Halo-independent tests of direct detection signals

or

What can we learn from a DM signal?

Stefan Vogl

JCAP 1508 (2015) 08, 039

arxiv:1505.05710

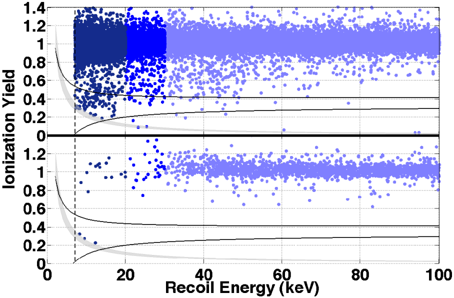
with M. Blennow, J. Herrero-Garcia and T. Schwetz

Oskar Klein centre

Outline

Motivation

- What are early dark matter detections going to look like?



CDMS-Si 1304.4279

Motivation

- most likely a bunch of anomalous events, an increase of the total rate etc.
- result probably controversial, insufficient information available to reconstruct all DM properties, ...

??

$\hookrightarrow$ Is the observed rate/ recoil spectrum consistent with other direct detection experiments?

??

$\hookrightarrow$ Is there a conservative statement about DM particle which can be made at this point?
How can we compare signal with other experiments/observations?

Some preliminaries

- the rate in a direct detection experiment depends on microscopic properties of the dark matter particle and the macroscopic properties of the dark matter halo

$$\mathcal{R}(E_R) \propto \mathcal{C}\eta(v_m^A)$$

- particle physics is encoded in $\mathcal{C}$ and η describes the velocity distribution

$$\mathcal{C} = \frac{\rho_\chi \sigma_\chi}{2 m_\chi \mu_{\chi p}^2} \qquad \text{and} \qquad \eta(v_m^A) = \int_{v>v_m^A} d^3 v \, \frac{f_{\rm det}(\vec{v})}{v}$$

- only DM particles with $v > v_m^A$ can produce recoil events with a given energy E_R

Bound 1: total rate

$$\eta(v_m^A) \equiv \int_{v>v_m^A} d^3v \, \frac{f_{\rm det}(\vec{v})}{v}$$
$$\leq \frac{1}{v_m^A} \int_{v>v_m^A} d^3v \, f_{\rm det}(v)$$
$$\leq \frac{1}{v_m^A}$$

bound from event number

$$N_{[E_1,E_2]} = M\,T\,\mathcal{C}\,\langle \eta(v_m^A) \rangle_{E_1}^{E_2} \rightarrow N_{[E_1,E_2]} \leq M\,T\,\mathcal{C}\,\langle 1/v_m^A \rangle_{E_1}^{E_2}$$

Consequence: $\sigma \rho_\chi \geq \ldots$

Bound 2: recoil spectrum

$$1 = \int_0^\infty dv\, \eta(v) \geq v_1 \eta(v_1) + \int_{v_1}^{v_2} dv\, \eta(v)$$

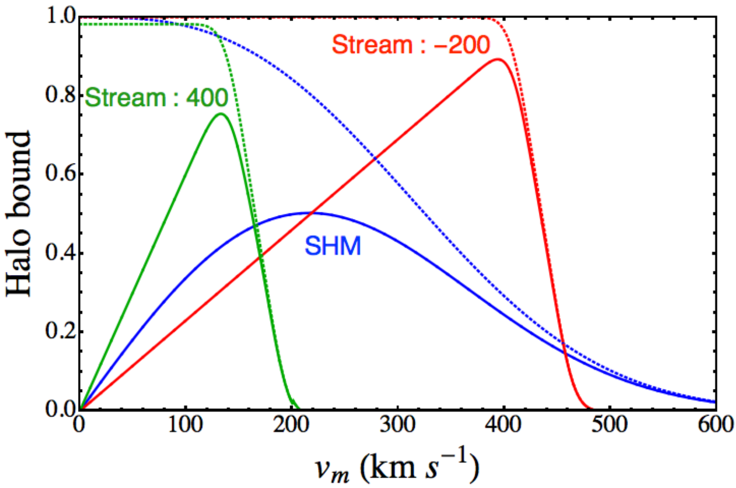
see also Feldstein, Kahlhoefer '14

bound from recoil spectrum

$$\eta(v_m^A) = \frac{\mathcal{R}(E_R)}{\mathcal{C}\, A^2 F_A^2(E_R)} \rightarrow 1 \geq \frac{1}{\mathcal{C} A^2} \left(v_1 \frac{\mathcal{R}(E_1)}{F_A^2(E_1)} + \int_{v_1}^{v_2} dv \frac{\mathcal{R}(E_R)}{F_A^2(E_R)} \right)$$

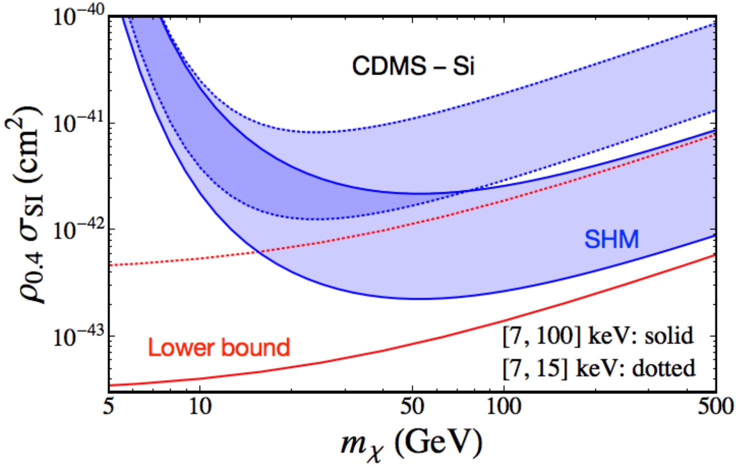
Consequence: $\sigma \rho_\chi \geq \ldots$

Strength of the halo bound



ratio of the upper bound to the true halo integral for the Standard Halo Model (SHM) and two exemplary streams

Lower bound on σ



three events $\Rightarrow$ bound on total rate

How to scrutinize the interpretation of a potential signal

- get at the particle physics in a DD signal
- try to extract particle physics information without committing to a astrophysical model
- compare signal with other experiments/observations
  - LHC
  - relic density
  - ...

An illustrative example: A toy analysis for a toy signal

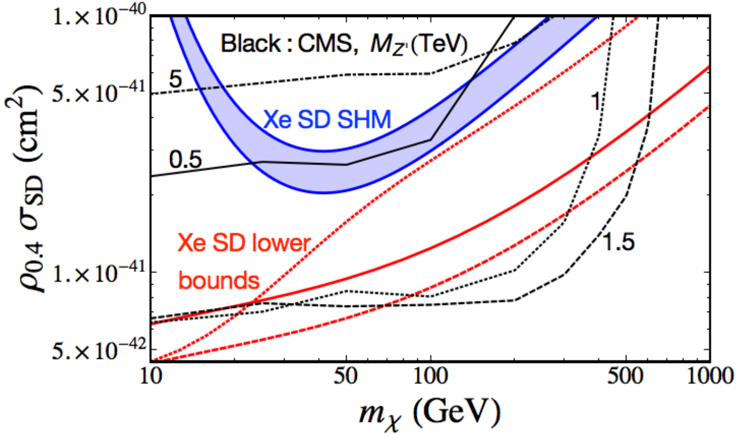
detector and signal

- $\sigma_{SD} = 5 \times 10^{-41}\,\mathrm{cm}^2$ and $\rho_\chi = 0.4\,\mathrm{GeV}/\mathrm{cm}^3$
- xenon based detector
- exposure 1 ton year
- 100% detector efficiency

interpretation

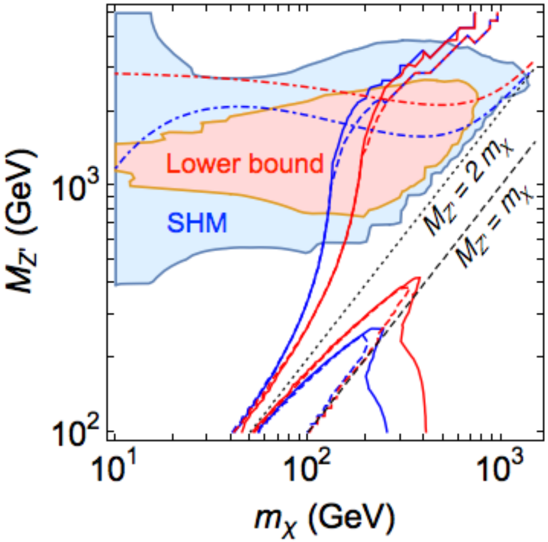
- simplified model
- Majorana DM χ + Z' mediator
- axial couplings to DM and quarks
- $\mathcal{L}_{int} = g_\chi \bar{\chi} \gamma_\mu \gamma^5 \chi Z'^\mu + g_q \bar{q} \gamma_\mu \gamma^5 q Z'^\mu$

Comparison with LHC exclusion



recast of CMS monojet search at 8 TeV using 19.7fb^{-1} 1408.3583

Dissecting the parameter space



Conclusions

- investigate halo-independent methods for direct detection signals
- robust halo-independent lower bound on σ
- interesting possibilities for cross examination with
  - LHC
  - relic density
  - indirect detection
  - ...