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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Outline

I. 0νββ and PandaX project

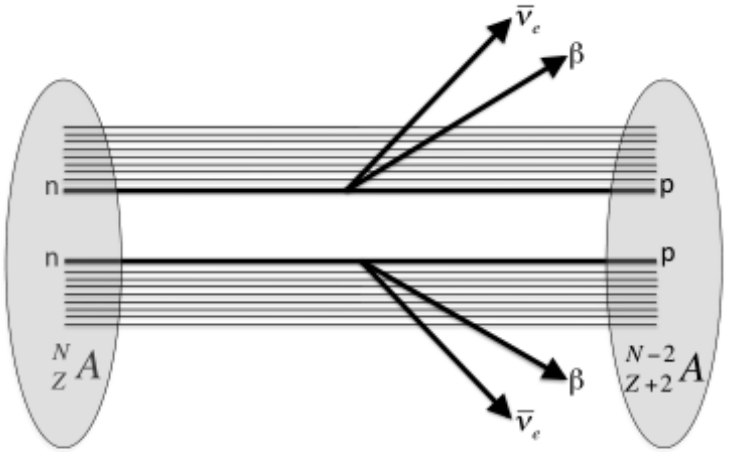
II. PandaX-III experiment

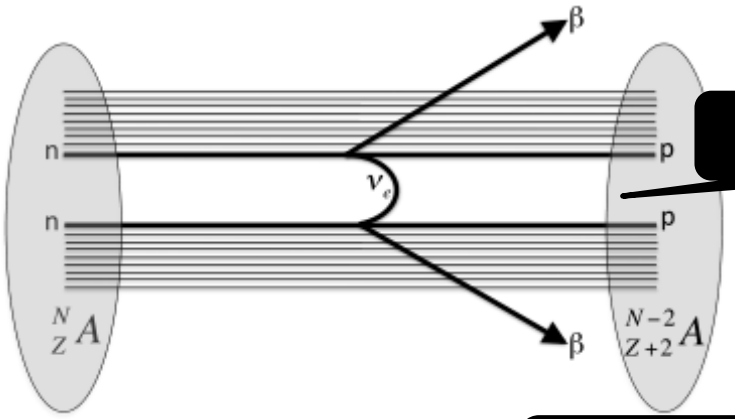
- Design of detector and subsystems
- Performance expected
- PandaX-III prototype TPC

III. Conclusions and perspectives

0νββ

$$^{N}_{Z}A \rightarrow ^{N-2}_{Z+2}A + 2\beta^- + 2\bar{\nu}_e$$

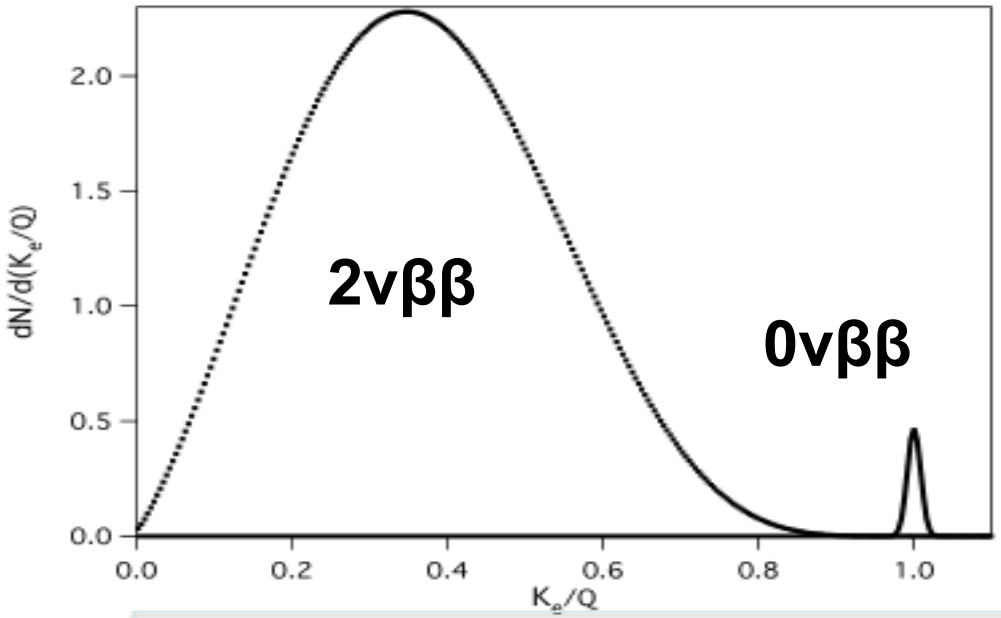




Majorana Neutrino

$$^{N}_{Z}A \rightarrow ^{N-2}_{Z+2}A + 2\beta^-$$

Lepton Number Conservation Violated

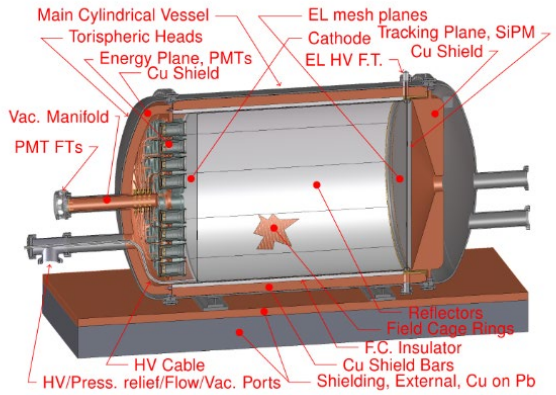


Q value of $^{136}_{56}Xe \rightarrow ^{136}_{58}Ba$:
2457.83(37) keV PRL 98, 053003(2007)

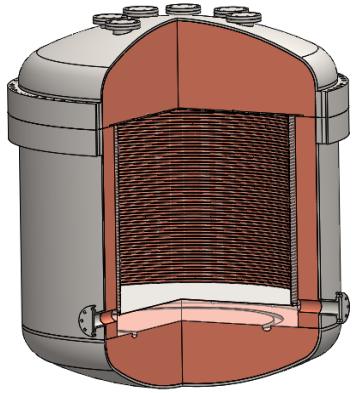
- 2νββ: 11 isotopes
- 0νββ: Majorana Neutrino? Lepton number violation?

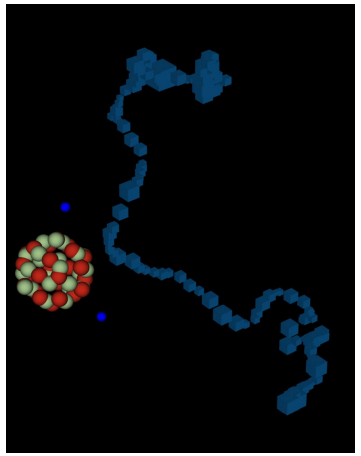
➢ Measure energies of emitted e$^-$,tracks

0νββ experiments



NEXT ^{136}Xe



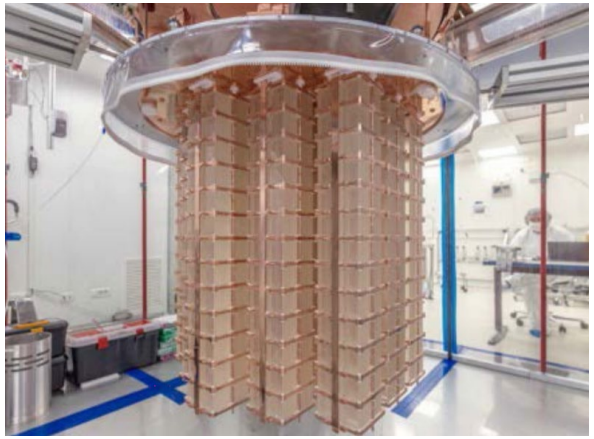


PandaX-III ^{136}Xe

Kamland-Zen

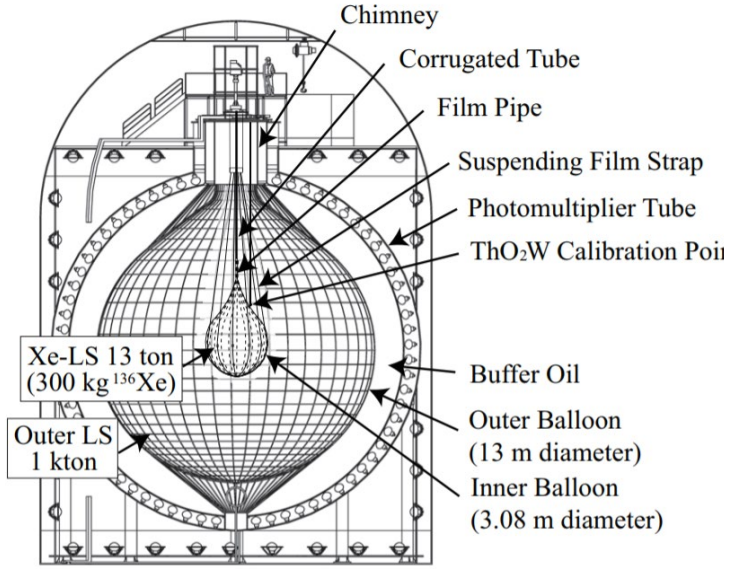
^{136}Xe

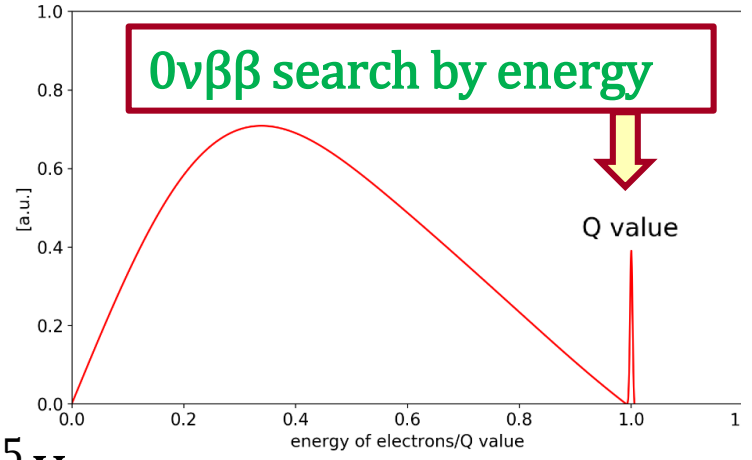
$T_{1/2}>1.07\times10^{26}$ y

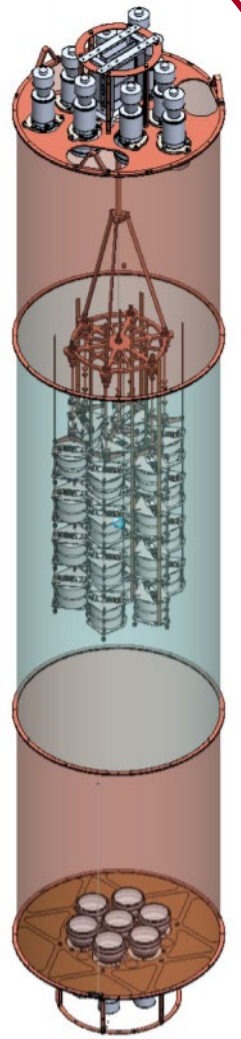


CUORE

$^{130}TeO_2$ $T_{1/2}>1.5\times10^{25}$ y







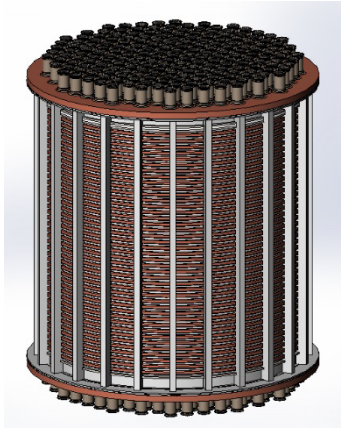
GERDA ^{76}Ge $T_{1/2}>8\times10^{25}$ y

PandaX project overview

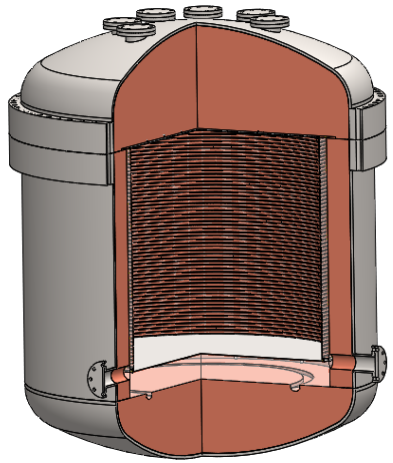
Dark matter WIMP searches | **0νββ searches**

PandaX-I: 120kg LXe
(2009 – 2014)

PandaX-II: 500kg LXe (2014 – 2019)



PandaX-4T: 4T LXe
(commissioning)



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

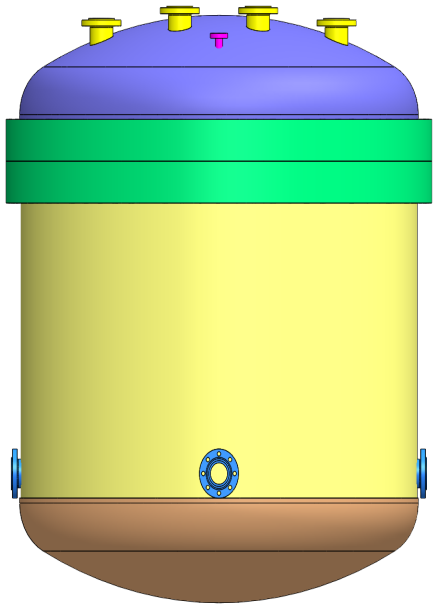
Liquide Xe ⟷ High pressure Xe

PandaX-III collaboration

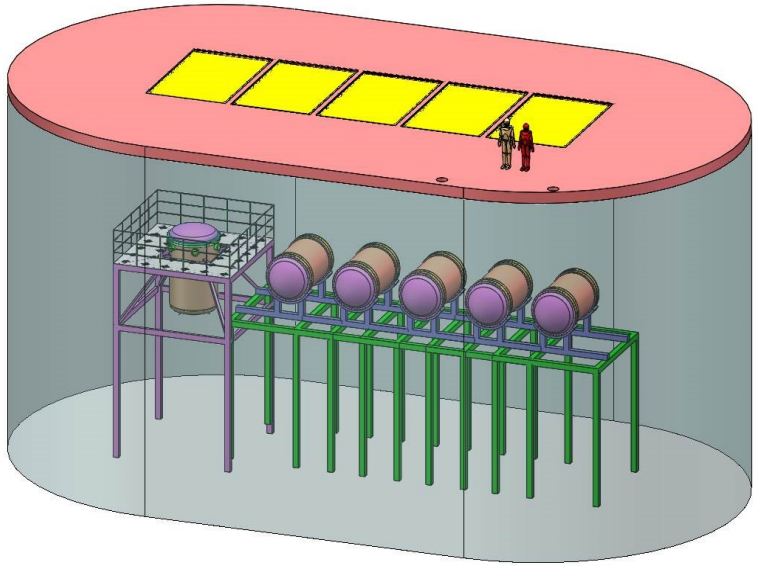
- **China**: *SJTU, USTC, Peking University, CIAE, Shandong University, CCNU*
- **Spain**: *Universidad de Zaragoza*
- **France**: *CEA Saclay*
- **US**: *University of Maryland*, LBNL
- **Thailand**: *SUT*

PandaX-III: search for 0νββ of ^{136}Xe

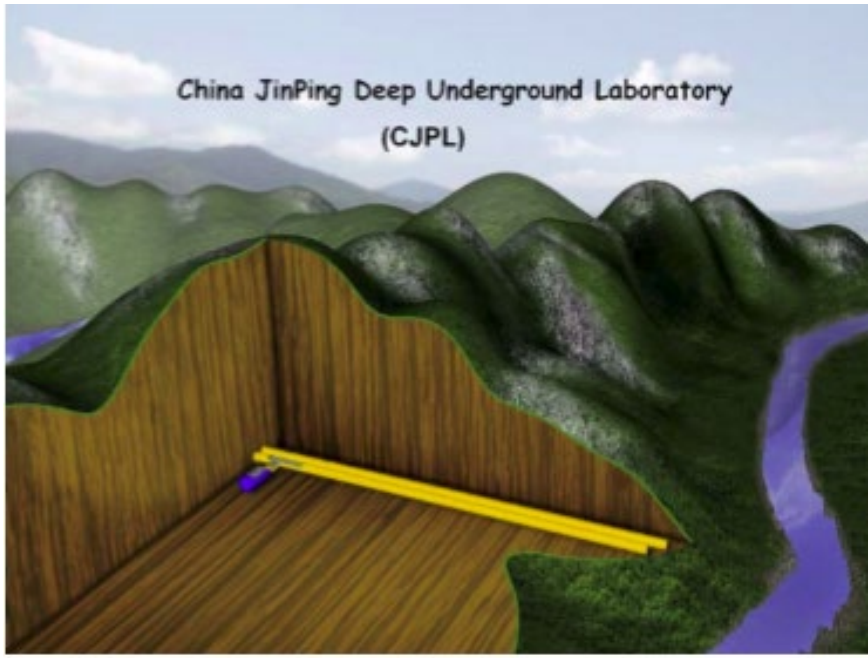
- First phase： 140 kg of 90% ^{136}Xe enriched gas TPC (Time Projection Chamber).
- Final phase： a ton scale experiment (5 modules of 200 kg).
- @ Hall #B2 at China Jin Ping underground Lab (CJPL-II): 5 m of ultra-clean water shielding in all directions



PandaX-III detector of first phase:
Long×2R of TPC： 1.2×1.6m



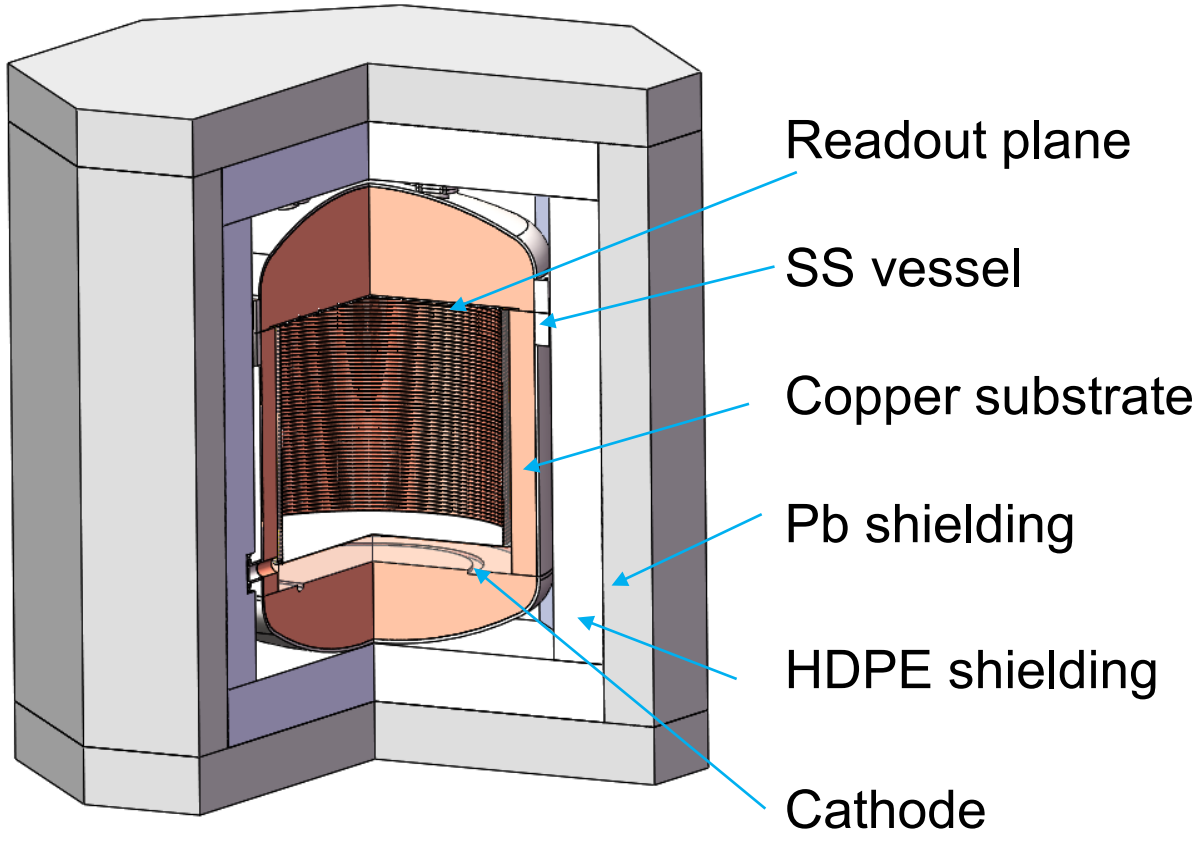
Tank of water at CJPL-II



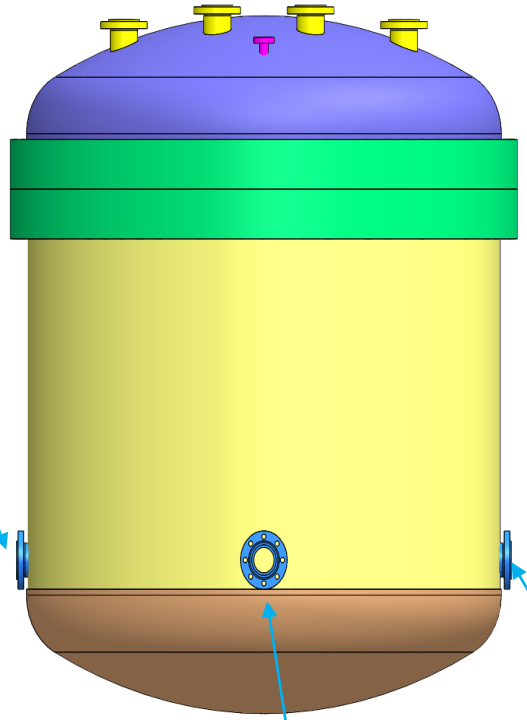
rock overburden of 2400 m
→muon rate of 1/m2·week

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 cm^2 Microbulk Micromegas (Micro-Mesh Gaseous Structure) for charge readout
- Readout: 2 series of strips (x, y)



HP SS (Stainless Steel) vessel



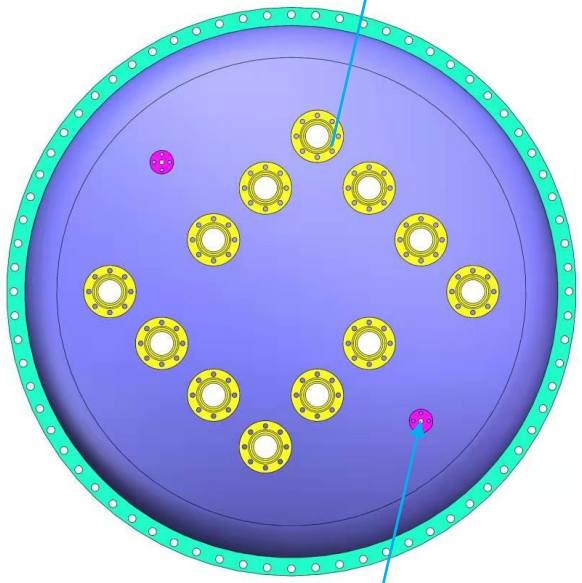
Vacuum pump

High voltage power

Gas inlet or outlet

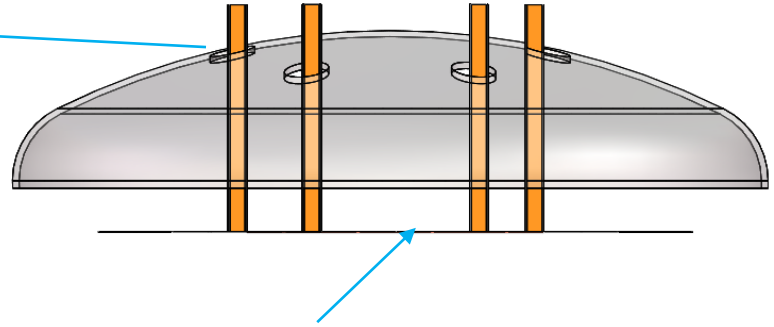
The forth one is backup

12×DN80，signal cables are glued in flanges



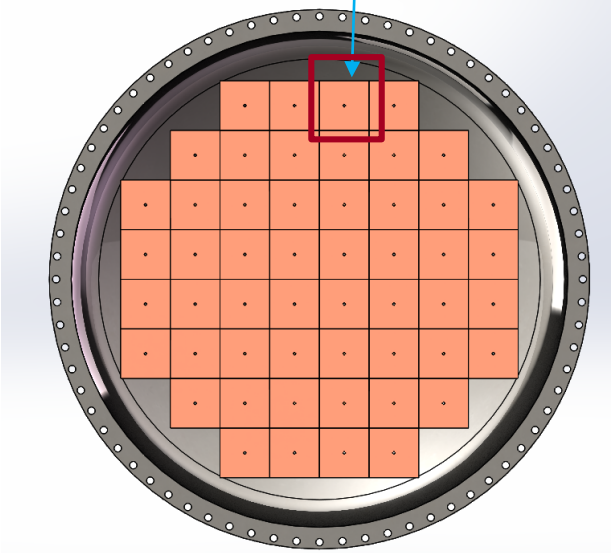
2×DN10, gas inlet or outlet

The second 2×DN10 flange is backup



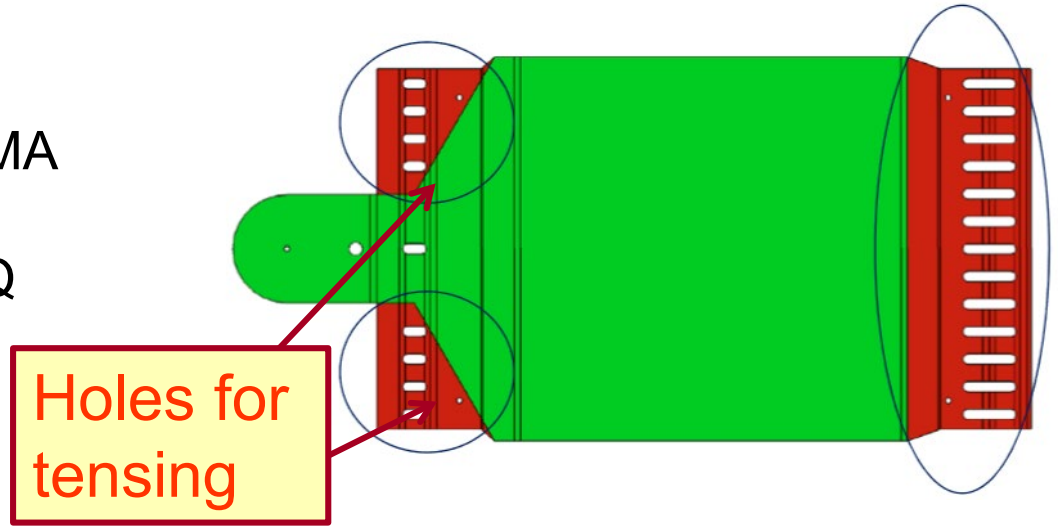
52 Microbulk Micromegas

- 20 X 20 cm
- 3 mm pitch size, 128 strip readouts

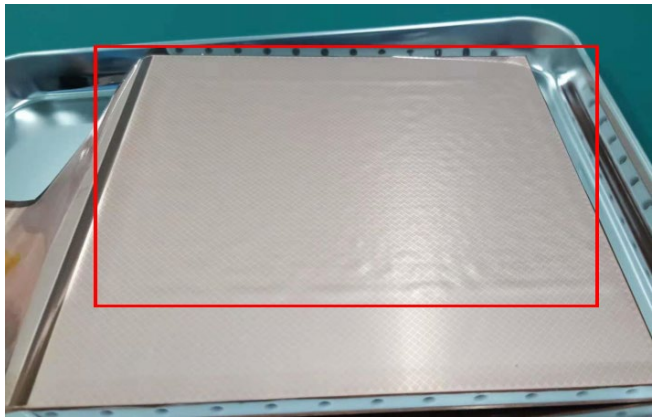


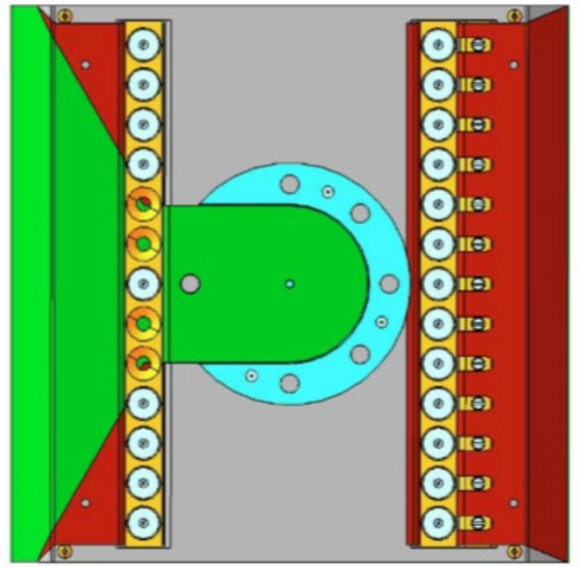
Micromegas and SR2M module

- 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}Xe 0νββ).



- 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

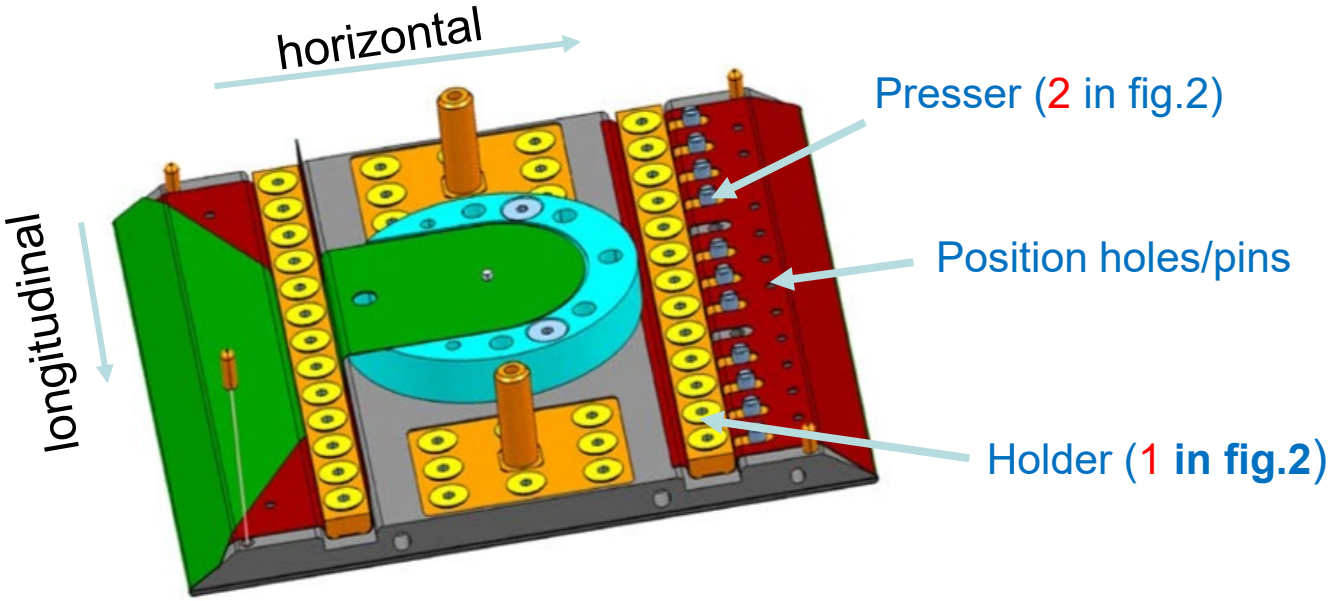


Fig.1 MM_V2 tensing scheme designed by Hector.Mirallas

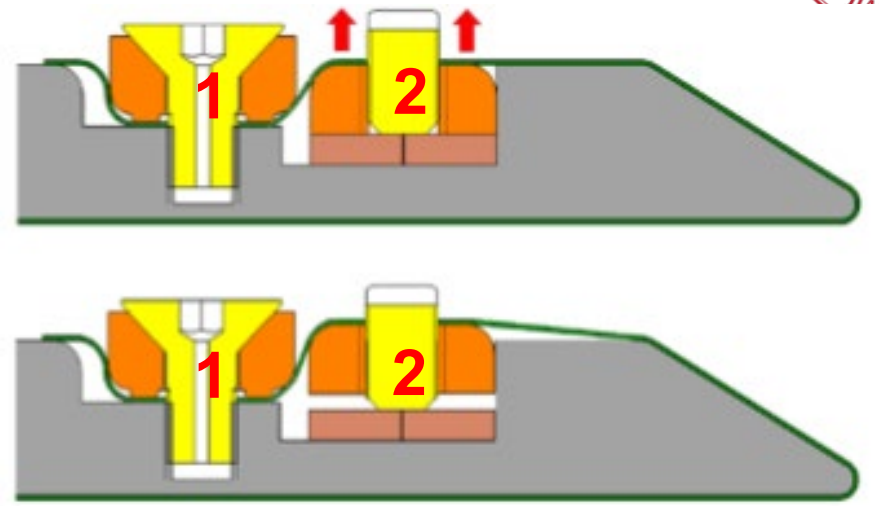
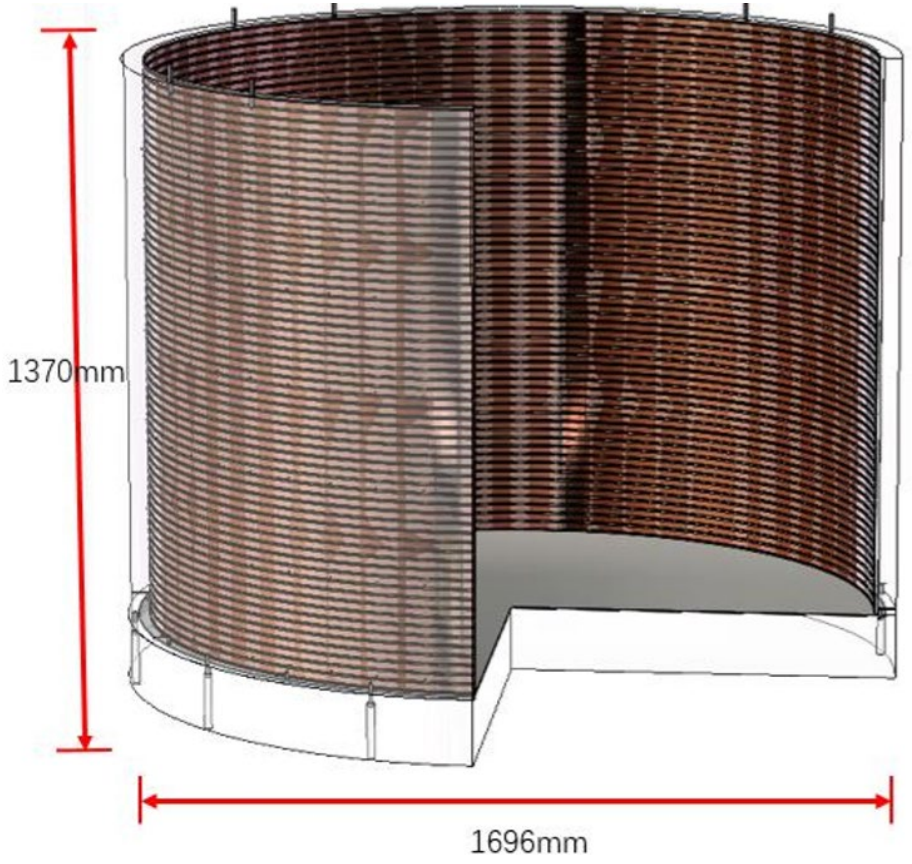


Fig.2 crossection drawing of the MM_V2 tensing scheme

Fig.3 Tensing a MMs_V2 film

- **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

Field cage

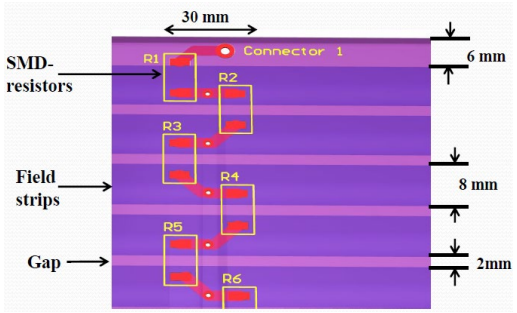


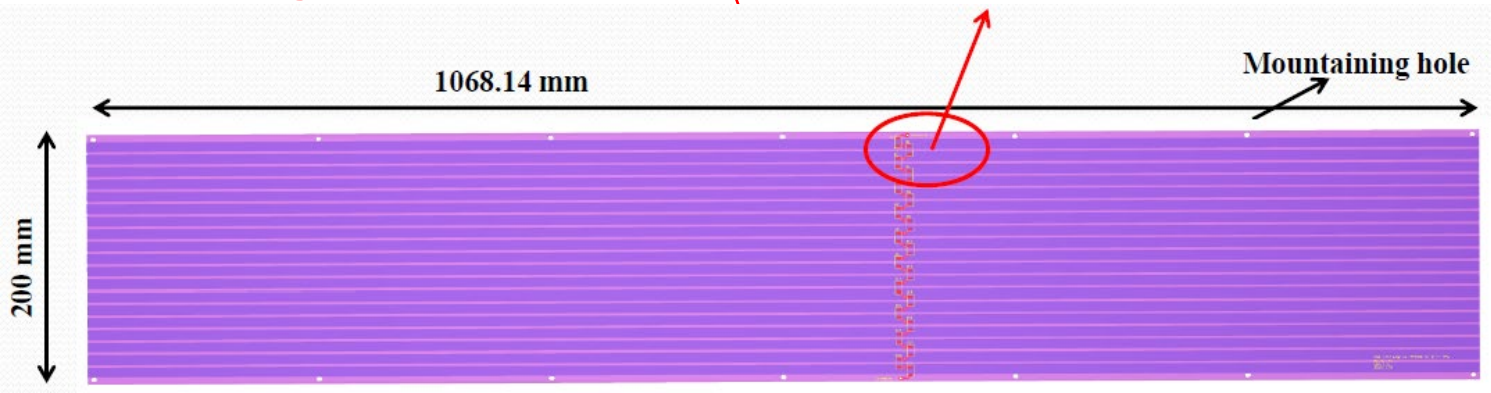
Design of field cage of full TPC

Kapton Flexible PCB + SMD resistors

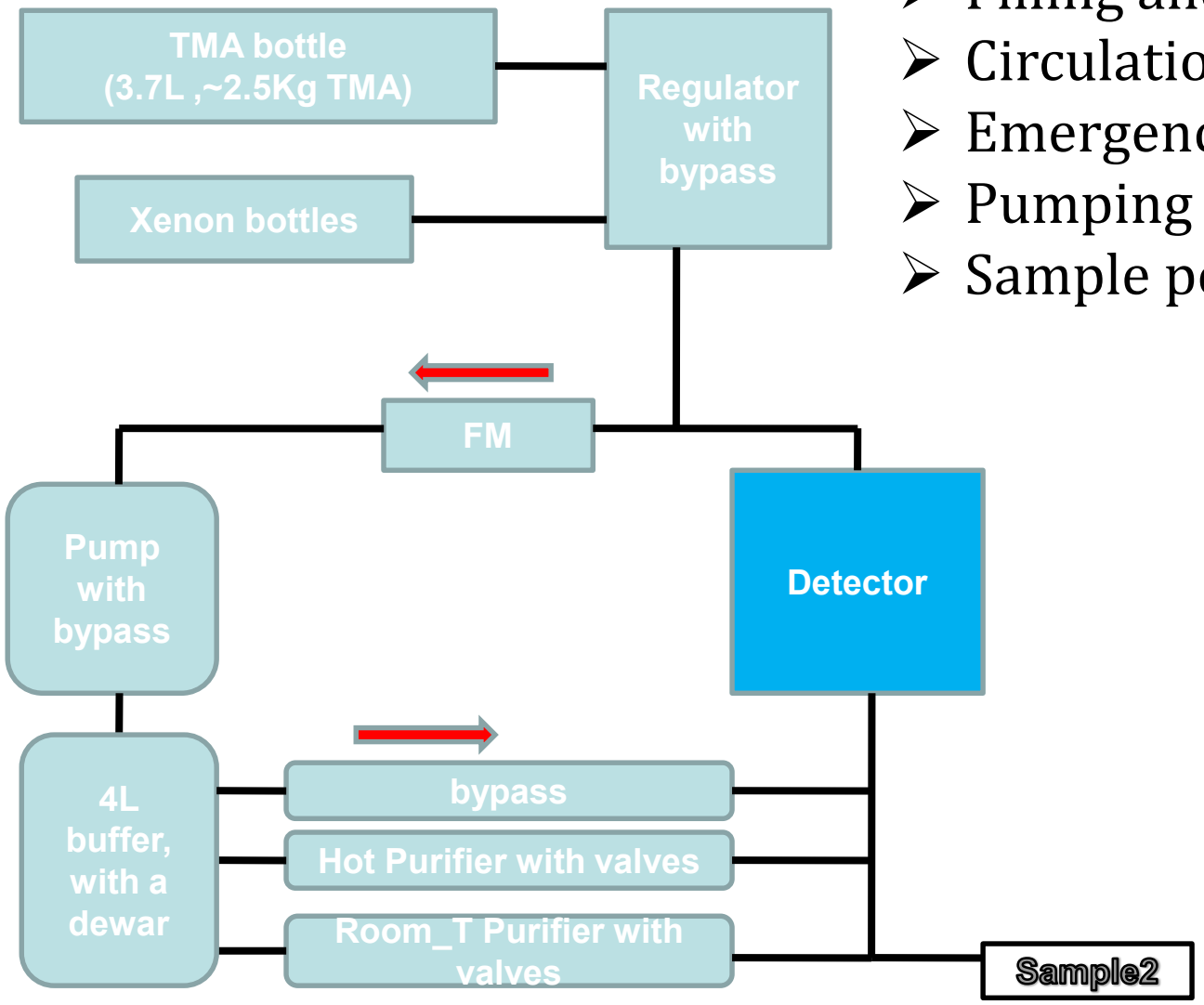
- We are testing this option with mini-TPC and prototype TPC at SJTU

Field cage in mini-TPC

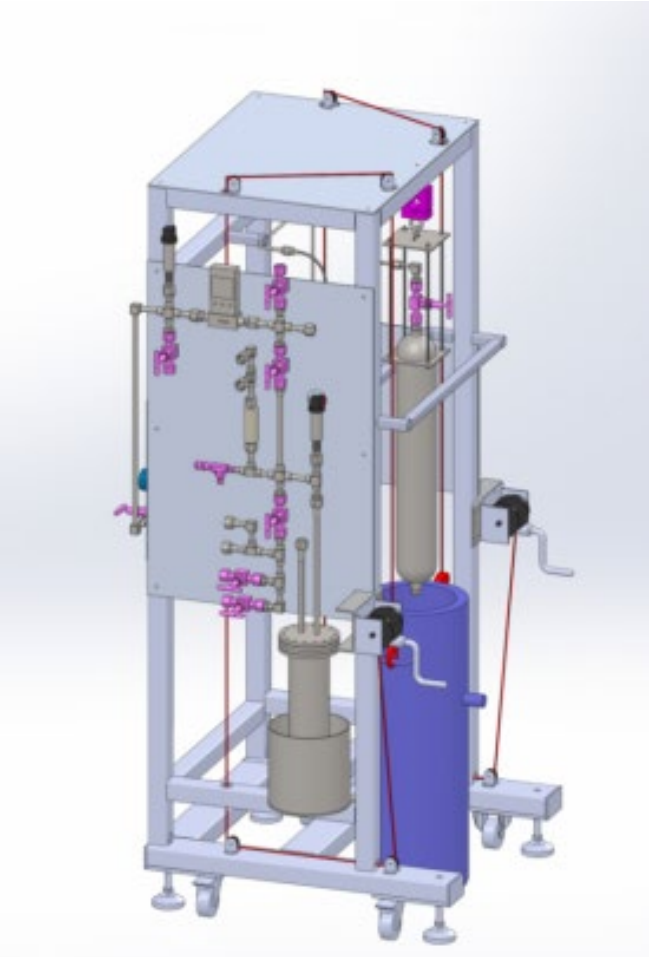




Gas system for PandaX-III in CJPL-II

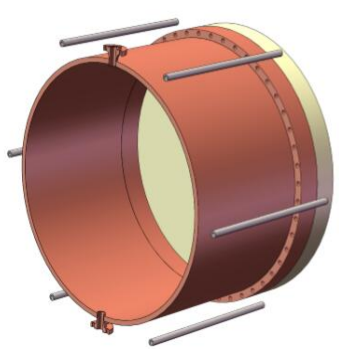


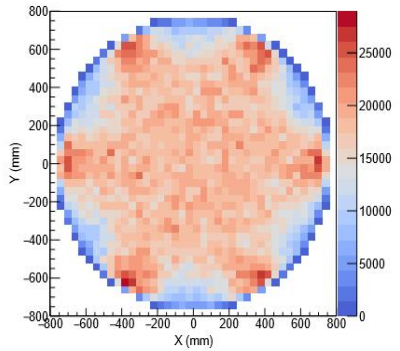
- Filling and mixing system;
- Circulation purification system;
- Emergency recovery;
- Pumping port;
- Sample port.

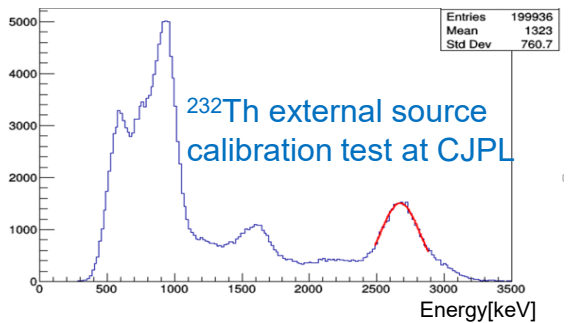


PandaX-III calibration

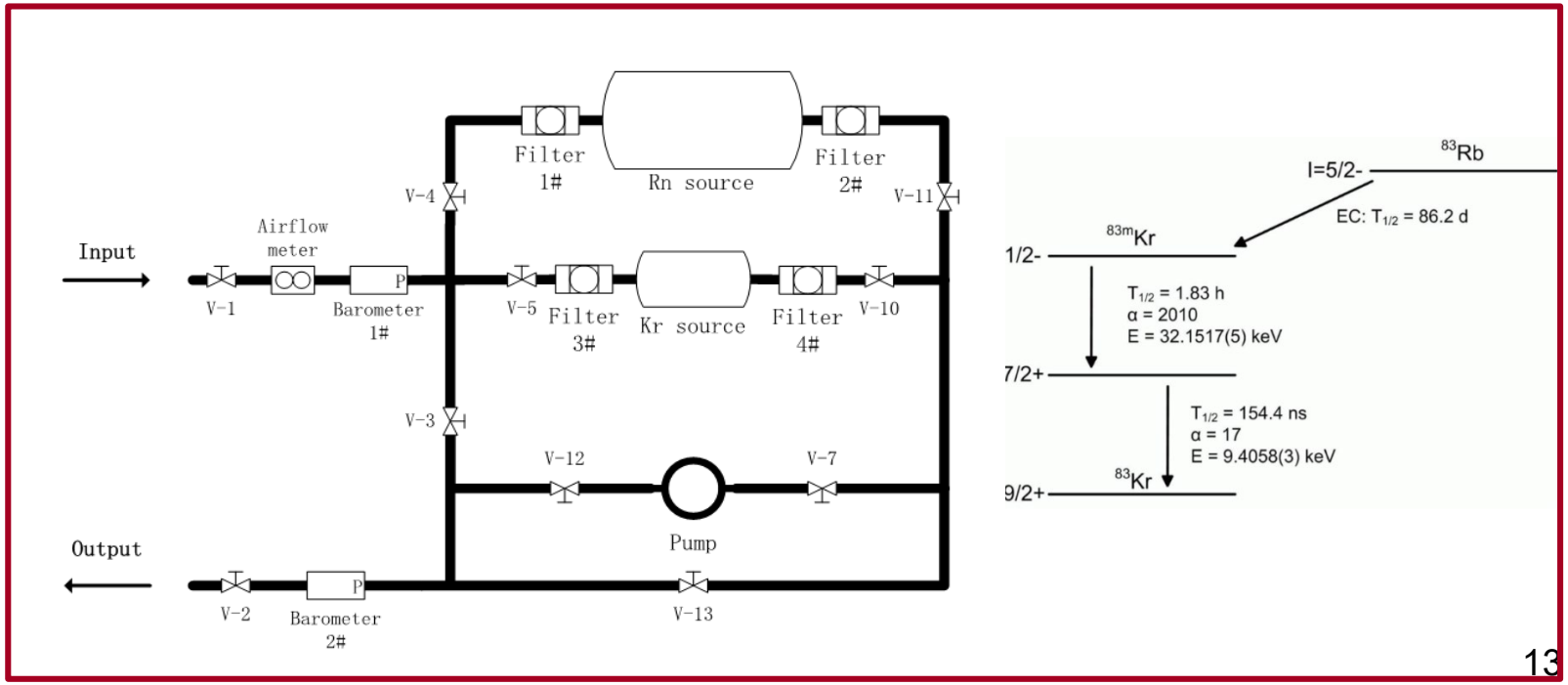
- External system
  - Measure non-linearity in the detector energy response
  - Absolute calibration at Q value of 0νββ
  - Calibration sources: ^{22}Na, ^{60}Co, ^{137}Cs and ^{232}Th



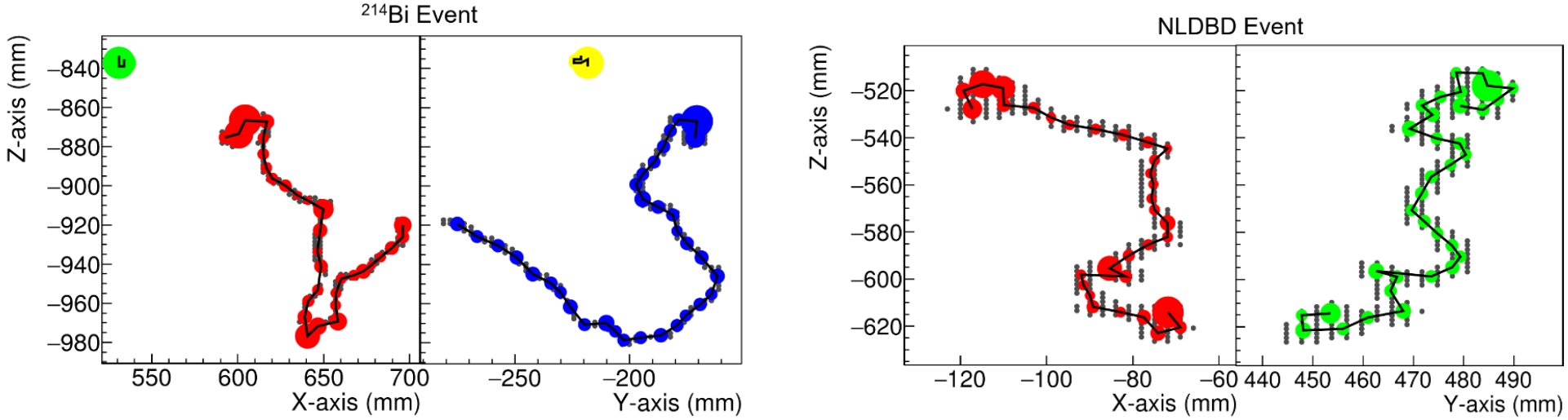




- Internal system
  - To generate events deep in the TPC with high calibration rate
  - Calibration sources (gas): ^{220}Rn and ^{83m}Kr
  - To calibrate energy response at Q value by using ^{220}Rn
  - To calibrate MM(s) uniformity and geometrical corrections by using ^{83m}Kr



Background budget and projected sensitivity



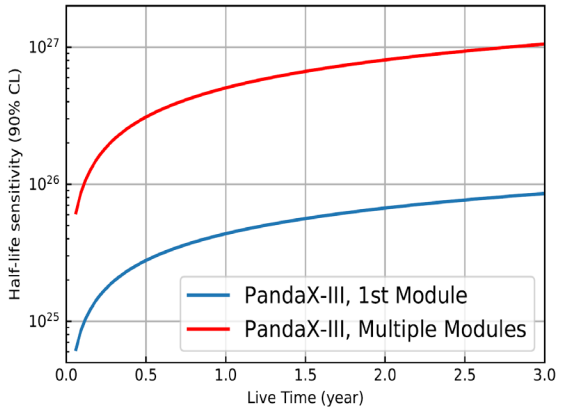
Reconstruction of the projected electron tracks (XZ and YZ) produced by two Monte Carlo simulated events

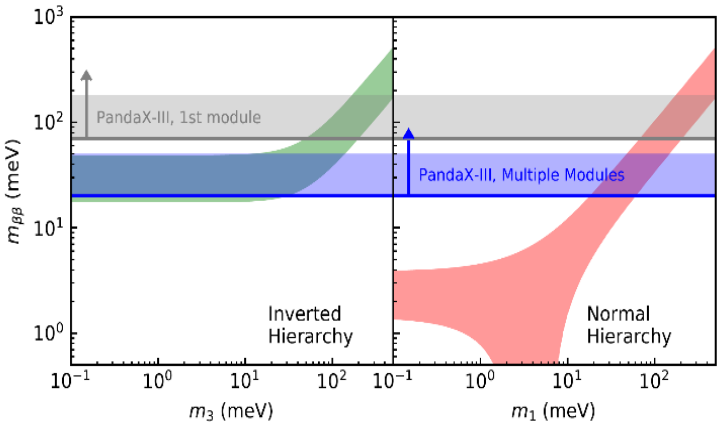
Background rate: 1 x 10^{-4} c/keV/kg/y in the ROI:

- Two independent Geant-4 MC: RESTG4 and BambooMC
- Topological analysis
  - ➢ Convolutional neural networks
  - ➢ Traditional track reconstruction

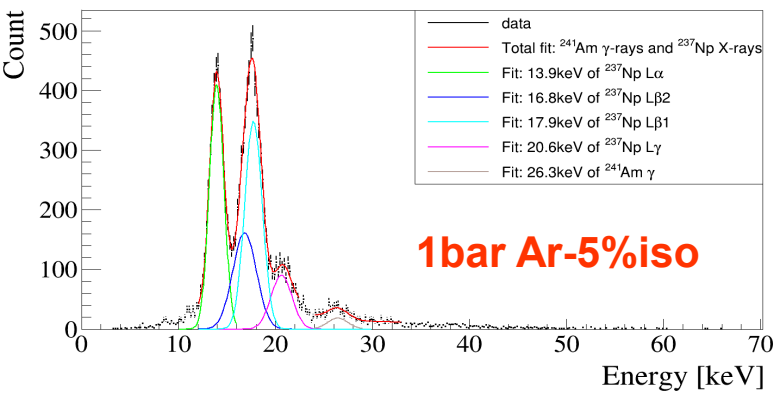
Sensitivity expected of 3 years' live time:

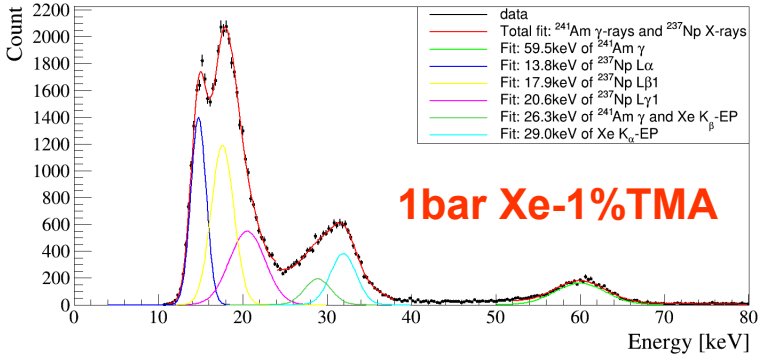
- First module: 8.5×10^{25} y half-life limit
- Ton-scale: 10^{27} y half-life limit

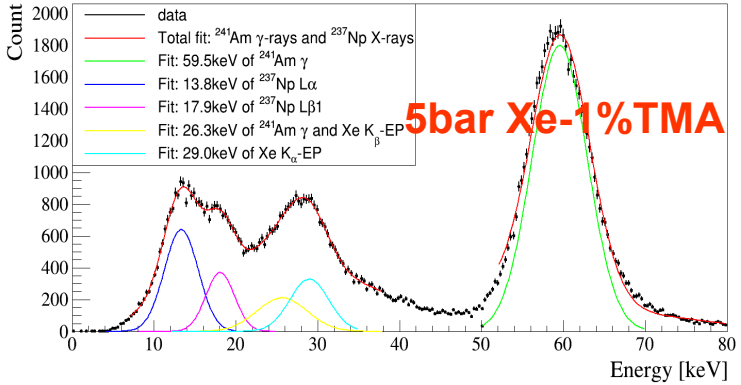


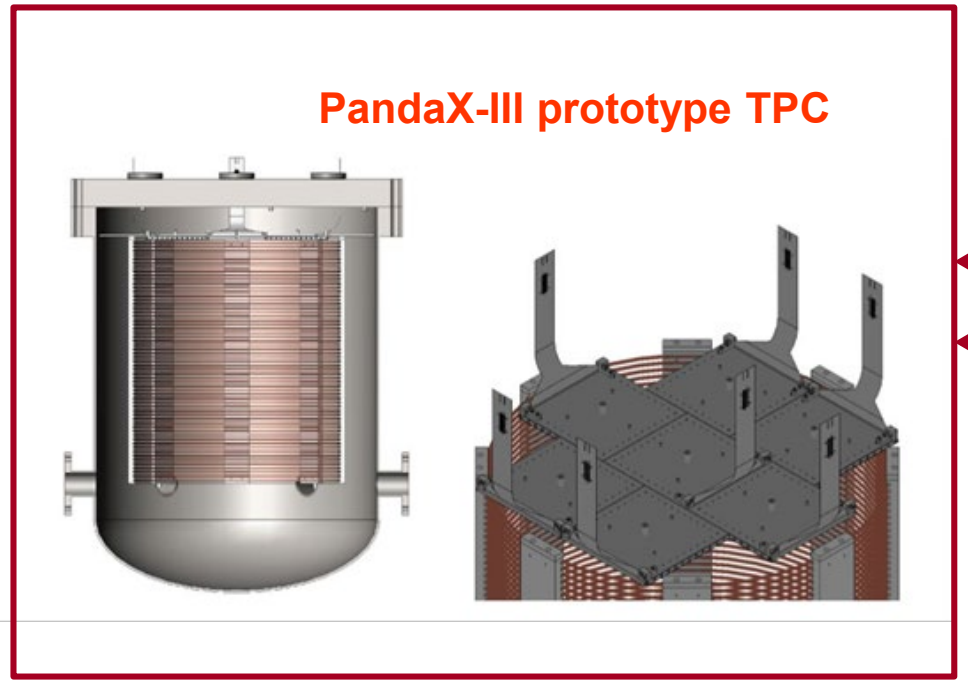


Overview of Prototype TPC

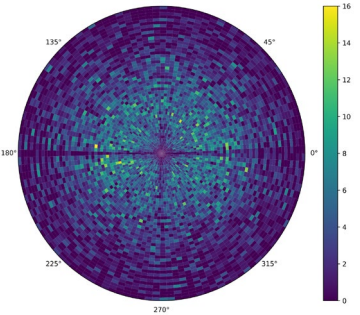




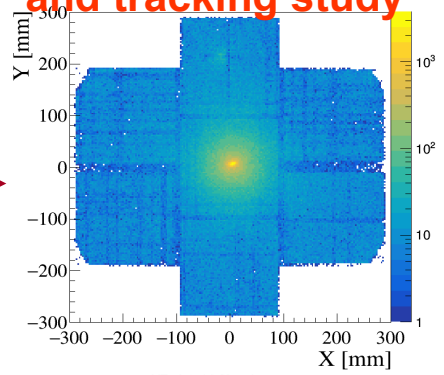




Muon track analysis

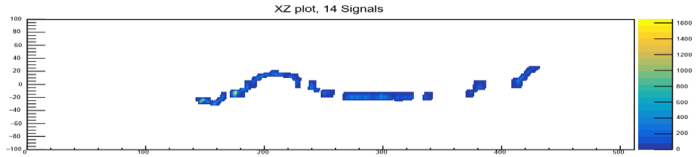


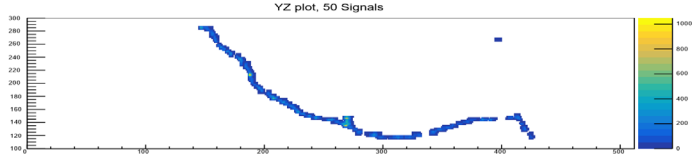
7 MMs data taking and tracking study



Prototype TPC (20kg Xe at 10bar in active region) with 7 MMs

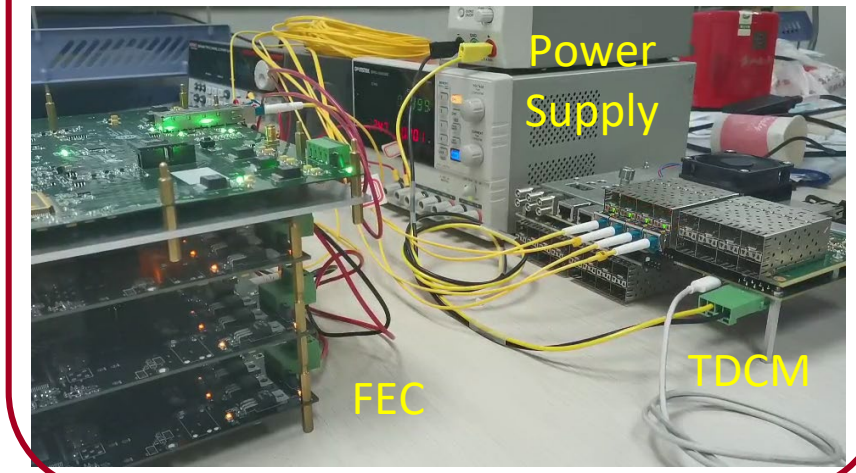
- Optimization for the design of MMs and readout plane
- Energy calibration of TPC
- Track reconstruction



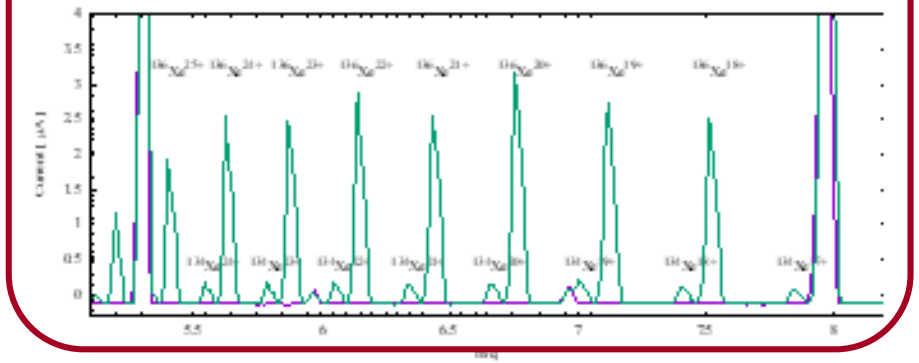


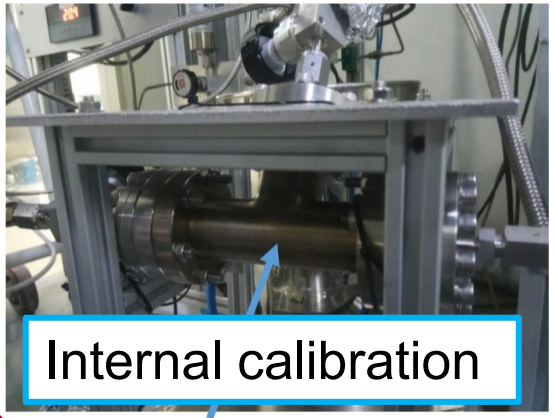
Status of the others

Electronics system

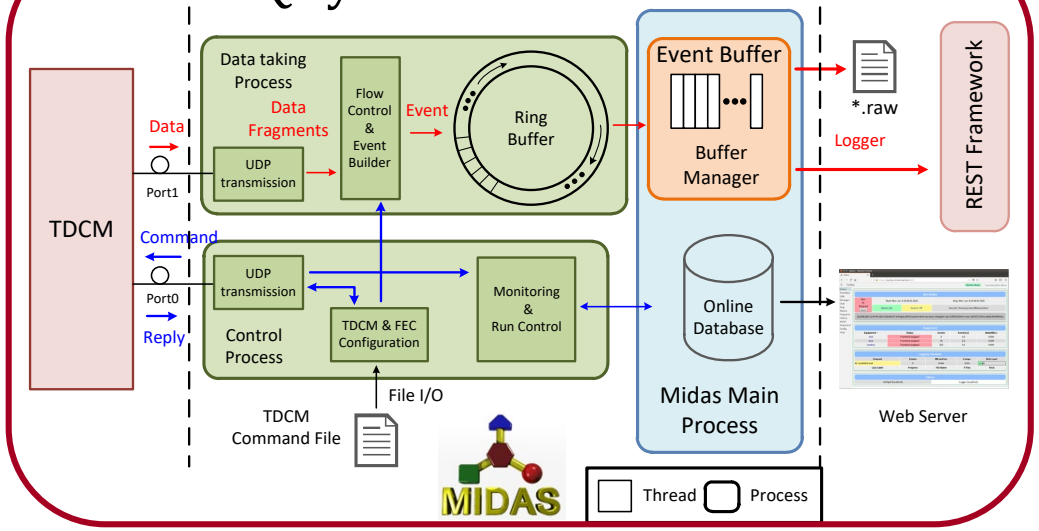


145 kg ^{136}Xe enriched at SJTU

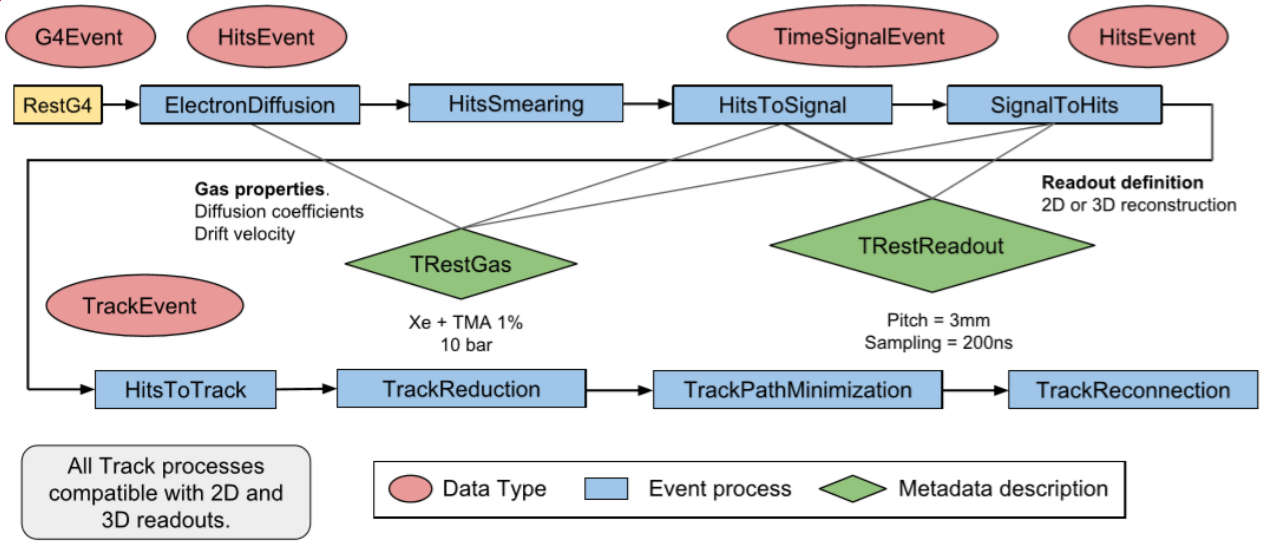




DAQ system



Simulation and data analysis

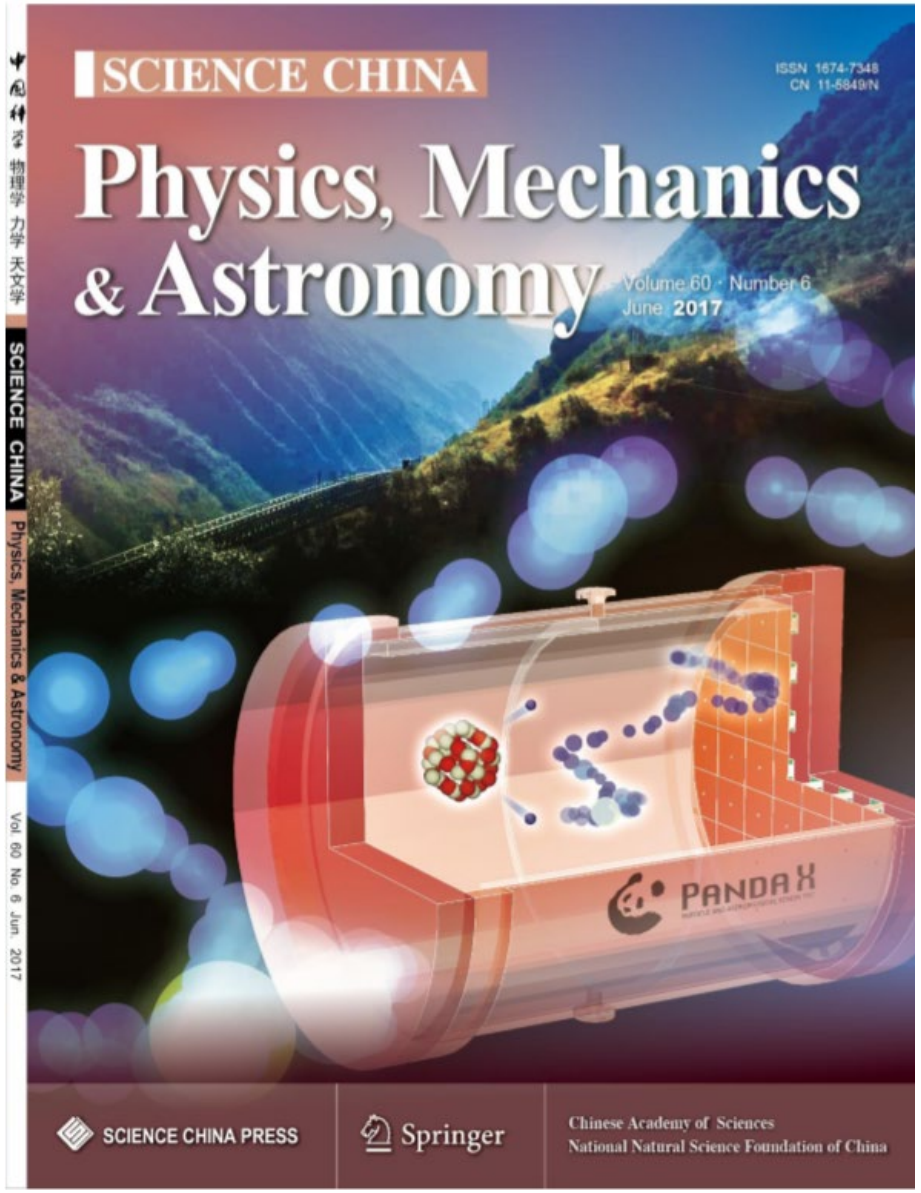


Conclusions and perspectives

- PandaX-III uses high pressure gas TPCs to search for double beta decay of ^{136}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:
SCIENCE CHINA Physics, Mechanics & Astronomy 60(6), 061011(2017)
ArXiv:1610.08883



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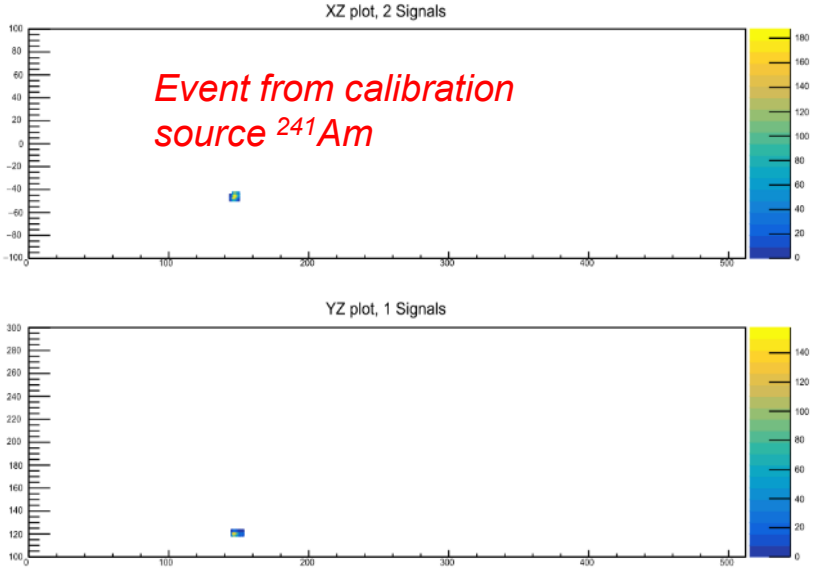
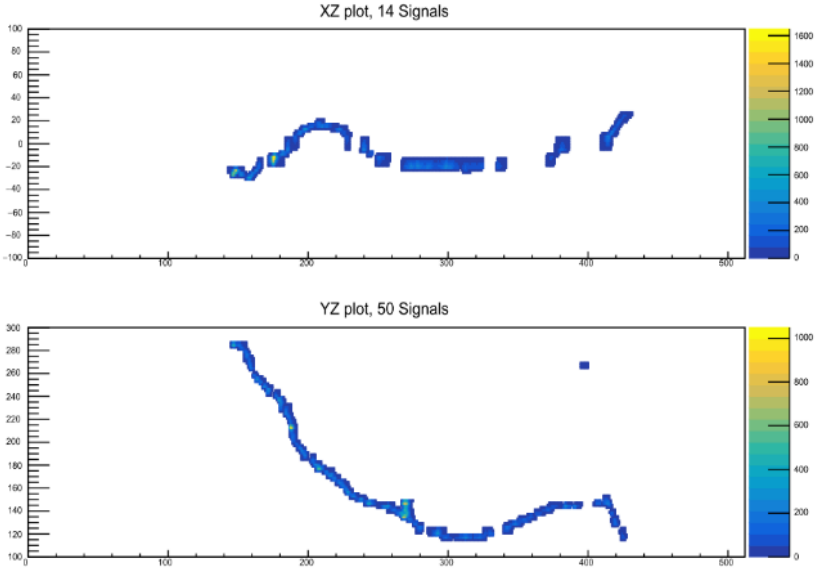
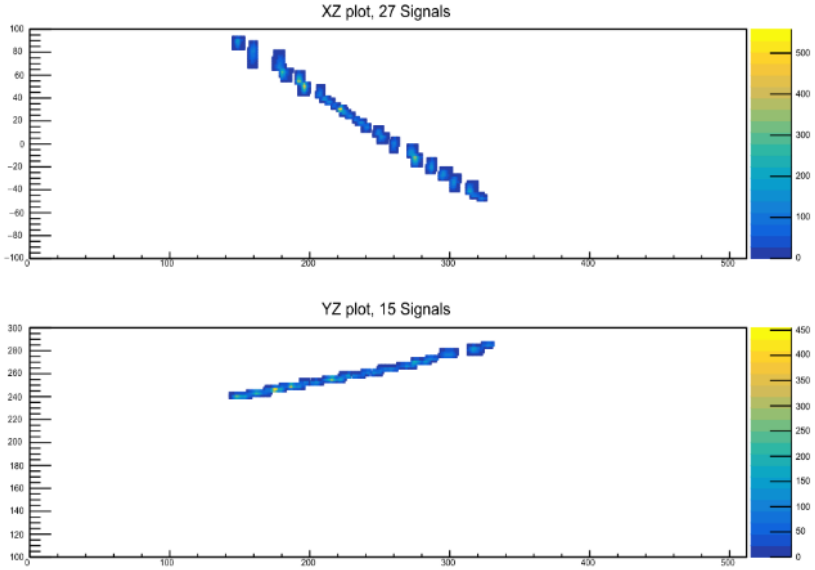
Event from calibration source ^{241}Am



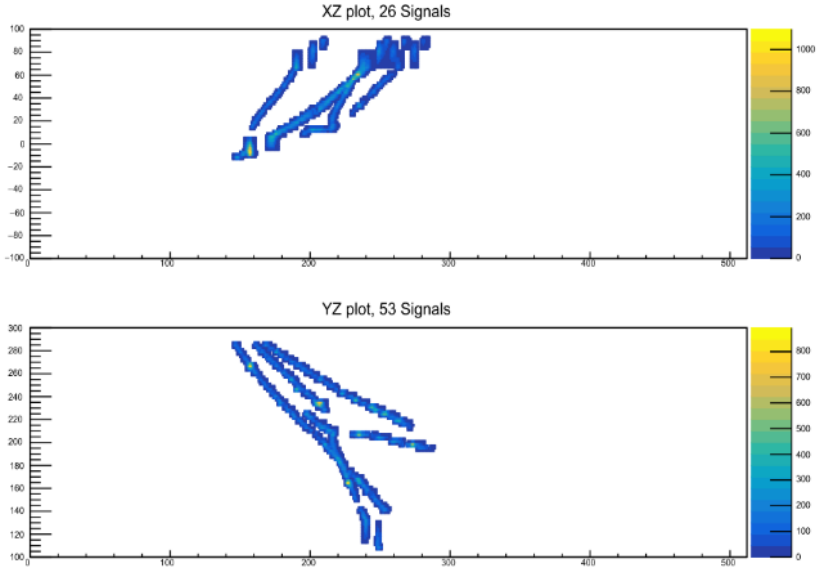
(a)



(b)



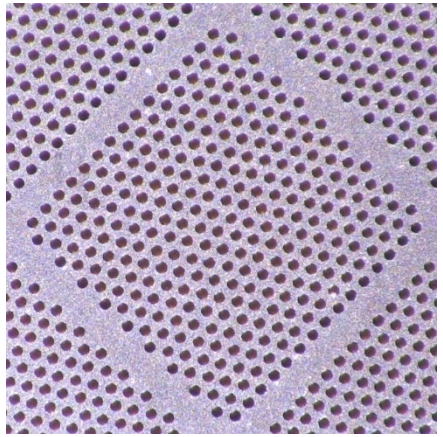
(c)

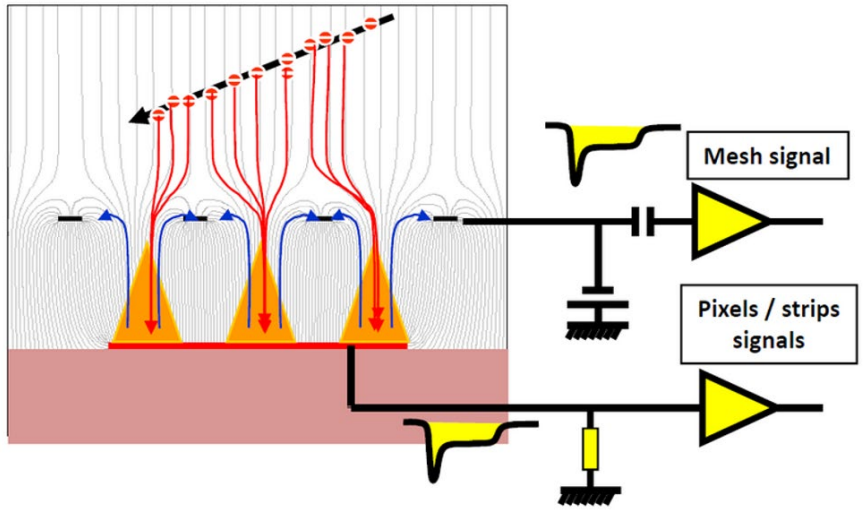


(d)

Microbulk Micromegas (MM)

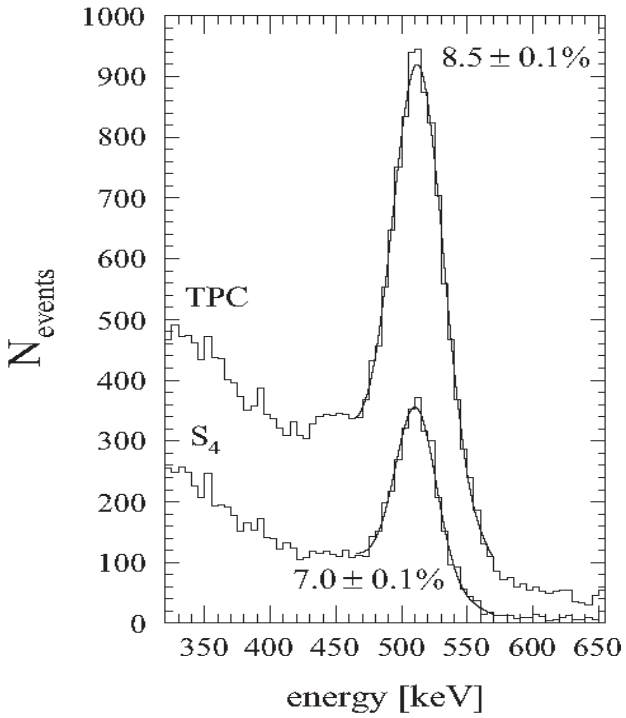
- Microbulk Micromegas (Micro-Mesh Gaseous Structure)
- Radio-purity: made of Copper and Kapton
- Amplification: ~1000X （**T-REX**） at 10 bar Xe:TMA（**trimethylamine**）(99%:1%)
- Energy resolution: 3% FWHM expected at 2.5 MeV(Q value of ^{136}Xe 0νββ)





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

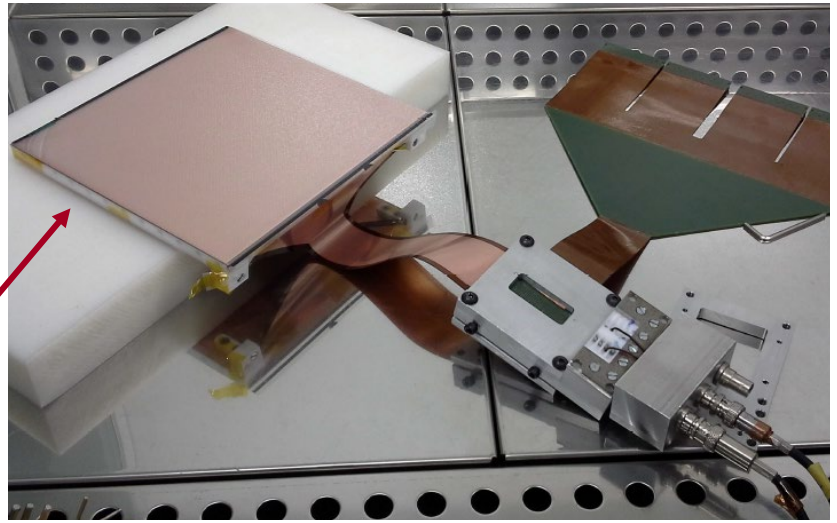
Energy spectrum of ^{22}Na

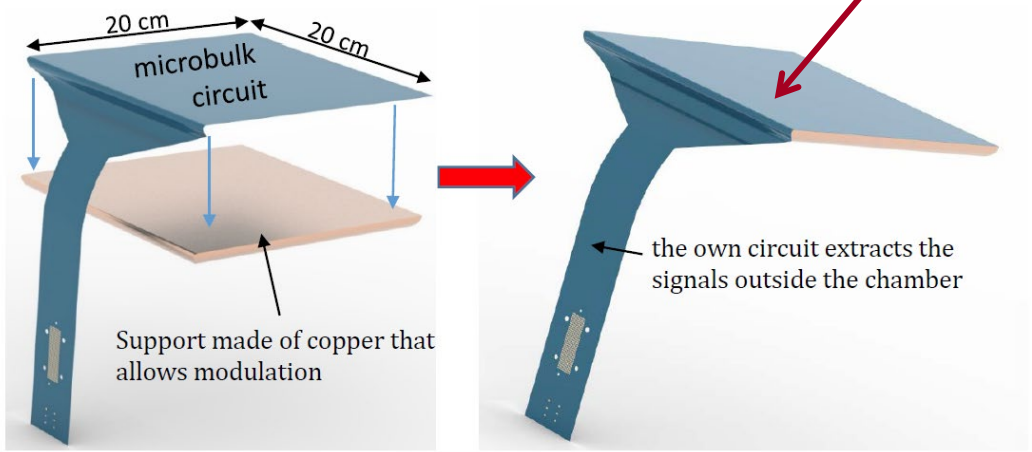


Gonzalez-Diaz, et al. *NIMA* 804 8 (2015)

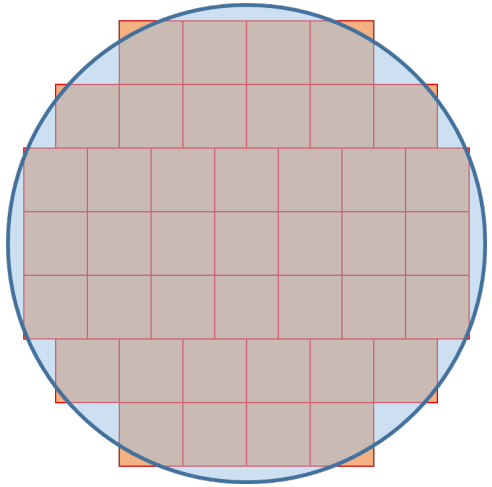
Micromegas in PandaX-III

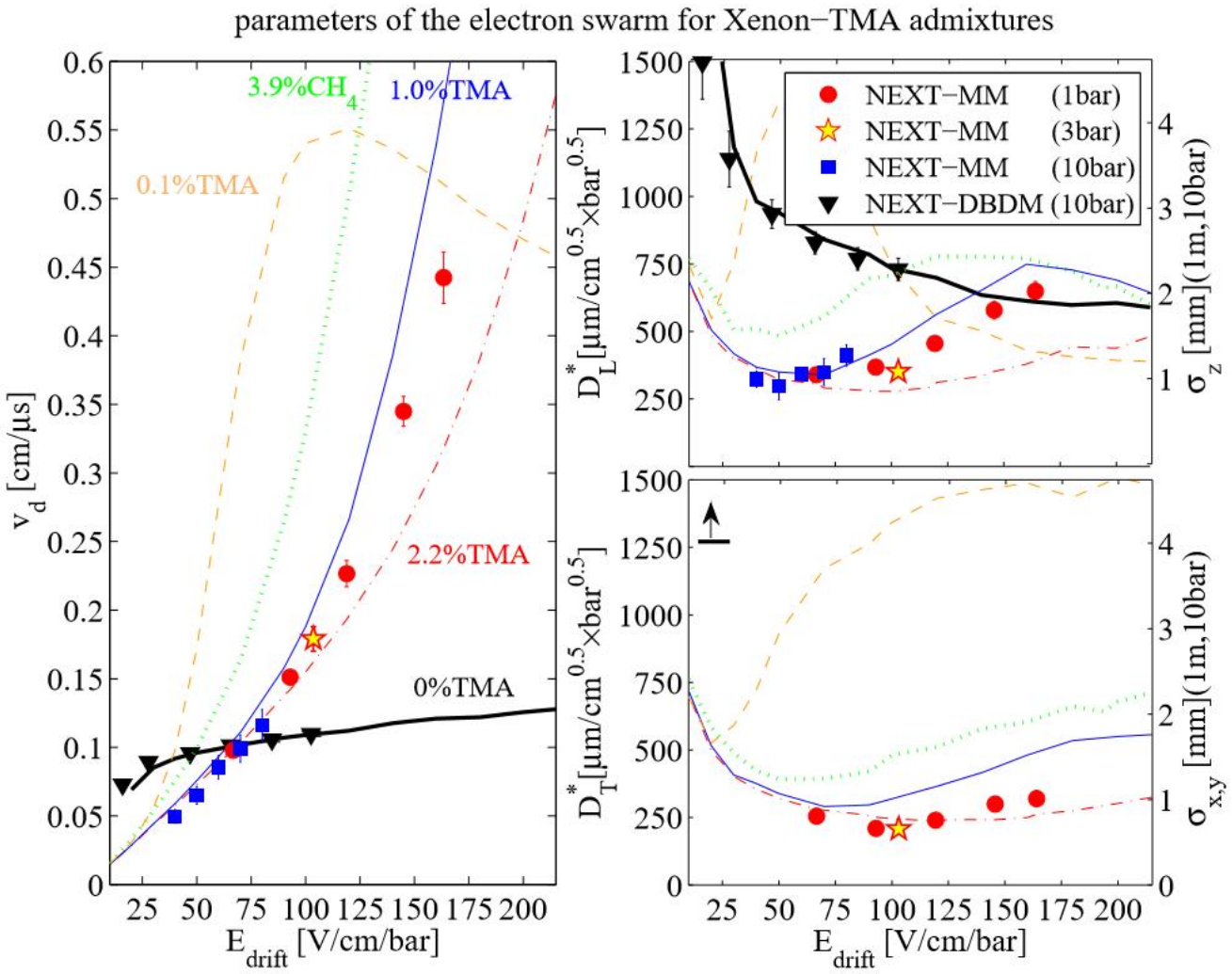
- Scalable Radio-pure Readout Module (SR2M)
  - Solderless system
  - Strip and mesh signal readout
  - Dead-zone-free arrangement
  - Designed by Zaragoza and SJTU
- 11 MMs produced at CERN:
  - 20 X 20 cm
  - 3 mm pitch size, 128 strip readouts





×41





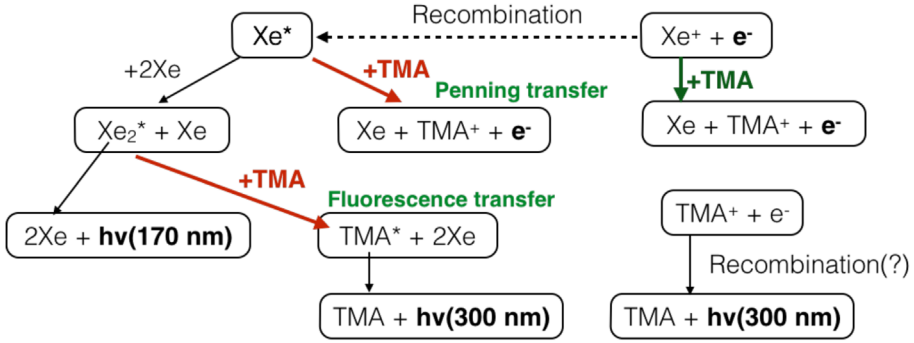


Figure 1. Simplified schematic of Xe and TMA reactions after initial ionization and excitation of Xe. We made the first direct measurement of the processes shown with red arrows.