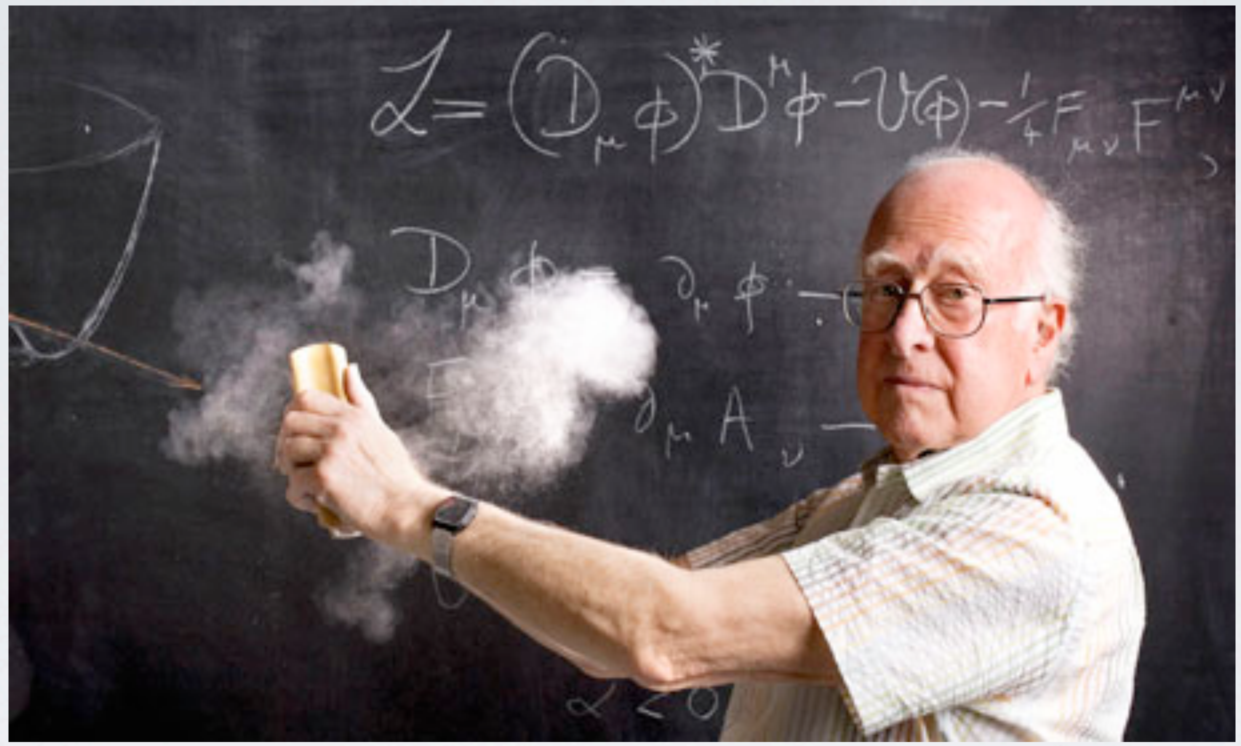
HINTS(?) FOR NEW PHYSICS BELOW THE WEAK SCALE

PCTS Higgs Workshop

April 25, 2013

HIGGS IS A BIG DEAL

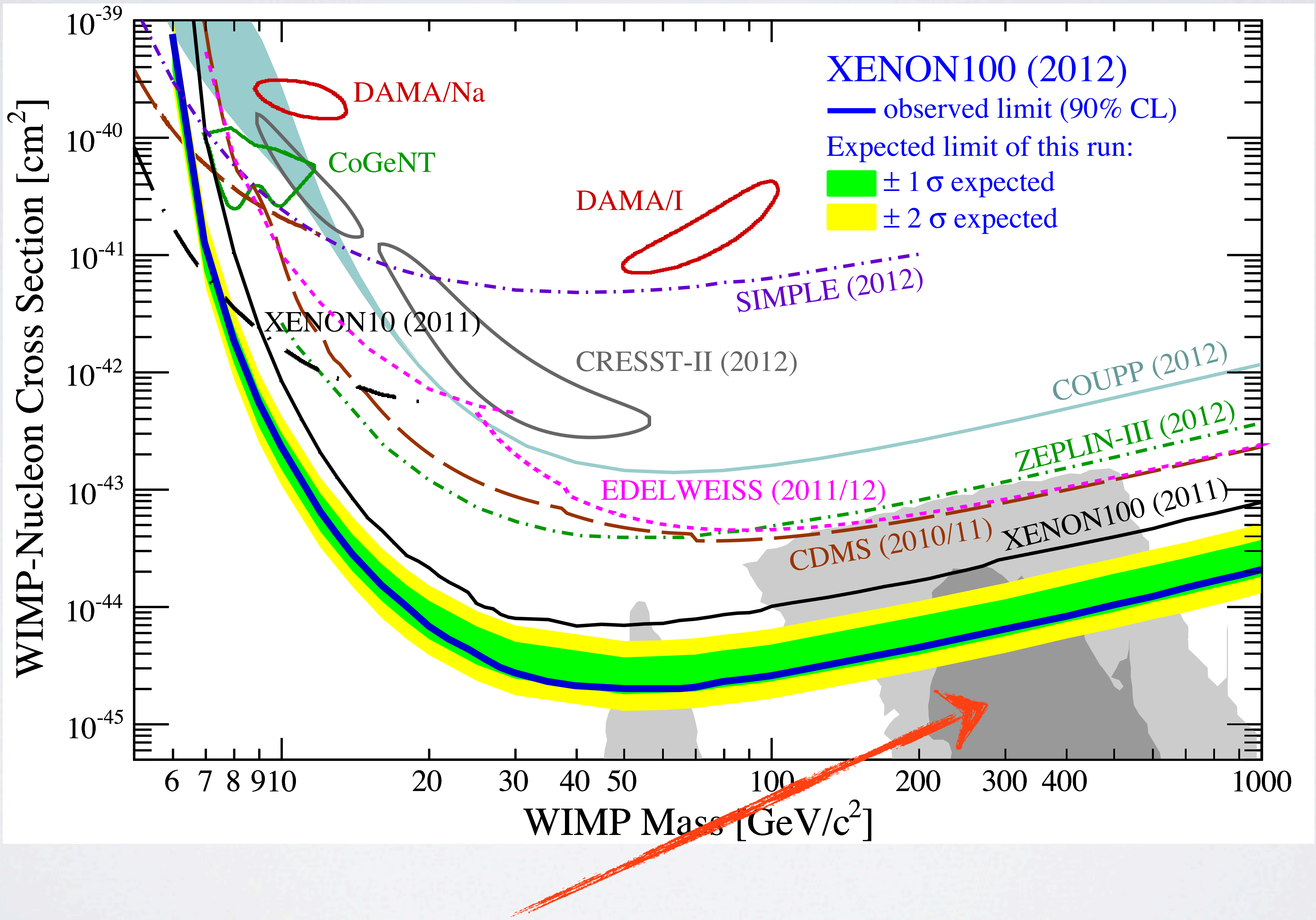


- First particle with unprotected mass
- Perturbative weak scale
- Moving on to precision studies:
  - putting the "Higgs" in "Higgs-like"

MOTIVATIONS FOR PRECISION

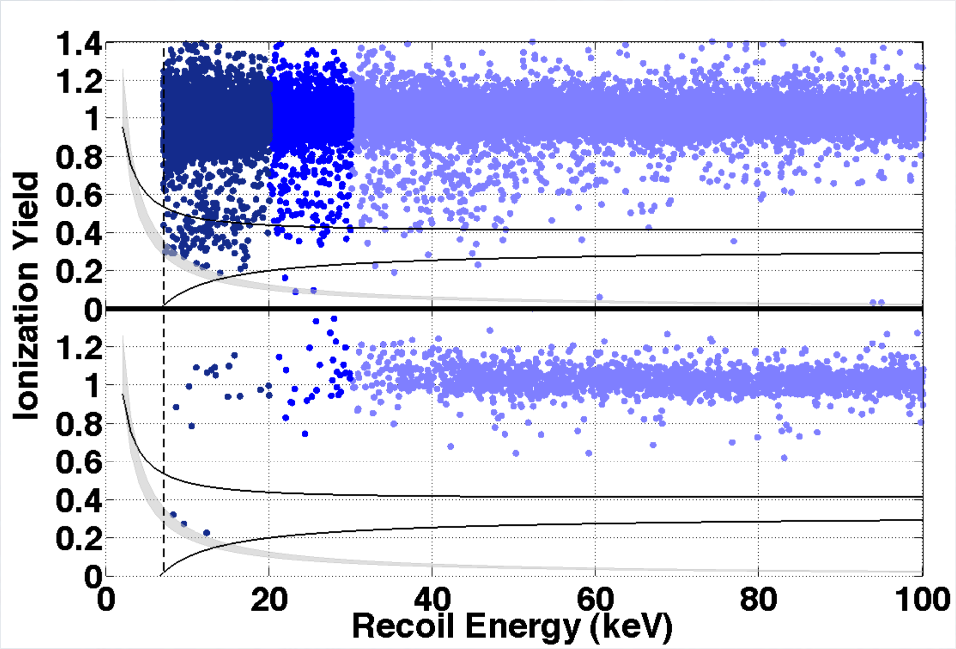
- Because we can
- If NP/SUSY is semi-decoupled are there physics motivations?
- I.e., indications of physics at/below the Higgs mass scale?

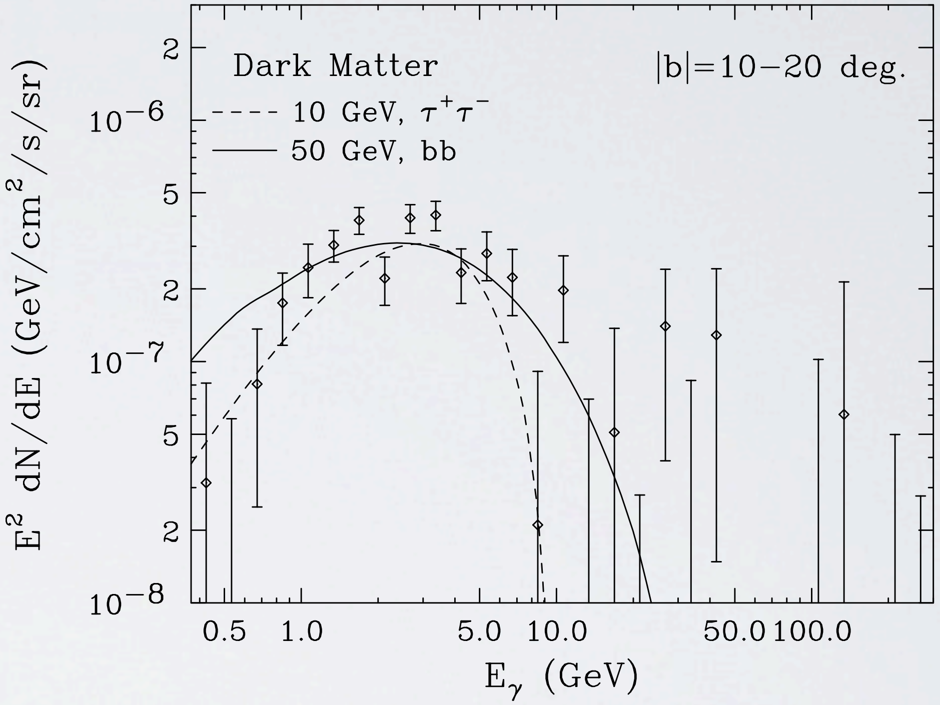
DARK MATTER AT WEAK SCALE

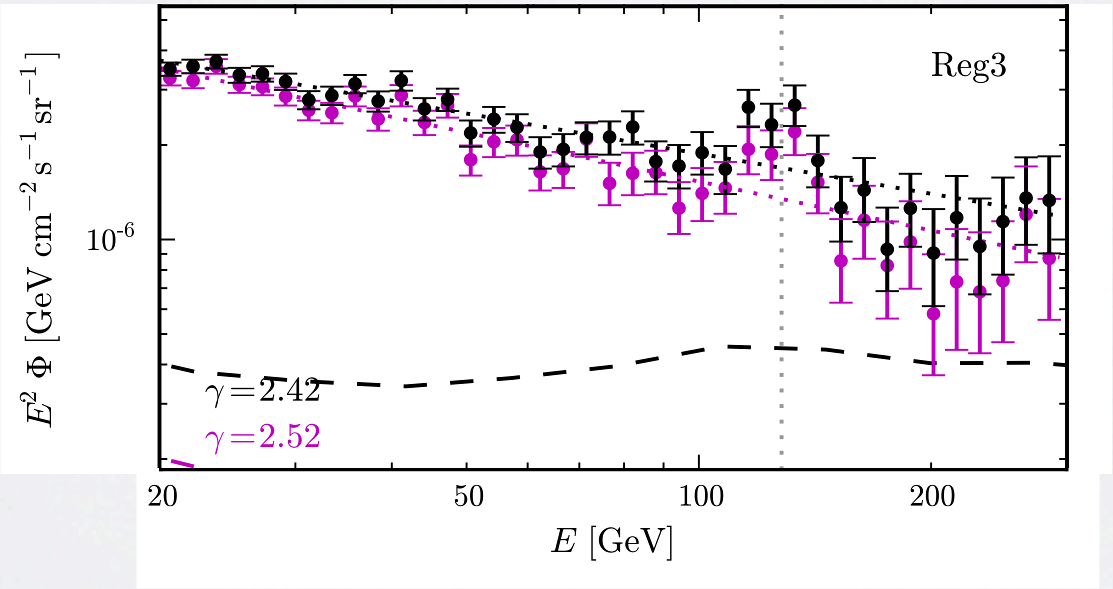


models where DM interacts via the Higgs

BUT THERE'S MORE

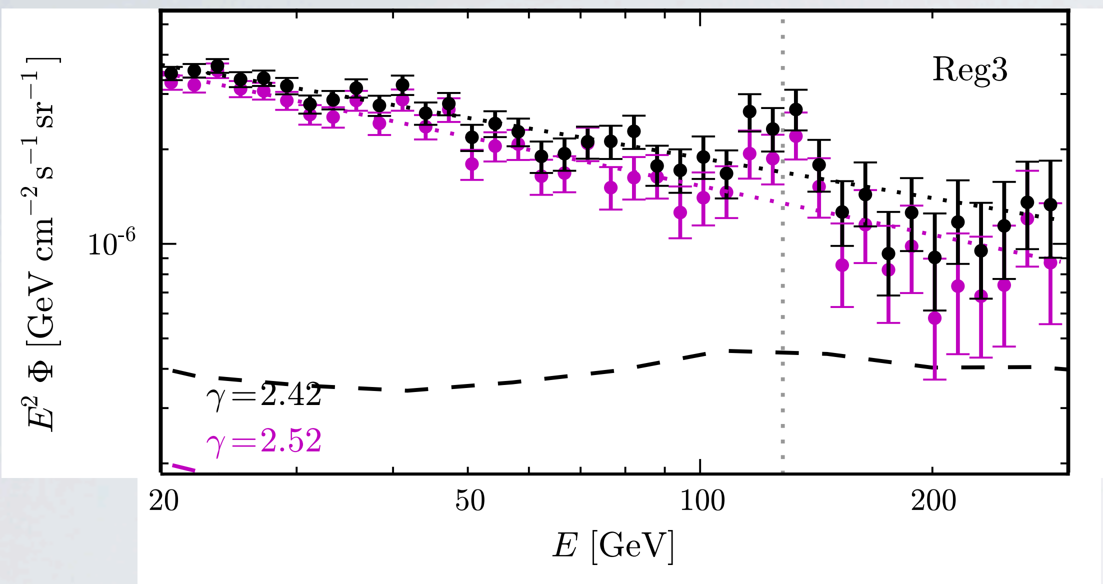


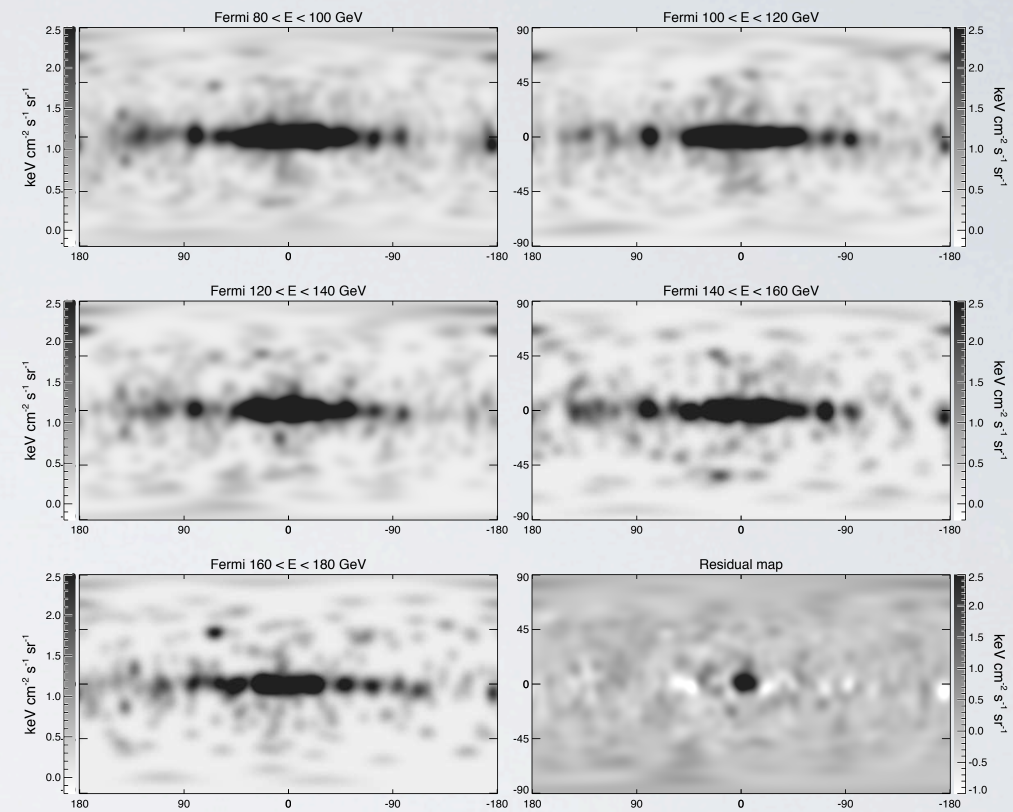


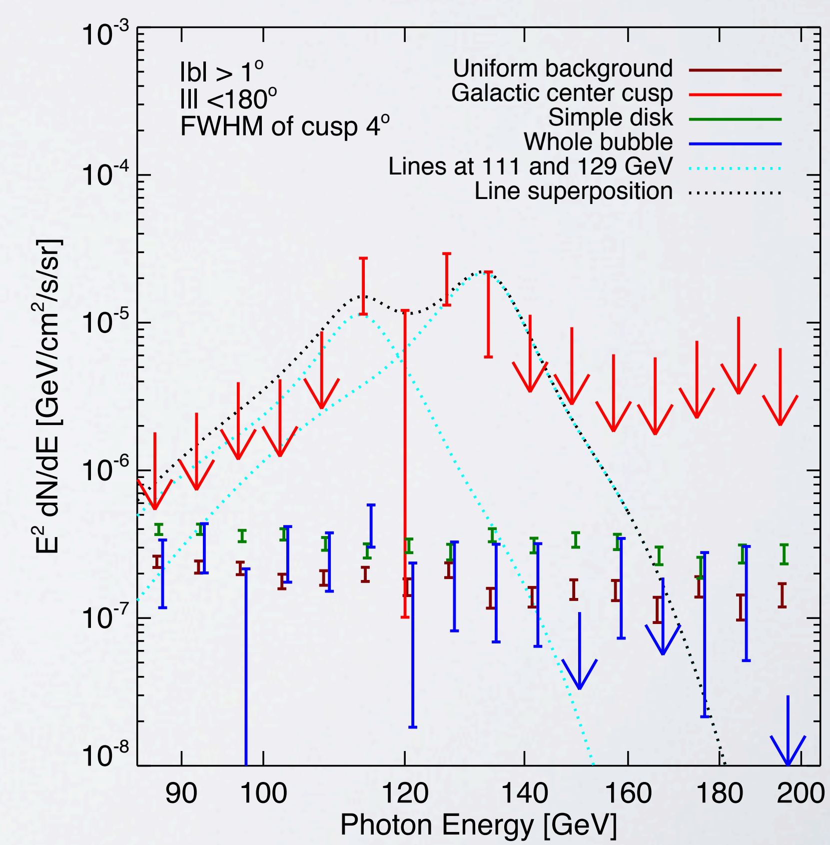


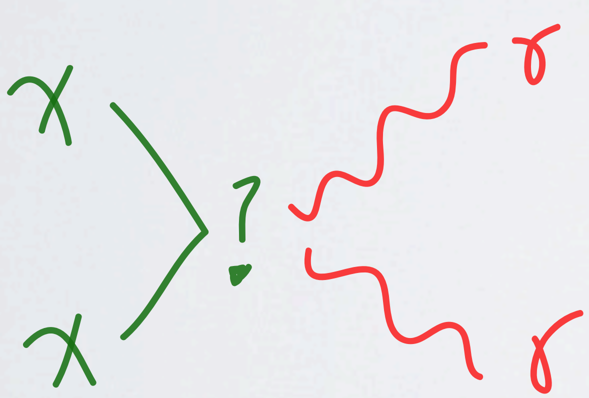
A FERMI LINE

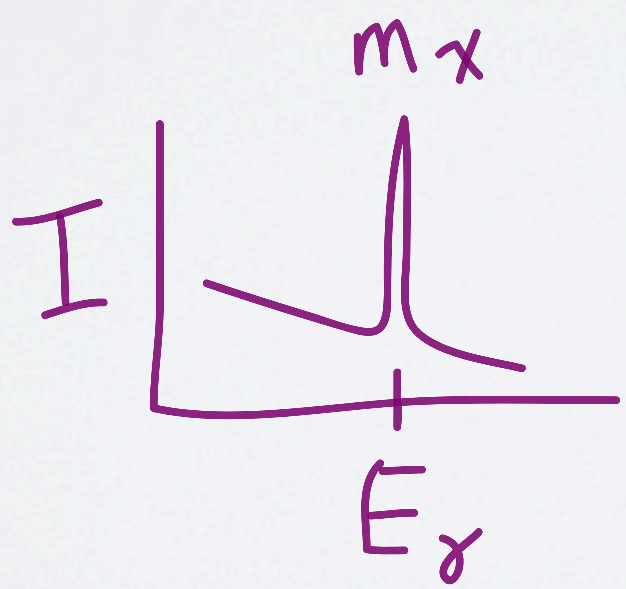
Weniger; Bringmann et al; Finkbeiner + Su...







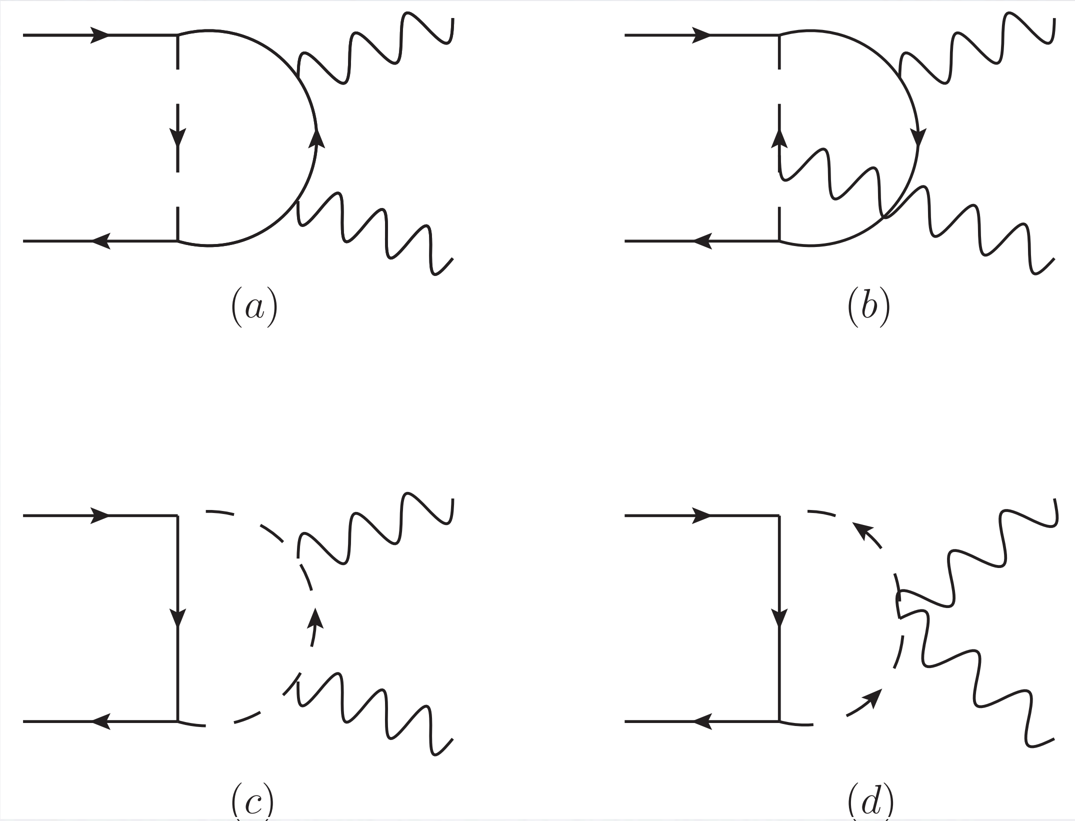




A FEW NUMBERS

- "Signal" is 20-40 photons
- Desired cross section is O(few) x $10^{-27}cm^3s^{-1}$
  (vs 3 x $10^{-26}cm^3s^{-1}$ for thermal relic abundance)
- Cross section depends on the halo model
- Rate bigger than naively expected for a WIMP
- Doesn't seem to have expected continuum emission (Buchmuller, Garny; Cohen, Lisanti, Slatyer, Wacker; Cholis, Tavakoli, Ulio)

STRONGLY COUPLED CHARGED STATES

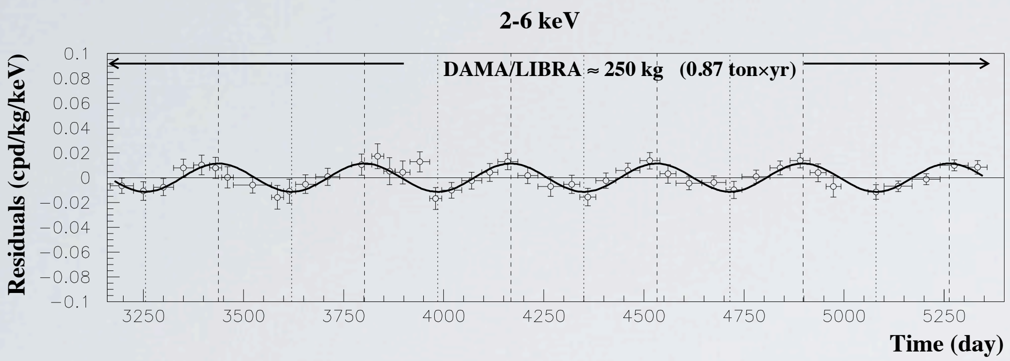


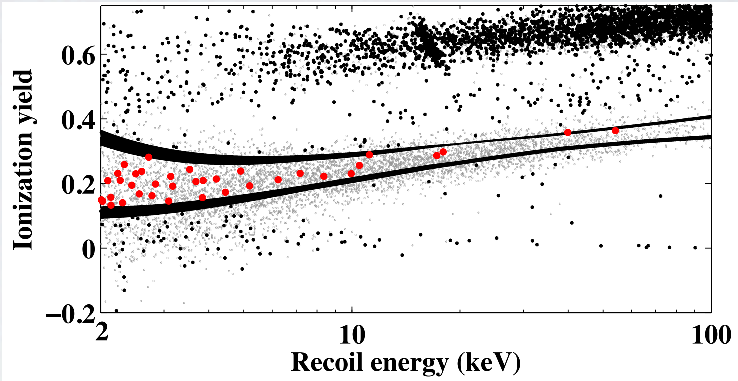
Loops of "charged things" near 100-200 GeV with large couplings to DM can yield this

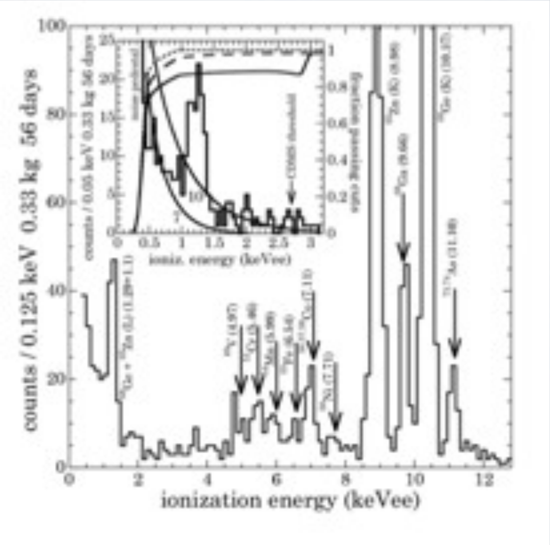
A similar ingredient can modify the $\gamma\gamma$ rate from Higgs decay

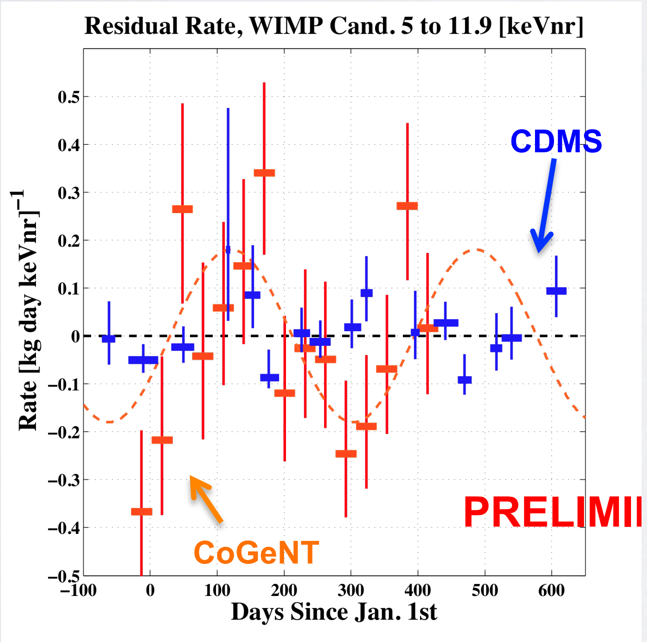
INVISIBLE HIGGS DECAYS

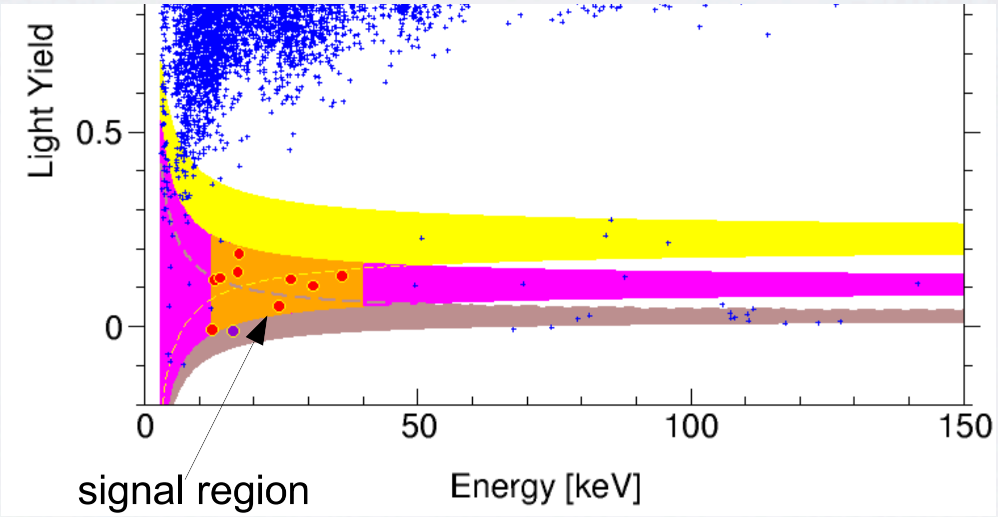
- Is there a motivation for a light state?

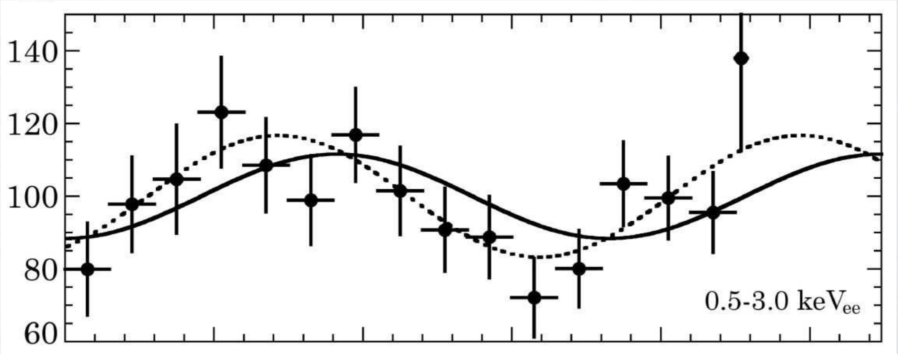

2-6 keV
DAMA/LIBRA ≈ 250 kg (0.87 ton×yr)
Residuals (cpd/kg/keV)
Time (day)


Ionization yield
Recoil energy (keV)


counts / 0.125 keV 0.33 kg 56 days
ionization energy (keVee)


Residual Rate, WIMP Cand. 5 to 11.9 [keVnr]
Rate [kg day keVnr]$^{-1}$
Days Since Jan. 1st
CDMS
CoGeNT
PRELIMI

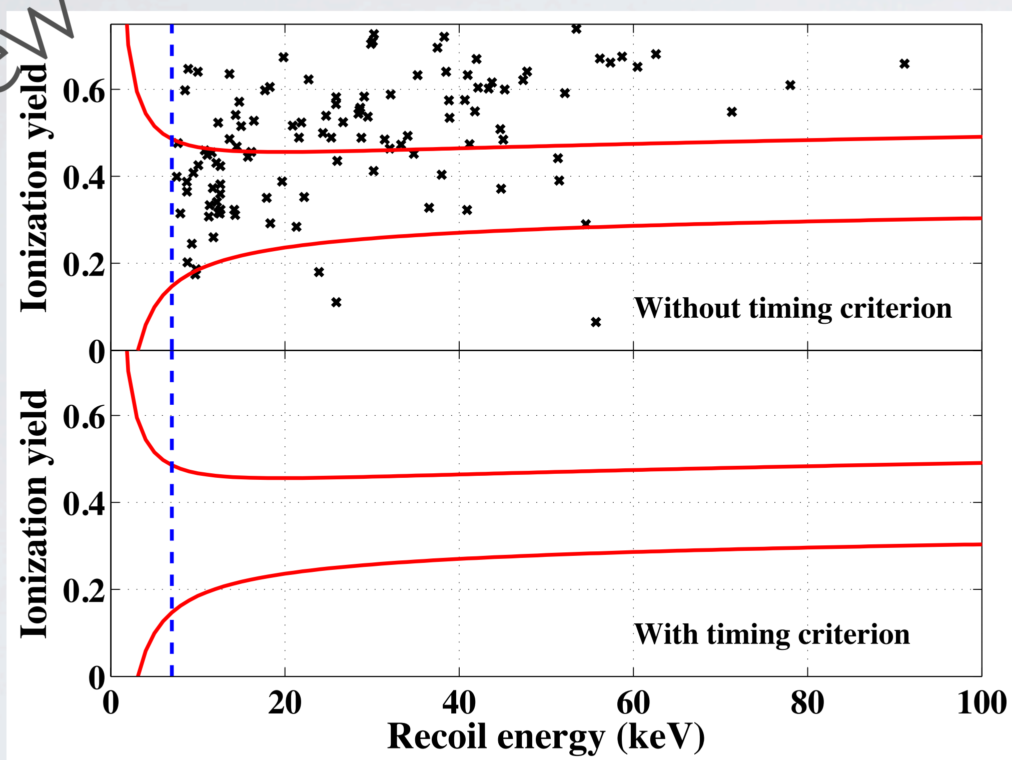

Light Yield
Energy [keV]
signal region

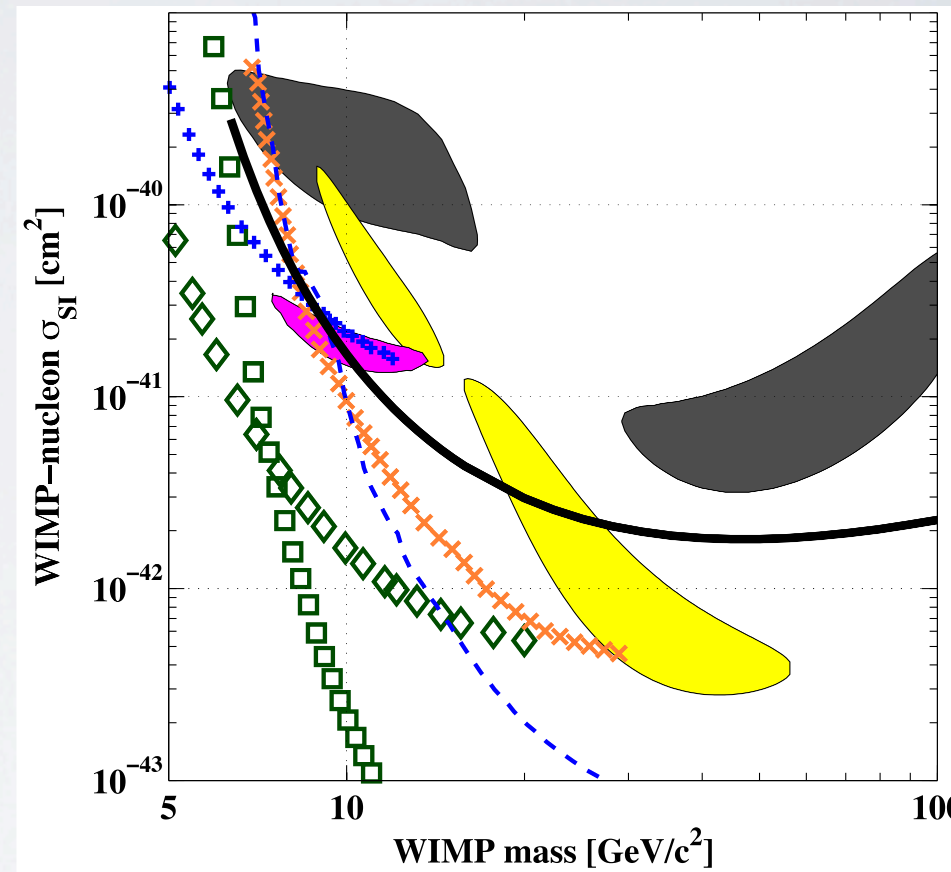

0.5-3.0 keV$_{ee}$

A NEW TWIST

CDMS-SI

New limits!



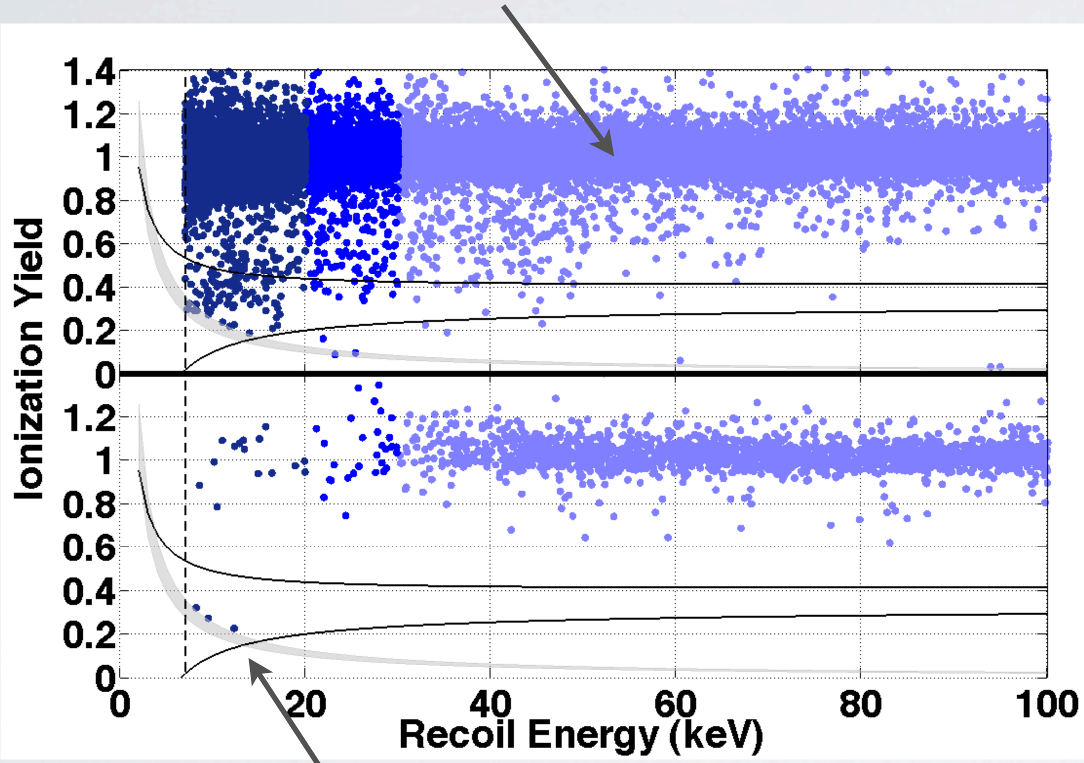


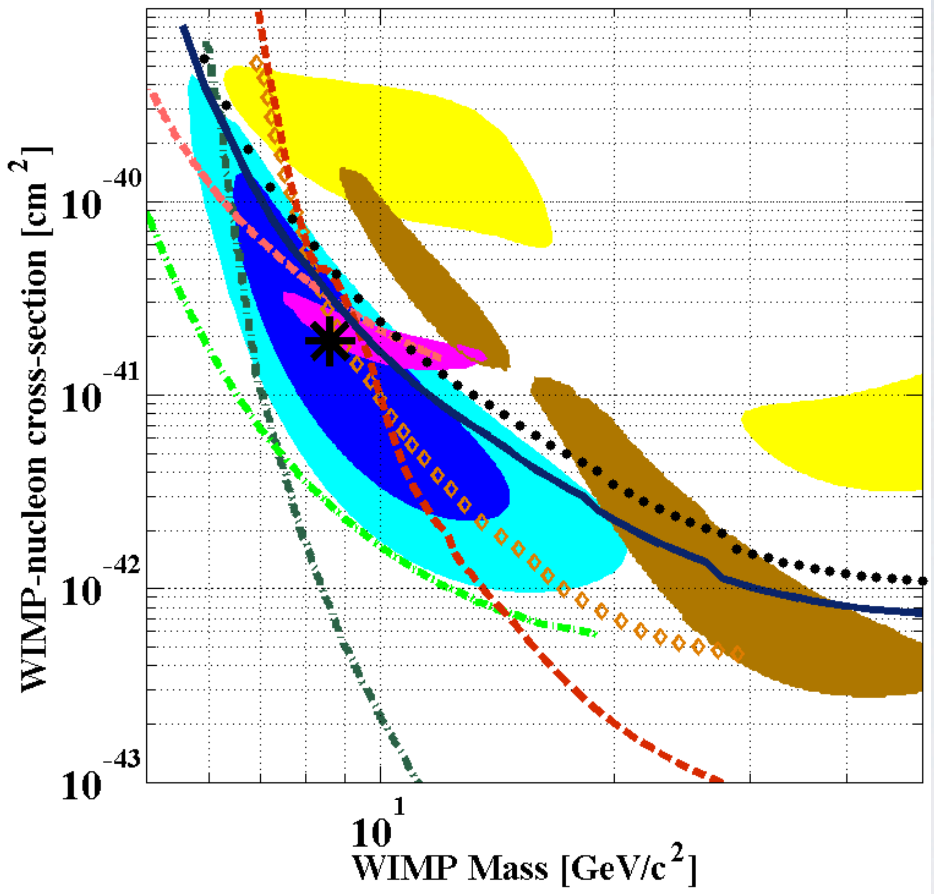
Appears arXiv April 14, 2013

CDMS-SI

Major differences:

color scheme





events

Appears arXiv April 15, 2013

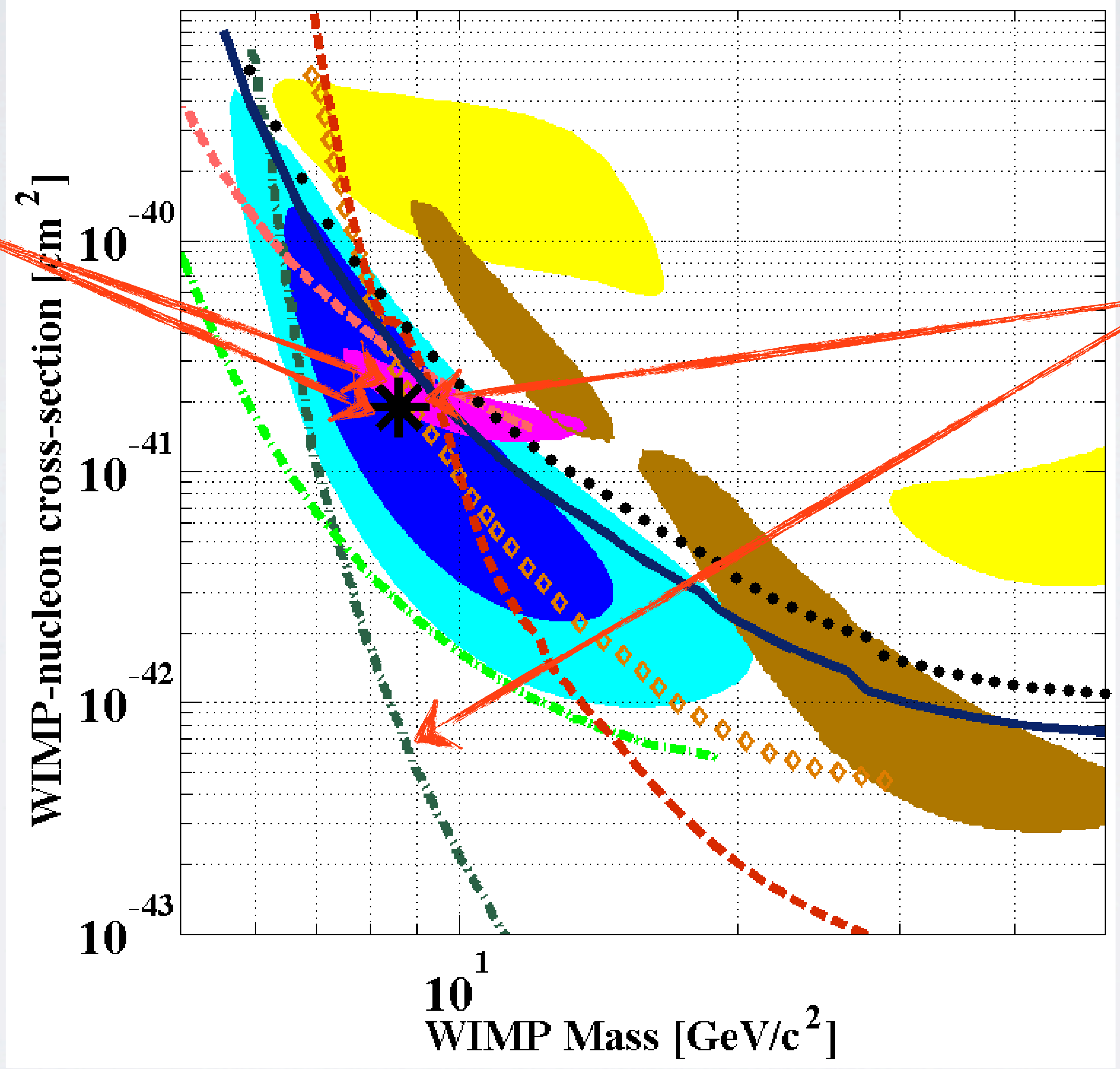
The most rapid development in an experimental result ever!

I HAVE SEEN THIS ONE BEFORE

I hope it’s not a bad remake

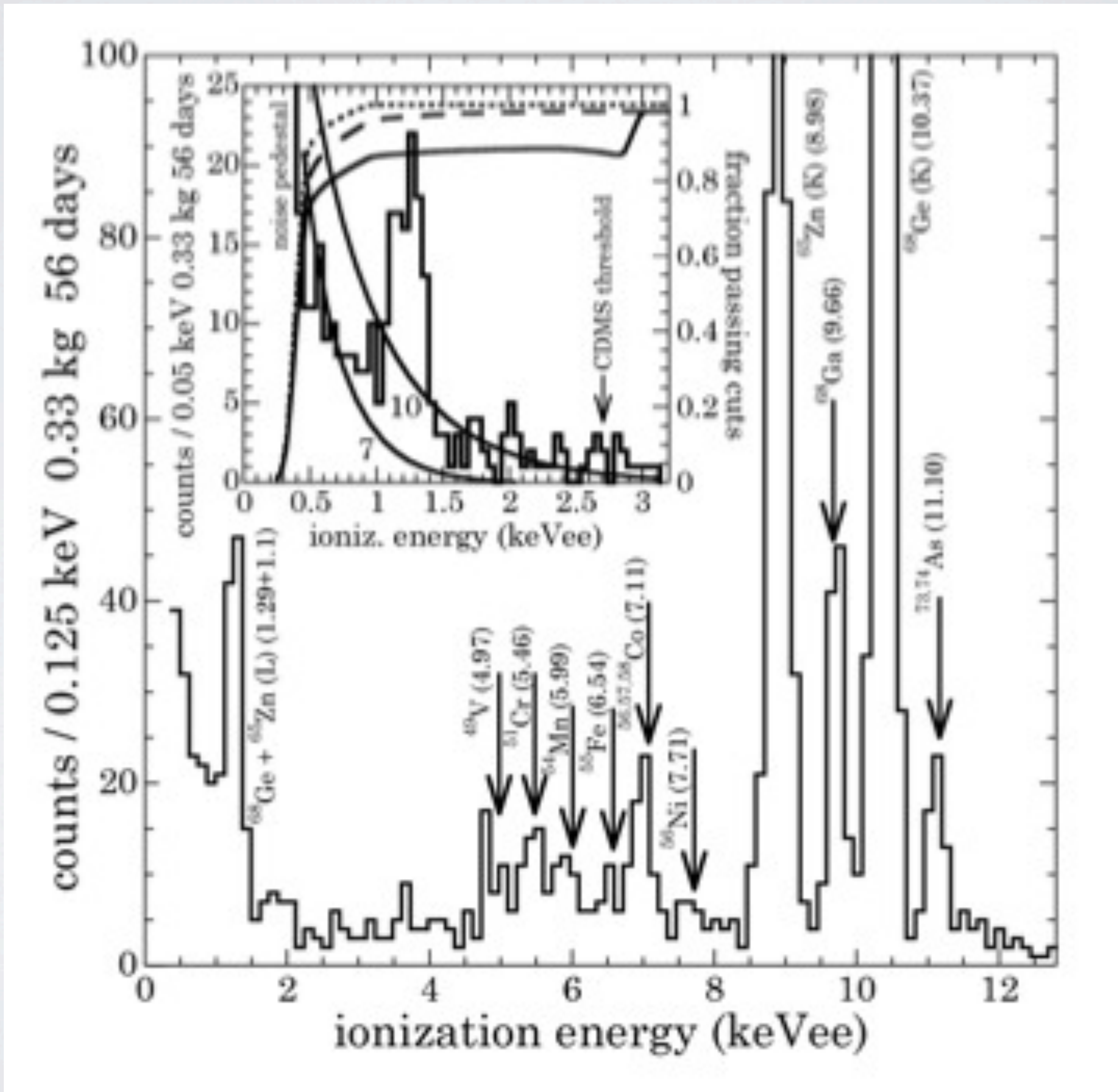
KEY QUESTIONS

how excited should I be by this?

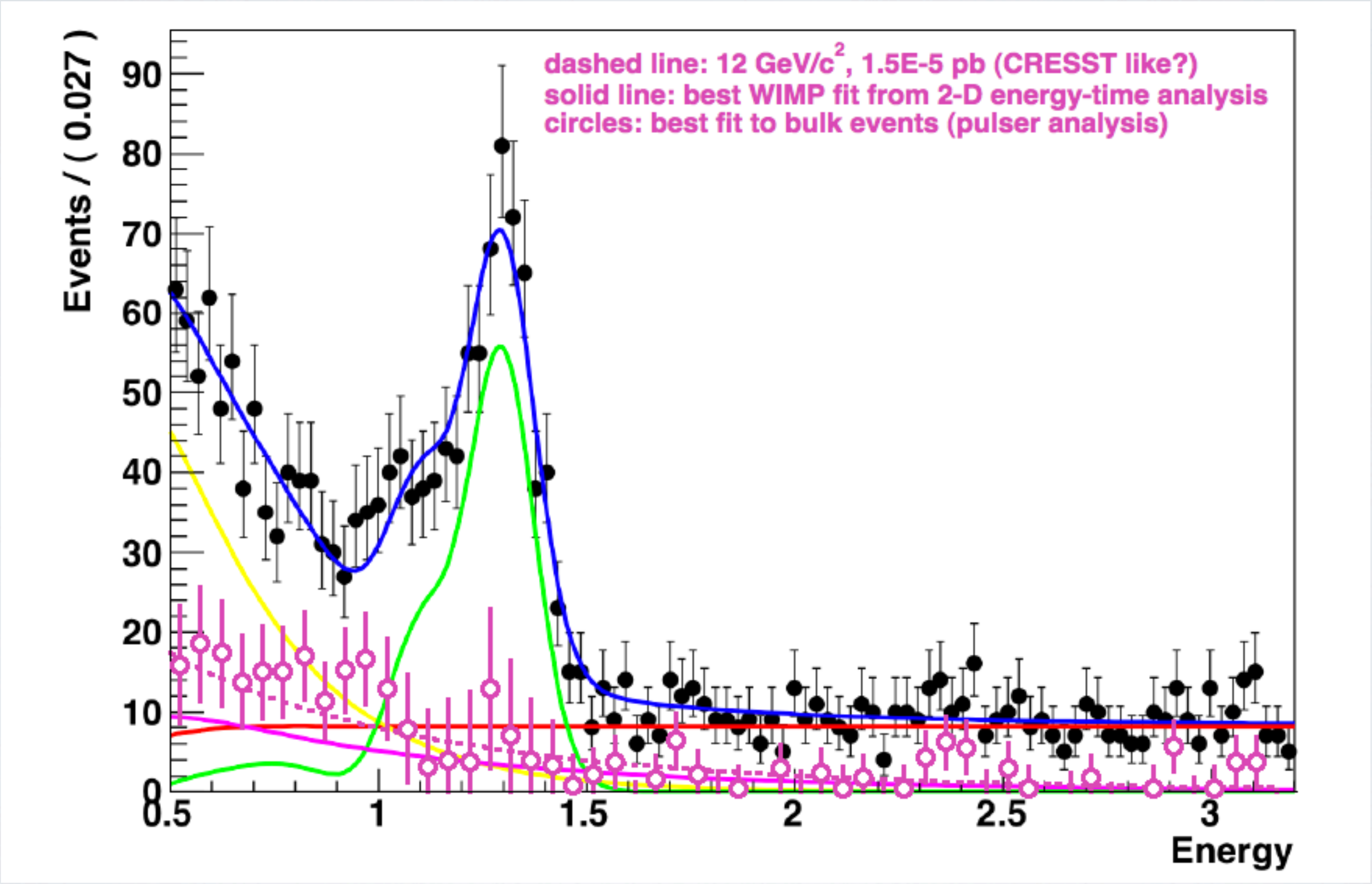


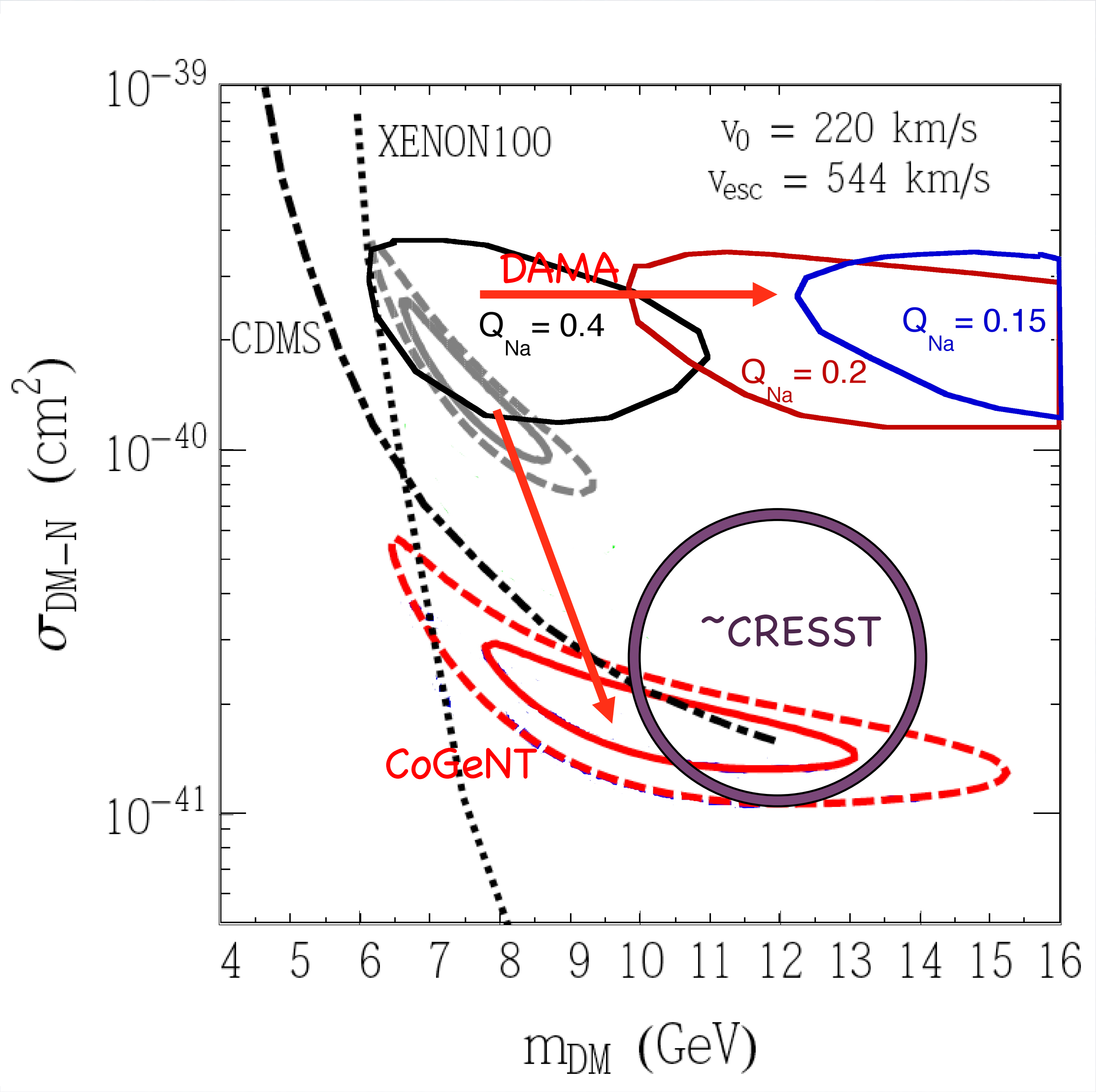
how worried should I be by this?

A BIT OF BACKGROUND



A BIT OF BACKGROUND





10^−39
10^−40
10^−41
XENON100
v0 = 220 km/s
vesc = 544 km/s
DAMA
CDMS
Q Na = 0.4
Q Na = 0.2
Q Na = 0.15
~CRESST
CoGeNT
σDM−N (cm2)
4 5 6 7 8 9 10 11 12 13 14 15 16
mDM (GeV)

- NB: Existing detectors are designed to find light WIMPs by accident

- NB: That is not the fault of light WIMPs

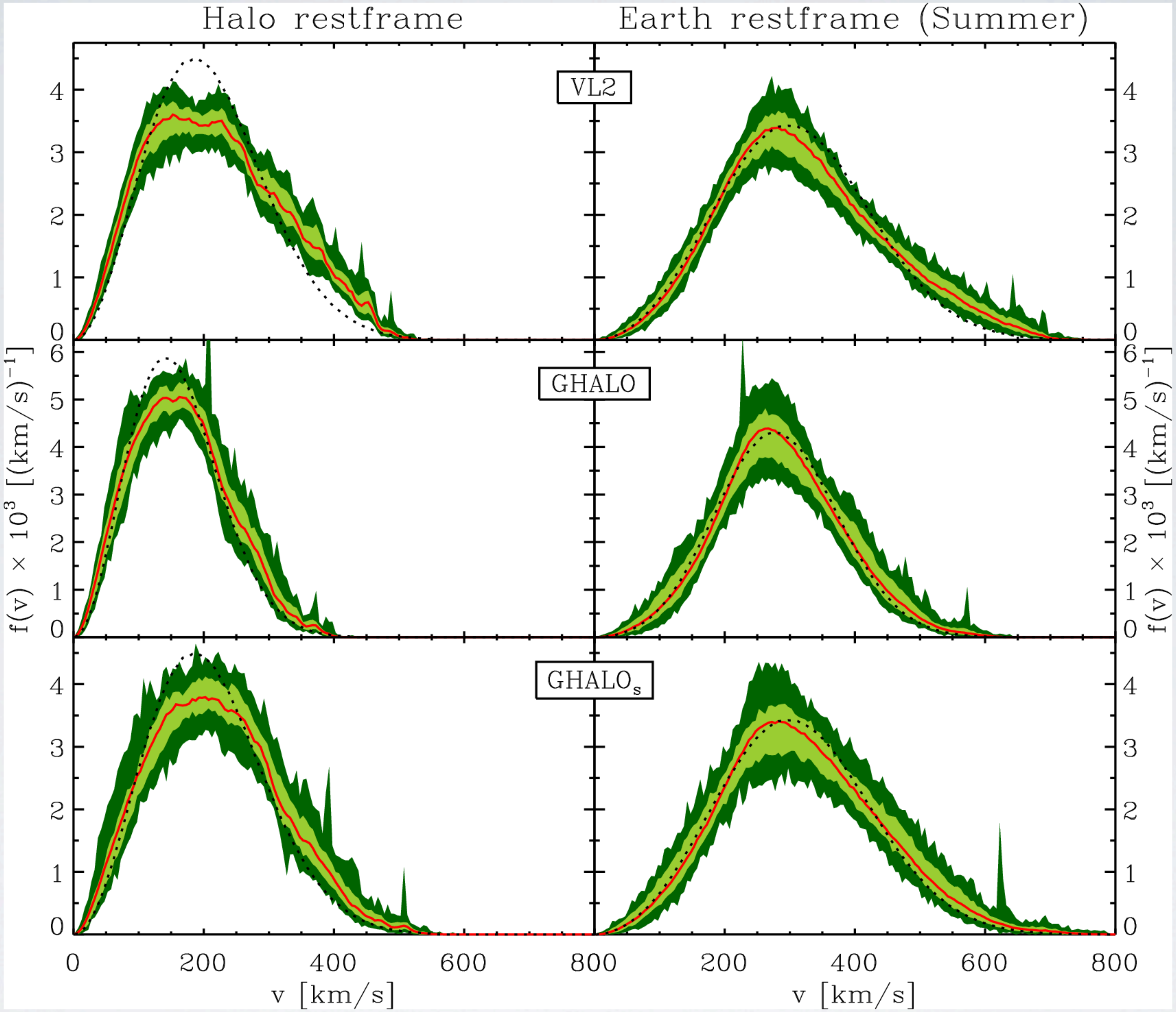
THE THEORIST BAG OF TRICKS

Appeal to astrophysics → Light WIMPs sample the tail of velocity distributions

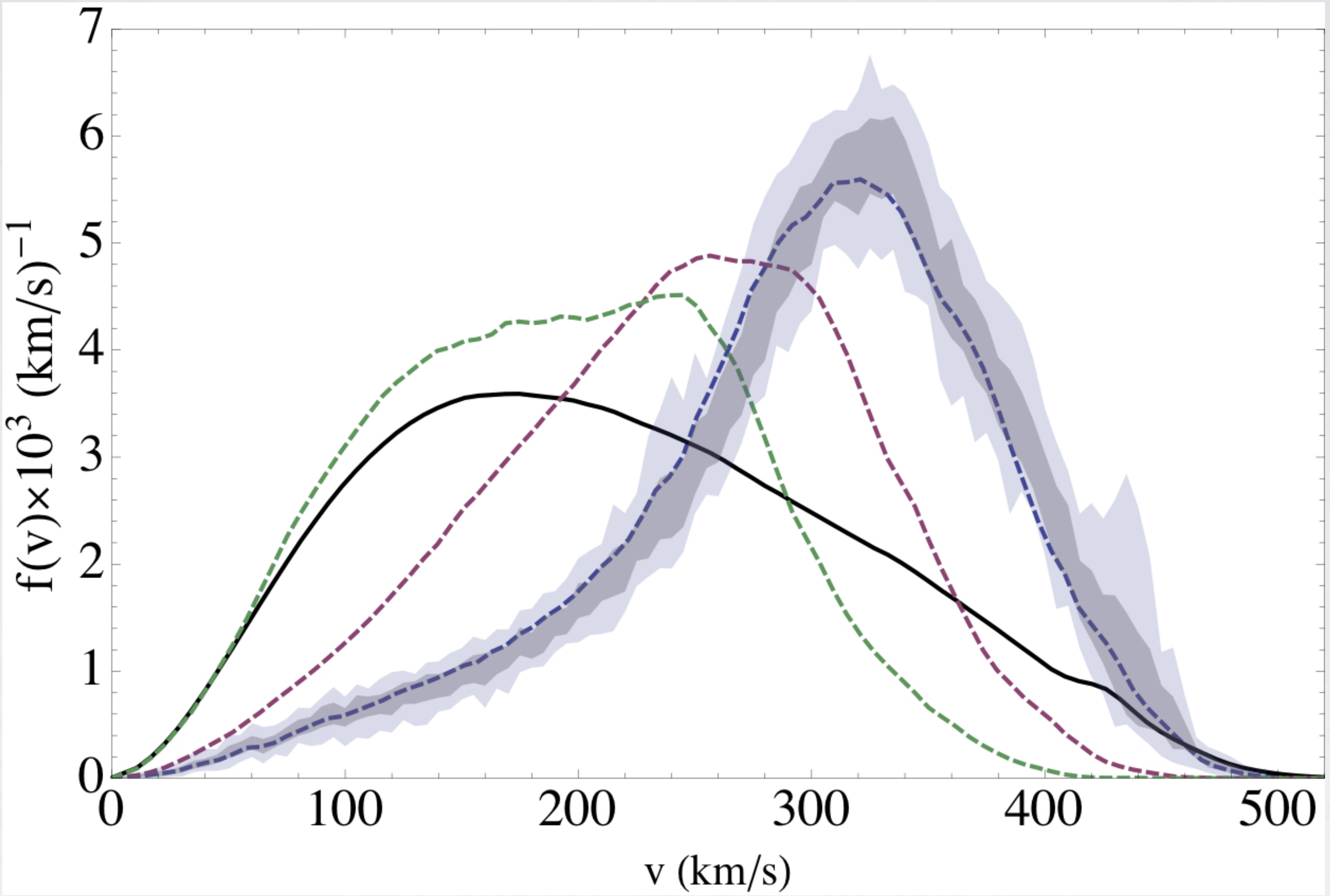
Appeal to particle physics → Why should a light WIMP act like a neutralino?

The model builder's last refuge...

Kuhlen, et al



MB generally good near the peak, generally not near the tail



Lisanti+Spergel; Kuhlen, Lisanti + Spergel

Debris flows modify w/o streams

TWO KEY POINTS

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

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

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

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

AN APPROACH

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

$$E_{xe} = \frac{\mu_{xe}^2 M_{si}}{\mu_{si}^2 M_{xe}} E_{si}$$

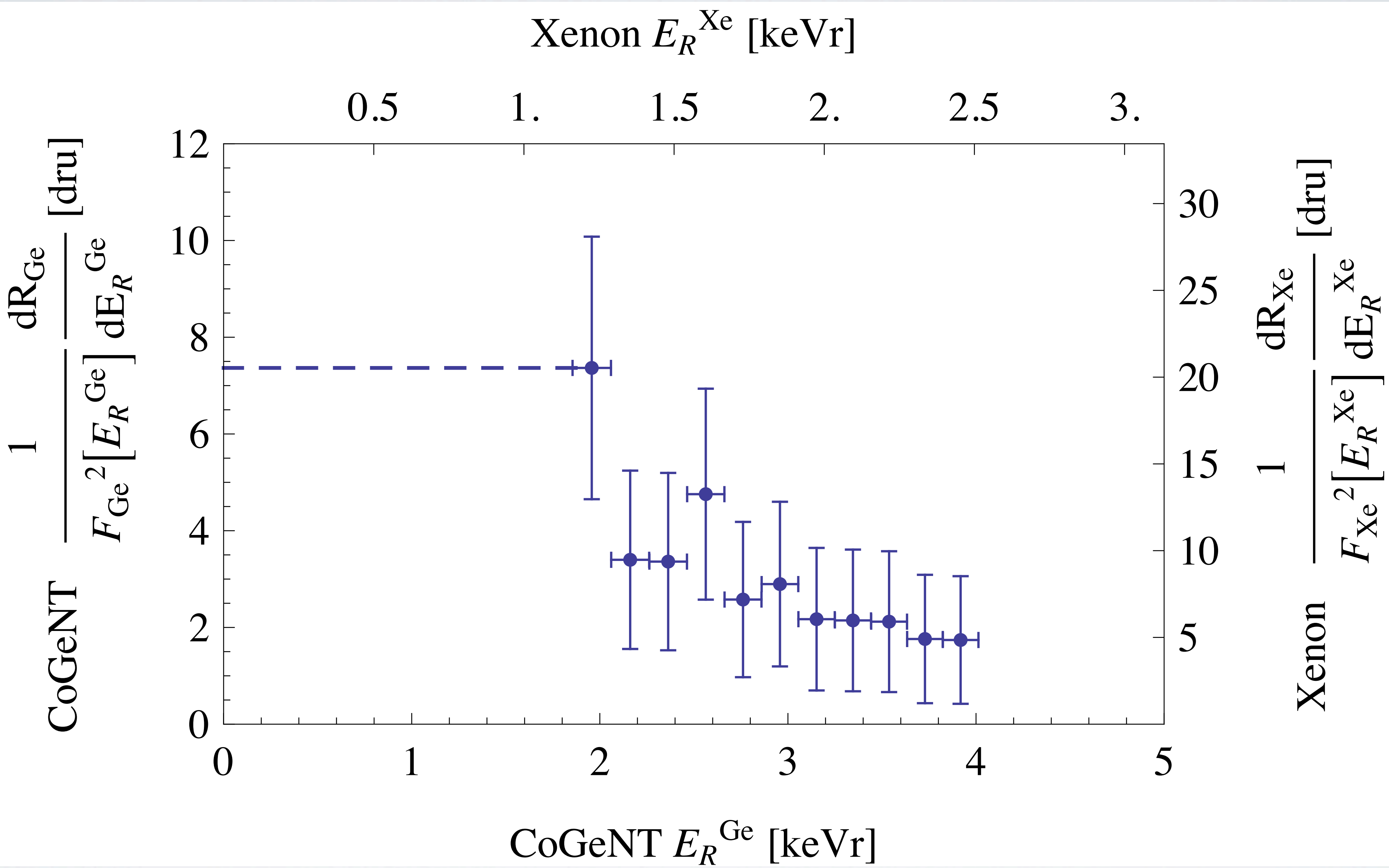
AN APPROACH

Invert:

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

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

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



Xenon E_R^{Xe} [keVr]
0.5
1.
1.5
2.
2.5
3.
CoGeNT $\frac{1}{F_{Ge}^2[E_R^{Ge}]}\frac{dR_{Ge}}{dE_R^{Ge}}$ [dru]
0
2
4
6
8
10
12
Xenon $\frac{1}{F_{Xe}^2[E_R^{Xe}]}\frac{dR_{Xe}}{dE_R^{Xe}}$ [dru]
5
10
15
20
25
30
0
1
2
3
4
5
CoGeNT E_R^{Ge} [keVr]

CONSTRAINTS?

What if your experiment

a) doesn't probe the same vmin space?

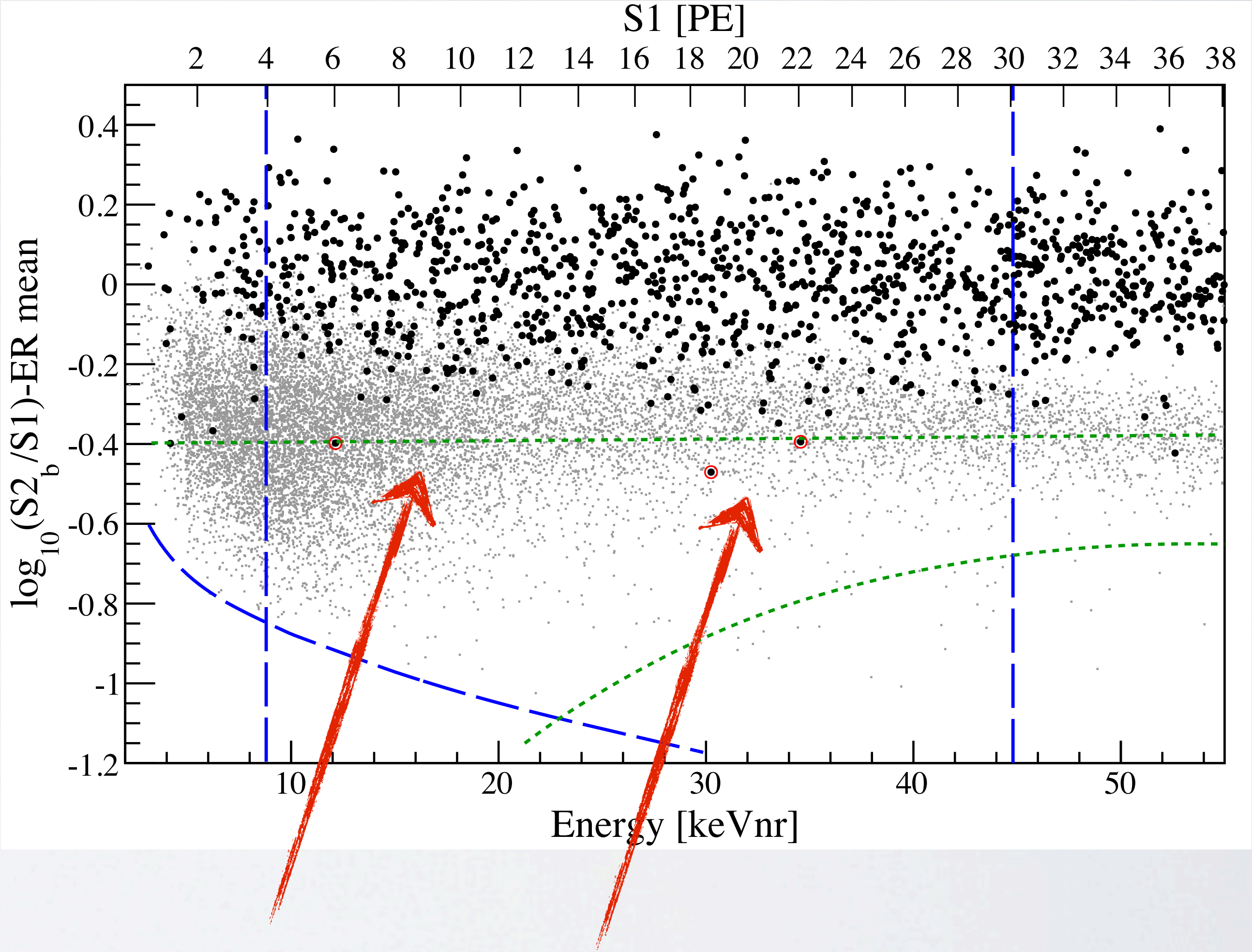
b) doesn't see anything?

Make a limit on g(v)

limiting g(v)

Note: g(v) is monotonic!

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



also Fox, Kribs, Tait 1011.1910; McCabe 1107.0741; ;Frandsen et al 1111.0292; Herrero-Garcia, Schwetz, Zupan 1112.1627, 1205.1345; Gelmini + Gondolo 1202.6539

Lack of events Gives constraints

at low E at high E

limiting g(v)

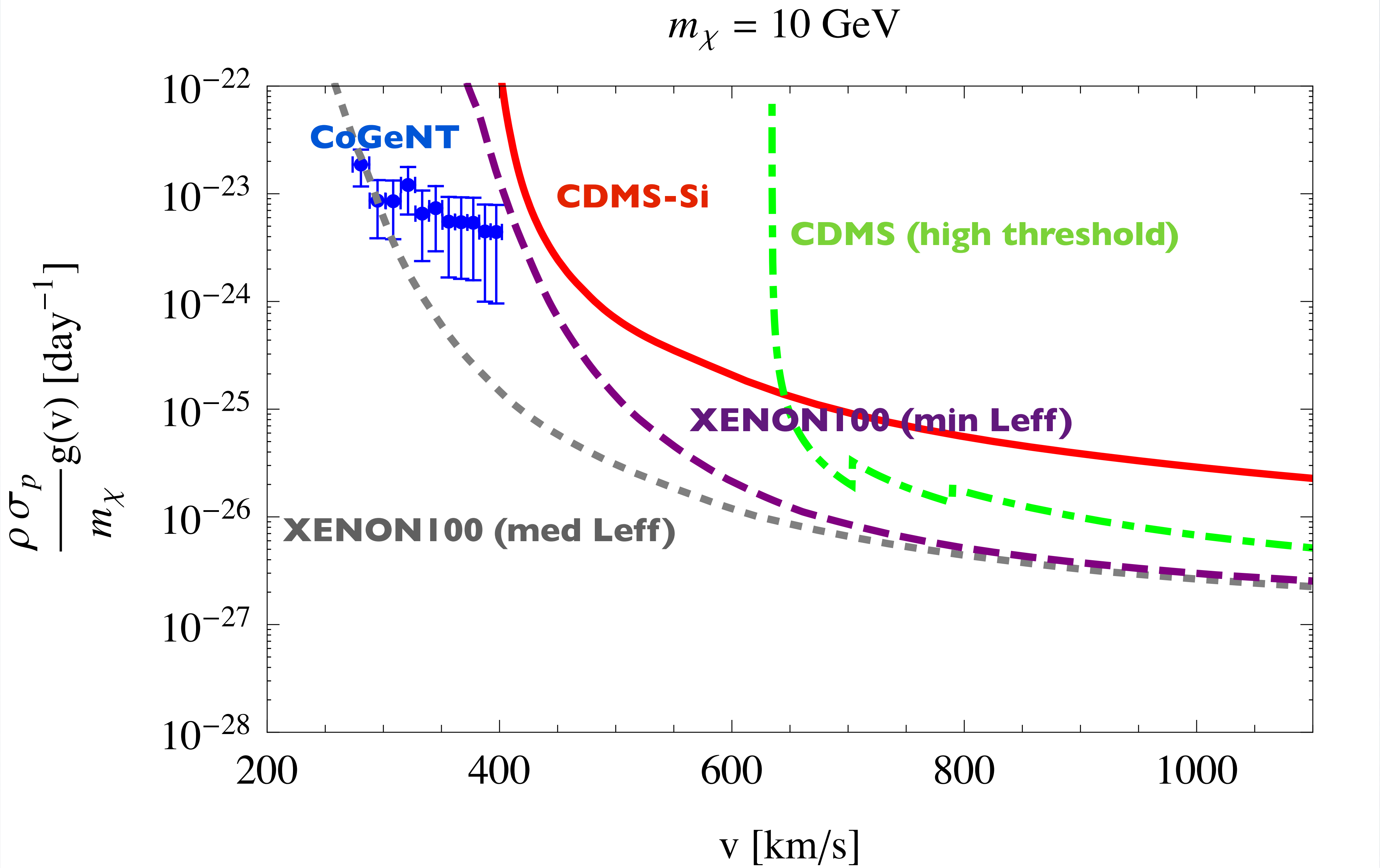
Most conservative assumption is theta function

$$g(v; v_1) = g_1 \Theta(v_1 - v)$$

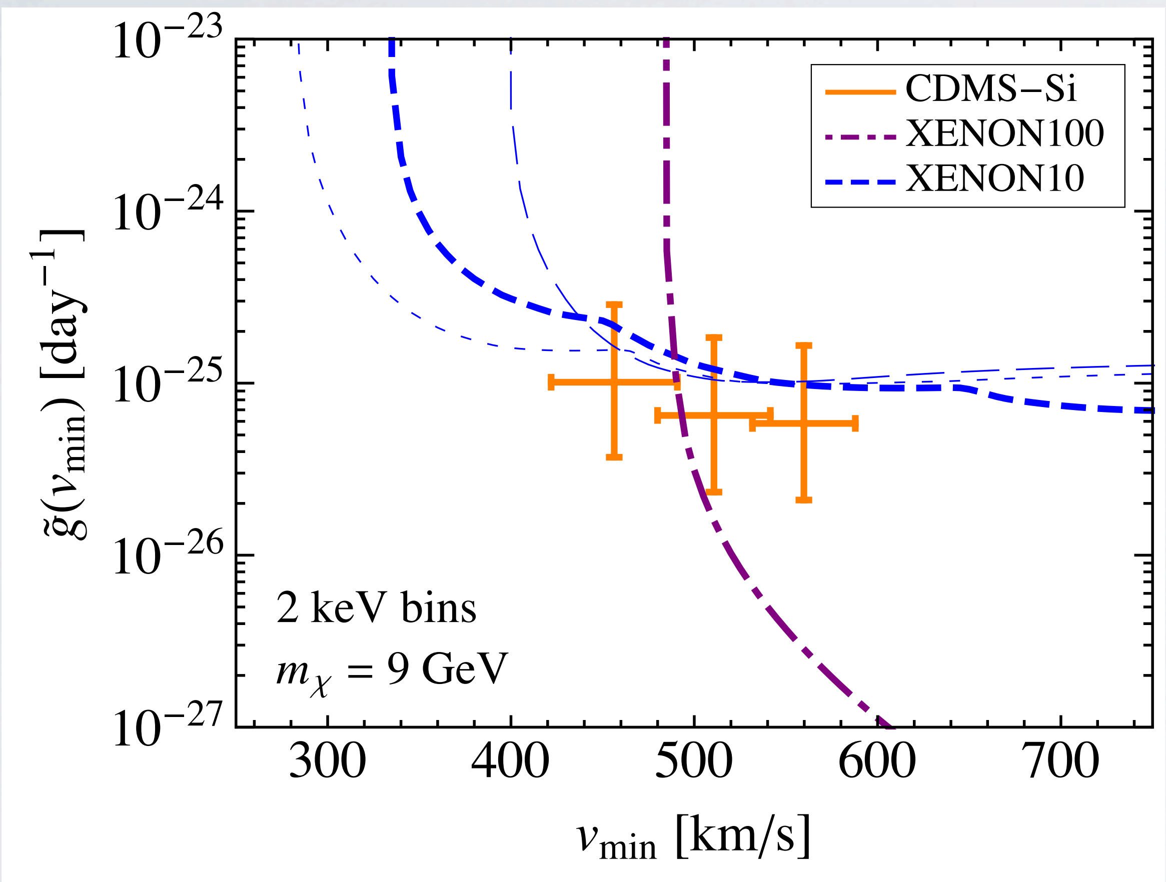
i.e., do not assume velocity extends to known but exponentially suppressed values at high velocity

$$\frac{dR}{dE_R} = \frac{N_T M_T \rho}{2 m_\chi \mu^2} \sigma(E_R)\, g_1 \Theta(v_1 - v_{min}(E_R))$$

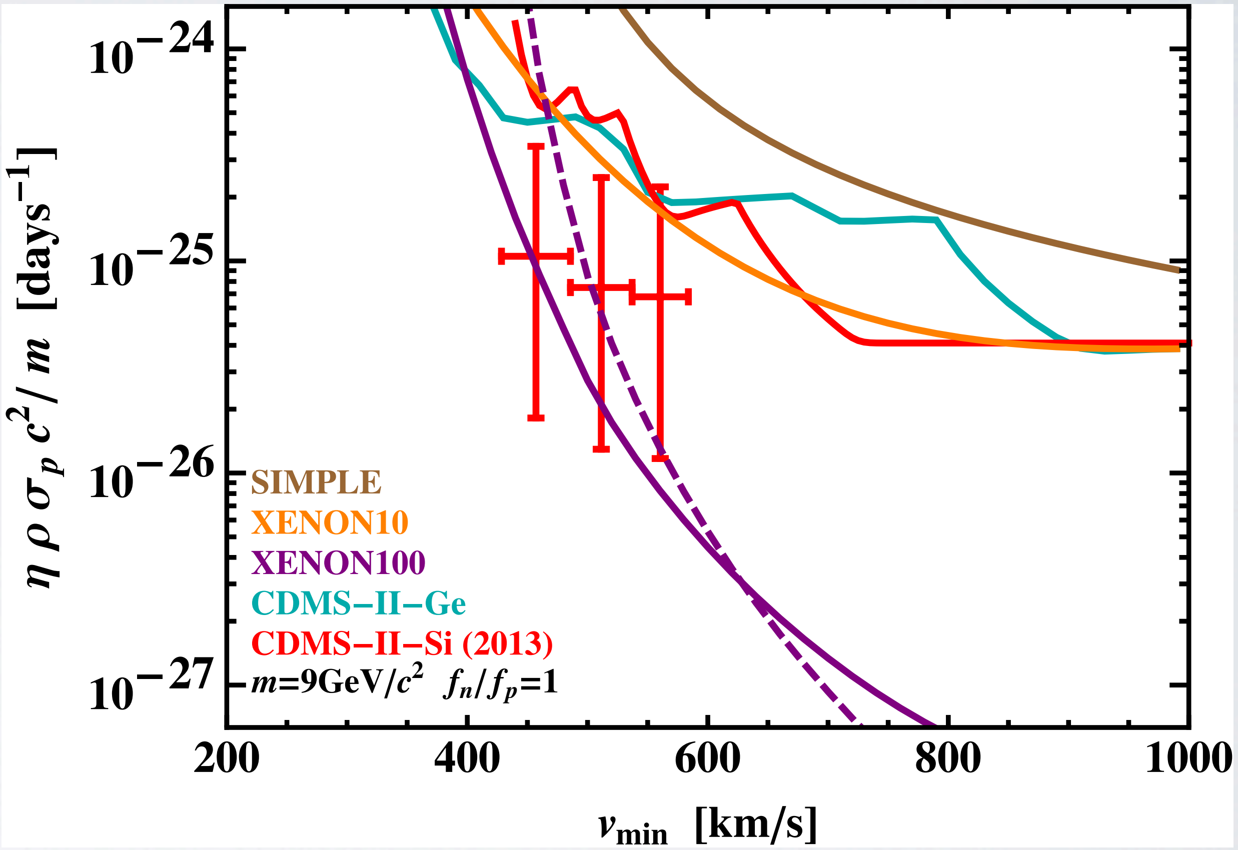
constraining g(v)



IN THE PRESENT CONTEXT

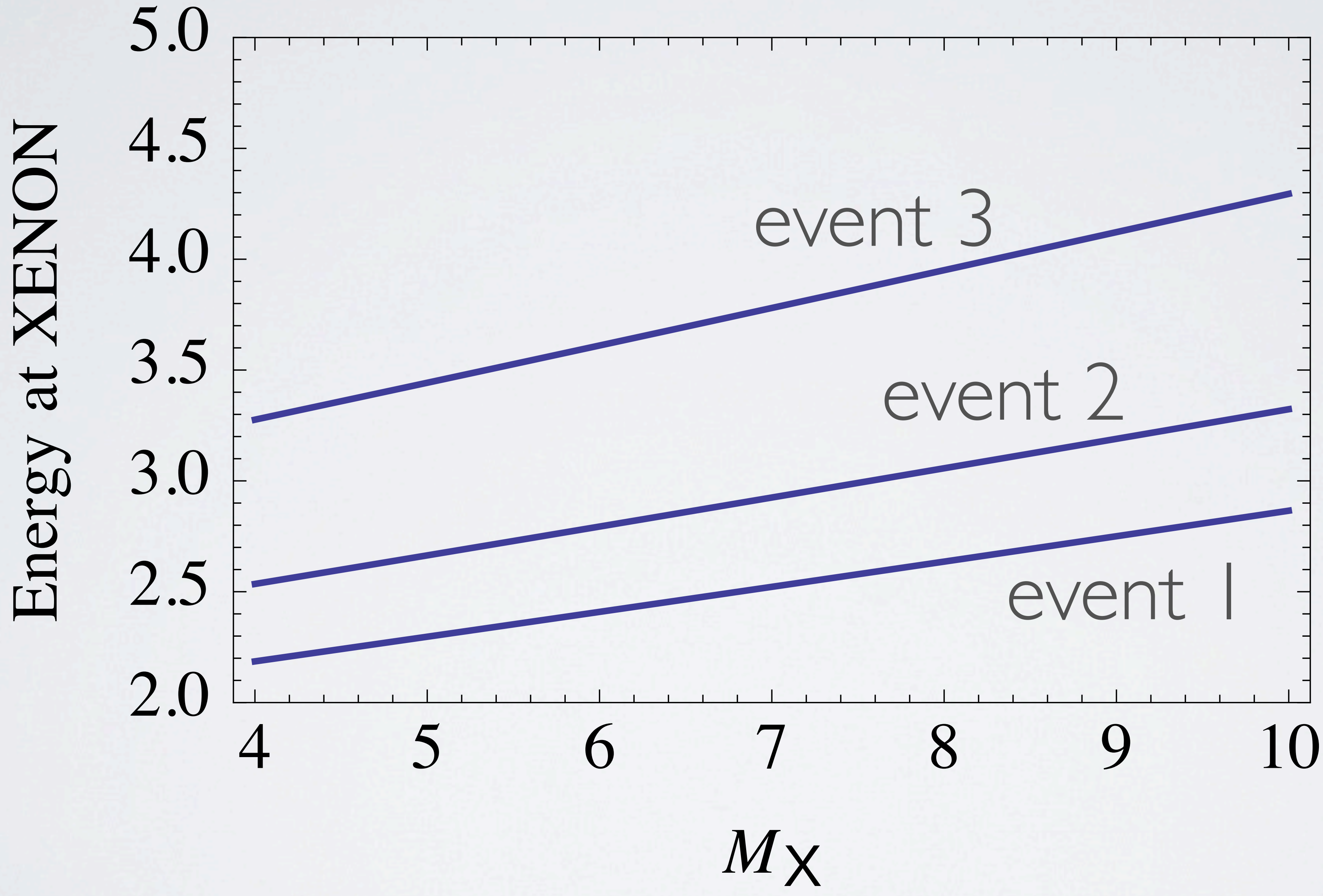


Frandsen et al

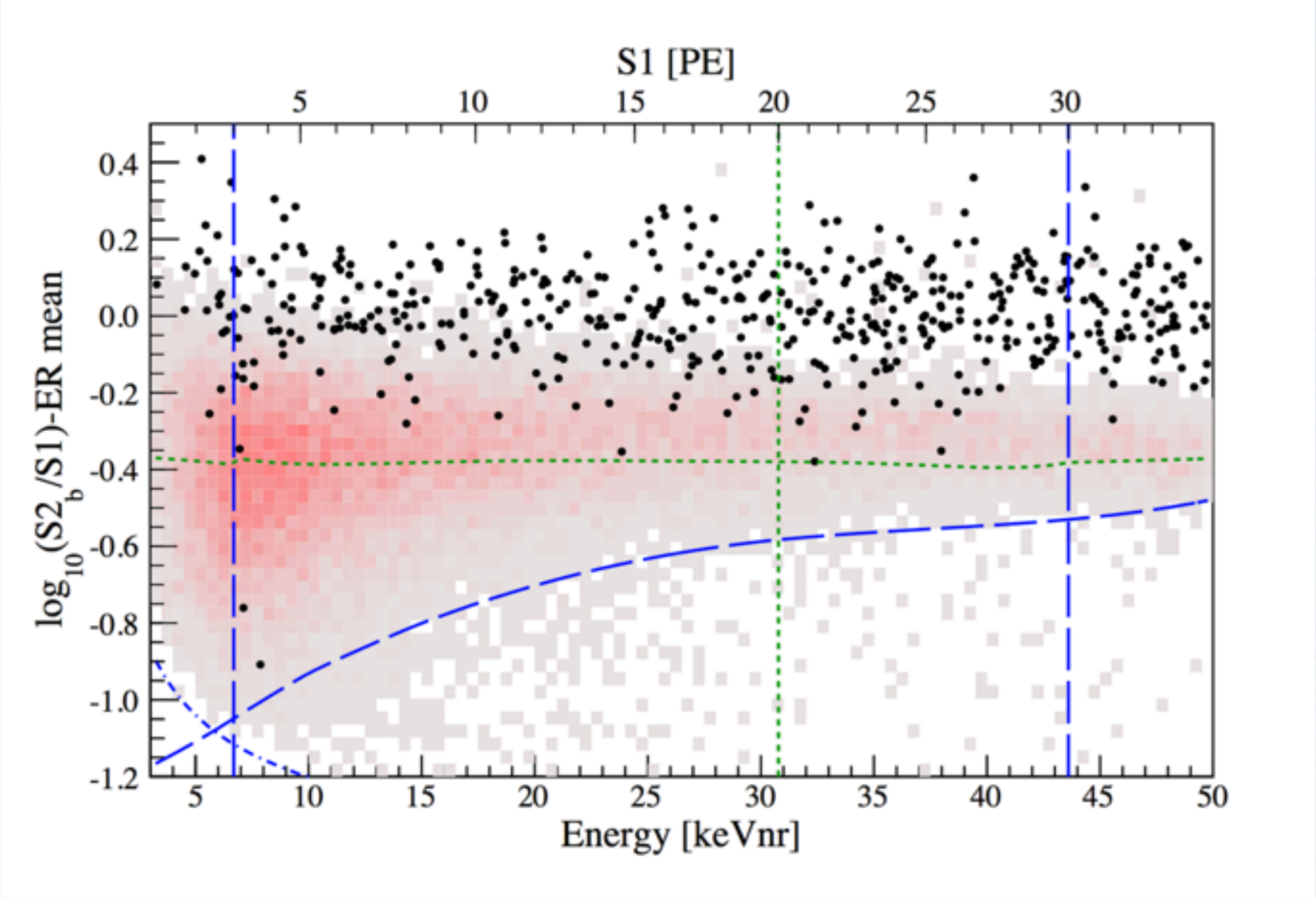


de Nobile et al

SOME NUMBERS

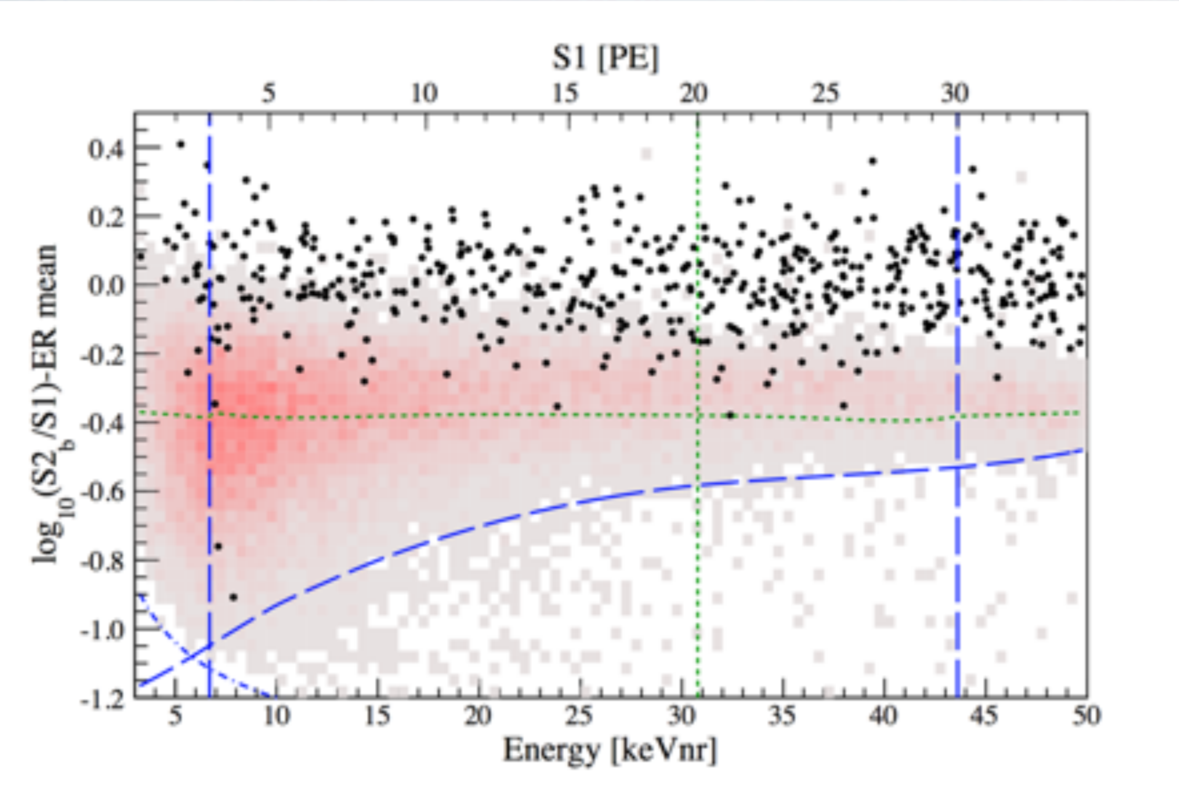


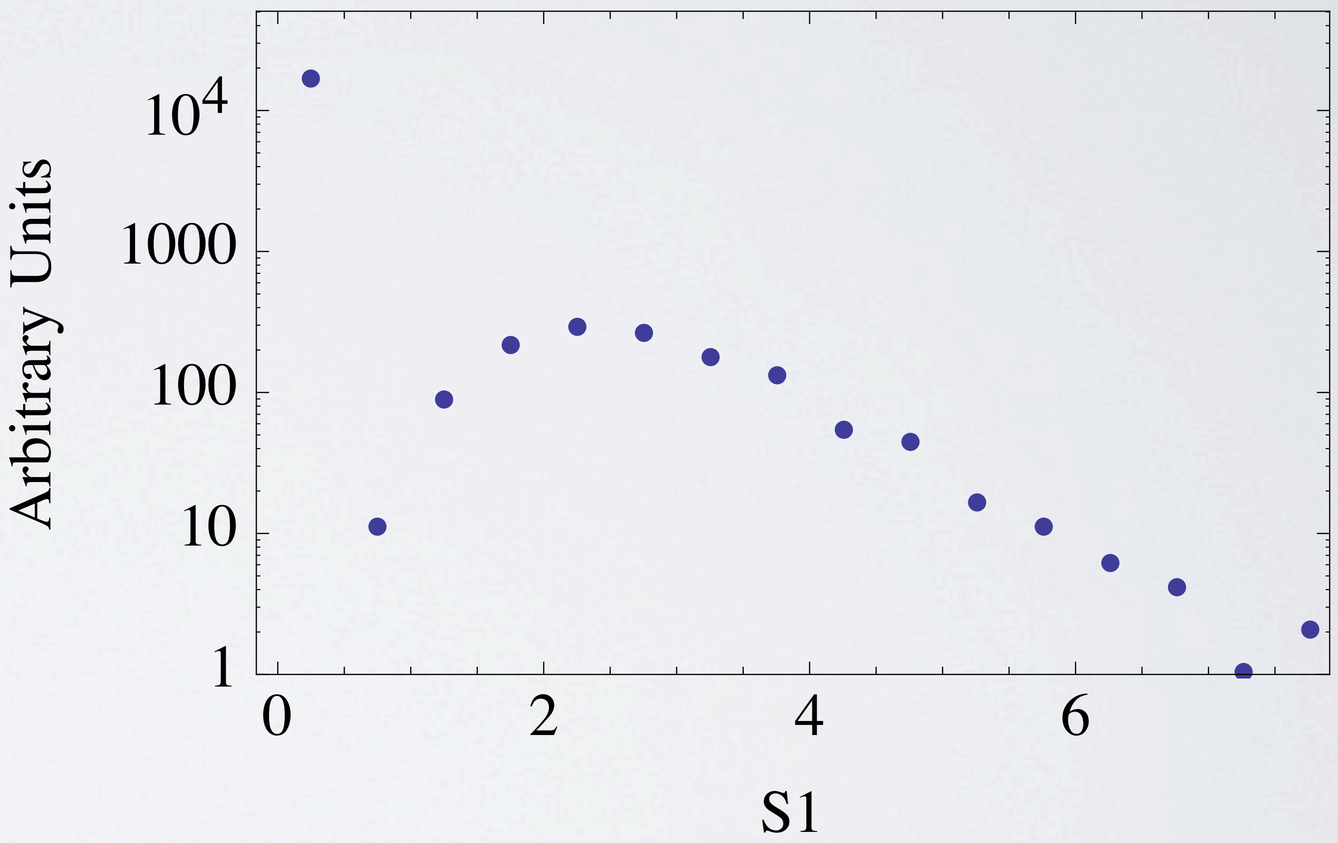
XENON100 doesn't have an *energy* threshold, it has a *light* threshold



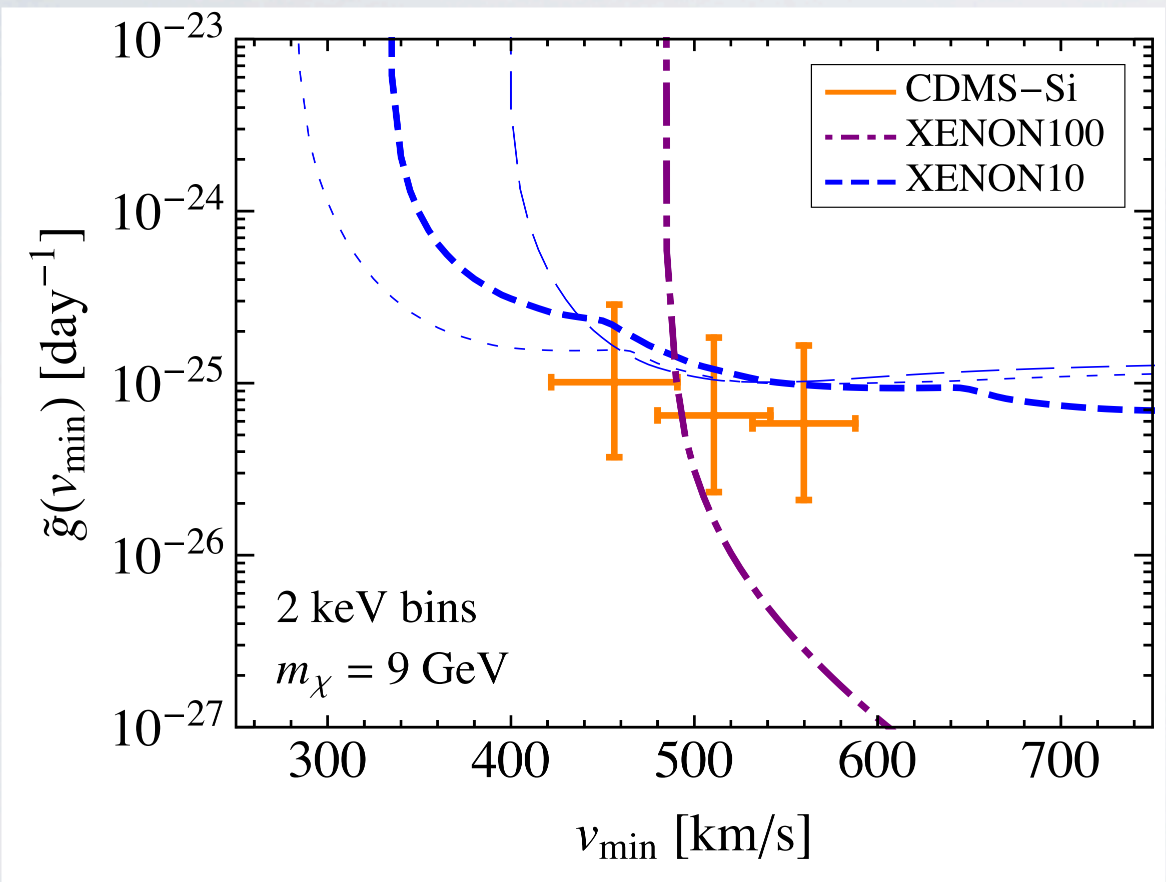
for a given energy, there is an expected amount of light (S1) and *fluctuations*

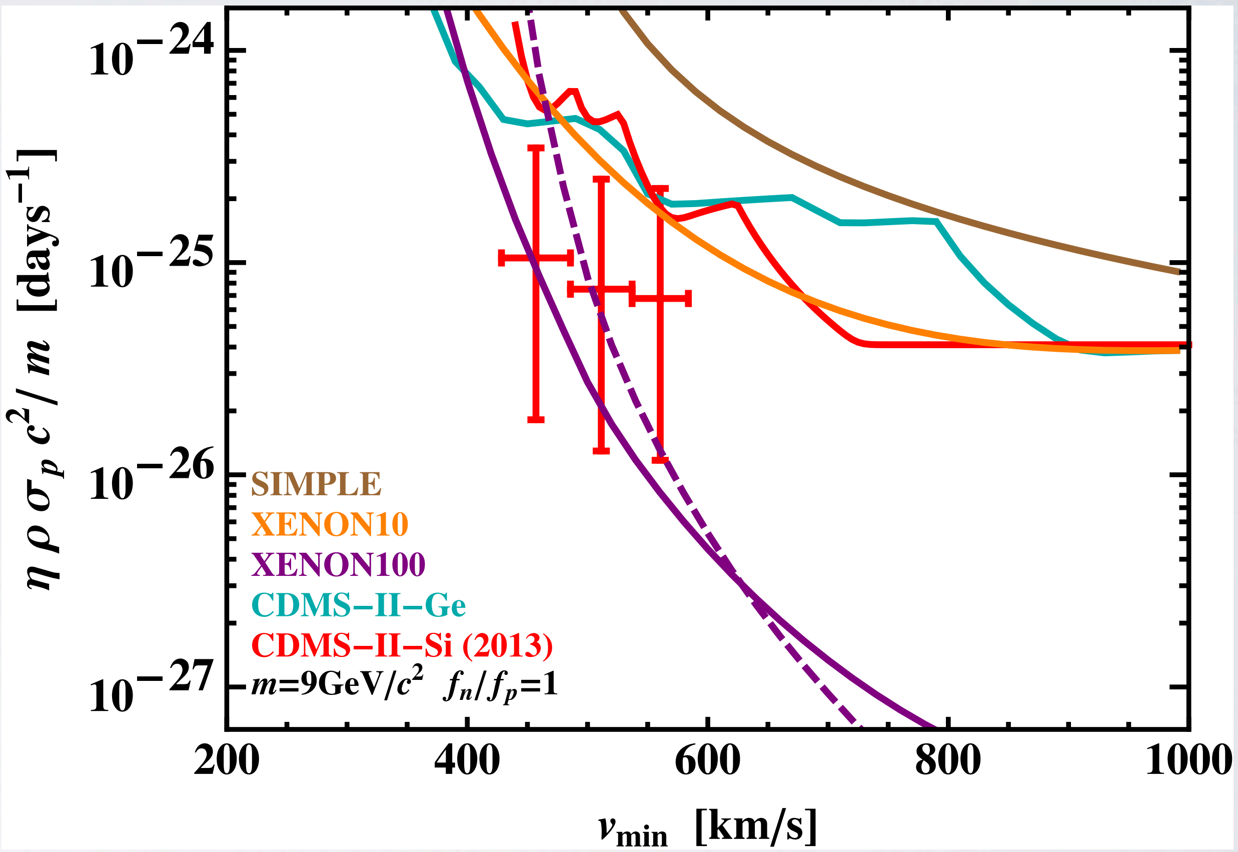
(simulated by P Sorensen)





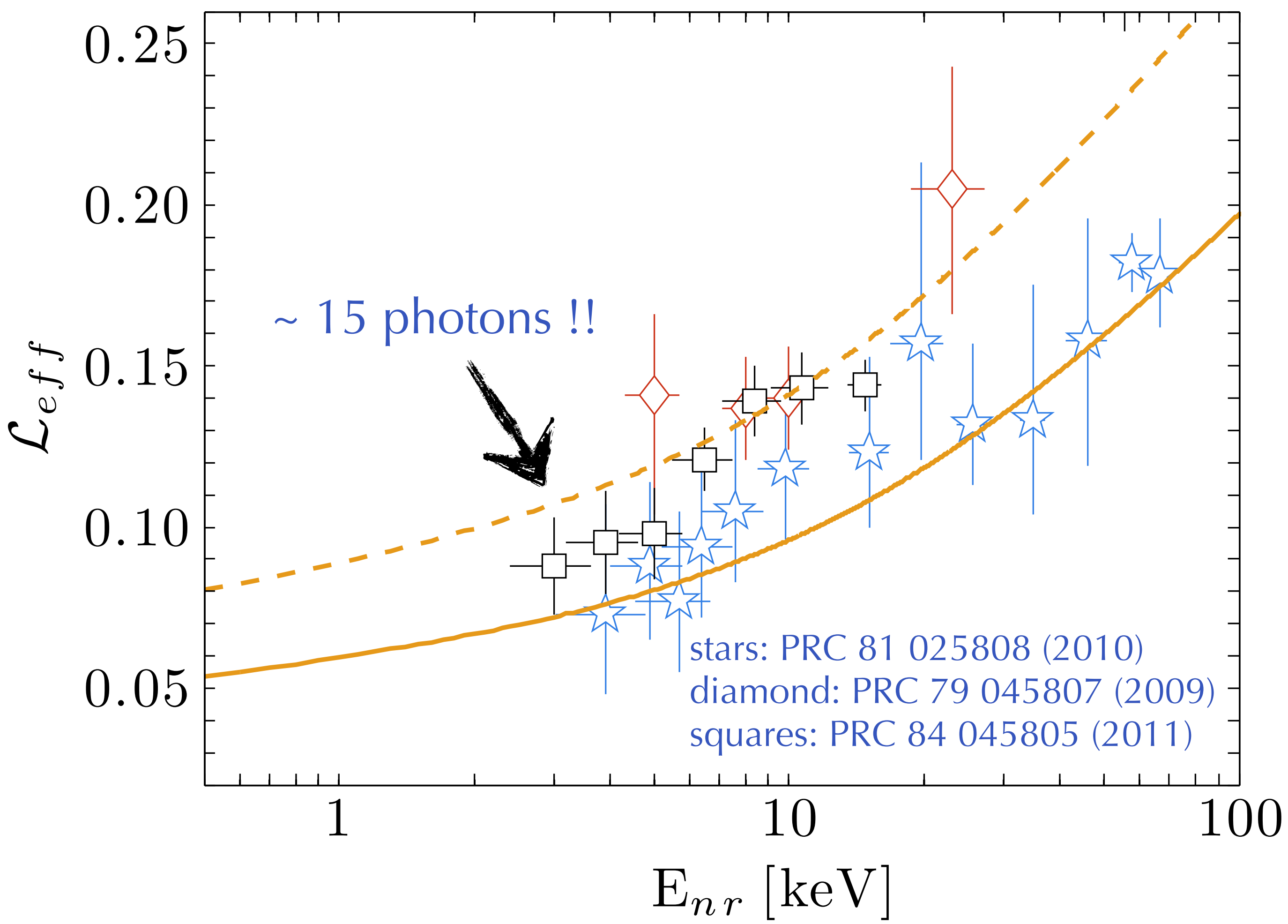
for 2.5 keV recoil



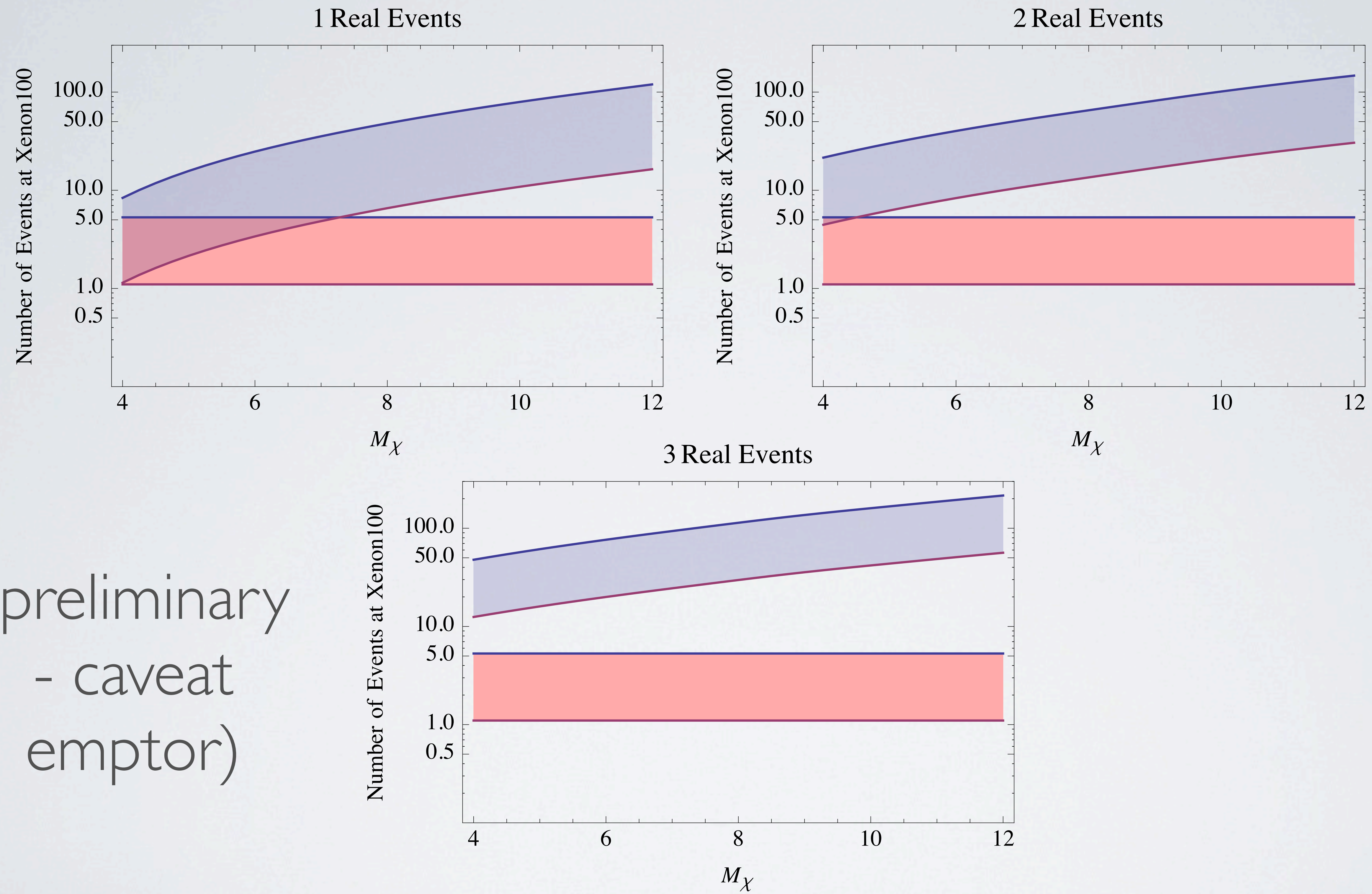


what to think?

photons / keV * 0.015



If you believe X then you should see Y

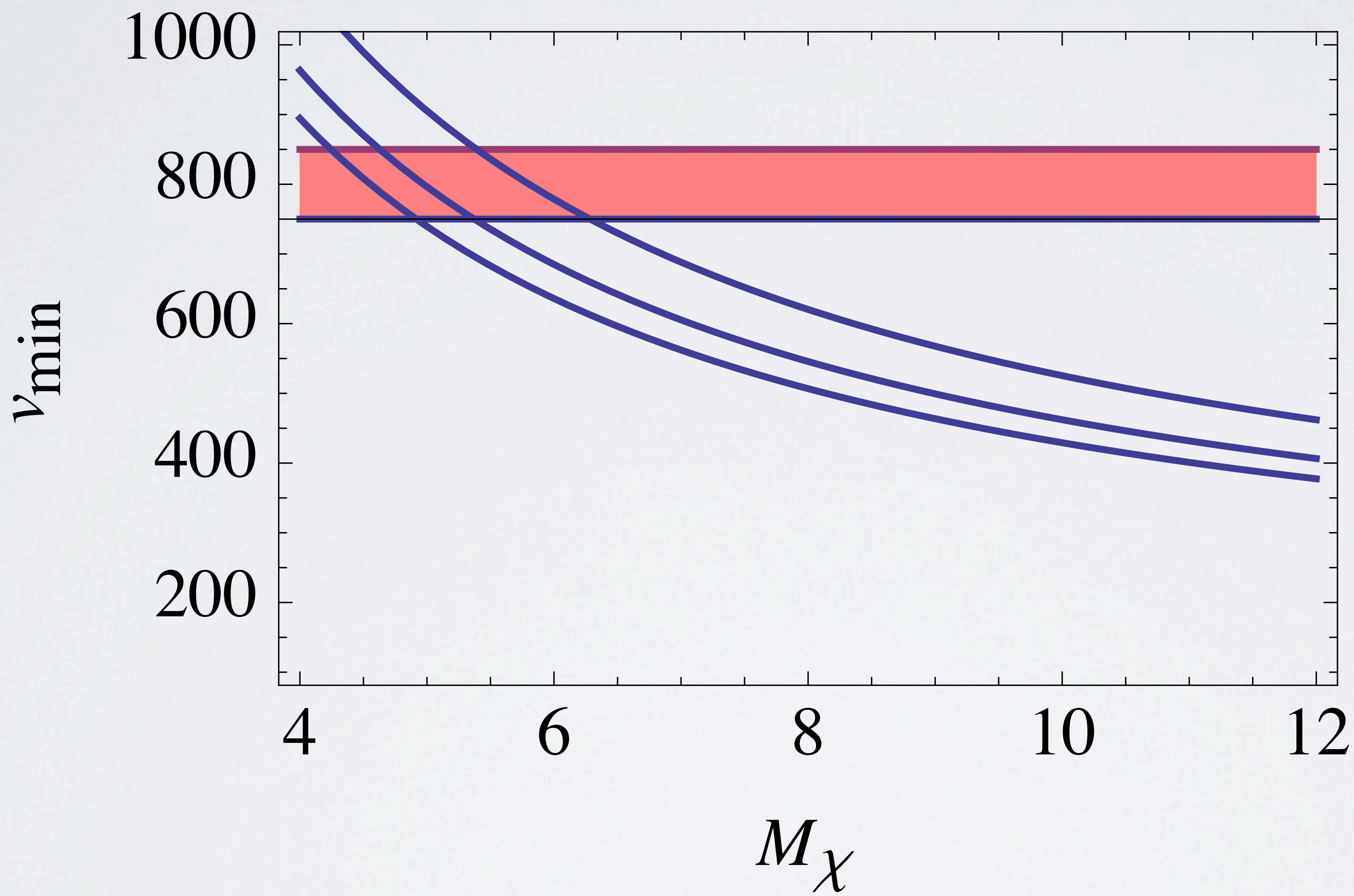


(preliminary - caveat emptor)

Best agreement at lowest masses

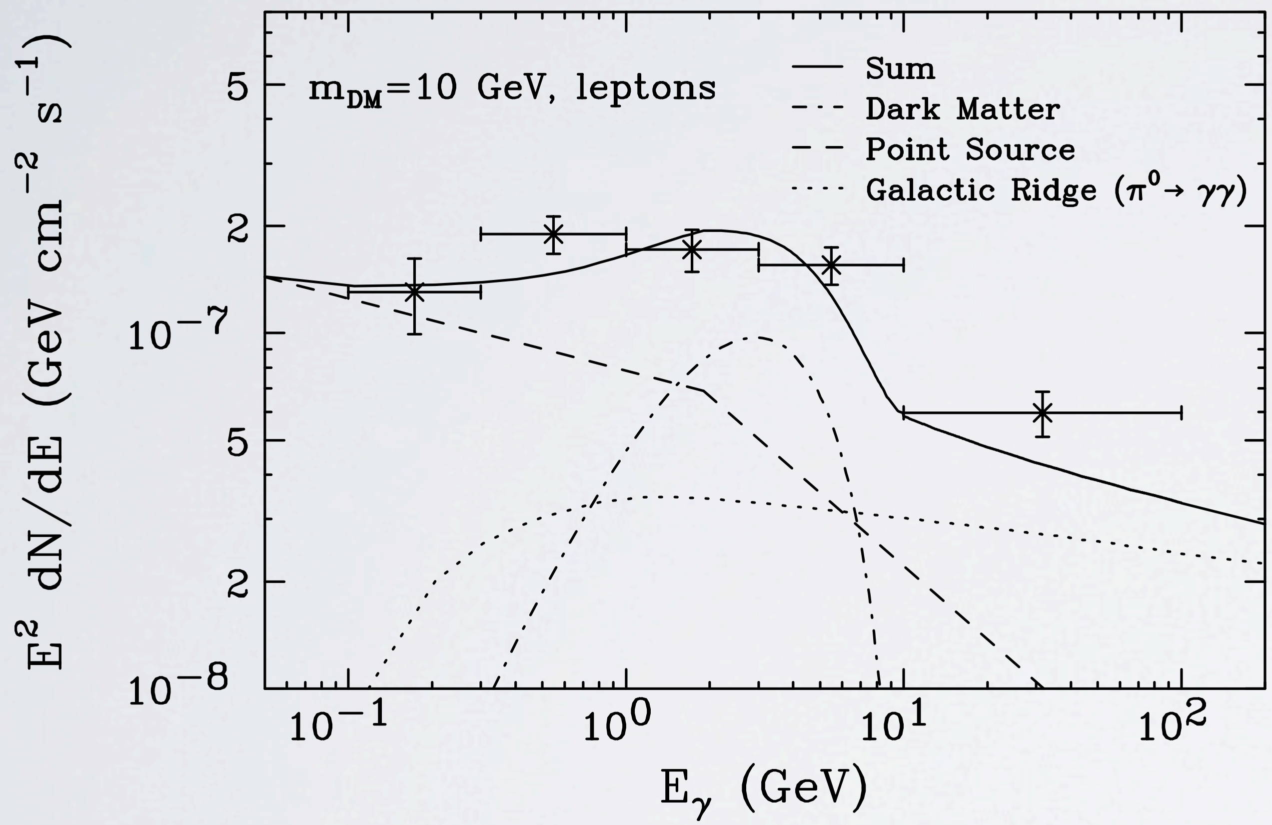
A FEW THOUGHTS

- want to be quantitative

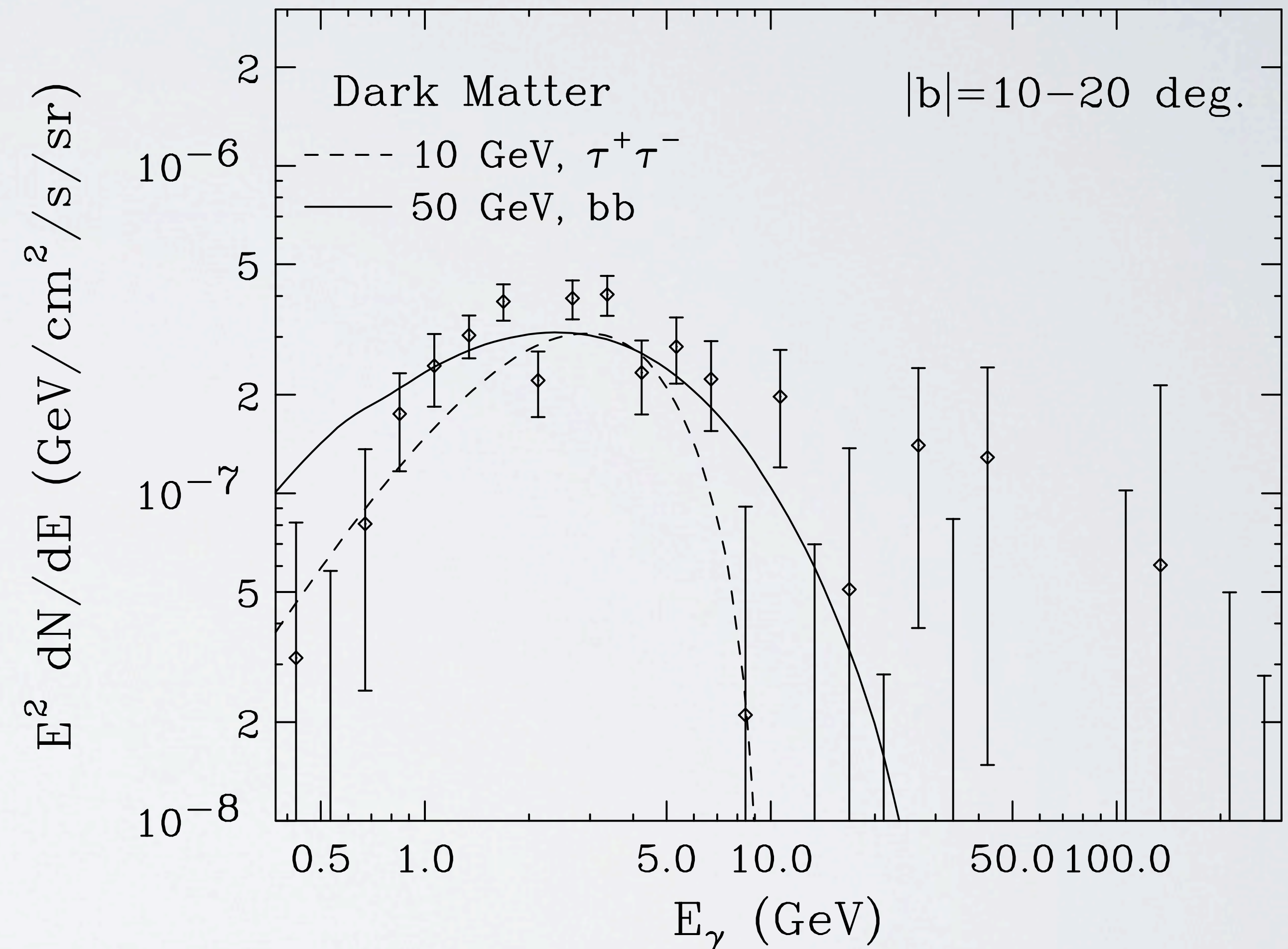


Halos matter most <6 GeV

NUMBERS MATTER



Hooper and Linden



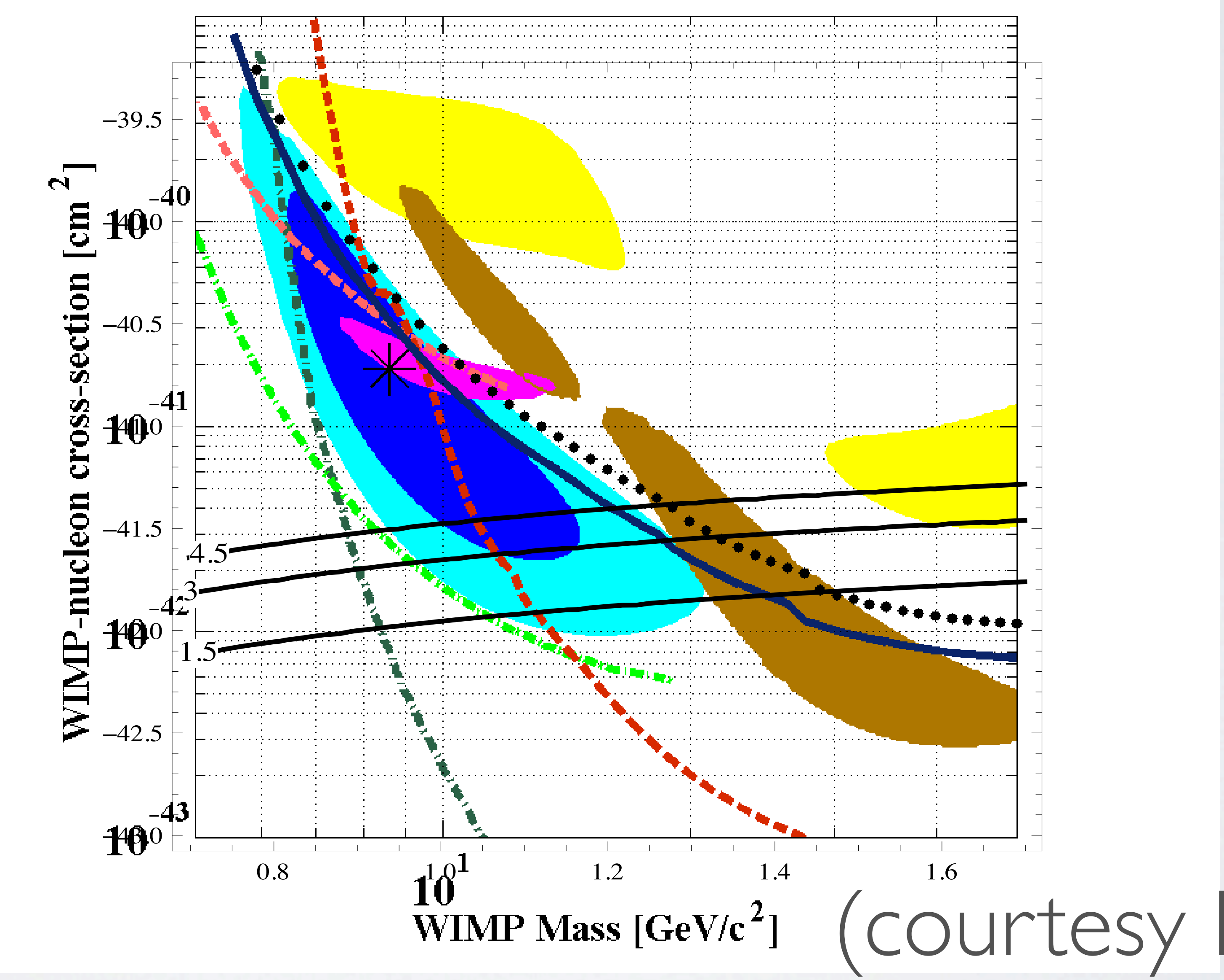
Hooper and Slatyer

A 10 GeV WIMP works in the GC, but does a ~10 GeV WIMP?

WHAT IS IT?

Higgs Exchange? ~ 10^-45 cm^2

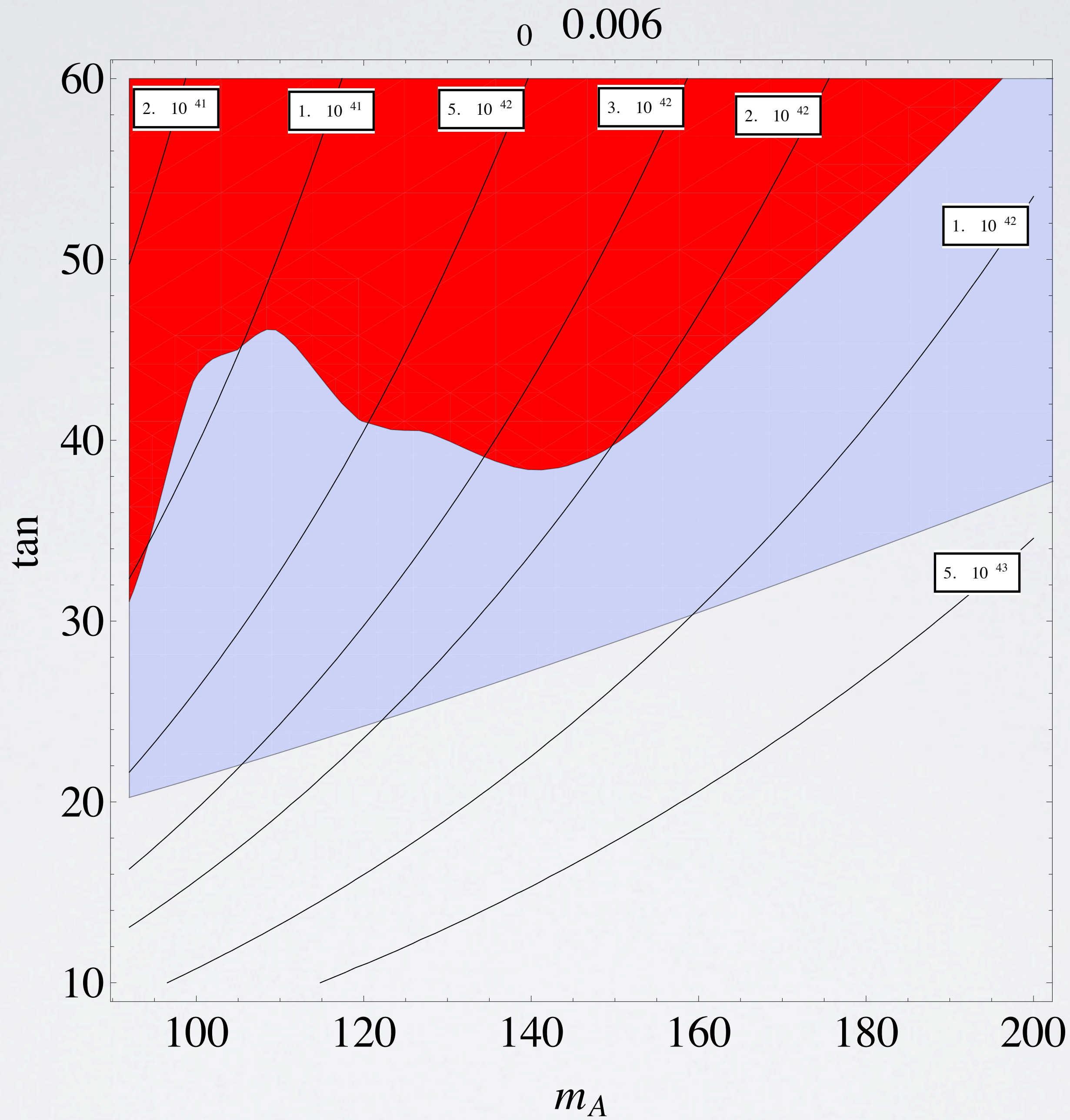
Z Exchange?



(courtesy D.Pinner)

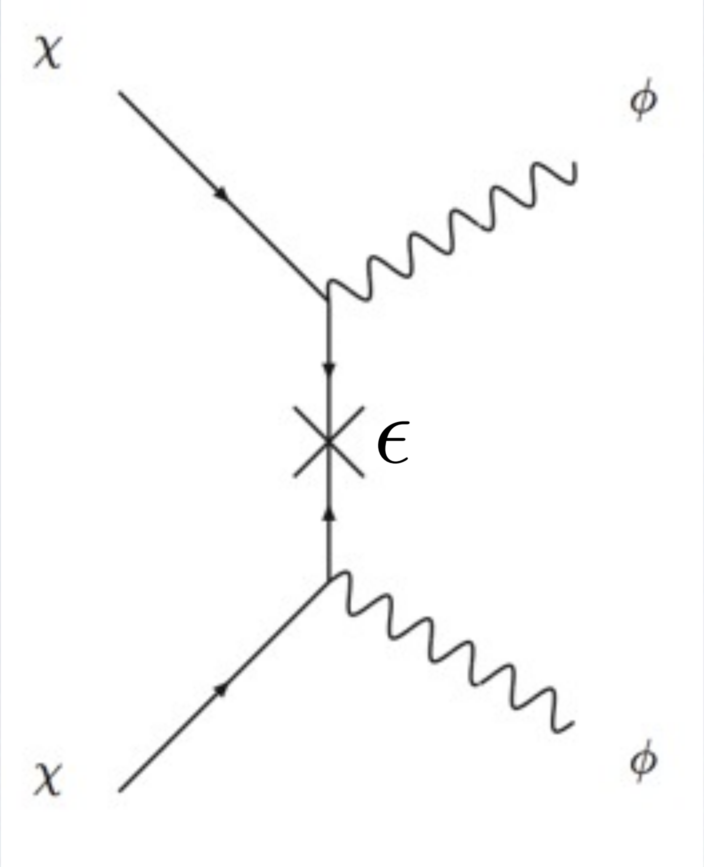
WHAT IS IT?

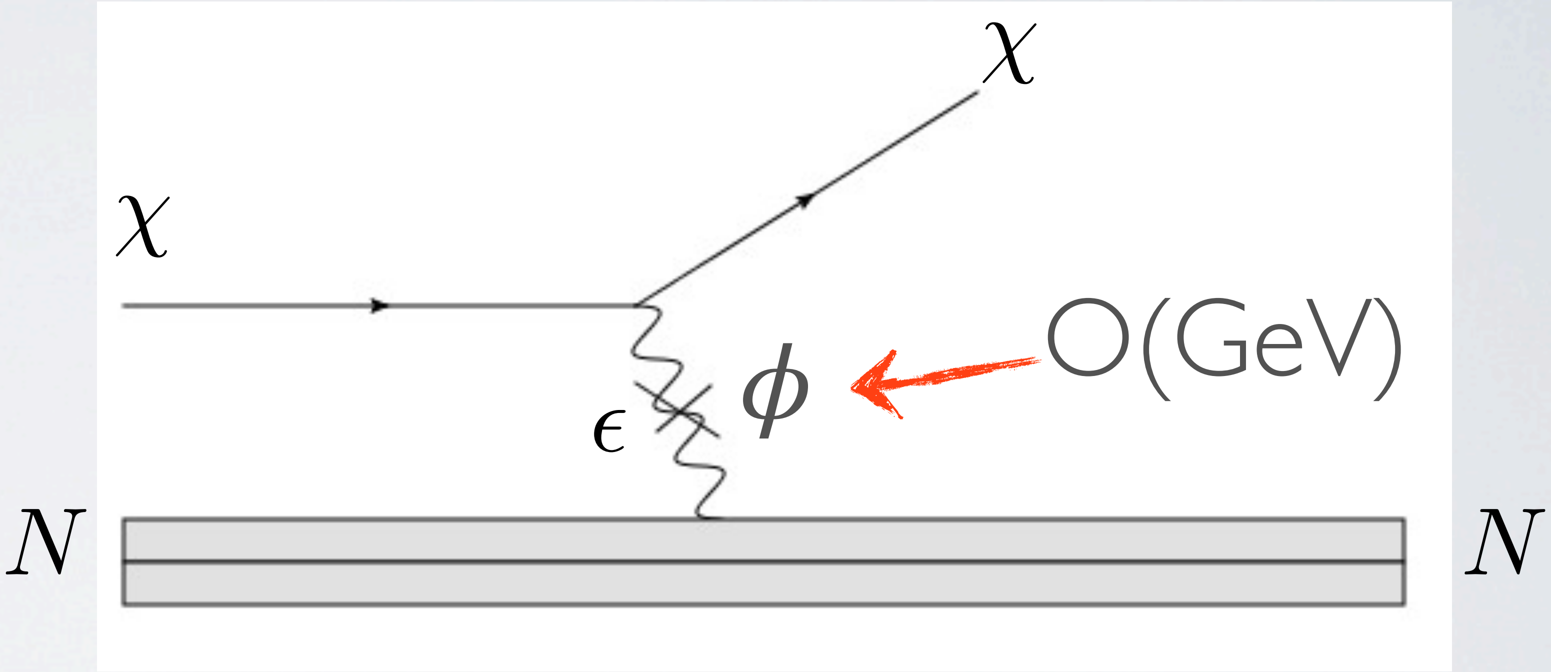
Pierce
+Zurek
'10



2HDM?

INTERACTIONS THROUGH A LIGHT SECTOR





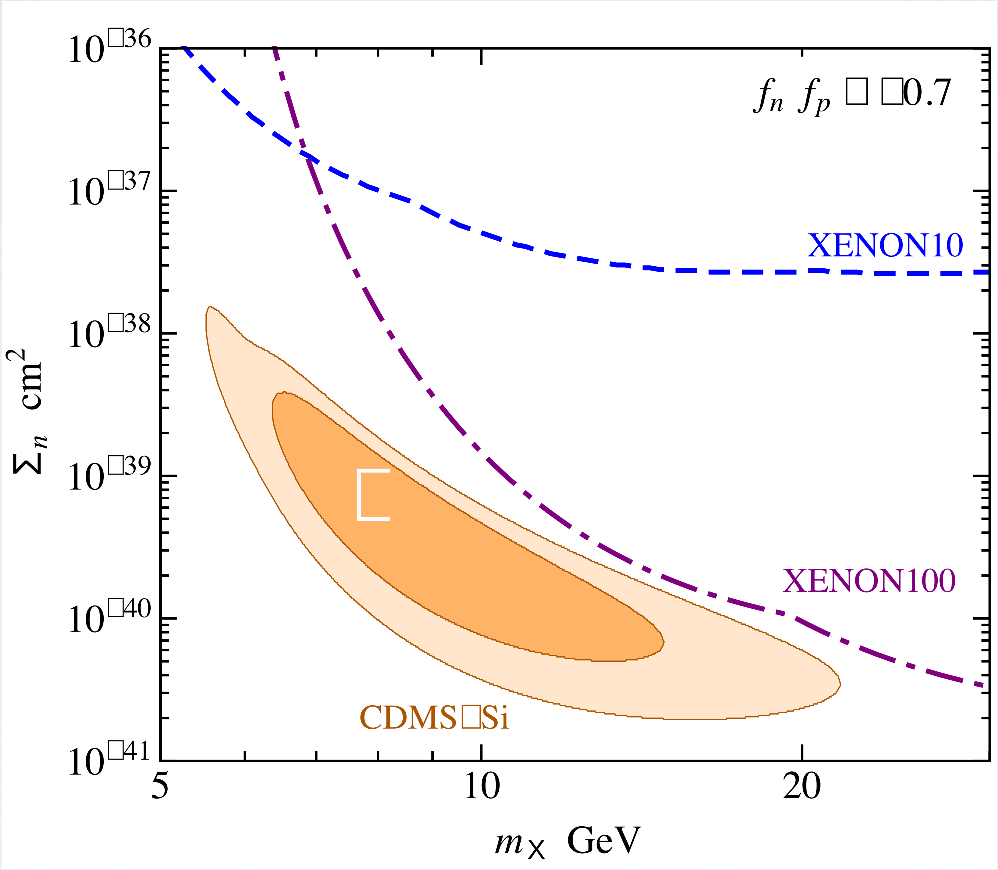
$$\sigma \approx \frac{\alpha_d^2}{m_\chi^2}$$

$$\sigma \approx \frac{\alpha_d \alpha_{EM} \epsilon^2}{m_\phi^4}$$

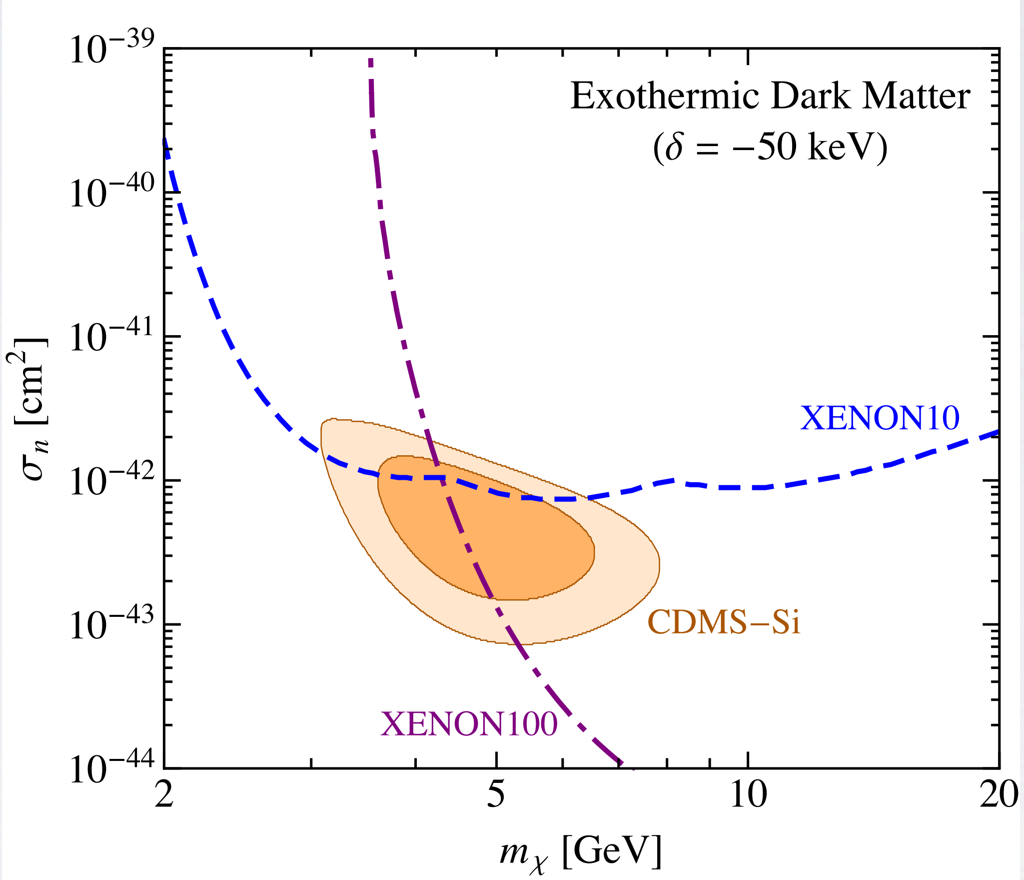
Significant parametric differences - can avoid overclosure *and* have large cross section

THE BOX OF TRICKS

Inelastic dark matter (endothermic)	Favors heavy targets
Inelastic dark matter (exothermic)	Favors light targets
Momentum dependent	Favors high thresholds
Generalized ($f_p \neq f_n$) couplings	(Dis)Favors Z=(A-Z)



Frandsen et al



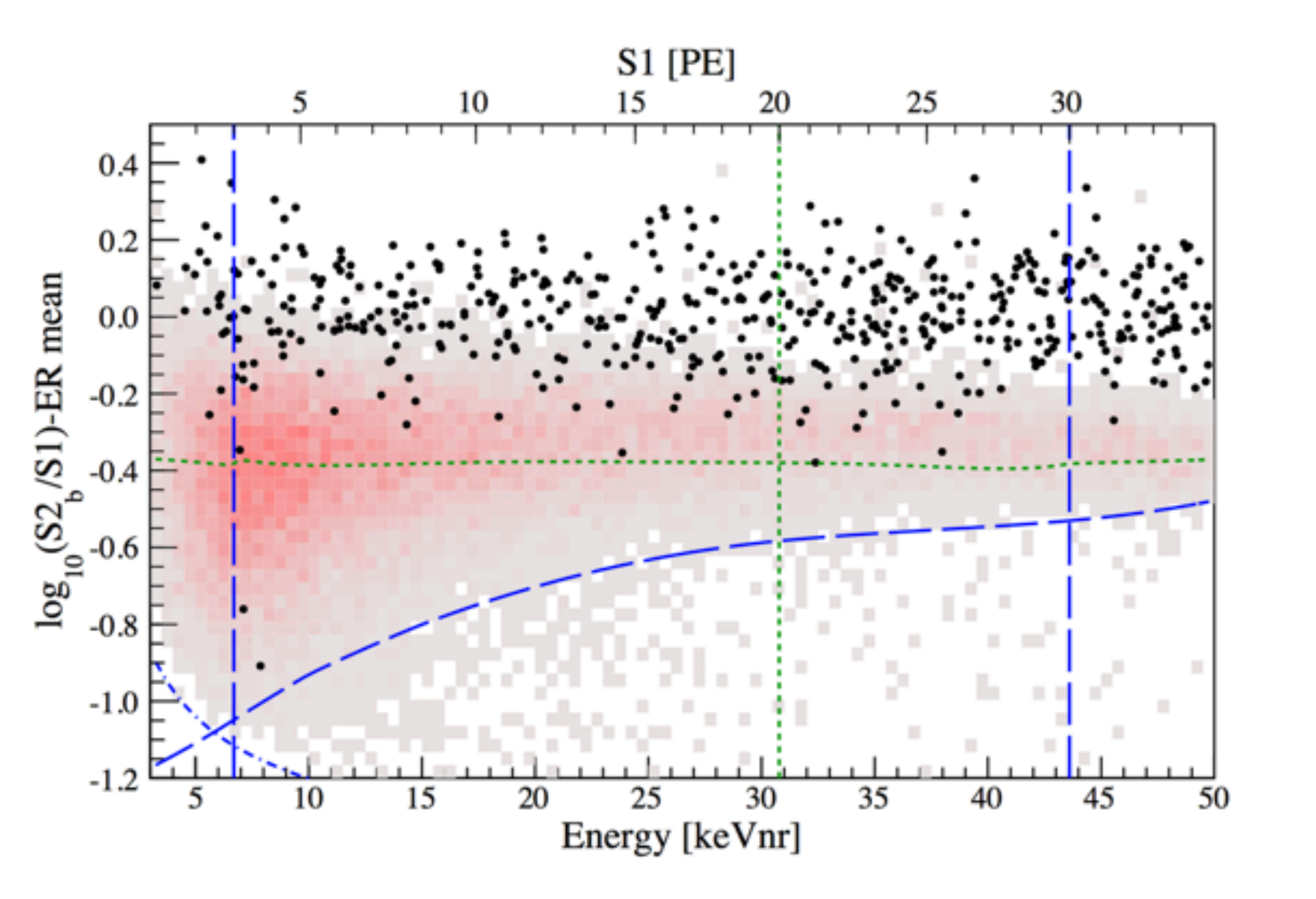
Frandsen et al

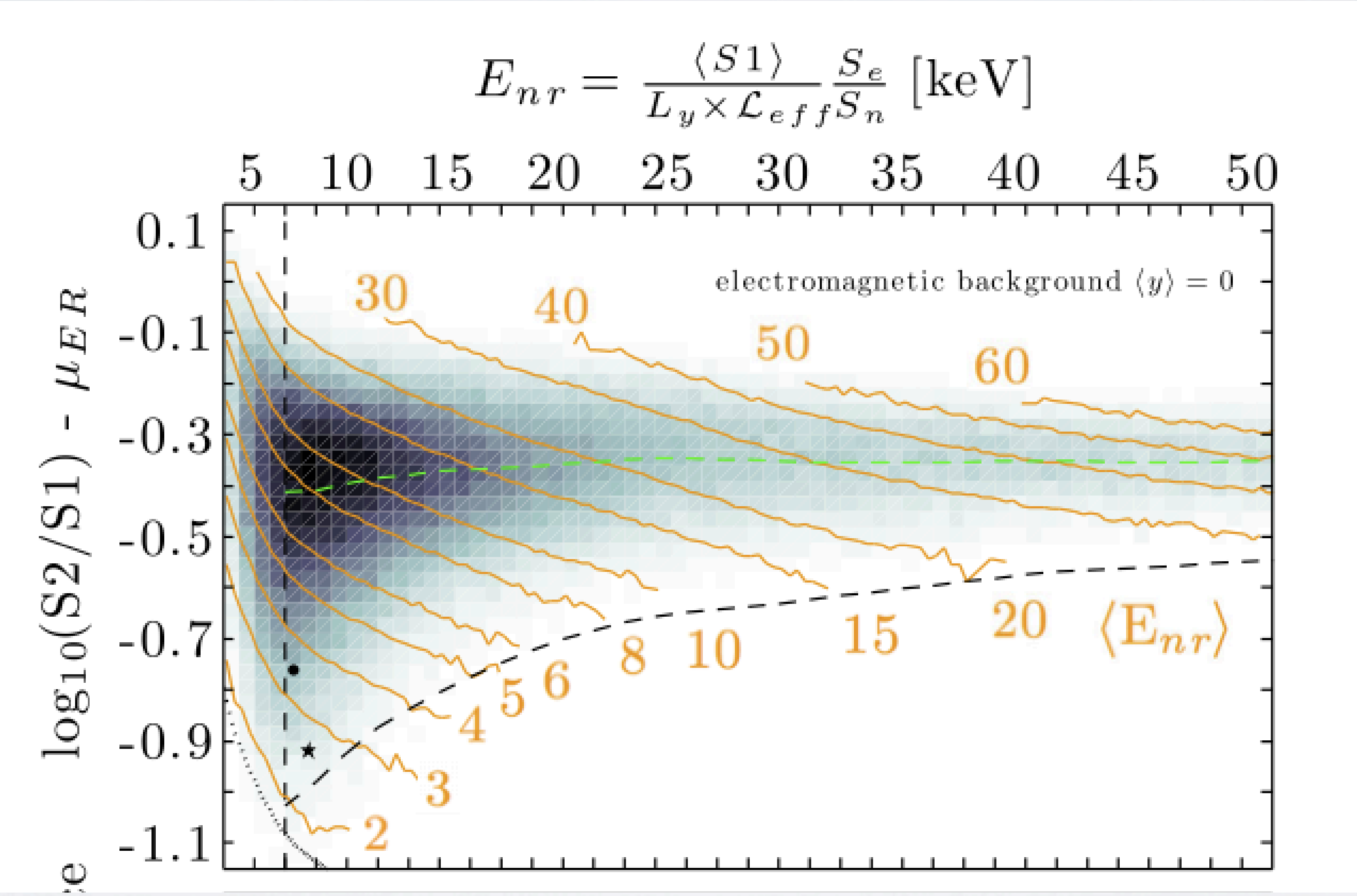
SO WHAT TO THINK?

Optimistic Neal

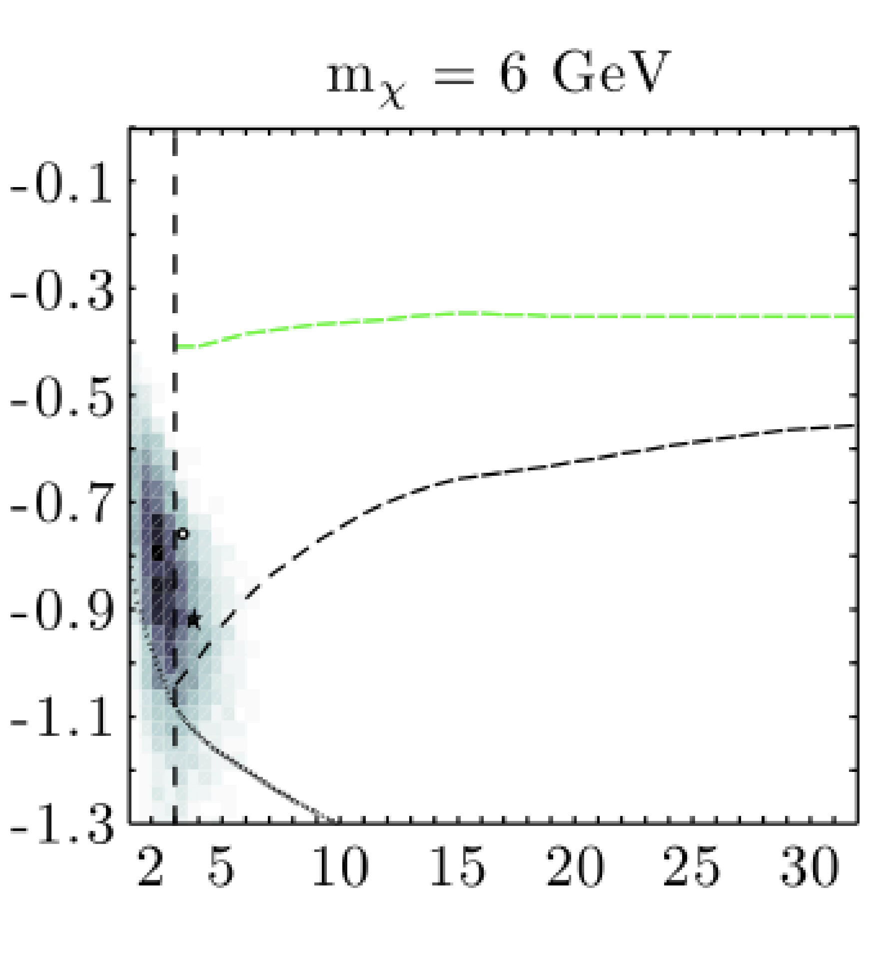
Hater Neal

- We have been finding light WIMPs in each round of experiments, the only difference being that the xsec gets lower
- These experiments will *always* find erroneous light WIMPs because unexpected backgrounds show up at the boundaries
- Ouji-board effect causes people to disregard real quantitative disagreements

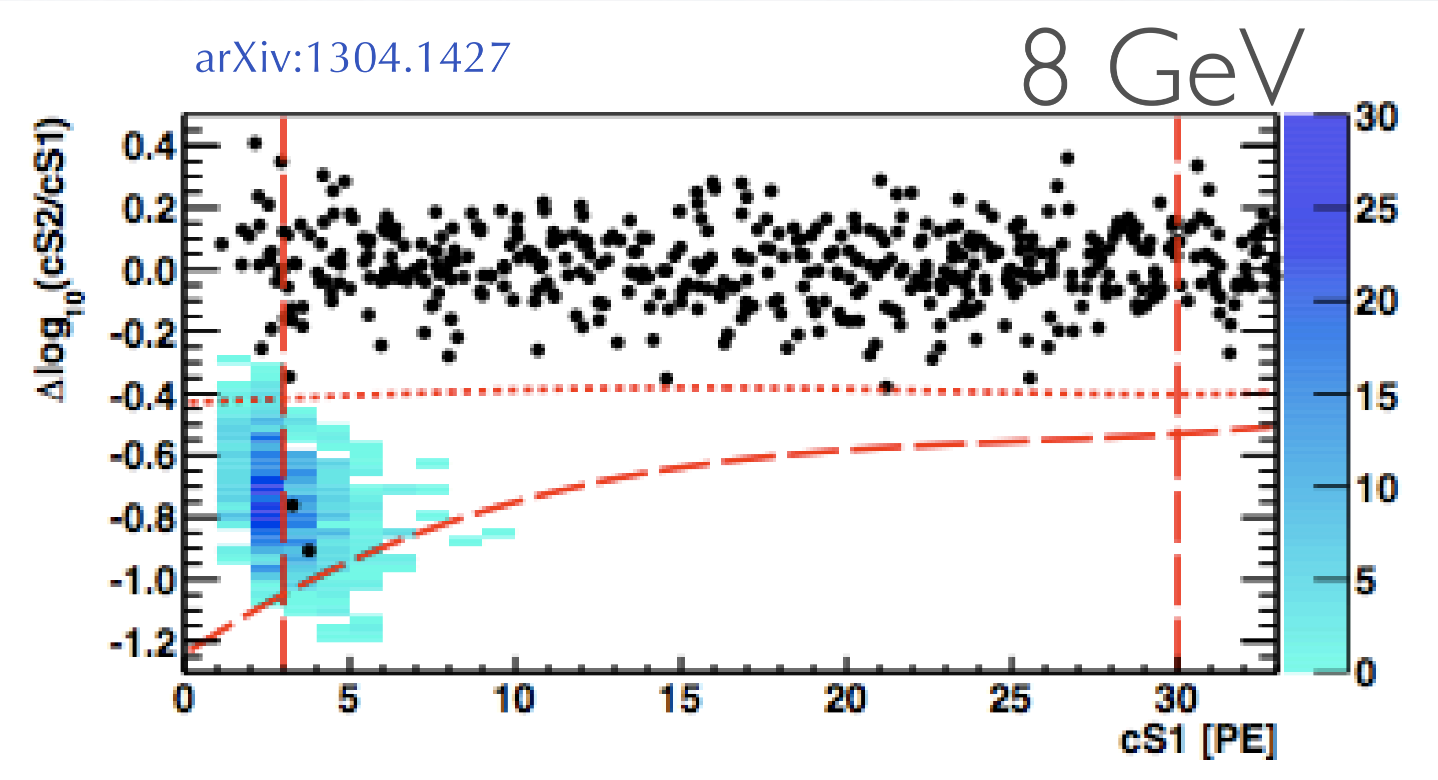

S1 [PE]
5
10
15
20
25
30
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
-1.2
$\log_{10}(S2_b/S1)$-ER mean
5
10
15
20
25
30
35
40
45
50
Energy [keVnr]



from P Sorensen MCTP talk



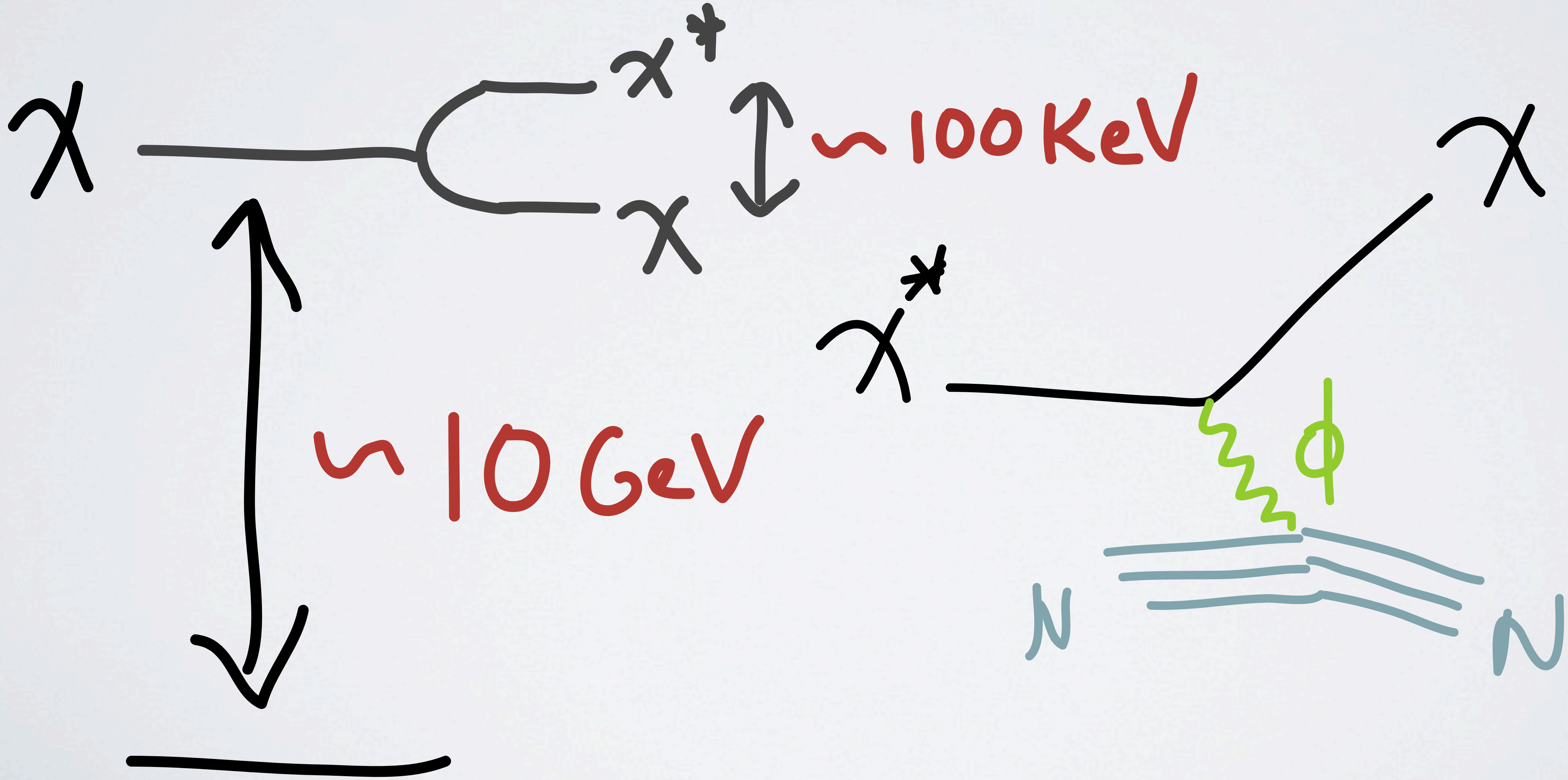
m_χ = 6 GeV
-0.1
-0.3
-0.5
-0.7
-0.9
-1.1
-1.3
2 5 10 15 20 25 30



arXiv:1304.1427
8 GeV
$\Delta\log_{10}$(cS2/cS1)
0.4 0.2 0.0 -0.2 -0.4 -0.6 -0.8 -1.0 -1.2
0 5 10 15 20 25 30
cS1 [PE]
30 25 20 15 10 5 0

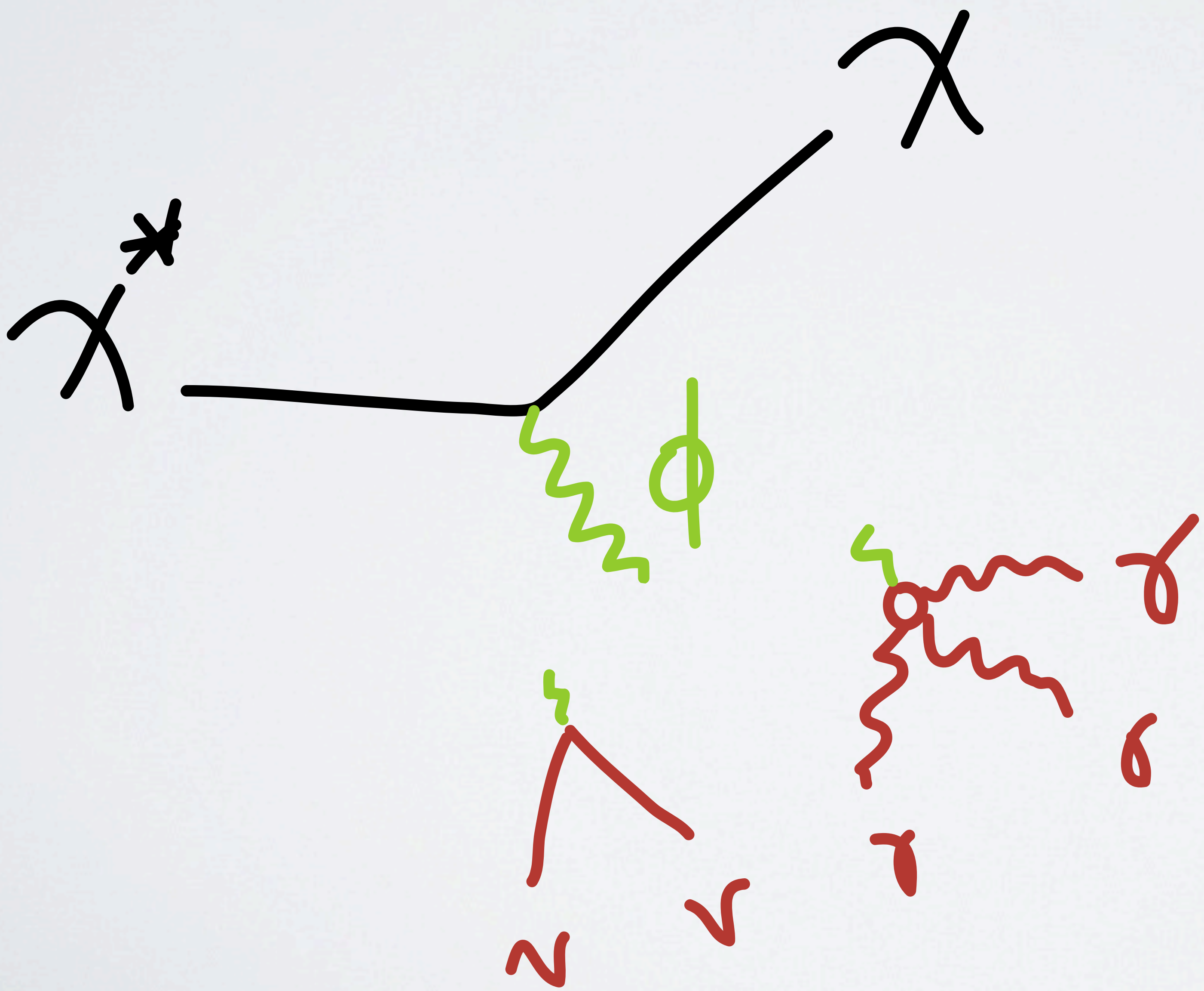
A SCENARIO

- Consider dark matter at 10 GeV interacting via dark force and excited state (i.e., Arkani-Hamed et al, but TeV=>10 GeV)



A SCENARIO

- Consider dark matter at 10 GeV interacting via dark force and excited state (i.e., Arkani-Hamed et al, but TeV=>10 GeV)



Finkbeiner et al '09

A SCENARIO

- Consider dark matter at 10 GeV interacting via dark force and excited state (i.e., Arkani-Hamed et al, but TeV=>10 GeV)

$$\Gamma_{\nu\nu} \approx \Gamma_n \left(\frac{\alpha_d}{\alpha_2}\right)\left(\frac{\epsilon M_Z^2}{m_b^2}\right)^2\left(\frac{|\delta|}{m_n - m_p}\right)^5\left(\frac{|\delta|}{M_Z}\right)^4$$
$$= \frac{1}{3\times 10^{21}\ \mathrm{sec}}\left(\frac{\delta}{\mathrm{MeV}}\right)^9\left(\frac{\epsilon}{10^{-3}}\right)^2,$$

excited state is cosmologically stable

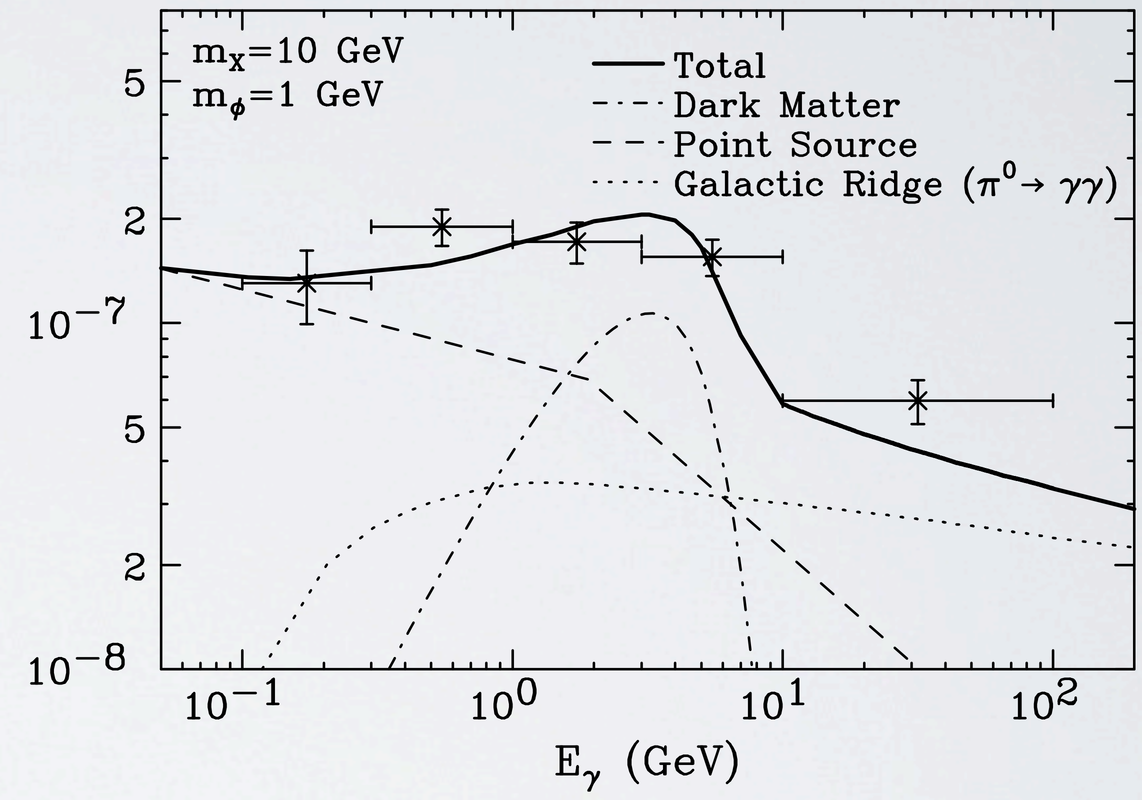
Finkbeiner et al '09

$$\Gamma_{3\gamma} \approx \Gamma_n \times \left(\frac{\alpha\alpha_d}{\alpha_2^2}\right)\times\left(\frac{\theta\epsilon M_Z^2}{m_b^2}\right)^2\times\left(\frac{\alpha^3}{4\pi}\right)\times\left(\frac{|\tilde\delta|}{m_n - m_p}\right)^5\times\left(\frac{|\tilde\delta|^4}{90\ m_e^4}\right)^2$$
$$= \frac{\theta^2}{8\times 10^{19}\ \mathrm{sec}}\left(\frac{\tilde\delta}{300\mathrm{keV}}\right)^{13}\left(\frac{\epsilon}{10^{-3}}\right)^2$$

exothermic inelastic scattering

A SCENARIO

- Annihilation in the inner galaxy



will this work for everything quantitatively? don’t know yet

CONCLUDING

- The Higgs is a new probe into weakly coupled physics at the 100 GeV scale
- Dark matter signals may motivate deviations from SM like properties
- Conclusions? I don't have any, but *these* anomalies should be resolved soon, I make no promises about future ones

Thanks very much!