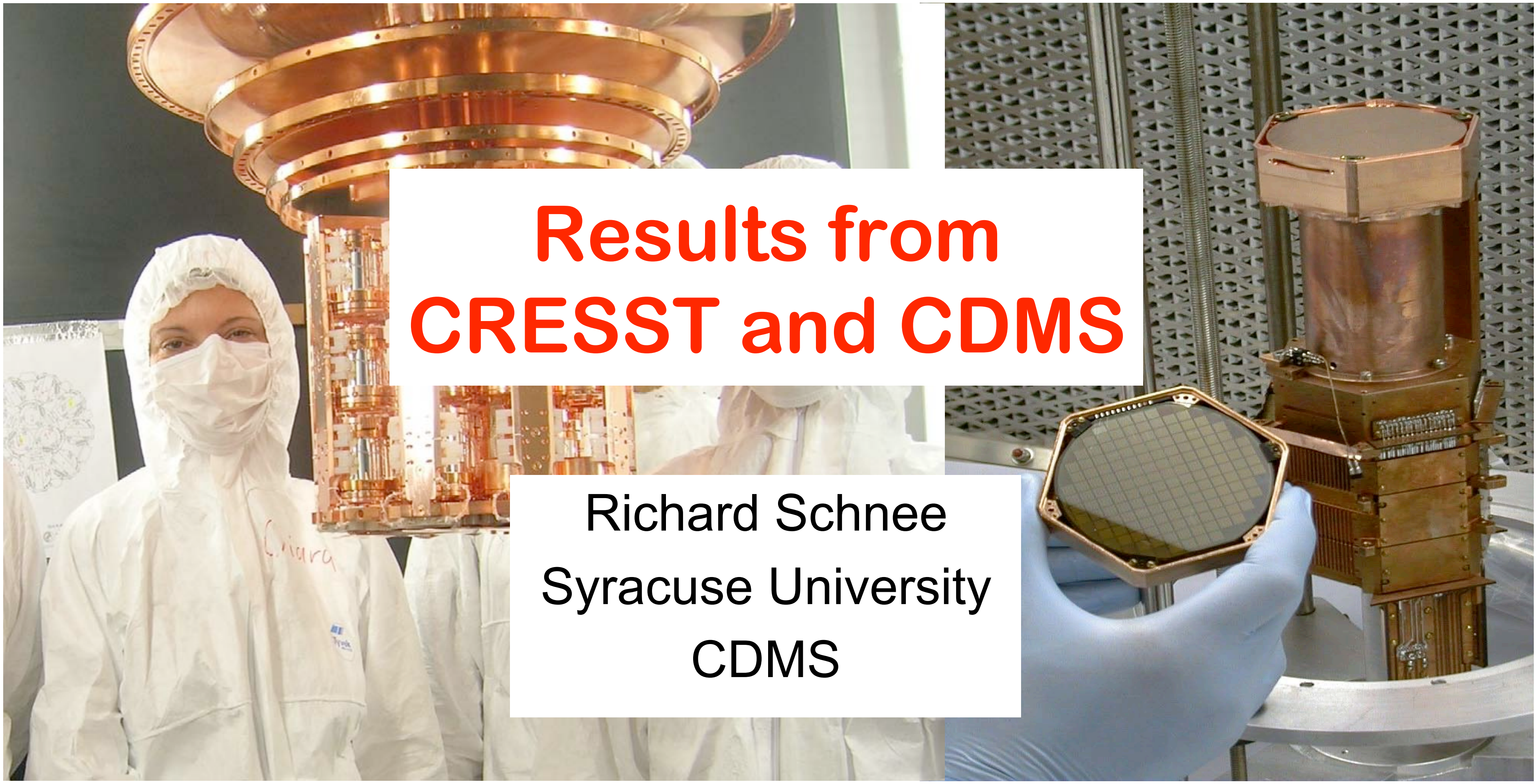


Results from CRESST and CDMS

Richard Schnee
Syracuse University
CDMS

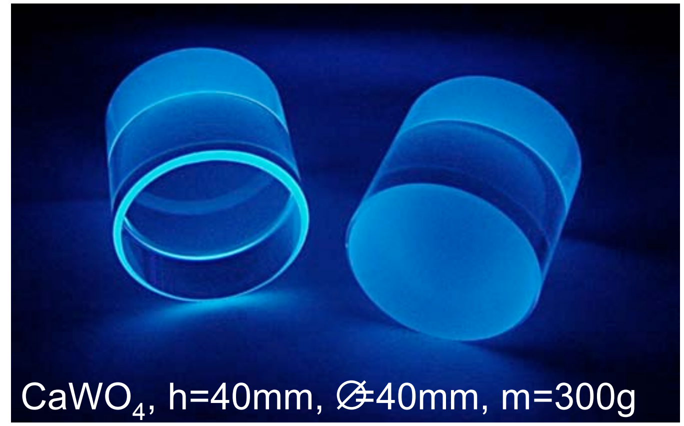
Thanks to Federica Petricca & Franz Proebst of CRESST for sharing slides and information

Exploring Low-Mass Dark Matter Candidates Workshop

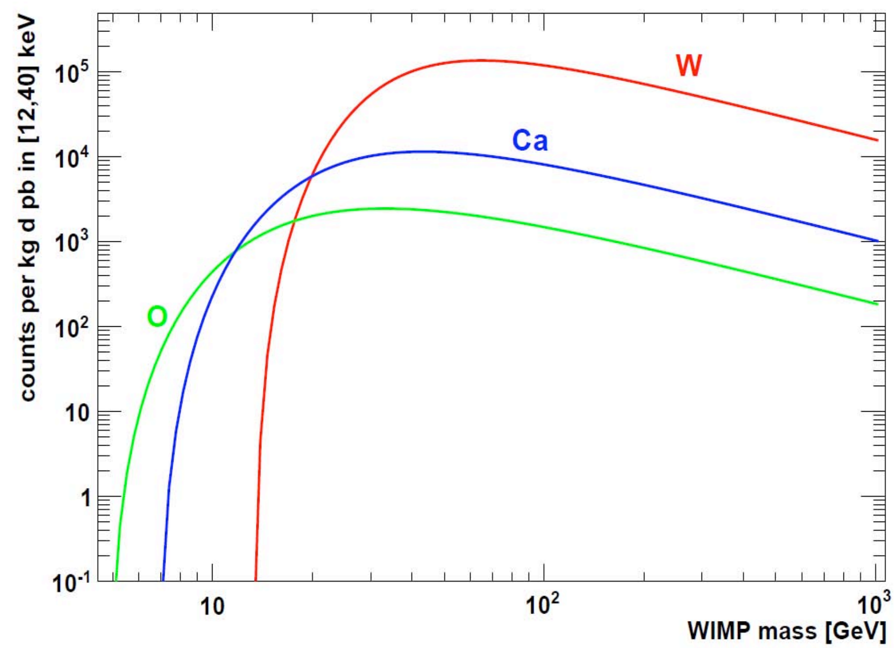
November 14, 2011

CRESST Target Material

- CRESST target:
  - scintillating $CaWO_4$ crystals
  - up to 33 in the current setup



- Coherent scattering:
  - $\sigma \propto A^2$
    $\rightarrow$ scattering in $CaWO_4$
    dominated by W
  - low WIMP masses:
    - W recoils below threshold
    - DM signal : O and Ca recoils

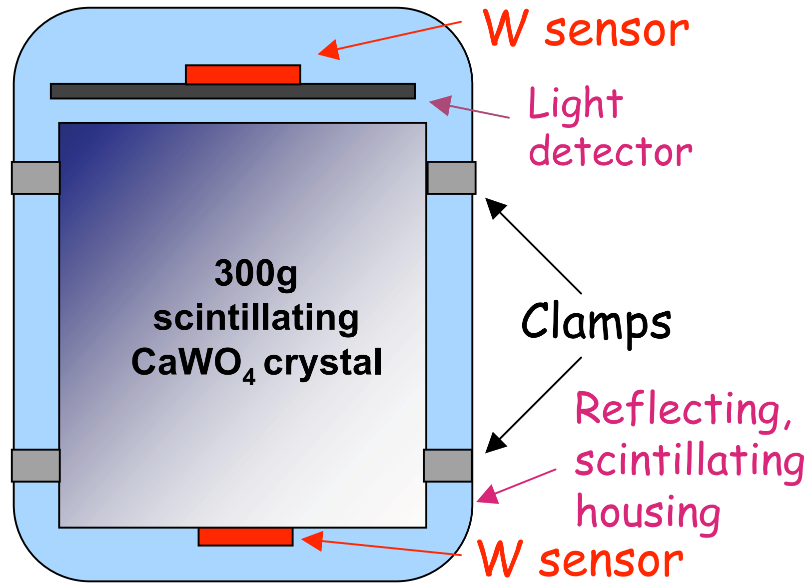


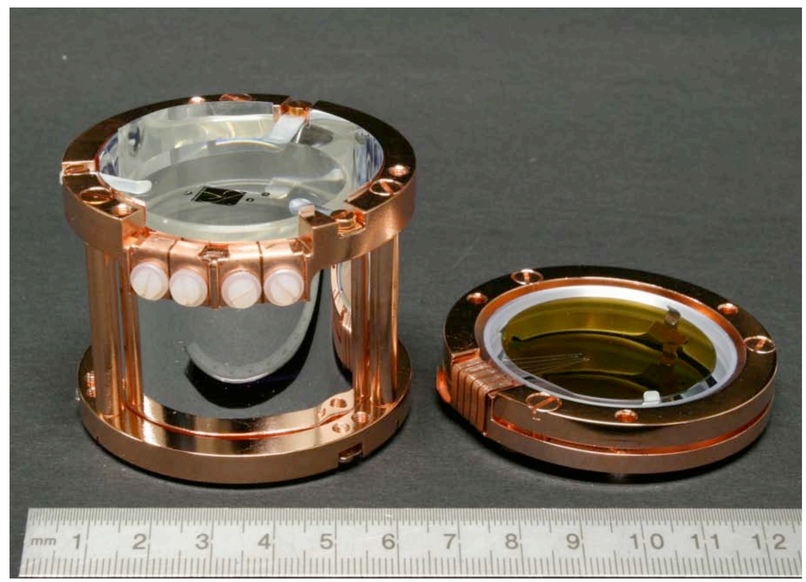
F. Petricca

CRESST Cryogenic Detectors

- Target crystals operated as ***cryogenic calorimeters*** (~10mK)
  - energy deposition in the crystal:
  - → mainly phonons
    - temperature rise detected with W-thermometers
    - measurement of **deposited energy *E*** (sub keV resolution at low energy)
  - → small fraction into **scintillation light *L*** (characteristic of the type of particle)

- Separate ***cryogenic light detector*** to detect the light signal





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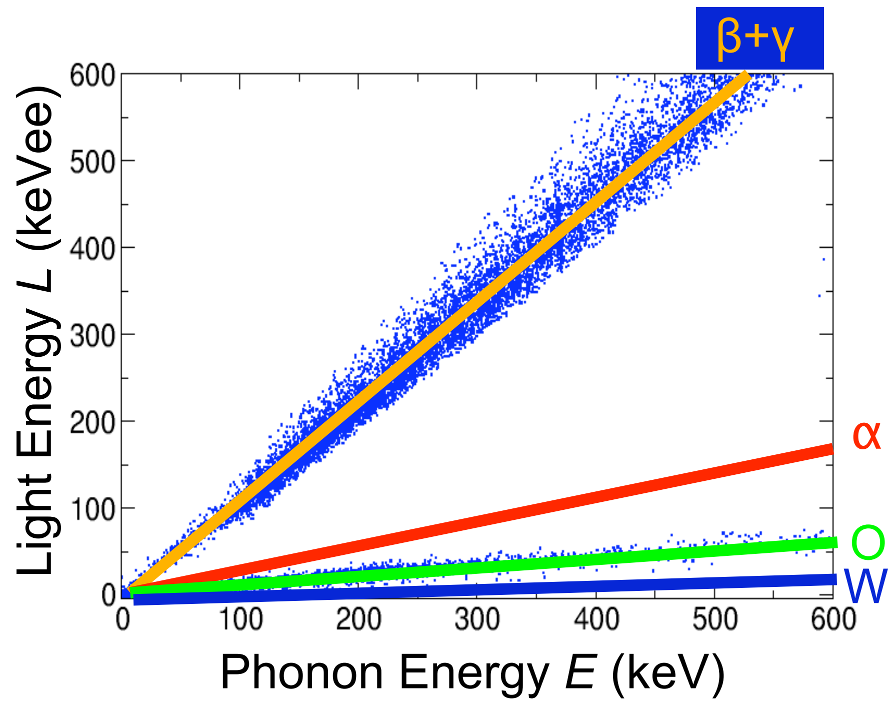
CRESST Event Discrimination

Light signal used to discriminate different types of interactions

- ***Light Yield (LY) = L / E***
  characteristic of the event type
  - LY(*e*-recoils) :1 by definition
  - LY(α) ~ 0.22
  - LY(O) ~ 0.1
  - LY(Ca) ~ 0.06
  - LY(W) ~ 0.04



- ***Excellent discrimination*** between potential signal events (***nuclear recoils***) and dominant radioactive background (***electron recoils***)
- Possible discrimination between different recoiling nuclei

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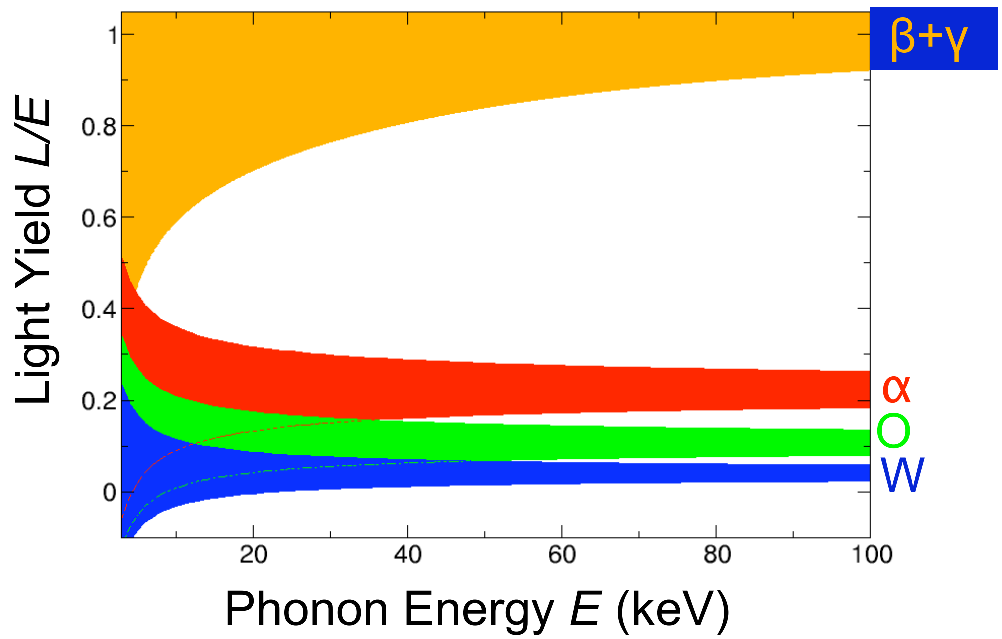


- ***Excellent discrimination*** between potential signal events (***nuclear recoils***) and dominant radioactive background (***e-recoils***)
- Possible discrimination between different recoiling nuclei
- Substantial overlap with zero-light events, such as ^{206}Pb recoils from ^{210}Po α-decays in clamps' surface

F. Petricca

The Latest CRESST Run

From June 2009 to April 2011

- 18 modules installed
  - → 10 fully operated (9 $CaWO_4$ + 1 $ZnWO_4$)
    - 8 300-g $CaWO_4$ used for the WIMP search
  - → 7 individual detectors used in addition to tag coincidences
- Neutron tests
- γ-calibrations with ^{57}Co and ^{232}Th

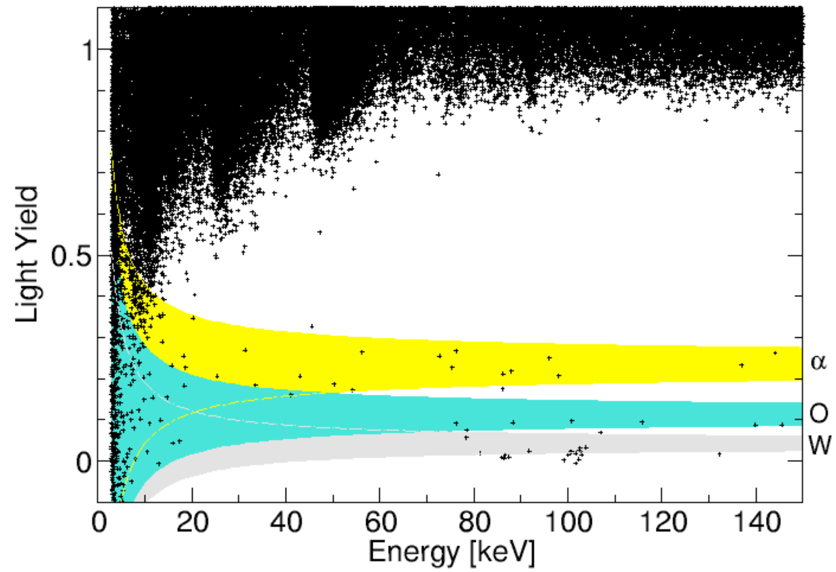
Total net exposure after cuts: ***730 kg days***

arXiv:1109.0702

F. Petricca

CRESST Observed Events

- highly populated *e*/γ band
- low-energy α-events
  - → α-contamination in the clamps holding the crystals
- ^{206}Pb nuclei from ^{210}Po α-decays
  - → ^{206}Pb recoils (103keV) from ^{210}Po α-decays at the surface of the clamps
- events in the O, Ca and W bands



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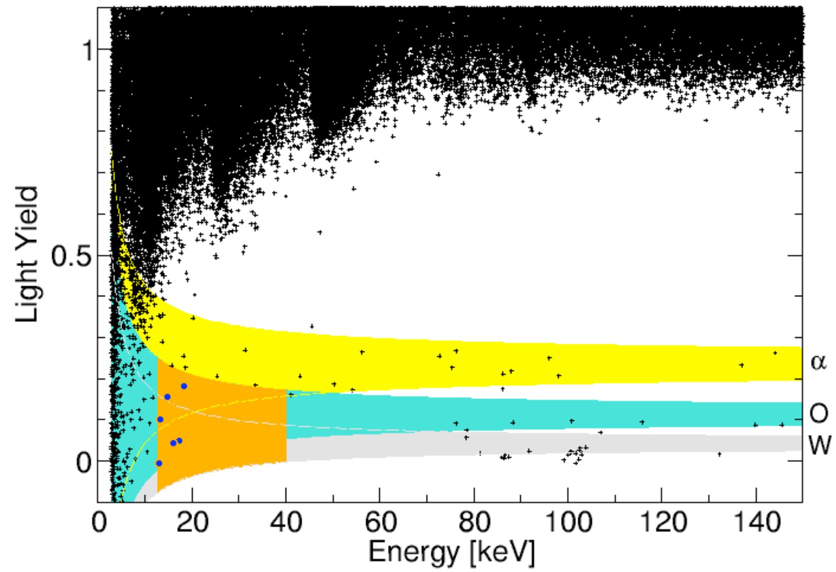

Acceptance region: O, Ca and W bands

- E_{max} : 40 keV (no significant WIMP signal expected above)
- E_{min} : e/γ leakage in the acceptance region =1 event (module dependent)

67 accepted events (730 kg days)

F. Petricca

Backgrounds in the Acceptance Region

- *e*/γ leakage at low energies
- α-events due to overlap with α-band
- neutrons (oxygen recoils in the acceptance region)
- degraded ^{206}Pb recoils from ^{210}Po α-decays

F. Petricca

Backgrounds in the Acceptance Region

- *e*/γ leakage at low energies
- α-events due to overlap with α-band
- neutrons (oxygen recoils in the acceptance region)
- degraded ^{206}Pb recoils from ^{210}Po α-decays

→***Estimate the contribution of these backgrounds and investigate a possible excess***

- Maximum likelihood analysis
  - simultaneous treatment of relevant parameters and uncertainties
  - parameterized model of backgrounds and of possible signal
- In the following: qualitative background estimate to illustrate the concepts used in the maximum likelihood analysis

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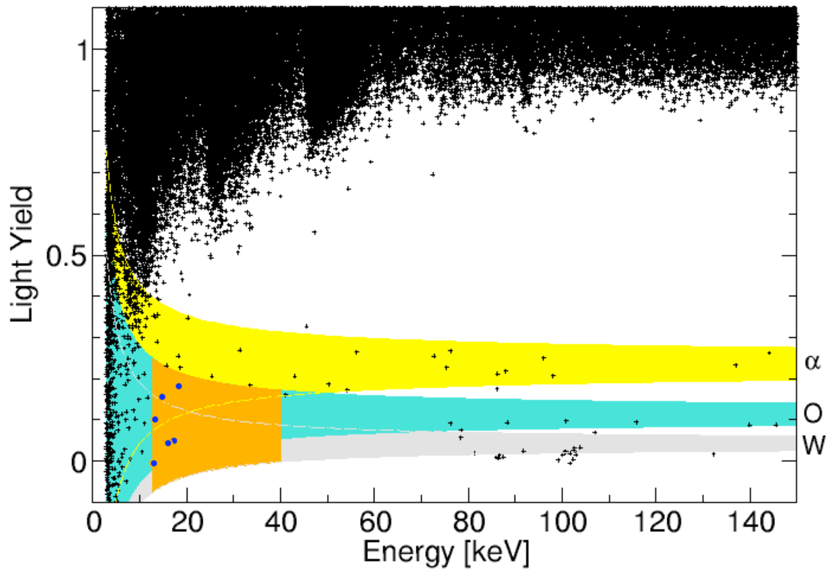
α Background in CRESST

- dN_α/dE of low-energy α-events flat within available statistics



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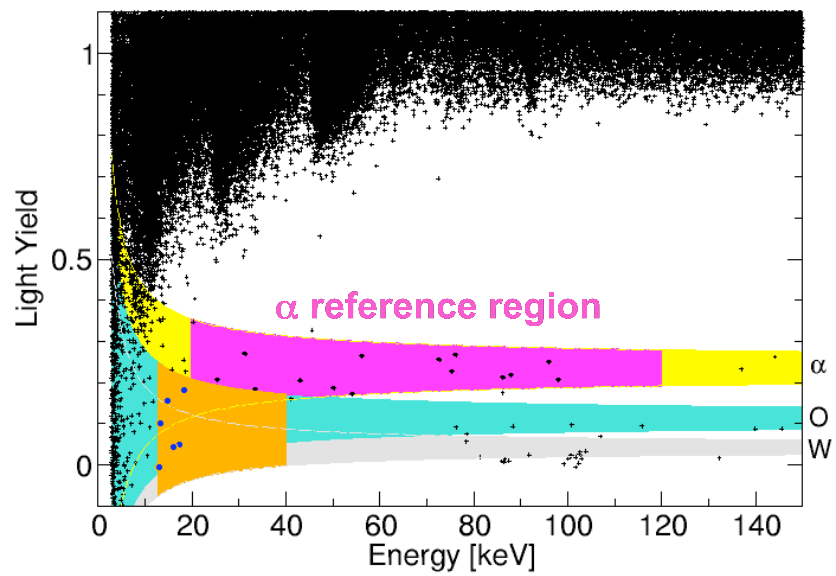
α Background in CRESST

- *dN_α/dE* of low-energy α-events flat within available statistics
- overlap-free reference region to determine *dN_α/dE*
- extrapolation to the acceptance region



- Simple estimate:

→ ~ 9.2 events

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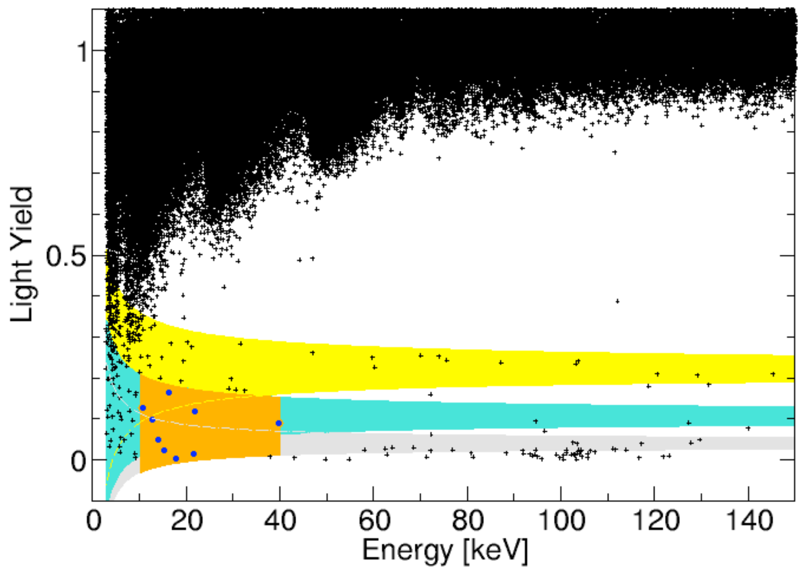
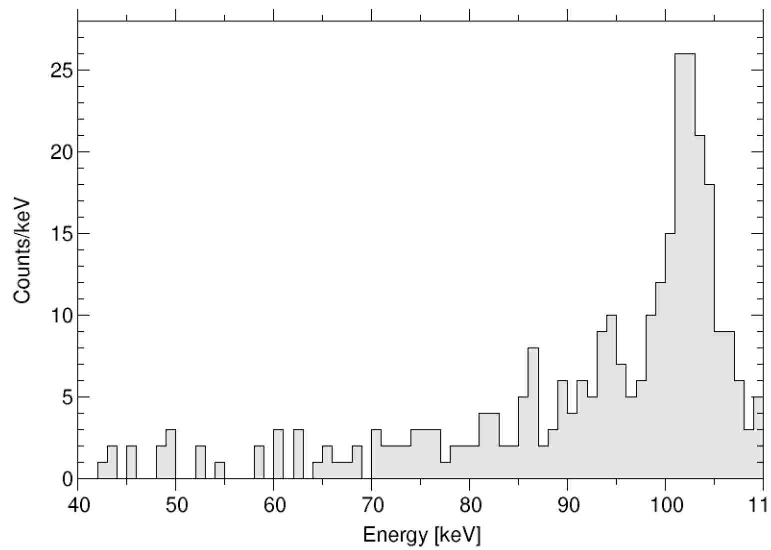
Pb Recoil Background in CRESST

- overlap-free reference region to model dN_{Pb}/dE





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Pb Recoil Background in CRESST

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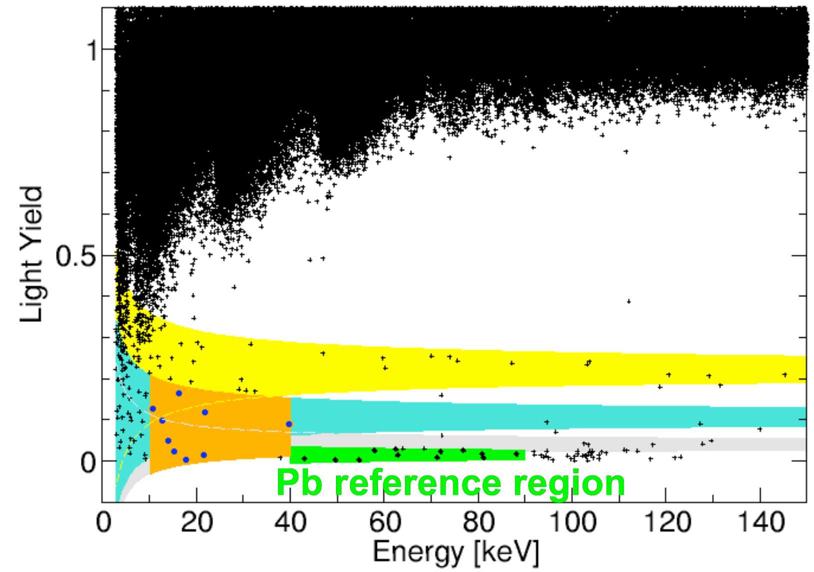

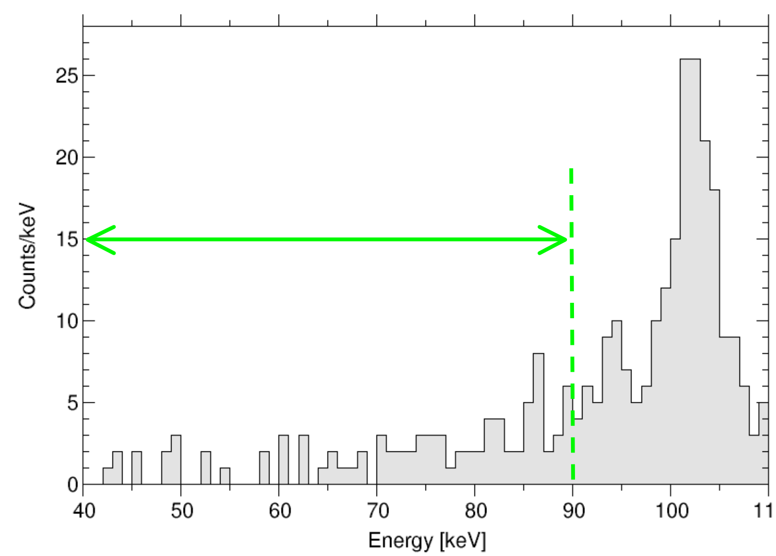

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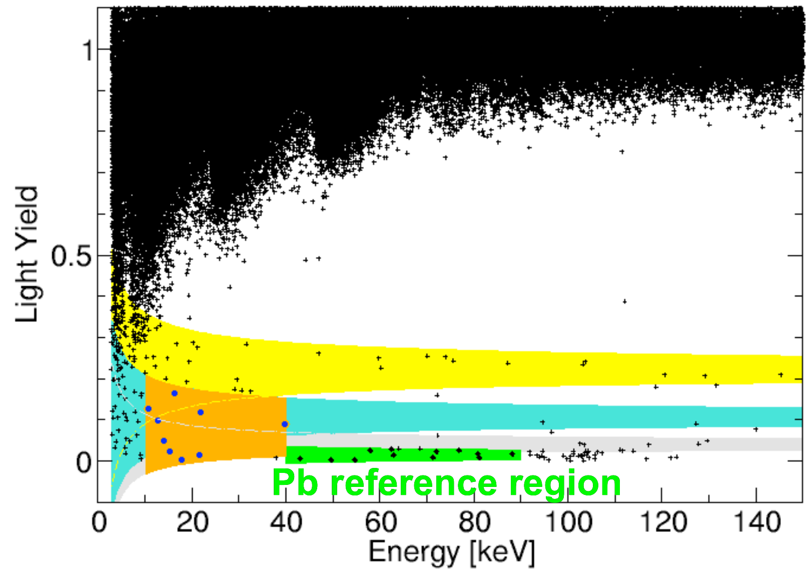
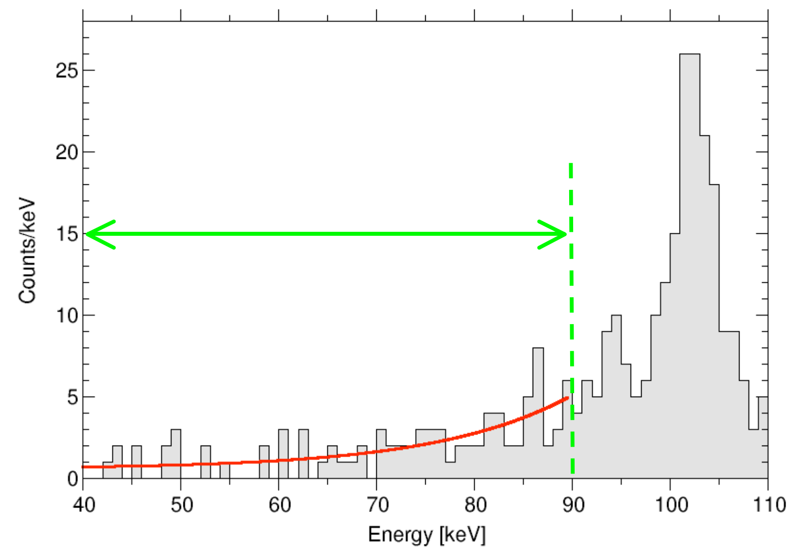
Pb Recoil Background in CRESST

- overlap-free reference region to model dN_{Pb}/dE
- model extrapolated to the acceptance region
- Simple estimate:

  → ~ 17 events

- Final likelihood analysis:
  - performed module-wise



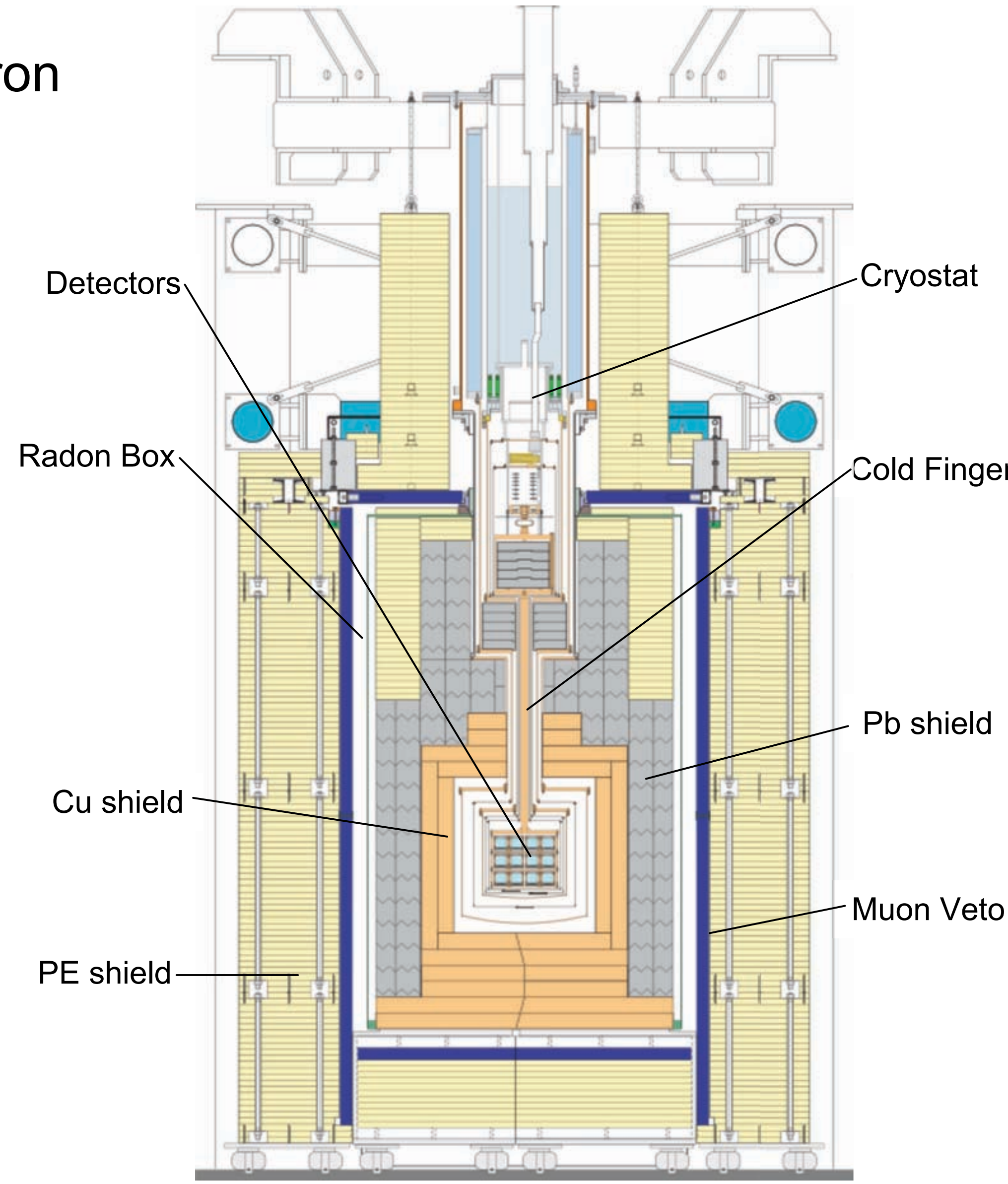


F. Petricca

n Background in CRESST

- Two different classes of neutron production mechanisms

  - radioactive processes
    - →spontaneous fission, (α,*n*) reactions
  - muon-induced neutrons
    - →muon missed by veto



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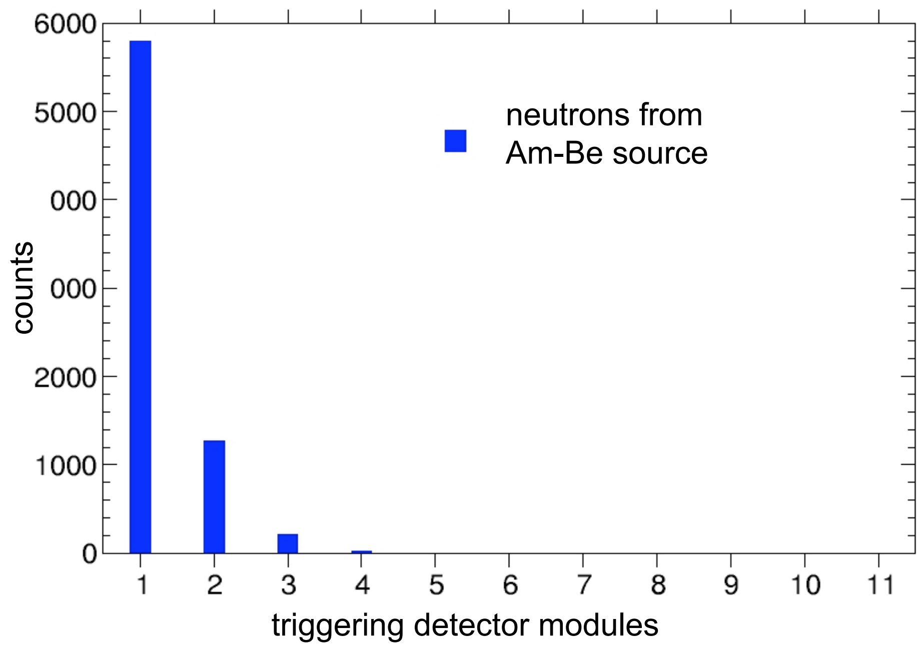
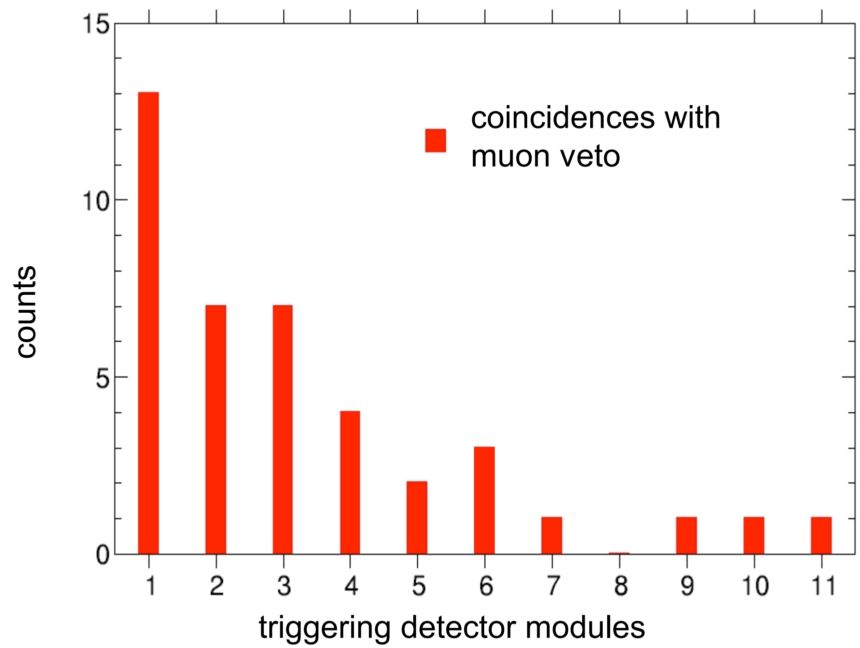
n Background in CRESST

- Characteristic feature of *n*: coincident events in more detectors (unlike WIMPs)
- Ratio between single and coincident events characteristic of the source
- Measurements to infer the pattern of coincidences for the different sources (at least one module with a signal in its acceptance region)





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n Background in CRESST

- Use observed coincidences to estimate the number of single neutron events
  - 3 coincidences observed in the Dark Matter data set
    - → 2 with 3 triggering detector modules
    - → 1 with 5 triggering detector modules
- Simple estimate (limiting cases):
  - neutrons from source: single/coincidence ~ 3.8

    → ~11.4 single events expected
  - muon induced neutrons: single/coincidence ~ 0.5

    → ~1.5 single events expected
- Final likelihood analysis:
  - considers the number of triggering detector modules of the individual events to distinguish the two contributions
  - considers the energy spectrum

F. Petricca

Results of CRESST Likelihood Analysis

- Total likelihood has two maxima in the parameter space
  - M1 global maximum
  - M2 slightly disfavored

Definition of the acceptance region

Very similar to the simple estimate

	M1	M2
e/γ events	8.00 ± 0.05	8.00 ± 0.05
α events	$11.5^{+2.6}_{-2.3}$	$11.2^{+2.5}_{-2.3}$
neutron events	$7.5^{+6.3}_{-5.5}$	$9.7^{+6.1}_{-5.1}$
Pb recoils	$15.0^{+5.2}_{-5.1}$	$18.7^{+4.9}_{-4.7}$
signal events	$29.4^{+8.6}_{-7.7}$	$24.2^{+8.1}_{-7.2}$
m_χ [GeV]	25.3	11.6
σ_{WN} [pb]	$1.6 \cdot 10^{-6}$	$3.7 \cdot 10^{-5}$

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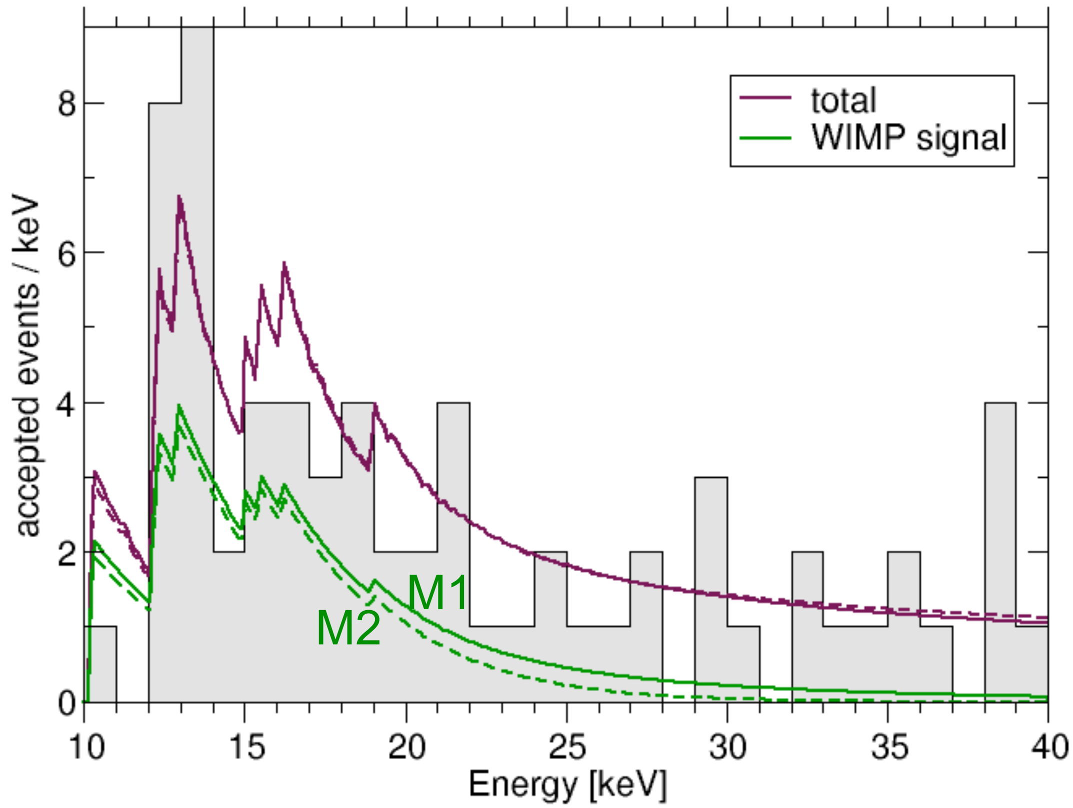
Results of CRESST Likelihood Analysis

Different nuclei present in our target

→ Two sets of WIMP parameters lead to a similar energy spectrum



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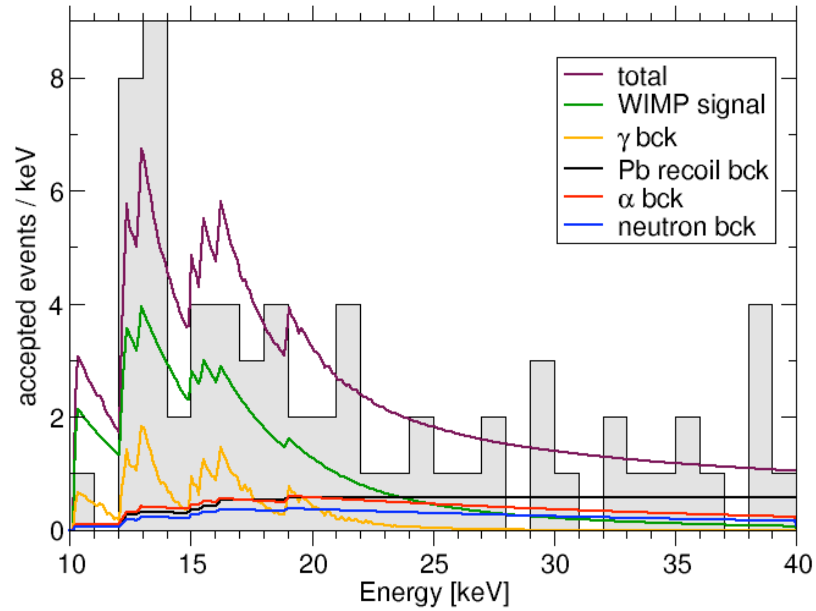
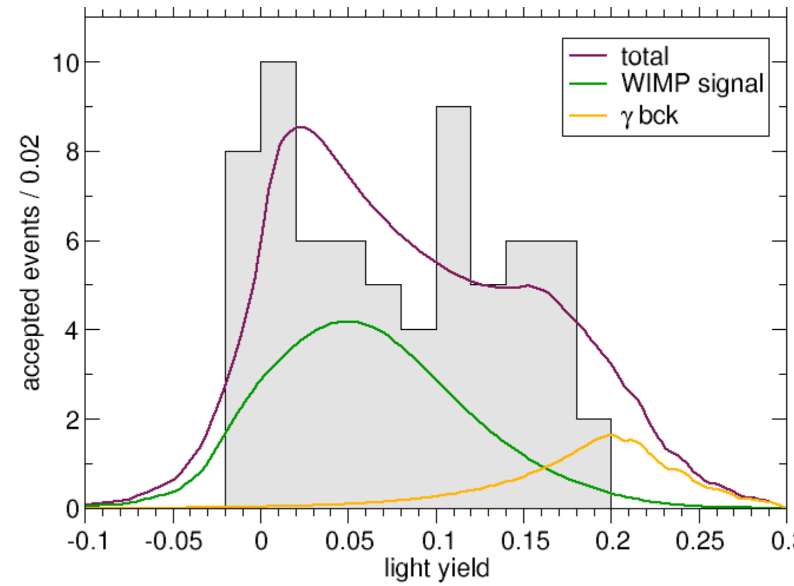
Results of CRESST Likelihood Analysis

- Energy spectra of α, neutron or Pb backgrounds do not resemble the expected WIMP signal and only the *e/γ* contribution has a similar shape



- Light yield spectrum of *e/γ* differs significantly from the expected WIMP signal and thus cannot explain the total LY distribution



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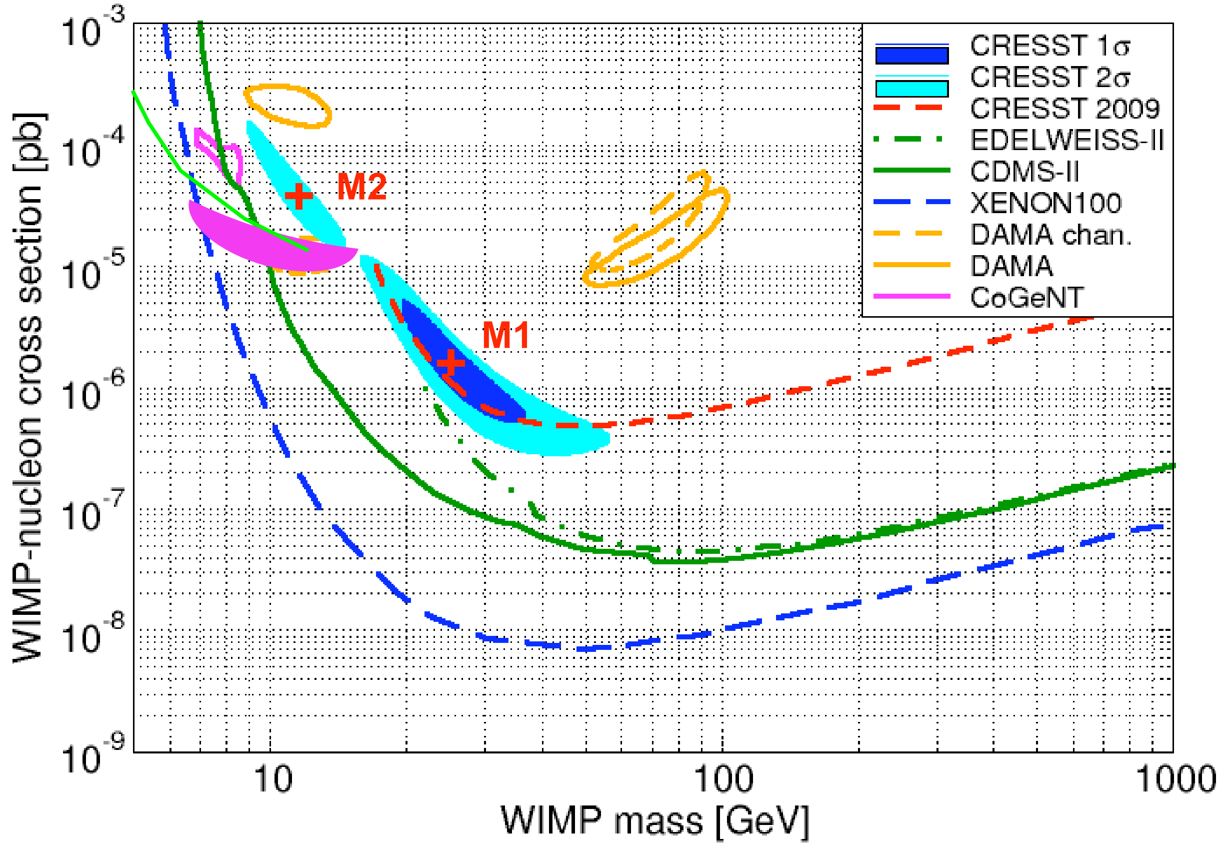
CRESST Results

- Known backgrounds unable to explain observed events
- Obtain good fit by adding light WIMPs
  - Statistical significance for a signal (likelihood ratio test)

4.7σ for M1

4.2σ for M2



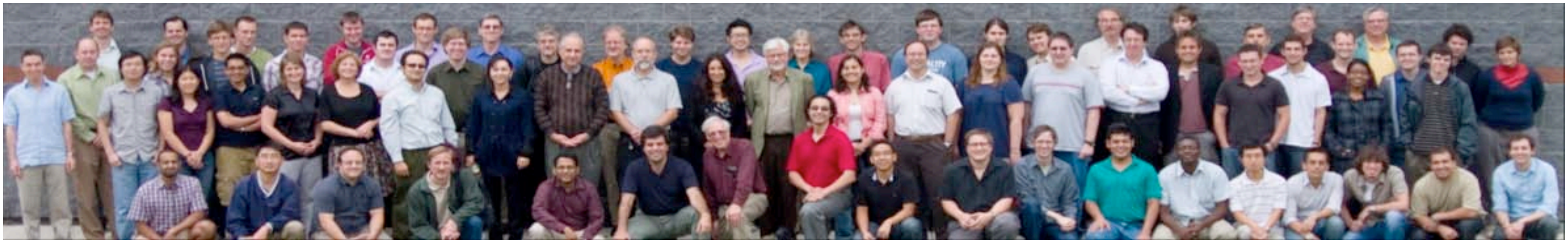
- Still relatively large background contribution
  - *Reduction of background necessary for clarification*

F. Petricca

CRESST Outlook

- Long successful physics run of CRESST
- Observed events difficult to explain with known backgrounds compatible with light WIMPs
- "Results from 730 kg days of the CRESST-II Dark Matter Search" submitted to European Physical Journal C, currently available on arXiv:1109.0702
- New physics run in preparation with several improvements aimed at background reduction:
  - Modification of the clamps holding the crystals to reduce α and Pb-recoils backgrounds
  - Installation of an additional internal neutron shielding to complement the present one
- Expected to start this year

CDMS/SuperCDMS Collaborations



California Institute of Technology
Z. Ahmed, J. Filippini, S.R. Golwala, D. Moore, R. Nelson, R.W. Ogburn

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

Fermi National Accelerator Laboratory
D. A. Bauer, F. DeJongh, J. Hall, D. Holmgren, L. Hsu, E. Ramberg, R.L. Schmitt, R. B. Thakur, J. Yoo

Massachusetts Institute of Technology
A. Anderson, E. Figueroa-Feliciano, S. Hertel, S.W. Leman, K.A. McCarthy, P. Wikus

NIST
K. Irwin

Queen's University
P. Di Stefano , C. Crewdson , J. Fox, O. Kamaev, S. Liu , C. Martinez, P. Nadeau , W. Rau, Y. Ricci

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R. Bunker, D.O. Caldwell, H. Nelson

University of Colorado Denver
B.A. Hines, M.E. Huber

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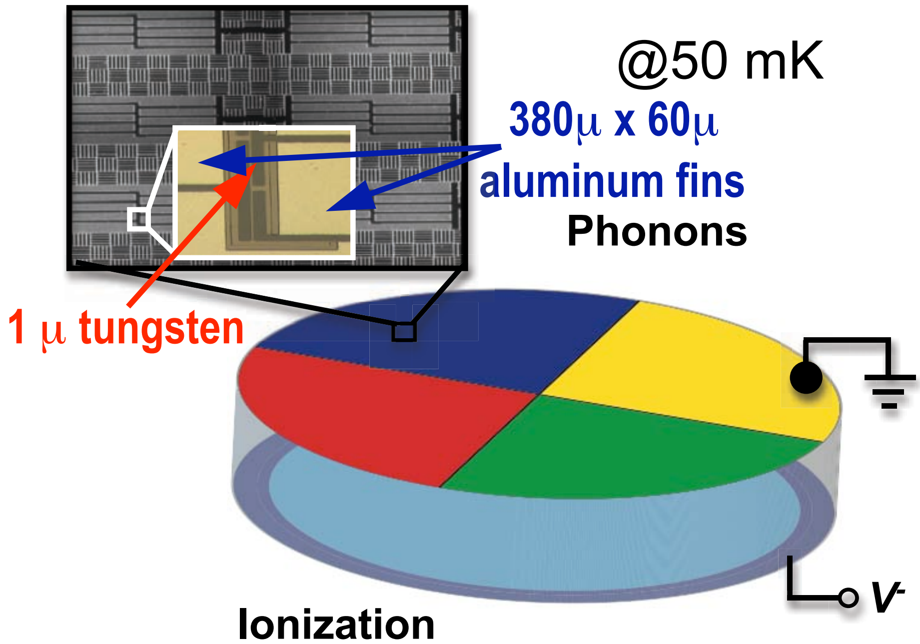
T. Saab, D. Balakishiyeva, B. Welliver

University of Minnesota
J. Beaty, H. Chagani, P. Cushman, S. Fallows, M. Fritts T. Hofer, V. Mandic, X. Qiu, R. Radpour, A. Reisetter, A. Villano, J. Zhang

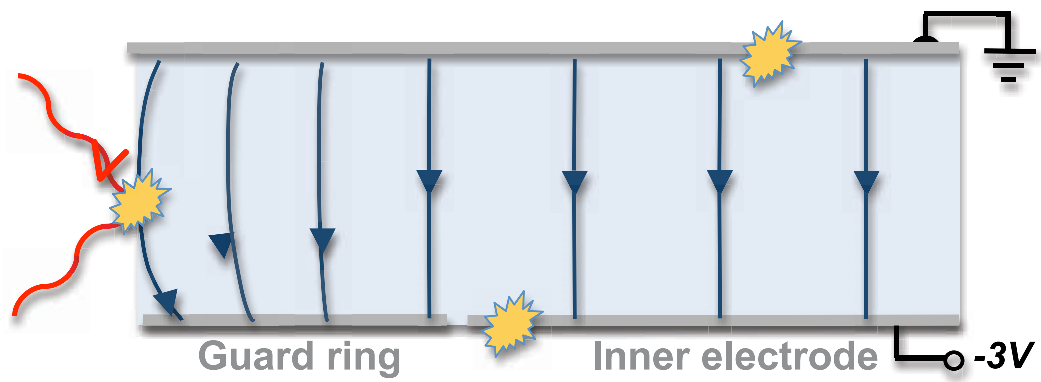
University of Zurich
S. Arrenberg, T. Bruch, L. Baudis, M. Tarka

CDMS: Ionization and Athermal Phonons



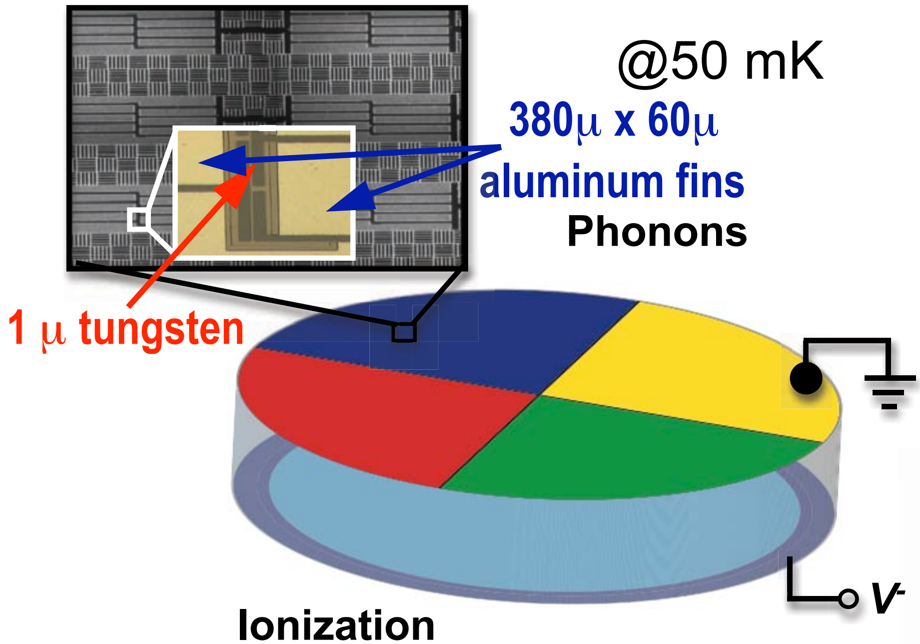
- 250 g Ge or 100 g Si crystals
- 1 cm thick x 7.5 cm diameter
- Collect athermal phonons:
  - Top/bottom surface event veto based on pulse shapes, timing, and energy partition in sensors

Measure ionization in low-field (~volts/cm) with segmented contacts to allow rejection of events near outer sidewall



Electric field lines near cylindrical wall

CDMS: Ionization and Athermal Phonons



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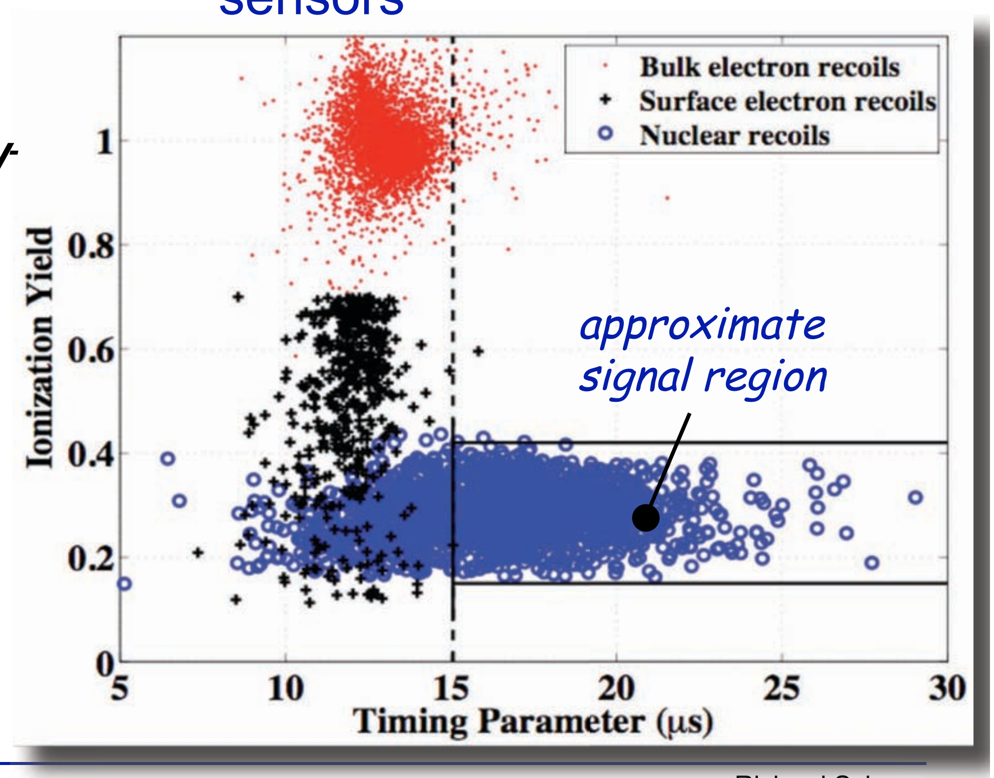
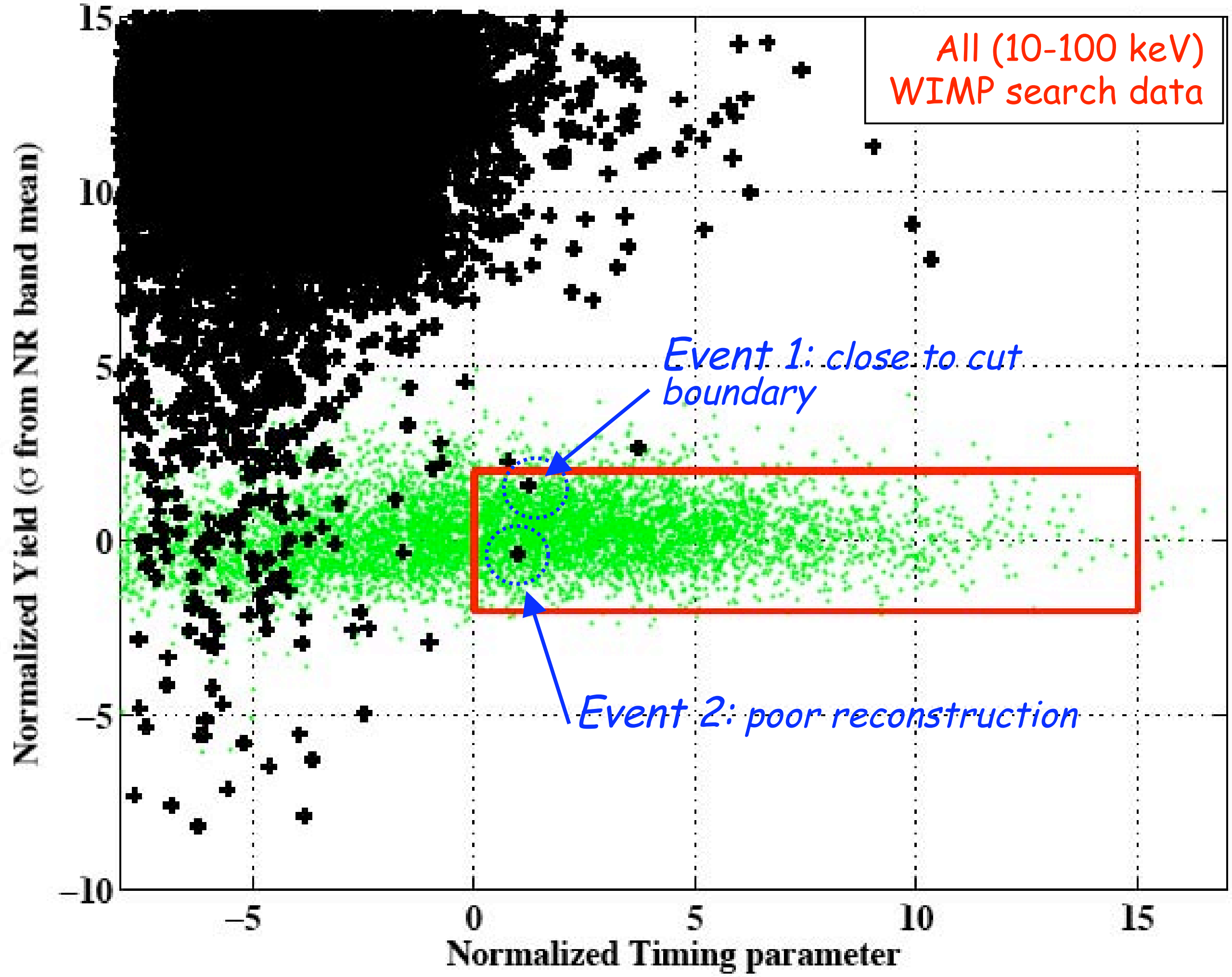


Measure ionization in low-field (~volts/cm) with segmented contacts to allow rejection of events near outer sidewall

Final CDMS II Ge WIMP-Search Data

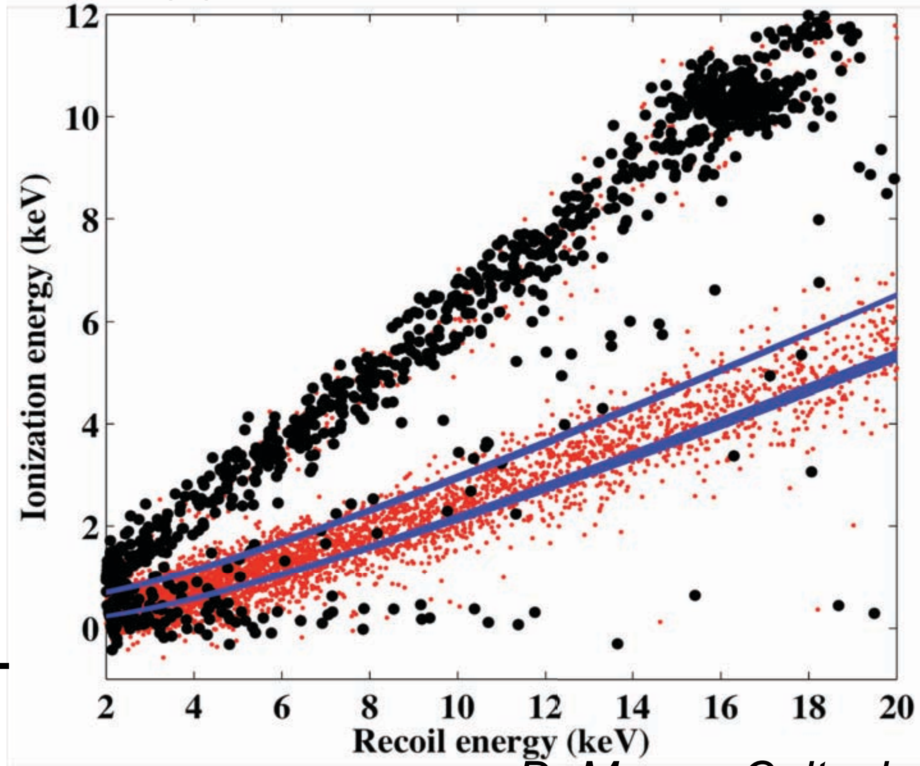
- 2007-2008 data
- 3.75 kg Ge
- 612 kg d raw
- All cuts set "blind"
  - ~30% efficiency
  - Expect 0.8 misidentified background events, 0.1 neutrons
  - P_0 = 23%



2 events in the signal band pass the timing cut; neither is "golden"

CDMS II Low-threshold Analysis

- Analyze with 2 keVr threshold to probe low-mass region
- Expect to be background-limited
  - No phonon-timing cut since ineffective below ~5 keV
  - Cut based on ionization yield is less effective
- Used 8 Ge detectors with lowest trigger thresholds
- 1/4 of data used to study backgrounds at low energy
  - Limits calculated from remaining 241 kg-day raw exposure
  - Results driven by detector with best resolution, smallest backgrounds (T1Z5)
- Nuclear-recoil acceptance region narrowed to avoid backgrounds, especially zero-charge events

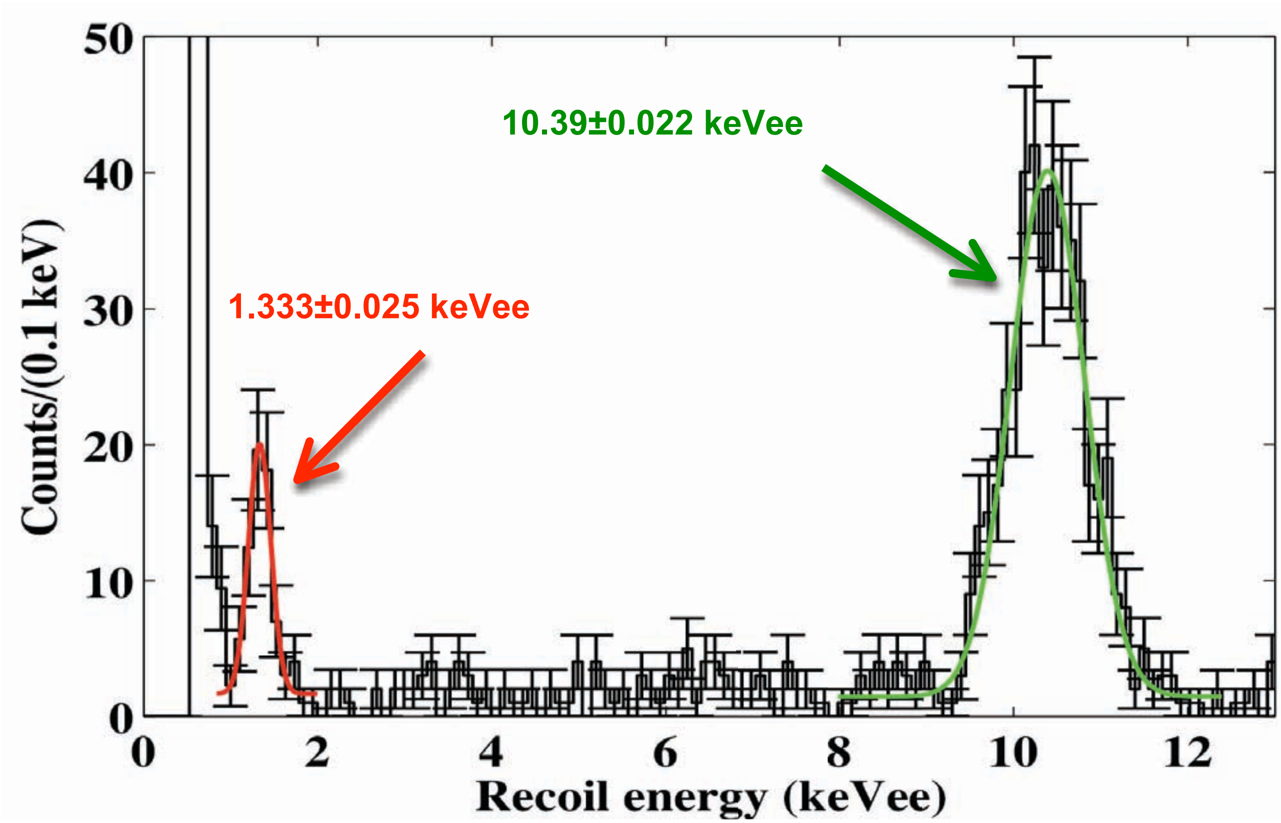


D. Moore, Caltech

Calibration of Energy Scale

- Phonon energy scale calibrated with electron-recoil lines at 1.298 keVee and 10.367 keVee
- Set scale to be conservative (i.e. overestimated) at the 90% CL.

Electron recoil phonon spectrum, T1Z5

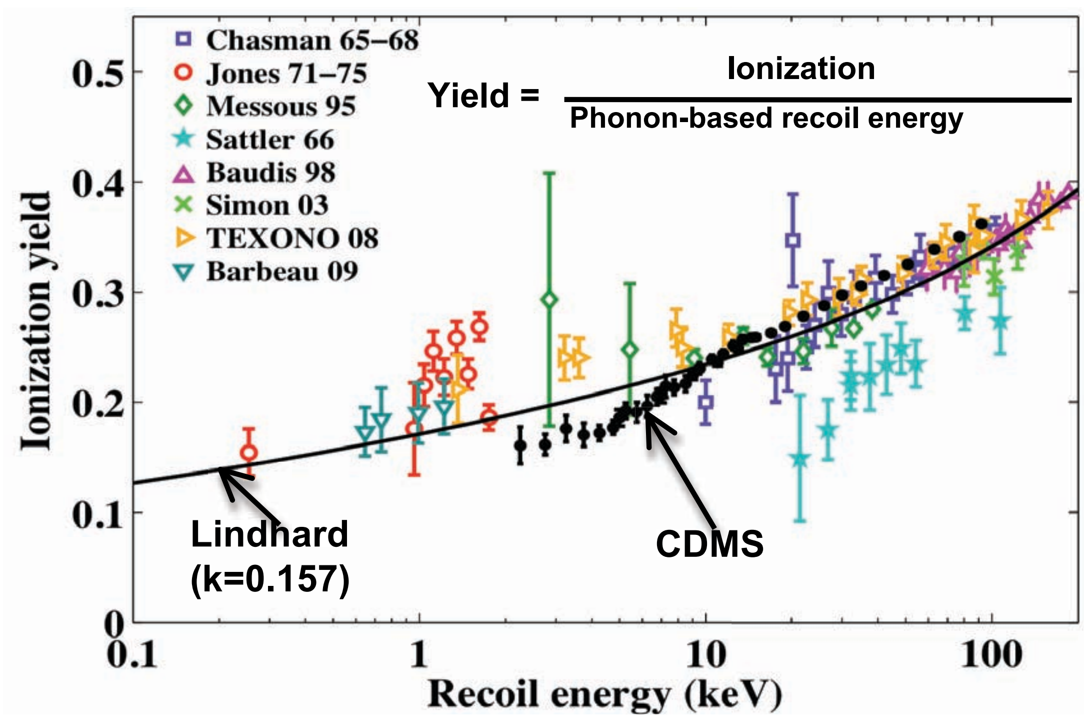


D. Moore, Caltech

Nuclear-Recoil Energy Scale

- Start by assuming same scale as for electron recoils
- Measure mean ionization yield as function of inferred recoil energy for calibration neutrons down to 4 keVr
  - More recently extended to 2 keVr
  - Comparison to past direct measurements in Ge shows reasonable agreement
  - Indicates that assumption is conservative at energies <10 keVr (so we keep it)
- Complementary determination based on neutron calibration spectrum in progress

Nuclear recoil ionization yield:



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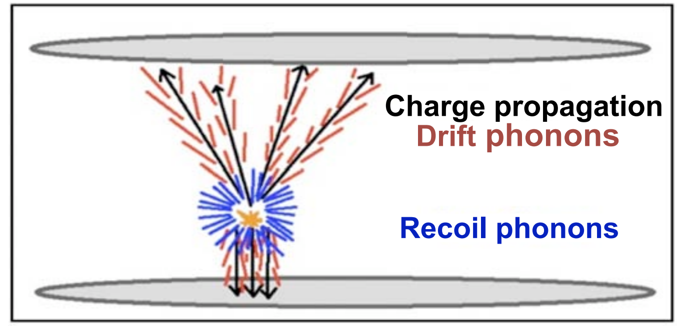
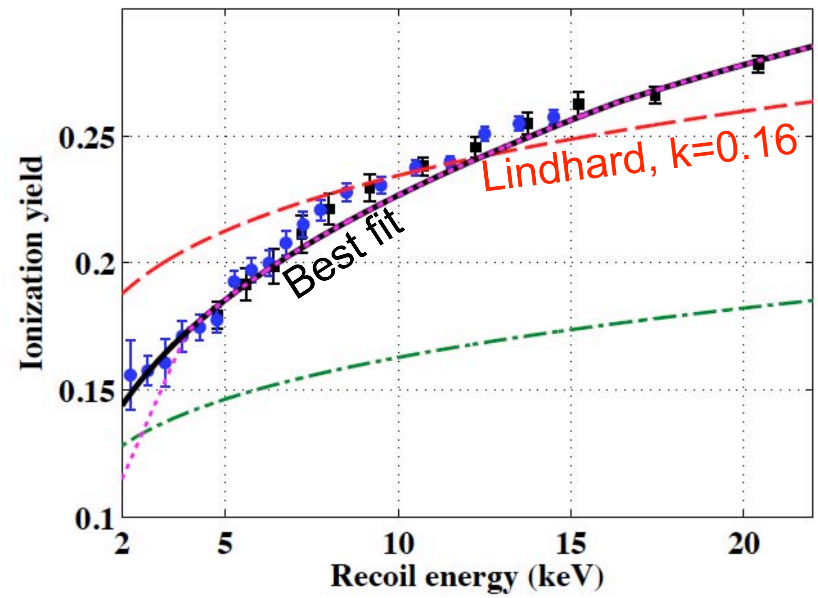
Nuclear Recoil Energy

- Nuclear recoil energy reconstructed from phonon signal alone
- Must subtract phonon energy due to “drift heating” created by drifting charge across detector
- Yield ~0.2, so drift heat contribution is small (~15%) at low energy



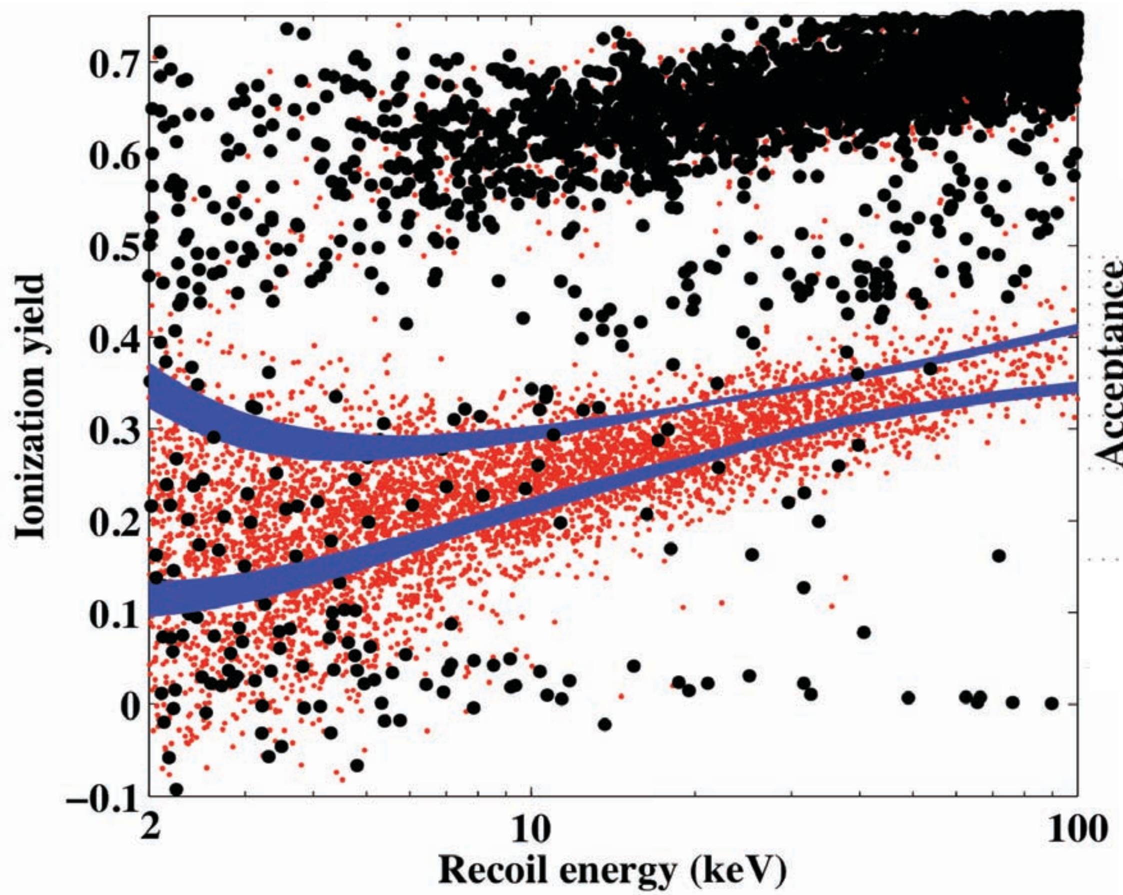
*Neganov and Trofimov, Otkryt. Izobret., **146**, 215 (1985)*
Luke, J. Appl. Phys., 64, 6858 (1988)

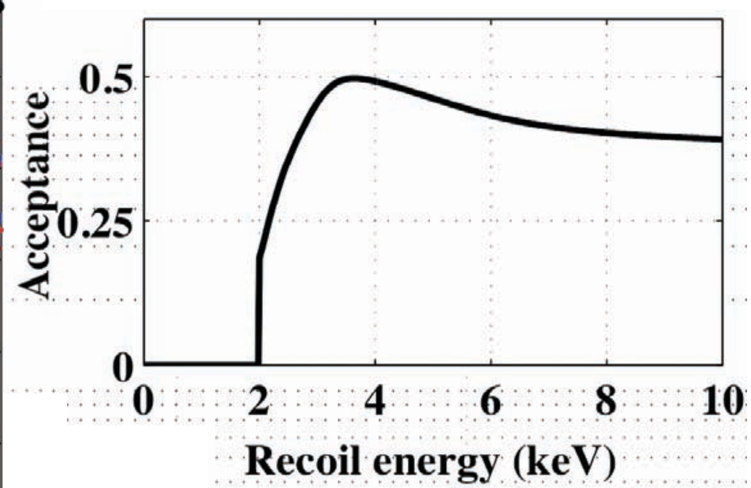


D. Moore, Caltech

WIMP-candidate Selection

- Nuclear recoil acceptance region defined as (+1.25,-0.5)σ band in ionization energy
  - Maximizes sensitivity including effects of systematics (uncertainty is fractionally large if efficiency is small)





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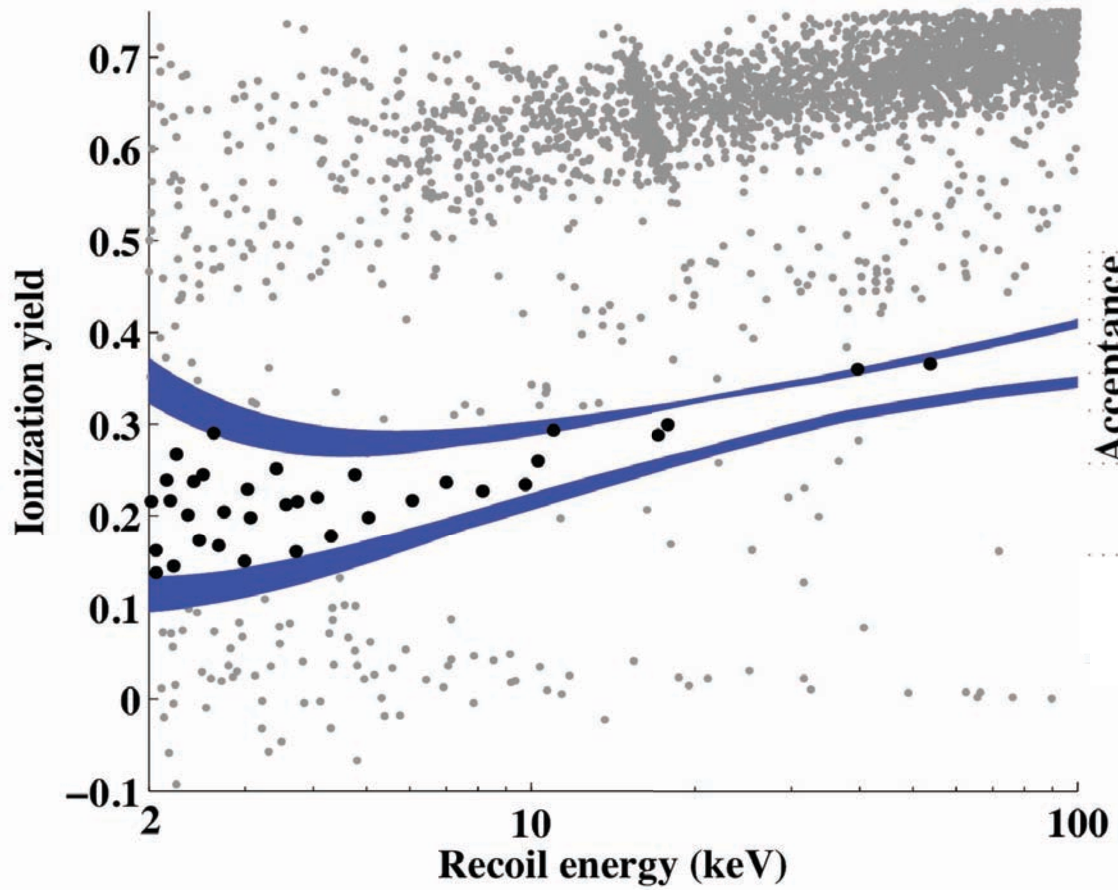

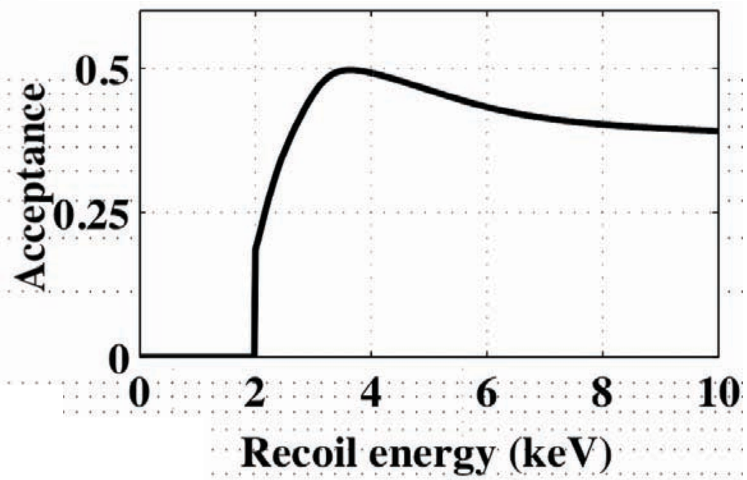

D. Moore, Caltech

CDMS II Low-threshold Results

- Detector with best resolution has lowest rate as expected
- We conservatively assume that all events could be WIMPs
  - no background subtraction, despite fact that our best estimates of known backgrounds can account for all events
- Resulting spectrum rules out possibility that all or most of CoGeNT's events are WIMPs
  - Inconsistent with most of CoGeNT's original ROI
  - Consistent after CoGeNT background correction

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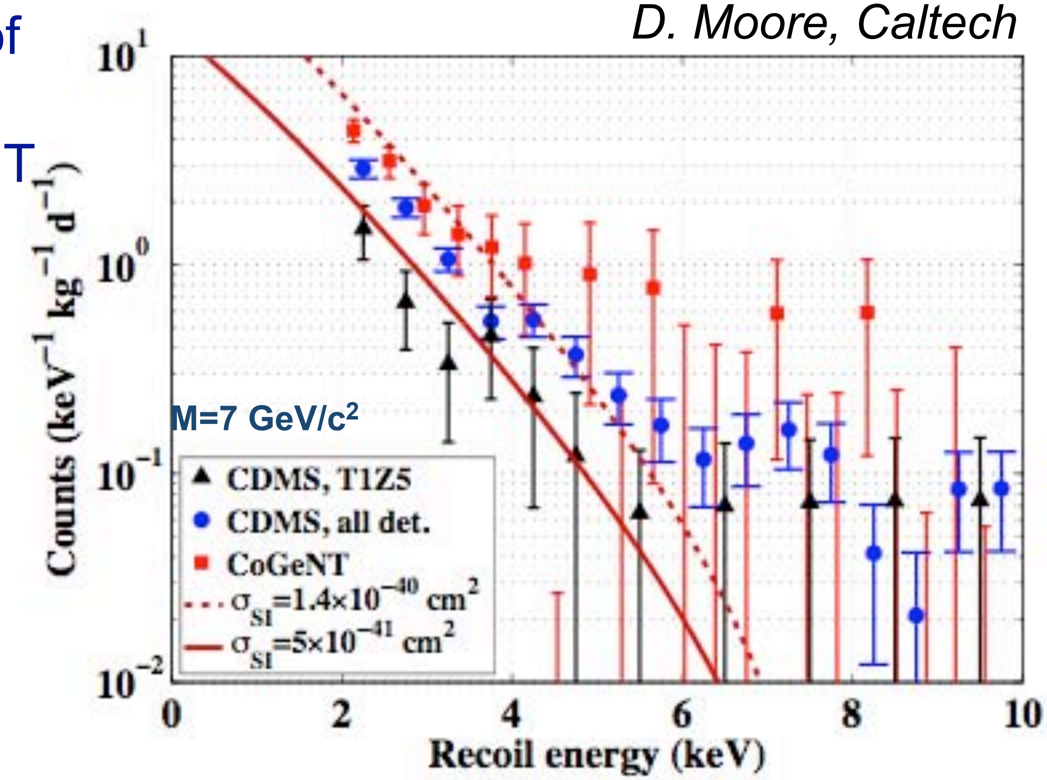

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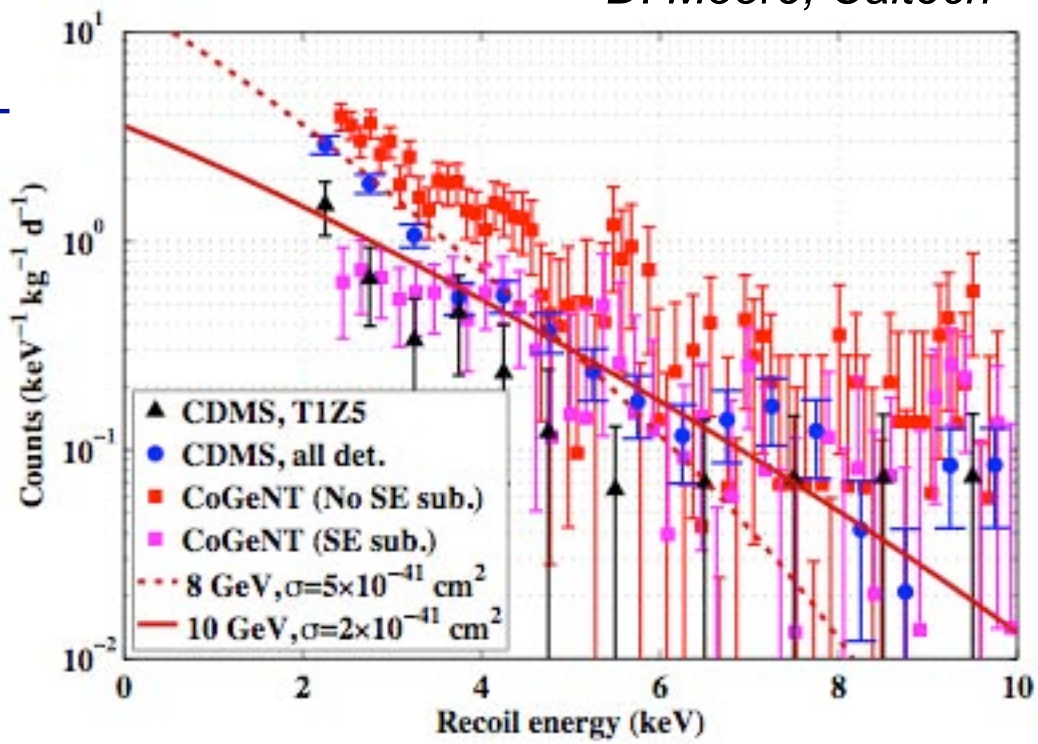

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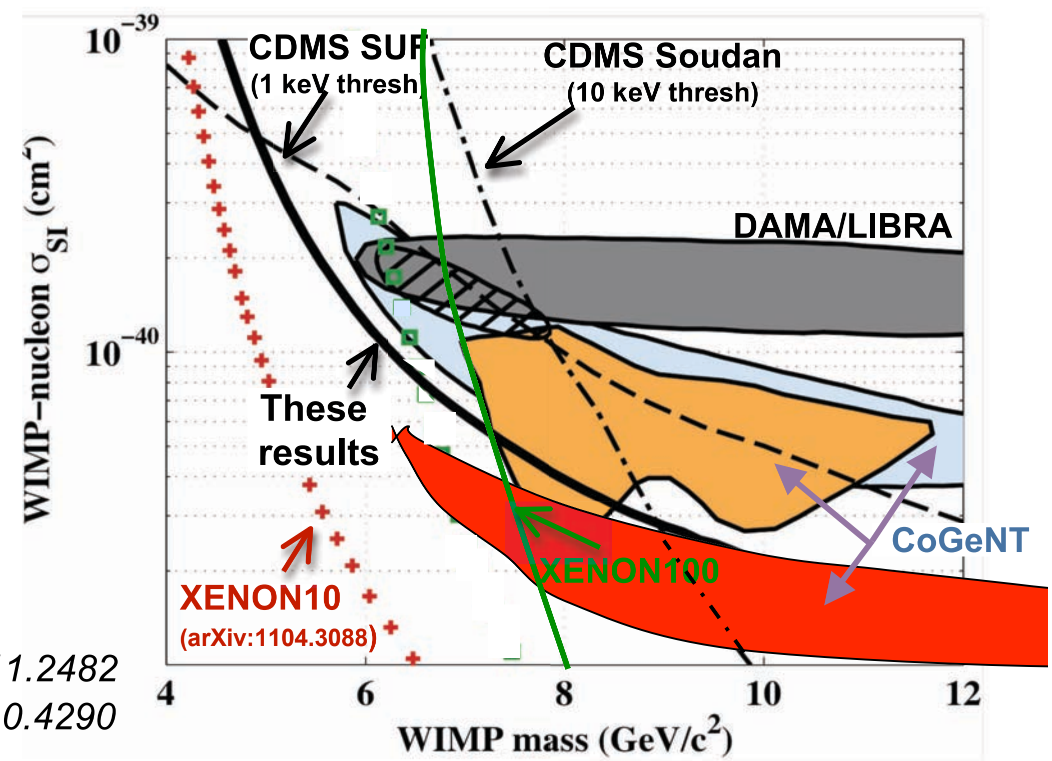
  - Consistent after CoGeNT background correction
- Also inconsistent with CRESST, DAMA/LIBRA under standard assumptions

90% CL upper limits on SI cross section

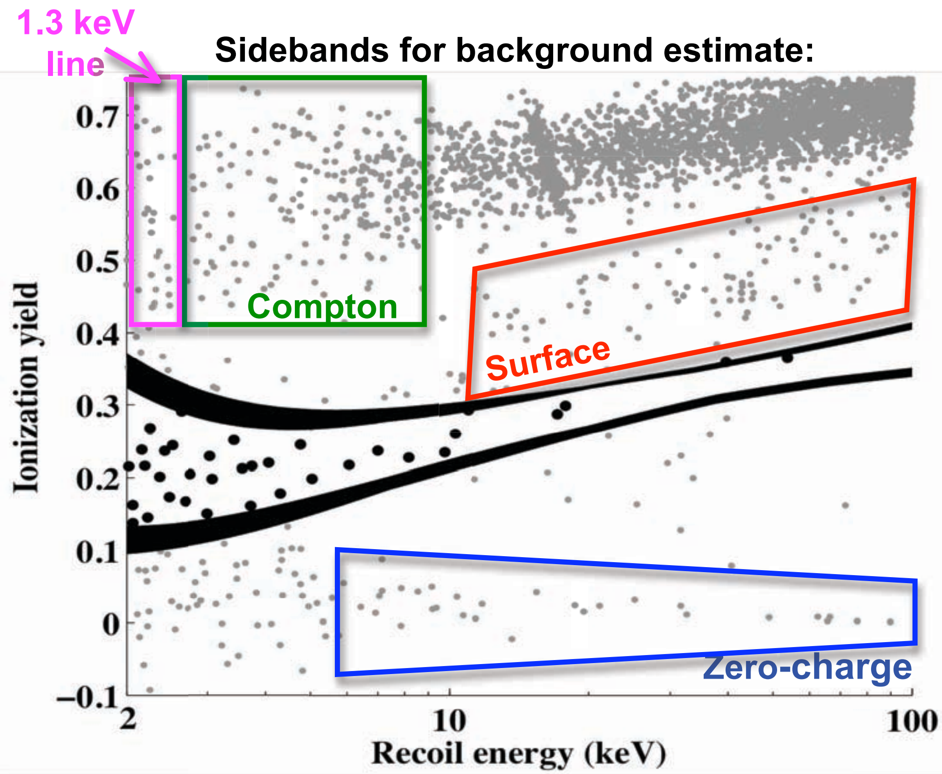


Ahmed et al., PRL **106**, 131302 (2011), *arXiv:1011.2482*
Akerib et al., PRD **82**, 122004 (2010), *arXiv:1010.4290*

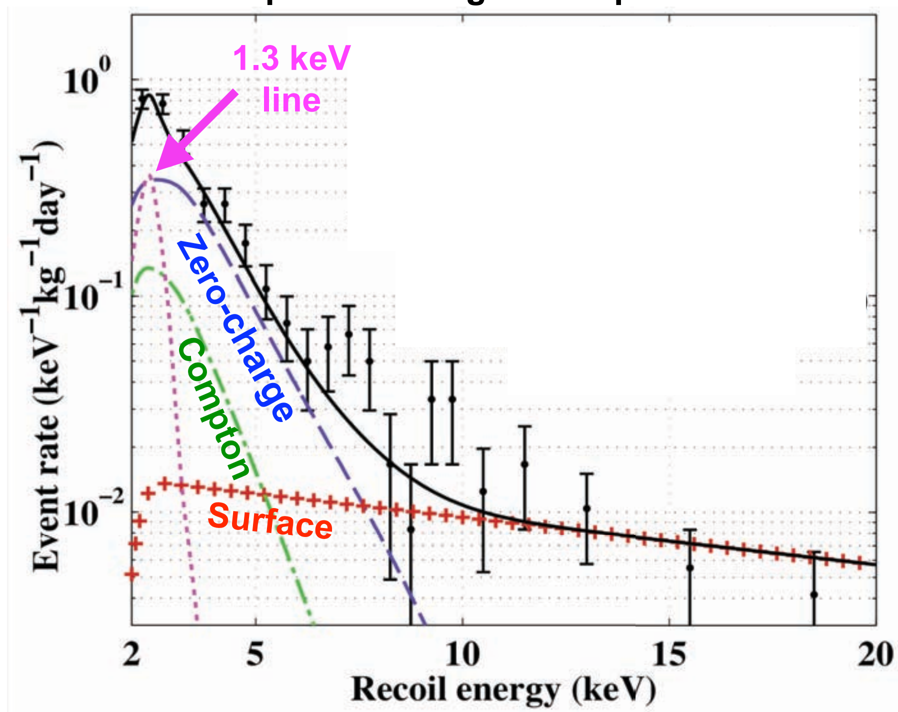
Electron Recoil Backgrounds

- Observed candidates can plausibly be explained by extrapolations of background estimates from sidebands
  - Possibly significant systematic errors due to extrapolations to low energy
- We do not subtract these backgrounds when setting limits

Sidebands for background estimate:



Expected background spectra:



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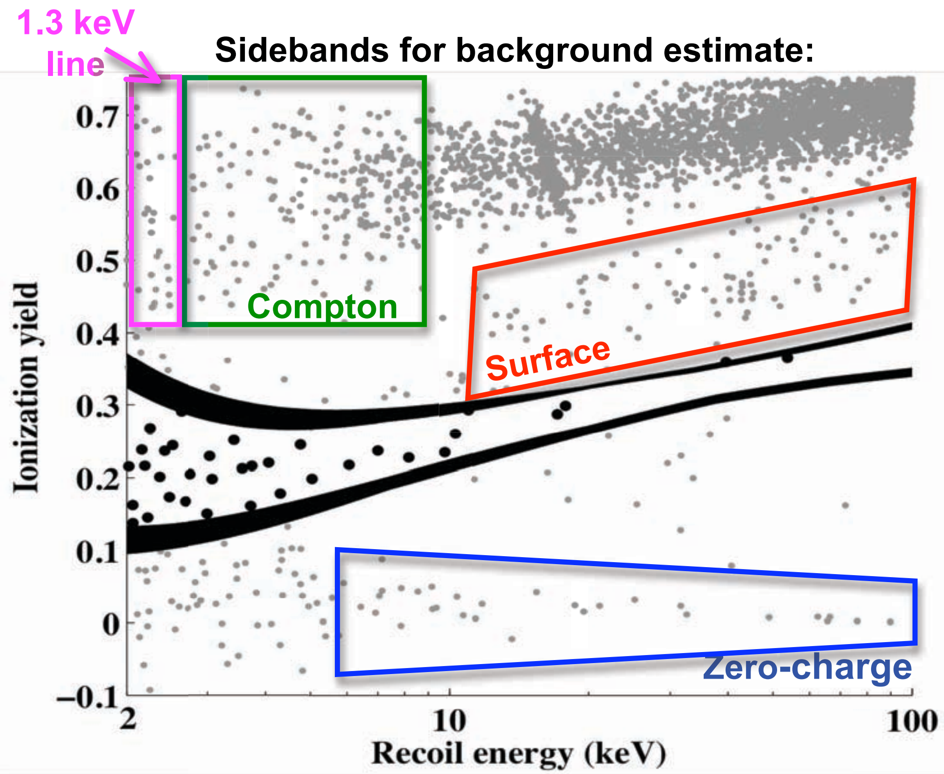
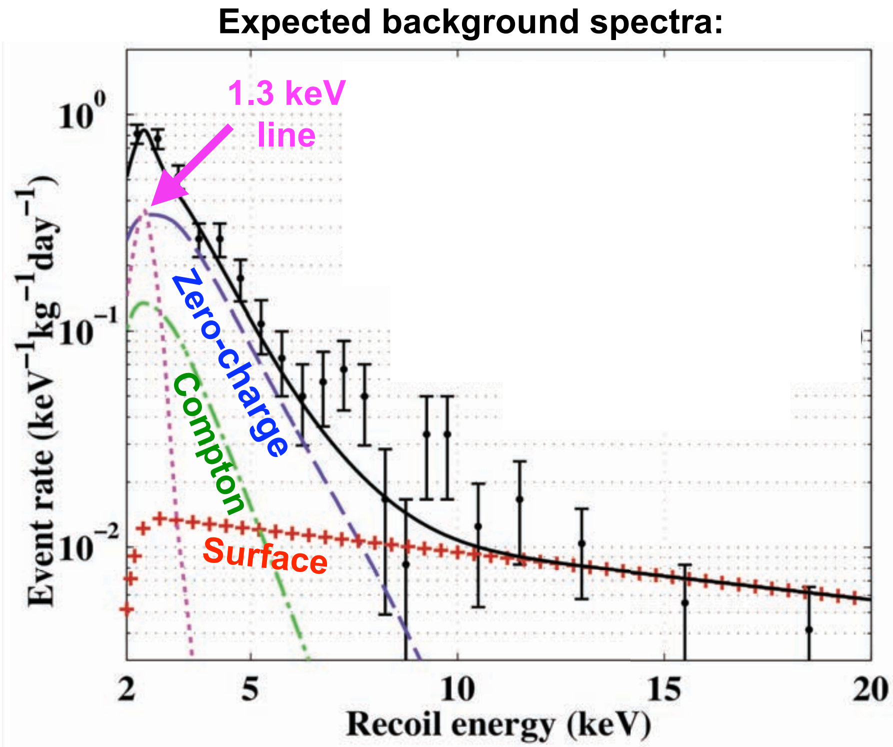
Electron Recoil Backgrounds

- Extrapolations from 1.3 keV line, Comptons are relatively safe
  - Ratio-of-gaussians shape in ionization yield, get E spectrum from high yield
- Extrapolations from surface events less sure (but small at low energy)
  - Energy spectrum ~ flat (betas + Comptons), yield known to factor of a few





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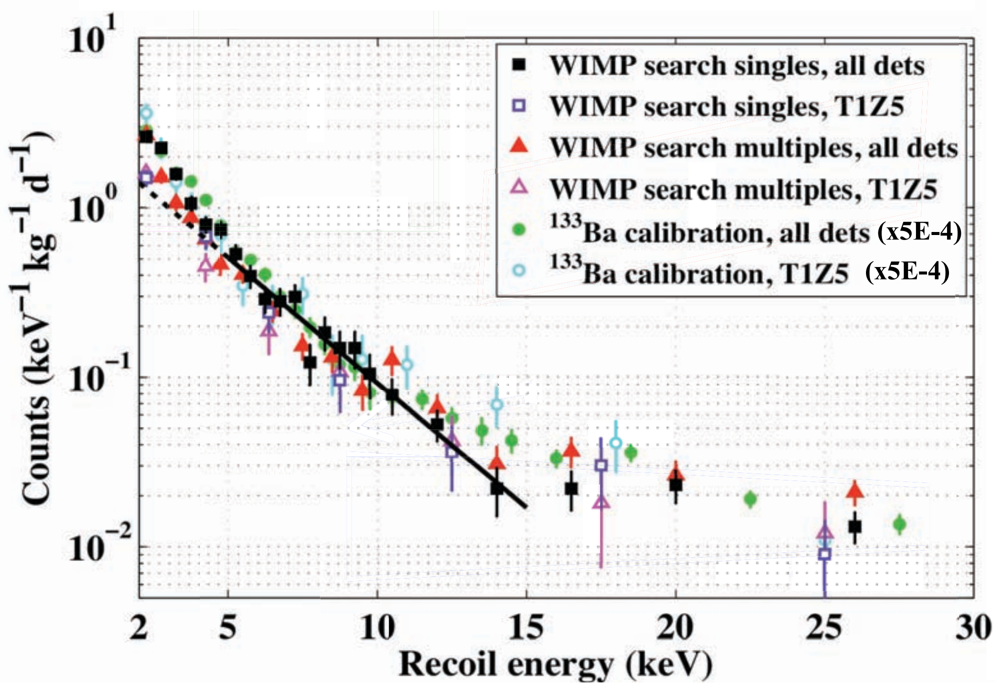
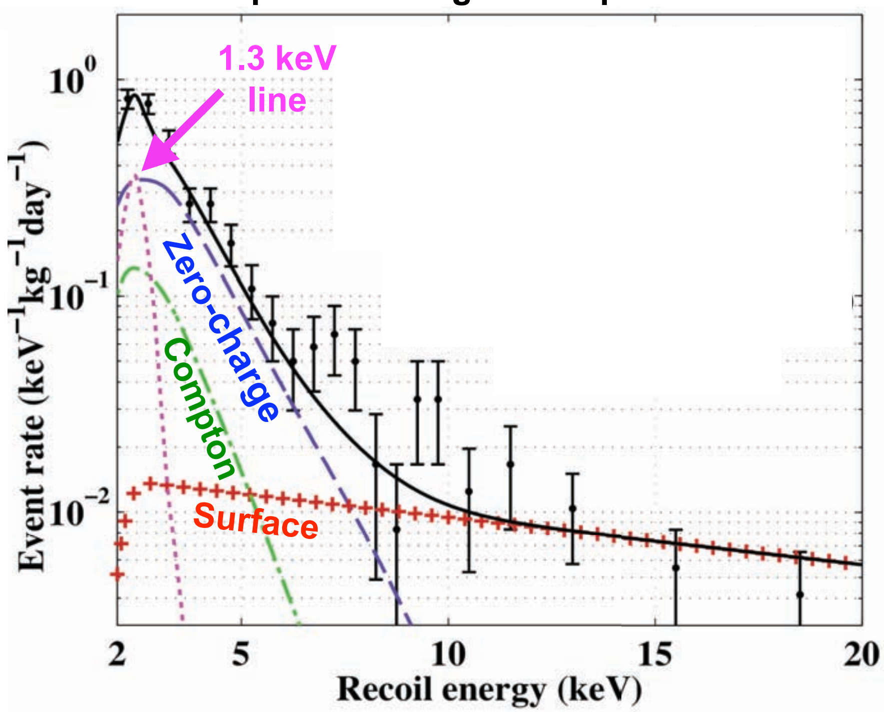
Electron Recoil Backgrounds

- Extrapolation of zero-charge background most important and least known
  - Extrapolation of exponential to low energy
  - Zero-charge in photon calibration have slightly steeper energy spectrum

Spectra of zero-charge events



Expected background spectra:



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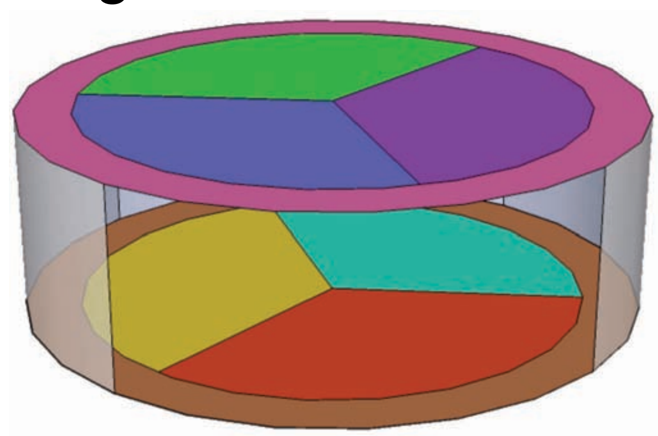
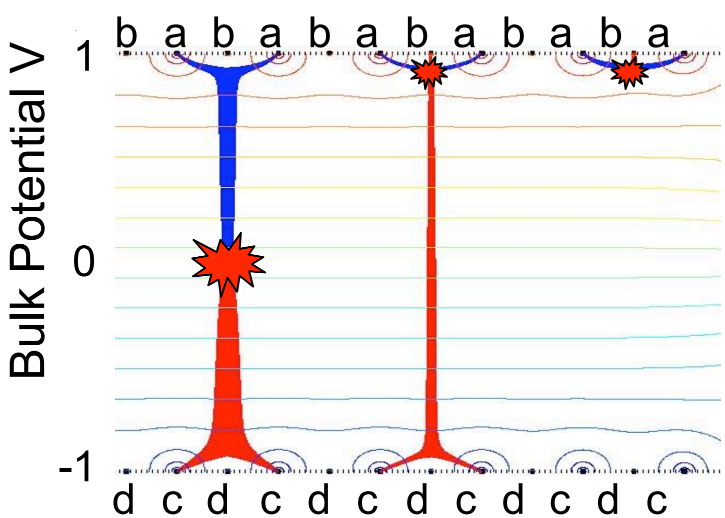
CDMS Present and SuperCDMS Future

- Analysis of annual modulation of nuclear-recoil and/or electron-recoil candidates at low energy is in progress
- Reanalysis of final CDMS II data, including the still-blinded Si detectors, is also in progress
  - Expect results by UCLA
- New detectors (thicker, better rejection, lower thresholds) under initial cooldown at Soudan

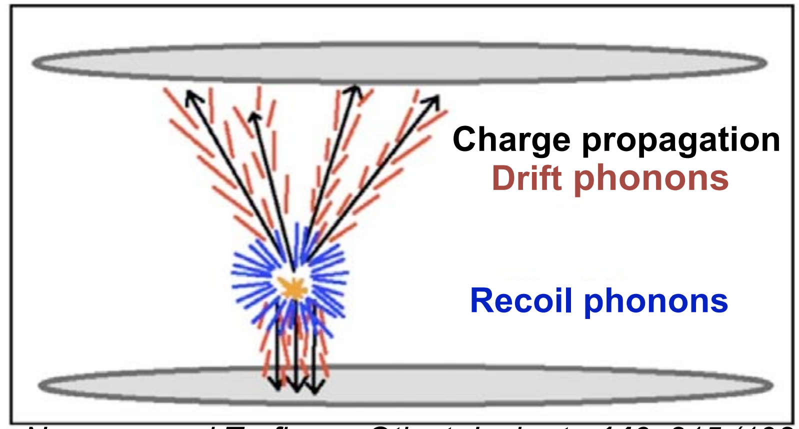




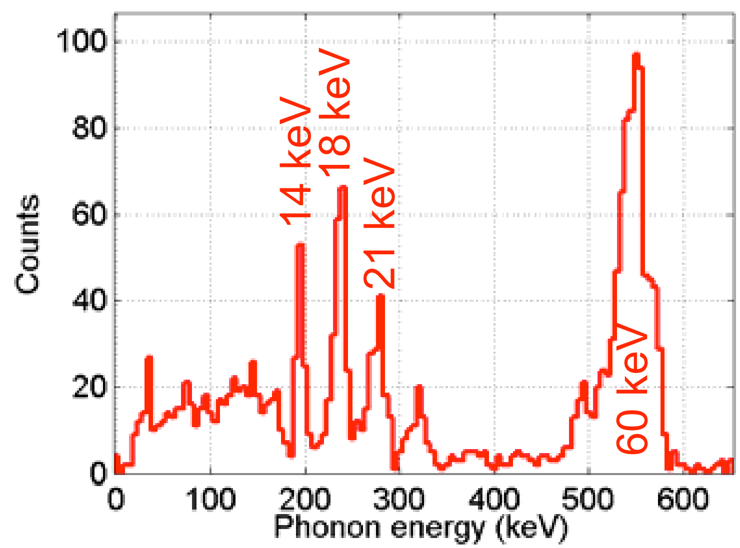
- Interdigitated electrodes improve rejection of surface events using symmetry, yield
- Phonon sensors on both sides improve timing cuts
- Phonon guard ring to reject high-radius zero-charge events

Reducing Threshold via High Voltage

- Drifting charges produce phonons proportional to the voltage bias
- Noise is approximately independent of bias
- Ionization measurement only, so no electron/neutron recoil discrimination
- Preliminary tests demonstrated ~50 eV thresholds with existing detectors
- Expect good fiducial-volume cut down to 150 eVr
- Considering plan to run 2 of the new detectors at high bias for part of the current run



Neganov and Trofimov, Otkryt. Izobret., ***146****, 215 (1985)*
Luke, J. Appl. Phys., 64, 6858 (1988), Luke et al., Nucl. Inst. Meth. Phys. Res. A, ***289****, 406 (1990)*

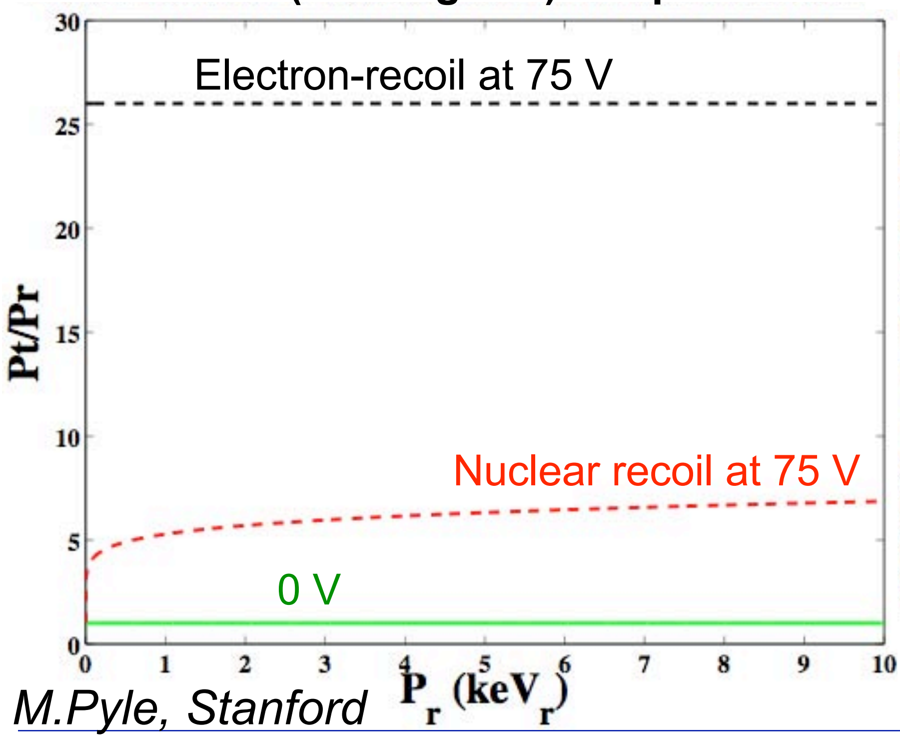


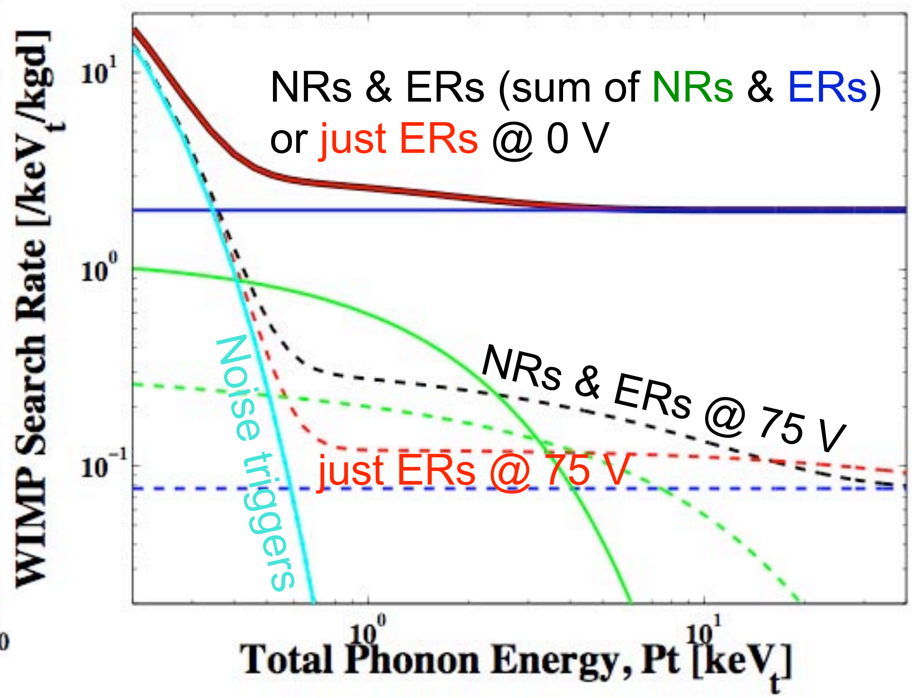
Akeriib et al., NIM A, ***520****, 163 (2004)*

Statistical Discrimination at High Voltage

- Since electron recoils have ionization yield ~5x that of nuclear recoils, increased voltage bias stretches ERs ~5x more than NRs
- Taking data at 2 or more biases allows statistical inference of fraction of events that nuclear recoils

“Stretch” (“Luke gain”) of Spectrum





M.Pyle, Stanford

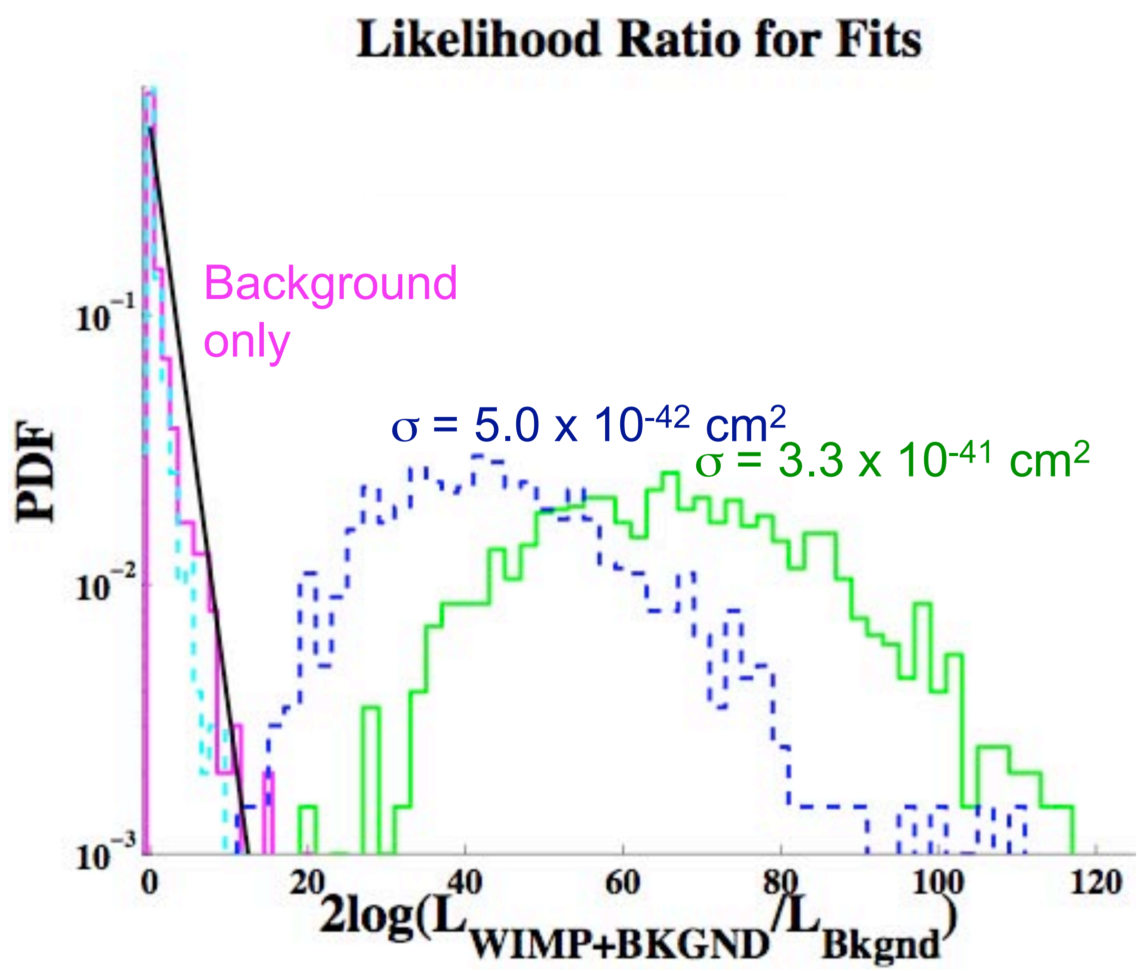
Statistical Discrimination at High Voltage

•Ran simulations to demonstrate ability to distinguish spectra of electron-recoil backgrounds only from backgrounds plus nuclear-recoil WIMPs

•With 20 kgd exposure can detect 7 GeV WIMP at 3.3 x 10^{-41} cm^2

•With 400 kgd exposure can detect 7 GeV WIMP at 5.0 x 10^{-42} cm^2

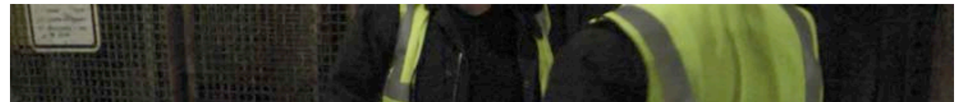
- Determine cross sections to factor of 20%

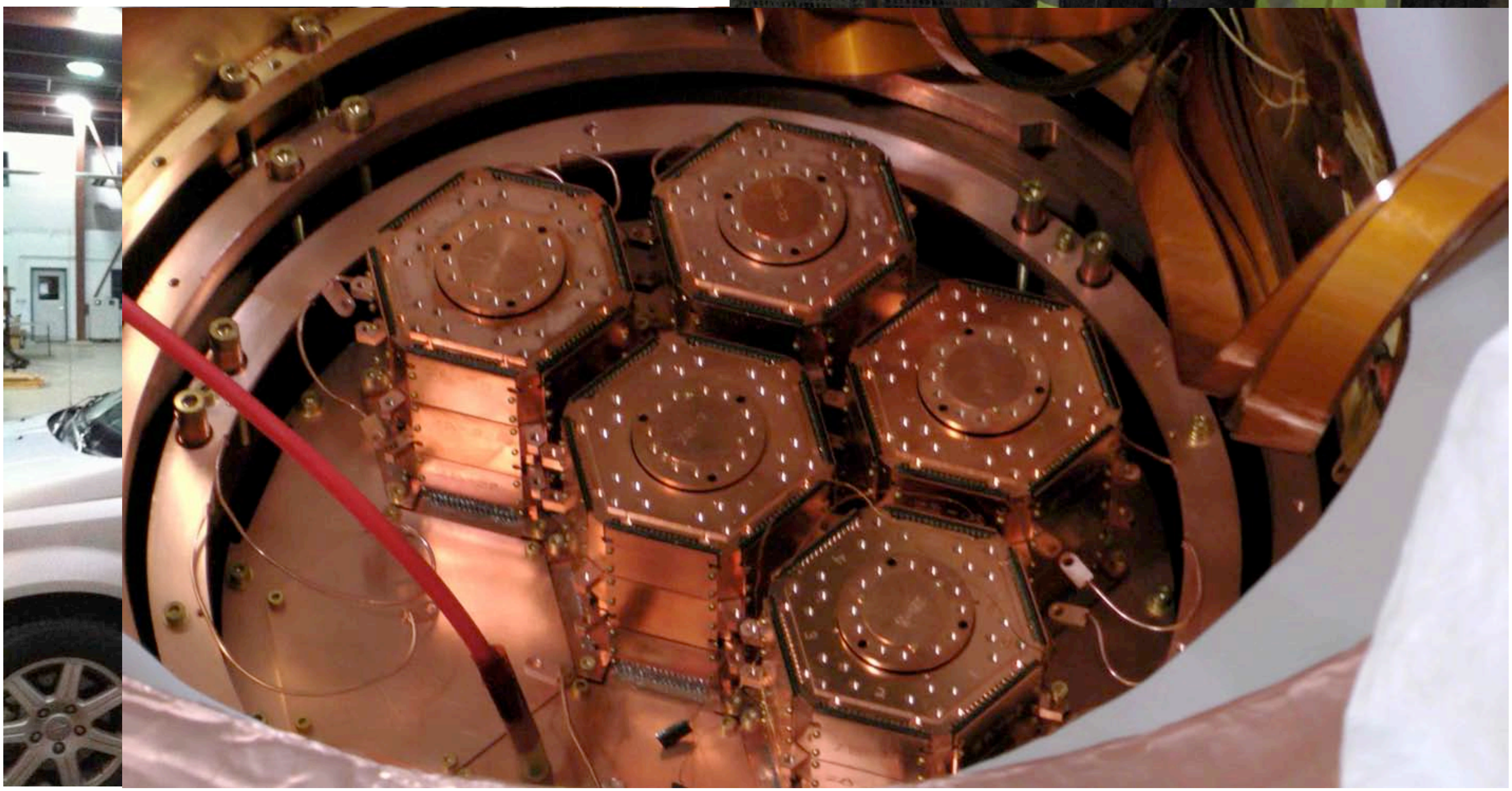


M.Pyle, Stanford

SuperCDMS Deployment

- 5 towers of 3 iZIPs each (~10 kg total) delivered to Soudan October 25, installed into icebox
- Cooldown underway





Conclusions

- CDMS II data reanalyzed with a 2 keV recoil energy threshold constrain low-mass WIMP interpretations of DAMA/LIBRA and CoGeNT.
  - Even without background subtraction
- Analysis of CDMS II data in progress (Si data and annual modulation) promises additional information soon.
- Run just starting should yield significant improvements in sensitivity to low-mass WIMPs due to better background rejection of new SuperCDMS detectors and ability to lower thresholds to ~100 eV using high-voltage operation.