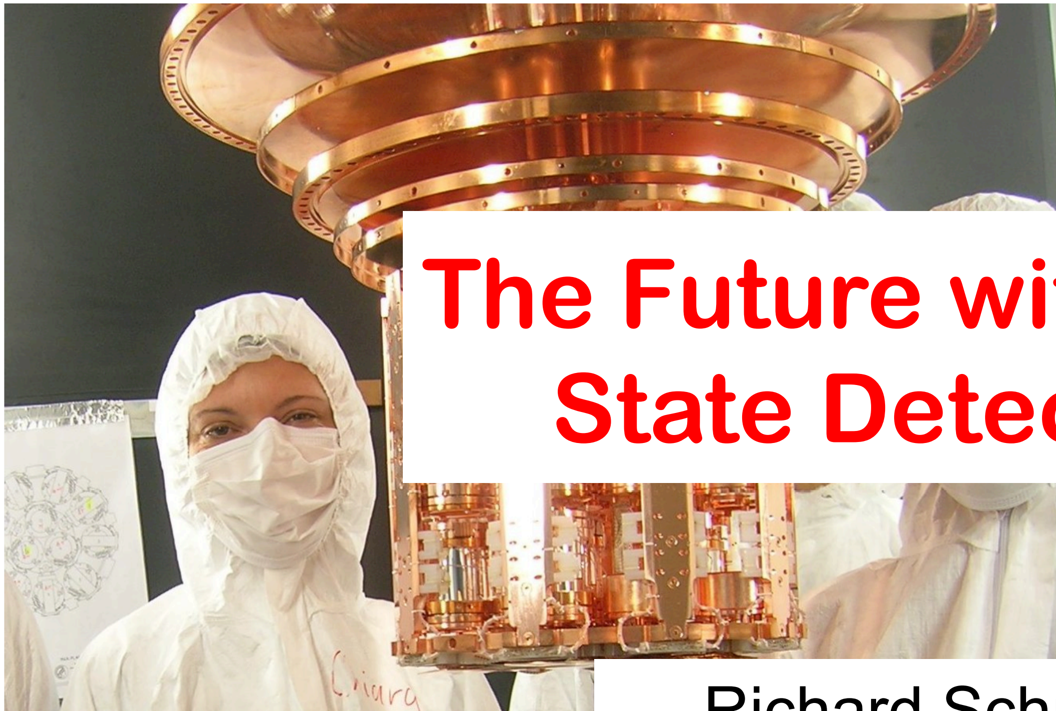
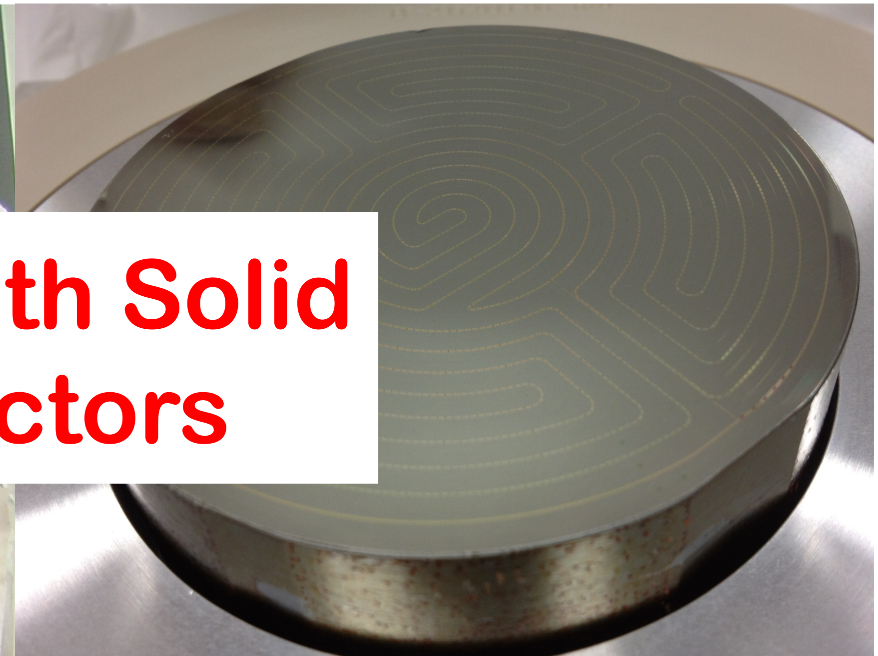
The Future with Solid State Detectors

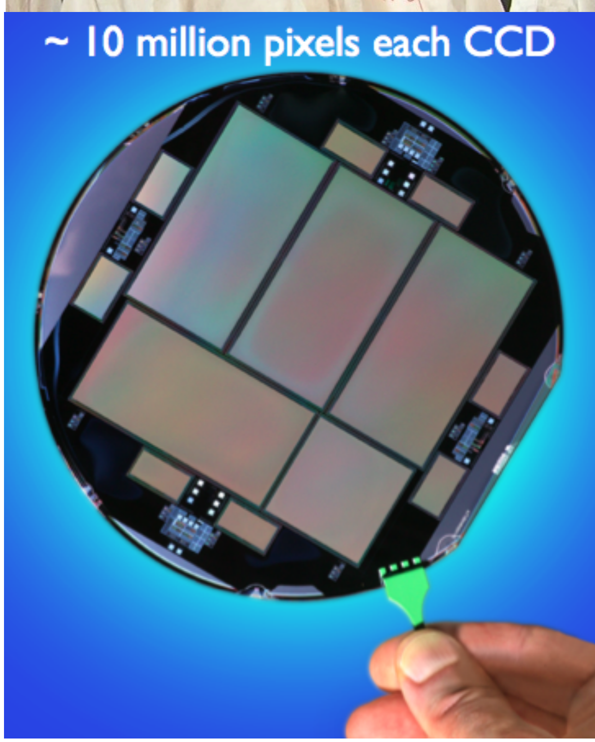


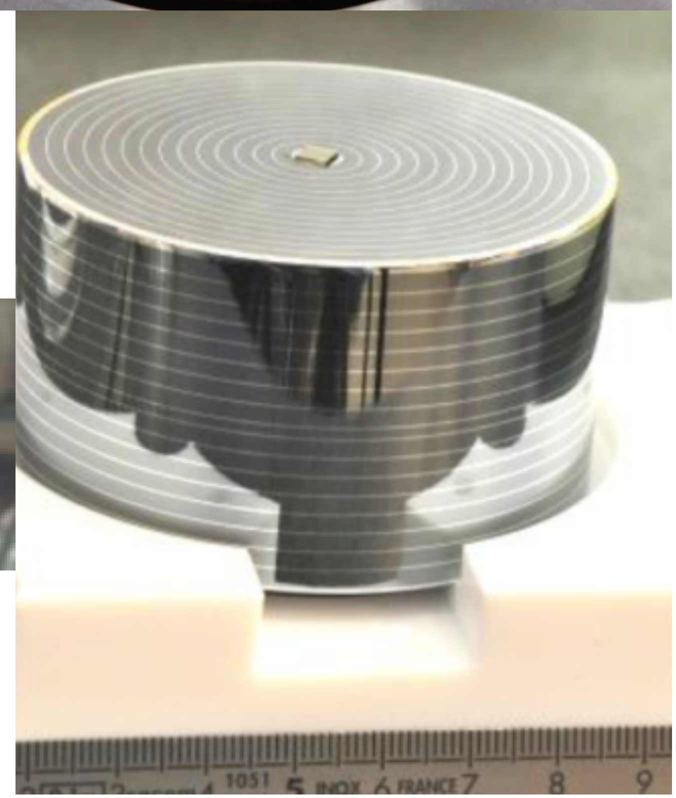


Richard Schnee

Syracuse University

SuperCDMS, DEAP/CLEAN





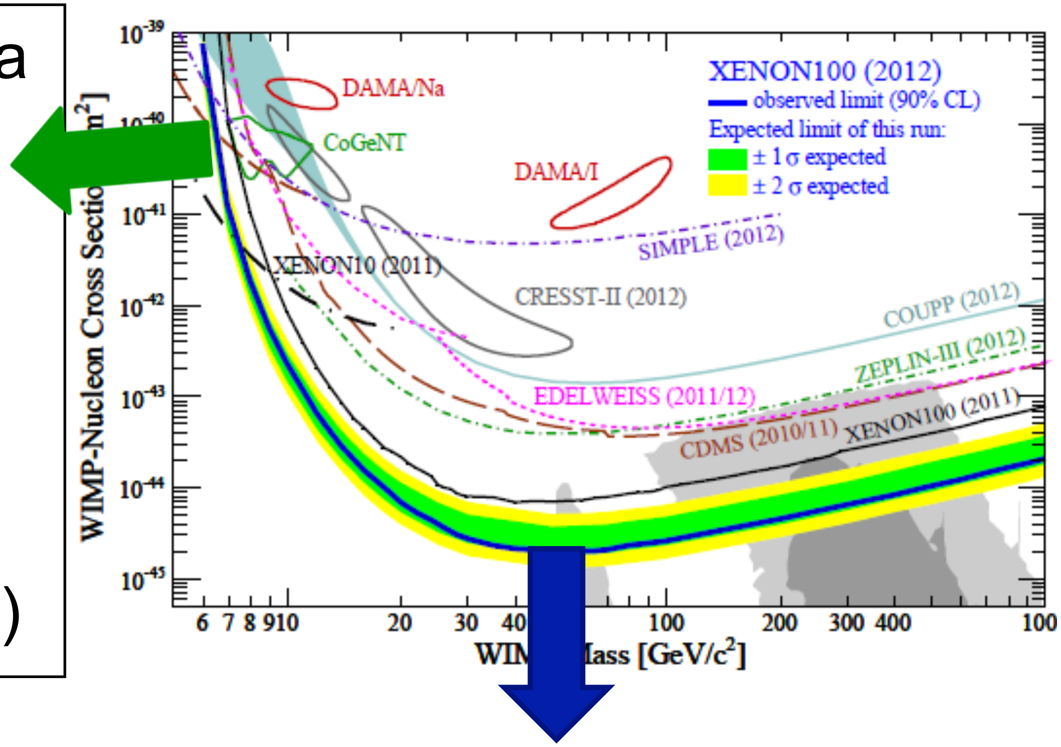
Aspen Winter Conference

Closing in on Dark Matter

February 2, 2013

Why Use Solid State Detectors?

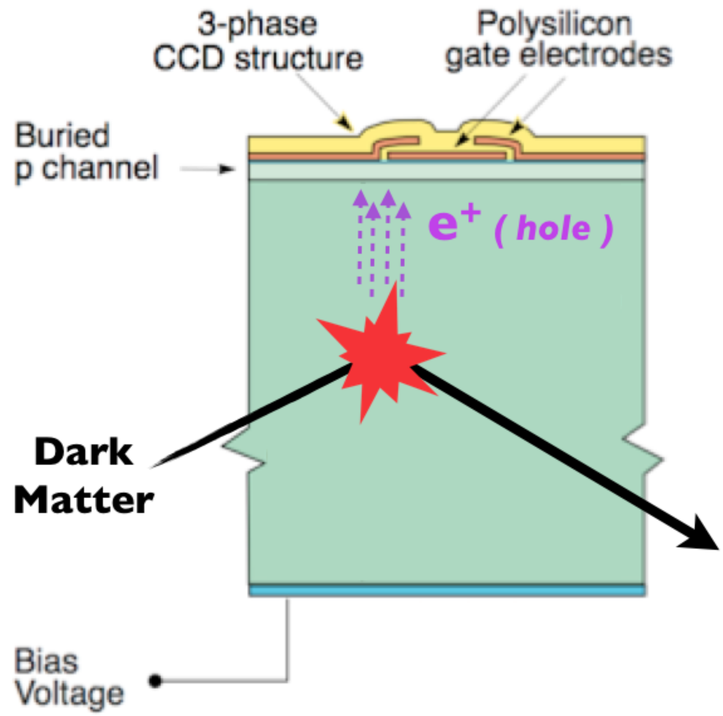
- Highest number of quanta
  - 10^5 phonons per keV
  - 300 e-h pairs per keV
  - vs. ~40 photons per keV for liquid nobles
- Robust low threshold
- Better exploitation in future (low-noise readout)



- Surest way to improve sensitivity below 10^{-46} cm^2
  - Radioactive background is known, small, fixed,
    - No diffusion
  - Excellent background rejection due to high signal-to-noise
  - Modularity provides robustness, ease of calibrations

Dark Matter in CCDs (DAMIC)

- Target consists of nuclei in silicon pixel detectors of thick (250 μm, 0.5 g) CCDs cooled to -150 C to reduce noise
  - 40 eVee energy threshold
  - "Skipper CCD" and digital filtering may reduce x10
- Fiducial-volume cuts based on amount of diffusion as holes drifted suppress external X-rays



B. Kilminster, FNAL

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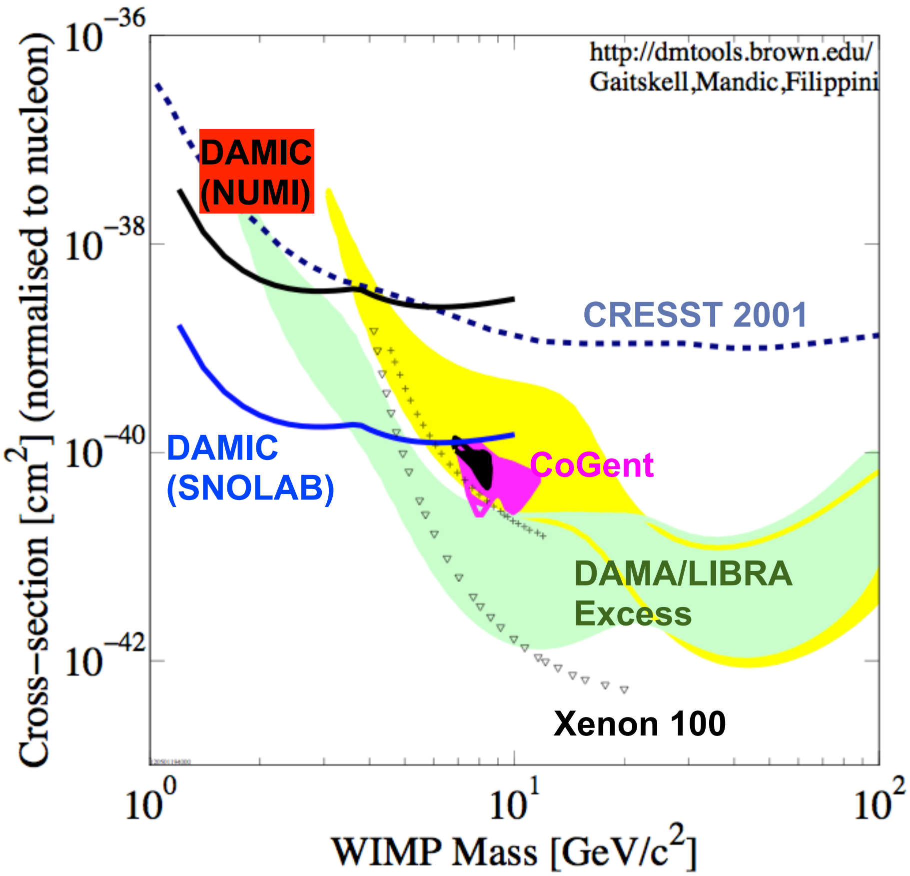
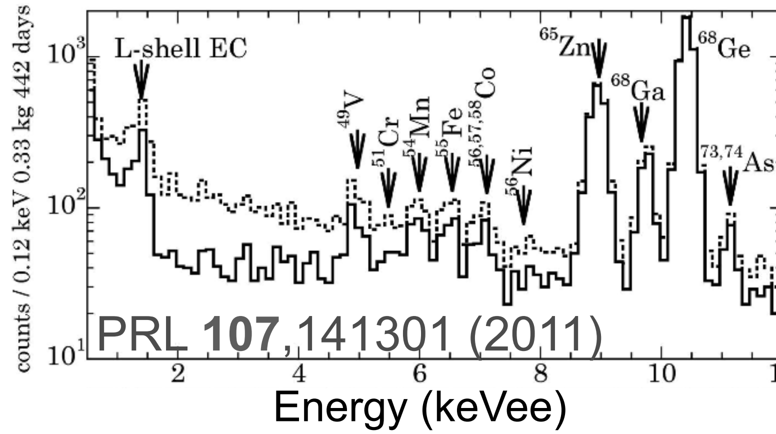
  - 40 eVee energy threshold
  - "Skipper CCD" and digital filtering may reduce x10
- Fiducial-volume cuts
- 107 g days at shallow site provide world's best limits for $M_W < 3.3$ GeV/c^2
- 10 g at SNOLAB now with poly shielding, cleaner materials expected to reduce dominant neutron background by 20x
- Goals of 100 g ($5M) at SNOLAB and DAMIC-SOUTH

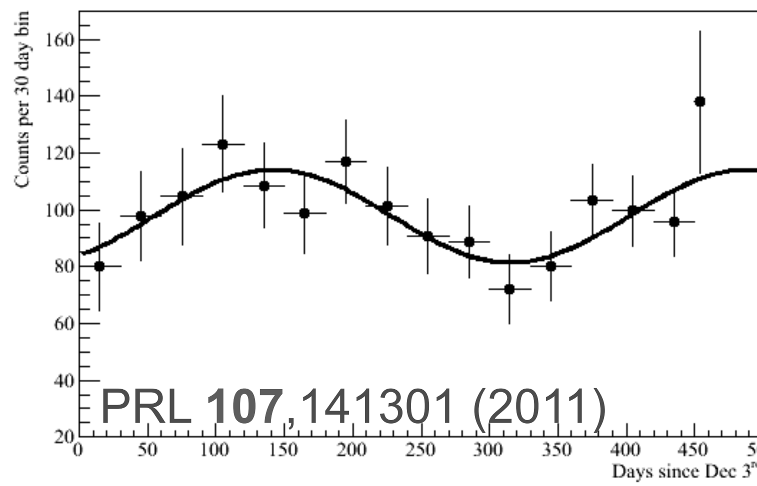


B. Kilminster, FNAL

P-type Point Contact Ge Detectors: PPCs

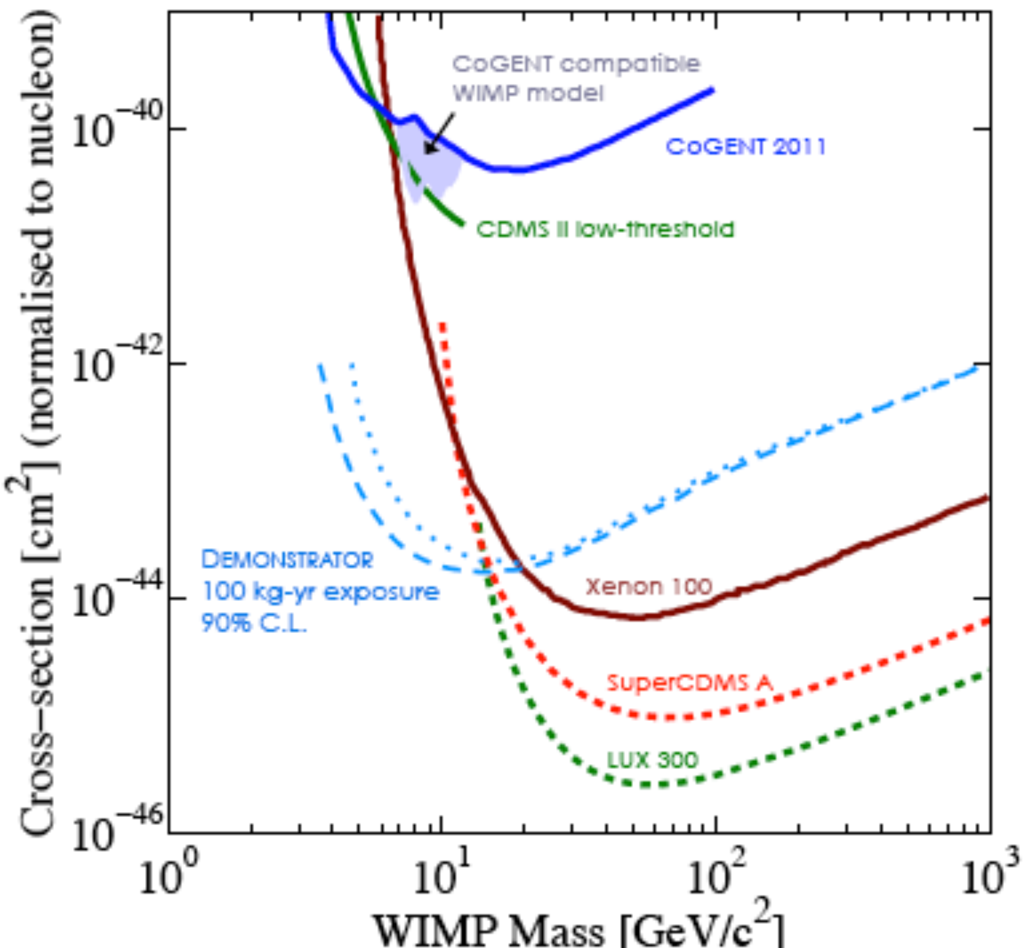
- Small detector capacitance allows ~400 eVee energy threshold
- Energy depositions near surface can be rejected by slow rise times
- **CoGeNT**: 1 Ge crystal (440 g) at the Soudan mine (data Dec 2009 – March 2011) shows an excess of events at low energies (PRL **107**, 141301 (2011))
- Also hint of annual modulation in the event rate (2.8 σ) [PRL **107**, 141301 (2011), arXiv:1208.5737]
- 607 days new data and counting





PPCs Future: C4 & MAJORANA Demonstrator

- **C4**: planned four ~1 kg Ge detectors, but not funded
  - LDRD-financed design of low-noise cryostat to reduce threshold to ~100 eVee
- **MJD**: Primary goal $0\nu\beta\beta$, plan 40 kg of Ge PPCs by end of 2014
  - Expect background to be dominated by cosmogenic ^3H in Ge
  - Ultraclean setup results in negligible gamma backgrounds



*Giovanetti et al, Journal of Physics: Conference Series **375** (2012) 012014 (TAUP 2011)*

Phonons and Ionization or Scintillation

2012
2013
2014
2015
2016
2017
2018
2019
2020
2021

Ge Phonons + Ionization

athermal W TES

SuperCDMS
Soudan
10 kg
5e-9 pb

thermal NTD

Edelweiss
Modane
10-32 kg
2e-9 pb

$CaWO_4$ Phonons + Scintillation

CRESST
Gran Sasso
>10x lower backgrounds

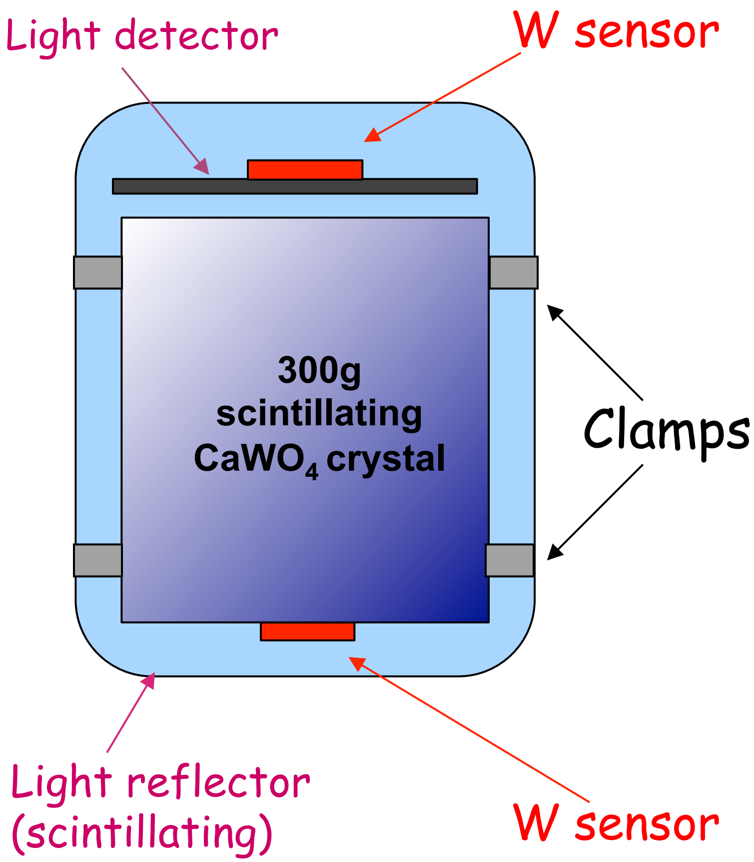
SuperCDMS
SNOLAB
200 kg
8e-11 pb

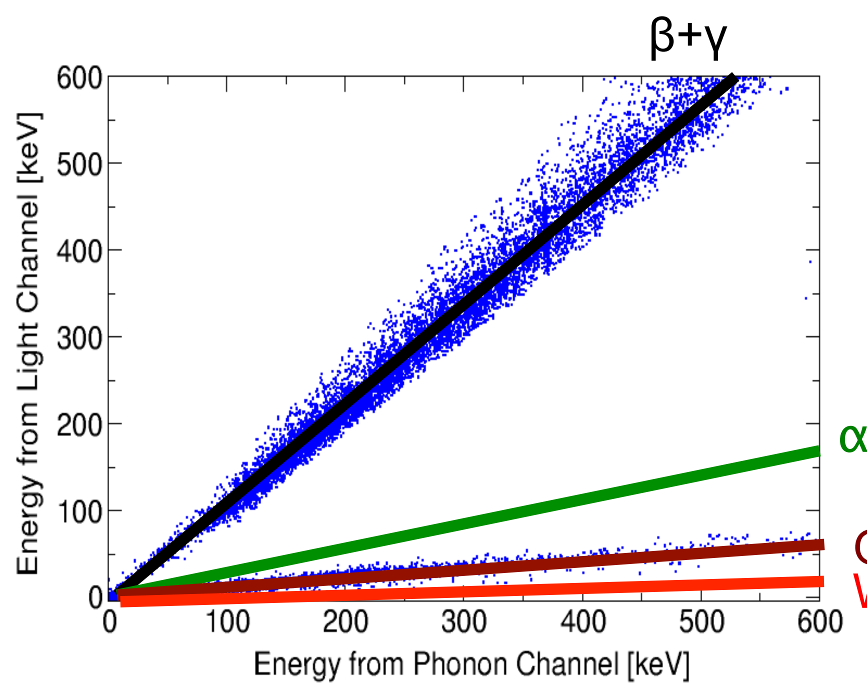
MOU since 2009
Increasing collaboration towards common experiment

EURECA
150 - 1000 kg
3e-10 to 2e-11 pb

CRESST-II: Phonons and Scintilation

- Nuclear recoils much smaller light yield than electron recoils
  - susceptibility to events that cause phonons but no light ("crackophonics," ^{206}Pb recoils from ^{210}Po α-decays in clamps surface)
- 8 $CaWO_4$ modules run June 2009 - April 2011, 730 kg days



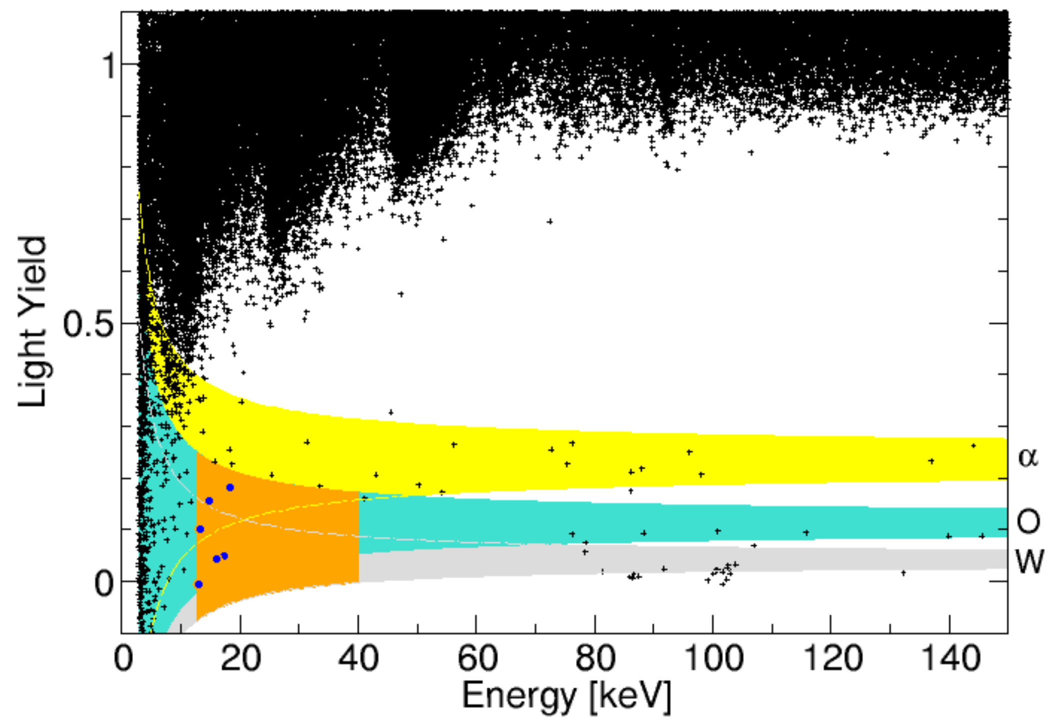


arXiv:1109.0702

W. Seidel

CRESST Results and Plans

- Known backgrounds (~40 events) unable to explain observed 67 events
  - But large systematic on α / Pb-recoils backgrounds (Astropart. Phys. **36**, 1, 77–82)



- New physics run in preparation aimed at background reduction:
  - Modification of the clamps to reduce α and Pb-recoils backgrounds
  - Installation of additional internal neutron shielding
  - Should confirm or rule out WIMP hypothesis, but achieving low enough backgrounds for future ton-scale experiment unclear

F. Petricca, J. Jochum

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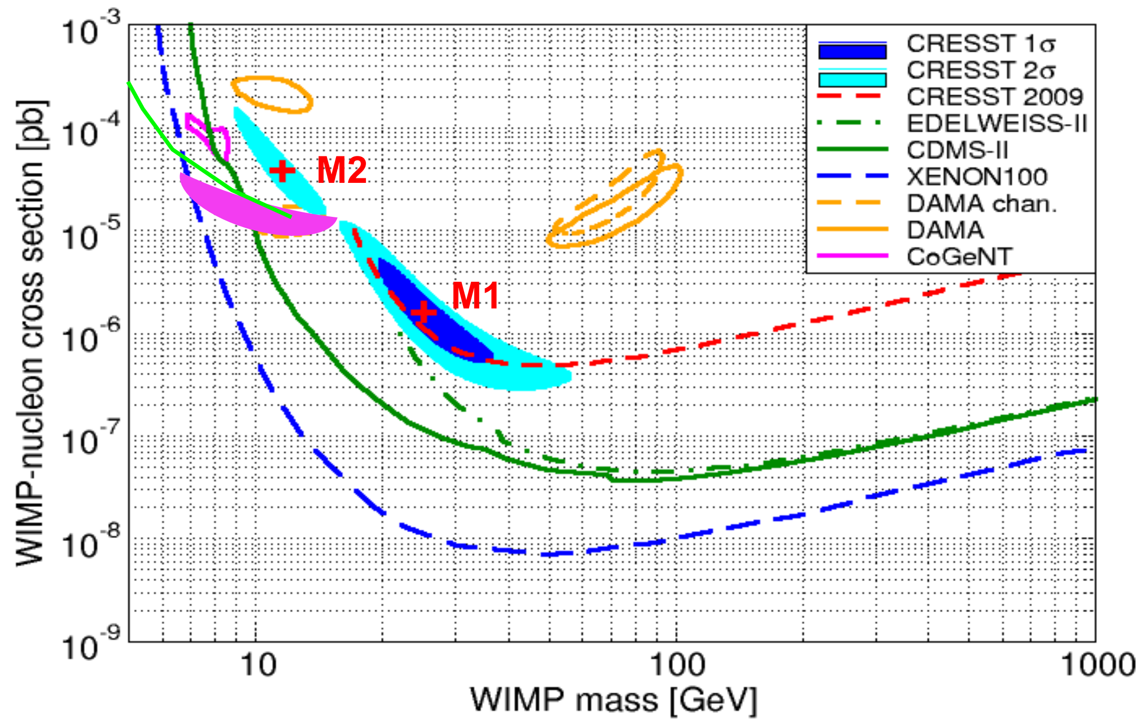

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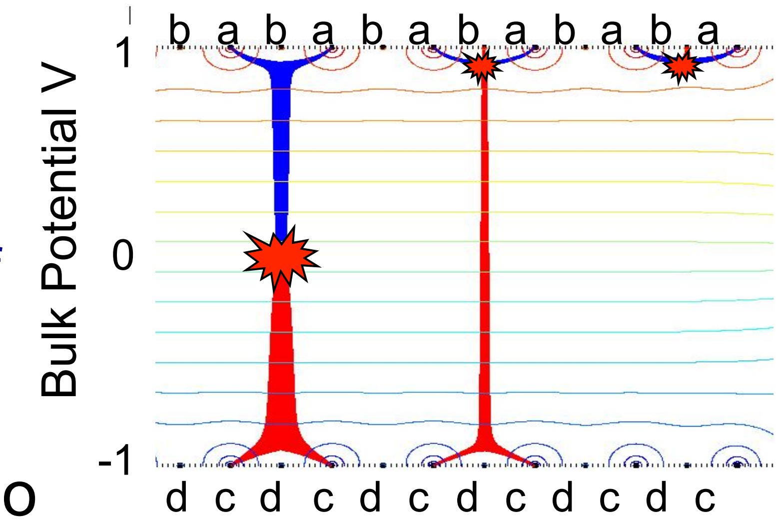
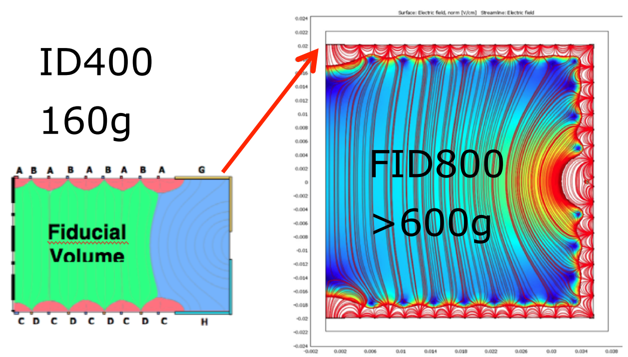
F. Petricca, J. Jochum

EDELWEISS-II and –III: Phonons and Ionization

- EDELWEISS-II Interdigitated Detectors (ID's) provide effective rejection of surface events
  - Ionization collected all on one side of detector instead of on both



- Improved EDELWEISS-III FID detectors interdigitate the sides too
  - Increase fiducial volume from 40% to 80%
  - Allow detector mass to be increased from 400 g to 800 g (double height)
  - Reduce gamma-ray background (~1 bkg event in EDW-II) from multiple Compton scatter with part in the guard region (had been low field + poor charge collection)



- Reduce (α,n) neutron background (~3 events in EDW-II) by better material selection, ~10 cm polyethylene shield

J. Gascon

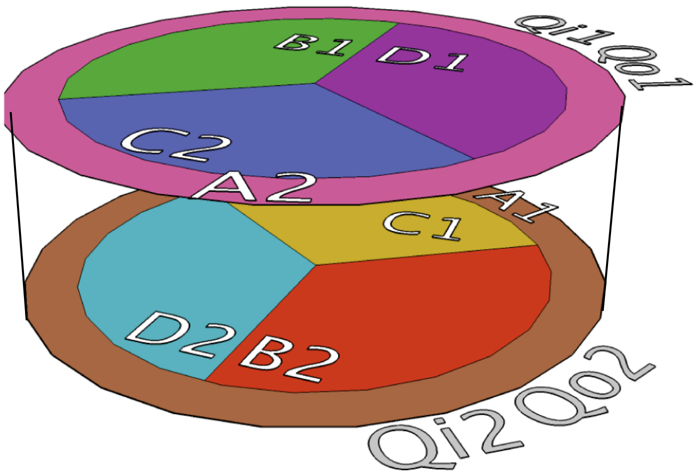
EDELWEISS-III Plans

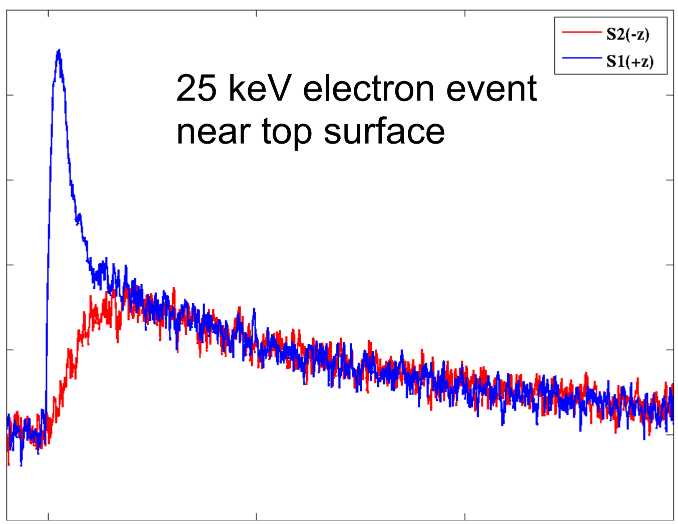
- Calibration run with 6 FIDs starting October 2012
- Run with 14 FIDs starting February 2013
  - Commissioning, large-statistics gamma calibration, more beta calibration
- Run with 40 starting in summer/autumn 2013
- First 3000 kgd by next winter, then 3000 kgd per 6 months
- Resolutions are improving with new electronics
  - 900 eV -> 650 eV for ionization, 1.25 -> <1 keV for heat
  - 500 eV achieved in tests (HEMT R&D to go down to 300 eV?)
- Expect average 10 keV threshold
  - Sensitivity for 3000 kgd to 3-4x10^{-9}pb
  - 3 keV thresholds on a few R&D detectors is possible (HEMT)
- Range of background from internal neutrons limits total exposure to 4500 kgd (2.5x10^{-9} pb at 15 keV) to 12000 kgd (10^{-9} pb at 15 keV)

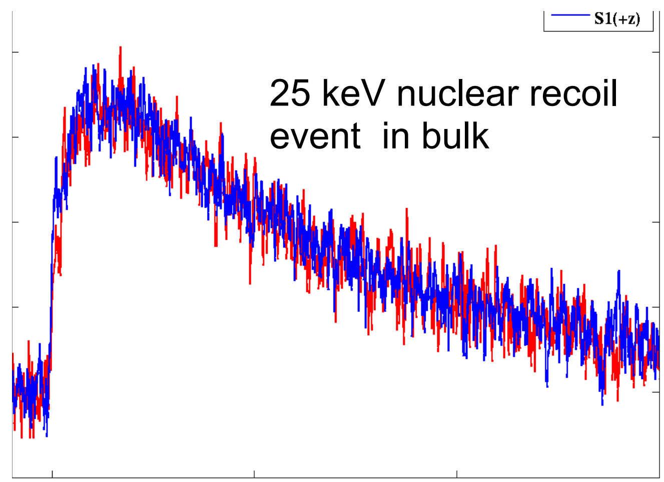
J. Gascon

SuperCDMS: Ionization & Athermal Phonons

- Interdigitated electrodes similar to EDELWEISS
  - As shown in Jeter Hall's talk, already demonstrated rejection of surface events good enough for SuperCDMS SNOLAB experiment
- Additional info from phonon sensors
  - xyz information from energy partition, timing
    - Phonon guard ring to reject high-radius surface events







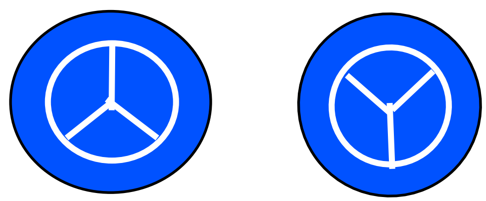
SuperCDMS SNOLAB R&D

- Scale up detectors
- Demonstrate
  - Procurement
  - Fabrication
  - Testing
  - Production (6 det/ mo)
- Improve readout
  - Tower engineering
  - New SQUID arrays
  - JFET→HEMT
- SNOLAB facility
  - Shielding design
  - Cryogenic system
  - Neutron veto

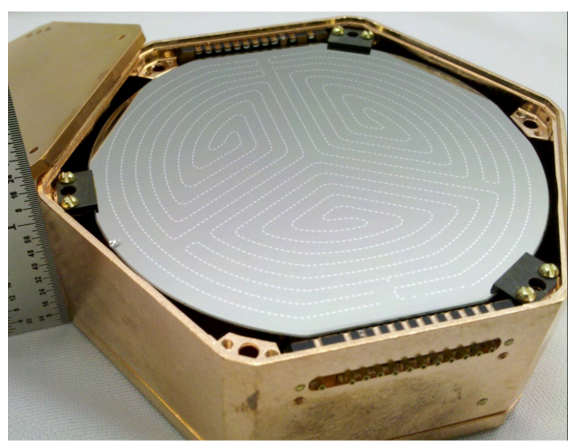
SuperCDMS Soudan

2.5 cm thick
3”diameter
620 g Ge

2 charge + 2 charge
4 phonon + 4 phonon



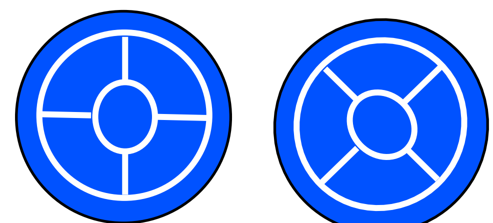
5 towers of 3 det each



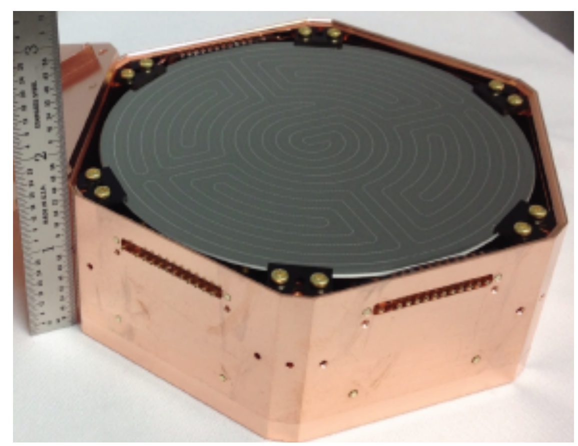
SuperCDMS SNOLAB

3.3 cm thick
4”diameter
1.38 kg Ge

2 charge + 2 charge
6 phonon + 6 phonon

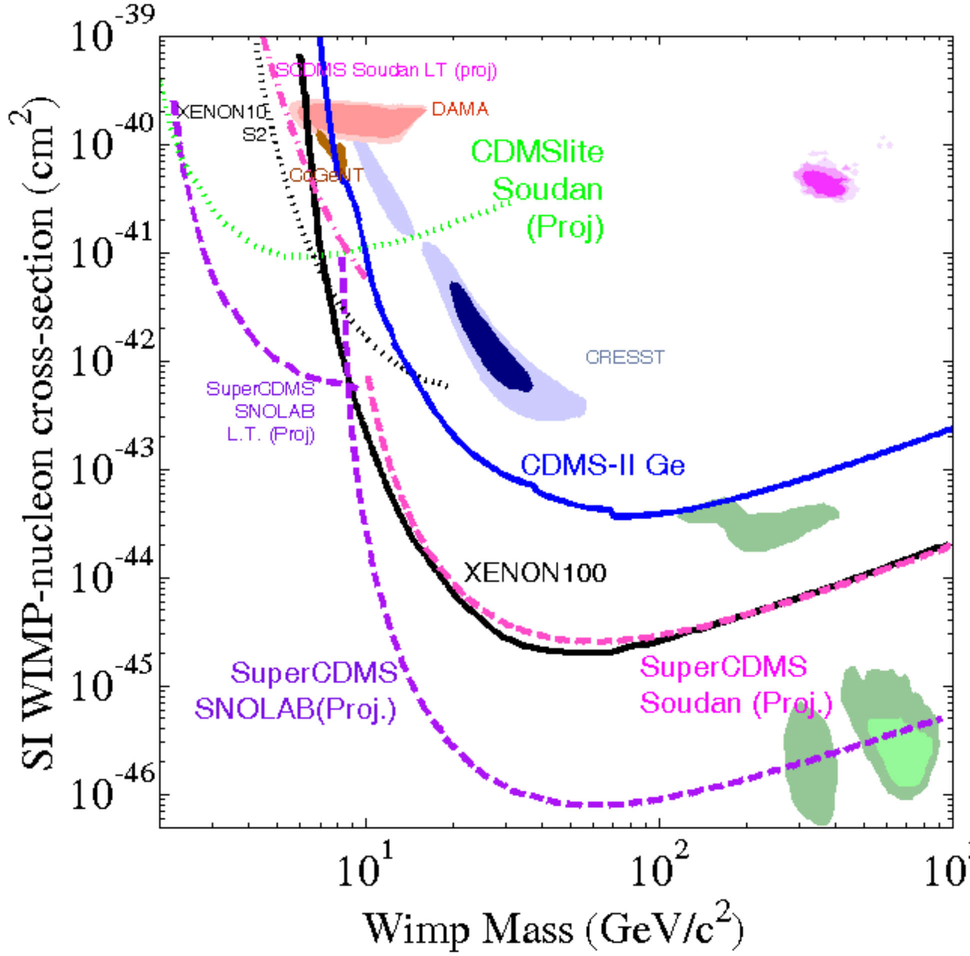


24 towers of 6 det each



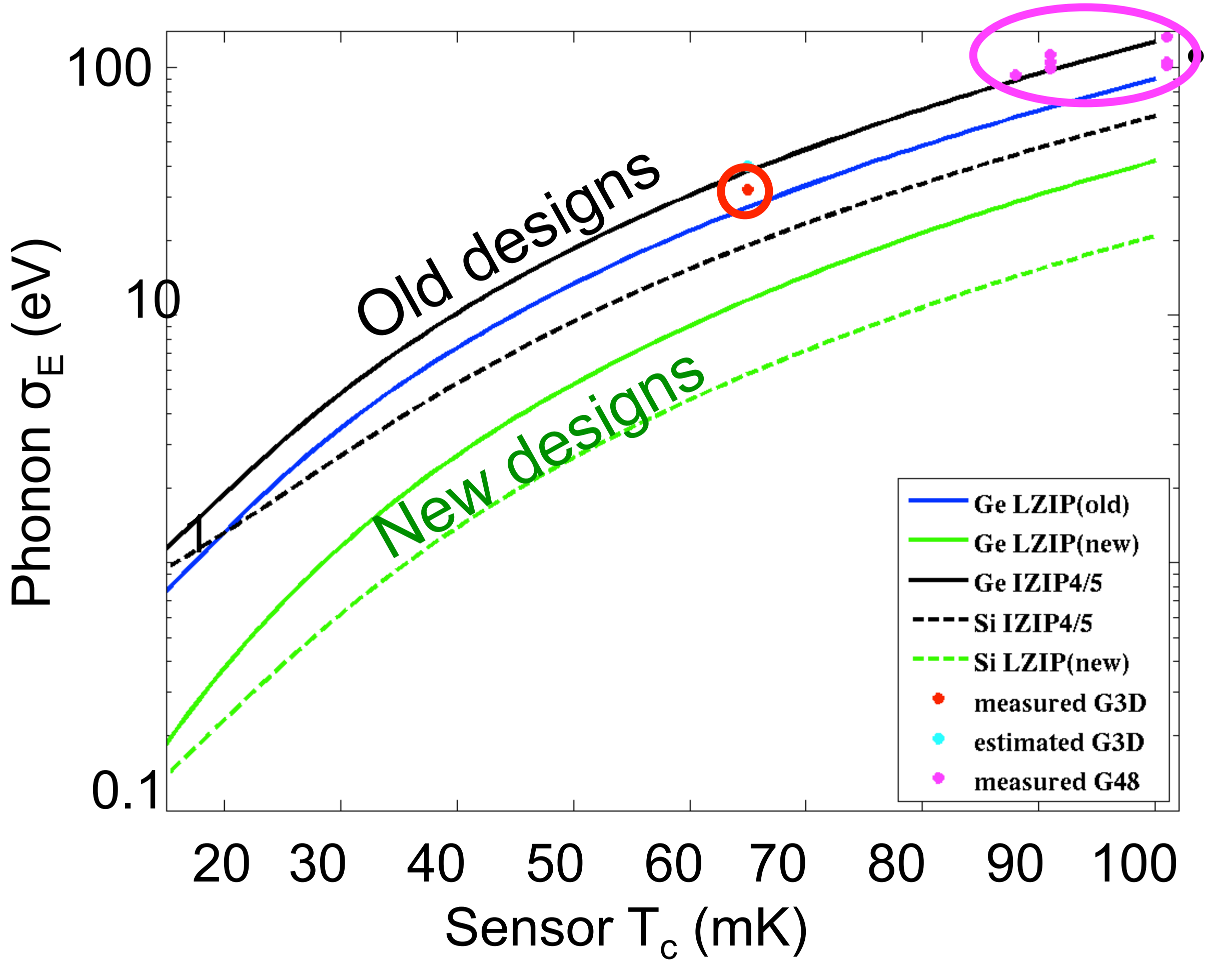
SuperCDMS SNOLAB Sensitivity

- Neutron backgrounds primary concern
  - Cosmogenic background kept small by added depth of SNOLAB
  - Careful materials selection/screening to reduce radiogenic neutrons
  - Neutron veto/monitor under consideration to reduce uncertainty, dependence on shielding radiopurity
  - Design study suggests 90% effective
- 200 kg for 4 years yields sensitivity $\sigma_{SI} < 8 \times 10^{-47}$ cm^2 for 60 GeV/c^2 WIMP



Lowering Thresholds with Athermal Phonons

Only recently was it realized that $\sigma_E \propto T_c^3$



M. Pyle, Stanford dissertation 2009

For T_c= 20 mK: x125 better energy resolution than CDMS!

- ~100 eV ➔ < 1 eV
- Harder cryogenics, new recipe for Tc

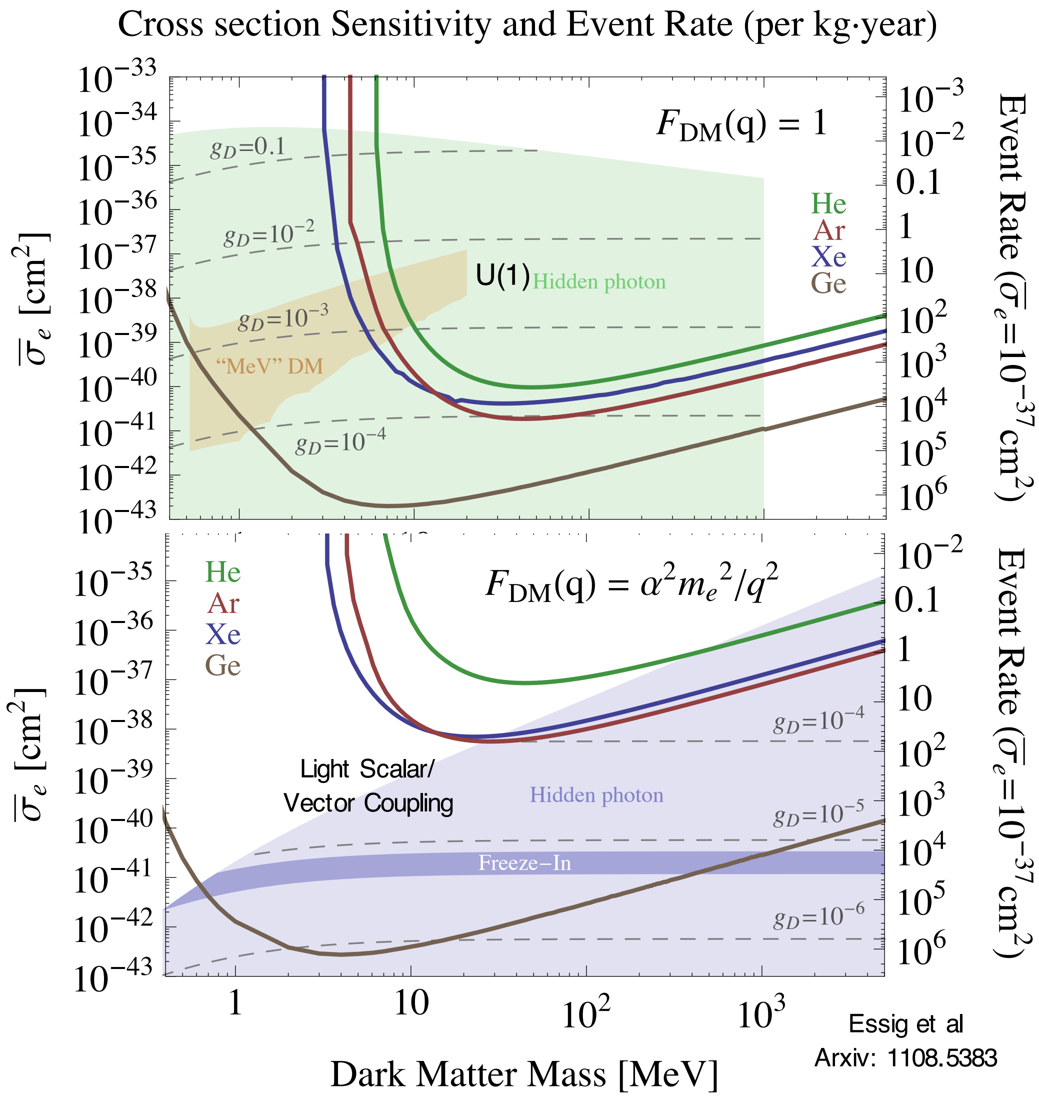
Single excitation sensitivity should be possible, greatly improving sensitivity to sub-GeV dark matter! (arXiv:1108.5383)

Sensitivity to sub-GeV Dark Matter

- Nuclear recoils wouldn't have enough energy
- May detect

$$DM + e^- \rightarrow DM + e^-$$

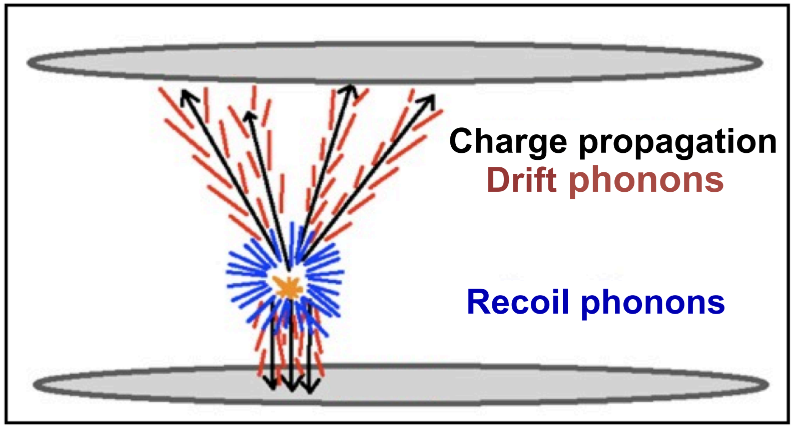
- Ideally requires single e^-/h^+ pair sensitivity
- Ge & Si much more sensitive than Ar, Xe, & He because of small bandgap
- Essig et al
  - arXiv: 1108.5383



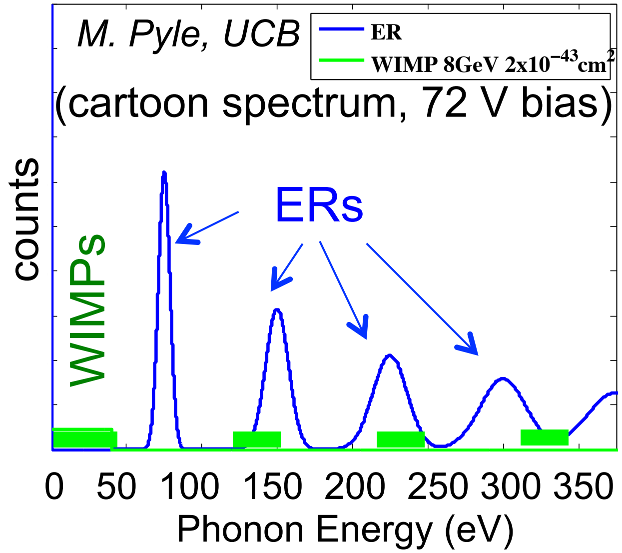
Essig et al
Arxiv: 1108.5383

Lowering Thresholds with Phonon Amplification

- Drifting charges produce "Luke" phonons proportional to the voltage bias
- Noise approximately independent of bias
- Preliminary tests demonstrated ~100 eVee thresholds
  - Expect to do better with PPCs
    - Mirabolfathi et al. in progress
- Ionization measurement only, so usually no electron/nuclear recoil discrimination
  - However, at lowest energies can look between e/h peaks
  - Or subtract ERs statistically by running at multiple biases (arXiv: 1201.3685)



*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)*



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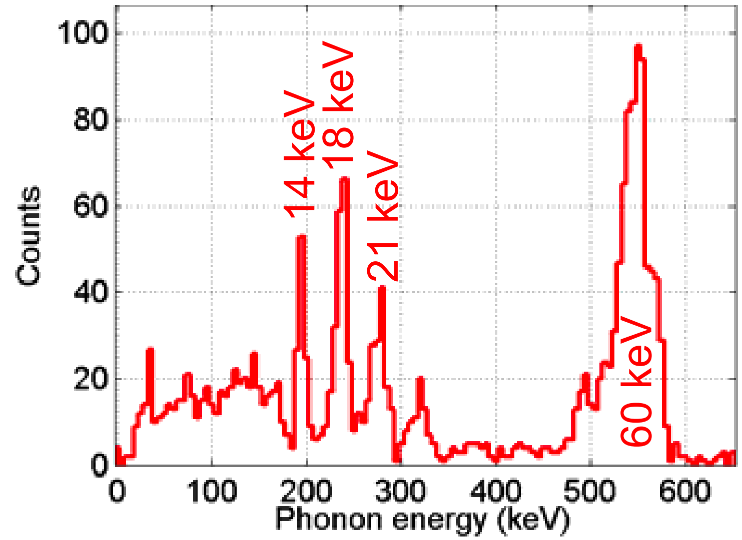
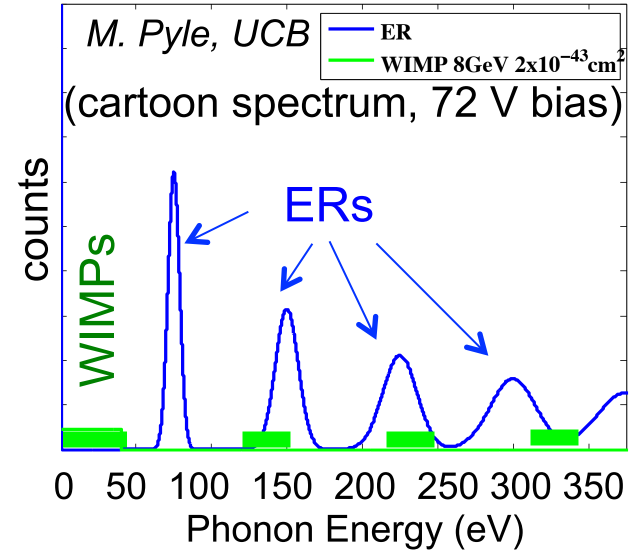


*Akeriib et al., NIM A, **520**, 163 (2004)*



Conclusions

- Both SuperCDMS and EDELWEISS Ge detectors provide robust, low-risk means to maximum sensitivity at ton mass.
- Solid-state technologies have fundamentally better energy resolution and threshold (more quanta per energy) than other techniques.
- Many low-noise readout technologies promise to lower energy thresholds to revolutionize sensitivity to low-mass WIMPs.
  - DAMIC as low as 4 eVee Si but with very low mass,
  - PPCs as low as 100 eVee Ge and likely very low backgrounds
  - Phonon detectors potentially ~10 eV using voltage amplification, or sub-eV via reducing T_c's of athermal phonon sensors