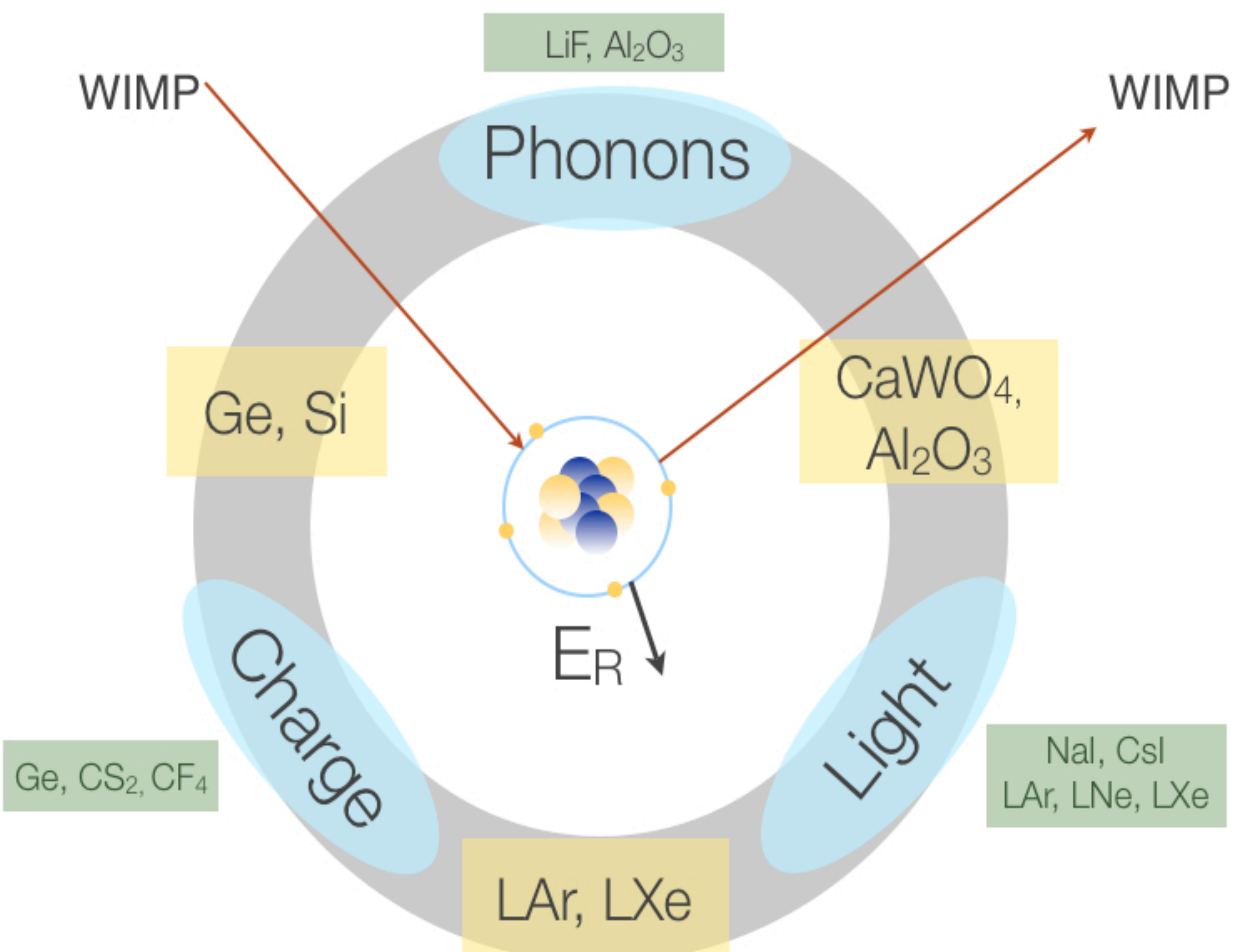
Recent results from CDMS II
Status and future of the SuperCDMS experiment

Silvia Scorza
Southern Methodist University
for the SuperCDMS Collaboration

9th Patras Workshop

Direct Dark Matter Experiment

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



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

The SuperCDMS Collaboration

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Time

CDMS II (Ge+Si)

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

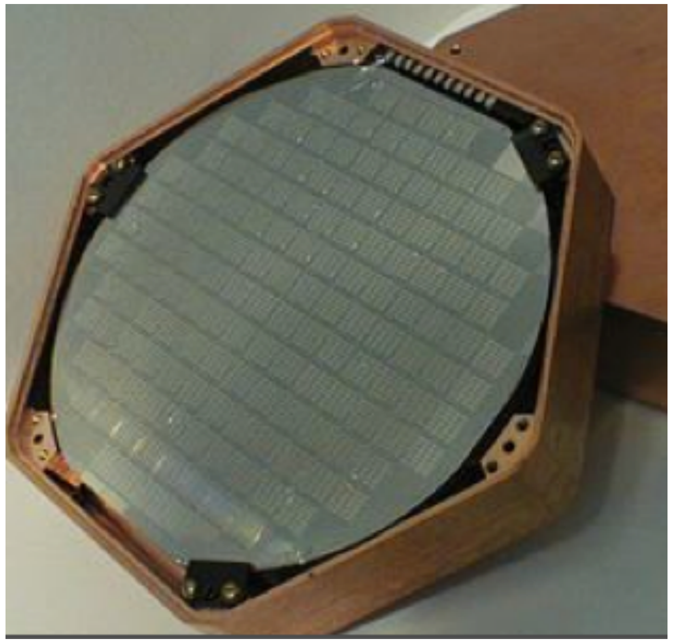
SuperCDMS Soudan

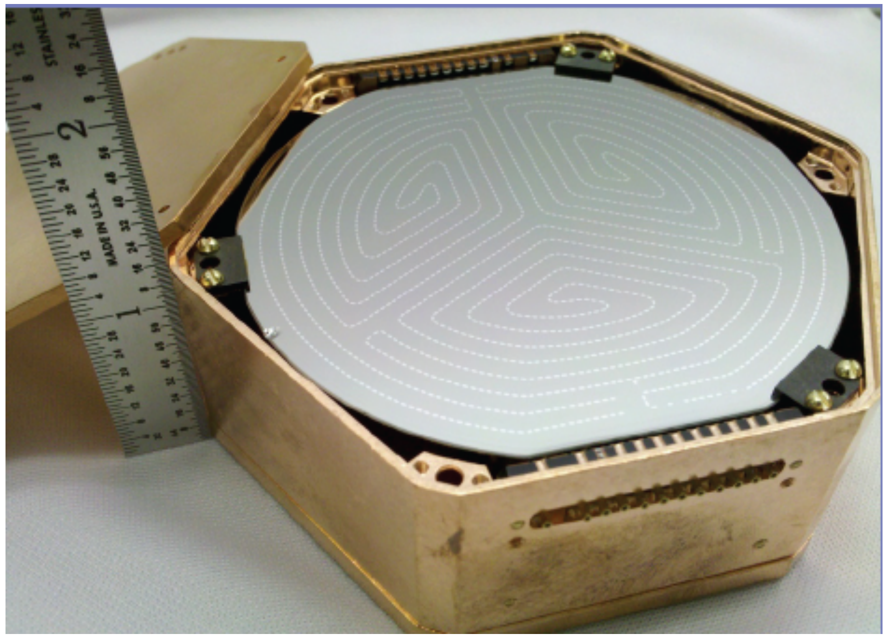
- Increased mass: 9.0 kg Ge (15 x 600 g)
- Increased acceptance
- Improved surface event discrimination

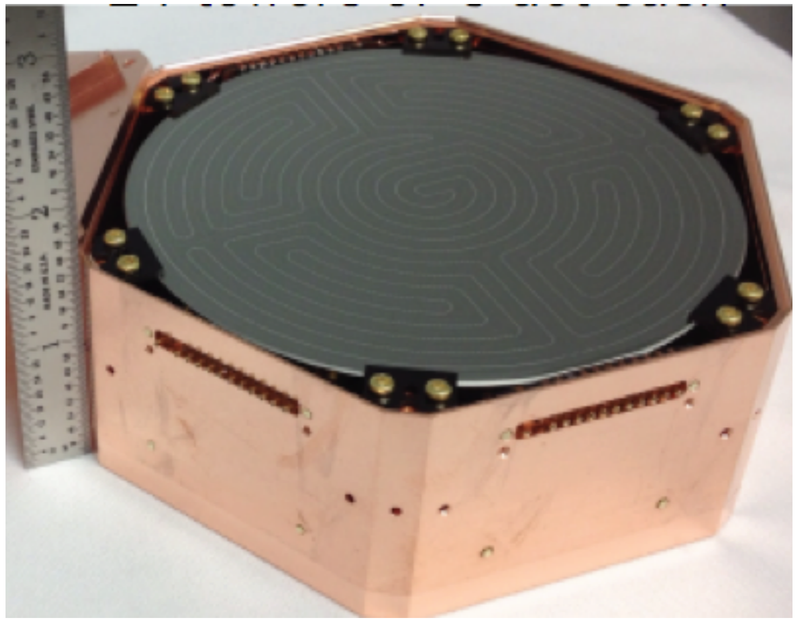
SuperCDMS SNOLAB

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

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







CDMS II

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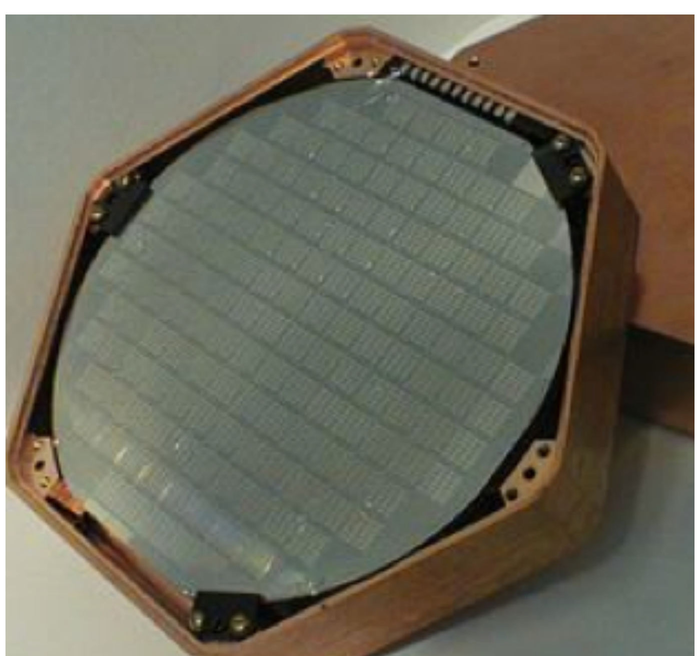

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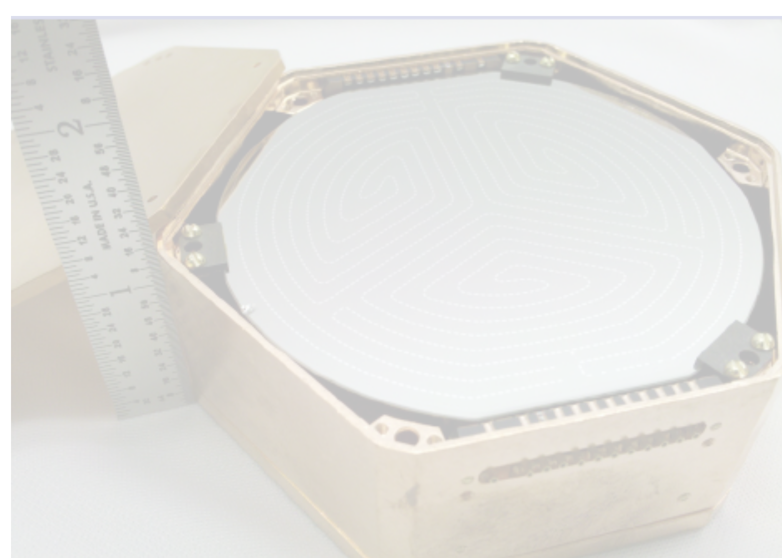

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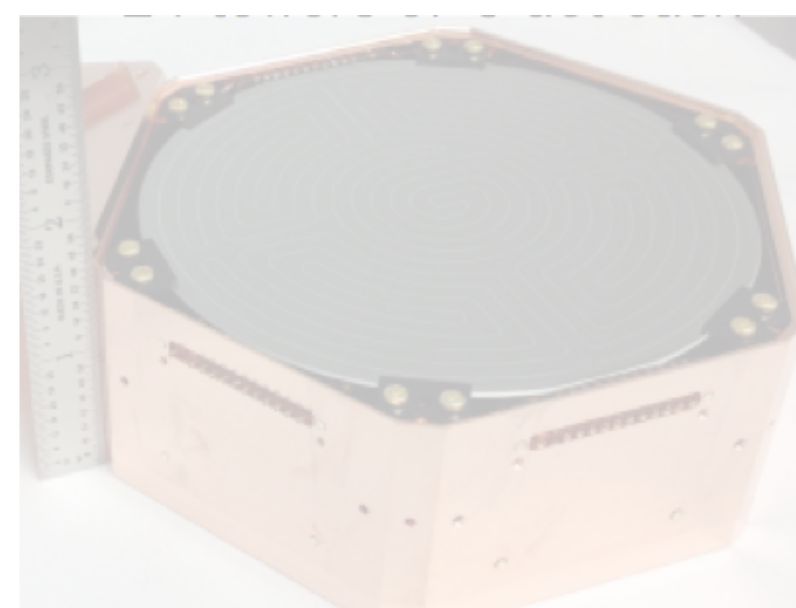
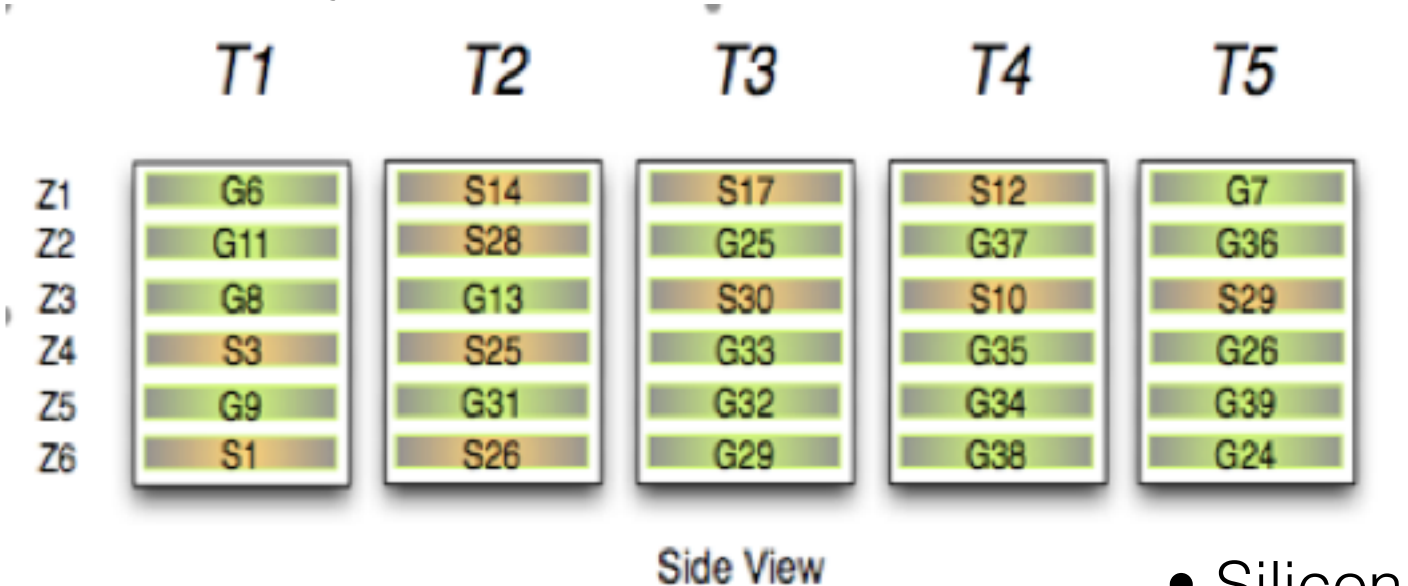
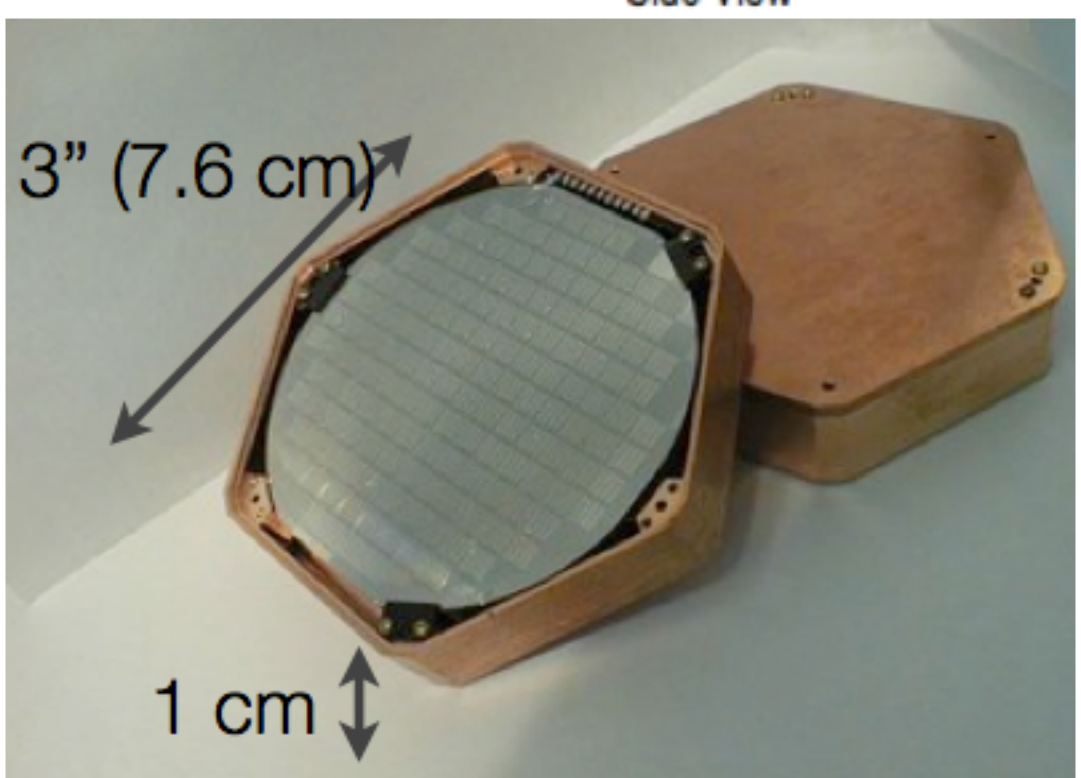
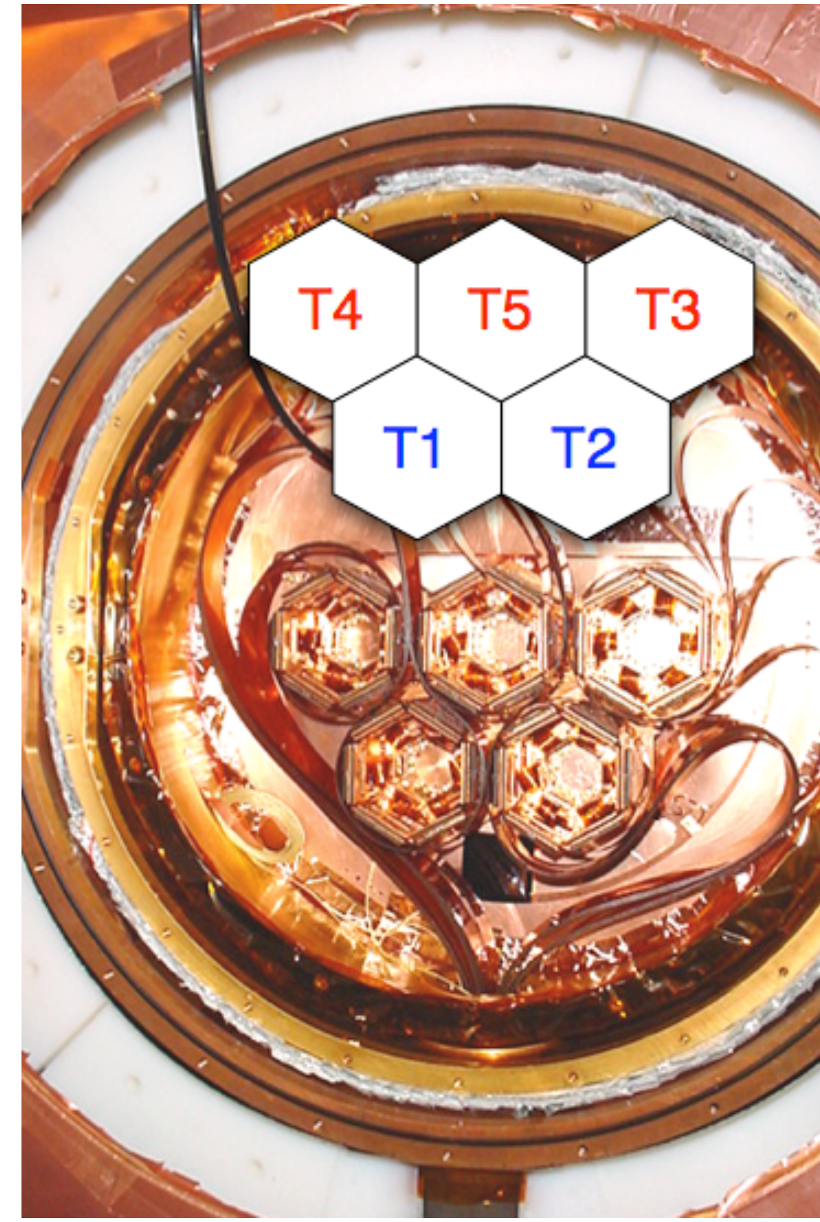


CDMS II: Si Analysis

CDMS II: Five towers, 30 detectors (19 Ge, 11 Si) installed and operated in the Soudan Underground Laboratory, MN, USA







- Silicon ZIP Detectors

  106 g crystals (1 cm x 7.6 cm)

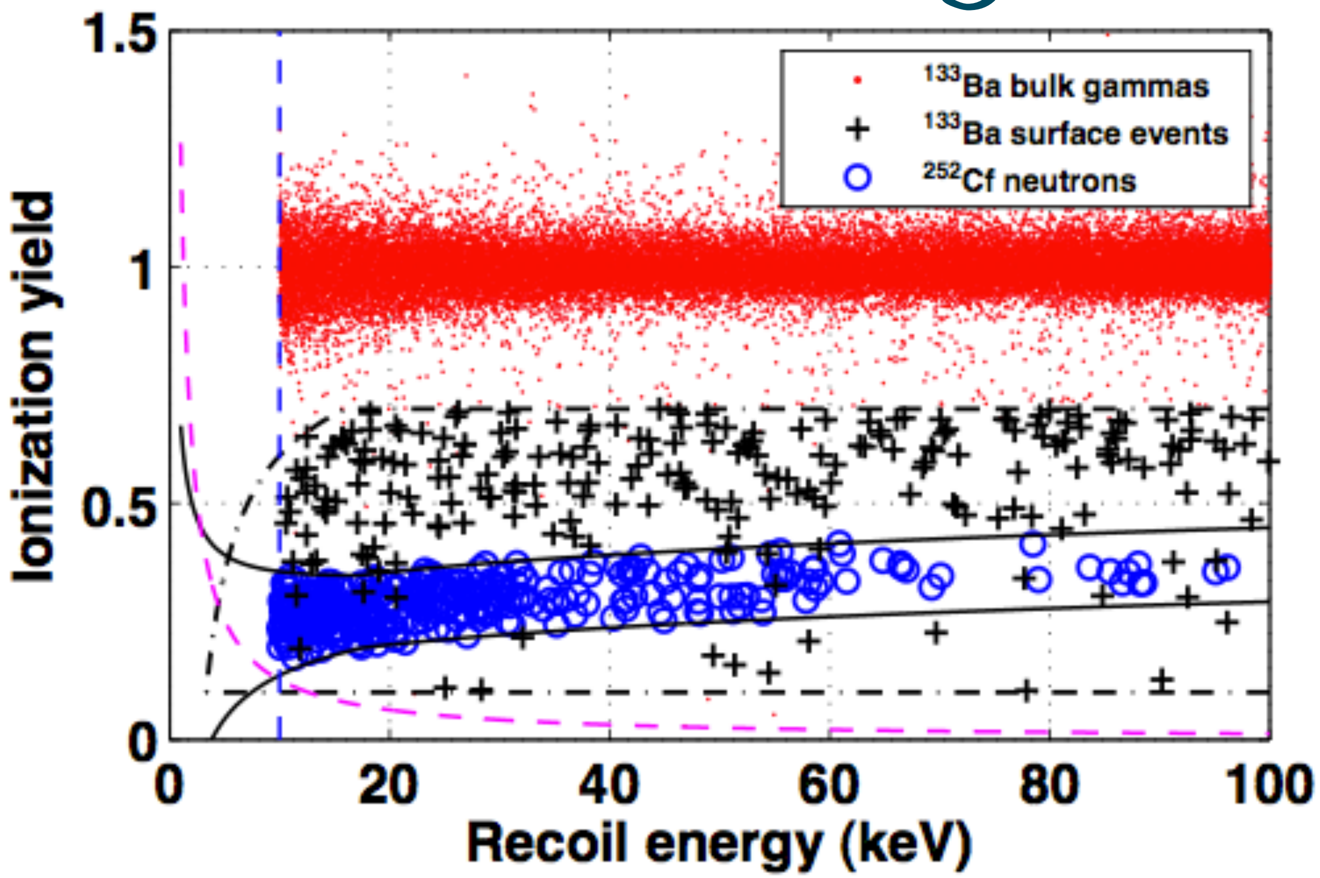
- CDMS II Exposure

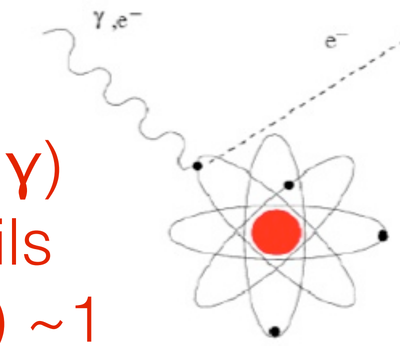
  July 2007 - Sept. 2008

  140.23 kg-days in 8 Si detectors

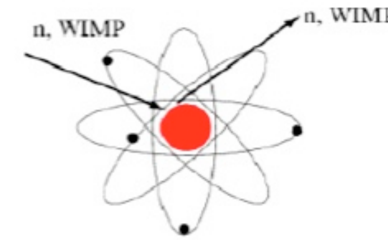
Lighter Si target nucleus is advantageous for low mass WIMP searches

Background Rejection

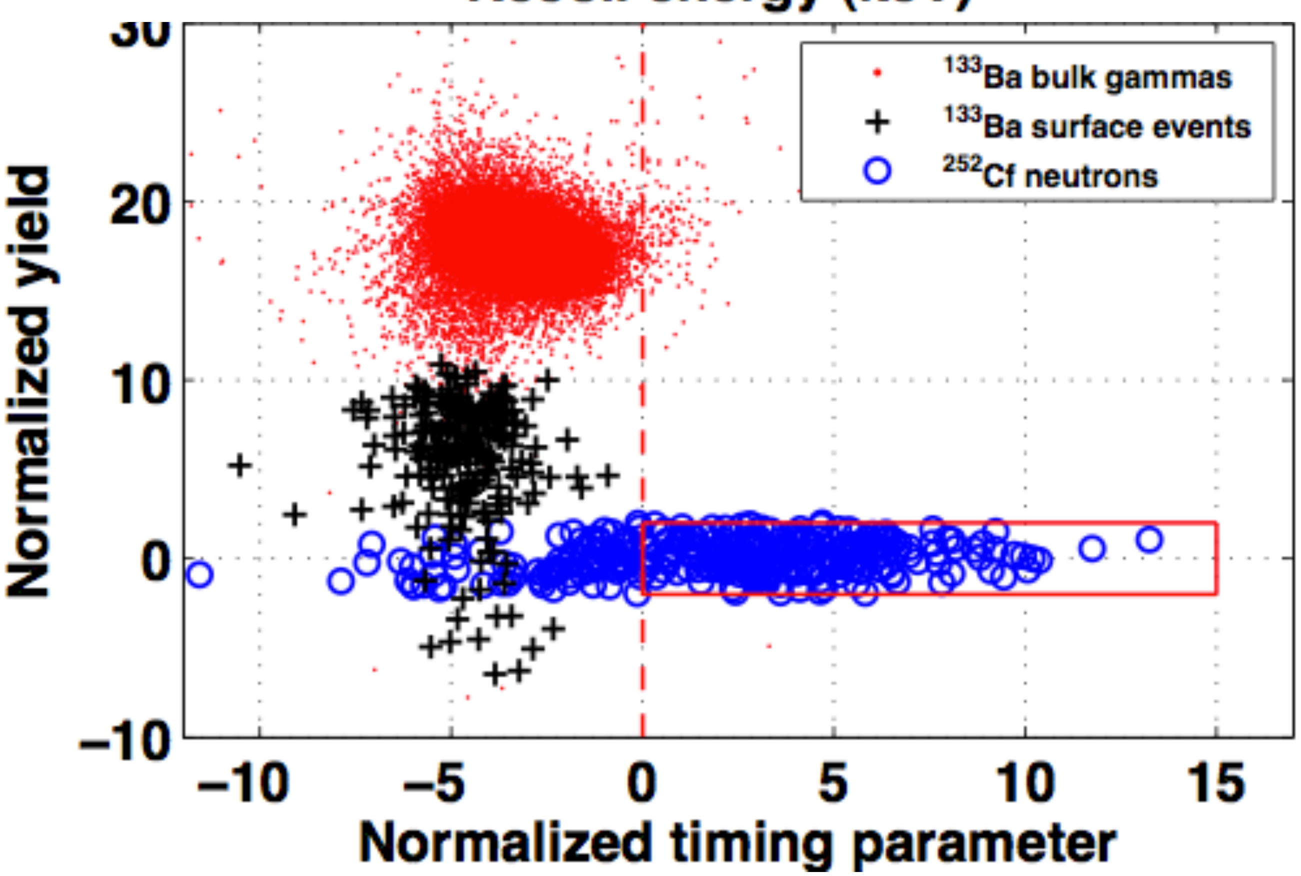




Most backgrounds (e, γ) produce electron recoils
Yield (Ionization/recoil) ~1



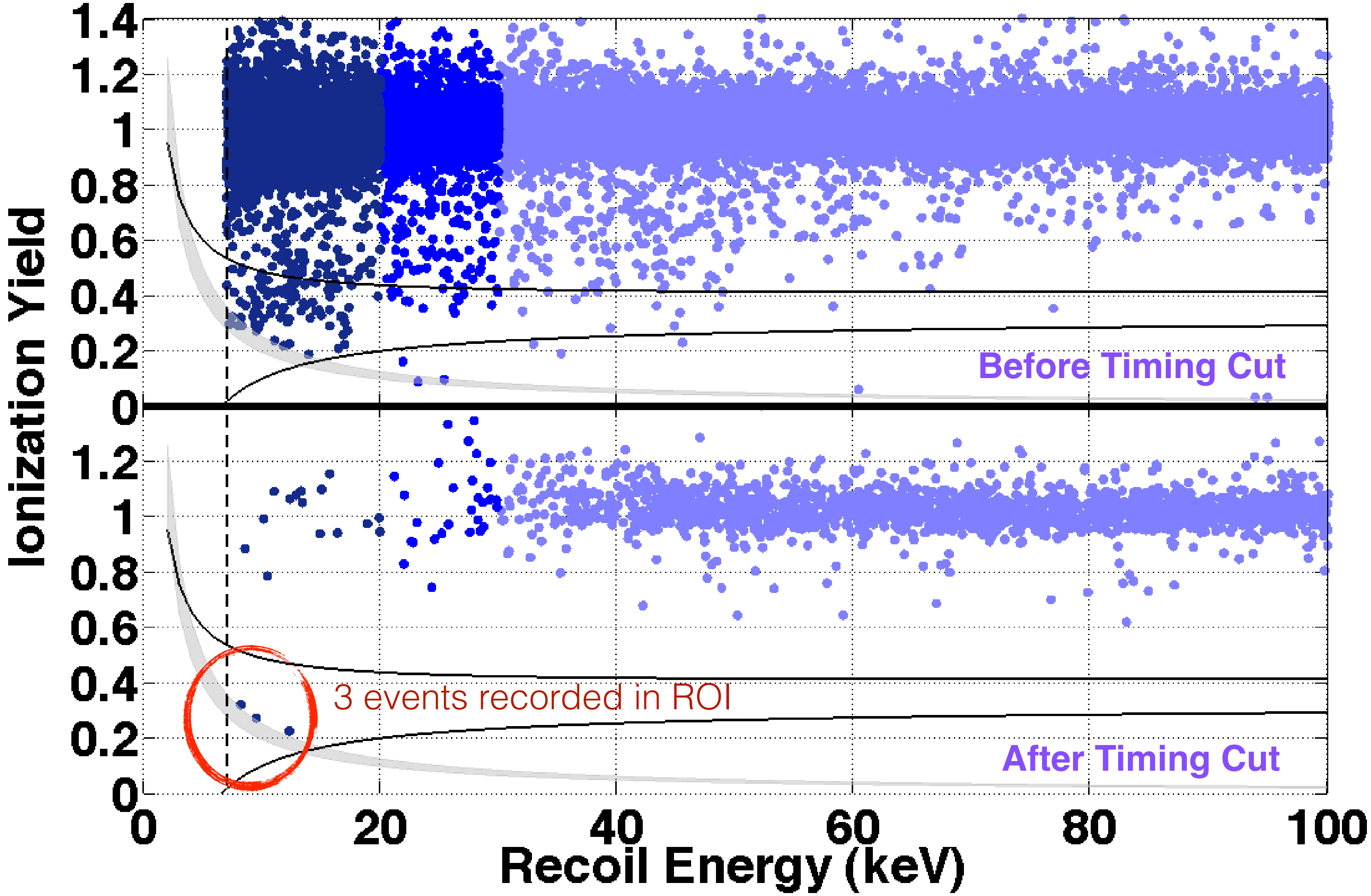
WIMPs and neutrons produce nuclear recoils
Yield (Ionization/recoil) ~0.3



Particles that interact close to the "surface dead layer" result in reduced ionization yield.
Surface events can be identified using timing properties of phonon signal

Ionization Yield + Timing Cut:
<1 in 10^6 electron recoils leaking in the ROI

Unblinding Data



- 140 kg-days raw exposure yields three events with expected background of <0.7 events

- Background estimate

  < 0.13 neutrons from cosmogenics & radiogenics

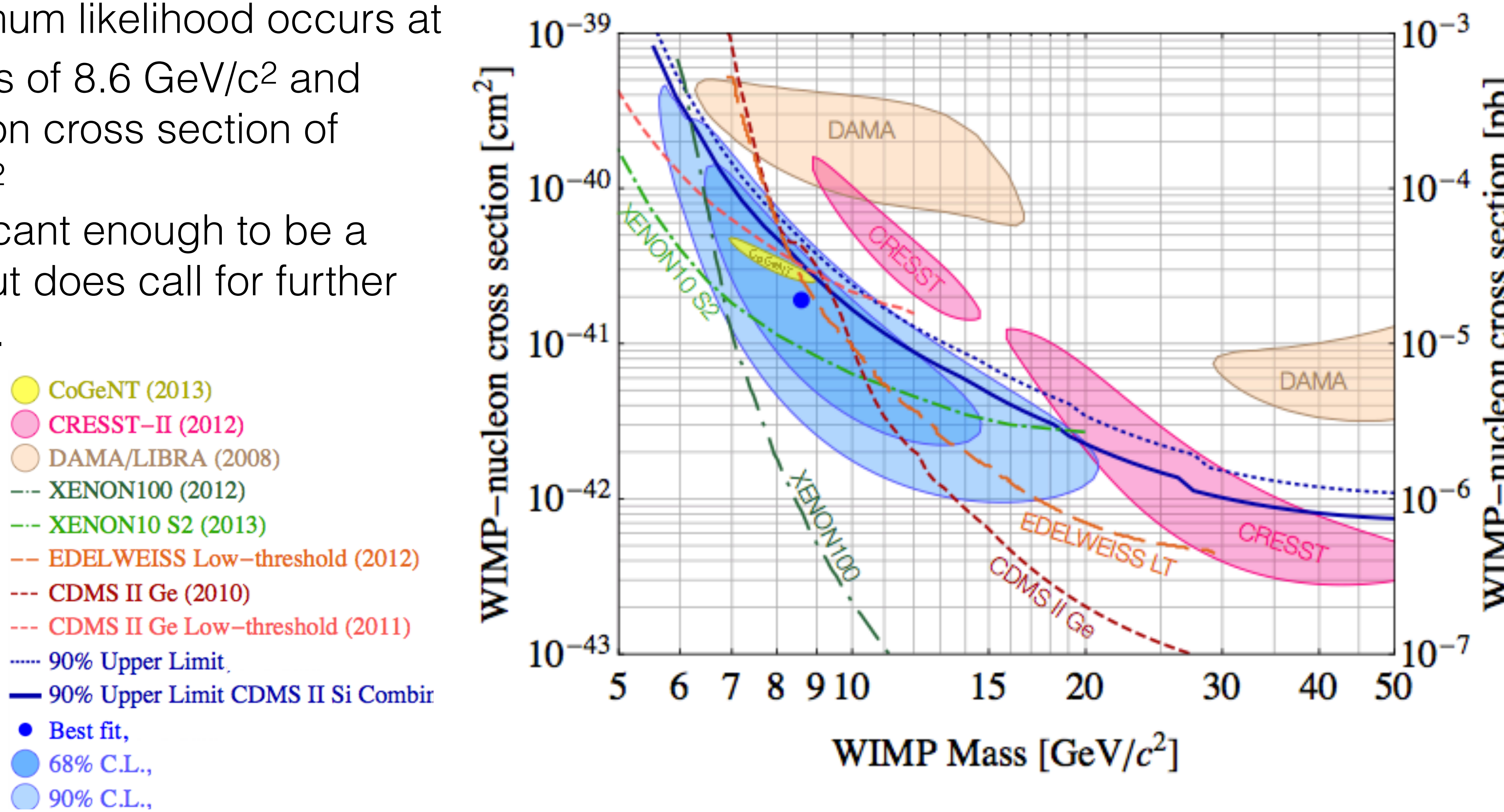
  $0.41^{+0.20}_{-0.08}(stat.)^{+0.28}_{-0.24}(syst.)$ surface events

  < 0.08 ^{206}Pb recoils from ^{210}Pb decays

CDMS II Si - Results

- Profile likelihood analysis favors WIMP+background hypothesis over known backgrounds as the source of signal at the 99.8% C.L. (~3σ)
- The maximum likelihood occurs at a WIMP mass of 8.6 GeV/c^2 and WIMP-nucleon cross section of 1.9x10^{-41}cm^2
- Not significant enough to be a discovery, but does call for further investigation.

- Optimal interval sets SI cross section < 2.4x10^{-41}cm^2 @ 90% C.L. for 10 GeV/c^2 WIMP



http://arxiv.org/abs/1304.42791304.4279v2

SuperCDMS Soudan

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- 35% NR acceptance

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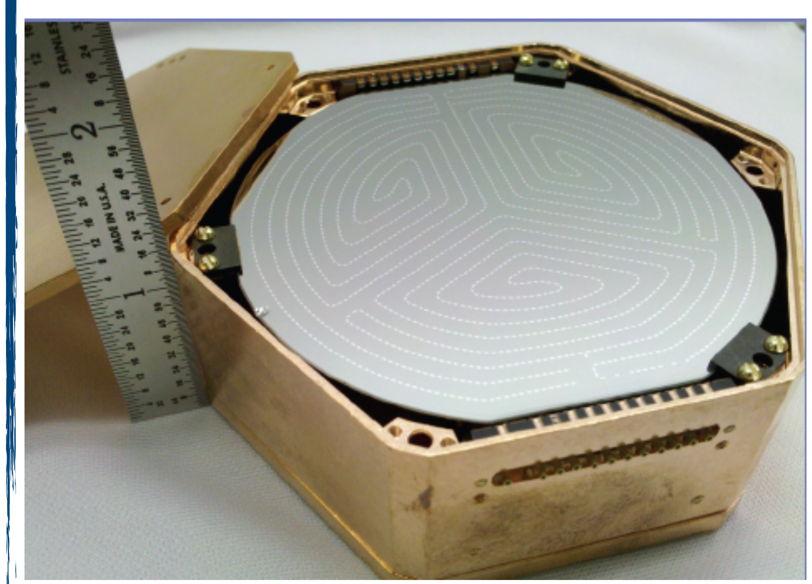
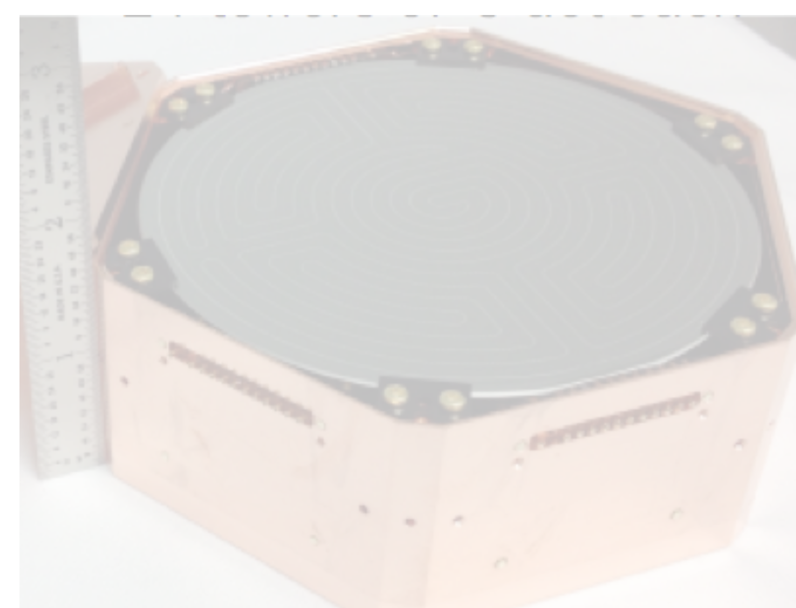
- **Improved surface event discrimination**



SuperCDMS SNOLAB

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

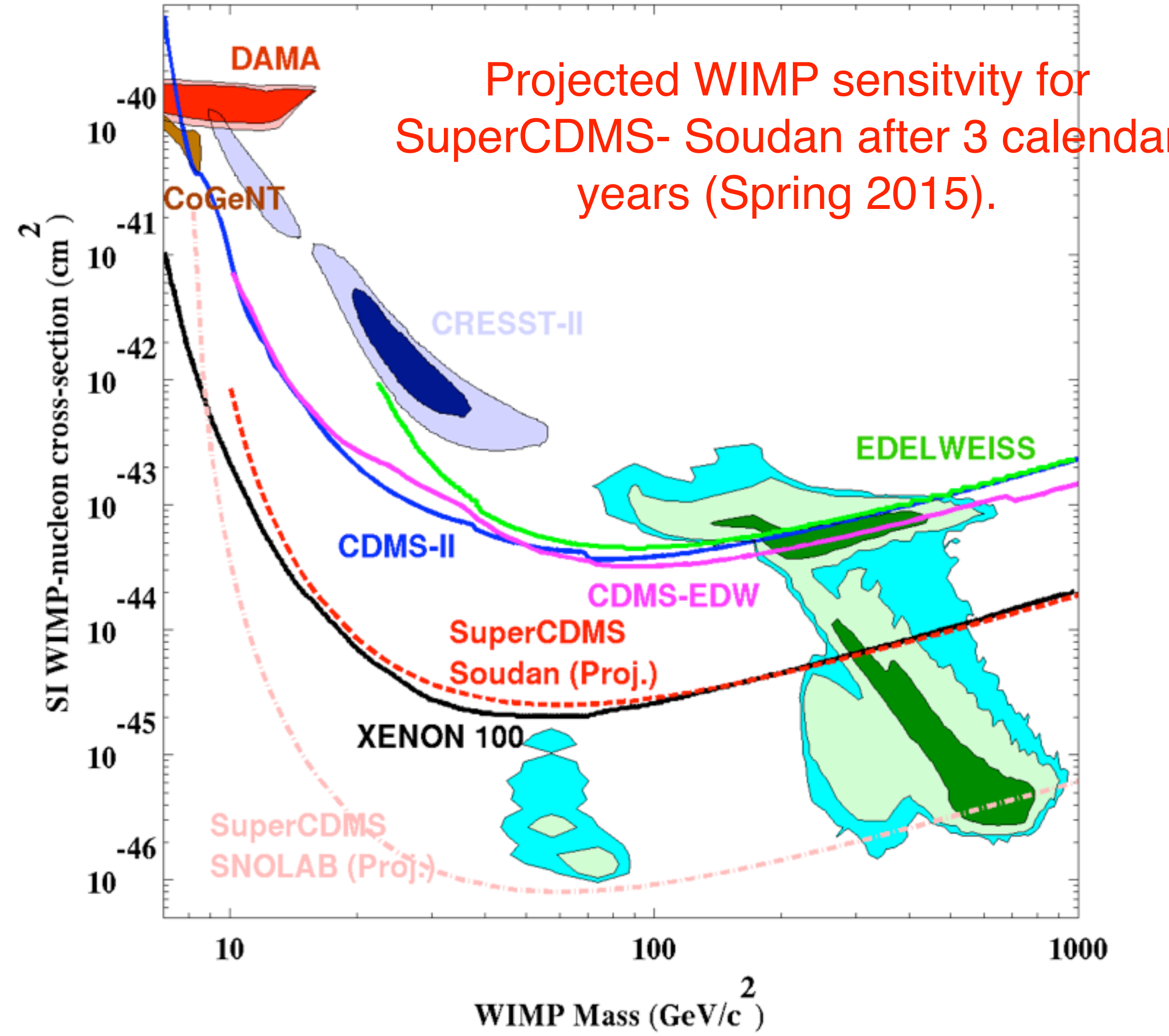
Projected sensitivity of 8 x 10^{-47} cm^2

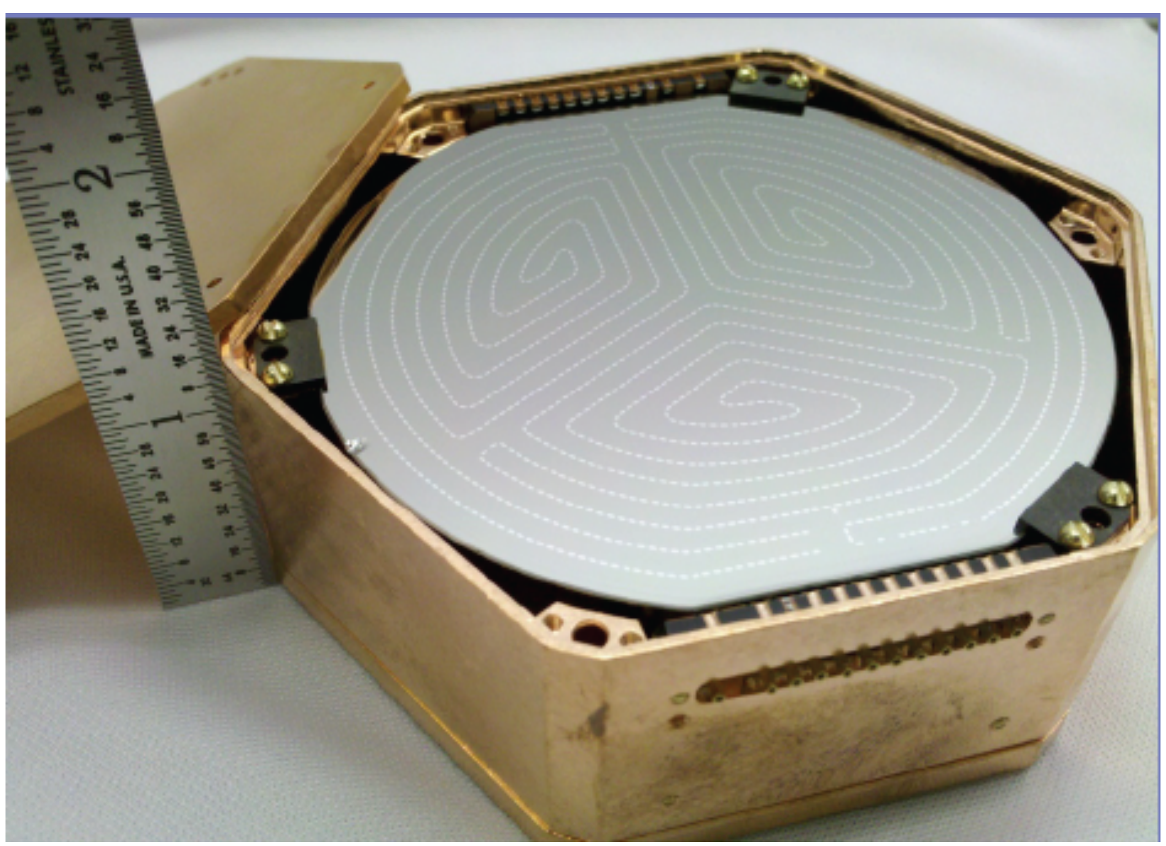


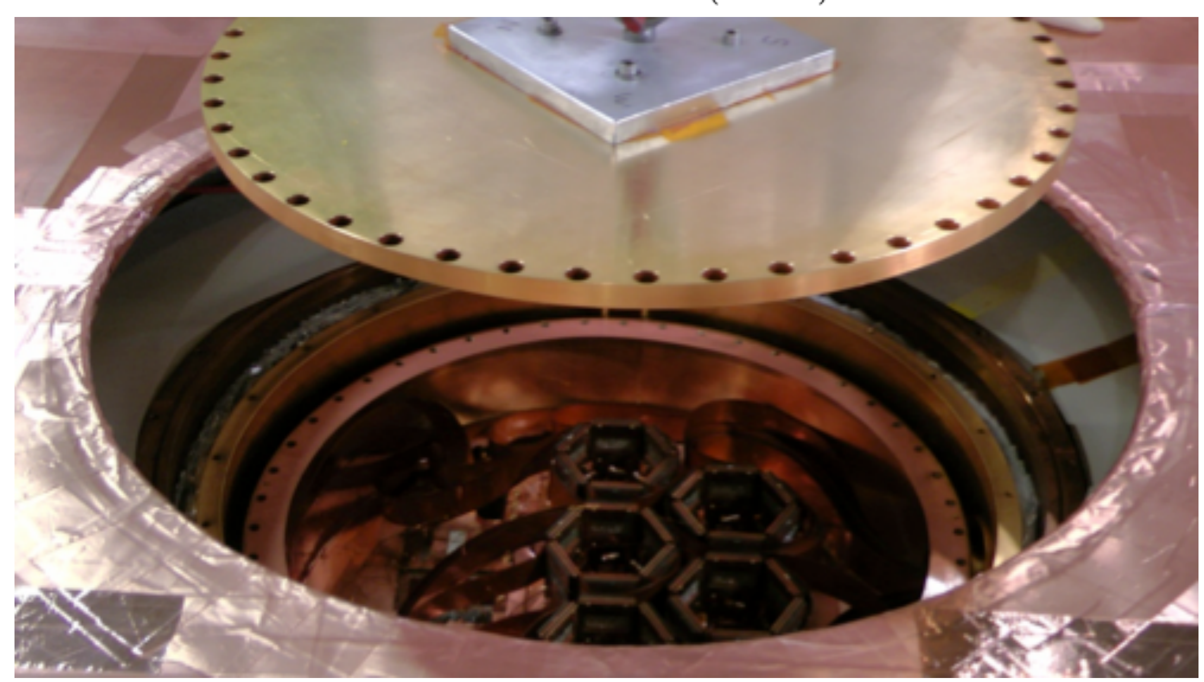
• Array of 15 iZIPs in the Soudan infrastructure built for CDMS-II

• Factor >x10 sensitivity increase over CDMS-II

- Larger detector mass (x2.5 thicker detectors)
- Fiducial fraction improved to ~50% from 35%
- Surface background negligible

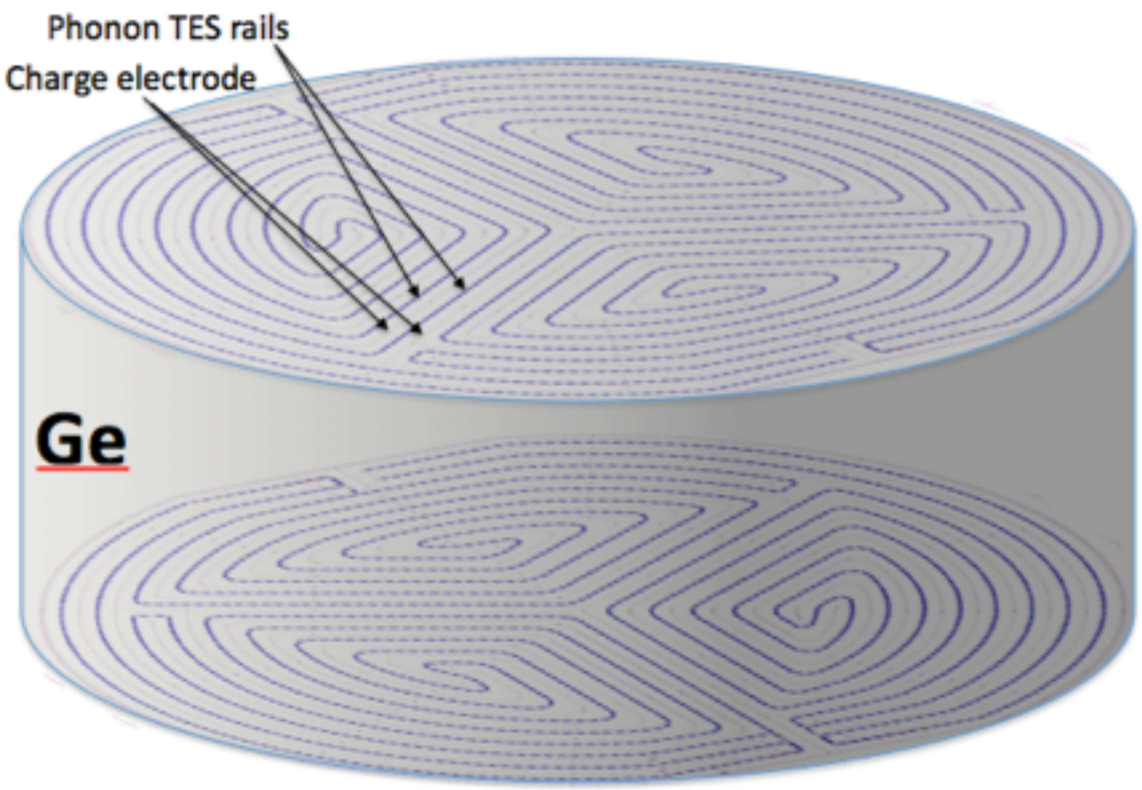


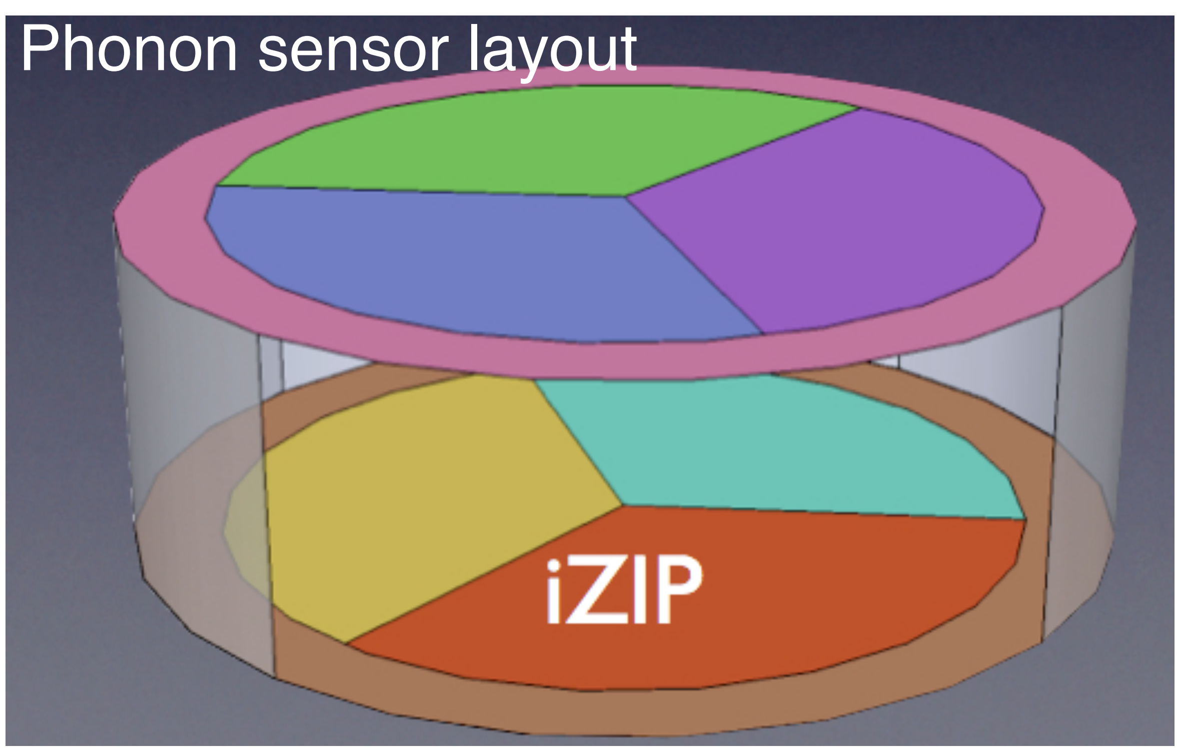




Installation complete Nov. 8, 2011.Detectors have been operating in DM-search mode since March 2012.

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

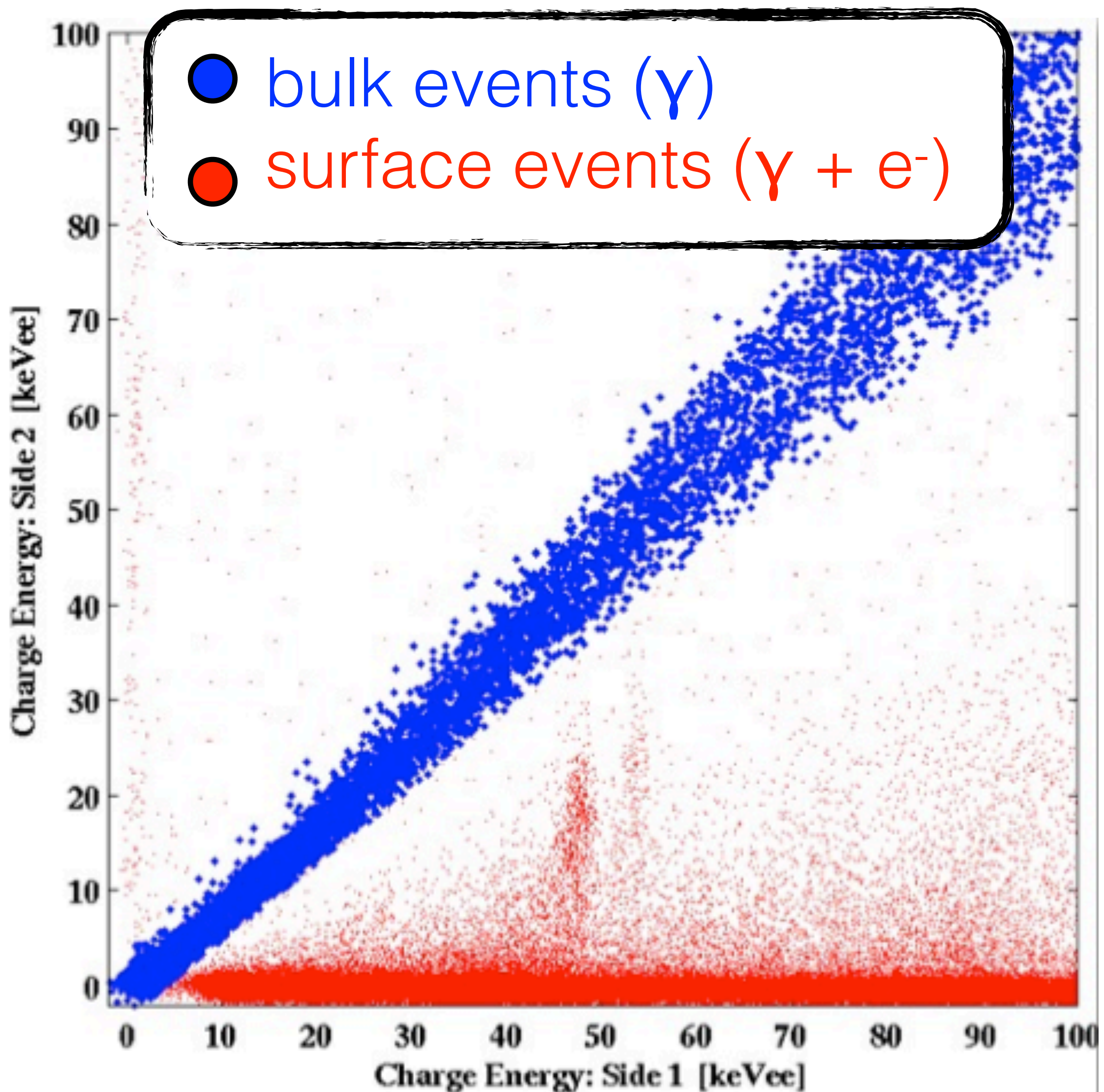
  Each side has one outer channel to reject zero charge events and 3 inner channels to reject surface events.

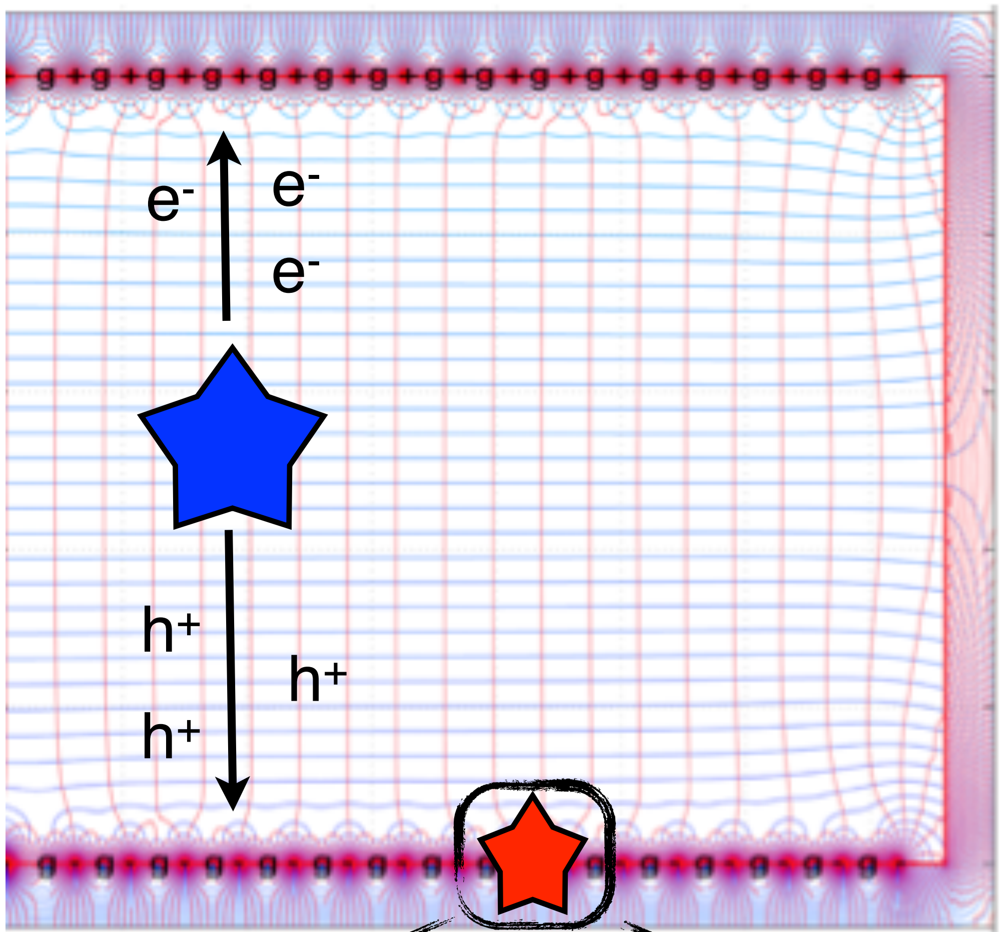
- Ionization channels can be used to reject surface events

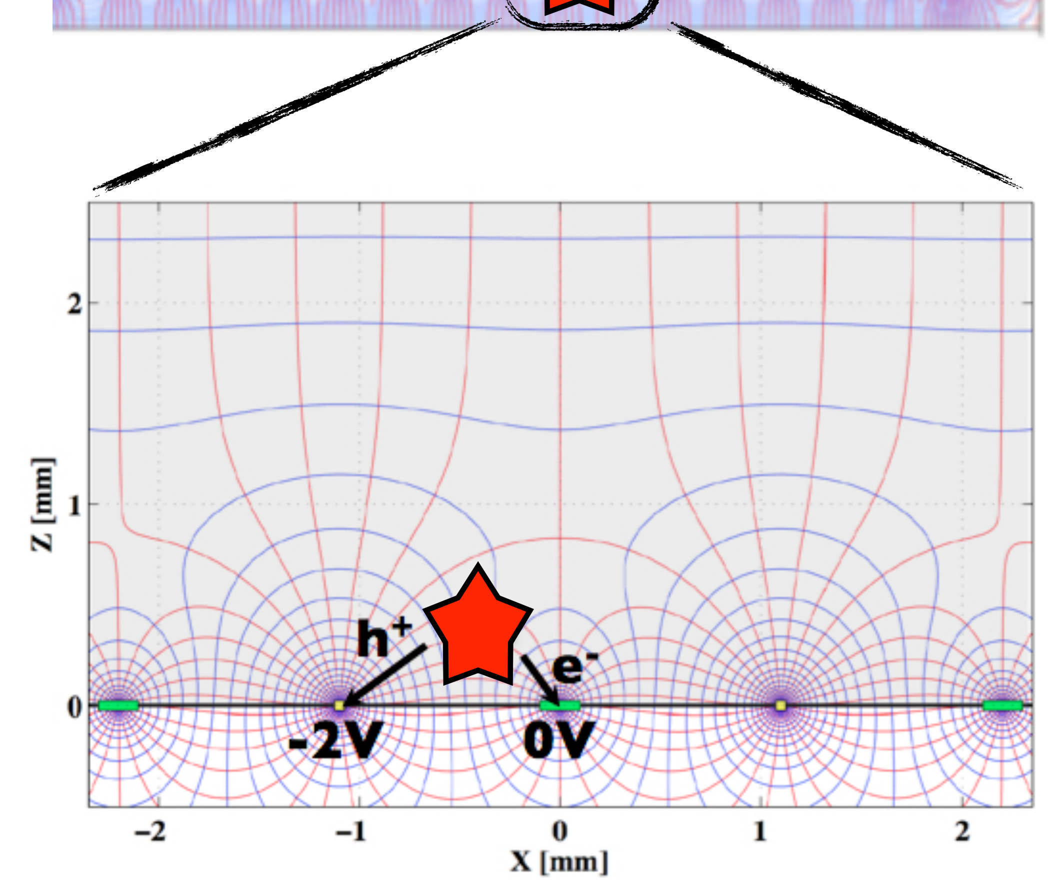
SuperCDMS iZIPs: Charge signal

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

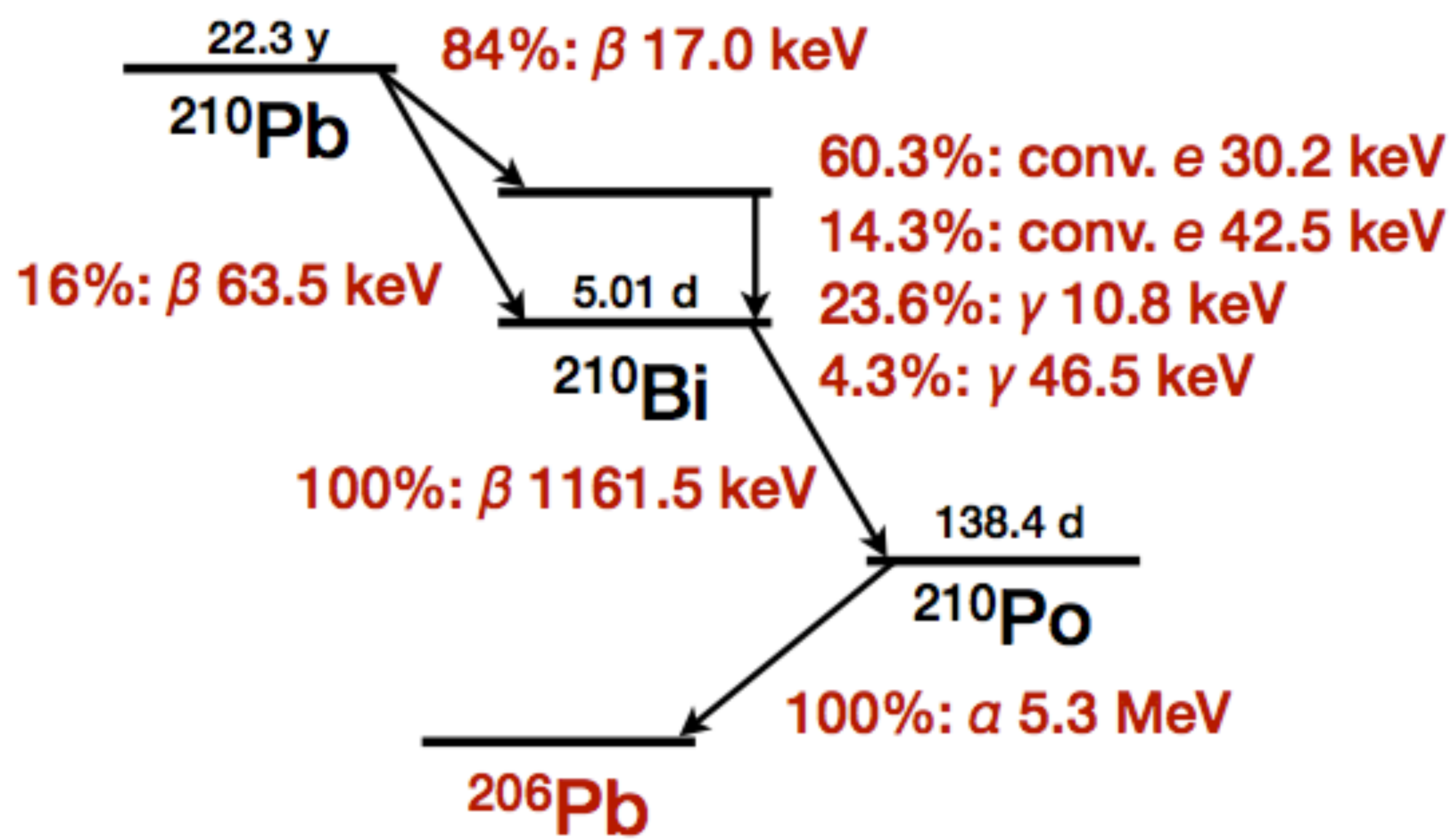
Installed ^{210}Pb implanted Si wafers facing two detectors

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



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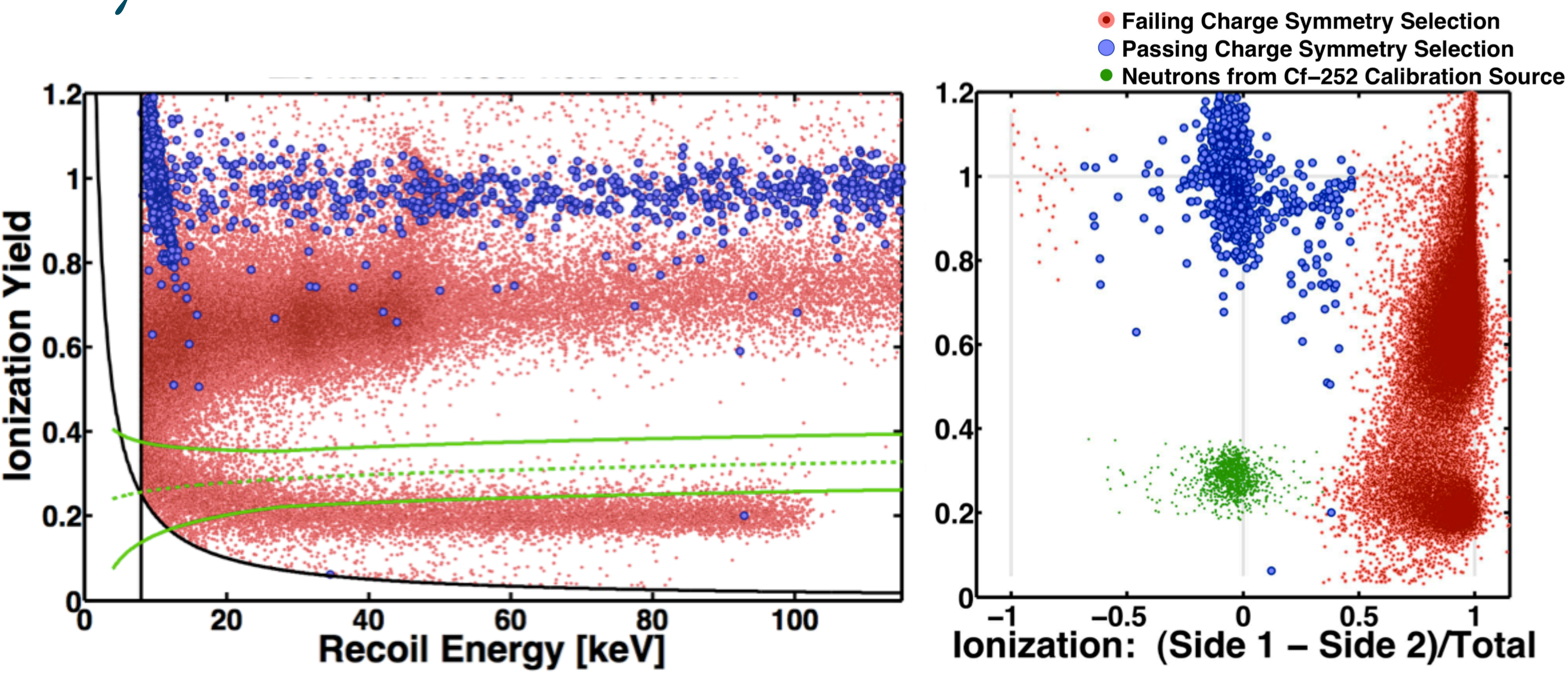
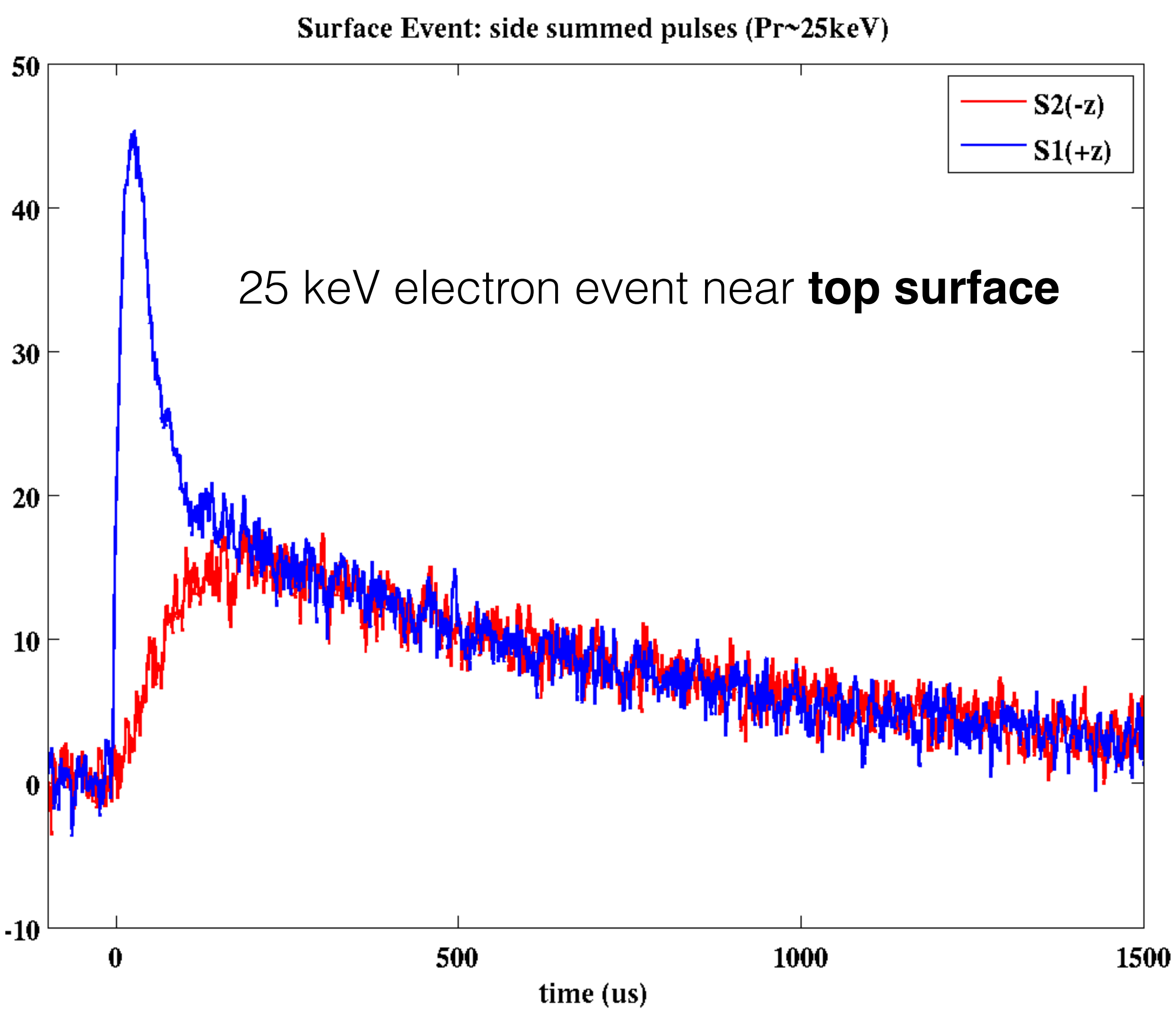


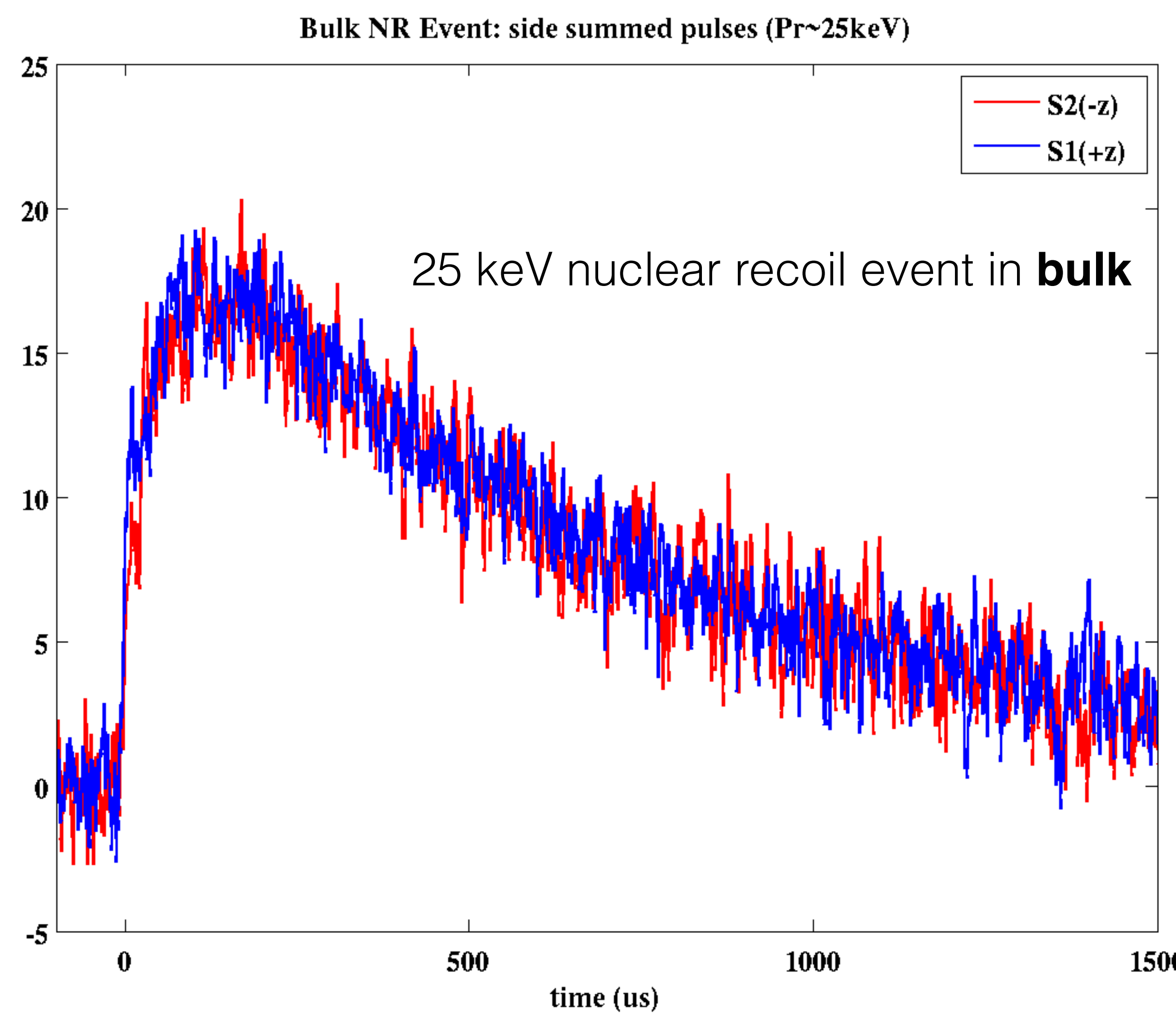
- ~65,000 electrons and ~15,000 ^{206}Pb recoil surface event collected from ^{210}Pb source.
- No events leaking into the signal region into ~50% fiducial volume (8-115 keVnr) in 37.6 live time days (March - July 2012)
- Limits surface events leakage to 1.7×10^{-5} @90% C.L.
- Ionization collection 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.)

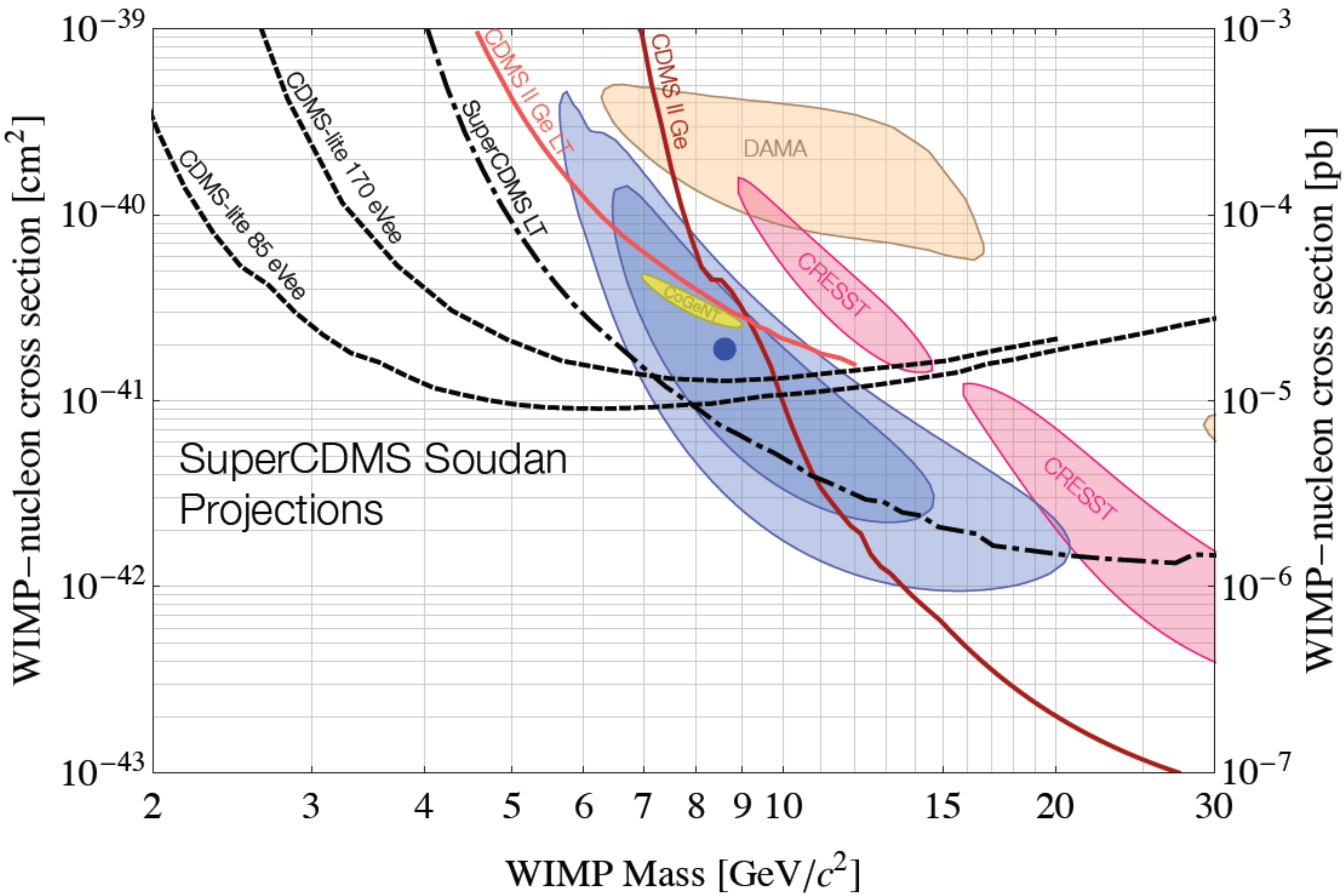
Low mass WIMP search

Low-Threshold search, optimizing the analysis to approach the hardware trigger threshold

- Nuclear recoil discrimination down to 2 keVr, but significant overlap of electron and nuclear recoil distributions
- Note that this projection assumes fewer events with no ionization detected

CDMSlite search, an ionization only search strategy with lower threshold

- Use Neganov-Luke amplification to increase the signal-to-noise for low- energy events
- Ionization energy from interaction gets amplified and measured through the total phonon energy Pt only



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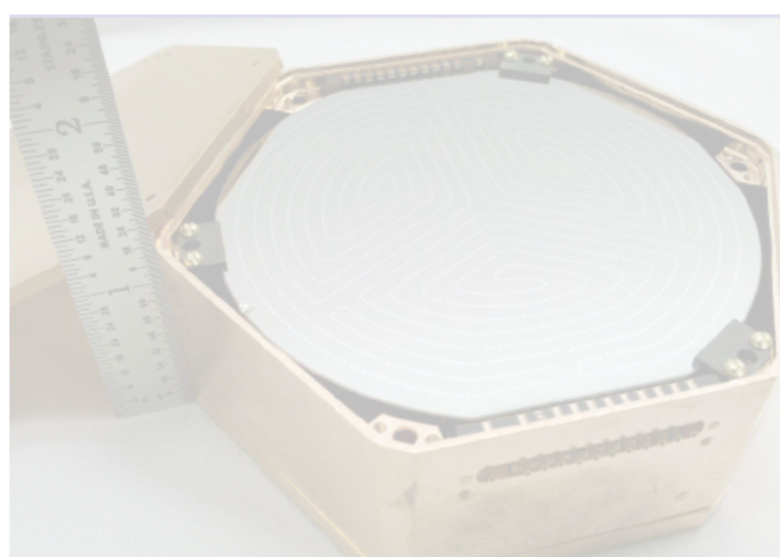

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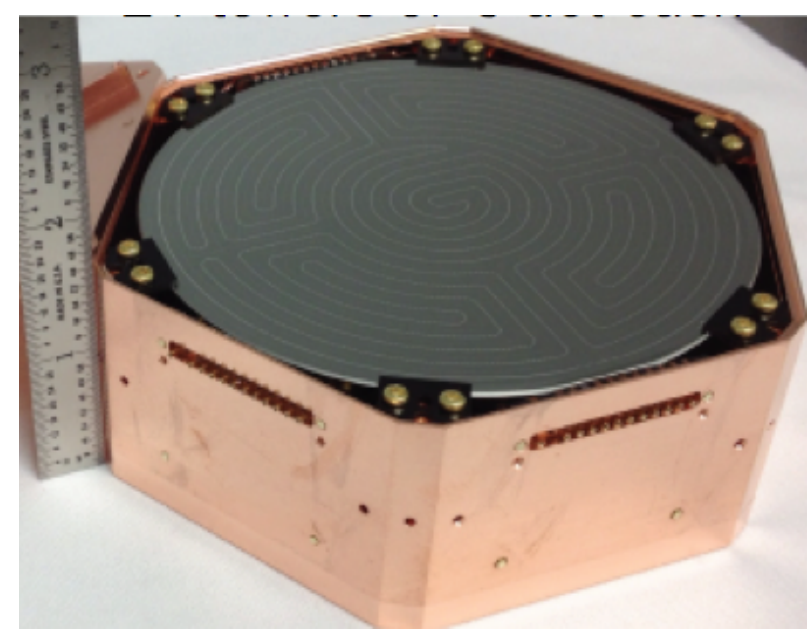

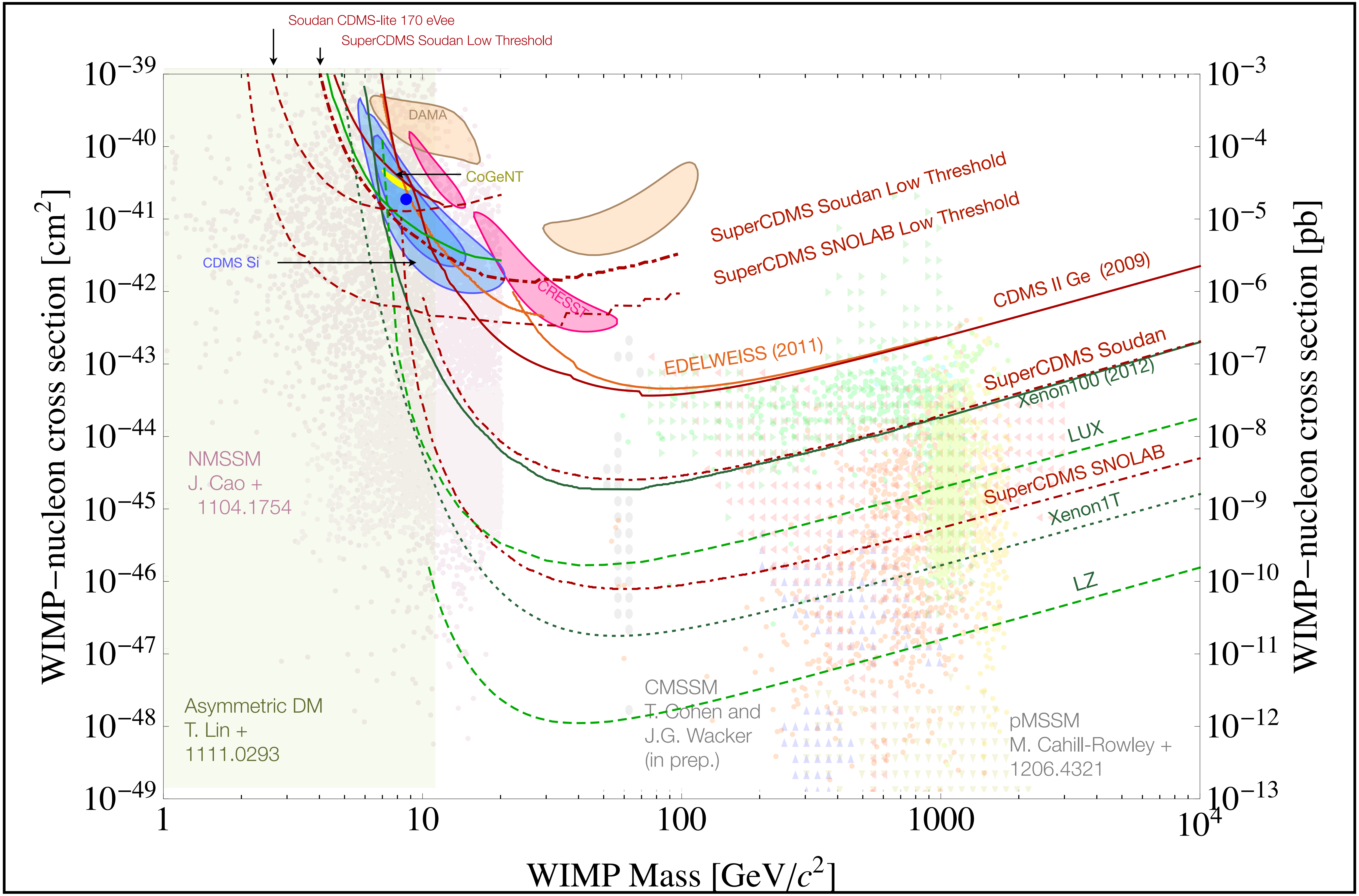
Soudan CDMS-lite 170 eVee
SuperCDMS Soudan Low Threshold
DAMA
CoGeNT
CDMS Si
CRESST
SuperCDMS Soudan Low Threshold
SuperCDMS SNOLAB Low Threshold
CDMS II Ge (2009)
EDELWEISS (2011)
SuperCDMS Soudan
Xenon100 (2012)
LUX
SuperCDMS SNOLAB
Xenon1T
LZ
NMSSM
J. Cao +
1104.1754
Asymmetric DM
T. Lin +
1111.0293
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]
10^{-39}
10^{-40}
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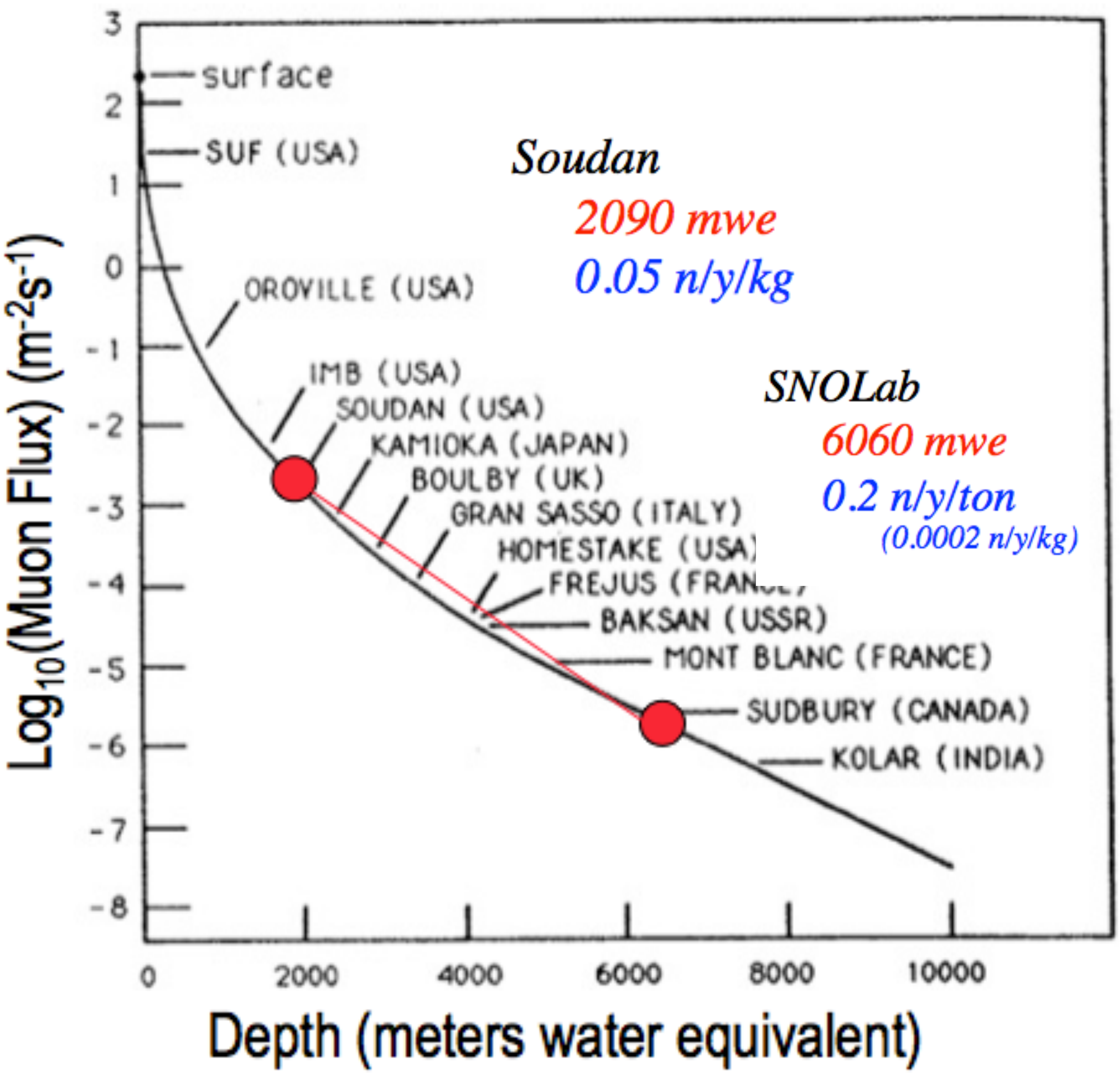
10^{-12}
10^{-13}
1
10
100
1000
10^4

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

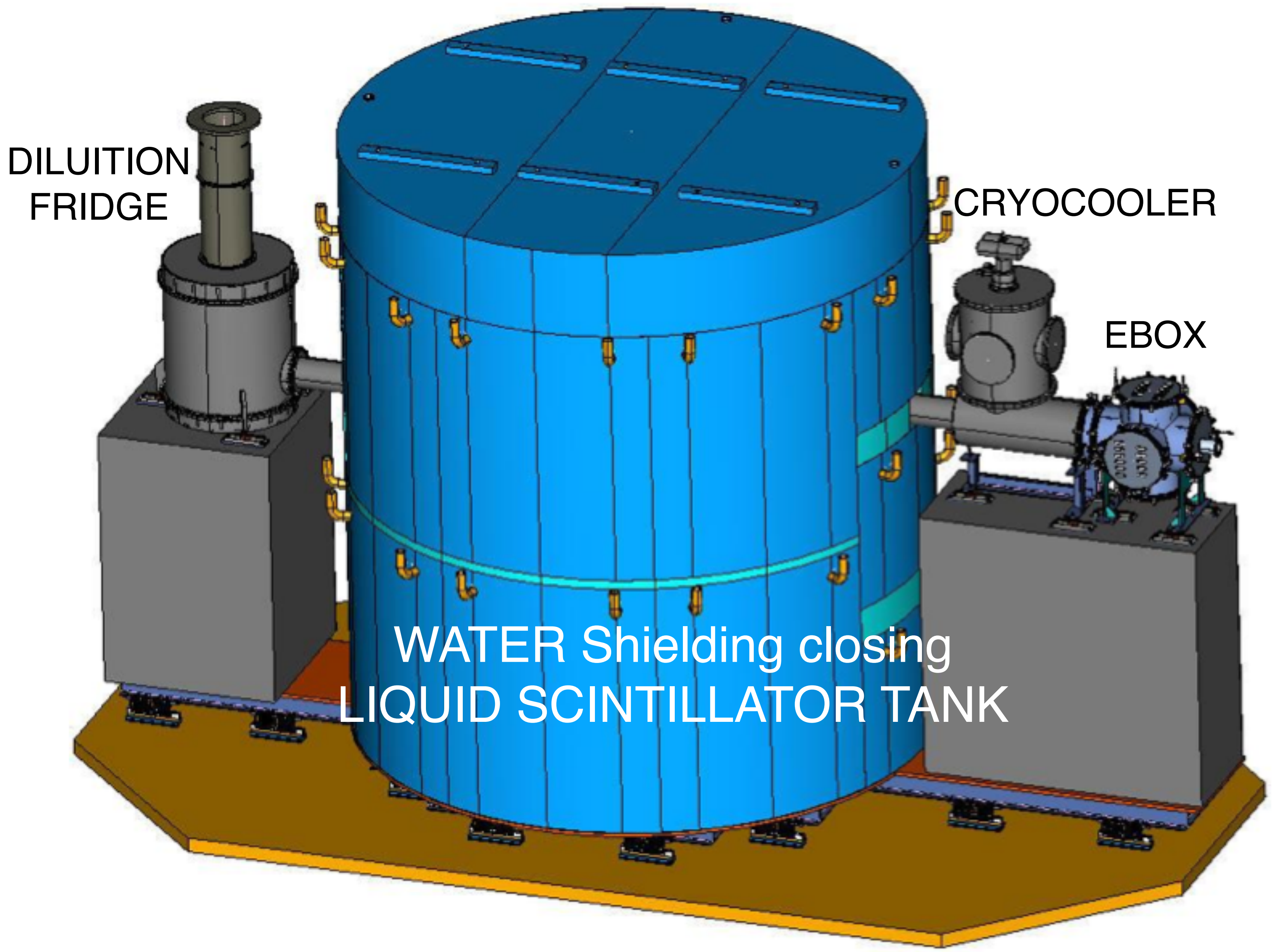
-> Expected to be negligible with passive shielding

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

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

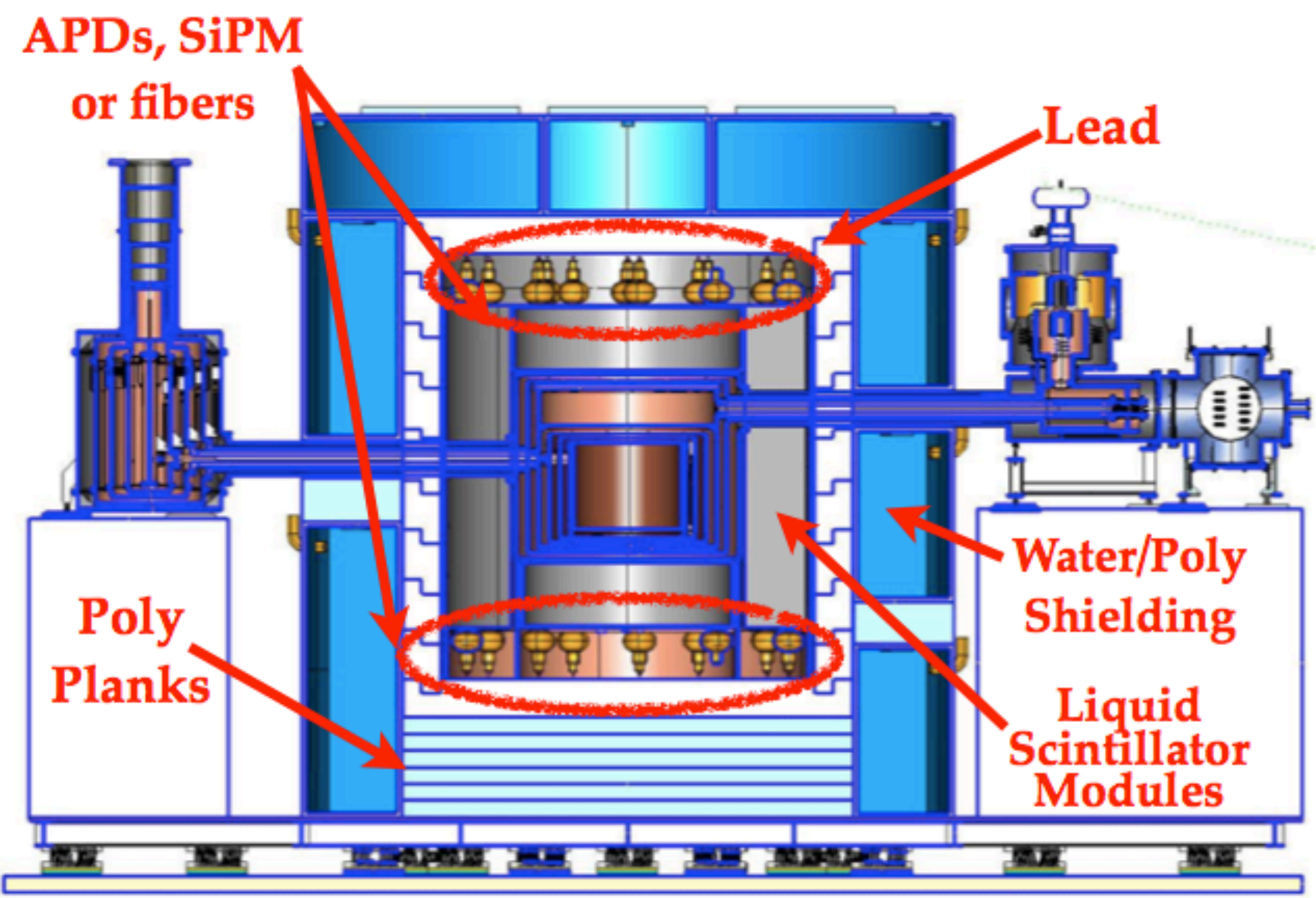
Experimental Set-up

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.

Alternate design: alternating layers of Gd-loaded poly/scintillator and lead.

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.

- 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

Thanks!

Back - up

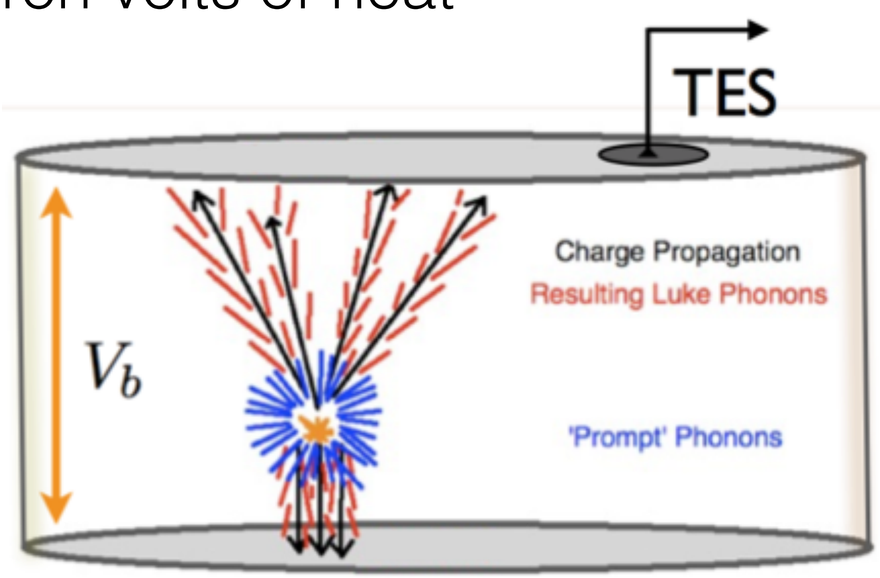
CDMSlite:

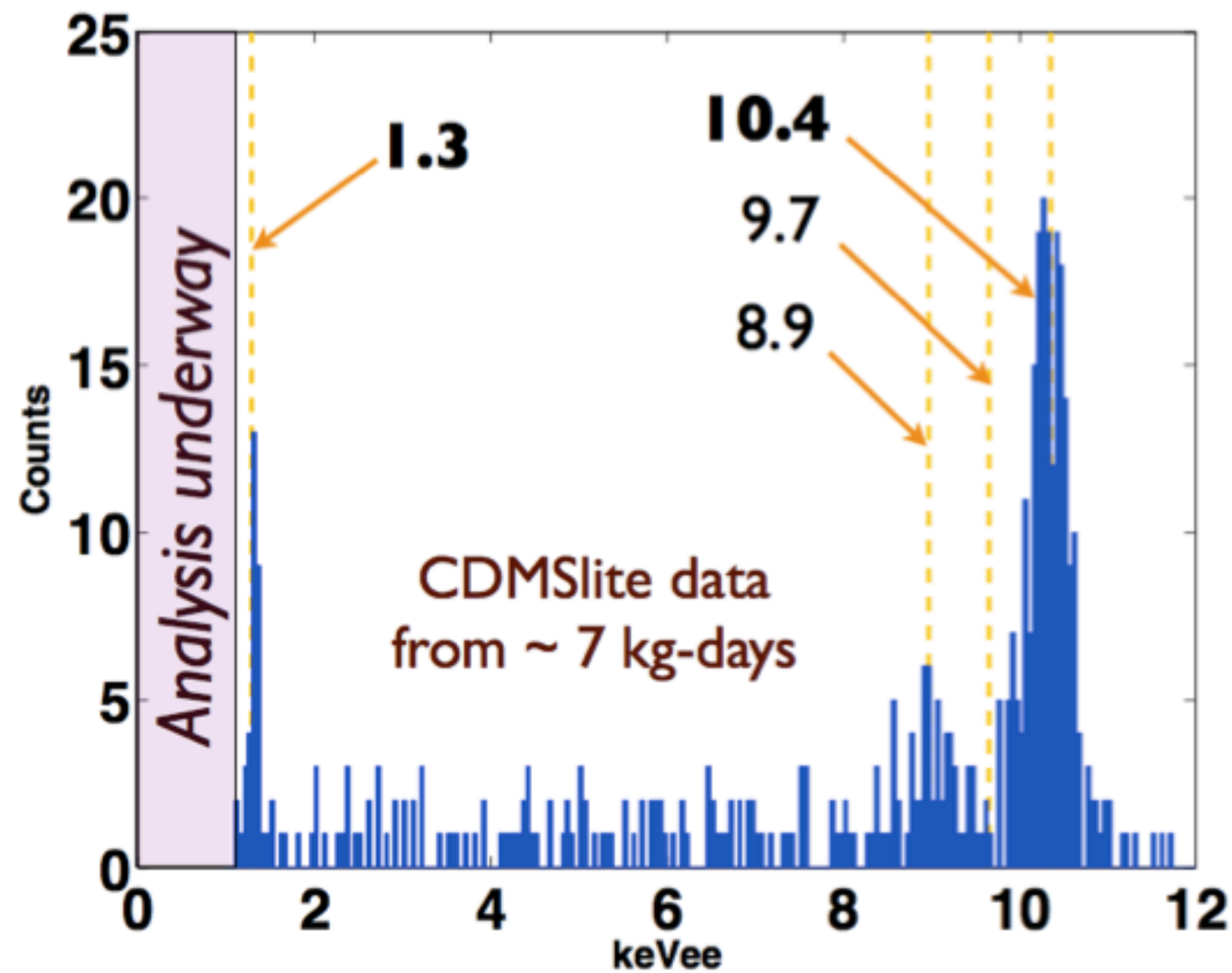
low ionization threshold experiment

CDMSlite strategy leverages Neganov-Luke amplification to realize low thresholds with high-resolution

- Ionization only, no event-by-event discrimination of nuclear recoils

Drifting N_e electrons across a potential, V, generates N_eV electron volts of heat

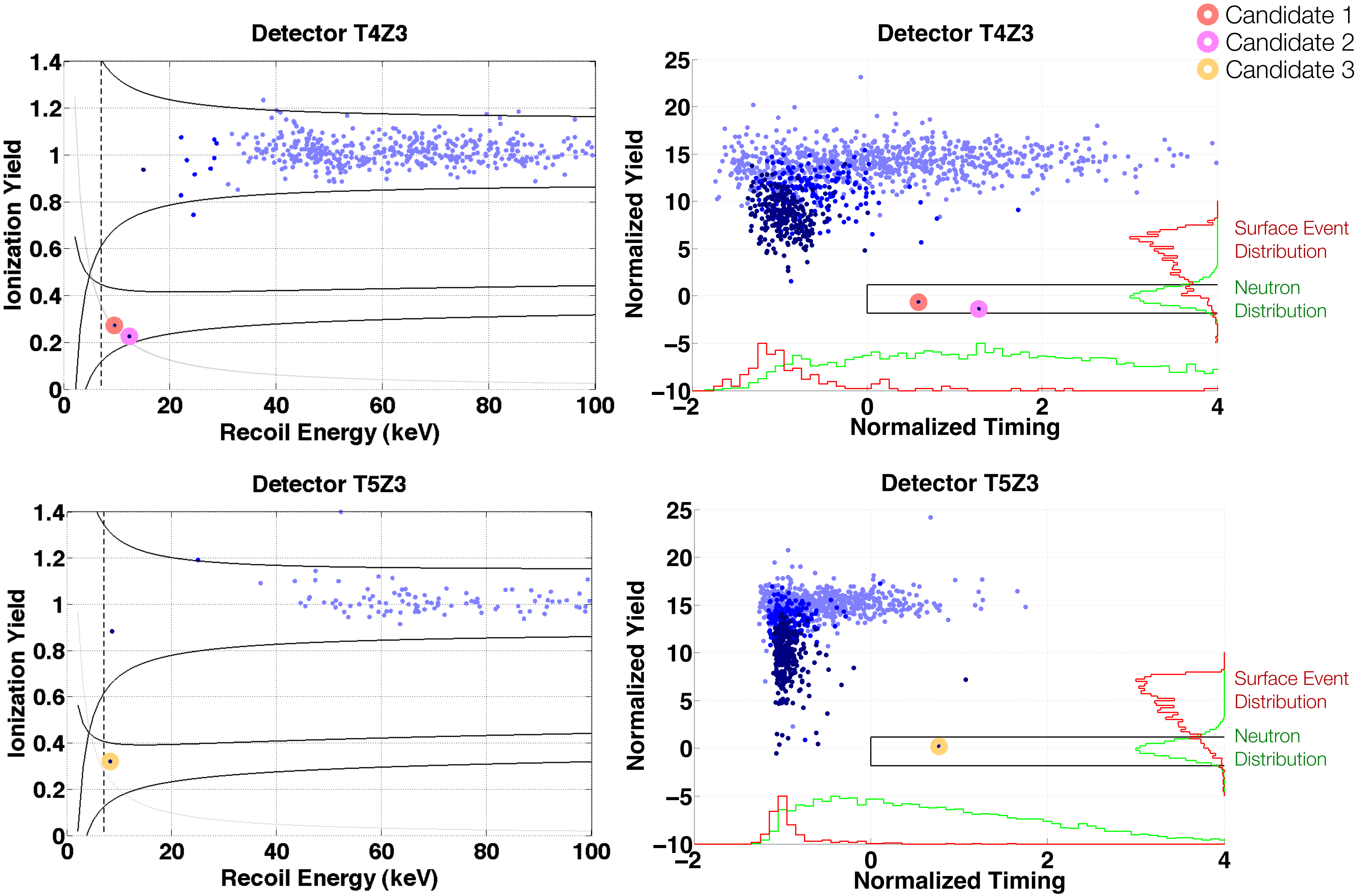




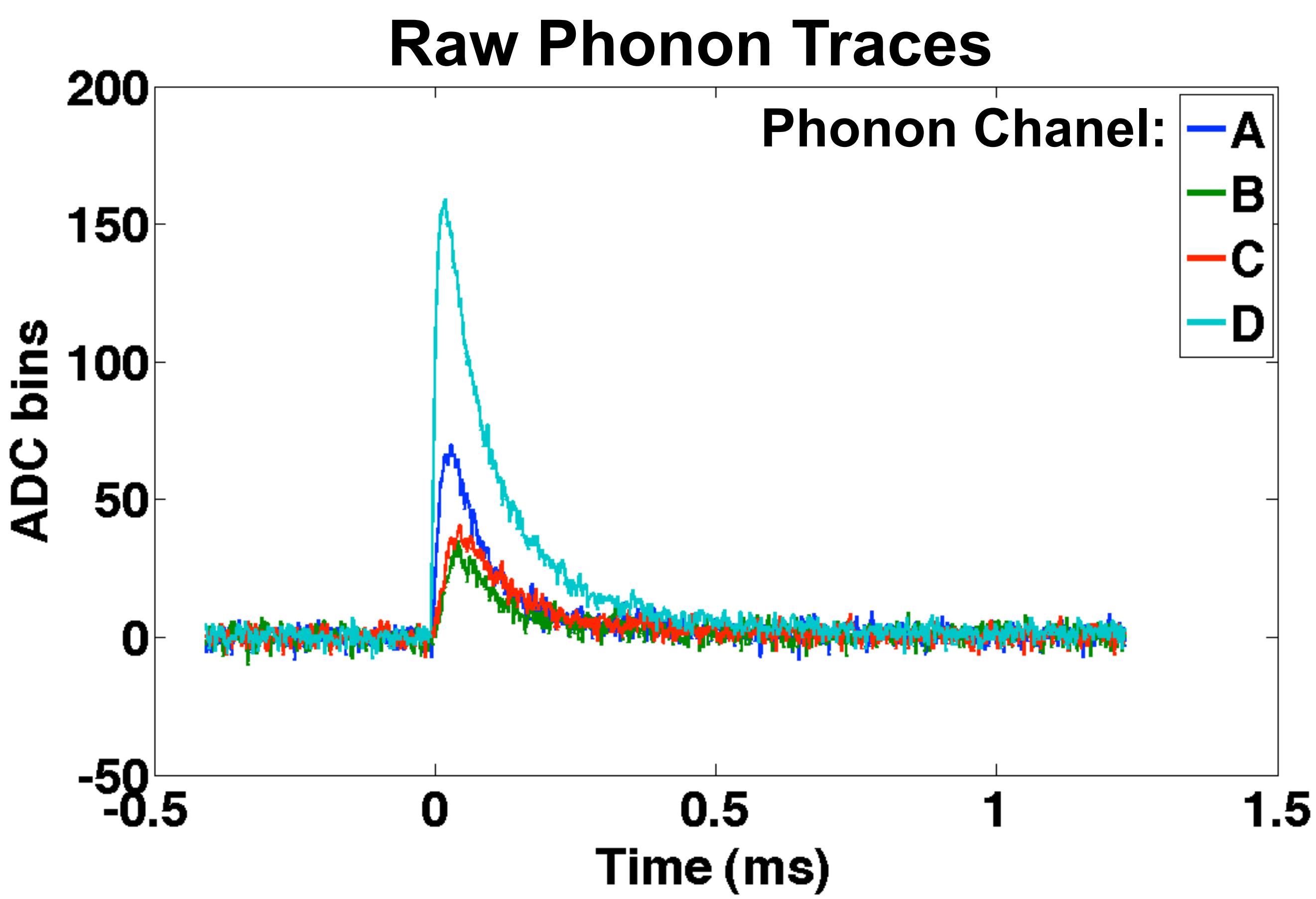
As a result of amplified Luke signal has excellent energy resolution ~13eVee

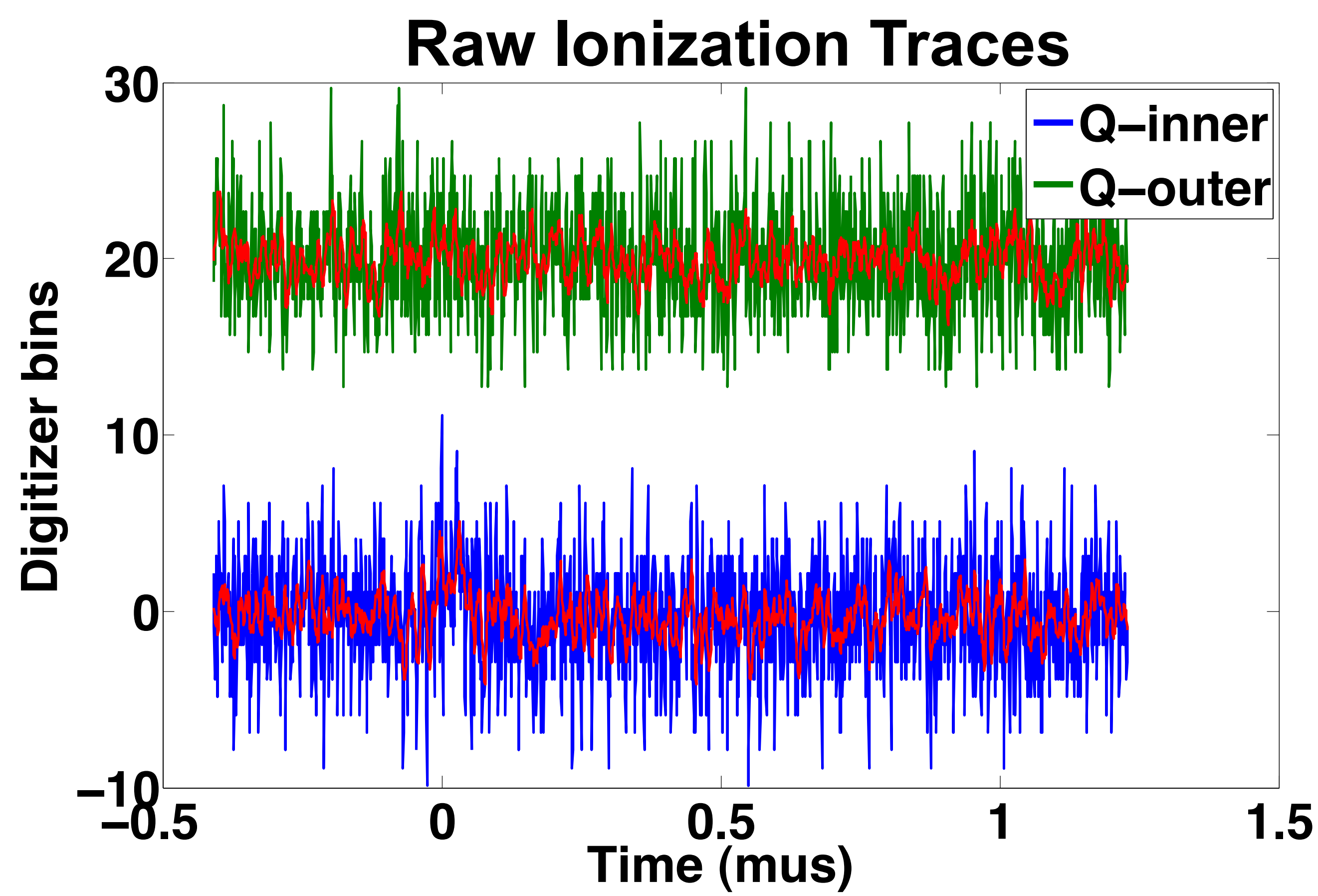
Can resolve various Ge activation lines

Three Events



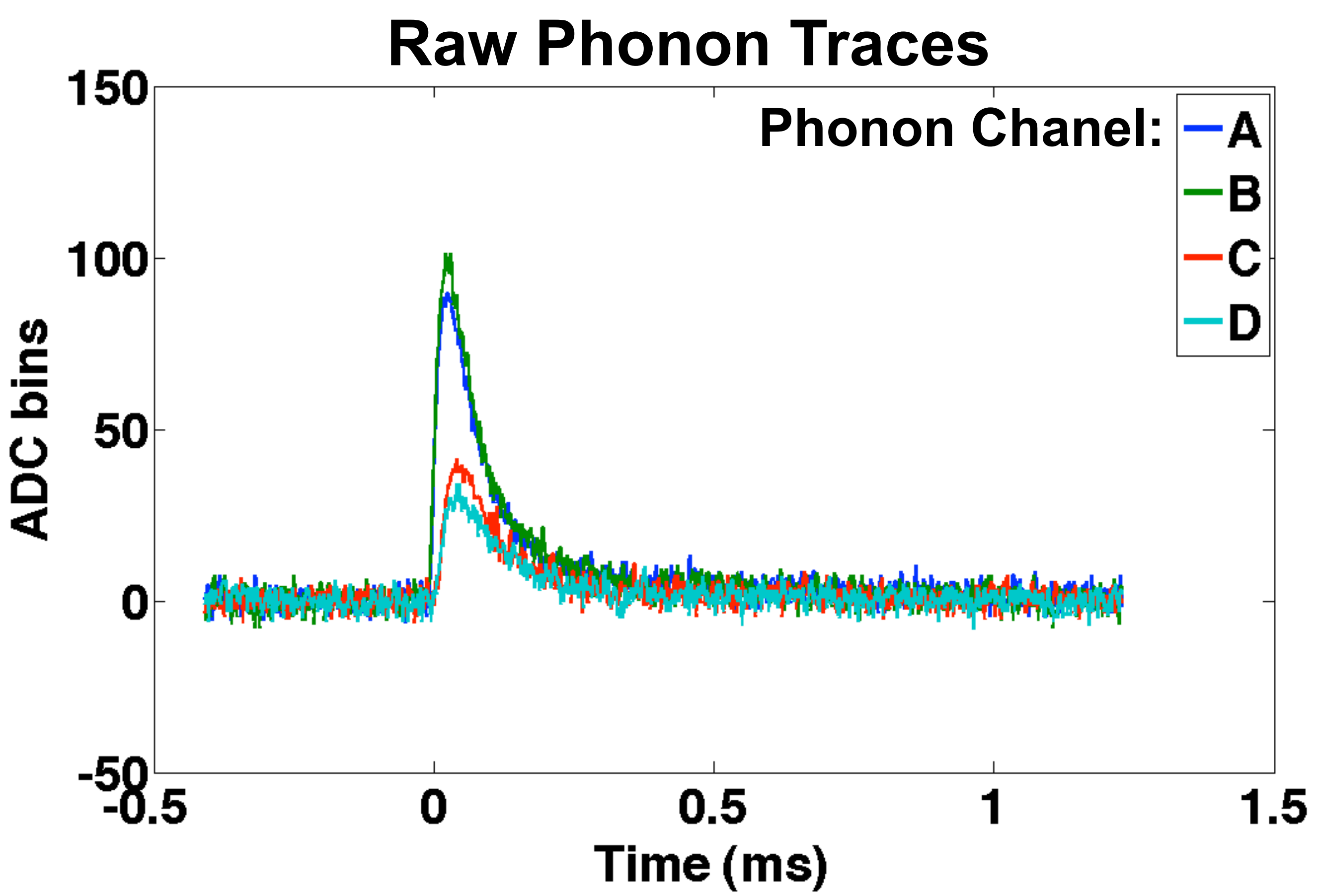
Candidate 1

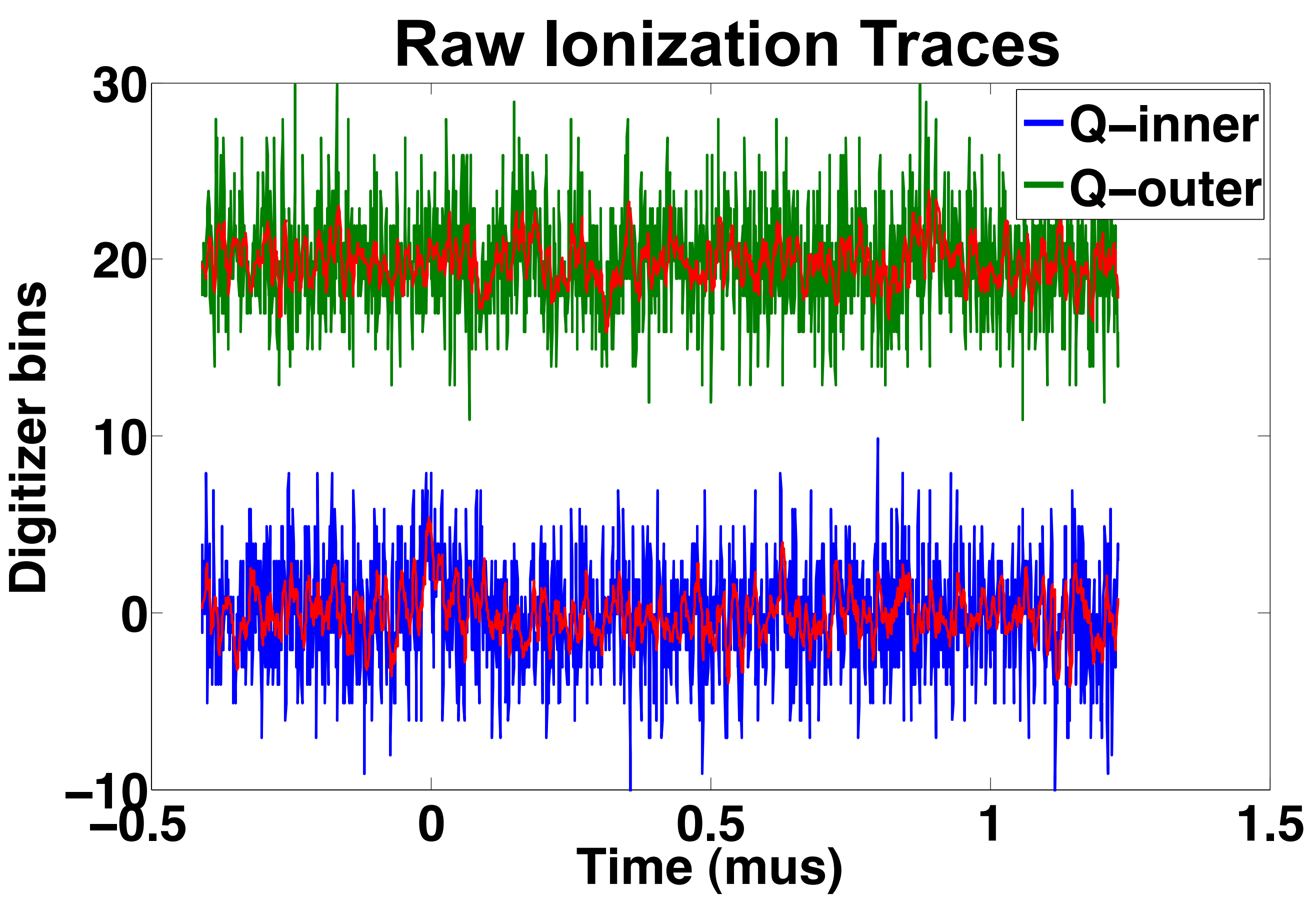




Detector	Recoil Energy	Yield	Charge Signal to Noise	Single Scatter Probability	Date
T4Z3	9.51 keV	0.27	4.87 σ	96.1%	July 1, 2008

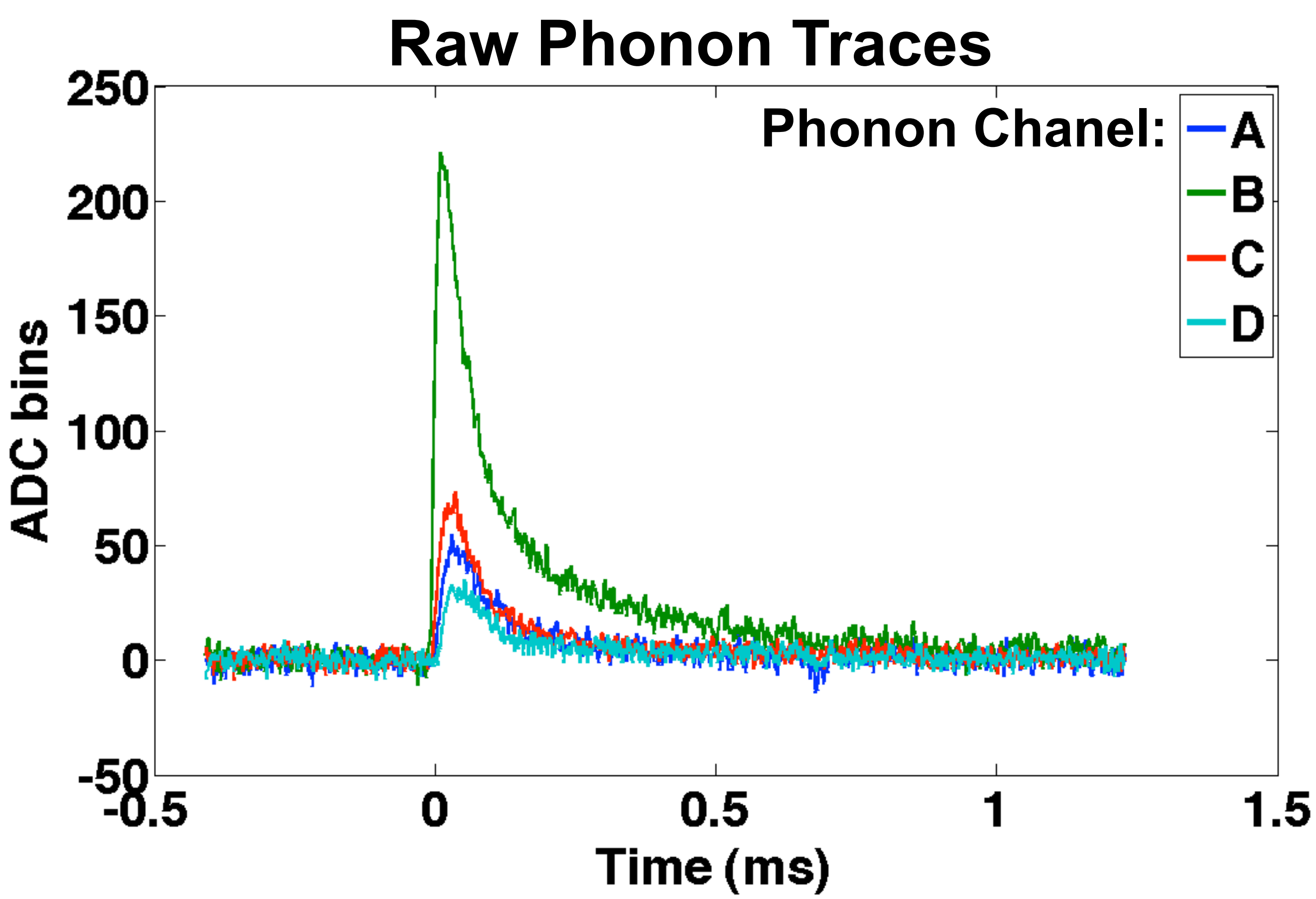
Candidate 2

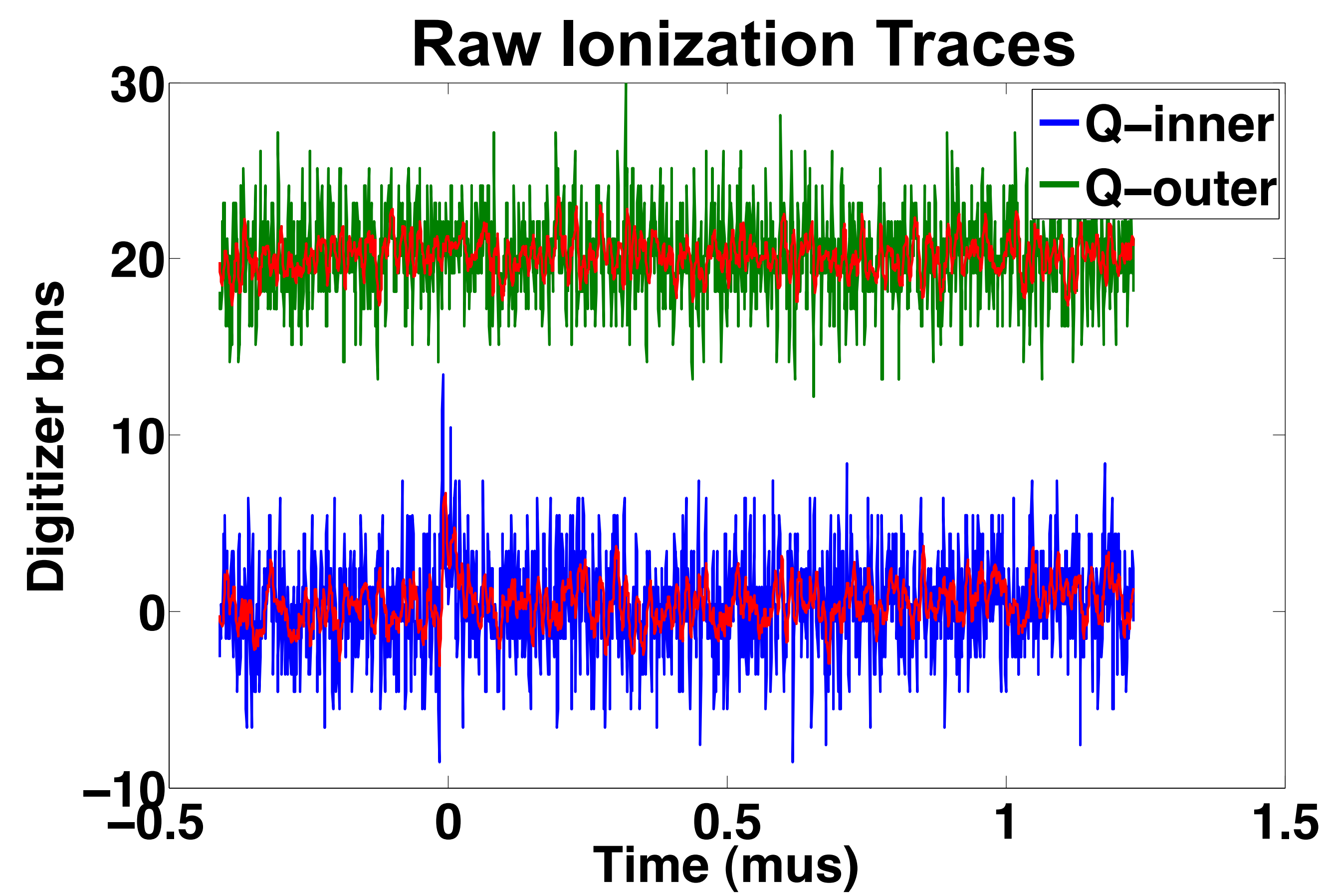




Detector	Recoil Energy	Yield	Charge Signal to Noise	Single Scatter Probability	Date
T4Z3	12.29 keV	0.23	5.11 σ	99.7%	Sep 6, 2008

Candidate 3



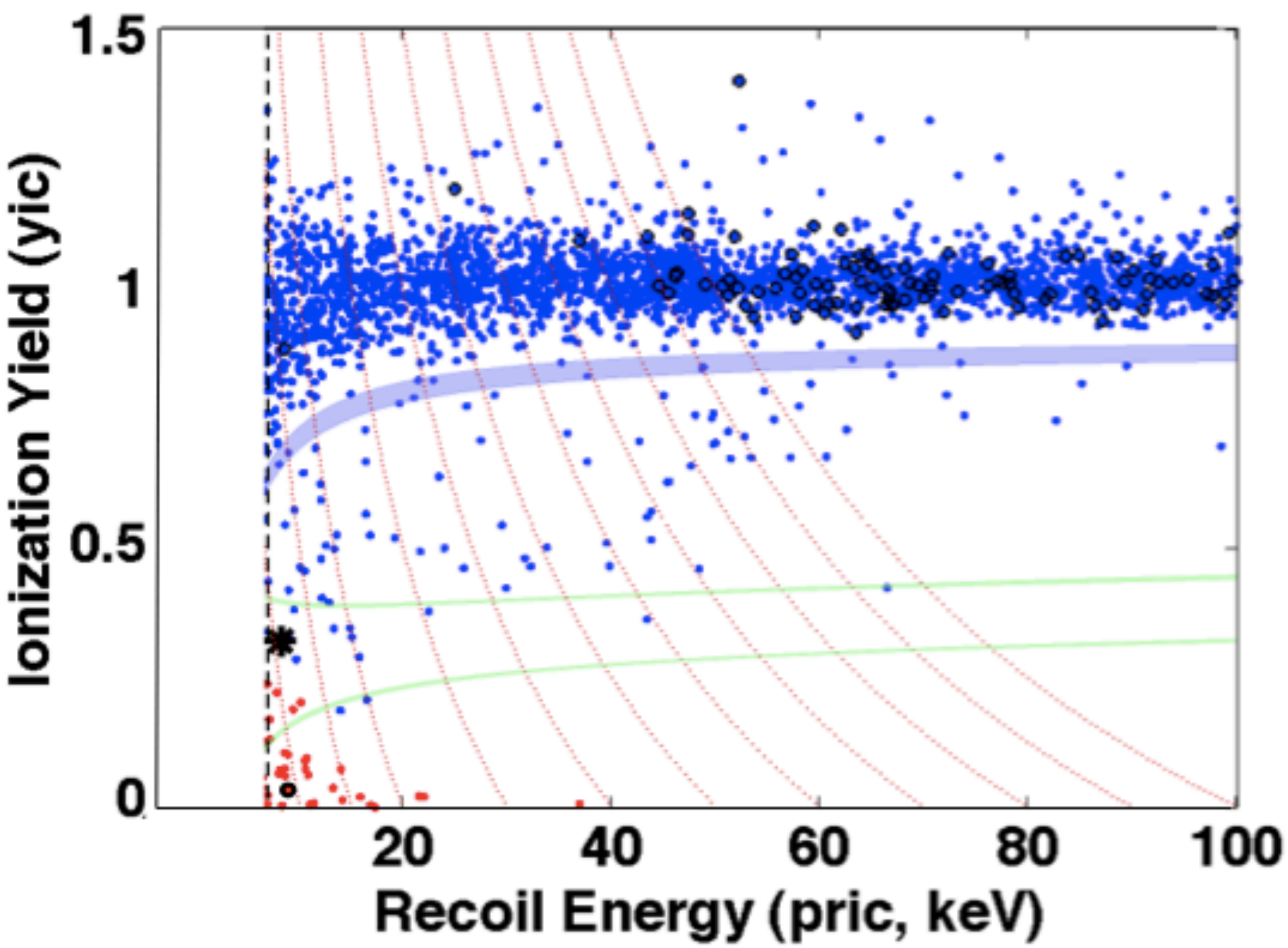


Detector	Recoil Energy	Yield	Charge Signal to Noise	Single Scatter Probability	Date
T5Z3	8.20 keV	0.32	6.66 σ	99.7%	March 14, 2008

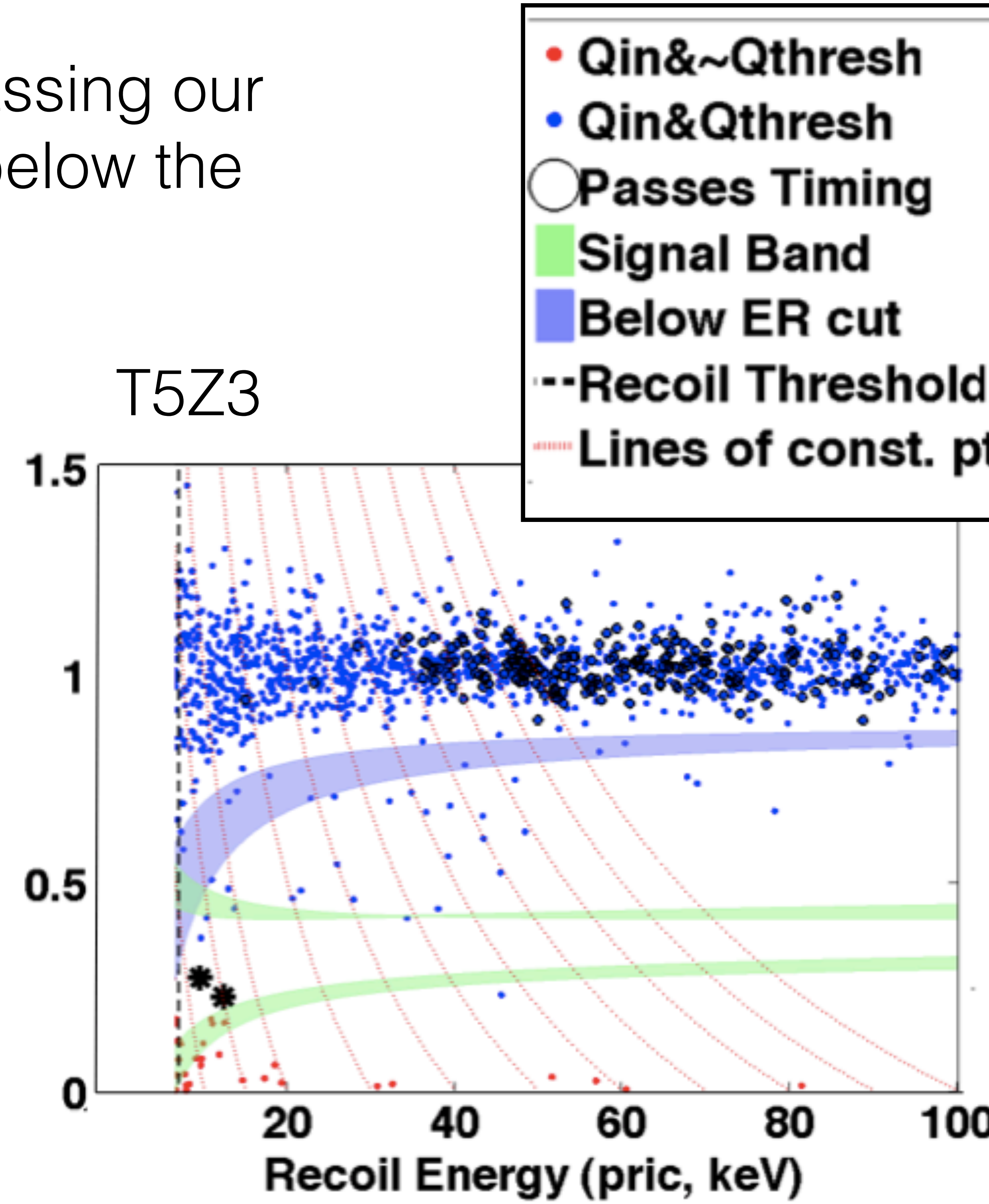
Events Below Charge Threshold

No large population of events passing our timing selection criteria is seen below the charge threshold

T4Z3



T5Z3

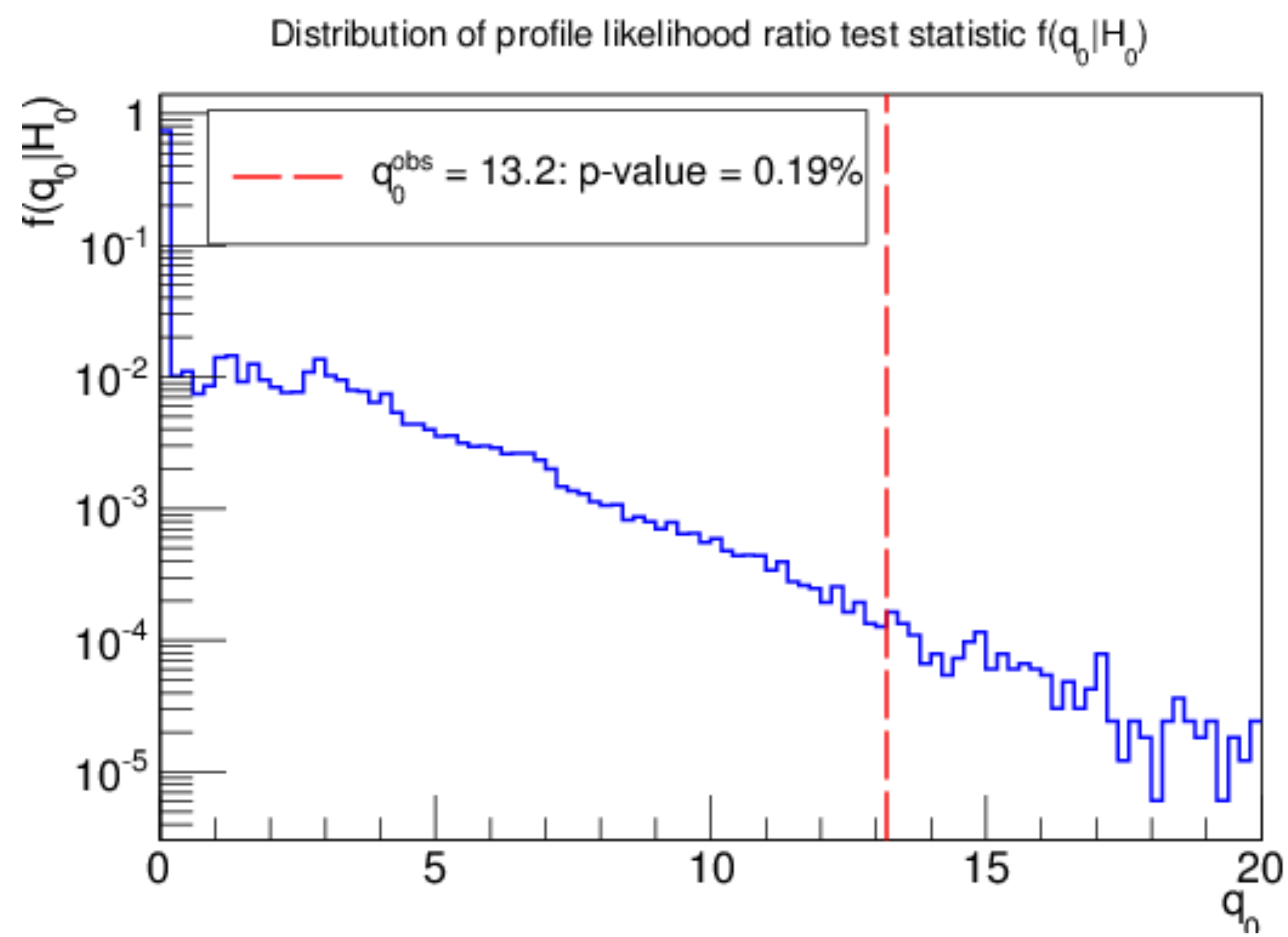


Profile Likelihood Analysis - cont.

Testing our known background estimate against a WIMP+background hypothesis

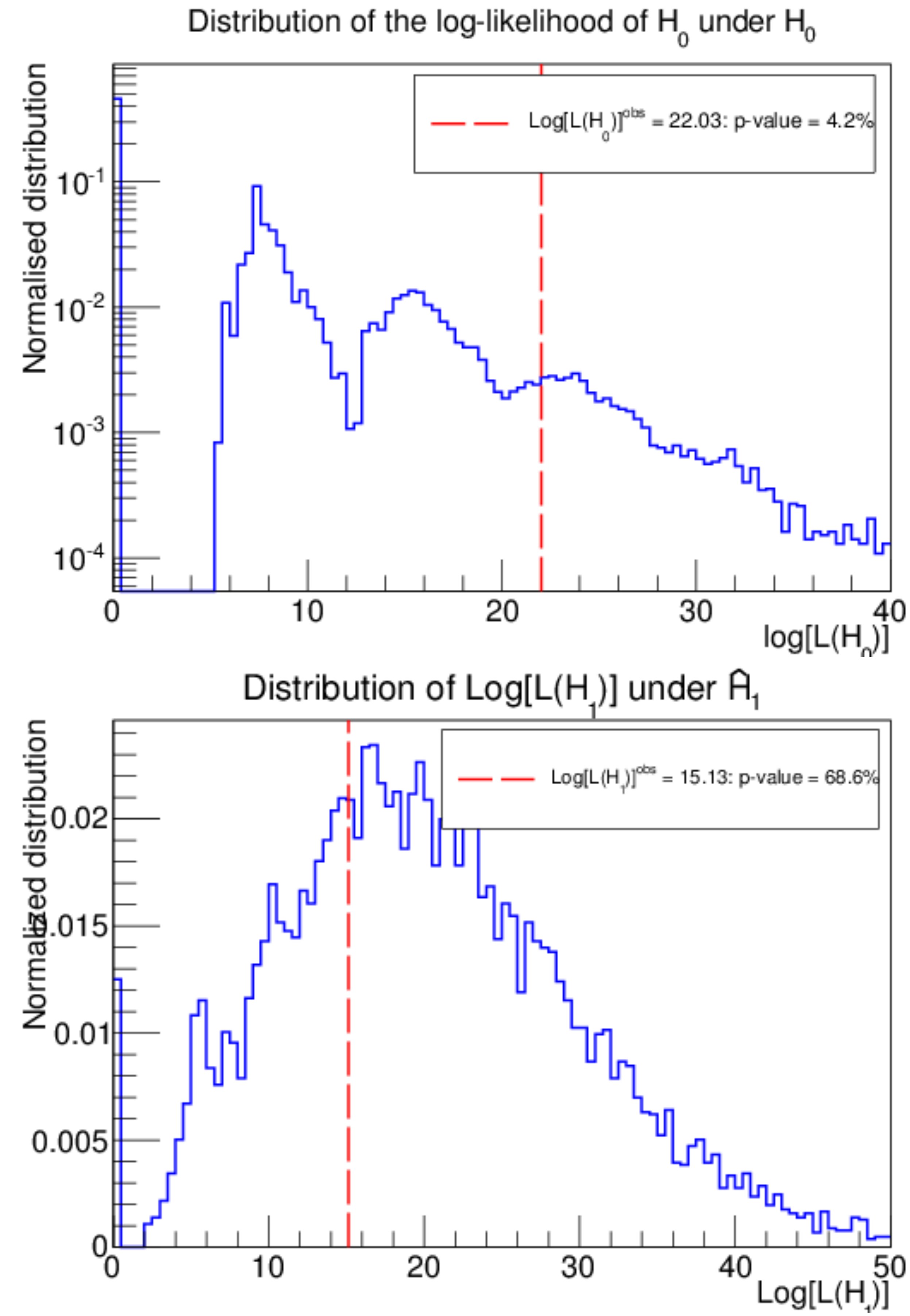
$$q_0 = -2\log\left\{\frac{\mathscr{L}(m_\chi, \sigma_{\chi-n}=0, \hat{\hat{\vec{\nu}}})}{\mathscr{L}(\hat{m}_\chi, \hat{\sigma}_{\chi-n}, \hat{\vec{\nu}})}\right\} \equiv 2\log\left\{\frac{\mathscr{L}(H_1)}{\mathscr{L}(H_0)}\right\}$$

- A likelihood ratio test favors a WIMP+background hypothesis over the known background estimate as the source of our signal at the 99.81% confidence level (p-value:0.19%, ~3σ).
- The maximum likelihood occurs at a WIMP mass of 8.6 GeV/c^2 and WIMP-nucleon cross section of 1.9×10^{-41} cm^2.



Profile Likelihood Goodness of Fit

- Its very important to check if the WIMP+background actually fits the data well.
- The goodness of fit of the known-background-only hypothesis is 4.2%
- The goodness of fit of the WIMP+background hypothesis is 68.6%



SuperCDMS SNOLAB

Assumed background

Background Event Type	Raw [/kg/yr]	Single Scatters [/kg/yr]	Expected Background [/kg/yr]	Expected Background number
electromagnetic events				
photon-sourced	882	281	2.8×10^{-5}	0.01
surface ^{210}Pb-sourced	228	50	$< 6.3 \times 10^{-4}$	< 0.24
neutrons				
radionuclide	5.8×10^{-4}	1.8×10^{-4}	1.7×10^{-4}	0.07
muon-induced	9.7×10^{-4}	7.0×10^{-5}	6.7×10^{-5}	0.03

Performance Requirements

Parameter	Demonstrated	Requirement
Mass per detector module	0.62 kg	1.38 kg
Leakage of photon-induced events	1×10^{-6}	1×10^{-7}
Leakage of surface events	$\leq 2.9 \times 10^{-5}$	1.2×10^{-5}
Trigger threshold for low-mass analysis	3 keV	0.7 keV
High-mass energy threshold	10 keV	10 keV
WIMP-search duty cycle	80%	80%
Detector fiducial volume %	63%	73%
Efficiency of additional WIMP-search cuts	92%	92%