CoGeNT:

neutrino & astroparticle physics using large-mass, ultra-low noise germanium detectors

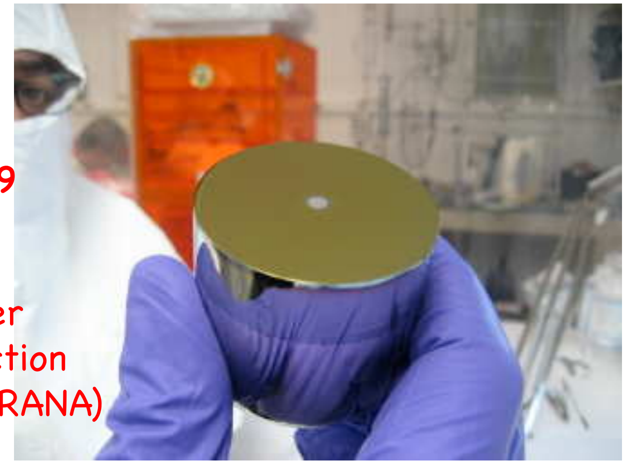
(CANBERRA, PNNL, ORNL, UC, UNC, UW)

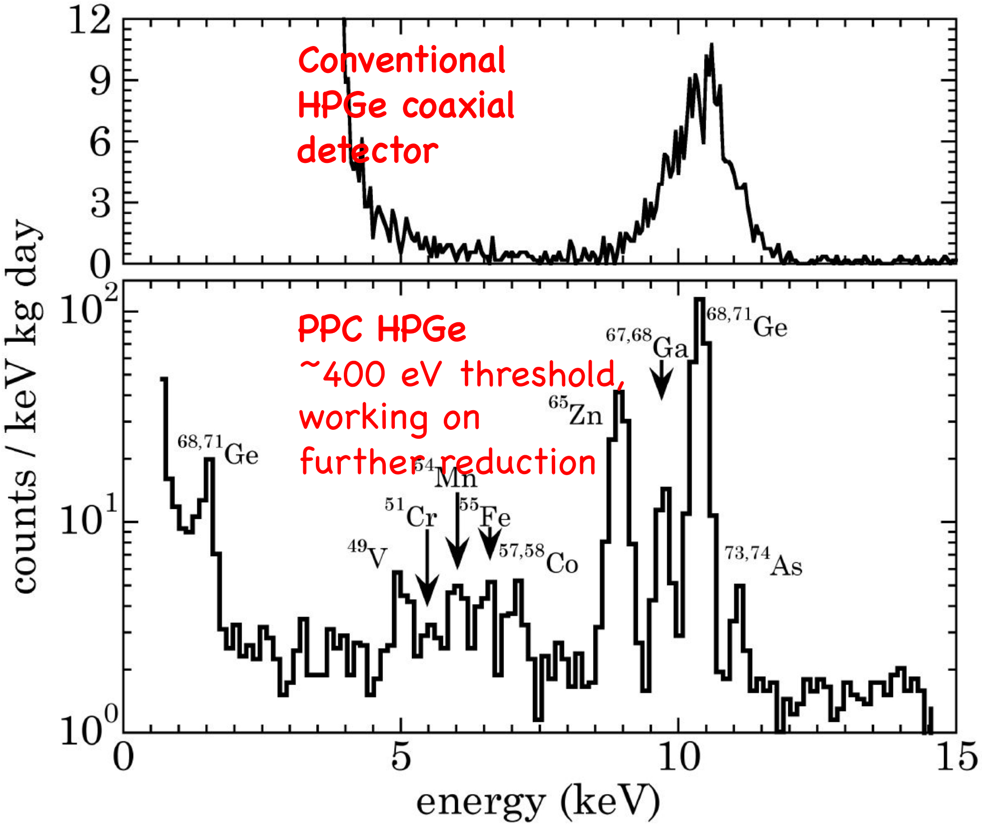
PPC HPGe

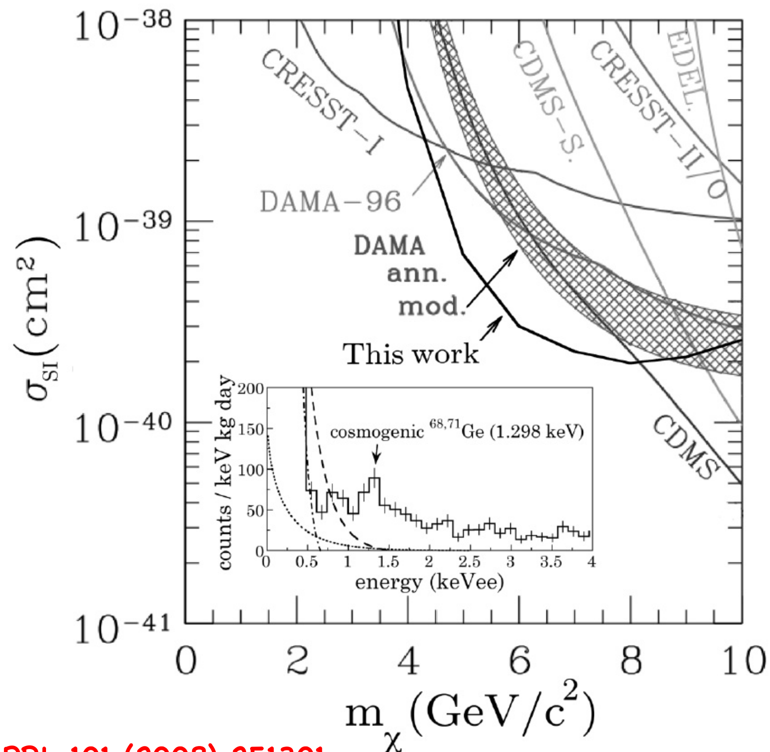
JCAP 09(2007)009

Applications:

- Light Dark Matter
- Coherent ν detection
- ββ decay (MAJORANA)





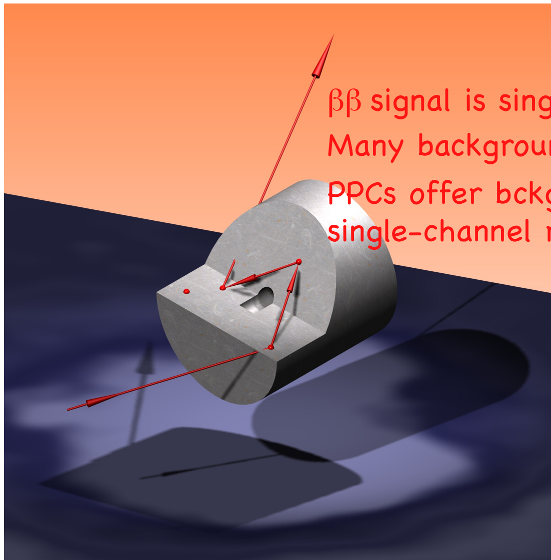


PRL 101 (2008) 251301

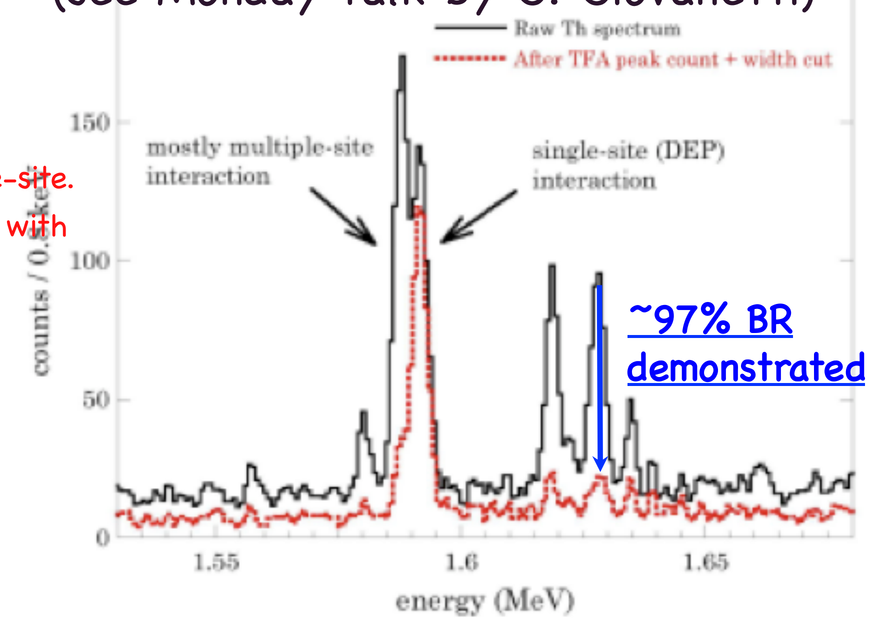
Extensive constraints on DAMA's claim:

- Light WIMPs
- Dark scalars
- Dark pseudoscalars

MAJORANA PPCs (see Monday talk by G. Giovanetti)



ββ signal is single-site.
Many backgrounds are multiple-site.
PPCs offer bckg discrimination with single-channel readout.



Detectors studied / in hand:

(table actually missing a few)

Owner	Dimensions	Mass	Resolution (1.33 MeV)	Manufacturer
U. Chicago (PPCI)	50 mm Ø x 44 mm	460 g	1.82 keV	Canberra
PNNL (PPCII)	50 mm Ø x 50 mm	527 g	2.15 keV	Canberra
LBNL (SPPC)	62 mm Ø x 44 mm	800 g	2.11 keV	LBNL
LANL (MJ70)	72 mm Ø x 37 mm	800 g	2.15 keV	PHD's
ORNL (MJ60)	62 mm Ø x 46 mm	740 g	4-4.5 keV	PHD's
U. Chicago (BEGe)	"standard"	450 g	<2 keV	Canberra
LBNL (Mini-PPCs)	20 mm Ø x 10 mm	17 g		LBNL
ORNL (Big BEGe)	90 mm Ø x 25 mm	850 g	1.95 keV	Canberra

Move to modified commercial "BEGe" detectors (quasiplanar PPCs)

~30 PPCs already characterized and stored for 60kg MAJORANA demonstrator

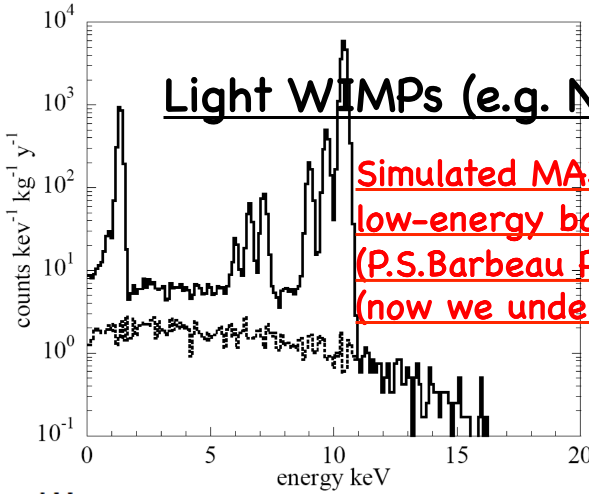
Crystal storage underground

GERDA switching to PPCs for 2nd phase

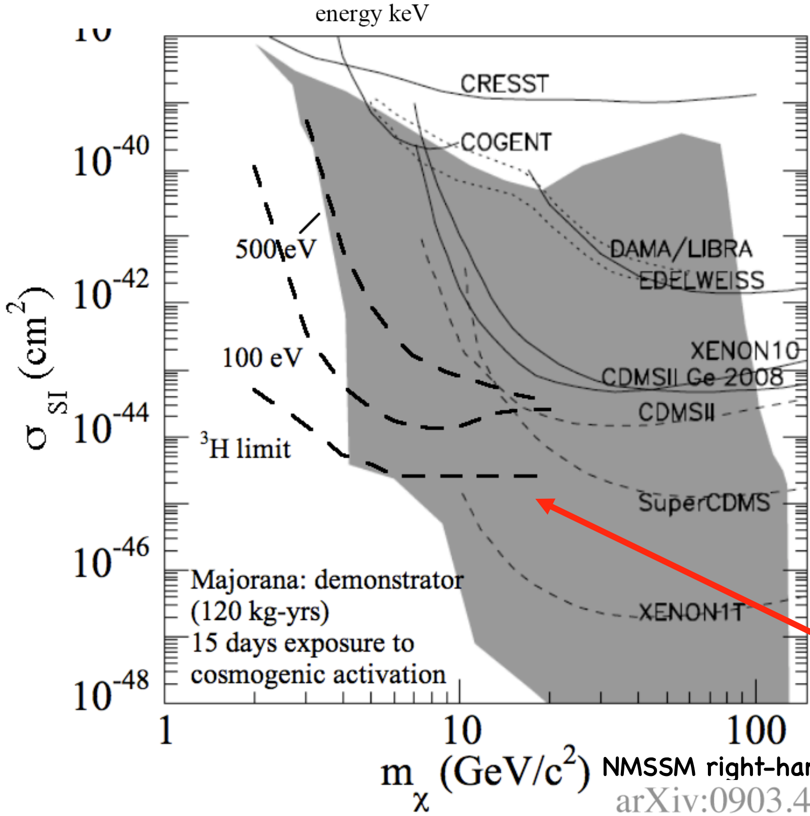
MAJORANA as a DM detector

(see Monday talk by G. Giovanetti)

Light WIMPs (e.g. NMSSM)



Simulated MAJORANA-demonstrator low-energy backgrounds (P.S.Barbeau Ph.D. Diss.) (now we understand these much better)

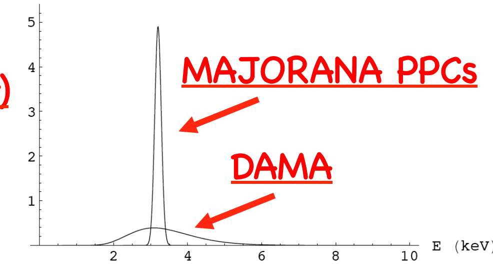


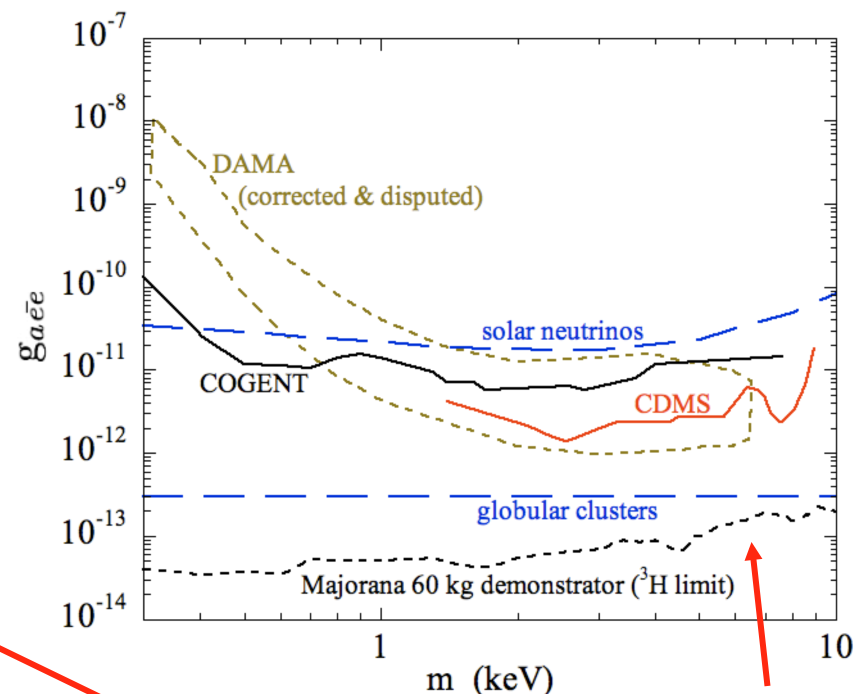
NMSSM right-handed sneutrino

arXiv:0903.4677v1

Pseudoscalars etc. (a.k.a."superWIMPs")

Energy resolution is key:



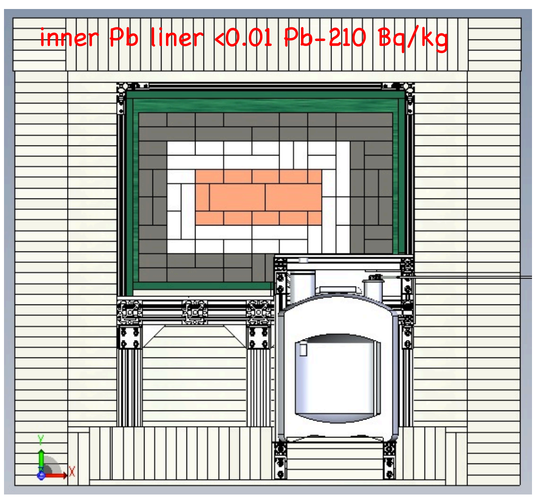


Possibility of reaching ^{3}H limit much nearer now with surface event rejection

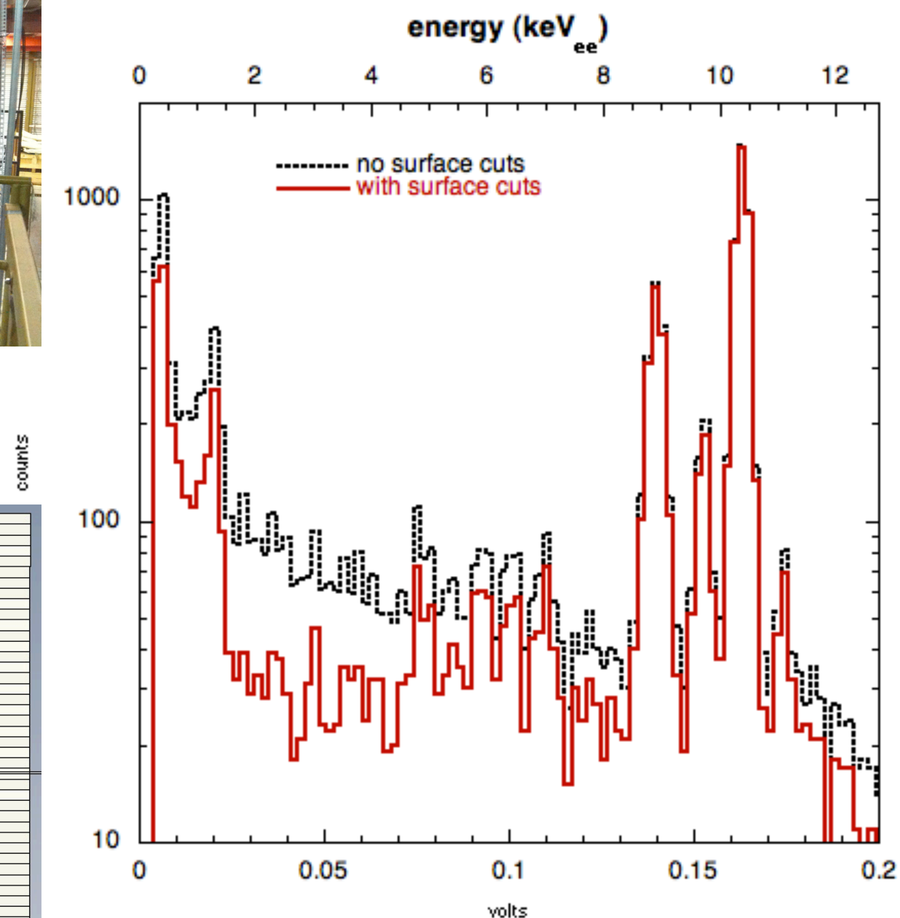
Making an excellent detector even better:
PPCs can reject surface events using rise-time cuts

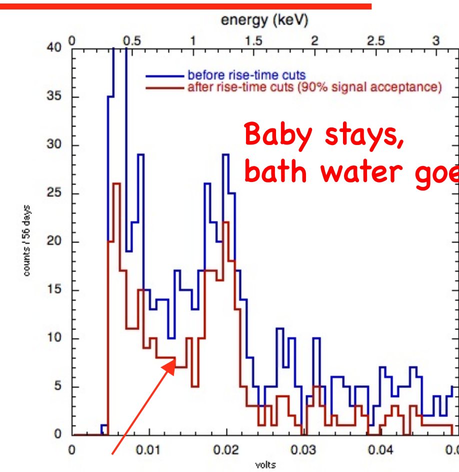
Based on a phenomenon ~40 years old (embarrasing!)

COGENT running
~20 m away from CDMS
(just to keep them honest… ;-)



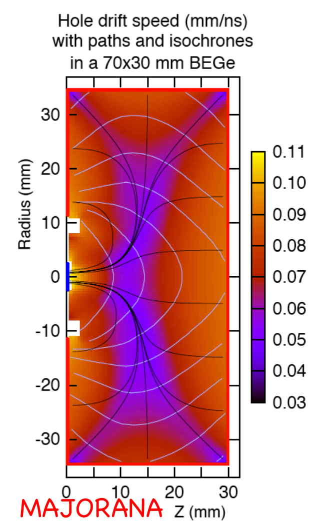
NOT nearly "best effort" yet.
MAJORANA Demonstrator
background goal is ~x1000 lower





Baby stays,
bath water goes

Bulk signal acceptance
monitored down to 1 keVee
via L/K EC peak ratios and
pulser calibrations.
Working on characterizing
surface background rejection
(large exposure required).



MAJORANA
BEGe (ORNL simulation)

Charge
Collection
time
modelled
(small
100 ns
correction)

An old “take-home message” transparency (pre-modulation)

- For m_χ ~7-11 GeV, a WIMP fits the data nicely (90% confidence interval on best-fit WIMP coupling incompatible with zero, good χ^2/dof).

- Red “island” tells you ~where to look (if you believe in WIMPs). Additional knowledge (e.g., more calibrations for fiducial volume and SA/BR) could wiggle it around some (so do the other regions shown, depending on who plots them).

- Not a big deal on its own, it simply means that our irreducible bulk-like bckg is ~exponential (the background model without a WIMP component fares just as well).

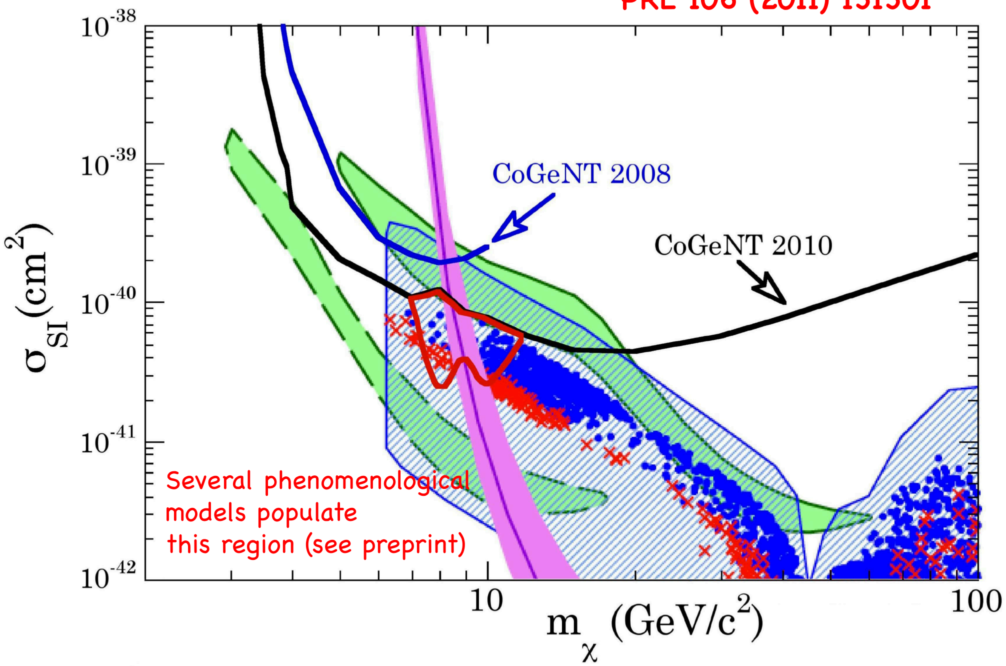
- We presently cannot find an obvious known source. But we can fancy some unexplored possibilities. It is not neutrons, and there is no evidence yet of detector contamination.

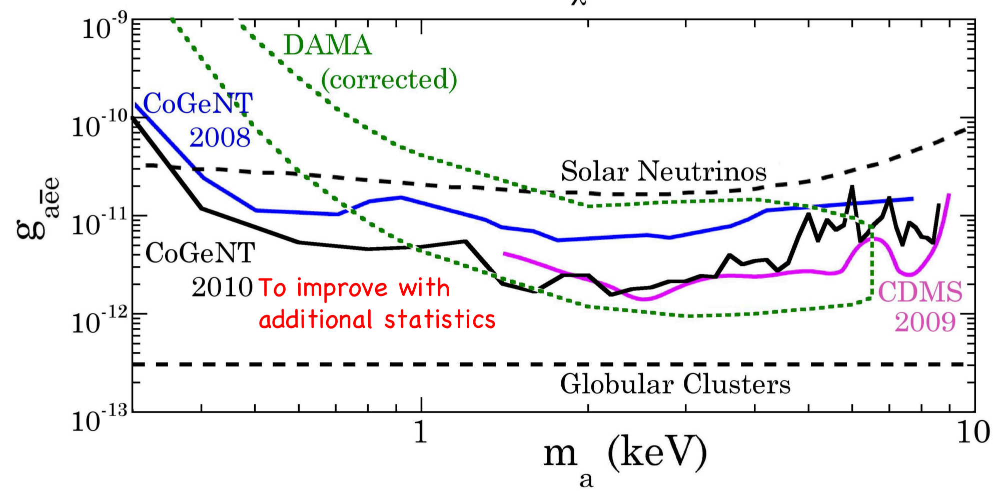
- The low-E excess is composed of asymptomatic **bulk-like** events (very different from electronic noise), coming in at a ~constant rate.

- The possible subject of interest is where we “got stuck” in phase space (a number of curious coincidences there), for a spectrum where most surface events are removed (<- major contributors to low-energy spectrum). Caveat Emptor: without DAMA, would we have models there?

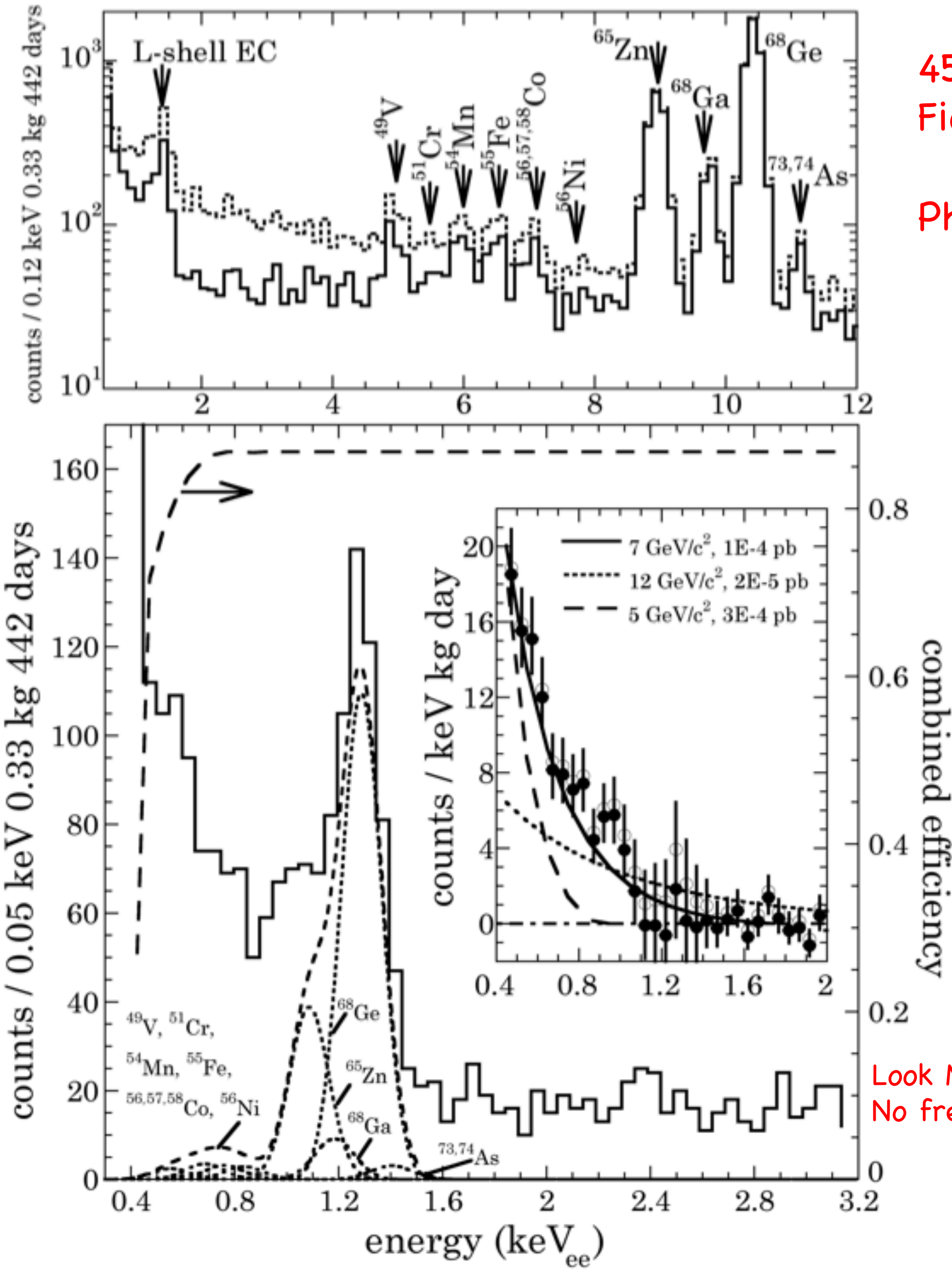
- We will attempt to strip the low-E data from known sources of background after a longer exposure, but all of them seem modest (see preprint). Planned additional calibrations will provide improved information on signal acceptance, background rejection and fiducial volume.

PRL 106 (2011) 131301





Everything was going well until March 17th (Soudan fire)…



458 days collected (442d live)

Fiducial mass~330 grams

Phys. Rev. Lett., in press

JOHN N. BAHCALL PHYSICAL REVIEW VOLUME 132, 1963

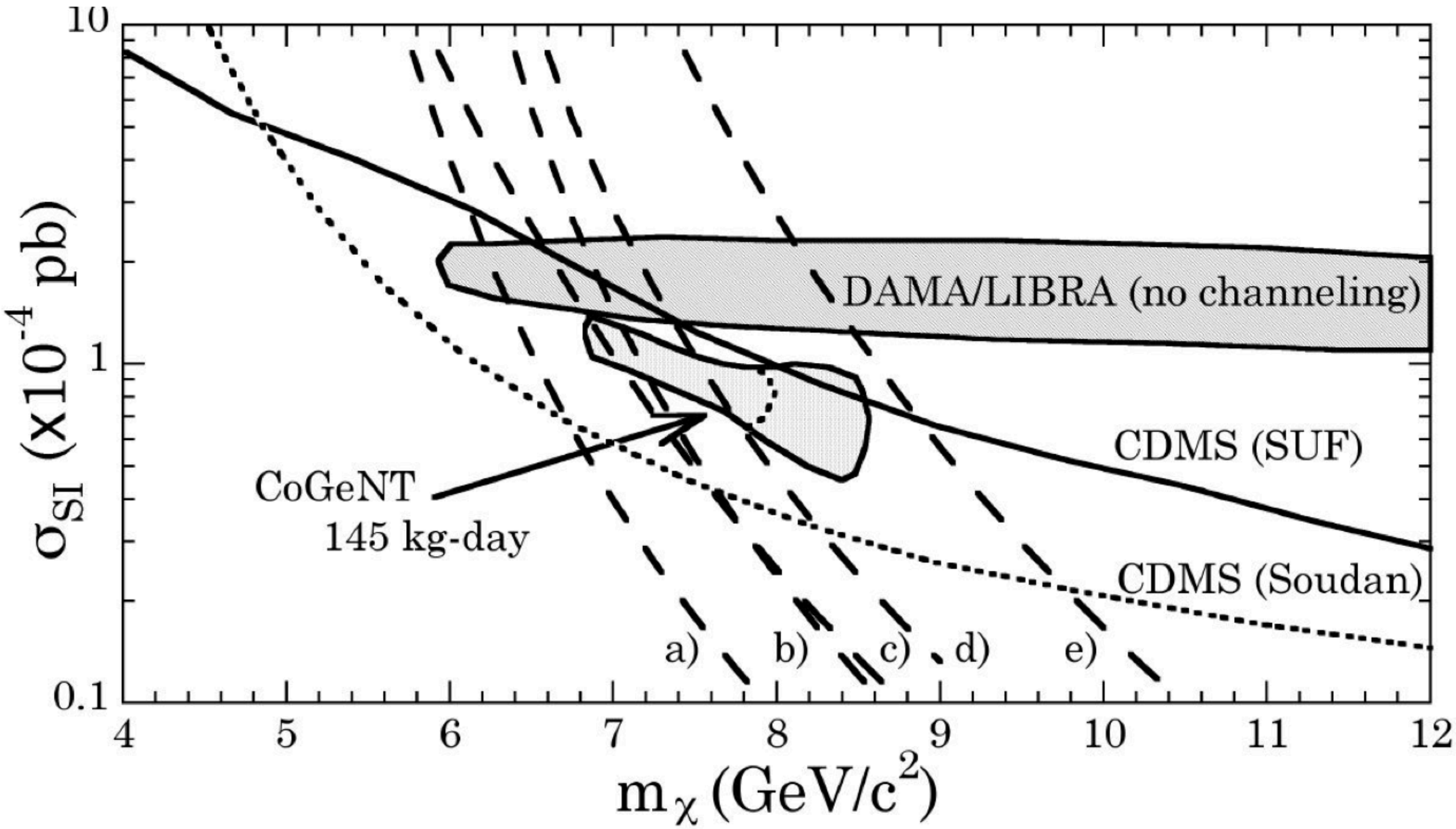
TABLE IV. Comparison of theoretical and experimental L/K capture ratio.

Isotope	$\left(\frac{g(2s')}{g(1s')}\right)^2$	Usual theoretical ratio [Eq. (13)]	Exchange-corrected ratio [Eq. (4)]	Observed ratio	Number of precision experiments
Ar^{37}	1.006	0.0820	0.099	0.100 ±0.003	4
Cr^{51}	1.014[a]	0.0882	0.101	0.1026 ±0.0004	1
Mn^{54}	1.020	0.0898	0.102	0.098 ±0.006	1
Fe^{55}	1.051	0.0936	0.106	0.106 ±0.003	2
Co^{57}	1.017	0.0915	0.103	0.099 ±0.011	1
Co^{58}	1.008	0.0907	0.102	0.107 ±0.004	1
Zn^{65}	1.041[a]	0.0970	0.108	0.119 ±0.007	1
Ge^{71}	1.083	0.103	0.114	0.1175 ±0.002	2
Kr^{79}	1.021[a]	0.102	0.111	0.108 ±0.005	1

Look Ma!

No free-parameters!

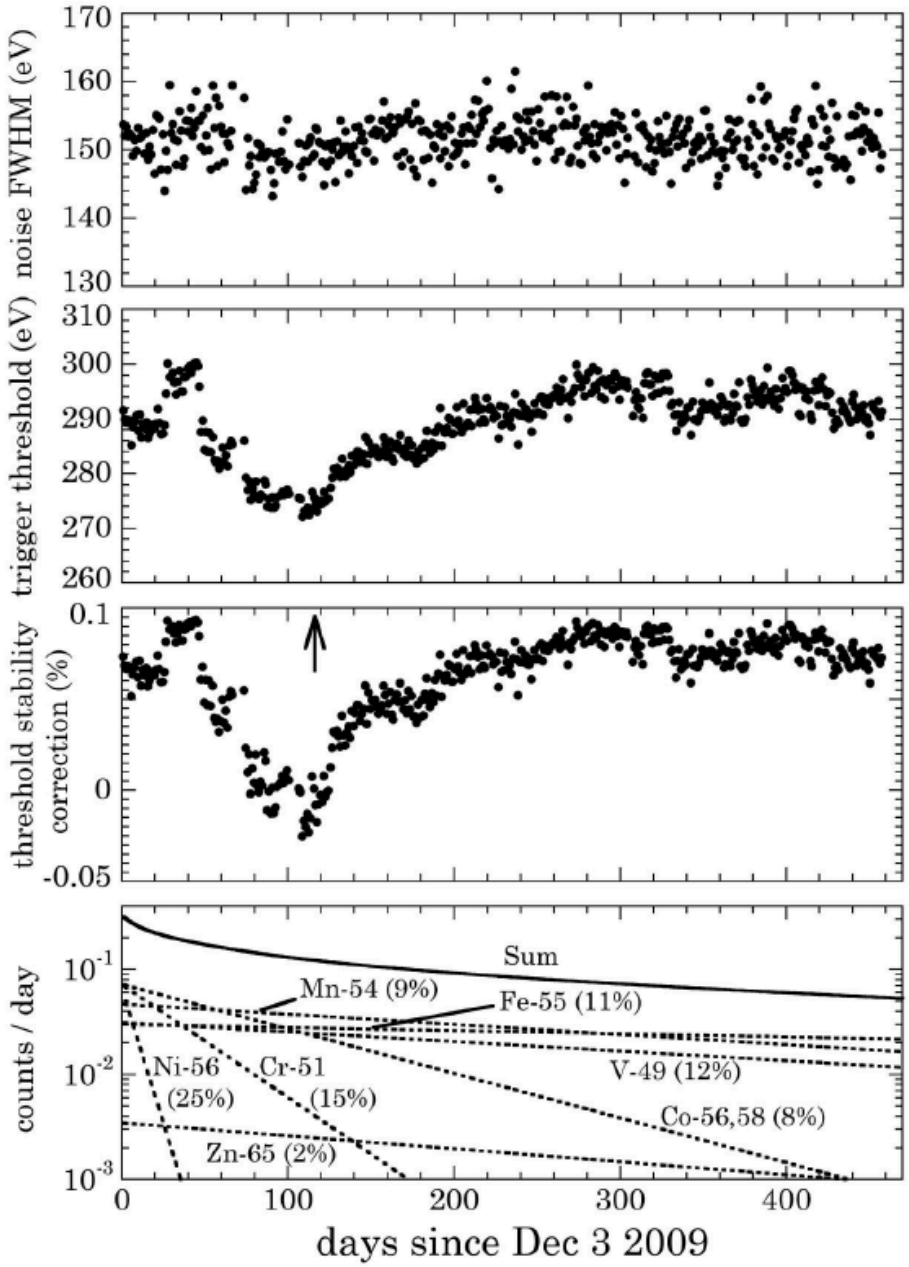
Everything was going well until March 17th (Soudan fire)...



- CoGeNT region considerably smaller than before (but within previous ROI), next to DAMA.

- Most CoGeNT uncertainties not included in this figure

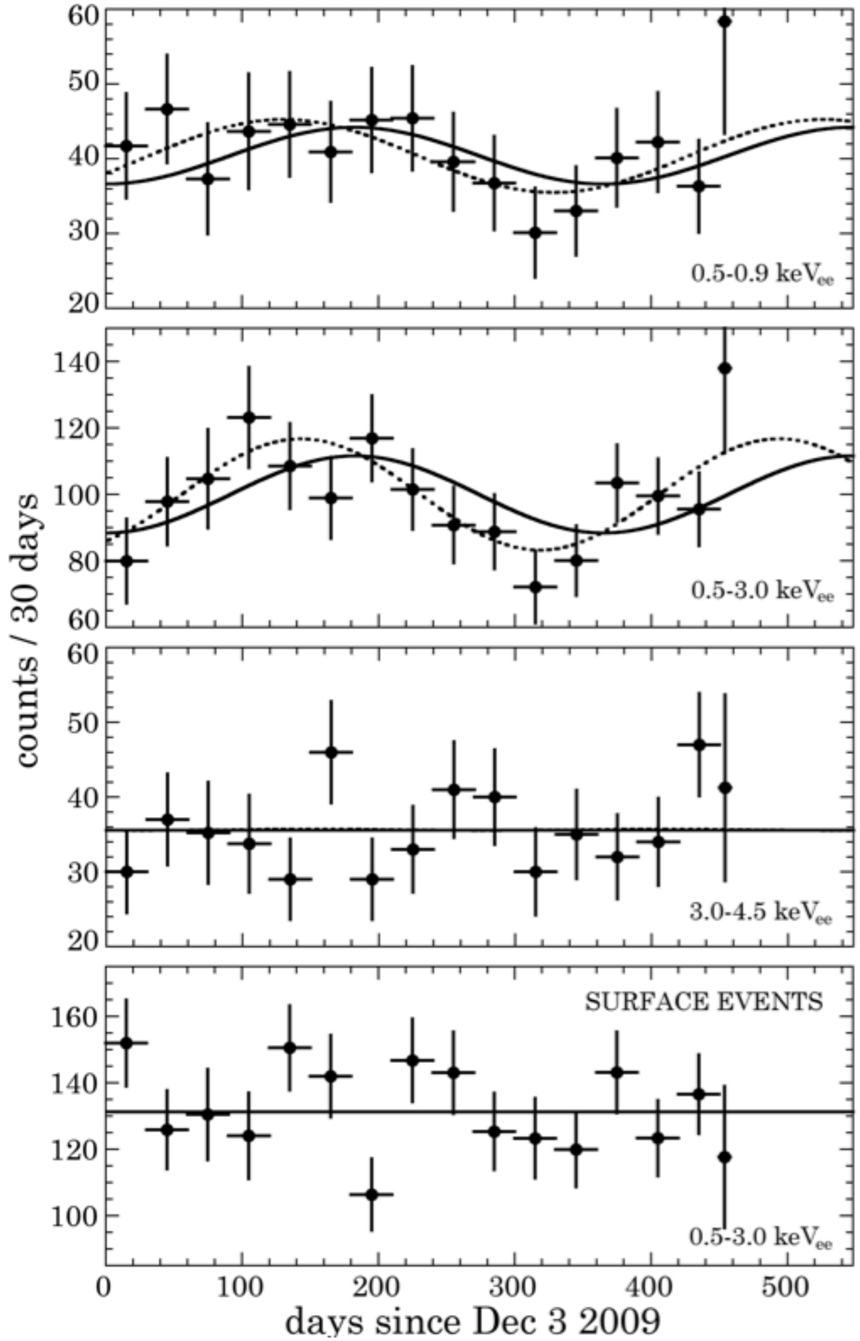
Everything was going well until March 17th (Soudan fire)…



- Excellent stability in detector noise and trigger threshold allows search for annual modulation. Augurs well for other PPC-based searches.

- L-shell peak correction necessary, but prediction is very robust and uncertainties small.

Everything was going well until March 17th (Soudan fire)...



- No fancy estimators tried (several available). Two basic unoptimized methods point at ~2.8σ preference of a modulated rate over the null hypothesis.

- Compatible with WIMP hypothesis expectations (amplitude, phase, period).

- Spectral and temporal analysis are *prima facie* congruent with a light-WIMP hypothesis.

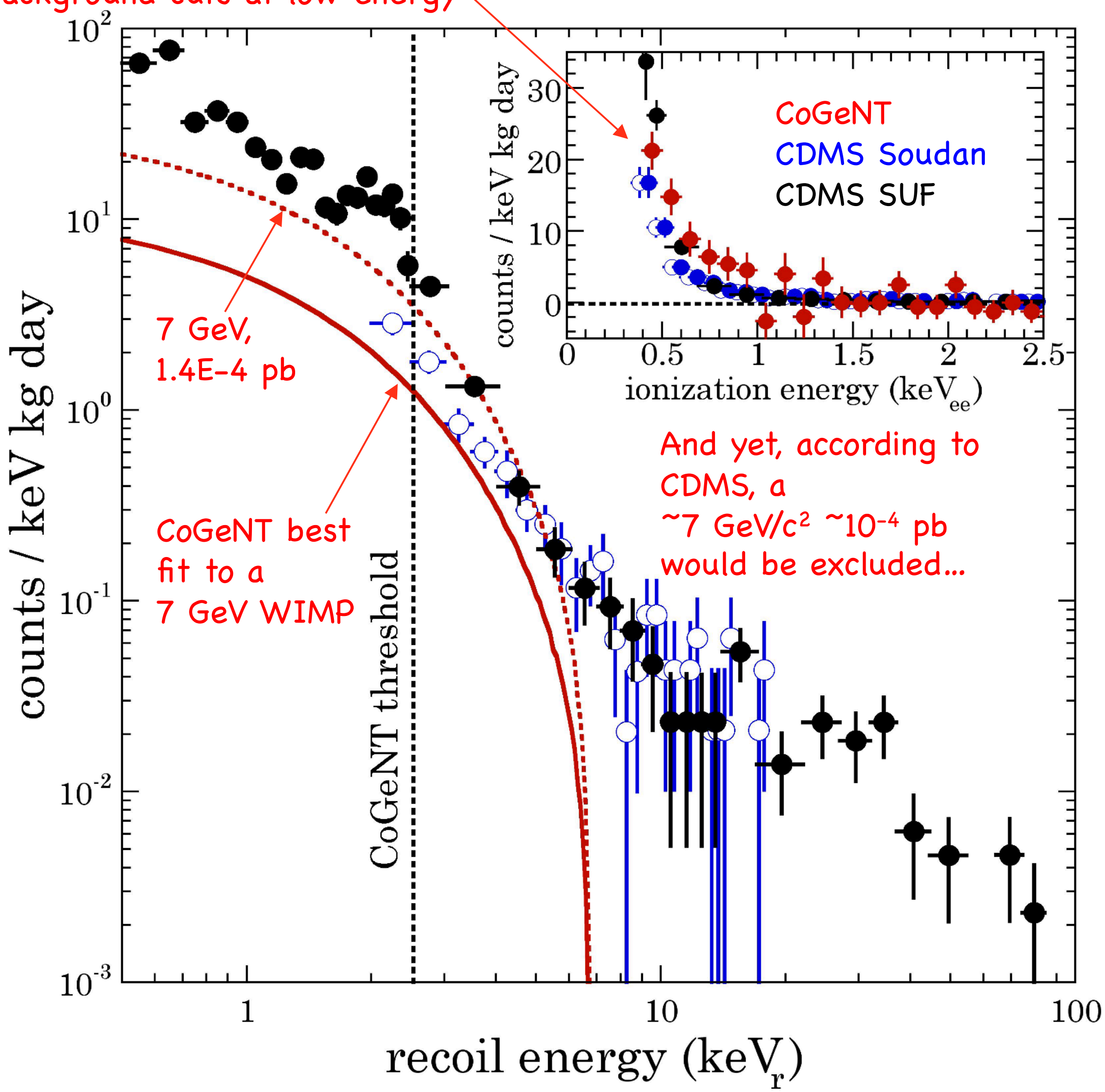
- Modulation absent for surface events and also at higher energies.

- Lots of independent interpretations via data-sharing, but a few are forgetting some basics. Hint: there must be reasons for the experimentalists to always include an exponential background in their models...

Can we make sense of the light-WIMP situation?

CoGeNT and CDMS arrive to similar irreducible spectra via orthogonal background cuts at low-energy

CDMS low-E recent results:



Critique (arXiv:1103.3481):

- Uncertainties in energy scale and method of calibration
- Uncertainties (and some clear WAGs) in background estimates
- Uncertainty in residual rate from cut selection: limits are mainly extracted from short exposure in a single detector (T1Z5). An alternative CDMS analysis during a different period in Soudan finds a 70% larger irreducible low-E rate for it (!!), but this issue is absent for a second detector (T1Z2).

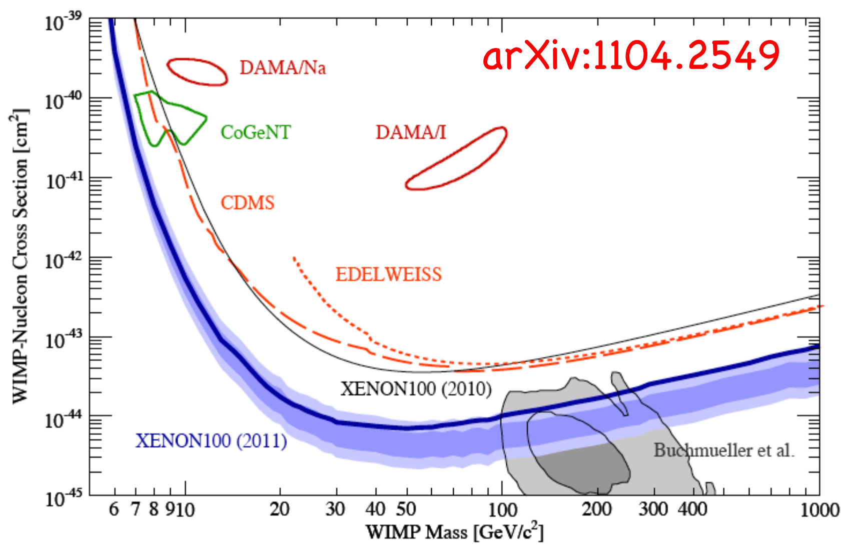
Is T1Z5 stable enough? What is the uncertainty in these limits from the choice of cuts?

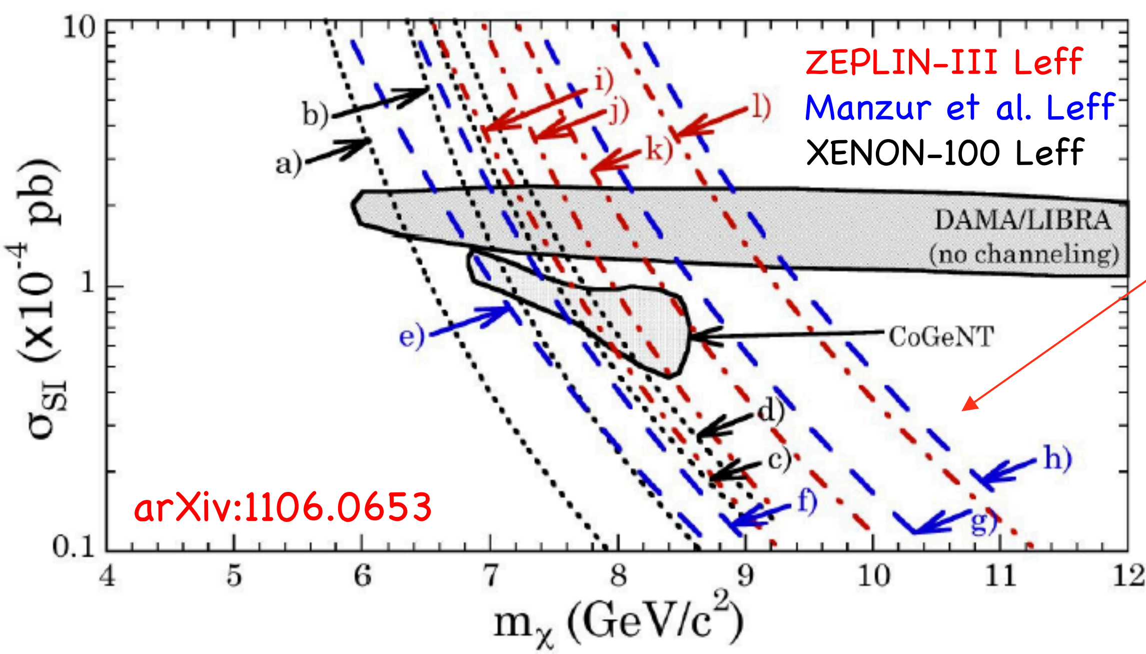
- Direct comparison of CoGeNT-CDMS irreducible spectra initially avoided (a much more straightforward indicator of relative sensitivity for experiments sharing a target).

Can we make sense of the light-WIMP situation?

XENON-100 low-E recent results:

Compare these two figures:



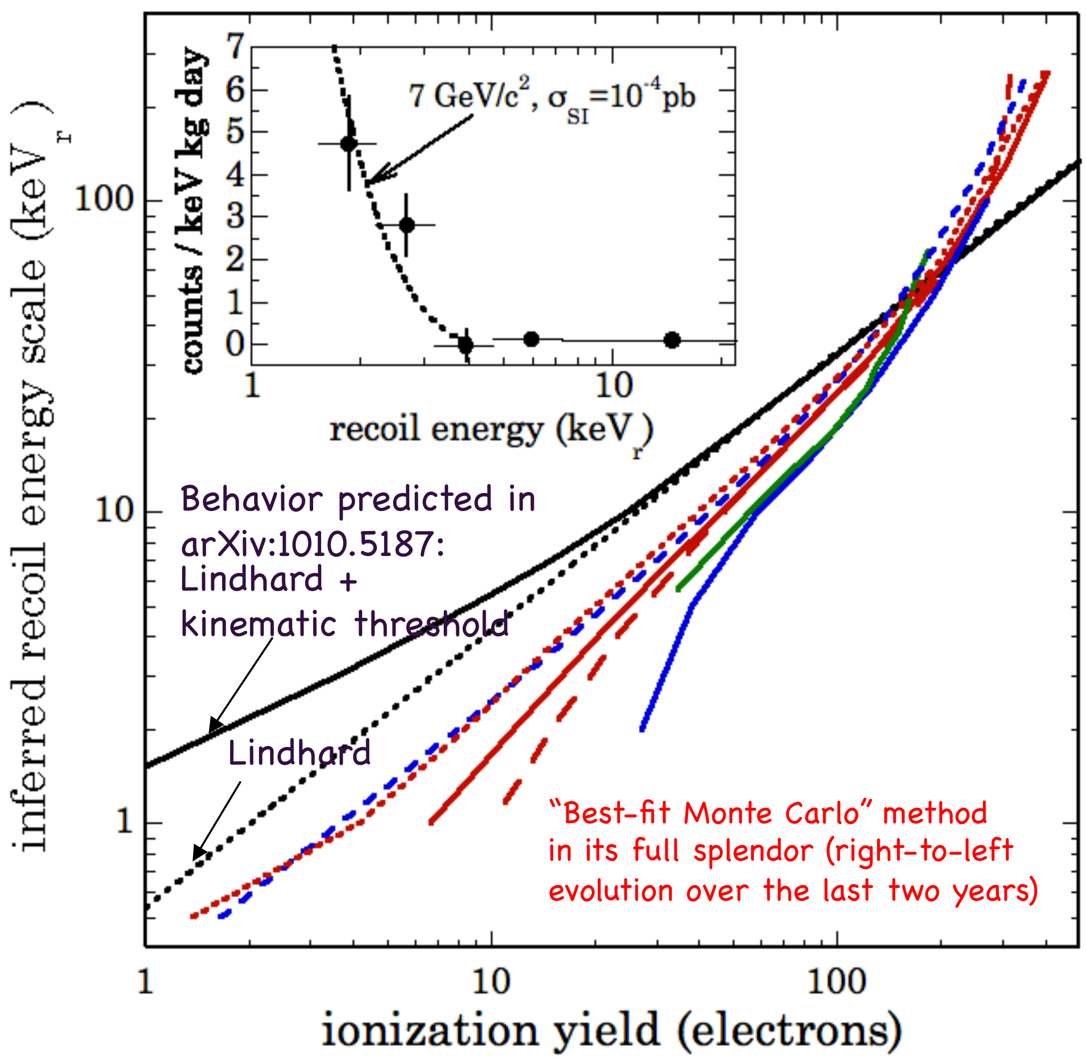


Critique (arXiv:1106.0653):

- Recent L_{eff} measurement represents progress, but still several important loose ends (energy resolution and L_{eff} **are not** independent magnitudes)
- Selective display of DAMA region (uncertainties not included)
- Issue with numerical calculation of uncertainties (does not pass self-consistency test = previous XENON100 results)
- Discussion of uncertainties and strong assumptions made (Leff, second-guessed events, Poisson vs. sub-Poisson) broomed under the carpet.
- Most recent ZEPLIN-III L_{eff} (in situ measurement) still pointing at a vanishing value at few keV_r.
- Low-energy Am/Be rates: are they what is expected? Crucial for credibility of claimed sensitivity.

Can we make sense of the light-WIMP situation?

XENON-10 low-E recent results:



An additional ~1 keV shift in energy scale turns "robust exclusion" into "evidence" for a light-WIMP (hey, why stop now?)

Critique (arXiv:1106.0653, 1010.5187):

- Very promising method.
- However, as is stands today: **pure drivel.**
- Some entirely misleading statements about "interesting" population of low-energy events.
- Energy scale employed clashes (by ~three orders of magnitude) with existing measurements of ionization yield in very low-energy Xe ion-surface literature.
- Seems like some XENON10 authors do not mind contradicting themselves. Continuously.
- No excuse for this (this energy scale can be measured via (n_{th},γ) calibrations in the relevant range)

Can we make sense of the light-WIMP situation?

XENON-10 low-E recent results:

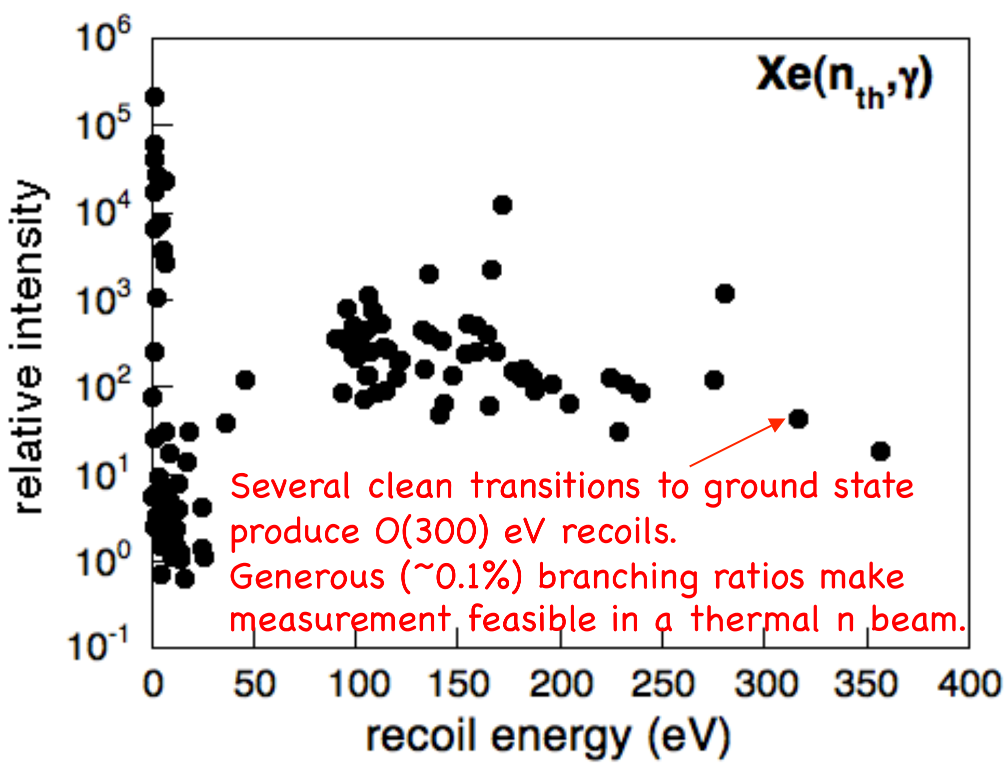
What an experimentalist would do: measure the energy scale (i.e., calibrate the S2 channel in the relevant energy range), THEN attempt to produce an exclusion.

Xenon is a target favorable to use of an old calibration method:

PHYSICAL REVIEW A VOLUME 11, NUMBER 4 APRIL 1975

Energy lost to ionization by 254-eV ^{73}Ge atoms stopping in Ge†

K. W. Jones and H. W. Kraner
Brookhaven National Laboratory, Upton, New York 11973
(Received 30 July 1974)



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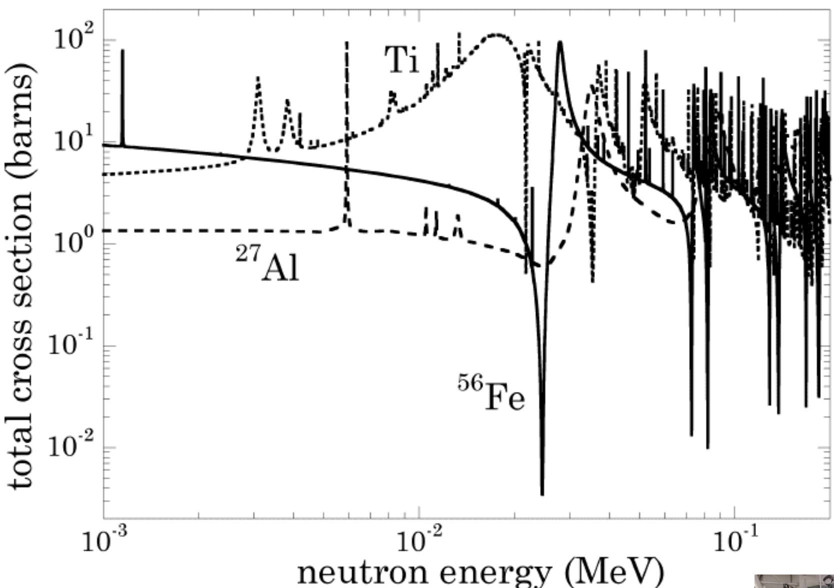
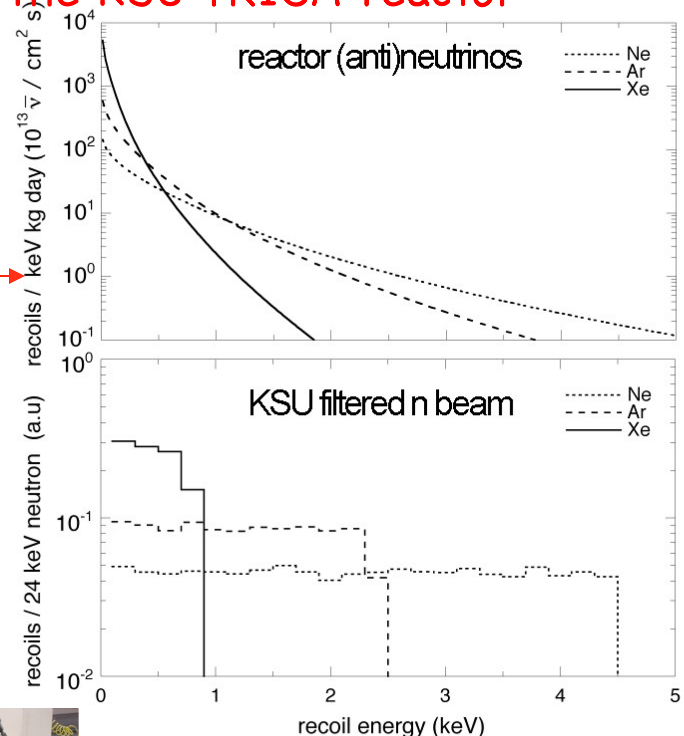
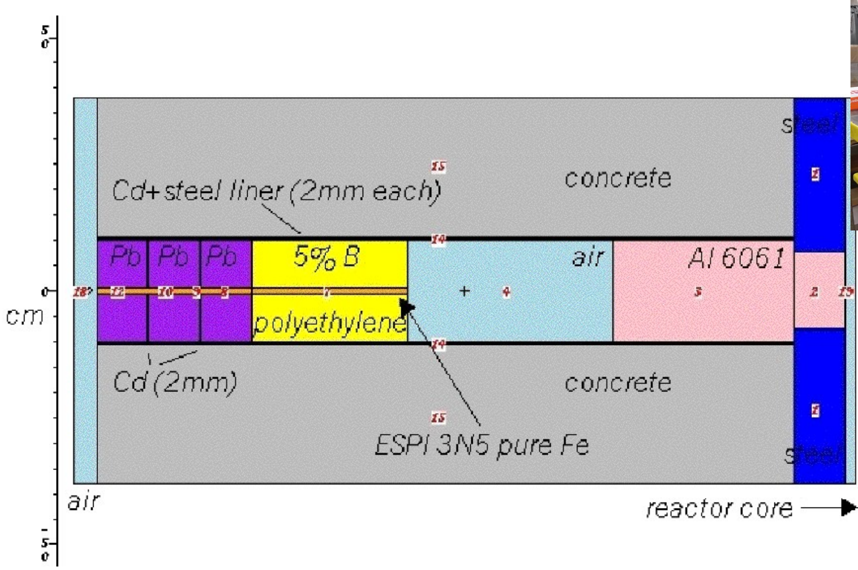
A dose of our own medicine:
PPC sub-keV recoil calibrations at the KSU TRIGA reactor



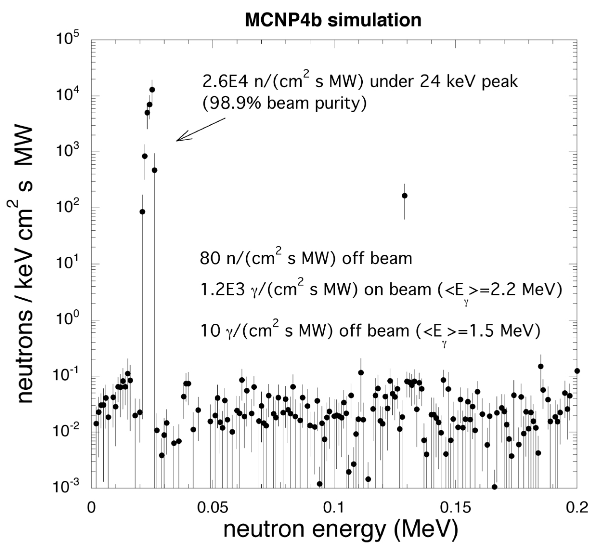
24 keV n's mimic reactor ν's



Fe-Al filter + Ti post-filter



MCNP filter design



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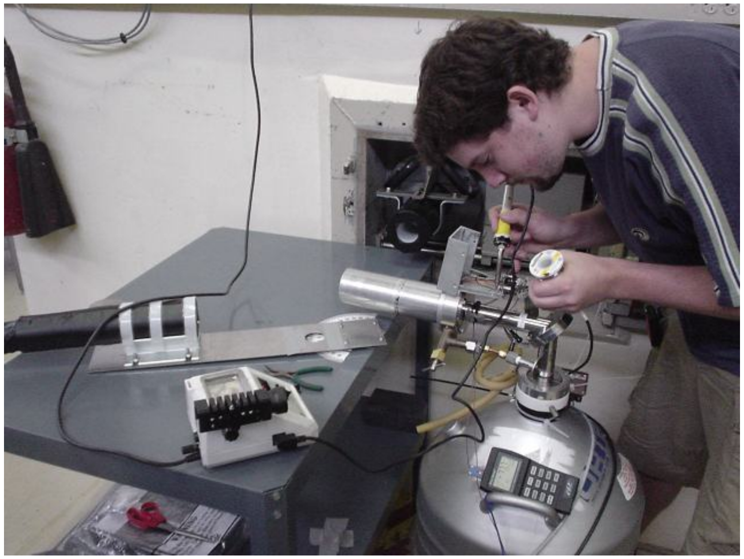
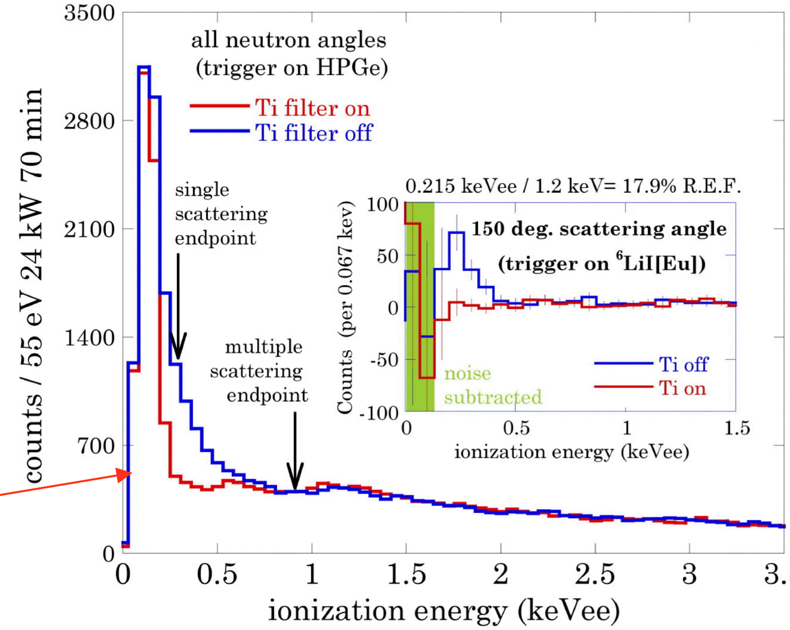
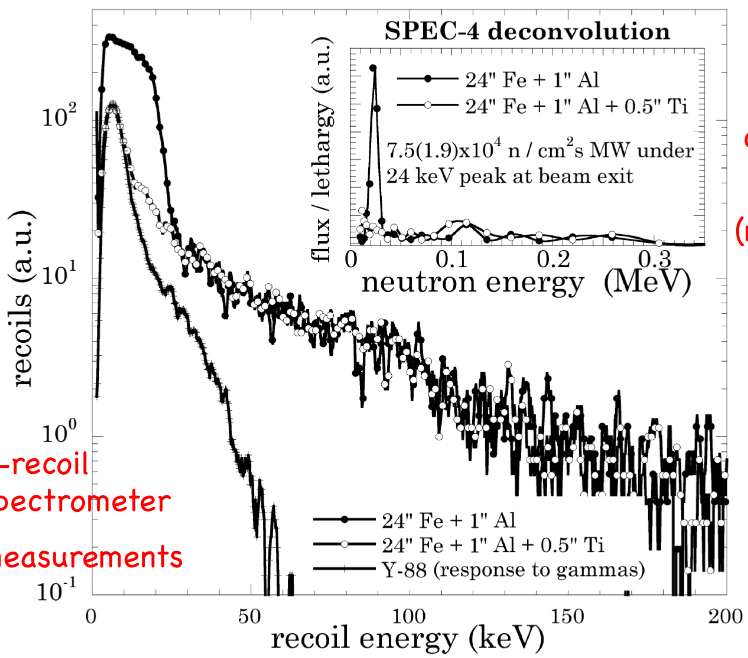


Ti post-filter "switches off" the recoils, leaving all backgrounds unaffected

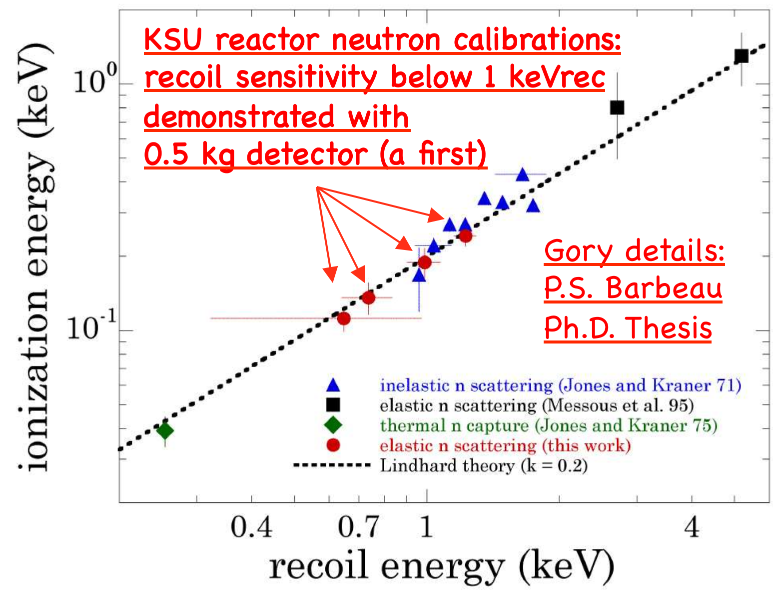




p-recoil spectrometer measurements

Beam characterization studies

(nucl-ex/0701011)

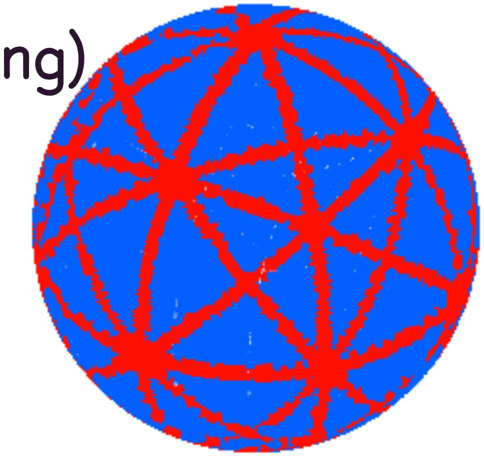


KSU reactor neutron calibrations: recoil sensitivity below 1 keVrec demonstrated with 0.5 kg detector (a first)

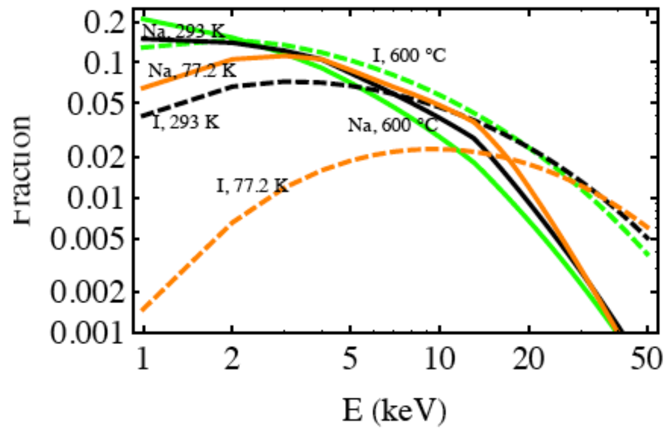
Gory details: P.S. Barbeau Ph.D. Thesis

Can we make sense of the light-WIMP situation?

DAMA uncertainties (Q_{Na}, channeling)

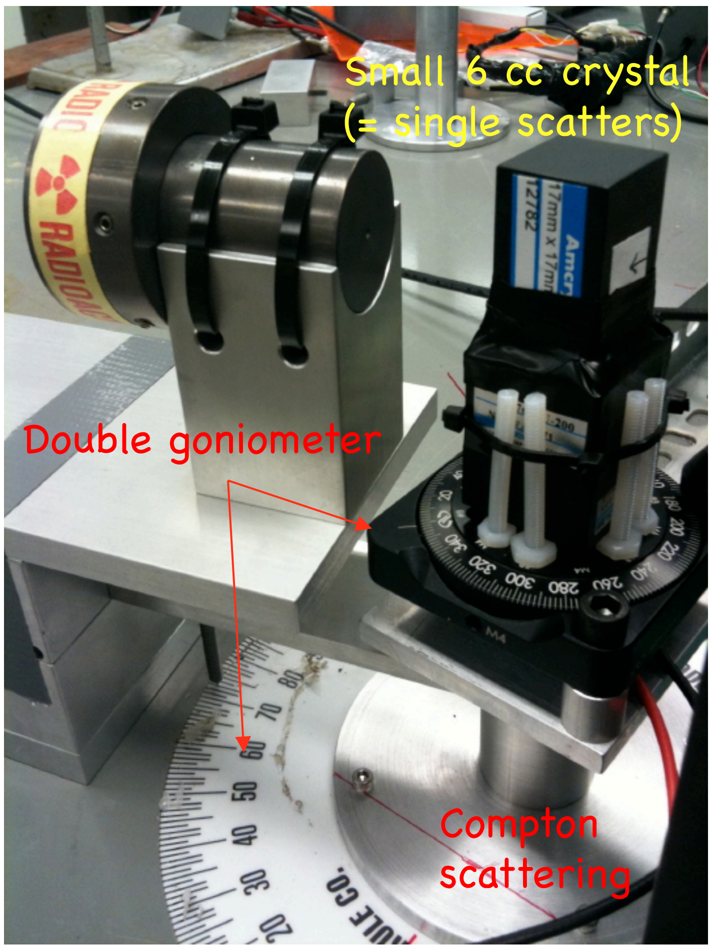


- Ongoing precision measurements of CsI[Na] and NaI[Tl] quenching factor and <u>CHANNELING</u> at UC to cast light on effects of methodology, kinematic cutoff, etc.

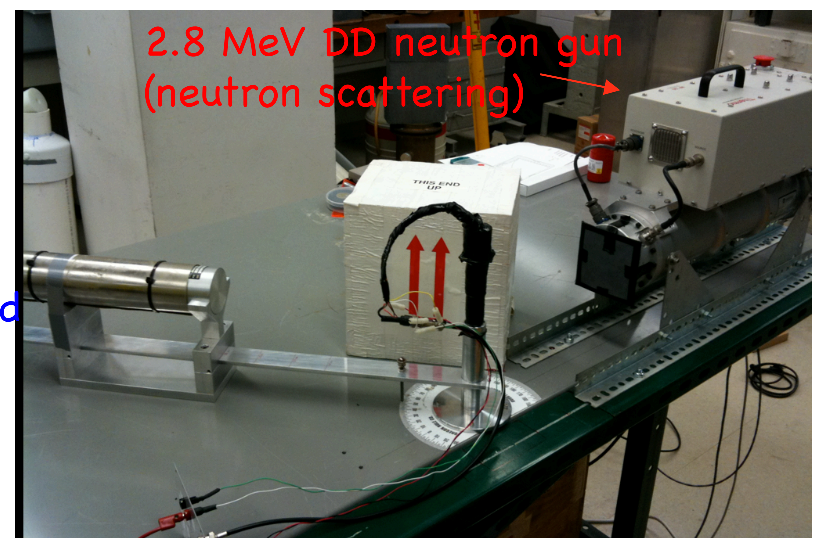


Bozorgnia, Gelmini & Gondolo
arXiv:1006.3110v1

Certain models predict non-negligible channeling: it <u>must be measured!!!</u>



* Response to both electron and nuclear recoils measured.
*Use of ultra bialkali PMT (40% QE) to avoid threshold effects (x3 light yield of previous meas.)
*Crystal with known (growth) axis orientation.



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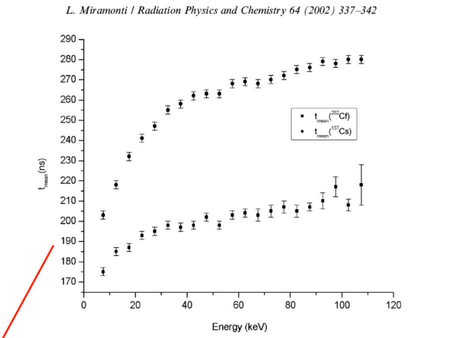
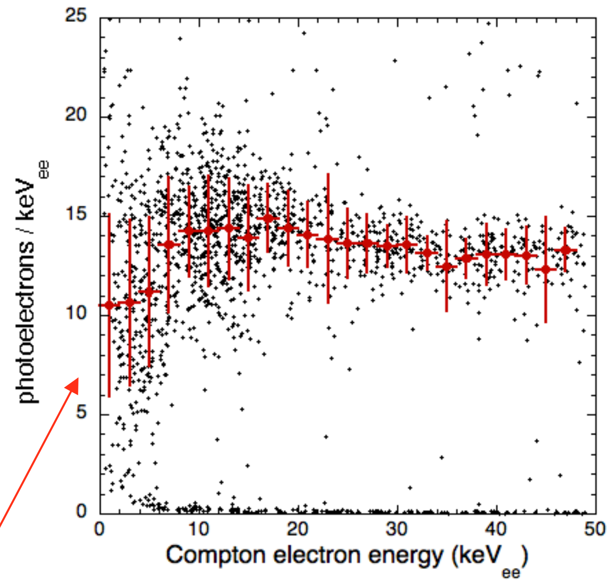
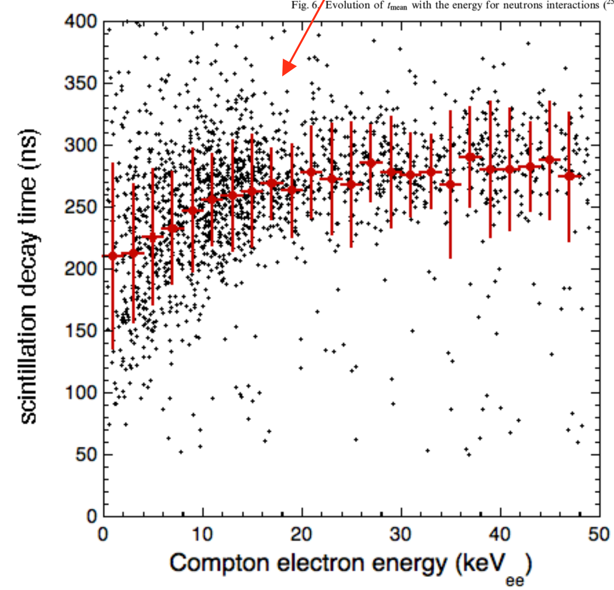


Fig. 6. Evolution of t_{mean} with the energy for neutrons interactions (^{252}Cf) and for gamma interactions (^{137}Cs).

PRELIMINARY DATA





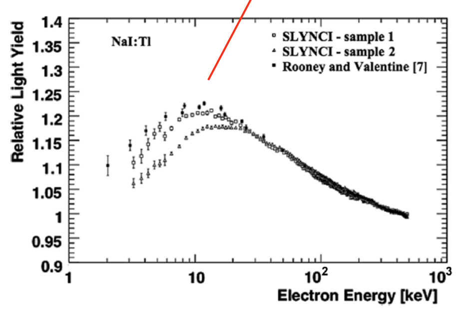


Fig. 8. Light yield response as a function of electron energy for NaI(Tl). Data are arbitrarily normalized to each other at 444 keV.

Compton scattering measurements reveal subtle low-E non-linearities expected for NaI[Tl], and excellent light yield via use of ultra-bialkali PMT (up to 15 PE/keV$_{ee}$, compare to 5 PE/keV$_{ee}$ in latest -Chagani 2008-)

Can we make sense of the light-WIMP situation?

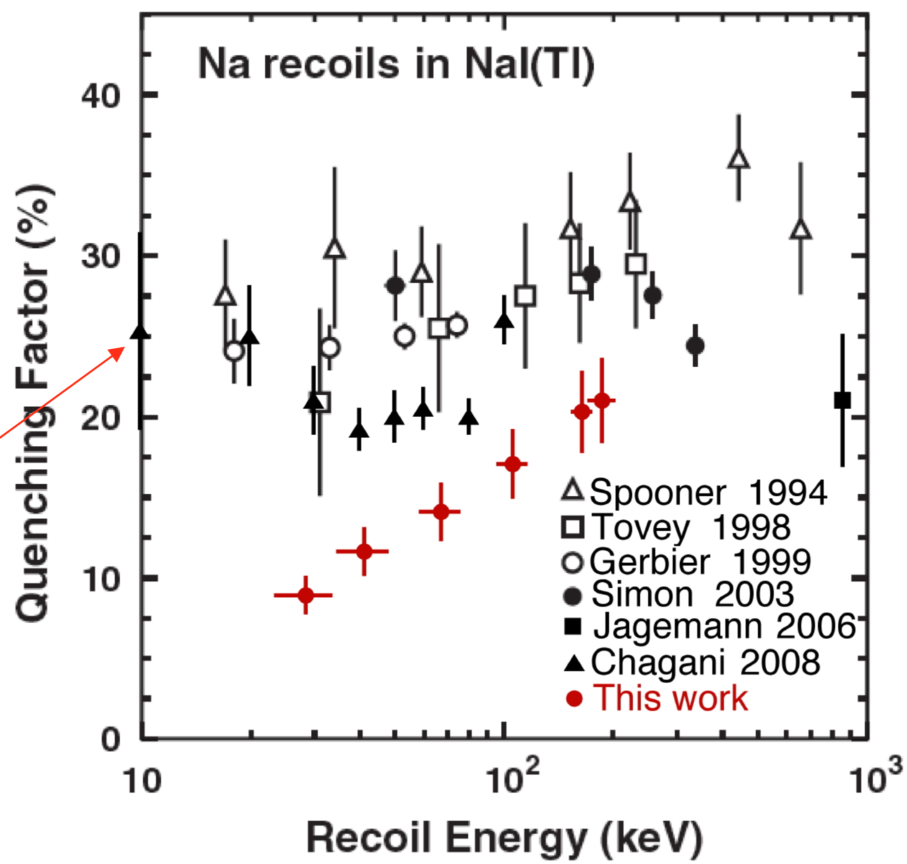
DAMA uncertainties (Q_{Na}, channeling)

- Ongoing precision measurements of CsI[Na] and NaI[Tl] quenching factor and **CHANNELING** at UC to cast light on effects of methodology, kinematic cutoff, etc.

PRELIMINARY DATA

Discussion of threshold effects affecting quenching factor measurements: Collar, arXiv:1010.5187

(you cannot expect a proper measurement of Q at 10 keV_r with just 5 PE/keV_{ee} and a ~100 cc crystal...)



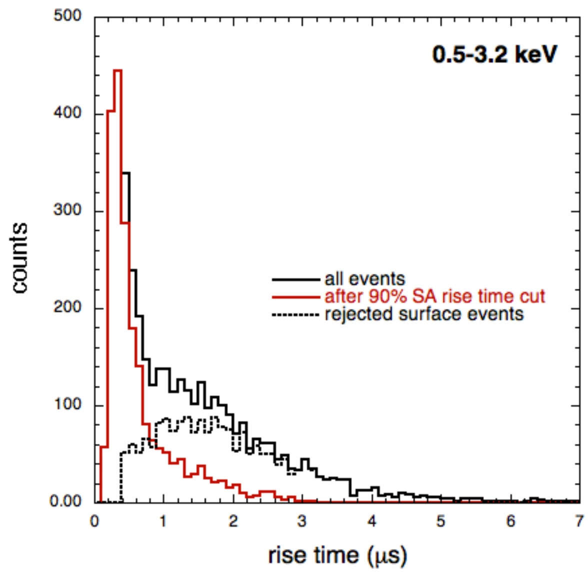
Surprisingly small quenching factor... (in a very clean measurement, away from threshold effects and with negligible multiple scattering).

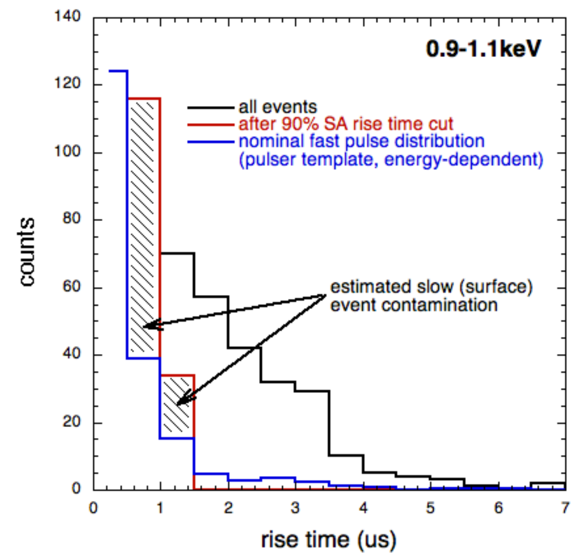
Several previous measurements do not account for NaI[Tl] non-linearity in electron recoil response.

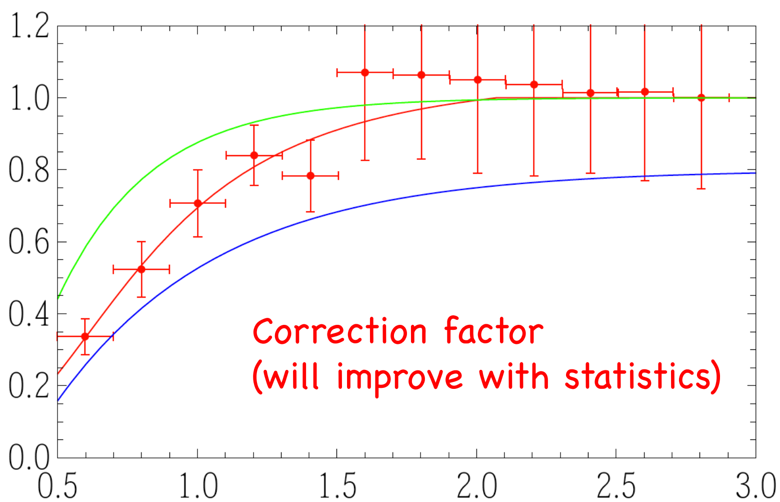
Can we make sense of the light-WIMP situation?

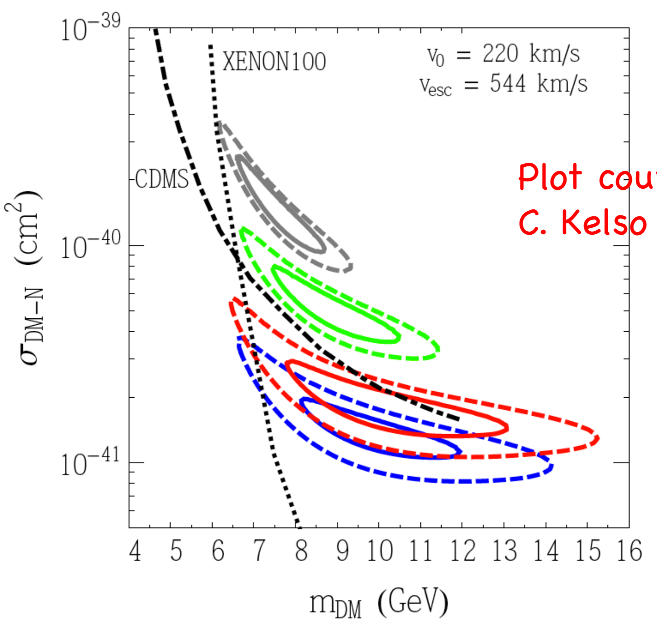
CoGeNT uncertainties (e.g., surface event rejection next to threshold)

PRELIMINARY (work in progress, not an exact science yet)





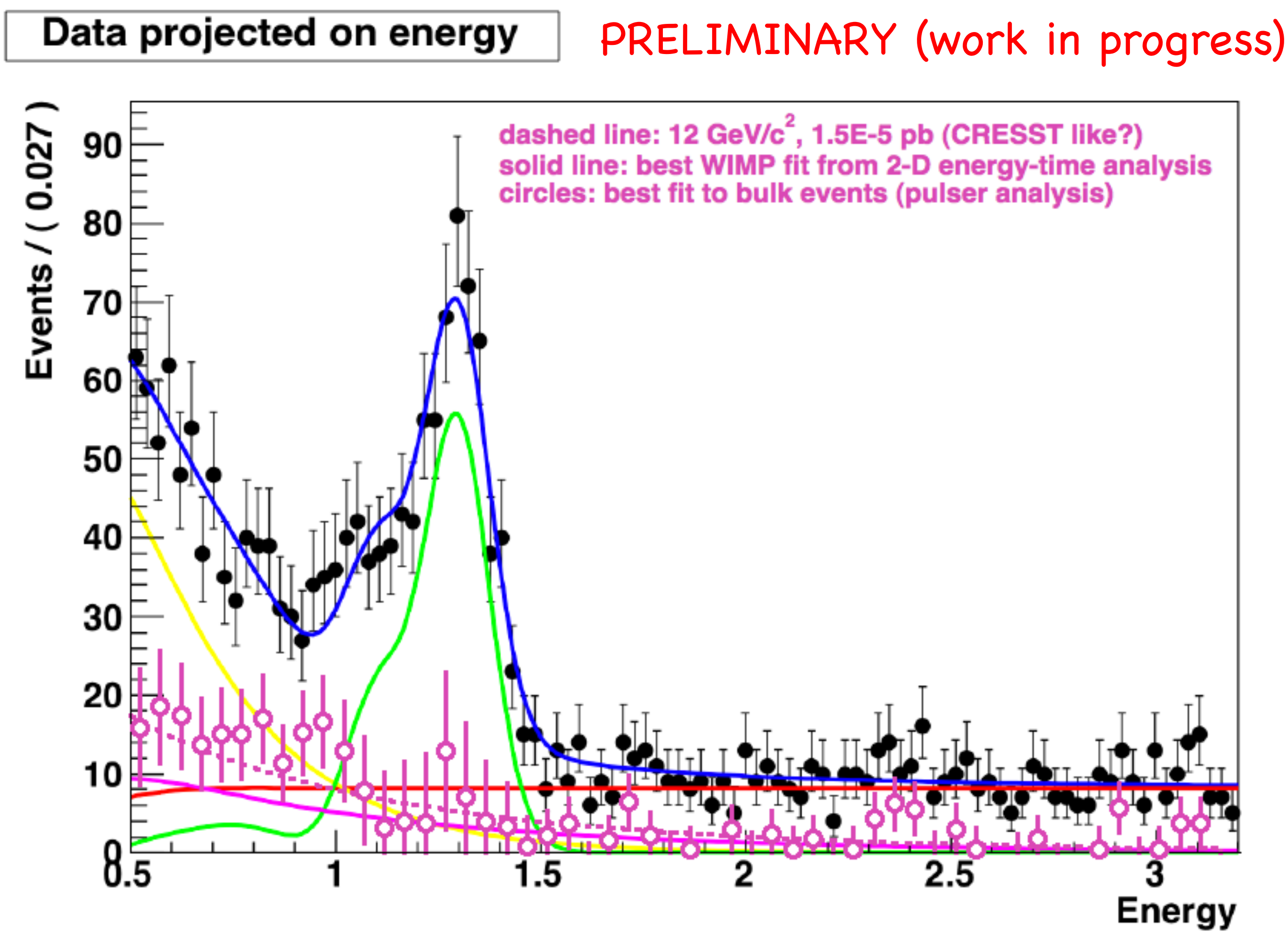




Plot courtesy
C. Kelso

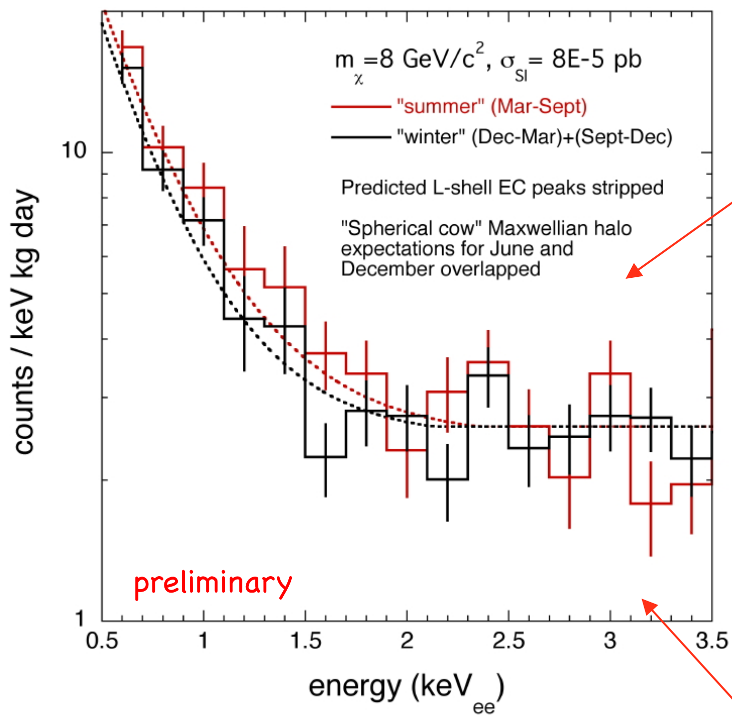
Can we make sense of the light-WIMP situation?

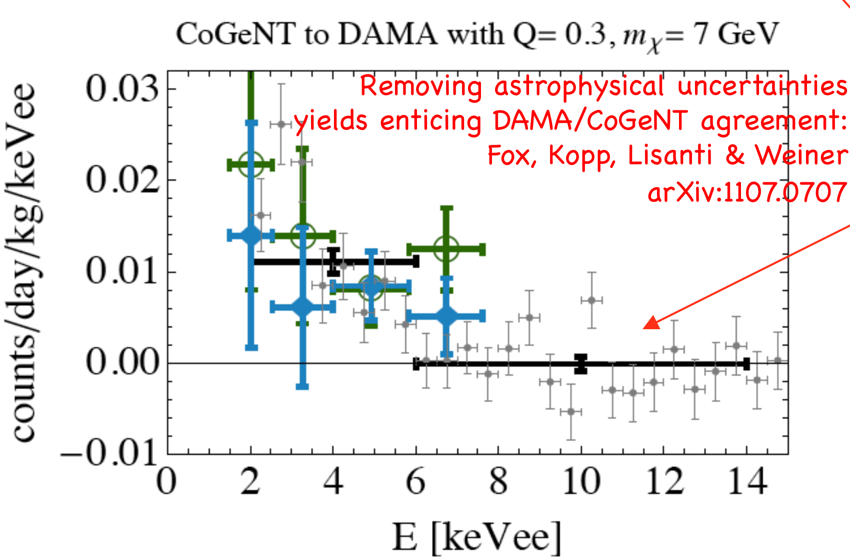
CoGeNT uncertainties (e.g., surface event rejection next to threshold)



Spectral and modulation analysis in CoGeNT seem to point to a similar WIMP mass & coupling, BUT then modulated amplitude is <u>definitely not</u> what you would expect from a vanilla halo (way too large).

Are DAMA, CoGeNT and CRESST in agreement, or not at all?





- What is the exact endpoint of the CoGeNT modulation? (hard to tell w/ just 15 mo)

- Surface background contamination next to threshold (analysis starting to be possible now with enough statistics) -> shifts CoGeNT ROI to lower coupling and larger mass (CRESST favored region?).

- Channeling at few %? Contemplated by some models, if you read papers carefully... What is the value of Q_{Na}?

- CoGeNT modulation larger than expected? (again, hard to tell after just 15 mo). If so, what happens to the DAMA ROI? Is a non-Maxwellian halo imperative?

- <u>Most importantly</u>, CoGeNT is now taking data again... (perhaps we should wait to see what happens next there before asking so many questions... 3σ effects come and go)

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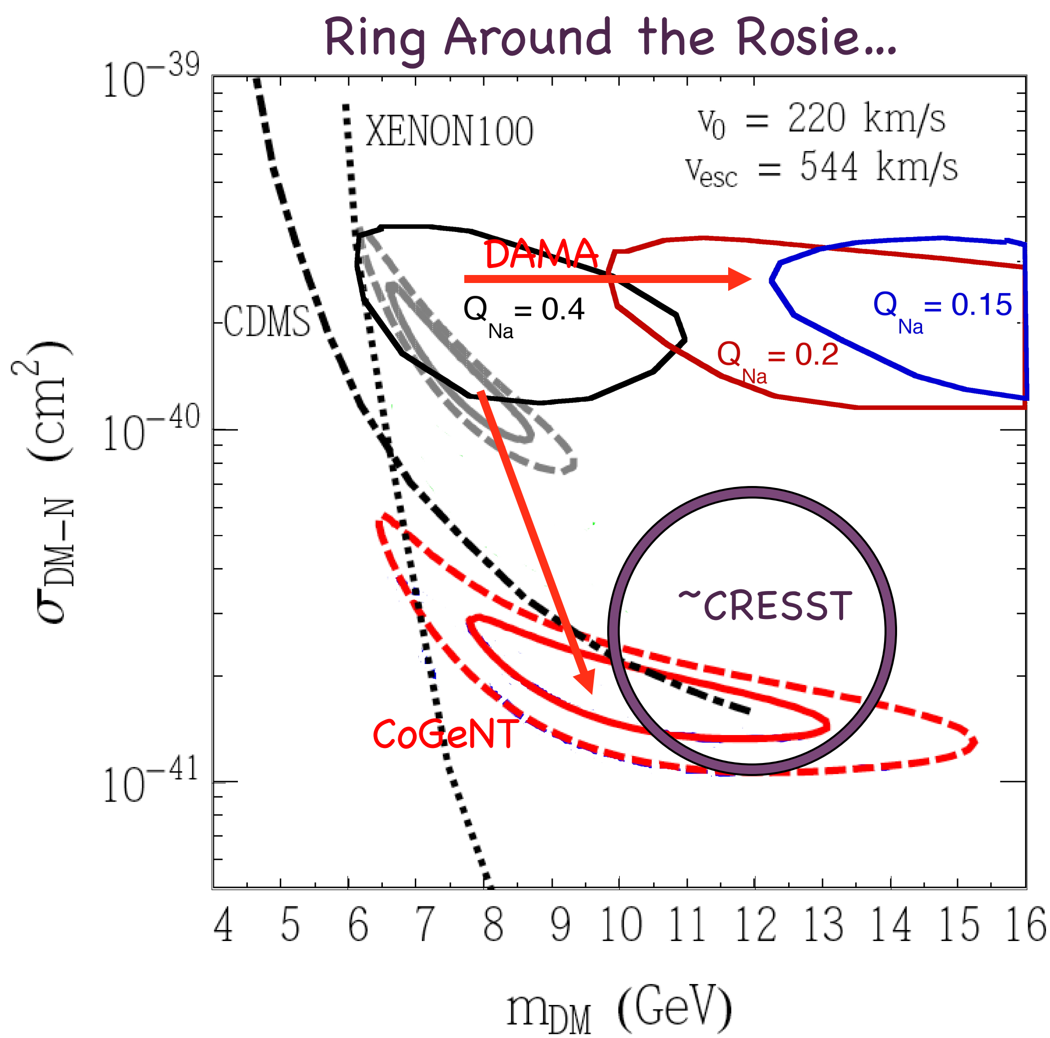
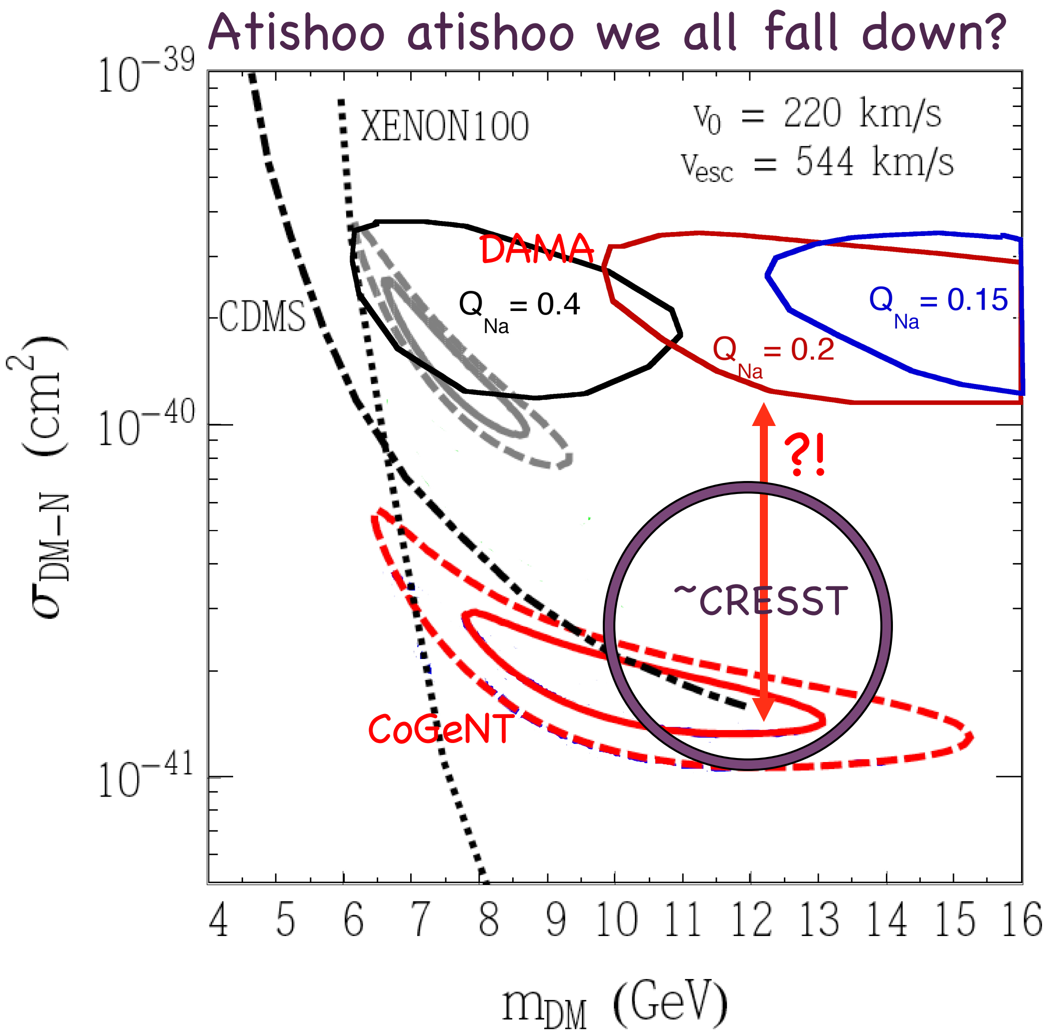


- Including surface event contamination next to threshold brings spectral and modulation CoGeNT analyses in close agreement at ~10-15 GeV.
- However, Q_{Na}~0.4 seems extremely unlikely after UC measurement, regardless of theoretical prejudice (see arXiv:1007.1005).
- … and the modulation observed by CoGeNT would be order-of-magnitude larger than expected from a standard Maxwellian halo.

Are DAMA, CoGeNT and CRESST in agreement, or not at all?



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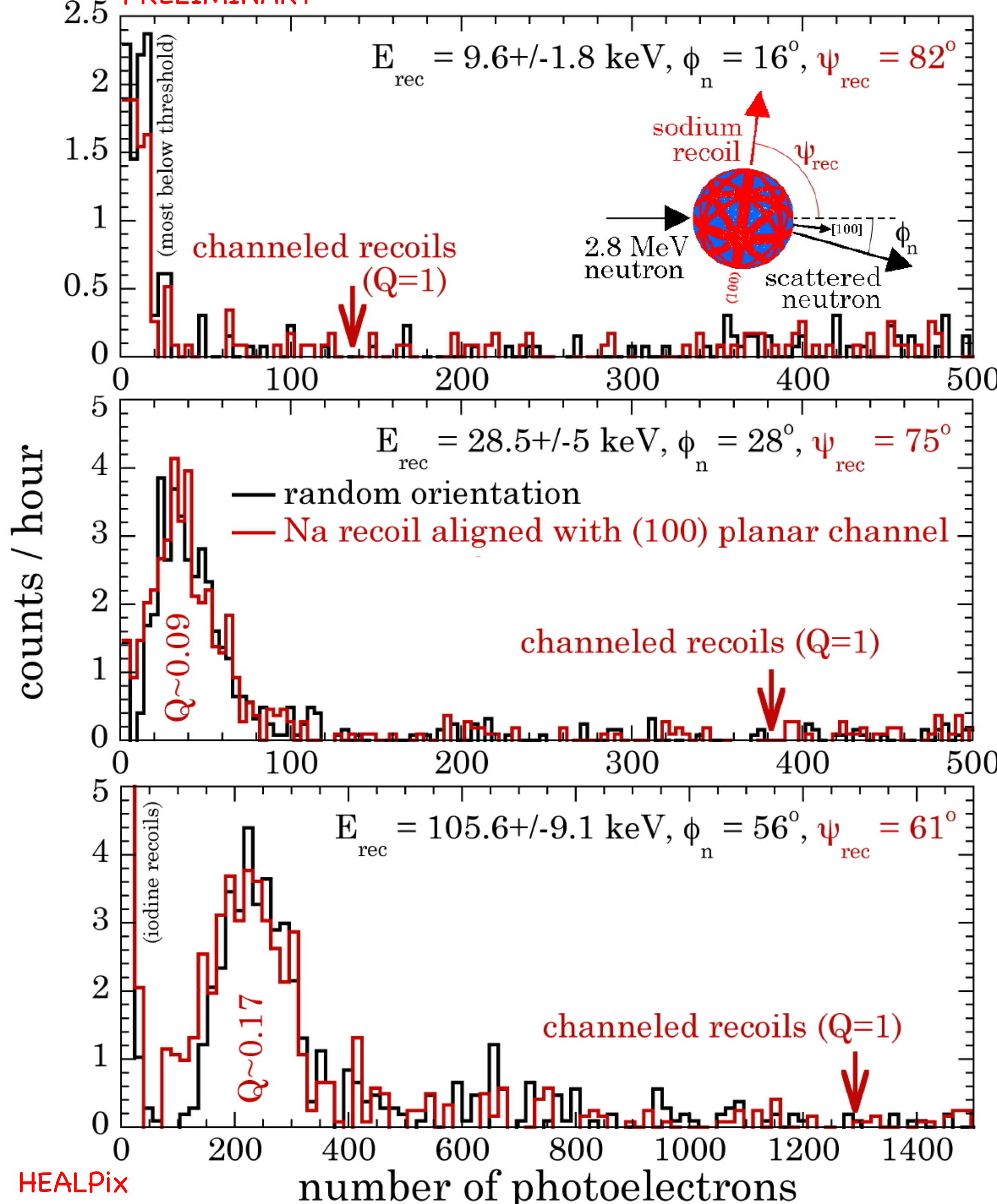
- ...DAMA floats an order of magnitude higher in coupling than COGeNT/CRESST. Are there ways to reconcile?:
  * Channeling
  * IVDM
  * streams, dark disk, etc...

(let us remember that DAMA is placed in σ vs m_χ space via the assumption of a Maxwellian halo: if modulation is really much larger, DAMA's σ becomes smaller...)

Are DAMA, CoGeNT and CRESST in agreement, or not at all?

PRELIMINARY



HEALPix
Courtesy N. Bozorgnia

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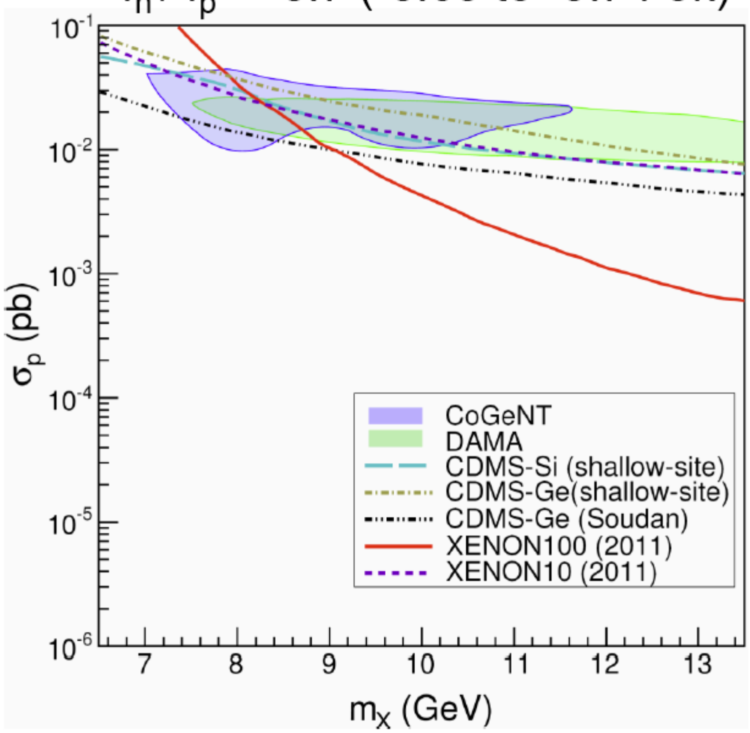
Are DAMA, CoGeNT and CRESST in agreement, or not at all?

ISOSPIN-VIOLATING DARK MATTER

Giuliani (2005); Chang, Liu, Pierce, Weiner, Yavin (2010); Feng, Kumar, Marfatia, Sanford (2011)

$f_n / f_p = -0.7$ (-0.63 to -0.74 ok)



Very intriguing possibility
(but let us hope XENON "tension" is not the motivation for such departures... we are not quite there yet)

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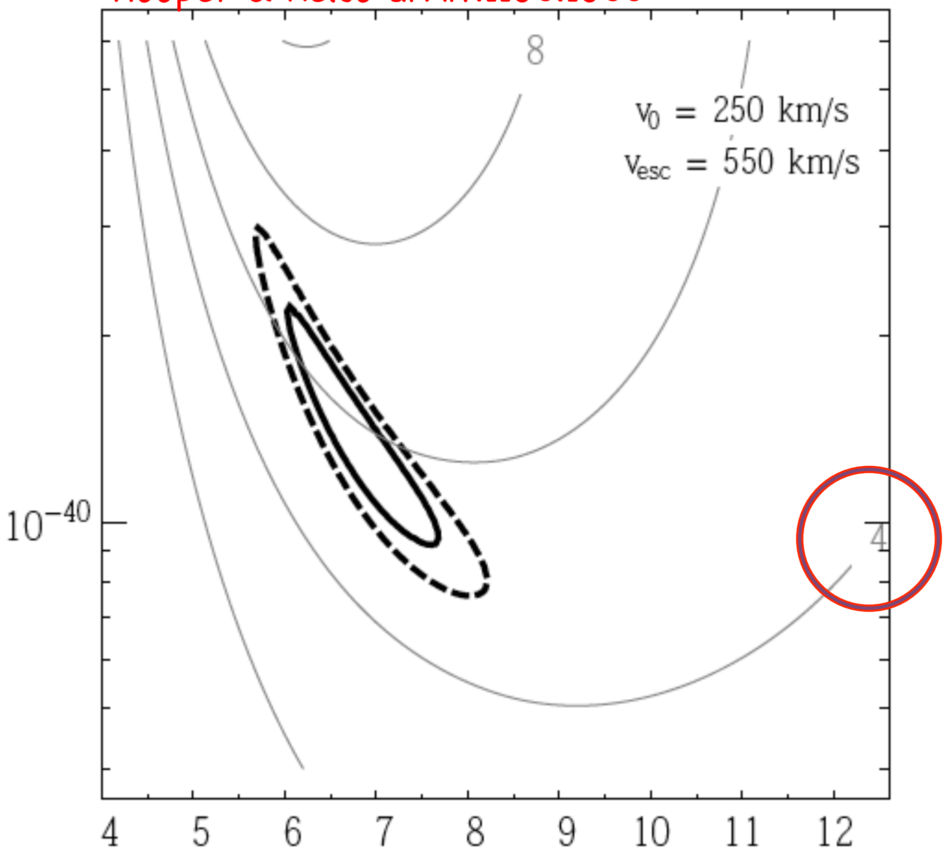
Hooper & Kelso arXiv:1106.1066



Some interesting incipient work:
A.M. Green: arXiv:1109.0916
Natajaran, Savage & Freese: arXiv:1109.0014

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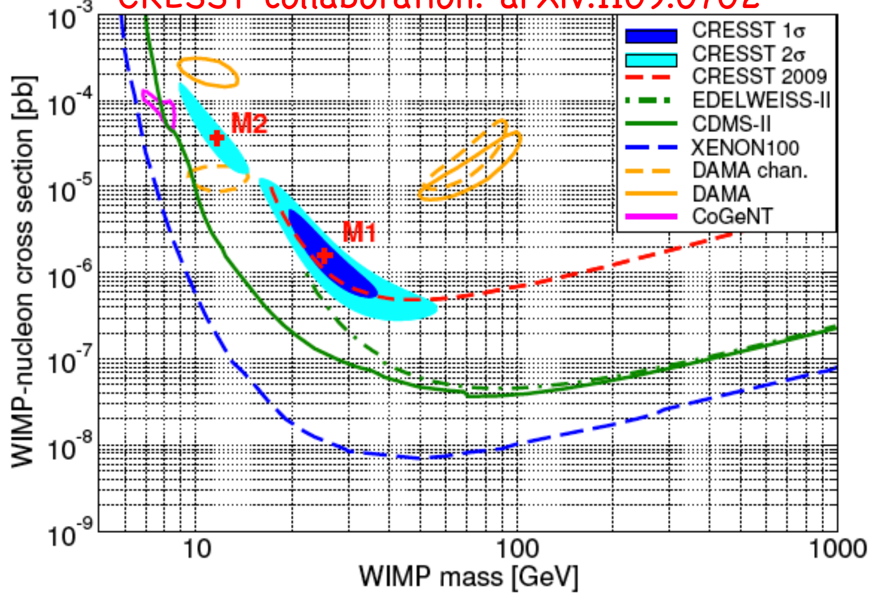
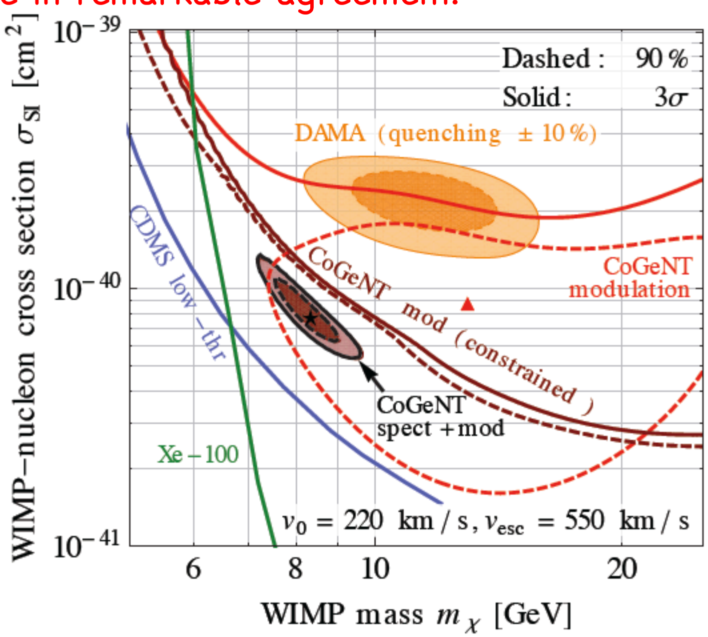
CRESST collaboration: arXiv:1109.0702



CoGeNT modulation ROI and CRESST M2 region seem to be in remarkable agreement.



P. Fox et al., arXiv: 1107.0717
See also Schwetz & Zupan arXiv: 1106.6241, P. Belli et al. arXiv: 1106.4667, etc.

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A few (personal) reflections:

* On a bad day: do we know enough about the halo, DM coupling mechanisms, etc. to be playing this game? The last few transparencies follow <u>very precisely</u> the Popperian definition of <u>pseudoscience</u>... (and yet, a cynic would argue that this may be the beginning of "precision" DM work).

* On a good day: I am reminded of the Adams/Leverrier prediction for Neptune (i.e., maybe we are about to learn something new out of this royal mess). Also of how much fun we've been poking at the "spherical cow" halo model.

("bad day" and "good day" above are exchangeable)

* On any given day: I look forward to more experimental data, and to an absence of bias in their interpretation.

And a brief desiderata:

* CDMS has collected ~10 times the low-E exposure of CoGeNT, spanning >4 annual cycles. Interest in light-WIMPs as a solution to the DAMA conundrum goes back to 2004 (Bottino *et al.*, later re-examined by Gelmini & Gondolo). This was the motivation for CoGeNT. For when a CDMS annual modulation analysis?

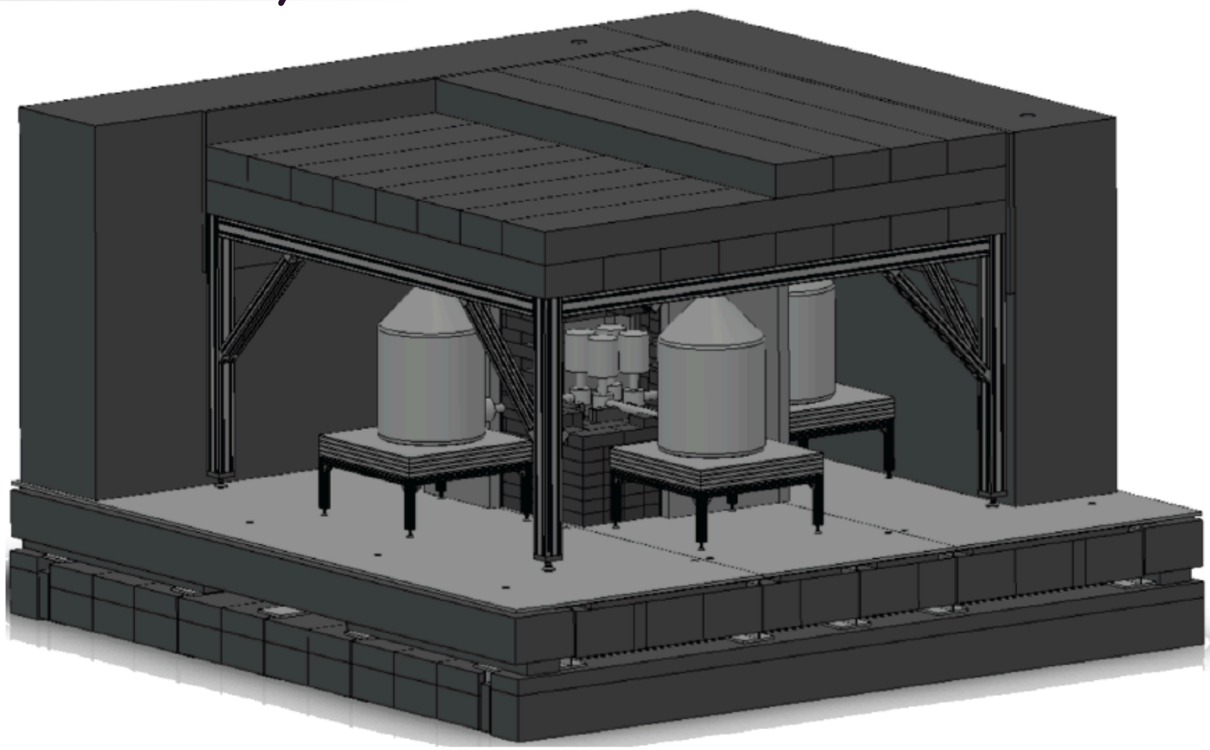
* Calibrations come before exclusions: the last time XENON presented a comparison between low-E neutron recoil rates and corresponding expectations was in 2007 (Manzur, APS meeting). It did not look good at all. Such data exist for XENON100. If the disagreement is as for XENON10, there are no low-mass exclusions to speak of.

(see H. Lippincott's COUPP talk on how to fold in a penalty in such a situation, if you need some direction).

UC/PNNL
design
CoGeNT-4
(C4)

Aiming to
reduce
parallel-f
noise
(and improving
backgrounds).

See talk by J. Orrell this afternoon

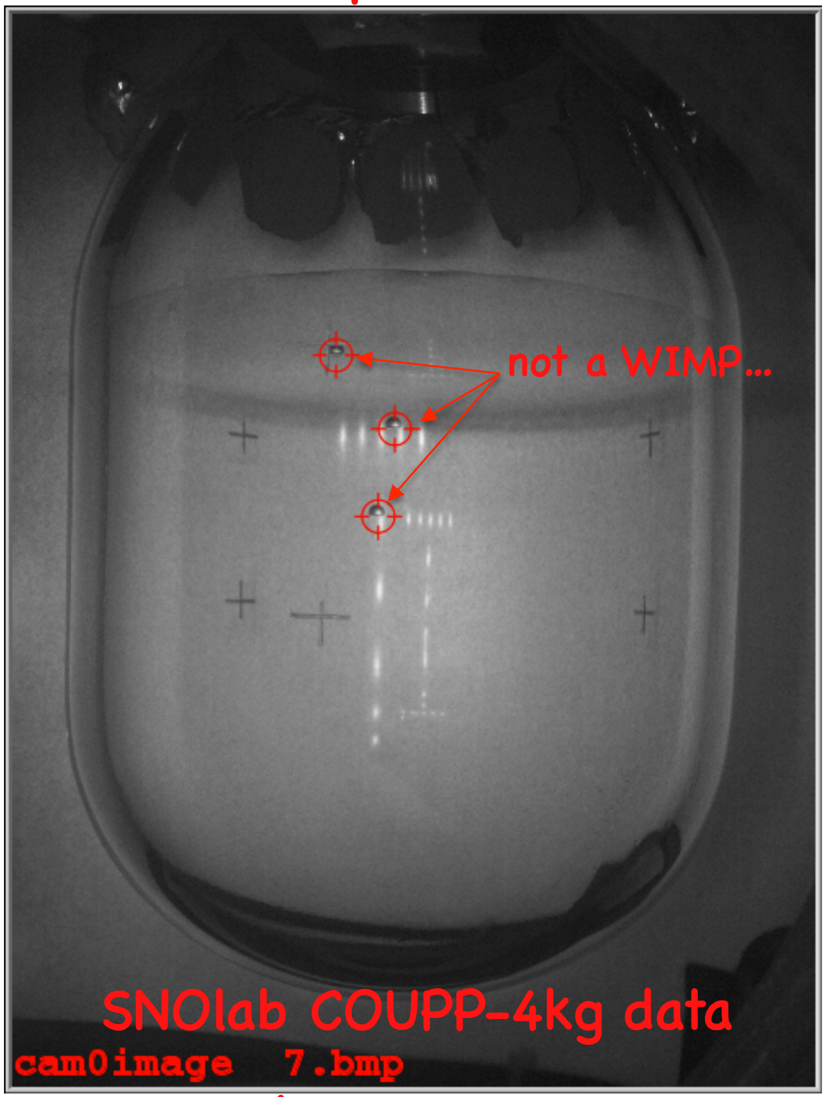


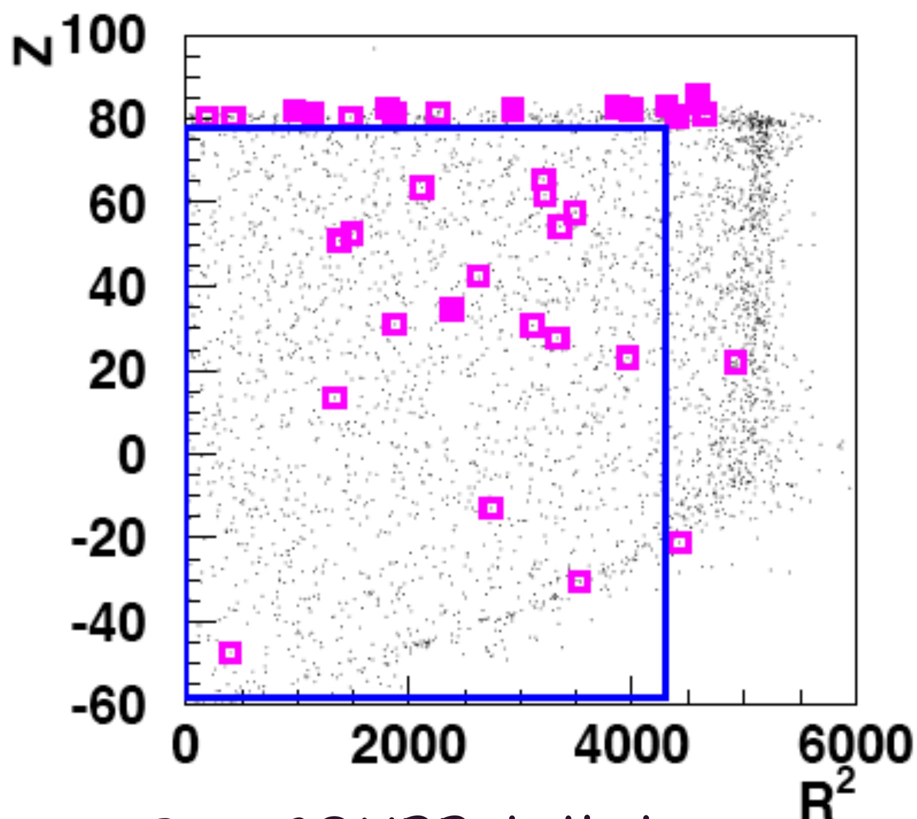
Roughly 10
times present
target mass
(annual modulation)

Expected start
end of 2011.

We have crossed the Rubicon:

Dark Matter experiments from now on to produce their own "WIMPs"





See COUPP talk by

H. Lippincott tomorrow

In agreement with Po-210 and U, Th in PZT and inspection windows. Replacement in progress.

About to say something meaningful about light-WIMPs...

COUPP's dubious distinction:

first DM experiment to see (α,n) neutrons