Recent Results from the PandaX Experiment

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On Behalf of Collaboration
Outline

1. Introduction
   - Dark Matter: WIMPs, Axion, ...
   - PandaX at China Jinping Underground Lab (CJPL)

2. Operation and Data Analysis
   - Energy Calibration
   - Electrical Recoil (ER) and Nuclear Recoil (NR)
   - Rad. Background: $^{85}$Kr, $^{137}$Xe...
   - Results: WIMPs (Spin-indep. and Spin-dep.)
   - Results: Axion (preliminary)

3. Summary and Future Plan
   - Operation of PandaX-I&II
   - Upgrade: PandaX-IV (4-ton Detector)
   - Upgrade: PandaX-III ($^{136}$Xe 0vbb)
The Mass in Our Universe

Dark energy 68.3%

Dark matter 26.8%
- WIMP?
- Axion?
- Dark Photon?
- ...

Ordinary matter
WIMP? Axion? ...

**WIMP**

- May freeze out early as universe cooling down
- Extremely small CS with normal matter
- Spin-Dependent or not?

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1977, Peccei-Quinn Sym. If the Symmetry breaks

----> **Axion**

- Good Theoretical Solution
- Good dark matter candidate

\[ L_{\text{eff}} = L_{\text{QCD}} + \frac{\theta^2}{32\pi} G_{\mu\nu} G^{\mu\nu} \]
China JinPing Underground Laboratory (CJPL-I)

Deepest in the world (1µ/week/m²) and Horizontal access!

2400m
From CJPL-I ➔ CJPL-II

Headrace Tunnels

Traffic Tunnels

Exp. Halls
PandaX: a Dual-phase Xe TPC

- **Energy**: Photon(S1)+e(S2)
- **Position**: XYZ(light pattern+TOF)
- **PID**: S1/S2
  - **ER**: photon, Axion, Dark Photon…
  - **NR**: neutron, WIMP, …
PandaX @ CJPL-I&II

PandaX-I: 120 kg DM experiment 2009-2014

PandaX-II: 500 kg DM experiment 2014-2018

PandaX-xT: multi-ton (~4-T) DM experiment Future

PandaX-III: 200 kg to 1 ton HP gas $^{136}$Xe 0vDBD experiment Future

CJPL-I

CJPL-II
PandaX-II Running History

- **Engineering Running**: from the beginning of 2015, Fix various problems

- **Commissioning Run I (Run8)**: 2015.11.22 – 12.14 (19.1 days 306kg, FV) with high Kr background (Phys. Rev. D. 39, 122009 (2016))

- **Commissioning Run II (Run9)**: First Low background Running, re-distillation to remove Kr, 2016.03.09-06.30 (79.6 days) PhysRevLett.117.121303

- **Running Now** smoothly at this moment!
PandaX-II, New Features

More than Large Volume

- **New IV**: inner vessel with clean Low Rad. SS
- **New PMTs**: 55+55, 3” High Quam Eff., improved base design (±650V).
- **New Veto** PMTs in skin
- **New OC**: overflow chamber at Bottom, save expensive Xenon
- **Better Reflector**: Improved Reflectivity
Electron Lifetime

- **Commissioning Run (run 8, 19.1 days)**
- **1st Physics Run (run 9, 79.6 days)**
- **Krypton Distillation**

- 2015.11.22---12.14
- 2016.03.09---06.30

A leak in the recirculation loop discovered and fixed.
Calibration Program

- **Electrical Recoil (ER)**
  - Internal/external ER peaks:
    - Detector uniformity corrections
    - Light/charge collection parameters
  - CH$_3$T injection: tritium beta decays
    - Simulate ER background

- **Nuclear Recoil (NR)**
  - Low rate AmBe neutron source:
    - Simulate DM NR signal

- **Energy Cali.**
- **Position Cali.**
- **ER/NR Cali.**
ER cal. w/ CH$_3$T $\beta$ source

- 18.0 hours of tritium data taken, with ~2800 low energy ER events collected
- 9 events leaked below NR median, (0.32+/−0.11)%
- Consistent with Gaussian expectation

Following method from PRD93 (2016)072009
162.4 hours of **AmBe** data taken, with ~3400 low energy single scatter NR events collected

- NR median curve and NR detection efficiency determined
Radiation Background

- ER background
  - $^{85}\text{Kr}$ (suppressed by a factor 10)
  - $^{127}\text{Xe}$ (due to surface exposure of Xe during distillation)
  - Others: U/Th/Rn...
  - Accidental background (determined by data)
Radioactive background: $^{85}\text{Kr in Xe}$

$^{85}\text{Kr}$, $T_{1/2} = 10.756\text{ y}$, Beta $E_{\text{max}} = 687\text{ keV}$
Identified by delayed $\beta-\gamma$ coincidence analysis

- Uniform distribution
- Significantly reduced after distillation

Waveform: one $\beta$

One $\gamma$
Average $^{127}\text{Xe}$ rate in the low energy DM search region ($<$10 keV) estimated to be $0.42 \pm 0.10$ mDRU (DRU = evt/kg/keV/day)
# Major Radiation Background

<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>Total</td>
<td>12.0</td>
<td>1.95</td>
</tr>
</tbody>
</table>
Final selection cuts

- **Volume Cut** (FV in Run 9 with 328.9 kg)
  - **Horizontal cut** determined by distribution of events with S1 between [45,200] PE and suppressed S2
  - **Vertical cut**: Upper boundary consistent with the previous analysis; Lower boundary determined by X-events from $^{127}$Xe MC

- **Threshold**
  - **S1 cut**: [3,45] PE
  - **S2 cut**: [100raw, 10000] PE
Final WIMP candidates (run 8&9)

Run8
ER median
NR median

Run9
ER median
NR median

Total exposure: 33,000 kg-day
Searching Results: WIMPs (Spin-Indep.)

2.5x10^{-46} \text{ cm}^2

Results: WIMPs (Spin-dep.)

Data Set for Axion Searching

- Almost the same data set as WIMP-search case, but E extended to 25keV
Solar Axion Sources

- Compton-like scattering (C)
- Axion-bremsstrahlung (B),
- Atomic-recombination (R),
- Atomic-deexcitation (D)

Searching Results: Solar Axion (Preliminary)
Galactic ALP Sources

- Milky Way Dark Matter
  - on the Earth location
    \[ \rho_{DM}^{(E)} \simeq 0.3 \text{ GeV/cm}^3 \]
    \[ \Phi_A = \rho_{DM}^{(E)} \cdot v_A/m_A = 9 \times 10^{15} \frac{\beta}{m_A} \]

- Detecting Rate by something like Xe
  - \[ R \simeq g_{Ae}^2 \left( \frac{1.2 \times 10^{19}}{A} \right) \left( \frac{m_A}{\text{keV/c}^2} \right) \left( \frac{\sigma_{pe}}{\text{barn}} \right) \text{kg}^{-1} \text{day}^{-1} \]
Searching Results: (Preliminary) Galactic Axion-Like Particles
**PandaX ---- in Future**

**PandaX-I:** 120 kg DM experiment  
2009-2014

**PandaX-II:** 500 kg DM experiment  
2014-2018

**PandaX-III:** 200 kg to 1 ton HP gas $^{136}$Xe 0vDBD experiment  
Future

**PandaX-xT:** multi-ton (~4-T) DM experiment  
Future

**CJPL-I**

**CJPL-II**

Changbo Fu @PPC2017
The New Exp. Hall, CJPL-II

The Cave

The Water Pool

13m
PandaX Upgrading

(CJPL-II).

- Water Shielding
  - 5000Ton pure water
  - U/Th <10^{-14} g/g
- Rn ctrl.
  - <1mBq/m^3 in water;
  - ~10Bq/m^3 in the cave
- Fresh air
PandaX-III&IV Modules

PandaX-III(0vbb)

- Better E Res. than liquid
- Position Sensitive

150Kg $^{136}$Xe (90%)

PandaX-4T

- **6ton** total, 4ton sensitive target
- 2019—2020 on-site assembling
Using data from PandaX-II (500kg) 79.6+19.1 days data, ~33,000 kg-day exposure, No WIMP was found.
  - Limits on SD and SI WIMP-nucleon cross sections were obtained.
Using data from PandaX-II (500kg) 79.6 days data, ~27,000 kg-day exposure, No Solar or Galactic ALP was found.
  - For Solar Axion, we set constraints, including $^{57}$Fe (preliminary).
  - For Galactic ALP, we set constraints in axion mass range about $[1, 10]$keV (preliminary).

We are under preparation to the future PandaX-4T program.
We are working on $^{136}$Xe 0vbb.
PandaX Collaboration

- Shanghai Jiao Tong U (2009-)
- Peking U (2009-)
- Shandong U (2009-)
- Shanghai Inst. App Phys, CAS (2009-)
- U of Science & Tech. (2015-)
- China Inst. of Atomic Energy (2015-)
- Sun Yat-Sen U (2015-)
- Yalong Hydropower (2009-)
- U of Maryland (2009-)
- U of Zaragoza(2015-)
- Suranaree U of Tech. (2015-)