Cryogenic Dark Matter Search (CDMS): Recent Results and Perspective

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Rencontres de Moriond EW, March 2012

- Quick review of WIMP detection principle
- Results
- Low energy territory
- Modulation?
- CDMS new detector design
- Perspective

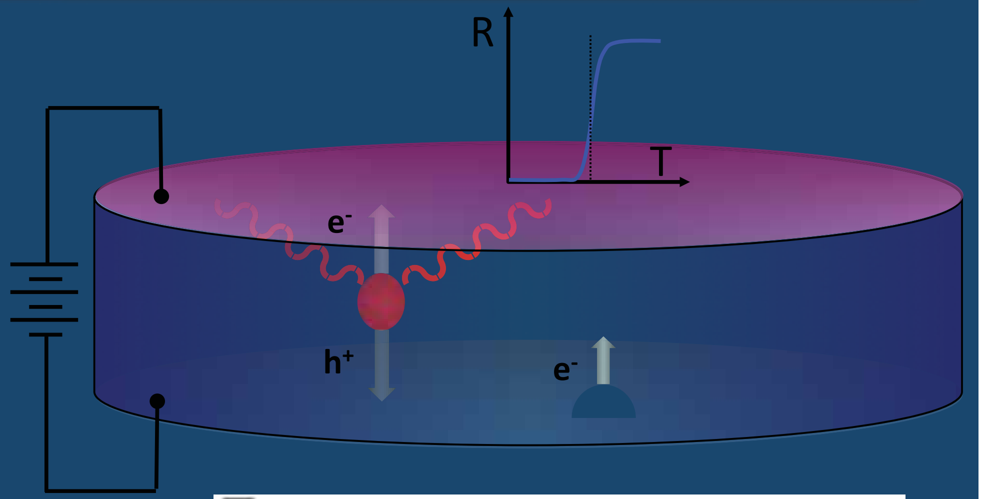
WIMP Direct detection challenges:

Backgrounds, Backgrounds and again Backgrounds

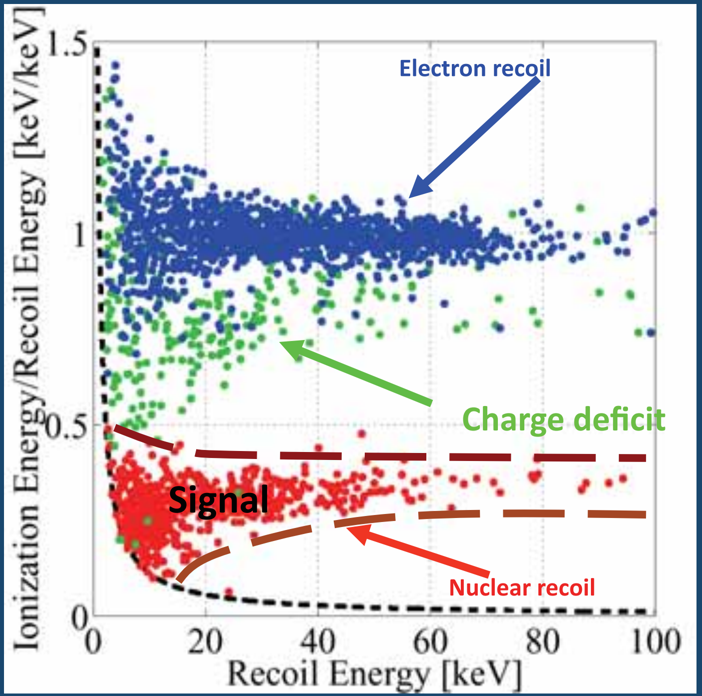
- Low recoil Energies and very low interaction rates:
  - ❑ ~ 10 keV
  - ❑ Current Exp Limit < 1 evt/100 kg/day, ~< 10^{-1} evt/kg/day
  - ❑ Goal < 1 evt/tonne/year, ~< 10^{-5} evt/kg/day
- Activity of typical Human
  - ❑ ~10 kBq (10^4 decays per second, 10^9 decays per day)
- Environmental Gamma Activity in unshielded detector
  - ❑ 10^7 evt/kg/day (all values integrated 0–100 keV).
  - ❑ This can be reduced to ~10^2 evt/kg/day using 25 cm of Pb.
  - ❑ Still very high rate compared to the expected signal.

An event-by-event discrimination based on Nuclear versus Electron recoil is therefore inevitable!

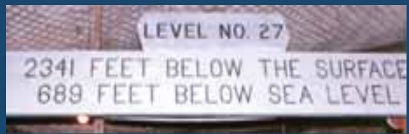
CDMS Principle

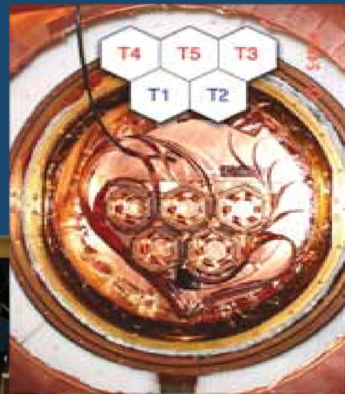


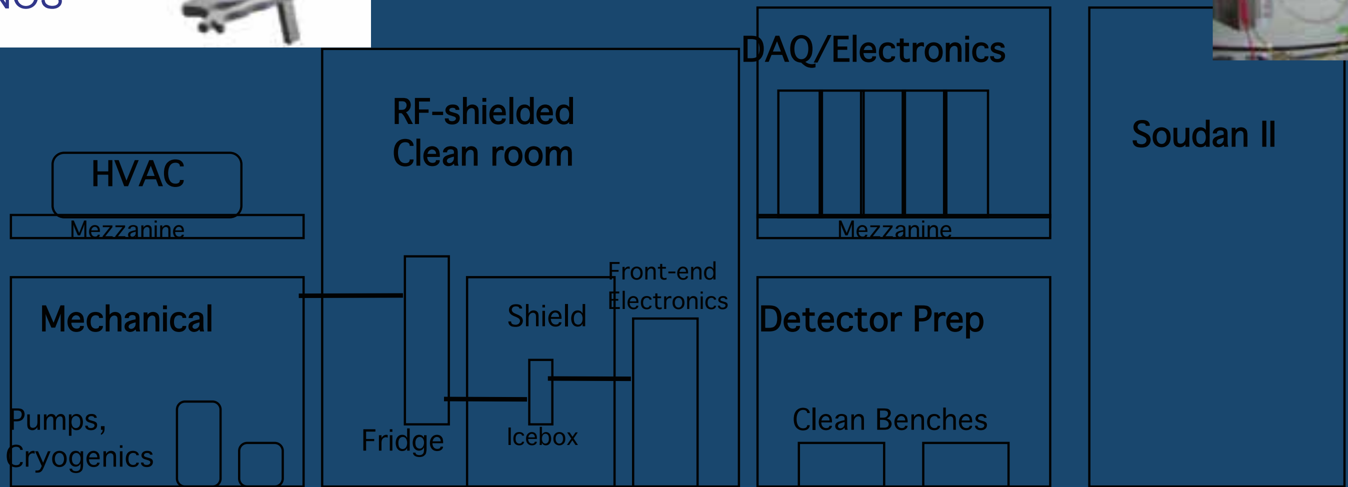
- Large Ge or Si crystals (~kg):
  cooled to: T < 0 .04 K
- Measure recoil energy via Lattice vibrations **(phonons)** in Ge or Si
- Measure the Ionization. E- field: ~3V/cm
- Ionizing power or Ionization Yield
  - **$Y_{electron\text{-}recoil} > Y_{nuclear\text{-}recoil}$**
  - Event-by-event discrimination
- Near surface events
  - Electron recoil but poor charge collection
  - Near geometrical boundaries
- CDMS has a solution:
  - Measure phonons before they reach equilibrium
  - Reconstruct the position of the events
  - Identify near surface events



CDMSII at Soudan







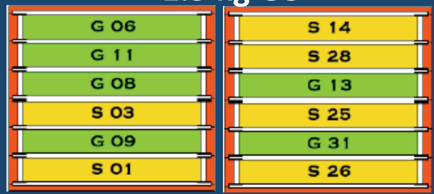
CDMS progress

1 kg Ge

52.6 kg.days
10/2003 to 01/2004

Phys. Rev. Lett. **93, 211301 (2004)**

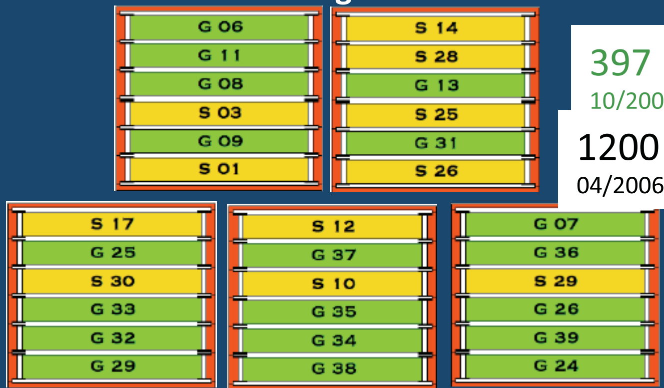
1.5 kg Ge



93.1 kg.days
03/2003 to 08/2004

Phys. Rev. Lett. **96, 011302 (2006)**

4.5 kg Ge

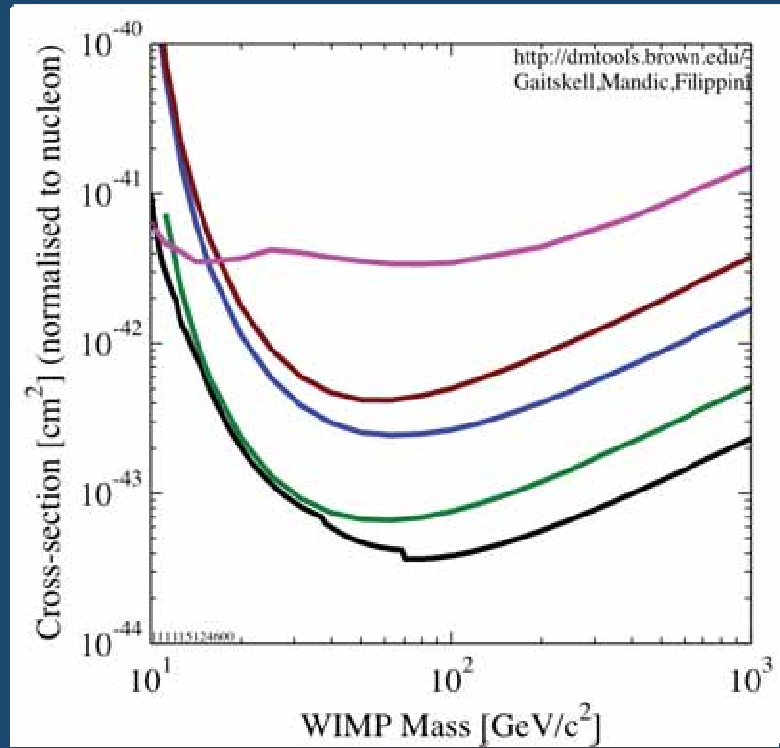


397 kg.days
10/2006 to 03/2007

1200 kg.days
04/2006 to 10/2008

Science **327, p. 1619, arXiv:0912.3592**

Phys. Rev. Lett. **102, 011301 (2009)**

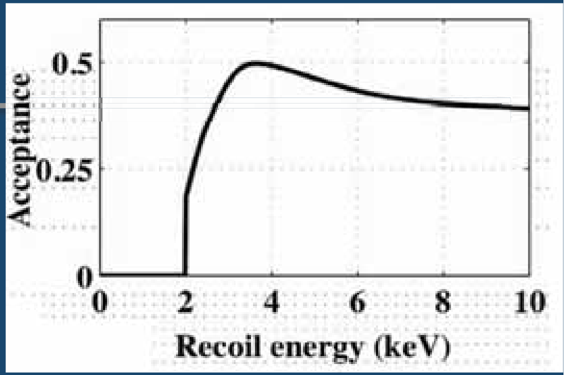


CDMS remains background free:
So far independent of the exposure!
But ZIPs seem to have reached their rejection limit and can't offer better sensitivities.

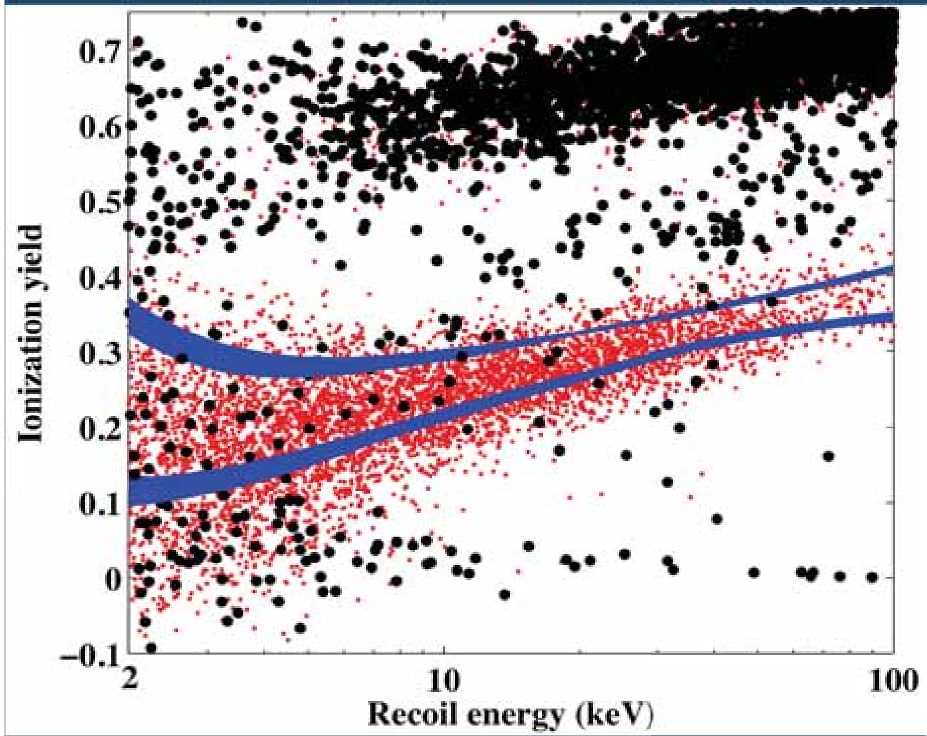
Low Threshold Analysis

Nuclear Recoil Selection

- Nuclear recoil acceptance region defined as (+1.25,-0.5)σ band in ionization energy
  - Maximizes sensitivity to nuclear recoils while minimizing expected backgrounds



Ionization Yield vs. Recoil Energy



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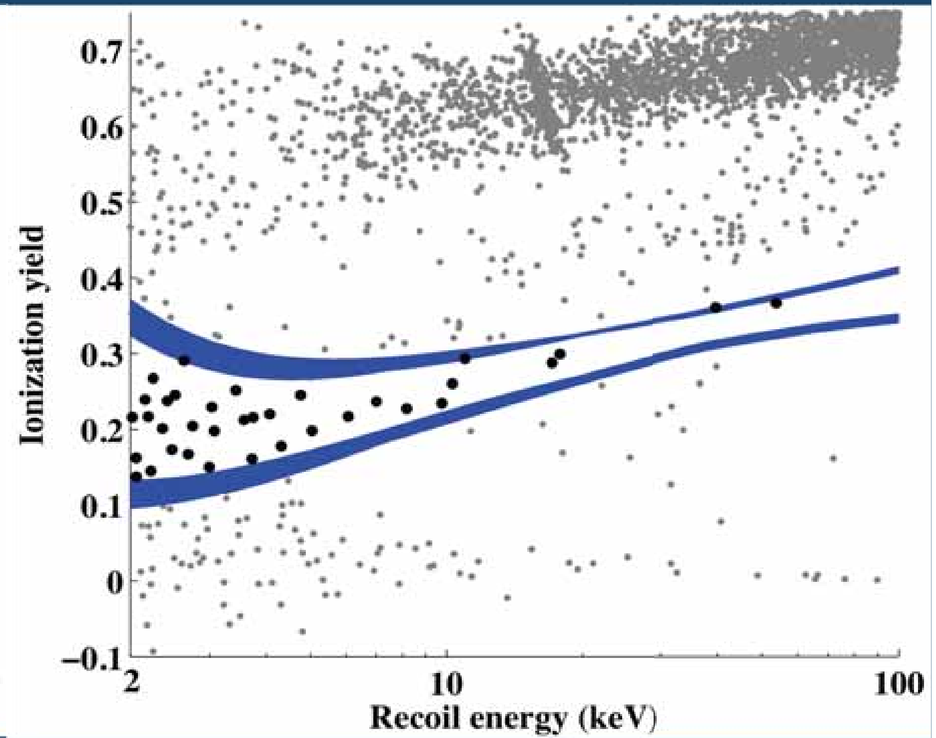


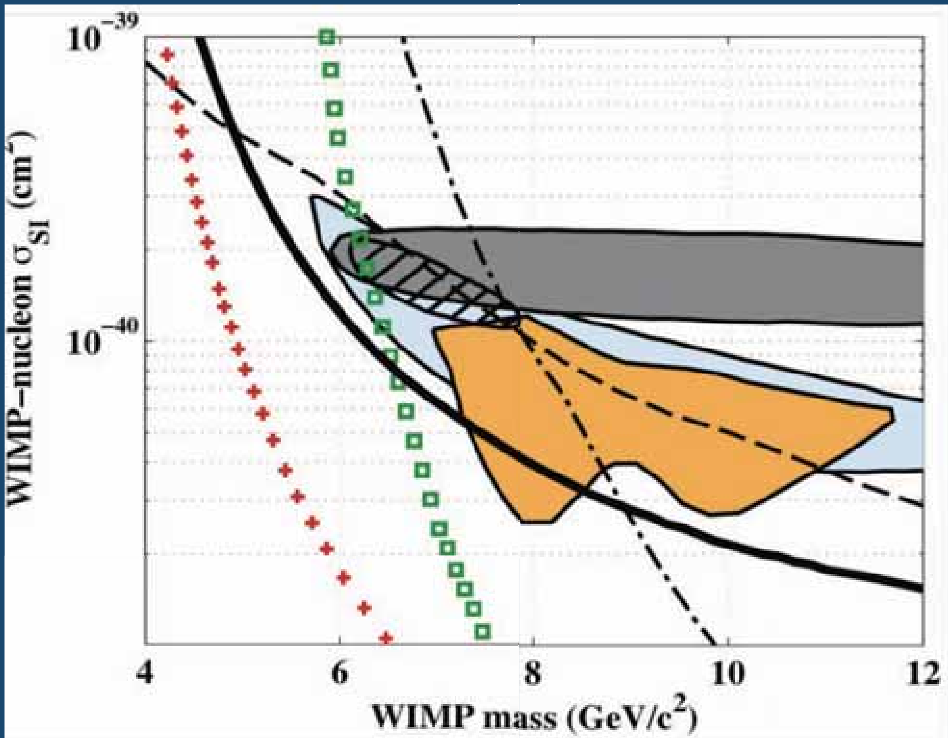
Comparison of WIMP search and neutron calibration data:

Limits

- Conservatively assume all candidates to be candidate events
  - No background subtraction!
- Limits set using optimum interval method:

  S. Yellin, PRD, 66, 032005 (2002); arXiv:0709.2701v1 (2007)
- Energy intervals ordered by detector
- For spin-independent, elastic scattering, 90% CL limits incompatible with DAMA/LIBRA and CoGeNT

90% CL upper limits on elastic scattering cross section



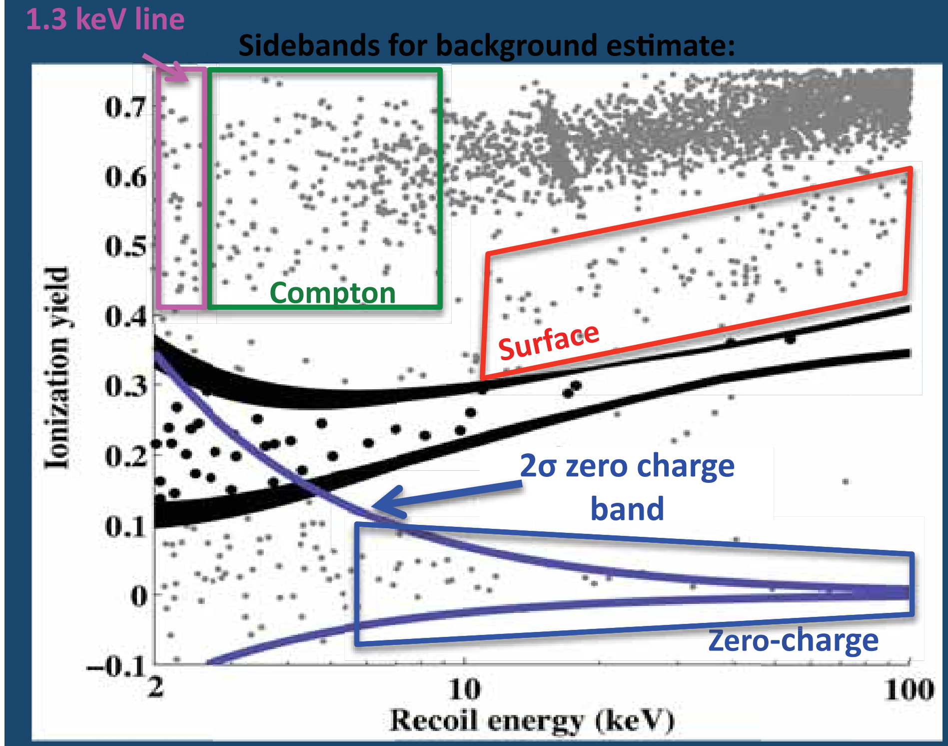
Ahmed et al., PRL 106, 131302 (2011)

Akerib et al., PRD 82, 122004 (2010), *arXiv:1010.4290*

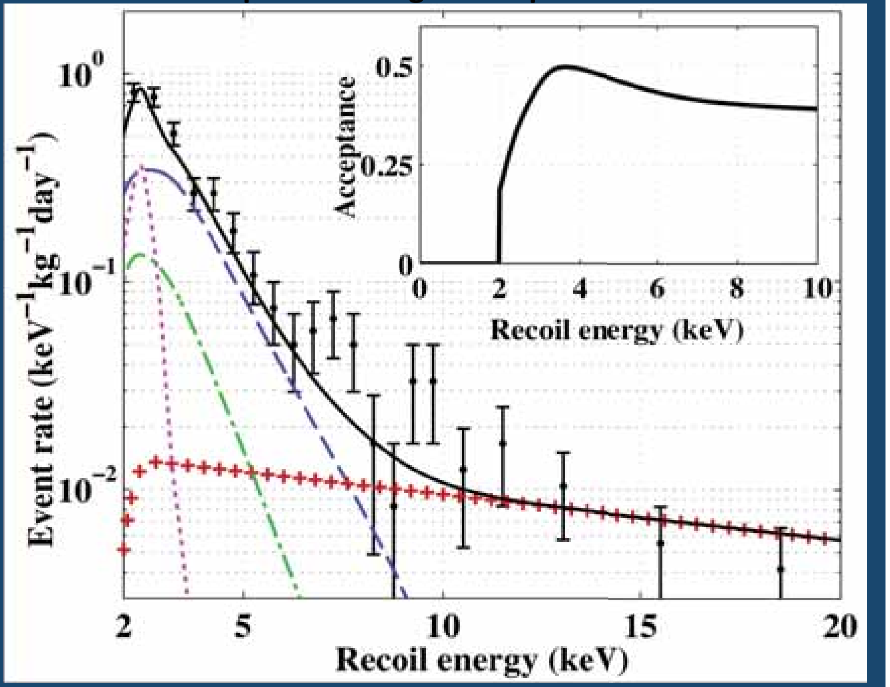
Electron Recoil Backgrounds

- 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:



Any hint of an Annual Modulation?

A Note On The Energy Scales

- CoGeNT or any single measurement detector is unable to determine the interaction type: Electron Recoil (ER) versus Nuclear Recoil (NR).
- But the ionization yield for an ER is different than an NR in Ge e.g. x3 at E~10 keV and x5 at E~keV i.e. For CoGeNT, NR and ER with the same recoil energy appear at two different energies.
- CDMS can reconstruct the recoil energy independent of the interaction type.
- When studying CoGeNT energy intervals, it is important to make an assumption of what type of recoil: ER or NR.
- $\textbf{keV}_{\textbf{ee}}$ is the scale which is used when all interactions are assumed to be of the type ER.

Search for Annual Modulation

- CDMS II data nearly two annual cycles, from Oct. 2006 to Sept. 2008

- Nuclear recoil acceptance region defined as ±2σ band in ionization energy to increase sensitivity

- We consider 3 energy intervals between 5 and 11.9 keV_{nr}:
  [5,7.3], [7.3,9.6], and [9.6,11.9] keV_{nr} equivalent to CoGent [1.2,1.8], [1.8,2.5], and [2.5,3.2] keV_{ee}
  - 5 keV_{nr} threshold high enough to have a nearly 100% trigger efficiency
  - 11.9 keV_{nr} maximum energy to match the highest energy of CoGeNT

- In the lowest energy bin, [5, 7.3] keV_{nr}, the nuclear-recoil rate measured for CDMS is:

  0.29 $[keV_{nr}\ kg\ day]^{-1}$

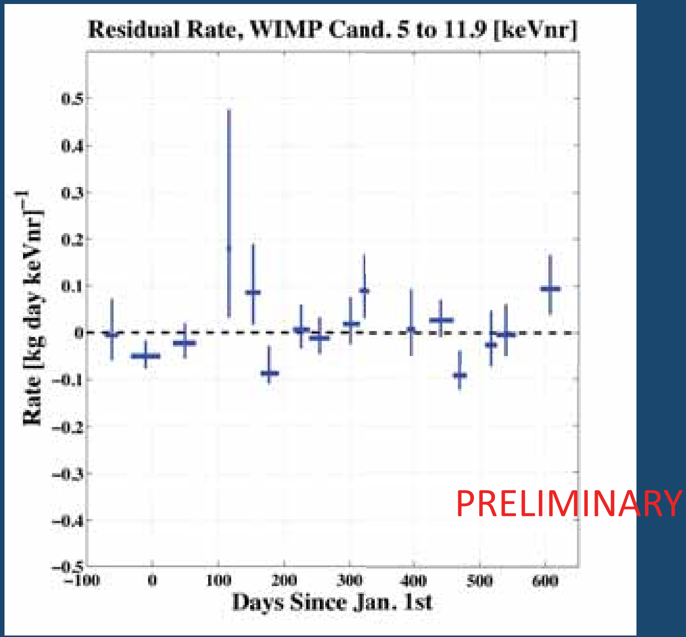
- Maximum likelihood estimate for the CoGeNT modulation amplitude

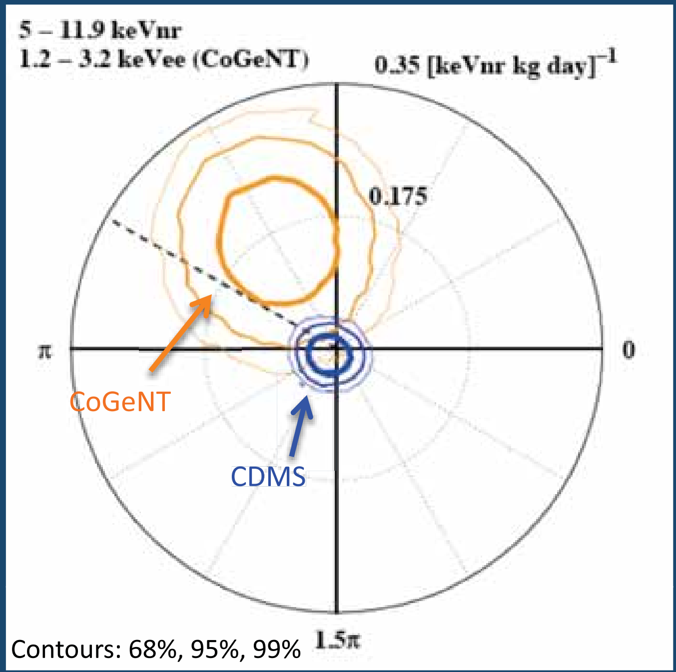
  is 0.35±0.015 $[keV_{nr}\ kg\ day]^{-1}$

→ Would require modulation fraction in CDMS of nearly 100%
(same for full energy range)

Results: Nuclear Recoil Singles

- No significant evidence for annual modulation
- In the energy range [5, 11.9] keV_{nr}, all modulated rate with amplitudes greater than 0.07 $[keV_{nr}\ kg\ day]^{-1}$ are ruled out with a 99% confidence.
  - Annual modulation signal of CDMS and CoGeNT are incompatible at >95% C.L. (preliminary) for the full energy range (if CoGeNT signal originates in a nuclear-recoil population)





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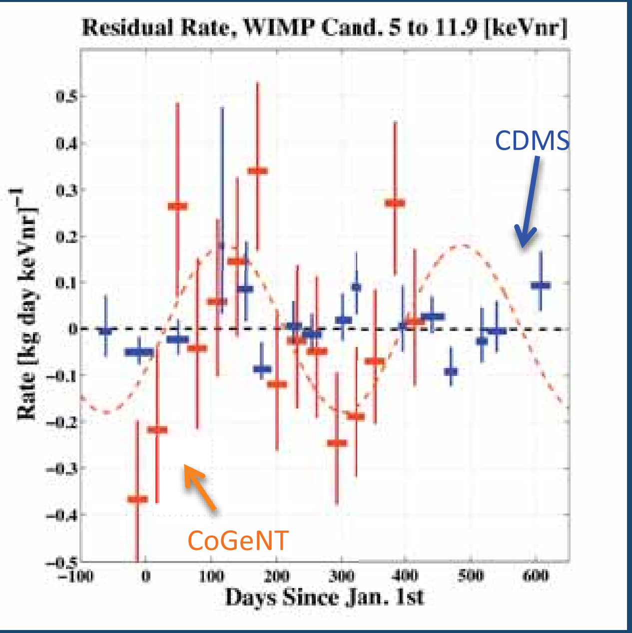
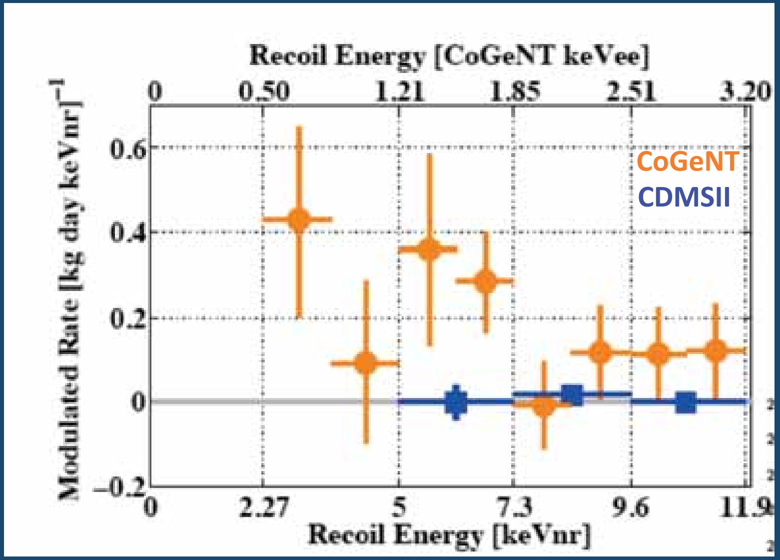


Amplitude of Modulation versus E:

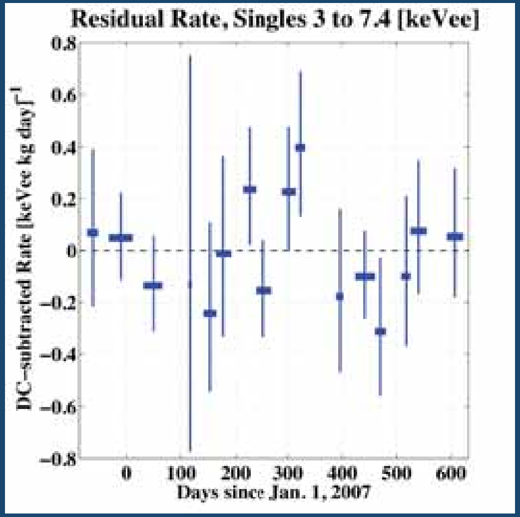
68 % confidence intervals, Phase=108 days



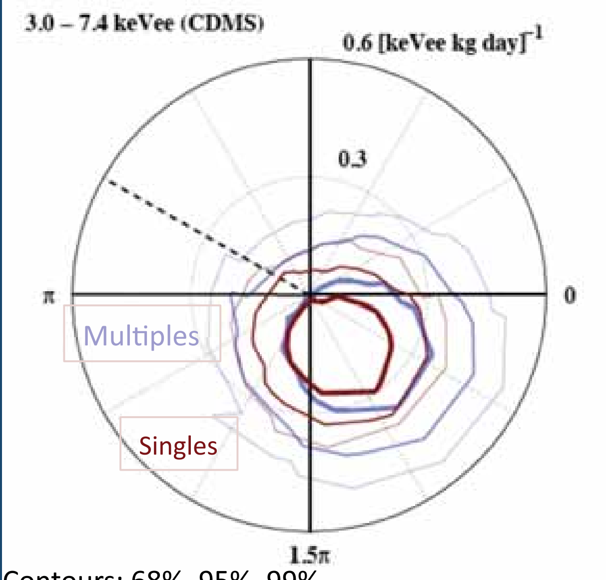
Results: Electron-recoil-dominated Singles/Multiples

- Data sample with no ionization-yield cut
- No significant evidence for annual modulation for both singles and multiples
- Little overlap with the energy range of CoGeNT under the hypothesis of an ER modulation. (3.2 keVee max for CoGeNT)

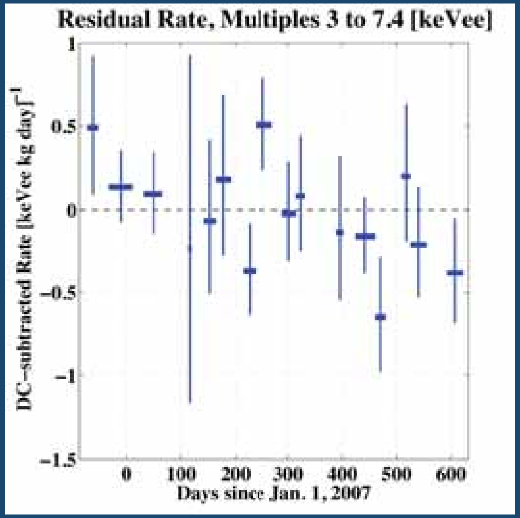
➔ This result cannot exclude the possibility that the modulation observed by CoGeNT is due to electron-recoils.



Singles



Contours: 68%, 95%, 99%

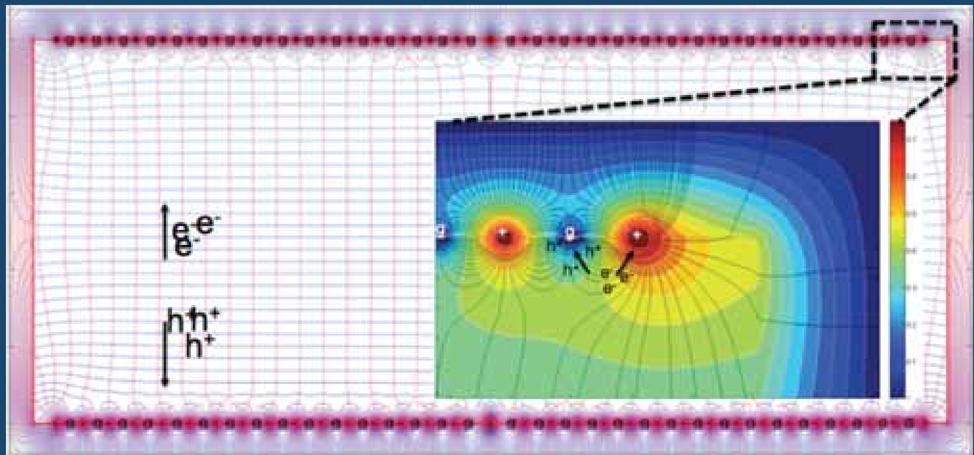


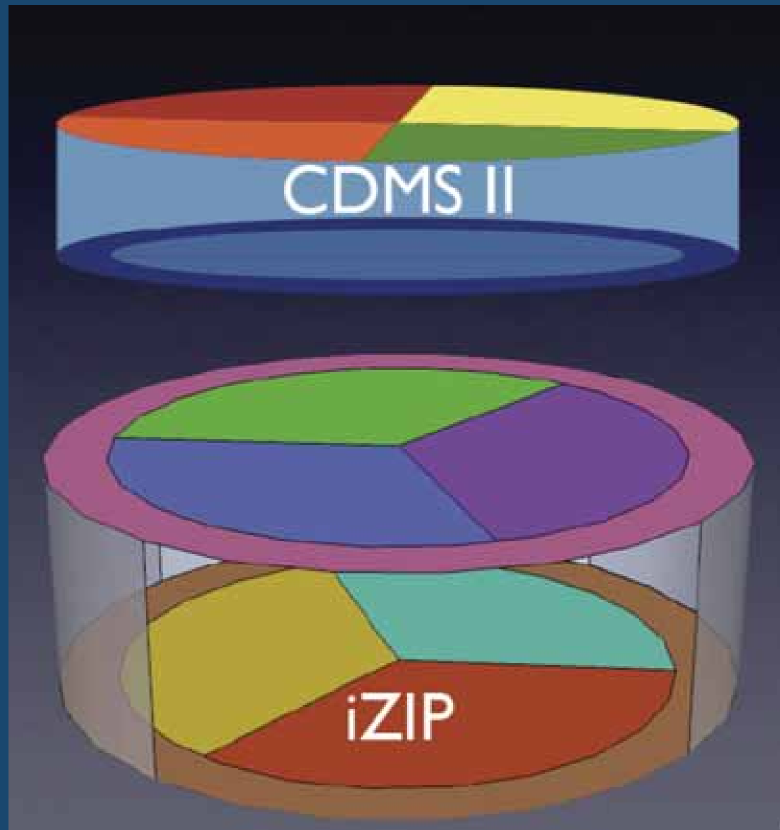
Multiples

CDMS current Status and Future Plans

CDMS New detector design: SuperCDMS Soudan

- New iZIP design:
  - Interleaved ionization and phonon sensors
  - Phonon sensors on both faces
  - Larger detector: 2.5 x CDMS II ZIPs
- Almost entirely remove near surface event background
  - 1:300,000 from ionization alone
- SuperCDMS currently running with 15 iZIPs:
  - Expect to reach 5-8 x 10^{-45} cm^2





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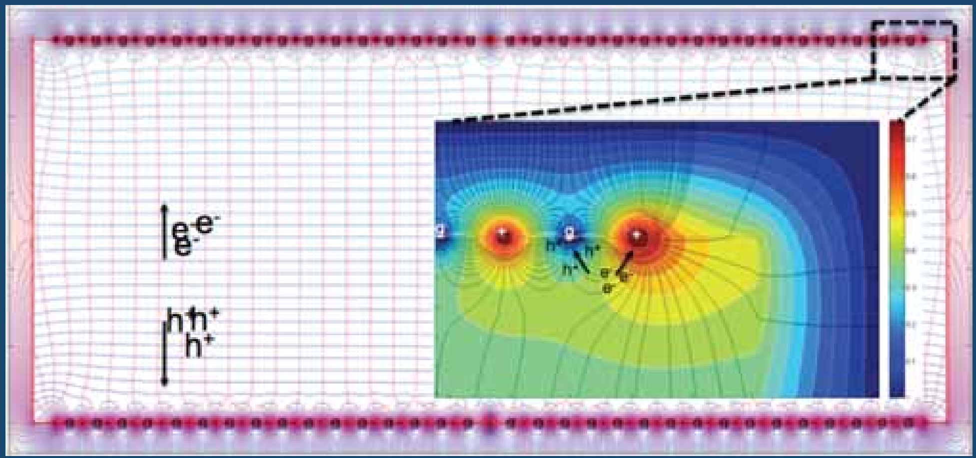
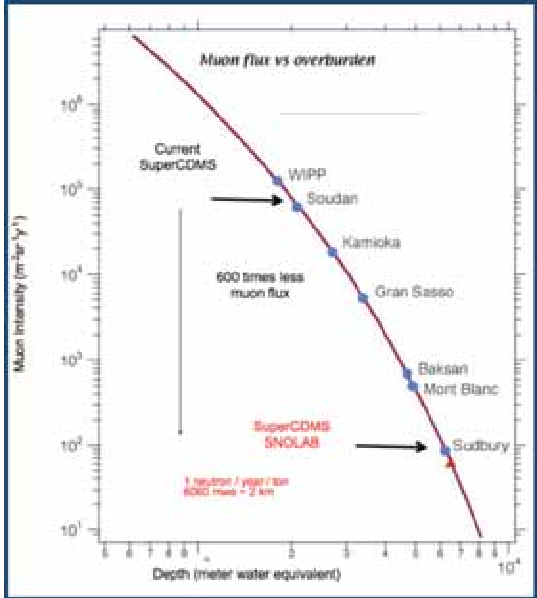
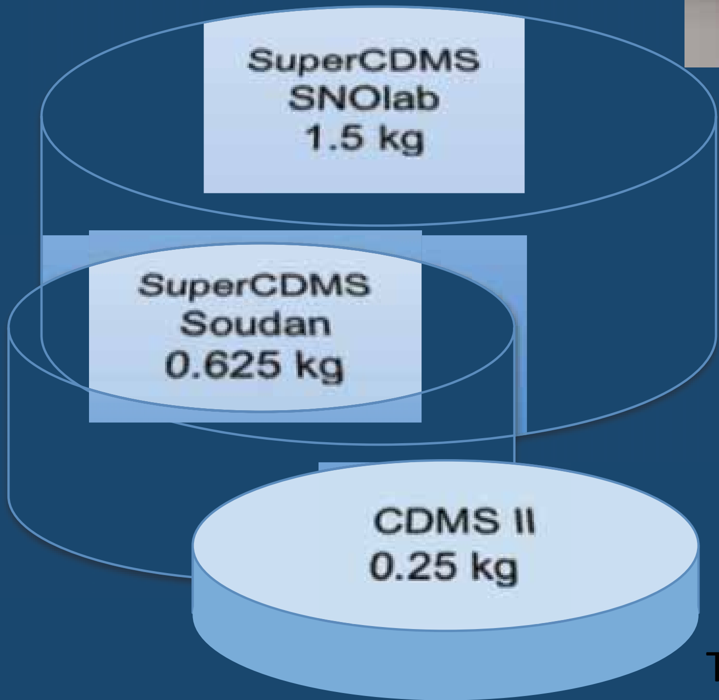


From CDMSII to SNOlab and Beyond



- Move to deeper site: SNOlab, Sudbury
- SuperCDMS SNOlab in R&D phase:
  - Acquired large crystals and testing.
  - Better background rejection.
  - Faster production throughput.
  - Increased resolution for low threshold
- GEODM:
  - After SuprCDMS SNOlab
  - 1.5 Ton of 5kg Ge detectors

R&D for 100 kg:
$3x10^{-46}$ cm^2



Total 9 kg projected:
~$5x10^{-45}$ cm^2

Total 4.5 kg could reach:
$3.8x10^{-44}$ cm^2

Conclusion

• CDMS technology based on simultaneous measurement of ionization and phonons in Ge detectors has already proven to be very promising for a background free experiment.

• CDMS major background i.e. near surface events, seems to be totally under control with the new detector design: iZIP.

• CDMS is currently running with 9 kg of Ge iZIP detectors and should reach sensitivity better than 8 x 10^{-45} cm^2.

• The results from the low threshold analysis of CDMSII not compatible with 7 GeV/c^2 WIMPs.

• CDMSII data doesn't show significant evidence for annual modulation for nuclear recoils between 5-11.9 keV_{nr}
  • Annual modulation signal of CDMS and CoGeNT are incompatible at >95% C.L. for the full energy range

• No significant evidence for annual modulation for electron-recoil dominated sample in the same energy range (corresponding to 3 – 7.4 keV_{ee}), however little overlap with the energy range of CoGeNT.

• SuperCDMS SNOlab is in the R&D phase to reach 3x10^{-46} cm^2 sensitivity.

CDMS/SuperCDMS Collaborations

DOE

NSF

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Massachusetts Institute of Technology
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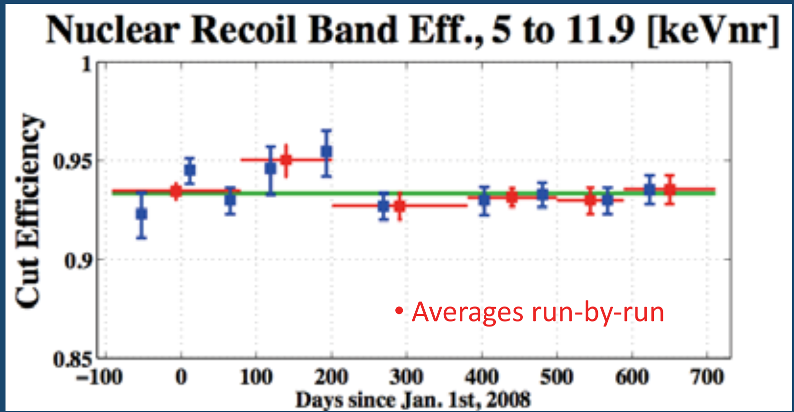
University of Minnesota
H. Chagani*, J. Beaty, P. Cushman, S. Fallows, M. Fritts, T Hofer*, O. Kamaev, V. Mandic, X. Qiu, R. Radpour*, A. Villano*, J. Zhang

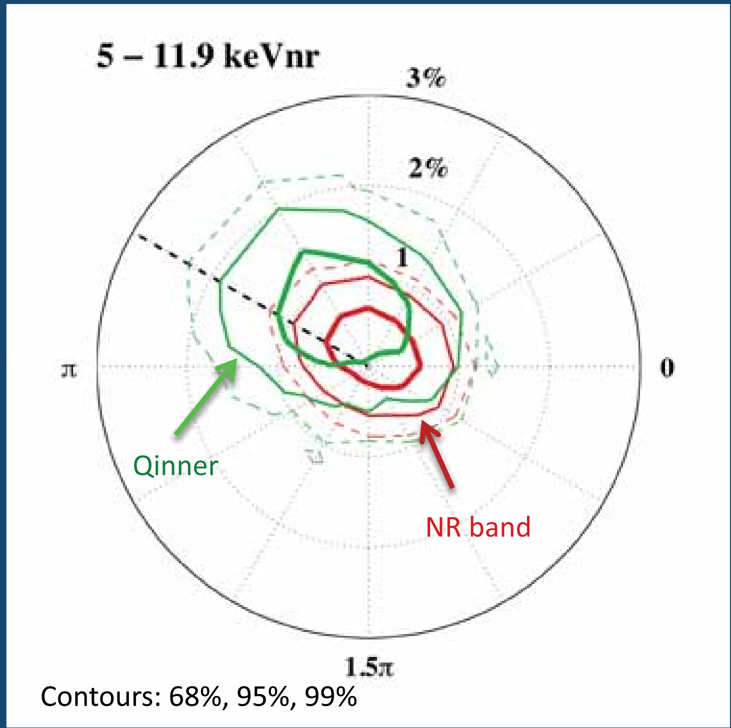
* new collaborators or new institutions in SuperCDMS

Stability Cut Efficiencies

- Test stability nuclear-recoil band and charge fiducial ("Qinner") cut efficiencies using calibration data

- Using Feldman-Cousins method, determine confidence limits on the amplitude and phase of annual modulation





- Nuclear-recoil cut: efficiency modulation upper limit of 1.2% at 90% confidence level

- Qinner cut: efficiency modulation upper limit 2.3 % at 90% confidence level

➢ Consistent with no modulation (similar constraints for all energy bins)