Directional sensitivity with phonon mediated detectors

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Perspective

- Dark matter
  - ~85% of mass content of the Universe
- Many particle candidates covering large range of masses
- If WIMPS are DM, isothermal Maxwell-Boltzmann distribution
- Expected challenges: low signal rate, low energy deposited
Searching for Dark Matter
Dark Matter Expected Rate

WIMP differential rate

\[ \frac{\partial^2 R}{\partial E_r \partial \Omega_r} = \frac{\rho_0 \sigma A^2}{4\pi m_\chi \mu_\chi^n} \times F^2(E_r) \hat{f}_{\text{lab}}(v_{\text{min}}, \hat{q}; t) \]

Velocity distribution

radon transform

\[ \hat{f}_{\text{lab}}(v_{\text{min}}, \hat{q}; t) = \frac{1}{N_{\text{esc}} \sqrt{2\pi \sigma^2_v}} \times \left[ \exp \left( -\frac{|v_{\text{min}} + \hat{q} \cdot v_{\text{lab}}|^2}{2\sigma^2_v} \right) - \exp \left( -\frac{v_{\text{esc}}^2}{2\sigma^2_v} \right) \right] \]

\[ \rho_0 \approx 0.3 \text{ GeV cm}^{-3}, \text{ dark matter local density} \]
\[ \sigma = \text{WIMP-nucleon cross section} \]
\[ A = \text{nuclear mass number} \]
\[ m_\chi = \text{dark matter mass} \]
\[ \mu_\chi^n = \text{WIMP-nucleon reduced mass} \]
\[ v_{\text{min}} = \sqrt{2m_N E_r / 2m_\chi^n}, \text{ minimum WIMP speed} \]
\[ F^2(E_r) = \text{Helm nuclear form factor} \]

Ciaran A. J. O’Hare et al, Phys. Rev. D 92, 063518
Dark Matter Direct Detection Status

https://inspirehep.net/record/1243804/files/New_LimitPlot3b.png
Coherent Neutrino-Nucleus Elastic Scattering (CENNS)

Flavor-blind Standard Model process

\[ \sigma_{\nu N \rightarrow \nu N} \sim \frac{G_F^2}{4\pi} N^2 E_{\nu}^2 \]

<table>
<thead>
<tr>
<th>Material</th>
<th>Cross Section (cm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ge</td>
<td>6.0 \times 10^{-41}</td>
</tr>
<tr>
<td>Ar</td>
<td>1.8 \times 10^{-41}</td>
</tr>
<tr>
<td>Si</td>
<td>7.4 \times 10^{-42}</td>
</tr>
</tbody>
</table>

Excellent tool to probe BSM Physics, but never utilized due to lack of low threshold detectors

Can detect CENNS in \(~\) 1 month

DOI: 10.1103/PhysRevD.93.013015
Two Questions, One Answer

Dark Matter

CENNS

CDMS Solid State Technology

- Sub 40 mK
- NR vs ER discrimination
- Recoil energy via phonons
- Charges via ~3 V/cm E-field

https://www.slac.stanford.edu/exp/cdms/default_files/image004.png
Luke-Neganov Gain

\[ E_{tot} = E_r + E_{\text{luke}} \]
\[ = E_r + n_{eh} e V_b \]
\[ = E_r \left( 1 + \frac{e V_b}{\varepsilon_{eh}} \right) \]

- Phonon noise doesn’t scale with the ionization bias:
  
  \[ \Rightarrow \quad \text{S/N} \uparrow \]

- In theory one can increase Bias to reach Poisson fluctuation limit:
  
  \[ \sqrt{F \varepsilon E} \]

Limitation: stochastic charge leakage

Contact-Free High Voltage Detector

Directional Dark Matter Searches

Directional Dark Matter Searches

- DRIFT experiment
- Time projection chamber (TPC) with low-pressure gas
- Advantage – strong directional effect
- Disadvantage – low exposure due to mass, high energy threshold
Possible Charge Creation Mechanism
Angle Dependent Energy Thresholds

\[ R(t) = \int_{4\pi} \int_{E_{th}(\theta, \phi)}^{E_{r}^{\max}} \frac{\partial^2 R}{\partial E_r \partial \Omega_r} dE_r d\Omega_r \]

- Collaboration with K. Nordlund et al, U. of Helsinki
- Molecular dynamics based on density functional theory (DFT)
- Large variation in energy threshold

F. Kadribasic et al. arXiv:1703.05371
• 1 eV Threshold

• Angular Threshold

• Integrated Rate
Summary

- G2 experiments search for dark matter over large mass range
- Novel detectors for beyond-G2 dark matter and neutrino experiments
- Directionality possible at single electron hole pair resolutions
Thank you