A new halo independent approach for direct dark matter searches

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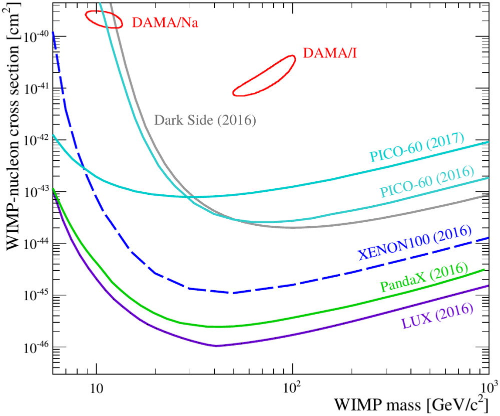
In collaboration with Alejandro Ibarra, arXiv:1703.09168

Common approach:

Assume SI or SD interaction only, $\rho_{\text{loc}} = 0.3\ \text{GeV}/\text{cm}^3$ and a Maxwell-Boltzmann velocity distribution.



[Undagoitia,Rauch 1509.08767]

Motivation

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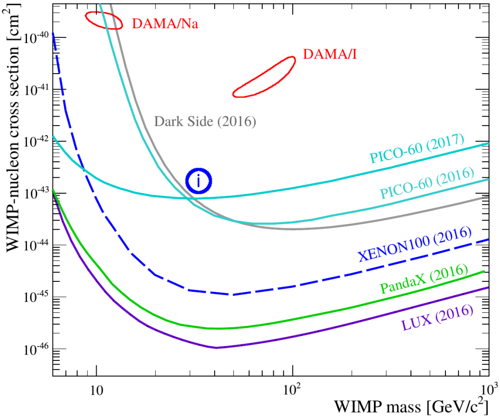

i: Ruled out by several experiments.

[Undagoitia,Rauch 1509.08767]

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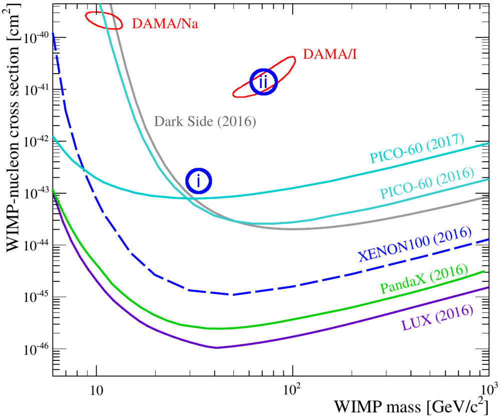

[Undagoitia,Rauch 1509.08767]

- i: Ruled out by several experiments.
- ii: Explains DAMA results, but is in tension with other experimental results.

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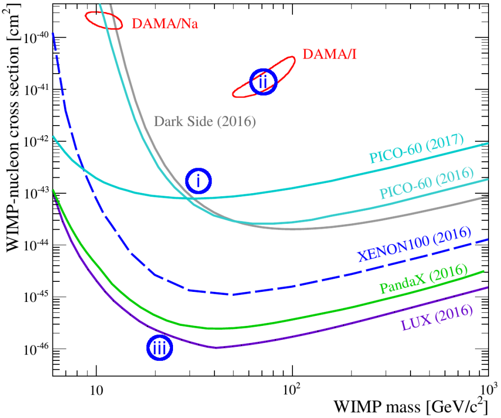

[Undagoitia,Rauch 1509.08767]

- i: Ruled out by several experiments.
- ii: Explains DAMA results, but is in tension with other experimental results.
- iii: Untested by current experiments but can be accessed by future experiments.

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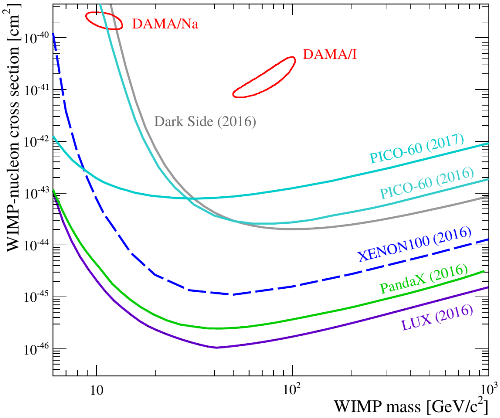


[Undagoitia,Rauch 1509.08767]

- What is the impact of astrophysical uncertainties?
- Do these conclusions hold for all f(v)?

Particle physics uncertainties

Dark matter mass

→ Between MeV and 100 TeV for thermally produced dark matter

Differential scattering cross section

$$\frac{d\sigma}{dE_R} = \frac{m_A}{2\mu_A^2 v^2}\left(\sigma_{SI} \cdot F_{SI}(E_R)^2 + \sigma_{SD} \cdot F_{SD}(E_R)^2\right)$$

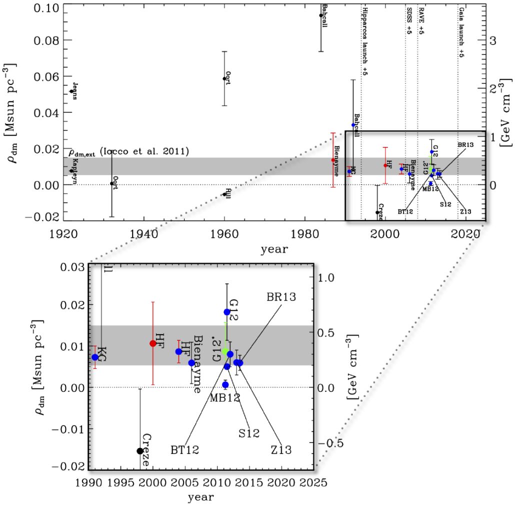
Cross section at zero momentum transfer

Form factors

→ Additional operators can arise in some DM frameworks.

Local dark matter density

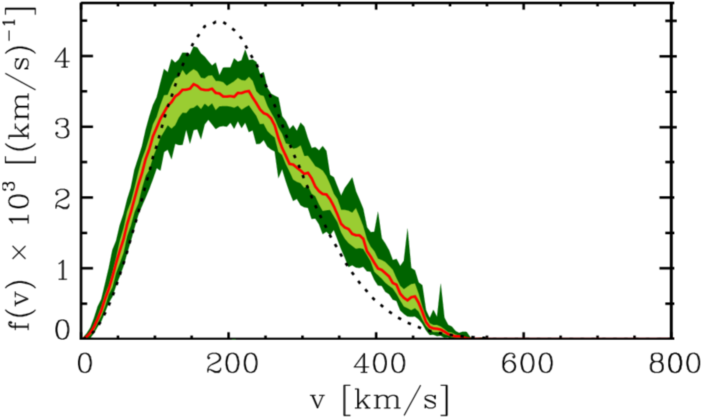
- ”local measurements”: Determined from vertical kinematics of stars near the sun ($\sim$ 1kpc).
- ”global measurements”: $\rho(r)$ is determined from rotation curves at large r and extrapolated to the position of the solar system.



[Read 1404.1938]

Local dark matter velocity distribution

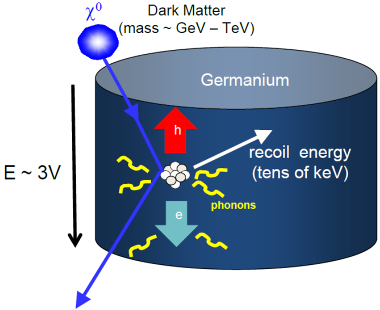
→ Completely unknown, relies on theoretical considerations.



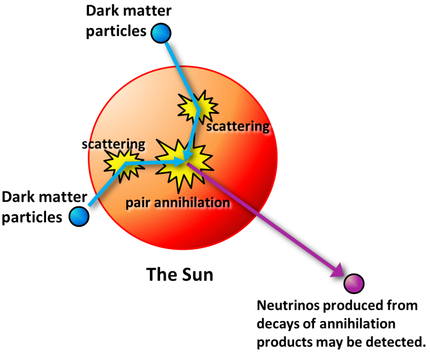
[Kuhlen et. al. 0912.2358]

We will consider the following dark matter search strategies:

Direct detection



Neutrino telescopes



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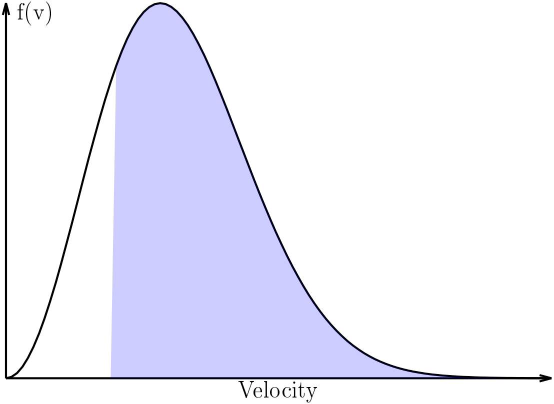
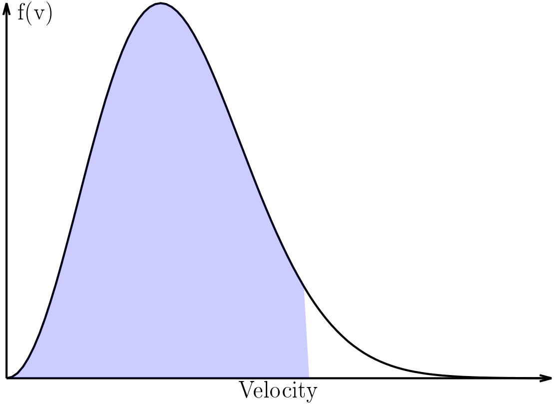


- Direct detection: Energy has to be transferred onto the nucleus $\rightarrow$ Lower limit on v

Complementarity



- Direct detection: Energy has to be transferred onto the nucleus → Lower limit on v
- Neutrino telescopes: Particles have to be captured gravitationally → Upper limit on v

Halo independent approach

- (σ,m_{DM}) is ruled out regardless of the velocity distribution if:

$$\min_{f(\vec{v})} \{R(\sigma, m_{DM})\} \big|_{constraints} \geq R_{max}$$

- (σ,m_{DM}) untestable regardless of the velocity distribution if:

$$\max_{f(\vec{v})} \{R(\sigma, m_{DM})\} \big|_{constraints} \leq 1$$

Constraints are provided by other experiments

$\rightarrow$ By using both a direct detection experiment and neutrino telescopes, we can probe the whole velocity distribution.

Halo independent approach

Step 1: $f(\vec{v})$ as superposition of streams

Following [Feldstein et. al. 1403.4606], we decompose the velocity distribution into a set of streams. Then, we discretise the integral:

$$f(\vec{v}) = \int dv_0^3\, f(v_0)\, \delta(v - v_0) \rightarrow \sum_i a_i\, \delta(\vec{v} - \vec{v}_i)$$

$$\text{Normalization: } \int dv^3\, f(\vec{v}) = 1 \rightarrow \sum_i a_i = 1$$

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→ The observables become linear equations:

$$\text{Number of events N} \;=\; \sum_i \mathrm{a}_i\, \mathrm{N}_{\vec{v}_i}$$

$$\text{Capture rate C} \;=\; \sum_i \mathrm{a}_i\, \mathrm{C}_{\vec{v}_i}$$

Halo independent upper limits

Step 2: Calculating the minimum and maximum

Since all equations are linear functions of the parameters a_i, we can perform this optimization with existing methods of linear programming.

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More precisely, we use the Simplex algorithm:

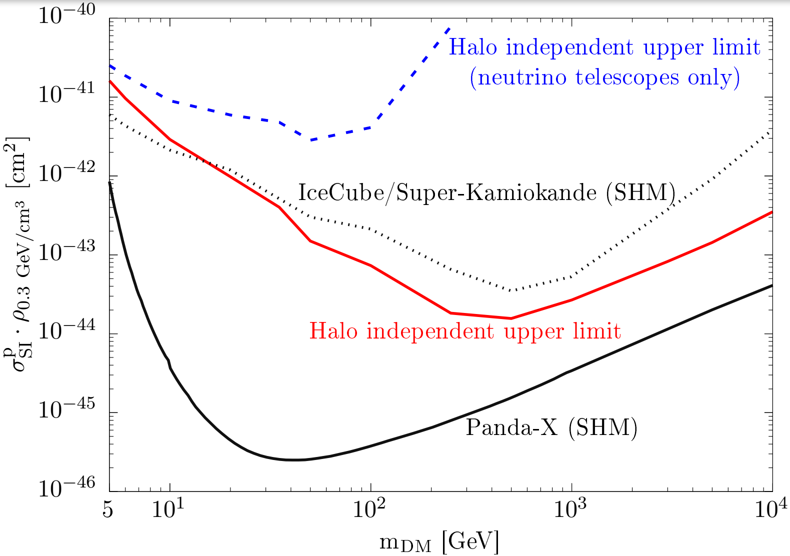
$$\text{optimize: } F(a_1, \ldots, a_n) = \sum_i a_i \cdot R_i^{(A)}$$

$$\text{Subject to: } \sum_i a_i \cdot R_i^{(B_\alpha)} \leq R_{\max}^{(B_\alpha)}, \;\; \alpha = 1, \ldots, p$$

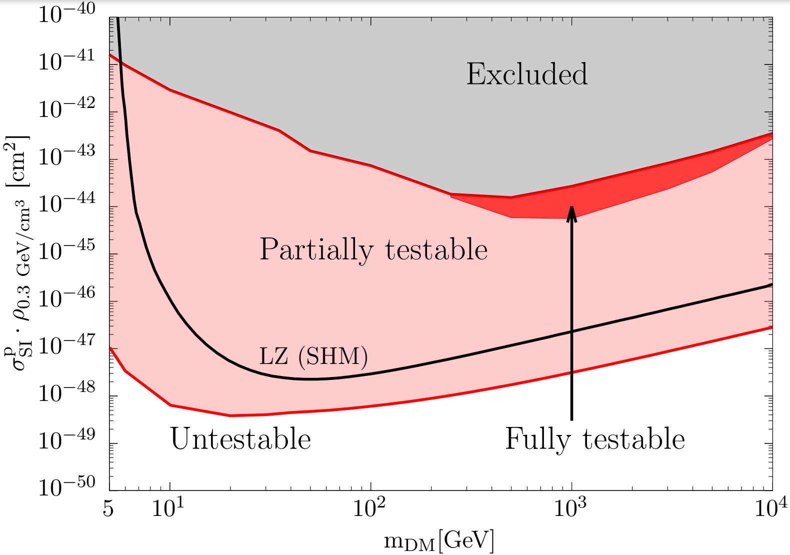
$$\text{and: } \sum_i a_i \cdot R_i^{(B_\alpha)} \geq R_{\min}^{(B_\alpha)}, \;\; \alpha = 1 + p, \ldots, p + q$$

$$\text{and: } \sum_i a_i = 1$$

Combining upper limits



Sensitivity of future experiments



Conclusions and outlook

- We developed a new method that provides a halo independent interpretation of direct dark matter searches.
- Some applications are:
  i. Derive halo independent upper limits from a set of null results.
  ii. Confront a detection claim in a halo independent way to null results.
  iii. Asses detection prospects for a future experiment in a halo independent way.
- Work in progress:
  $\rightarrow$ Derive fully halo and particle physics independent limits.
  $\rightarrow$ Take into account perturbations of smooth distributions and uncertainties of the local dark matter density.