The SuperCDMS Dark Matter Experiment

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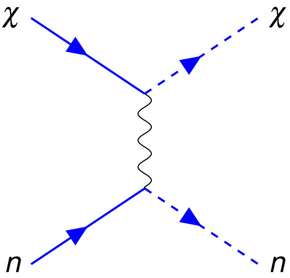
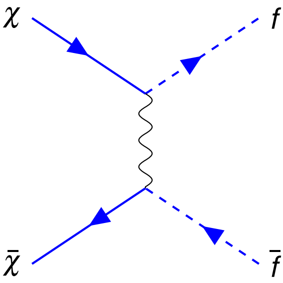
Dark Matter Search

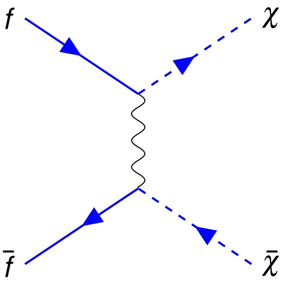
Direct Detection

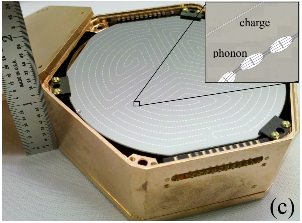


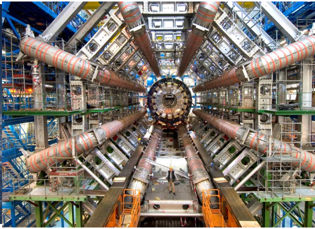
Indirect Detection



Prod. @ Collider







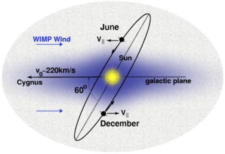
Direct Detection Search Strategies

Counting

- After eliminating convential sources of backgrounds anything left over must be Wimps
- Current limits show $<$1keV/kg/year.

Annual Modulation

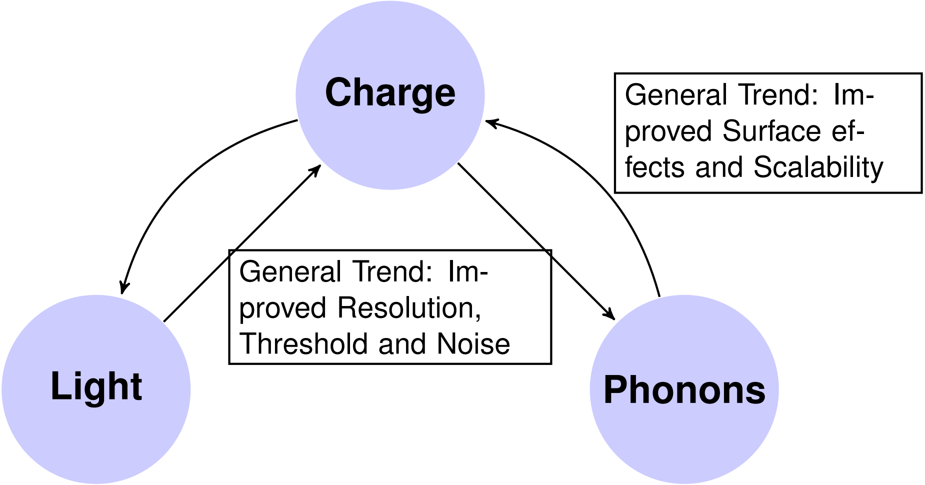
- WIMP detection rate varies slightly due to Earth's motion through halo.
- This technique requires precise control over the experiment's condition throughout the year.



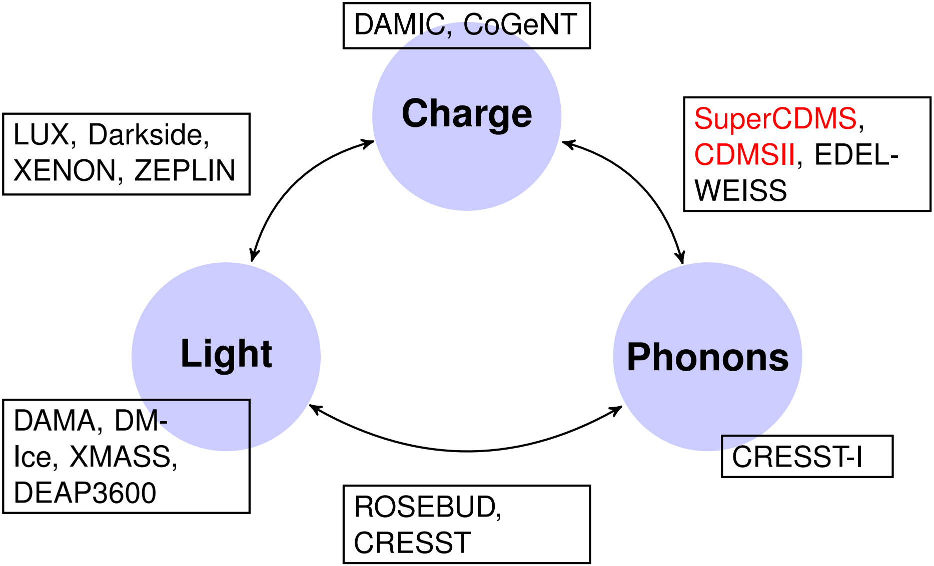
Diurnal Modulation

- The WIMP rate varies due to Earths rotation.
- This requires directional detectors to interpret a signal as a WIMP signal.

Direct Detection of Dark Matter – Principals of detection



Direct Detection of Dark Matter – The Experiments



Common issues to Direct detection Experiments

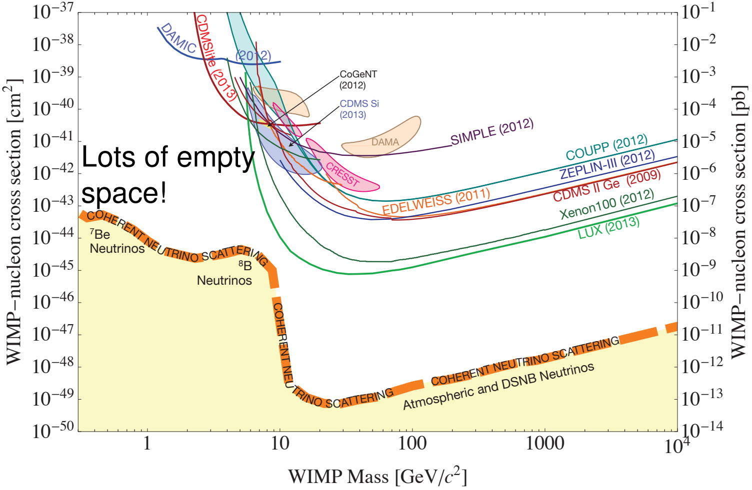
Minimizing Backgrounds is the name of the game

- Sensitivity without backgrounds: $\propto (t)$
  Sensitivity with backgrounds: $\propto (t)^{\frac{1}{2}}$

Background Sources:
Decay Chains from, Th, Co, U, Kr etc. in the surrounding material as well as neutrons induced by cosmic rays.

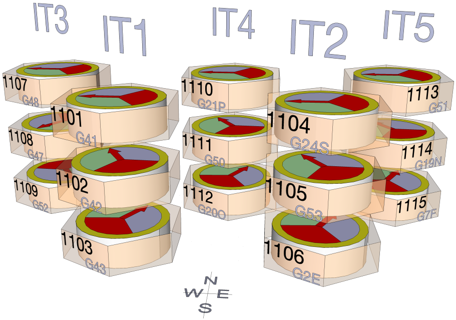
- γ and β events are electron recoils and can be separated
- α events tend to not be a big issue for most experiments
- Neutrons from fission decays in the surrounding materials and neutrons induced by cosmic rays are difficult to separate from WIMPs and great care must be taken to go deep underground as well as use clean materials

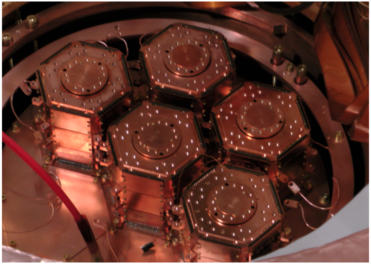
Current Landscape – Motivation for low-mass WIMPs



SuperCDMS – Overview

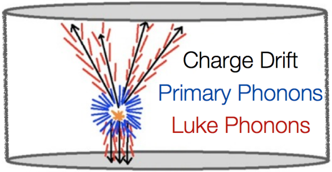
- Upgrade to CDMS II
- 15 Ge Cryogenic Solid State Detectors operated at 50–60 mK
- Continuous operation from March 2012 to July 2014
- 9 kg of total target mass





Cryogenic Solid State Detectors

- The Technique: Collect heat (phonons) in addition to ionization or light from solid state detectors held at cryogenic temperatures ($<\sim$60mK).
- Strength of this technique:
  - Proven excellent background discrimination
  - Purity of detector materials
  - Low thresholds and very good energy resolution
- Weakness of this technique:
  - Difficult to scale to large detector masses.
  - Surface effects can mimic a WIMP signal

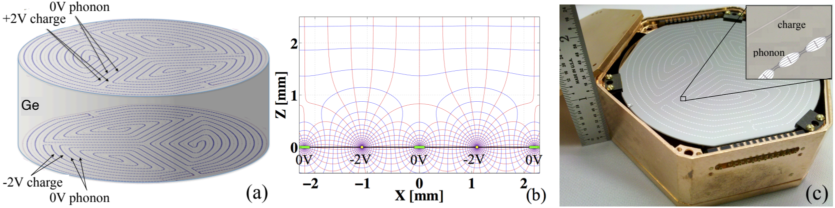


God made the bulk; surfaces were invented by the devil. – Wolfgang Pauli

Current and planed experiments using this technique:

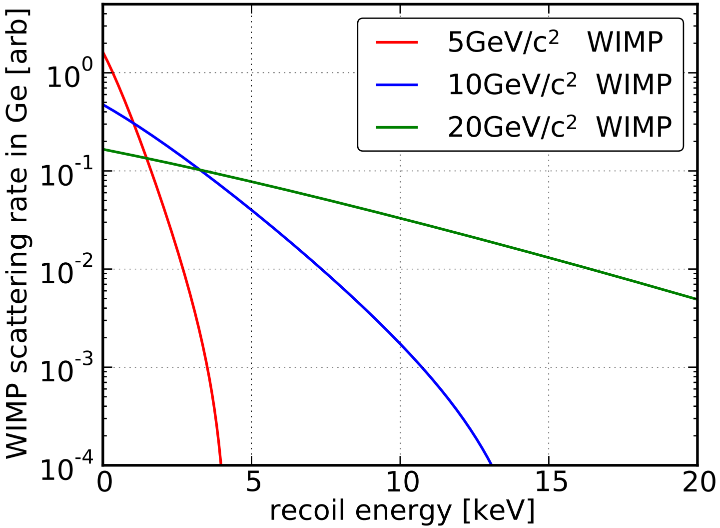
SuperCDMS Soudan/SNOLAB, EDELWEISS II/III, CRESST II/III, Eureca

SuperCDMS – The iZIP

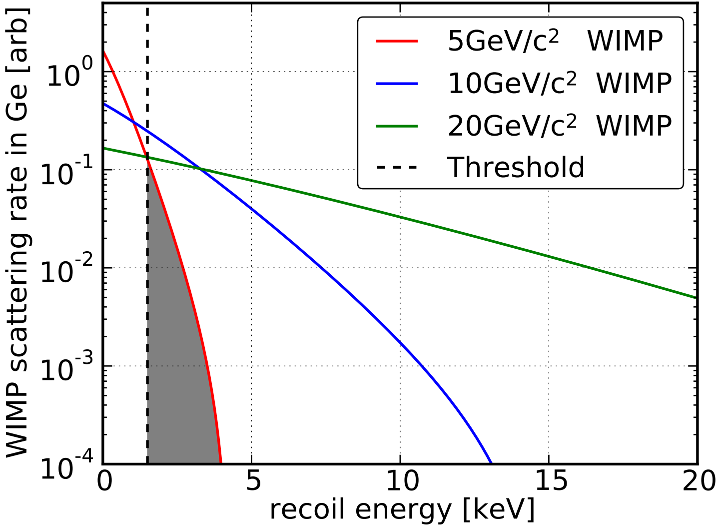


- Both phonon and charge sensors layouts are shown in panels (a) and (b).
- The crystals are biased at $+2\mathrm{V}$ and $-2\mathrm{V}$, which produces a large electric field in the bulk as well as near the surfaces, to pull electrons and holes to opposite crystal faces.
- The electrode configuration for the SuperCDMS iZIP was optimized to produce E-field (b) that help eliminate surface events.

Low Mass WIMPs with SuperCDMS

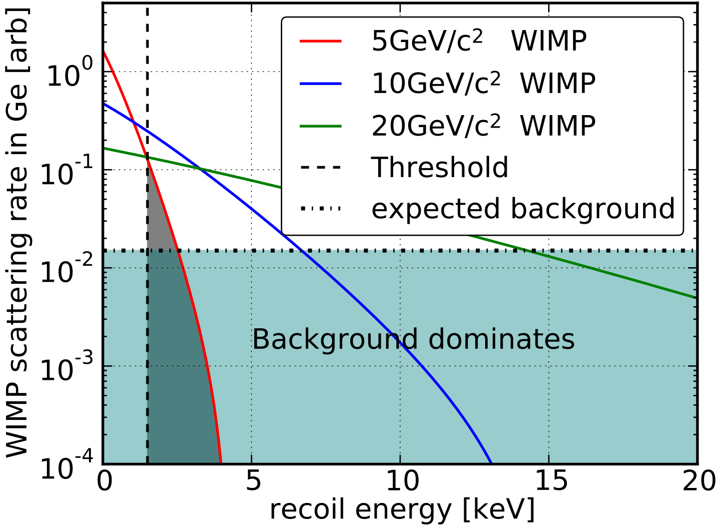


Low Mass WIMPs with SuperCDMS



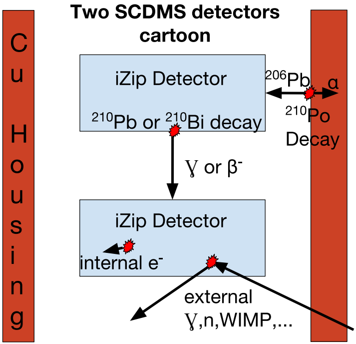
Lowering the thresholds is the name of the game!

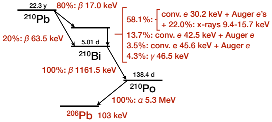
Low Mass WIMPs with SuperCDMS



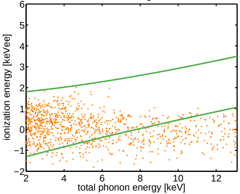
Lowering the thresholds and the background is the name of the game!

SuperCDMS low-threshold backgrounds

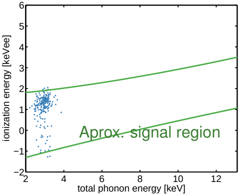




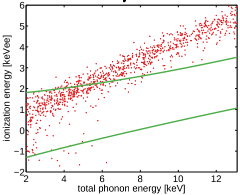
^{210}Pb decay chain



Internal Activation



External γ

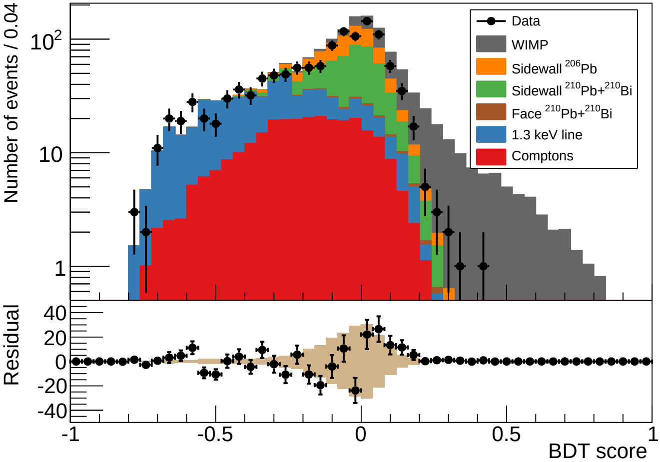


SuperCDMS low-threshold analysis strategy

SuperCDMS low-threshold analysis strategy

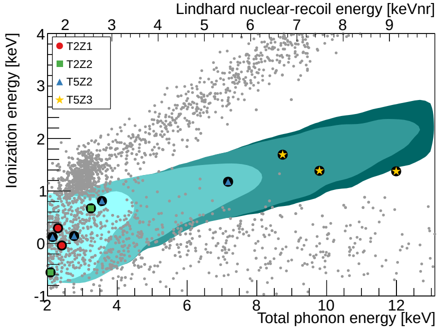
- Choose only the 7 detectors with the lowest thresholds ($\sim$ 1.3–5 keV thresholds)
- Model the backgrounds using a GEANT4 simulation of the dominant background (^{210}Pb decay chain events)
- Use machine learning to get discrimination between signal and background
- Do a blind analysis optimized for exclusion

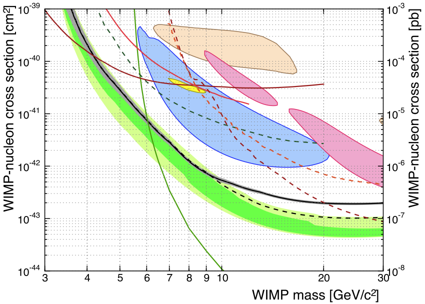
SuperCDMS low-threshold background model



Data as compared to our background model as a function of the machine learning parameter. A 10 GeV/c^2 WIMP signature is also shown in gray.

SuperCDMS low-threshold result

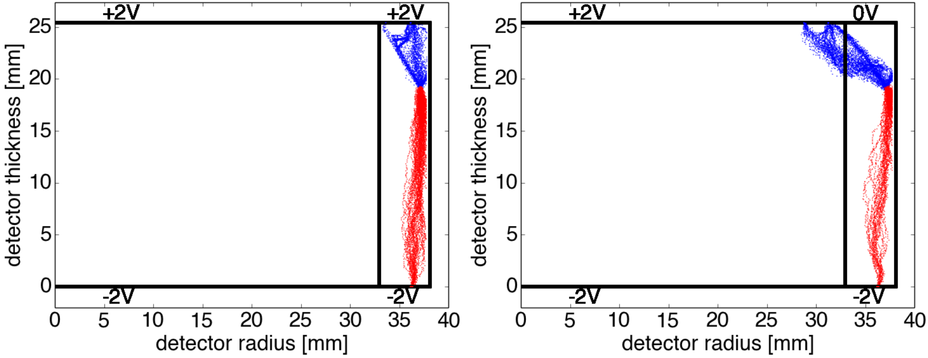




The figure on the left shows the final events, as well as the region a WIMP signal would be expected. The figure on the right shows the final limit of this analysis.

arXiv:1402.7137

SuperCDMS low-threshold result – The 3 T5Z3 events

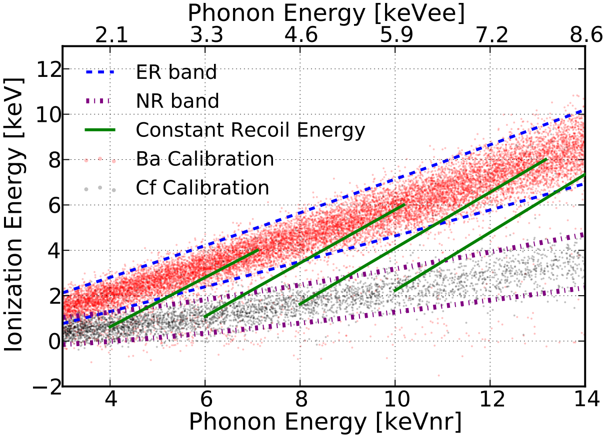


The figure on the left shows a charge simulation for a fully functioning detector (e^-: blue, h^+: red). T5Z3 has a short on the outer charge channel. Using COMSOL to produce an accurate E-field shows that the same simulated event produces a much different result.

Likelihood Analysis of CDMS II data

- The SuperCDMS-LT analysis did not employ a Likelihood technique.
- In the presence of backgrounds Likelihood techniques promise better sensitivity and discover potential.
- CDMS II as a test bench for a Likelihood Analysis.

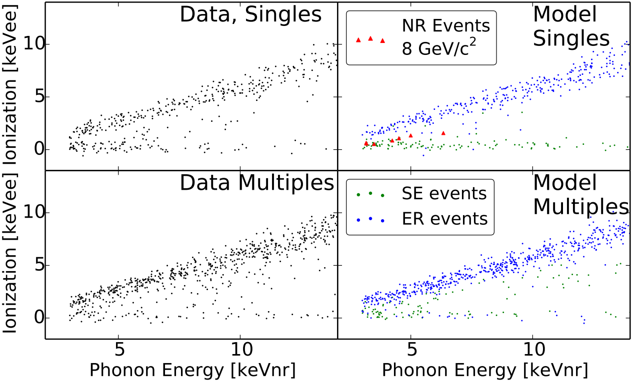
The Likelihood Analysis canvas



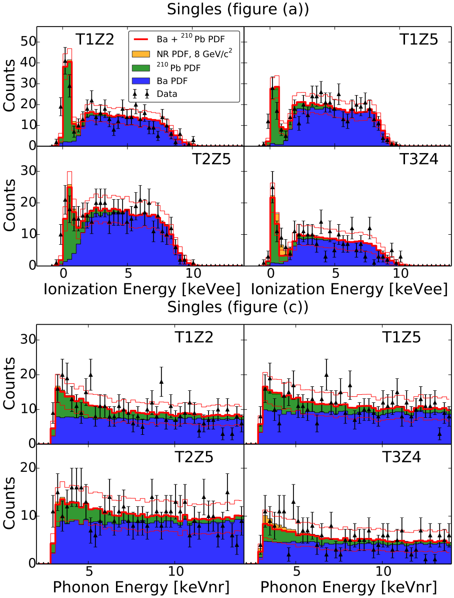
Likelihood Analysis of CDMS II data

- Surface Events (SE) come from a ^{210}Pb decay chain simulation, while Electron Recoil (ER) events are approximated by ^{133}Ba calibration data.
- This is done for both singles and multiples.

The Likelihood Analysis canvas

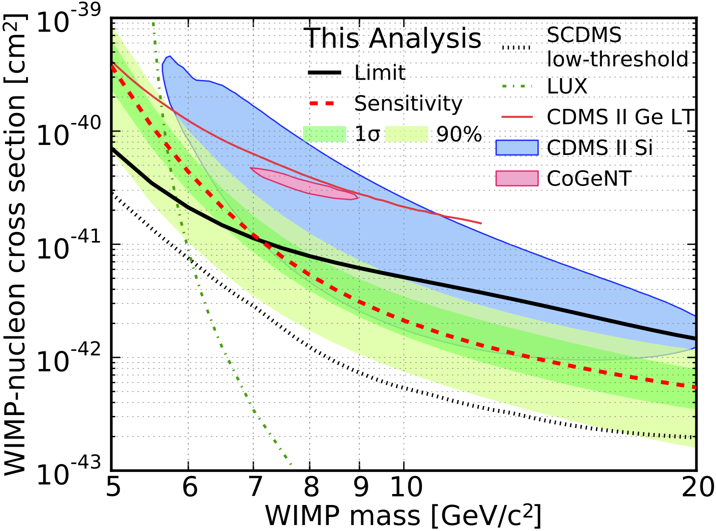


Likelihood Analysis of CDMS II data



Looking at both phonon energy and charge energy projections, we observe that in order to match data, both the SE simulation and the calibration data is needed. Fitting the data shows good agreement with the model!

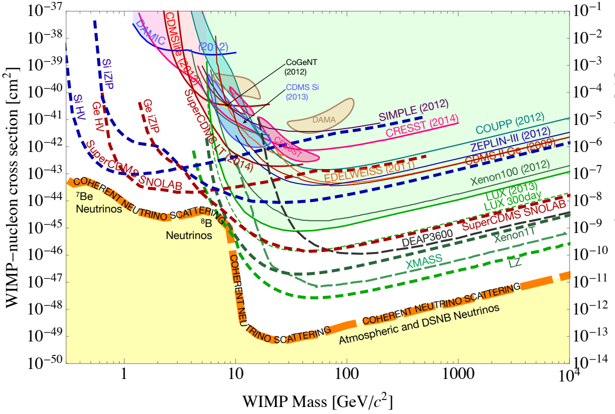
Likelihood Analysis of CDMS II data – Result



arXiv:1410.1003

SuperCDMS SNOLAB – the Future

- The SCDMS SNOLAB experiment is funded and moving forward.
- More Target mass, with a mix of Ge and Si detectors.
- Deeper mine (SNOLAB) to reduce cosmic ray induced neutrons.
- Better material screening to reduce intrinsic radioactivity by a factor of 200.
- Potential for an active neutron veto.
- Detectors with lower thresholds; achieved through optimized fabrication processes and improved electronics.



Theorist inputs for future experiments

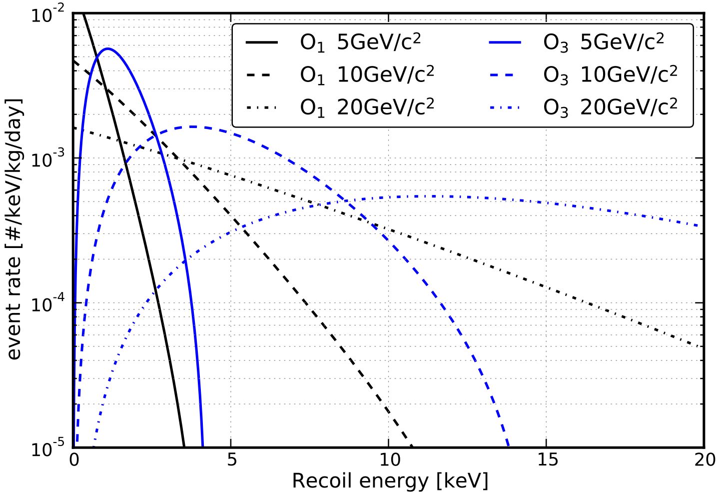
Traditional Counting experiment in Dark Matter Physics

- A signal 'box' is created, and cuts are optimized to remove background events from this signal box, and allow signal events to pass the cuts.
- Often the expected background in the 'signal box' is zero events – any event ending up in the signal box is interesting!

Improved Dark Matter search techniques

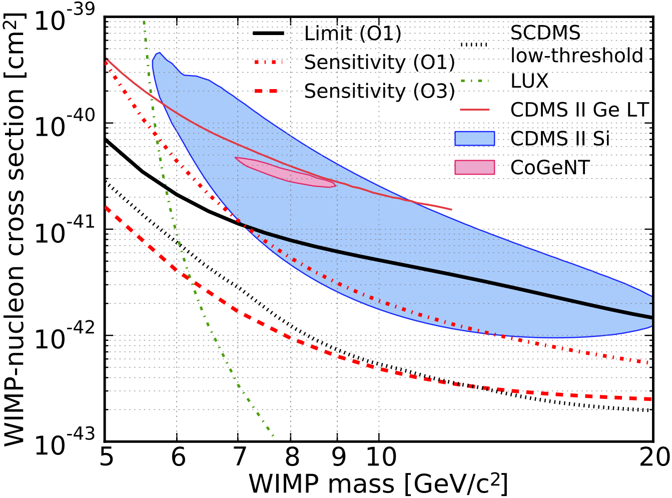
- Build a background model from simulations/calibration data in order to help machine learning algorithms distinguish background from signal events.
- Use Likelihood analysis to improve limits as well as the discovery potential.
- This means cuts can be looser, and more background is allowed into the 'signal box'.
- Depends on an accurate background model and an accurate signal model.

Theorist inputs for future experiments – an example



Liam Fitzpatrick provided starting code to do this work. Many thanks to Kristi Schneck who converted the code for general use and who is currently writing a paper on this subject. She may also be looking for a job in 6 month or so! arXiv:1211.2818

Theorist inputs for future experiments – an example



We can recompute the sensitivity assuming either a standard interaction (O1) or the modified interaction (O3). The figure shows that significantly different results are obtained depending on the input signal PDF.

Conclusions

- Data analysis for SuperCDMS Soudan is currently ongoing and showing that we benefit from using advanced analysis techniques.
- SuperCDMS SNOLAB is funded and is moving forward, with the promise of being the worlds best low-mass WIMP detector.
- We are starting to interface with theorists in order to draw more complete exclusion curves and to hopefully discover WIMPS! Liam Fitzpatrick on the theory side and Kristi Schneck have been leading this work, but we ready to test your theories and interface with you.
- Come find me at a coffee break if you would like to discuss possible collaboration.

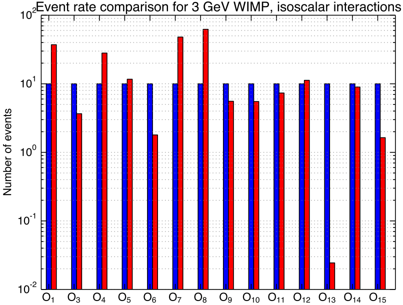
Thank you for your attention

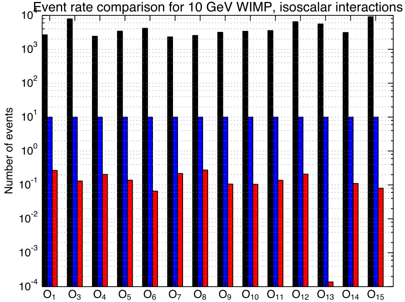
The South pole circa -44C. Nice and warm in government issued clothing.

Soudan mine head frame, circa -35C. Very cold in my California 'optimized' clothing.

Backup Slides

Backup Slides – G2 Event Rate Comparison





Ge: Blue,
Si: Red,
Xe: black
EFT result in G2 experiments if 10 events are observed in Ge