Latest Results and Status of PandaX Experiment

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Outline

❖ WIMP search result with PandaX-II full exposure data (131.7 ton-day)

❖ Preliminary result of Axion search from low energy ER events

❖ Status of next generation PandaX-4T experiment
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
  • Prompt S1 (scintillation)
  • Delayed S2 (ionization)
  • 3-dimensional position reconstruction
  • Electron recoil vs nuclear recoil discrimination

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: 96.3 days
  - Run 11, span 2: 147.9 days

- Full data analysis
  - New position reconstruction
  - New detector response model
  - Improved background evaluation
New Position Reconstruction

❖ Turn off 7 malfunctioned PMTs
  • 5 top and 2 bottom

❖ Simulation-based position reconstruction
  • Optical simulation of the detector

❖ Trained with evenly distributed $^{83\text{m}}\text{Kr}$ calibration events
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
## 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>
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

- Interpolation from $^{218}$Po and $^{214}$Bi
- The depletion ratio measured from $^{222}$Rn calibration (end-of-run)

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**
New 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

- **PandaX-II full exposure:** 3.0±1.5 events in WIMP signal region
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 ± 0.2</td>
<td>0.18 ± 0.05</td>
<td>0.20 ± 0.06</td>
<td>0.40 ± 0.07</td>
</tr>
<tr>
<td>$^{222}$Rn</td>
<td>0.19 ± 0.10</td>
<td>0.17 ± 0.02</td>
<td>0.19 ± 0.02</td>
<td>0.19 ± 0.02</td>
</tr>
<tr>
<td>$^{220}$Rn</td>
<td>0.01 ± 0.01</td>
<td>0.01 ± 0.01</td>
<td>0.01 ± 0.01</td>
<td>0.01 ± 0.01</td>
</tr>
<tr>
<td>Flat ER (mDRU)</td>
<td>0.20 ± 0.10</td>
<td>0.20 ± 0.10</td>
<td>0.20 ± 0.10</td>
<td>0.20 ± 0.10</td>
</tr>
<tr>
<td>ER (material)</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
</tr>
<tr>
<td>Solar $\nu$</td>
<td>0.0022</td>
<td>0.0022</td>
<td>0.0022</td>
<td>0.0022</td>
</tr>
<tr>
<td>$^{136}$Xe</td>
<td>1.61 ± 0.24</td>
<td>0.57 ± 0.11</td>
<td>0.61 ± 0.12</td>
<td>0.81 ± 0.12</td>
</tr>
<tr>
<td>$^{127}$Xe (mDRU)</td>
<td>0.14 ± 0.03</td>
<td>0.0069 ± 0.0017</td>
<td>&lt; 0.0001</td>
<td></td>
</tr>
<tr>
<td>$^3$H (mDRU)</td>
<td>0</td>
<td></td>
<td>0.17</td>
<td></td>
</tr>
<tr>
<td>Neutron (mDRU)</td>
<td></td>
<td>0.0022 ± 0.0011</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Accidental (event/day)</td>
<td>0.014 ± 0.004</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Surface (event/day)</td>
<td>0.041 ± 0.008</td>
<td>0.063 ± 0.0013</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
WIMP Search

- S1 [3, 45] PE and Fiducial volume 329 kg
- Blinded analysis for Run 11
- Total 1220 events, 38 below NR median
  - Consistent with background expectation

<table>
<thead>
<tr>
<th></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>
Event Distributions

- Distribution of events with high WIMP hypothesis likelihood

- 3 events in Run 9 and 7 events in Run 11

Run 9: 26.2 ton-day
Run 11: 80.3 ton-day

[Preliminary]
Constraints on WIMP Model

❖ Spin-independent Interaction

❖ Exclusion limits on SI
• $2.1 \times 10^{-46}$ cm$^2$ for 40 GeV
• $1.4 \times 10^{-45}$ cm$^2$ for 400 GeV

❖ Will submit tomorrow

Best-fit for $m_c=400$ GeV
4.2 events -> $\sigma_{\chi n}=3.2 \times 10^{-46}$ cm$^2$
$p$-value of 0.19 -> 0.92 $\sigma$
Axion Search

❖ Axion signal in xenon detector: low energy ER events

❖ With full exposure
  • Expand the energy window to 25 keV
  • Reduce the FV to 250 kg

❖ Dominant background: Spectrum fitting to the data
  • $^{127}$Xe: decay away in Run 11
  • Flat ER: $^{85}$Kr, $^{222}$Rn, materials
  • Tritium: appearing since Run 10

❖ Critical background spectra obtained from calibration
Background Spectrum

❖ Tritium spectrum
  • Two injection calibrations
  • T1 (Right after Run 9) and T2 (End of run)

❖ Flat ER spectrum
  • Estimated from $^{220}\text{Rn}$ calibration after Run 10

❖ Systematic uncertainty
  • Detector response model parameters
  • Non-linearity of data-taking baseline suppression
  • Theoretical uncertainty
Tritium Background

- No direct measurement
- Unbinned likelihood fit on Run 10, 11-1, 11-2 independently

<table>
<thead>
<tr>
<th>Run</th>
<th>Tritium level</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>0.044±0.008 µBq/kg</td>
</tr>
<tr>
<td>11-1</td>
<td>0.050±0.010 µBq/kg</td>
</tr>
<tr>
<td>11-2</td>
<td>0.050±0.009 µBq/kg</td>
</tr>
</tbody>
</table>

- Consistent with a constant rate
  - Total fitted 0.049±0.005 µBq/kg
Background-only Fit

- Fit the data energy spectrum with tritium contribution floating
- Total data 2200 events
- Estimated background 2209.3±46.3
  - Consistent with data within 1σ

<table>
<thead>
<tr>
<th>Events</th>
<th>Run 9</th>
<th>Run 10</th>
<th>Run 11-1</th>
<th>Run 11-2</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{127}$Xe</td>
<td>81.2</td>
<td>3.7</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>tritium</td>
<td>0</td>
<td>60.4</td>
<td>73.3</td>
<td>113.9</td>
</tr>
<tr>
<td>accidental</td>
<td>1.3</td>
<td>0.6</td>
<td>0.6</td>
<td>1.0</td>
</tr>
<tr>
<td>neutron</td>
<td>0.6</td>
<td>0.4</td>
<td>0.5</td>
<td>0.7</td>
</tr>
<tr>
<td>$^{136}$Xe</td>
<td>2.6</td>
<td>2.5</td>
<td>3.1</td>
<td>4.9</td>
</tr>
<tr>
<td>flat ER</td>
<td>574.5</td>
<td>196.6</td>
<td>325.3</td>
<td>761.7</td>
</tr>
<tr>
<td>Total</td>
<td>660.2 ± 23.5</td>
<td>264.2 ± 14.8</td>
<td>402.8 ± 19.4</td>
<td>882.1 ± 31.6</td>
</tr>
<tr>
<td>Data</td>
<td>658</td>
<td>259</td>
<td>401</td>
<td>882</td>
</tr>
</tbody>
</table>
Background plus Signal Fit

- With tritium and axion contribution floating
  - Degeneracy confirmed due to similar shapes

- No significant best-fit signal yield

- Similar fitting quality to bkgd-only fit
  - Indicating limited sensitivity from our data

- Analysis is work-in-progress
New Experimental Hall at CJPL-II

- A general facility containing an ultrapure water shield of 4500 m$^3$ to host large scale DM and 0ν2β experiments
PandaX-4T Experiment

- 4-ton liquid xenon in sensitive volume
- Drift region: 1.2m(H) x 1.2m(D)
- 3-in PMTs, 169 top/199 bottom
- 1-in veto PMT 126
Expected Sensitivity

- 6-ton-year: expecting 10x more sensitive than PandaX-II
- 1-ton-year: definitive test of the XENON1T low energy ER result

![Expected Sensitivity Diagram]

- **PandaX-4T 6 ton-year**
  - SI: WIMP-nucleon $\sigma$ [	ext{cm}^2]
  - **PandaX-4T**
  - **PandaX-II (2017)**
  - **PandaX-II (2016)**
  - **XENON1T (2018)**
  - **LUX (2017)**

- **PandaX-4T 1 ton-year**
  - $g_{ae}$ [	ext{GeV}^{-1}]
  - **CAST ($m_\chi < 10$ meV)**
  - **stellar cooling**
  - **XENON1T (this work)**
Under Construction

- 10k Clean Room
- Distillation Tower
- Ultra-pure water system
- Detector
- Cooling Bus
Summary and Outlook

❖ PandaX-II has completed successfully in 2019
❖ PandaX-4T experiment, x10 more sensitive than PandaX-II, is the next generation
❖ Temporary infrastructure construction in B2 hall of CJPL-II recently completed
❖ Onsite detector assembly is work-in-progress
❖ Expected commissioning of PandaX-4T: end of 2020
❖ Stay tuned!

Thank You!
Backup
### Post-unblinding cut

<table>
<thead>
<tr>
<th>Cut</th>
<th>Run 9</th>
<th>Run 10</th>
<th>Run 11</th>
</tr>
</thead>
<tbody>
<tr>
<td>All triggers</td>
<td>24502402</td>
<td>18369083</td>
<td>49885025</td>
</tr>
<tr>
<td>Single S2 cut</td>
<td>9806452</td>
<td>6731811</td>
<td>20896629</td>
</tr>
<tr>
<td>Quality cut</td>
<td>331996</td>
<td>543393</td>
<td>2708838</td>
</tr>
<tr>
<td>DM search window</td>
<td>76036</td>
<td>74829</td>
<td>257111</td>
</tr>
<tr>
<td>FV cut</td>
<td>392</td>
<td>145</td>
<td>710</td>
</tr>
<tr>
<td>BDT cut</td>
<td>384</td>
<td>143</td>
<td>695</td>
</tr>
<tr>
<td>Post-unblinding cuts</td>
<td>384</td>
<td>143</td>
<td>693</td>
</tr>
</tbody>
</table>

Wrongly reconstructed S1 due to coherent noise pickup

2nd S2 wrongly identified as multiple S1

![Waveform Diagram](image-url)
Light Yield and Charge Yield

- Fitted from our calibration events
- Consistent with world data