Astroparticle Physics with a Generation-3 Liquid Xenon Detector

Rafael F. Lang
Purdue University
rafael@purdue.edu
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Dark Matter
- Dark photons
- Axion-like particles
- Planck mass

WIMPs
- Spin-independent
- Spin-dependent
- Sub-GeV

Sun
- Solar pp neutrinos
- Solar Boron-8 neutrinos

Big Bang
- Neutrinoless double beta decay
- Double electron capture

Supernova
- Supernova neutrinos
- Multi-messenger

Cosmic Rays
- Atmospheric neutrinos
**Coherent Elastic Scattering**

For both **WIMPs** & **solar/supernova \( \nu \):**

\[
\frac{\lambda_{\text{deBroglie}}}{2\pi} = \frac{\hbar}{p} \sim \frac{197 \text{ MeV fm}}{100 \text{ GeV} \ 10^{-3} \text{c}} \sim \frac{197 \text{ MeV fm}}{10 \text{ MeV}} > r_{\text{nucleus}}
\]

\[\rightarrow\] interact with entire nucleus: \( \sigma \propto A^2 \)

Recoil degenerate in transferred momentum \( p \)

\[\rightarrow\] for some parameter space WIMPs and neutrinos indistinguishable: “neutrino floor”

(not really a floor)
Best limits all from LXe experiments

Priors include Z-mediation through a box, Z'- or Higgs-mediation, Z-mediation at $10^{-10}$ abundance
Strong Program Going Forward

Start next year to probe another 2 orders of magnitude

\[ \chi + N \rightarrow \chi + N \]
Simple scattering kinematics: degenerate in momentum

Heavy WIMP, $v \sim 10^{-3}c$

Coherent Neutrino-Nucleus Scattering: light $v$, $v \sim c$
Neutrino Floor is far, far away

Current program leaves a WIMP gap
Neutrino Floor is far, far away

Current program leaves a WIMP gap

Atmospheric neutrinos require generation-3 experiment

\[ \chi/\nu + N \rightarrow \chi/\nu + N \]
Goal: probe WIMPs down to the atmospheric floor
need to measure atmospheric $\nu$ CEvNS

Scale-up LXe TPC technology

Start after LZ & XENONnT, ~2026

8M€ R&D funding, on roadmaps, collaborations and expressions of interest, whitepaper in prep
Xe: Spin-Dependent Sensitivity

Half of Xe isotopes carry spin!

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Sensitivity [cm²]</th>
<th>WIMP mass [GeV/c²]</th>
</tr>
</thead>
<tbody>
<tr>
<td>LUX (2016)</td>
<td>10⁻³⁶</td>
<td>10¹</td>
</tr>
<tr>
<td>PandaX-II (2018)</td>
<td>10⁻³⁷</td>
<td>10²</td>
</tr>
<tr>
<td>XENON100 (2016)</td>
<td>10⁻³⁸</td>
<td>10³</td>
</tr>
<tr>
<td>XENON1T (1 t×yr, this work)</td>
<td>10⁻³⁹</td>
<td></td>
</tr>
</tbody>
</table>

PICO is better for proton coupling

In general, Xe is great EFT target
Many other interesting channels

Axion-Like Particles:

Sub-GeV WIMPs:

Dark Photons:

Leptophilic models:

χ + Xe/e⁻ → χ + Xe/e⁻
Probe Dark Matter Flux Beyond Planck Mass

Kinematics only depend on reduced mass

Become flux limited only at $m_\chi^{\text{max}} \sim 10^{19}$ GeV

\[ \left( \frac{A}{m^2} \right) \left( \frac{T}{10\text{yr}} \right) \]

→ Generation-3 experiment probes beyond Planck-scale, using dedicated multi-scatter search

Bramante, Broerman, Rafael & Raj 1803.08044; also 1812.09325

Still need to work out exact interpretation of results

Digman, Cappiello, Beacom, Hirata & Peter 1907.10618
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Elastic pp solar neutrino scattering

Also measure $\sin^2 \theta_W$ to a few percent

Cerdeno+ 1604.01025
Solar $^8$B CEvNS ~2023

Here: simulation of 1000 days LZ

electronic recoil background
dark matter nuclear recoils

~36 $^8$B solar neutrino nuclear recoils

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Solar Metallicity with $^8$B CEvNS

Get 90 events/t/year above 1keV$_{nr}$

BOREXINO: 7% measurement using CC & spectral fit:

Decisive measurement using generation-3 experiment
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<100MeV Atmospheric Neutrino CEνNS

\[ \nu_{\mu,e} + N \rightarrow \nu_{\mu,e} + N \]

preliminary, 200t yr, using NEST

need >500 t years:

Atm. \( \nu \) discovery in Xenon \((g_1=0.3)\)

Exposure (tonne yr)

Significance, \( Z(\sigma) \)

68% CI (statistical)

\( \mu=1, \text{Med}[Z] \)

\( \pm 20\% \) (systematic)
Supernova Neutrino CEvNS

flavor-independent: complementary measurement

supernova neutrino CEvNS

\[ \nu_x + N \rightarrow \nu_x + N \]

sensitivity beyond SMC

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Abundance 8.9%: No (expensive) enrichment

\[ ^{136}\text{Xe} \rightarrow ^{136}\text{Ba} + 2e^- \]

Yanina Biondi, this conference

expect update soon

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CNO Neutrinos in 60t Xenon

$\nu_e + e^- \rightarrow \nu_e + e^-$

$^{136}$Xe hurts, i.e. use depleted target

CNO detection significance

Newstead, Strigari & Rafael 1807.07169
[2/0] $\nu$EC$\beta^+$ of $^{124}$Xe in natXe

Abundance 0.1%
Unique signature

XENON1T should be sufficient to observe 2$v$EC$\beta^+$

Relevant to search for 0$v$EC$\beta^+$ as it’s competitive

Brings new information on flavor violation

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Physics with a Generation-3 LXe TPC

Dark Matter:
- *spin-independent WIMPs*
- *spin-dependent WIMPs*
- EFT couplings and inelastic WIMPs
- GeV and MeV WIMPs (“S2-only”)
- **Planck mass dark matter**
- Migdal & Bremsstrahlung searches
- Cosmic Ray Upscattered Dark Matter
- Annual modulation searches
- Magnetic Inelastic WIMPs
- inelastic scattering (\(^{129}\text{Xe}\))
- axial-vector coupling
- Leptophilic models
- Mirror & luminous DM
- Axion-like particles
- SuperWIMPs
- Dark photons

Neutrinos:
- *solar pp neutrinos*
- coherent neutrino-nucleus scattering
- \(^{8}\text{B}\) solar neutrinos
- Galactic supernovae
- neutrino oscillations
- sterile neutrinos
- neutrino magnetic moment
- CNO neutrinos
- \(0\nu\beta\beta\) decay of \(^{136}\text{Xe}\)
- \(2\nu\beta\beta\) decay of \(^{136}\text{Xe}\)
- ECEC on \(^{124}\text{Xe}\)
- \(EC\beta^+\) on \(^{124}\text{Xe}\)

Plus:
- solar axions
- fractionally charged particles