The PandaX Dark Matter Experiment

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(On behalf of the PandaX Collaboration)

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Outline

• Introduction
• The PandaX-I Detector
• Data Analysis and Results of PandaX-I
• Future programs of PandaX
• Summary
China JinPing Laboratory (CJPL)

Sichuan
Southwest China

2400m of rock overburden

Muon flux ~ 63cts/m$^2$/year
Roadmap of PandaX

- PandaX = Particle and Astrophysical Xenon Experiments
Infrastructure

• Cryogenics and Gas Handling: “Cooling Bus”
• Shield with Polyethylene, copper and lead
• Used in both PandaX-I & II
TPC of PandaX-I

120 kg of LXe

15 cm

Cathode

60 cm

143 R8520 PMTs 1"

“Skin”

37 R11410 PMTs 3"

Key design goal: high light collection efficiency

TeVPA 2015, Kashiwa Japan
PandaX-I First Results

- 37kg x 17.4 live days of data
- Disfavor all previously positive signals
- At low mass region, our results more constraining than XENON100 first results with similar exposure


- PandaX 37x17 kg-day, NEST
- PandaX 37x17 kg-day, Xenon100 L_{eff}
- XENON100 40x11 kg-day
- XENON100 34x225 kg-day
- LUX 118x85 kg-day (no LY below 3 keV_{n})
- CDEX 2014
- SuperCDMS
- CoGENT 2014
- CDMS II-Si
- DAMA/LIBRA
- CRESST-II 2012
PandaX-I Full Exposure Run

- 80.1 live-day $\times$ fiducial mass 54 kg ($\times$ 7 exposure)
- Calibrations with much larger statistics (ER/NR)
- Updated energy modeling at low recoil energy and improved treatment to low mass WIMPs
- Better understanding/modeling of background
- Blinded analysis: FV and energy acceptance defined blindly using FoM based on background expectation and exposure
- Likelihood approach to final results

Detector Parameters

$^{129}$Xe: 40 keV
$^{131}$Xe: 80 keV

$E_{ee}^{ce} = w \left( \frac{S1}{PDE} + \frac{S2}{\text{gas gain} \times EEE} \right)$

- $w = 13.7$ eV (NEST)
- Photon detection efficiency (PDE): 9.55(1.0)%
- Electron extraction efficiency (EEE): 82.1(7.4)%

neutron calibration with $^{252}$Cf
Nuclear Recoil Band

- Observe significant “single scatter” events with suppressed S2
- “X”-events in chargeless region
  - Below cathode (5cm)
  - “Skin”
Nuclear Recoil Band after cut

- Charge pattern cut developed to remove the “X”-events effectively.
- MC with NEST model agrees well with the data
ER/NR discrimination

- ER data measured by $^{60}$Co calibration
- ER median and $\pm 2\sigma$
- NR median
- 300 PE $S_2$ cut

<table>
<thead>
<tr>
<th>Event Type</th>
<th># events</th>
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<tbody>
<tr>
<td>total</td>
<td>1520</td>
</tr>
<tr>
<td>Below NR median</td>
<td>12</td>
</tr>
<tr>
<td>Accidental</td>
<td>1.6</td>
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</tbody>
</table>

- "Leakage" = 10.4/1520 = 0.68(23)%
- Expected Gaussian: 0.5%
**ER background**

<table>
<thead>
<tr>
<th>Source</th>
<th>background level (mDRU)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Top PMT array</td>
<td>4.7±2.3</td>
</tr>
<tr>
<td>Bottom PMT array</td>
<td>2.3 ± 1.5</td>
</tr>
<tr>
<td>Inner vessel components</td>
<td>3.8 ± 2.2</td>
</tr>
<tr>
<td>TPC components</td>
<td>1.9 ± 0.9</td>
</tr>
<tr>
<td>$^{85}$Kr</td>
<td>2.6 ± 1.2</td>
</tr>
<tr>
<td>$^{222}$Rn &amp; $^{220}$Rn</td>
<td>0.5 ± 0.2</td>
</tr>
<tr>
<td>Outer vessel</td>
<td>0.9±0.6</td>
</tr>
<tr>
<td>Total expected</td>
<td>16.7±3.9</td>
</tr>
<tr>
<td>Total observed</td>
<td>23.6±3.5</td>
</tr>
</tbody>
</table>

![Blinded region](image1)

![High energy region](image2)

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Accidental Background

- Coincidence combination of isolated S1 and S2

![Graph showing accidental background distribution]

23 Hz

240/day

Accidental distribution

300 PE S2 cut to suppress the accidental backgrounds
Blinded Analysis

- Fiducial volume and S1 cut determined blindly by maximizing the counting sensitivity based on the background expectation below the NR median

<table>
<thead>
<tr>
<th></th>
<th>ER</th>
<th>Accidental</th>
<th>Neutron</th>
<th>Total expected</th>
</tr>
</thead>
<tbody>
<tr>
<td>All</td>
<td>503.7</td>
<td>35.1</td>
<td>0.35</td>
<td>539.1</td>
</tr>
<tr>
<td>Below NR med</td>
<td>2.5</td>
<td>4.2</td>
<td>0.18</td>
<td>6.9</td>
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All the values are expectations!
Unblinded Vertex Distribution

Data/MC agree well!

Data template
Data CoG
MC

MC
Search For DM

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<td>542</td>
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<tr>
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<td>2.5</td>
<td>4.2</td>
<td>0.18</td>
<td>6.9</td>
<td>7</td>
</tr>
</tbody>
</table>

- 7 events found in the DM search region, still consistence with the background expectation.
Limits on DM

- Full exposure results with an improved analysis confirmed the finding from the first results, disfavoring all positive WIMP claims
- Tighter bound than superCDMS above WIMP mass of 7 GeV/c²
- Best reported* WIMP limits below 5.5 GeV/c² in xenon community

Profile likelihood fit using DM and background distribution.

*LUX chose a cutoff below 3 keVnr, whereas we used the NEST model all the way.
PandaX-II: 500 kg LXe

- Started construction June 2014
- Presently under commissioning
- Expect to start dark matter data taking in 2015
- Expected running time for physics: 2 years
PandaX-II Expected Sensitivity

PandaX-II sensitivity assumes:

- 300 kg x 365 day
- 4.4 PE/keVee (@122 keV)
- S1 range: [3, 47] PE
- ER rejection 99.75%
- NR acceptance 35%
- <3.7 background events

PandaX-II covers significant region in the SUSY WIMP parameter space.
PandaX future Programs

- CJPL-II (ready in 2016)
- Double beta decay (PandaX-III) and ultimate DM (PandaX-IV)
Summary

• PandaX-I finished DM search with 80.1 day × 54 kg exposure
  • Data disfavor previously reported signals from other experiments
  • Tighter bound than superCDMS above WIMP mass of 7 GeV/c^2
  • Best reported WIMP limits below 5.5 GeV/c^2 in xenon community

• Learn A LOT from PandaX-I experience
• PandaX-II being commissioned.
• More PandaX programs planned in CJPL-II.
Backup Slides
Nuclear recoil band: data vs MC

- Established quantitative understanding of the “X” event by Monte Carlo
- Tuned MC (efficiency applied) is able to reproduce the full NR distribution observed in the data
Low NR energy model
Comparison of analysis thresholds

TeVPA 2015, Kashiwa Japan
Unbinned likelihood function

\[
\mathcal{L} = \text{Poiss}(N_m | N_{exp}) \times \Pi_{i=1}^{N_m} \left[ \frac{N_{DM}(1 + \delta_{DM})P_{DM}(s_1^i, s_2^i)e_{NR}(s_1^i, s_2^i)}{N_{exp}} \right. \\
+ \left. \frac{N_{ER}(1 + \delta_{ER})P_{ER}(s_1^i, s_2^i)}{N_{exp}} \right. \\
+ \left. \frac{N_{Acc}(1 + \delta_{Acc})P_{Acc}(s_1^i, s_2^i)}{N_{exp}} \right. \\
+ \left. \frac{N_{nbkg}(1 + \delta_{nbkg})P_{nbkg}(s_1^i, s_2^i)e_{NR}(s_1^i, s_2^i)}{N_{exp}} \right] \\
\times G(\delta_{DM}, 0.2)G(\delta_{ER}, 0.15)G(\delta_{Acc}, 0.1)G(\delta_{nbkg}, 0.5)
\]

Expected shape of ER background same as that in $^{60}$Co calibration!
DM PDF

\[ \Pi_{i=1}^{N_{DM}} \left[ \frac{N_{DM} (1 + \delta_{DM}) P_{DM}(S1^i, S2^i) \epsilon_{NR}(S1^i, S2^i)}{N_{exp}} \right] \]

Average DM efficiency (WIMP mass dep):

\[ \langle \varepsilon_{DM} \rangle = \int P_{DM}(S1, S2) \epsilon_{NR}(S1, S2) dS1 dS2 \]
PandaX-I sensitivity

![Graph showing PandaX-I 2015 sensitivity, PandaX-I 2015 upper limit, high PDE/EEE, low PDE/EEE, LUX 2013, SuperCDMS 2014, and CRESST-II new compared to WIMP mass (GeV/c^2) vs. WIMP-nucleon cross section (cm^2).]