The unbearable lightness of being: CDMS versus XENON

Durham University

IP3

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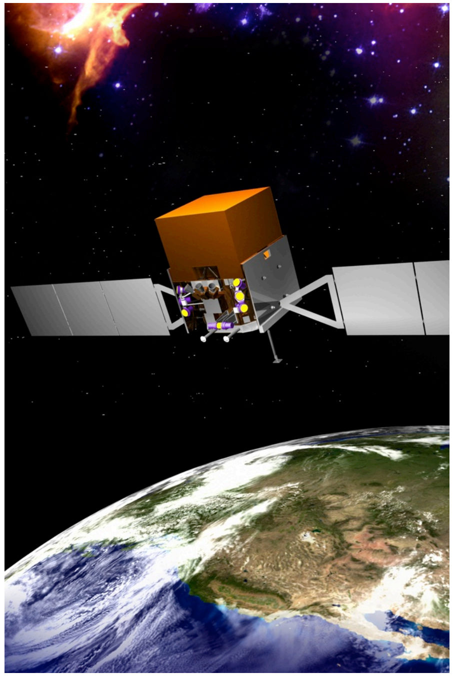
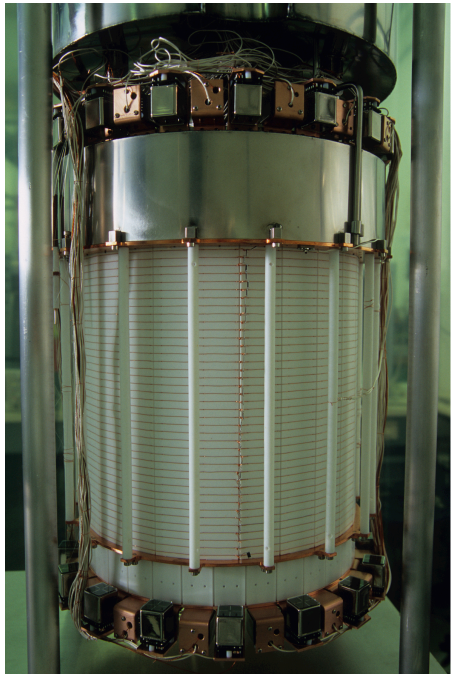
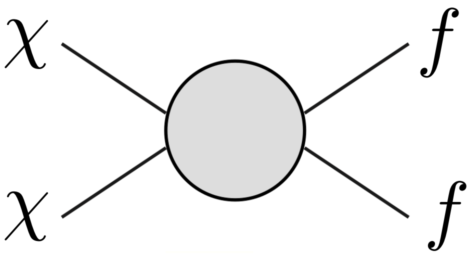
Ripples in the Cosmos, Durham – 22nd July 2013

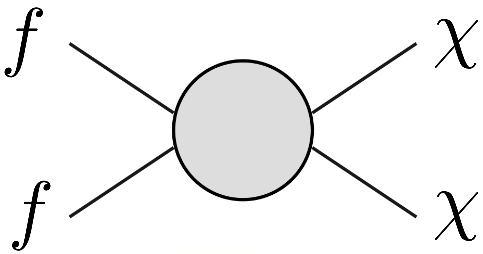
Searches for (WIMP) dark matter

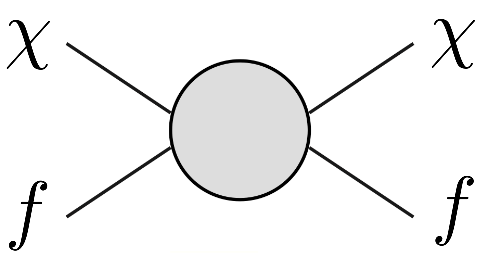
- Indirect detection
- Collider production
- Direct detection



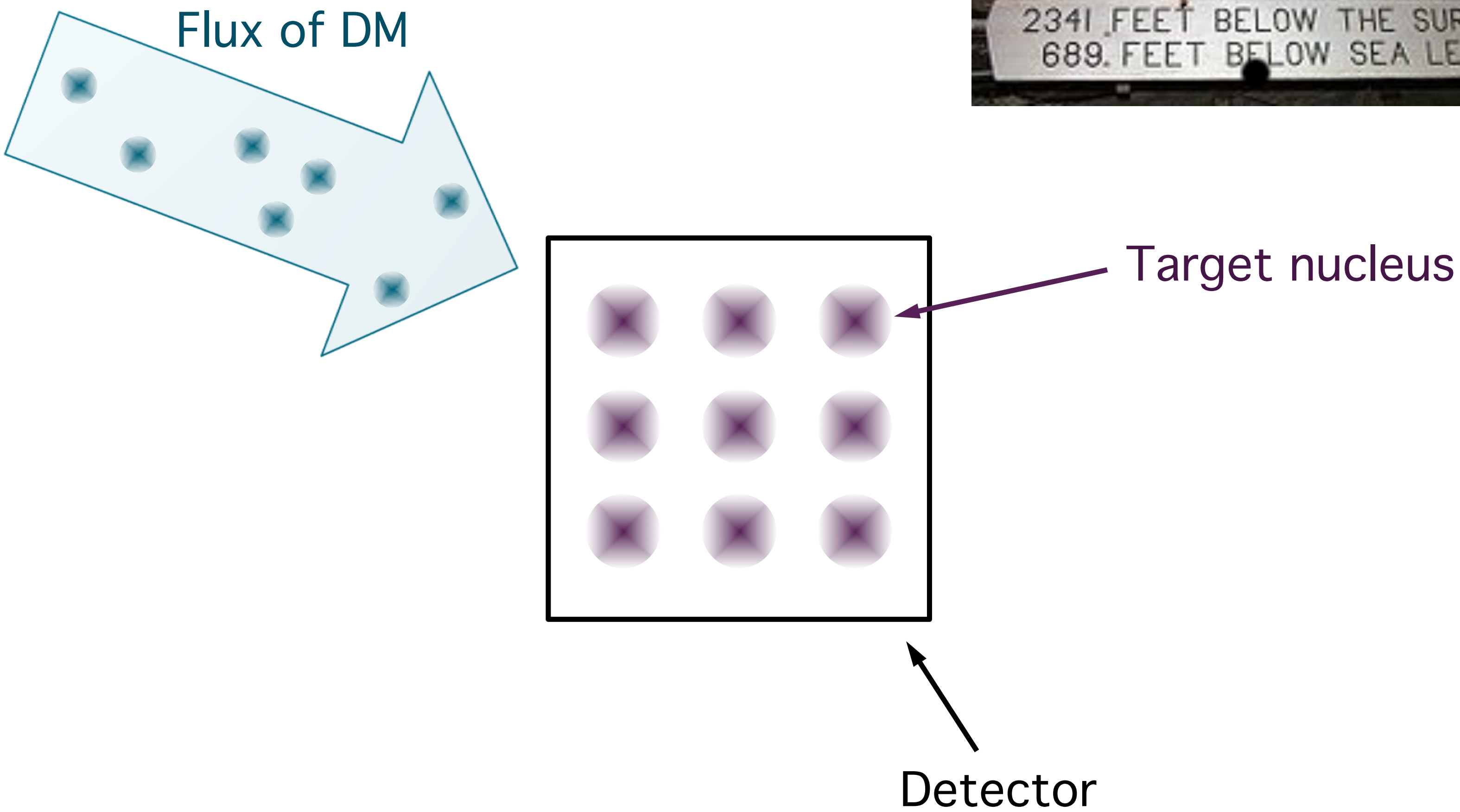




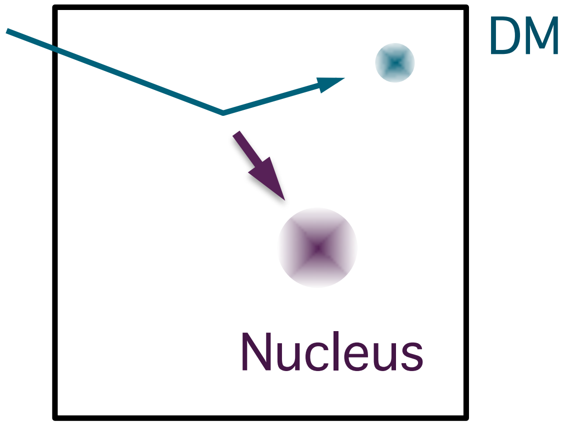




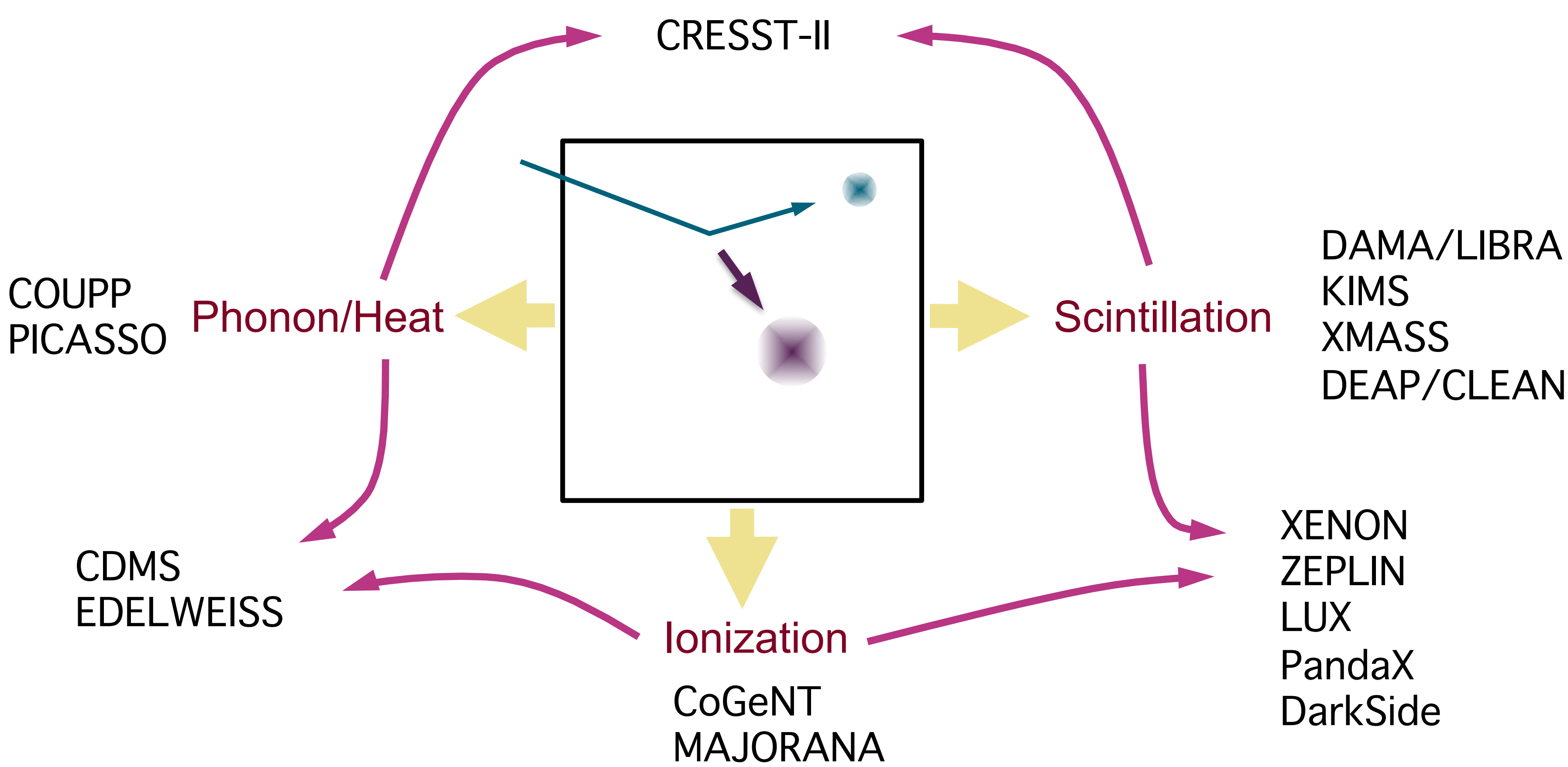
Direct detection



Direct detection



Direct detection

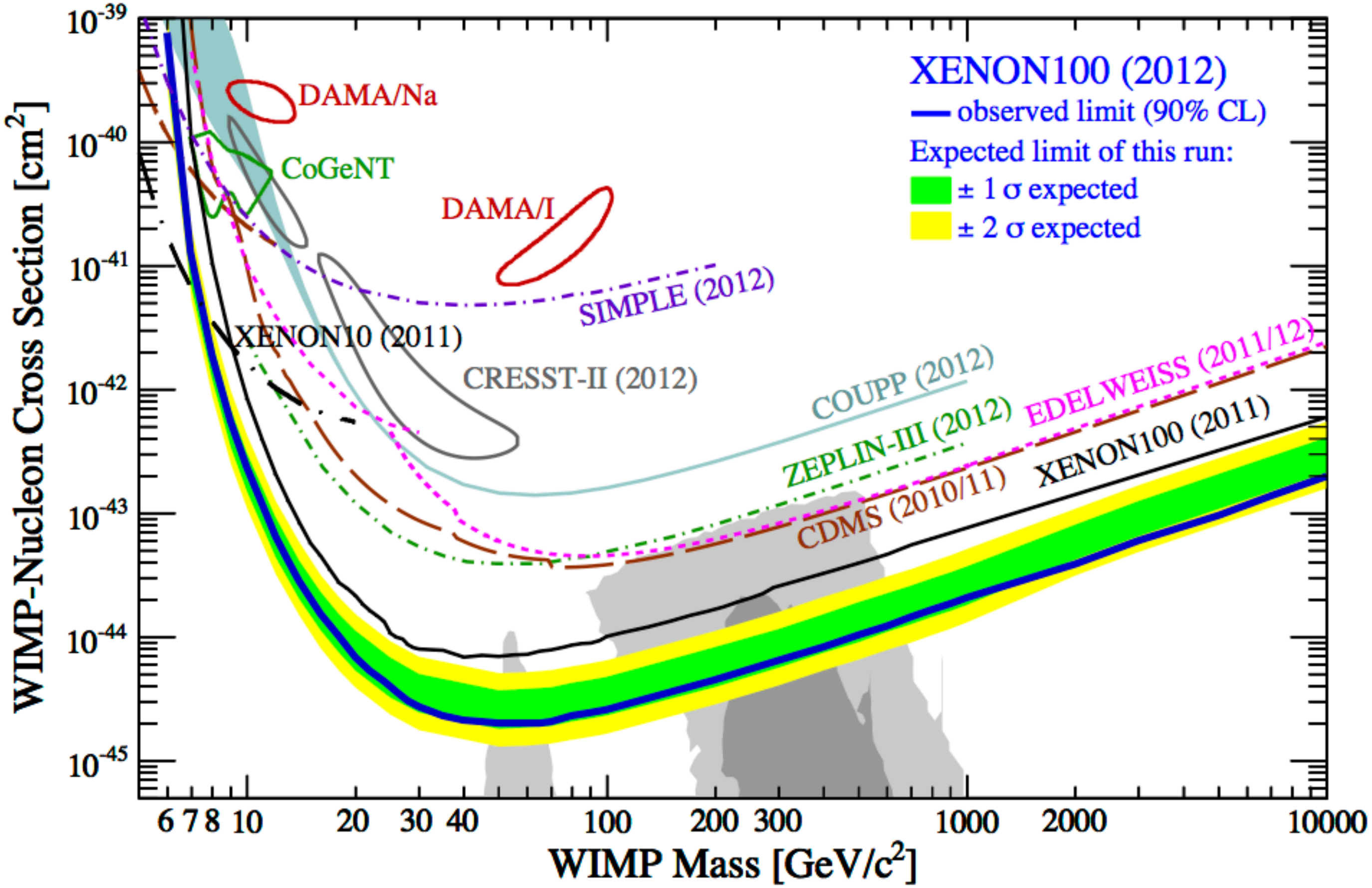


Roadmap for this talk

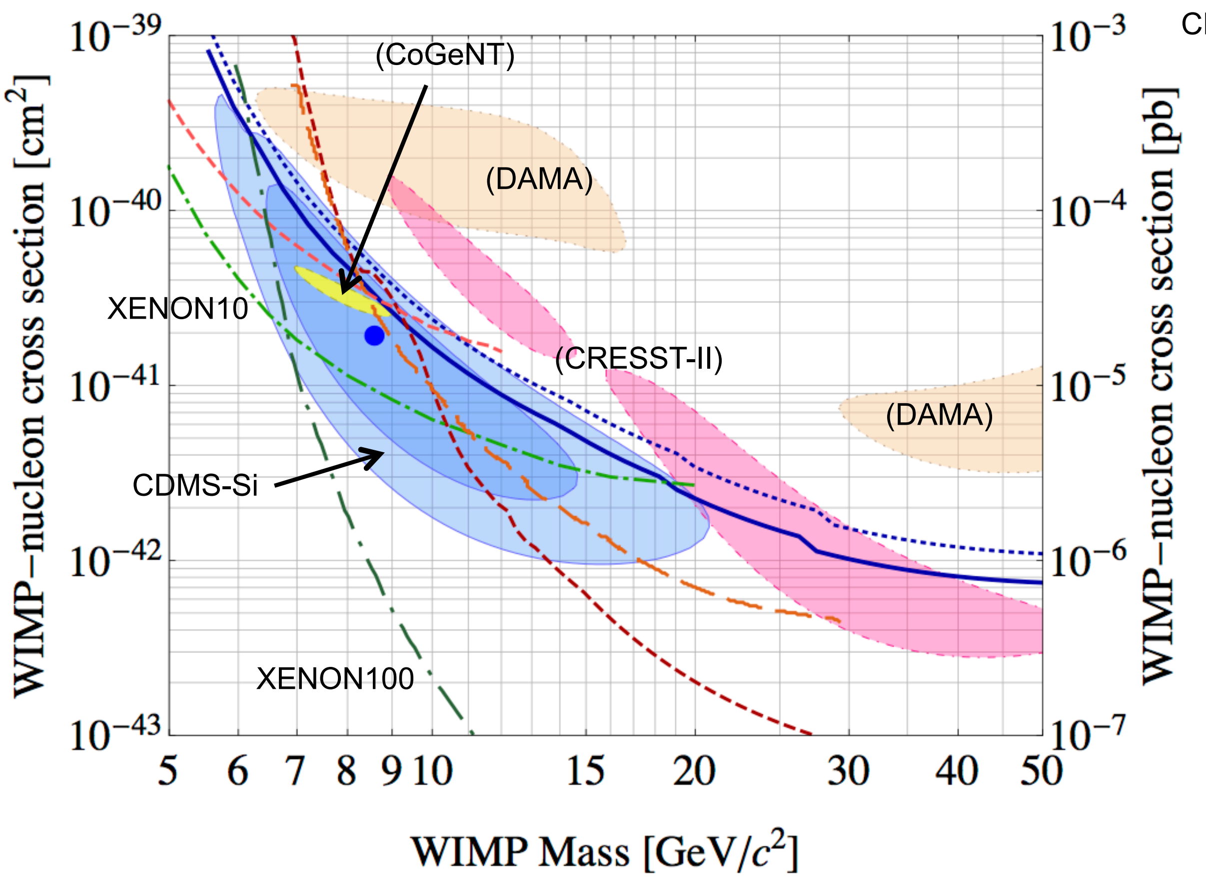
- Summary of direct detection experimental results: focus on XENON10, XENON100 and CDMS-Si
- Compare CDMS-Si and XENON10/XENON100:
  1. under the standard theoretical assumptions
  2. beyond the standard theoretical assumptions

Latest results

XENON100: 1207.5988



Latest results: low mass region

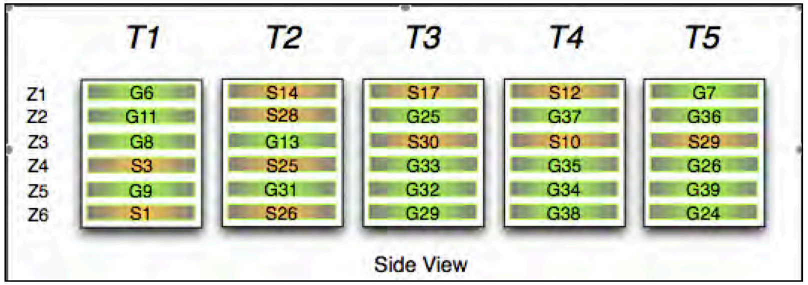


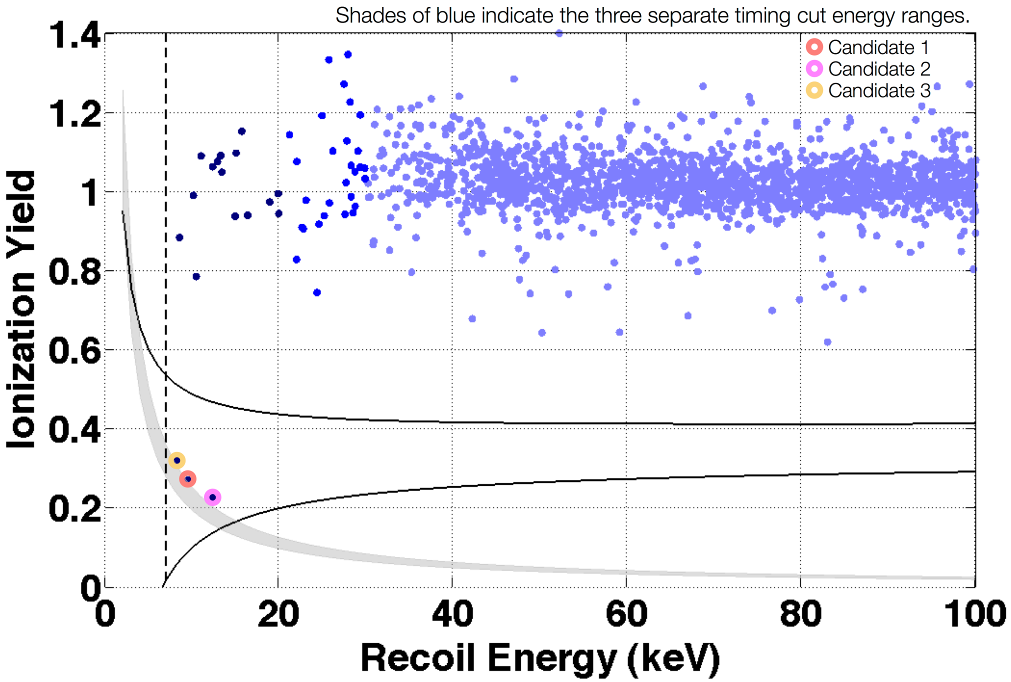
- Focus on CDMS-Si, XENON10 and XENON100 in this talk

CDMS-Si

CDMS-II: 1304.4279

- 140 kg-days (July 2007- Sept 2008) with silicon detectors
- Previous CDMS results used germanium detectors



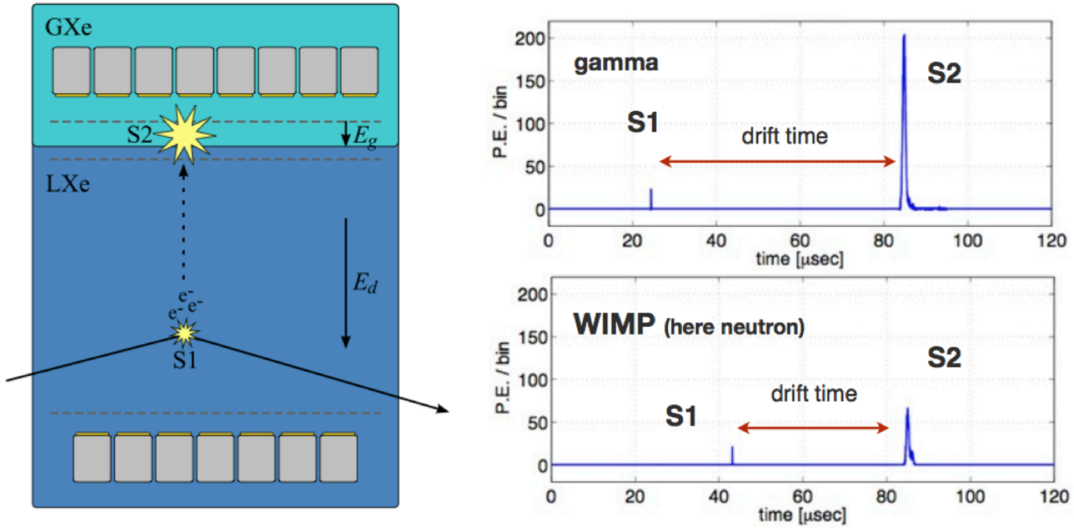


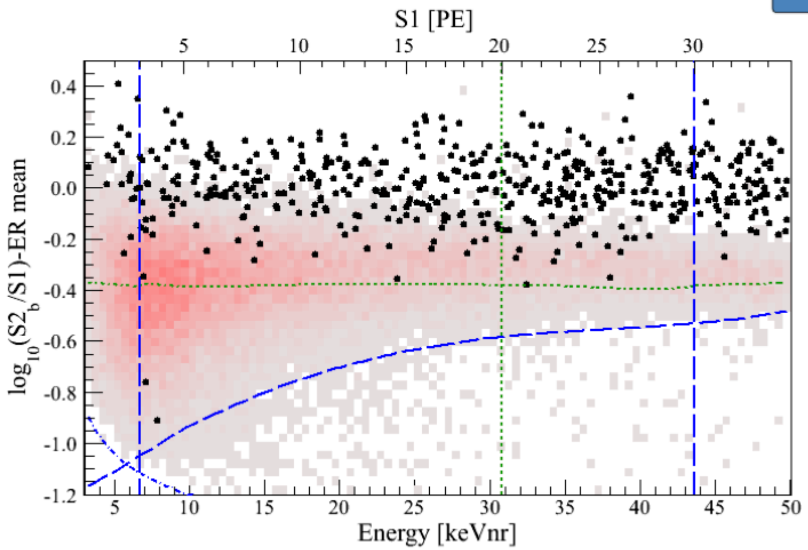
- Three events passed all cuts (0.7 expected)
- DM + background hypothesis preferred over known-background only hypothesis at 99.8% C.L.

XENON100

XENON100: PRL, 1207.5988

- S2/S1 discriminates between electronic and nuclear recoils



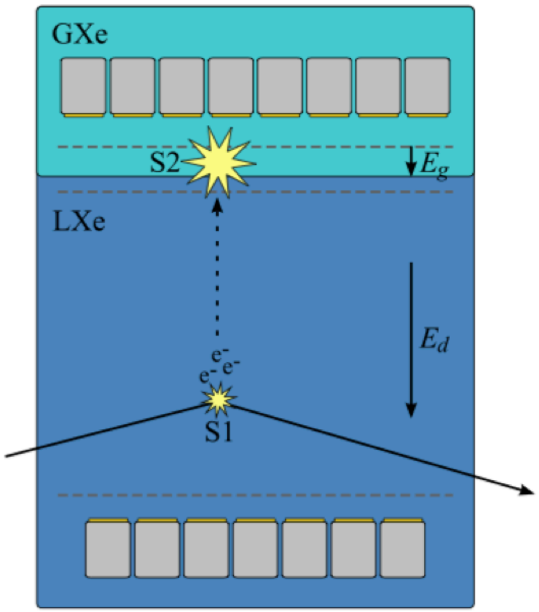


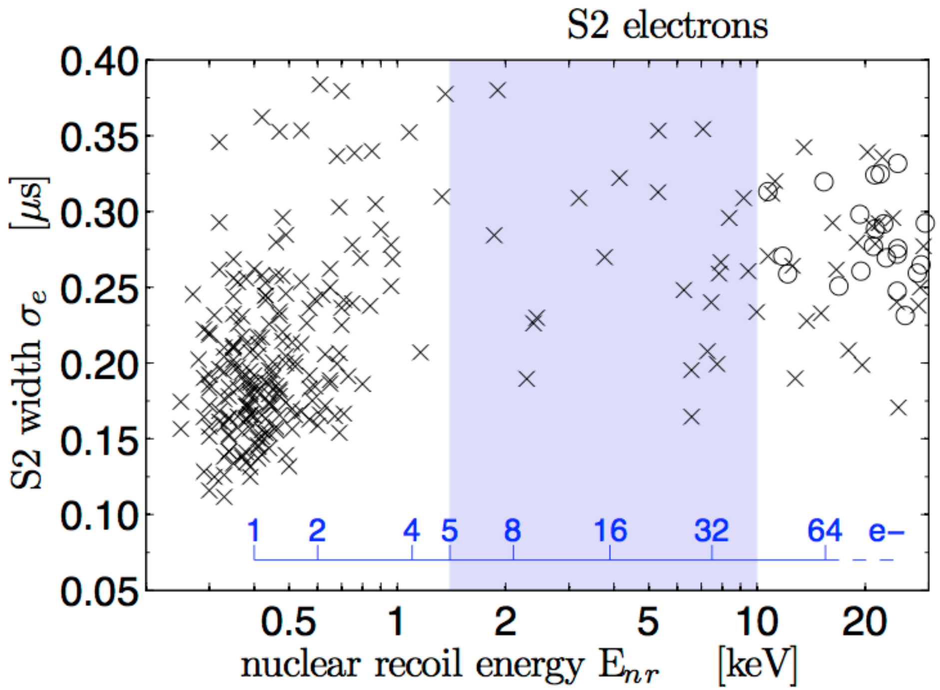
- Two events passed all cuts in 225-day run (1.0 ± 0.2 expected)

XENON10 (S2-only)

XENON10: PRL, 1104.3088

- XENON10 analysed 12-day run (from 2006) with S2-only:
- – Pro: Energy threshold of S2 is significantly lower than S1
- – Con: Lose electronic/nuclear recoil discrimination (23 events in the signal region)

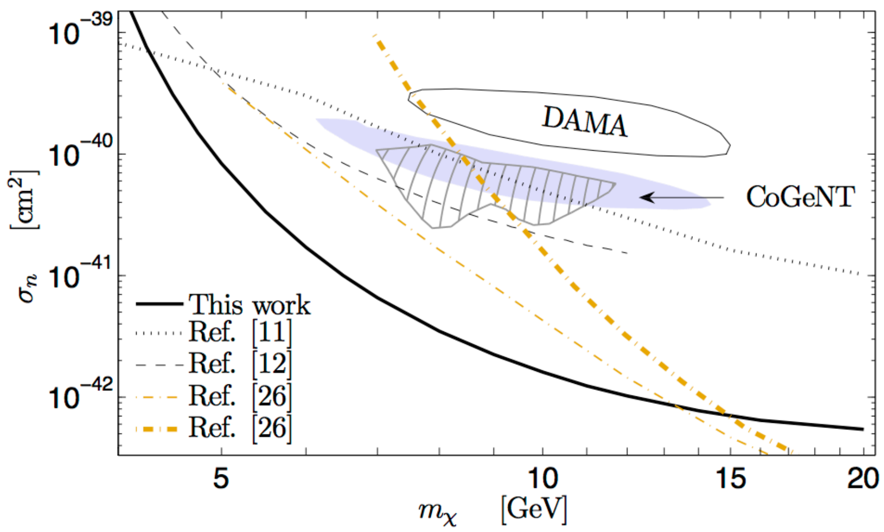




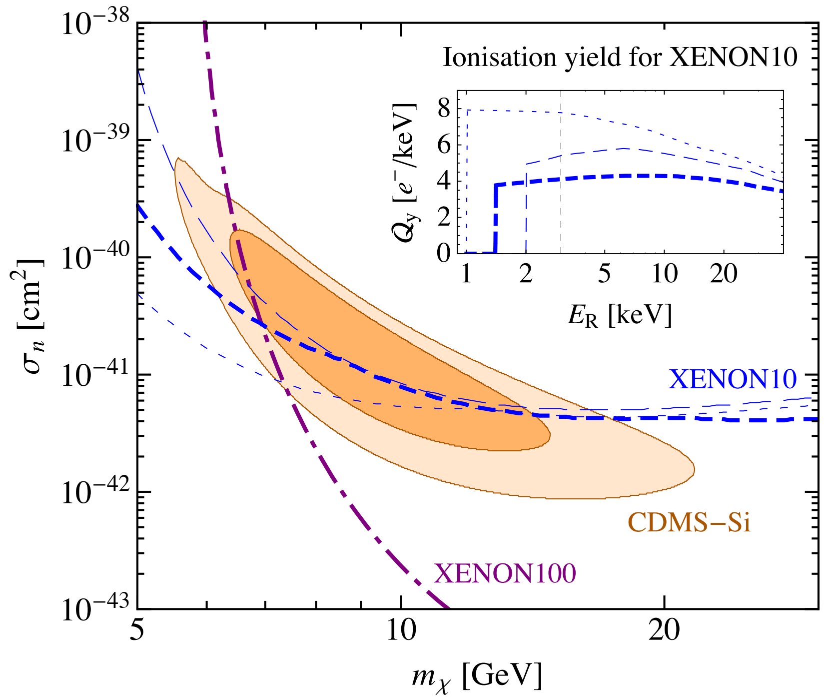
XENON10 (S2-only) limit

XENON10: PRL, 1104.3088

- Published XENON10 limit in PRL paper:



- Our analysis did not agree:

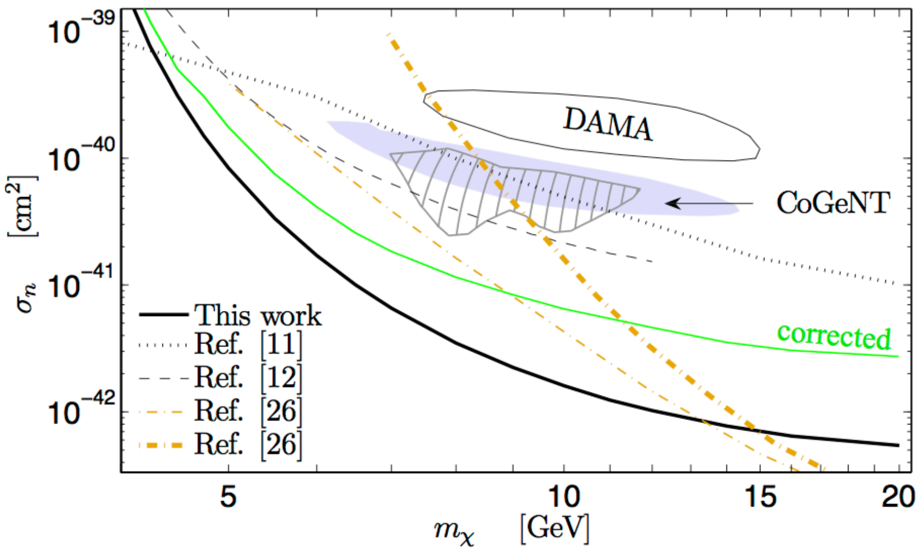


Frandsen, Kahlhoefer, Sarkar, CM, Schmidt-Hoberg: 1304.6066

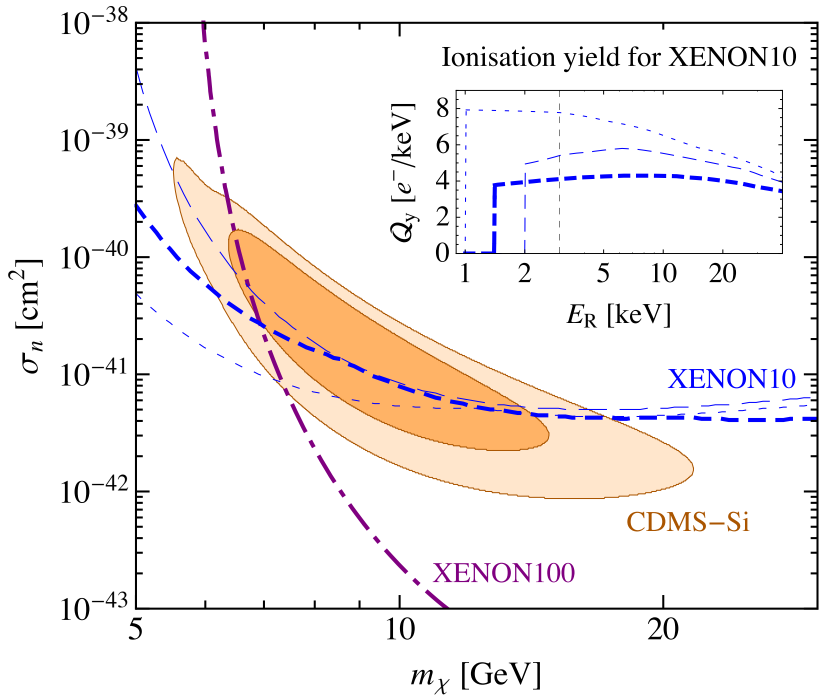
XENON10 (S2-only) limit

XENON10: PRL, 1104.3088

- Published XENON10 limit in PRL paper
- Erratum with corrected limit agrees with our analysis:

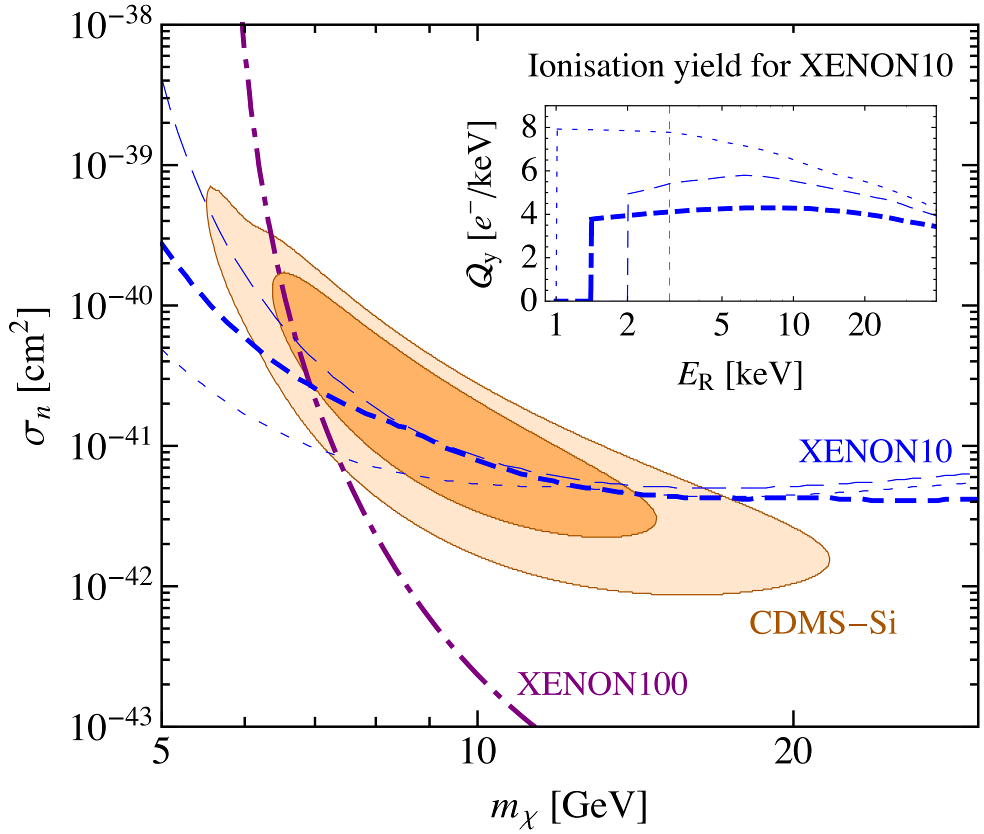


- Our analysis did not agree:



Frandsen, Kahlhoefer, Sarkar, CM, Schmidt-Hoberg: 1304.6066

Summary of experimental results



Frandsen, Kahlhoefer, Sarkar, CM, Schmidt-Hoberg: 1304.6066

- Small region of compatibility between CDMS-Si signal and XENON10 and XENON100 limits

Confronting experiment with theory

- Rate for spin-independent scattering:

$$\frac{dR}{dE_{\rm R}} = {\rm flux} \cdot \frac{d\sigma}{dE_{\rm R}}$$

where $${\rm flux} = \frac{\rho_\chi}{m_\chi} \int_{v_{\rm min}} v f(v)\, d^3v \ , \qquad \frac{d\sigma}{dE_{\rm R}} = A^2 \frac{m_N \sigma_n}{2\mu_{n\chi}^2 v^2}$$

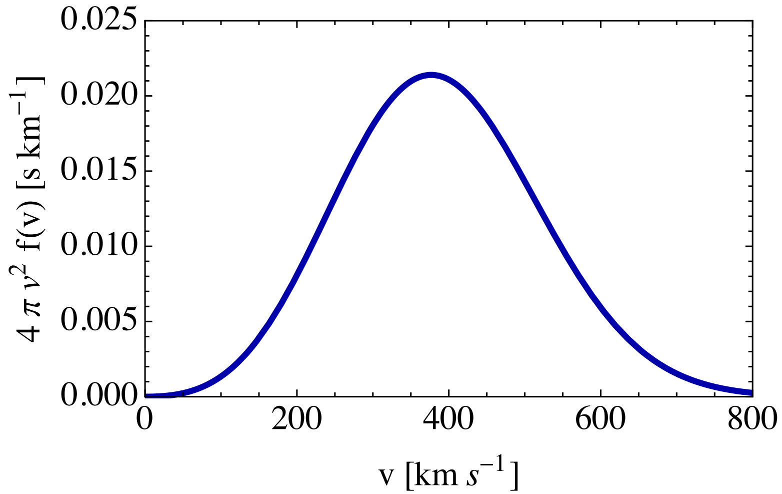
- $v_{\rm min} = \sqrt{\frac{m_N E_{\rm R}}{2\mu_N}}$: minimum DM speed for nucleus to recoil with energy

- Standard theoretical assumptions:
  1. 'Standard Halo Model'
  2. Short range interaction
  3. Equal couplings to protons and neutrons
  4. Elastic scattering

Standard Halo Model

- Truncated Maxwell-Boltzmann velocity distribution (in Galactic frame):

$$f(v) = \begin{cases} N_0 \exp\left(-\frac{v^2}{v_0^2}\right) & v < v_{\rm esc} \\ 0 & v > v_{\rm esc} \end{cases}$$

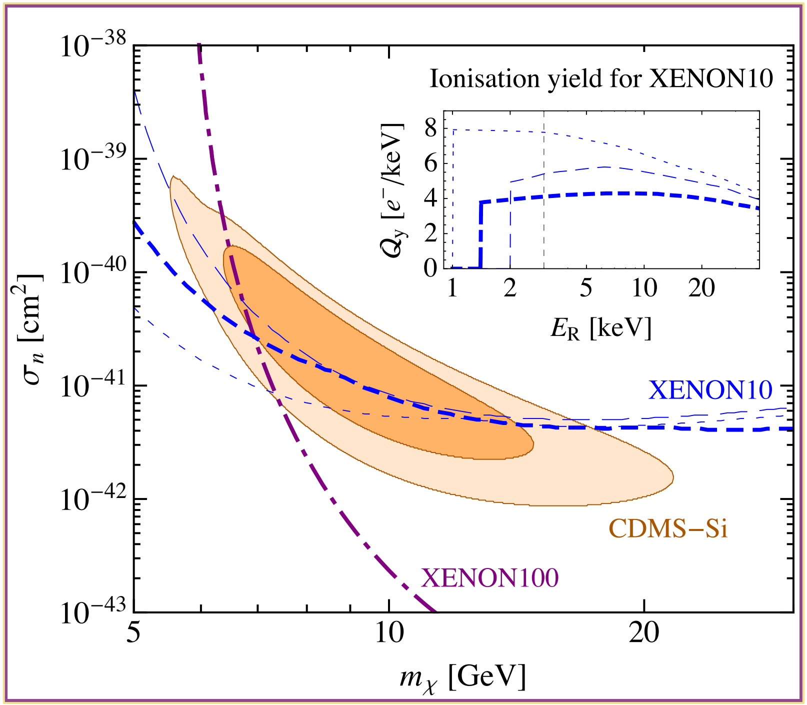


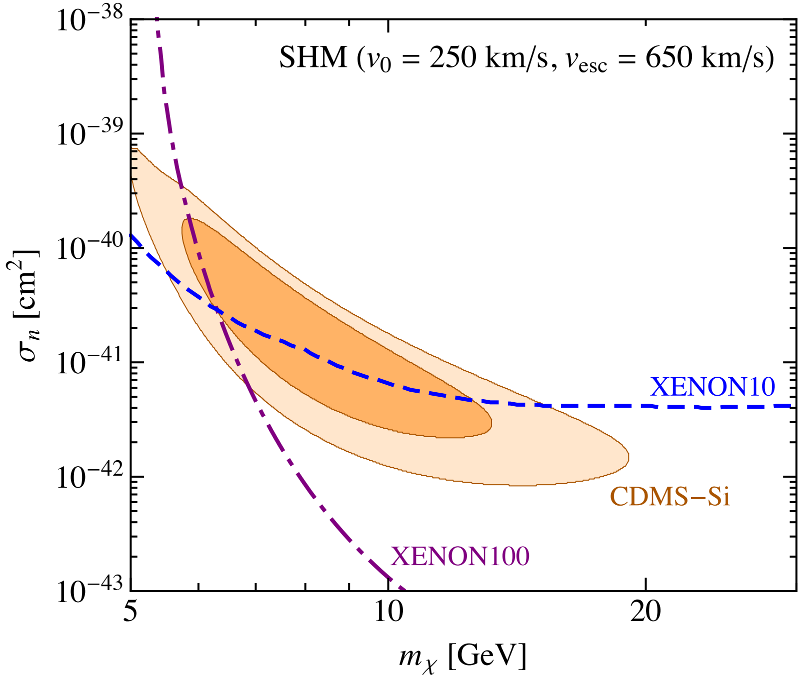
- Canonical values are $v_0 = 220\ \text{kms}^{-1}$ and $v_{\rm esc} = 544\ \text{kms}^{-1}$

- Typical ranges are: $200\ \text{kms}^{-1} \lesssim v_0 \lesssim 250\ \text{kms}^{-1}$ McMillan, Binney: 0907.4685
  $498\ \text{kms}^{-1} \lesssim v_{\rm esc} \lesssim 608\ \text{kms}^{-1}$ RAVE survey: 0611671

Beyond the Standard Halo Model

1. Vary galactic parameters:



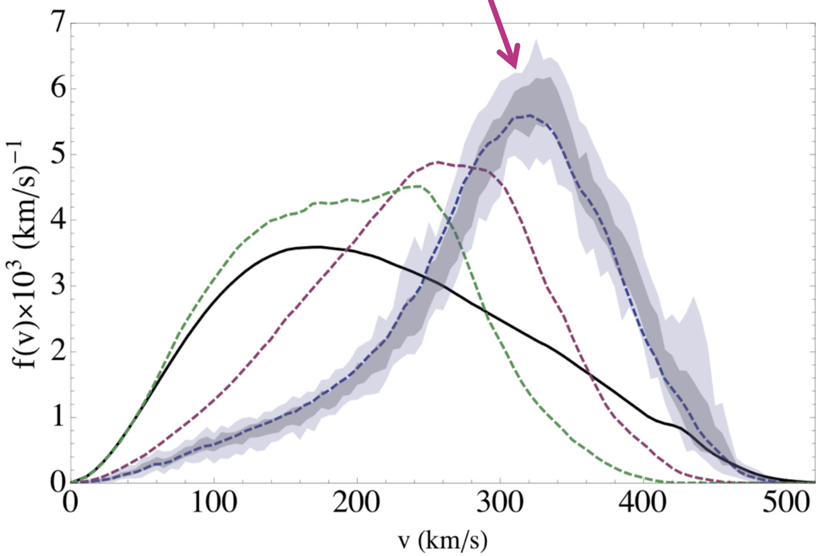


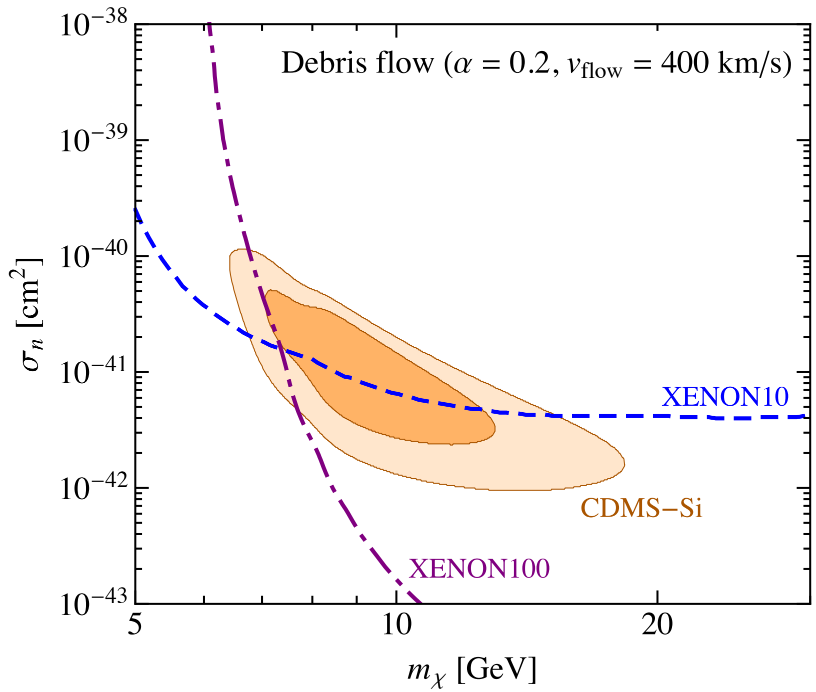
Beyond the Standard Halo Model

Lisanti, Spergel: 1105.4166
Kuhlen, Lisanti, Spergel: 1202.0007

2. Introduce a ‘debris flow’:

Tidally stripped (from subhalos) component near the galactic centre





- Modifying astrophysical-parameters does not improve agreement

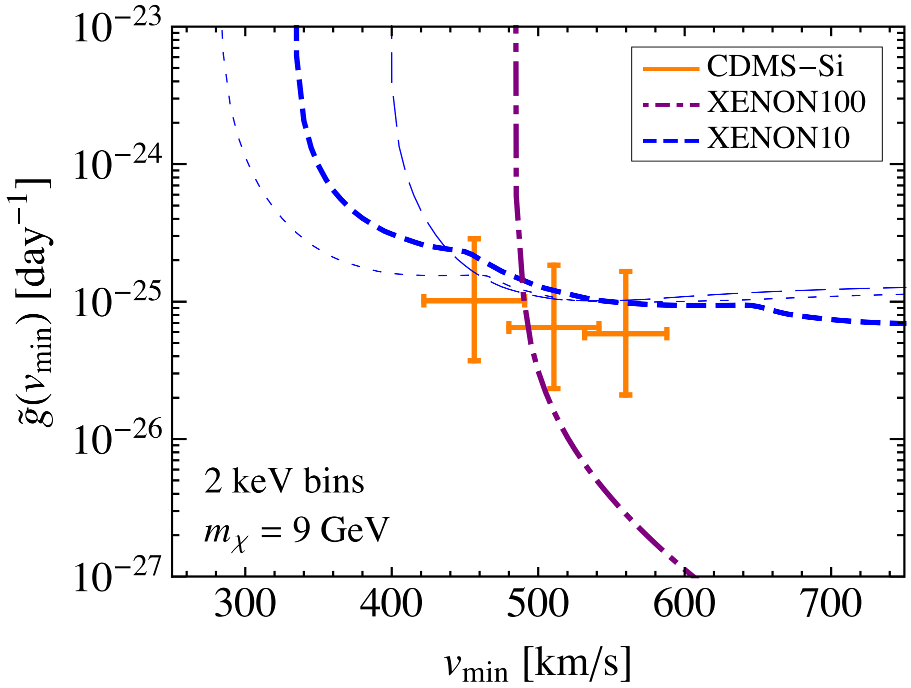
Mapping results to velocity integral

- Scattering rate depends on the ‘velocity integral’
- Changes in astrophysical parameters enter here

Fox, Liu & Weiner: 1011.1915

$$\frac{dR}{dE_\mathrm{R}} \propto g(v_\mathrm{min}) = \int_{v_\mathrm{min}} \frac{f(v)}{v} d^3 v$$

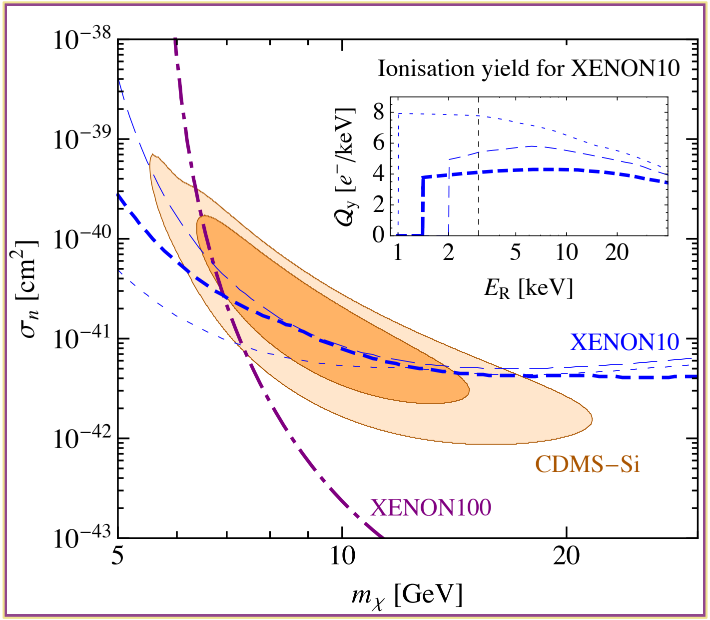
- CDMS-Si, XENON10 and XENON100 probe same ‘velocity integral’

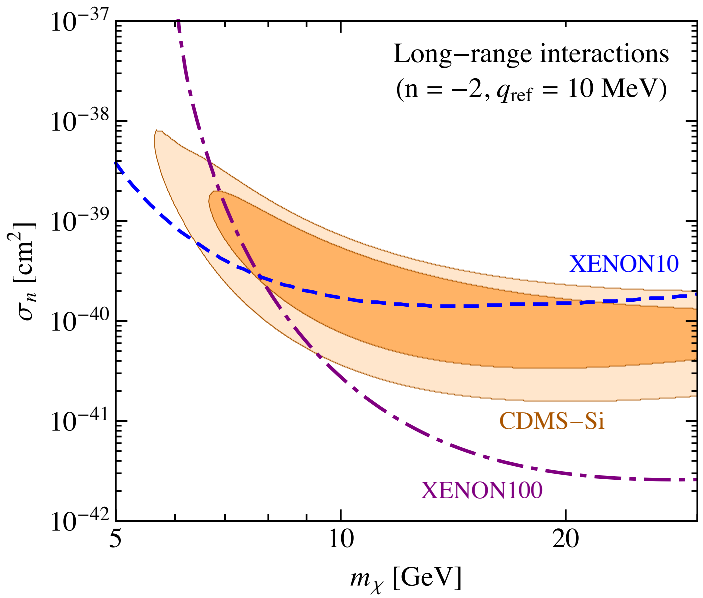


➢ Cannot improve agreement by varying astrophysical parameters

Beyond short range interactions

- Standard assumption: DM scatters with a short range contact interaction – via a 'heavy ($m_{\rm med} \gg 50~{\rm MeV}$) mediator'
- Parameterise long-range interaction by: ($q^2 = 2m_N E_{\rm R}$ is the momentum transfer) $$\frac{d\sigma}{dE_{\rm R}} \rightarrow \left(\frac{q^2}{q^2_{\rm ref}}\right)^n \frac{d\sigma}{dE_{\rm R}}$$





- Agreement does not improve: $q \propto v_{\rm min}$ for light DM

Beyond equal p and n couplings

- Assumed equal couplings to protons and neutrons
- More generally: $\frac{d\sigma}{dE_{\mathrm{R}}} \propto [Z + f_n/f_p(A-Z)]^2$
- If $f_n/f_p < 0$, get destructive interference
- Known mediators:

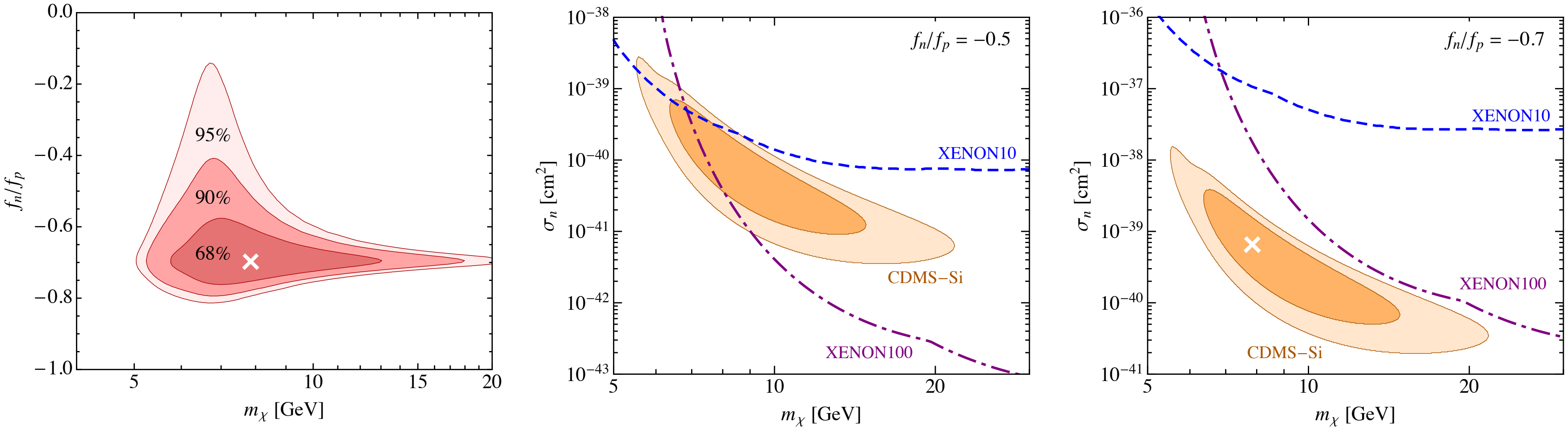
  - Photon: $f_n/f_p = 0$
  - *Z*-boson: $f_n/f_p = \frac{-1}{1-4\sin^2\theta_W} \approx -13.2$
  - Higgs: $f_n/f_p \approx 1$

- DM mediated by new *Z'* could give other values

See Frandsen et al: 1107.2118 & 1204.3839

Beyond equal p and n couplings

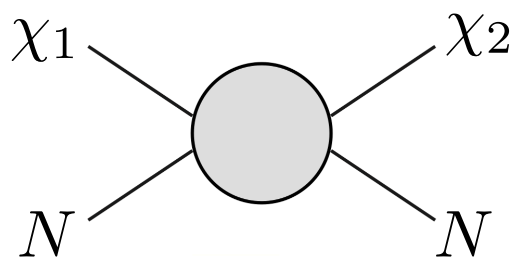
- Assumed equal couplings to protons and neutrons
- More generally: $$\frac{d\sigma}{dE_{\mathrm{R}}} \propto \left[Z + f_n/f_p(A-Z)\right]^2$$

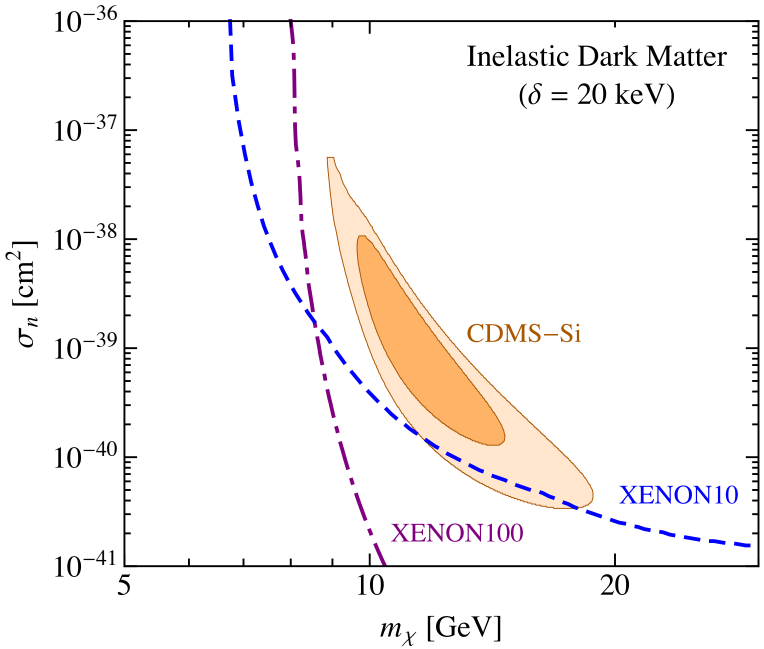


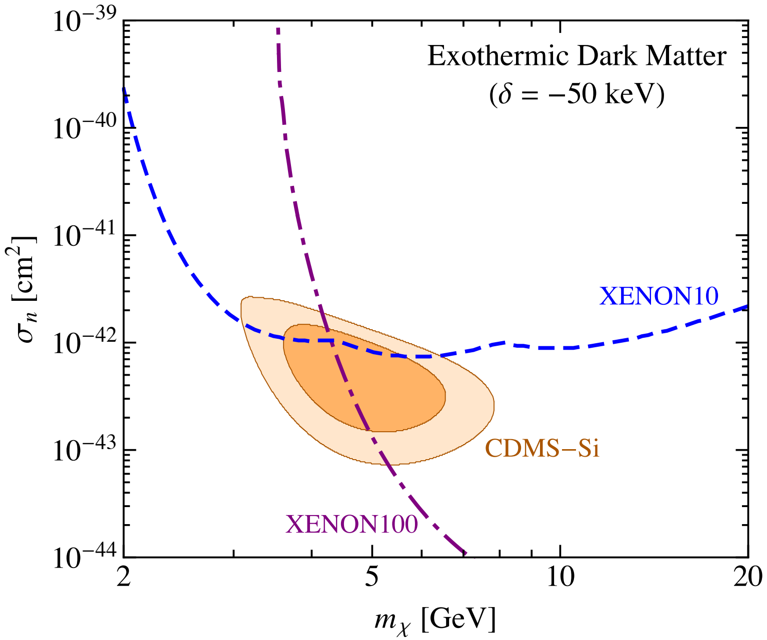
- Xenon constraints can be significantly weaker

Beyond elastic scattering

- For inelastic scattering, can up-scatter ($\delta = m_2 - m_1 > 0$) or down-scatter ($\delta < 0$) to a different mass eigenstate







- 'Down-scattering' enhances rate for light target nuclei

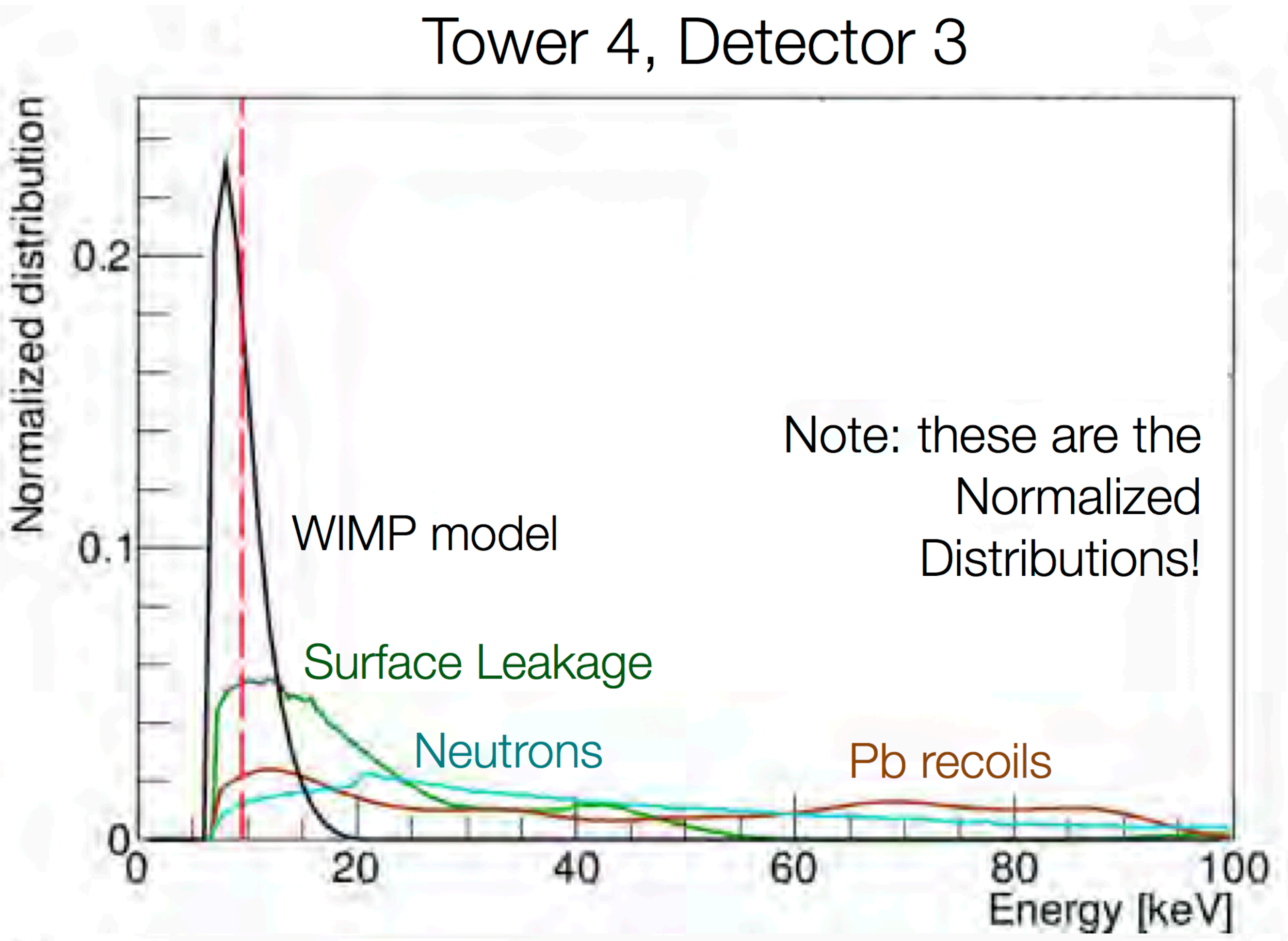
Summary

- CDMS-Si detected 3 events:
  - DM + background hypothesis preferred at ~ 3σ C.L.
- Strong constraints from XENON10 and XENON100

- Attempts to alleviate tension:
  - Vary astrophysical parameters ✗
  - Short range interaction ✗
  - Distinct couplings to protons and neutrons ✓
  - Inelastic scattering:
    - Up-scattering ✗
    - Down-scattering ✓

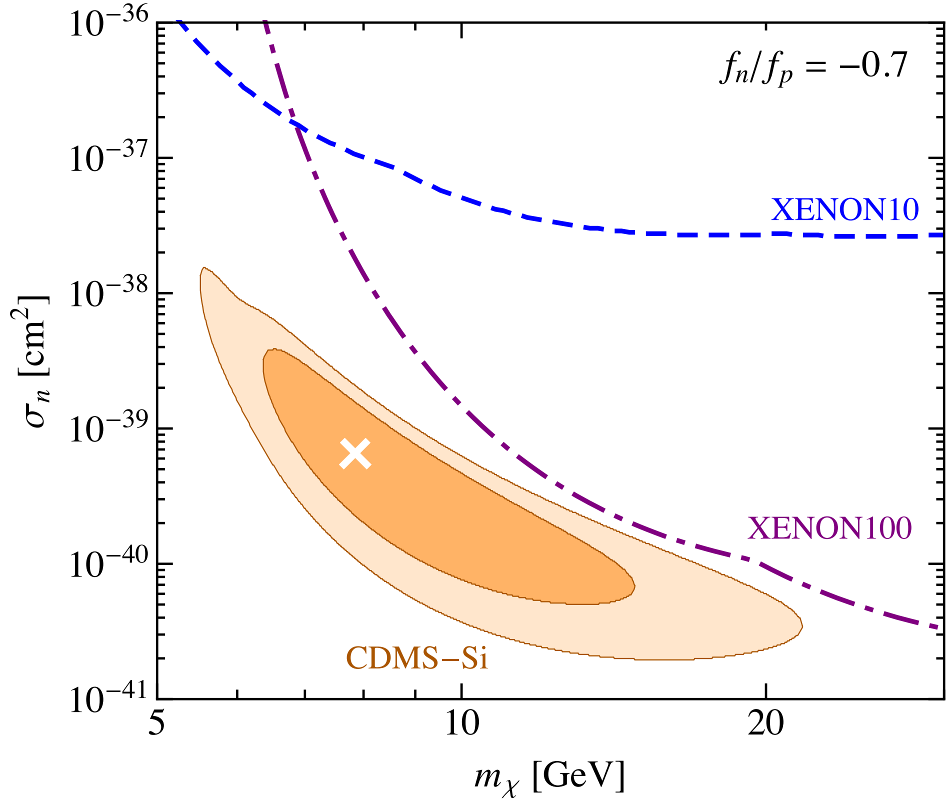
Backup slides – CDMS-Si signal

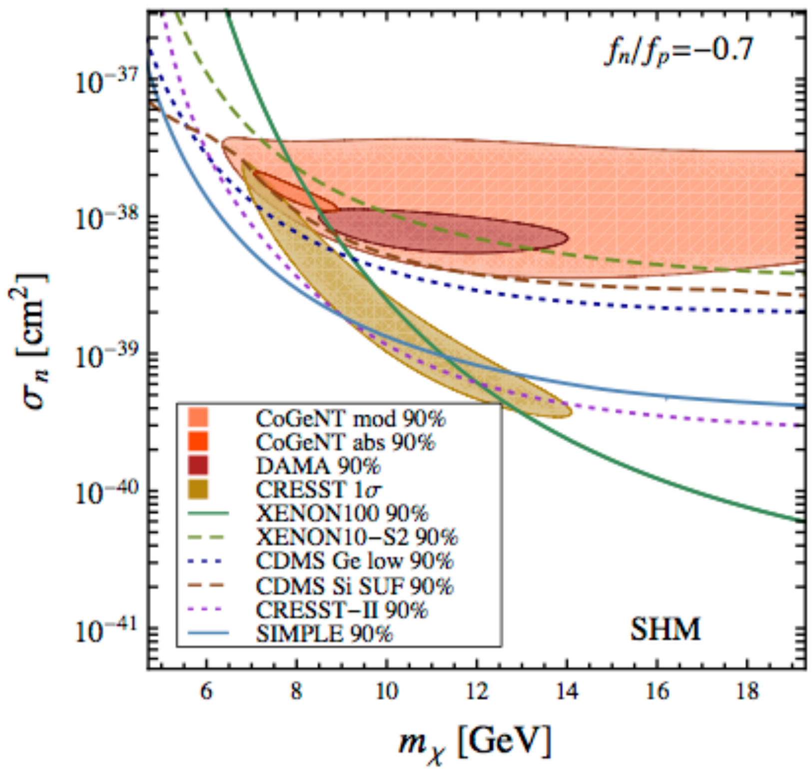
CDMS-Si background distribution



Limits for fn/fp=-0.7

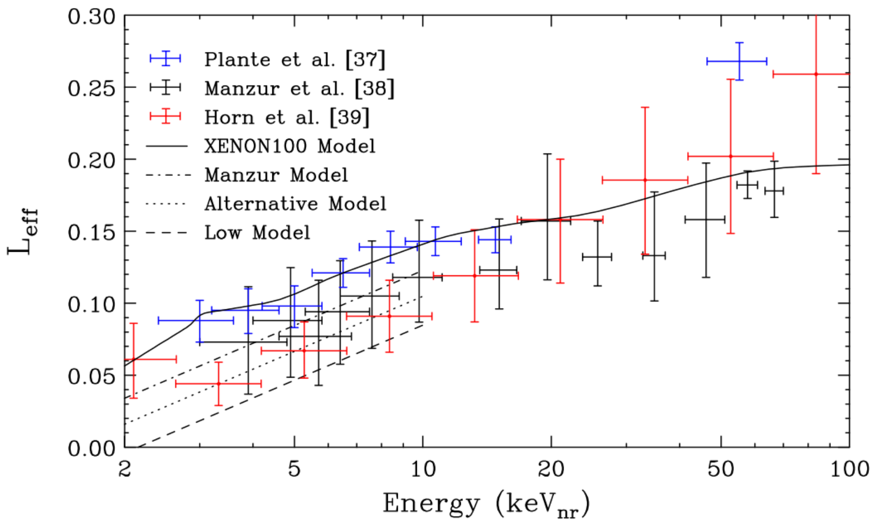
Frandsen, Kahlhoefer, CM, Sarkar,
Schmidt-Hoberg:1111.0292

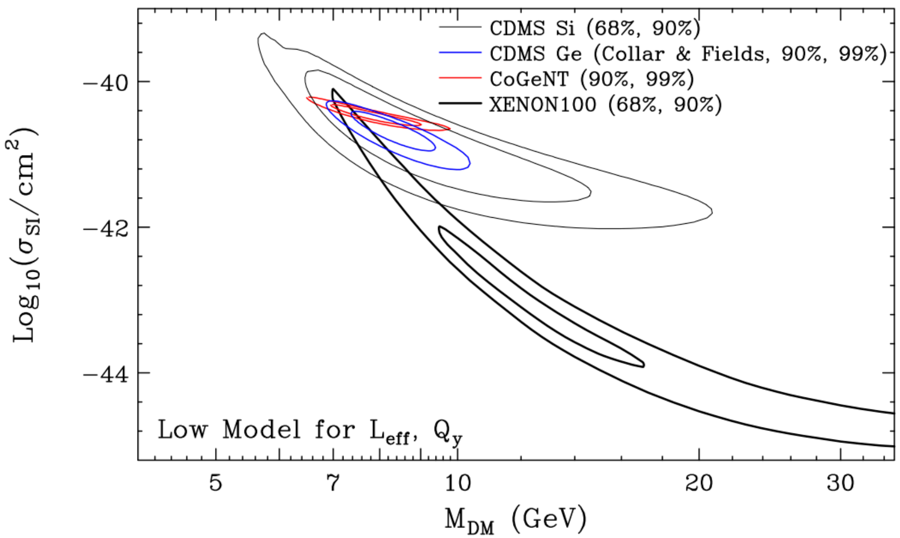


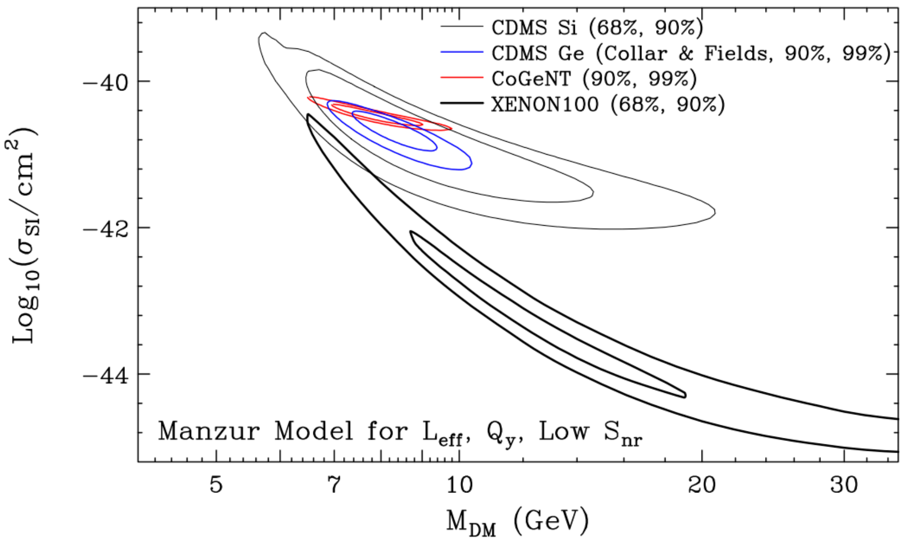


Signal at XENON100?

Hooper: 1306.1790





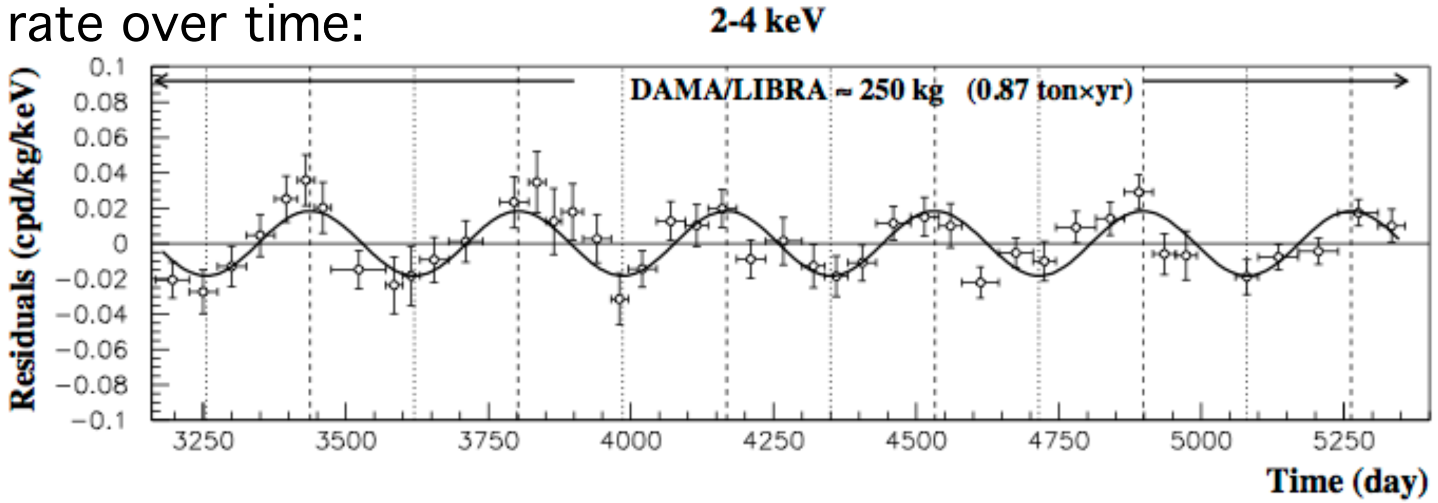


Backup slides – other signals

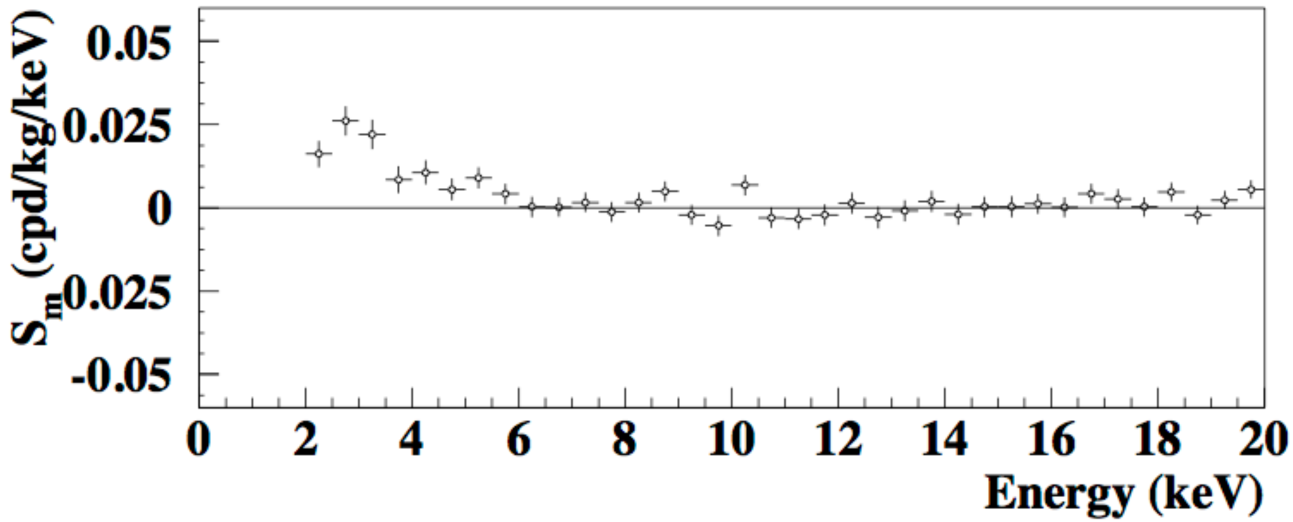
DAMA/LIBRA

Bernabei et al:1002.1028

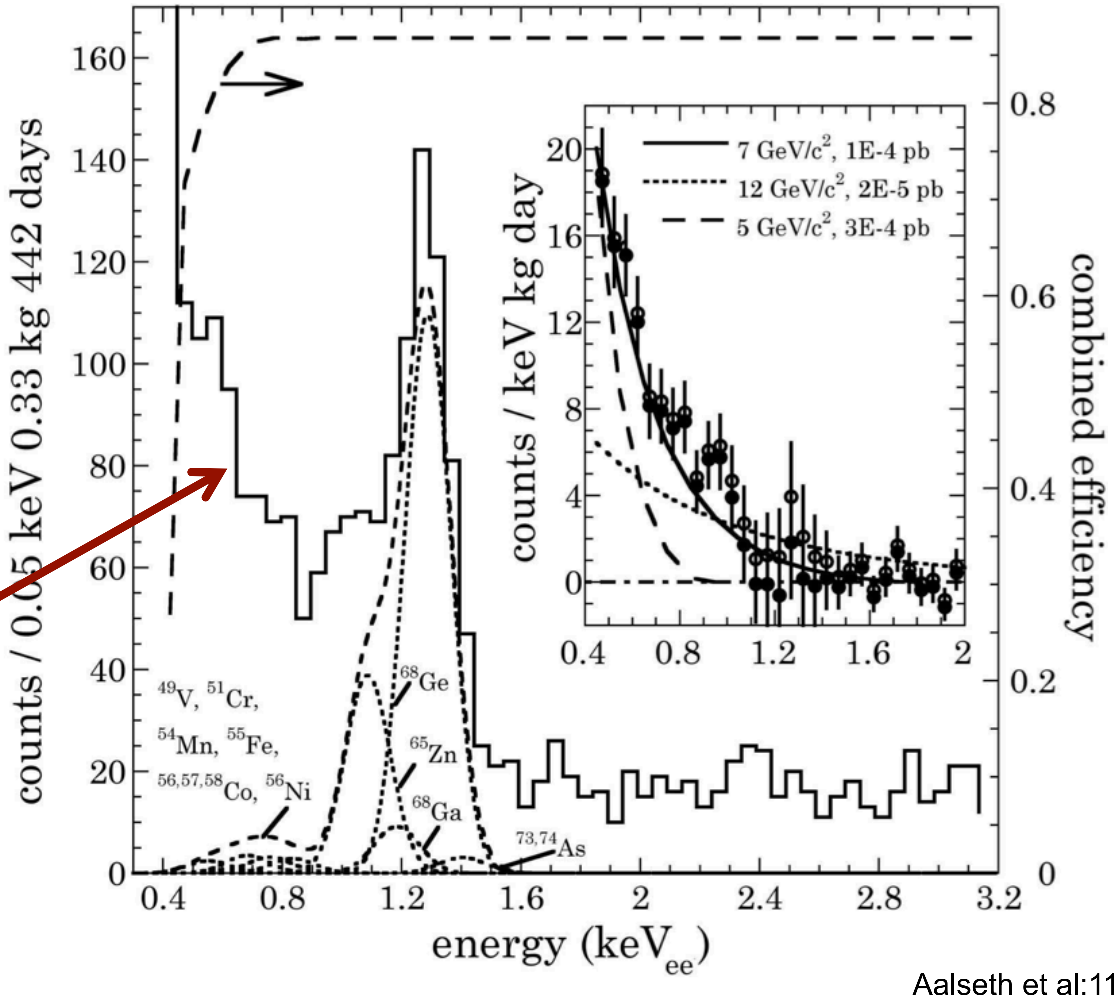
Event rate over time:



Modulation amplitude:



CoGeNT (Ge) – unmodulated signal

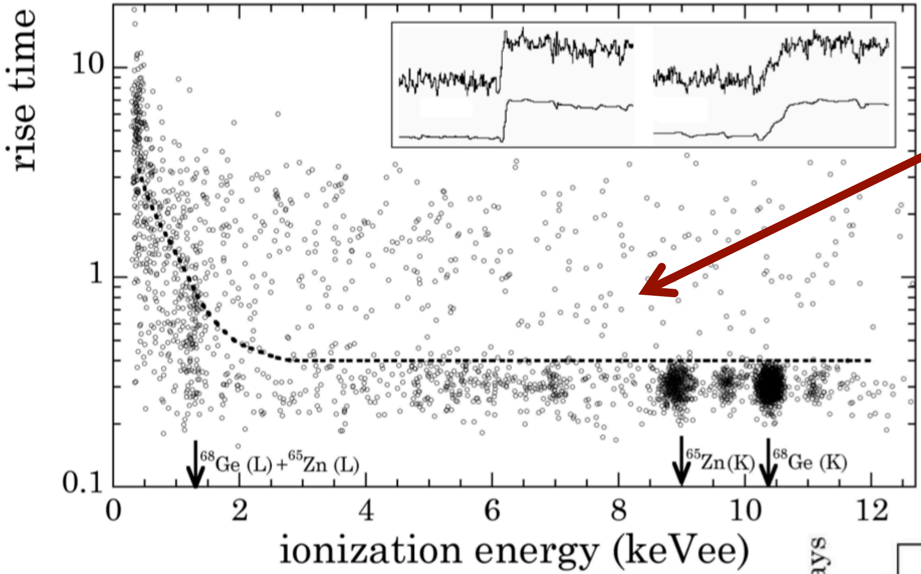


'Excess':
Dark matter?
Background?

Aalseth et al:1106.0650

CoGeNT – surface event cut

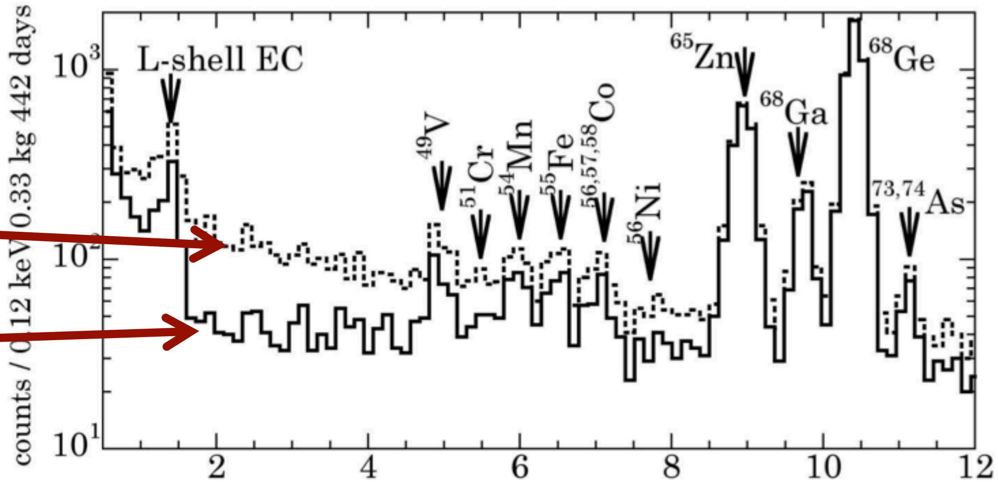
Aalseth et al:1002.4703



Cut events with large rise time

Pre-cut

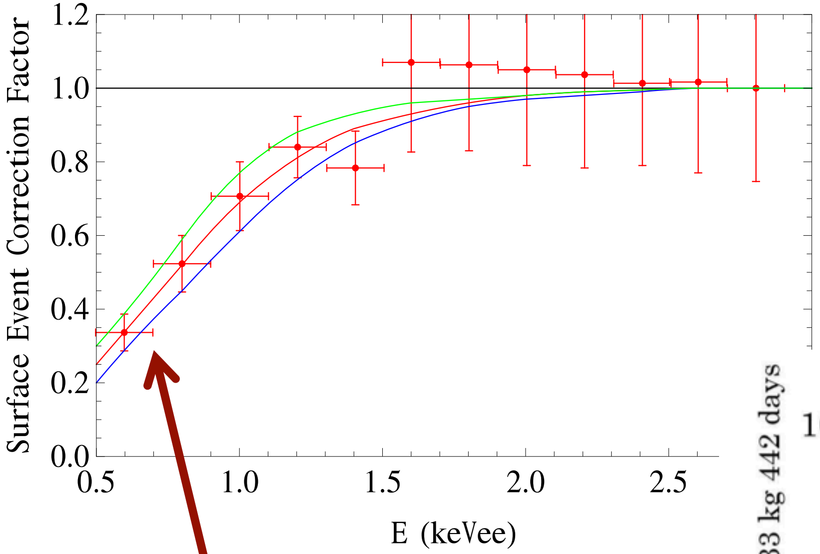
Post-cut



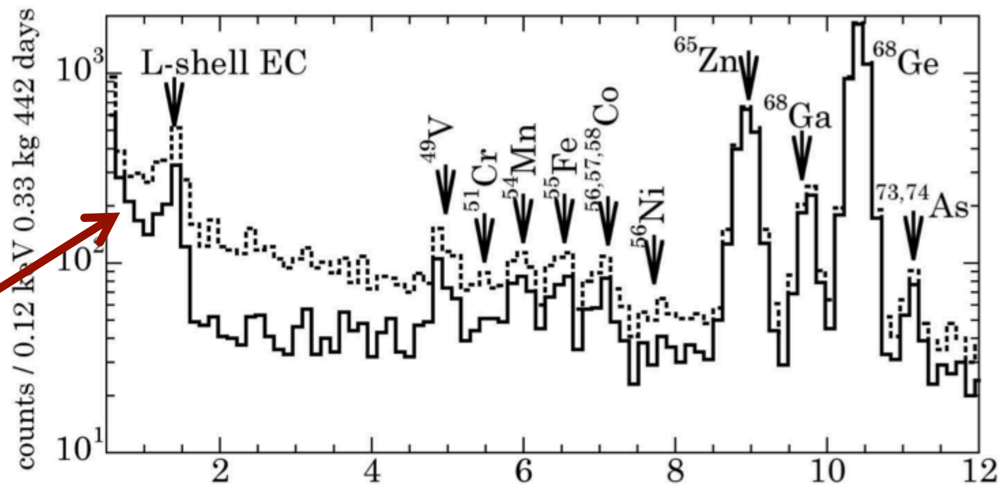
Aalseth et al:1106.0650

CoGeNT – at TAUP (Sept. 2011)

Cut may not be efficient at low energies:



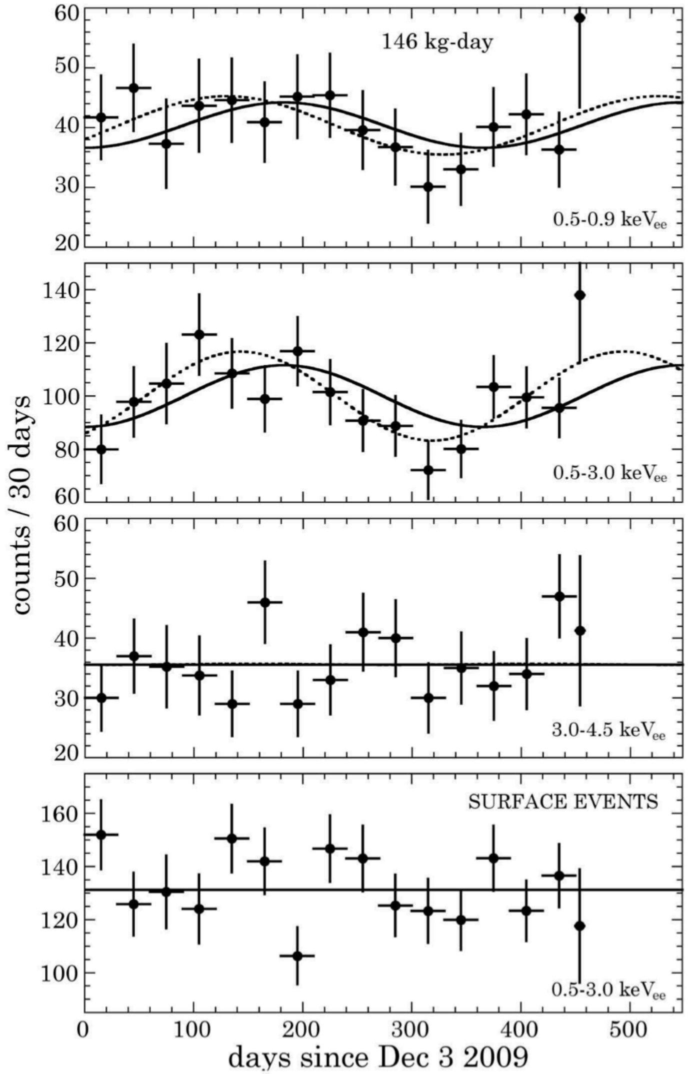
Is there any excess left if we remove another 70% of the events?



CoGeNT – modulated signal

Modulation preferred at $2.8\,\sigma$

Aalseth et al:1106.0650

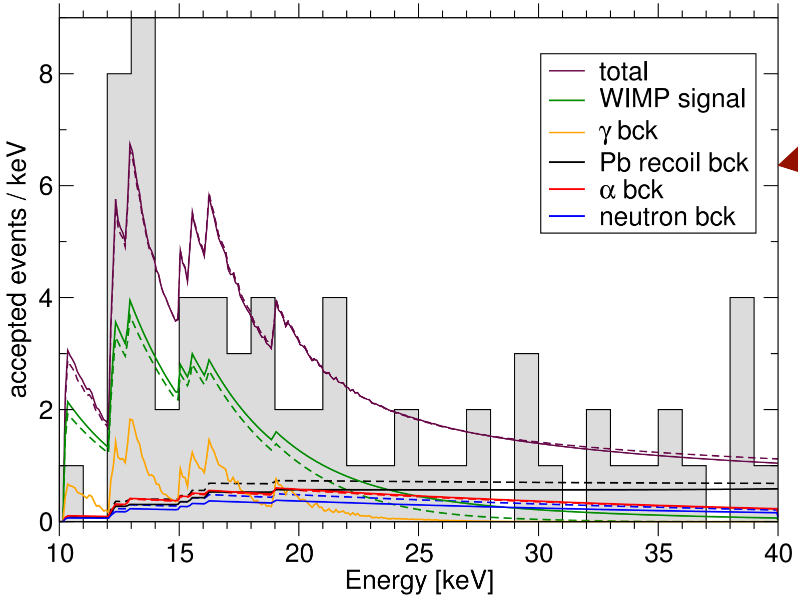


Modulation below 3 keV$_{ee}$

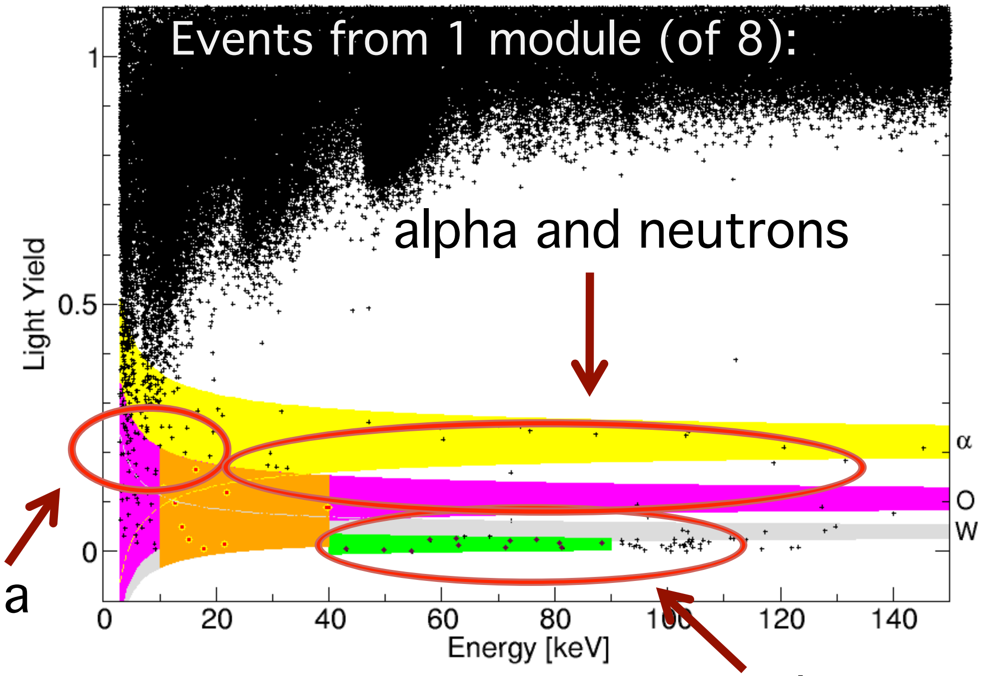
Surface events do not modulate

CRESST-II ($CaWO_4$)

Angloher et al :1109.0702



Four main backgrounds



gamma

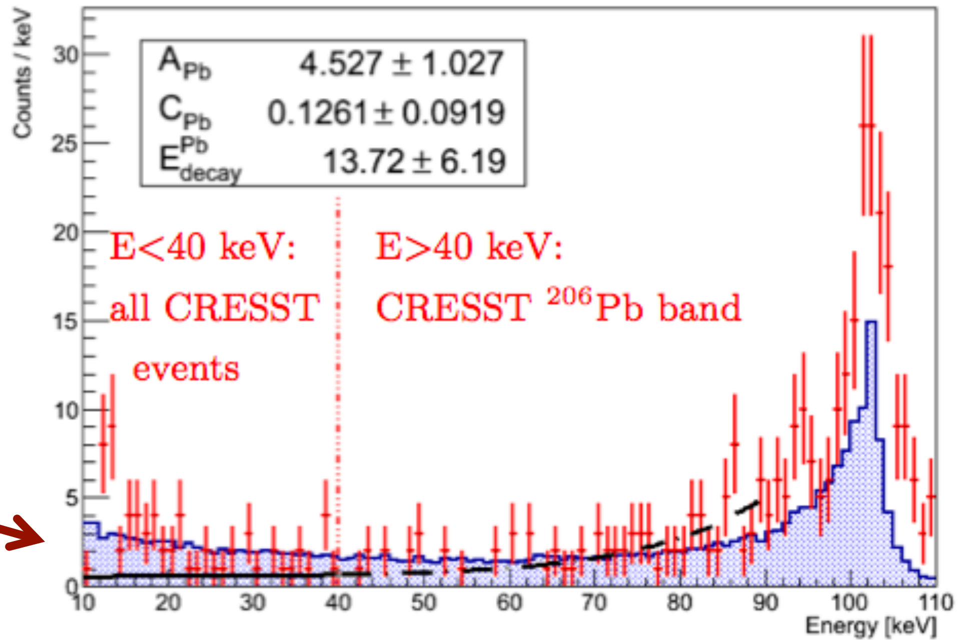
Pb

CRESST-II: Pb recoils

- CRESST-II simulations (black line) indicate that the spectrum should be flat at low recoil energies

- Simulations by Kuzniak et al. find that it rises

  ...is there any excess left to explain?



Kuzniak, Boulay, Pollmann:1203.1576

Consistency of all experiments?

- No known model to bring all experiments into agreement