University of Southern Denmark

Pinning Down Light Dark Matter

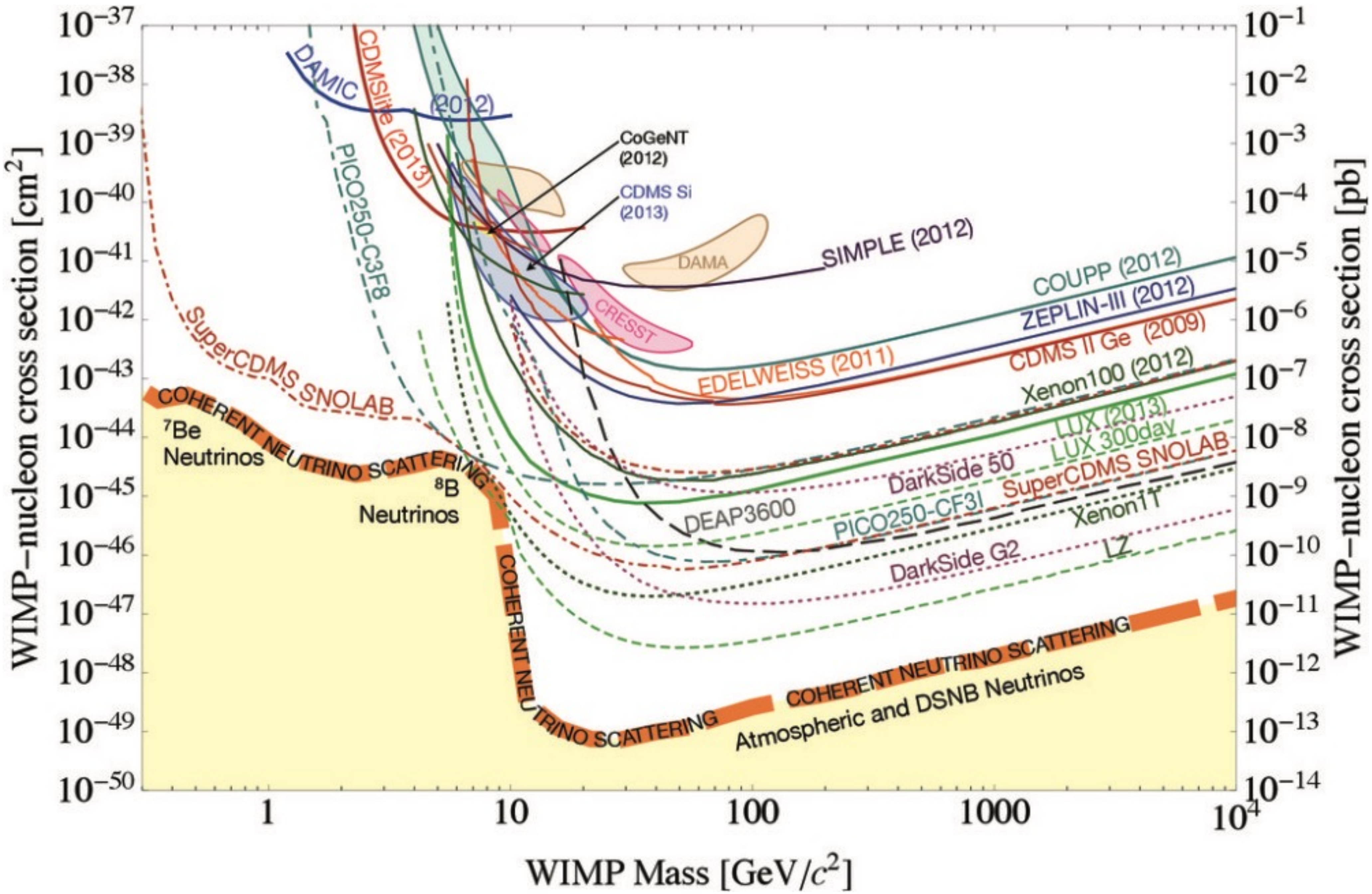
Chris Kouvaris

CP3 - Origins

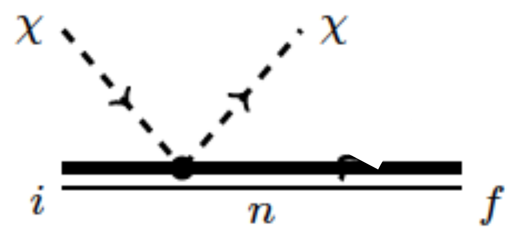
Particle Physics & Origin of Mass

Rencontres du Vietnam, 8 August 2018

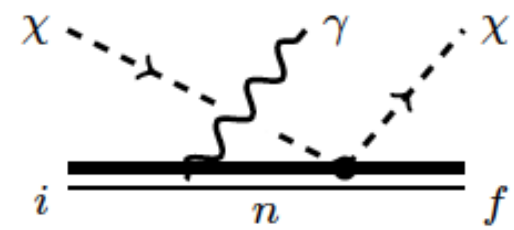
Probing New Territory in Dark Matter Direct Detection



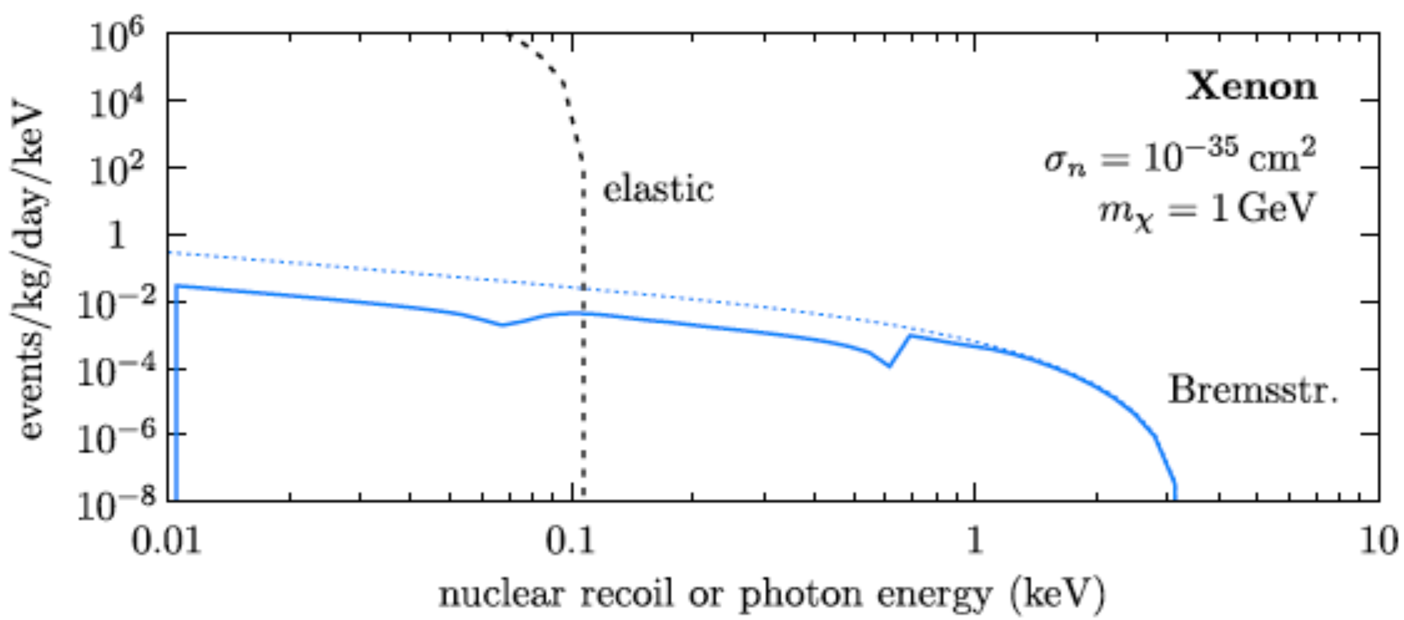
Probing sub-GeV Dark Matter



$$\mu_{N\text{min}} = \sqrt{\frac{m_N E_{R\text{th}}}{2}}\frac{1}{v_{\text{max}}}$$



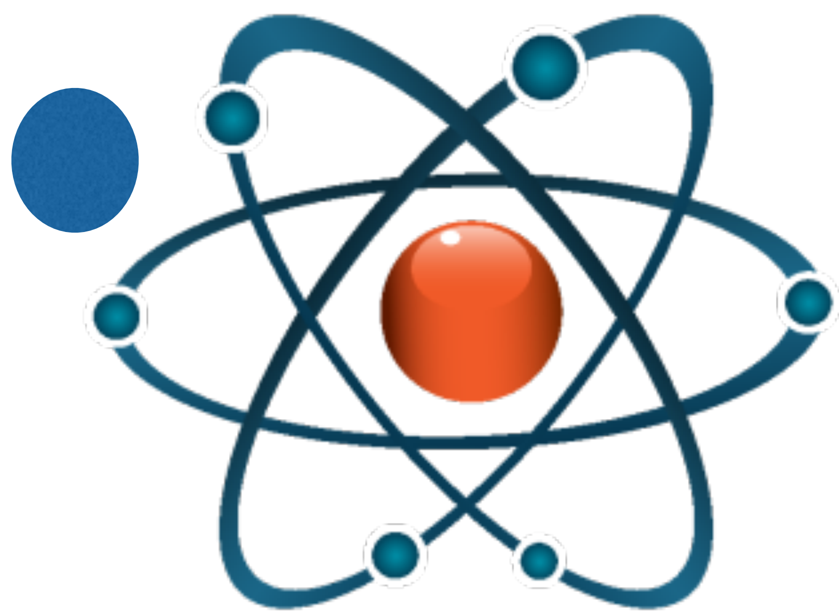
$$\mu_{N\text{min}} = \frac{2\omega_{\text{th}}}{v_{\text{max}}^2}$$



CK, Pradler Phys. Rev. Lett '17

Probing sub-GeV Dark Matter

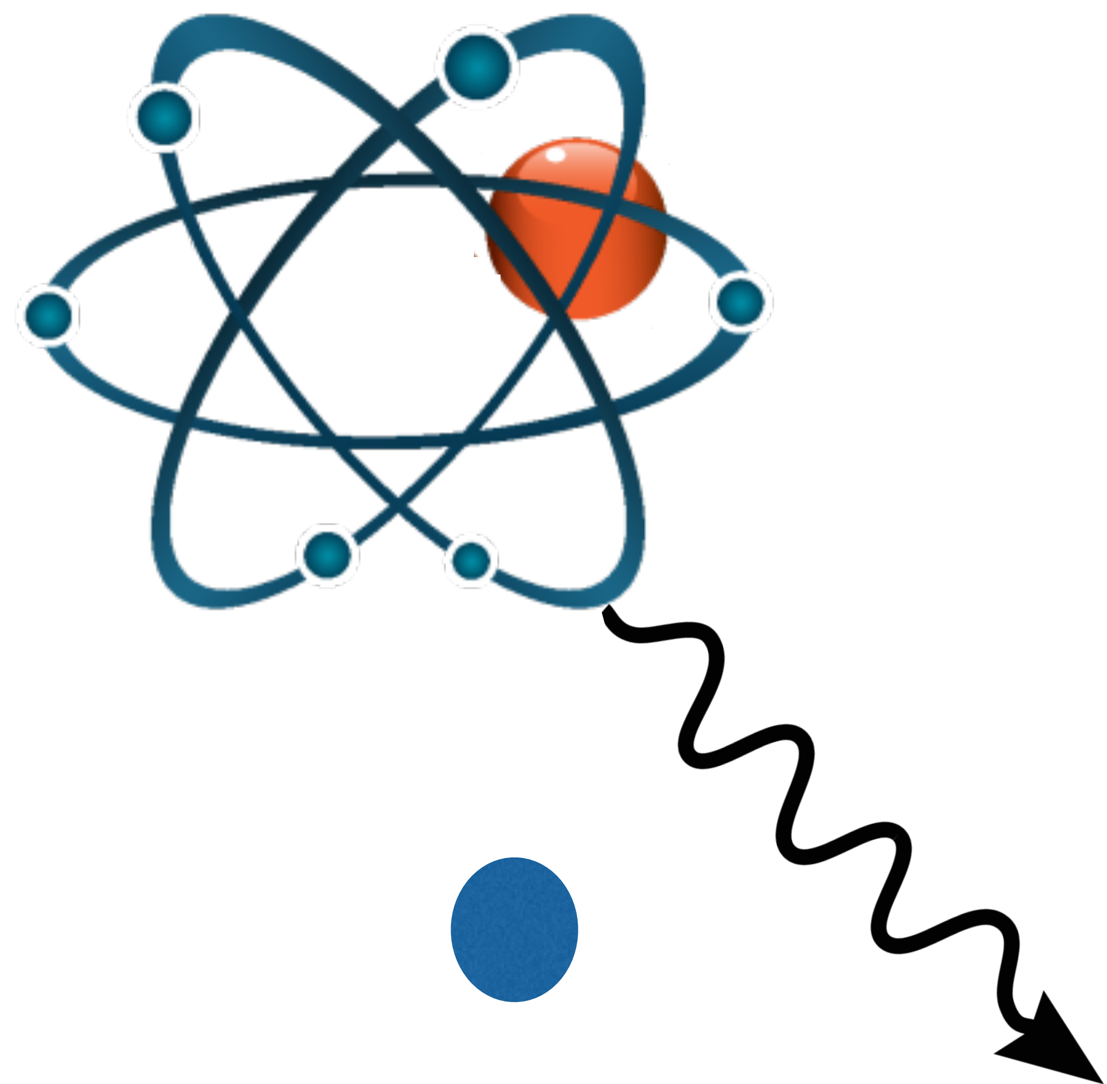
Probing sub-GeV Dark Matter



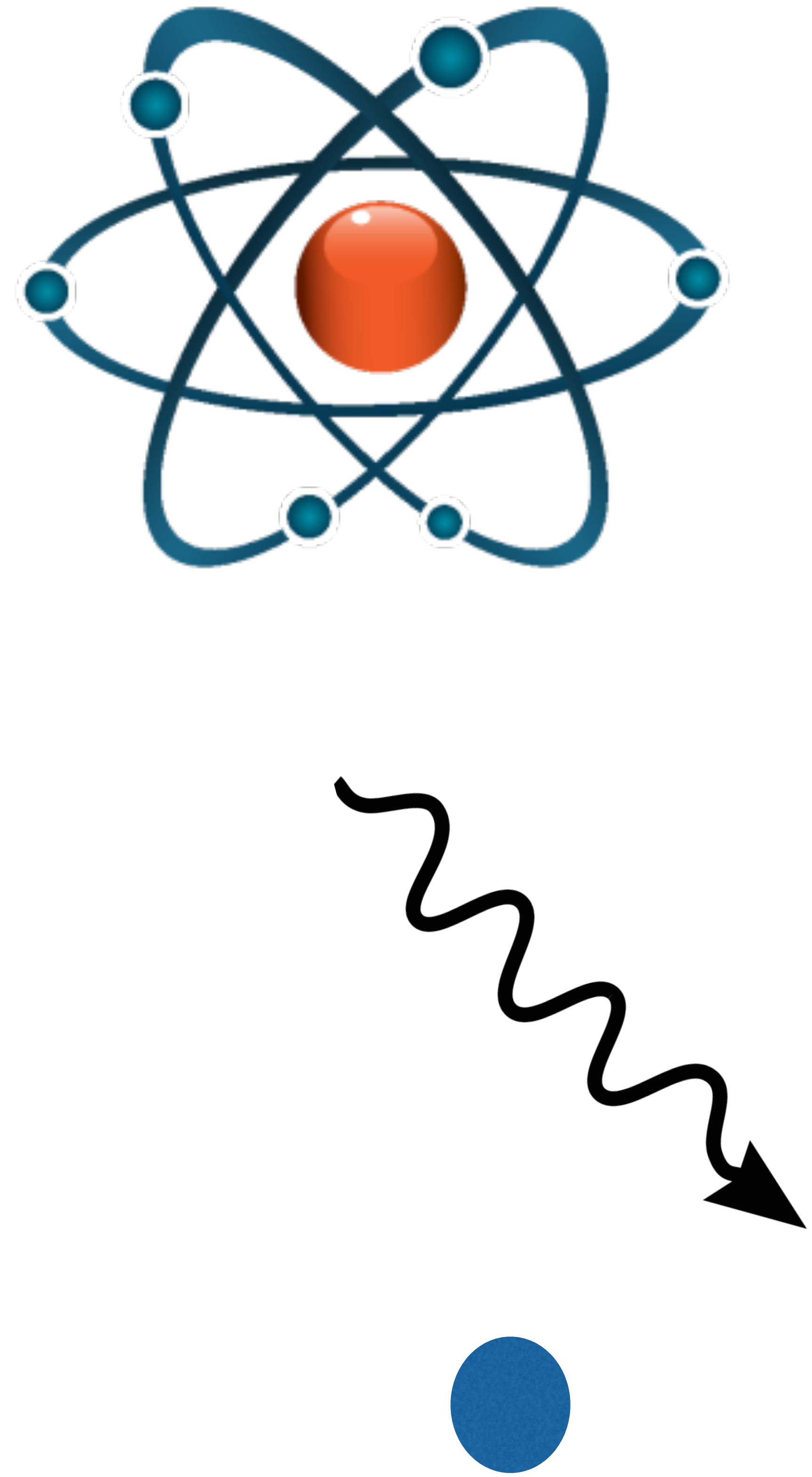
Probing sub-GeV Dark Matter

Probing sub-GeV Dark Matter

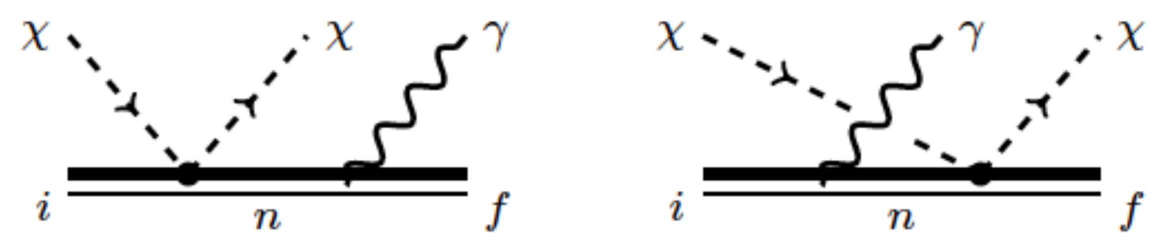
Probing sub-GeV Dark Matter



Probing sub-GeV Dark Matter



Probing sub-GeV Dark Matter

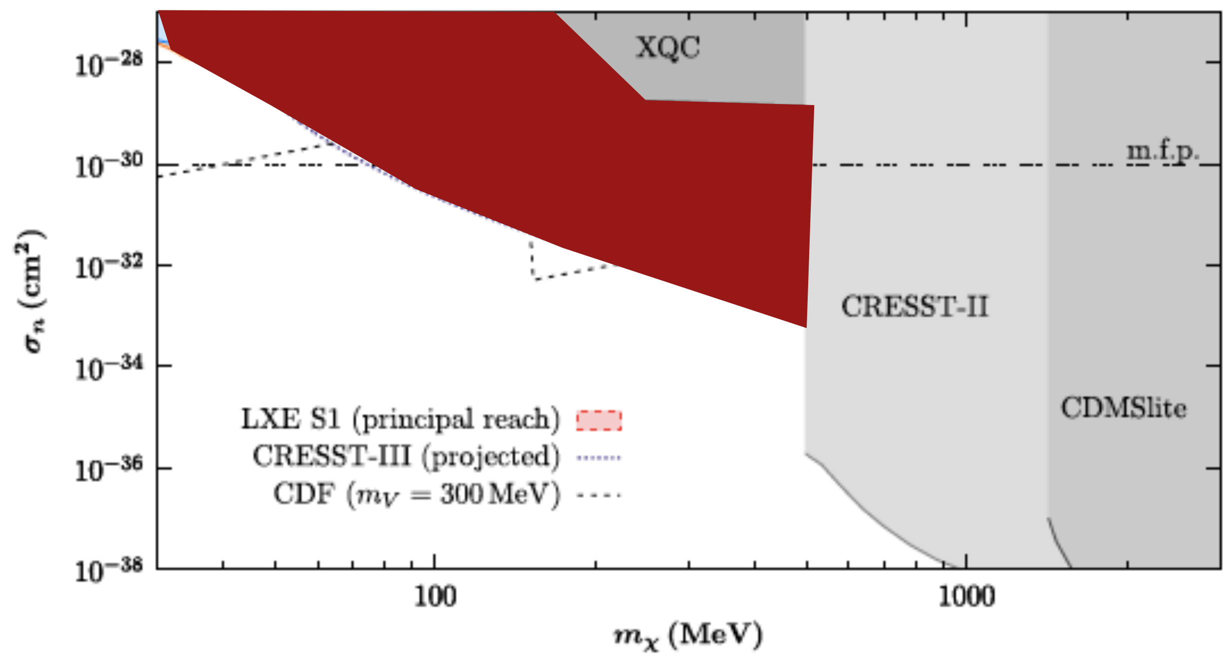


$$|V_{fi}|^2 = 2\pi\omega|M_{\rm el}|^2 \left| \sum_{n,n\neq i} \left[\frac{(\mathbf{d}_{fn}\cdot\hat{\mathbf{e}}^*)\,\langle n|e^{-i\frac{m_e}{m_N}\mathbf{q}\cdot\sum_\alpha \mathbf{r}_\alpha}|i\rangle}{\omega_{ni}-\omega} + \frac{(\mathbf{d}_{ni}\cdot\hat{\mathbf{e}}^*)\,\langle f|e^{-i\frac{m_e}{m_N}\mathbf{q}\cdot\sum_\alpha \mathbf{r}_\alpha}|n\rangle}{\omega_{ni}+\omega} \right] \right|^2$$

$$\frac{d\sigma}{d\omega dE_R} = \frac{4\omega^3}{3\pi}\frac{E_R}{m_N}\frac{m_e^2|\alpha(\omega)|^2}{\alpha} \times \frac{d\sigma}{dE_R}\Theta(\omega_{\rm max}-\omega)$$

CK, Pradler PRL '17

Probing New Parameter Space

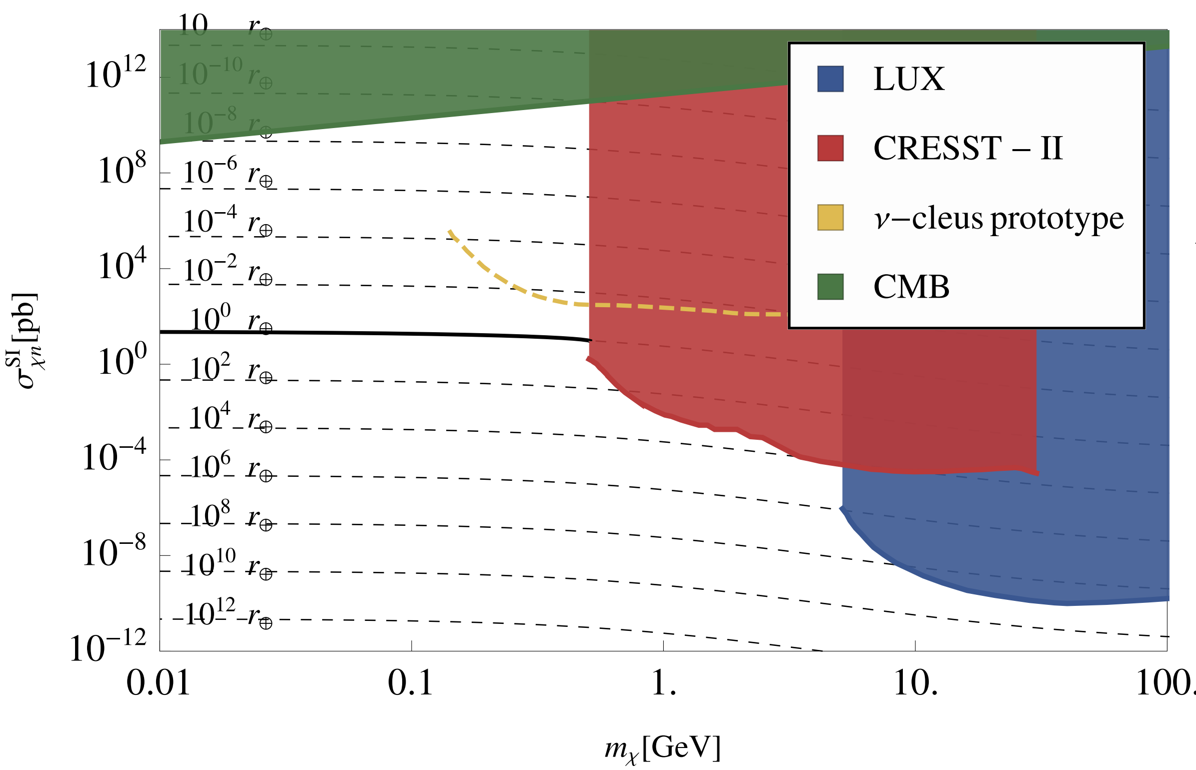


CK, Pradler Phys. Rev. Lett '17,
McCabe '17

This is the tip of the iceberg of what inelastic channels can offer

- "Converting" a conventional detector to a directional one
- Address the neutrino floor problem
- Resonant Scattering
- Generalize to final states that leave the atom excited: Simultaneous double photon production that bears zero background
- Majorana Experiment will test our formula with a neutron beam on a semiconductor target

Dark Matter in the Shadow of the Earth



Emken, CK, '17

There is light dark matter phase space that might not be covered by underground experiments even if they lower their energy threshold due to effective stopping by the rock.

Need for detectors in shallow sites or on surface
However this would increase the background!

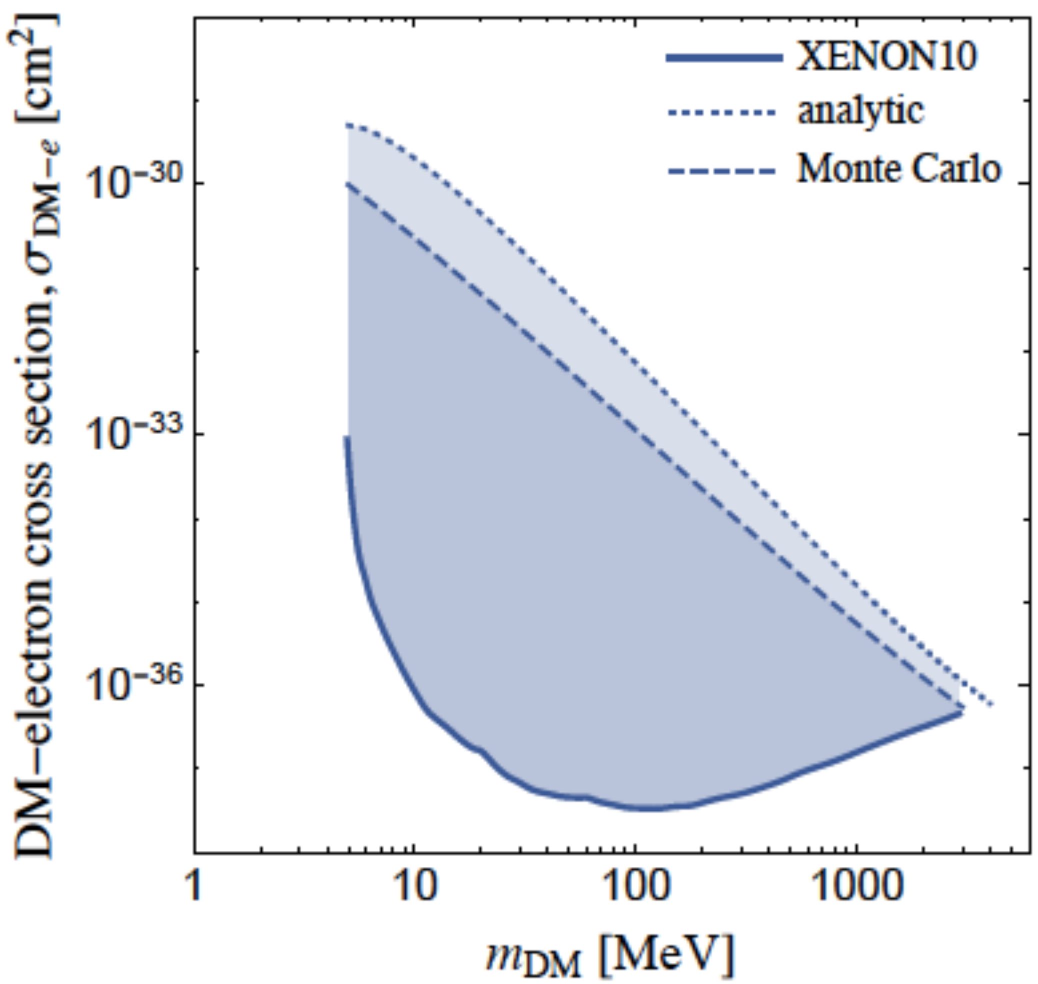
Observing a daily varying dark matter signal
Avignone Collar '93, CK, Shoemaker '14, Foot Vagnozzi '15

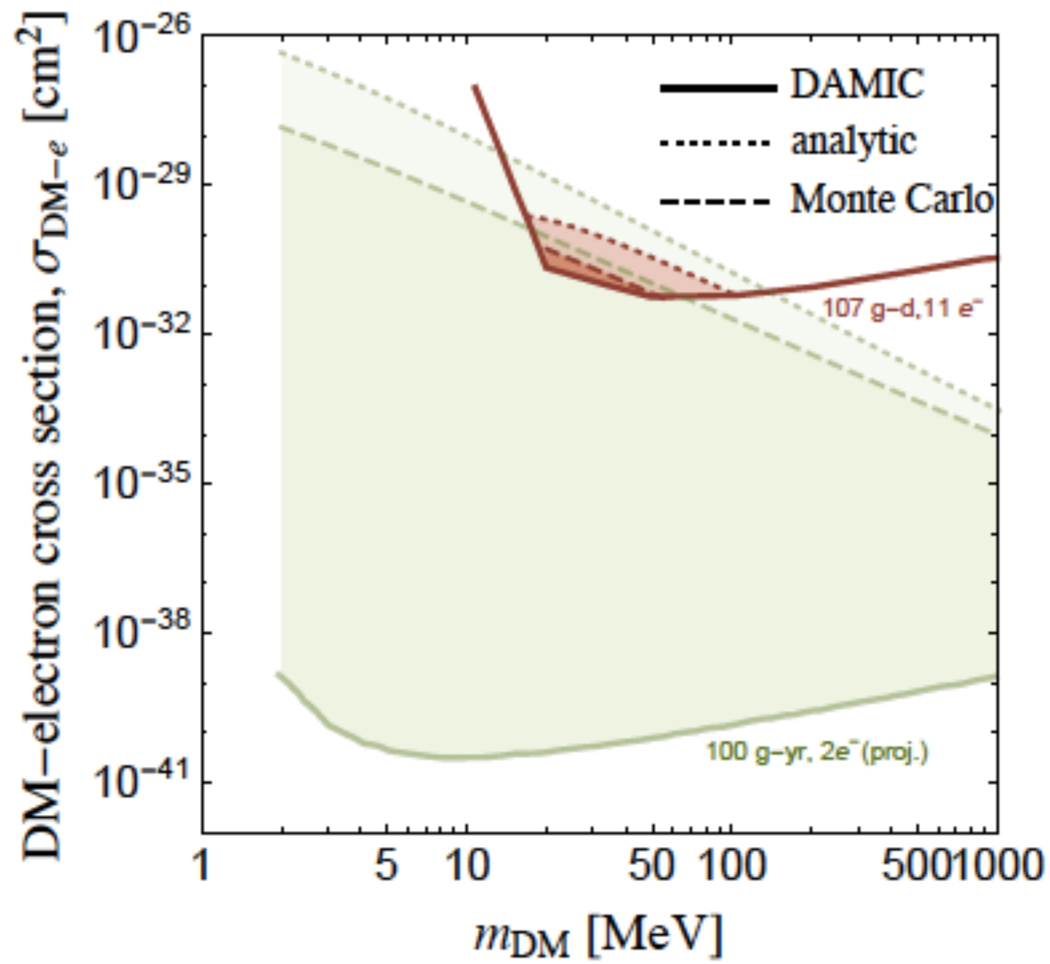
- Ideal for portable detectors like DAMIC can be placed either on the surface or in shallow sites
- Best latitude at the southern hemisphere ~43 degrees. Chile, Argentina, Australia, New Zealand

The effect can be probed also in directional detectors manifesting itself as a top-down asymmetry CK'15

Re-visiting Direct Detection Limits

$$\mathscr{L} \supset g_X \bar{X}\gamma^\mu X A'_\mu + \varepsilon F_{\mu\nu}F'^{\mu\nu} + m_\phi^2 A'_\mu A'^\mu$$





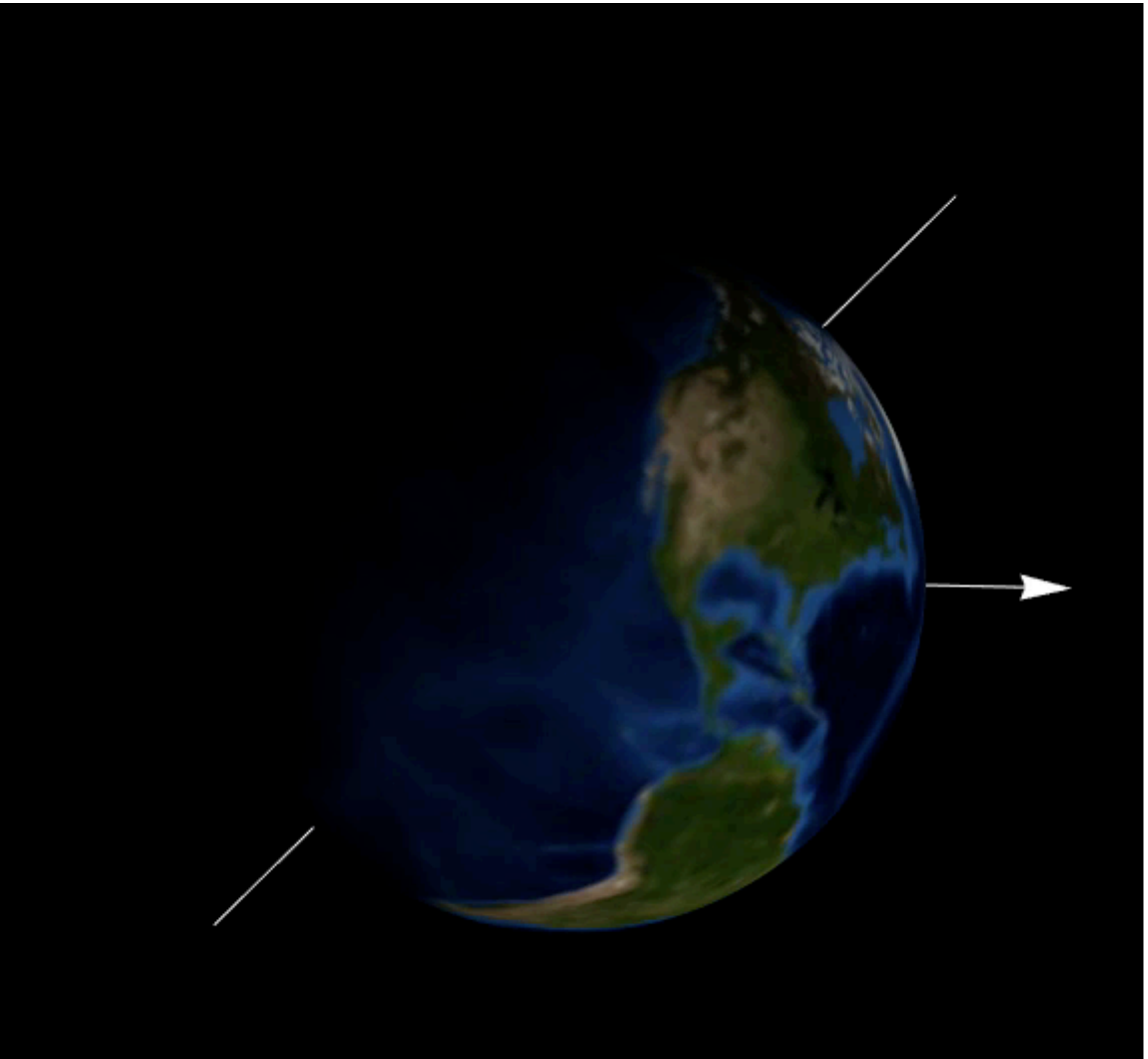
Essig, Fernandez-Serra, Mardon, Soto, Volansky, Yu, '16, Emken, CK, Shoemaker '17

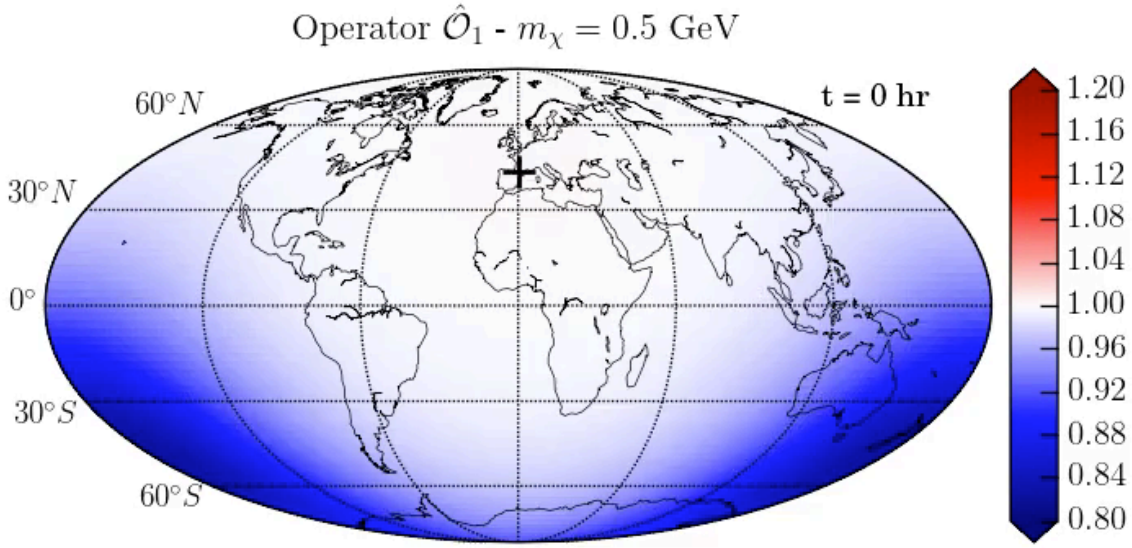
Experiment	Depth [m]	E_{thr}[eV]
XENON10	1400	12.4
DAMIC	100	40
DAMIC (proj.)	100	$\sim 1-2$

Daily Modulation in the Dark Matter Signal

The dark matter signal in underground detectors has three types of diurnal modulation:

- Shadowing effect
- Gravitational focusing Sikivie, Wick '02, Alenazi Gondolo '06, CK, Nielsen '15
- Rotational velocity of the Earth





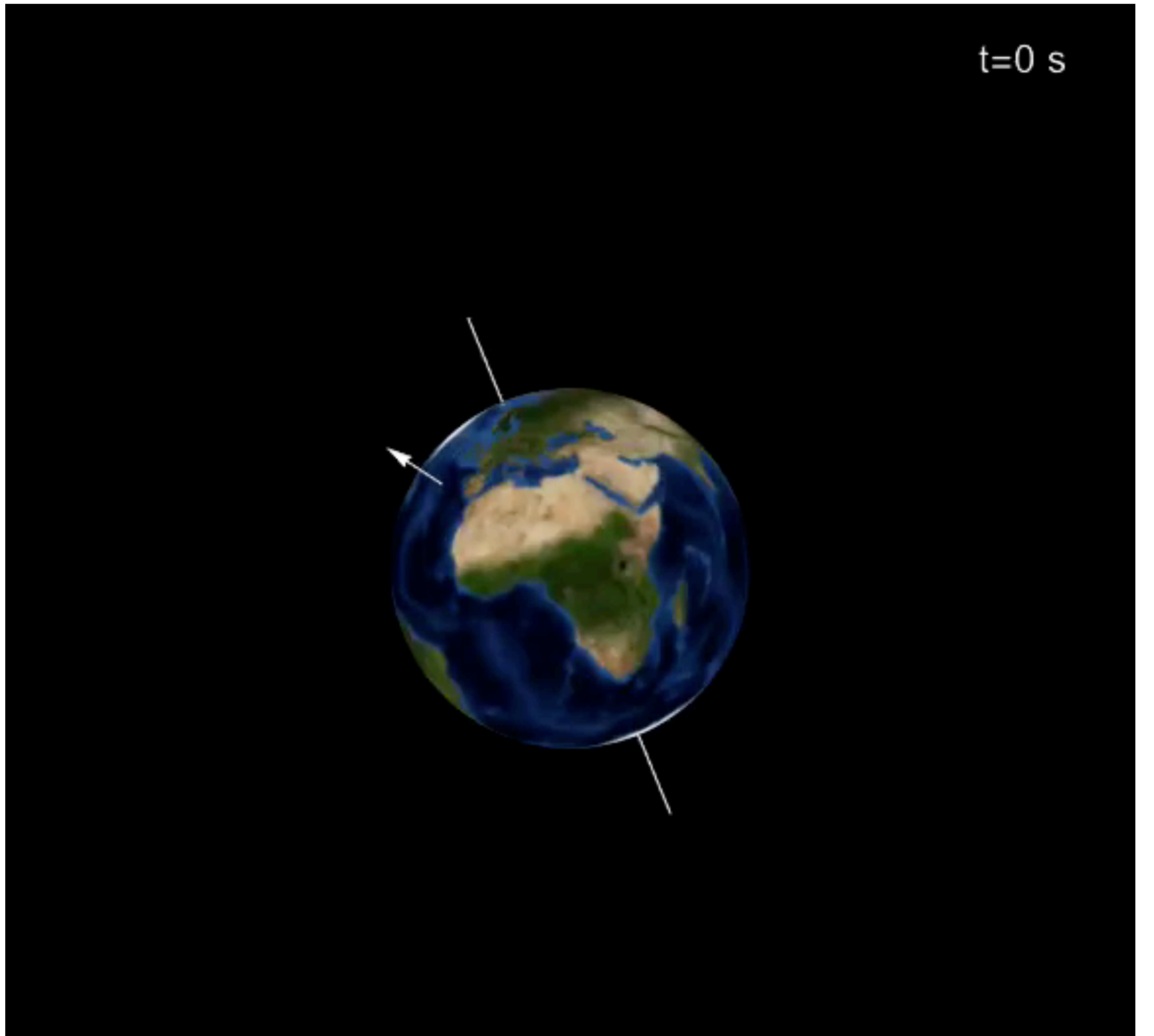
Relative rate enhancement due to Earth-scattering *(attenuation only)*

Kavanagh, Catena, CK '17

DAMASCUS: Dark Matter on Supercomputers

Performing a simulation of trillions of DM particles on ABACUS

- fully parallelized code
- publicly available
- state-of-the-art composition and density profiles of the Earth
- Precise Recoil Spectrum
- Test self-consistency of experiments
- Probe Currently Elusive Dark Matter

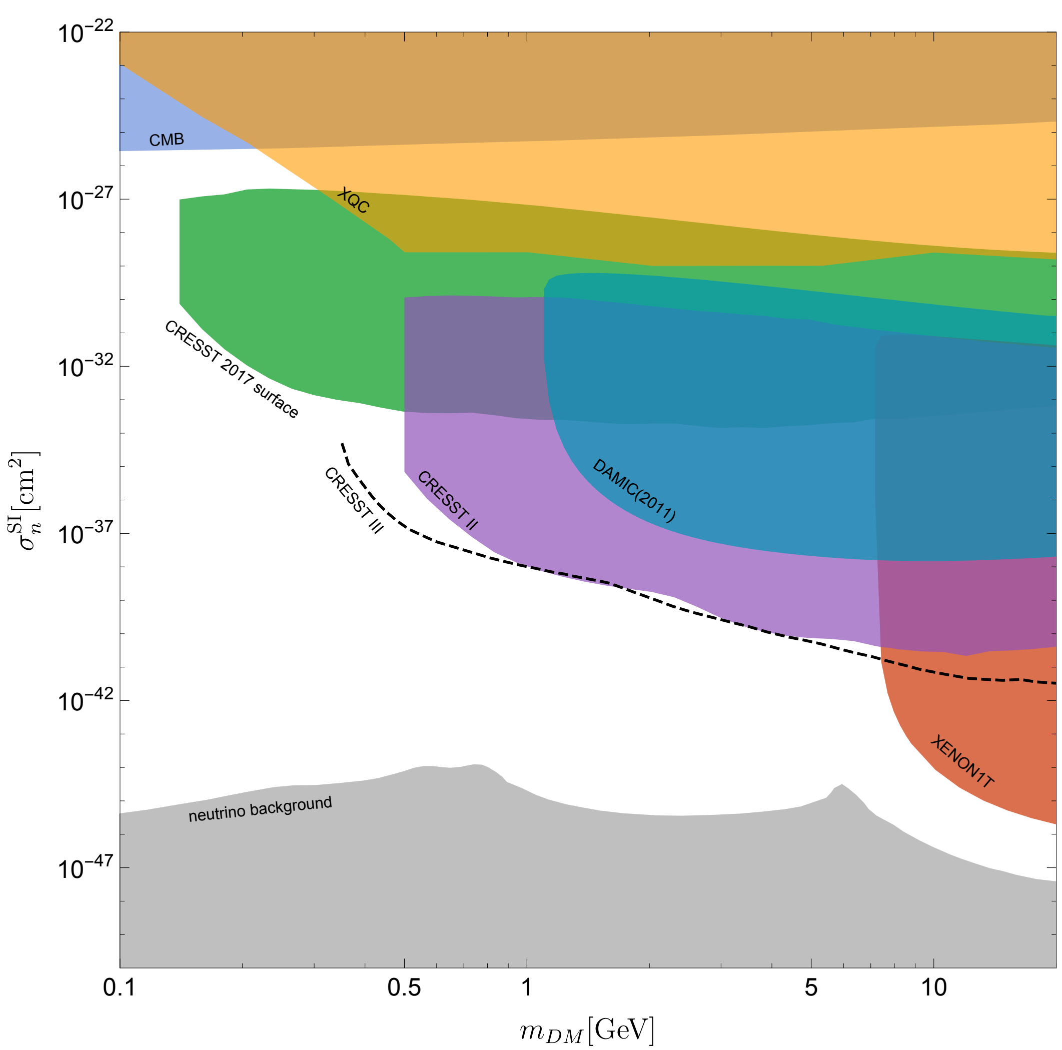


How Blind are Underground Detectors to Strongly Interacting Dark Matter?

There is a critical cross section above which no detection is possible for a given depth.

The critical cross section is independent of the exposure, so detectors can be blind for part of the parameter space regardless of how long they accumulate data.

Monte Carlo simulations using DAMASCUS-Crust including atmosphere, shielding and crust



Emken, CK '18

Conclusions

Inelastic Channels

- New Limits
- Reducing effectively the energy threshold of current detectors
- "Converting" non-directional detectors to directional ones

Shadow Effect

- probing elusive DM with shallow detectors
- precise recoil spectrum