“无中微子双贝塔衰变”研讨会，珠海

Searching for 0νββ of ^{136}Xe with PandaX-III

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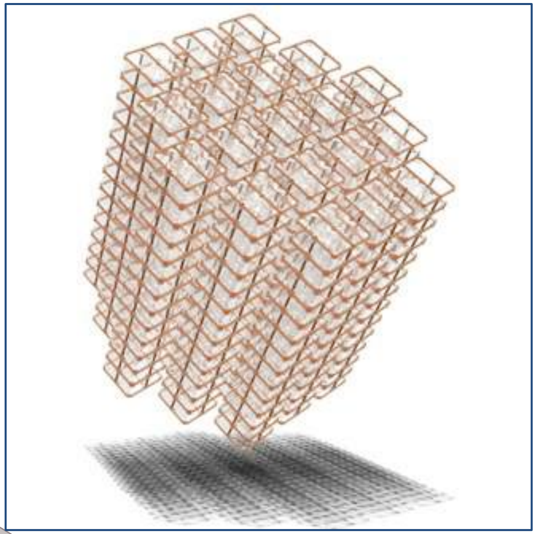
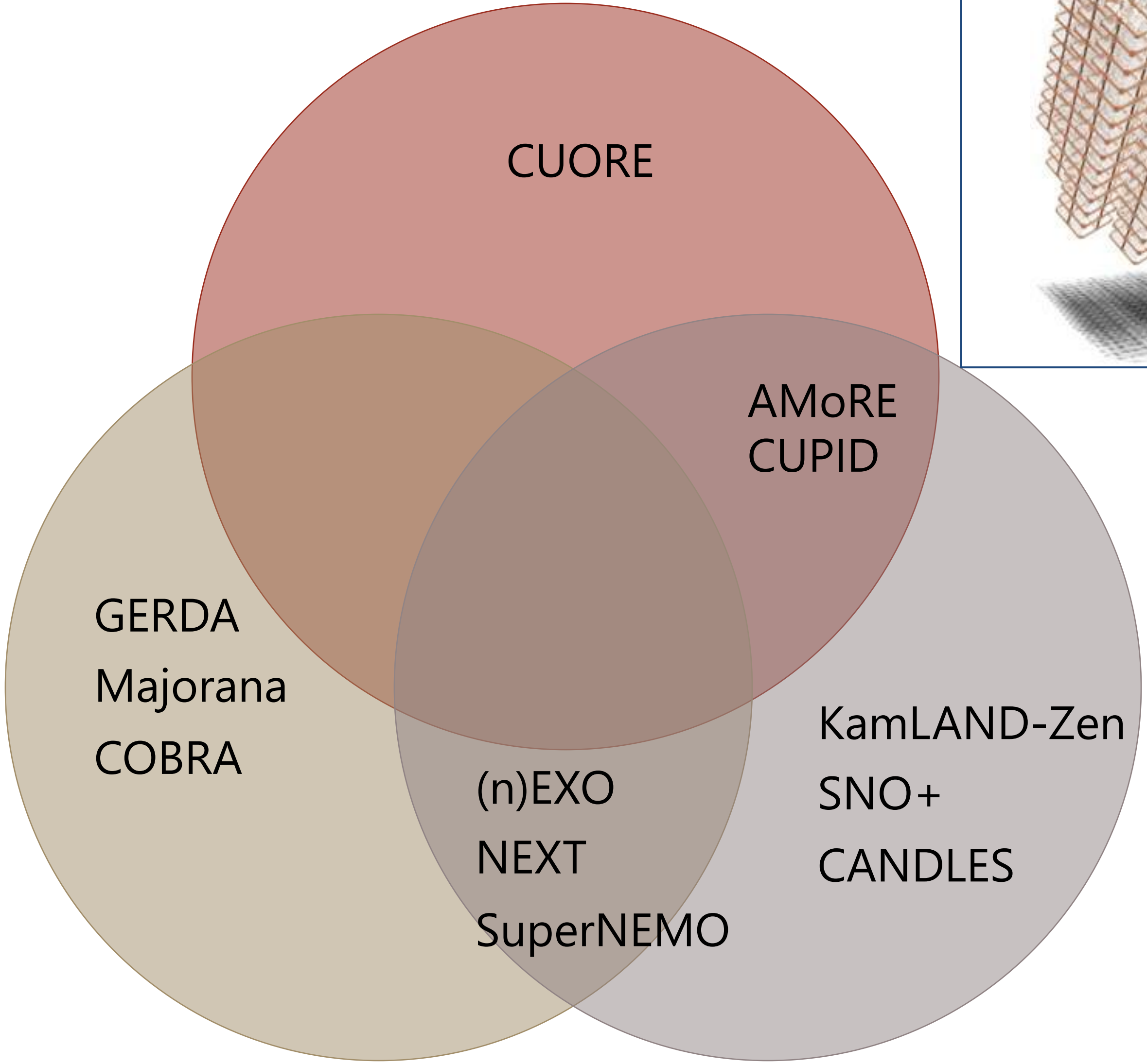
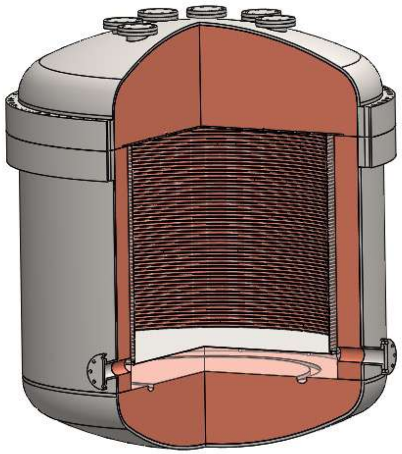
2021/05/22

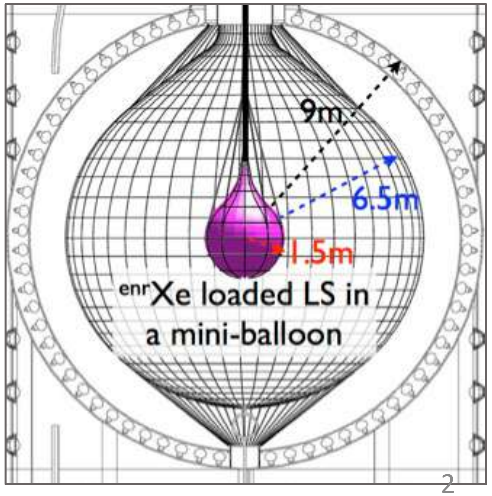
Detection channels

$$(T_{1/2}^{0\nu})^{-1} = F_N \frac{|\langle m_{\beta\beta} \rangle|^2}{m_e^2}$$





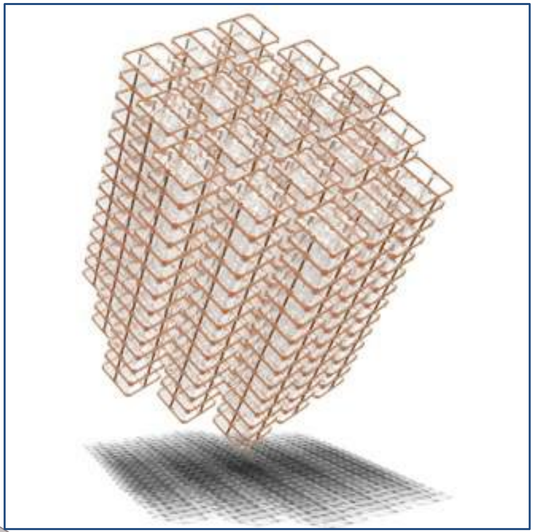


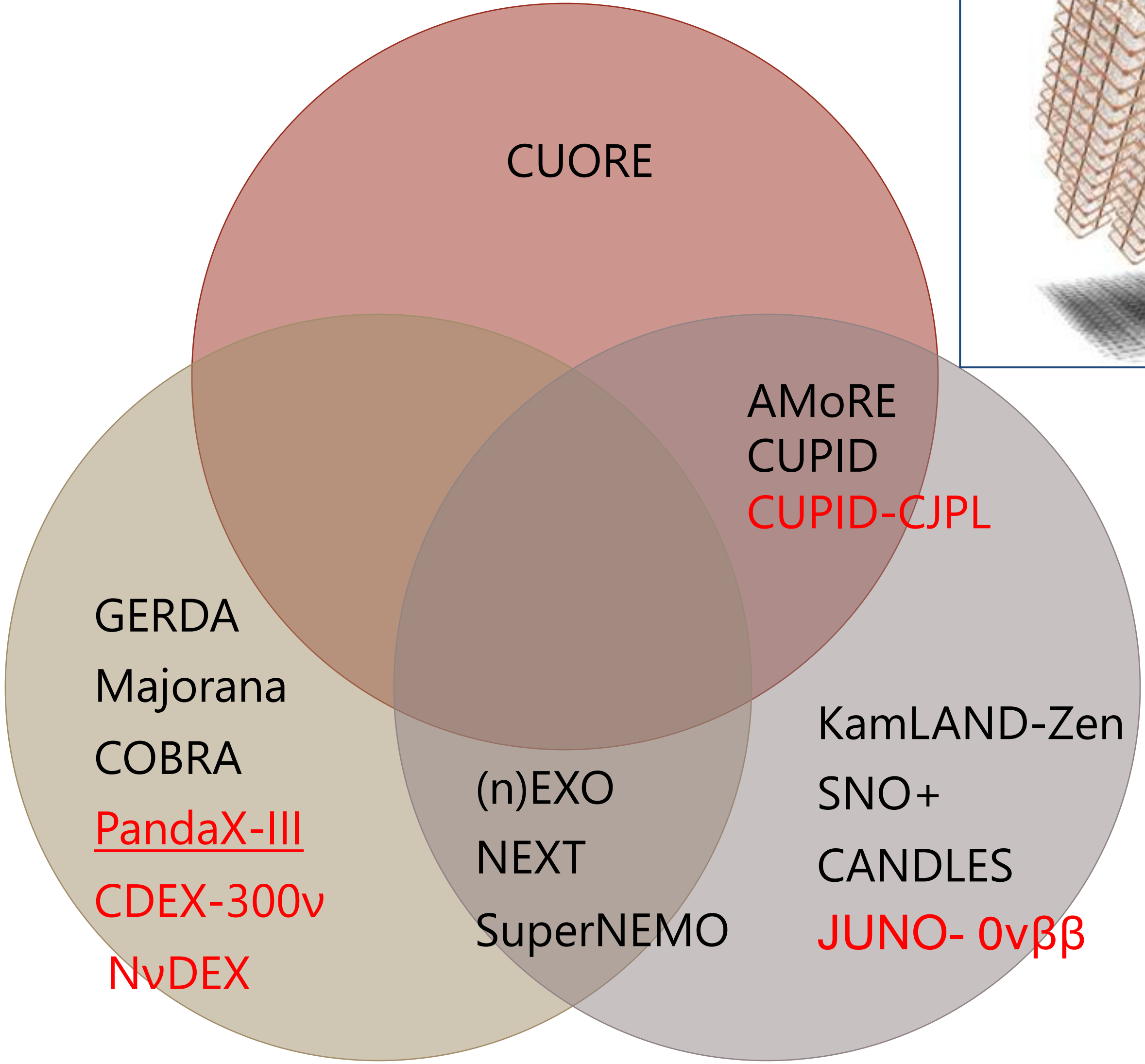


Detection channels

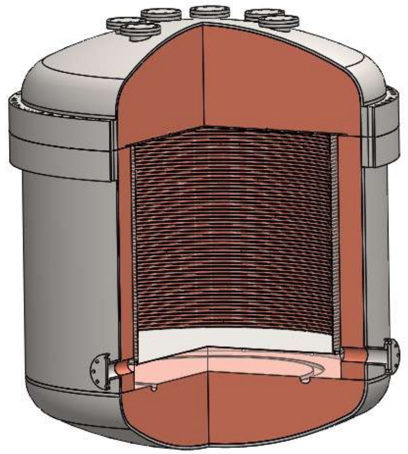
$$(T_{1/2}^{0\nu})^{-1} = F_N \frac{|\langle m_{\beta\beta}\rangle|^2}{m_e^2}$$

Phonons

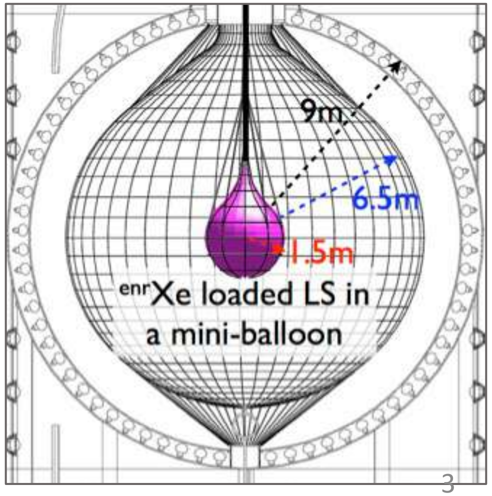




Electrons/holes



Photons



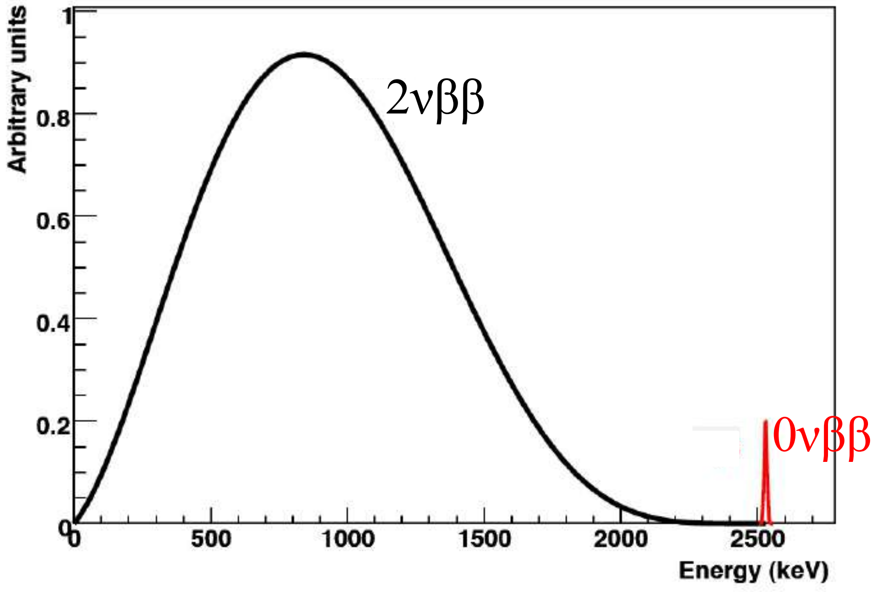
Detection of double beta decay

- Examples:

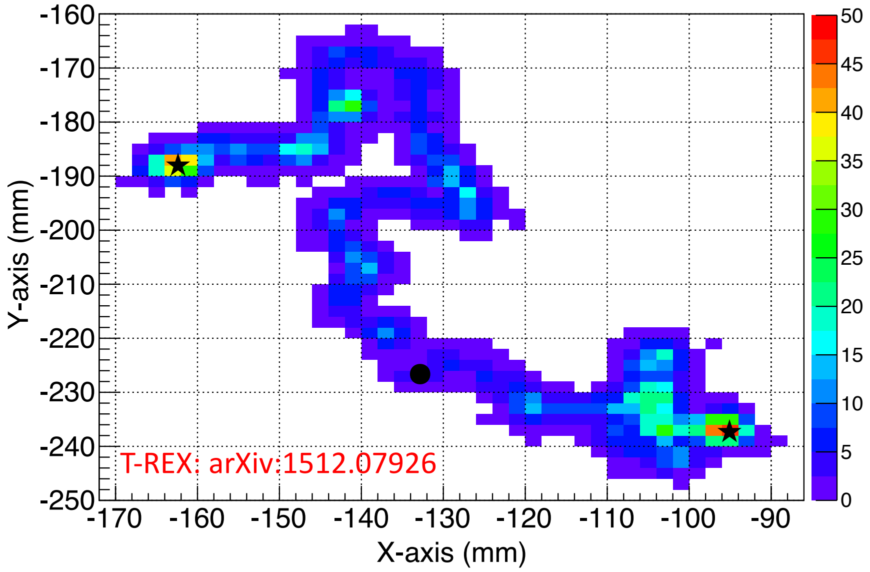
$$^{136}_{54}Xe \rightarrow ^{136}_{56}Ba + 2e^- + (2\bar{\upsilon})$$

$$^{130}_{52}Te \rightarrow ^{130}_{54}Xe + 2e^- + (2\bar{\upsilon})$$

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



Sum of two electrons energy



Simulated track of 0νββ in high pressure Xe

PandaX Detectors

PandaX-I: 120kg LXe
(2009 – 2014)

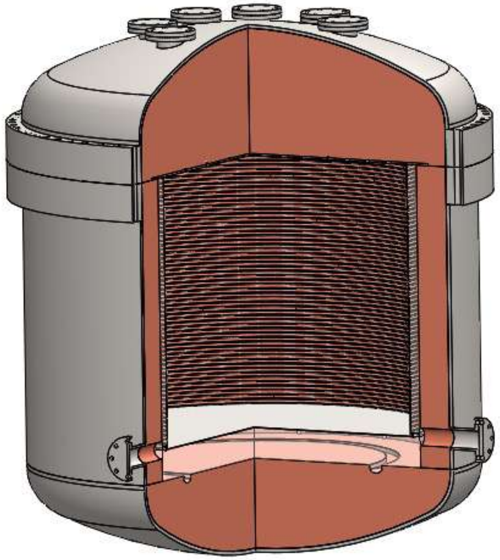
PandaX-II: 500kg LXe
(2014 – 2018)

PandaX-xT LXe
(future)

WIMP searches
(0νββ as well)

PRL 117, 121303 (2016)
…
…

PandaX-III: 100kg - 1 ton
HPXe for 0νββ (future)

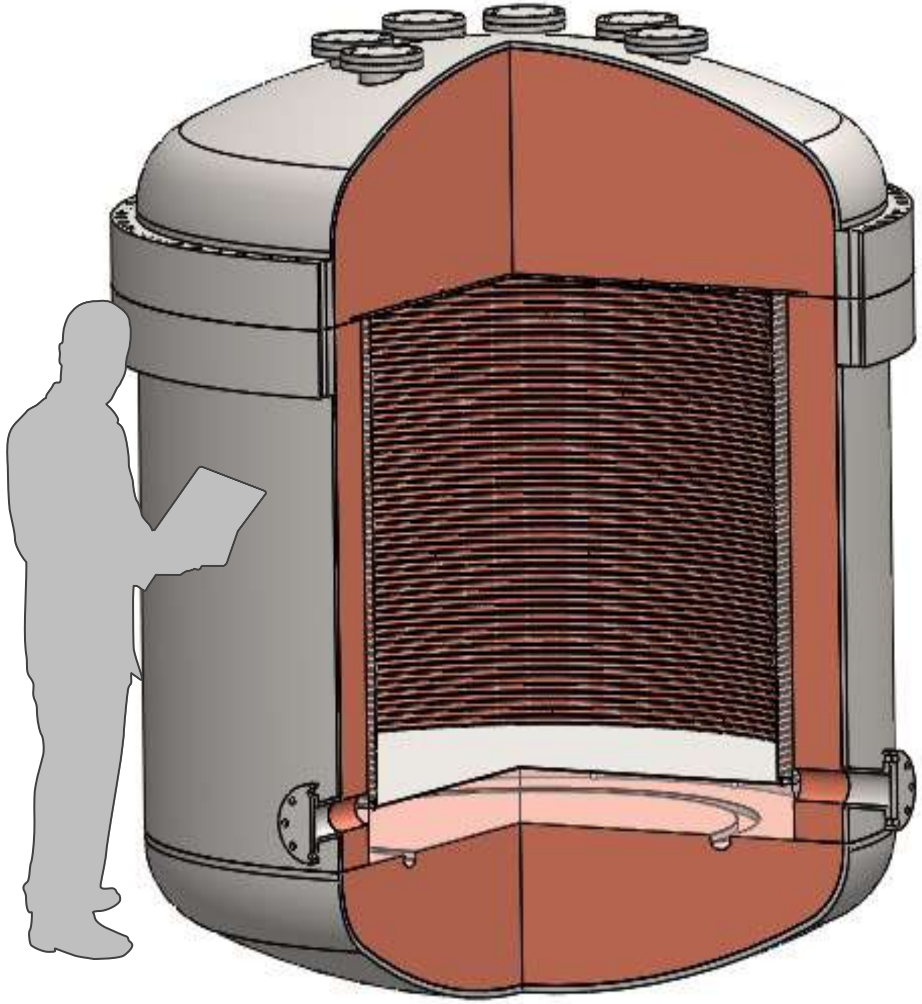


Outline

- Characteristics of high pressure gaseous TPC for $0\nu\beta\beta$
- Hardware development
  - Micromegas detector modules
  - Prototype TPC and test setups
  - Electronics and DAQ
  - Infrastructure
- Simulation and analysis efforts

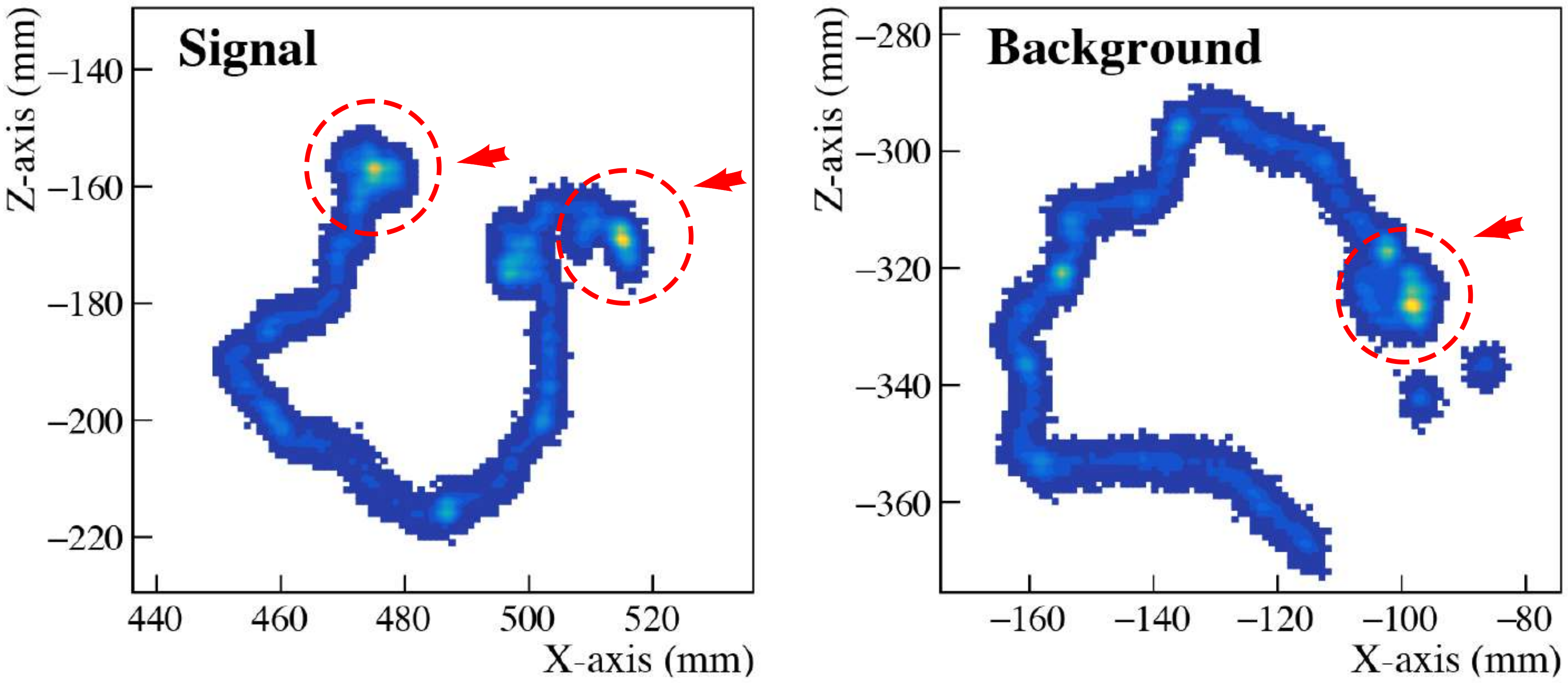
PandaX-III: high pressure gaseous TPC for $0\nu\beta\beta$ of ^{136}Xe

- TPC: 100 kg scale high pressure TPC at 10 bar operating pressure
- Charge only readout with millimeter level spatial resolution
- Good energy resolution and tracking capability for signal-background discrimination



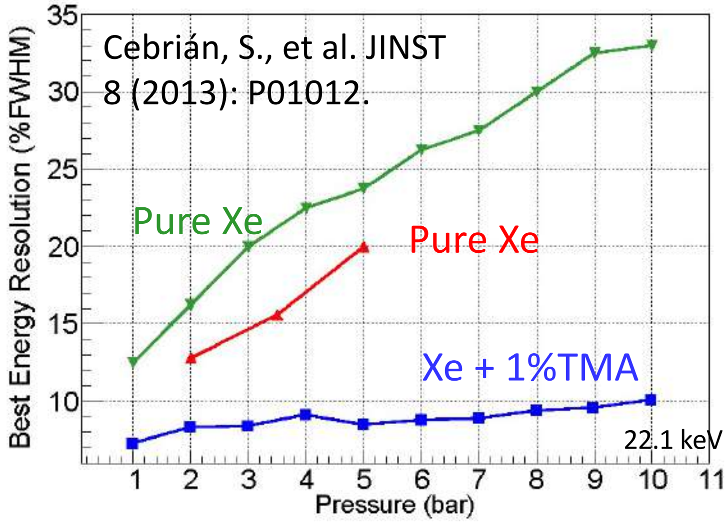
0νββ of ^{136}Xe in gasesous TPC

- Electrons from ^{136}Xe travel around 10 cm in 10 bar xenon
- Mostly one single track
- Two Bragg blobs at the ends (two electrons)

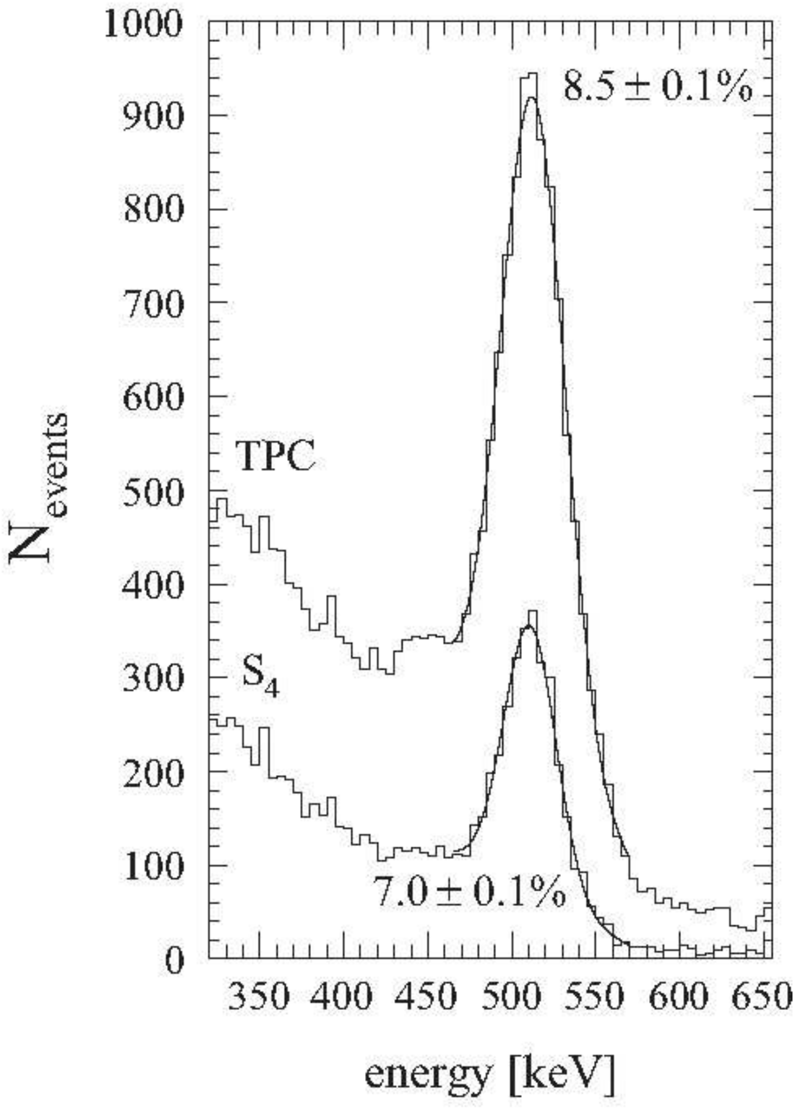


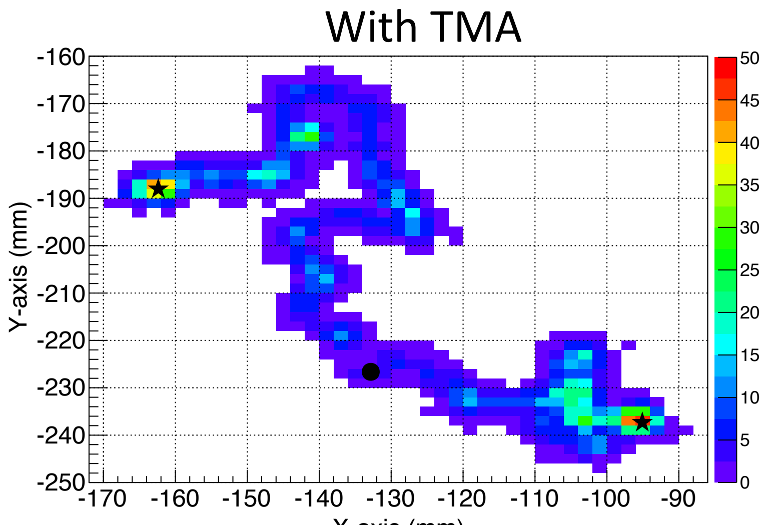
Gas medium: Xe +TMA (三甲胺)

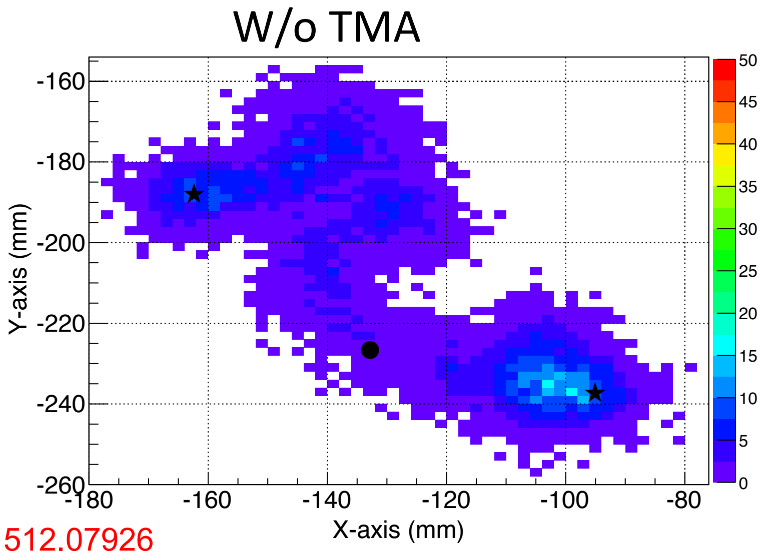
- Better energy resolution: 3% FWHM (@Q $_{0\nu\beta\beta}$) (expected)
  - TMA suppress light; more ionization
  - TMA as a quencher, increase the stable working voltage
- Better tracks
  - TMA suppress diffusion



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



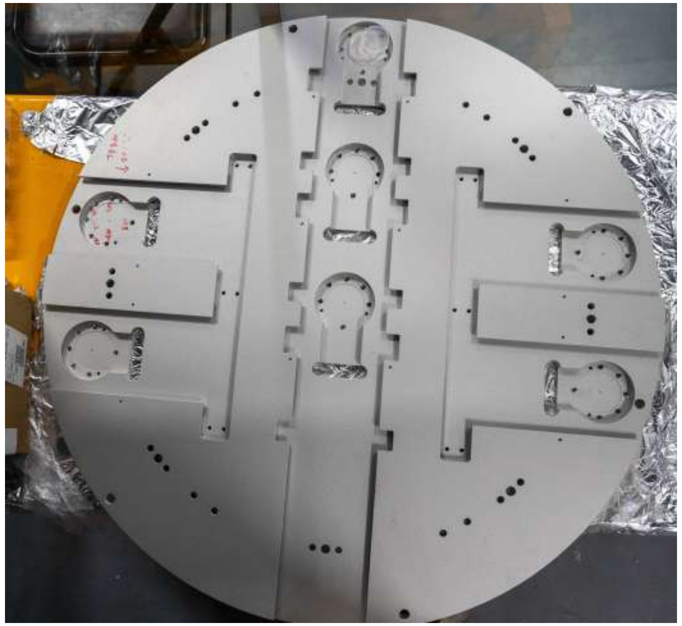




T-REX: arXiv:1512.07926

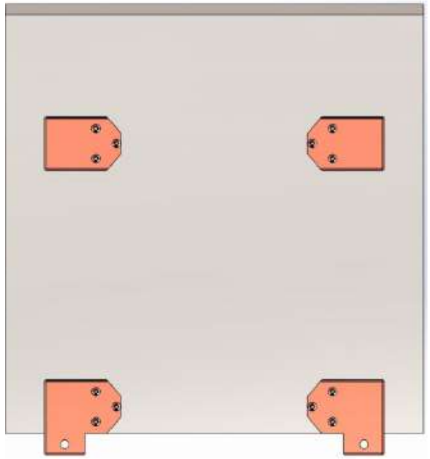
Charge readout plane

Prototype backplate



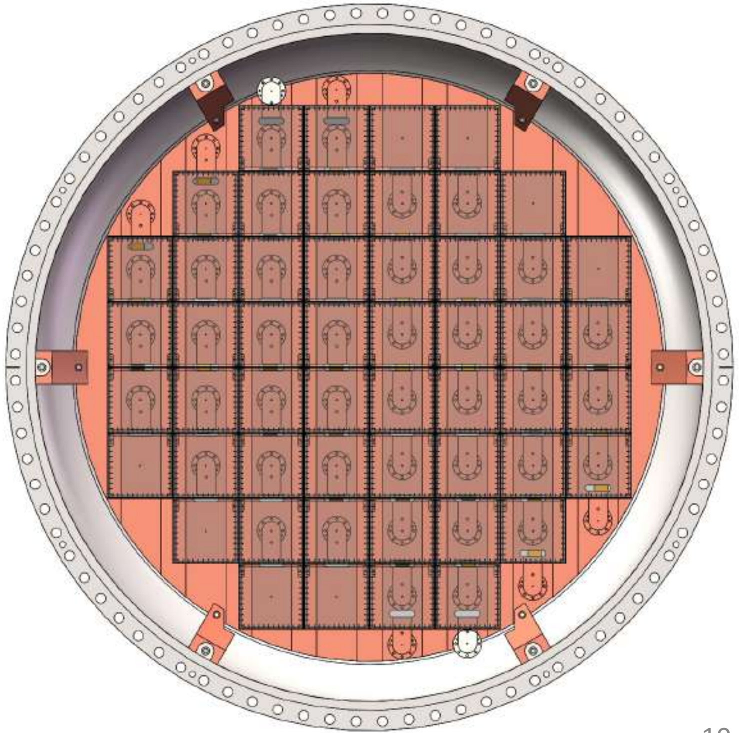
- 52 Micromegas modules mounted on a backplate
- Mosaic layout to cover readout planes
  - Minimal dead zone
  - Strip and mesh signal readout
  - Second iteration with custom-designed face-to-face connectors

+



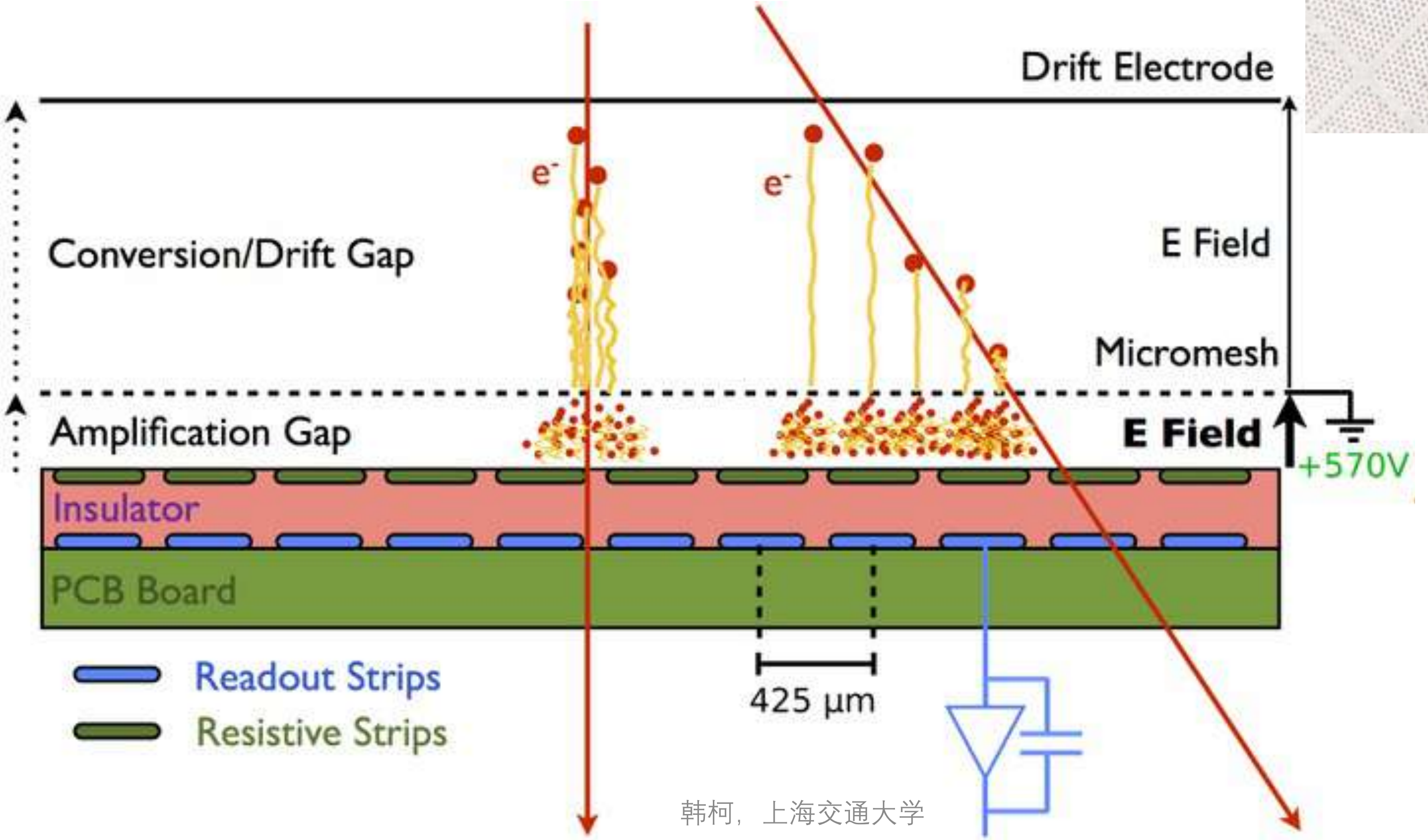
+ mesh

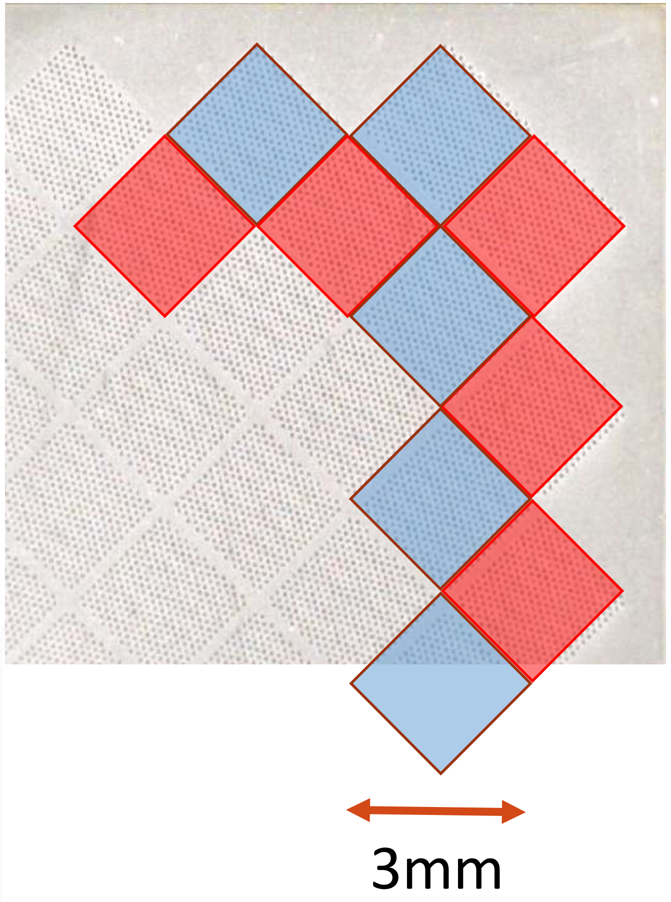
×52



Charge-only readout plane with MicroMegas (MM)

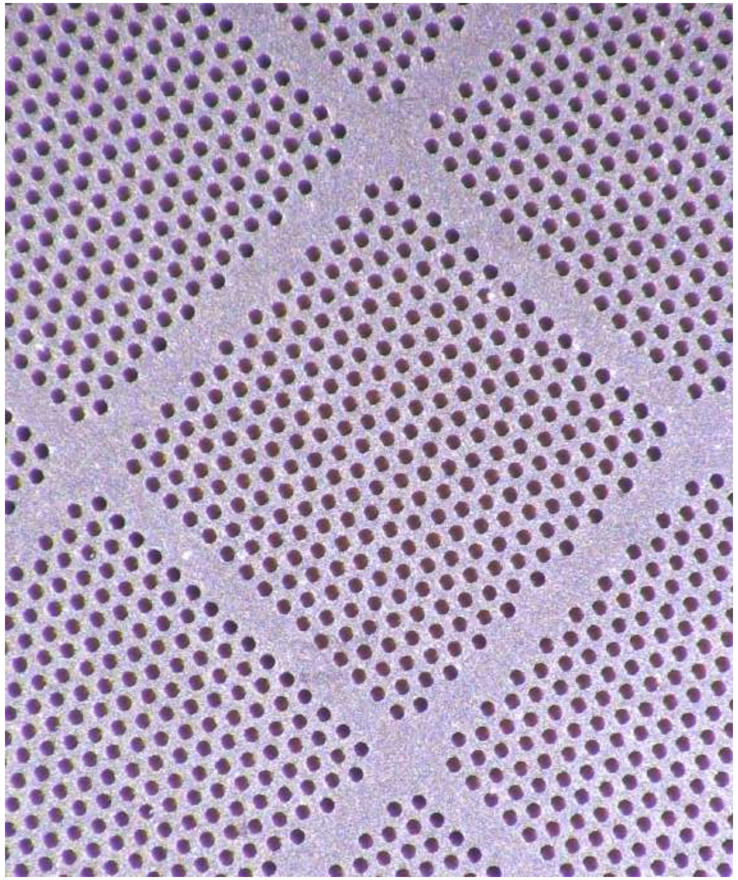
- MicroMegas amplifies drift electron signal via avalanche
  - >1000 gain expected in 10 bar xenon (100 um gap)
- 3mm pitch
- Strip readout to have reasonable number of readout channels





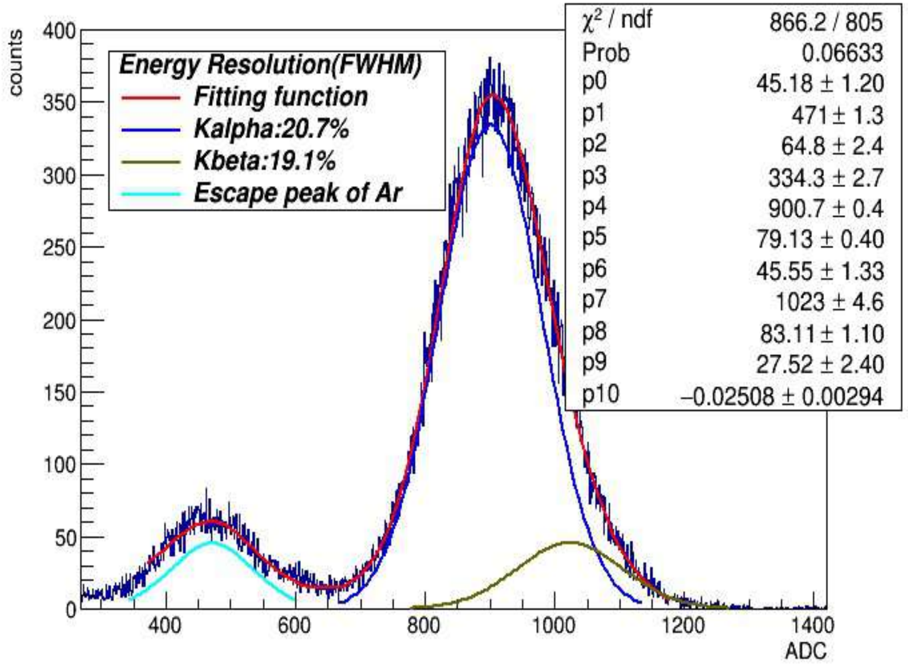
Microbulk --> Thermal bonding Micromegas from USTC

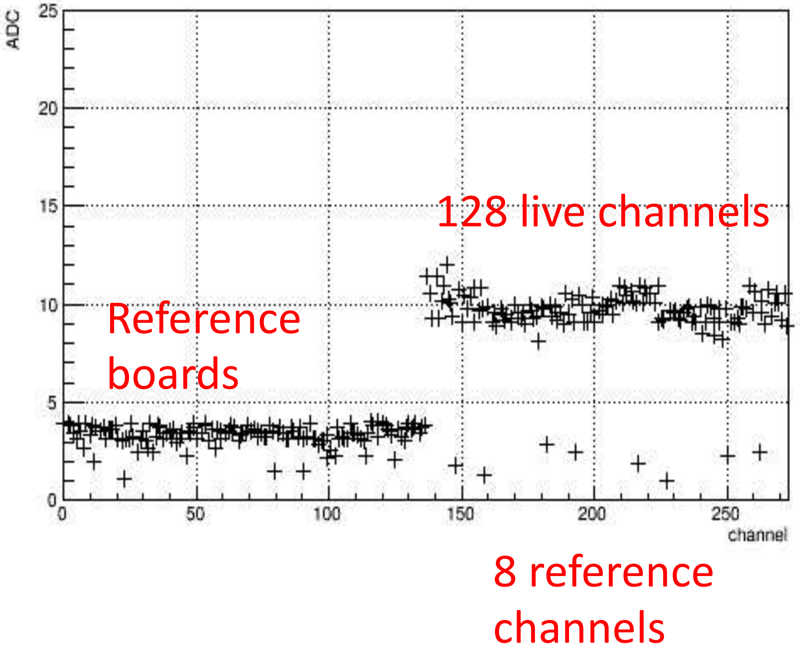
- Original choice was Microbulk Micromegas from CERN
- Switched to thermal bonding Micromegas from USTC since early 2020



Recent progress on USTC thermal bonding MM

- Now 5th version of thermal bonding Micromegas under testing.
- Tested in 1/8/10 bar argon mixture gases.
- Best energy resolution at 6 keV (^{55}Fe) is 15% in 1 bar argon/CO_2.
- No dead channels!



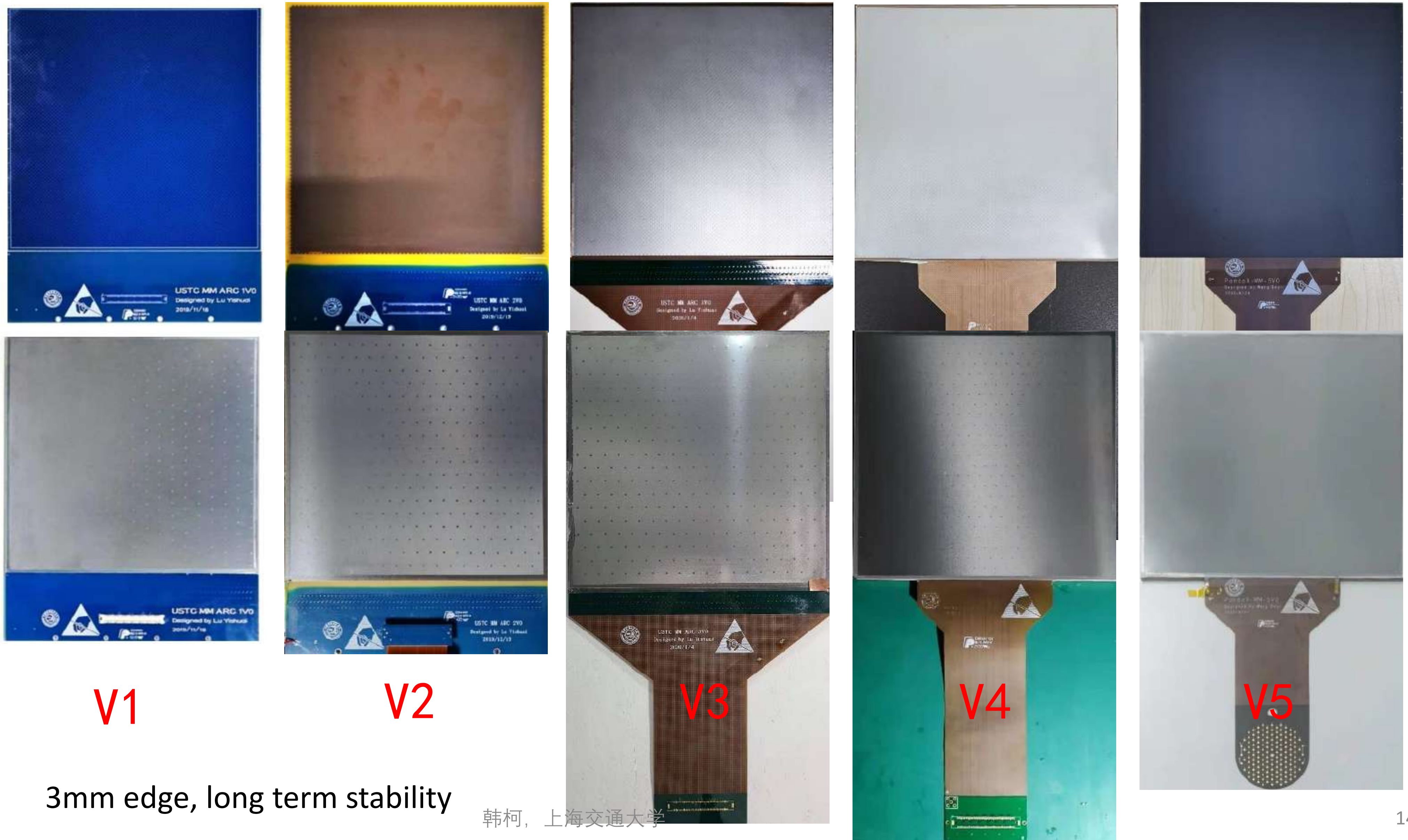


Development of thermal bonding Micromegas

Low background, Energy resolution, uniformity

Readout PCB

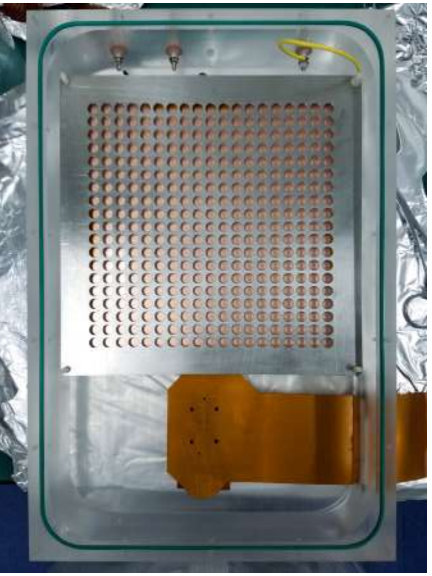
Thermal bonding MM



3mm edge, long term stability

Test setups, prototype, and full vessel at SJTU

1 MM,
flow gas



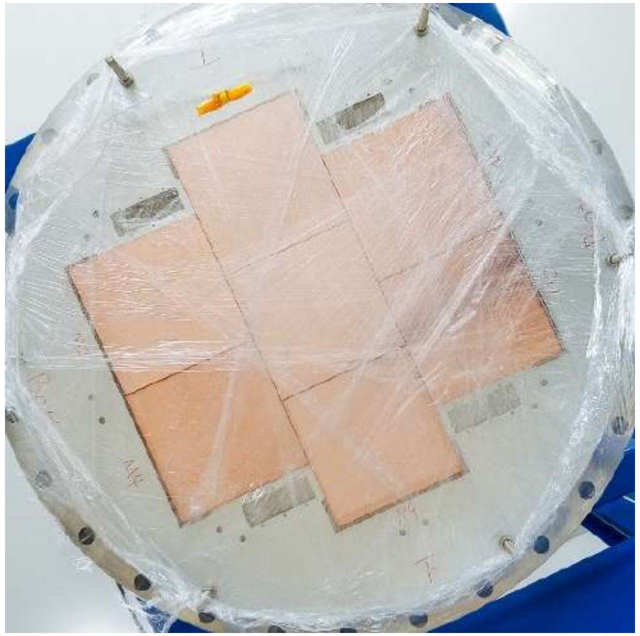
MiniTPC:
1 MM,
16 bar

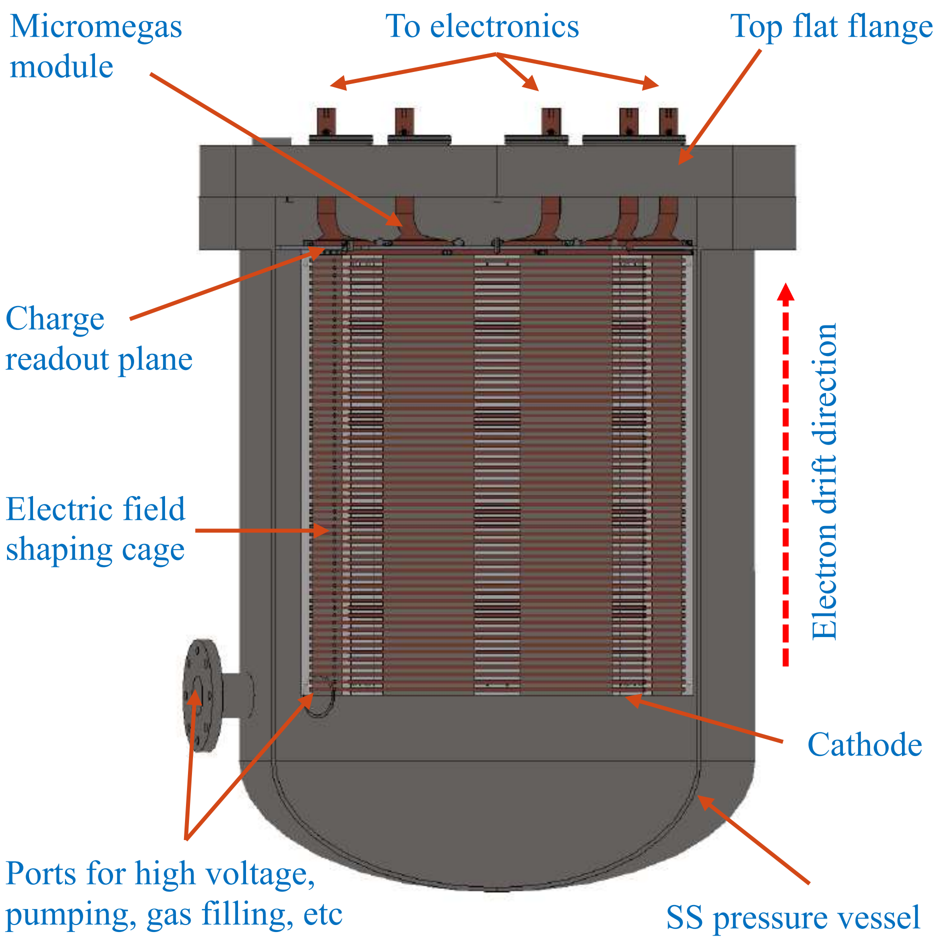
Prototype TPC:
7 MM, 10 bar

Full vessel: low background SS, 4 m^3 inner volume

Prototype TPC at Shanghai

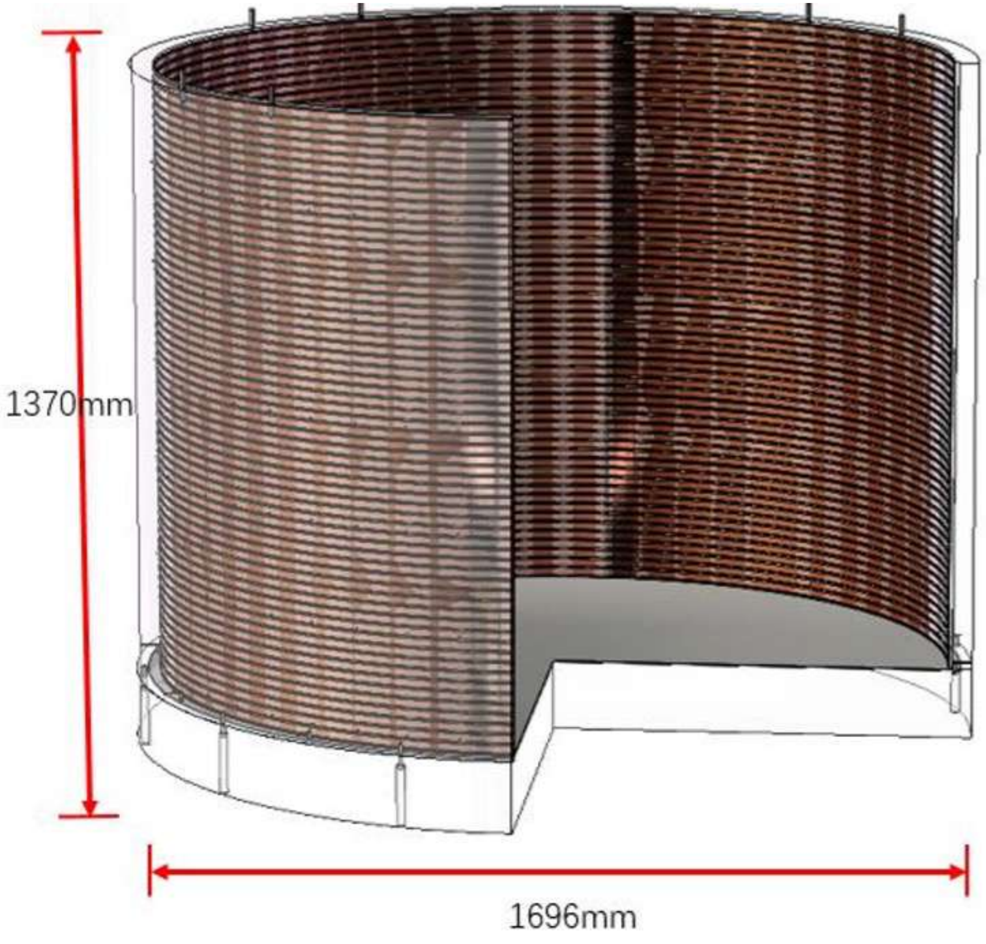
- About 600 L inner volume
- Field cage: 66 cm diameter, 78 cm drift length
- 16 kg of xenon at 10 bar
- SS pressure vessel
- 7 MM





Field cage

- Tiled Kapton Flexible PCB + SMD resistors
- Tested in small and medium scale
  - HV performance comparable with copper bar options
- Fabricated by TangChen (JUNO vendor) for low background control



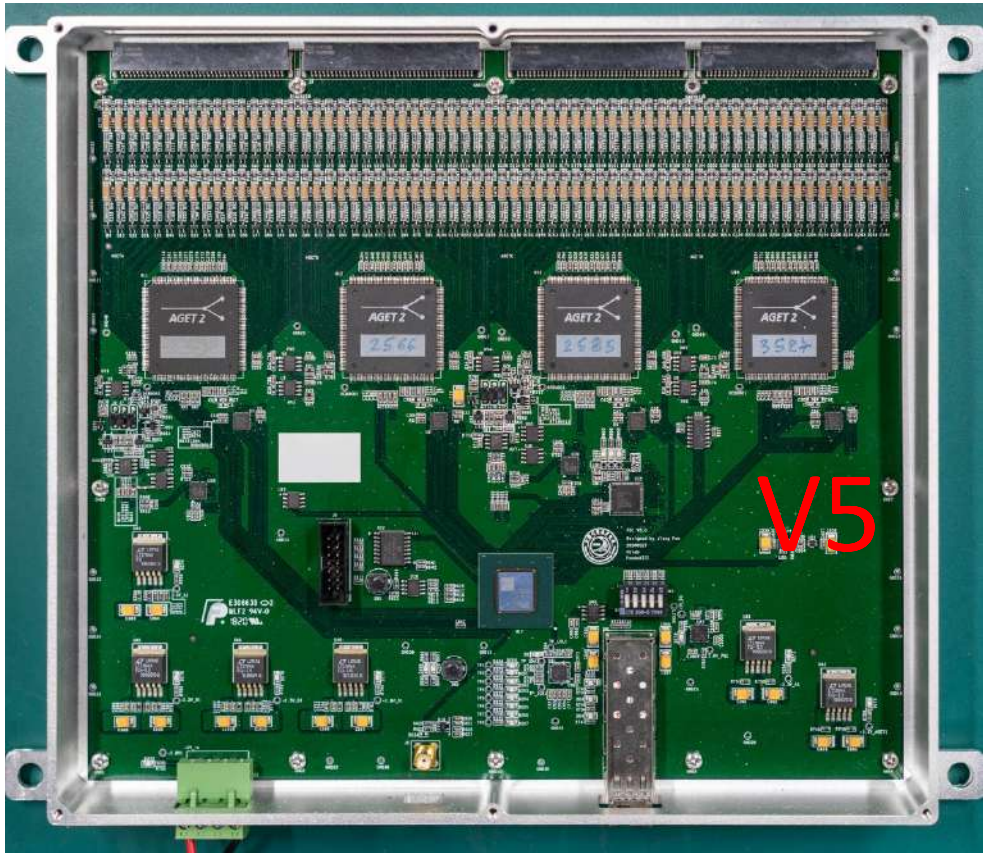
Design of field cage of full TPC

Front end electronics

Frontend electronics based on AGET

ASIC chips

- 64 channel per AGET
- 512 sampling point per channel
- Dynamic range up to 10 pC
- Sampling rate: 1 MHz to 100 MHz

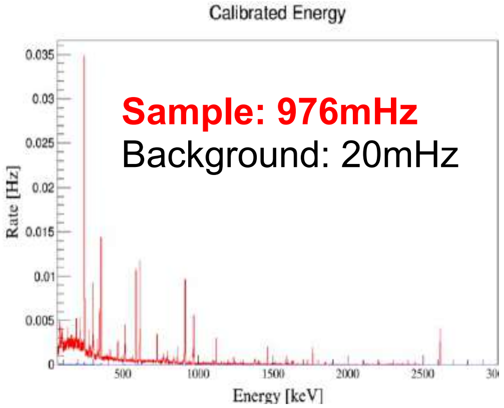


V6 for mass production, in progress

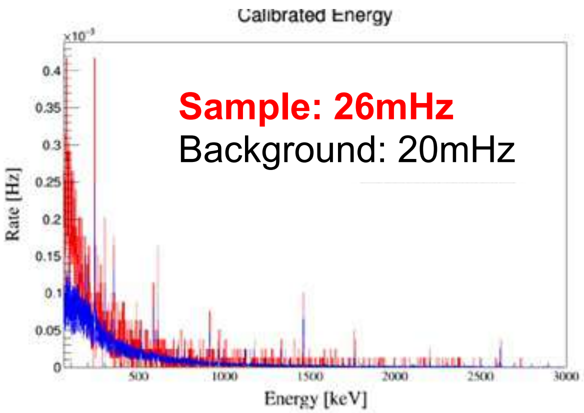
Quest for low background

FEC with FR4

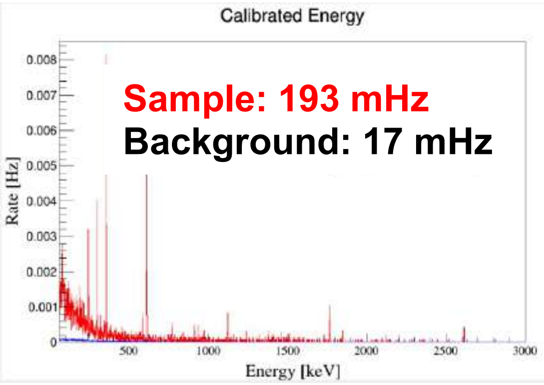
FEC V5 with Kapton



FEC with FR4



FEC board with Kapton



FEC with Kapton

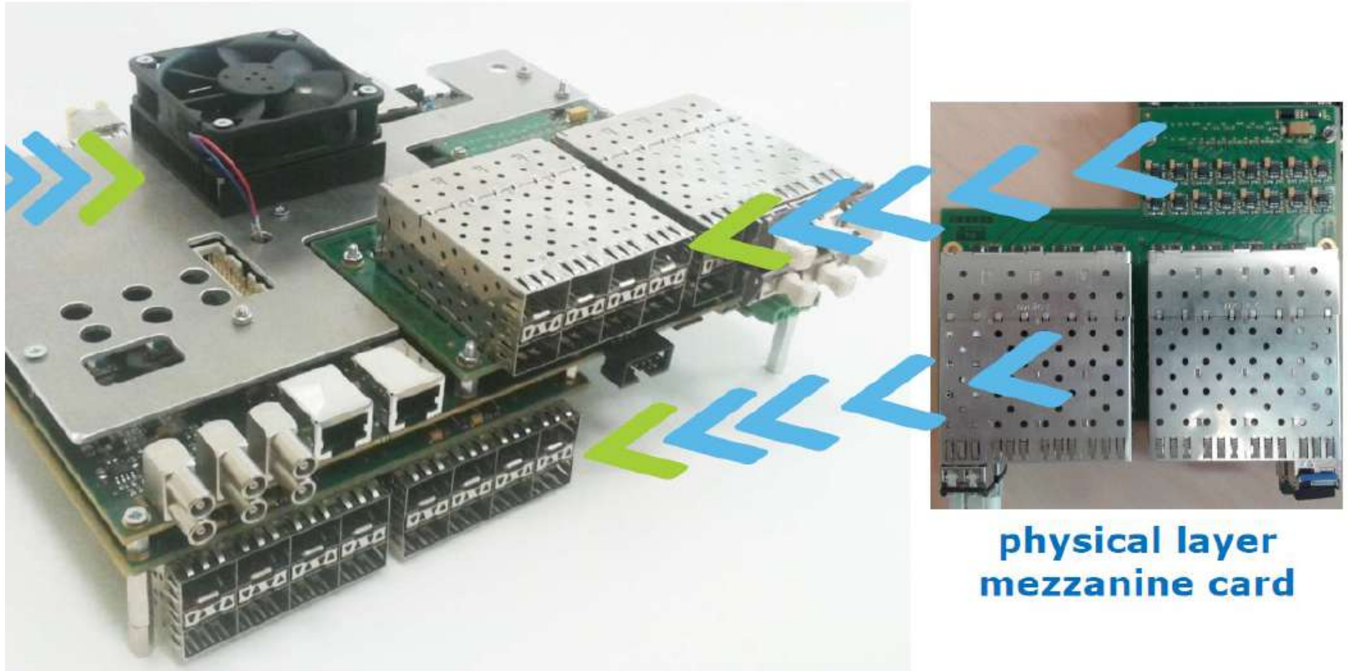
Low background connector

found by USTC

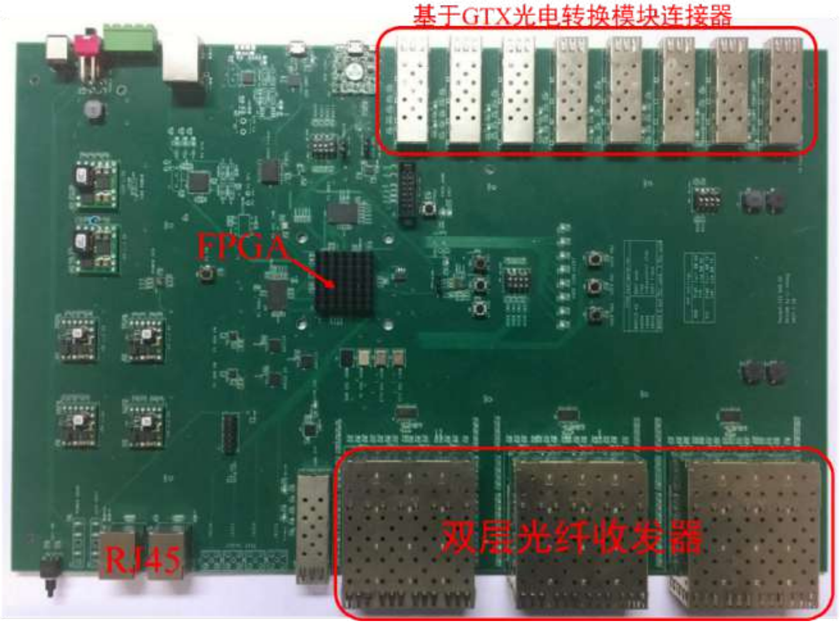
Backend

Backend: The Trigger and Data Concentrator Module – TDCM

- Designed by Saclay for PandaX-III and T2K-II
- A custom-made 6U form factor carrier board with two physical layer mezzanine cards for 32 FECs
- Backup option: DCM from USTC

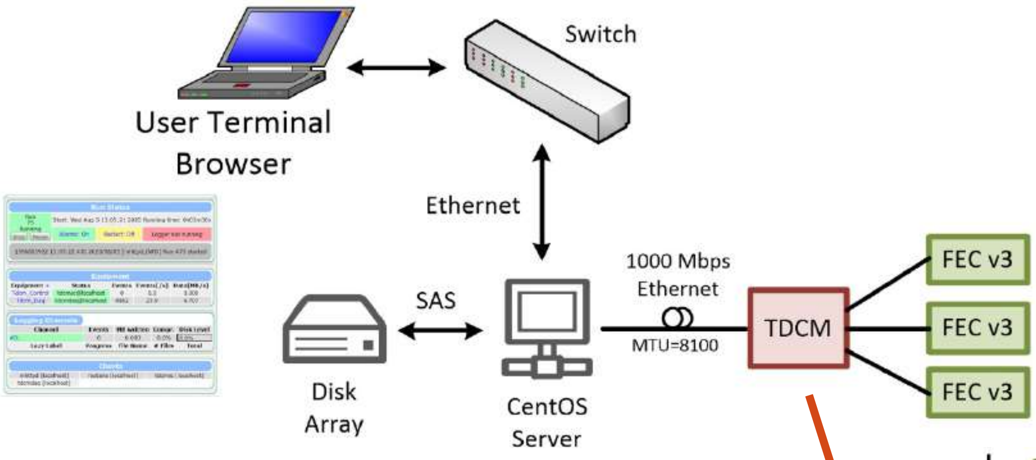


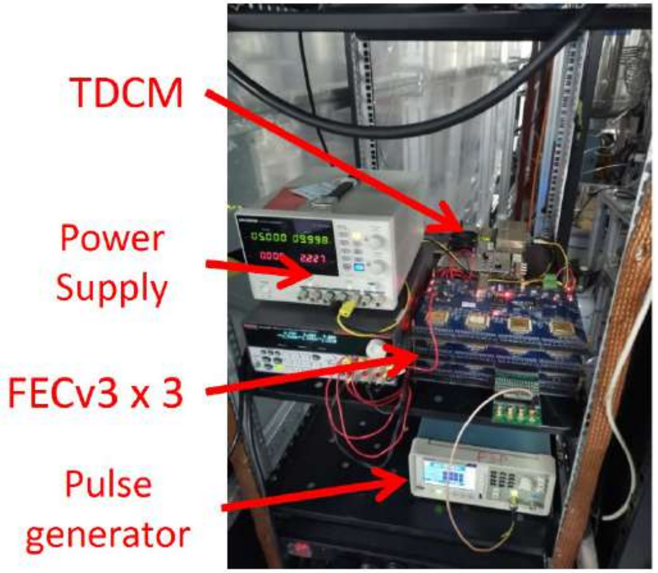
physical layer mezzanine card

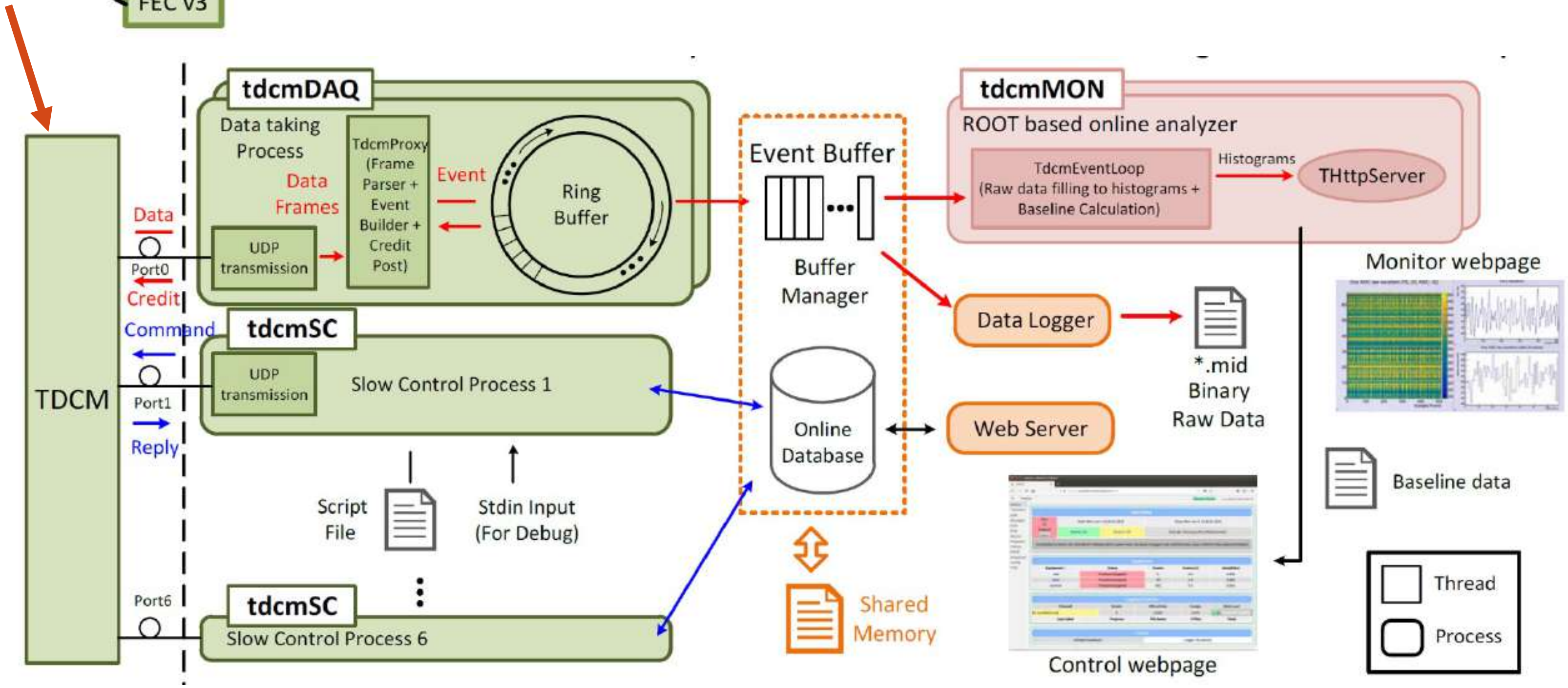


DAQ chain

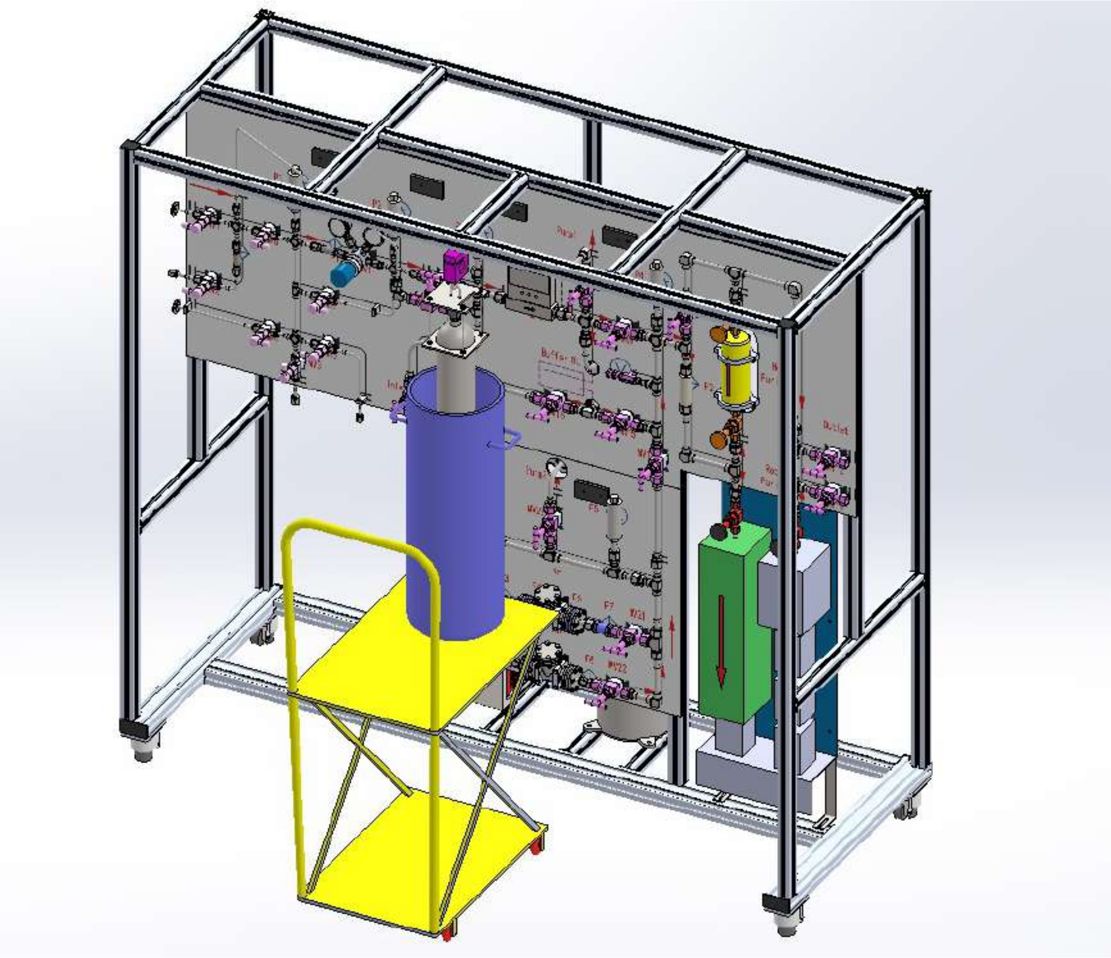
- DAQ chain joint test is on-going with promising results
- DAQ software based on MIDAS reaches stable state



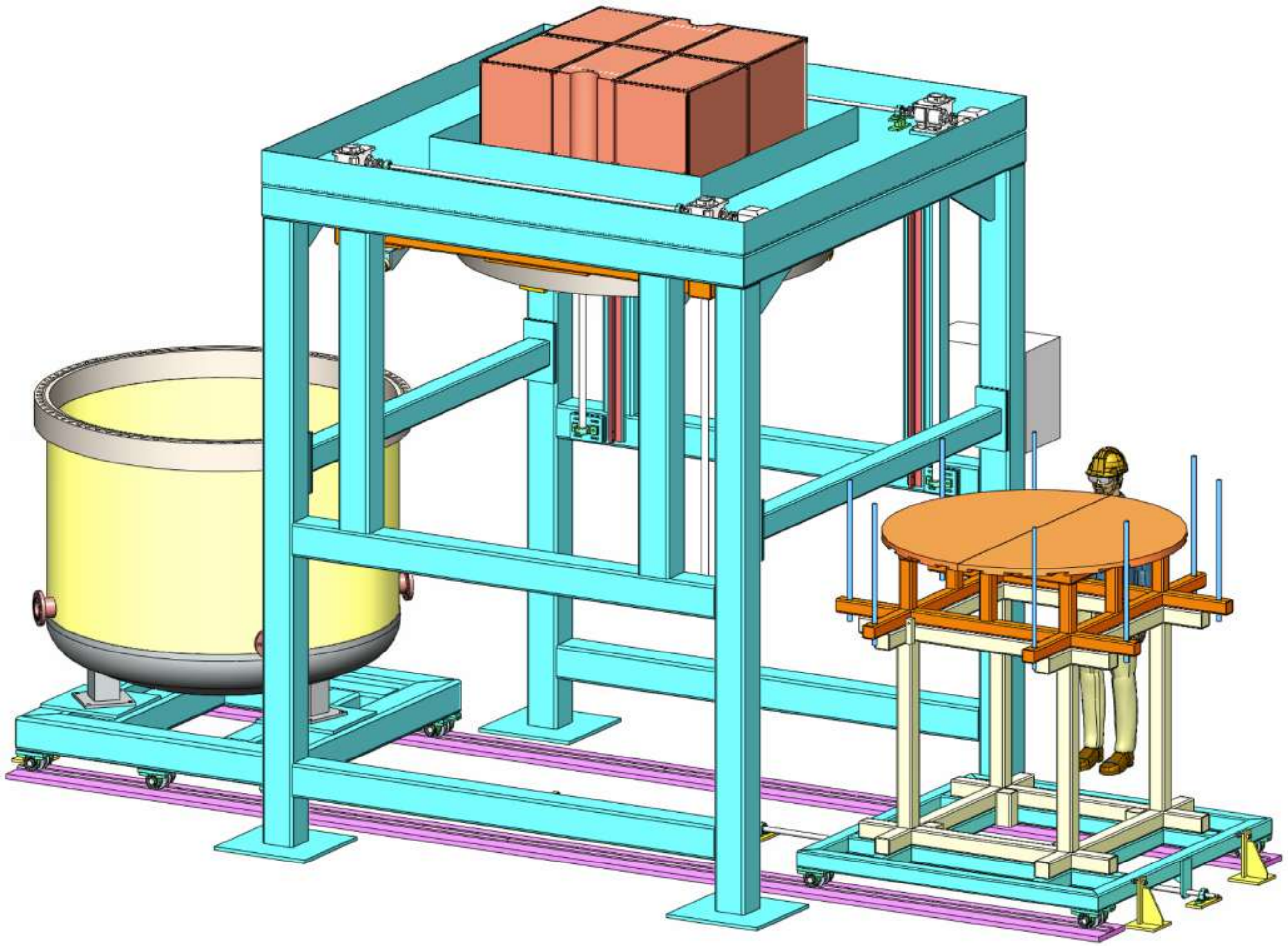




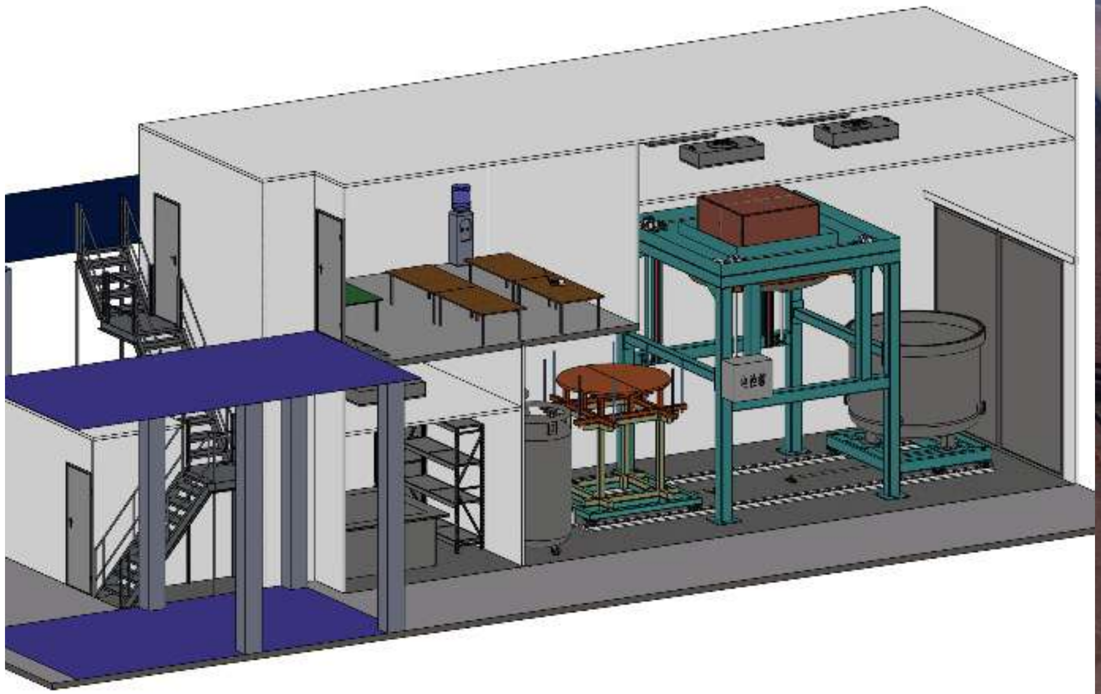
Gas circulation and purification system



Detector installation fixture

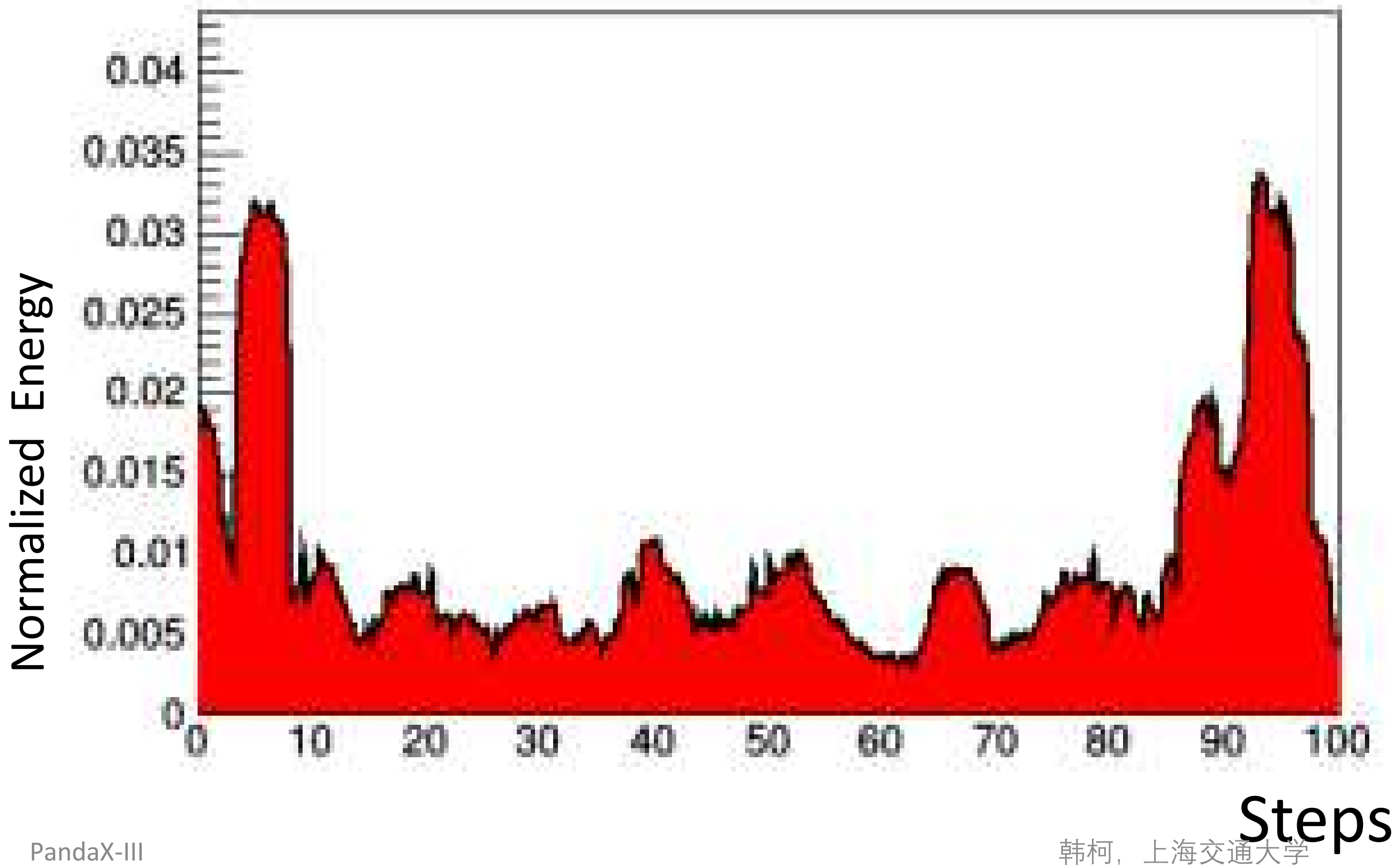


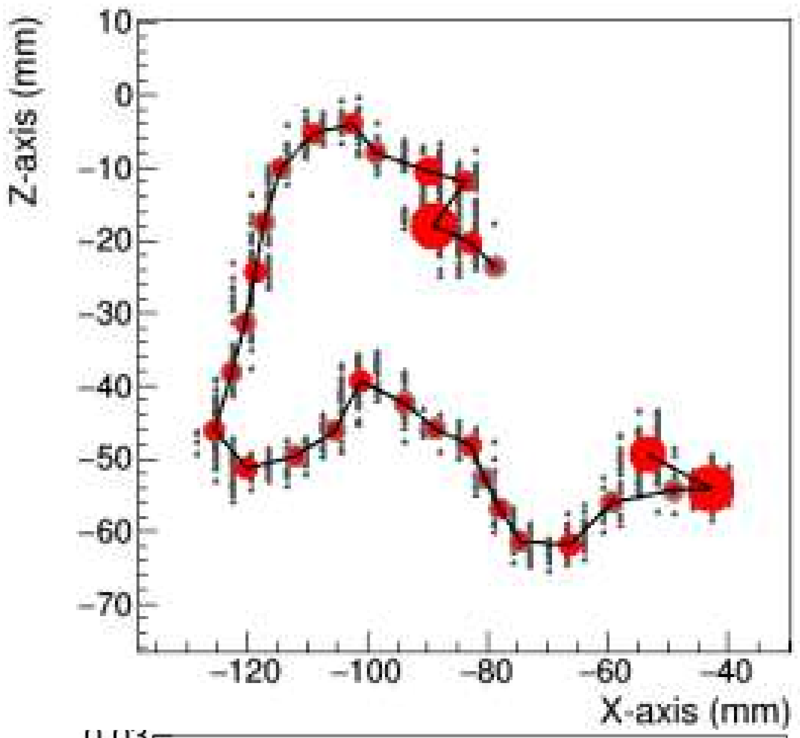
Clean room at CJPL-II

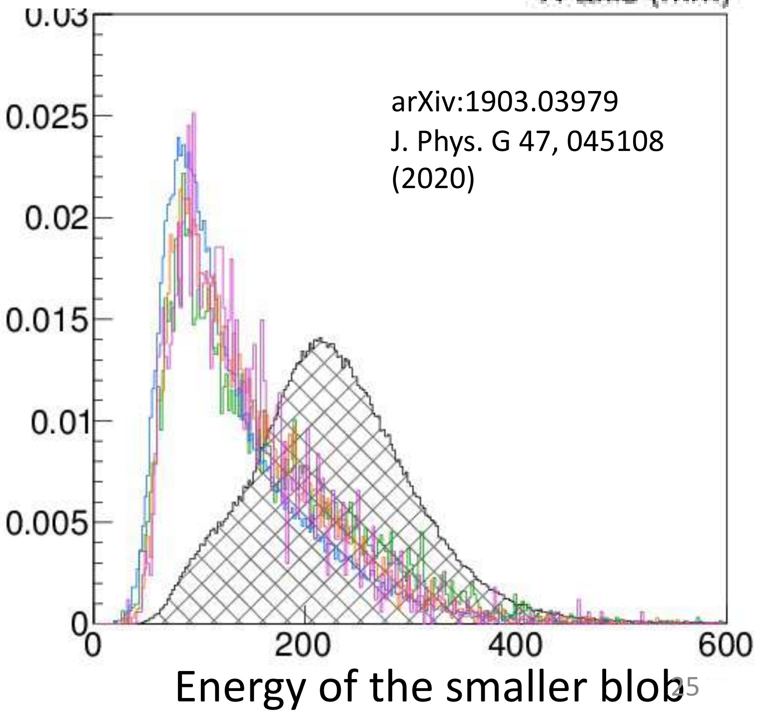


Traditional “cut” based analysis

- Reconstructing tracks in XZ, YZ planes
- Number of tracks optimization by tuning “track distance”
- Energy of end blobs cut optimization

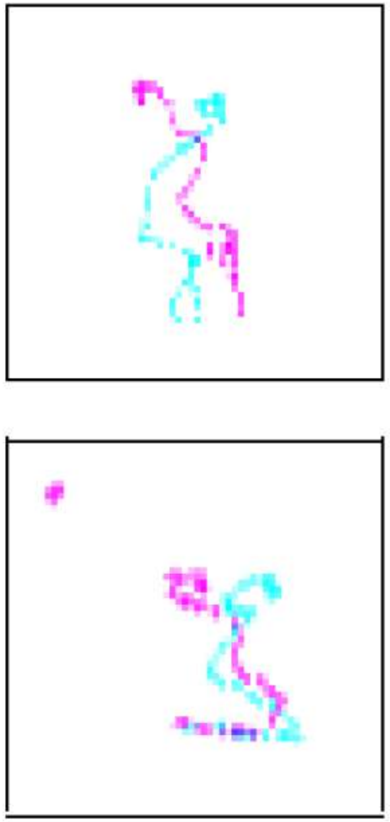


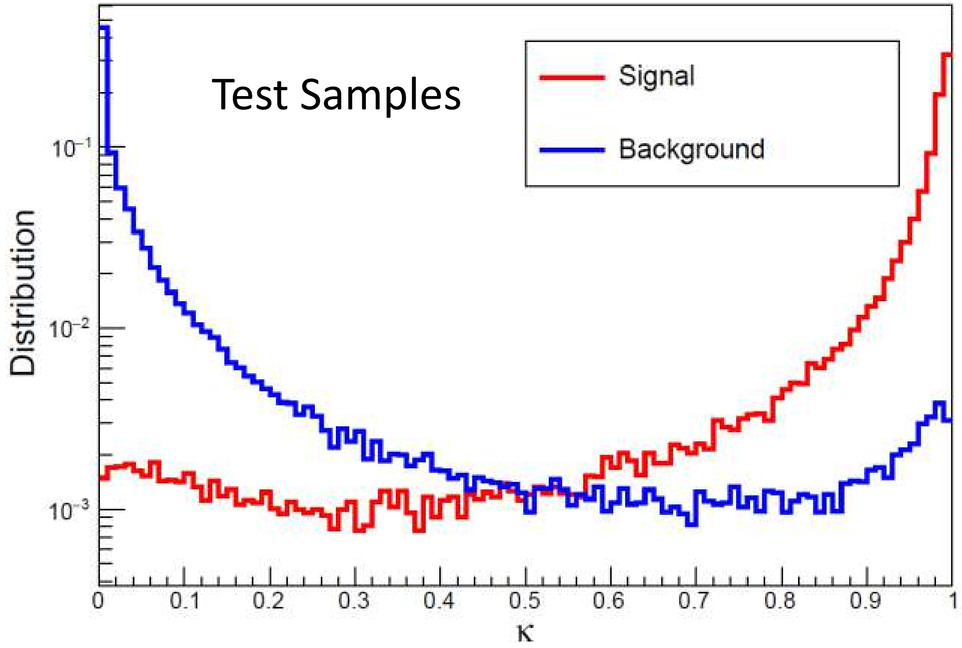




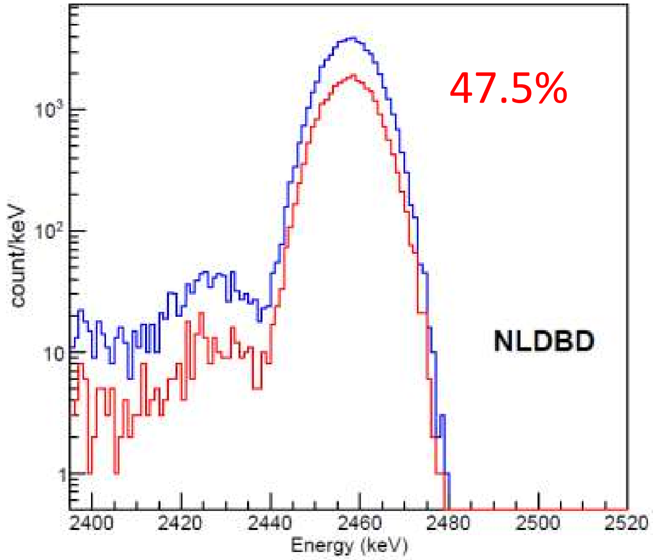
Convolutional Neural network (CNN) for track classification

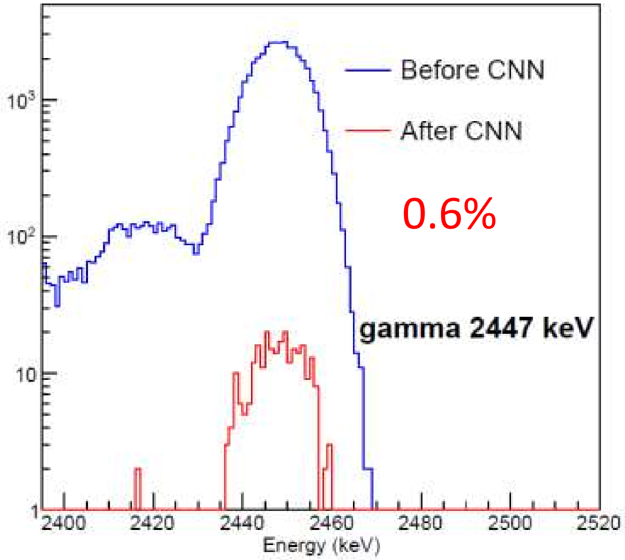
- XZ, YZ 2D snapshots of an event as input of CNN to spill out an index of signal/background
- Prepare image collections for CNN training, validation, and classification.
- No track reconstruction needed.
- More effective than traditional cut based approach.





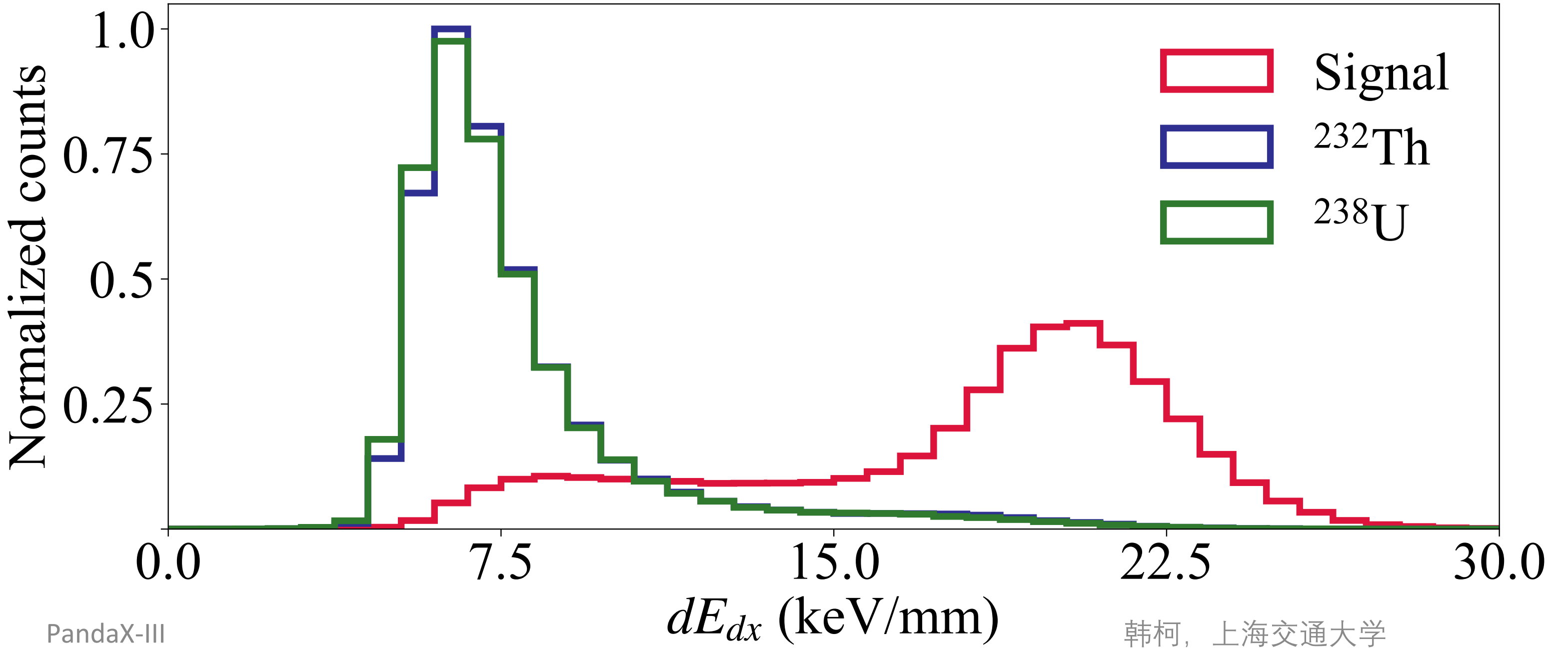
arXiv:1802.03489, Sci. China Phys. Mech. Astron. 61 (2018) 101007

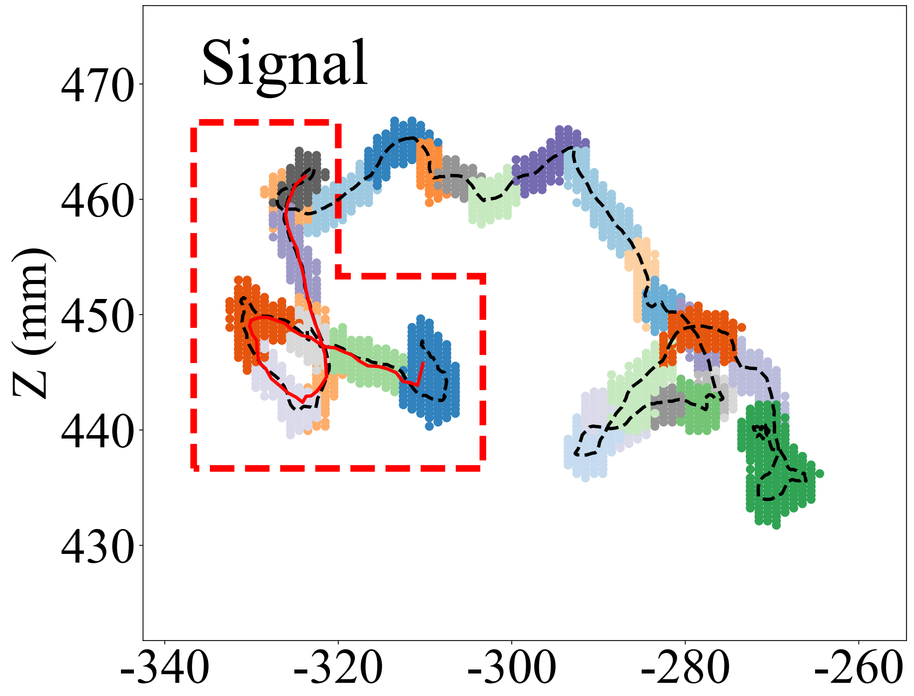


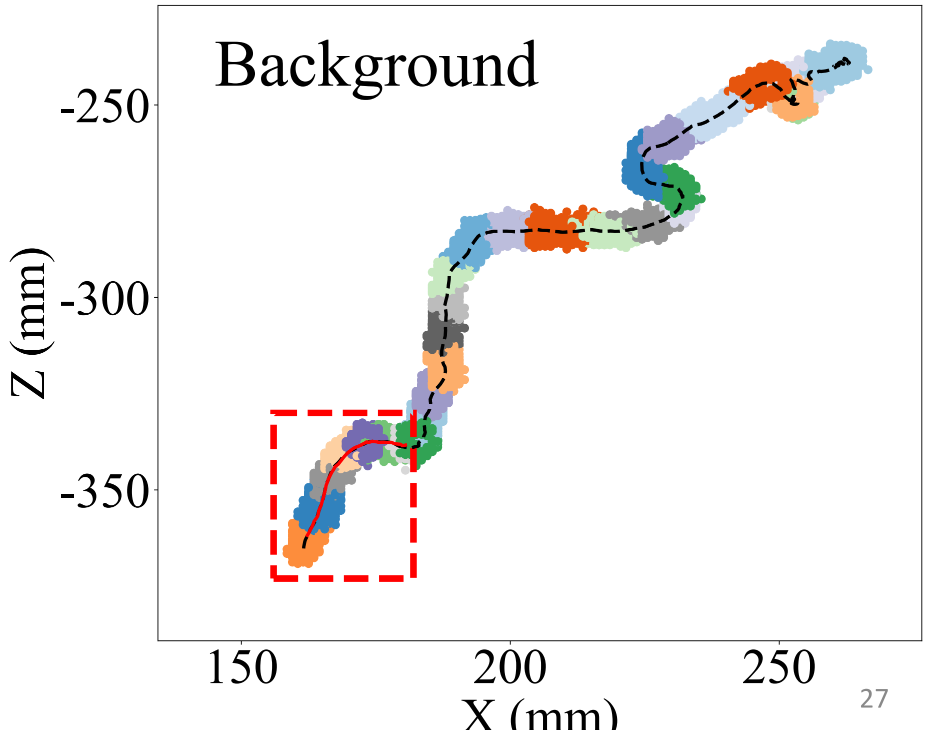


Kalman filter based track reconstruction

- Iterative process with Kalman filter in Bayesian formalism to better reconstruct the tracks and calculate dE/dx
- Improve 0νββ search sensitivity by 3 times to 2.7×10^{26}year
- Tao Li (SYSU), Shaobo Wang, et al arXiv:2102.08221

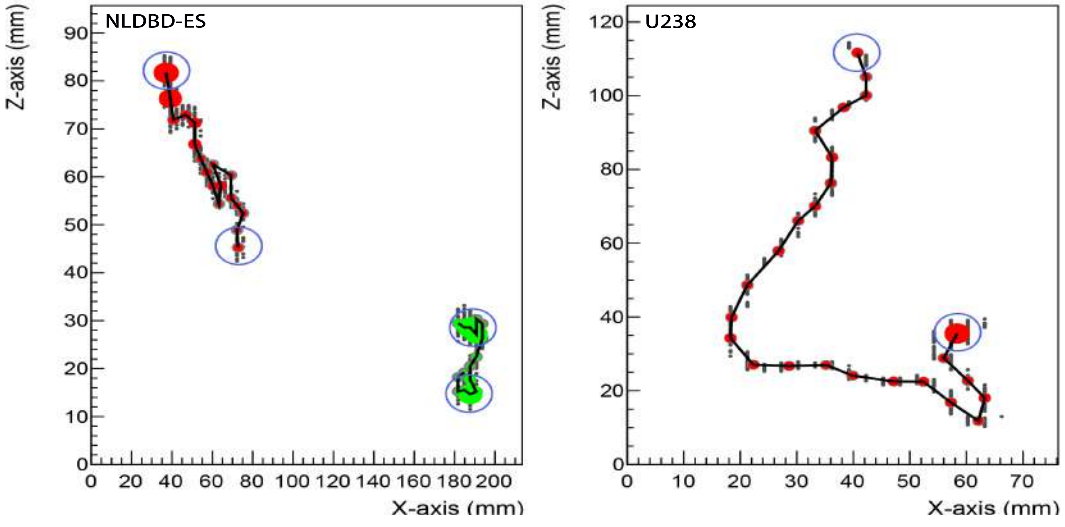


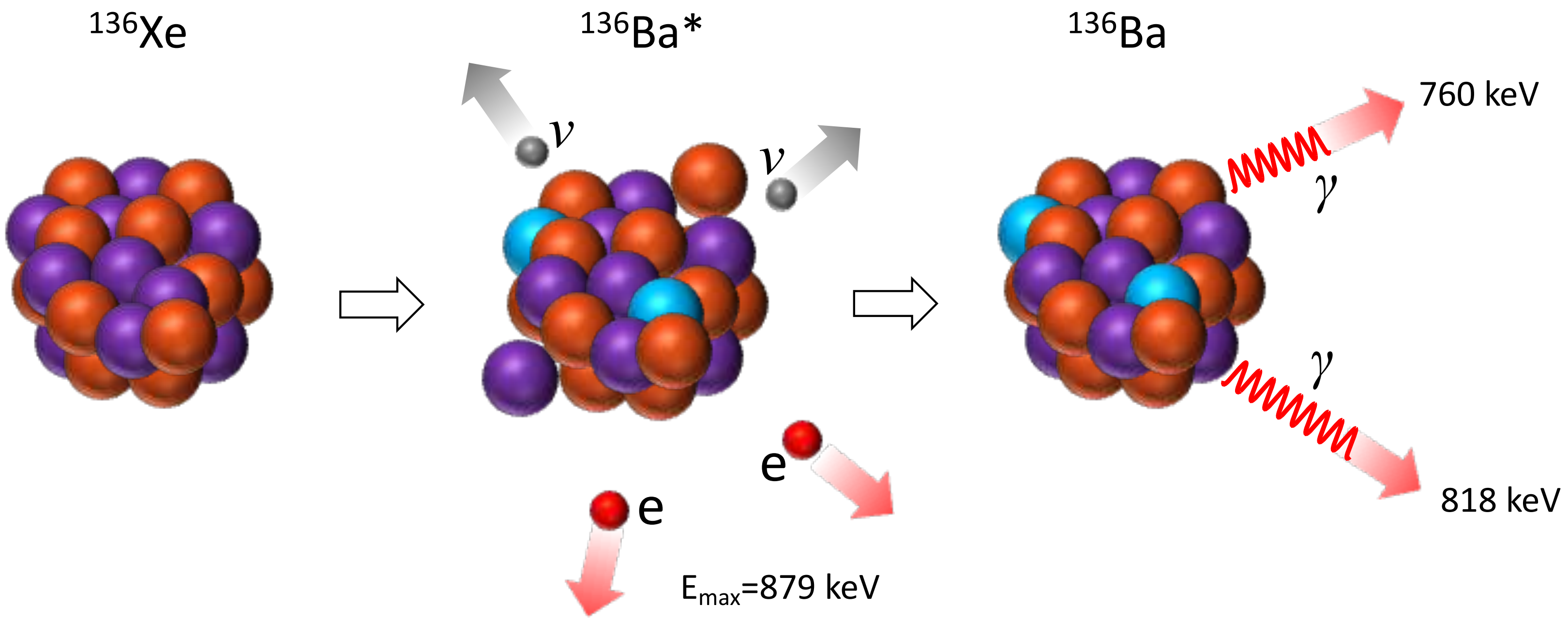




Double beta decay to excited states

- Double beta decay to excited states of ^{136}Ba
- Dual-electron + Gamma emission: clearer signature
- Position sensitivity and dual-beta/gamma discrimination to enhance search sensitivity: NLDBD-ES by 4.8 times, and DBD-ES by 1.8 times.





Summary

- PandaX-III 100-kg scale high pressure gas TPC module
  - Sub-systems move forward
  - Assembly starts soon
- Half-life sensitivity with 3 years of data: 9× 10^{25} yr (90% CL)
  - Will fully exploit tracking feature to further improve the sensitivity