TOWARD ANOMALY FREE DARK MATTER

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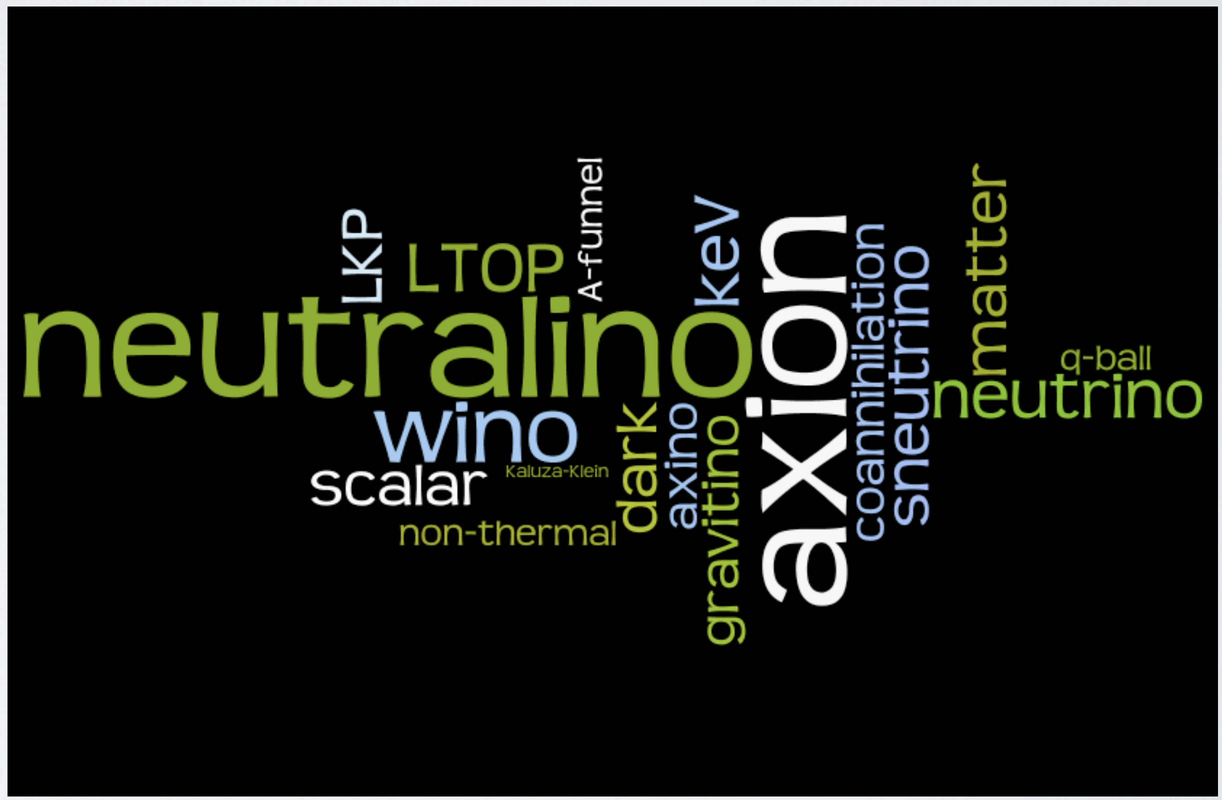
CCPP - NYU
Pheno 2011
5/10/11

THE EVOLUTION OF DARK MATTER THEORY

Pre-2008

Theory driven: Hierarchy problem (neutralino, WIMP, KKDM), Strong CP (axion), etc



THE EVOLUTION OF DARK MATTER THEORY

2008+

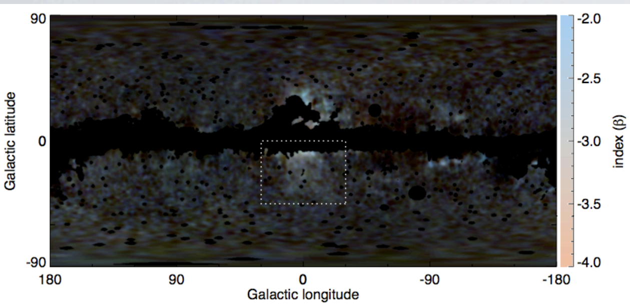
Anomaly driven:
light WIMPs, inelastic WIMPs, leptophilic WIMPs, decaying WIMPs, light mediators, CiDM, quirky DM, asymmetric DM...

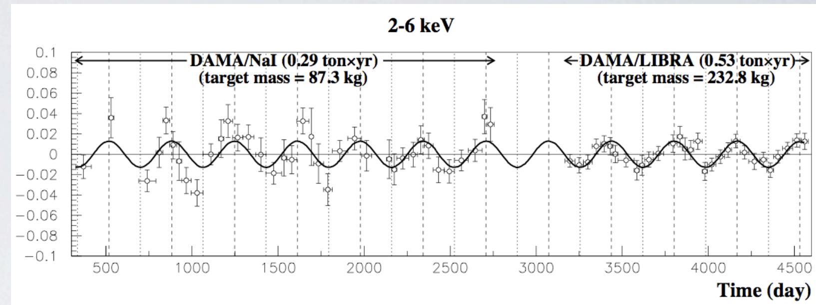
THE EVOLUTION OF DARK MATTER THEORY

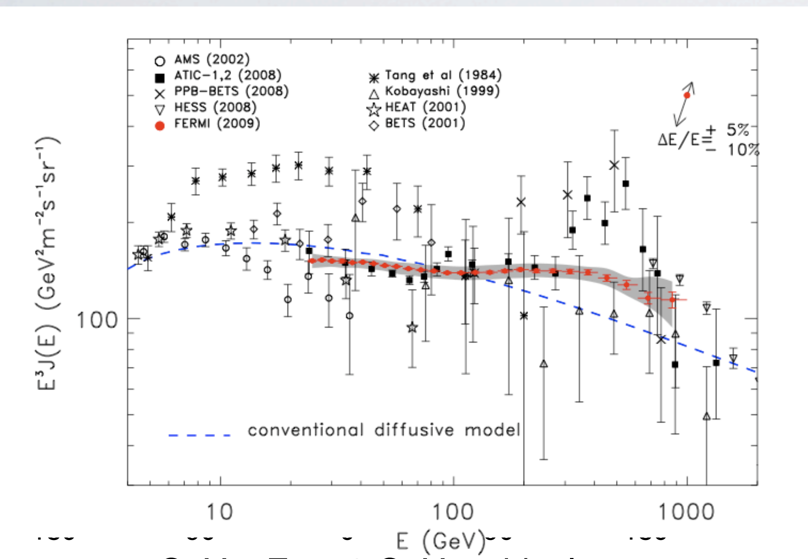
2011+

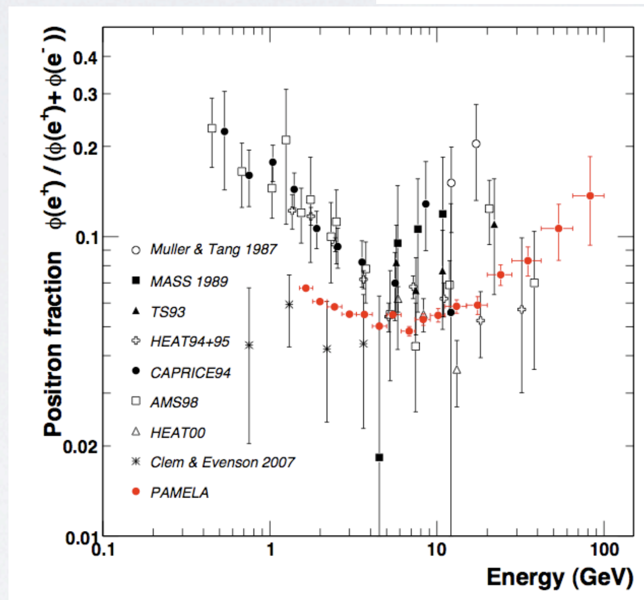
?

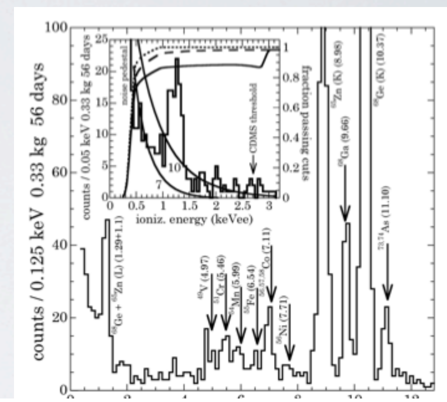
PHENO = ANOMALIES



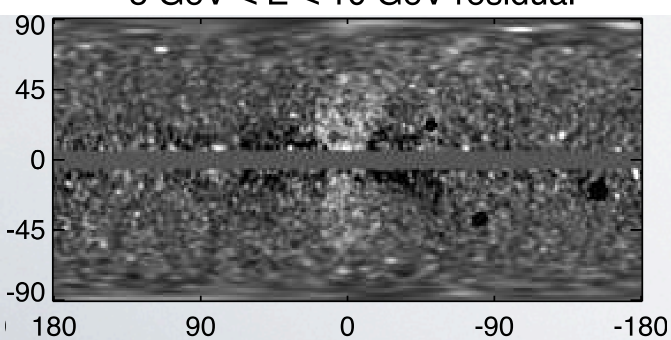


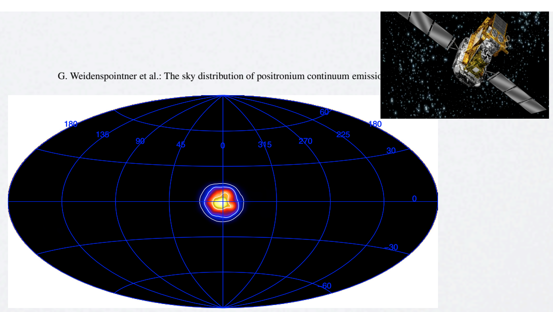


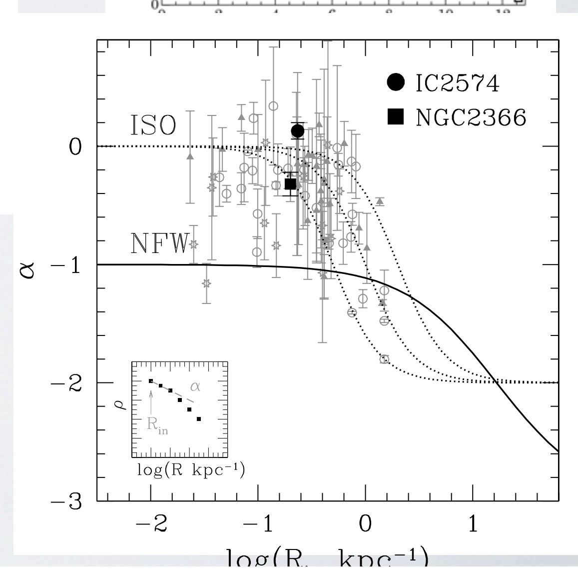




5 GeV < E < 10 GeV residual

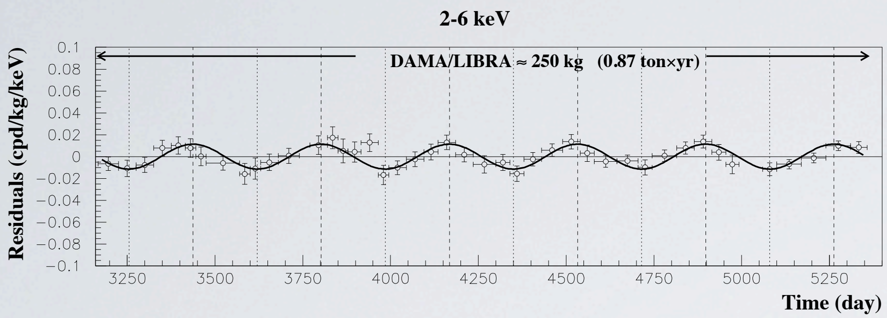






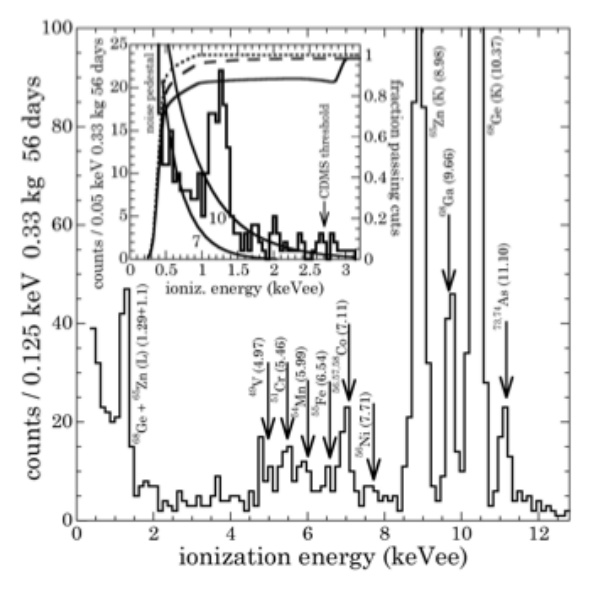
ARE ANY OF THE DIRECT DETECTION "HINTS" ACTUALLY HINTS?

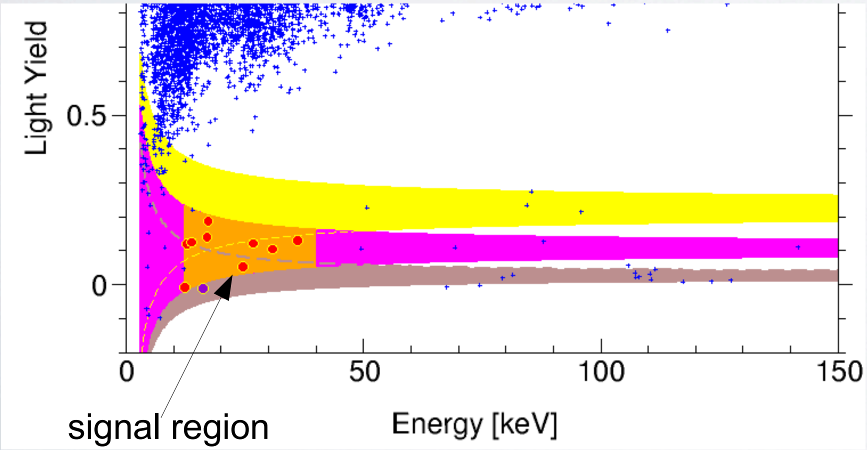
HINTS?



DAMA

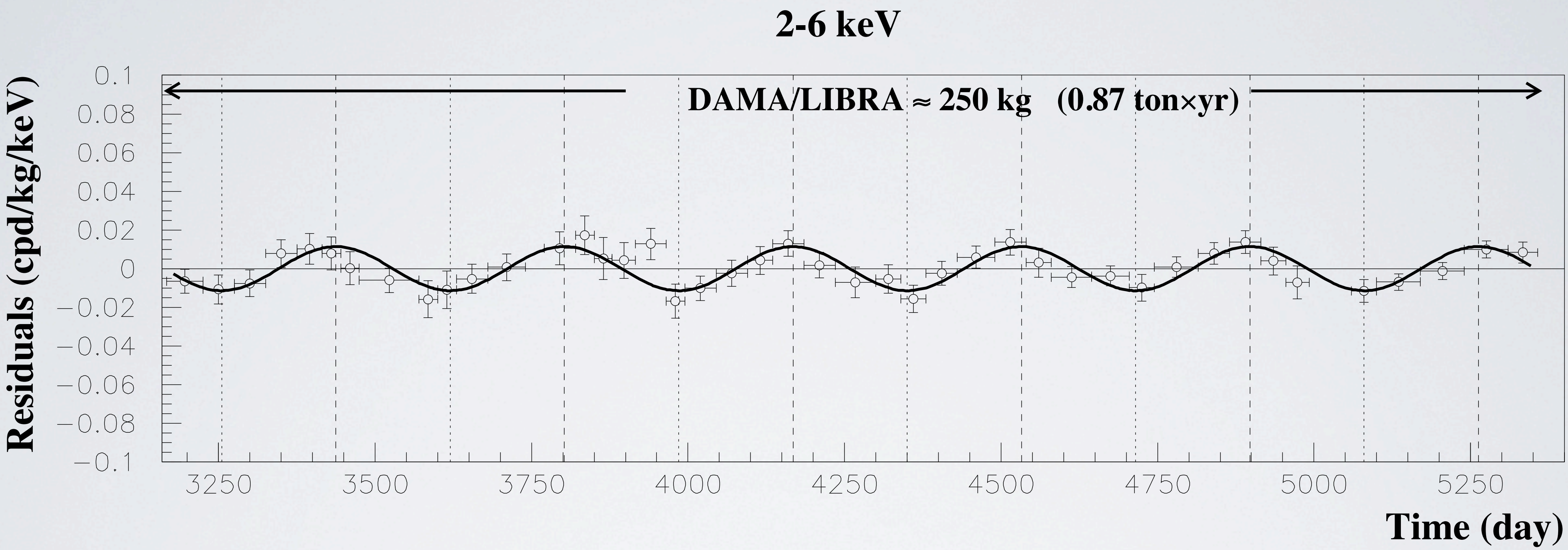
CoGeNT



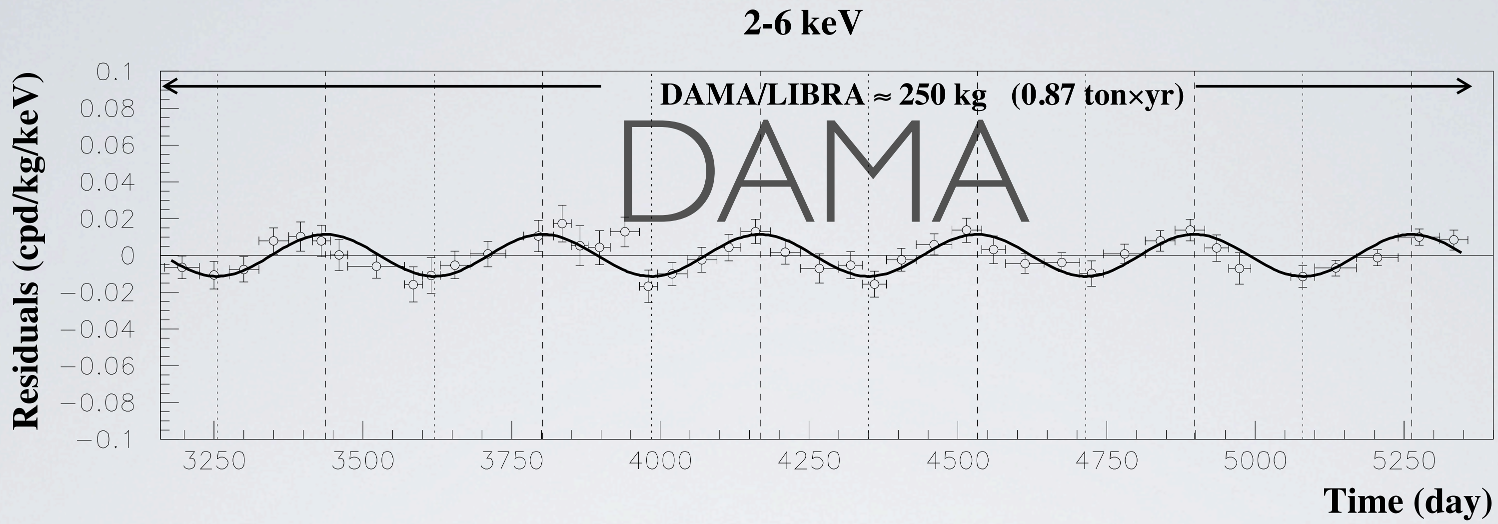


CRESST

DAMA


2-6 keV
DAMA/LIBRA ≈ 250 kg (0.87 ton×yr)
Residuals (cpd/kg/keV)
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)

DAMA

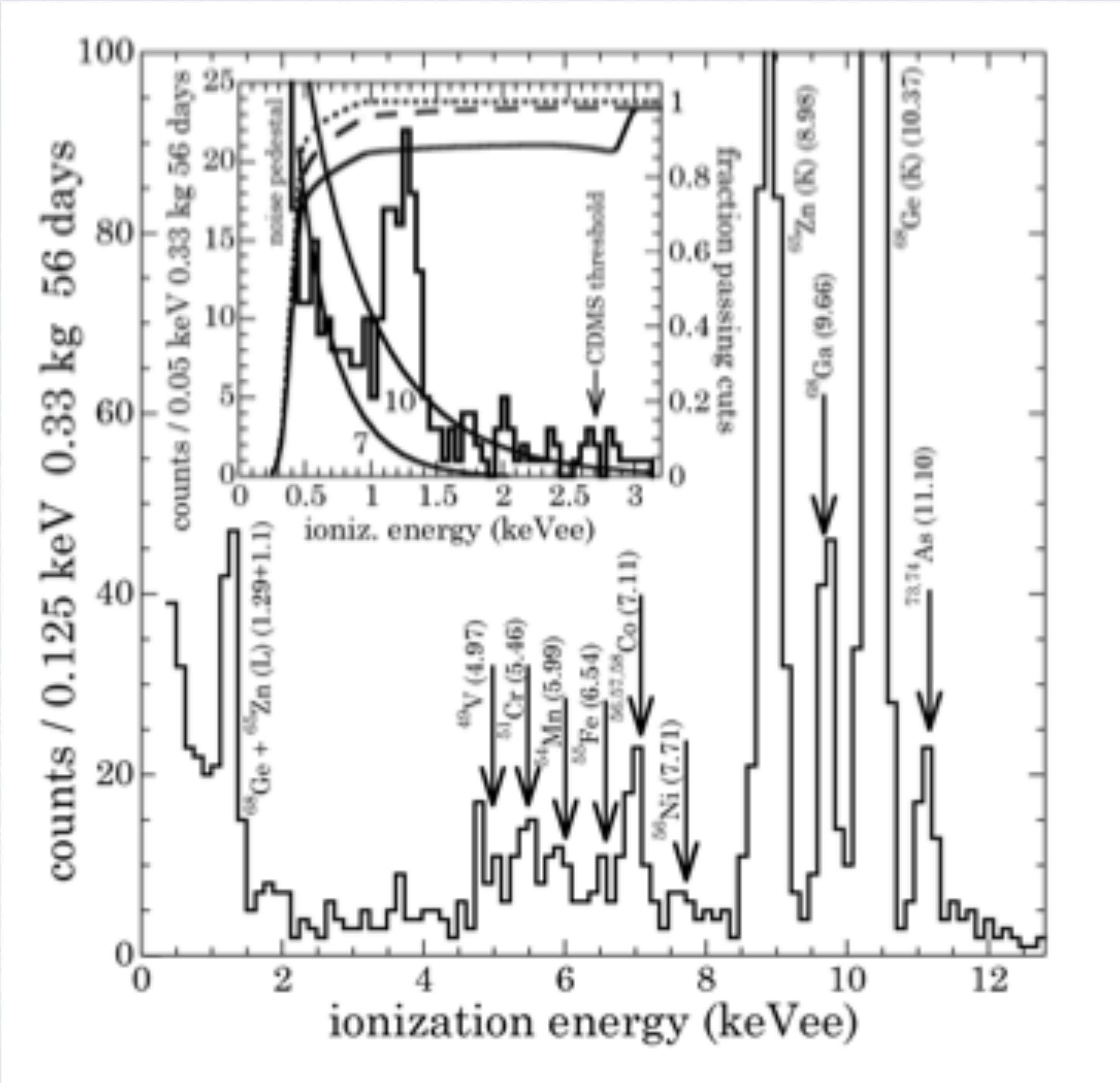


- What is it: annual modulation in scintillation events in 100/250 kg NaI(Tl) crystal - DM?

- What's to like: single hit, stable phase, low energy, no candidate "conventional" explanations

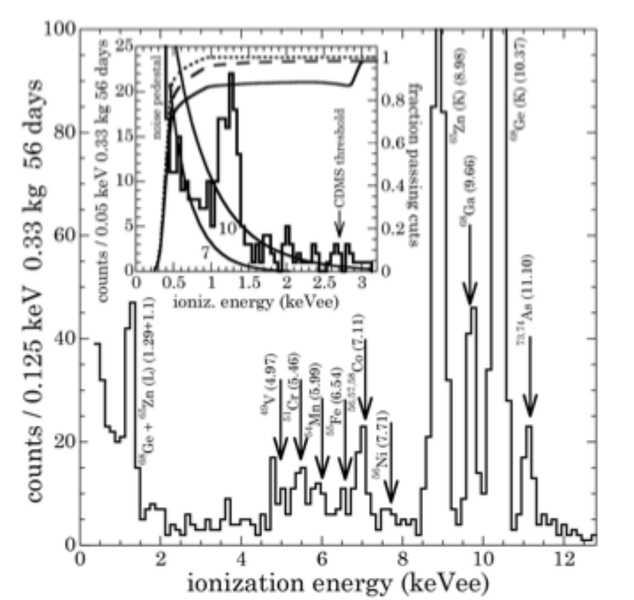
- What's not to like: null results from other exps, data are still unavailable, no event discrimination

COGENT



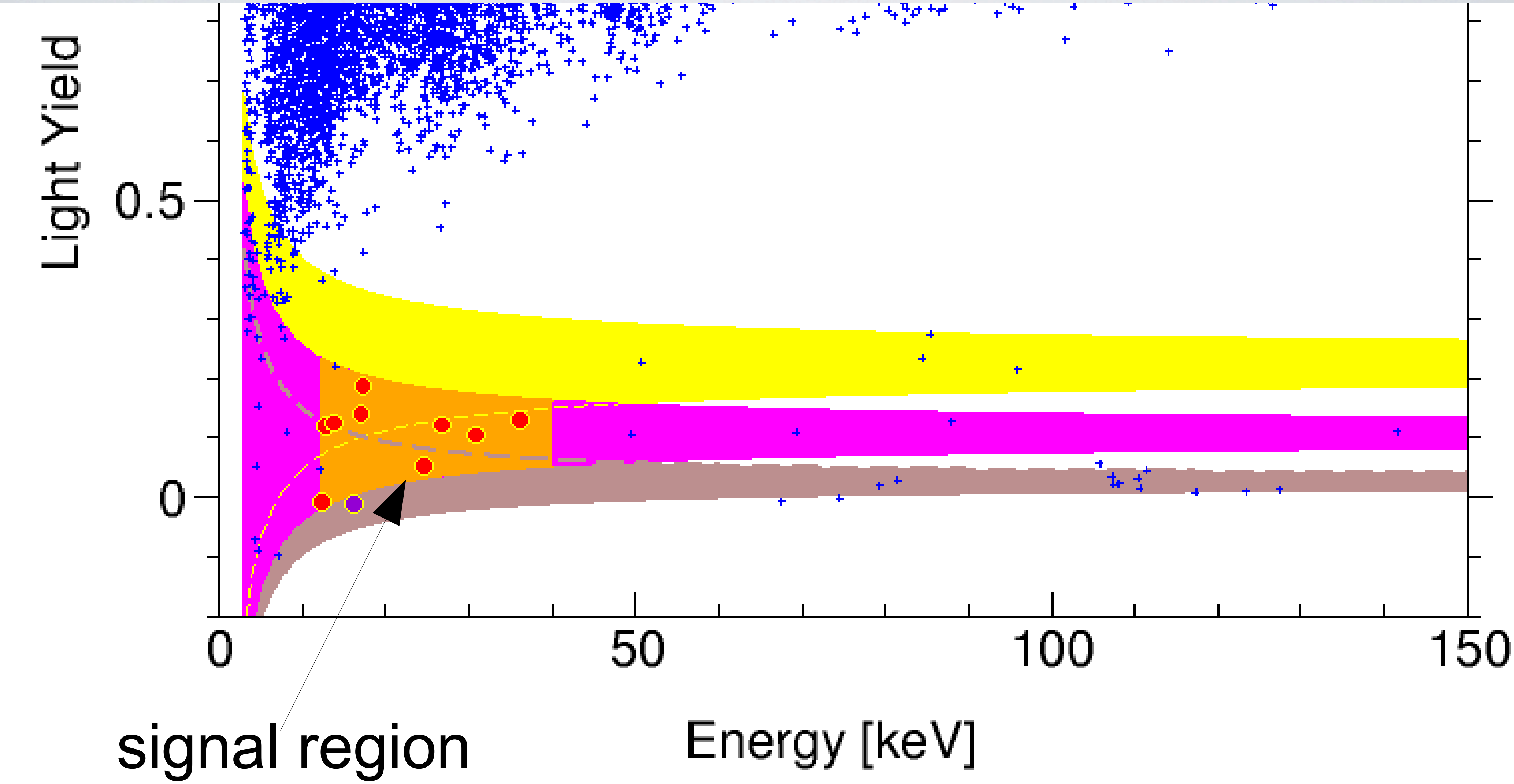
counts / 0.125 keV 0.33 kg 56 days
ionization energy (keVee)
counts / 0.05 keV 0.33 kg 56 days
ioniz. energy (keVee)
fraction passing cuts
noise pedestal
CDMS threshold
^{68}Ge + ^{65}Zn (L) (1.29+1.1)
^{49}V (4.97)
^{51}Cr (5.46)
^{54}Mn (5.99)
^{55}Fe (6.54)
^{56,57,58}Co (7.11)
^{56}Ni (7.71)
^{65}Zn (K) (8.98)
^{68}Ga (9.66)
^{68}Ge (K) (10.37)
^{73,74}As (11.10)

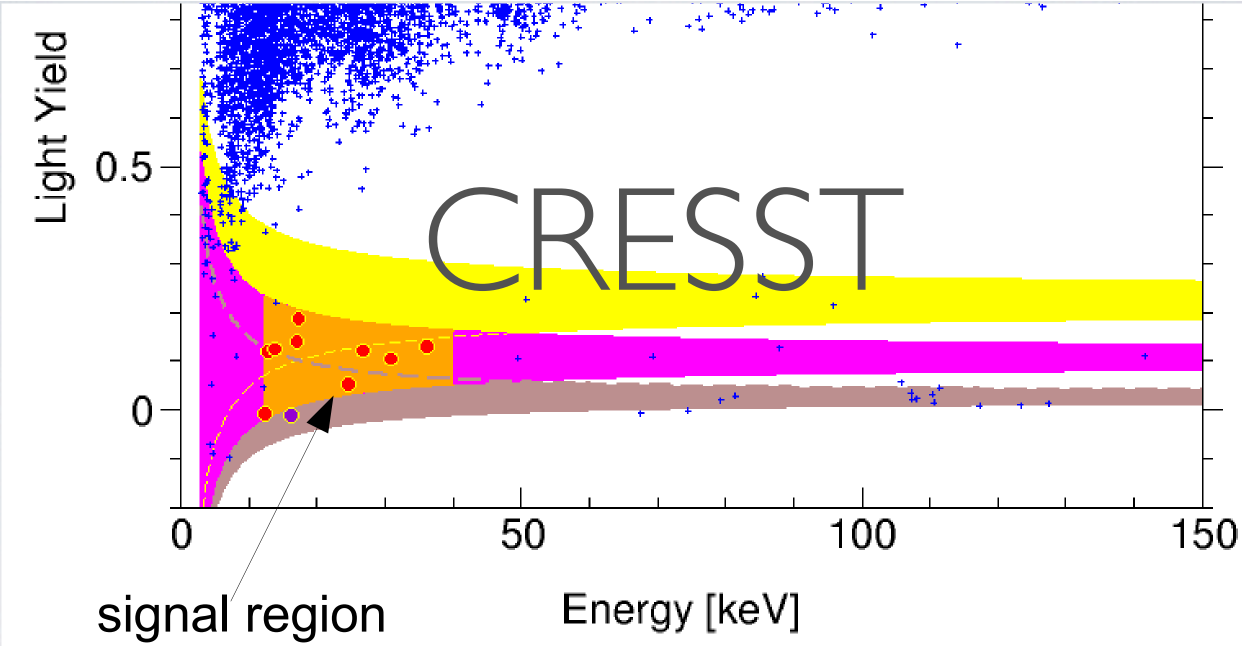
COGENT



- What is it: events in an ionization experiment, ×10 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, no *clear* corroborating features [yet] (modulation), null results from other exps

CRESST



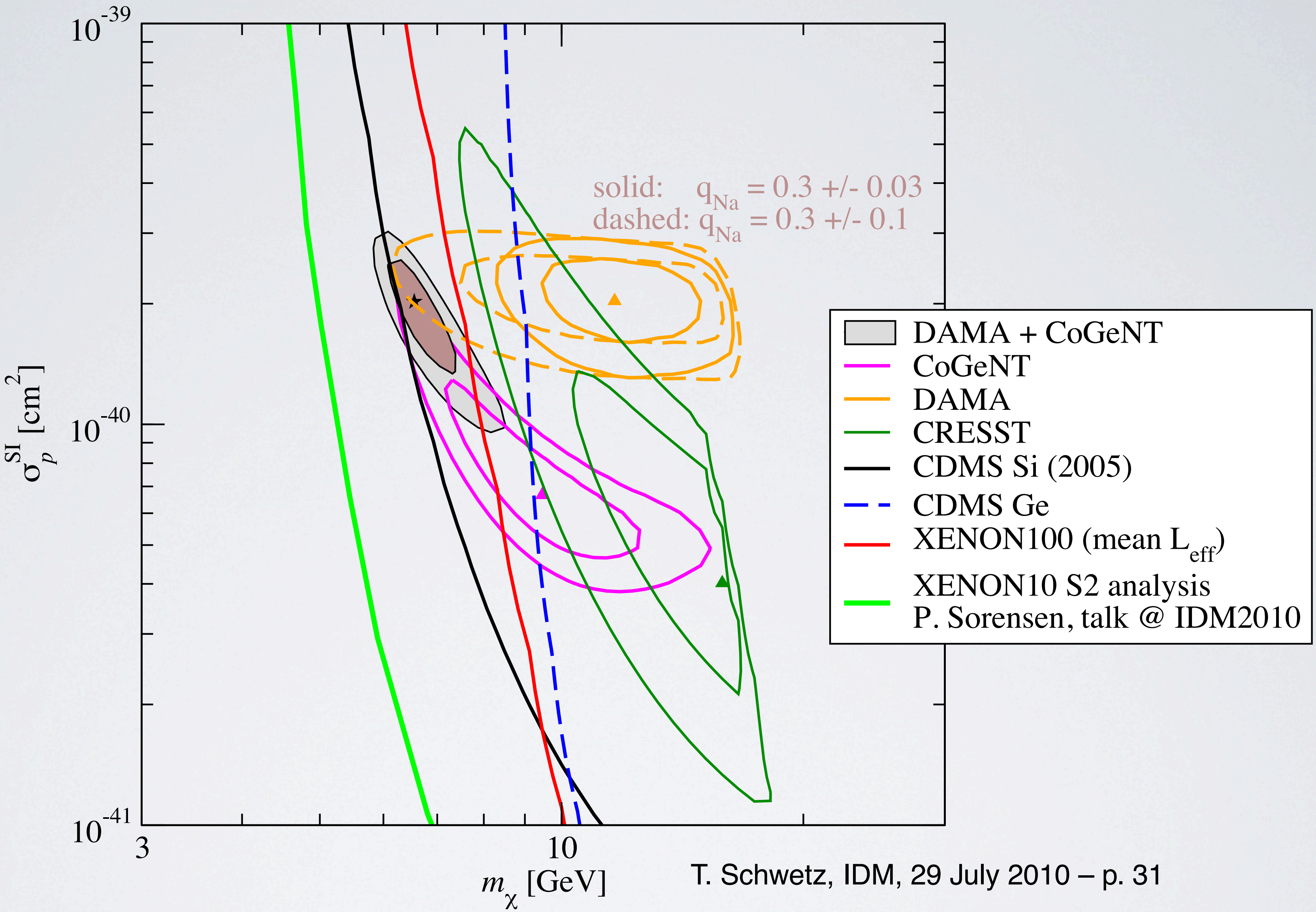


- What is it: an excess of events in a $CaWO_4$ detector, consistent with Oxygen scattering (~10-40 keV)

- 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

- The same beast?



T. Schwetz, IDM, 29 July 2010 – p. 31

don't *really* line up, but within spitting distance

NB: *Not* MSSM (Kuflick, Pierce, Zurek '10)

THE CONTROVERSY

3) **Comments on arXiv:1006.0972 'XENON10/100 dark matter constraints in comparison with CoGeNT and DAMA: examining th**
J.I. Collar, . Jun 2010. 2pp. Temporary entry
e-Print: **arXiv:1006.2031** [astro-ph.CO]

References | LaTeX(US) | LaTeX(EU) | Harvmac | BibTeX | Keywords | Cited 10 times
Abstract and Postscript and PDF from arXiv.org (mirrors: au br cn de es fr il in it jp kr ru tw uk za aps lanl)
Bookmarkable link to this information

4) **Response to arXiv:1005.2615.**
J.I. Collar, D.N. McKinsey, . May 2010. Temporary entry
e-Print: **arXiv:1005.3723** [astro-ph.CO]

References | LaTeX(US) | LaTeX(EU) | Harvmac | BibTeX | Cited 15 times
Abstract and Postscript and PDF from arXiv.org (mirrors: au br cn de es fr il in it jp kr ru tw uk za aps lanl)
Bookmarkable link to this information

5) **Reply to the Comments on the XENON100 First Dark Matter Results.**
The XENON100 Collaboration, . May 2010. Temporary entry
e-Print: **arXiv:1005.2615** [astro-ph.CO]

References | LaTeX(US) | LaTeX(EU) | Harvmac | BibTeX | Keywords | Cited 14 times
Abstract and Postscript and PDF from arXiv.org (mirrors: au br cn de es fr il in it jp kr ru tw uk za aps lanl)
Bookmarkable link to this information

6) **Comments on 'First Dark Matter Results from the XENON100 Experiment'.**
J.I. Collar, D.N. McKinsey, . May 2010. Temporary entry
e-Print: **arXiv:1005.0838** [astro-ph.CO]

References | LaTeX(US) | LaTeX(EU) | Harvmac | BibTeX | Keywords | Cited 22 times
Abstract and Postscript and PDF from arXiv.org (mirrors: au br cn de es fr il in it jp kr ru tw uk za aps lanl)
Bookmarkable link to this information

7) **First Dark Matter Results from the XENON100 Experiment.**
By XENON100 Collaboration (E. Aprile *et al.*). May 2010. (Published Sep 24, 2010). 4pp.
Published in **Phys.Rev.Lett.105:131302,2010**.
e-Print: **arXiv:1005.0380** [astro-ph.CO]

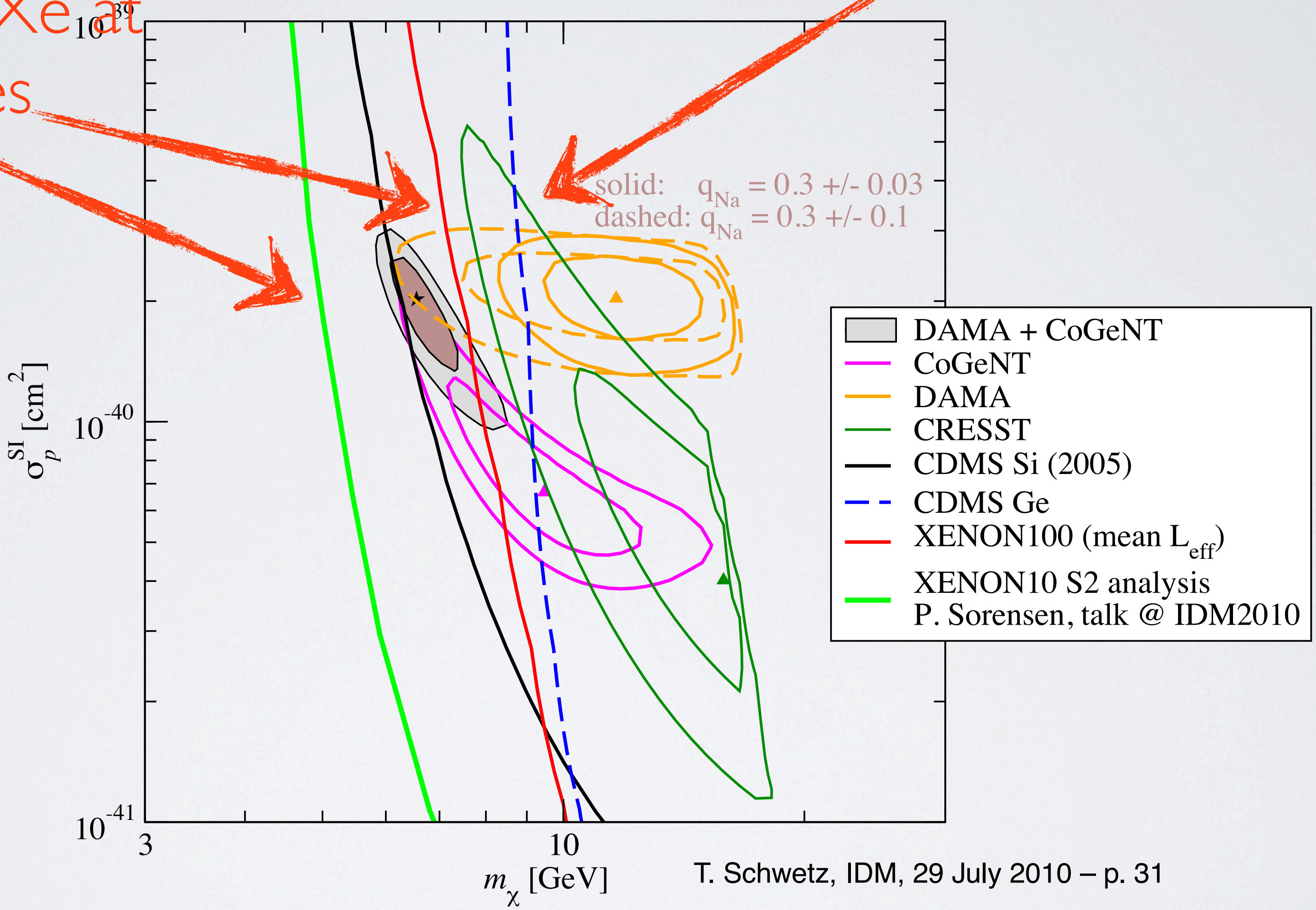
TOPCITE = 50+
References | LaTeX(US) | LaTeX(EU) | Harvmac | BibTeX | Keywords | Cited 103 times
Abstract and Postscript and PDF from arXiv.org (mirrors: au br cn de es fr il in it jp kr ru tw uk za aps lanl)
Journal Server [doi:10.1103/PhysRevLett.105.131302]
EXP XENON
Bookmarkable link to this information

FIND KEYWORD BIG TIZZY

THE CONTROVERSY

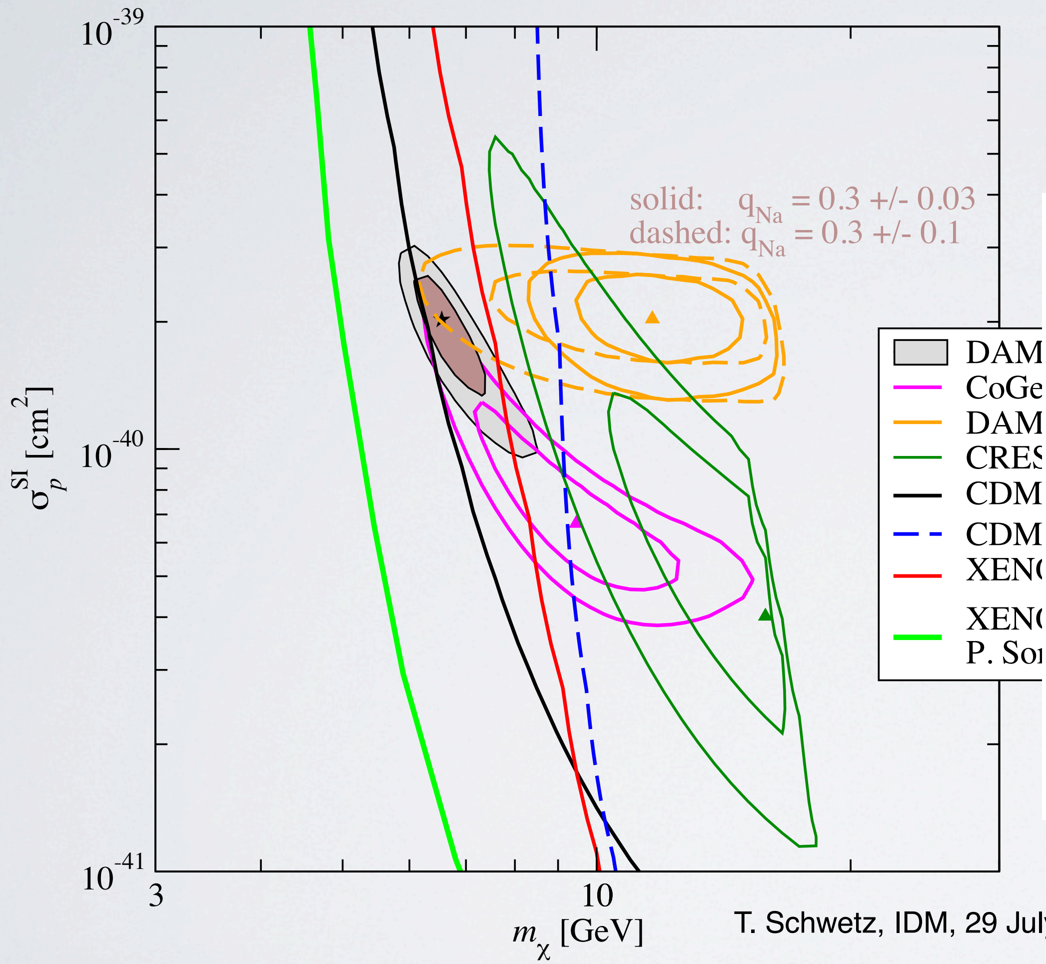
Limits from XENON invoke unmeasured properties of LXe at low energies

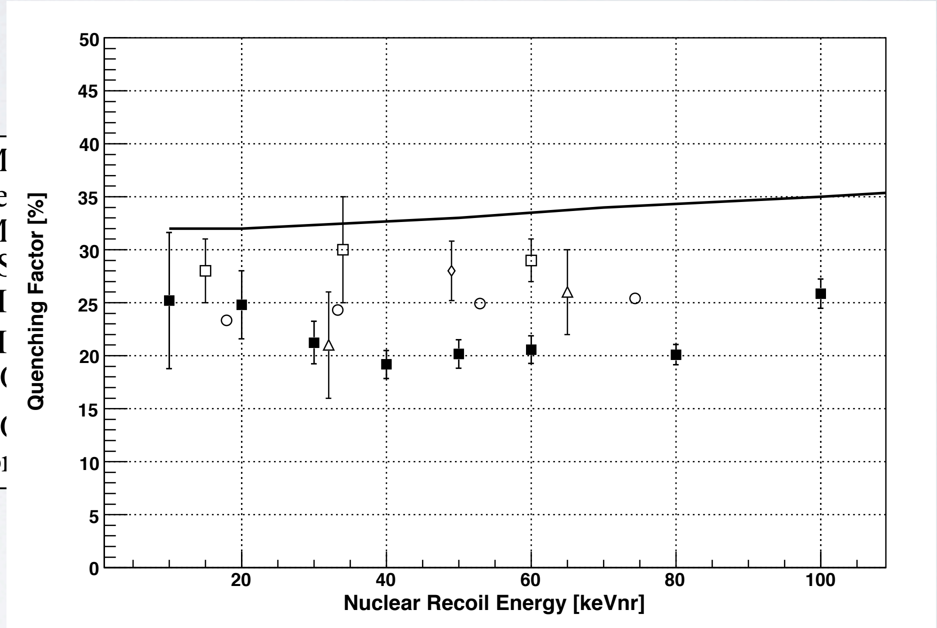
DAMA/CoGeNT agreement requires generous assumptions about QNa



Need the "jet energy scale" of each detector

UNDERSTANDING DAMA





T. Schwetz, IDM, 29 July 2010 – p. 31

ARE THERE UNCERTAINTIES?

nuclear physics

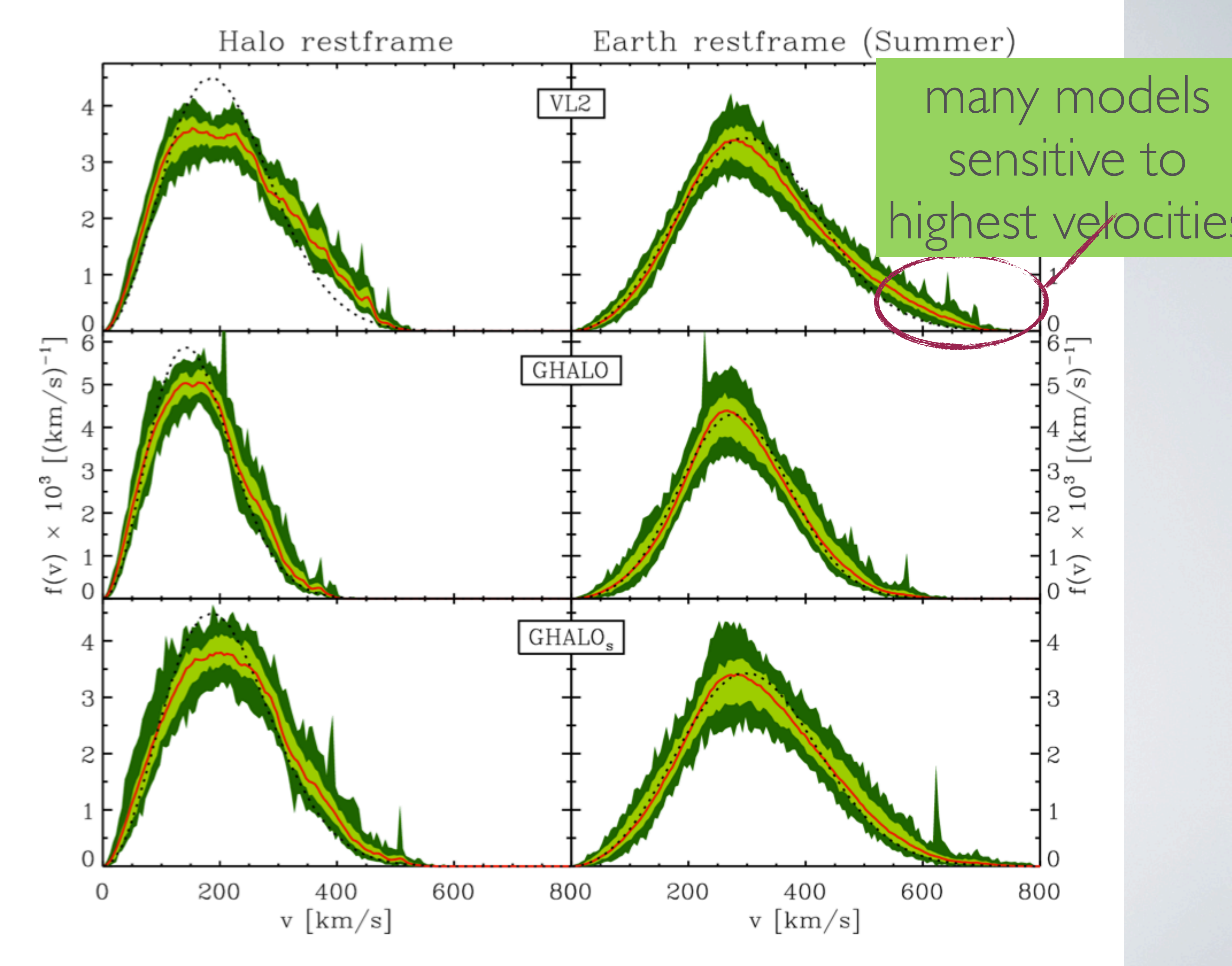
$$\frac{dR}{dE_R} = N_T M_N \frac{\rho_\chi \sigma_n}{2 m_\chi \mu_{ne}^2} \frac{(f_p Z + f_n (A-Z))^2}{f_n^2} F^2[E_R] \int_{\beta_{min}}^{\infty} \frac{f(v)}{v} dv.$$

particle physics **astrophysics**

PP: Type of interaction, mediator

NP: Form factor - when de Broglie wavelength of interaction is comparable to nuclear size - resolve that it is not a point particle ($q^2 \sim 2 M_N E_R \Rightarrow E_R \sim 100$ keV) (Duda, Gondolo+Kemper 0608035)

AP: How many particles are there at a given velocity *in the Earth frame*


Halo restframe
Earth restframe (Summer)
VL2
GHALO
GHALO$_s$
f(v) × 10^3 [(km/s)$^{-1}$]
v [km/s]
many models
sensitive to
highest velocities

APPLES TO APPLES

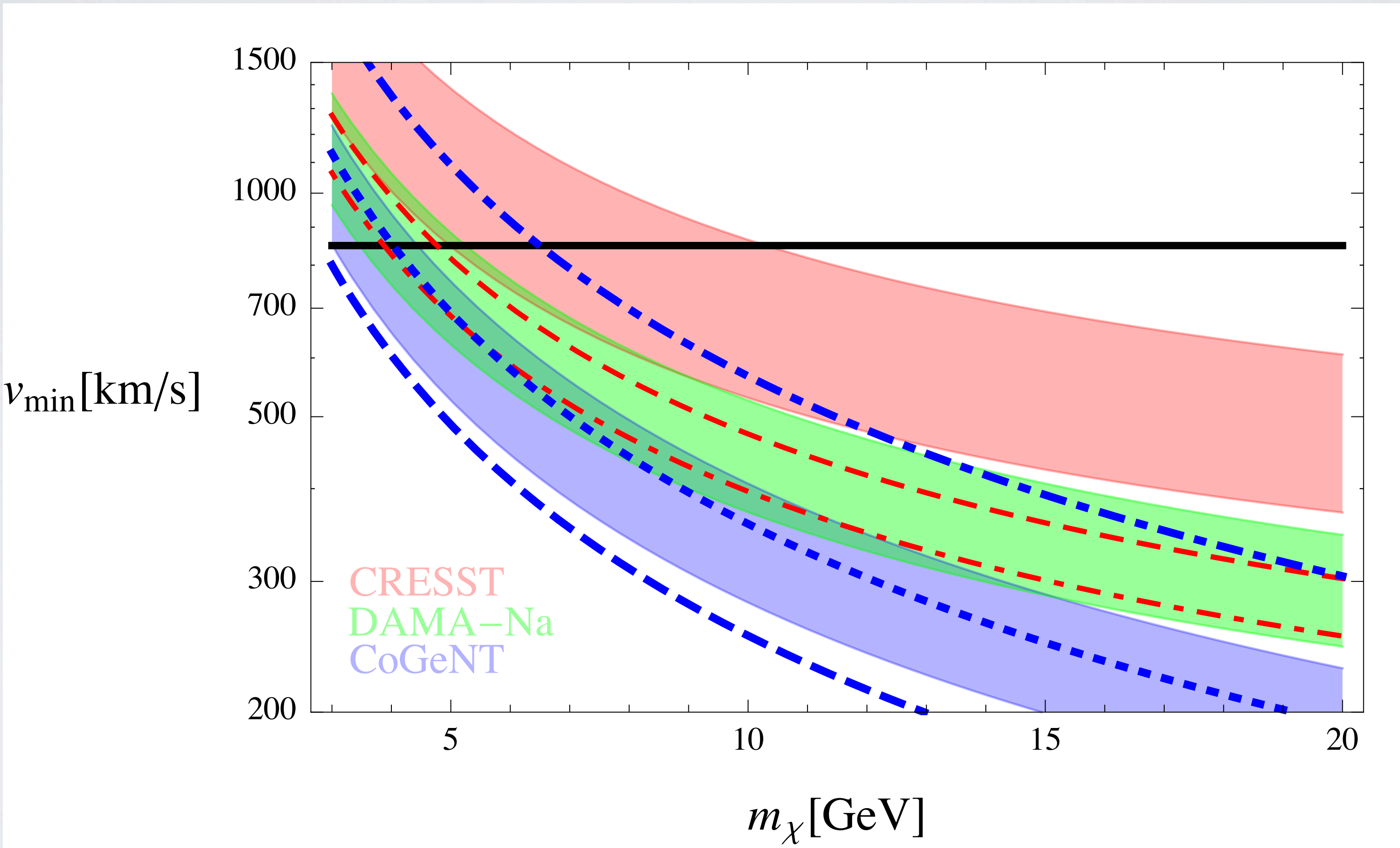


FIG. 1: v_{min} thresholds for various experiments. Solid bands are CRESST Oxygen band, 15-40 keV (*red, top*), DAMA Na band 6.7-13.3 keV (*green, middle*), CoGeNT Ge 1.9-3.9 keV (*blue, bottom*). Constraints are Xenon 1, 2 and 5 keV (*dashed, dotted, and dot-dashed, thick blue*), and CDMS-Si 7 and 10 keV, (*dot-dashed and dashed, thin red*).

INTEGRATING OUT ASTROPHYSICS

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

$$[E_{low}^{(1)}, E_{low}^{(1)}] \Longleftrightarrow [v_{min}^{low}, v_{min}^{high}] \Longleftrightarrow [E_{low}^{(2)}, E_{high}^{(2)}],$$

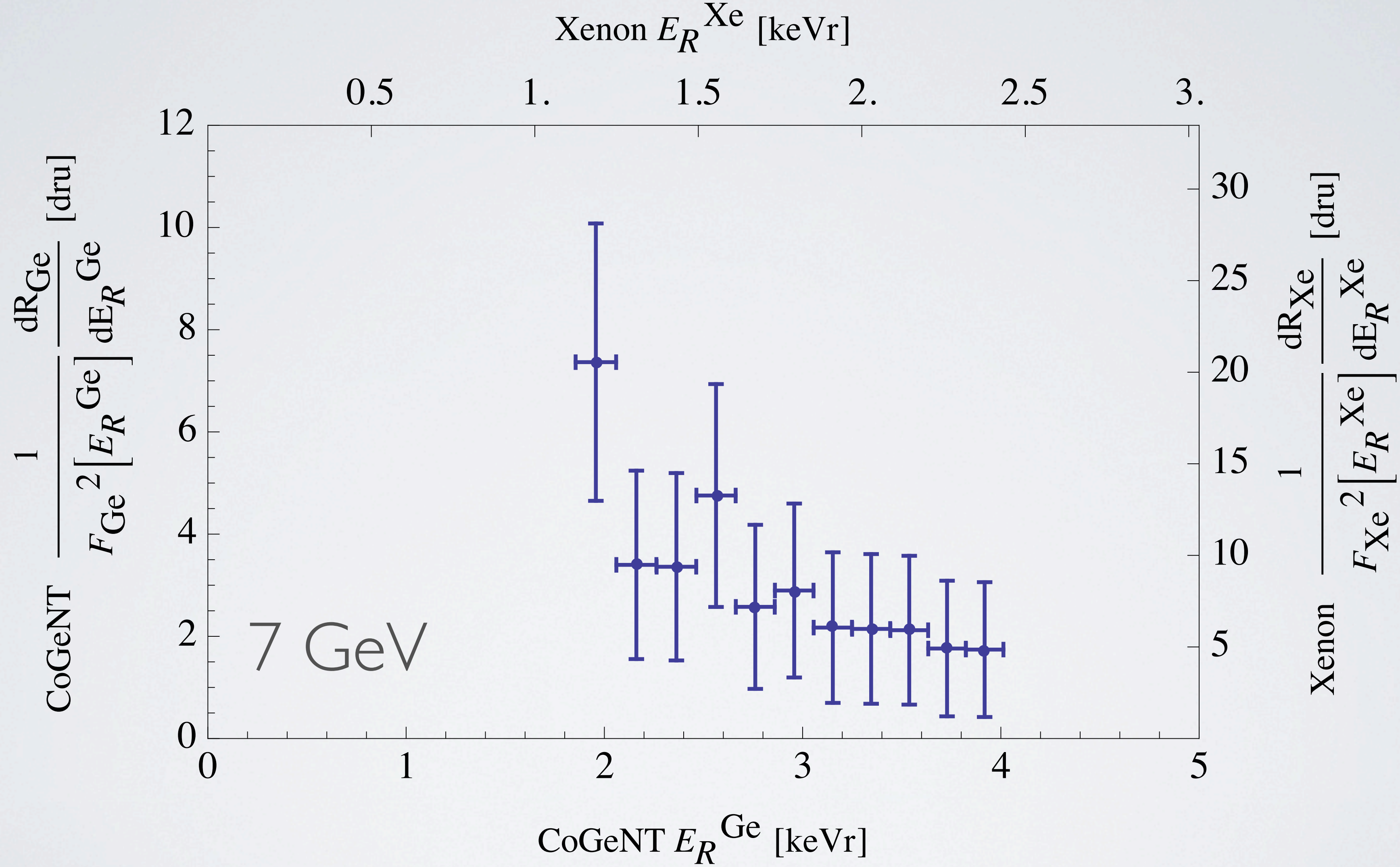
$$\frac{dR}{dE_R} = \frac{N_T M_T \rho}{2 m_\chi \mu^2} \sigma(E_R)\, g(v_{min}) \longrightarrow g(v) = \frac{2 m_\chi \mu^2}{N_T M_T \rho \sigma(E_R)} \frac{dR_1}{dE_1}$$

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

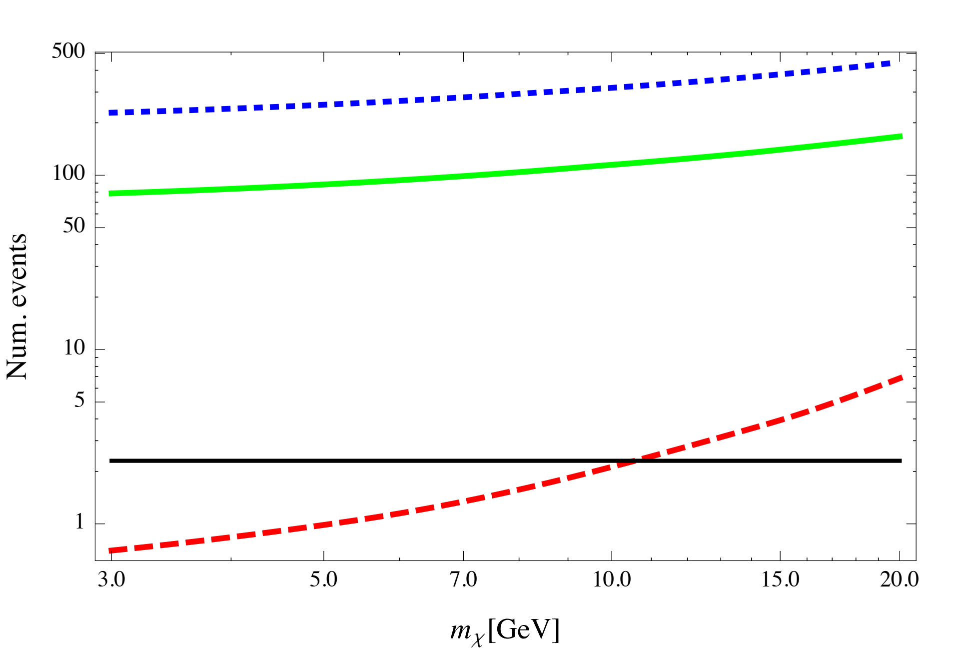
A direct prediction of the rate
at experiment 2 from experiment 1

Liu, Fox, NW '10

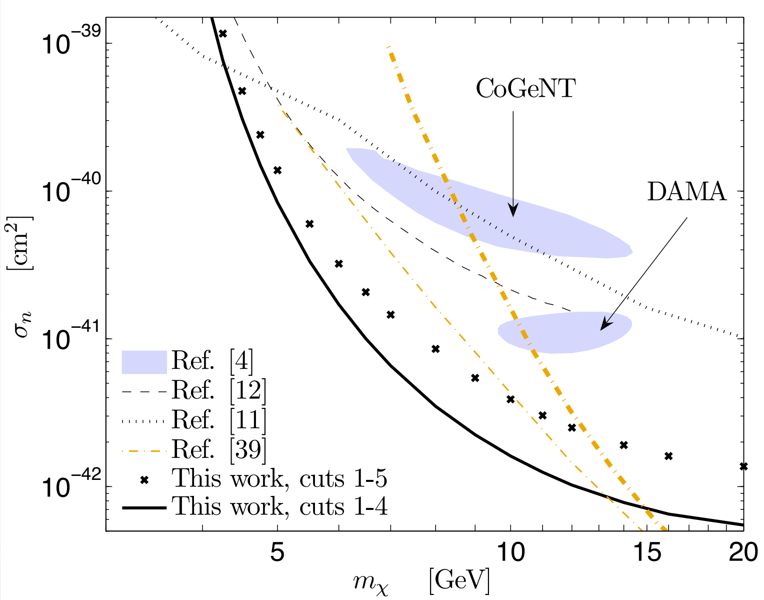
MAPPING RATES

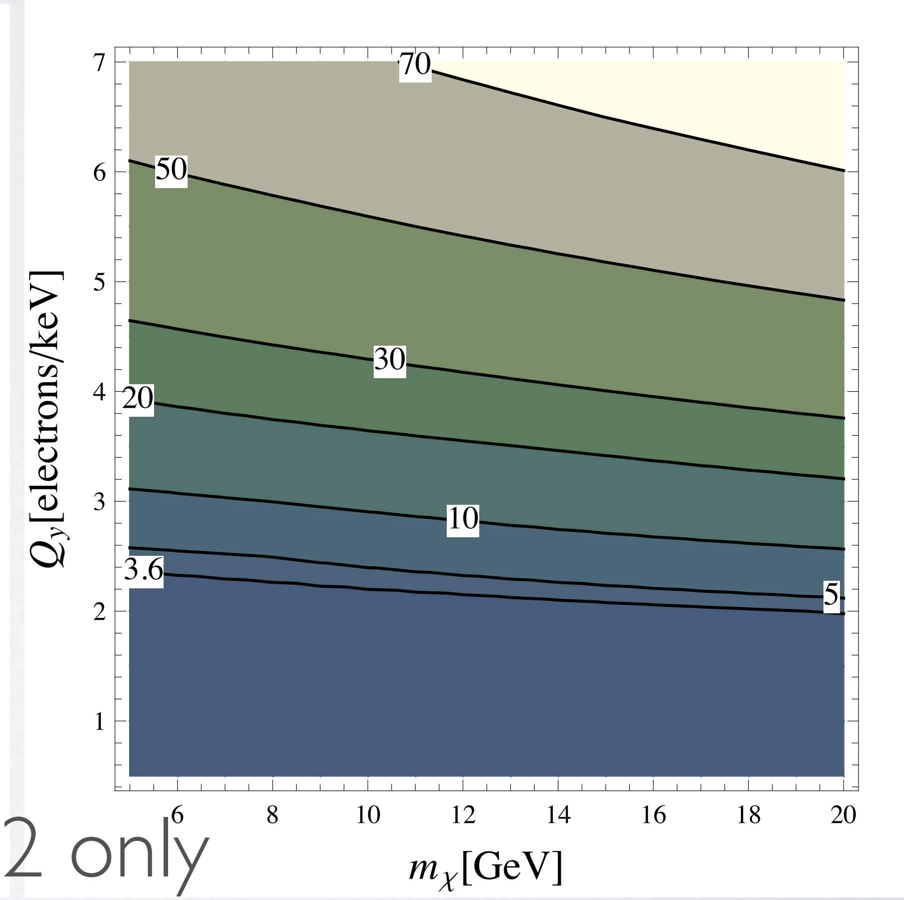


COGENT->XENON10



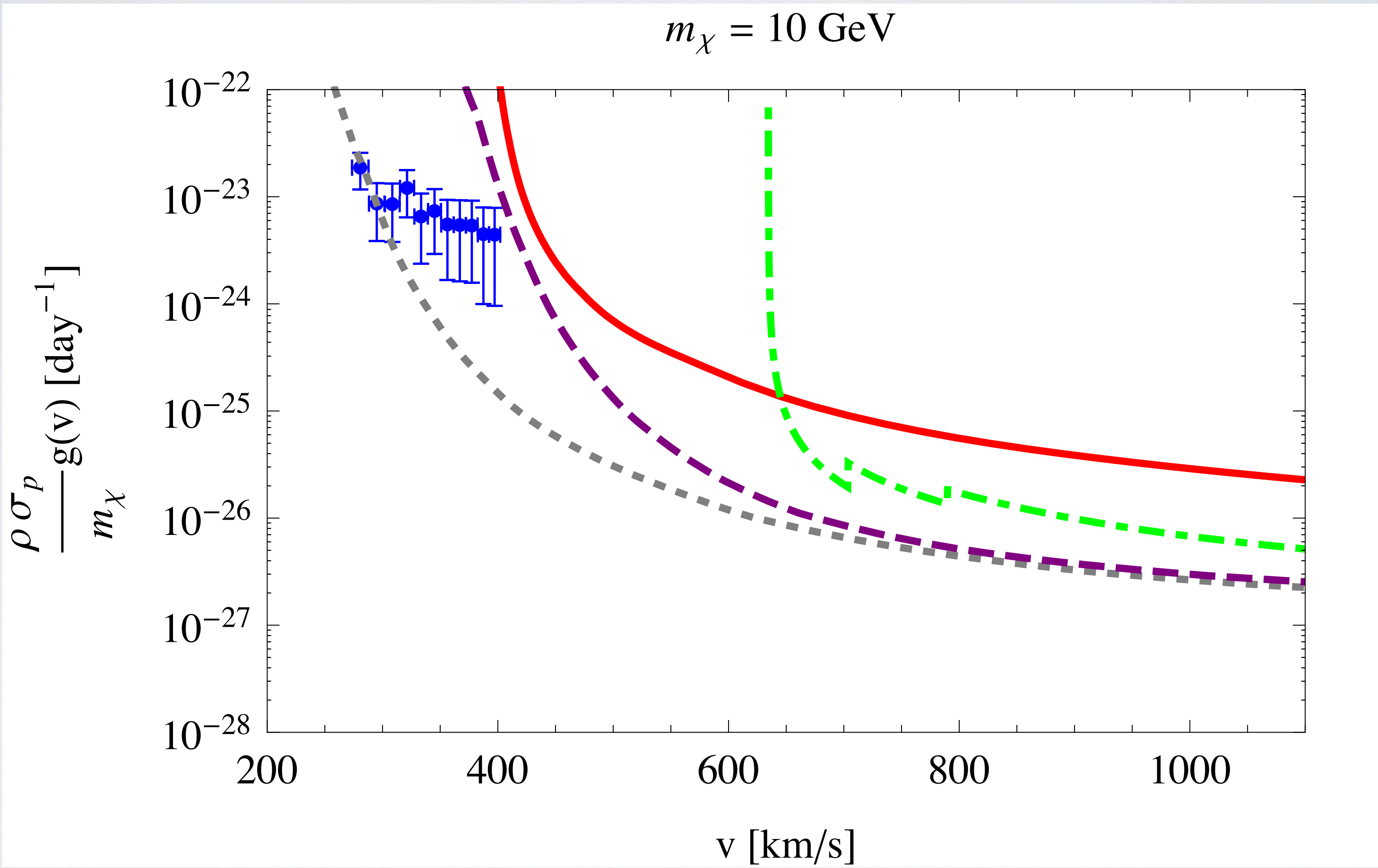
S1+S2





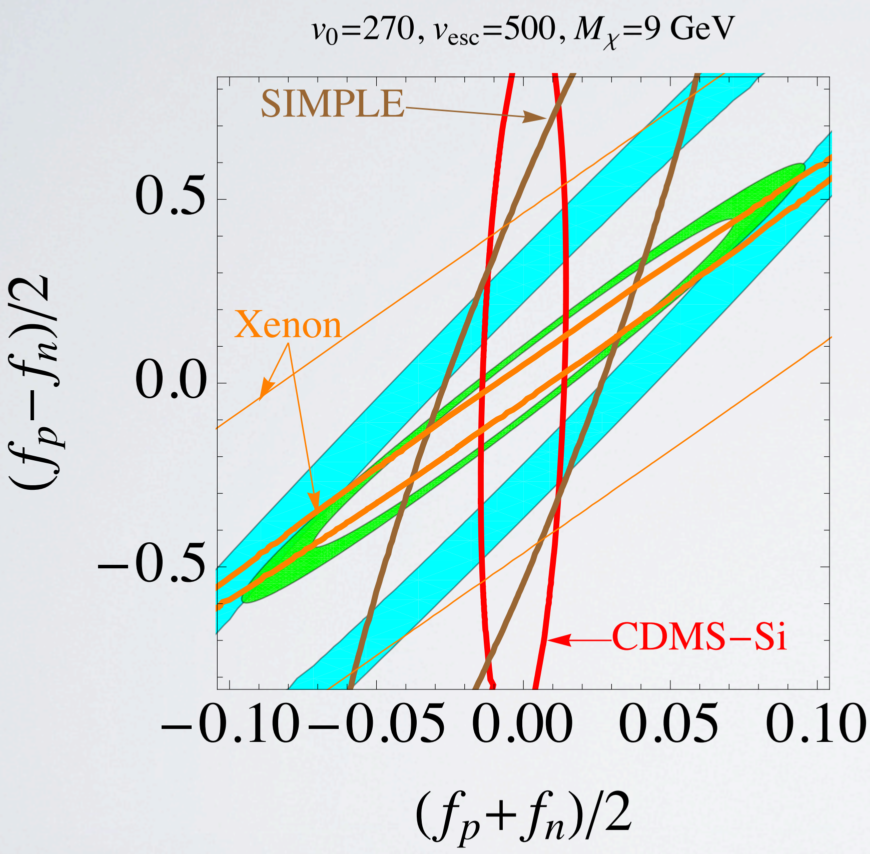
S2 only

INDEPENDENT LIMITS

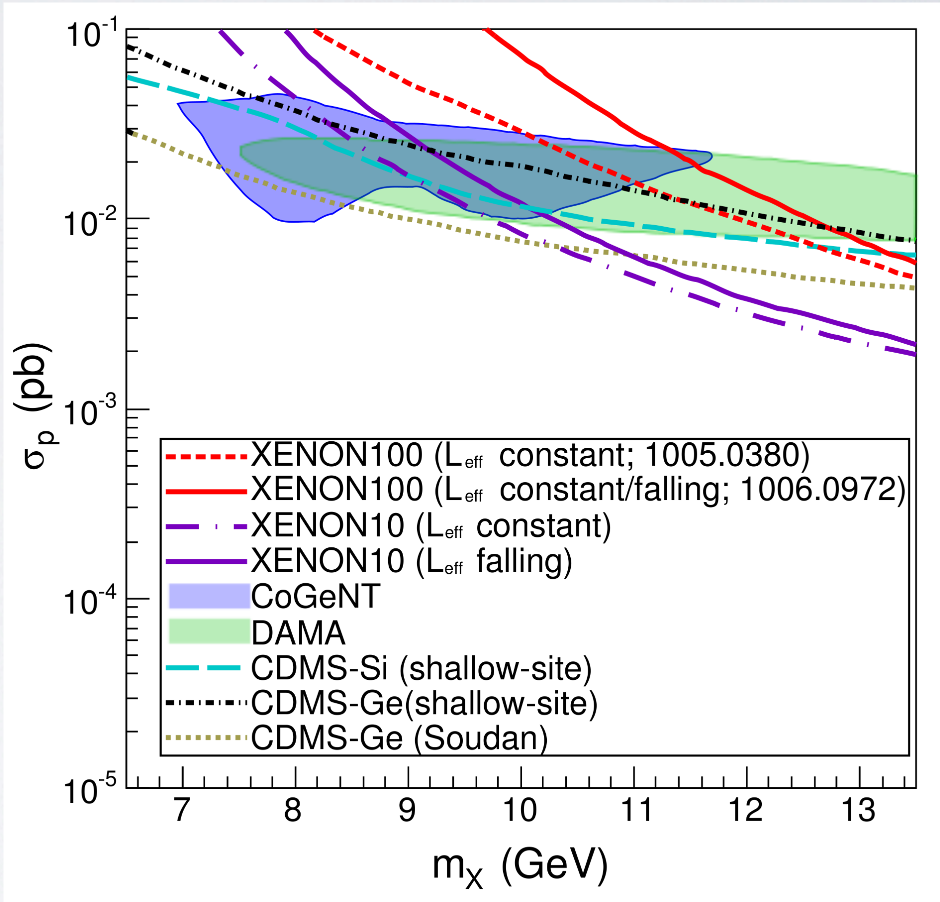


$$g(v_{min}, t) = \int_{v_{min}}^{\infty} dv\, \frac{f(v,t)}{v} \qquad g(v_{min}) = \frac{2 m_\chi \mu^2}{N_A \kappa\, m_p\, \rho\, \sigma(E_R)} \frac{dR_1}{dE_1}$$

SHIFT COUPLINGS TO HELP?

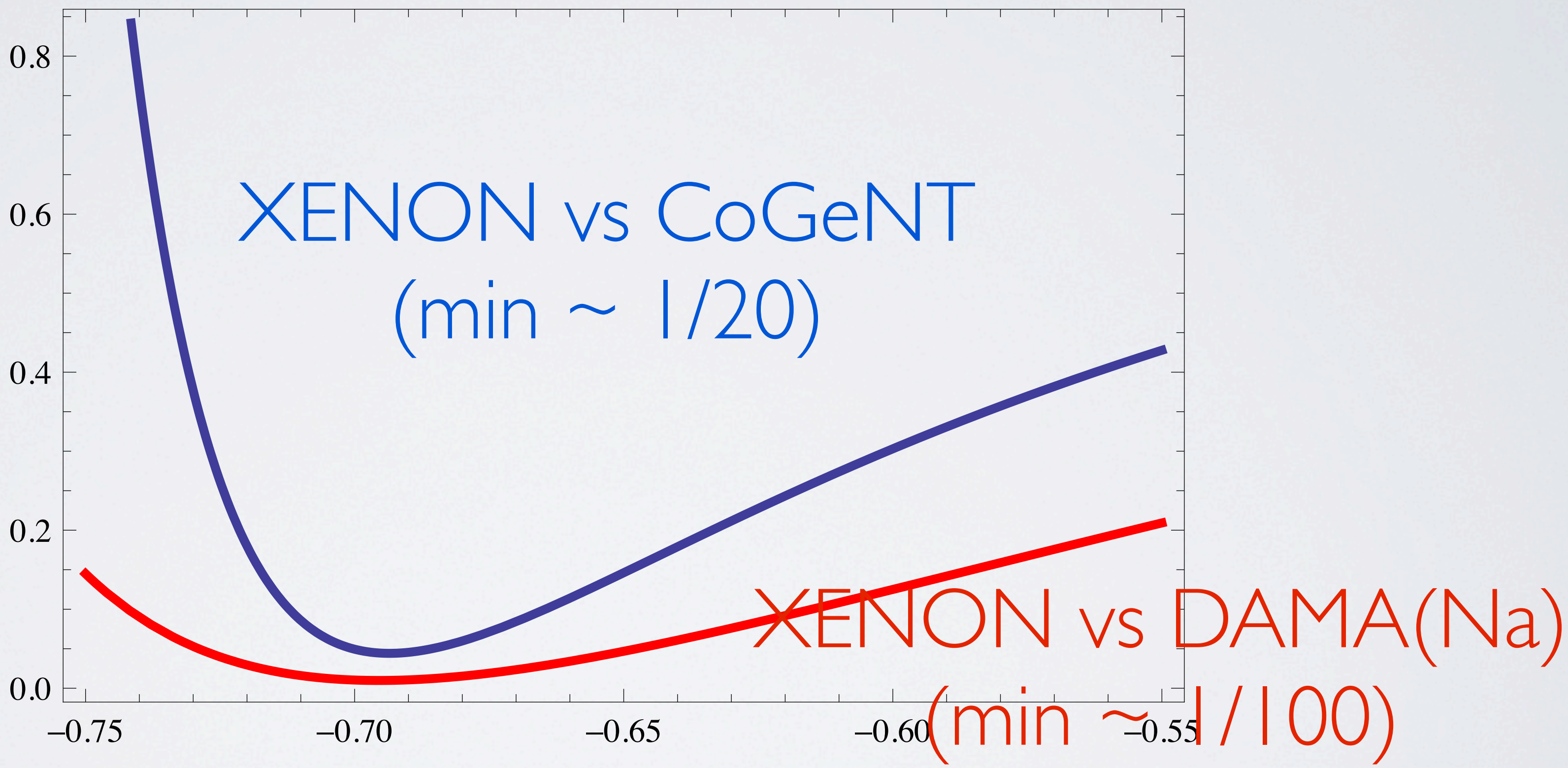


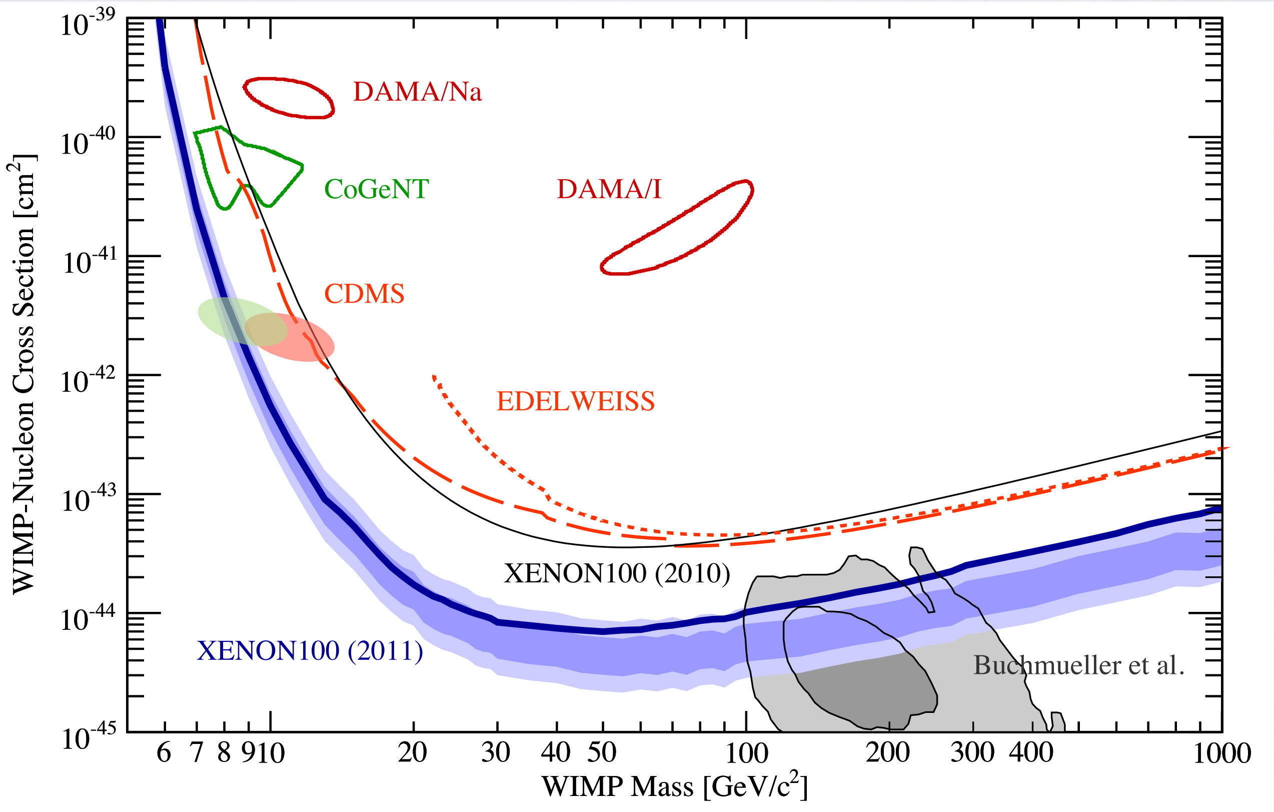
Chang et al 1004.0697



Feng, Kumar, Marfatia, Sanford 1102.4311

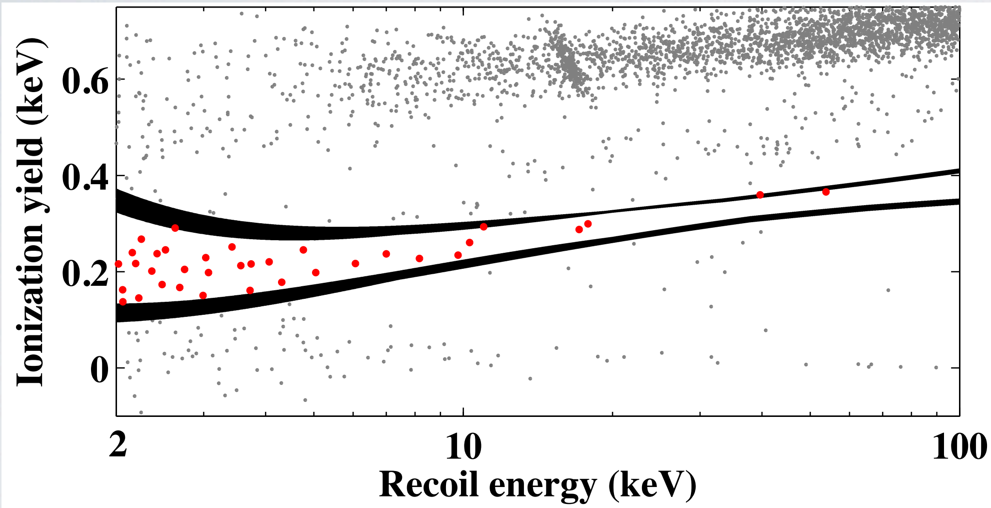
SHIFT COUPLINGS TO HELP?

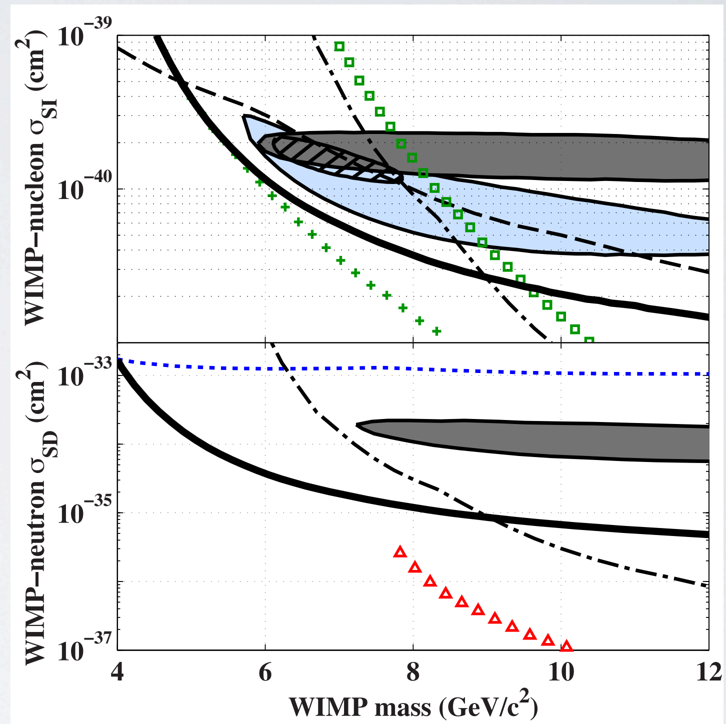


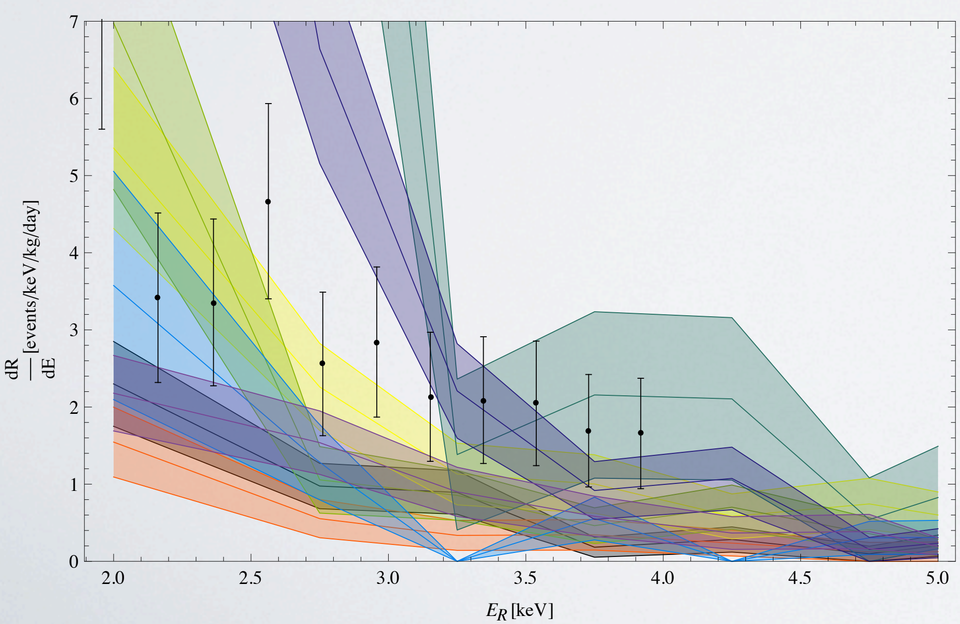


10^-39
10^-40
10^-41
10^-42
10^-43
10^-44
10^-45
WIMP-Nucleon Cross Section [cm^2]
DAMA/Na
CoGeNT
DAMA/I
CDMS
EDELWEISS
XENON100 (2010)
XENON100 (2011)
Buchmueller et al.
6 7 8 910 20 30 40 50 100 200 300 400 1000
WIMP Mass [GeV/c^2]

CDMS LOW THRESHOLD

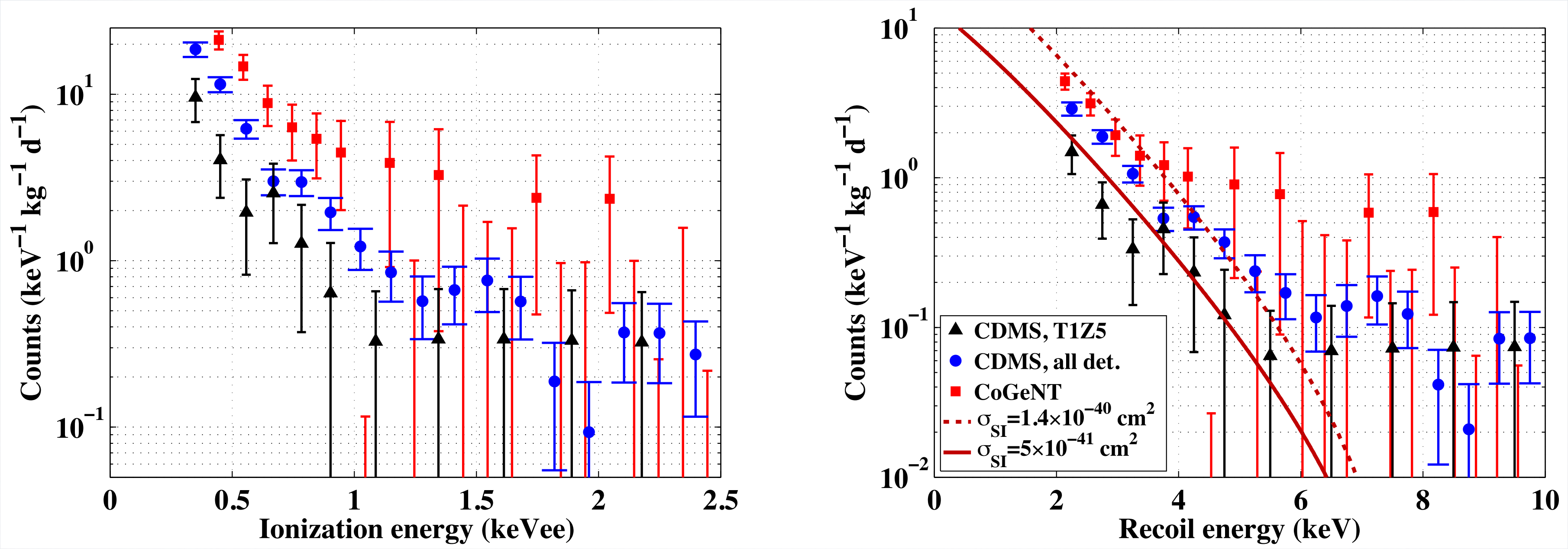






Same target. Appears to exclude CoGeNT...

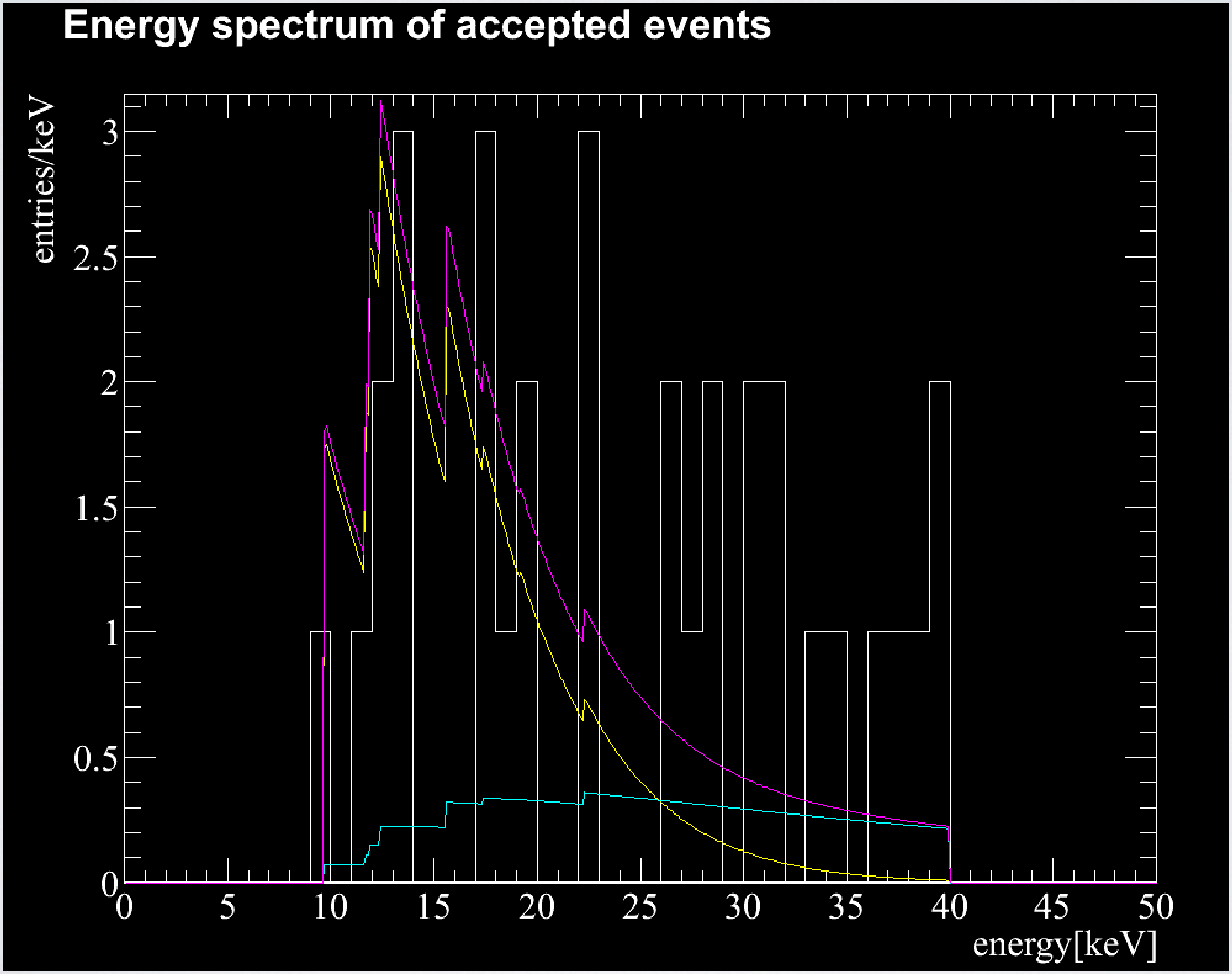
CDMS LOW THRESHOLD



WHERE ARE WE W/ COGENT

- Limits from CDMS, XENON (ionization+scintillation, ionization only) seem strong
- Ball is in CoGeNT court: better knowledge of shape, properties/significance of modulation, etc - new info can reinvigorate
- Status: already 120 kg day recorded (vs 18.5), expected update soon; CoGeNT-4 installation this summer. Modulation?

CRESST

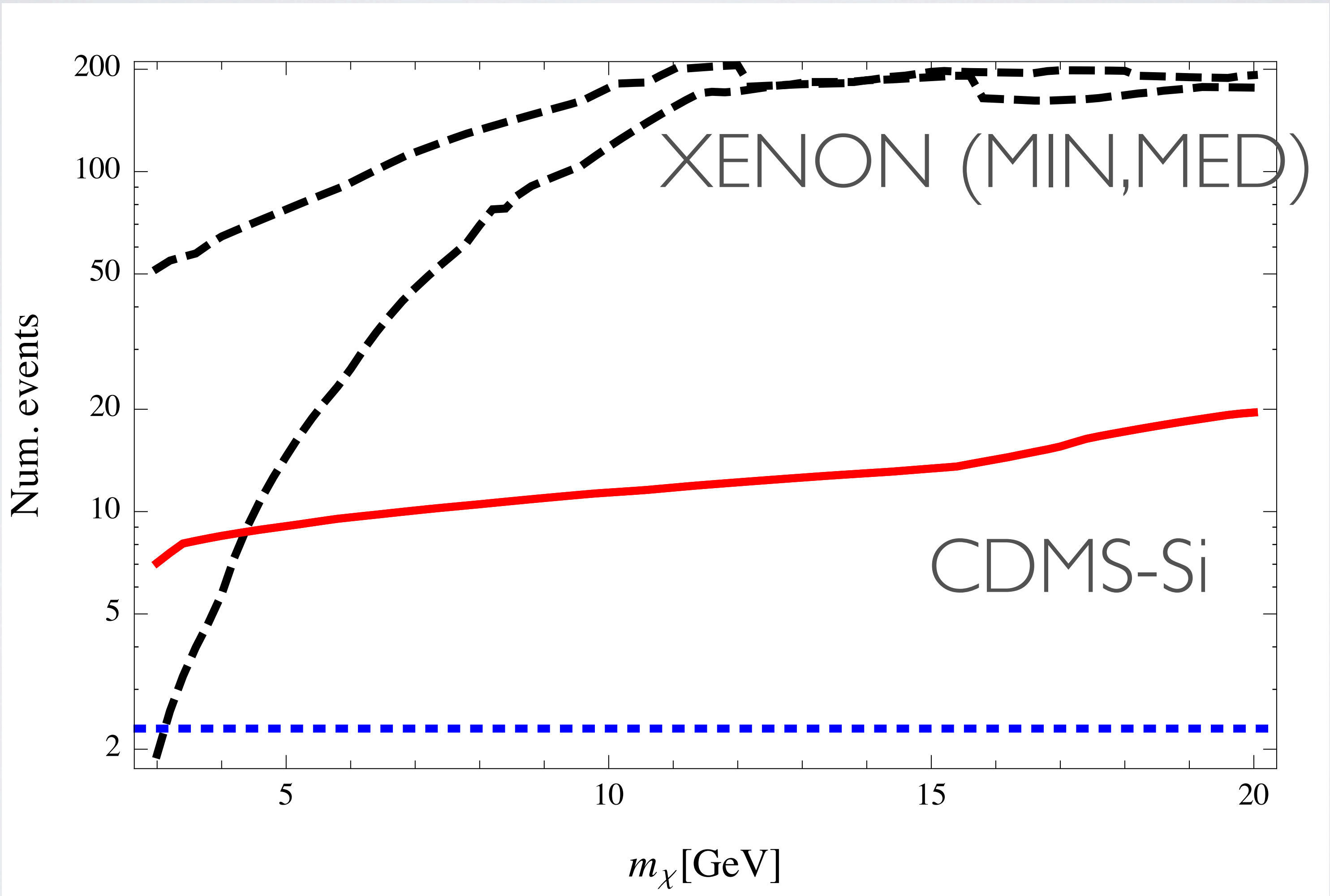

Energy spectrum of accepted events
entries/keV
3
2.5
2
1.5
1
0.5
0
0
5
10
15
20
25
30
35
40
45
50
energy[keV]

MAP CRESST

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

Look at integral

CRESST AT XENON10/CDMS-SI



OTHER EXPLANATIONS OF DAMA

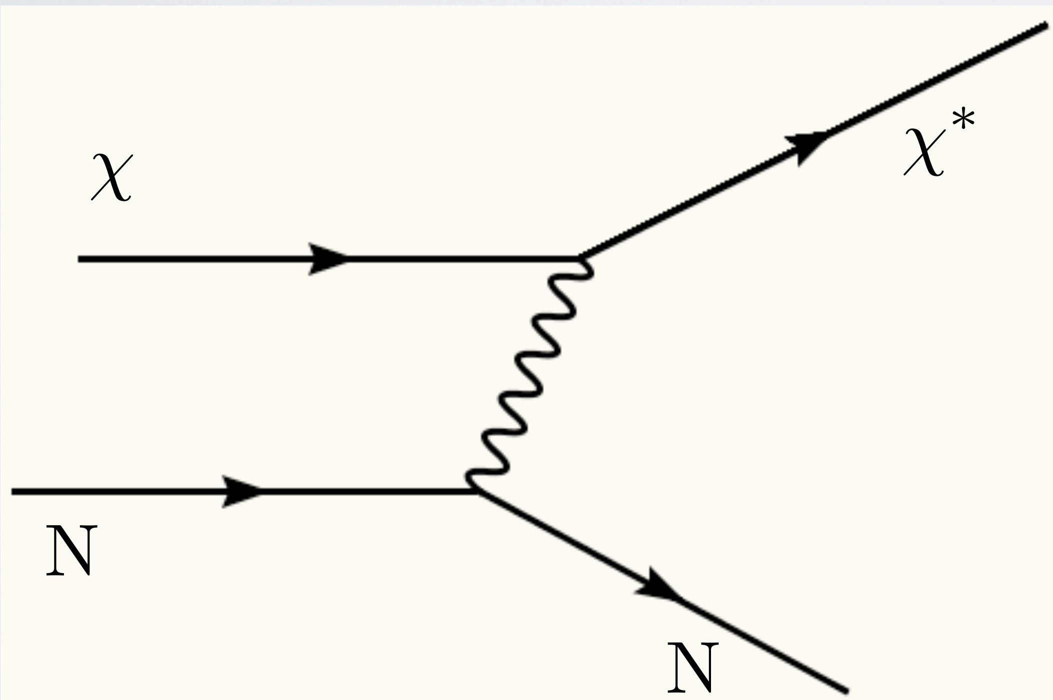
- What if it's not a light WIMP?

"INELASTIC" DARK MATTER

D.Tucker-Smith, NW, Phys.Rev.D64:043502,2001;Phys.Rev.D72:063509,2005

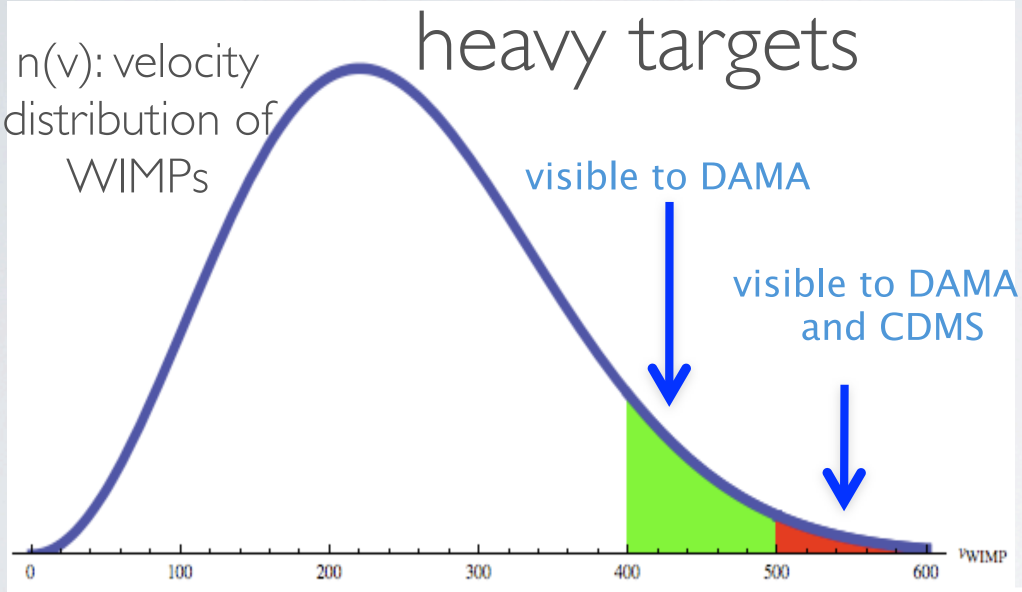
- With dark forces, DM-nucleus scattering must be inelastic

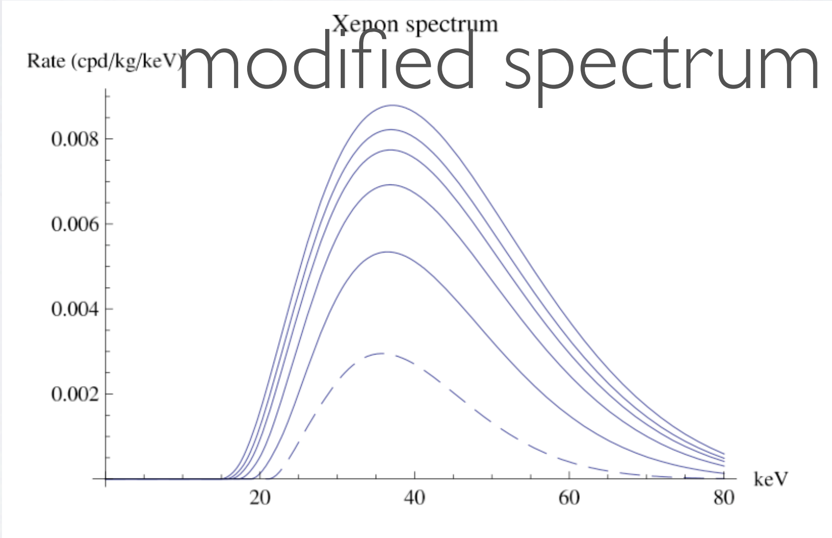
- If dark matter can only scatter off of a nucleus by transitioning to an excited state (100 keV), the kinematics are changed dramatically

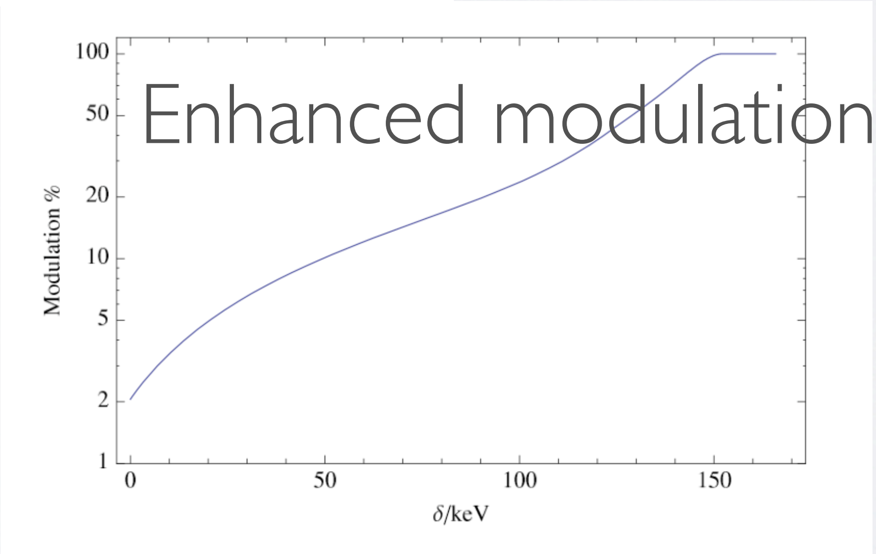


$$\frac{\mu_{\chi N} v^2}{2} > \delta$$

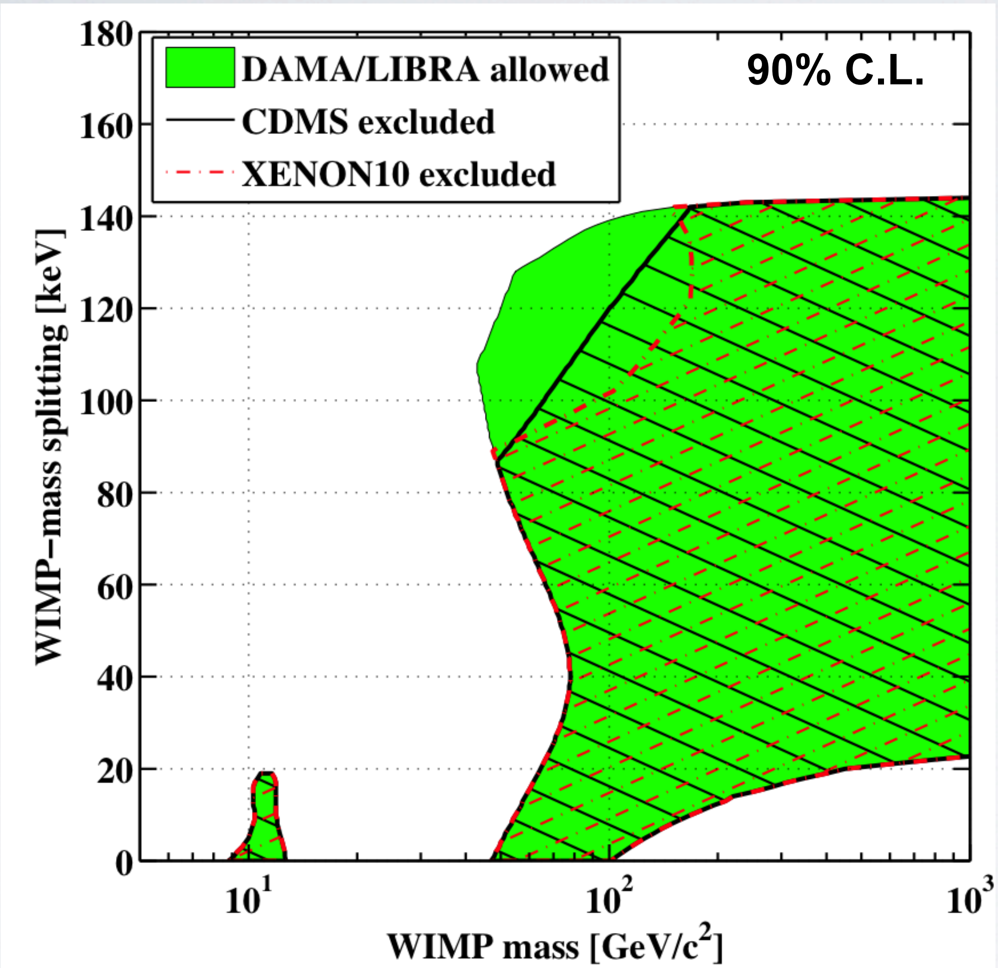
EFFECTS ON WIMP SEARCHES





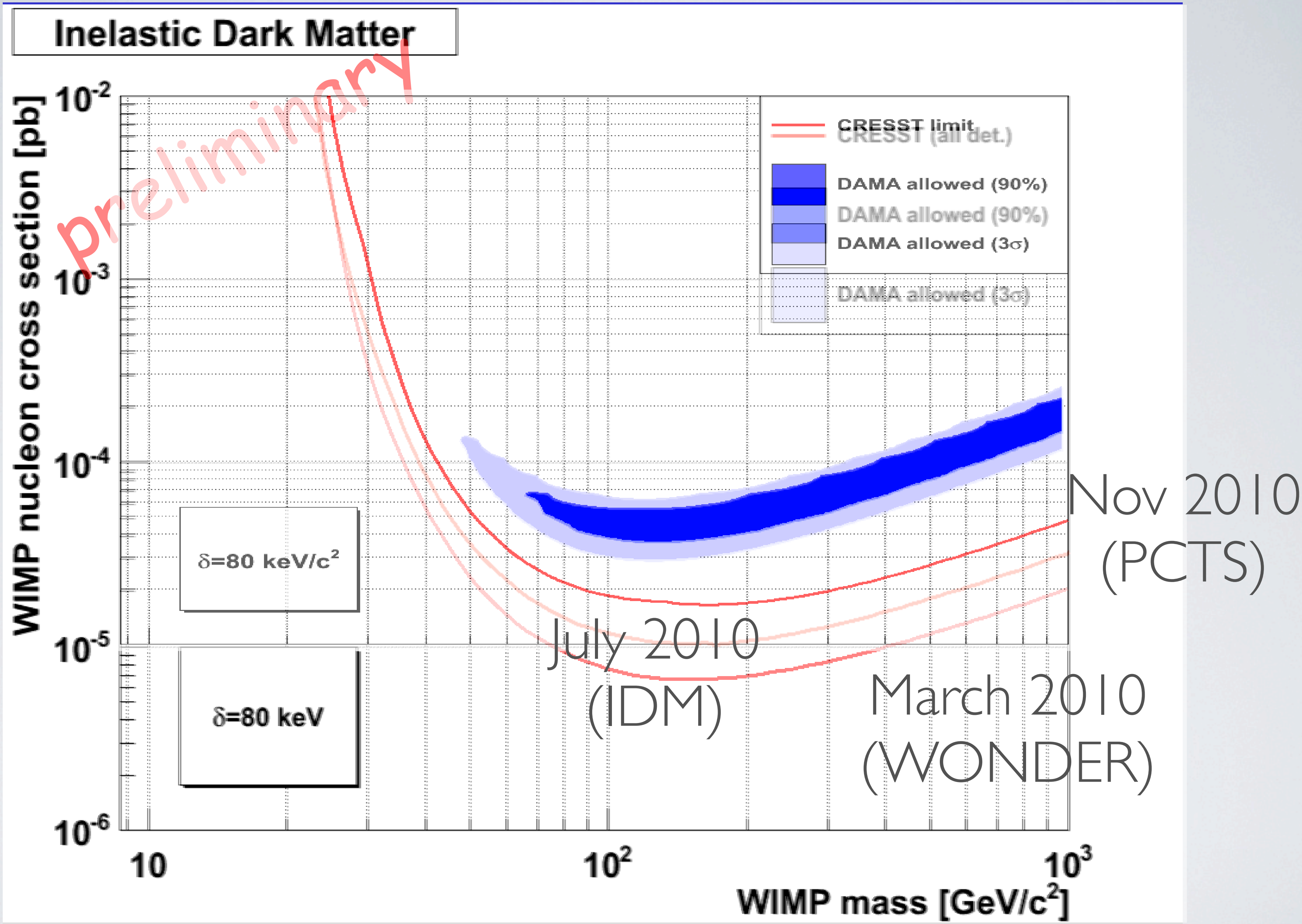


IDM CONSTRAINTS EARLY 2010

- 

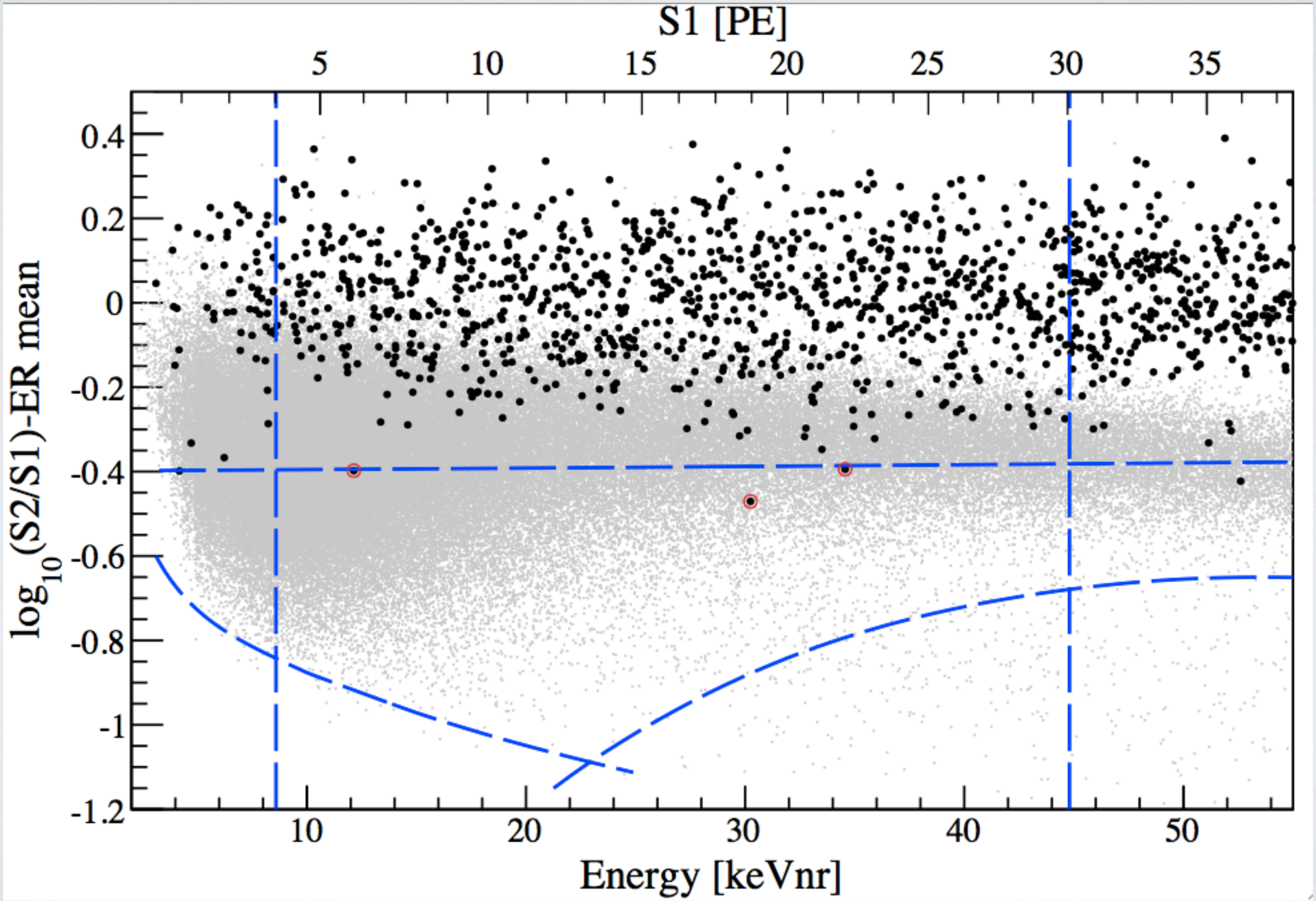
Tight constraints from CDMS, XENON (shown), also ZEPLIN,

Assume Maxwellian - must be in the highly modulated regime

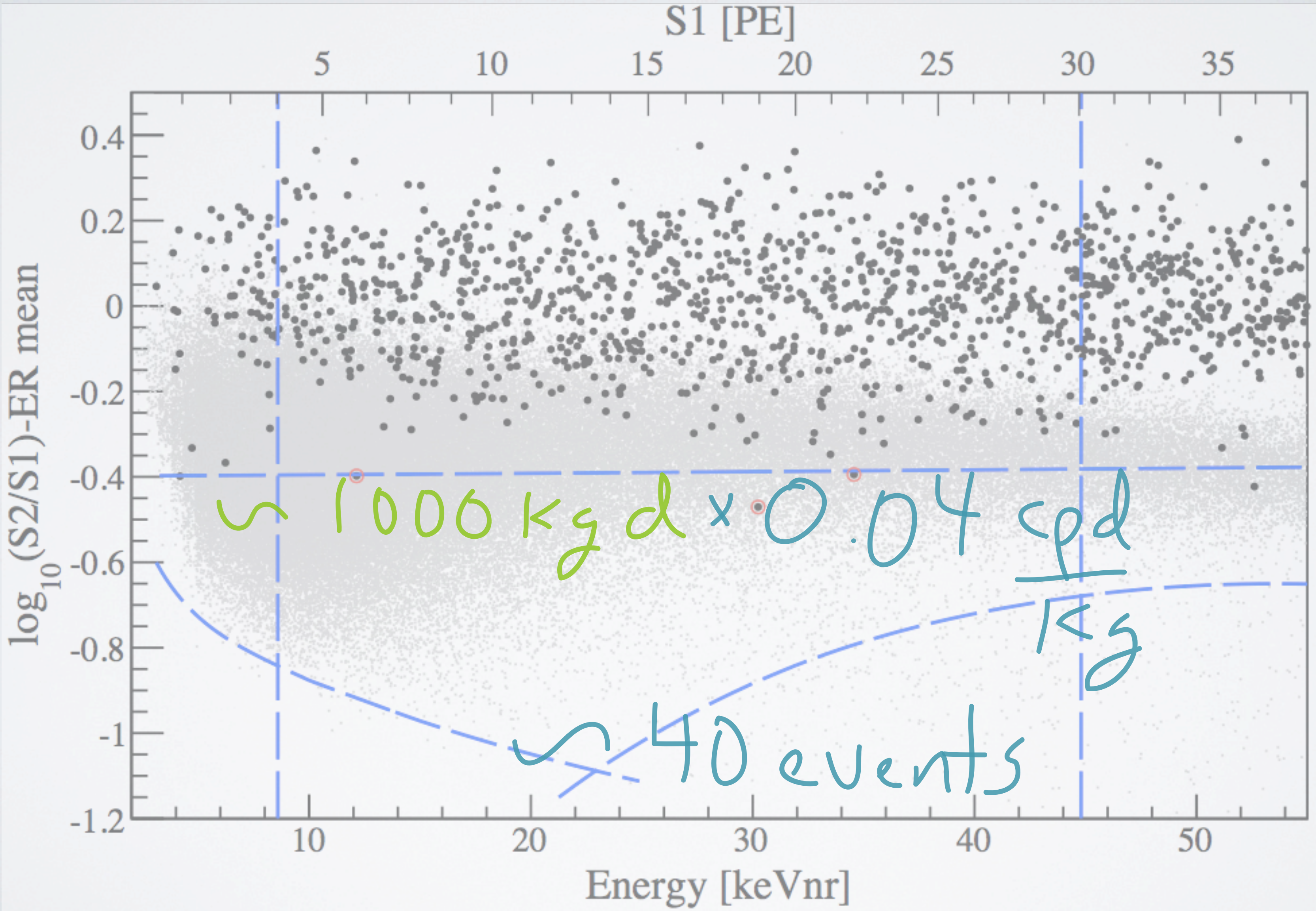


Currently excluded by ~1.5 assuming MB halo

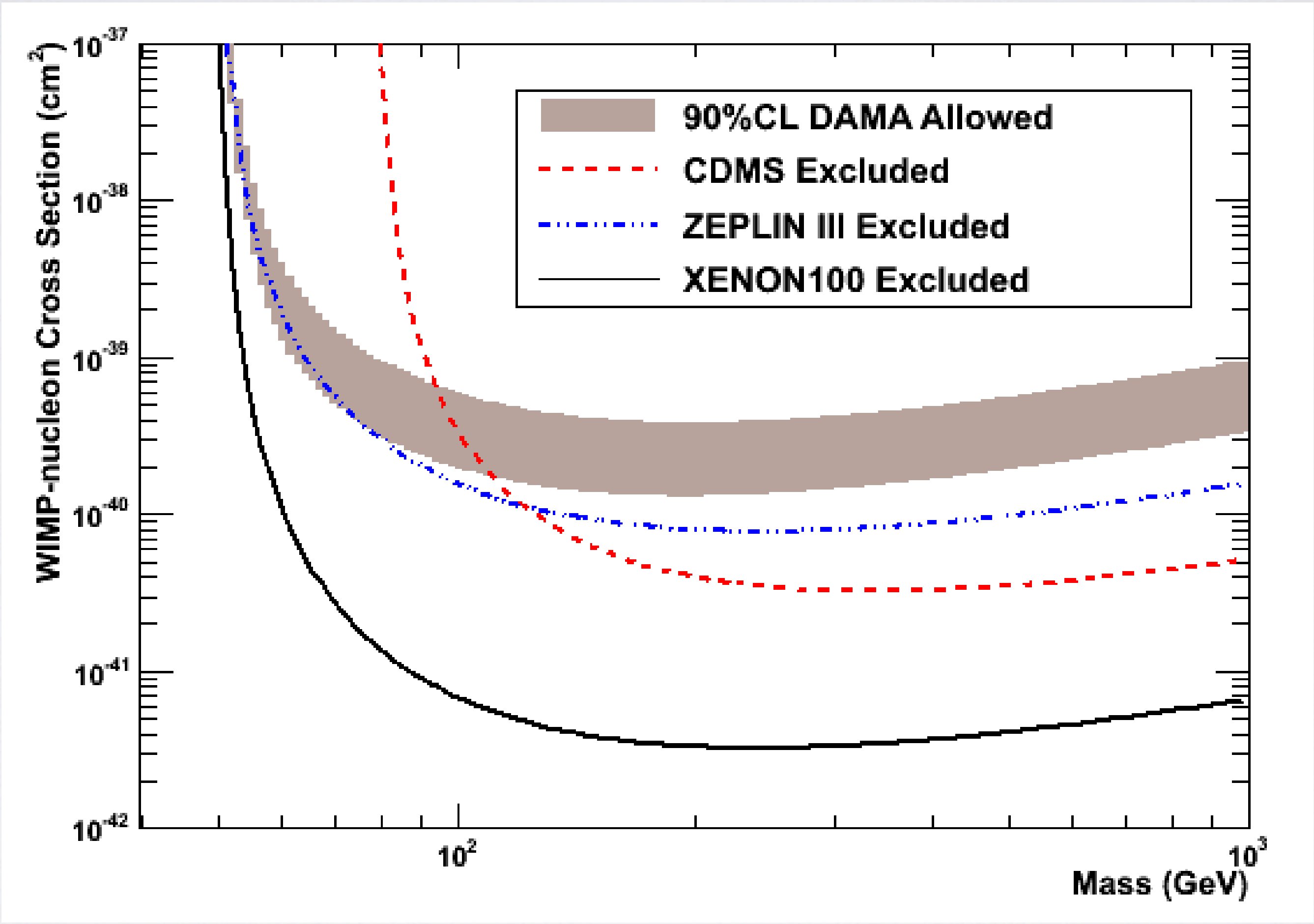
XENON100+IDM



XENON100+IDM

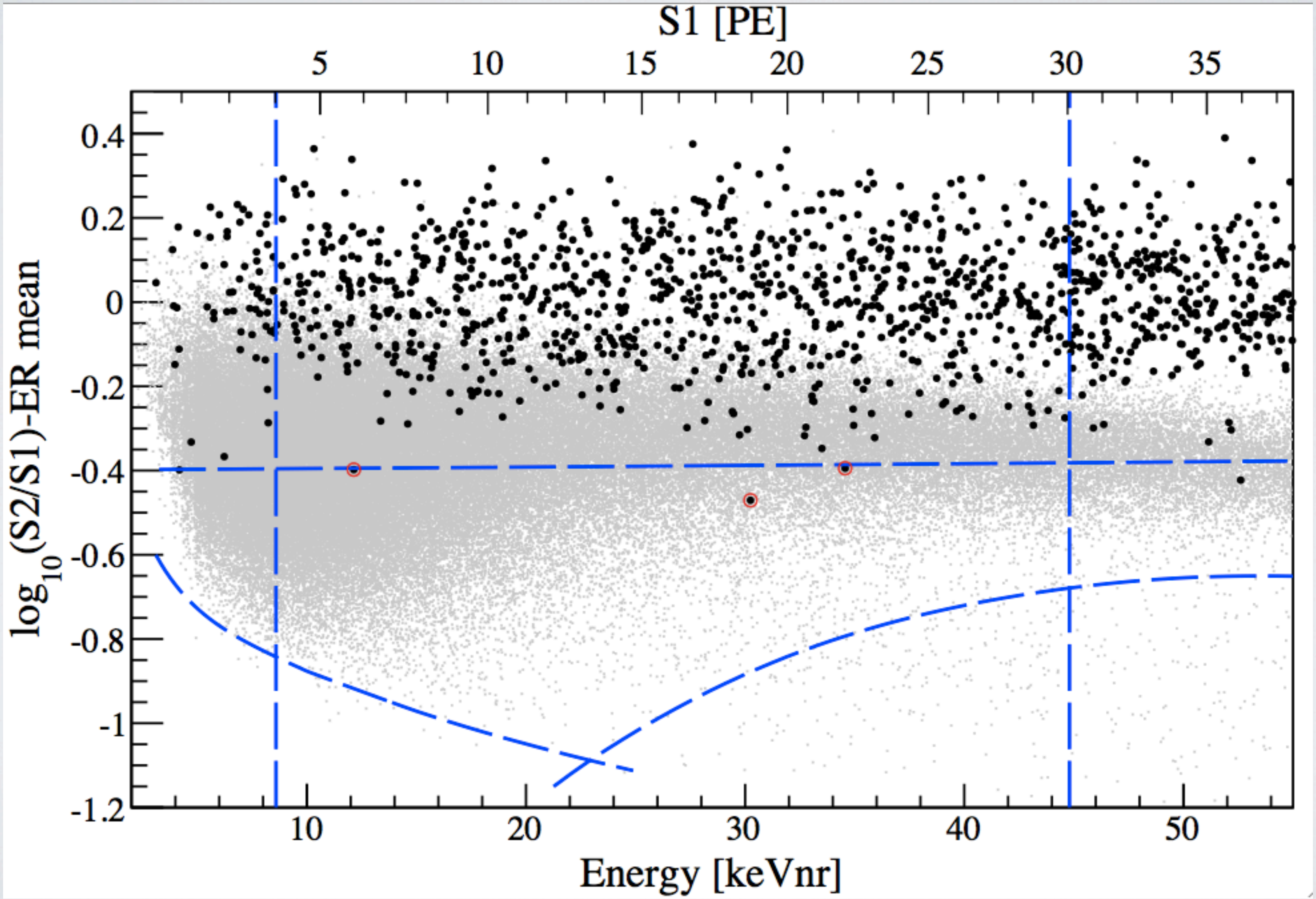


XENON100

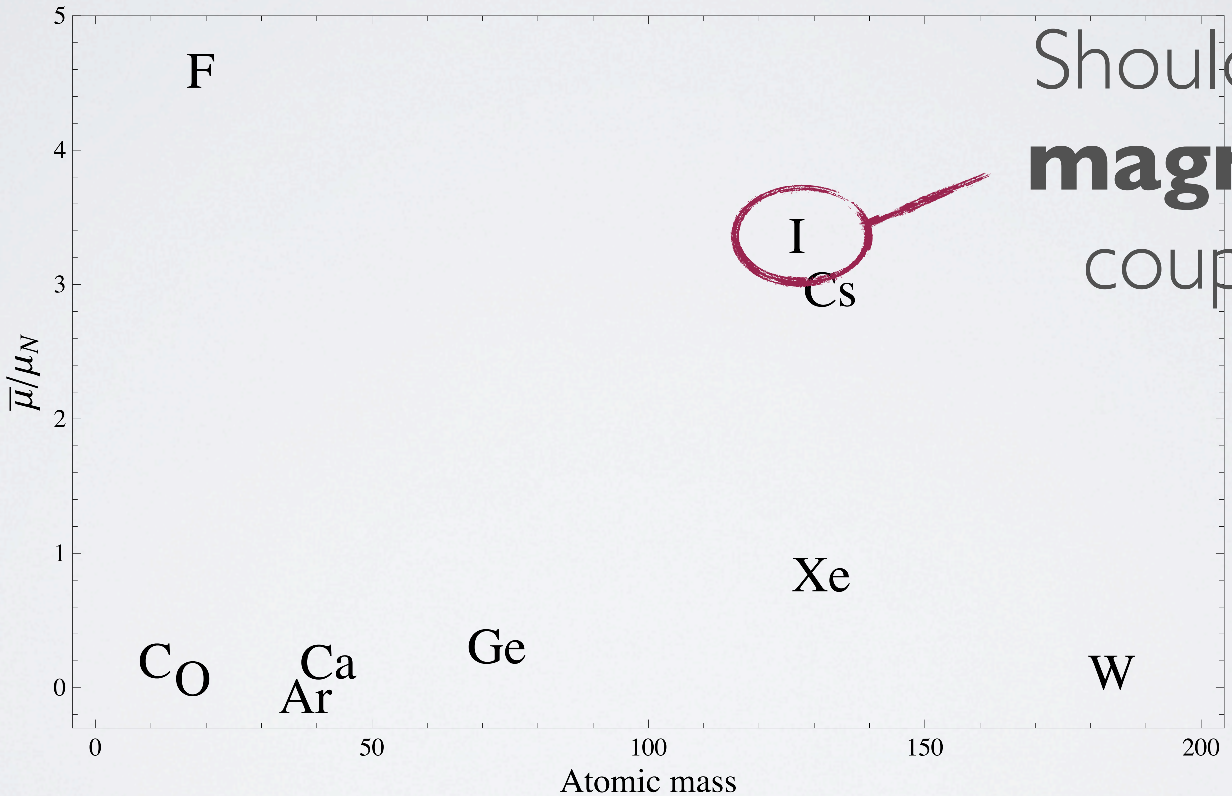


90%CL DAMA Allowed
CDMS Excluded
ZEPLIN III Excluded
XENON100 Excluded
WIMP-nucleon Cross Section (cm^2)
10^{-37}
10^{-38}
10^{-39}
10^{-40}
10^{-41}
10^{-42}
10^2
10^3
Mass (GeV)

XENON100+IDM



THE TARGETS OF DARK MATTER DETECTION



Should consider **magnetically** coupled iDM

Chang, NW, Yavin '10

Also: SDiDM Kopp, Schwetz, Zupan '09

Isotope	Atomic mass (m_a/u)	Natural abundance (atom %)	Nuclear spin (I)	Magnetic moment (μ/μ_N)
^{127}I	126.904473 (5)	100	$^5/_2$	2.81328

Isotope	Atomic mass (m_a/u)	Natural abundance (atom %)	Nuclear spin (I)	Magnetic moment (μ/μ_N)
^{124}Xe	123.9058942 (22)	0.09 (1)	0	
^{126}Xe	125.904281 (8)	0.09 (1)	0	
^{128}Xe	127.9035312 (17)	1.92 (3)	0	
^{129}Xe	128.9047801 (21)	26.44 (24)	$^1/_2$	-0.777977
^{130}Xe	129.9035094 (17)	4.08 (2)	0	
^{131}Xe	130.905072 (5)	21.18 (3)	$^3/_2$	0.691861
^{132}Xe	131.904144 (5)	26.89 (6)	0	
^{134}Xe	133.905395 (8)	10.44 (10)	0	
^{136}Xe	135.907214 (8)	8.87 (16)	0	

$\bar{\mu}_{Xe} \sim 0.5$

$\bar{\mu}_{I} \sim 2.8$

$$\Rightarrow \left(\frac{\bar{\mu}_I}{\bar{\mu}_{Xe}}\right)^2 \sim 30$$

Requires

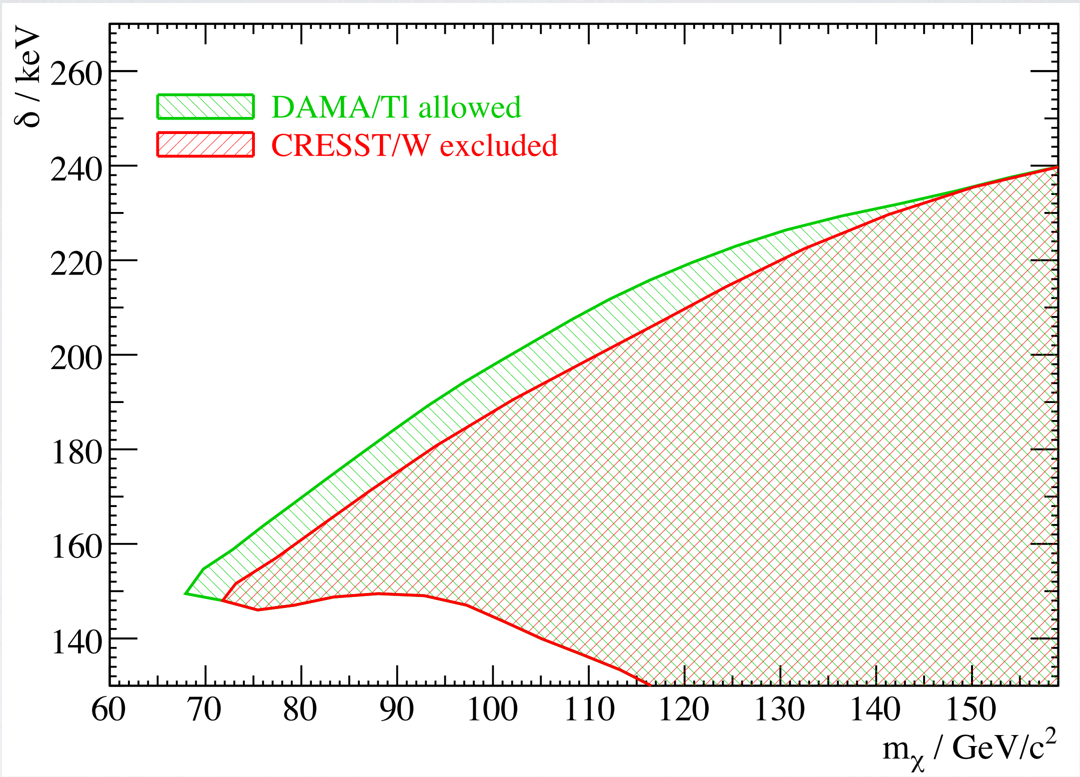
$\mu_\chi \sim 10^{-2}\,\mu_N$

NB: Charge-dipole scattering

AN IMPURE THOUGHT

DAMA is not NaI but NaI(Tl)

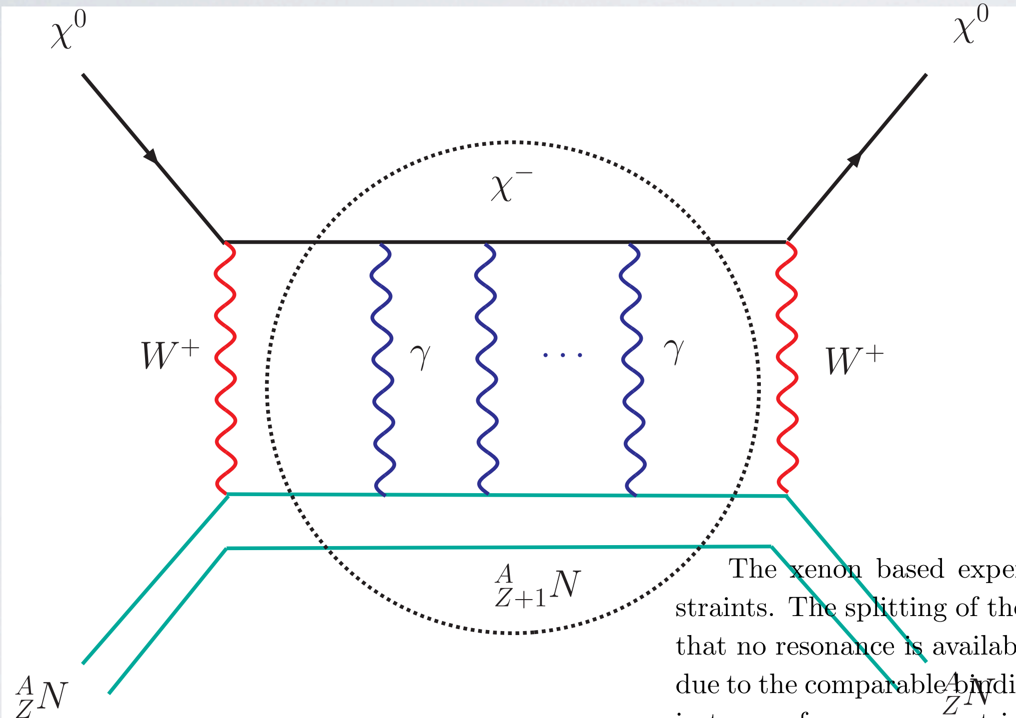
DETECTOR PROPERTIES

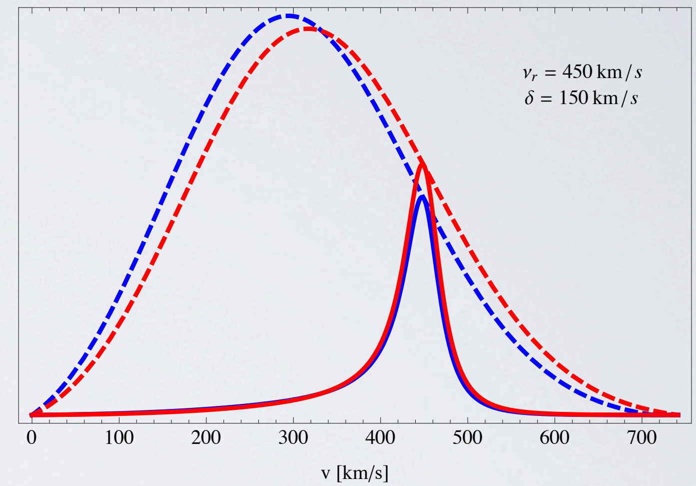


- Tuned at 5% level
- Requires 10^3 larger cross sections and larger

OTHER IDEAS

RESONANT DARK MATTER

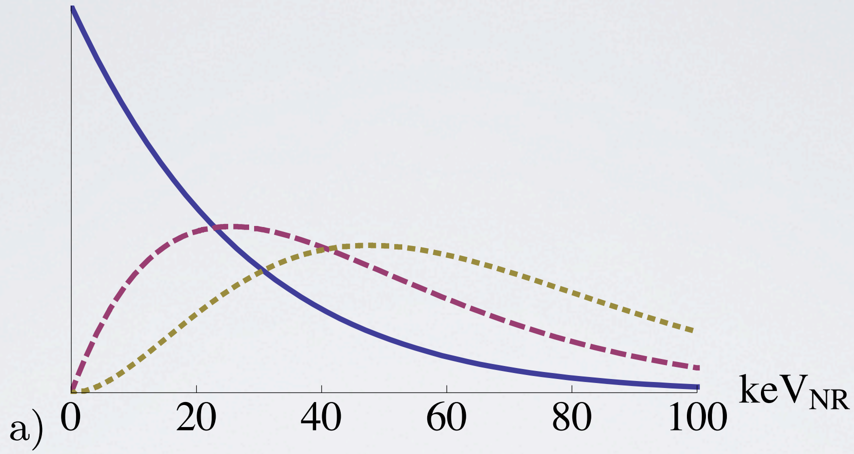


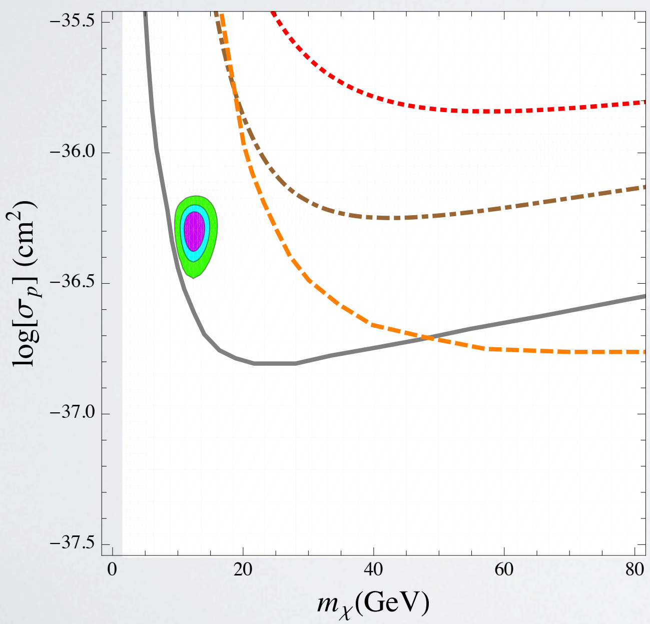


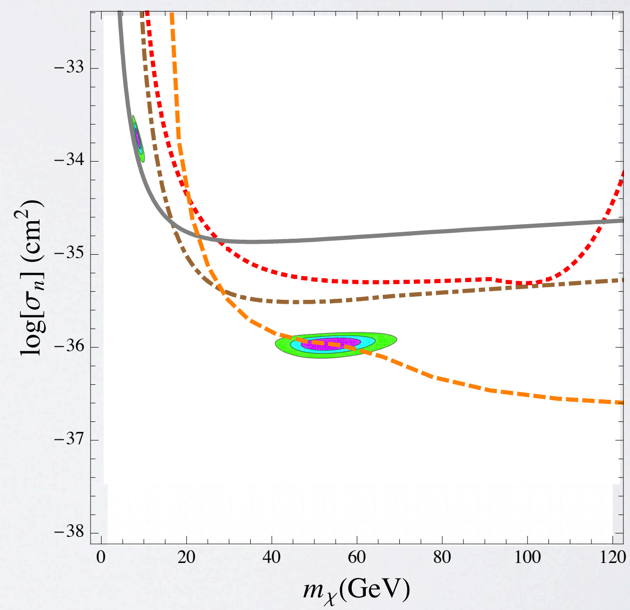
The xenon based experiments of ZEPLIN and XENON may also present strong constraints. The splitting of the appropriate energy levels in $^{129}_{55}Cs$ is $\sim$ 500 keV, so it is possible that no resonance is available for these xenon experiments. However, it is difficult to be sure due to the comparable binding energies of iodine and xenon and the preponderance of different isotopes of xenon present in the detectors. For simplicity we have concentrated throughout on one of the high abundance isotopes. Furthermore, rDM has the feature of increased modulation (see Fig. 2) and the XENON data was taken between October and February, which somewhat weakens their bounds on rDM. Similar to the case II for DAMA, the spectral lines corresponding to the isotopes of cesium may be the dominant signals at the ZEPLIN and XENON. A more detailed study of the spectra and number of the predicted events in other experiments and the allowed resonance speeds for each experiment is warranted.

Bai, Fox

MOMENTUM DEPENDENT SPIN DEPENDENT SCATTERING





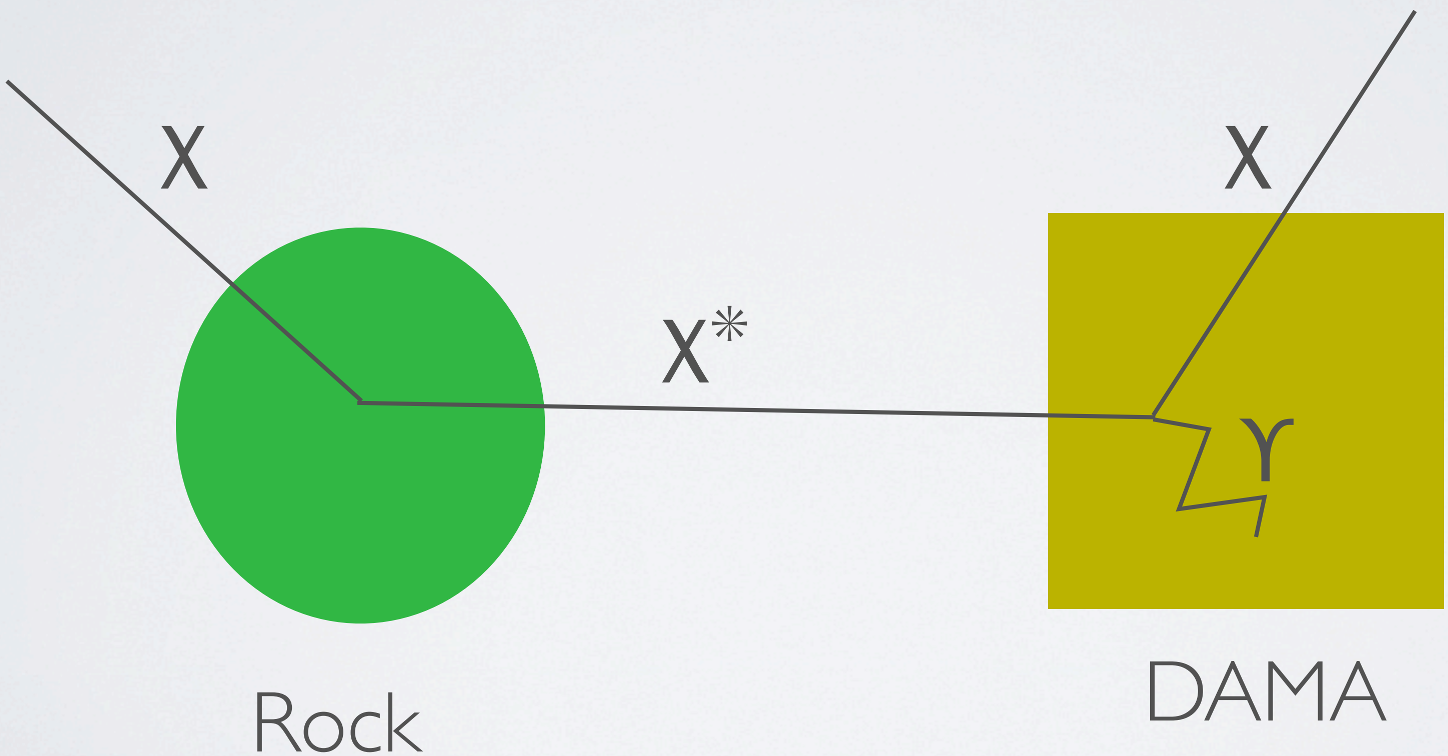


enormous cross sections - a model? Chang, Pierce NW

NEW IDEAS

Luminous Dark Matter

Brian Feldstein,[1] Peter W. Graham,[2] and Surjeet Rajendran[3]



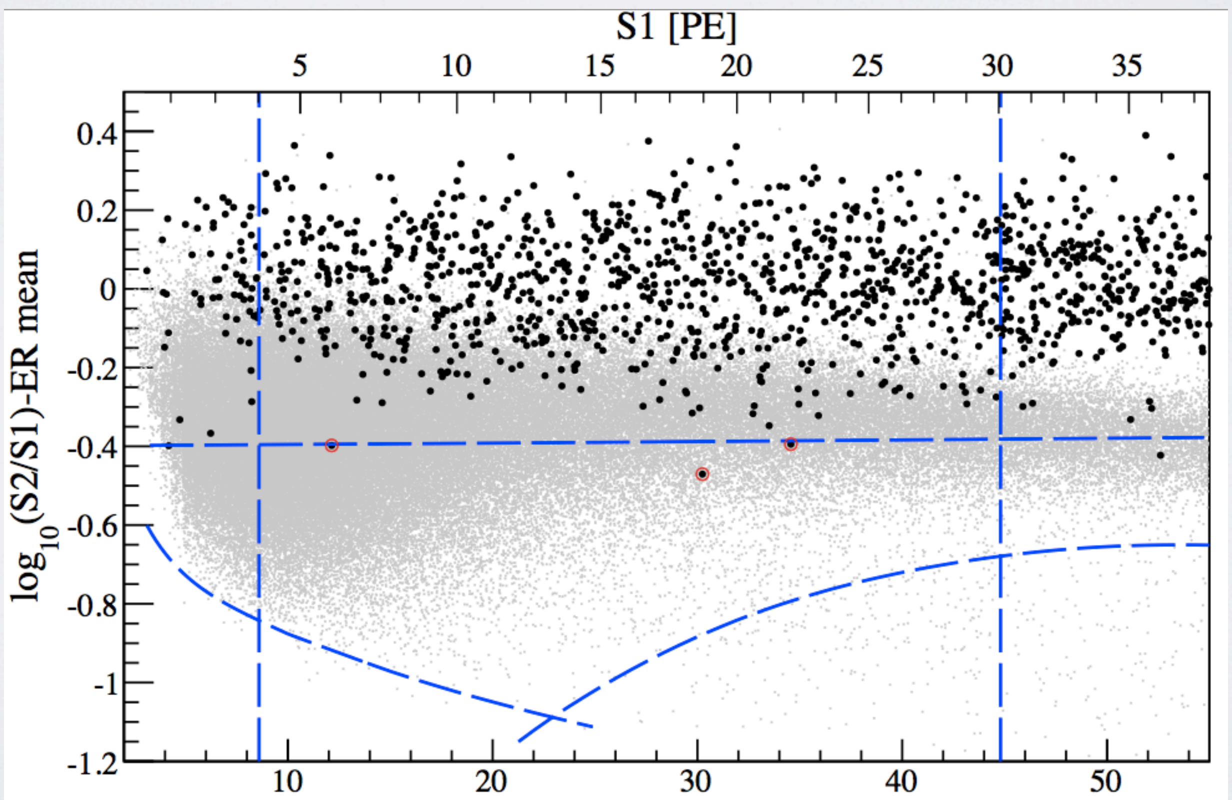
Electronic signal proportional to **volume** of detector

ELECTRON SCATTERING

Luminous Dark Matter

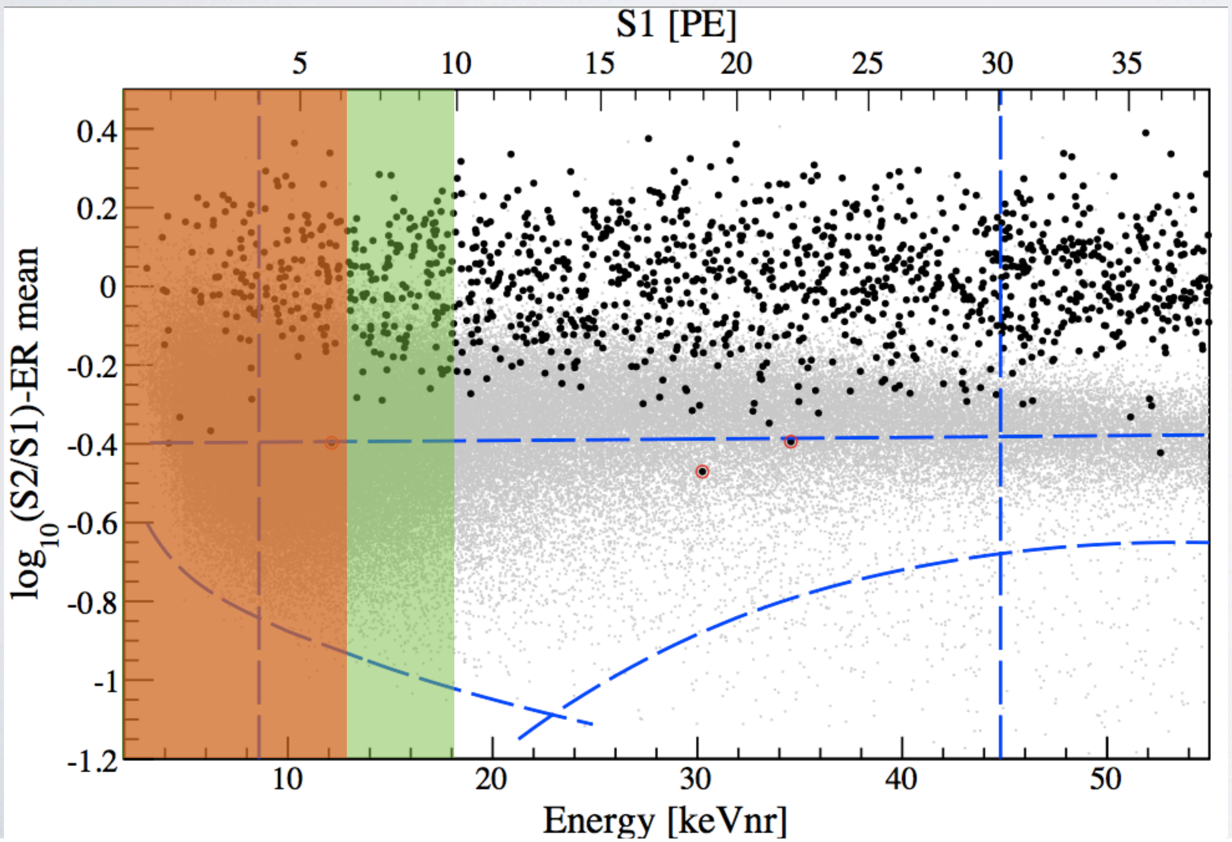
Brian Feldstein,[1] Peter W. Graham,[2] and Surjeet Rajendran[3]

proportional to volume



$$\frac{\left(0.04\,\frac{\text{cpd}}{\text{kg}} \times 24 \times 9.7\,\frac{\text{kg}}{\text{crystal}}\right)}{(10.2\,\text{cm})^2 \times 25.4\,\text{cm} \times 24} \times 200\pi\,\text{cm}^2 \times 30\,\text{cm}$$

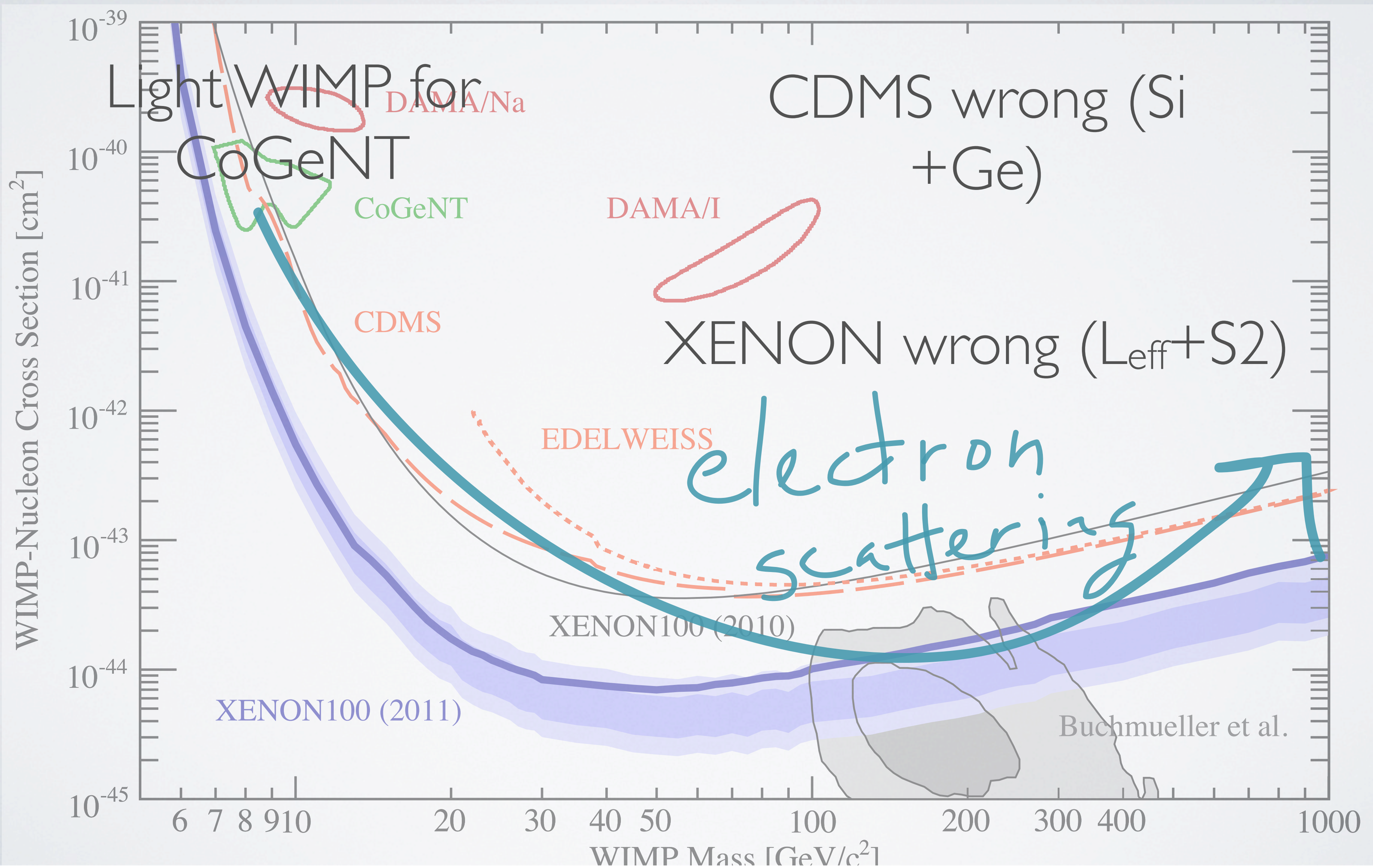
$$\sim 2.7\,\frac{\text{counts}}{\text{day}}$$



WHERE WE ARE

What you want

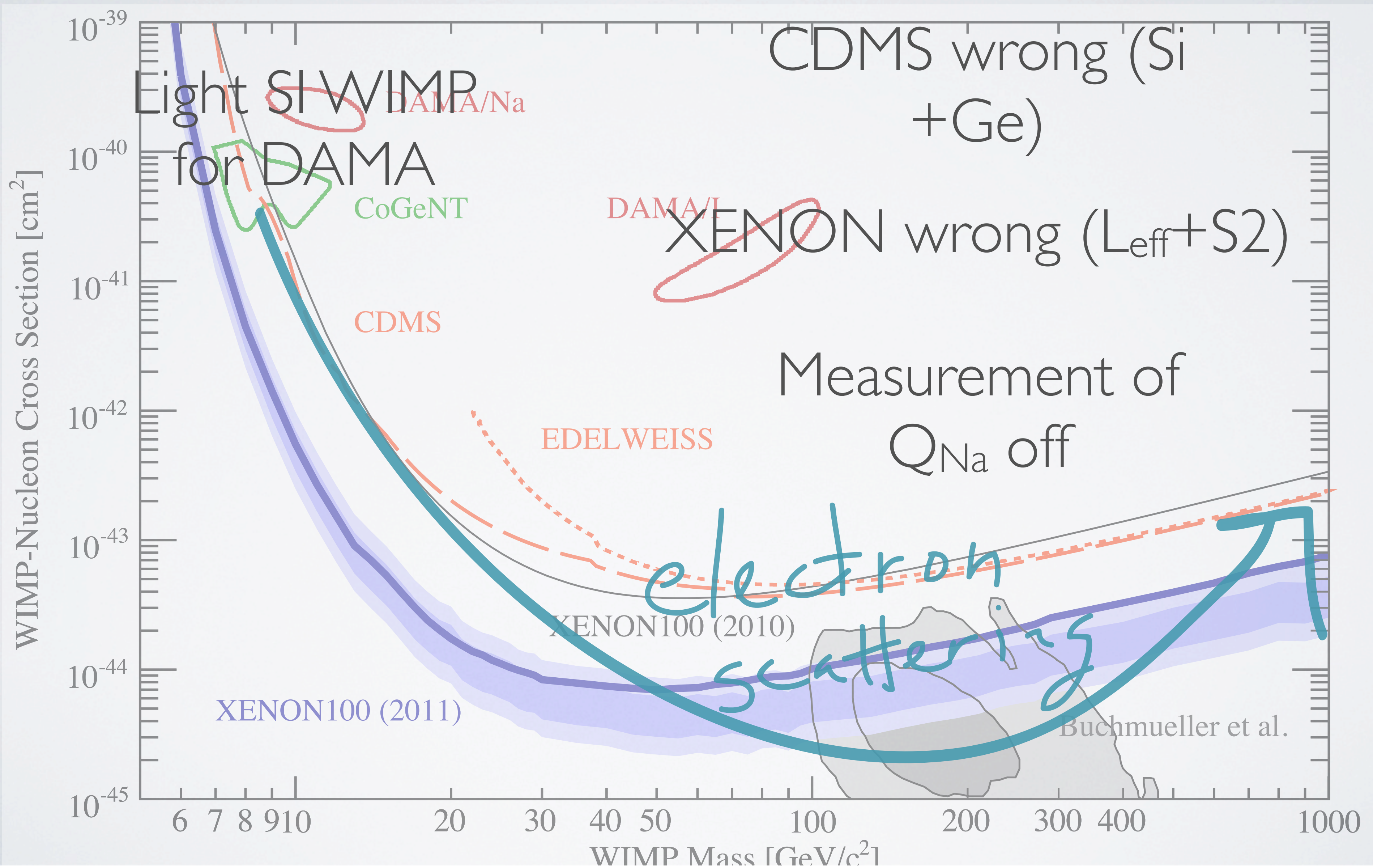
What you need



WHERE WE ARE

What you want

What you need



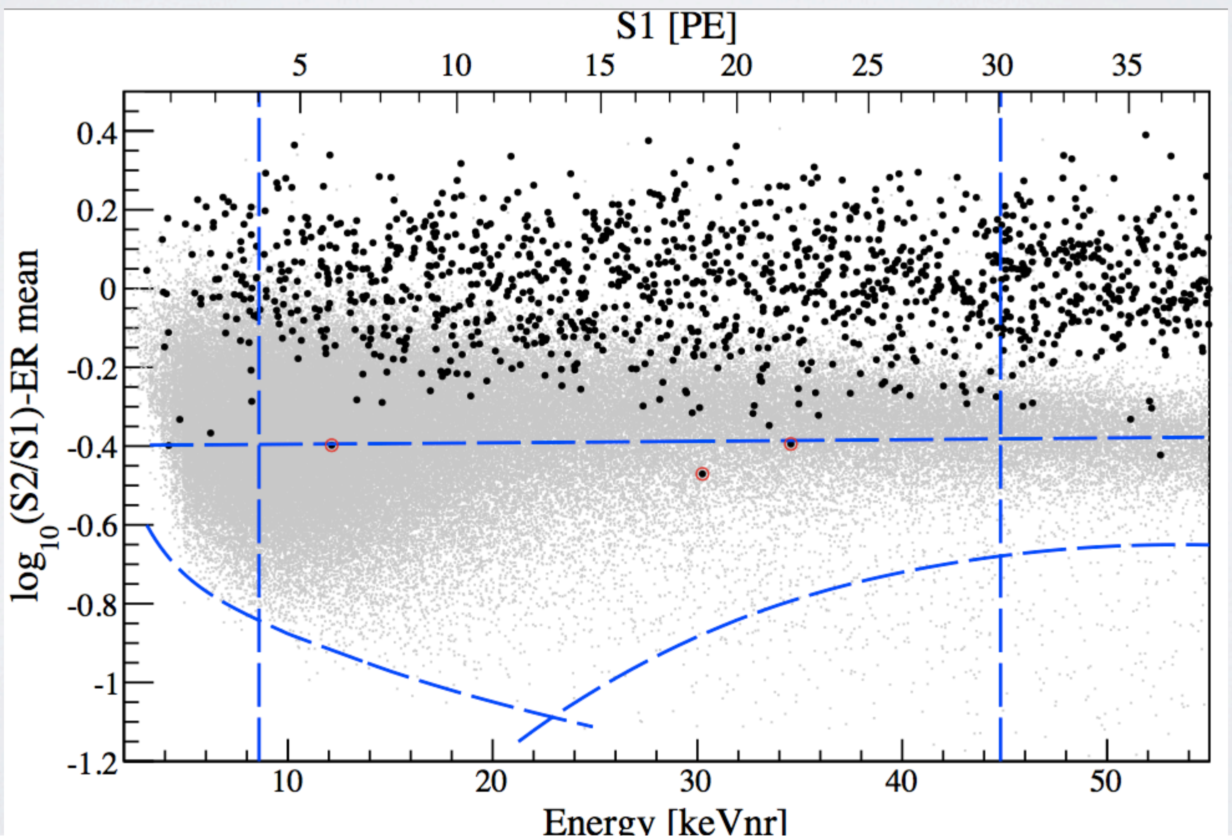
WHERE WE ARE

What you want

Luminous
DM

What you need

something to help out
(efficiencies?) and
a funny background



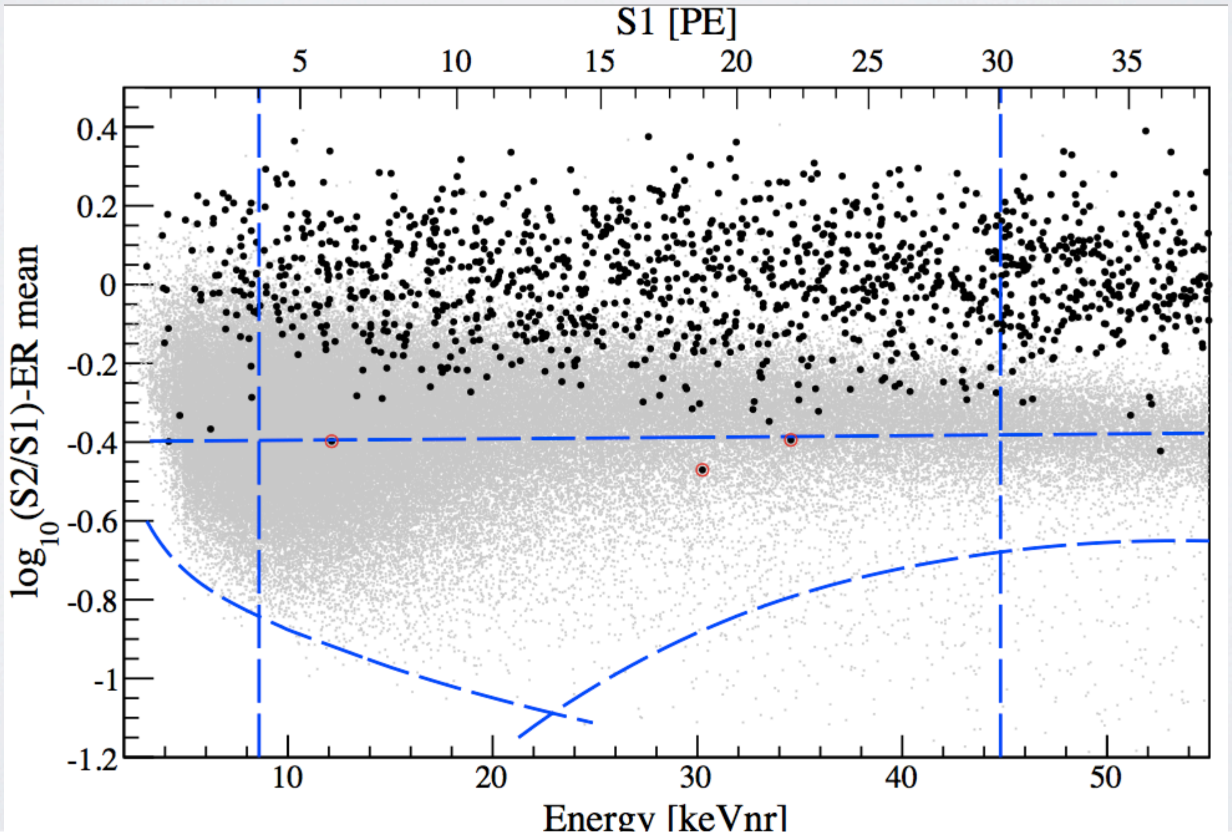
WHERE WE ARE

What you want

Resonant DM

What you need

Theorists not to calculate limits



WHERE WE ARE

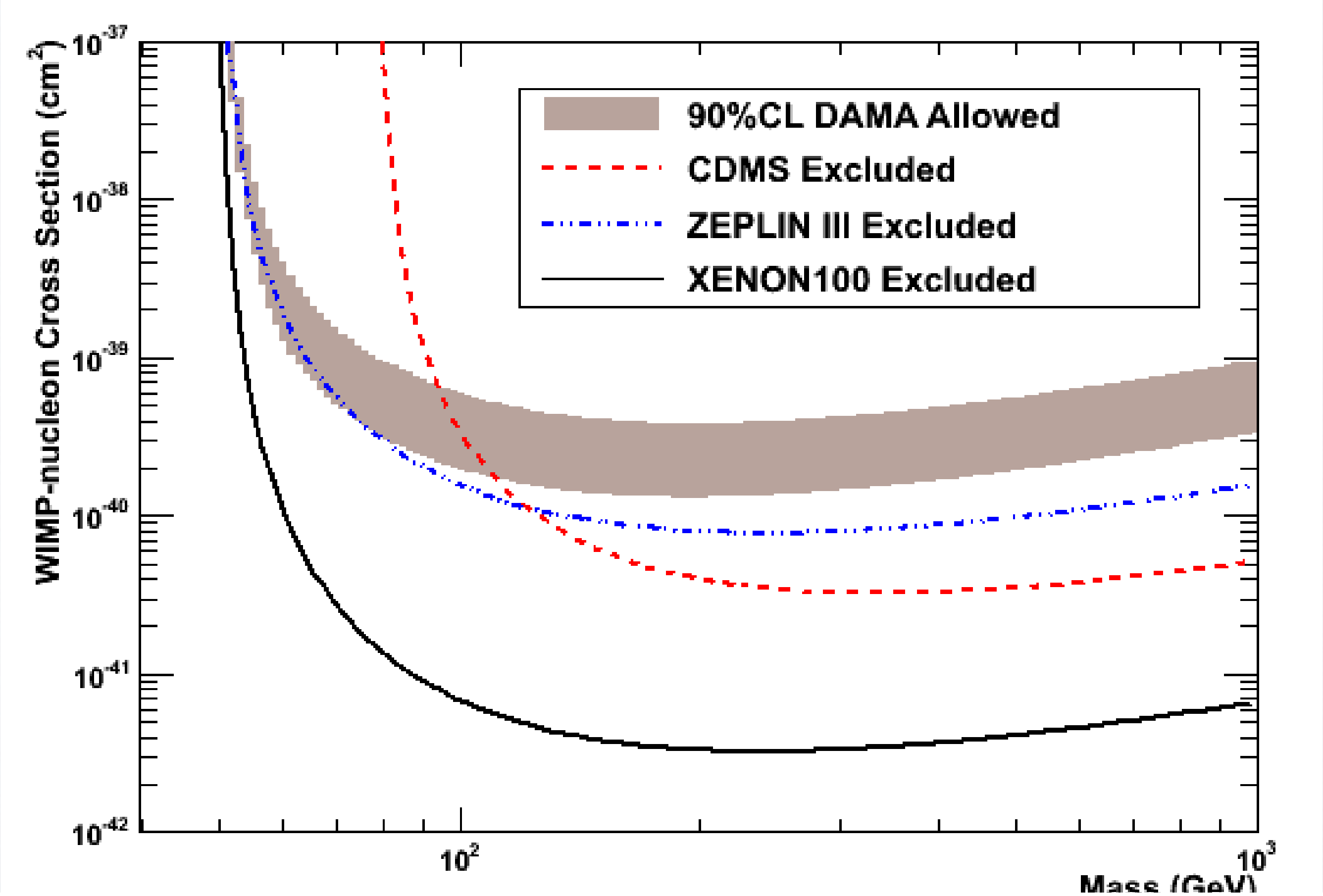
What you want

iDM

What you need

XENON to have absolutely no idea what they are doing

(or 30 events just outside the window)



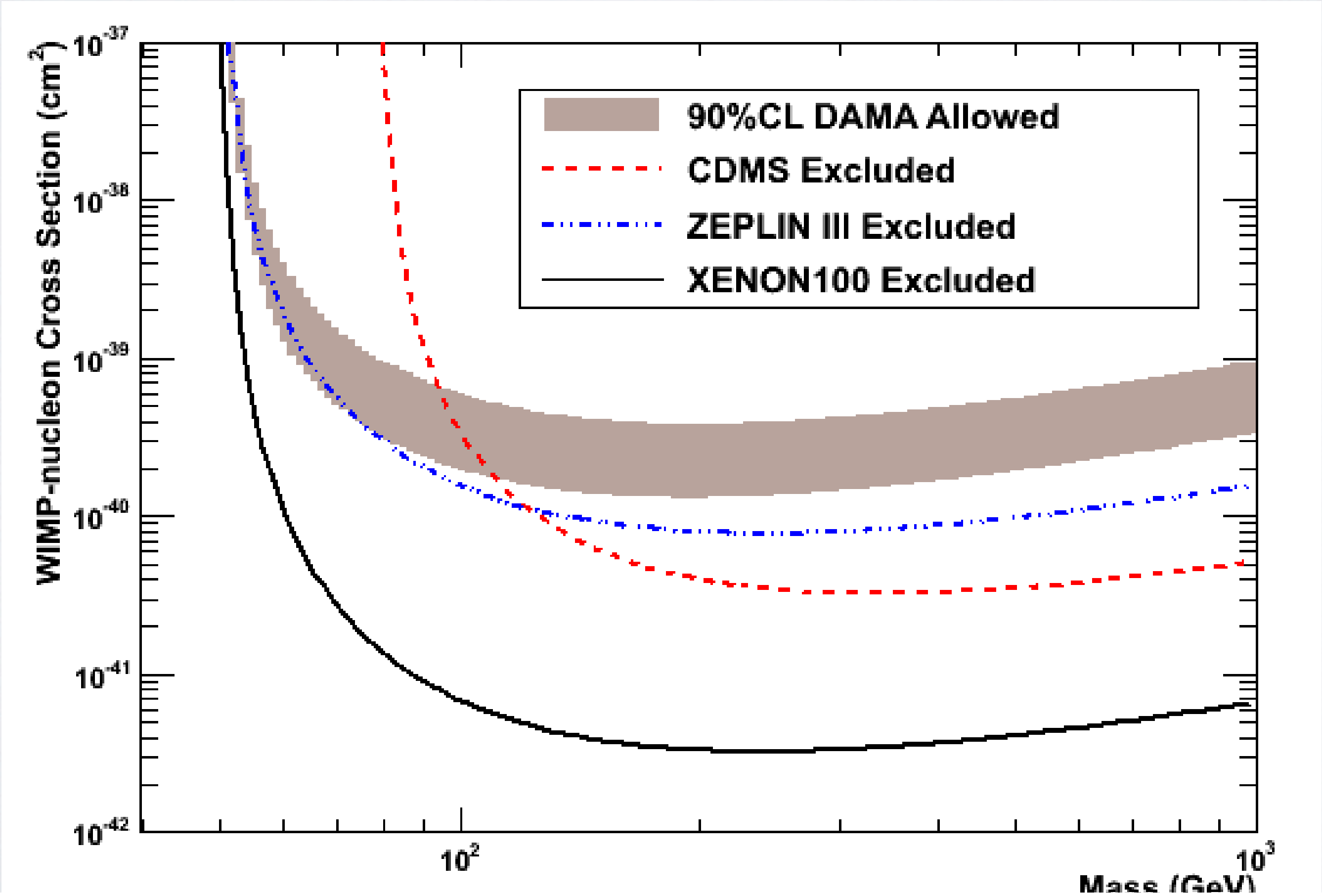
WHERE WE ARE

What you want

iDM

What you need

Thallium scattering and some tuning



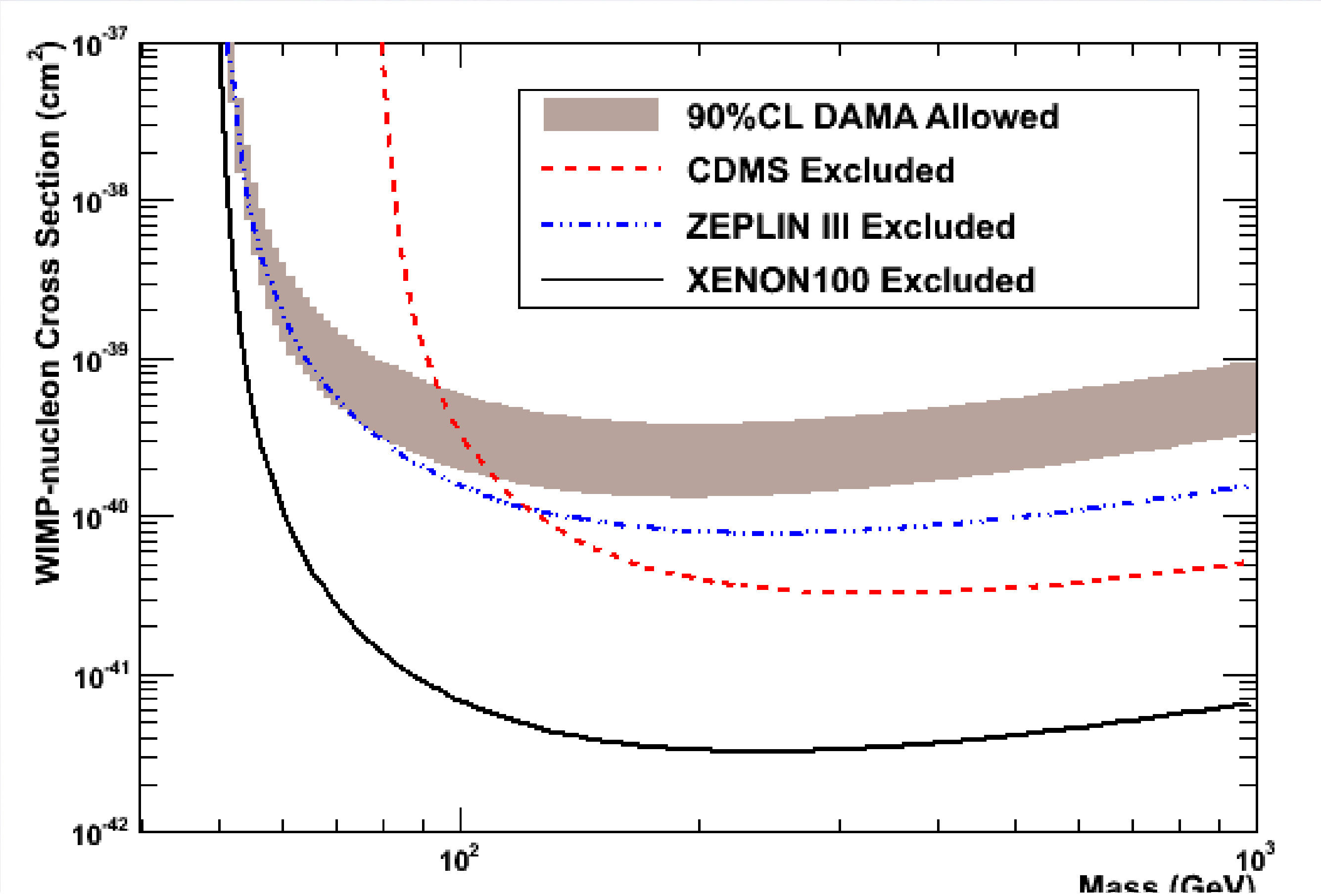
WHERE WE ARE

What you want

MiDM

What you need

Large modulation fraction and a large dipole



WHAT TO LOOK FORWARD TO

- XENON100 unblinding/results part II
- CoGeNT update
  - Removal of L-shell peaks, modulation study
- COUPP First results (CF_3I) (running at high threshold)
  - C**F₃**I ⇒ Light dark matter
  - C**F₃**I ⇔ **Na**I(Tl), CF₃**I** ⇔ Na**I**(Tl)
- KIMS (CsI(Tl)), 1 yr study
  - **Cs****I**(Tl) ⇔ Na**I**(Tl), CsI(**Tl**) ⇔ NaI(**Tl**)

TOWARD ANOMALY FREE DARK MATTER

- A variety of anomalies have pushed forward our thinking about DM - *there are still theoretical possibilities to explain them*
- What results will answer the questions?
- DAMA - KIMS/COUPP on Tl/I; COUPP for Na
- CoGeNT - CDMS?
- What about CoGeNT modulation?
- When you have no idea what you're looking for, anything that makes you think of a new approach is a *good* thing

DAMA->XENON

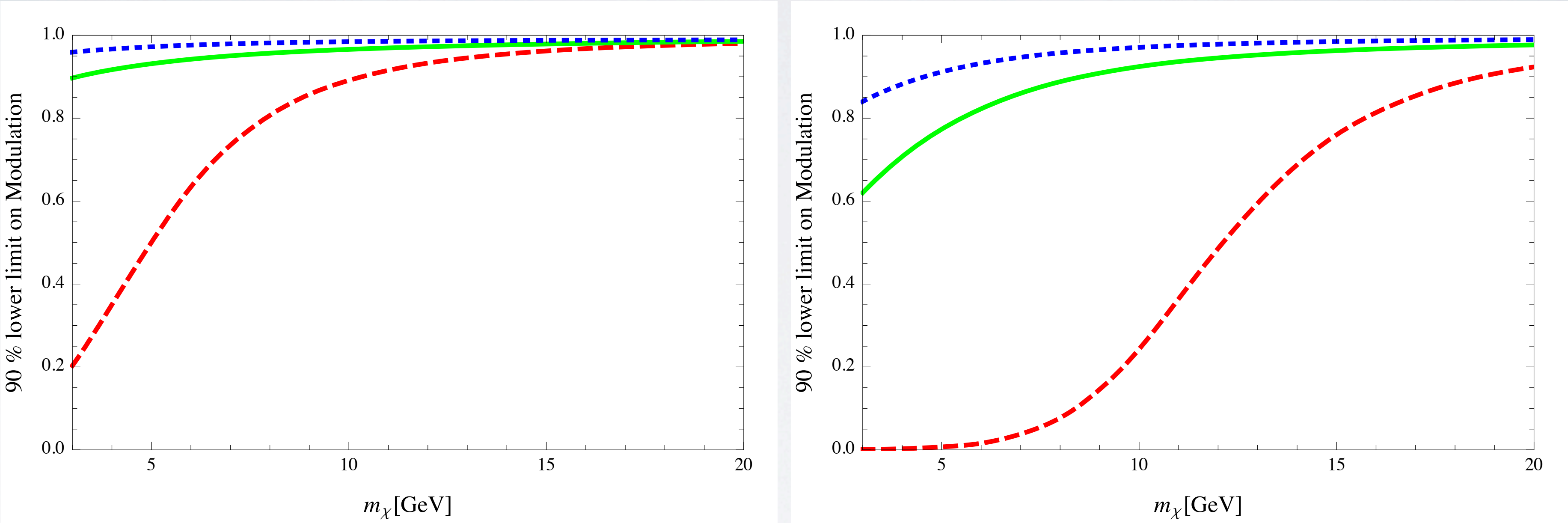


FIG. 6: The 90% C.L. lower limit on the modulation fraction allowed by XENON10 data, for a quench factor in sodium of 0.3 (LH plot) and 0.45 (RH plot) and for 3 cases of $\mathcal{L}_{eff}$, MIN (dashed red), MED (solid green) and MAX (dotted blue).