The LUX Experiment

Karen Gibson on behalf of the LUX Collaboration

Identification of Dark Matter

July 26, 2012
Large Underground Xenon experiment

LUX is a two-phase xenon time-projection chamber (TPC) designed to search for WIMPs scattering off of Xe nuclei.

Begin data-taking at 4850’ level of Homestake mine in Lead, SD by end of 2012.

Large, very quiet fiducial region

Estimate ~1 electron recoil event every 4 days in 100 kg in energy range of interest: 5-25 keVr.
LUX Collaboration consists of 16 member institutions, 12 from the US and 4 from Europe

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LUX - A Xenon Time Projection Chamber
Liquid Xe TPC detectors

- Look for scintillation signals
- Need good scintillator
  - Xe has excellent ph. absorption → full energy deposit at WIMP energies (5-25 keV)
- Need few/removable radioactive backgrounds
  - $^{85}$Kr - readily removable to ppt level
- Need good light collection
- Get best background separation via two-phase detector
Advantages of noble liquid detectors

- Current/future DM searches need \( \geq O(100 \text{ kg}) \) target mass
- Cryogenic problem is generally much simpler for noble liquids \( O(100 \text{ K}) \) than for crystal or semiconductor detectors \( O(10 \text{ mK}) \)
- \( T_{LXe} \approx 170 \text{ K} \) at 2 atm
- Self-shielding increases active volume as detector size increases

Scalability!!!
Use charge vs light to identify NR

\[ \text{ER} \rightarrow 122 \text{ keV } \gamma \text{ from } ^{57}\text{Co} \]

Ratio of electrons to photons produced in interaction distinguishes between electronic and nuclear recoil

The LUX Detector

See Carmen Carmona’s talk for details
Cryostat

- Top thermosyphon
- Feedthroughs
- Titanium cryostats
- Anode and electron extraction grids
  - Expect ~ 1 kV/cm in liquid
- 300 kg active liquid xenon
- Cathode grid
- Photomultiplier tubes
  - 122 Hamamatsu R8778, 12 stage 2.2” PMTs
- Xenon recirculation and heat exchanger
  - Constantly circulate and purify Xe in gas phase
- PTFE reflector panels
  - Expect reflectivity in liquid > 95%
- Bottom thermosyphon
Detector “internals”

Aim to achieve ~1 kV/cm between cathode and gate grids

Liquid level ≈5 mm above gate grid
PMTs

Hamamatsu R8778, 12 stage 2.2” PMTs

Developed for XMASS experiment
⇒ sensitive to 175 nm scintillation
⇒ can withstand pressures up to 5 atm
⇒ can operate at 170 K
⇒ quantum efficiency ~33%

Expect 1.2 n/yr/PMT
⇒ 150 n/yr total

Dominant expected background in WIMP search!
Water shield

300 T de-ionized water shield, 20’ high, 25’ diameter SS tank
- reduce cavern & cosmogenic backgrounds

Instrumented with 20 Hamamatsu R7081 10” diameter PMTs for veto of coincident NR candidates
Sanford Underground Research Facility
Sanford Underground Research Facility
Deadwood, SD is down the street...
Former Homestake gold mine is now home of low background science

4.3 km.w.e. shielding at 4850’ level
Davis campus at 4850’ level
Surface commissioning

Spent autumn 2011 through winter 2012 commissioning LUX detector systems above ground while Davis campus was under preparation.
First things first - stable operation!

Pressure stability ~0.4% over 5 days

Stable circulation of 35 slpm => 300 kg/day with < 5 W heat load
We see signals!

In fact, we see a lot of signals!
Obtain fair xenon purity

Obtain $204 \pm 6 \text{ (stat)}$ $\mu$s despite non-optimal circulation path $\Rightarrow 25 \text{ cm electron drift length}$

Aim for 1 m electron drift length for DM search
Obtain fair xenon purity

Obtain $204 \pm 6$ (stat) $\mu$s despite non-optimal circulation path $\Rightarrow 25$ cm electron drift length

Aim for 1 m electron drift length for DM search
Studies of $^{222}$Rn $\alpha$ daughters

We made a diagnostic $^{222}$Rn injection to image the circulation path after discovering the compromise.

Estimate extremely pessimistic contamination of 11 n/yr from $^{222}$Rn injection, 7.5% of PMTs

See Carlos Faham’s talk for details.

$S_{1\text{ weighted}} = S_{1\text{ top}} \cdot \cos(0.33) + S_{1\text{ bottom}} \cdot \sin(0.33)$
Studies of $^{222}\text{Rn} \alpha$ daughters

We made a diagnostic $^{222}\text{Rn}$ injection to image the circulation path after discovering the compromise

![Graph showing alpha time evolution in LUX 17.1 min]

S$_{1\text{weighted}} = S_{1\text{top}} \cdot \cos(0.33) + S_{1\text{bottom}} \cdot \sin(0.33)$

Estimate extremely pessimistic contamination of 11 n/yr from $^{222}\text{Rn}$ injection, 7.5% of PMTs

See Carlos Faham’s talk for details
We find excellent light collection

Obtain 8 phe/keV from 662 keV $\gamma$ ($^{137}$Cs source) $\Rightarrow$ scaling to 122 keV at 500 V/cm gives 6 phe/keV

See Matthew Szydagis’s talk for details
LUX has developed a realistic, Geant4-based simulation of detector geometry, which utilizes a data-motivated scintillation model.


Simulation provides accurate estimates of $S_1$ and $S_2$ signals, given tuning of light collection parameters on $S_1$ calibration signals.

Realistic LUX simulation
Comprehensive study of light collection using simulation

Simulation estimates PTFE reflectivity > 95% and photoabsorption length > 5 m from study of $^{137}$Cs, activated Xe, and $\alpha$ daughters from $^{222}$Rn decay chain

See Matthew Szydagis’s talk for details
x-y position reconstruction

Position reco obtained using ZEPLIN III Mercury algo (V. Solovov et al., arXiv:1112.1481v1)

See Carlos Faham’s talk for details
Estimate of x-y position resolution

Can identify $^{214}\text{Bi}$-$^{214}\text{Po}$ coincident events and use it to probe the statistical component of the position resolution.

We estimate ~7mm stat. resolution in x or y for $\alpha$’s in the detector bulk.

See Carlos Faham’s talk for details.
Going underground...
CMS detector lowered 100 m in sixteen pieces, ranging from 300 T to 1900 T
We have observed a new boson with a mass of
$125.3 \pm 0.4 \ (\text{stat}) \pm 0.5 \ (\text{syst})$
at significance level of 5 $\sigma$
LUX detector was moved underground July 11-12, 2012
LUX detector was moved underground July 11-12, 2012

LUX detector (3 T) transported 1.9 km, 420 m of which were linear translation!
73% DARK ENERGY
23% DARK MATTER
3.6% INTERGALACTIC GAS
0.4% STARS, ETC.
Projected LUX sensitivity

Conservative 15% effective light collection
Optimistic 20% effective light collection

30,000 kg-days, 50% (60%) nuclear recoil acceptance window for log(S2/S1) and 1 kV/cm field

WIMP search window of 3 phe $\Rightarrow$ 4.3 keVnr
(3.4 keVnr) to ~25 keVnr

See Matthew Szydagis’s talk for details
Beyond LUX, LUX+ZEPLIN=LZ

Designed to use same water tank as LUX

7 T fiducial Xe, 8.6 T total, scintillation signals read out with ≈500 Hamamatsu R11410 3” PMTs

Two-step veto uses water shield + liquid scintillator in acrylic vessel, as well as instrumented Xe outside active region

See Tom Shutt and Dave Malling’s talks for details
We look forward to interesting results from the LUX program in the next year!

Liquid xenon detectors are very powerful tools in the direct search for dark matter!

Hopefully we will be able to present something exciting at the next IDM!!!
Back-up
Water shield background reduction
Translation between \((T-B)/(T+B)\) and z-position in active region

![Graph showing the relationship between z-position and \((T-B)/(T+B)\)](image_url)

LUXSim