Theoretical Perspectives on DAMA and other Direct Detection Anomalies

Neal Weiner
CCPP NYU
July 29, 2010

Searching for DM

* Want multiple positive signals from different experiments
* Want to understand null results in consistently within a model

Searching for DM

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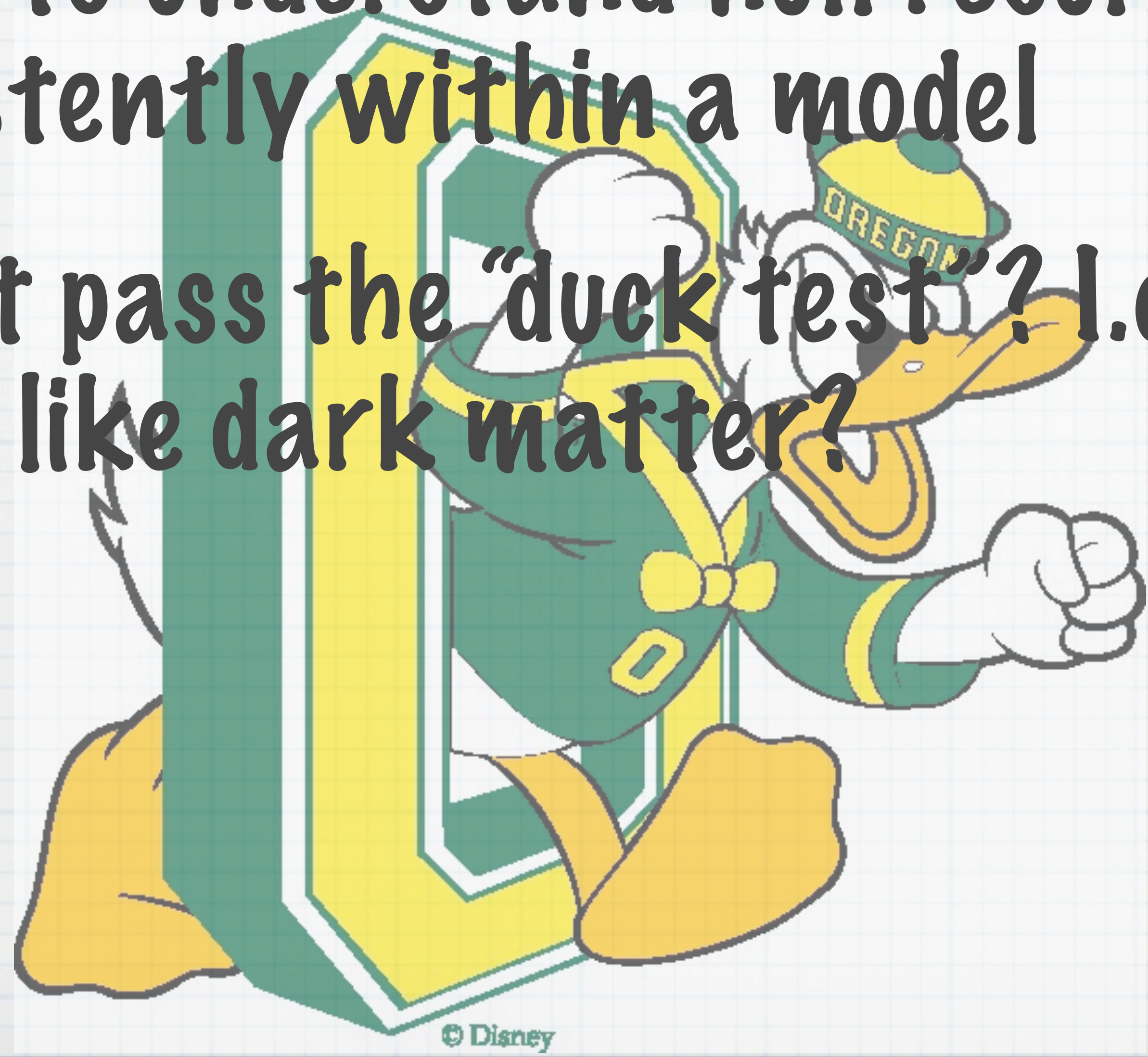
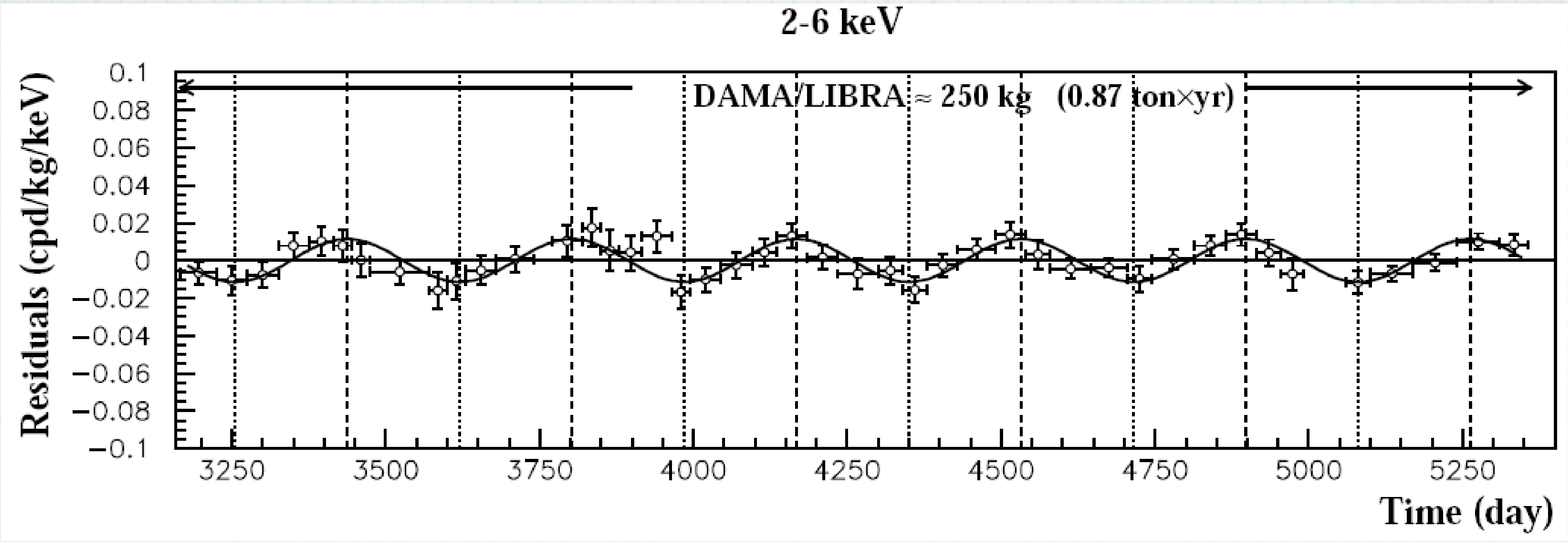
- Want to understand null results in consistently within a model

Searching for DM

* Want multiple positive signals from different experiments
* Want to understand null results in consistently within a model
* Does it pass the "duck test"? I.e., does it quack like dark matter?



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)

Different Directions for DAMA

* light, inelastic, resonant, mirror matter, spin dependent...

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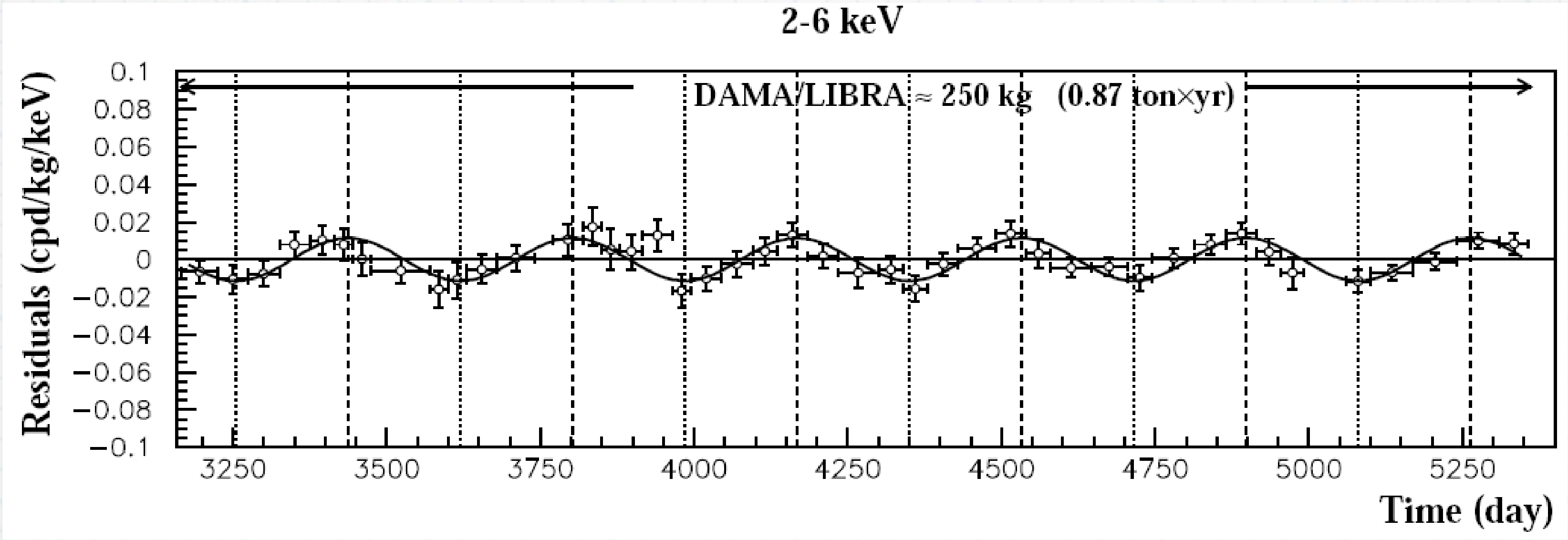
(in this talk)

Light WIMPs?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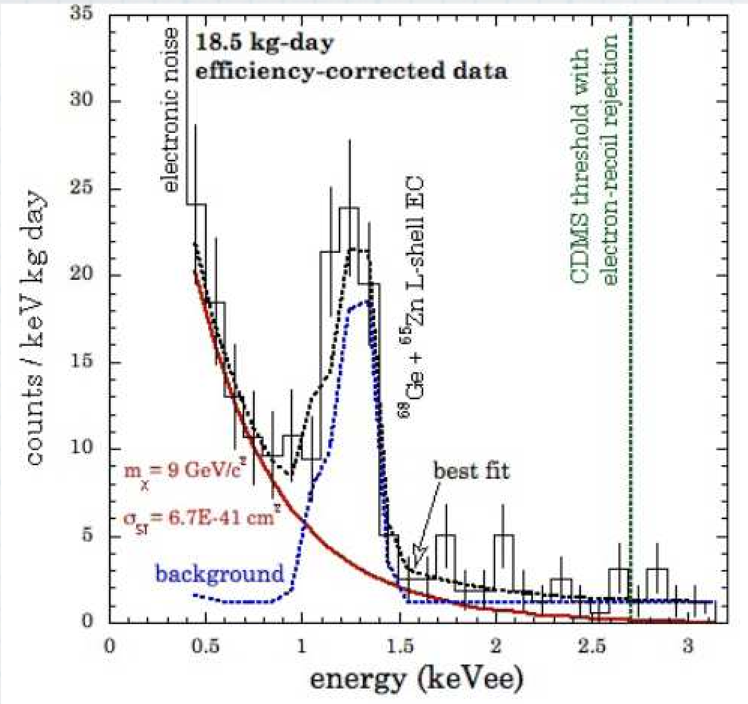
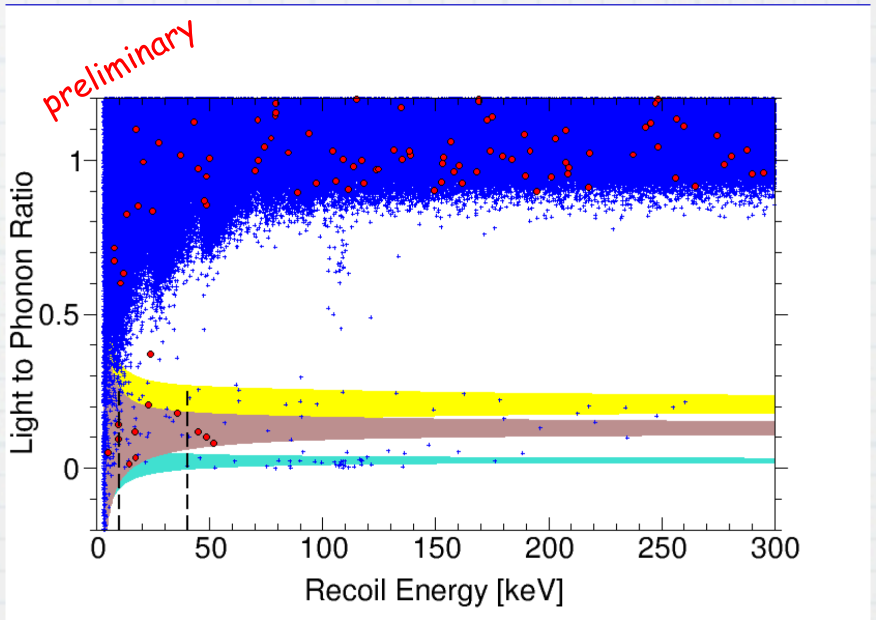
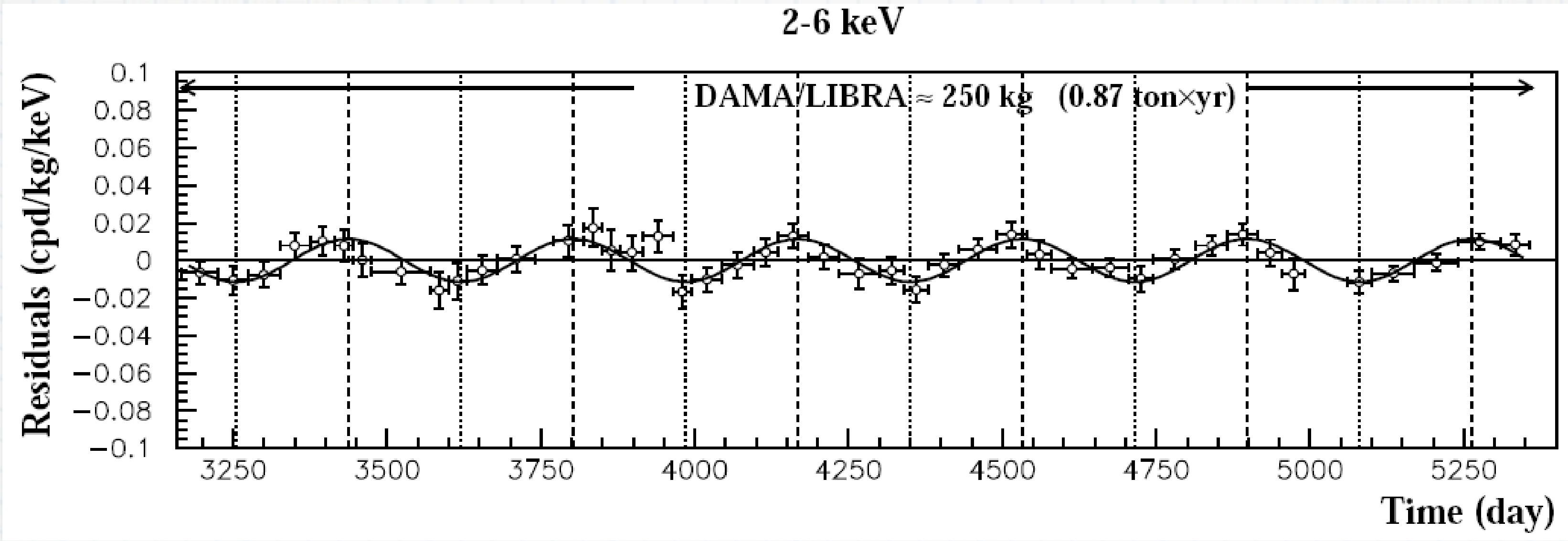
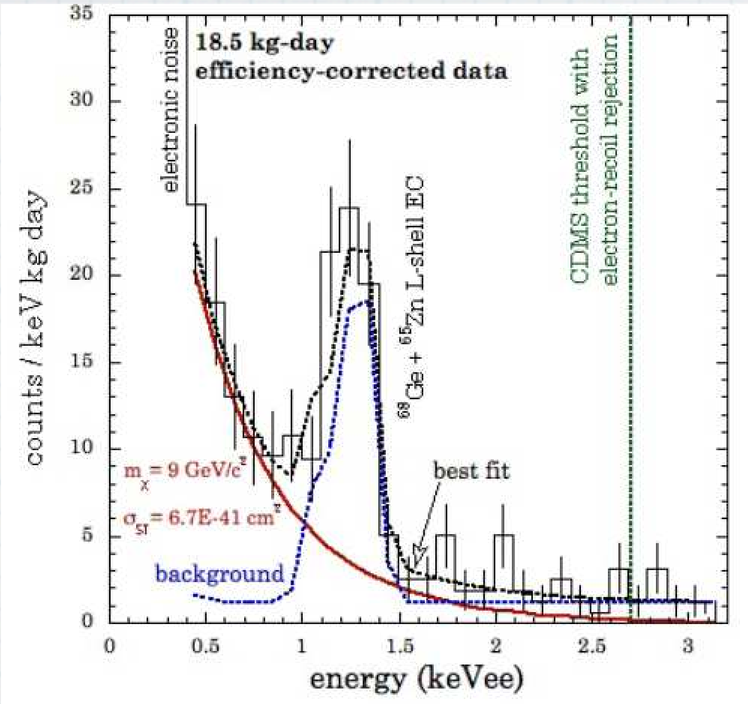

18.5 kg-day
efficiency-corrected data
electronic noise
CDMS threshold with
electron-recoil rejection
68Ge + 65Zn L-shell EC
best fit
background
counts / keV kg day
energy (keVee)

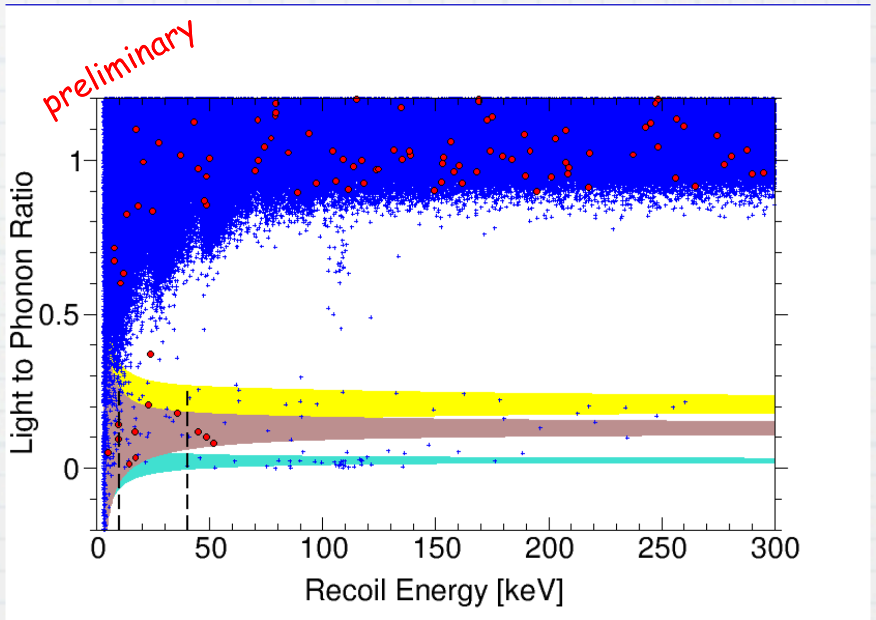

preliminary
Light to Phonon Ratio
Recoil Energy [keV]

Light WIMPs?

quack

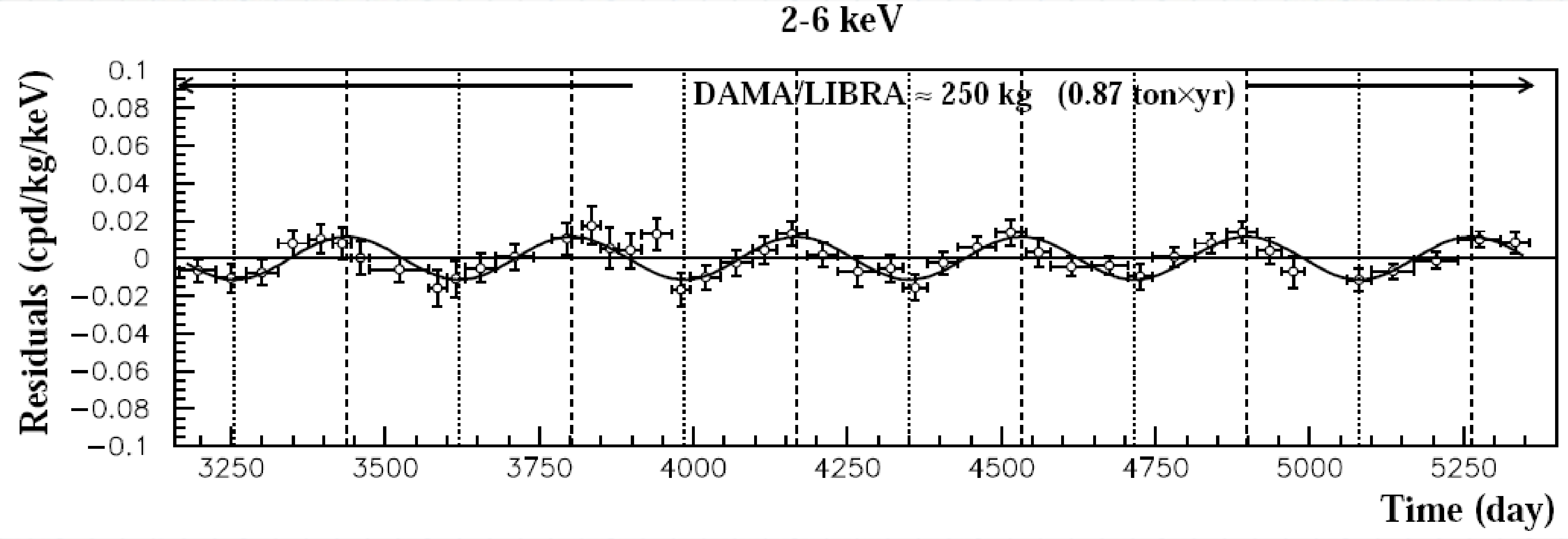


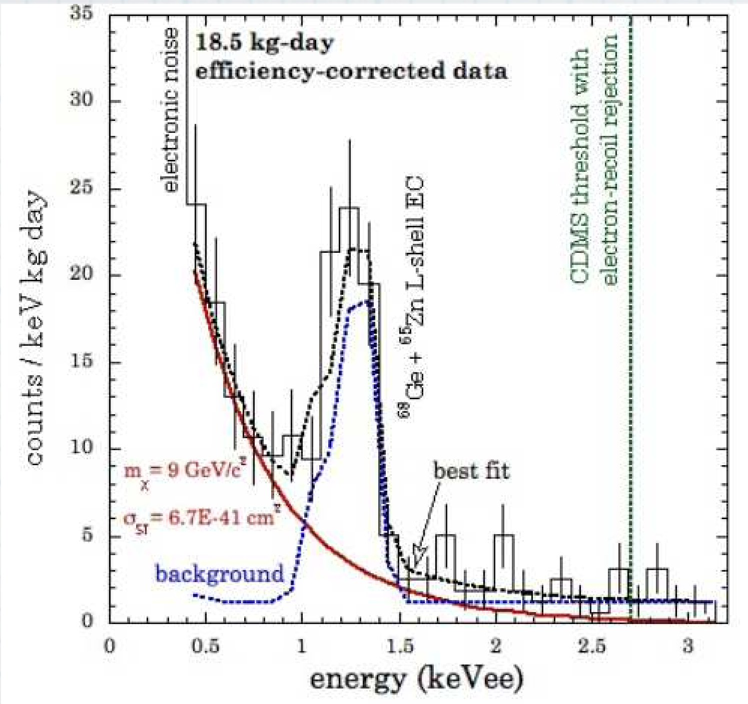


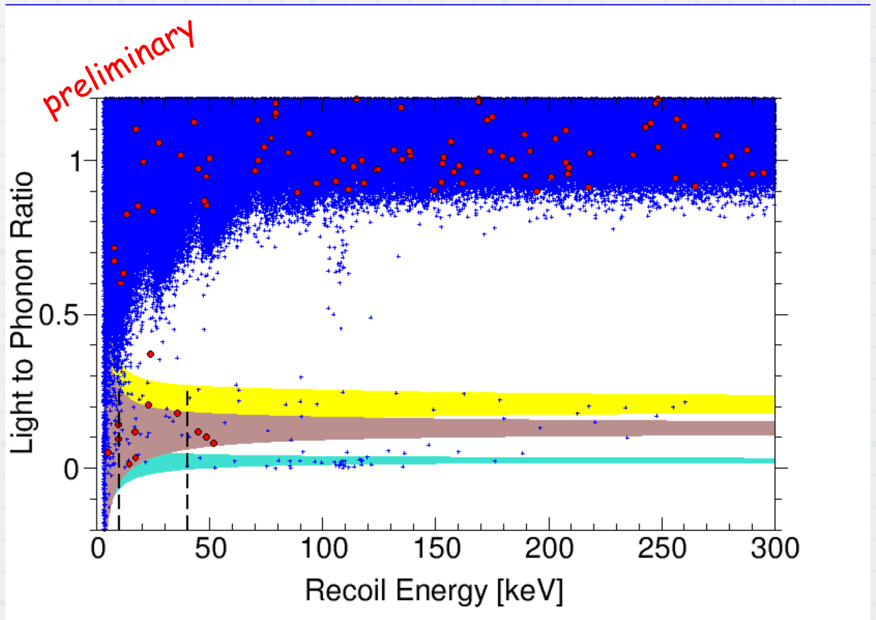


Light WIMPs?

quack



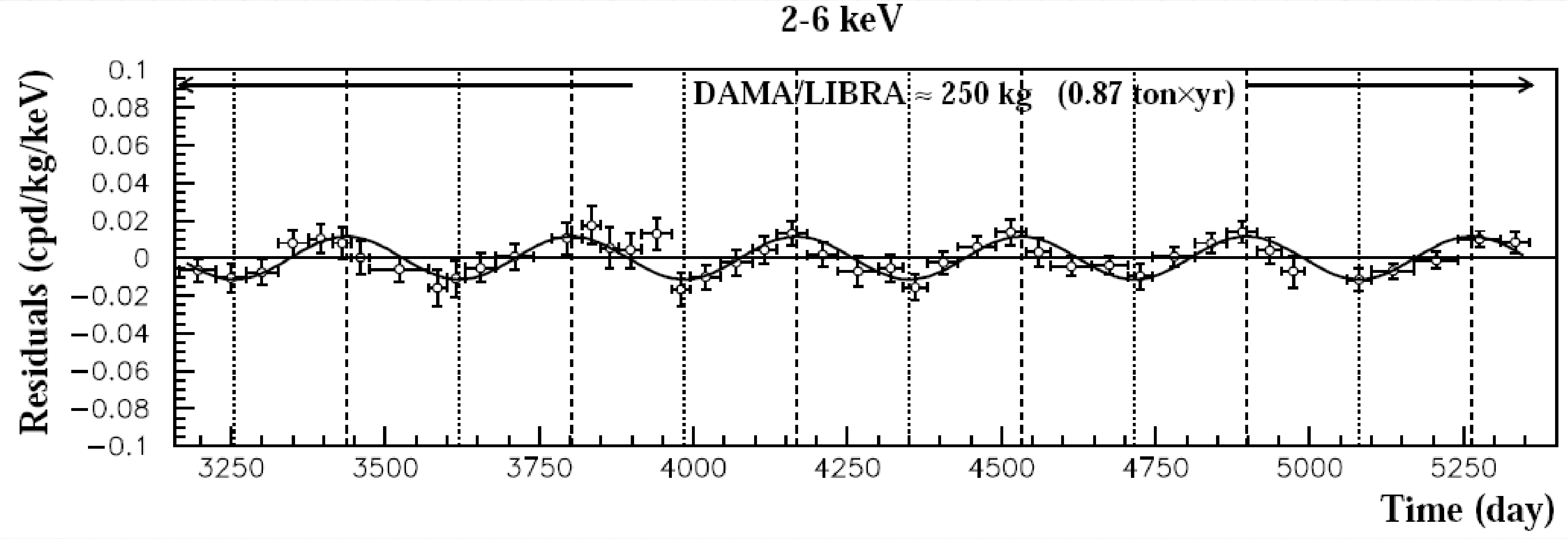


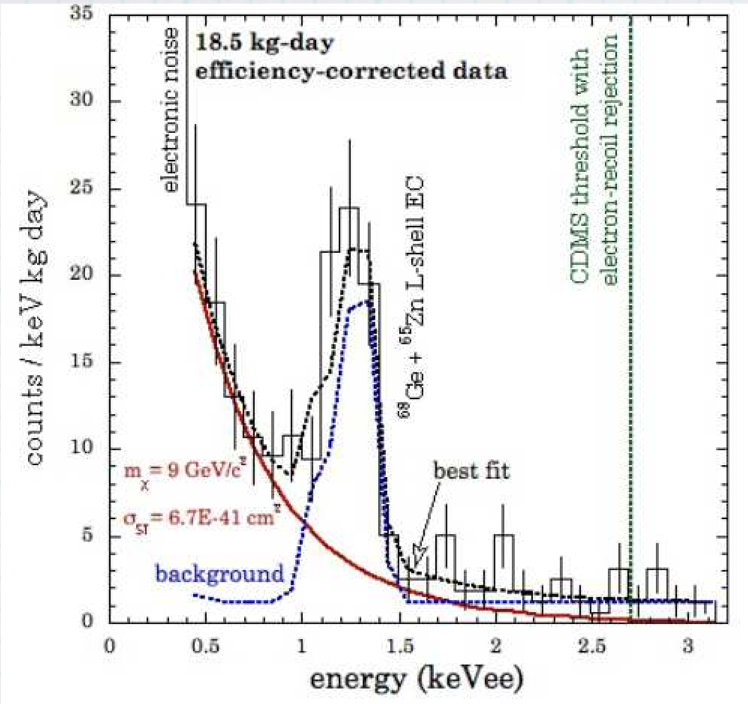


quack

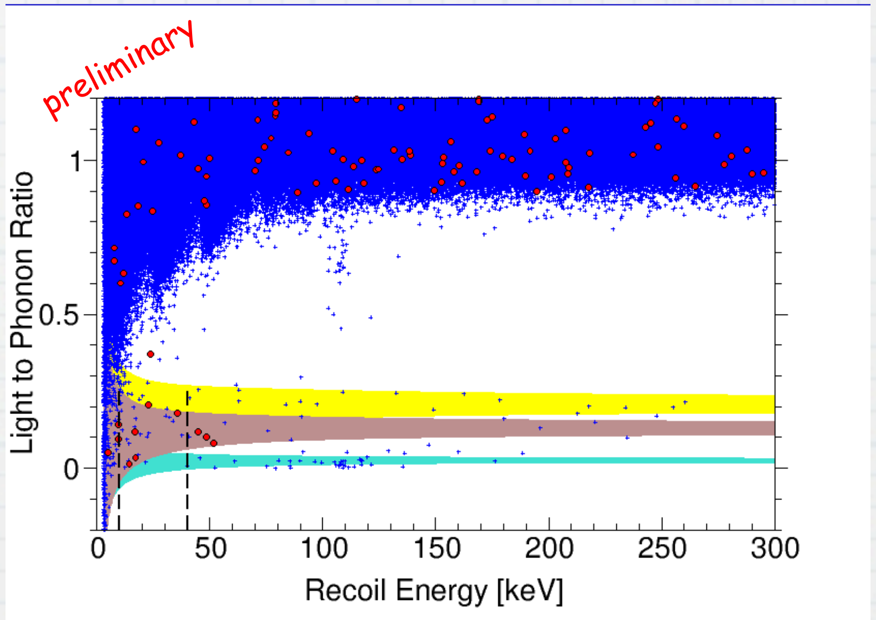
Light WIMPs?

quack





quack



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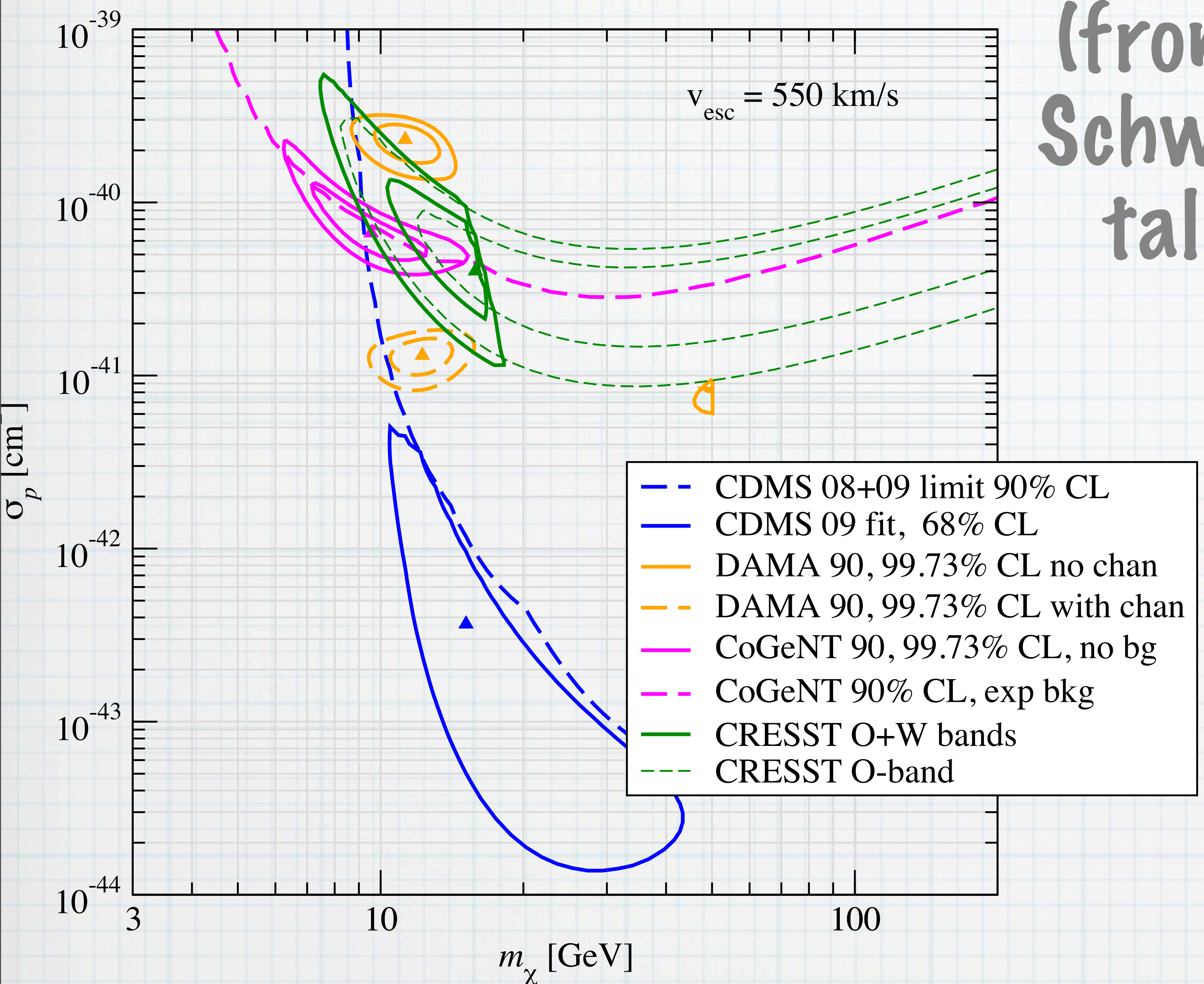
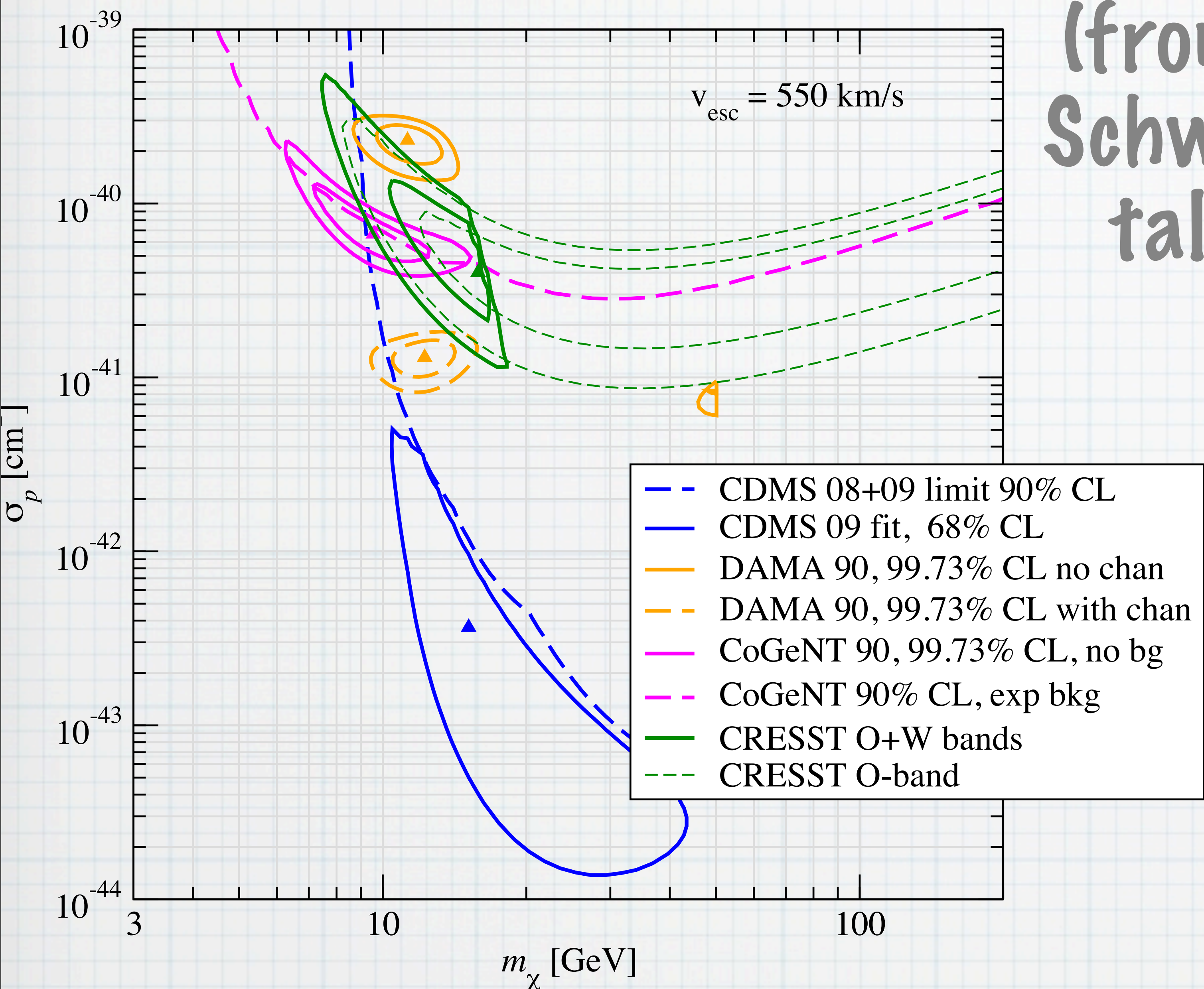


(from T. Schwetz talk)

NB: CRESST region speculative



(from T. Schwetz talk)

NB: CRESST region speculative

Requires non-standard WIMP (not MSSM, anyway)

Light neutralinos with large scattering cross sections in the minimal supersymmetric standard model

Eric Kuflik, Aaron Pierce, and Kathryn M. Zurek

Michigan Center for Theoretical Physics, University of Michigan, Ann Arbor, MI 48109

(Dated: July 20, 2010)

Motivated by recent data from CoGeNT and the DAMA annual modulation signal, we discuss collider constraints on minimal supersymmetric standard model neutralino dark matter with mass in the 5-15 GeV range. The lightest superpartner (LSP) would be a bino with a small Higgsino admixture. Maximization of the dark matter-nucleon scattering cross section for such a weakly interacting massive particle requires a light Higgs boson with $\tan\beta$ enhanced couplings. Limits on the invisible width of the Z boson, combined with the rare decays $B^\pm \to \tau\nu$, and the ratio $B \to D\tau\nu/B \to D\ell\nu$, constrain cross sections to be below $\sigma_n \lesssim 5 \times 10^{-42}$ cm^2. This indicates a higher local Dark Matter density than is usually assumed by a factor of roughly six would be necessary to explain the CoGeNT excess. This scenario also requires a light charged Higgs boson, which can give substantial contributions to rare decays such as $b \to s\gamma$ and $t \to bH^+$. We also discuss the impact of Tevatron searches for Higgs bosons at large $\tan\beta$.

Tensions?

What's "ruled out"?

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* Exclusion limits = Air travel

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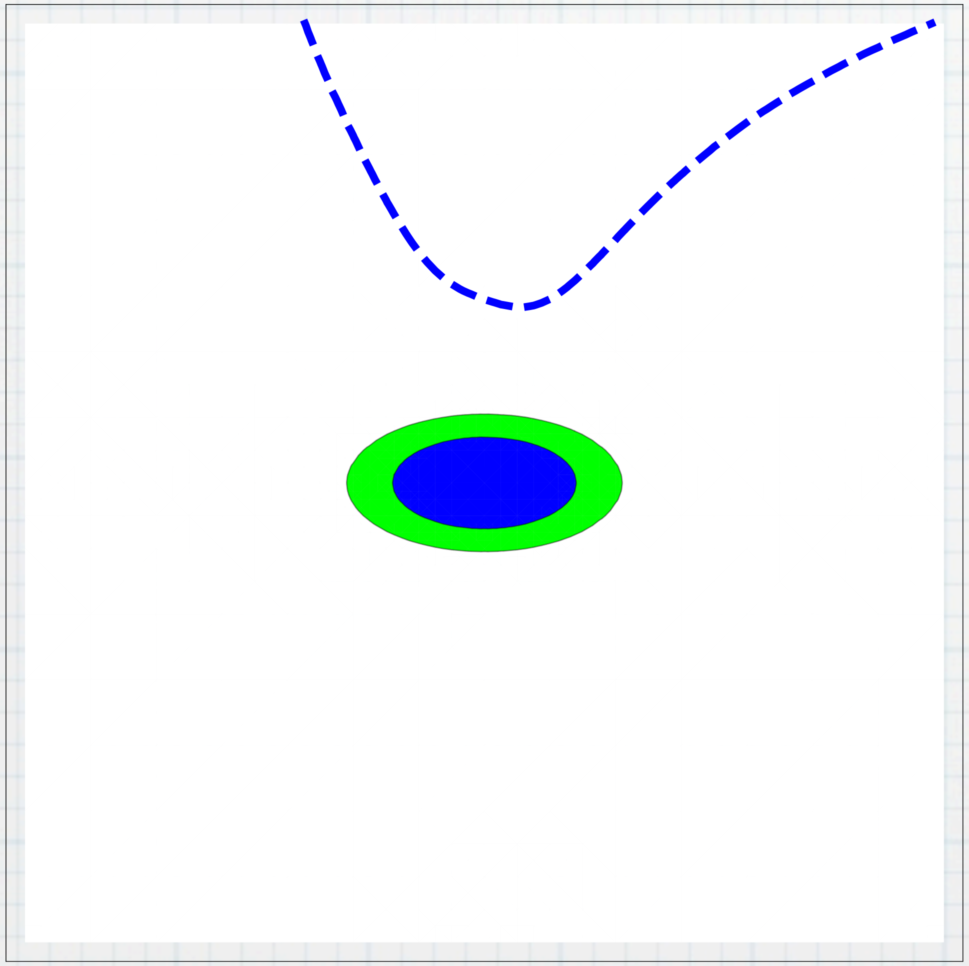
No limit

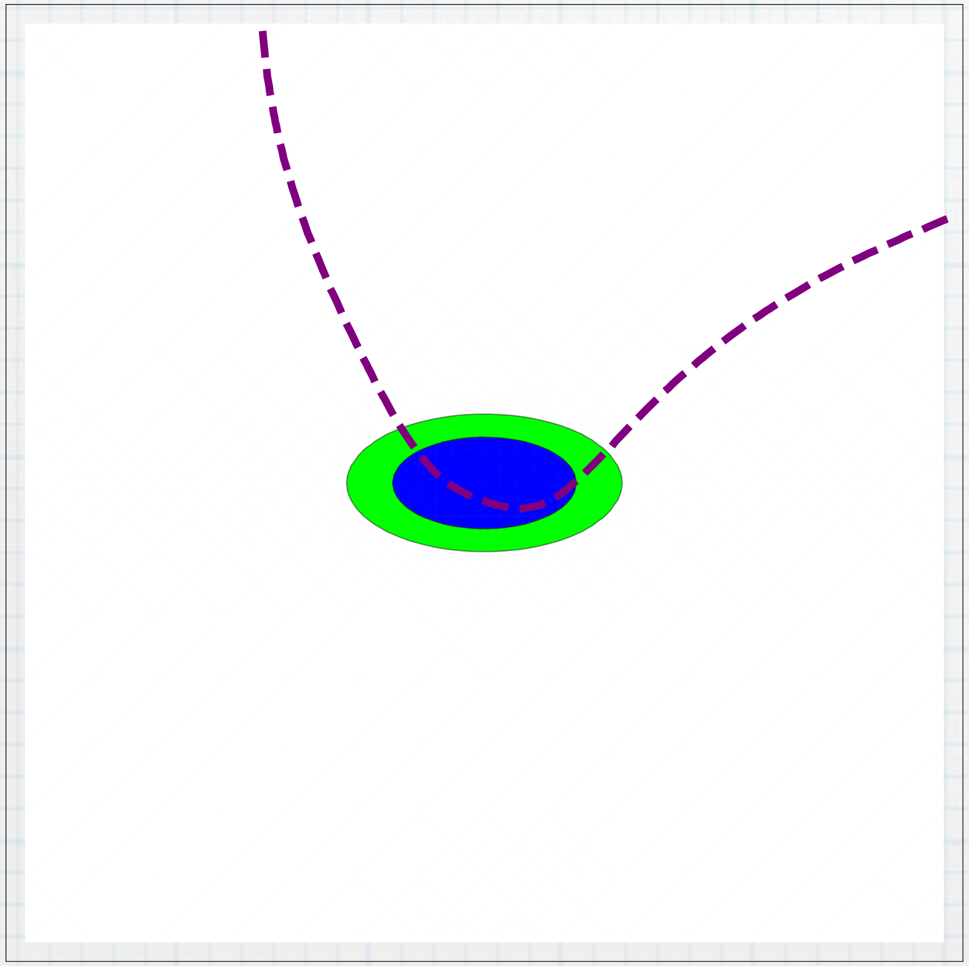


Relaxed, comfortable, where you want to be
(absent positive data)

What's "ruled out"?

* Exclusion limits = Air travel

O(1)

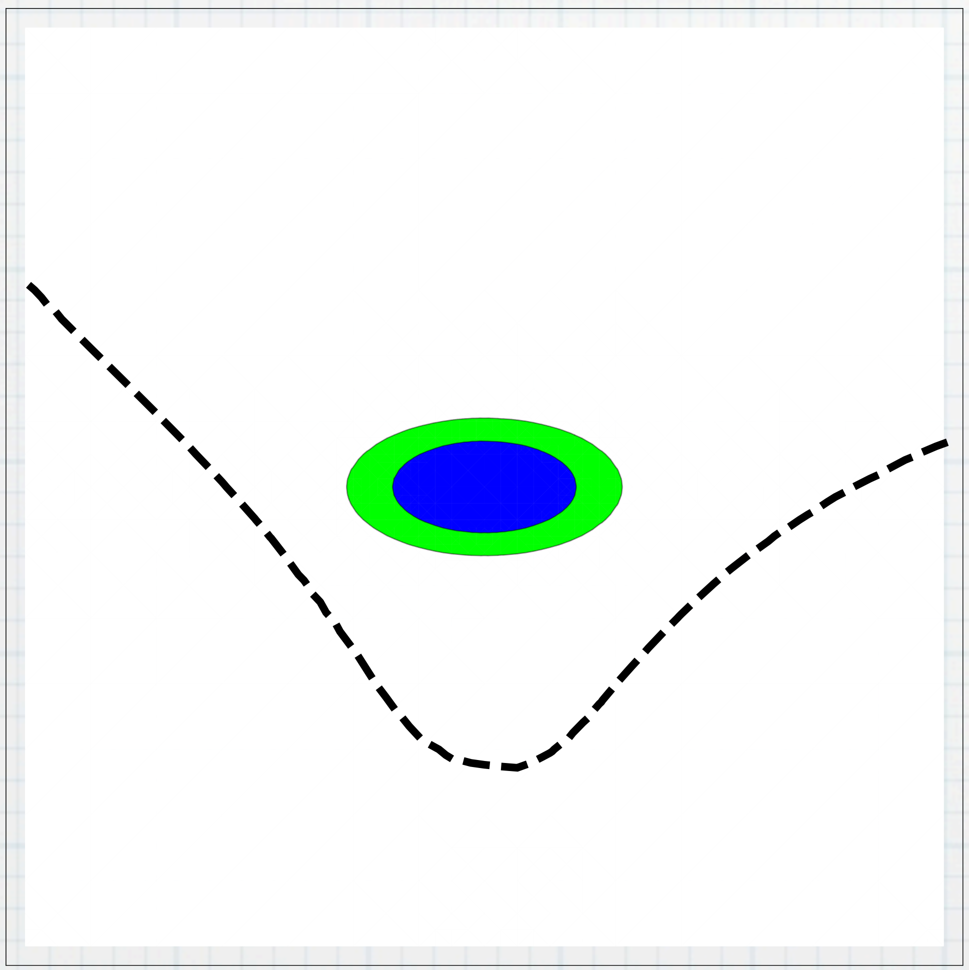


Not so bad, all things considered, but you'd like to see something

What's "ruled out"?

* Exclusion limits = Air travel

O(5-10)

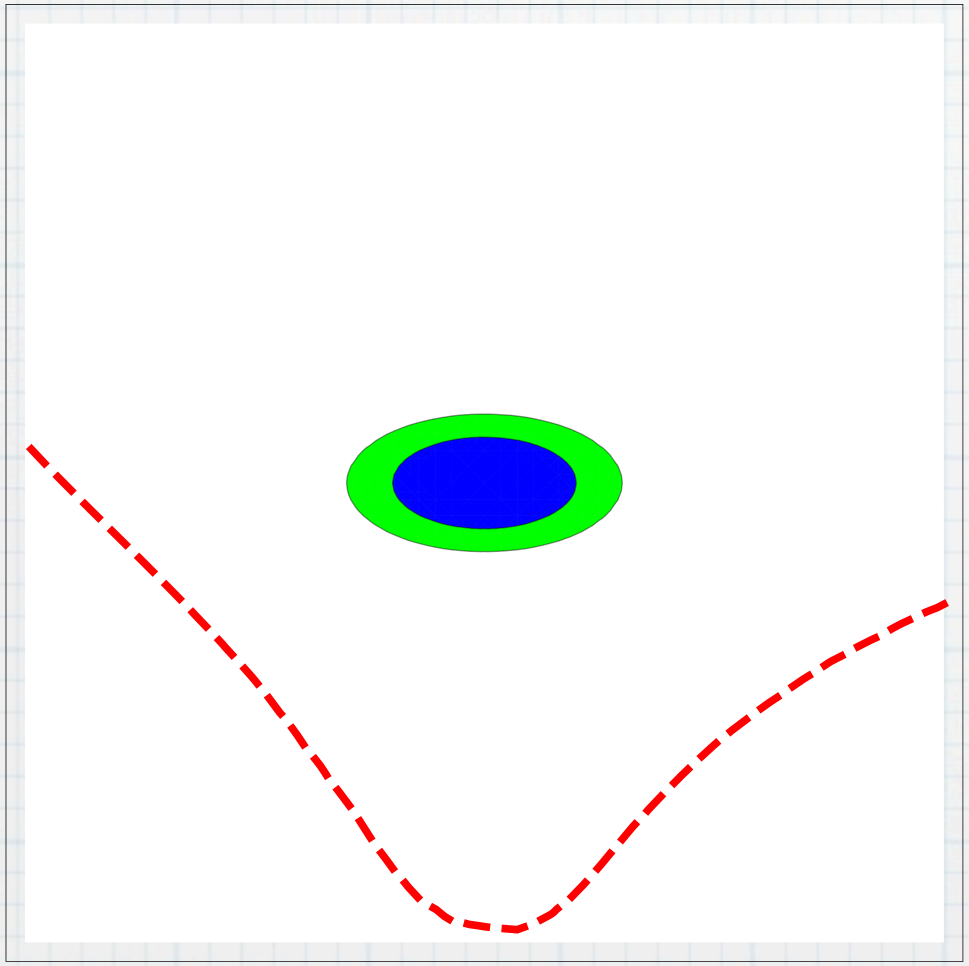


Smiling, making the best of things, but you're pretty uncomfortable

What's "ruled out"?

* Exclusion limits = Air travel

O(10+)



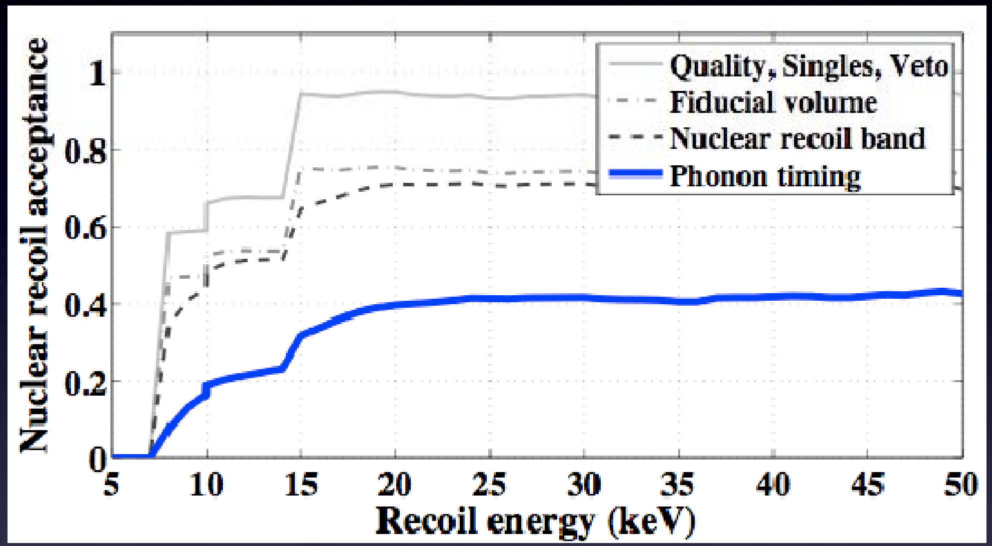
Consideration of the model leads to major discomfort

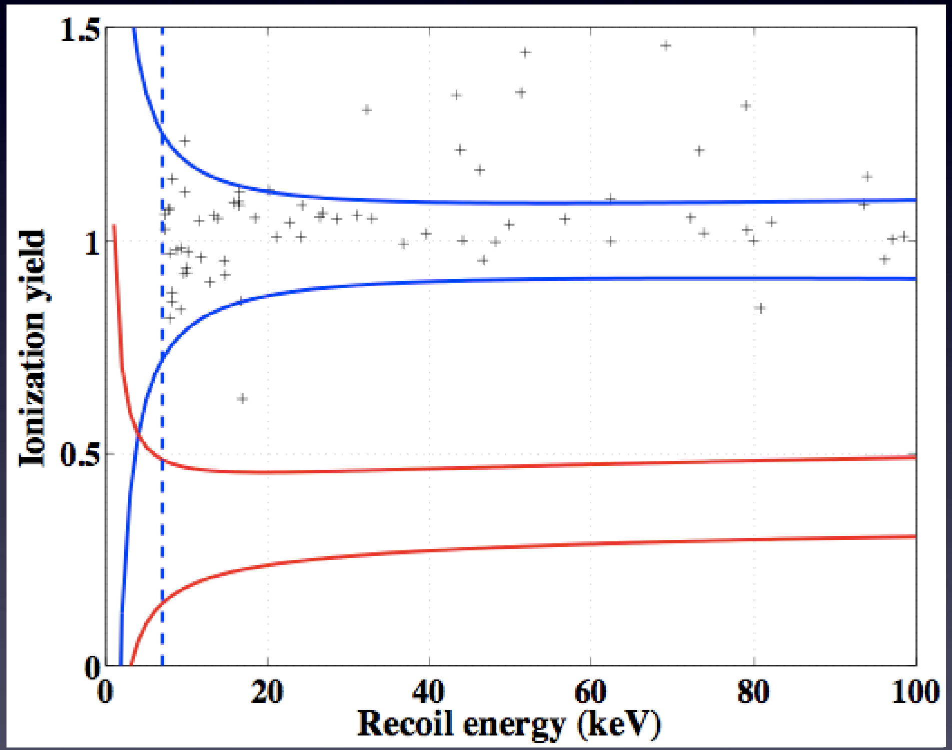
So where are we?

Si ZIP Analysis

Box opened **December 3, 2008,** for **6 inner Si ZIPs**

(Remaining 2 Si at Tower ends dropped for poor background)





53.5 raw kg-d Si

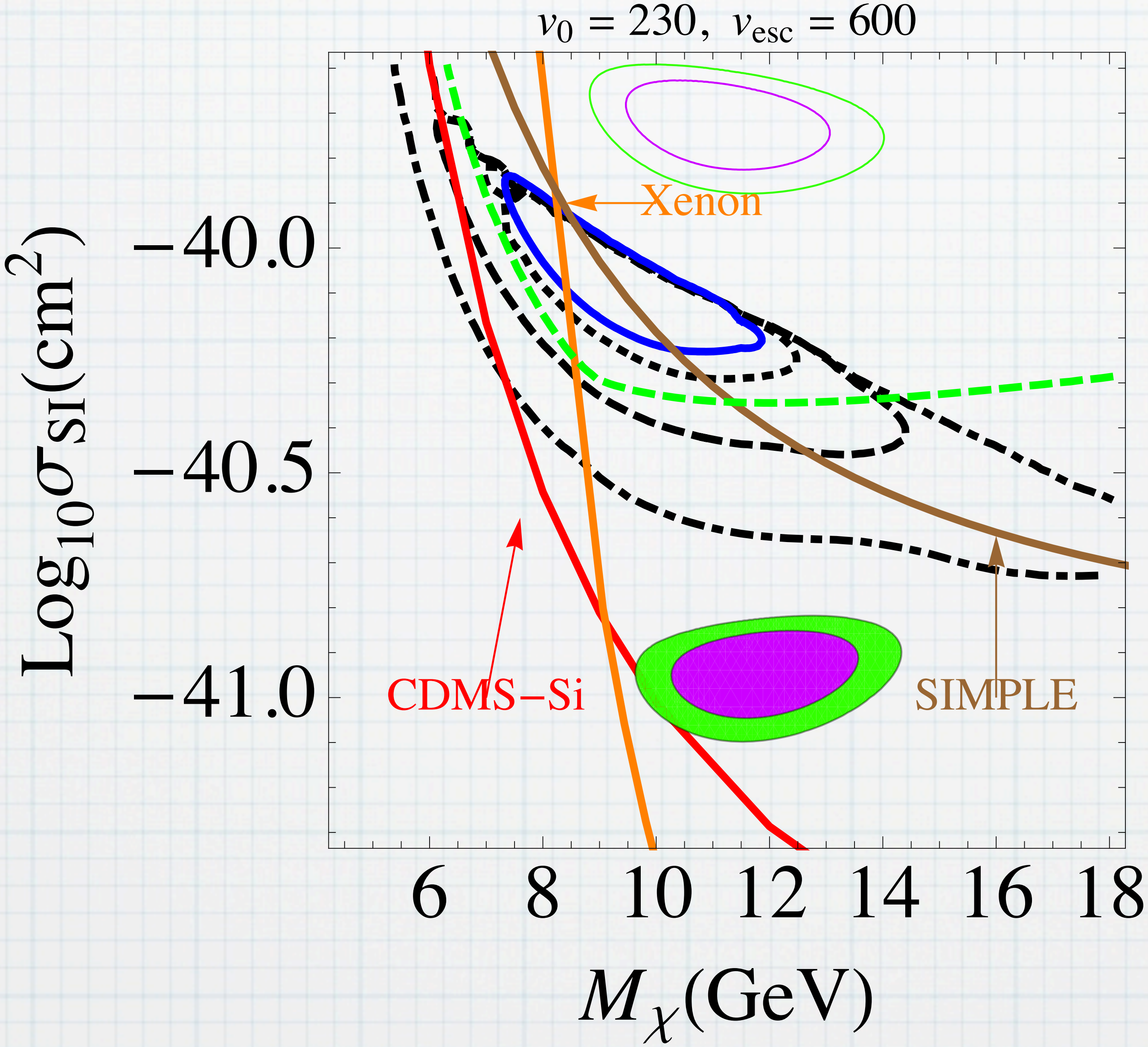
17.9 kg-d WIMP equiv. @ 60 GeV/c^2

Surface background

$1.1^{+0.9}_{-0.6}(stat.) \pm 0.1(syst.)$

No events observed

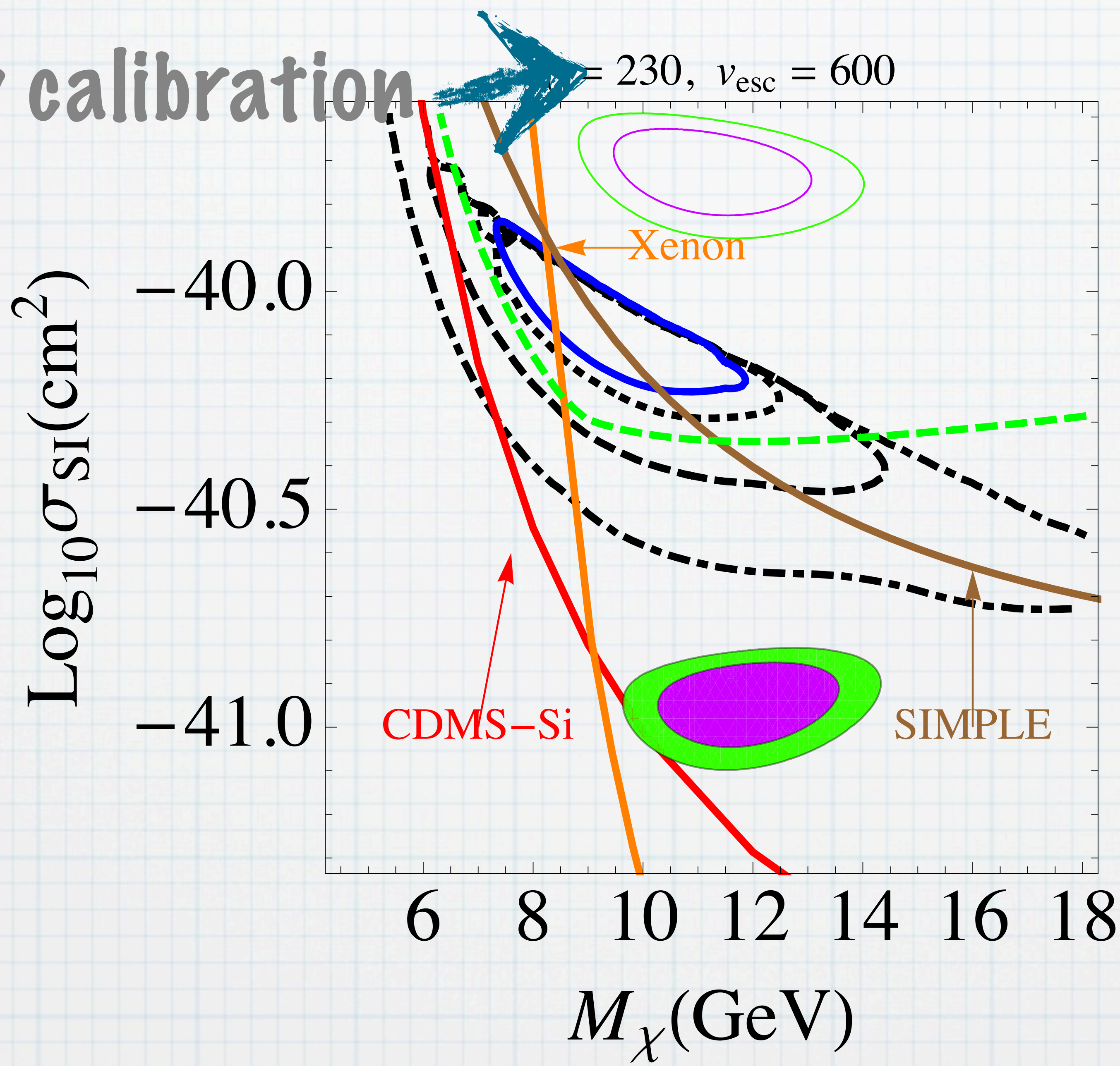
Energy threshold



Waiting for blessed CDMS analysis

Energy threshold

energy calibration

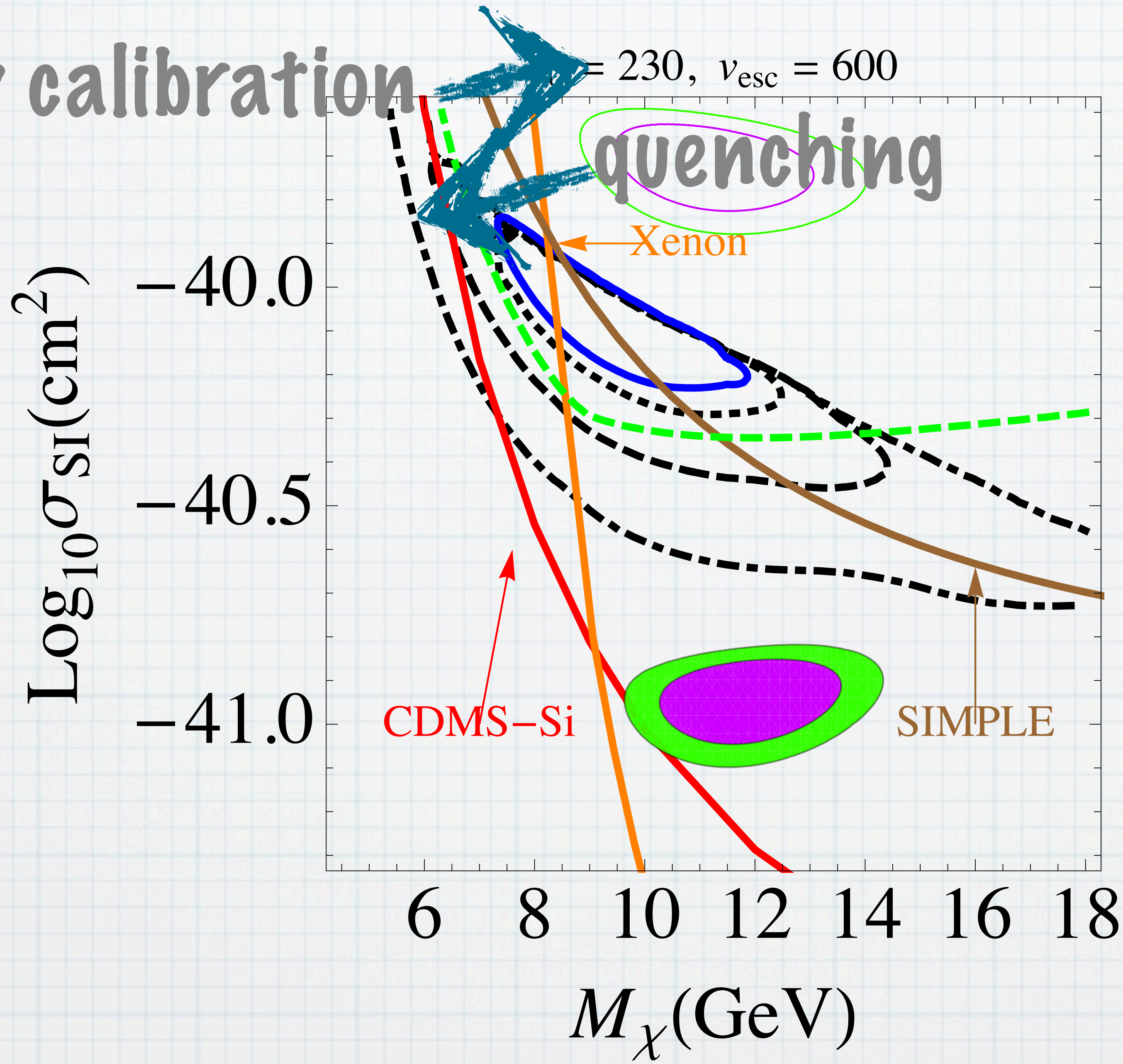


Waiting for blessed CDMS analysis

Energy threshold

energy calibration

quenching



Waiting for blessed CDMS analysis

Energy threshold

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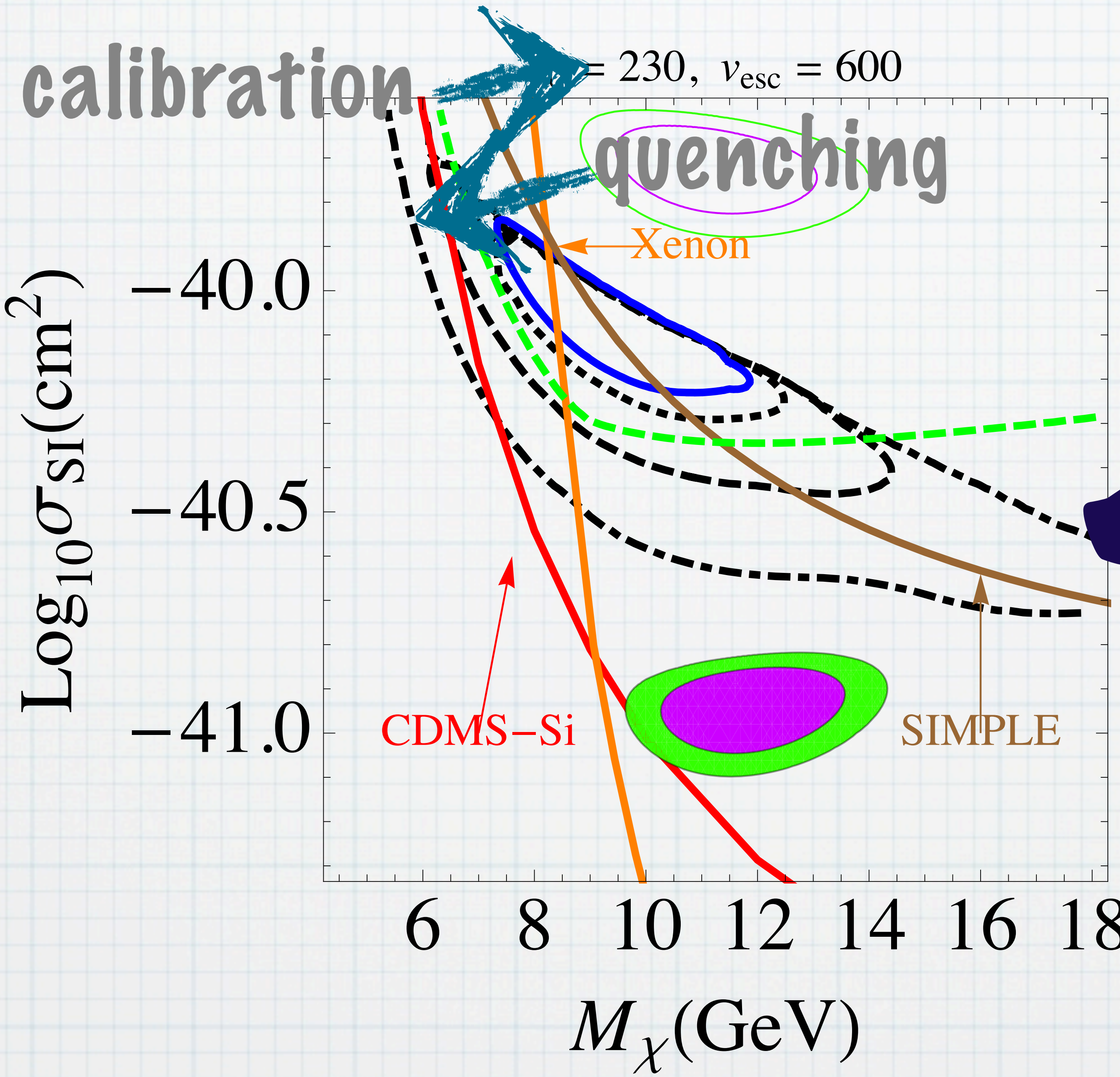

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Energy threshold

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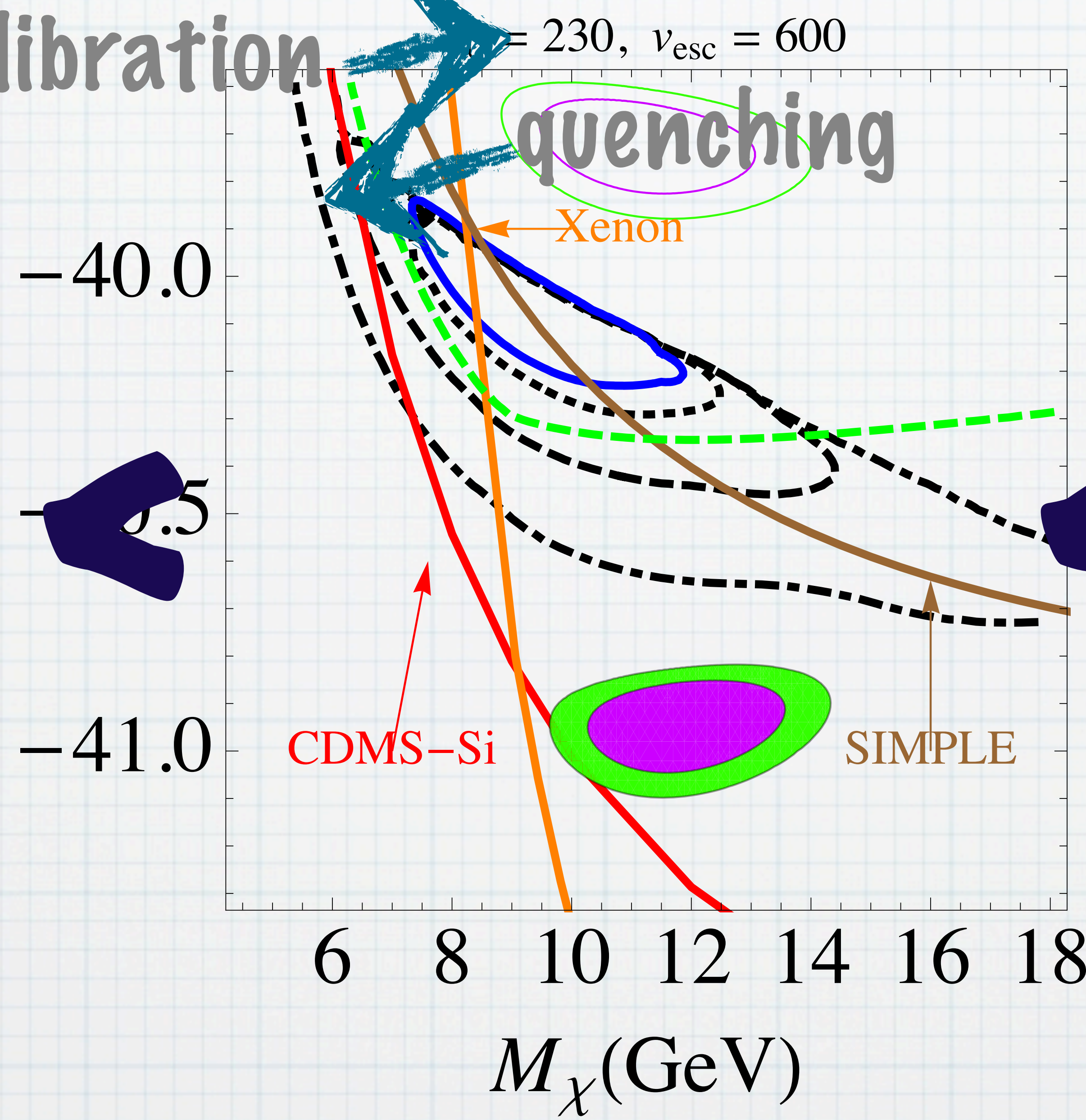
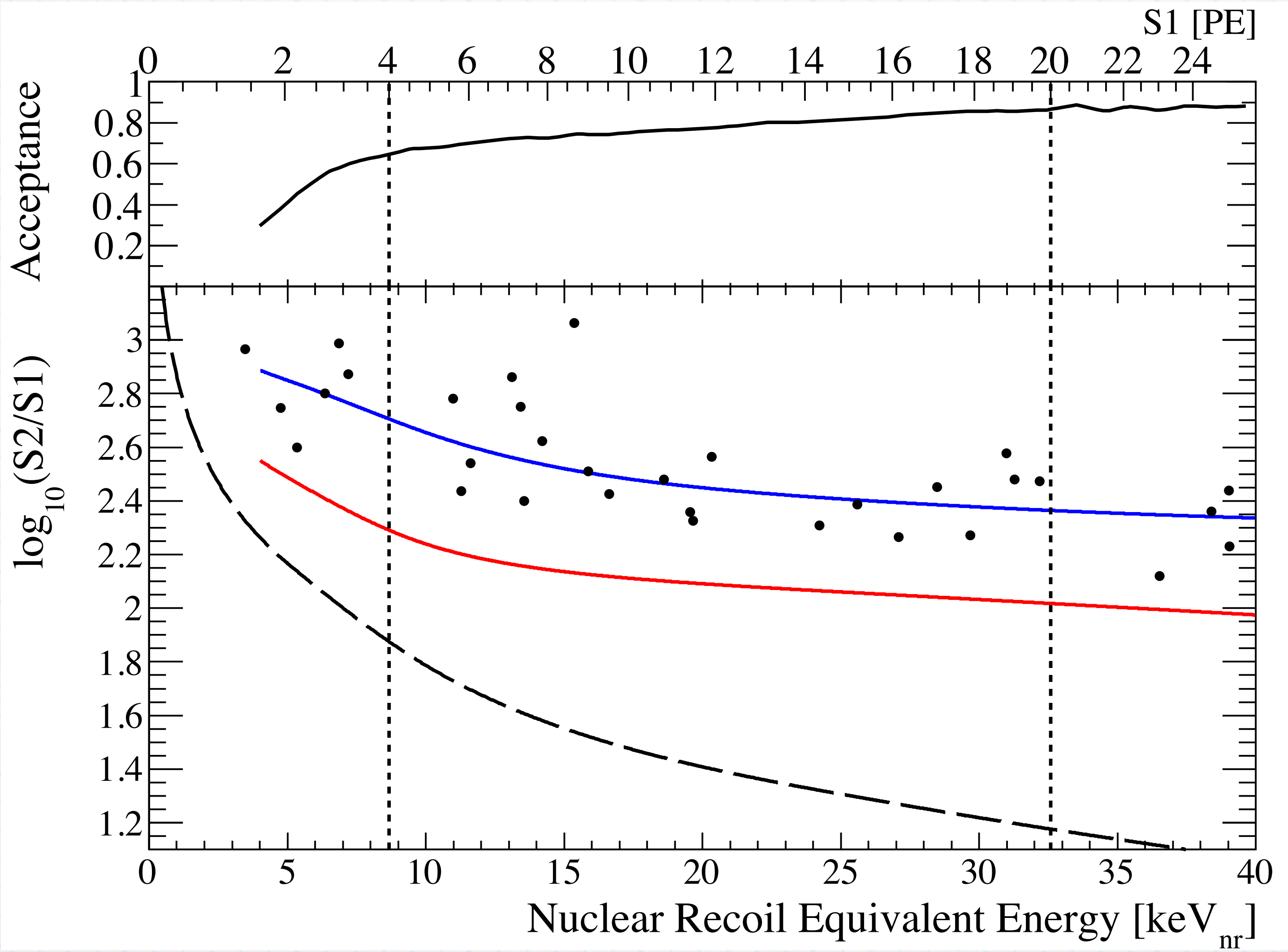
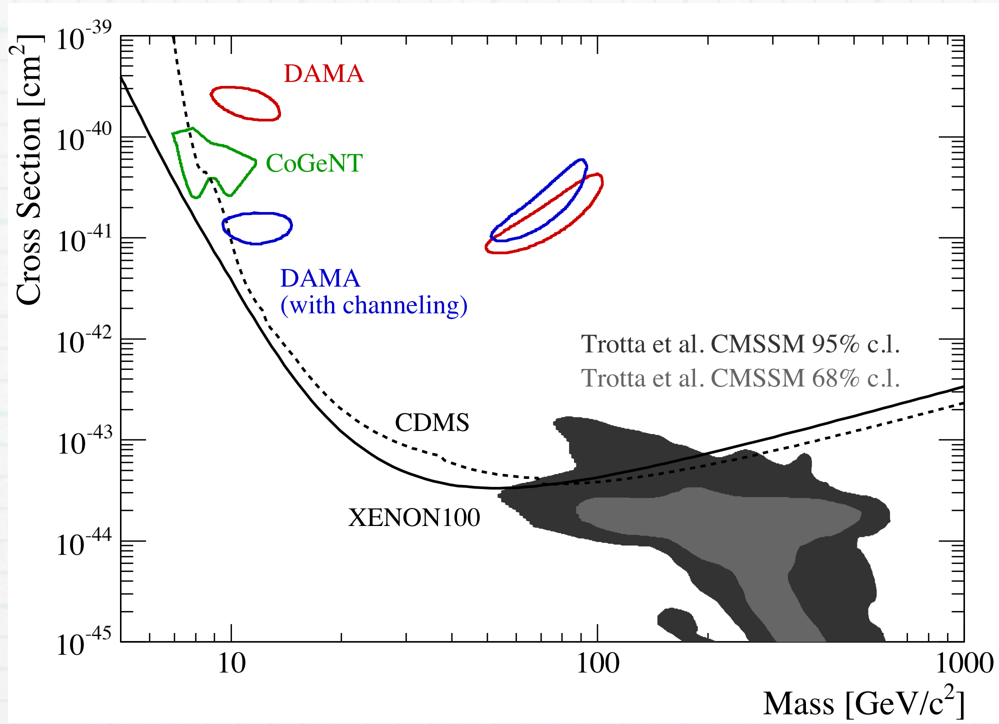


Waiting for blessed CDMS analysis

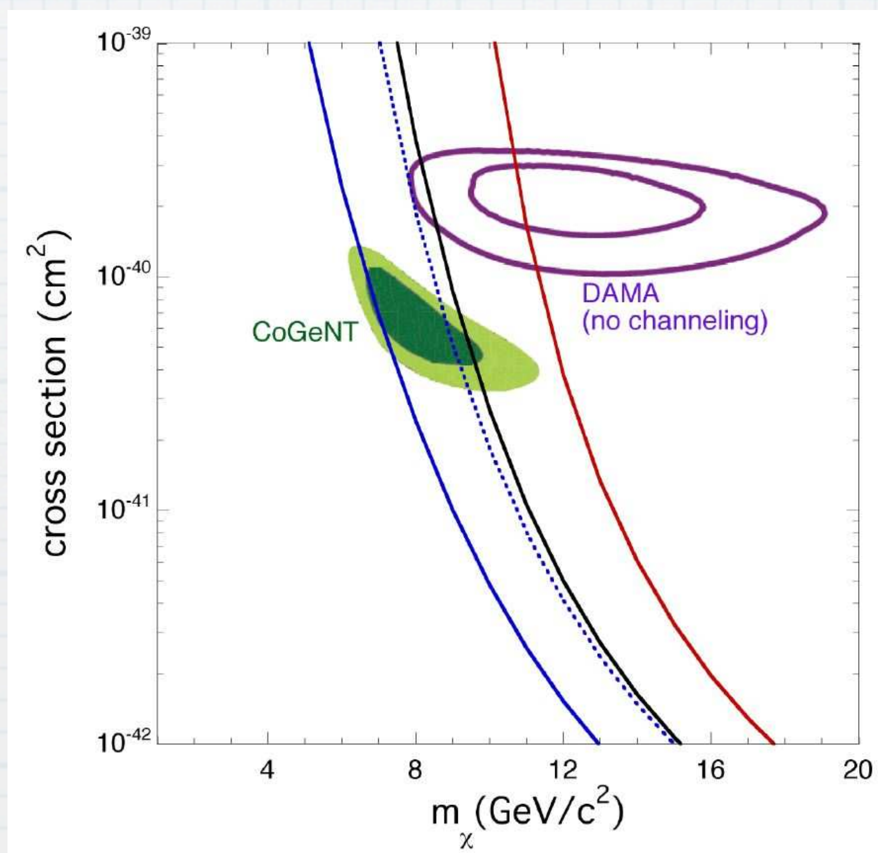
XENON limits



XENON limits

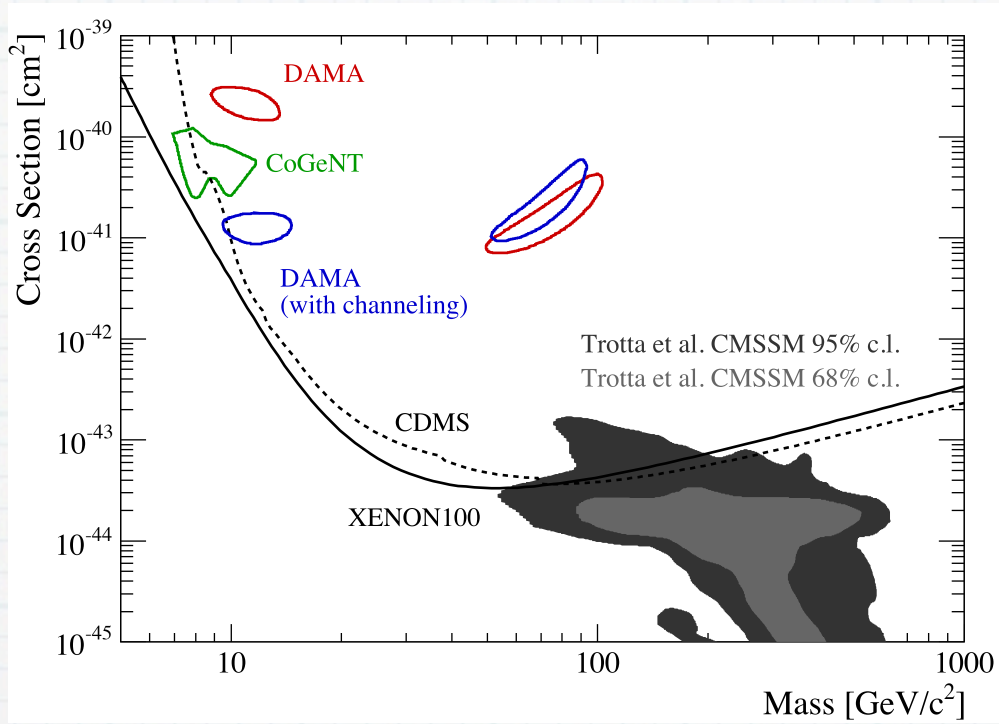


XENON collaboration



Collar et al

XENON limits



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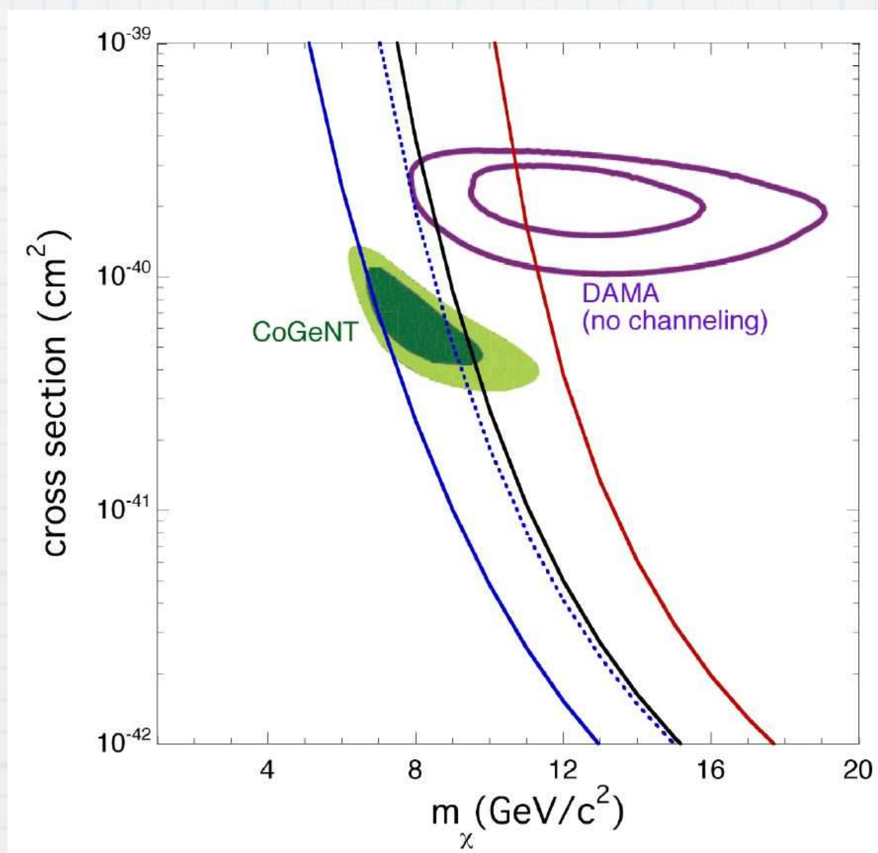

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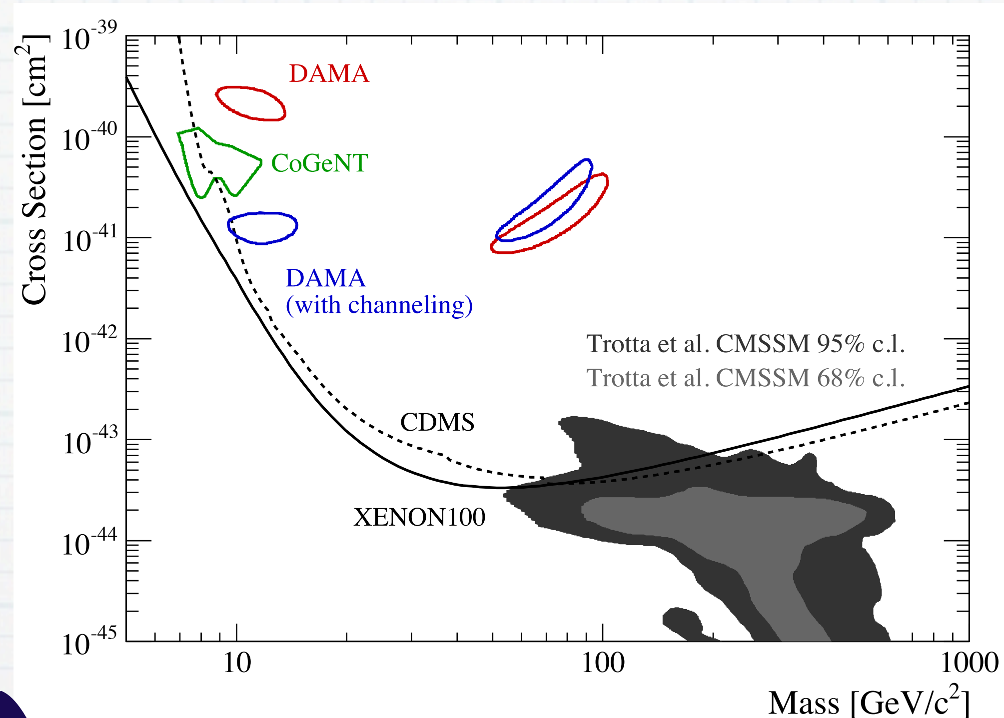
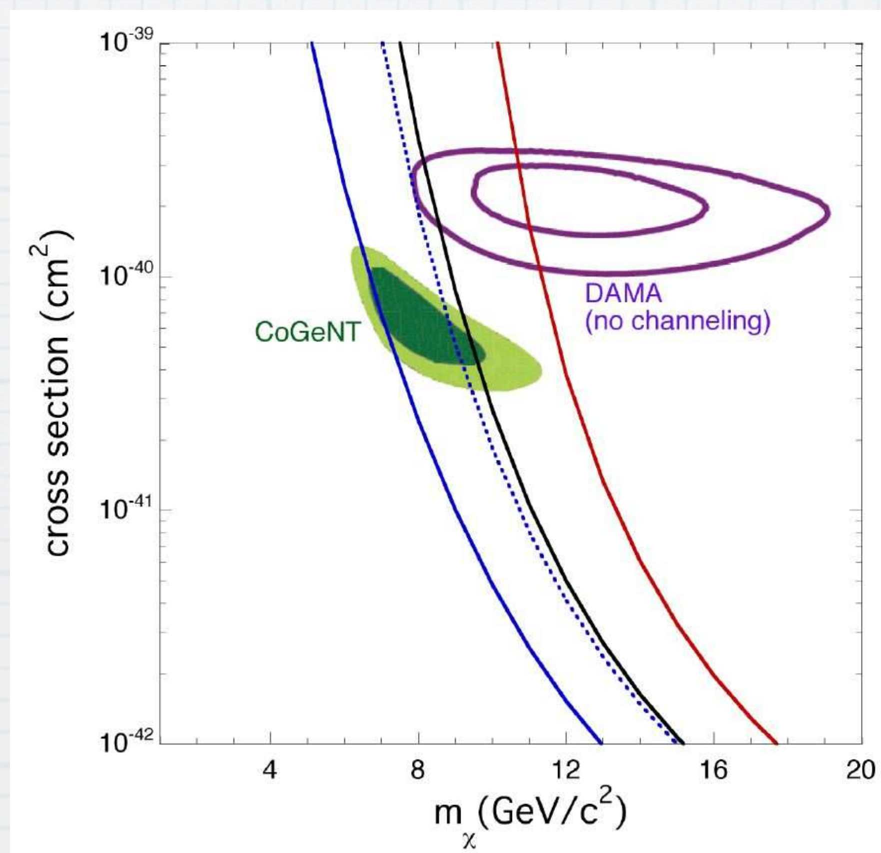
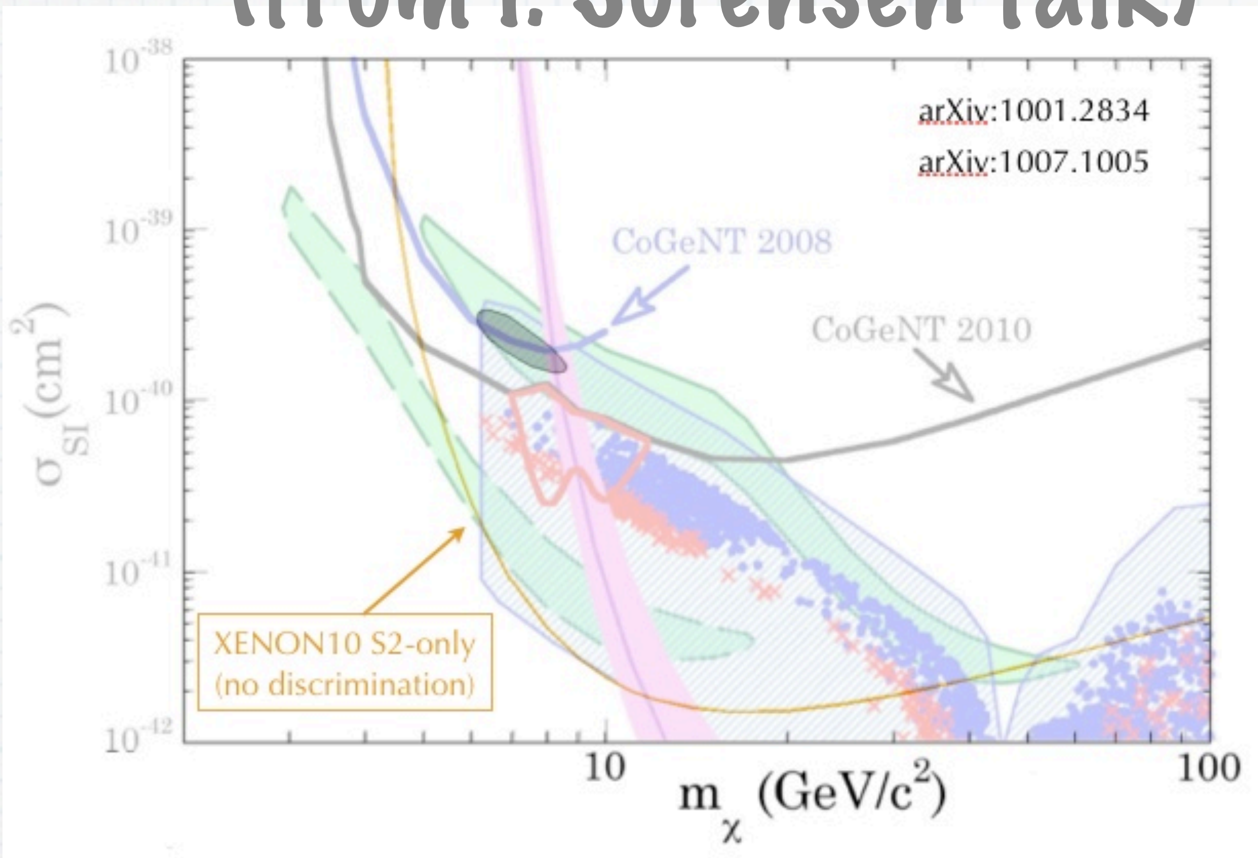


XENON collaboration

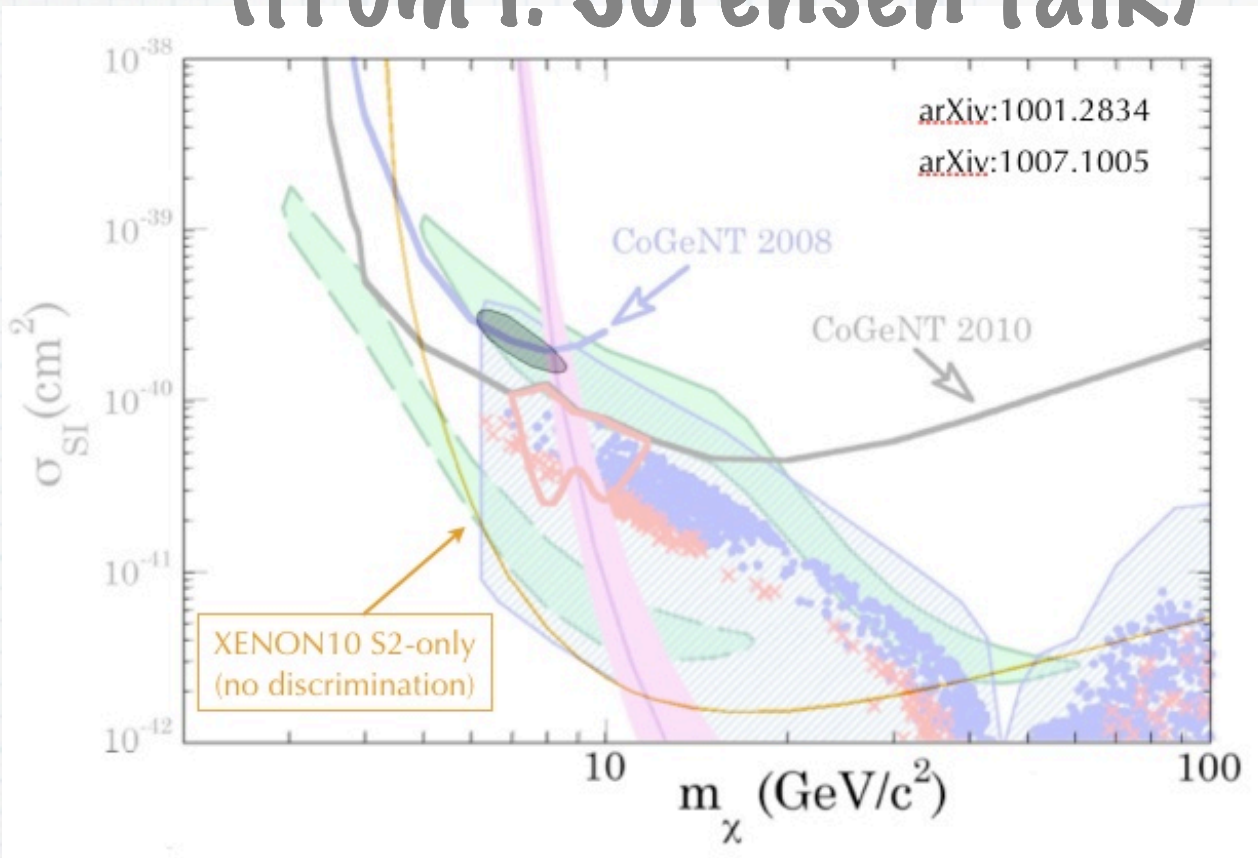


Collar et al

S2 only
(from P. Sorensen talk)



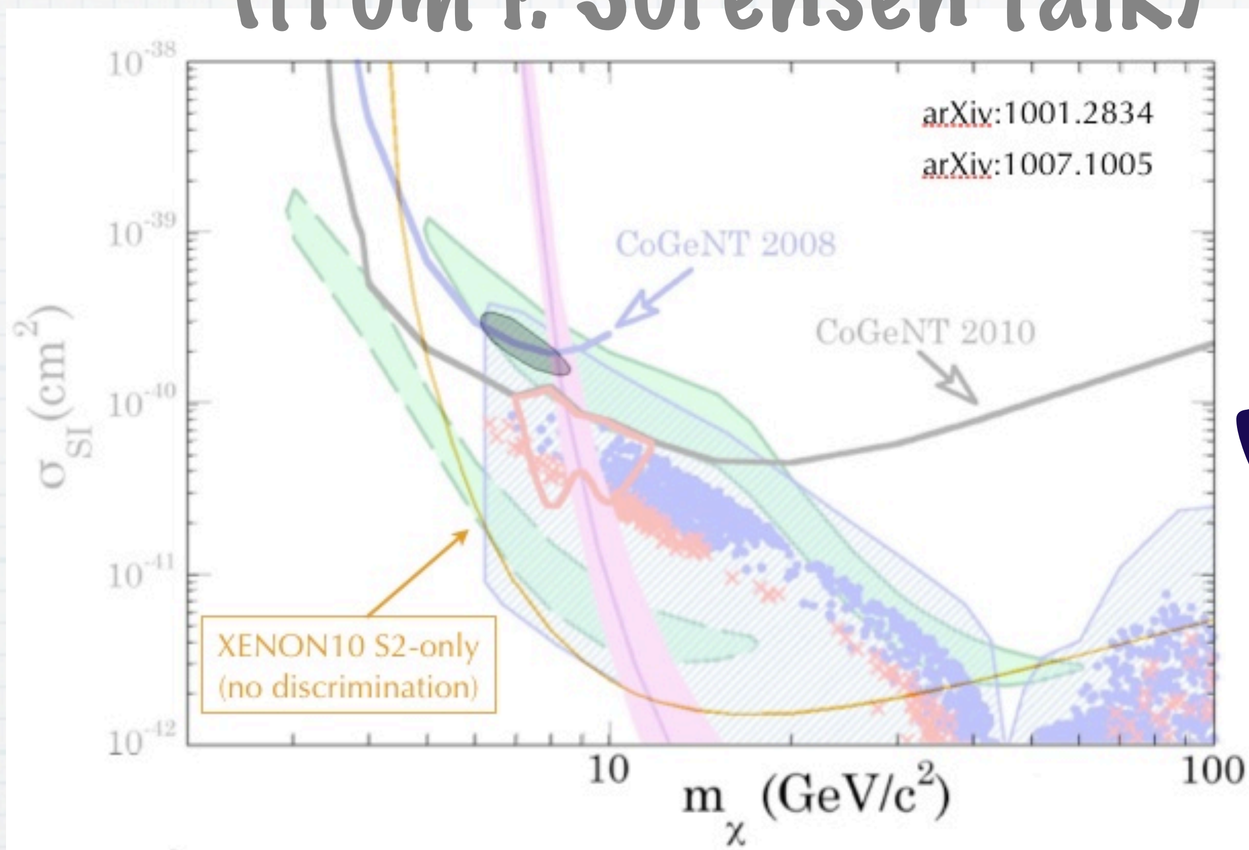
S2 only
(from P. Sorensen talk)



?

S2 only

(from P. Sorensen talk)



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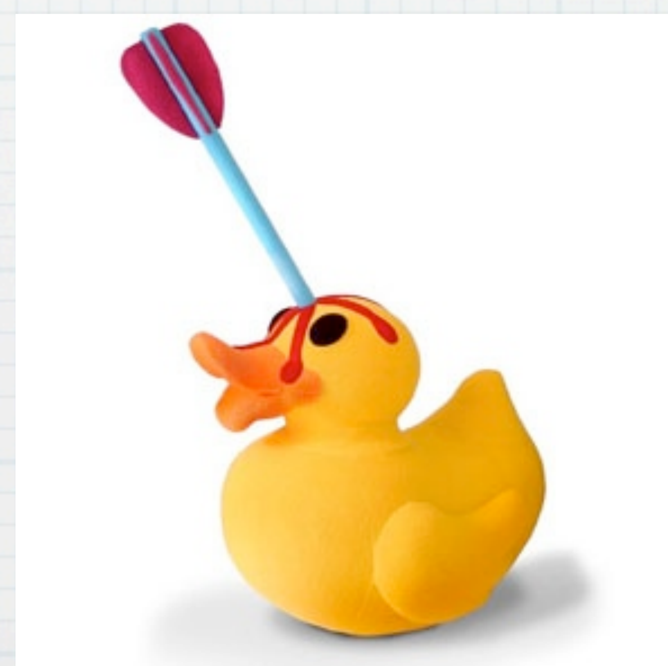

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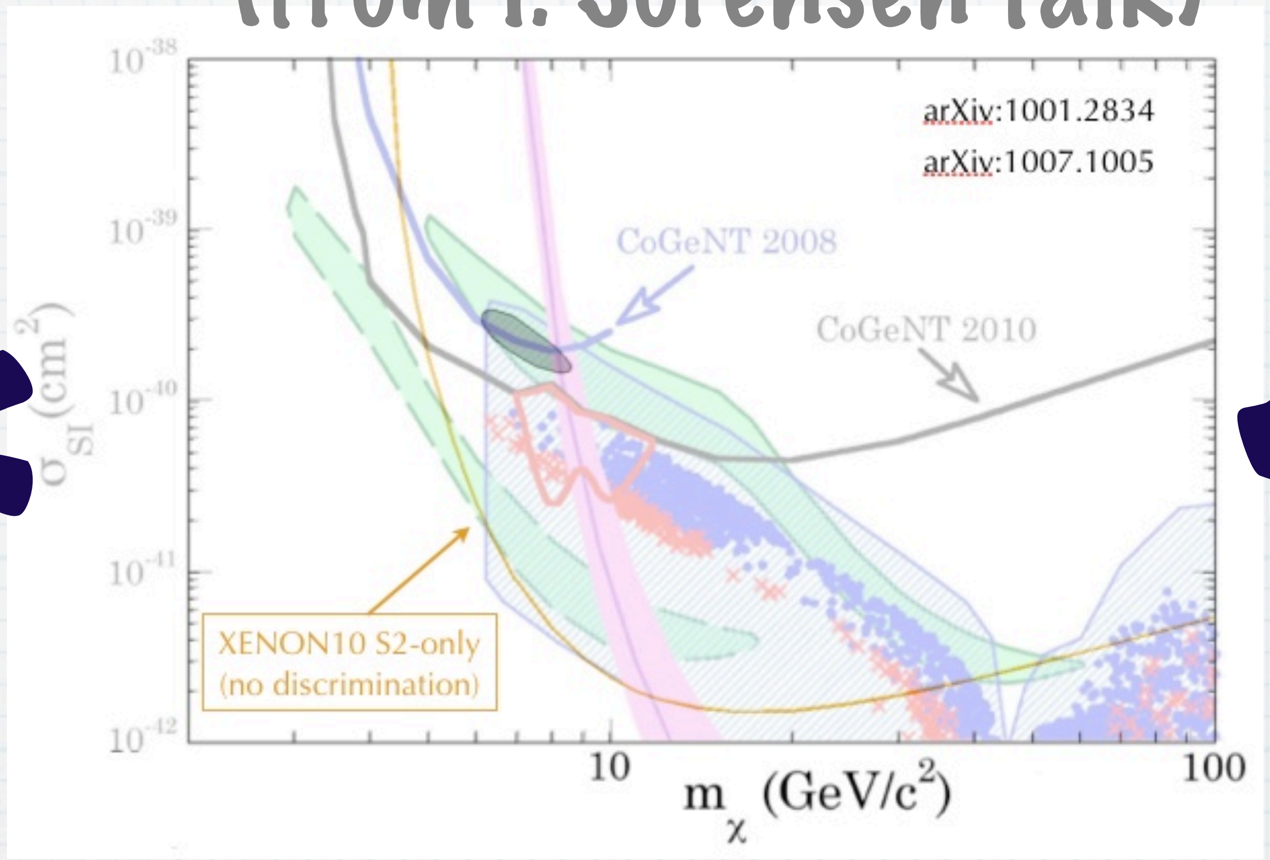

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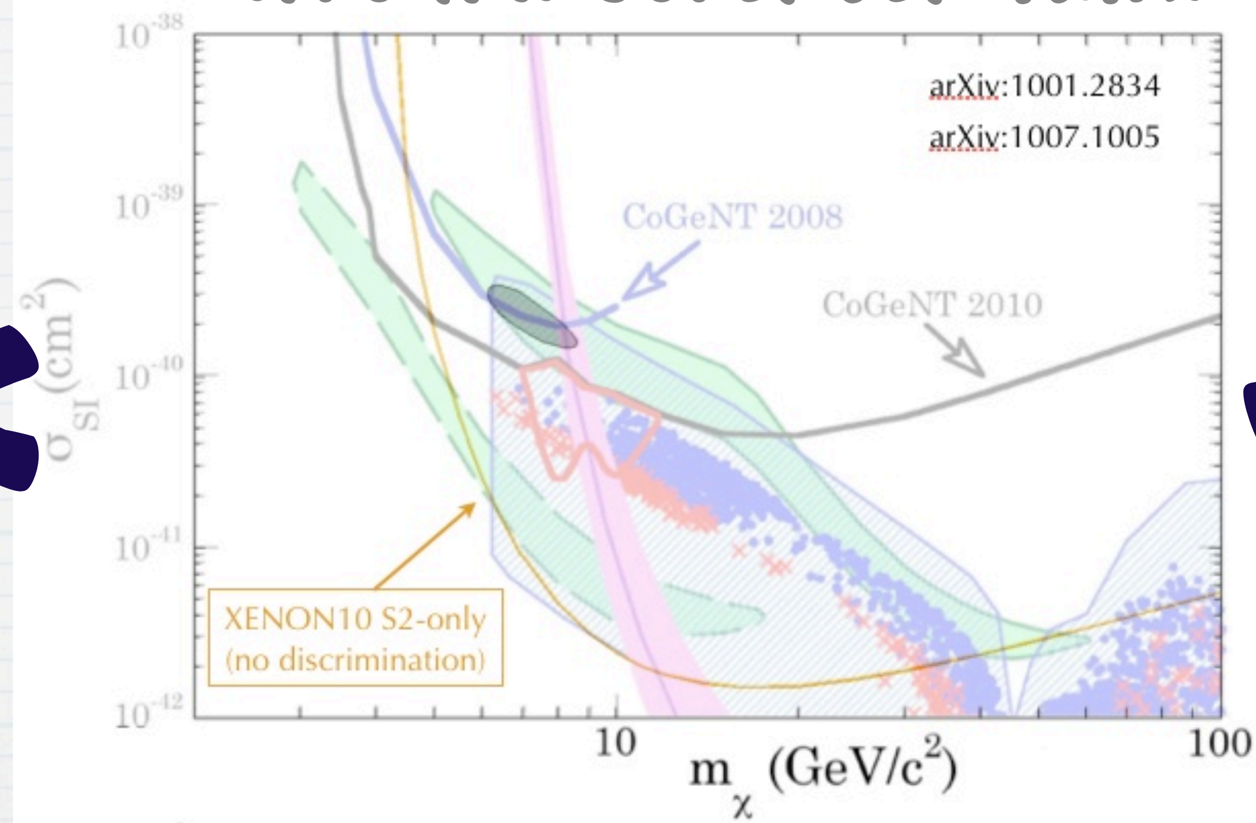
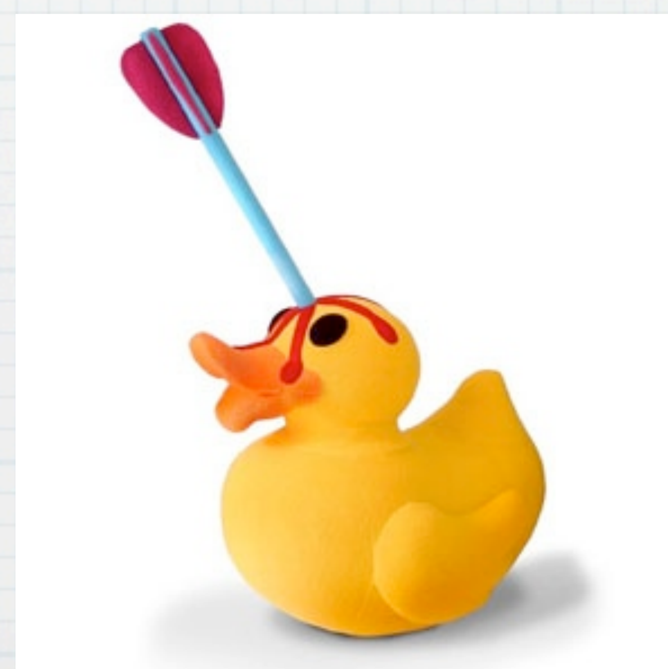
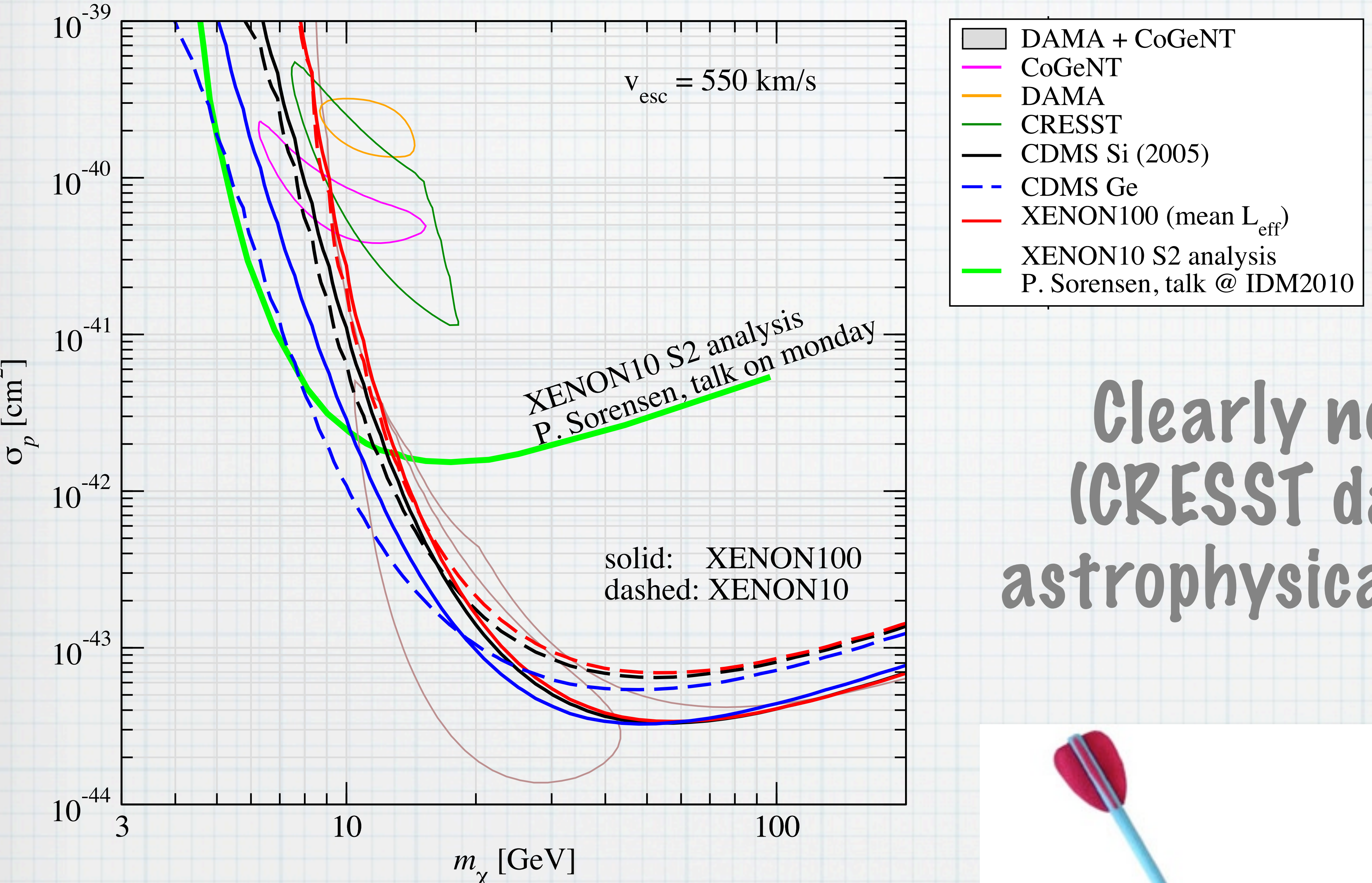


Preliminary: uncertainties not fully explored



?

(from T. Schwetz talk)

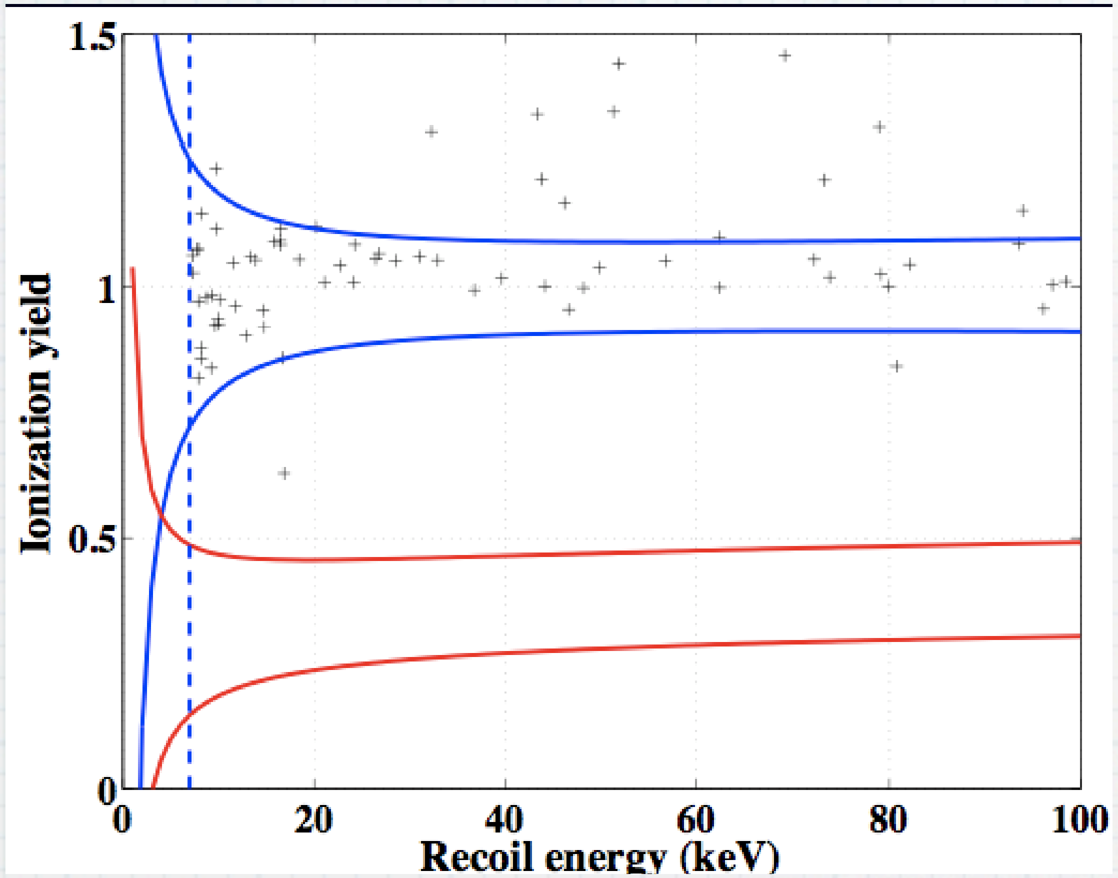


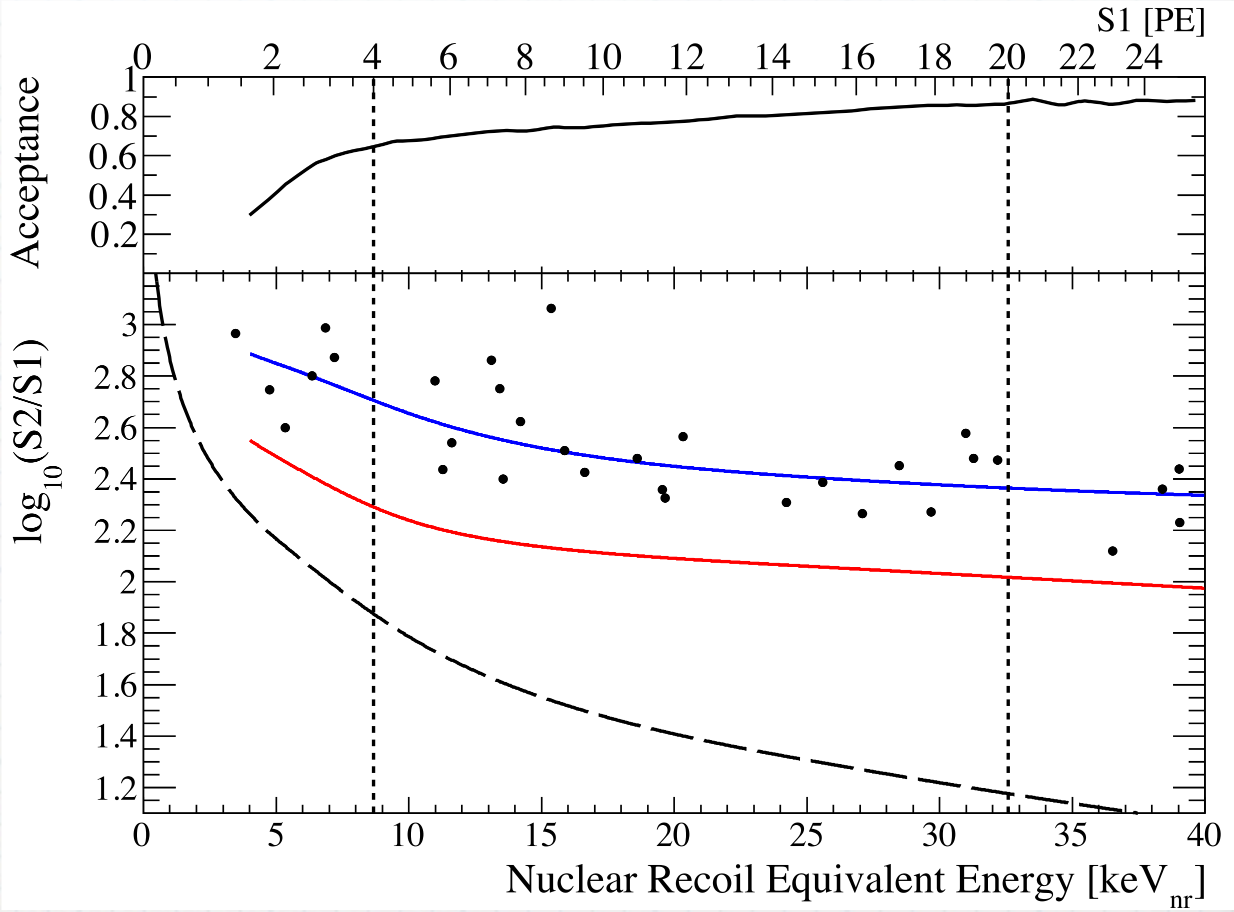
Clearly need more info (CRESST data, studies in astrophysical uncertainties)

Preliminary: uncertainties not fully explored

?

More qualitatively:

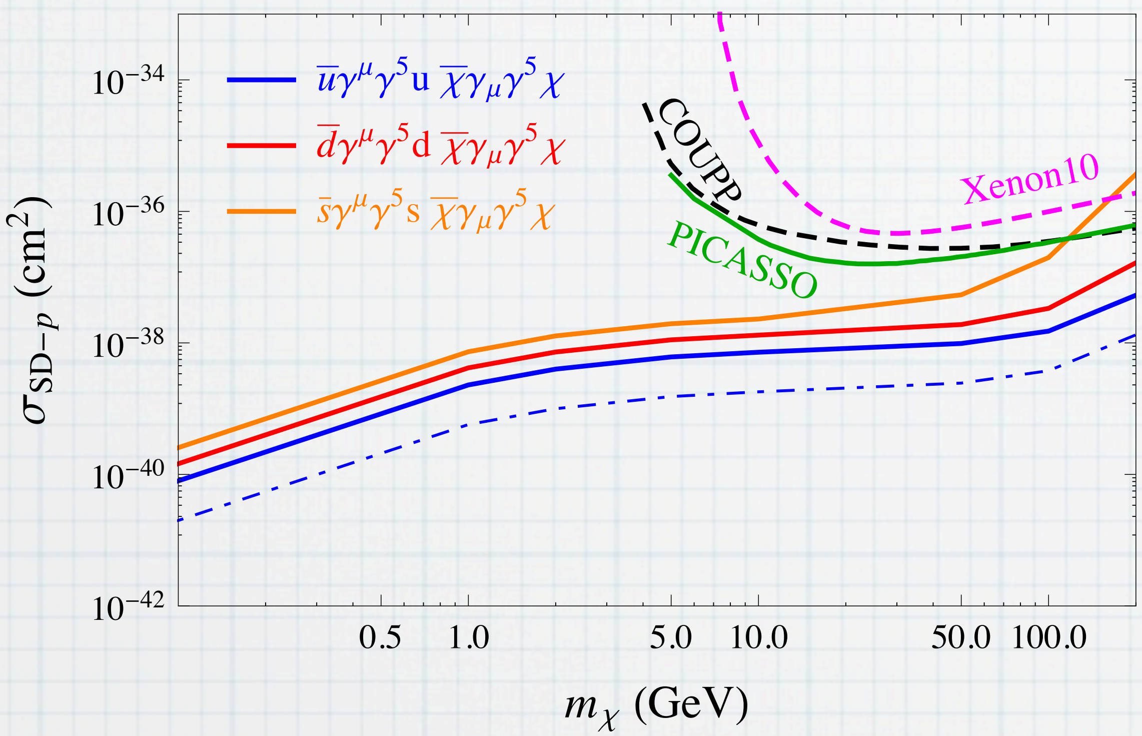


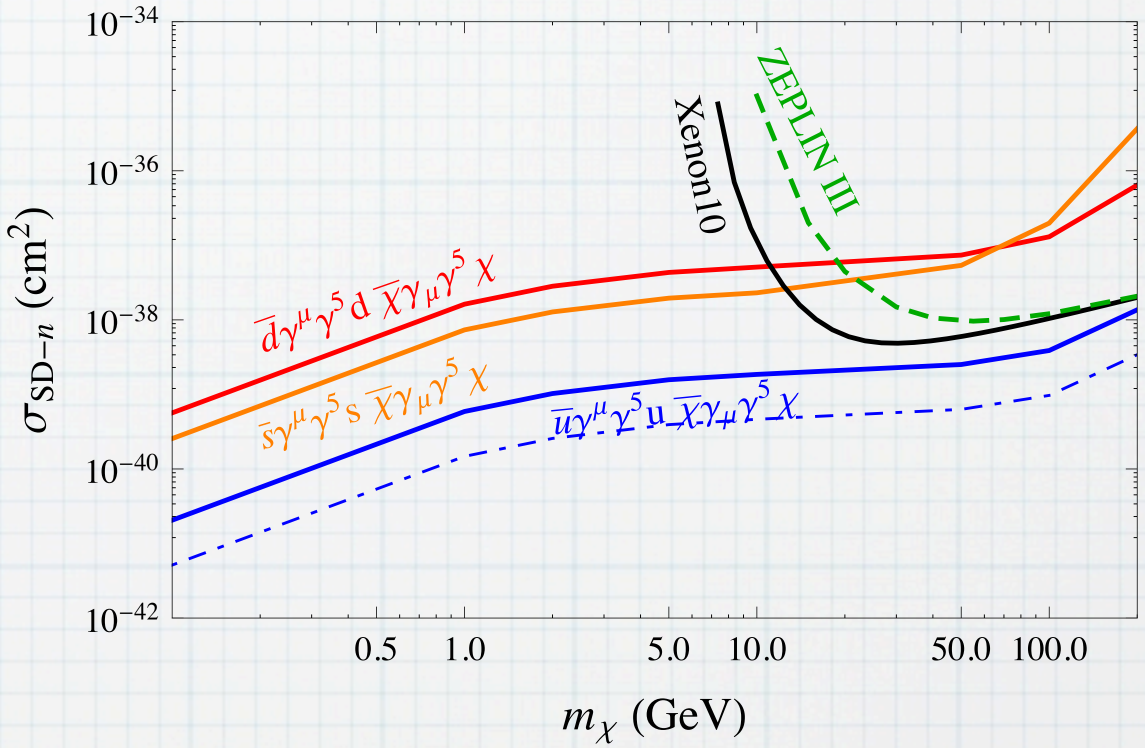


where are the events? Escapable? Perhaps, but troubling nonetheless

An aside on spin-dependent

(monojet + MET)



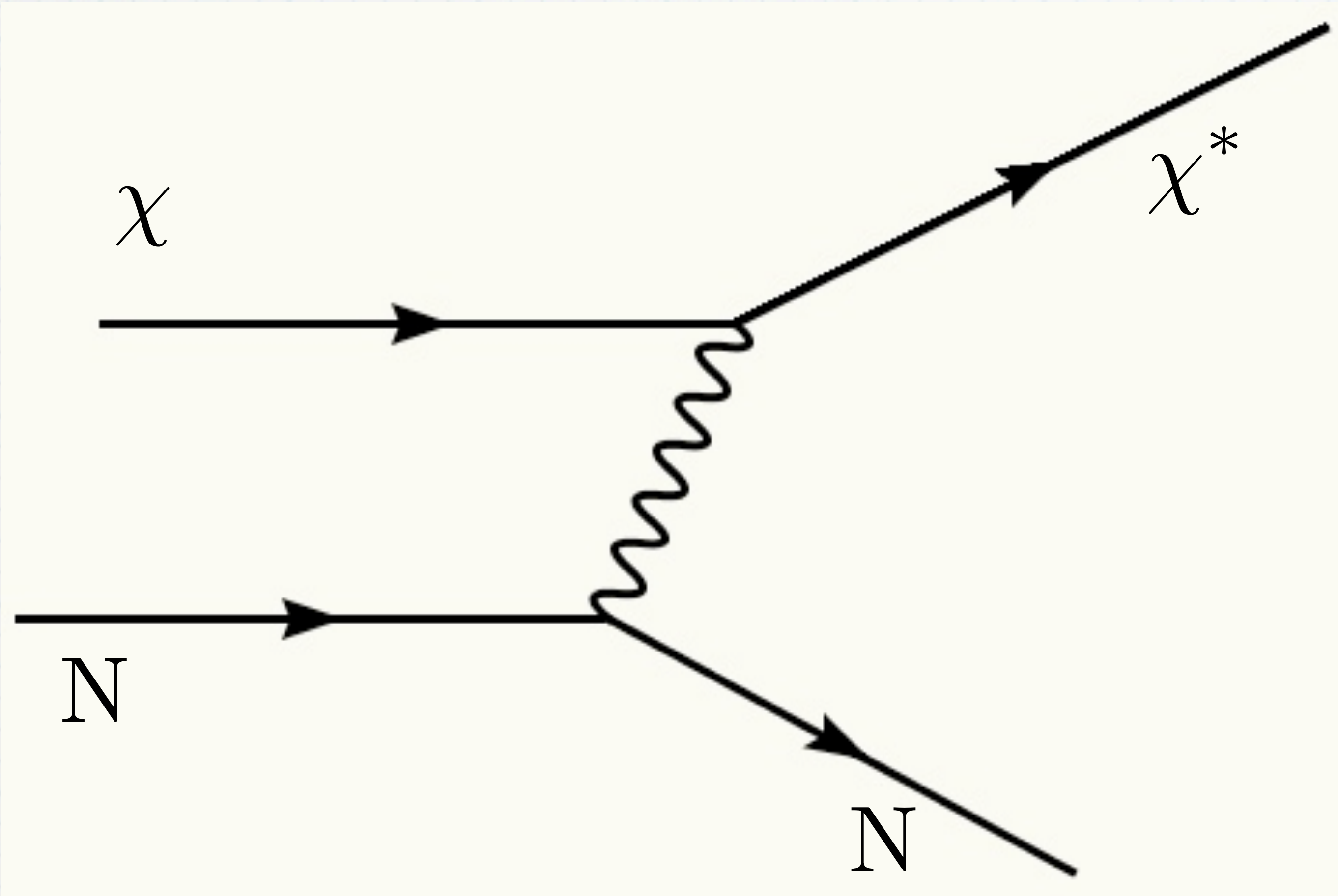


Bai, Fox, Harnik (1005.3597); Also Goodman et al (1005.1286)

Limits weakened if mediated by new, light force carrier

Inelastic Dark Matter

D.Tucker-Smith, NW 2001



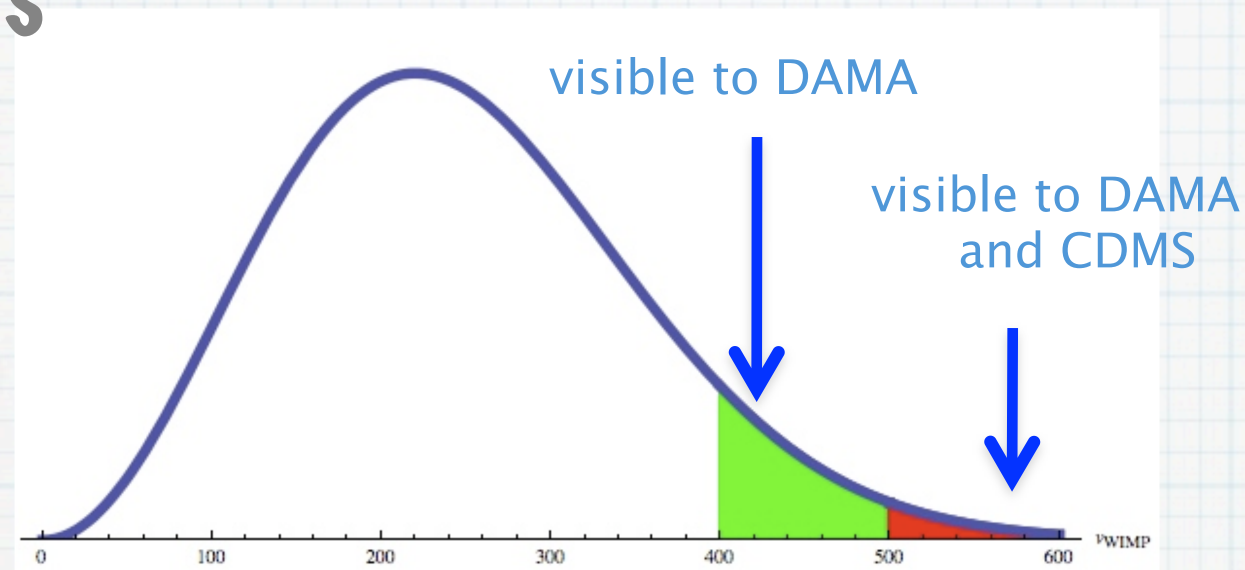
$$\beta^2 \geq \frac{2\delta}{\mu}$$

Analogous to neutron-proton splitting or excited states of atom

100 GeV WIMP, split by ~ 100 keV

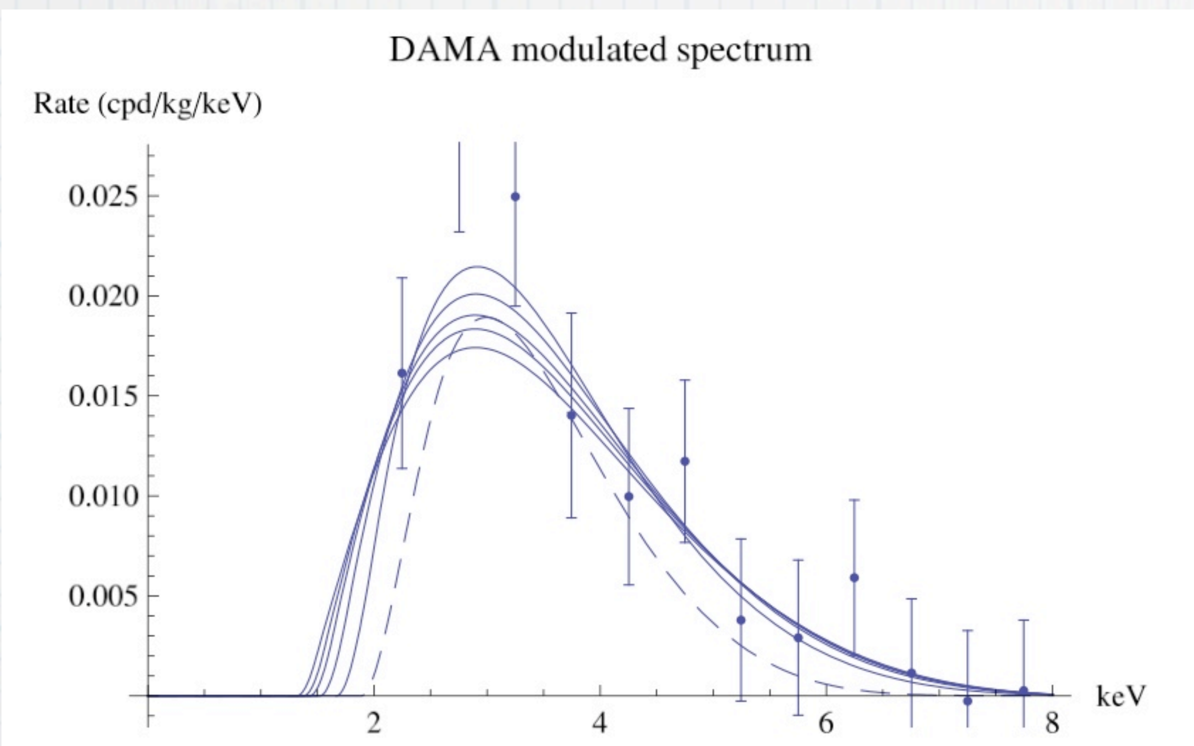
heavy targets

n(v): velocity distribution of WIMPs



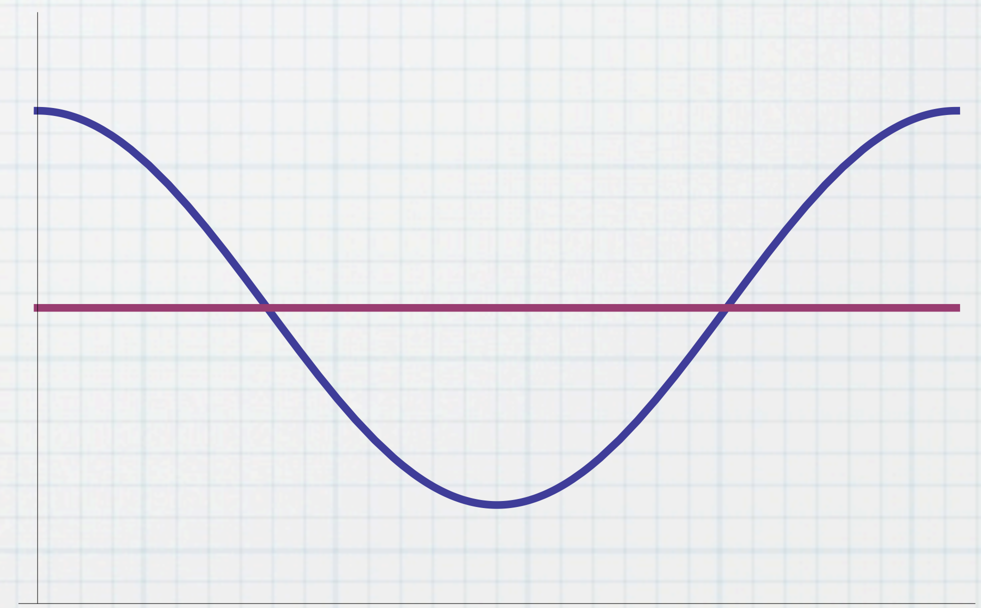
WIMP velocity in km/s

$$\beta^2 \geq \frac{2\delta}{\mu}$$



modified spectrum (low threshold no longer helps)

S0

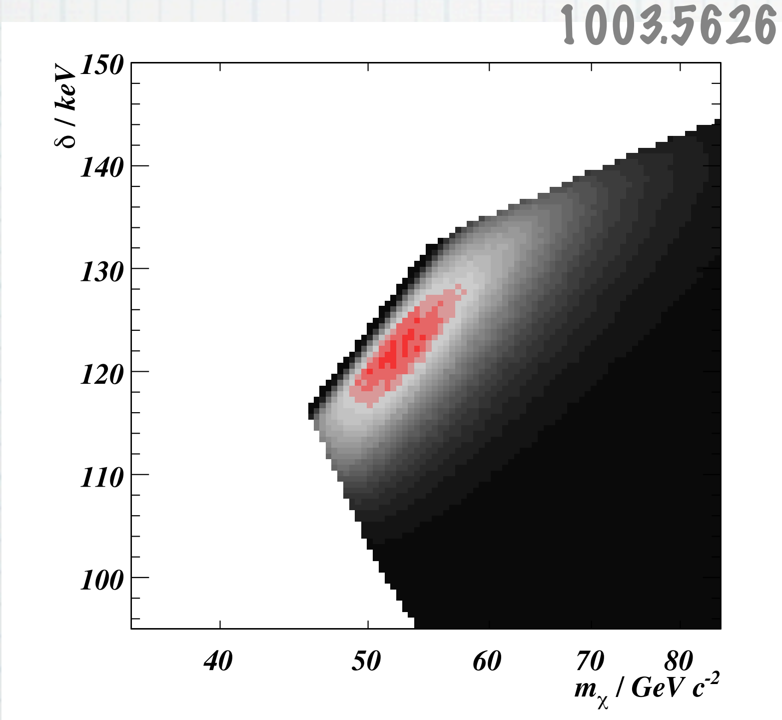


large modulation

Tensions

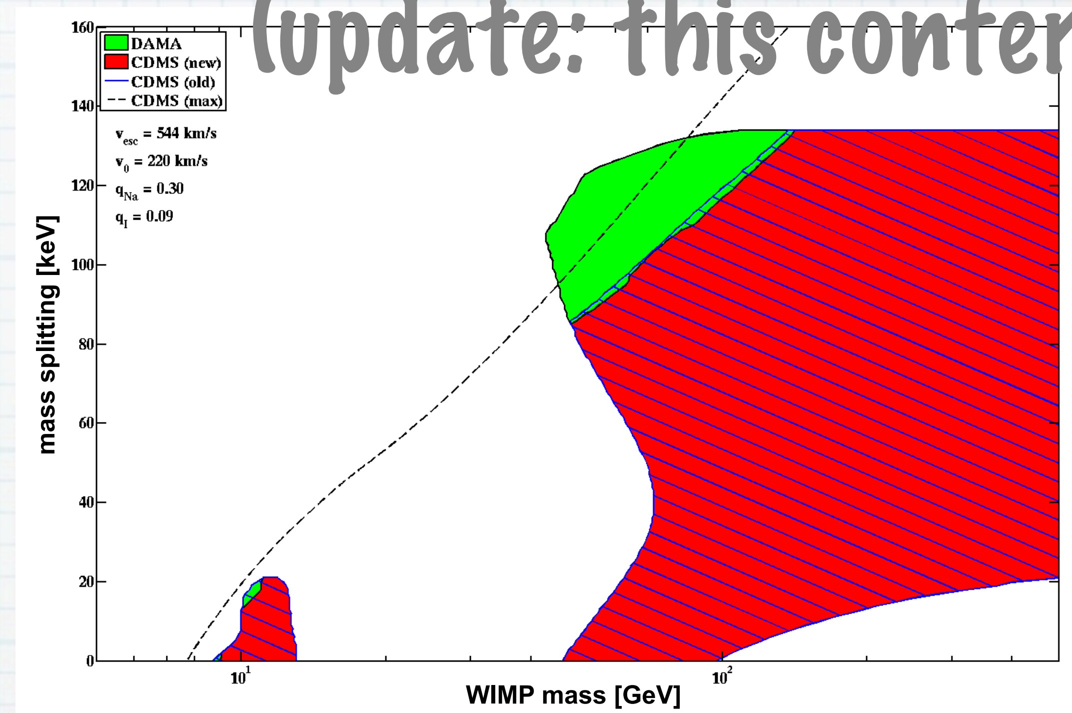
ZEPLIN III

1003.5626

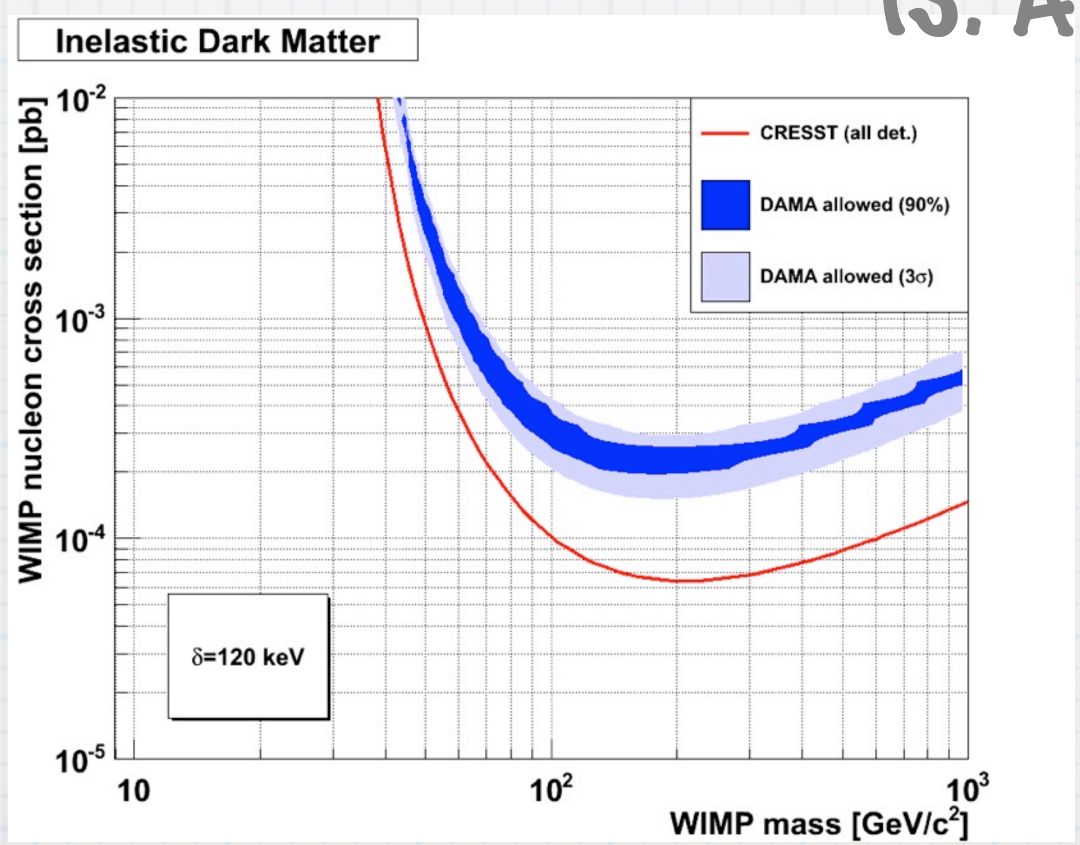


CDMS, XENON

(update: this conference)



(S. Arrenberg talk)



(W. Seidel talk)

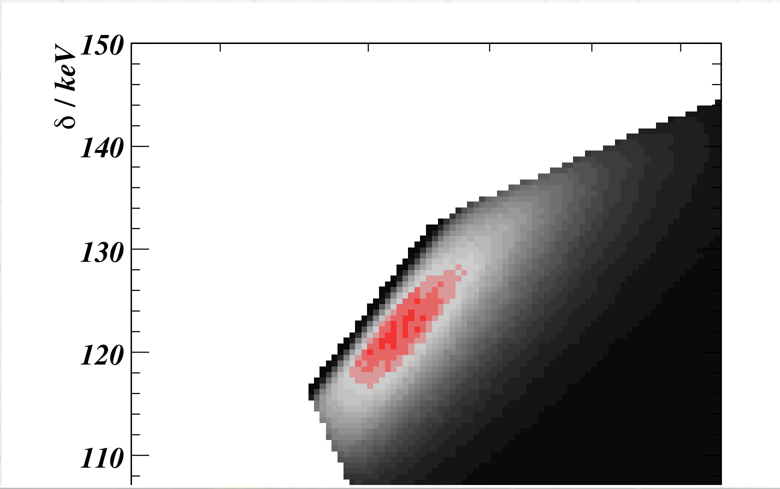
CRESST II

(this conference)

less than factor of two

Tensions

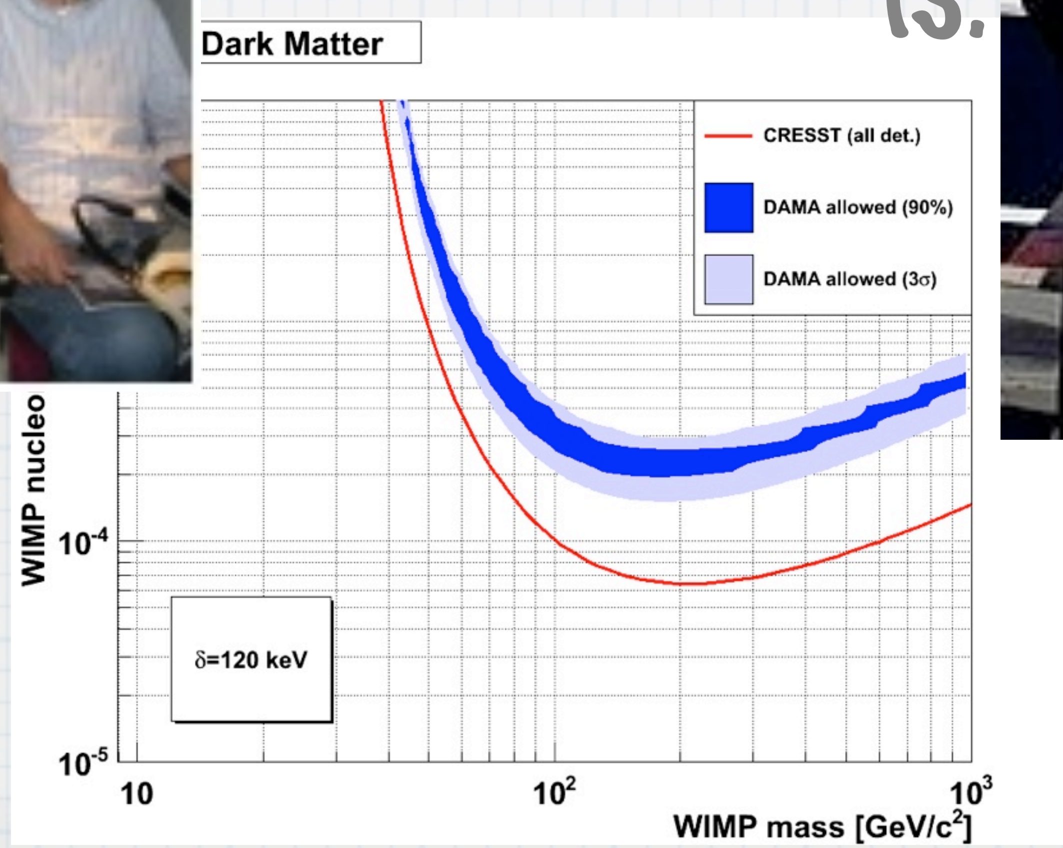
ZEPLIN III



CDMS, XENON

(update: this conference)

somewhere between these two



(this conference)

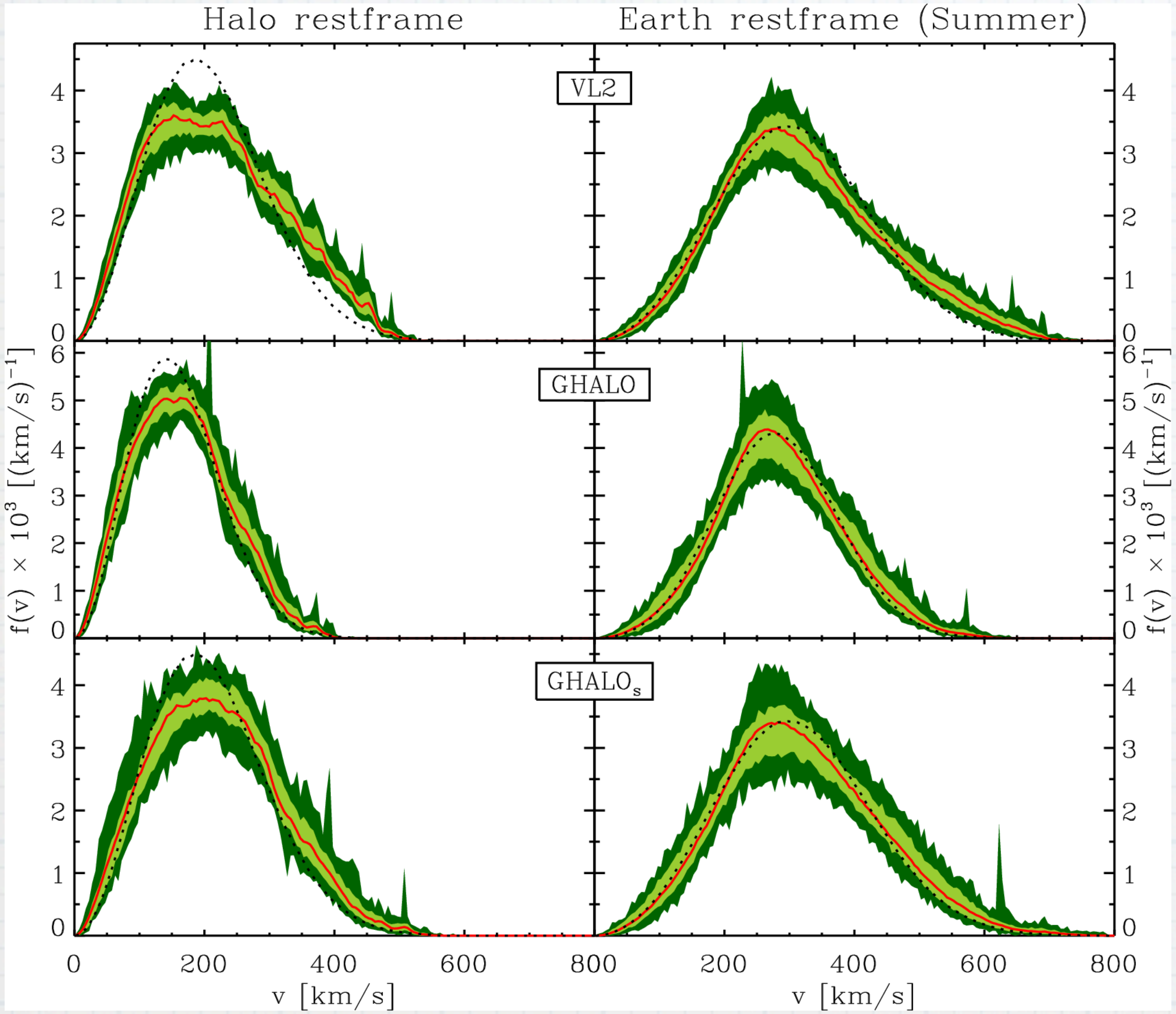
(W. Seidel talk)

less than factor of two

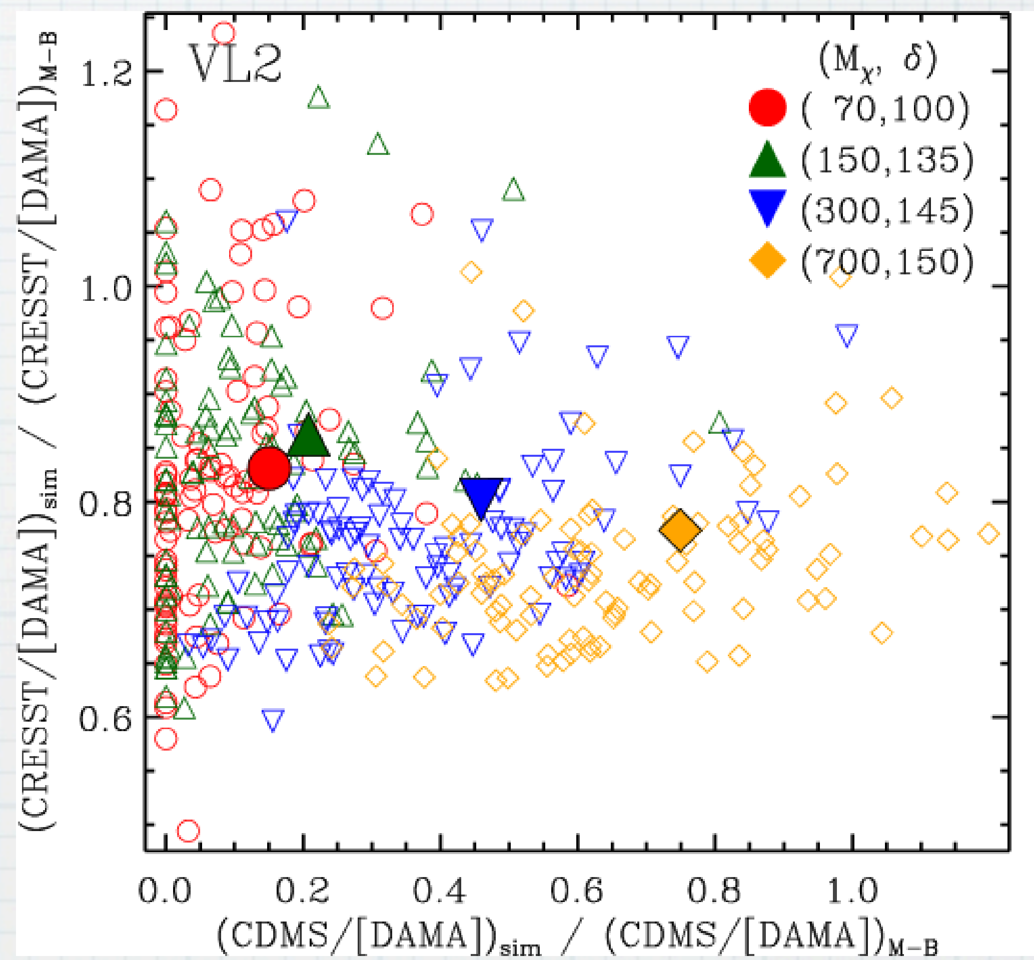
Whither a factor of two?

* Astrophysics
* Particle Physics

N-body halo models

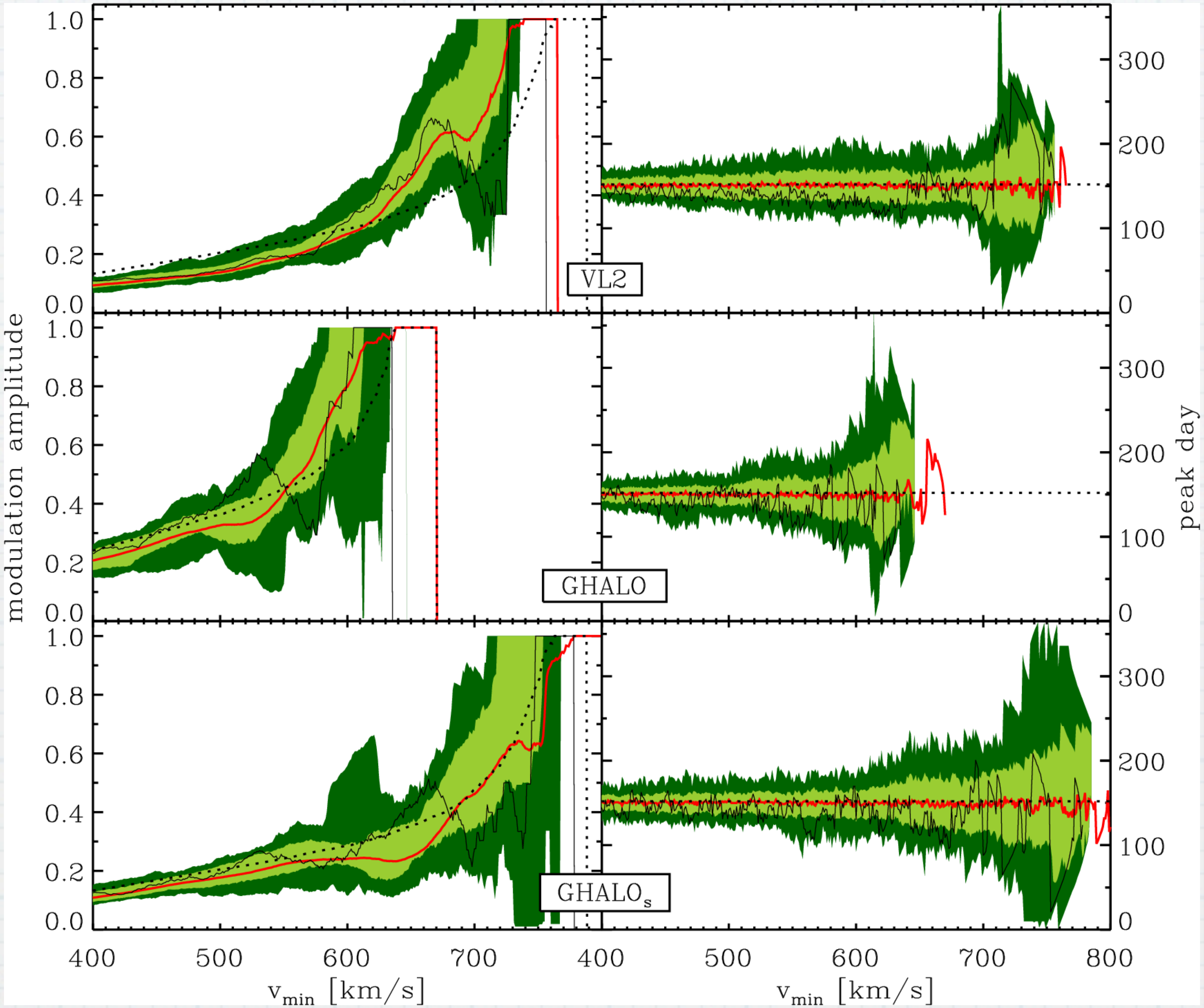


Via Lactea II, GHALO simulations



Kuhlen, et al
(0912.2358)

Modulation amplitude



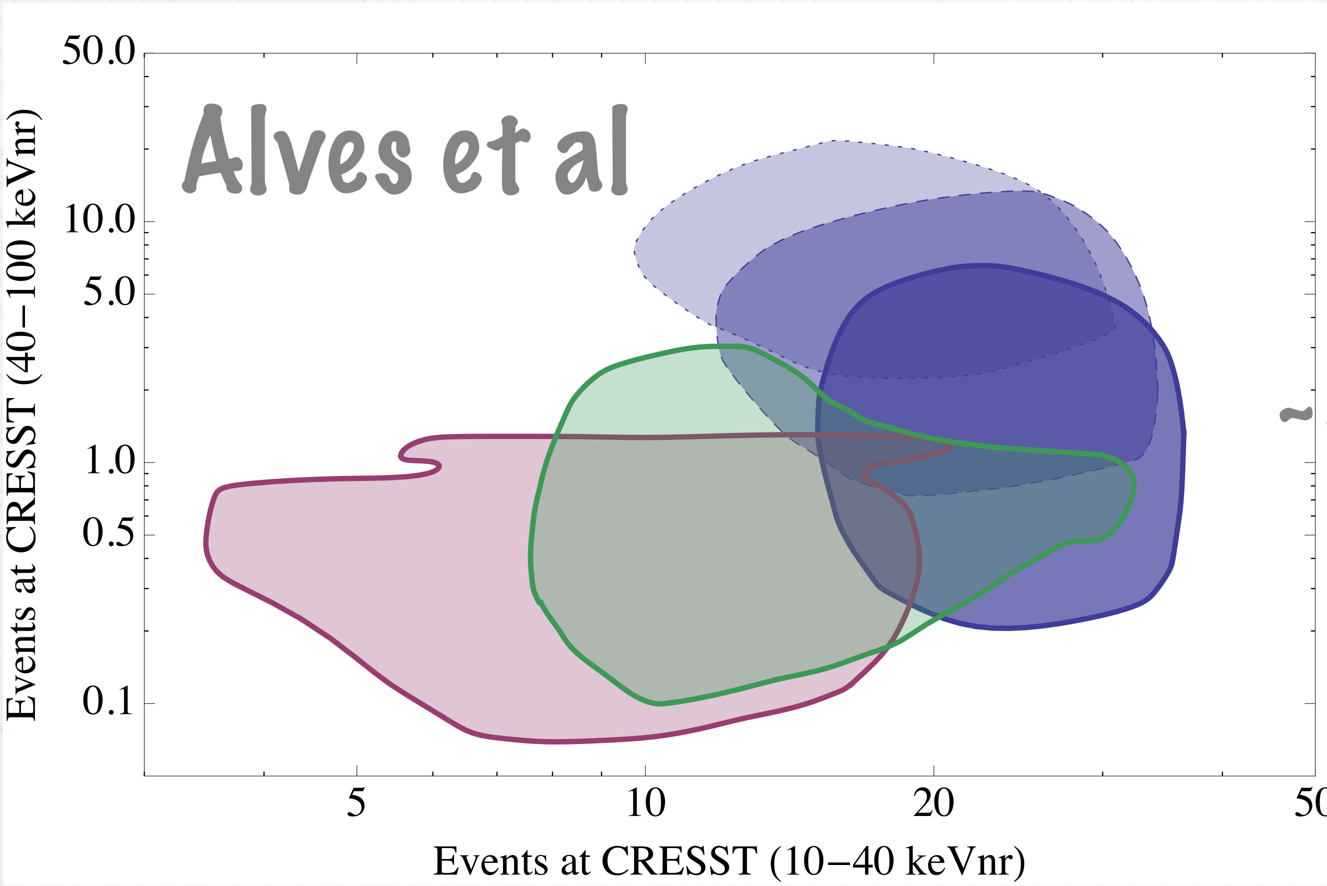
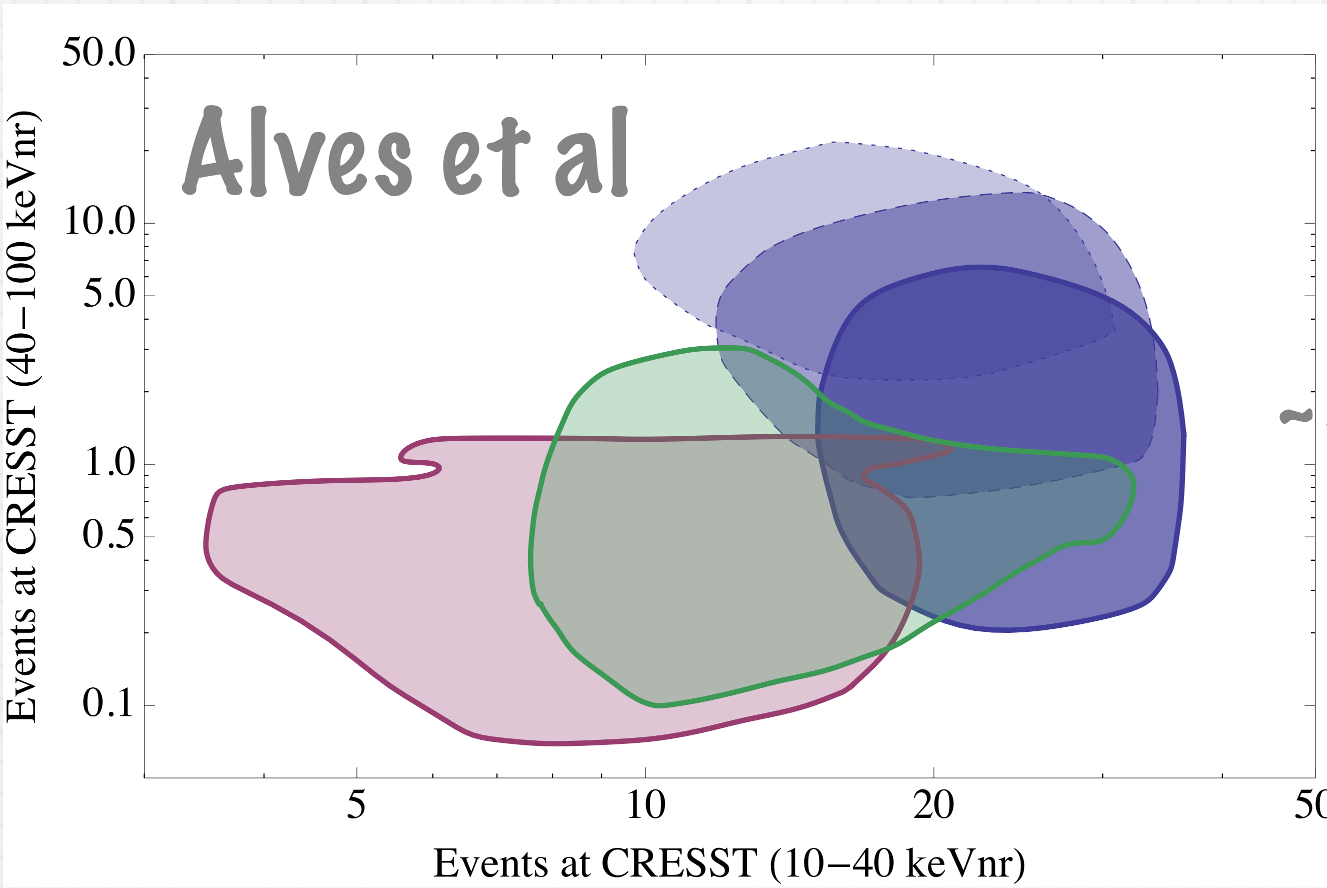


FIG. 2: Average counts at CRESST per 100 kg-d for regular iDM (blue), FFiDM with $F_{\rm dm}(q) \propto E_R$ (green), and DM streams (red). The effect of lowering the quenching factor is illustrated for $Q_{\rm I} = 0.07$ (dashed blue) and $Q_{\rm I} = 0.06$ (dotted blue). The contours enclose all points with $\chi^2 \leq 18$.

extreme cases
- factor of 8
take
~100 W events at CRESST
to ~ 15-20



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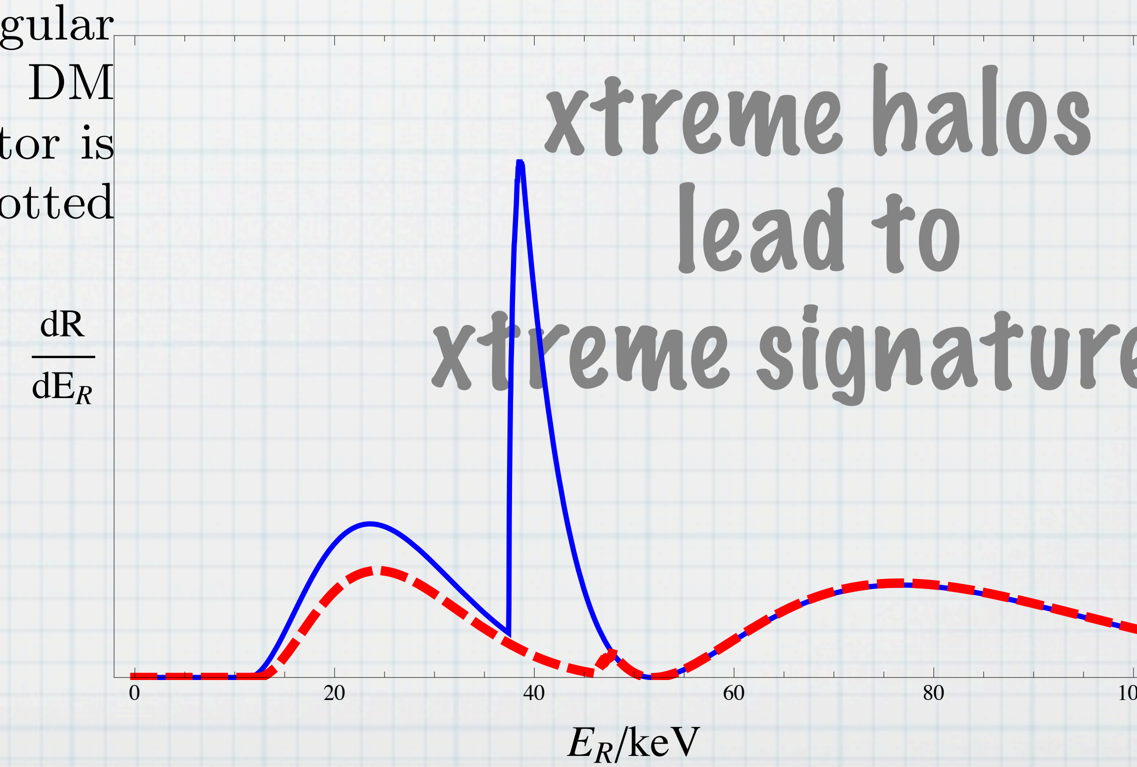
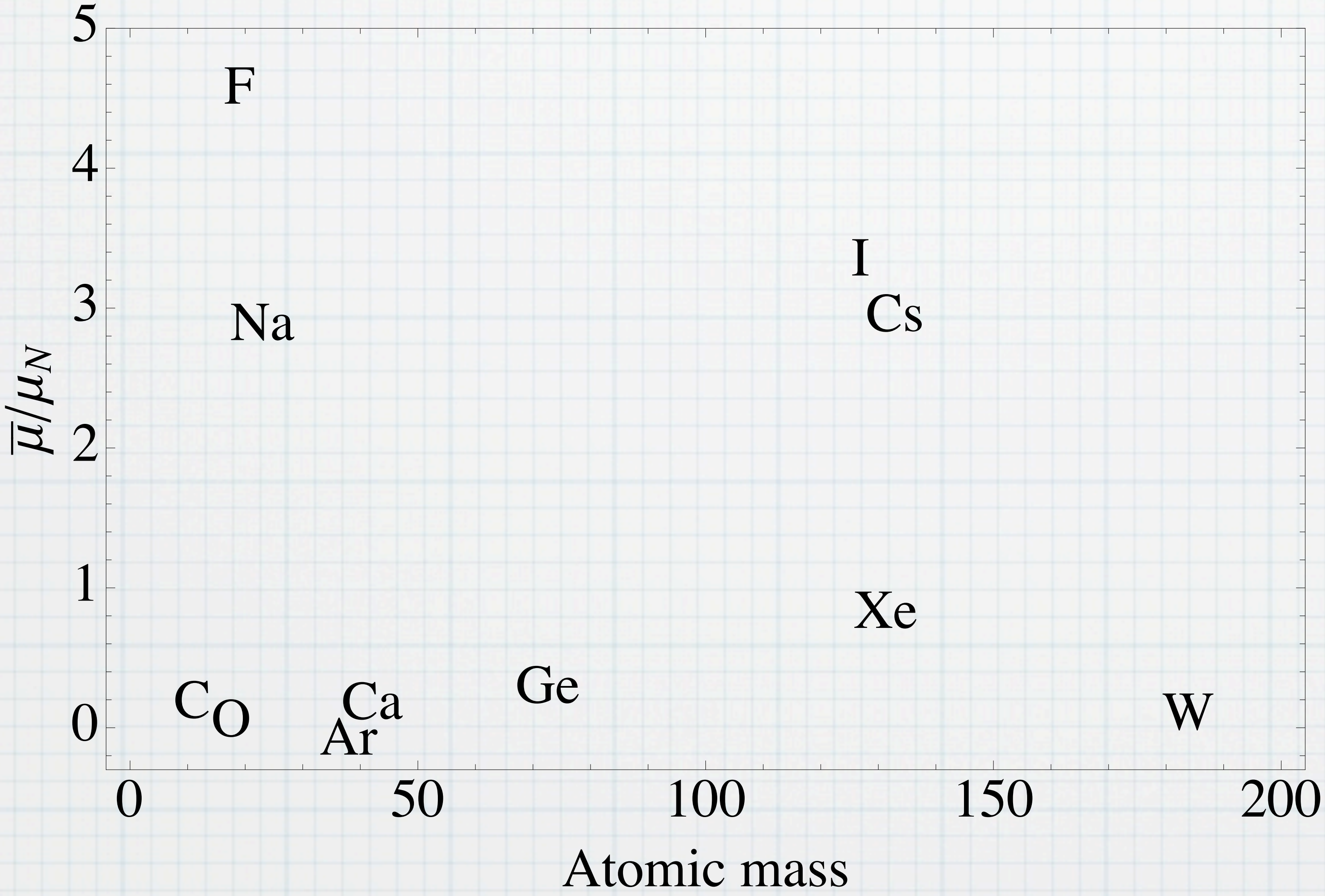


xtreme halos
lead to
xtreme signatures

R. Lang, NW

Particle Physics

* What are the properties of NaI?



large magnetic dipole moments!

What if iDM couples dominantly magnetically?

Magnetic Inelastic Dark Matter

S. Chang, NW, I. Yavin to appear

$$\mathcal{L} \supset \left(\frac{\mu_\chi}{2}\right) \bar{\chi}^* \sigma_{\mu\nu} F^{\mu\nu} \chi + c.c.$$

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$$\frac{d\sigma}{dE_R} = \frac{d\sigma_{\rm DD}}{dE_R} + \frac{d\sigma_{\rm DZ}}{dE_R} \qquad (4)$$

$$\begin{aligned} \frac{d\sigma_{\rm DD}}{dE_R} &= \frac{16\pi\alpha^2 m_N}{v^2} \left(\frac{\mu_{nuc}}{e}\right)^2 \left(\frac{\mu_\chi}{e}\right)^2 \\ &\times \left(\frac{S_\chi+1}{3S_\chi}\right)\left(\frac{S_N+1}{3S_N}\right) F_D^2[E_R] \end{aligned} \qquad (5)$$

$$\begin{aligned} \frac{d\sigma_{\rm DZ}}{dE_R} &= \frac{4\pi Z^2\alpha^2}{E_R} \left(\frac{\mu_\chi}{e}\right)^2 \left[1 - \frac{E_R}{v^2}\left(\frac{1}{2m_N} + \frac{1}{m_\chi}\right)\right. \\ &- \left.\frac{\delta}{v^2}\left(\frac{1}{\mu_{N\chi}} + \frac{\delta}{2m_N E_R}\right)\right] \left(\frac{S_\chi+1}{3S_\chi}\right) F^2[E_R] \end{aligned} \qquad (6)$$

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big uncertainties in magnetic form factor

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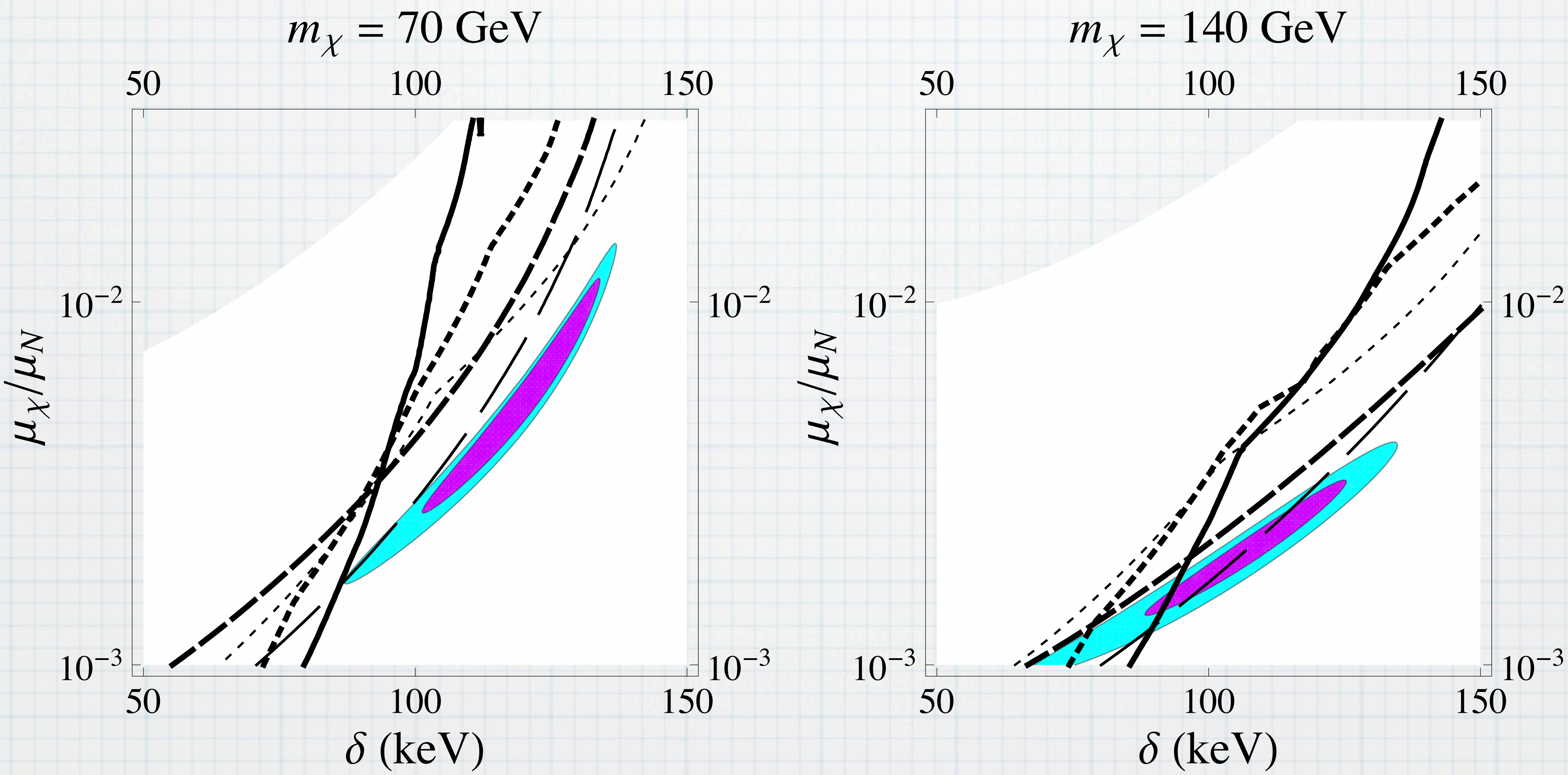
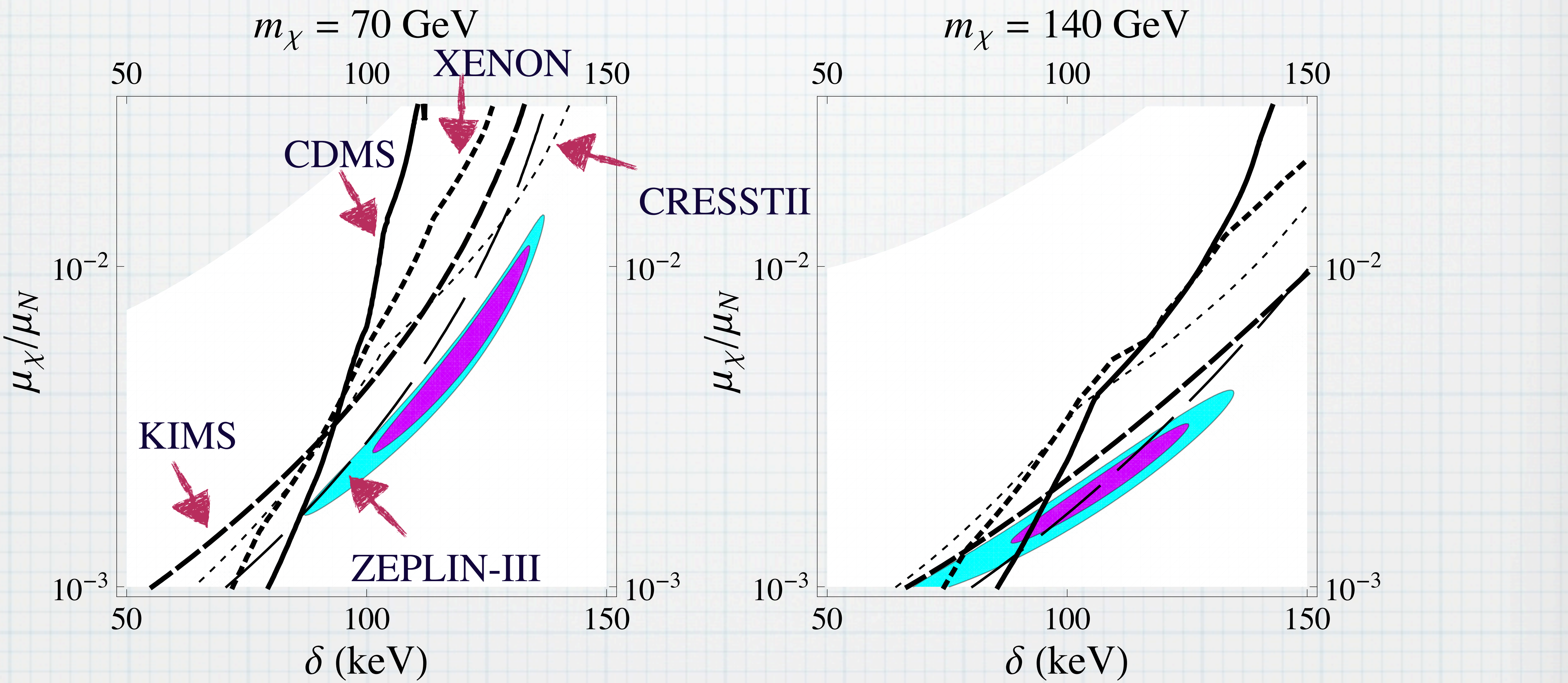
Magnetic iDM Parameter Space



NB: CRESST II = Commissioning run

Magnetic iDM Parameter Space



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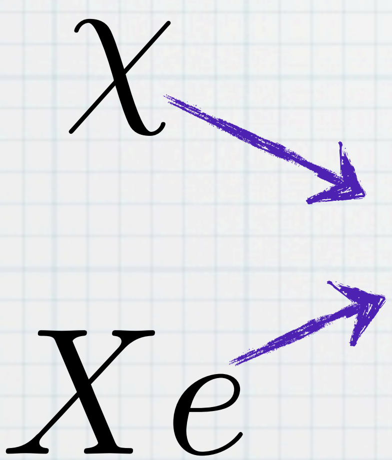
New Signature: Delayed Coincident Events

χ

Xe

New Signature: Delayed Coincident Events



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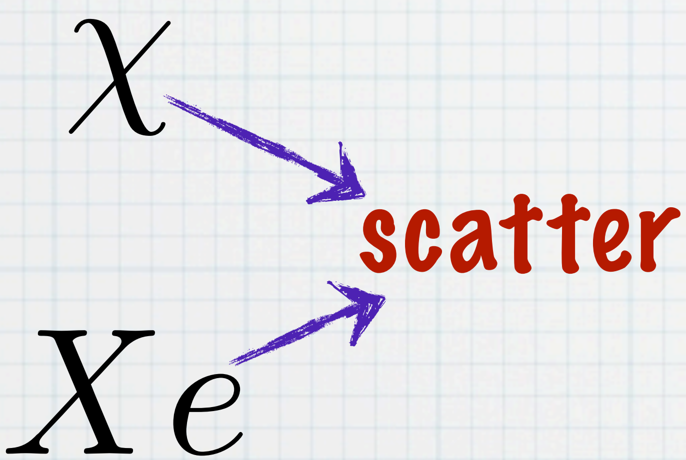

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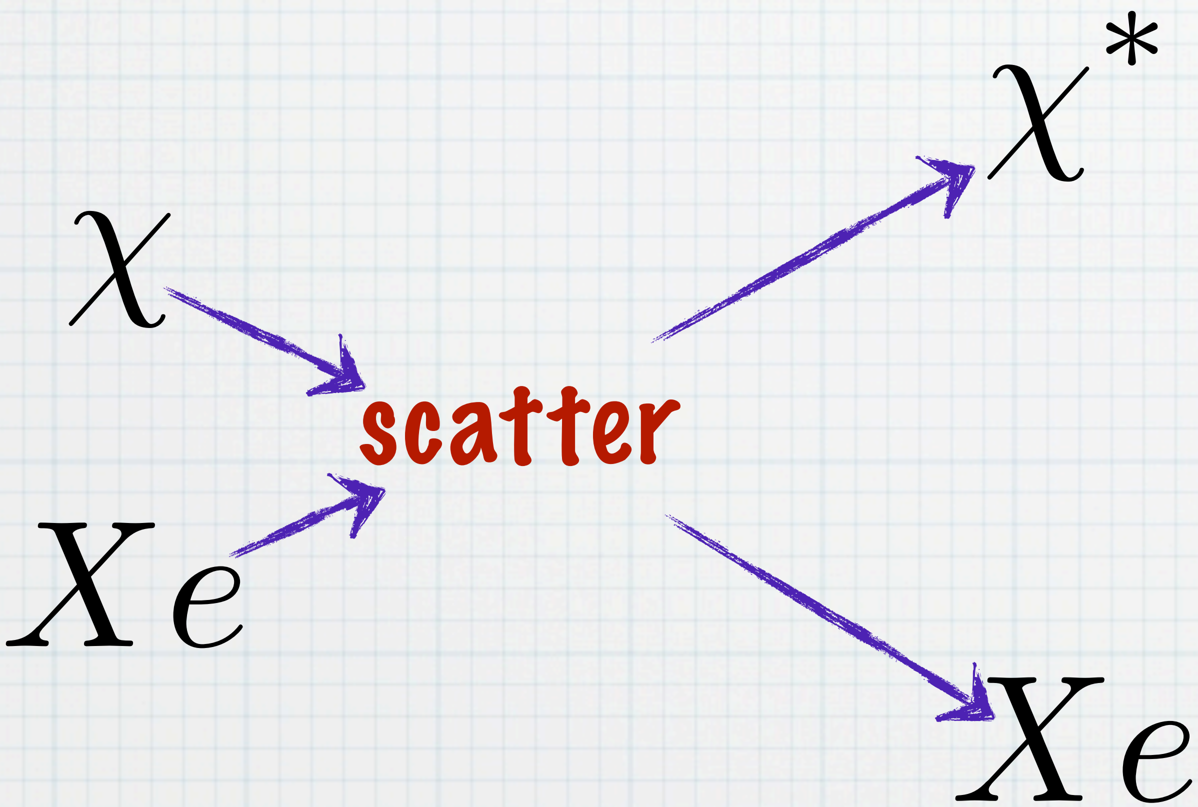

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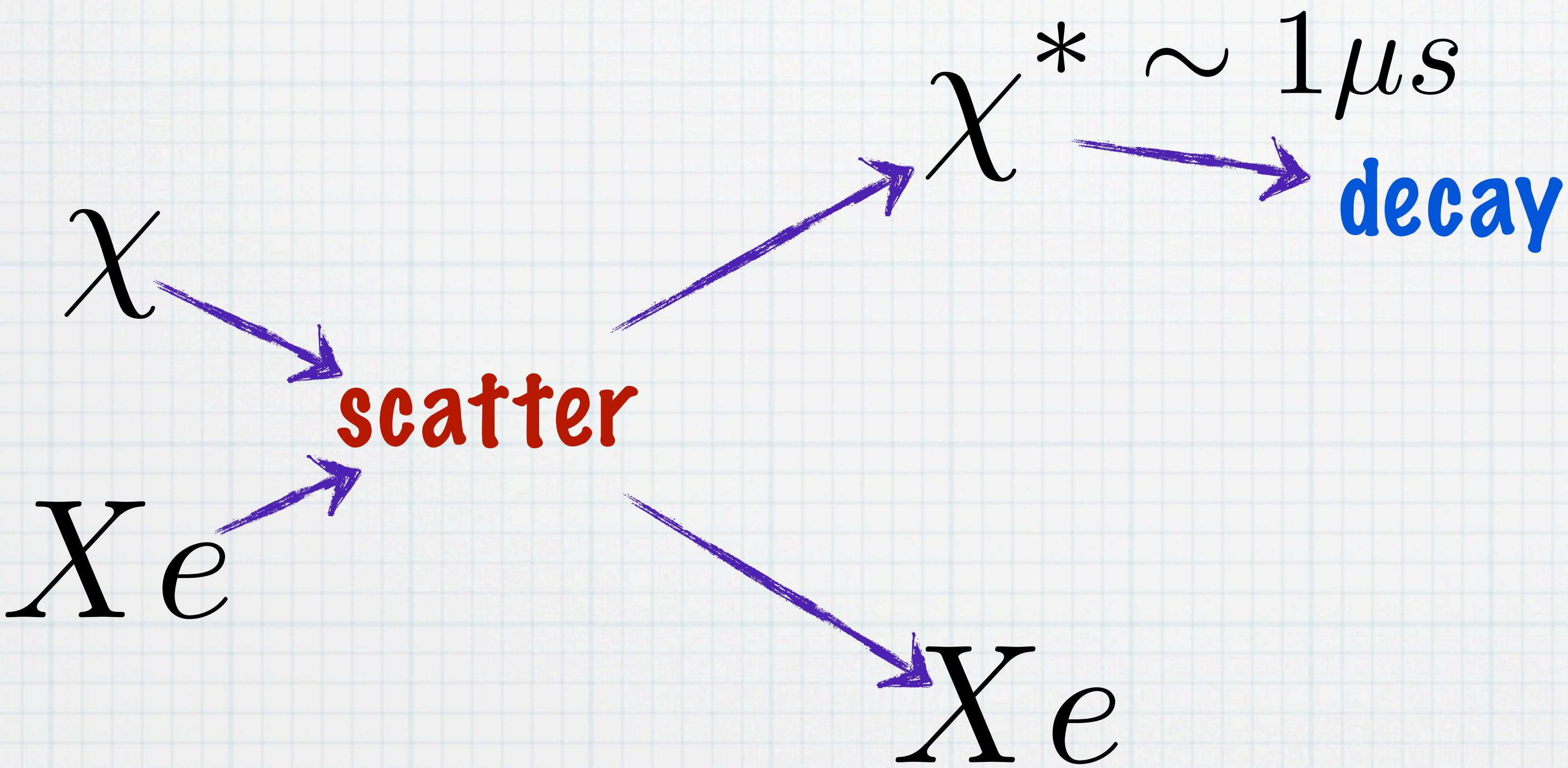

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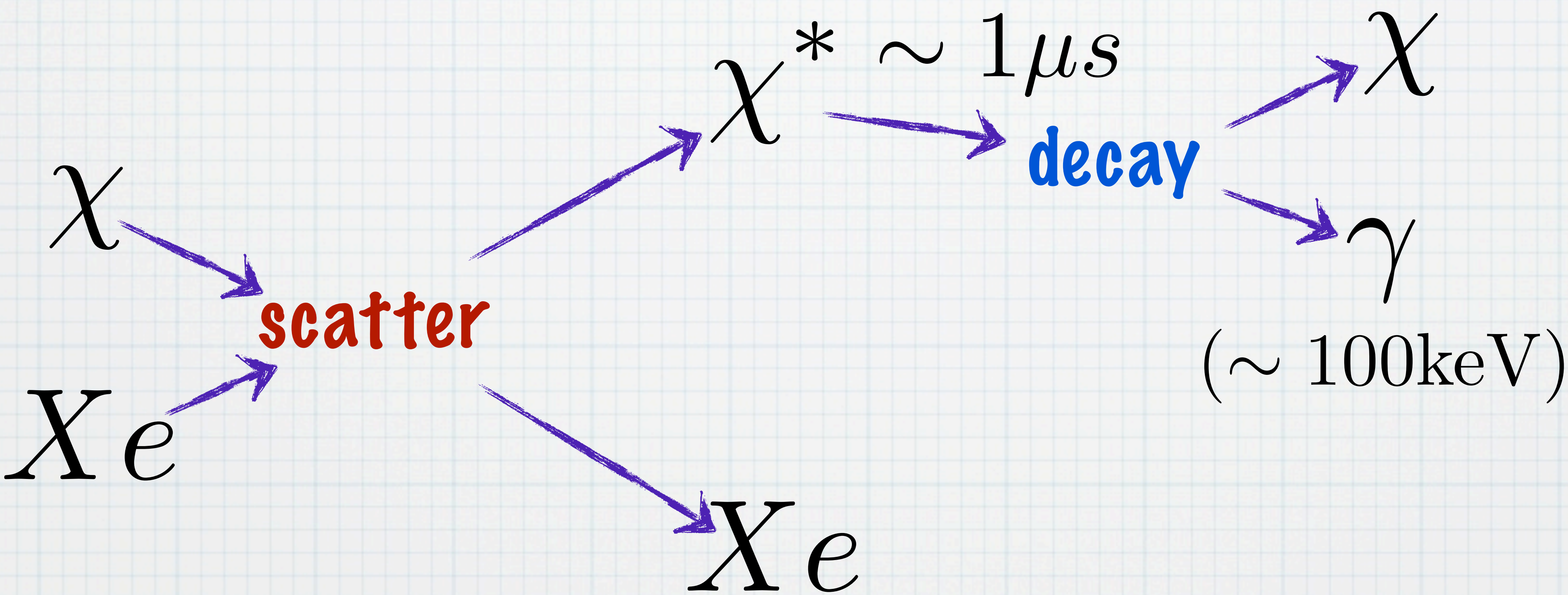

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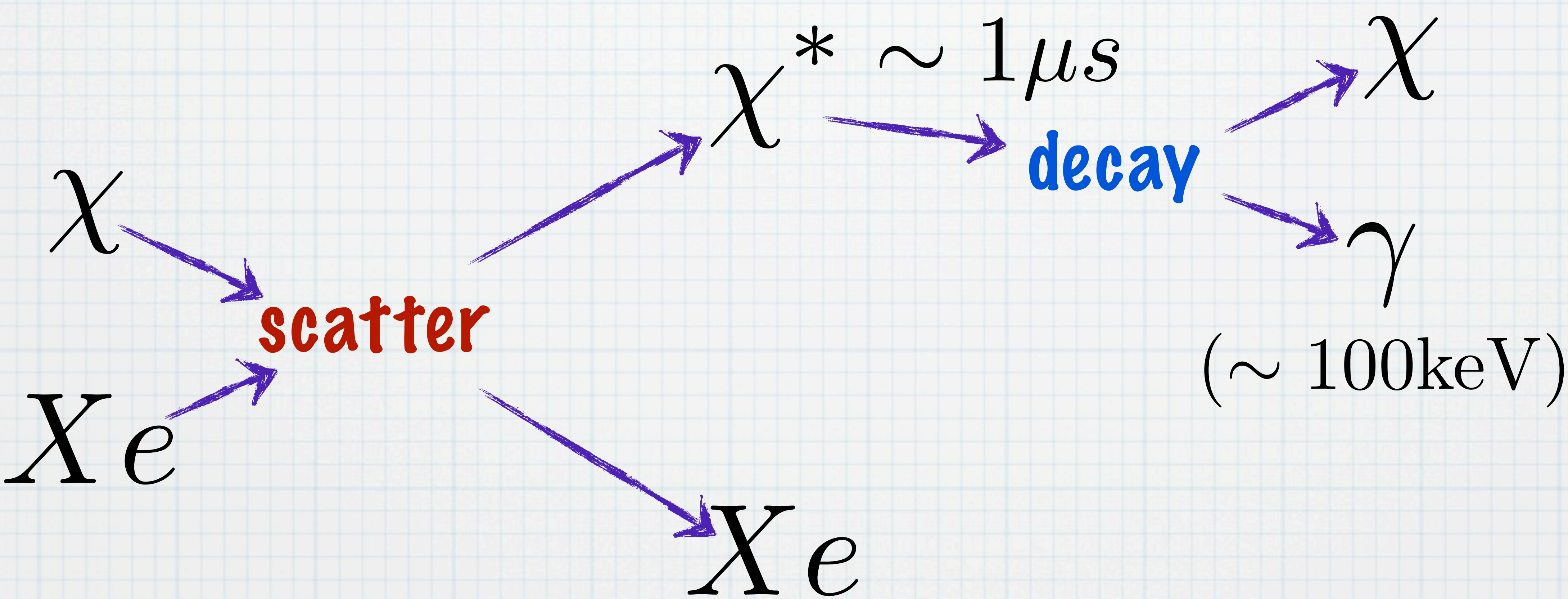

NR in fiducial volume, followed by gamma ~ 1 μs (should fail current search cuts)

A Theorist's Perspective on DAMA

* DAMA modulation has prompted significant reexamination of theoretical assumptions
* No current scenario passes the "duck test"
* Light DM seems in trouble from Xe-S2
    * Preliminary - uncertainties need to be explored!

* Maxwellian/Electric iDM seems to be in trouble by just under a factor of 2
* Is iDM "very unlikely" to explain DAMA?
  * Using realistic halos easily gives ~ 2 (as much as almost 10 for extreme assumptions)
* Magnetic iDM seems easily consistent with all results at the moment
  * Need to look for double coincidences in large Xe detectors

* Thank you very much!

Impure Thoughts on Inelastic Dark Matter

Spencer Chang,[1] Rafael F. Lang,[2] and Neal Weiner[3]
[1] *Physics Department, University of California Davis, Davis, CA 95616*
[2] *Physics Department, Columbia University, New York, NY 10027*
[3] *Center for Cosmology and Particle Physics, Department of Physics, New York University, New York, NY 10003*

The inelastic dark matter scenario was proposed to reconcile the DAMA annual modulation with null results from other experiments. In this scenario, WIMPs scatter into an excited state, split from the ground state by an energy δ comparable to the available kinetic energy of a Galactic WIMP. We note that for large splittings δ, the dominant scattering at DAMA can occur off of thallium nuclei, with A∼205, which are present as a dopant at the 10^{-3} level in NaI(Tl) crystals. For a WIMP mass $m_\chi \approx 100\,\mathrm{GeV/c^2}$ and $\delta \approx 200\,\mathrm{keV}$, we find a region in $\delta - m_\chi$−parameter space which is consistent with all experiments. These parameters in particular can be probed in experiments with thallium in their targets, such as KIMS, but are inaccessible to lighter target experiments. Depending on the tail of the WIMP velocity distribution, a highly modulated signal may or may not appear at CRESST-II.

thallium scattering?

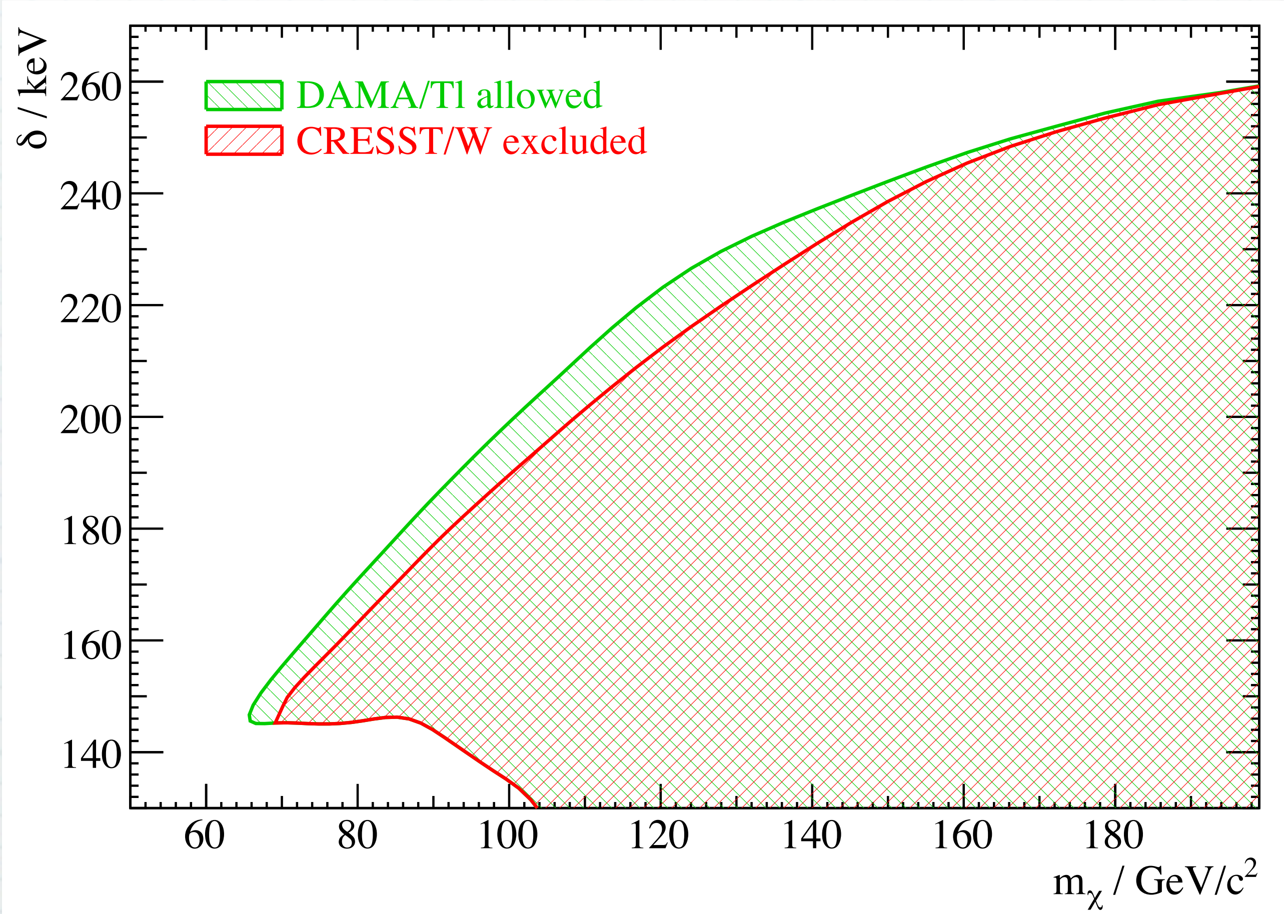

FIG. 1: The DAMA-allowed range of $\delta - m_\chi$−parameter space for χ − Tl scattering only (green hatched region) and constraints from CRESST-II (red hatched region). In the remaining allowed range of splittings δ, no scattering on sodium or iodine occurs. These contributions to signal at lower δ are neglected here.