PandaX-III: a high pressure Xenon detector for neutrinoless double beta decay search

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On behalf of the PandaX-III collaboration

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I. $0\nu\beta\beta$ and PandaX project

II. PandaX-III experiment
   ➢ Design of detector and subsystems
   ➢ Performance expected
   ➢ PandaX-III prototype TPC

III. Conclusions and perspectives
\[ \frac{N}{Z} A \rightarrow \frac{N-2}{Z+2} A + 2\beta^- + 2\bar{\nu}_e \]

- 2\nu\beta\beta: 11 isotopes
- 0\nu\beta\beta: Majorana Neutrino? Lepton number violation?

- Measure energies of emitted e\(^{-}\), tracks

\textbf{Q value of} \[ ^{136}\text{Xe} \rightarrow ^{136}\text{Ba} \]:
2457.83(37) keV

\textit{PRL} 98, 053003(2007)
$0\nu\beta\beta$ experiments

Kamland-Zen
$^{136}\text{Xe}$
$T_{1/2} > 1.07 \times 10^{26} \text{ y}$

CUORE
$^{130}\text{TeO}_2$
$T_{1/2} > 1.5 \times 10^{25} \text{ y}$

Gerda
$^{76}\text{Ge}$
$T_{1/2} > 8 \times 10^{25} \text{ y}$

0$\nu\beta\beta$ search by energy
PandaX project overview

Dark matter WIMP searches

PandaX-I: 120kg LXe (2009 – 2014)

PandaX-II: 500kg LXe (2014 – 2019)

0νββ searches

PandaX-4T: 4T LXe (commissioning)

PandaX-III: HPXe 140kg - 1 ton (future)

PandaX-III collaboration

- **China**: SJTU, USTC, Peking University, CIAE, Shandong University, CCNU
- **Spain**: Universidad de Zaragoza
- **France**: CEA Saclay
- **US**: University of Maryland, LBNL
- **Thailand**: SUT
PandaX-III: search for 0νββ of $^{136}\text{Xe}$

- First phase: 140 kg of 90% $^{136}\text{Xe}$ enriched gas TPC (Time Projection Chamber).
- Final phase: a ton scale experiment (5 modules of 200 kg).
- @ Hall #B2 at China Jin Ping underground Lab (CJPL-II): 5 m of ultra-clean water shielding in all directions

PandaX-III detector of first phase: $\text{Long} \times 2R$ of TPC : $1.2 \times 1.6\text{m}$

Tank of water at CJPL-II

Tank of water at CJPL-II

China Jinping Deep Underground Laboratory (CJPL)

rock overburden of 2400 m $\Rightarrow$ muon rate of 1/m²·week
PandaX-III detector of 1st phase

- 10 bar Xe-(1%)TMA (trimethylamine)
- Dry shielding
- TPC: Single-end charge readout on the upper side, the cathode on the bottom
- 52 20X20 cm² Microbulk Micromegas (Micro-Mesh Gaseous Structure) for charge readout
- Readout: 2 series of strips (x, y)
HP SS (Stainless Steel) vessel

- **Vacuum pump**
- **High voltage power**
- **Gas inlet or outlet**
- **The forth one is backup**

**2×DN10, gas inlet or outlet**

**12×DN80, signal cables are glued in flanges**

**52 Microbulk Micromegas**
- 20 X 20 cm
- 3 mm pitch size, 128 strip readouts

**The second 2×DN10 flange is backup**
• Micromegas and SR2M module

  • Microbulk Micromegas (MMs):
    - Radio-purity: made of Copper and Kapton
    - Amplification: ~thousand (T-REX) at 10 bar Xe:TMA (trimethylamine) (99%:1%)
    - Energy resolution: 3% FWHM expected at 2.5 MeV (Q value of $^{136}\text{Xe}$ $0\nu\beta\beta$).

  • Scalable Radio-pure Readout Module (SR2M)
    - Designed by Zaragoza and SJTU
    - MMs films produced at CERN
    - 1st version: MMs film glued on a copper supporter
    - The surface of MMs in the prototype TPC bulged
    - 2nd version: Tensing
The new version of SR2M

- Mechanically tense the Micromegas to avoid any glue
- Horizontal position fixed by the holders at both ends
- Longitudinal position fixed by the position pins/holes
- Tension provided by the lifted pressers
Kapton Flexible PCB + SMD resistors

- We are testing this option with mini-TPC and prototype TPC at SJTU

Field cage in mini-TPC

Design of field cage of full TPC
Gas system for PandaX-III in CJPL-II

- Filling and mixing system;
- Circulation purification system;
- Emergency recovery;
- Pumping port;
- Sample port.

TMA bottle (3.7L, ~2.5Kg TMA)
Regulator with bypass
Xenon bottles

FM

Pump with bypass
4L buffer, with a dewar

bypass
Hot Purifier with valves
Room_T Purifier with valves

Detector
PandaX-III calibration

• External system
  - Measure non-linearity in the detector energy response
  - Absolute calibration at Q value of $0\nu\beta\beta$
  - Calibration sources: $^{22}\text{Na}$, $^{60}\text{Co}$, $^{137}\text{Cs}$ and $^{232}\text{Th}$

• Internal system
  - To generate events deep in the TPC with high calibration rate
  - Calibration sources (gas): $^{220}\text{Rn}$ and $^{83m}\text{Kr}$
  - To calibrate energy response at Q value by using $^{220}\text{Rn}$
  - To calibrate MM(s) uniformity and geometrical corrections by using $^{83m}\text{Kr}$
Background budget and projected sensitivity

Reconstruction of the projected electron tracks (XZ and YZ) produced by two Monte Carlo simulated events

Background rate: $1 \times 10^{-4}$ c/keV/kg/y in the ROI:
- Two independent Geant-4 MC: RESTG4 and BambooMC
- Topological analysis
  - Convolutional neural networks
  - Traditional track reconstruction

Sensitivity expected of 3 years’ live time:
- First module: $8.5 \times 10^{25}$ y half-life limit
- Ton-scale: $10^{27}$ y half-life limit
Overview of Prototype TPC

Prototype TPC (20kg Xe at 10bar in active region) with 7 MMs
- Optimization for the design of MMs and readout plane
- Energy calibration of TPC
- Track reconstruction

1bar Ar-5%iso

1bar Xe-1%TMA

5bar Xe-1%TMA
Status of the others

Electronics system

145 kg $^{136}$Xe enriched at SJTU

Internal calibration

Simulation and data analysis
Conclusions and perspectives

- PandaX-III uses high pressure gas TPCs to search for double beta decay of $^{136}\text{Xe}$
- Gas TPC provides unique background suppression with tracking capability
- Phased approach: 140 kg first, then ton-scale with multiple modules
- 20-kg scale prototype TPC with 7 MM has been built and under commissioning
- The construction of the detector and the subsystems are going on
Thank you!

More details from our CDR:
SCIENCES CHINA Physics, Mechanics & Astronomy 60(6), 061011(2017)
ArXiv:1610.08883
Event from calibration source $^{241}$Am

(a)

(b)

(c)

(d)
Microbulk Micromegas (MM)

- Microbulk Micromegas (Micro-Mesh Gaseous Structure)
- Radio-purity: made of Copper and Kapton
- Amplification: $\sim 1000X$ (T-REX) at 10 bar Xe:TMA (trimethylamine) (99%:1%)
- Energy resolution: 3% FWHM expected at 2.5 MeV (Q value of $^{136}$Xe $0\nu\beta\beta$)

S. Aune et al., *JINST* 9 (2014) P01001

Micromegas in PandaX-III

- Scalable Radio-pure Readout Module (SR2M)
  - Solderless system
  - Strip and mesh signal readout
  - Dead-zone-free arrangement
  - Designed by Zaragoza and SJTU
- 11 MMs produced at CERN:
  - 20 X 20 cm
  - 3 mm pitch size, 128 strip readouts
parameters of the electron swarm for Xenon–TMA admixtures

![Graphs showing drift velocity vs. electric field strength for different TMA concentrations.]

Figure 1. Simplified schematic of Xe and TMA reactions after initial ionization and excitation of Xe. We made the first direct measurement of the processes shown with red arrows.