PandaX-4T Background Control Program

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On behave of the PandaX-4T collaboration
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Content

• Evidence for dark matter and landscape
• Two-phase liquid/gas Xenon(Xe) TPC
• The PandaX-4T experiment
• Background control program
• Summary
Dark matter evidence

Rotation curve of spiral galaxy M33

The dark matter landscape

From Wikipedia
Energy deposition

- **WIMP**
  - Ionization: 10% energy
  - Light: 1% energy, fastest
  - Phonons/heat: 100% energy, lowest
Detection method

CoGent (HPGe)  
DMTPC (gas dir.)  
DRIFT (gas dir.)

Ionization  
10% energy

Light  
1% energy fastest

WIMP

Phonons/heat  
100% energy lowest

Superheated liquids  
(PICO, Picasso, Simple, Coupp)

Inorganic scintillators (DAMA/LIBRA, KIMS)  
Single-phase liquid nobles (DEAP, XMASS, MiniCLEAN)

5/23/17
Detection method

CoGent (HPGe)  
DMTPC (gas dir.)  
DRIFT (gas dir.)

Ionization  
10% energy

Light  
1% energy  
fastest

2-phase nobles (PandaX, LUX/LZ,  
XENON-1T/nT, Darkside, ArDM)

Inorganic scintillators (DAMA/LIBRA, KIMS)  
Single-phase liquid nobles (DEAP, XMASS, MiniCLEAN)

WIMP

Phonons/heat  
100% energy  
lowest

Superheated liquids (PICO, Picasso, Simple,  
Coupp)
Detected method

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DMTPC (gas dir.)
DRIFT (gas dir.)

Ionization
10% energy

2-phase nobles (PandaX, LUX/LZ, XENON-1T/nT, Darkside, ArDM)

Light
1% energy fastest

Inorganic scintillators (DAMA/LIBRA, KIMS)
Single-phase liquid nobles (DEAP, XMASS, MiniCLEAN)

Semiconducting calorimeters (CDMS. Edelweiss)

Superheated liquids (PICO, Picasso, Simple, Coupp)

Cryogenic crystal (CRESST II)

Detection method

WIMP

Phonons/heat
100% energy lowest

TARGET
Two-phase TPC techniques

- **High purity Xe target**
  - High light yield
- **S1: prompt scintillation signal**
  - High light yield
- **S2: delayed ionization signal**
  - Electroluminescence in vapor phase
  - Sensitive to single ionization electrons
- **S1 + S2 event by event**
  - Electron recoil background rejection by ratio of charge(S2)/light(S1)
- **3D event reconstructions**
  - Z position from S1-S2 drift time
  - X-Y positions from S2 light pattern
  - Reject external background
China Jingping Underground Lab (CJPL)

- Deepest (6800 m.w.e )
- Horizontal access

Muon rate: 1 count/week/m²
PandaX-4T experiments

PandaX = Particle and Astrophysical Xenon Experiments

- 14m(H) x 14m(W) x 65m(L) water pool
- Water Shielding
  - 4500 Ton pure water
  - U and Th concentration < 10^{-14} \text{ g/g}

Experimental Hall

CJPL-II

Water pool for shielding
PandaX-4T experiment

PandaX-4T TPC and cryostats

TPC Drift region: $\Phi \sim 1.2m$, $H \sim 1.2m$
Background assay techniques

- High purity gamma spectroscopy
- ICPMS
- Radon emanation system
- Alpha spectroscopy
- Kr measurement system
HPGe

- Copper and lead shielding
- Vacuum chamber to avoid air radon contribution

<table>
<thead>
<tr>
<th>Type</th>
<th>Energy scale [keV]</th>
<th>Weight of Crystal [kg]</th>
<th>Relative efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>detector1</td>
<td>ORTEC P-type</td>
<td>10 - 3000</td>
<td>3.69</td>
</tr>
<tr>
<td>detector2</td>
<td>Canberra P-type</td>
<td>3-3000</td>
<td>0.63</td>
</tr>
</tbody>
</table>

Background spectrum and simulation

MDA vs energy
ICPMS

- Class-10 Cleanroom for sample preparation, Peking University
- Microwave digestion system
- Standard calibration solution
- Acid distillation system
- Copper measured protocol

<table>
<thead>
<tr>
<th>Sample</th>
<th>$^{232}$Th pg/g</th>
<th>$^{238}$U pg/g</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cu 1</td>
<td>0.22±0.07</td>
<td>0.37±0.08</td>
</tr>
<tr>
<td>Cu 2</td>
<td>0.28±0.14</td>
<td>0.37±0.07</td>
</tr>
<tr>
<td>Cu 3</td>
<td>0.27±0.07</td>
<td>0.59±0.19</td>
</tr>
<tr>
<td>Cu 4</td>
<td>0.16±0.07</td>
<td>0.58±0.04</td>
</tr>
<tr>
<td>Cu 5</td>
<td>0.14±0.07</td>
<td>0.54±0.15</td>
</tr>
<tr>
<td>Average*</td>
<td>0.21±0.06</td>
<td>0.49±0.10</td>
</tr>
</tbody>
</table>

Detection Limits:
- $0.035$ pg $^{232}$Th/g (0.14 μBq $^{232}$Th/kg)
- $0.073$ pg $^{238}$U/g (0.90 μBq $^{238}$U/kg)
Radon emanation system

Principle

Counting chambers

0.7L T-tub
Efficiency: 12.7±1.0%
Blank: 0.05±0.01mBq

7.4L chamber
Efficiency: 27.4±0.4%
Blank: 1.72±0.40mBq
Radon emanation system

Cold trap system

Emanation chambers

Volume: 400L
Blank: 22.0±0.3mBq

Volume: 7.4L
Blank: 3.03±0.45mBq
Alpha detector

- Investigate the surface radon daughters (Pb-210 and Po-210) before/after multiple cleaning methods or packing methods.
Kr measurement system

Principle

- Xenon is frozen
- Krypton is unaffected
- RGA's sensitivity is about one part in $10^6$
- Exit of the cold trap can be up to $10^6$ times enriched in krypton

Measure concentrations of krypton in a xenon sample down to the order of one part in $10^{12}$

~2 ppt
Backgrounds

**Background sources:**
- Kr-85
- Rn-222
- neutrino induced background
- cosmic muon
- neutrons/gammas from material
- surface contamination

**Assay techniques:**
- high purity gamma spectroscopy
- ICPMS
- radon emanation system
- alpha spectroscopy
- Kr measurement system

**Solutions:**
- distillation tower
- deep underground lab
- water shielding
- radon removal system
- low radioactive material selection
- low radon emanation material
- Level 1000 cleanroom
- cleanliness protocols
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Distillation Tower

- The goal of purification level: $\text{Kr/Xe} \leq 3 \times 10^{-12}$ (3ppt)
- Commercial xenon contains $10^{-6}$ of Kr. 6 order of magnitude reduction is crucial in facilitating the high-sensitivity, low-background experiments.
- High efficiency of Xe collection: 99%
- Large Xe produce rate: 10kg/h.
- Can remove Rn to 35% with online distillation via reverse operation. The flow rate for Rn removal is 56kg/h.

The boiling point of liquid xenon is 165K at 1 atmosphere, while that of krypton and radon are 120K and 211K.

Kr distillation tower for PandaX-4T
Number of Theoretical Plates: 17
Tower Height: 8m
Tower Diameter: 125mm
Backgrounds

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Deep underground lab

**Muon rate:** 1 count/week/m²

![Muon rate graph](image)

**Radon removal system**

Radon concentration:  
Input: ~130 Bq/m³  
Output: <0.4 Bq/m³ (@90% CL)
Water shielding

Water measurement with ICPMS:

<table>
<thead>
<tr>
<th></th>
<th>$^{232}$Th [ppt]</th>
<th>$^{238}$U [ppt]</th>
</tr>
</thead>
<tbody>
<tr>
<td>underground water</td>
<td>0.279±0.036</td>
<td>142.1±0.6</td>
</tr>
<tr>
<td>Ultra-pure water</td>
<td>0.064±0.016</td>
<td>0.030±0.001</td>
</tr>
</tbody>
</table>

Ultrapure water system
Background sources:
- Kr-85
- Rn-222
- Neutrino induced background
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Assay techniques:
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- ICPMS
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- Alpha spectroscopy
- Kr measurement system

Solutions:
- Distillation tower
- Deep underground lab
- Water shielding
- Radon removal system
- Low radioactive material selection
- Low radon emanation material
- Level 1000 cleanroom
- Cleanliness protocols
Low radioactive material selection

- Assay and assess all candidate detector materials and components with many dedicated screening techniques prior to adoption

<table>
<thead>
<tr>
<th>Summarize of components for the PandaX-4T experiment</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Radioactivity: mBq/unit</strong></td>
</tr>
<tr>
<td>SS 3000 kg</td>
</tr>
<tr>
<td>Copper 200 kg</td>
</tr>
<tr>
<td>PTFE 200 kg (XENON1T)</td>
</tr>
<tr>
<td>R11410 PMT 368 pics</td>
</tr>
<tr>
<td>R11410 Window(Quartz) 368 pics (XENON1T)</td>
</tr>
<tr>
<td>R11410 Stem(Al$_2$O$_3$) 368 pics (XENON1T)</td>
</tr>
<tr>
<td>R8520 PMT 144 pics</td>
</tr>
</tbody>
</table>
Background sources:
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Solutions:
- distillation tower
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- low radon emanation material
- Level 1000 cleanroom
- cleanliness protocols
Cleanliness protocols

• Level 10000 cleanroom for experimental hall
• Level 1000 cleanroom with radon free air for TPC assembly
• Material surface treatment:
  • Copper:
    degrease
    etching: Citric acid and hydrogen peroxide
    passivation: hydrogen peroxide
    clean: DI water
  • Stainless Steel:
    degrease
    etching: 20% HNO₃ + 0.1% HF
    passivation: 15% HNO₃
    clean: DI water
Summary

• Materials screening programme well underway

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

<table>
<thead>
<tr>
<th>Source</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>$^{222}$Rn</td>
<td>0.0114±0.0012</td>
<td>-</td>
</tr>
<tr>
<td>$^{85}$Kr</td>
<td>0.0053±0.0011</td>
<td>-</td>
</tr>
<tr>
<td>$^{136}$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>
</tbody>
</table>

2-year yield (evts) $1001.6\pm102.2$ $5.7\pm1.0$

after selection (evts) $2.5\pm0.3$ $2.3\pm0.4$
Thank you