Direct Detection Sub-K Experiments

P5 Meeting at Fermilab

April 19, 2006

Blas Cabrera

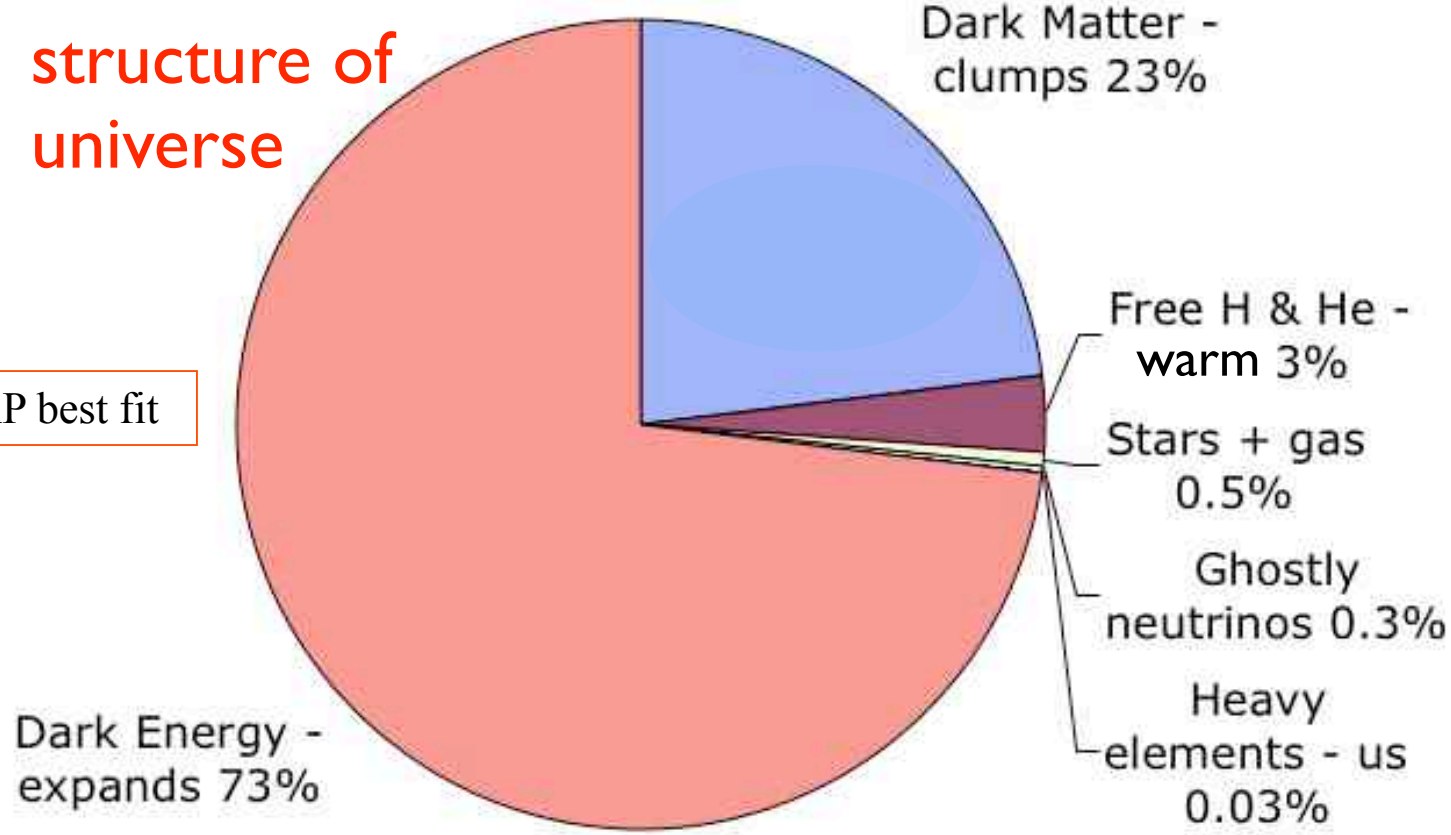
Spokesperson SuperCDMS Collaboration

- Overview and endorsement of Dark Matter SAG for input to P5
- CDMS-II results and status of five Tower run
- Proposals to proceed with SuperCDMS 25 kg experiment
  - NSF MRI proposal for cryosystem ($2M - FY07)
  - Two SuperTowers at Soudan ($2M DOE/$2M NSF - FY07)
  - SuperCDMS 25 kg at SNOLab ($5M DOE/$5M NSF -FY08)
- SuperCDMS plans towards future ton-scale experiments
- EDELWEISS and CRESST status & plans leading to EUREKA
- Comparisons with liquid experiments: XENON, WArP, COUPP
- Conclusions

Composition of the Cosmos

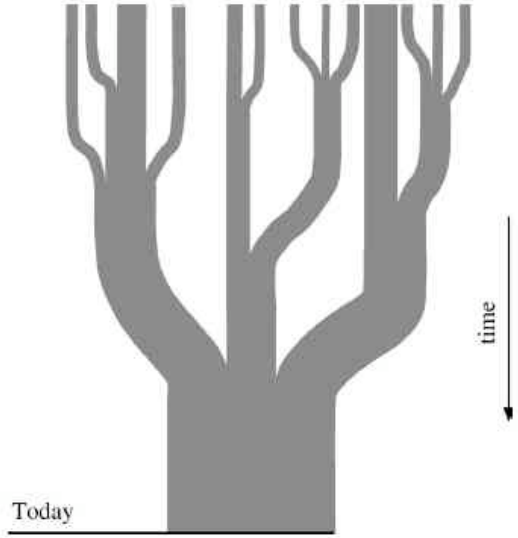
Dark matter forms structure of universe

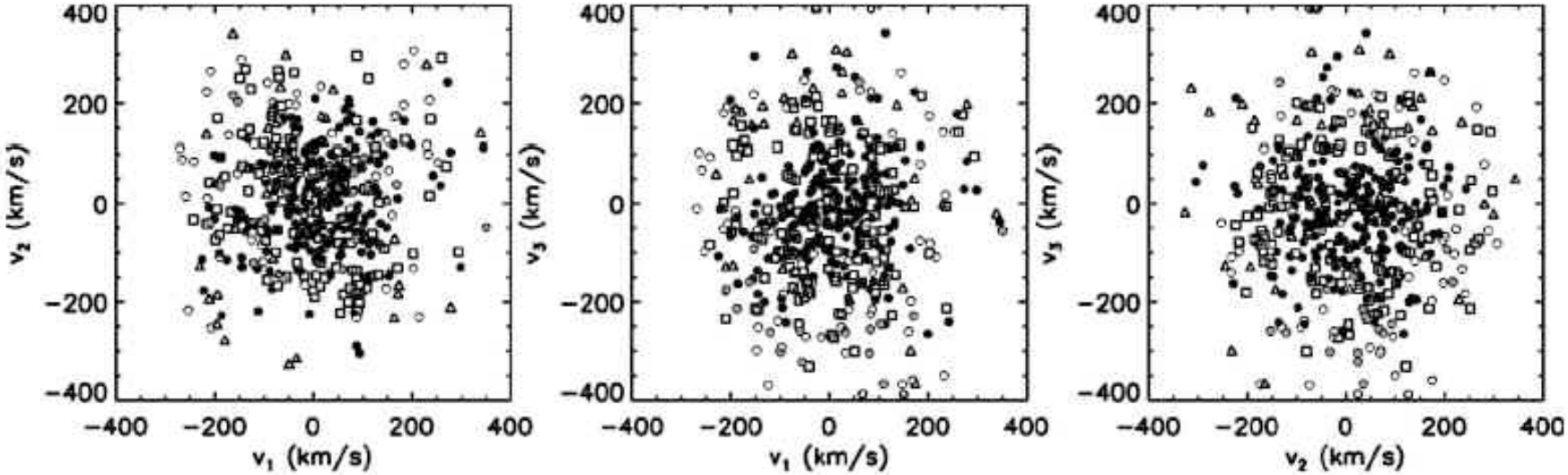
WMAP best fit



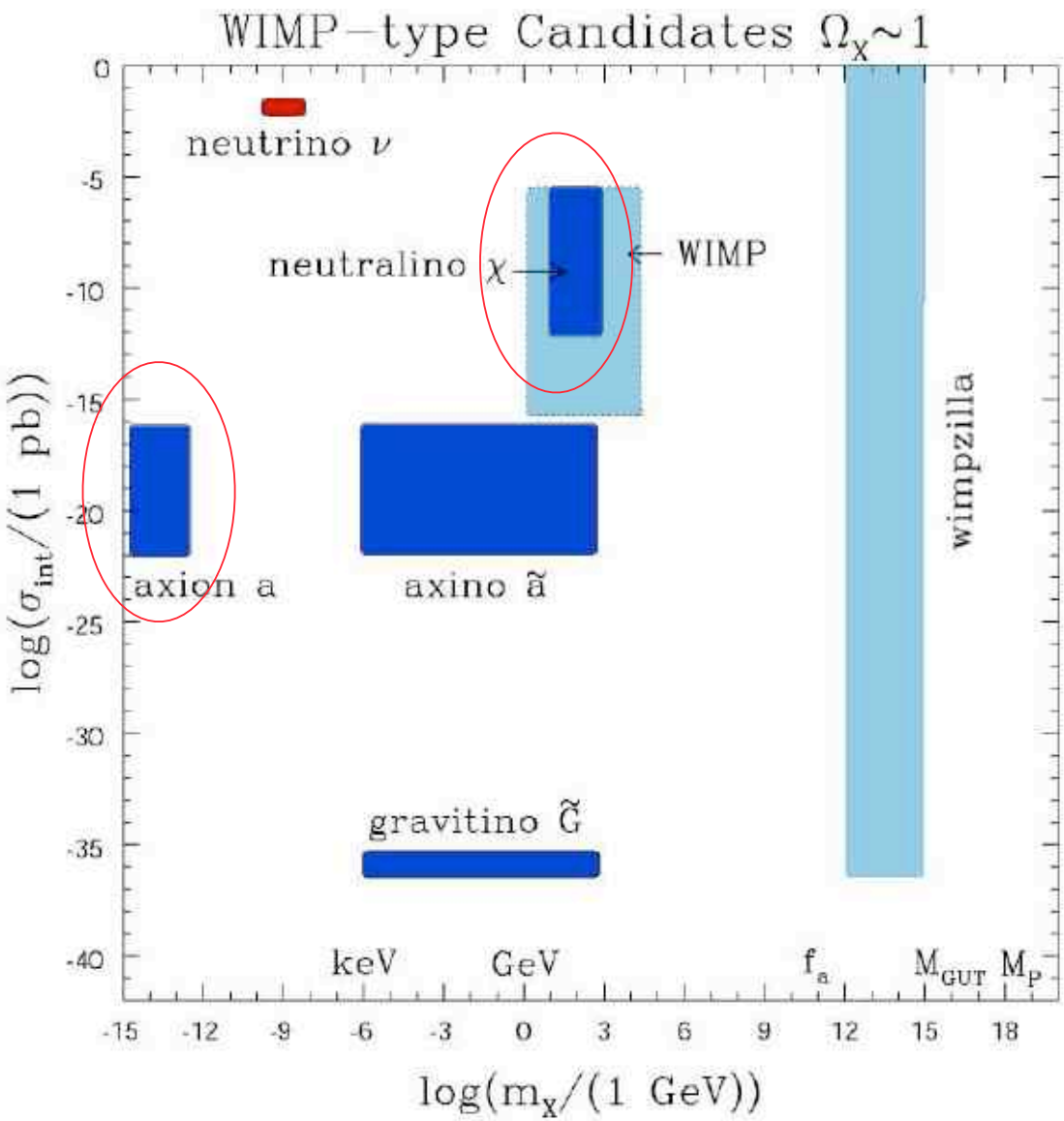
Numerical simulations for DM Halos

- The phase-space structure of a dark-matter halo: Implications for dark-matter direct detection experiments, e.g., A. Helmi, S. White, and V. Springel
  PRD 66, 063502 (2002)
- Solar system moves with respect to zero mean velocity halo at 220 km/s





What is the dark matter?

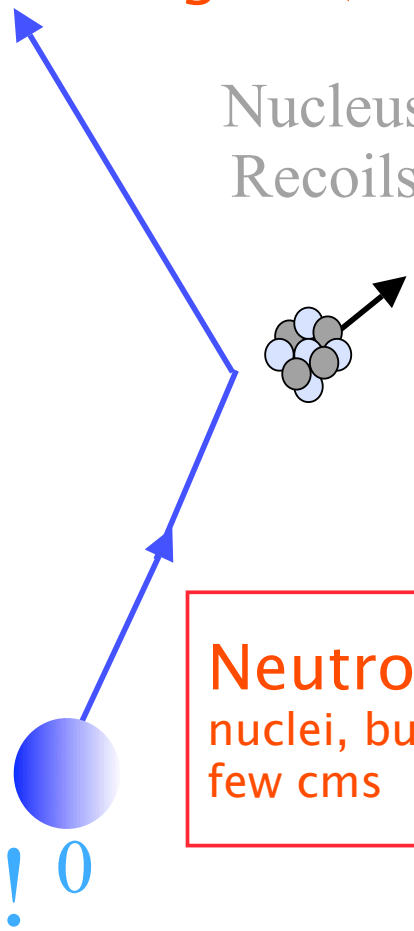


- neutrino ν – hot DM
- neutralino χ
- "generic" WIMP
- axion a
- axino $\tilde{a}$
- gravitino $\tilde{G}$
- wimpzilla,. . .

L. Roszkowski

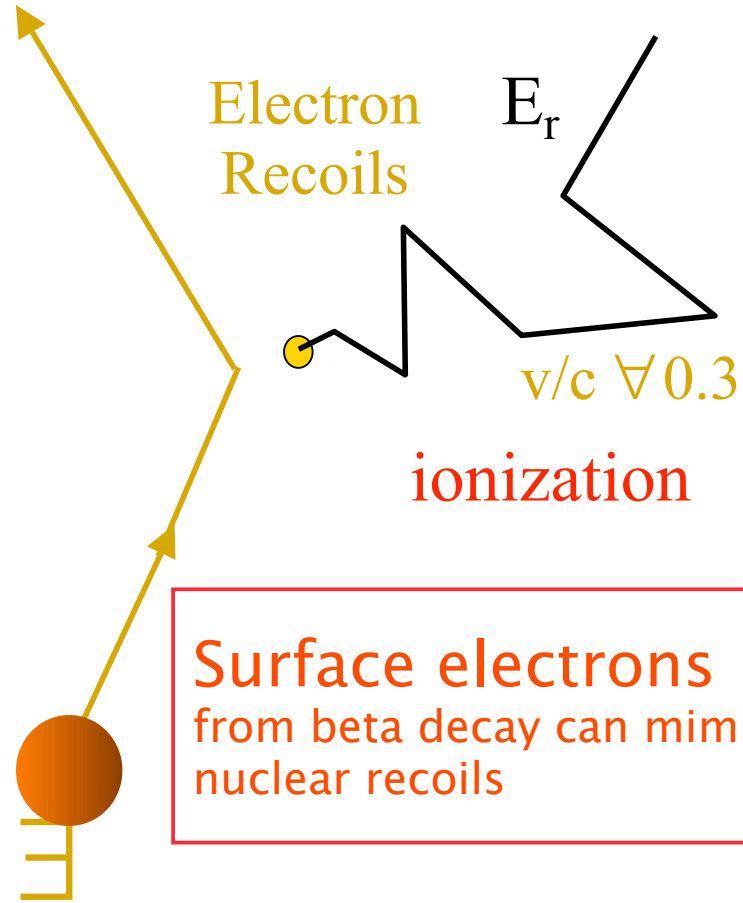
The Signal and Backgrounds

Signal (WIMPs)



Neutrons also interact with nuclei, but mean free path a few cms

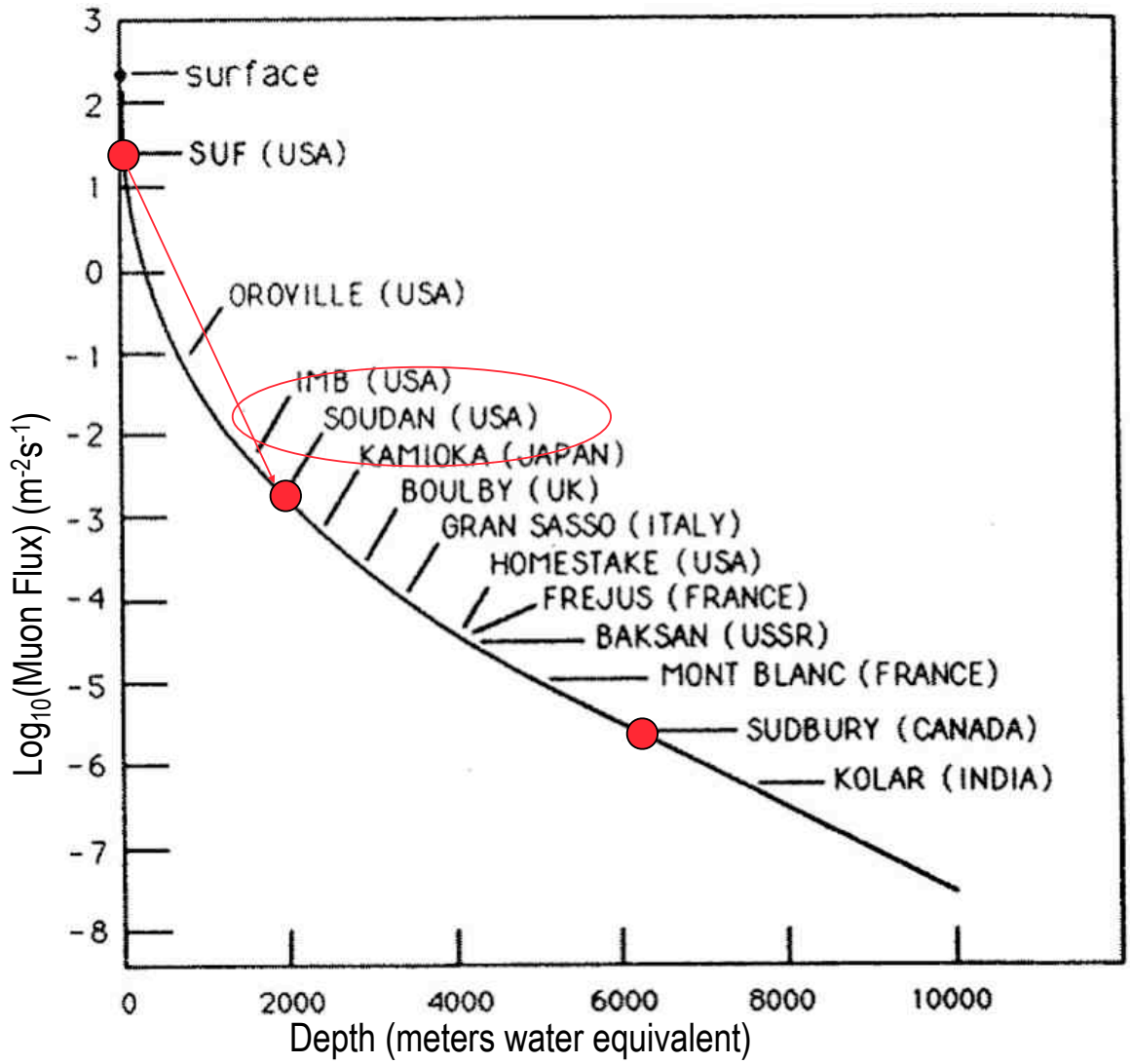
Background (gammas)



Surface electrons from beta decay can mimic nuclear recoils

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 Collaboration

PRL **96,** 011302 (2006) PHYSICAL REVIEW LETTERS week ending 13 JANUARY 2006

Limits on Spin-Independent Interactions of Weakly Interacting Massive Particles with Nucleons from the Two-Tower Run of the Cryogenic Dark Matter Search

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(CDMS Collaboration)

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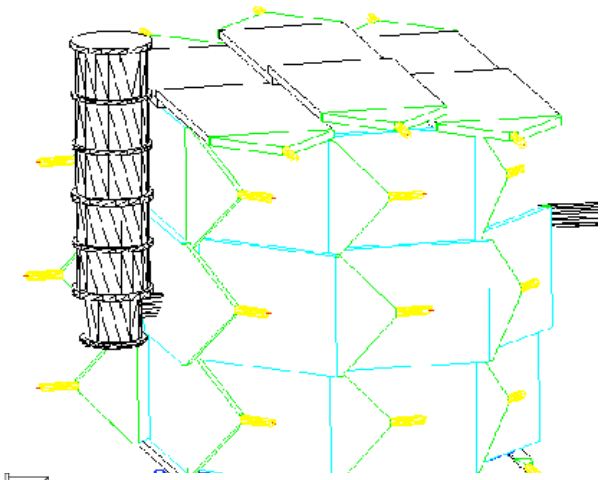
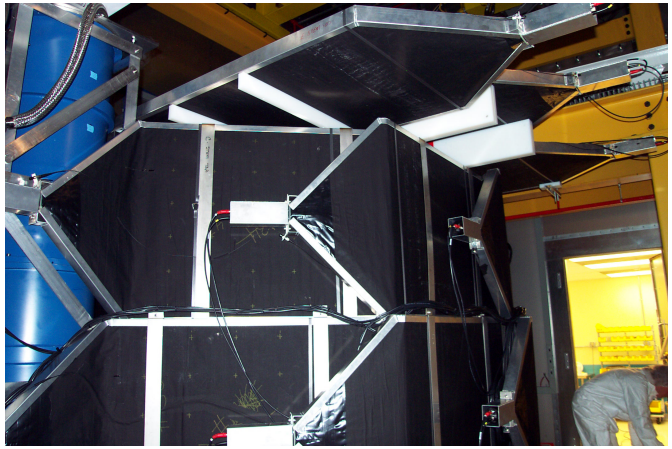
(Received 9 September 2005; published 3 January 2006)

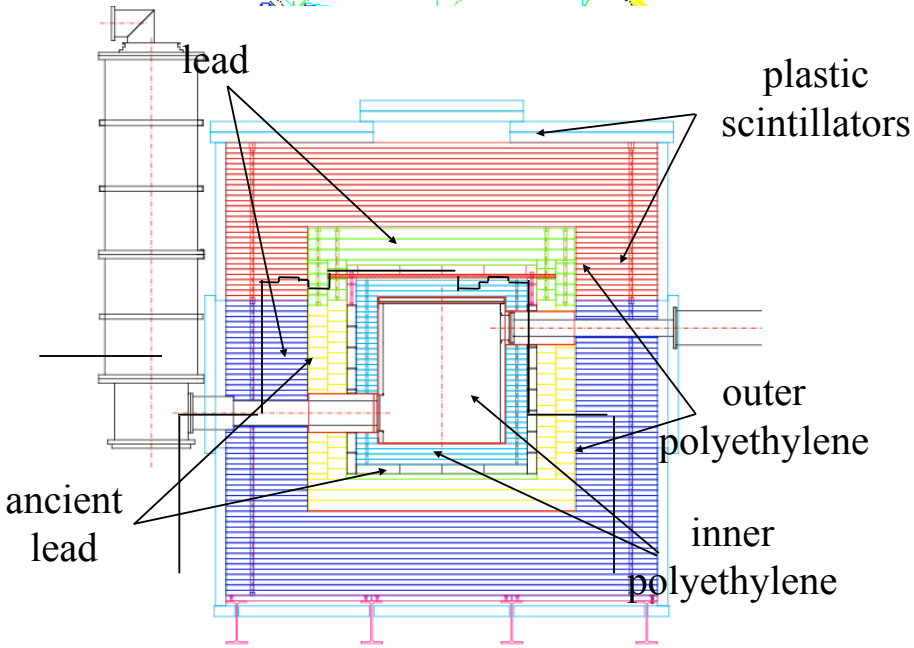
We report new results from the Cryogenic Dark Matter Search (CDMS II) at the Soudan Underground Laboratory. Two towers, each consisting of six detectors, were operated for 74.5 live days, giving spectrum-weighted exposures of 34 (12) kg d for the Ge (Si) targets after cuts, averaged over recoil energies 10–100 keV for a weakly interacting massive particle (WIMP) mass of 60 GeV/c^2. A blind analysis was conducted, incorporating improved techniques for rejecting surface events. No WIMP signal exceeding expected backgrounds was observed. When combined with our previous results from Soudan, the 90% C.L. upper limit on the spin-independent WIMP-nucleon cross section is 1.6×10^{-43} cm^2 from Ge and 3×10^{-42} cm^2 from Si, for a WIMP mass of 60 GeV/c^2. The combined limit from Ge (Si) is a factor of 2.5 (10) lower than our previous results and constrains predictions of supersymmetric models.

- Spokesperson:
  Bernard Sadoulet
- Co-spokesperson:
  Blas Cabrera
- Project Manager:
  Dan Bauer
- Executive Com Chair
  David Caldwell

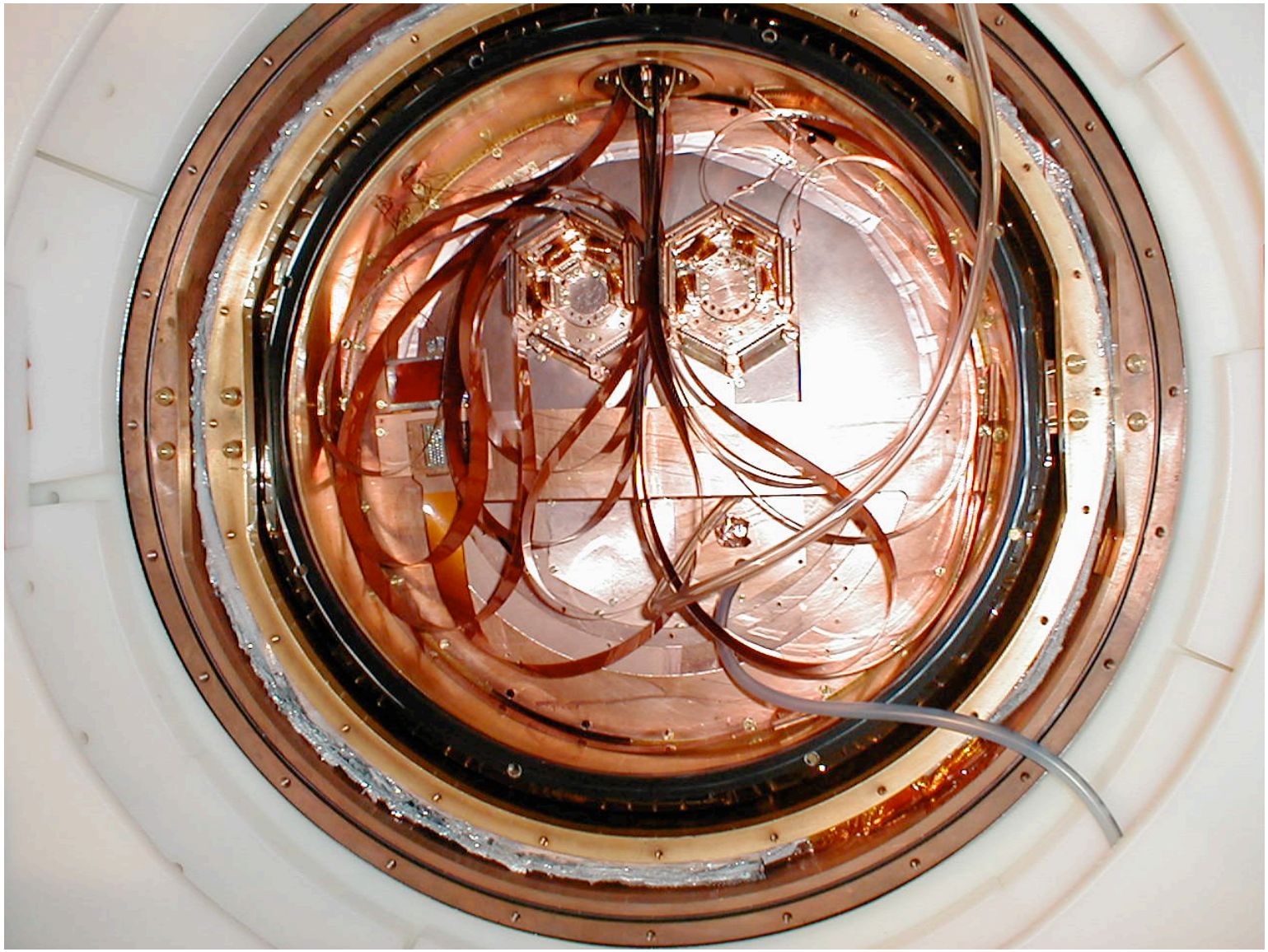
CDMS-II Soudan facility







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



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

Tower of 6 ZIPs

Tower 1

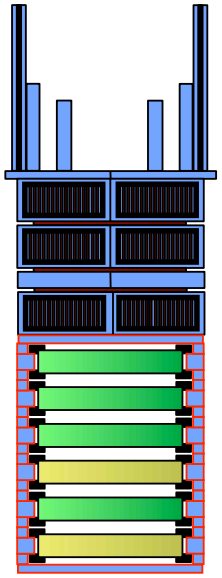
4 Ge

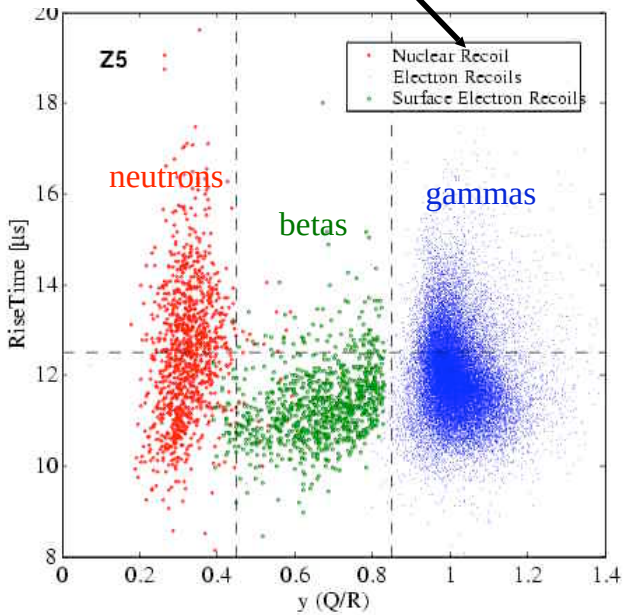
2 Si

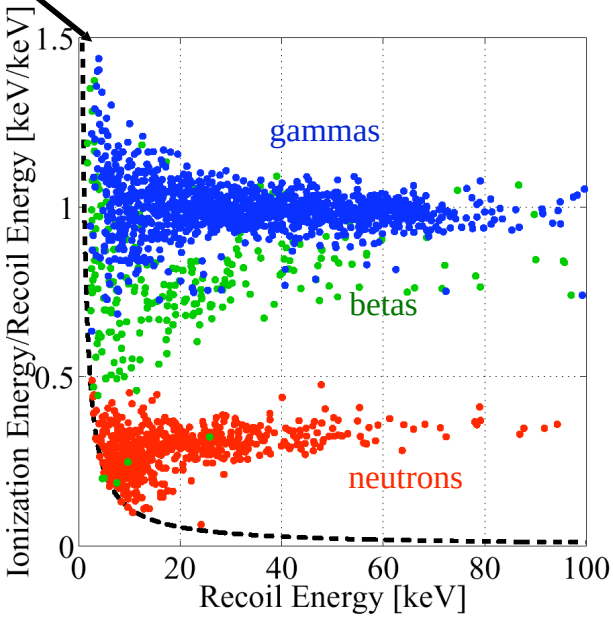
Tower 2

2 Ge

4 Si

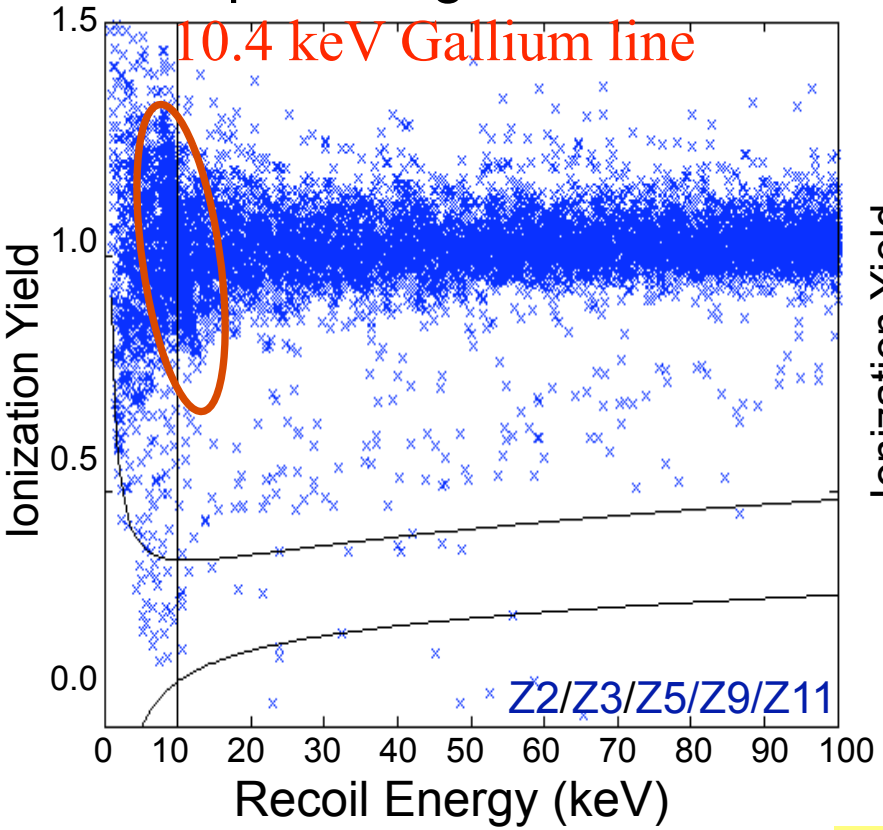




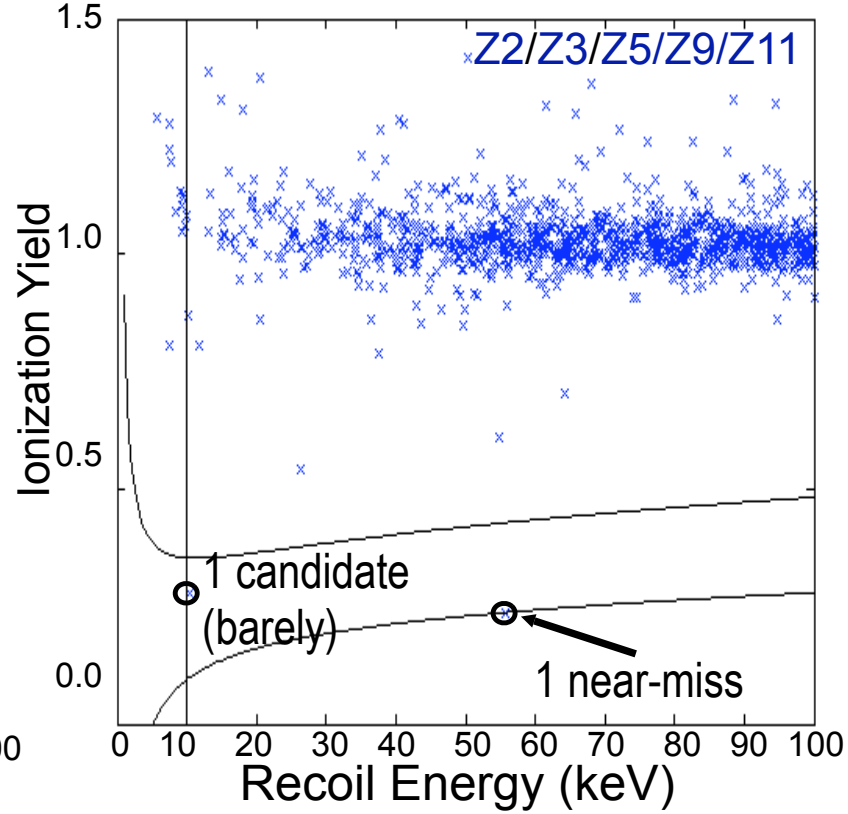


WIMP search data (5 Ge ZIPs ~53 kg-d)

Prior to phonon pulse shape timing cuts



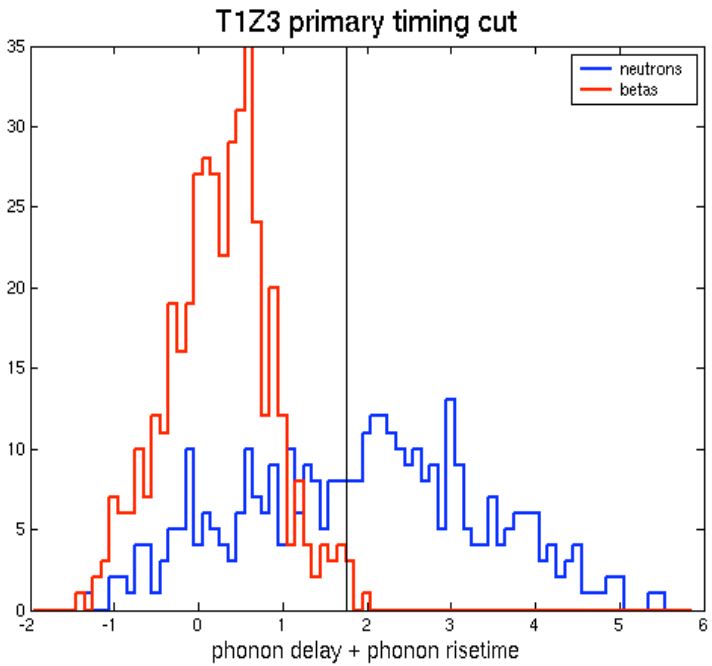
After timing cuts, which reject most electron recoils

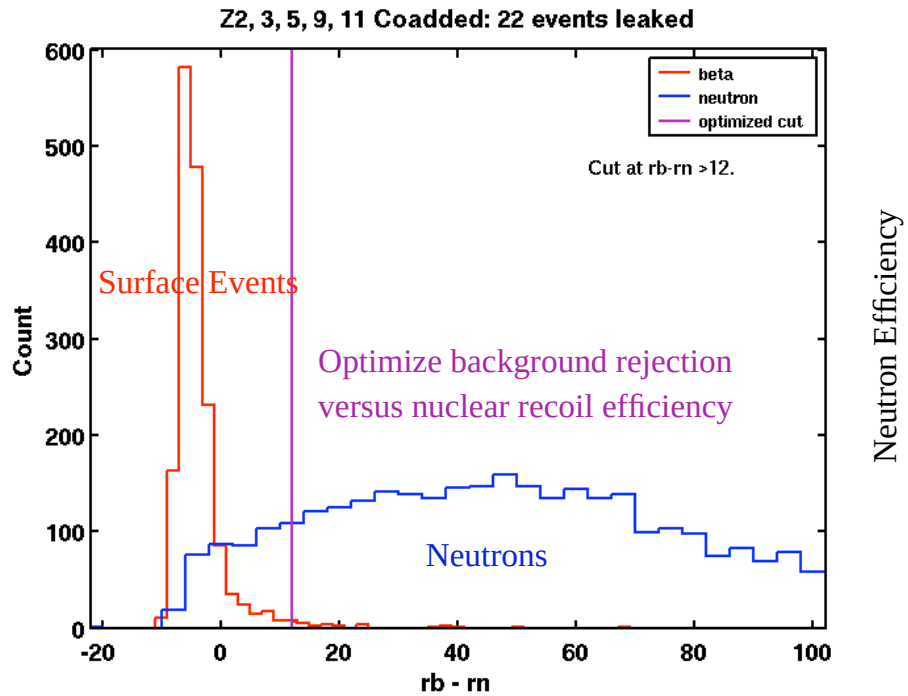


Background ESTIMATE: 0.37 ± 0.20 (sys.) ± 0.15 (stat.) electron recoils, 0.05 recoils from neutrons expected

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!



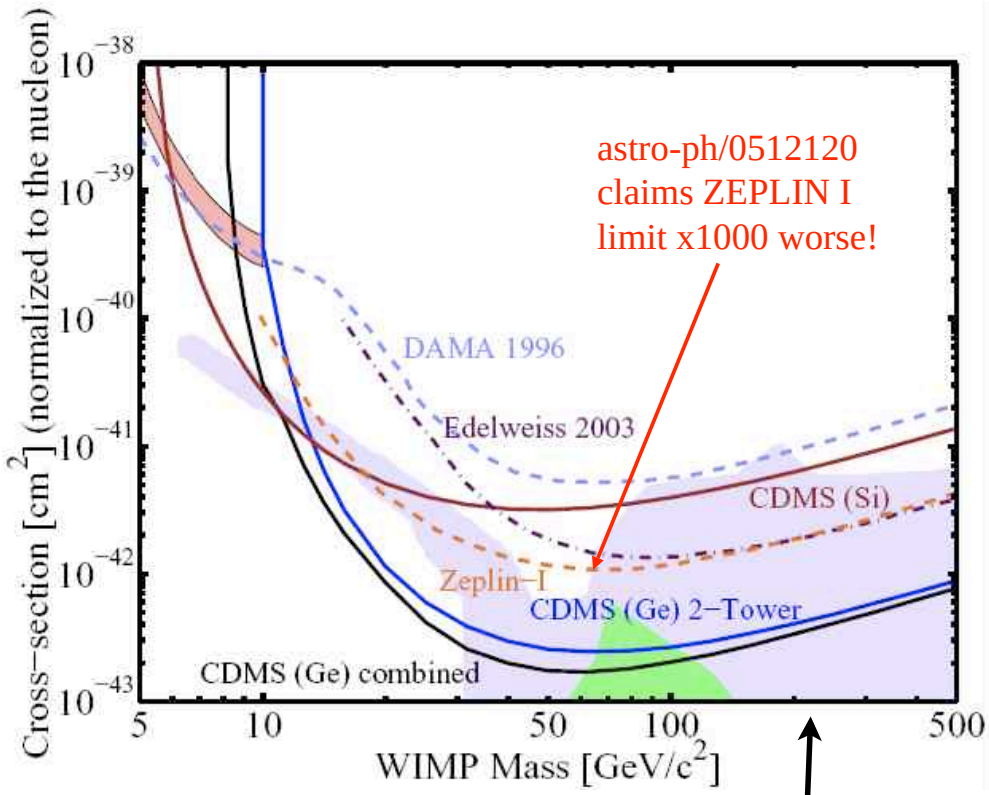


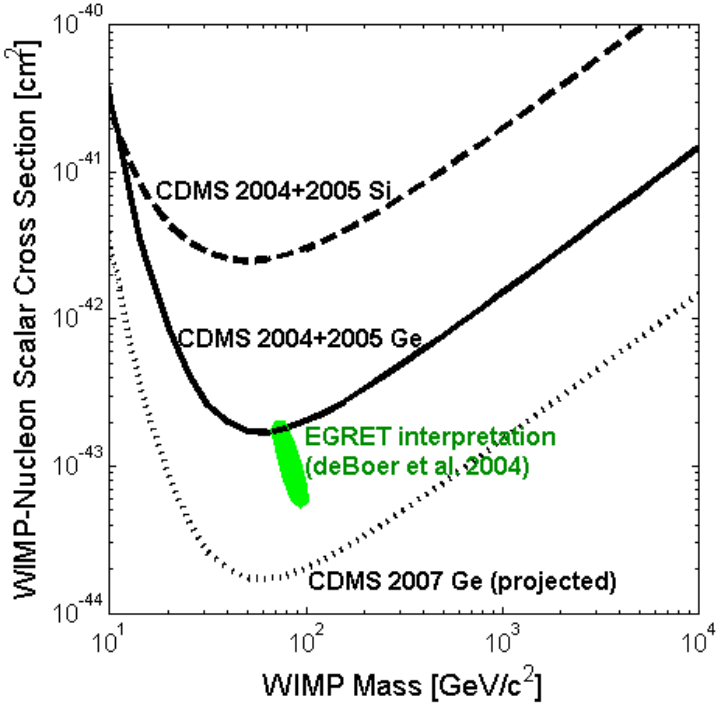
Chi-square (background pulse shape) - Chi-squared (neutron pulse shape)

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

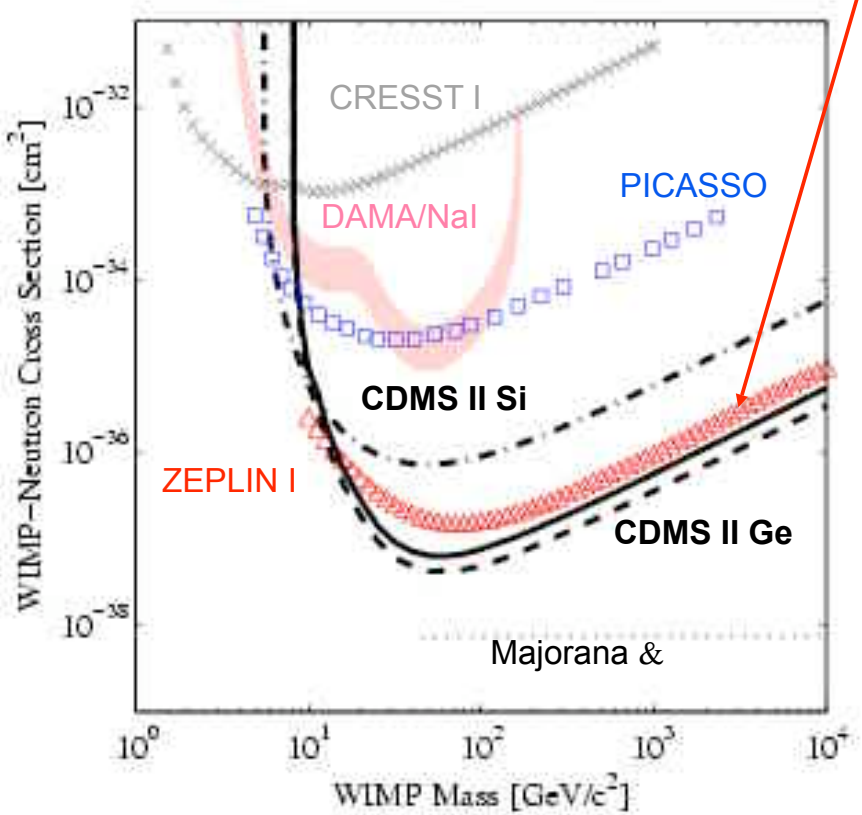
For further details see PRL 96, 011302 (2006)

Spin Dependent WIMP limits

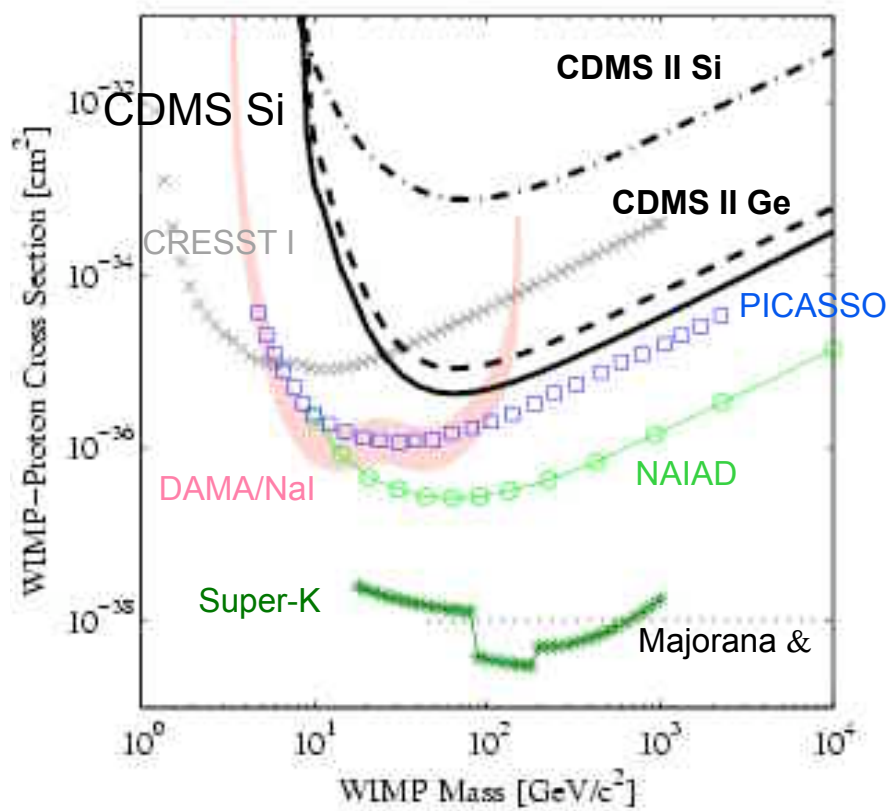
Spin-sensitivity from ^{73}**Ge** (J=9/2, 7.7%) and ^{29}**Si** (J=1/2, 4.7%)

astro-ph/0512120
claims ZEPLIN I
limit x1000 worse!

"n" scattering

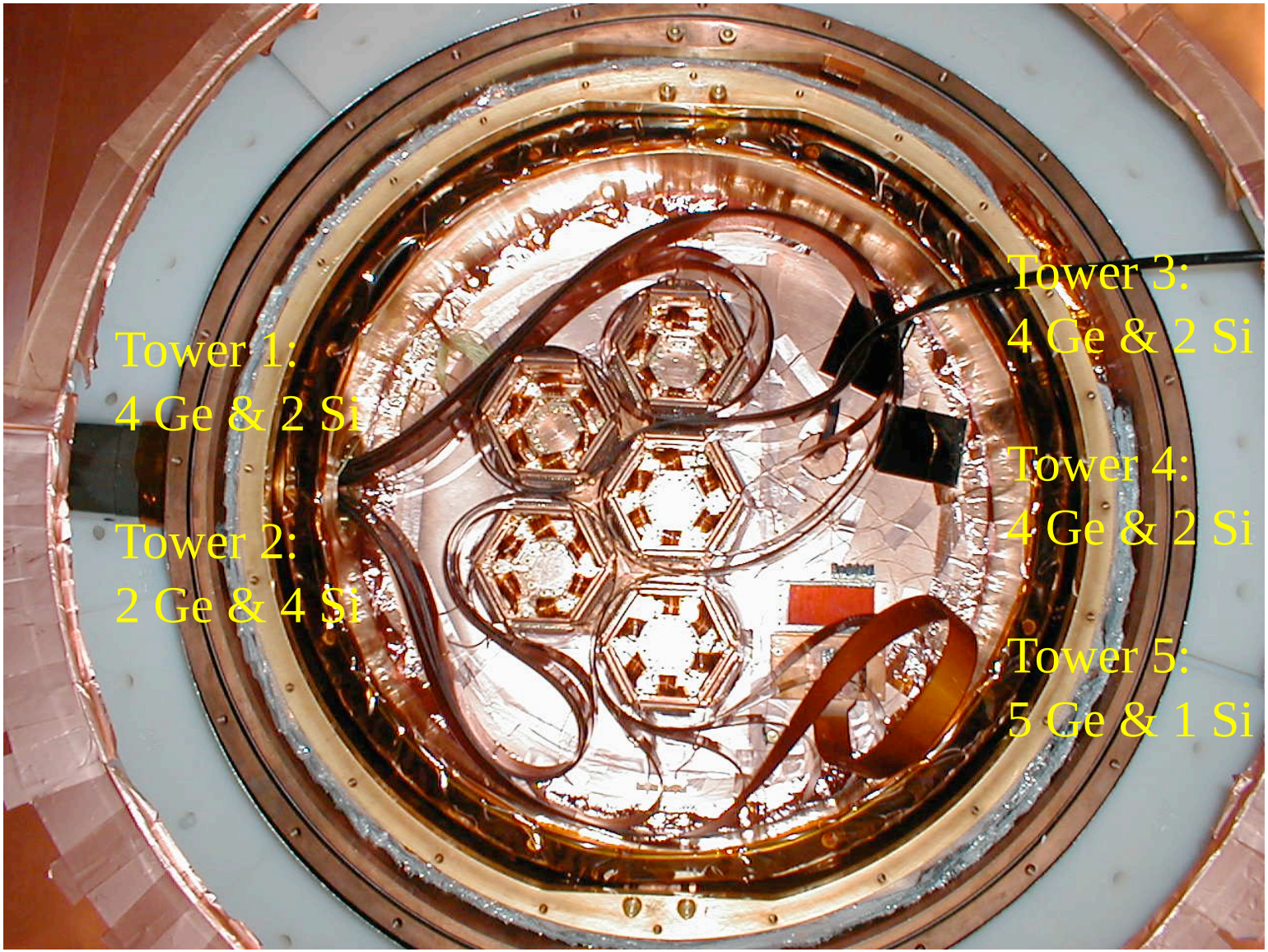


"p" scattering



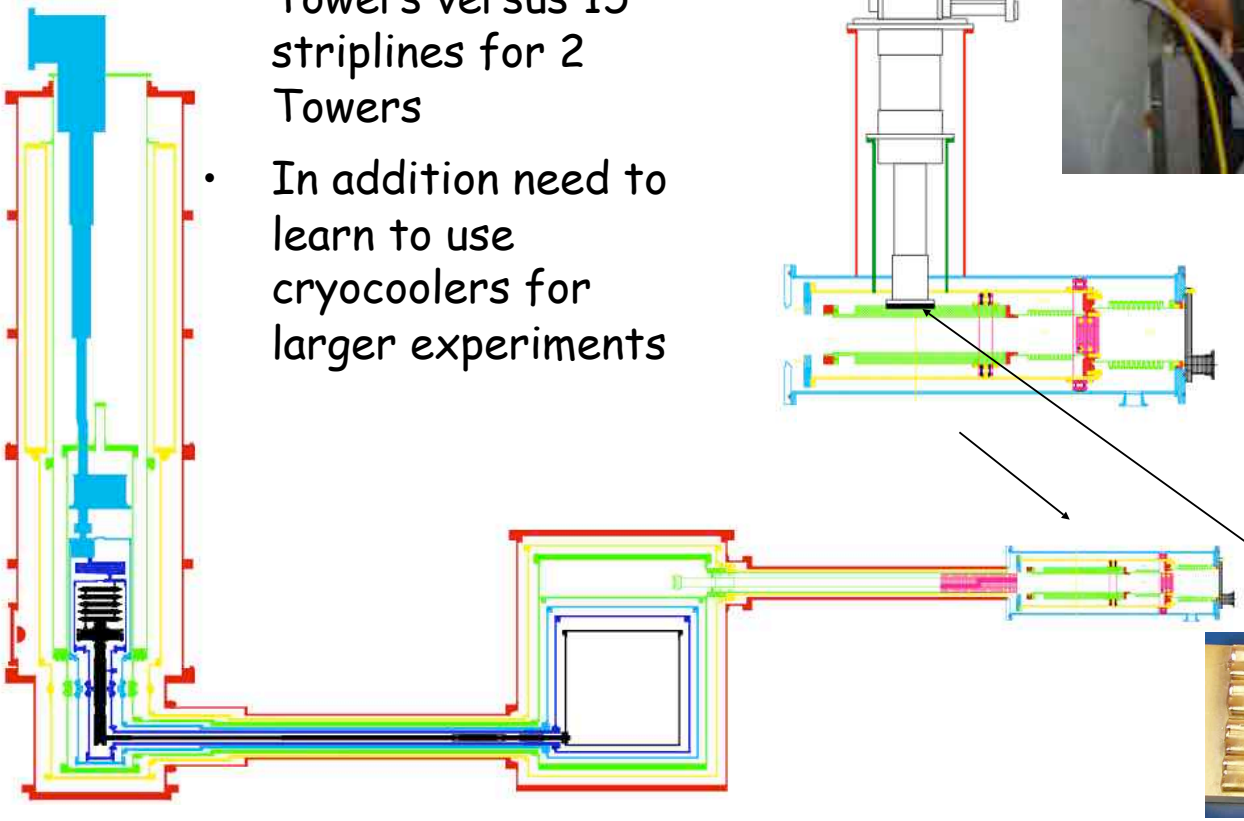
For further details see PRD D73, 011102 (2006)

Five Towers now in Soudan

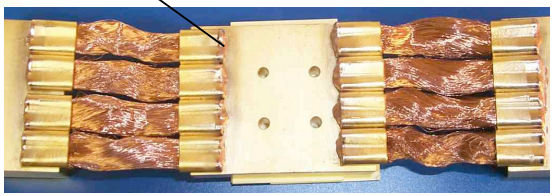


Added Cryocooler w/ Vibration Isolation

- 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.**

SuperCDMS Strategy

- We understand that full SuperCDMS program (phased program to final 1 ton) will not be reviewed in the near term before technical comparisons are possible with other technologies
- We argue strongly that the correct short term decision is to review and approve SuperCDMS 25 kg experiment (demonstrated technology in hand and can be done below the major program bar)
- We endorse Dark Matter SAG & P5 to set near and long term priorities for DM community within the US HEP program. Then in about three years convene a broad technology review for ton scale.

Proposal to DOE and NSF - May 06

SuperCDMS 25 kg Experiment

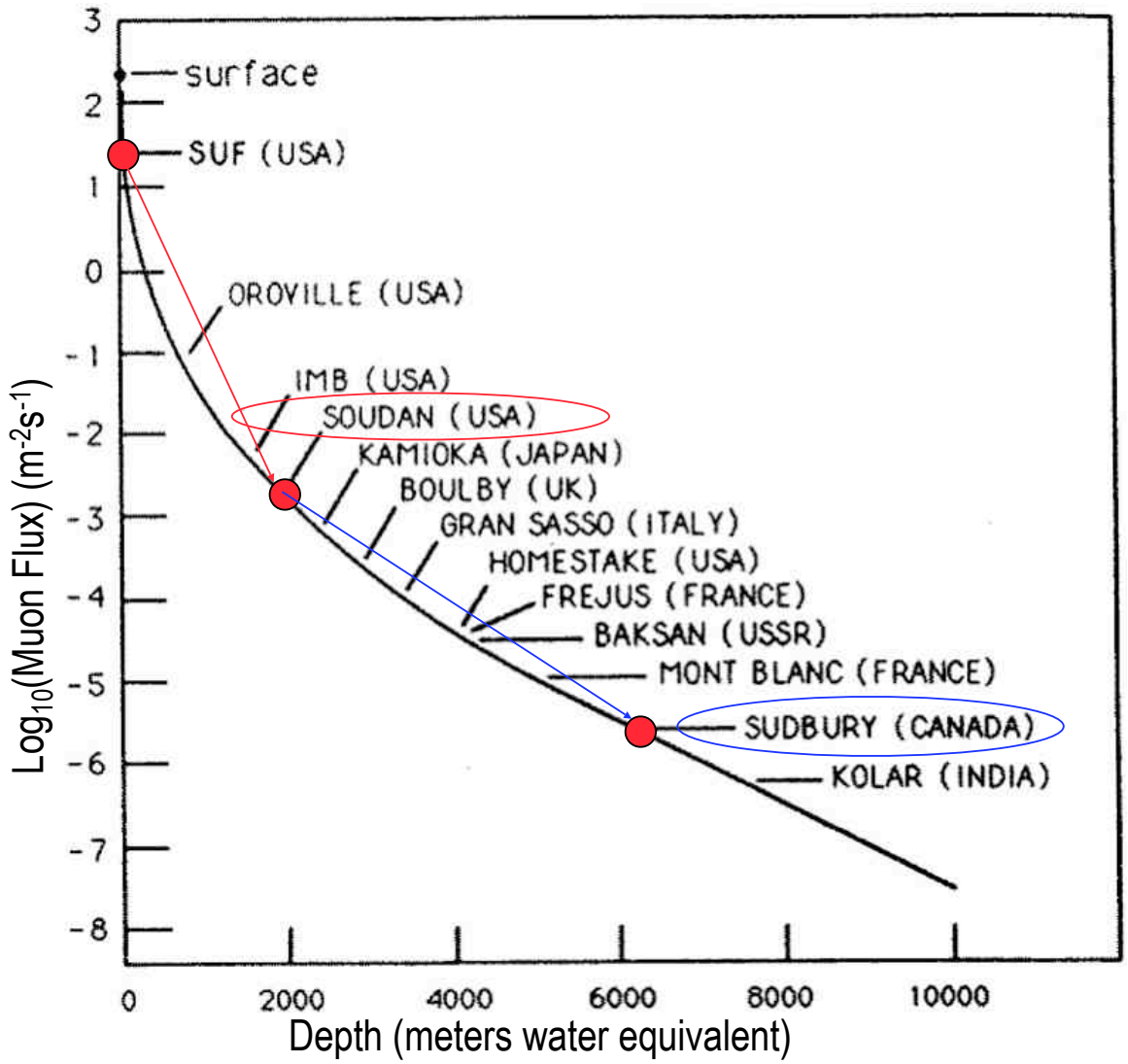
The SuperCDMS Collaboration

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

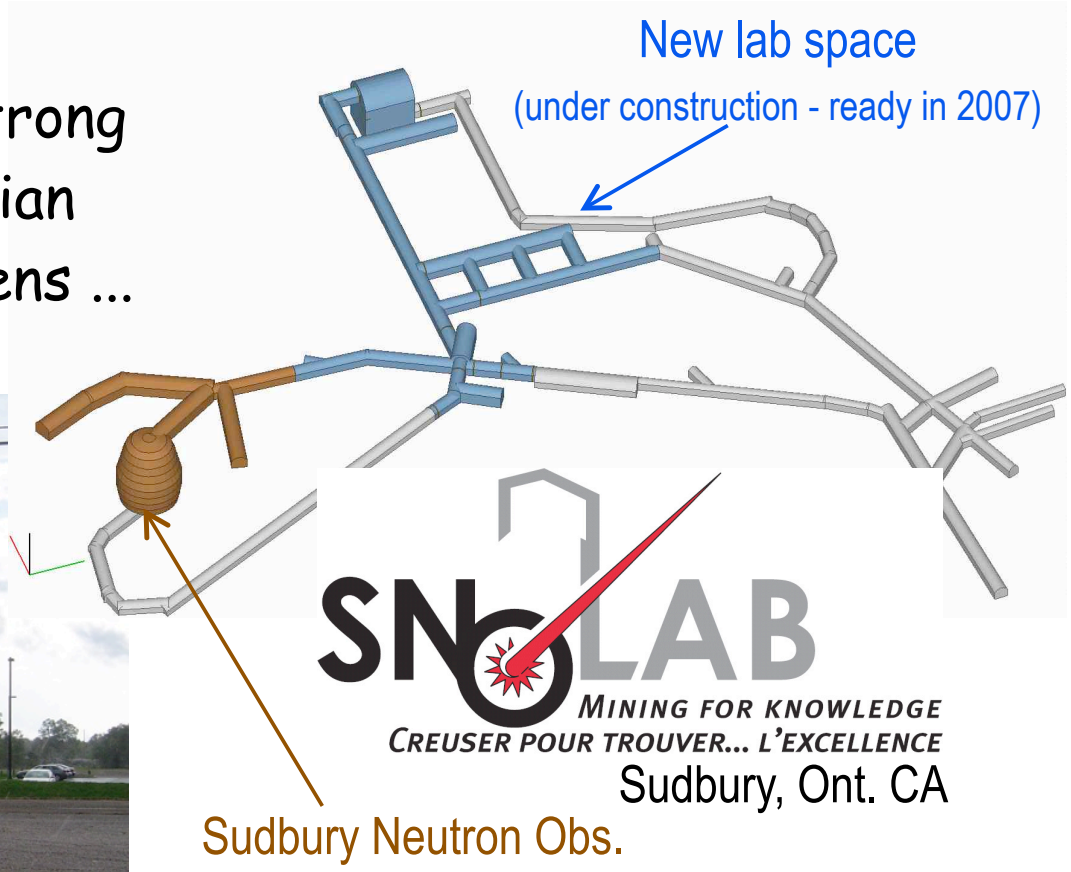
SUF (17 mwe), Soudan (2090 mwe), & SNOLab (6060 mwe)

- 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 endorsement letter received

→ We strongly endorse the SuperCDMS project as a natural extension of the CDMS program and encourage a detailed assessment of the experimental layout and infrastructure needs.

Since receipt of the original LOI for SuperCDMS the collaboration has adopted a phased approach to their experiment starting with a target mass of ~25 kg and building towards ~150 kg. The collaboration is working directly with SNOLAB personnel to define the experimental layout and infrastructure needs. While funding for the project is being sought, the collaboration should keep SNOLAB management well informed on the impending schedule and any intention that might divert from the existing strategy.

– SNOLab EAC

- The Collaboration must confirm that its intention is to locate this experiment at SNOLAB
- The Collaboration must continue to work with SNOLAB to define exactly what resources are required.
- The Collaboration must indicate the time scale on which it expects to secure funding for work at SNOLAB

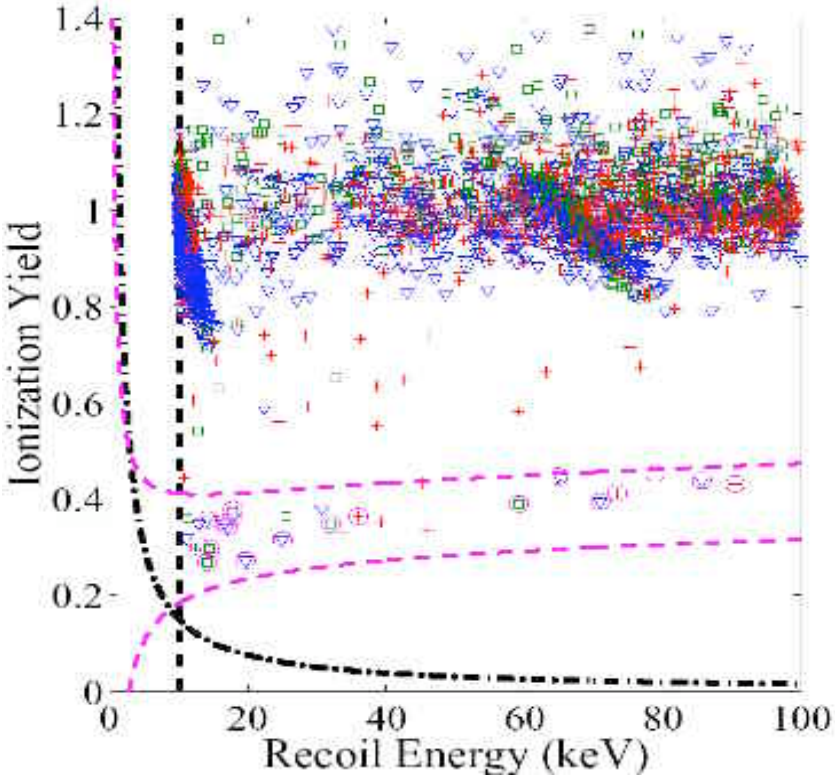
– D. Sinclair, SNOLab Director - 14 Oct 2005

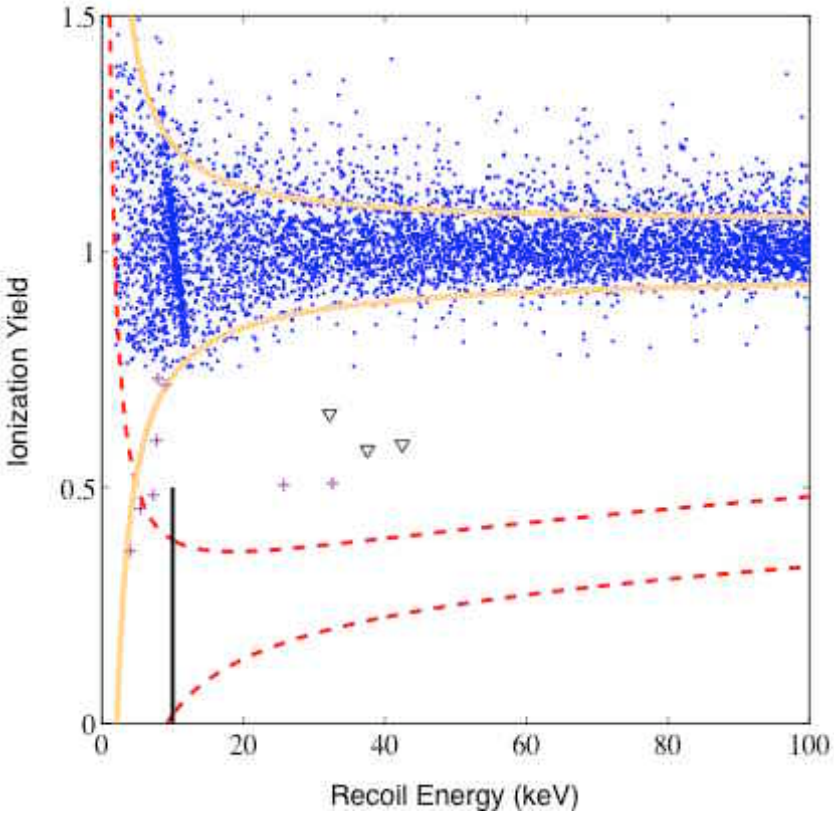
1) We confirm our intention to locate SuperCDMS at SNOLAB.
2) We will continue to work with SNOLAB staff to define the specific needs.
3) We are discussing with our funding agency representatives at the Department of Energy and the National Science Foundation, and with the Fermilab Directorate, our request for a review this winter of the 25-kg experiment. We are hopeful that a such review will take place in time for a possible funding start in FY2007 (1 Oct 2006).

SuperCDMS collab - 23 Oct 2005

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:

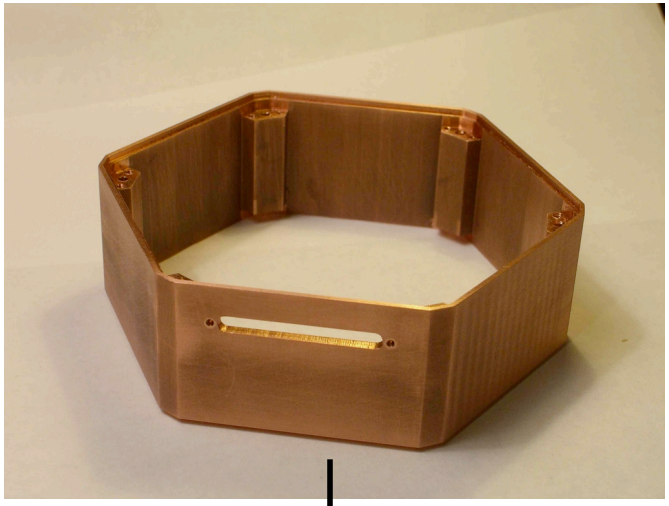
3" dia x 1 cm => 0.25 kg of Ge

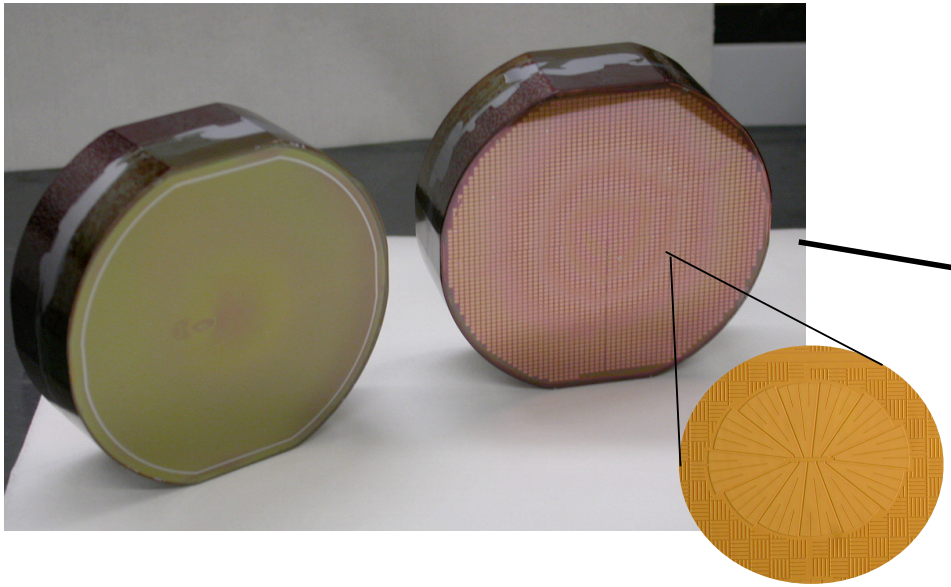
Existing ZIPs

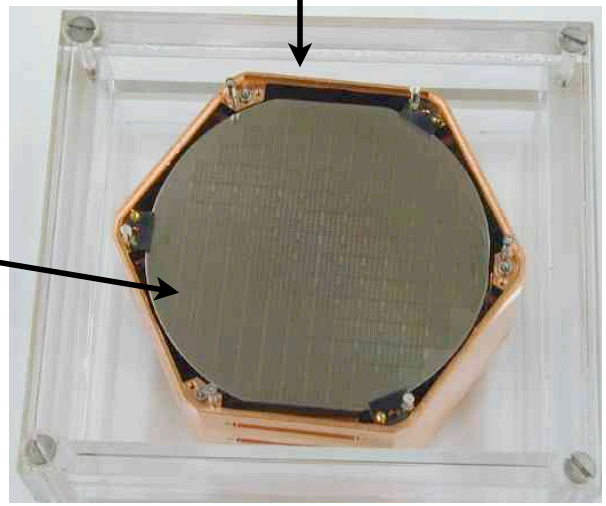
SuperCDMS ZIPs:

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

ZIPs for SuperCDMS



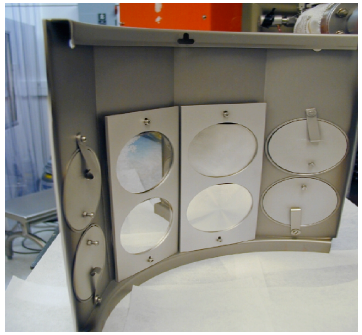


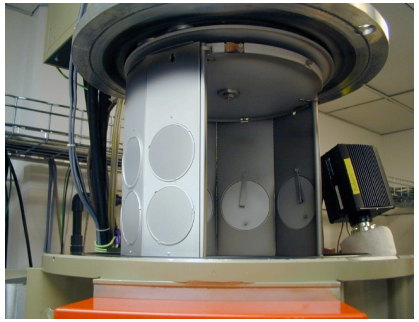


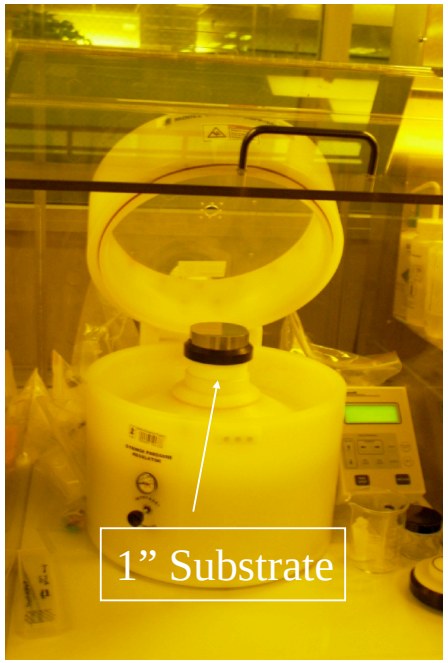
Completed 1" thick Si ZIP

Modifications for 1" processing

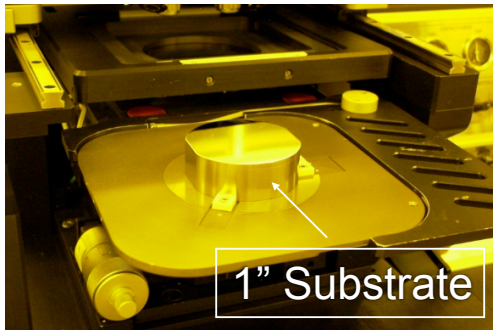
sputtering
(design complete
parts in shop)







spinner
(ready)



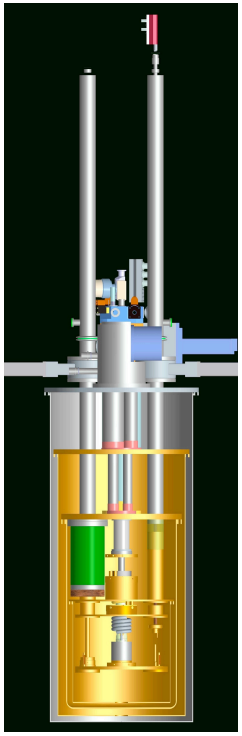
aligner (ready)

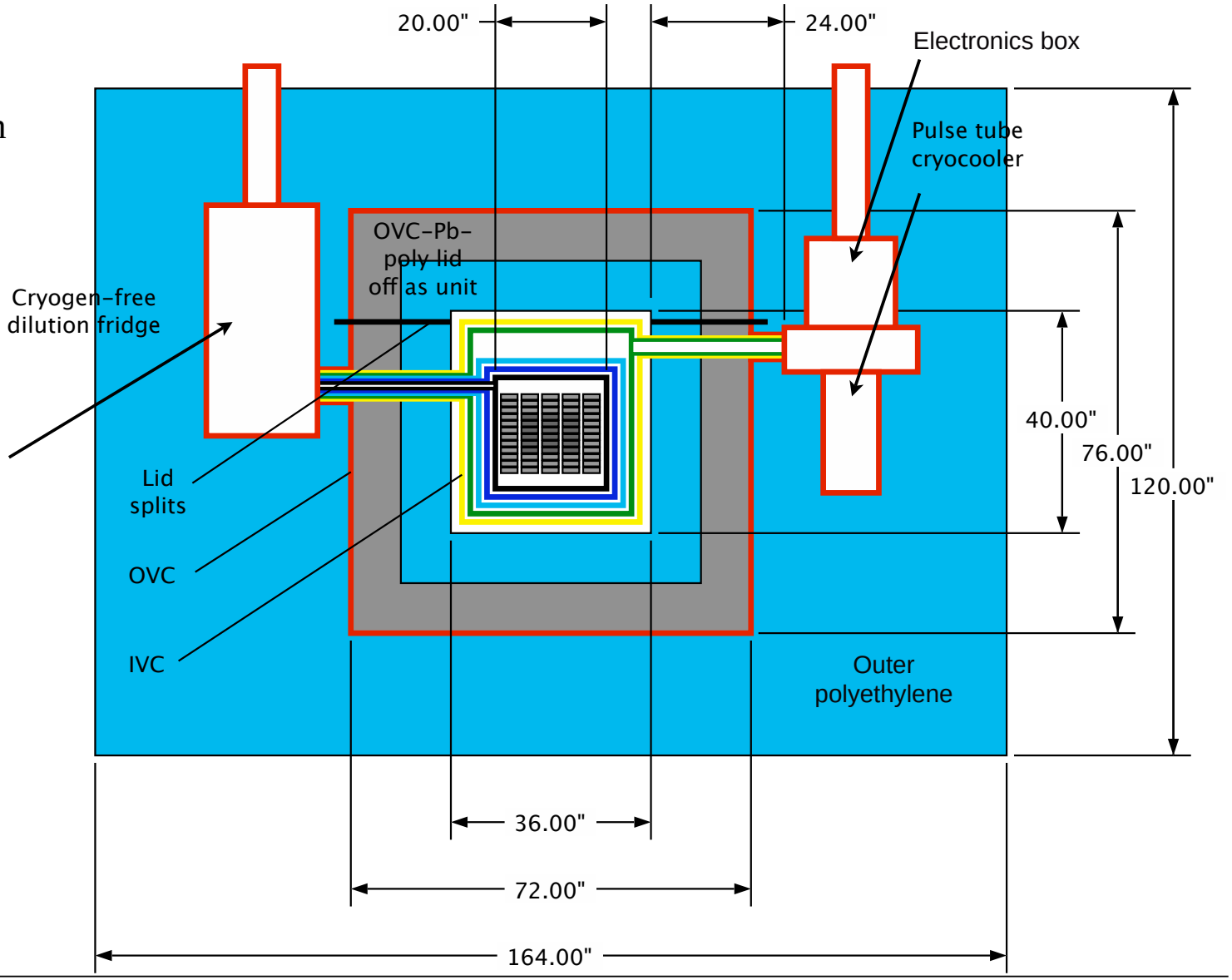
started first Ge 1" thick fabrication last week

dry etch
(design
complete)

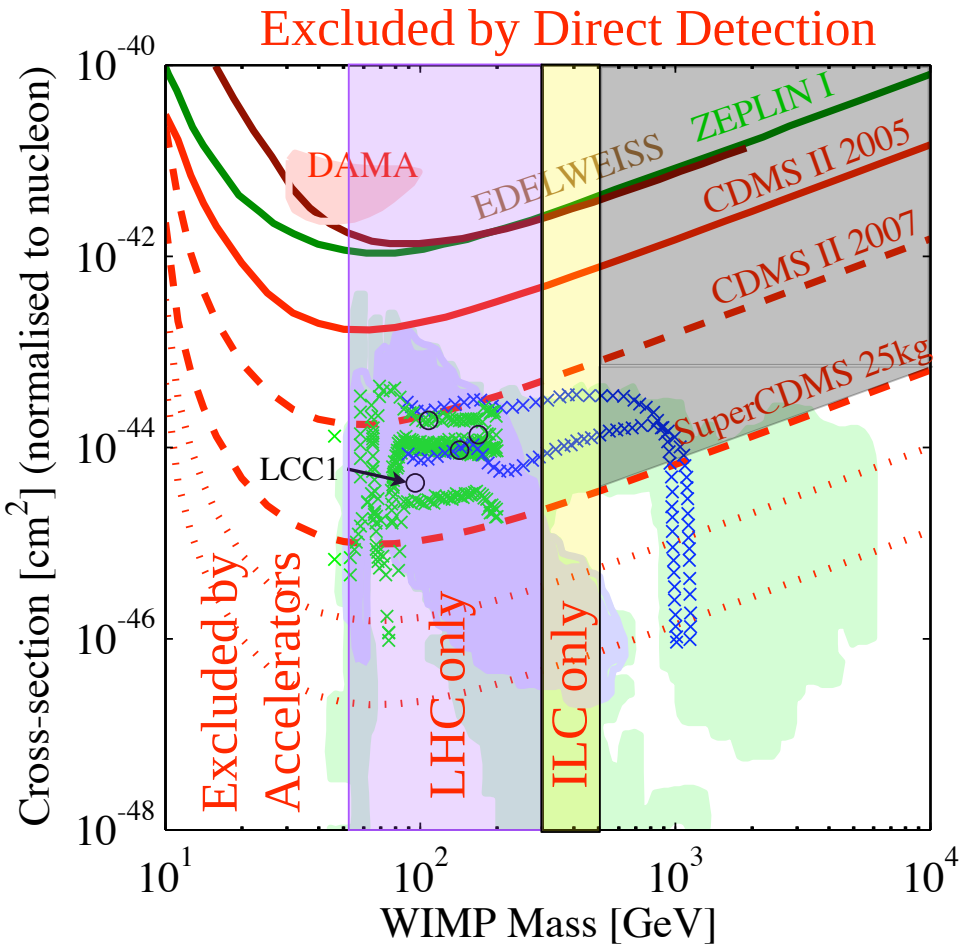
Schematic of new 'SNObox'

Exploring cryocooler system with little or no cryogen servicing



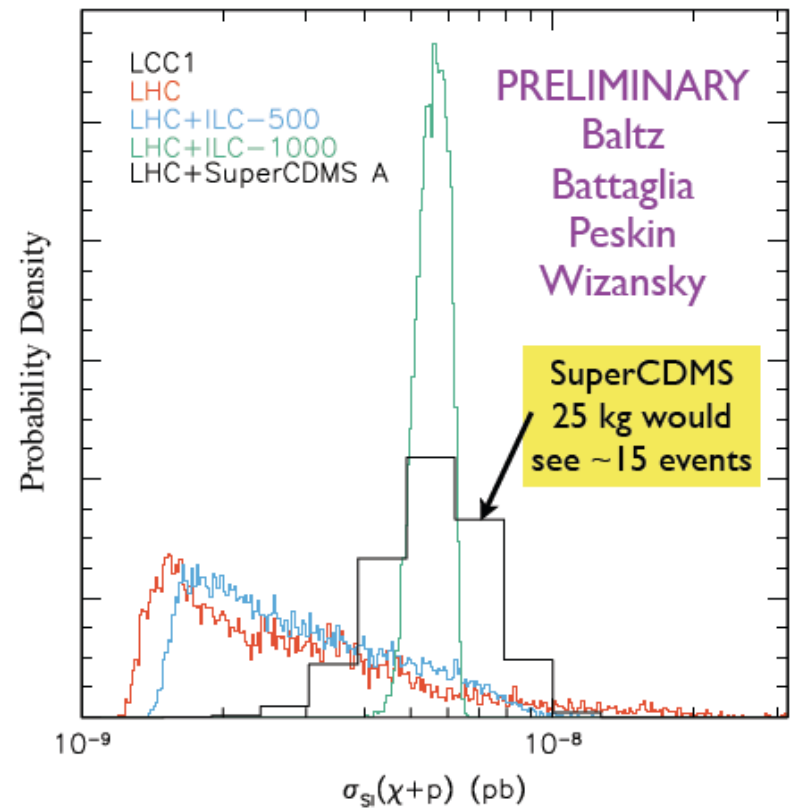


Does the LHC supplant SuperCDMS?



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

Project Cost Projections for SuperCDMS [$M]

FY	2007		2008		2009		2010		2011		2012		2013		2014		2015	
Agency	DOE	NSF	DOE	NSF	DOE	NSF	DOE	NSF	DOE	NSF	DOE	NSF	DOE	NSF	DOE	NSF	DOE	NSF
CDMS II	.7	.2	.7	.2														
Ops	0.9		0.9															
SCDMS	2	4	3	3	2	2												
25 kg Proj	6		6		4													
SCDMS					.9	.3	.9	.3	.9	.3								
25 kg Ops					1.2		1.2		1.2									
SCDMS					1	1	3	3	3	3								
150kg Proj					2		6		6									
SCDMS											.9	.3	.9	.3	.9	.3		
150 kg Ops											1.2		1.2		1.2			
SCDMS											4	4	5	5	5	5	5	5
1 ton Proj											8		10		10		10	
SCDMS																	.9	.3
1 ton Ops																	1.2	
Totals	2.7	4.2	3.7	3.2	3.9	3.3	3.9	3.3	3.9	3.3	4.9	4.3	5.9	5.3	5.9	5.3	5.9	5.3
	6.9		6.9		7.2		7.2		7.2		9.2		11.2		11.2		11.2	

Budget assumptions and comments

- Assume base program support for scientific staff continues near present levels per group, expect to add some groups.
- Operations costs include M & S (~$500-600k/yr from Fermilab) and travel (~$200-300k/yr each from DOE & NSF).
- The $16M SuperCDMS 25 kg construction project is very similar in scale to the CDMS-II project, so we have an excellent cost basis estimate for facilities and detector production ($823K/year DOE and $977K/year NSF).
- Beyond the 25 kg experiment, we propose to move towards ton scale experiment with intermediate $50M SuperCDMS 150 kg experiment, including scaling up detector production.
- Important to support detector R&D as part of project funds and keep continuous effort without gaps. We had to reduce fabrication staff by 50% between CDMS-II & SuperCDMS.

"Discovering the Quantum Universe" p5

1. **SOLVING THE MYSTERIES OF MATTER AT THE TERASCALE.** The LHC should discover the Higgs and other new particles. Experiments at the linear collider would then zoom in on these phenomena to discover their secrets. Properties of the Higgs may signal extra dimensions of space or explain the dominance of matter over antimatter. Particle interactions could unveil a universe shaped by supersymmetry.
2. **DETERMINING WHAT DARK MATTER PARTICLES CAN BE PRODUCED IN THE LABORATORY AND DISCOVERING THEIR IDENTITY.** Most theories of Terascale physics contain new massive particles with the right properties to contribute to dark matter. Such particles would first be produced at the LHC. Experiments at the linear collider, in conjunction with dedicated dark matter searches, would then discover whether they actually are dark matter.
3. **CONNECTING THE LAWS OF THE LARGE TO THE LAWS OF THE SMALL.** From a vantage point at the Terascale, the linear collider could function as a telescope to probe far higher energies. This capability offers the potential for discoveries beyond the direct reach of any accelerator that could ever be built. In this way, the linear collider could bring into focus Einstein's vision of an ultimate unified theory.

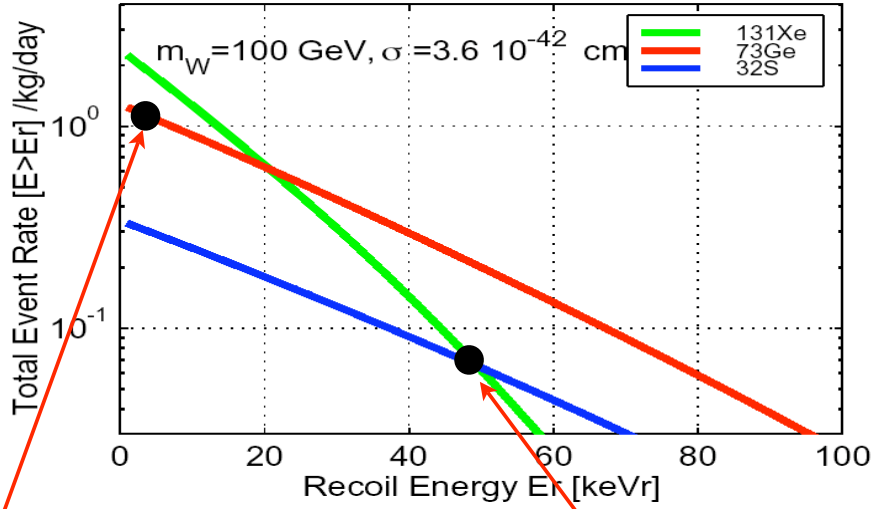
- **Dark Matter one of the three major themes of HEPAP report to EPP2010**
  - more exactly: it takes the combination of LHC/ILC and dedicated dark matter searches will discover the nature of dark matter

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 scintillation (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)

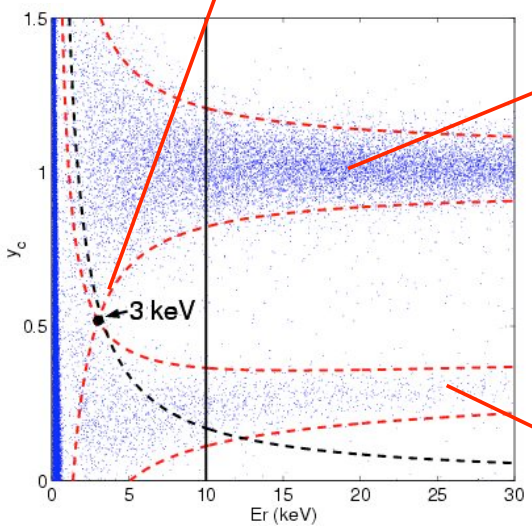
Threshold comparison and importance

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

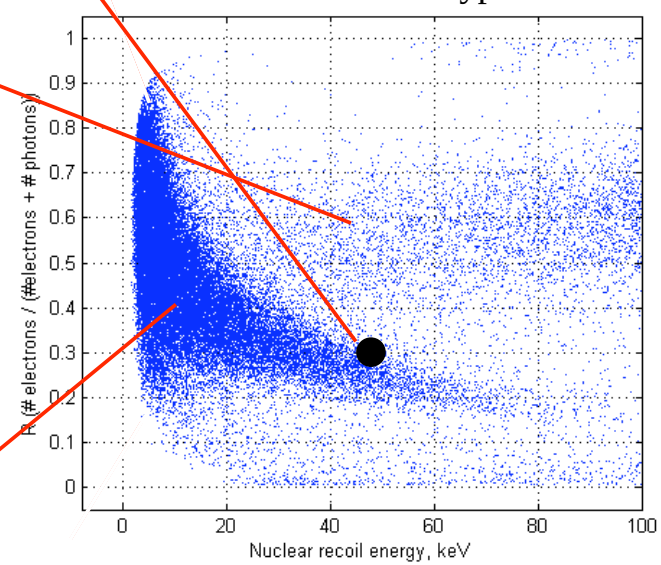


gammas

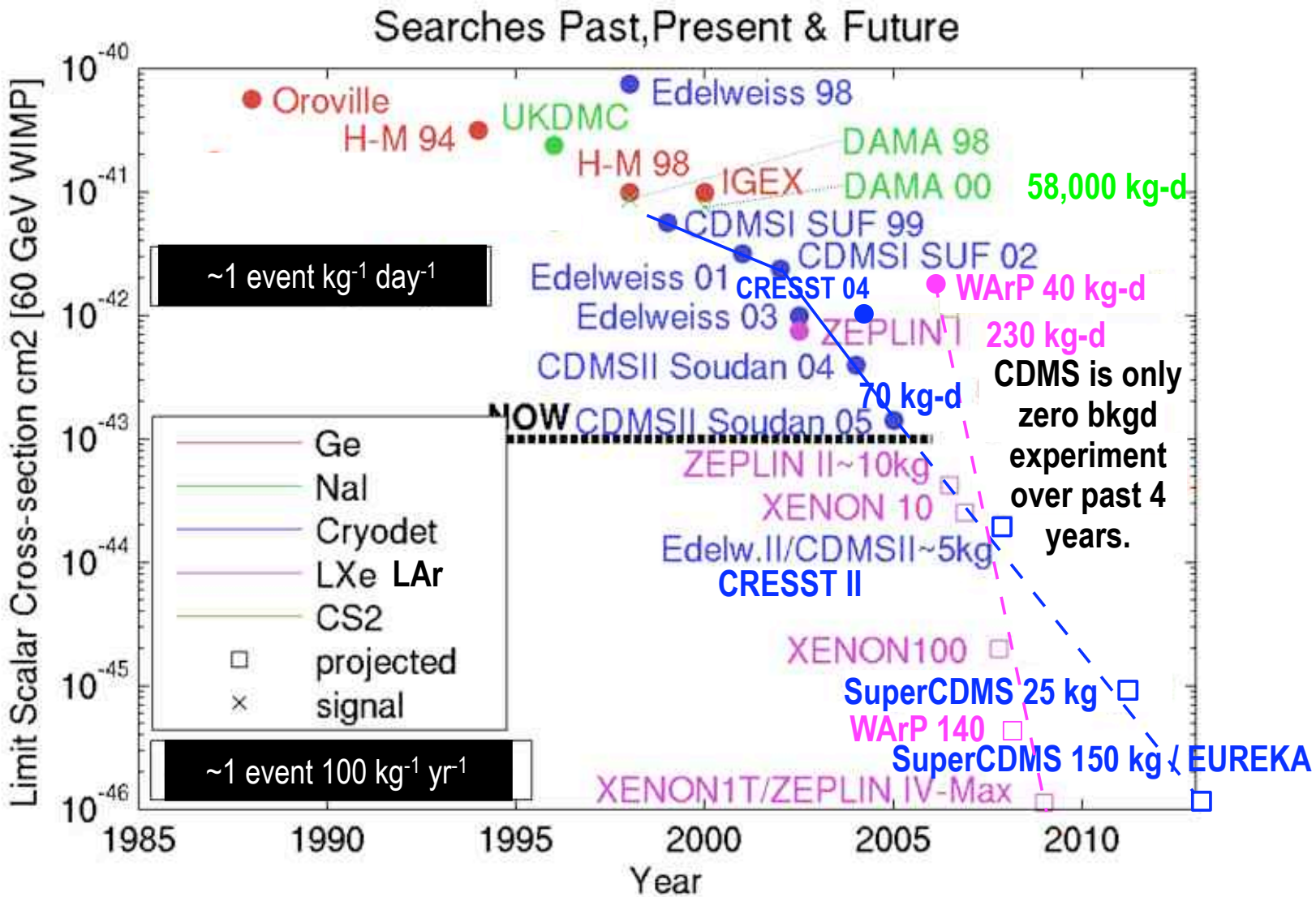
counting statistics

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

- Soudan Towers 1&2 leads 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 DarkSAG as input to P5.
- Ton-scale major program will not be approved for 2-3 years and will consider all technologies - need more than one.
- NEVERTHELESS, 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.