RECOILING AGAINST THE DARK UNIVERSE: CDMS and the Hunt for Dark Matter

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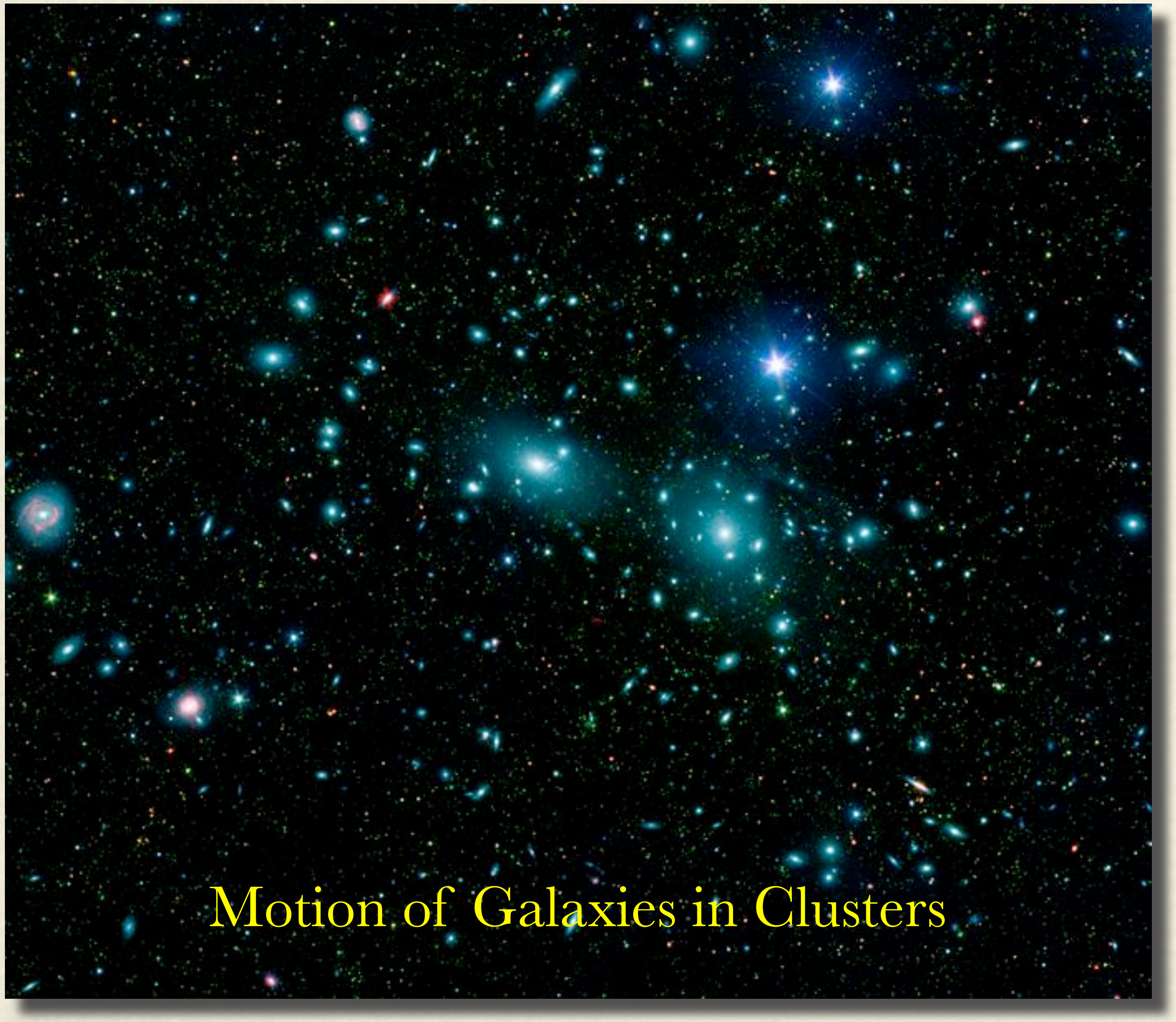
CDMS Analysis Coordinator

Overview

- What we know and what we don’t know about dark matter
- CDMS-II experiment
  - detection principle
  - results from 5 - tower run
  - current status
- The future
  - SuperCDMS
  - backgrounds

Introduction to Dark Matter

First Evidence for Dark Matter



First evidence for dark matter came from studies of galaxy clusters by Zwicky in 1933.

1970

Rotation Curves of Galaxies

Nearly 40 years after Zwicky's discovery, Rubin and Ford made the next big advance in observing dark matter.

Vera Rubin

NGC 4414

NASA/JPL-Caltech/GSFC/SDSS

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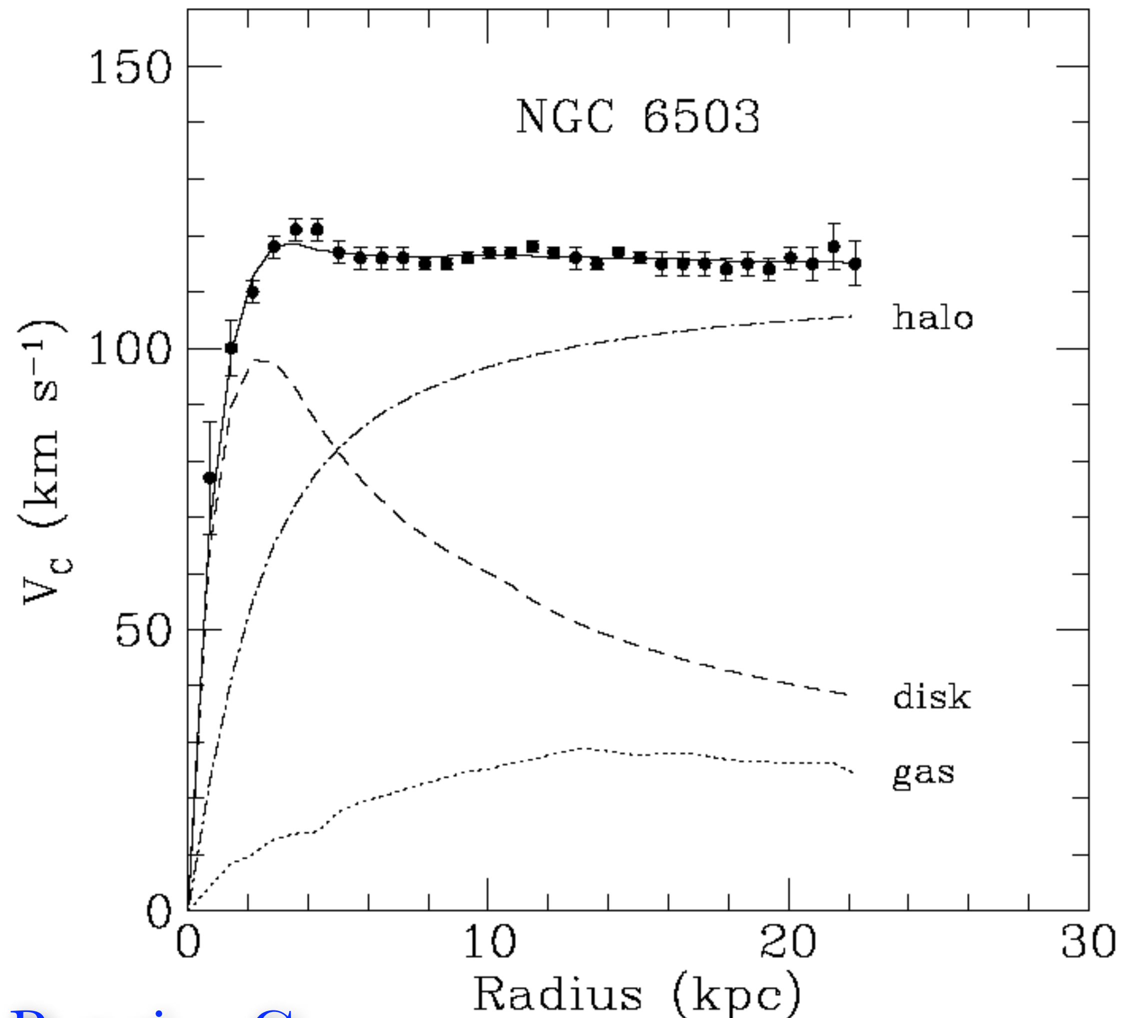
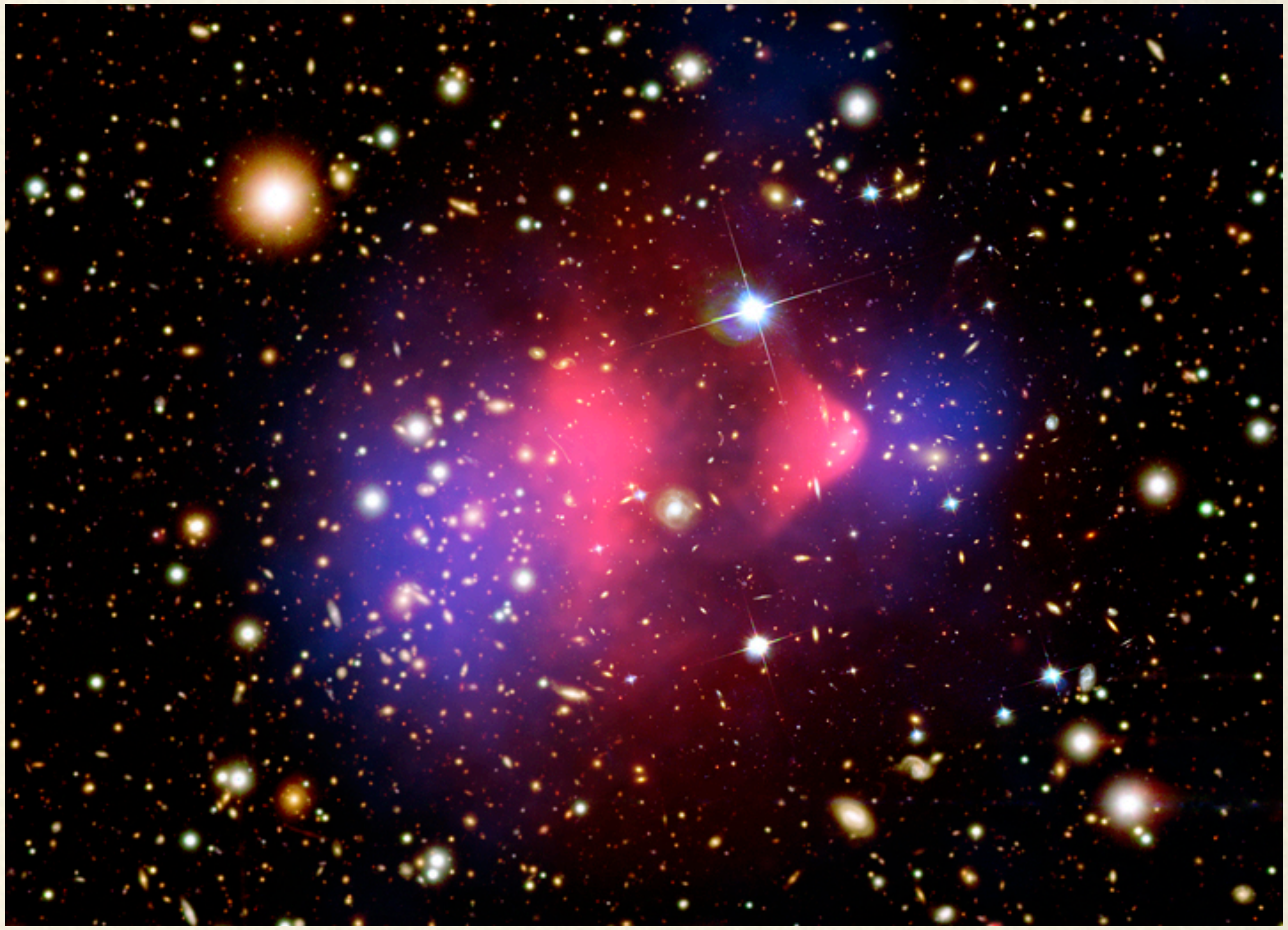
Vera Rubin



Rotation Curves

The Bullet Cluster

- Observations of the **Bullet Cluster** in the **optical** and **x-ray** fields combined with **gravitational lensing** provide compelling evidence that the dark matter is particles.
- In this picture:
  - **Red - measurements of x-rays emitted from gas interactions**
  - **Blue - measurements of matter distribution from gravitational lensing**
  - **Background is optical map of luminous matter**



Clowe et al., ApJ, 648, 109

blue = lensing
red = x-rays

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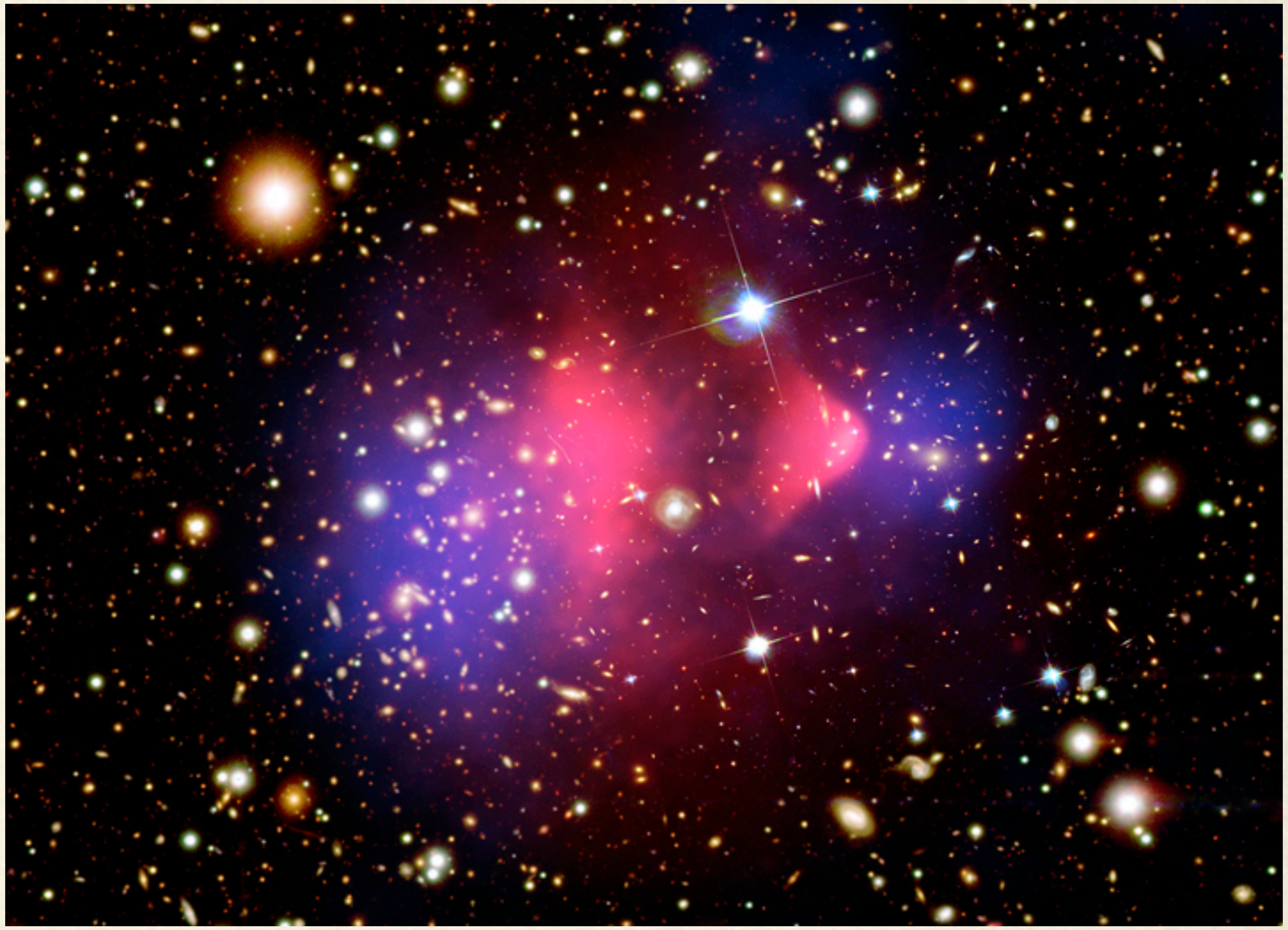

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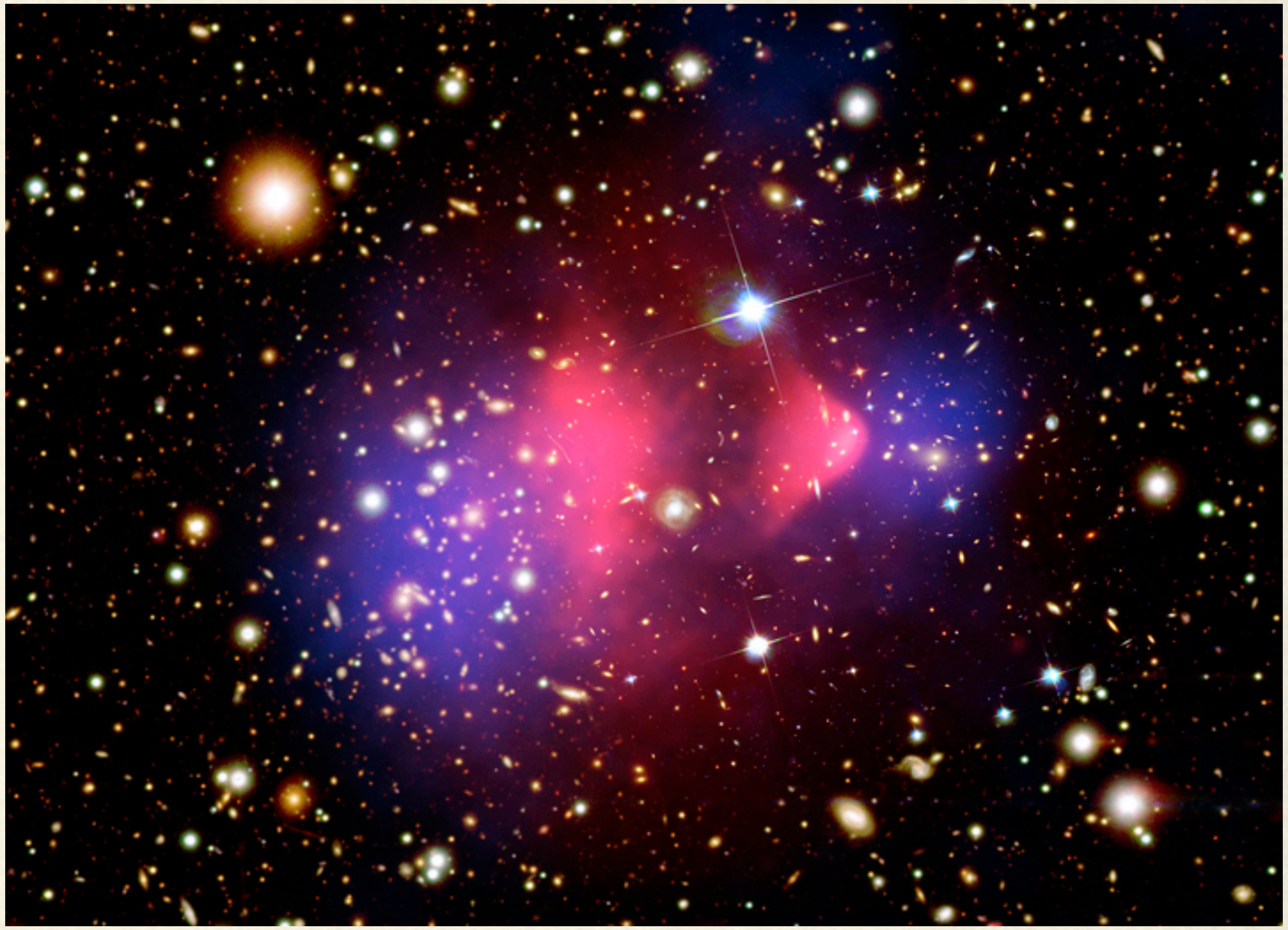
The Bullet Cluster

- Observations of the **Bullet Cluster** in the **optical** and **x-ray** fields combined with **gravitational lensing** provide compelling evidence that the dark matter is particles.
- Gravitational lensing tells us mass location
  - No dark matter = lensing strongest near gas
  - Dark matter = lensing strongest near stars



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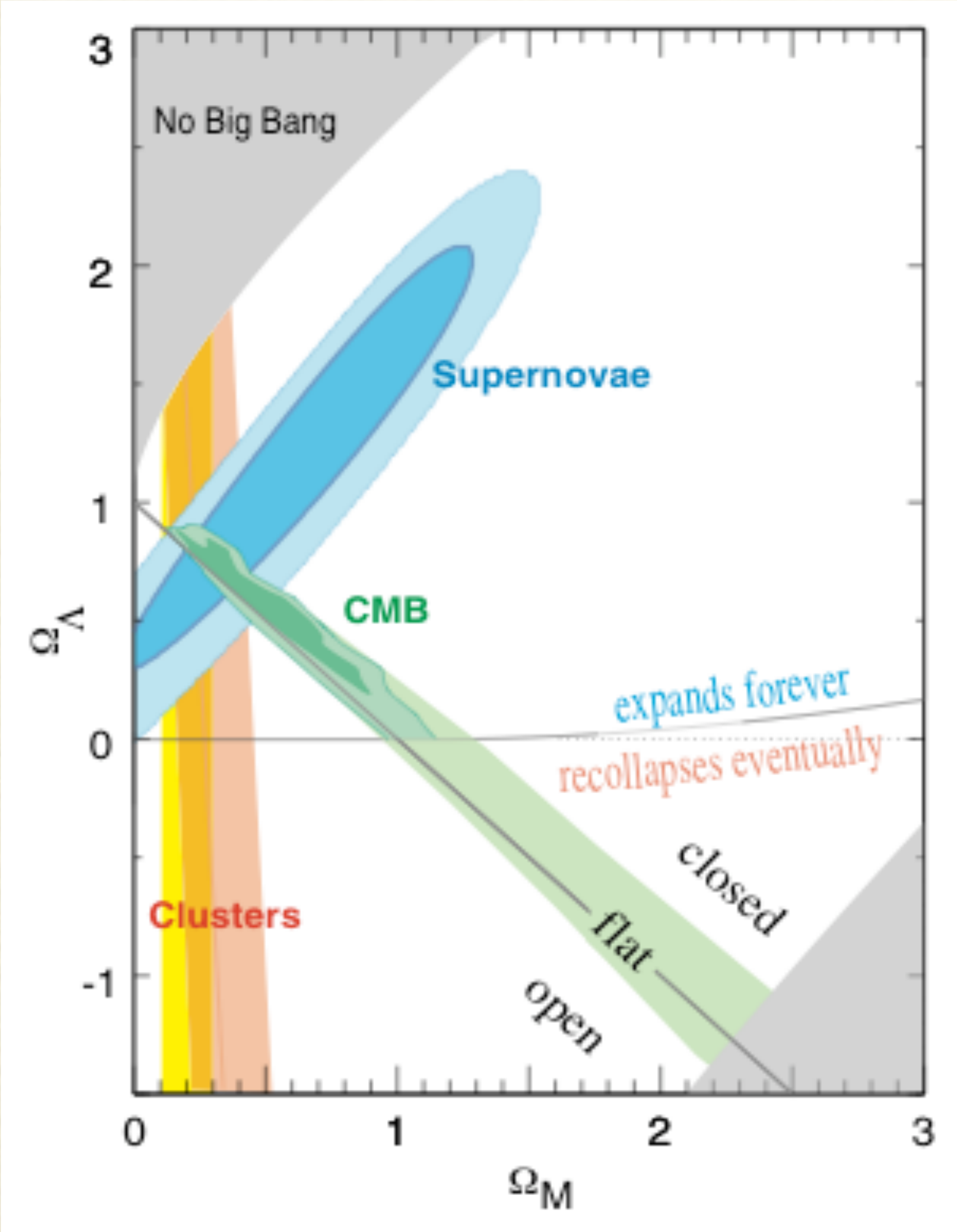
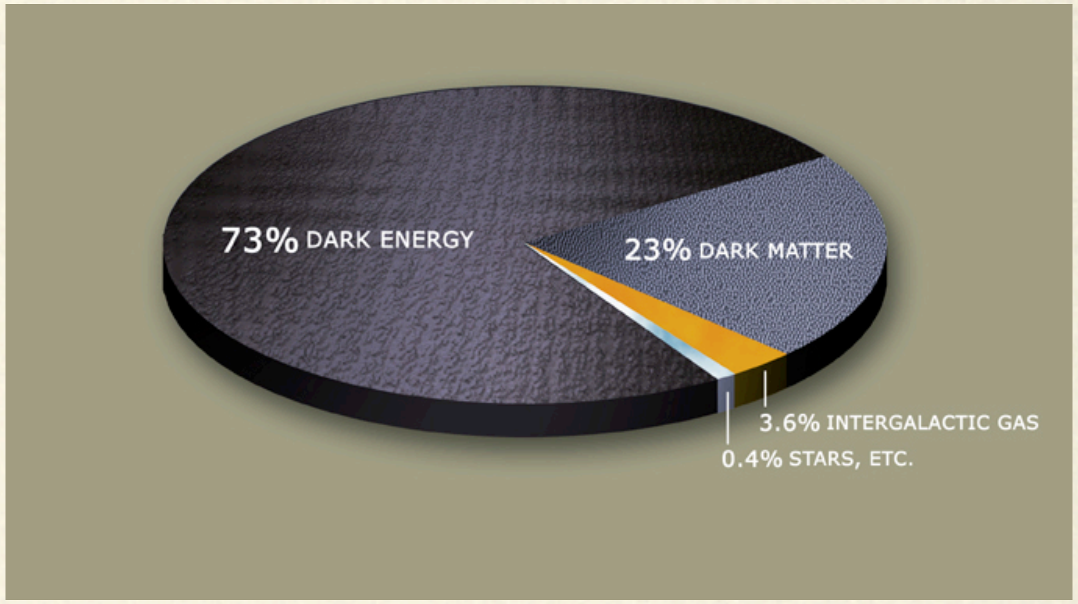
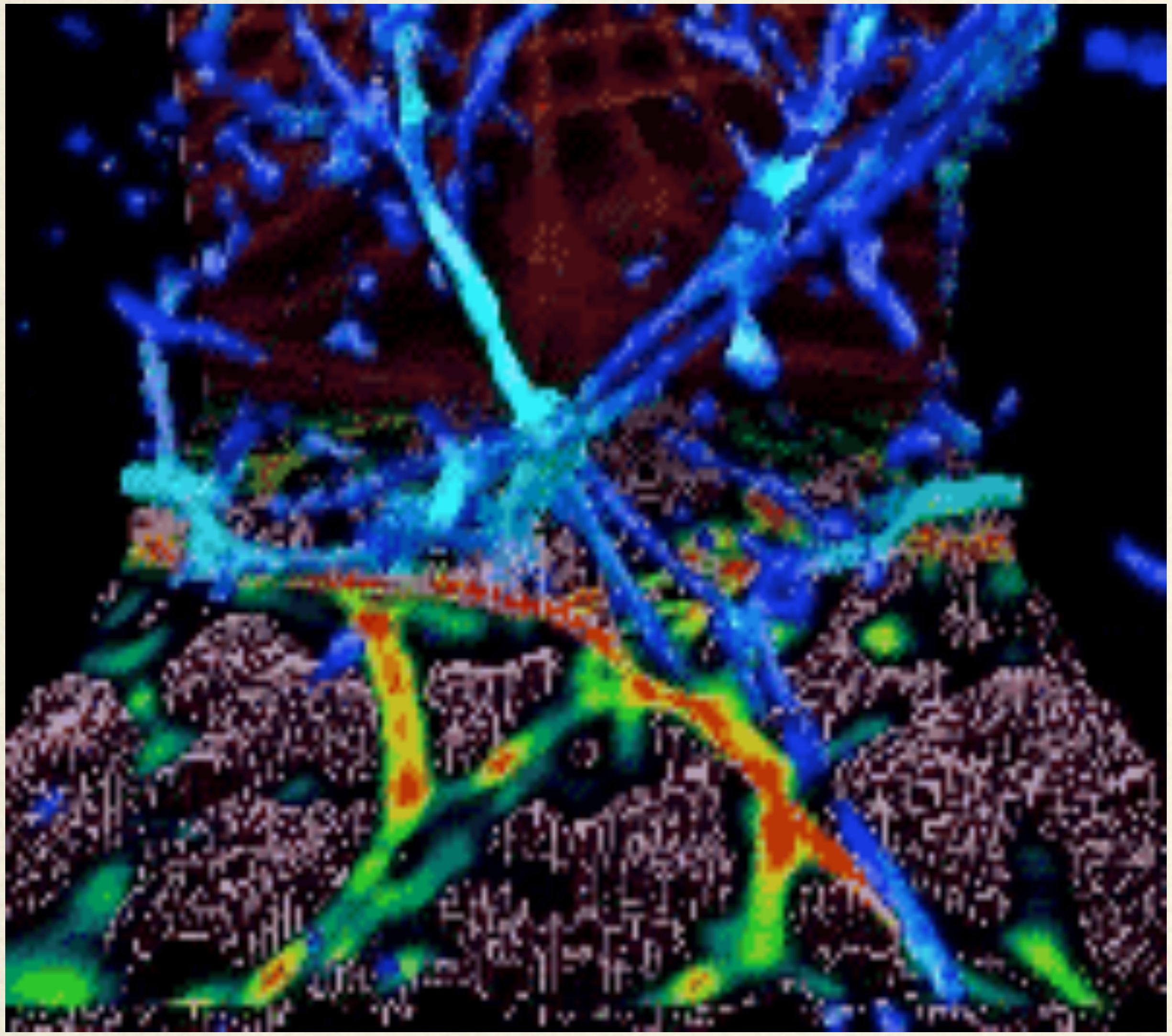
The Cosmic Pie





- Measurements from CMB + supernovae + LSS indicate that **~23% of our Universe is composed of dark matter**.

What Could Dark Matter Be?



- **Warm** or **Cold**?
  - ordinary νs can not make up LSS of universe

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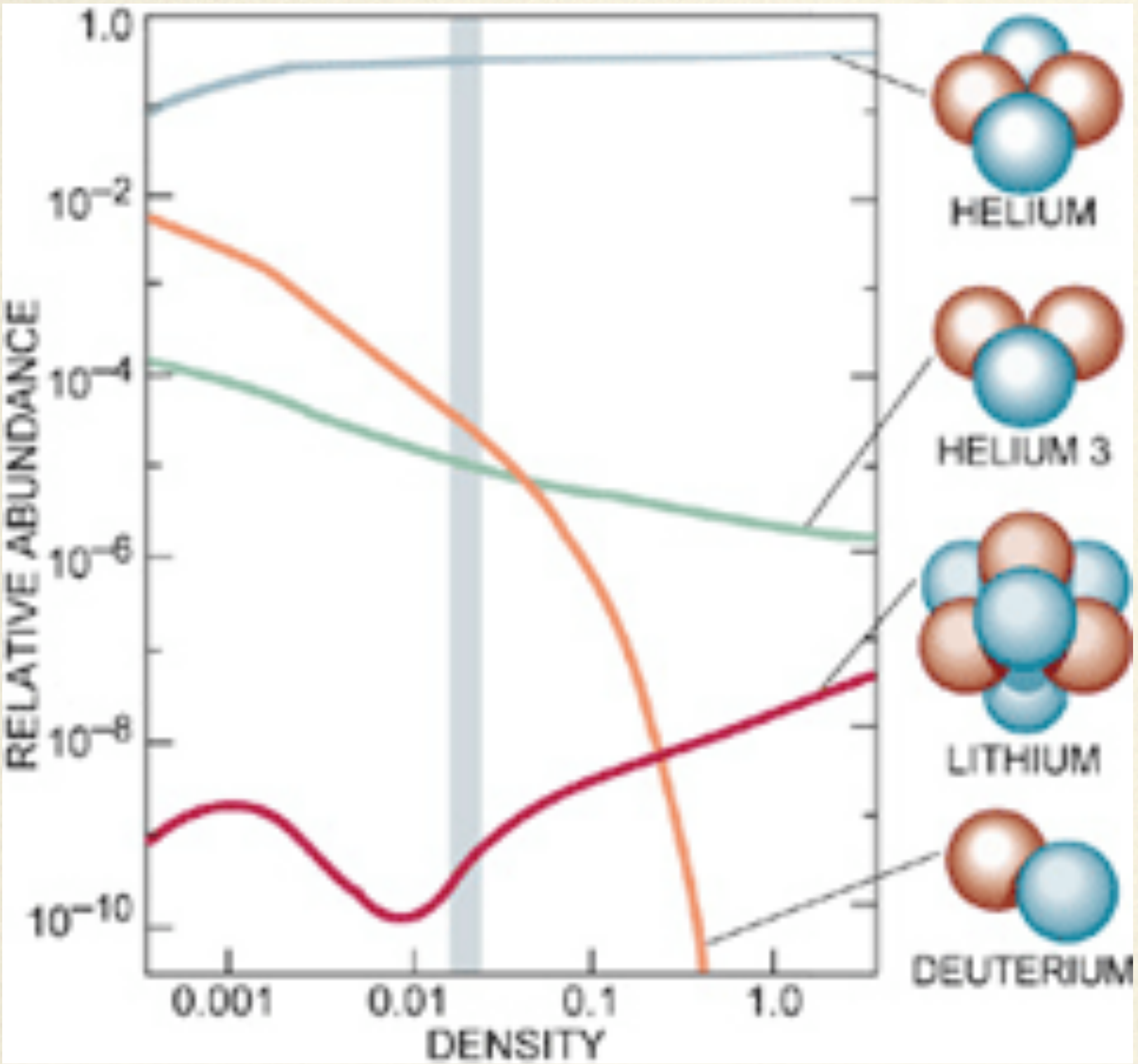
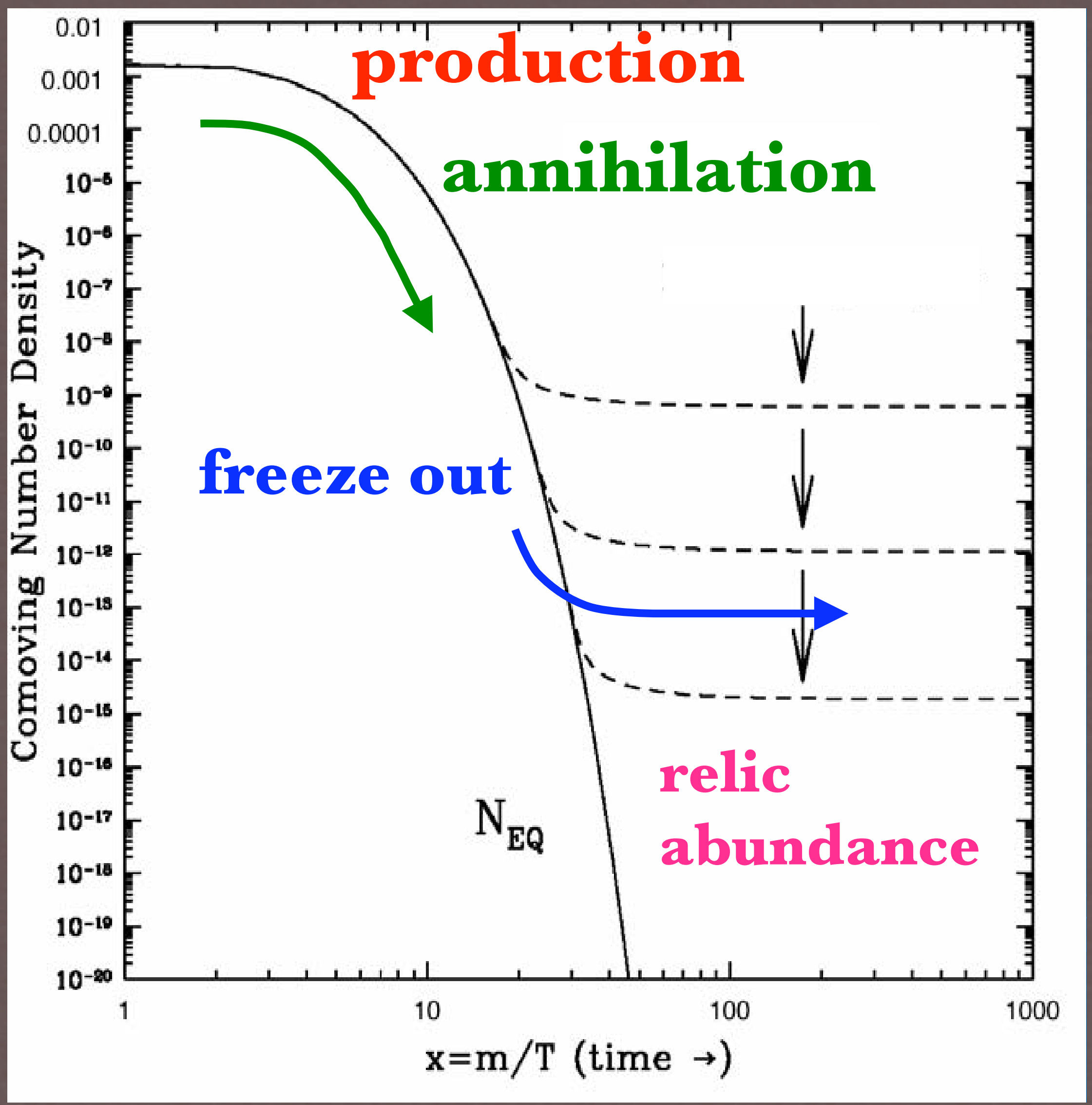


- Warm or **Cold**?
  - ordinary vs can not make up LSS of universe
- Baryonic or **Non-Baryonic**?
  - to avoid skewing formation of light elements in BBN

A Candidate is Born!



$$\Omega_\chi h^2 \approx \frac{3 \times 10^{-27}}{< \sigma_\chi v >}$$

Weakly **I**nteracting **M**assive **P**articles

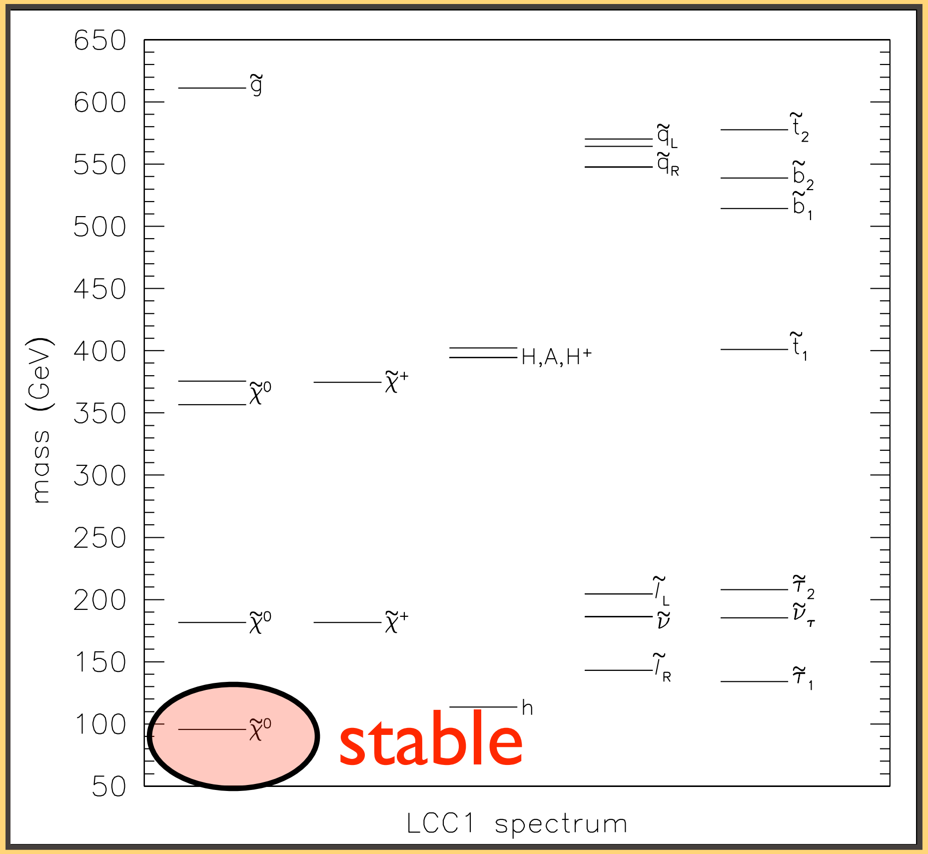
- New stable, **massive** particle produced thermally in early universe
- **Weak-scale** cross-section gives observed relic density

WMAP $0.095 < \Omega h^2 < 0.129$

$$\sigma_\chi \approx 10^{-37} cm^2$$

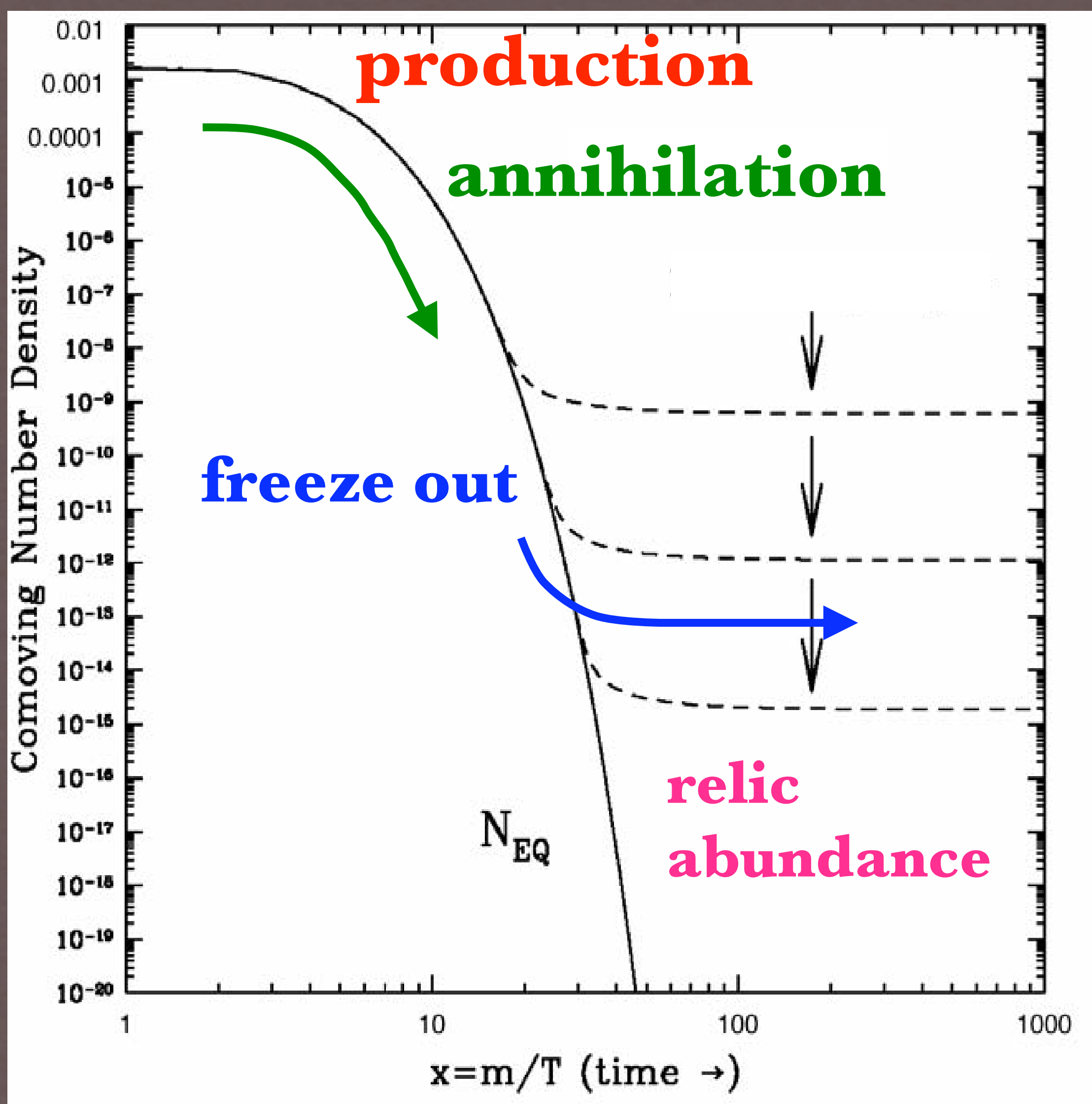
Motivated by Particle Physics Too!

- New TeV physics required to explain radiative stability of weak scale.
  - SuperSymmetry
  - Extra Dimensions
  - ...
- These theories give rise to convenient dark matter candidates.
  - LSP, LKP



Baltz et al., PRD **74**, 103521 (2006)

Happy Coincidence!



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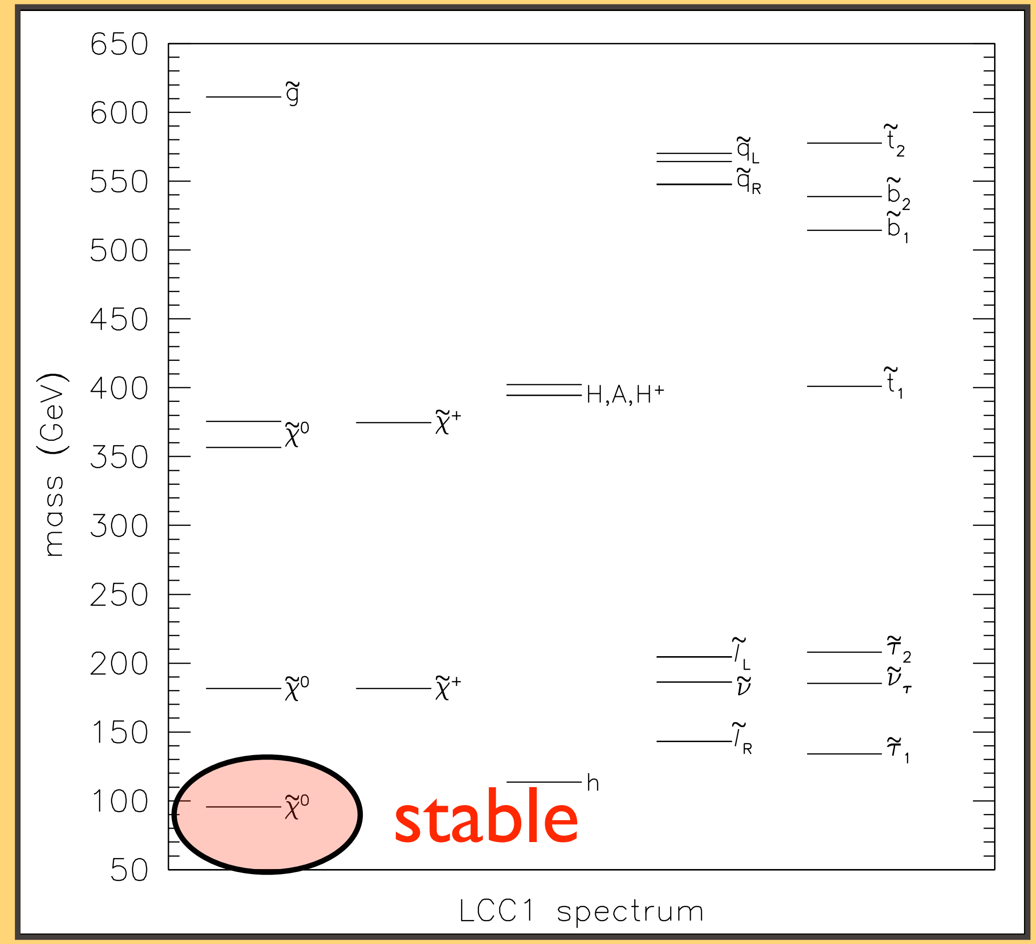

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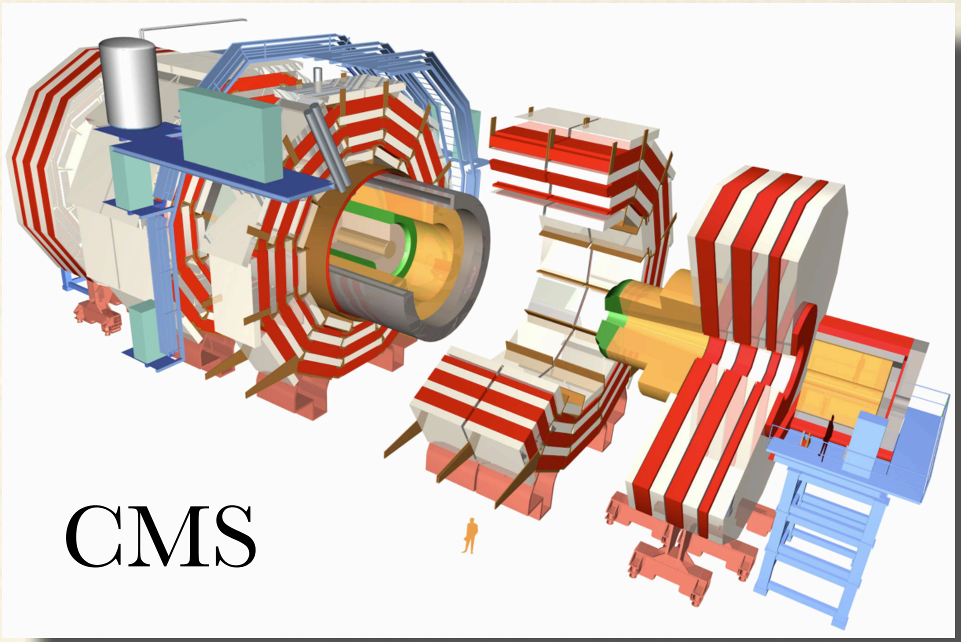
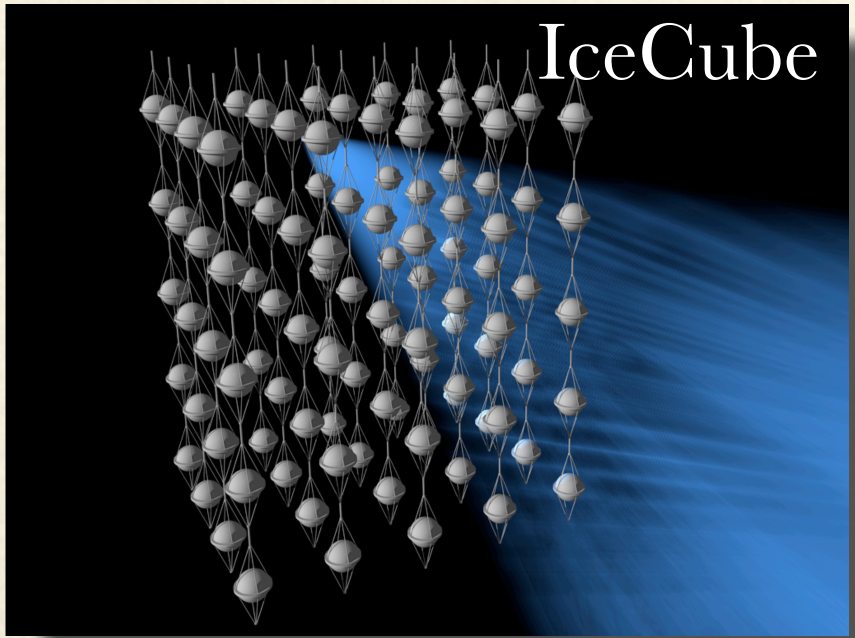
How Do We Detect WIMPs?

WIMP scattering on earth



WIMP production on earth



WIMP annihilation in the cosmos

Direct Detection Event Rates

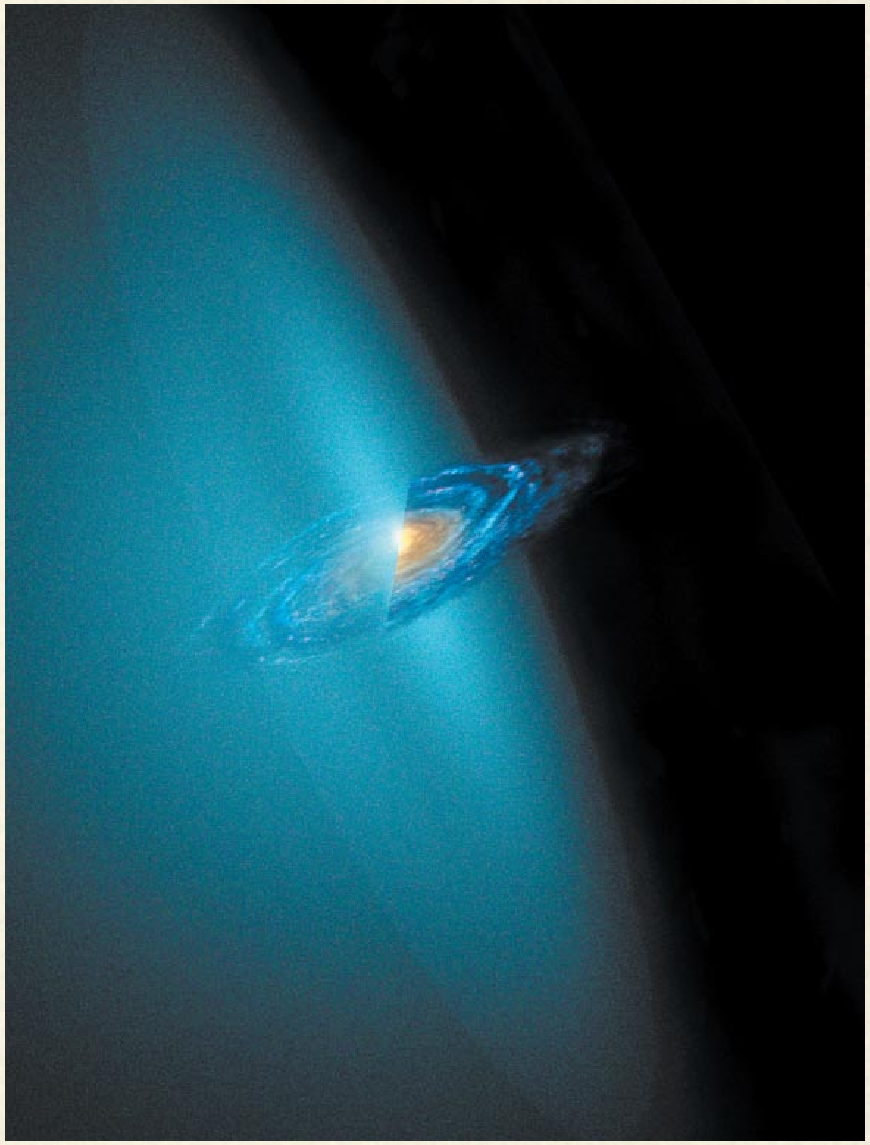
Interaction Details

spin-independent,
coherent scattering

→ $\sigma_\chi \propto A^2$

"Spherical Cow" Halo Model

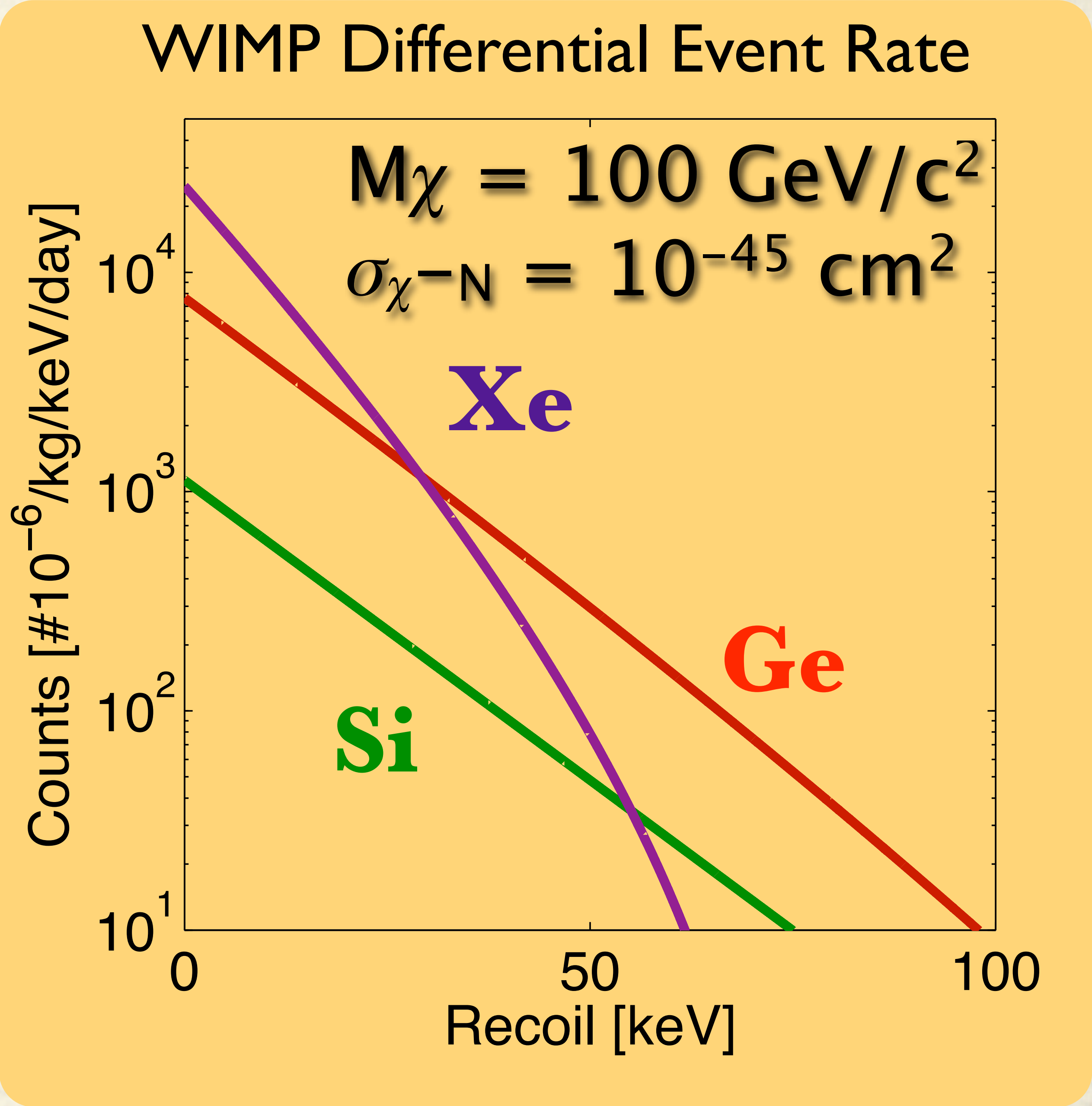
$\rho_o = 0.3\ \mathrm{GeV/cm^3}$,
Maxwellian distrubution,
$v_o = 220\ \mathrm{km/s}$,
$v_{esc} = 650\ \mathrm{km/s}$



D. Cline, *Scientific American* 2003

Direct Detection Event Rates

- Elastic scattering of a WIMP deposits small amounts of energy into recoiling nucleus (~ few 10s of keV)
- Featureless exponential spectrum
- **Expected rate: < 0.01/kg-d**
- Radioactive background of most materials higher than this rate.

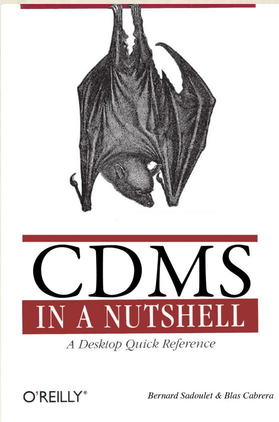


Detection Challenges

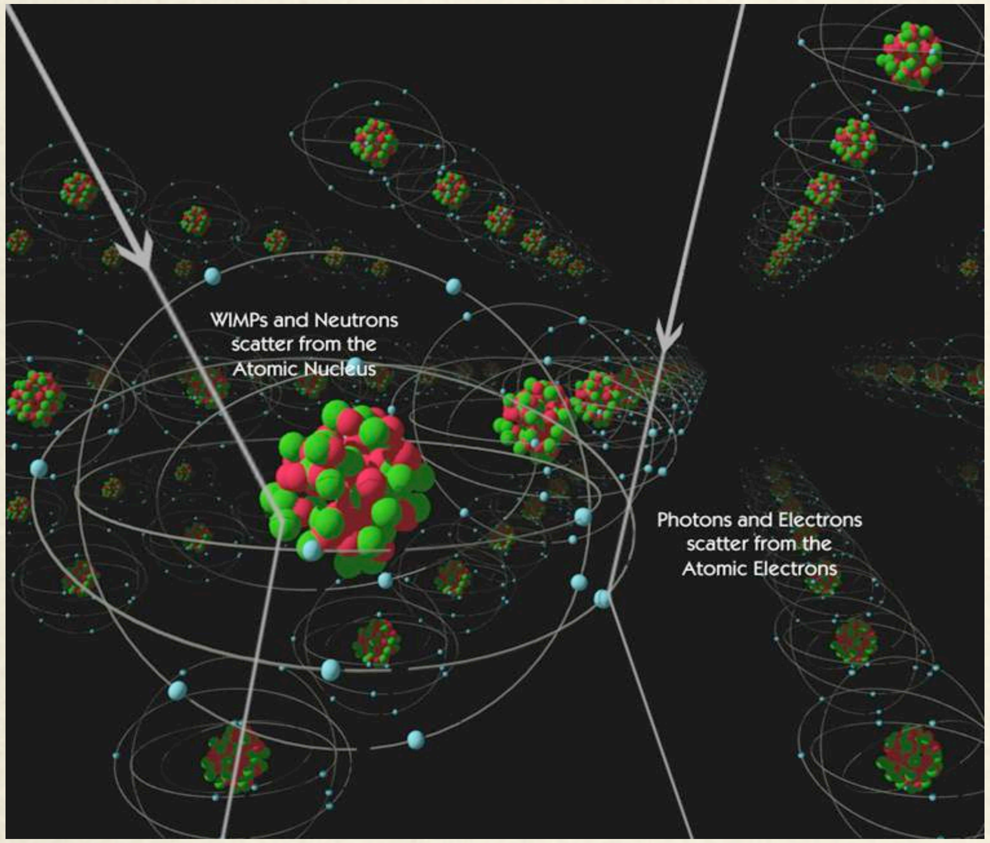
- **Low energy thresholds** (~10 keV)
- Ridged **background controls**
  - Clean materials
  - shielding
  - discrimination power
- Substantial **Depth**
  - neutrons look like WIMPS
- **Long exposures**
  - large masses, long term stablility

CDMS-II

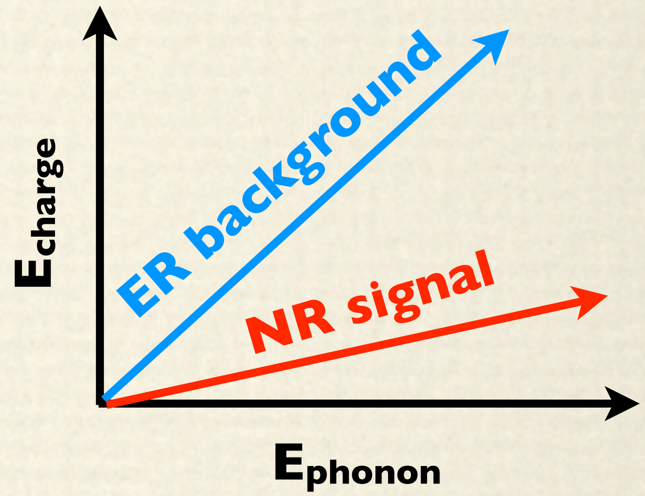
CDMS-II: The Big Picture



Use a combination of **discrimination** and **shielding** to maintain a **"zero background"** experiment with **low temperature** semiconductor detectors



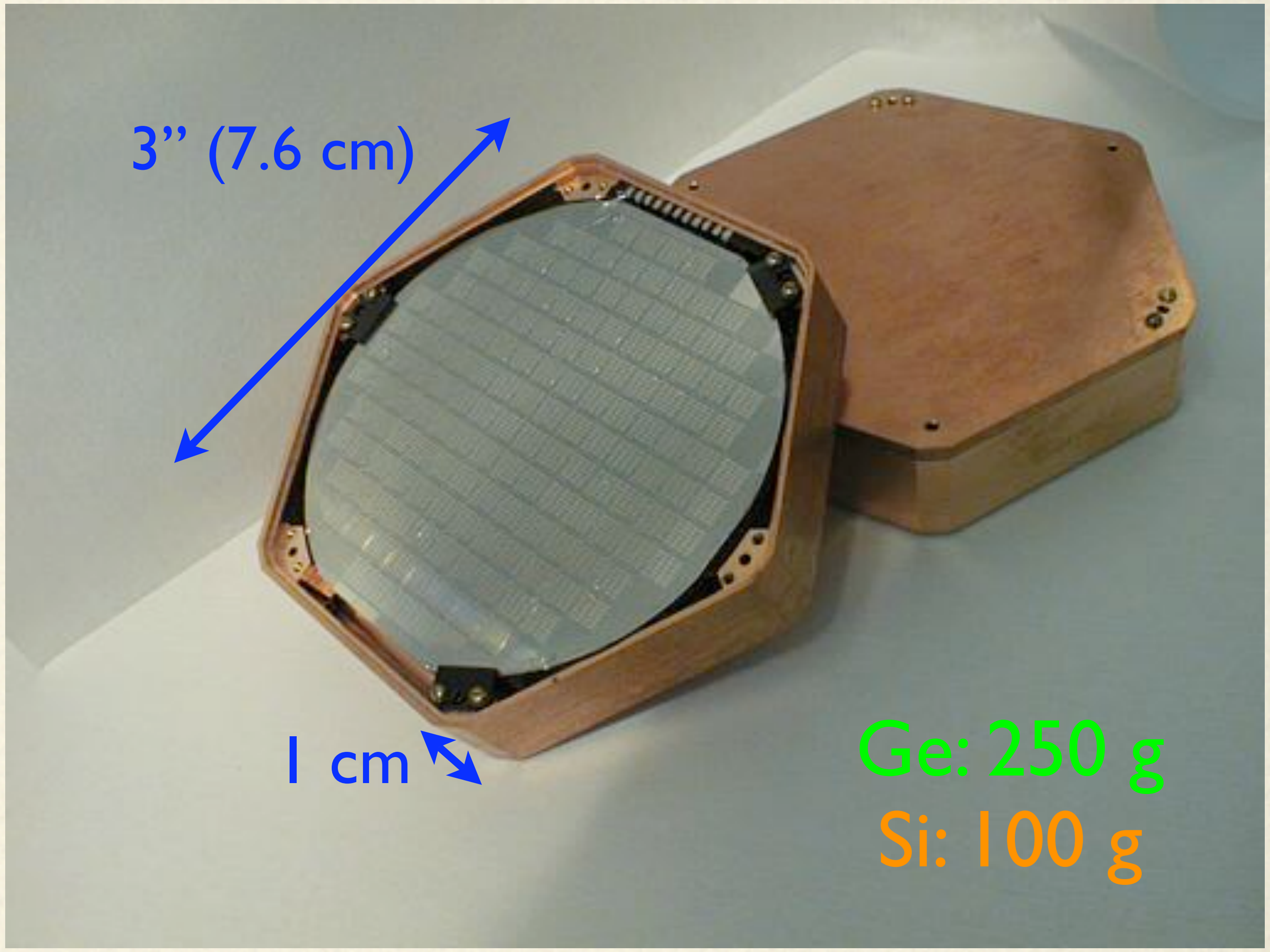
Discrimination from measurements of **ionization** and **phonon energy**.



Keep backgrounds low as possible through shielding.

CDMS-II ZIP Detectors

- **Z**-sensitive **I**onization and **P**honon mediated
- **250 g Ge** or **100 g Si** crystals (1 cm thick, 7.5 cm diameter)
- Photolithographically patterned to **collect athermal phonons** and **ionization signals**
    - xy-position imaging
    - Surface (z) event rejection from pulse shapes
- **30 detectors** stacked into **5 towers** of 6 detectors



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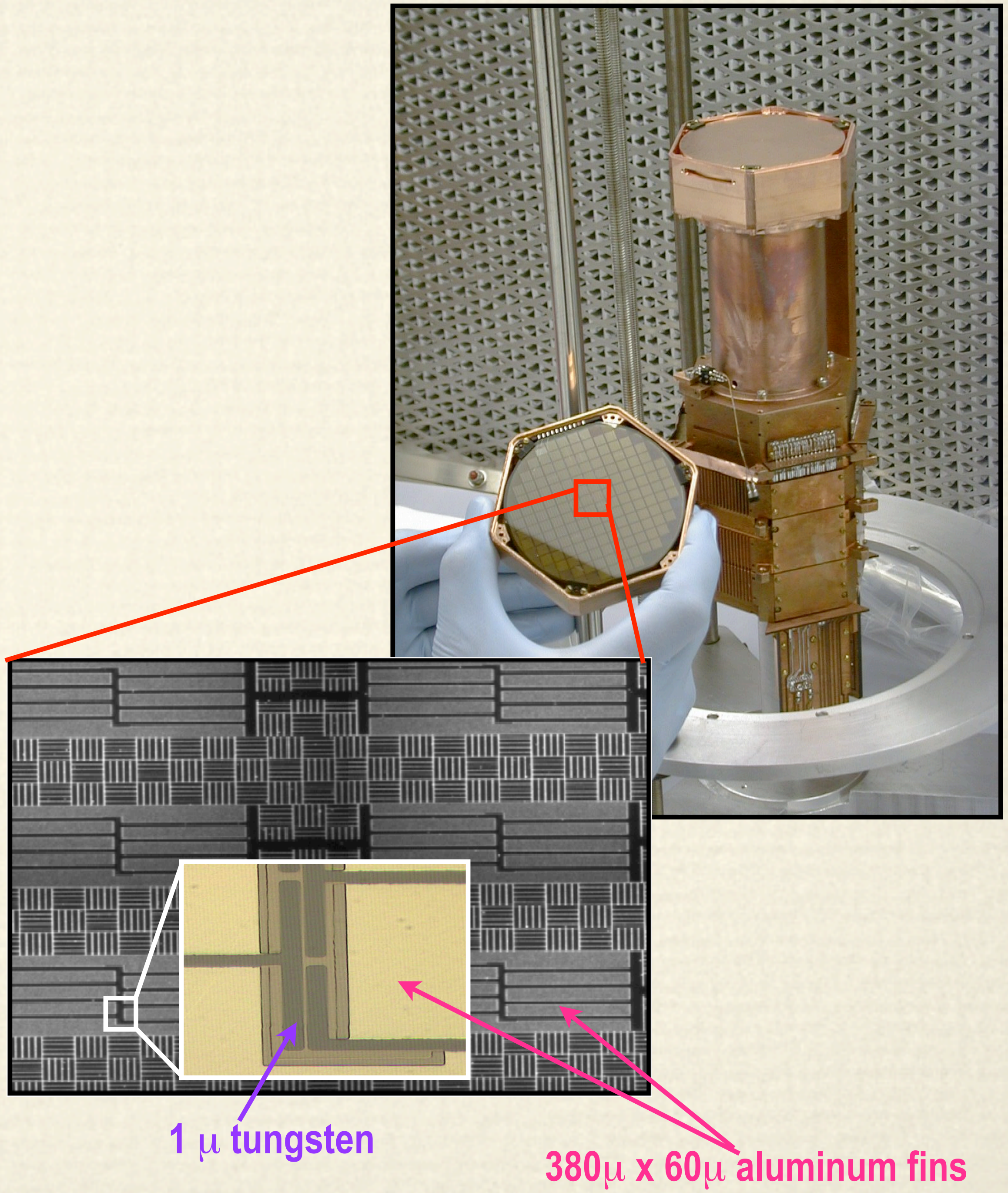
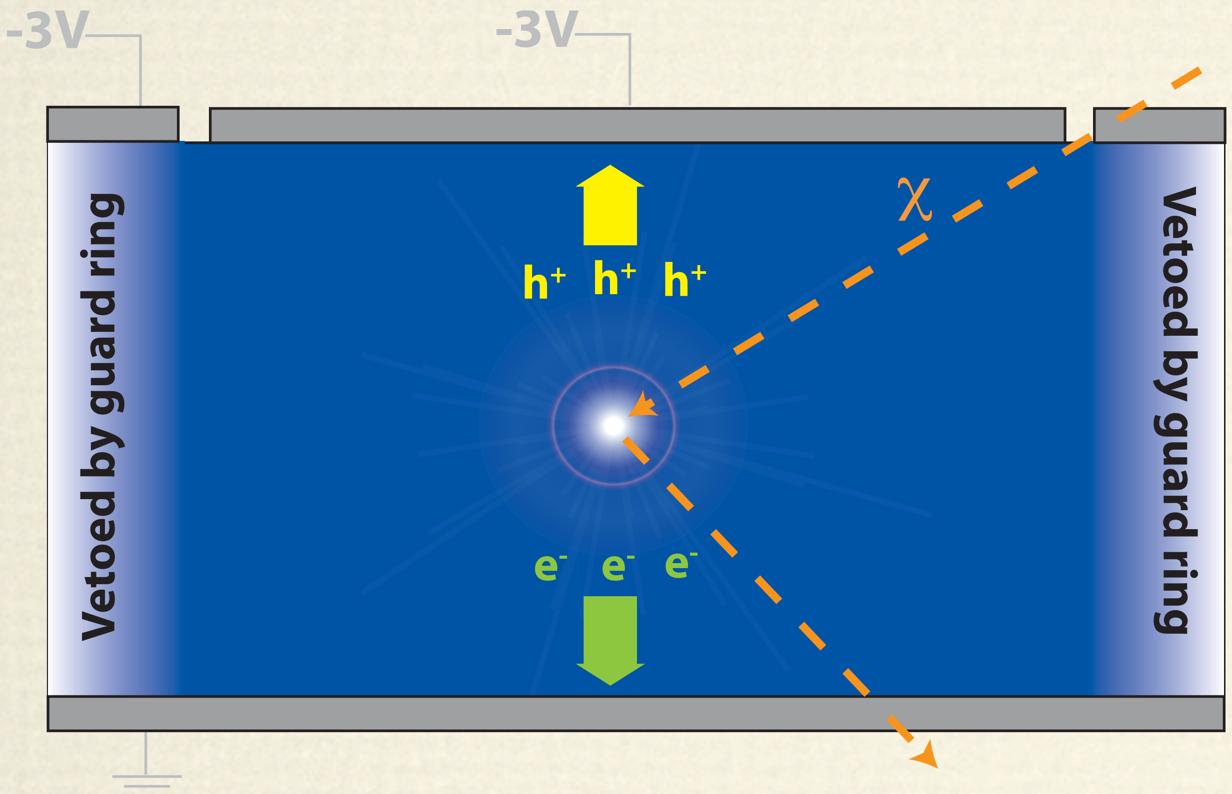
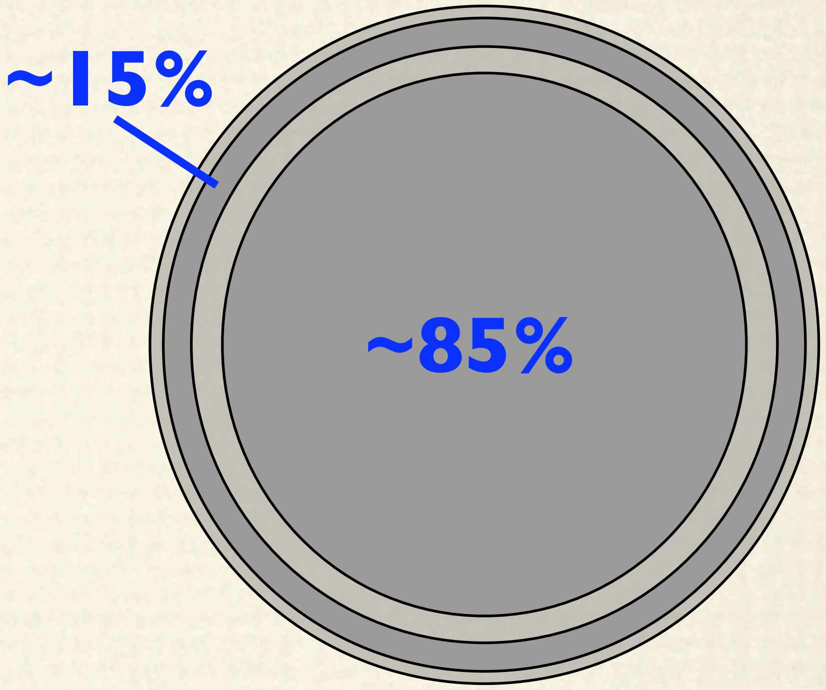


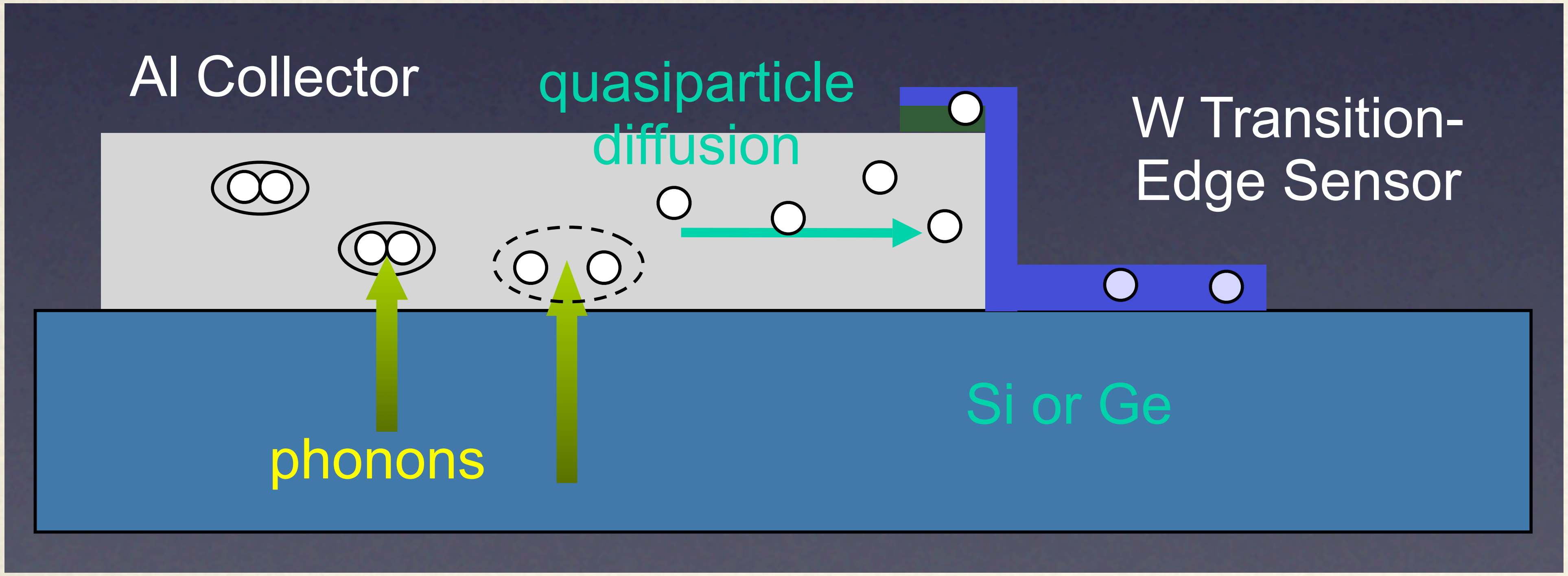
ZIP Detectors: Charge





Inner Channel: ionization measurement
Outer Channel: fiducial volume

ZIP Detectors: Phonons



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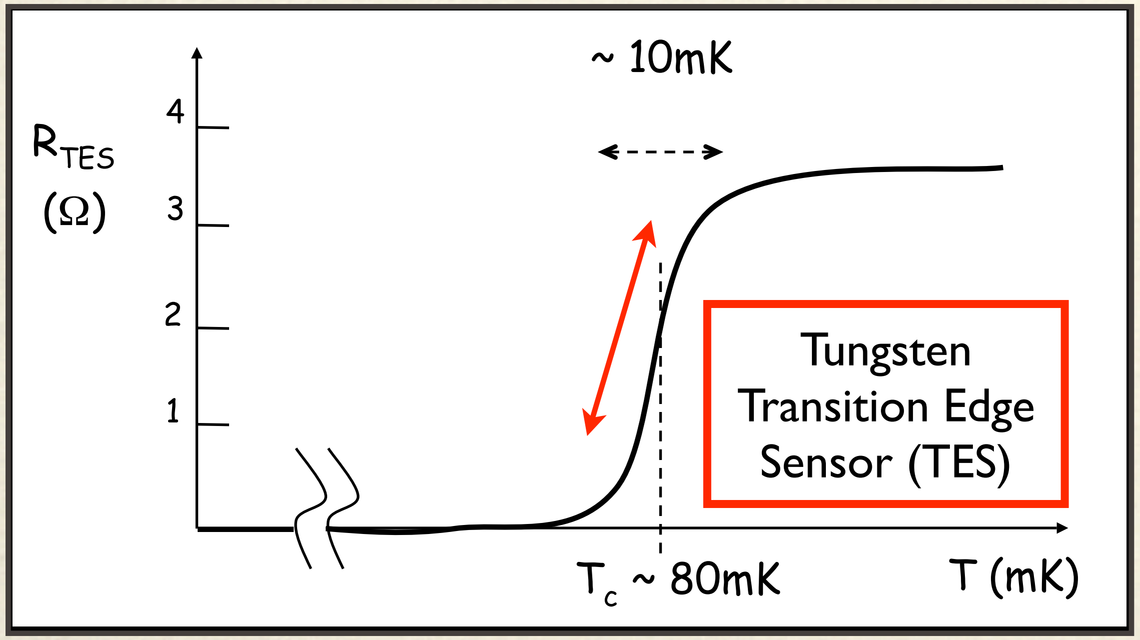
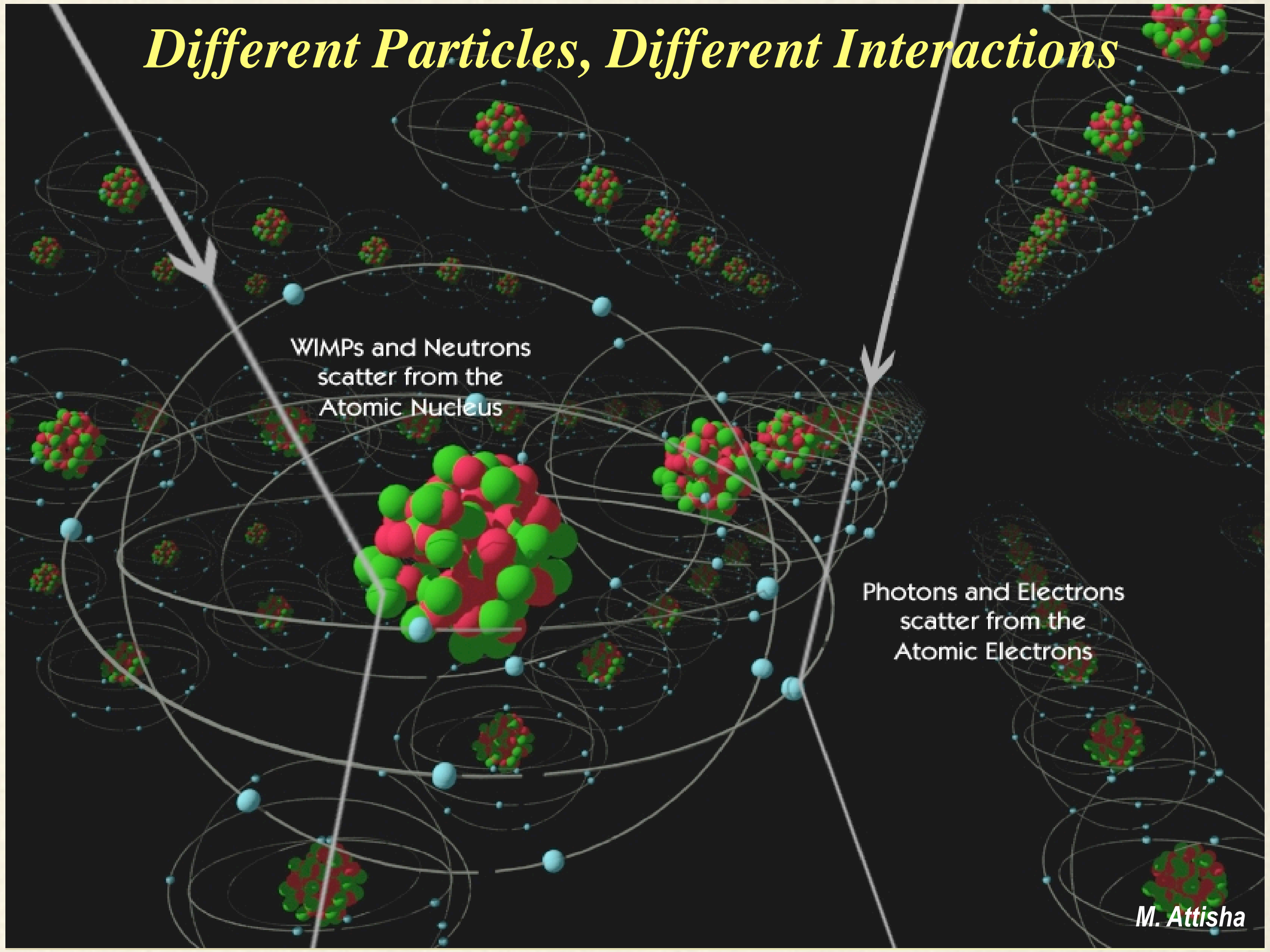


4 SQUID readout channels, each reads out 1036 TESs in parallel

Background Rejection

- Most backgrounds (e, γ) produce electron recoils
- WIMPS and neutrons produce nuclear recoils.



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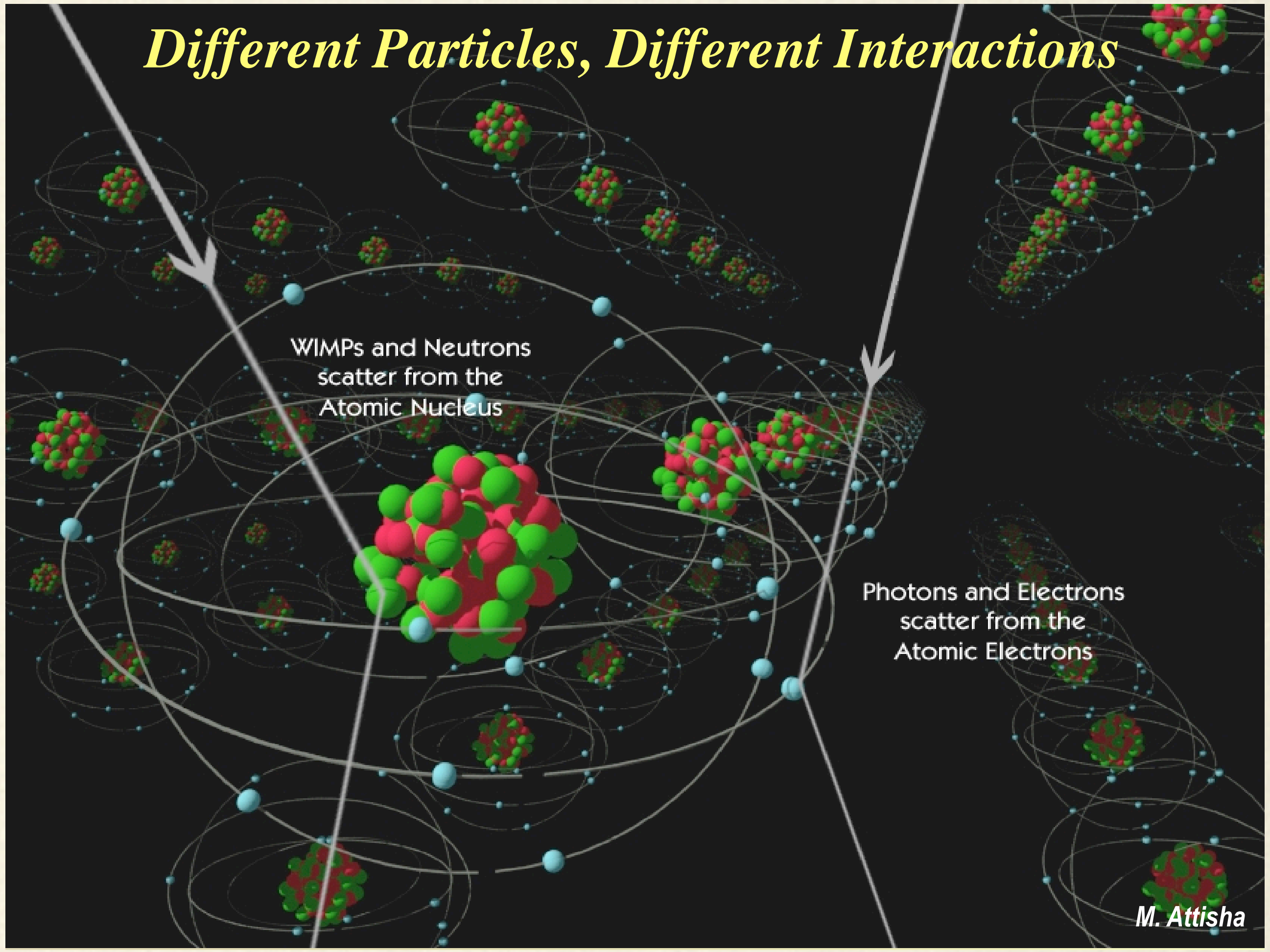

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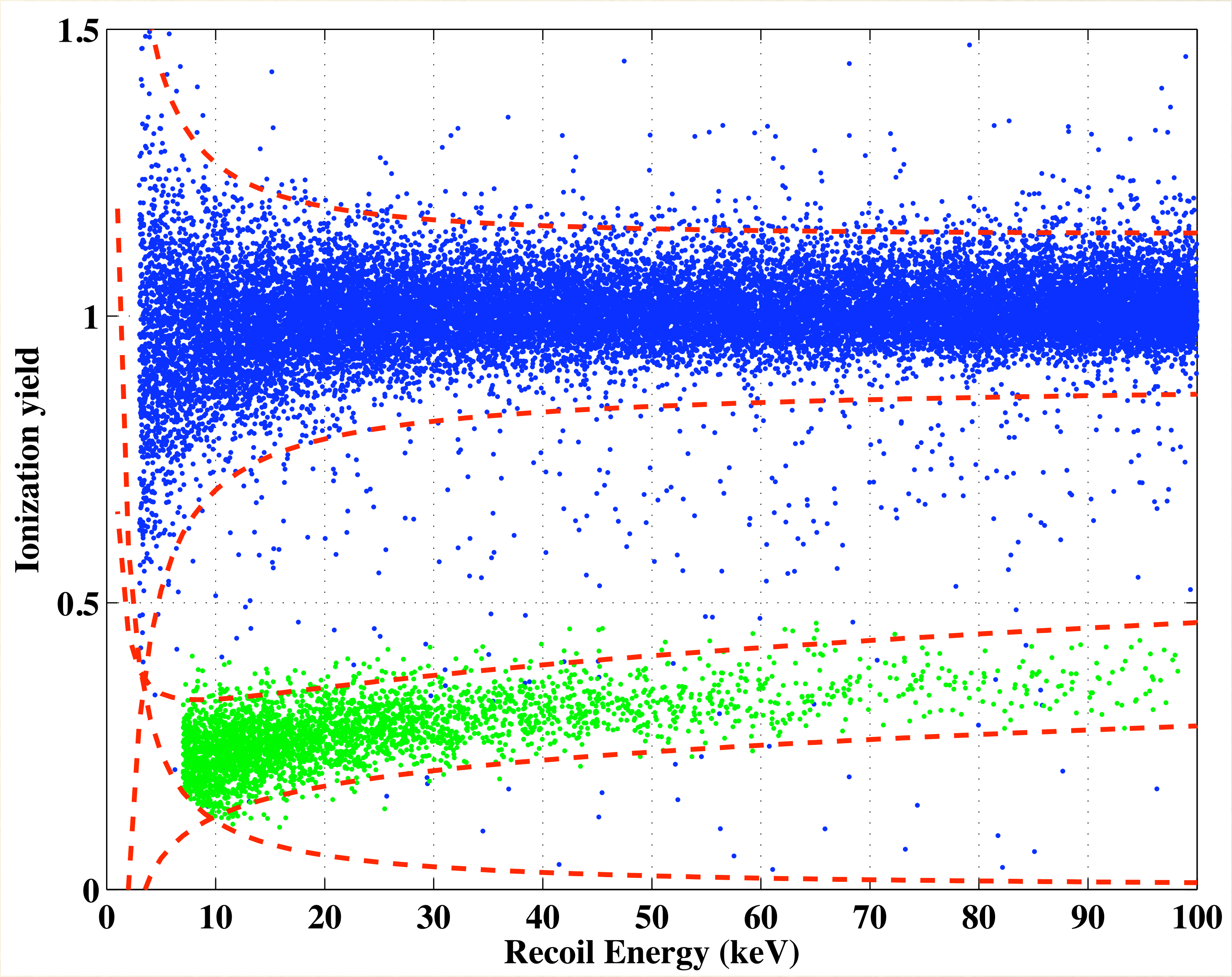

Background Rejection

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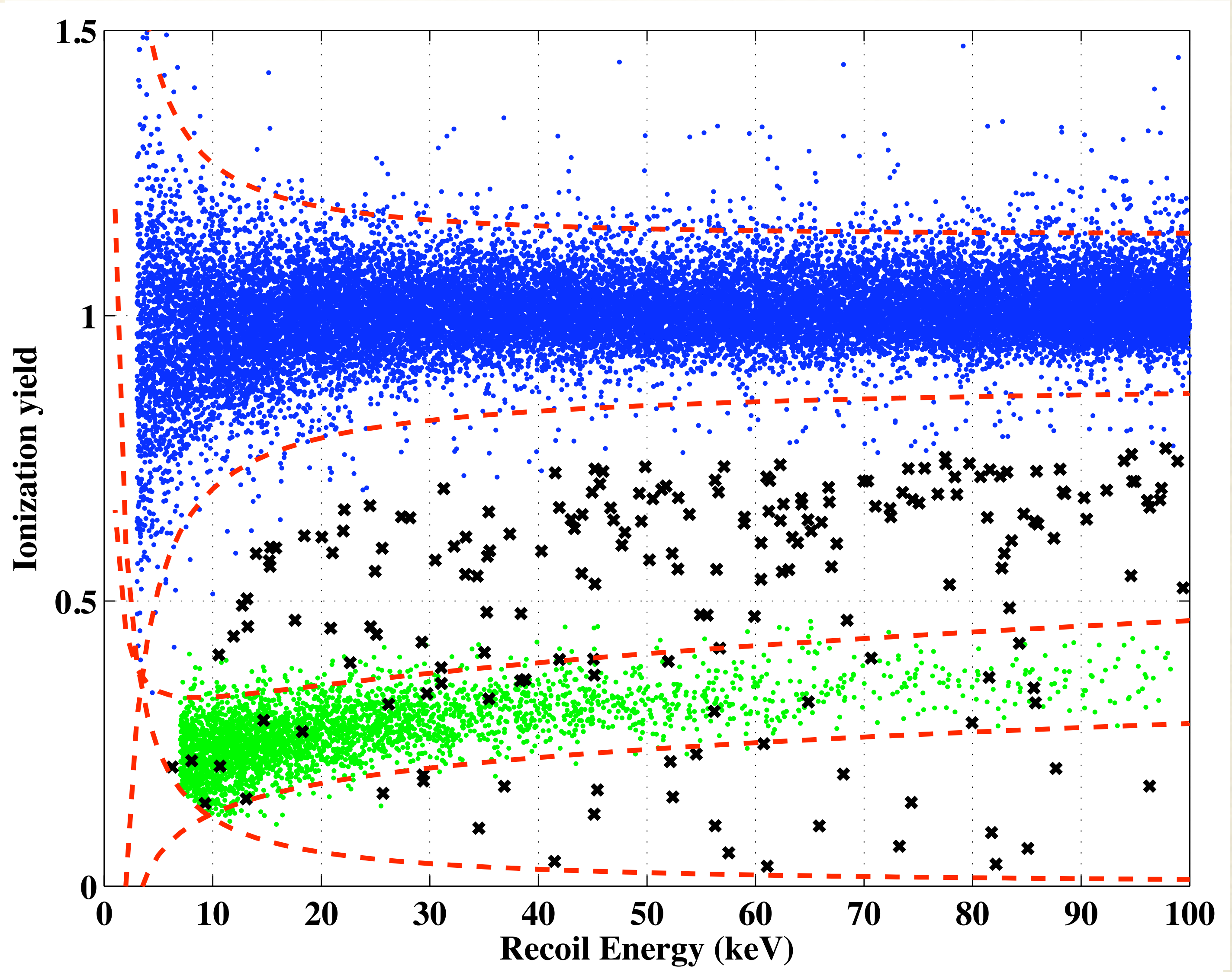
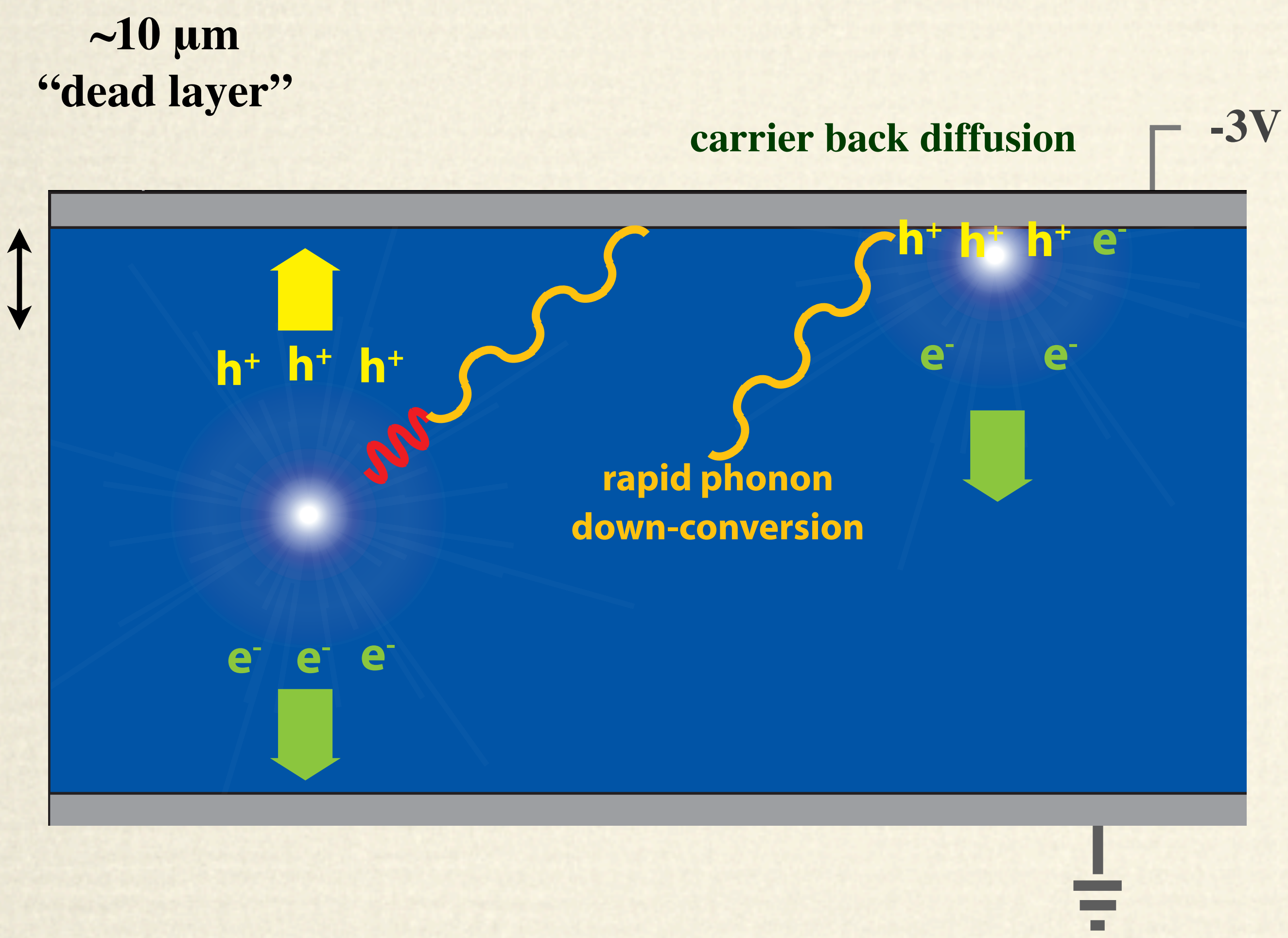
- Ionization yield (ionization energy per unit phonon energy) strongly depends on particle type.
- Particles that interact in the "surface dead layer" result in reduced ionization yield.

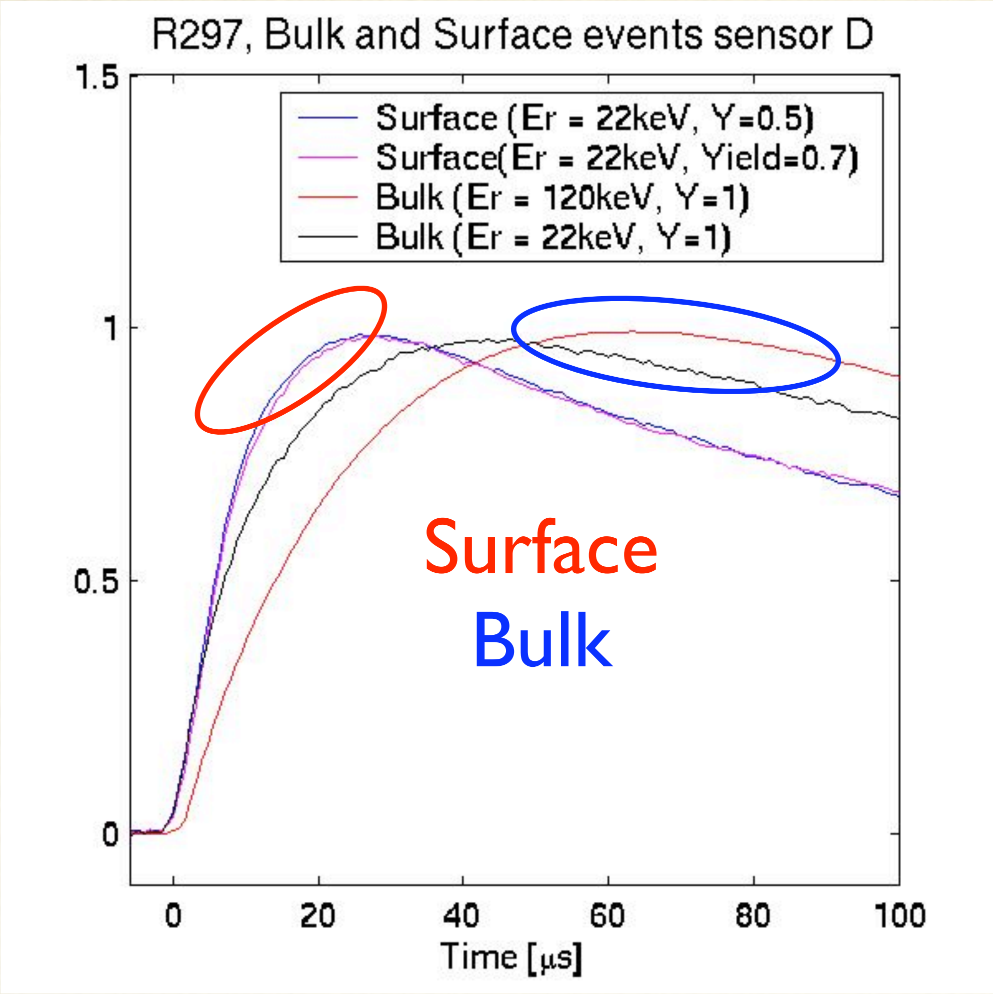


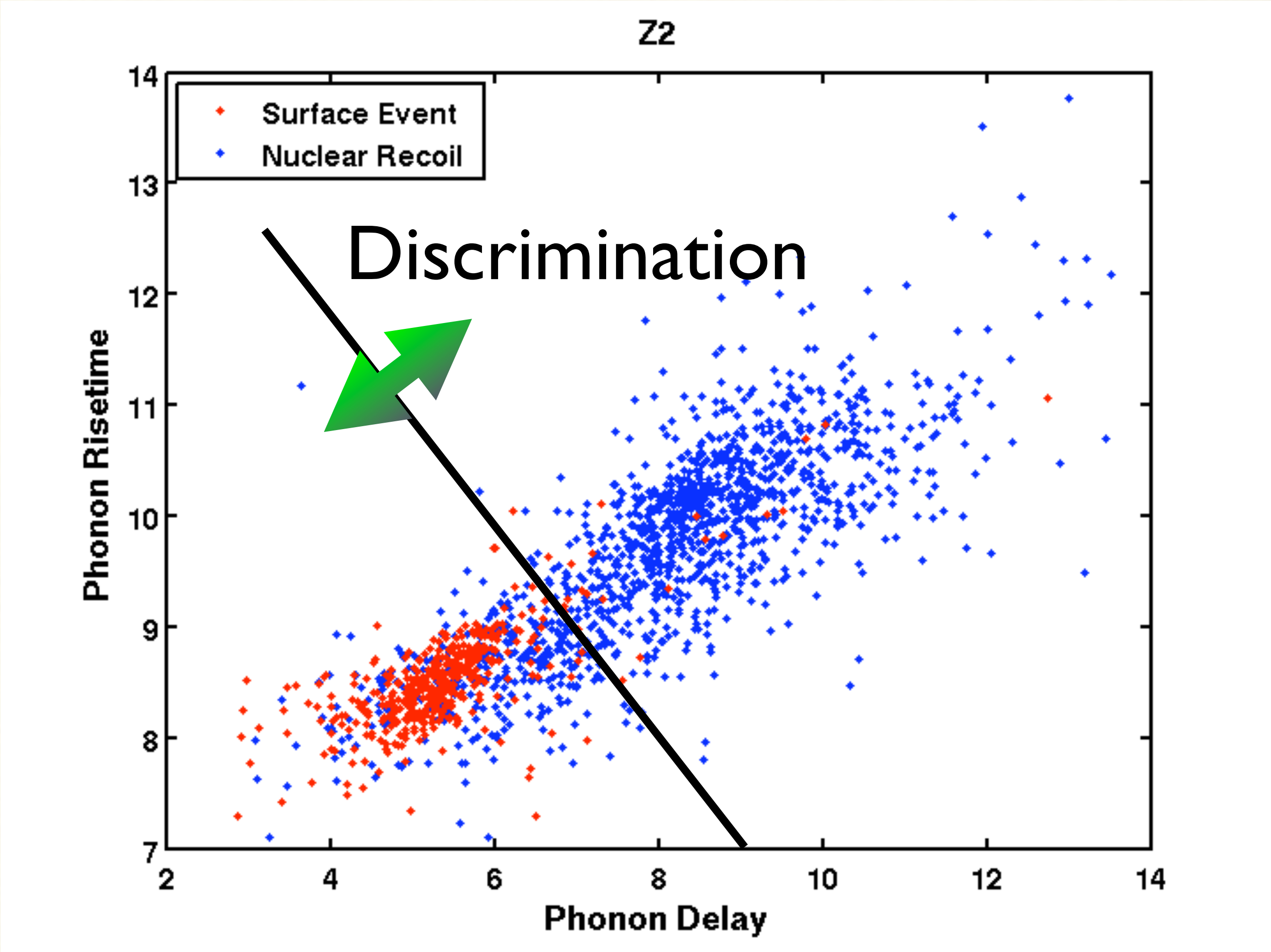
Reduced Ionization Yield



- Reduced charge yield is due to carrier back diffusion in surface events.
- "Dead layer" is within ~10µm of the surface.

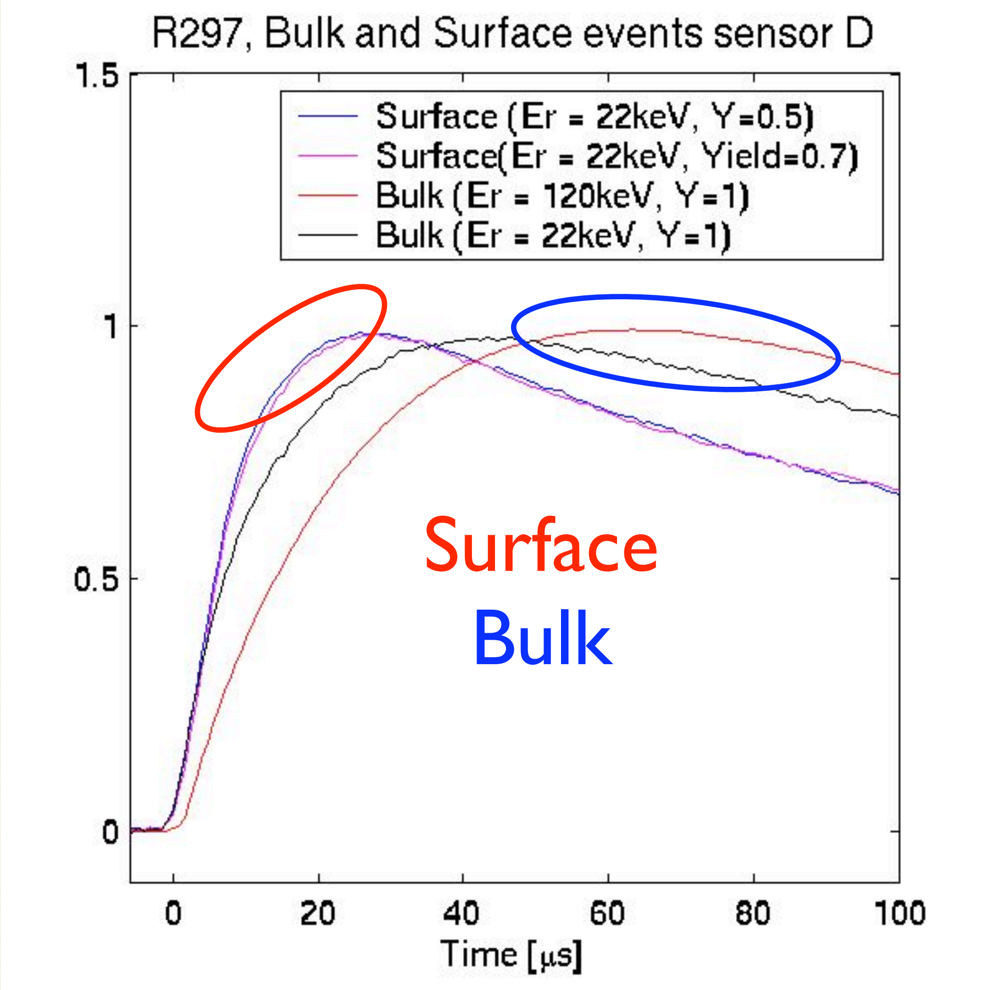
Surface Event Rejection

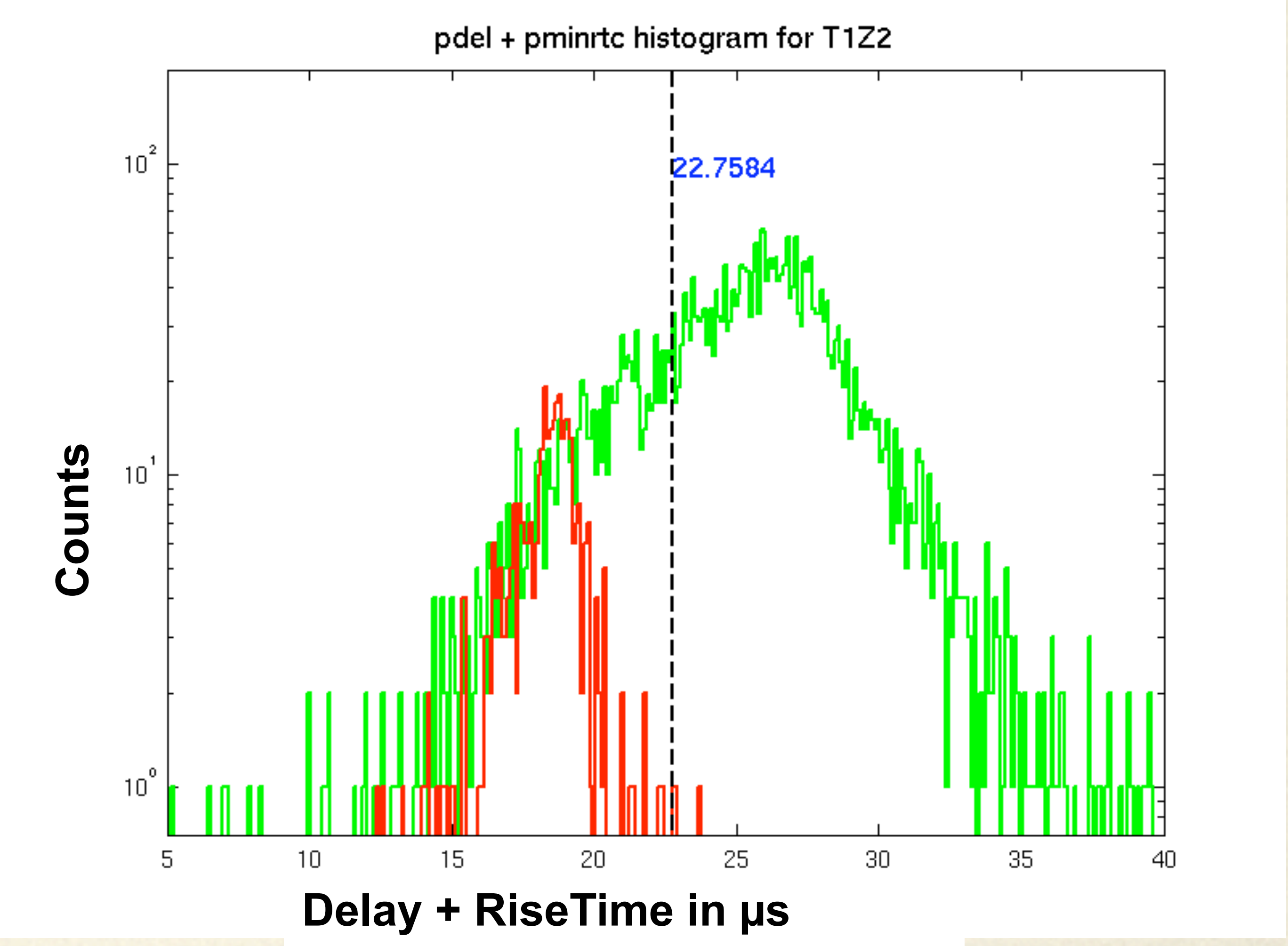




- Phonons near surface travel faster, resulting in shorter risetimes of phonon pulse.
- Selection criteria set to accept ~0.5 background events.

Surface Event Rejection





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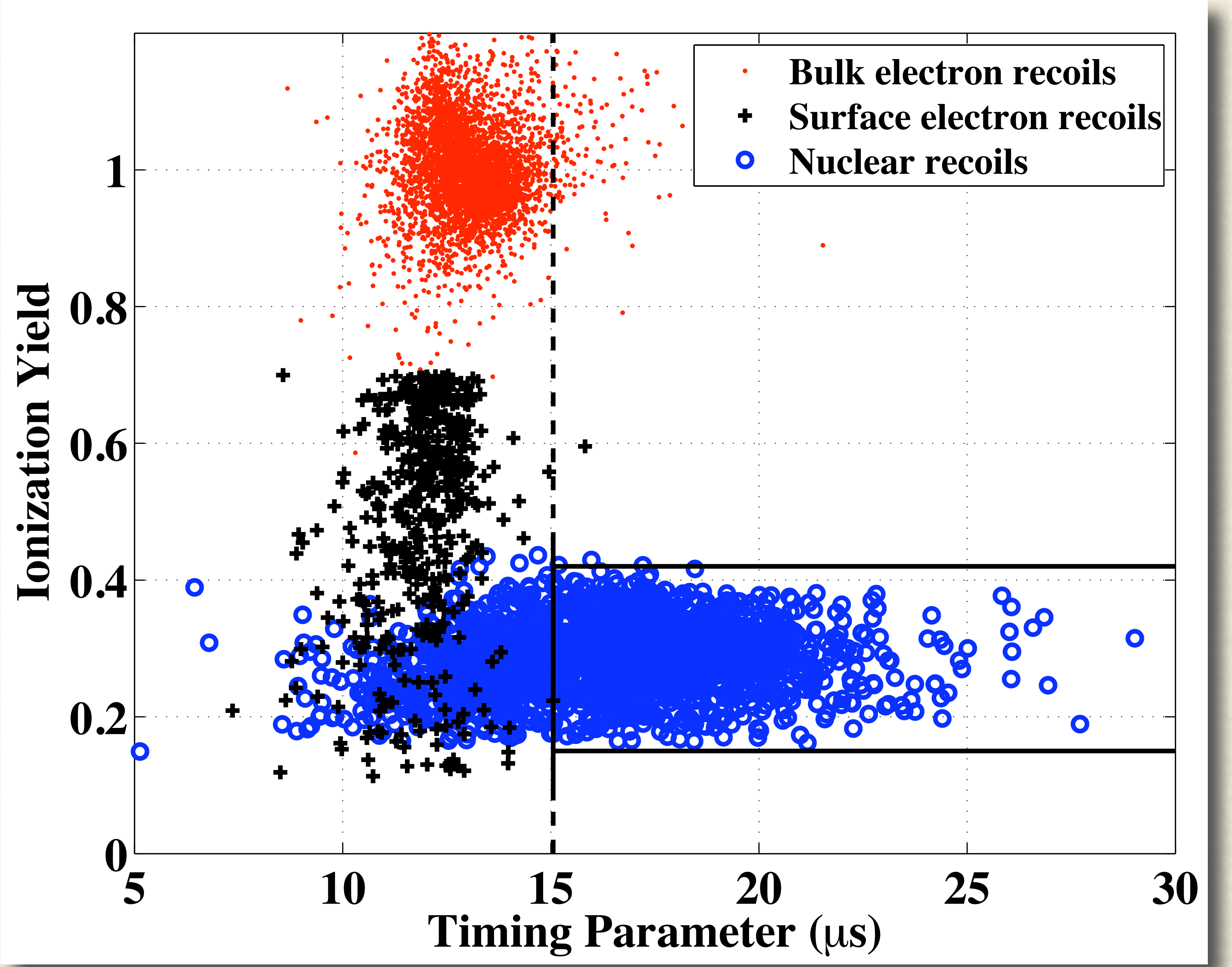
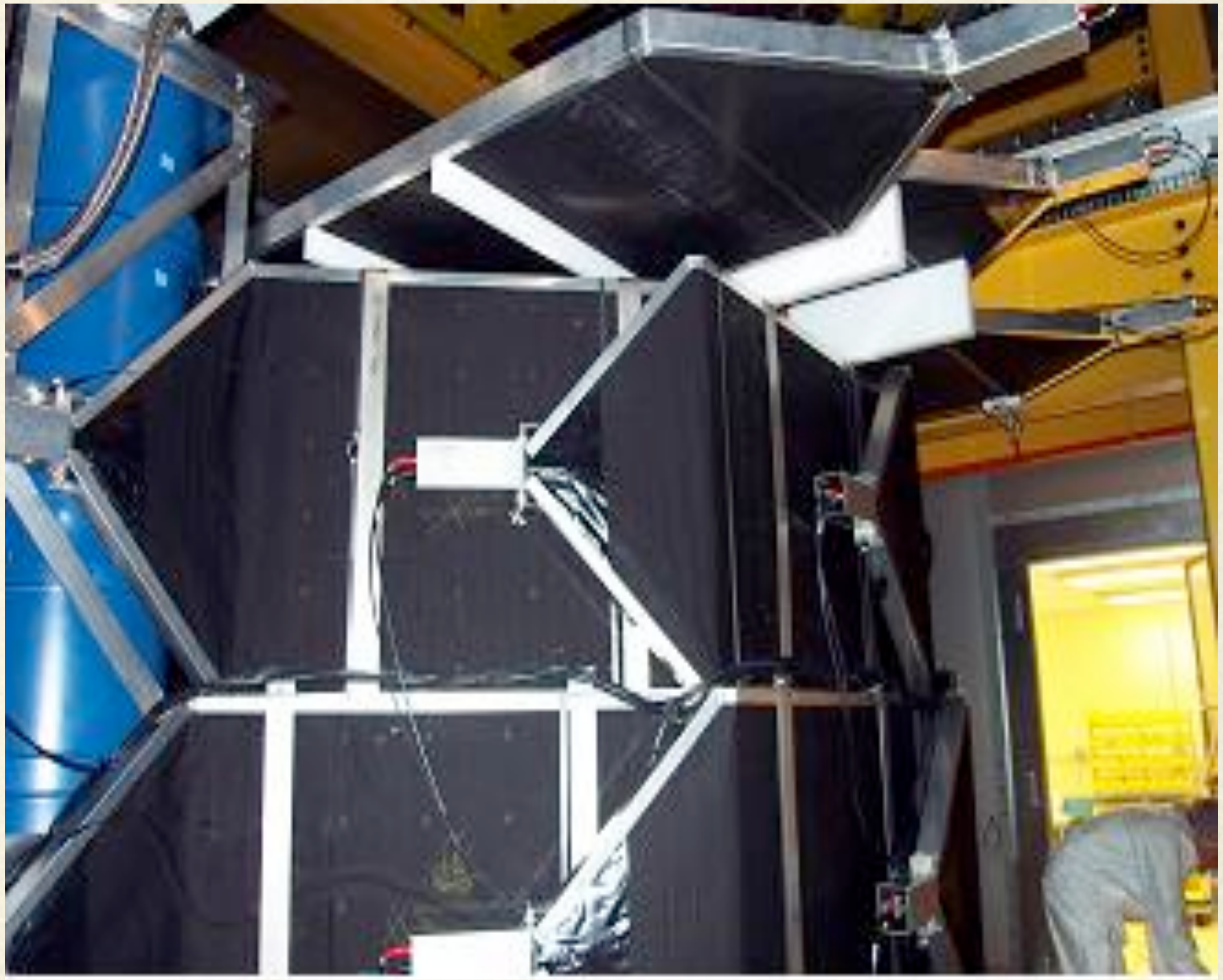
Another View of Discrimination



Peeling the Shielding Onion

Active Muon Veto:
rejects events from cosmic rays



Peeling the Shielding Onion

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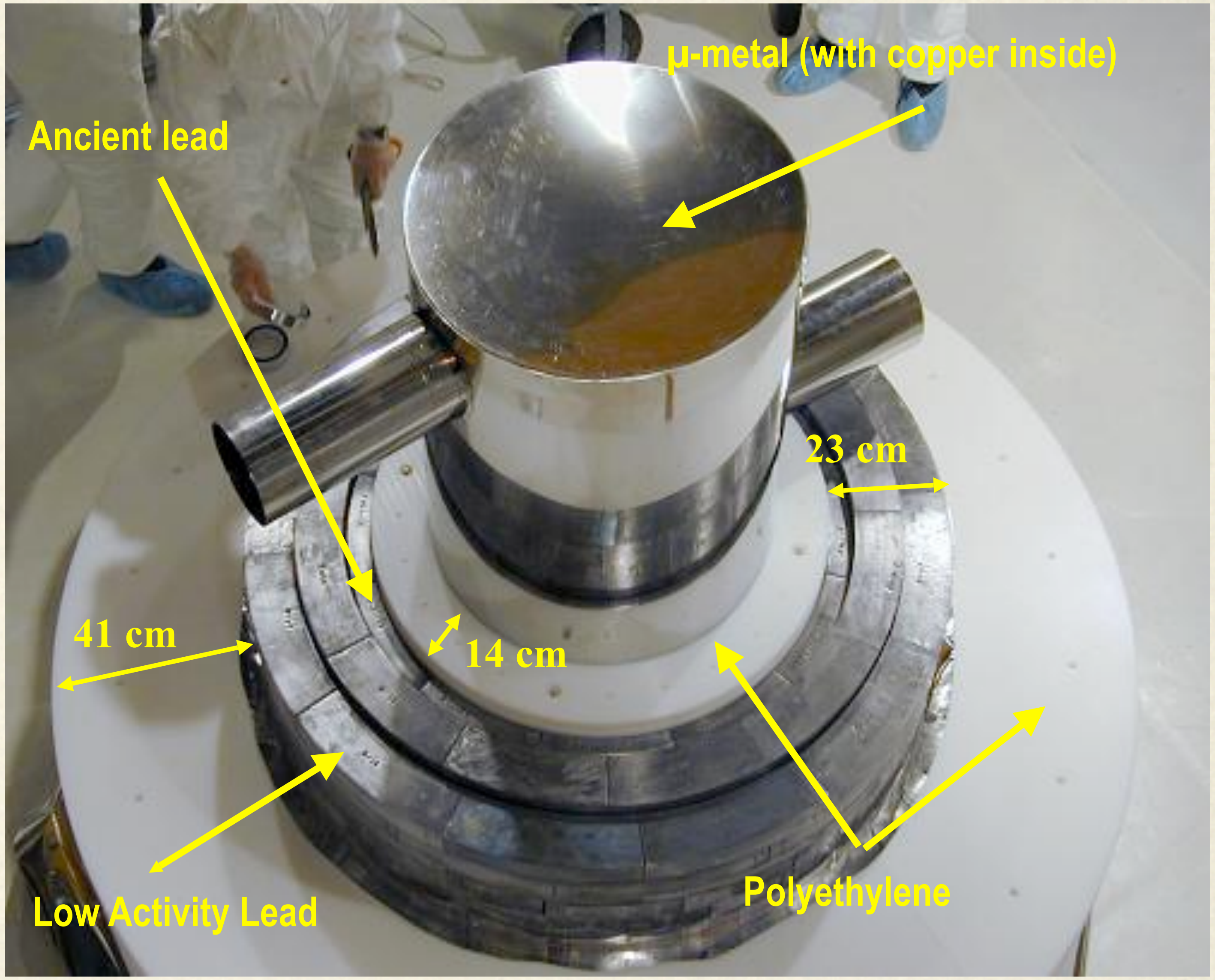
Pb: shielding from gammas resulting from radioactivity

Polyethyene: moderate neutrons produced from fission decays and from (α,n) interactions resulting from U/Th decays



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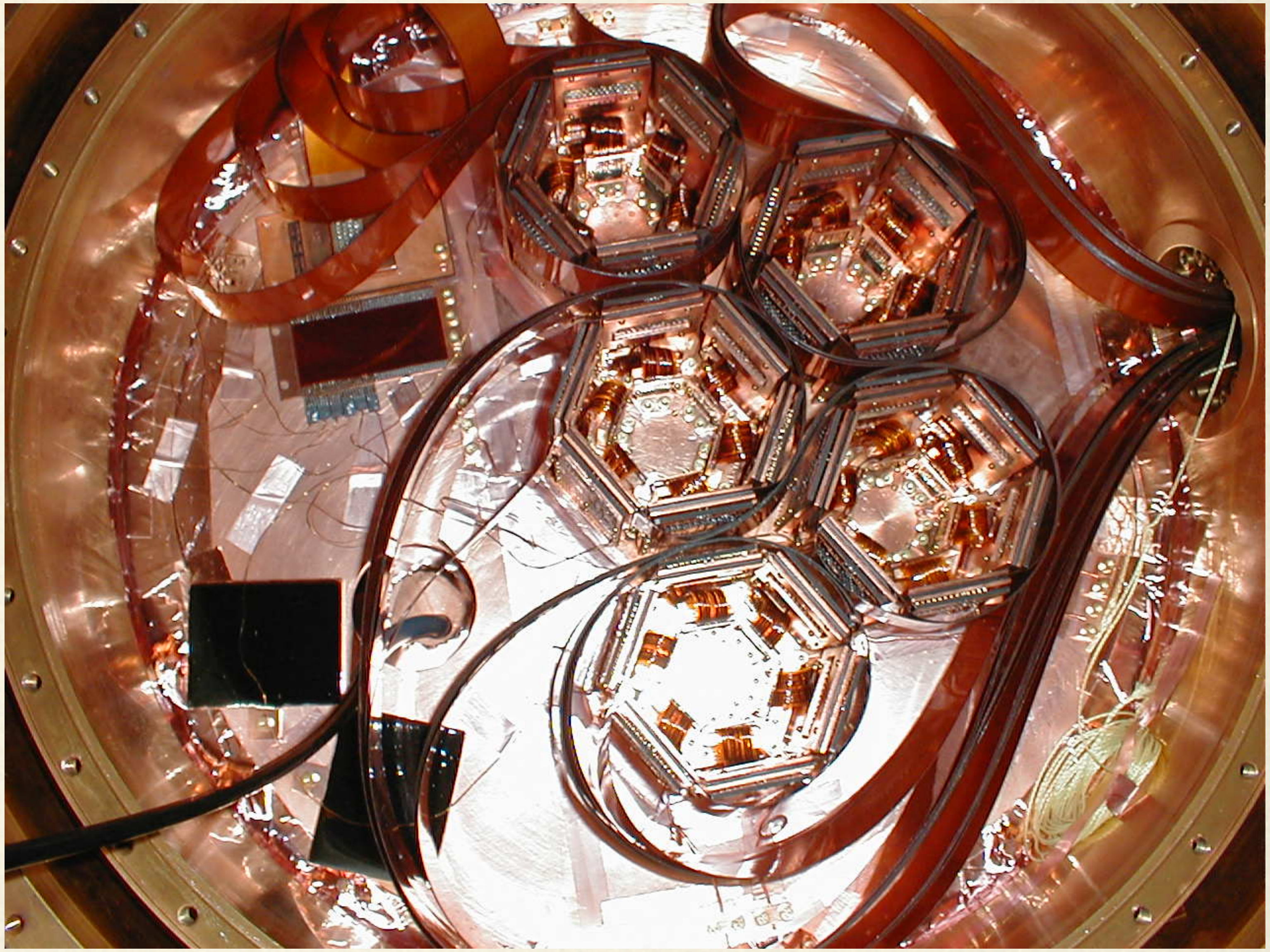

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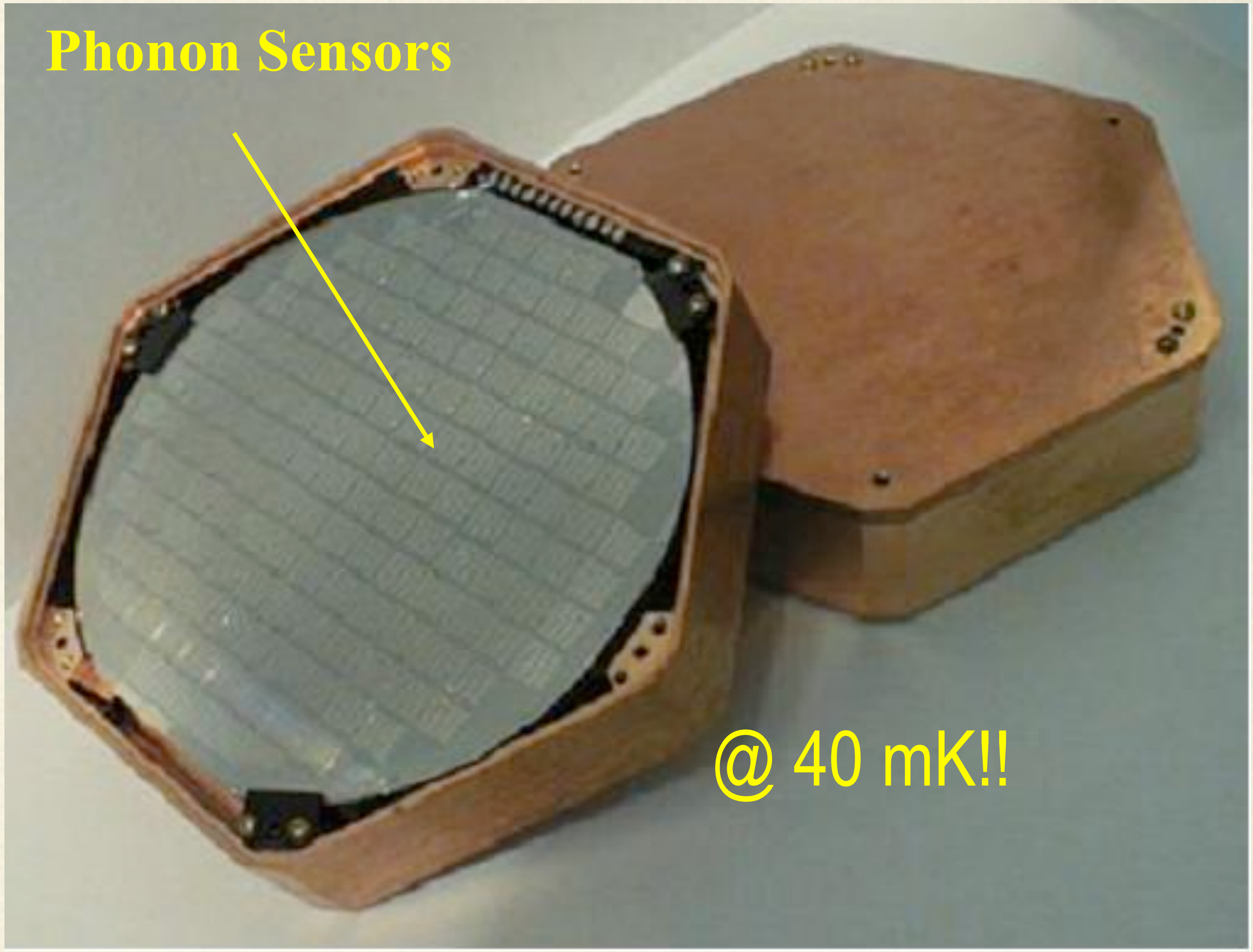
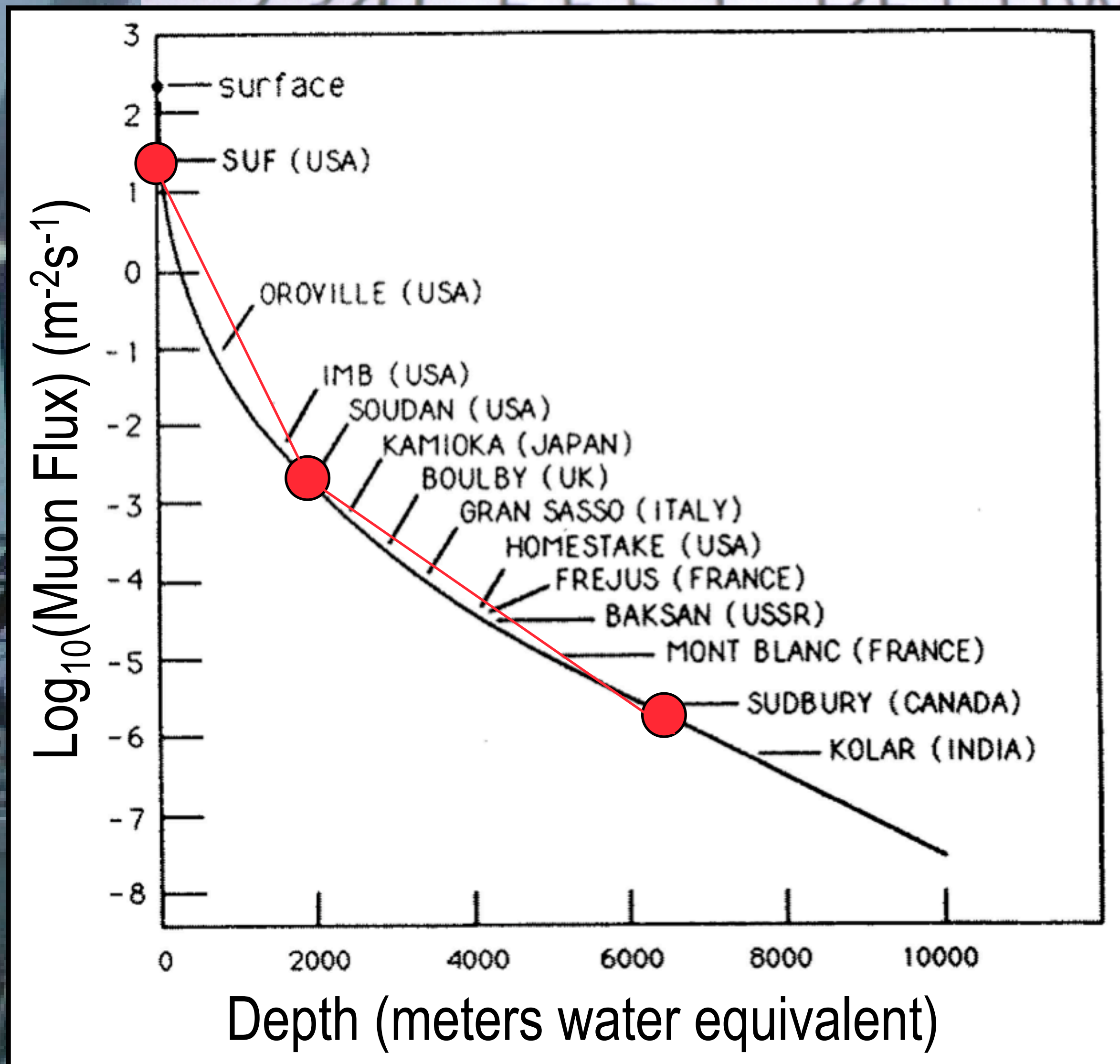



LEVEL NO. 27
2341 FEET BELOW THE SURFACE
689 FEET BELOW SEA LEVEL



SUF

17 mwe

0.5 n/d/kg

(182.5 n/y/kg)

Soudan

2090 mwe

0.05 n/y/kg

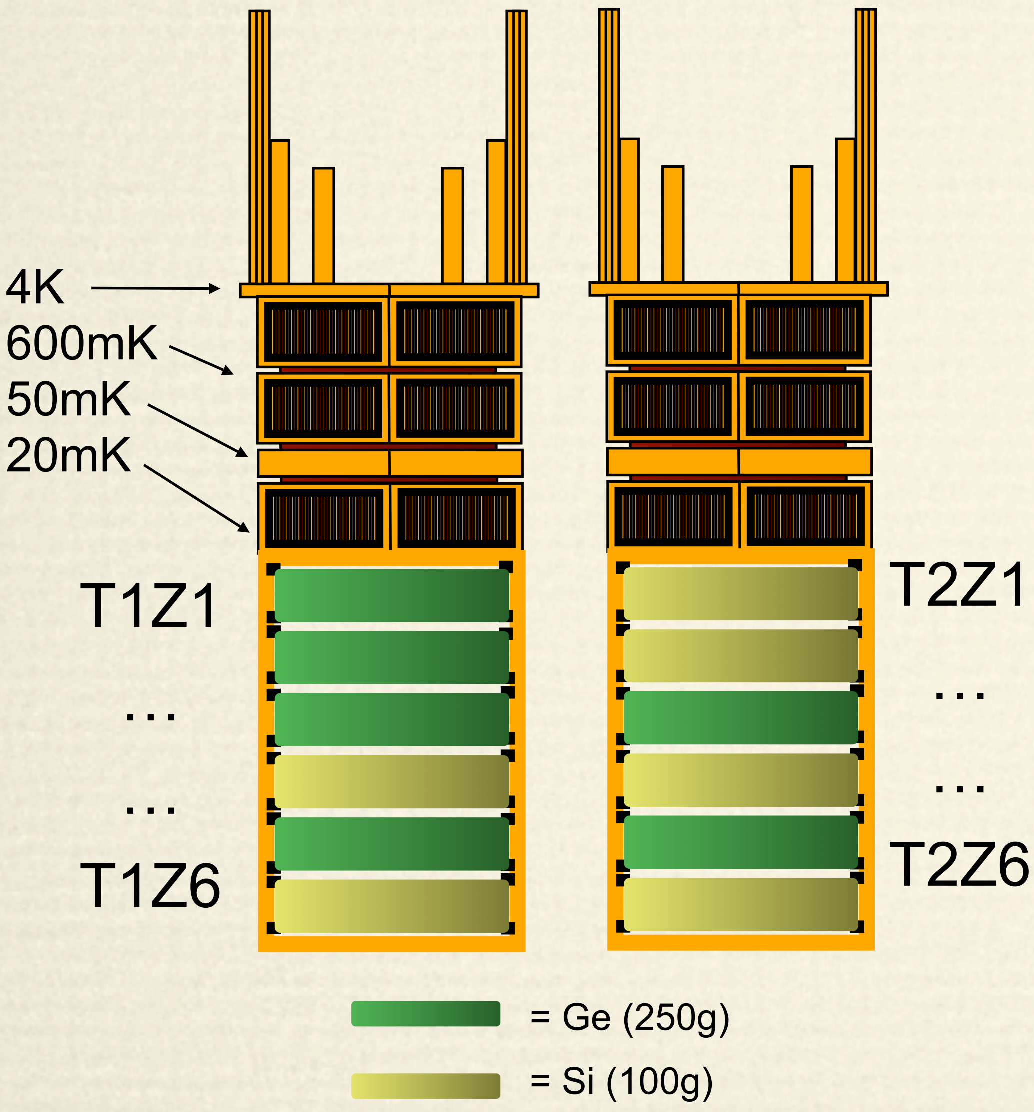
SNOLab

6060 mwe

0.2 n/y/ton

(0.0002 n/y/kg)

Initial Runs at Soudan



Run 118: 52.4 live days (2003-4)
1 kg Ge + 0.2 kg Si

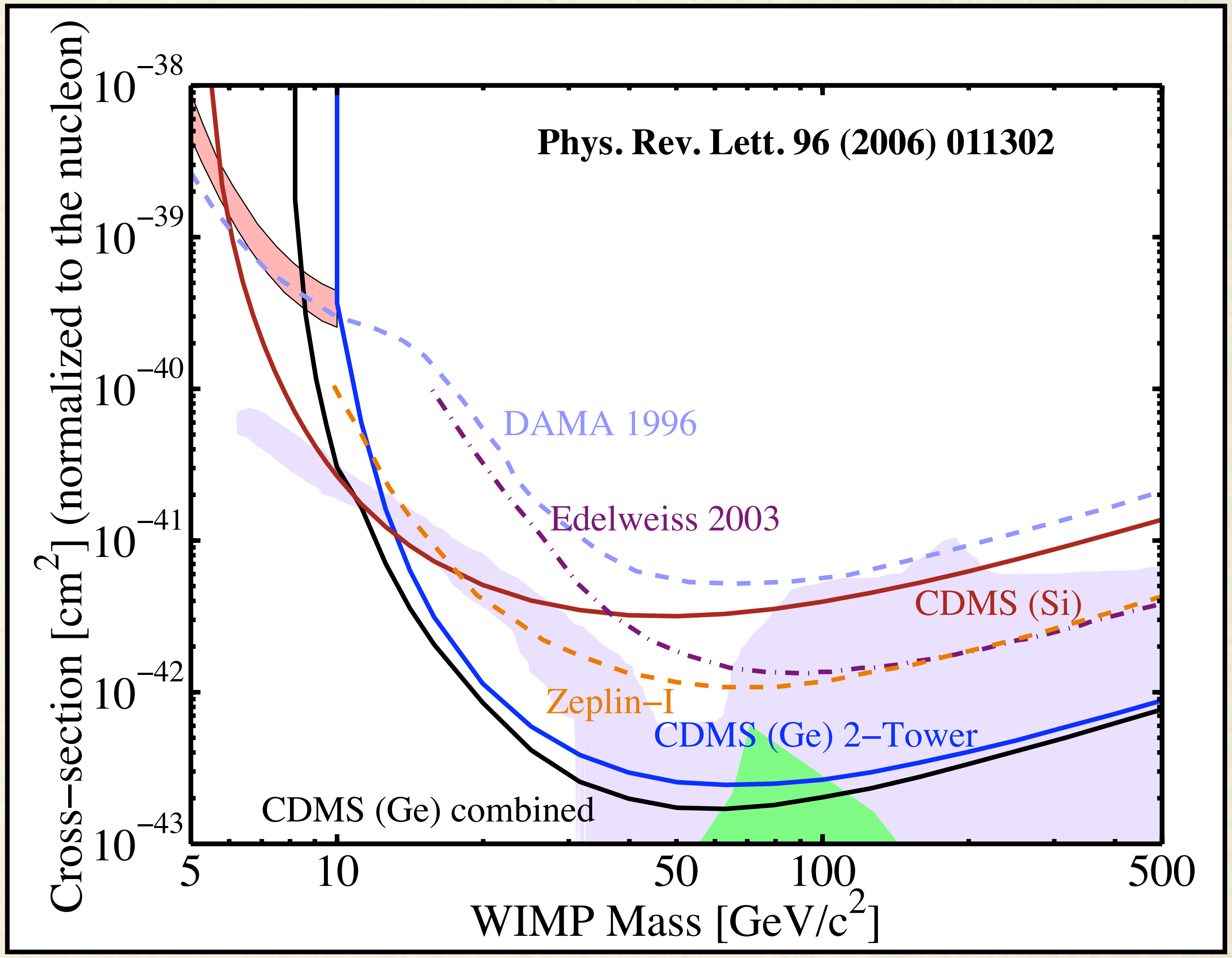
PRL **93**, 211301 (2004)
PRD **72,** 052009 (2005)

Run 119: 74.5 live days (2004)
1.5 kg Ge + 0.6 kg Si

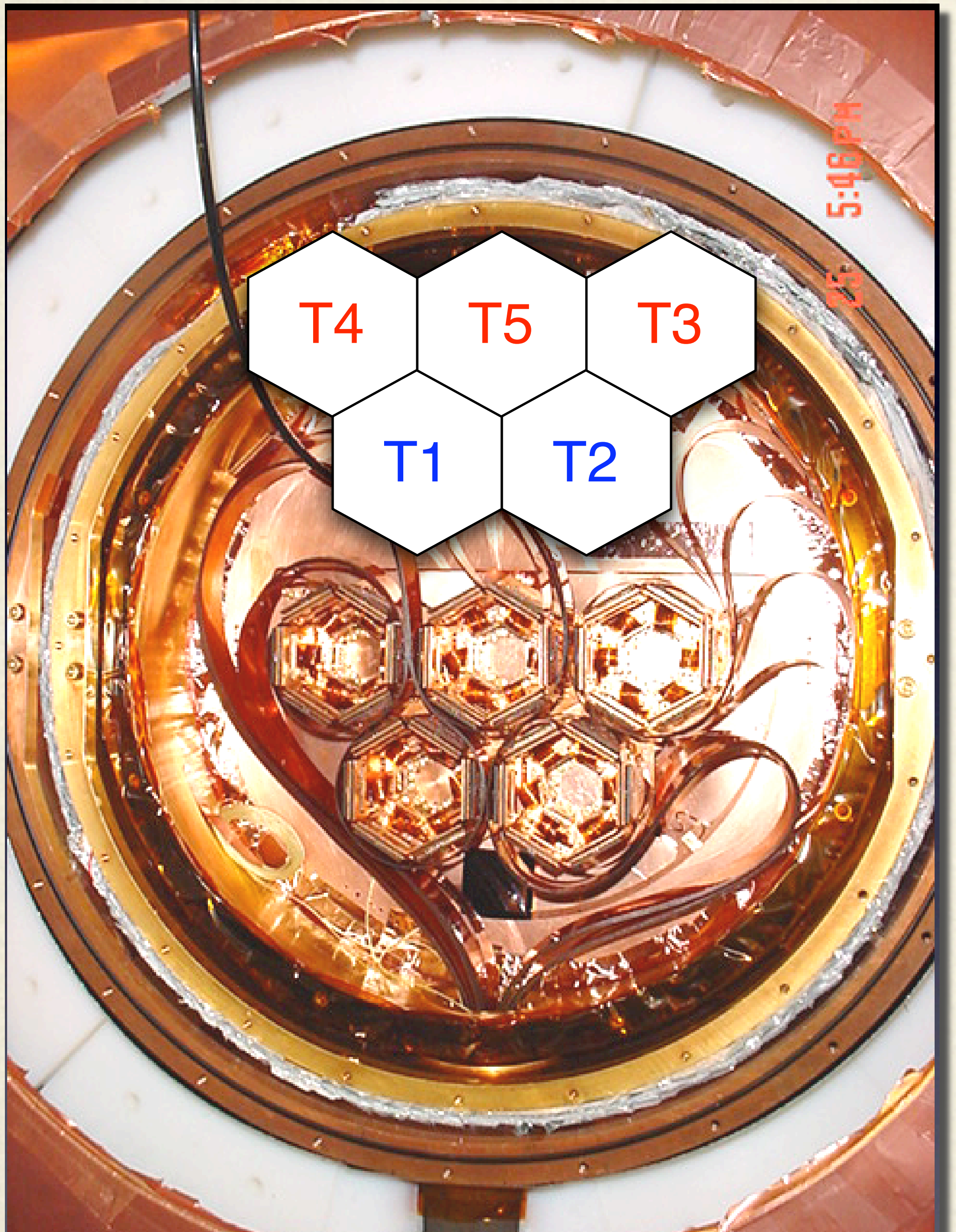
PRL **96**, 011302 (2006) *Combined reanalysis 2008 (in preparation)*

Two Tower Limits (2005)

- Upper limit on WIMP-nucleaon spin-independent σ is **1.6 x 10^{43} cm^2** for a WIMP of mass **60 GeV**.
- Excludes large regions of SUSY parameter space under some frameworks.
  - A. Bottino et al, Phys. Rev D 69, 037302 (2004) in purple.
  - J. Ellis et al., Phys. Rev. D 71, 095007 (2005) in green



CDMS-II Experiment

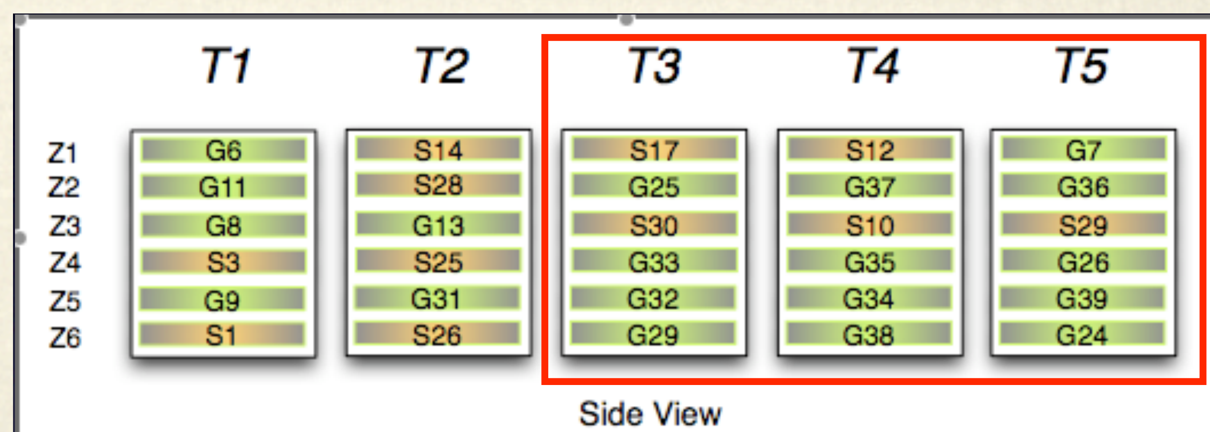


30 detectors installed and operating in Soudan since June 06

4.75 kg Ge, 1.1 kg Si

Six Data runs so far:

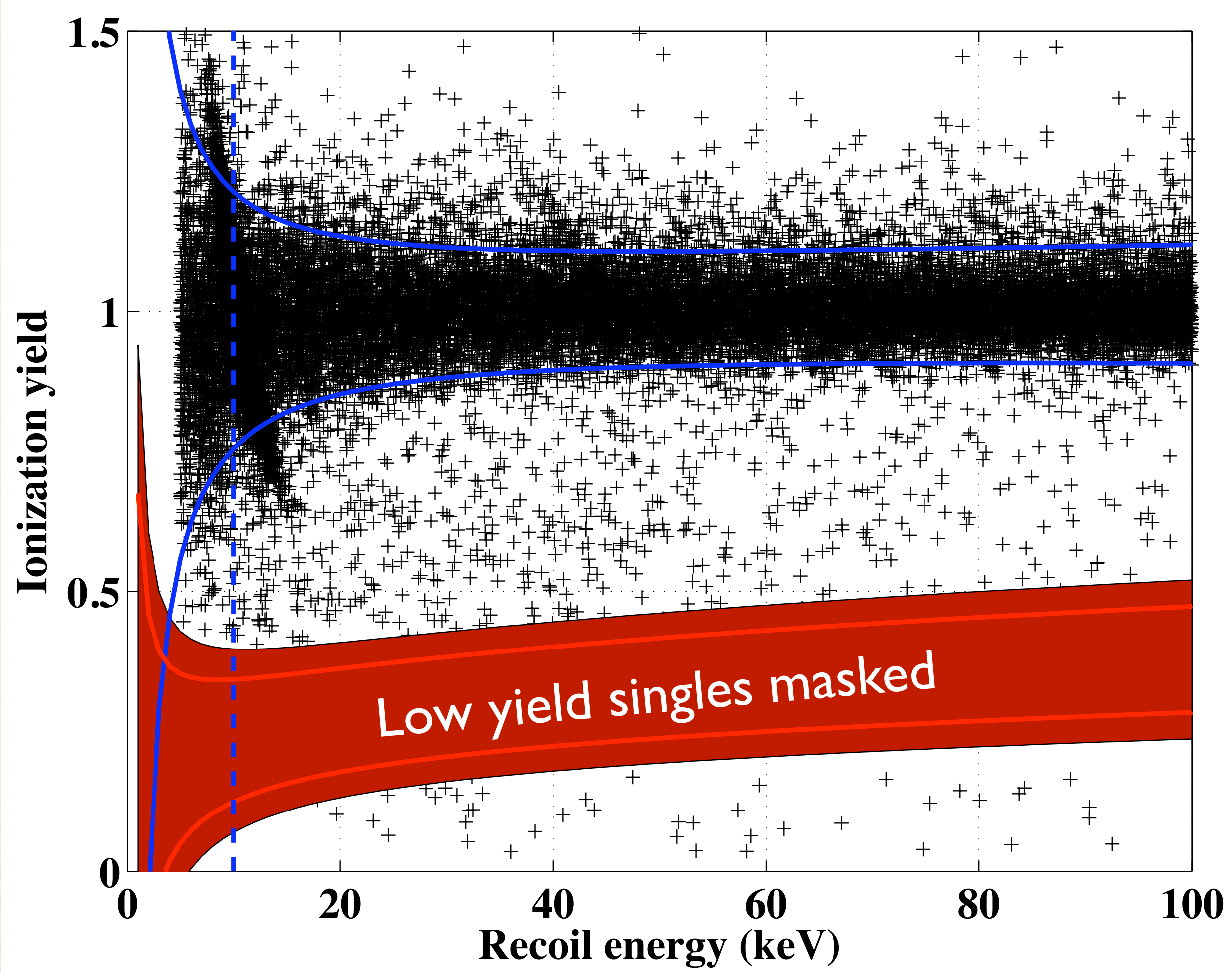
R123 (10/06 - 3/07): 430 kg-days (Ge raw)
R124 (4/07 - 7/07): 224 kg-days (Ge raw)
R125 (7/07 - 1/08): 380 kg-days (Ge raw)
R126 (1/08 - 5/08): 221 kg-days (Ge raw)
R127 (5/08 - 8/08): 165 kg-days (Ge raw)
R128 (8/08 - 9/08): 74 kg-days (Ge raw)
R129 (1/08): ongoing



First Five Tower Results (2008)

Blind Analysis:

Event selection and efficiencies were calculated without looking at the signal region of the WIMP-search data.



Event Selection:

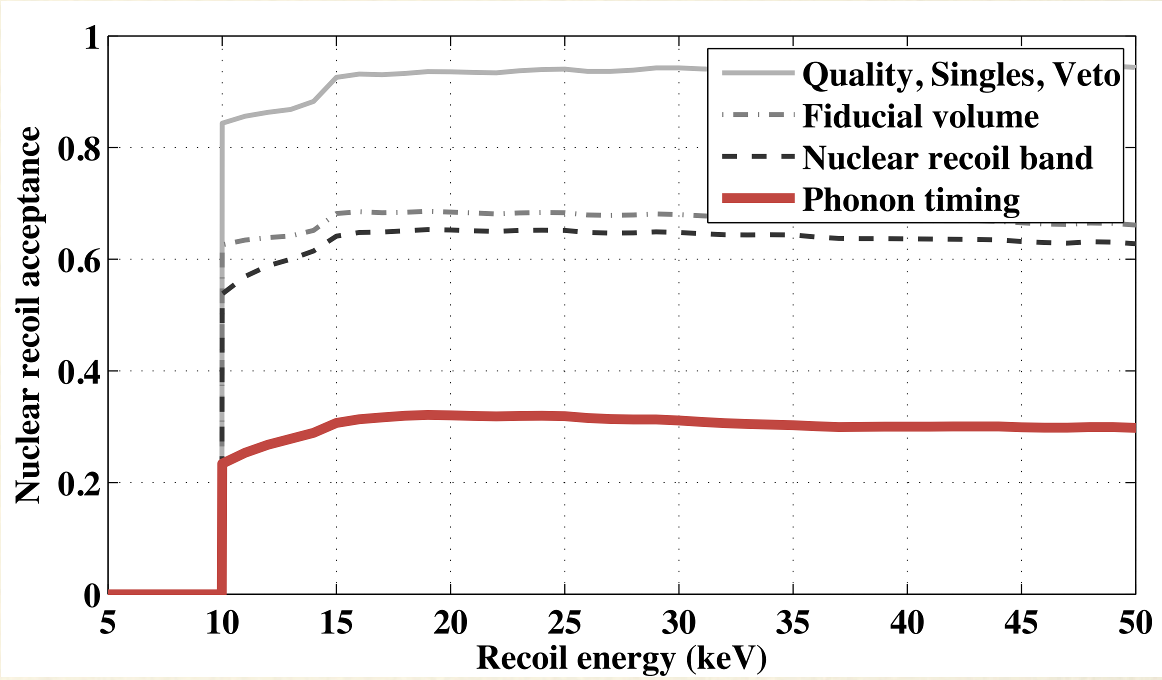
- ☑ ***Veto-anticoincidence cut***
- ☑ ***Single-scatter cut***
- ☑ ***Q_{inner} (fiducial volume) cut***
- ☑ ***Ionization yield cut***
- ☑ ***Phonon timing cut***

Summary of Blind Analysis

Surface Background

Estimated number of background events to pass surface cut in Ge

$$0.6^{+0.5}_{-0.3}(stat.)^{+0.3}_{-0.2}(syst.)$$



Neutron Backround

Poly Cu (α,n): < 0.03
Pb (fission): < 0.1
Cosmogenic: < 0.1 (MC 0.03-0.05)
8 vetoed neutron multiples seen
0 vetoed singles seen

397 raw kg-d
121 kg-d WIMP equiv. @ 60 GeV/c^2

Opening the Box

Box opened Monday, February 4 for 15 Ge ZIPs.
Remaining 8 Si and 1 Ge undergoing further leakage studies.

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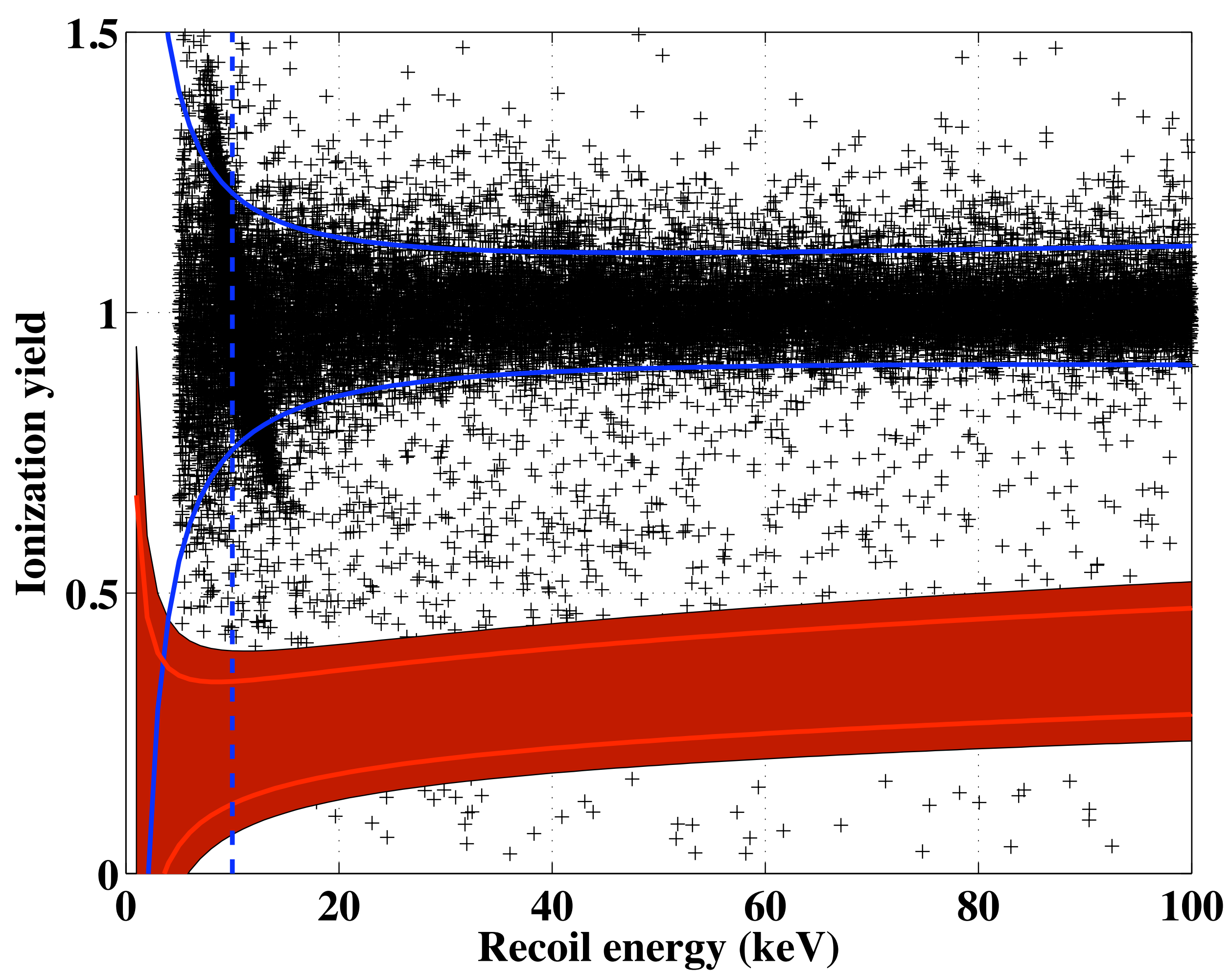
3σ region masked

☑ Hide unvetoed singles



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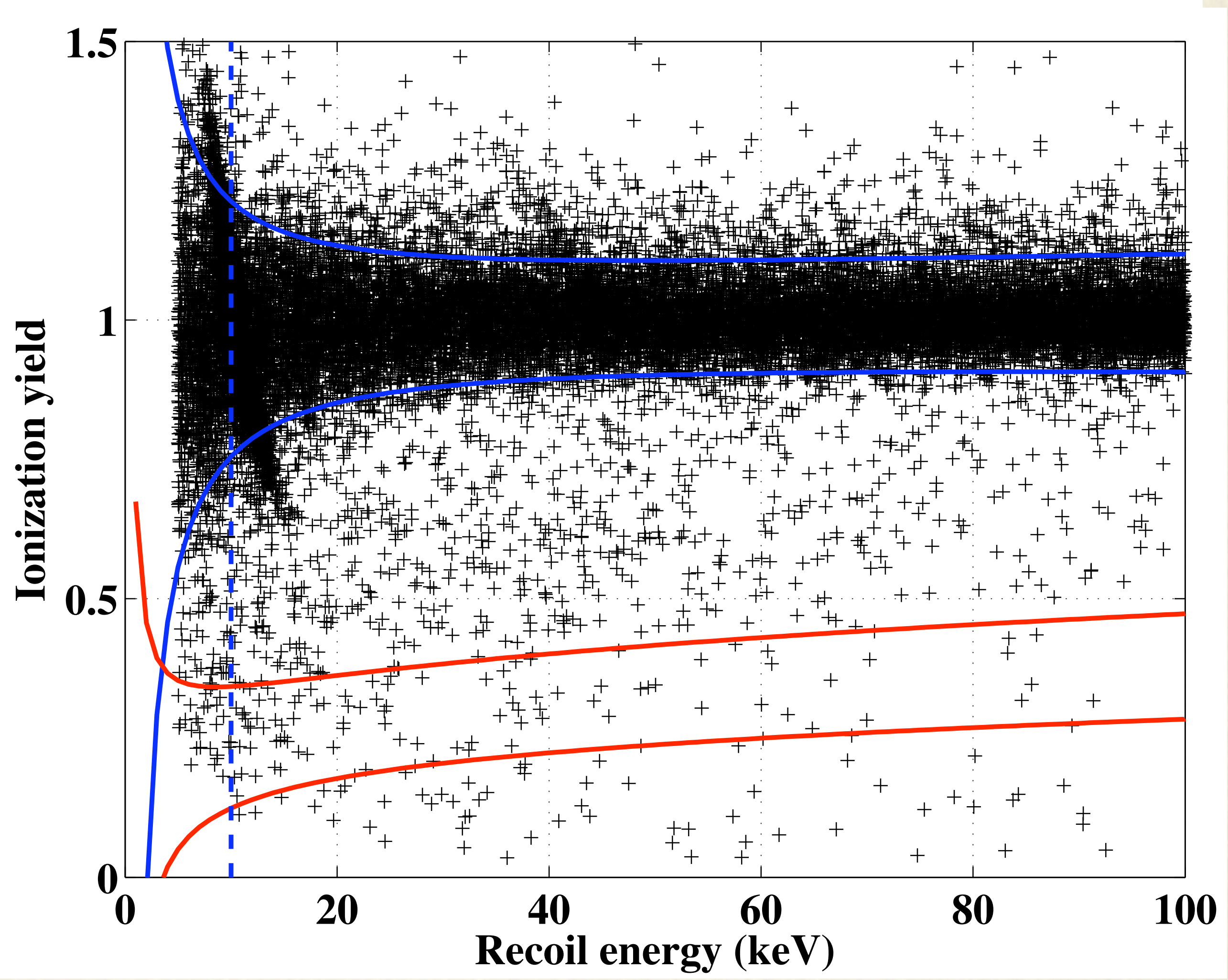
Lift mask, see 97 singles failing timing cut



Opening the Box

Box opened Monday, February 4 for 15 Ge ZIPs.
Remaining 8 Si and 1 Ge undergoing further leakage studies.

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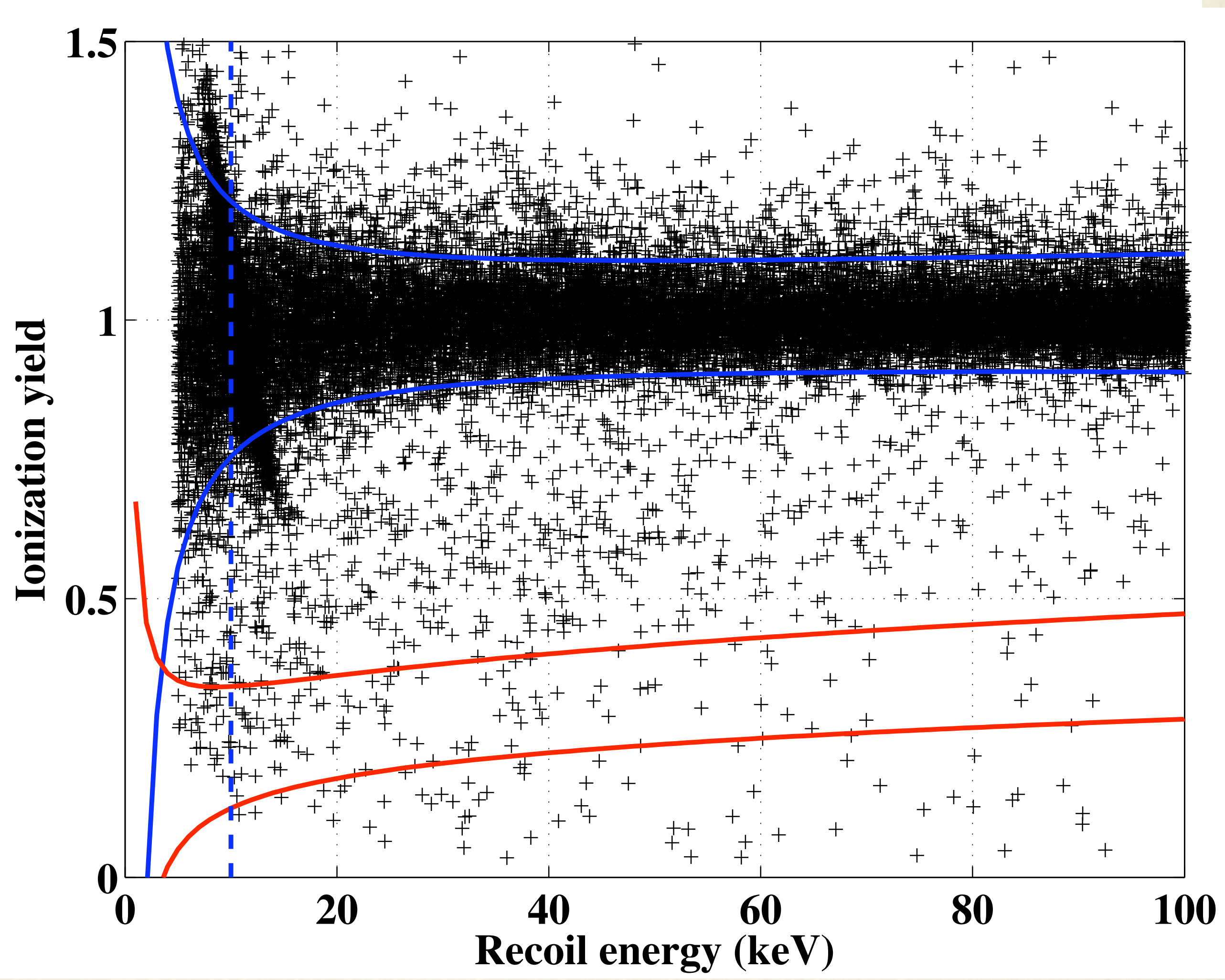

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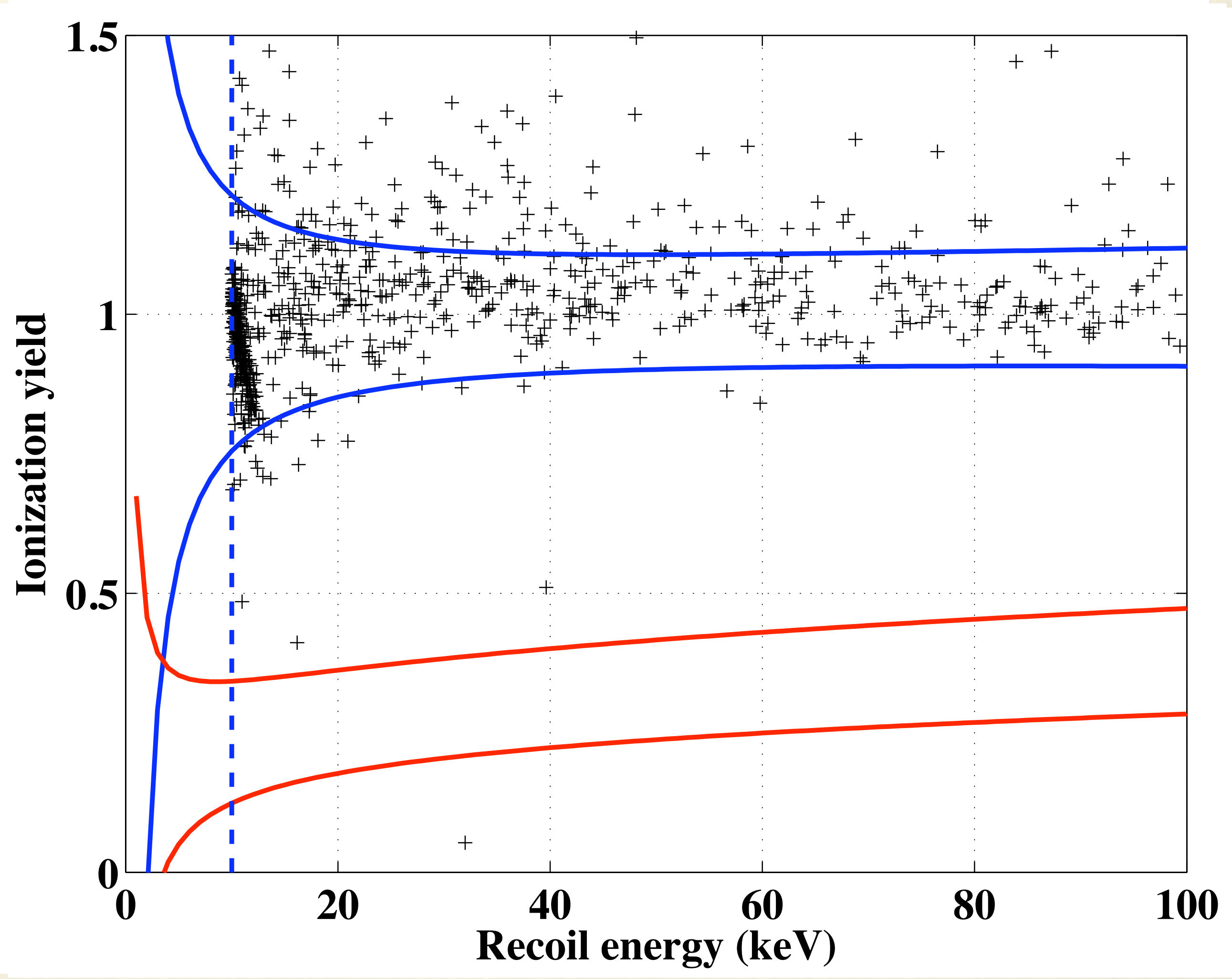
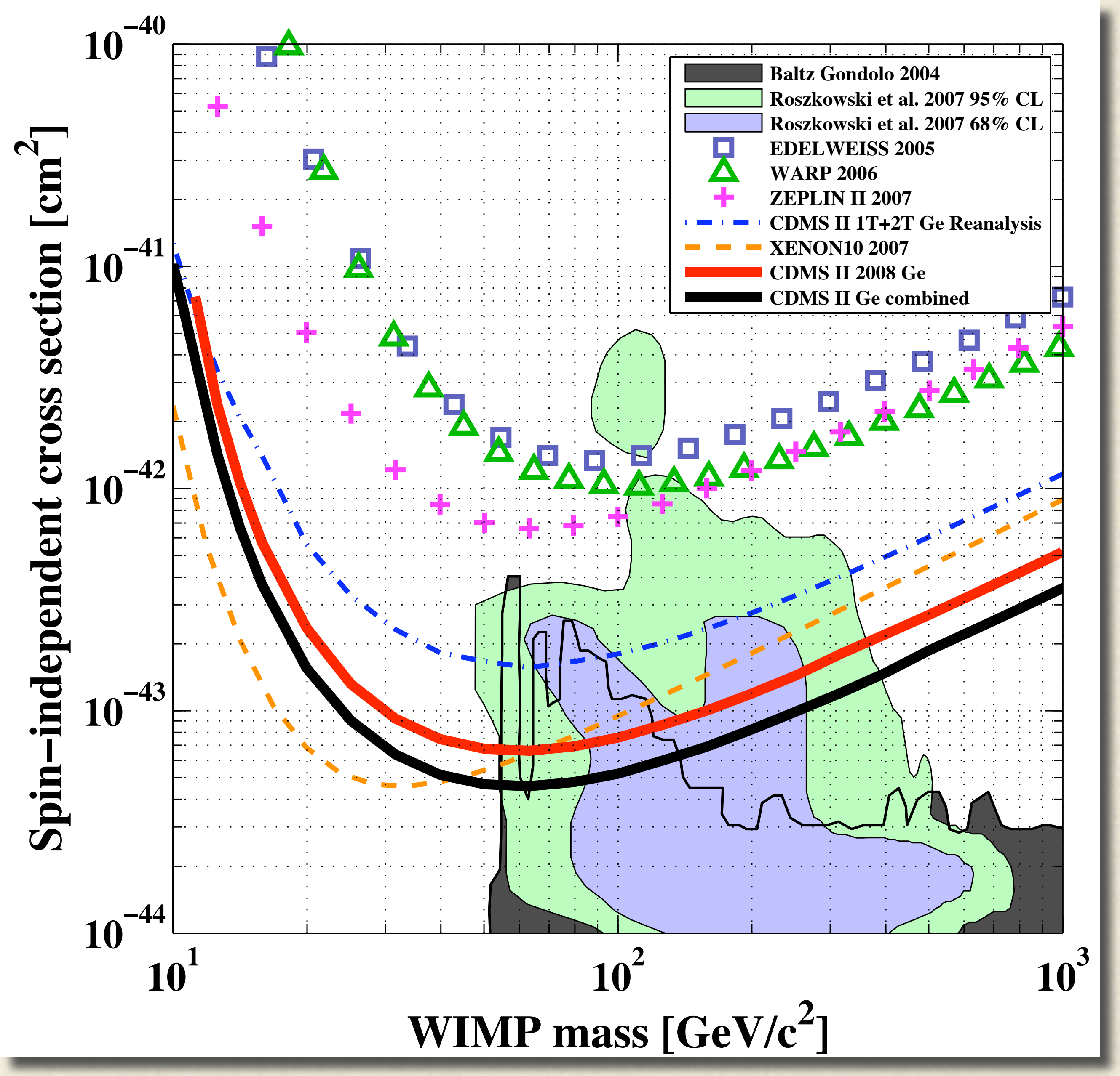
NO EVENTS OBSERVED!



Five Tower Limits (2008)

- Upper limit at the 90% C.L. on the WIMP-nucleon cross-section is **4.6 x 10^{-44} cm^2** for a WIMP of mass **60 GeV/c^2**

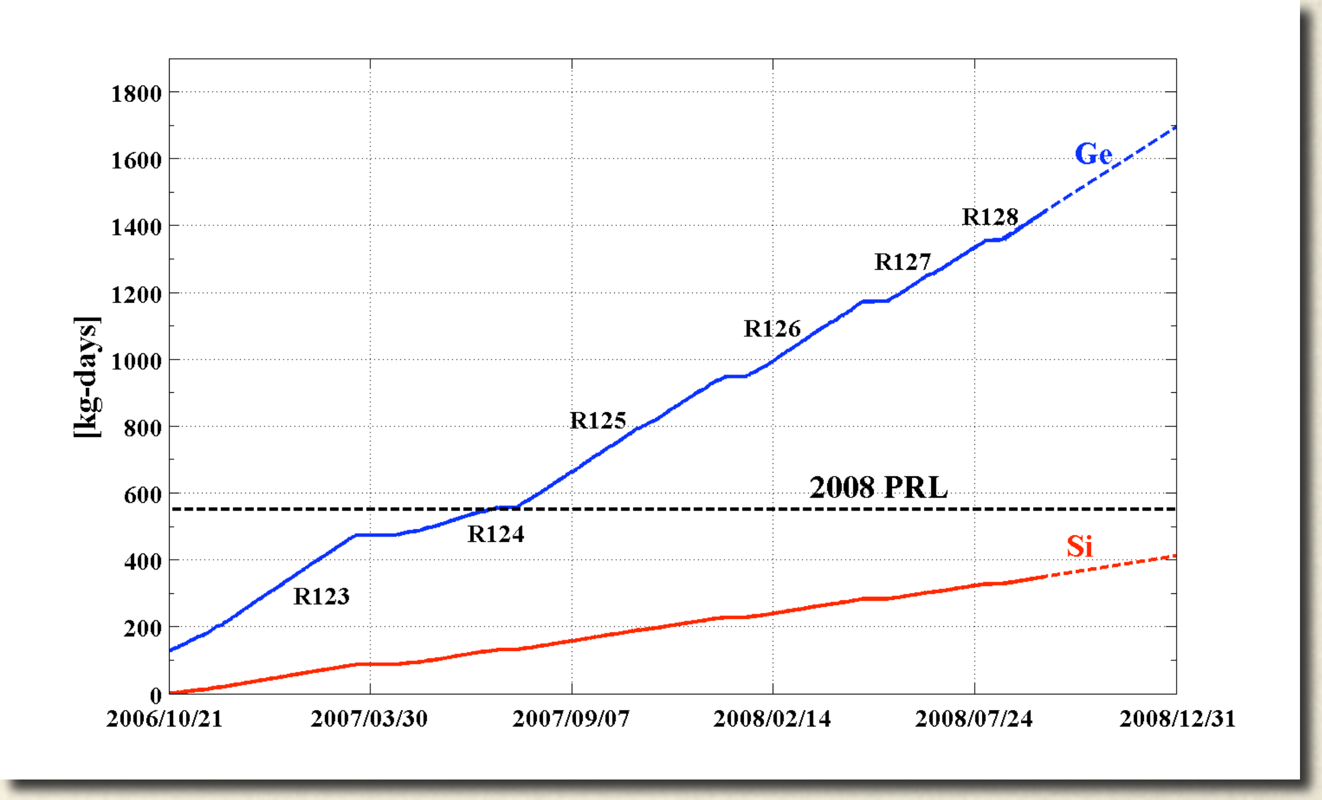


Submitted PRL

Preprint at:
- http://cdms.berkeley.edu
- arXiv:0802.3530

CDMS II Completion

- Currently have **~ 1400 kg-days** raw exposure
- Expected sensitivity at the end of 2008, based on **1692 kg-days** raw data is **~ 2×10^{-44} cm^2** for a WIMP of mass **60 GeV/c^2** (projected background 0.5 event).
- A WIMP cross-section of **4×10^{-44} cm^2** would result in **4 expected events** (99%-C.L. detection).

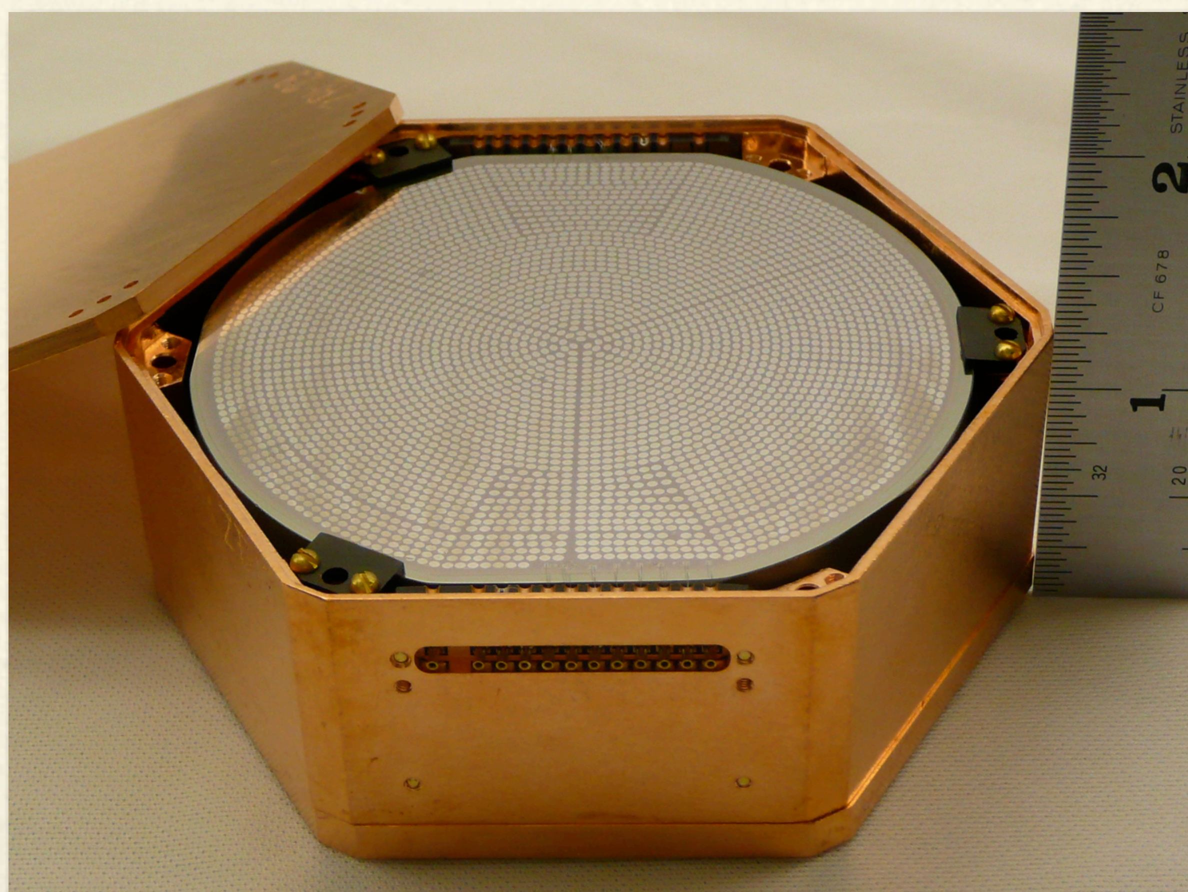


The Future

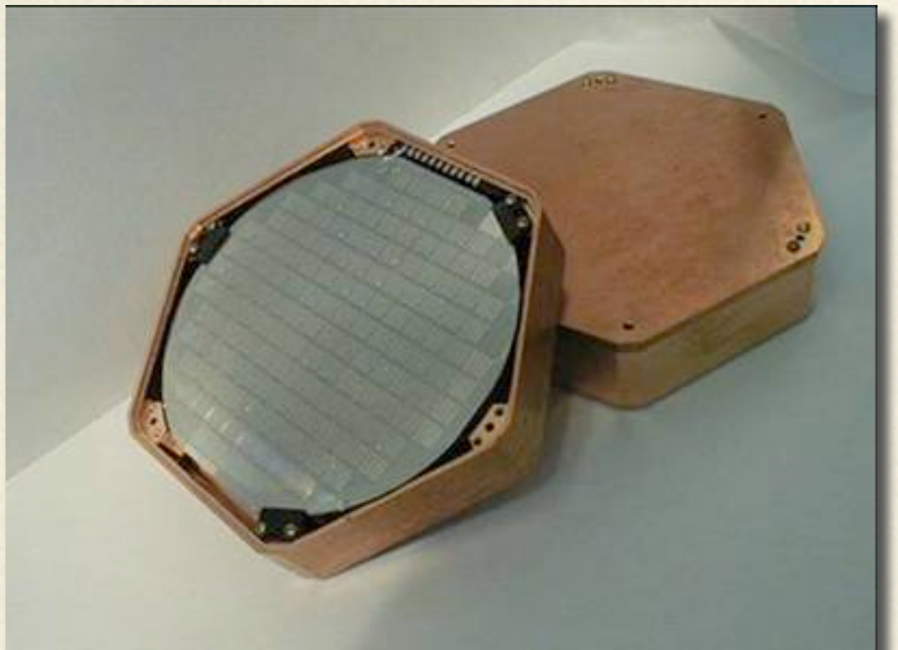
SuperCDMS

Development project funded to build and deploy 2 **SuperTowers**.

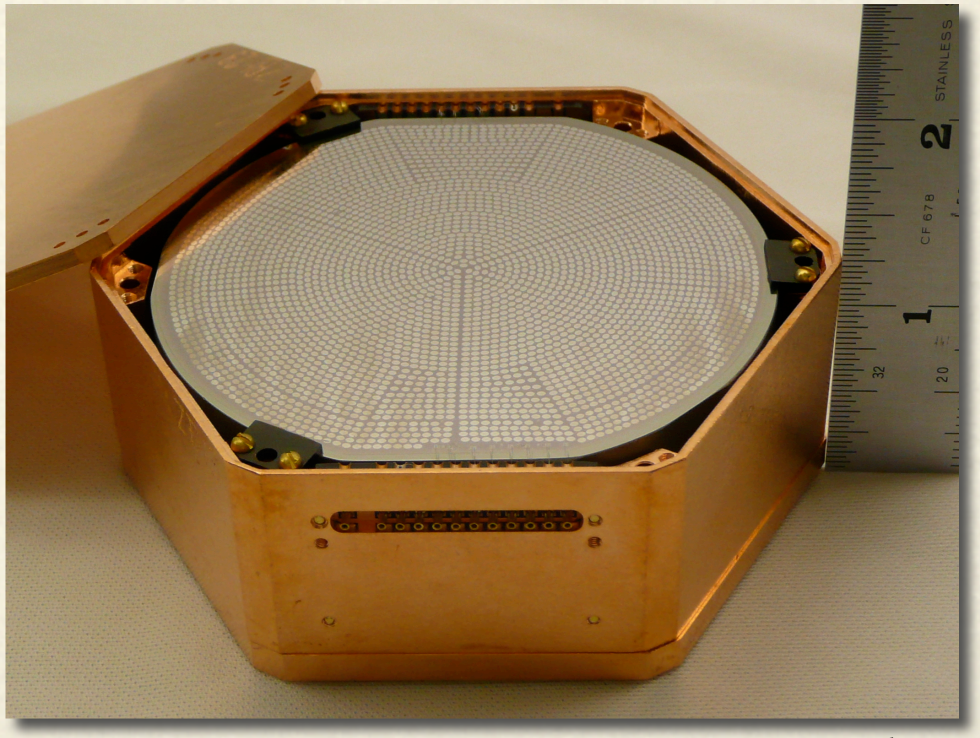
Proposed **SuperCDMS Soudan** project to build, deploy and operate 3 additional SuperTowers, total **15 kg Ge**.



SuperCDMS Detectors



- **SuperTower** = five 1-inch thick detectors + two 1-cm thick ionization only detectors
- **Increase thickness** (2.5 x).
  - better surface/volume
  - increase manufacture



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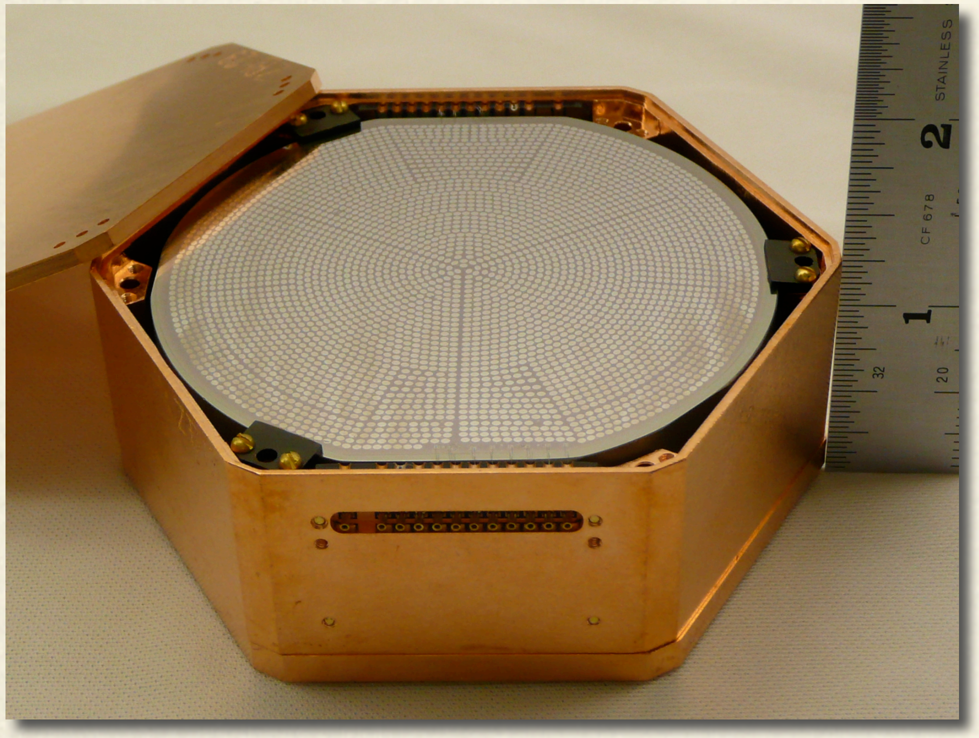

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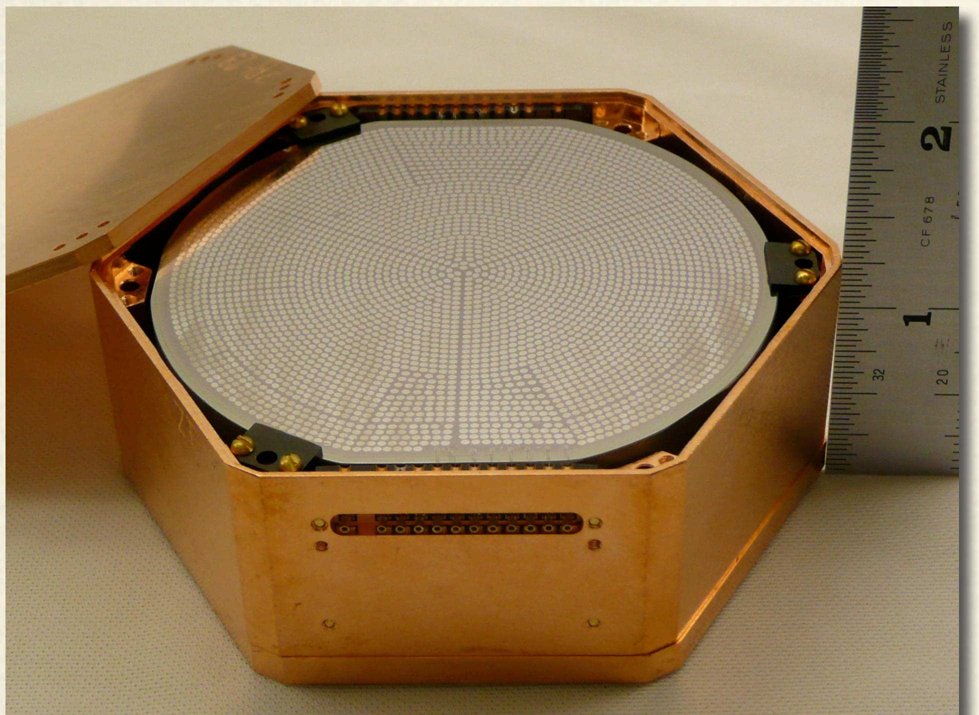

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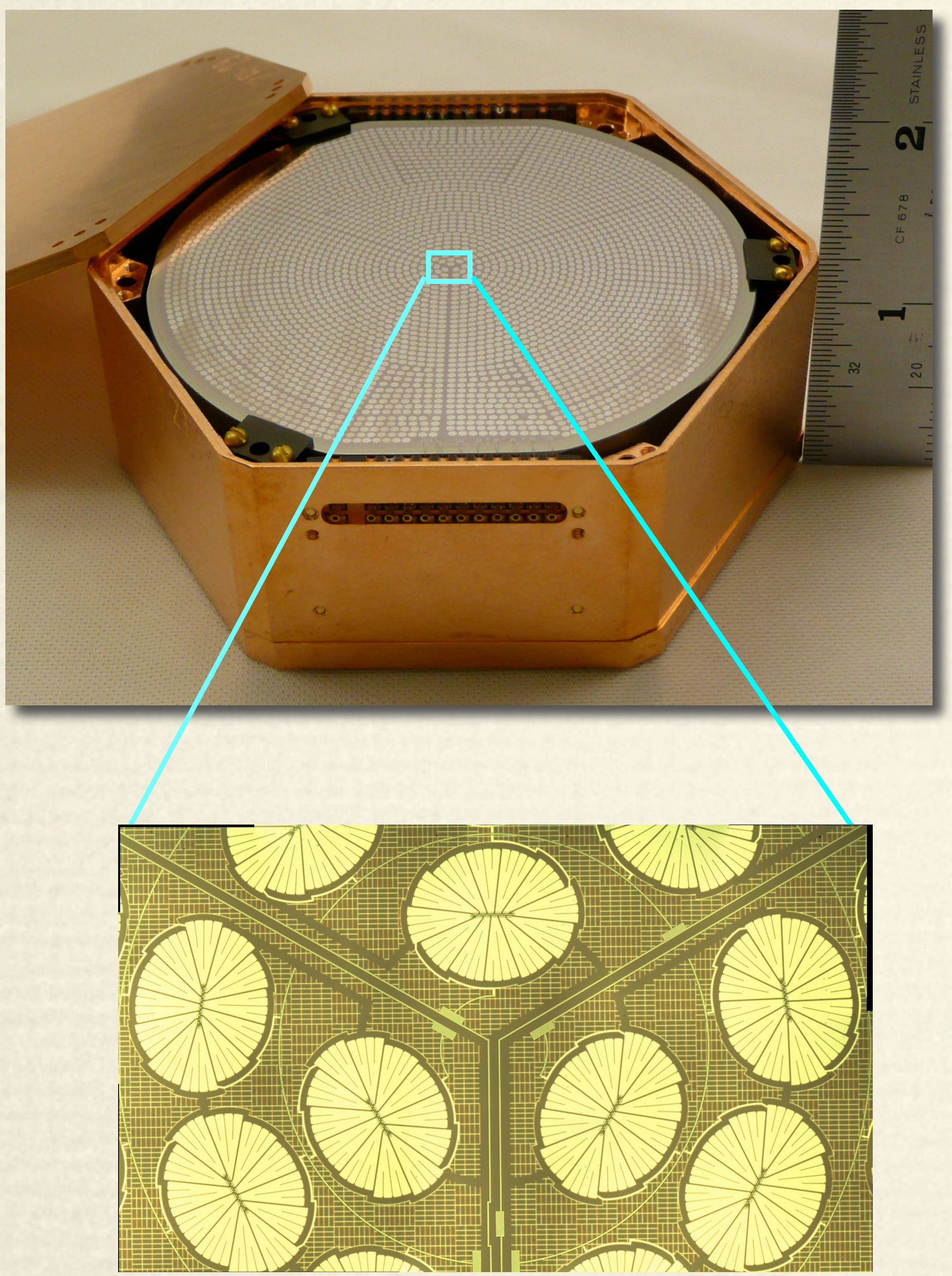

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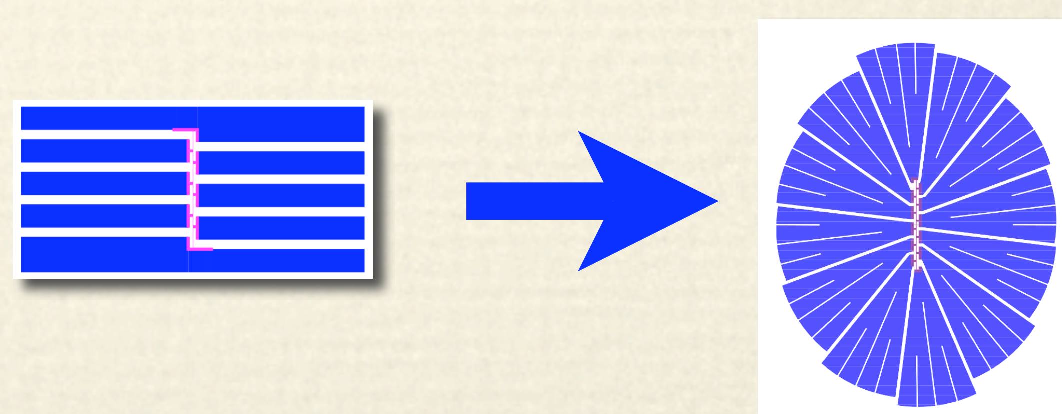

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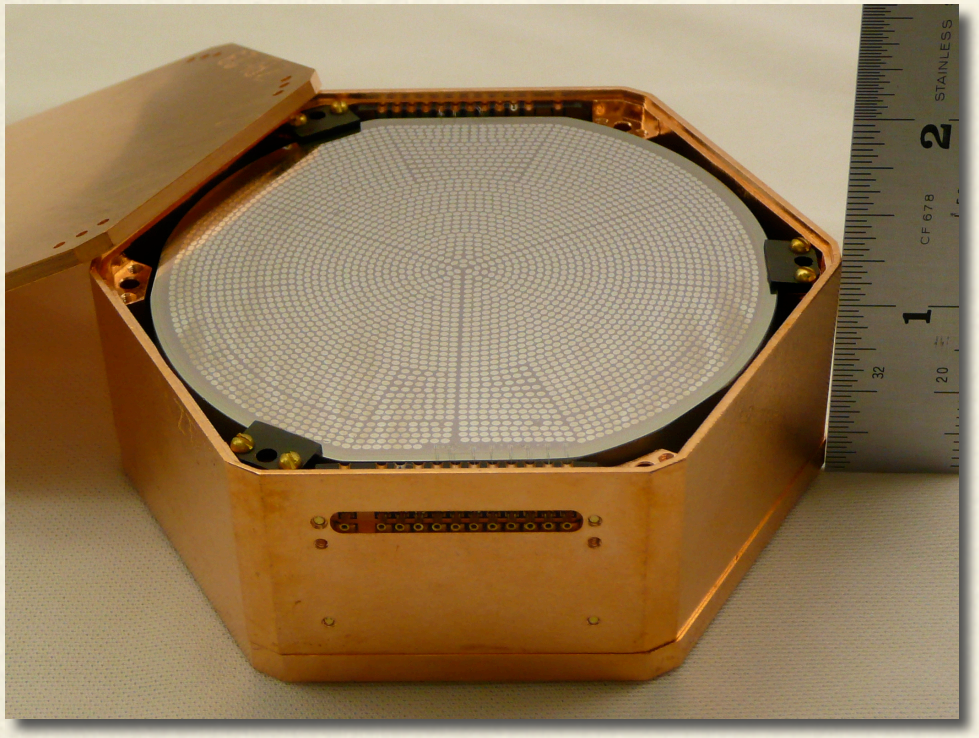

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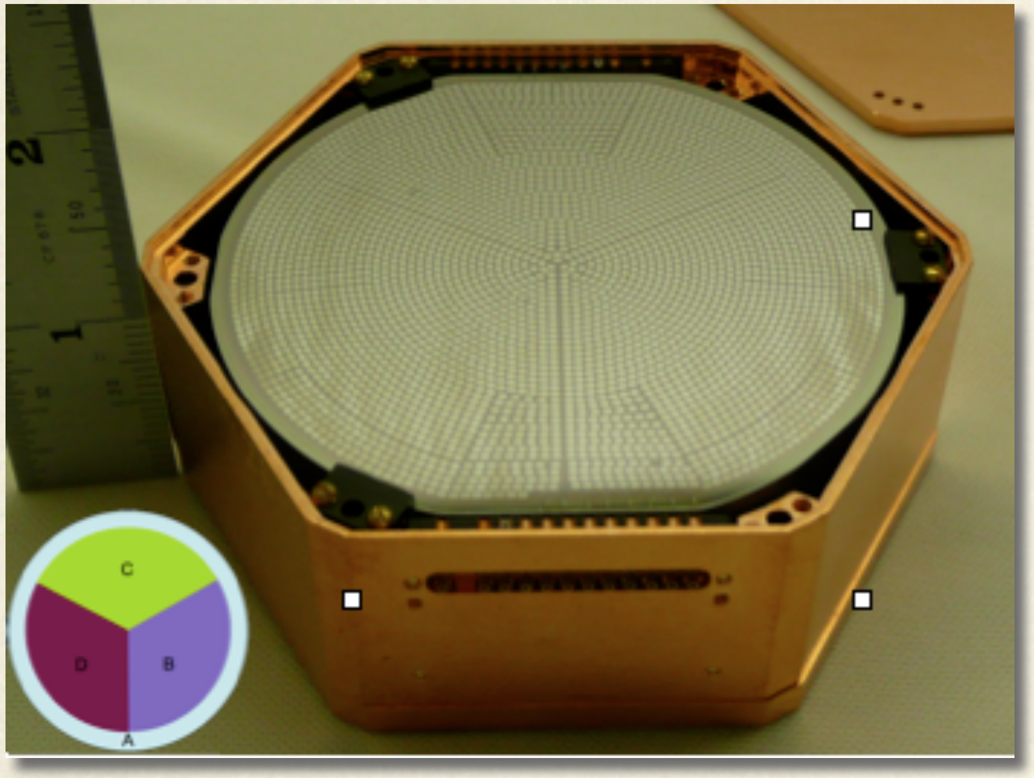

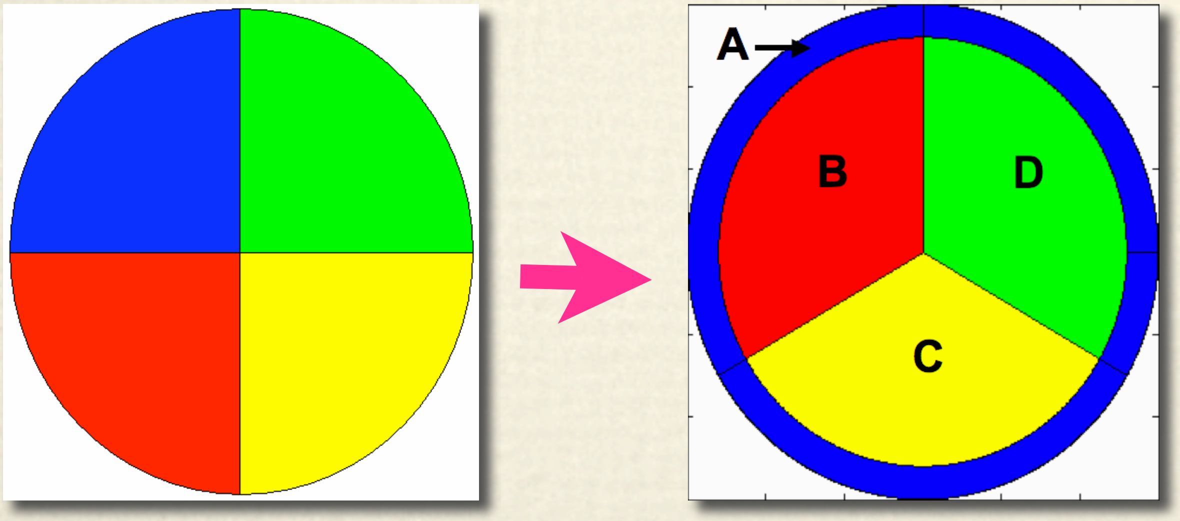

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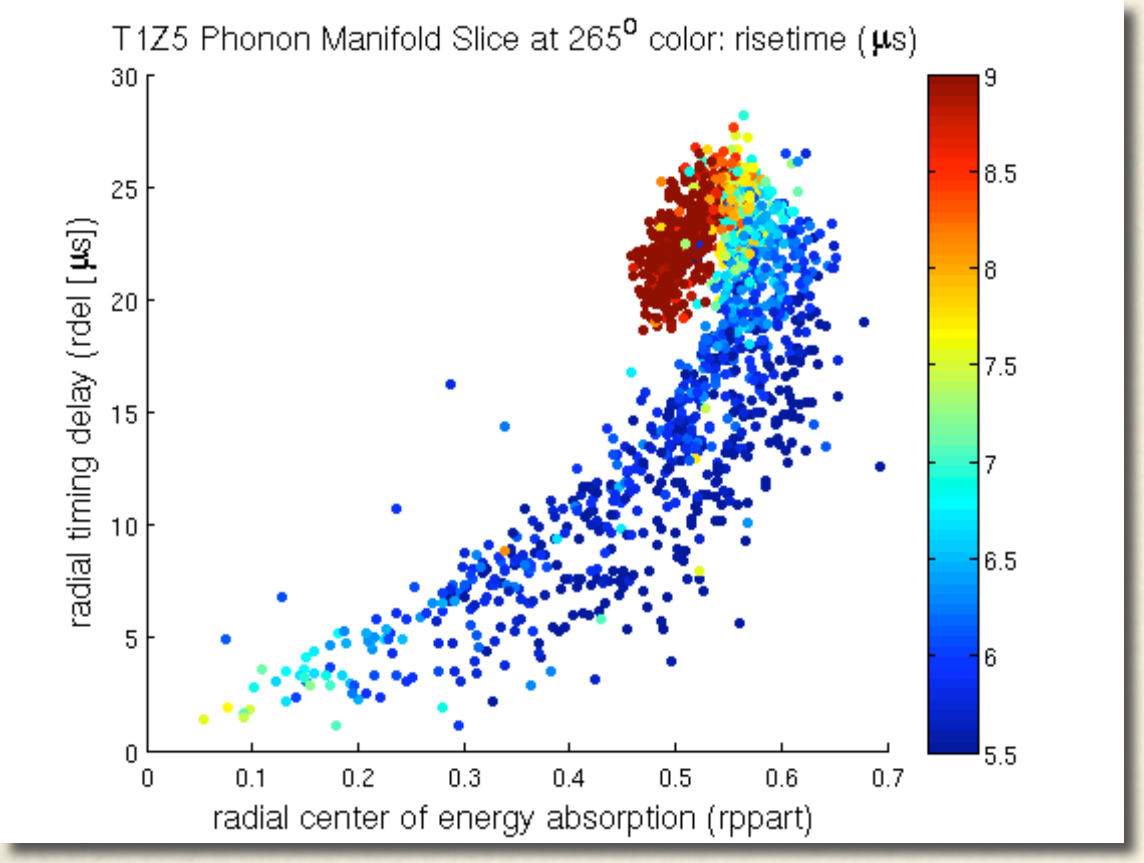
Phonon Sensor Layout



- Events at large radius have delay times similar to events at intermediate radius.
- Effect due to phonons reflecting off outer cylindrical walls back into central region of detector.

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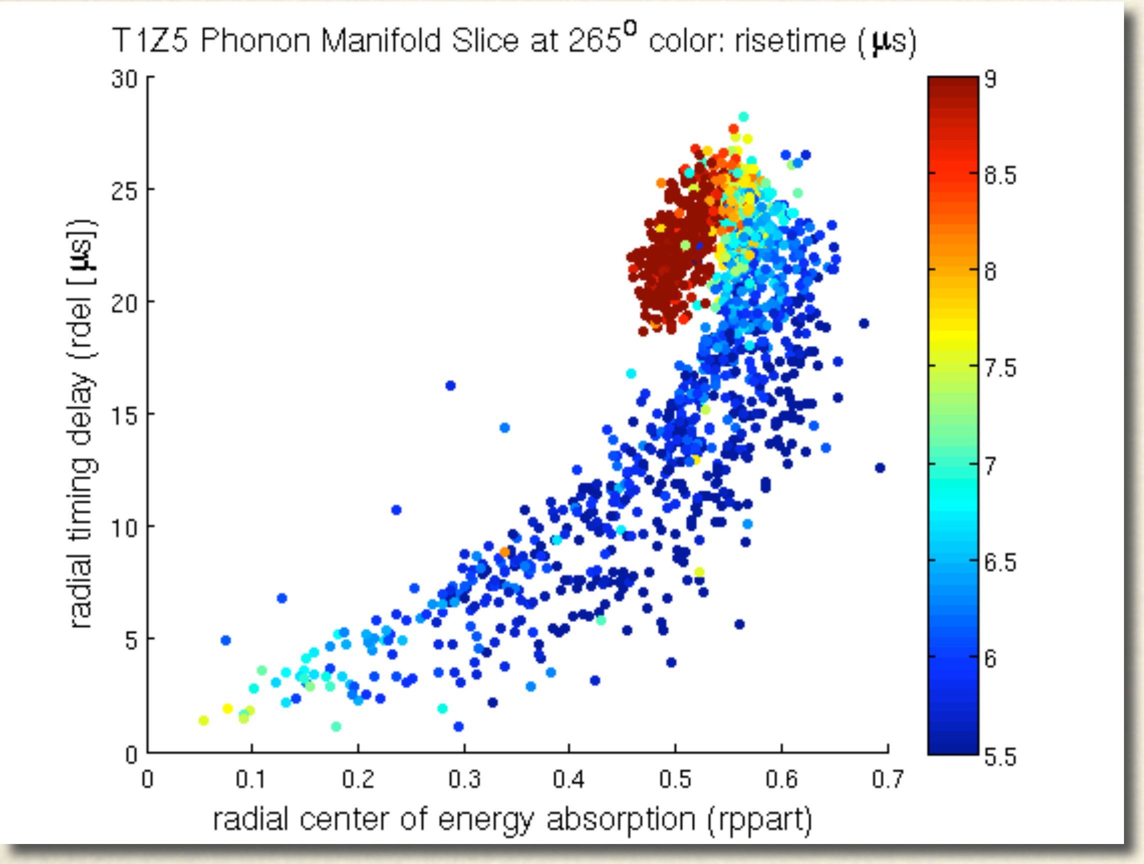

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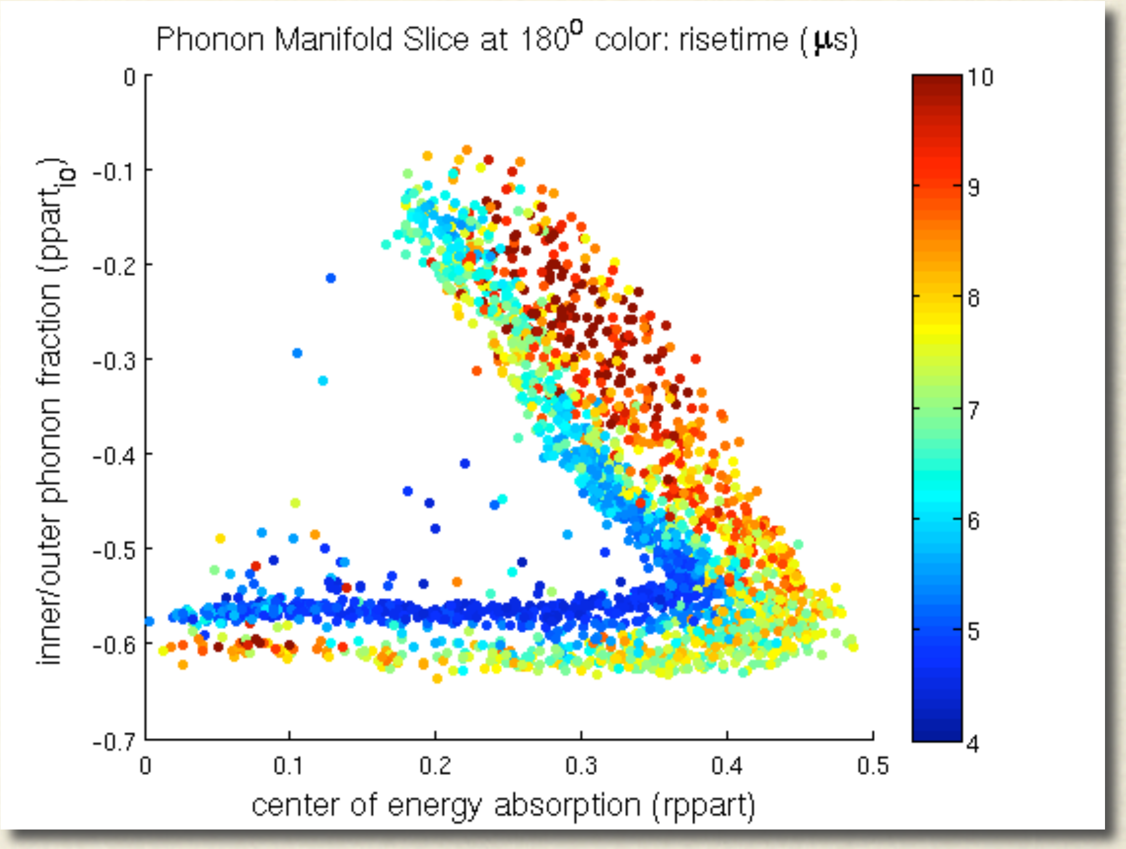
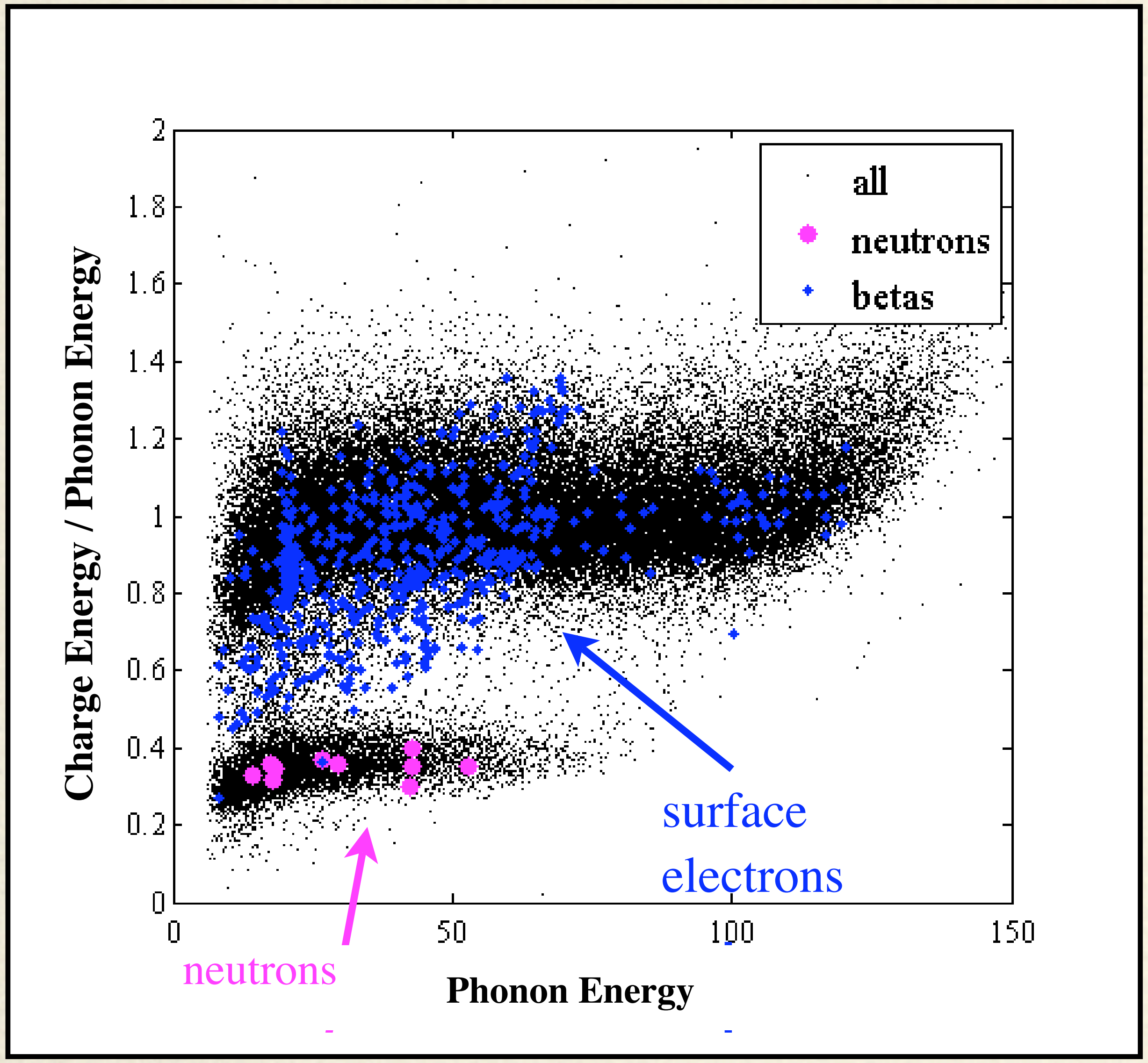
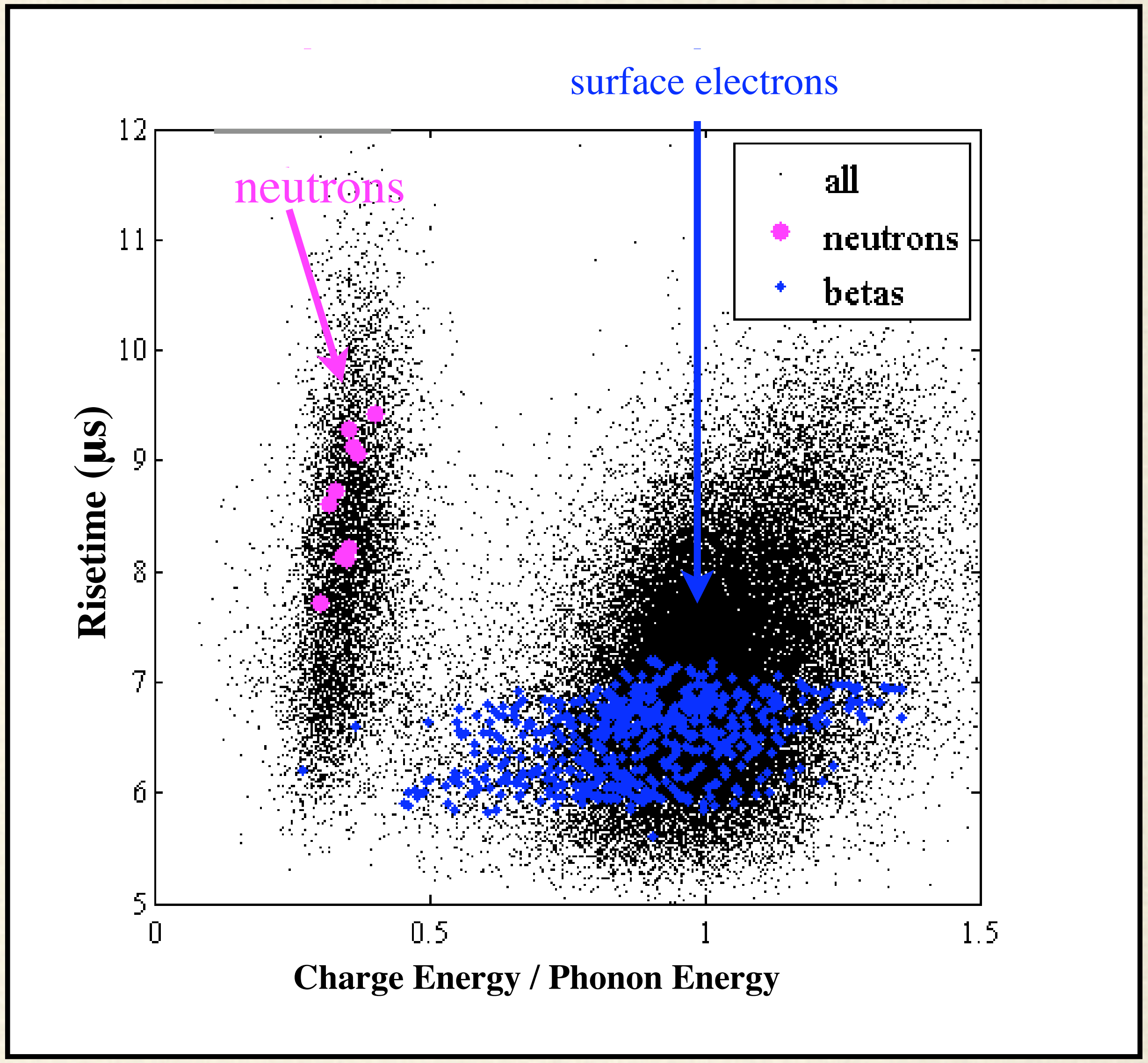


- New metric compares start times of inner 3 channels to the start time of outer channel, breaks degeneracy.

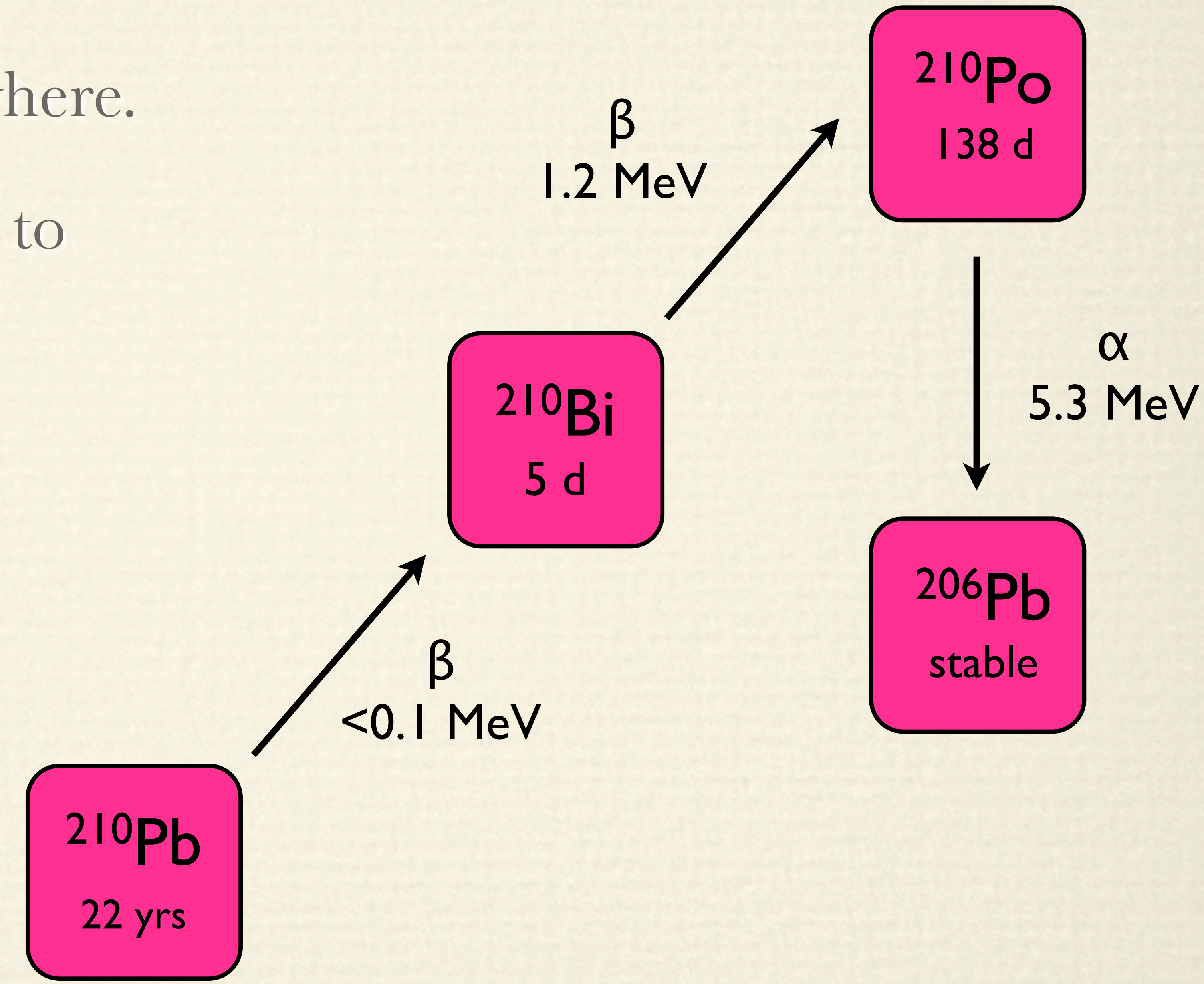
SuperCDMS Detectors





Surface Events: Radon Contamination

- Airborne **radon** is everywhere.
- It decays relatively quickly to **^{210}Pb (1/2 live 22yrs)**.



Surface Events: Radon Contamination

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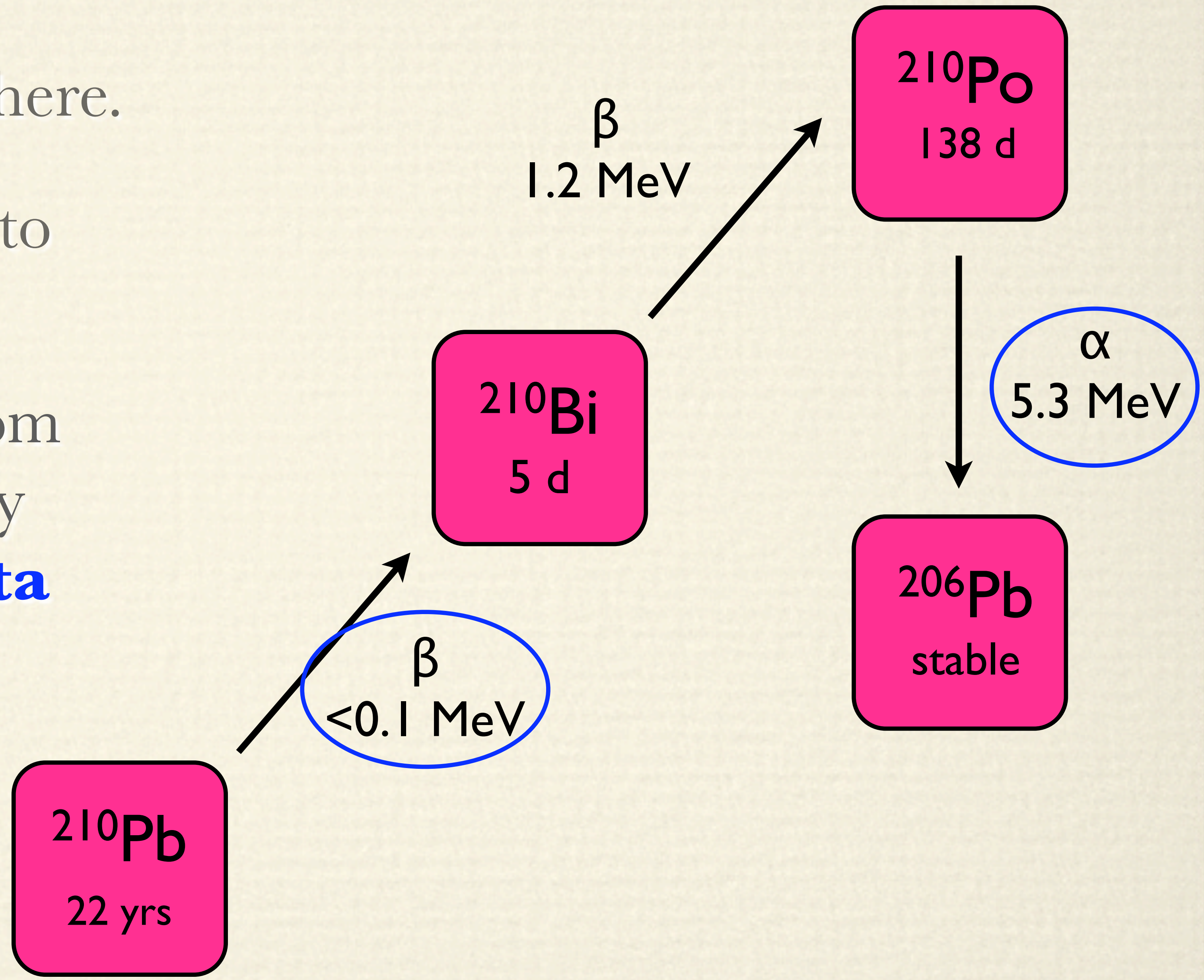
- It decays relatively quickly to **^{210}Pb (1/2 live 22yrs)**.
- Detector contamination from ^{222}Rn can be determined by **measuring alpha or beta particles** given of during these decays.

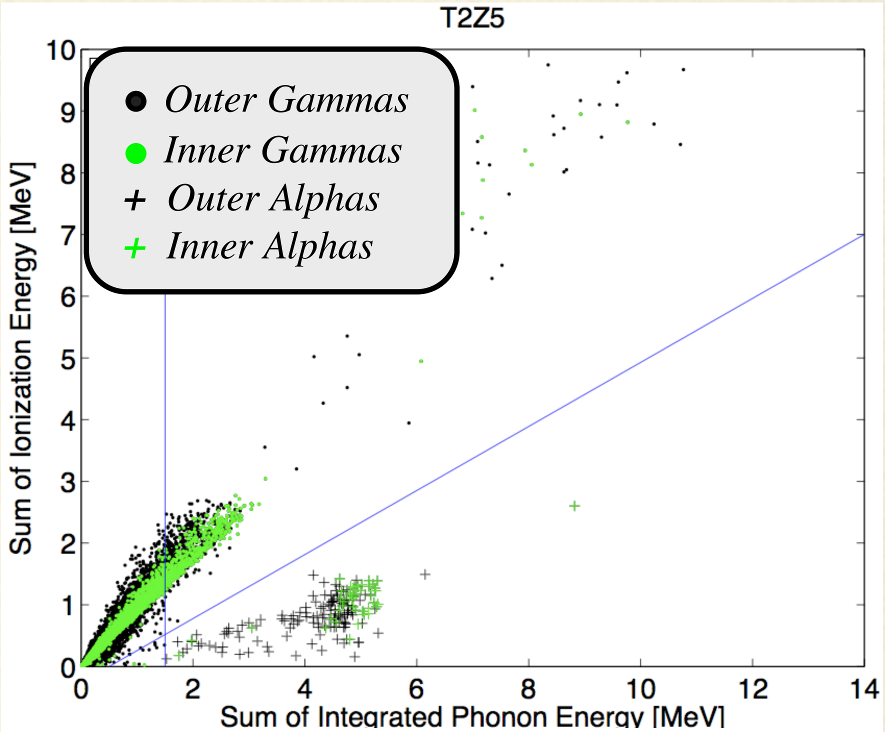


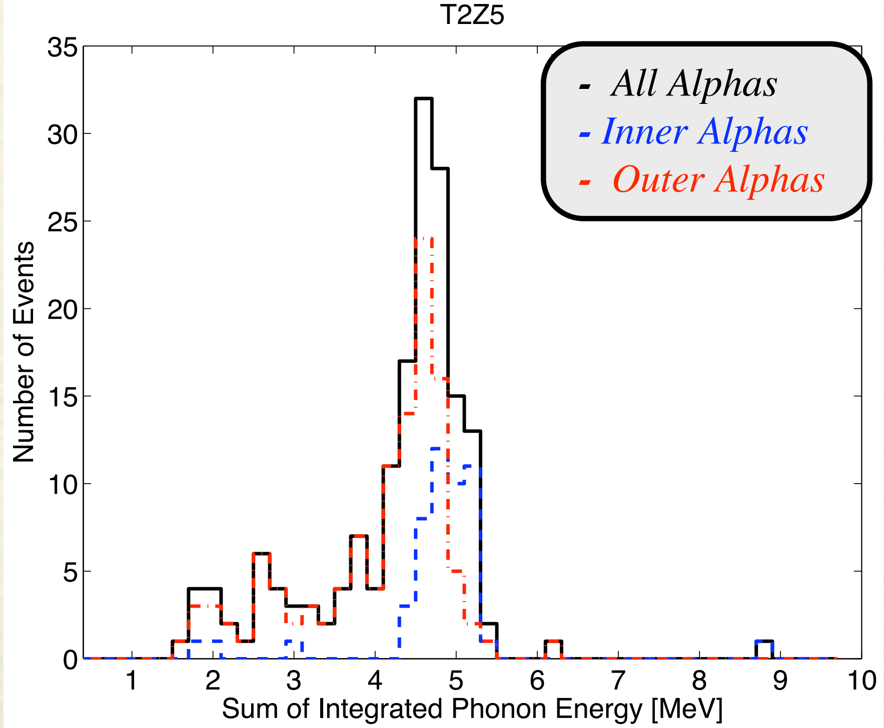
Surface Event: α Measurements

- We identify alphas by **reconstructing phonon and charge energies** for events in the MeV range.

- Events contained in the inner charge electrode have energy consistent with **^{210}Po alphas at 5.3 MeV**.

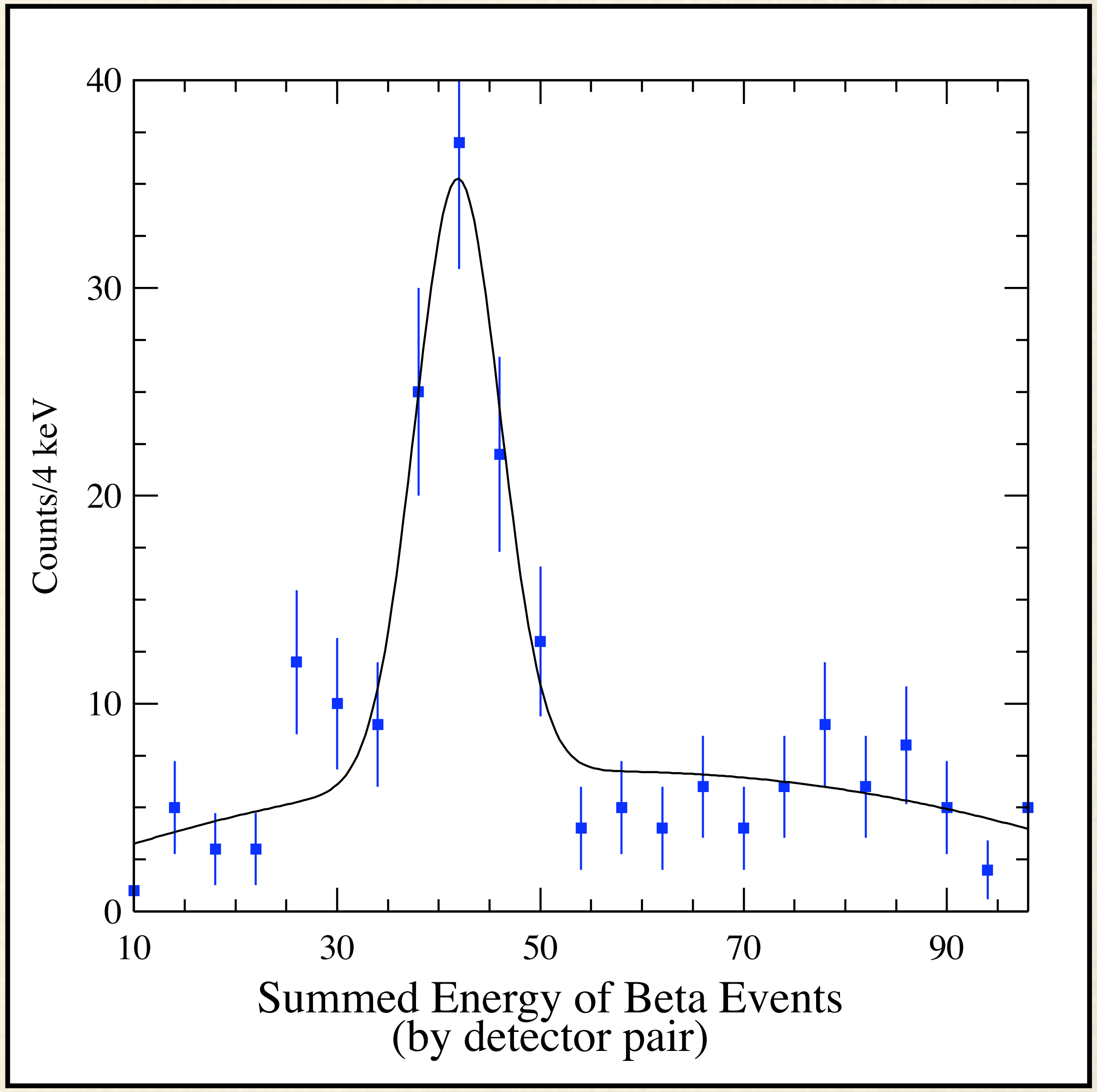
- **Alphas** are observed at a rate of **0.4/detector/day**.





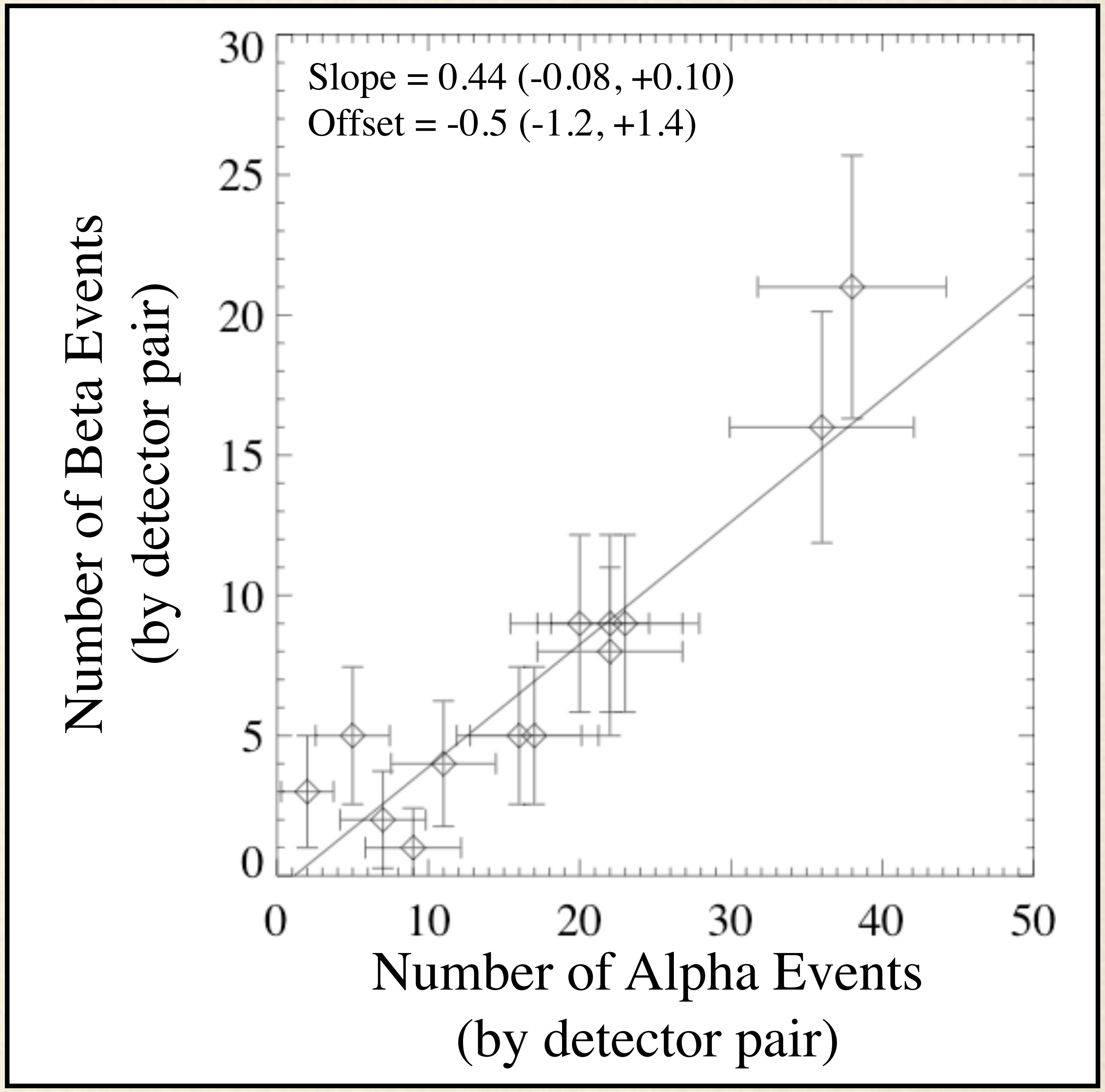
Surface Events: β Measurements

- **Betas** from **^{210}Pb** decays are identified by looking for **coincident beta events** in neighboring detectors.
- This class of events produce a broad spectrum, **45 keV peak** of beta events consistent with predictions from **^{210}Pb**.

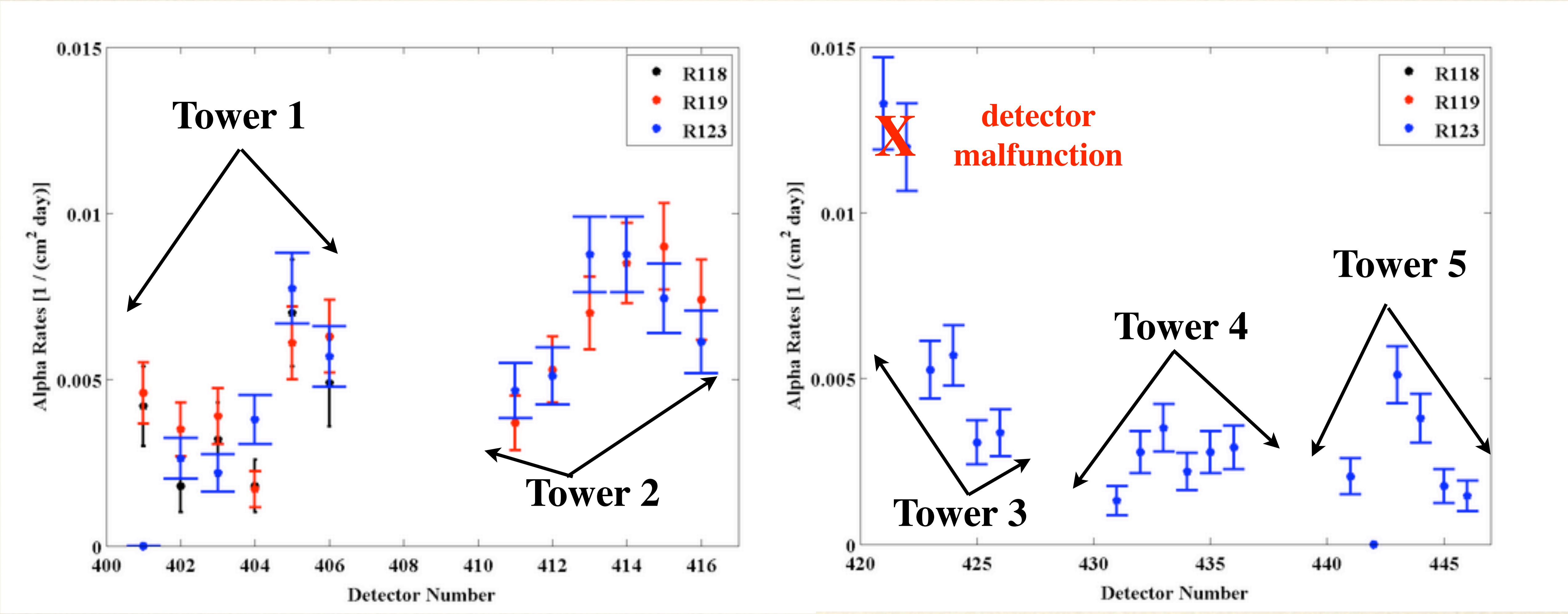


Alpha-Beta Correlation Analysis

Correlation between events identified in the 45 keV beta peak and alpha analyses for detector pairs is strong, corroborating the identification of the peak with ^{210}Pb.

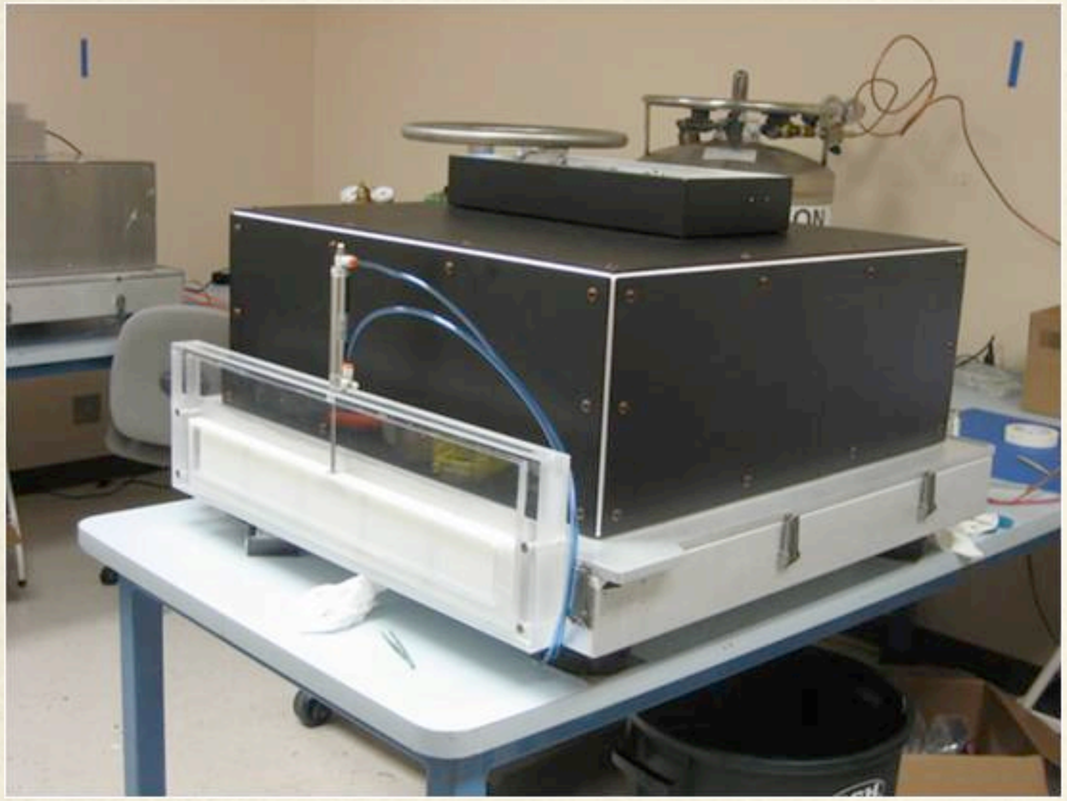


Improved Background Rates



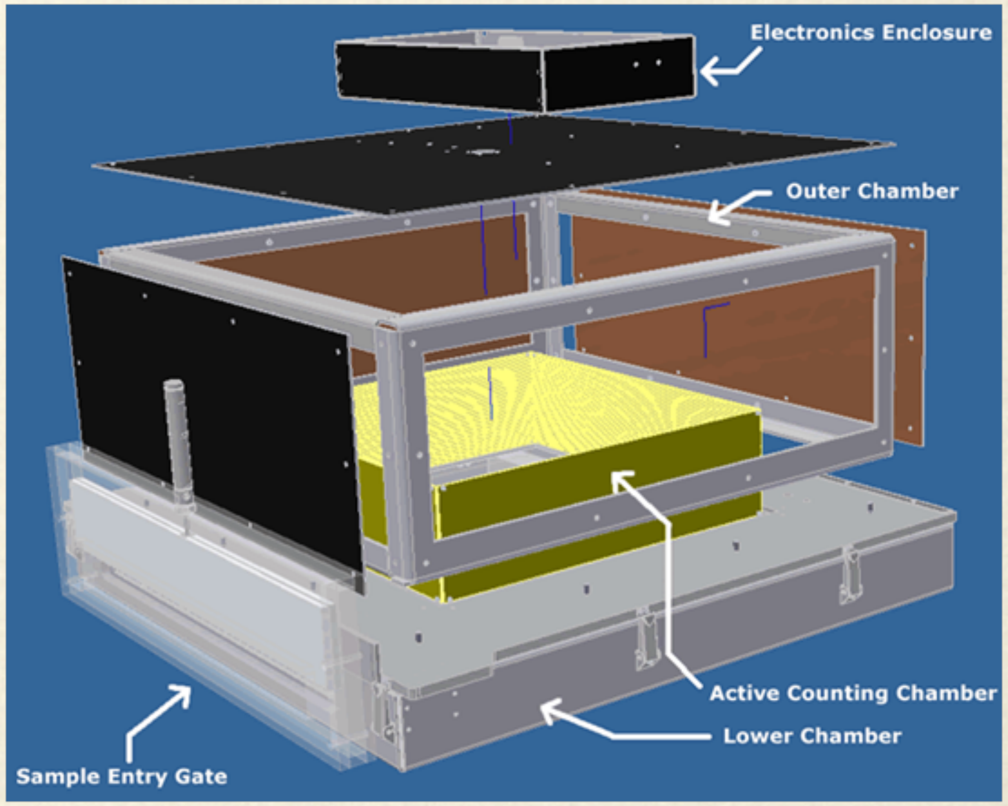
Alpha rates attributed to radon are a factor of ~ 2 times better in the new detectors.

XIA Alpha Counter

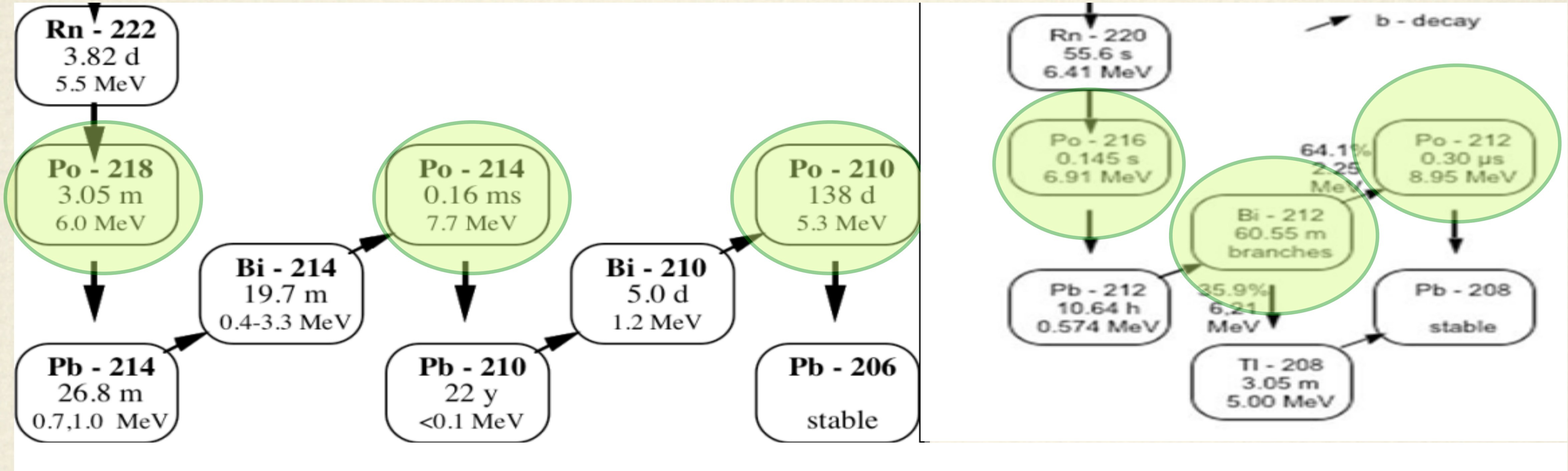


- **XIA UltraLo 1800 prototype** evaluation and testing at Stanford
- Counting area: **1800 cm^2**
- Advertised sensitivity: **2.5 x 10^{-3}/cm^2/day**

- Easiest way to **monitor ^{210}Pb** contamination is to measure **alpha-particle emission**.
- Goal: **0.32/detector/day**
  4.6x10^{-3}/cm^2/day



Initial Studies: ^{232}Th & ^{238}U



- Use Van der Graff generator to collect and then deposit Th & U daughters onto a Si wafer.
  - Expect to see α-peaks at ~ 6 MeV, 7 MeV and 9 MeV.

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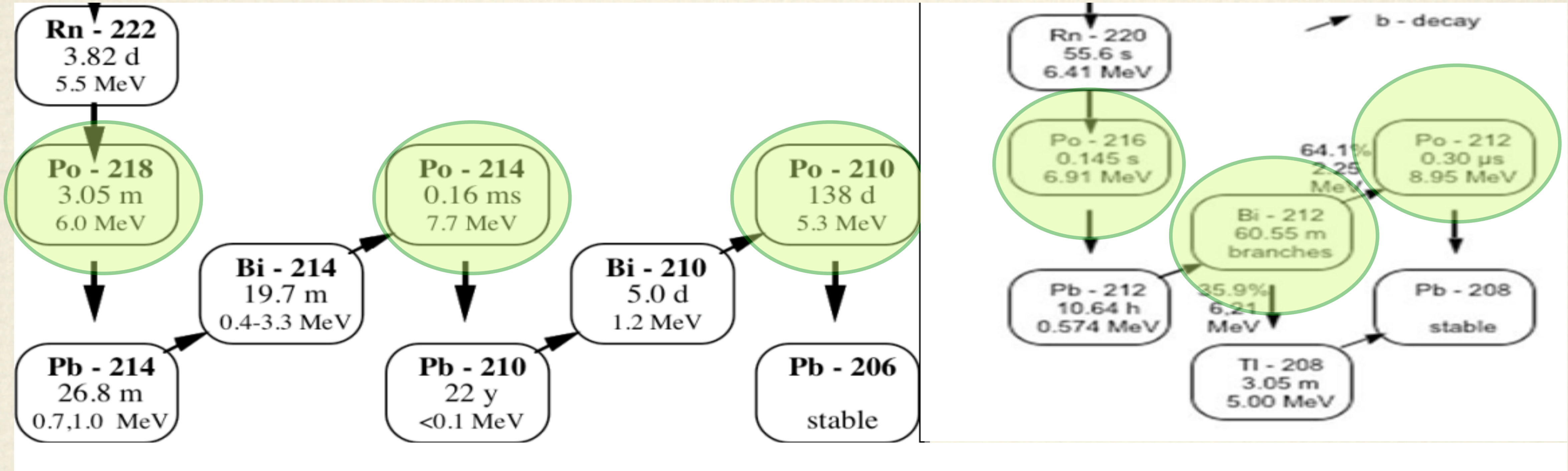

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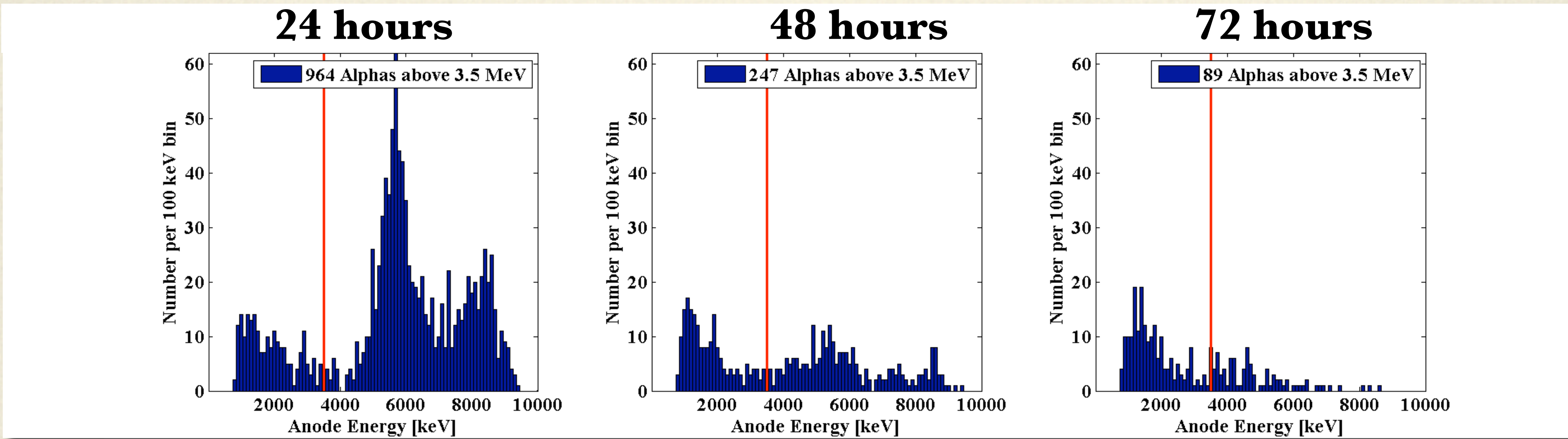

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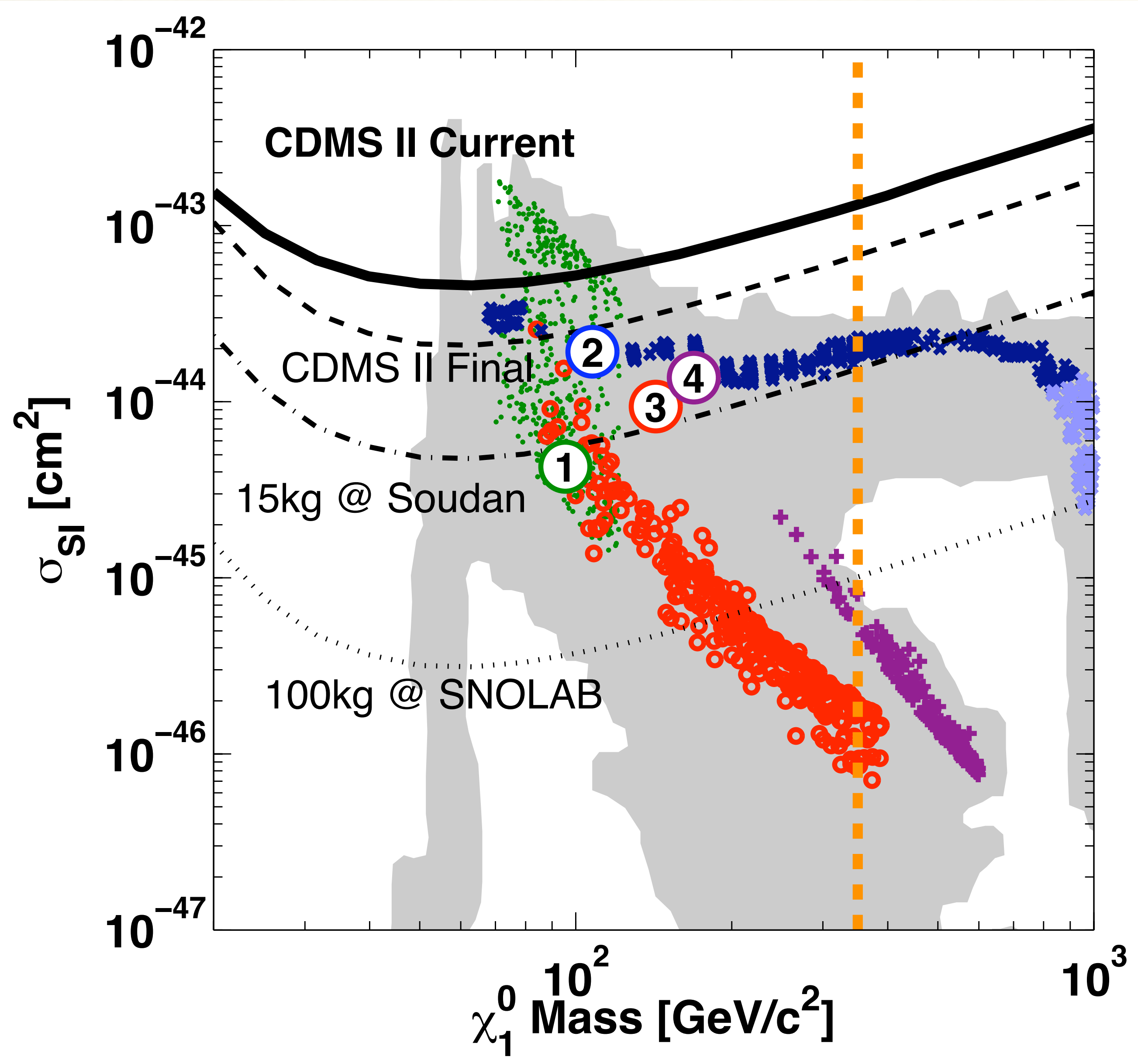
Counter Progress and Plans

- We have made improvements to the counter and made gains in the alpha identification algorithms.
- We continue to identify and screen cleaner materials.
- Plan to use counter to evaluate contamination by the different detector fabrication stages using witness samples.
- Eventually, detector will be moved to FermiLab where it will be used to screen detectors.

Future Sensitivity



	Livetime [kg-days]	Sensitivity @60GeV [cm^2]
CDMS II	1692	$2.1\text{x}10^{-44}$
SCDMS 15 kg	7823	$4.8\text{x}10^{-45}$
SCDMS 100kg	97,705	$3.1\text{x}10^{-46}$

Conclusions

- Currently CDMS is operating and taking data at the design level of five towers of detectors.
- Data taken between Oct. 2006 and July 2007 has been analyzed and a cross section limit of $< 4.6 \times 10^{-44} cm^2$ (90% CL) was placed for a WIMP of mass 60 GeV/c^2.
- SuperCDMS is an experiment under development by the CDMS collaboration which is planned for operation in Soudan. For this purpose we have enhanced the design of the CDMS detector.
- In an effort to operate our experiment in a 'background-free' mode, we are working to characterize and mitigate background events from the decay of omnipresent radon.