Large Underground Xenon Experiment

Mani Tripathi, TeV Particle Astrophysics, SLAC, July 13, 2009.
LUX Collaboration

12 Member Institutions (incl. 2 National Labs)

~20 Senior Personnel, ~6 Engineers, ~7 Postdocs, ~15 Students.

Steadily growing. (Not shown: Harvard University, Moscow Engineering Physics Inst.)
The LUX detector

~ 6m diameter Water Cerenkov Shield.

Dual phase detector - aspect ratio ~1.2
Two Signal Technique

Time

Primary (S1)

Secondary (S2)

0–350 µs depending on depth

~40 ns width

~1 µs width

Liquid phase

Gas phase

PMT Array

Anode Grids

Cathode

Interaction

E_{AG} > E_{GG} > E_{GC}

E_{AG}

E_{GG}

E_{GC}
LUX Approach to DM search

Maximise WIMP rate  --  choice of Xe as target  
    large total mass of target \( \sim 100 \text{ kg fiducial} \)

Minimize internal background sources  --  new sensor developments  
    new materials -- titanium cryostat  
    purification techniques

Absorb/Tag external backgrounds  --  active water cherenkov shield  
    active liquid scintillator bottle?

Maintain stable operations over long periods  --  extensive monitoring  
    frequent calibrations

Well understood detector response  --  in-situ Kr-83m calibration?
Why Xenon?

Recoil Spectra

Higher Sensitivity in the range 2keV < E < 20 keV.

Mani Tripathi, July 2009
Why Xenon? (contd.)

- Very powerful self-shielding in Xe.
- Effective when size > attenuation length
- Mass > 300 kg.
Backgrounds (Gamma)

- **Internal** strong self-shielding against PMT activity (main source of background events). Double Compton scatters are rejected.

- **External** large water shield with muon veto. Very effective for cavern γ
Backgrounds (Neutrons)

- **Internal**
  Neutrons ($\alpha$,n) & fission $\ll \gamma + \beta$.
  $\sim$65% double scatter.
  (PMTs are the main source)

- **External** large water shield with muon veto.
  - Very effective for cavern $\pi$, and HE neutrons from muons
  - Possible upgrade of adding Gd to the water.
Water Shield & Veto

- Veto on incoming muons via Cherenkov light signal.

- Tag thermalized neutrons generated within the detector.

- Gd (0.2%) in water gives a capture efficiency of > 90% for thermal neutrons, followed by an 8 MeV gamma cascade.
Water Shield (Contd.)

Cost-effective and scalable. Very low gamma backgrounds with readily achievable $<10^{-11}$ g/g purity for water.

Effective against fast neutrons.

72% of ROI neutrons capture in the Gd-H$_2$O shield
19% of ROI neutrons capture in the active Xe target
99% reduction!
LUX Parameters

- 350 kg Dual Phase liquid Xe TPC
- 2 KV/cm field in liquid, 5 KV/cm for extraction and 10 KV/cm field in gas phase
- 60 PMTs (Hamamatsu R8778) each in top and bottom arrays
- 3D-imaging TPC eliminates surface activity, defines fiducial
- ~100 kg achievable in the fiducial volume
γ/neutron Discrimination

Differences in recombination efficiency is exploited to discriminate between electron and nuclear recoils.

Figure of merit derived from plots of:
Log (charge escaping recombination/total primary light produced) … Next slide.
These measurements were made above ground, but agree well with Xenon10 experience.
Simulated Signal in LUX

Electron recoil background $\sim 2.6 \times 10^{-4}$ dru (based on screening of materials)

300 days acquisition

100 kg fiducial mass

Using same ER and NR bands as XENON10

$L_{\text{eff}} = 0.19$
Power of self-shielding

XENON10 Data -- 5.4 kg, 59 days

LUX Simulation -- 100 kg, 100 days

Red points are for a simulated signal of 100 GeV WIMP and a cross section $5 \times 10^{-45}$ cm$^2$. Open points are for 25 kg fiducial.
LUX Goals

• 99.3 – 99.9% Electron Recoil background rejection for 50% Neutron Recoil acceptance, in the range 5 keVr < E < 25 keV

• $\gamma + \beta$ rate < $8 \times 10^{-4}$ events/kg/keVee/day with 99.4% rejection (conservative)

• 10 month run w/ 50% NR acceptance (net 15,000 kg-days)

• DM reach $\sigma \sim 4 \times 10^{-46}$ cm$^2$
  (Equivalent to an event rate of $\sim 0.4/100$kg/month in 100kg fiducial)

(SuperCDMS Goal @ SNOLab: Gross Ge Mass 25 kg (x 50% fid) for 1000 days running)
### GOAL FOR WIMP SIGNAL SENSITIVITY AND REFERENCE LEVELS (UPPER LIMITS) FOR BACKGROUNDS (5–25 keVr, 1.3–8 keVee)

<table>
<thead>
<tr>
<th>Goal</th>
<th>NR Avg. Diff. Rate evts/keVr/kg/day</th>
<th>ER Avg. Diff. Rate evts/keVee/kg/day</th>
<th>Total Rate for a FV exposure of 30,000 kg-days (net live)</th>
</tr>
</thead>
<tbody>
<tr>
<td>WIMP (m = 100 GeV, σ = 7x10^{-46} cm²)</td>
<td>1.4x10^{-5}</td>
<td></td>
<td>8.6</td>
</tr>
<tr>
<td>WIMP (after NR acceptance of 45%)</td>
<td>6.5x10^{-6}</td>
<td></td>
<td>3.9</td>
</tr>
<tr>
<td>ER Flat Spectrum (before ER rej.)</td>
<td></td>
<td>8.3x10^{-4}</td>
<td>180</td>
</tr>
<tr>
<td>ER Flat Spectrum (after ER rej. 99.4%)</td>
<td></td>
<td>4.8x10^{-6}</td>
<td>1.0</td>
</tr>
<tr>
<td>NR Neutron Spectrum</td>
<td>3.7x10^{-6}</td>
<td></td>
<td>2.2</td>
</tr>
<tr>
<td>NR Neutron Spectrum (after NR acceptance of 45%)</td>
<td>1.7x10^{-6}</td>
<td></td>
<td>1.0</td>
</tr>
</tbody>
</table>

*Conservative*
Status

- NSF/DoE funding received in 2008.
- DUSEL site selection => LUX can deploy as part of Homestake’s Early Implementation Program => Sanford Lab.
- Detector components have been all designed and are in various stages of production.
- A surface facility at Sanford Lab for assembling LUX will become available ~Oct 2009.
- Deployment underground anticipated ~Feb 2010.
- Full scale prototype cryostat with 60 kg Xe under test
- Final, Ti cryostat, internal parts under fabrication
- Integration at Sanford lab surface, Sept 09.
Cryostat Assembly at Case
Titanium

Grade CP1 generally good. CP2 had high counts in 2 samples.

<table>
<thead>
<tr>
<th>Sample Type</th>
<th>Grade</th>
<th>Dim.</th>
<th># of piece</th>
<th>Total weight</th>
<th>Counted At</th>
<th>U</th>
<th>Th</th>
<th>K-40</th>
<th>Sc-46</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>ppb</td>
<td>mBq/kg</td>
<td>ppb</td>
<td>mBq/kg</td>
</tr>
<tr>
<td>Ti1</td>
<td>3/8&quot; plate</td>
<td>CP1</td>
<td>2.5&quot; x 6&quot;</td>
<td>4</td>
<td>1.87 kg</td>
<td>Oroville</td>
<td>&lt;0.2</td>
<td>&lt; 2.5</td>
<td>&lt;0.4</td>
</tr>
<tr>
<td>Ti2</td>
<td>3/16&quot; plate</td>
<td>CP2</td>
<td>4&quot; x 6&quot;</td>
<td>20</td>
<td>7.55 kg</td>
<td>SOLO</td>
<td>10.4</td>
<td>130</td>
<td>17.5</td>
</tr>
<tr>
<td>Ti3</td>
<td>0.358&quot; plate</td>
<td>CP2</td>
<td>~ 1.3&quot; x 6&quot;</td>
<td>8</td>
<td>1.55 kg</td>
<td>SOLO</td>
<td>85</td>
<td>35</td>
<td></td>
</tr>
<tr>
<td>Ti6</td>
<td>3/16&quot; plate</td>
<td>CP1</td>
<td>4&quot; x 6&quot;</td>
<td>20</td>
<td>7.98 kg</td>
<td>Oroville</td>
<td>&lt;0.03</td>
<td>&lt;0.4</td>
<td>&lt;0.2</td>
</tr>
<tr>
<td>Ti7</td>
<td>1&quot; plate</td>
<td>CP1</td>
<td>2&quot; x 6&quot;</td>
<td>8</td>
<td>7.201 kg</td>
<td>Oroville</td>
<td>&lt;0.02</td>
<td>&lt;0.05</td>
<td>&lt;0.04</td>
</tr>
<tr>
<td>Ti8</td>
<td>0.063&quot; sheet</td>
<td>CP1</td>
<td>4&quot; x 6&quot;</td>
<td>40</td>
<td>4.399 kg</td>
<td>Oroville</td>
<td>&lt;0.1</td>
<td>&lt;0.4</td>
<td>&lt;0.3</td>
</tr>
</tbody>
</table>

Sample activated in air transport.
Not a problem for construction materials. 86 days half-life.
Internal Assembly
Real Time Pulse Finding in Trigger

1 - FPGA (XC3SD3400A)
2 - FX2-LP (USB 2.0)
3 - Analog Input Channels
4 - ADCs
5 - Analog passive filters
6 - Analog active filters
7 - NIM-IN
8 - NIM-OUT
9 - NIM-Timestamping (CLK,RST)
10 - External Clock
11 - Spy Channel
12 - HDMI
13 - USB Connector
14 - JTAG Connector
15 - VME Connector (POWER +5V)
16 - External Power (+5V)
Circulation and Purification System

Gas-phase purification using SAES getter. Demonstrated flow rate of 50 slpm.
Internal Backgrounds

- $^{85}$Kr - beta decay
  - Goal for 20 tons scale: $10^{-14}$ Kr/Xe.
  - Chromatographic system: $<\sim 2$ ppt to date

- Rn: require $\sim < mBq$ total.
- Other gasses: $^3$H, $^{14}$C. Should be manageable.

System at Case has achieved 2 kg/day.
Calibration Using $^{83m}$Kr


Two lines at 32.1 keV and 9.4 keV improve calibration at low energies.

Source introduced
Sanford Lab: Surface Facility

Clean room

Laboratory

Main Entrance/Loading Dock

Office/Meeting Room

Mechanical Room

LUX detector

Water Tank (3 m diameter)
Davis Cavern
Plans for Davis Cavern
LZ3/LZ20 Collaboration

Merger with ZEPLIN-III collaboration. Plus, some new US groups joining in. New members:

A. Murphy, C. Ghag, E. Barnes, A. Hollingsworth, P. Scovell
Edinburgh University, United Kingdom

Imperial College London, United Kingdom

G. Kalmus, P. Majewski, B. Edwards
STFC Rutherford Appleton Lab, United Kingdom

I. Lopes, V. Chepel, J. Pinto da Cunha, F. Neves, A. Lindote, V. Solovov, C. Silva
LIP - Coimbra, Portugal

D. Akimov, V. Belov, A. Burenkov, A. Kobyakin, A. Kolvalenko, V. Stekanhov
ITEP - Moscow, Russia

J. Siegrist, Bob Jacobsen, Lawrence Berkeley National Laboratory

H. Nelson, University of California, Santa Barbara

Bob McKeown, CalTech [LZ3 only]
Future Program: Scaling Up

- **Purity for charge and light**
  - Required purity demonstrated.
  - LUX attacking engineering to achieve high reliability.

- **Light collection**
  - Current understanding -> 20 ton scale ok.
  - Better measurements

- **Backgrounds**
  - Scaling current technology, dominated by PMTs: LZ20 \( \sim 60\% \) fiducial
    - PMTs: x10 improvement likely. (Currently demonstrated for XMASS).
  - Active shield: 99\% neutron tag, 90-99\% gamma tag
  - Goal: increase fiducial mass to \( \sim 80\% \) at 3 ton scale, \( \sim 90\% \) at 20 ton scale.
  - Purity requirements for Xe (primarily Rn, Kr) near state of art: SNO Borexino

- **Mechanics, safety:** LUX is dry run for 20 ton scale.

- **Xe procurement.**
  - World production \( \sim 45 \) tons/year, at \( \leq \$1\)M/ton.
## Estimate of Target Sensitivities

<table>
<thead>
<tr>
<th>Target</th>
<th>Energy Threshold * / assumed signal acceptance</th>
<th>Fiducial Mass required for 25 WIMP events in 100 live-days ††</th>
<th>Total number of ER events in Fiducial Mass for 100 live-days **</th>
<th>Max acceptable leakage in ER Rejection</th>
</tr>
</thead>
<tbody>
<tr>
<td>Xe TPC</td>
<td>2 keVr / 80%</td>
<td>100 kg</td>
<td>17</td>
<td>0.05</td>
</tr>
<tr>
<td>Ar (†)</td>
<td>40 keVr / 90%</td>
<td>1.5 tonnes</td>
<td>2 x 10^8</td>
<td>5 x 10^-9</td>
</tr>
<tr>
<td>Ar (†)</td>
<td>80 keVr / 90%</td>
<td>6.5 tonnes</td>
<td>8 x 10^8</td>
<td>1 x 10^-10</td>
</tr>
<tr>
<td>Ge (CDMS)</td>
<td>10 keVr / 50%</td>
<td>350 kg</td>
<td>2 x 10^5</td>
<td>5 x 10^-6</td>
</tr>
</tbody>
</table>

(Assume 100 GeV, 4E-45 cm^2)
Akerib, Gaitskell et al (assume natural Ar)
Long Term (contd.)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>LUX</td>
<td>Construction</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Operations</td>
<td>30 tonne-days</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LZ3</td>
<td>Construction</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Operations</td>
<td>300 tonne-days</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LZ20 Project</td>
<td>Above Ground Pre-Construction</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Below Ground Construction</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Operations</td>
<td>13,500 tonne-days</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Extended running</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

S4 Prop.

Preliminary Design Report Phase

Final Design Report Phase

LZ20 Development
New 3" PMTs -- Hamamatsu R11065
With x2 collection area of R8778.

Background target for U/Th of 1/1 mBq.
**Long Term Program**

- **LUX** (construction 2008-2009, data in 2010)
- **LZ3** (construction 2010-2011, data in 2012-2013)
Summary

The LUX collaboration is firmly in place with a sound management structure and requisite funding.

Detector design is complete.

Cryostat, components, sub-systems, electronics etc are being produced.

Sanford Lab is projecting surface facility availability in Oct-Nov 2009 and Underground facility in Feb-mar 2009.

LUX and ZEPLIN groups are together proposing a future program at DUSEL.