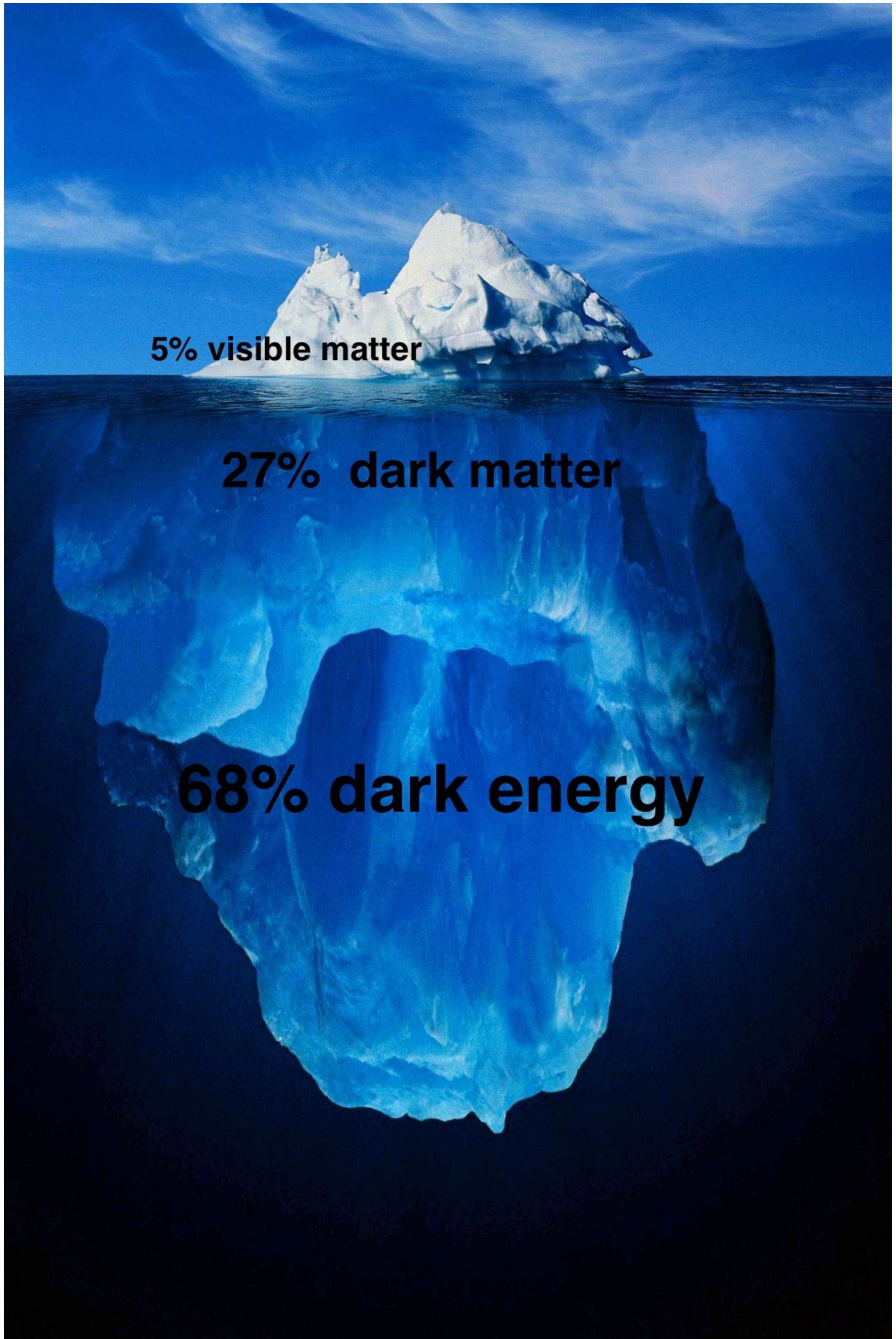
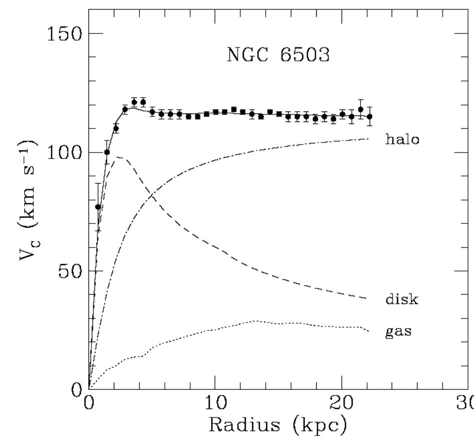
Background control in SuperCDMS experiment

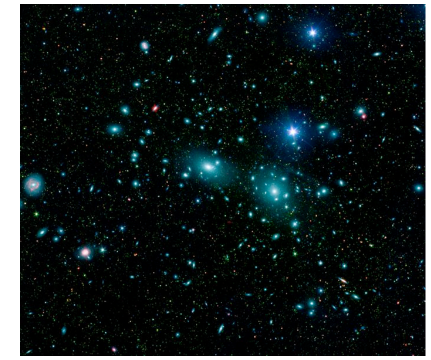
Silvia Scorza
Southern Methodist University

Dark Matter

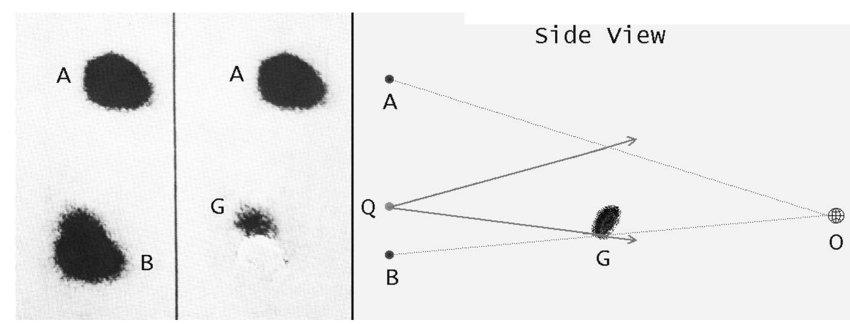




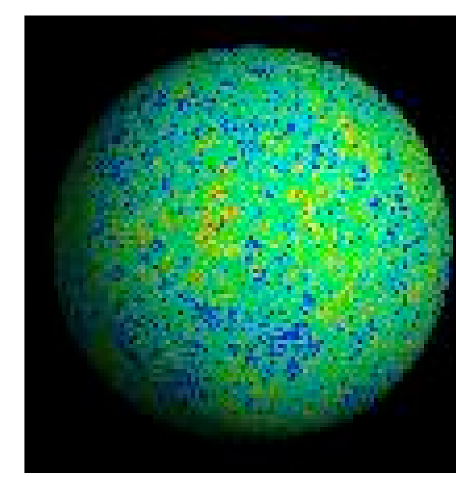
Rotation Curves

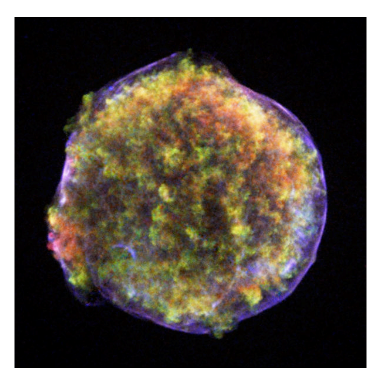

Motion of Galaxies in Clusters

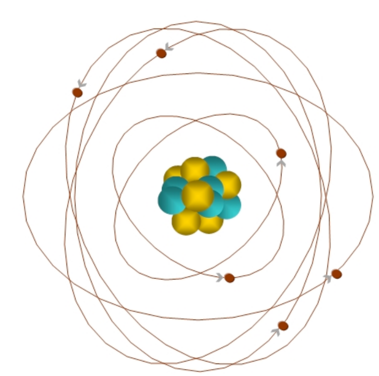

Galaxy clusters



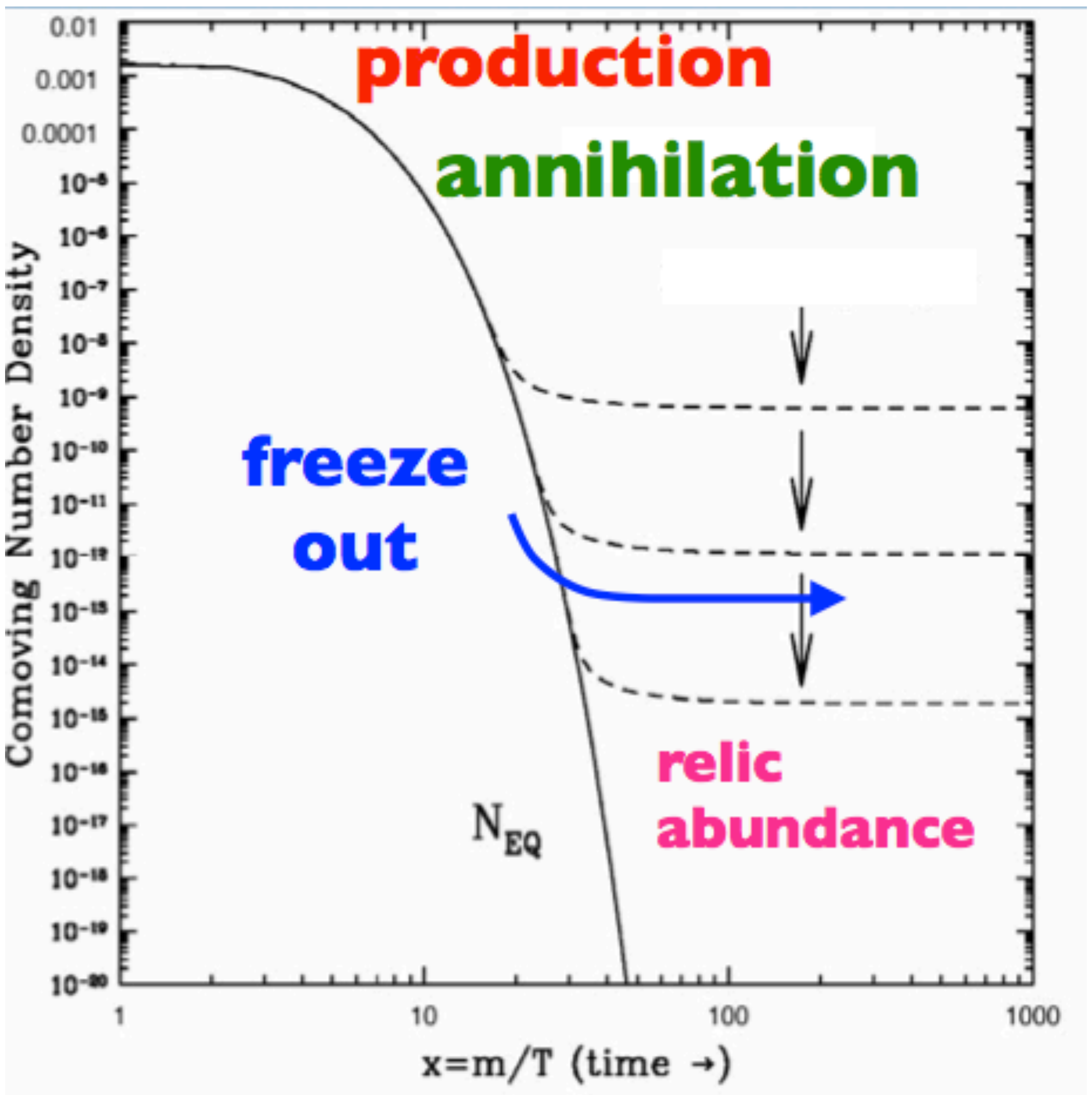
Gravitational Lensing


Microwave background


Supernovae Ia


Big Bang nucleosynthesis

WIMP Dark Matter



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

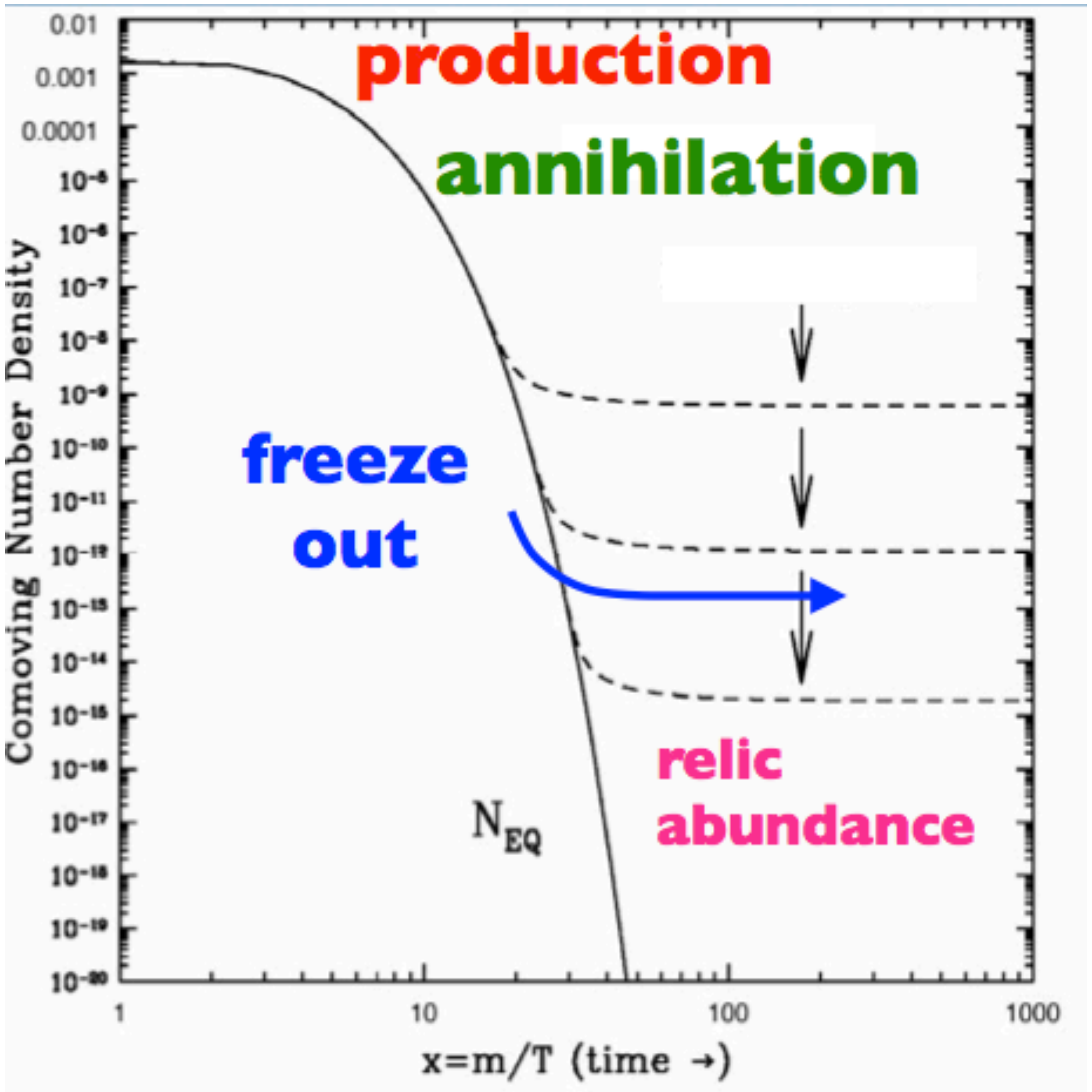
Weakly Interacting Massive Particle

New stable, massive particle produced thermally in early universe

Weak-scale cross-section gives observed relic density

Planck: $\Omega_\chi h^2 = 0.1199 \pm 0.0027$

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



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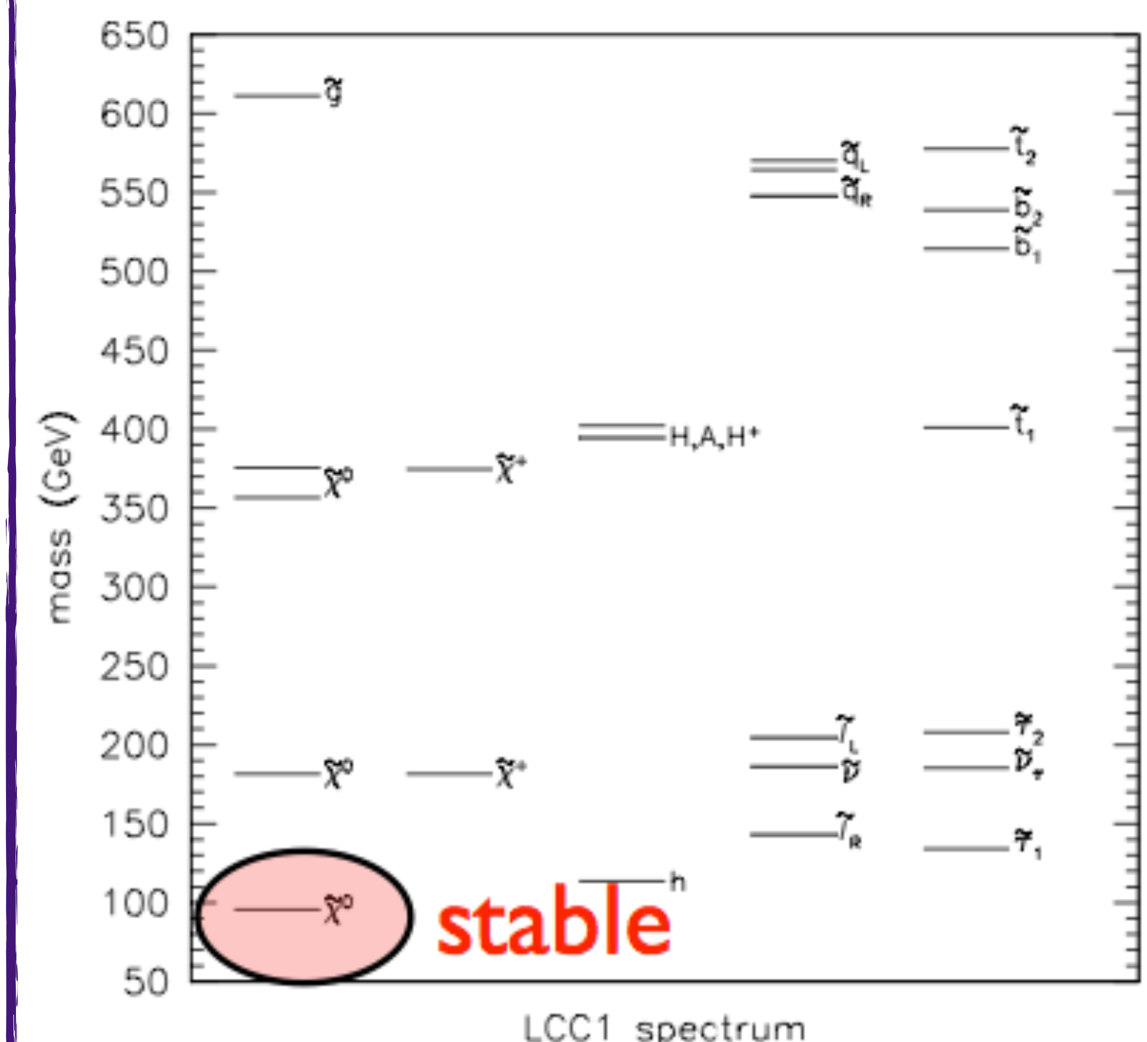
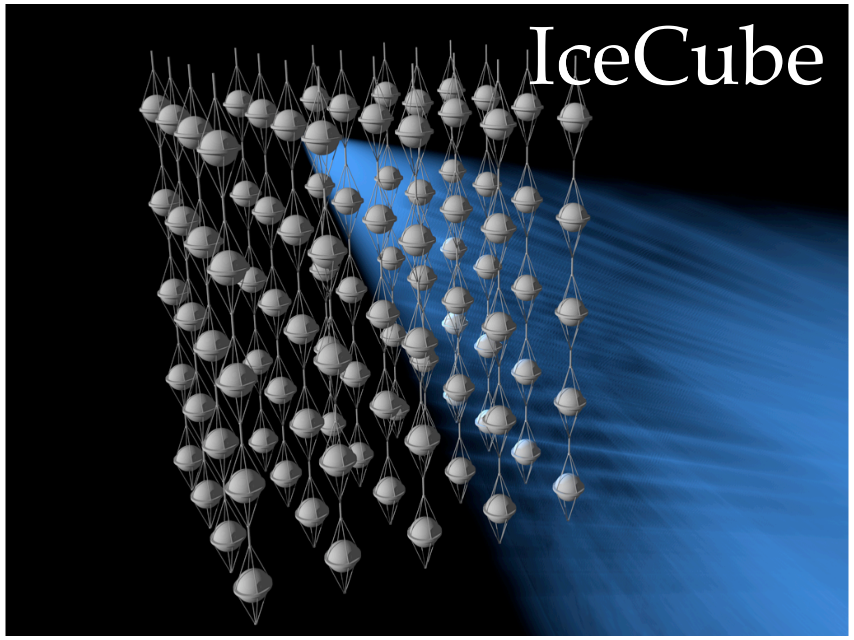


How to Detect WIMP Dark Matter

← WIMP scattering on Earth

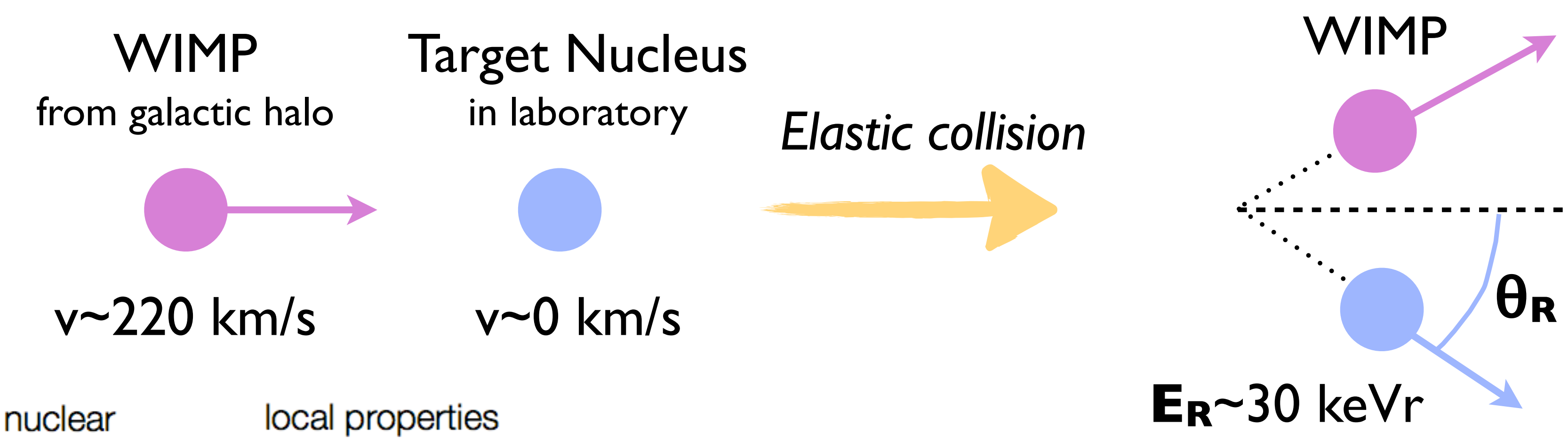
WIMP production on Earth →



← WIMP annihilation in the cosmos

Direct Detection of Dark Matter

Detection of the energy deposited due to elastic scattering off target nuclei

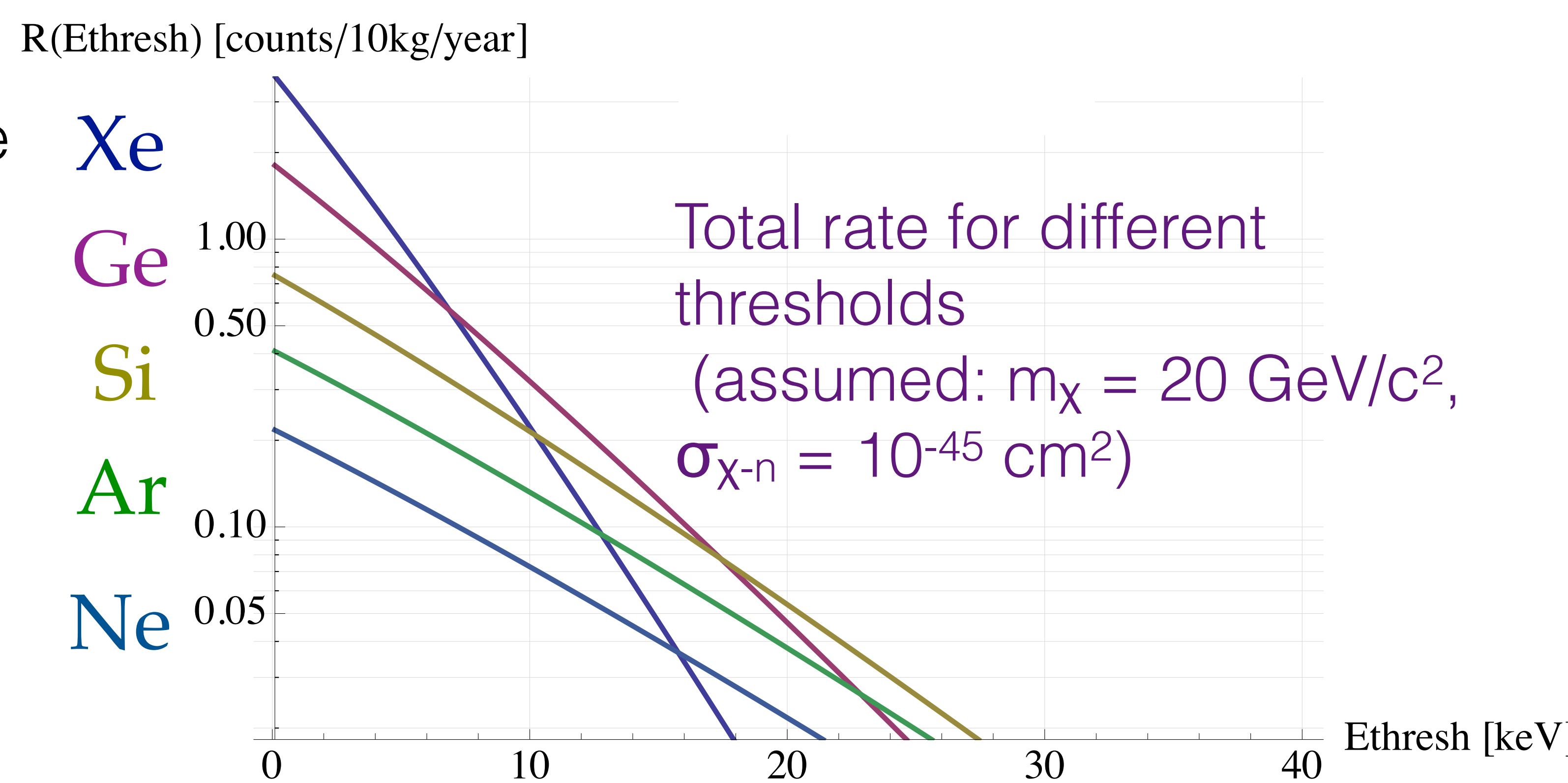


particle theory · nuclear structure · local properties of DM halo

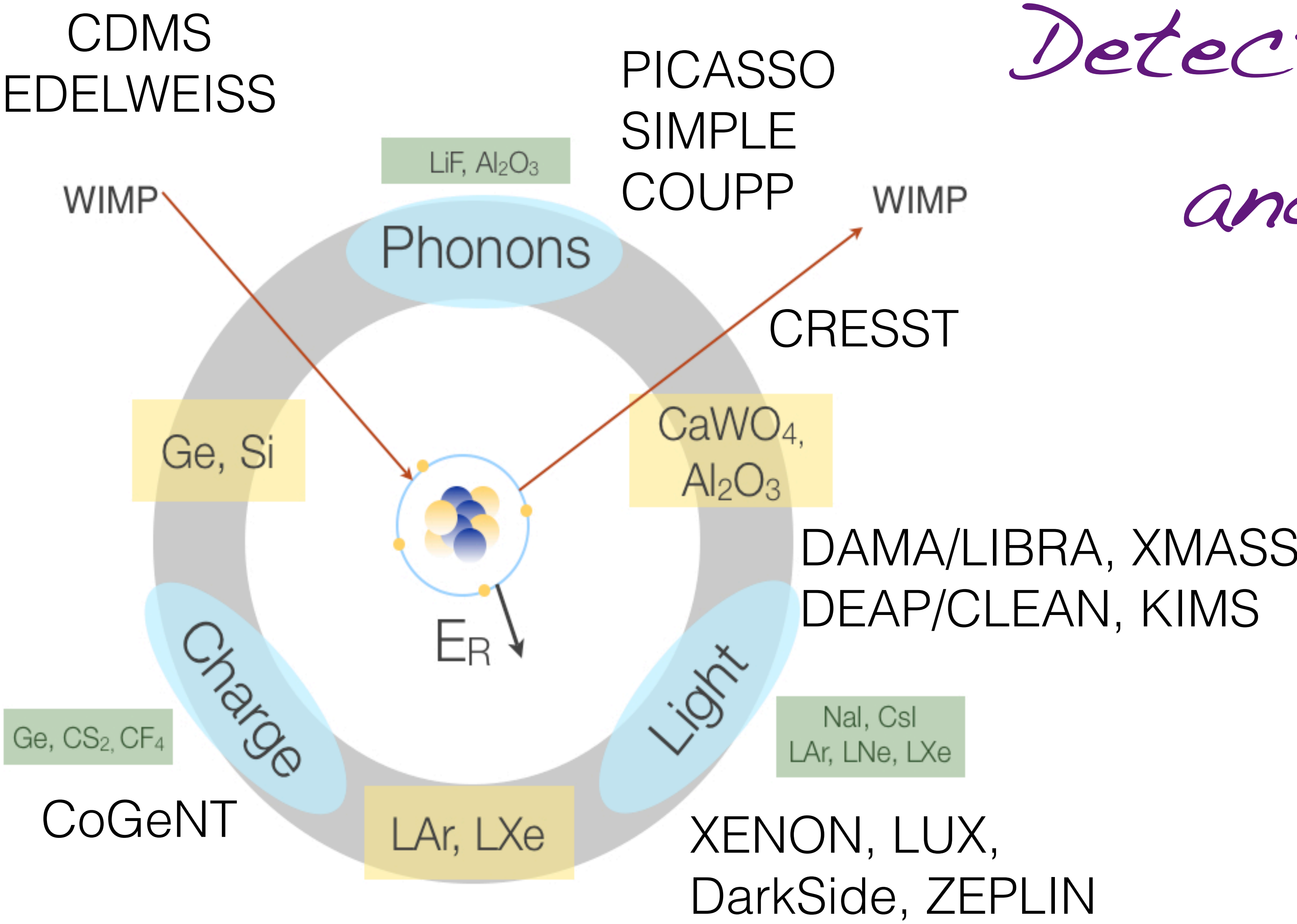
Interaction Rate [events/keV/kg/day]

$$\frac{dR}{dE_R} = \frac{\sigma_o}{m_\chi}\,\frac{F^2(E_R)}{m_r^2}\,\frac{\rho_o\, T(E_R)}{v_o\sqrt{\pi}}$$

- Energy spectrum and rate depend on details of WIMP distribution in the dark matter halo.
- Assume isothermal and spherical, Maxwell-Boltzman distrubution
  - v_{rms} = 270 km/s , v_o = 220 km/s, v_{esc} = 544 km/s
  - ρ_o = 0.3 GeV/cm3

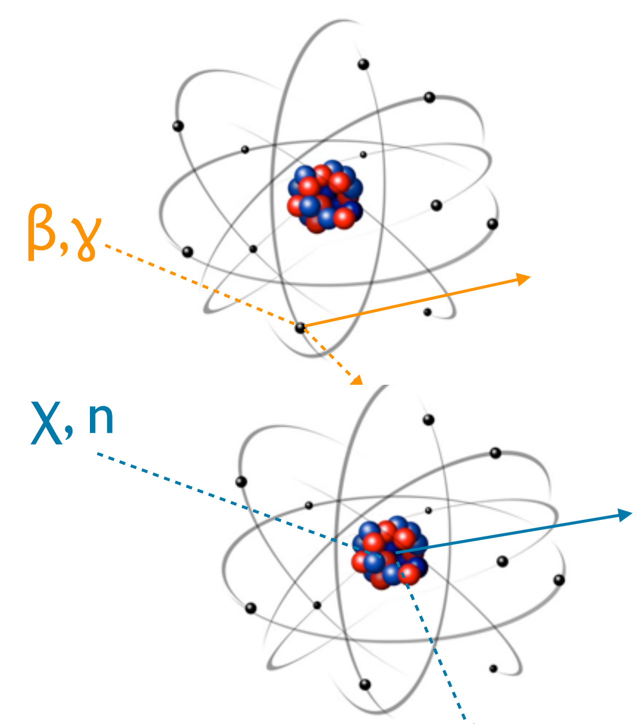


Detection Techniques and Background

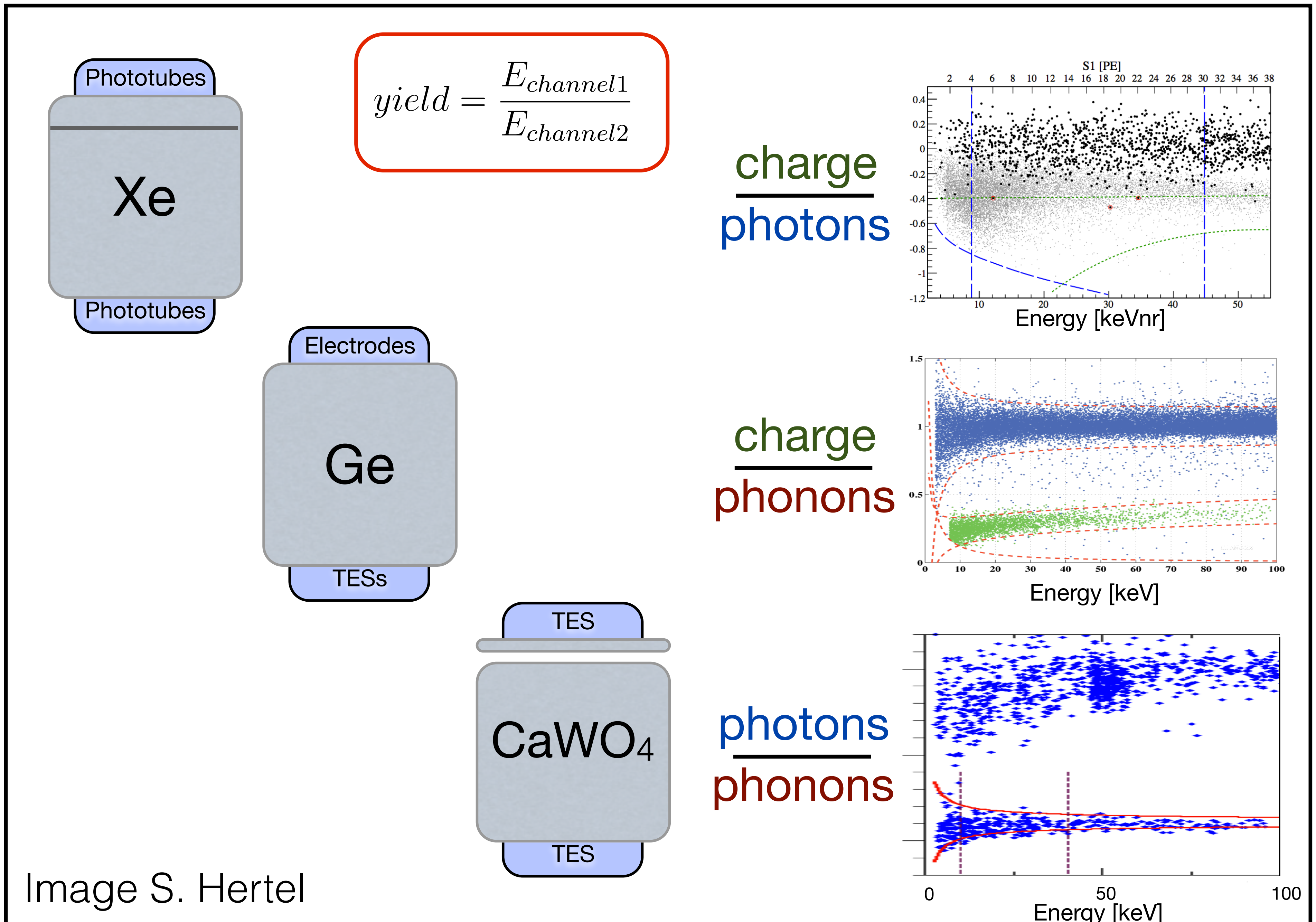


- Dominant background: electron recoil
(→ γ and β particles)

- WIMP signal = nuclear recoil
Beware of neutron scattering: irreducible background



Detection Principles: Particle Dependent Response



CRESST, DarkSide, EDELWEISS, LUX, SuperCDMS, XENON, etc.

Experimental constraints

- Elastic scattering of a WIMP deposits small amounts of energy into recoiling nucleus (~ few 10s of keV)
- Featureless exponential spectrum
- Expected rate

  - < 5 interaction per ton per day (3.8×10^{-44} cm^2 for $m_\chi = 70$ GeV)

  - Radioactive background of most materials higher than this rate.

Experimental challenges

- Low energy thresholds (<10 keV)
- Long exposures
  - ➡ Large masses, long term stability
- Rigid background controls
  - ➡ Shielding
  - ➡ Clean materials
  - ➡ Discrimination power
- Substantial Depth
  - ➡ Neutrons look like WIMPS

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Shielding

Passive shielding scheme for current phase and for future SuperCDMS SNOLAB experiment

Screening and material assay

XIA- UltraLo alpha counter at LUMINA

Discrimination power

Background rejection power of iZIP detectors

Minimize Backgrounds: Site Underground

Need at least 1000 m rock (~3000 mwe) overburden to reduce muon rate by ~10^5

Nigel Smith - DM2012

Minimize Backgrounds: Active Muon Vetoes

Rejects events from cosmic rays

- Scintillating panels
- Water Shield

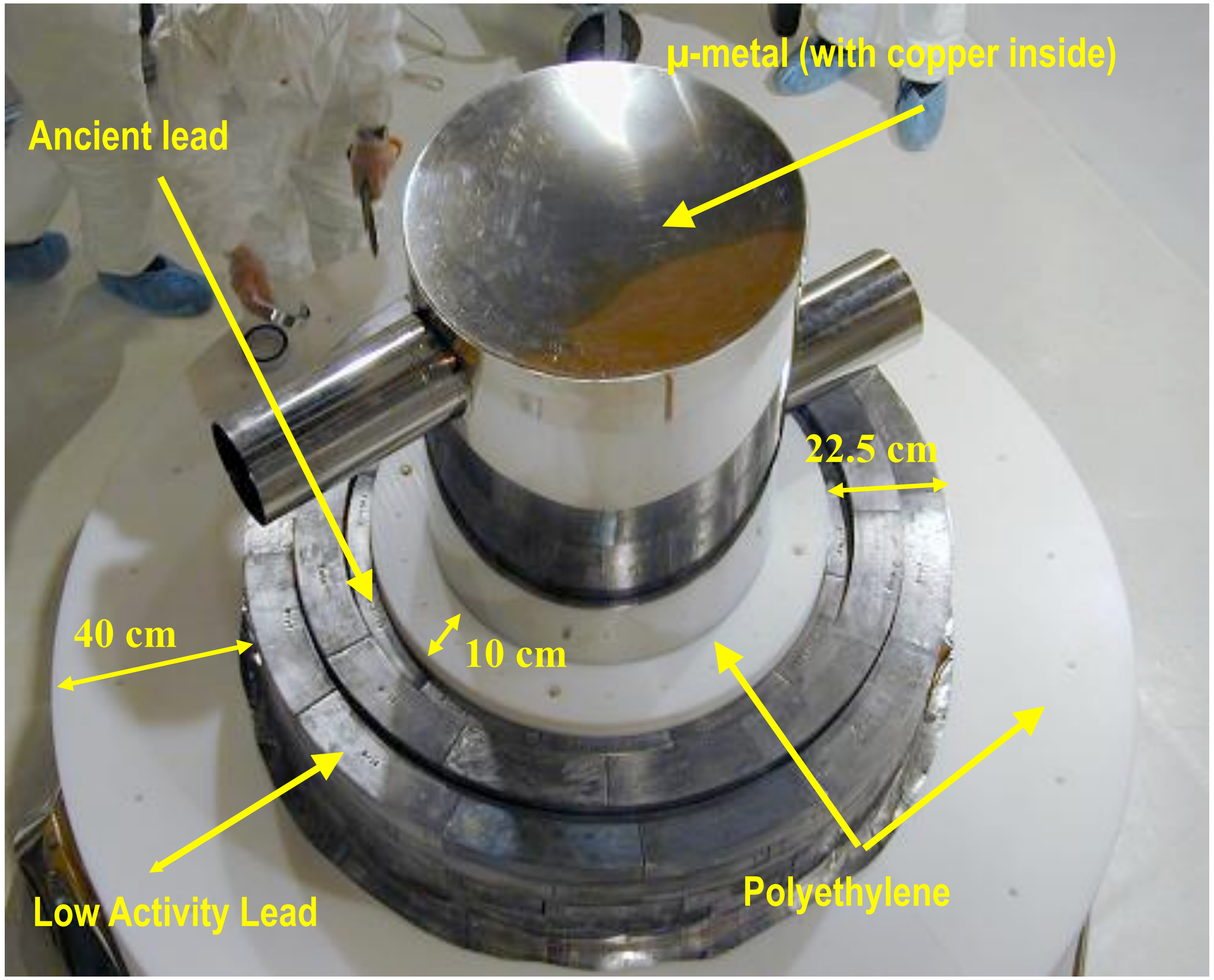
SCDMS active muon veto

LUX water shield

Minimize Backgrounds: Passive Shielding

Pb: shielding from gammas resulting from radioactivity

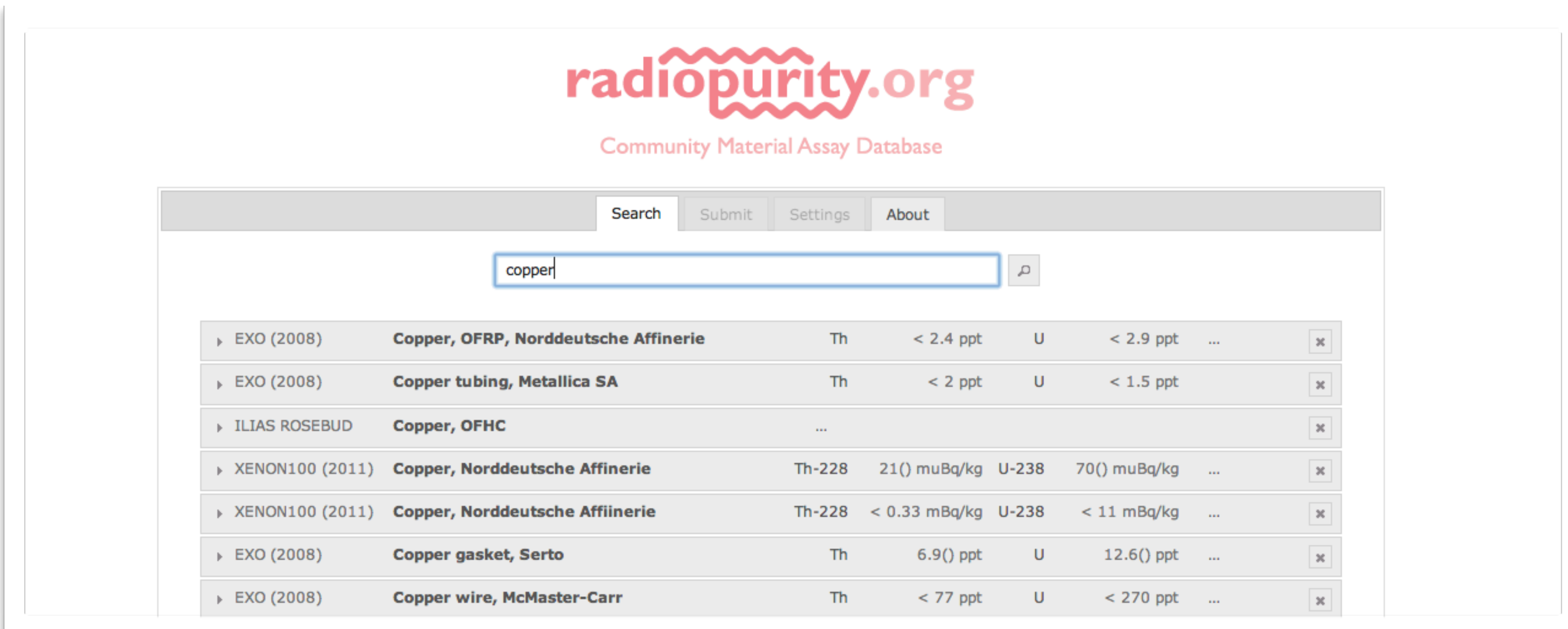
Polyethylene:
moderate neutrons produced from fission decays and from (α,n) interactions resulting from U/Th decays



SCDMS - Layers of Polyethylene and Lead

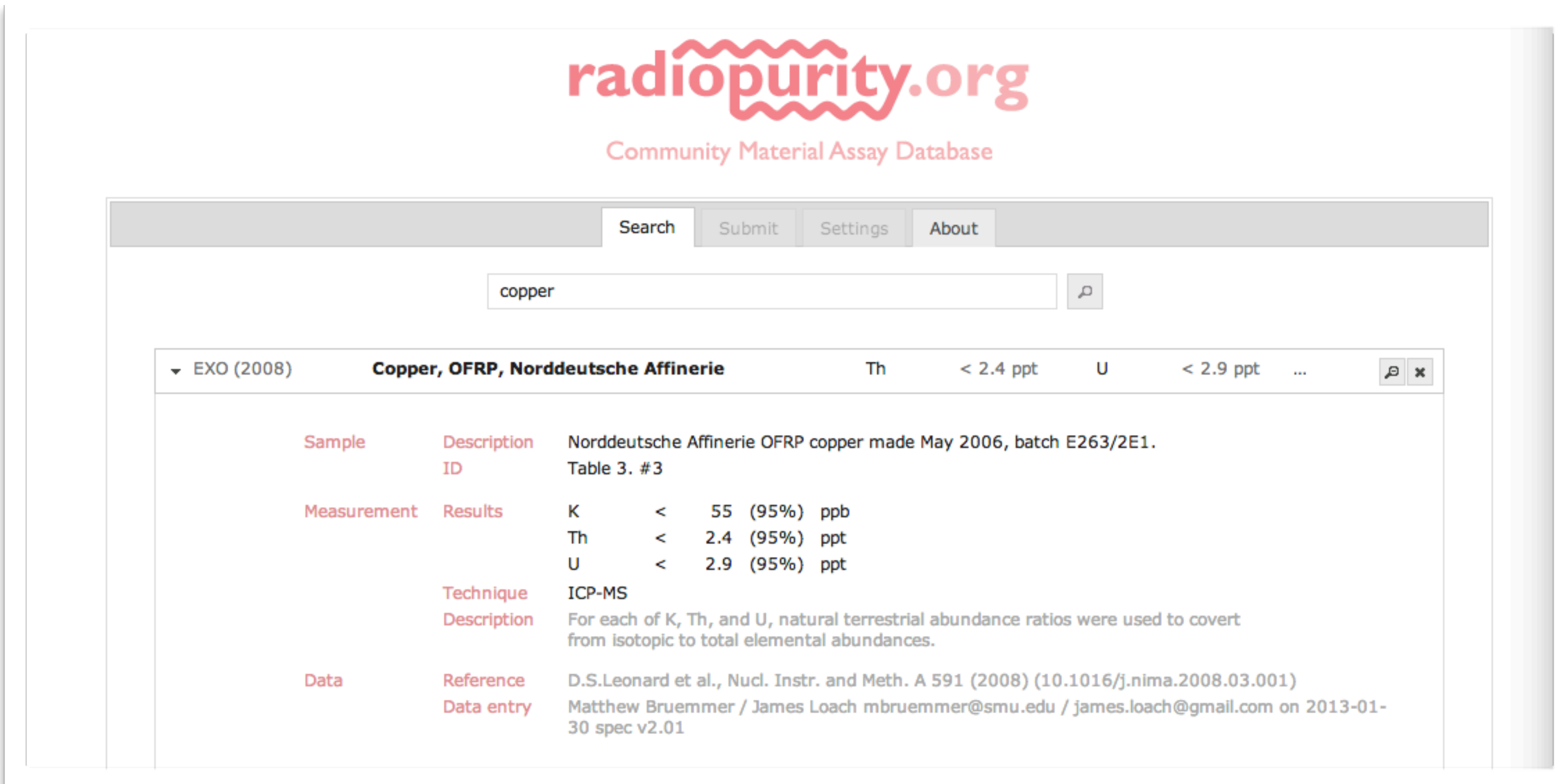
Minimize Backgrounds: Clean Materials

http://radiopurity.org



Supported by AARM, LBNL, MAJORANA, SMU, SJTU & others

Minimize Backgrounds: Clean Materials



Supported by AARM, LBNL, MAJORANA, SMU, SJTU & others

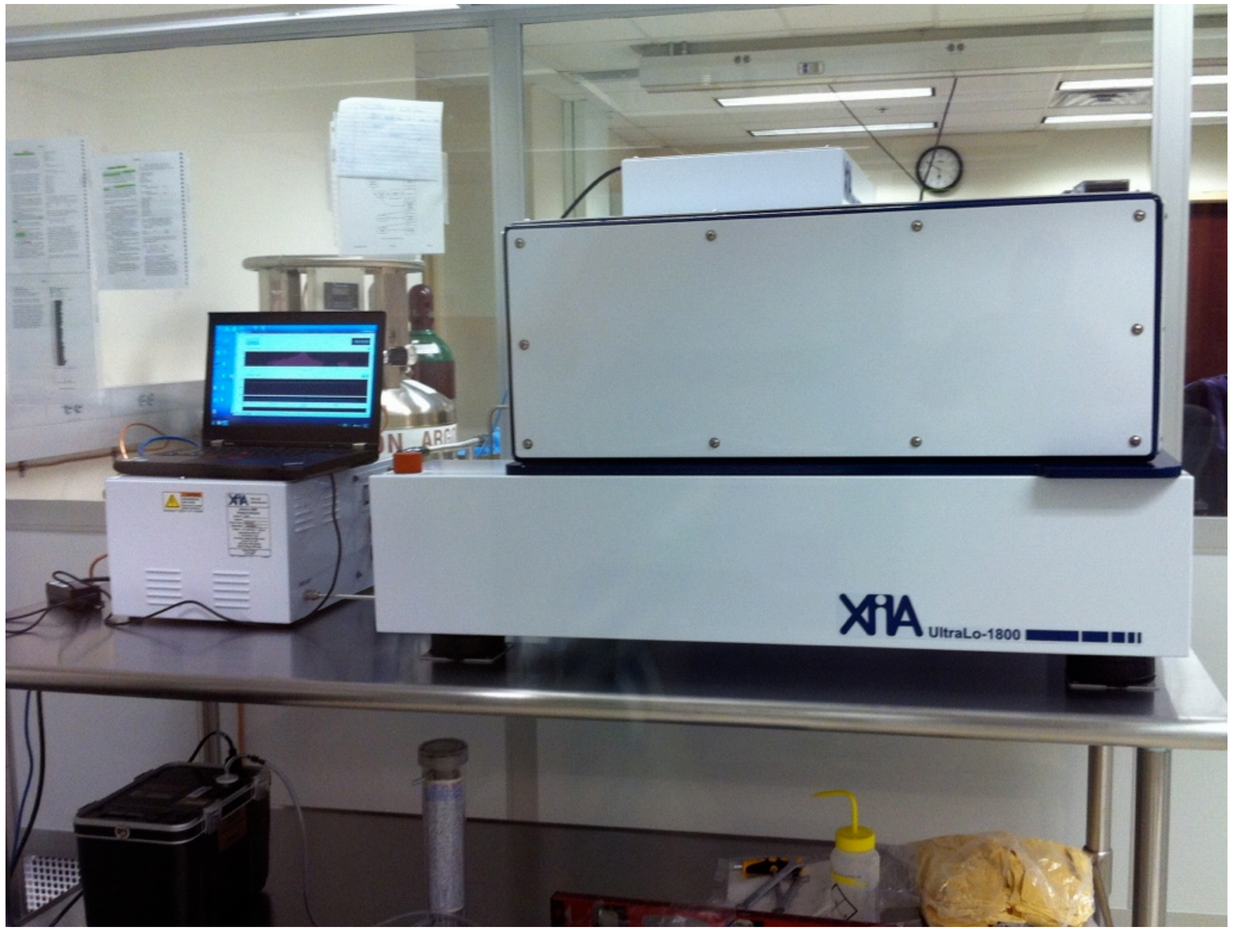
Estimate backgrounds

Background studies include an extensive **simulation** work. It can help with studying background suppression or rejection strategies, and investigation of requirements on the depth, the amount of active/passive shielding, the purity of materials, the veto efficiency, etc.

Screening and material assay:

Materials selection and assay program is crucial to achieving the science goals of the experiment. The scientific goals of the experiment explicitly state backgrounds for various types of ionizing radiation that are required to achieve the desired dark matter sensitivity.

These background specifications translate directly into specifications on radioactive materials used in the experiment.



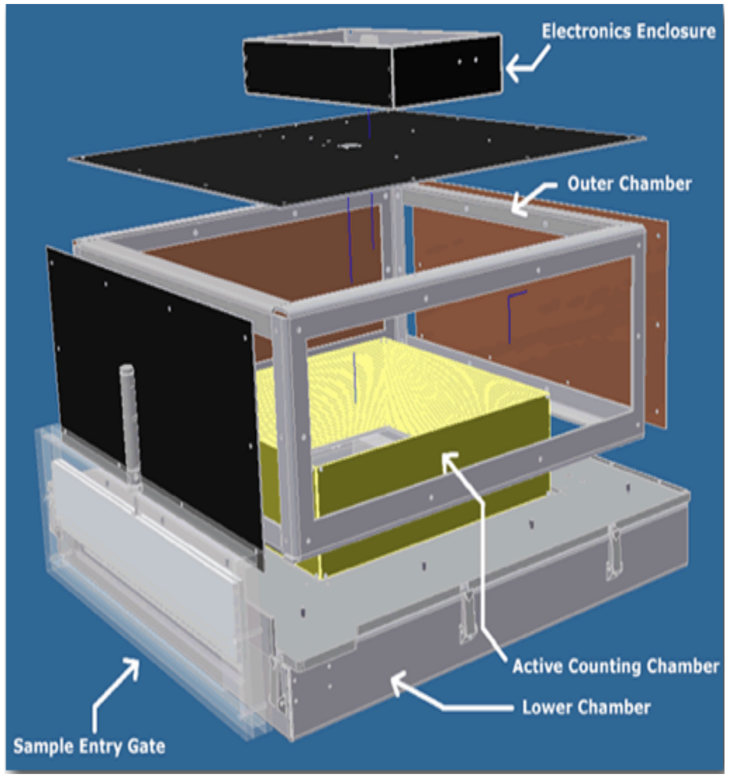
XIA: what?

It is a low background alpha-particle counter

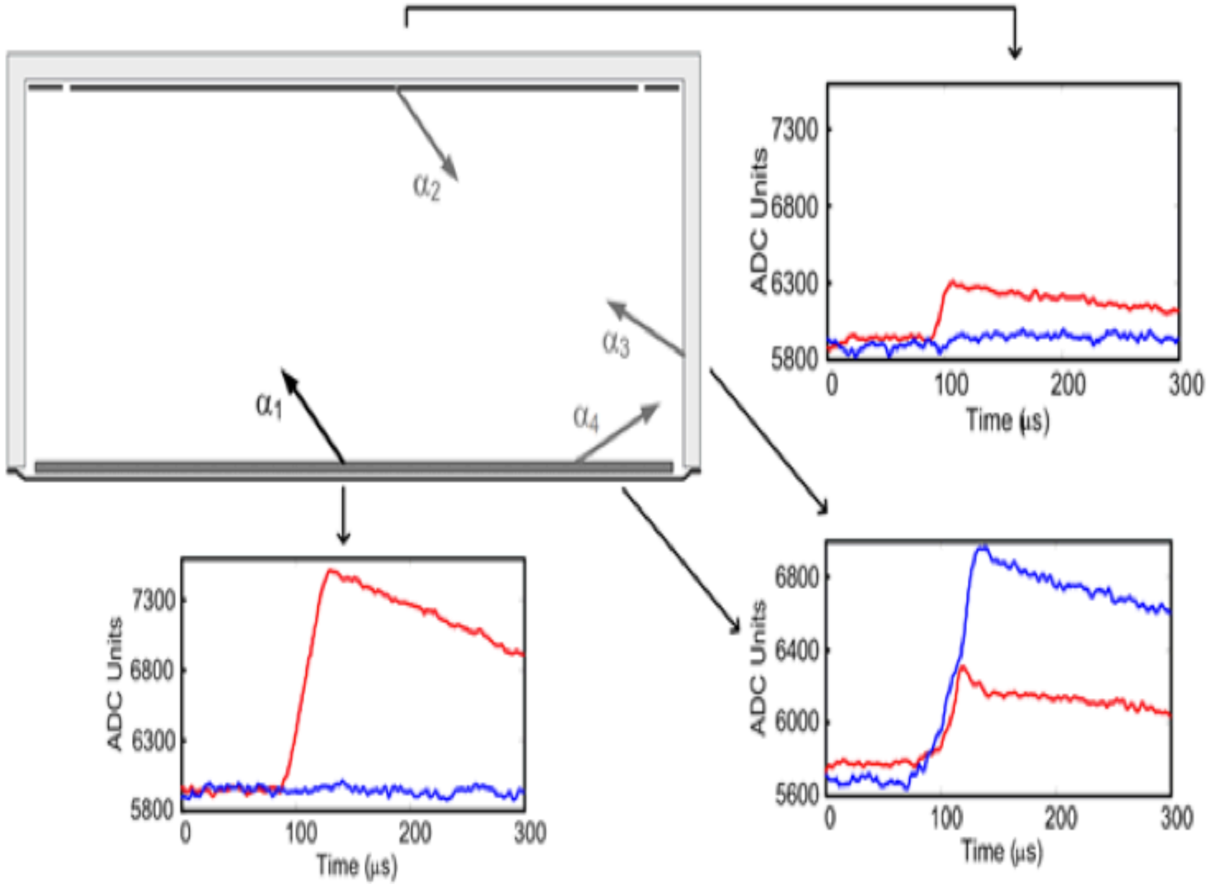
Drift Chamber:
- 21 x 21 inches
- 15 inches tall

Counting Area:
- Adjustable inner electrode size: 1800 cm^2 square or 707 cm^2 circular area
- 1 inch guard ring

Argon gas purge:
- 20 L/m prior to data taking (45 min purge)
- 4 L/m during normal operation



The UltraLo-1800 is a revolutionary design that employs Electronic Background Suppression to drive achievable background rates to **0.002 alpha/cm2/hr** or lower.



Alphas (α1):
Energy > 2 MeV, little guard ring activity, rise time between 60-80 μs (user can modify lower rise time threshold)

Ceiling(α2): low energy, low rise time

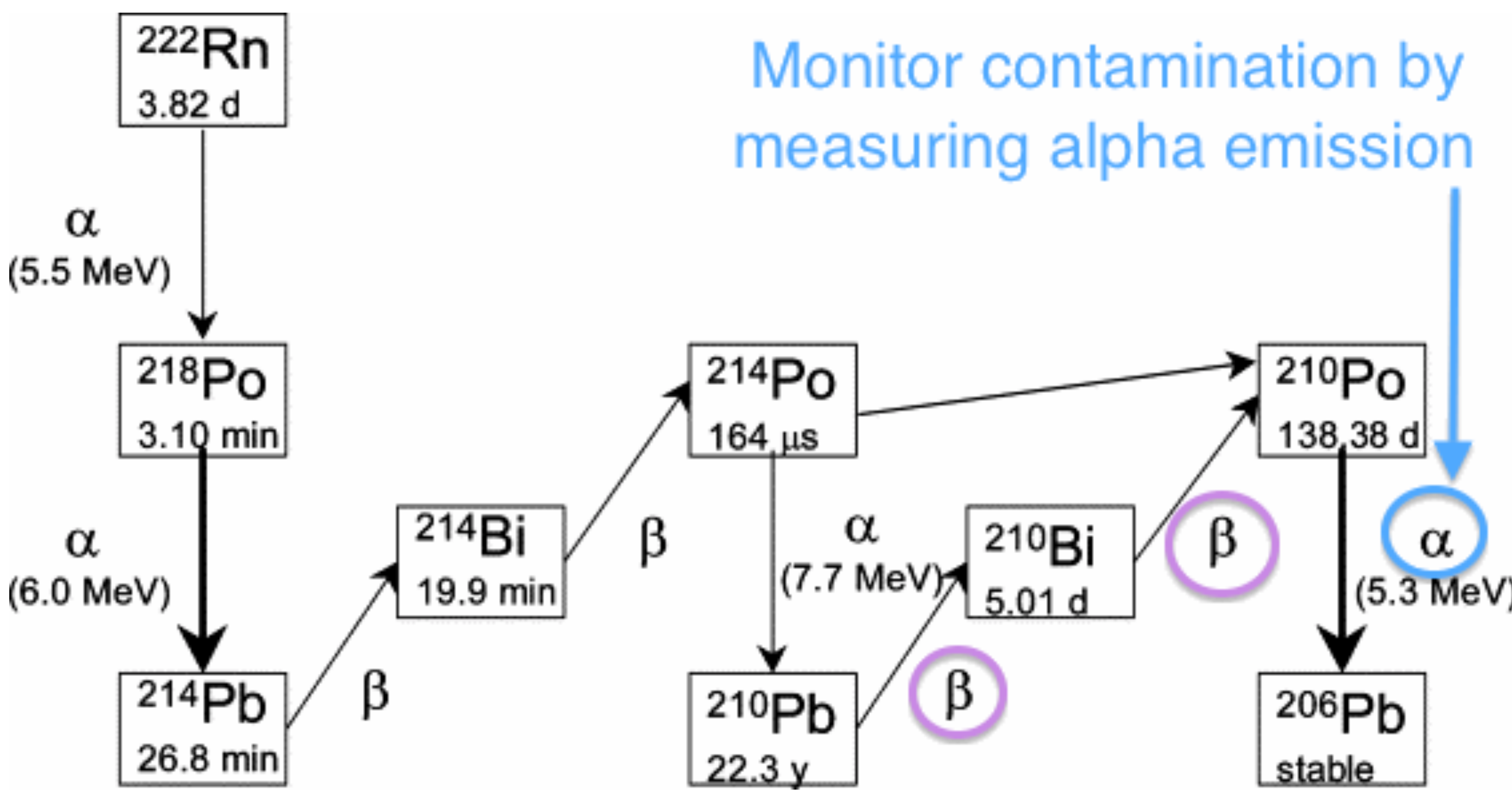
Sidewall(α3-4): significant guard ring activity

Noise: events not fitting into other classification

XIA: why?

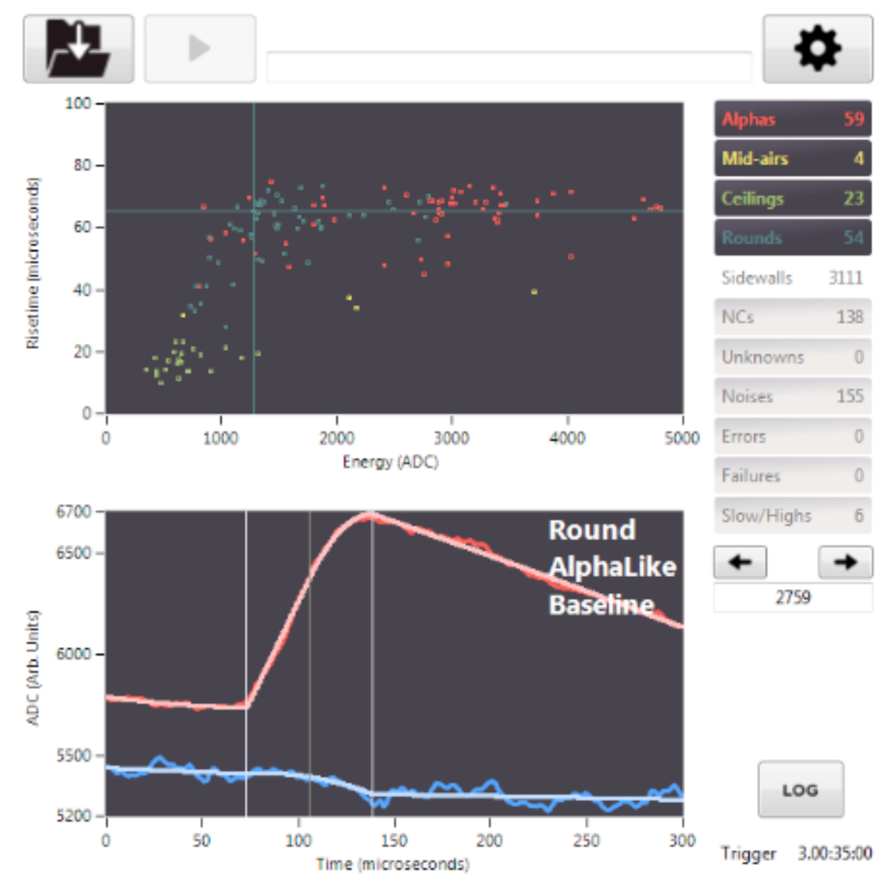
Beware of the surface radioactive contaminants introduced during the production, handling, treatment and storage of detector components.

^{222}Rn daughters emitted in the atmosphere are electrically charged and they can stick on detectors surfaces with a relatively high probability of remaining fixed



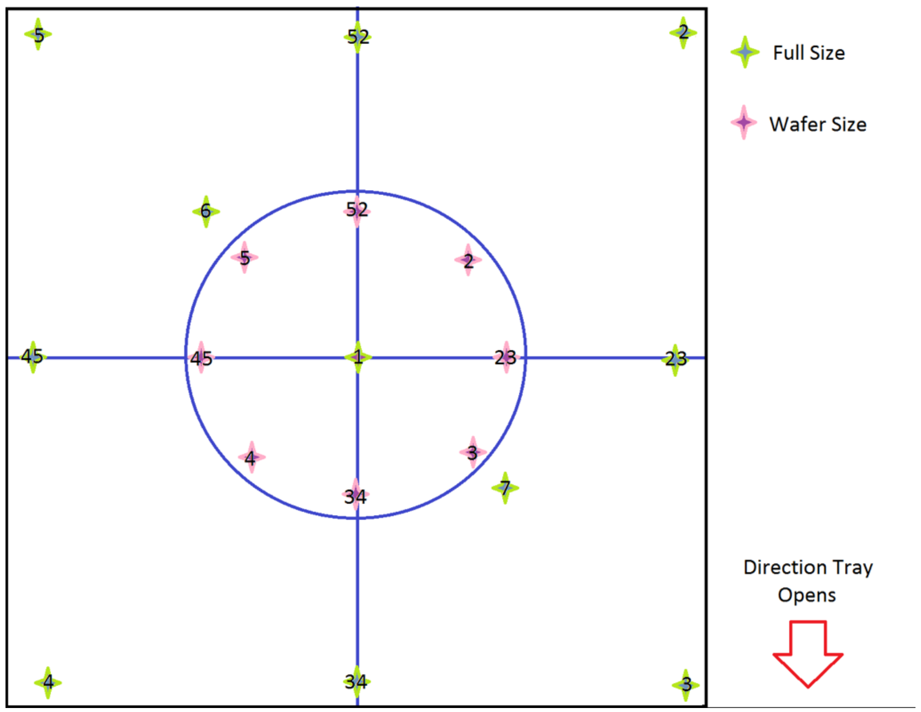
XIA Commissioning phase

Monitoring empty tray level -
detector sensitivity



We are running the XIA with teflon covering the tray – performing cleaning procedures with RADIACWASH wipes monthly.
Average empty tray emissivity:
0.0011 ± 0.0003 alpha/cm^2/hr

Th230 calibration and collection efficiency



Clear signature: ^{230}Th decays via an alpha of 4.8 MeV
Tray position study: spatial characterization of the tray response for both wafer and full size counting area with a ^{230}Th source
Collection efficiency decreases as we move further away from the center.

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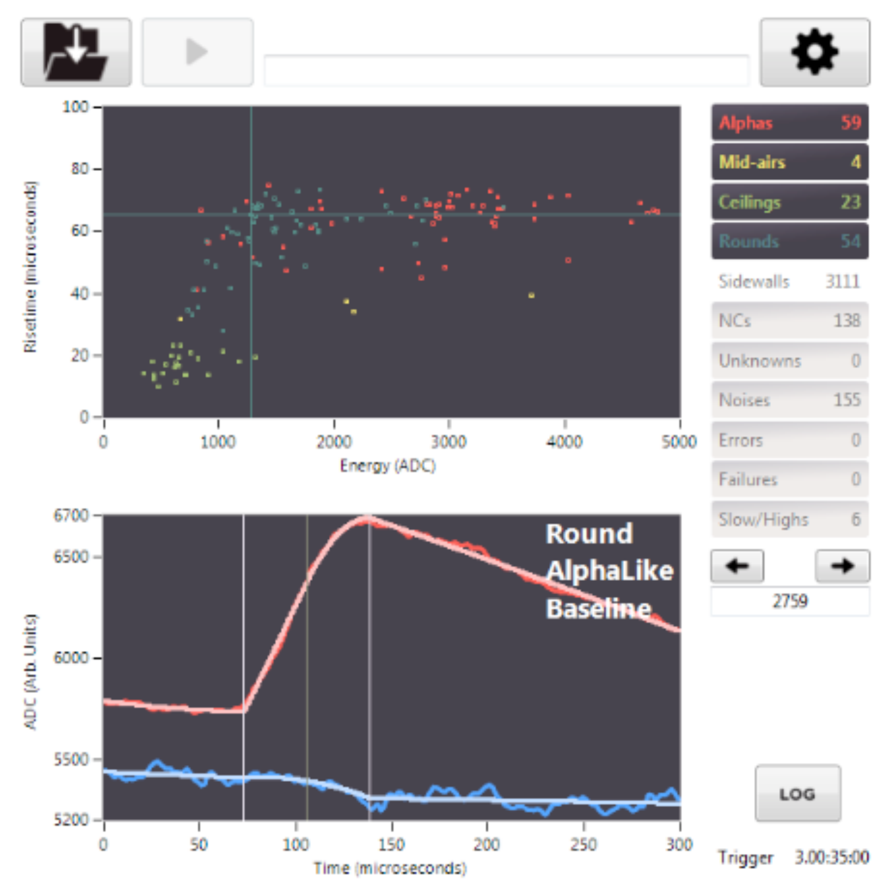

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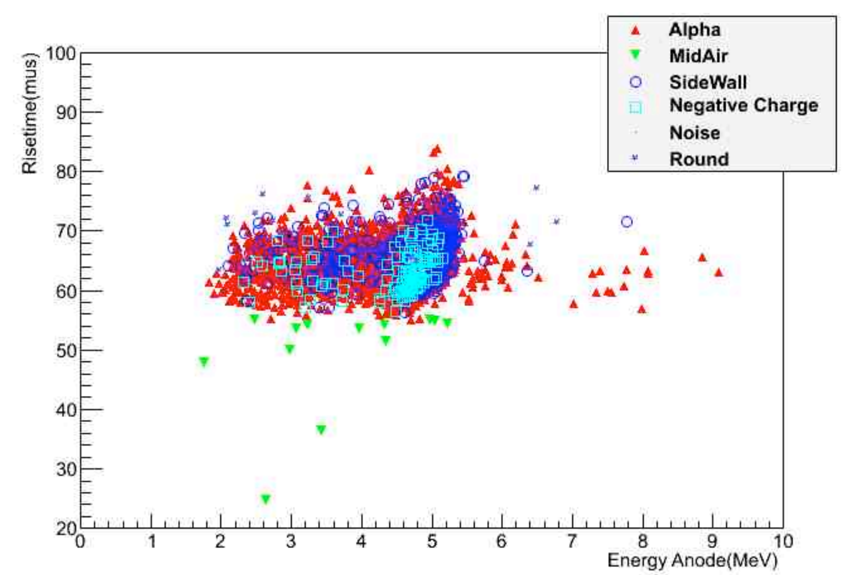

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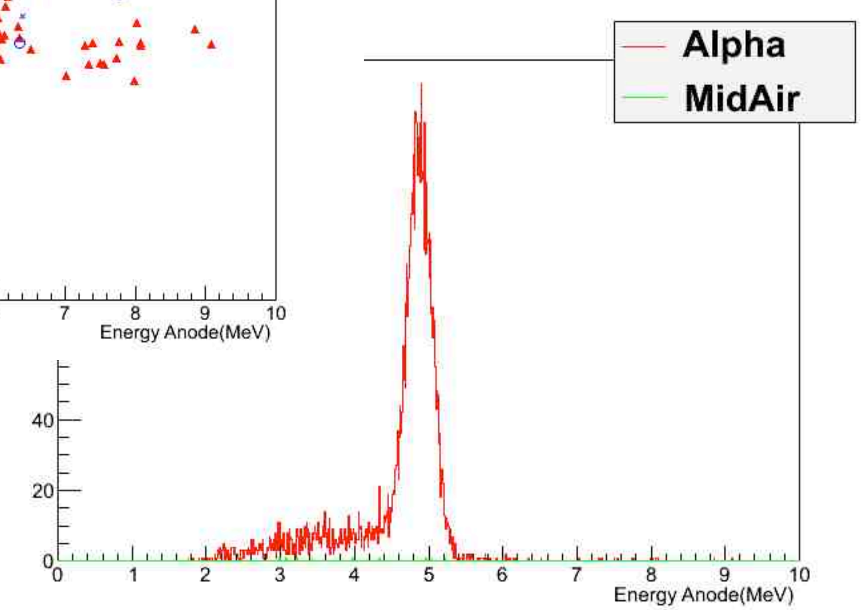

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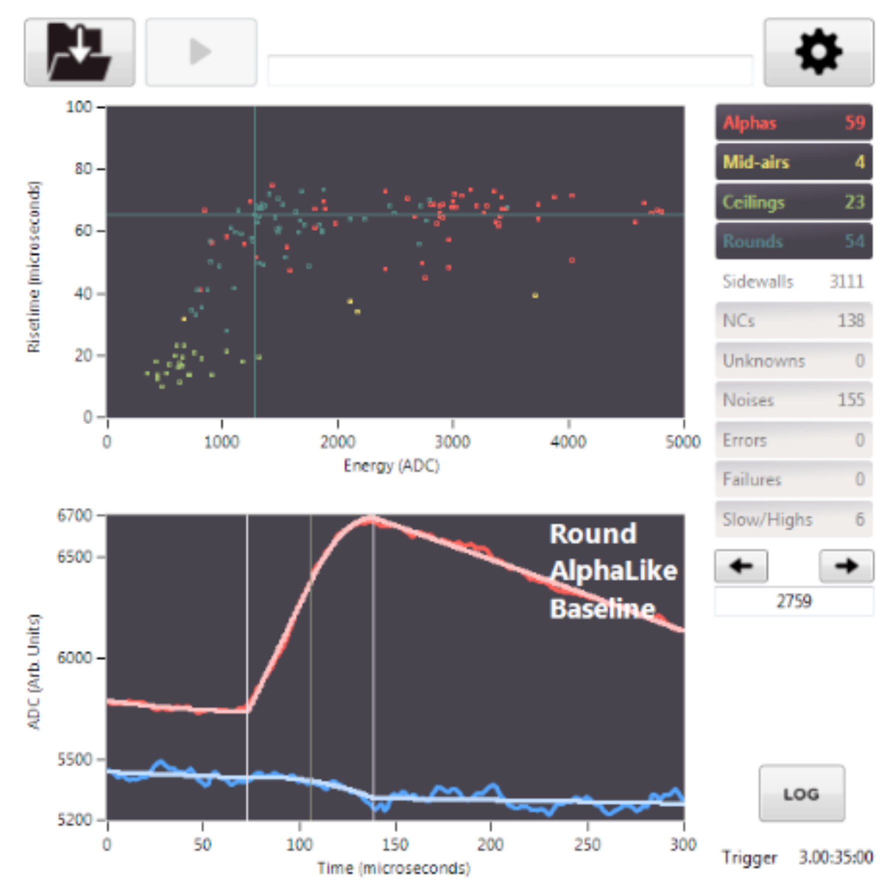

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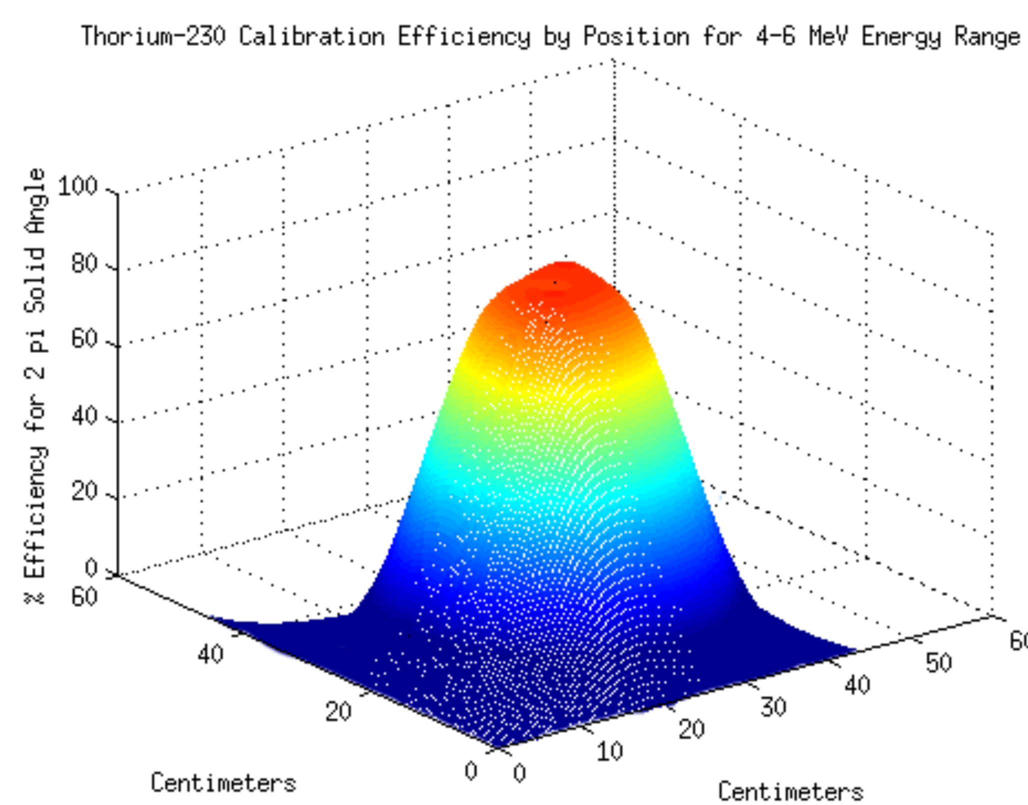
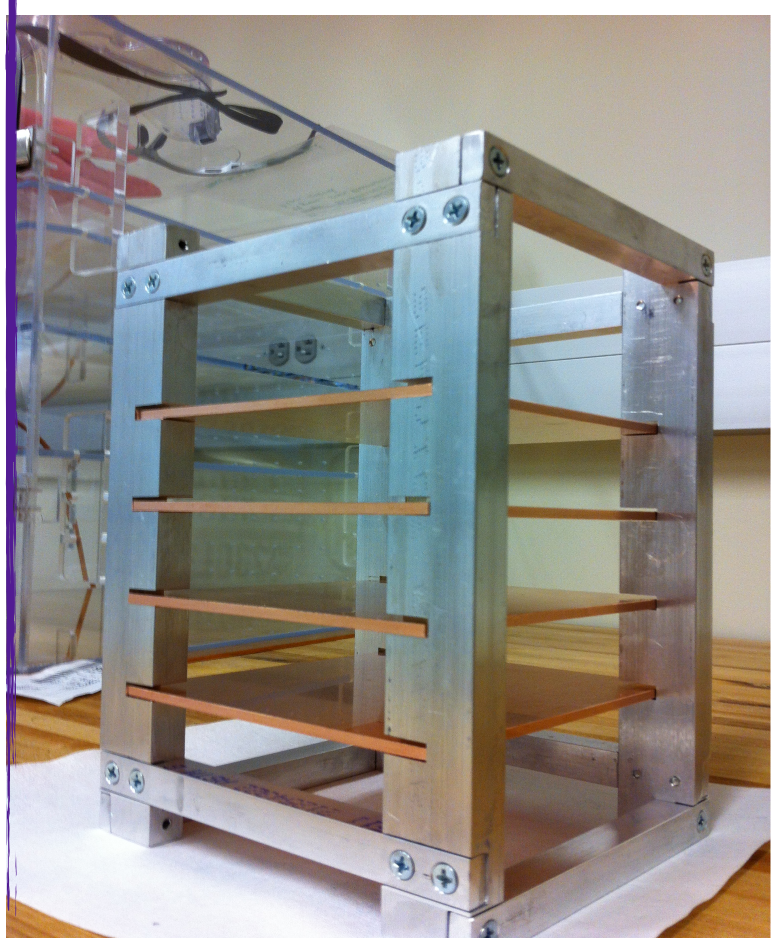


Radon studies

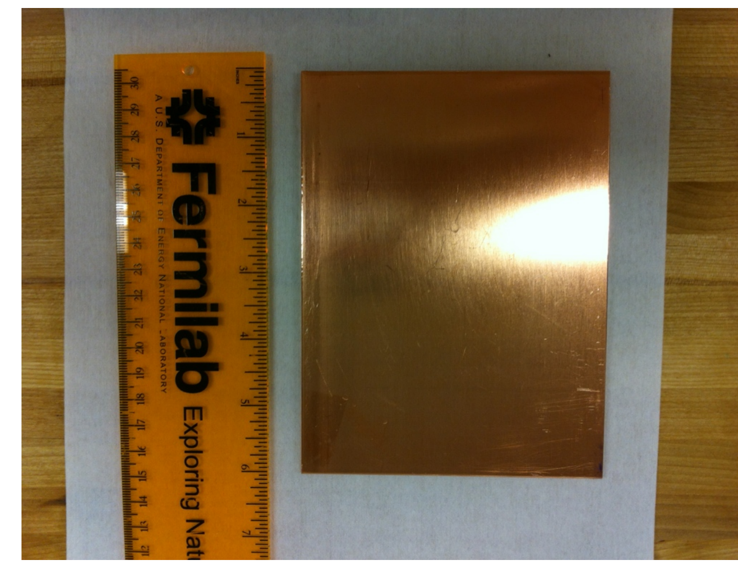
Radon progeny deposition onto samples and cleaning procedure techniques

- Acrylic samples (AC) - presented by M.Nakib at LRT2013
- Copper samples (FNAL + SMU) in fieri

The radon contamination of four Cu samples started on March, 27th 2013 at FNAL.
The samples are exposed to radon (^{226}Ra , ^{222}Rn passive source) in an Al vessel under a fume hood in Lab3 (FNAL).
The contamination lasted 3 months.

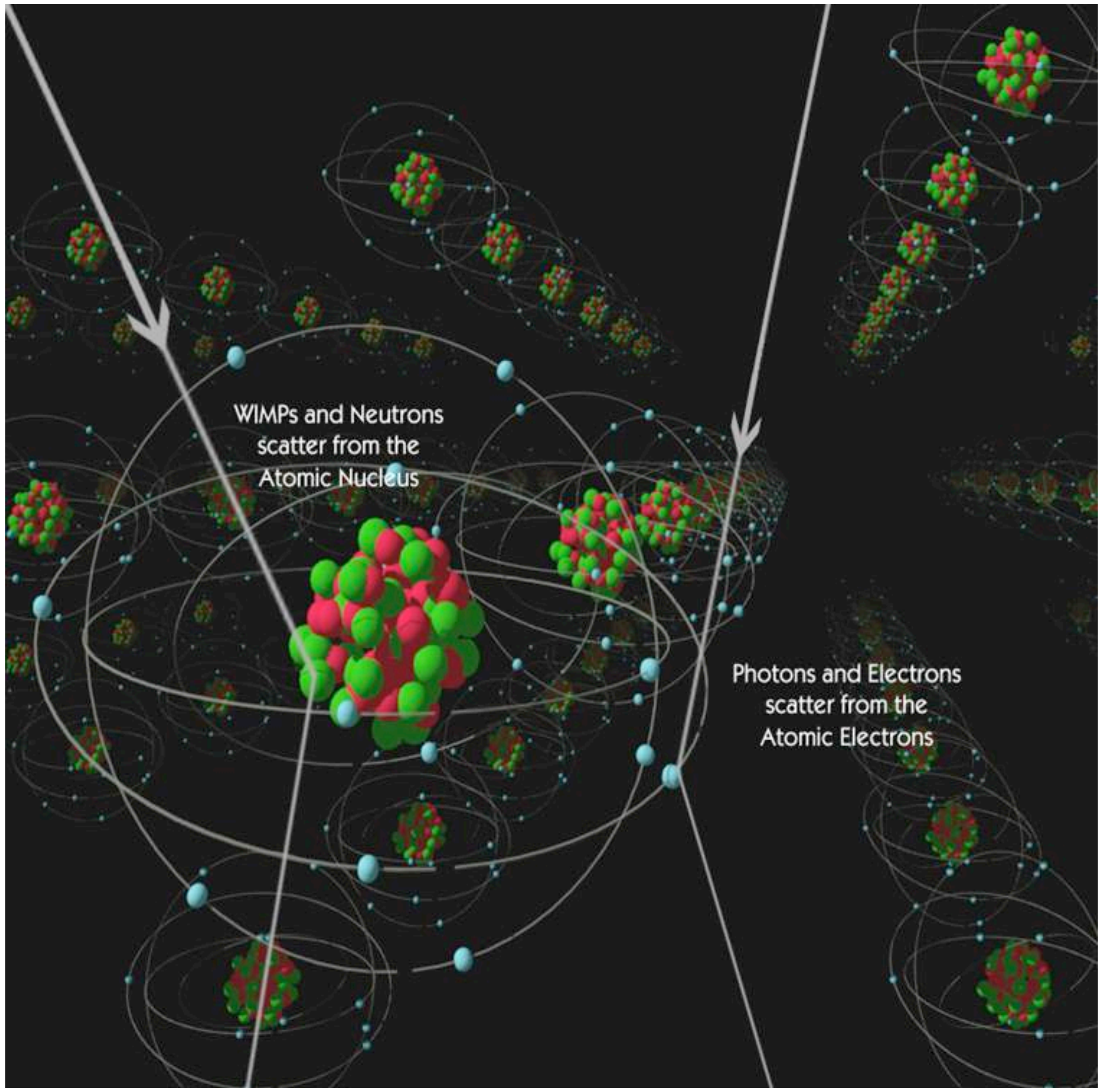


Goal: investigate cleaning procedure techniques to mitigate the effects of the sources of the low energy (0-100 keV) events from bi- products of the Rn decay chain.

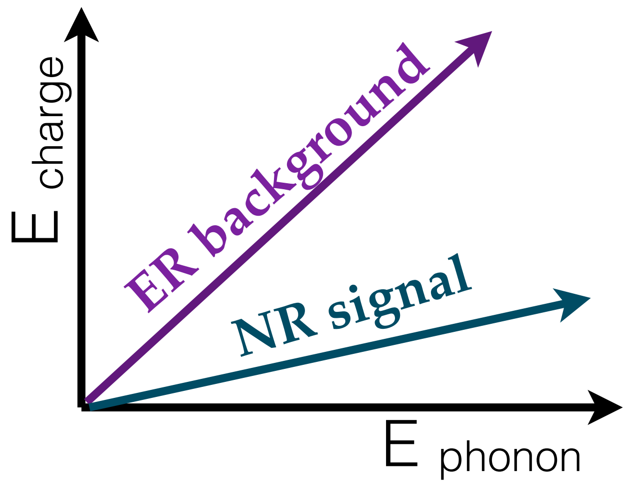


CDMS/SuperCDMS in a Nutshell

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



Particle ID: measurements of ionization and phonon energy.



Keep backgrounds as low as possible through shielding and material selection.

CDMS II (Ge+Si)

- 4.6 kg Ge (19 x 240 g)
- 1.2 kg Si (11 x 106g)
- 35% NR acceptance

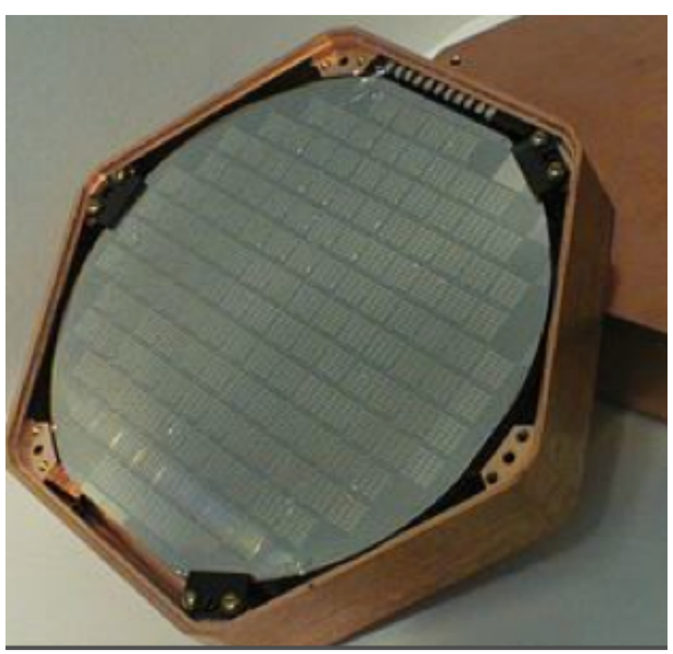
SuperCDMS Soudan

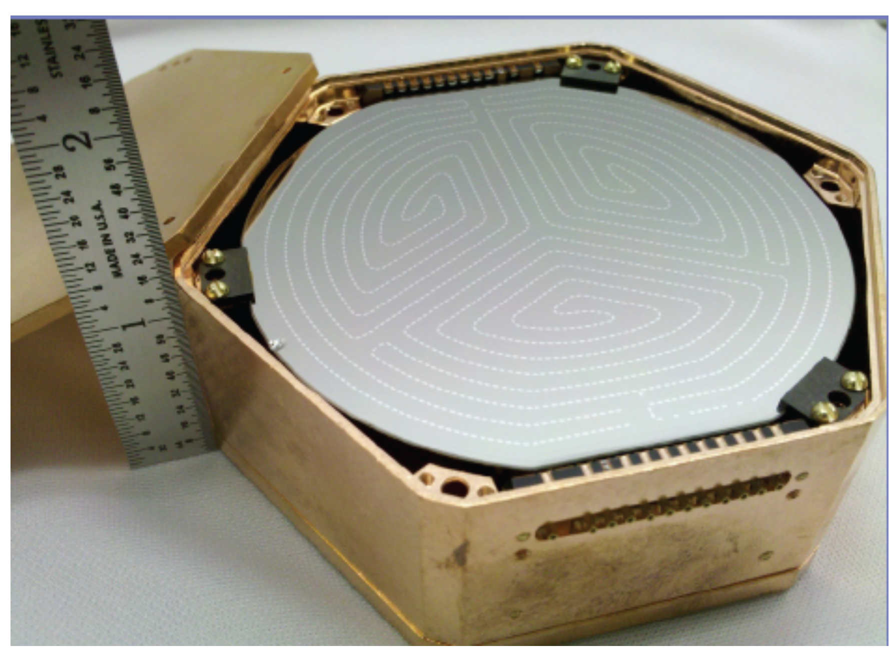
- Increased mass: 9.0 kg Ge (15 x 600 g)
- Increased acceptance
- Improved surface event discrimination

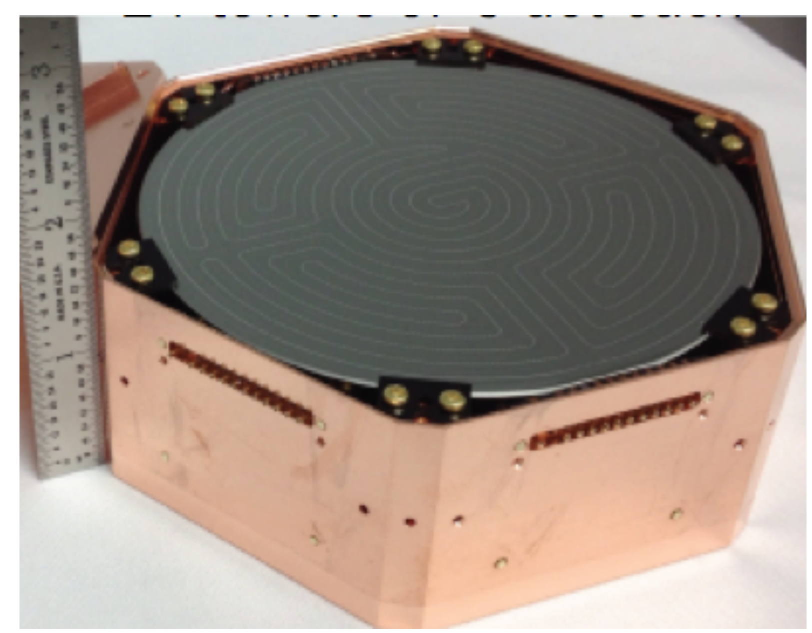
SuperCDMS SNOLAB

- Proposed 200kg Ge array
- Extensive R&D underway
- Scale to 1 kg crystals

Projected sensitivity of 8 x 10^{-47} cm^2







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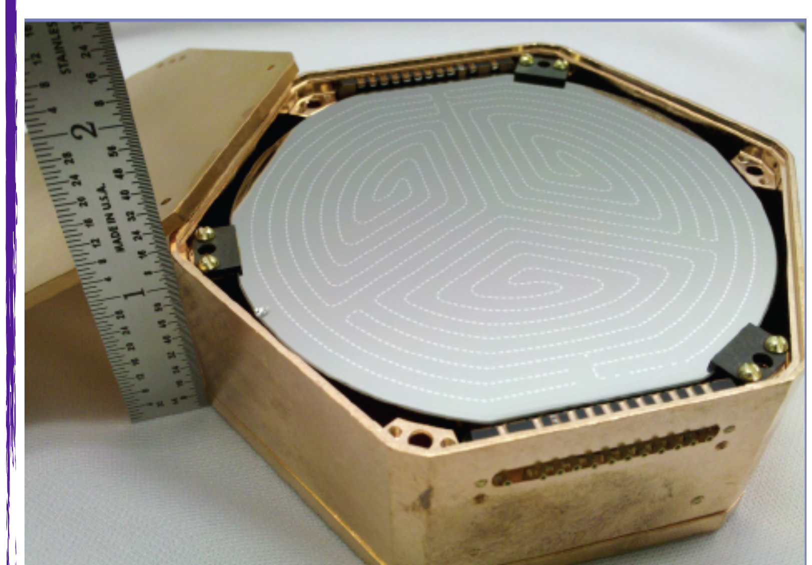

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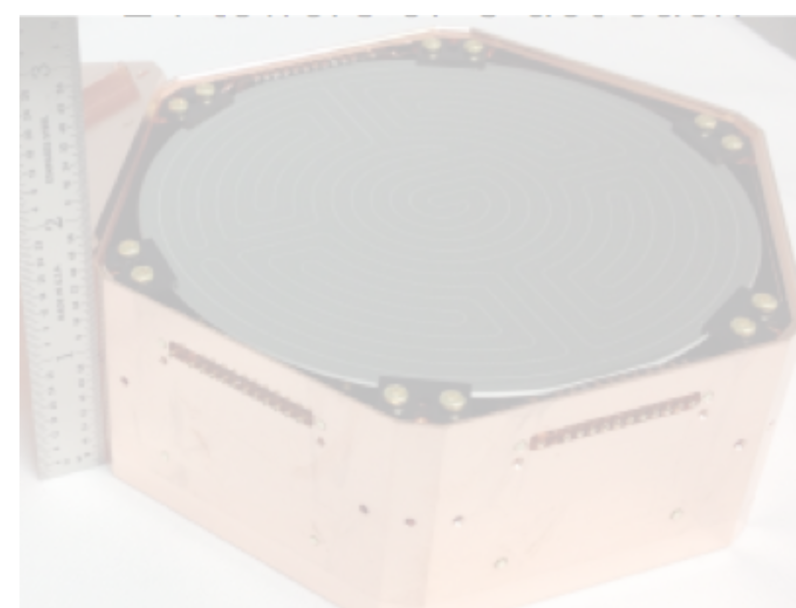
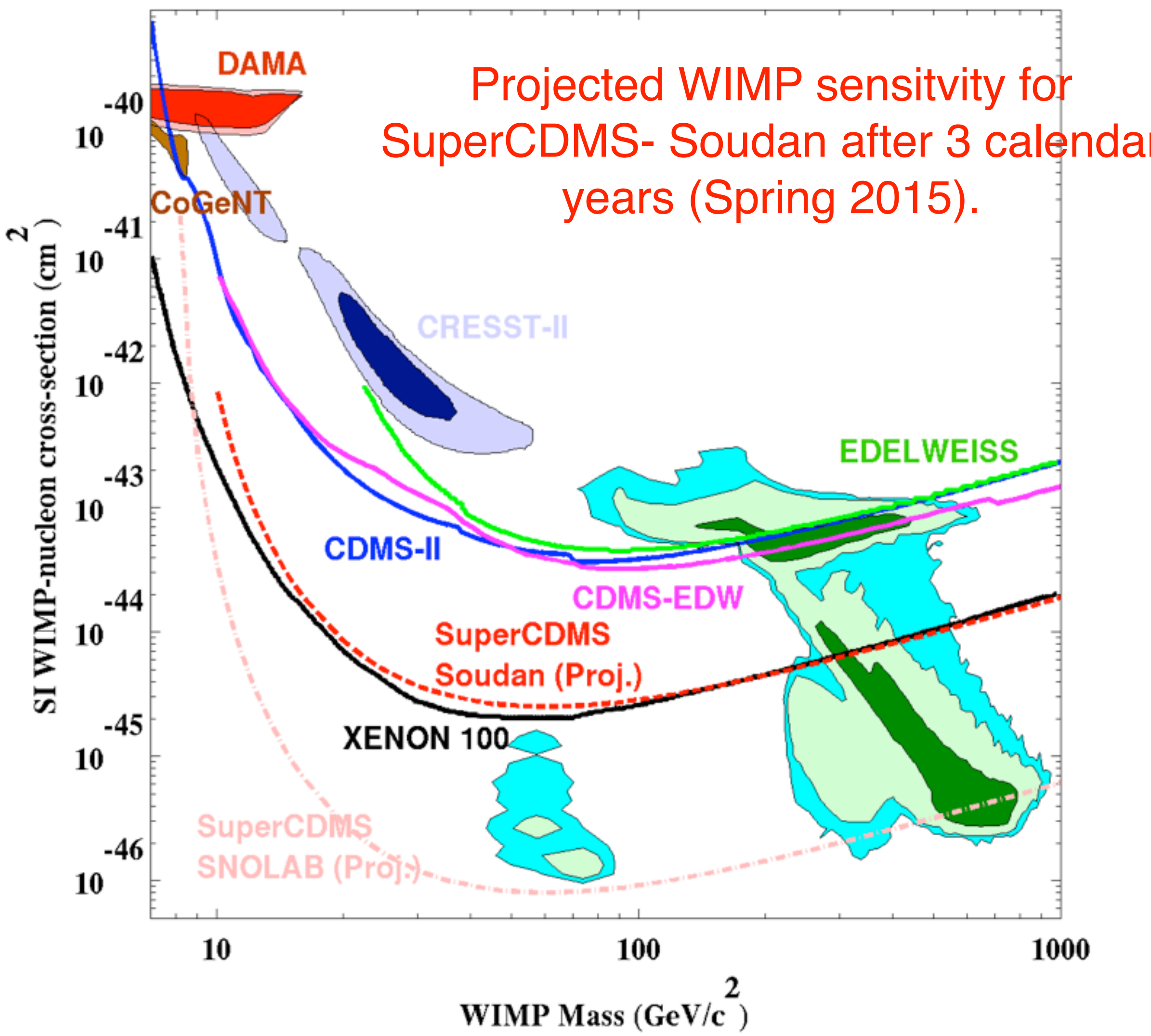
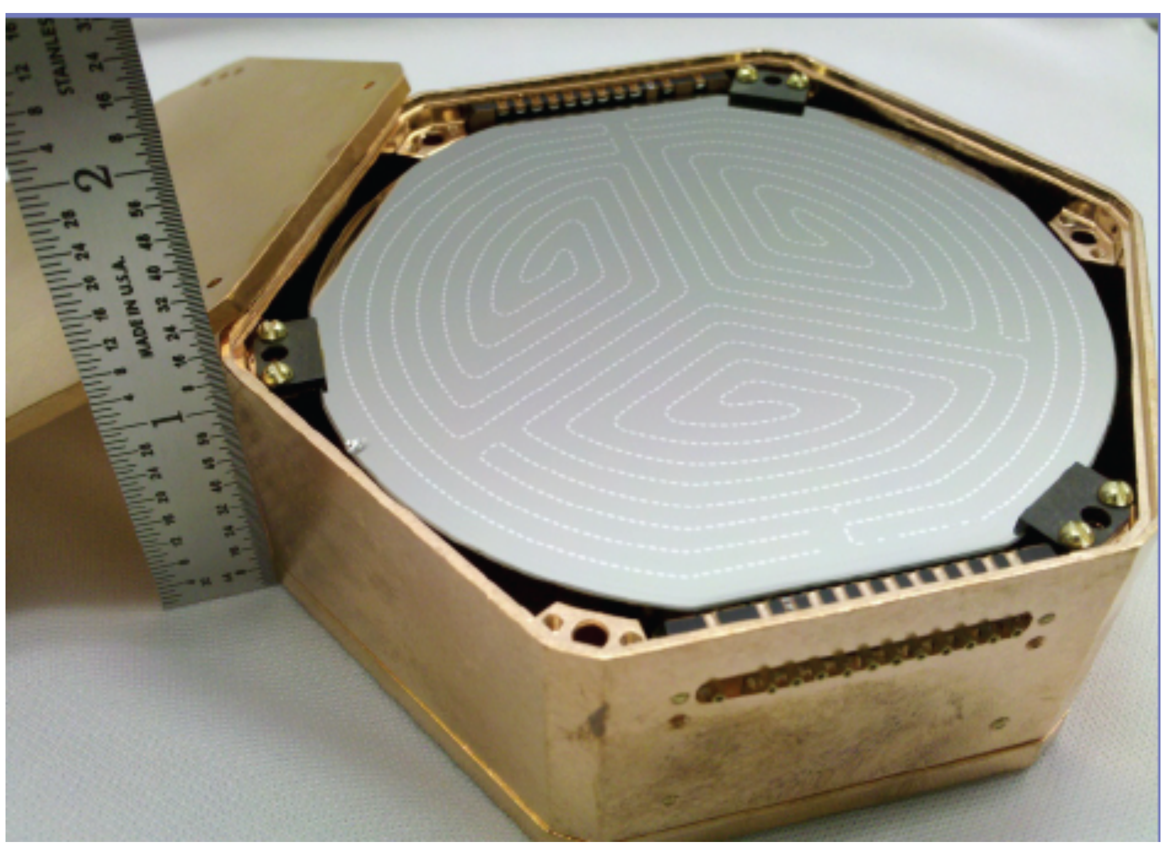


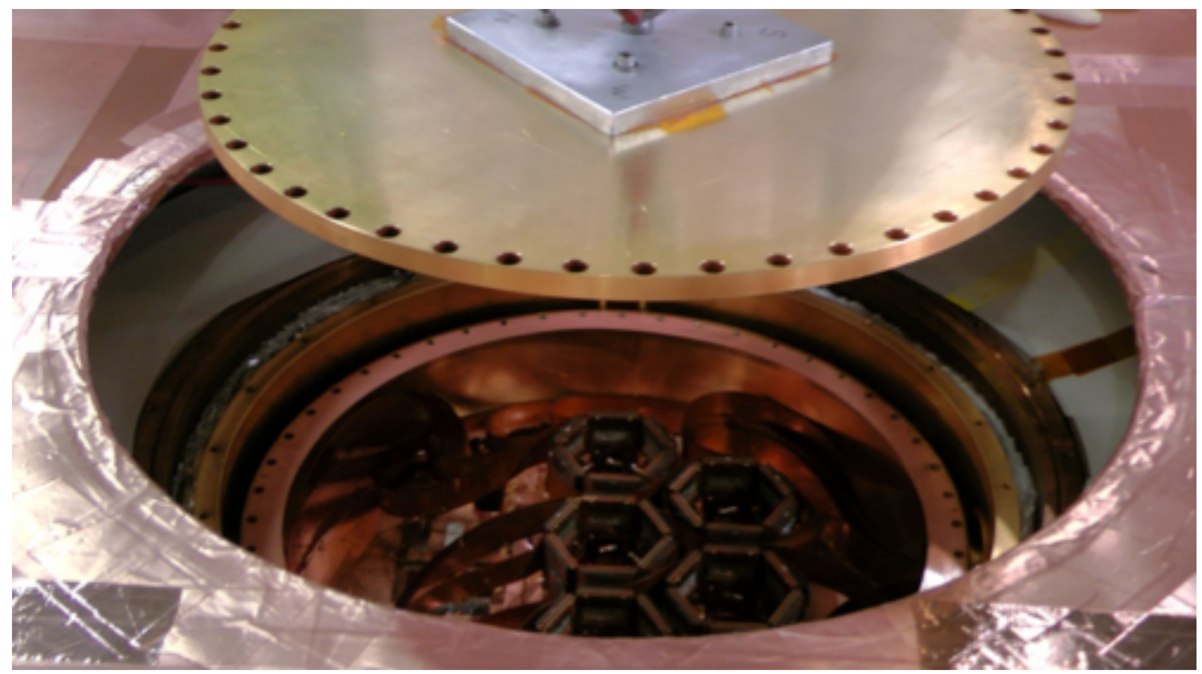

LEVEL NO. 27
2341 FEET BELOW THE SURFACE
689 FEET BELOW SEA LEVEL

- SuperCDMS Soudan: array of 15 iZIPs in the Soudan infrastructure built for CDMS-II

- Factor >x10 sensitivity increase over CDMS-II
    - Larger detector mass (x2.5 thicker detectors)
    - Fiducial fraction improved to ~50% from 35%
    - Surface background negligible

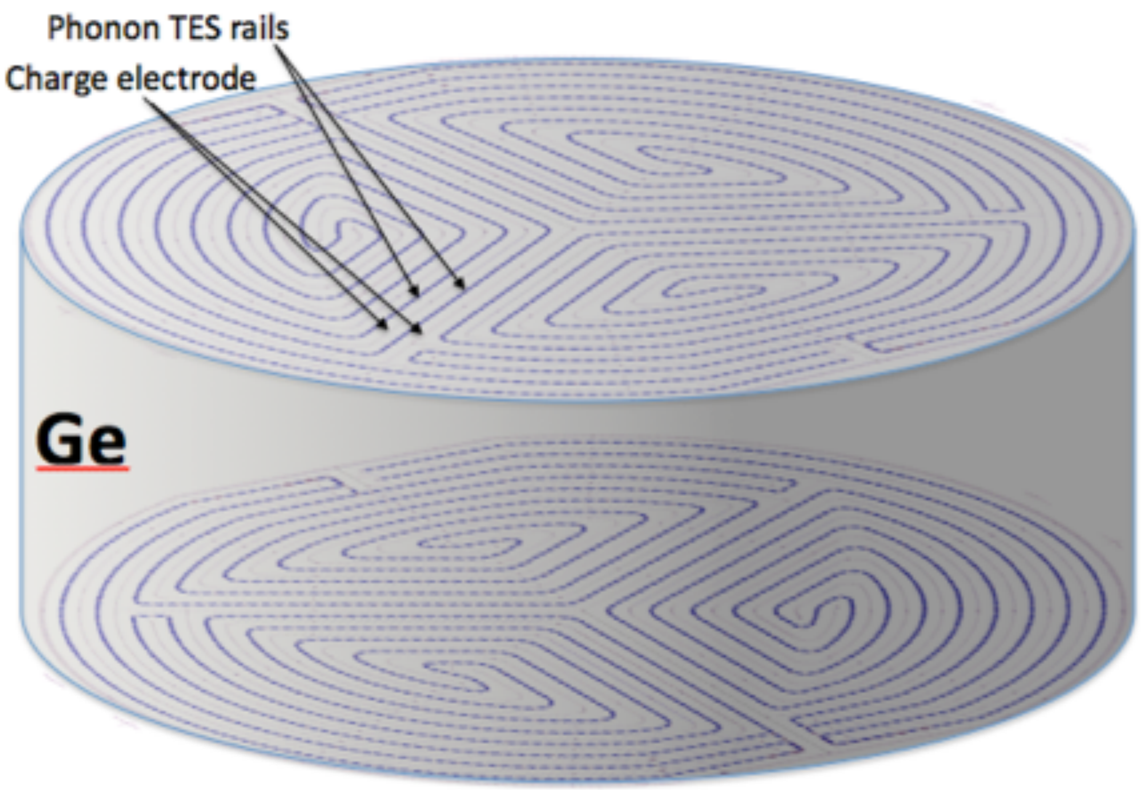


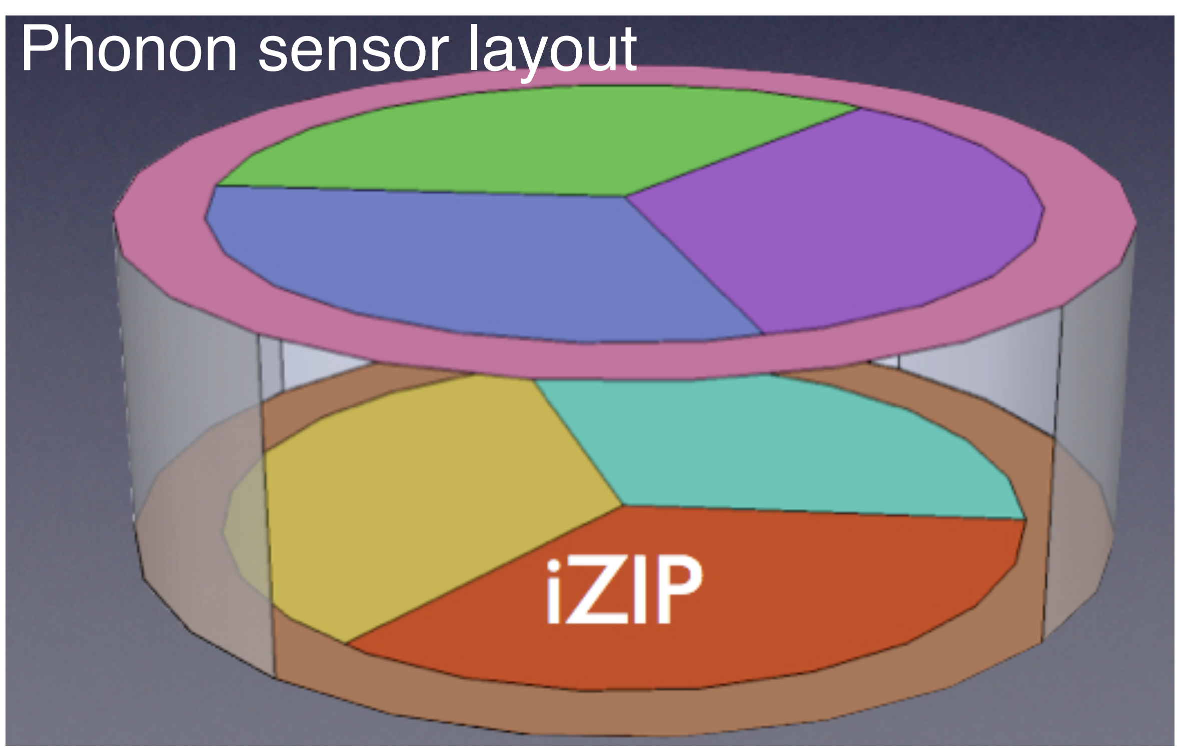




Installation complete Nov. 8, 2011.Detectors have been operating in DM-search mode since March 2012.

The iZIP





- 76 x 25 mm interleaved ZIP (iZIP) double sided detectors

  (2.5x thicker than CDMS II)

- Ionization electrodes are interleaved with narrow strips of phonon sensors.

  Phonon sensors optimized to enhance phonon signal to noise ratio

- Optimized phonon sensor layout

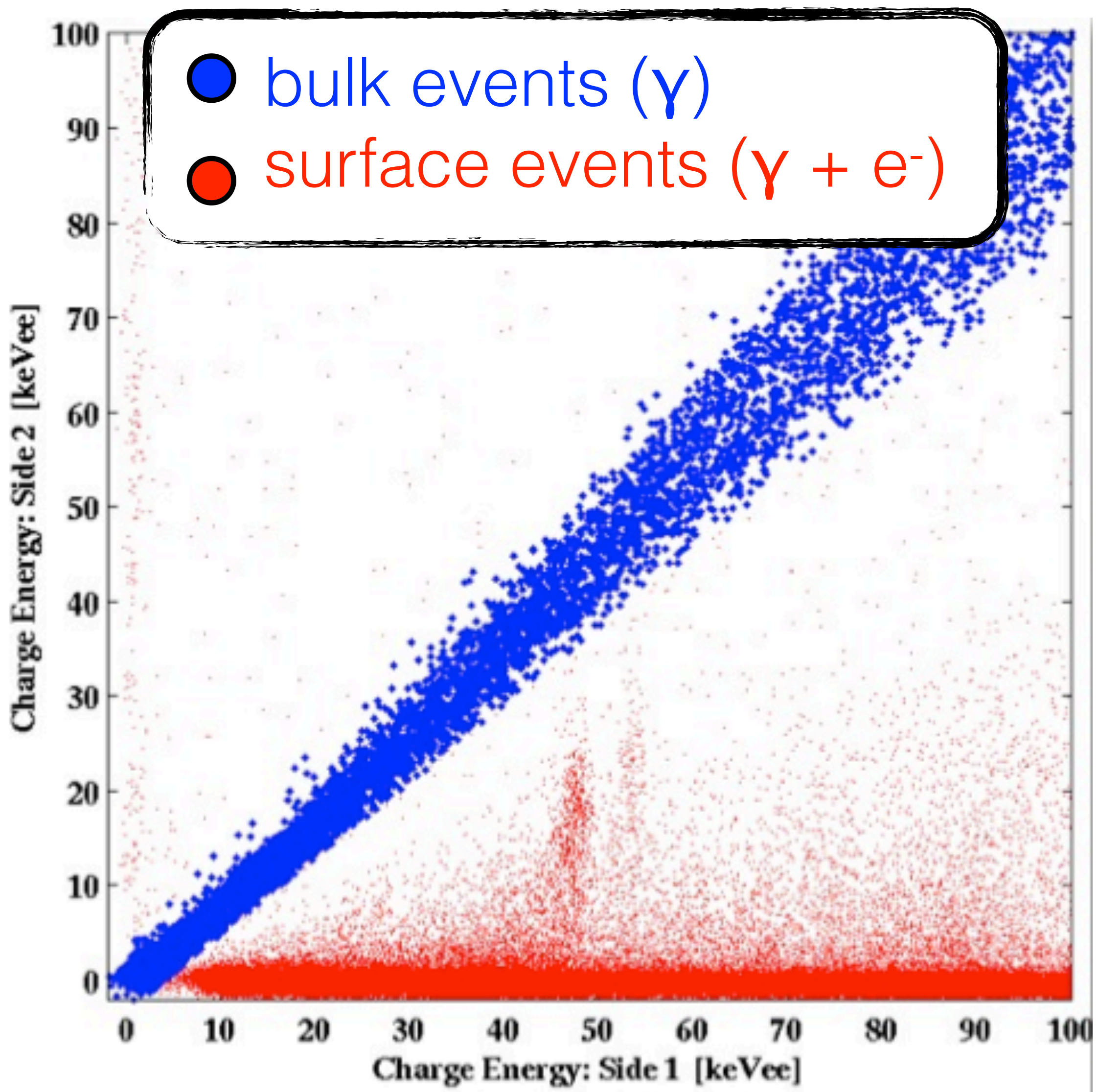
  Each side has one outer channel to reject zero charge events and 3 inner channels to reject surface events.

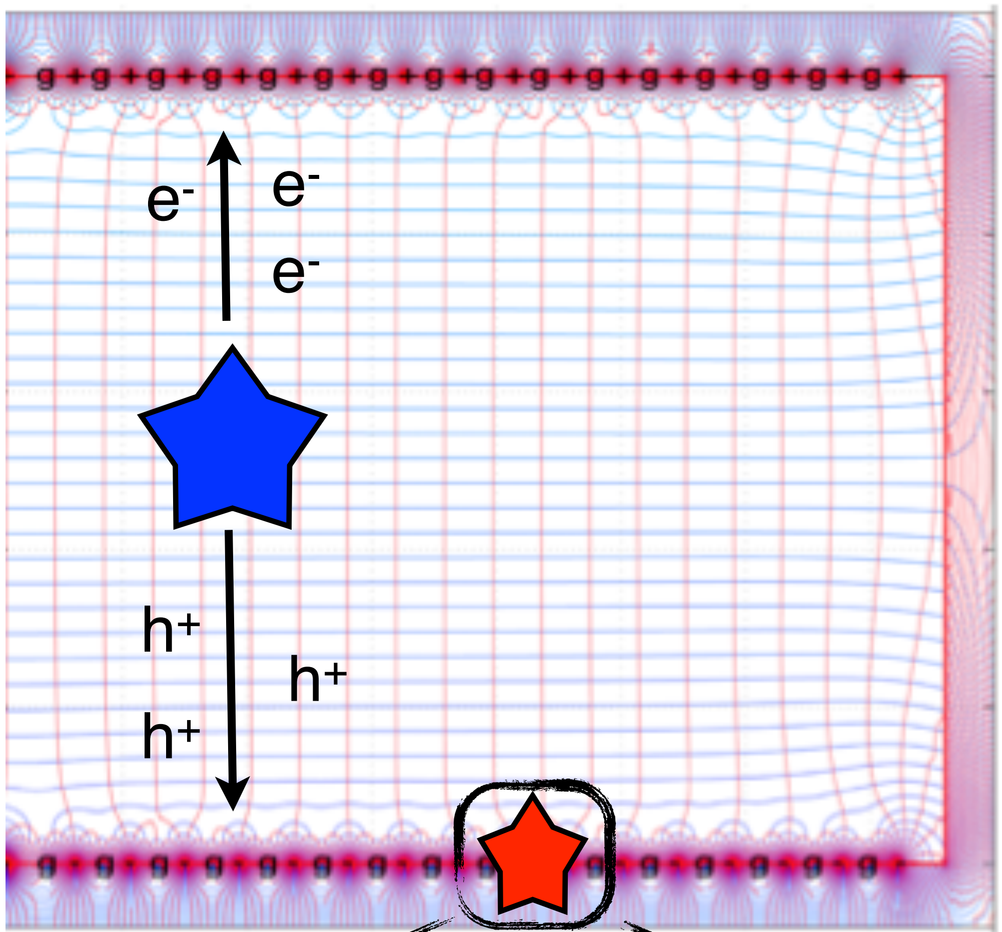
- Ionization channels can be used to reject surface events

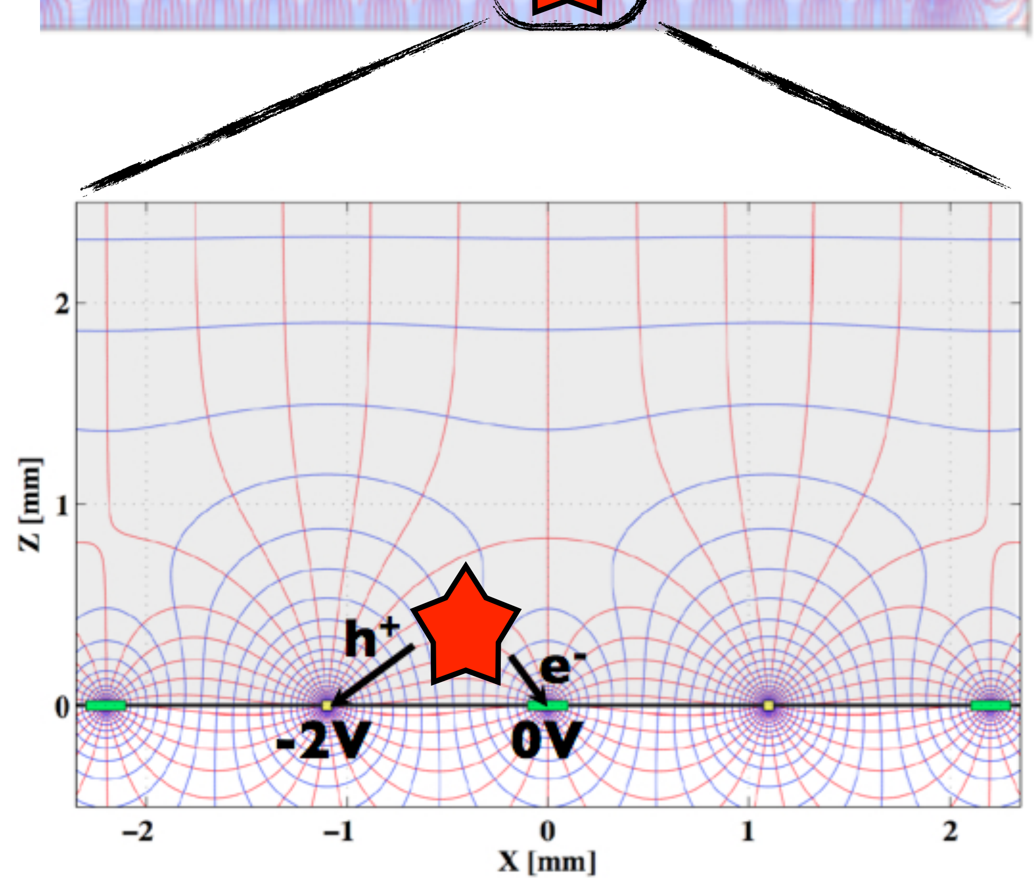
SuperCDMS iZIPs: Charge signal

Bulk Events:
Equal but opposite ionization signal appears on both sides of each detector (symmetric)

Surface Events:
Ionization signal appears on one detector side (asymmetric)







SuperCDMS Soudan: ^{210}Pb test

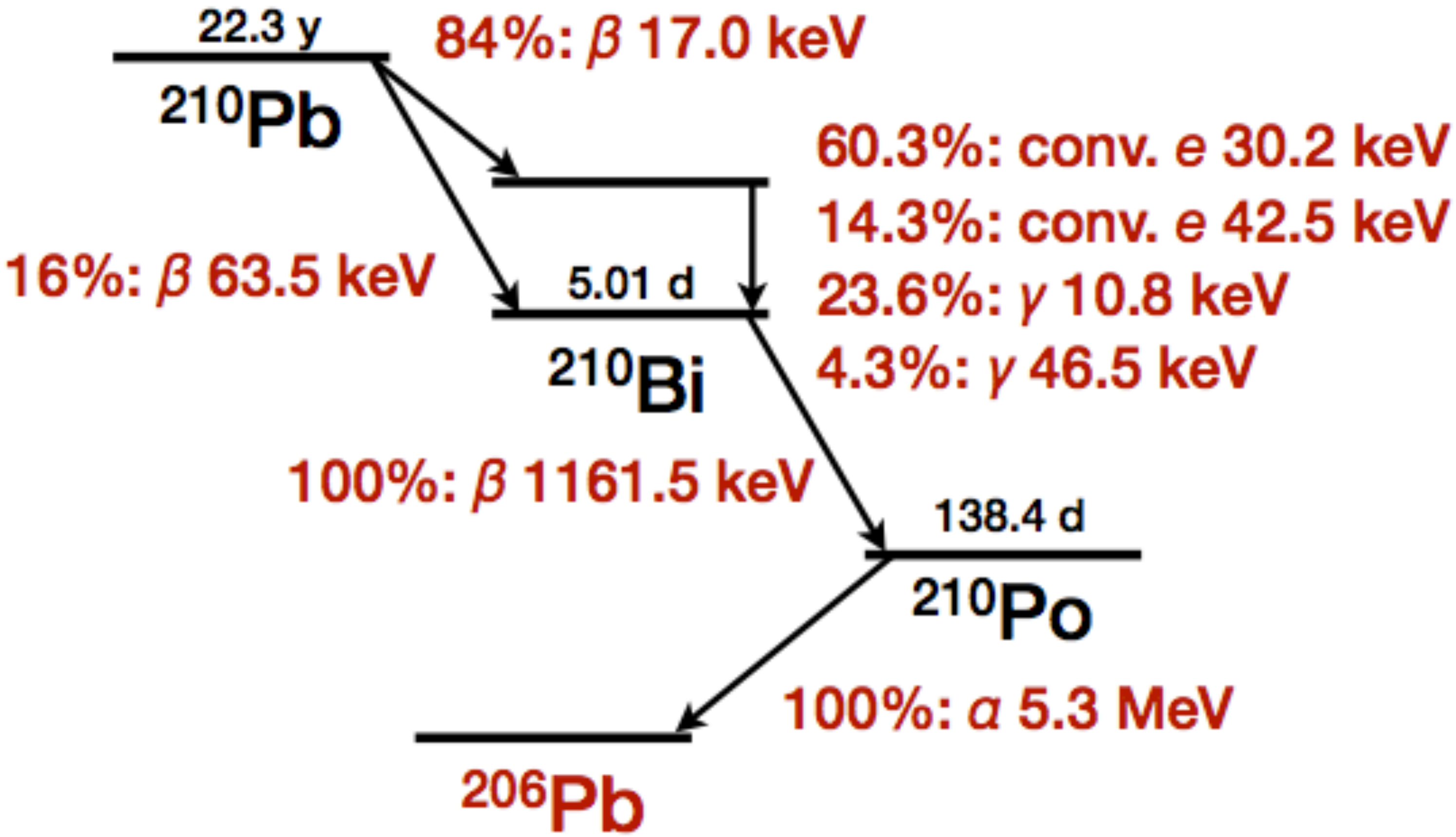
Installed ^{210}Pb implanted Si wafers facing two detectors

Activity of 1000 Pb decays per day

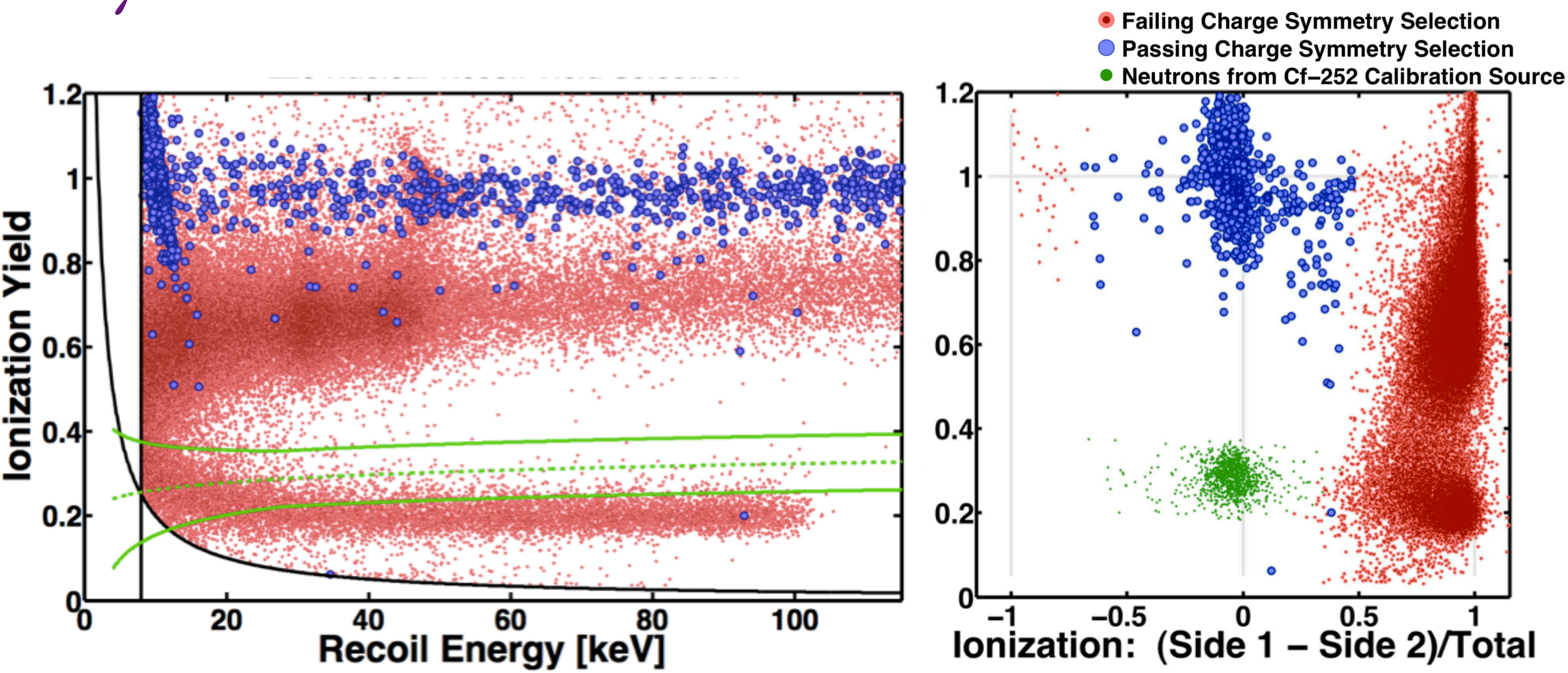
Allows performance verification of surface event identification

CDMS-II achieved 1:1200 rejection with a 35% fiducial volume

The goal for a 200 kg array of iZIPs (SuperCDMS-SNOLAB) is 70 times better rejection with twice the fiducial volume



SuperCDMS Soudan: ^{210}Pb test



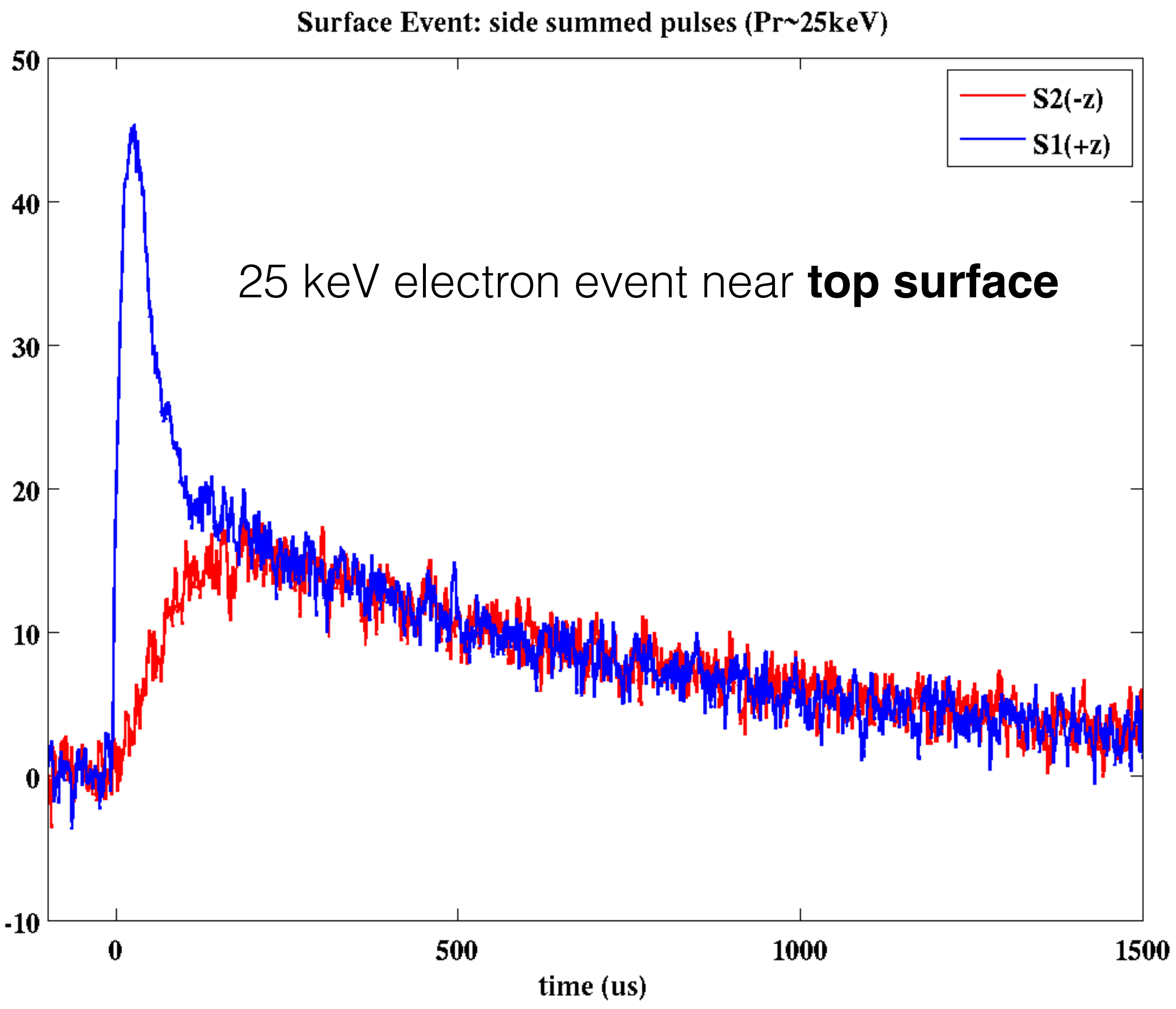
- ~65,000 electrons and ~15,000 ^{206}Pb recoil surface event collected from ^{210}Pb source.
- No events leaking into the signal region into ~50% fiducial volume (8-115 keVnr) in 37.6 live time days (March - July 2012)
- Limits surface events leakage to 1.7 x 10^{-5} @90% C.L.
- Ionization collection at the surface is significantly improved over CDMS-II detectors
- Good enough for a 0.3 ton-year exposure for SuperCDMS@ SNOLAB!

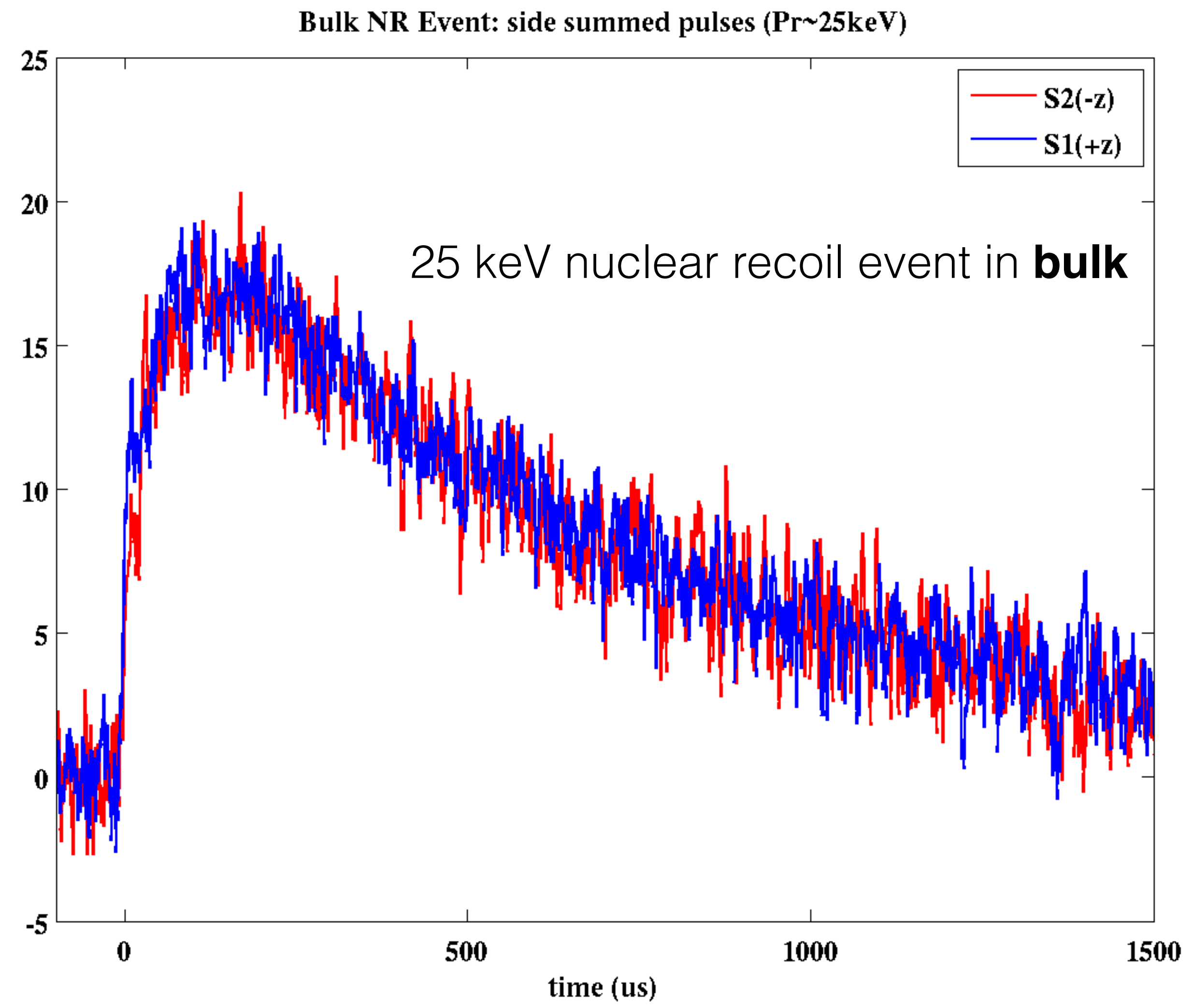
http://arxiv.org/abs/1305.2405

SuperCDMS iZips: Phonon signal

Phonon timing pulse information still possible.

Surface electron vs bulk nuclear recoil event discrimination





PULSE SHAPE HAS NOT YET BEEN USED! (It's not needed.)

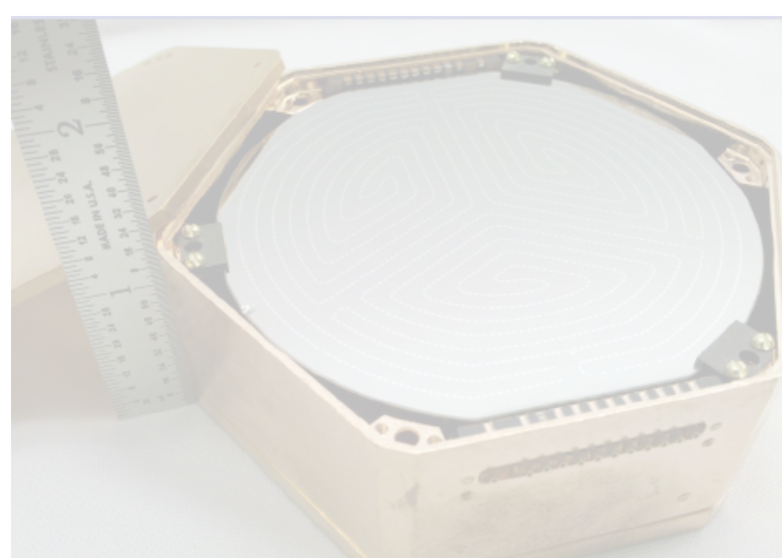
SuperCDMS SNOLAB

CDMS II (Ge+Si)

- 4.6 kg Ge (19 x 240 g)
- 1.2 kg Si (11 x 106g)
- 35% NR acceptance

SuperCDMS Soudan

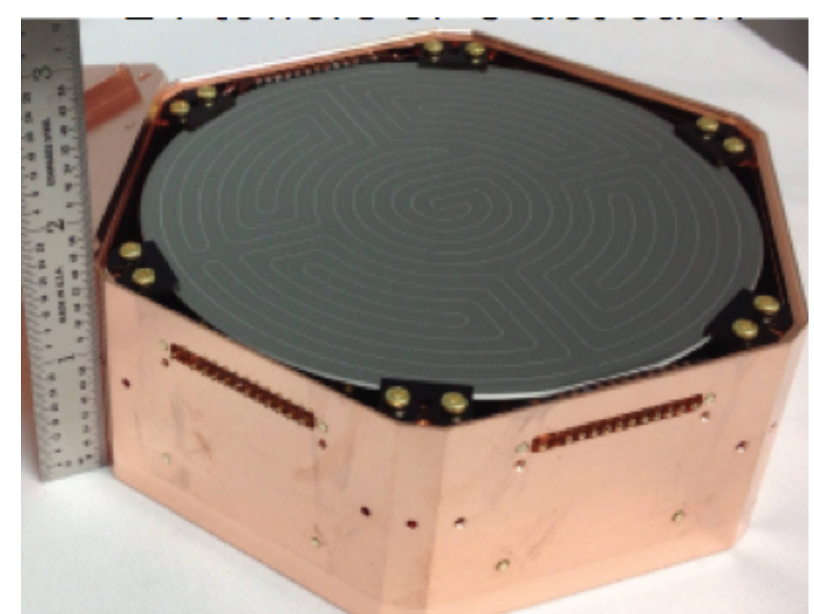
- Increased mass: 9.0 kg Ge (15 x 600 g)
- Increased acceptance
- Improved surface event discimination

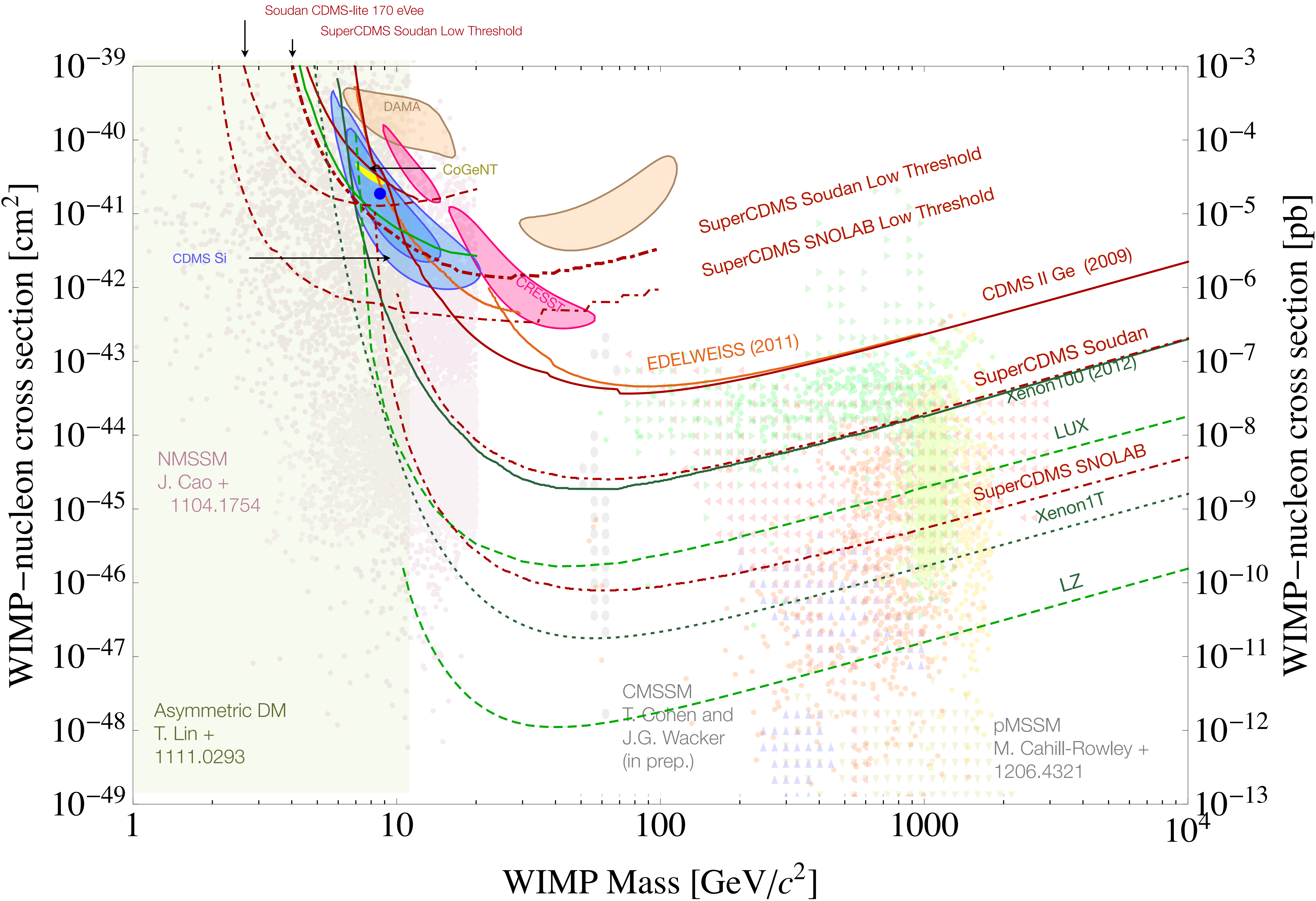


SuperCDMS SNOLAB

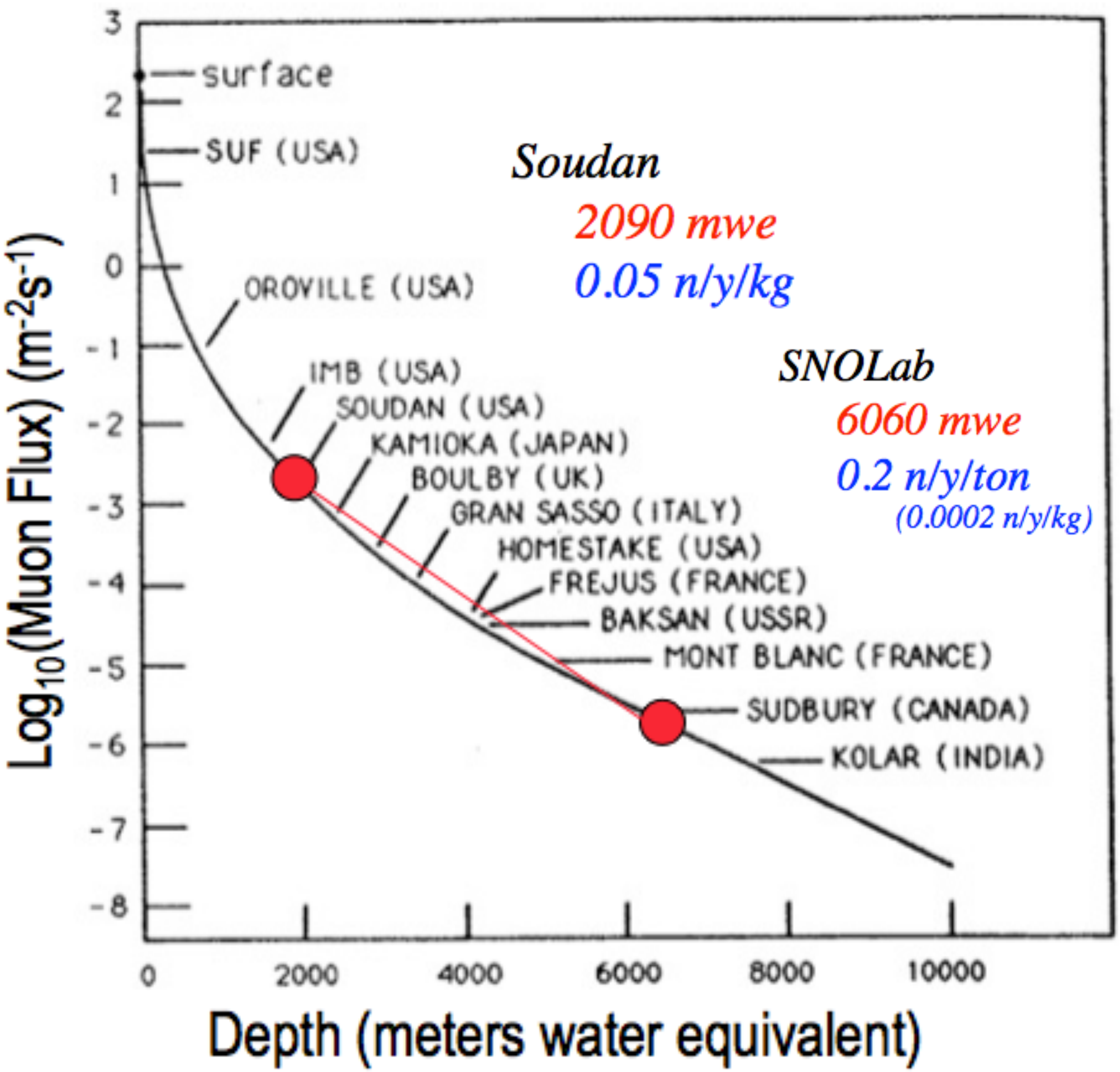
- **Proposed 200kg Ge array**
- **Extensive R&D underway**
- **Scale to 1 kg crystals**

Projected sensitivity of 8 x 10^{-47} cm^2




Soudan CDMS-lite 170 eVee
SuperCDMS Soudan Low Threshold
DAMA
CoGeNT
CDMS Si
CRESST
SuperCDMS Soudan Low Threshold
SuperCDMS SNOLAB Low Threshold
CDMS II Ge (2009)
EDELWEISS (2011)
SuperCDMS Soudan
Xenon100 (2012)
LUX
SuperCDMS SNOLAB
Xenon1T
LZ
NMSSM
J. Cao +
1104.1754
Asymmetric DM
T. Lin +
1111.0293
CMSSM
T. Cohen and
J.G. Wacker
(in prep.)
pMSSM
M. Cahill-Rowley +
1206.4321
WIMP–nucleon cross section [cm^2]
WIMP–nucleon cross section [pb]
WIMP Mass [GeV/c^2]

Deeper underground



- Reduce muon flux by factor of 500
- Reduce high-energy neutron flux by a factor 100
- Only need to worry about neutrons from residual radioactivity only

Resulting from fission and alpha-n interactions from U, Th in cavern rock

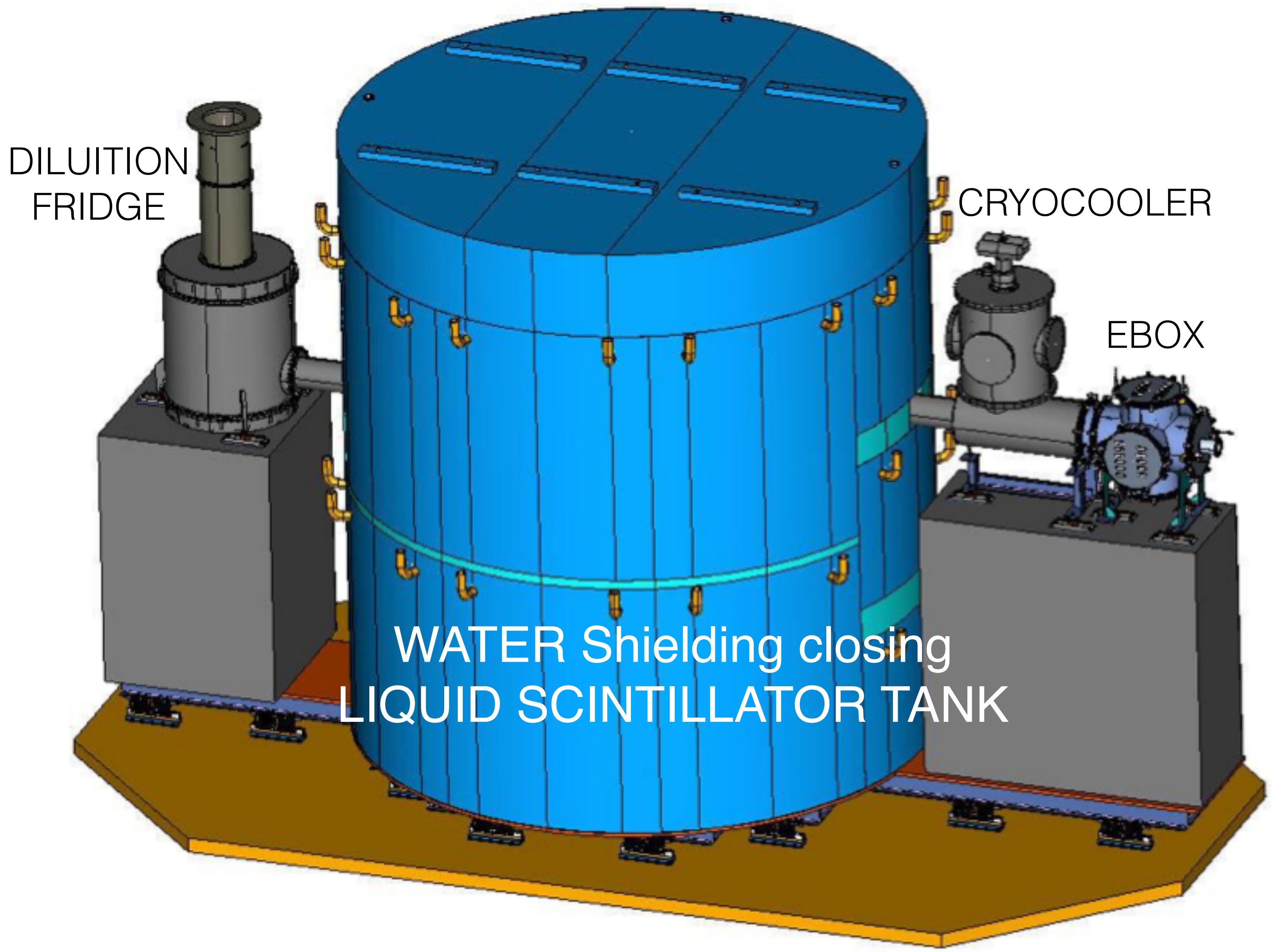
-> Expected to be negligible with passive shielding

Resulting from fission and alpha-n interactions from U, Th in copper cans, shielding and supports.

-> Expected to be ~1, depending on material cleanliness

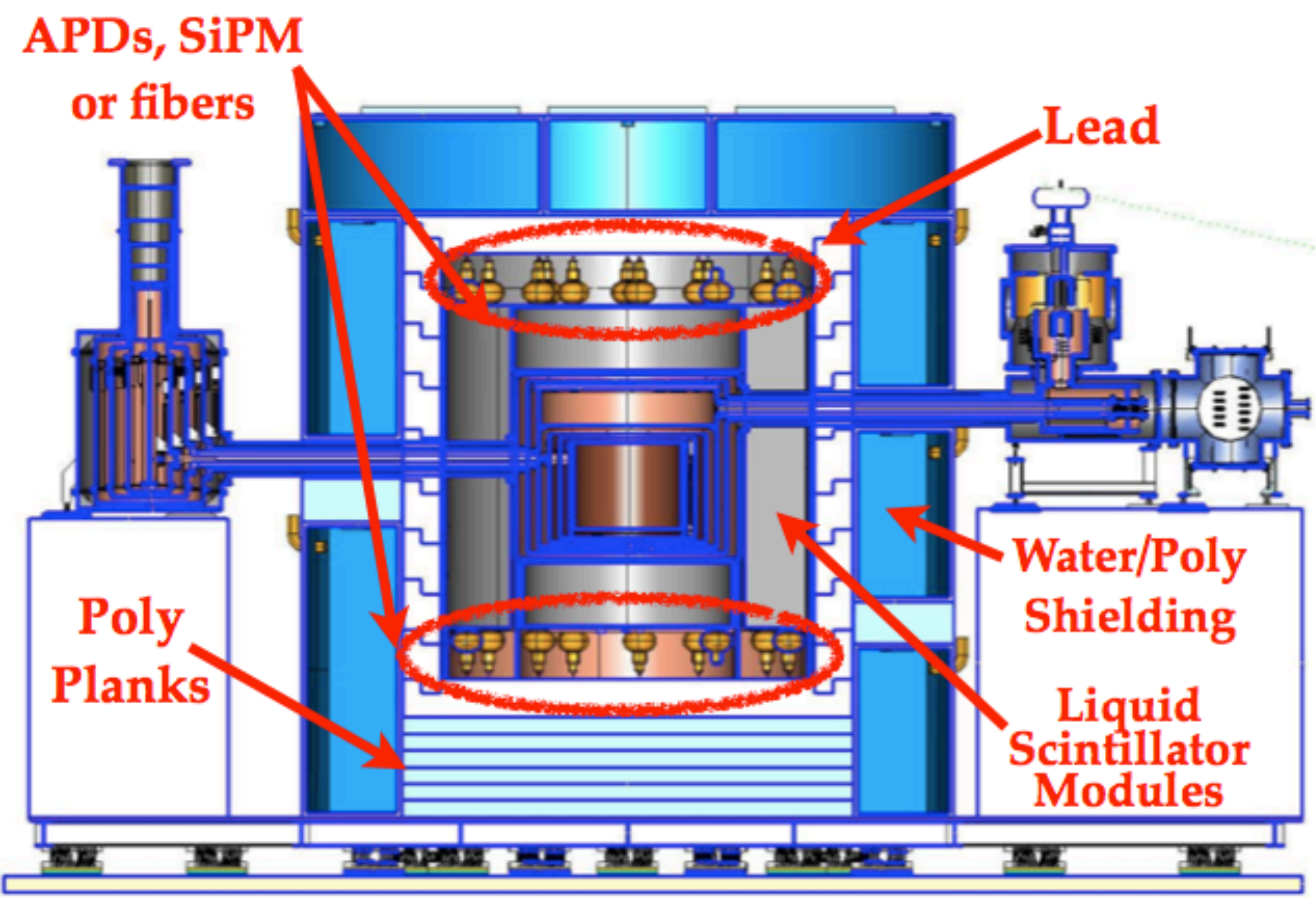
Experimental Set-up

Dimensions:
13 feet diameter
14 feet height



- Cryostat volume of up to 400 kg target
- 200 kg experiment with sensitivity of 8 x 10^{-47} cm^2 at 60 GeV/c^2
- Pb/Cu shielding for external radiation
- Increased PE shielding (neutrons)
- Possible neutron veto

Current Design



Surround the cryostat with a high efficiency neutron detector to tag neutrons.

Modular tanks of liquid scintillator, with radial thickness 0.4 m, viewed by phototubes.

Details of scintillator to use (water, Gd or B loaded) under consideration.

LAB doping

Boron

-> ALPHA (~3 MeV) + GAMMA (500keV)
-> observed light may be as low as 50keVee

Challenges:
minimize environmental radioactivity by
constructing the detector out of
radiopure materials,
developing a clean boron-loaded
scintillator,
utilizing adequate shielding for the
neutron veto.
energy threshold

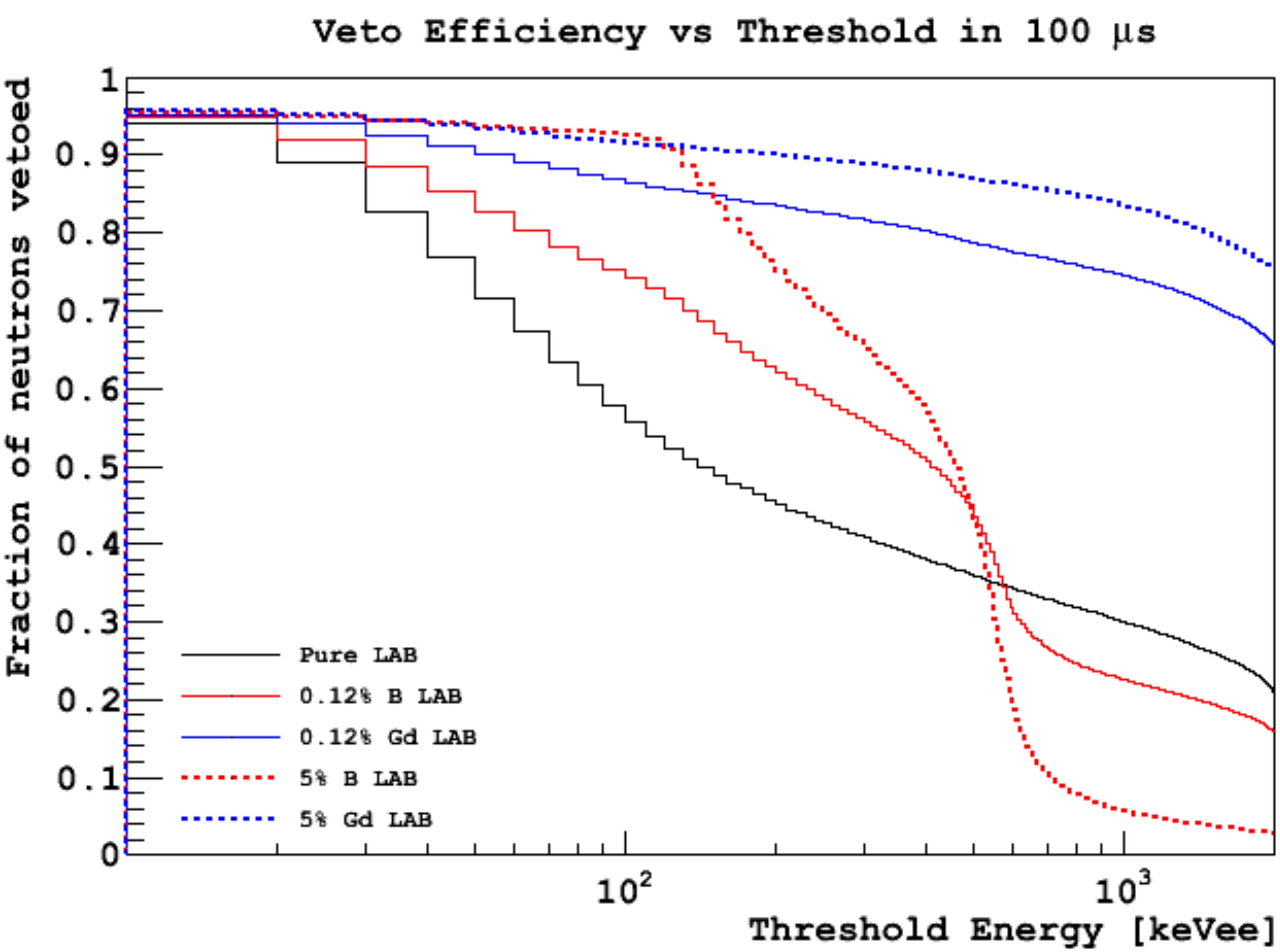
Gadolinium

-> GAMMA cascade 8MeV
(> ^{208}Tl line ~2.7MeV)

- Reduction outer shielding
- It has been demonstrated by Daya Bay experiment

BUT
decreased efficiency for detecting
internal neutrons
possible introduction of radio
contaminant (Gd is less pure than B)

Efficiency



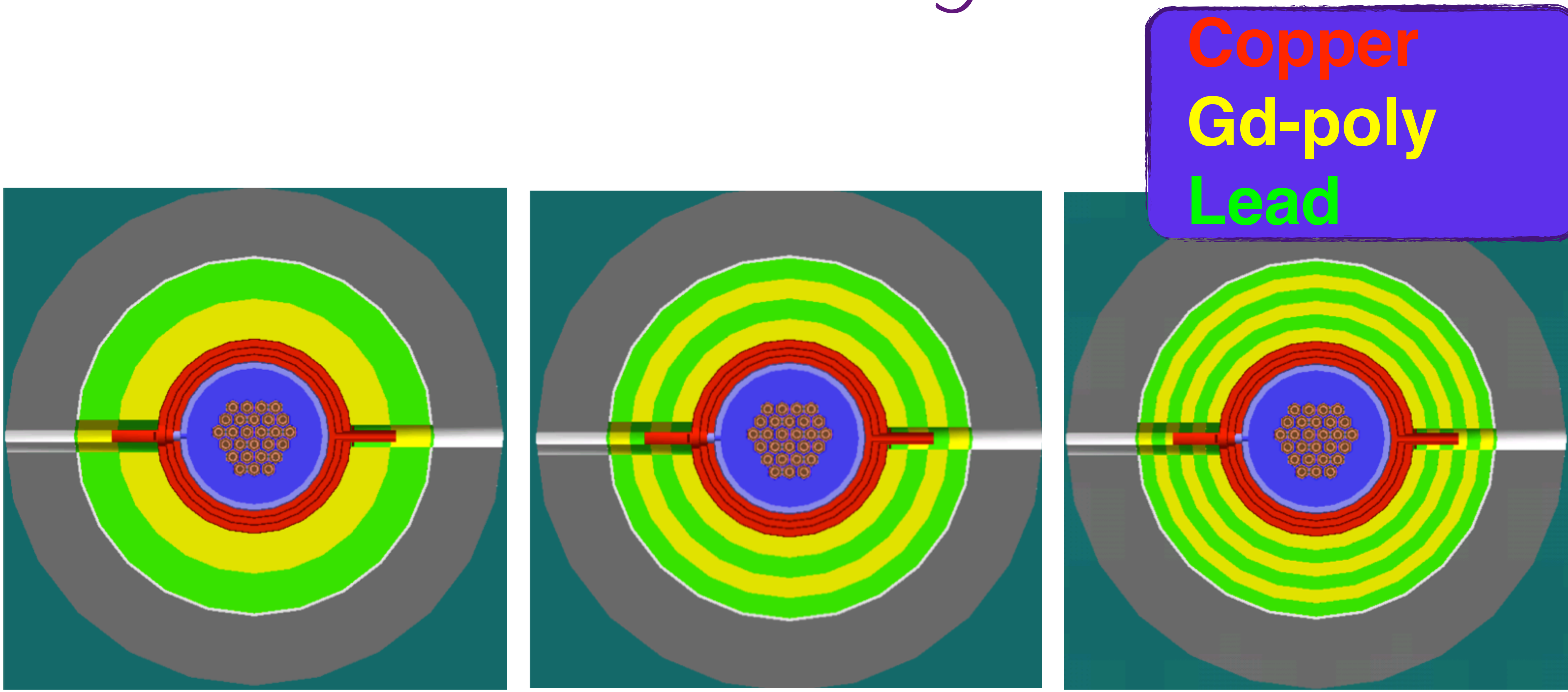
Veto efficiency vs threshold for 100mus veto times for recoil events.

Recoil events: passing the energy deposition criteria (10 -100keV) and >10% of the deposited energy must have come via recoils

Any WIMP candidate in coincidence with a veto energy deposit larger than the chosen energy threshold would be tagged and rejected.

Gd-doped LAB is less threshold dependent.

Alternate Design



- Alternating layers of Gd-loaded poly/scintillator and lead.
- Preliminary studies underway.

Conclusions

- SuperCDMS-Soudan (~9 kg) is taking data with iZIP detectors and expects to reach a WIMP-nucleon sensitivity of 2 x 10^{-45} cm^2 for spin- independent interactions.

- We have demonstrated surface event rejection with the new iZIP detector design using ^{210}Pb sources which paves the way for better than 10^{-46} cm^2 sensitivity at SNOLAB.

- Screening facility at LUMINA Lab is an important instrument for any background-free experiment (direct dark matter, double beta decay experiments)

- Ongoing studies are assessing the necessity and feasibility of including a neutron veto in the SuperCDMS-SNOLAB design

- SuperCDMS-SNOLAB will extend the sensitivity by over an order of magnitude with an increased target mass of 200 kg and suppression of backgrounds through better shielding design, materials selection, and materials handling as well as the added depth to suppress backgrounds from cosmic-ray showers

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