Novel Aspects of Dark Matter Direct Detection

Yue Zhang

Carleton University

IPP TownHall

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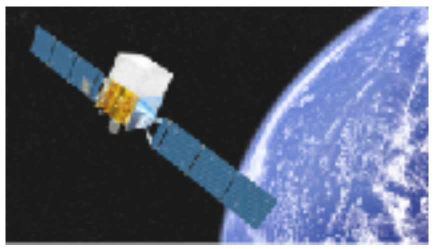
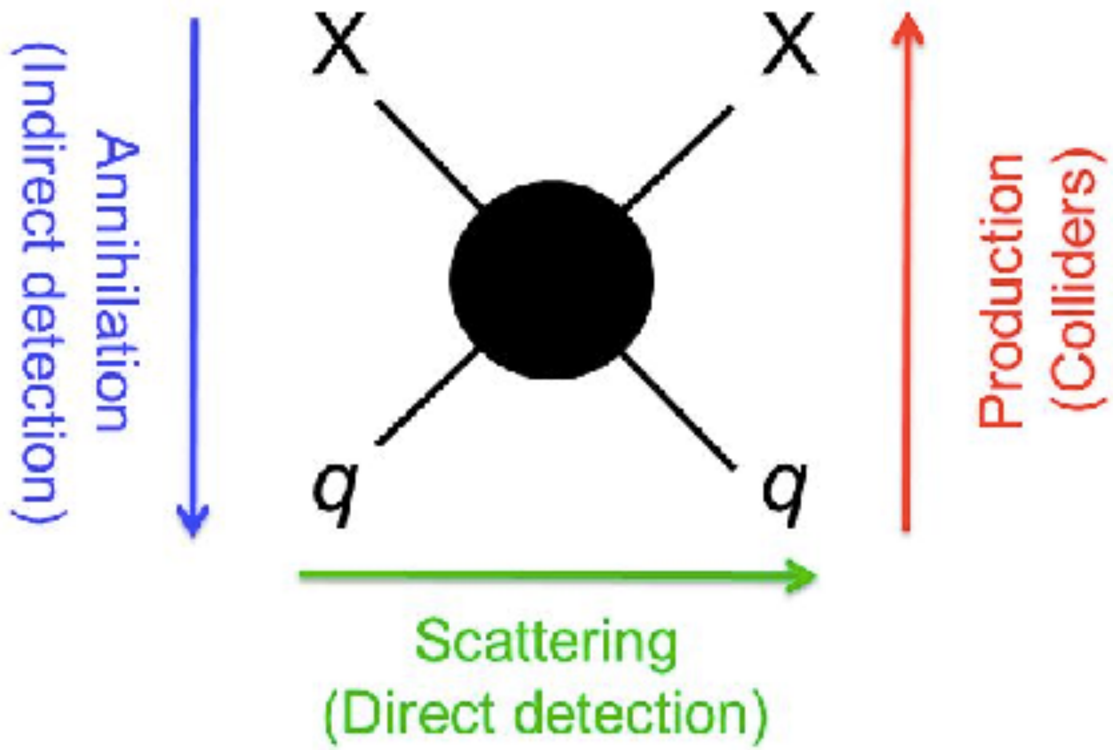
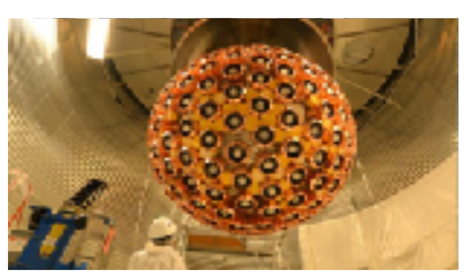
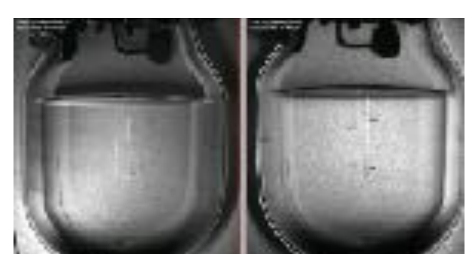
Cast A Wide Net for Dark Matter

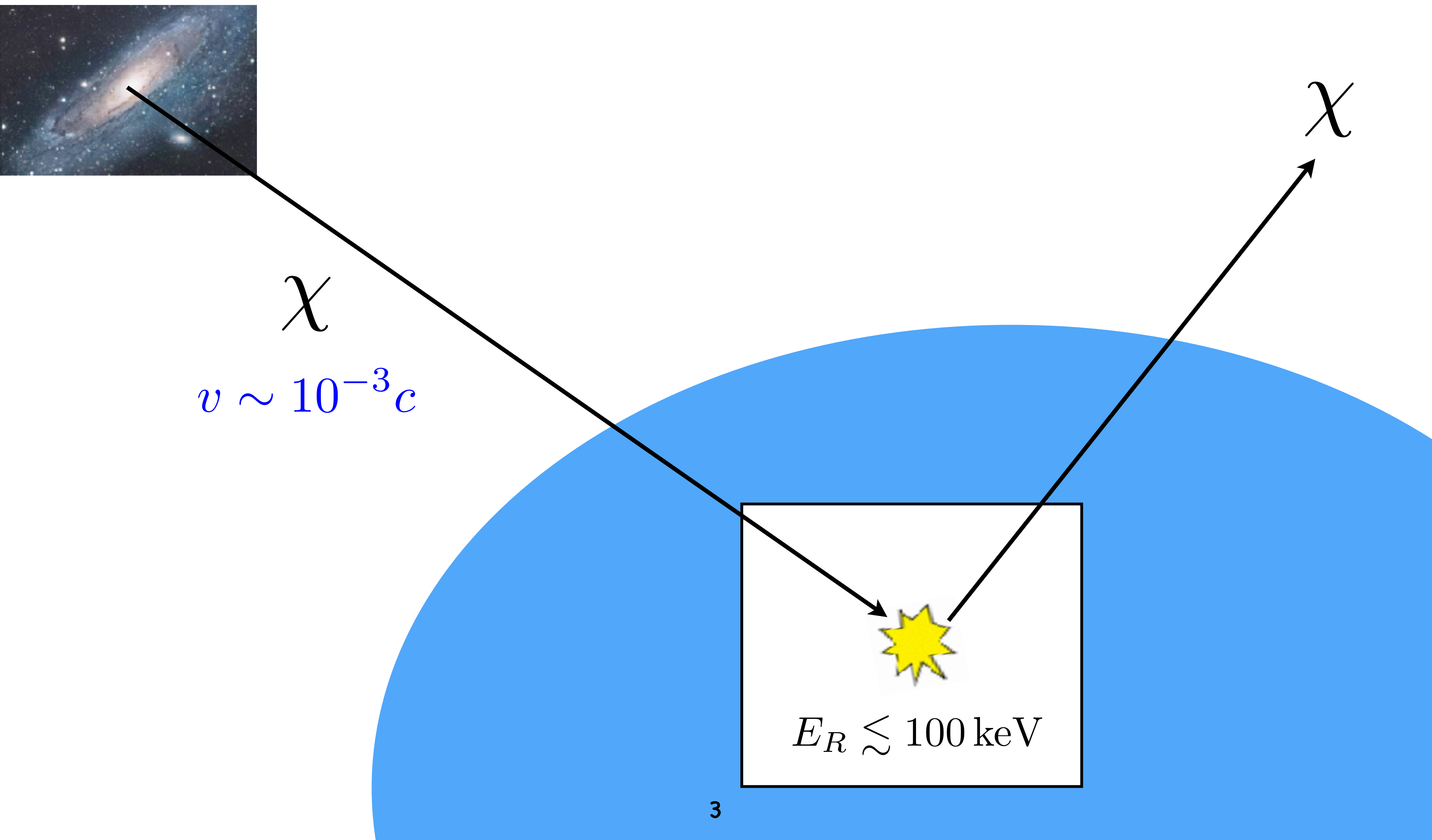








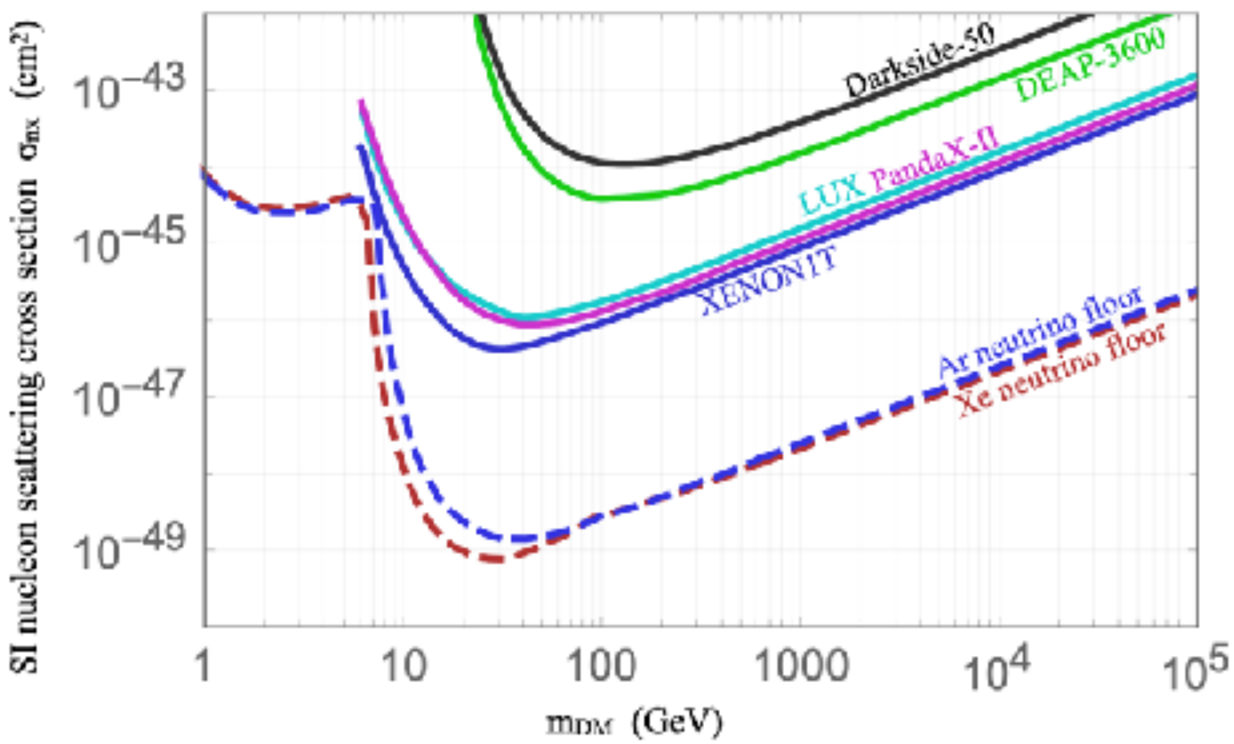
Direct Detection



Standard Assumptions

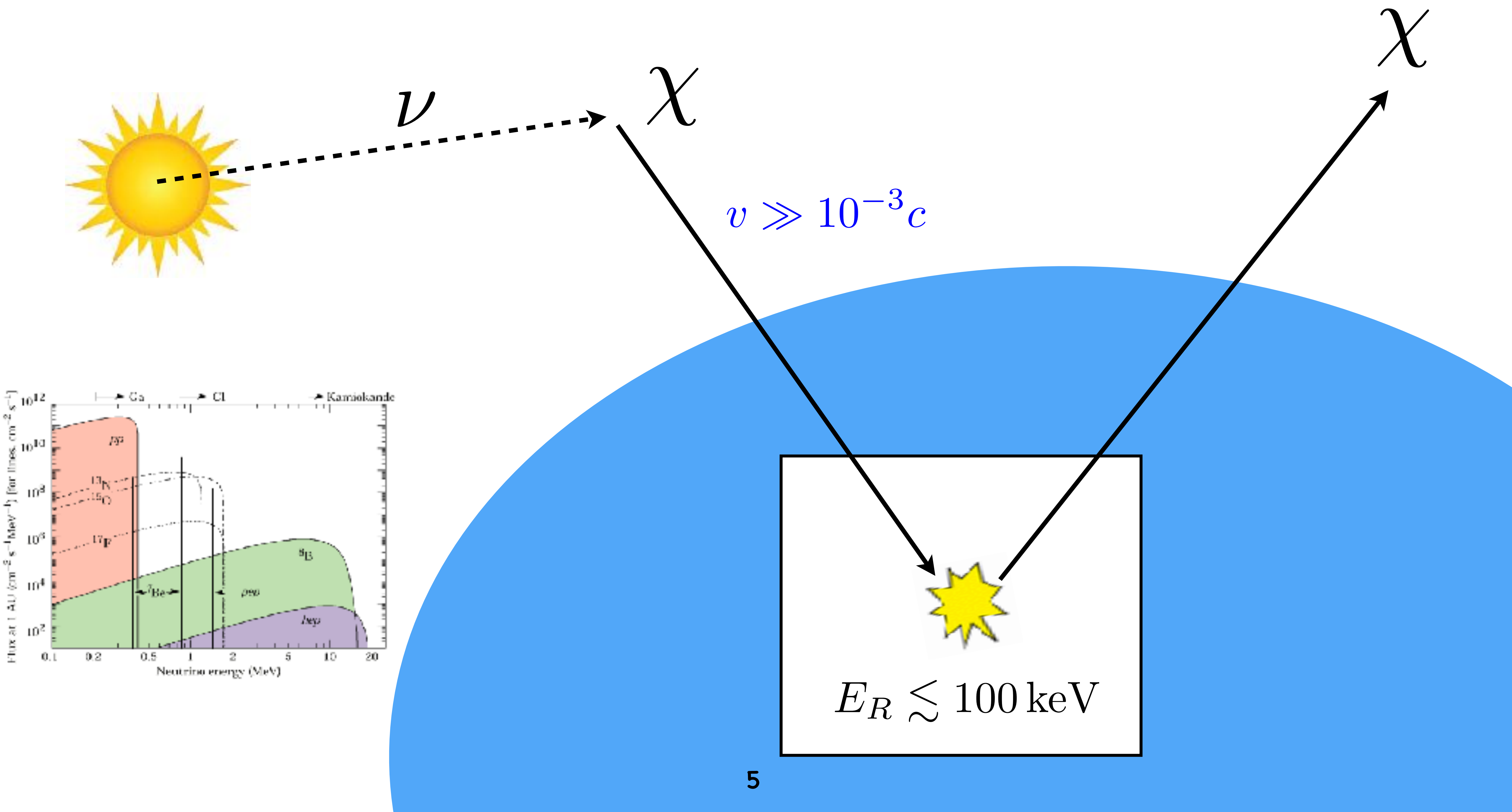
- Standard halo velocity distribution: $v \sim 10^{-3}c < v_{esc}$.
- Recoil energy in the ballpark of dark matter kinetic energy.

Is it possible to go beyond these?



Can Dark Matter Travel Faster?

A new acceleration mechanism: using solar neutrinos.



The First Try

Consider sub-GeV dark matter. Kinematics:

- Elastic neutrino-dark matter scattering $\nu + \chi \to \nu + \chi$

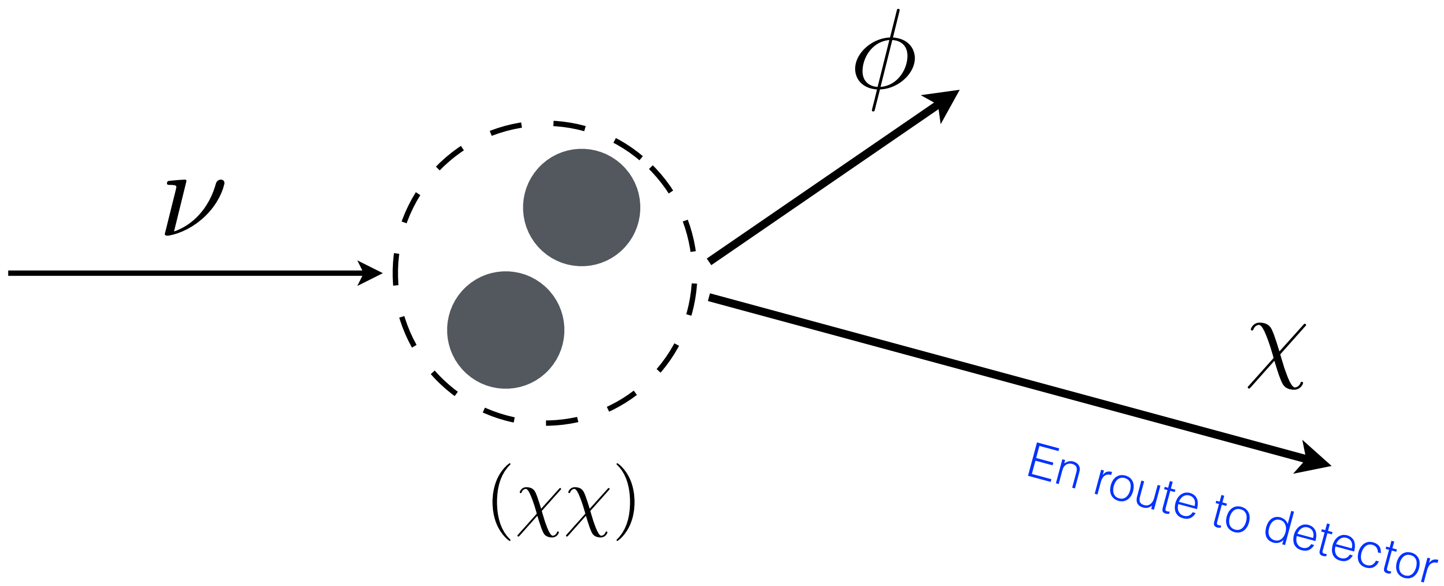
$$p_\chi \sim E_\nu$$

- When such dark matter strikes on nuclear target $\chi + A \to \chi + A$

$$q \sim p_\chi, \quad E_R \sim \frac{E_\nu^2}{m_A}$$

Similar story as the solar neutrino background (^{8}B neutrinos)

Composite Dark Matter



Introduce a neutrino portal interaction: $(LH)(\chi\phi)$

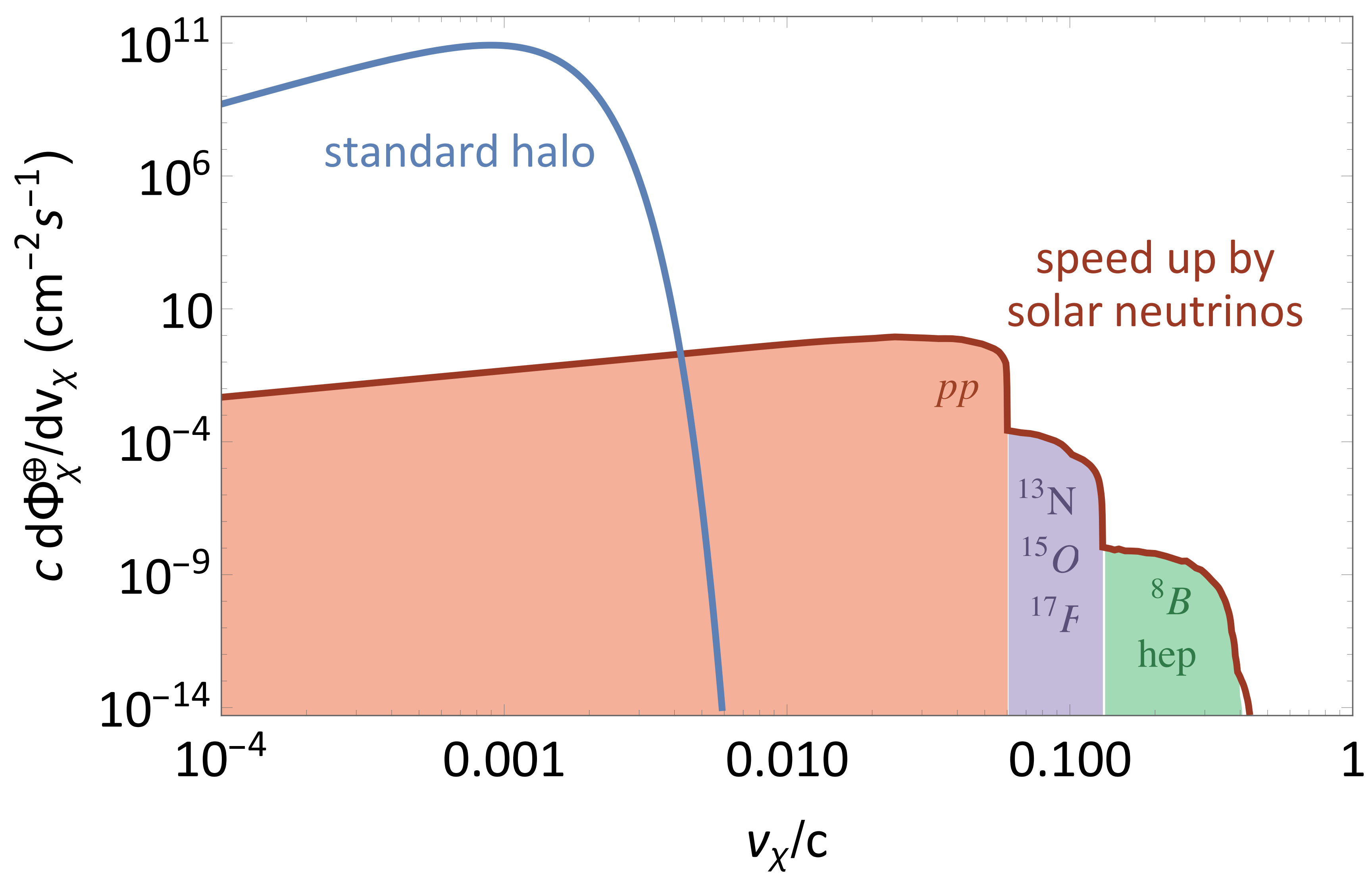
Final state χ obtains a parametrically higher momentum

$$p_\chi \sim \sqrt{m_\chi E_\nu} \gg E_\nu \quad (\text{for } m_\chi \gg E_\nu)$$

Even the pp neutrinos could yield large enough recoil energies.

YZ (2001.00948)

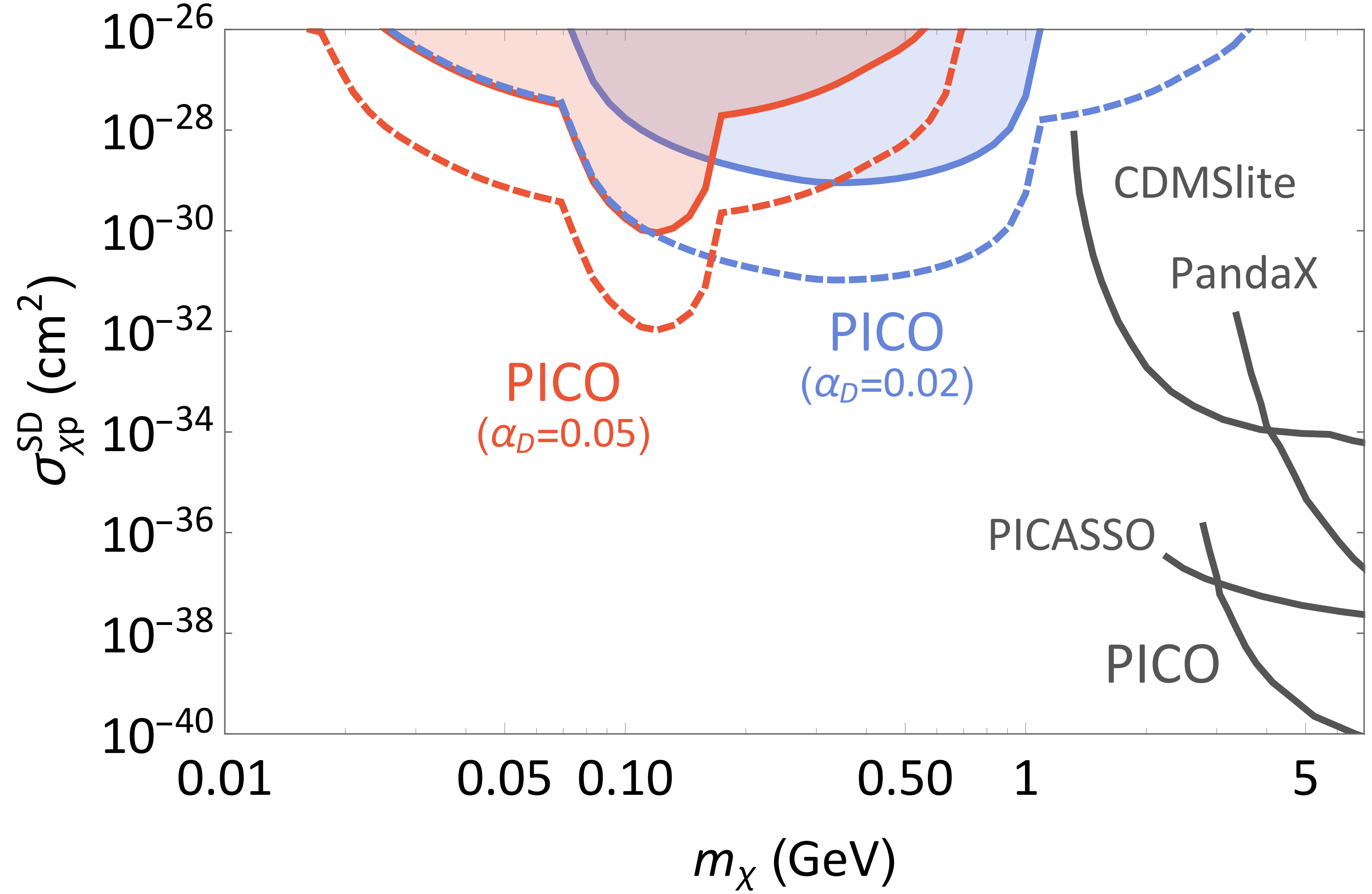
Velocity Distribution



$$(m_\chi = 100\,\mathrm{MeV}, \quad \lambda_{\nu\phi\chi} = 0.7, \quad \alpha_d = 0.05)$$

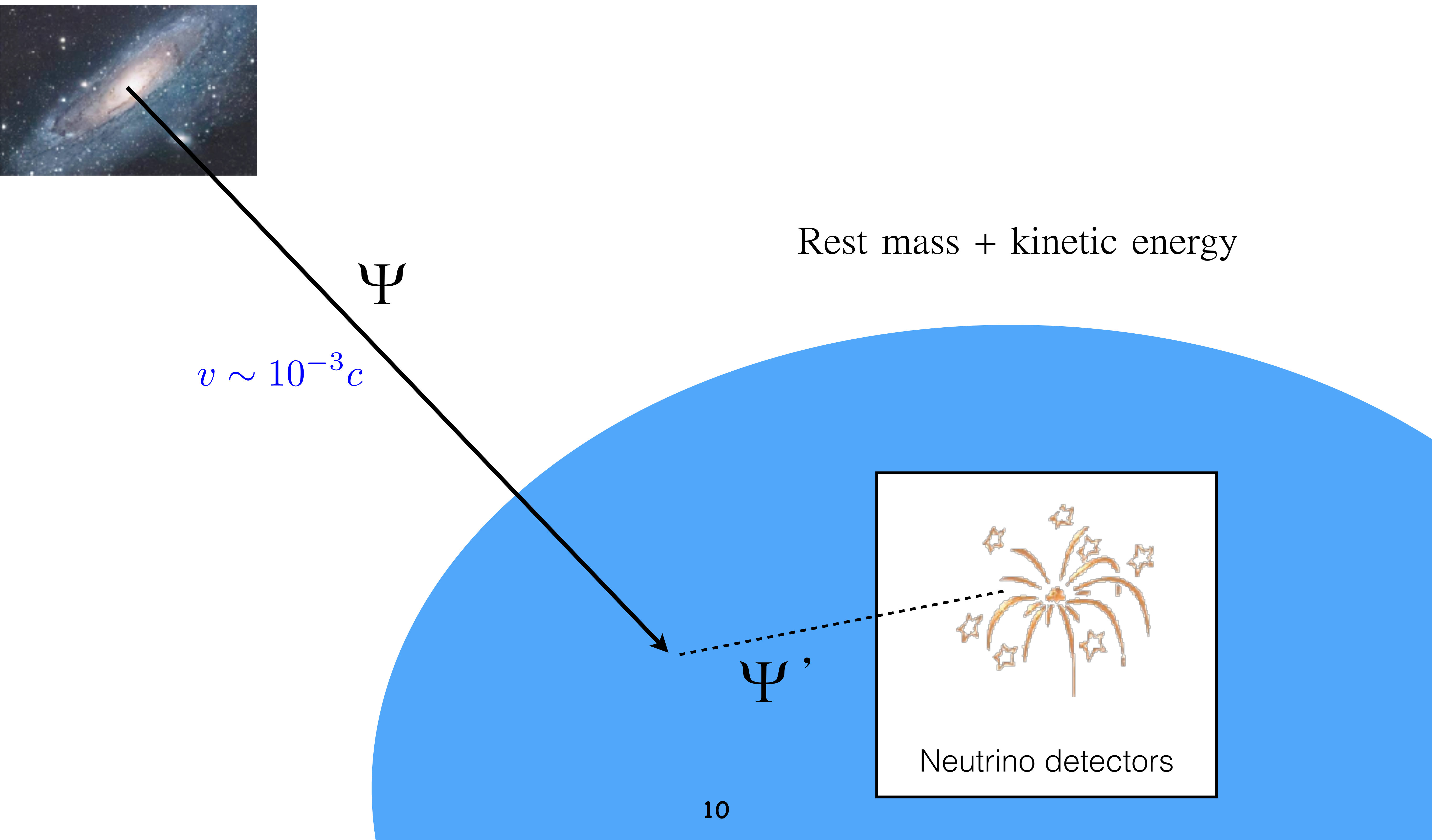
YZ (2001.00948)

Reinterpreting Results

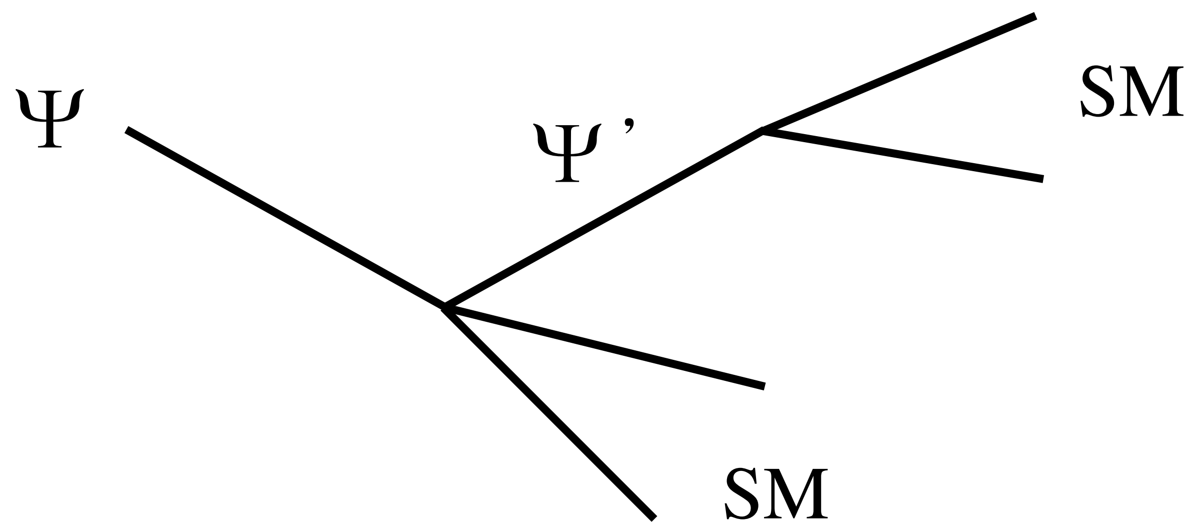


YZ (2001.00948)

Beyond Kinetic Energy?



Challenge: the decay



- Conflict: Need a large enough scattering rate & Ψ ' to decay quickly, whereas Ψ should be cosmologically long lived.

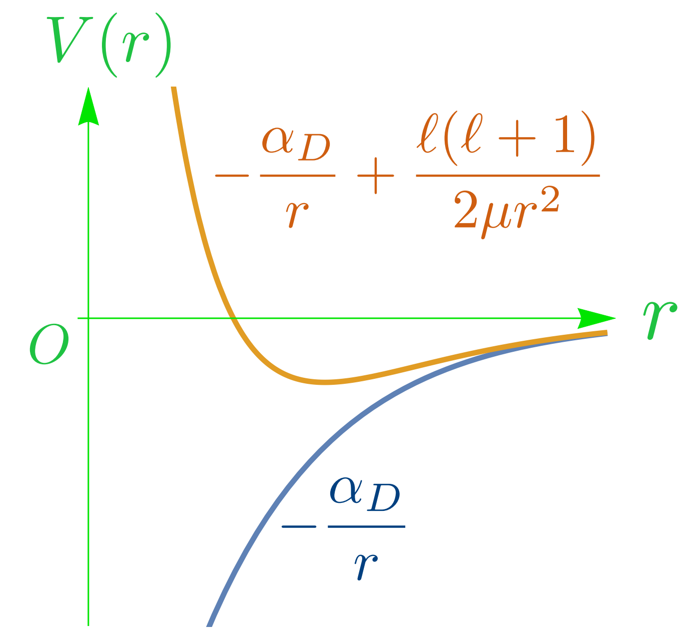
$$\sigma \lesssim 10^{-60}\,\mathrm{cm}^2 \left(\frac{1\,\mathrm{GeV}}{m_\Psi}\right)^2 \left(\frac{\Psi' \text{ decay length}}{10\,\mathrm{meter}}\right) \left(\frac{10^{28}\,\mathrm{sec}}{\Psi \text{ lifetime}}\right)$$

Self-Destructing Dark Matter

Ψ could be long lived due to its internal structure: a bound state made of elementary dark particles χ, $\bar{\chi}$, with high orbital angular momentum, ℓ>>1.

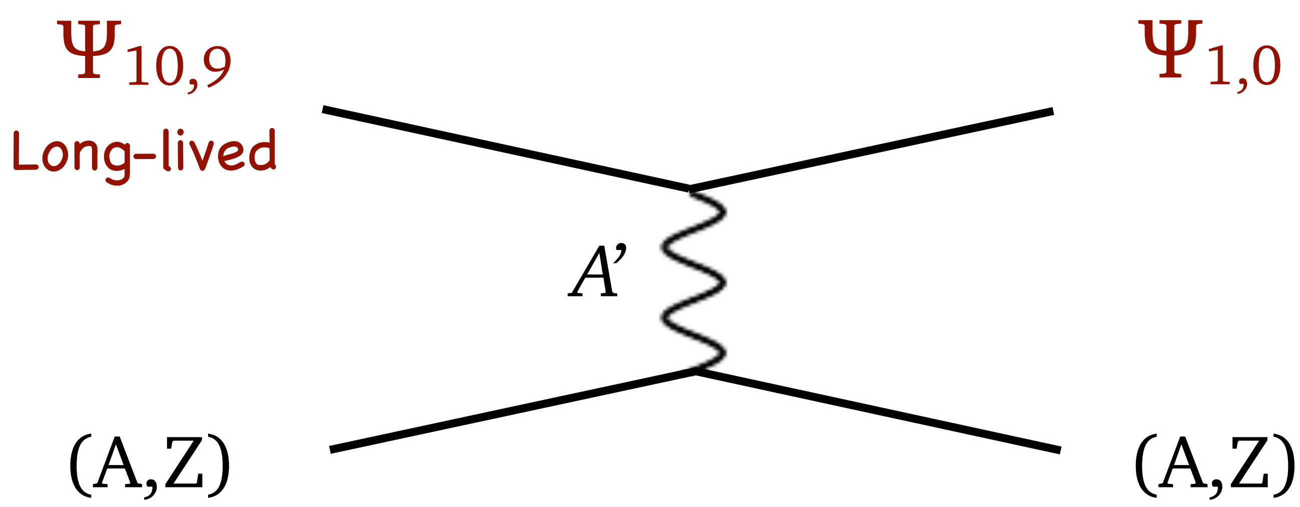
- Cannot easily directly annihilate thanks to the potential barrier

- Cannot easily de-excite if the binding energy difference is smaller than the force carrier or mediator.



Grossman, Harnik, Telem, YZ (1712.00455)

Self-Destruction Process



Followed by prompt decay of $\Psi_{1,0}$

$$\tau(\Psi_{1,0} \to A'A') = (\alpha_D^5 m_\chi/2)^{-1} \simeq 2 \times 10^{-14}\,\mathrm{sec}\left(\frac{\alpha_D}{0.01}\right)^{-5}\left(\frac{m_\chi}{1\,\mathrm{GeV}}\right)^{-1}$$

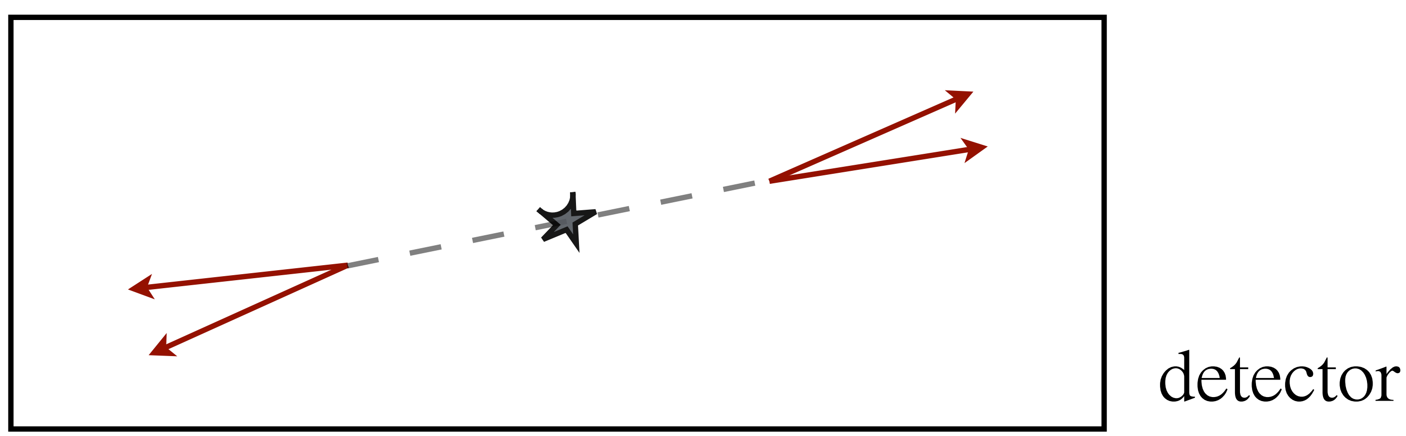
Grossman, Harnik, Telem, YZ (1712.00455)

Self-Destruction Signals

$\Psi_{1,0} \to A' A' \to 2(e^+e^-)$ could produce two pairs of e^+e^-.

- Each pair carries energy set by m_χ.
- Invariant mass set by $m_{A'}$.

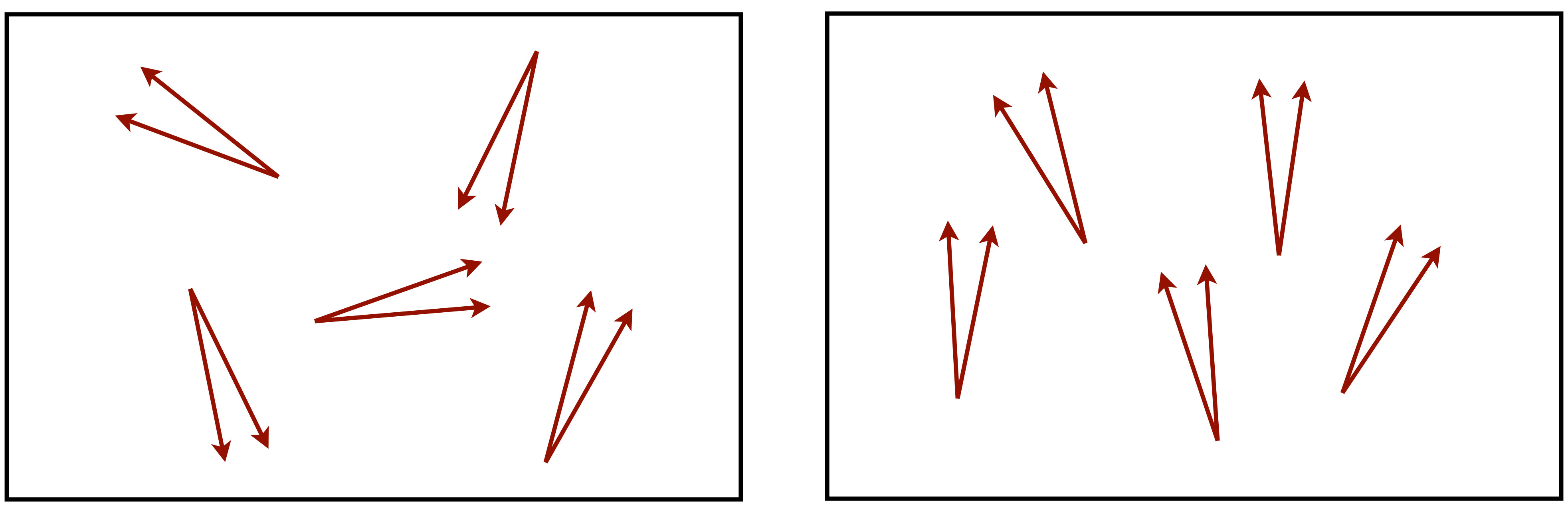
A' decay length $\lesssim$ 10 meter, observe both pairs, back to back.



Directionality

Dark photon *A'* could be long lived, $c\tau \gtrsim 10$ m. Scattering on earth, only one *A'* travels to detector — see single pair.

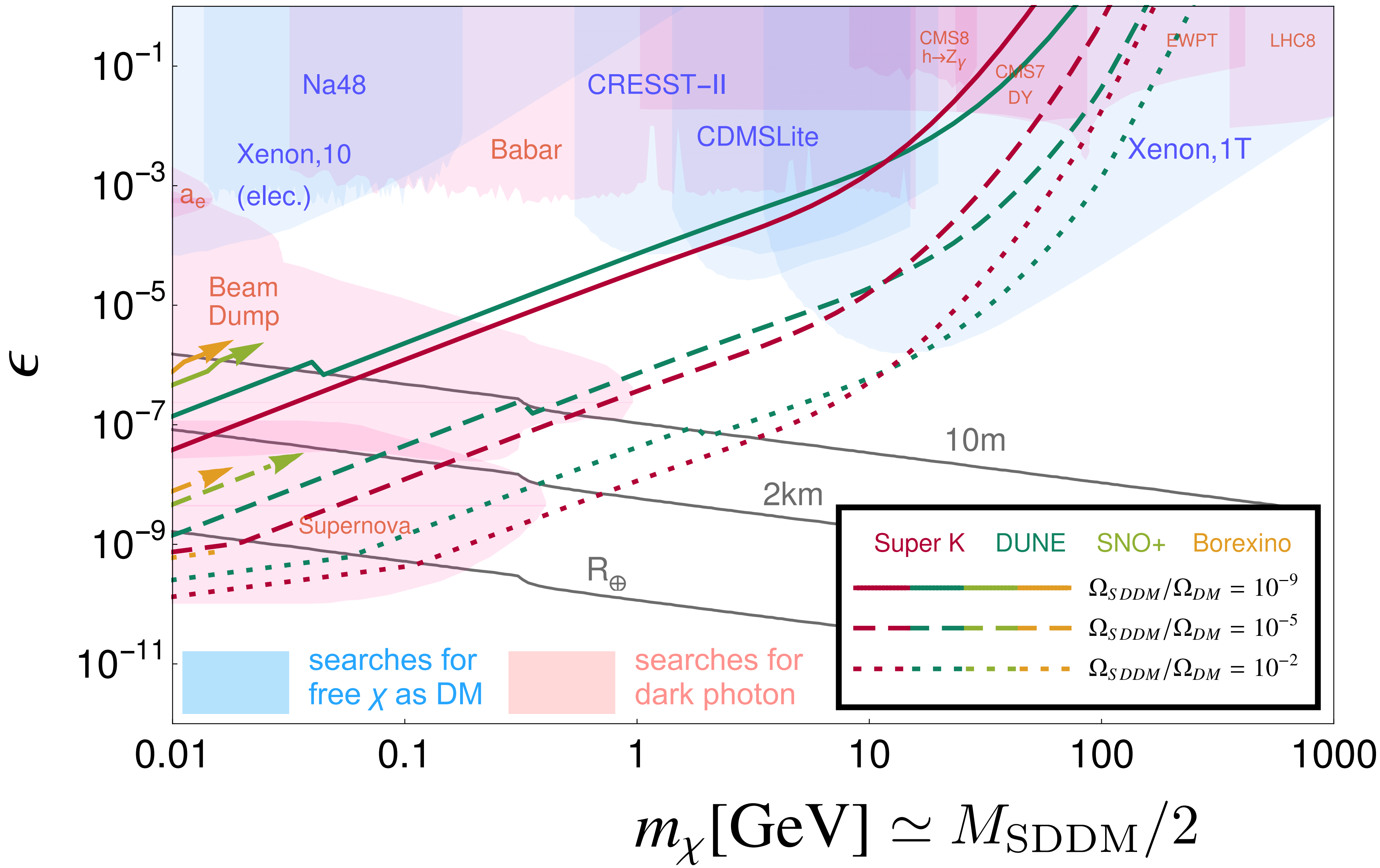
- $c\tau \lesssim$ km: isotropic
- $c\tau \gg$ km: most pairs up-going



detector detector

Powerful Reach with SDDM

$\alpha_\phi = \alpha_{A'} = 0.01,\ m_{A'} = (2/3)m_\chi,$ 100 Events/year



Early universe production:
[Geller, Telem, 2001.11514]

Grossman, Harnik, Telem, YZ (1712.00455)

Summary

To find dark matter, we need both persistence and open mind.

Dark matter may originate from dark sectors with rich physics, plausible to consider bound states (analogy to our world).

I discussed two scenarios of composite dark matter, where direction detection occurs beyond the standard picture.

We will be getting more and more instrumentally prepared for discovering these surprises.

Thanks!