Large Underground Xenon
Dark Matter Search
Matthew Szydagis, University of California, Davis,
on behalf of the LUX collaboration
7th International Workshop on the Dark Side of the Universe, KITPC, September 26, 2011
**The LUX Collaboration**

**Brown**
- Richard Gaitskell: PI, Professor
- Simon Fiorucci: Research Associate
- Monica Pangilinan: Postdoc
- Jeremy Chapman: Graduate Student
- Carlos Hernandez Faham: Graduate Student
- David Malling: Graduate Student
- James Verbus: Graduate Student

**Case Western**
- Thomas Shutt: PI, Professor
- Dan Akerib: PI, Professor
- Mike Dragowsky: Research Associate Professor
- Carmen Carmona: Postdoc
- Ken Clark: Postdoc
- Tom Coffey: Postdoc
- Karen Gibson: Postdoc
- Adam Bradley: Graduate Student
- Patrick Phelps: Graduate Student
- Chang Lee: Graduate Student
- Kati Pech: Graduate Student

**Harvard**
- Masahiro Morii: PI, Professor
- Michal Wasenko: Postdoc
- John Oliver: Electronics Engineer

**Lawrence Berkeley + UC Berkeley**
- Bob Jacobsen: Professor
- Jim Siegrist: Professor
- Bill Edwards: Engineer
- Joseph Rosson: Engineer
- Mia Ihm: Graduate Student

**Lawrence Livermore**
- Adam Bernstein: PI, Leader of Adv. Detectors Group
- Dennis Carr: Mechanical Technician
- Kareem Kazkaz: Staff Physicist
- Peter Sorensen: Postdoc

**University of Maryland**
- Carter Hall: PI, Professor
- Douglas Leonard: Postdoc

**UC Santa Barbara**
- Harry Nelson: PI, Professor
- Dean White: Engineer
- Susanne Kyre: Engineer

**LIP Coimbra**
- Isabel Lopes: PI, Professor
- Jose Pinto da Cunha: Assistant Professor
- Vladimir Solovov: Senior Researcher
- Luiz de Viveiros: Postdoc
- Alexander Lindote: Postdoc
- Francisco Neves: Postdoc
- Claudio Silva: Postdoc

**SD School of Mines**
- Xinhua Bai: PI, Professor, Physics Group Leader
- Mark Hanardt: Graduate Student

**Texas A&M**
- James White: PI, Professor
- Robert Webb: Professor
- Rachel Mannino: Graduate Student
- Tyana Stiegler: Graduate Student
- Clement Sofka: Graduate Student

**UC Davis**
- Mani Tripathi: PI, Professor
- Robert Svoboda: Professor
- Richard Lander: Professor
- Britt Holbrook: Senior Engineer
- John Thomson: Senior Machinist
- Matthew Szydagis: Postdoc
- Jeremy Mock: Graduate Student
- Melinda Sweany: Graduate Student
- Nick Walsh: Graduate Student
- Michael Woods: Graduate Student
- Sergey Uvarov: Graduate Student

**University of Rochester**
- Frank Wolfs: PI, Professor
- Wojtek Skutski: Senior Scientist
- Eryk Druszkiewicz: Graduate Student
- Mongkol Moongweluwan: Graduate Student

**U. South Dakota**
- Dongming Mei: PI, Professor
- Wengchang Xiang: Postdoc
- Chao Zhang: Postdoc
- Oleg Perevozchikov: Postdoc

**Yale**
- Daniel McKinsey: PI, Professor
- Peter Parker: Professor
- James Nikkel: Research Scientist
- Sidney Cahn: Lecturer/Research Scientist
- Alexey Lyashenko: Postdoc
- Ethan Bernard: Postdoc
- Blair Edwards: Postdoc
- Louis Kastens: Graduate Student
- Nicole Larsen: Graduate Student

The most recent collaboration meeting was held in Lead, SD in March 2011.

Collaboration was formed in 2007 and fully funded by DOE and NSF in 2008.
Direct detection of WIMP dark matter

\[ \rho \sim 300 \text{ proton masses per liter of space.} \]

If \( M_{\text{WIMP}} = 100 \text{ GeV}, \) then 3 WIMPs/L.

Typical orbital velocity
\[ \sim 230 \text{ km/s, or 0.1\% speed of light.} \]

Coherent scalar interactions:
\[ \sigma \text{ proportional to } A^2. \]

Rate < 1 event / kg / 100 days, or much, much lower
Energy usually deposited in 2 channels
- Excitation => scintillation in liquid (S1)
- Ionization => more scintillation in liquid (e-’s recombine) or in the gas (S2)
- Energy lost to heat for nuclear recoils. Makes signal smaller, but makes it different.

The Physics of Noble Element Scintillation
Self-shielding of LXe, a dense liquid, is extremely powerful

Fiducial volume cut rejects most backgrounds

hard for a gamma or a neutron to cross the full volume without scattering more than once

low-energy gammas that can mimic a WIMP should not even make it to the fiducial volume

external neutrons and gammas have to face water shield first anyway…
Electron Recoils

vs.

Nuclear Recoils

Ionization-to-scintillation ratio allows discrimination between common radioactivity and WIMP events. Background rejection factor of 99.5%.

Well-established technology and methodology (XENON10/100, Xed, LUX0.1, ZEPLIN-III, others).
Davis Cavern @ Homestake, March 2011
(Former Home of the Homestake Solar Neutrino Experiment)
Dual-Phase Liquid Xenon Time Projection Chamber (TPC), 350 kg in total mass
O(1) kV/cm drift field in liquid, and O(10) kV/cm field in the gas stage for S2 production
122 Hamamatsu R8778 PMTs are divided equally between top and bottom
3-D imaging via TPC technique defines ~100 kg fiducial mass, self-shielding used
LUX Detector - Overview

- LN bath column
- Titanium Vessels
- PMT holding copper plates
- Feed-throughs for cables / pipes
- Radiation shield
- Anode grid
- Dodecagonal field cage + PTFE reflector panels
- Cathode grid
- Counterweight

Dimensions:
- 59 cm
- 49 cm
LUX – Surface Facility @ Homestake
Recent progress: LUX cryostat successfully cooled to liquid xenon temperature – May 2011

Putting it all together on the surface first…
PMTs and Signals

Photomultiplier Tubes (PMTs)
- Hamamatsu R8778 (2” diameter)
- Gain of 3.3 \times 10^6 (DM search mode)
- Average QE of 33% at room temperature and 178 nm wavelength
- Very low in background

\begin{figure}
\centering
\includegraphics[width=0.5\textwidth]{led_calibration.png}
\caption{LED Calibration for PMT BA0215 at 1500 V}
\end{figure}

\begin{align*}
\mu &= 140.8 \text{ mVns} \\
\sigma &= 6.4 \\
\text{Gain} &= 3.5 \times 10^7 \pm 4.1 \times 10^5 \\
\text{Res} &= 0.289
\end{align*}
Custom-built analog electronics and custom-built digital trigger
- Can identify S1 and S2 pulses in real time, trigger on S1, S2, or S1+S2 for events
- Specially shaped signals for the digitizer, digital trigger, and analog trigger
- 1.5 kHz acquisition rate w/o dead time => dark matter calibrations w/ zero dead time
- 99.99% zero suppression, and can trigger by position and by energy
- 95% of single photoelectrons constitute >5σ upward fluctuation in baseline noise
- 120 keV_{ee} dynamic range with dark matter search gains
Pulse Only Digitization (POD) Mode and DDC-8 Trigger System

- 24 pretrigger samples and 31 posttrigger samples recorded
- Rolling average of baseline recorded with each pulse (16, 32, 64, or 128 samples)
- 2 double-hagenauer filters (S1 and S2) and robust threshold logic
Kr Removal

- $^{85}\text{Kr}$ - 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)
New analytic technique to detect krypton at the part-per-trillion level


GOAL: O(10) ppt $^{85}\text{Kr}$
- Leads to an event rate of O(0.1) events in the 2-10 keV$_{ee}$ regime after $10^4$ kg-days and 99.5% rejection of e$^-$ recoils

University of Maryland
Calibrations

- External gamma/neutron sources: insertion into water tank
- Two internal sources: only way to obtain low energy calibrations in detector center.
  - $^{83}$Kr: energy calibration (Yale)
  - Tritium source: electron recoil discrimination (Maryland)

Source strengths chosen such that there is no pileup (200 Hz is max)

$^{137}$Cs
$^{208}$Tl
Am/Be
$^{252}$Cf

L.W. Kastens et al., A $^{83}$Kr$^m$ source for use in low-background liquid xenon time projection chambers, 2010 JINST 5 P05006
Simulations

- Very thorough and flexible Geant4 simulation of the geometry: **LUXSim**
  - For understanding the light collection efficiency for the PMTs
  - For helping know the physics reach
  - Component-centric approach in Geant
  - Includes the small background contributions from all the components: decay chain generator
  - 3-D visualization with OpenGL: shoot particles
- Results in minutes or hours at most with $10^5 - 10^6$ photons, analysis fast

-LUXSim paper in preparation
LUX Monte Carlo of the First 40 days

- Red Points: WIMP events after only 40 days assuming a WIMP model for mass 100 GeV at current best 90% CL exclusion sensitivity
- Blue Points: Total # of single scatter electron recoil events (before any cuts) after 40 days of running
- LUX – strong emphasis on WIMP discovery / Plan to run LUX for 300 days

XENON100 4,000 kg-days for comparison. Note much higher electron recoil rate
Cryogenics: Thermosyphon Cooling System

- TS successfully run in May 2011.
- Max cooling rate is 1 K/hr.
- Held target temperature (175-185 K) for days with 50 W PID heaters.
- Heat exchange system more than 95% efficient.
LUX dark matter sensitivity

Status: LUX is now being tested on the surface at Homestake. Moving underground in December of 2011.
Evolution over Time

- Projections based on
  - Known background levels
  - Previously obtained electron attenuation lengths
  - Previous discrimination factors

- Careful fiducial volume selection
  - <1 nuclear recoil event during planned exposure (total)

LUX (constr: 2009-2010, ops: 2011-2012)
100 kg x 300 days
1,500 kg x 500 days
13,500 kg x 1,000 days
NOTE: Masses not finalized.
‘S’->Sanford Lab. ‘D’->DUSEL.
A Brief Summary

- Two signals: discrimination between nuclear, electron recoils when looking at ratio of S2 to S1
- Self-shielding of Xe helps you even more
- Powerful and flexible LUX DAQ
- Proven $^{85}$Kr removal and measurement systems
- Thorough calibration with different sources inside and out
- Robust Monte Carlo simulation of geometry and physics
- Proven cryogenic system
- Incredible discovery potential
- Undergoing testing on surface right now, with the underground deployment around the corner
Extra Slides
Can also detect electronegative impurities at a less than 1 ppb level.

- Open leak valve, bypass gas purifier.
- Flow through gas purifier.
- Bypass gas purifier.
- Close leak valve to measure backgrounds.

Xe is constant due to cold trap.

18 ppb N$_2$
5 ppb O$_2$
0.25 ppb CH$_4$

~few ppm Ar

arXiv:1002.2742
Heat Exchanger Operates >96% Efficient

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

Demonstrated Heat Exchanger Performance

- Red square: Required cooling without heat exchanger
- Blue diamond: Measured power with heat exchanger

>96% efficiency

Flow (tons Xe/day) vs. Power (W)

Circulating gas system
Xe displacer (270 kg Al)
Parallel plate heat exchanger
4 PMT, 0.5 kg Detector

LUX 0.1