New Results from the Final Runs of the CDMS II Experiment

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SMU

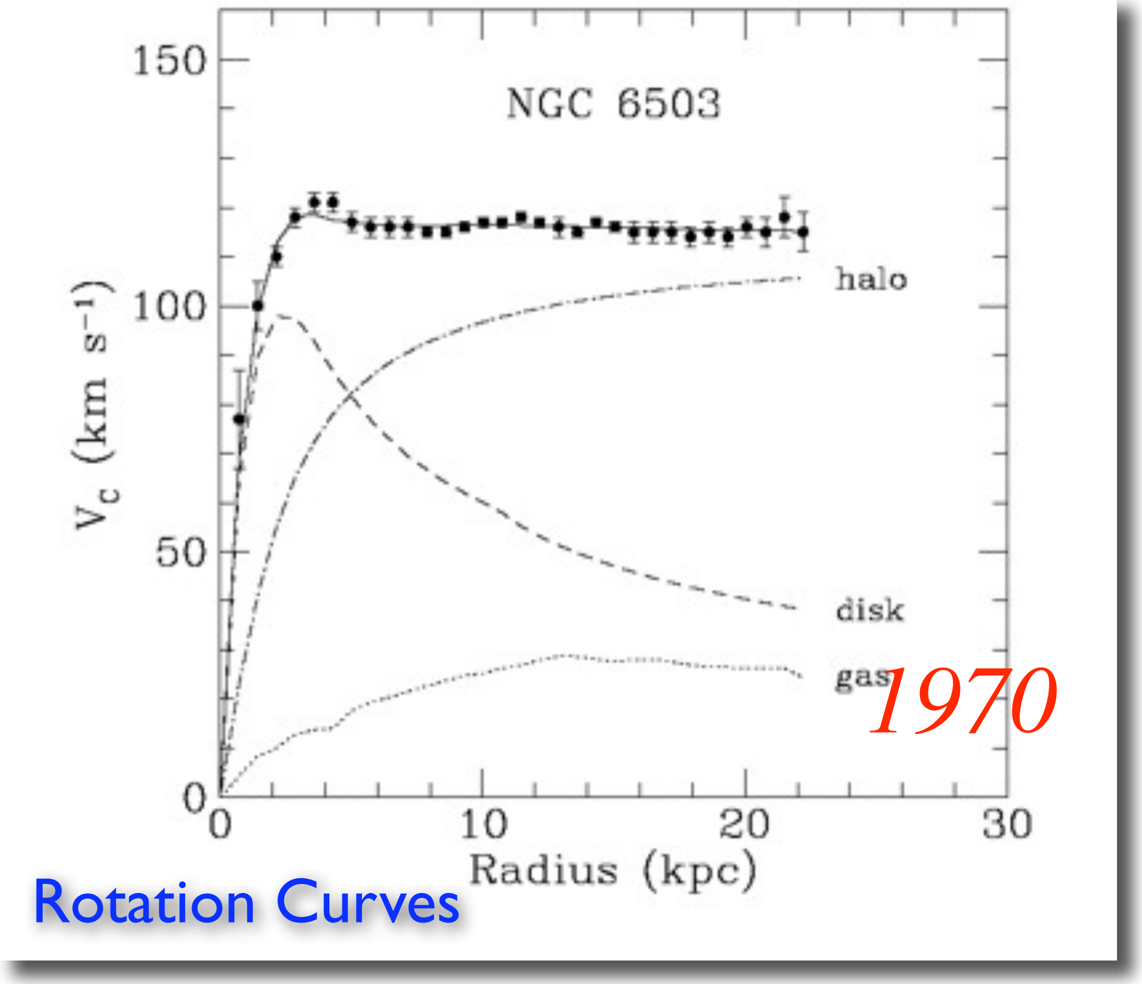
CDMS

Overview

- What we know and what we don't know about dark matter
- CDMS-II experiment
  - detection principle
  - first results from the final CDMS II data runs
- The future
  - SuperCDMS

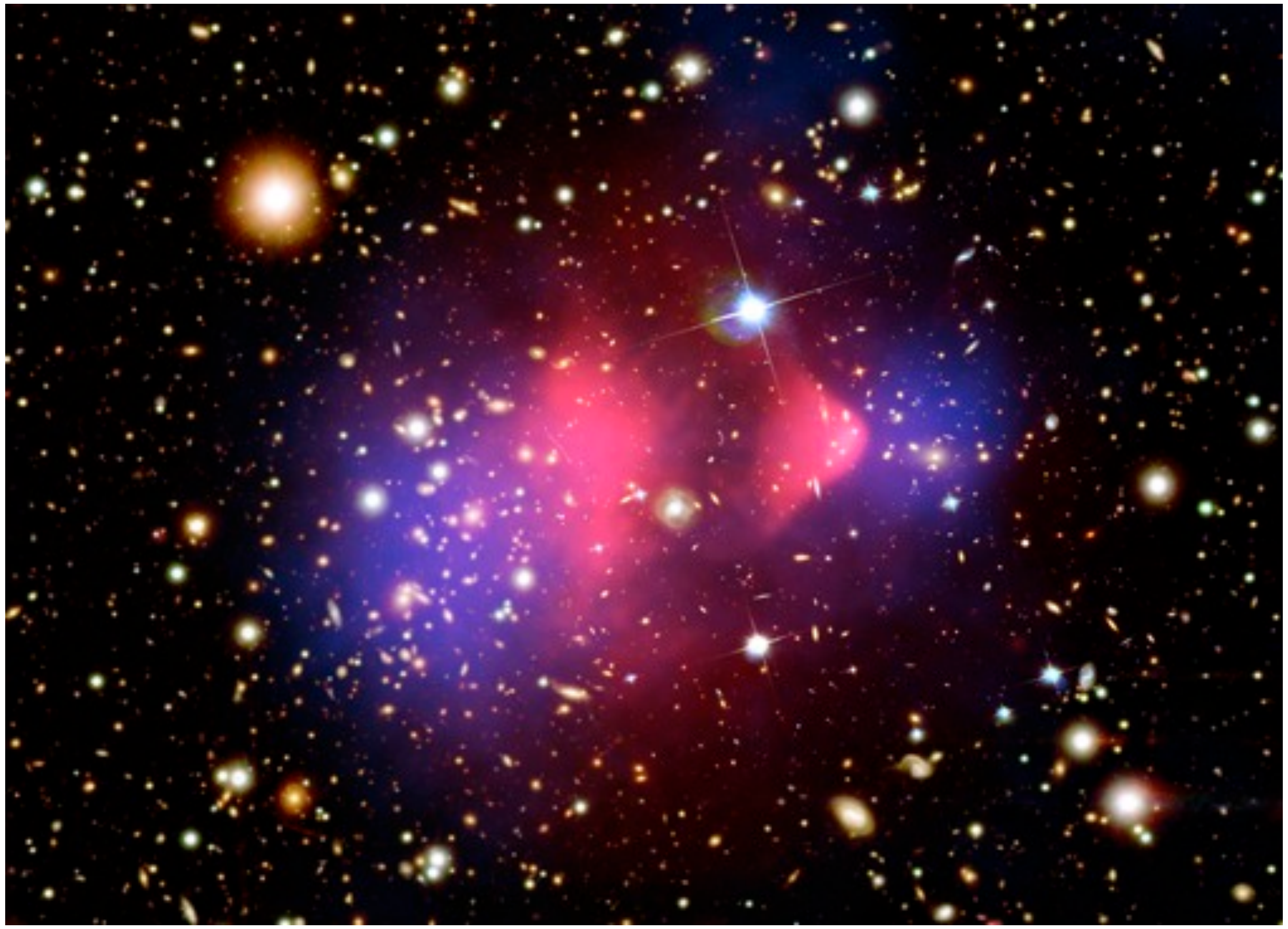
Introduction to Dark Matter

The Evidence for Dark Matter



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.



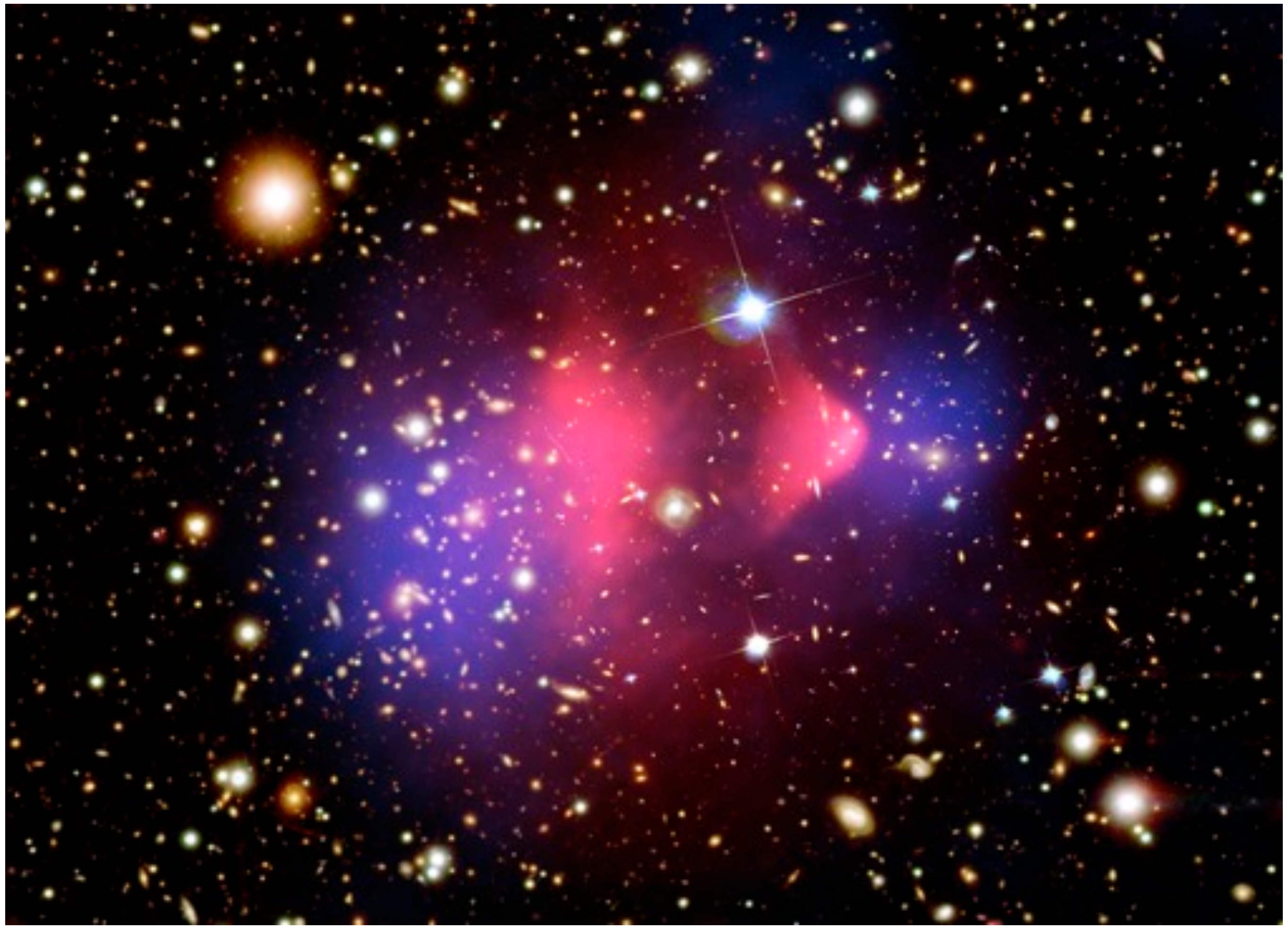
Clowe et al., ApJ, 648, 109

blue = lensing
red = x-rays

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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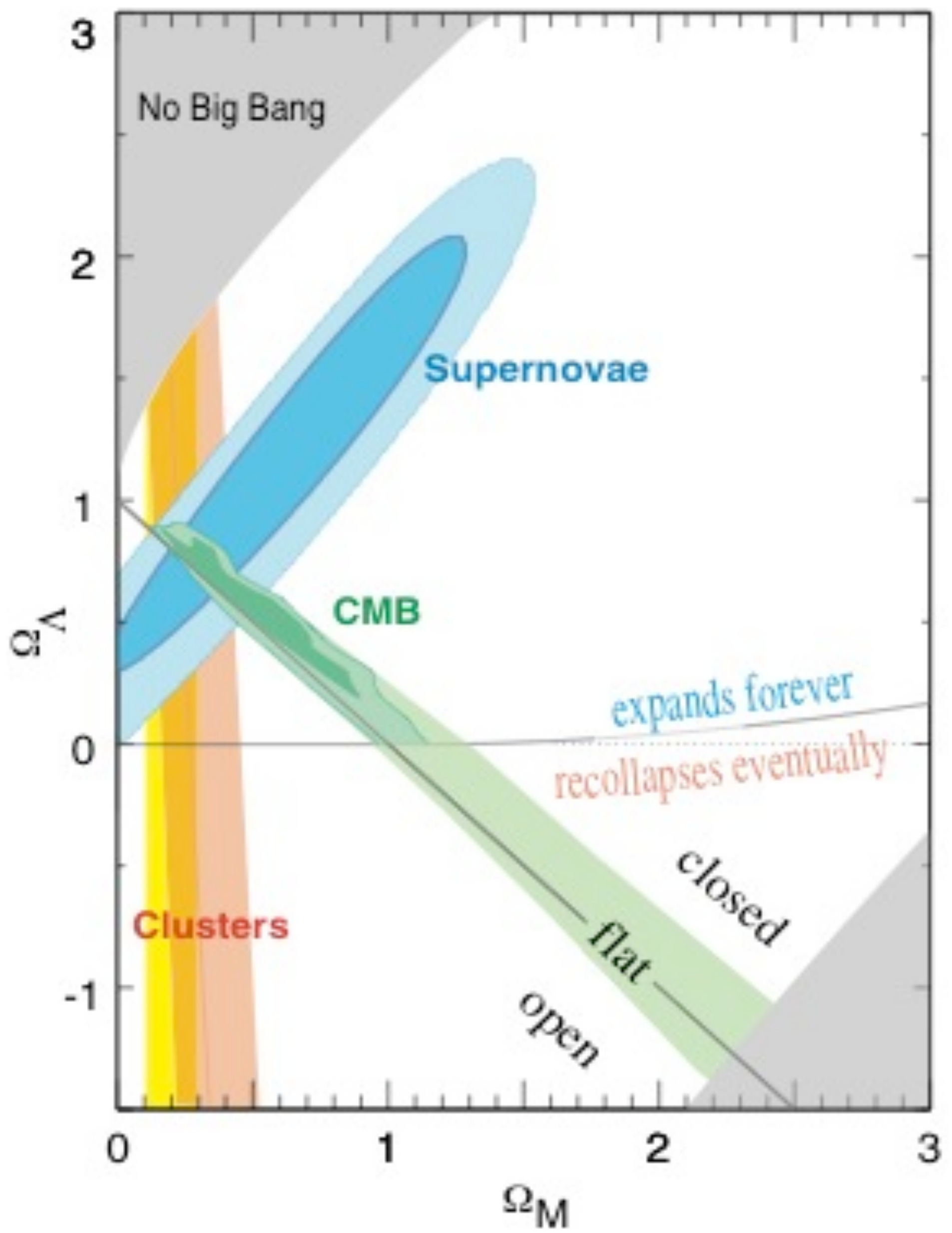
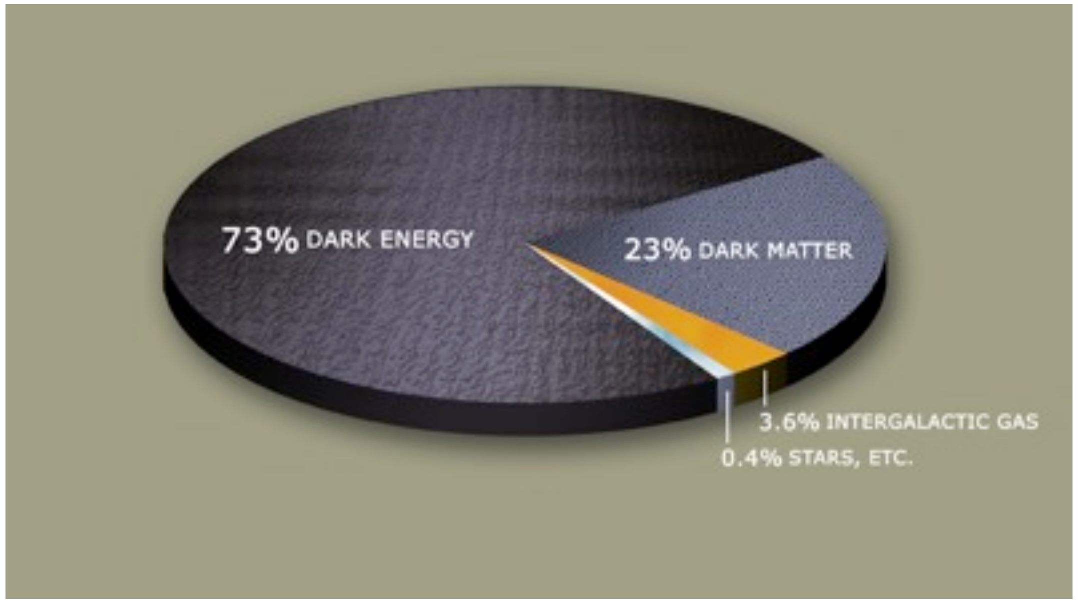
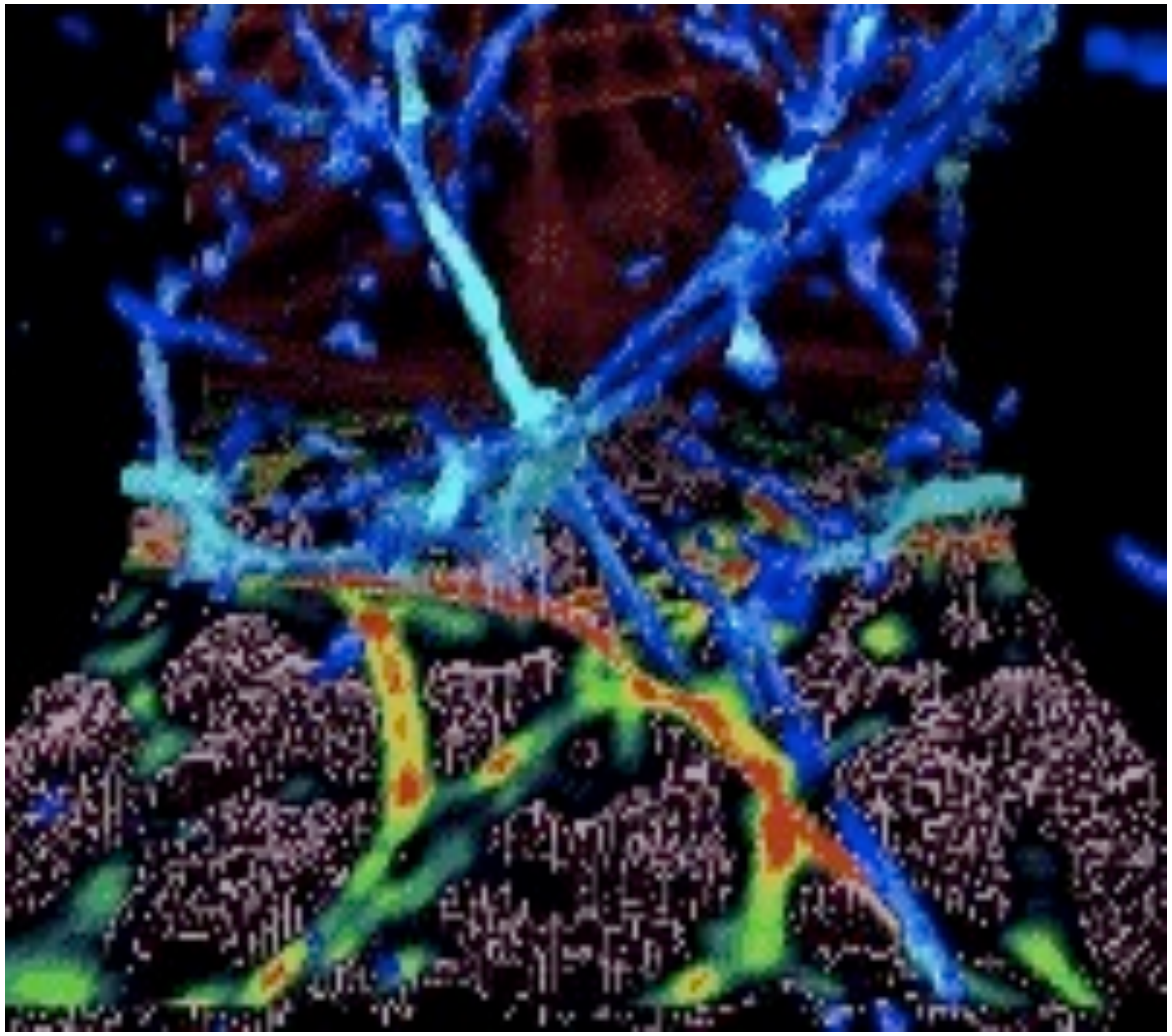
The Cosmic Pie





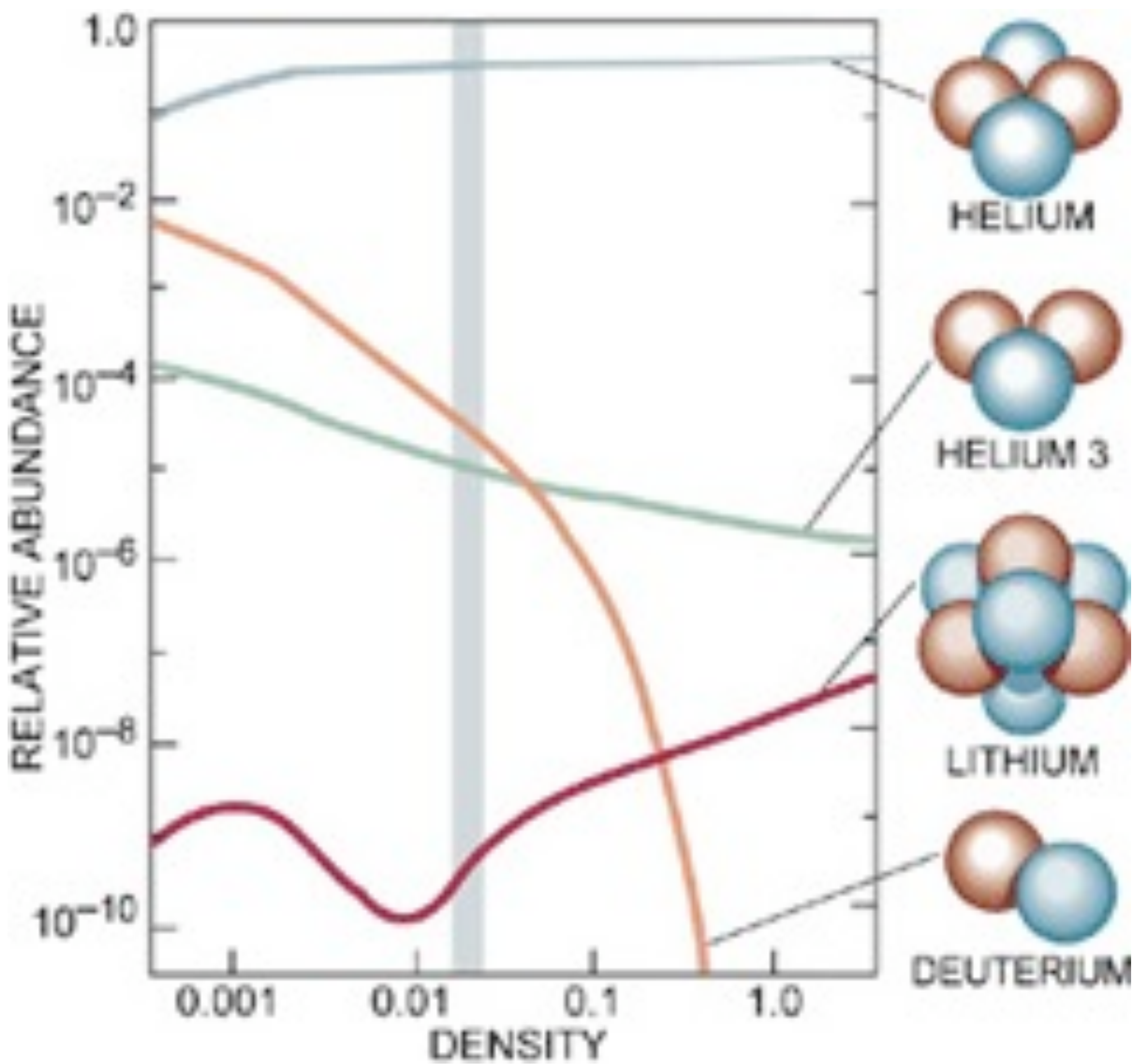
- Measurements from CMB + supernovae + LSS indicate that **~23% of our Universe is composed of dark matter**.

What Could Dark Matter Be?



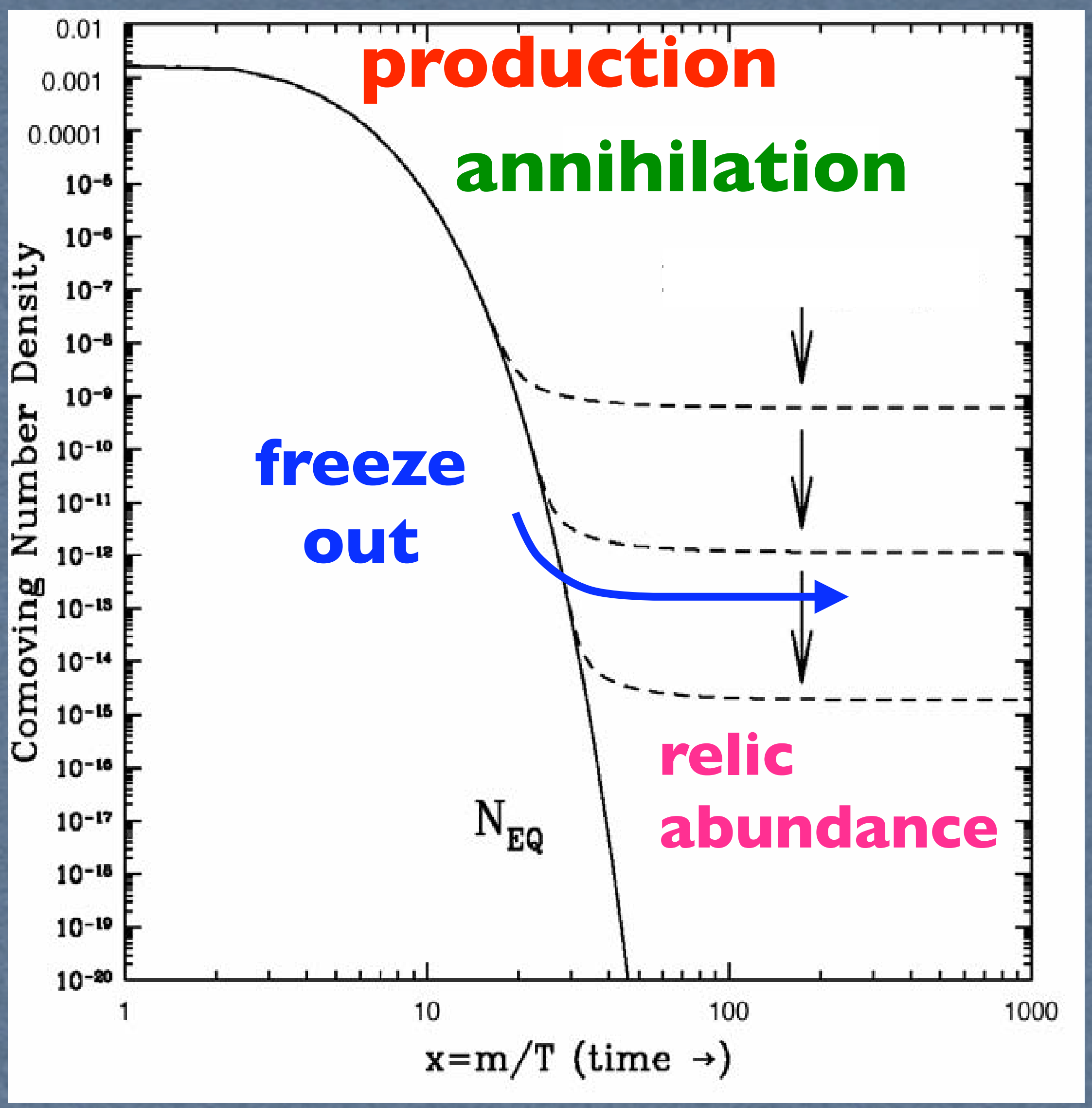
- Warm or **Cold**?
  - ordinary νs can not make up LSS of universe

What Could Dark Matter Be?



- Warm or **Cold**?
  - ordinary νs 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 Interacting Massive Particles

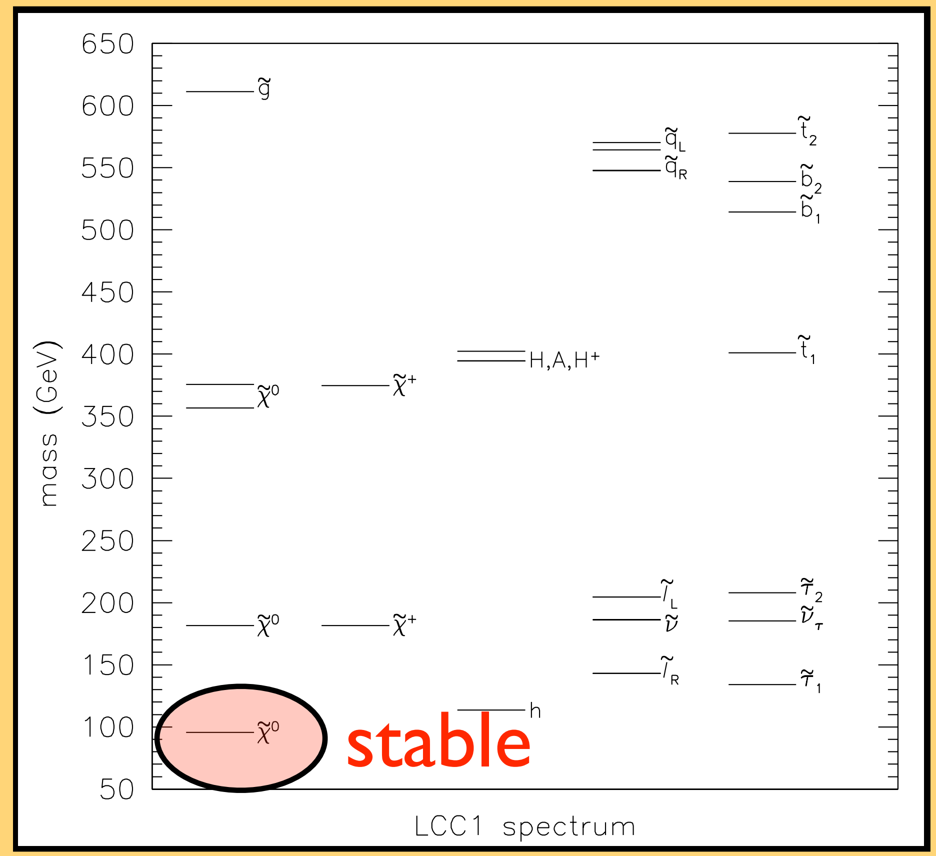
- New stable, **massive** particle produced thermally in early universe
- **Weak-scale** cross-section gives observed relic density

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

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

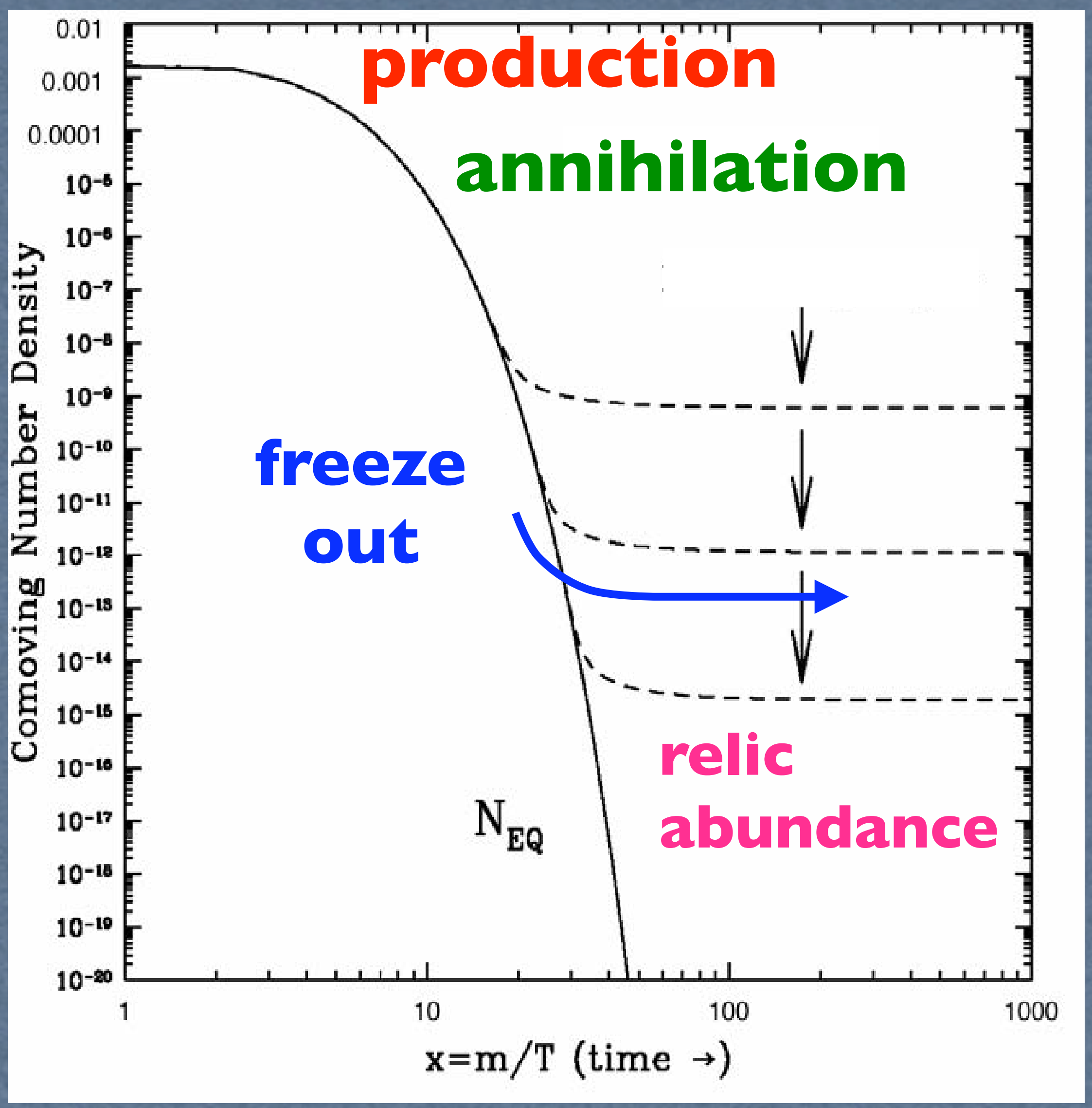
Motivated by Particle Physics Too!

- New TeV physics is 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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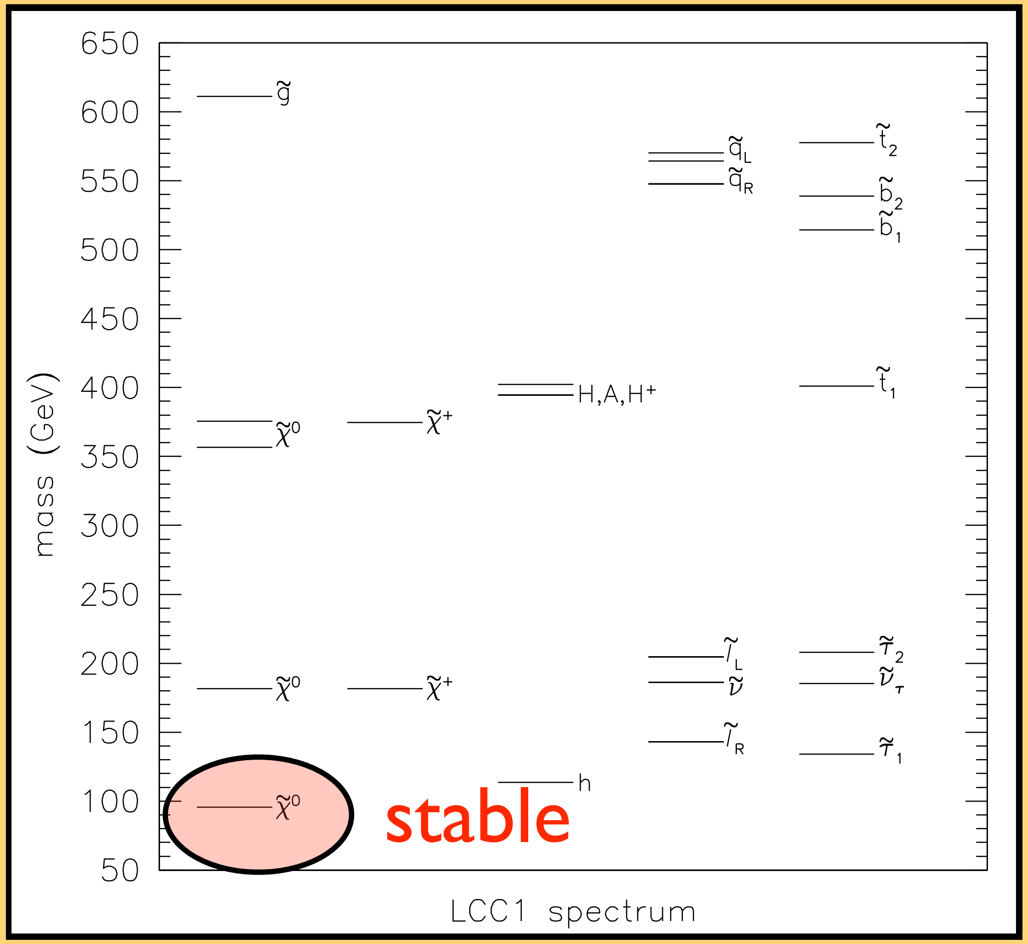


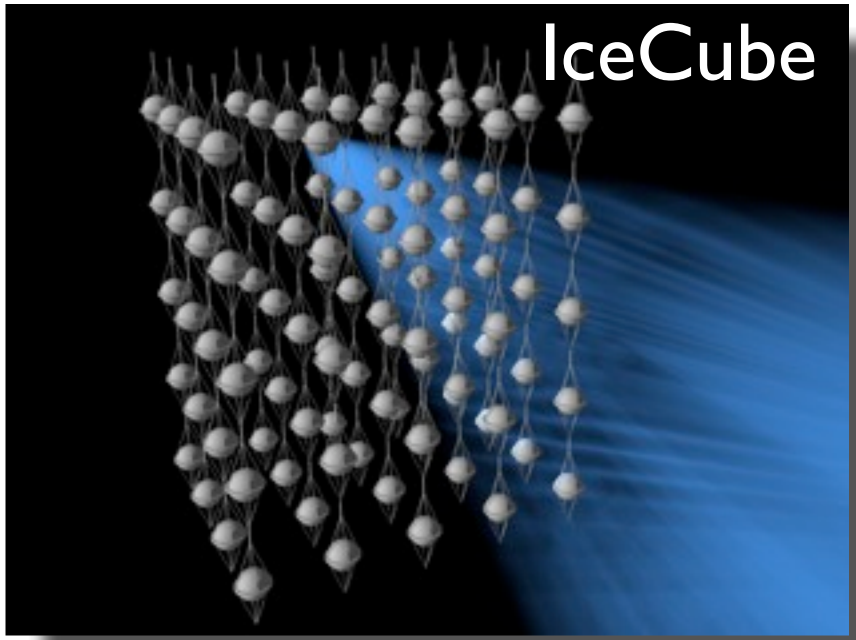
Baltz et al., PRD **74**, 103521 (2006)

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

How Do We Detect WIMPs?

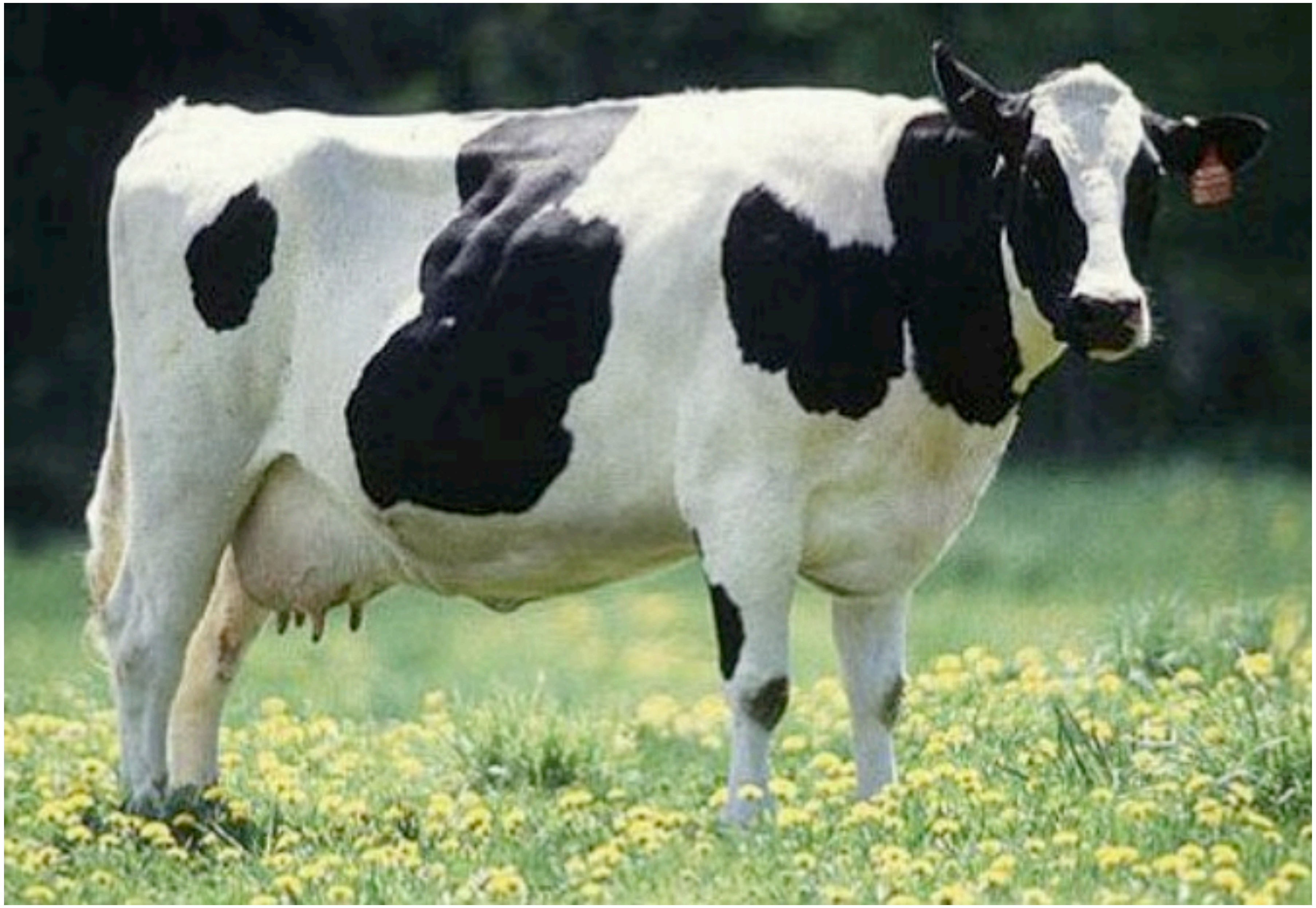
WIMP scattering on earth

WIMP production on earth



WIMP annihilation in the cosmos

The Spherical Cow

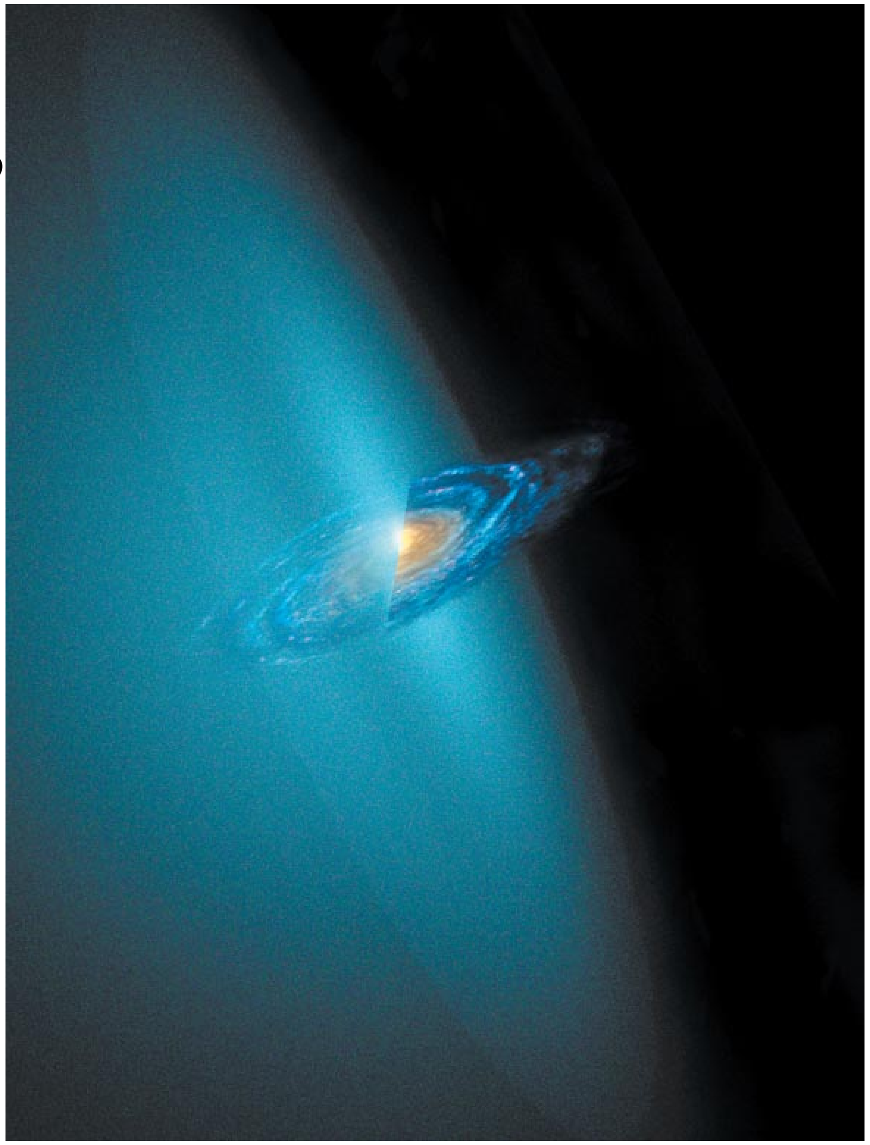


The Spherical Cow

Direct Detection Event Rates

“Spherical Cow” Halo Model

local density (ρ_o) = 0.3 GeV/cm^3,
Maxwellian distrubution,
rms velocity (v_o) = 220 km/s,
v_{esc} = 650 km/s



Direct Detection Event Rates

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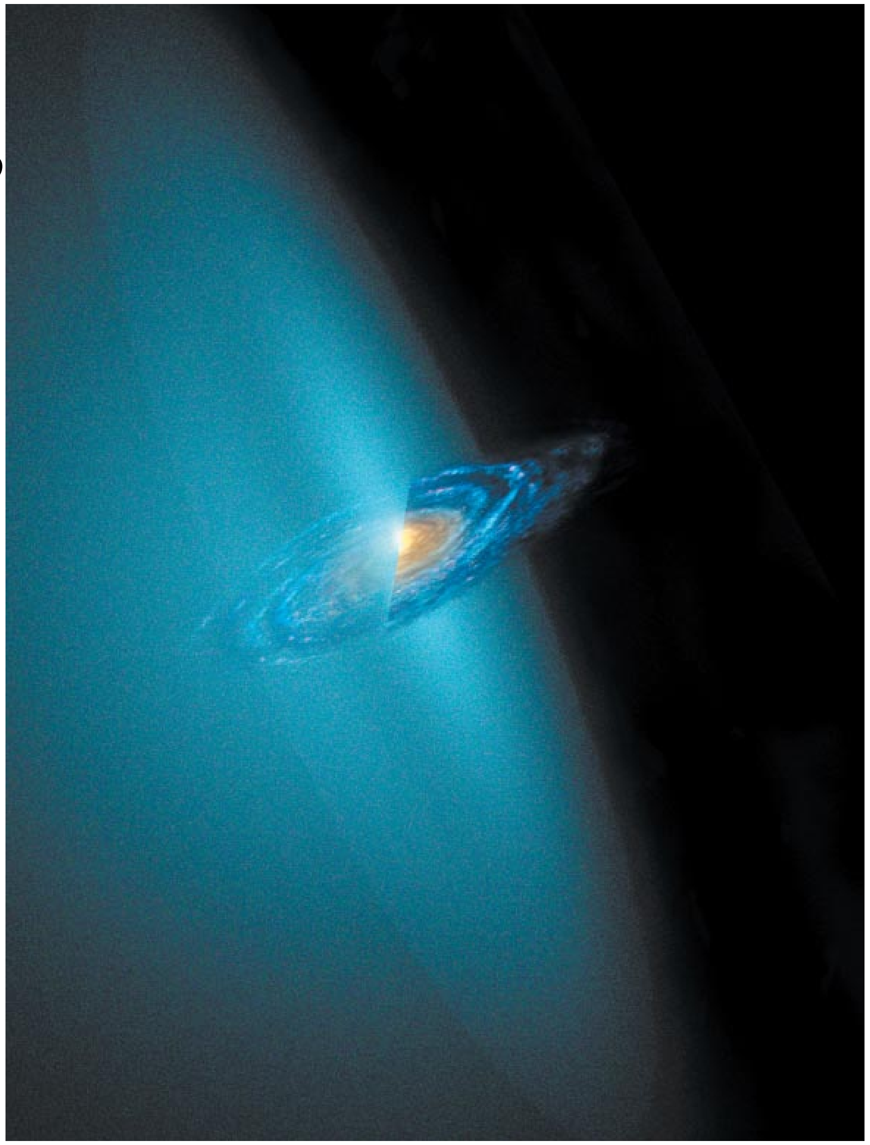


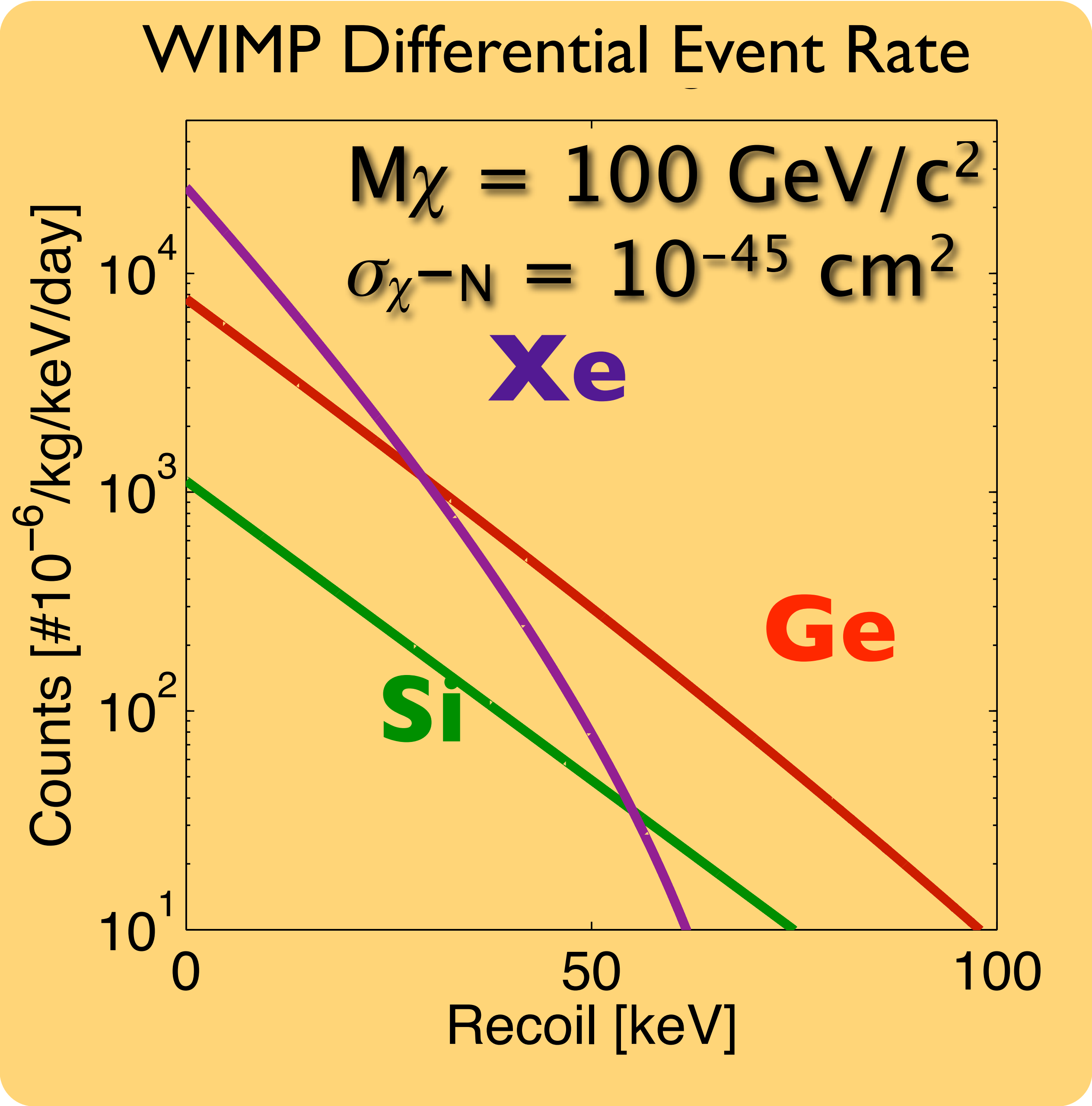
Interaction Details

spin-independent,
coherent scattering

$$\rightarrow \quad \sigma_\chi \propto A^2$$

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)

✓ Rigid **background controls**

- ➡ Clean materials
- ➡ shielding
- ➡ discrimination power

✓ Substantial **Depth**

- ➡ neutrons look like WIMPS

✓ **Long exposures**

- ➡ large masses, long term stablility

CDMS II

The CDMS Collaboration

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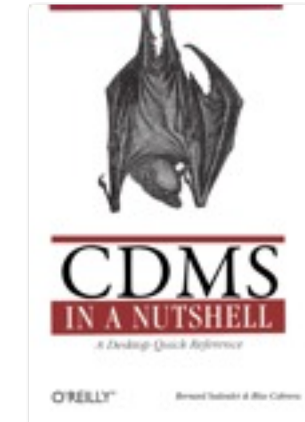
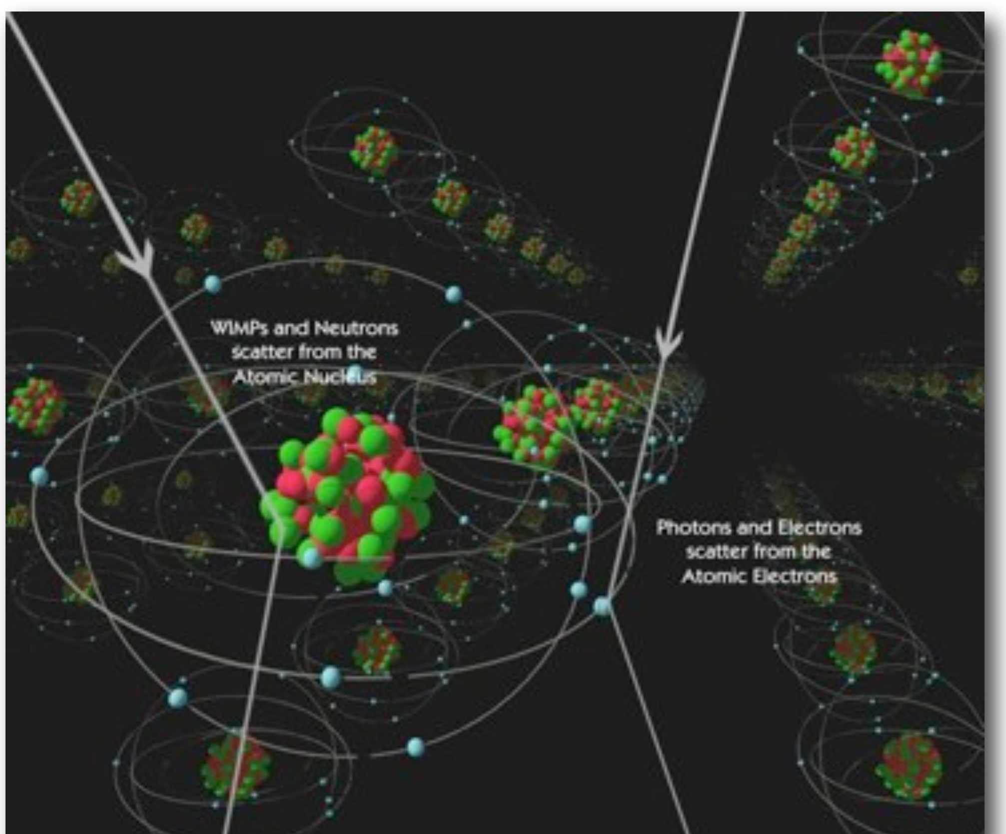
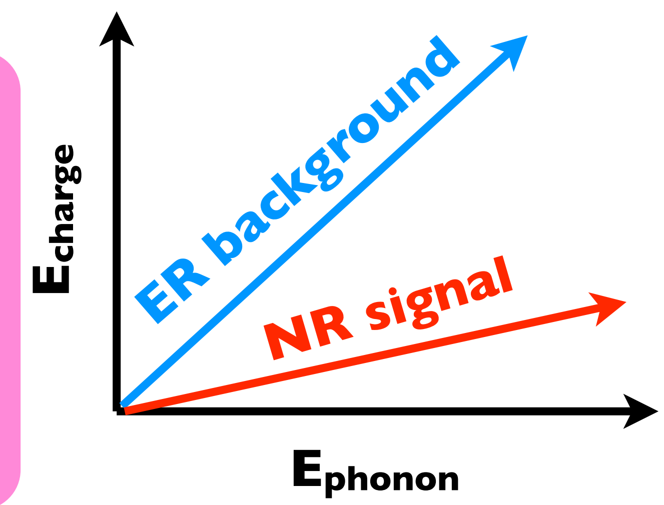
CDMS-II: The Big Picture



Use a combination of **discrimination** and **shielding** to maintain a **“<1 event expected background”** experiment with **low temperature** semiconductor detectors



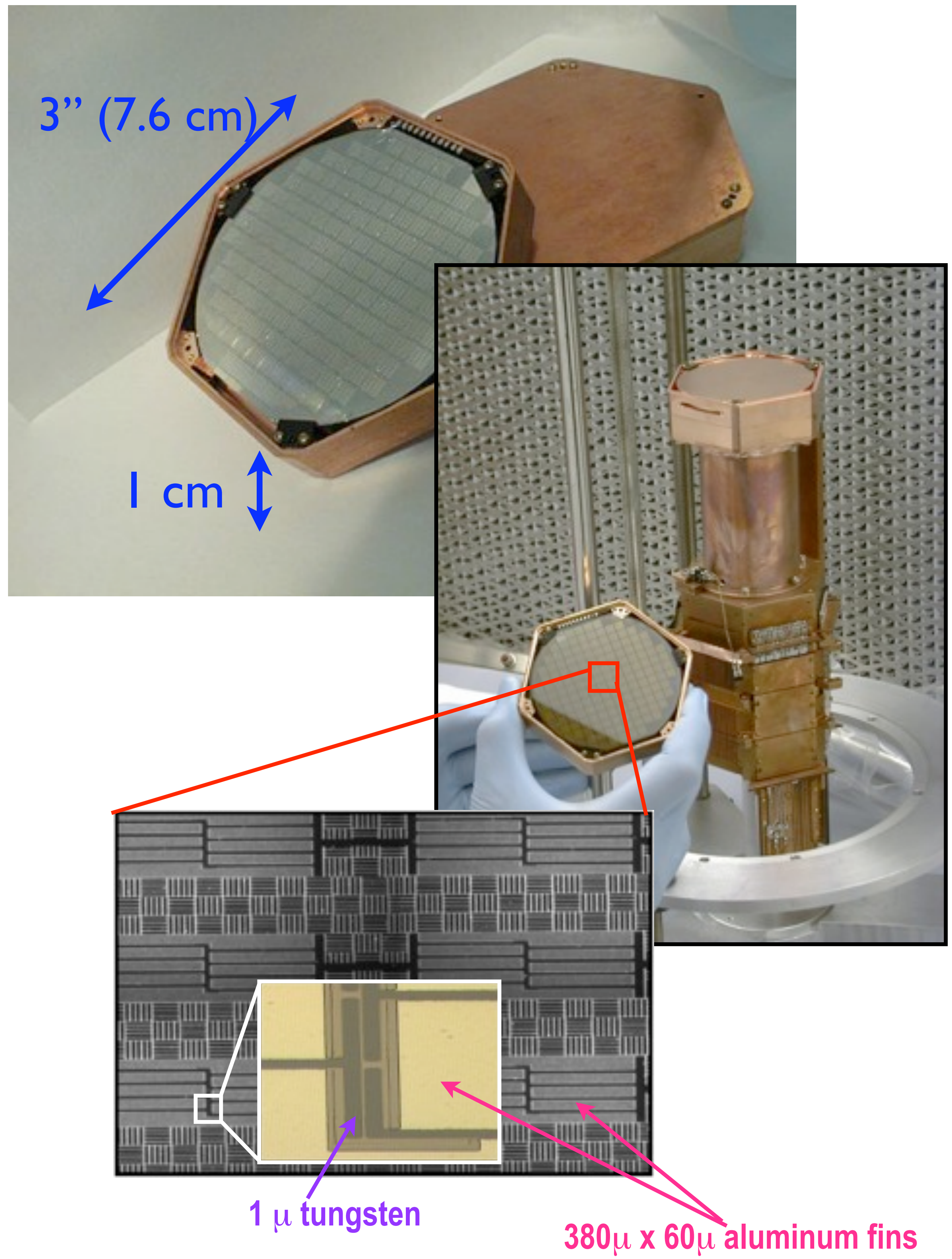
Discrimination from measurements of **ionization** and **phonon energy**.



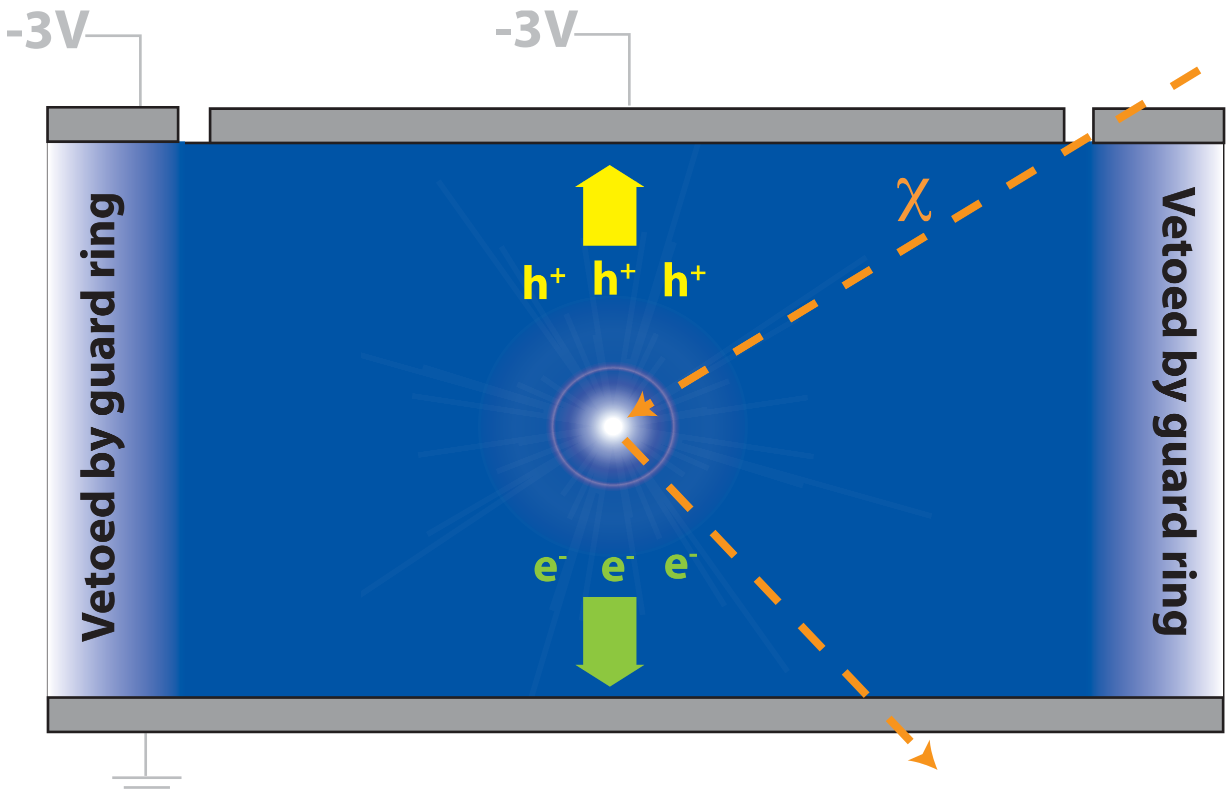
Keep backgrounds low as possible through shielding and material selection.

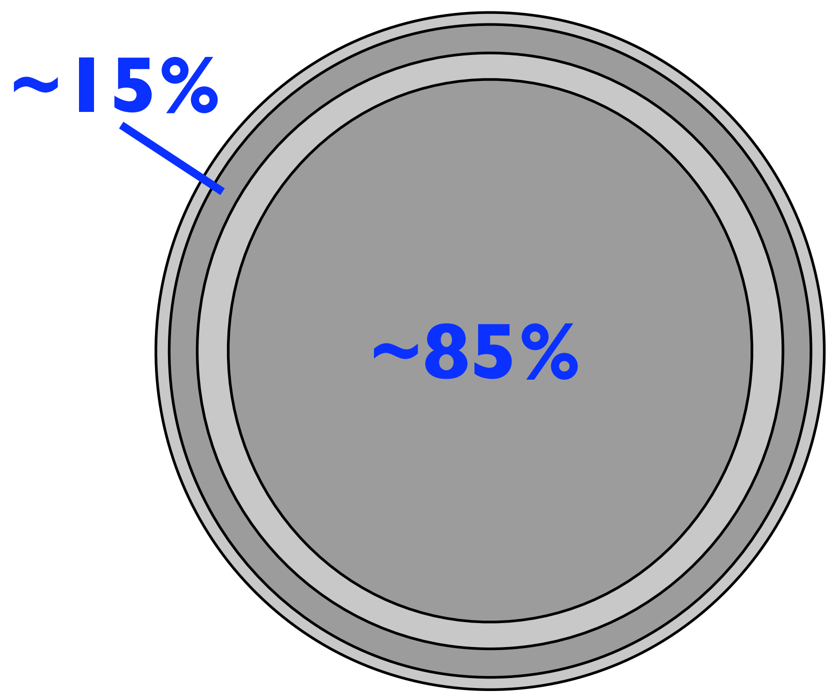
CDMS-II ZIP Detectors

- **Z**-sensitive **I**onization and **P**honon mediated
- **230 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 and timing
- **30 detectors** stacked into **5 towers** of 6 detectors



ZIP Detectors: Charge

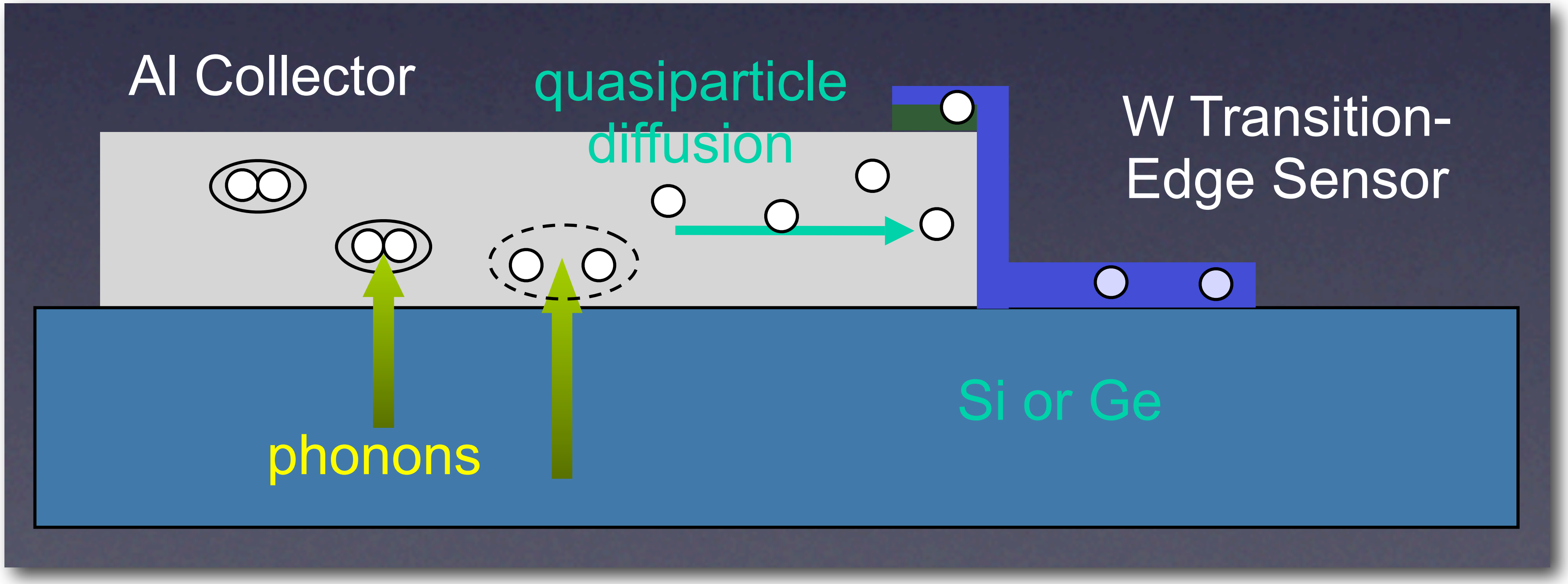




Inner Channel: ionization measurement

Outer Channel: fiducial volume

ZIP Detectors: Phonons



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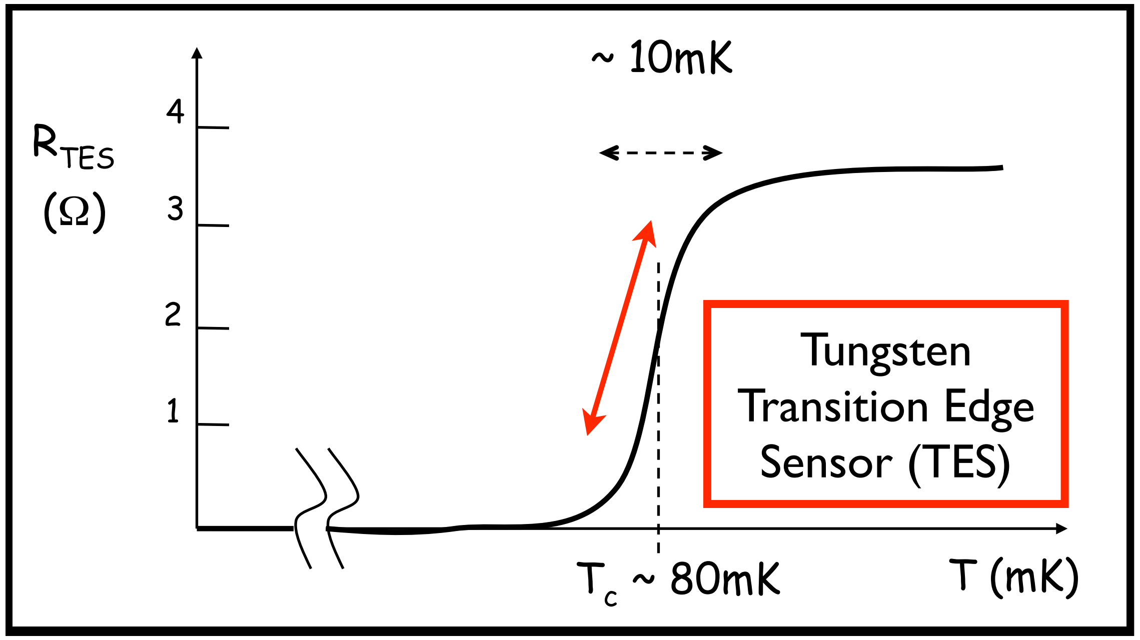
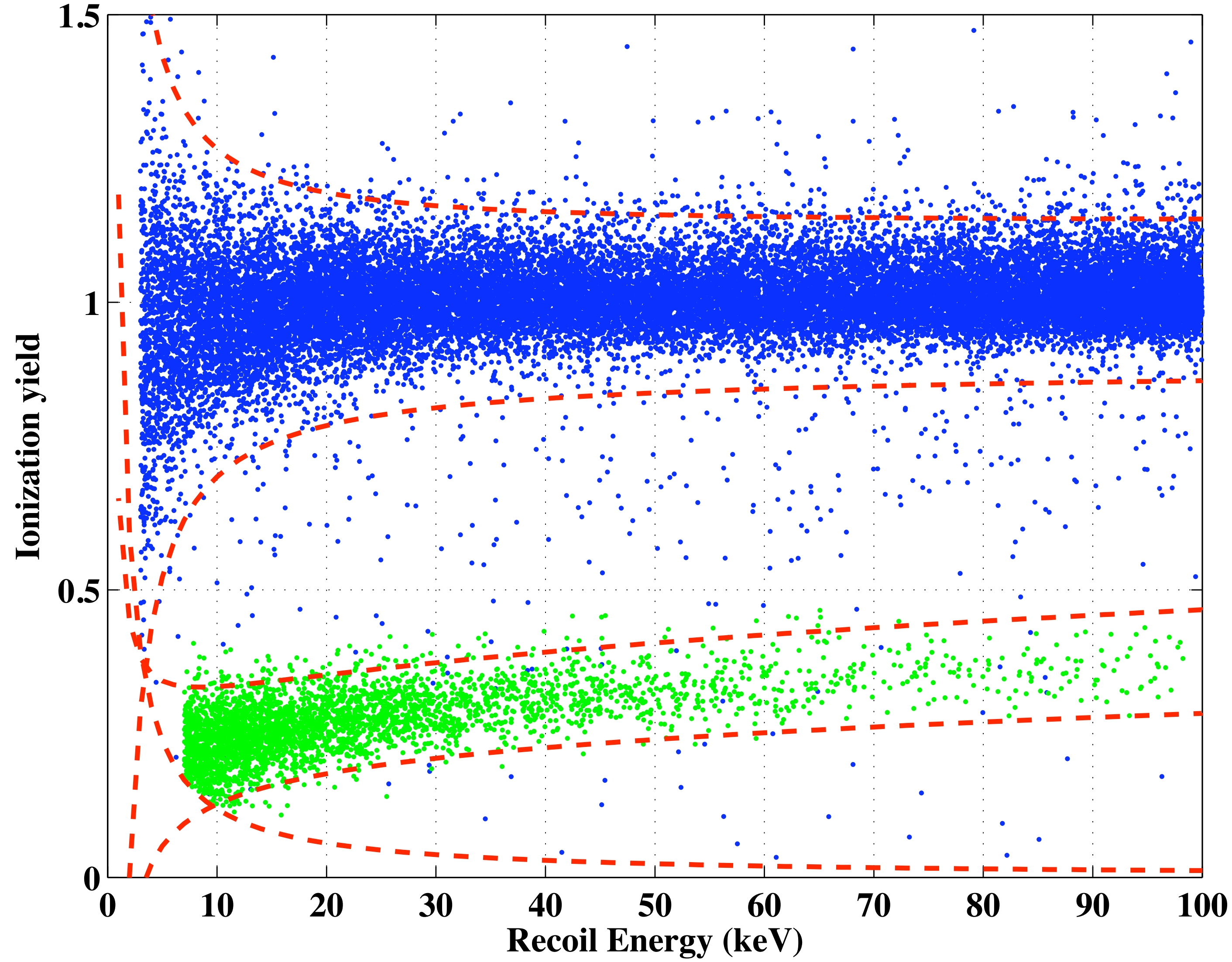


4 SQUID readout channels, each reads out 1036 TESs in parallel

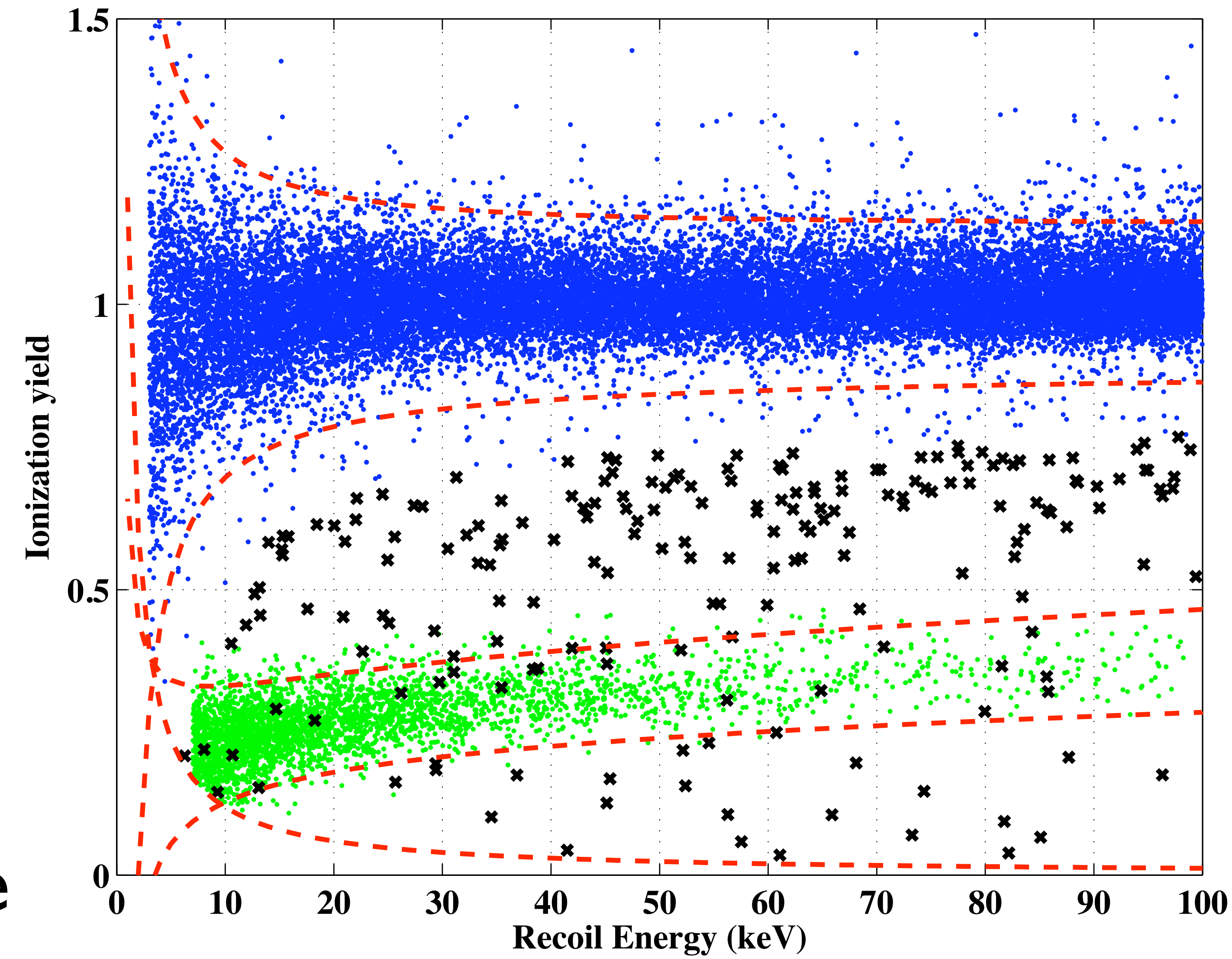
Background Rejection

- Most backgrounds (e, γ) produce electron recoils
- WIMPS and neutrons produce nuclear recoils.
- Ionization yield (ionization energy per unit phonon energy) strongly depends on particle type.

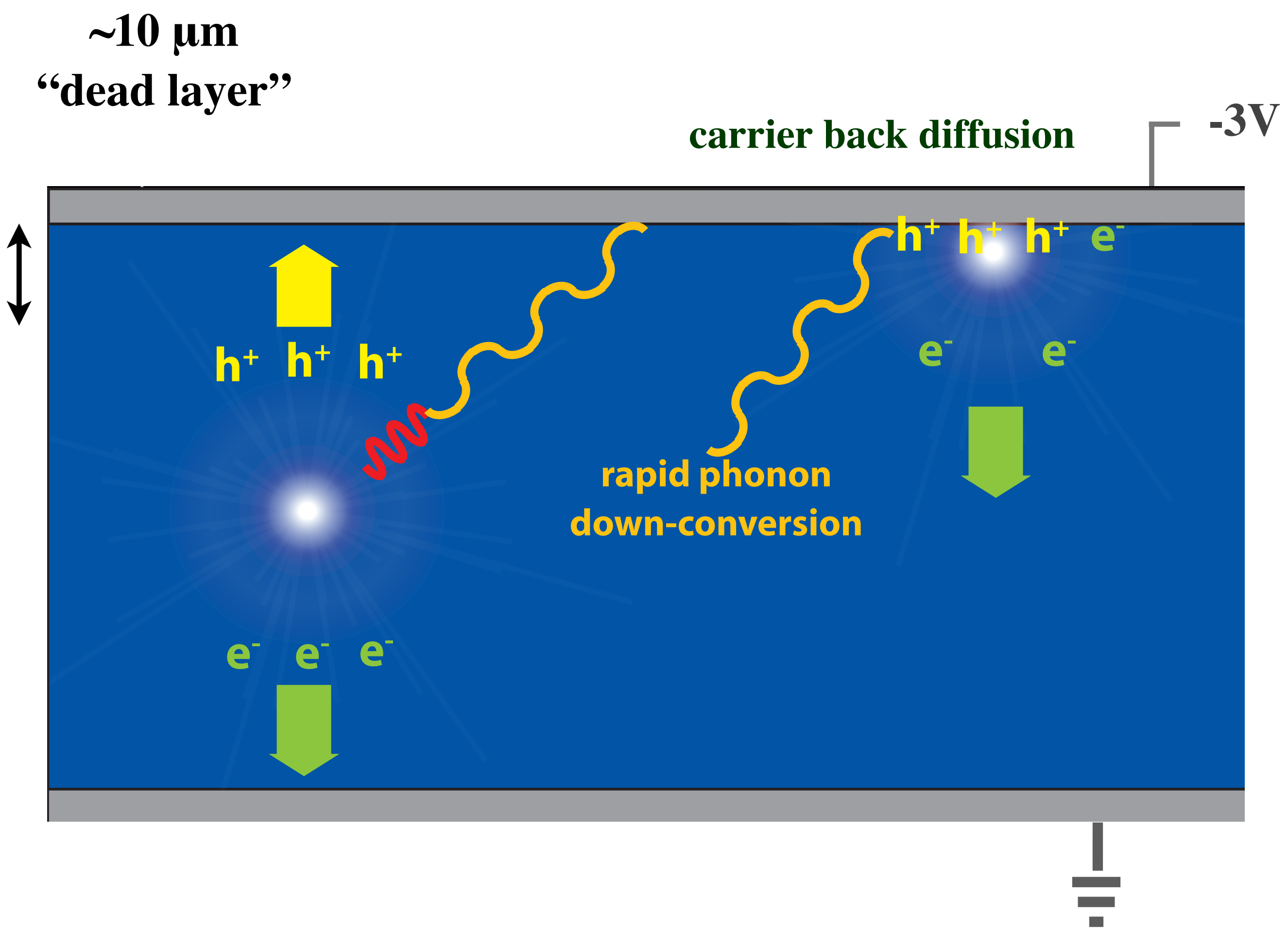


Background Rejection

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

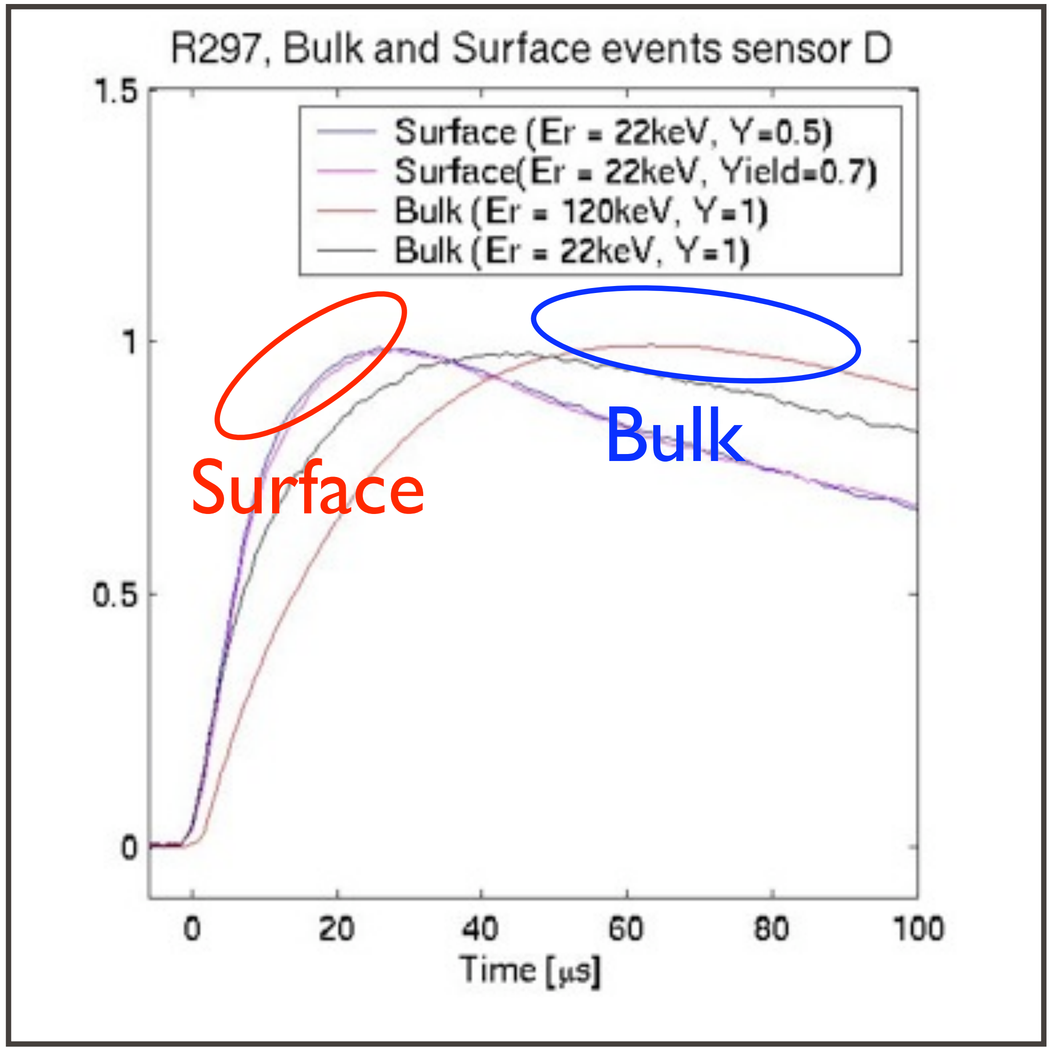


Reduced Ionization Yield

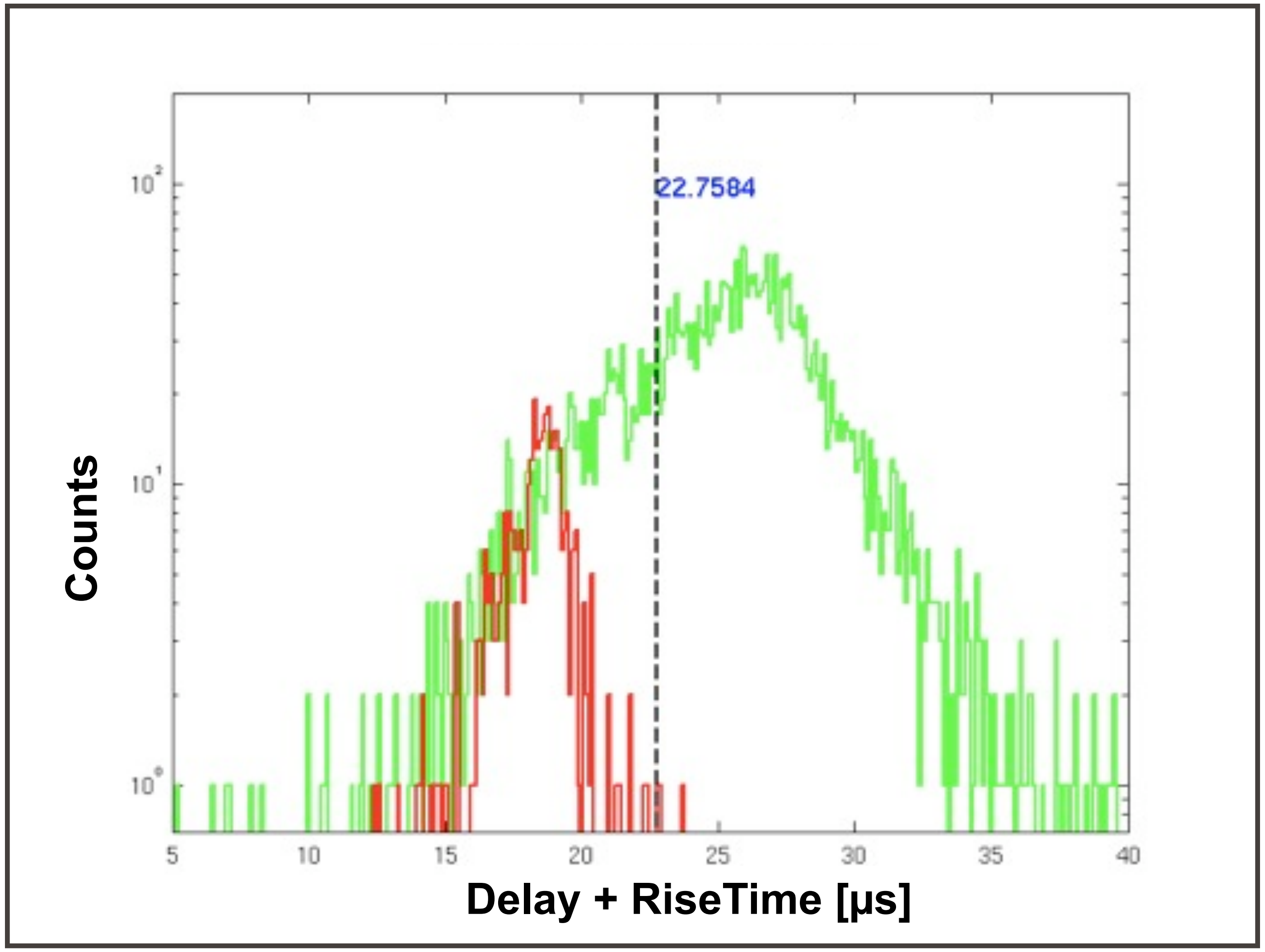


- Reduced charge yield is due to carrier back diffusion in surface events.
- "Dead layer" is within ~10µm of the surface.

Surface Event Rejection

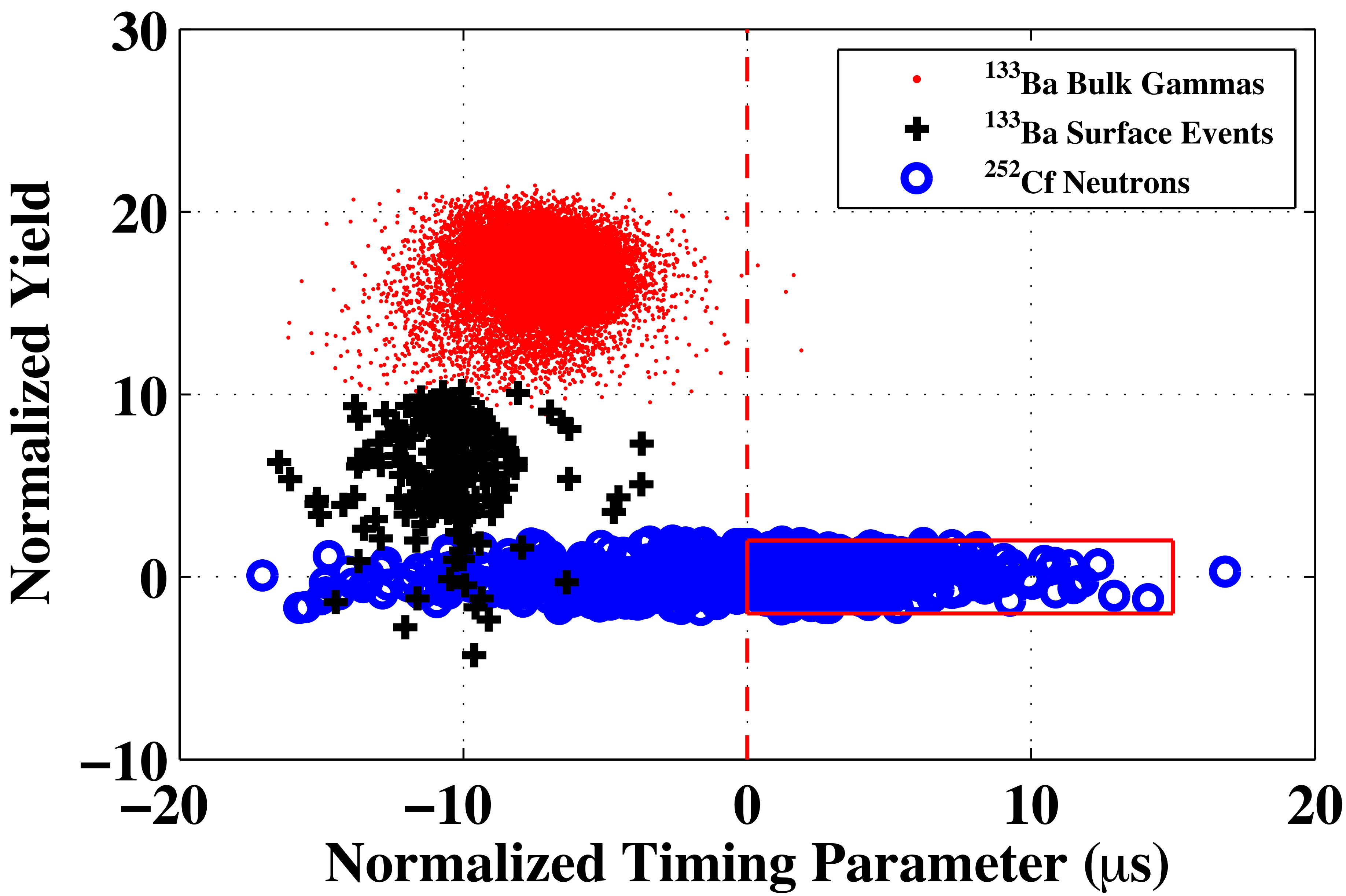


Phonons near surface travel faster, resulting in shorter risetimes of phonon pulse.

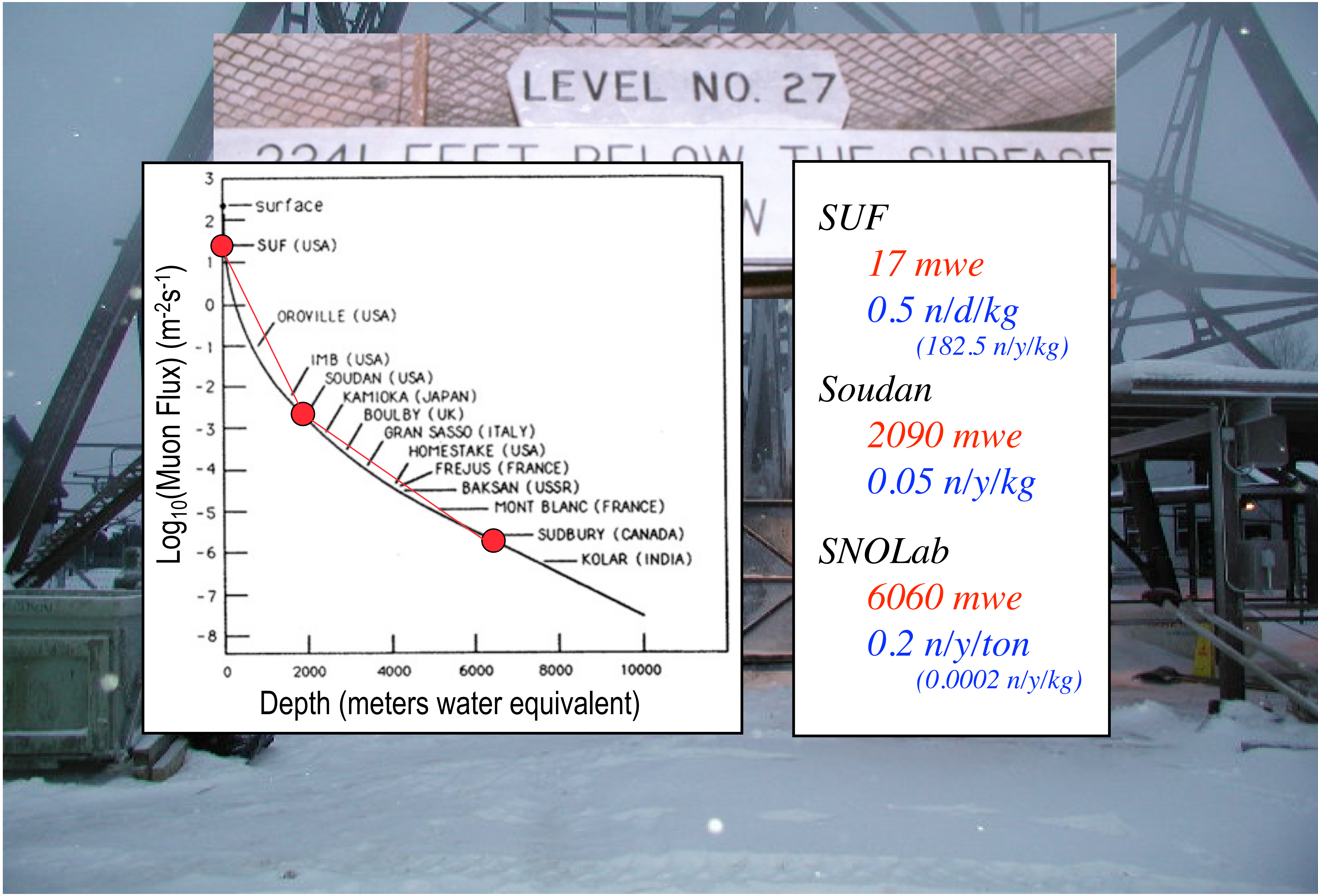


Selection criteria set to accept ~0.5 background events.

Another View of Discrimination




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

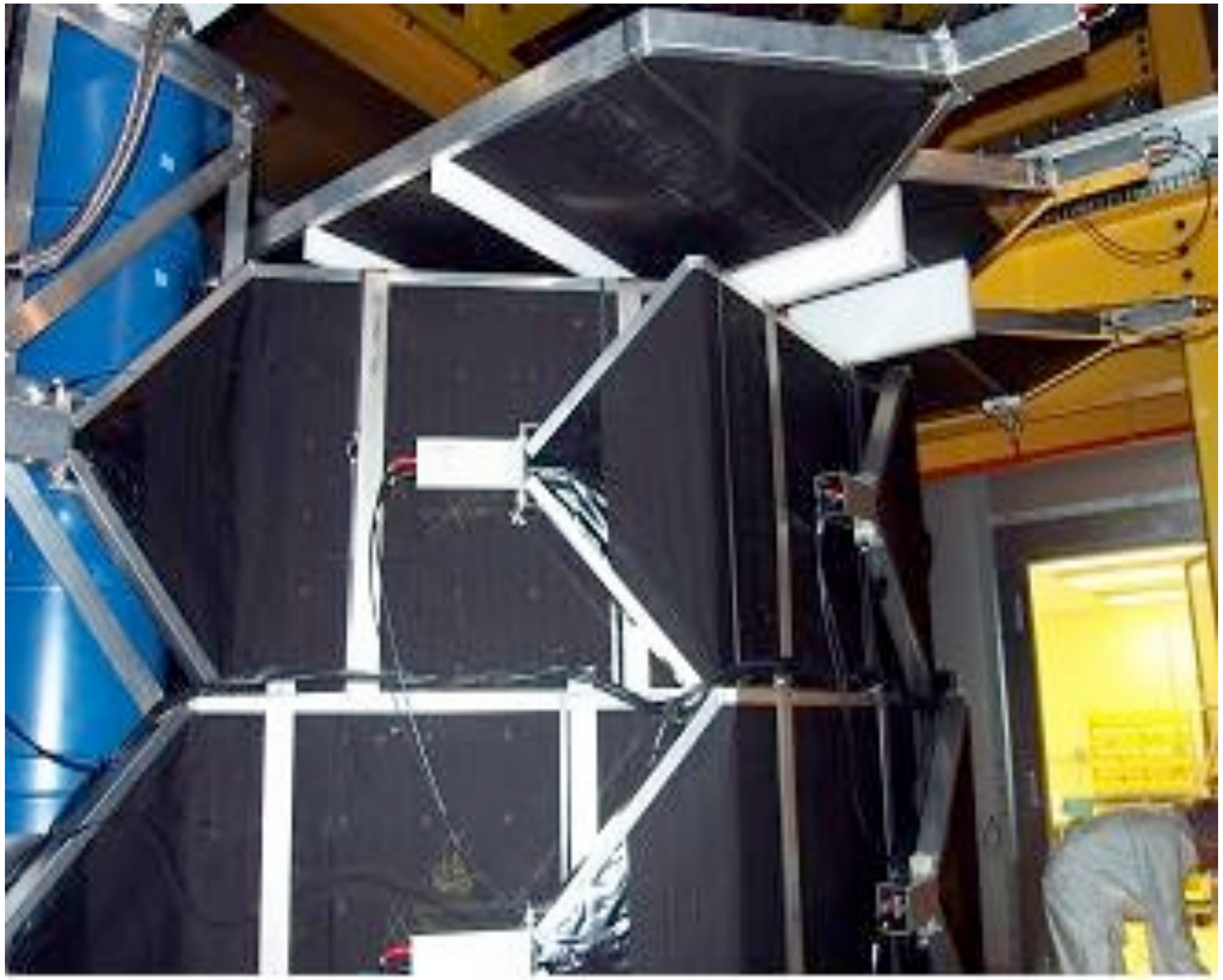
6060 mwe

0.2 n/y/ton

(0.0002 n/y/kg)

Peeling the Shielding Onion

Active Muon Veto:
rejects events from cosmic rays



Peeling the Shielding Onion

Active Muon Veto:
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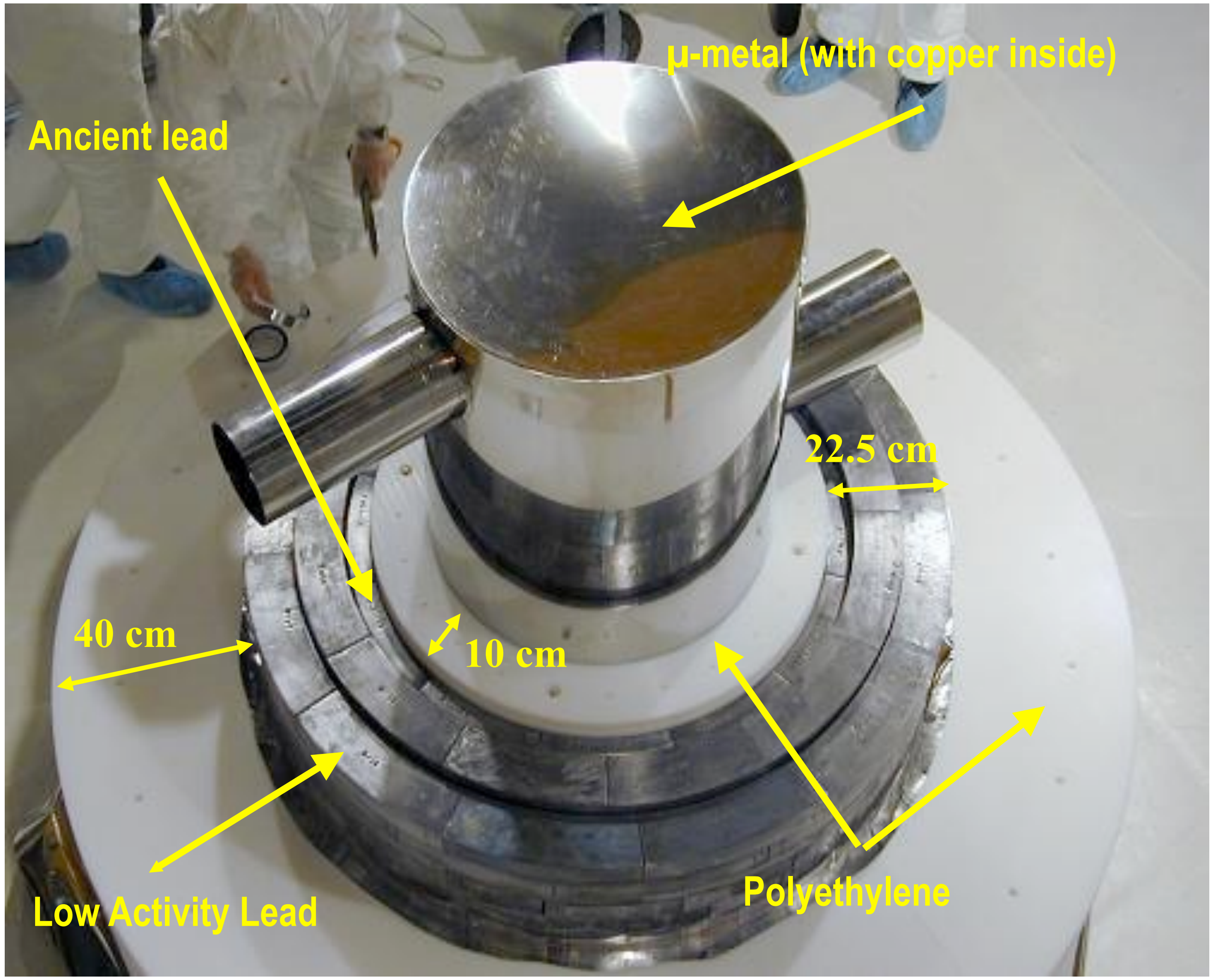
Pb: shielding from gammas resulting from radioactivity

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



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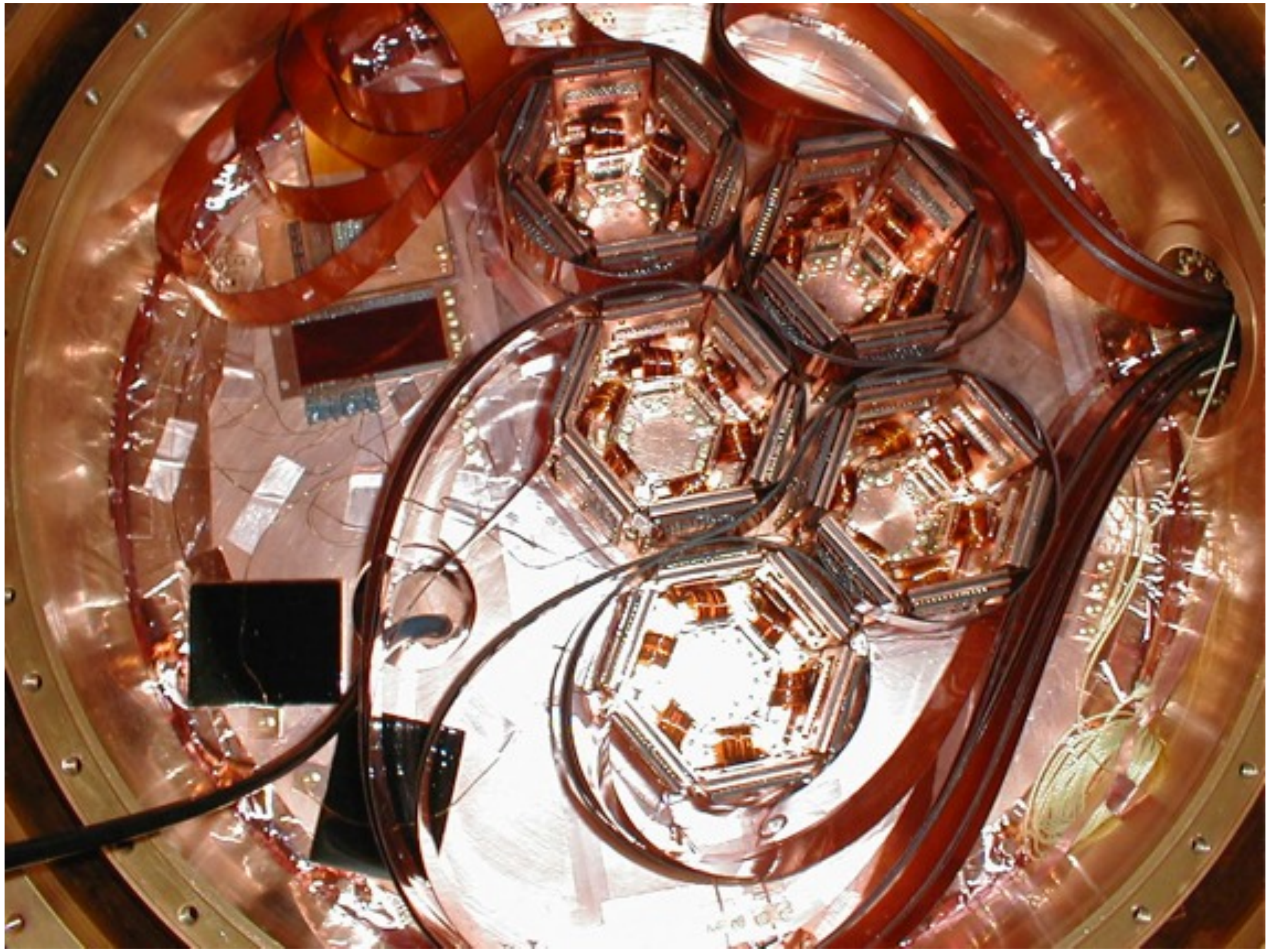
Cu: shielding from gammas



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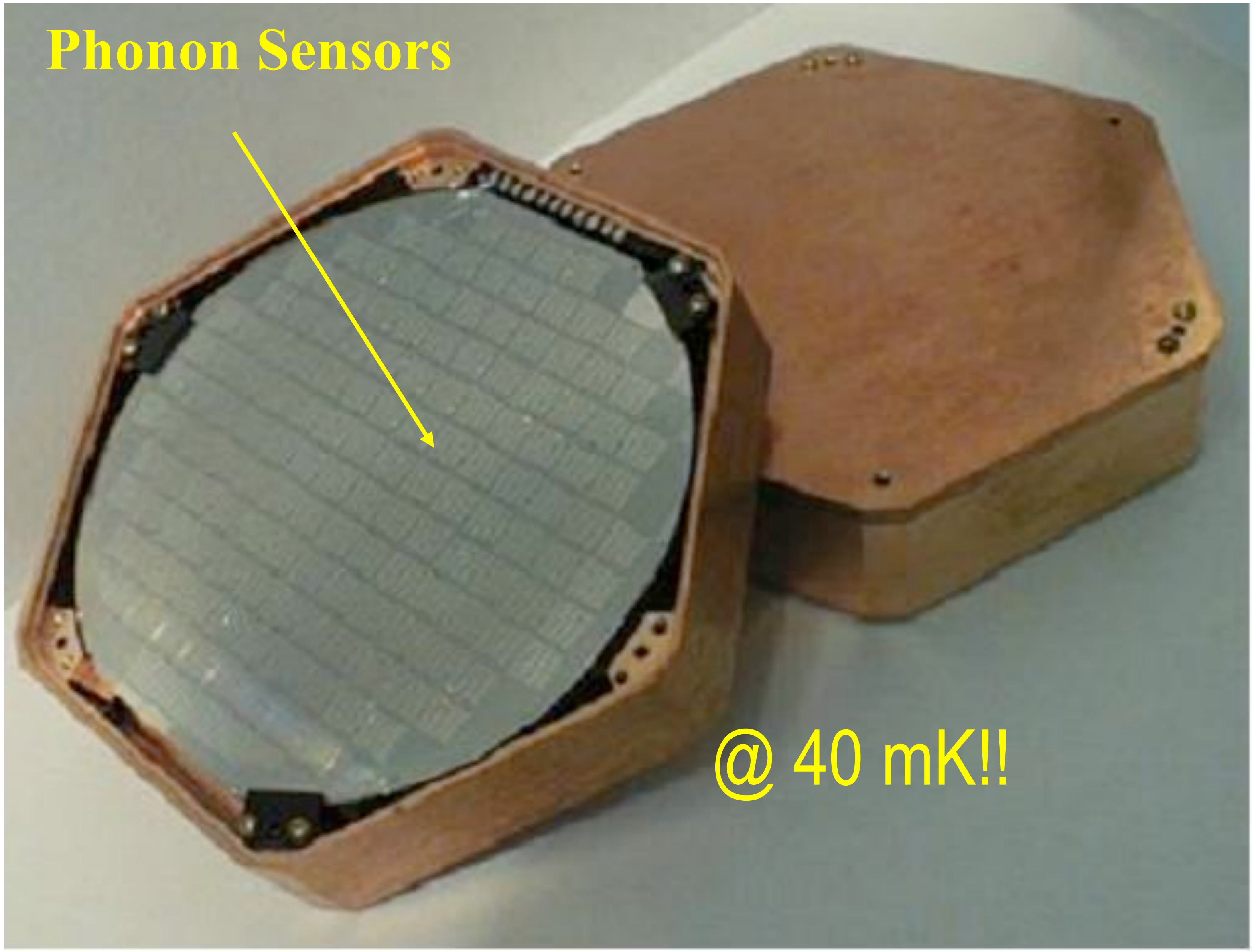
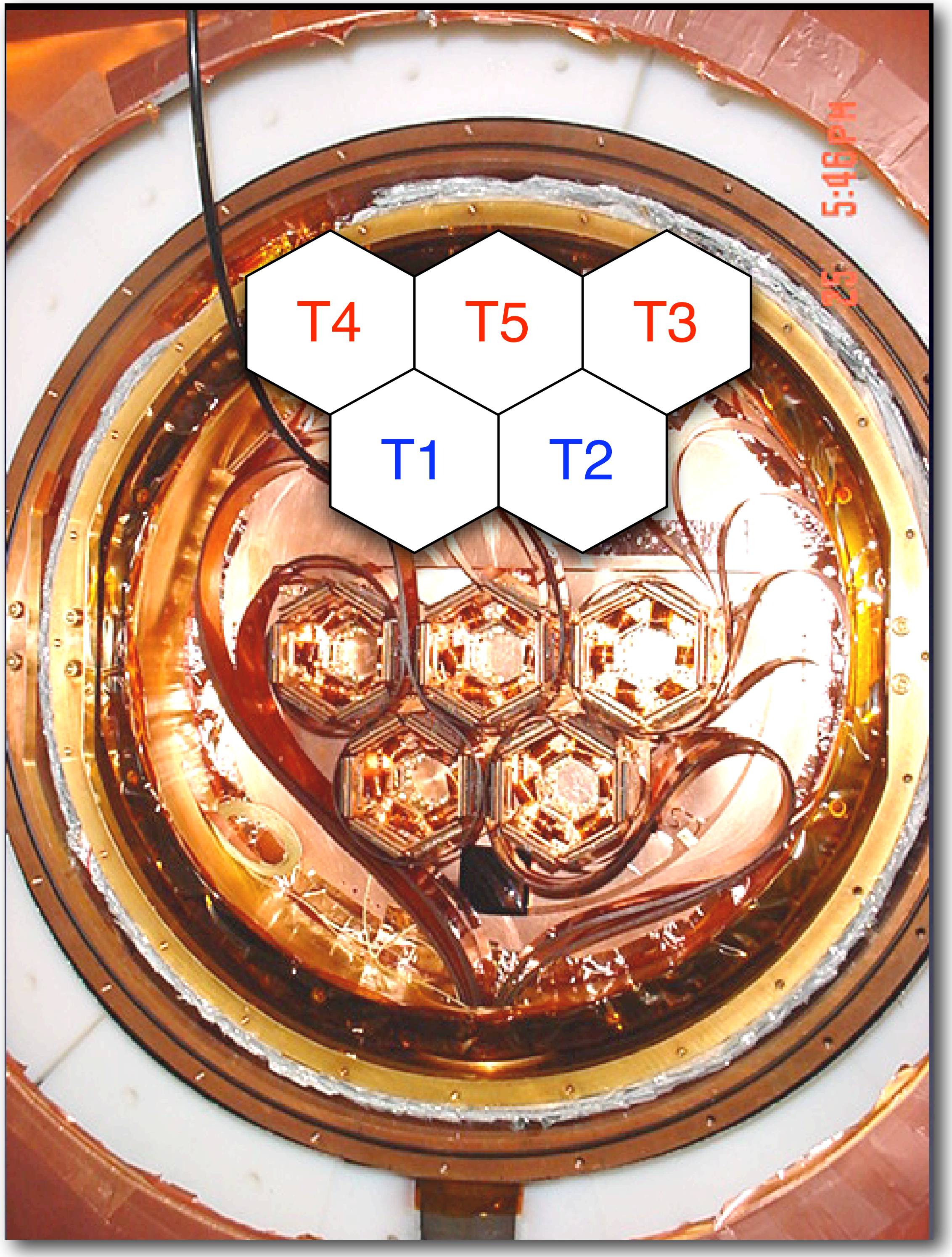


CDMS II Experiment



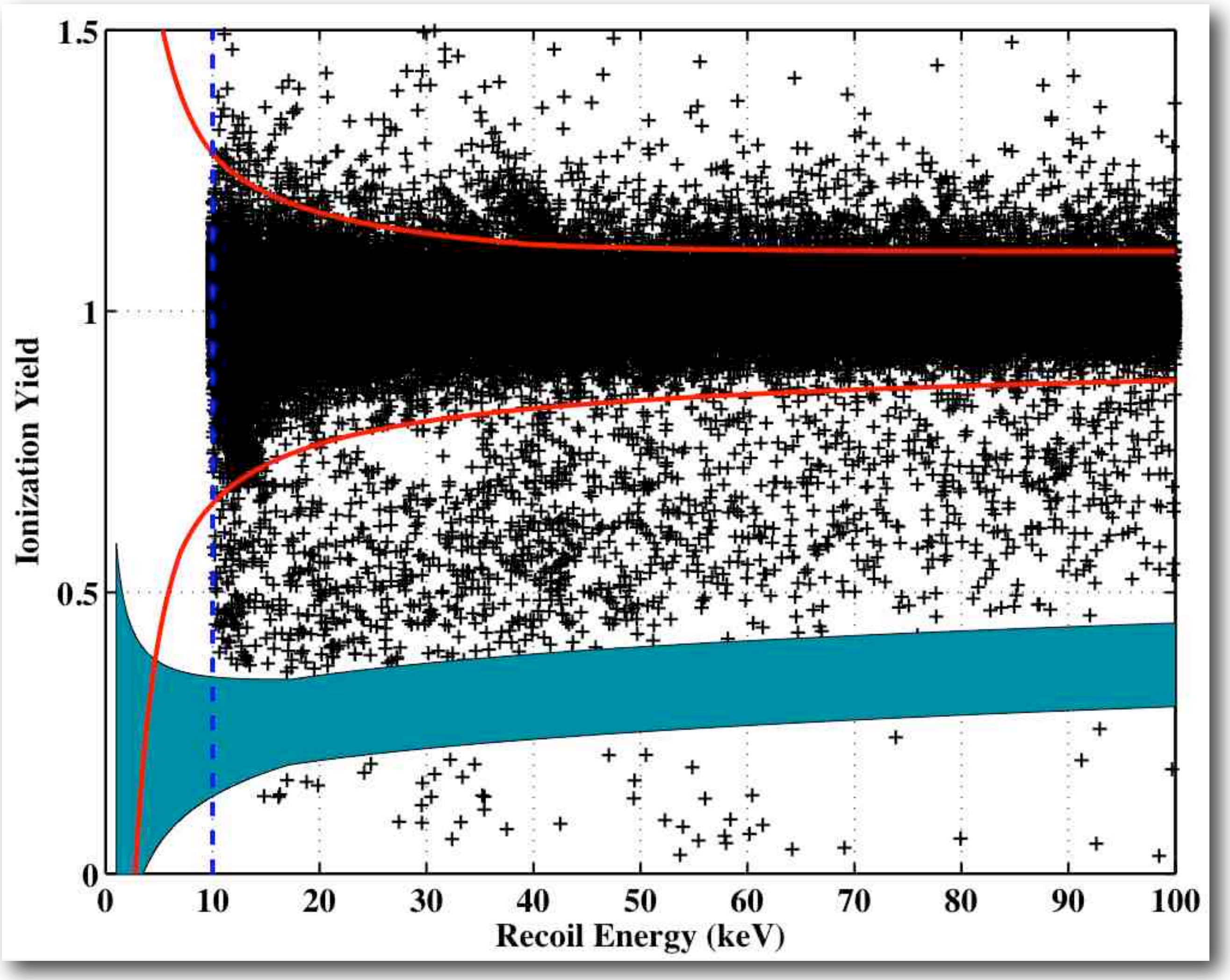
- 30 detectors installed and operating in Soudan since June 2006.
  - 4.75 kg of Ge, 1.1 kg of Si

- **Seven Total Data Runs:**
  - ✓ R123 - R124:
    - taken: (10/06 - 3/07) (4/07 - 7/07)
    - exposure: ~400 kg-d (Ge “raw”)
    - PRL 102, 011301 (2009)
  - ✓ R125 - R128
    - taken: (7/07 - 1/08) (1/08 - 4/08) (5/08 - 8/08) (8/08 - 9/08)
    - exposure: ~ 600 kg-d (Ge “raw”)
  - ✓ R129:
    - taken: (11/08 - 3/09)

Results from Final Data

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*

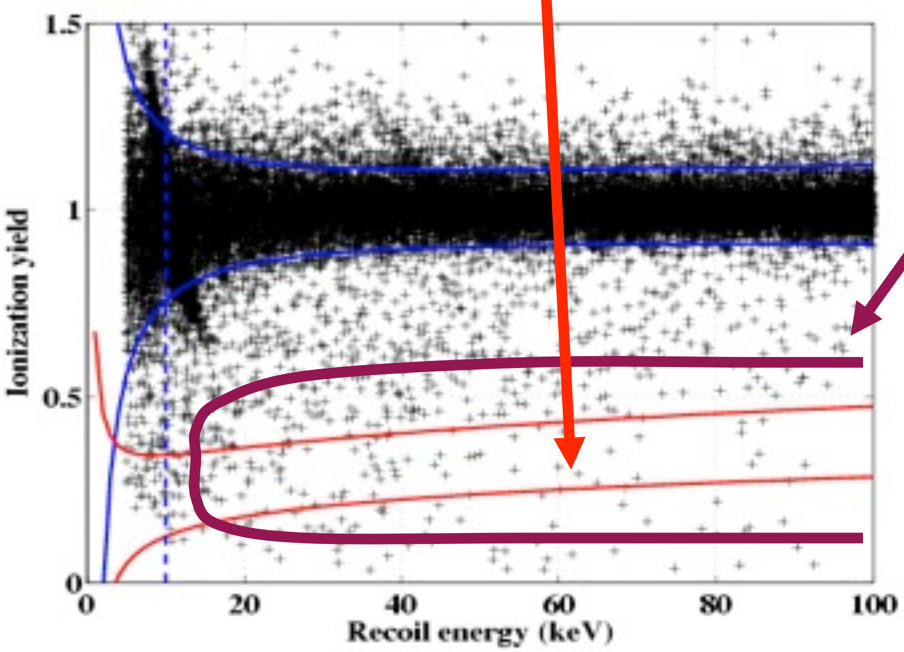
Surface Event Background

$$\text{Expected Surface “leakage”} = \frac{N^{\text{Sideband}}_{\text{pass cut}}}{N^{\text{Sideband}}_{\text{fail cut}}} * N^{\text{data}}_{\text{fail cut}}$$

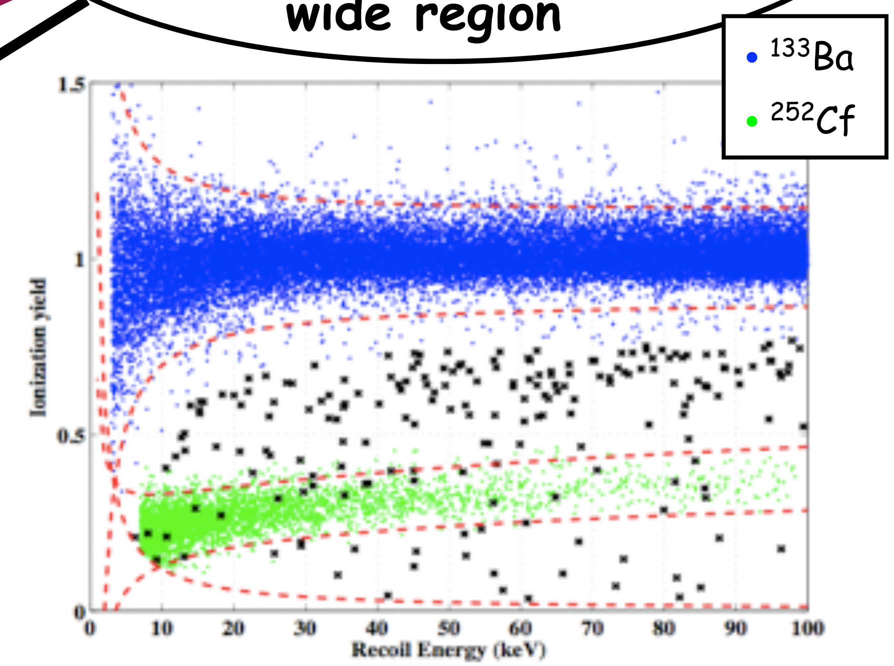
Method 1
Use multiple-scatters in NR band

Method 2
Use singles and multiples just outside NR band

Method 3
Use singles and multiples from Ba calibration in wide region



Correct for systematic effects due to different distributions in energy and face



Combined Estimate = $0.6 \pm 0.1(\text{stat.})$

Neutron Background

Cosmogenic:

3 vetoed, single scatter events

$$\frac{N^{MC}_{\text{unvetoed, SS, NR}}}{N^{MC}_{\text{vetoed, SS, NR}}} * N^{data}_{\text{vetoed, SS, NR}} = 0.04^{+0.04}_{-0.03}(\text{stat.})$$

Radiogenic:

Materials measured using conventional HPGe detector @ 77 K
Spectra confirmed by Monte Carlo.
Contamination levels used as inputs to Geant4 simulation.

0.03 - 0.06 events

Projected Sensitivity

612 raw kg-days
194.1 kg-d WIMP equiv.
@ 60 GeV/c^2
(10 -100 keV analysis
energy range)

Surface Background

$0.6 \pm 0.1(\text{stat.})$

Neutron Background

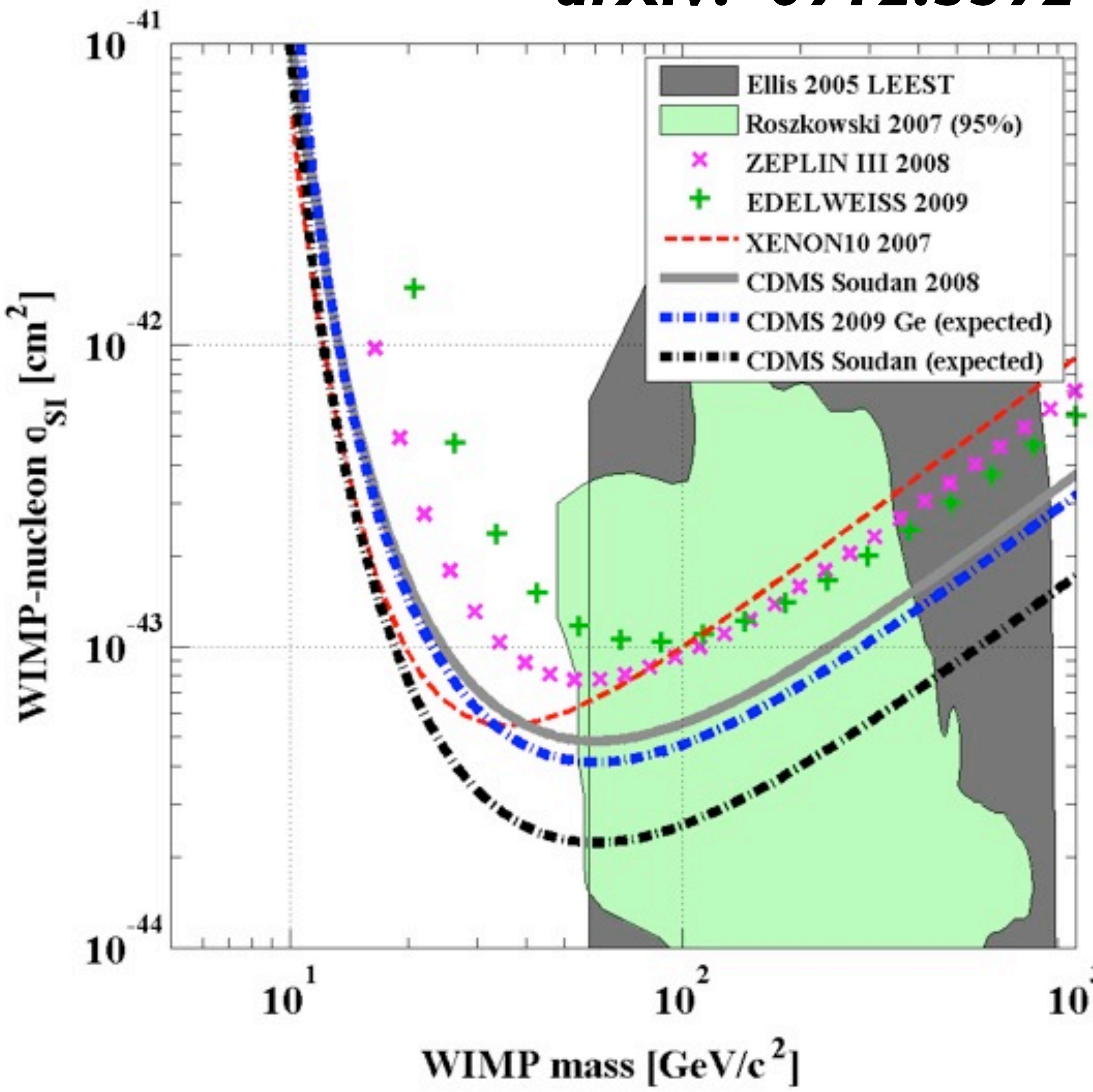
Cosmogenic

$0.04^{+0.04}_{-0.03}(\text{stat.})$

Radiogenic

0.03 - 0.06

arXiv: 0912.3592

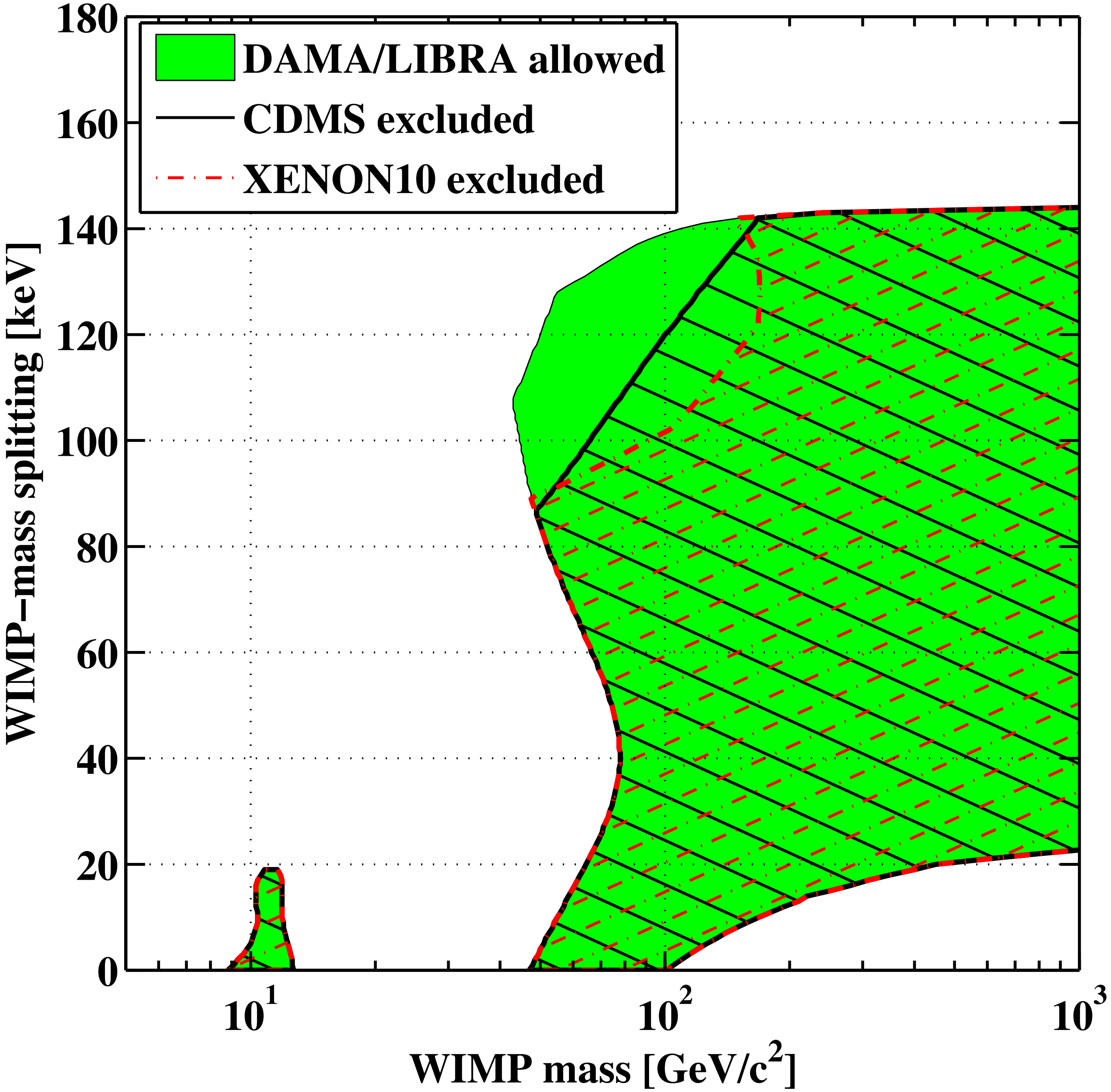


Inelastic Scattering

Disfavor all DAMA/LIBRA allowed region except for WIMPs of mass ~100 GeV with mass-splittings ~80-140 keV

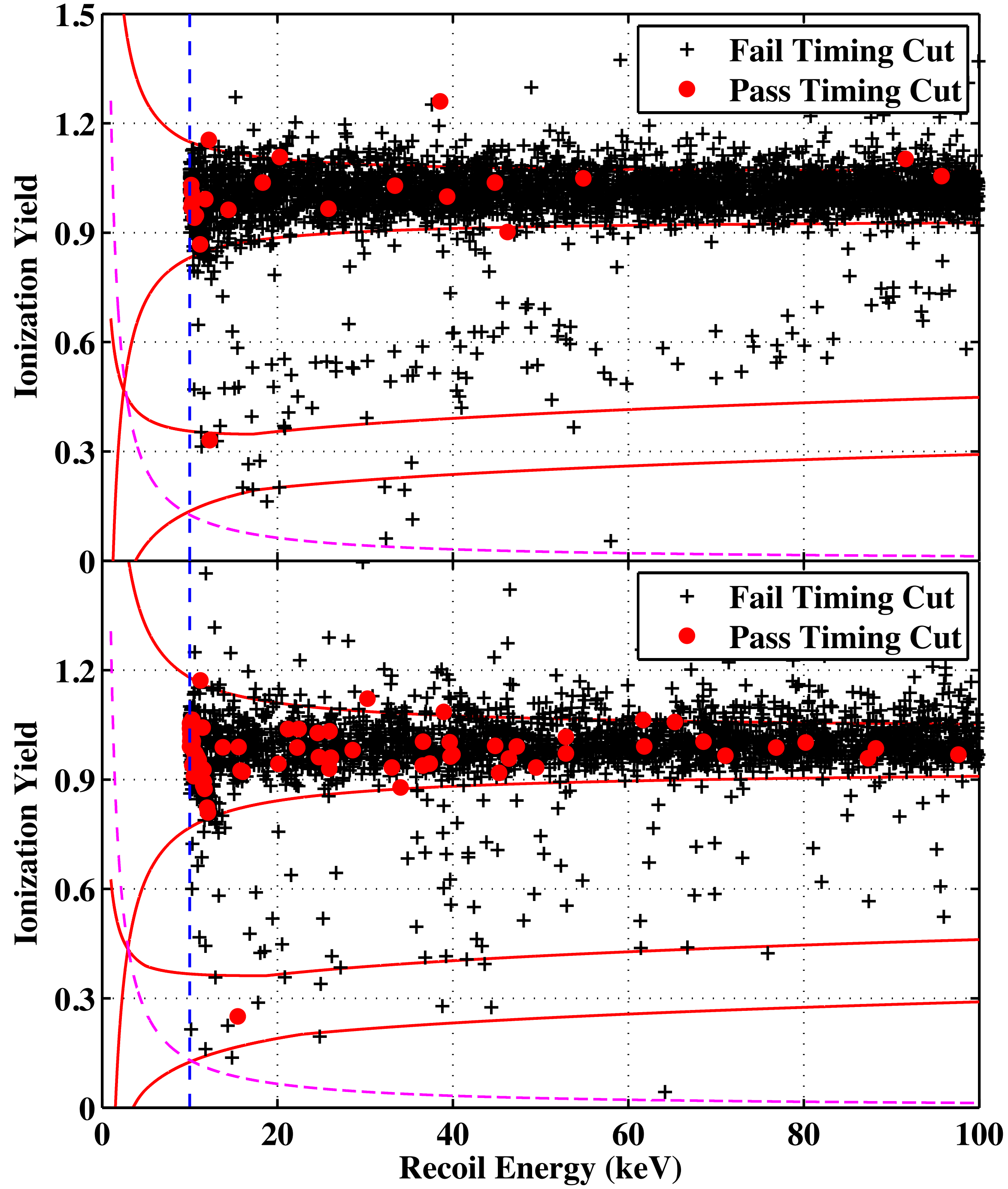
Shown are only regions for which CDMS II and XENON10 are not compatible with DAMA/LIBRA at the 90% C.L.

arXiv: 0912.3592

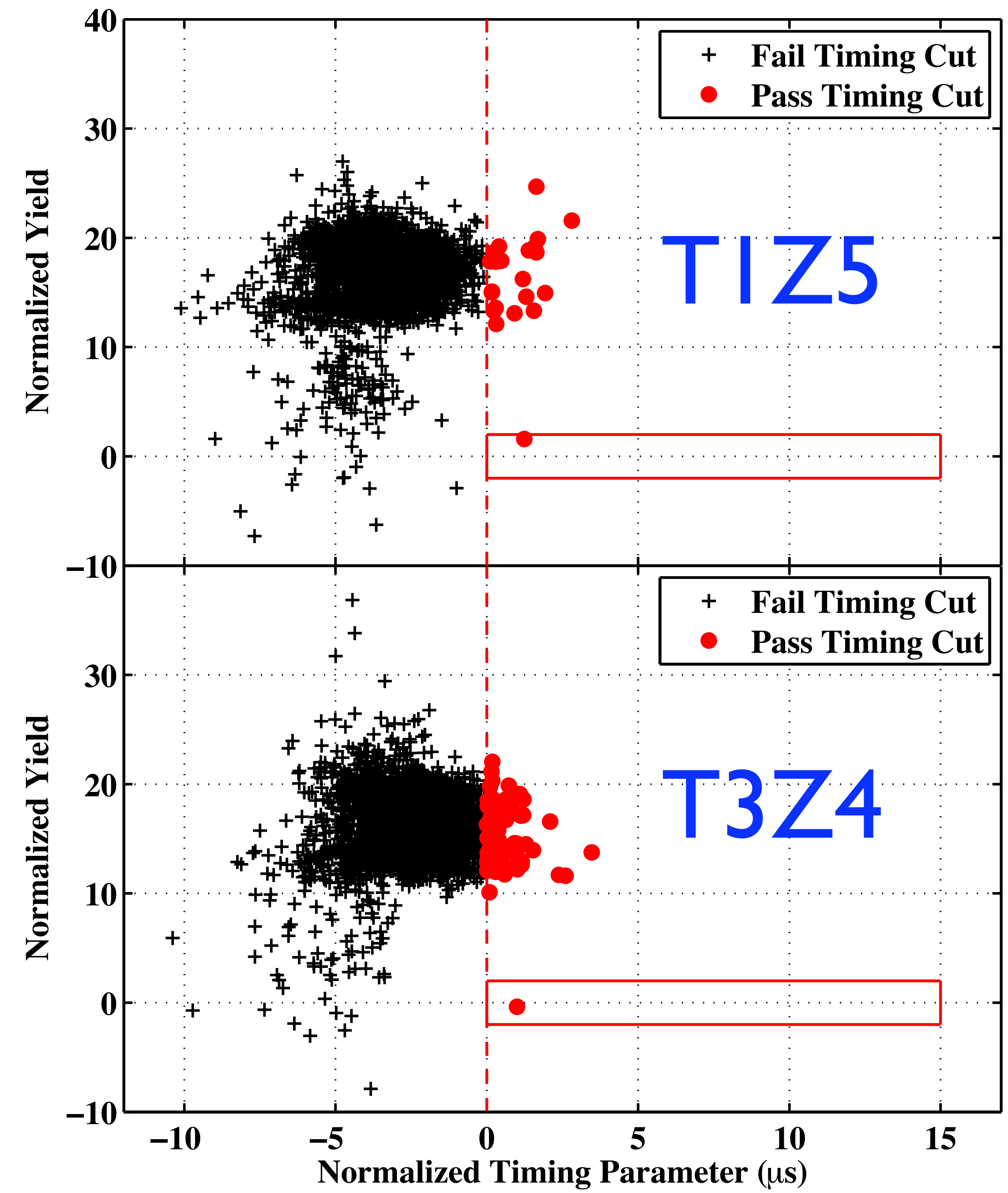


Closer Examination of Observed Events

Event Yield, Timing and Energy



arXiv: 0912.3320



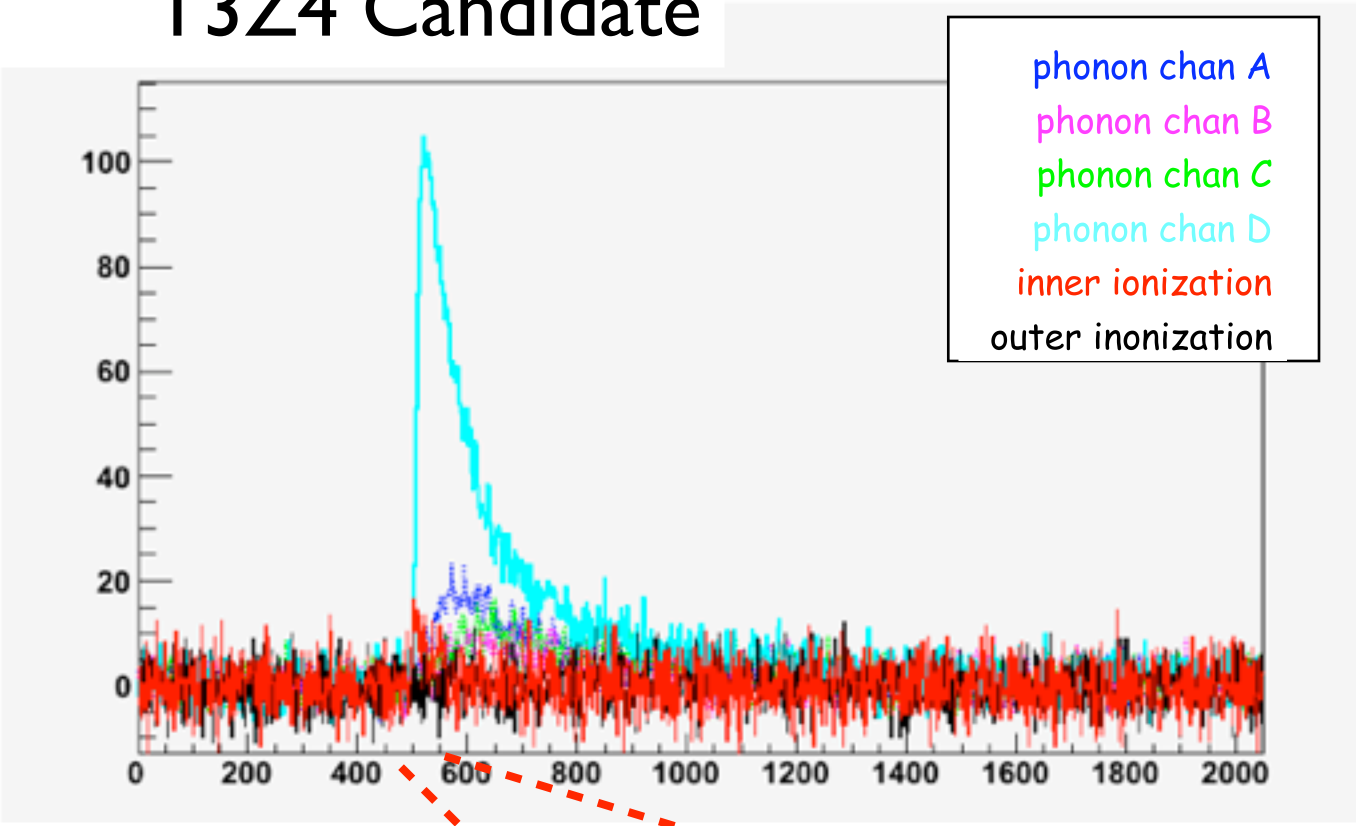
What More Can We Say?

- The two events occur during a time of nearly ideal detector performance.
- They are separated in time by several months and occur on detectors in different towers (T1Z5 and T3Z4).
- They occur on inner detectors where we have a stronger handle on our background estimate.

Data Quality Item	Result
muon veto performance	*good*
neutralization	*good*
KS tests	*normal*
noise levels	*typical*
pre-pulse baseline rms	*typical*
background electron-recoil rate	*typical*
surface event rate	*typical*
radial position	*well-contained*
single-scatter identification	*good*
special running conditions	*no*
operator recorded issues	*no*

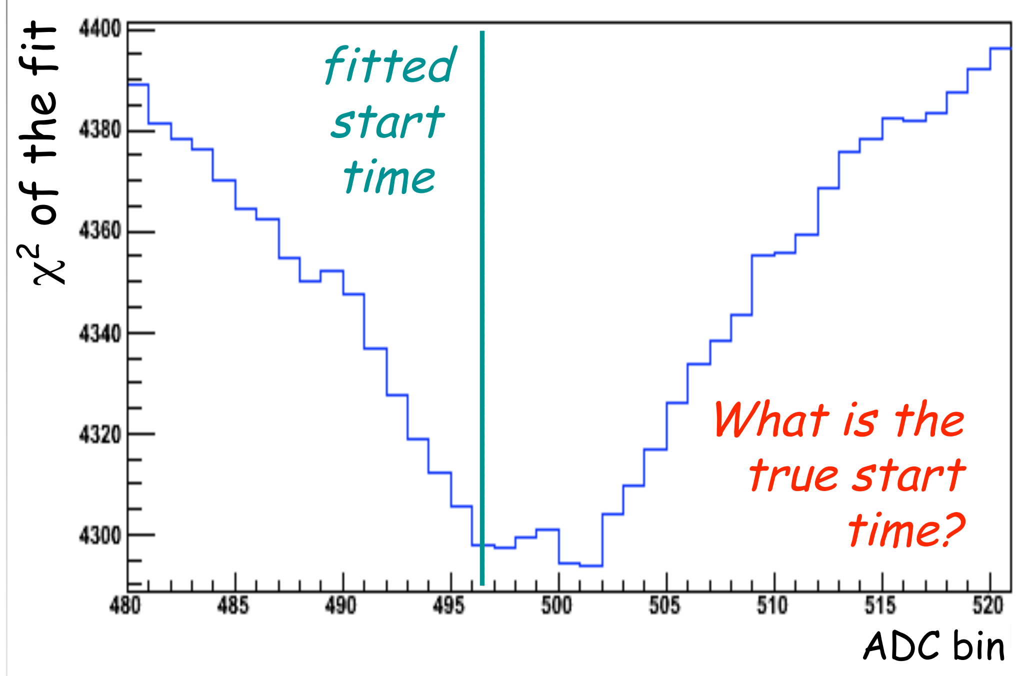
Reconstruction Checks

T3Z4 Candidate

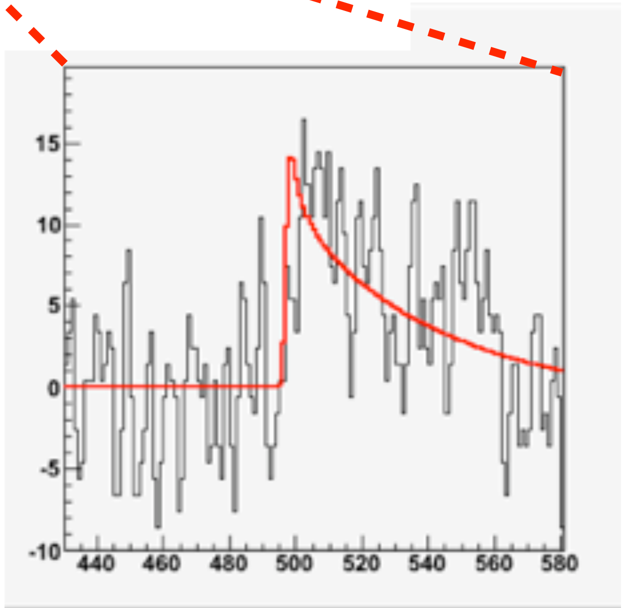


ionization and phonon energies look good, phonon timing looks good, ...

... but could be problem with charge start time



Raw Unfiltered Data.



Note: This effects some events with ionization energy < ~6 keV. It does not effect candidate event on T1Z5.

Reconstruction (Cont.)

- A refined calculation of the surface background taking into account larger errors in the timing estimate a low energy produced a post-unblinding leakage estimate of

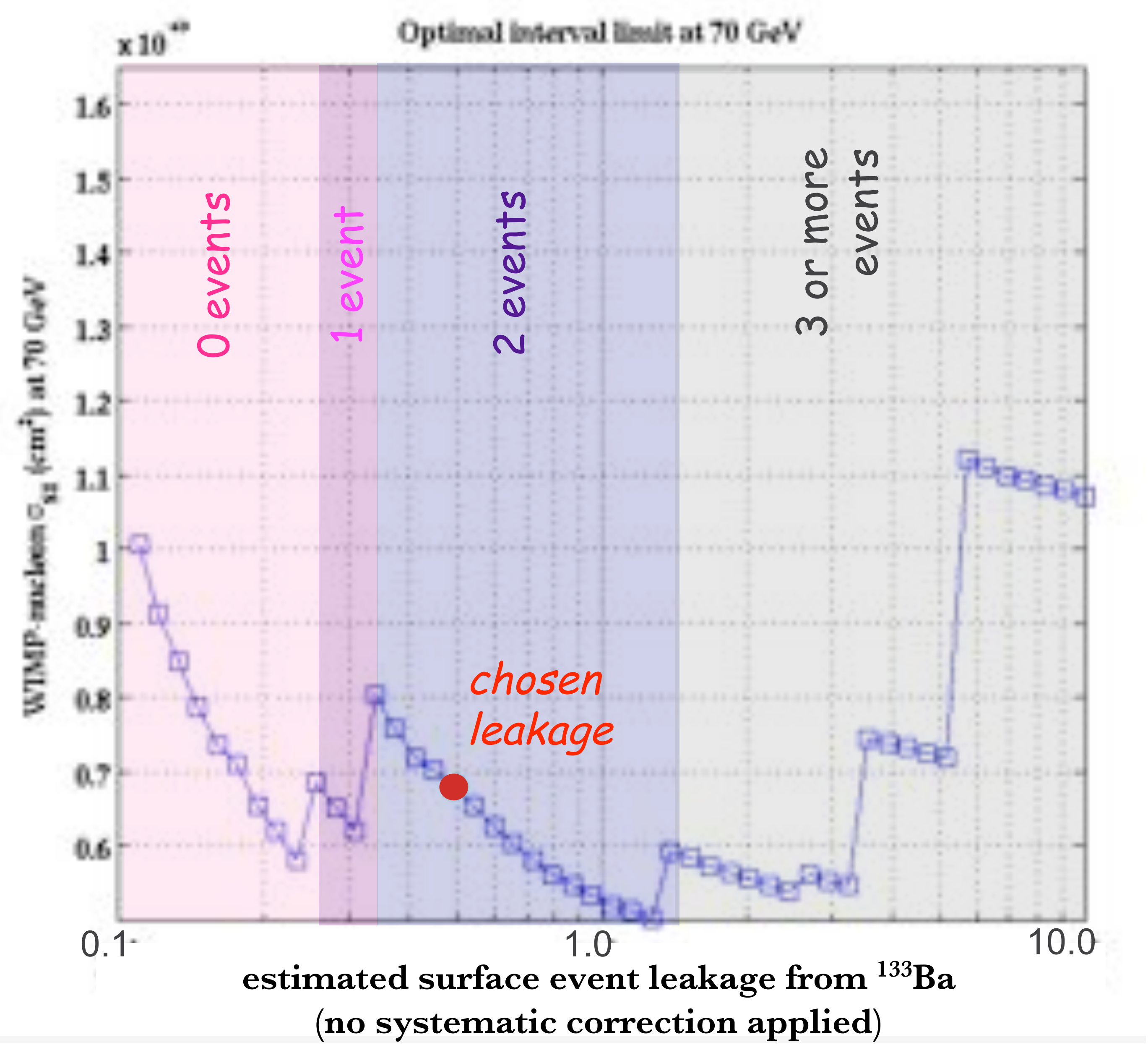
$$0.8 \pm 0.1(\text{stat.}) \pm 0.2(\text{syst.})$$

- Based on this revised estimate the **probability of observing 2 or more events is 23%** (includes neutron + surface event background).

- With an improved reconstruction algorithm which includes this χ^2-fit, this pulse may fail the timing cut, but other events may be let into the signal region.

What Would it Take to Exclude these Events?

- Reducing the surface event estimate by ~1/2 would remove both candidates while reducing our exposure by 28%
- Additional events would not enter the signal region until we increased the surface event estimate by a factor of ~2.



Final Comments on this Analysis

Our results cannot be interpreted as significant evidence for WIMP interactions.

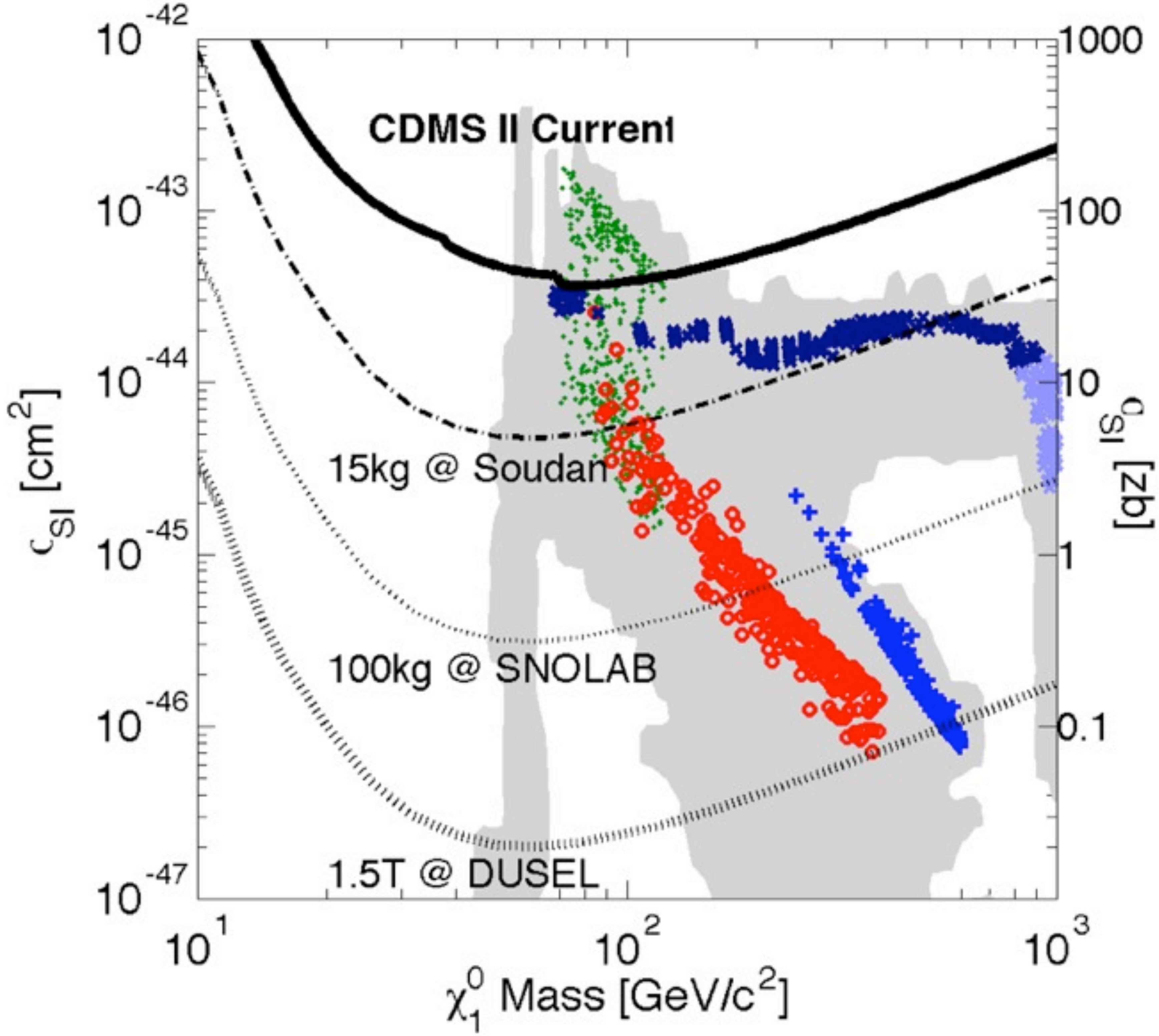
However, we cannot reject either event as signal.

The Future

Next Step: SuperCDMS

- Last CDMS II data taken on March 18, 2009
- March 19, 2009: Warm up to begin the installation and commissioning of the first SuperCDMS detectors. Commissioning runs of the first SuperCDMS tower is underway.
- Fabrication of remaining detectors for the SuperCDMS Soudan project (15 kg Ge deployed in existing Soudan setup) underway. Installation and commissioning summer 2010.
- Eventual goal: SuperCDMS SNOLAB (100 kg Ge deployed at SNOLAB)

Sensitivity of Future Detectors



Conclusions

- **We observe 2 events in the first analysis of the final data taken by CDMS II between July 07 and Sept. 08. This yields a cross section limit of < 3.8 x 10^{-44}cm^2 (90% CL) for a WIMP of mass 70 GeV/c^2 when combining this result with previous analyses.**
- **The results of this analysis cannot be interpreted as significant evidence for WIMP interactions, but we can not reject either event as a signal.**
- **The first SuperTower of detectors has been installed and is operating in the Soudan Underground Laboratory. Remaining SuperTowers of detectors are planned to be installed in Summer 2010.**
- **Stay tuned for this coming year. Several other promising technologies (liquid nobles, bubble chambers, ...) will have exciting results.**