Enhanced Search Sensitivity to Double Beta Decay of ^{136}Xe to Excited States with Topological Signatures

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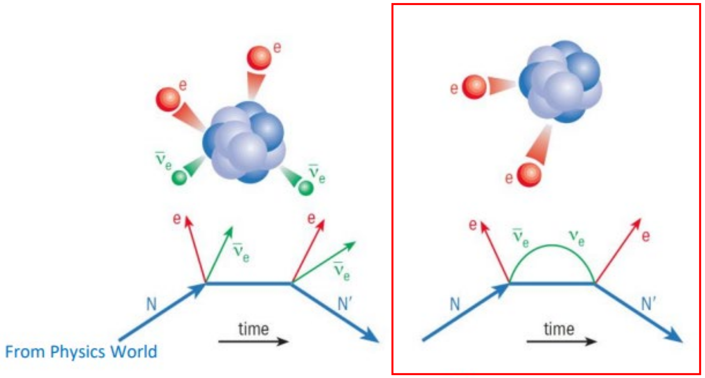
2021/11/16

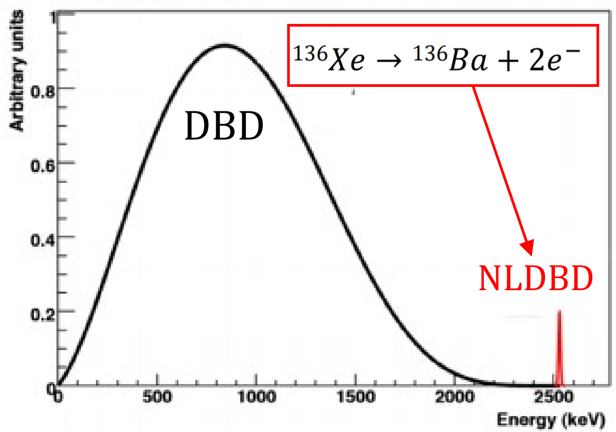
PandaX-III group: search for NLDBD of ^{136}Xe

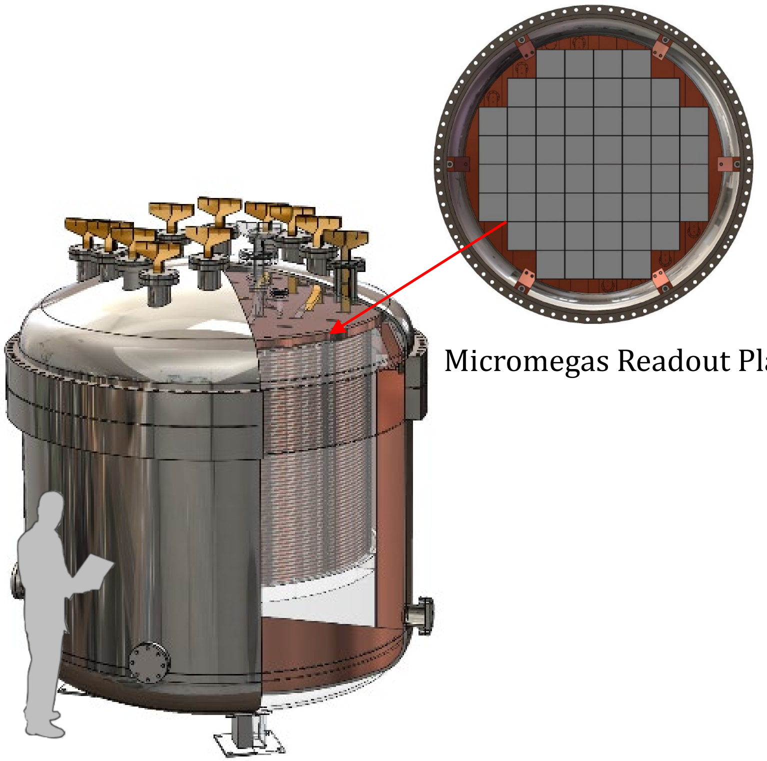
- TPC: 140 kg scale high pressure gaseous TPC with 52 20×20cm^2 Micromegas
- Main design features: good energy resolution and tracking capability

DBD NLDBD



Majorana Neutrino $\bar{\nu} = \nu$





PandaX-III detector of first phase

Location of PandaX series experiments

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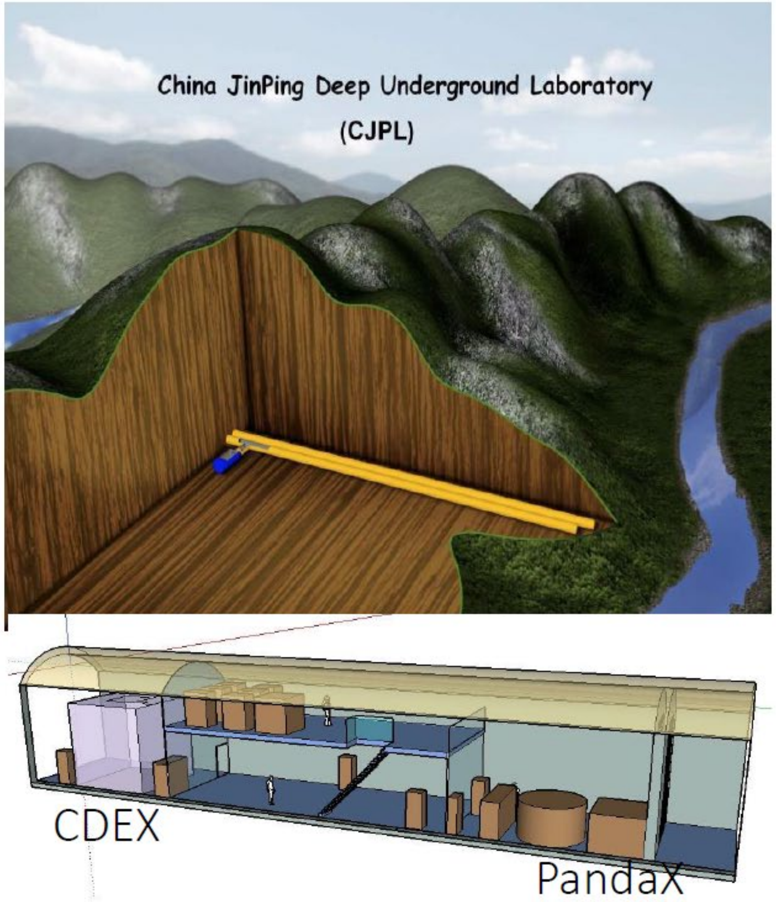
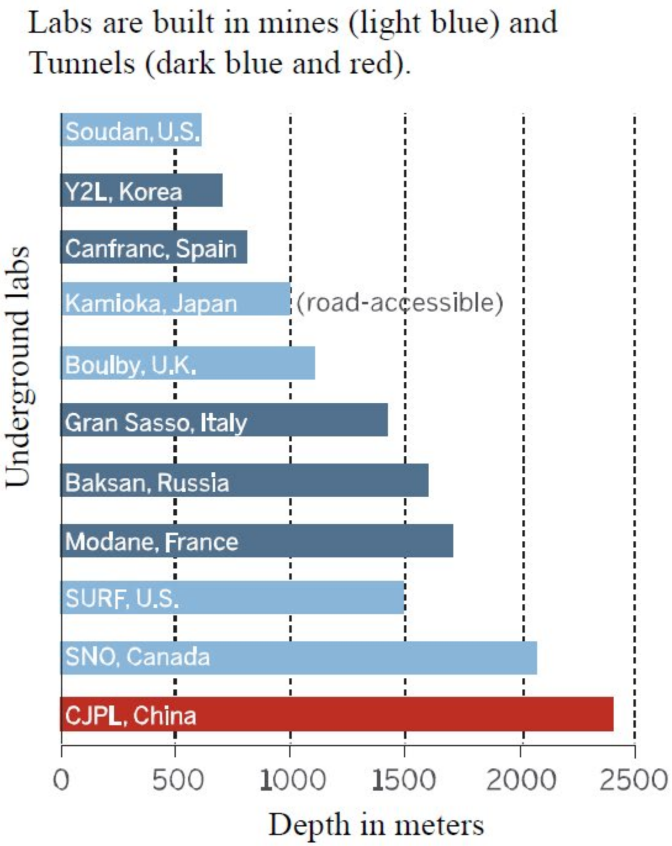




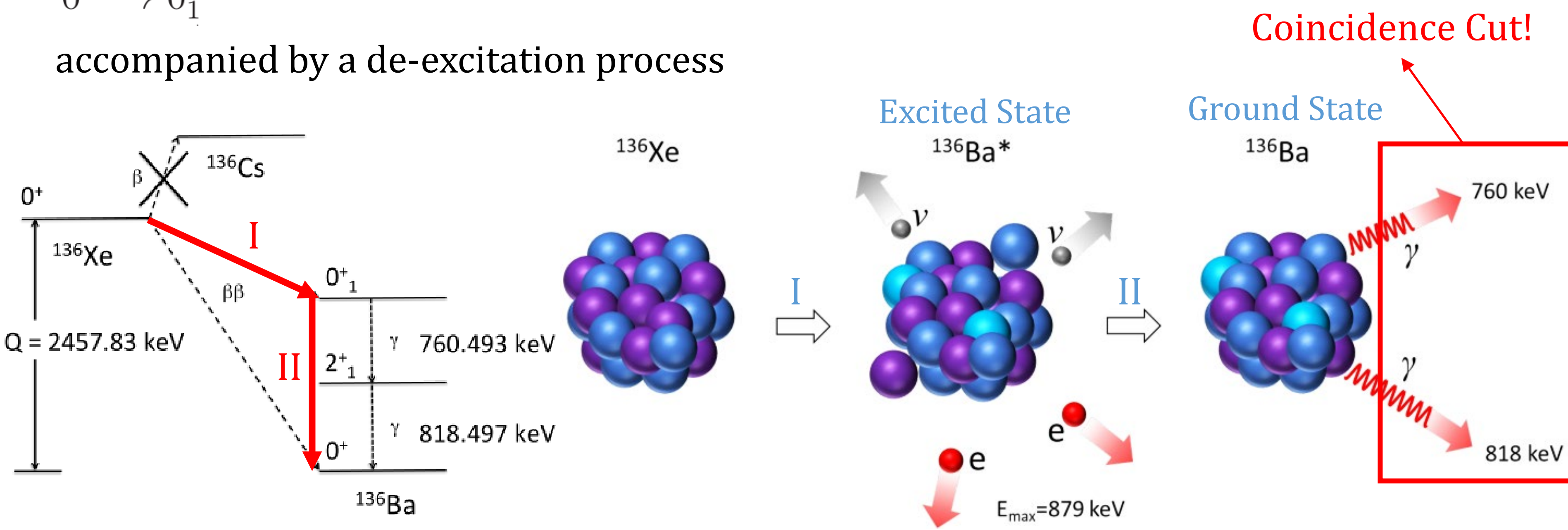
The schematic diagram (left) and depth of China Jinping Underground Laboratory

Master thesis work:
I. Simulation of (NL)DBD-ES of ^{136}Xe
II. Hardware work

- NLDBD-ES of ^{136}Xe:

  $0^+ \to 0_1^+$

  accompanied by a de-excitation process



- Motivation:

  To identify NLDBD-ES signals from various background

Component	Material	Size	Activity ^{238}U	^{232}Th	^{60}Co	^{40}K
Vessel	Stainless Steel	2.5 t	500 μBq/kg	320 μBq/kg	-	-
Liner	Copper	22.63 t	0.75 μBq/kg	0.2 μBq/kg	2	23
Field Cage	Acrylic	723 kg	13.68 μBq/kg	4.48 μBq/kg	-	-
Micromegas	Copper	2 m^2	45 nBq/cm^2	14 nBq/cm^2	-	-

Work Flow

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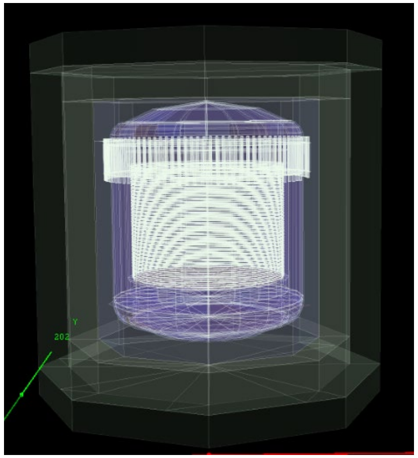
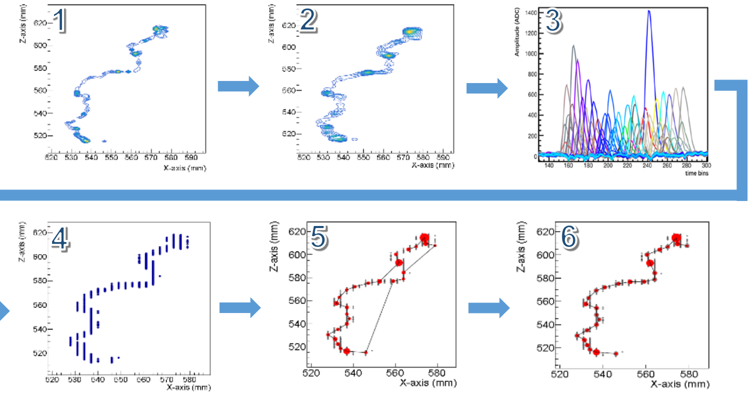
1. Track Reconstruction

Detector Geometry



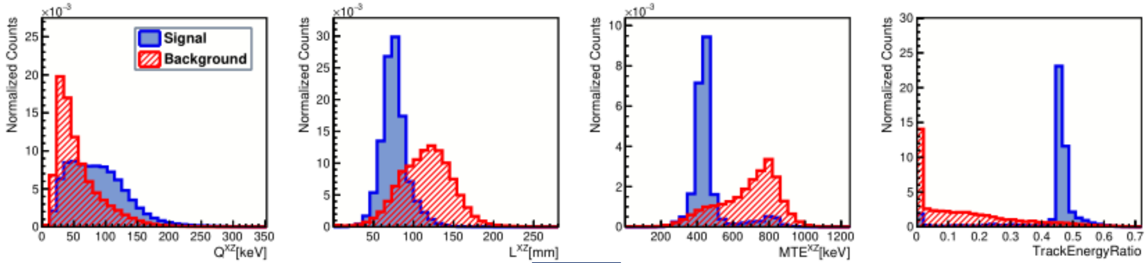
Track Reconstruction (Main Part)

Based on Geant4, Decay0, Root, Garfield, REST



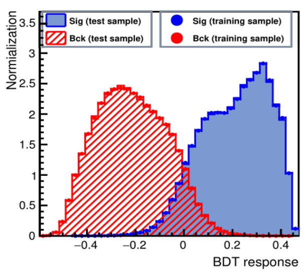
2. Topological Parameters

Feature Distributions

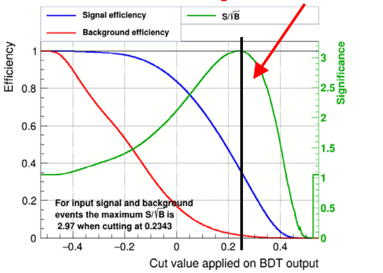


3. TMVA Classification

Discriminator Profile



Efficiencies and Optimal Value



Sensitivity Estimation

Background	ROI [keV]			
	878.8	1639.3	1697.3	2457.8
Liner ^{238}U	6.0	0.0	0.0	0.0
Liner ^{232}Th	2.1	0.0	0.0	0.0
Liner ^{60}Co	41.9	0.2	0.2	0.3
Liner ^{40}K	26.8	0.0	0.0	0.0
MM ^{238}U	29.0	0.2	0.3	0.2
MM ^{232}Th	6.5	0.0	0.0	0.1
SS ^{238}U	3.4	0.0	0.0	0.0
SS ^{232}Th	3.3	0.0	0.0	0.0
Acrylic ^{238}U	47.7	0.4	0.3	0.1
Acrylic ^{232}Th	20.0	0.1	0.11	0.2
Total background	186.6	1.0	1.0	0.9
Signal efficiency	16.3%	2.4%	2.3%	0.2%
Sensitivity [yr]	1.09×10^{25}	1.74×10^{25}	1.65×10^{25}	1.54×10^{24}

Topological features of NLDBD-ES:

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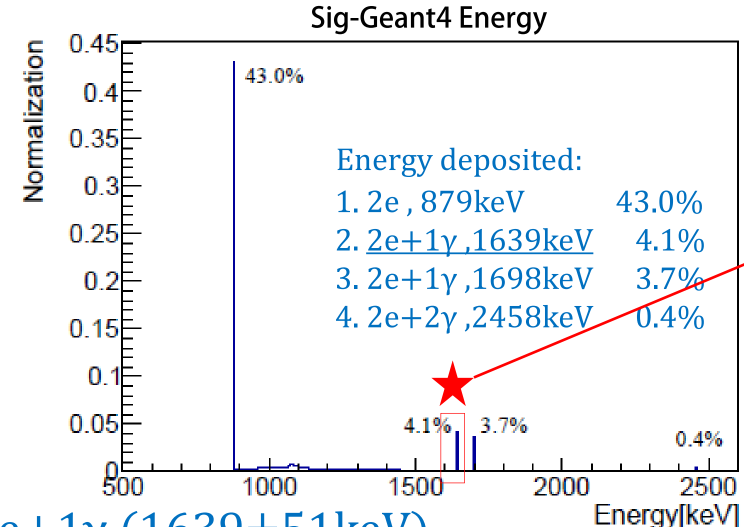
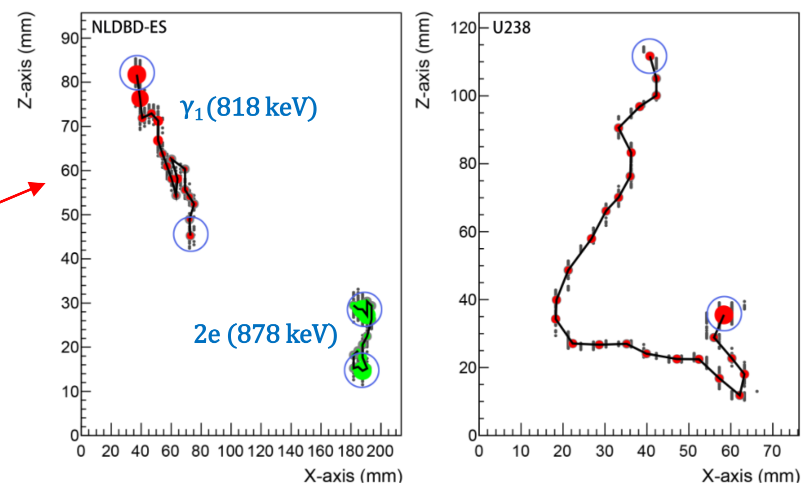
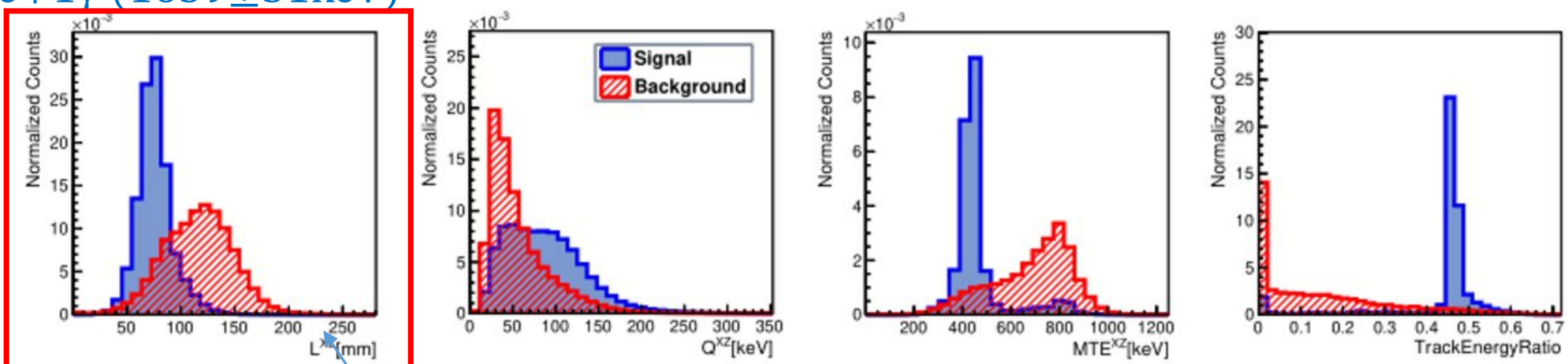
- NLDBD-ES: 2e (879keV) + γ_1 (760keV) + γ_2(818keV)
- 4 Different ROIs: 2e, 2e+γ_1, 2e+γ_2, 2e+γ_1+γ_2

Hard to deposit fully in gas





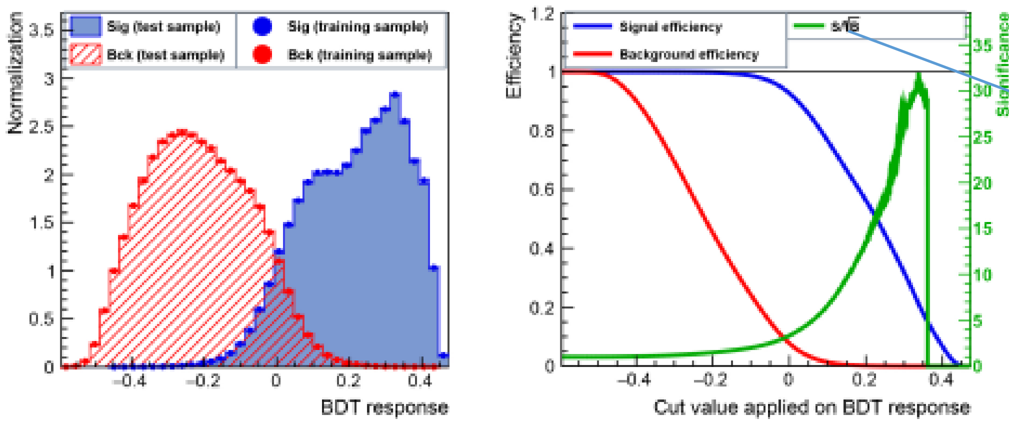
2e+1γ (1639±51keV)



Length of the most energetic track

Result:

➢ TMVA output of 2e+1γ (1639±51keV) ROI



Threshold Cut:

$$\epsilon_s/\sqrt{\epsilon_b} \rightarrow \text{Max}$$

Topological	Sig Eff	Bck Eff	Sensitivity *[yr]	Reference value [yr]
NLDBD-ES	43%	5.0×10^{-4}	1.7×10^{25} (90%CL)	2.4×10^{25} by KamLAND-Zen
DBD-ES	56%	9.6×10^{-2}	4.1×10^{23} (90%CL)	$10^{23}\sim10^{25}$ in theory

*: Sensitivity is calculated based on 3 years exposure.

➢ Sensitivity of NLDBD-ES and DBD-ES of 136Xe could be improved by a factor of 4.8 and 1.8 with topological signatures

Hardware work: I. Detector Design
II. Mini TPC Test

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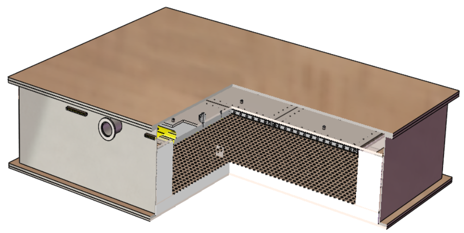
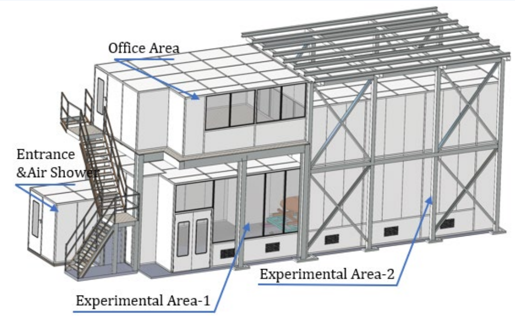


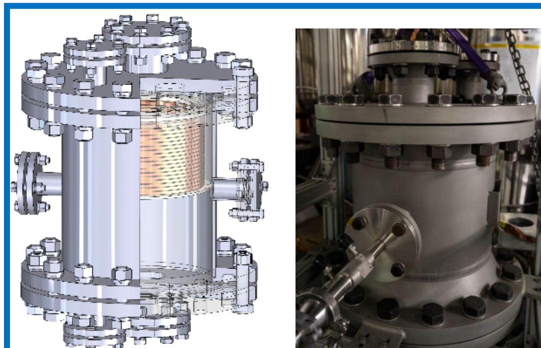
Surface Radioactivity Detector



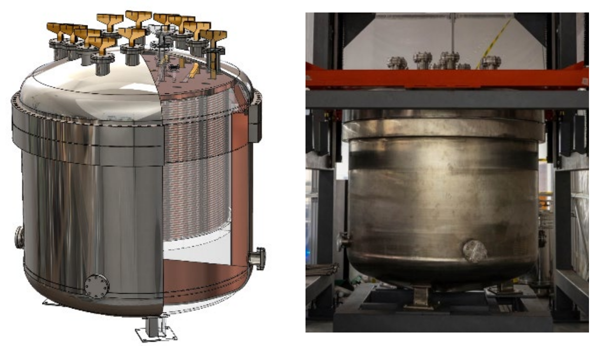
PandaX-III Clean Room Design

undergraduate *graduate*

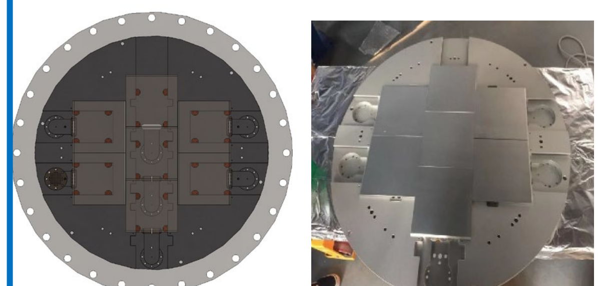
2016 2017 2018 2019 2020 2021



Mini TPC Design

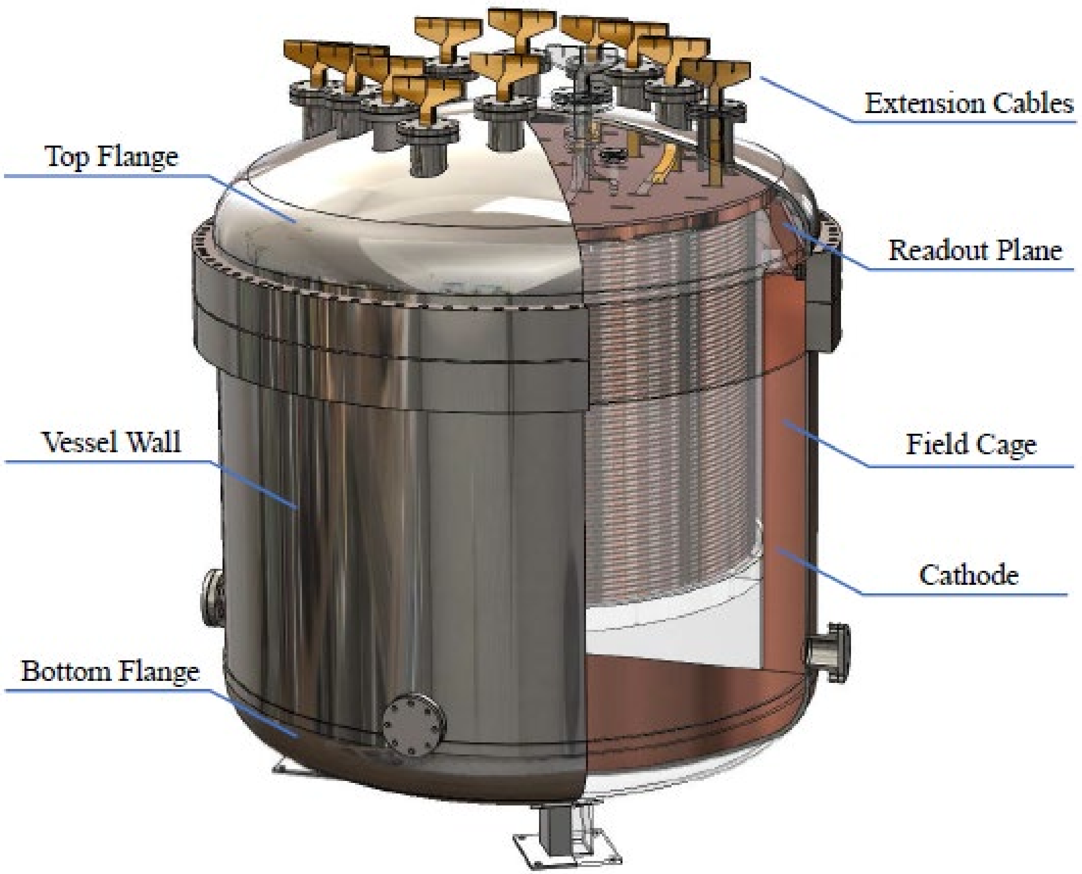


PandaX-III TPC Design

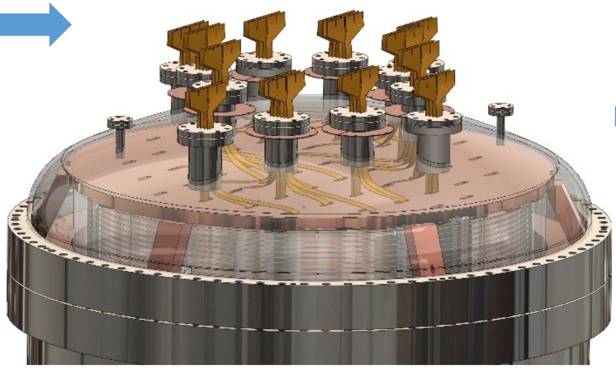


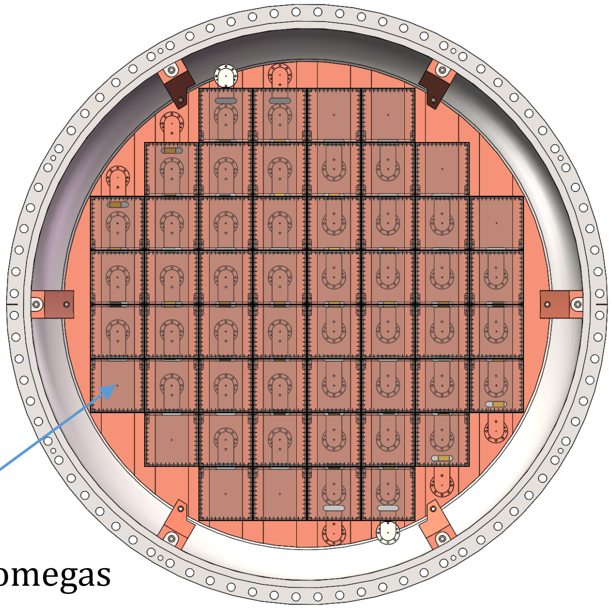
Prototypal Readout Plane Design

PandaX-III TPC Detector

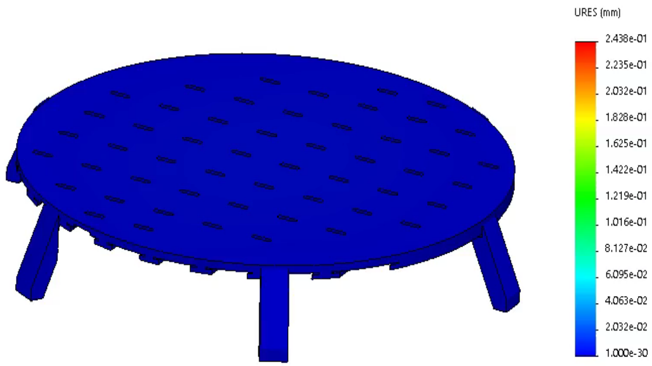


PandaX-III detector of first phase





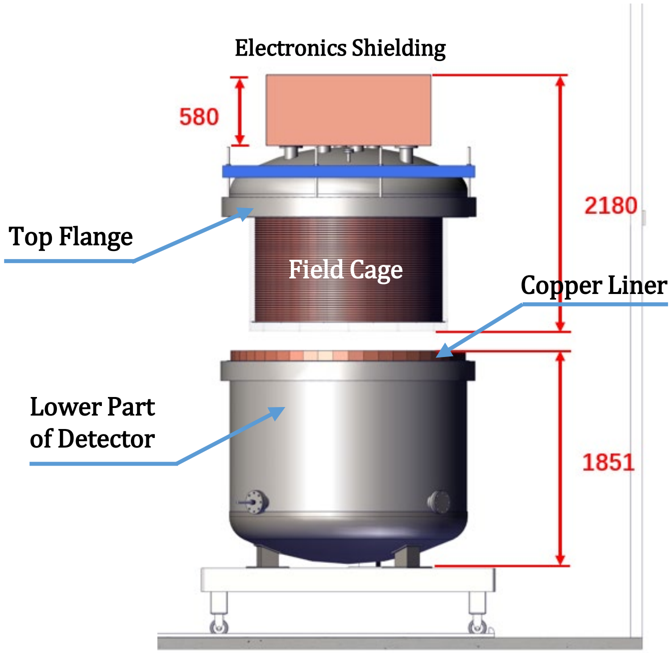
Deformation Simulation of Readout Plane

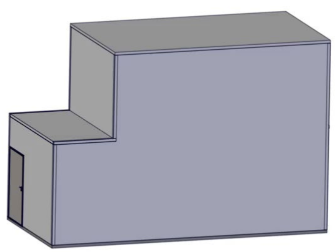


Static Simulation:
Assuming that the total weight is 1500 N and evenly distributed on the readout plane (the total weight of 5mm-thickness MM plates and other components):

Max Displacement: 0.18mm
Max Stress: 14.1MPa

Design of Installation Procedures

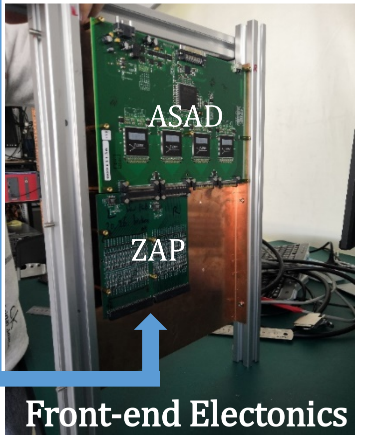




Hardware work: I. Detector Design
II. Mini TPC Test

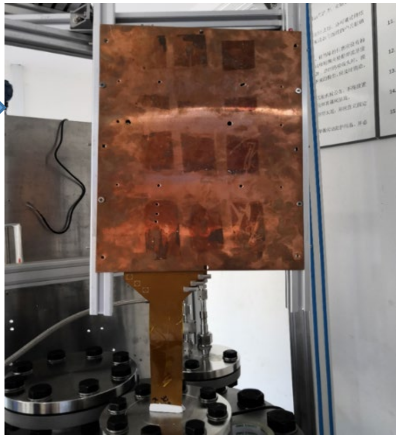
Mini TPC

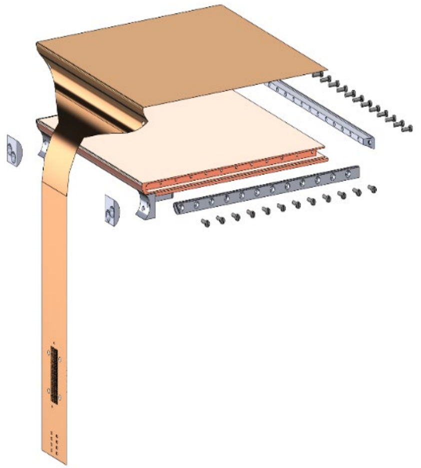
First Version (2017~2019)

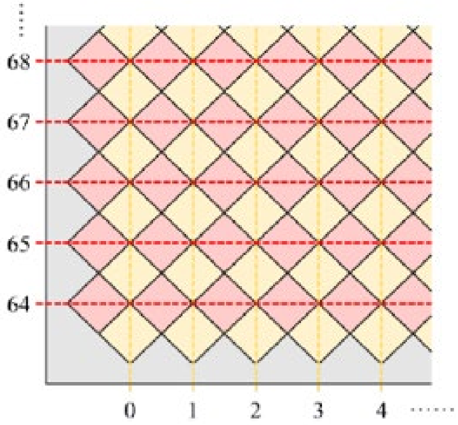


Microbulk Micromegas

Shielding Box







64 X- & 64 Y- channels

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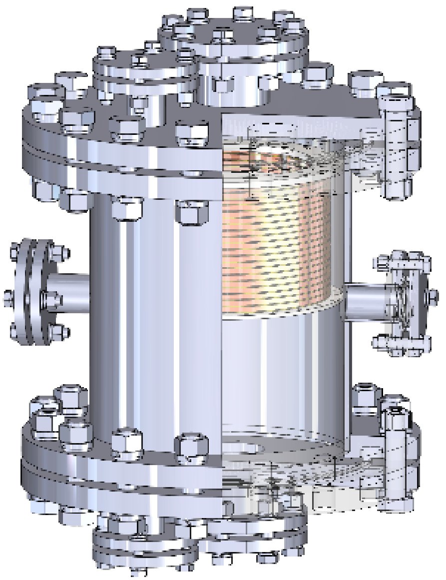
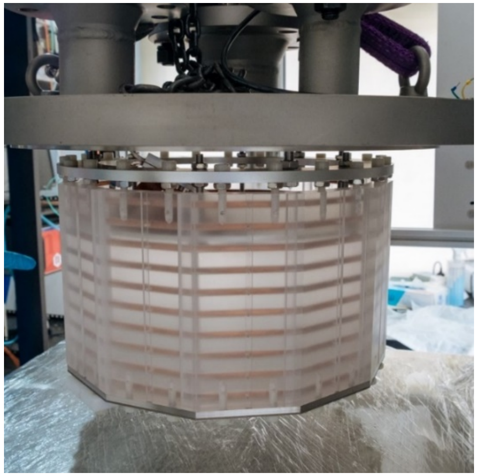
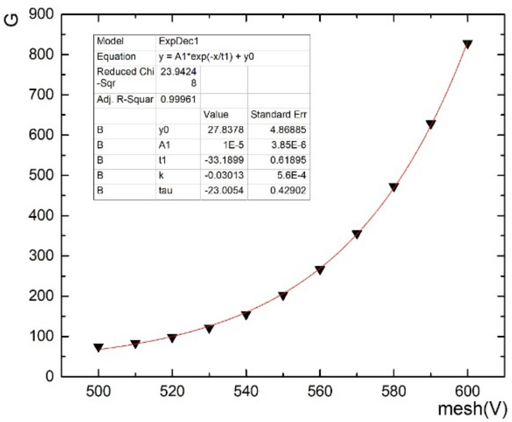
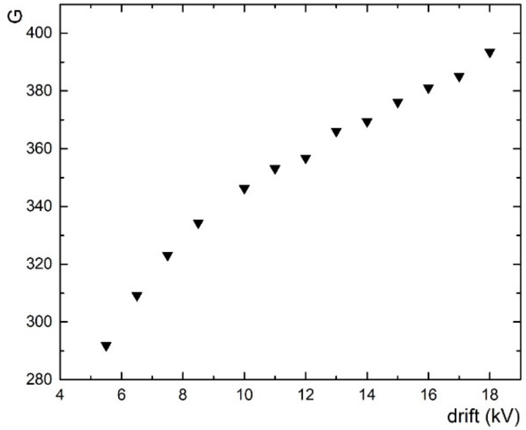




Gain vs. mesh or drift voltage



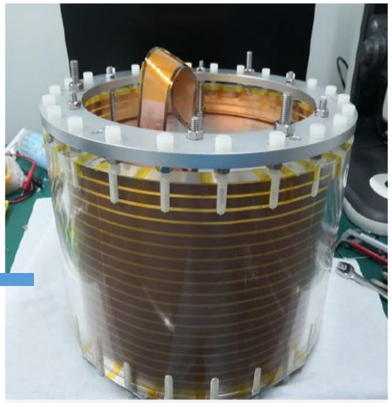
Drift=17 kV



Mesh=570 V

The second version of mini TPC

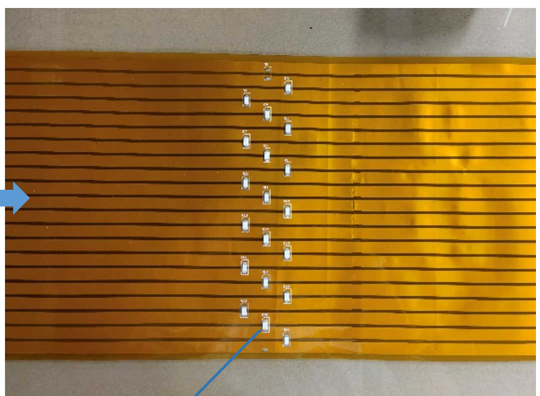
Mini TPC (1 MMs)



Prototype TPC (7 MMs)

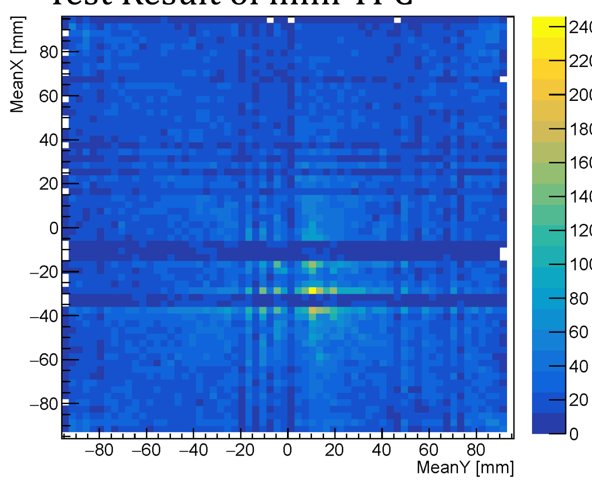
First Phase TPC (52 MMs)

Flexible PCB Board

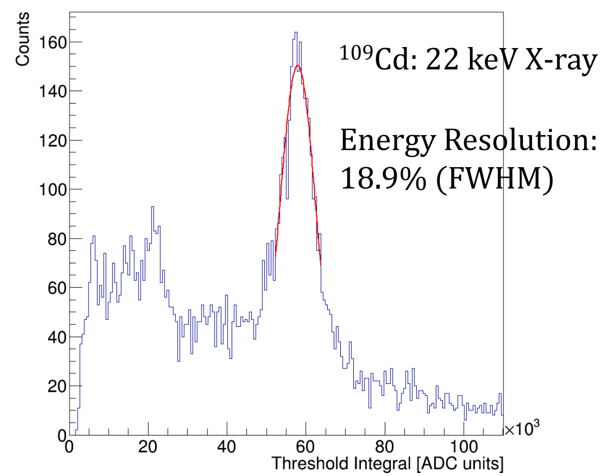


1Gohm R

Test Result of mini TPC



Hitmap



Spectrum

Summary

- Simulation work 2019-2021
  (*published in April*)
  1. NLDBD-ES
  2. DBD-ES

- Hardware work 2016-2021
  1. Detector Design
  2. Mini TPC test:
     2.1 the testbed of Micromegas
     2.2 PCB board-version works

Enhanced search sensitivity to the double beta decay of ^{136}Xe to excited states with topological signatures

Chen Xie[1], Kaixiang Ni[1], Ke Han[1*], and Shaobo Wang[1,2*]

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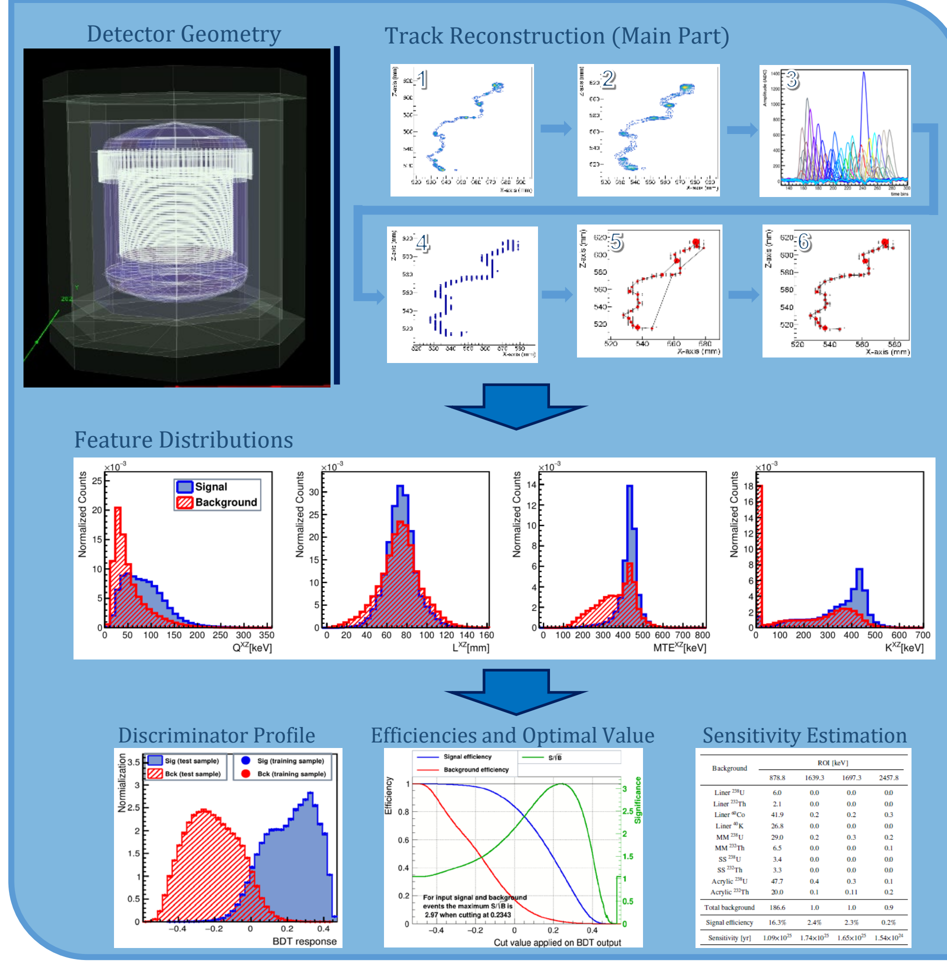
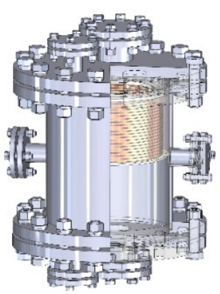
The double beta decay of ^{136}Xe to excited states of ^{136}Ba (DBD-ES) has not yet been discovered experimentally. The experimental signature of such decays, one or two gamma rays following the beta signals, can be identified more effectively in a gaseous detector with the help of topological signatures. We have investigated key parameters of particle trajectories of DBD-ES with Monte Carlo simulation data of the proposed PandaX-III detector as an example. The background rates can be reduced by about one order of magnitude while keeping more than half of signals with topological analysis. The estimated half-life sensitivity of DBD-ES can be improved by 1.8 times to 4.1×10^{23} year (90% C.L.). Similarly, the half-life sensitivity of neutrinoless double beta decay of ^{136}Xe to excited states of ^{136}Ba can be improved by a factor of 4.8 with topological signatures.

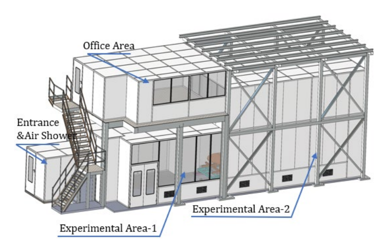
neutrino, double beta decay, topological signatures, background suppression

PACS number(s): 14.60.Pq, 29.40.Gx, 23.40.-s

Citation: C. Xie, K. Ni, K. Han, and S. Wang, Enhanced search sensitivity to the double beta decay of ^{136}Xe to excited states with topological signatures, Sci. China-Phys. Mech. Astron. **64**, 261011 (2021), https://doi.org/10.1007/s11433-020-1693-6







Thanks!

PandaX (Particle and Astrophysical Xenon)

- Target: search for Dark Matter (PandaX-IV)and Neutrinoless Double Beta Decay (PandaX-III)
- Detector: liquid and gaseous ^{136}Xe Time Projection Chamber (TPC)

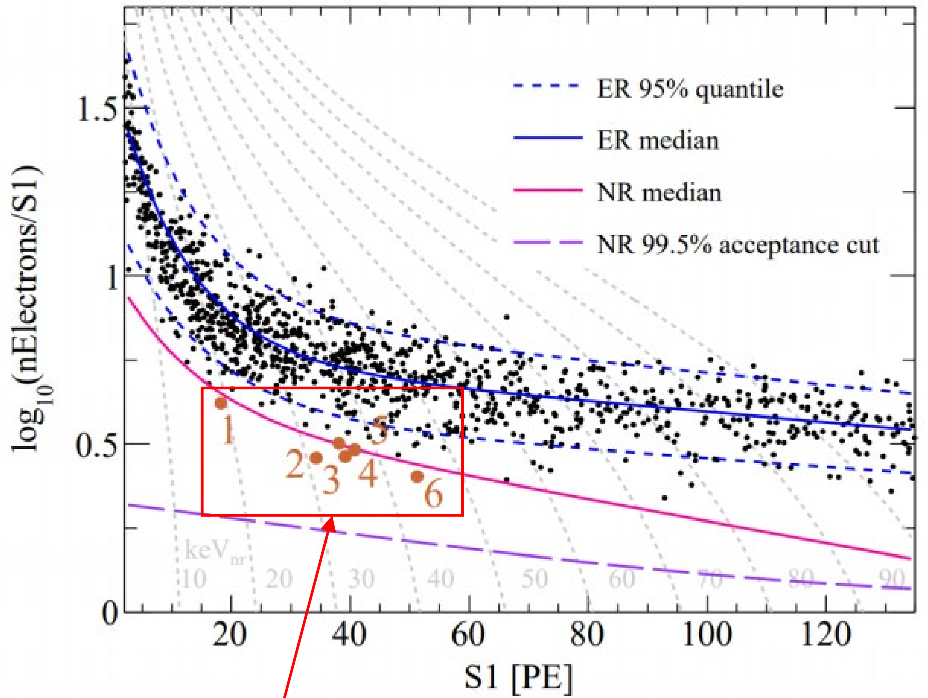
Me

PandaX Collaboration Group

Latest result of PandaX-4T

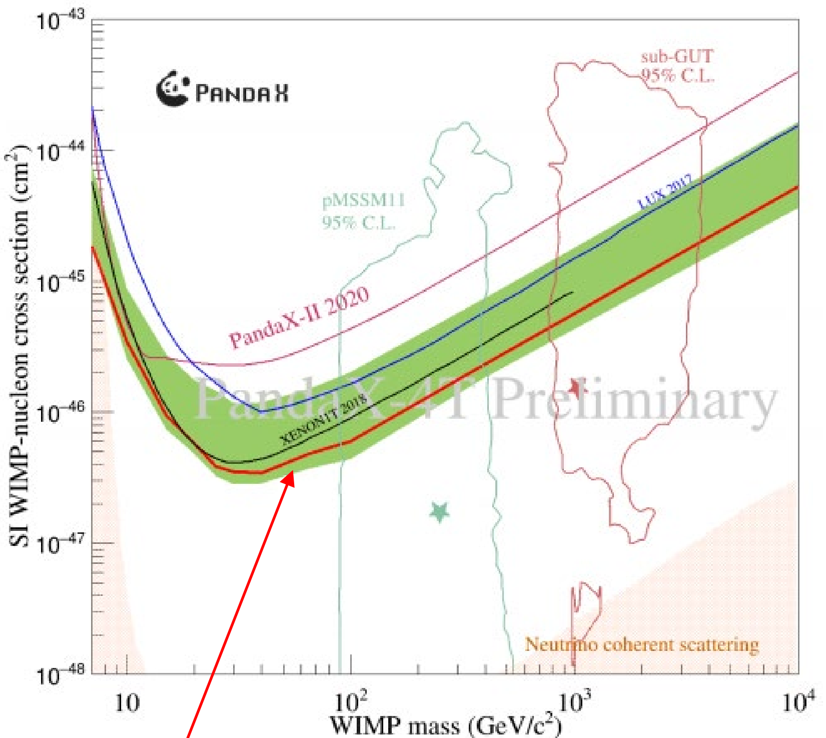
Exposure: 0.63 ton•year

Dark matter candidates



6 events in the signal region
But they are all backgrounds

WIMP-nucleon exclusion limits



Our limit is ~1.3 times stronger than XENON1T around 40GeV/c^2