The LUX DIRECT DARK MATTER SEARCH

Alex Murphy

IPPP Senior Experimental Fellow
Outline

1. Who we are
2. Where we are
3. What we do
3. How well have we done?
4. How well can we do?
5. What’s next?
Who we are
Where we are
Cosmic rays produce backgrounds that can be particularly problematic.

Going deep underground reduces cosmic ray muon flux by ~1,000,000.

Wherever would someone find such a place...?
Just 15 minutes down the road...
The 8-m diameter LUX water tank (to contain LZ), Davis Campus, 4850-ft u/g level, Sanford Underground Research Facility
What we do
**Liquid Xenon TPCs**

- **S1: LXe is an excellent scintillator**
  - Light yield: >60 ph/keV (0 field)
  - Scintillation light: 178 nm (VUV)

- **S2: Even better ionisation detector**
  - S1+S2 allows mm vertex reconstruction
  - Sensitive to single ionisation electrons

- **Well suited to WIMP searches**
  - Density: 3 g/cm$^3$
  - Scalar WIMP-nucleon scattering rate $dR/dE < A^2$
  - Odd-neutron isotopes ($^{129}$Xe, $^{131}$Xe) enable spin-dependent sensitivity
  - Excellent ionisation threshold: ‘light WIMP’ searches using S2 only
  - No intrinsic backgrounds ($^{85}$Kr can be removed, low rate from $^{136}$Xe)
  - Easily scaled with no loss of performance (actually improves!)
top hit pattern:
x-y localization

\[ \Delta t : z \text{ localisation} \]
top hit pattern: x-y localization

Ratio of S2 to S1 depends on whether an electron or a neutron is recoiling.
Most backgrounds are electron recoils (gamma-rays or beta particles)
top hit pattern: x-y localization

Allows us to reject >99.5% of background
A typical event...

A 1.5 keVee electron recoil (combined energy reconstruction)
How well have we done?

…the LUX 2013 result, briefly
Calibrations

Tritium provides very high statistics electron recoil calibration (200 events/phe) Neutron calibration is consistent with NEST + simulations

Gray contours indicate constant energies using a S1-S2 combined energy scale
Neutron background predicted to be 0.06 events in 85.3 day (90\% C.L. from multiple scatter analysis of 0.37 events)

ER leakage 0.64 +/- 0.16 events below NR mean
Spatial distribution of events

...85.3 live days, 118 kg FV
$S_2/S_1$ distribution of events

Region where WIMPs might be expected

Profile likelihood ratio analysis used

...85.3 live days, 118 kg FV
So what?

- p-value for the background-only hypothesis of 0.35 ("cannot distinguish from background only")

- But size, duration, thresholds, & low background combine to give world-leading result
Spin independent result

D.S. Akerib et al. PRL 112 (2014) 091303
Low mass region

D.S. Akerib et al. PRL 112 (2014) 091303

>800 citations (HEP-INSPIRE)
How well can we do?
Recent Improvements…

- High-statistics calibration with CH$_3$T
- High-statistics calibration with DD neutron sources
- Absolute measures of $Q_\gamma$ and $L_\gamma$, to low threshold
- Optimization of grid voltages, “conditioning”, Increased extraction field by 17%
- Optimization of event selection criteria
- Improved study of systematics
- New modeling
- More data… now with cosmogenic $^{127}$Xe ($t_{1/2}=36.4$ days) decayed away
Tritium

- Internally-deployed tritium source provides ER from 0 to 18 keVee
- ER light and charge yields down to ~1 keVee!
- Excellent understanding of background (since the background is overwhelmingly ER)
- Provides precise determination of ER/NR leakage, as a function of S1
- Uniformly distributed, with $^{83}\text{mKr}$, accurate fiducial volume
- Purification system removes methane $\tau < 12h$

Fit optimised for extraction efficiency

PRELIMINARY


**DD-generator neutrons**

- Calibration of NRs *in situ*
- No reliance on AmBe, $^{252}$Cf, models from old data, extrapolations from small calibration chambers…
- Double scatters; absolute energy deposition from scattering angle

---

![Graphs showing the calibration process for neutron detectors with a cut-off at 3 keVr for 2013 analysis.](image)

*NEST 1.0 still too conservative*

*Modified NEST for re-analysis*
Updated discrimination

New: DIGITAL individual photon counting, useful at low energies

99.80 (±0.0003 ± 0.01) % discrimination (S1<50). Note, PLR used in real analysis.

Approximate location of 150 phe cut, lowered from 200 phe previously (8 => 6 e⁻s)

Widths indicated +/- 1.28-sigma (1-sided 90%)
12% efficiency for the detection of a primary scintillation photon (‘g1’), Previously 14% quoted

43% extraction, coupled with ~25 detected photons per single electron (‘g2’)

Doke plot
How well can we do?

- Now conducting a new 300 live-day run
- Blinded by ‘salting’
- Sensitivity gains: x2-4 at high mass, “better” at low mass.
- Can also apply the improved analysis to previous data...
- …Publication on this ‘soon’…

![Graph showing WIMP-nucleon cross section vs. m_WIMP (GeV/c^2)](image)

- LUX (2013), 85 live days
- XENON100 (2011), 100 live days
- XENON100 (2012), 225 live days
- CDMS II Ge
- Edelweiss II
- ZEPLIN III
What’s next?
Longer term: Bigger is better!

**LUX-ZEPLIN:**
- 3x linear size of LUX
- ~100x more sensitive
- 482 ULB 3” PMTs
- 100 kV cathode
- 3 ms electron lifetime
- 4.5 keVr S1 threshold
- 99.5% NR/ER discrimination
- New skin veto and outer LS detector
- Uses much of the same infrastructure (including water tank)
- CD1 approved!
- Construction begins 2016 (some aspects 2015!); Data 2018/19?
Backgrounds

Intrinsic

- $^{85}$Kr - mitigated by purity (c. 0.02 ppt)
- Rn - require c. mBq (c.f. μBq in NLDBD)
- 2NDBD - dominates, but only above WIMP search energy window
- U/Th/K - extensive screening programme, material selection and fiducialised away
- Activation - underground storage, $t_{1/2}$ and fiducialised away

Astrophysical

- solar pp electron scattering: 99.5% discrimination, ~1.5 evt in full exposure
- $^8$B coherent nuclear scattering: <1 above threshold
- Atmospheric and diffuse SN neutrinos <1 in full exposure
Feedback from Modern Physics course last year…

“Enthusing”  “Inspiring”
Exciting times ahead....

Thank you all for listening!
Extra Slides
**Extraction Efficiency:**

We have three different measurements of the extraction in situ and all agree within errors.

- The value we quote comes from the Doke plot analysis.
- We can also measure our extraction efficiency by comparing the charge yield for alphas to previous work by Aprile.
- The third method performs a fit to the tritium spectrum floating g1 and g2.
- The agreement between the three different methods gives us confidence in that number.
- In addition, electric field simulations show that our extraction efficiency at this extraction field is consistent with the work of Gushkin.
Claims of Detection

Is something wrong?

Are you sure?

Nope.

Yeah, why do you ask?

ONLY ALAN WAS PREPARED TO ACKNOWLEDGE THE ELEPHANT IN THE ROOM.
Dark Matter RyePA
Dakota Shivers Brewing
Rye Beer

6.6% ABV  No IBU  ☀️☀️☀️ (3.96)