The LUX-ZEPLIN Dark Matter Search

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for the LZ collaboration

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KAIST Munji Campus, Daejeon, Korea
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A direct-detection search, looking primarily (but not only) for WIMP dark matter with liquid xenon
1) IBS Center for Underground Physics (South Korea)
2) LIP Coimbra (Portugal)
3) MEPhI (Russia)
4) Imperial College London (UK)
5) STFC Rutherford Appleton Lab (UK)
6) University College London (UK)
7) University of Bristol (UK)
8) University of Edinburgh (UK)
9) University of Liverpool (UK)
10) University of Oxford (UK)
11) University of Sheffield (UK)
12) Black Hill State University (US)
13) Brookhaven National Lab (US)
14) Brown University (US)
15) Fermi National Accelerator Lab (US)
16) Lawrence Berkeley National Lab (US)
17) Lawrence Livermore National Lab (US)
18) Northwestern University (US)
19) Pennsylvania State University (US)
20) SLAC National Accelerator Lab (US)
21) South Dakota School of Mines and Technology (US)
22) South Dakota Science and Technology Authority (US)
23) Texas A&M University (US)
24) University at Albany (US)
25) University of Alabama (US)
26) University of California, Berkeley (US)
27) University of California, Davis (US)
28) University of California, Santa Barbara (US)
29) University of Maryland (US)
30) University of Massachusetts (US)
31) University of Michigan (US)
32) University of Rochester (US)
33) University of South Dakota (US)
34) University of Wisconsin - Madison (US)
35) Washington University in St. Louis (US)
36) Yale University (US)
Why use liquid xenon?
Why use liquid xenon?

Large signal

- Scalar WIMP-nucleus interactions feature an $A^2$ dependence on the scattering rate.
- Natural xenon contains ~50% odd isotopes, giving high sensitivity to spin-coupled interactions.

$M_\chi = 50 \text{ GeV}, \sigma_{\text{nucleon}} = 10^{-46} \text{ cm}^2$

Rate [evts/tonne/yr/keV]

Recoil Energy [keV]

Xenon
Germanium
Argon
Why use liquid xenon?

Low background

1. Easily scalable to large size
2. 3-D localization of events
3. 1 and 2 permit an ultra-low-background inner region to be defined.

* "DRU" = evt/kg/day/keV
Moore's Law

Doubling every 2 years

Factor 10 every 6.5 years
The LUX-ZEPLIN Dark Matter Search

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Limit Scalar Cross-section cm² [60 GeV WIMP]

~ 1 event kg⁻¹ day⁻¹

~ 1 event 100 kg⁻¹ yr⁻¹

Year


Homestake
Oroville
H-M '94
UKDMC
H-M '98
IGEX
DAMA '98
CDMS I SUF '99
DAMA '00
Edelweiss '01
CDMS I SUF '02
Edelweiss '03
ZEPLIN I
CDMS II Soudan '04
WARP '07
ZEPLIN II
LIBRA '08
H-M '98
IGEX
DAMA '98
CDMS I SUF '99
DAMA '00
Edelweiss '01
CDMS I SUF '02
Edelweiss '03
ZEPLIN I
CDMS II Soudan '04
WARP '07
ZEPLIN II
LIBRA '08

SuperCDMS also focuses on light WIMPs

Courtesy R. Gaitskell
Dark Matter Searches: Past, Present & Future

Limit Scalar Cross-section cm² [60 GeV WIMP]

10^{-40} - 10^{-47}

1985 - 2020

~ 1 event kg⁻¹ day⁻¹
~ 1 event 100 kg⁻¹ yr⁻¹

- Ge
- NaI
- Cryodet
- Liq. Noble

- Projected
- Signal

SuperCDMS also focuses on light WIMPs

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Year


Homestake

Oroville

H-M '94

UKDMC

IGEX

DAMA '98

DAMA '00

DAMA '04

Edelweiss '98

Edelweiss '00

Edelweiss '01

Edelweiss '03

Edelweiss '09

Edelweiss '11

CDMS I SUF '99

CDMS I SUF '02

CDMS I SUF '04

CDMS II Soudan '04

CDMS II Soudan '10

CDMS II Soudan '14

CDMS II Soudan '18

ZEPLIN I

ZEPLIN II

ZEPLIN III

LUX '14

LUX '15

LUX '16

LUX '17

LUX '18

LUX '19

LUX '20

XENON1T '19

XENON1T '20

XENON10

XENON100

XENON100 '10

XENON100 '11

XENON100 '12

XENON100 '13

XENON100 '14

XENON100 '15

XENON100 '16

XENON100 '17

XENON100 '18

XENON100 '19

XENON100 '20

XENON1T '17

XENON1T '18

XENON1T '19

XENON1T '20

SuperCDMS Soudan '14

SuperCDMS Soudan '15

SuperCDMS Soudan '16

SuperCDMS Soudan '17

SuperCDMS Soudan '18

SuperCDMS Soudan '19

SuperCDMS Soudan '20

DEAP3600 '18

DEAP3600 '19

DEAP3600 '20

PandaX '15

PandaX '16

PandaX '17

PandaX '18

PandaX '19

PandaX '20

CRESST '11

CRESST '12

CRESST '13

CRESST '14

CRESST '15

CRESST '16

CRESST '17

CRESST '18

CRESST '19

CRESST '20

LUX 300kg

XMASS 800kg

LUX ZEPLIN

Courtesy R. Gaitskell
The LUX-ZEPLIN Dark Matter Search

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Limit Scalar Cross-section cm² [60 GeV WIMP]

~ 1 event kg⁻¹ day⁻¹

~ 1 event 100 kg⁻¹ yr⁻¹

Moore’s Law

Courtesy R. Gaitskell
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Dual-phase time projection chamber (TPC)

- Main target is liquid xenon (180 K).
- Primary scintillation light (S1) emitted from interaction vertex
- Ionized e\textsuperscript{-} drift to the liq. surface; produce prop. light as they travel through gas (S2).

S1 and S2 permit:
  - Energy reconstruction
  - 3-D position reconstruction
  - Background rejection

Details in our Technical Design Report: arXiv/1703.09144
WIMPs: expected signal

- Majority of BG is from electronic recoils (ER).
- WIMPs detected via nuclear recoils (NR).
- ER and NR have different S1 / S2 ratio.

- Shape of observed spectrum gives info on WIMP mass.
- Low mass sensitivity affected by NR from $^8$B solar neutrinos (7±3 events in 1000d).
Sanford Underground Research Facility

LUX/LZ, located on the 4850 level (~1.5 km underground) in Lead, South Dakota. Solar neutrinos first detected here. Muon flux down by $10^7$. 
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LZ: factor of ~50 larger fiducial than LUX

Lower backgrounds

(See talk by L. Tvrznikova)
The LUX-ZEPLIN Dark Matter Search

LZ

- 7 tonnes active mass.
- Active LXe “skin” veto (outside of TPC)
- Gd-loaded LAB scintillator veto
- LUX’s water shield
- External liquefaction/purification tower
TPC

SECTION VIEW OF LXE TPC
- Top PMT array
- Side Skin PMTs
- TPC field cage

GAS PHASE AND ELECTROLUMINESCENCE REGION
- Anode
- Gate
- LXe surface
- Weir trough
- Skin PMT

HV CONNECTION TO CATHODE
- Cathode grid
- Reverse-field region
- Side skin PMT mounting plate
- Bottom PMT array
The LUX-ZEPLIN Dark Matter Search

Photomultiplier Tubes

Hamamatsu

R11410

R8520

R8778 (recycled from LUX)

Main TPC

Xe “skin” veto

Scintillator veto

R5912
Outer detector

• Gd-doped LAB liquid scintillator.

• Neutron and gamma veto.

• $4\pi$ coverage

• Cutouts for cryogenics, electronics, neutron tubes, HV

• Screener vessel already deployed in LUX water shield, good results.
Backgrounds

No vetoes

With vetoes (LXe skin and liquid scint.)
Scientific Reach — Standard WIMPs

\[
\log_{10}(\sigma_p) \text{ [pb]}
\]

- LZ 90\%CL Median (Baseline)
- LZ 90\%CL Median (Goal)
- CMSSM (1\sigma)
- CMSSM (2\sigma)

\[
\sigma_p \text{ [cm}^2]\]

1 event
3\sigma significance
1000 tonne-years

ν-N coherent scattering

WIMP mass [GeV/c^2]

Zeplin-III (2011)
PandaX (2016)
LUX WS2013+WS2014-16
XENON1T (2017)
Scientific Reach — Axions and ALPs

DM ALPs

Solar axions

\[ g_{\text{ke}} \times 10^{-10} \]

\[ g_{\text{ke}} \times 10^{-11} \]

\[ g_{\text{ke}} \times 10^{-12} \]

\[ g_{\text{ke}} \times 10^{-13} \]

\[ g_{\text{ke}} \times 10^{-14} \]

\[ g_{\text{ke}} \times 10^{-15} \]

\[ m_A \text{ [keV/c}^2\text{]} \]

\[ 10^{-5} \]

\[ 10^{-4} \]

\[ 10^{-3} \]

\[ 10^{-2} \]

\[ 10^{-1} \]

\[ 1 \]

The LUX-ZEPLIN Dark Matter Search
Summary

• Noble-liquid TPCs leading the field in WIMP sensitivity

• LZ is the successor to ZEPLIN and LUX. 7 tonnes LXe (5.6 tonnes fiducial)

• LZ will reach sensitivity of $2.3 \times 10^{-48}$ cm$^2$ for SI WIMP-nucleon interactions. Other dark-matter results expected as well.

• LZ is at an advanced stage. Construction already begun, planning for first signals in 2019.
Backup
# Backgrounds

<table>
<thead>
<tr>
<th>Source</th>
<th>ER</th>
<th>NR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material contamination</td>
<td>6.22</td>
<td>0.07</td>
</tr>
<tr>
<td>Contam. in LXe*</td>
<td>916</td>
<td>0.43</td>
</tr>
<tr>
<td>Physics backgrounds**</td>
<td>322</td>
<td>0.72</td>
</tr>
<tr>
<td>Total (raw)</td>
<td>1240</td>
<td>1.22</td>
</tr>
<tr>
<td>Total (99.5% ER rej., 50% NR acc.)</td>
<td><strong>6.2</strong></td>
<td><strong>0.61</strong></td>
</tr>
</tbody>
</table>

* Mostly radon
** Astrophysical neutrinos, $2\nu\beta\beta$ from $^{136}\text{Xe}$