PandaX-III high pressure xenon TPC for neutrinoless double beta decay search

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On behalf of the PandaX-III collaboration

The 9th Asian Forum for Accelerators and Detectors (AFAD)

Outline

I. Neutrinoless double beta decay($0\nu\beta\beta$)

II. PandaX-III experiment

- Design of detector
- Performance expected

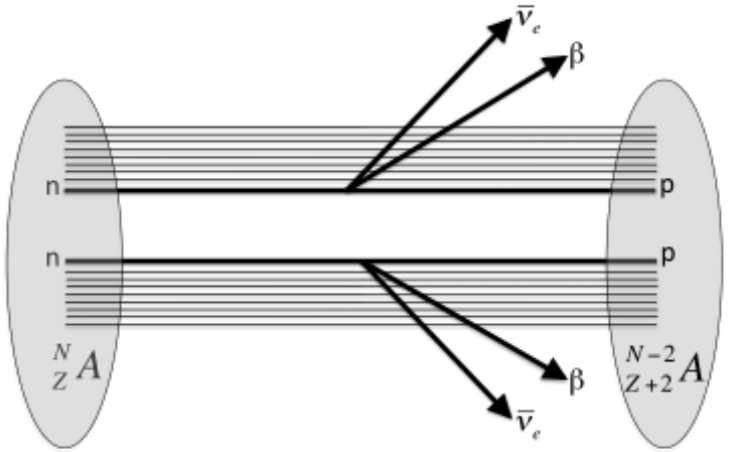
III. PandaX-III prototype TPC

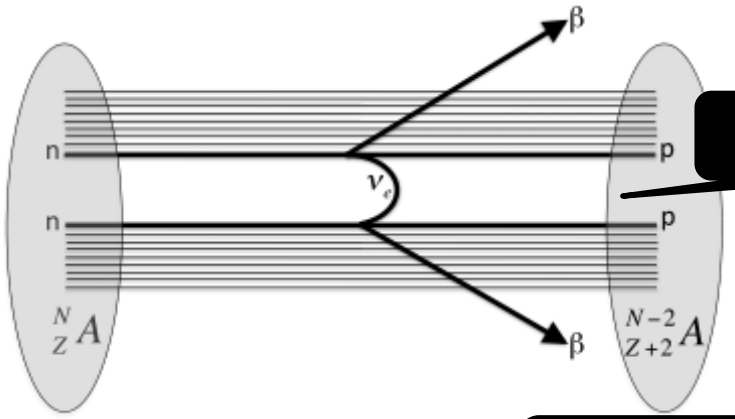
- Commissioning
- First results of data-taking

IV. Conclusions and perspectives

0νββ

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

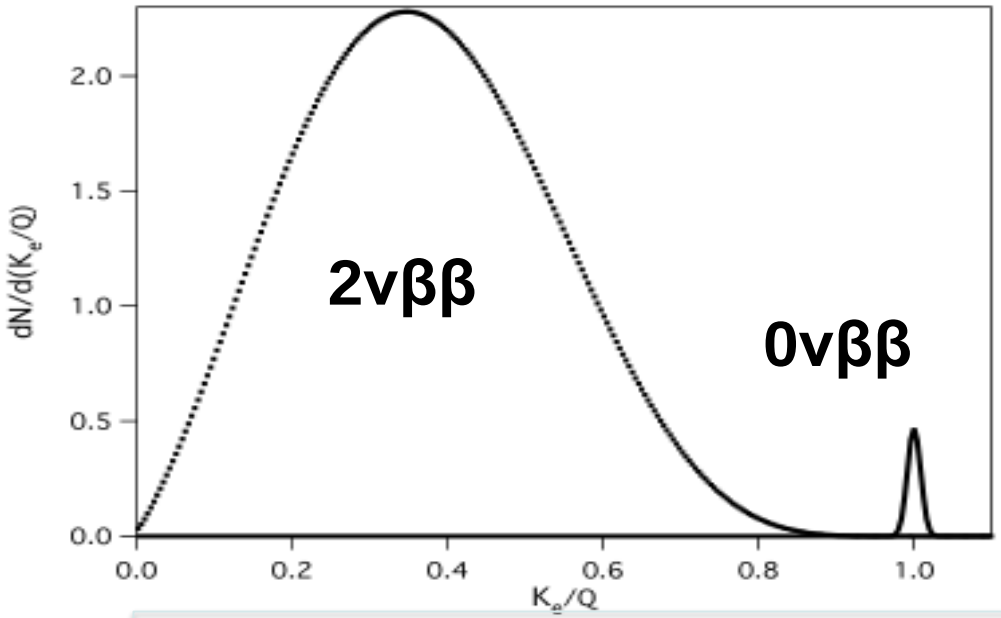




Majorana Neutrino

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

Lepton Number Conservation Violated



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

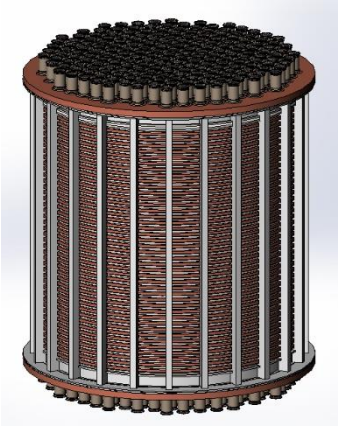
- 2νββ: 11 isotopes
- 0νββ: Majorana Neutrino? Lepton number violation?

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

PandaX project overview

PandaX-I: 120kg LXe
(2009 – 2014)

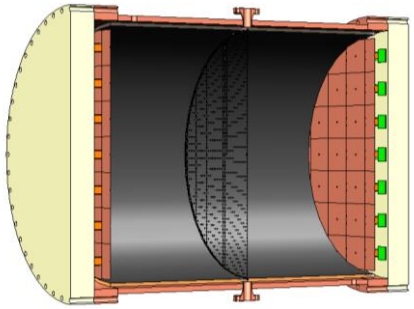
PandaX-II: 500kg
LXe (2014 – 2018)



PandaX-xT: xT
LXe (future)

Dark matter
WIMP searches

accumulated a wealth of experience in TPC and low background experiment

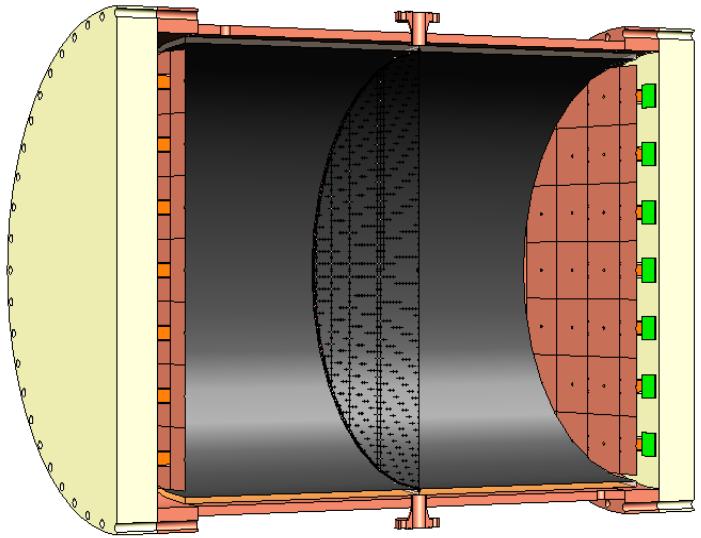


PandaX-III: 200kg - 1 ton HPXe (future)

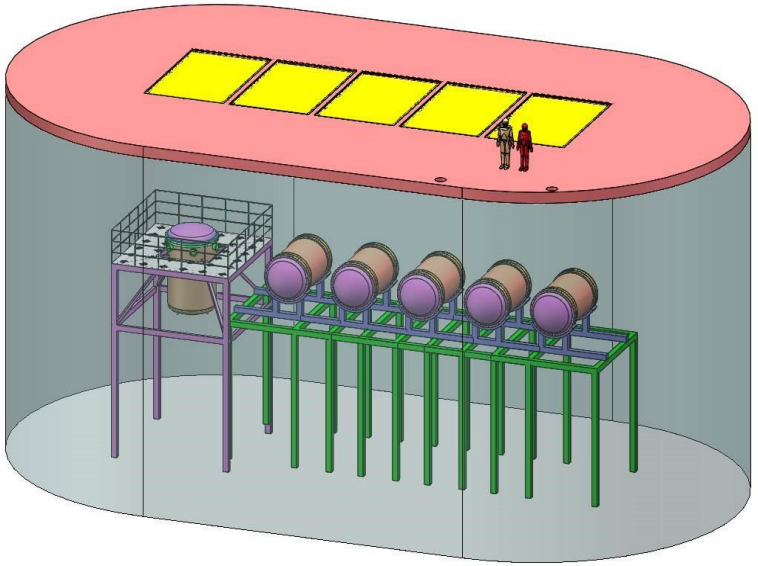
0νββ searches

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

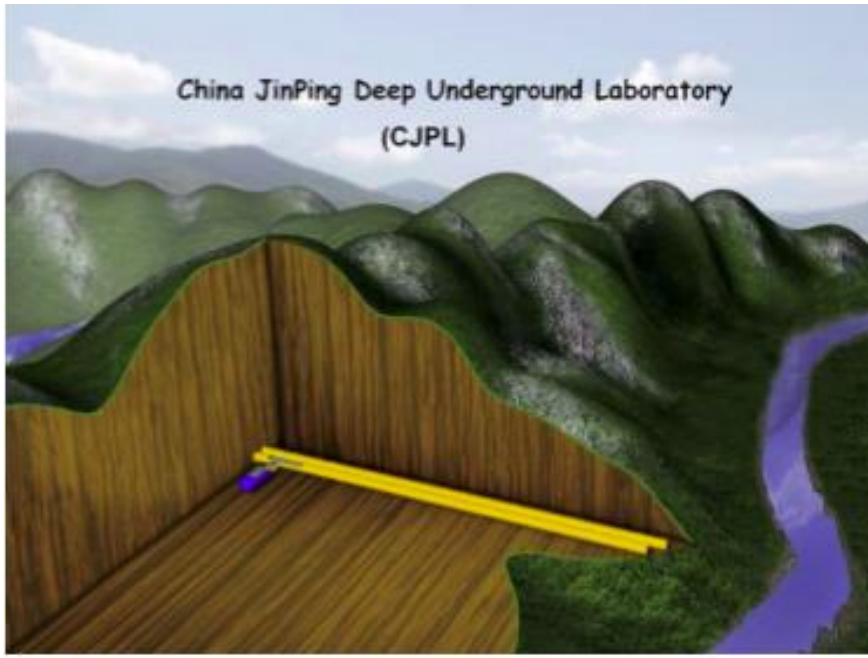
- First phase： 200 kg of 90% ^{136}Xe enriched gas TPC (Time Projection Chamber).
- Final phase： a ton scale experiment (5 modules).
- @ Hall #B2 at China Jin Ping underground Lab (CJPL-II): 5 m of ultra-clean water shielding in all directions



PandaX-III detector of first phase: Long×2R: 2m*1.5m

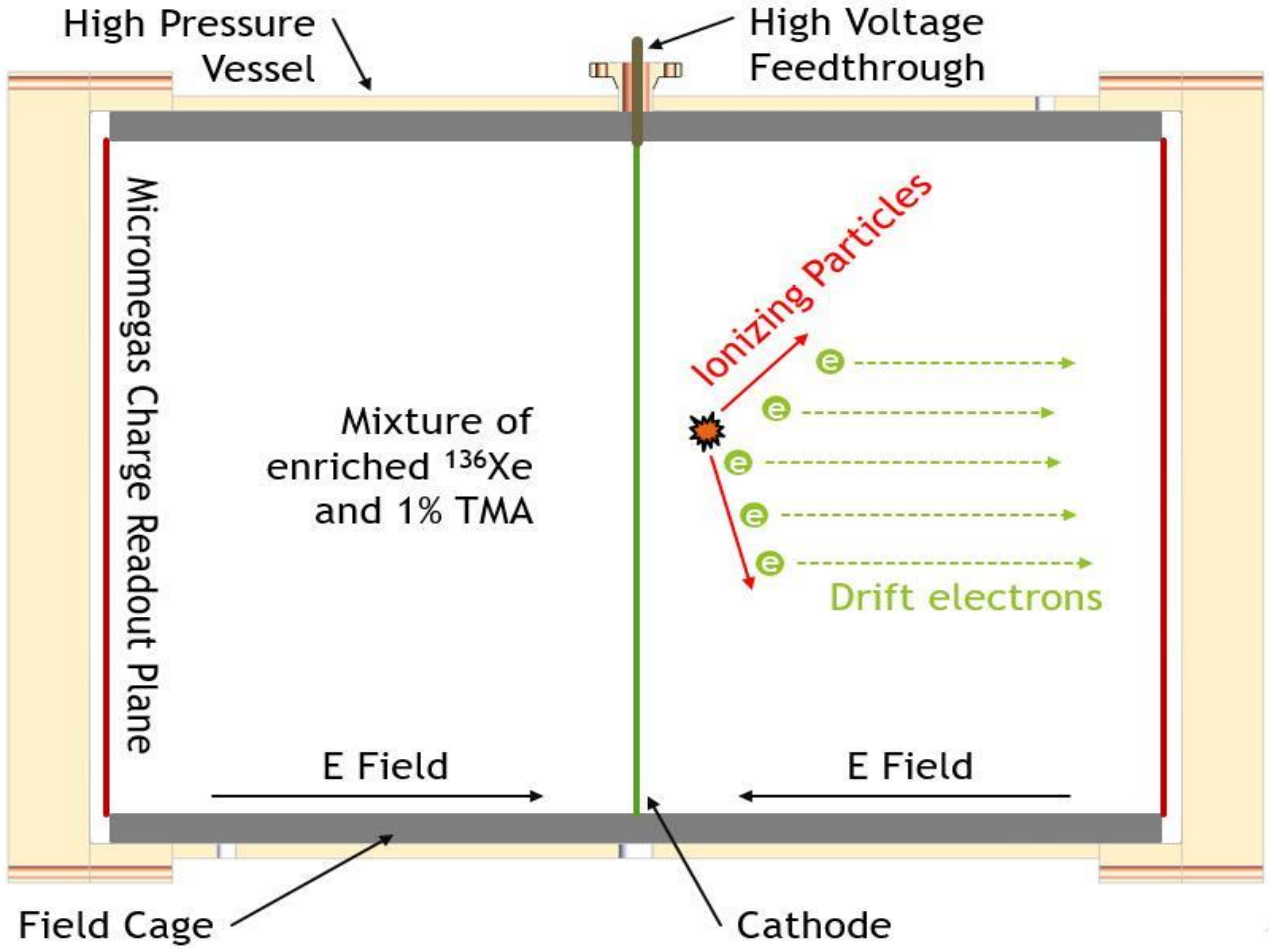


Tank of water at CJPL-II



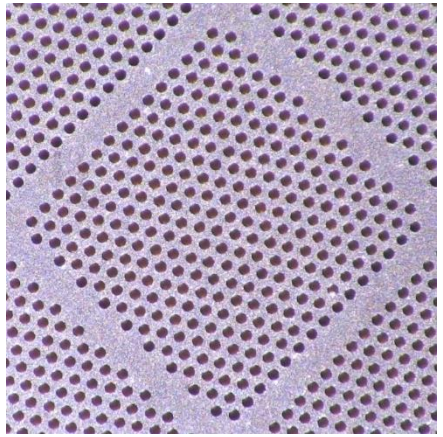
PandaX-III detector of 1st phase

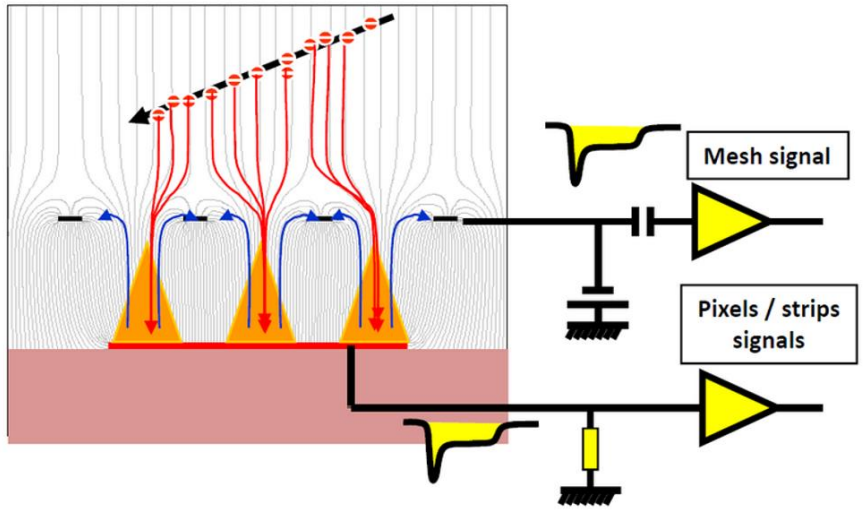
- 10 bar Xe-(1%)TMA (**trimethylamine**)
- TPC : symmetric, double-end charge readout with cathode in the middle
- 82 20X20 cm^2 Microbulk Micromegas (Micro-Mesh Gaseous Structure) for charge readout
- Readout: 2 series of strips (x, y)



Microbulk Micromegas (MM)

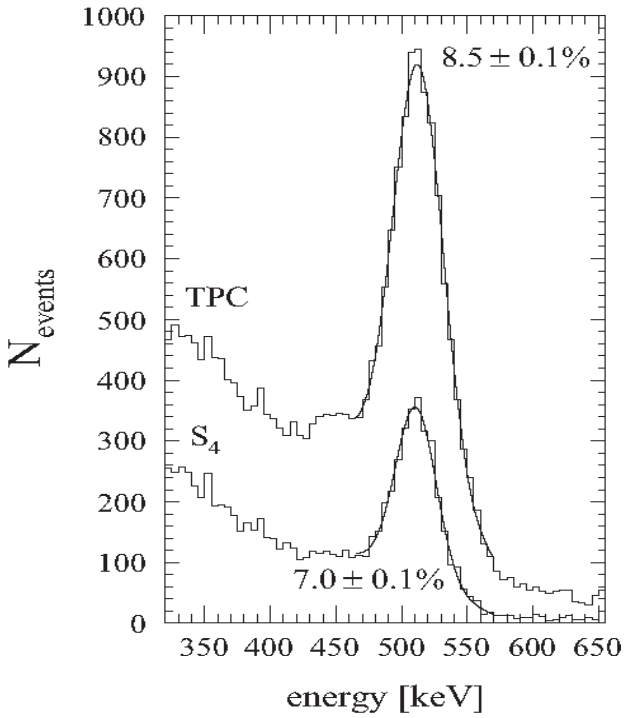
- Microbulk Micromegas (Micro-Mesh Gaseous Structure)
- Radio-purity: made of Copper and Kapton
- Amplification: ~1000X （**T-REX**）at 10 bar Xe:TMA（**trimethylamine**）(99%:1%)
- Energy resolution: 3% FWHM expected at 2.5 MeV(Q value of ^{136}Xe 0νββ)





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

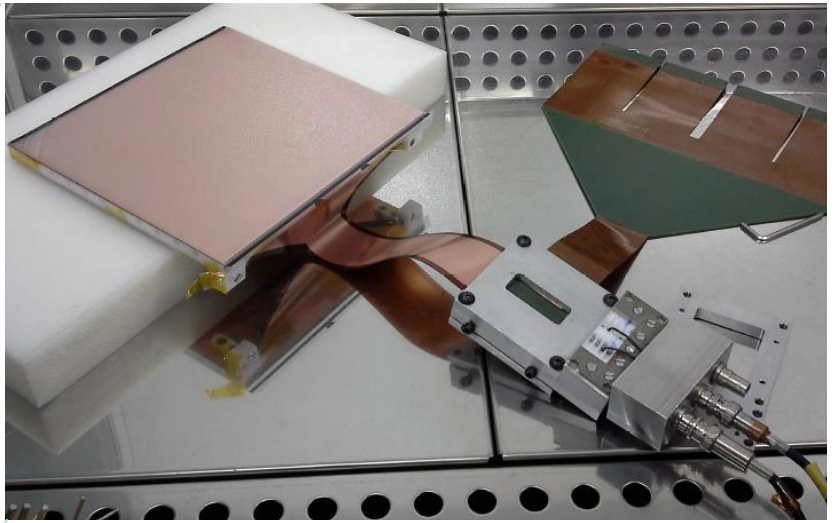
Energy spectrum of ^{22}Na

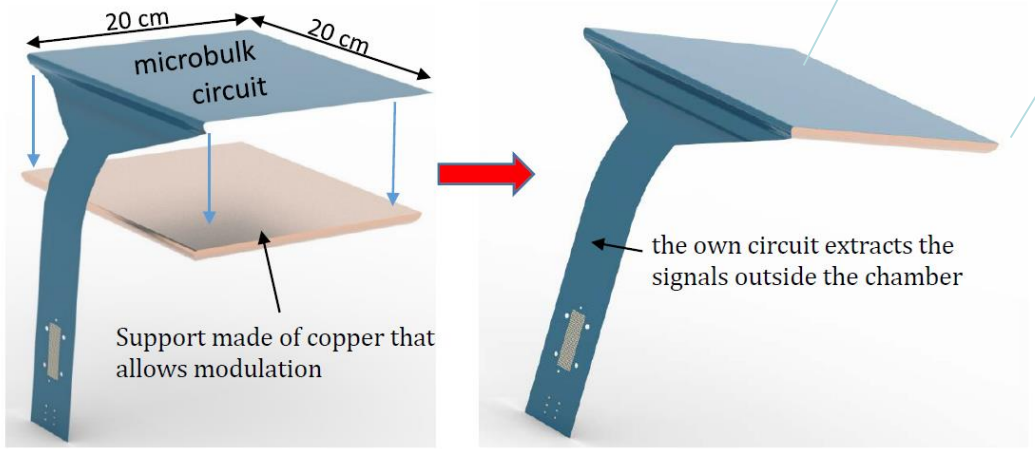


Gonzalez-Diaz, et al. *NIMA* 804 8 (2015)

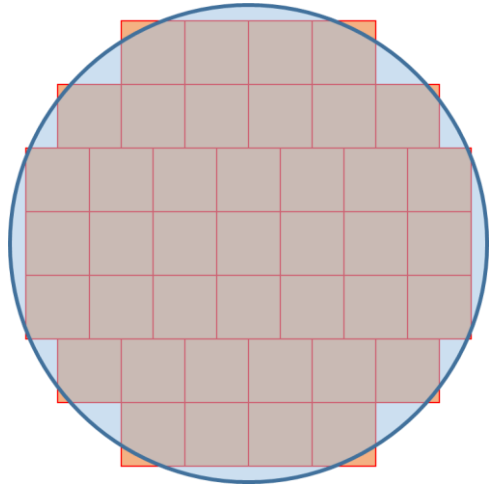
MM in PandaX-III

- 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

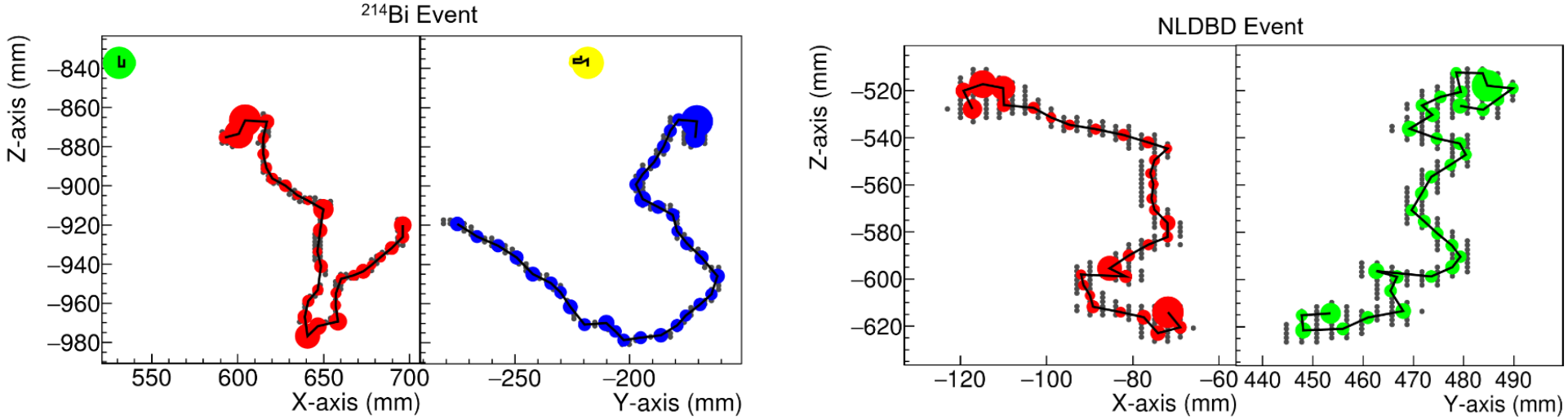




×41



Background budget and projected sensitivity



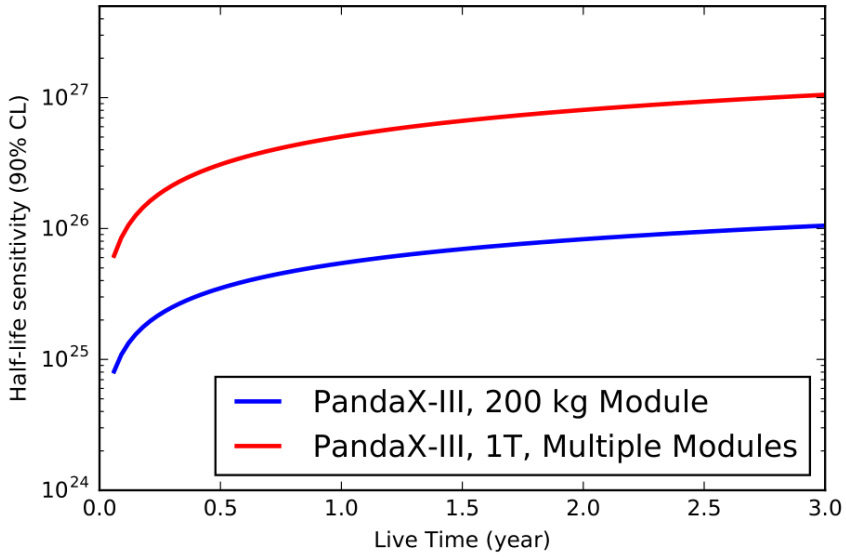
Reconstruction of the projected electron tracks (XZ and YZ) produced by two Monte Carlo simulated events

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

- Two independent Geant-4 MC: RESTG4 and BambooMC
- Topological analysis

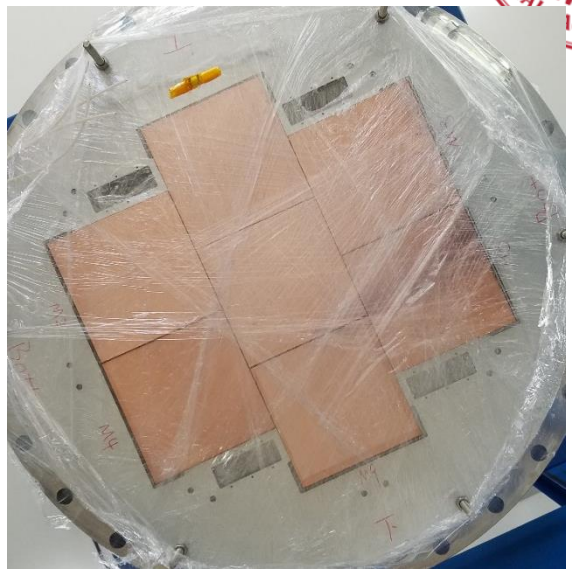
Sensitivity expected:

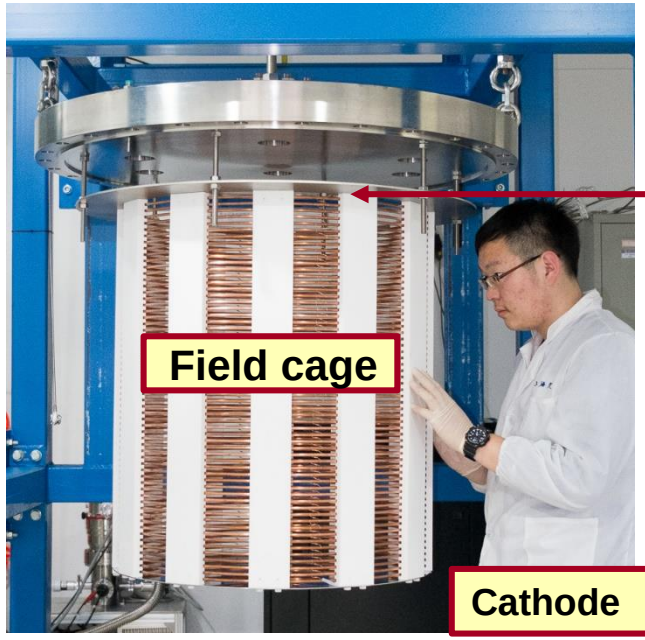
- First module: 10^{26} y half-life limit
- Ton-scale: 10^{27} y half-life limit

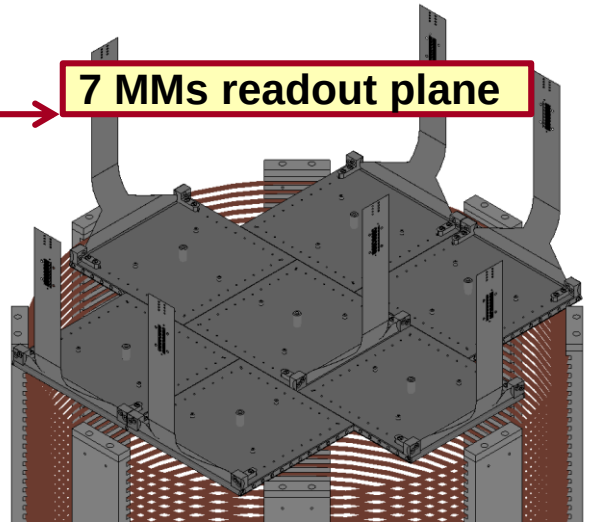


Prototype TPC

- Vessel: 600L(20kg Xe at 10bar in active region)
- 7 Micromegas modules
- Drift distance: 78 cm
- To optimize the design of Micromegas readout plane
- To study the energy calibration of TPC
- To develop algorithm of 3D track reconstruction

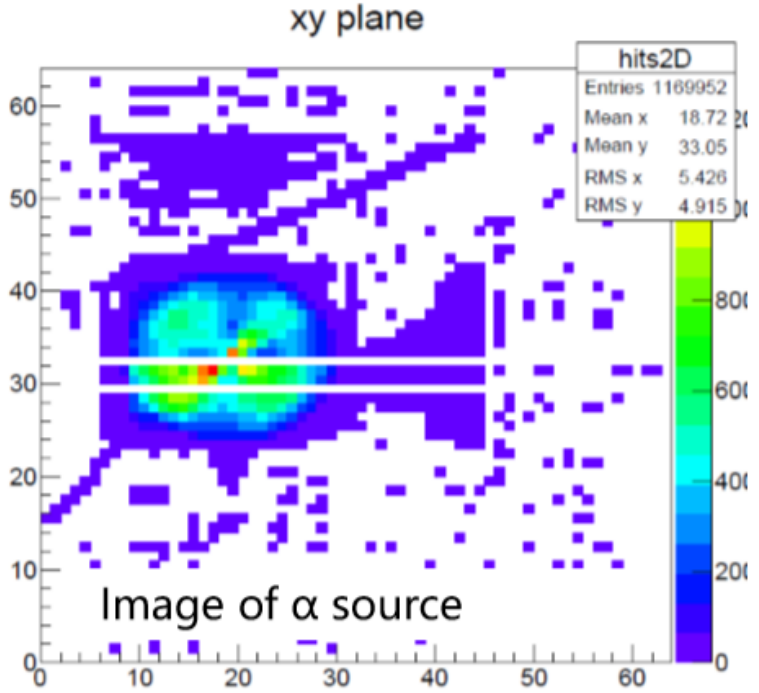




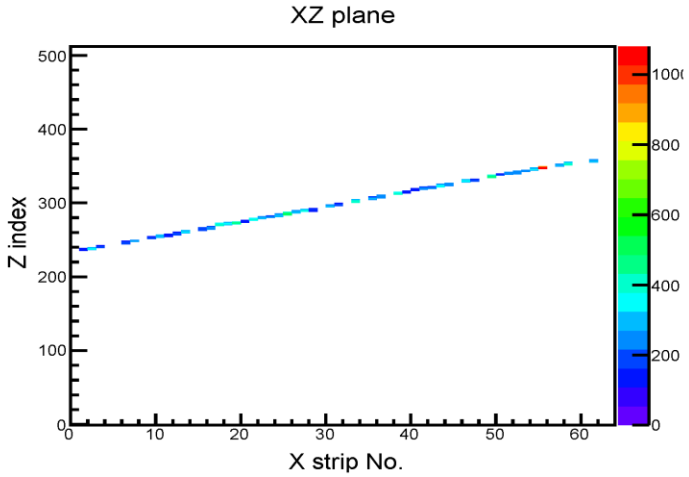


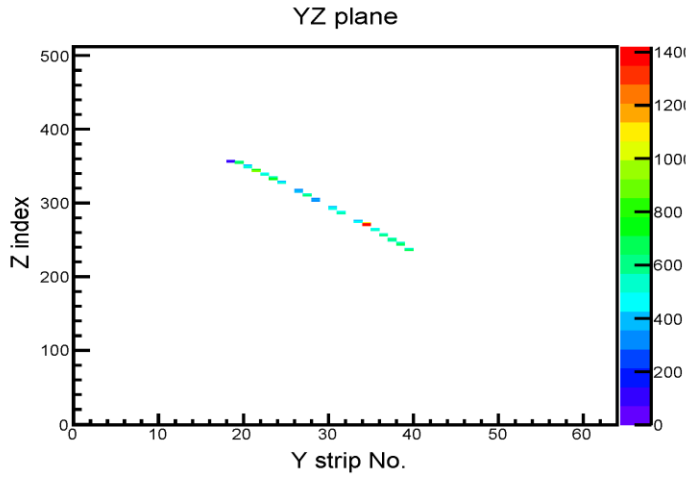
Prototype commissioning

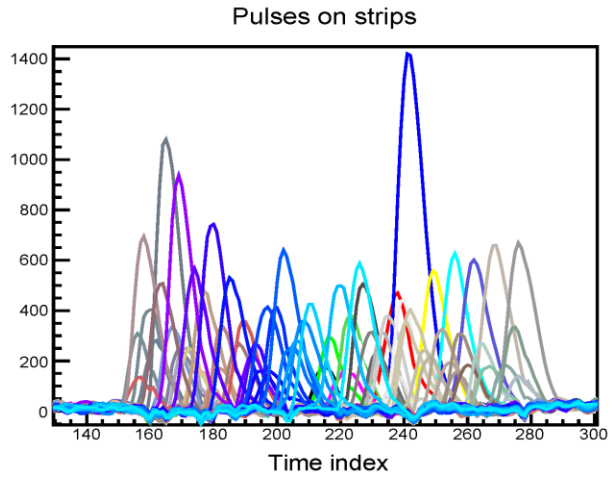
- One Micromegas mounted firstly
- Alpha source data-taking
  - ^{241}Am source
  - Gas: Xe, Xe/TMA and Ar/CO2



Muon track at 2 bar Xe:TMA

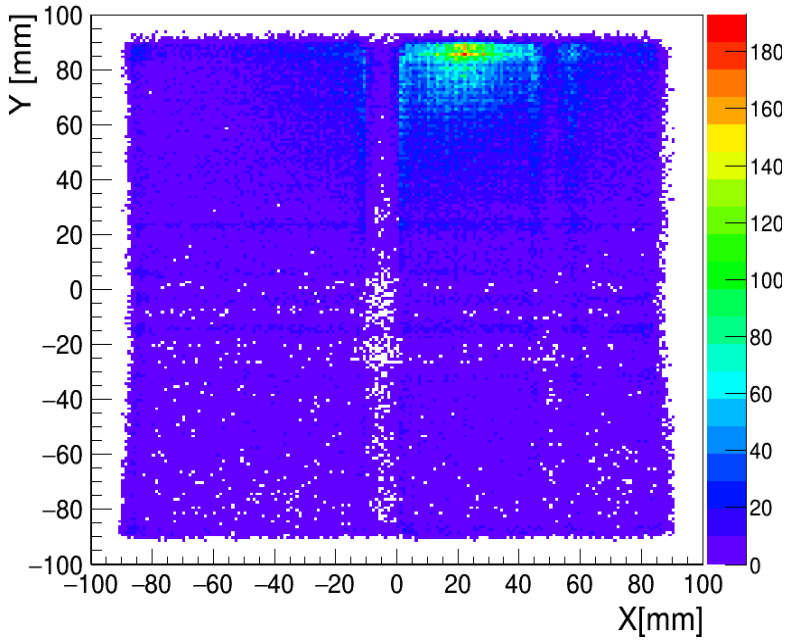


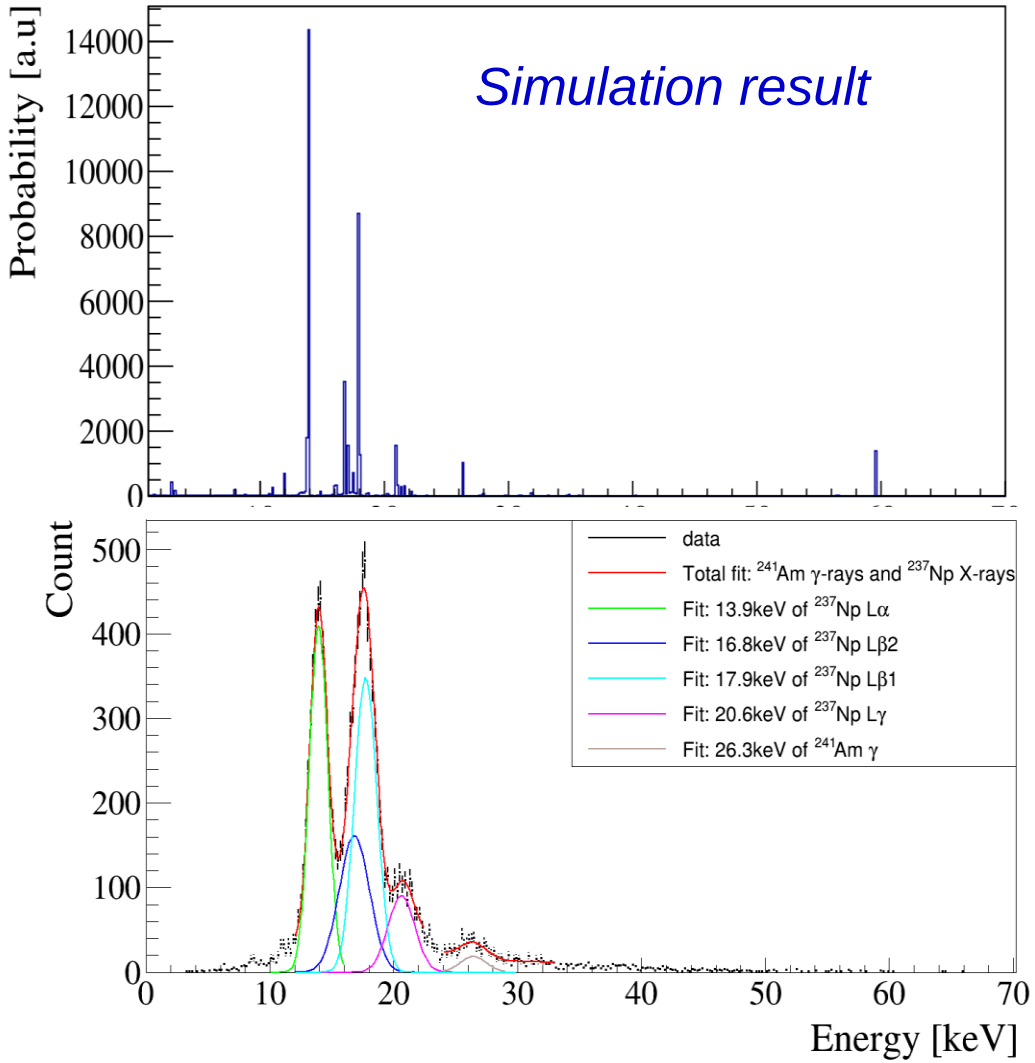




Data taking with Ar:(5%)isobutene

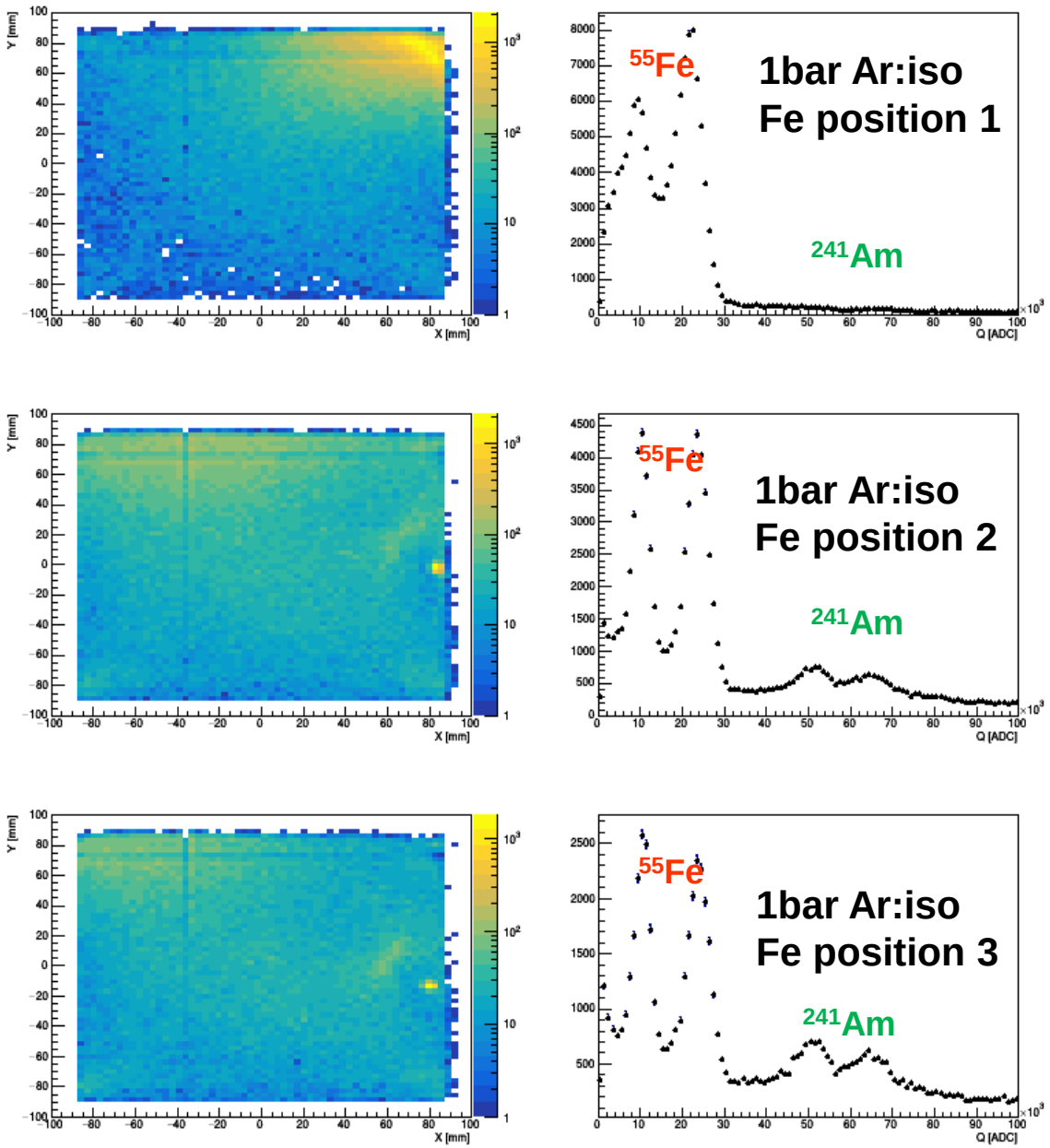
- Gamma source data taking
  - ^{241}Am source (α was blocked)
  - Gas: 1bar Ar:(5%)isobutene
- Energy resolution:
  - 12.5% FWHM at 13.9keV: Np Lα peak
  - 9.3% FWHM at 26.3keV: Am gamma peak

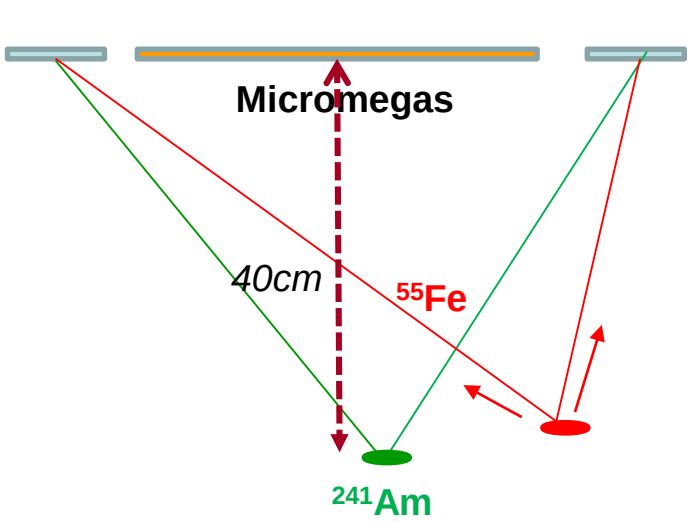


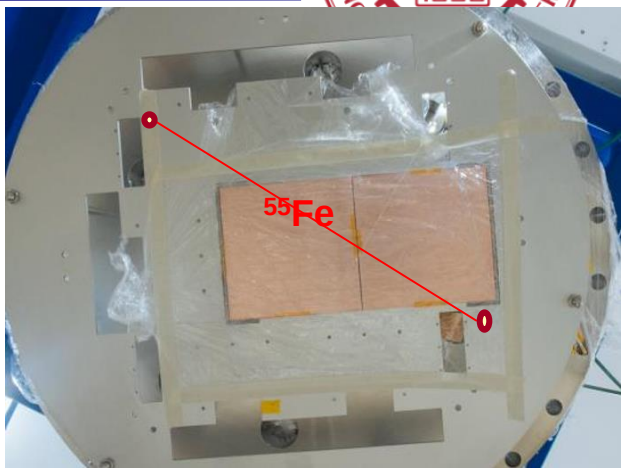


Energy spectrum detected of ^{241}Am

Data taking with Ar:(5%)isobutene



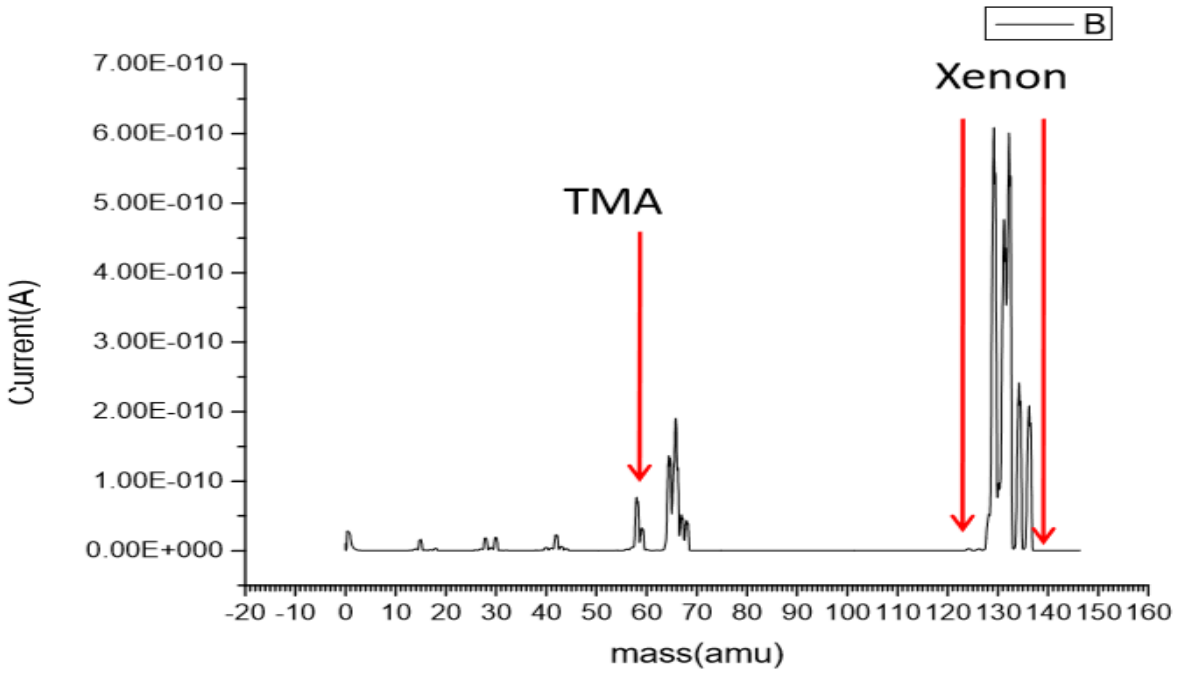


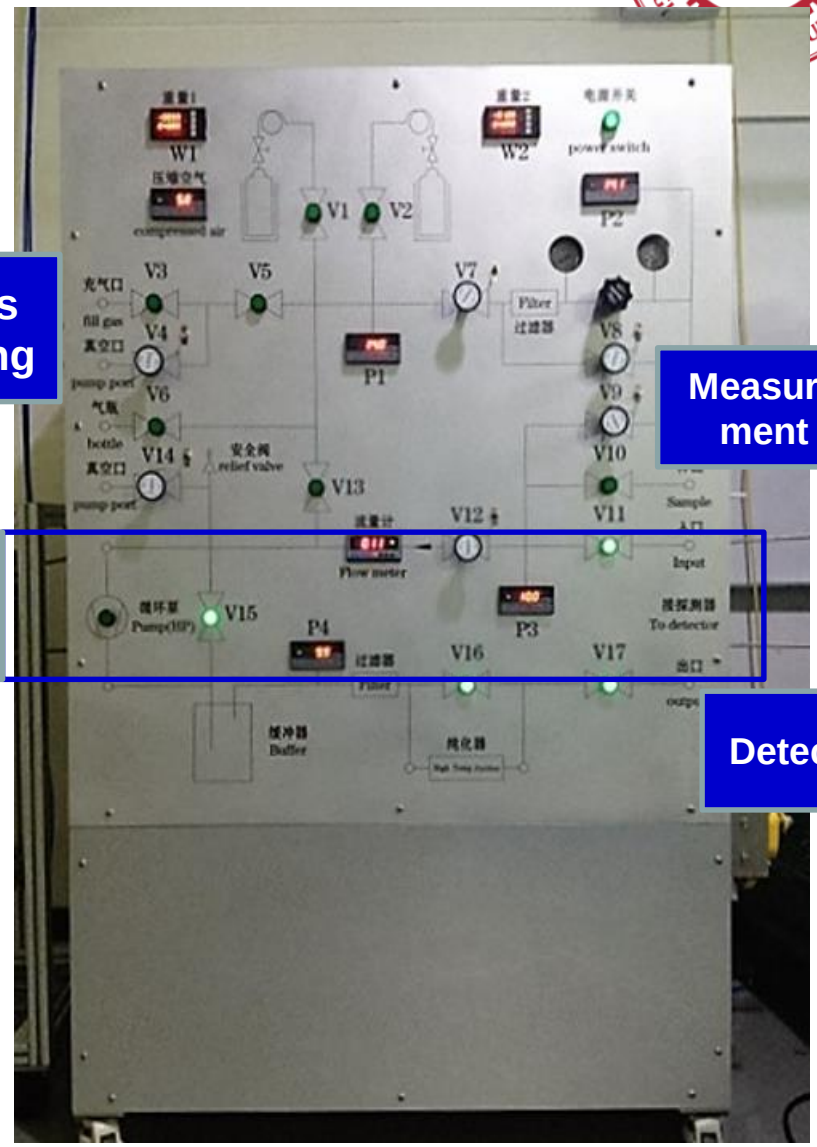


- 2 SR2Ms mounted
- Data taking:
  - Gas (1~10 bar): Ar:Iso (95%:5%)
  - Source :^{241}Am (gamma) and ^{55}Fe (gamma)
    - ~20% FWHM at 5.95keV: Fe gamma peak
    - ~13% FWHM at 13.9keV: Np Lα peak
- Preparing for Xe:TMA data taking
  - Leak check
  - Mixture gas analysis

Xe and TMA gas operation

- Gas filling: TMA, then Xe
- Gas content measurement
- Gas circulation and purification
- Gas recovery

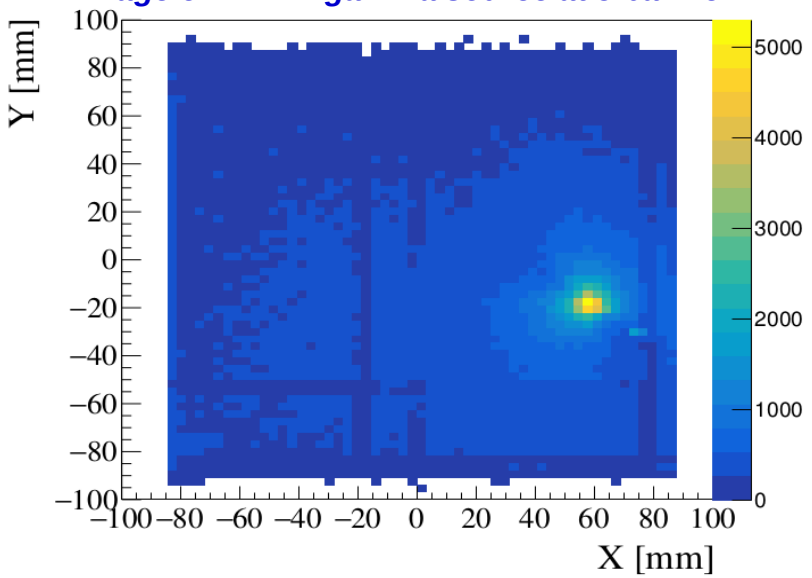


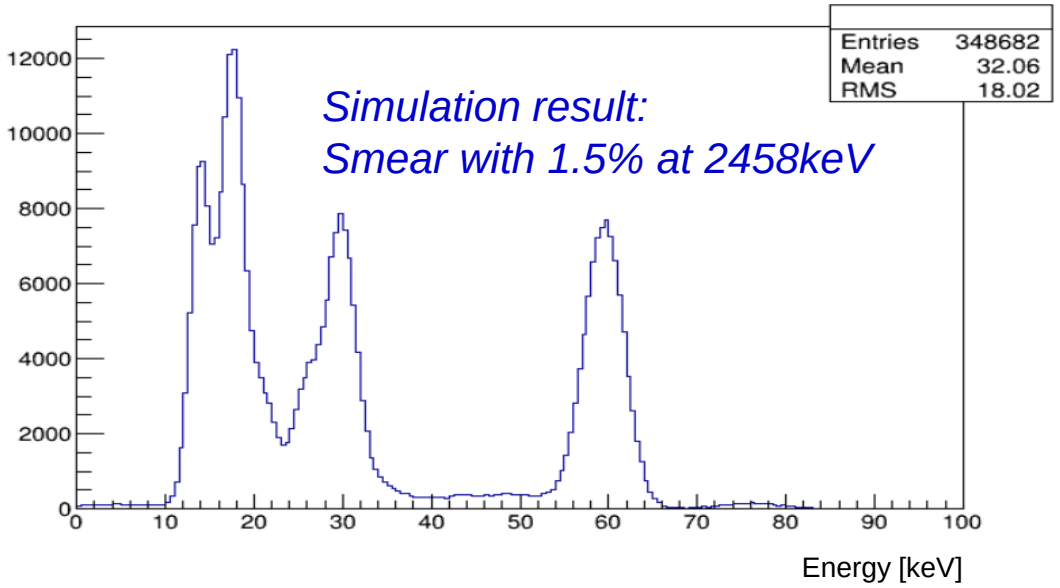


Data taking with Xe:(1%)TMA

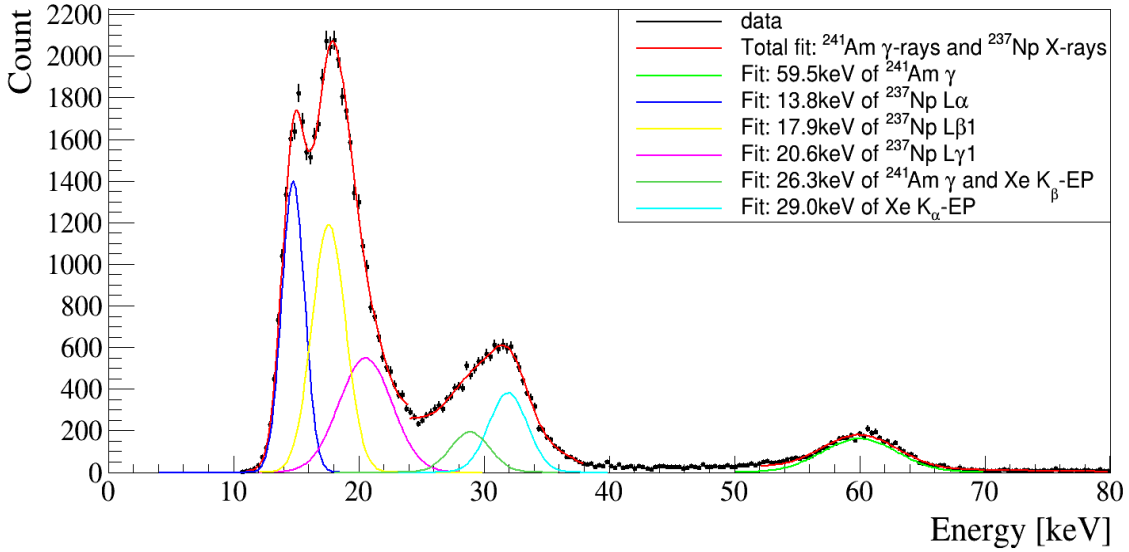
- ^{241}Am gamma source
- 55Fe was moved outside
- 1 bar Xe:(1%) TMA mixture gas
- Energy resolution: ~11.8% FWHM at 59.5keV

image of ^{241}Am gamma source at 5 bar Xe:TMA





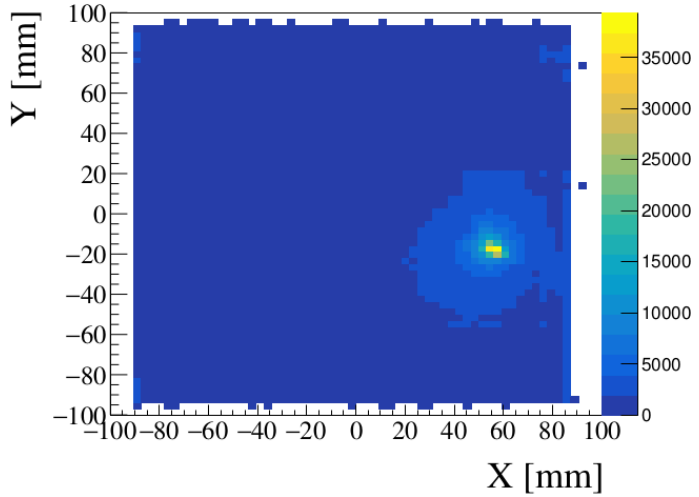
Energy spectrum detected of ^{241}Am



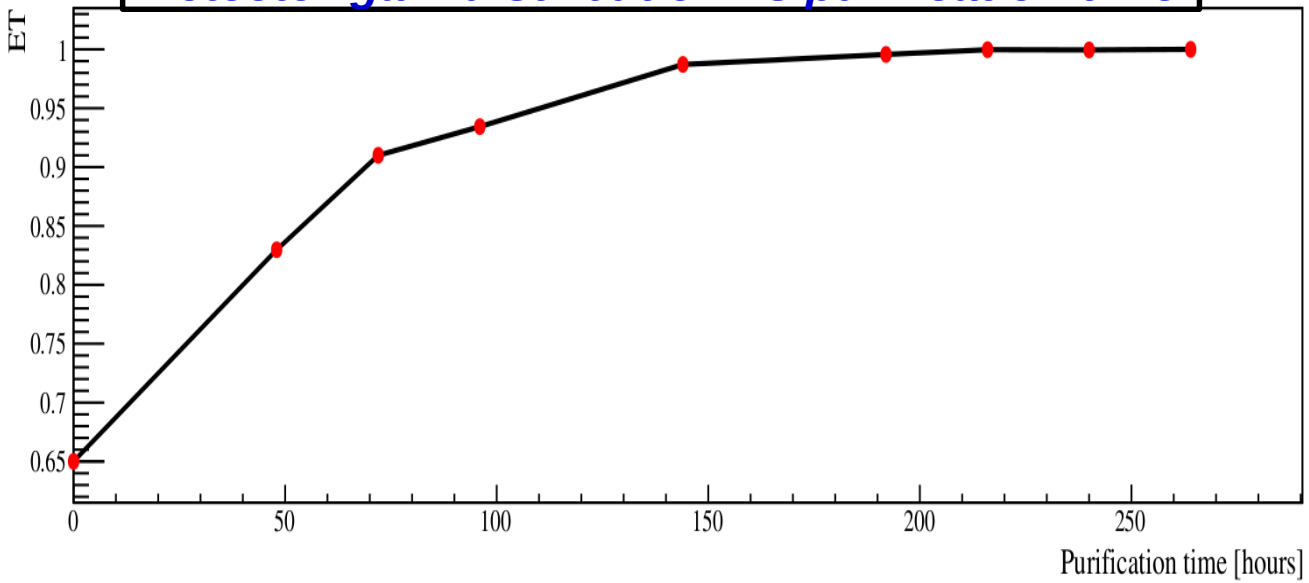
5bar Xe:(1%)TMA data-taking

- ^{241}Am gamma source
- The detector gain became stable after gas purification
- Energy resolution: ~14.1% FWHM at 59.5keV

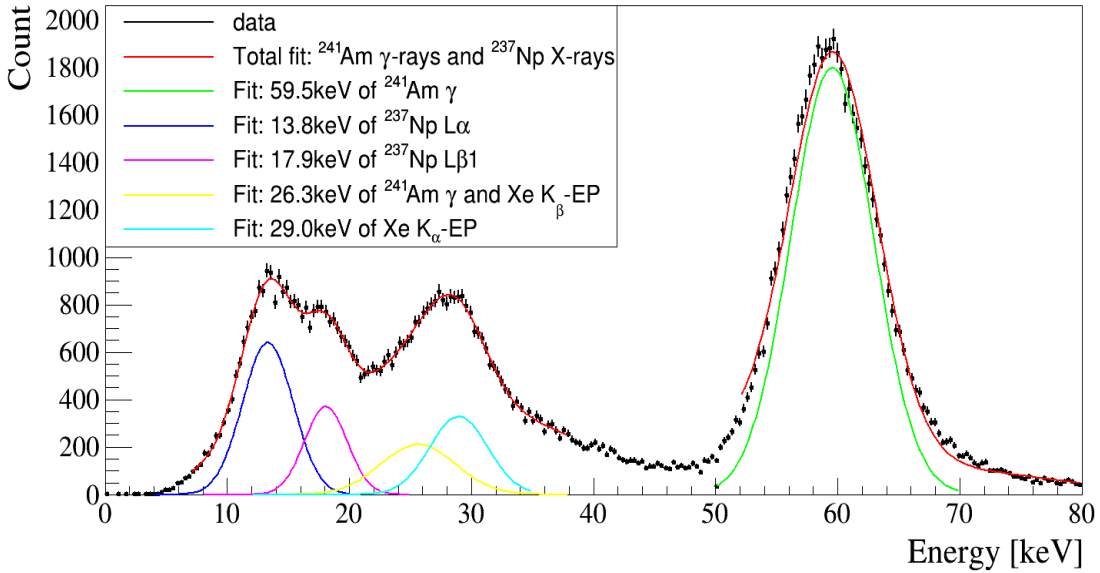
image of ^{241}Am gamma source at 5 bar Xe:TMA



Detector gain distribution vs purification time



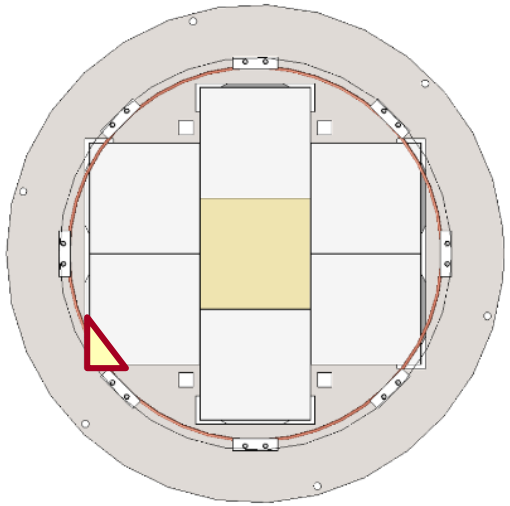
Energy spectrum detected of ^{241}Am

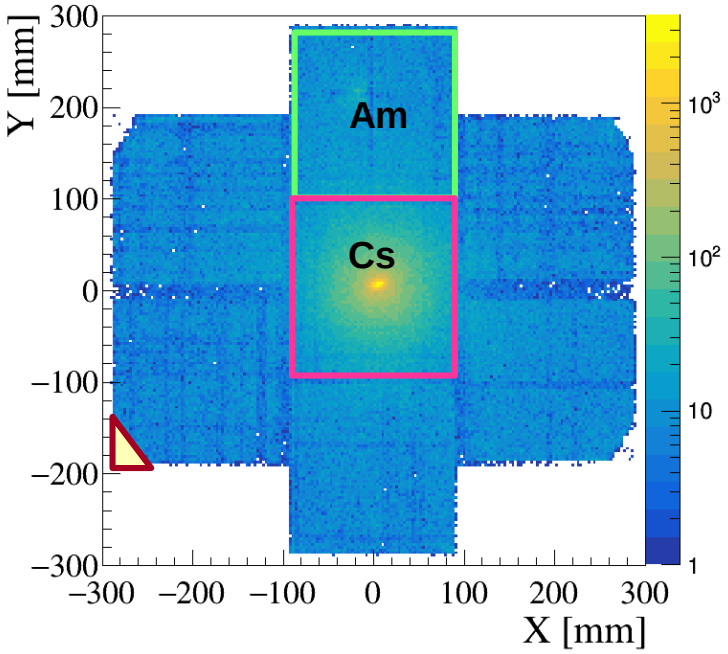


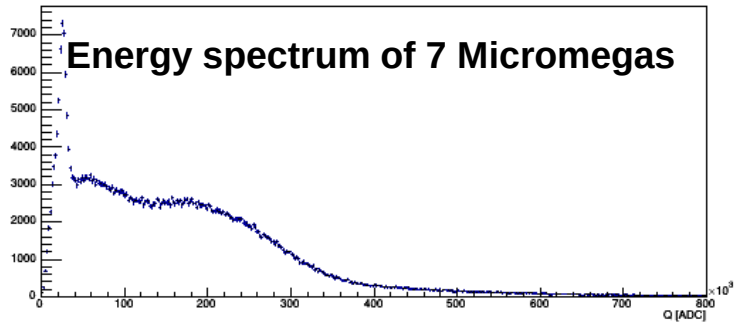
Commissioning of 7 Micromegas

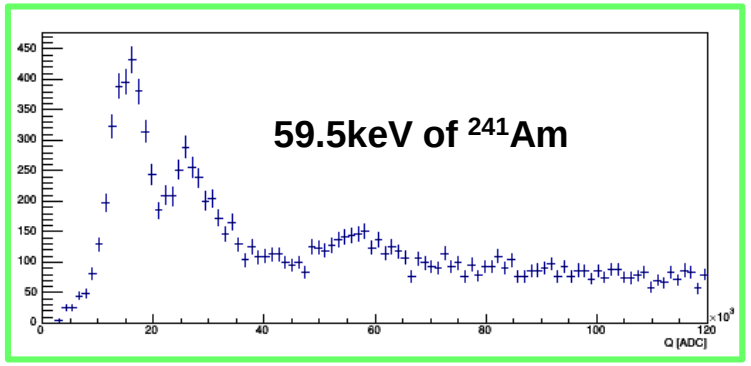
- 7 Micromegas modules have been installed to the TPC
- Now filled with 5 bar Ar:Iso to benchmark its performance
  - No leaks
  - Drift and mesh HV are Okay.
  - Checking bad strips and getting ready for data taking.
- ^{137}Cs and ^{241}Am gamma sources are installed in the TPC
- Will run up to 10 bar of Xe+TMA

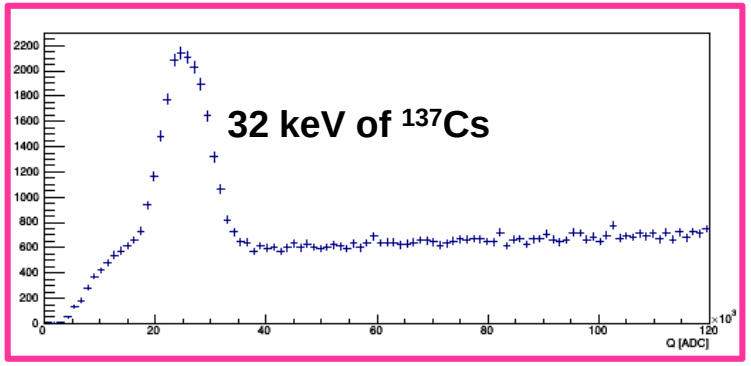
7 Micromegas data taking











- Only the image of Cs source in the center:
  - higher radioactivity of Cs
- Low events statistics of corners of 4 Micromegas
  - These 4 corners out of the field cage
- Energy spectrum of Am and Cs
  - To select the region of the calibration sources
- 661 keV of Cs was missing
  - Long attenuation longer
  - Leak check at 10 bar of Ar:isobutene
  - To run up to Xe:TMA

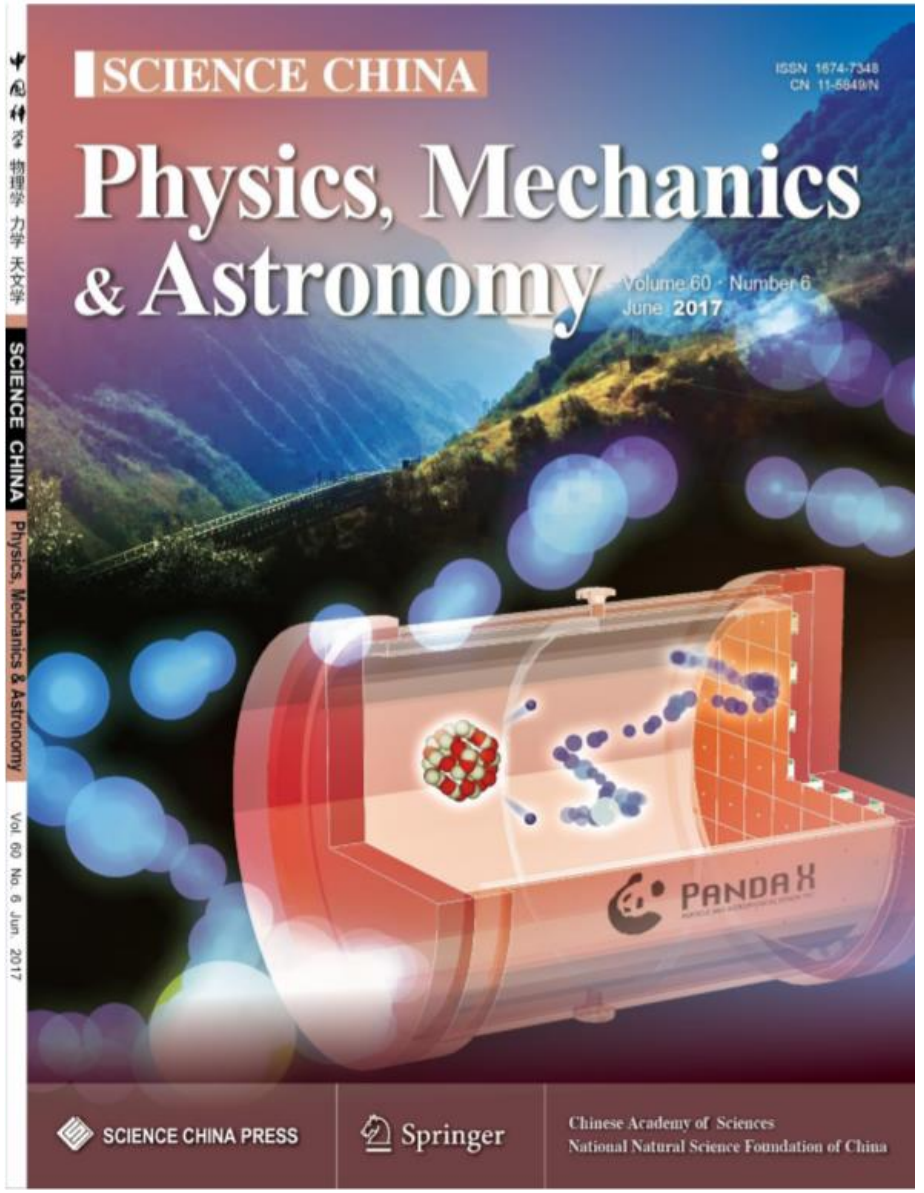
Conclusions and perspectives

- 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: 200 kg first, then ton-scale with multiple modules
- 20-kg scale prototype TPC with 7 MM has been built and under commissioning, the first result was encouraging, we are preparing for 10 bar Xe-TMA mixture gas data taking

PANDA X
PARTICLE AND ASTROPHYSICAL XENON TPC

Thank you !
谢谢 !

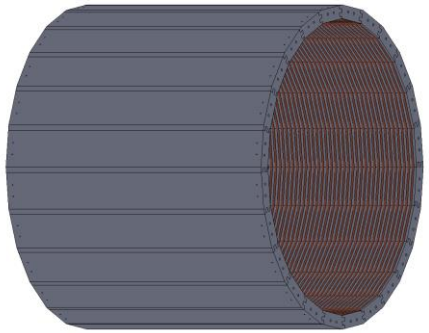
More details from our CDR:
SCIENCE CHINA Physics, Mechanics & Astronomy 60(6), 061011(2017)
ArXiv:1610.08883



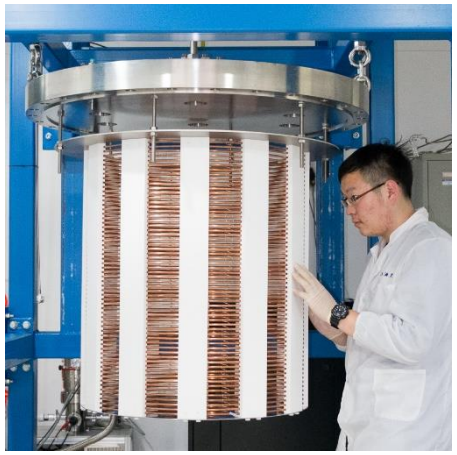
Back Up

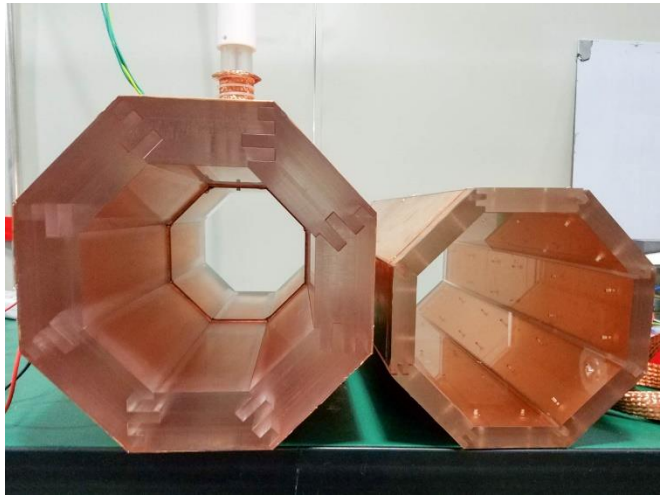
Field cage

- Option 1: Copper shaping rings + resistors + external Teflon (or Acrylic) supporting bars
  - ➢ Mature technology
  - ➢ Used and tested extensively in PandaX-I and PandaX-II
  - ➢ Supporting bars are critical :
  - ✓ Dielectric strength
  - ✓ Displacer for ^{136}Xe
- Option 2: Resistive coating on the acrylic pieces
  - ➢ Diamond-like carbon sputtering or commercial DLC or Ge film
  - ➢ SUT (Thailand) is collaborating with SJTU on developing this option
  - ➢ Field simulation is under way



Prototype TPC field cage



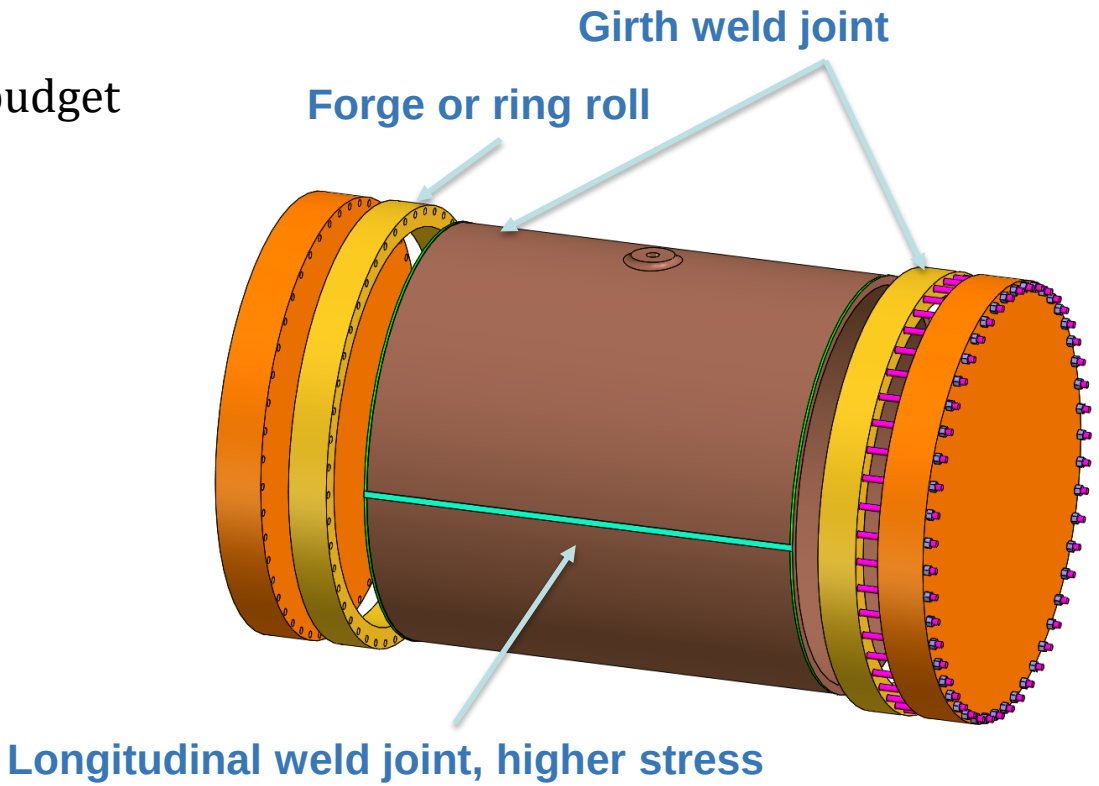


High pressure vessel

- High gas pressure and radio-pure
- Baseline approach: oxygen-free copper welded with E-beam technique
  - Barrel is technologically challenging
  - Still a major contributor to our background budget

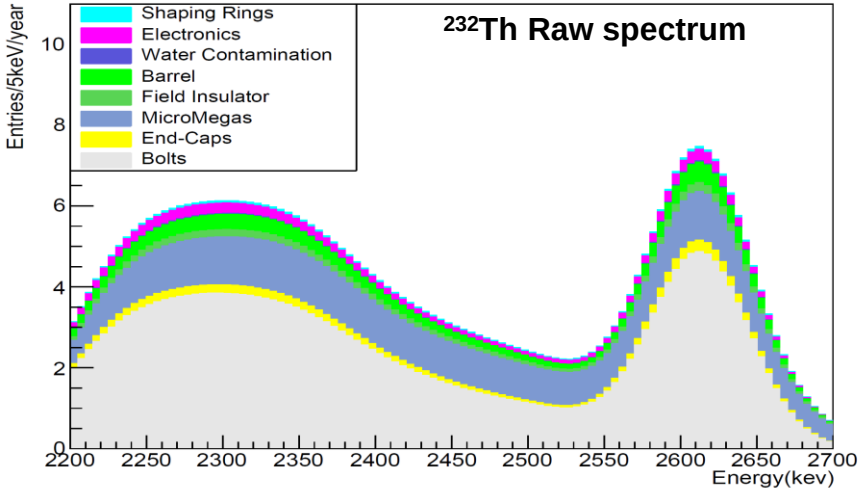
Copper Vessel:
- **15 cm thick end caps**
- **3.2 cm thick side wall**
- **About 9 ton of OFHC copper**

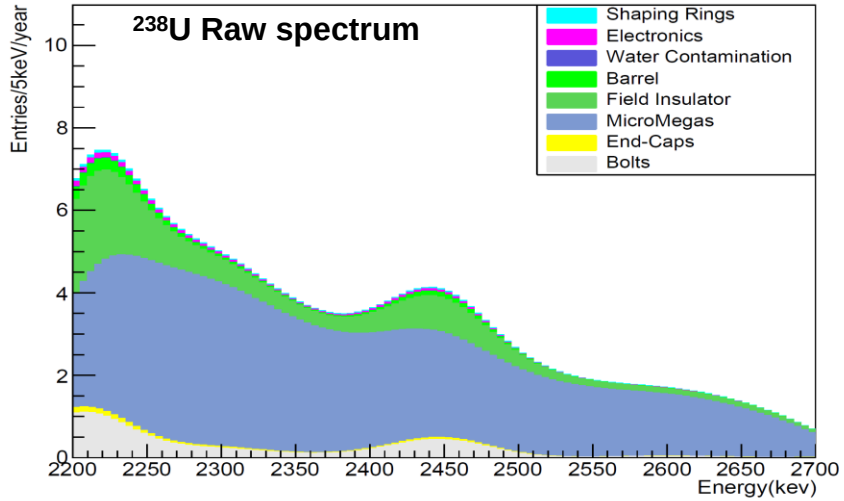
Possibility of fabrication in China or Germany
- **Connex (contractor, machining)**
- **Pro-Beam (E-beam welding)**
- **CSN (OFHC copper)**



MC Simulations

- Two independent Geant-4 based MC packages: RESTG4 and BambooMC
- Background budget :Use measured U/Th contamination upper limits from literature as inputs
  - ➢ 3.5 x 10^{-3} c/keV/kg/y in the ROI ($Q_{0\nu\beta\beta}$ -2σ, $Q_{0\nu\beta\beta}$ +2σ)
  - ➢ Bolts and MM are dominating (MM input contamination is "weak", since little material mass is available for counting)

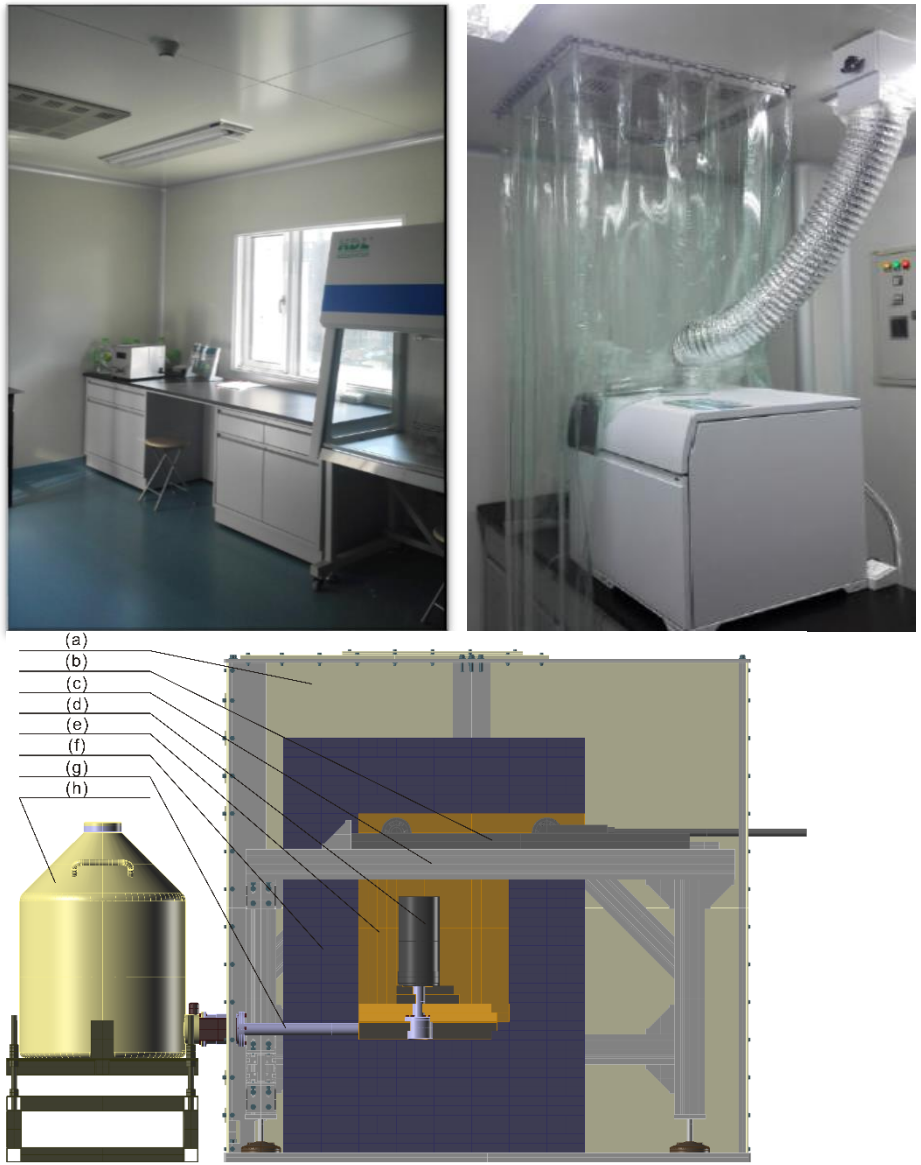




- With topological analysis
  - ➢ About X35 background reduction from topological analysis (strong simulation confidence)
  - ➢ 1 x 10^{-4} c/keV/kg/y in the ROI

Radio-purity control

- ICP-MS (Inductively Coupled Plasma Mass Spectrometry) recently commissioned at PKU (Beijing)
  - Agilent 7900 ICP-MS
  - Class 10 clean room; class 1 for the ICP-MS hood
- HPGe detectors at CJPL and SJTU
- Low radioactivity environment
  - Radon sealant on the wall of Hall 4
  - Rn-free air in the detector assembly region of the lab
  - Rn-control in water shield
  - Rn-emanation measurements

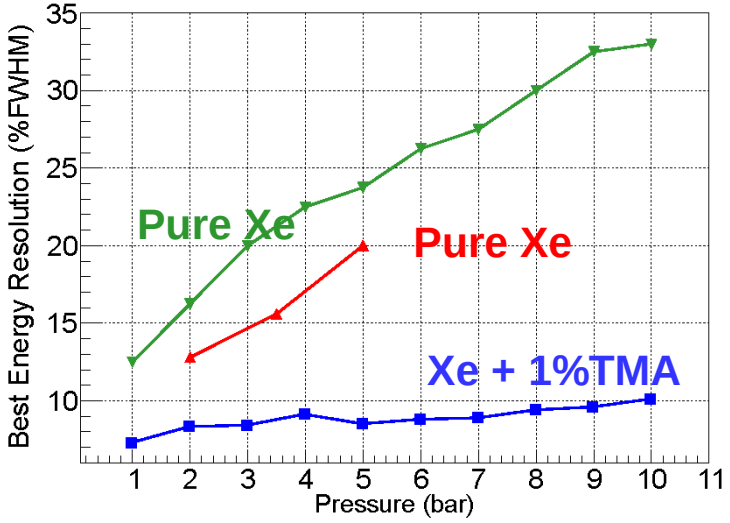


Schematic of the PandaX γ-ray counting station

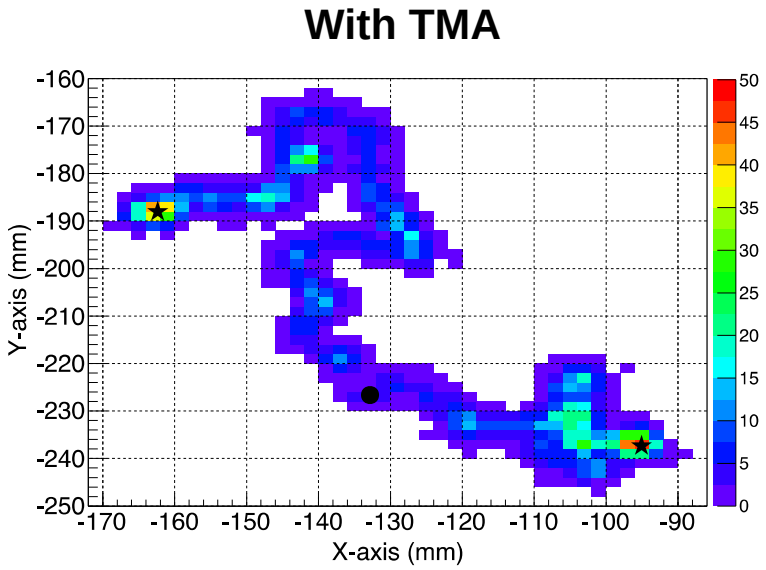
Operation gas in TPC

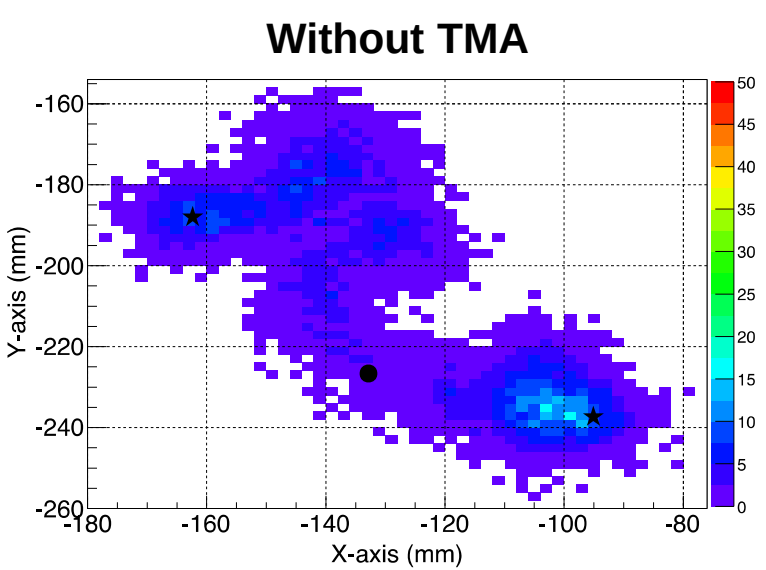
Xe +TMA mixture:

- Better energy resolution: extrapolated from 511keV and 1.2MeV peaks: 3% FWHM (@$Q_{0\nu\beta\beta}$)
- Better tracks: TMA suppresses electron diffusion
- Better operation: TMA as a quencher

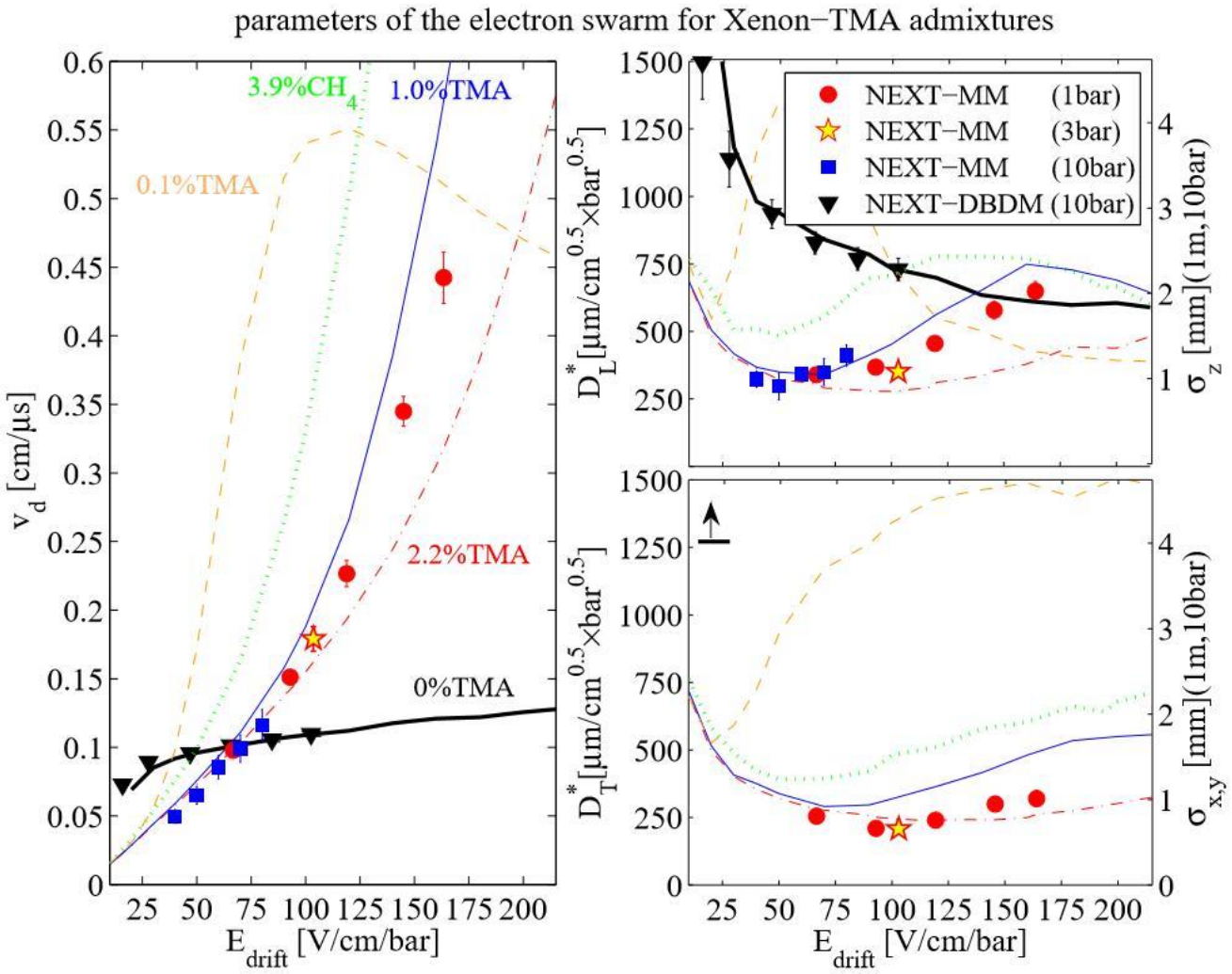


Cebrián, S., et al. JINST 8 (2013): P01012.





T-REX: arXiv:1512.07926



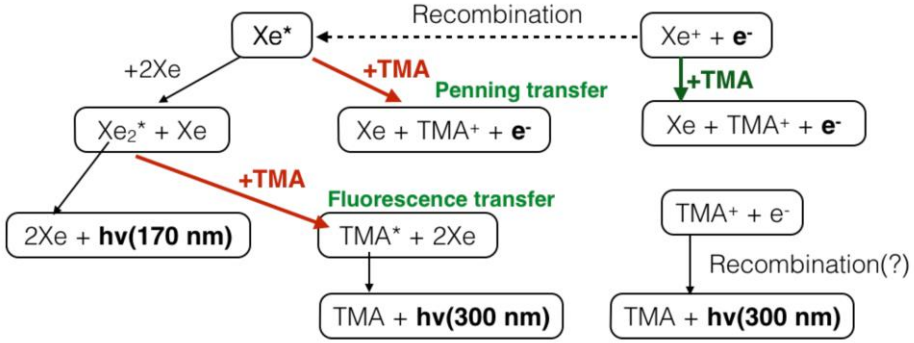
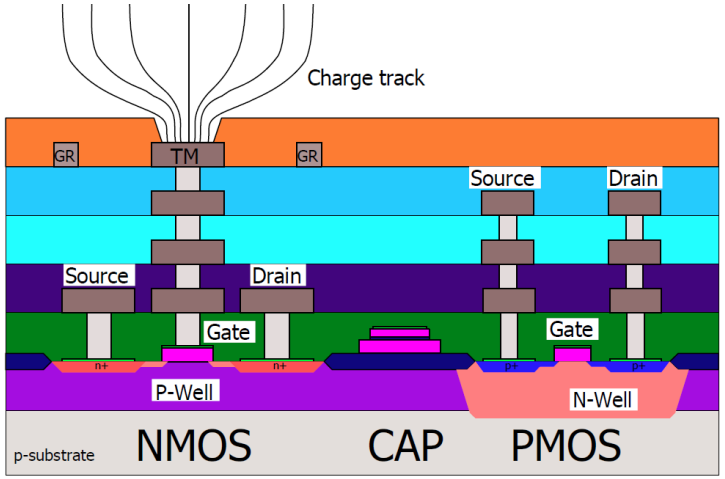


Figure 1. Simplified schematic of Xe and TMA reactions after initial ionization and excitation of Xe. We made the first direct measurement of the processes shown with red arrows.

Future energy resolution improvement

- TopMetal Direct Charge Sensor (CCNU&Berkeley)
  - Direct pixel readout without gas amplification
  - 20e noise
  - First 10x10 cm readout plane in production



- Alternative (bulk and Microbulk) Micromegas technologies (Saclay)
  - Strip Mesh readout
  - More uniform amplification gaps.