The PandaX-4T Dark Matter Experiment

Low Background Control

Zhicheng Qian
Institute of Nuclear and Particle Physics
Shanghai Jiao Tong University
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Summary

Background Estimation

PandaX-4T Detector & Current Status

Introduction
Dark matter

![Graph showing velocity versus distance for dark matter observations.]

- Observations from starlight
- Observations from 21 cm hydrogen
- Expected from the visible disk

**Velocity (km s⁻¹)**

![Diagram illustrating dark matter experiments and categories: WIMP, Ionization, Light, Heat.]

- **WIMP**: CoGenT, DMTPC, DRIFT
- **Ionization**: PandaX, LUX/LZ, XENON, ArDM, Darkside
- **Light**: DAMA/UBRA, KIMS, DEAP, XMÉSS, MiniCLEAN
- **Heat**: CRESST II
- **CDMS**
- **Target**
- **PICO, Picasso, Simple, Coupp**

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Dual-phase xenon TPC technique

• S1: prompt scintillation signal
• S2: delayed ionization signal

Signal feature

Advantages of Time Projection Chamber (TPC)

• Liquid xenon shielding ability no long-life isotopes easy to be purified
• 3-D position reconstruction Z position from S1-S2 drift time X-Y positions from S2 photomultiplier (PMT) pattern
• Identification of electron recoil (ER) and nuclear recoil (NR) signals
PandaX project

PANDAX = Particle and Astrophysical Xenon Experiments

- **PandaX-I:** 120 kg
- **PandaX-II:** 580 kg
- **PandaX-4T:** 4 tons

2009 → 2014 → 2019

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China Jinping Underground Laboratory

Jingping Underground Laboratory, Sichuan, China
2400-m marble overburden

Cosmic ray flux
about 1.2 events/m²/week

Radioactivity of natural marble
$^{238}\text{U} \sim 4 \text{ Bq/kg}$, $^{232}\text{Th} \sim 0.6 \text{ Bq/kg}$, $^{40}\text{K} \sim 4 \text{ Bq/kg}$

Horizontal access
convenient

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PandaX-4T layout
Distillation system for removing $^{85}\text{Kr}$ and $^{222}\text{Rn}$

<table>
<thead>
<tr>
<th>Distillation Tower</th>
<th>PandaX-II (achieved)</th>
<th>PandaX-4T (designed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{\text{nat}}\text{Kr}$ level</td>
<td>6 ppt</td>
<td>0.1 ppt</td>
</tr>
<tr>
<td>$^{222}\text{Rn}$ level</td>
<td>$^{222}\text{Rn} \sim 25 \text{ μBq/kg}$</td>
<td>$^{222}\text{Rn}\leq1 \text{ μBq/kg}$</td>
</tr>
<tr>
<td>Operation mode</td>
<td>Offline</td>
<td>Offline and online</td>
</tr>
</tbody>
</table>

- Successfully commissioned the tower
- 0.5 ppm $^{\text{nat}}\text{Kr}/\text{Xe}$ in commercial xenon reduced to <10 ppt (RGA + cold trap system limit) after distillation
- $^{222}\text{Rn}$ can be removed during online distillation
Cryogenics and xenon handling system

• Designed total cooling power: > 360 W @ 178 K
• Operating two cooling heads (plus one spare) for ~6 tons liquid xenon, capable to liquify ~0.7 tons liquid xenon per day
• Expected flow rate of online circulation with zirconium getter ~100 slpm
# PMT, Electronics & DAQ

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Total channels</th>
<th>FADC Sampling Rate</th>
<th>Trigger mode for DM runs</th>
<th>Data transmission</th>
</tr>
</thead>
<tbody>
<tr>
<td>PandaX-II</td>
<td>158</td>
<td>100 MS/s</td>
<td>Global Trigger (for S2 signals)</td>
<td>Daisy chains, limit ~80 MB/s</td>
</tr>
<tr>
<td>PandaX-4T</td>
<td>~500</td>
<td>250 MS/s</td>
<td>Triggerless (channel self-trigger)</td>
<td>Parallel Readout, limit ×10</td>
</tr>
</tbody>
</table>

**Average rate:**
- 540 Hz for room temperature
- 20 Hz for low temperature (-60 °C in cold chamber)
- 5.5E6 for gain
- 1300-1500 V for high voltage

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TPC

Drift region: 1.2 m(H) x 1.2 m(D)

Designed field:
- Drift: 400 V/cm
- Extraction: 6 kV/cm

- 3-inch PMTs, 169 top/199 bottom
- 1-inch veto PMTs, 144

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Background Sources

Material Background
PMT, Stainless Steel, PTFE, Copper

Background in xenon target
$^{222}$Rn, $^{85}$Kr, $^{136}$Xe

Physics background
$^8$B, hep, $^7$Be neutrinos
Low Background Control

**Materials screening with variety of ultra-low radioactive detection techniques**

**HPGe**
- Sensitivity: ~mBq/kg

**ICPMS @PKU**
- Sensitivity: ~ppt

**Radon emanation measurement system**
- Sensitivity: ~2 mBq

**Krypton counting station**
- Sensitivity: ~10 ppt

**Alpha Mega detector**
- Blank rate: <24 counts/day

**Radon emanation trap system**
- Sensitivity: ~0.05 mBq
**Low Background Control**

**Before**

![Before image](image1)

**After**

![After image](image2)

**Copper plate**

**Teflon bolts/nuts**

**Rigorous cleaning procedures established**

<table>
<thead>
<tr>
<th>Copper</th>
<th>PTFE</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Degrease:</strong> 1% Alconox® + ultrasonic cleaning (2 times, 15 min each)</td>
<td><strong>Ultrapure water + ultrasonic cleaning (15 min)</strong></td>
</tr>
<tr>
<td><strong>Pickling:</strong> 1% H$_2$SO$_4$+3%H$_2$O$_2$ (5 min)</td>
<td><strong>Acetone + ultrasonic cleaning (15 min)</strong></td>
</tr>
<tr>
<td><strong>Passivation:</strong> 1% C$_6$H$_8$O$_7$ (5 min)</td>
<td><strong>Alcohol + ultrasonic cleaning (15 min)</strong></td>
</tr>
<tr>
<td></td>
<td><strong>Ultrapure water + ultrasonic cleaning (15 min)</strong></td>
</tr>
<tr>
<td></td>
<td><strong>Immersed in 35% Ultrapure HNO3 (1 week)</strong></td>
</tr>
<tr>
<td></td>
<td><strong>Ultrapure water + ultrasonic cleaning (15 min)</strong></td>
</tr>
</tbody>
</table>
Background Budget

mDRU = $10^{-3}$ events/day/kg/keV

(4.9±0.5) $\times 10^{-2}$ mDRU

- Neutrino 18%
- Inner Vessel 13%
- Outer Vessel 18%
- PMT 9%
- PTFE 1%
- Copper 2%
- $^{222}$Rn, $^{85}$Kr, $^{136}$Xe 39%

Stainless Steel

(2.8±0.5) $\times 10^{-4}$ mDRU

- Neutrino 29%
- Inner Vessel 17%
- Outer Vessel 19%
- PMT 28%
- PTFE 5%
- Copper 2%
- Neutrino 29%
- $^{222}$Rn, $^{85}$Kr, $^{136}$Xe

Fiducial mass: 2.8 tons

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Sensitivity

- Projected WIMP sensitivity is $6 \times 10^{-48}$ cm$^2$ with 5.6-ton-year exposure for 40 GeV/c$^2$ WIMP mass

<table>
<thead>
<tr>
<th>Unit: events</th>
<th>ER</th>
<th>NR</th>
</tr>
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<tbody>
<tr>
<td>2-year yield</td>
<td>2.5±0.3</td>
<td>2.3±0.4</td>
</tr>
</tbody>
</table>
Summary

- CJPL-II B2 PandaX-4T facilities is ready since 2019/8
- Rigorous material assay and cleaning procedures have been established to control the background contribution
- Subsystem installation and assembly have been completed
- PandaX-4T commissioning is ongoing
- Real data coming soon, stay tuned
Thanks.

Zhicheng Qian
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2021/5/25, TIPP 2021
## Background budget

<table>
<thead>
<tr>
<th>Sources</th>
<th>ER in mDRU</th>
<th>NR in mDRU</th>
</tr>
</thead>
<tbody>
<tr>
<td>Materials</td>
<td>0.0210±0.0042</td>
<td>(2.0 ± 0.3) × 10^{-4}</td>
</tr>
<tr>
<td>$^{222}\text{Rn}$</td>
<td>0.0114±0.0012</td>
<td>–</td>
</tr>
<tr>
<td>$^{85}\text{Kr}$</td>
<td>0.0053±0.0011</td>
<td>–</td>
</tr>
<tr>
<td>$^{136}\text{Xe}$</td>
<td>0.0023±0.0003</td>
<td>–</td>
</tr>
<tr>
<td>Neutrino</td>
<td>0.0090±0.0002</td>
<td>(0.8 ± 0.4) × 10^{-4}</td>
</tr>
<tr>
<td>Sum</td>
<td>0.049±0.005</td>
<td>(2.8 ± 0.5) × 10^{-4}</td>
</tr>
<tr>
<td>2-year yield (evts)</td>
<td>1001.6±102.2</td>
<td>5.7±1.0</td>
</tr>
<tr>
<td>after selection (evts)</td>
<td>2.5±0.3</td>
<td>2.3±0.4</td>
</tr>
</tbody>
</table>