LUX dark matter sensitivity

LUX: 30,000 kg-days

CDMS

XENON100

http://dmtools.brown.edu/
Gaitskell,Mandic,Filippini

Cross-section [cm$^2$] (normalised to nucleon)

WIMP Mass [GeV/c$^2$]
Start with a large target mass

350 kg of liquid xenon
LUX simulation of self-shielding

PMT array

LUX300v4_R8778H - Top PMTs, Bot PMTs
(U 18.00, Th 17.00, K 30.00, Co 8.00 mBq/PMT)
(All Events) (5-25 keVee) (RFR=5 cm)

PMT array

log_{10} DRU

Depth [cm]

Radius [cm]

DRU = cts/keVee/kg/clay
Simulation of self-shielding in liquid xenon

Fiducial volume cut rejects most backgrounds
Kinematics provides strong rejection

~MeV $\gamma$

DRU = cts/keVee/kg/clay
Kinematics provides strong rejection

\[ \sim \text{keV deposition} \]

\[ \sim \text{MeV } \gamma \]
Kinematics provides strong rejection

\[ \sim \text{MeV} \gamma \]

\[ \sim \text{keV deposition} \]

forward scattering
Kinematics provides strong rejection

~ MeV γ

must cross full volume without interacting again

~ keV deposition

forward scattering
Control backgrounds with a careful screening program

<table>
<thead>
<tr>
<th></th>
<th>Screening Result</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>U238</td>
</tr>
<tr>
<td><strong>PMTs</strong></td>
<td>mBq/PMT</td>
</tr>
<tr>
<td><strong>Ti</strong></td>
<td>mBq/kg</td>
</tr>
<tr>
<td><strong>Cu</strong></td>
<td>mBq/kg</td>
</tr>
<tr>
<td><strong>PTFE</strong></td>
<td>mBq/kg</td>
</tr>
<tr>
<td><strong>HDPE</strong></td>
<td>mBq/kg</td>
</tr>
<tr>
<td><strong>Stainless steel</strong></td>
<td>mBq/kg</td>
</tr>
</tbody>
</table>

**Type 304 stainless steel used in electric field grids

*Cosmogenic equilibrium at 1 mile above SL; decays below ground
Control backgrounds with a careful screening program

<table>
<thead>
<tr>
<th></th>
<th>Unit</th>
<th>Screening Result</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>U238</td>
</tr>
<tr>
<td>PMTs</td>
<td>mBq/PMT</td>
<td>9.5±0.6</td>
</tr>
<tr>
<td>Ti</td>
<td>mBq/kg</td>
<td>&lt;0.18</td>
</tr>
<tr>
<td>Cu</td>
<td>mBq/kg</td>
<td></td>
</tr>
<tr>
<td>PTFE</td>
<td>mBq/kg</td>
<td>&lt;3</td>
</tr>
<tr>
<td>HDPE</td>
<td>mBq/kg</td>
<td>&lt;0.5</td>
</tr>
<tr>
<td>Stainless steel**</td>
<td>mBq/kg</td>
<td></td>
</tr>
</tbody>
</table>

**Type 304 stainless steel used in electric field grids

*Cosmogenic equilibrium at 1 mile above SL; decays below ground

~1/3 of LUX design goals
Control backgrounds with a careful screening program

<table>
<thead>
<tr>
<th>Unit</th>
<th>Screening Result</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>U238</td>
</tr>
<tr>
<td>PMTs</td>
<td>mBq/PMT</td>
</tr>
<tr>
<td>Ti</td>
<td>mBq/kg</td>
</tr>
<tr>
<td>Cu</td>
<td>mBq/kg</td>
</tr>
<tr>
<td>PTFE</td>
<td>mBq/kg</td>
</tr>
<tr>
<td>HDPE</td>
<td>mBq/kg</td>
</tr>
<tr>
<td>Stainless steel**</td>
<td>mBq/kg</td>
</tr>
</tbody>
</table>

**Type 304 stainless steel used in electric field grids

*Cosmogenic equilibrium at 1 mile above SL; decays below ground

Clean titanium cryostat
Kr Removal

• $^{85}$Kr - beta decay
  – Separate commercial Xe/Kr (ppb-ppm g/g)
  – Goals (LUX): 10 ppt
  – Chromatographic system developed for XENON10: < 2 ppt demonstrated at 2 kg/day production

• LUX system
  – 60 kg charcoal column, ~20x pumping speed
  – Vacuum Xe recovery ~ 8kg/day (2 month processing)
Detection of krypton at the part-per-trillion level

open leak valve

1.5 ppt Kr

Partial Pressure (Torr)

Time (seconds)

D = 3/8”

D = 1.5”

Leak Valve

Cold Trap

Low Conductance Plumbing

Xenon System

Turbo Pump

RGA

arXiv:1103.2714v3
Nuclear recoil discrimination

Electron-recoil discrimination factor of ~180
LUX Detector - Overview

- Titanium Vessels
- Dodecagonal field cage + PTFE reflector panels
- PMT holding copper plates
- LN bath column
- Radiation shield
- Anode grid
- Dodecagonal field cage + PTFE reflector panels
- Cathode grid
- Counterweight

Dimensions:
- 59 cm
- 49 cm
LUX PMTs

- 122 x 2” diameter R8778 Hamamatsu
- U/Th 10/2 mBq/PMT
- Demonstrated QE: average=33%, max 39% at 175 nm
- U/Th content ~ 9/3 mBq/PMT
Thermosyphon cooling system
Xenon Purity measured in a 60 kg test run

- 0.2 tonnes circulation per day
- ~9 hr time constant for purification
- > 2 m electron drift length achieved (> 1000 us) with 60kg target
- Errors dominated by use of 5 cm test cell drift within large cryostat
Liquid xenon heat exchanger: 96% Efficient

Demonstrated - 18 W required to circulate 0.4 tonnes of Xe a day
Evaporate Liquid > Gas / Purification -> Re-condense Liquid

![Demonstrated Heat Exchanger Performance](image)

- Required cooling without heat exchanger
- Measured power with heat exchanger

>96% efficiency
External calibration sources

133Ba, 137Cs, 22Na, 208Tl, 241Am/Be
Internal calibration sources: $^{83}$Kr and Tritium

$^{83}$mKr conversion electrons
($T_{1/2} = 1.86$ hours)

- Chemical form is $\text{CH}_3\text{T}$
- Remove with zirconium getter
- Dozens of tritium injection & removal experiments performed
- One-pass removal efficiency > 99%

Tritium beta decay ($T_{1/2} = 12.6$ yrs)

- 9.4 keV
- 32.1 keV

L. Kastens et al., Phys. Rev. C80: 045809, 2009,
Sanford Lab – Lead, South Dakota, USA
Sanford Lab – Lead, South Dakota, USA
Sanford Lab Surface Facility - Occupied by LUX since fall 2009
Test deployment of LUX in the Surface Facility Water Tank – April 2011
May 2011: first cool-down of LUX titanium cryostat

Flexible Temperature Control
Davis Cavern @ Sanford Lab, September 2009
Davis Cavern @ Sanford Lab, March 2011
The LUX Detector

~ 6m diameter Water Cerenkov Shield.

Dual phase detector - aspect ratio ~1.2

350 kg Dual Phase Liquid Xenon Time Projection Chamber, fully funded by NSF and DOE
2 kV/cm drift field in liquid, 5 kV/cm for extraction, and 10 kV/cm in gas phase.
122 PMTs (Hamamatsu R8778) in two arrays
3D imaging via TPC eliminates surface events, defines 100 kg fiducial mass
LUX: The First 40 Days

LUX signal and background expectation for 4,000 kg-days net exposure. WIMP events assume $m = 100$ GeV, $\sigma = 1 \times 10^{-44}$ cm$^2$.

- **Red Points:** WIMP events after only 40 days (equivalent exposure to all of XENON100 run) assuming a WIMP model for mass 100 GeV at current best 90% CL Exclusion Limit.

- **Blue Points:** Total # of single scatter electron recoil events in LUX (before any other cuts) after 40 days of running. Expect only 11 events in 100 kg fiducial x 40 days for a net 4,000 kg-days exposure.

- **LUX - Strong Emphasis on WIMP Discovery / Plan to run LUX for 300 days**

arXiv:1104.2549

XENON100 4,000 kg-days result for comparison.

Note higher ER rate - ~800 events in 100 days x 40 kg fiducial ~60% due to 85Kr with remaining 40% due to Compton scattering of external gamma background.
LUX Collaboration

Yale, CWRU, UC Santa Barbara, Brown, TAMU, UC Davis, Harvard, LLNL, LIPP Coimbra, Rochester, LBNL, Maryland, SDSMT, USD