LUX-ZEPLIN (LZ) Status

Attila Dobi
Lawrence Berkeley National Laboratory
June 10, 2015
WIN-2015. Heidelberg
LZ = LUX + ZEPLIN

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29 institutions currently
About 160 people
Continuing to expand internationally

University of Alabama
University at Albany SUNY
Berkeley Lab (LBNL), UC Berkeley
Brookhaven National Laboratory
Brown University
University of California, Davis
Fermi National Accelerator Laboratory
Lawrence Livermore National Laboratory
University of Maryland
Northwestern University
University of Rochester
University of California, Santa Barbara
University of South Dakota
South Dakota School of Mines & Technology
South Dakota Science and Technology Authority
SLAC National Accelerator Laboratory
Texas A&M
Washington University
University of Wisconsin
Yale University
<table>
<thead>
<tr>
<th>Year</th>
<th>Month</th>
<th>Activity</th>
</tr>
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<tbody>
<tr>
<td>2012</td>
<td>March</td>
<td>LZ (LUX-ZEPLIN) collaboration formed</td>
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<tr>
<td></td>
<td>May</td>
<td>First Collaboration Meeting</td>
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<td></td>
<td>Septembe</td>
<td>DOE CD-0 for G2 dark matter experiments</td>
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<td>2013</td>
<td>November</td>
<td>LZ R&amp;D report submitted</td>
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<tr>
<td>2014</td>
<td>July</td>
<td>LZ Project selected in US and UK</td>
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<td>2015</td>
<td>April</td>
<td>DOE CD-1/3a approval, similar in UK</td>
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<td>Beginning procurements(Xenon, PMT, cryostat)</td>
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<td>2016</td>
<td>April</td>
<td><strong>DOE CD-2/3b approval, baseline, all fab starts</strong></td>
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<tr>
<td>2017</td>
<td>June</td>
<td><strong>Begin preparations for surface assembly @ SURF</strong></td>
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<td>2018</td>
<td>July</td>
<td><strong>Begin underground installation</strong></td>
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<tr>
<td>2019</td>
<td>Feb</td>
<td><strong>Begin commissioning</strong></td>
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Sanford Underground Research Facility in South Dakota

Davis Cavern 1480 m (4300 mwe)
LZ in LUX Water Tank

LUX to be removed by early 2017
Water tank kept
Scale Up ≈50 in Fiducial Mass

LZ
Total mass - 10 T
WIMP Active Mass - 7 T
WIMP Fiducial Mass - 5.6 T
Xe Detector

Section view of TPC

Upper PMT Array
Weir structure
TPC field cage

Electroluminescence region and gas phase

Anode Liquid surface
Gate
Skin PMT

HV umbilical and connection to cathode

Cathode grid
Reverse field region
Skin PMT
Lower PMT array

247 PMT
241 PMT
180 total Skin PMT
Xe Detector PMTs

✦ R11410-22 3” PMTs for TPC region
  □ Extensive development program, 50 tubes in hand, benefit from similar development for XENON1T, PANDA-X and RED
  □ Materials ordered and radioassays started prior to fabrication.
  □ First production tubes early 2016.
  □ Joint US and UK effort

✦ R8520-406 1” for skin region
High Voltage Studies

Testing for cathode HV at Yale moving to LBNL and Berkeley. Also development at IC London.

✦ Cathode voltage Design goal: 200 kV
✦ LZ nominal operating goal: 100 kV (750 V/cm)
✦ Feedthrough prototype tested to 200 kV (Dielectric Sciences 2077)
Cryostat Vessels

- UK responsibility
- Low background titanium chosen
- Ti slab for all vessels (and other parts) received and has been assayed
- Contributes < 0.05 NR+ER counts in fiducial volume in 1,000 days after cuts
Remove Kr to <15 ppq (10^{-15} g/g) using gas chromatography.

- Best LUX batch 200 ppq
- Setting up to process 200 kg/day at SLAC
- Have a sampling program to instantly assay the removal at SLAC and continuously assay in situ
LZ Calibrations

- Demonstrated in LUX. Calibrate The Signal and Background Model in situ.
  - DD Neutron Generator (Nuclear Recoils)
  - Tritiated Methane (Electron Recoils)

Tritium Beta Spectrum Measured in LUX
Background Modeled

Just LXe TPC

Use LXe skin, Outer Det.

Fid. Mass

3.8 T

5.6 T

2.2 bkg events, 1,000 days
Projected Sensitivity - Spin Independent
(LZ 5.6 Tonnes, 1000 live days)

- Excellent projected sensitivity limited by neutrinos only.

2×10^{-48} \text{ cm}^2
Other Physics...

- Axions
- Effective Field Theory Interaction Decomposition
- Neutrinoless Double Beta Decay
  - $\sim 600$ kg of $^{136}$Xe in active volume
  - $2 - 5 \times 10^{26}$ year half life
- Neutrino Physics
  - Coherent neutrino-nucleus scattering
  - Solar
  - Supernova
Coherent $\nu$-nucleus Scattering

- LZ may be the first to observe coherent neutrino-nucleus scattering
- $^8\text{B}$ Recoils mimic low mass WIMPs
- WIMP Search 3-30 keV
- Expect $\sim 10\, ^8\text{B}$ events and 0.5 events from others

- DSN and atmospheric neutrinos will become the dominant background for experiments beyond LZ.
ν-electron Scattering
- The dominant background

With 99.5% electron recoil rejection (at 50% nuclear recoil acceptance)

- Wimp Search 1.5-6.5 keVee (and before 99.5% electron recoil rejection)
  - ~270 PP solar events
  - ~40 2νBB

- Improve measured solar neutrino luminosity to <5% from 10%

Electron recoils from $^{85}$Kr, $^{222}$Rn and PMTS are less than 10% of PP solar neutrino rate
Conclusions

◆ LZ Project well underway, with procurement of Xenon, PMTs and cryostat vessels started along with prototype and assay programs

◆ LZ benefits from the excellent LUX calibration techniques and understanding of background

◆ LZ sensitivity expected to be finally limited by neutrino-induced `background’
Extra Slides
Xe Detector Prototyping

✦ Extensive program of prototype development underway

✦ Three general approaches

  □ Testing in liquid argon, primarily of HV elements, at Yale and soon at LBNL
  
  □ Design choice and validation in small (few kg) LXe test chambers in many locations: LLNL, Yale-> UC Berkeley, LBNL, U Michigan, UC Davis, MEPhI
  
  □ System test platform at SLAC. Phase I about 100 kg of LXe starting soon with complete prototype TPC
Design Status Summary

- Conceptual, and in some cases more advanced design, completed for all aspects of detector
- Conceptual Design Report to appear on arXiv
- Acquisition of Xenon started
- Procurement of PMTs and cryostat started
- Collaboration - wide prototype program underway to validate design
- Backgrounds modeling and validation well underway
Tritiated-Methane, The Ideal ER Calibration Source

- Methane diffuses much slower than bare tritium.
- Dissolved uniformly in the xenon.
- Removed with standard purification technology.
- Used to calibrate the fiducial volume.

- Single Scatter ER events in energy region of interest: 0.1 keV to 18 keV
- Mean energy: 5 keV
- Peak energy: 2.5 keV
Adelphi DD108 Neutron Generator Installed Outside LUX Water Tank

- This cut eliminates shine from passive materials and ensures 95% of neutrons in beam sample have energy within 4% of 2.45 MeV.

- The mean energy of neutrons produced at 90° by the DD108 was measured to be 2.45 ± 0.05 MeV at Brown University.
LZ Underground at SURF

Years of experience at SURF from LUX

Control room

LN storage room

LZ detector inside water tank

Xenon storage room
Sensitivity with SUSY Theories
Sensitivity with Competition
Response of Xe to Neutrinos

arXiv: 1307:5458

Event rate $[\text{ton.year.keV}^{-1}]$

Recoil energy $[\text{keV}]$
LZ - At the neutrino `knee'  
arXiv: 1408.3581

After LZ, extremely large detectors would be needed.
Monitoring $^{85}$Kr background in LUX xenon

- Measure $^{84}$Kr and to infer $^{nat}$Kr/Xe
- Assume atmospheric abundance: $^{85}$Kr/$^{nat}$Kr ratio: $2 \times 10^{-11}$
- Background goal: < 5 ppt Kr/Xe
- By the time $^{85}$Kr decays show up in data analysis... It's too late!
  
  Set Xenon100 back a year (1 liter of air is all it takes)

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<tr>
<th>Source</th>
<th>Background Rate $[mDRU_{ee}]$</th>
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<tr>
<td>$\gamma$ rays</td>
<td>$1.8 \pm 0.2_{stat} \pm 0.3_{sys}$</td>
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<tr>
<td>$^{127}$Xe</td>
<td>$0.5 \pm 0.02_{stat} \pm 0.1_{sys}$</td>
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<tr>
<td>$^{214}$Pb</td>
<td>$0.11 - 0.22$ ($0.20$ expected)</td>
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<tr>
<td>$^{85}$Kr</td>
<td>$0.17 \pm 0.10_{sys}$</td>
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</tbody>
</table>

Total predicted: $2.6 \pm 0.2_{stat} \pm 0.4_{sys}$
Total observed: $3.6 \pm 0.3_{stat}$

arXiv:1403.1299
Spin Dependent Neutron
Spin Dependent Proton
Time Evolution

Ge, NaI no discrimination

Ge, w/discrim.

ZEPLIN-III

LXe, w/discrim.

LUX

XENON 1T

LZ  $2 \times 10^{-48}$ cm$^2$

90% CL SI Cross Section Upper Limit [cm$^2$ per nucleon, $M_{WIMP} = 50$ GeV/c$^2$]