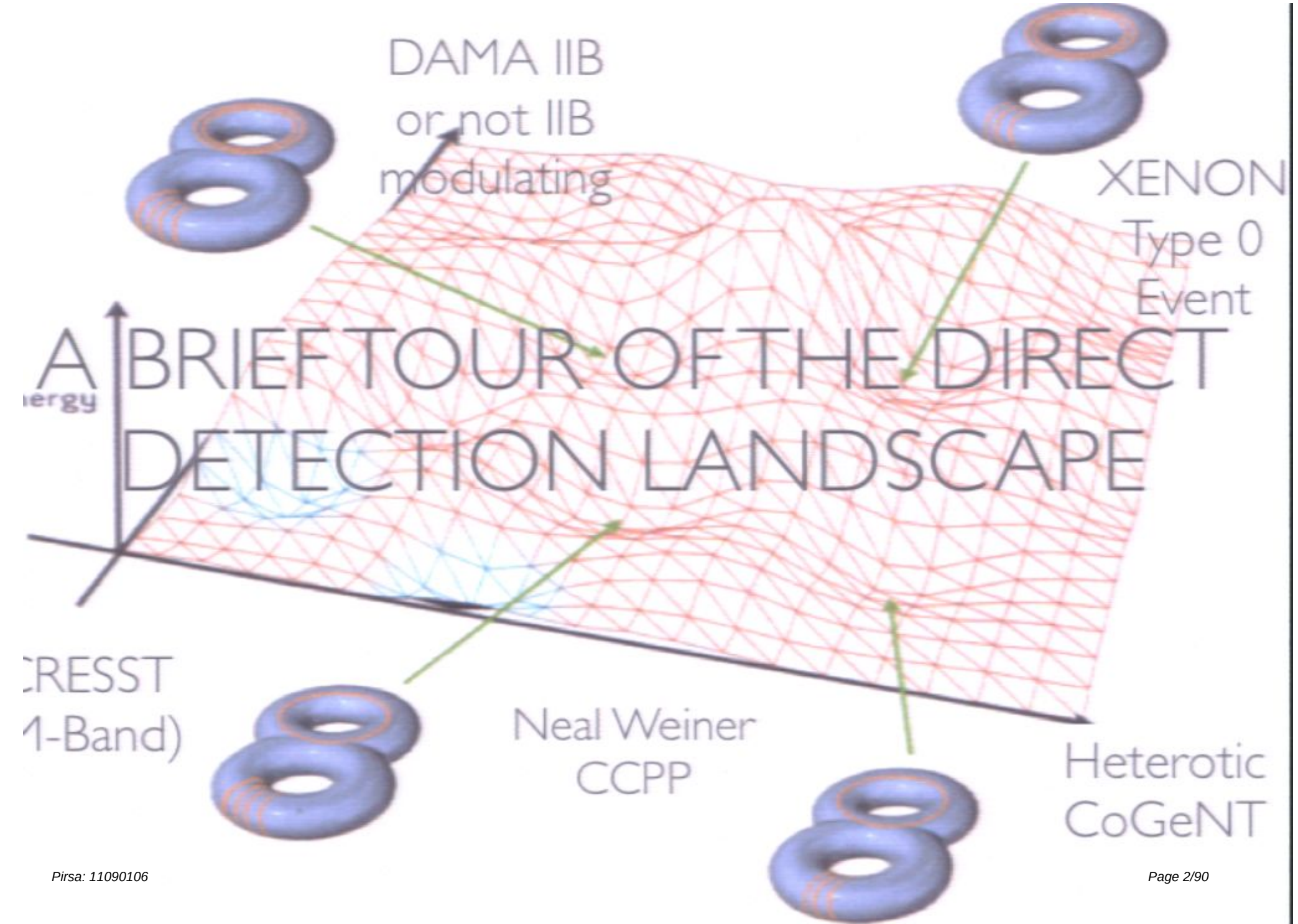
Title: A Tour of the Direct Detection Landscape

Date: Sep 22, 2011 09:00 AM

URL: http://pirsa.org/11090106

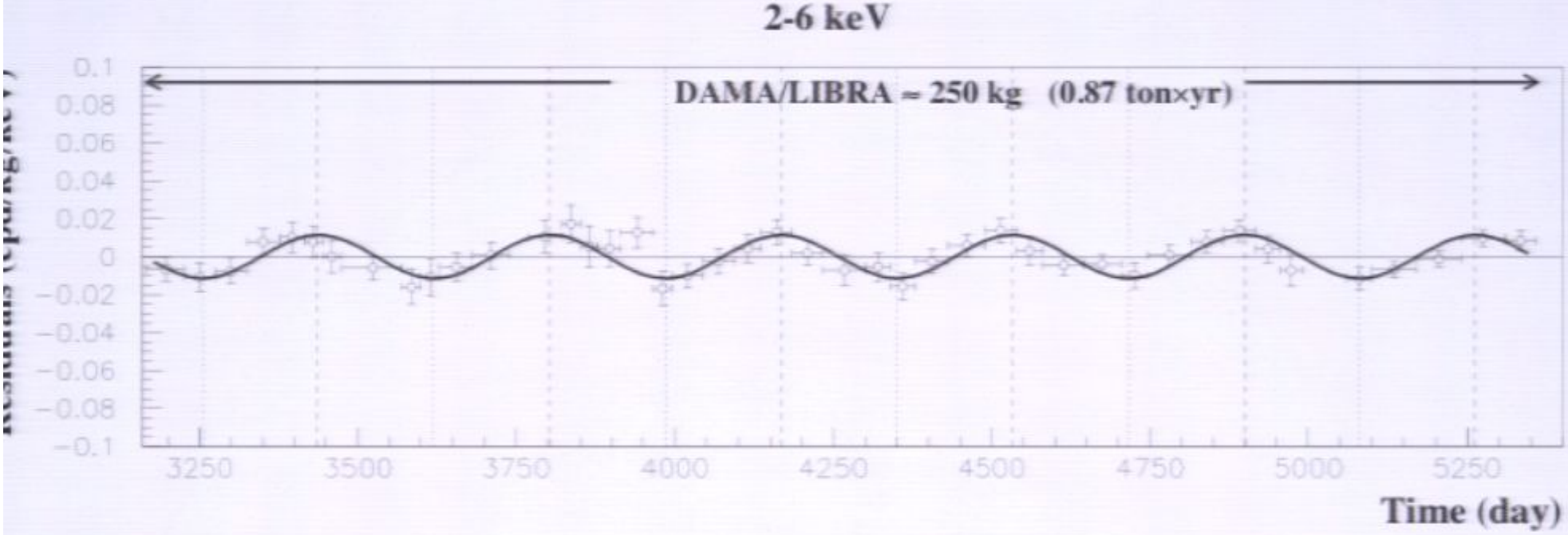
Abstract: A wide range of results have led to a confusing situation in the area of direct WIMP detection. I'll review the status of these results. The features of the results imply that almost any explanation will require a departure from standard assumptions (Maxwellian halo, elastic WIMP scattering or otherwise) so I'll review the techniques to compare experiments without appealing to these assumptions. In particular, I'll comment on the status of light WIMPs and the iodine interpretations of DAMA (such as inelastic dark matter) in light of the most recent results.

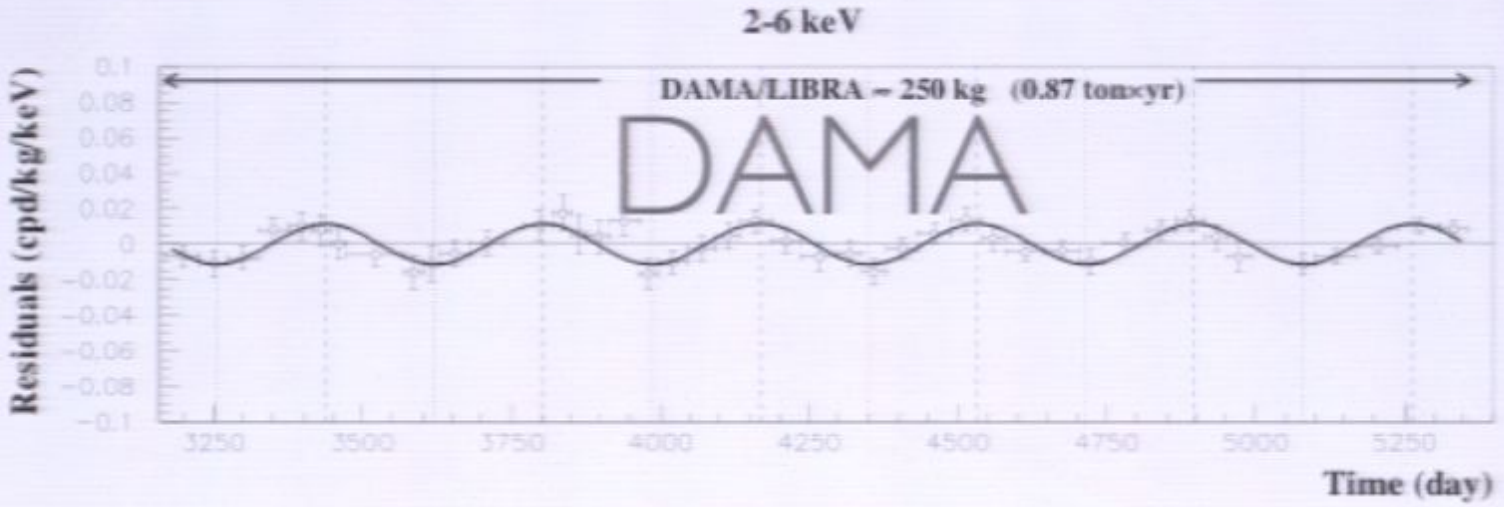

DAMA IIB
or not IIB
modulating
XENON
Type 0
Event
A BRIEF TOUR OF THE DIRECT
DETECTION LANDSCAPE
ergy
CRESST
1-Band)
Neal Weiner
CCPP
Heterotic
CoGeNT

WHAT THE HECK IS GOING ON?

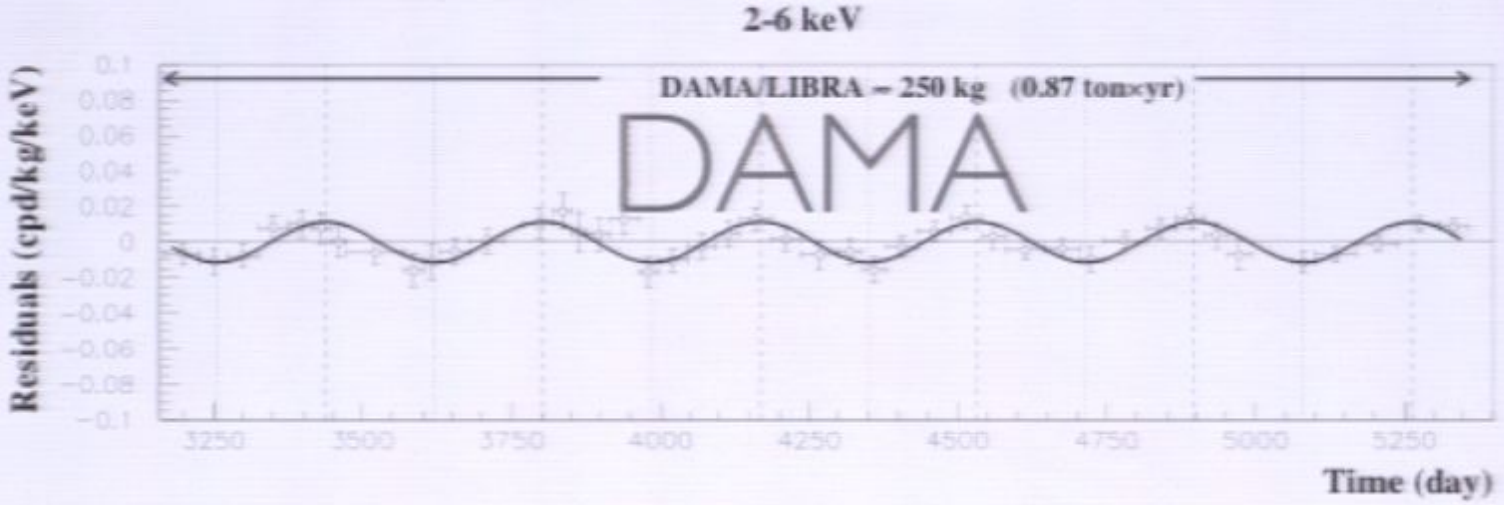
- A whole bunch of experiments have data
- To leading order, no one agrees with anyone
- So let's talk about that

DAMA


2-6 keV
DAMA/LIBRA ≈ 250 kg (0.87 ton×yr)
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
3250
3500
3750
4000
4250
4500
4750
5000
5250
Time (day)



- What is it: annual modulation in scintillation events in 100/250 kg NaI(Tl) crystal - DM?



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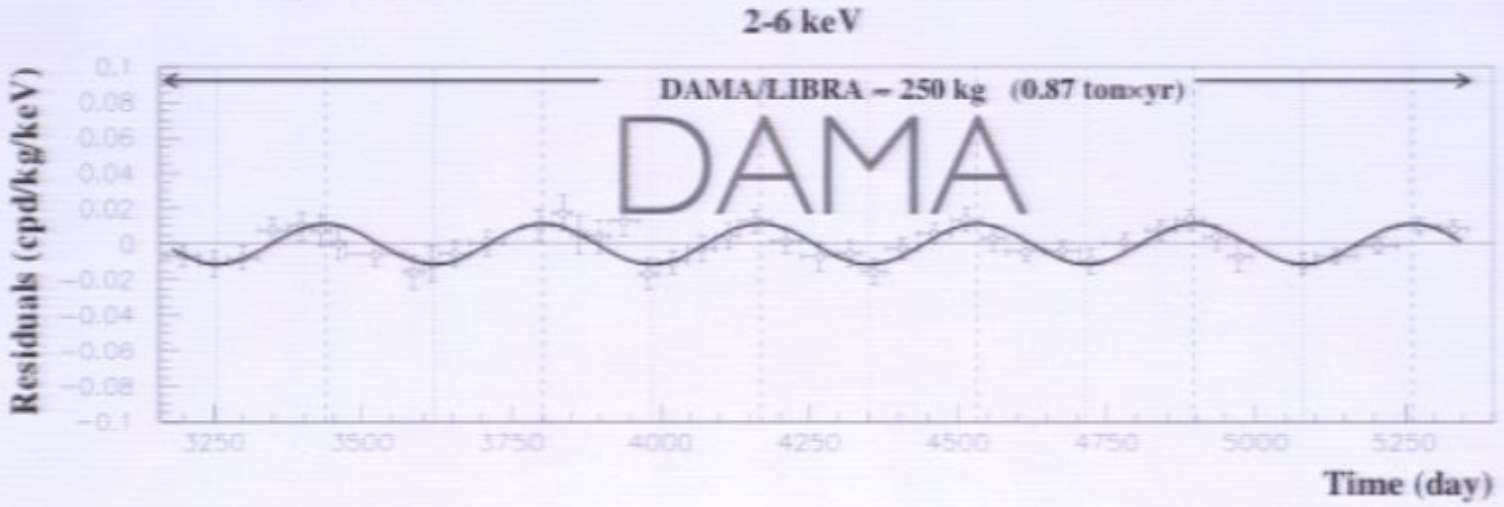


- What is it: annual modulation in scintillation events in 100/250 kg NaI(Tl) crystal - DM?
- What's to like: single hit, stable phase, low energy, no candidate "conventional" explanations
- What's not to like: null results from other exps, data are still unavailable, no event discrimination

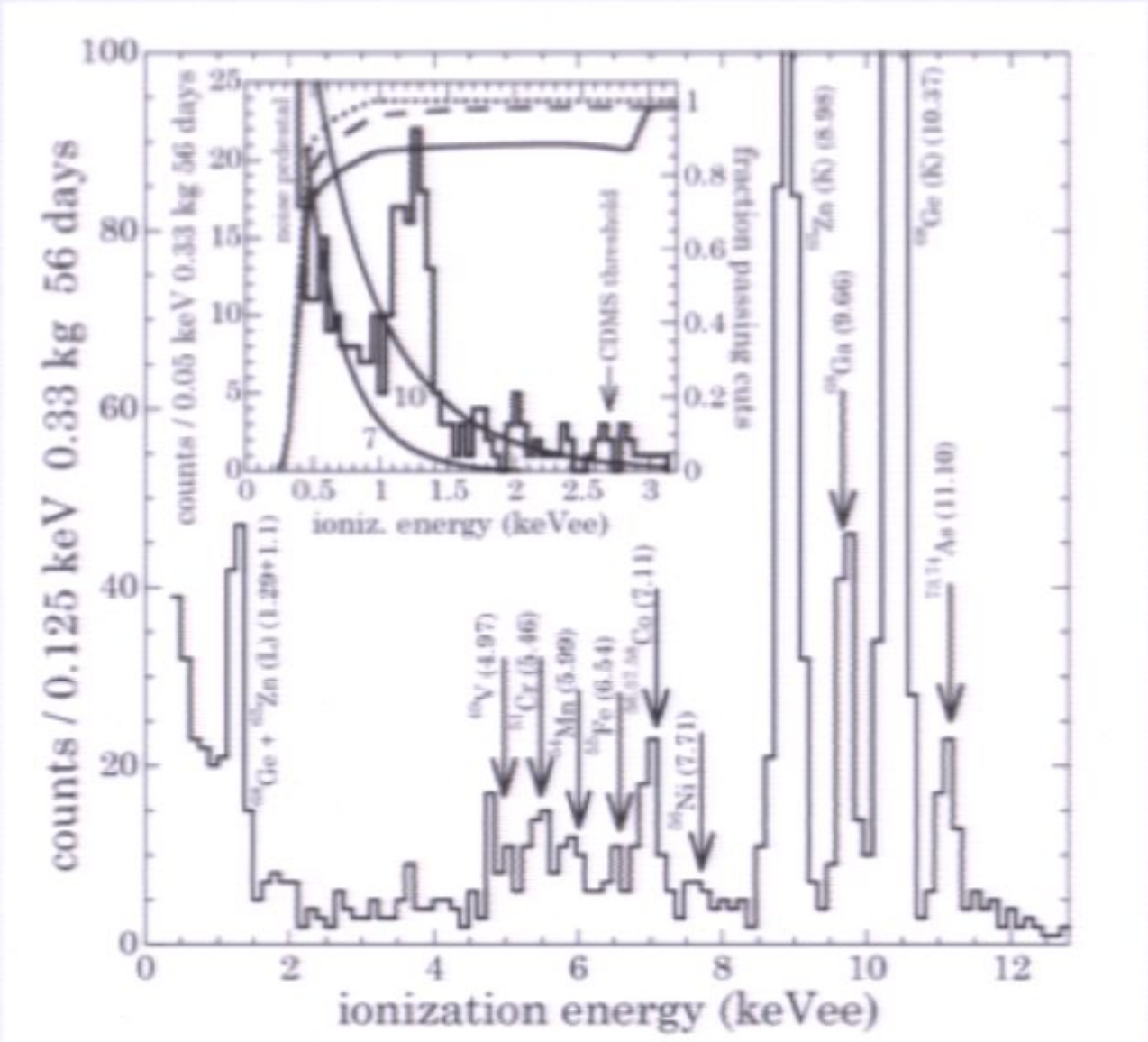
IT USED TO BE VERY SIMPLE

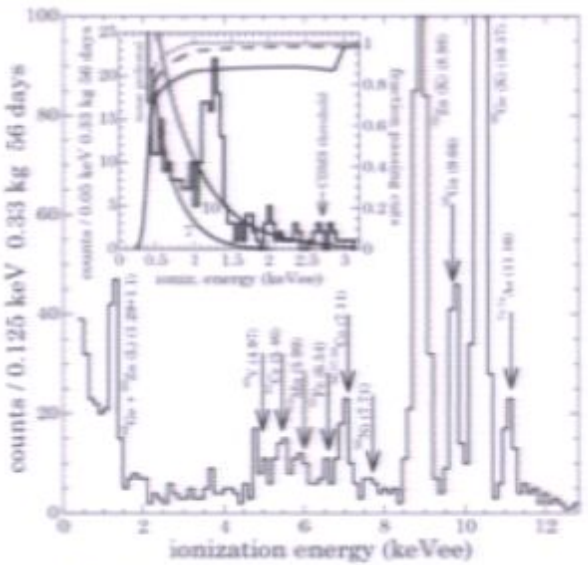
Light WIMP
Spin independent
spin dependent
dipole
...

Heavy WIMP
inelastic DM
[iodine,
thallium,
magnetic]
resonant DM
...

Alternative WIMP
magnetic iDM
w/ deexcitation
luminous DM
...

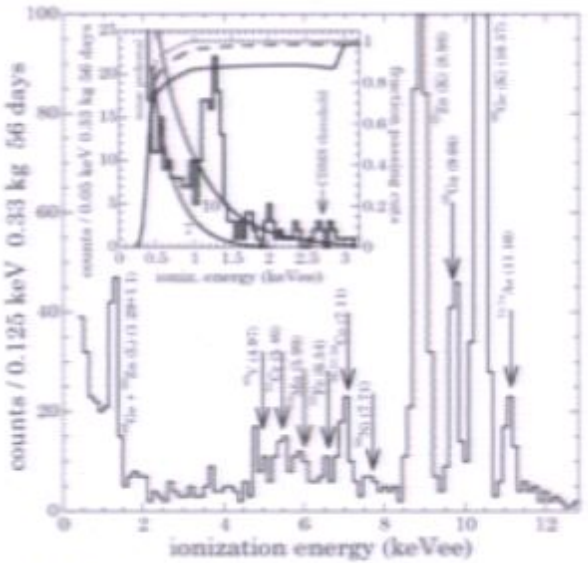
COGENT


counts / 0.125 keV 0.33 kg 56 days
ionization energy (keVee)
counts / 0.05 keV 0.33 kg 56 days
ioniz. energy (keVee)
fraction passing cuts
CDMS threshold
noise pedestal
^{65}Zn (K) (8.98)
^{68}Ga (9.66)
^{68}Ge (K) (10.37)
^{71}As (11.10)
^{68}Ge + ^{65}Zn (L) (1.29+1.1)
^{49}V (4.97)
^{51}Cr (5.46)
^{54}Mn (5.99)
^{55}Fe (6.54)
^{56,57,58}Co (7.11)
^{56}Ni (7.71)



COGENT

- What is it: events in an ionization experiment, x10 larger than expected background - DM?



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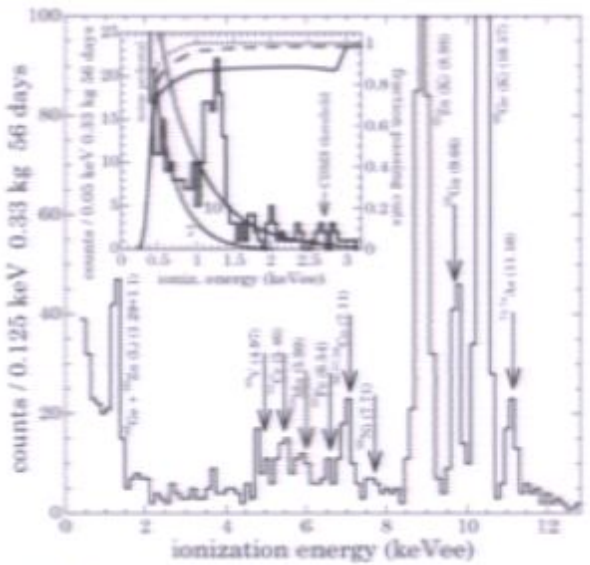
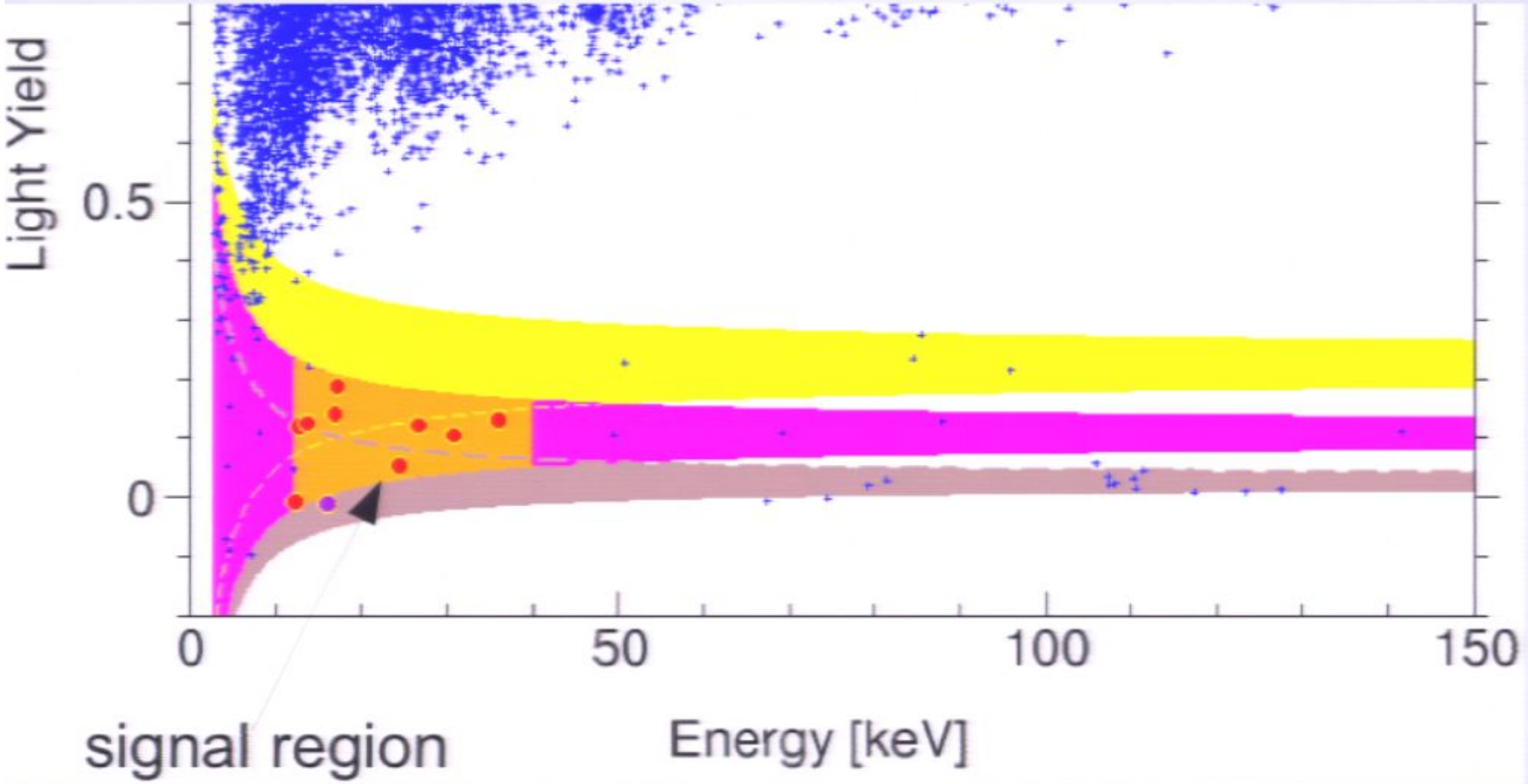
- What's to like: excellent energy resolution/calibration, good statistics

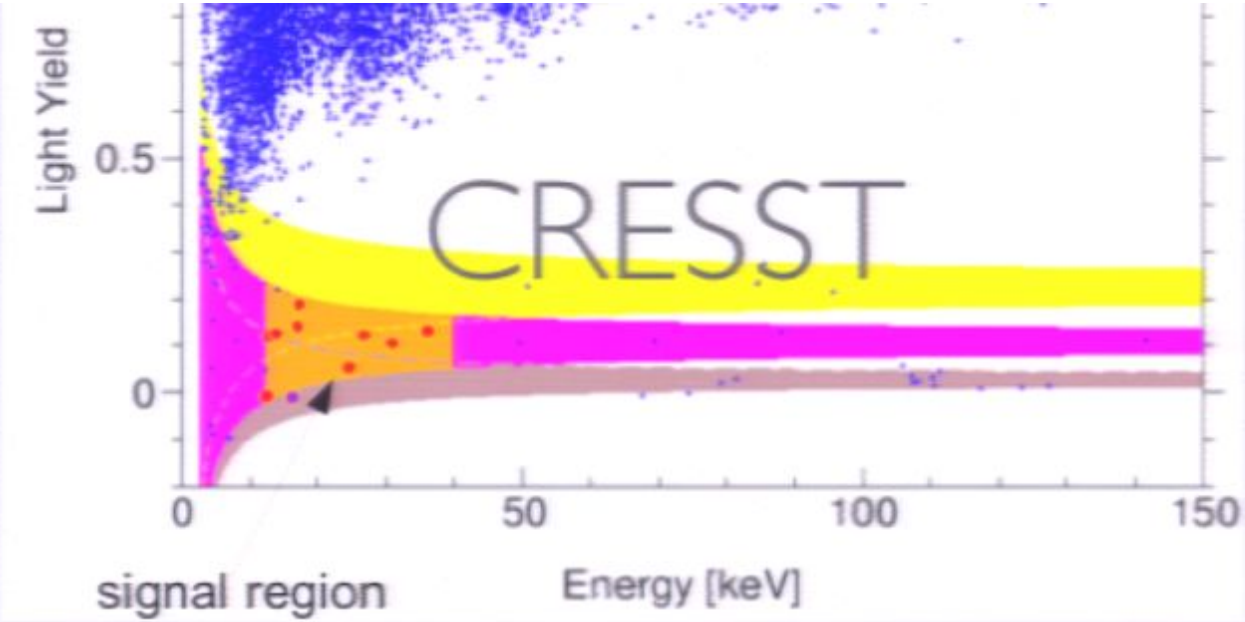


COGENT

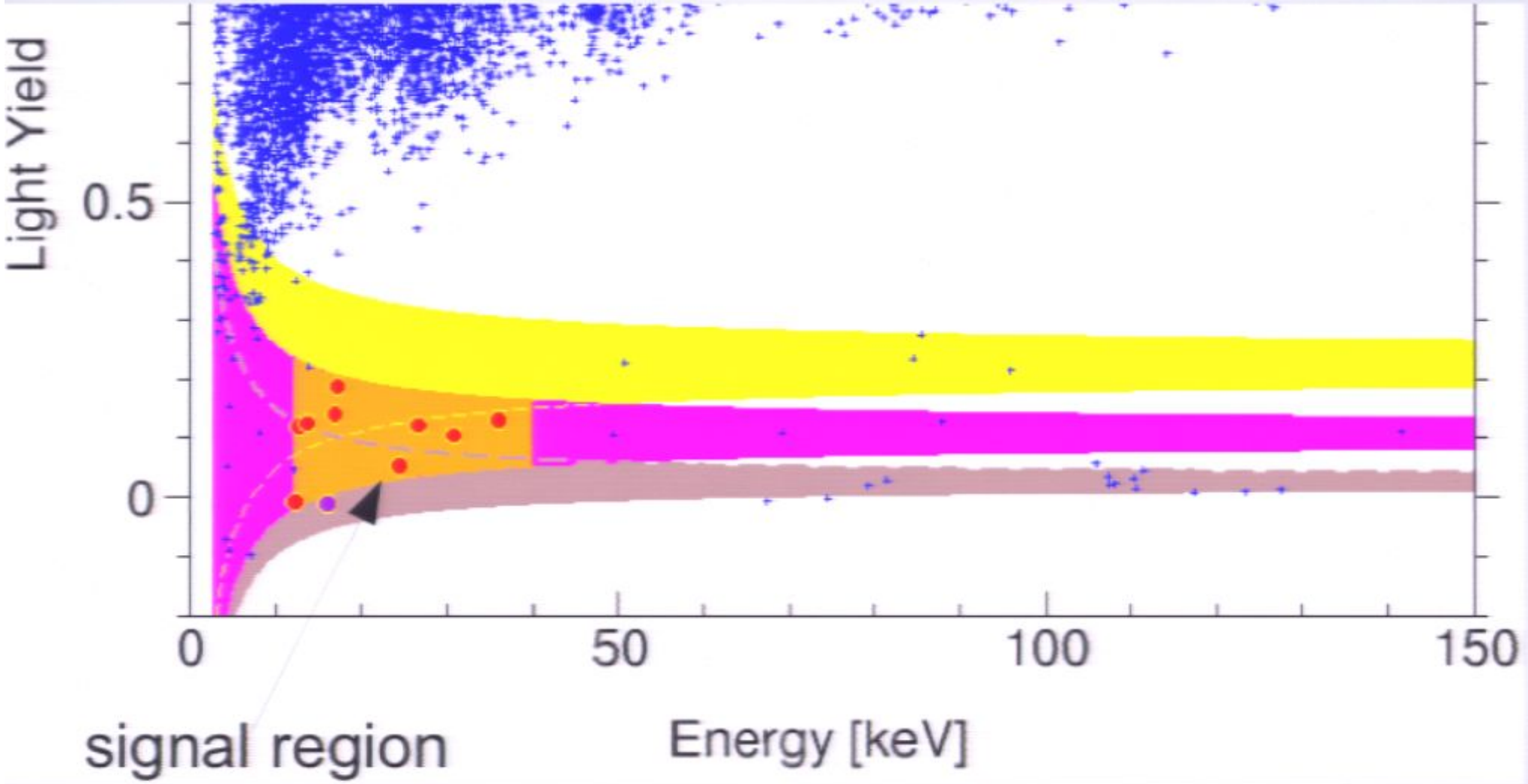
- What is it: events in an ionization experiment, x10 larger than expected background - DM?
- What's to like: excellent energy resolution/calibration, good statistics
- What's not to like: no discrimination, hasn't been mercilessly beaten for a decade, modulation not clearly overlapping exponential, null results from other exps

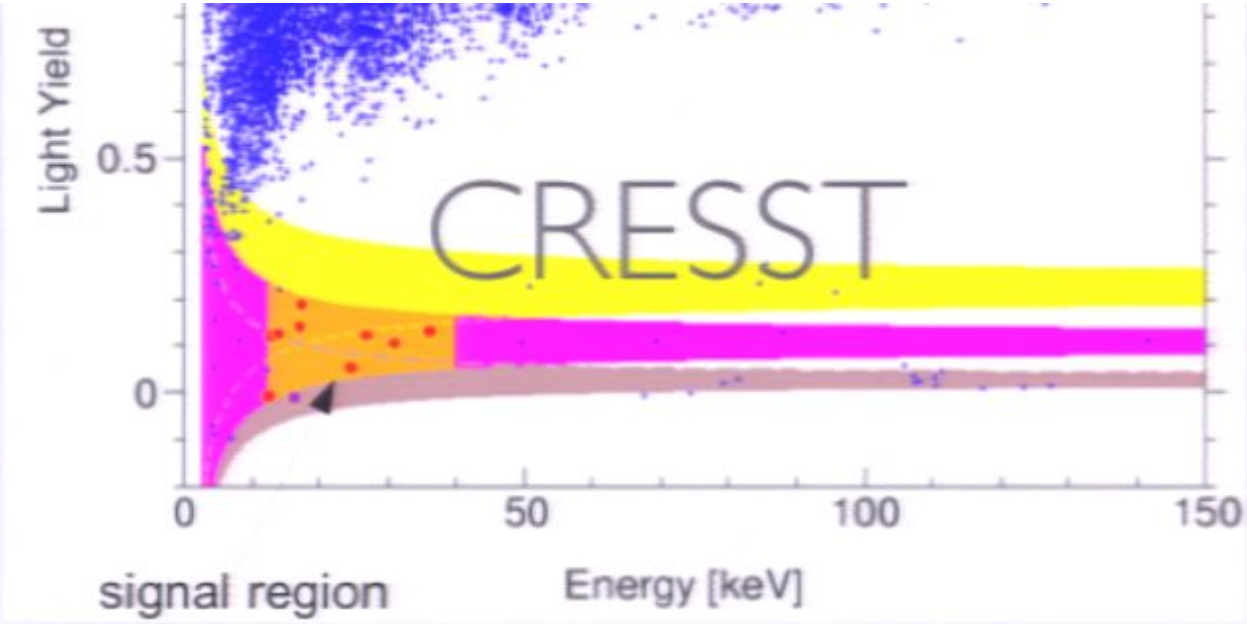
CRESST



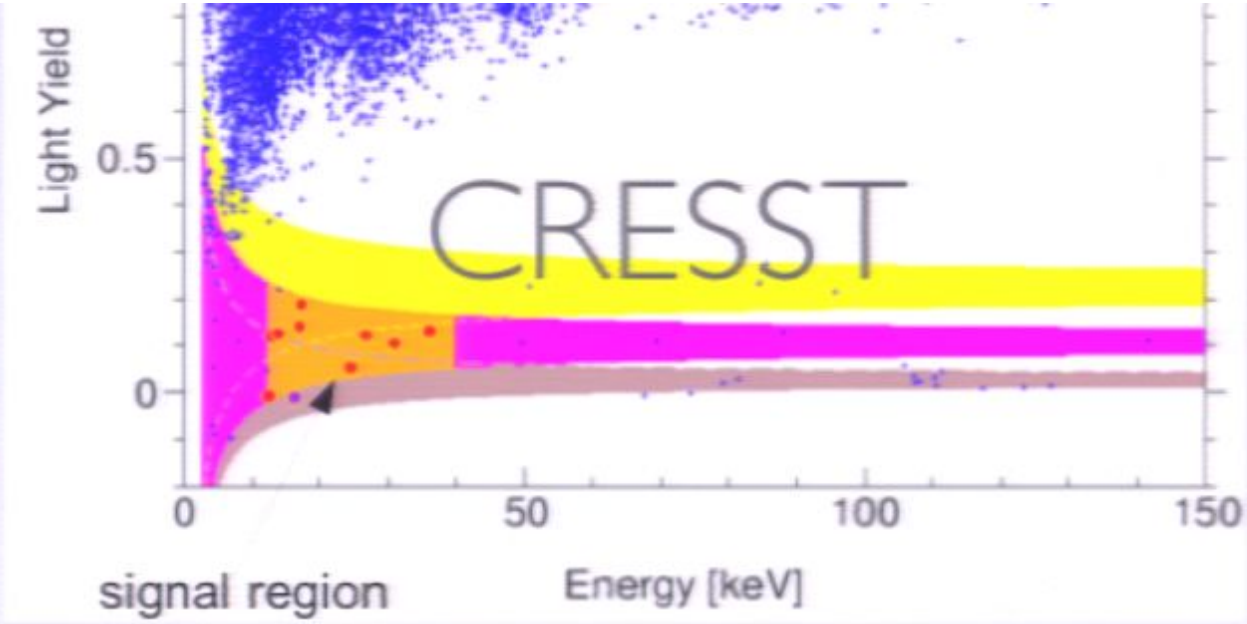

Light Yield
0.5
0
CRESST
0
50
100
150
signal region
Energy [keV]

CRESST





- What is it: an excess of events in a $CaWO_4$ detector, consistent with Oxygen scattering (~10-40 keV)



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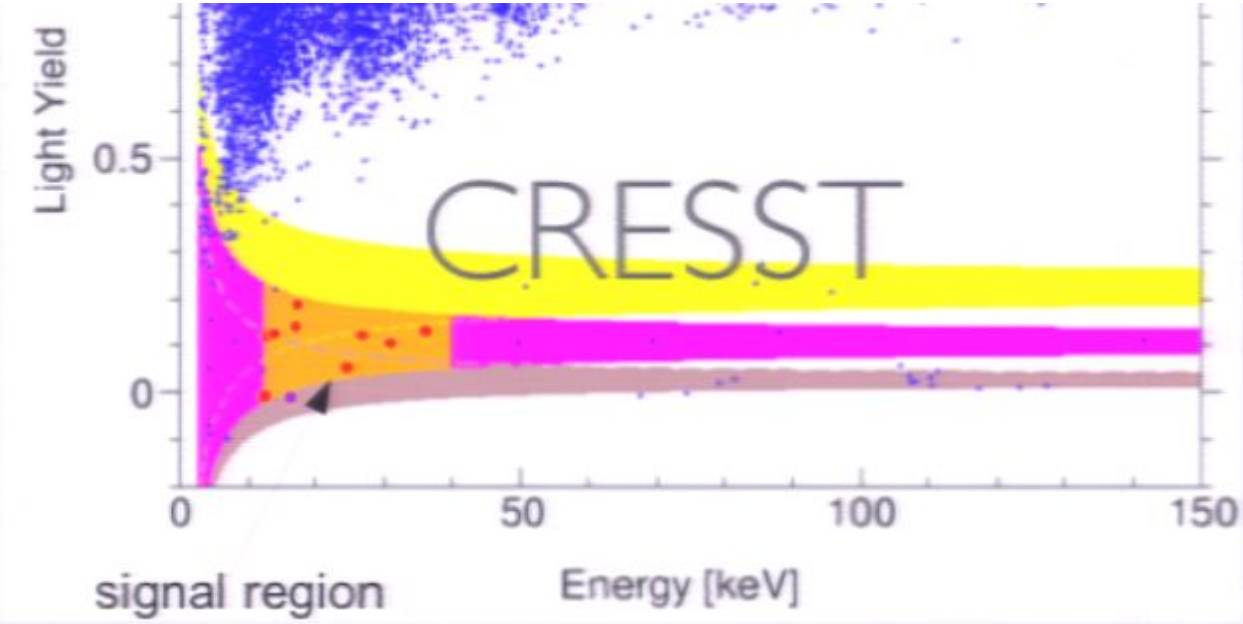
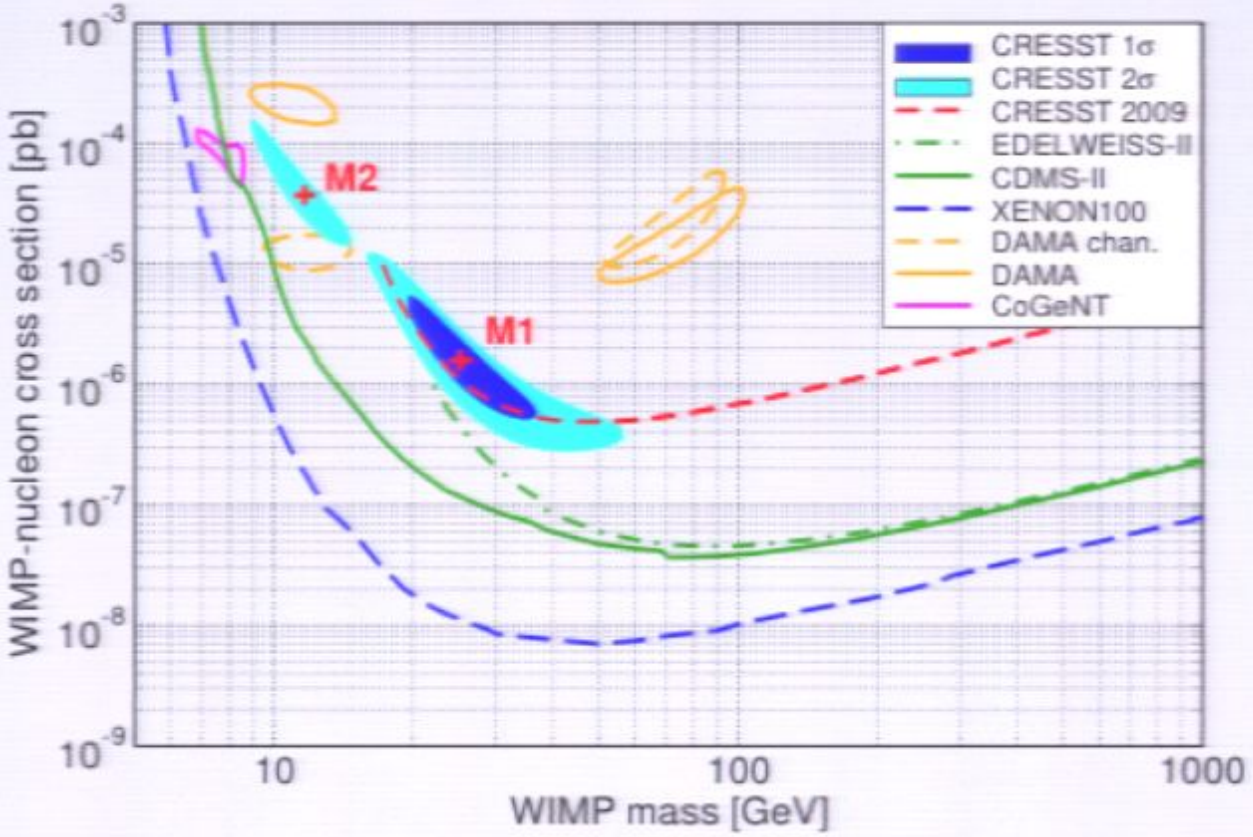


- What is it: an excess of events in a $CaWO_4$ detector, consistent with Oxygen scattering (~10-40 keV)
- What's to like: good discrimination vs electron recoil, not muon induced neutrons
- What's not to like: lots of events at high (15 keV+ energy, should have been seen elsewhere), signal lies left, right, above and below clear background sources, still have only seen 2 of 9 detectors, naively low energy looks too clean to be WIMP

EXCITING LIGHT WIMPS

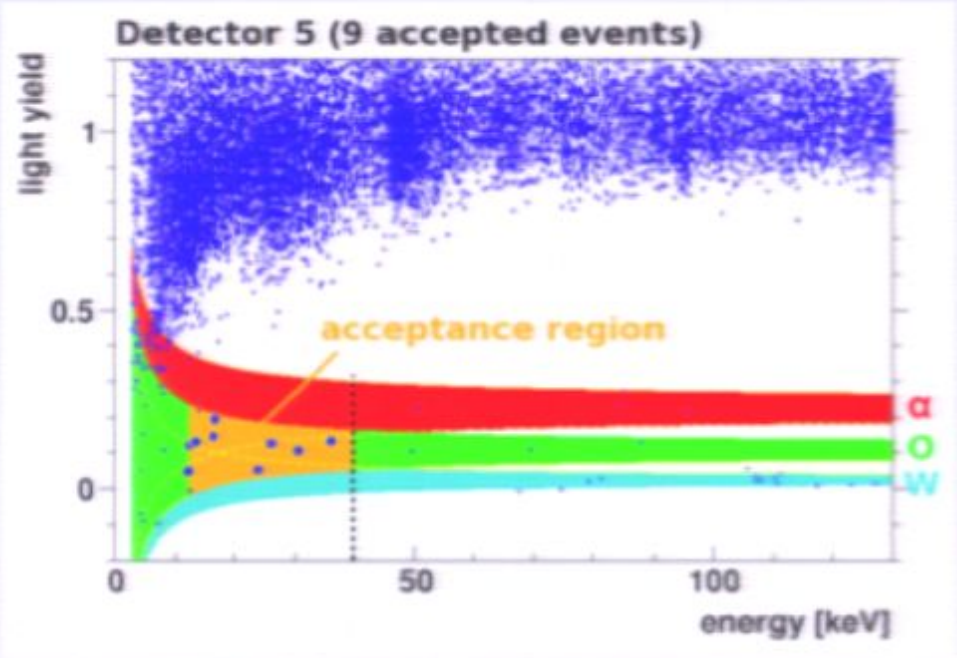
- DAMA scattering through Na
- CRESST scattering through O (and Ca)
- CoGeNT low energy scattering on Ge

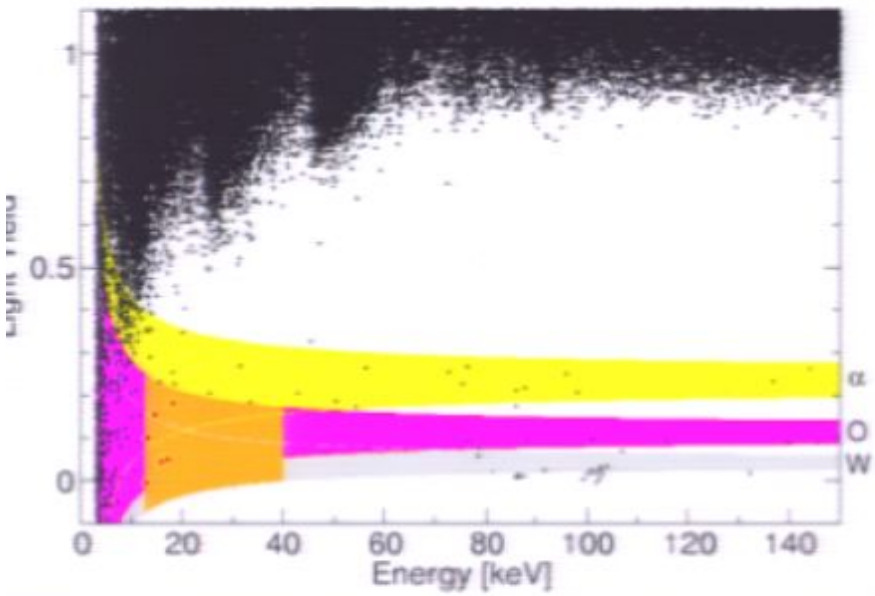
IS THIS CONSISTENT?

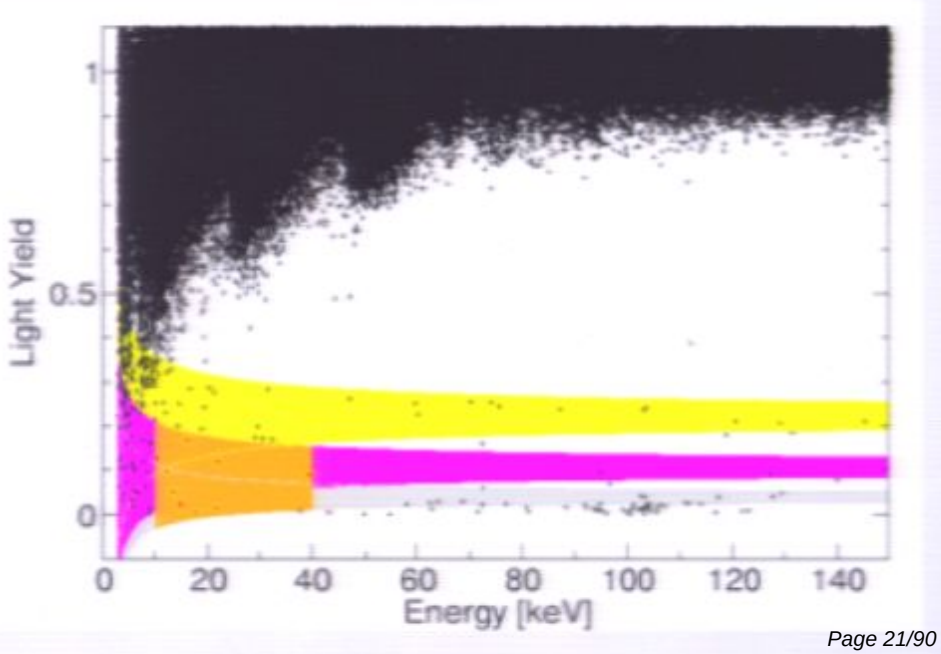


NB: This is not a metric space!

2 (3) detectors?

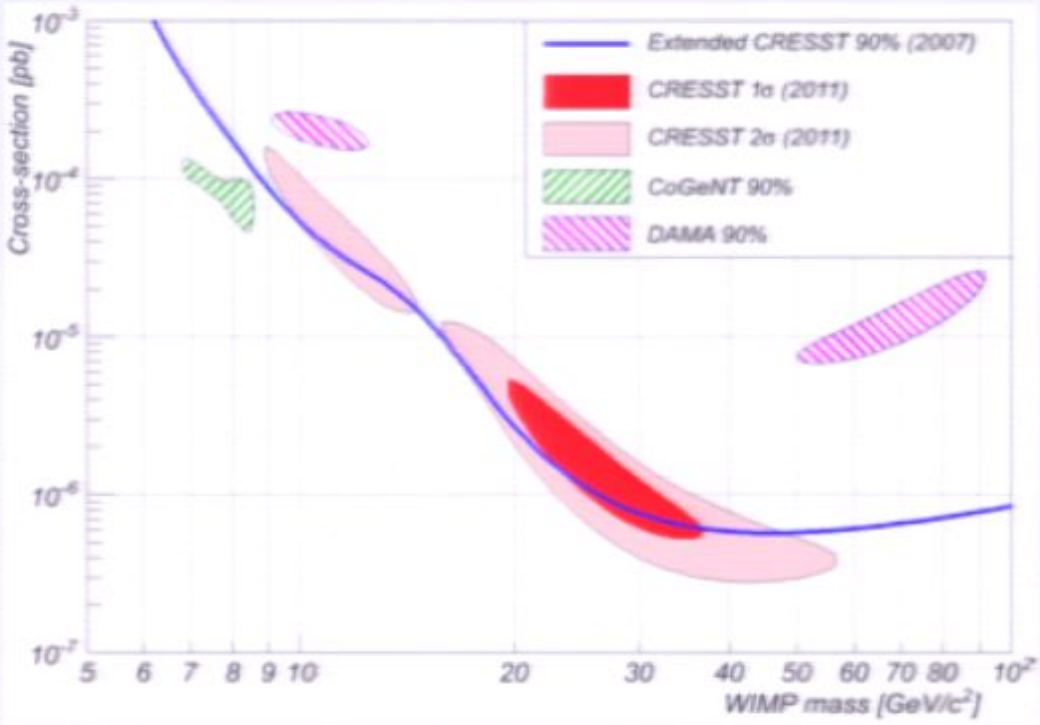






One must reverse engineer to say anything

IS THIS SELF-CONSISTENT?



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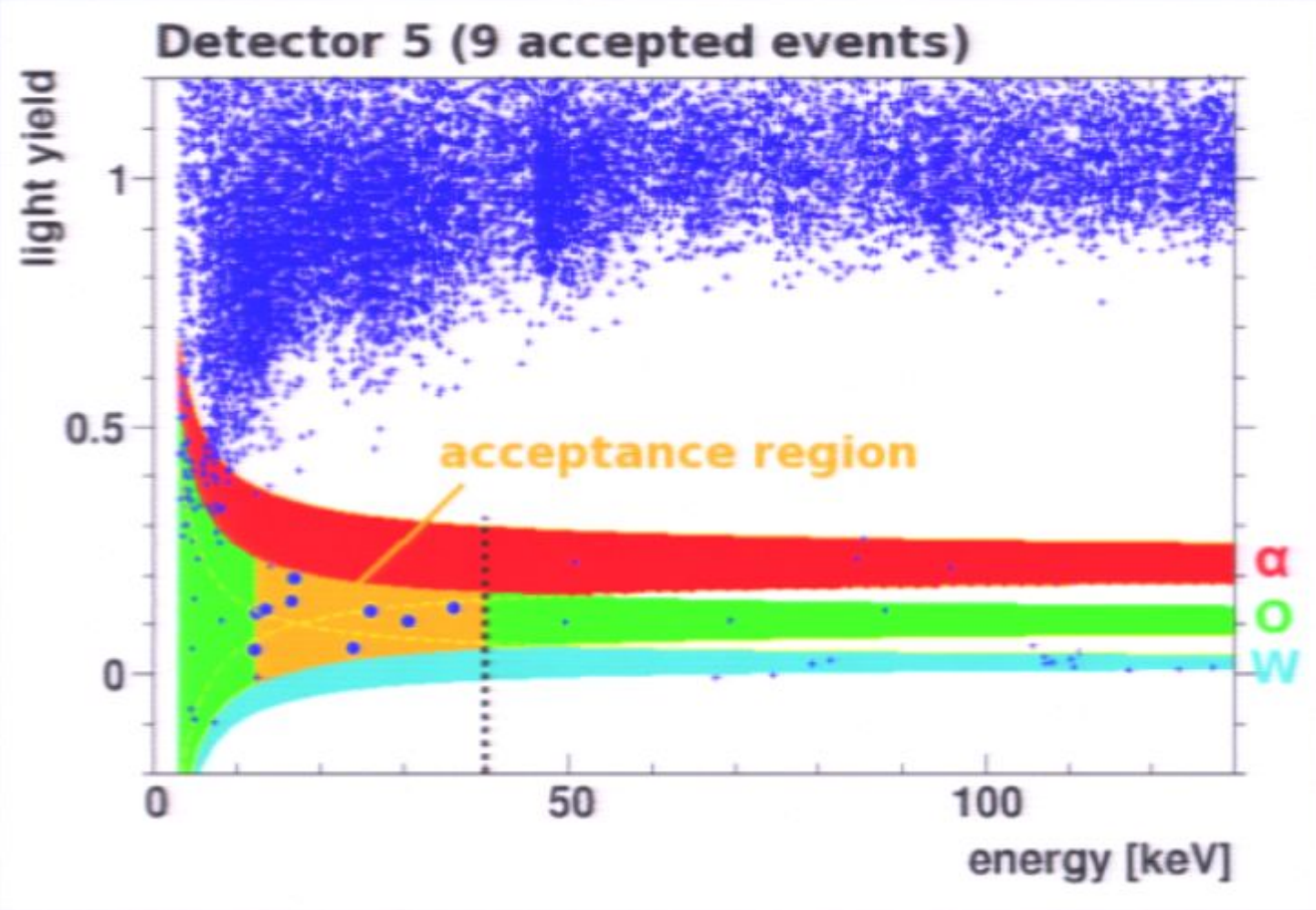
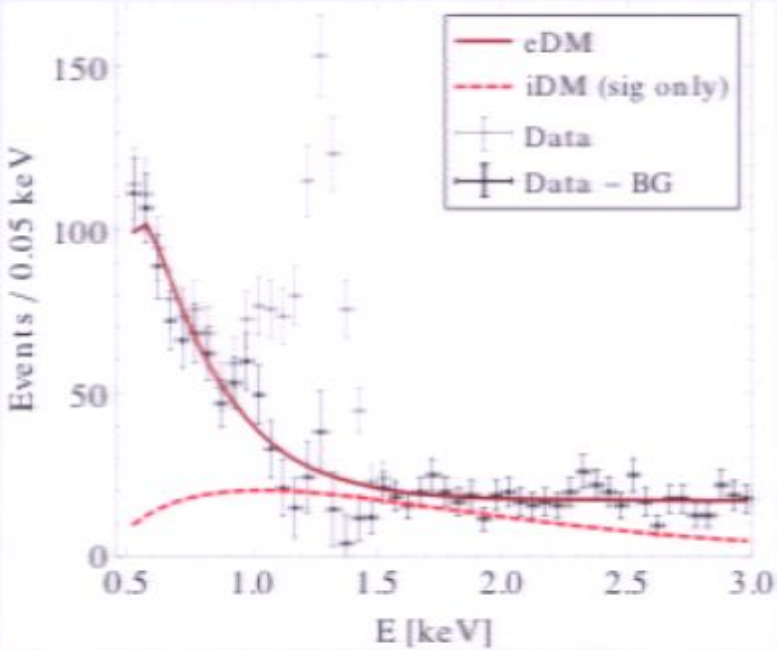
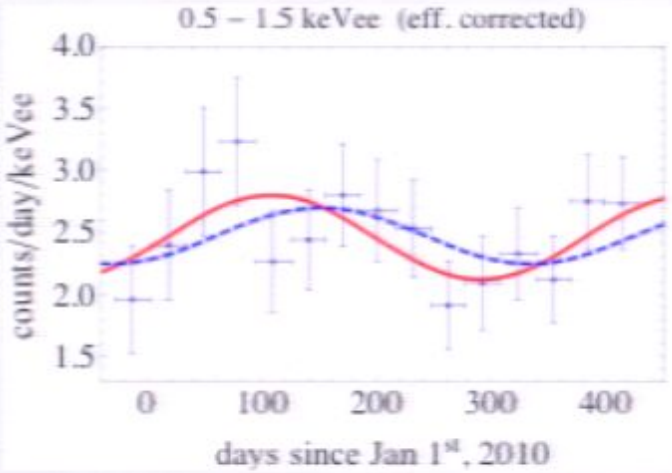
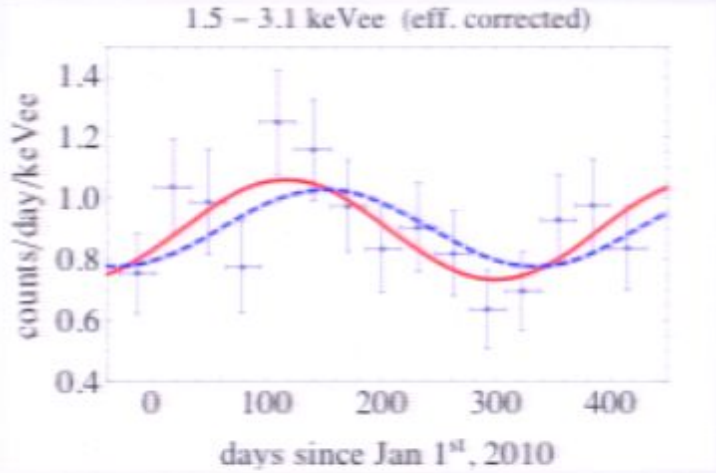
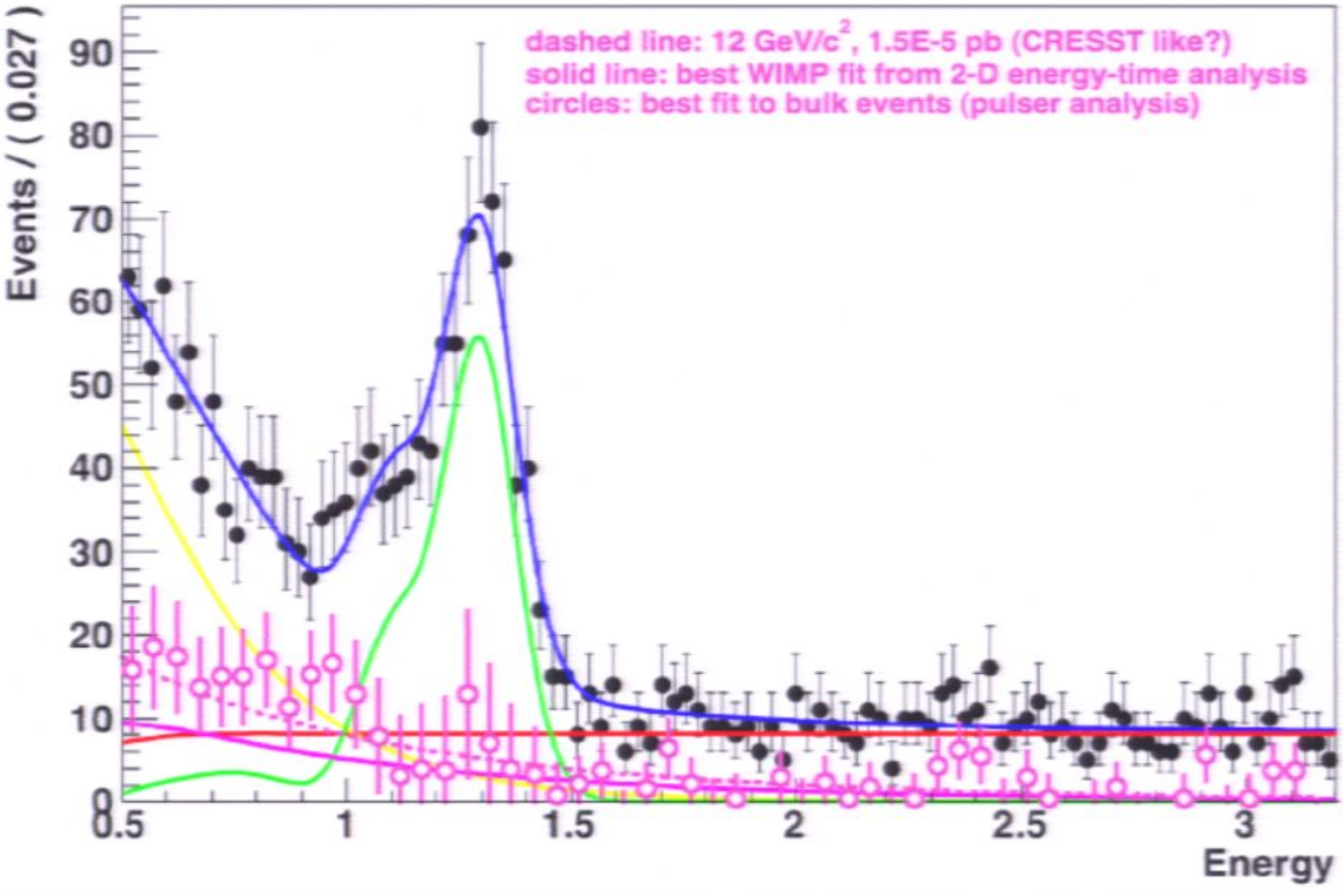


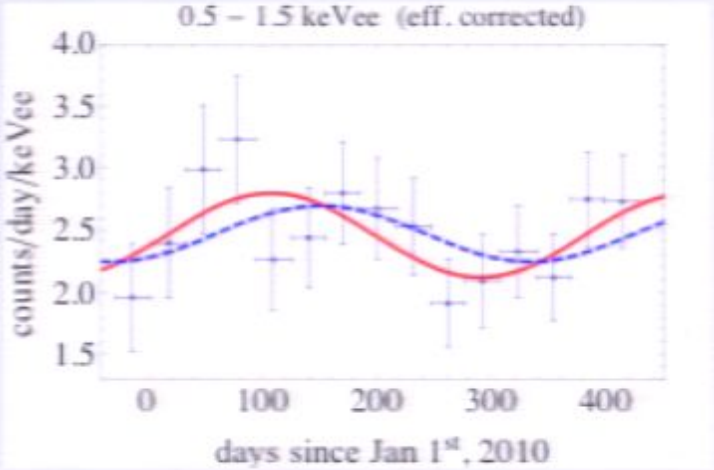
M2 predicts 28 events in lower half O band between 5-10 keV (vs 4 or 5) and 86 between 3-10 (vs 5)

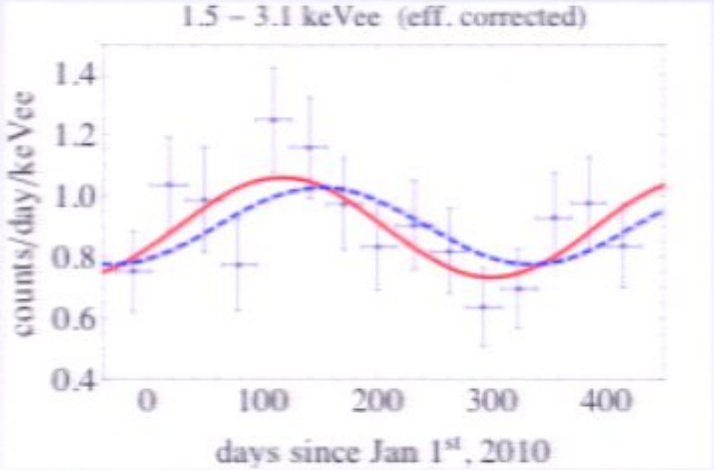

eDM
iDM (sig only)
Data
Data – BG
Events / 0.05 keV
E [keV]

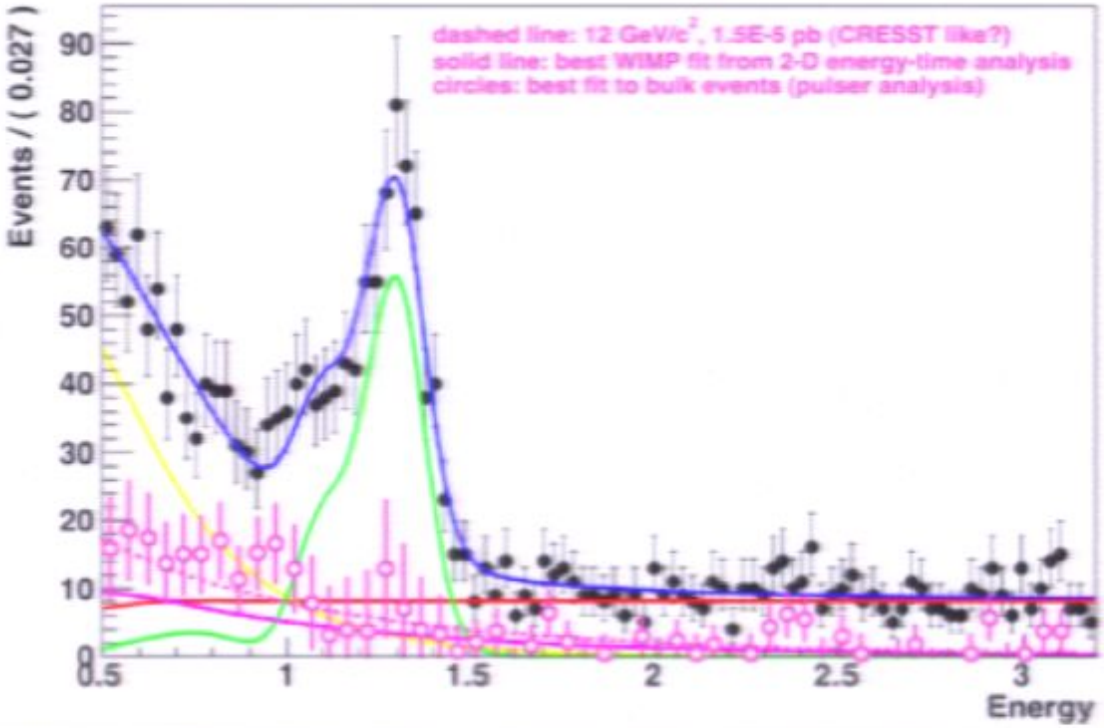

0.5 – 1.5 keVee (eff. corrected)
counts/day/keVee
days since Jan 1st, 2010


1.5 – 3.1 keVee (eff. corrected)
counts/day/keVee
days since Jan 1st, 2010


dashed line: 12 GeV/c^2, 1.5E-5 pb (CRESST like?)
solid line: best WIMP fit from 2-D energy-time analysis
circles: best fit to bulk events (pulser analysis)
Events / (0.027)
0
10
20
30
40
50
60
70
80
90
0.5
1
1.5
2
2.5
3
Energy

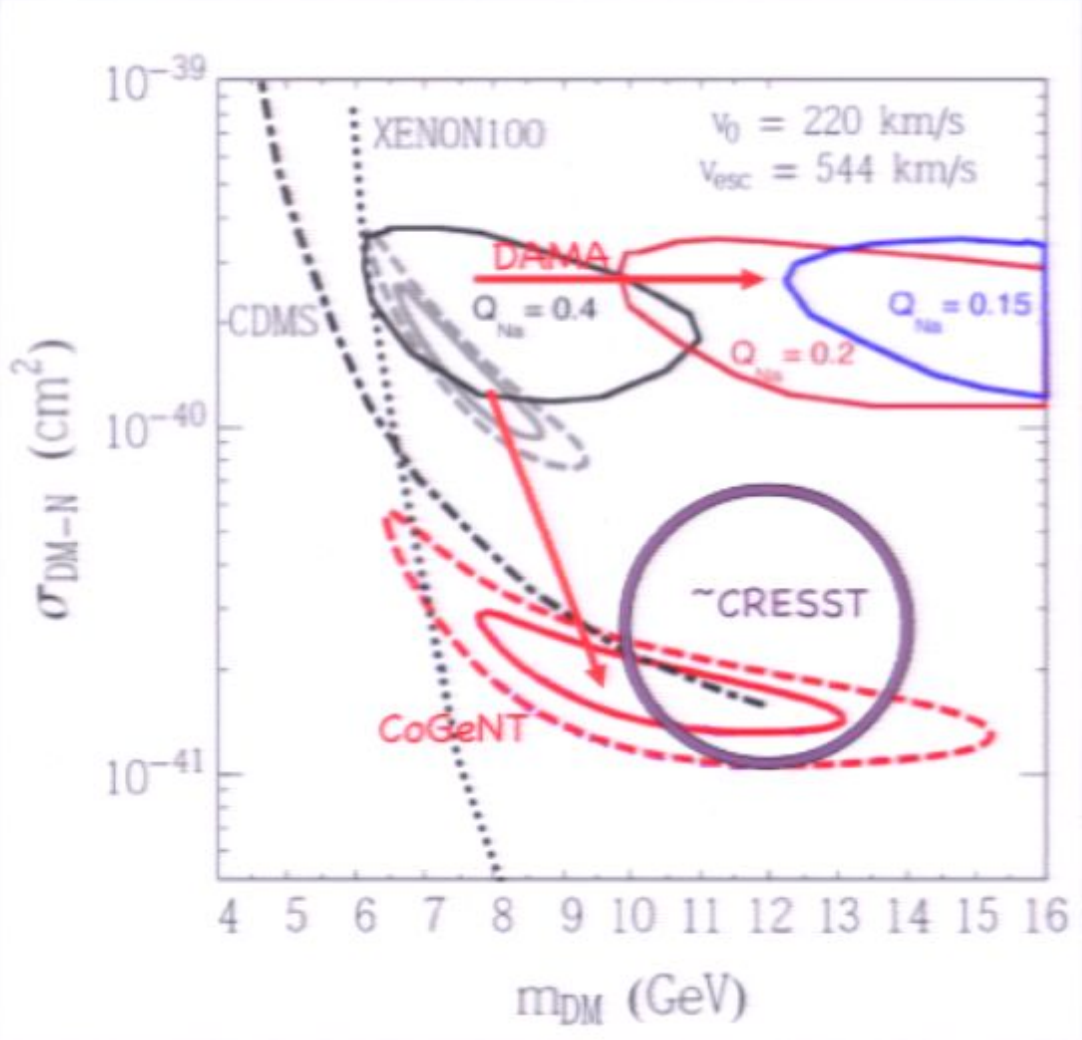




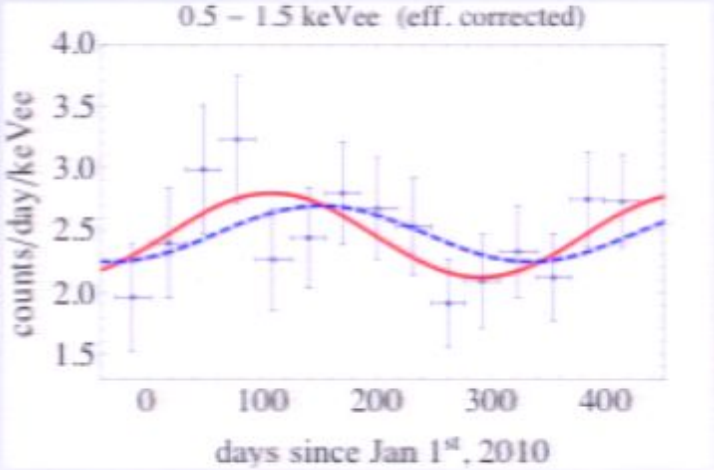


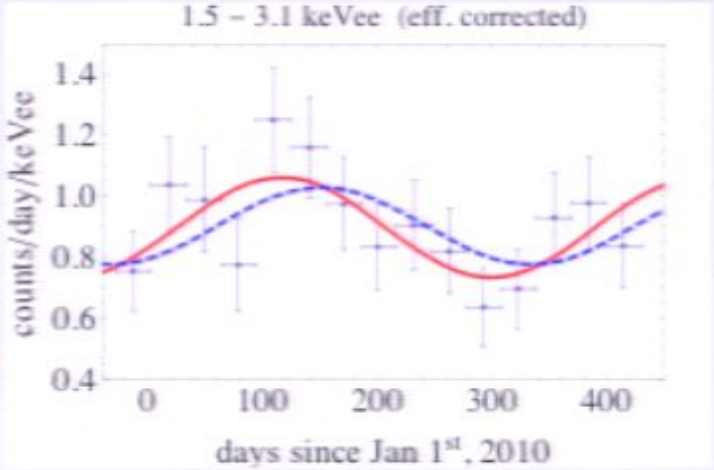
I count about 50 (or maybe 100?) events up here
If efficiencies are O(1) =>
0.37 (0.74) cpd/kg
vs 0.78

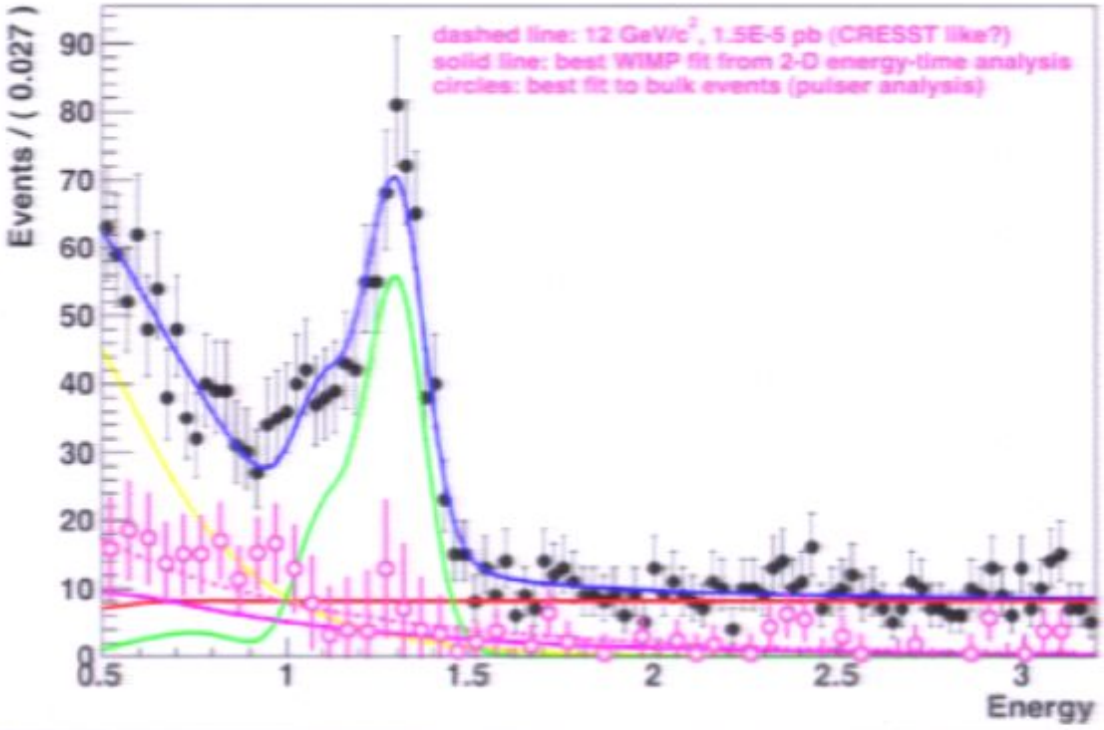
so is it modulating?



Note: there is no a priori conflict with CDMS if count rate is x2 lower at CoGeNT







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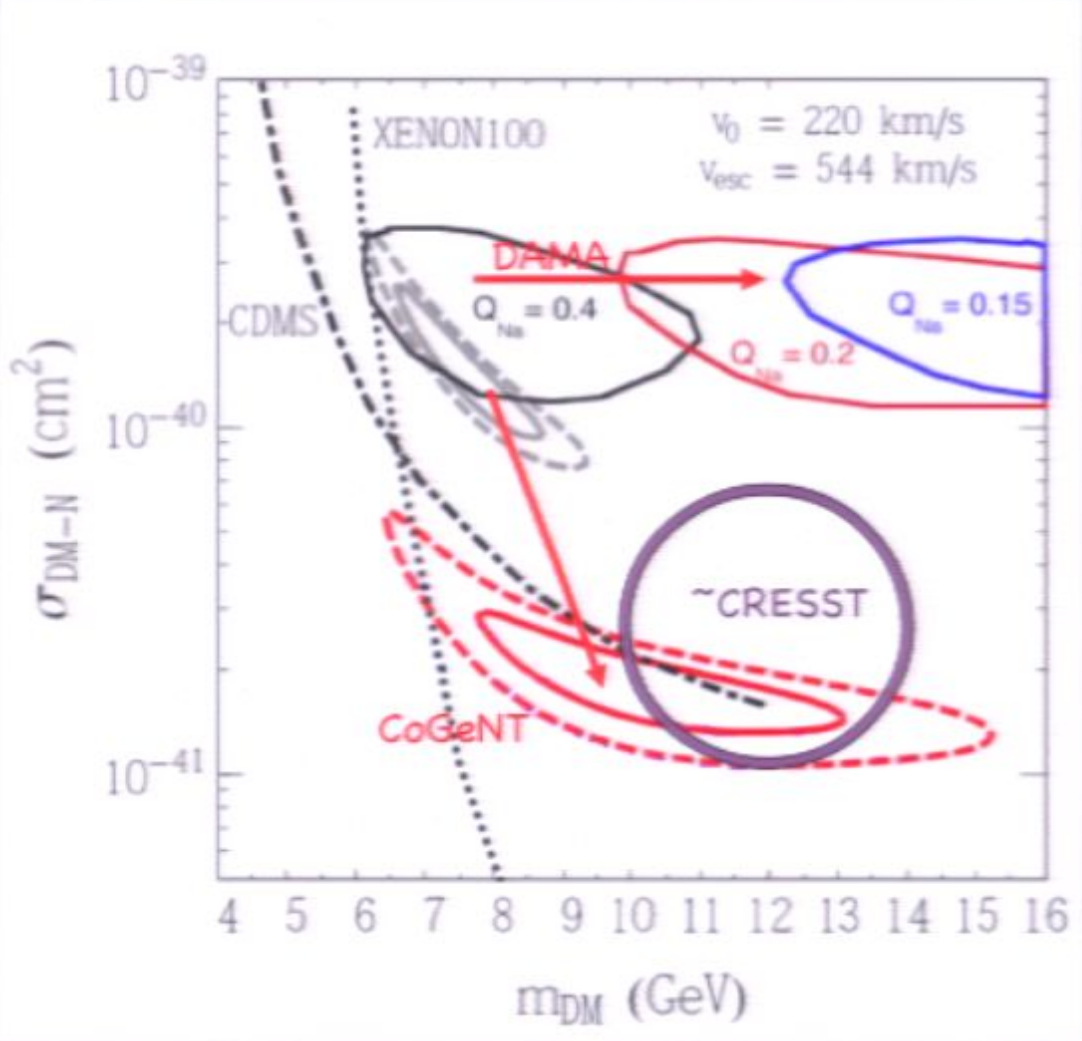


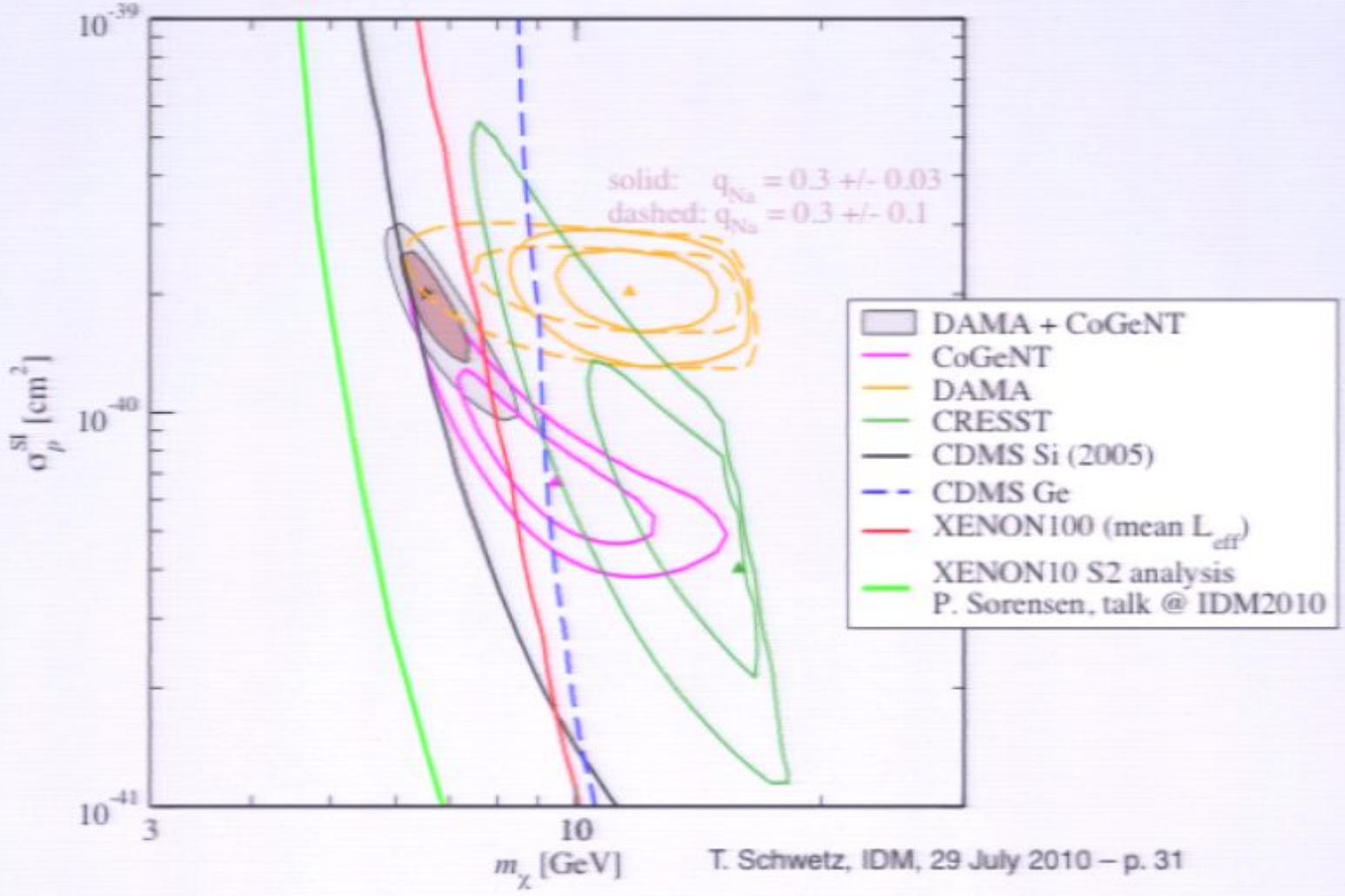
Note: there is no a priori conflict with CDMS if count rate is x2 lower at CoGeNT

LIGHT WIMP SUMMARY

- Nothing overlaps
- Modulation is way higher than expected
- Simple extrapolation leads to conflicts with null results
- What to do?


HALO
WARS
The model builder's last refuge...

WHAT HAPPENS TO THIS PLOT?



T. Schwetz, IDM, 29 July 2010 – p. 31

THE GOAL

What can we say about direct detection experiments without making any appeal to halo models?

- Find Dark Matter
- ~~Determine DM mass~~
- ~~Determine DM interaction strength~~

TWO KEY POINTS

$$\frac{dR}{dE_R} = \frac{N_T M_T \rho}{2 m_\chi \mu^2} \sigma(E_R)\, g(v_{min})$$

$$g(v_{min}) = \int_{v_{min}}^{\infty} d^3v \, \frac{f(\mathbf{v}, t)}{v}$$

$$\sigma_{SI}(E_R) = \sigma_p \frac{\mu^2}{\mu_{n\chi}^2} \frac{(f_p Z + f_n (A - Z))^2}{f_p^2} F^2(E_R)$$

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1) all the energy dependence is in two functions

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1) all the energy dependence is in two functions

$$v_{min} = \sqrt{\frac{M_T E_R}{2\mu^2}}$$

2) there is a 1-1 mapping between velocity and energy

THE IDEA: PART 1

- Suppose you want to compare two experiments, 1 and 2

$$[E^{1}_{low}, E^{1}_{high}] \Rightarrow [v^{1,low}_{min}, v^{1,high}_{min}]$$

nap the energy range studied in experiment 1 to a velocity space range

THE IDEA: PART 1

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map velocity space range back to energy space for experiment 2

$$[v^{1,low}_{min}, v^{1,high}_{min}] \Rightarrow [E^{2}_{low}, E^{2}_{high}]$$

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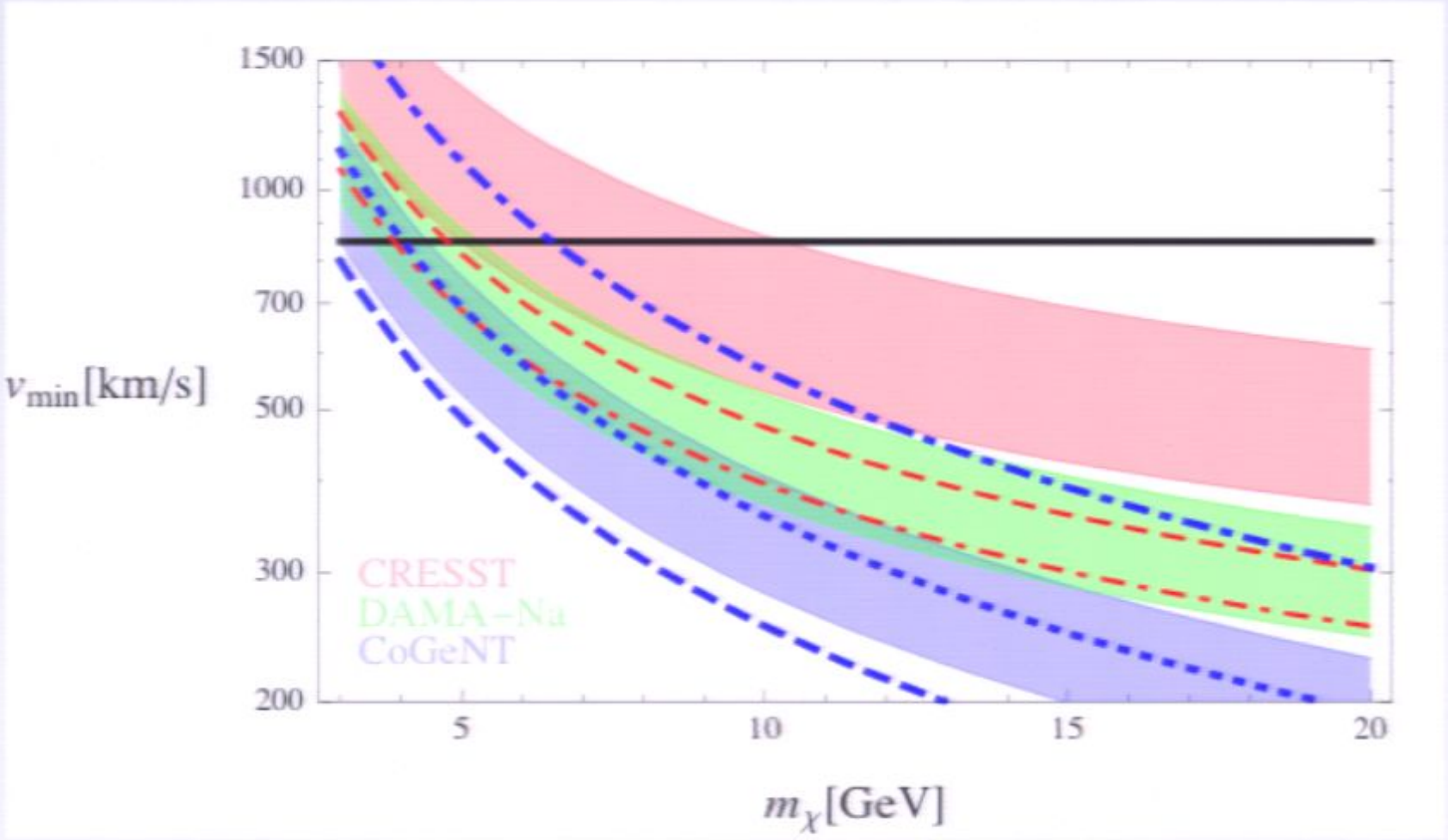
map velocity space range back to energy space for experiment 2

$$[v^{1,low}_{min}, v^{1,high}_{min}] \Rightarrow [E^{2}_{low}, E^{2}_{high}]$$

we now have an energy range where the experiments are studying the *same* particles

$$[E^{1}_{low}, E^{1}_{high}] \Leftrightarrow [E^{2}_{low}, E^{2}_{high}]$$



Approx. range	O	Na	Si	Ar	Ge	Xe
CoGeNT (Ge): 2 - 4	4.3 - 8.6	3.9 - 7.8	3.6 - 7.2	3.0 - 6.0	2 - 4	1.3 - 2.5
DAMA (Na): 6 - 13	6.6 - 14	6 - 13	5.5 - 12	4.6 - 10	3.1 - 6.7	1.9 - 4.2
CRESST (O): 15 - 40	15 - 40	14 - 36	12 - 33	10 - 28	6.9 - 19	4.3 - 12

TABLE I: Conversion of energy ranges (all in keV) between various experiments/targets for a 10 GeV DM particle, using the expression in (7).

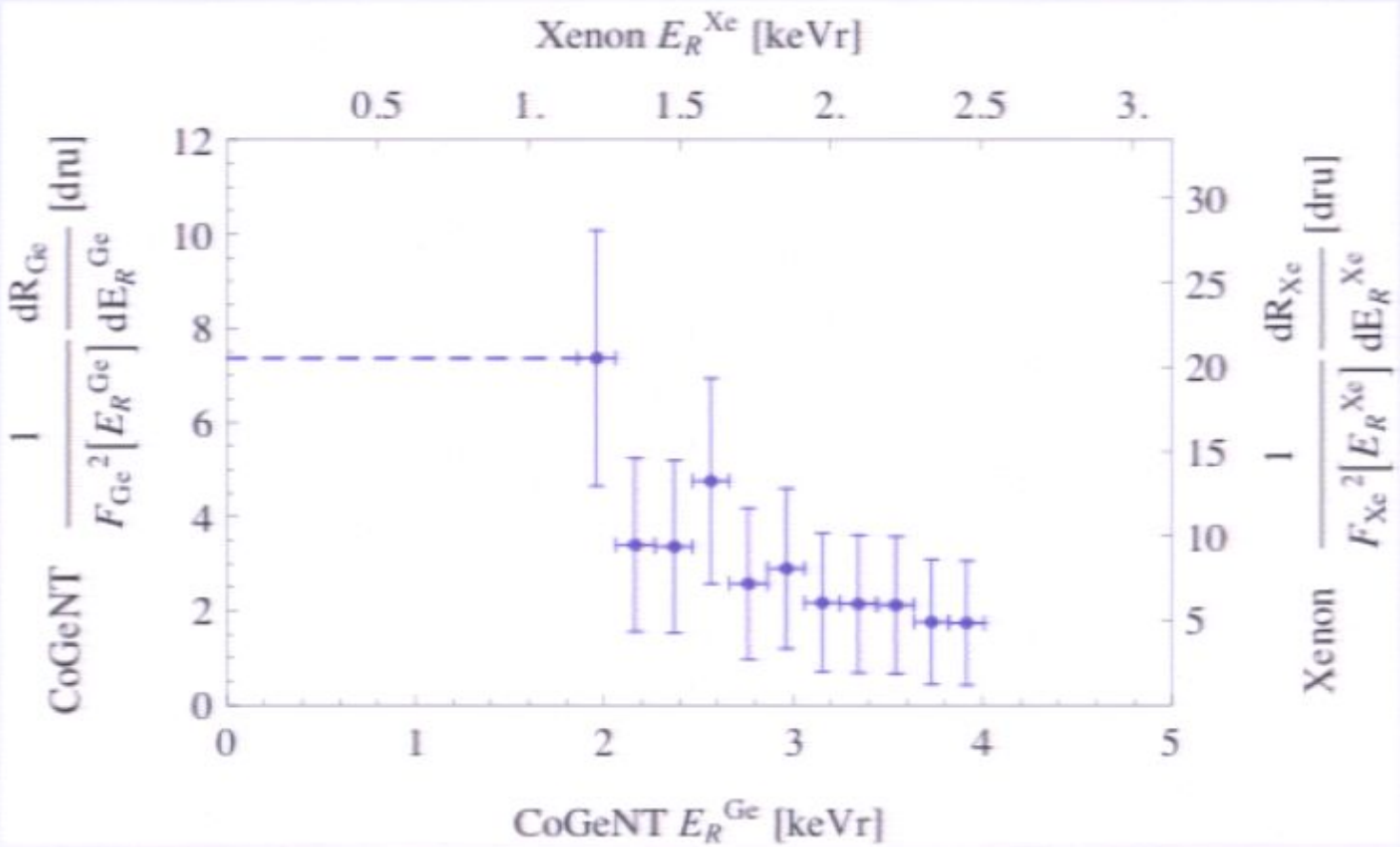
THE IDEA: PART 2

Invert:

$$\frac{dR}{dE_R} = \frac{N_T M_T \rho}{2 m_\chi \mu^2} \sigma(E_R)\, g(v_{min}) \longrightarrow g(v) = \frac{2 m_\chi \mu^2}{N_T M_T \rho \sigma(E_R)} \frac{dR_1}{dE_1}$$

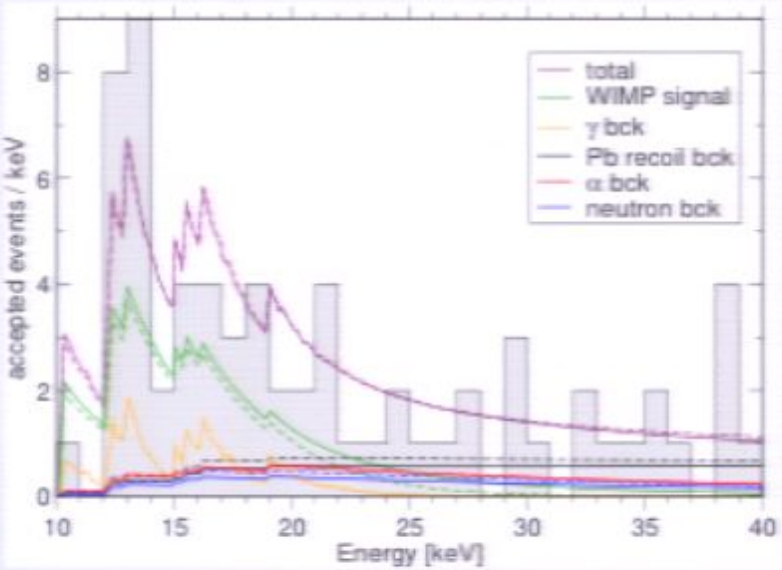
$$\frac{dR_2}{dE_R}(E_2) = \frac{C_T^{(2)}}{C_T^{(1)}} \frac{F_2^2(E_2)}{F_1^2\left(\frac{\mu_1^2 M_T^{(2)}}{\mu_2^2 M_T^{(1)}} E_2\right)} \frac{dR_1}{dE_R}\left(\frac{\mu_1^2 M_T^{(2)}}{\mu_2^2 M_T^{(1)}} E_2\right)$$

A direct prediction of the rate
at experiment 2 from experiment 1



But if these are not the current data, then I don't know what to say...

module	$E_{\mathrm{acc}}^{\mathrm{min}}$ [keV]	acc. events
Ch05	12.3	11
Ch20	12.9	6
Ch29	12.1	17
Ch33	15.0	6
Ch43	15.5	9
Ch45	16.2	4
Ch47	19.0	5
Ch51	10.2	9
total	-	**67**



(plots from preliminary data)

module	E_{acc}^{min} [keV]	acc. events
Ch05	12.3	11
Ch20	12.9	6
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Ch33	15.0	6
Ch43	15.5	9
Ch45	16.2	4
Ch47	19.0	5
Ch51	10.2	9
total	-	**67**

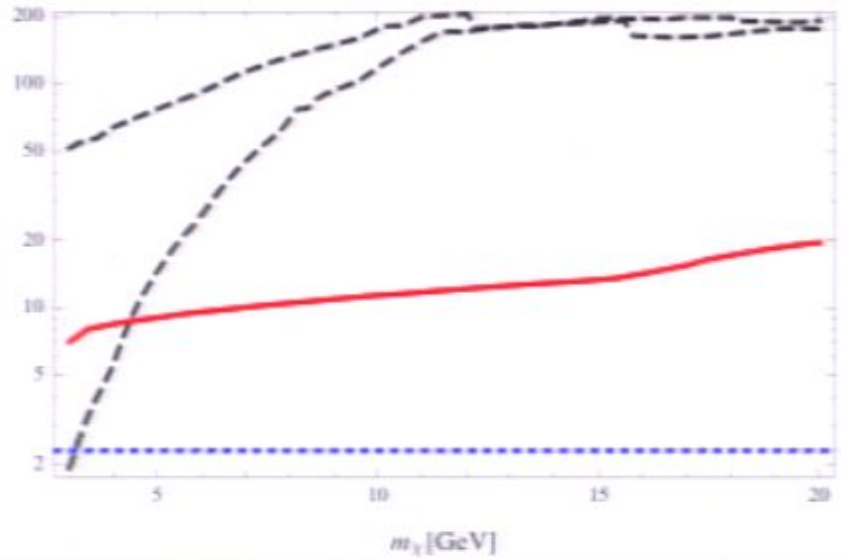
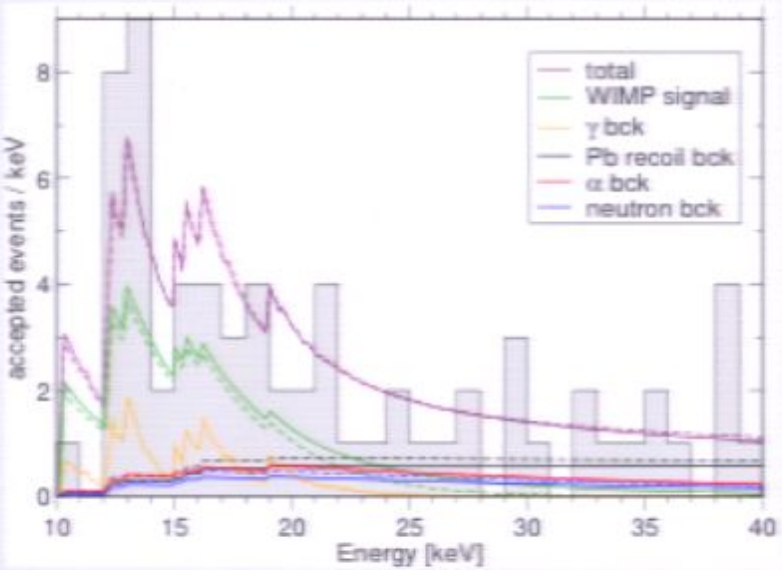
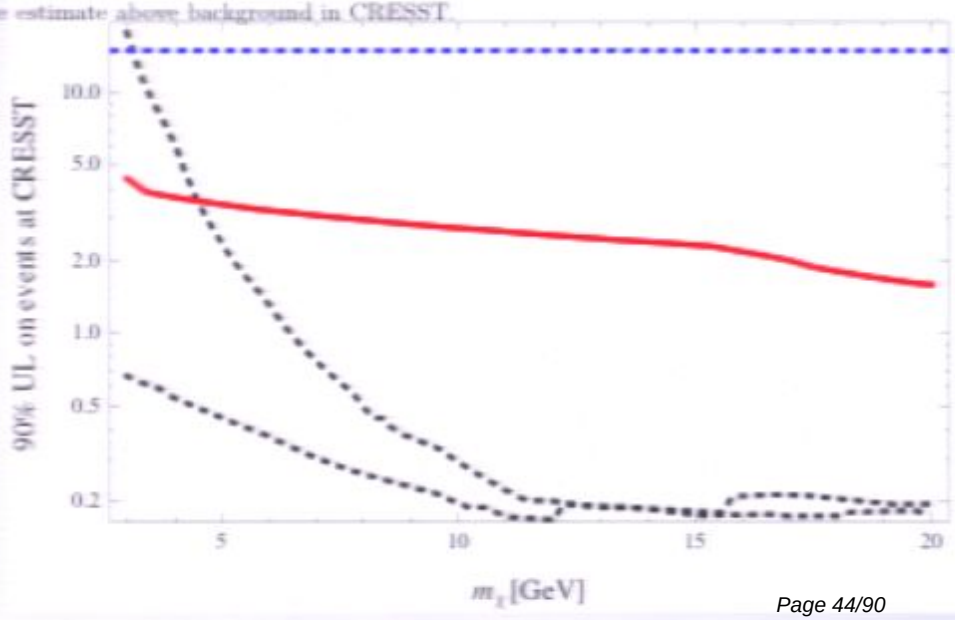


FIG. 5: LH plot: the CRESST prediction for the total number of events at CDMS-Si (solid red) and XENON10, for $\mathcal{L}_{eff}^{MIN}$ (dashed black) and $\mathcal{L}_{eff}^{MED}$ (dotted black), the dotted (blue) line is the 90% C.L. upper limit on the number of events allowed by CDMS-Si. RH plot: the 90% C.L. upper limit on the number of events at CRESST as predicted by CDMS-Si (solid red) and XENON10, again for $\mathcal{L}_{eff}^{MIN}$ (dashed black) and $\mathcal{L}_{eff}^{MED}$ (dotted black), the dotted (blue) line is the number of events we estimate above background in CRESST.





Bin	CoGeNT	Ge	Na (Q=0.3)	Si	O	Xe
1	[0.5,0.9] 0.90 ± 0.72	[2.3,3.8] 0.23 ± 0.18	[1.5,2.5] 0.078 ± 0.062	[4.5,7.6] 0.035 ± 0.028	[5.8,9.9] 0.011 ± 0.009	[1.4,2.3] 0.72 ± 0.58
2	[0.9,1.5] 0.37 ± 0.55	[3.8,6.1] 0.1 ± 0.149	[2.5,4.0] 0.035 ± 0.052	[7.6,11.9] 0.015 ± 0.023	[9.9,15.6] 0.005 ± 0.008	[2.3,3.7] 0.31 ± 0.46
3	[1.5,2.3] 0.48 ± 0.22	[6.1,8.9] 0.136 ± 0.063	[4.0,5.8] 0.049 ± 0.022	[11.9,17.5] 0.021 ± 0.01	[15.6,22.8] 0.007 ± 0.003	[3.7,5.4] 0.41 ± 0.19
4	[2.3,3.1] 0.27 ± 0.23	[8.9,11.6] 0.08 ± 0.068	[5.8,7.6] 0.029 ± 0.025	[17.5,22.8] 0.013 ± 0.011	[22.8,29.8] 0.004 ± 0.004	[5.4,7] 0.23 ± 0.2

CoGeNT signal

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1	[0.5,0.9] 0.90 ± 0.72	[2.3,3.8] 0.23 ± 0.18	[1.5,2.5] 0.078 ± 0.062	[4.5,7.6] 0.035 ± 0.028	[5.8,9.9] 0.011 ± 0.009	[1.4,2.3] 0.72 ± 0.58
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CoGeNT modulation/CRESST signal

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CoGeNT modulation/CRESST signal

For XENON100 need full efficiency Green's functions to calculate limits

LIGHT SUMMARY:

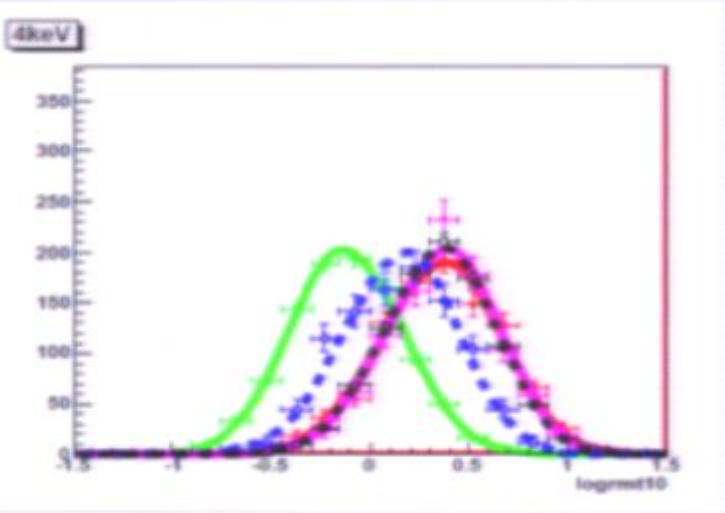
- Even if you abandon halo model constraints, I don't know how to fit everything together (w/o introducing something like double scatters a la MiDM)

HEAVY WIMPS

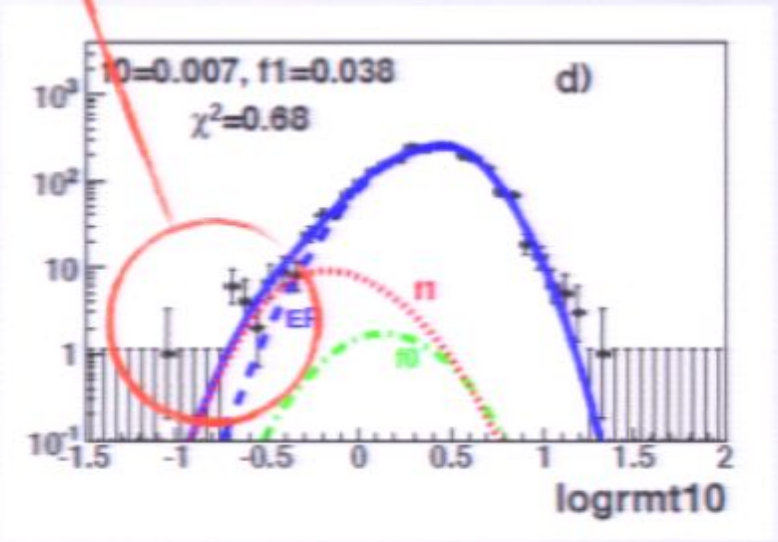
HEAVY WIMPS FOR DAMA

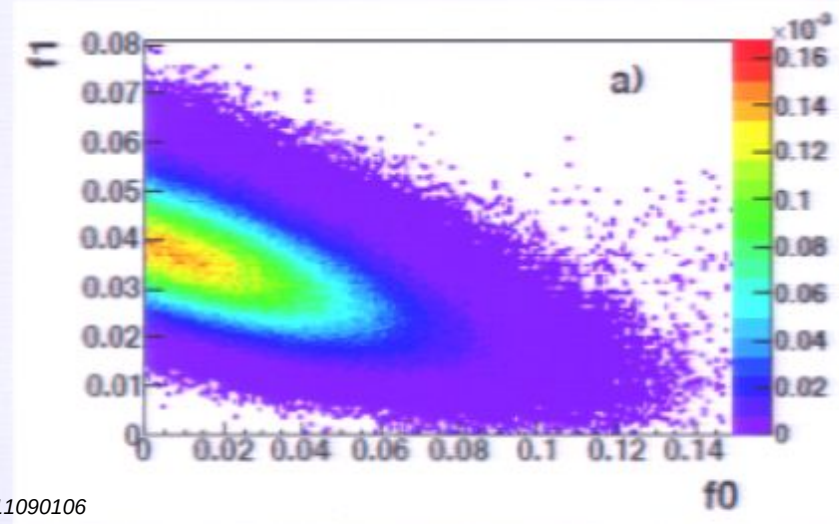
- What if the scattering is off iodine?
- inelastic DM, resonant DM, but otherwise?
- KIMS (CsI), COUPP (I)
- XENON100 (Xe - similar to I in mass)
- CRESST (W - but related)

KIMS



Trying to fit this
=> pull for lots of SA





Calibration?
Can you even find
NRs with this?

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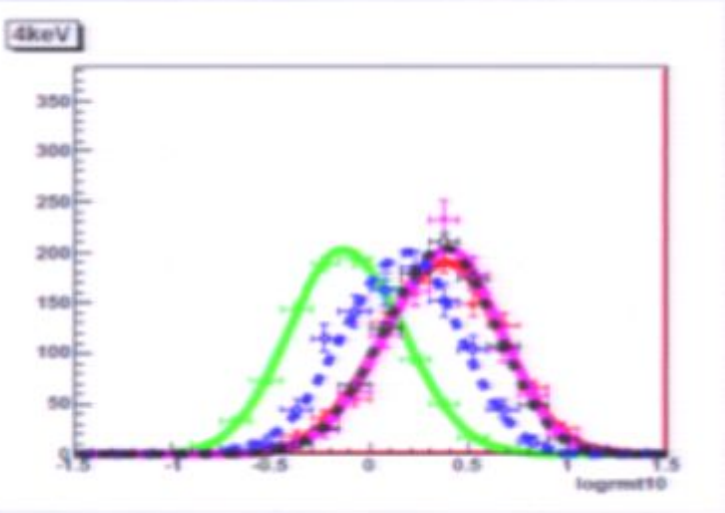
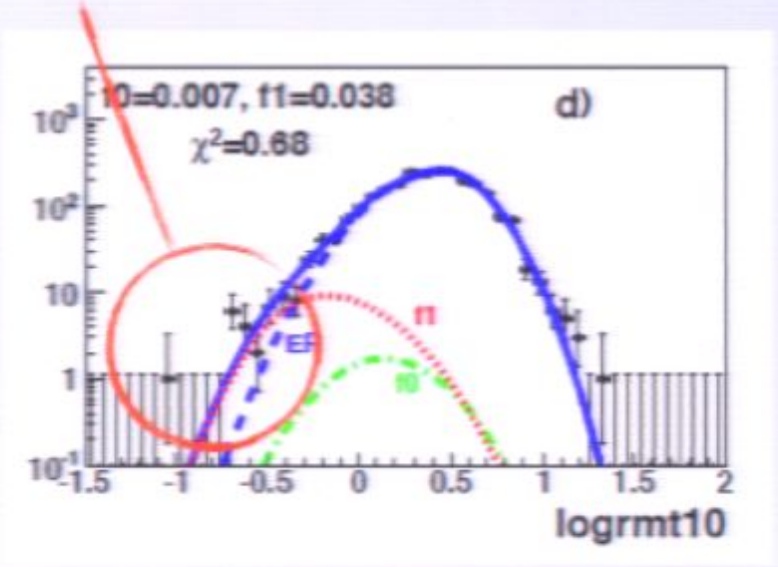
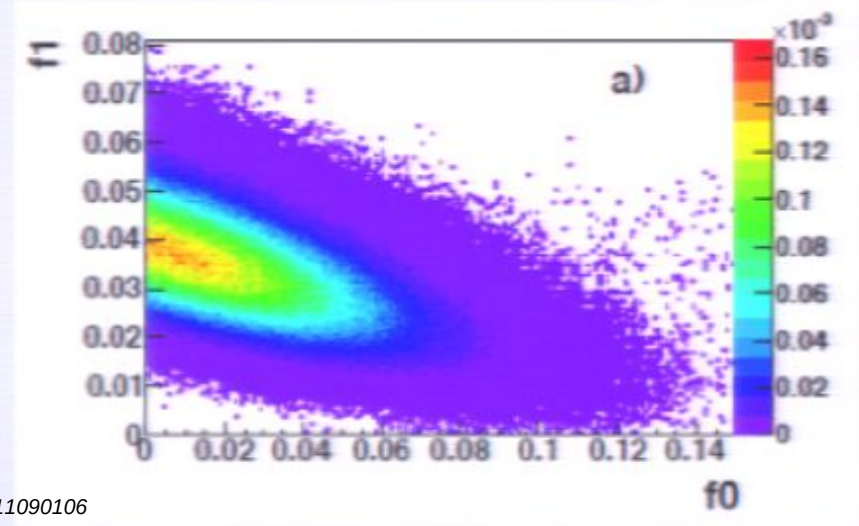


Trying to fit this
=> pull for lots of SA





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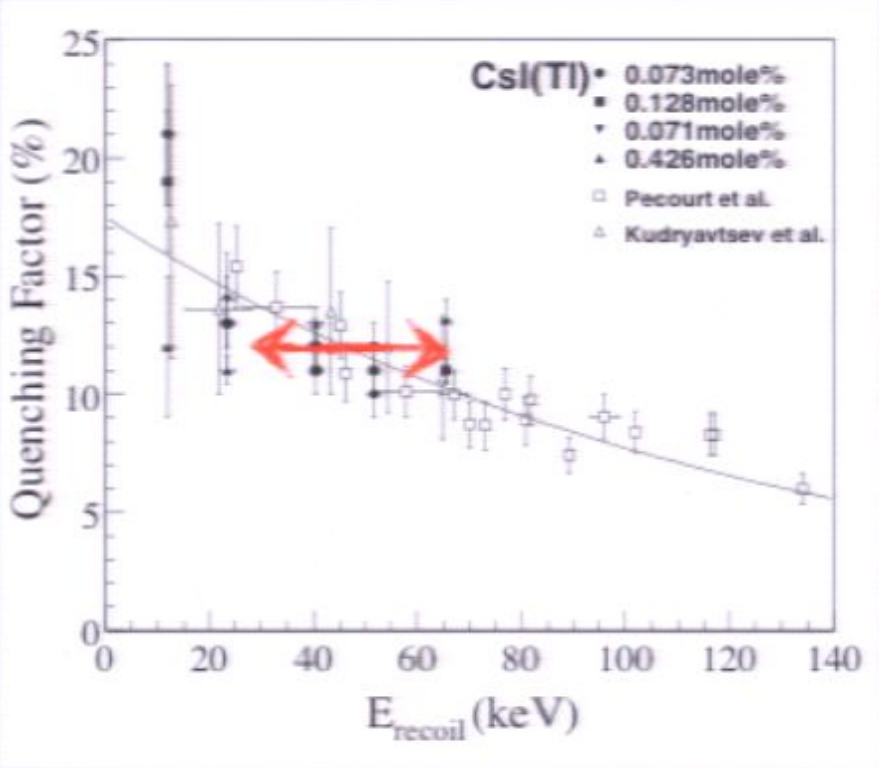
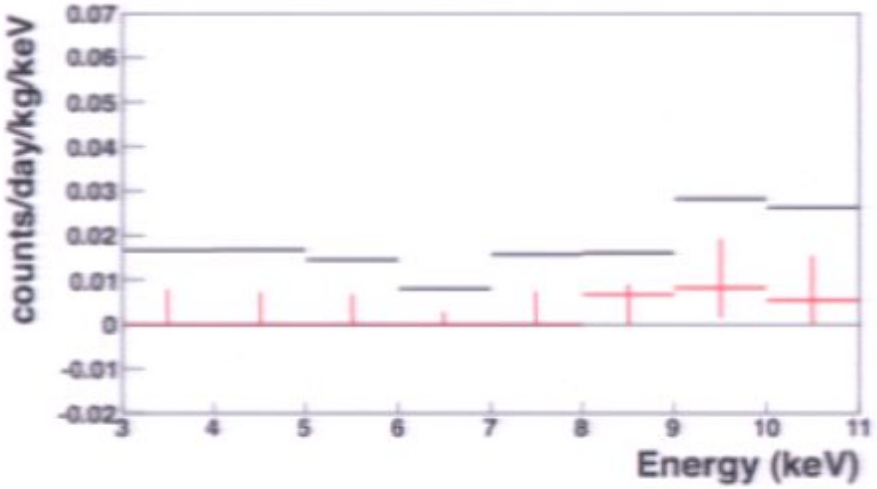
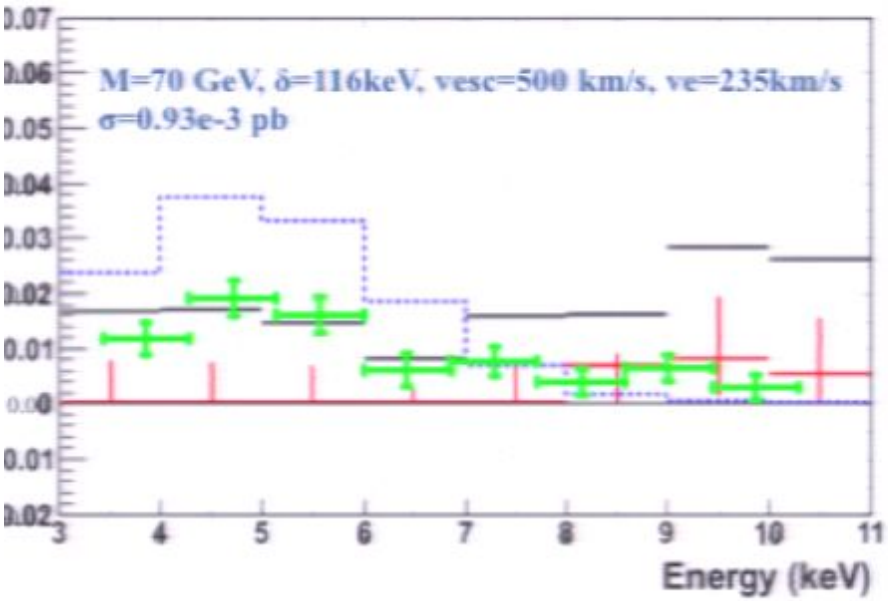


Total scintillation energy (E q(E))
falls at high energies

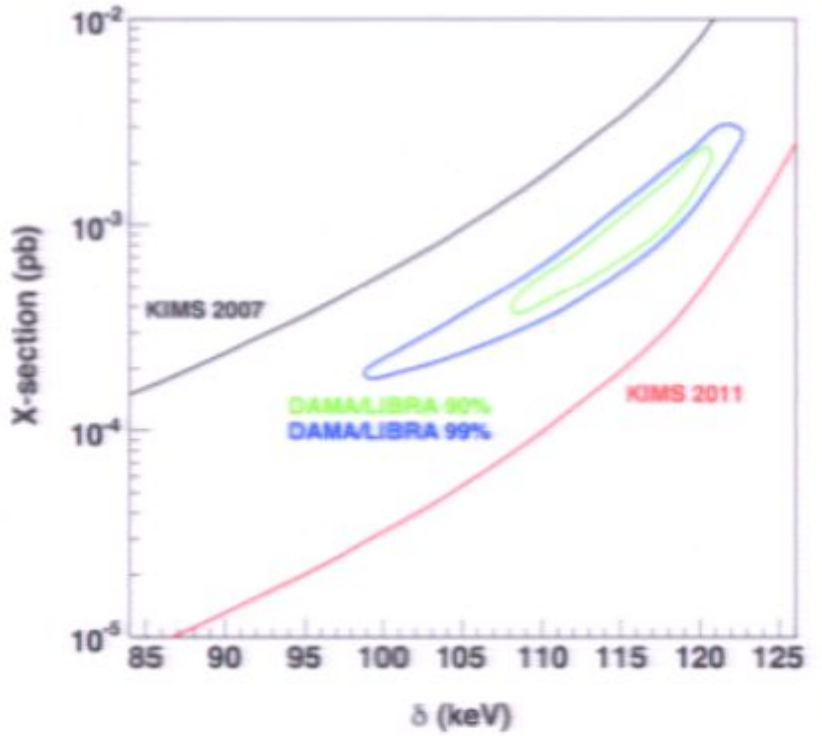
Seems unphysical
- I'll use q=0.12

KIMS Nuclear recoil event rate





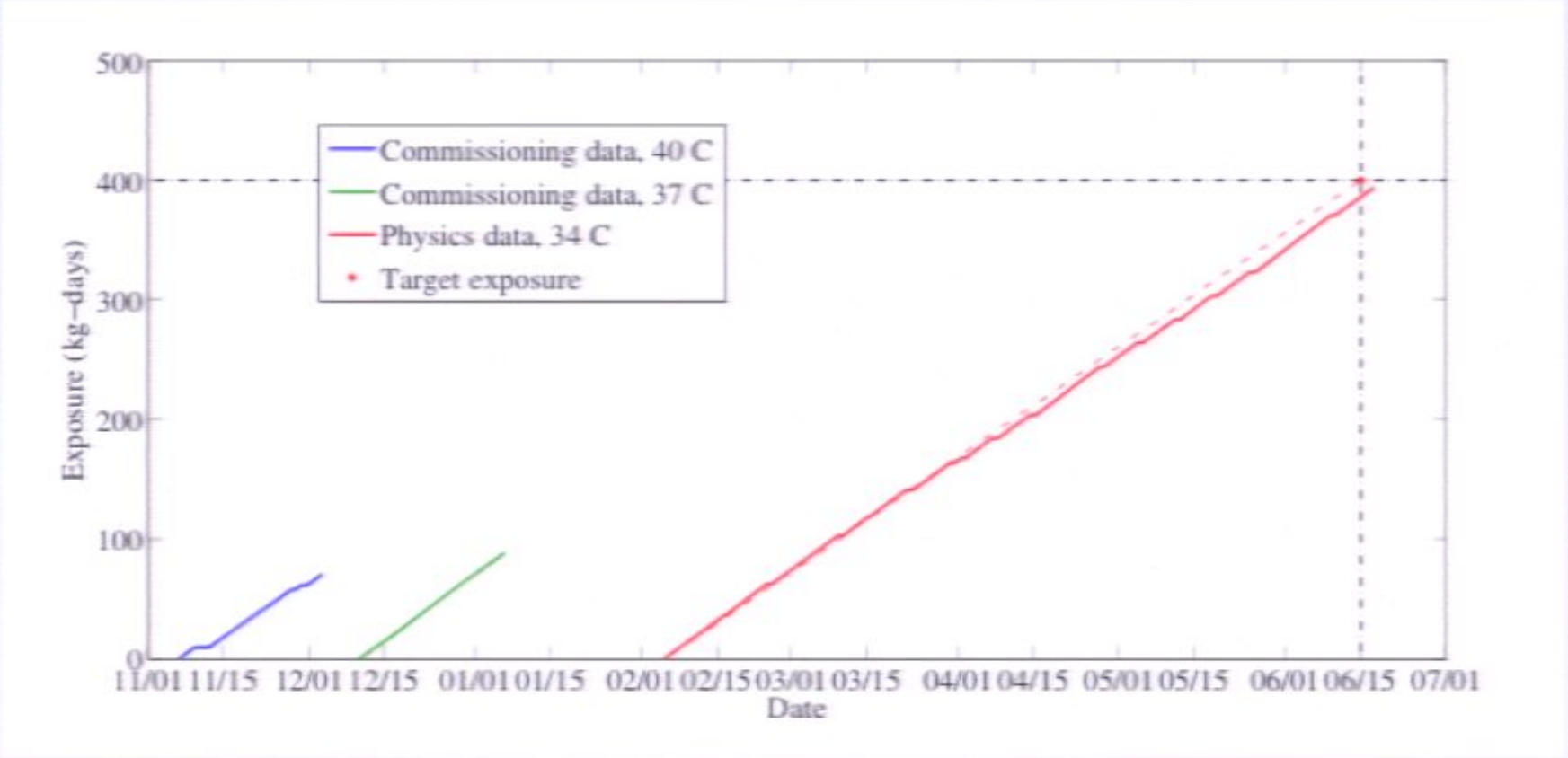
Excluded?



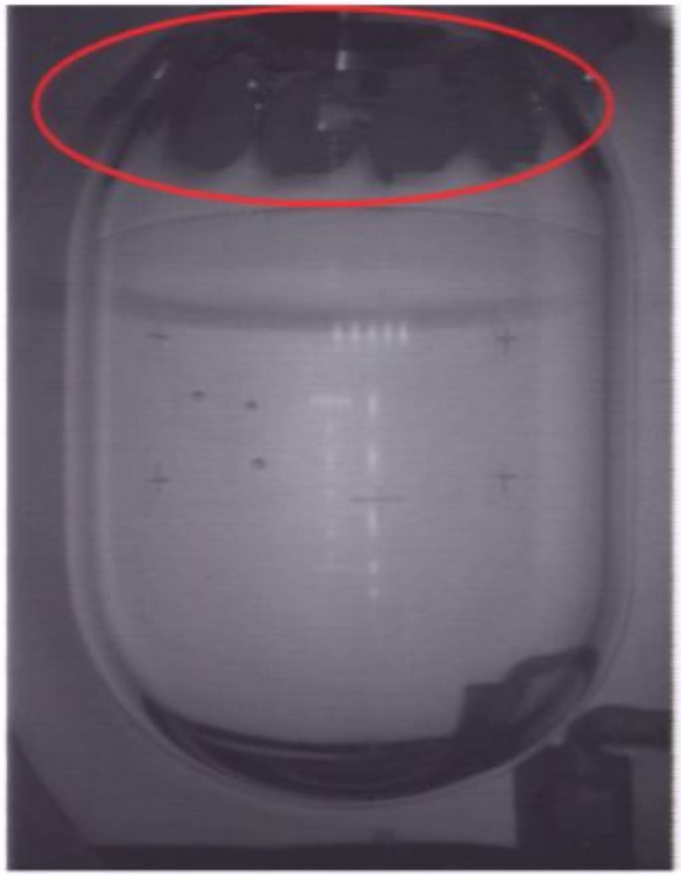
DAMA q=0.07, KIMS q=0.12

From a model independent perspective, I-scattering is still allowed by KIMS. (And may be even better depending on NR efficiency.)

COUPP


Commissioning data, 40 C
Commissioning data, 37 C
Physics data, 34 C
Target exposure
Exposure (kg−days)
Date
0
100
200
300
400
500
11/01
11/15
12/01
12/15
01/01
01/15
02/01
02/15
03/01
03/15
04/01
04/15
05/01
05/15
06/01
06/15
07/01

- Single bubble background of 0.026 events/kg/day at 15 keV threshold
- One 2-bubble event at same threshold (two 3-bubble events at 10 keV threshold)
- We have found lower radioactivity salts for the piezos
- Replacing the pressure windows with synthetic quartz viewports

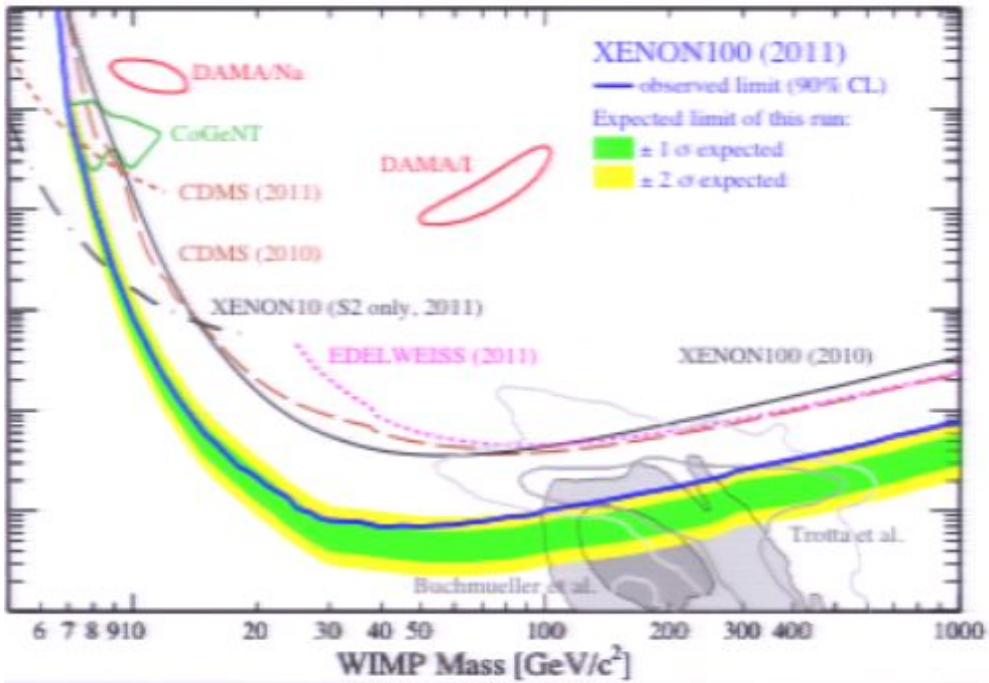


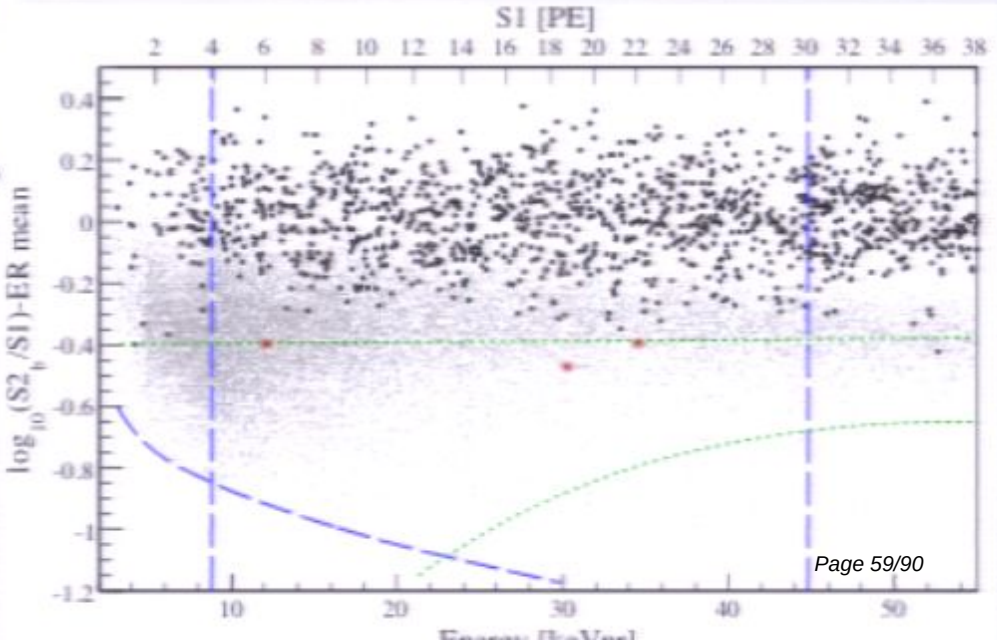
Guess: 0.026 cpd/kg x
390 day ~ 10 events
90% UL of 0.04

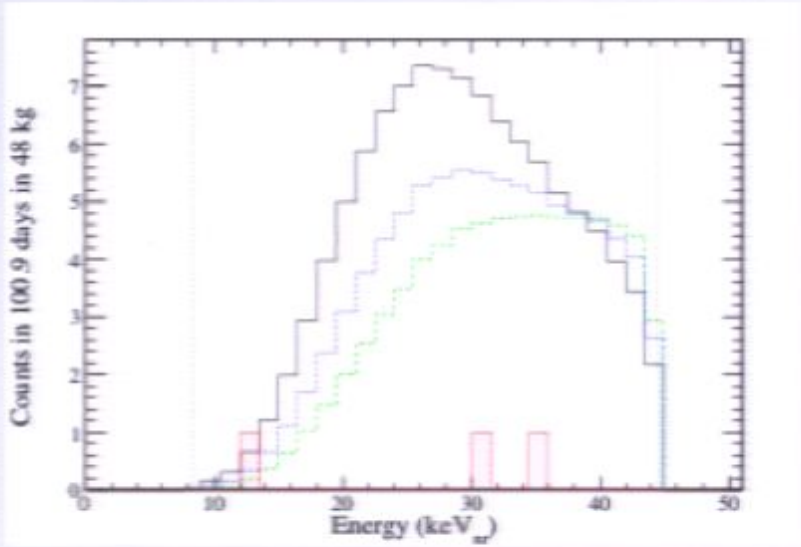
DAMA predicts:
0.036/0.031 100%/87% efficiency
(0.023-0.049)/(0.02-0.043)
90% CL

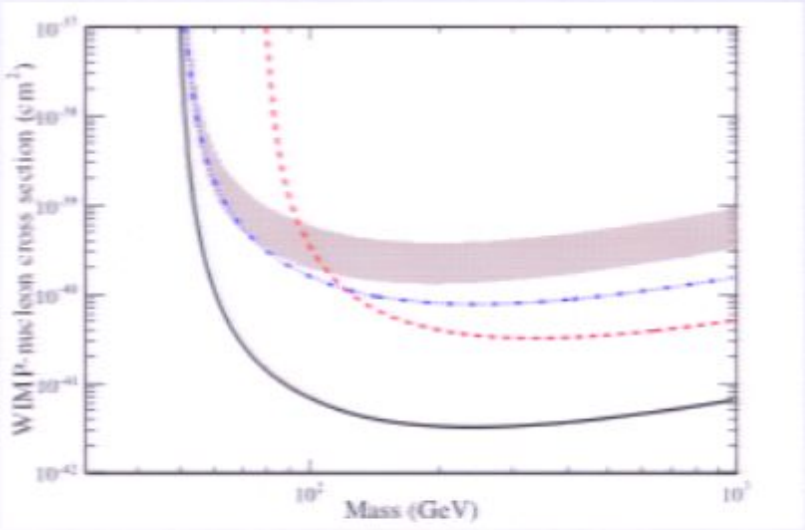
Appears ok - but requires O(1) [really 1] modulation

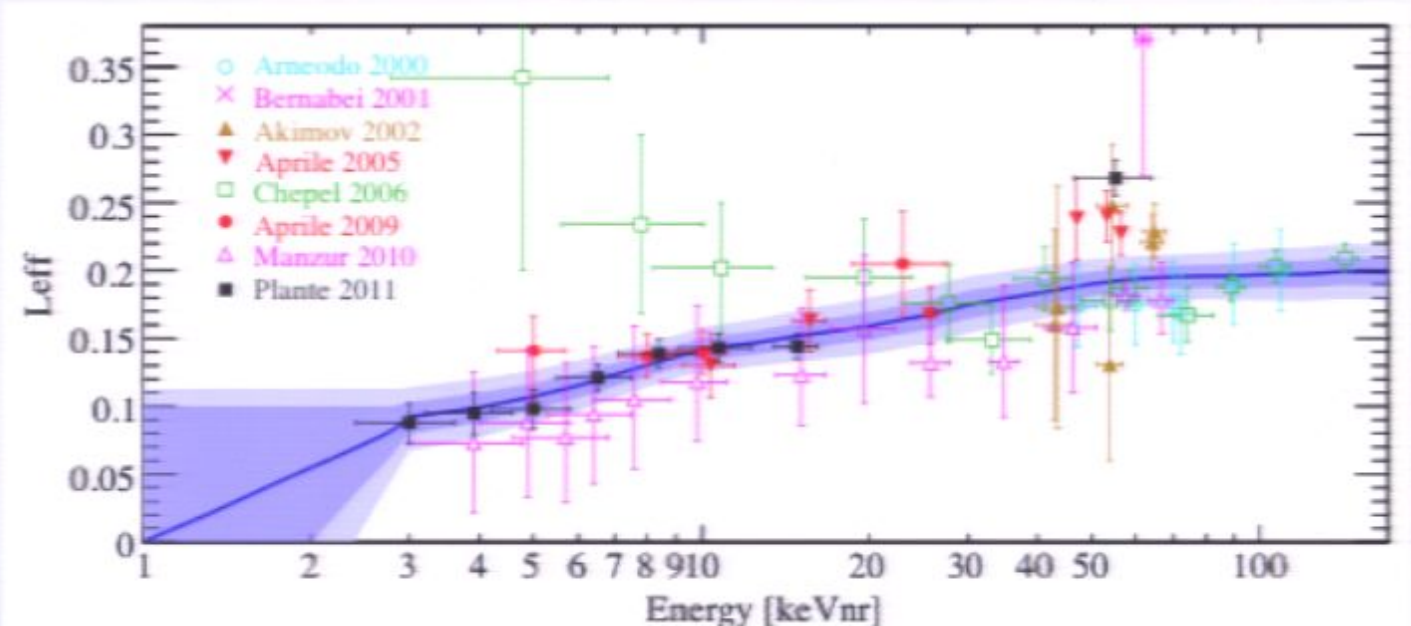
XENON?


XENON100 (2011)
observed limit (90% CL)
Expected limit of this run:
± 1 σ expected
± 2 σ expected
DAMA/Na
CoGeNT
DAMA/I
CDMS (2011)
CDMS (2010)
XENON10 (S2 only, 2011)
EDELWEISS (2011)
XENON100 (2010)
Trotta et al.
Buchmueller et al.
6 7 8 9 10 20 30 40 50 100 200 300 400 1000
WIMP Mass [GeV/c²]

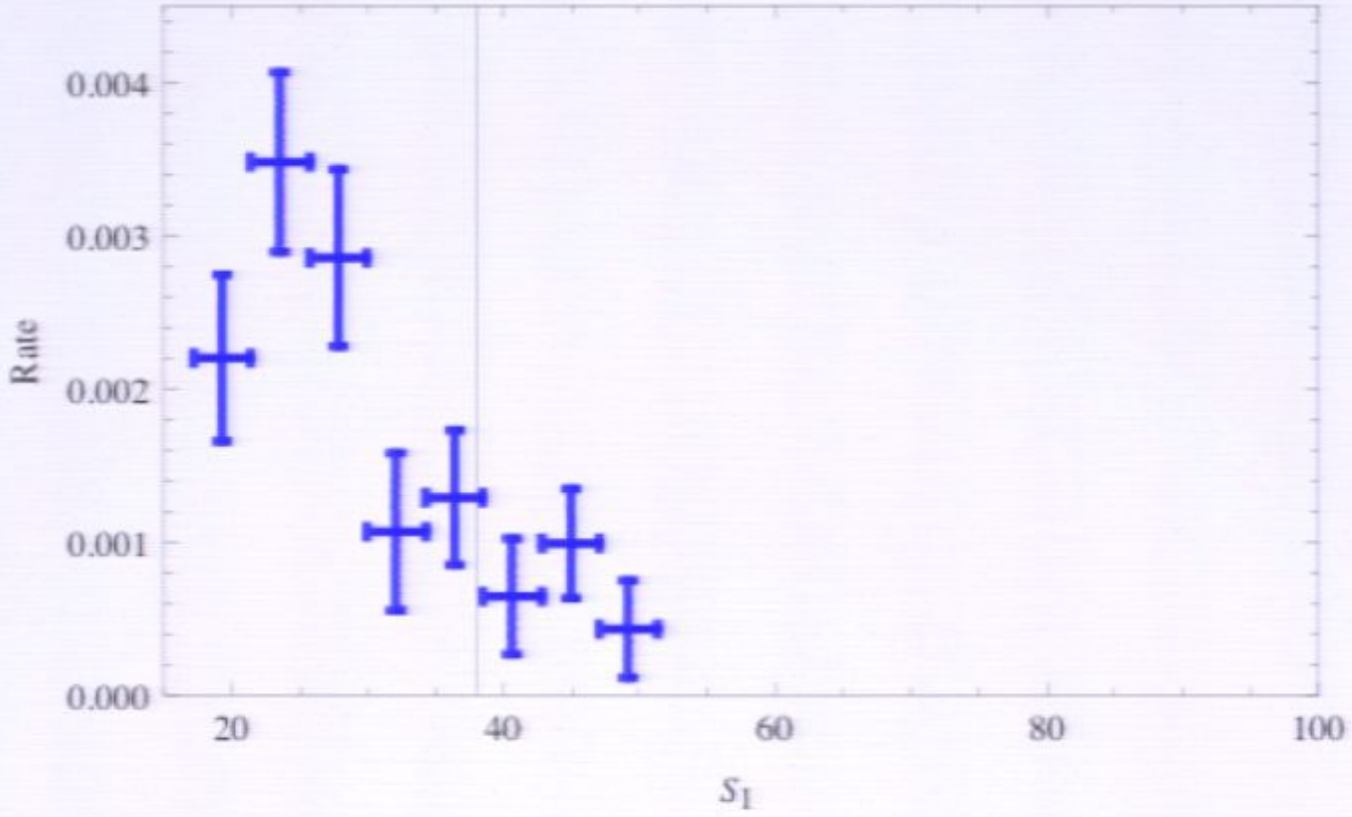

S1 [PE]
2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
-1.2
log10(S2b/S1)-ER mean
10 20 30 40 50


Counts in 100.9 days in 48 kg
Energy (keV$_{nr}$)

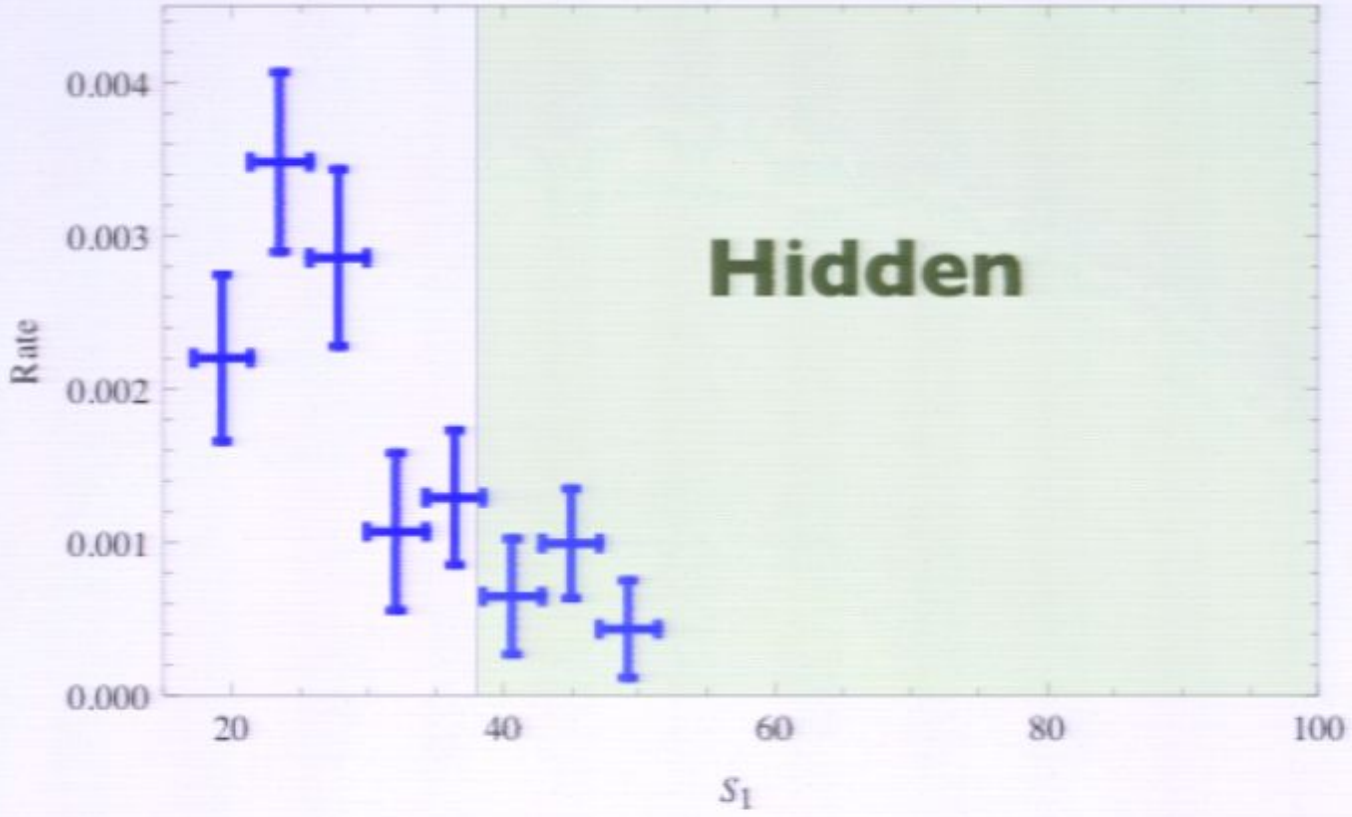

WIMP-nucleon cross section (cm^2)
Mass (GeV)


Arneodo 2000
Bernabei 2001
Akimov 2002
Aprile 2005
Chepel 2006
Aprile 2009
Manzur 2010
Plante 2011
Leff
Energy [keVnr]

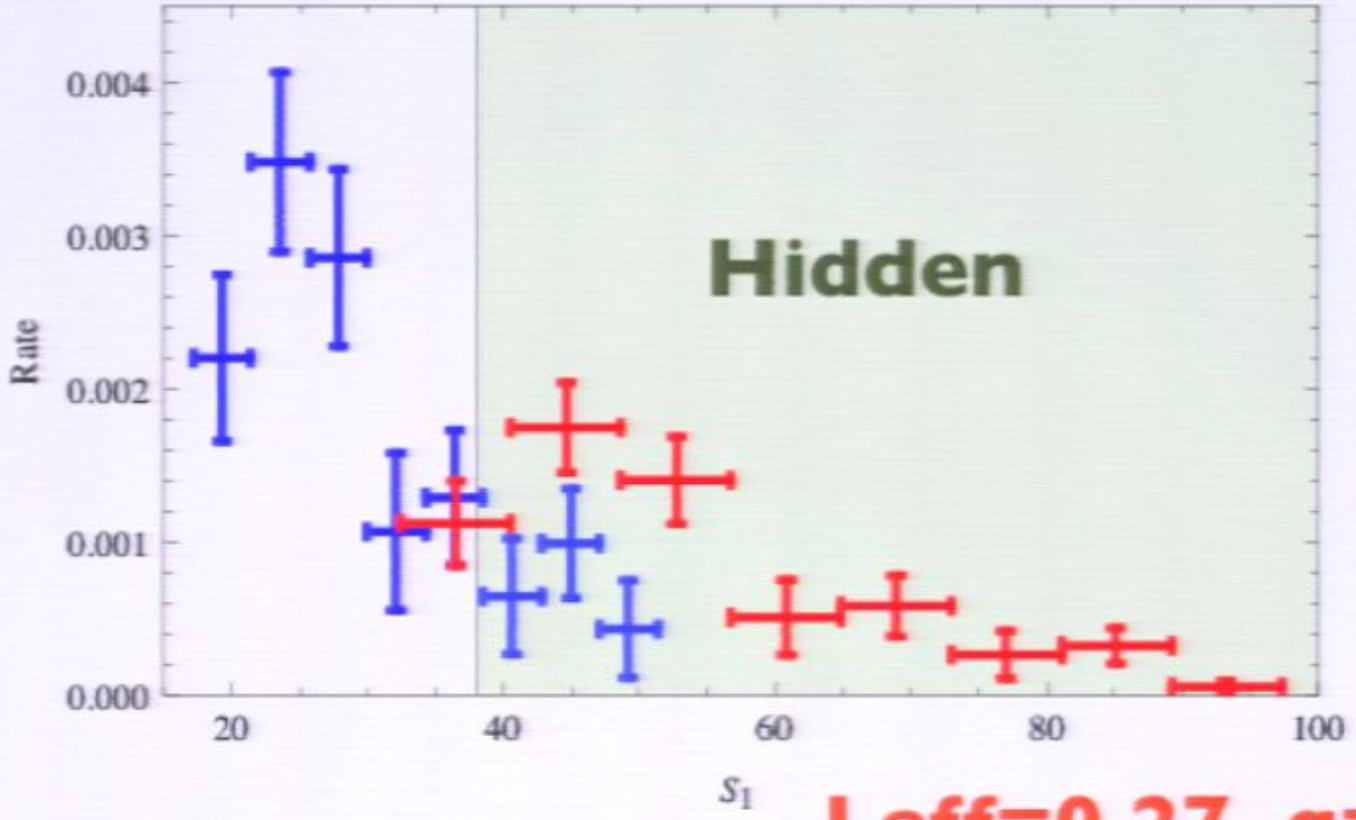
Leff=0.19, q=0.08



Leff=0.19, q=0.08

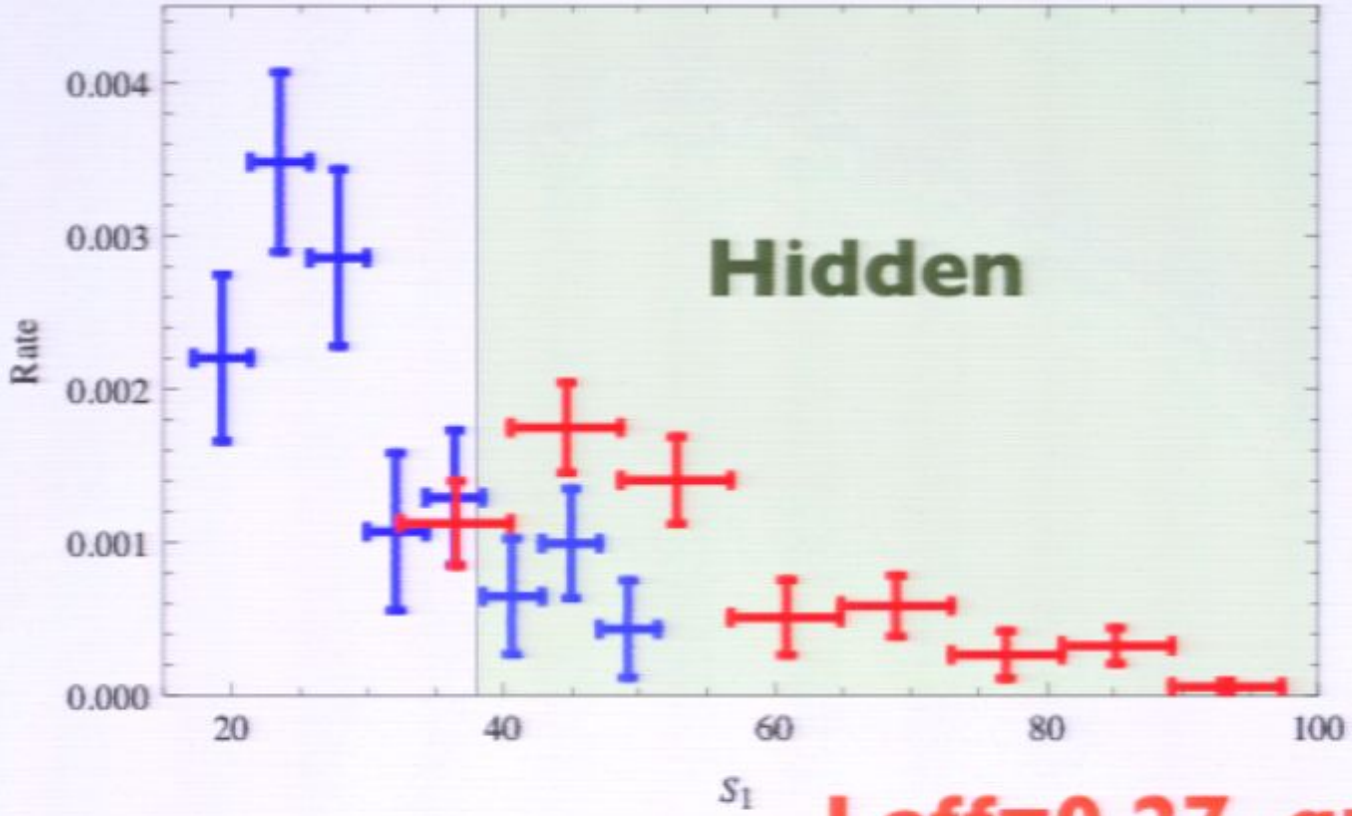


Leff=0.19, q=0.08



Leff=0.27, q=0.06

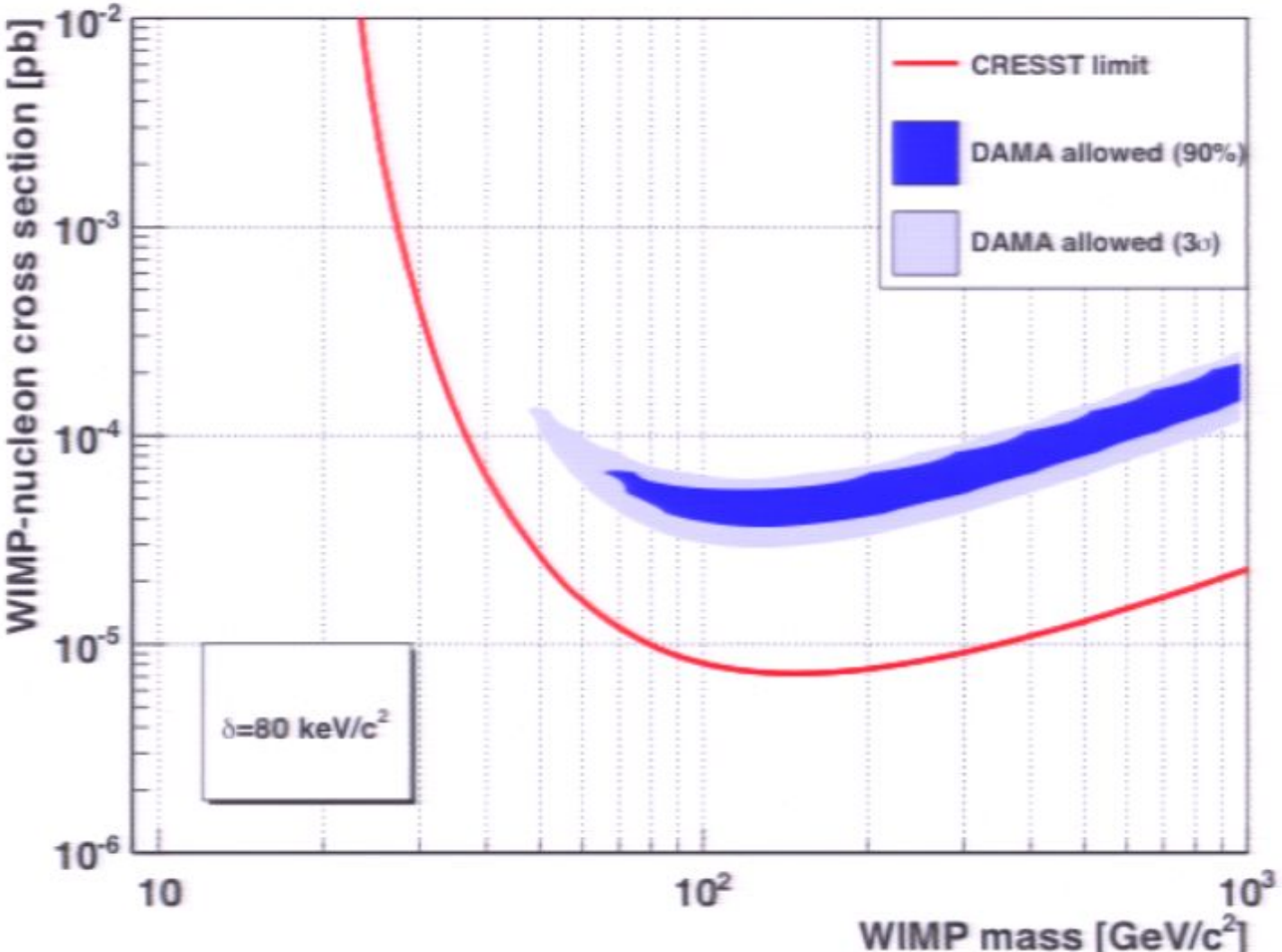
Leff=0.19, q=0.08

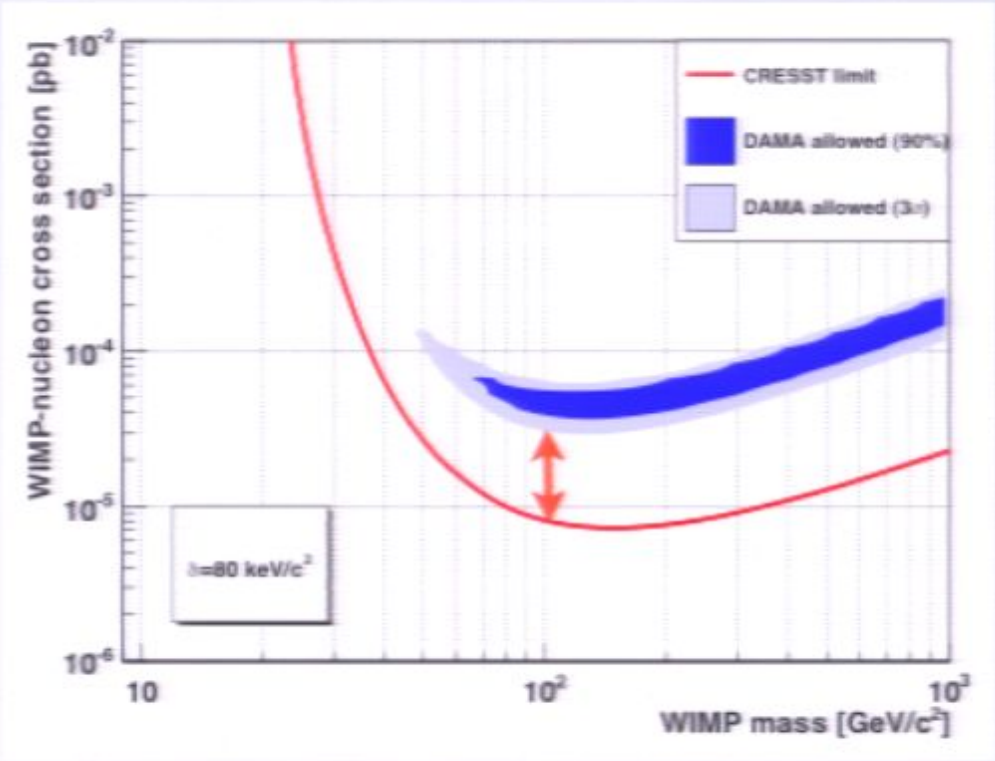


Leff=0.27, q=0.06

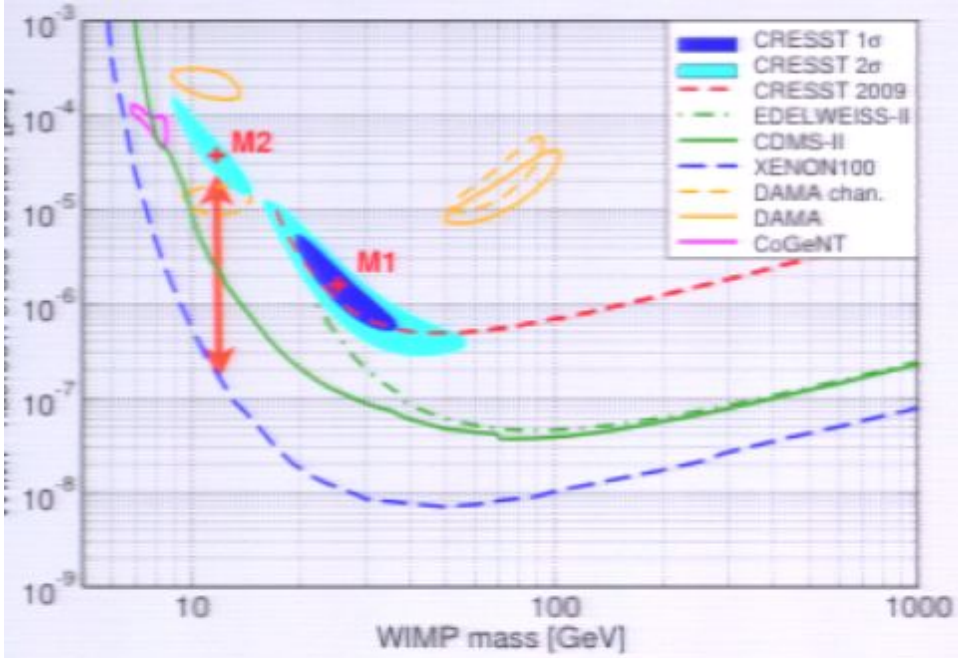
Not a requirement: magnetic and spin dependent couplings can suppress

What CRESST said about iDM at TAUP

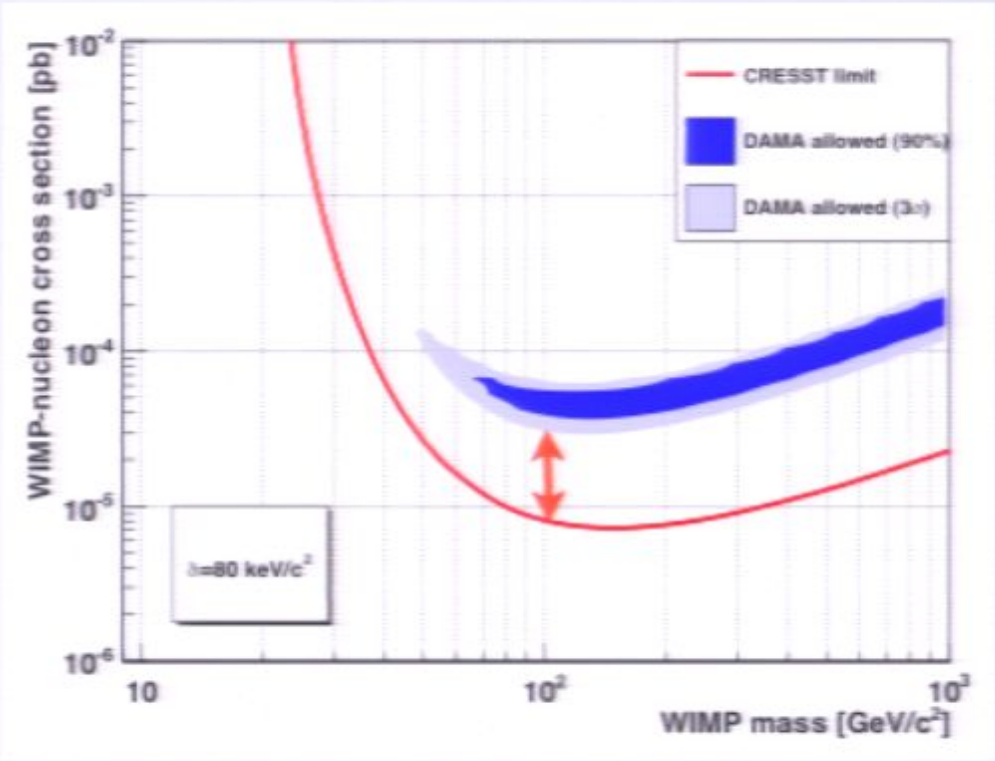




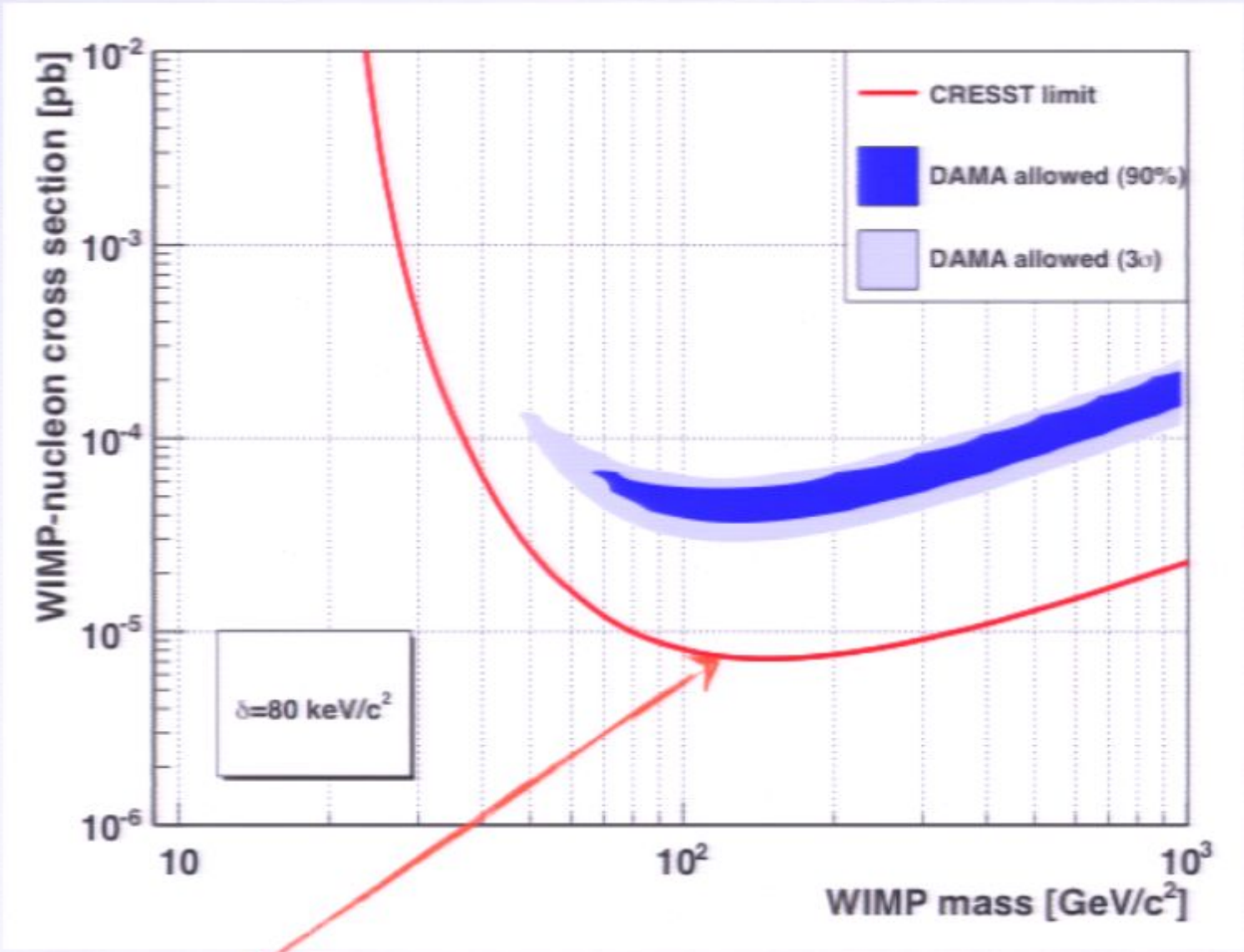
Factor of 4
"ruled out"



Factor of 100
"considerable tension"

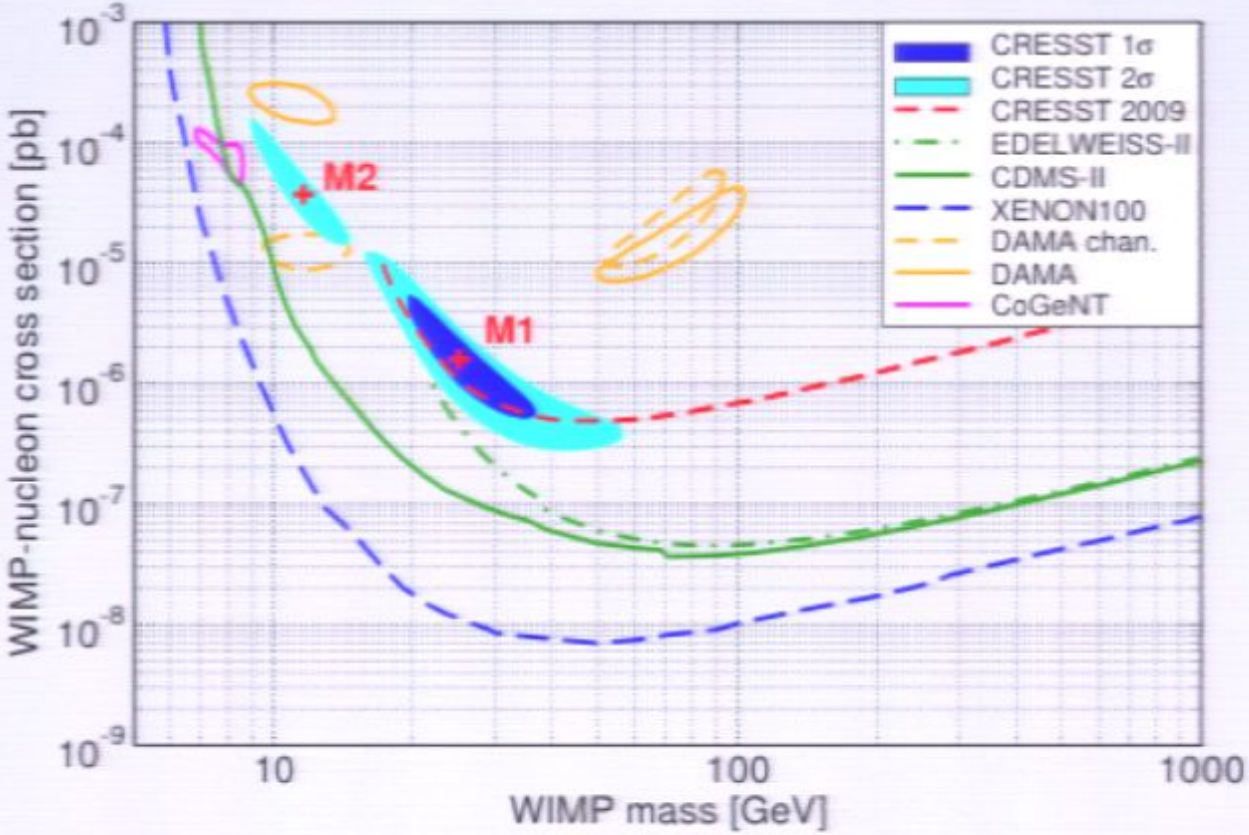


Factor of 4
"ruled out"



42 events => 90% Poisson limit implies 33 W events

Is CRESST really pointing toward light WIMPs?



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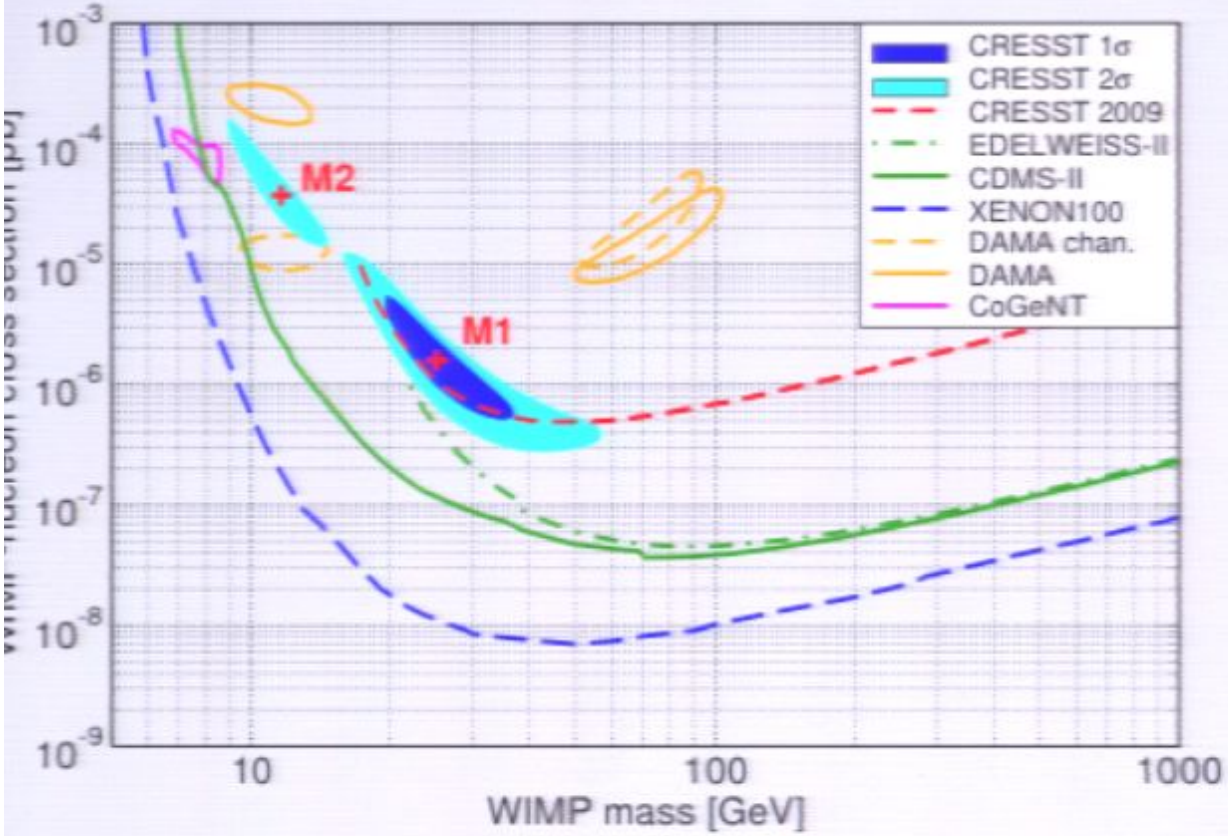

M1:

2.0 O events

7.3 Ca events

19.6 W events

(67% W)

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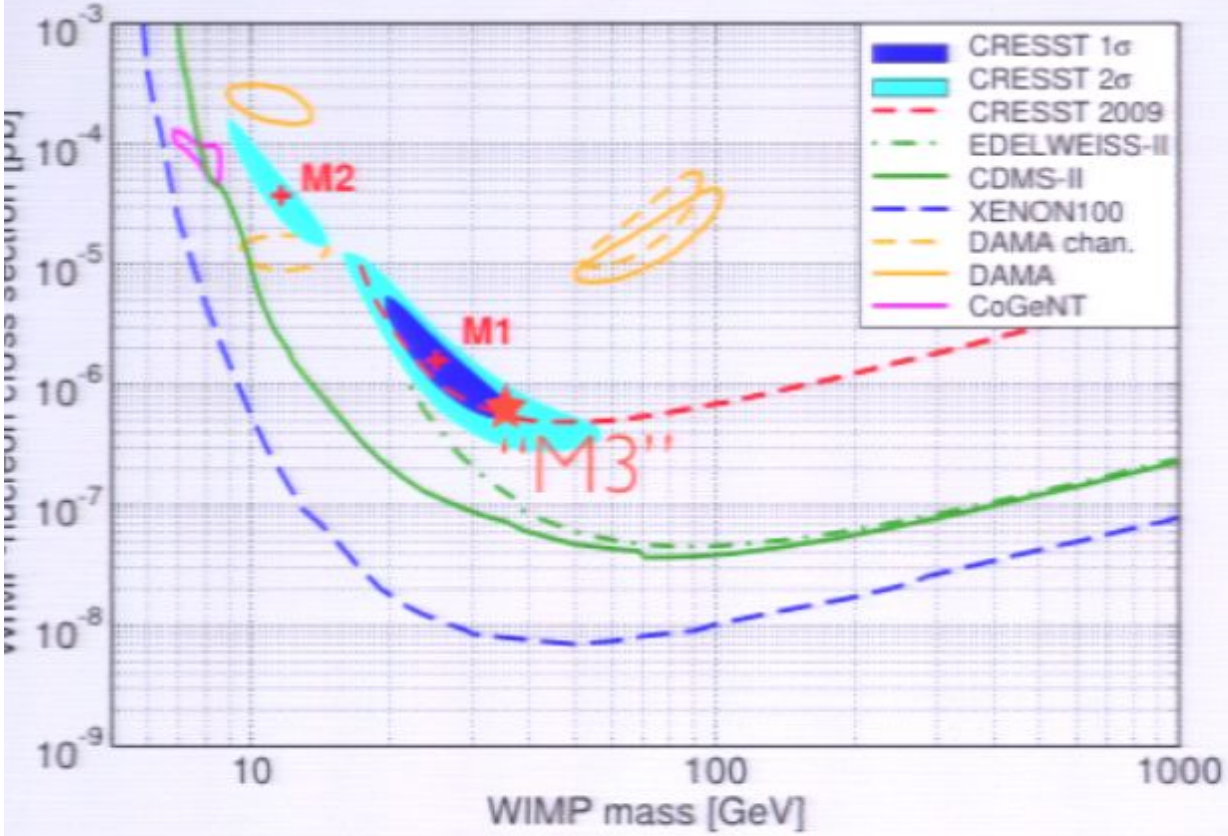

M1:

2.0 O events

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19.6 W events

(67% W)

"M3"

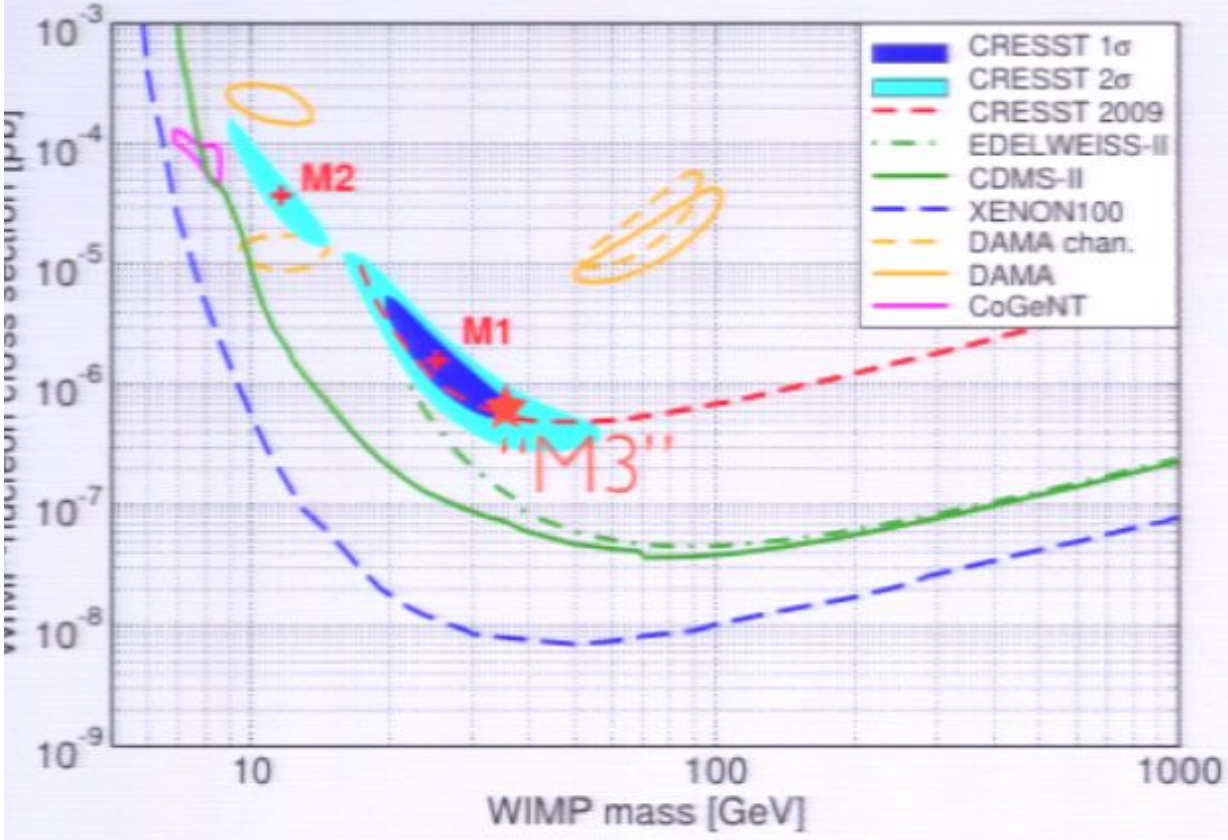
0.8 O events

3.8 Ca events

26.5 W events

(85% W)

Is CRESST really pointing toward light WIMPs?

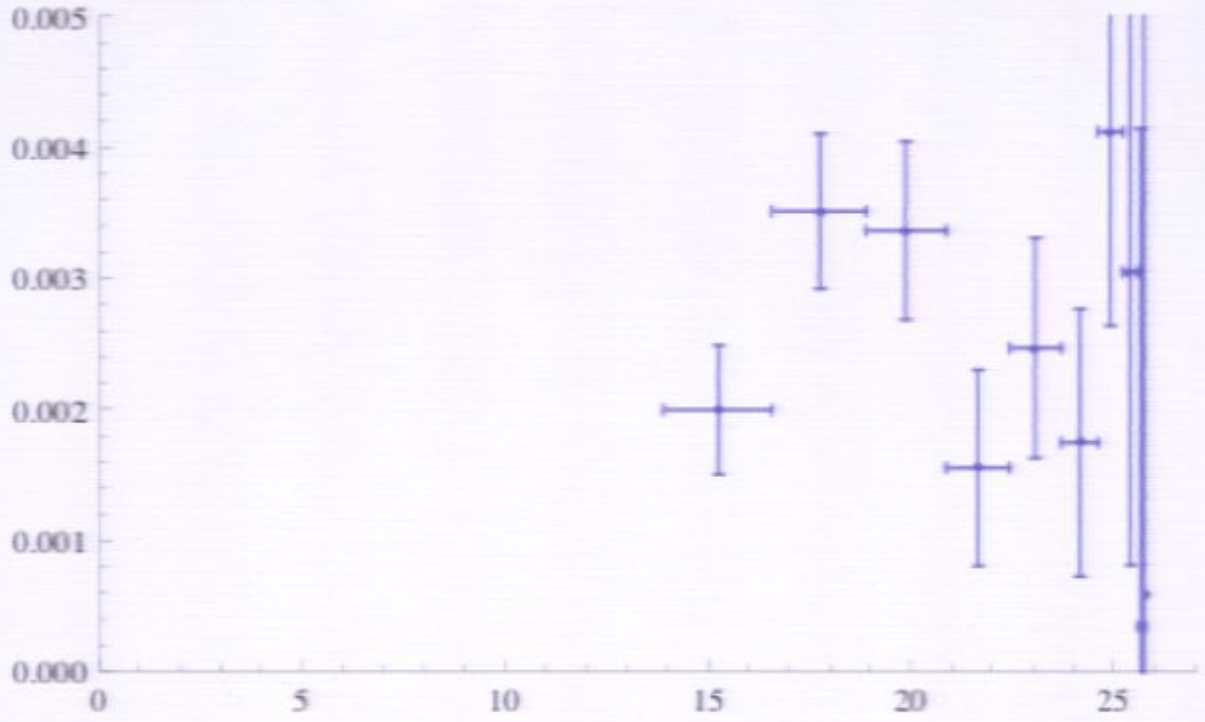


M1:
2.0 O events
7.3 Ca events
19.6 W events
(67% W)

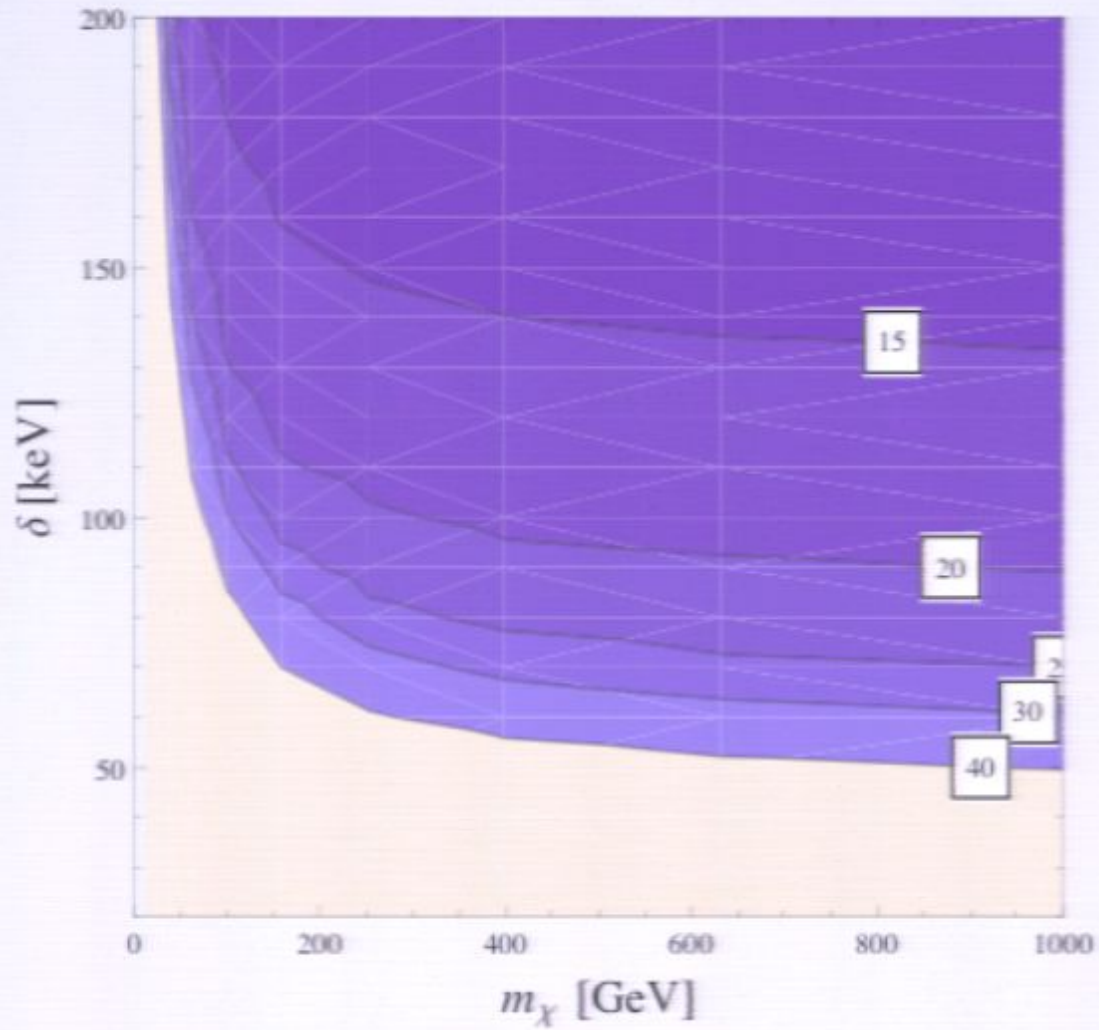
"M3"
0.8 O events
3.8 Ca events
26.5 W events
(85% W)

Without seeing the full data set, the presented fits and iDM limits all indicate that an excess in the W band is in better agreement

DAMA=>CRESST



m=150, d=150



DAMA=>CRESST yields pretty good rates
(compared to guesstimate W band rates)

SUMMARY

SUMMARY

- More data has led to more confusion

SUMMARY

- More data has led to more confusion
- Hopefully more data will help
- Something about insanity and expecting different results

SUMMARY

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- That said, I don't know how to get CoGeNT/CRESST/DAMA to work with the limits for light WIMPs

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- Of course, I don't know what CoGeNT is right now, nor CRESST
- I also don't know the limits from XENON100 at high SI
- Something here about more data

SUMMARY

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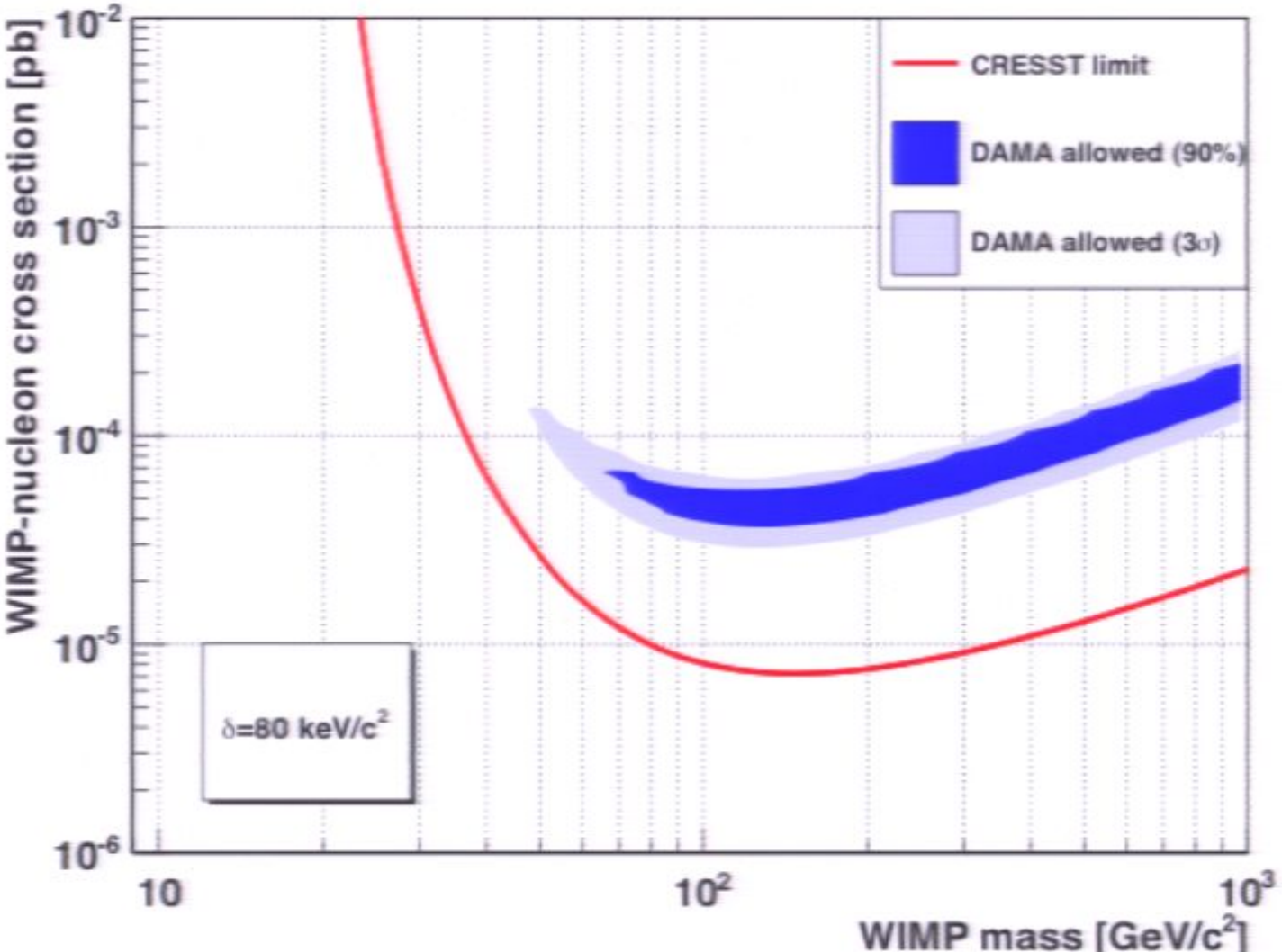
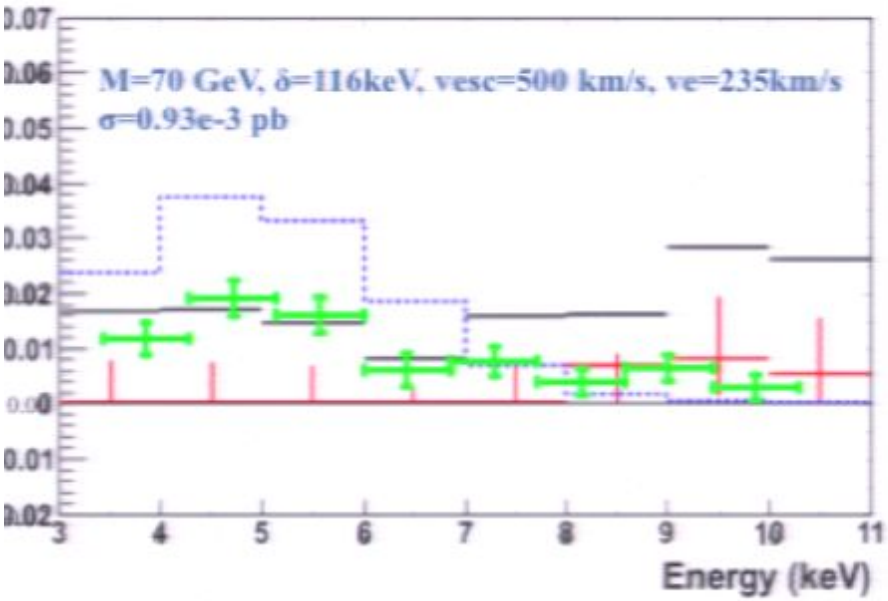
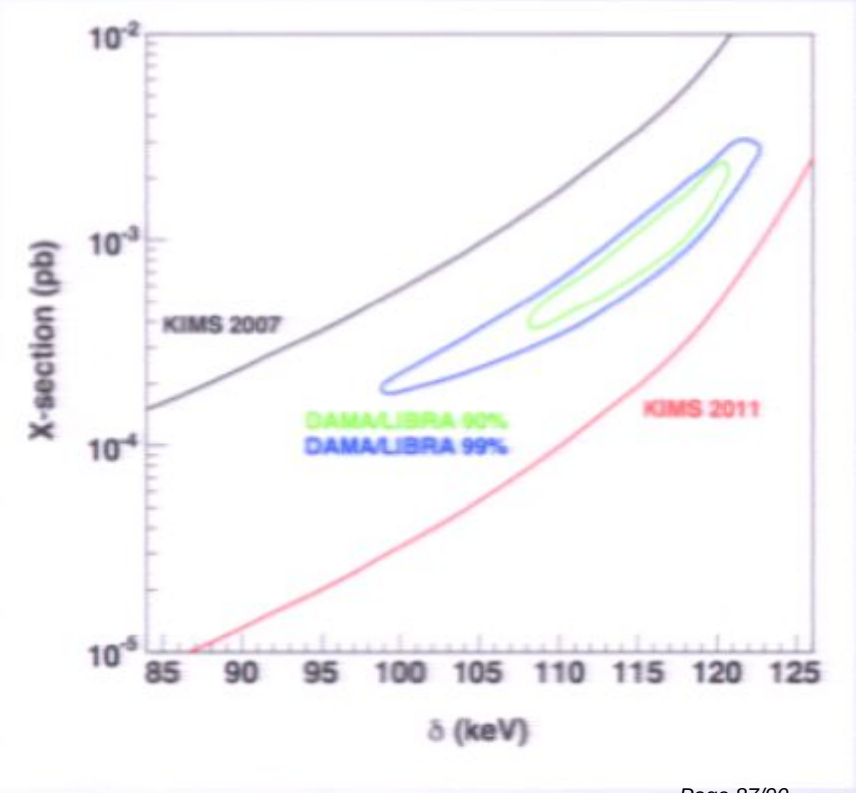
- What is the smoking gun result?

What CRESST said about iDM at TAUP



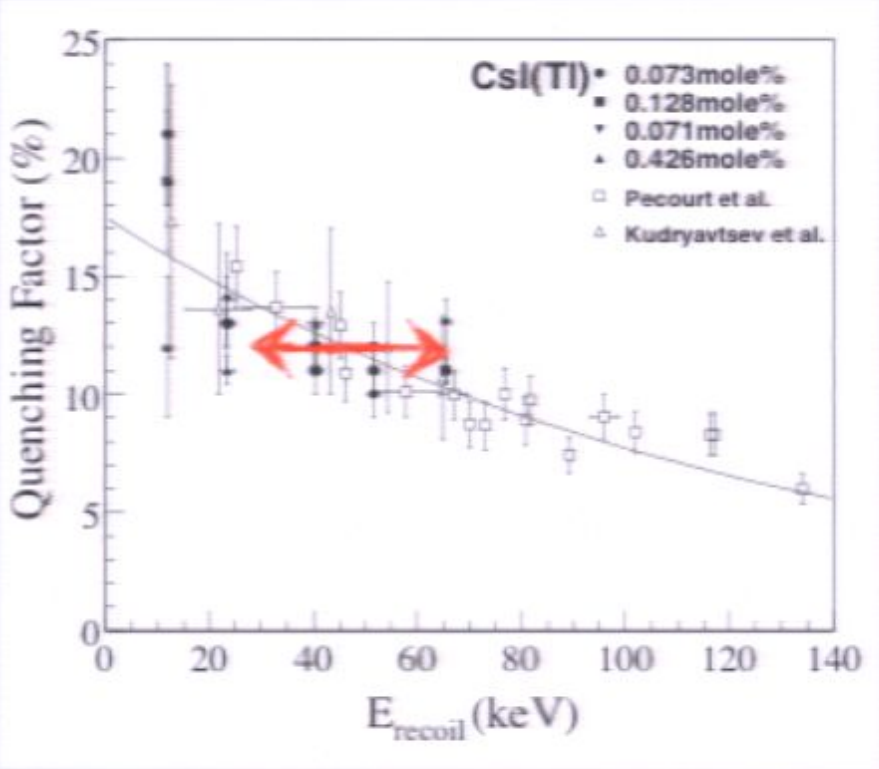


Excluded?



DAMA q=0.07, KIMS q=0.12

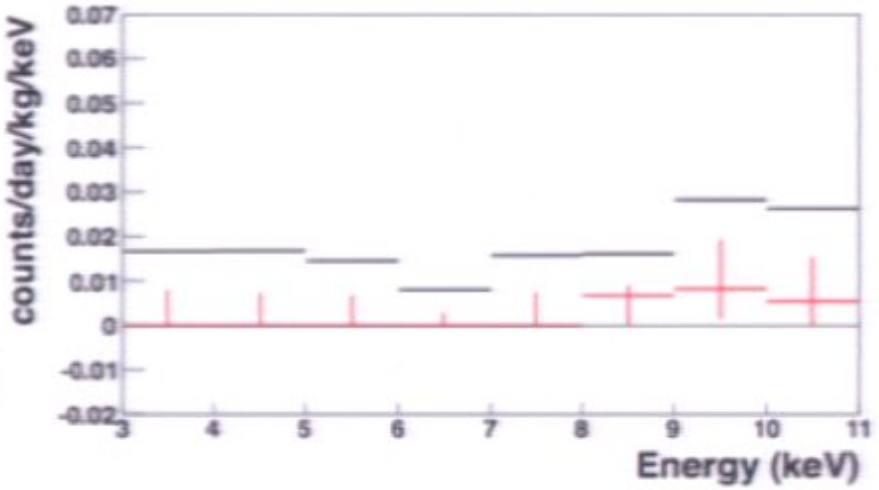
From a model independent perspective, I-scattering is still allowed by KIMS. (And may be even better depending on NR efficiency.)

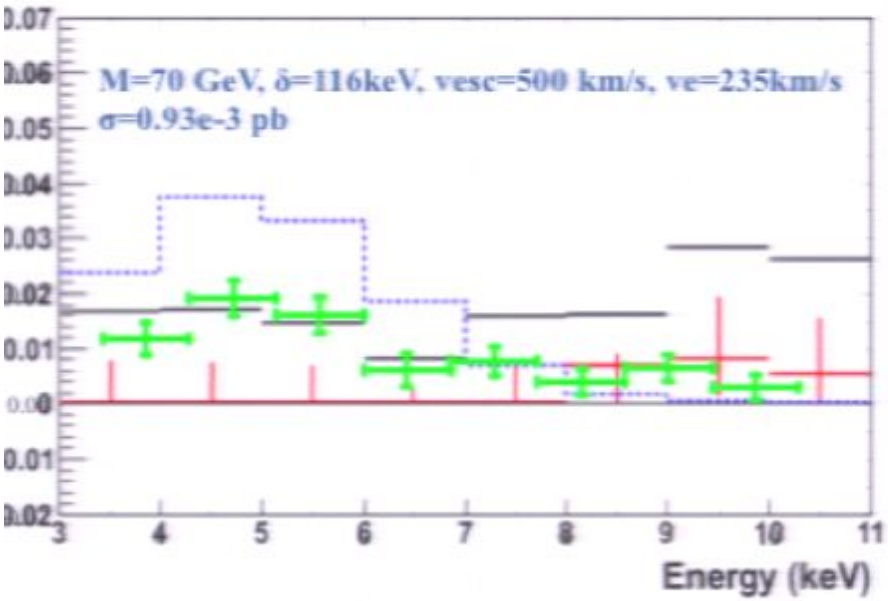


Total scintillation energy (E q(E)) *falls* at high energies

Seems unphysical
- I'll use q=0.12

KIMS Nuclear recoil event rate





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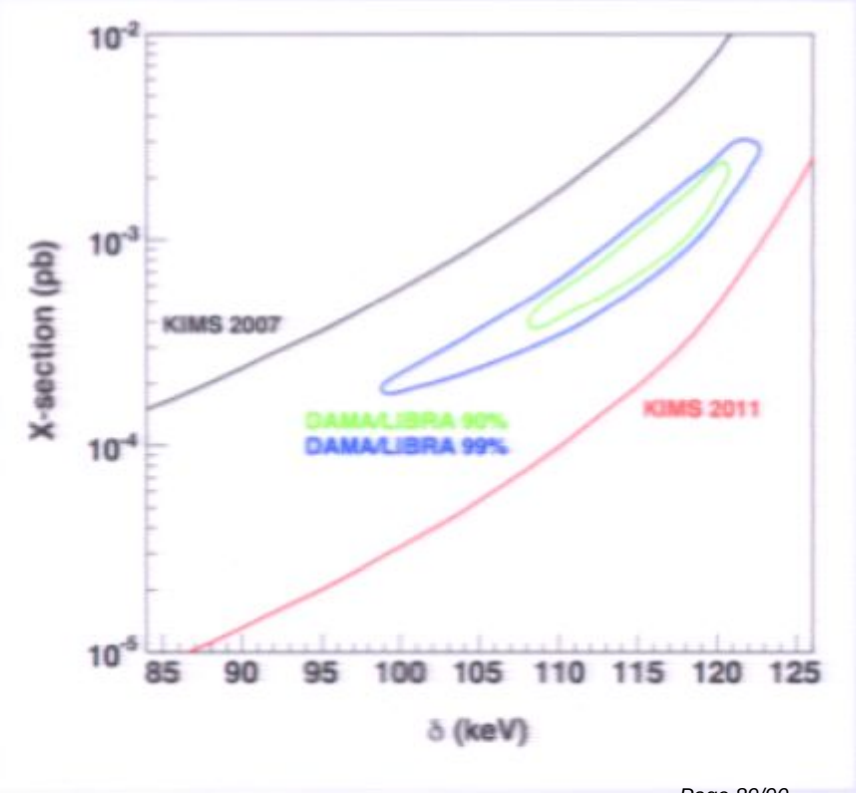

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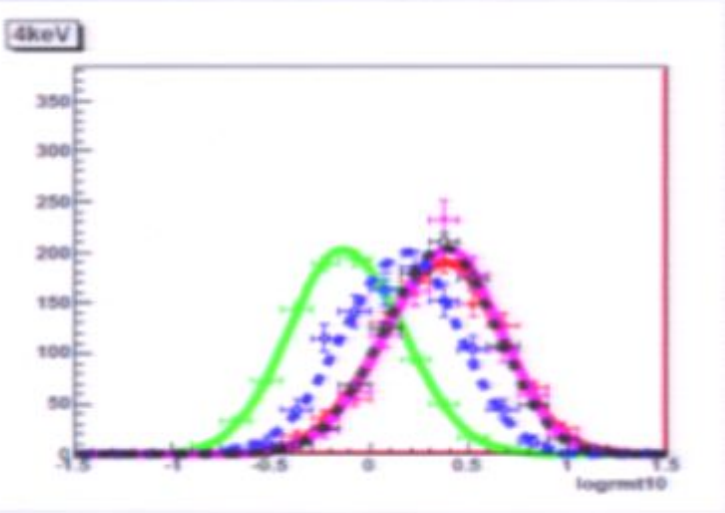
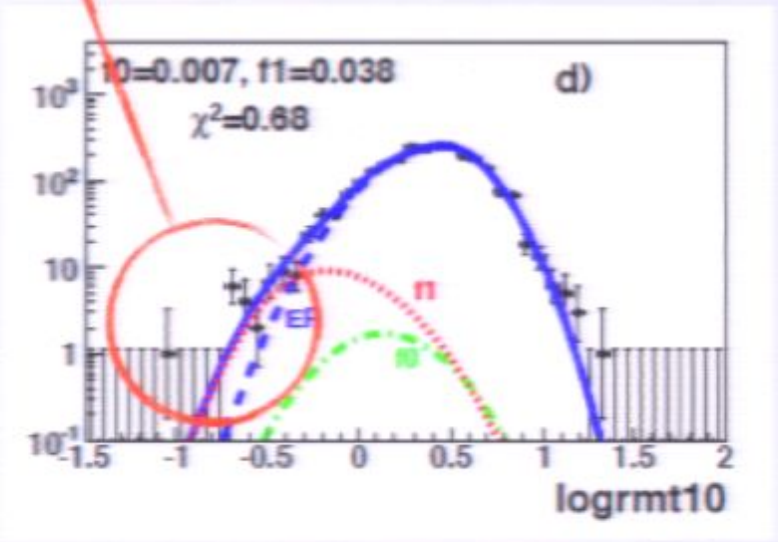
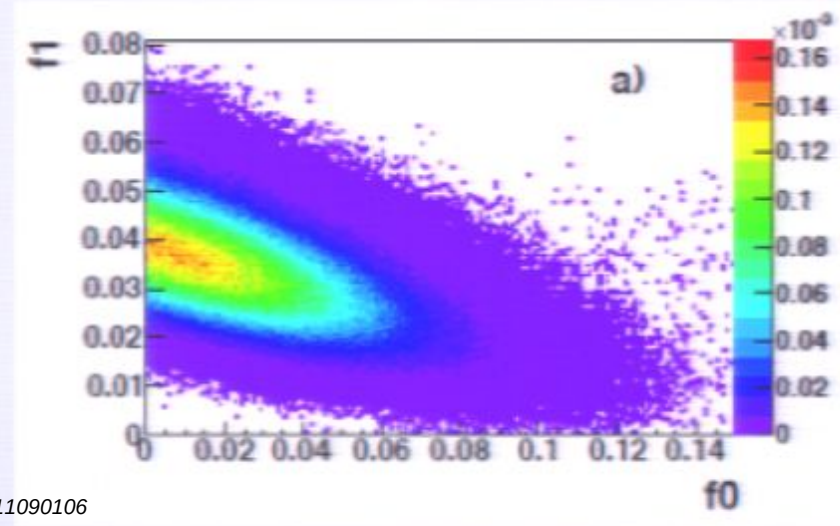
KIMS



Trying to fit this
=> pull for lots of SA





Calibration?
Can you even find
NRs with this?