Design and commissioning of the PandaX-III prototype time projection chamber

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outline

Neutrinoless double beta decay (NLDBD)

PandaX-III experiment

PandaX-III prototype TPC

• detector setup

• commissioning in Argon and Xenon
Neutrinoless double beta decay (NLDBD)

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Neutrinoless double beta decay (NLDBD)

Neutrino mass origin

\[ \nu(\bar{\nu}) \rightarrow \text{<Dirac mass>} \rightarrow \nu(\bar{\nu}) \]

Or

\[ \nu(\bar{\nu}) \rightarrow \text{<Majorana mass>} \rightarrow \bar{\nu}(\nu) \]

\( (A, Z) \rightarrow (A, Z + 2) + 2e^- + 2\bar{\nu} \)

Neutrinoless Double Beta Decay (NLDBD)

The neutrinoless double beta decay equivalent to the Majorana neutrino Schechter and Valle, Phys. Rev. D25 (1982) 2951
Neutrinoless double beta decay (NLDBD)

**NLDBD experiment**

(A, Z) → (A, Z + 2) + 2e^- + (2\bar{\nu})

**Kamland-Zen**

\[ ^{136}\text{Xe} \]

\[ T_{1/2} > 1.07 \times 10^{26} \text{ y} \]

Illustration of the DBD spectrum

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**CUORE**

\[ ^{130}\text{TeO}_2 \]

\[ T_{1/2} > 1.5 \times 10^{25} \text{ y} \]

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**GERDA**

\[ ^{76}\text{Ge} \]

\[ T_{1/2} > 8 \times 10^{25} \text{ y} \]

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A. Gando et al.  

C. Alduino et al.  
Phys. Rev. Lett. 120:132501, 2018

M. Agostini et al.  
outline

Neutrinoless double beta decay (NLDBD)

PandaX-III experiment

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• detector setup

• commissioning in Argon and Xenon
China Jin-Ping underground Laboratory

- Rock overburden of 2400 m
- Muon rate of $1/m^2 \cdot \text{week}$
- Water tank with a volume of $5000 \text{ m}^3$
PandaX-III experiment

High pressure gaseous TPC

Time Projection Chamber (TPC)

200 kg of xenon at 10 bar in the fiducial volume

- Long tracks in gas

The preliminary design of the PandaX-III detector
Identifying tracks: total background suppression rate of ~35%

- The energy “blob” at the end of the tracks
- Number of tracks

With the expected background suppression rate,

- expected total background rate of ~$1 \times 10^{-4}$ cts/keV·kg·year
- expected detection efficiency of 35%
- expected energy resolution of 3% (FWHM) at $^{136}$Xe Q value

the simulated exclusion sensitivity of the 200 kg detector (90%) after 3 year’s exposure is $1 \times 10^{26}$ years for the NLDBD half life.
Neutrinoless double beta decay (NLDBD)

PandaX-III experiment

**PandaX-III prototype TPC**

- detector setup
- commissioning in Argon and Xenon
The vessel

- A stainless steel vessel with a thickness of 8 mm and a volume of ~600 L
- Test with 15 bar nitrogen and 10 bar xenon/argon
Micromegas as the readout plane

Micro mesh gaseous structure

The readout plane

Micromegas module

Top flat flange

Through hole for hanging rods

Copper ring

Micromegas holding plate

PMT slot

Diameter: 880mm
Micromegas module

The active surface of Micromegas: 20 cm×20 cm film with thickness 0.2 mm, made from kapton & copper

The amplification hole is 50 μm in both depth and diameter

Chess board repartition of the 2D phase, forming a "mesh". Read out with 64 Y strips and 64 X strips

Zoom view of the corner of the Micromegas surface
**Micromegas module**

Copper backboard

Copper rim embedded in side PTFEs

Field simulation with the rims working

- Drift field: 100 V/cm

"Dead zone" without the rim

- Mesh: -600V
- Int rim: -650V
- Ext rim: -800V
Micromegas module

128 strip readouts and 4 pairs of electrode integrated on one soft kapton “tail”

Glued with epoxy on the flange; measured leak rate: <2 g (xenon)/feedthrough · year

connected to a flexible kapton cable

**Electronics:**
- AGET (ASIC for Generic Electronic system for TPCs)
  - Sampling frequency up to 100 MHz
  - 512 sampling points
  - Dynamic range from 120 fC to 10 pC
Field cage and cathode

Field cage:
59 copper shaping rings in a drift length of 78 cm

Cathode:
1 cm Teflon shielding

0.01 mA at -79.5 kV in open air;
<0.01 mA at -95.0 kV in 10 bar nitrogen
Neutrinoless double beta decay (NLDBD)

PandaX-III experiment

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Tracks and hitmap

A muon track in 5 bar Xe+(1%) TMA

A gamma track in 1 bar Ar+(5%) isobutane

Hitmap of the track centers in 5 bar Xe+(1%) TMA
The gain curve vs purification time in xenon mixture

stable after 200 hours

The electron transmission (ET) curve in argon mixture

Field contraction in the drift region

The amplification field is fixed at (74 kV/cm); the drift field from 0.039 to 0.149 kV/cm


High recombination rate
In 1 bar Argon+(5%) Isobutane
PandaX-III prototype detector – Commissioning with 1 Micromegas

Simulated spectrum

Smeared spectrum ($\sim \sqrt{E}$) in 1 bar Ar+(5%) isobutane

Smeared spectrum ($\sim \sqrt{E}$) in 5 bar Xe+(1%) TMA (with cut applied)

$^{237}$Np peak

$^{241}$Am peak

$xenon$ escape peak

$^{241}$Am source put inside the detector
Drift field = 0.123 kV/cm; Amplification field = 74 kV/cm;

Cut:

- Cut the triggered channels per event
- Cut the baseline variations, pulse shape, etc.
- Positioning cut: avoid dead strips

11.9% FWHM resolution at 17.8 keV
PandaX-III prototype detector – Commissioning with 1 Micromegas

Result in 5 bar Xe+(1%)TMA

Drift field = 0.333 kV/cm; Amplification field = 88 kV/cm;

After applying the similar cut criteria to choose target gamma events:

15.4% FWHM resolution at 59.5 keV

19.3% at 29.0 keV,
28.2% at 26.3 keV,
22.7% at 17.8 keV,
and 36.5% at 13.9 keV.
PandaX-III prototype detector – Commissioning with 7 Micromegas

**Commissioning with 7 Micromegas**

**Hitmap of the track centers in 5 bar Ar+(5%) Isobutane**

- 13.9 to 17.8 keV peak (Am$^{241}$)
- 59.5 keV peak (Am$^{241}$)
- 32 keV peak (Cs$^{137}$)

Spectrums for events near the Cs$^{137}$ source

Spectrums for events near the Am$^{241}$ source
Conclusion

The Pandax-III experiment:

- an underground search for the neutrinoless double beta decay of $^{136}$Xe, sited at CJPL-II;
- PandaX-III utilizes the high pressure (10 bar) gaseous TPC with an active xenon mass of 200 kg, and Micromegas as the readout plane.

The Pandax-III prototype:

- A prototype TPC with an active mass of 20 kg of xenon at 10 bar
- A tesselation of 7 Micromegas modules as the readout plane
- Commissioning with 1 Micromegas, achieving an energy resolution of 11.9% at 17.8 keV in Ar-Isobutane; 15.4% at 59.5 keV in Xe-TMA;
- Commissioning with 7 Micromegas in Argon and Xenon
Thank you!