Dark matter detection via atomic interactions

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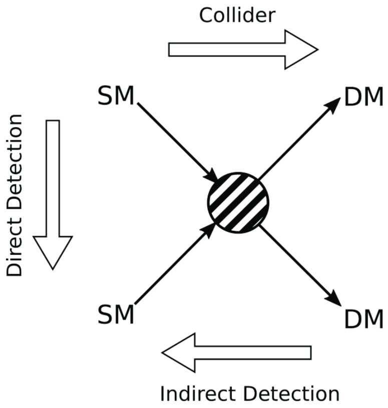

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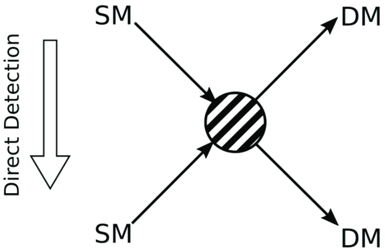

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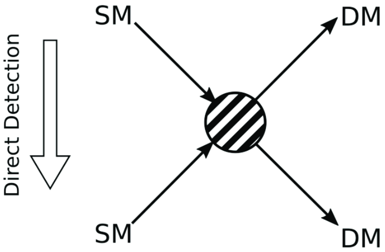

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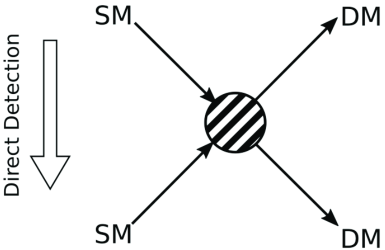
- Sub-GeV WIMPs are less researched
  - Could scatter off atomic electrons at detectable rates [1]



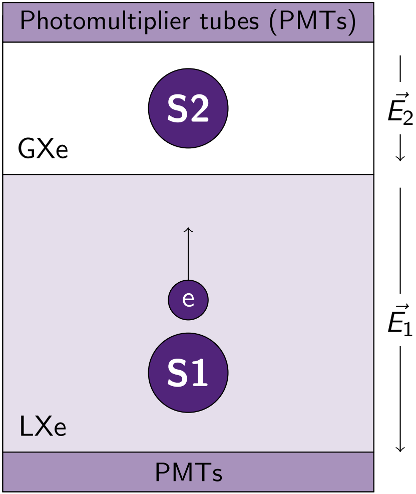
Direct Detection: XENON Experiments

XENON detectors are **dual phase xenon time-projection chambers**

Gives two types of scintillation signals:

- S1: prompt scintillation signal in liquid xenon (LXe)
- S2: delayed electroluminescence in gaseous xenon (GXe)

More detectors planned with same working principle



Calculations

- To compare theory to direct detection experiments, we need to calculate the DM-electron cross-section,

$$\frac{\langle \mathrm{d}\sigma v \rangle}{\mathrm{d}E} = \frac{\bar{\sigma}_e}{2m_e} \int \mathrm{d}v \frac{f(v)}{v/c} \int_{q_-}^{q_+} a_0^2 q \mathrm{d}q | \, F_\chi^\mu(q) \,|^2 \, K(E,q)$$

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$K(E,q)$ is the 'atomic excitation factor':

$$K_{njl} \equiv E_H \sum_m \sum_f |\langle f | e^{i\mathbf{q}\cdot\mathbf{r}} | njlm \rangle|^2 \varrho_f(E)$$

Considerations when calculating K

The nucleus is a very important region for DM-electron scattering!

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So, for a 'full' calculation, we need to:

1. use the relativistic Hartree-Fock method for each bound state, then;
2. take the resulting Hartree-Fock potential, and;
3. solve the Dirac equation for each continuum state in the energy and momentum grid.

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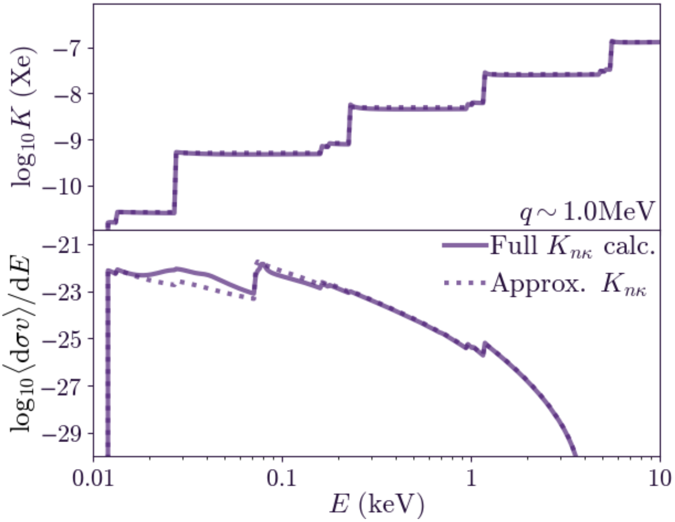
- Accurate for argon and xenon when continuum energy is small
- Much faster when using pre-generated tables for $K_{n\kappa}$

Approximating K



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- the *energy resolution* [2] by smearing $\mathrm{d}R/\mathrm{d}E$ using a Gaussian, g with an energy-dependent width, σ, and;

$$\frac{\mathrm{d}S}{\mathrm{d}E} = \varepsilon(E) \int_0^\infty g_\sigma(E' - E) \frac{\mathrm{d}R(E')}{\mathrm{d}E'} \mathrm{d}E'$$

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- the *detection efficiency* [2] by correcting the smeared rate with the total efficiency, $\varepsilon(E)$.

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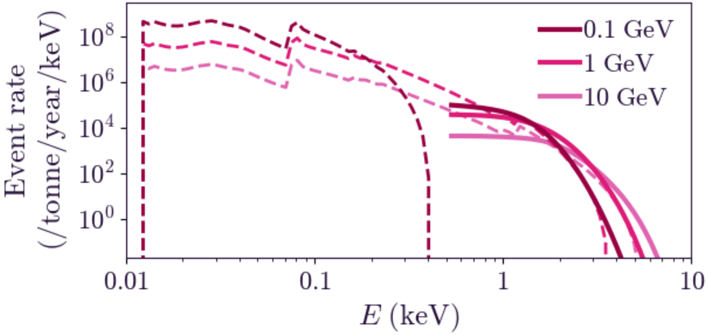
Event Rates: Theoretical vs. Observable



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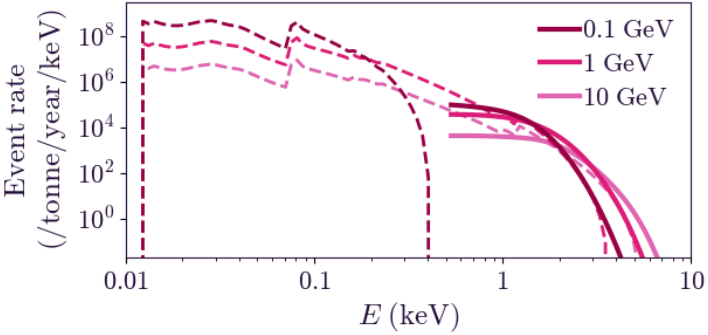

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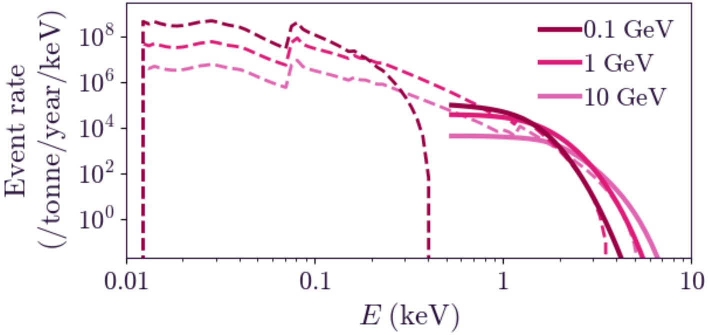

- The low-energy detector response has a significant impact on the results for DM-electron scattering
- The Gaussian energy resolution allows low energy events to 'leak' into the high energy regions

Conclusion & Next Steps

- Accurate atomic physics depiction necessary for DM-electron scattering
- Detector response in low energy range has a large effect on event rates
- Consider many-body effects
- Release atomic factors for public use
  - $K-$values largely independent of DM model, so easy for others to use
- Compare to XENONnT results
- Public release of code

References
[1] B. M. Roberts et al. *Physical Review D*, 93(11):1-22, 2016.
[2] E. Aprile et al. *Physical Review D*, 102(7):72004, 2020.
[3] B. M. Roberts and V. V. Flambaum. *Physical Review D*, 100(6):63017, 2019.
[4] B. M. Roberts, V. V. Flambaum, and G. F. Gribakin. *Physical Review Letters*, 116(2):1-5, 2016.