Status of Direct Searches for Low Mass WIMPs

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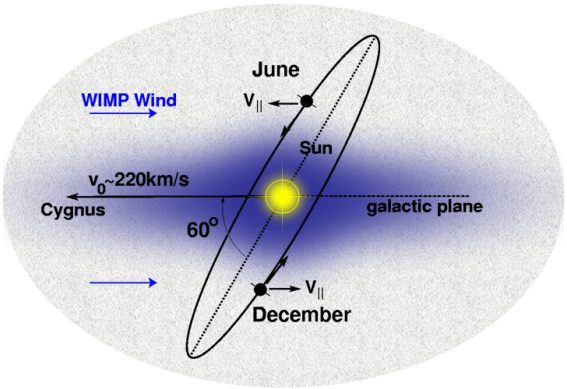
IPA

Madison Wisconsin, May 15, 2013

Are we seeing evidence for WIMPs?

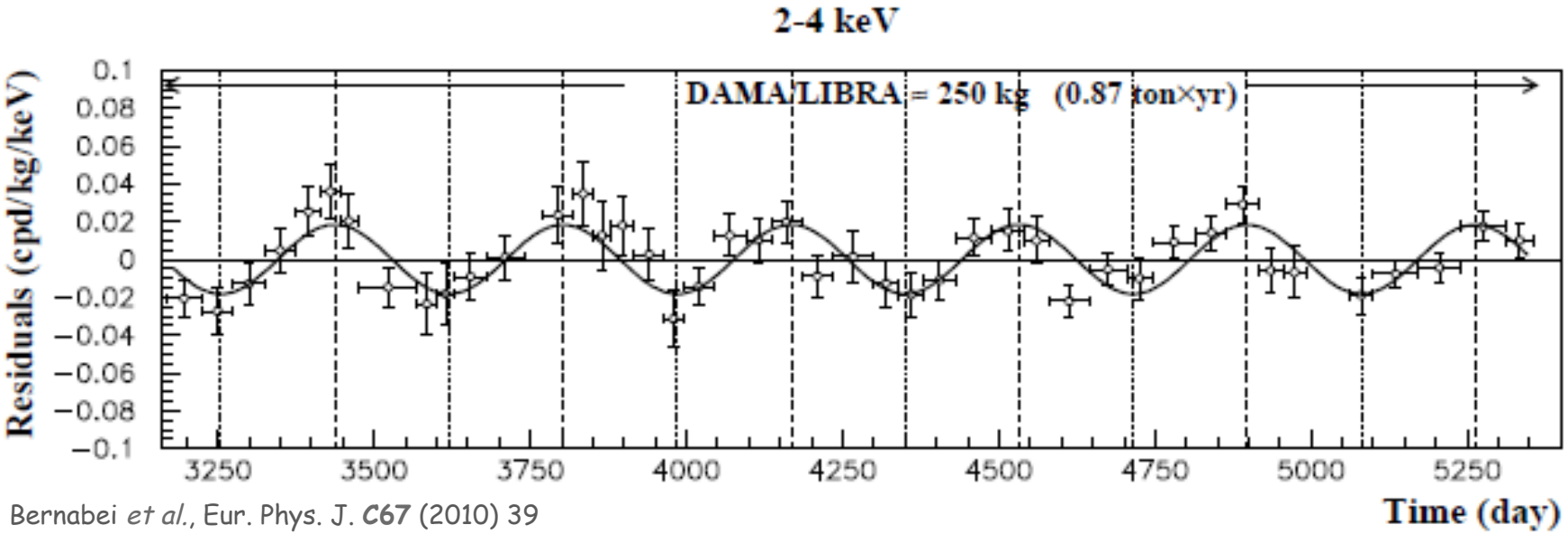
DAMA



- Using an array of radiopure NaI crystals, DAMA/NaI reported an annual modulation in event rate consistent w/ dark matter, observed over 7 annual cycles

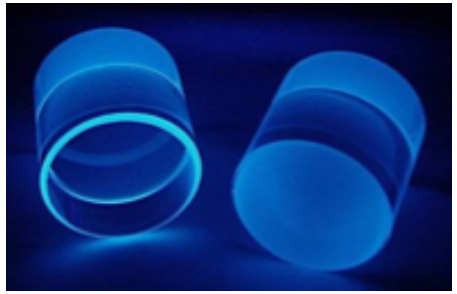
- In 2008, follow-up experiment, DAMA/LIBRA, confirms the annual modulation. Together the DAMA experiments report an effect with a statistical significance of 8.9σ

- To date no other experiments have confirmed this signal, yet efforts are ongoing to directly test this – *see talk by M. Kauer on DM-Ice*



Bernabei *et al.*, Eur. Phys. J. **C67** (2010) 39

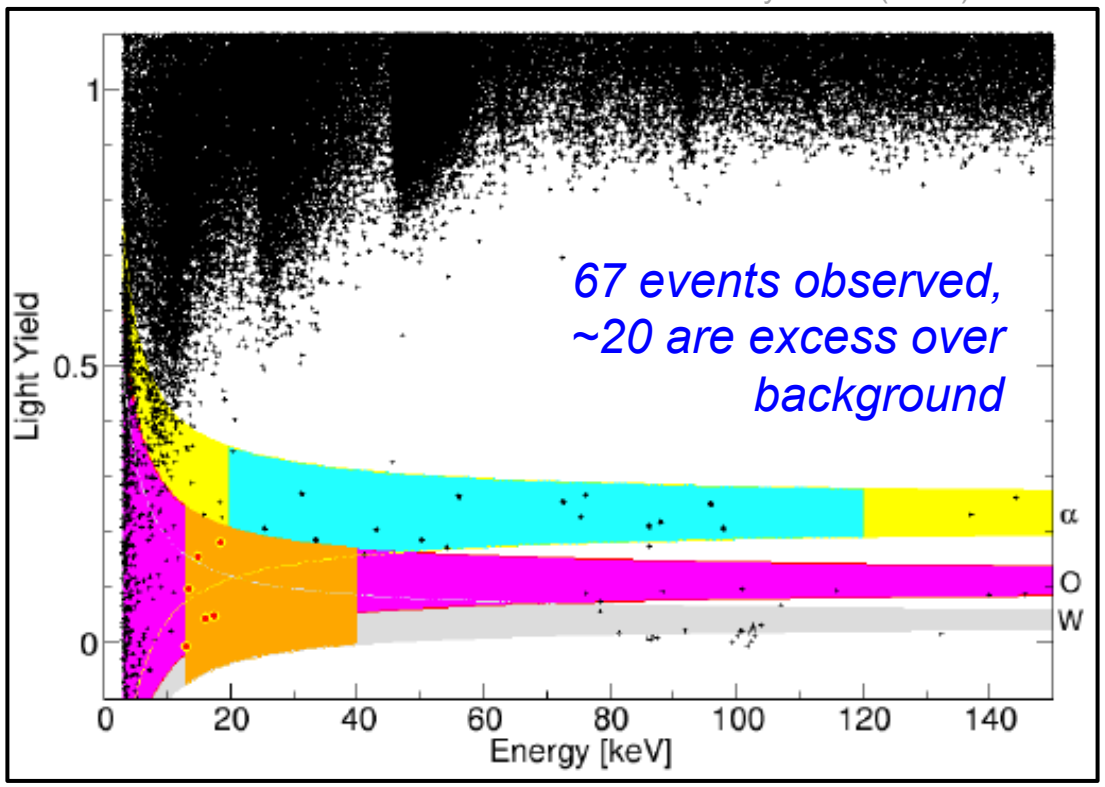
CRESST

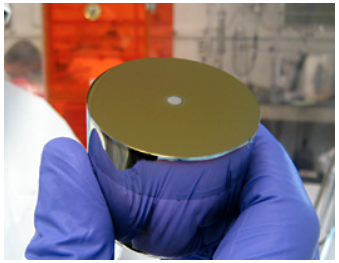


- Looks for WIMP scatters off of Ca, W and O nuclei
- $CaWO_4$ crystals detect scintillation light and phonons, providing capability to identify scatters off specific nuclei

Eur. Phys. J. C (2012) 72:1971

- Analysis of data taken in 2011 reveals excess *nuclear recoils* at >4σ significance, which are consistent with WIMPs
- Favored masses and cross sections are in tension with other experiments; now trying to reduce Rn-daughter contaminants in detector housing components (clamps)





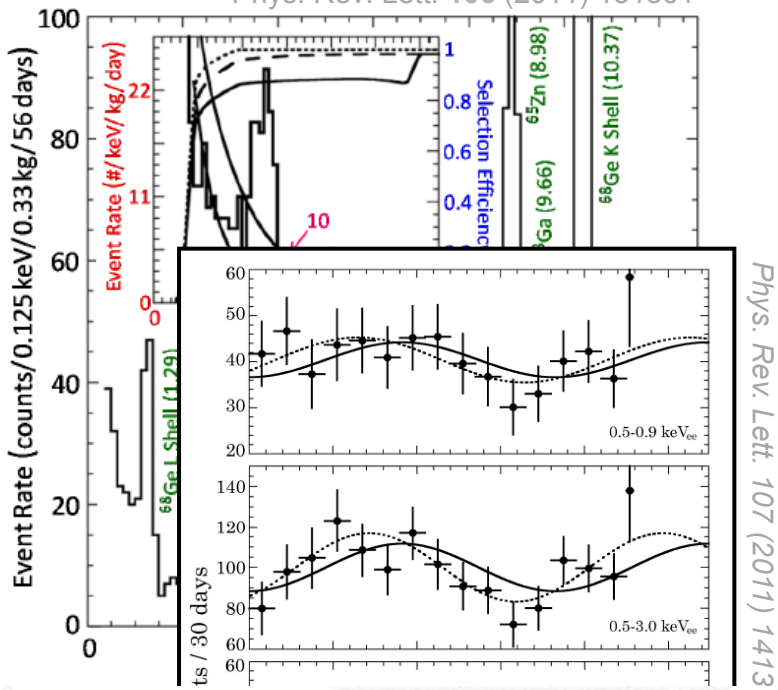
CoGeNT

In 2010, CoGeNT using PPC Ge to push ionization thresholds down to <0.5 keV; reported an excess of low-energy events with spectrum consistent with a ~10 GeV/c^2 WIMP

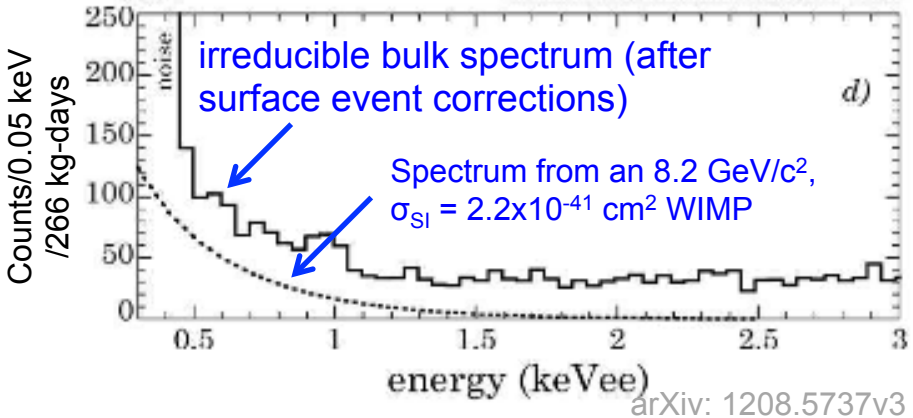
In 2011, reports a modulation of events in the 0.5-3.0 keVee region with ~2.8σ significance, corresponding to a large fractional modulation

2011/2012: CoGeNT revises background estimates and reports smaller, but still statistically significant, excess of low energy events

Phys. Rev. Lett. **106** (2011) 131301



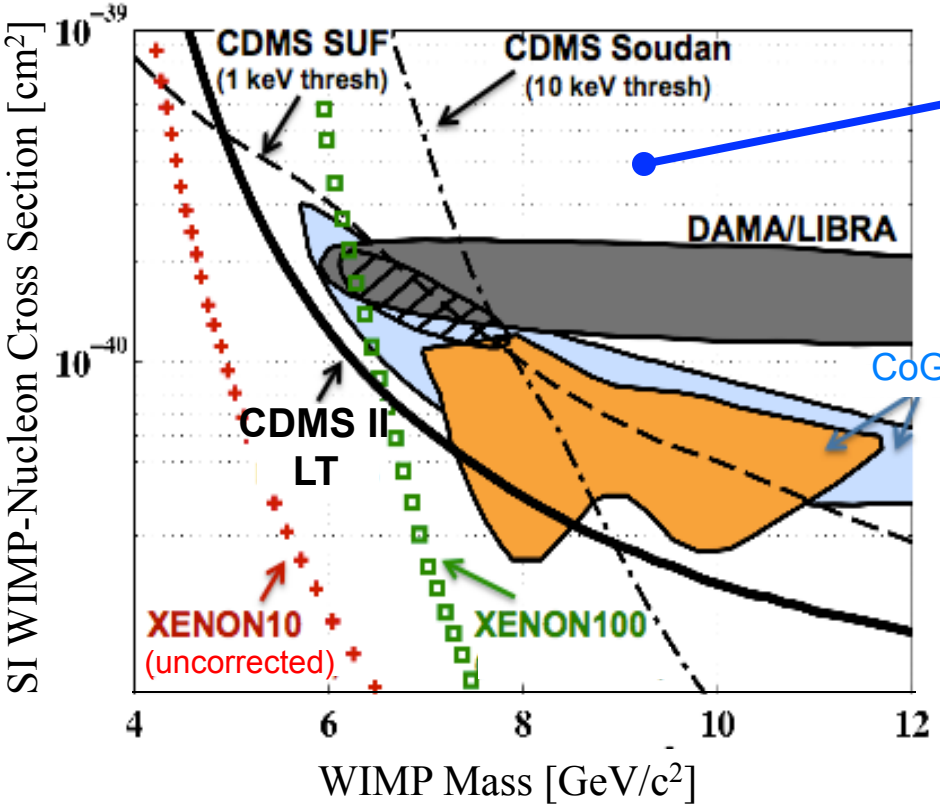
Phys. Rev. Lett. 107 (2011) 1413



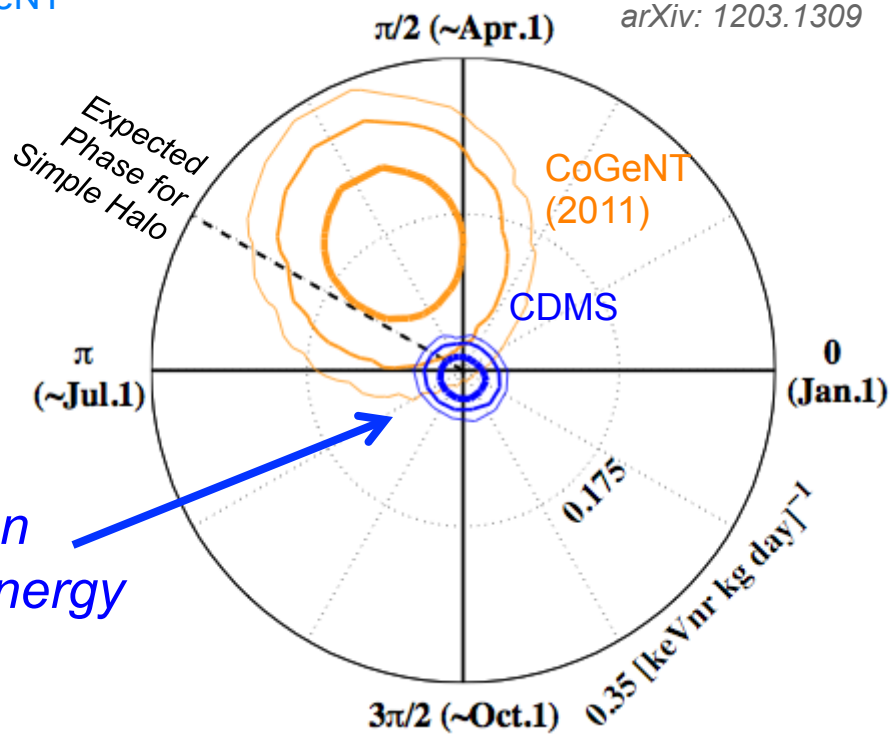
arXiv: 1208.5737v3

…not so fast!

Null Results from Ge Low Threshold and XENON10/100



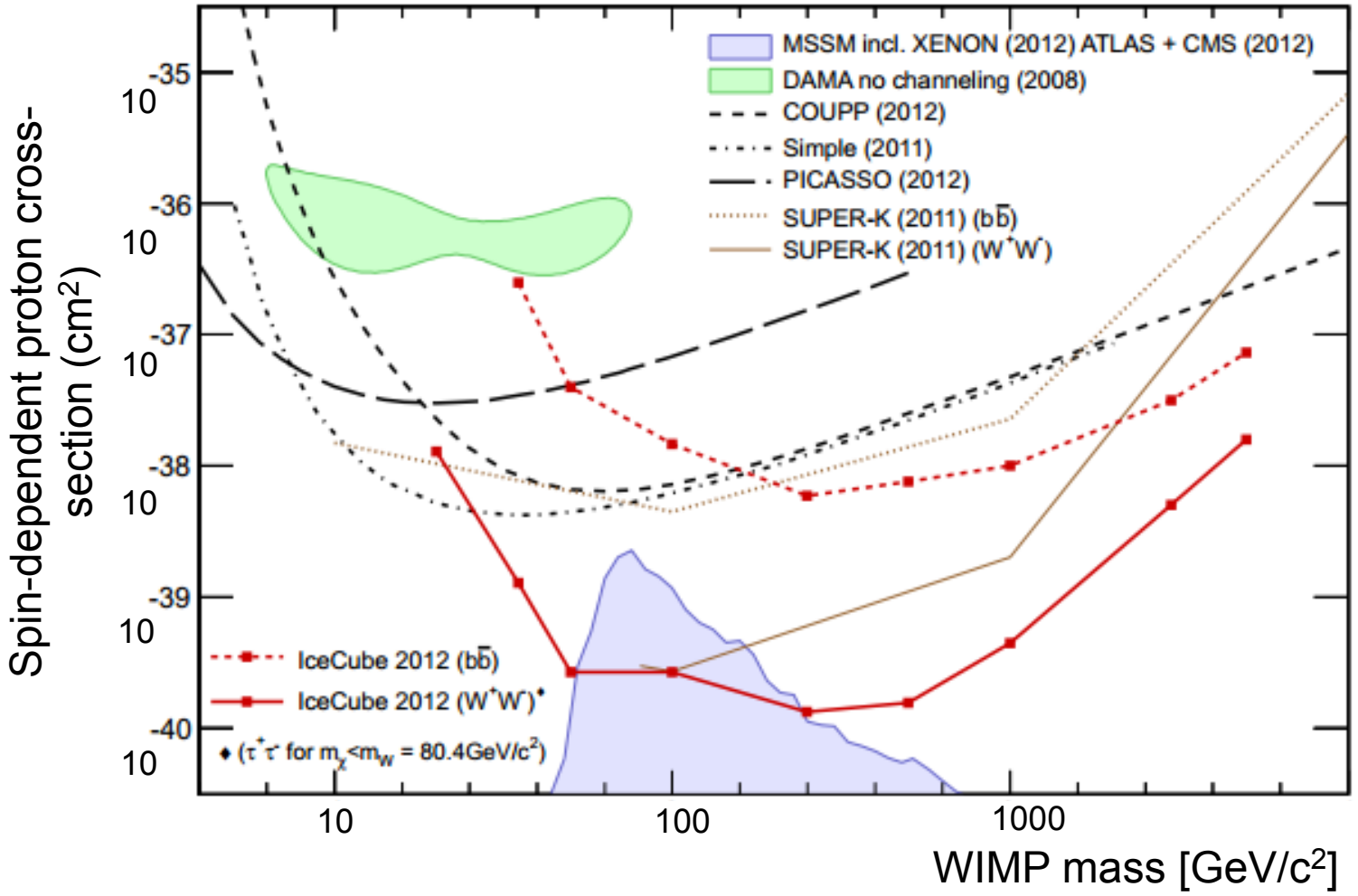
CDMS II, XENON 100, XENON 10 and EDELWEISS all set upper limits based on rate of events seen in signal regions. No background subtraction



2012: CDMS II looked for an annual modulation of low energy recoils and didn't see any

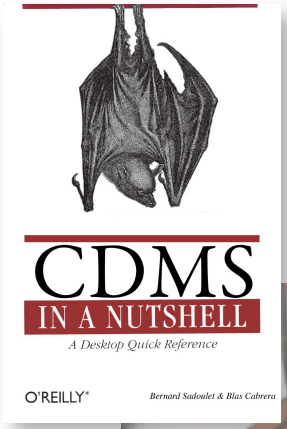
Spin-Dependent Constraints

Best direct detection limits on SD proton-WIMP couplings are from bubble chamber and liquid droplet detectors

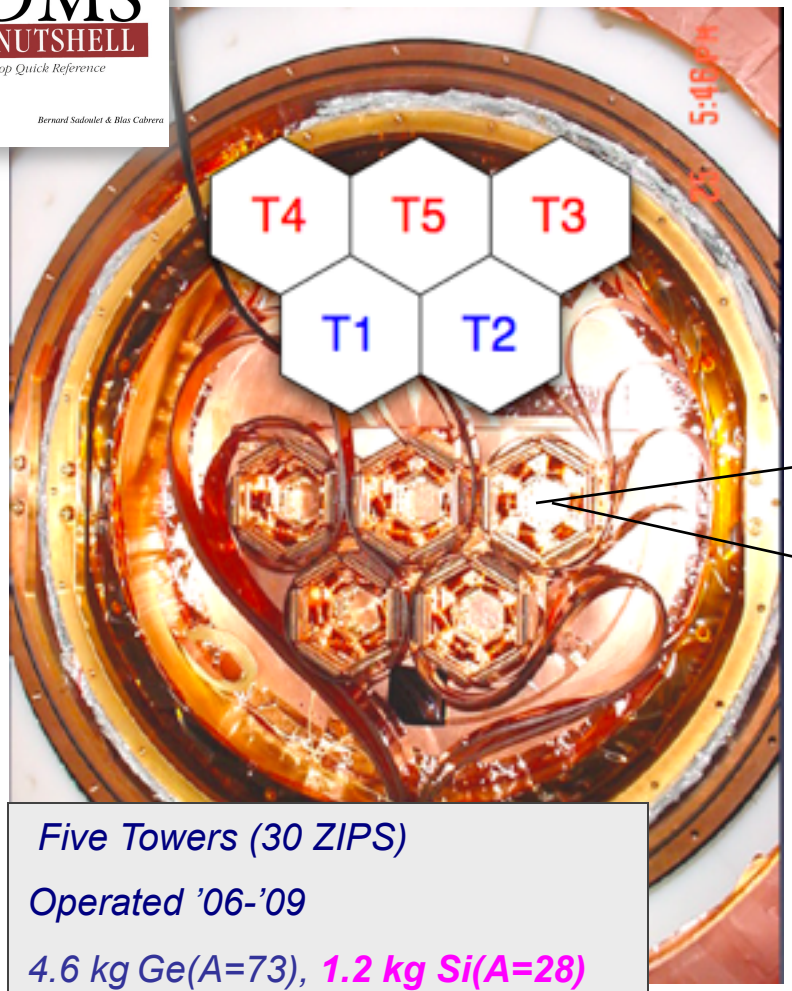


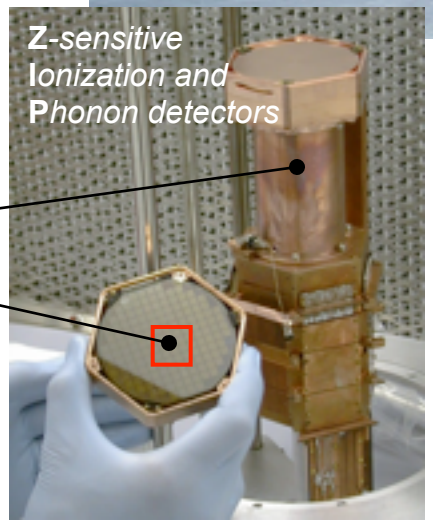
(limits on neutron coupling led by XENON100 – see talk by K. Lim for more)

…or maybe so?



CDMS II Search with Silicon





Lighter Si target nucleus is advantageous for low mass WIMP searches !

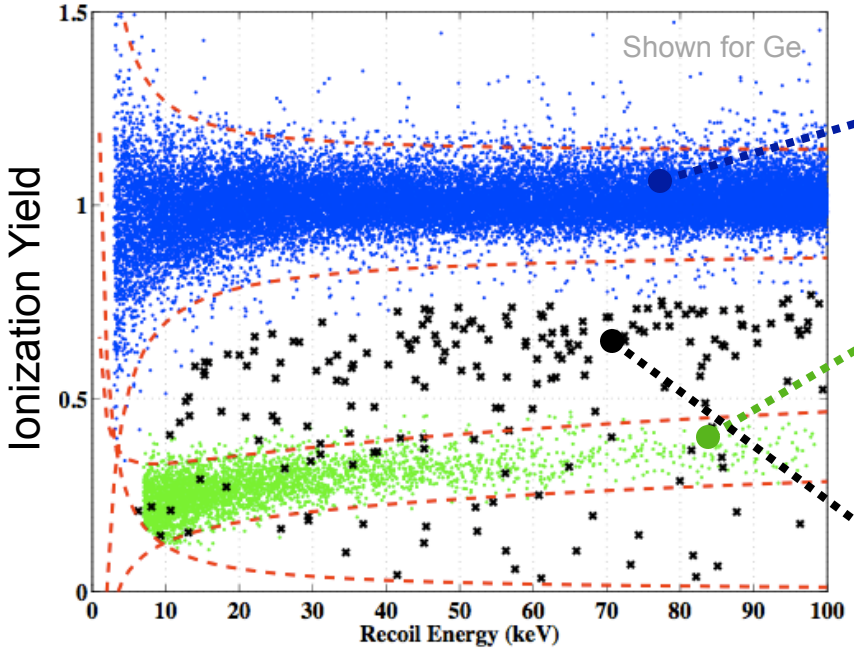
Five Towers (30 ZIPS)

Operated '06-'09

4.6 kg Ge(A=73), ***1.2 kg Si(A=28)***

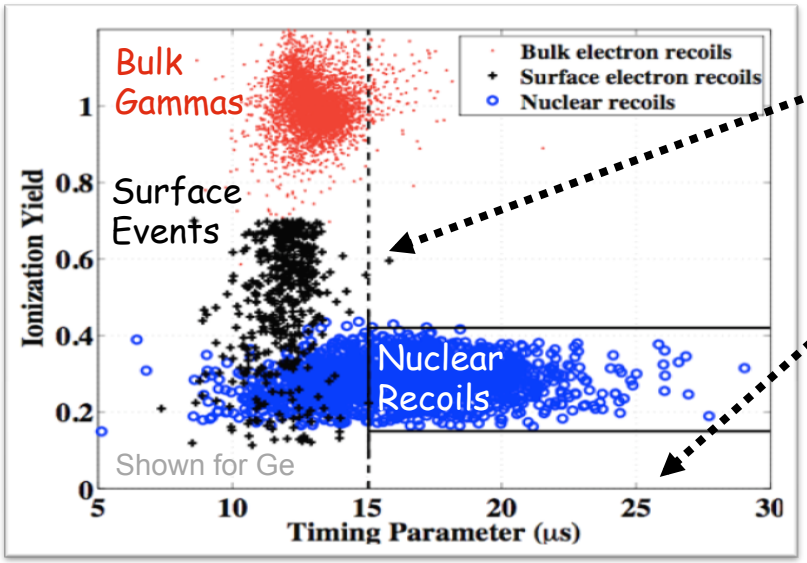
Reporting results from blind analysis of 140 kg-days of Si data (8 detectors), gathered from July 2007- September 2008

The CDMS Strategy



- Most backgrounds (e, γ) produce electron recoils
- WIMPs and neutrons produce nuclear recoils

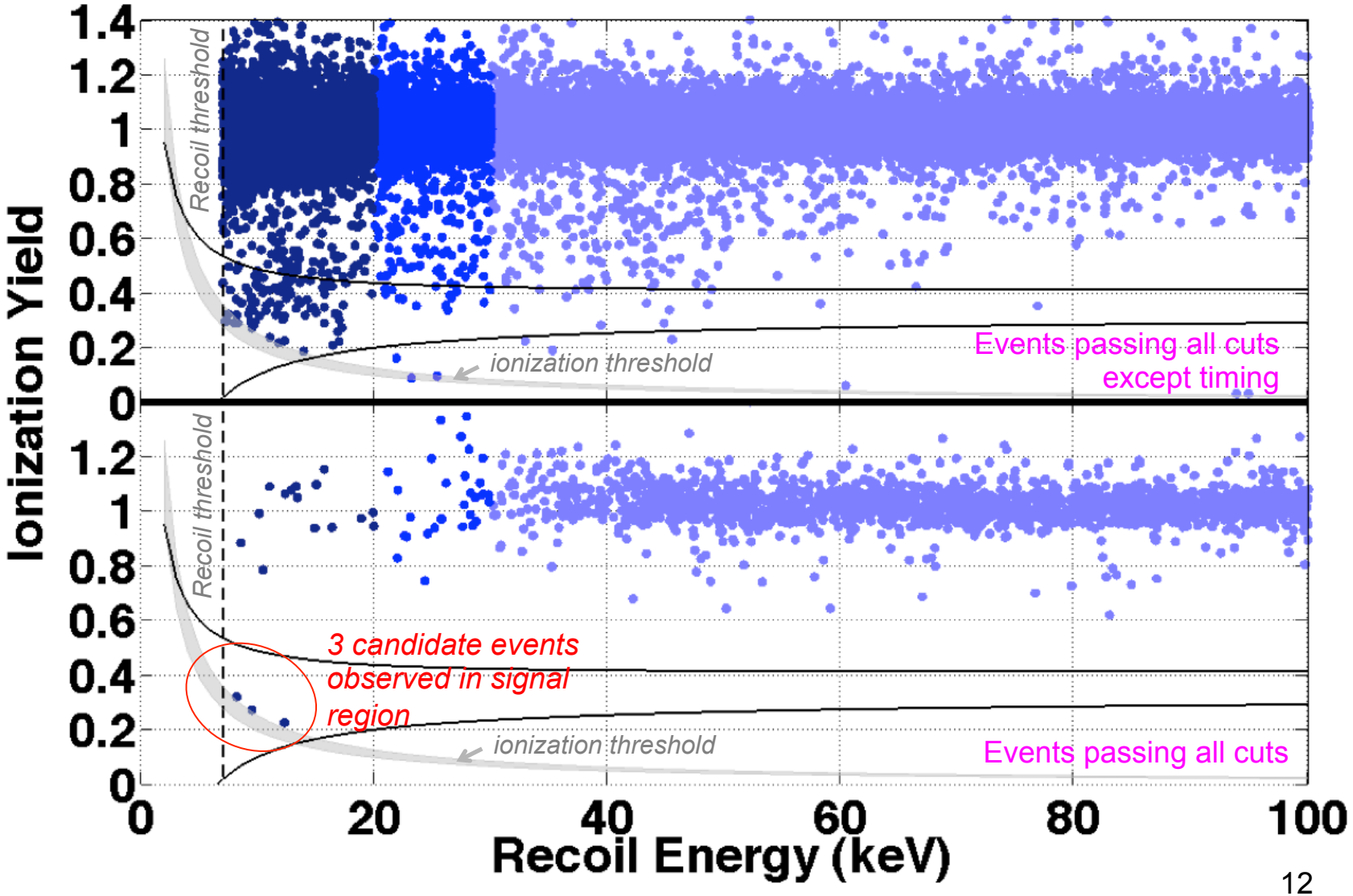
Ionization yield (ionization energy per unit recoil energy) strongly depends on recoil type



- Particles that interact in the "surface dead layer" result in reduced ionization yield
- These surface events can be rejected through a phonon pulse shape cut (optimized in 3 bins of recoil energy)

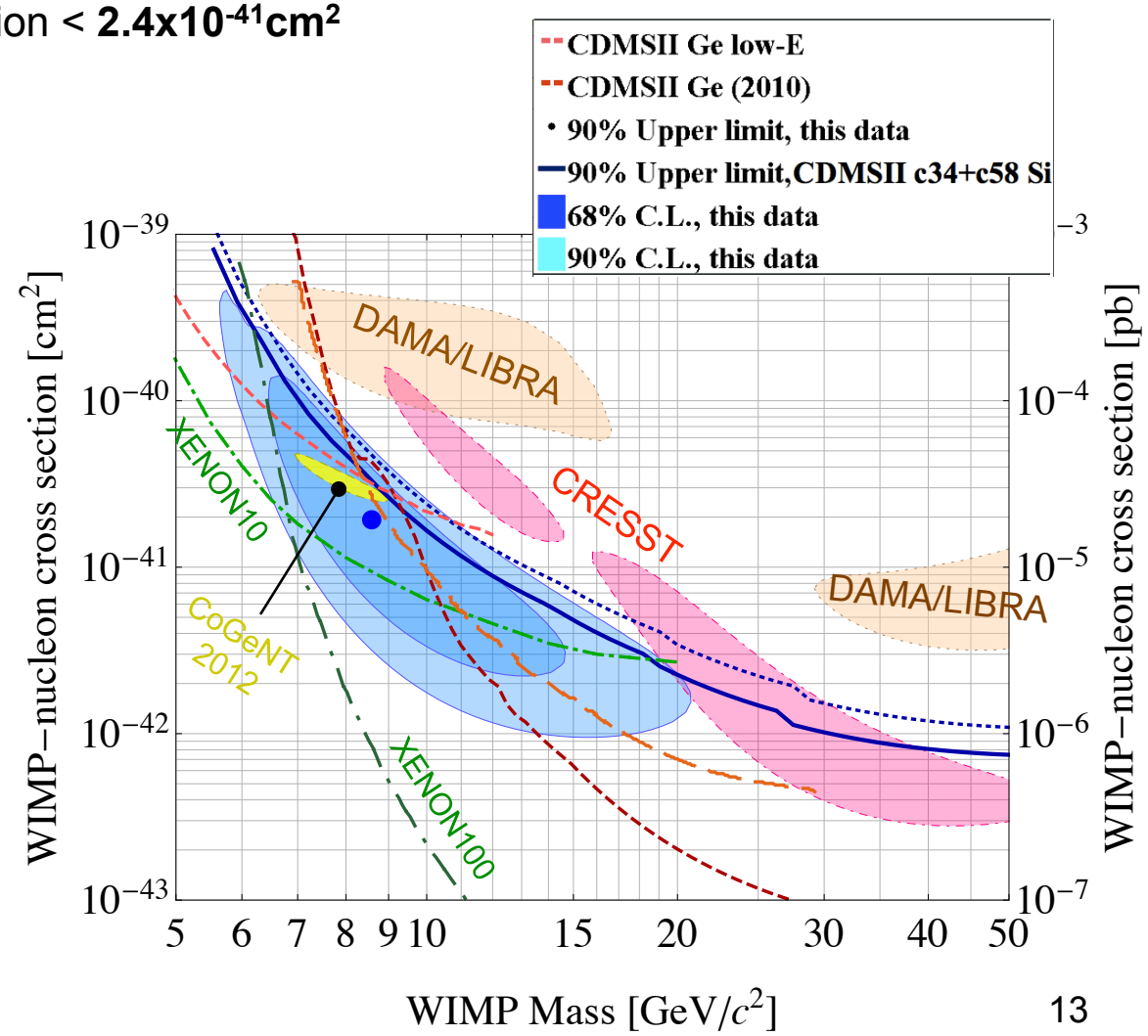
Ionization yield + timing result in < 1 in 10^6 electron recoils leaking into the signal region

Unblinding Results



Data Interpretations

- **140 kg-days** raw exposure yields three events with expected background of <0.7 events
- Optimal interval sets SI cross section < **2.4×10^{-41} cm^2 @ 90% C.L. for 10 GeV/c^2 WIMP**
- Probability of a statistical fluctuation producing ≥ 3 events anywhere in signal region is 5.4%
- Profile likelihood analysis favors WIMP+background hypothesis over known backgrounds as the source of signal at the **99.8% C.L. (~3σ)**
- The maximum likelihood occurs at a WIMP mass of **8.6 GeV/c^2** and WIMP-nucleon cross section of **1.9×10^{-41} cm^2**
- Not significant enough to be a discovery, but does call for further investigation.

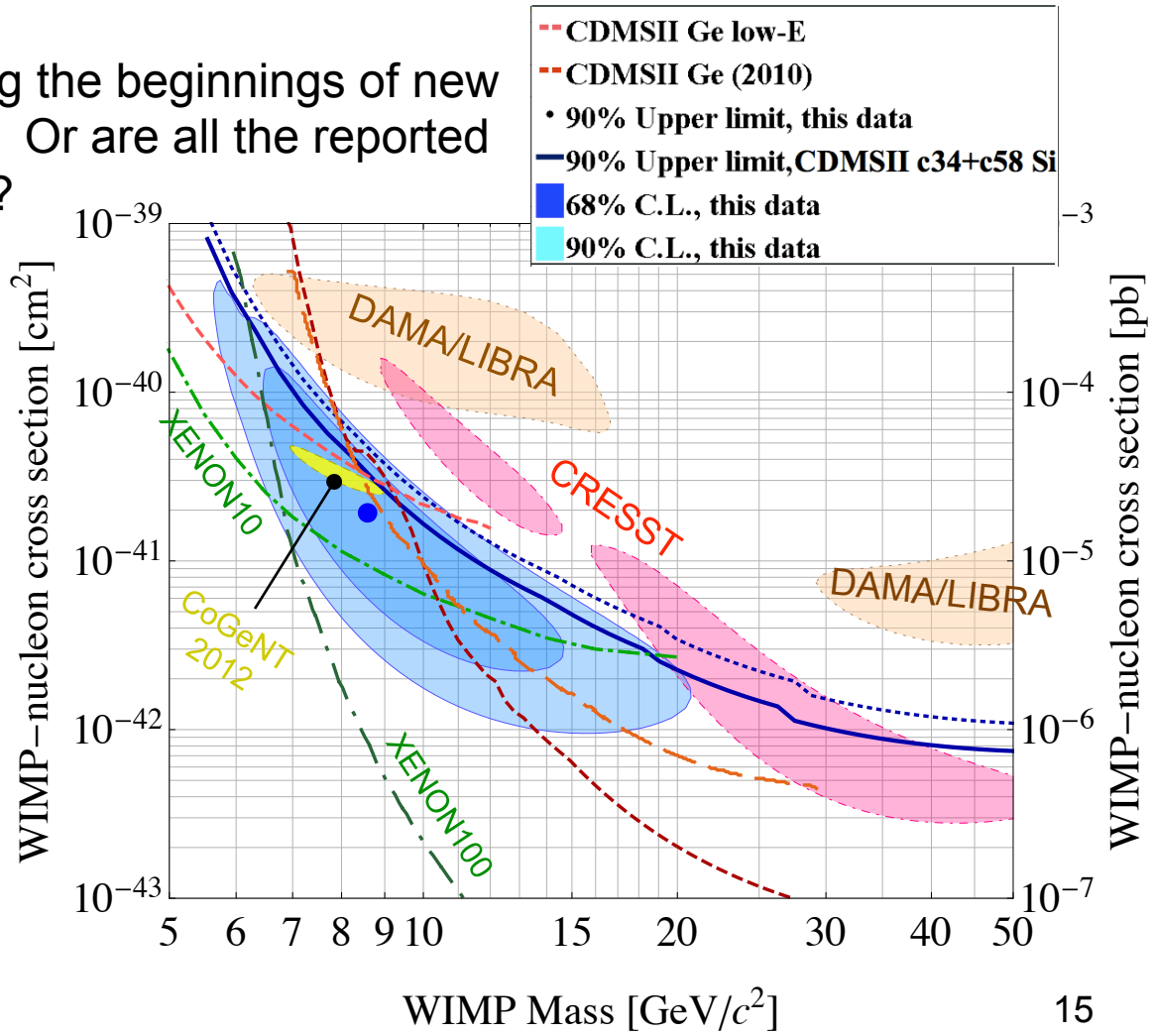


arXiv: 1304.4279v2

Where are we now?

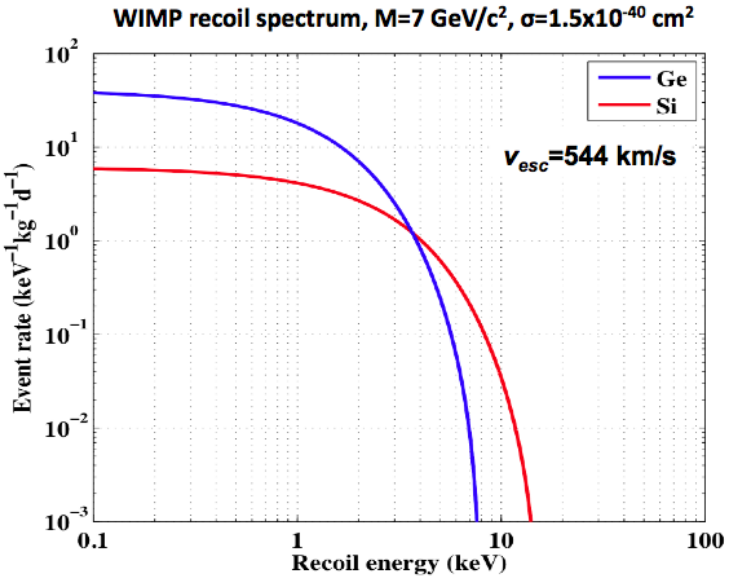
The overall picture

- The field continues to be in a state with “hints” of signals from some experiments and null results from others. Hints aren’t in strong agreement with each other either
- Does this mean we are seeing the beginnings of new particle physics phenomena? Or are all the reported excesses due to background?
- Aside from DAMA, no other experiment’s results are high in statistical significance and no one else has claimed to be seeing WIMPs
- The stakes are high! It’s difficult to resist playing the “what if…” game.



arXiv: 1304.4279v2

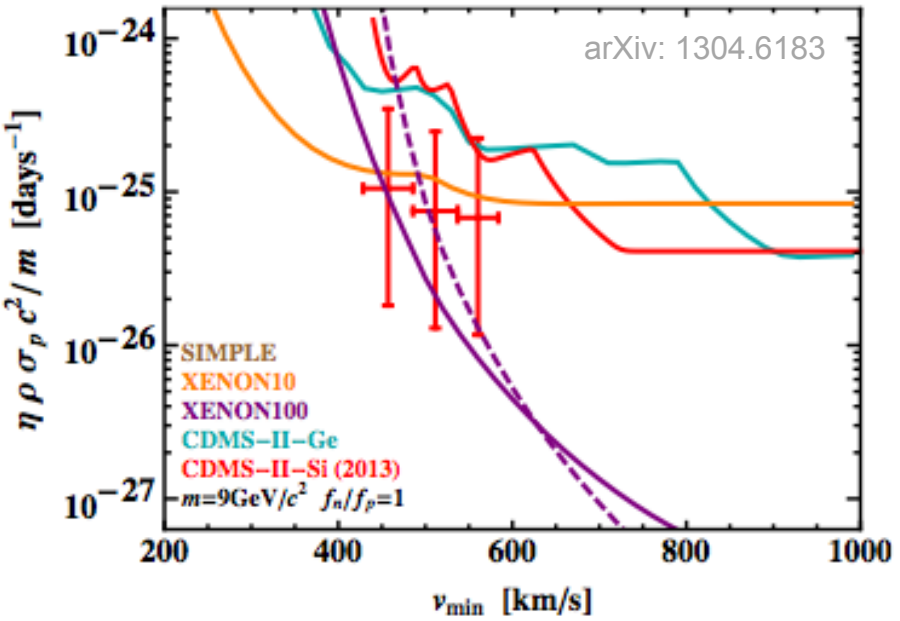
What if it's astrophysical uncertainty?



Searches for low mass WIMPs can be sensitive to uncertainties in astrophysical parameters in ways that depend on the target nucleus mass

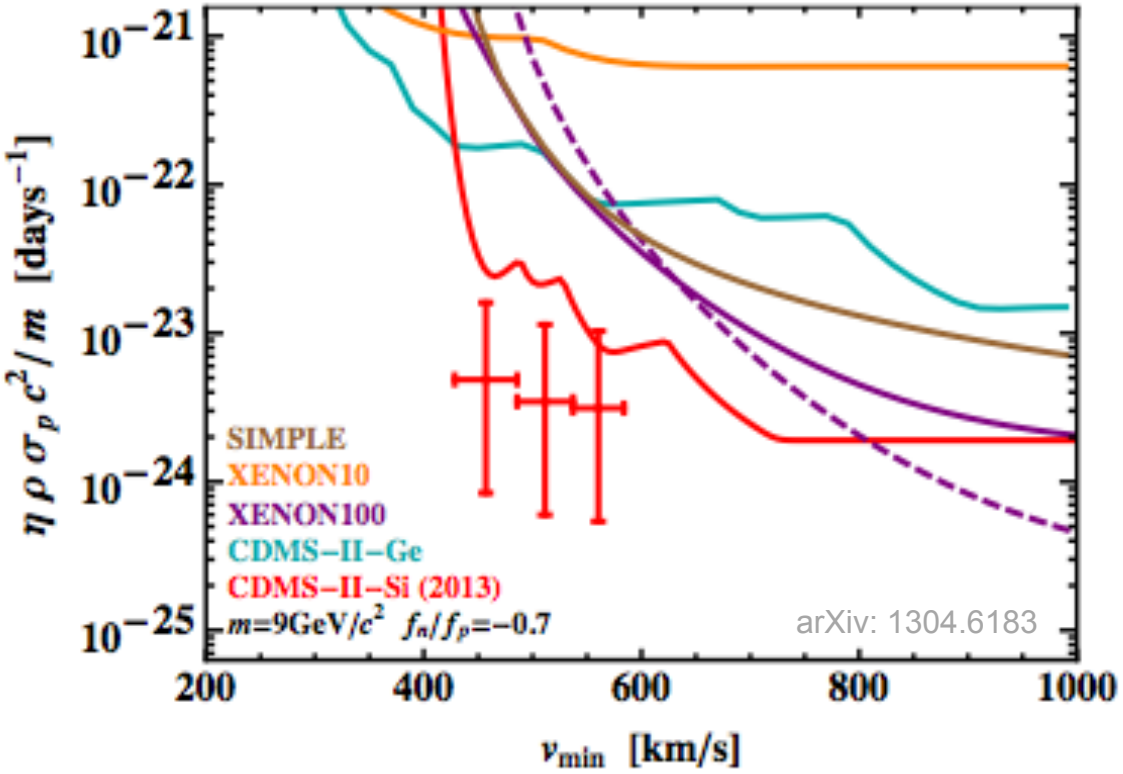
Could that resolve the tension between experiments?

Can remap from default "cross-section vs mass" into a halo-independent space. In this example, tensions between Xe and Si data remain so it seems astrophysical uncertainties are not enough(!)



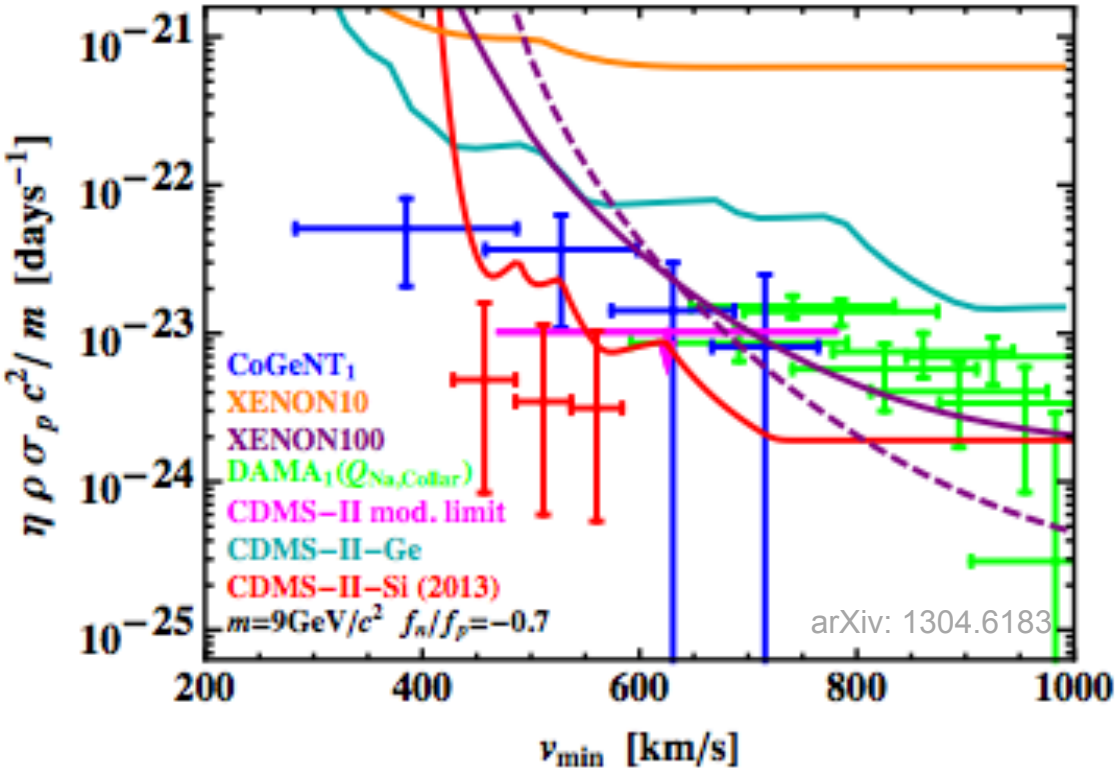
What if it's a non-standard interaction?

As another example, tensions between Si and all Xe data can be removed by applying isospin violation (coupling of WIMPs differs between protons and neutrons).



What if it's a non-standard interaction?

…but this choice of parameters does not resolve CoGeNT and DAMA compatibility with other experiments, so this alone is not enough to explain the whole picture



What if its experimental uncertainty (or error)?

Can be a touchy subject…

Many other attempts at reconciliation have been made, but the fact remains, these data are difficult to reconcile with each other, even before CDMS II Si was added to the picture

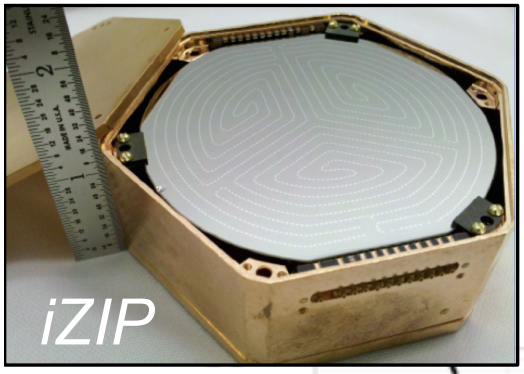
The pessimists remind us that at least one (or several) of the measurements could be suffering from flaws (energy scale systematics, unknown backgrounds or even unlucky statistical fluctuations of background)

The optimists in all of us do not want the theoretical community to give up their creative attempts here

Experimentalists have their work cut out for them for the moment (!)

Path towards resolution

Avoid systematics near the energy threshold by designing experiments where recoils of interest are well above the threshold



SuperCDMS Soudan

Coming soon to a conference near you!

9 kg of Ge iZIP detectors gathering physics data since March 2012

iZIP's solve the problem of surface events for a next-generation dark matter search !

SuperCDMS Soudan Projections

Anticipated Fall: iZIP low threshold, ~2 keVnr analysis

Anticipated Summer: first ultra-low threshold, ~170 keVee CDMSlite

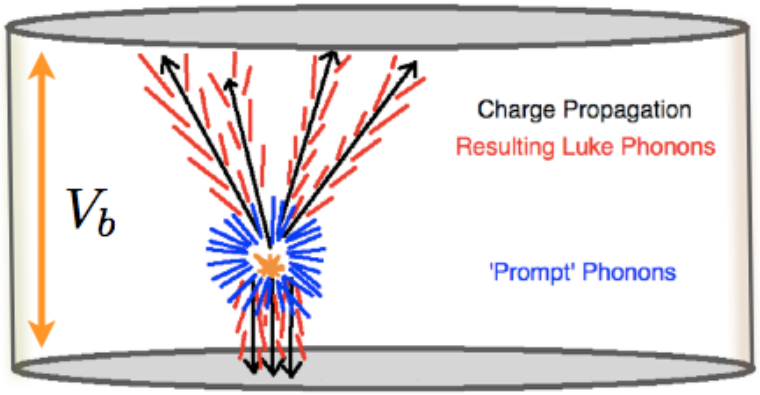
(Ultra) Low Ionization Threshold Experiment: CDMSlite

Neganov-Luke amplification of phonon response allows operation at very low energy thresholds

(Ultra) Low Ionization Threshold Experiment: CDMSlite

Neganov-Luke amplification of phonon response allows operation at very low energy thresholds

How does it work?

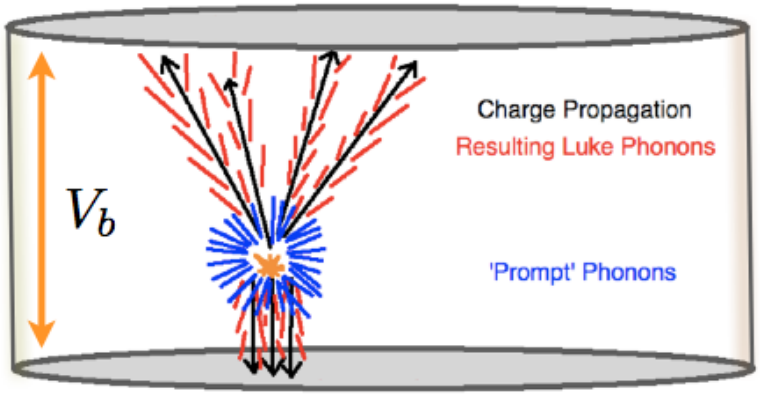


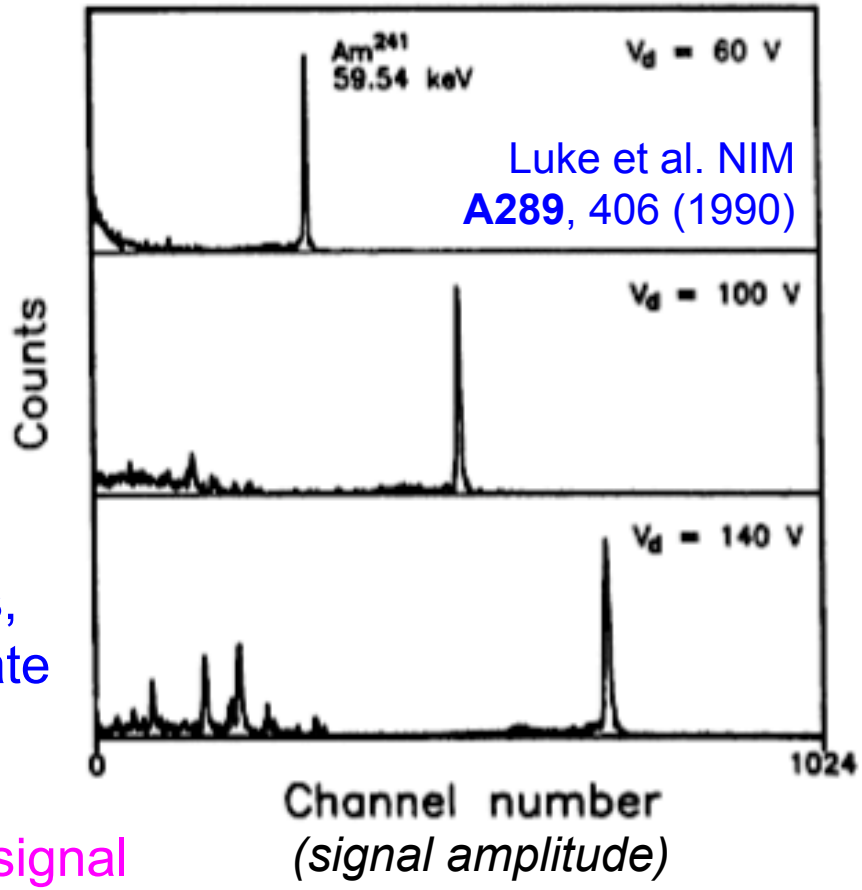
In addition to detecting recoil phonons, resulting electrons and holes will radiate phonons proportional to V_{bias} as they drift to the electrodes.

(Ultra) Low Ionization Threshold Experiment: CDMSlite

Neganov-Luke amplification of phonon response allows operation at very low energy thresholds

How does it work?





Luke et al. NIM **A289**, 406 (1990)

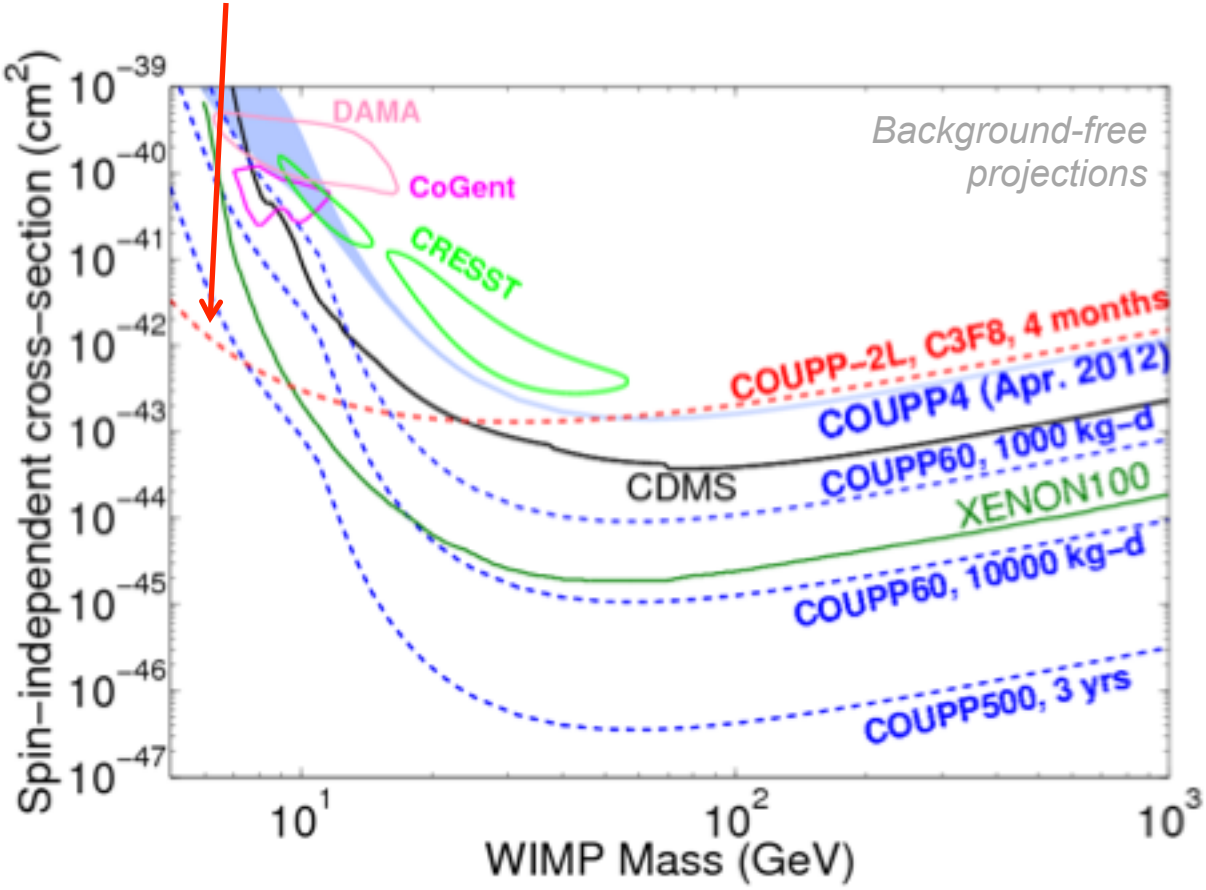
In addition to detecting recoil phonons, resulting electrons and holes will radiate phonons proportional to V_{bias} as they drift to the electrodes.

➔ Apply large V_{bias} to amplify ionization signal

"COUPP-4lite" (official name still under debate)

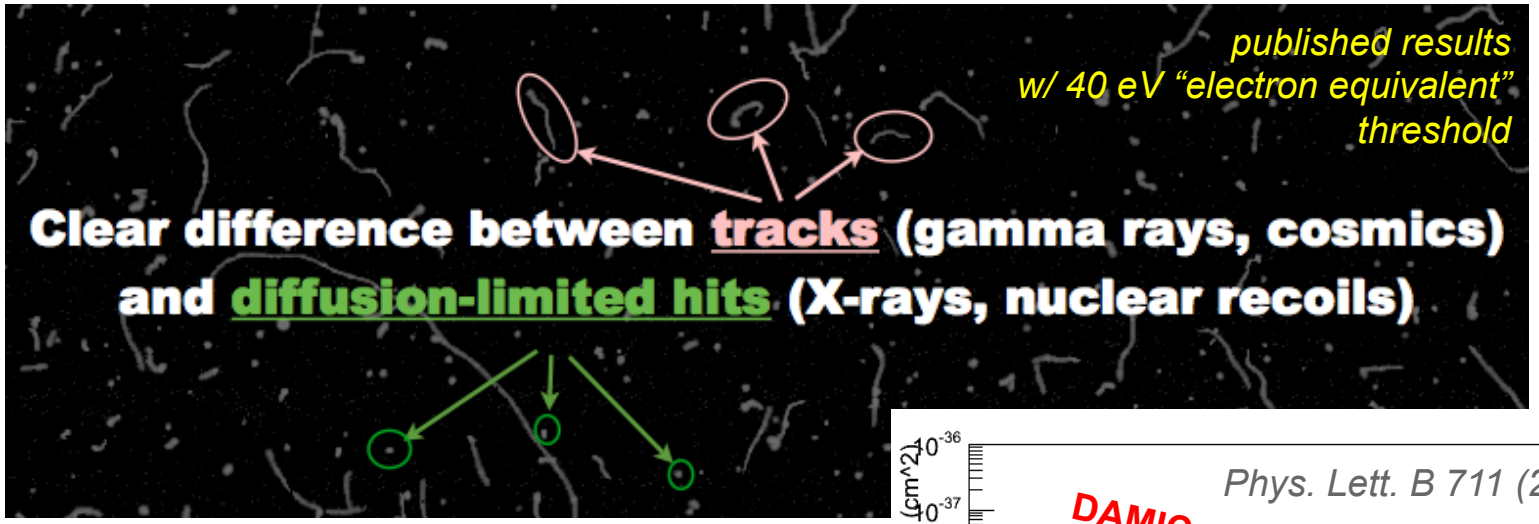
will replace target CF_3I fluid with C_4F_{10} to yield impressive sensitivity at low masses (and significant gains in SD sensitivities)

- Improved efficiencies at low recoil energies compared to CF_3I
- PICASSO has long-time experience with this fluid
- Will be a joint project between COUPP and PICASSO
- First bubbles expected this summer



- see talk by R. Neilson for more

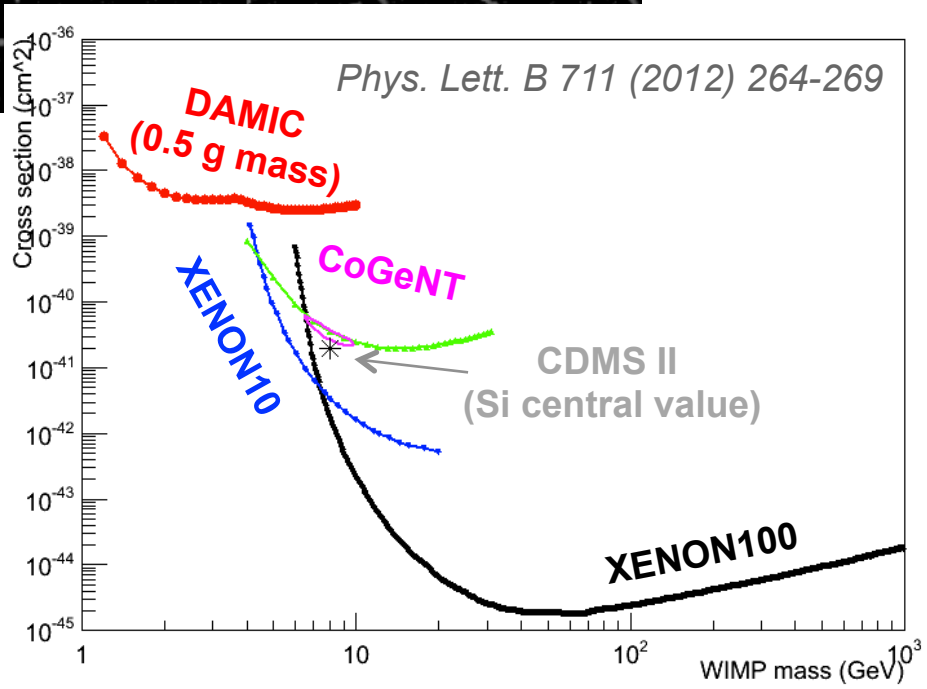
Dark Matter in CCD's (DAMIC)



Aside from CDMS, the only other direct detection experiment with a Si target, but with significantly different technology!

DAMIC100 will have 100g of target and could see O(100) events per year for 8.6 GeV/c^2 WIMP and $\sigma = 2\times10^{-41}\text{cm}^2$

- see J. Zhou's talk for more



Conclusion

Even for the skeptics, this situation remains an important puzzle to resolve

Despite restricting discussion to low mass WIMPs, there are too many endeavors and too little time (!) – I apologize if I left your favorite experiment out of the discussion

DAMA, CRESST, CoGeNT and now CDMS Si are all reporting excess events which may be interpreted as low mass WIMP scatters

However, other experiments such as XENON100, XENON10, EDELWEISS and CDMS Ge are reporting null results for low mass WIMPs

Stay tuned!

There are many ongoing efforts to shed light on the situation. New data and new theoretical work will significantly revise the picture on a very short timescale

Thank you