The SuperCDMS Dark Matter Search

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The Electroweak Scale: Unraveling the Mysteries at the LHC

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The History of (Super)CDMS

- CDMS started out in the early 90's as the *Pilot Dark Matter Experiment*, a collaboration between Stanford University, U.C. Berkeley, and U.C. Santa Barbara

- Mid 90's: The *CDMS* experiment is born. Located at the Stanford Underground Facility (very shallow depth), the collaboration had grown to 11 institutions (mostly by fission, but with some fusion). 13 events were observed in the signal region for an exposure of 28 kg-d. WIMP cross-sections larger than $\sigma \approx 3\text{x}10^{-42}$ cm^2 for $m_\chi \gtrsim 50$ GeV/c^2 were excluded. **PRL 84, 5699 (2000)**.

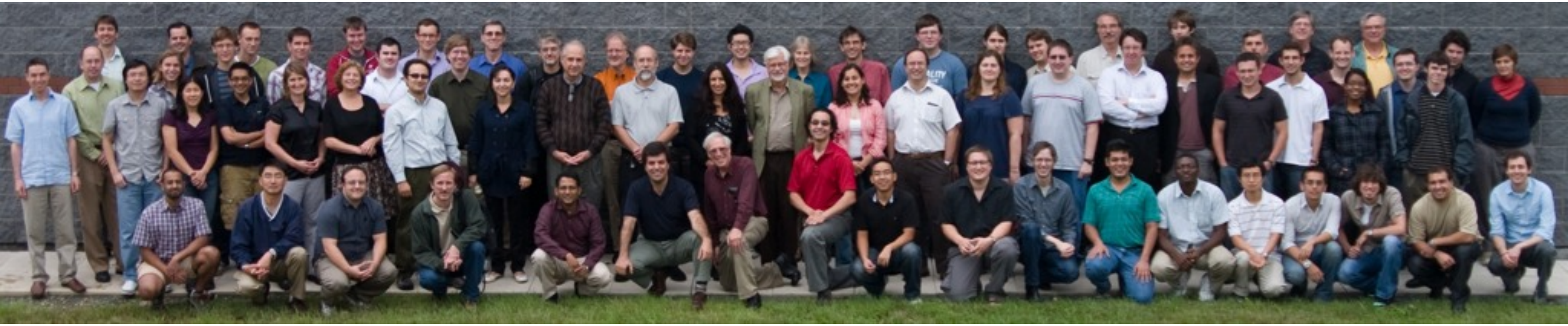
- 2000: *CDMS II* is born. Mostly the same institutions but the number of people was growing. 1 event was observed in the signal region for an exposure of 20 kg-days. WIMP cross-sections larger than $\sigma \approx 4\text{x}10^{-43}$ cm^2 for $m_\chi \gtrsim 60$ GeV/c^2 were excluded. **PRD 72, 052009 (2005)**.

- Jan 2010: The results from the initial analysis of the full CDMS II data set published. 2 events was observed in the signal region for an exposure of 1 kg-year. WIMP cross-sections larger than $\sigma \approx 4\text{x}10^{-44}$ cm^2 for $m_\chi \gtrsim 70$ GeV/c^2 were excluded. **Science 327, 1619 (2010)**.

The Future of (Super)CDMS

- Since 2010: *CDMS II* has evolved into *SuperCDMS*. The collaboration has grown to 18 institutions and more people than can be listed on one slide. (Significant amount of fusion, but no need to worry about a chain reaction, we're nowhere near the size of a collider collaboration yet.)
    - *SuperCDMS @ Soudan*: 2012-2014. Operating 10 kg detector payload, anticipating a sensitivity of $\sigma \approx 5 \times 10^{-45}$ cm^2
    - *SuperCDMS @ SNOLAB*: 2016-2020 (projected). Plan on operating 200 kg detector payload, anticipating a sensitivity of $\sigma \approx 8 \times 10^{-47}$ cm^2

The SuperCDMS Collaboration



California Institute of Technology

Fermi National Accelerator Laboratory

Massachusetts Institute of Technology

Queen's University

Santa Clara University

SLAC / Kavli Institute for Particle Astrophysics and Cosmology

Southern Methodist University

Stanford University

Syracuse University

Texas A&M University

Universidad Autónoma de Madrid

University of British Columbia

University of California, Berkeley

University of California, Santa Barbara

University of Colorado, Denver

University of Evansville

University of Florida

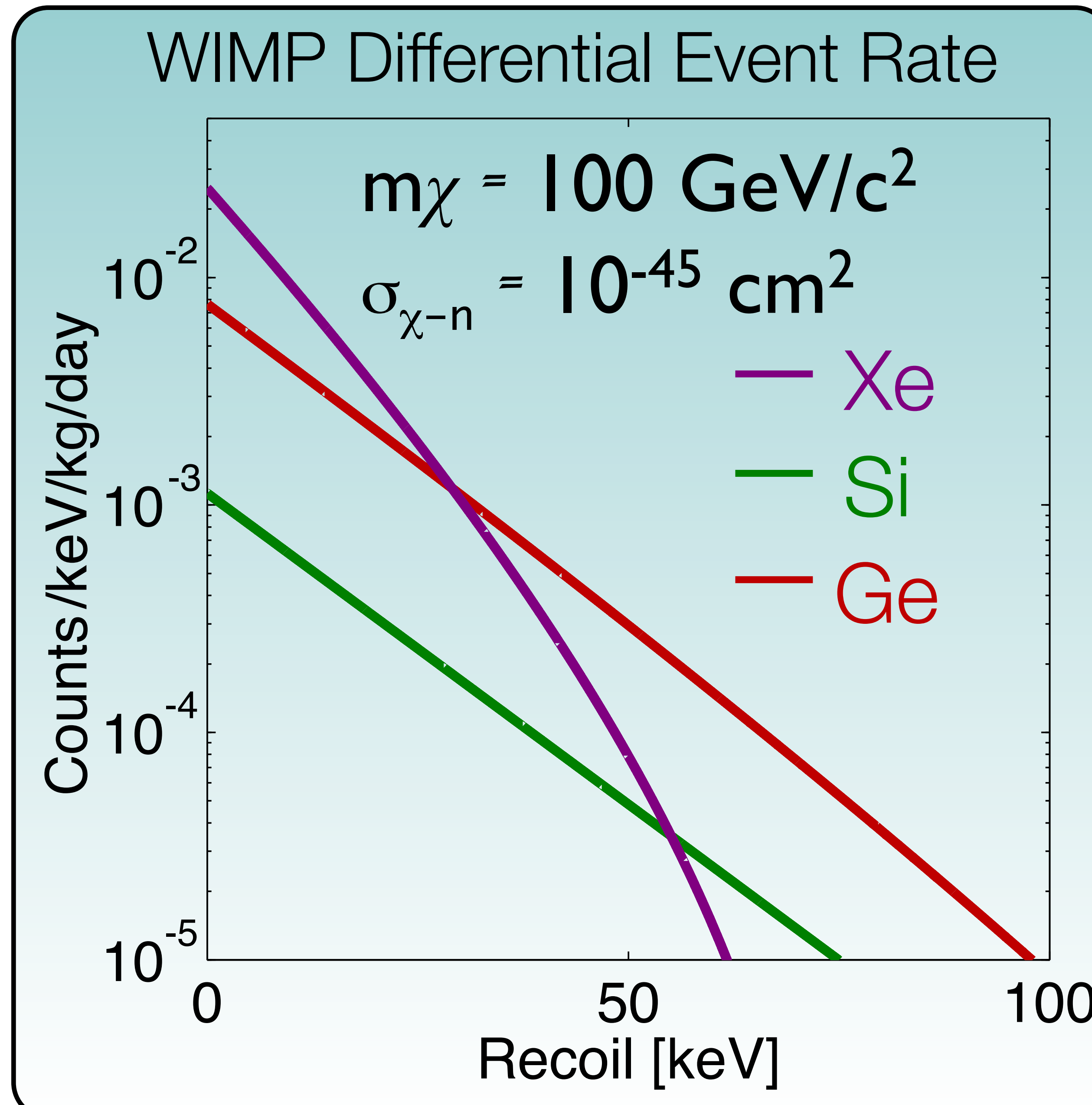
University of Minnesota

The Idiot's Guide to Dark Matter Detection

- Step 1: Make a detector out of a material with which the WIMPs can interact (in this case Ge).
- Step 2: Figure out how to determine when an interaction occurs.
- Step 3: Sit back and count the events. Compare with theoretical predictions, publish paper, give talks.

The Slightly More Realistic Guide to Dark Matter Detection

- Step 1: Make a detector out of a material with which the WIMPs can interact (in this case Ge).
- Step 2: Figure out how to determine when an interaction occurs.
    - Step 2.5: Figure out how to measure some kinematical property of the interaction, i.e. recoil energy.
- Step 3: Sit back and obtain a spectrum. Make a more quantitative comparison with theoretical predictions, publish paper, give talks.



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The Real World Guide to Dark Matter Detection

- Step 1: Make a detector out of a material with which the WIMPs can interact (in this case Ge).
- Step 2: Figure out how to determine when an interaction occurs.
    - Step 2.5: Figure out how to measure some kinematical property of the interaction, i.e. recoil energy.
- Step 3: Realize that for every potential WIMP interaction there are $\gtrsim 10^{13}$ events from unwanted background sources.
- Step 4: Take a deep breath and think real hard about your career choice.

This is what makes dark matter searches very hard!

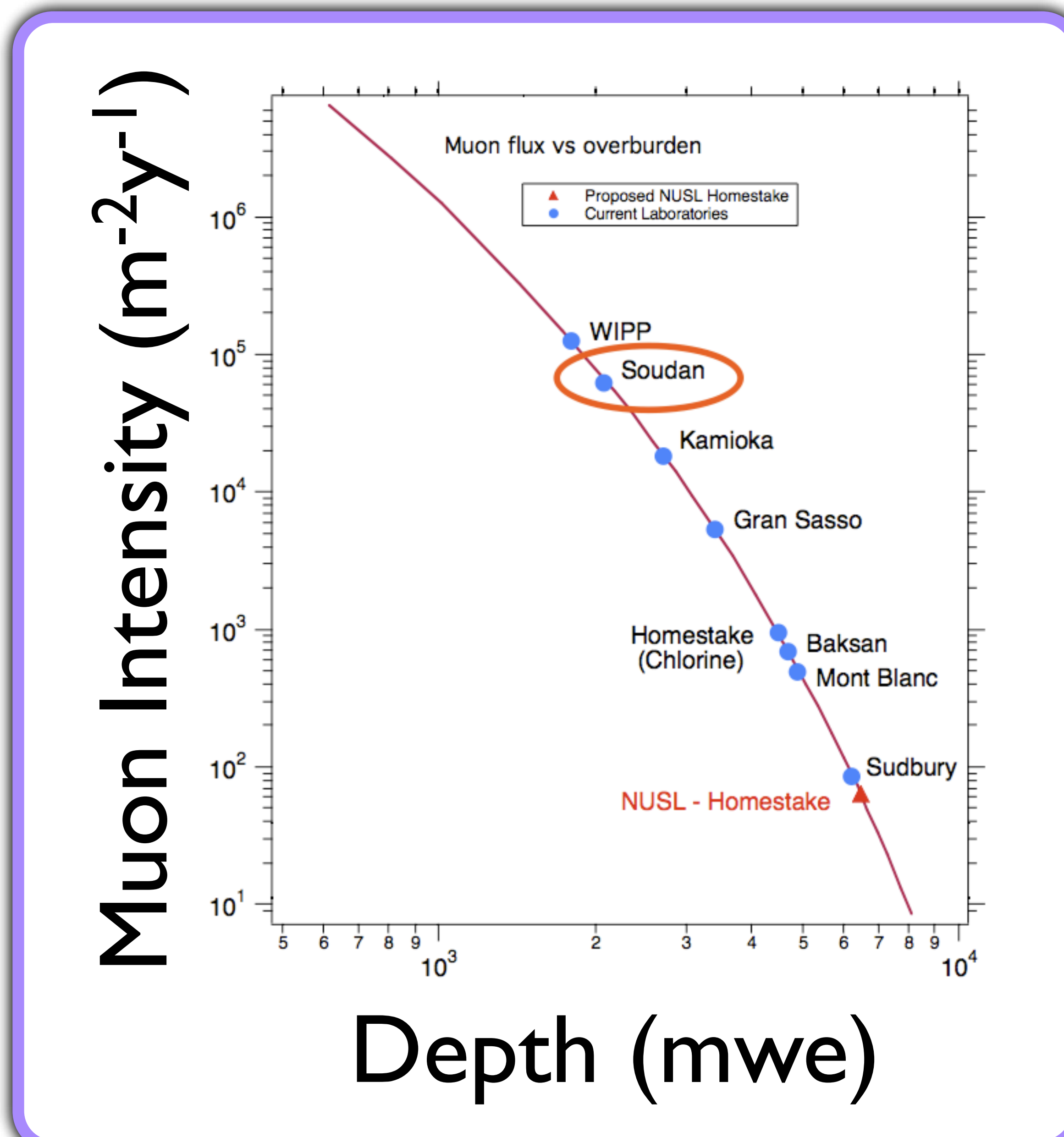
Sources of & Remedies for the Background

- The sources of background we face:
  - Radioactive decays from naturally abundant radio-isotopes
  - Radioactive decays from “created” radio-isotopes (i.e. activated materials)
  - Interactions from Cosmic rays and their induced daughter particles
- The solutions we can implement:
  - Work with the cleanest (most radio-pure) materials you can get to minimize the rate of backgrounds from within the detector and its closest components
  - Install passive (active) shielding to suppress (detect) background from the surroundings of the experiment
  - Minimize the fabrication & handling time of the detectors, to suppress activation due to surface cosmic ray fluxes
  - Go underground. the only way to escape the cosmic ray flux and its associated cosmogenic backgrounds

CDMS Observation Strategy

1. Try to suppress all backgrounds

780 m rock	(2090 m water equiv.)
Active veto	muon scintillator
Polyethylene	neutron moderation
Lead	shields gammas
Ancient Lead	shields ^{210}Pb betas
Polyethylene	shields ancient lead
Radiopure Copper inner can	
Radiopure Ge “target”	



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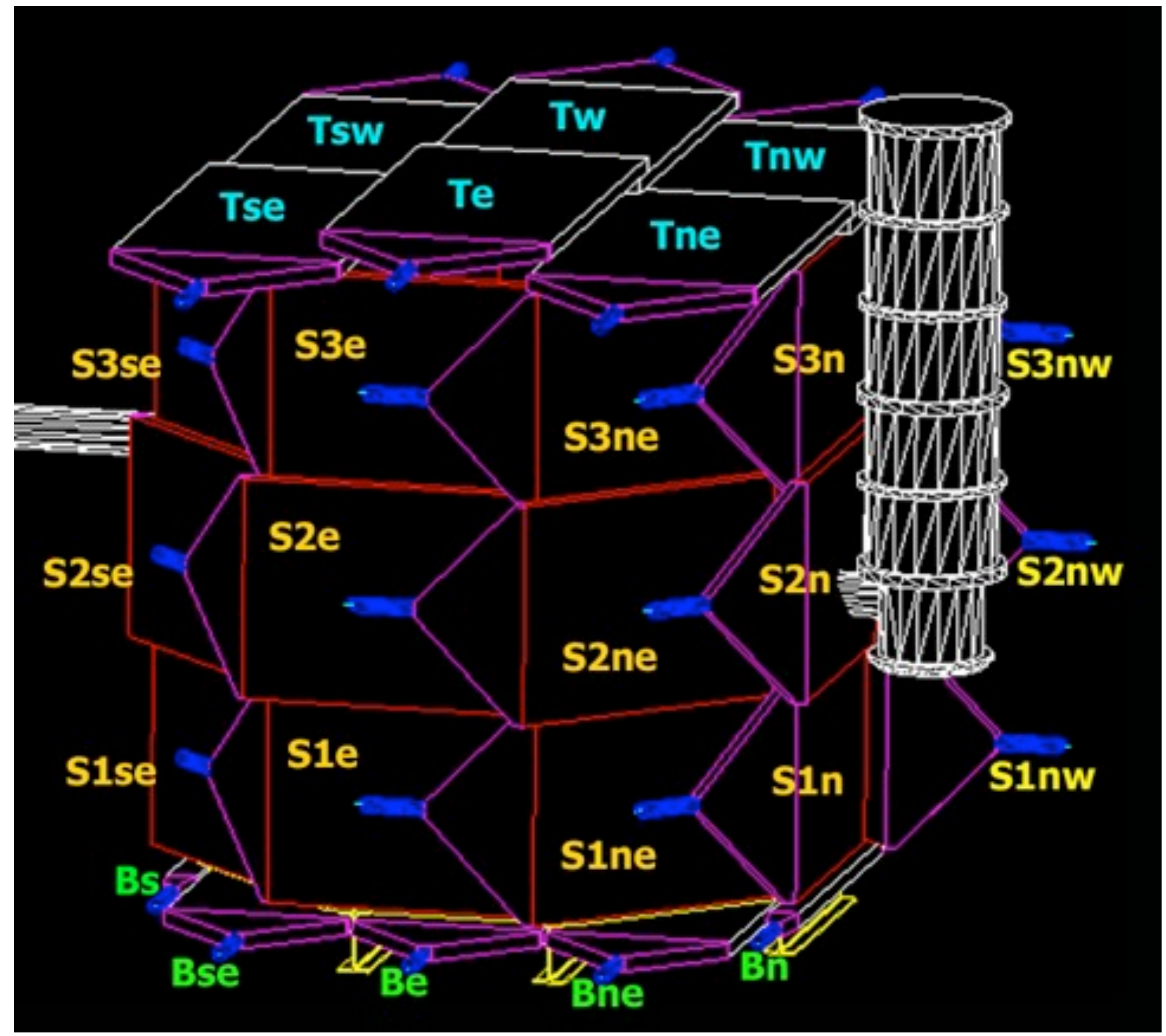

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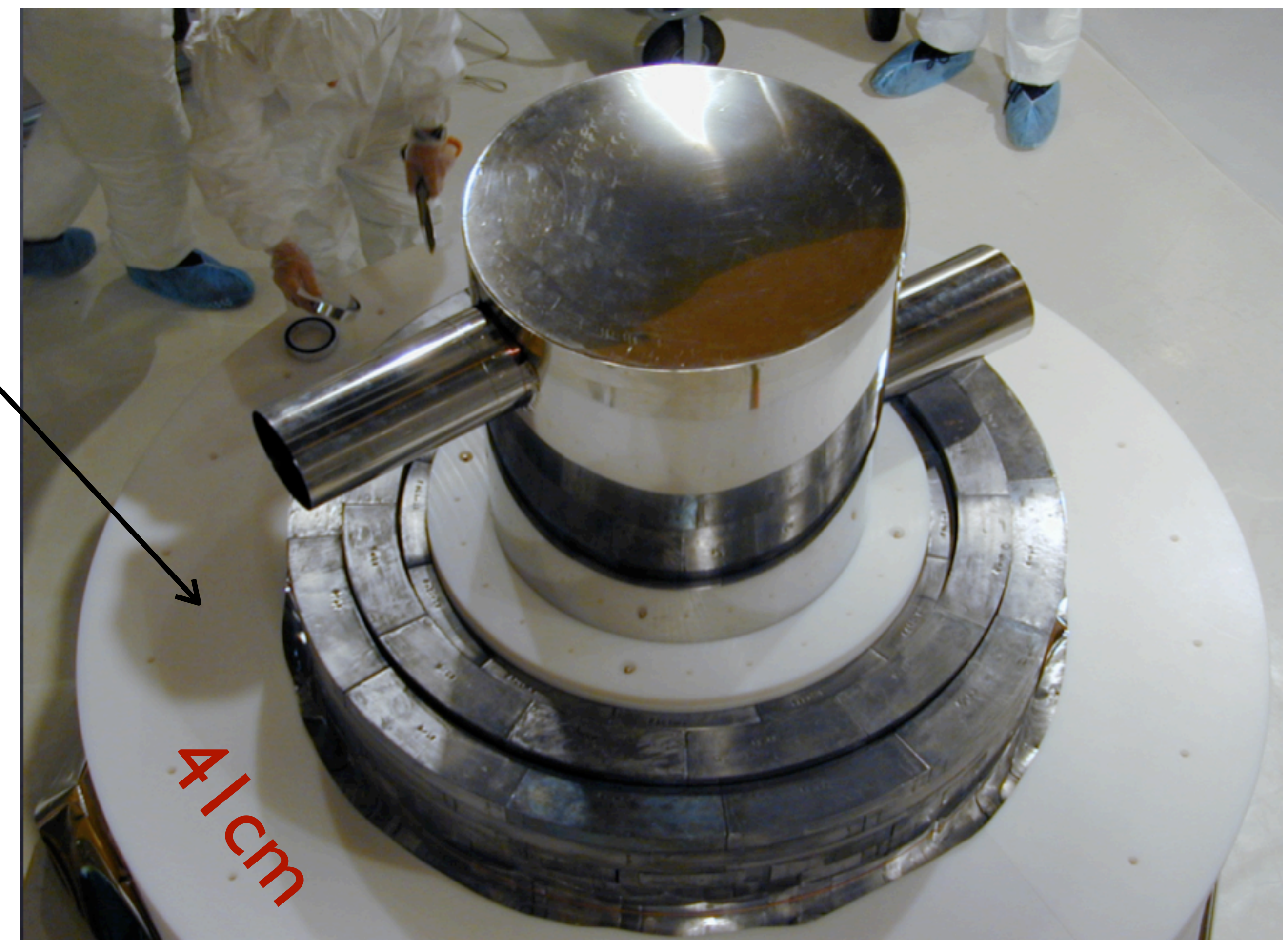

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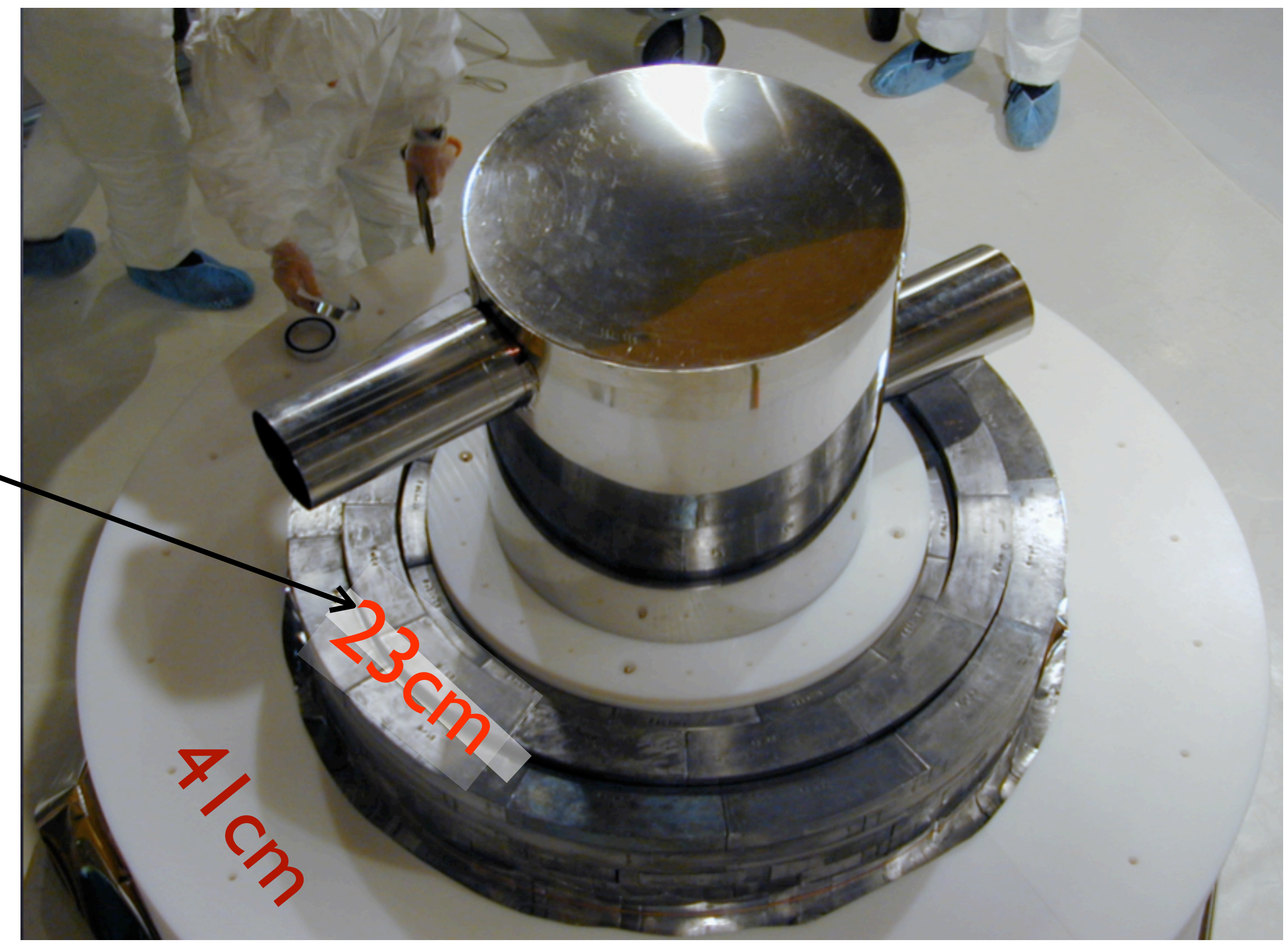

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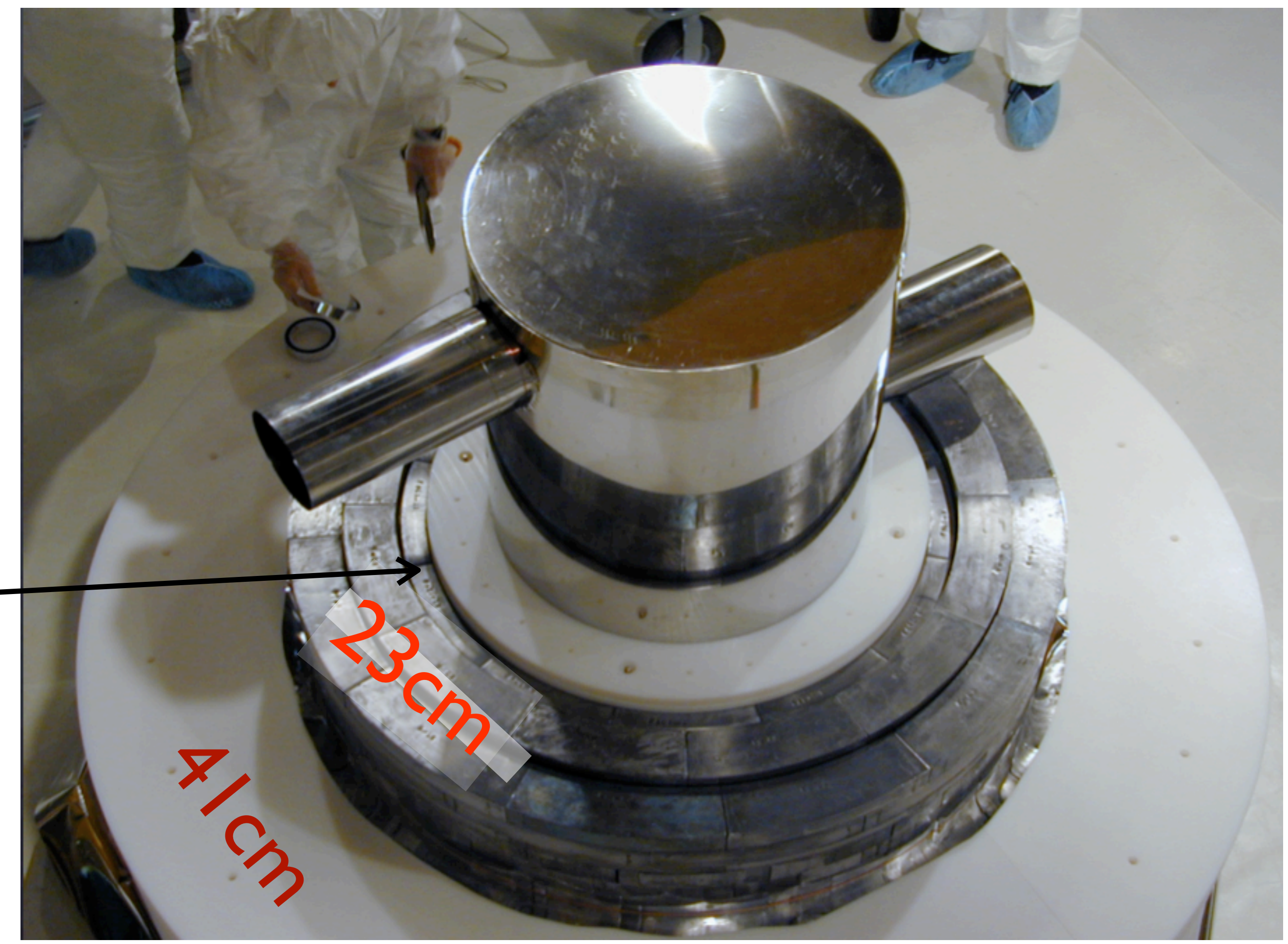

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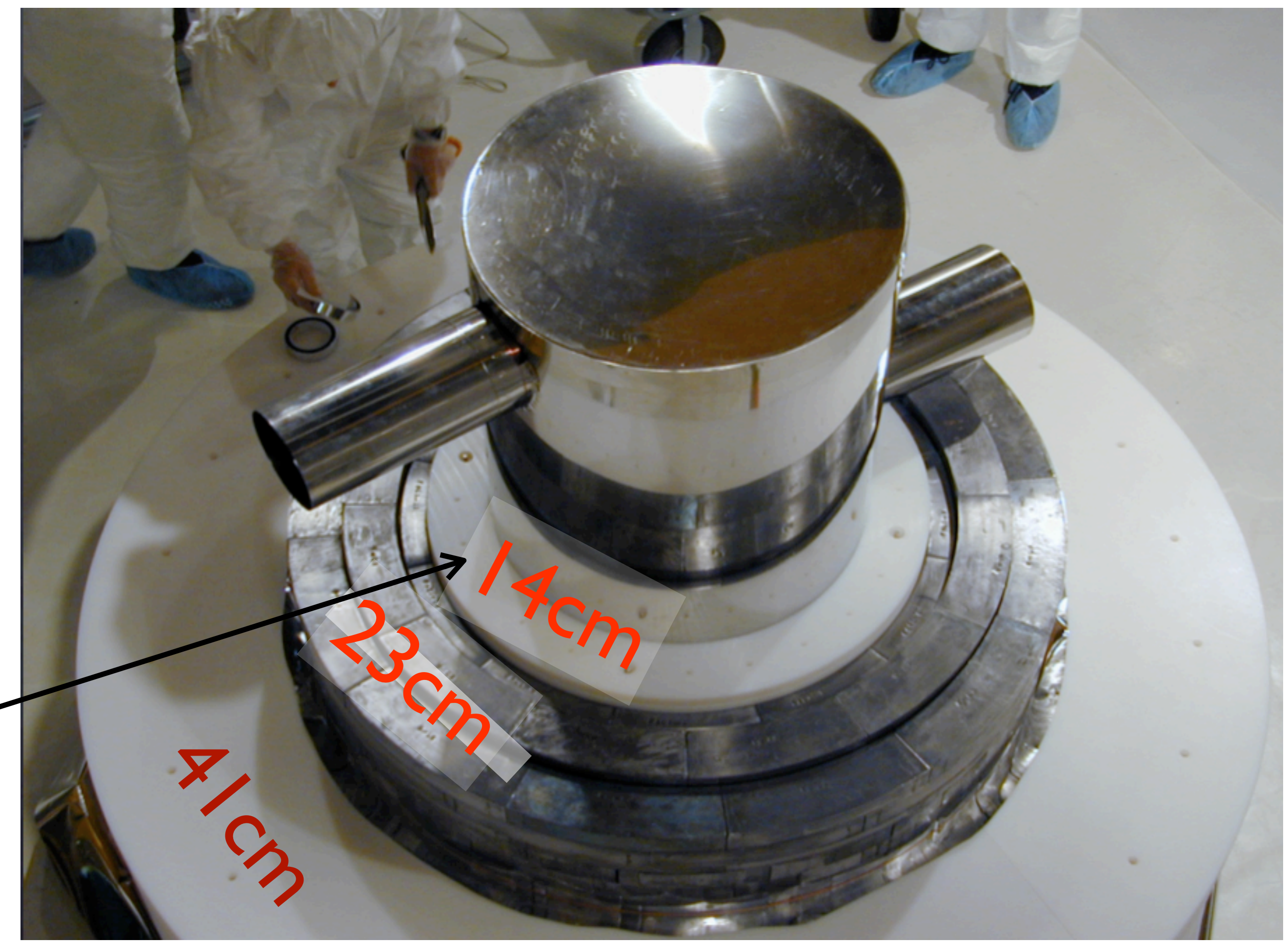

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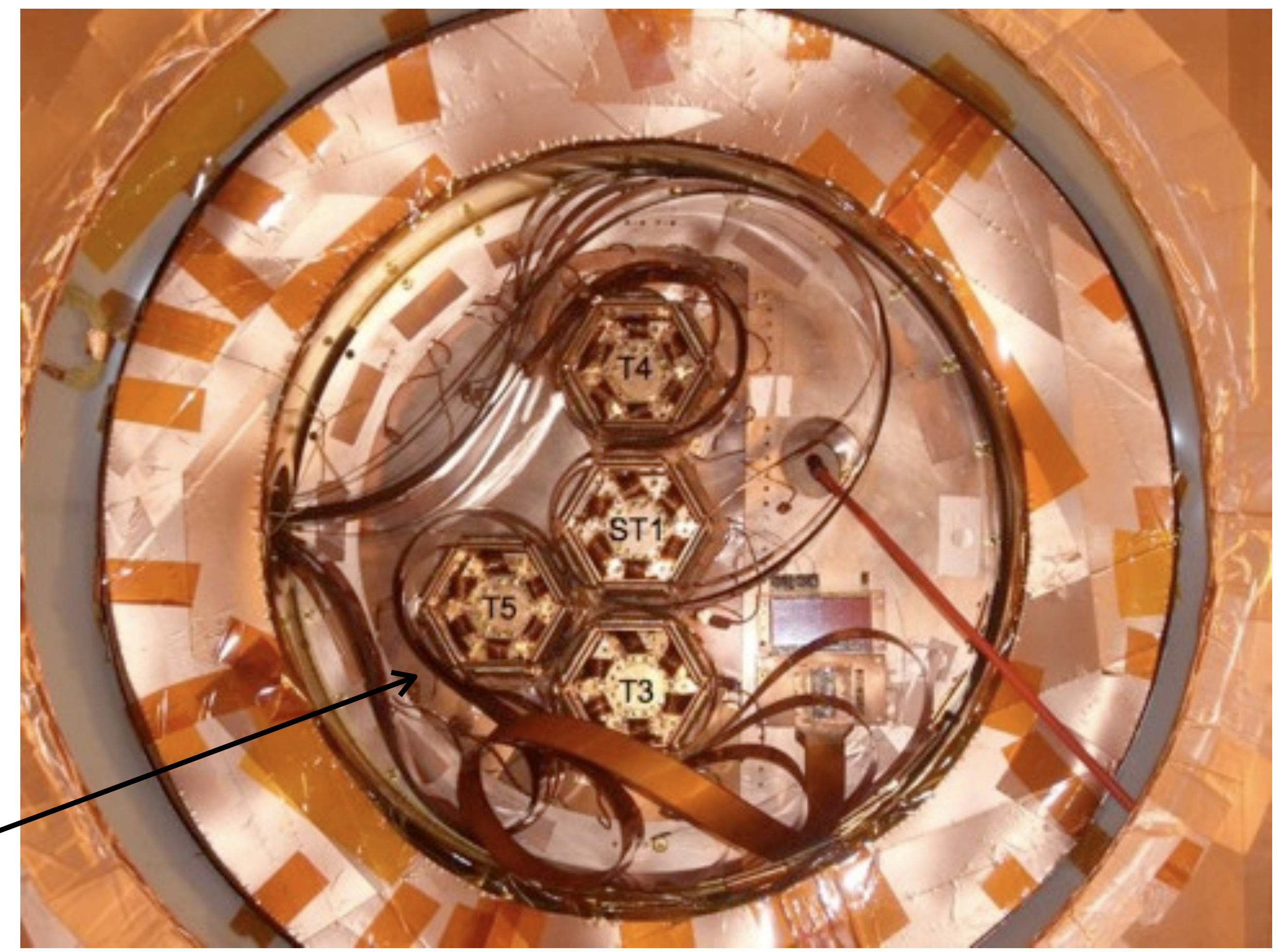

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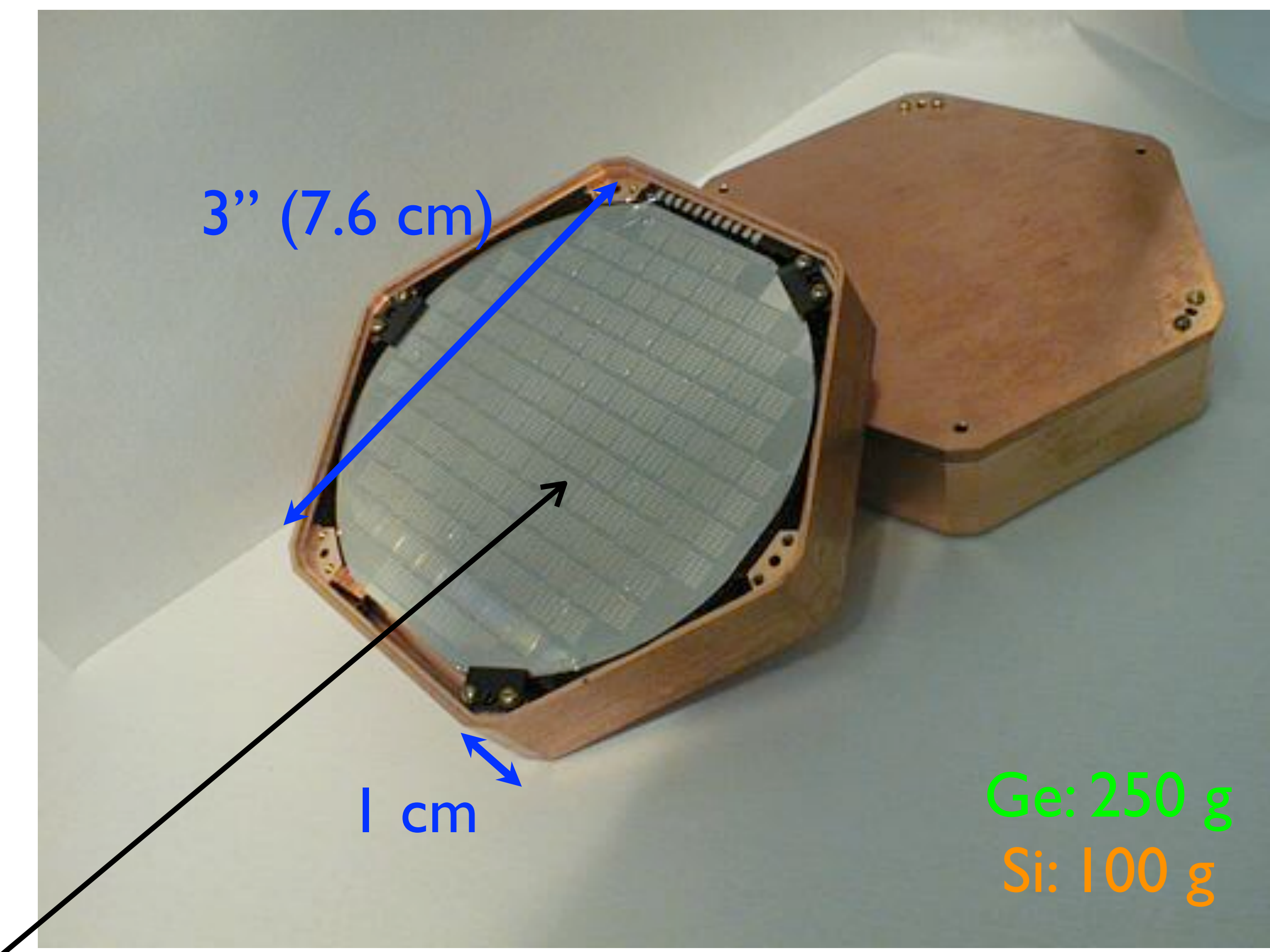


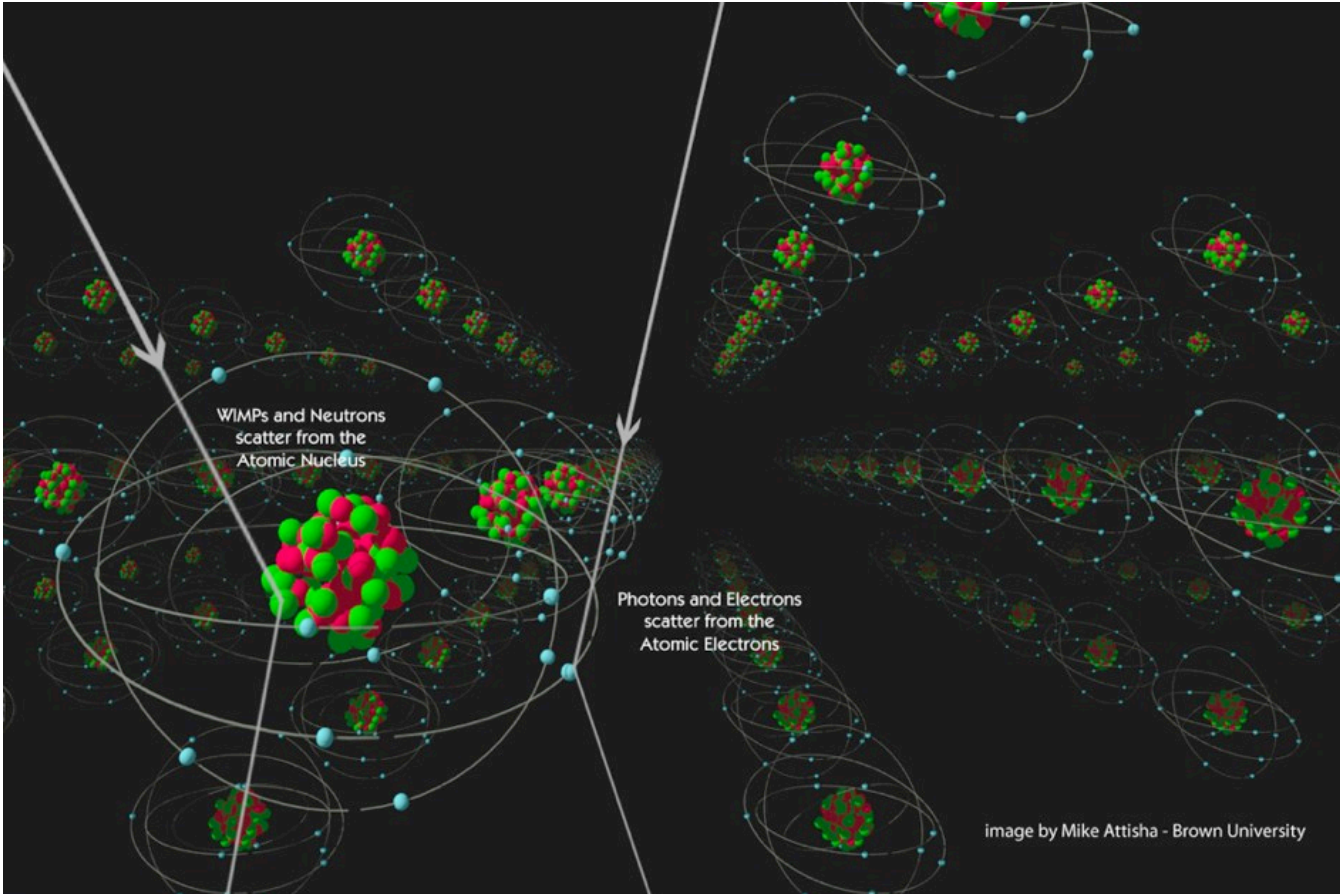
CDMS Observation Strategy

2. Identify the remaining backgrounds

- What is left after all that is done is a rate of ~ 1 event/kg/keV/day above a few keV hitting the detector.

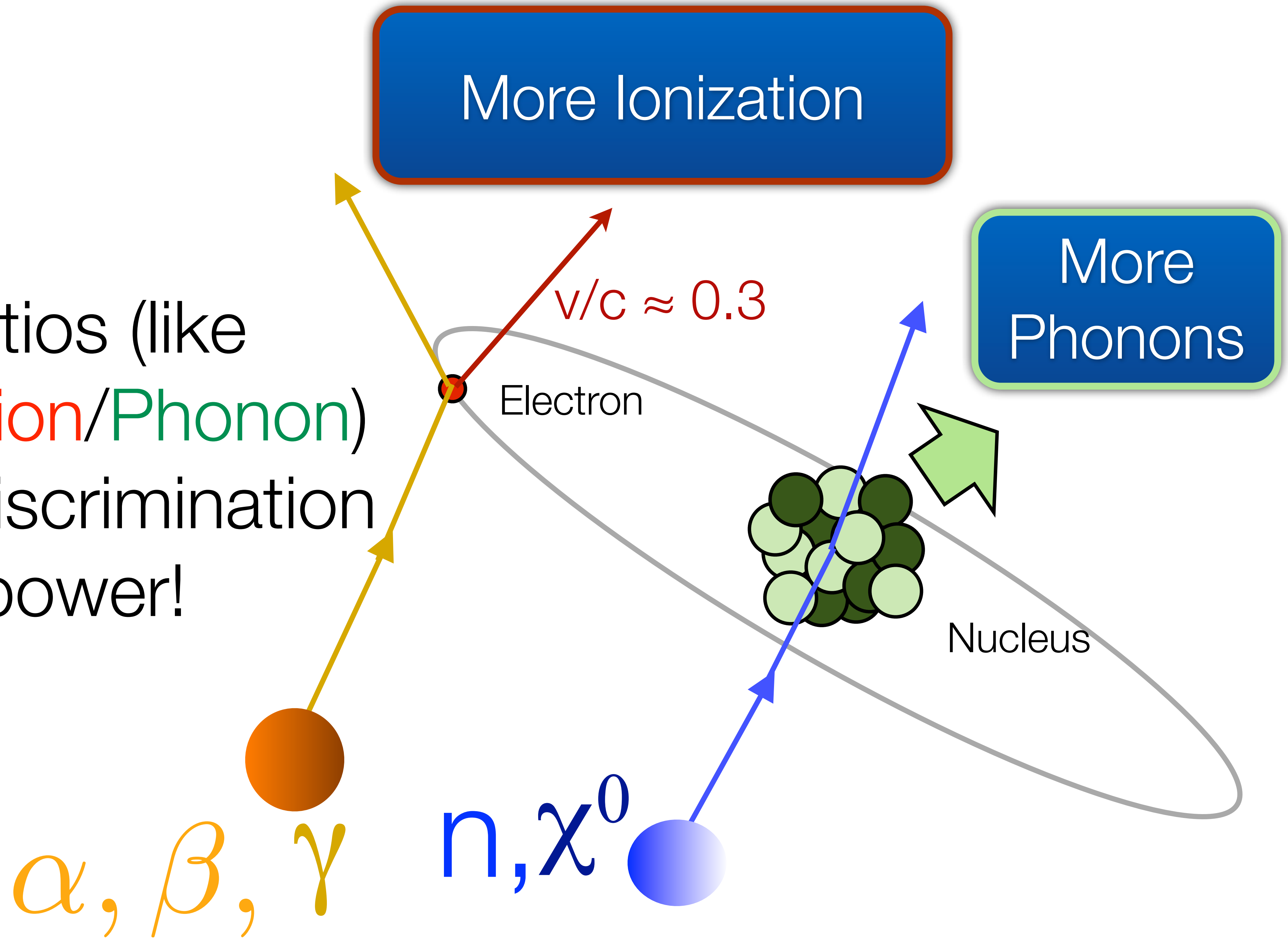
- The ability to perform even-by-event discrimination (i.e. Particle ID in the language of collider physics) allows us to extract a small WIMP signal from the remaining event.

- This requires a difference in the behavior of signal and background interactions.



Detector Physics to the Rescue

Even-by-event discrimination

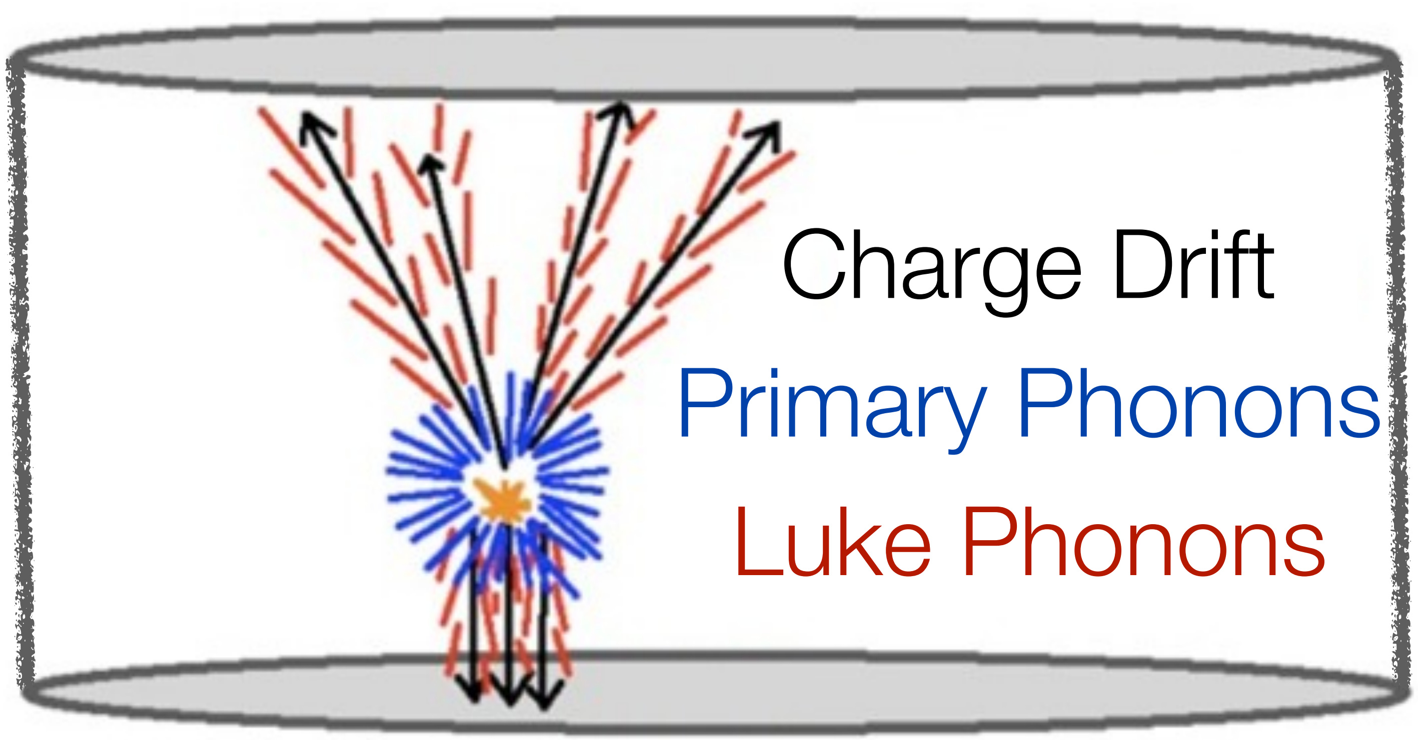


Ratios (like Ionization/Phonon) have discrimination power!

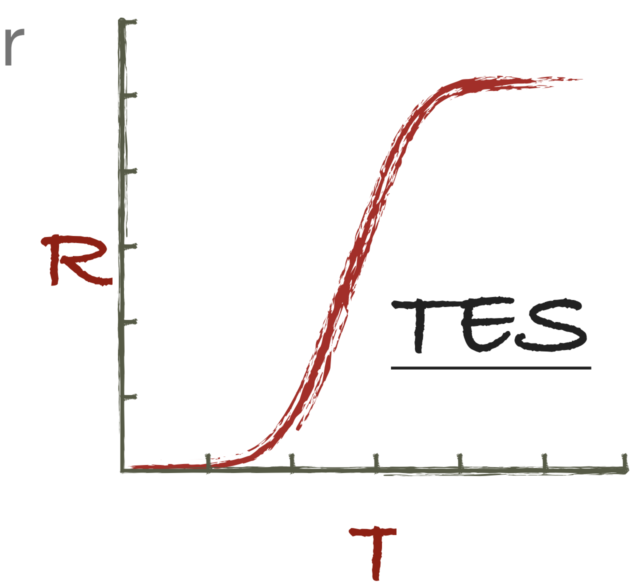
The CDMS Phonon & Ionization Signals

- A particle interaction in the detector creates a population of phonons and a population of electrons & holes.

- An electric field of a few V/cm across the detector causes the electrons (holes) to flow to the electrodes at the top (bottom) where they are measured with a charge amplifier.



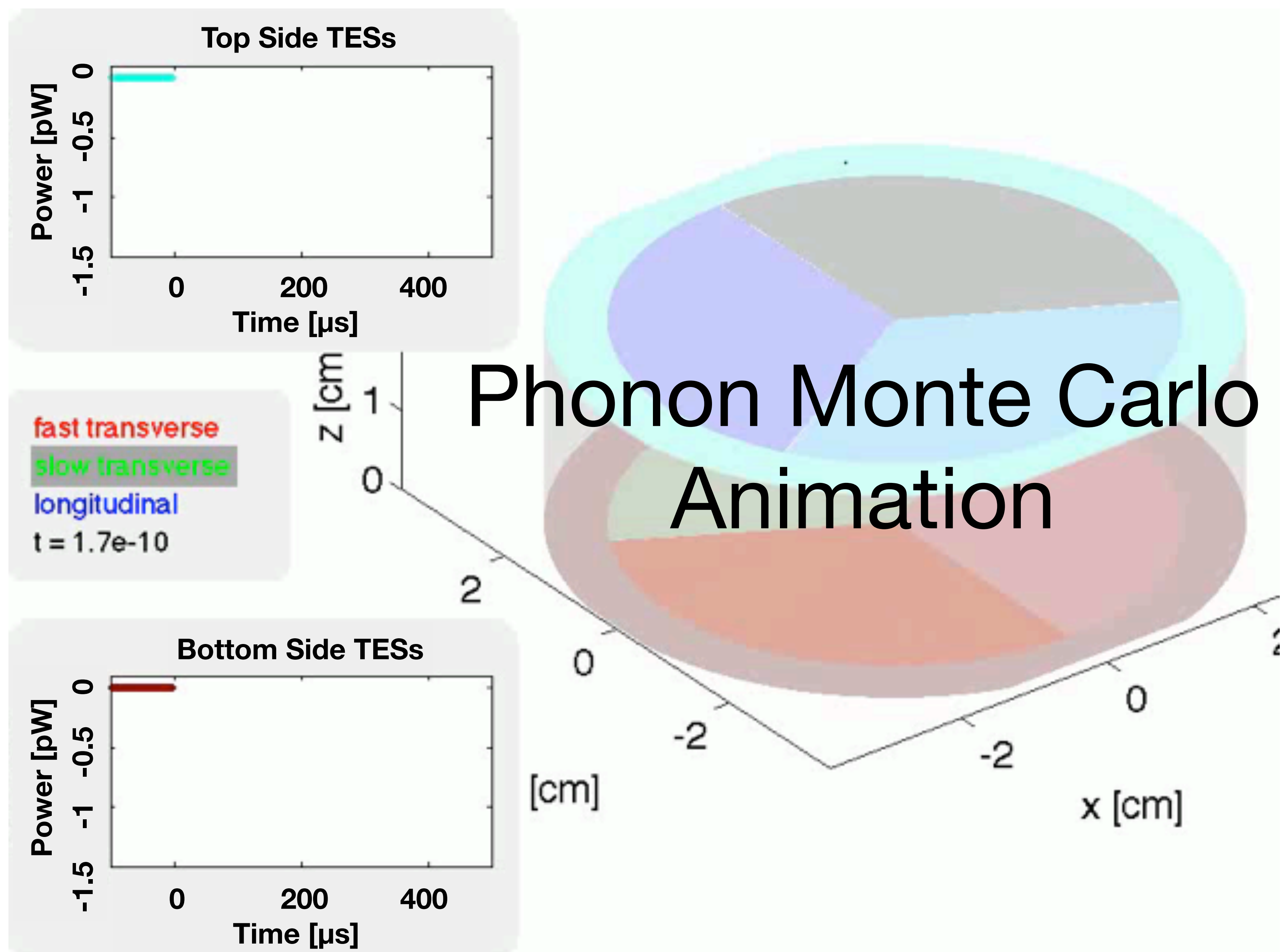
- The phonons propagate to the surface where they are measured with a Transition Edge Sensor



Event Discrimination and Energy Calibration

- A detailed understanding of the condensed matter processes is needed to fully understand the detector response and quantify the performance of the event discrimination cuts

SuperCDMS Detector Monte Carlo



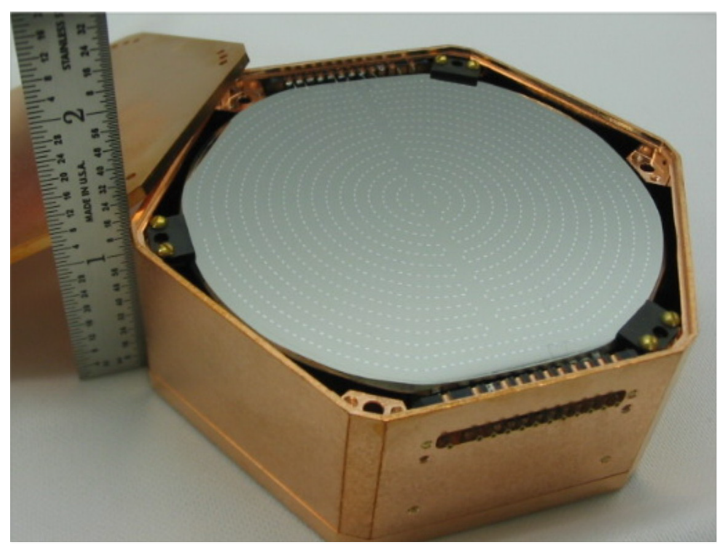
The Evolving Detector - Mass

- As the experiment explores regions of lower WIMP-proton cross-section the mass of the detectors increases to keep improving to allow the necessary detector payload/exposure to be reached.

A CDMS II ZIP

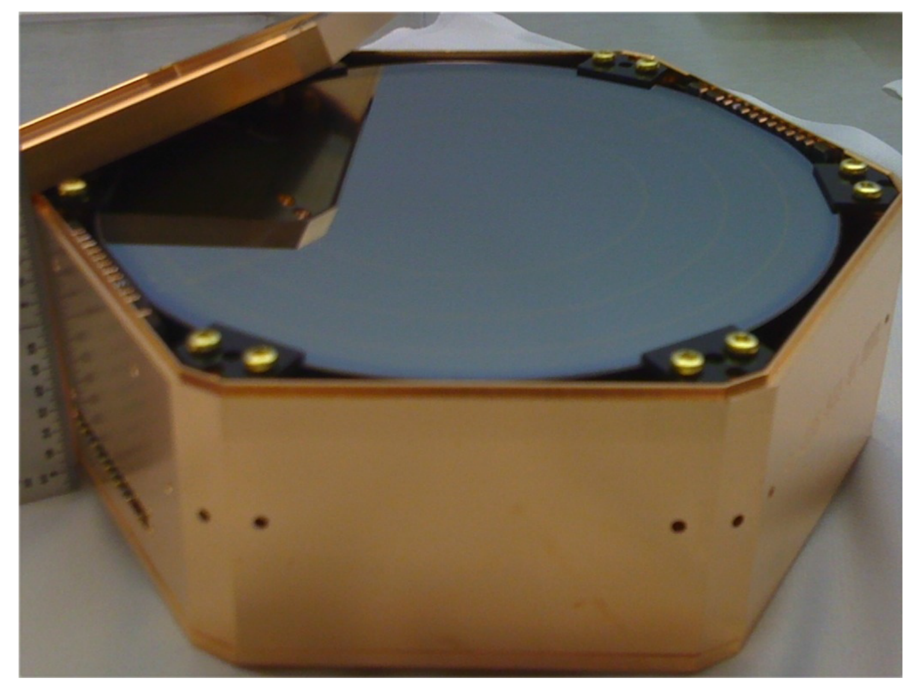
Single-sided
1 cm thick x 3”diameter
250 g mass

A SuperCDMS @ Soudan iZIP



Double-sided
2.5 cm thick x 3”diameter
620 g mass

A SuperCDMS @ SNOLAB iZIP

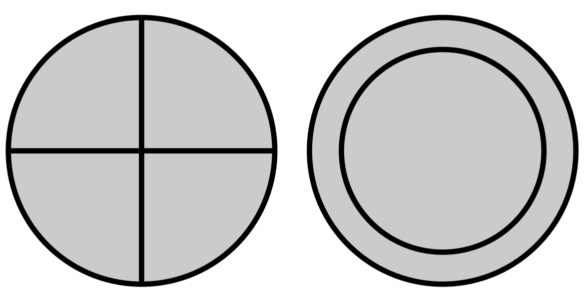


Double-sided
3.3 cm thick x 4”diameter
1.38 kg mass

The Evolving Detector - Sensor Design

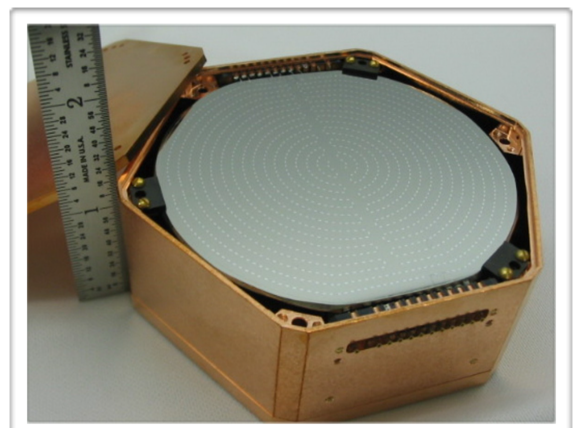
- As the experiment explores regions of lower WIMP-proton cross-section the design and performance of the detectors must keep improving to allow the necessary sensitivity to be reached.

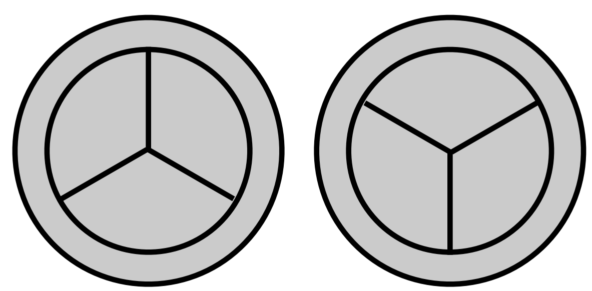
A CDMS II ZIP



4 phonon channels on one surface
2 charge channels on other surface
Deploy 5 Towers of 6 detectors each
Total mass ~ 7.5 kg

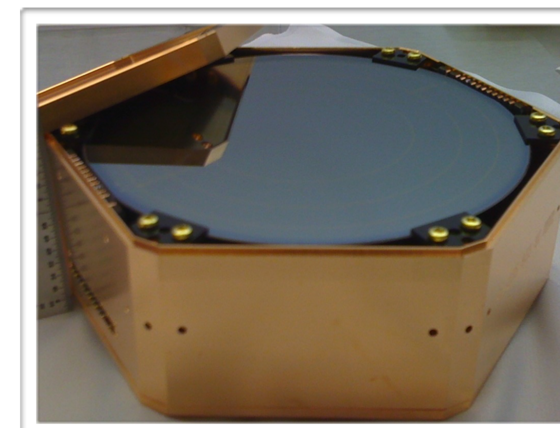
A SuperCDMS @ Soudan iZIP

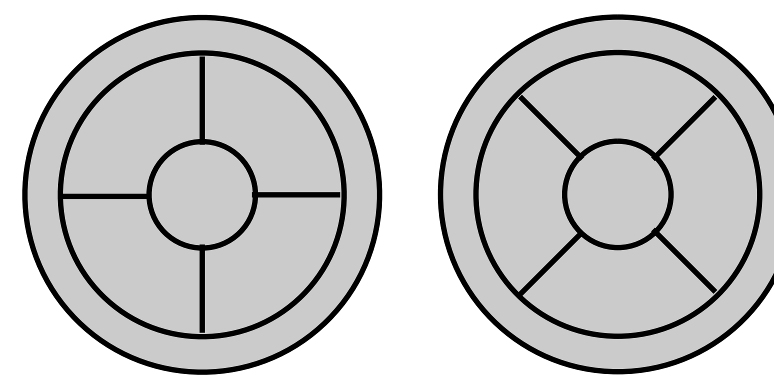




4 phonon & 2 charge channels on EACH surface
Deploy 5 Towers of 3 detectors each
Total mass ~ 9.3 kg

A SuperCDMS @ SNOLAB iZIP

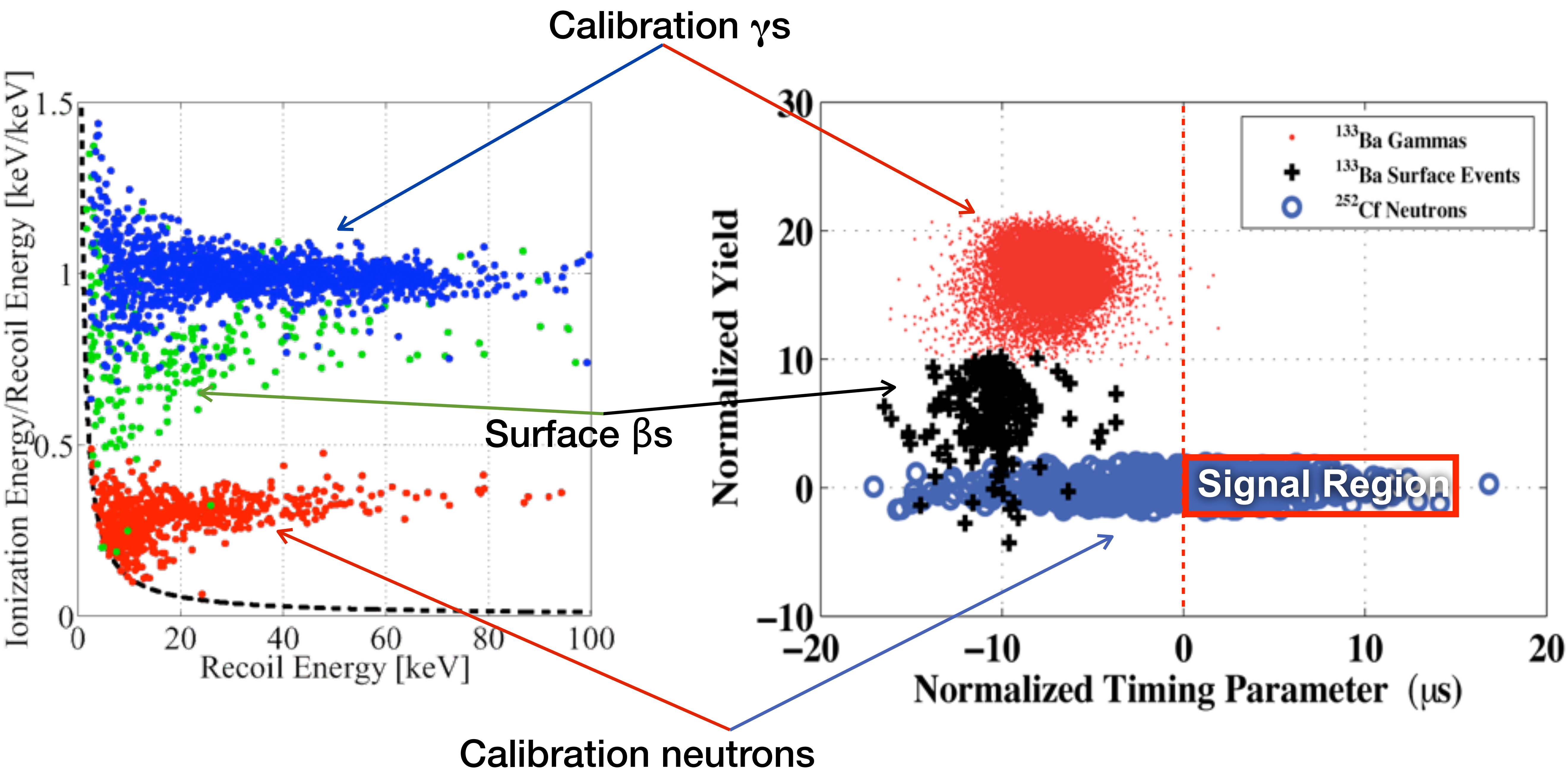




6 phonon & 2 charge channels on EACH surface
Deploy 24 Towers of 6 detectors each
Total mass ~ 199 kg

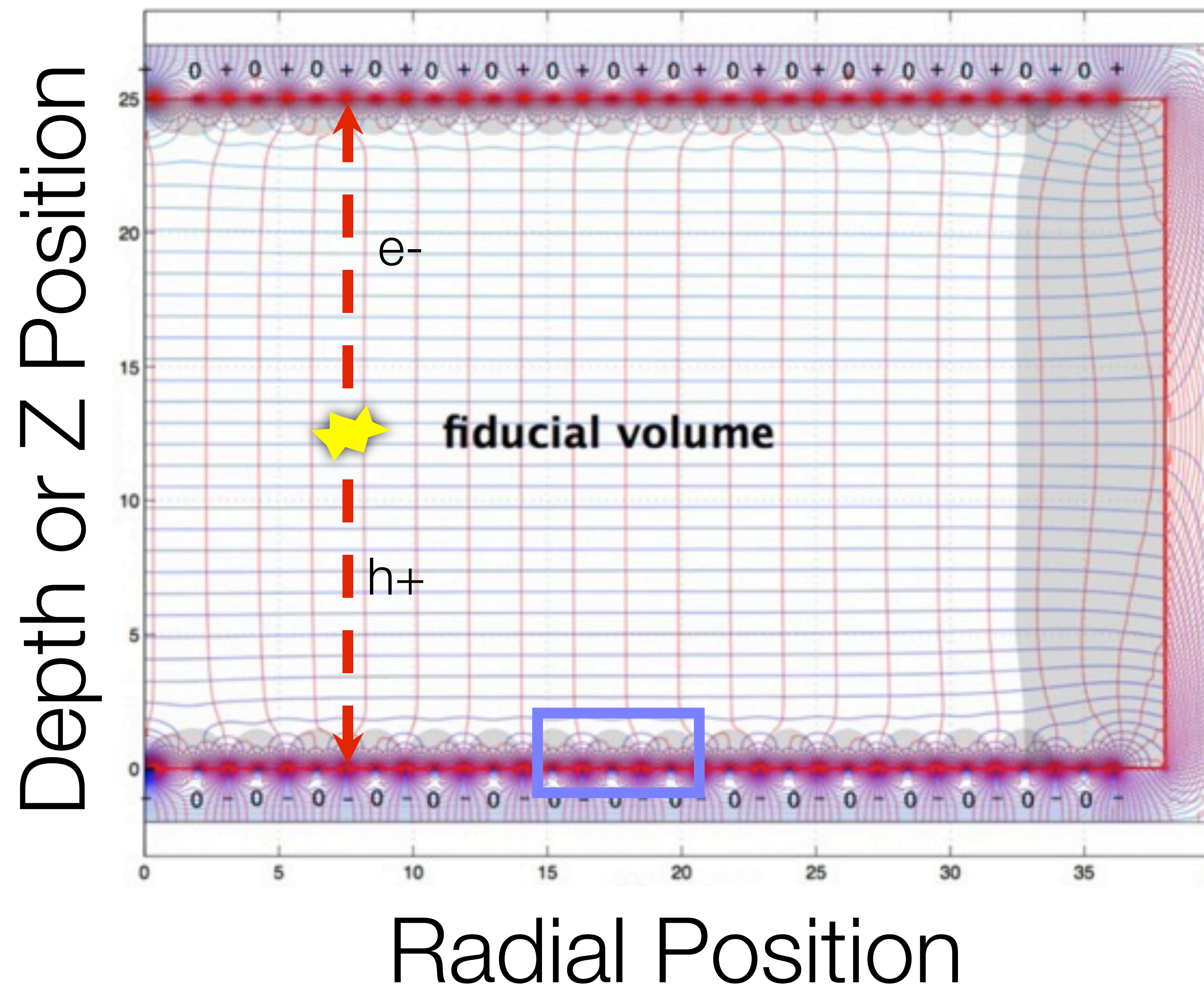
Electron Recoil Rejection in CDMS II

- Using the ionization yield and phonon timing information a electron recoil rejection of better than 10^{-6} was achieved.



The New SuperCDMS Detectors: iZIP

- Interactions in the bulk of the detector create charge signals on both (top/bottom) sides {just like CDMS II}.



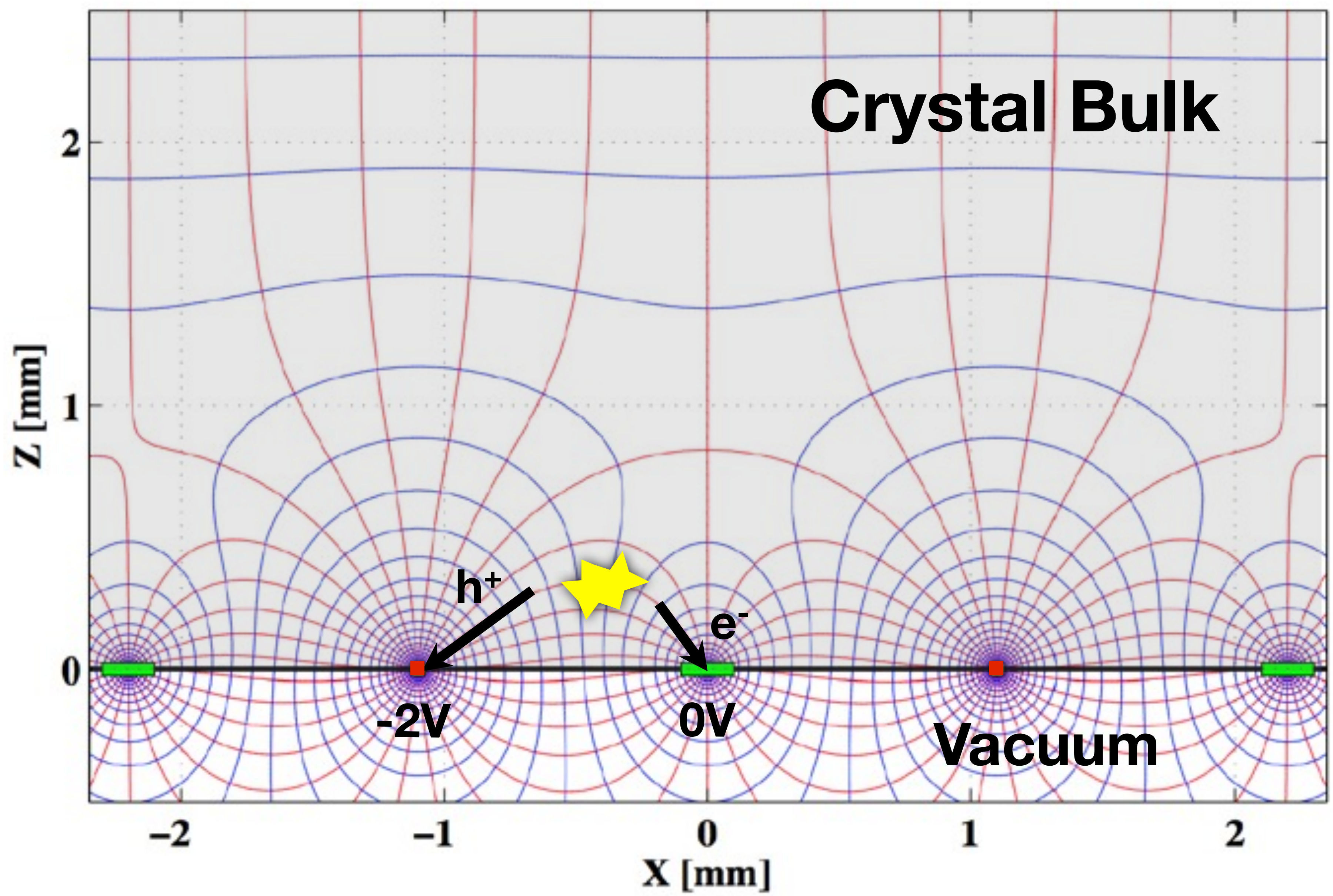
Electron Recoil Rejection in iZIPs

Surface Event Rejection Using the Charge Channels

- But, when an interaction occurs near the surface, a charge signal appears on one side only.

Phonon Sensors

Charge Sensors

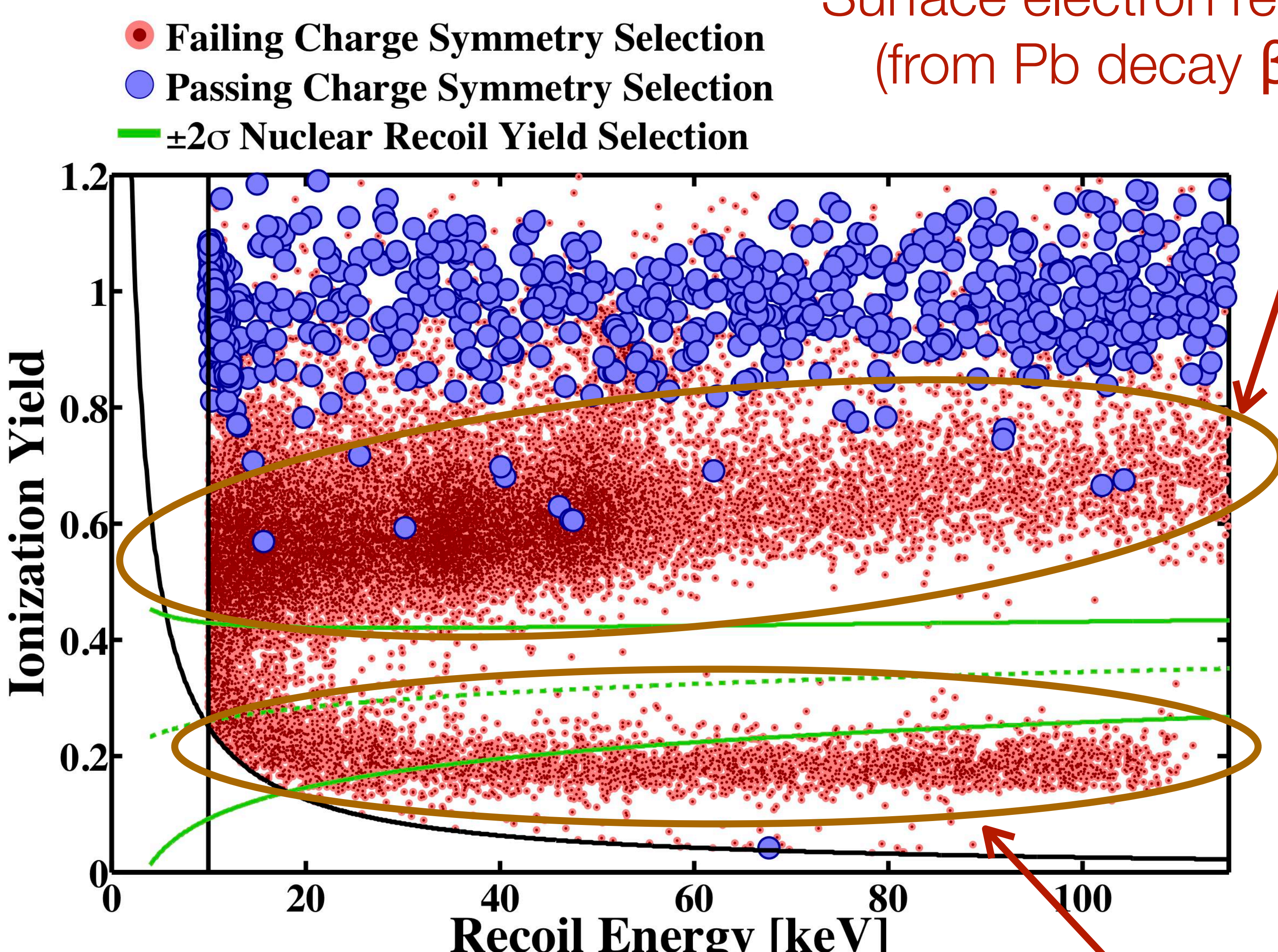


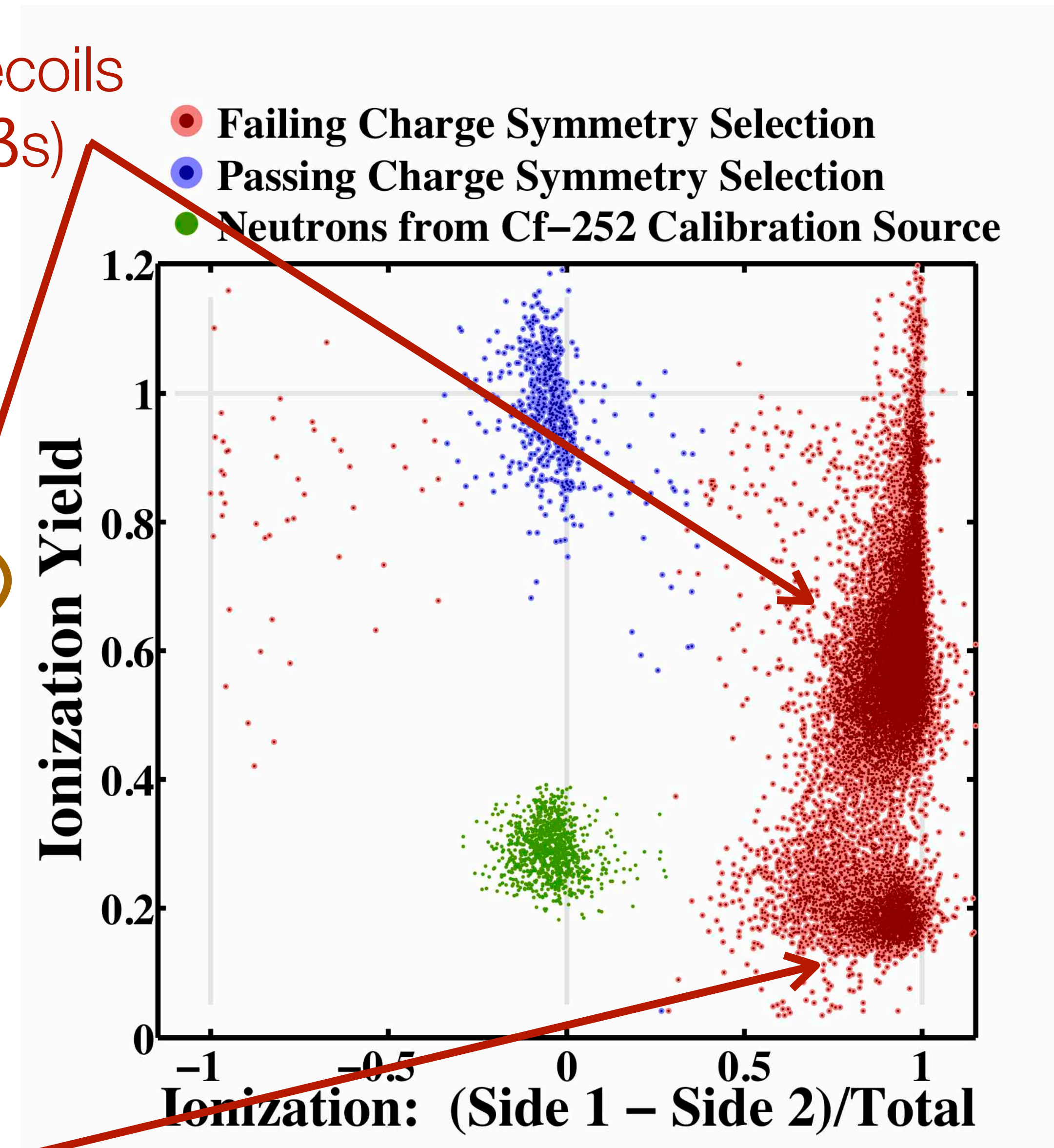
<0.005 surface events over the entire exposure of the experiment.

Performance of the Surface Event Rejection

Since March 2012, 80,000 events (65000 betas & 15000 Pb recoils) were collected during the current Soudan run. Using information only from the charge channel we have a demonstrated rejection of < 2.9×10^{-5} with a 65% cut efficiency.

Surface electron recoils (from Pb decay βs)

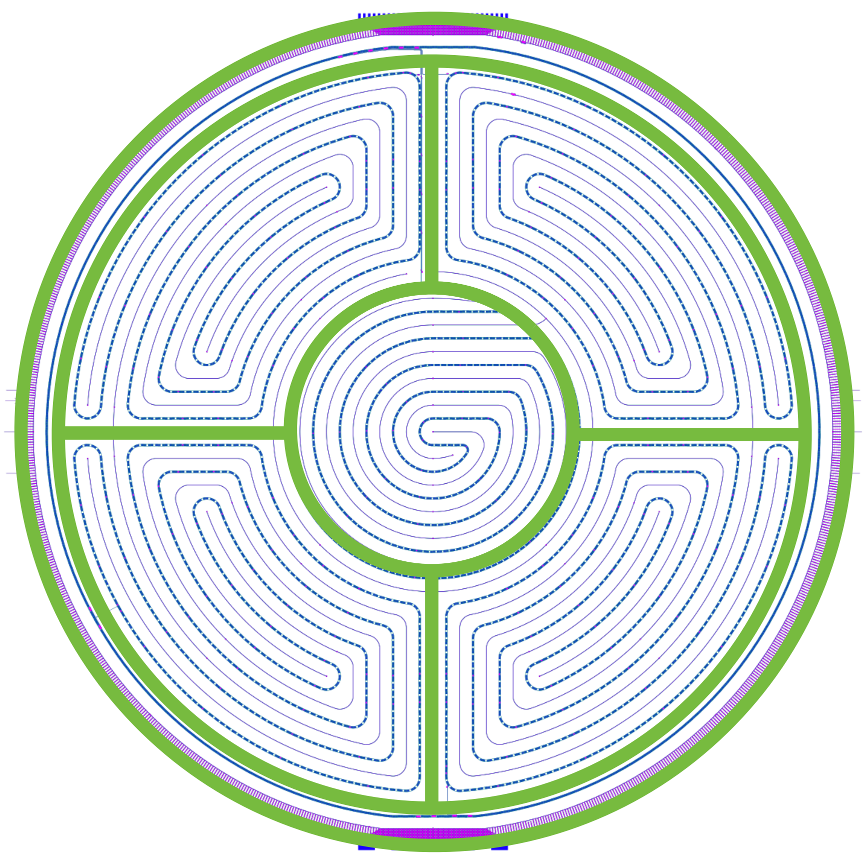


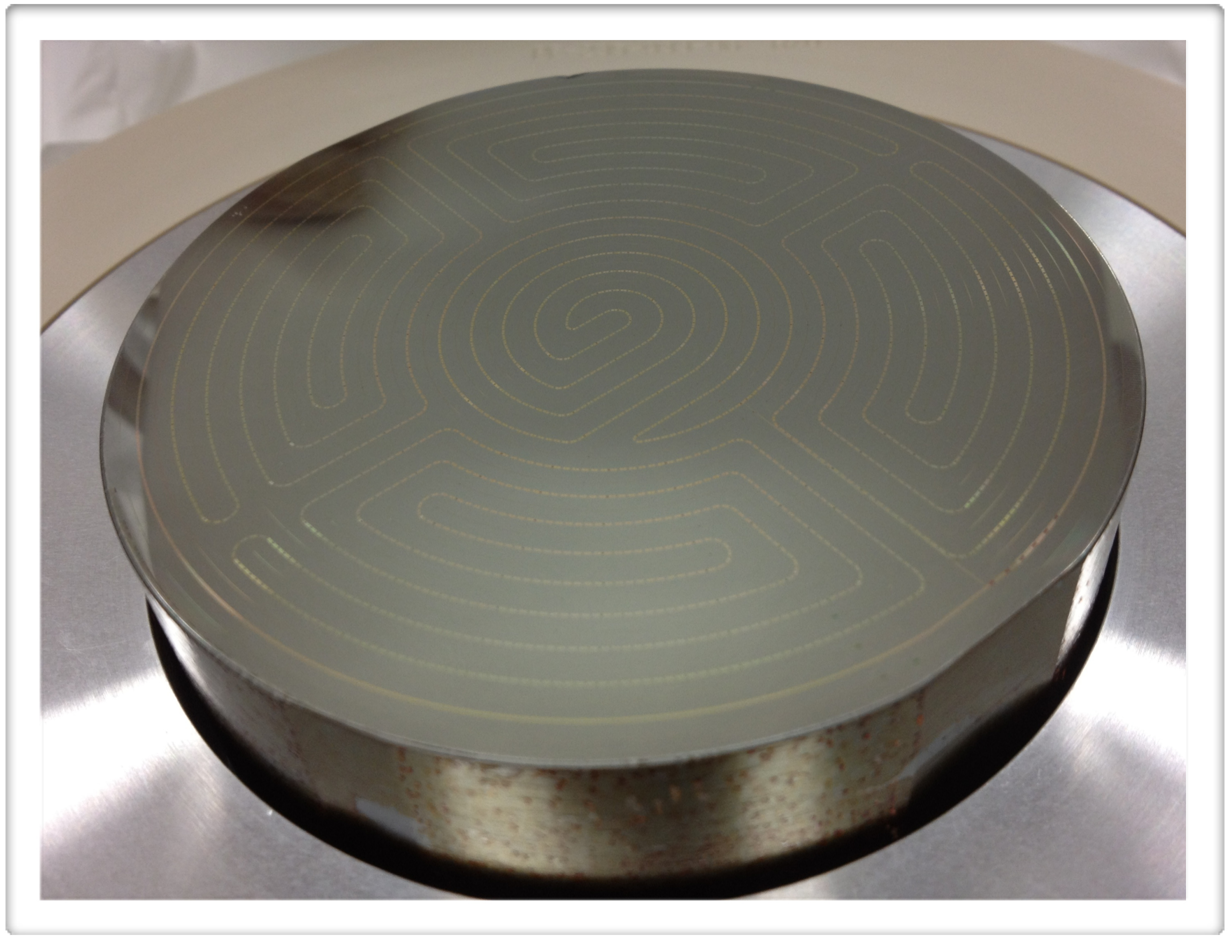


^{206}Pb recoils

The SuperCDMS@SNOLAB iZIP

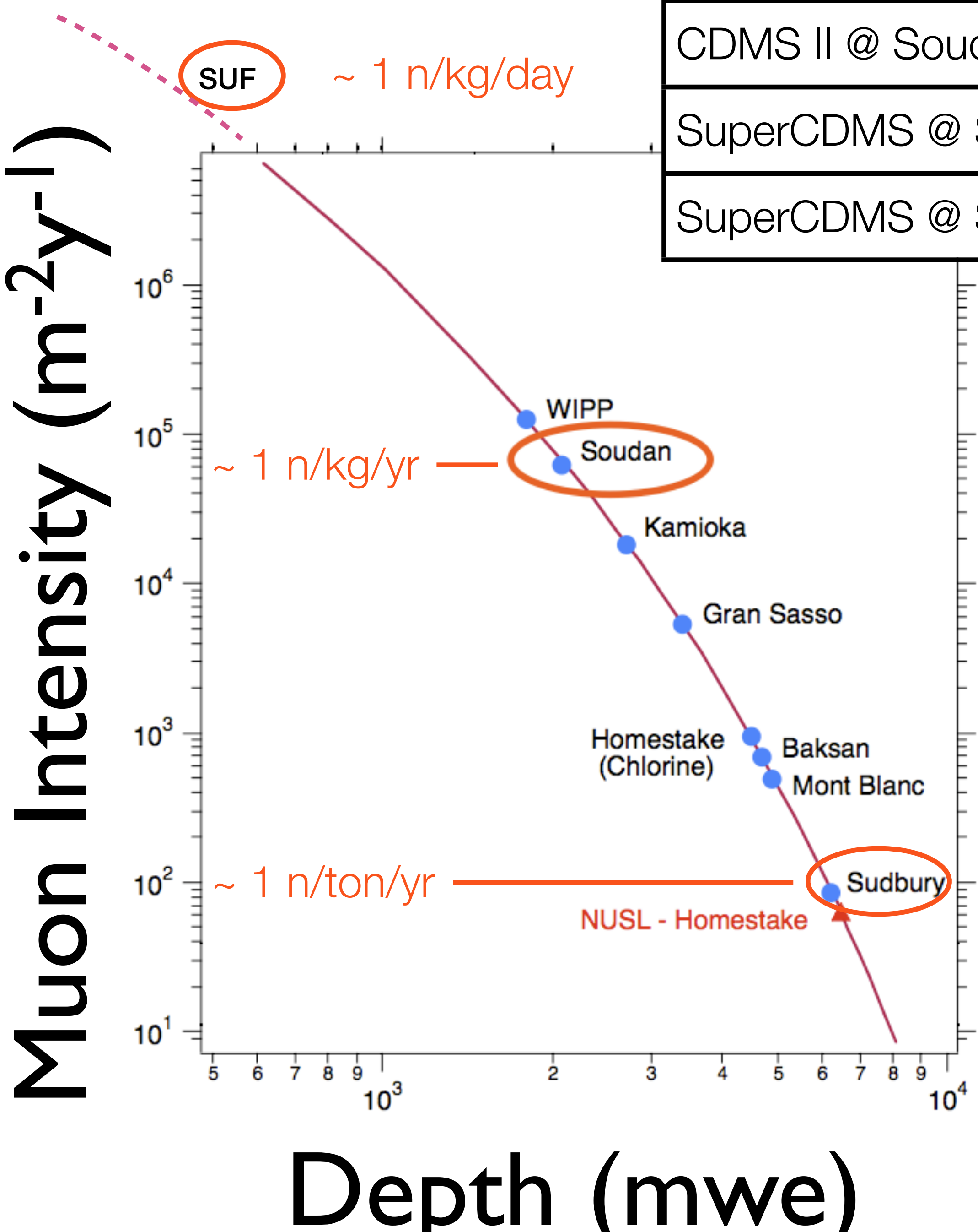
- The first fully patterned 4” detector has been fabricated and is currently being tested.





Background Rejection keeps pace with Exposure

Experiment	Net Exposure	Cosmogenic Neutrons	Radiogenic Neutrons	Surface Events	Fiducial Volume
CDMS I @ SUF	28 kg-d	18		2	
CDMS II @ Soudan	1 kg-y	0.01	0.07	1.2	37%
SuperCDMS @ Soudan	6 kg-y	0.07	0.34	0.005	68%
SuperCDMS @ SNOLAB	385 kg-y	0.03	0.1	< 0.24	73%

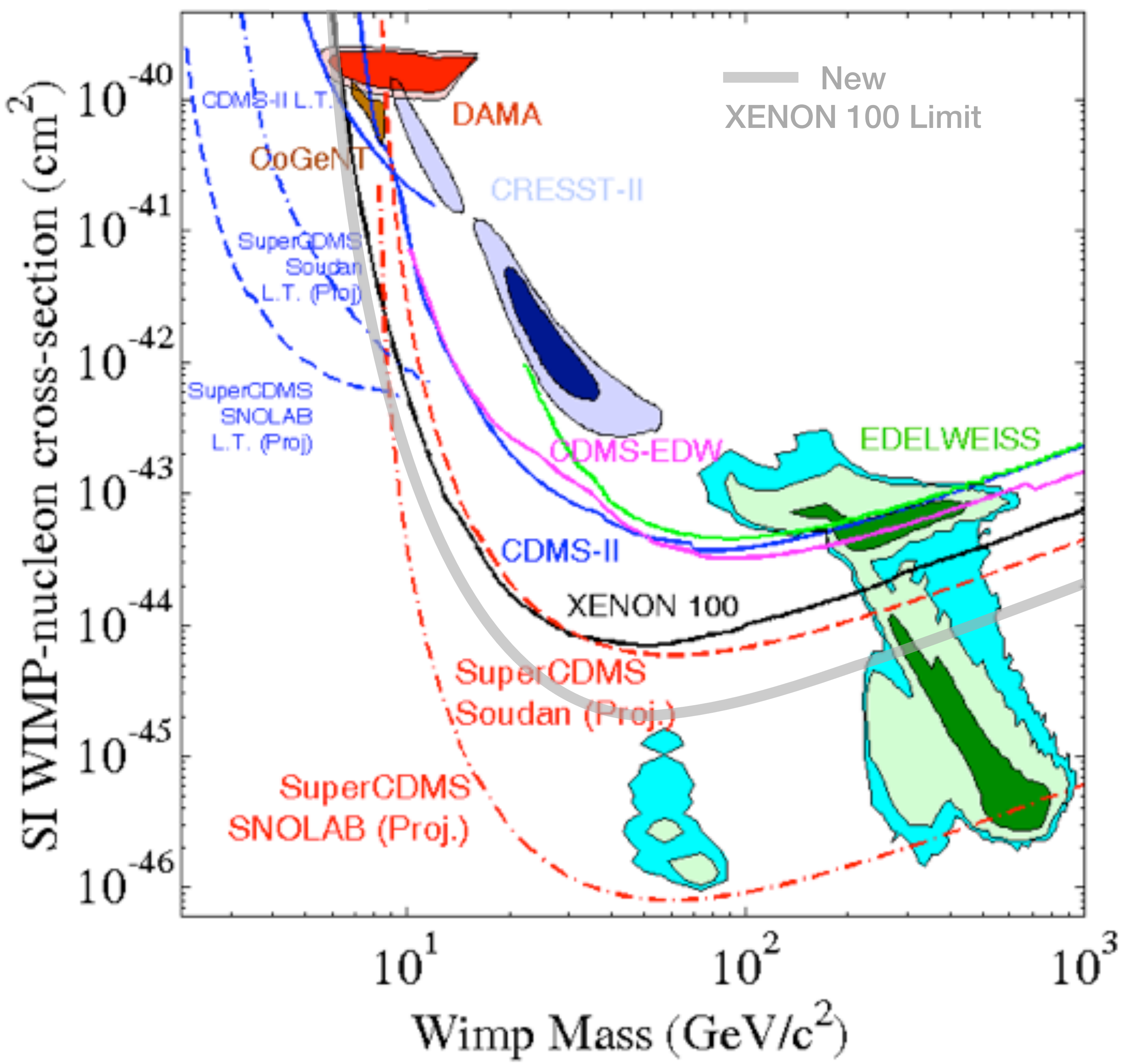


- Bulk photon rejection of 10^{-7}
  Surface "beta" rejection of 10^{-5} achieved
- Muon veto not needed at SNOLAB, but a neutron veto/monitor could reduce dependence on shielding radio-purity

The SuperCDMS Road Map

- The SuperCDMS program aims to probe the WIMP scattering parameter space down to $\sigma \approx 10^{-46}$ cm^2 by the end of the decade.

- It is very easy to make projections (just take your current limit and divide by 100), but SuperCDMS is the only experiment so far to have demonstrated the rejection performance required to achieve the projected sensitivities



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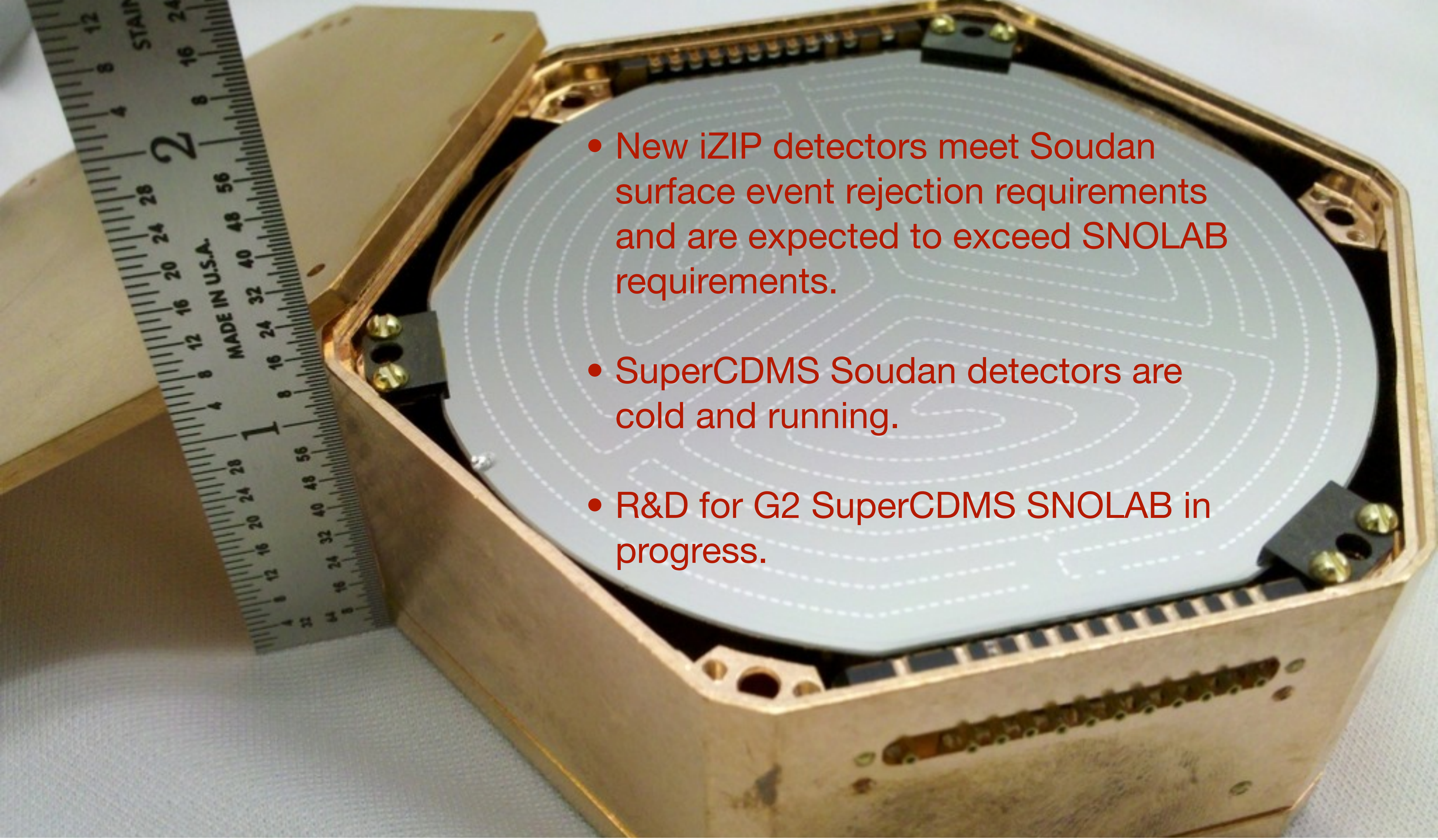
So, when are we going to see WIMPs?

To borrow a phrase from a very patient man:

“*The strongest of all warriors are these two — Time and Patience.*”
— Leo Tolstoy, War and Peace

In others words, hopefully before 50th anniversary of the SLAC Summer Institute,

…… or maybe not.



- New iZIP detectors meet Soudan surface event rejection requirements and are expected to exceed SNOLAB requirements.
- SuperCDMS Soudan detectors are cold and running.
- R&D for G2 SuperCDMS SNOLAB in progress.

Parting Thoughts

… such sweet sorrow