WIMP search with the full PandaX-II exposure

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On behalf of the PandaX collaboration
Outline

• Introduction to dark matter and PandaX

• WIMP search with PandaX-II full exposure data
  • Refined algorithms in the analysis
  • Unblinding data and results of the WIMP search

• Summary
Introduction to dark matter

1930s, F. Zwicky

CMB anisotropy

Galaxy rotation curve

Gravitational lensing

Large-scale structure formation

Bullet cluster
Dark matter candidates

- Weakly interacting massive particles (WIMP), hypothetical particles in the 100 GeV mass range with weak interaction can explain the abundance.
Detectability

\[ \chi + SM \rightarrow \chi' + SM' \]

\[ \chi + \bar{\chi} \rightarrow SMs \]

Direct detection

Indirect detection

Collider search

\[ SMs \rightarrow \chi(s)+(SMs) \]
PandaX Collaboration

• Particle and Astrophysical Xenon Experiment
  • Formed in 2009
China Jinping Underground Laboratory

- Deepest (6800 m.w.e): < 0.2 muons/m²/day
- Horizontal access: 9 km long tunnel
- CJPL-II: new experiment halls

Kick-off of CJPL-II facility construction project, July 20, 2019
PandaX Dark Matter Experiment

- Dual-phase Xenon TPC
- Origin of an event
  - Nuclear recoils (NR): neutron, WIMPs
  - Electron recoils (ER): gamma, beta
  - Alpha particles
- Energy deposition
  - Excitation, Ionization, Heat
- Signals
  - Prompt light S1 ($\sum_{i=1}^{N_{\text{PMT}}} S_{1i}$)
  - Electroluminance S2 ($\sum_{i=1}^{N_{\text{PMT}}} S_{2i}$)
- Events of interest for WIMP search
  - Single scattering NR with one S1 and S2 in 0-10 keV$_{ee}$
PandaX Dark Matter Experiment

PandaX-I: 120 kg
2009-2014

PandaX-II: 580 kg
2014-2019

PandaX-4T: 4 ton
2019-
PandaX-II Full Exposure Data

- 2019.06 “End-of-Run” completed
- Total exposure: 131.7 ton-day
  - Run 9: 79.6 days (published)
  - Run 10: 77.1 days (published)
  - Run 11, span 1: 96.4 days
  - Run 11, span 2: 147.9 days

- Refined algorithms
  - New position reconstruction
  - New detector response model
  - Improved background evaluation
New Position Reconstruction

- Trained with evenly distributed $^{83\text{m}}$Kr calibration events
- Turn off 7 malfunctioned PMTs
  - 5 top and 2 bottom
- Simulation-based position reconstruction
  - Optical simulation of the detector
  - A better construction of photon-response function for each PMT
New Response Model

- Calibration data
  - ER events: tritium and $^{220}$Rn
  - NR events: AmBe
- NEST 2.0 based response model
  - with data quality cut efficiency

**Graphs:**
- AmBe Run10/11
- Tritium Run 9
- $^{220}$Rn Run10/11
## Background Sources

<table>
<thead>
<tr>
<th>Source</th>
<th>Evaluation</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{127}\text{Xe}$</td>
<td>35.5 day lifetime, decay away in Run 11</td>
</tr>
<tr>
<td>$^{3}\text{H}$</td>
<td>Introduced after Run 9, fitted from data, see later</td>
</tr>
<tr>
<td>$^{222}\text{Rn}$</td>
<td>Depletion effect from measurement</td>
</tr>
<tr>
<td>$^{85}\text{Kr}$</td>
<td>Not a constant due to air leakage in Run 11</td>
</tr>
<tr>
<td>neutrons</td>
<td>Data-driven estimation</td>
</tr>
<tr>
<td>surface events</td>
<td>Data-driven extrapolation</td>
</tr>
<tr>
<td>accidental events</td>
<td>Newly trained BDT discriminator</td>
</tr>
</tbody>
</table>
**222Rn Background**

- Major ER contribution from $^{214}$Pb
  - Charged Rn progenies attracted to the cathode with negative HV
  - Less contribution in fiducial volume: “depletion effect”

- New method to evaluate ER event rate from $^{214}$Pb
  - The depletion ratio measured from $^{222}$Rn calibration (end-of-run)
  - Interpolation from $^{218}$Po and $^{214}$Bi
  - PandaX-II $^{214}$Pb level: 10µBq/kg
Surface Background

- Surface events
  - Mostly ER events from Rn plate-out
  - Losing S2 on the surface, shifting below ER region
- Data-driven extrapolation from outside FV region

JINST 14 (10): C10039, 2019
Neutron Background

- New evaluation based on high energy gammas (HEGs)
  - Neutron events associated with HEGs (neutron capture, nuclear de-exciation)
  - Scale factor (neutron events / HEGs) from MC simulation with HEGs included
  - Tested in AmBe calibration data

![AmBe calibration](image1)

![Dark matter run10 with a rejection cut](image2)

8/20/20 D.Zhang
Background Budget for Low Energy Events

- Compared with Run 10, more background contributions in Run 11
- $^{85}$Kr and tritium

<table>
<thead>
<tr>
<th>Item</th>
<th>Run 9</th>
<th>Run 10</th>
<th>Run 11, span 1</th>
<th>Run 11, span 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{85}$Kr</td>
<td>$1.19 \pm 0.2$</td>
<td>$0.18 \pm 0.05$</td>
<td>$0.20 \pm 0.06$</td>
<td>$0.40 \pm 0.07$</td>
</tr>
<tr>
<td>Flat ER 222Rn</td>
<td>$0.19 \pm 0.10$</td>
<td>$0.17 \pm 0.02$</td>
<td>$0.19 \pm 0.02$</td>
<td>$0.19 \pm 0.02$</td>
</tr>
<tr>
<td>Components 220Rn</td>
<td>$0.01 \pm 0.01$</td>
<td>$0.01 \pm 0.01$</td>
<td>$0.01 \pm 0.01$</td>
<td>$0.01 \pm 0.01$</td>
</tr>
<tr>
<td>(mDRU) ER (material) 210Pb</td>
<td>$0.20 \pm 0.10$</td>
<td>$0.20 \pm 0.10$</td>
<td>$0.20 \pm 0.10$</td>
<td>$0.20 \pm 0.10$</td>
</tr>
<tr>
<td>Solar ν</td>
<td>$0.01$</td>
<td>$0.01$</td>
<td>$0.01$</td>
<td>$0.01$</td>
</tr>
<tr>
<td>$^{136}$Xe</td>
<td>$0.0022$</td>
<td>$0.0022$</td>
<td>$0.0022$</td>
<td>$0.0022$</td>
</tr>
<tr>
<td>Total flat ER (mDRU)</td>
<td>$1.61 \pm 0.24$</td>
<td>$0.57 \pm 0.11$</td>
<td>$0.73 \pm 0.08$</td>
<td>$1.03 \pm 0.08$</td>
</tr>
<tr>
<td>$^{127}$Xe (mDRU)</td>
<td>$0.14 \pm 0.03$</td>
<td>$0.0069 \pm 0.0017$</td>
<td>&lt;0.0001</td>
<td></td>
</tr>
<tr>
<td>$^{3}$H (mDRU)</td>
<td>$0$</td>
<td></td>
<td></td>
<td>$0.17$</td>
</tr>
<tr>
<td>Neutron (mDRU)</td>
<td></td>
<td></td>
<td>$0.0022 \pm 0.0011$</td>
<td></td>
</tr>
<tr>
<td>Accidental (event/day)</td>
<td></td>
<td></td>
<td>$0.014 \pm 0.004$</td>
<td></td>
</tr>
<tr>
<td>Surface (event/day)</td>
<td>$0.041 \pm 0.008$</td>
<td></td>
<td>$0.063 \pm 0.0013$</td>
<td></td>
</tr>
</tbody>
</table>
Unblinding data and results of the WIMP search

- **WIMP**
  - NRs, separated from the ER band
  - Searching window
    - S1 [3, 45] PE
    - Fiducial volume 329 kg
- **Blinded analysis for Run 11**
- **Total 1220 events, 38 below NR median**
  - Consistent with background expectation (best fit with)

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**dR/dE example with different WIMP masses,**
\[ \sigma = 1 \times 10^{-31} \text{cm}^2 \]

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<table>
<thead>
<tr>
<th>Run</th>
<th>ER</th>
<th>Accidental</th>
<th>Neutron</th>
<th>Surface</th>
<th>Total fitted</th>
<th>Total observed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Run 9</td>
<td>381.1</td>
<td>2.20</td>
<td>0.77</td>
<td>2.13</td>
<td>387 ± 23</td>
<td>384</td>
</tr>
<tr>
<td>Below NR median</td>
<td>2.3</td>
<td>0.46</td>
<td>0.36</td>
<td>2.12</td>
<td>5.3 ± 0.5</td>
<td>4</td>
</tr>
<tr>
<td>Run 10</td>
<td>145.6</td>
<td>1.07</td>
<td>0.47</td>
<td>2.66</td>
<td>150 ± 14</td>
<td>143</td>
</tr>
<tr>
<td>Below NR median</td>
<td>1.3</td>
<td>0.23</td>
<td>0.22</td>
<td>2.65</td>
<td>4.4 ± 0.6</td>
<td>0</td>
</tr>
<tr>
<td>Run 11, span 1</td>
<td>219.4</td>
<td>1.03</td>
<td>0.59</td>
<td>6.23</td>
<td>227 ± 19</td>
<td>224</td>
</tr>
<tr>
<td>Below NR median</td>
<td>3.7</td>
<td>0.32</td>
<td>0.32</td>
<td>6.20</td>
<td>10.5 ± 1.1</td>
<td>13</td>
</tr>
<tr>
<td>Run 11, span 2</td>
<td>451.0</td>
<td>1.60</td>
<td>0.91</td>
<td>9.68</td>
<td>464 ± 30</td>
<td>469</td>
</tr>
<tr>
<td>Below NR median</td>
<td>7.5</td>
<td>0.50</td>
<td>0.49</td>
<td>9.64</td>
<td>18.2 ± 4.2</td>
<td>21</td>
</tr>
<tr>
<td>Total</td>
<td>1197.2</td>
<td>5.9</td>
<td>2.72</td>
<td>20.7</td>
<td>1227 ± 51</td>
<td>1220</td>
</tr>
<tr>
<td>Below NR median</td>
<td>14.9</td>
<td>1.51</td>
<td>1.39</td>
<td>20.6</td>
<td>38.4 ± 6.0</td>
<td>38</td>
</tr>
</tbody>
</table>

The best fitting of a 400 GeV WIMP
Event Distributions

- Distribution of events with high WIMP hypothesis likelihood (400 GeV)
- 3 events in Run 9 and 7 events in Run 11
Constraints on WIMP Model

- Spin-independent Interaction

- Exclusion limits on SI
  - \(2.0 \times 10^{-46} \text{ cm}^2\) for 15 GeV
  - \(2.1 \times 10^{-46} \text{ cm}^2\) for 40 GeV
  - \(1.4 \times 10^{-45} \text{ cm}^2\) for 400 GeV

Best-fit for \(m_c = 400\) GeV
4.2 events \(\rightarrow s_{cn} = 3.2 \times 10^{-46} \text{ cm}^2\)
p-value of 0.19 \(\rightarrow 0.92\)
Thanks for your attention!

Dr. Xiaopeng Zhou will present the searches on solar axions and neutrinos with enhanced magnetic moment.