PandaX-4T Xenon Detector For Rare Physics Search

Ning Zhou (SJTU)
On behalf of PandaX Collaboration
TIPP2017
2017/05/22-26, Beijing
Outline

• Motivation
• PandaX experiment
• 4-ton LXe detector
  – TPC
  – Electronics
  – Background control
  – Xenon handling
• Outlook
Motivation

- LXe Detector for measuring rare physics events
- Dark Matter Direction Detection
  - Xenon detectors leading sensitivity for massive DM
  - Cross-check with indirect detection and collider search
- Neutrinoless double beta decay
  - $^{136}\text{Xe} \rightarrow ^{136}\text{Ba} + 2\text{e}^-$
  - Majorana neutrino? Anti-matter? Neutrino mass?
- Neutrino detection
  - Neutrino-nucleus coherent
  - Solar $^8\text{B}$, DSNB
PandaX Experiment

- **Particle and Astrophysical Xenon Experiments**
  - Formed in 2009, ~50 people

- **PandaX-II 500kg results published at PRL**
  - World-leading sensitivity in 2016

- **Plan to build a 4-ton Xenon detector**
  - to push the DM SI sensitivity down to $10^{-47}$ cm$^2$

Phase I:
- 120 kg DM
- 2009-2014

Phase II:
- 500 kg DM
- 2014-2017

PandaX-xT:
- multi-ton DM
- 2016-

PandaX-III:
- 200 kg to 1 ton
  - $^{136}$Xe 0vDBD
- 2016-
Detector Principle

• Double phase Xenon Time Projection Chamber
  – Mature technique
  – Sensitive to massive DM candidate
  – Self-shielding property
  – Signal/background discrimination
  – ...

• Dark matter detection in Xenon detector
  – Incoming DM collide with Xenon atom
  – Two signatures
    • S1: scintillation light in LXe upon scattering
    • S2: scintillation light in GXe due to ionization electron
  – Reconstruct the collision energy and 3-D position
China Jinping Underground Laboratory

- Deepest in the world (1µ/week/m²)
- Horizontal access!
PandaX Experiment Space at CJPL-II

- Height 14m
- Width 14m
- Length 65m
- Water tank, depth of 13m
Overview of PandaX-4ton experiment

- PMT
- ADC
- Trigger

Electronics

- Storage/Filling / Recuperation
- Cooling
- Purification

Xenon Handling

Low Bkgd Measurement
- Xenon Rectifying
- Water Screening
- Bkgd Control

TPC

Drift Chamber
- Electric Field
- Veto System
Large Scale TPC

- Drift region: $\Phi \sim 1.2\text{m}$, $H \sim 1.2\text{m}$
  - Xenon in sensitive region $\sim 4\text{ton}$
- Design goal:
  - High signal efficiency
  - Large and uniform electric field
  - Veto ability
**Signal Collection Efficiency**

- In PandaX-II, photon detection efficiency reaches 11.76%
- PMT: Hamamatsu R11410 with QE > 30%

- Light collection efficiency: ~40%
  - High reflectivity of PTFE (full coverage): >98%
  - PMT dense array: 169 in circular array and 199 in hexagonal array
Electric Field

- Large and uniform electric field
  - To ensure ER/NR separation, energy and position resolution, signal efficiency, etc

<table>
<thead>
<tr>
<th>Electric Field (V/cm)</th>
<th>Drift (LXe)</th>
<th>Extraction (GXe)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Xenon100</td>
<td>530</td>
<td>12000</td>
</tr>
<tr>
<td>LUX</td>
<td>50-600</td>
<td>3000</td>
</tr>
<tr>
<td>PandaX-II</td>
<td>400</td>
<td>6000</td>
</tr>
<tr>
<td>PandaX-4ton</td>
<td>400</td>
<td>6000</td>
</tr>
</tbody>
</table>

- Four electrodes: drift and extraction
  - Anode, grid, cathode and screen

- Shaping rings:
  - 60 sets to maintain upward field at the edge
Electrodes and Shaping Rings

- **Electrodes:**
  - Diameter of 1.2 m: mesh and/or wire
  - High light transparency ~ 90%
  - Sustain high voltage of 55 kV
  - Small deformation ~1mm

- **Shaping rings:**
  - Deformation of electric field < 1%
Veto System

- Xenon in skin area: 1 ton
- Suppress gamma background
  - Compton scattering in skin area
  - Veto efficiency 50% ($50\text{keV}_{ee}$)
- 1” PMT:
  - 72 top and 72 bottom
Electronics

- More channels
  - 512 channels (including 3” PMT and 1” veto PMT)
- Lower threshold
  - Trigger-less data-taking
  - Multi-channel PMT readout
Background Control

• Germanium (Ge) detector and ICPMS
  – Measure the material radioactivity
  – Select pure materials for detector construction

• Inner and outer vessels
  – Stainless steel with the lowest radioactivity
  – Pure copper

• PTFE
  – $^{238}\text{U}$, $^{232}\text{Th} < 0.5 \text{ mBq/kg}$
**$^{85}$Kr Measurement and Rectification System**

- **$^{85}$Kr could be a major background**

- **Rectifying tower at CJPL**
  - $^{85}$Kr 1ppb -> 1ppt for 5kg/hour
  - Secondary rectification -> 0.1 ppt

- **$^{85}$Kr measurement system**
  - To reach a sensitivity of 0.1-0.01 ppt

### Table II. Summary of ER backgrounds from different com-

<table>
<thead>
<tr>
<th>Item</th>
<th>Run 8 (mDRU)</th>
<th>Run 9 (mDRU)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{85}$Kr</td>
<td>11.7</td>
<td>1.19</td>
</tr>
<tr>
<td>$^{127}$Xe</td>
<td>0</td>
<td>0.42</td>
</tr>
<tr>
<td>$^{222}$Rn</td>
<td>0.06</td>
<td>0.13</td>
</tr>
<tr>
<td>$^{220}$Rn</td>
<td>0.02</td>
<td>0.01</td>
</tr>
<tr>
<td>Detector material ER</td>
<td>0.20</td>
<td>0.20</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>12.0</strong></td>
<td><strong>1.95</strong></td>
</tr>
</tbody>
</table>
$^{222}$Rn Control

- $^{222}$Rn leaked into Xenon
- Current level at PandaX-II: 50µBq/kg
- For PandaX-4T, the goal is to reach 1µBq/kg
Xenon Handling: Storage, Cooling and Purification

• **Storage:** 5-6 ton xenon
  - 6set 4x4 (50kg, 40L)
  - Filling speed: 600 – 1000kg/day

• **Cooling bus:** 2 modules
  - modular design at PandaX-II(500kg)

• **Online purification**
  - Remove impurities (O₂, H₂O)
  - Maintain a high electron life time
Background Level

- Background from materials and neutrino

<table>
<thead>
<tr>
<th>Background for DM search [0, 10 keV_{ee}]</th>
<th>mDRU</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electronic Recoil: materials</td>
<td>0.020</td>
</tr>
<tr>
<td>Electronic Recoil: $^{222}$Rn</td>
<td>0.011 (1 µBq/kg)</td>
</tr>
<tr>
<td>Electronic Recoil: $^{85}$Kr</td>
<td>0.005 (0.1 ppt)</td>
</tr>
<tr>
<td>Electronic Recoil: $^{136}$Xe</td>
<td>0.002</td>
</tr>
<tr>
<td>Electronic Recoil: Solar Neutrino</td>
<td>0.009</td>
</tr>
<tr>
<td>Total Electronic Recoil</td>
<td>0.047</td>
</tr>
<tr>
<td>Total Nucleus Recoil</td>
<td>$3 \times 10^{-4}$</td>
</tr>
</tbody>
</table>
Expected Sensitivity

- With exposure reaching 6 ton-year
- DM SI sensitivity could reach $\sim 10^{-47} \text{cm}^2$
Project Timescale

• 2016: Project R&D started

• 2017-2018: Produce all components and test

• 2019-2020: On-site assembling and commissioning

• 2021-2022: Data-taking
Summary and Outlook

• PandaX experiment with 500kg Xenon has reached the world frontier of dark matter direct detection.
• PandaX-4ton could be a multi-purpose detector for rare signal searches like dark matter, 0vbb and neutrino.
• The new detector is expected to have very high signal collection efficiency, high energy and positron reconstruction resolution and very low background.
• With 8-year’s accumulation, PandaX collaboration plan to build the new experiment in the future ~4 years.

• Thank you!