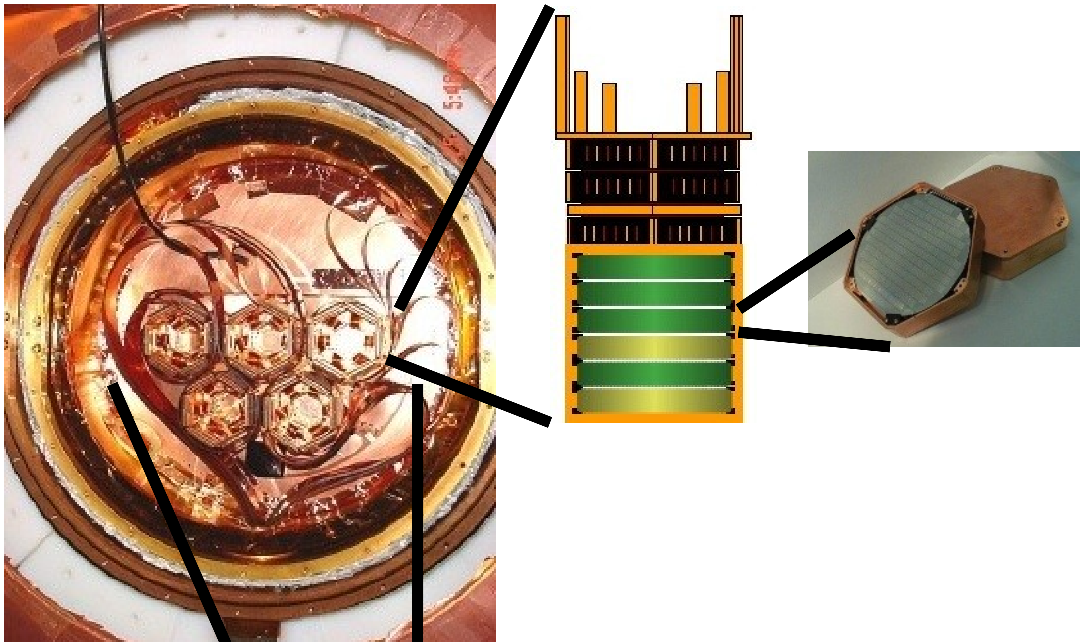
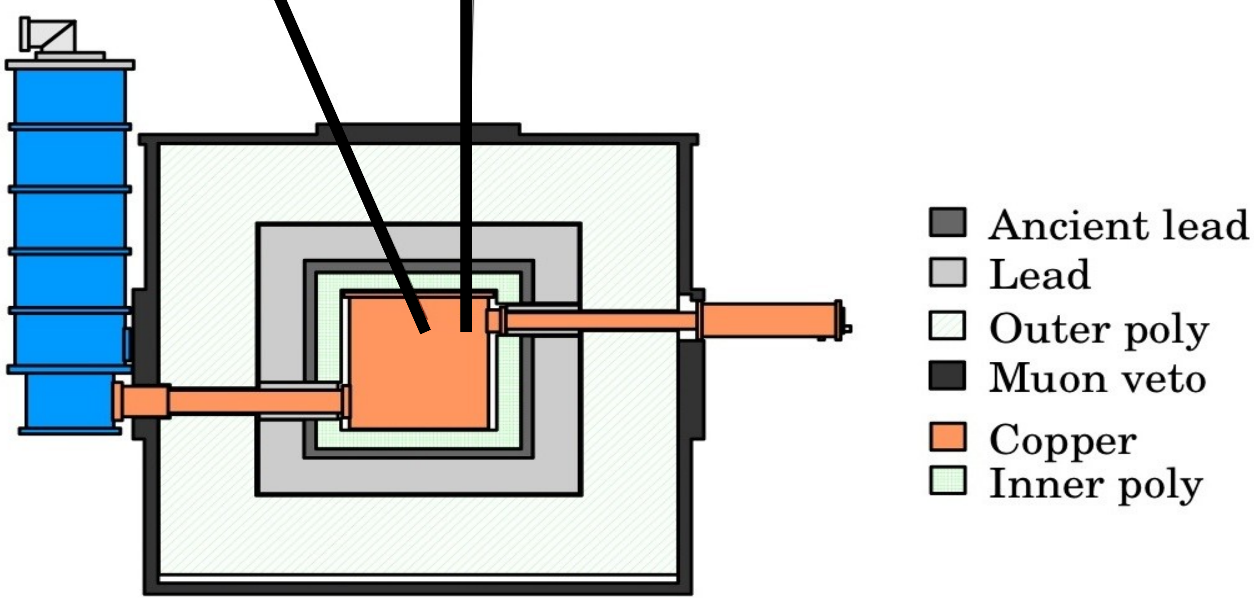
Search for Dark Matter with the CDMS Experiment

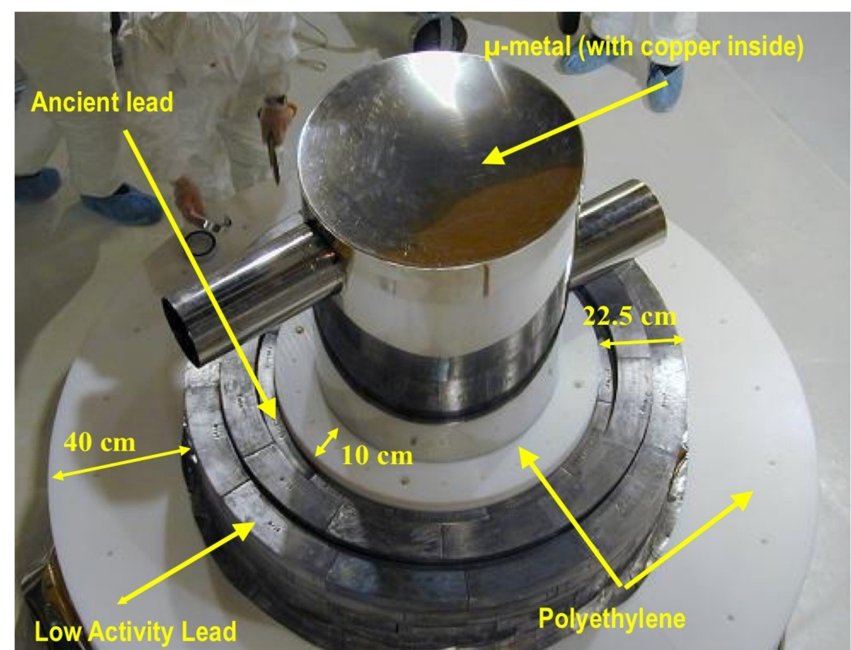
Sebastian Arrenberg
University of Zürich
for the CDMS Collaboration
Weak Interactions and Neutrinos, WIN '09
Perugia, Sep. 16th, 2009

The CDMS Setup & Shielding



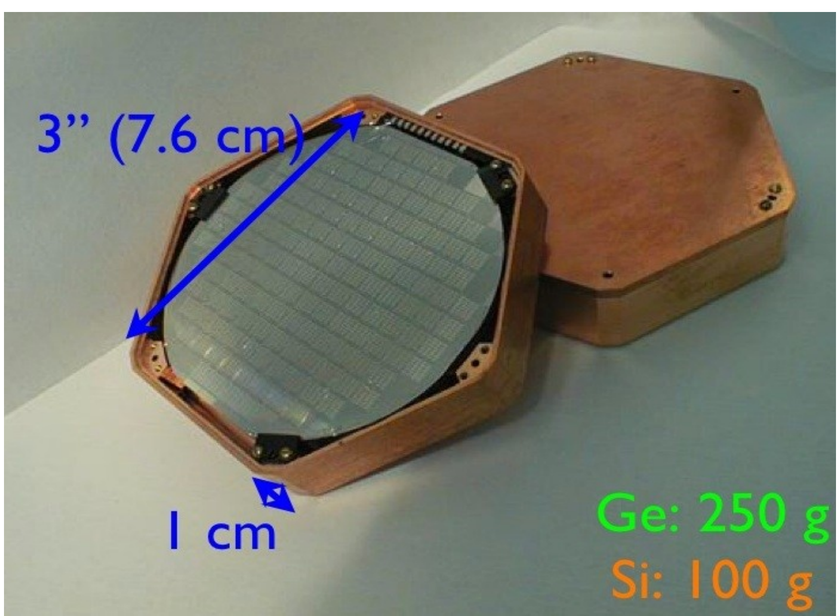
- 5 towers with 6 detectors each
- active veto against high energetic muons
- passive shielding:
  - lead against gammas from radioactive impurities
  - polyethylene to moderate neutrons from fission decays and from (α,n) interactions resulting from U/Th decays



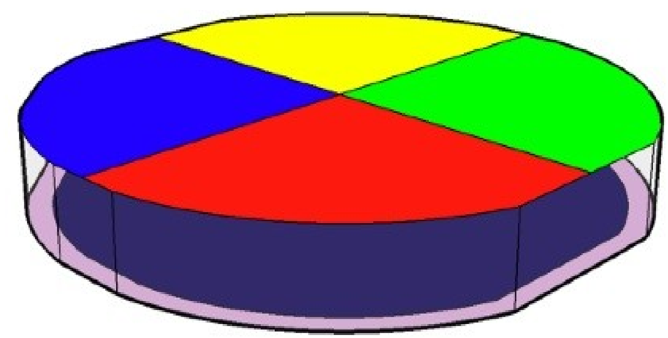


The CDMS ZIP Detectors

- 19 Ge and 11 Si semiconductor detectors
- operated at cryogenic temperatures (~40 mK)
- 2 signals from interaction (ionization and phonon) ⟶ event by event discrimination between electron recoils and nuclear recoils
- z-sensitive readout
- xy-position imaging



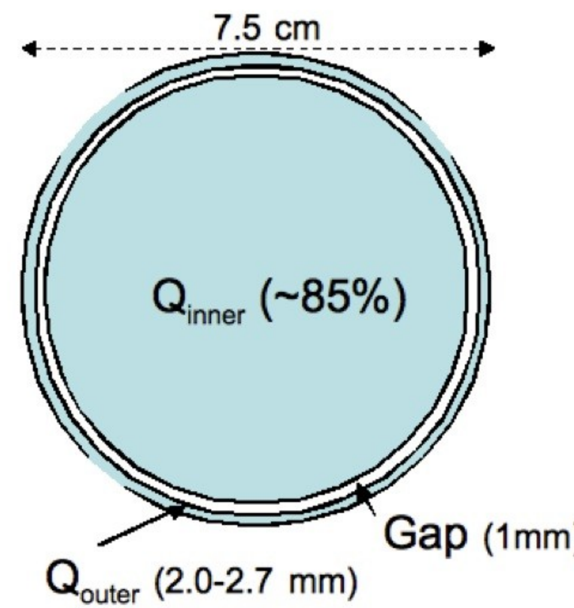
Phonon readout:
4 quadrants of
phonon sensors

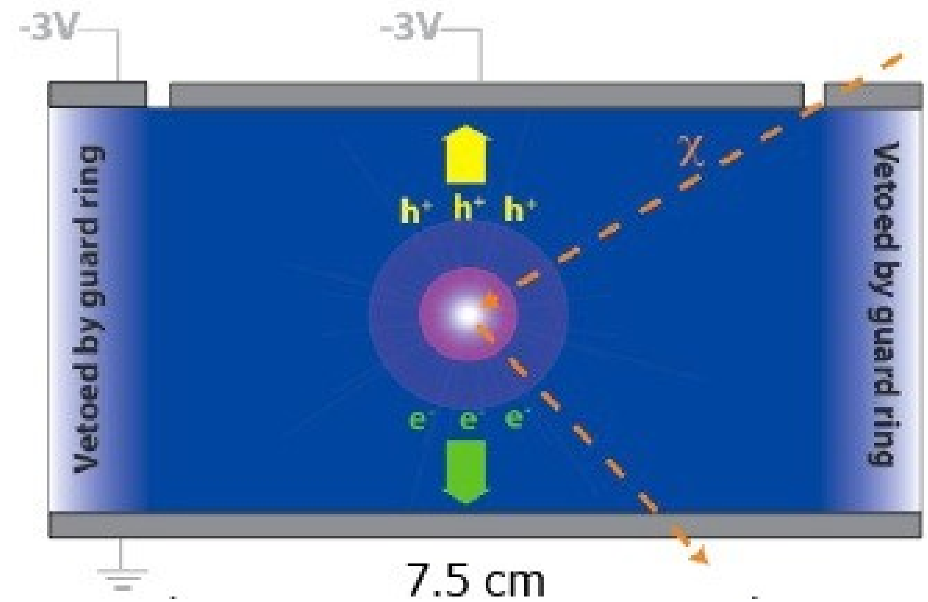


Charge readout:
2 concentric
electrodes

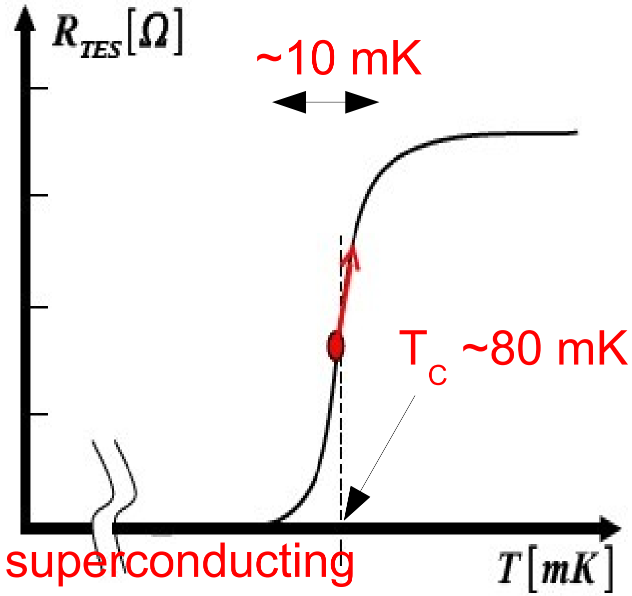
The Ionization Readout

- interaction creates electron hole pairs
  - → seperate using applied electric field
    - → collect charges on electrodes on surface
- drift field of 3 V/cm (4V/cm) on Ge (Si) detectors
- interaction at crystal edges can have incomplete charge collection
  - → use outer electrode as guard ring
    - → omit qouter events
- low-energy resolution: 3-4%





The Phonon Readout

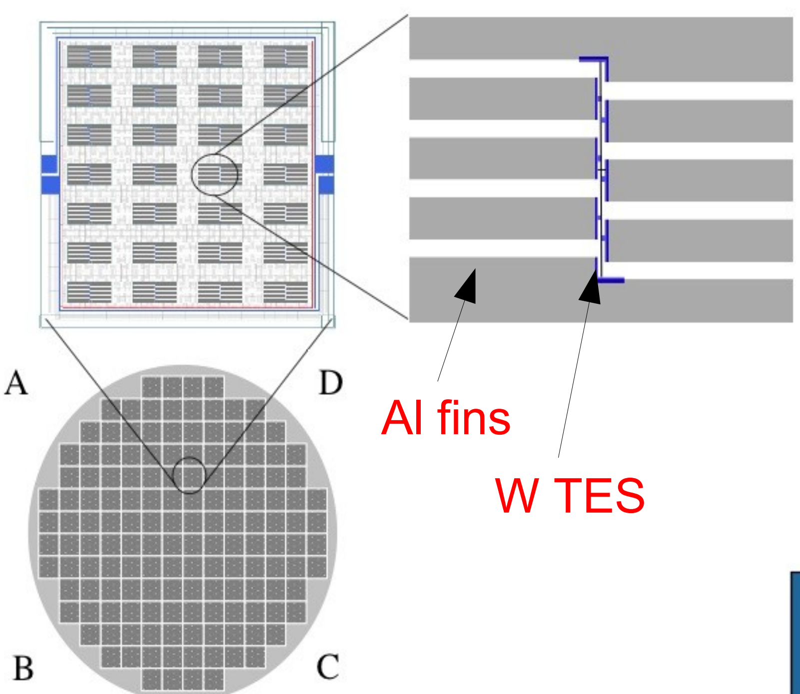


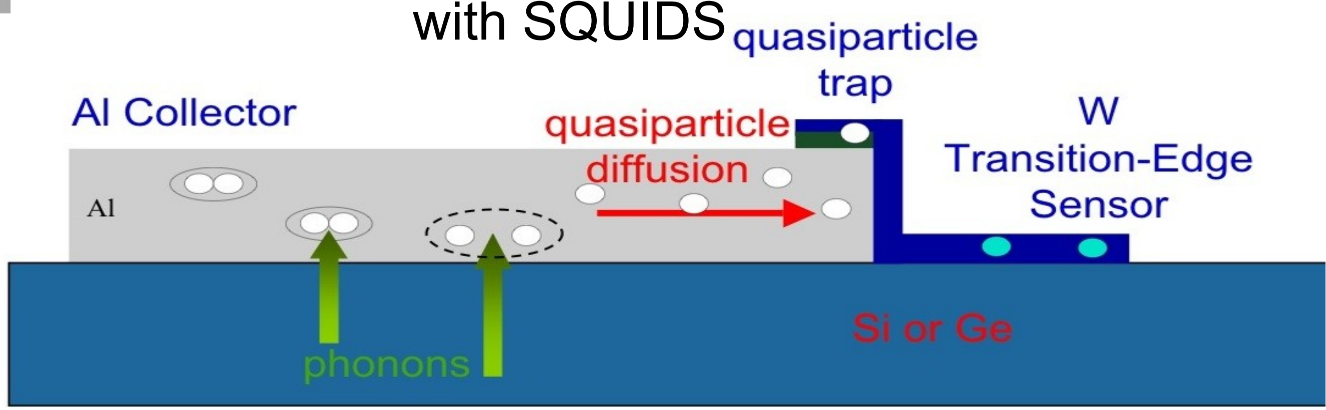
- segmented phonon readout (4 quadrants)
- each quadrant consists of 1036 tungsten TES (Transition Edge Sensors)
- fast response time ~5 μs
- low energy resolution: ~5%
- tungsten strips set just below the edge of superconductivity using bias voltage

→ energy deposition raises temperature

→ conductivity changes to normal

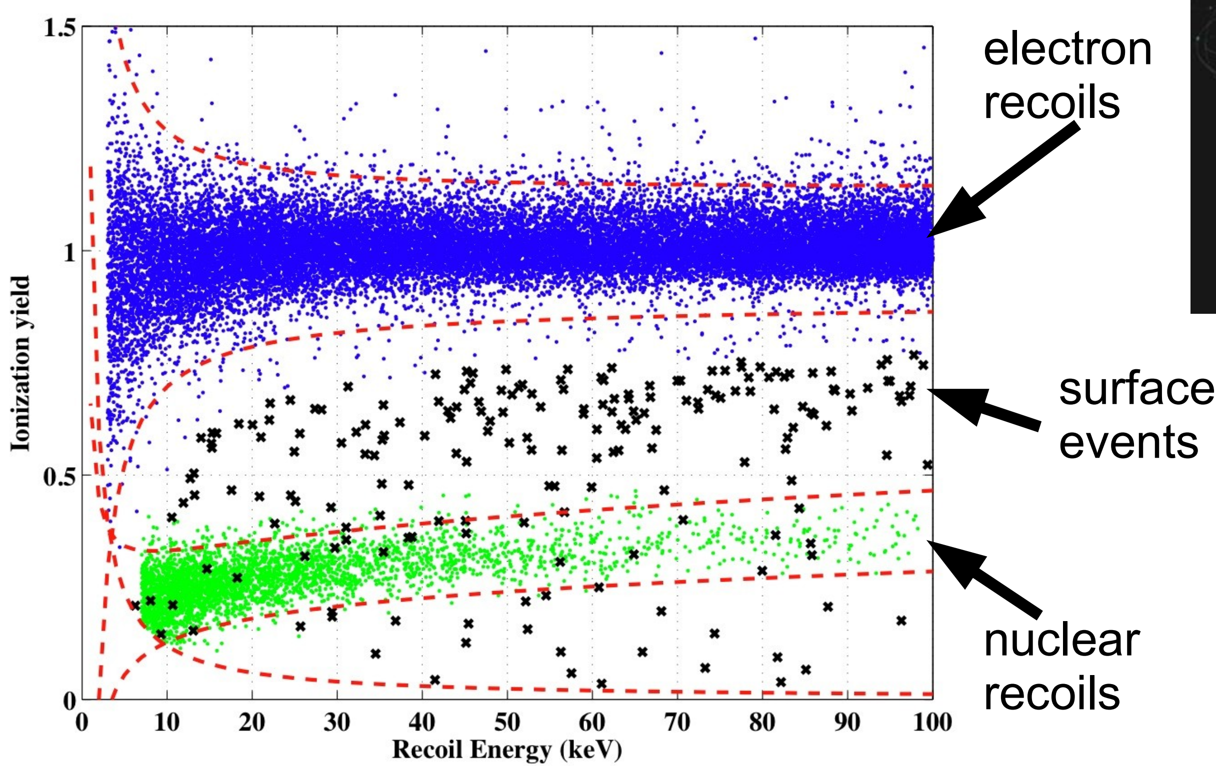
→ dramatic lowering of current read out with SQUIDS

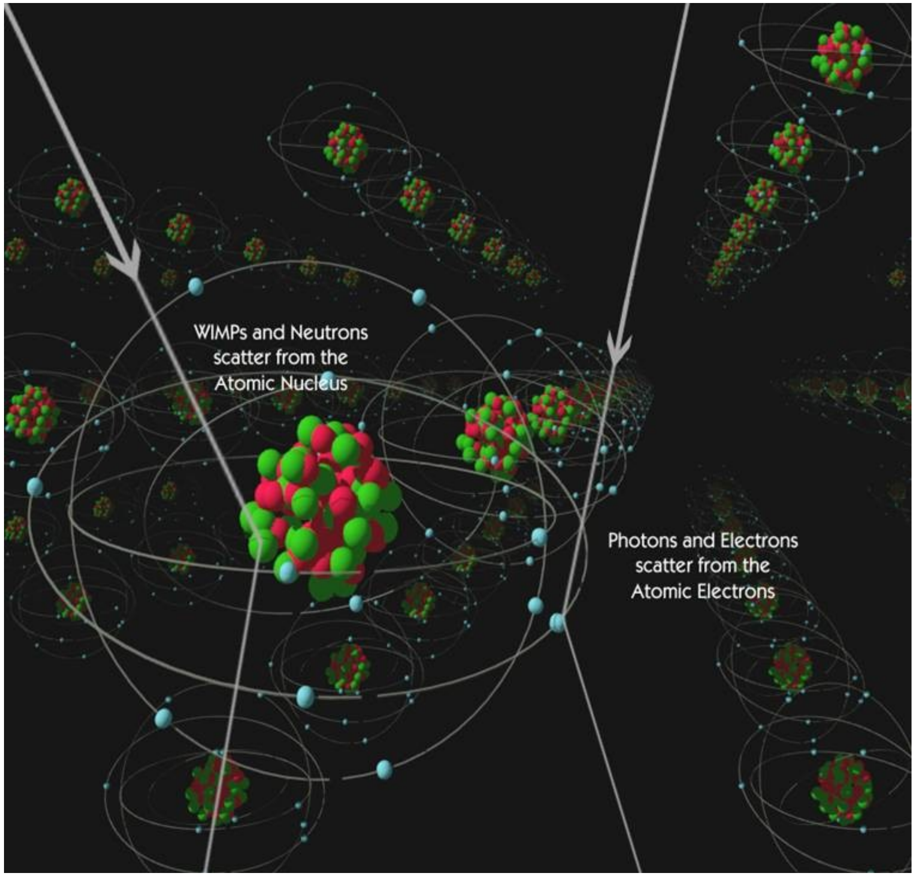




Primary Background Rejection

- most backgrounds (e, γ) produce electron recoils
- neutrons and WIMPs produce nuclear recoils which have a suppressed ionization signal
- define ionization yield as $y = \frac{E_{charge}}{E_{recoil}}$



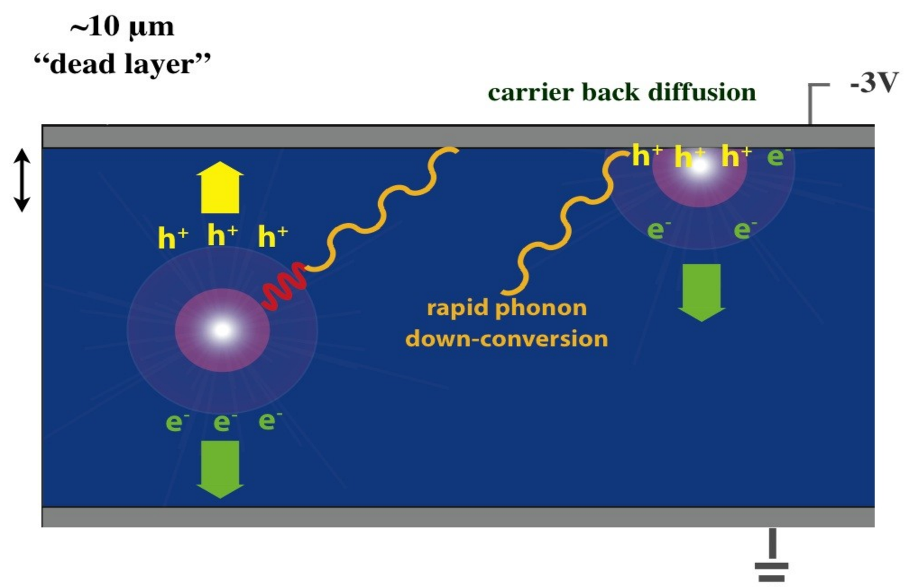


- better than 1:10000 rejection of electron recoils based on ionization yield alone
- dominant remaining background: low-yield surface events

Surface Events and Contamination

- reduced charge yield due to back-diffusion of charge carriers at the detector surface

- surface event background can be fully accounted for by two sources:
  1. low-energy electrons induced by the ambient photon flux from radioactive impurities in the experimental setup
  2. ^{210}Pb contamination of the detector surfaces

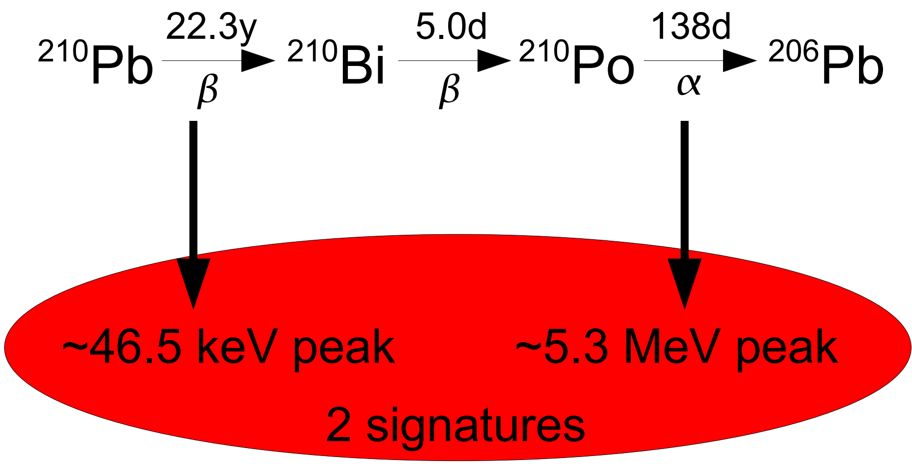


^{210}Pb contamination?

- detetctors are exposed to environmental Radon during fabrication, testing, ...

- ^{210}Pb is a decay product of ^{222}Rn and can be deposited on the detector surfaces

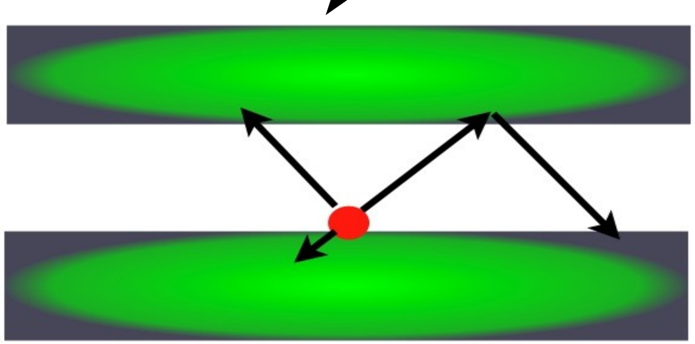
- decay chain:

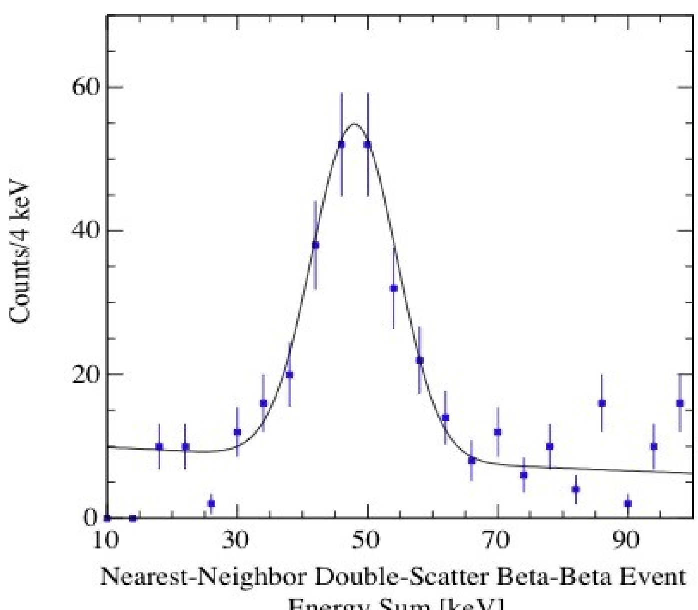


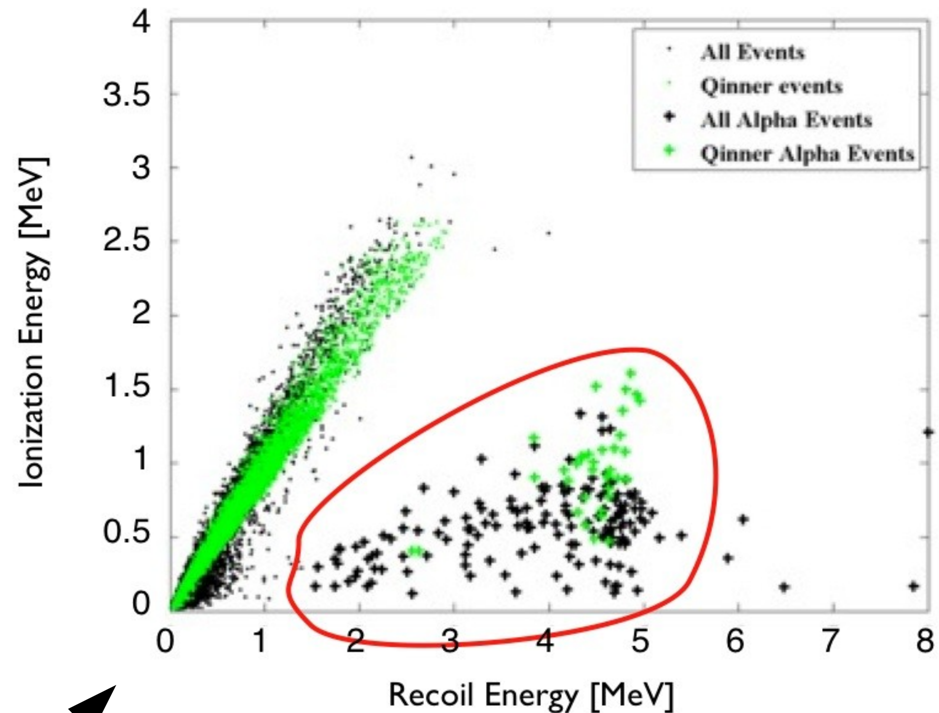
- significant reduction of this contribution for new towers (T3-T5)

Evidence for ^{210}Pb Contamination

Sum over adjacent detectors (NND) to search for 46.5 keV peak!

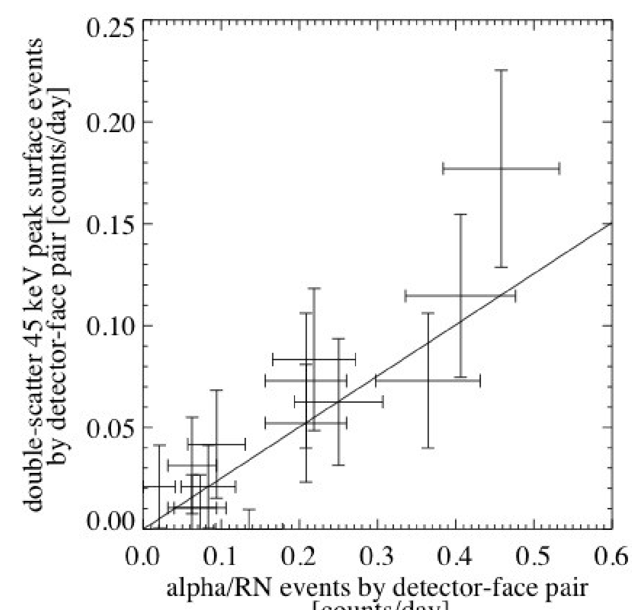






Check for low yield α's!

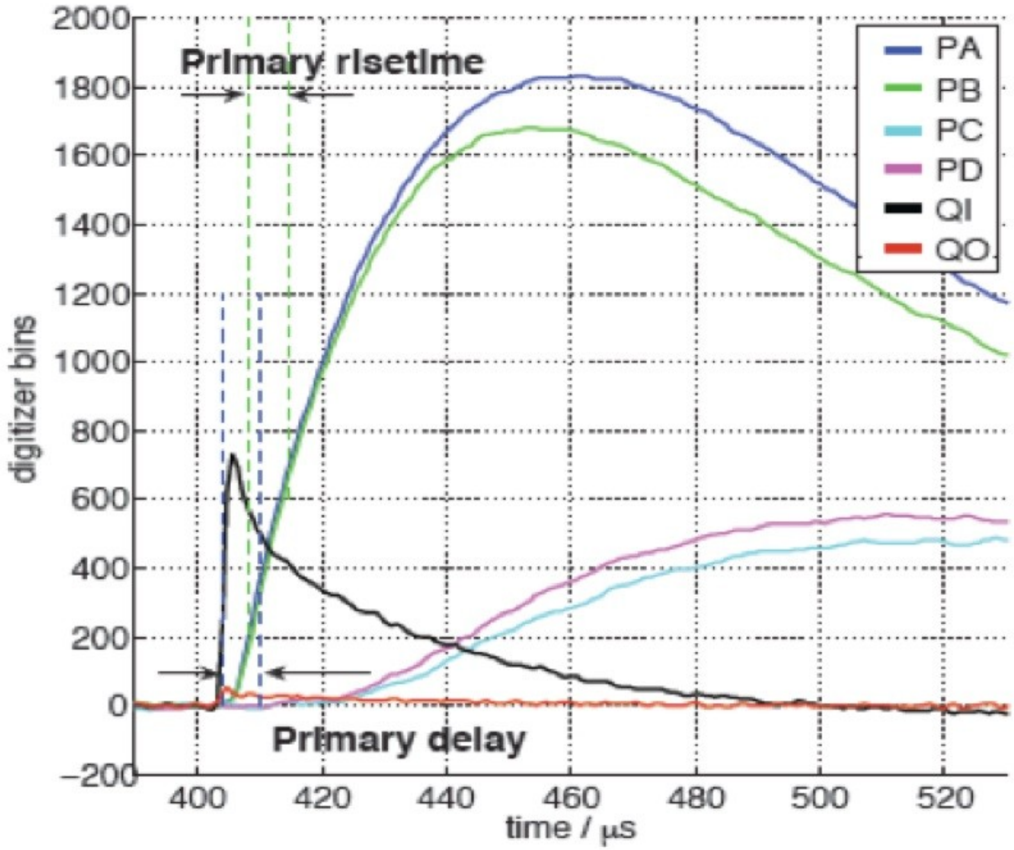
We see a strong correlation between both signatures.

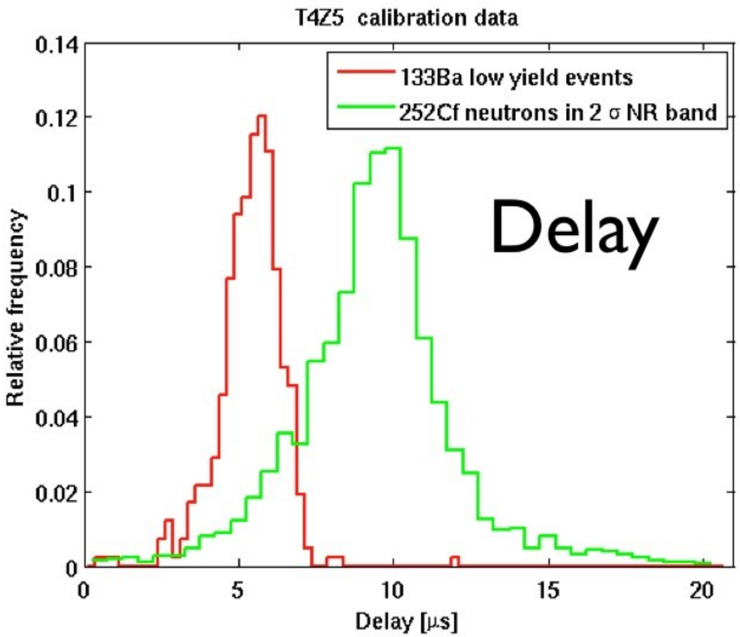


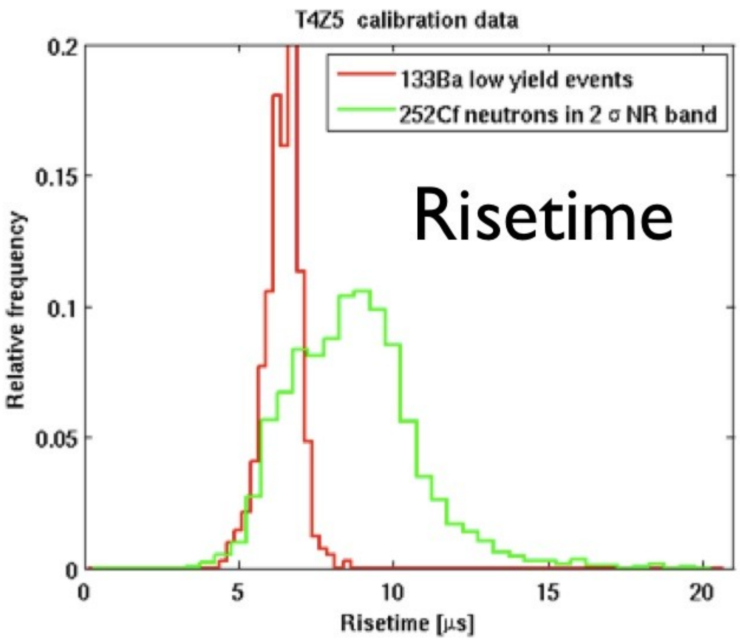
Phonon Timing

Surface events are faster in timing than bulk nuclear recoils.

Use timing as discriminator to get rid of surface events.





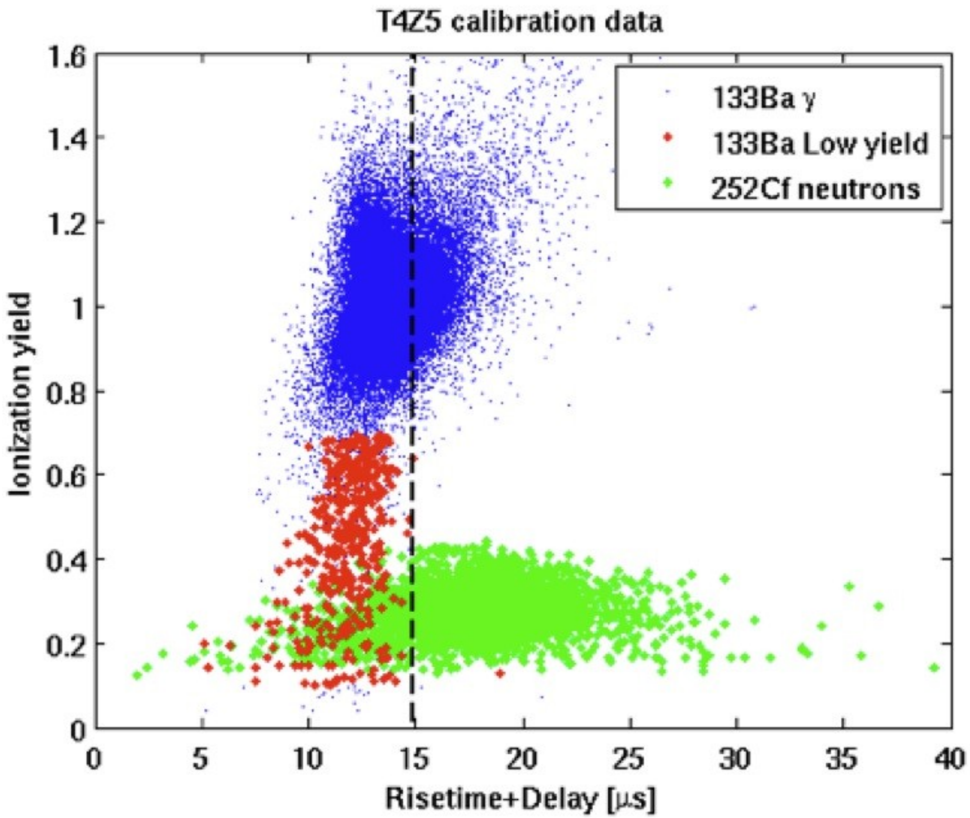


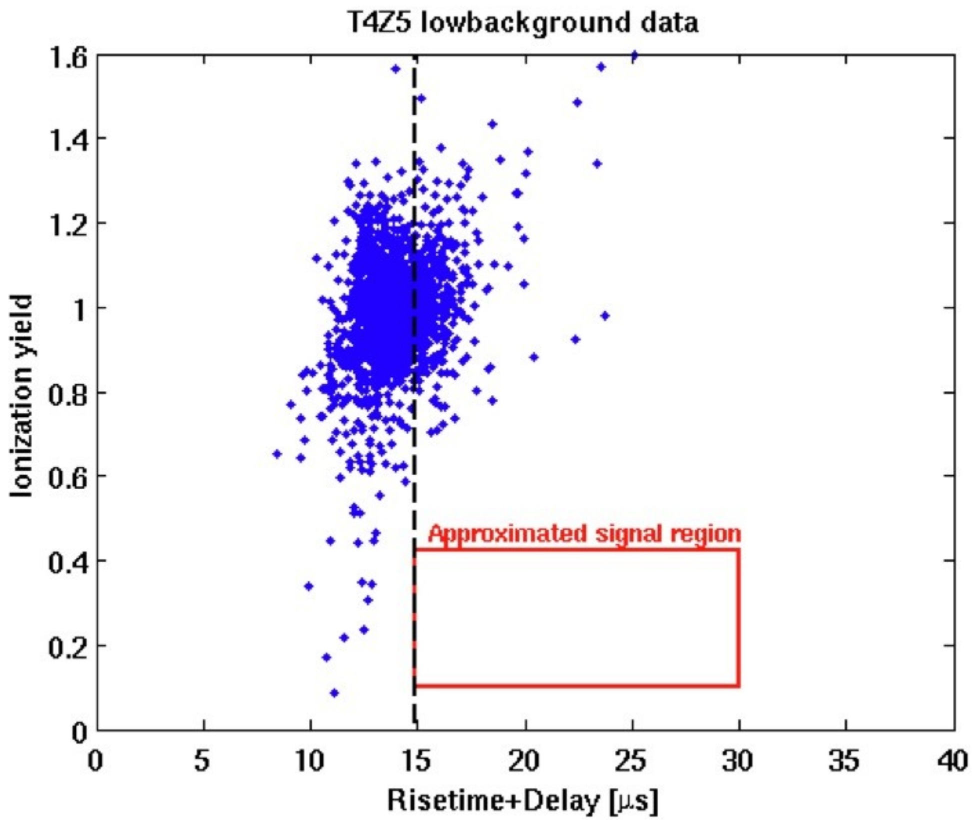
Surface Event Rejection

- use risetime+delaytime to define timing cut on calibration data
- allow ~0.5 events total laekage within WIMP search data

→

- apply cut to lowbackground data
- surface event rejection ~200:1

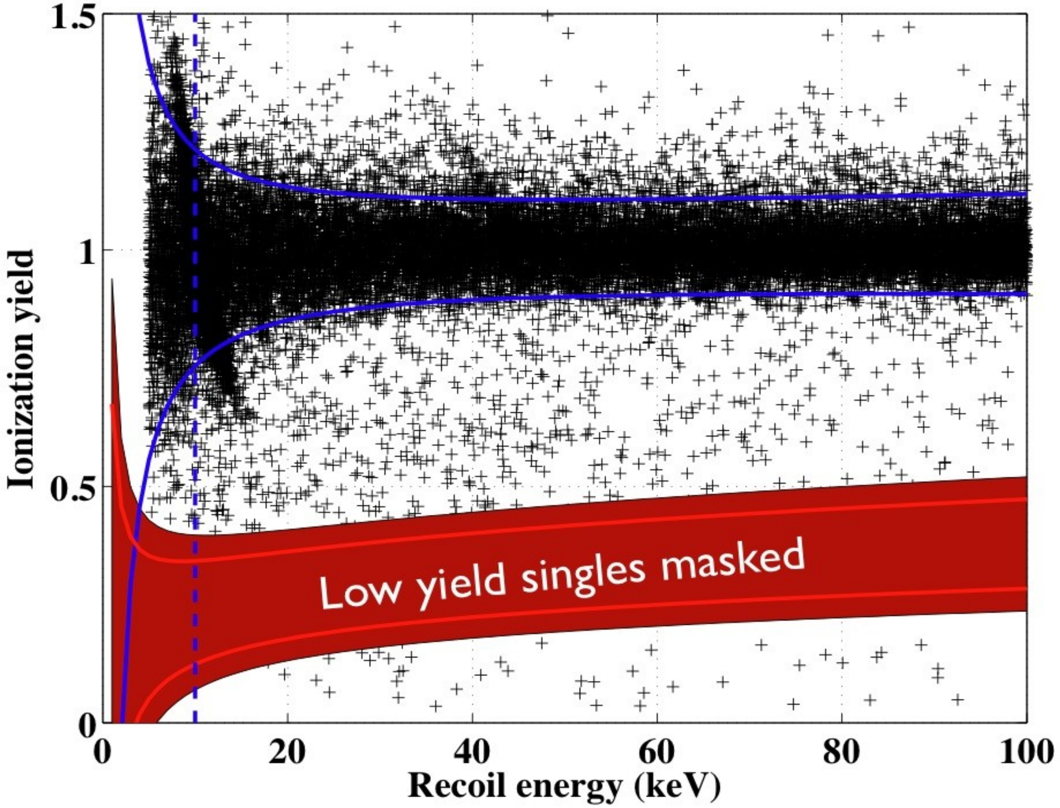


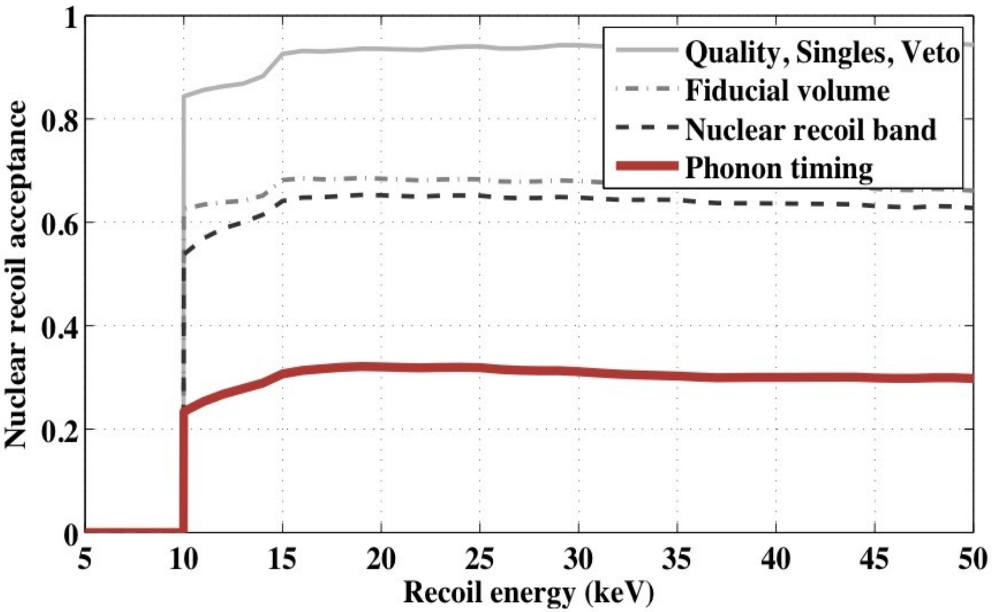


Analysis Technique

Blind Analysis
Set all cuts and calculate efficiencies **before** looking at the signal region of the WIMP-search data.

Cut criteria for WIMP candidates:
- energy range: 10-100 keV
- data quality
- veto-anticoincidence
- single-scatters
- inside fiducial volume (qinner cut)
- inside 2σ nuclear recoil band
- no surface event (phonon timing)





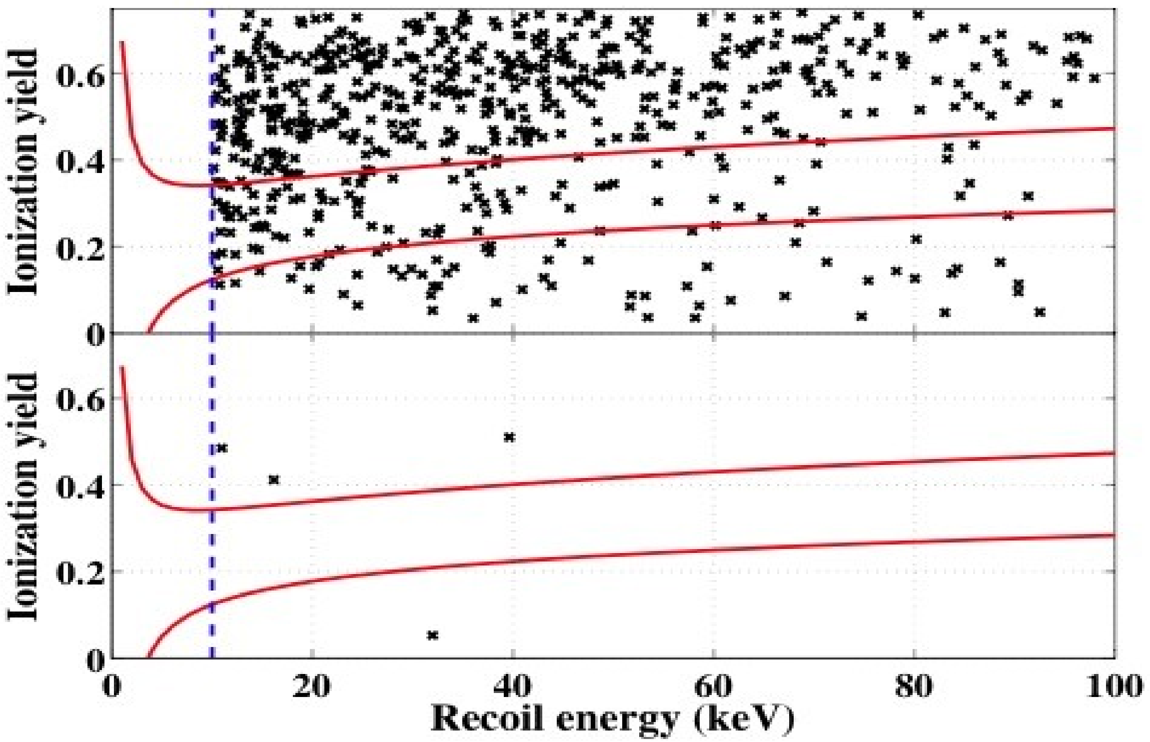
Analysis Summary

- 398 kg-days raw exposure
- no events observed in signal region after applying timing cut

Background summary
- expected number of surface leakage events:

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

- estimated neutron background:
  (α,n): < 0.03
  fission: < 0.1
  cosmogenic: < 0.1

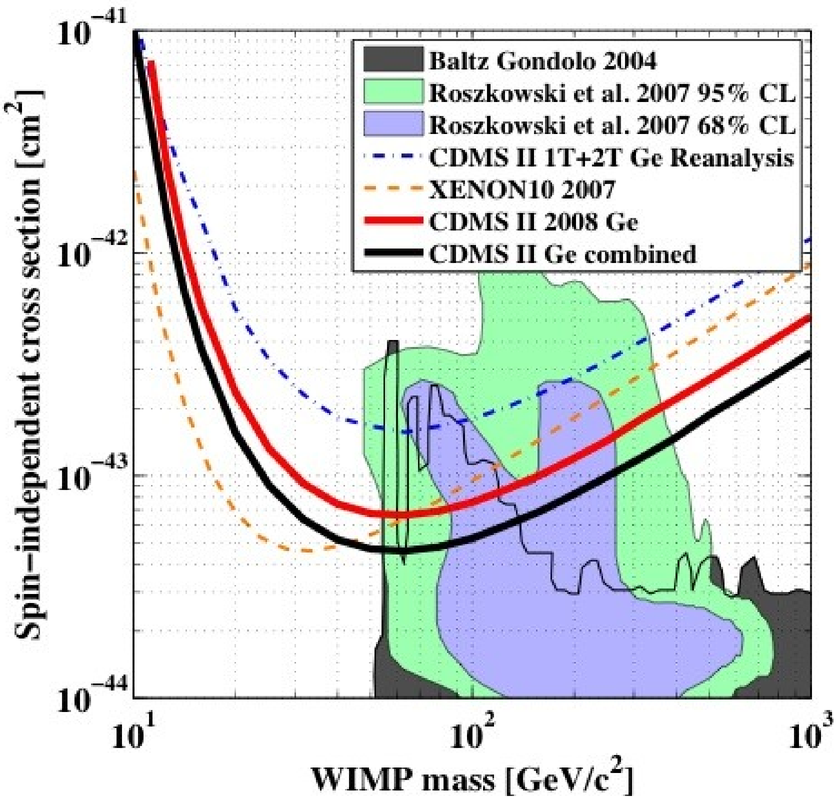


Before applying timing cut!

After applying timing cut!

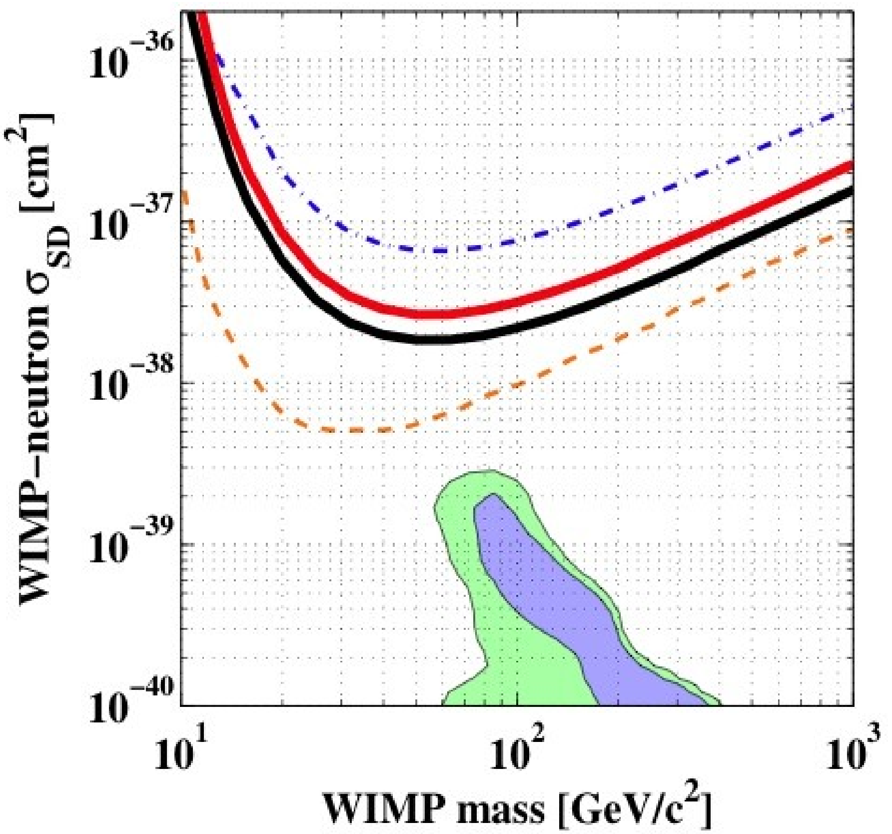
Results

Spin-independent cross section limits



$4.6x10^{-44}$ cm^2 @ 60 GeV
(combined with previous CDMS data)

Spin-dependent cross section limits

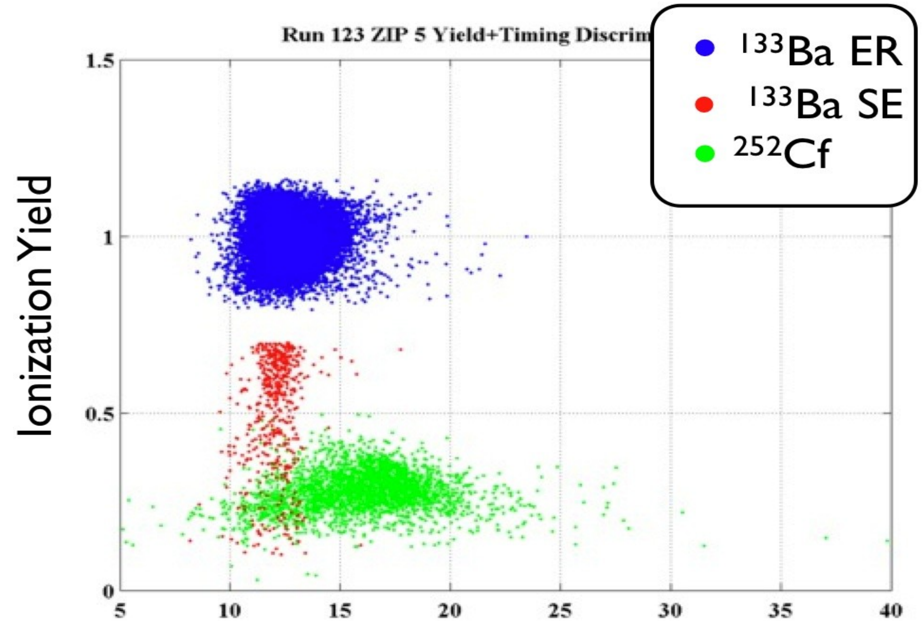


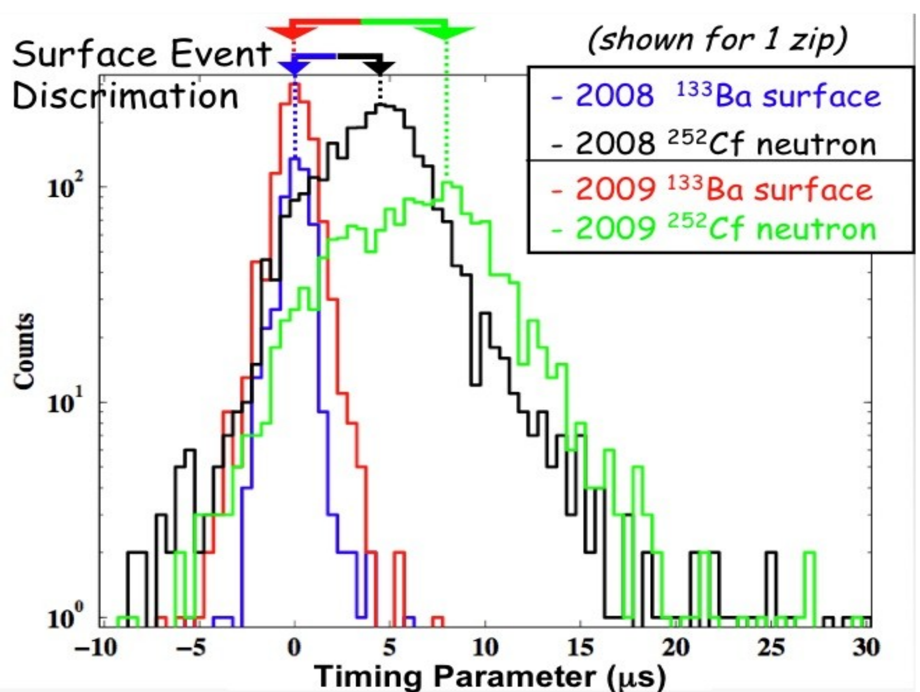
$1.8x10^{-38}$ cm^2 @ 60 GeV
(combined with previous CDMS data)

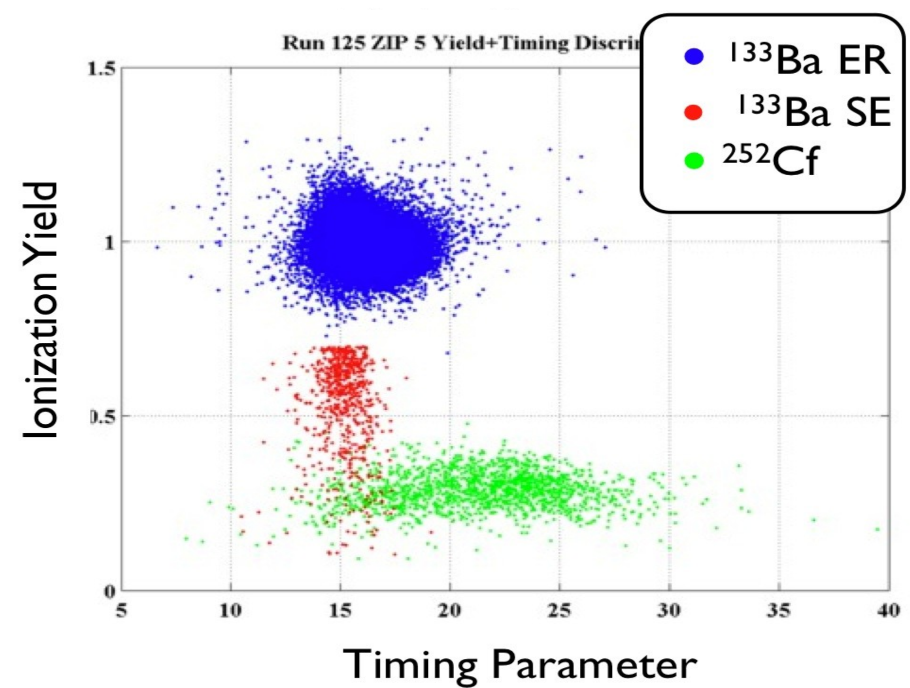
World leading 90% C.L. upper limit on scalar interaction cross sections for WIMP masses above 44 GeV!

Ongoing Analysis...

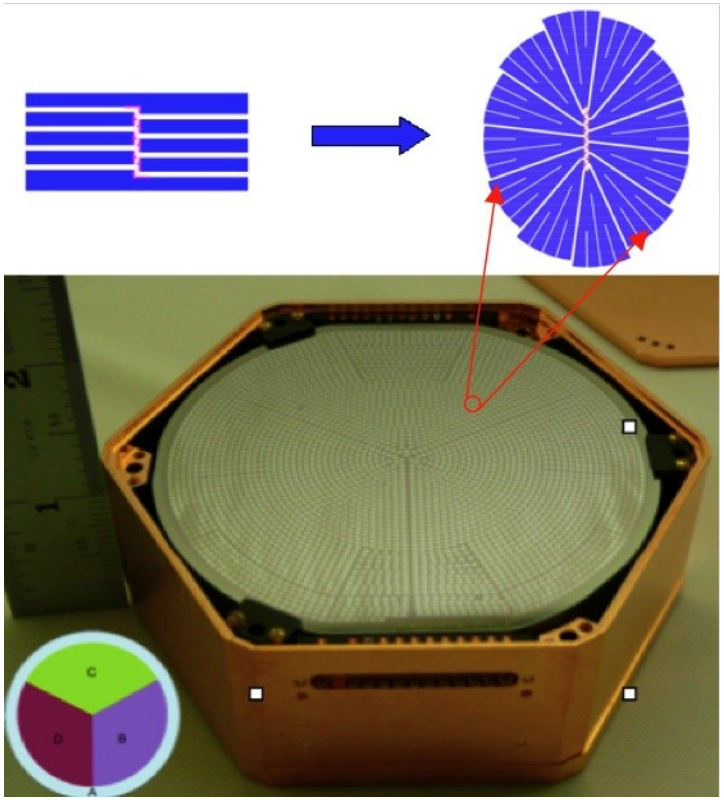
- exposure of ~700 kg-days after basic quality cuts in analysis pipeline
- timing of new data looks promising in obtaining higher detection efficiency
- new results expected in ~1 month



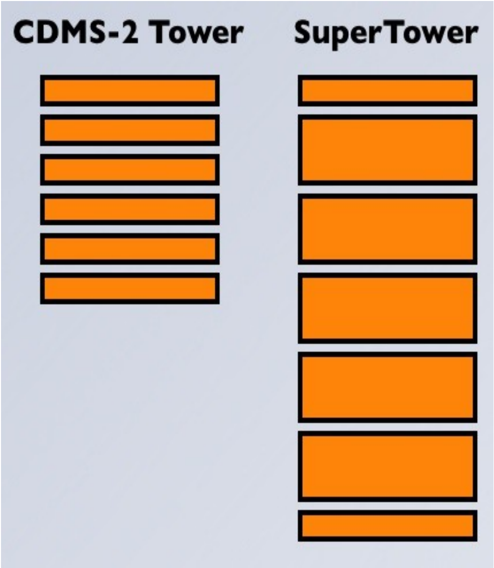




SuperCDMS



- 2.5 times more massive Ge detectors (1-inch thick)
- reduced surface/volume ratio to decrease background
- “endcap“ Ge veto detectors in each tower
- improved Al fin layout for better phonon collection
- modified phonon sensor layout with outter phonon guard ring similar to outter charge electrode
- first SuperTower already installed in Soudan

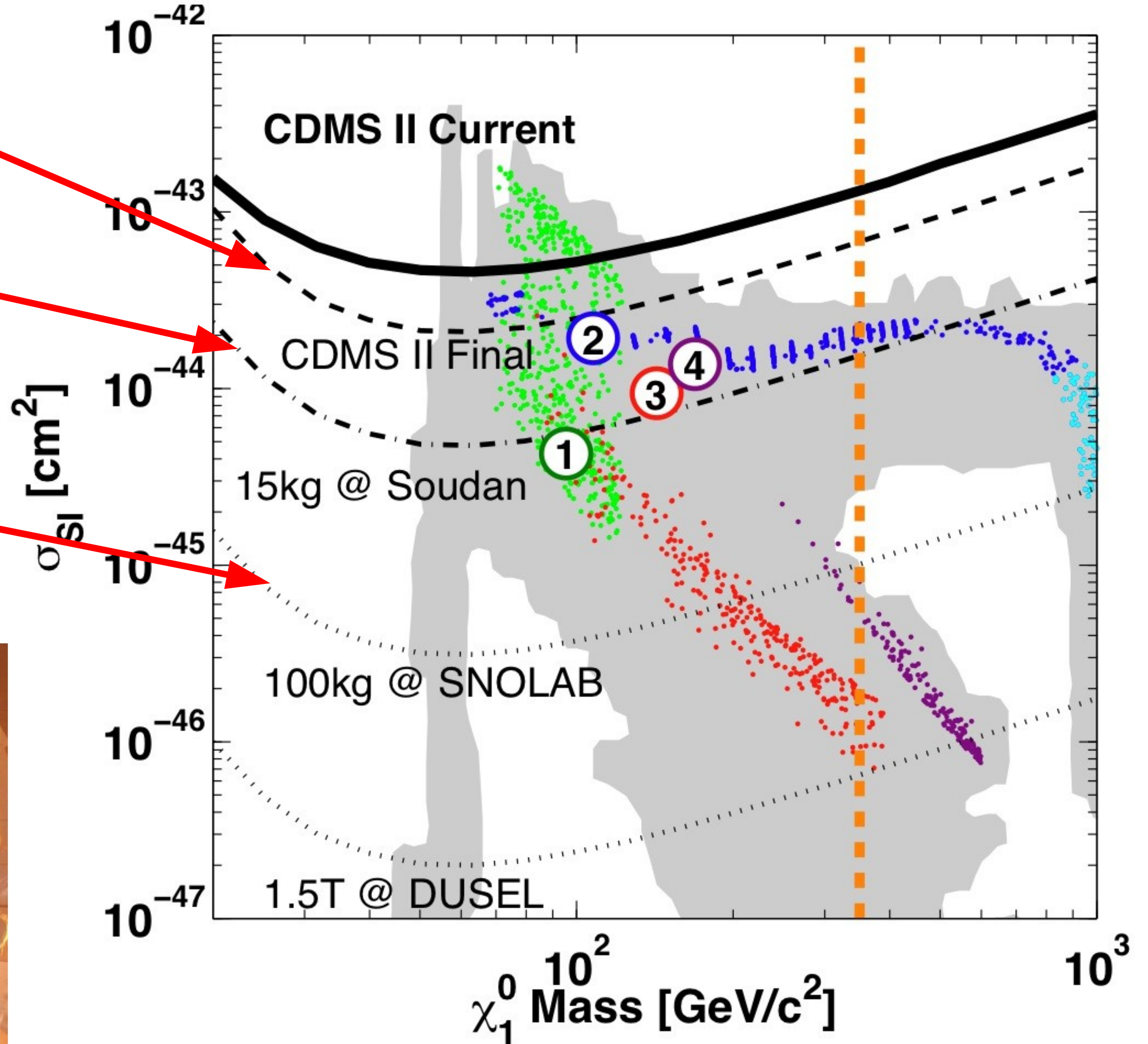


The Future of CDMS

CDMS II @ Soudan
results expected in
~1 month

SuperCDMS @ Soudan
15 kg of Ge
~2 years of operation

SuperCDMS @ SNOLAB
100 kg of Ge
~3 years of operation

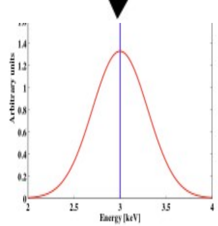


What else can we look for?

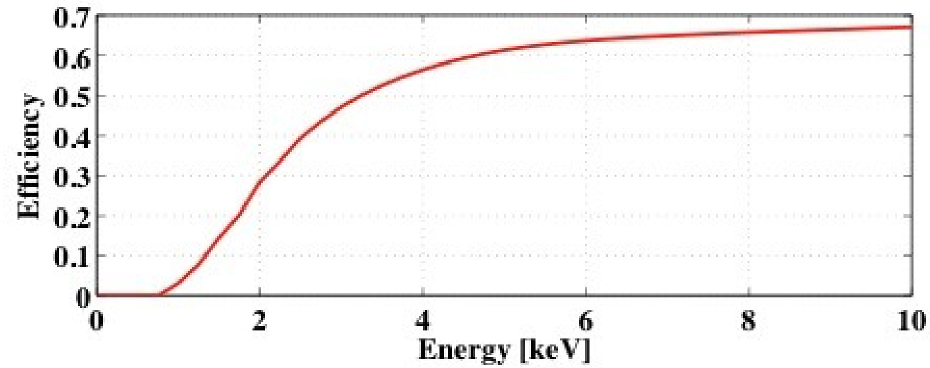
Analyze the low-energy electron-recoil spectrum!

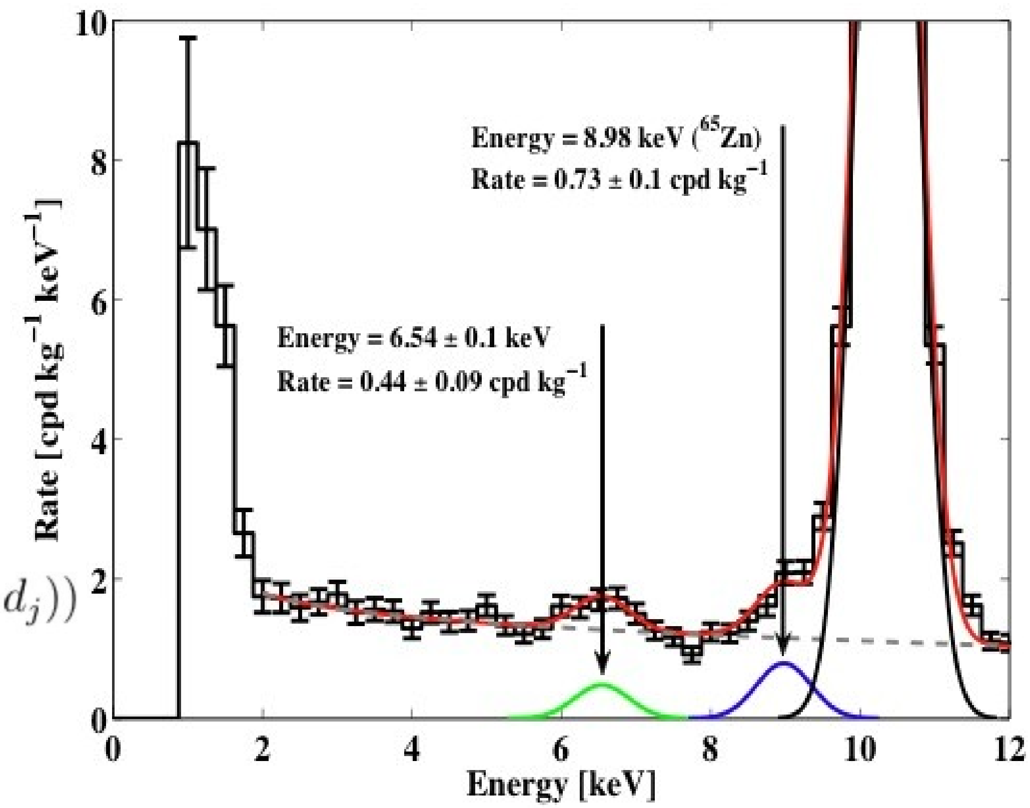
- analysis window: 2.0 – 8.5 keV
- background rate: ~1.5 cpd/kg/keV
- peak near 6.5 keV likely caused by de-excitation of ^{55}Mn from cosmogenic activation
- search for excess above background by maximizing the unbinned log-likelihood function for each energy:

$$Log(\mathcal{L}) = -R_T + \sum_{i,j} Log(\lambda \cdot \mathcal{R}(E_i, d_j) + B(E_i, d_j))$$



No excess found!

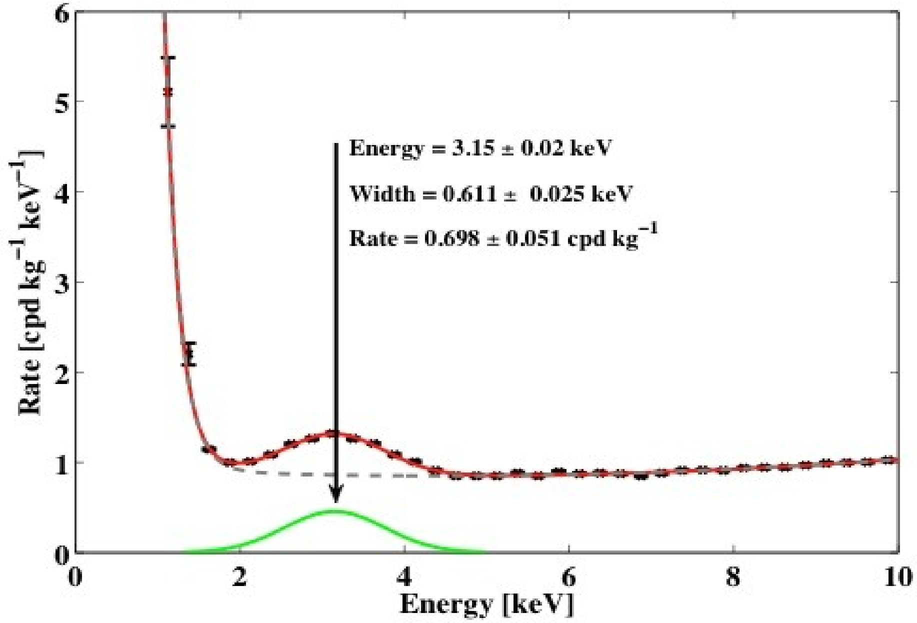


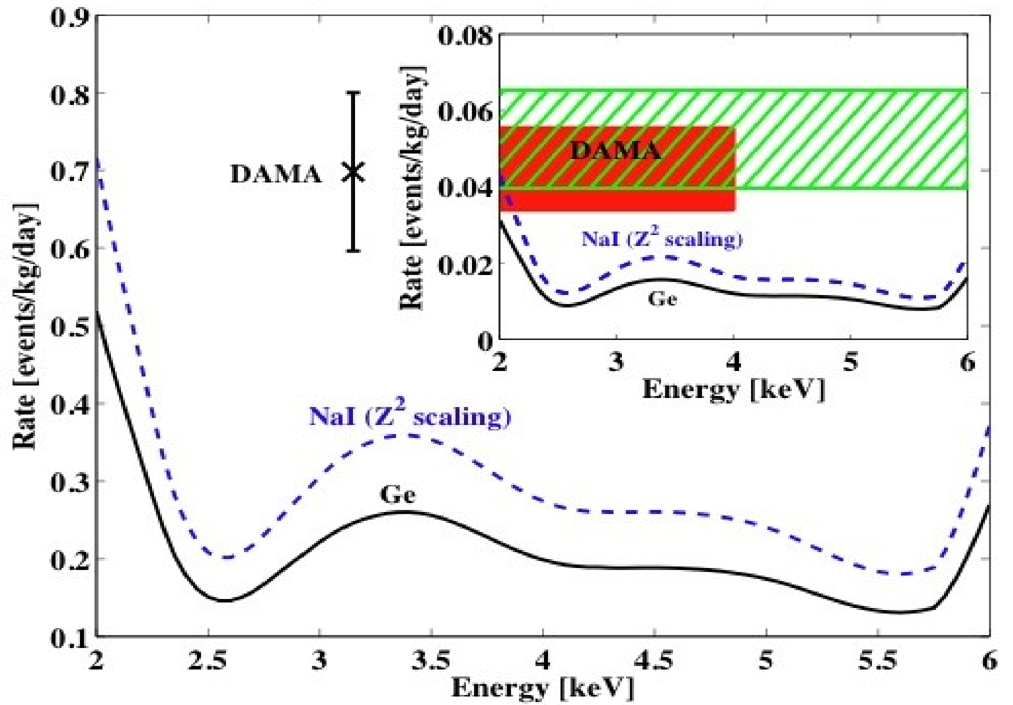


Comparison with DAMA/LIBRA

- interpret possible excess above background as an X-ray from a decaying dark matter particle
- assume that excess in DAMA/LIBRA spectrum is of electromagnetic origin
- we do **not** subtract a contribution from ^{40}K (3.2 keV) in the DAMA/LIBRA spectrum
- use simple toy model for scaling of rates: $\sigma \sim Z^2$
- conservatively assume 6% modulation

CDMS and DAMA/LIBRA results seem to be inconsistent. However, we need an actual particle model for a physical interpretation.





Relic Axions

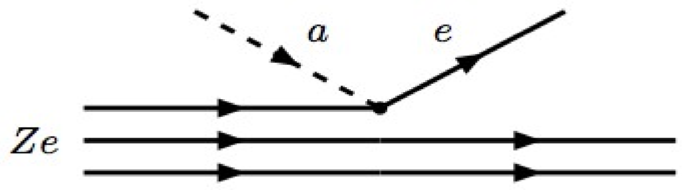
- interpret possible excess above background as signal from relic axions distributed in the local halo

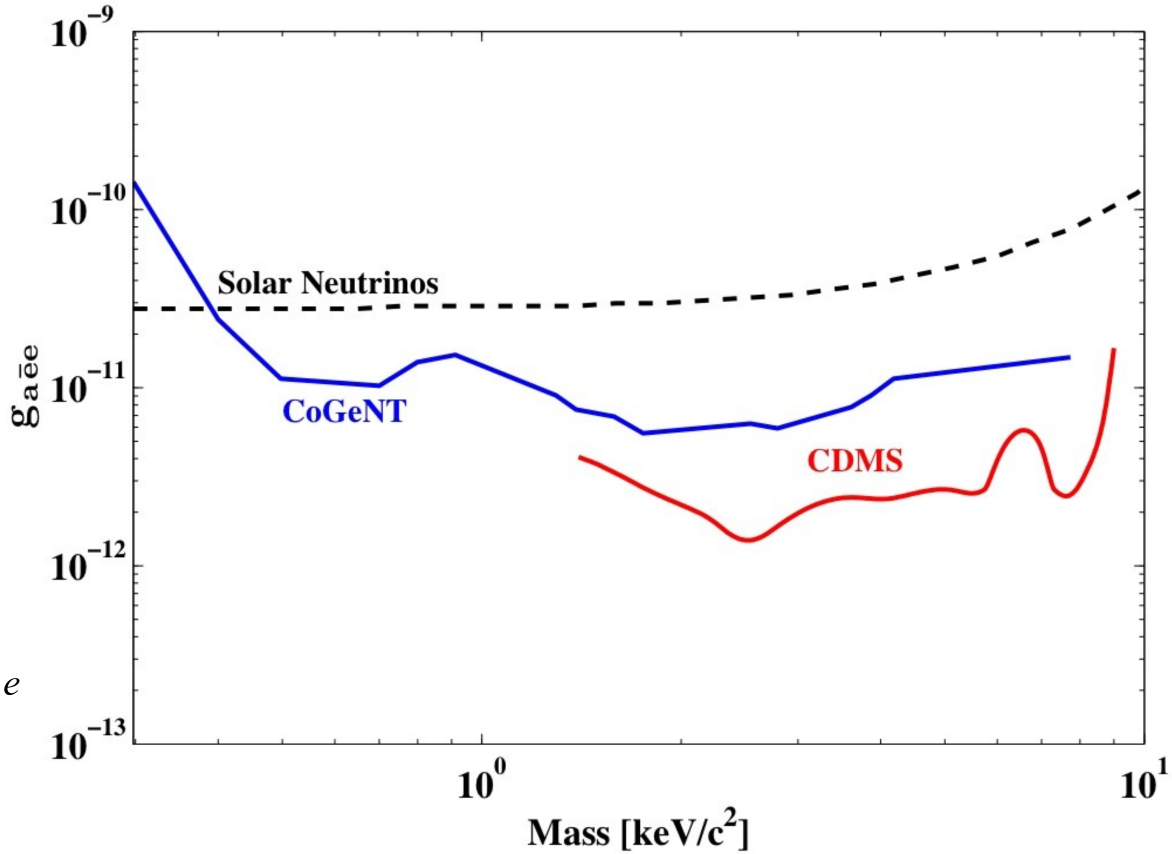
- axions have originally been postulated to solve the strong CP problem

- axio-electric coupling: energy of electron given by the mass of the axion

- annual modulation rate is highly suppressed

- world leading 90% C.L. upper limit on axio-electric coupling $g_{a\bar{e}e}$ for axion masses between 1.4 and 9 keV





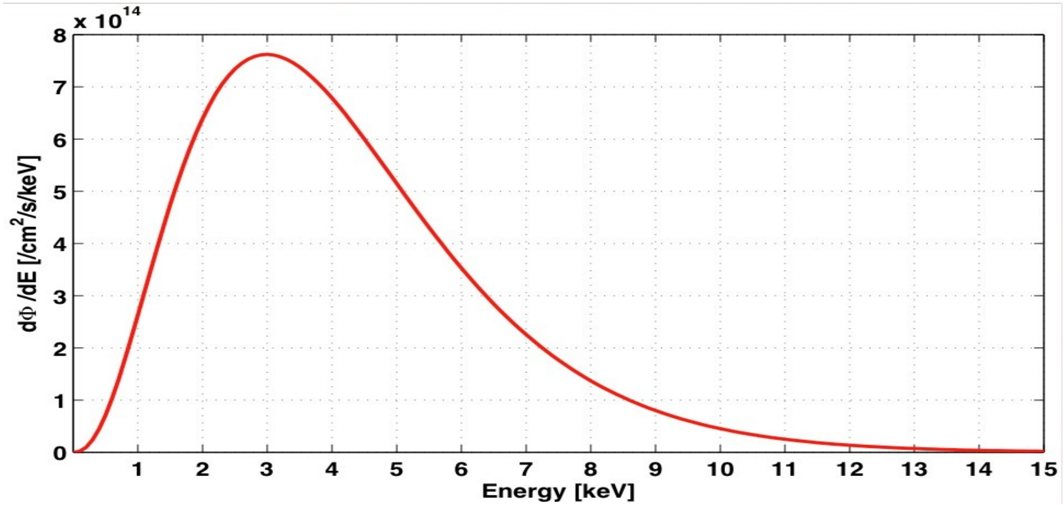
Solar Axions

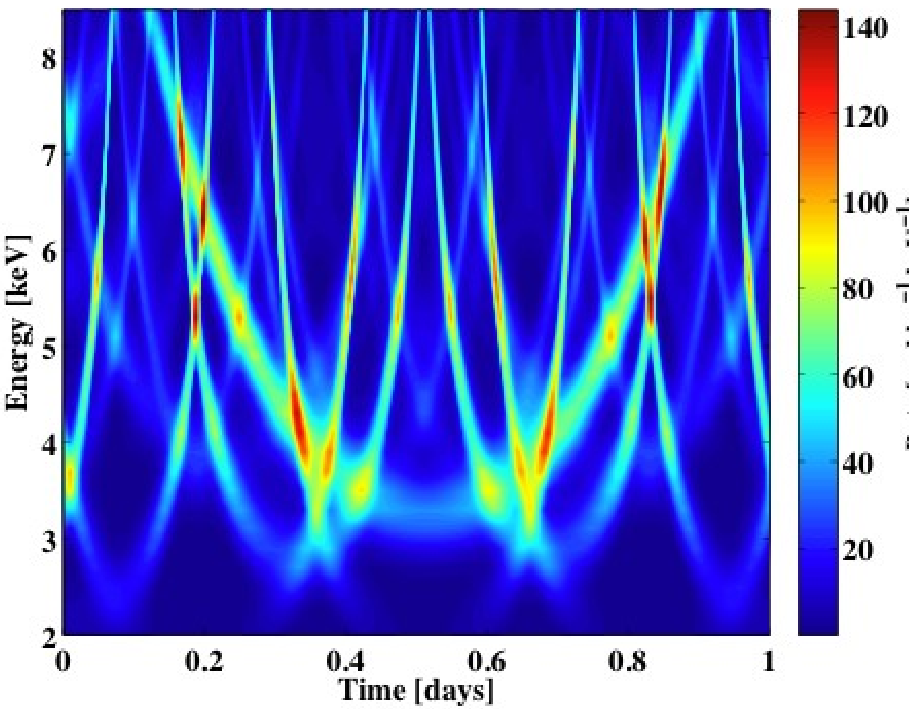
- conversion of photons into axions inside the sun's strong electromagnetic field

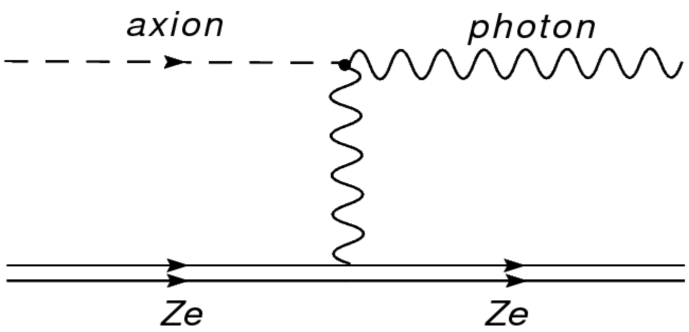
- back-conversion of axions into photons in the nuclear Coulomb field (Primakov effect)

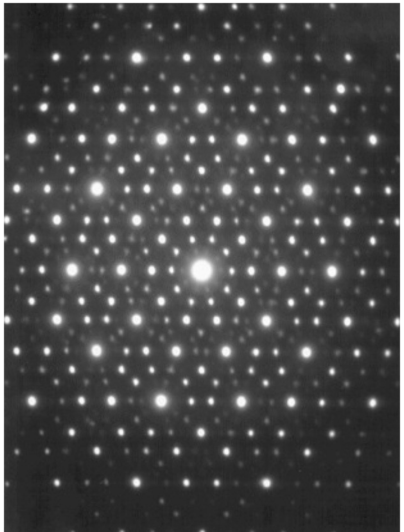
- conversion rate depends on the incident beam direction and the distance to the sun

- unique signature due to coherence effect in crystal lattice (Bragg condition)



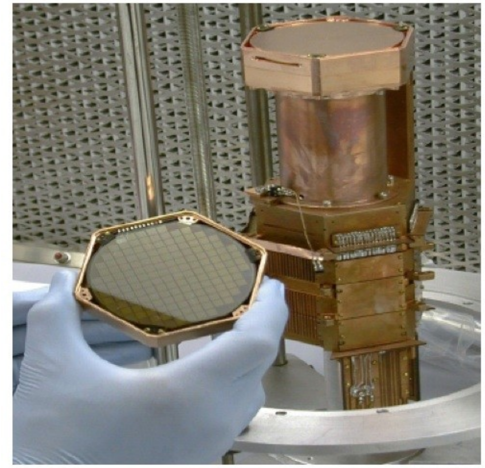


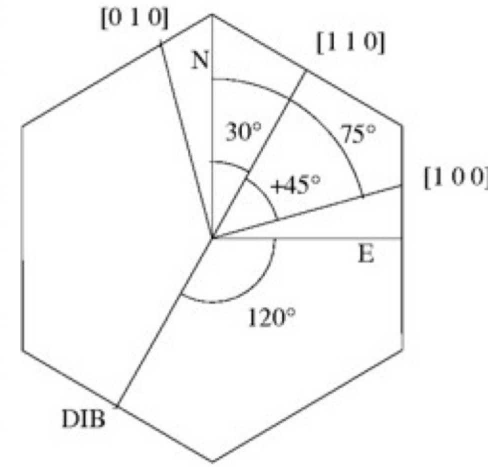




Solar Axion Search Results

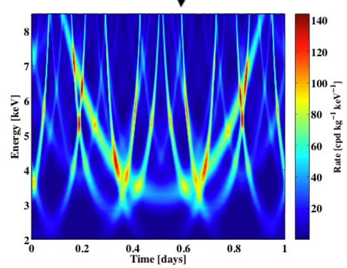
- first precise measurement of absolute crystal plane orientations in this type of experiment



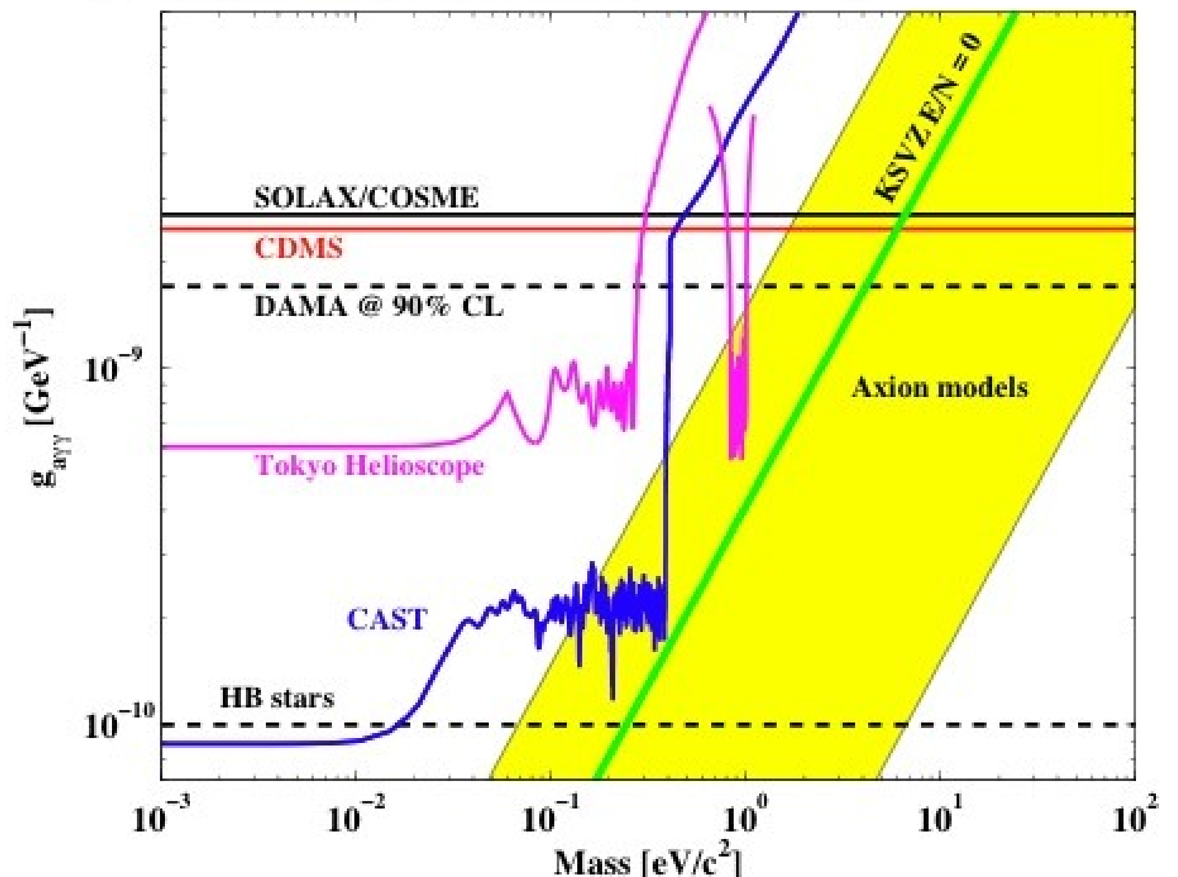


- maximize the unbinned log-likelihood function:

$$Log(\mathcal{L}) = -R_T + \sum_{i,j} Log(\lambda \cdot \mathcal{R}(E_i, t_i, d_j) + B(E_i, \not{t}_i, d_j))$$



No indication of axion conversion into photons is observed!



- 95% C.L. upper limit on Primakov coupling $g_{a\gamma\gamma}$: $2.4 \cdot 10^{-9}$ GeV^{-1}

Summary

- Currently CDMS sets the world leading excluxion limit on scalar WIMP-nucleon cross sections above 44 GeV.

- Last CDMS data had zero background.

- New data-taking was finished on March 18th this year. New results are expected in about a month.

- First SuperCDMS Tower has been built and installed in the Soudan mine. Initial tests are ongoing.

- Steady progress to zeptobarn cross sections (10^{-45} cm^2) and smaller.

- We started to look not only for “standard“ dark matter interactions.

The CDMS Collaboration

Brown University
M. Attisha, R. Gaitskell, J.-P. Thompson

Caltech
Z. Ahmed, S. R. Golwala, D. Moore, R.W. Ogburn

Case Western Reserve University
D. S. Akerib, C. N. Bailey, K. Clark, M. Danowski,
M.R. Dragowsky, D. R. Grant, R. Hennings-Yeomans

Fermilab
D. A. Bauer, M. B. Crisler, D. DeJongh, J. Hall,
D. Holmgren, L. Hsu, E. Ramberg, J. Yoo

MIT
E. Figueroa-Feliciano, S. Hertel, S. Leman,
K. McCarthy, P. Wikus

NIST
K. Irwin

Queens University
W. Rau

Santa Clara University
B. A. Young

Stanford University
P.L. Brink, B. Cabrera, J. Cooley, M. Pyle, S. Yellin

Syracuse University
M. Kiveni, M. Kos, R.W. Schnee

Texas A&M
R. Mahapatra

University of California, Berkeley
M. Daal, J. Filippini, N. Mirabolfathi, B. Sadoulet, D. Seitz,
B. Serfass, K. Sundqvist

University of California, Santa Barbara
R. Bunker, D. O. Caldwell, H. Nelson, J. Sander

University of Colorado at Denver
M. E. Huber

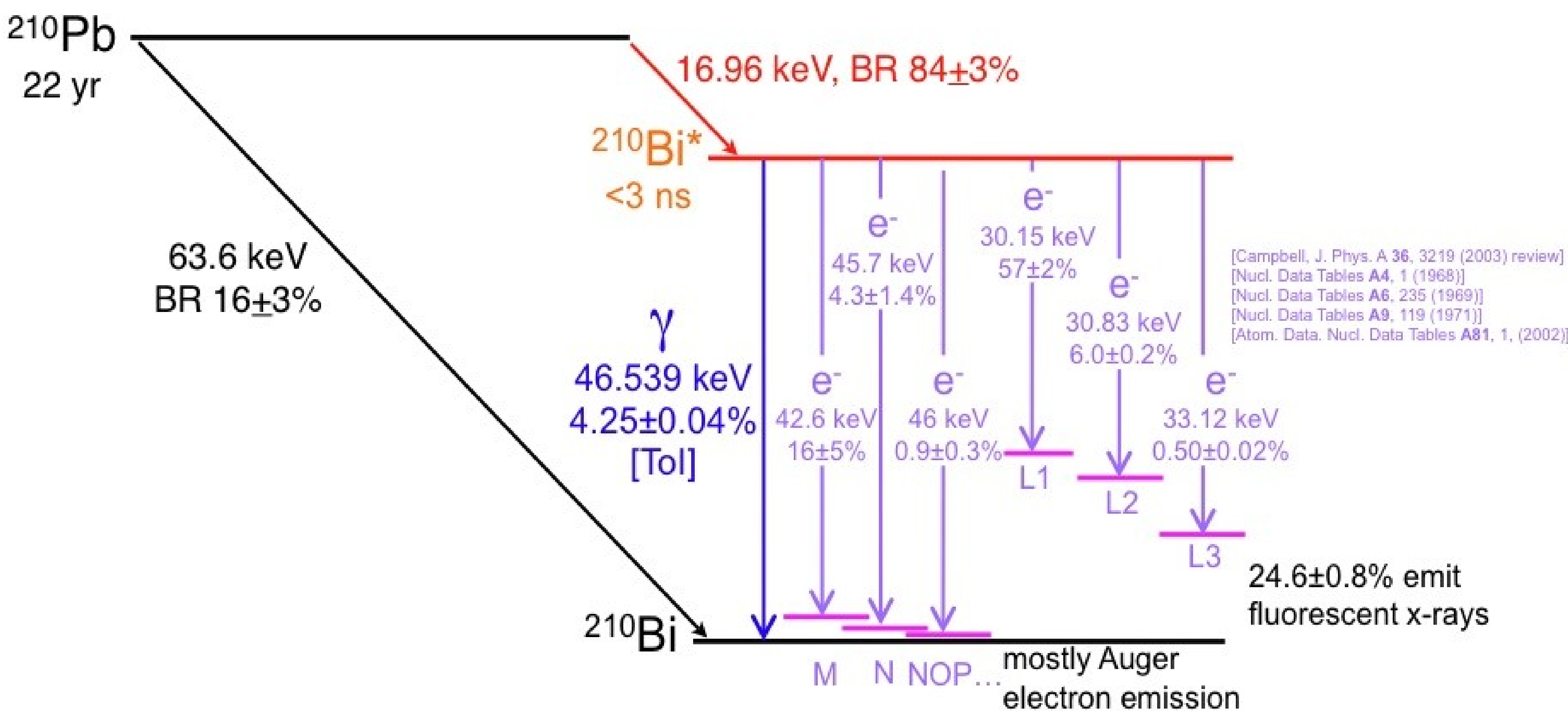
University of Florida
A. Achelashvili, T. Saab, D. Balakishiyeva, G. Sardane

University of Minnesota
P. Cushman, L. Duong, M. Fritts, V. Mandic, X. Qiu,
A. Reisetter, O. Kamaev

University of Zurich
S. Arrenberg, T. Bruch, L. Baudis

Backup Slides

^{210}Pb Decay Scheme



Signature of ^{210}Pb decay: ~46.5 keV peak of NND events