PandaX Dark Matter Search

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On Behalf of the PandaX Collaboration
Outline

• Introduction to WIMP search and liquid xenon experiments
• PandaX experiment and China Jinping Underground Laboratory
  ➢ Published results from PandaX
• 2017 data and preliminary physics analysis
• PandaX Future
After 30 years of direct detection and over 5 orders of magnitude improvement in detection sensitivity, WIMPs are still at large!

Theorists are getting impatient...
Salient points:

- Indirect detection in AMS-II (and DAMPE, soon) might have observed tantalizing signals at TeV scale that could come from DM annihilation.
- Experimental sensitivity has covered only part of regions where theories predict.
- We are still 3 orders of magnitude away from the “neutrino floor”, after which experimental handle “may” still exist.
Xenon experiments are leading the pack

• Xenon has no long-lived radioactive isotopes that contaminate the search ($^{136}\text{Xe}$ ββ-decay and Rn might become important in very large detectors).

• Xenon dual-phase technology measures both scintillation and charge, allowing excellent self-shielding and exploiting electric/nuclear recoil differences

• There appears no show stopper yet on the large size xenon dual phase technology

Past and present: 10kg ➔ 100kg ➔ 250kg ➔ 500kg ➔ 2ton

Future ➔ 7 ton ➔ 30 ton? ➔ 100 ton?
Dual phase xenon experiments

Dark matter: nuclear recoil (NR)

γ background: electron recoil (ER)

Multi-site scattering background (ER or NR)

\((S2/S1)_{NR} \ll (S2/S1)_{ER}\)
Three xenon experiments (using similar tech)

- **XENON collaboration** (led by Columbia U, jointly by a few other inst. in US and a large European participation, funded by NSF and European agency)
  - XENON10, XENON100, XENON1T, XENONnT
- **LUX-(ZEPLIN) collaboration** (mainly US and British Inst., funded by DOE)
  - LUX(250kg), LZ(7ton)
- **PandaX collaboration** (SJTU and coll. Inst., funded by Chinese agencies)
  - PandaX-I, PandaX-II, PandaX-4T, PandaX-30T
LUX

- Combination of both science runs (95+332 live-days)
- SI cross section limit, \(1.1 \times 10^{-46} \text{ cm}^2 @ 50 \text{ GeV/c}^2\)
- Currently also leading the SD WIMP-n sensitivity
XENON1T First Results  (talk tomorrow afternoon)

- World leading bkg level: $0.2 \times 10^{-3}$ evt/day/kg/keV
- First SR: 1024 kg x 34.2 day, no candidate found
- Minimum limit: $7.7 \times 10^{-47}$ cm$^2$ @ 35 GeV

largest LXe TPC ever built
cylinder: $96 \times 97$ cm
active LXe target: 2.0t (3.2t total)
248 PMTs (Hamamatsu R11410-21)

arXiv:1705.06655
PandaX experiment and Jinping Underground Laboratory
PandaX collaboration

Started in 2009

- Shanghai Jiao Tong University (2009-)
- Peking University (2009-)
- Shandong University (2009-)
- Shanghai Institute of Applied Physics, CAS (2009-)
- University of Science & Technology of China (2015-)
- China Institute of Atomic Energy (2015-)
- Sun Yat-Sen University (2015-)
- Yalong Hydropower Company (2009-)
- University of Maryland (2009-)
China Jinping Underground Laboratory

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

\( \text{PANDA}_X = \text{Particle and Astrophysical Xenon Experiments} \)

**Phase I:**
- 120 kg DM
- 2009-2014

**Phase II:**
- 500 kg DM
- 2014-2018

**PandaX-xT:**
- multi-ton DM
- future

**PandaX-III:**
- 200 kg to 1 ton
- \(^{136}\text{Xe} 0\text{vDBD}
- future
First delivery of PandaX equipment to Jinping lab, Aug. 16, 2012
PandaX apparatus
Final Results from PandaX-I

- Completed in Oct. 2014, with 54.0 x 80.1 kg-day exposure
- Data strongly disfavor all previously reported claims
- Competitive upper limits for low mass WIMP in xenon experiments
PandaX-II Detector

- 60 cm x 60 cm cylindrical TPC
- 580-kg of LXe in sensitive region, 1.2-ton LXe in total
- 55 top + 55 bottom R11410 3” target PMTs (split –ve and +ve HV)
- 24 top + 24 bottom R8520 1” VETO PMTs
Configuration of fields

<table>
<thead>
<tr>
<th></th>
<th>Cathode (-kV)</th>
<th>Gate (-kV)</th>
<th>Drift field (V/cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Run9</td>
<td>-29.3</td>
<td>-4.95</td>
<td>400</td>
</tr>
<tr>
<td>Run10</td>
<td>-24.0</td>
<td>-4.95</td>
<td>320</td>
</tr>
</tbody>
</table>

Ref: LUX: 180 V/cm, XENON1T: 120 V/cm

Drift field in Run10 was lowered to avoid spurious discharge from the cathode.
PandaX-II run history

- Mar. 9 – June 30, low background with 10-fold reduction of Kr (Run9, 79.6 days)
- Nov. 22 – Dec. 14, Physics commission (Run8, 19.1 days, stopped due to high Krypton background)
- Jul – Oct, ER calibration & tritium removal
- Nov. 2016 – Apr 2017, 2nd distillation campaign and recommissioning
- Apr. 22 – July 15, dark matter data taking (Run10, 77 days)

- Run9 = 79.8 days, exposure: 26.2 ton-day
- Run10 = 77.1 days, exposure: 27.9 ton-day
- Largest reported DM exposure to date
PandaX-II Run8+9 SI and SD results

Minimum elastic SI exclusion:
$2.5 \times 10^{-46} \text{ cm}^2$ @ 40 GeV/c$^2$

Minimum $\chi$-n SD cross section limit:
$4.1 \times 10^{-41} \text{ cm}^2$ at 40 GeV/c$^2$
Run9 axion search results

Among the leading axion search on axion-electron coupling using DD experiments
Run9 on inelastic dark matter

- Opened up energy window to access initial-final mass difference up to 300 keV (high mass DM, ~TeV)
- Tightest direct constraint on this to date (to be published)
2017 new data and results
New SI DM search results from Run10

- Improved trigger threshold
- Channel-by-channel SPE efficiency ($\varepsilon_{ZLE}$)
- Improved detector ER/NR response model
- 2.5 times reduction in total background
  - $\text{Kr85} \downarrow 6 \text{ times}$
  - Accidental $\downarrow 3 \text{ times}$
  - $\text{Xe127} \downarrow 13 \text{ times}$
ER calibration using tritiated methane (a technique pioneered by LUX collaboration)

- Selected data with electron lifetime $\sim 700 \, \mu$s, $\sim 8000$ low energy ER events
- Events leaked below the NR median: 0.53(8)%
- Consistent with Gaussian estimate

99.9% NR acceptance from MC

AmBe band median

$S_2 > 100PE$
NR calibration with AmBe data

A tuning of the $N_{ex}/N_{i}$ (excitation/ionization) parameter was made on the NEST model, after which data and MC yield good agreement.
### Background level

<table>
<thead>
<tr>
<th></th>
<th>Run9 (mDRU)</th>
<th>Run10 (mDRU)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Xe127</td>
<td>0.42</td>
<td>0.033</td>
</tr>
<tr>
<td>Tritium</td>
<td>0</td>
<td>0.22</td>
</tr>
<tr>
<td>Kr85</td>
<td>1.19</td>
<td>0.20</td>
</tr>
<tr>
<td>Rn222</td>
<td>0.13</td>
<td>0.10</td>
</tr>
<tr>
<td>Rn220</td>
<td>0.01</td>
<td>0.02</td>
</tr>
<tr>
<td>Detector ER</td>
<td>0.20</td>
<td>0.21</td>
</tr>
<tr>
<td>Solar neutrino</td>
<td>0.01</td>
<td>0.01</td>
</tr>
<tr>
<td>Xe136</td>
<td>0.0022</td>
<td>0.0023</td>
</tr>
<tr>
<td>Total</td>
<td>1.95</td>
<td>0.79</td>
</tr>
</tbody>
</table>

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

Original $^{127}$Xe (cosmogenic, 36-day $\tau_{1/2}$)
gone, additional introduced by a fresh “surface” bottle. Down 13 times

Based on best fit to data (later)

Reduced 6 times

These are consistent between Run 9 and Run 10

Reduced 2.5 times
Event reduction after consecutive cuts

<table>
<thead>
<tr>
<th></th>
<th>Run 9</th>
<th>Run 10</th>
</tr>
</thead>
<tbody>
<tr>
<td>All triggers</td>
<td>24502402</td>
<td>18369083</td>
</tr>
<tr>
<td>Low E search window</td>
<td>131097</td>
<td>111856</td>
</tr>
<tr>
<td>Final candidate in FV</td>
<td>389</td>
<td>177</td>
</tr>
</tbody>
</table>

Run10 background level significantly reduced.
Events @ large radius with suppressed S2: electron loss on the wall due to field irregularity
The noisy outer PMT caused biased reconstructed position, particularly for suppressed S2 (deeper in the TPC)
Residual events are uniformly distributed in the detector

All high level cuts remained identical in Run9 and Run10 except the vertical drift time cut (different drift field)
FV = 361.5 kg of LXe
Distribution of events (run10)

Total events: 177
- Expected background below NR median: 2.05 evts with ~20% uncertainty
- Observed: 0

Appears to have a downward fluctuation of background!
Energy spectrum

- MC: best fit background (fixed shapes). All components agree with expectation within uncertainties
- Data and expected background in good agreement
Combined analysis with Run9

- Total exposure = 54 ton-day (world largest set)
- Background separately estimated in two runs but with common systematics
- Combined likelihood function with background: flat ER ($^{85}$Kr, Rn and others), $^{127}$Xe, tritium, accidental, neutron)
- PDFs produced by MC with tuned ER/NR and detector models

$$\mathcal{L}_{\text{pandax}} = \left[ \prod_{n=1}^{n_{\text{set}}} \mathcal{L}_n \right] \times \left[ G(\delta_{\text{DM}}, \sigma_{\text{DM}}) \prod_b G(\delta_b, \sigma_b) \right].$$

$$\mathcal{L}_n = \text{Poiss}(N_{\text{meas}}^n | N_{\text{exp}}^n) \times \left[ \prod_{i=1}^{N_{\text{meas}}^n} \frac{N_{\text{DM}}^n (1 + \delta_{\text{DM}}) P_{\text{DM}}^n(S_i^1, S_i^2)}{N_{\text{exp}}^n} + \sum_b \frac{N_b^n (1 + \delta_b) P_b^n(S_i^1, S_i^2)}{N_{\text{exp}}^n} \right].$$

Example PDFs:
- flat ER
- 1 TeV DM
Preliminary Results on elastic SI DM-nucleon scattering

- Profile likelihood fits made to the data in grids of \((m_{\chi}, \sigma_{\chi})\).
- 90% upper limits produced comparison of test statistic to toy MC, and power-constrained to \(-1\sigma\).
- Improved from PandaX-II 2016 limit \(~4\) times for mass\(>30\) GeV.
- More constraining than LUX and XENON1T 2017.
- Best limit, is \(6\times10^{-47}\) cm\(^2\) at \(m_{\chi} \sim 45\) GeV.
- talk by Y. Yang, tomorrow afternoon.
PandaX Future
PandaX new home: CJPL-II

8 experimental Halls, 14(H)x14(W)x65(L) m each.

B2, PandaX site!
Experimental hall
PandaX-xT Experiment

- Preparing new experiments in CJPL-II, hall #B2
- Intermediate stage:
  - PandaX-4T (4-ton target) with SI sensitivity $\sim 10^{-48}$ cm$^2$
  - On-site assembly and commissioning: 2019-2020
- Eventual goal: G3 xenon dark matter detector ($\sim 30$T) in CJPL to “neutrino floor” sensitivity
PandaX-III: High pressure $^{136}$Xe TPC

- 0νDBD signal: two electrons emitting from the same vertex with a summed energy at the Q value (tracking essential)
- TPC: 200 kg, 10 atm, symmetric, double-ended charge readout plane with micromegas module with cathode in the middle
- Four more upgraded modules for a ton scale experiment
- Published CDR recently: ArXiv:1610.08883
Conclusion

• Searching for WIMPs is far from over.
• PandaX experiment since 2012 has gone through two generations of detectors, improving detection sensitivity by almost three orders of magnitude.
• The most recent result has the world-largest exposure (54 ton-day), setting a currently leading WIMP detection sensitivity, particularly at TeV scale. (The best limit is $6 \times 10^{-47}$ cm$^2$ at $m_\chi \sim 45$GeV).
• PandaX will continue to develop larger scale detectors.