The Challenge of Interpreting Direct Detection Data

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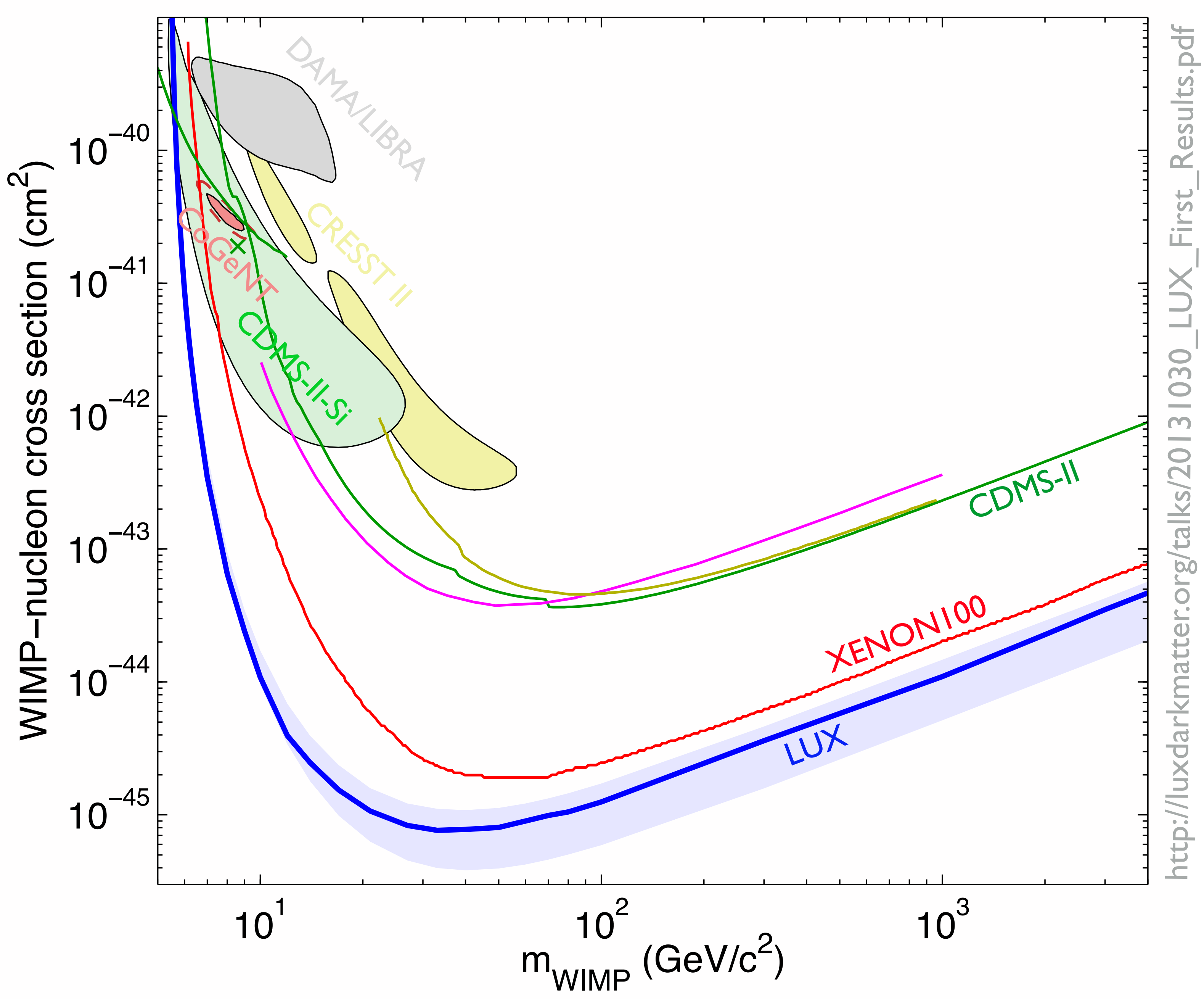
Assumptions

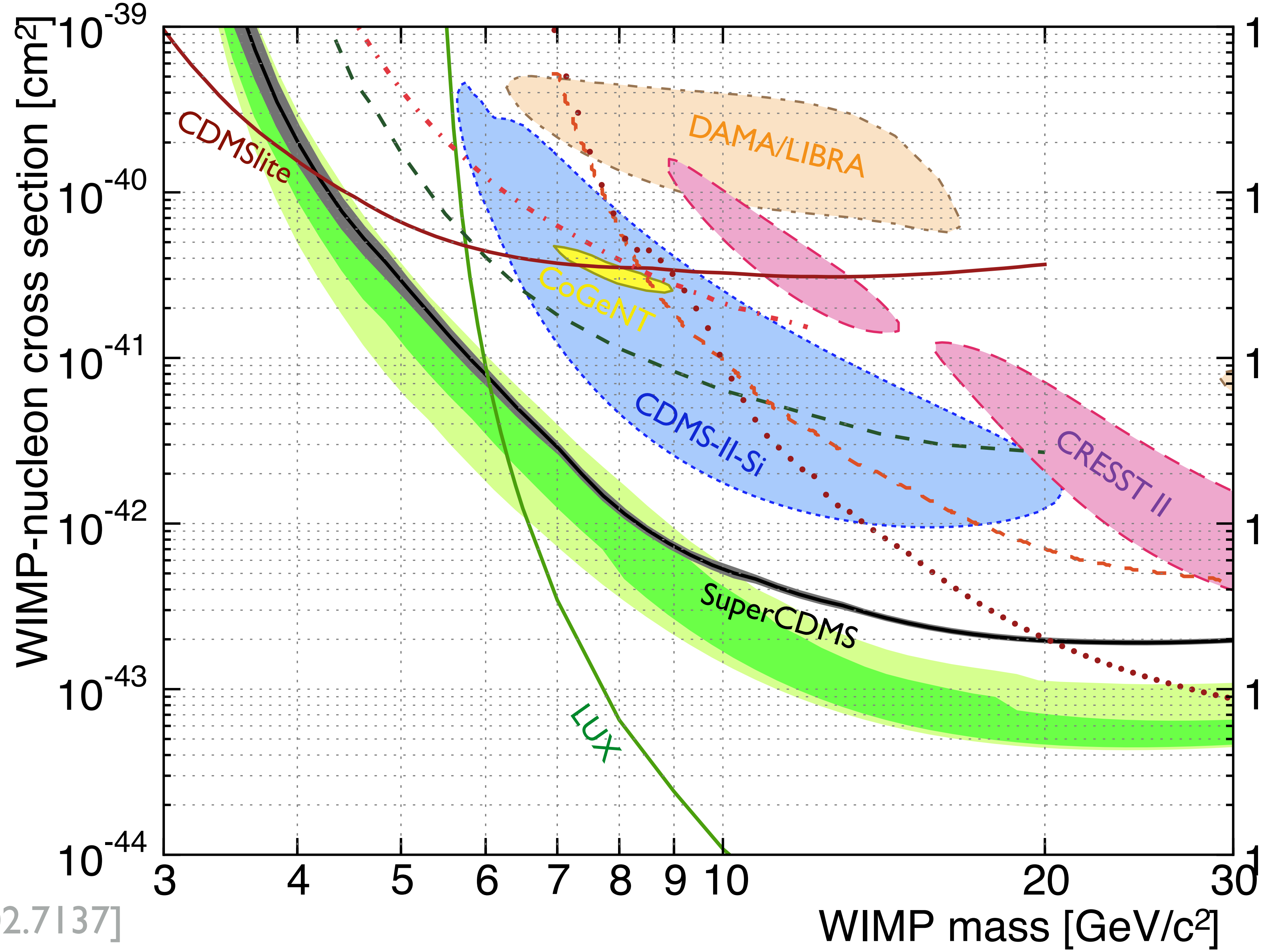
- WIMPs: Weak-scale interacting DM particles
  non-relativistic, with mass 1 GeV - 10 TeV

- Actually, only one kind of particle
  like approximating SU(3)xSU(2)xU(1) as “just hydrogen”

Limits and fits



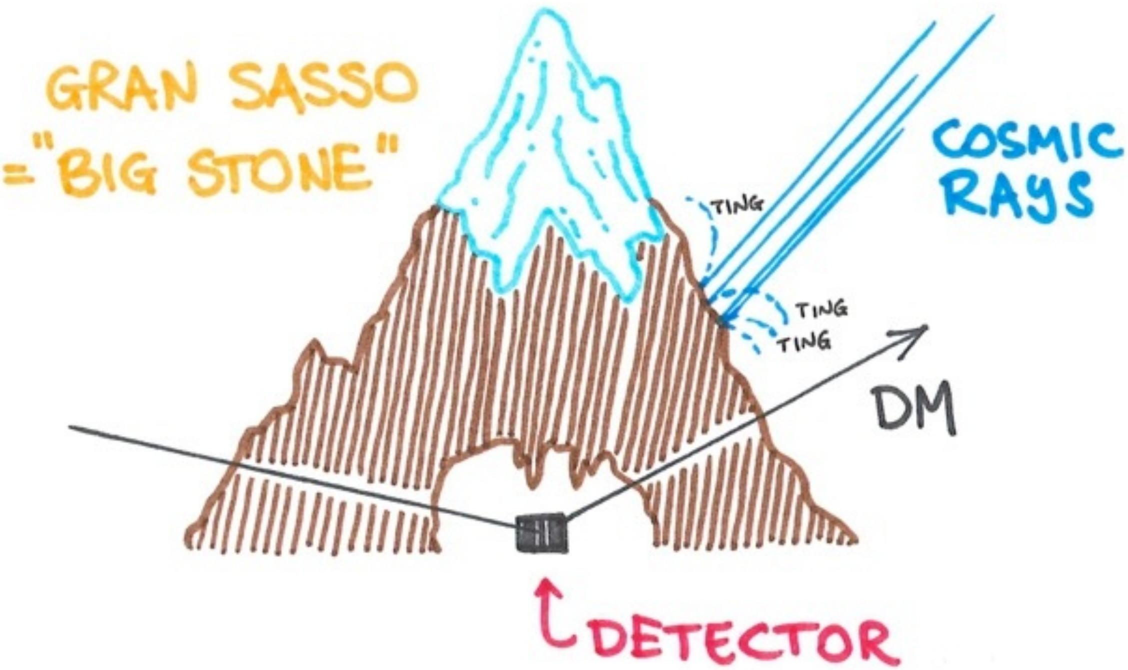
Limits and fits

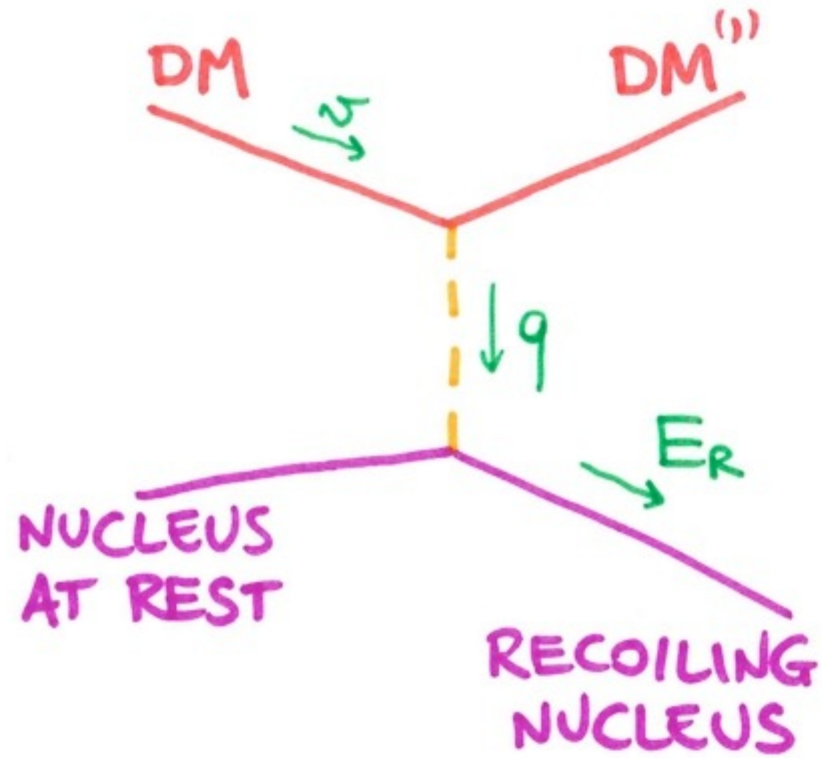


[1402.7137]

DM direct detection

Basically explained by





$$\frac{\mathrm{d}R_T}{\mathrm{d}E_\mathrm{R}} = n_T \Phi_\mathrm{DM}(t) \frac{\mathrm{d}\sigma_T}{\mathrm{d}E_\mathrm{R}}$$

DM direct detection

The basic ingredient is the recoil rate

$$\frac{\mathrm{d}R_T}{\mathrm{d}E_\mathrm{R}} = n_T \Phi_\mathrm{DM}(t) \frac{\mathrm{d}\sigma_T}{\mathrm{d}E_\mathrm{R}}$$

Target density

DM-nucleus cross section

$$\Phi_\mathrm{DM} = \frac{\rho}{m_\mathrm{DM}} v\, f(\vec{v}, t)\, \mathrm{d}^3 v$$

DM flux (has an annual modulation due to Earth's rotation around the sun)

Direct detection rate

$$\frac{\mathrm{d}R_T}{\mathrm{d}E_\mathrm{R}} = \frac{\xi_T}{m_T}\frac{\rho}{m_\mathrm{DM}}\int_{v_\mathrm{min}(E_\mathrm{R})}^{v_\mathrm{esc}} \mathrm{d}^3 v\, f(\vec{v},t)\, v \frac{\mathrm{d}\sigma_T}{\mathrm{d}E_\mathrm{R}}(E_\mathrm{R},\vec{v}\,)$$

ρ DM local density

ξ_T target mass fraction

$f(\vec{v},t)$ DM velocity distribution

v_esc galactic escape velocity

$$R_{[E_1',E_2']}(t) = \sum_T \int_{E_1'}^{E_2'} \mathrm{d}E'\, \epsilon_1(E') \int_0^\infty \mathrm{d}E_\mathrm{R}\, \epsilon_2(E_\mathrm{R}) G_T(E', Q_T E_\mathrm{R}) \frac{\mathrm{d}R_T}{\mathrm{d}E_\mathrm{R}}$$

E' detected energy

$\epsilon_1,\ \epsilon_2$ efficiencies

$G_T(E', Q_T E_\mathrm{R})$ detector resolution

Q_T quenching factor

Differential cross section

$$\frac{\mathrm{d}\sigma_T}{\mathrm{d}E_\mathrm{R}} \sim |\langle N|\mathscr{L}_{q,g}|N\rangle|^2\, \mathcal{A}_T^2\, F_T^2(E_\mathrm{R})$$

$\mathscr{L}_{q,g}$ fundamental Lagrangian

$|N\rangle$ nucleon state

$F_T(E_\mathrm{R})$ nuclear form factor

$\mathcal{A}_T$ coherence factor

$$\mathcal{A}_T \cong \begin{cases} A_T & \text{spin-independent} \\ Z_T & \text{millicharged DM} \\ Z_T f_p + (A_T - Z_T) f_n & \text{isospin-violating} \\ Z_T, \mu_T & \text{magnetic moment DM} \\ J_T & \text{spin-dependent} \\ \ldots & \ldots \end{cases}$$

Uncertainties

$$R_{[E_1',E_2']}(t) = \sum_T \int_{E_1'}^{E_2'} \mathrm{d}E'\, \epsilon_1(E') \int_0^\infty \mathrm{d}E_\mathrm{R}\, \epsilon_2(E_\mathrm{R}) G_T(E', Q_T E_\mathrm{R}) \frac{\mathrm{d}R_T}{\mathrm{d}E_\mathrm{R}}$$

Experiment

$$\frac{\mathrm{d}R_T}{\mathrm{d}E_\mathrm{R}} = \frac{\xi_T}{m_T} \frac{\rho}{m_\mathrm{DM}} \int_{v_\mathrm{min}(E_\mathrm{R})}^{v_\mathrm{esc}} \mathrm{d}^3 v\, f(\vec{v}, t)\, v \frac{\mathrm{d}\sigma_T}{\mathrm{d}E_\mathrm{R}}(E_\mathrm{R}, \vec{v})$$

Astrophysics

$$\frac{\mathrm{d}\sigma_T}{\mathrm{d}E_\mathrm{R}} \sim |\langle N | \mathscr{L}_{q,g} | N \rangle|^2 \mathcal{A}_T^2\, F_T^2(E_\mathrm{R})$$

Particle physics

Uncertainties

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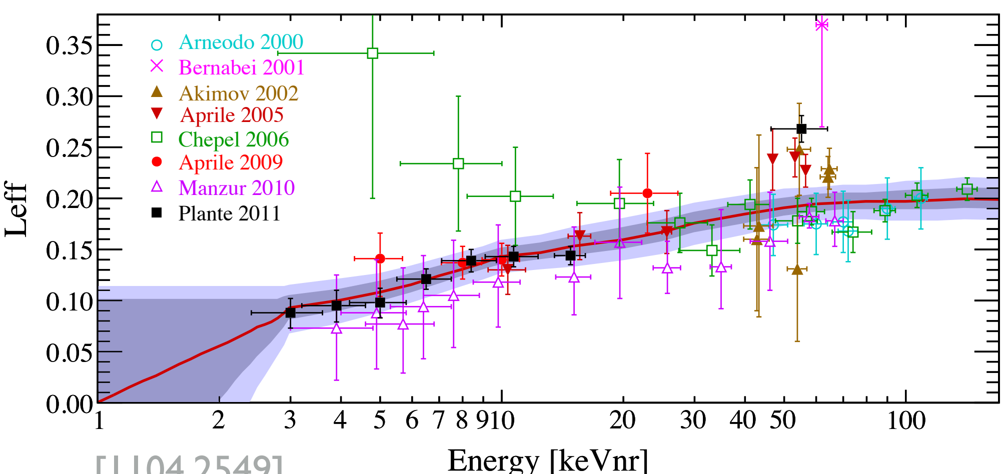

[1104.2549]

Uncertainties

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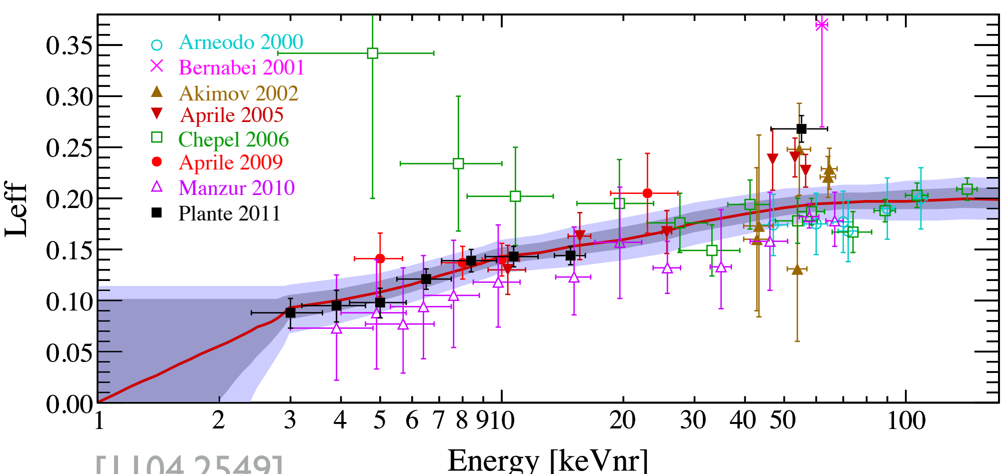

[1104.2549]

Uncertainties

$$R_{[E'_1,E'_2]}(t) = \sum_T \int_{E'_1}^{E'_2} \mathrm{d}E'\, \epsilon_1(E') \int_0^\infty \mathrm{d}E_\mathrm{R}\, \epsilon_2(E_\mathrm{R}) G_T(E', Q_T E_\mathrm{R}) \frac{\mathrm{d}R_T}{\mathrm{d}E_\mathrm{R}}$$

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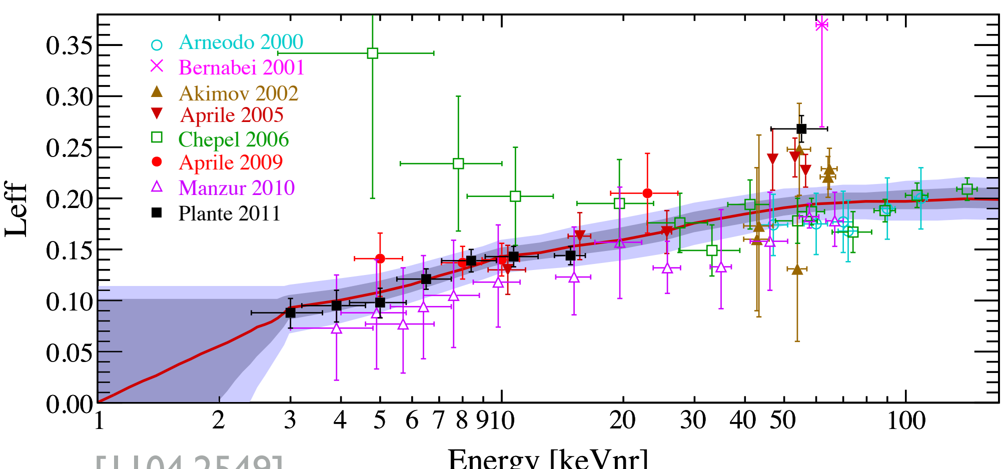

[1104.2549]

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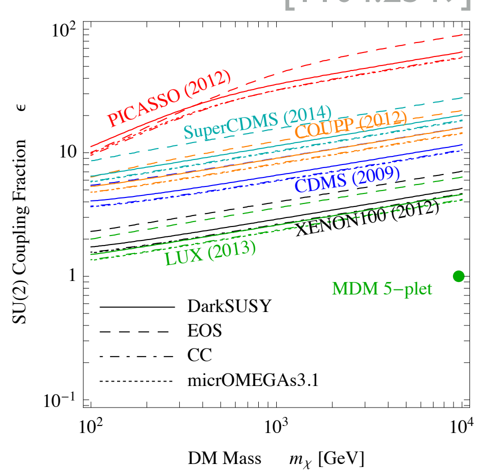
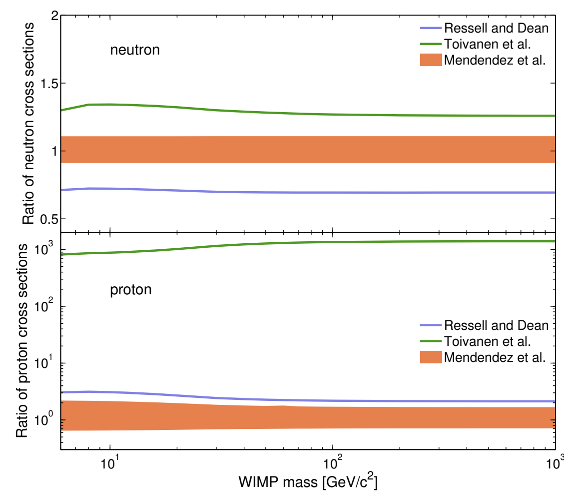
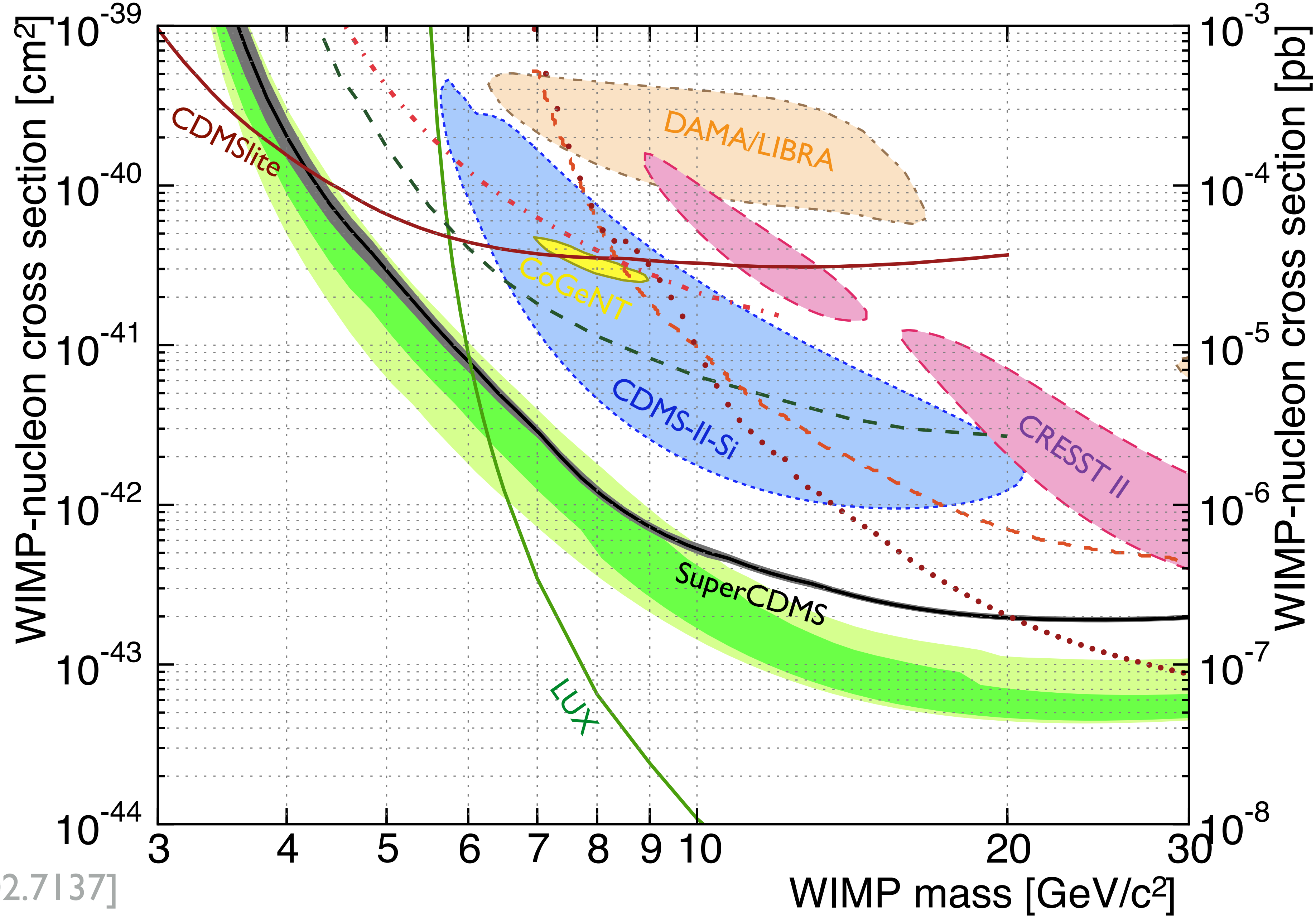




[1301.6620]

Back to this plot

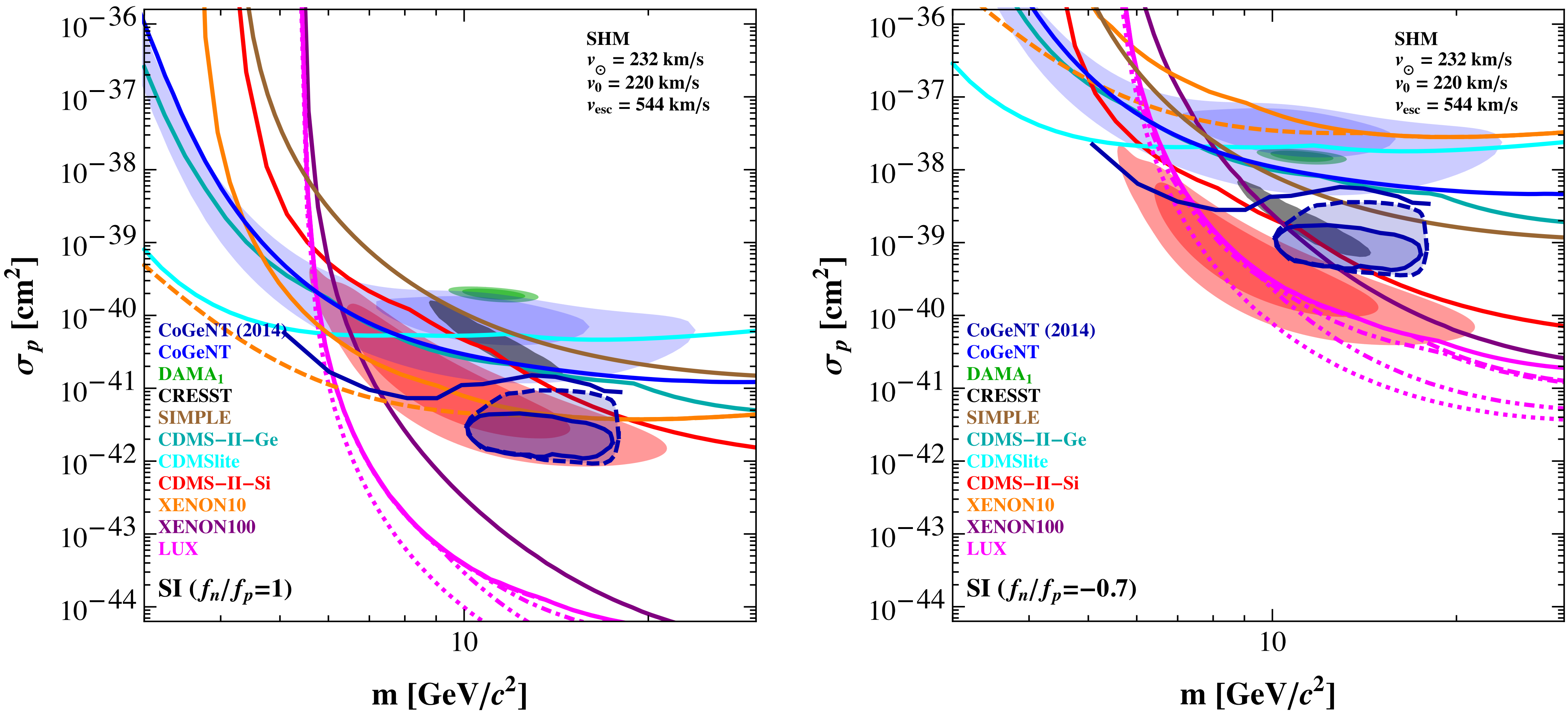


[1402.7137]

Assumptions behind this plot

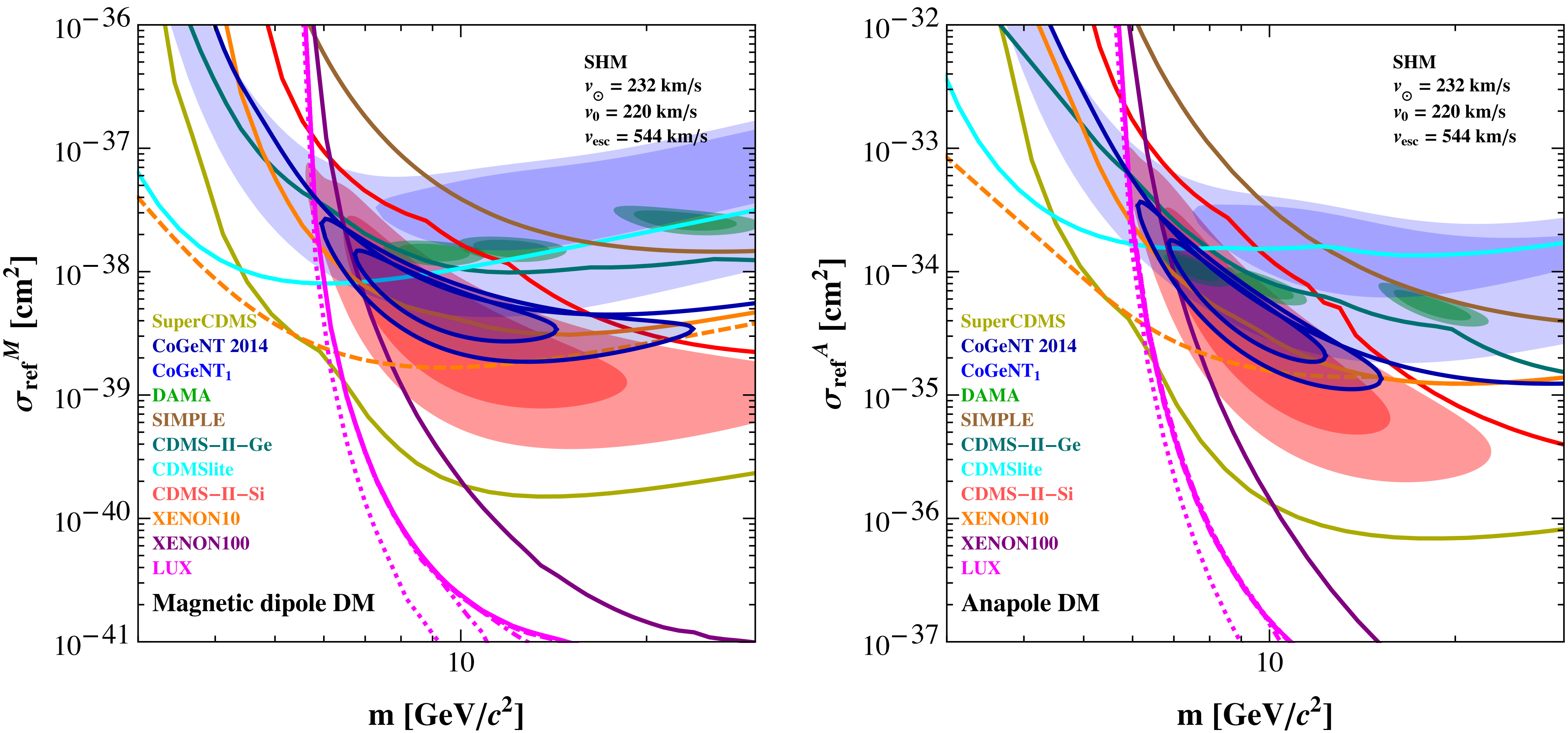
- Spin-independent interaction (with isospin-symmetric coupling)
- Truncated Maxwell-Boltzmann velocity distribution (Standard Halo Model)

Turning the interaction knob



[1311.4247]

Turning the interaction knob



[1401.4508]

Astrophysical uncertainties

$$R_{[E_1',E_2']}(t) = \sum_T \int_{E_1'}^{E_2'} \mathrm{d}E' \, \epsilon_1(E') \int_0^\infty \mathrm{d}E_\mathrm{R} \, \epsilon_2(E_\mathrm{R}) G_T(E', Q_T E_\mathrm{R}) \frac{\mathrm{d}R_T}{\mathrm{d}E_\mathrm{R}}$$

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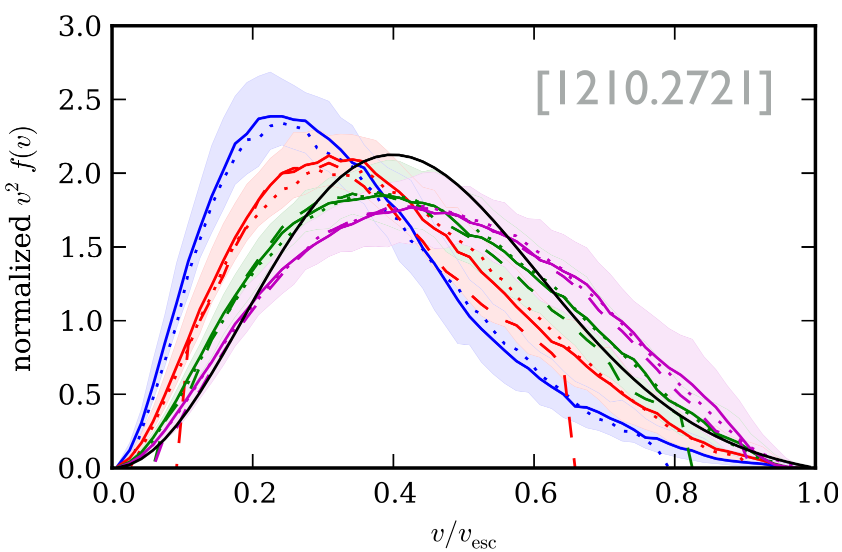
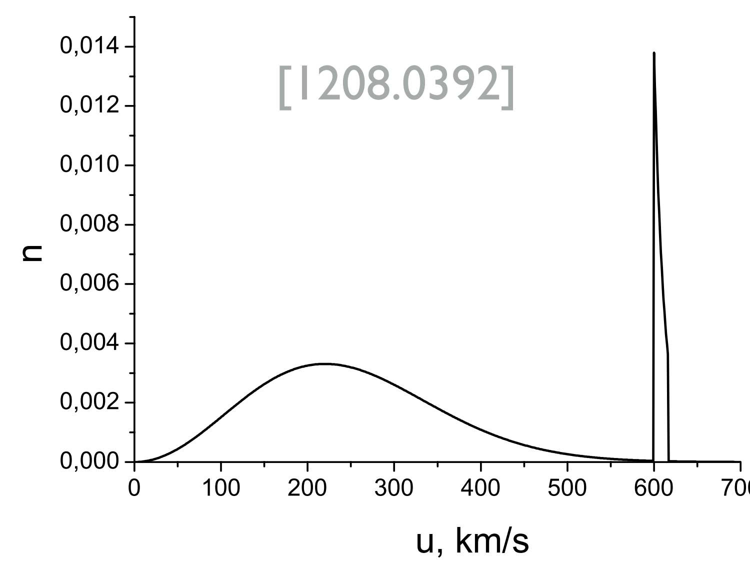
Particle physics





Three approaches

- Marginalize over astrophysical uncertainties
  see e.g. Arina [1310.5718] and references therein

- Try to find alternative halo models, either driven by physical arguments or by fitting simulations or observations
  see e.g. references in Freese, Lisanti, Savage [1209.3339]

- Try to factor astrophysics out of your problem as much as you can
  Fox, Liu, Weiner [1011.1915], Frandsen, Kahlhoefer, McCabe, Sarkar, Schmidt-Hoberg [1111.0292][1304.6066], Gondolo, Gelmini [1202.6359] + Del Nobile, Huh [1304.6183][1306.5273][1311.4247][1401.4508], Herrero-Garcia, Schwetz, Zupan [1112.1627][1205.0134] + Bozorgnia [1305.3575], Feldstein, Kahlhoefer [1403.4606], Fox, Kahn, McCullough [1403.6830]

Tweaking the rate

$$R_{[E_1',E_2']}(t) = \int_0^\infty \mathrm{d}v_{\min}\, \tilde{\eta}(v_{\min}, t)\, \mathcal{R}_{[E_1',E_2']}(v_{\min})$$

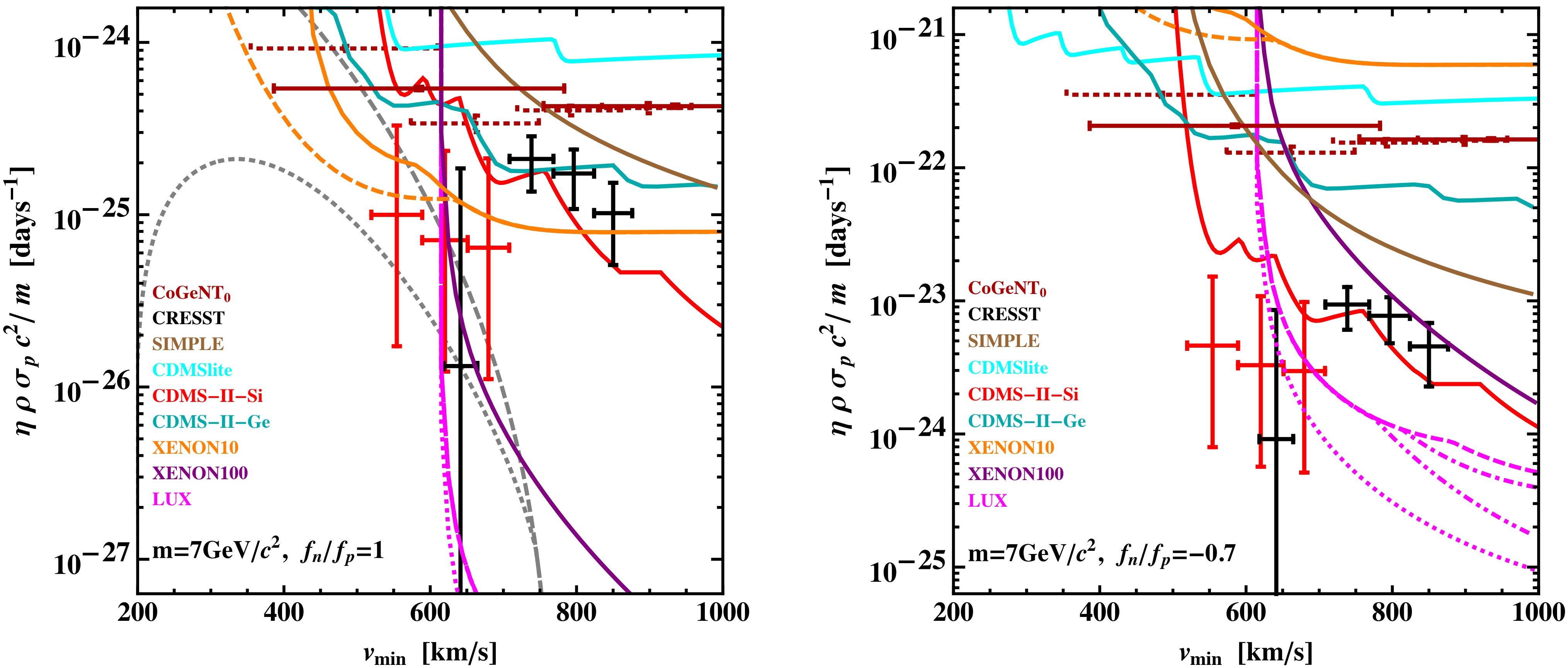
$$\tilde{\eta}(v_{\min}, t) \equiv \frac{\rho \sigma_{\rm ref}}{m_{\rm DM}} \int_{v_{\min}}^\infty \mathrm{d}^3 v\, \frac{f(\vec{v}, t)}{v}$$

detector-independent,
unknown function of $v_{\min}$
to be determined by data

known function
determined by:

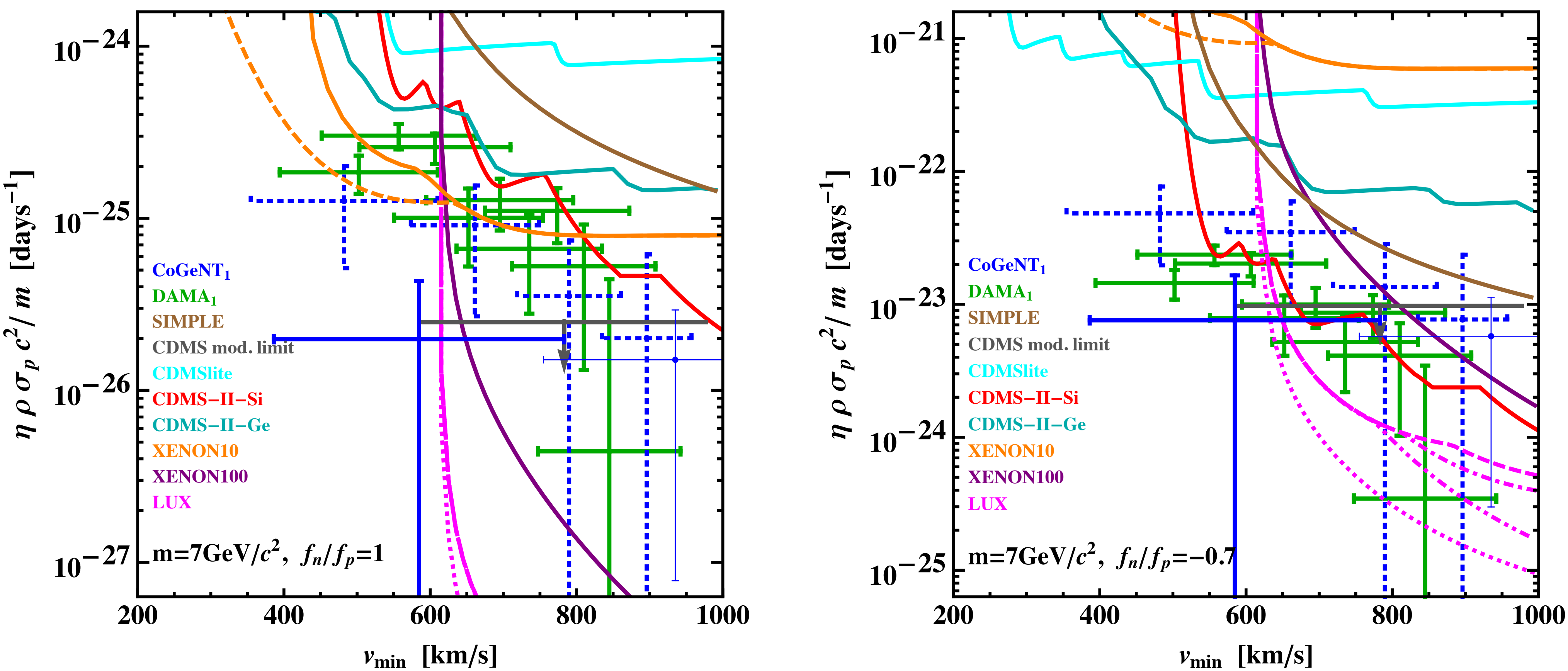
- detector
- interaction
- DM mass

Halo-independent plot



[1311.4247]

Halo-independent plot



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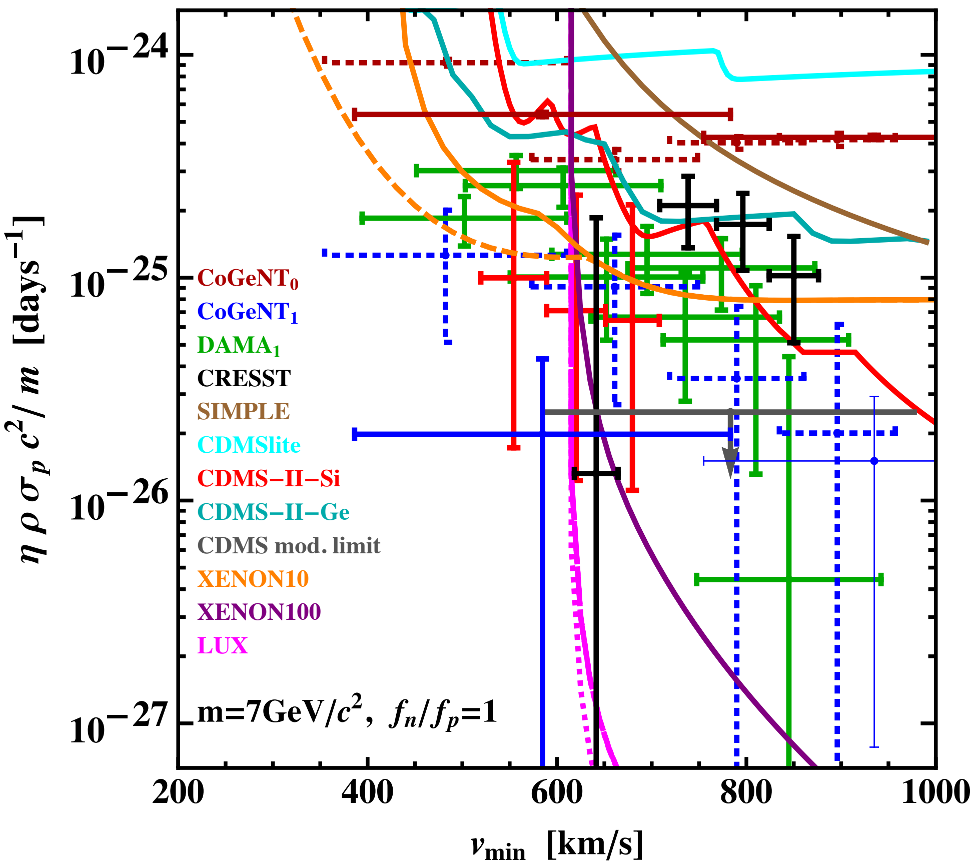
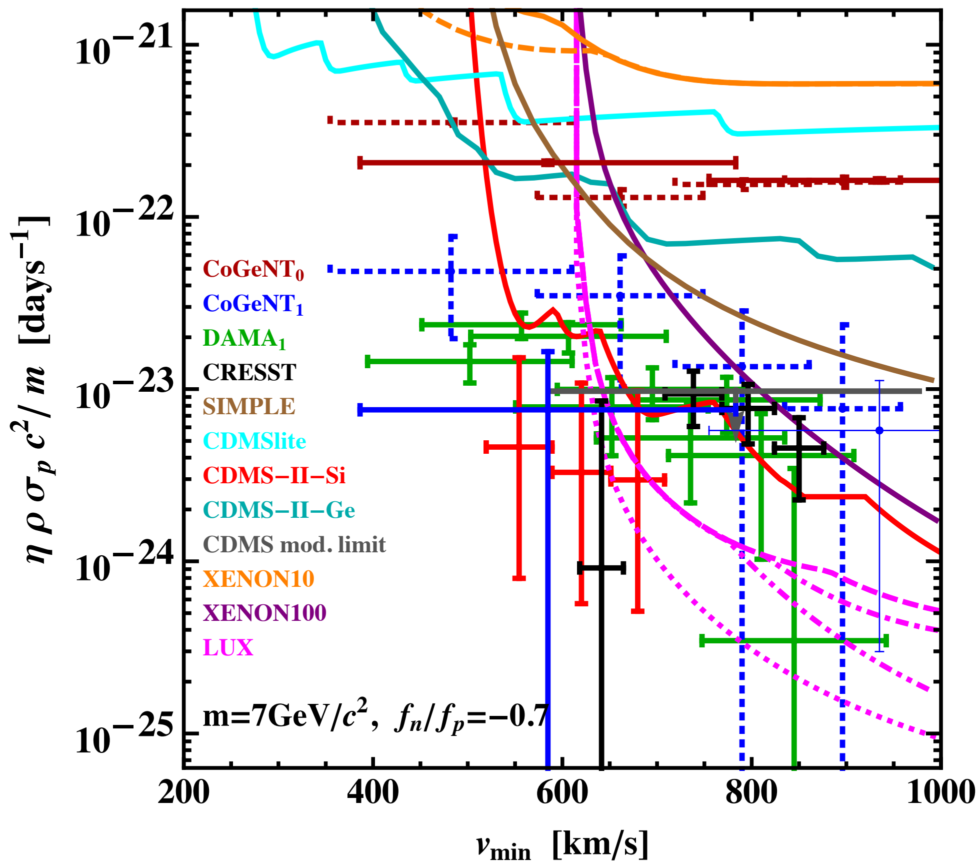
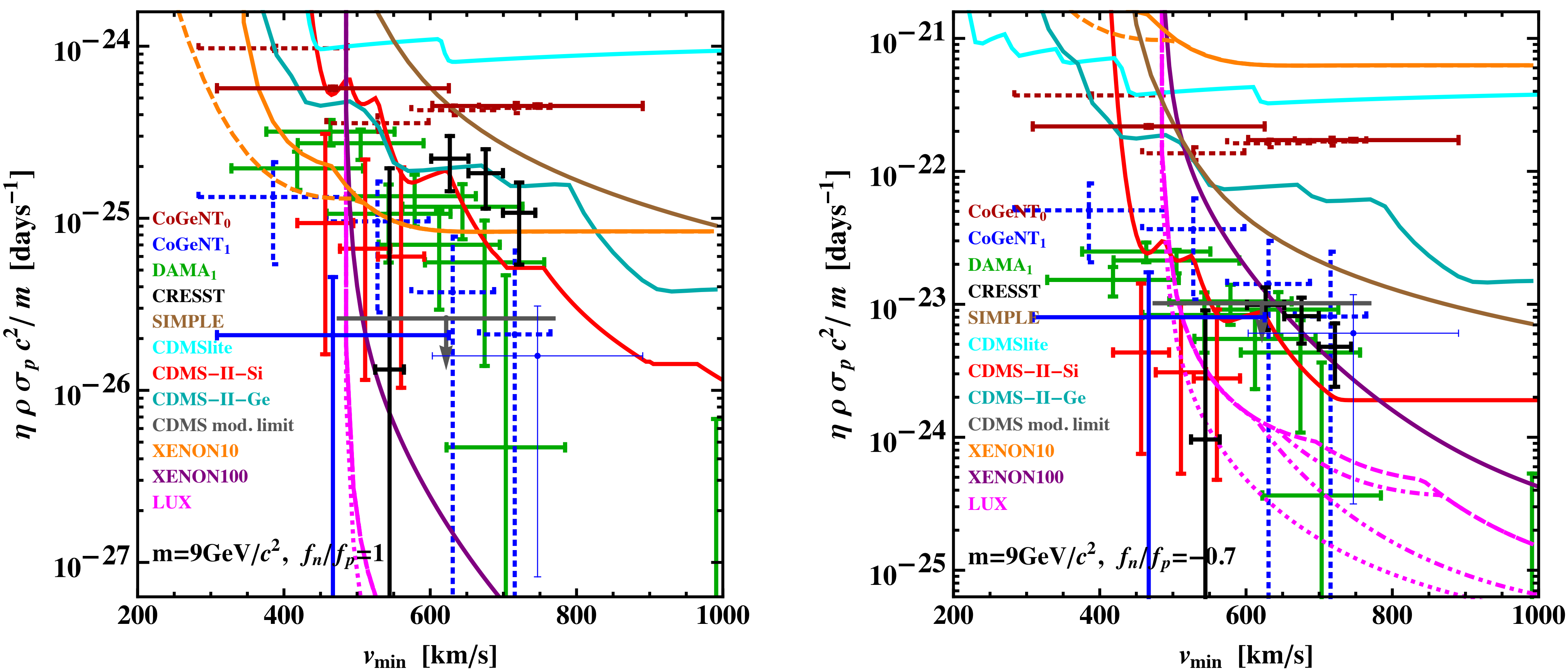
Halo-independent plot





[1311.4247]

Halo-independent plot



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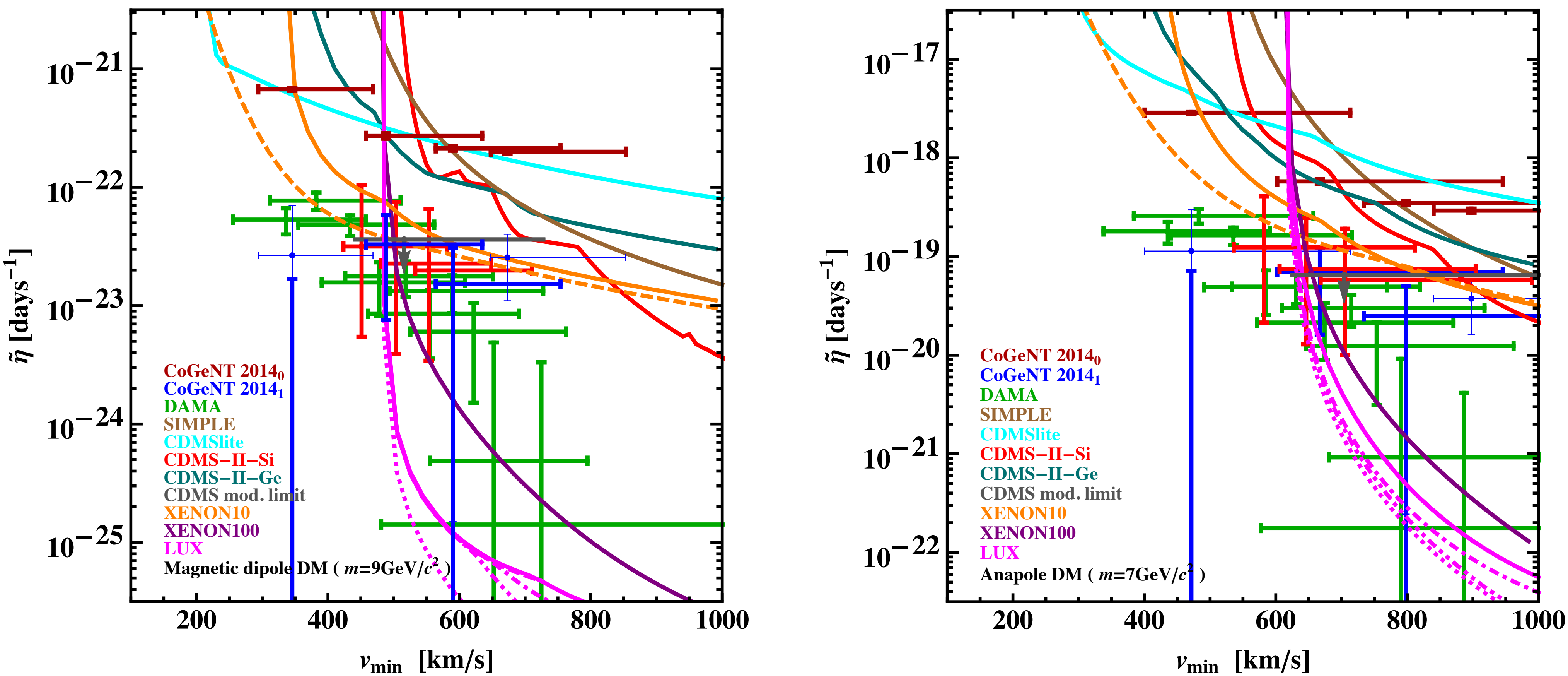
Halo-independent plot



[1401.4508]

Conclusions

With an eye on trying to explain current direct detection experiments,

- Much work has been done in trying new roads to interpret the data
- Uncertainties are being investigated (and possibly reduced)
- Model-independent methods are being devised
- Possible explanations are being proposed
- Experiments keep being developed

Outlook

Difficult to think what we should
be doing differently or better:

- Large community of "dark matter enthusiasts"
- Big ongoing effort to detect the ~~bastard~~ DM
- Many experiments
- Different detection strategies: direct, indirect, collider

A lesson from the LHC

Theorists have long been biased by the mirage of new physics at the Electroweak scale, e.g. Supersymmetry (or WIMPs)

But the Higgs might well be the only new fundamental particle the LHC will ever see

The secret message is:

- be open-minded
- do not exclude possibilities a priori
- look for the darn thing everywhere