THE LARGE UNDERGROUND XENON EXPERIMENT

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Rencontres de Moriond – Very High Energy Phenomena in the Universe – March, 14 2013
# The LUX Collaboration

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- Brian Tennyson, Graduate Student

16 Institutions, 4 European
Dark Matter

- Direct WIMP detection.
- Present in most SSM.
- Elastic scattering.
  - $\sigma \sim A^2$
- Nuclear recoil
  - Looking in $\sim$5-25 keV$_{nr}$ range.

- Dark Matter Pie Chart
  - Today is 2013/3/14…
LUX Layout

- Two titanium cryostats in a water shield/muon veto.
Dual Phase Xe TPC

• Energy deposition causes prompt scintillation and ionization.

• Light observed by 122 PMTs.

• Primary scintillation signal (S1)
  • Secondary ionization signal (S2)
    • Drift e⁻ to gas gap.

• X,Y
  • Use PMT hit map.

• Z
  • S1-S2 time separation
Why Xenon?

- 130 nucleons
- High density $\rightarrow$ self shielding.
- Transparent to its own scintillation light.
- Allows fiducialization of detecting medium.
  - Great for scaling experiment size.
- Commercial purification systems available.
- Condenses above LN temperatures (-108°C).
Nuclear Recoil Discrimination

Recombination relatively enhanced for NR

>99.5% ER Rejection
50% NR acceptance
Shielding

- **Xenon**
  - 3 g/cm²
  - Software optimized fiducialization.
    - ~100 kg
  - It’s quiet in the middle: $x10^{-6}$ reduction.

**Water Tank Background Reductions**

- Water Tank
  - Gamma reduction: $x10^{-9}$
  - Neutron reduction: $x10^{-3}$
  - Active shield for muon tagging.

**Punchline**: External backgrounds subdominant
## Backgrounds

<table>
<thead>
<tr>
<th>PMT</th>
<th>Activity [mBq/PMT]</th>
<th>$^{238}\text{U}$ ($^{226}\text{Ra}$)</th>
<th>$^{232}\text{Th}$ ($^{228}\text{Ra}$)</th>
<th>$^{40}\text{K}$</th>
<th>$^{60}\text{Co}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>R8778</td>
<td>9.5 ± 0.6</td>
<td>2.7 ± 0.3</td>
<td>66 ± 6</td>
<td>2.6 ± 0.2</td>
<td></td>
</tr>
<tr>
<td>R11410 MOD</td>
<td>&lt;0.4</td>
<td>&lt;0.3</td>
<td>&lt;8.3</td>
<td>2.0 ± 0.2</td>
<td></td>
</tr>
</tbody>
</table>

- Detector component radiopurity database.
  - Ti, Cu, PTFE, PMTs, bolts, etc.

- PMTs
  - High QE (~33%)
  - *Largest BG in LUX*
  - ~1 n/yr/PMT
LUX Deployment at SURF

- Sanford Underground Research Facility
- Homestake mine
- Surface run
  - These results.

- Running at 4850 ft. below surface
  - 1480 km
  - 4300 m.w.e.

4.4 x 10^{-9} \mu/cm^2/sec muon rate
Calibrations

- **External sources**
  - **Source tube**
    - $^{137}$Cs, $^{252}$Cf, AmBe, $^{57}$Co, $^{133}$Ba, $^{22}$Na, $^{60}$Co, $^{228}$Th

- **Internal**
  - **Injection**
    - $^{222}$Rn, $^{83m}$Kr
  - **Activation**
    - $^{129m}$Xe, $^{131m}$Xe

$^{137}$Cs (662 keV $\gamma$) Light Yield

Activated xenon

- 164 keV
- 236 keV (39.6 + 196.6 keV)
LUXSim/NEST

• Much work towards accurate and precise simulation.
  • Geometry
  • Radioactivity
  • Physics

• Noble Element Simulation Technique*
  • Enhancing Geant4-based simulations of liquid and gaseous noble elements.
  • Fast microphysics.
  • Correct cesium energy resolution from first principles.

*2011 JINST 6 P10002; arxiv:1106:1613
Position Reconstruction

- Mercury position reconstruction algorithm
  - ZEPLIN-III
  - arXiv: 1112.1481v1

- Grid Events 
  - Events “shaped” around grid due to E-field.
  - Discern 5 mm grid pitch
  - Grid $\alpha$ events.
  - Good predictor.

- $^{214}$Bi-$^{214}$Po coincidence 
  - $^{214}$Bi $\beta$ followed by $^{214}$Po $\alpha$
  - 7 mm res. with bulk $\alpha$ events.

C. Faham
Established Run Parameters

- 100 days of stable running above ground.
- Proved sub systems functional to intended surface run design parameters.

- Light Collection
  - 8 phe/keVee (center of detector, 662 keV)
  - ≥4 phe/keVee (field-adjusted, scaled to 122 keV)
  - $4\pi$ PTFE “Light Cage”

- Purity/Drift time
  - 35 slpm (300 kg/day)
  - Best electron drift time: $204 \pm 6$ (stat) $\mu$s
  - Longest drift length: 25 cm
Underground Deployment

July 11-12, 2012
Underground Deployment
Underground Deployment
Current Status

- Underground
- Water tank filled
- Online
- Condensed
- Purifying
- Calibrating
- *Preparing for 60 day DM run.*
DM Limits for 300 day run

Parameter Assumptions

- Realistic run parameters.
- 30,000 kg-days
- 15% light collection.
- 11 m photon absorption length.
- Modest purity improvement.
- 50% NR acceptance.
- $4.3 \text{ keV}_{\text{nr}}$ – $25 \text{ keV}_{\text{nr}}$
Summary

370 kg Dual Phase Liquid Xe TPC
- 3D imaging
- Effective Xe purification – 300 kg/day at <10 ppt Krypton
- Conservative Analysis Assumptions:
  >99.5% ER background rejection with 50% NR acceptance, $E_{th} > 4.3$ keV$_{nr}$

Backgrounds
- External: large water shield with active muon veto
  - very effective for rock $\gamma$ and n and muon-related neutrons
  - very low $\gamma$ backgrounds from ultra-pure water
- Internal: reduced by material selection and fiducialization
  - demonstrated BG $\gamma + \beta < 5 \times 10^{-4}$/keVee/kg/day, dominated by PMTs
  - neutrons ($\alpha$,n) and fission are subdominant

Physics Reach
- DM $\sigma \sim 2 \times 10^{-45}$ cm$^2$ in 2 weeks live time.
- Expect $\sigma < 3 \times 10^{-46}$ cm$^2$ with 300 day run.

Status
- Underground, online, condensed, purifying, calibrating.
- Preparing for 60 day DM run.
BACKUP SLIDES
Nuclear Recoil Discrimination

Recombination relatively enhanced for NR

Electron Recoil

Nuclear Recoil

>99% ER Rejection
50% NR acceptance

Energy Deposition

Ionization Signal

Recombination

Scintillation Signal

Ionization

Xe$^+$ + e$^-$

+Xe

Xe$_2^+$

+ e$^-$

Xe$^*$

Xe$^{**}$ + Xe

2Xe

2Xe

Xe$_2^*$

Cs (gamma source)

AmBe (neutron source)

175 nm

Triplet 27 ns

Singlet 3 ns

175 nm
Conservative calculations for these processes indicate that <0.01 events are expected as a consequence of this radon injection in the WIMP region of interest in a 300-day run.

$^{214}$Bi lone beta (18% BR) $\rightarrow$ Po-214 7.7 MeV alpha

$Q = 3.2 \text{ MeV}$

Half-life is 164 $\mu$s

Range of beta (mean $E$, 642 keV) in LXe is $\sim$1.5 mm.

Alpha range in LXe is $\sim$50 $\mu$m.

This coincidence event is highly localized in $x,y,z$
LUX DAQ/Data Flow

Data Acquisition:
- Custom built analog amplifier chain - Maximize signal sensitivity
- Sophisticated trigger system based on DDC-8 - Maximize low energy threshold and trigger capabilities.
- Pulse Only Digitization (POD) eliminates baseline from the data stream - Improve maximum acquisition rate to 1.3kHz
Thermosyphon

- Passive cooling system using LN₂ bath
- High thermal conductivity (~55 kW/K/m)
- Temperature controlled via N₂ pressure and PID heater
The first 76 days of LUX

Comparing nominally equivalent kg-days for 100 kg LUX fiducial versus 34 kg XENON fiducial but LUX has much greater sensitivity/kg-day because of cleaner signal/fewer BG events.

LUX (Monte Carlo)

~20 ER events
~1 WIMP / 8 days
76 days x 100 kg fiducial

XENON100

~180 ER events
225 days x 34 kg fiducial

arXiv:1104.2549

LUX signal and background expectation for 7,600 kg-days net exposure. WIMP events assume m = 100 GeV, \( \sigma = 3 \times 10^{-45} \) cm². Assumes 100 kg fiducial. Given very low ER rate, can significantly increase fiducial in early running.

XENON100 7,600 kg-days result for comparison. Note higher ER rate - ~180 events primarily due to Compton scattering of external gamma background.