Suicidal Dark Matter

Yue Zhang
Northwestern University

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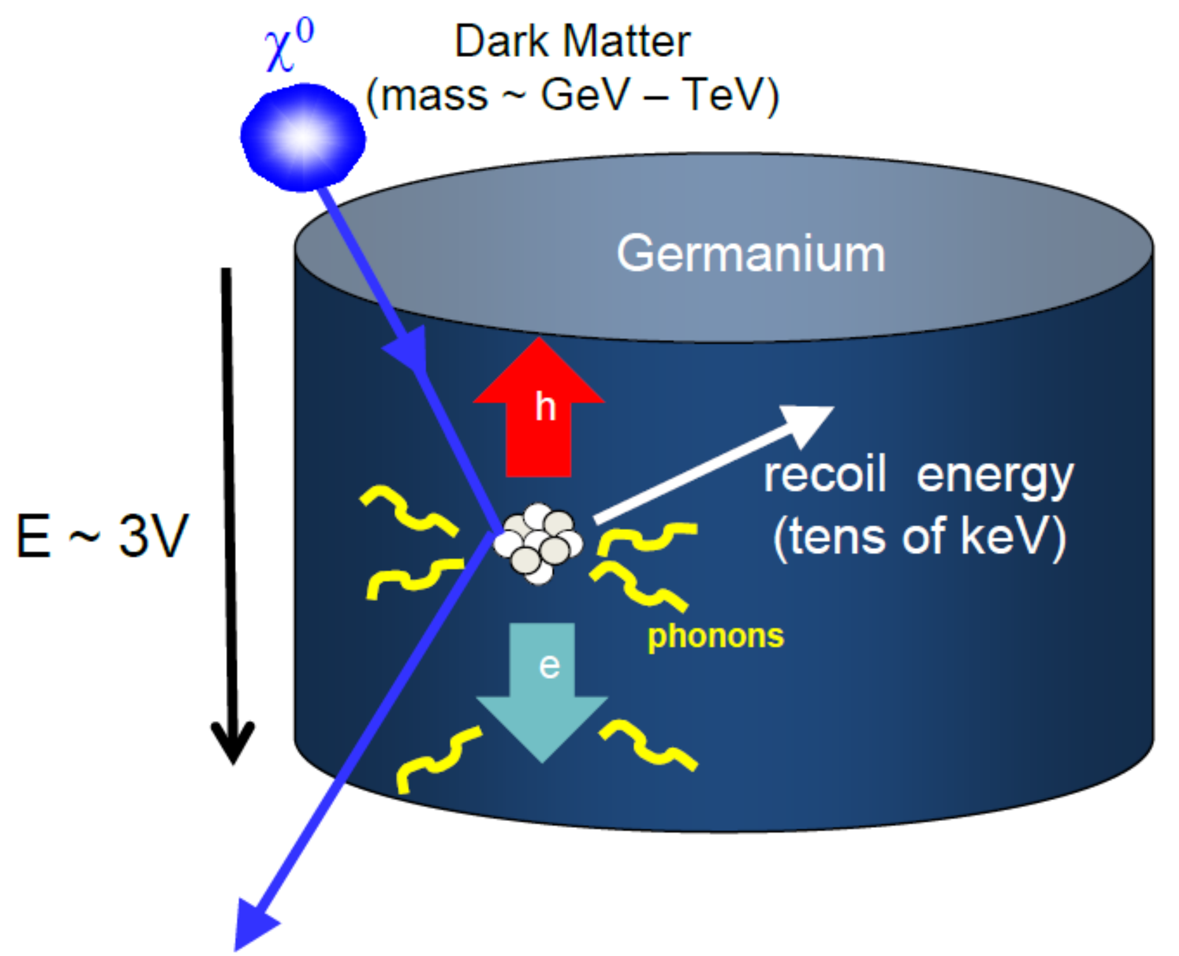
In collaboration with Yuval Grossman, Roni Harnik & Ofri Telem, to appear soon.

Dark Matter Direct Detection

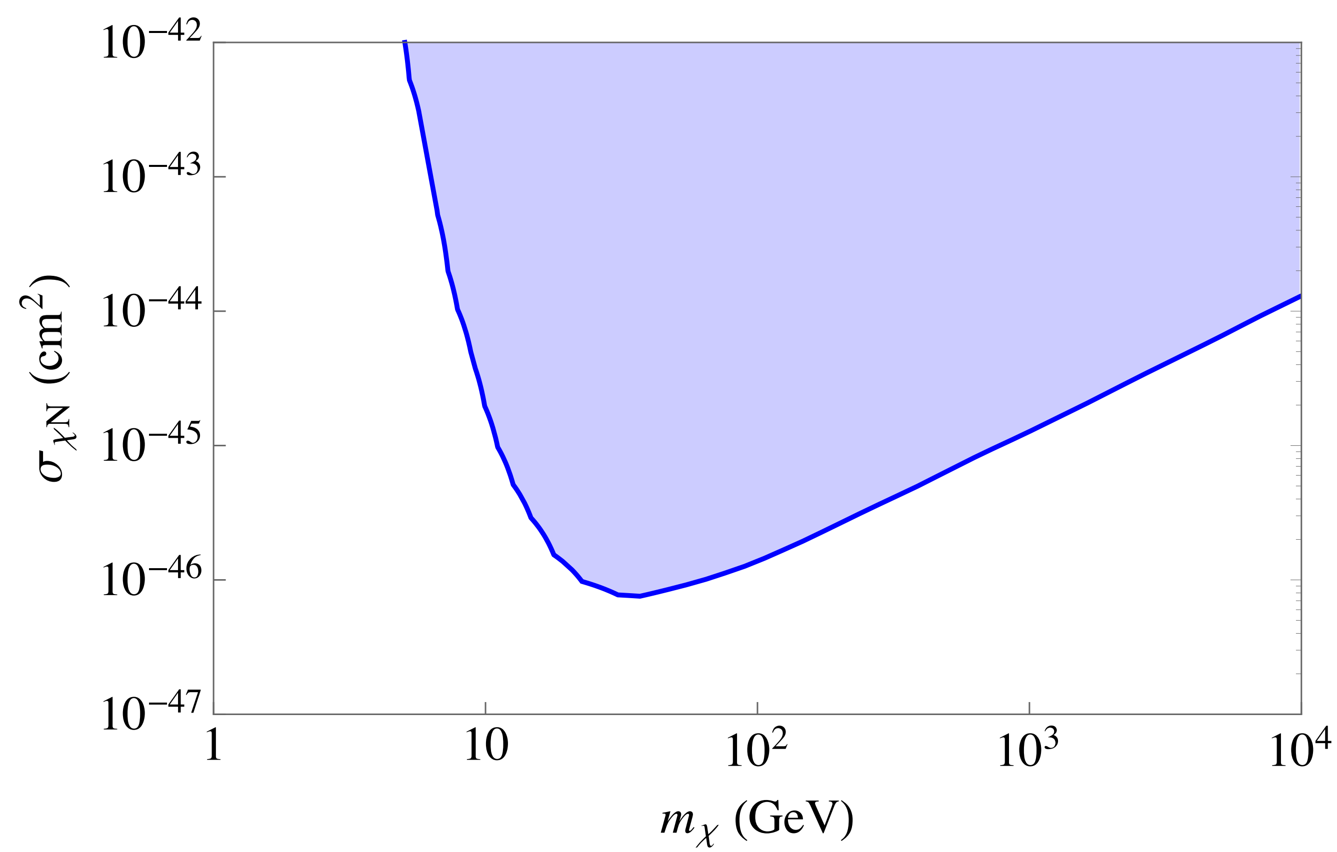
We know dark matter exists in nature, how to detect it?



Available Energy

Recoil energy ~ $\mu v^2/2$, with v ~10^{-3}.

Lighter dark matter ⇒ smaller recoil energy. Threshold for traditional detectors ~ few keV. To explore lighter DM requires new technology & DM-electron interaction.



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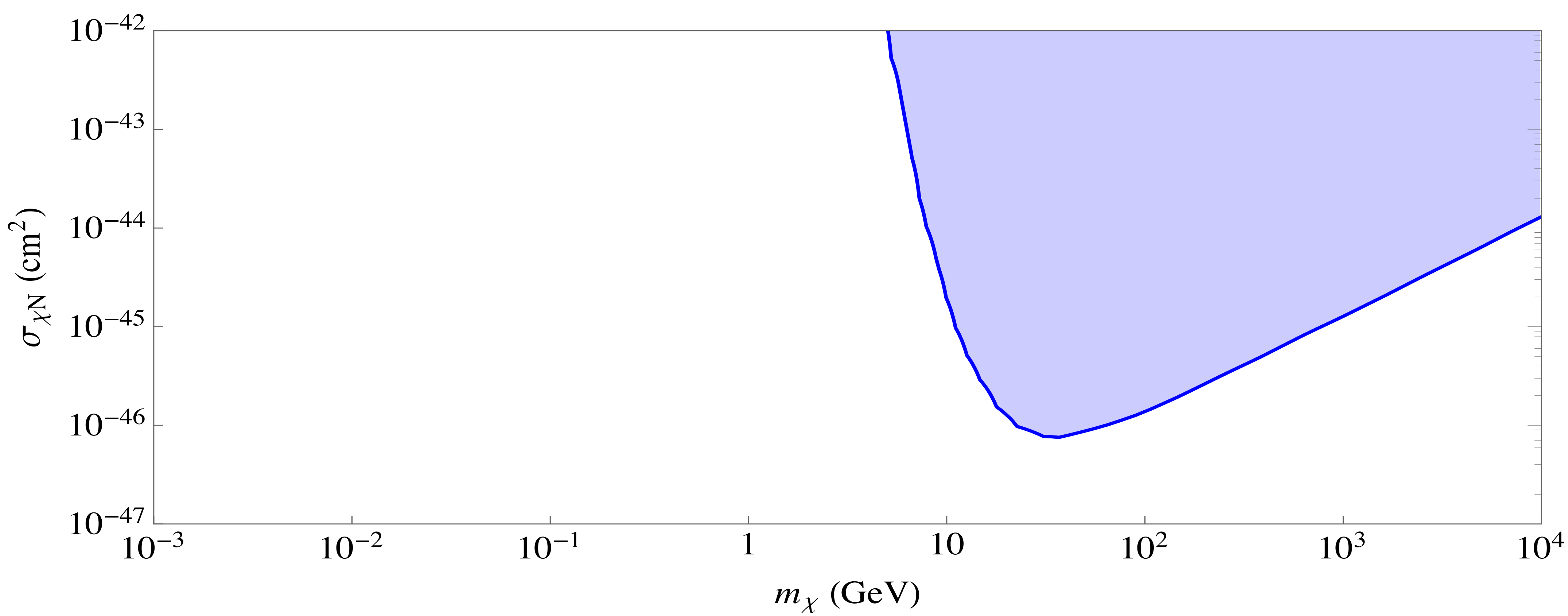


Suicidal Dark Matter

1) There are models where ALL the mass turns into energy.

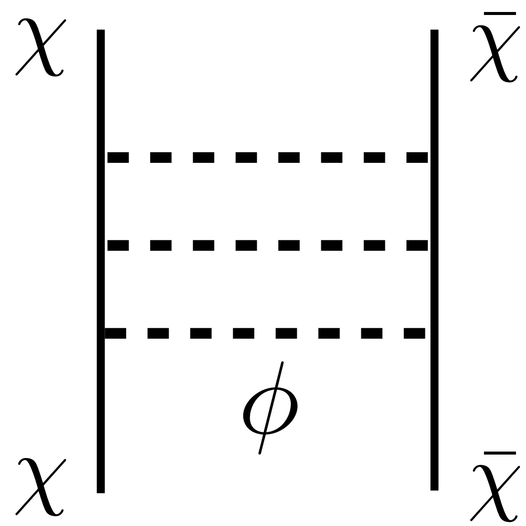
2) Such models can be detected in neutrino experiments.

No threshold obstacle. Most conveniently realized if dark matter are in bound states — from a dark sector.

Clearly a very desirable possibility given the current status of a pending discovery.

Example 1: Rydberg Bound States

A dark force ϕ binds χ and $\bar{\chi}$ into a metastable bound state;
A dark photon V serve as a mediator to SM sector.



Direct annihilation into ϕ or V

$$\Gamma_{n,s,\ell\to V's,\ \mathrm{or}\ \phi's} \sim \left(\frac{\alpha_D}{n}\right)^{2\ell+3} \alpha_D^{(5-C)/2} m_\chi$$

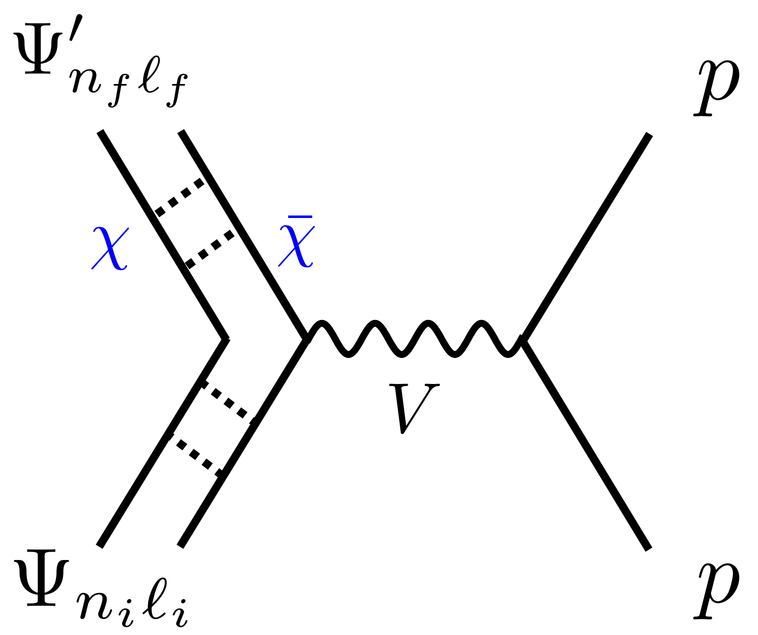
De-excitation via off-shell dark photon

$$\Gamma_{n,s,\ell\to(n-1),s,(\ell-1)} \sim \frac{\kappa^2\alpha\alpha_D^{13}m_\chi^5}{n^{19}m_V^4}$$

If α_D=0.01, m_χ=1GeV, the n=10, l=9 state long-lived enough.

Suicidal Scattering

Becomes unstable after hitting a detector (momentum transfer)



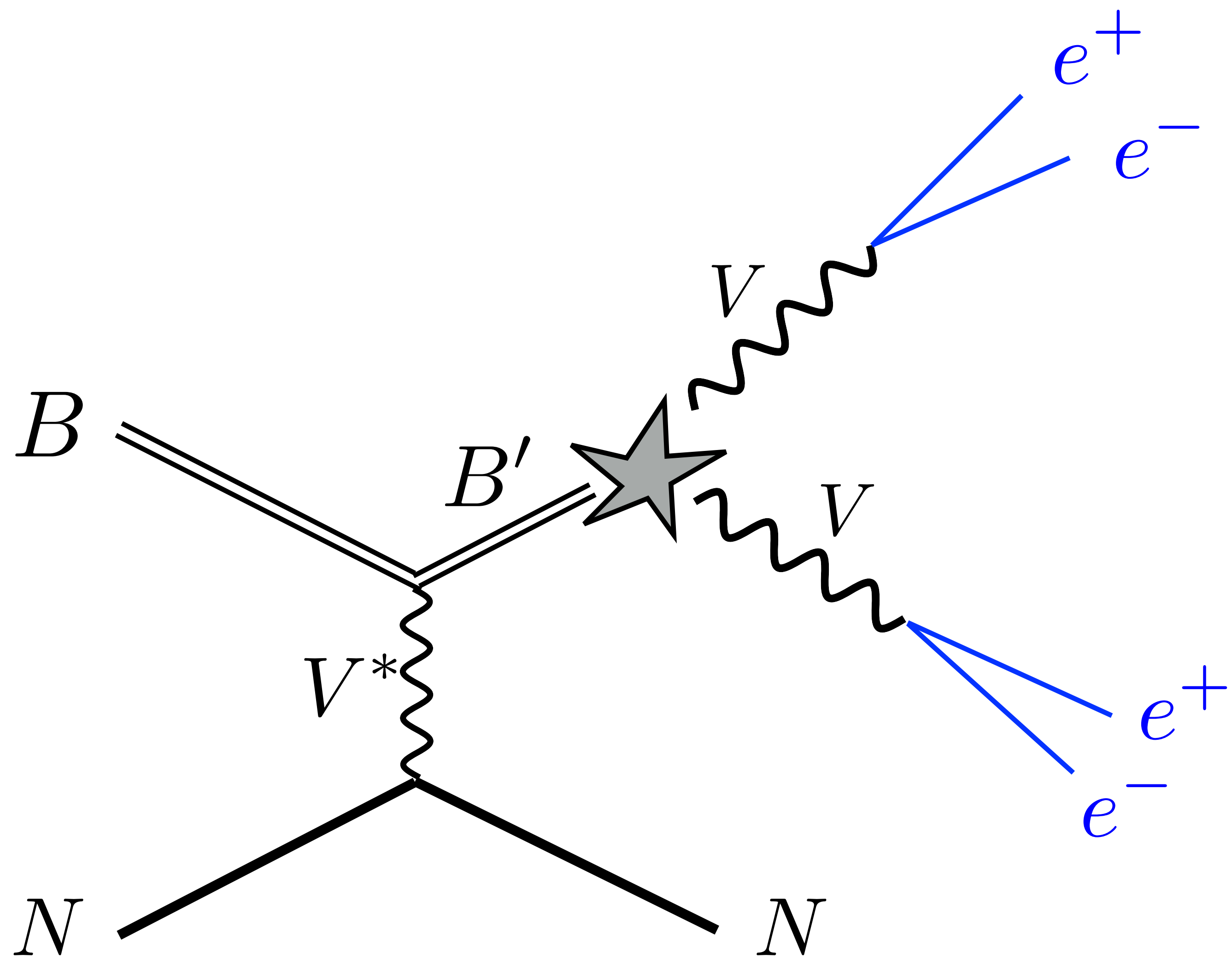
$$F(\vec{q}) = \int d^3x \Psi'^*_{n_f \ell_f} \Psi_{n_i \ell_i} (e^{i\vec{q}\cdot x} - e^{-i\vec{q}\cdot x})$$

- q too small, screening
- q too large, dissociation

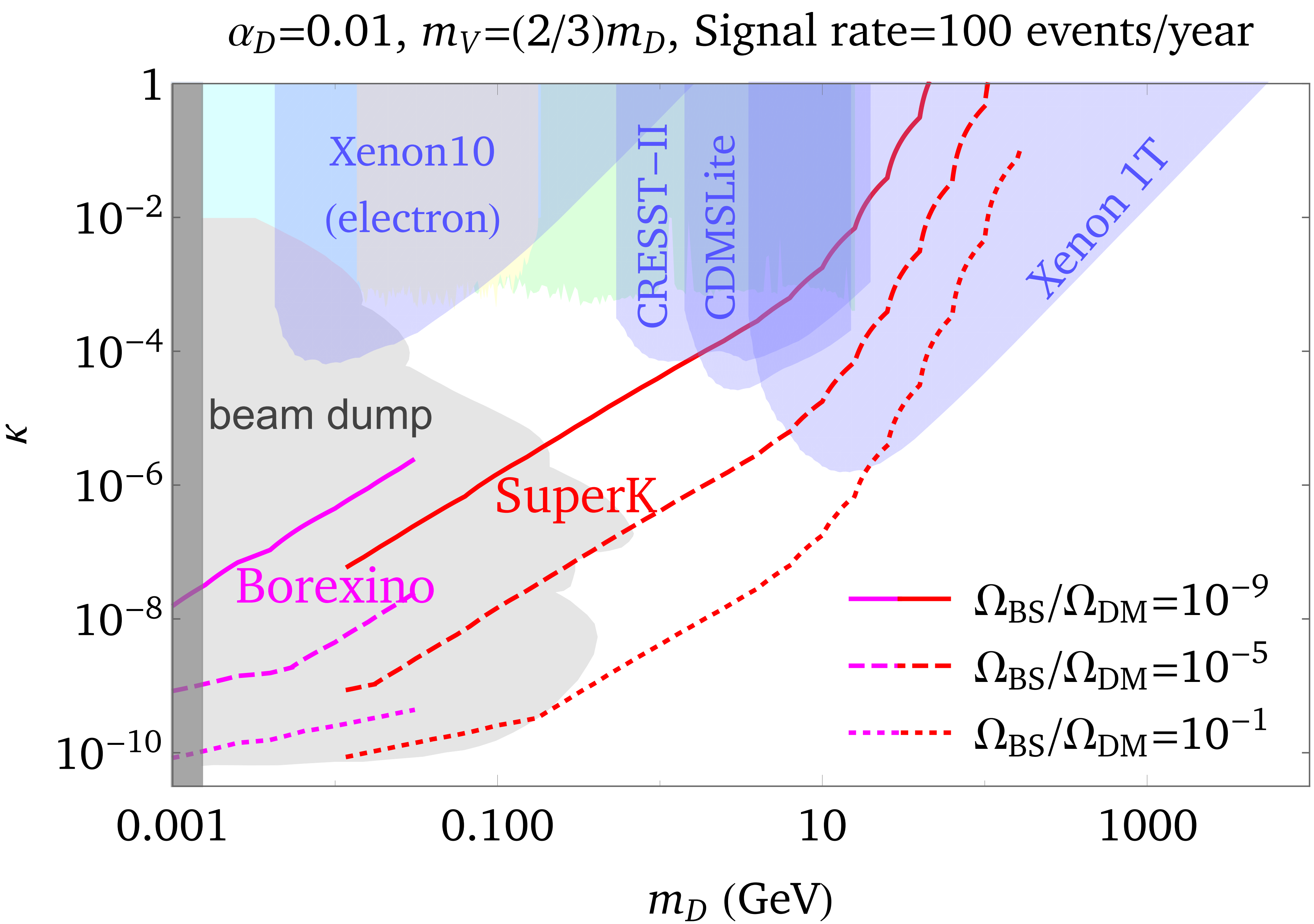
If $\Psi'_{n_f \ell_f}$ decays inside the detector, deposited energy ≈ $2m_\chi$.

For MeV to GeV dark matter, neutrino detectors are best places to search for such a candidate.

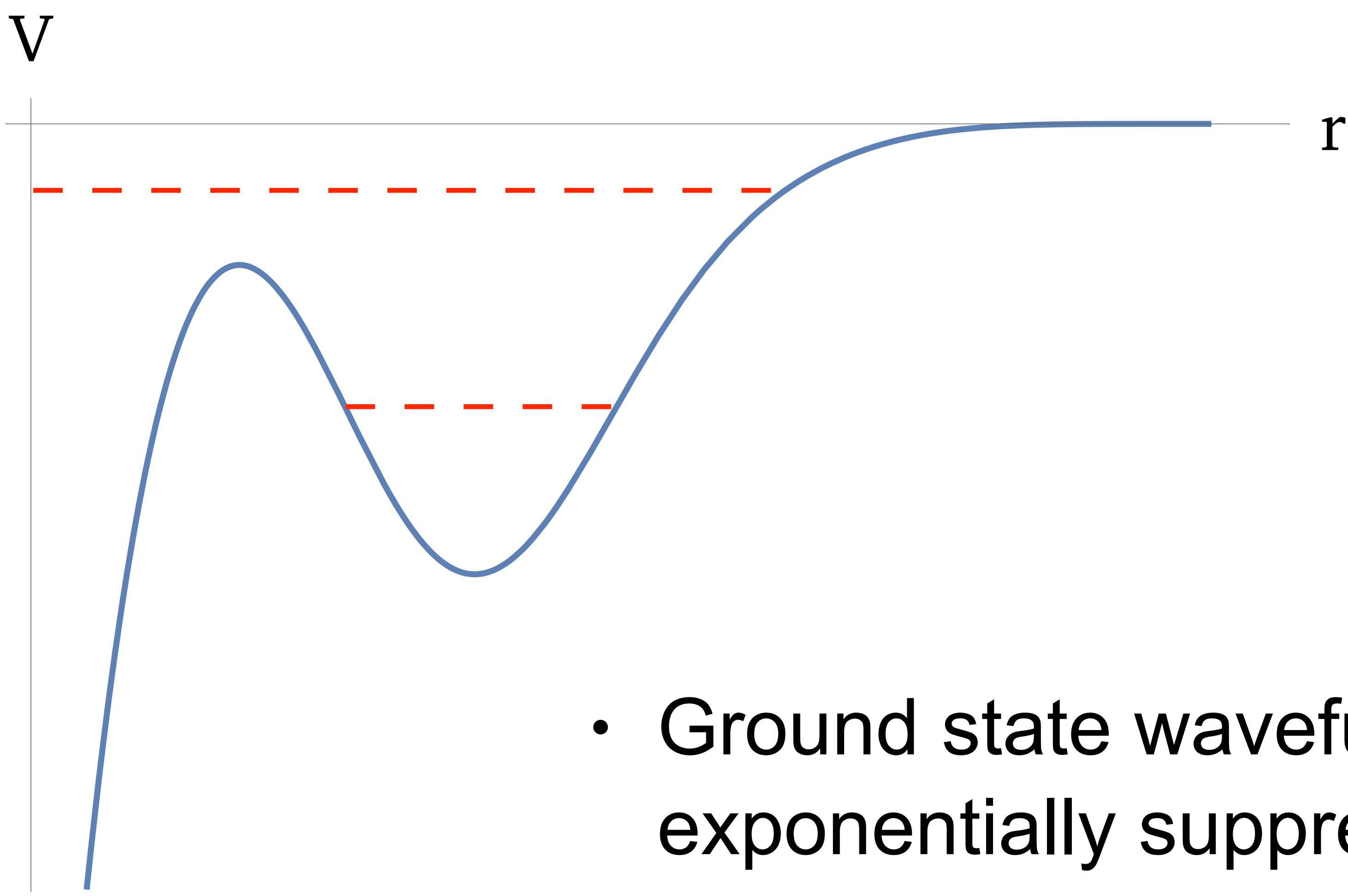
Suicidal Scattering Picture



New Constraints



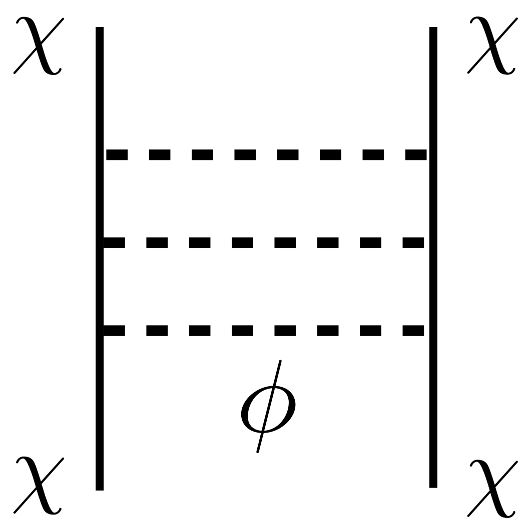
Example 2: Tunneling Stabilization



- Ground state wavefunction exponentially suppressed at origin.
- Unsuppressed for excited state.
- Can be realized with 3 dark forces

Example 3: Symmetry Stabilization

Same sign χ χ bound state can exist via scalar exchange (or a confining dark force) & Stable if U(1) χ-number is conserved.



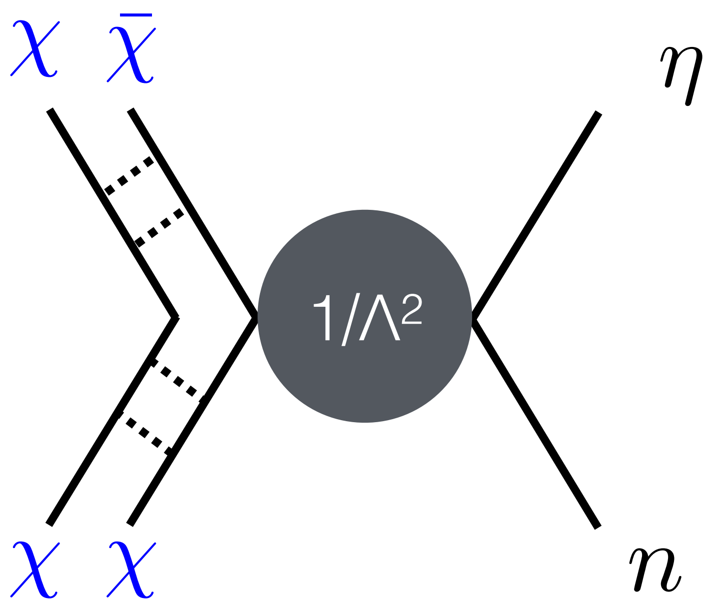
Assume the χ-number = baryon number

	neutron n	χ	η
B-number	1	a	$-1-2a$

A higher dimensional portal operator allowed

$$\mathcal{O} = \frac{\chi\chi n\eta}{\Lambda^2}$$

Signatures of Interacting w. Detector



- Turn into unstable bound state (similar suicidal signal)
- Neutron disappears (new isotope decays in minutes) — secondary signal
- η simply flies away

Mass range of η for ($\chi\chi$) bound state and neutron not decaying into each other

$$m_n - 2m_\chi + BE < m_\eta < m_n + KE$$

Remarks

1) The suicidal scattering of DM bound state occurs more often inside the detector than during its path across the galaxy.

$$\frac{n_{\rm baryon\ \ in\ \ detector}}{n_{\rm baryon\ \ in\ \ galaxy}} \sim 10^{23} \qquad\qquad \frac{\tau_{\rm detector}}{\tau_{\rm galaxy}} \sim 10^{-20}\left(\frac{L}{10\,{\rm meter}}\right)$$

2) The scattering induced indirect detection bound is much weaker than direct detection described in this talk.

$$\tau_{\rm BS} \gtrsim 10^{26}\,{\rm sec} \quad \Rightarrow \quad \sigma_{\rm BS-baryon} \lesssim 1\,{\rm pb} \qquad \text{for } \ \Omega_{\rm BS}/\Omega_{\rm DM} \sim 1$$

$$\sigma_{\rm Super-K, 100\,events/year} \sim 10^{-12}\,{\rm pb}$$

Conclusion

To verify the existence of particle dark matter, direct detection is a must, if ever possible.

We are still lacking an experimental signal, be open minded.

Light dark matter is harder to leave a signal in direct detection if only the kinetic energy is available — A much better world if all the energy including rest mass is deposited.

In this talk, I discussed three models of suicidal dark matter & (large) neutrino detectors are best places for the search.