Progress of PandaX-III detector

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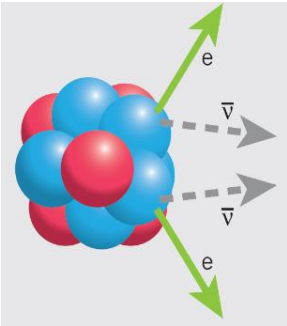
On behalf of PandaX-III
2021/10/22

第十届全国先进气体探测器研讨会

Outline

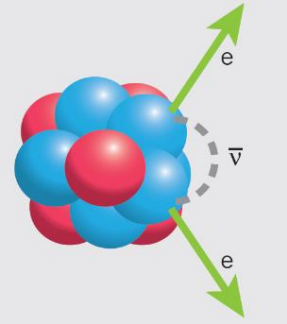
- Background
- Detection principle and prototype detector
- Full detector progress (by subsystems)
  - Vessel and fixture
  - Field cage
  - Gas system
  - DAQ
- Software progress
- Sensitivity projection
- Conclusion and outlook

Physical background: NLDBD



2νββ: $(A, Z) \rightarrow (A, Z+2) + 2e^- + 2\bar{\nu}_e$

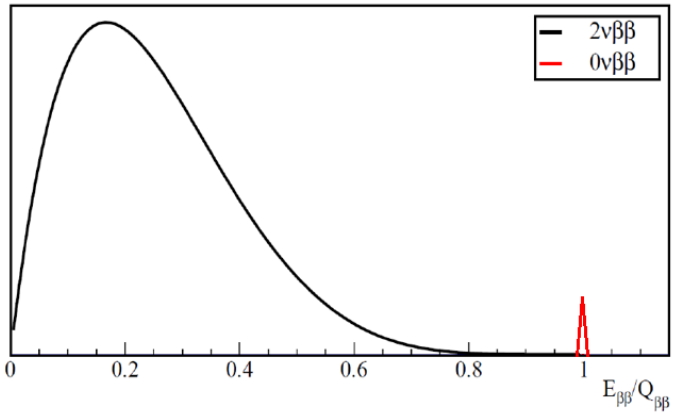
- Already observed, within standard model
- ~$10^{19\text{-}21}$ years of half life



0νββ: $(A, Z) \rightarrow (A, Z+2) + 2e^-$

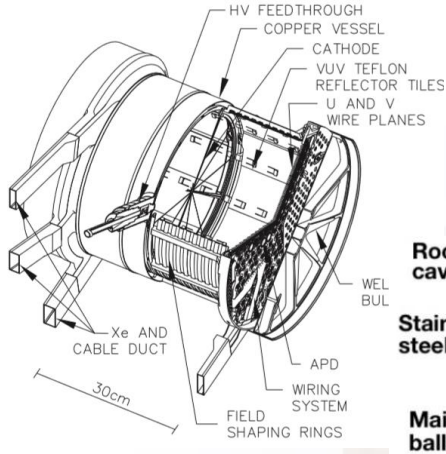
- > 10^{25} years of half life, very hard to observe!
- New physics!

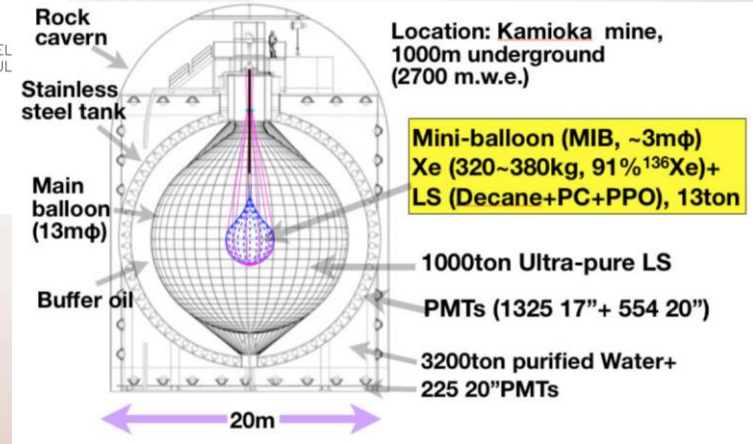
Majorana Neutrino?
Neutrino mass?
Lepton number violation?



Xenon NLDBD experiments over world:

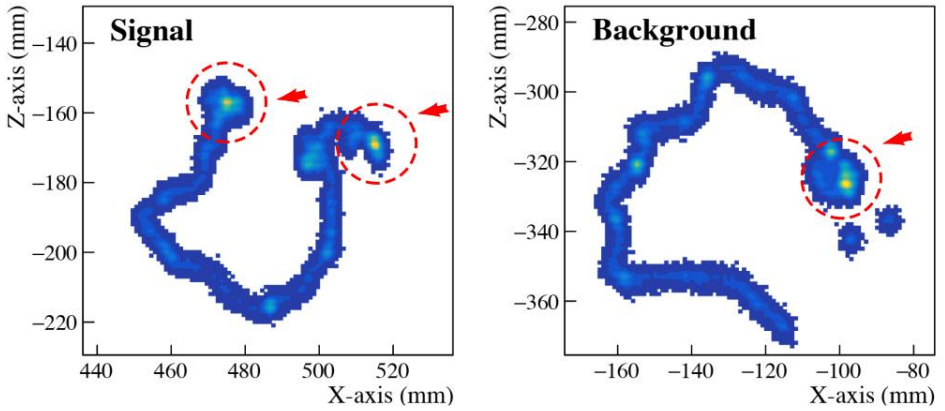
- EXO-200: liquid xenon TPC
- KamLAND-Zen: liquid scintillator with dissolved xenon, best result in the field





NLDBD track in gas detector

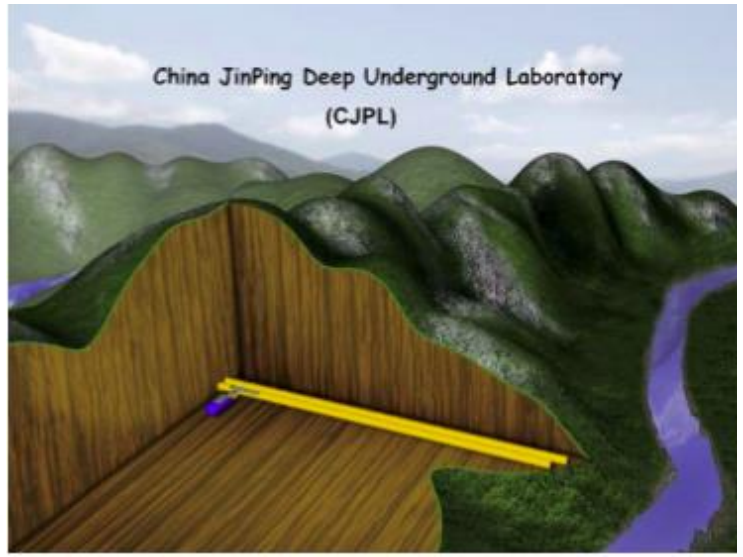
- Bragg peak of each electron track:
  - NLDBD: two electrons, two Bragg peaks
  - Gamma background: one electron, one Bragg peak
- Twist, track length, etc:
  - Different for NLDBD/bkg event
- Different algorithms too quantify these feature:
  - Topological calculation
  - Kalman filter
  - Machine learning, etc.

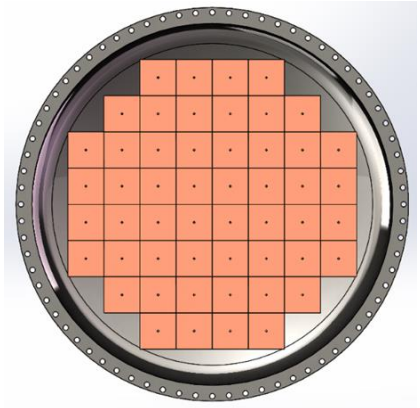


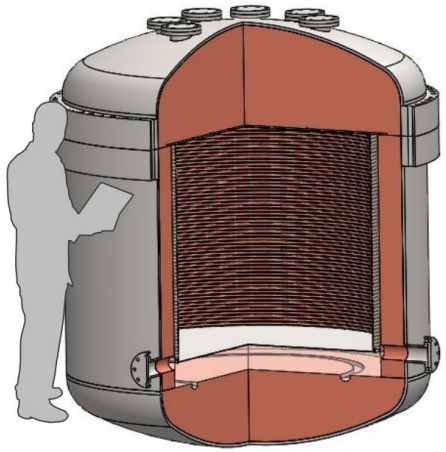
Tracks carry extra information beyond energy/position of the event, which helps to improve NLDBD sensitivity!

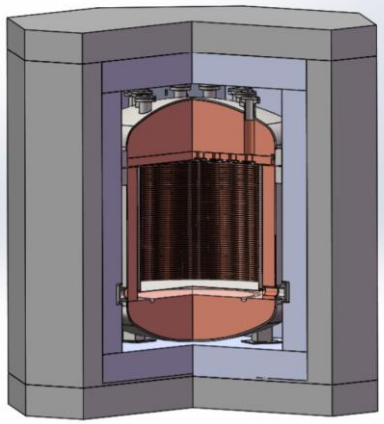
PandaX-III detector

- Located in CJPL, 2400m underground
- External dry shielding plus inner copper shielding
- High pressure xenon gas TPC
  - Contains 140kg of 10 bar enriched Xe-136 in 2.4m^3 TPC
  - Typical track length: 20cm in 10 bar xenon
  - Use TMA as quencher to suppress scintillation and diffusion
  - Charge readout with 52 MicroMegas
- Detect track and improve NLDBD sensitivity



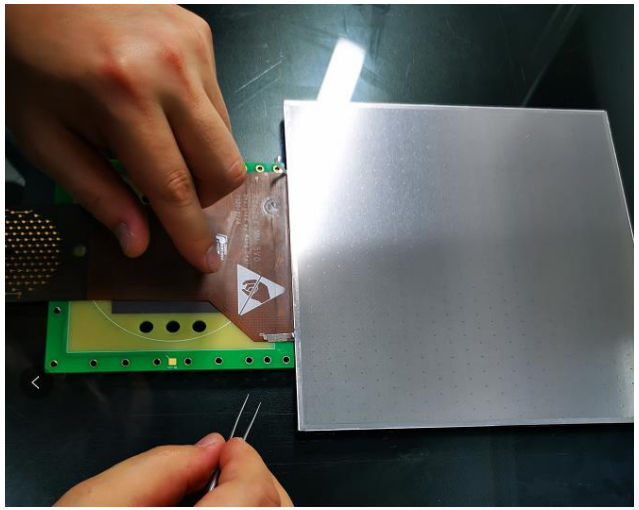




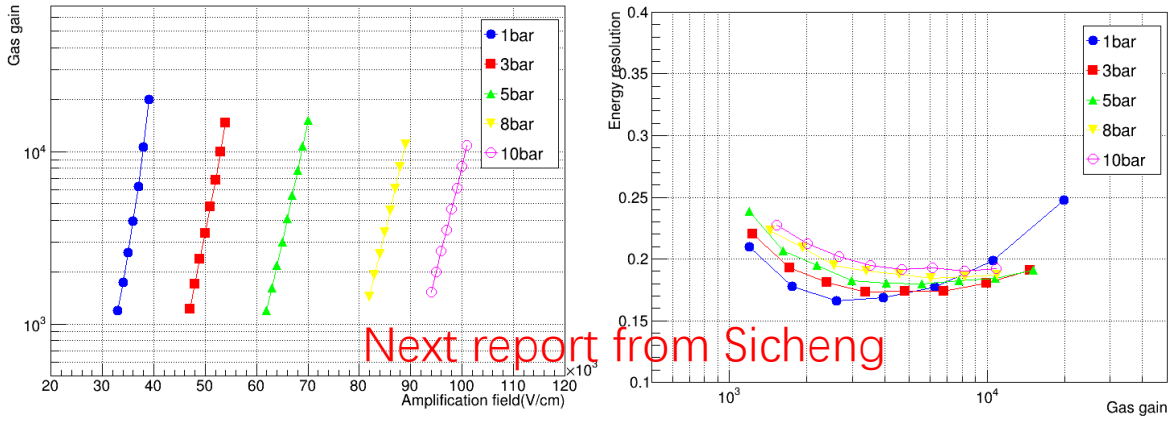


New Thermal Bounding Micromegas(TBMM)

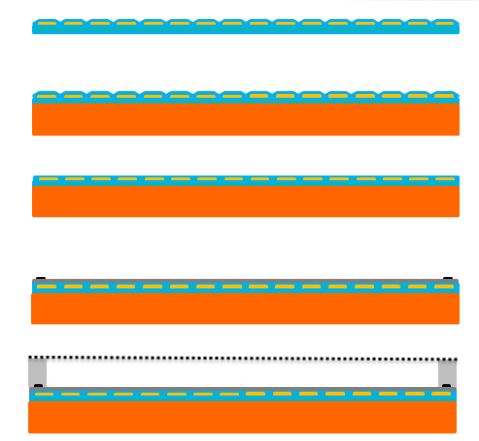
- Collaborate with USTC to develop TBMM, since early 2020
- Version 6 is being tested now in SJTU
- Performance(of production id V513):
  - Energy resolution: 19% at 10bar argon at 5.9keV
  - Gain: 8000 at 10bar argon with 100V/cm amp. Field
- Some flatness and uniformity problem



Gain and energy resolution of V513 at different pressure



Next report from Sicheng



柔性PCB

压接支撑板

打磨

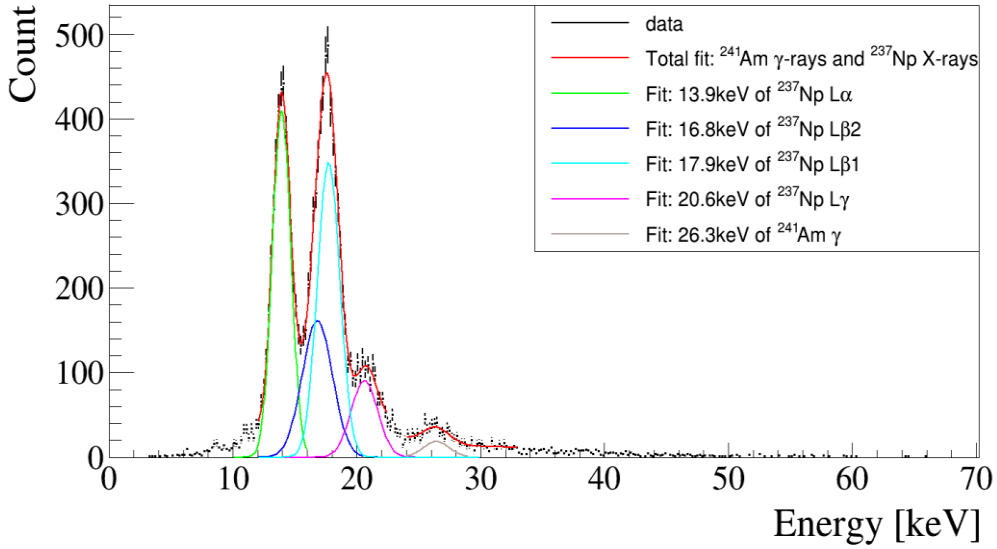
镀锗、贴垫片

热压接

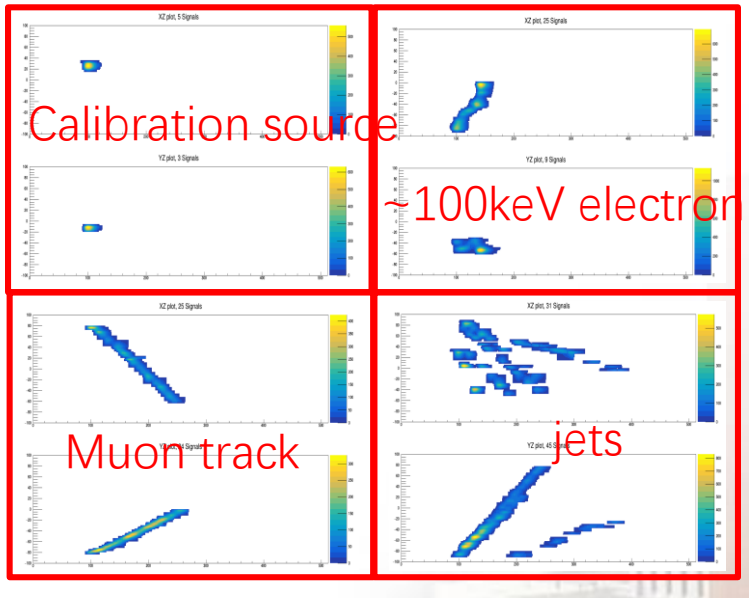
Prototype detector

- Performed several runs to verify technology
- Energy resolution: ~14.1% FWHM at 59.5keV at 10bar Xenon+TMA
- Track is detectable and distinguishable

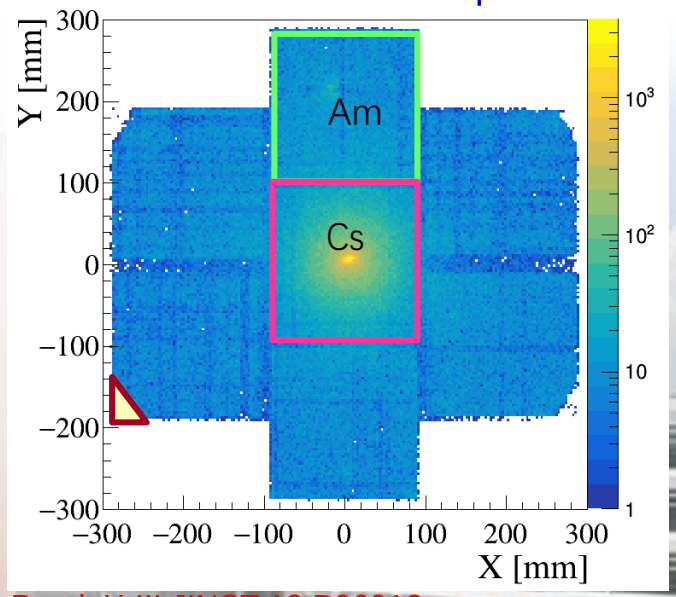
Energy spectrum of ^{241}Am in 5bar



Different tracks in 5bar Ar



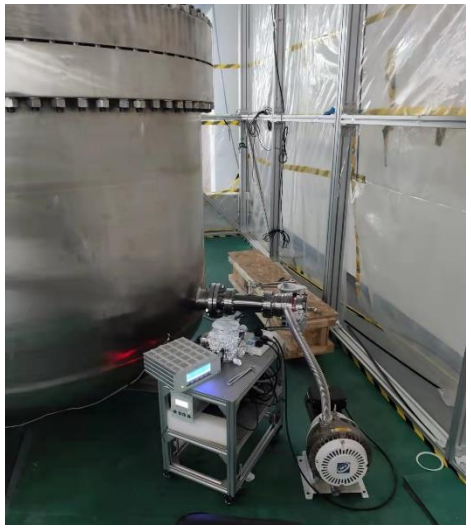
Track hitmap

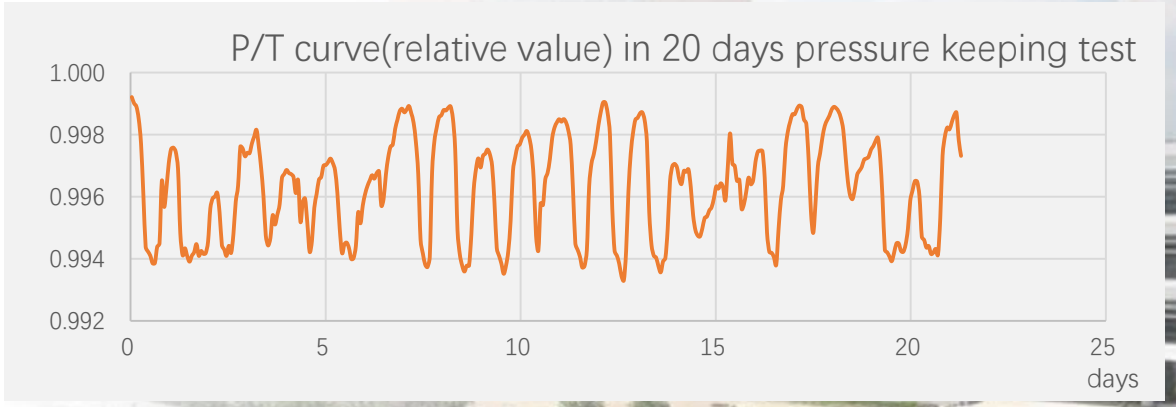


PandaX-III JINST 13 P06012; arXiv: 1804.02863

Full detector: main vessel

- Low background stainless steel vessel
- Design: 4m^3 inner volume, 2.3m main flange
- Low background SS from Taigan
- Manufactured in Shanghai
- High Pressure test & Vacuum test passed in SJTU (2020/9/9 to 2021/4/18)
  - Vacuum: ~10mPa at far end of the pump
  - Pressure keeping: leak rate < 0.01L.bar/h at 10 bar

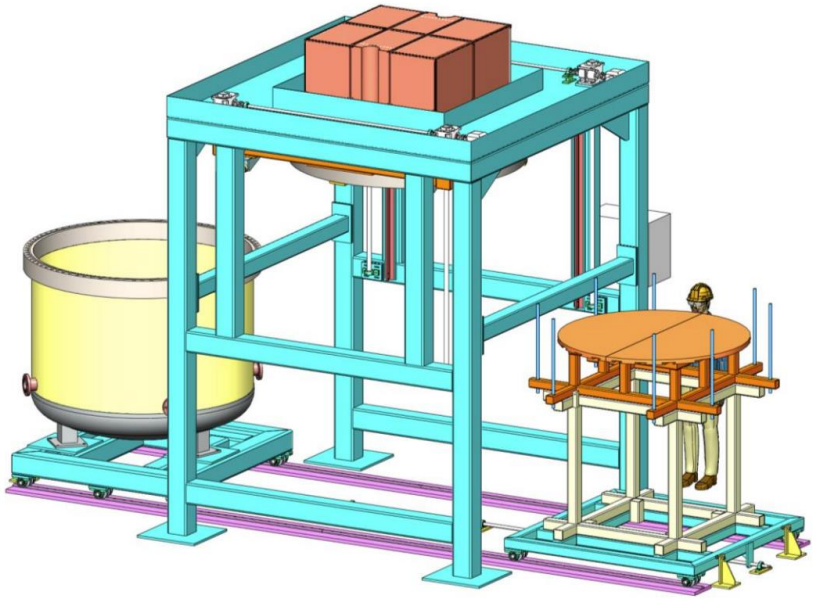


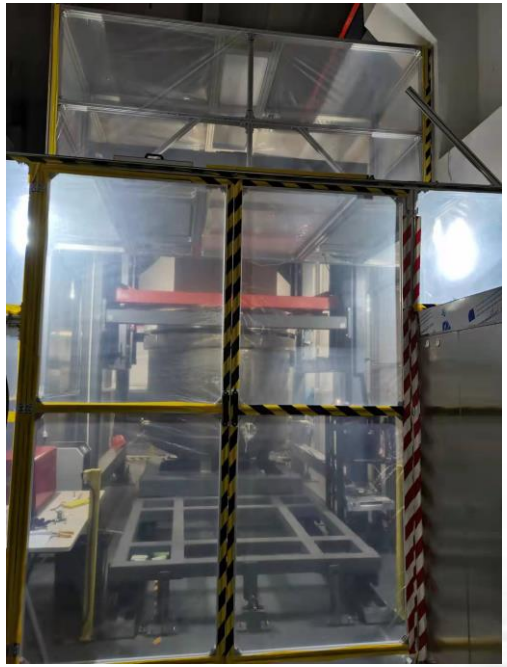


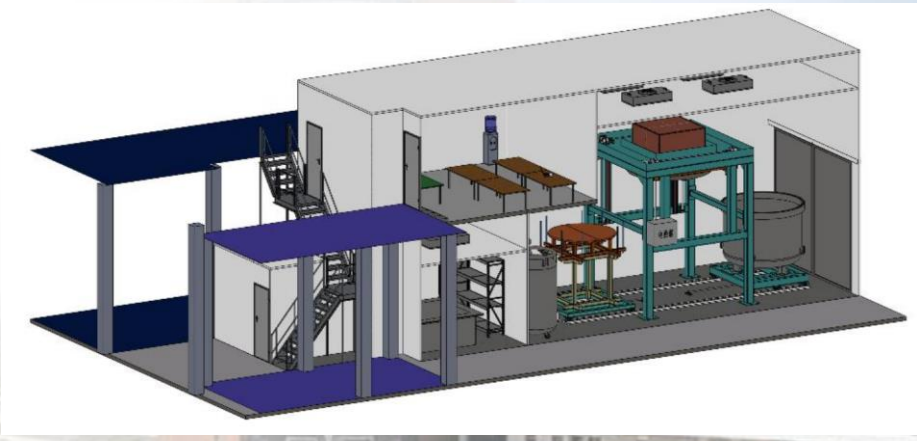
Fixture and lab infrastructure

- Fixture Design: railed platform + lifters
- Installed in SJTU after vessel test (2021/4/20 – 2021/6/2)

- Lower level clean tent installed in SJTU for test run(2021/8/19 – 2021/8/27)
- High level clean room built in CJPL-II for physical run

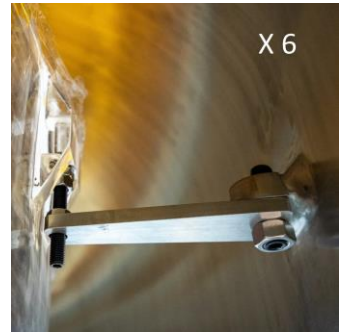


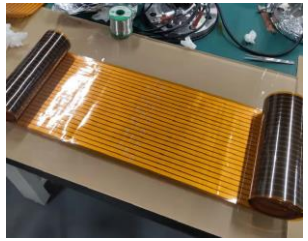


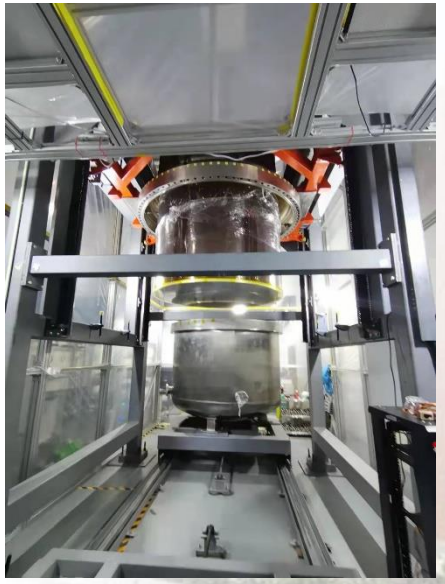


Field cage

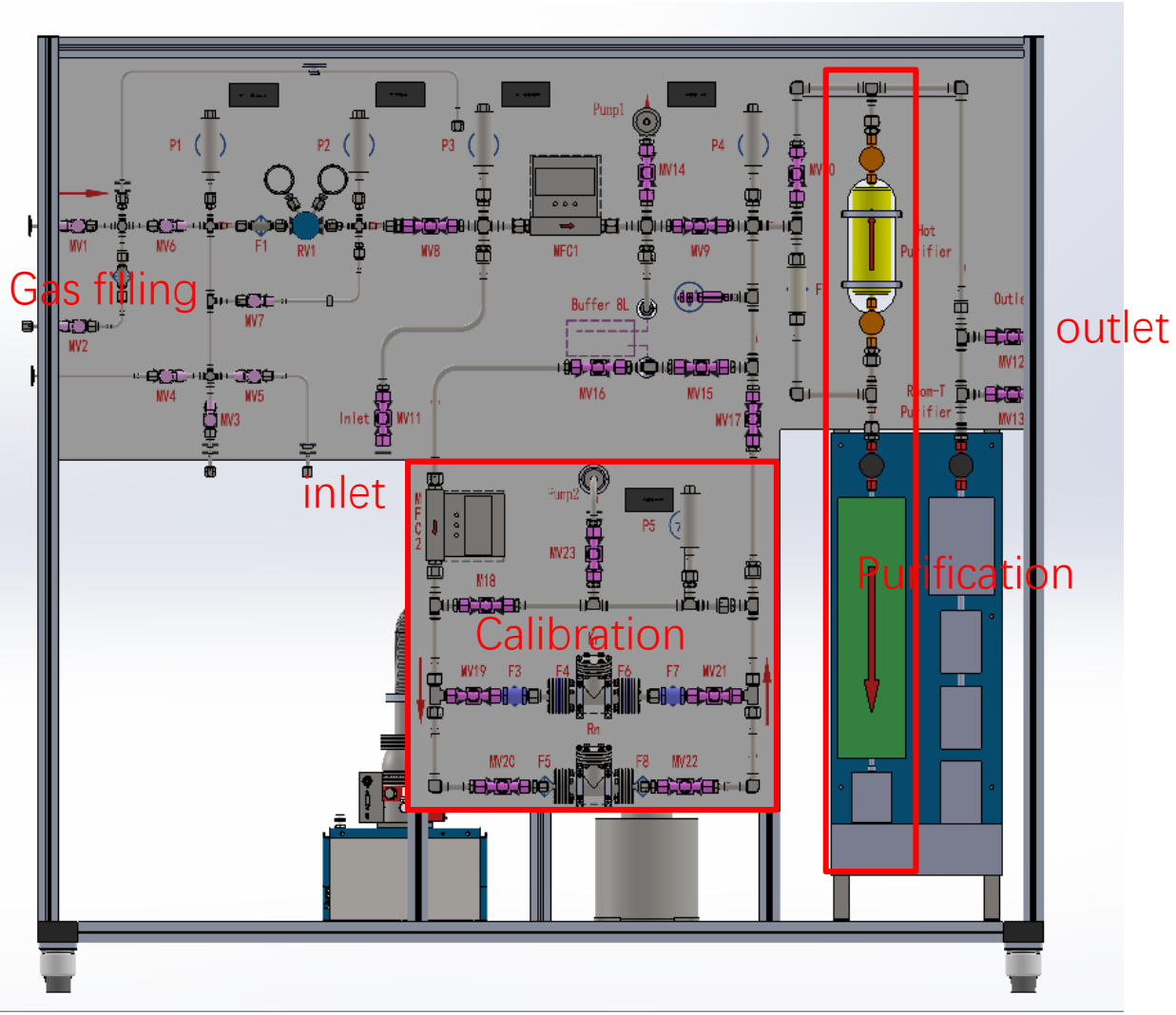
- Assembled field cage (2021/8/13)
  - Acrylic: 2.4 m^3 volume
  - Paste FPC as shaping rims
- Passed high voltage test (2021/9/22)
  - Reached designed voltage of 120kV(1kV/cm field), stable for 3 hours.
- Installed on the vessel (2021/10/18)







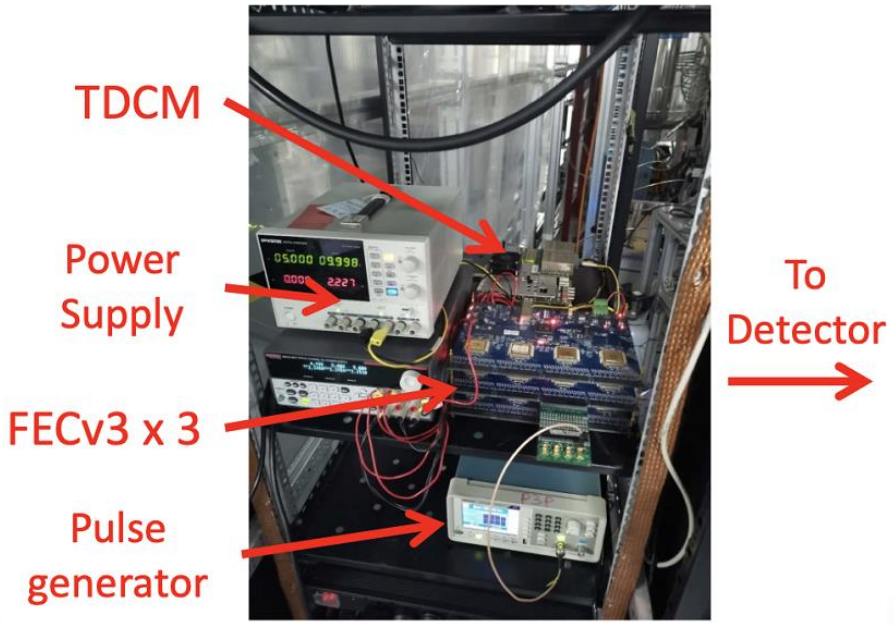
Gas system and inner calibration source

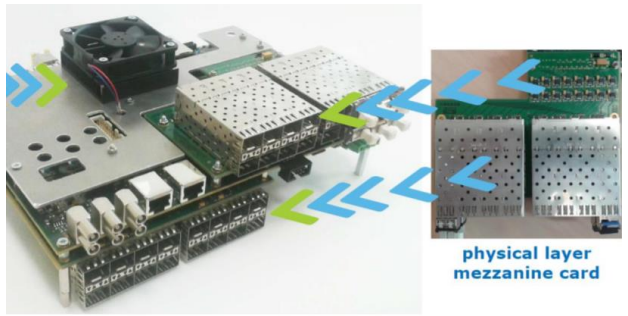


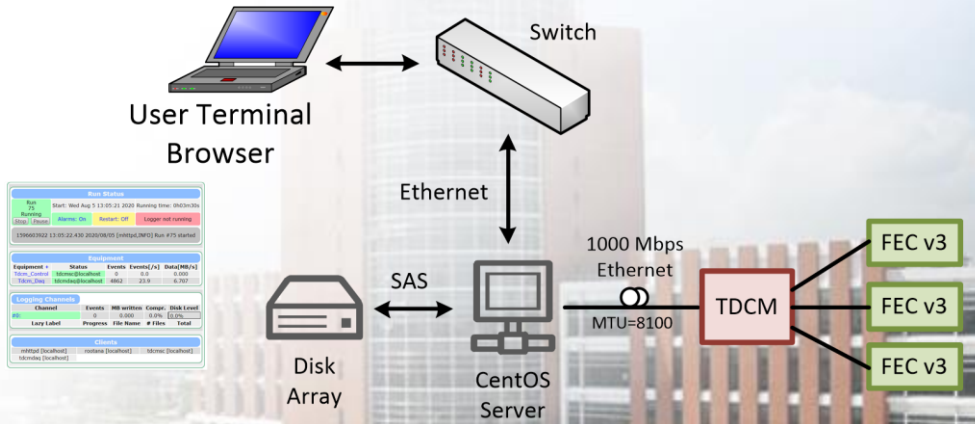
- Designed functionality: gas mixing, circulation, purification and **calibration injection**
- Two source chambers:
  - Kr-83 source(low energy)
  - Rn-220 source(high energy)
- Arrived SJTU in Aug. 2021
- Tested vacuum, circulation and purification, works fine (2021/10/18)
- Calibration source chamber integrated.

Electronics

- Connection: Detector → FEC → TDCM → DAQ software.
- FEC (Collaborate with USTC)
  - 4 AGET chips on board, 64 channels pre chip, 512 sampling points per channel
  - Designed for low radioactivity, use Kapton PCB and low background components
- Full data chain tested on prototype detector in Nov. 2020
  - Cooperation with maximum 3 FEC boards
  - Data taking works fine

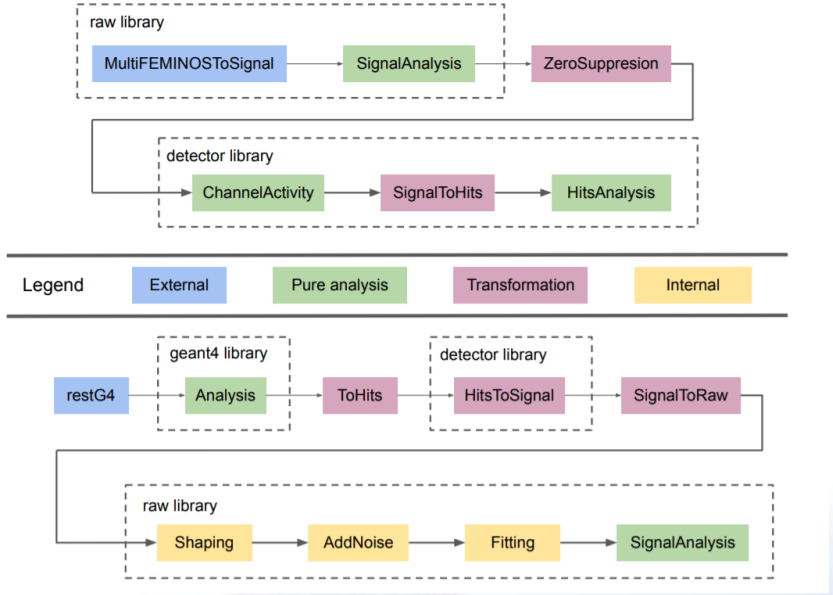






Software for data analysis

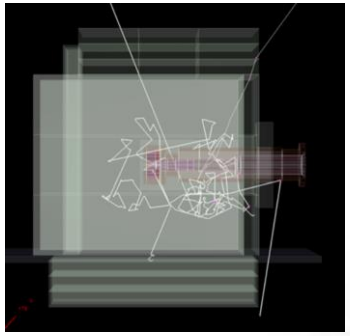
- REST(Rare Event Search Toolkit) software (for physics)
  - Collaborate with University Zaragoza
  - ROOT based universal toolkit
  - Unified simulation and analysis **data flow**
  - Applied in multiple experiments, mostly gas detectors
- Open sourced since Jan. 2021, find it in https://github.com/rest-for-physics/framework

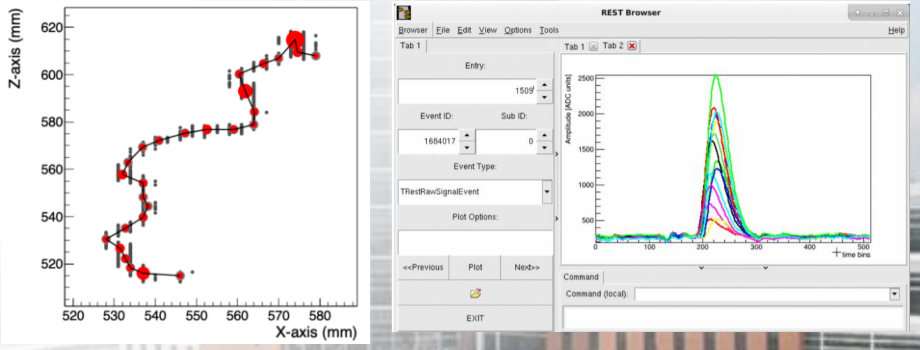


Functionalities:

- Simulation with Geant4, Garfield++
- File reading of various DAQ system
- Event viewing
- Self contained algorithms: raw data analysis, track reconstruction, etc.

...





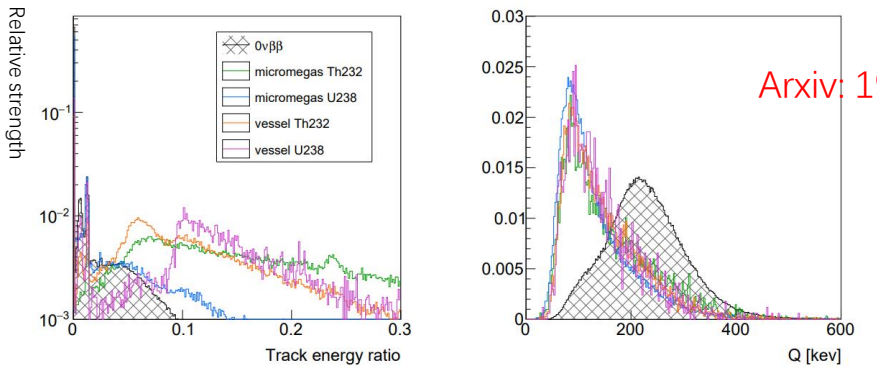
Arxiv: 2109.05863

Sensitivity projections

- NLDBD (from CDR): **1×10^{26} yr** with 3 years exposure
- NLDBD associating Kalman filter: **2.7×10^{26} yr** with 5-year live time

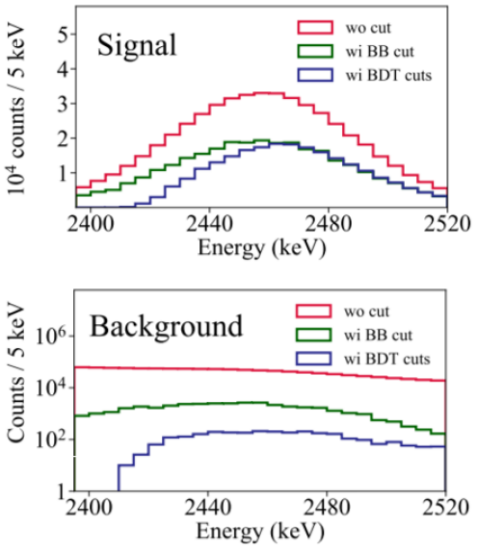
  J. High Energ. Phys. 2021, 106 (2021)
- NLDBD to Ba-136 excited states: **1.7×10^{25} yr** with 3 years exposure

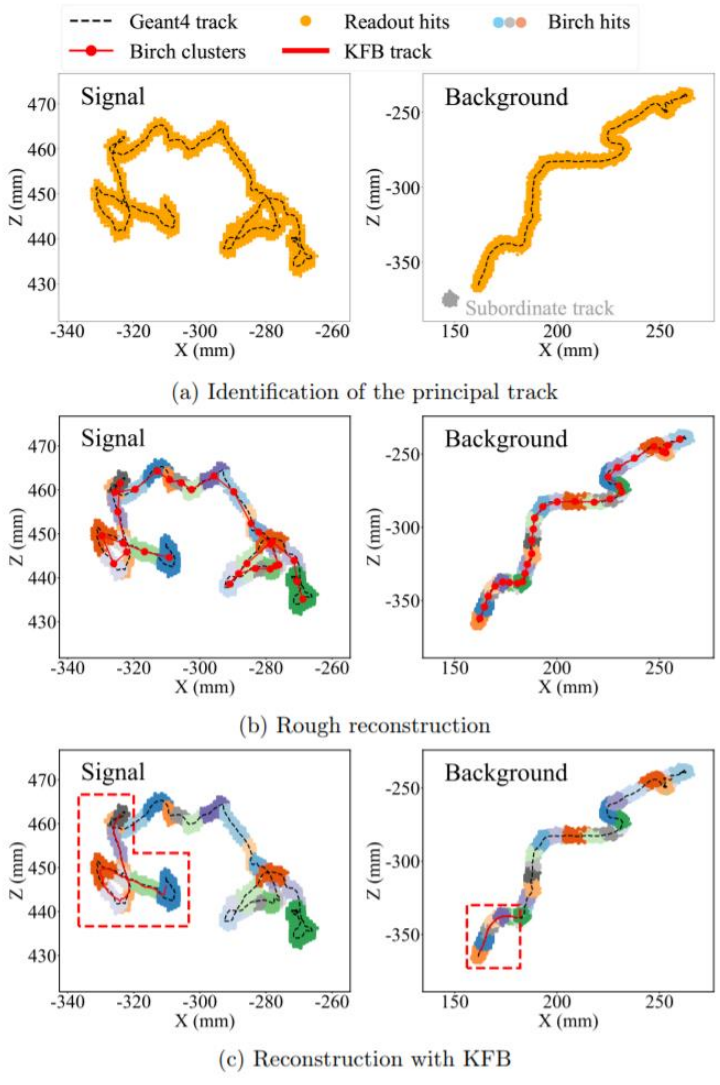
  Sci.China Phys.Mech.Astron. 64 (2021) 6, 261011



Arxiv: 1903.03979

Topological parameters. Signal and background has different distribution





Left: Track processing with Kalman filter.
Up: Anticipated spectrums for signal and background applying: no cuts, topological cuts and all cuts. The background will have additional ~10 times suppression when we use Kalman

Conclusion and outlook

- Neutrinoless double beta decay is a hard experiment
- PandaX-III is trying to detect tracks to improve NLDBD sensitivity
- Each subsystems are progressing normally
- Various algorithms are being developed to improve NLDBD sensitivity

- The most challenging part is MicroMegas.
- If the latest version of MicroMegas are tested OK, we can start mass production and hopefully install the whole detector earlier next year.

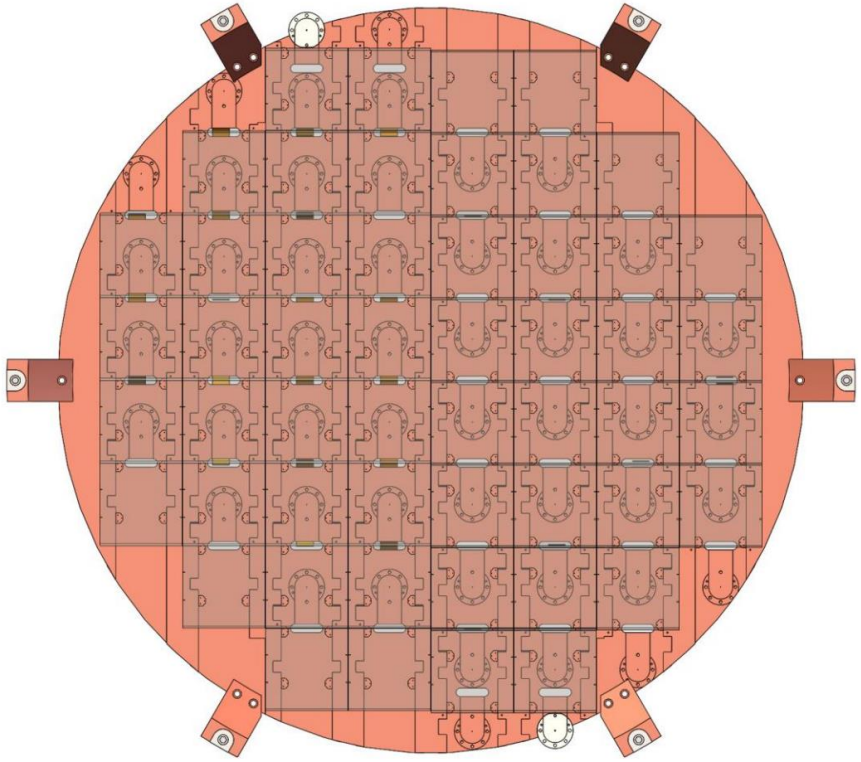
上海交通大學

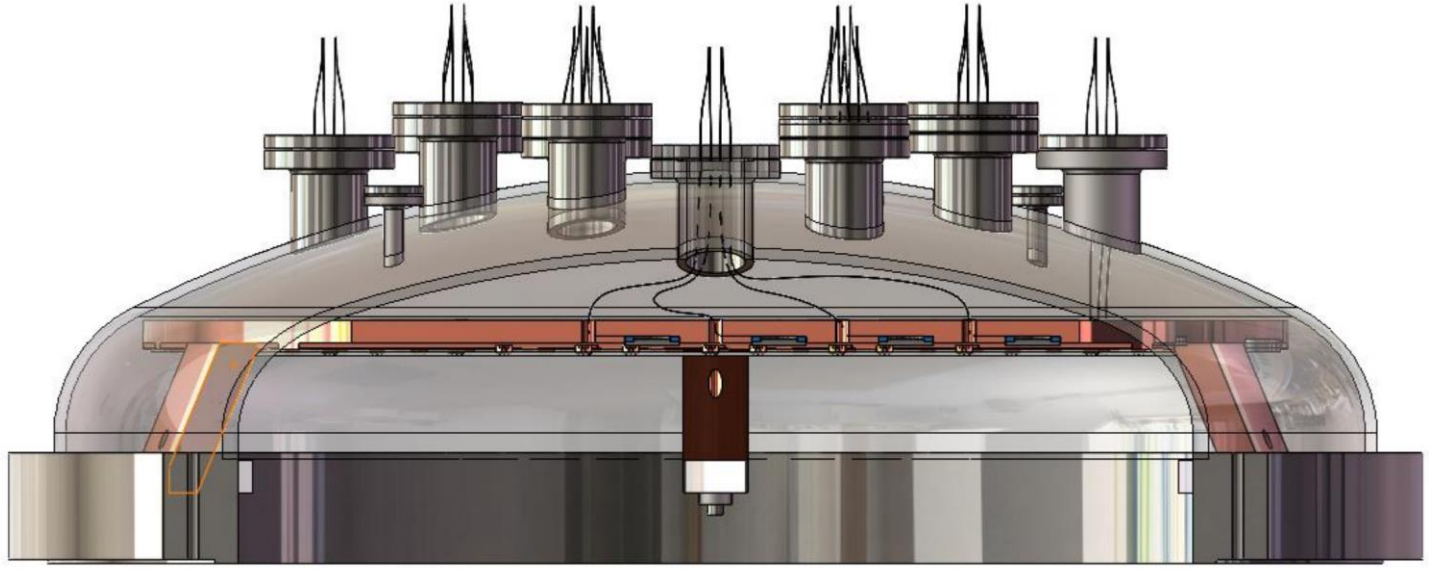
Thanks!

Backup

Readout plane

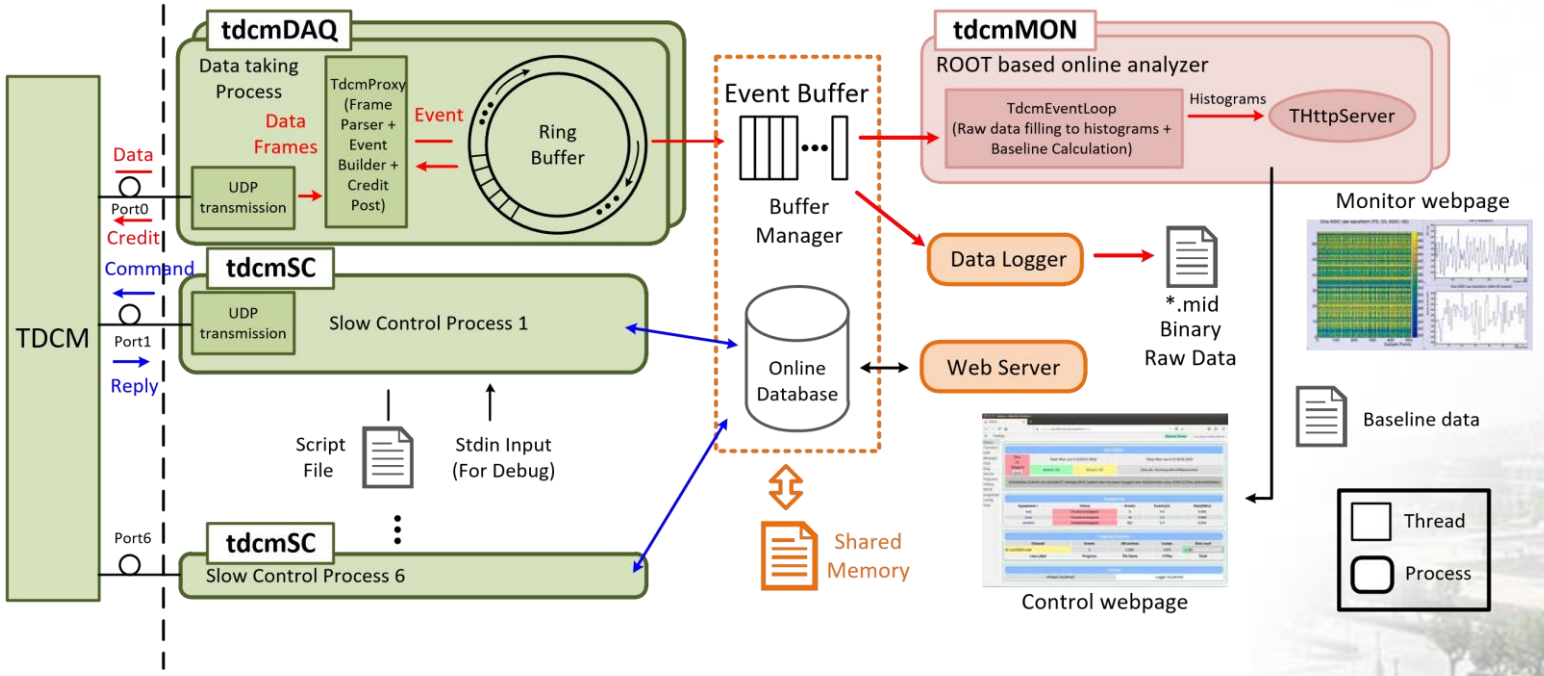
- Hanging 52 MicroMegas on top of the detector
- Still under design

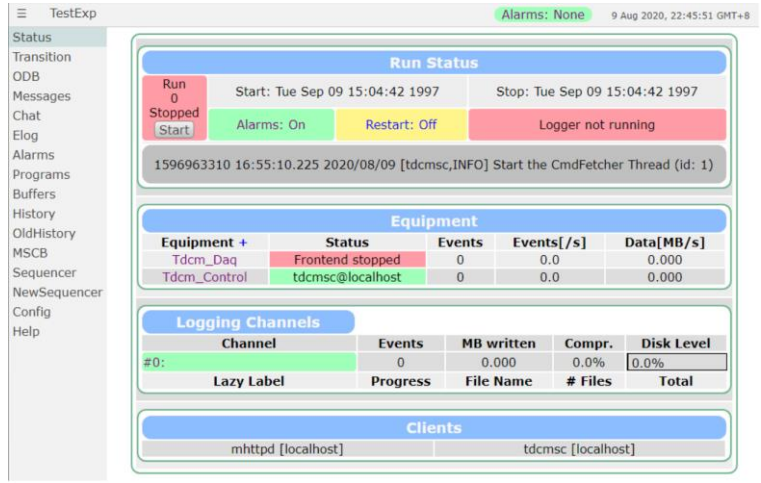


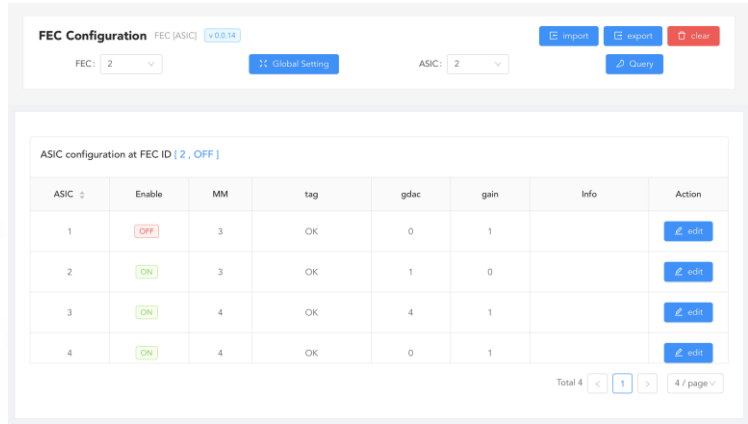


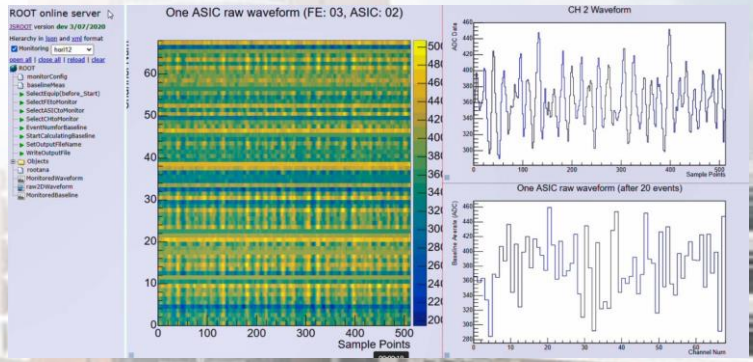
DAQ system

- Based on Midas framework, database
- Use web pages to operate daq, Implemented functionalities:
  - Start/Stop data taking, data formatting
  - TDCM and FEC configuration
  - Online waveform monitoring









High voltage connection

- HV cable → Tube connector → Feedthrough flange → L adaptor → field cage