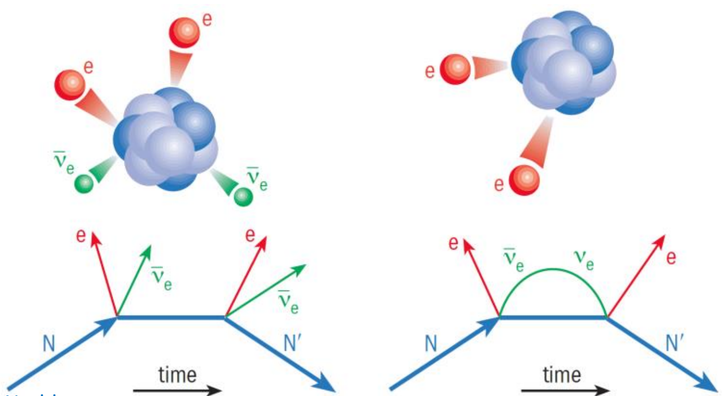
PandaX-III: 0νββ search at CJPL

Ke Han (韩柯)
Shanghai Jiao Tong University
On behalf of the PandaX-III Collaboration

Detection of double beta decay



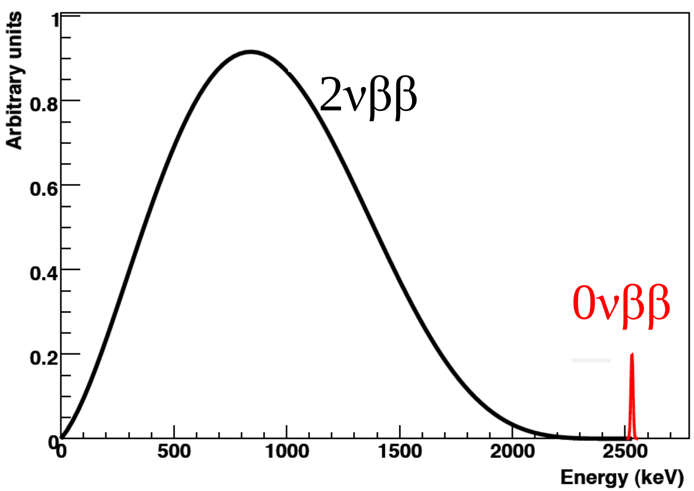
From Physics World

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

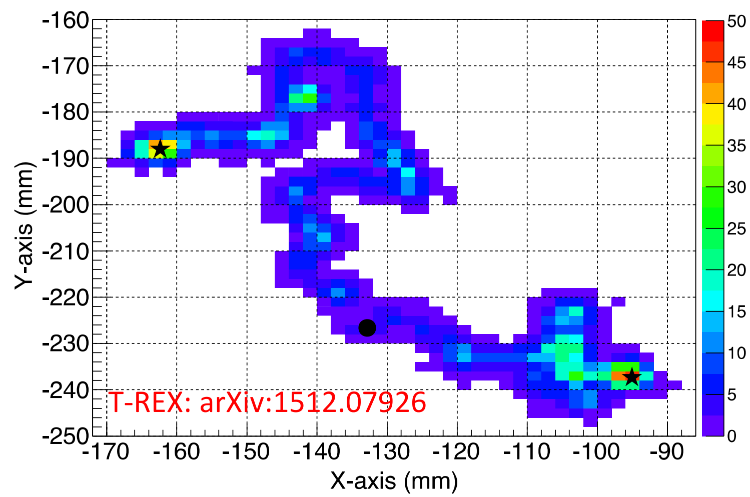
- Example:

$$^{136}Xe \rightarrow {}^{136}Ba + 2e^{-} \ + (2\bar{\nu}_e)$$

- Measure energies of emitted e⁻
- Electron tracks are a huge plus
- Daughter nuclei identification



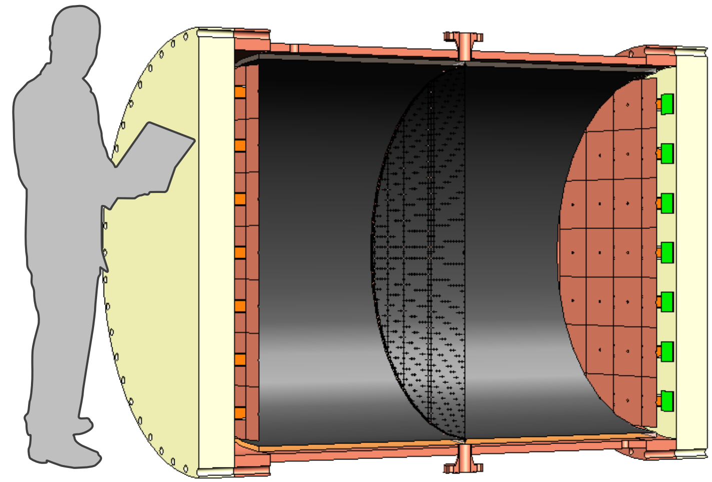
Sum of two electrons energy

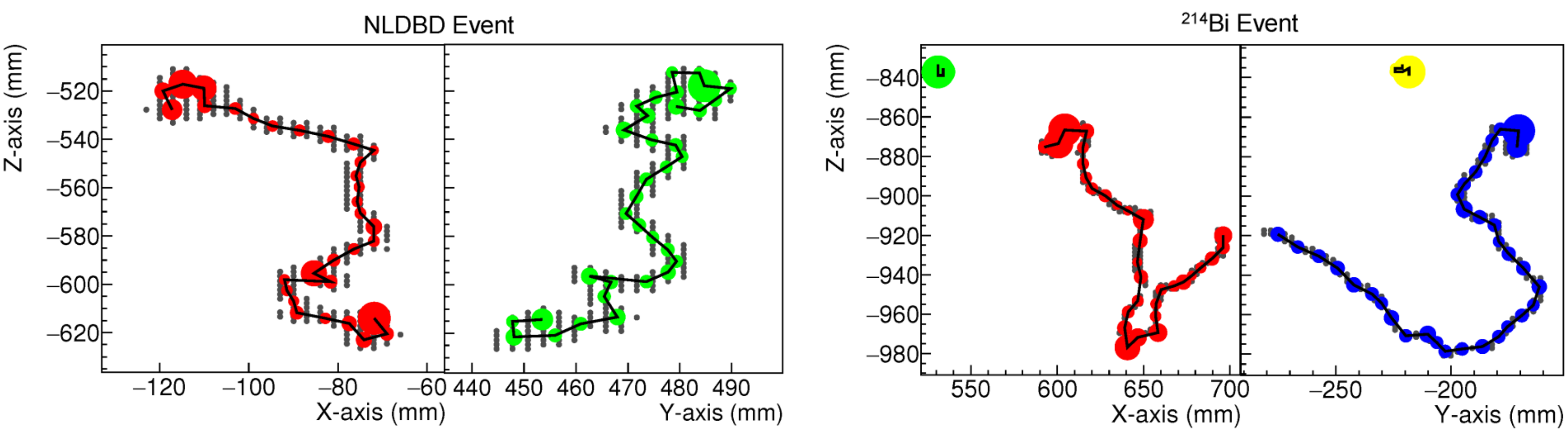


Simulated track of 0νββ in high pressure Xe

PandaX-III: high pressure gas TPC for $0\nu\beta\beta$ of ^{136}Xe

- TPC: 200 kg scale, symmetric, double-ended charge readout, with 10 bar of ^{136}Xe
- Main features: good energy resolution and background suppression with tracking

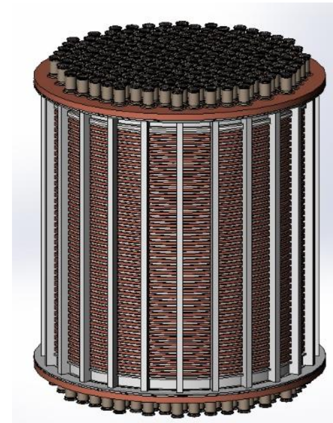




PandaX Projects

PandaX-I: 120kg LXe
(2009 – 2014)

PandaX-II: 500kg LXe
(2014 – 2018)

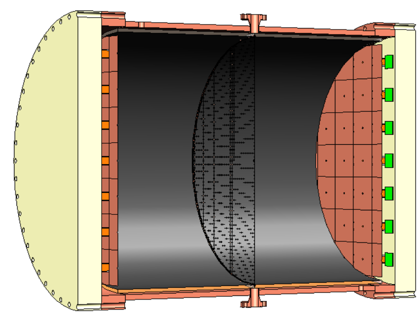


PandaX-xT LXe
(Future)

Dark matter WIMP searches

See Ning Zhou’s Talk

PRL 117, 121303 (2016)

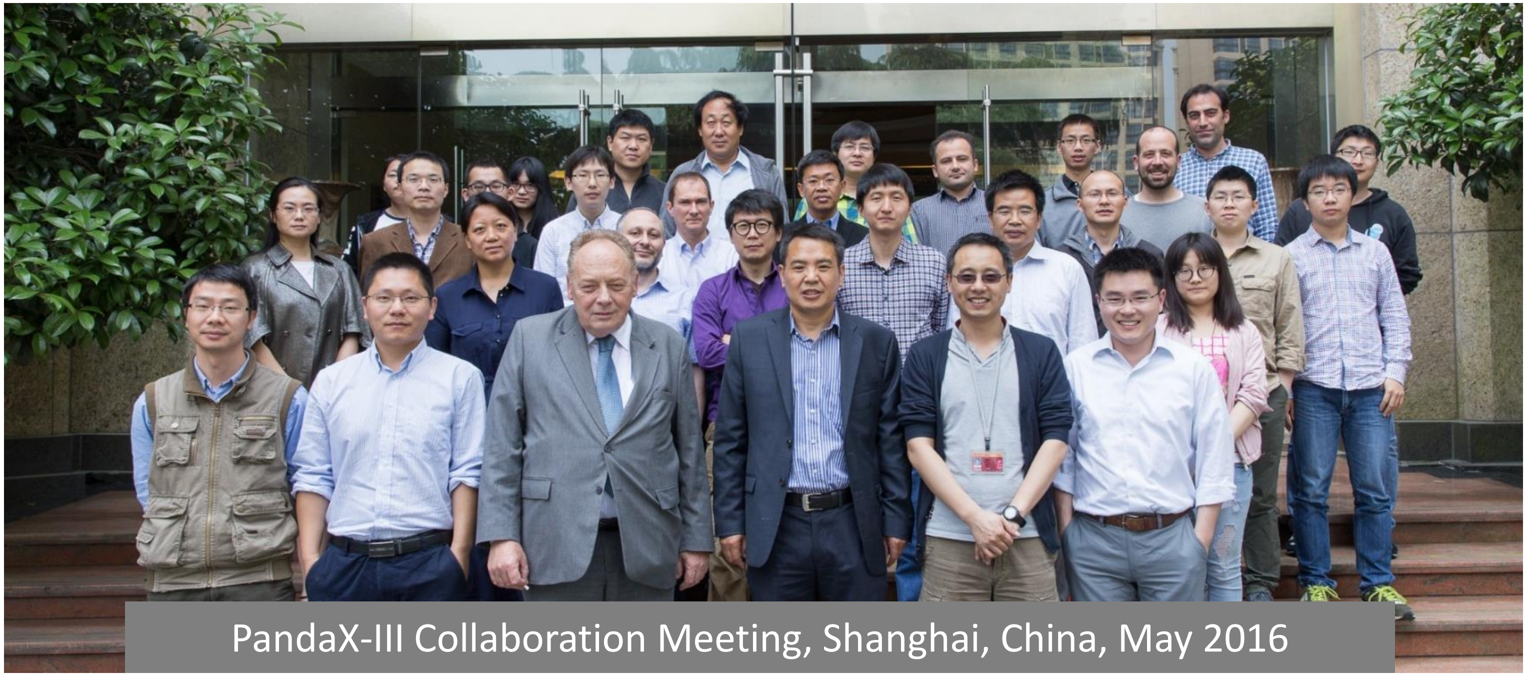


0νββ searches

PandaX-III:
200kg - 1 ton HPXe (Future)

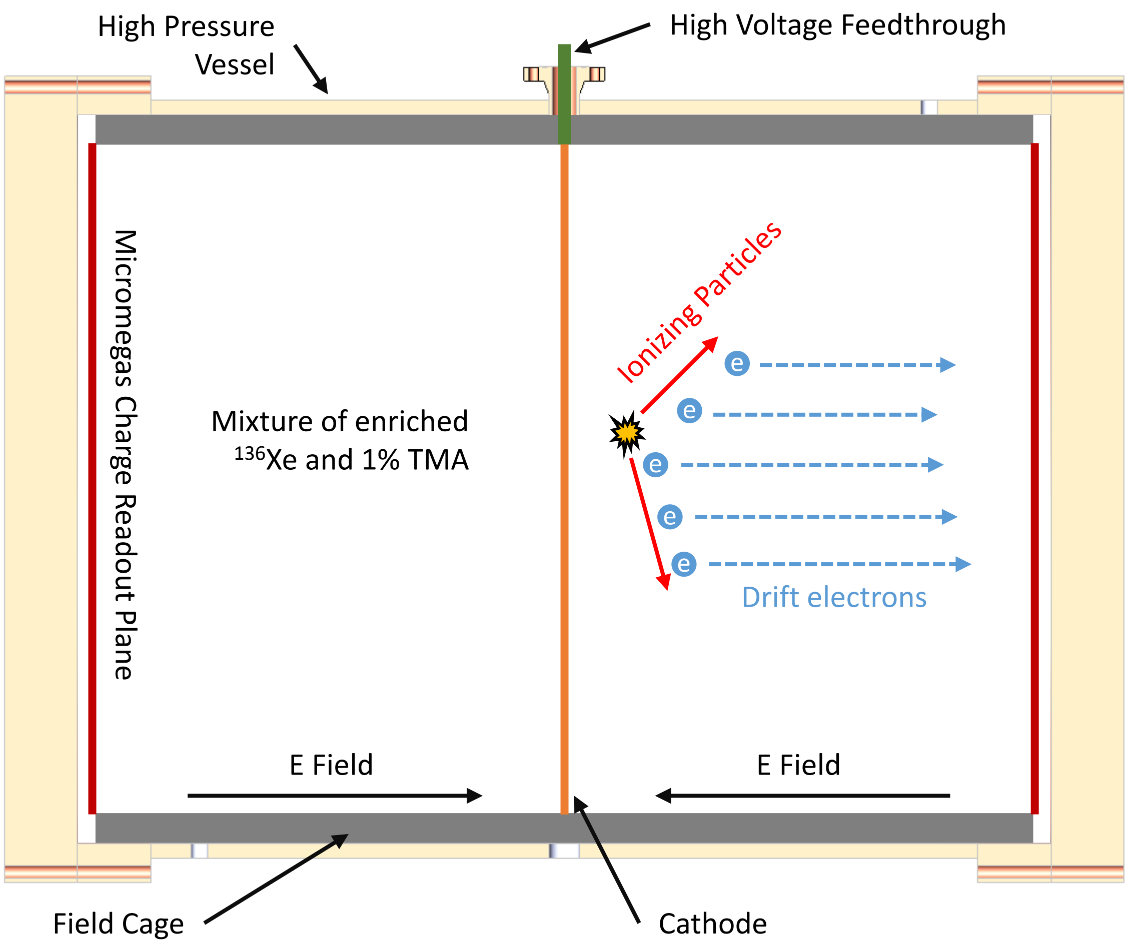
PandaX-III collaboration

- China: Shanghai Jiao Tong University, University of Science and Technology of China, Peking University, China Institute of Atomic Energy, Shandong University, Sun Yat-Sen University, Central China Normal University
- Spain: Universidad de Zaragoza
- France: CEA Saclay
- US: University of Maryland, Lawrence Berkeley National Laboratory
- Thailand: Suranaree University of Technology

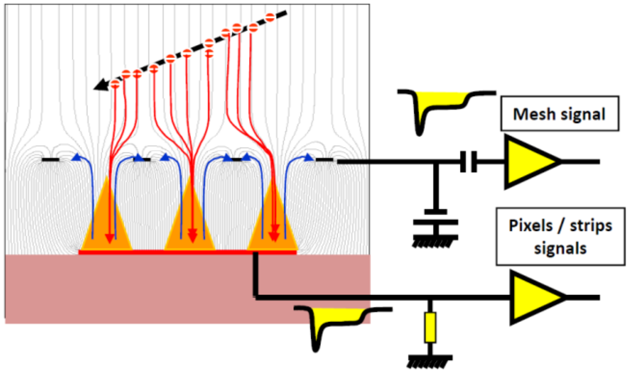


PandaX-III Collaboration Meeting, Shanghai, China, May 2016

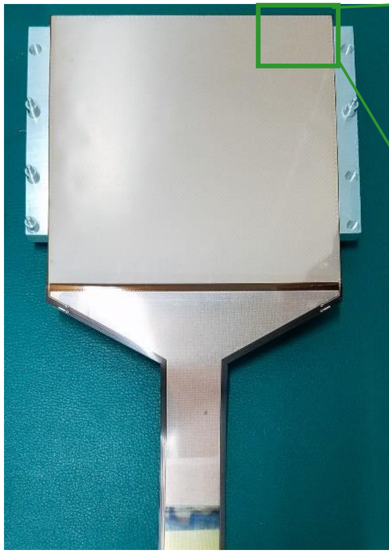
PandaX-III TPC illustrated

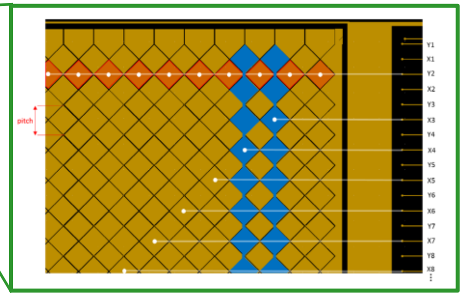


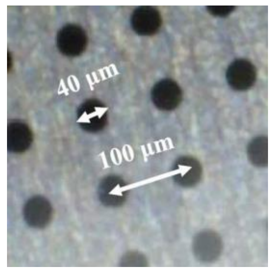
- ~4m^3 active volume
- 10 bar working pressure
- ~10000 readout channels
- Xe+TMA gas mixture
- Charge-only readout with microbulk Micromegas



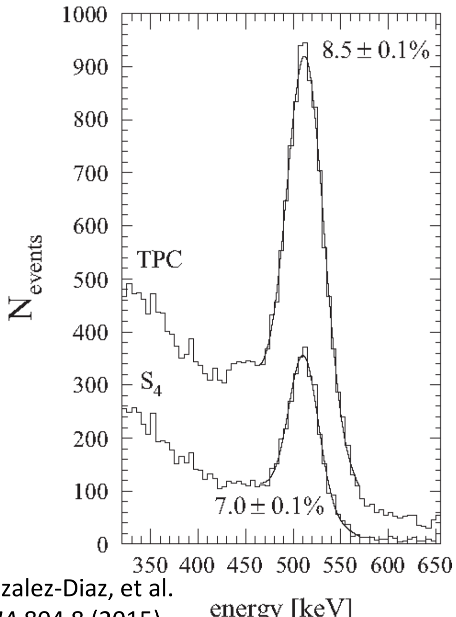
Microbulk MicroMegas (MM)



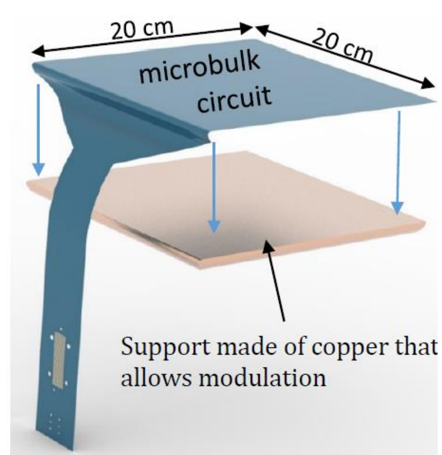


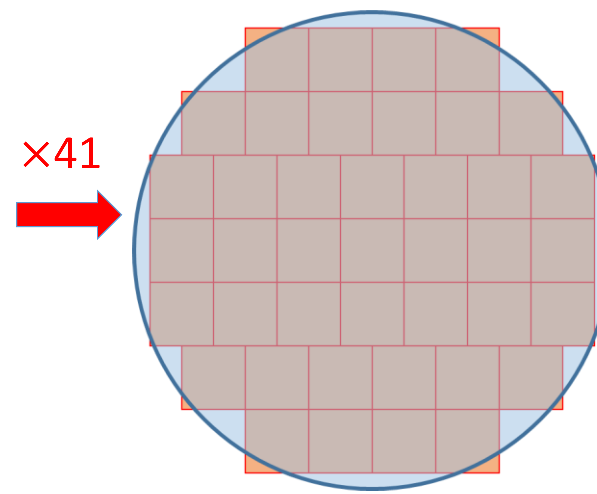


- Microbulk MicroMegas films made of Copper and Kapton only
  - Perfect for radio-purity purpose
  - 20 by 20 cm
- XY strip readout
  - 3 mm pitch size, 128 strip readouts
- ~ 1000X gain with Xe+TMA
- 3% energy resolution expected at 2.5 MeV.
- Mosaic layout to cover readout planes
  - Scalable Radio-pure Readout Module (SR2M)

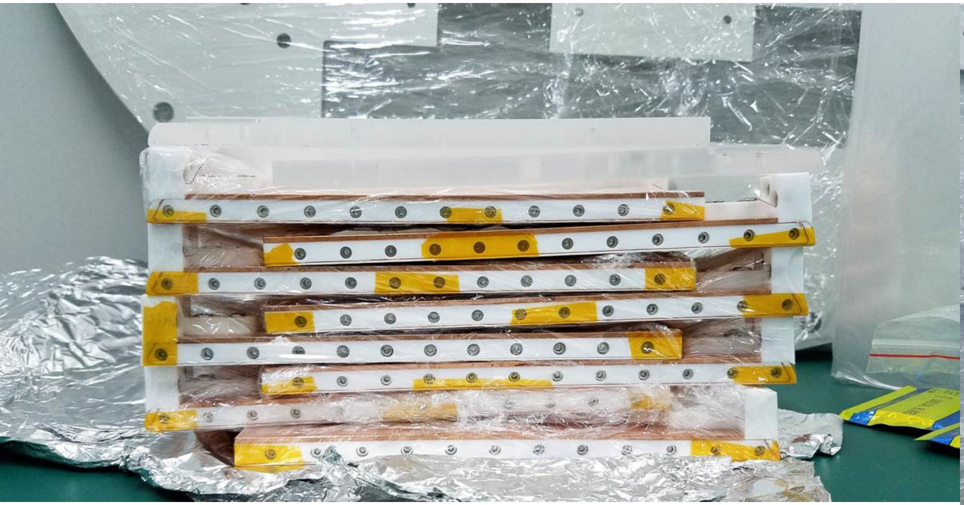


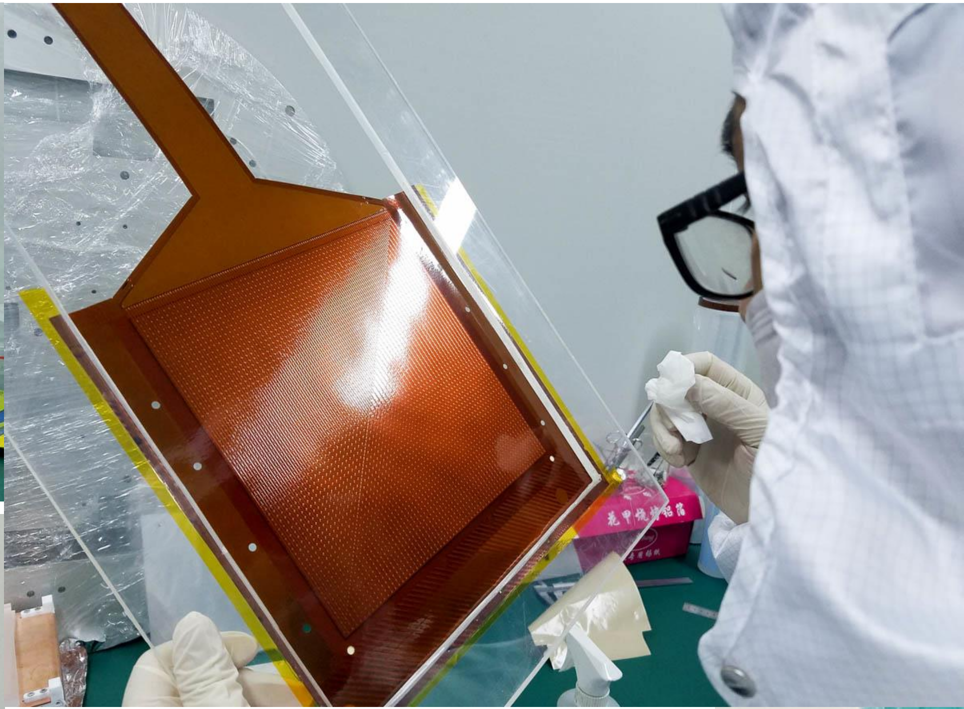
Gonzalez-Diaz, et al. *NIMA* 804 8 (2015)

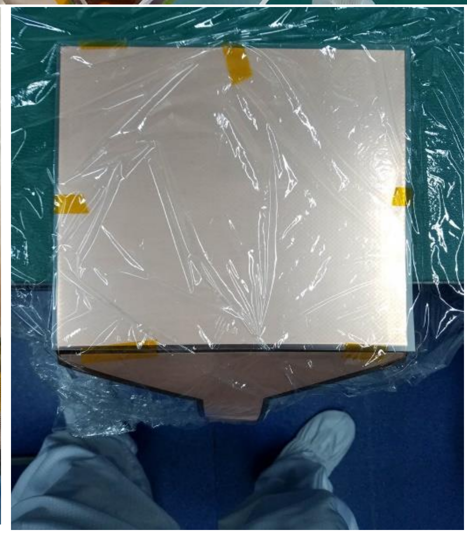




From MM films to SR2M



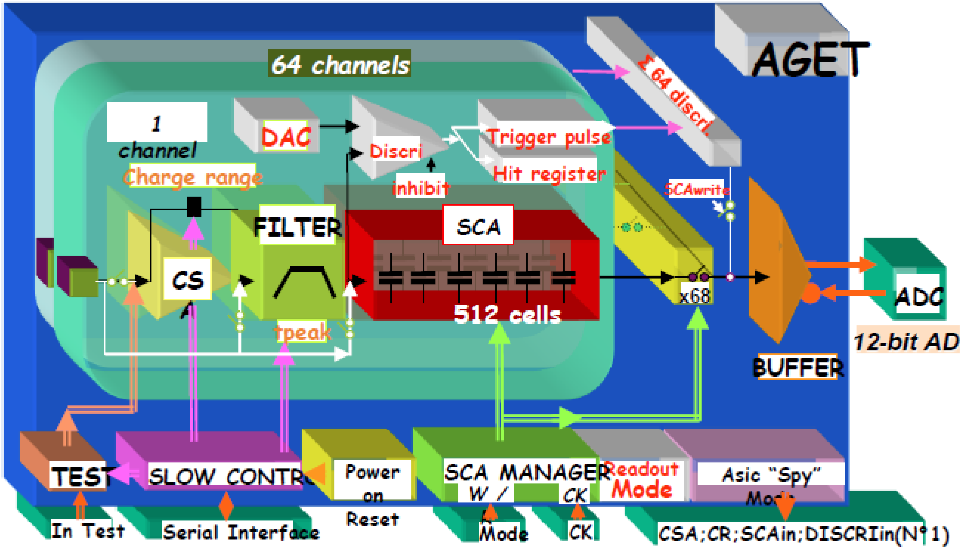


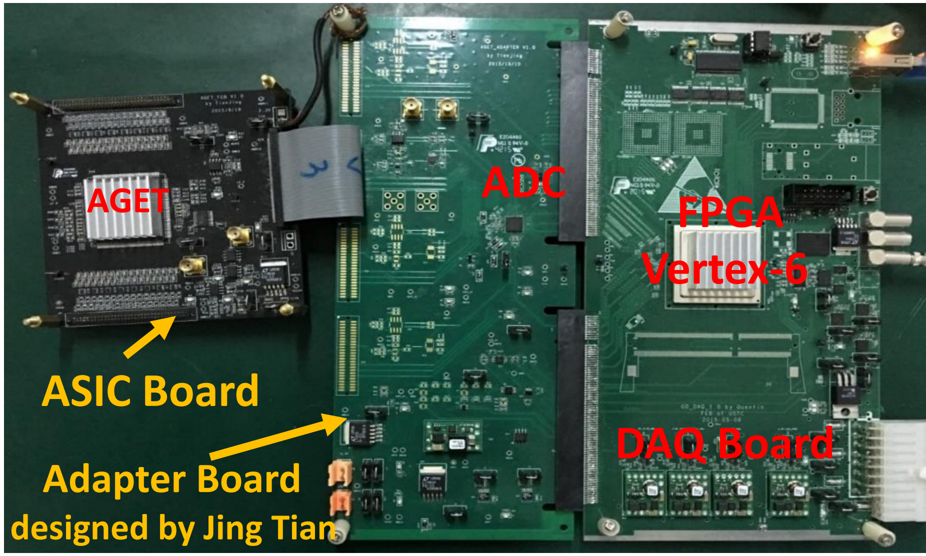


Electronics

- ASIC AGET chips: generic electronics for TPC from CEA-Saclay
  - 350 nm CMOS, mature technology
  - 64 channel multiplex
  - 512 sampling point per channel
  - 12 bit ADC
  - Dynamic range up to 10 pC
  - Sampling rate: 1 MHz to 100 MHz

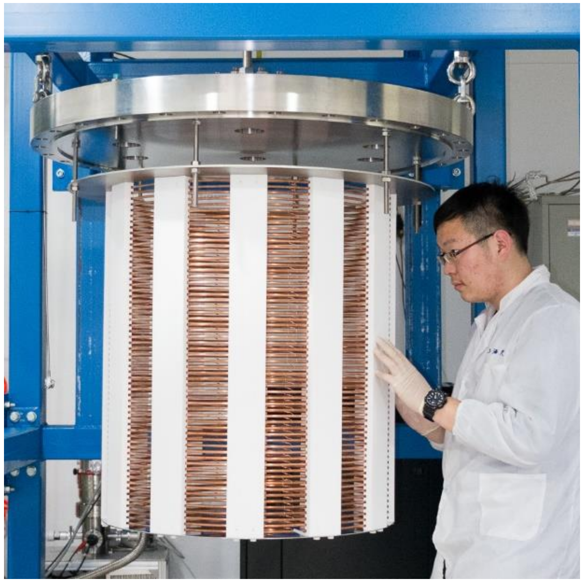
- Commercial daq suite ASAD+CoBo tested and used for our prototype TPC
- Two versions of custom front end electronics card designed and tested
- AGET performance tested and validated

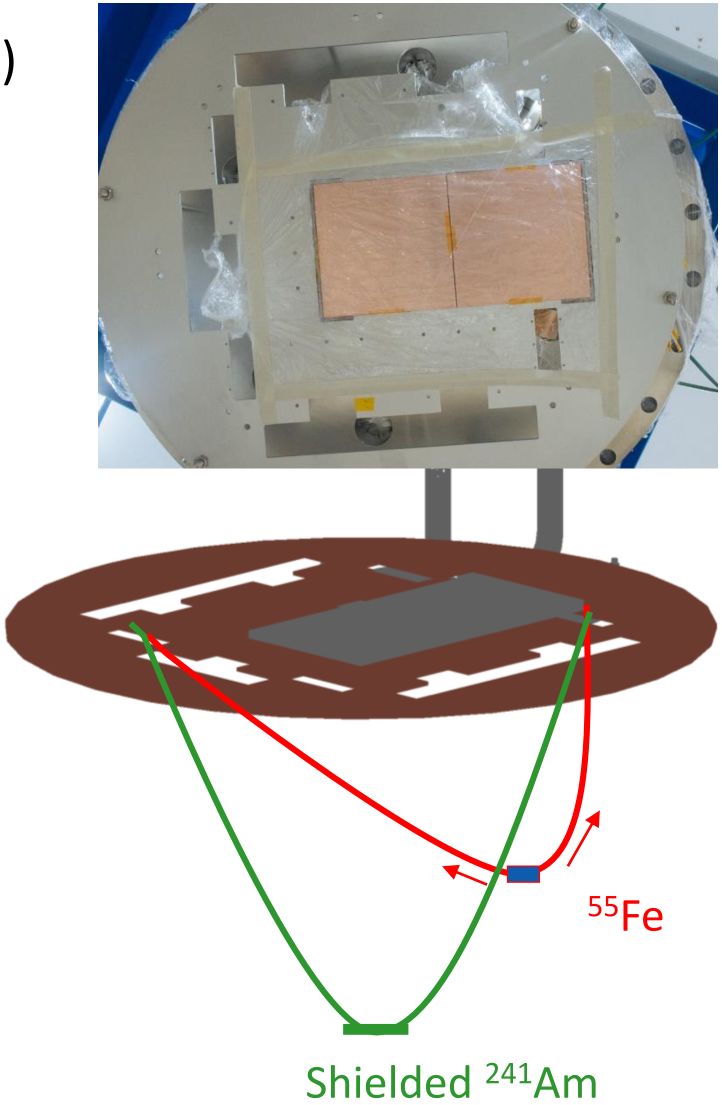




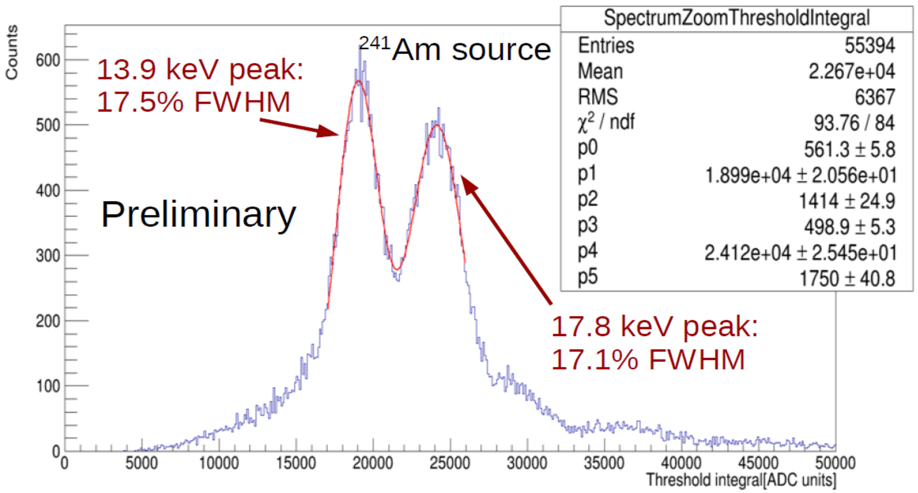
Prototype TPC at SJTU

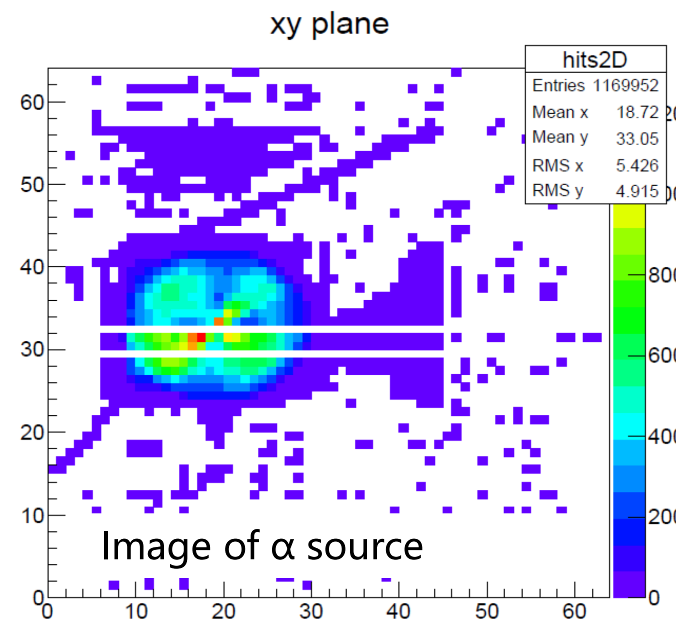
- 16 kg of xenon at 10 bar (active mass within TPC)
  - Single-ended TPC
- Data taking with Ar, Xe, Xe+TMA at different pressures
- Two Micromegas modules installed. Movable source used for calibration



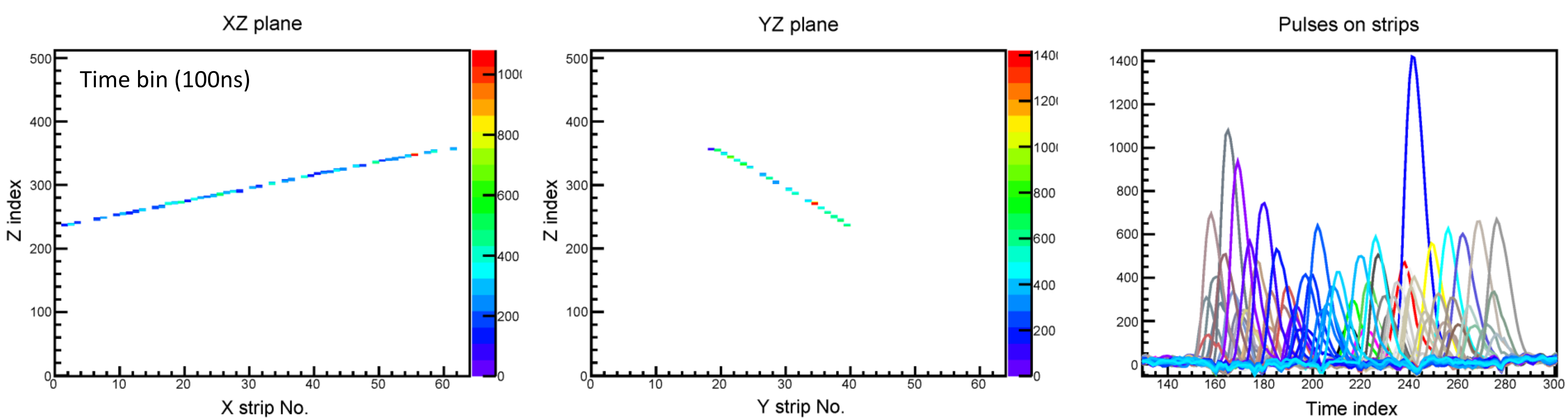


Commissioning the prototype TPC





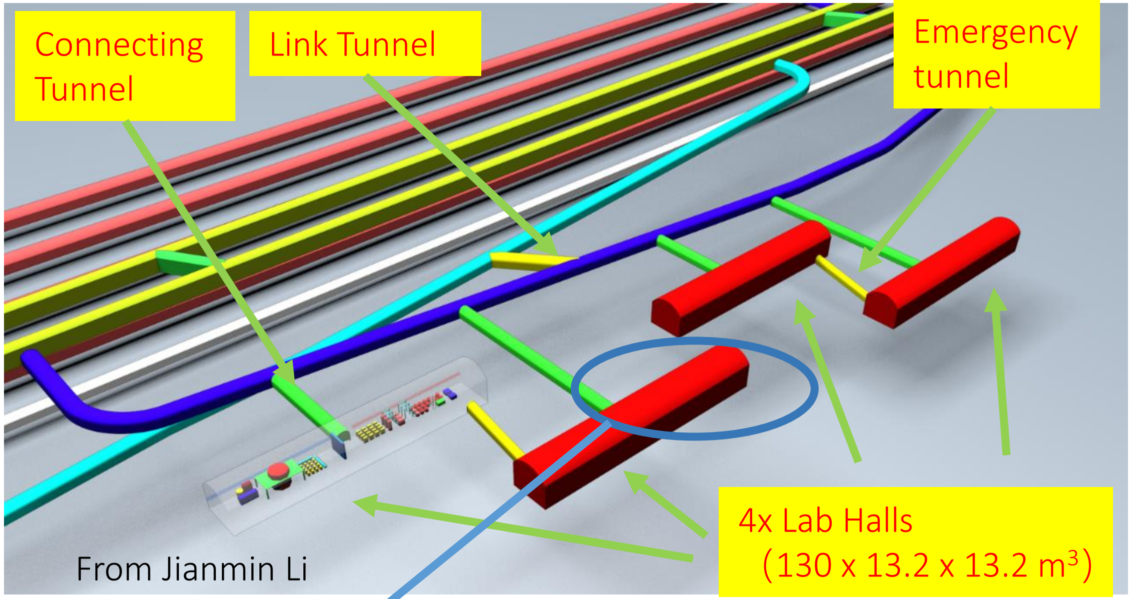
Muon track

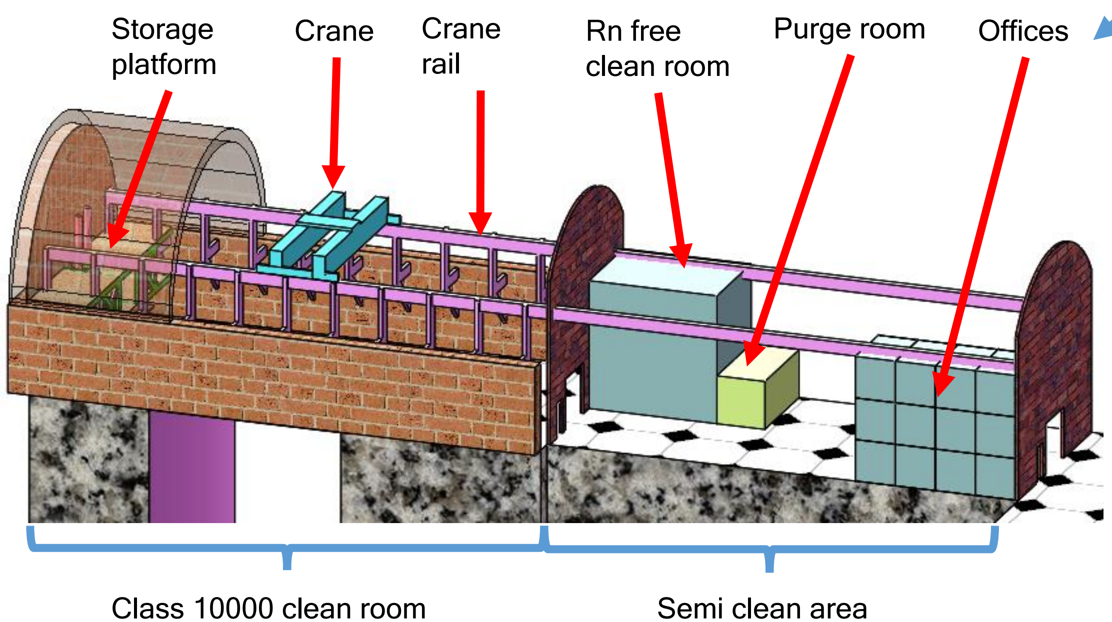


PandaX hall at CJPL-II

CJPL phase II Experiments

- PandaX projects
- CDEX WIMP search
- JUNA (accelerator)
- Geo/Solar neutrino detector
- ……





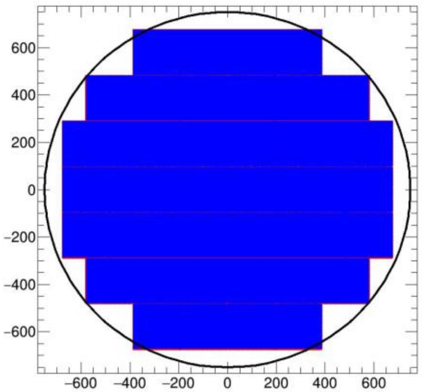
PandaX at Hall B2

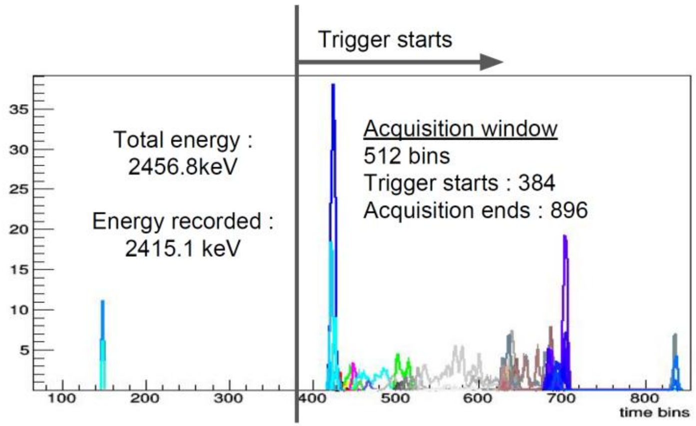
- Extra excavation for the water shielding pool (finished)
- Shared facility of DM and 0νββ searches

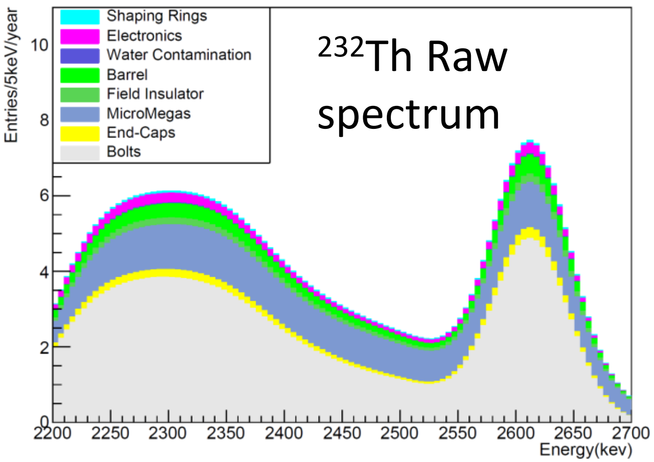
Background budget

Two independent Geant-4 based MC packages: RESTG4 and BambooMC

- Treat PandaX-III as a simple calorimeter
- Then add detector response
- Calculate signal efficiency and background rejection
- ×35 background reduction from topological analysis
    - Track reconstruction and blob identification at both ends
    - Convoluted neural network

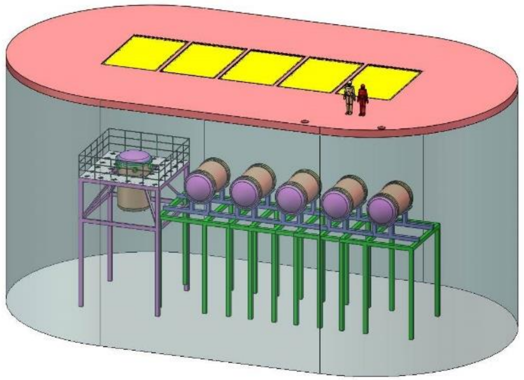


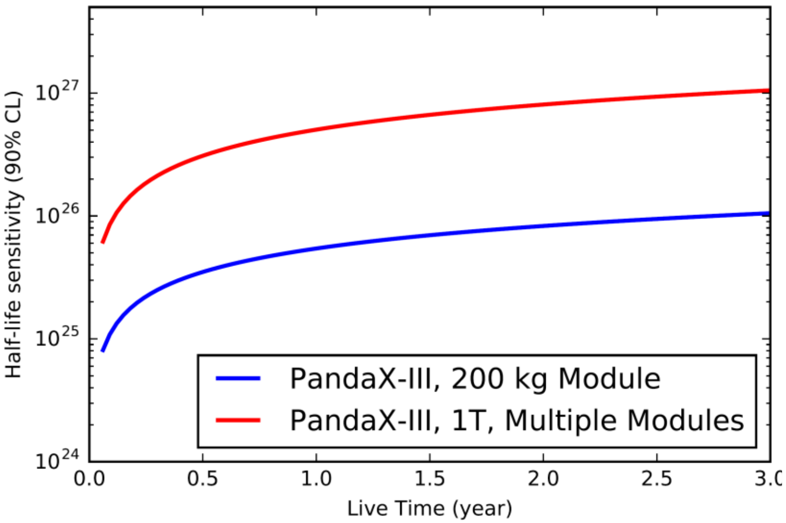


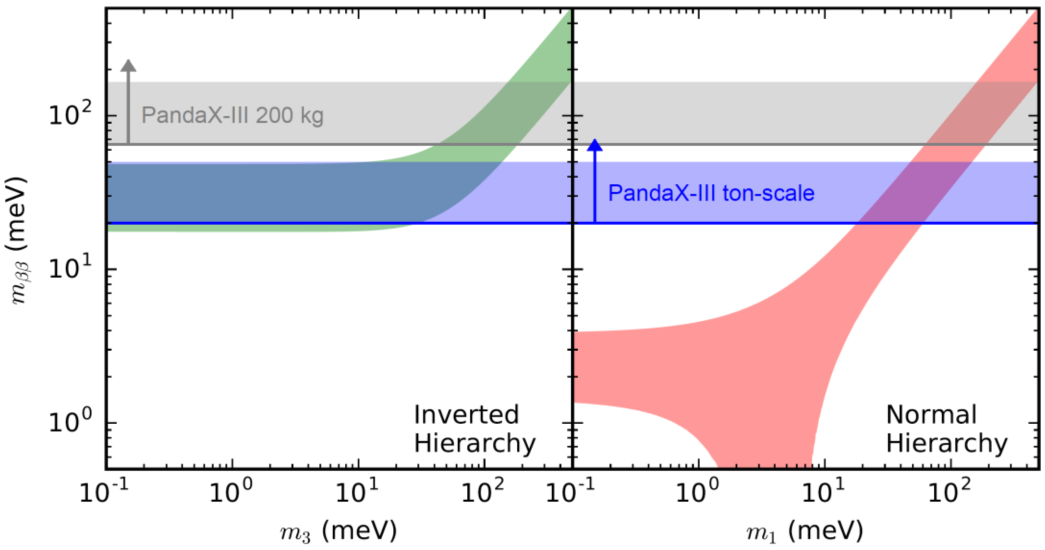


Sensitivity projection

- First 200-kg module:
  - Microbulk Micromegas for charge readout
  - 3% FWHM, 1 x 10^{-4} c/keV/kg/y in the ROI
- Ton-scale:
  - Four more modules with upgraded charge readout and better low-background material screening.
  - 1% FWHM, 1 x 10^{-5} c/keV/kg/y in the ROI

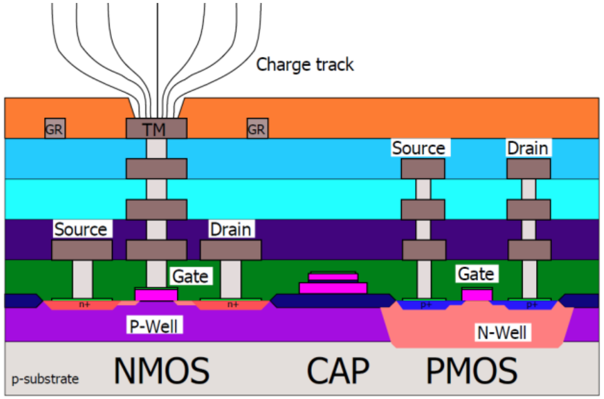




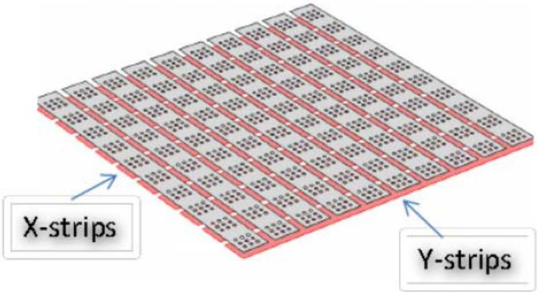


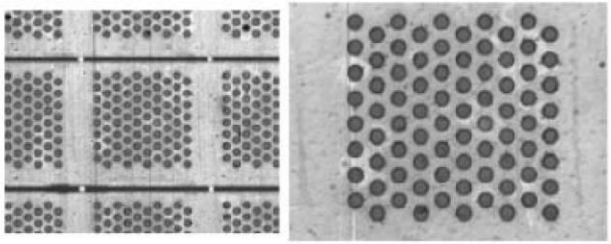
Future energy resolution improvement

- TopMetal Direct Charge Sensor
  - Direct pixel readout without gas amplification
  - First 10x10 cm readout plane in production
  - (See Yuan Mei's talk)



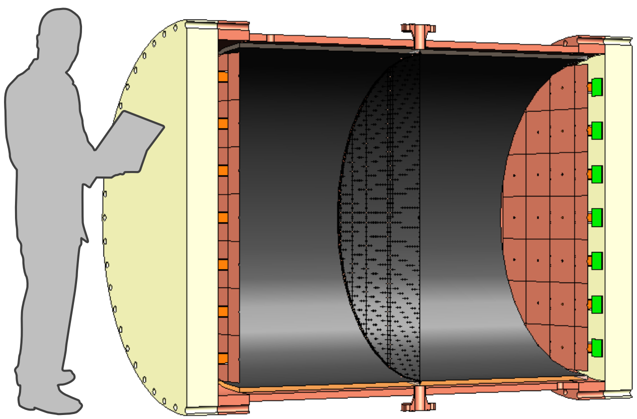
- Alternative Micromegas technologies
  - Improvement on bulk and microbulk technologies

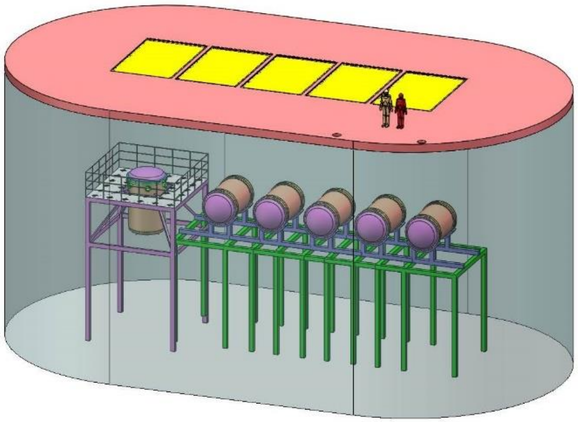




Conclusion

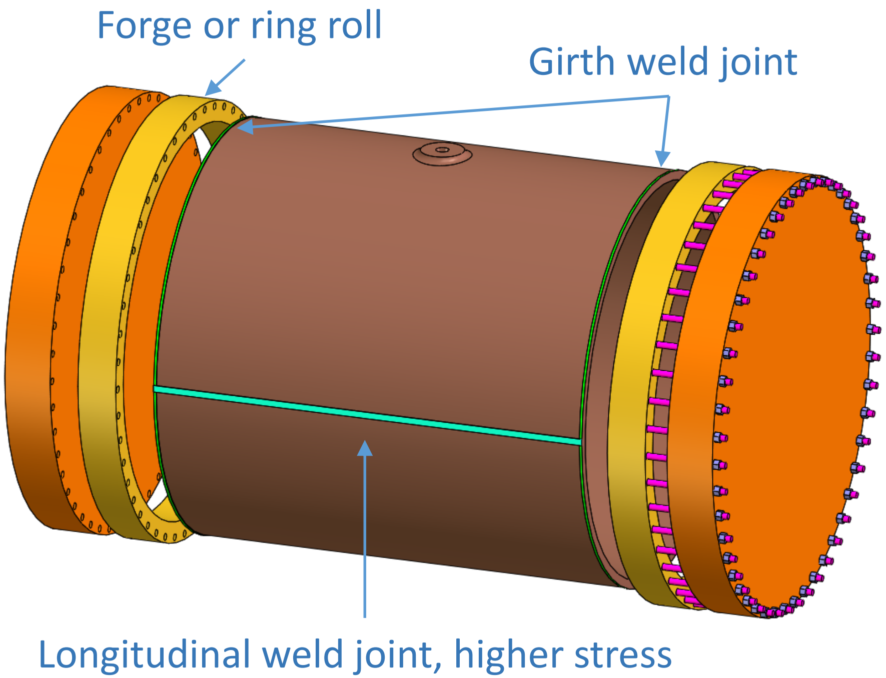
- PandaX-III uses high pressure xenon TPCs to search for double beta decay
- Phased approach: 200 kg first, then ton-scale with multiple modules
- 20-kg scale prototype TPC has been built and under commissioning
- PandaX Hall B2 at CJPL-II is being furbished for future $0\nu\beta\beta$ and dark matter detectors.
- More details from our CDR: ArXiv:1610.08883





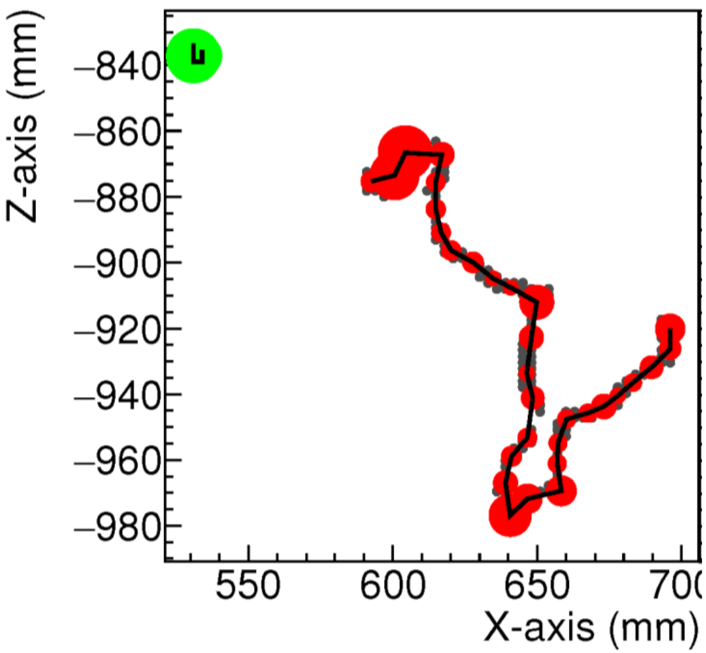
High pressure vessel

- High gas pressure and radio-pure
- Baseline approach: oxygen-free copper welded with E-beam technique
  - 15 cm thick end caps
  - 3.2 cm thick side wall
  - About 9 ton of OFHC copper
  - Technologically challenging
  - Still a major contributor to our background budget
- Alternatively:
  - Titanium vessel with copper lining

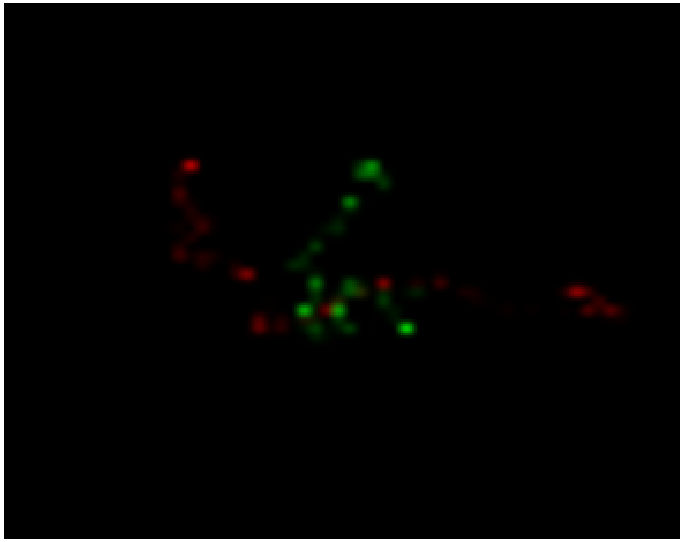


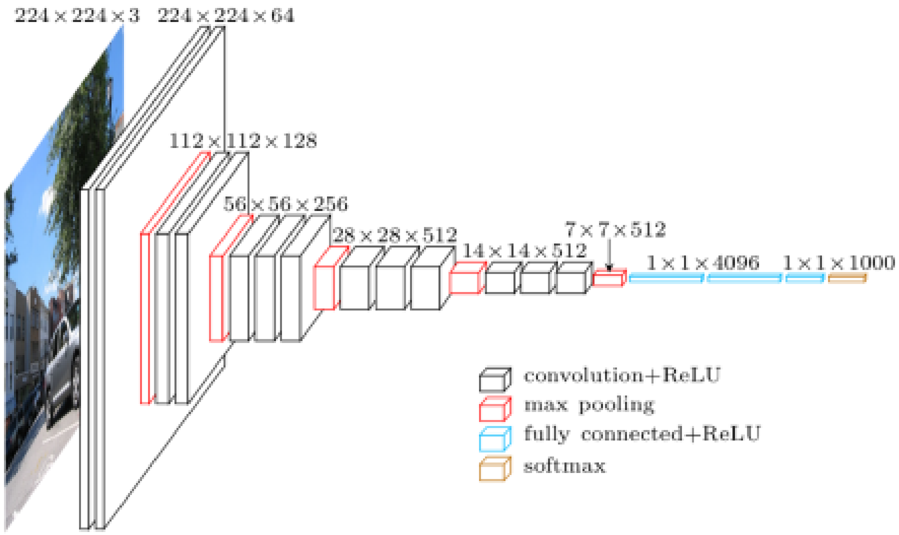
	Isotope	Activity	Background (CPY)		BI (10^{-5}c/(keV·kg·y))	
			BambooMC	RestG4	BambooMC	RestG4
Laboratory walls	^{238}U	9.9 Bq/kg	< 0.40 ± 0.03	< 0.09± 0.01	-	<0.4
	^{232}Th	4.4 Bq/kg	< 0.22 ± 0.02	< 0.15± 0.01	-	<0.6
Water	^{238}U	0.12 μBq/kg	0.20 ± 0.1	0.22 ± 0.03	0.74	0.86
	^{232}Th	0.04 μBq/kg	0.24 ± 0.06	0.55 ± 0.03	0.96	2.21
Barrel	^{238}U	0.75 μBq/kg	1.73 ± 0.12	1.77 ± 0.1	6.9	7.05
	^{232}Th	0.2 μBq/kg	4.63 ± 0.18	4.55 ± 0.05	18.5	18.2
	^{60}Co	10 μBq/kg	9.8 ± 1.0	9.9 ± 0.9	39.0	39.7
End-caps	^{238}U	0.75 μBq/kg	0.83 ± 0.11	0.90 ± 0.11	3.3	3.6
	^{232}Th	0.2 μBq/kg	2.4 ± 0.1	2.2 ± 0.1	9.8	9.0
	^{60}Co	10 μBq/kg	4.4 ± 1.0	4.2 ± 0.9	17.8	16.7
Bolts	^{238}U	0.5 mBq/kg	7.5 ± 1.5	7.3 ± 0.9	30.1	29.2
	^{232}Th	0.32 mBq/kg	39.8 ± 2.7	46.7 ± 1.9	159	186.3
Field insulator	^{238}U	4.94 μBq/kg	15.0 ± 0.5	15.7 ± 0.3	59.9	62.6
	^{232}Th	0.1 μBq/kg	2.69 ± 0.03	2.61 ± 0.1	10.7	10.4
and rings	^{238}U	0.75 μBq/kg	0.67 ± 0.01	0.72±0.05	2.7	2.9
	^{232}Th	0.2 μBq/kg	0.95 ± 0.01	0.92 ± 0.03	3.8	3.7
Electronics	^{238}U	0.26 Bq	1.0 ± 0.3	2.4 ± 0.5	4.2	9.5
	^{232}Th	0.07 Bq	2.8 ± 0.2	4.1 ± 0.5	11.3	16.3
Micromegas	^{238}U	45 nBq/cm^2	60.5 ± 1.7	63.7 ± 1.8	241.6	254.4
	^{232}Th	14 nBq/cm^2	23.5 ± 0.6	25.3 ± 0.6	93.9	101
Cathode	^{214}Bi	2 nBq/cm^2	4.1 ± 0.2	3.3 ± 0.1	16.5	13.2

Table 5 The raw background contribution from different parts in the laboratory and the detector by taking the 3% FWHM detector resolution into account. BI stands for *Background Index*.



Z-axis (mm)
−840
−860
−880
−900
−920
−940
−960
−980
550
600
650
X-axis (mm)





224 × 224 × 3
224 × 224 × 64
112 × 112 × 128
56 × 56 × 256
28 × 28 × 512
14 × 14 × 512
7 × 7 × 512
1 × 1 × 4096
1 × 1 × 1000
convolution+ReLU
max pooling
fully connected+ReLU
softmax