Looking for WIMPs in the Galactic Halo: the Cryogenic Dark Matter Search

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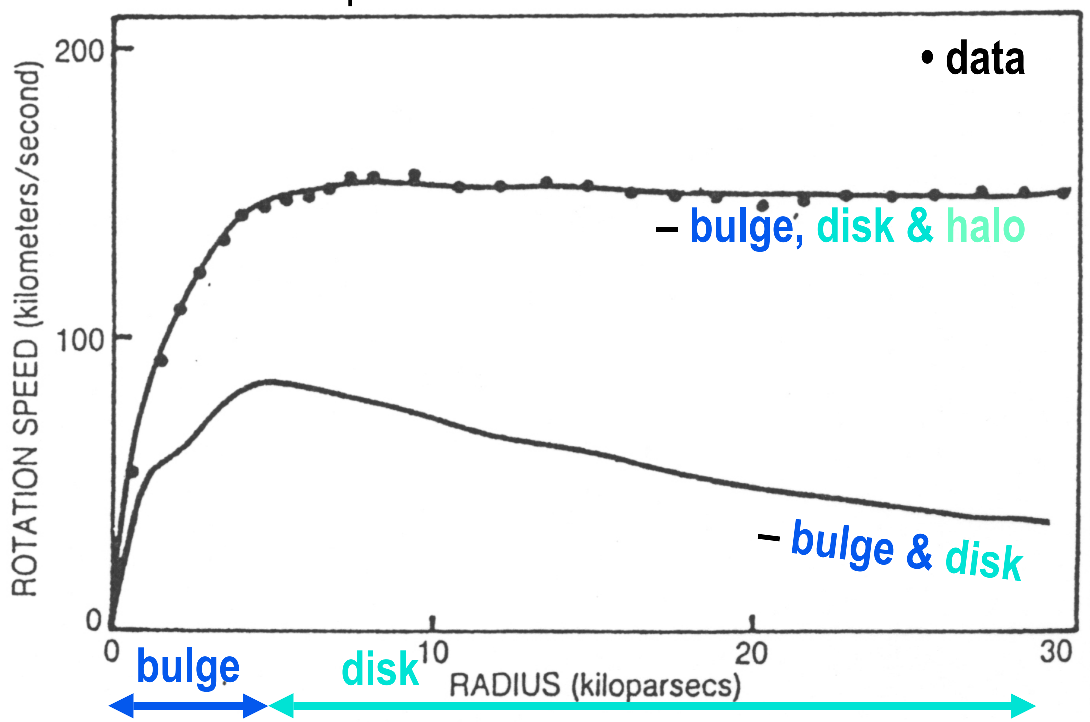
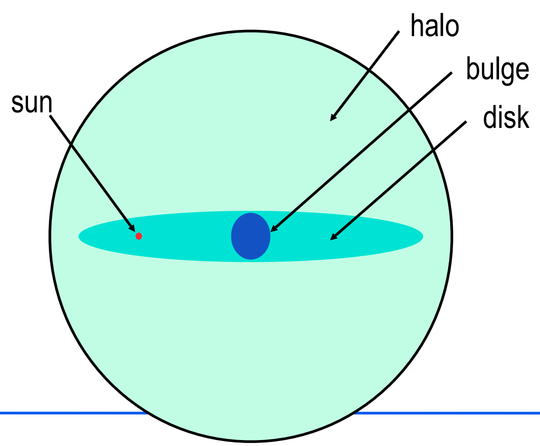
Dynamical Evidence: Galactic Halos

Galaxies – 10-100 kpc





$$F_{\text{centripetal}} = F_{\text{gravity}}$$

$$\frac{mV_r^2}{r} = \frac{GmM_{\text{total}}(r)}{r^2}$$

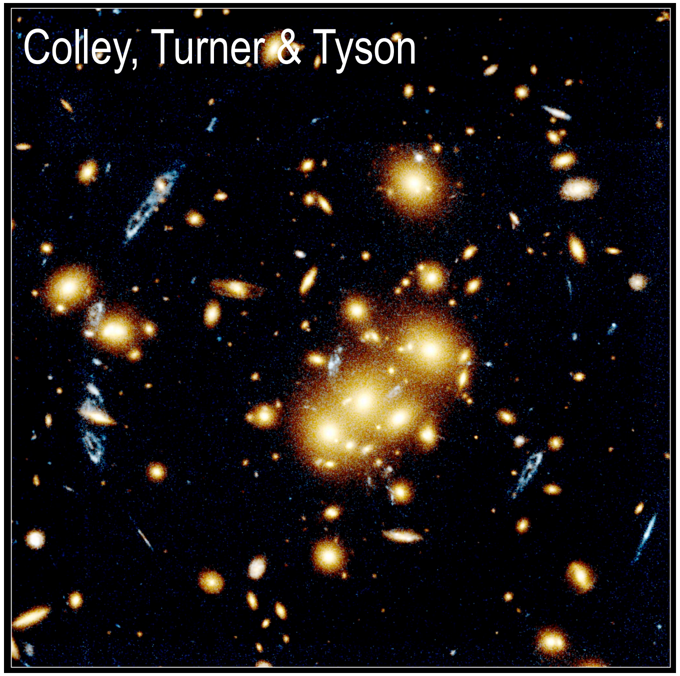
$$V_r = \sqrt{\frac{GM_{\text{total}}(r)}{r}}$$

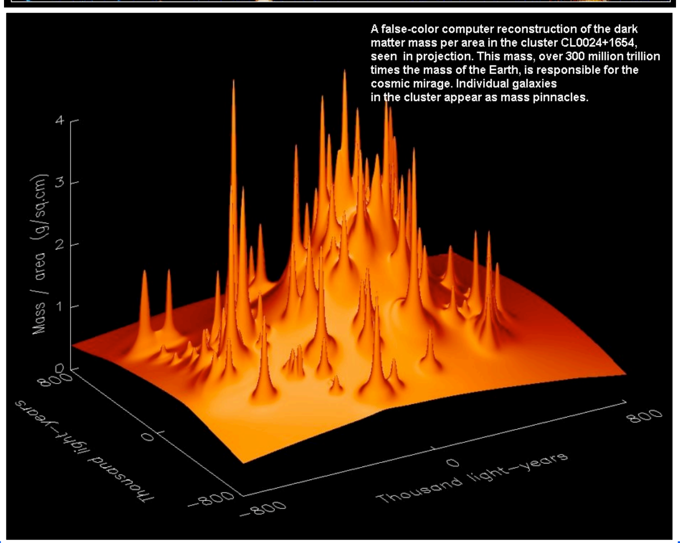
$$\rho_{\text{dark}}(r) \propto \frac{1}{1+(r/r_c)^2}$$

$$\Omega_{\text{dark}} \geq 10\Omega_{\text{stars}}$$

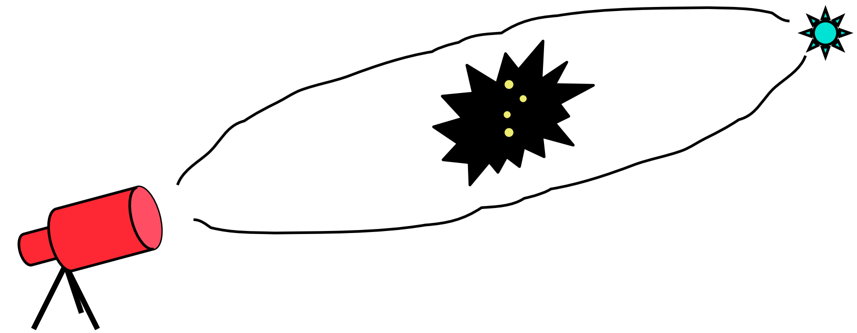
$$\Omega \equiv \rho/\rho_{\text{critical}}$$

Dynamical Evidence: Galaxy clusters





Clusters – 1-10 Mpc



Independent methods:

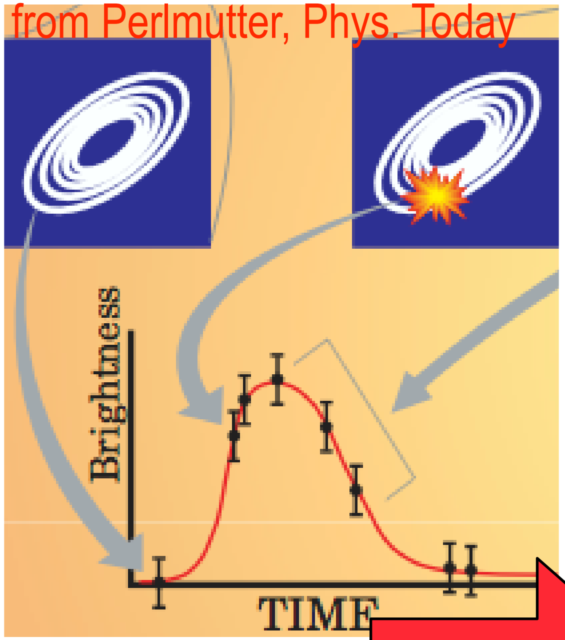
- **Lensing**
- **Virial thm:** $\langle T\rangle = -\frac{1}{2}\langle U\rangle_{dyn}$
- **x-rays from bound gas**

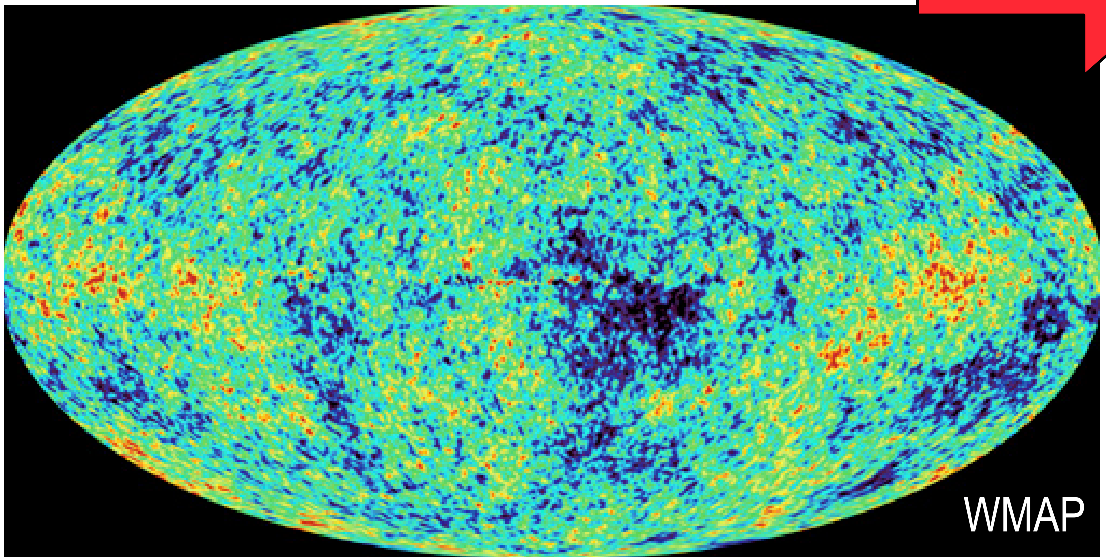
→ $\Omega_{dark} = \rho/\rho_{crit} = 0.3$

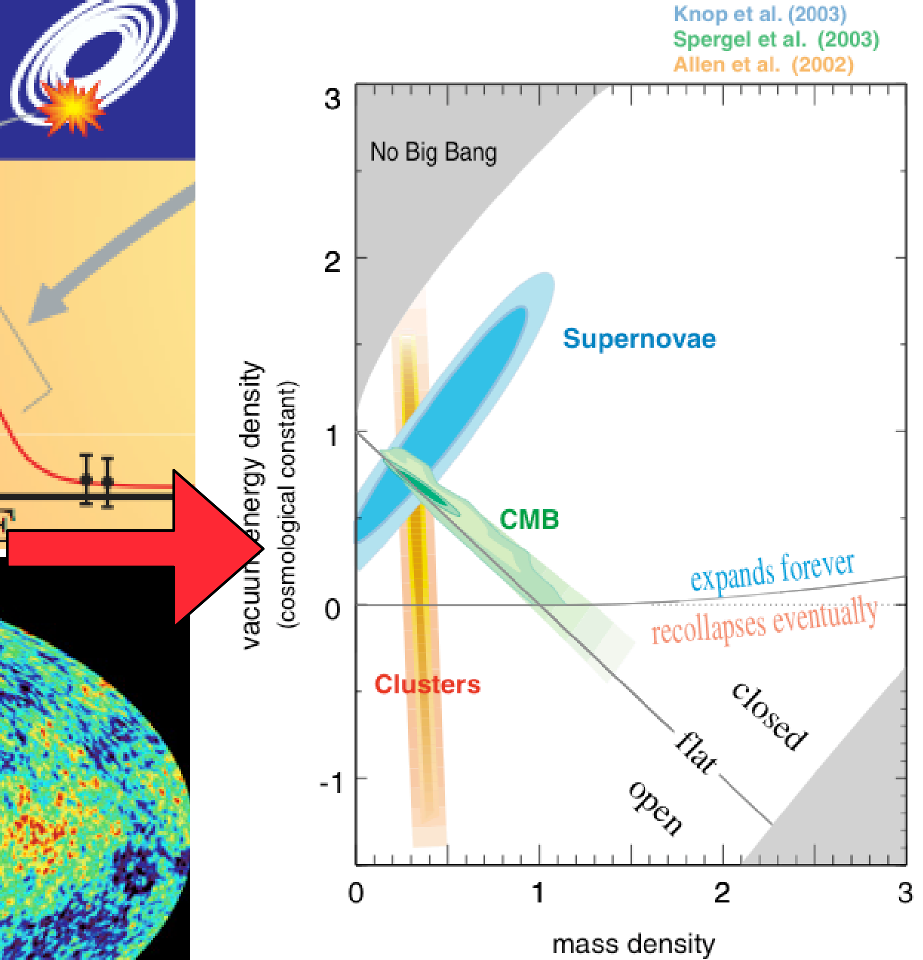
→ **dark matter dominates**

$\rho_{dark} > 30\ \rho_{lum}$

Standard Cosmology



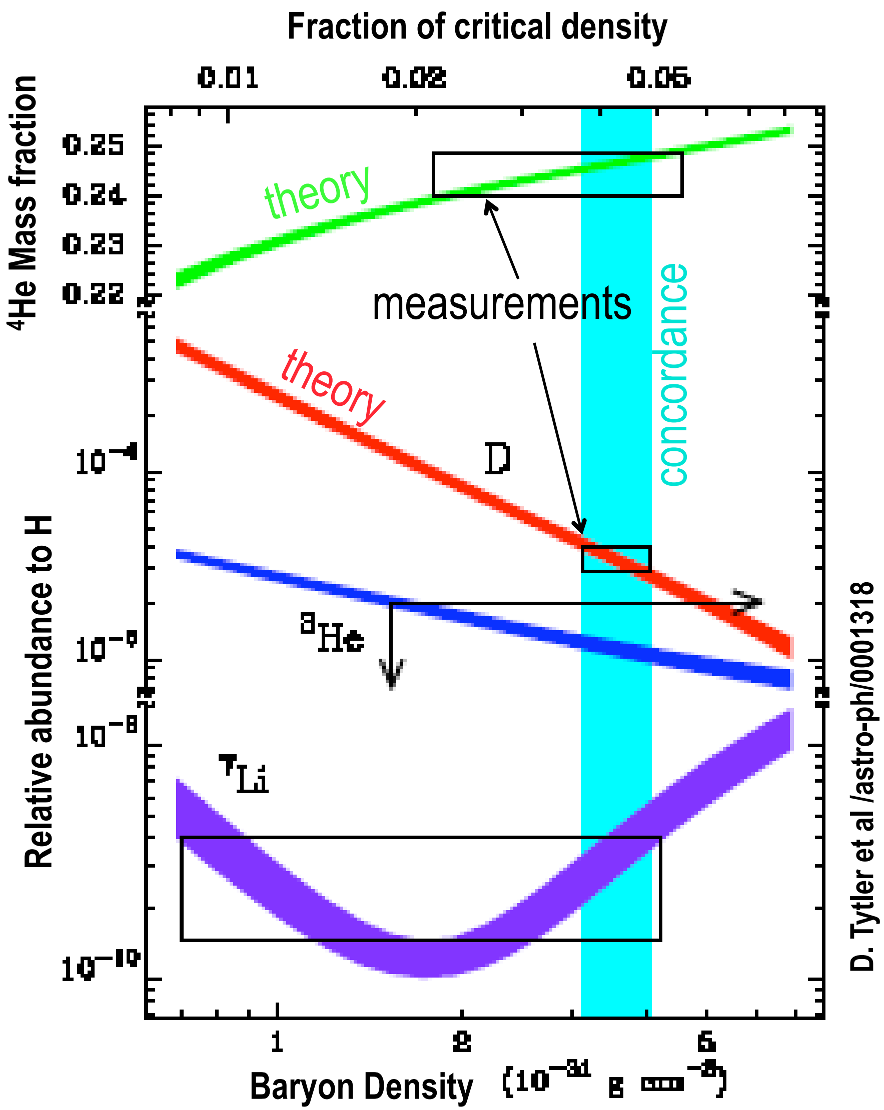




Too few baryons

- Big Bang Nucleosynthesis
  - Constrain baryon density based on relative abundance of light elements from hot big bang
  - One-parameter model: baryon density
  - Best constraint: D/H in primordial gas clouds (Burles & Tytler)

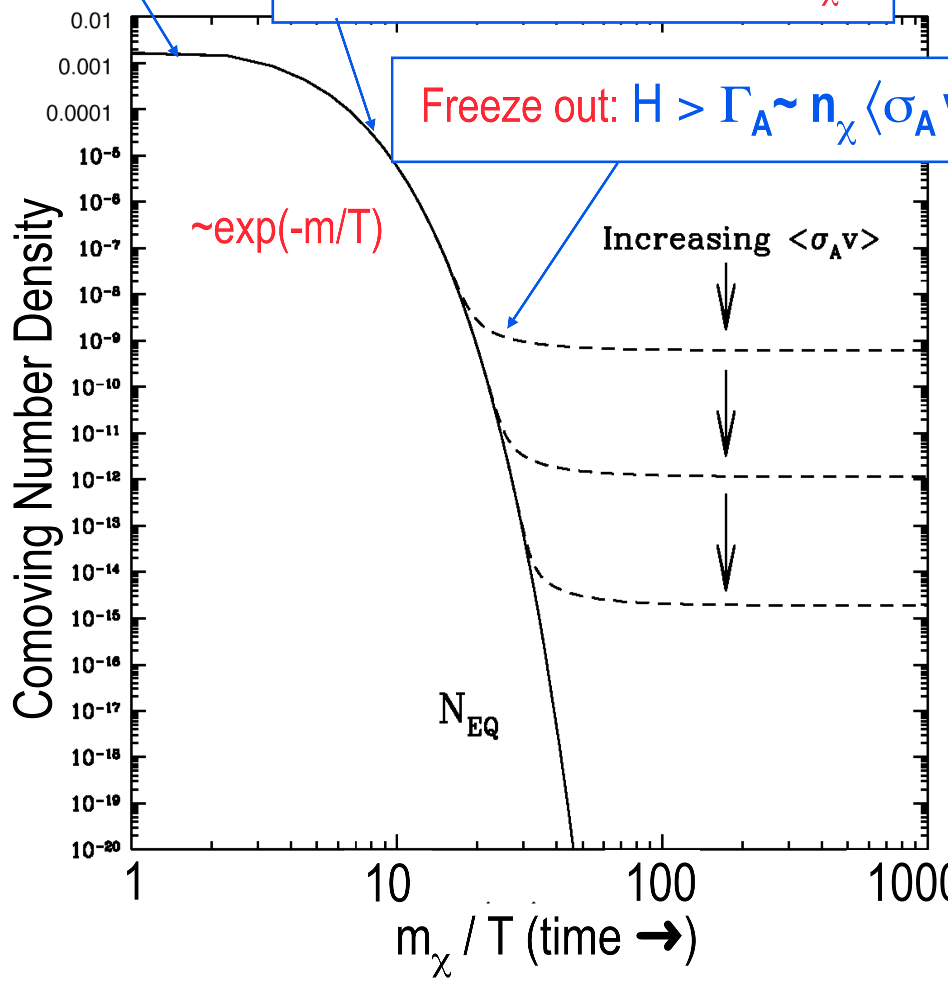
$\Omega_{Baryons} = 0.05 \pm 0.005$



Non-Baryonic Dark Matter

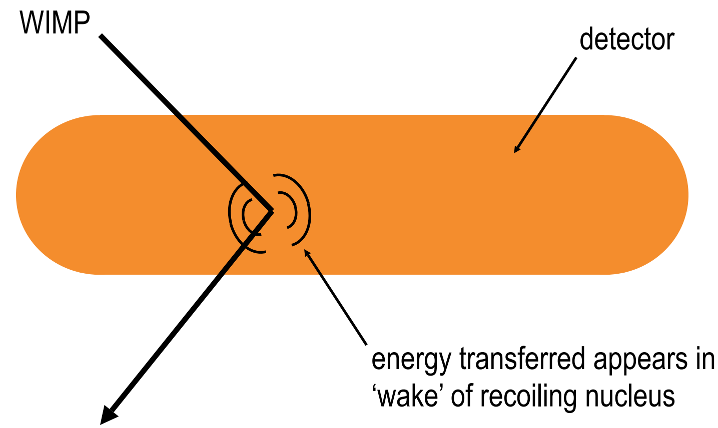
- **Matter density**
  - $\Omega_{Matter} = 0.30 \pm 0.04$
- **Big Bang Nucleosynthesis**
  - $\Omega_{Baryons} = 0.05 \pm 0.005$
- **Nature of dark matter**
  - Non-baryonic
  - Large scale structure predicts DM is 'cold'
- **WIMPs – Weakly Interacting Massive Particle**
  - ~10--1000 GeV Thermal relics
  - $T_{FO} \sim m/20$
  - $\sigma_A \sim$ electroweak scale

SUSY/LSP

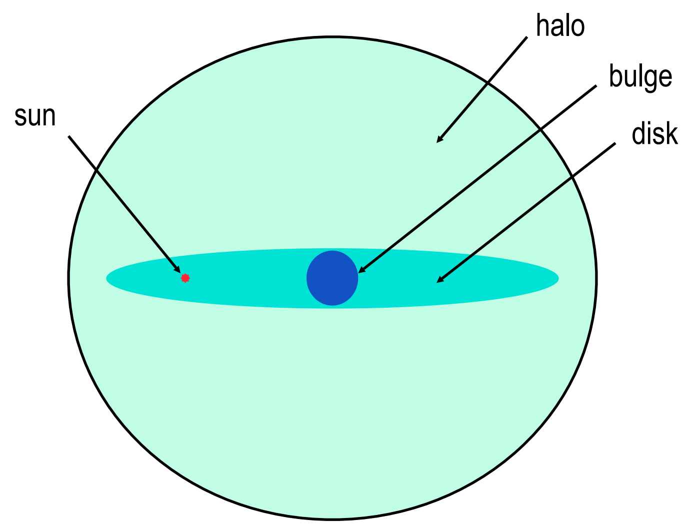


WIMPs in the Galactic Halo

WIMPs – the source of Mass in the Rotation Curves?

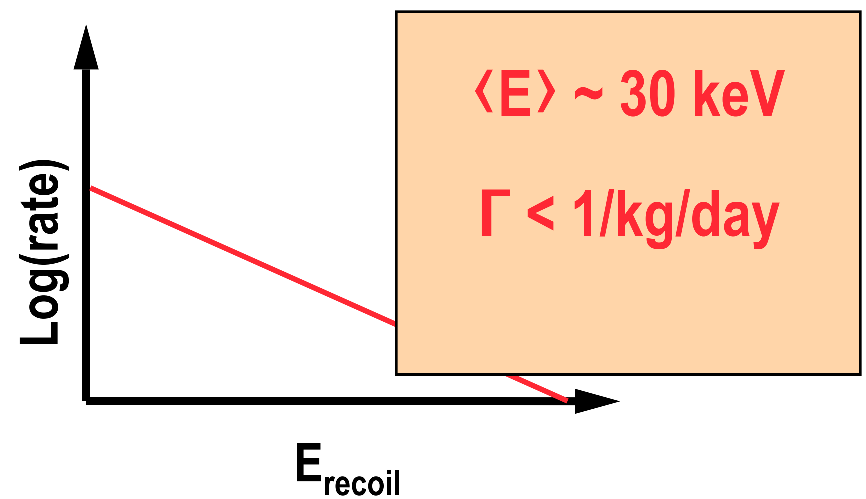


WIMP-Nucleus Scattering

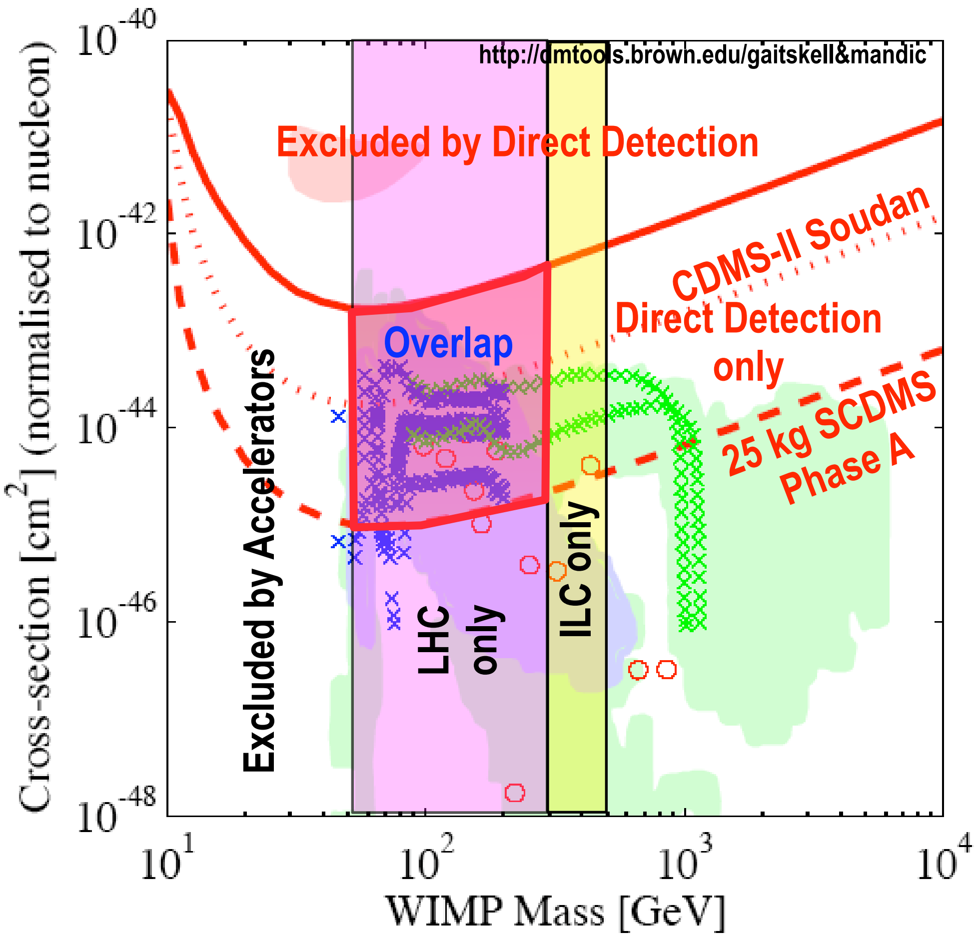


The Milky Way

Scatter from a Nucleus in a Terrestrial Particle Detector



Direct Detection and Accelerators

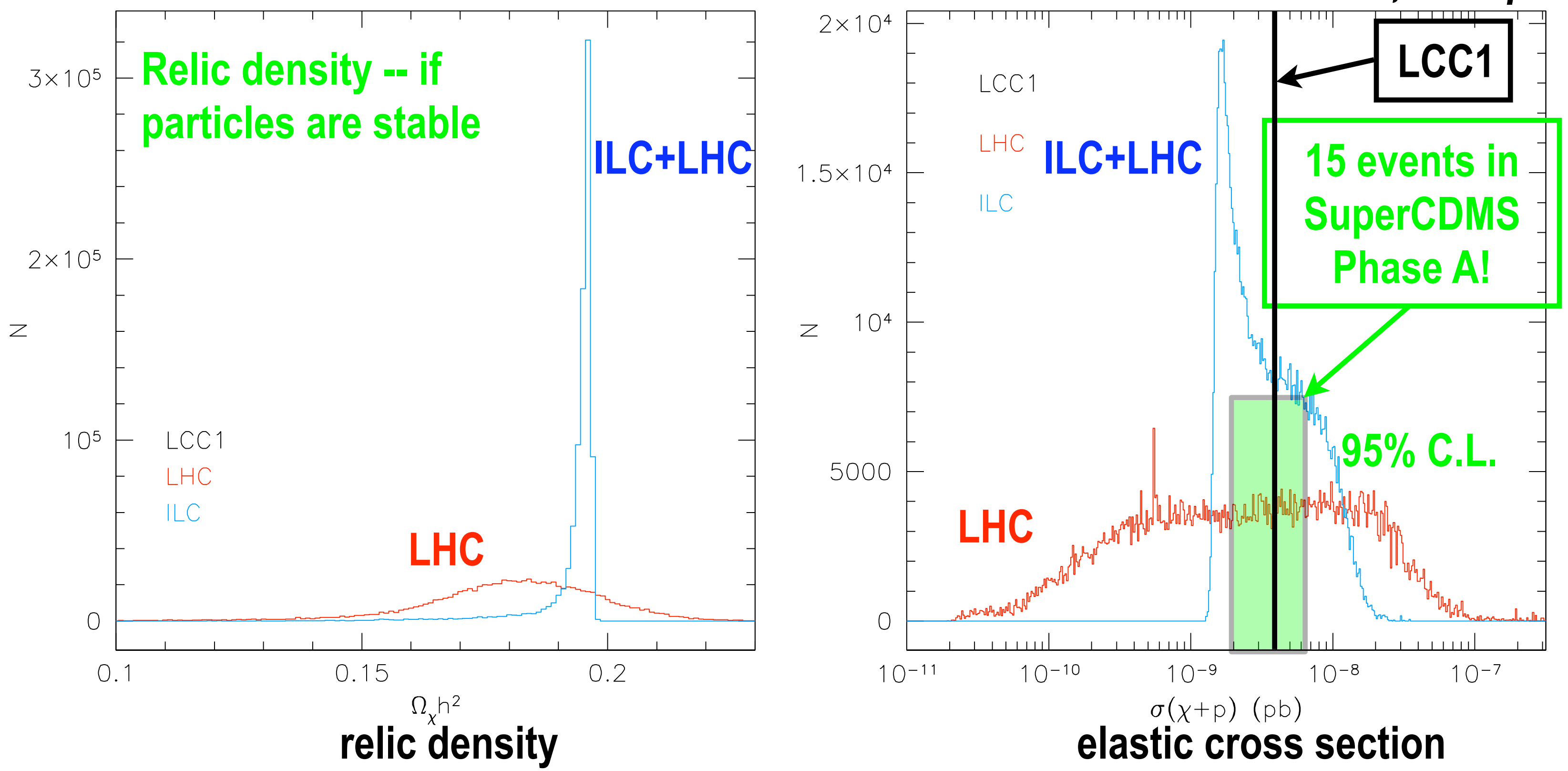


- **Broad mass range of Direct Detection**
  - LHC has 2 Tev limit for gluino, squark, slepton: neutralinos only up to 300 GeV in most SUSY models
  - Direct Detection may indicate a mass too large for LHC but reachable by ILC
- **Accelerators reach down to lower elastic cross section**
  - Potential guidance for direct detection searches
- **Rich Physics in overlap region of LHC and SuperCDMS-25 kg**
  - Exciting opportunity to establish concordant model

WIMPs and SUSY

- **LHC/ILC constraints compared with direct DM searches**
  - Specify a benchmark model, eg, here LCC1 is mSugra 'bulk region,' consistent with WMAP relic density
  - Explore range of all models compatible with accelerator data
  - Constrain secondary parameters

Baltz and Peskin, 2005 prelim.

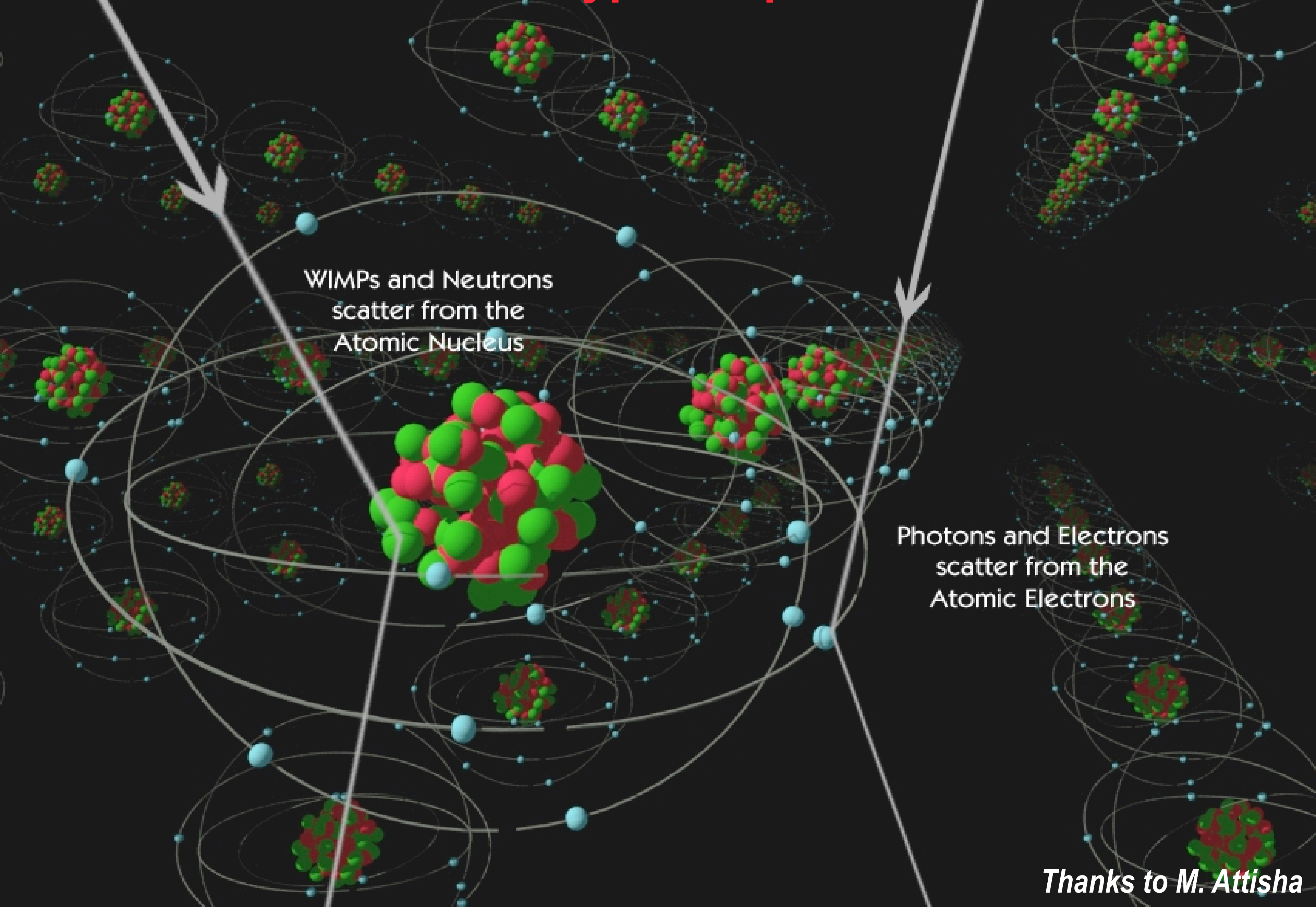


How do we make measurements?

What nature has to offer

What you hope for!

Different types of particles

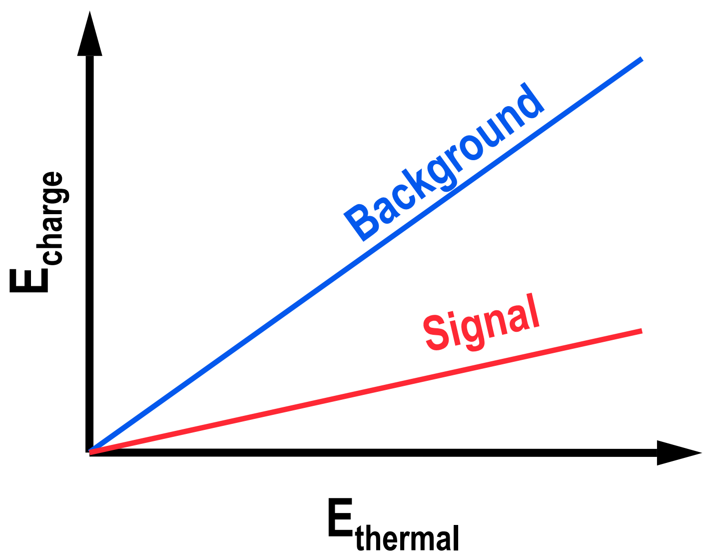


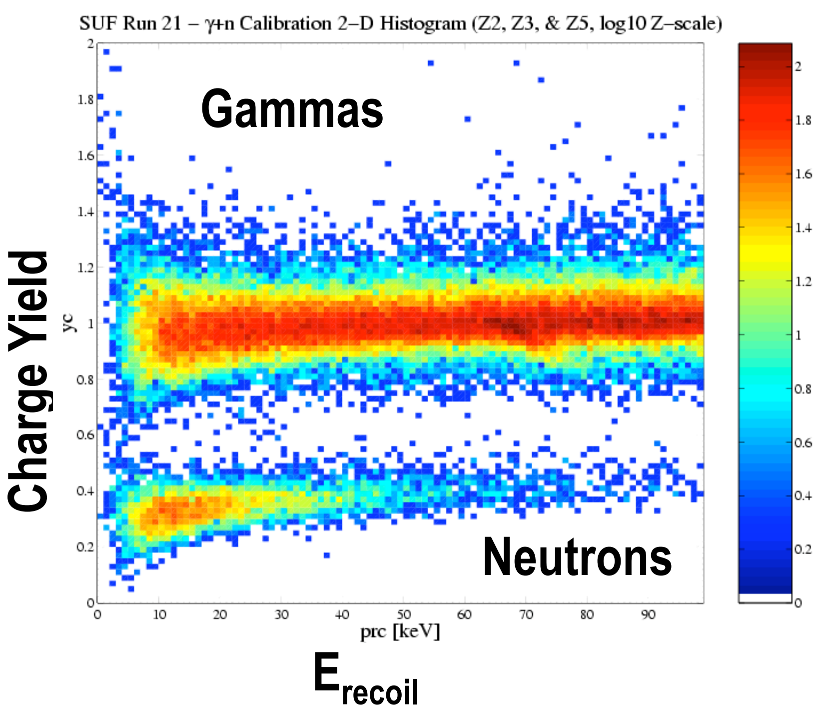
Thanks to M. Attisha

Getting rid of the 'haystack': Recoil Discrimination

WIMPs 'look' different – recoil discrimination

- Photons and electrons scatter from electrons
- WIMPs (and neutrons) scatter from nuclei





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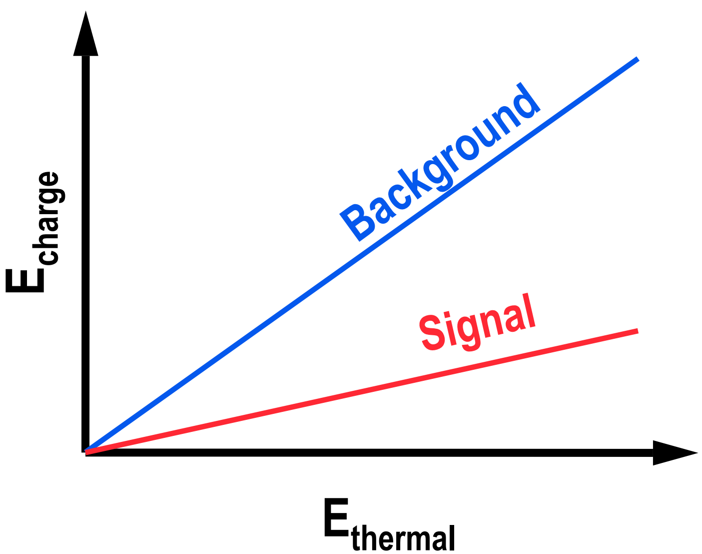
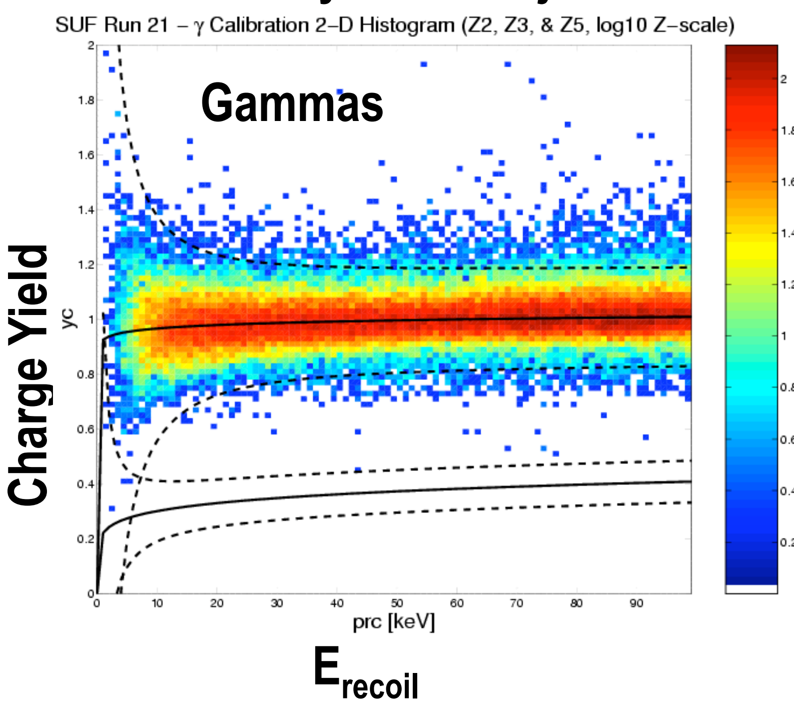
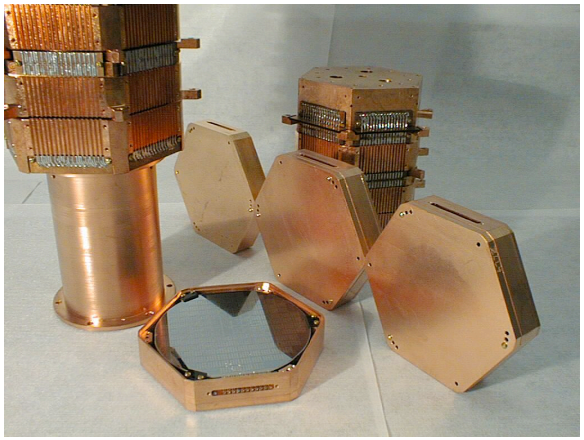


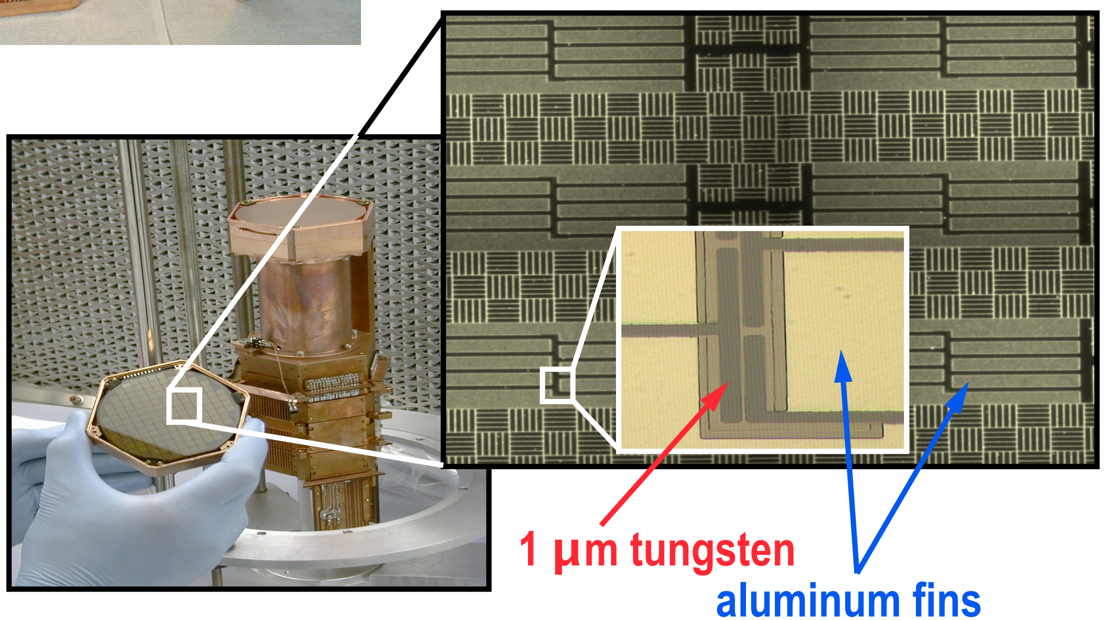
~10 years of rejection



‘Cryogenic’ detectors



- Heat sensitive detectors sensitive to *individual particle interactions.*
- Operated near absolute zero (“cryogenic”)
- Our experiment is called the Cryogenic Dark Matter Search (CDMS)

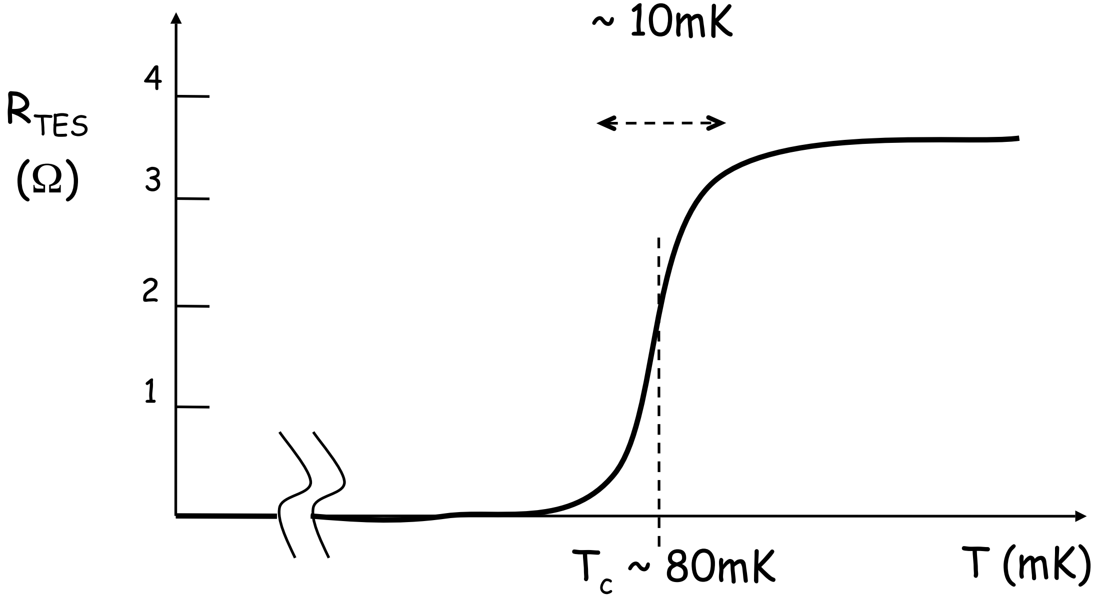


- The detectors are cooled in dilution refrigerators to ~20mK

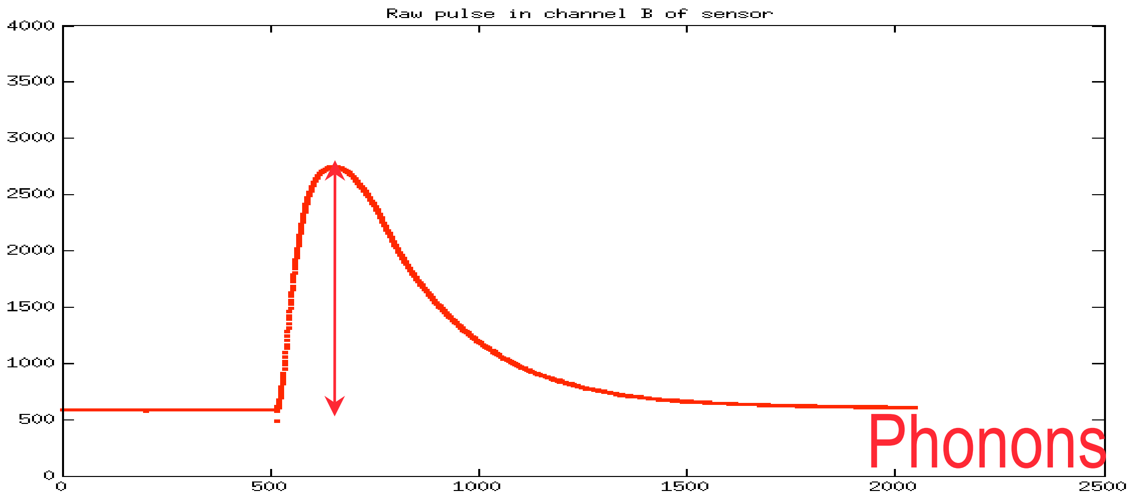
Superconducting Films: Ultrasensitive Thermometers

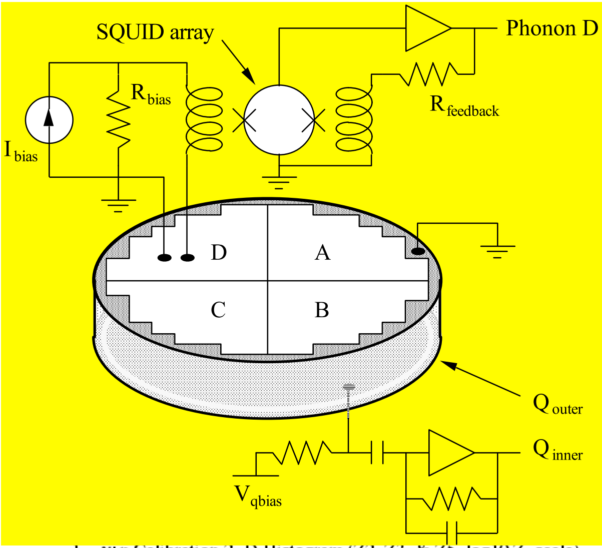
Superconducting films that detect minute amounts of heat

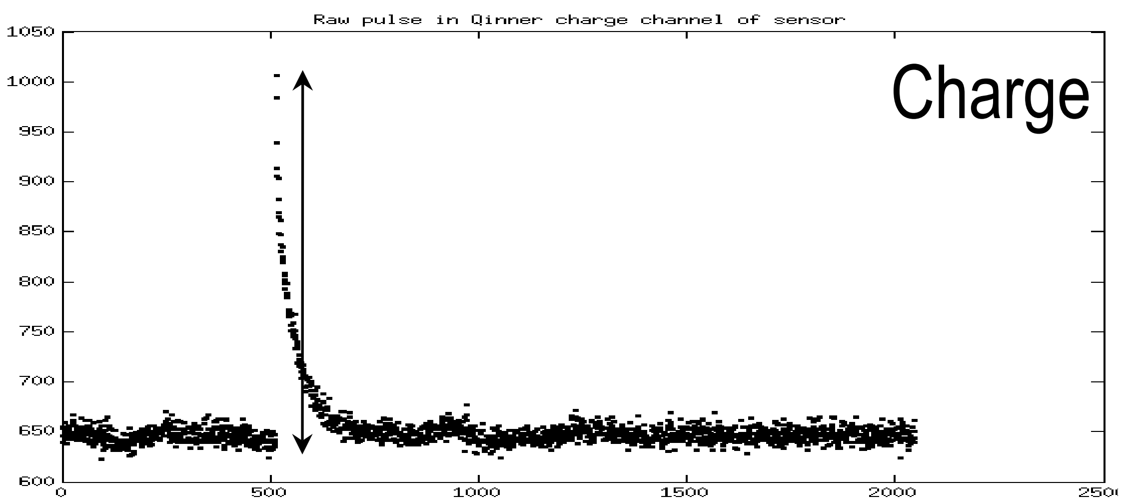
Transition Edge Sensor sensitive to fast athermal phonons

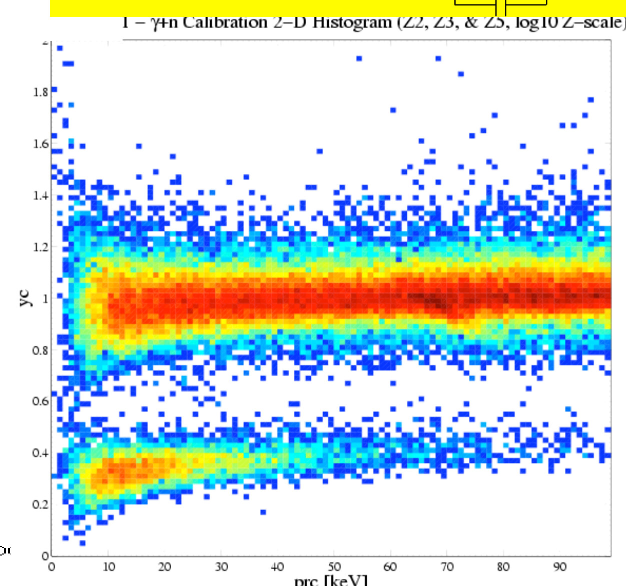


The Voltages We Measure







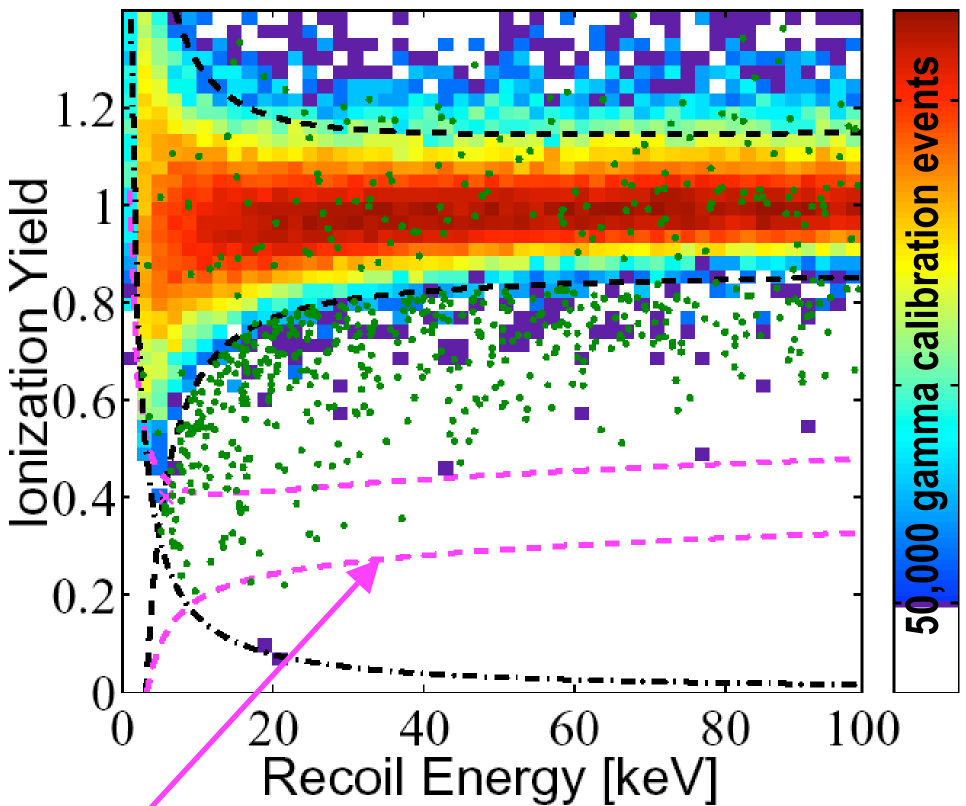


Charge/Phonons

Phonons – Charge = Recoil energy

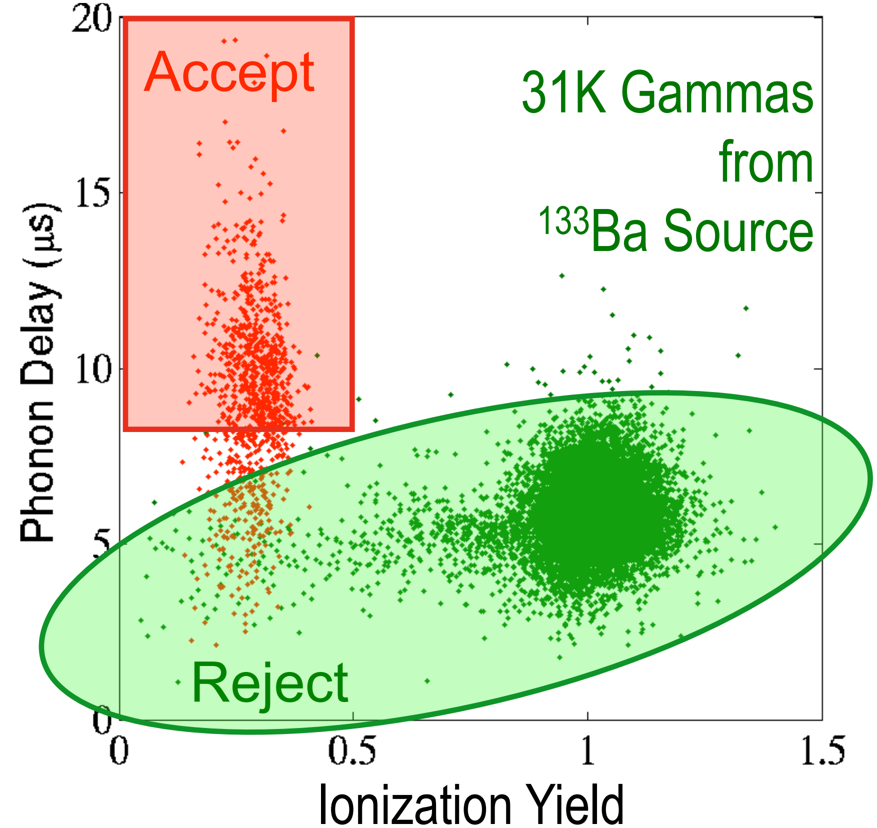
Betas: a low-yield background source

- Particles (electrons) that interact in surface "dead layer" of detector result in reduced ionization yield



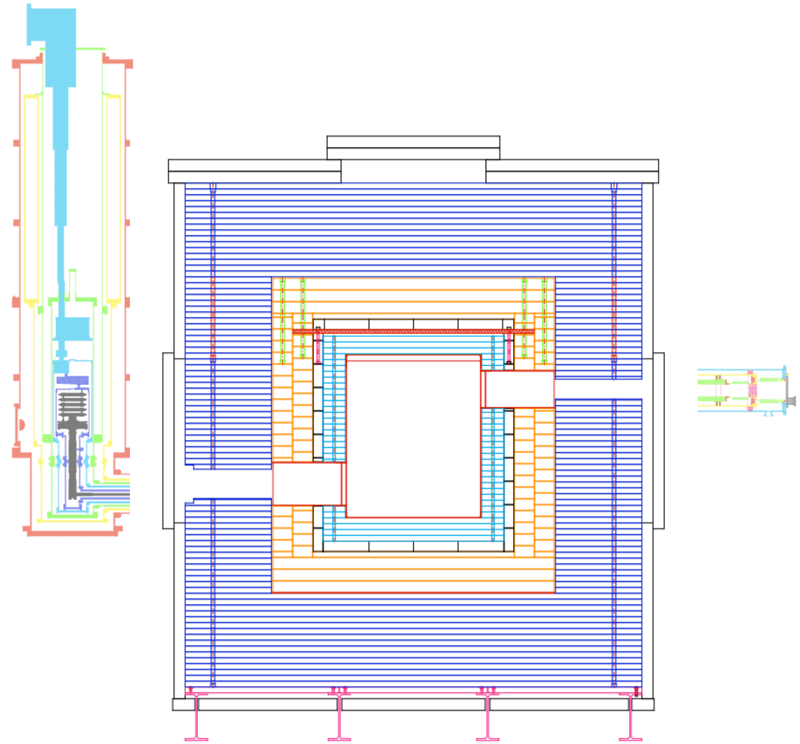
Nuclear-recoil WIMP-signal region

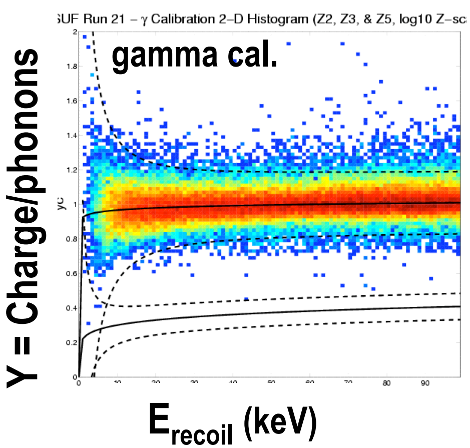
Neutrons from ^{252}Cf source

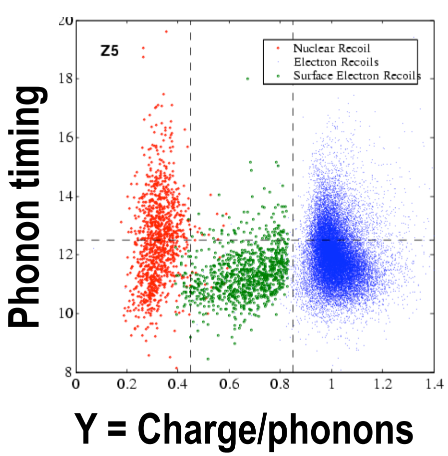


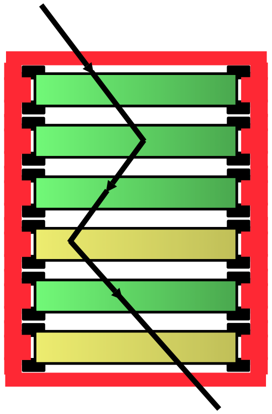
CDMS Strategy

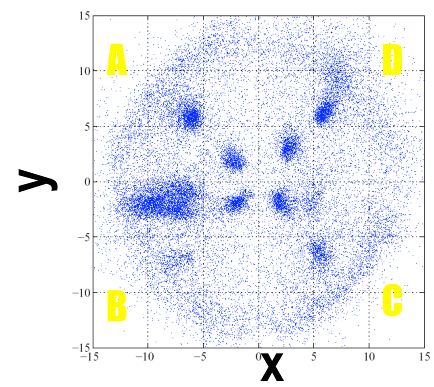
- Minimize residual contamination
- Underground site: hadrons, μ
- Muon veto: cosmogenic γ, β, n
- Pb shield: γ, β
- Polyethylene shield (moderator): n
- Charge yield: γ, β
- Phonon-pulse timing: surface events (β)
- Multiple-scatters: n
- Silicon vs Germanium: n
- Position information: optimization/systematics



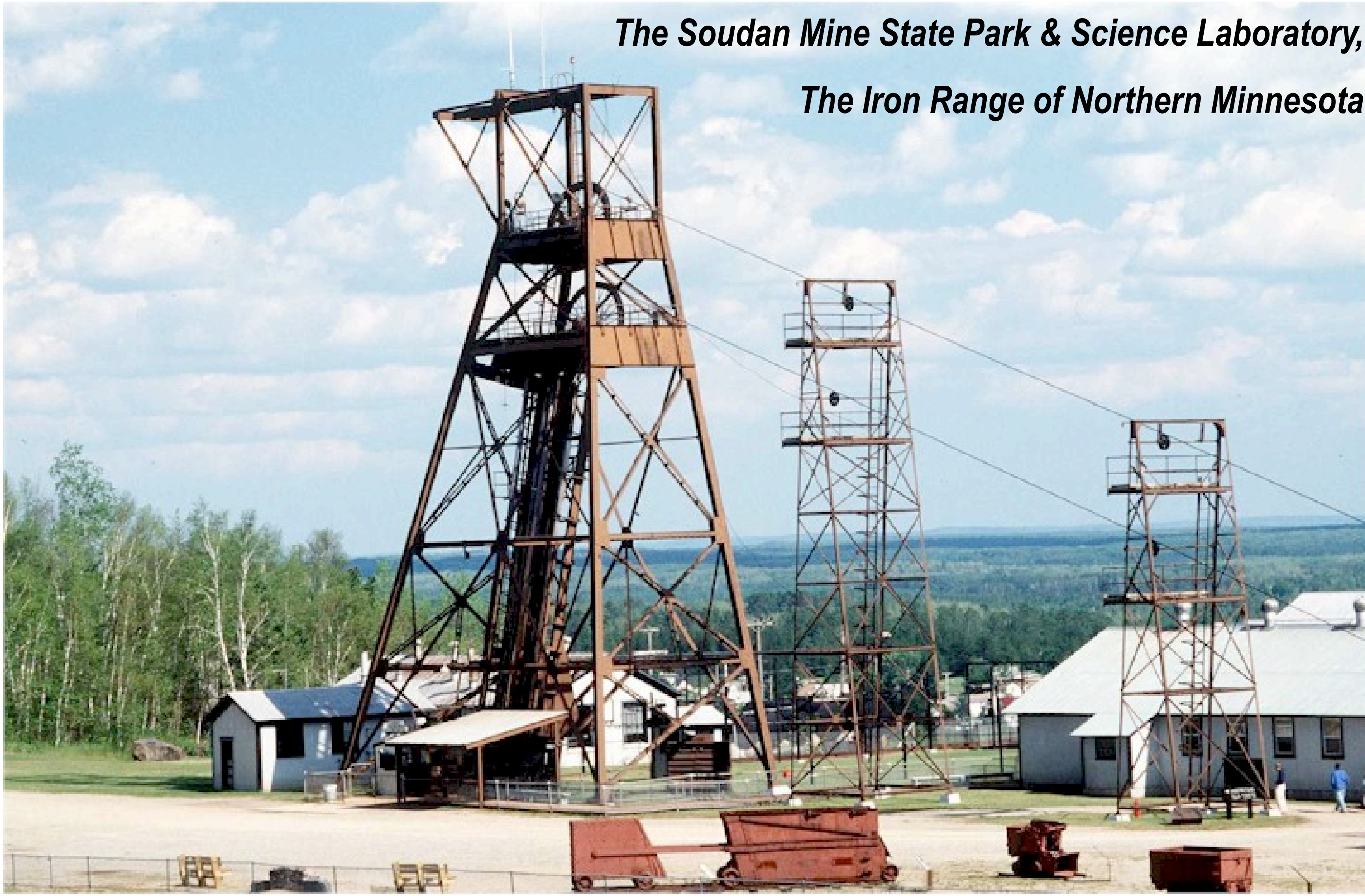








Got Neutrons? – Go Deep…

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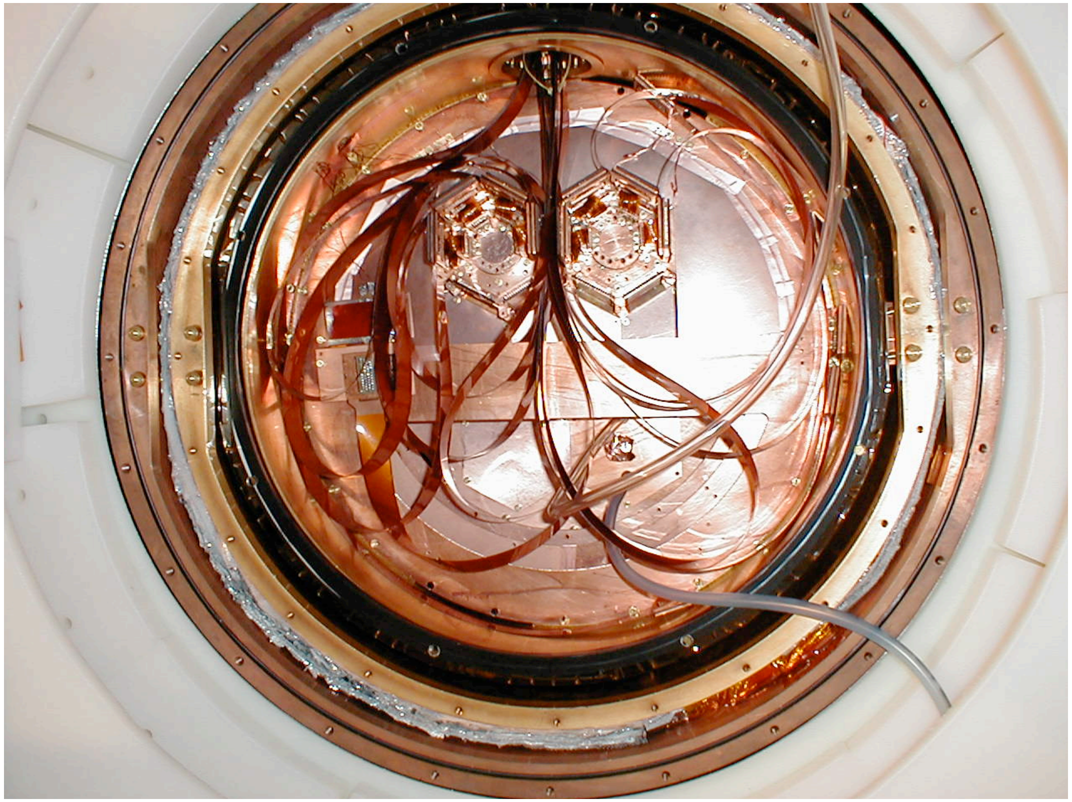
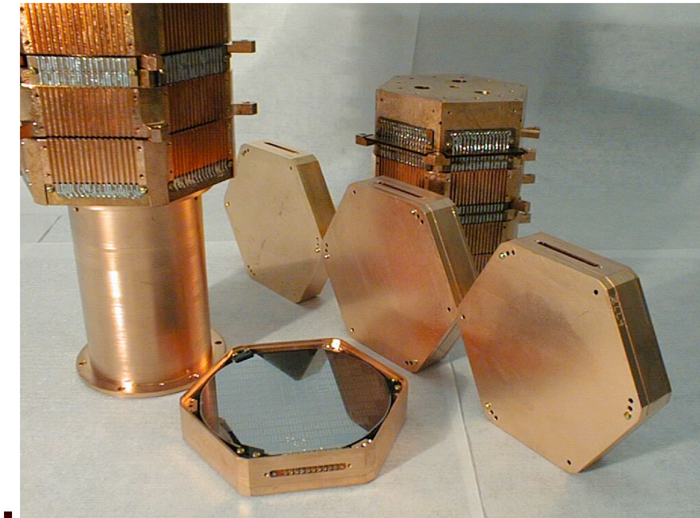
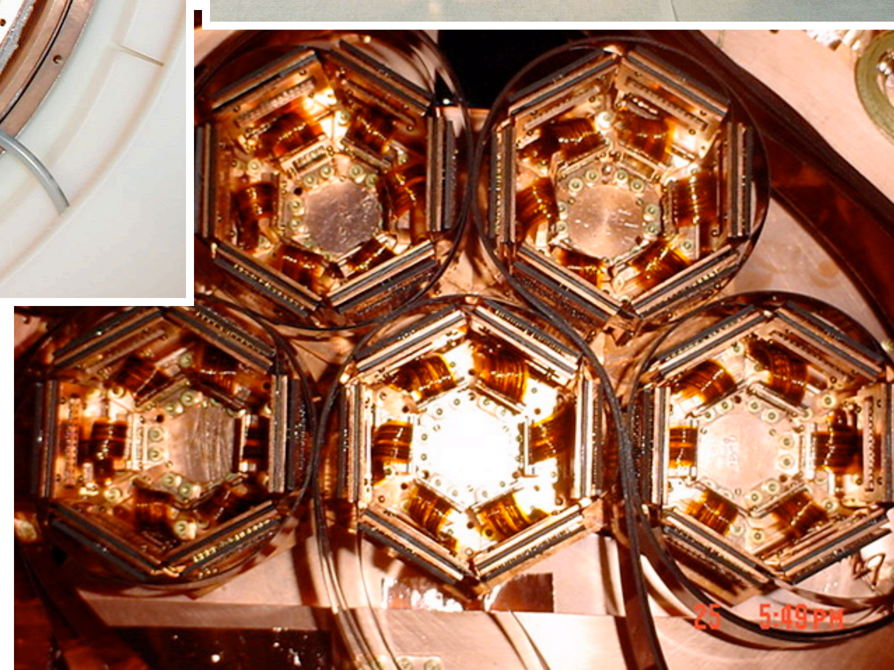
The CDMS II Apparatus

- The Soudan Mine refrigerator includes a low-radioactivity '*clean room'* shielded environment
- Science data commenced October 2003
- 2000 mwe depth
  - ~10^5 reduction in muon flux
  - ~400x reduction in fast neutrons
- Results from running first two "Towers"

Detector Towers in Soudan







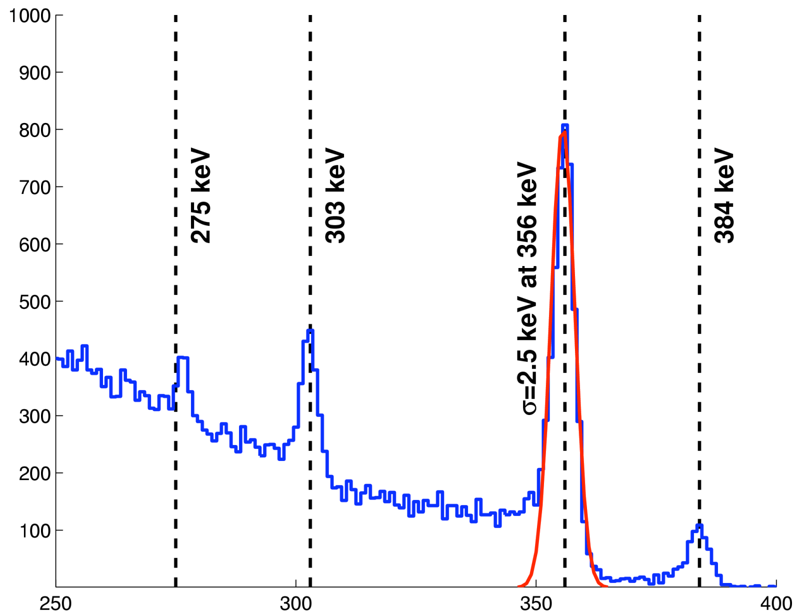
2 towers operated in ‘03-’04

Full 5 towers now ready to go…

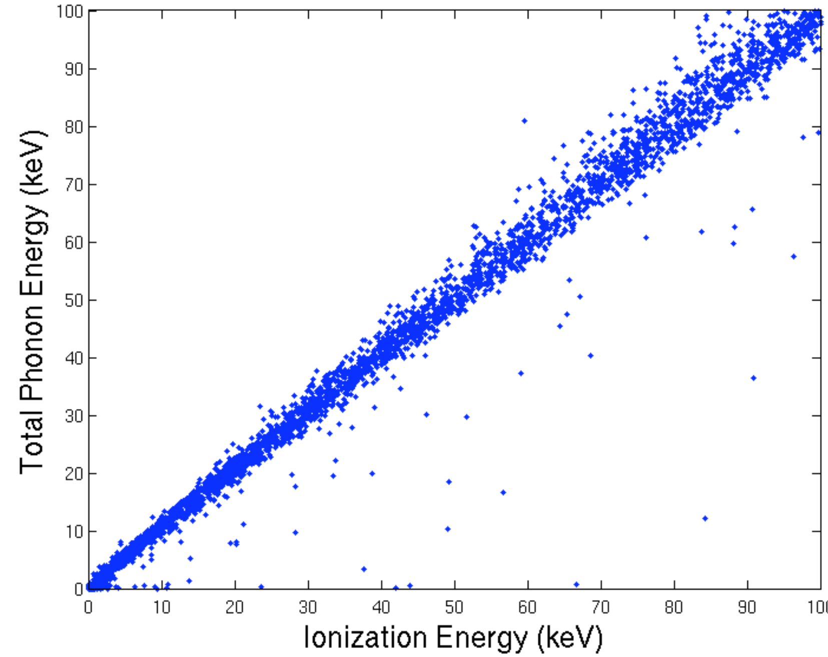
In situ Energy Calibration (after position corrections)

Ionization Energy resolution
8-10 keV (at 356 keV)
0.3 keV (at 10 keV)

^{133}Ba peaks in a Ge ZIP



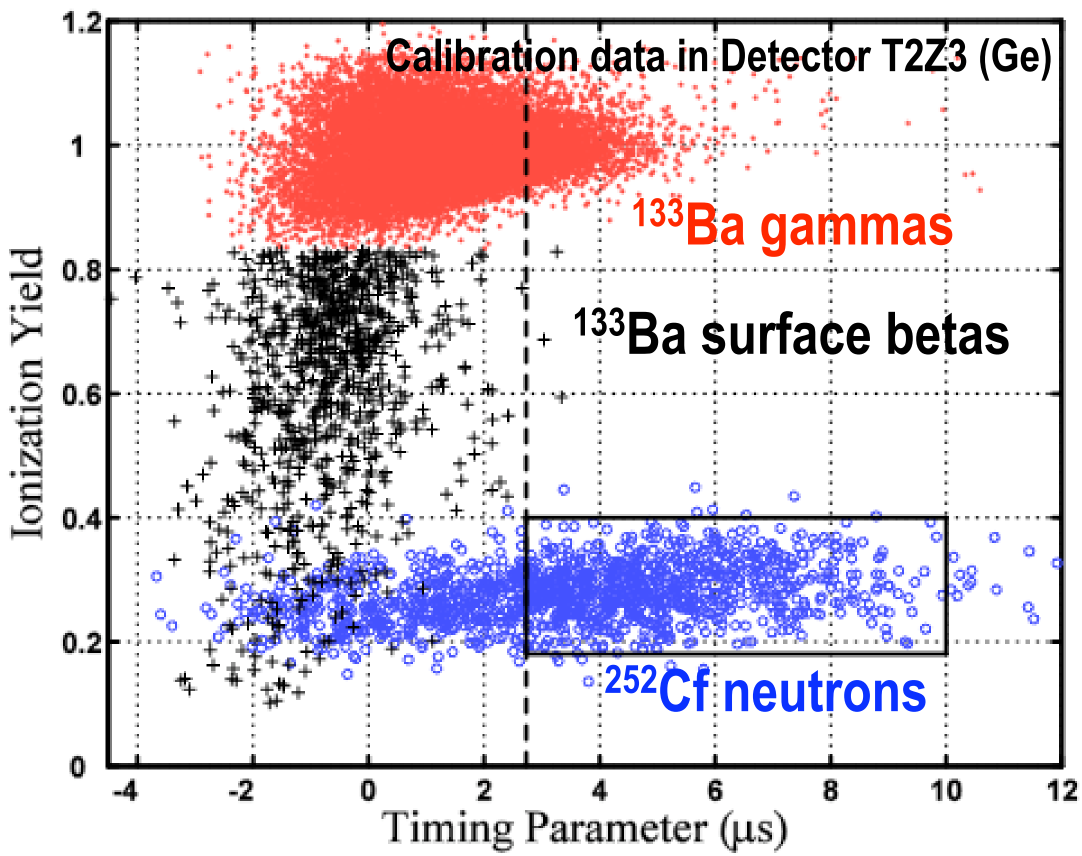
Ionization energy (keV-ee)

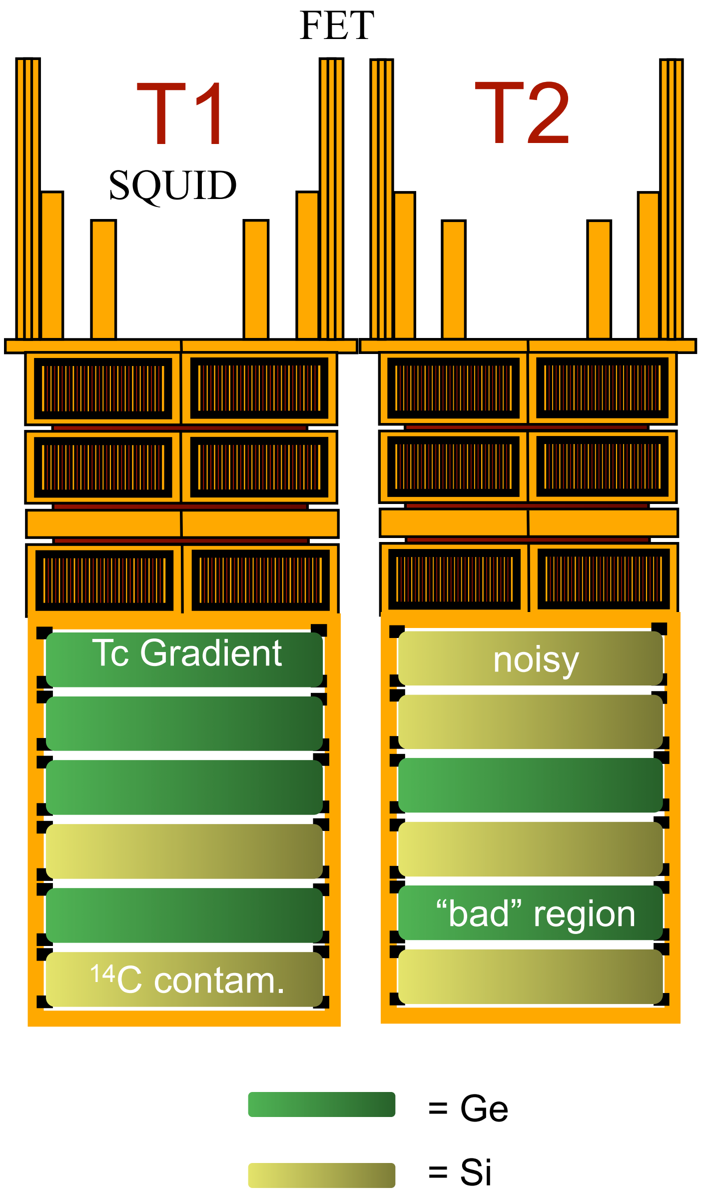


Normalize phonon recoil energy to ionization energy for gammas from ^{133}Ba.

Mask signal region: Blind analysis to minimize bias

- **Cuts set on calibration data and non-masked WIMP-search data**
  - timing parameter
  - ionization yield
  - problem detectors/channels

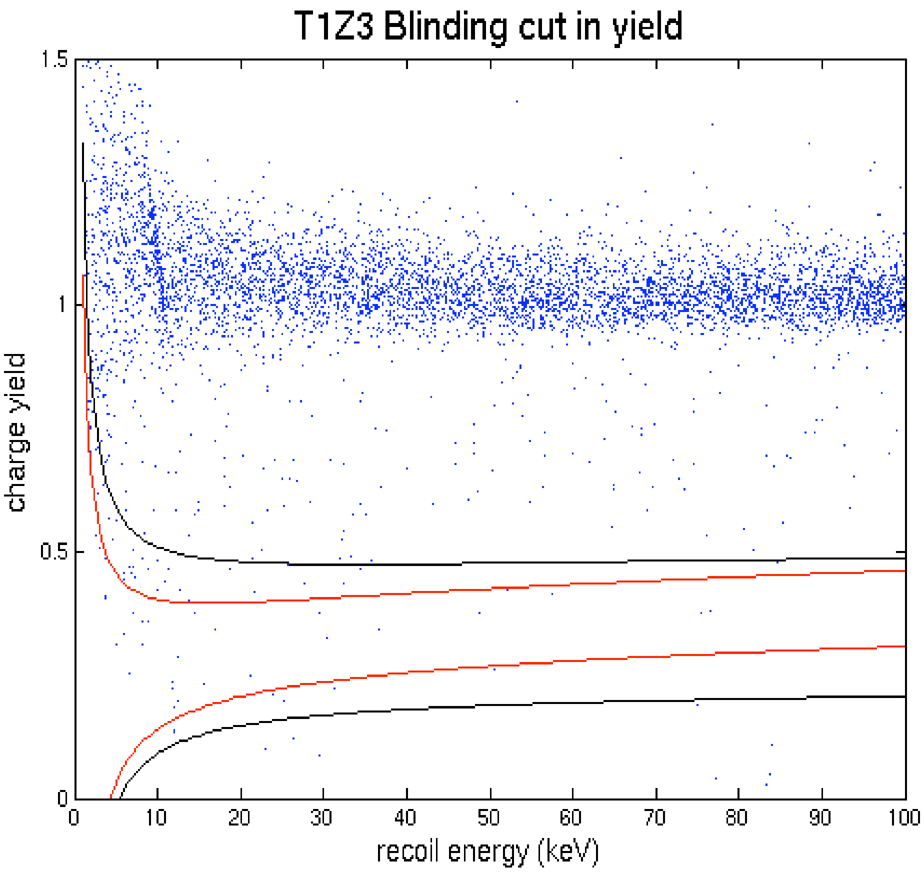




CDMS Blind Analysis & Background Leakage

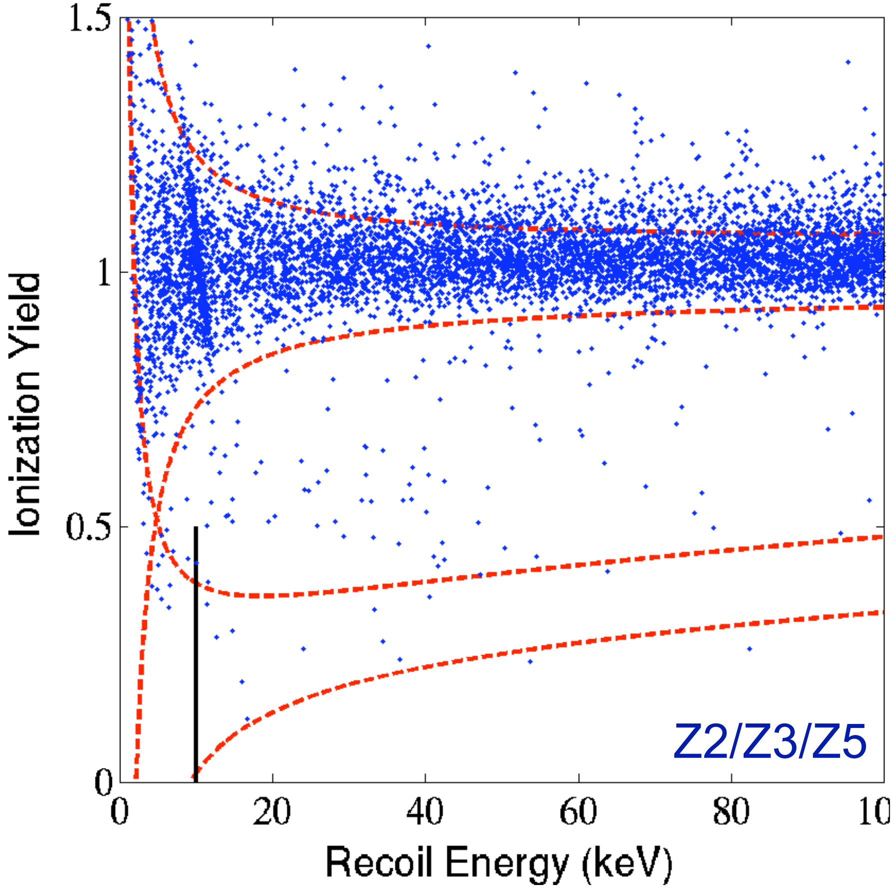
- Mask signal region in WIMP-Search Data
  - hide oversized nuclear-recoil band, single-scatter, unvetoed
- Base cuts on calibration data (previous slide)
- Estimate leakage by normalizing to non-masked WIMP search data
  - eg, multiple-scatter events in reduced-yield region predicts leakage into signal region
  - Tune cuts for ~0.5 background
- Signal region defined by neutron calibration
- UNBLIND

non-masked WIMP search data: events in nuclear recoil band are multiple scatters

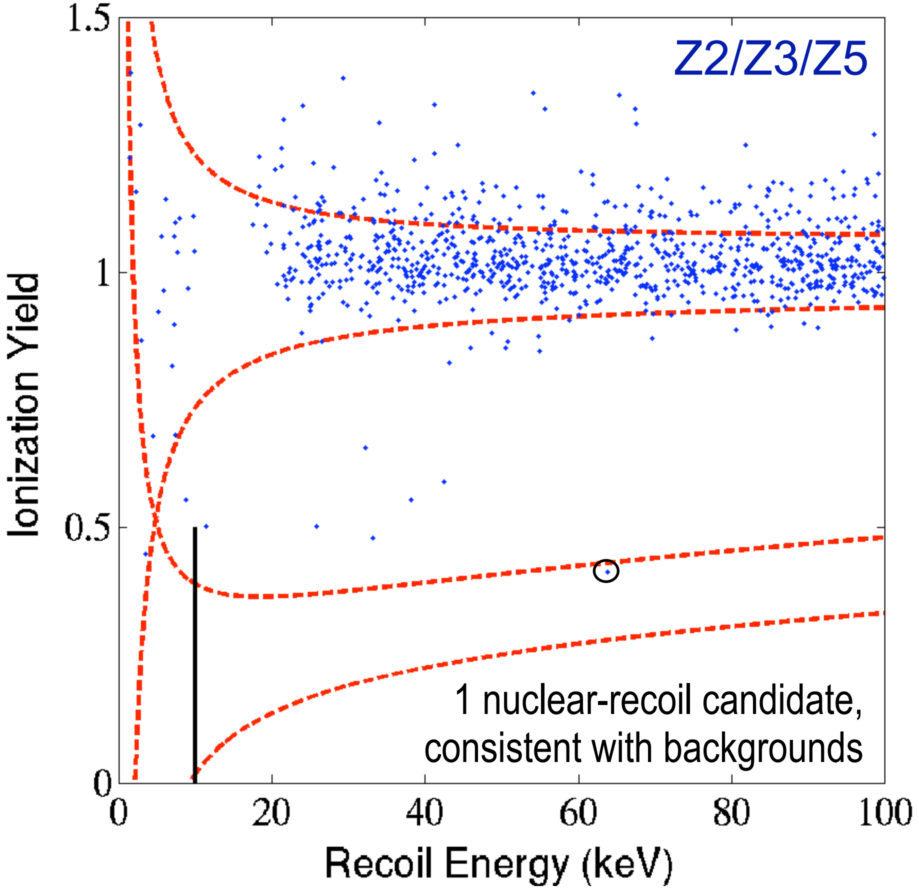


First Soudan Run WIMP-search data

Before timing cuts



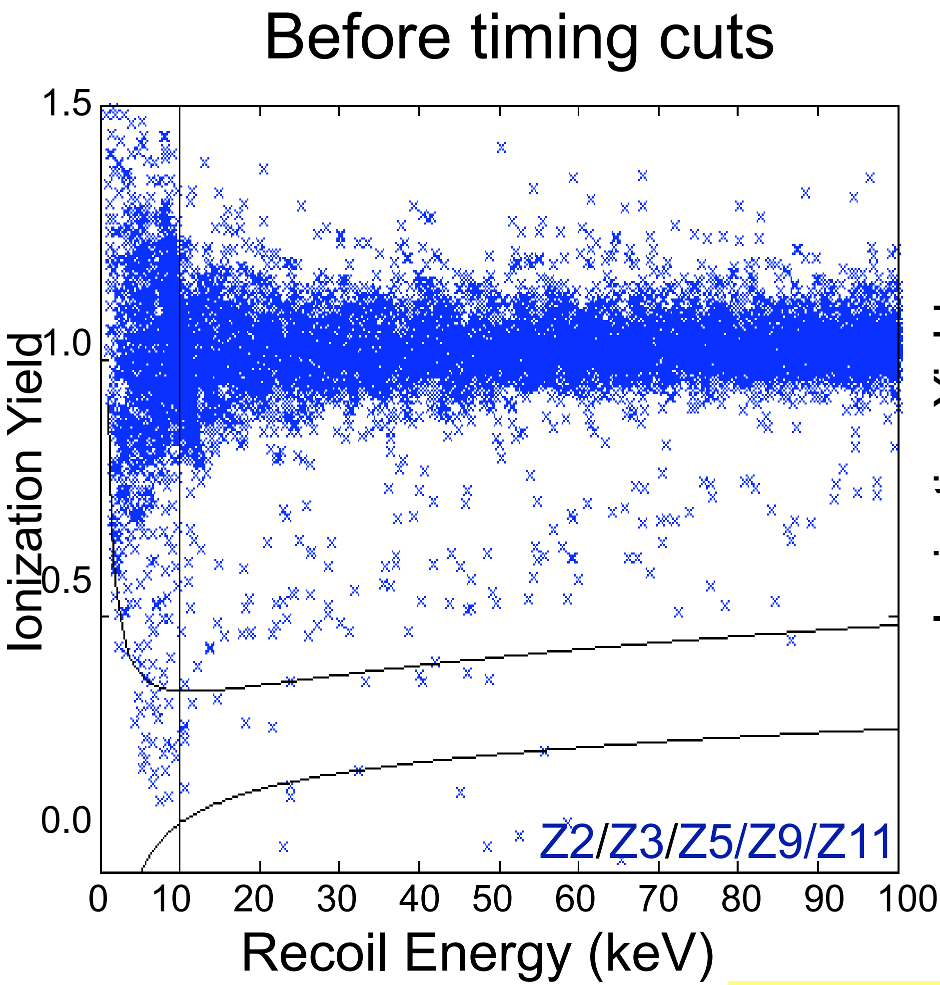
After timing cuts

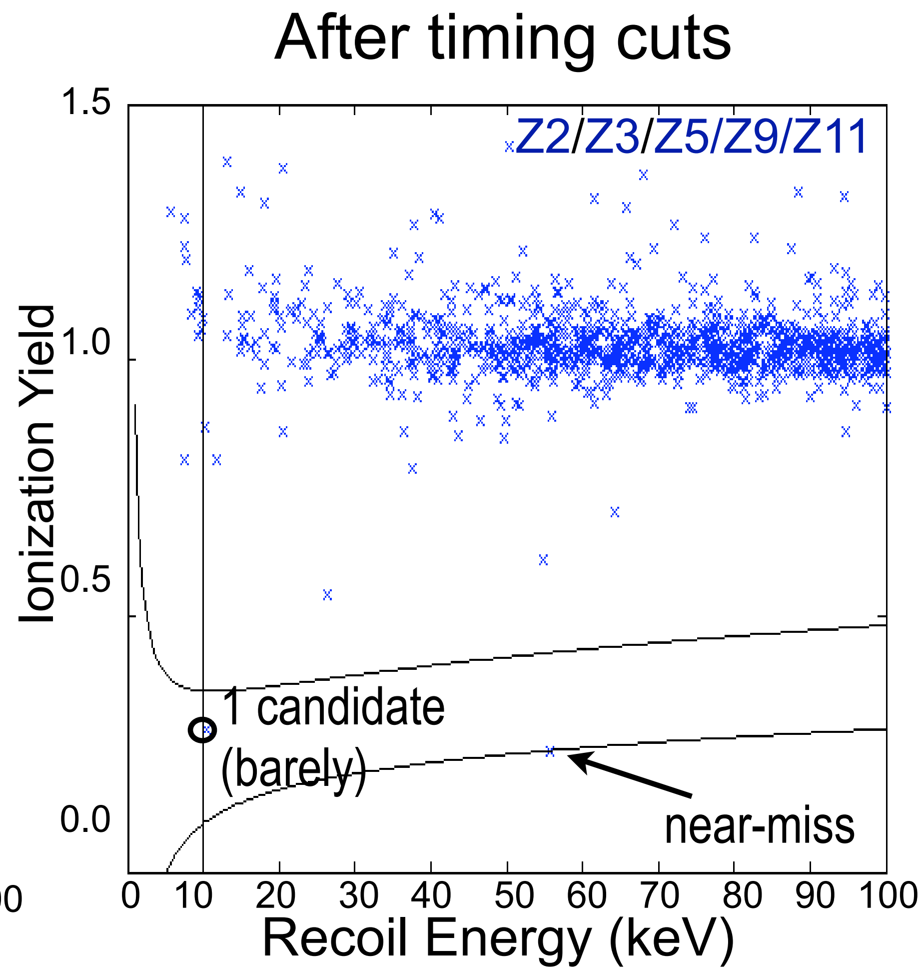


19 kg-d after cuts

0.7 ± 0.35 misidentified electrons (w/Z1),
0.02 recoils from neutrons expected (w/ Z1)

Second Soudan Run WIMP-search data



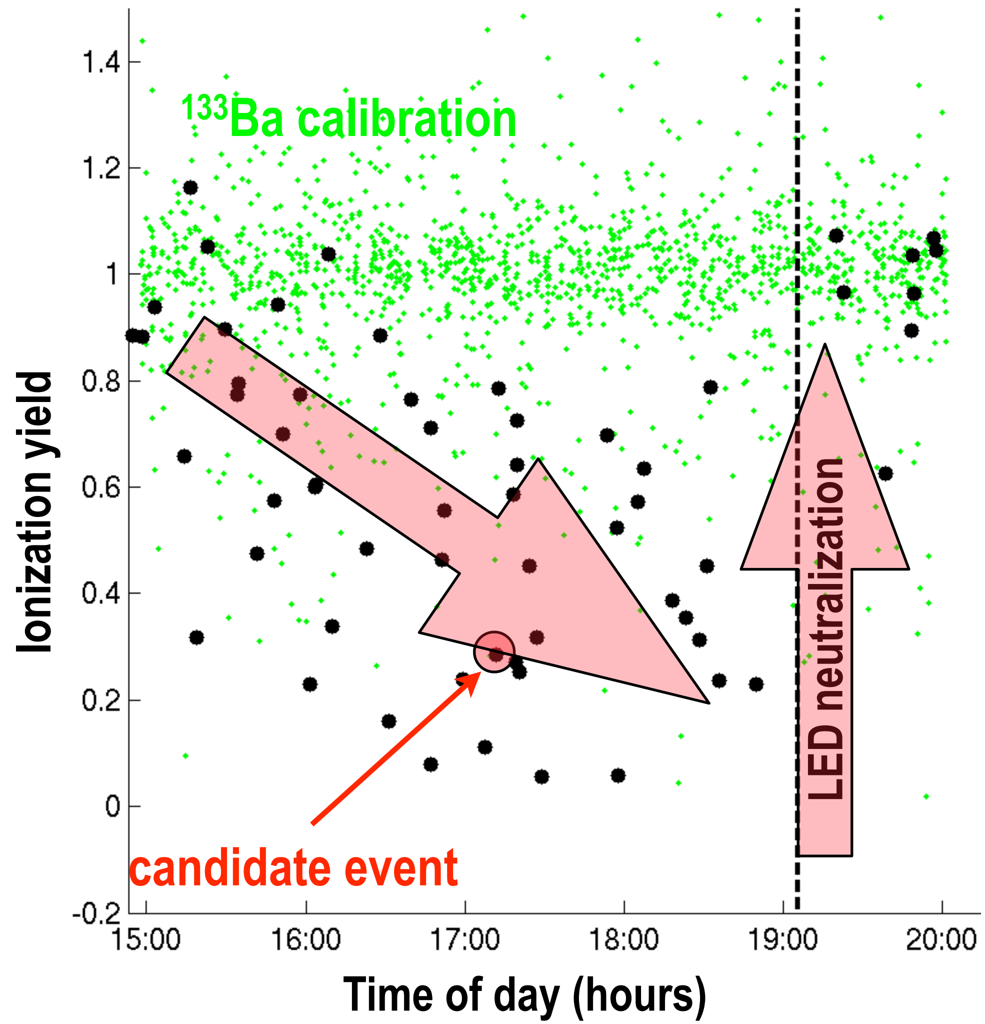


34 kg-d after cuts

ESTIMATE BKG: 0.4 ± 0.2 (sys.) ± 0.2 (stat.) electron recoils, 0.05 recoils from neutrons expected.
Optimized for ~0.5 background events

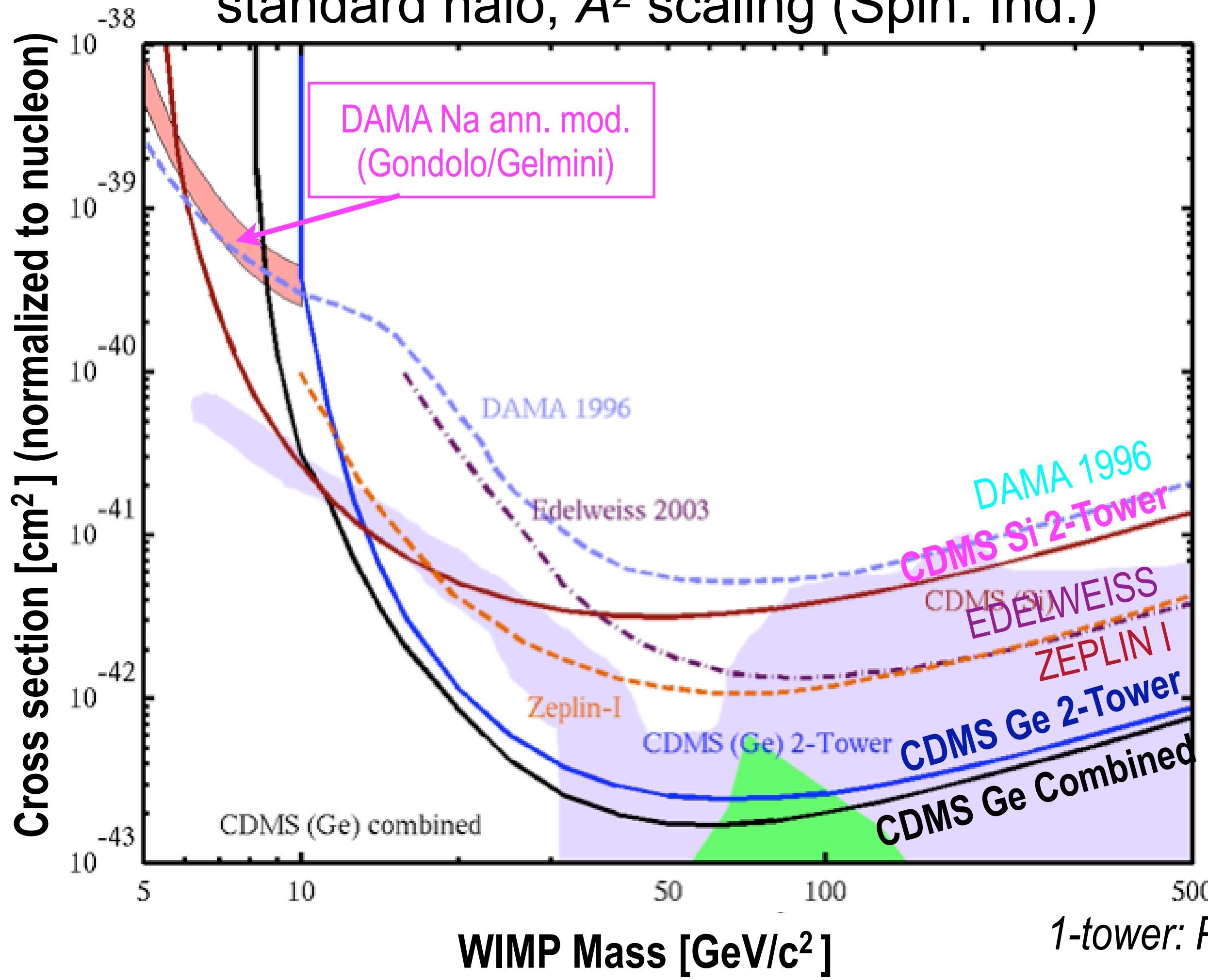
Candidate event: poor neutralization

- **Automatic LED flash every 4 hours to discharge trapping sites**
- **The one candidate event comes from a run with poor neutralization!**
  - anomalous population of low-yield events
  - improved screening for next run
  - anyway, consistent with background
  - included (worsen) upper limit on cross section



1st Year CDMS Soudan Combined Limits

90% CL upper limits assuming standard halo, A^2 scaling (Spin. Ind.)

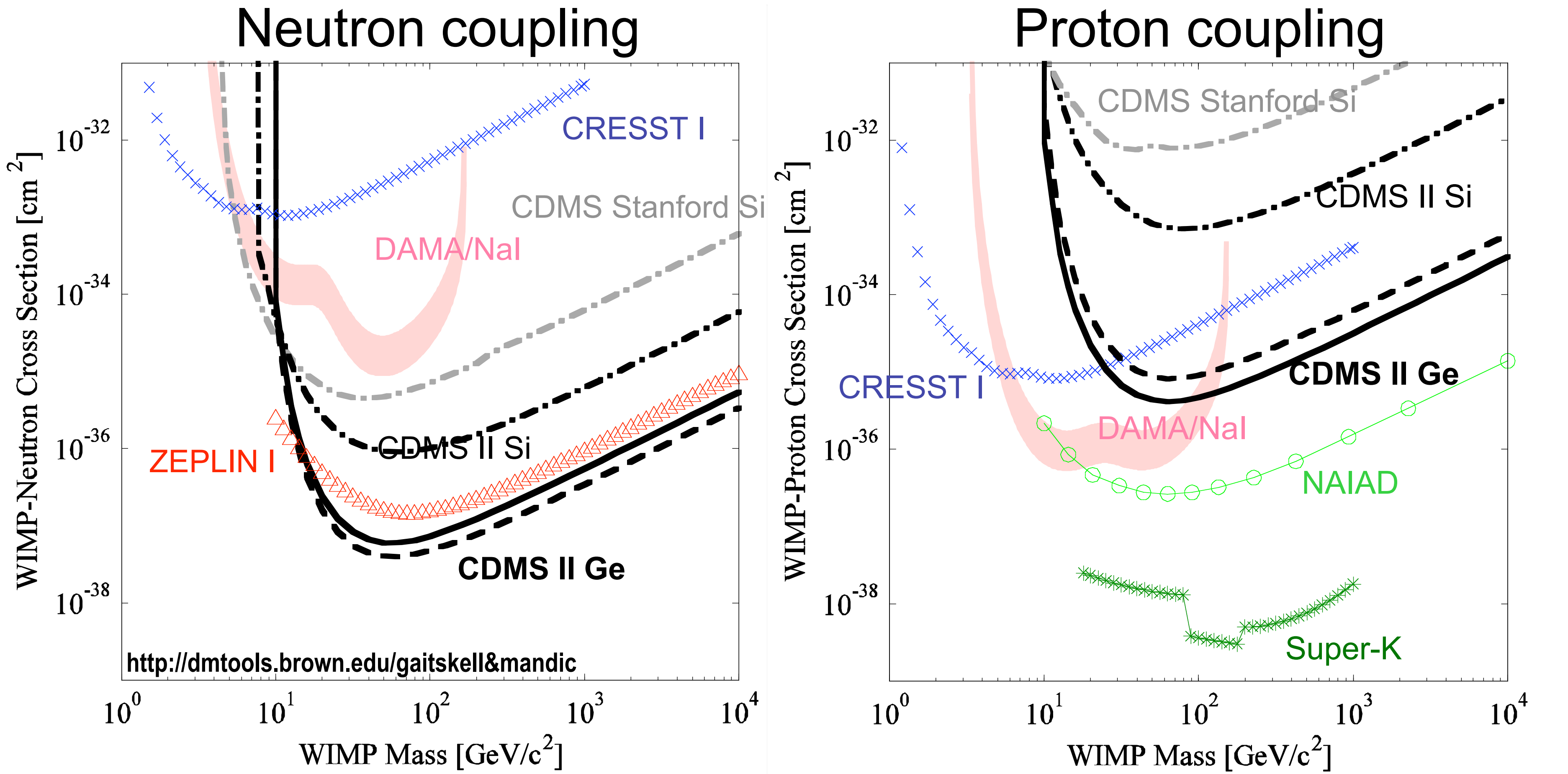


- **Upper limits on the WIMP- nucleon cross section are 1.7×10^{-43} cm^2 for a WIMP with mass of 60 GeV/c^2**
  - **Factor 10 lower than any other experiment**
- **Excludes regions of SUSY parameter space under some frameworks**
  - **Bottino et al. 2004 in magenta (relax GUT Unif.)**
  - **Ellis et al. 2005 (CMSSM) in green**

*1-tower: Phys. Rev. Lett. **93**, 211301 (2004); astro-ph/0507190 (PRD - in press)*

2-tower and combined: astro-ph/0509259

Spin-Dependent WIMP limits



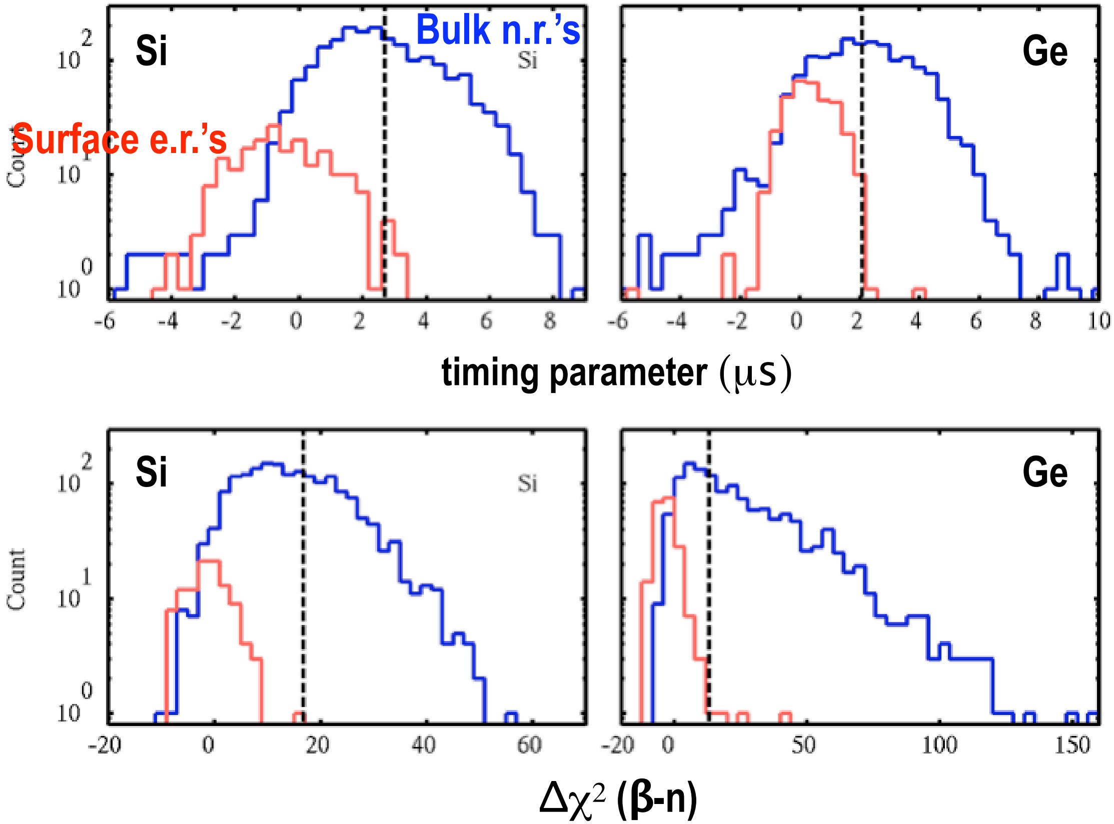
astro-ph/0509269

Following the method of C. Savage, P. Gondolo, and K. Freese, PRD70, 123513 (2004) (astro-ph/0408346).

Improvement to surface rejection

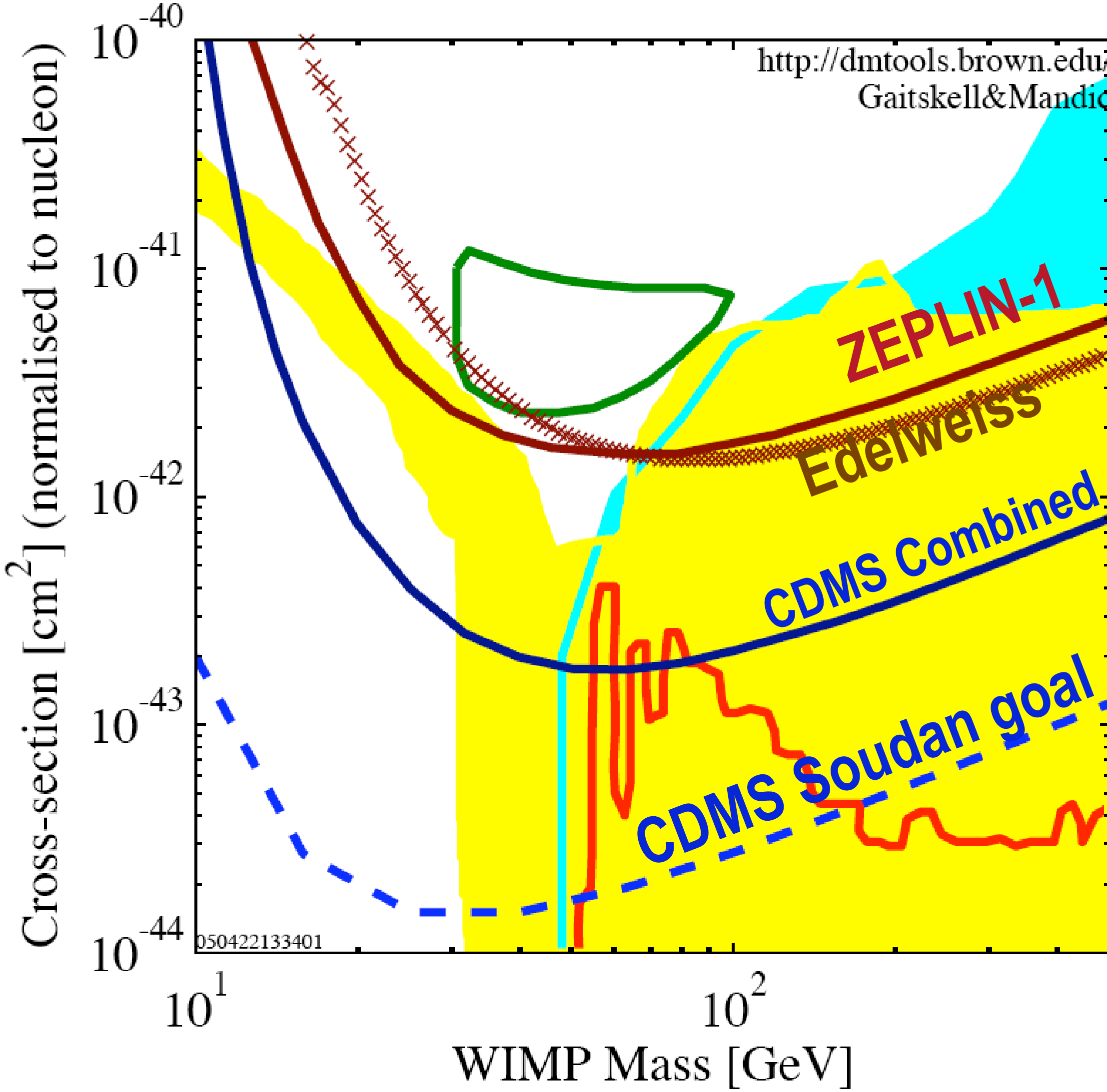
- Performed 4 other blind analyses (consistent results - 20%)
  - Primary analysis (Ge) based on simple/robust timing parameters -- energy-corrected delay + risetime -- chosen before unmasking
  - More sophisticated analyses -- more detector information (position, phonon energy partitions)

Better rejection for planned exposure: can expect approx. zero background in 5-tower run



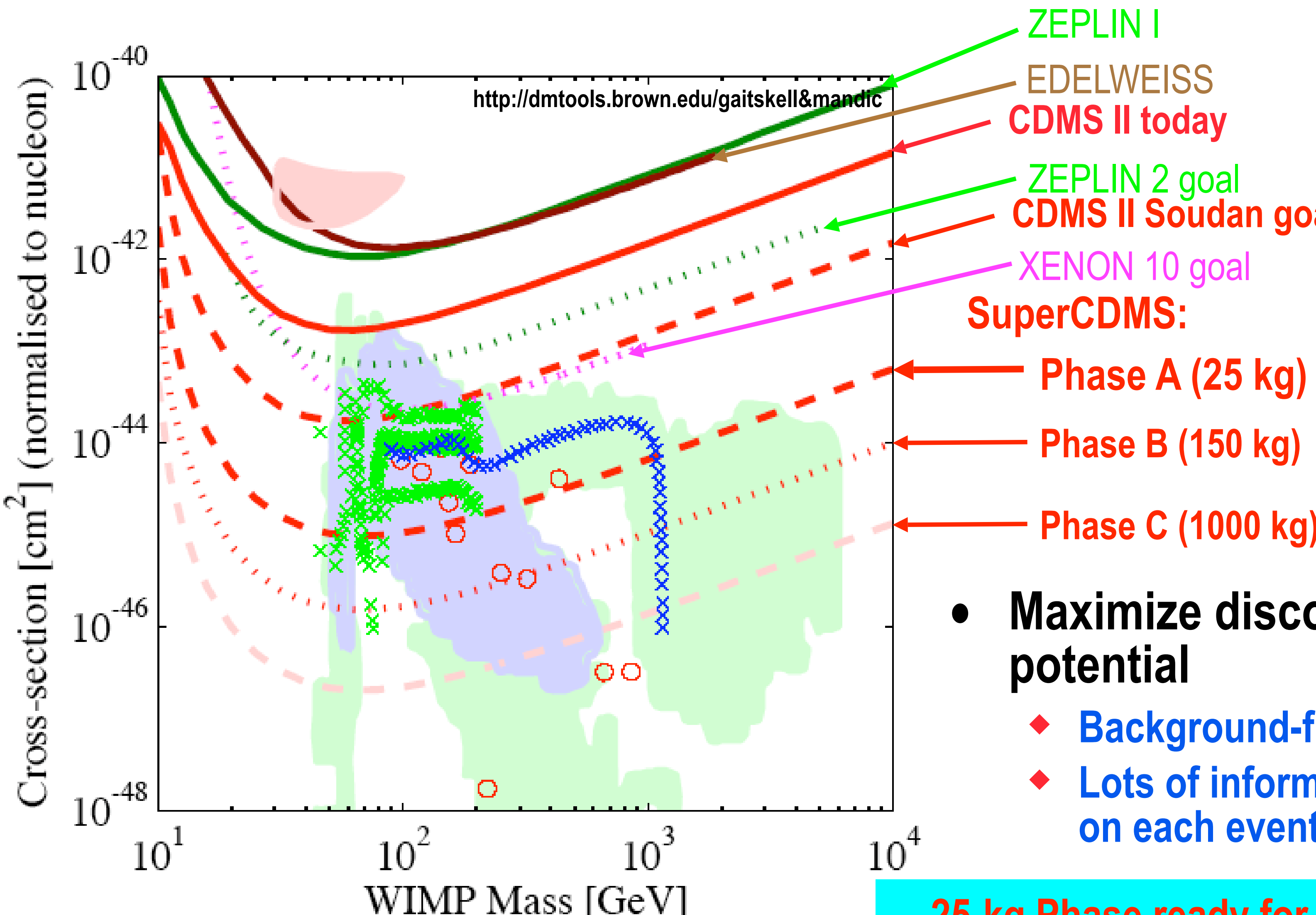
Projected CDMS Sensitivity

Started 5-Tower Run



- Additional improvements
  - Cryogenics, backgrounds, DAQ
  - Currently commissioning
- 30 detectors in 5 towers of 6
  - 4.75 kg of Ge, 1.1 kg of Si to run through 2006
  - Improve sensitivity x10

SuperCDMS: phased approach to 1-ton

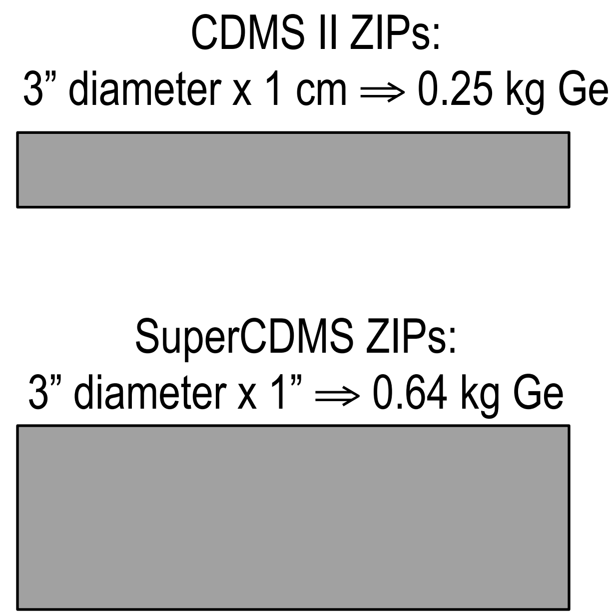


- **Maximize discovery potential**
  - Background-free
  - Lots of information on each event

25-kg Phase ready for review

Phase A: technology baseline

- **Increase thickness from 1 cm to 1 inch**
  - Less surface area per mass, so 2.54x fewer background surface events per unit mass
  - Eases production -- make fewer detectors for a given mass
- **Optimize amorphous-Si electrodes**
  - Yield-only discrimination of ZIPs is 2x worse than older detectors made with different recipe. Return to old recipe (17:83 H_2:Ar atmosphere) and optimize.



Also working to develop other, potentially more significant improvements (more on that) -- above two straightforward changes may well be enough.

Photon and Electron Backgrounds

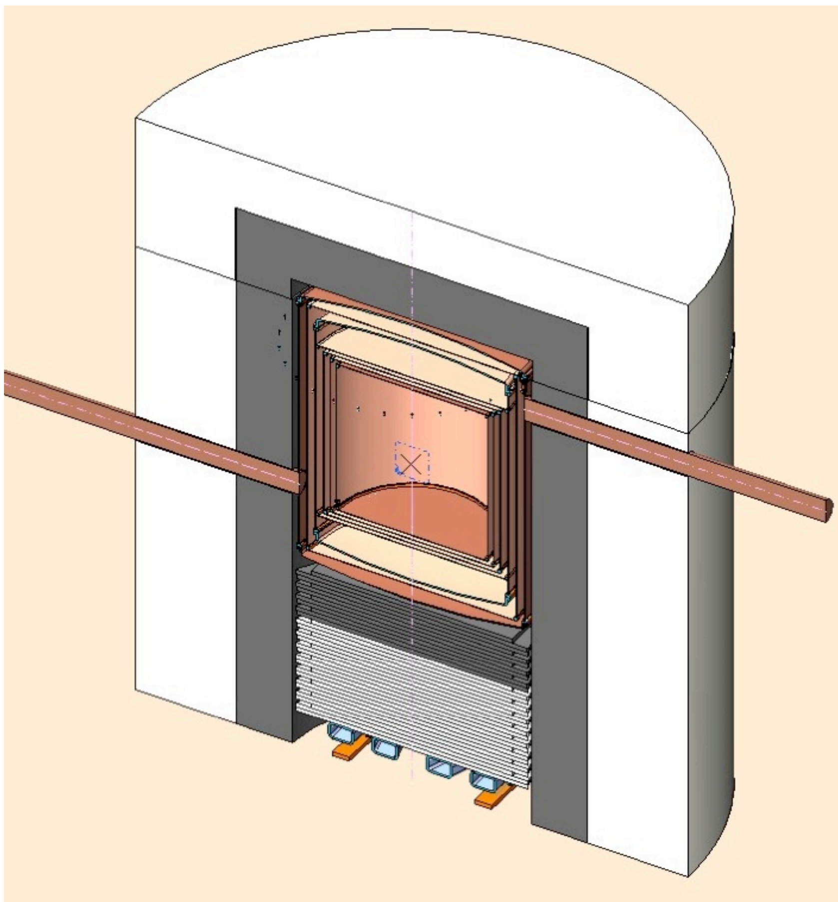
SuperCDMS Phase A: zero background goal in reach

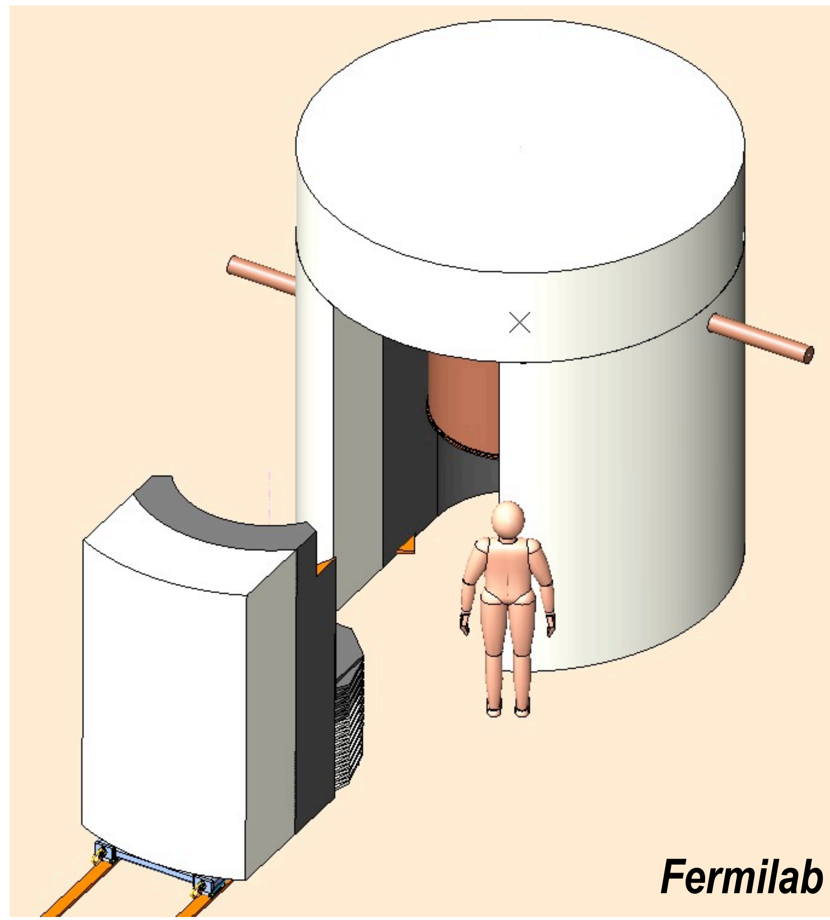
	Photons	Electrons
Current raw rate (events/ exposure) [25 kg, 500 days]	1 x 10^6	2 x 10^3
Published rejection	10^6:1	130:1
Rate after rejection	1	10
In hand	0.5	5
Improve detectors (5x)	0.5	1
Improve analysis (2x)	0.5	0.5
Reduce rates	0.5	0.5
Phase A Goal	0.5	0.5

- Improve rejection
  - in hand: better phonon-timing cuts give ≥350:1 rejection
  - by further analysis improvements
  - via improving detectors
- Reduce raw rates via better shielding, cleanliness
- Electrons in Phase A:
  - for 25 kg in 500 days expect 5 events
  - detector improvements alone are sufficient
    - thickness 2.5x
    - contacts 2x

Cryostat & Shield Design Concepts

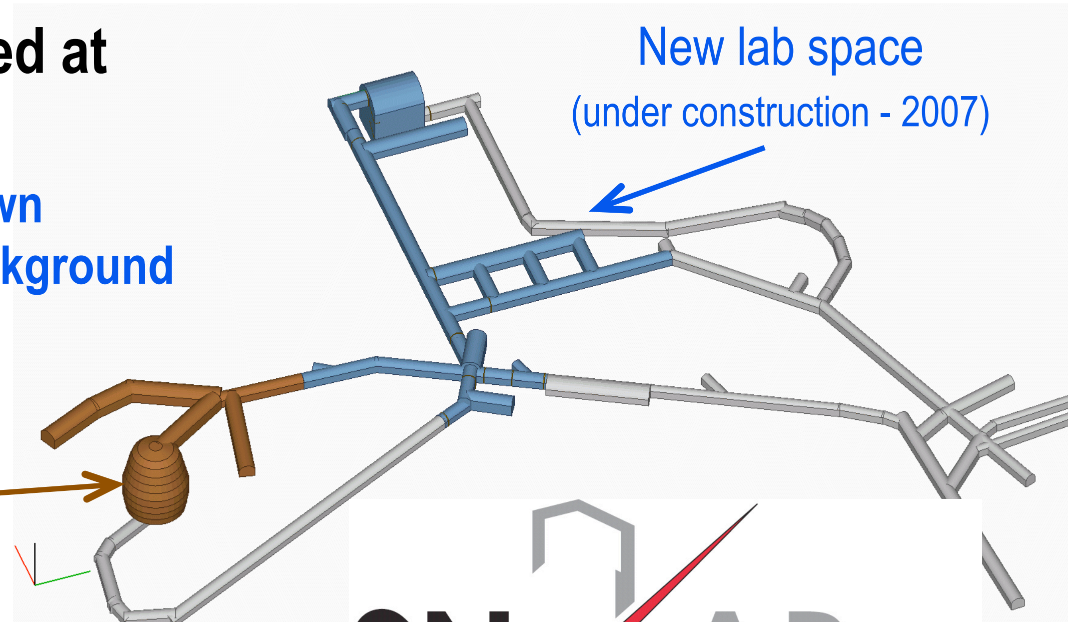
- Design concepts with low head-clearance
- Allows for 50% increase in neutron moderator
  - fission and (alpha,n) processes

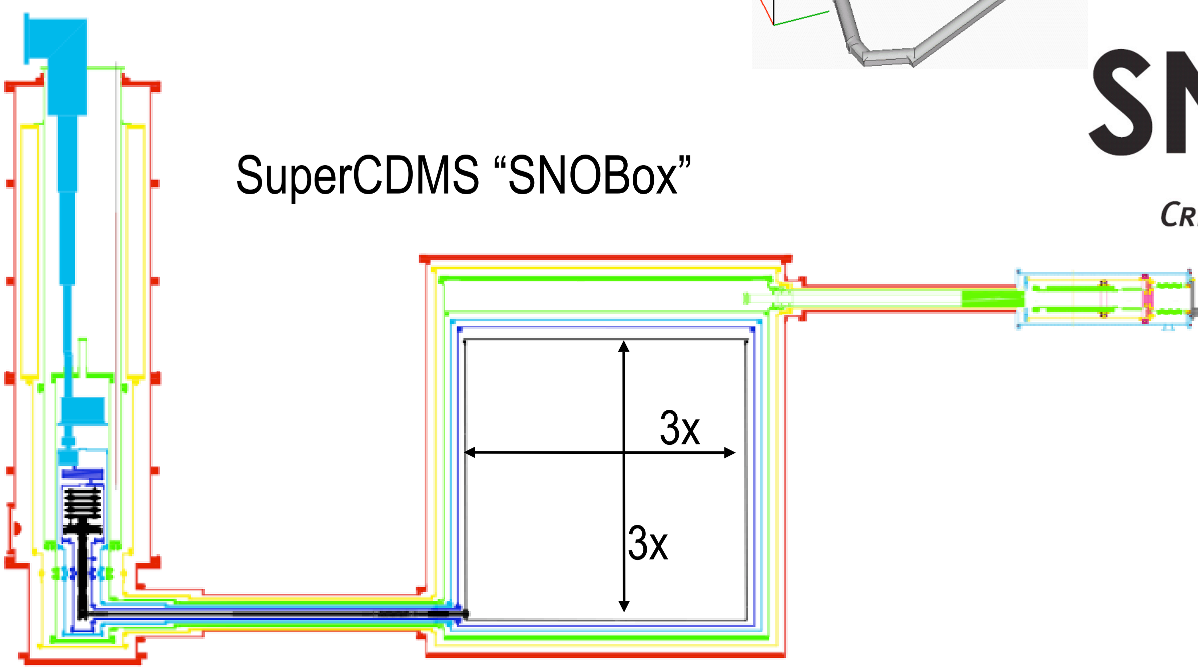




SNOBox at SNOLab

- **New cryostat could be sited at SNOLab**
  - **Depth required to drive down muon-induced neutron background**





MINING FOR KNOWLEDGE
CREUSER POUR TROUVER... L’EXCELLENCE

Sudbury, Ont. CA

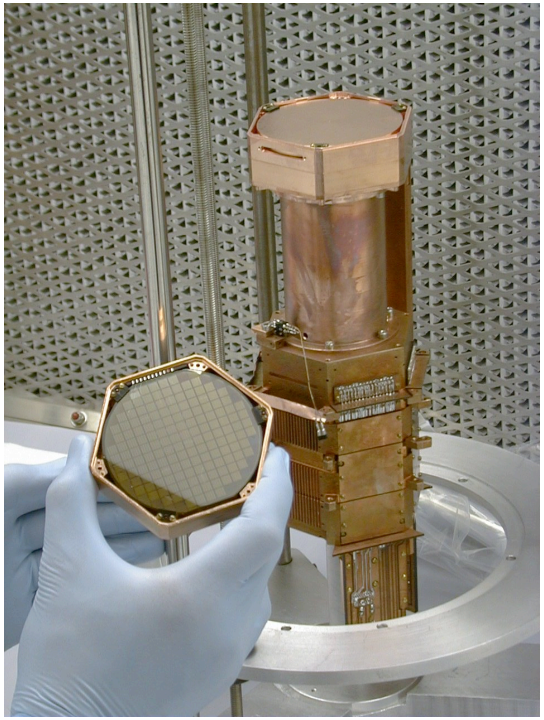
Summary

- Dark matter remains a fundamental mystery
  - Strong and timely ties to frontier HEP at accelerators
  - An essential aspect finding a concordant model
    - dark matter in the laboratory ≠ dark matter in the halo!
  - Recognized as high priority in various NRC and Advisory group studies
- CDMS
  - forefront technology
  - best sensitivity to date
- SuperCDMS is ready to begin 25 kg Phase
  - Explore interesting SUSY region on similar time scale to LHC
  - Potential to provide key info to ILC
  - Strong case for funding on SNOLab time scale
  - Expansion capability a good match for SNOLab
  - Engineering challenges at SNOLab straightforward
  - Exciting opportunities for new collaborators to participate now and establish path for the future

The CDMS Collaboration

2002 collaboration meeting, 2000 feet underground

Thank you…



…and visit us on the web at

cdms.case.edu