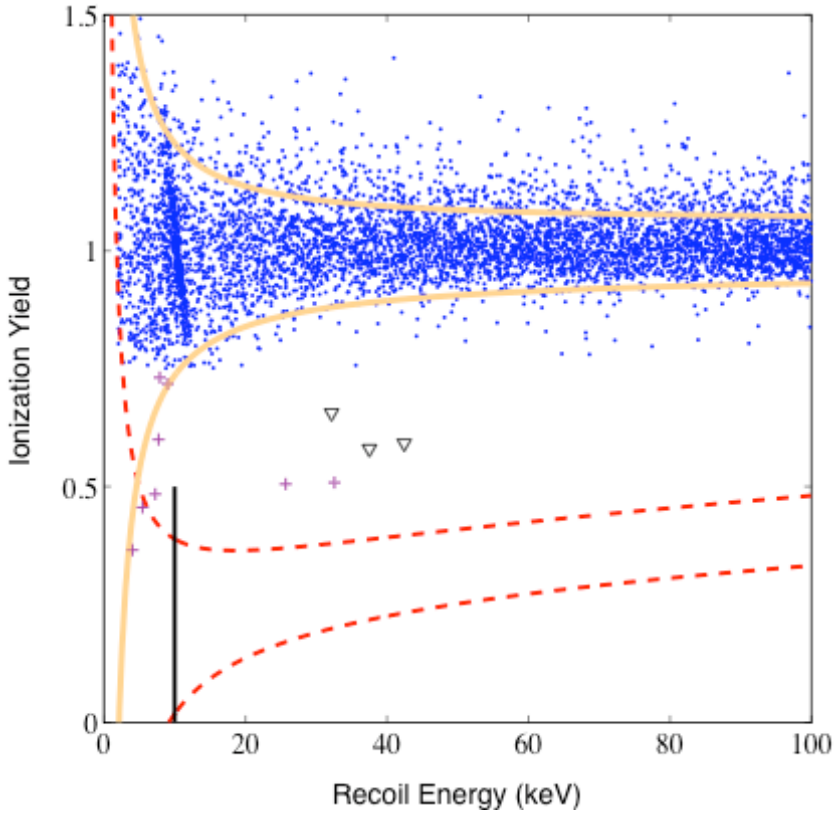
Sudbury Neutron Obs.

ST1&2 Soudan -> SNOLab like Tower 1 SUF -> Soudan

- Tower 1 (4 Ge & 2 Si) at SUF then at Soudan



19 neutron events at SUF



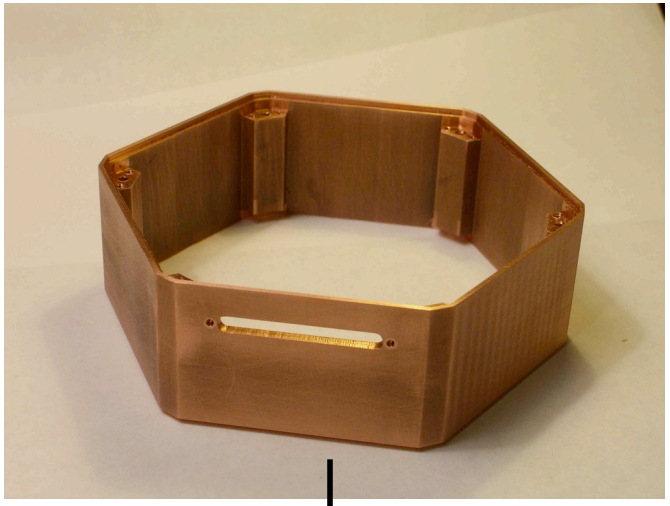
0 events at Soudan

Baseline detector for SuperCDMS

CDMS-II ZIPs:

3" dia x 1 cm => 0.25 kg of Ge

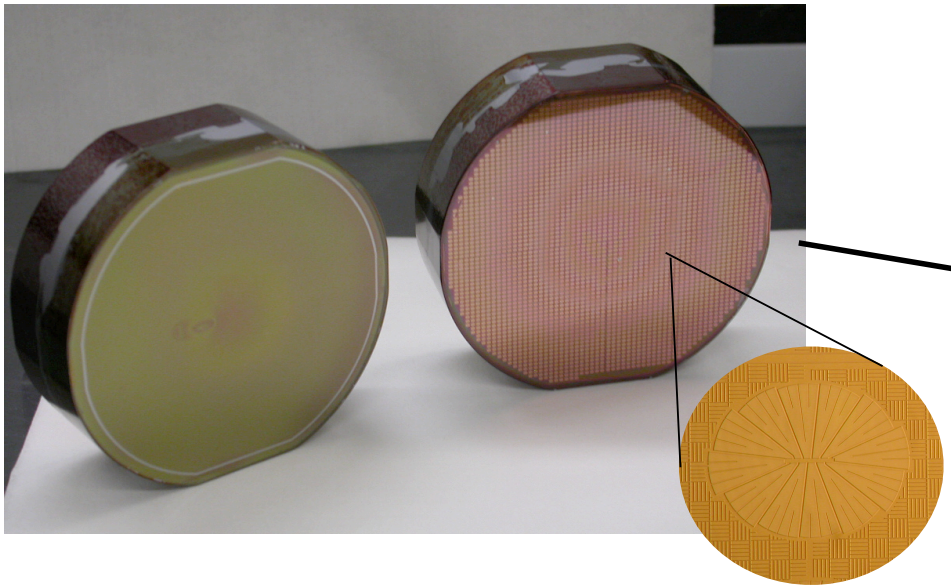
Existing ZIPs

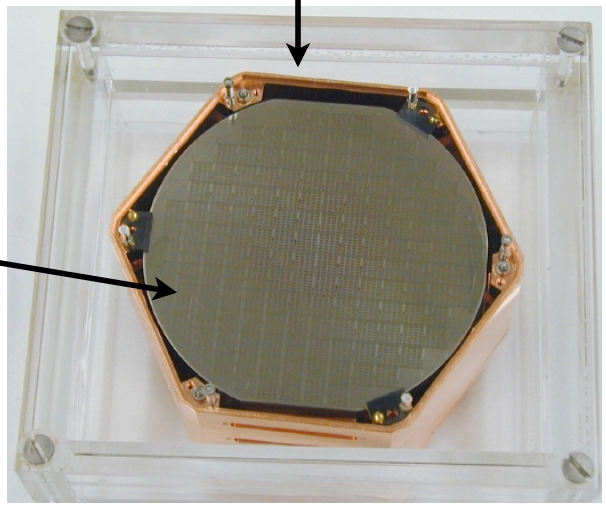


SuperCDMS ZIPs:

3" dia x 1" => 0.64 kg of Ge

ZIPs for SuperCDMS

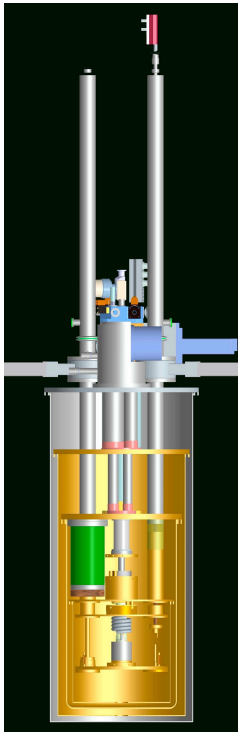


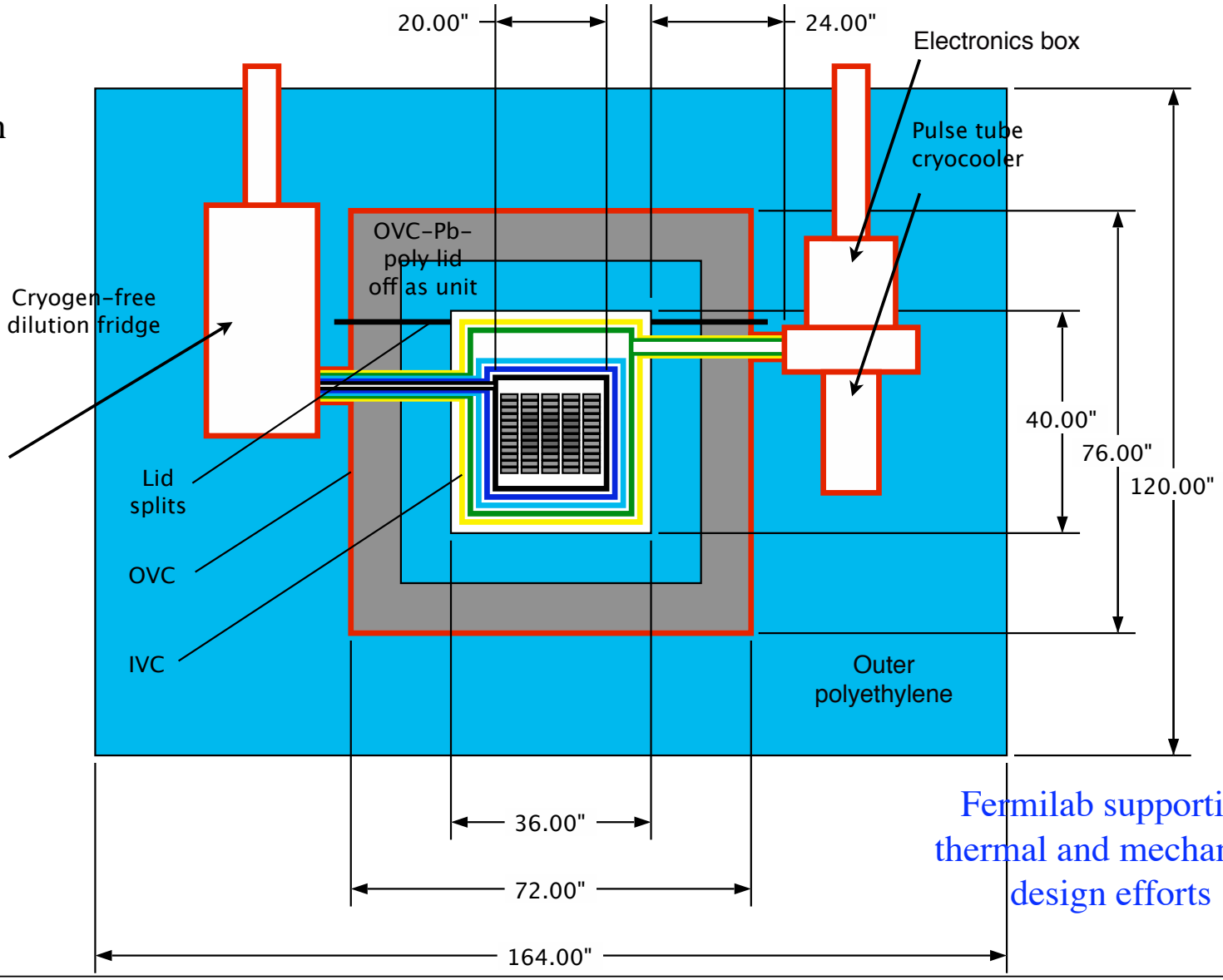


Completed 1" thick Si ZIP

Schematic of new 'SNObox'

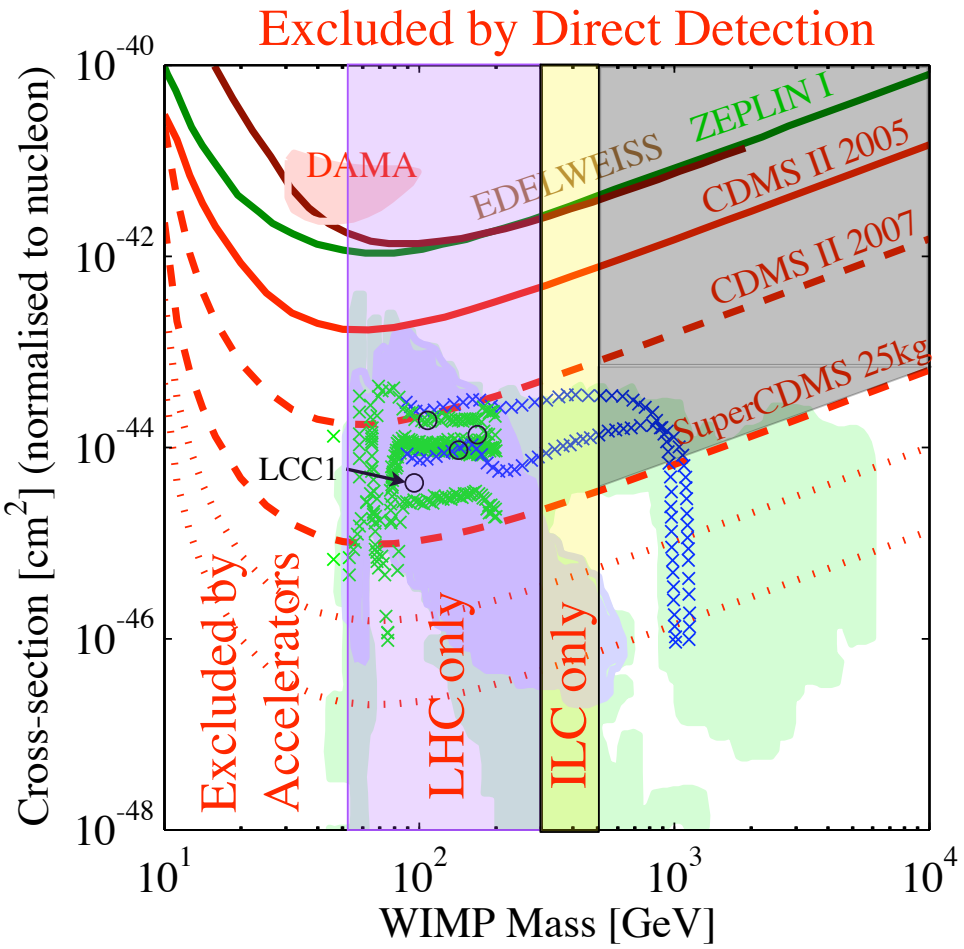
Exploring cryocooler system with little or no cryogen servicing



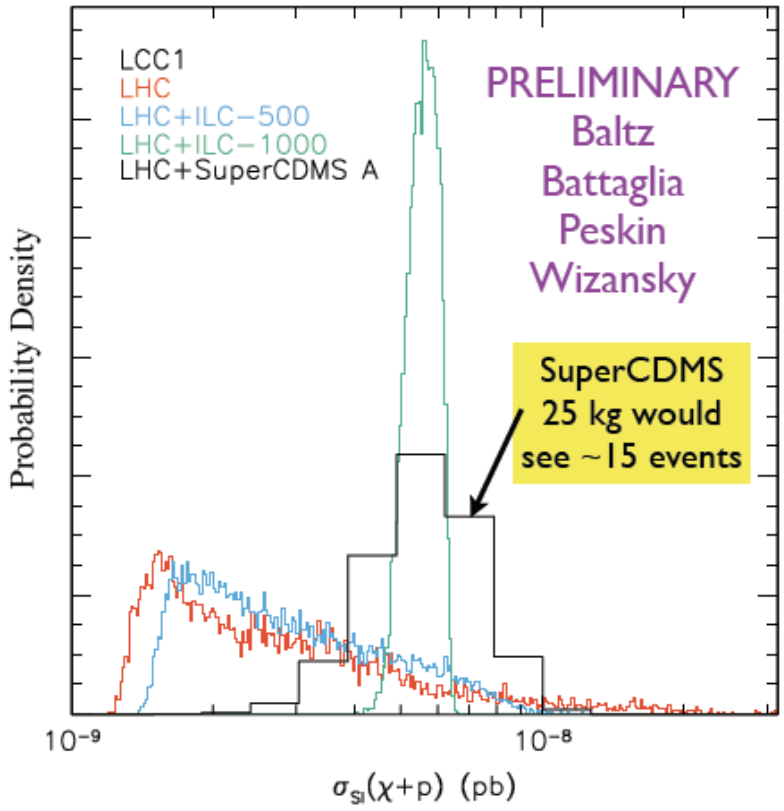


Fermilab supporting thermal and mechanical design efforts

Does the LHC supplant SuperCDMS?



Accelerators are *mass-limited*
⇒ spectral info, but often can't see LSP or deduce its relic density



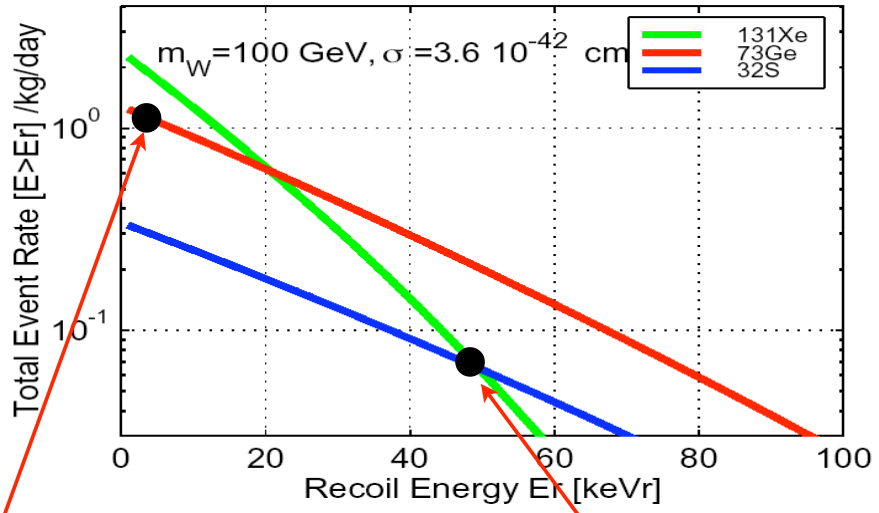
CDMS is *cross section-limited*
⇒ TeV WIMPs detectable, direct connection to cosmology

Compare with Competition

- NaI - annual modulation with no discrimination (<6 pe/keV)
  - DAMA signal is suspect because near threshold (systematics)
  - LIBRA - 250 kg new installation (still no discrimination)
- Cryogenic technologies - lowest intrinsic threshold (10^6 phon/keV)
  - (Super)CDMS Ge & Si ionization + phonon + timing (1 event every 70 kg-d)
  - EDELWEISS Ge thermal + ionization (no timing) - (1 event every 7 kg-d)
  - CRESST $CaWO_3$ thermal + scintillation (no light for W)
- Liquid Xe & Ar - intrinsically high threshold (~1 pe/keV)
  - ZEPLIN I (uncalibrated result) & XMASS scintillation
  - XENON scintillation + ionization (need demo of threshold & stability)
  - WArP scintillation + ionization + risetime - (8 events in 40 kg-d)
- Superheated liquids - no energy resolution (counting)
  - COUPP CF_3Br & CF_3I (need demo of stability)
- TPC DRIFT - good for directionality (near term not enough mass)

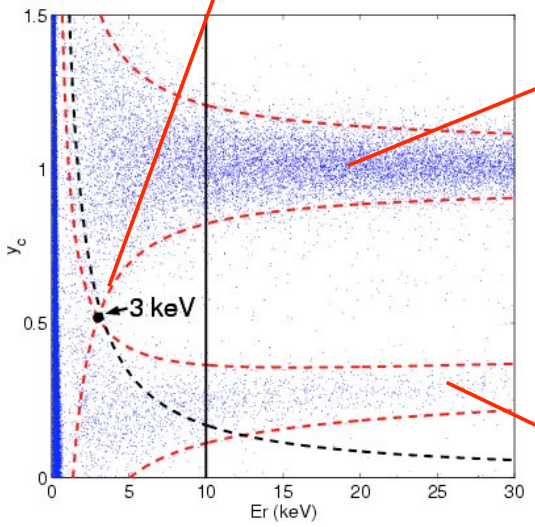
Threshold comparison and importance

Best resolution from sub-K experiments allows better discovery potential



In the end, the tails of the background distributions determine the sensitivity

Best CDMS Ge ZIP

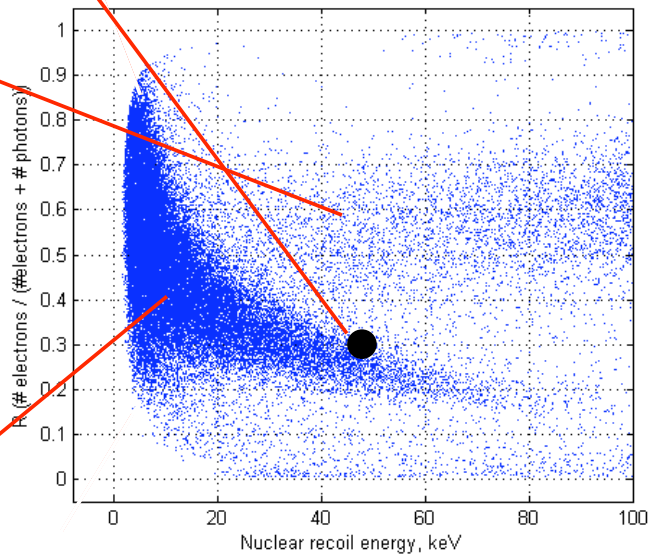


gammas

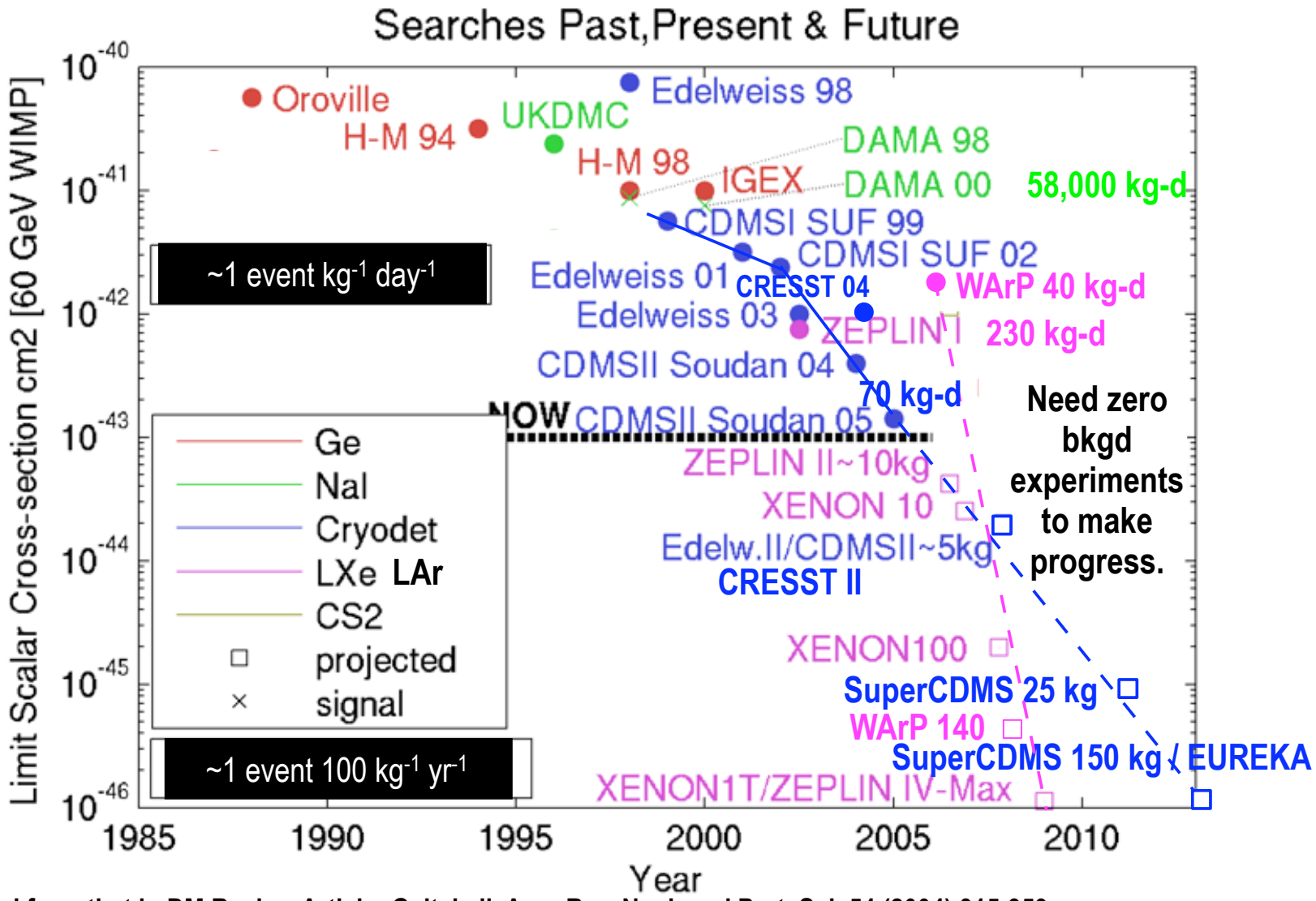
counting statistics

n-recoils

XENON Prototype



DM Direct Search Advances (2006)



Plot updated from that in DM Review Article: Gaitskell, Ann. Rev. Nucl. and Part. Sci. 54 (2004) 315-359

Conclusion

- TES detectors are now a well established technology and are at the forefront of sensitivity for all energy scales including optical, x-ray and dark matter searches.
- Soudan Towers 1&2 lead field by x10 - spin-independent limits PRL 2006 and spin dependent limits PRD RC 2006.
- Soudan Towers 1-5 will start mid-2006 and run through 2007 for an additional x10 improved sensitivity.
- Strong science case for ton scale direct detection major project(s), so we endorse Dark Matter SAG as input to P5. Should have more than one technology and target material.
- WE ARE READY TO PROCEED WITH THE SuperCDMS 25 kg EXPERIMENT NOW, CAN KEEP COSTS RELIABLY BELOW THE MAJOR PROJECT LEVEL, AND WE CAN MAINTAIN THE US LEAD IN THIS RESEARCH WHICH IS COMPLEMENTARY TO LHC AND FUTURE ILC.