Halo-independent tests of direct detection signals

or

What can we learn from a DM signal?

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Outline

1. Introduction
2. A bound on the halo integral
3. Scrutinizing a potential signal
4. Conclusions
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, ...

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

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.

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

- Particle physics is encoded in \( C \) and \( \eta \) describes the velocity distribution.

\[ C = \frac{\rho \chi \sigma \chi}{2m_\chi \mu^2_\chi \rho} \quad \text{and} \quad \eta(v_m^A) = \int_{v>v_m^A} d^3v \frac{f_{\text{det}}(\vec{v})}{v} \]

- Only DM particles with \( v > v_m^A \) can produce recoil events with a given energy \( E_R \).
Bound 1: total rate

\[ \eta(v_m^A) \equiv \int_{v > v_m^A} d^3v \frac{f_{\text{det}}(\vec{v})}{v} \]

\[ \leq \frac{1}{v_m^A} \int_{v > v_m^A} d^3v f_{\text{det}}(v) \]

\[ \leq \frac{1}{v_m^A} \]

bound from event number

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

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

\[ \eta(v_m^A) = \frac{R(E_R)}{CA^2F_A^2(E_R)} \rightarrow 1 \geq \frac{1}{CA^2} \left( v_1 \frac{R(E_1)}{F_A^2(E_1)} + \int_{v_1}^{v_2} dv \frac{R(E_R)}{F_A^2(E_R)} \right) \]

Consequence: \( \sigma \rho_\chi \geq \ldots \)
ratio of the upper bound to the true halo integral for the Standard Halo Model (SHM) and two exemplary streams
Lower bound on $\sigma$

$\rho_{0.4} \sigma_{\text{SI}} \text{ (cm}^2\text{)}$

CDMS – Si

SHM

Lower bound

[7, 100] keV: solid
[7, 15] keV: dotted

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
  - ...

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An illustrative example: A toy analysis for a toy signal

detector and signal

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

interpretation

- simplified model
- Majorana DM $\chi + Z'$ mediator
- axial couplings to DM and quarks
- $L_{int} = g_\chi \bar{\chi} \gamma_\mu \gamma^5 \chi Z'^\mu + g_q \bar{q} \gamma_\mu \gamma^5 q Z'^\mu$
Comparison with LHC exclusion

recast of CMS monojet search at 8 TeV using 19.7fb$^{-1}$
Dissecting the parameter space
Conclusions

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

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