Search for neutrinoless double beta decay with high pressure Xenon gas TPC

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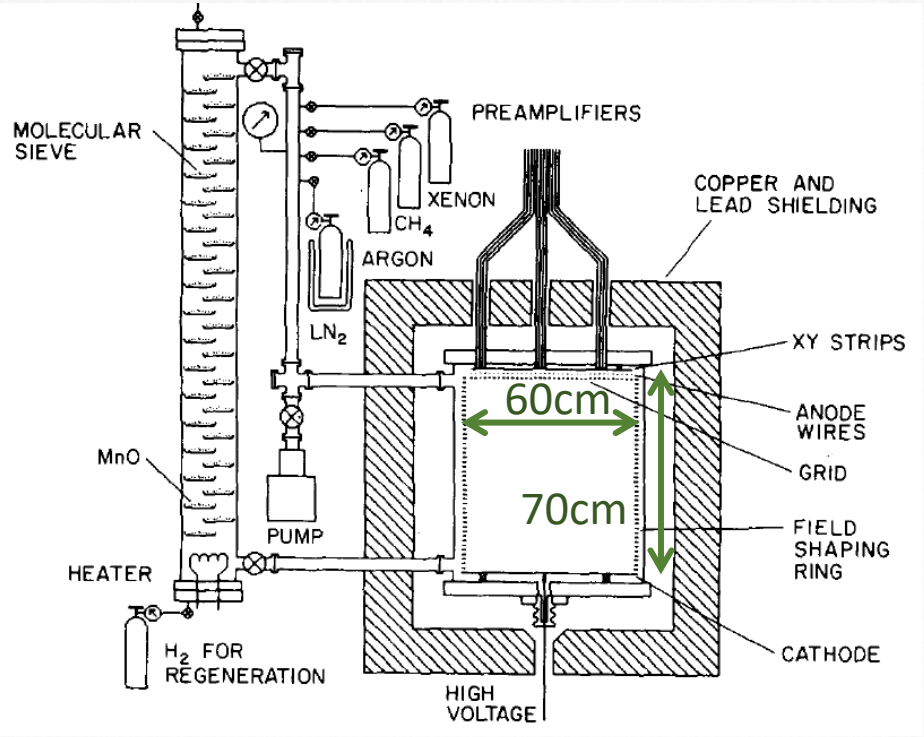
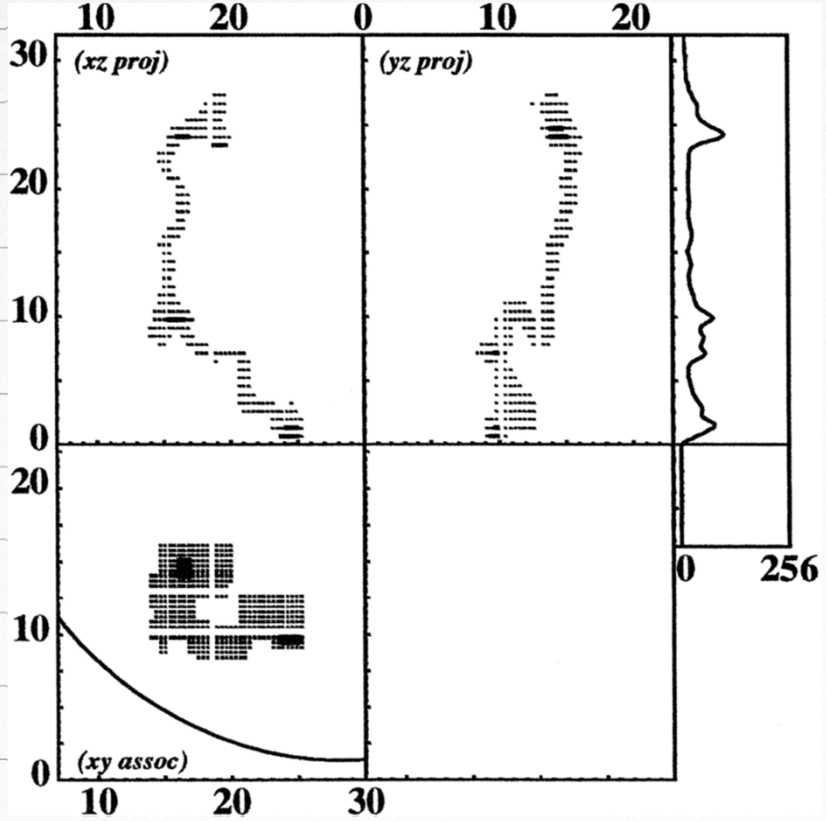
I appreciate materials from
- L. Arazi, “Status of the NEXT project” VCI2019
- S. Wang, “PandaX-III high pressure xenon TPC for neutrinoless double beta decay search”, VCI2019

Gotthard experiment



Nucl.Instrum.Meth. A259 (1987) 459-465



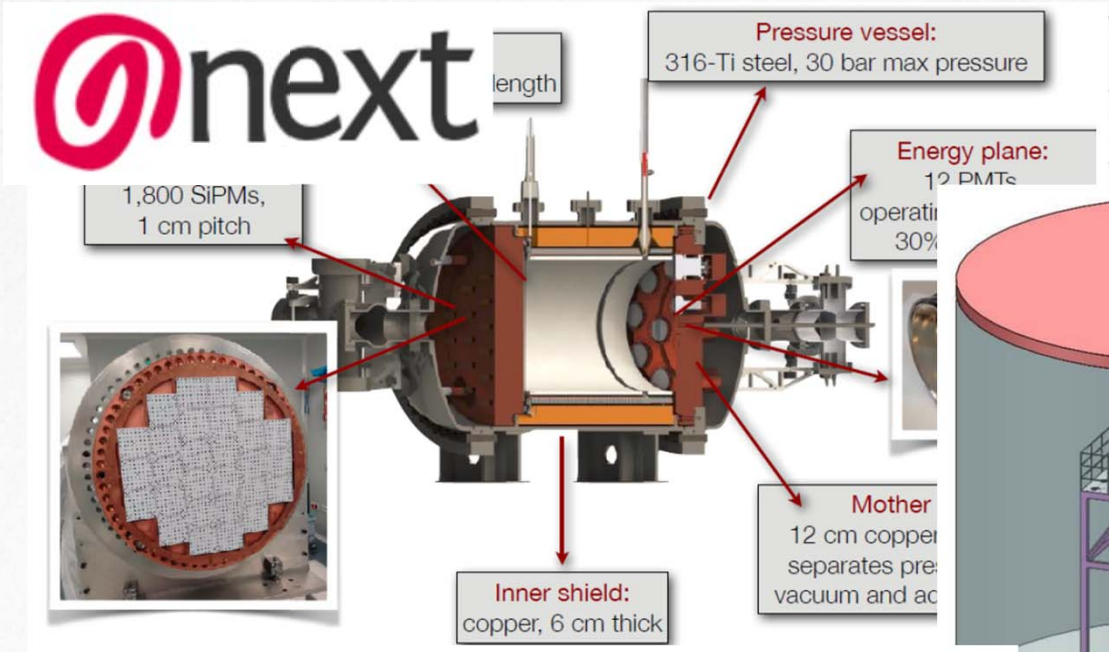
Physics Letters B 434 1998. 407–414

TPC with wire avalanche multiplication

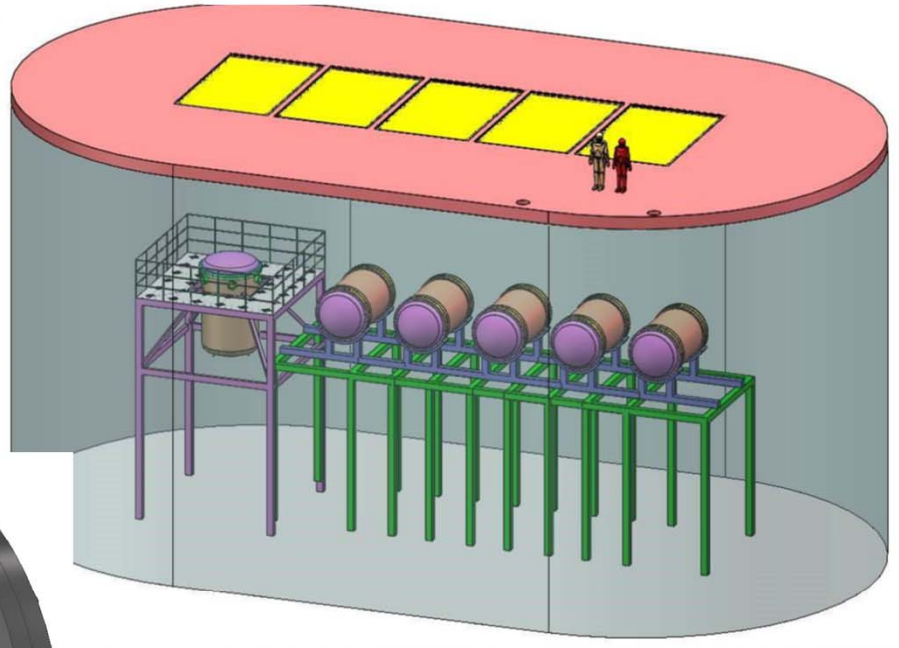
5 atm. $Xe+CH_4$ 3.3kg of ^{136}Xe

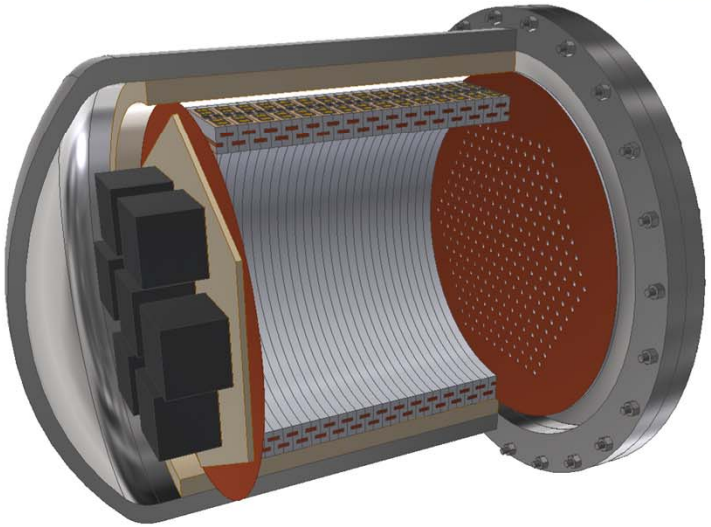
$\Delta E/E(FWHM)=6.6\%$

And now,



PANDA X
PARTICLE AND ASTROPHYSICAL XENON TPC





AXEL

Why high pressure Xenon gas TPC?

Cons

✓ The detector too big.

Not so much.

@10bar, 1 ton Xenon is a $2.7\mathrm{m} \times 2.7\mathrm{m} \times 2.7\mathrm{m}$ cube.

✓ Self-shielding is weak.

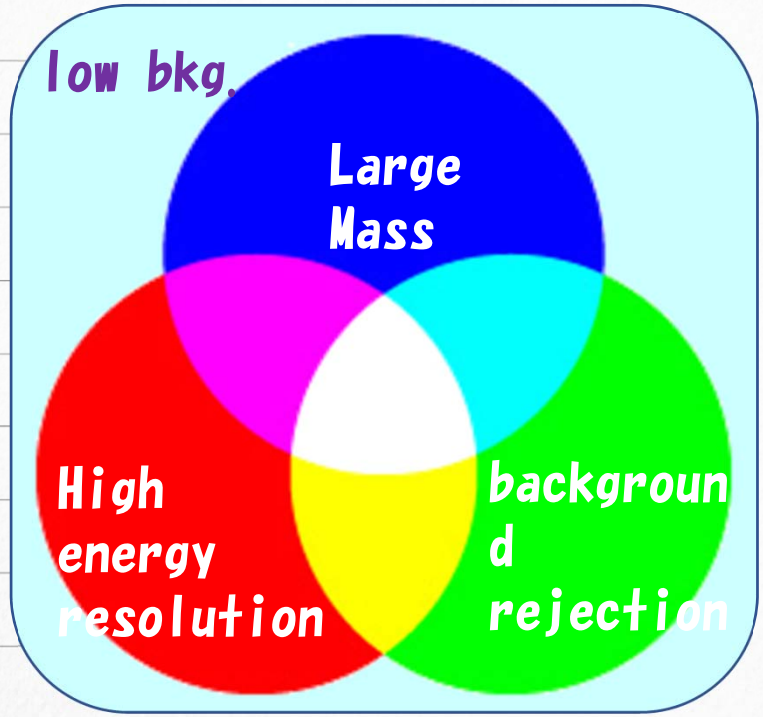
Yes. Radiation length is 155cm@10bar

Pros

✓High energy resolution

✓ event pattern

α's and most of γ's can be discriminated



Xenon gas
elementary process of signal generation

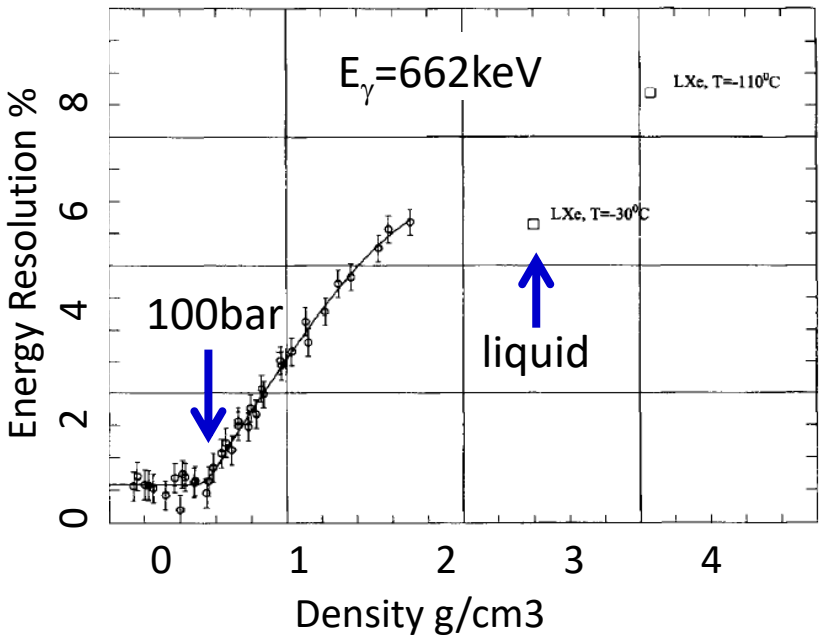
Scintillation and electroluminescence (EL) if ~pure

- timing → z-position reconstruction w/ Ionization signal
- wavelength ~170nm (VUV)
  require VUV sensors or wavelength shifter
  induce discharge

Ionization

- intrinsic energy resolution
  (FWHM) 0.25% @2.48MeV
  - worsen at >100 bar
- diffusion is large
  bad for track pattern
  ↓ by addition of other gases,
  but scint. & EL yield ↓

Energy resolution of the Xenon Ion chamber
A. Bolotnikov, B. Ramsey Nucl. Instr. And Meth. A396(1997) 360



Xenon gas process for Ionization signal readout

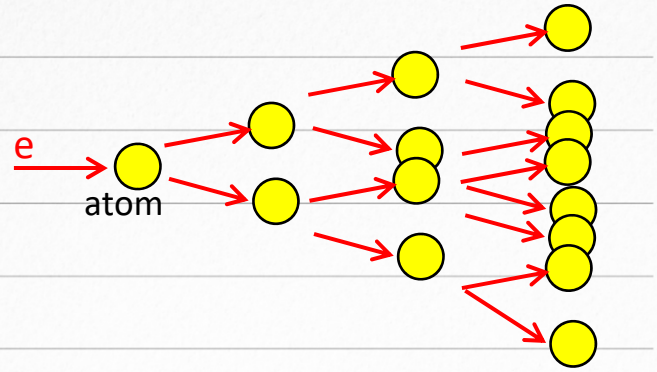
Induction

- energy resolution deteriorated by low S/N for large size

Avalanche multiplication

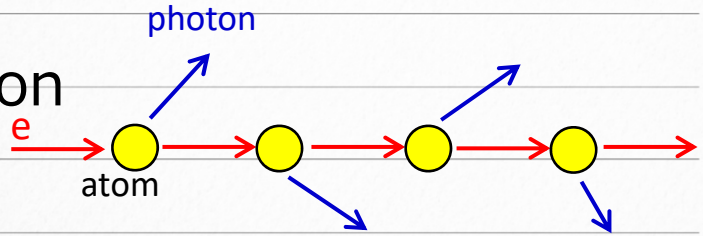
- modern technologies of micro-pattern
- energy resolution deteriorated
- Need UV quenching gas mixture

  scintillation suppressed → z reconstruction issue



Electroluminescence (EL) multiplication

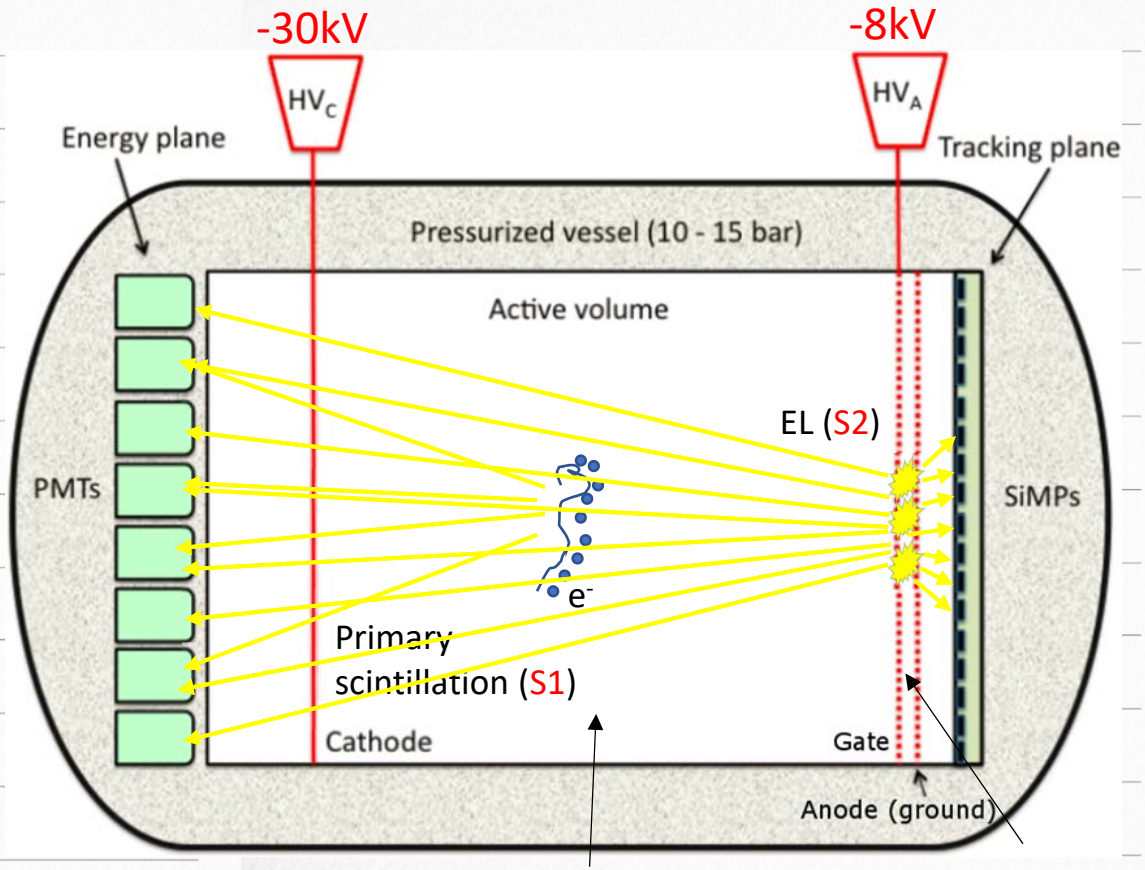
- good energy resolution
- spatial resolution limited by photon sensor size



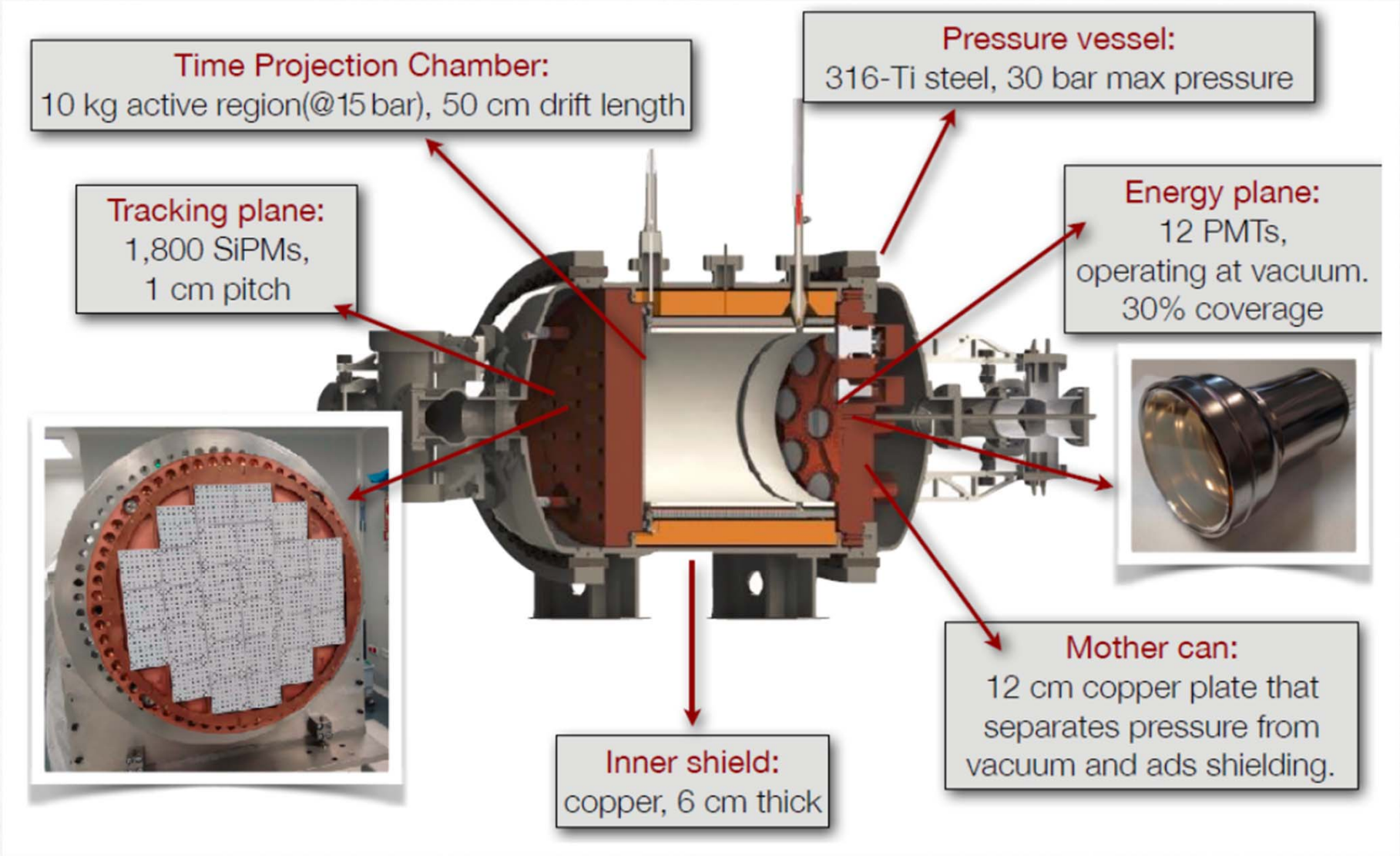
Neutrino Experiment with Xenon TPC

- Most progressed HP Xe-gas TPC experiment
- at Canfranc Underground Laboratory, Spain

- pure Xe
- T_0 by detecting Scinti. w/ PMT's
- Energy by measuring EL w/ PMT's
- event topology by SiPM's

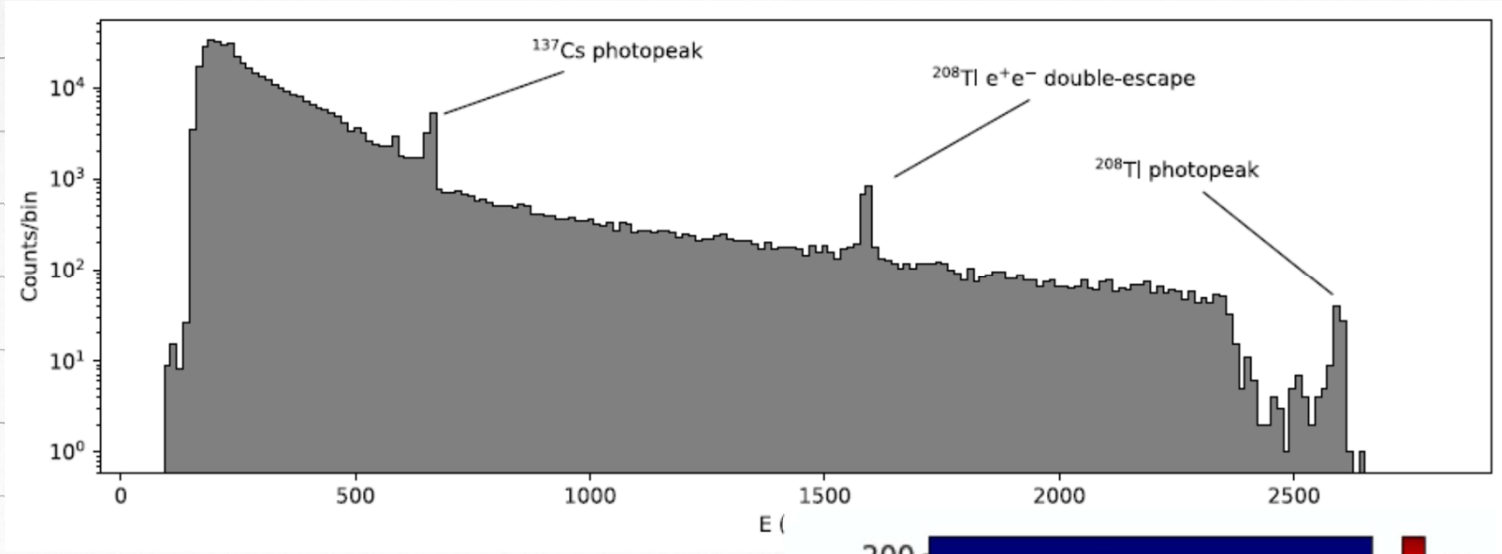


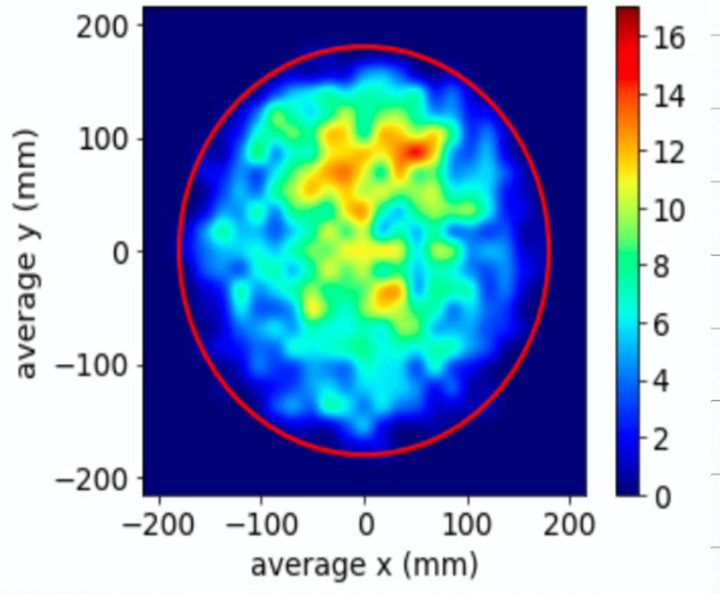
Running prototype: NEXT-White (NEW) ~10 kg Xe



F. Monrabal *et al.* (NEXT collaboration), arXiv:1804.02409

Energy resolution



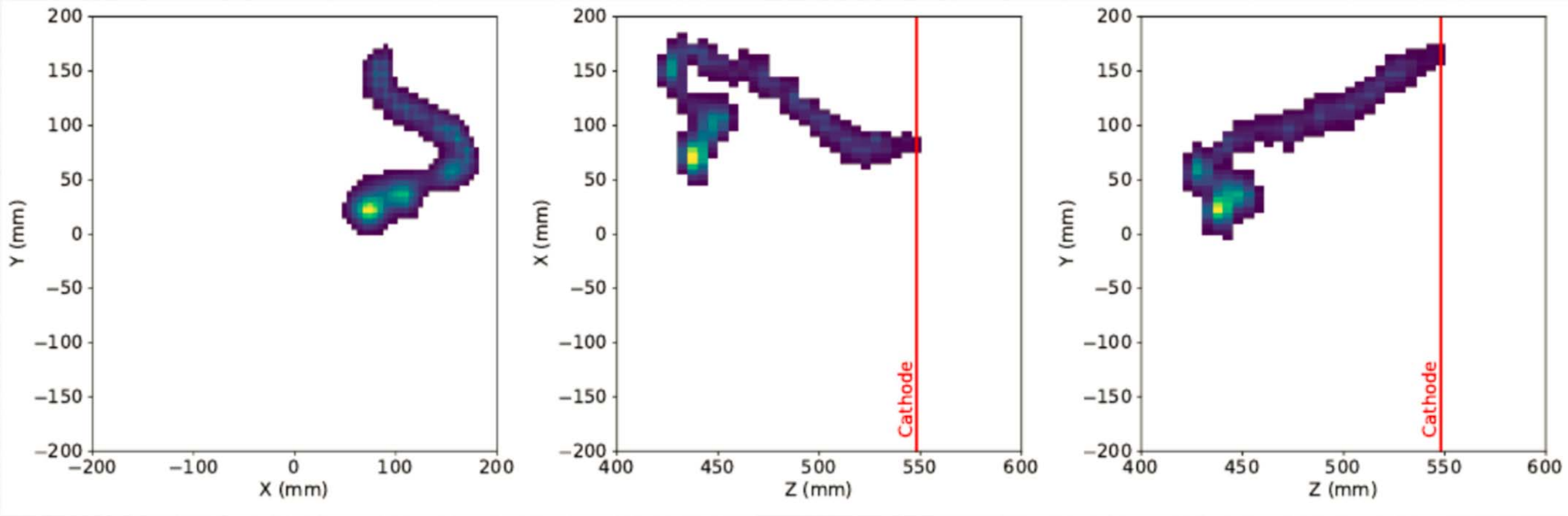


^{208}Tl 2615 keV full absorption peak

Interpolates to 0.85% FWHM at $Q_{\beta\beta}$

J. Renner *et al.* (NEXT collaboration), 2018 *JINST* 13 P10020, arXiv:1808.01804.

Track topology in NEW

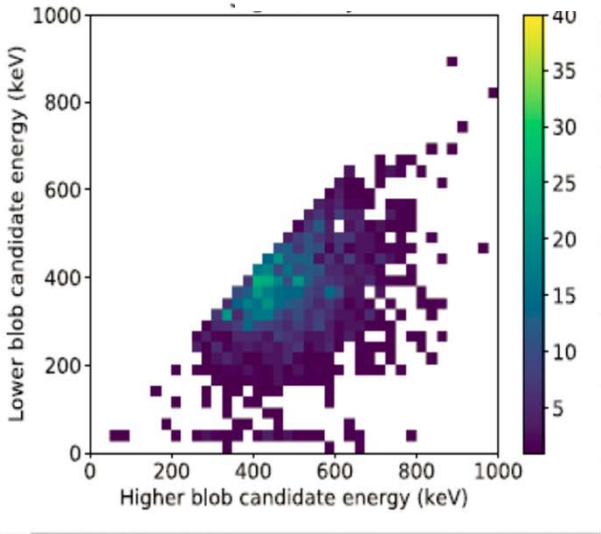


Beta emission from the cathode

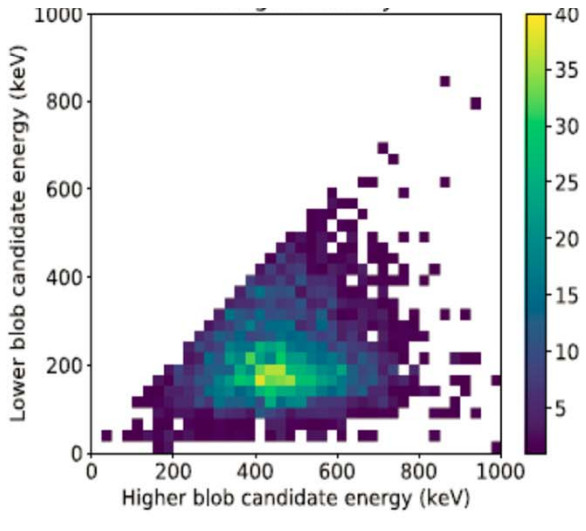
P. Novella, et al. (NEXT collaboration) *JHEP* 1810 (2018) 112, arXiv:1804.00471

Signal/background discrimination using blobs

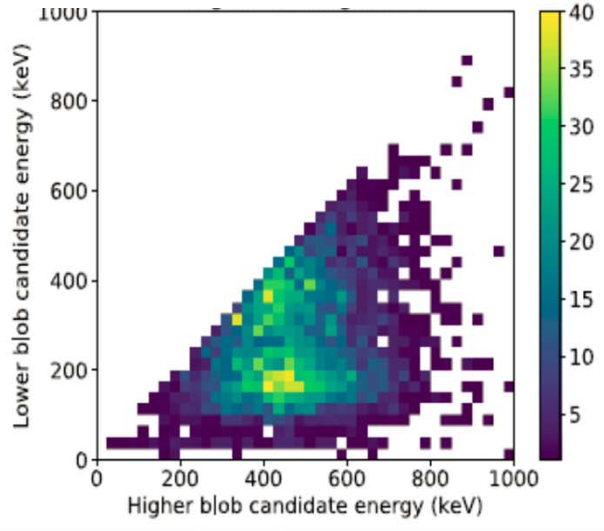
signal



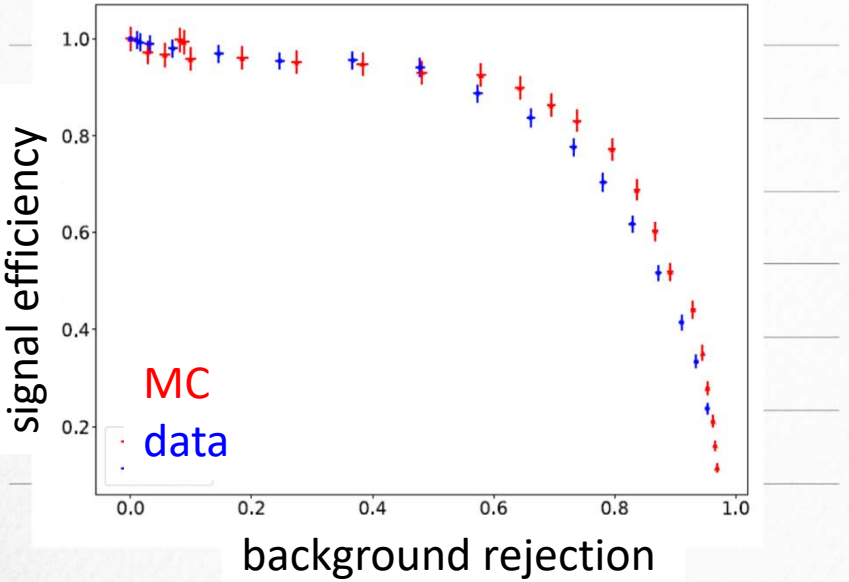
background



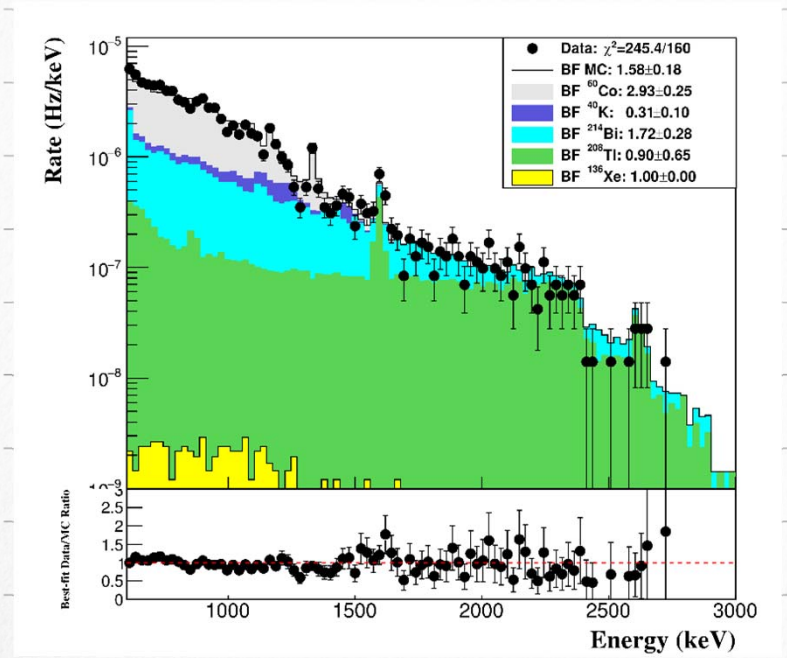
signal+background



^{208}Tl escape peak events: MC and data



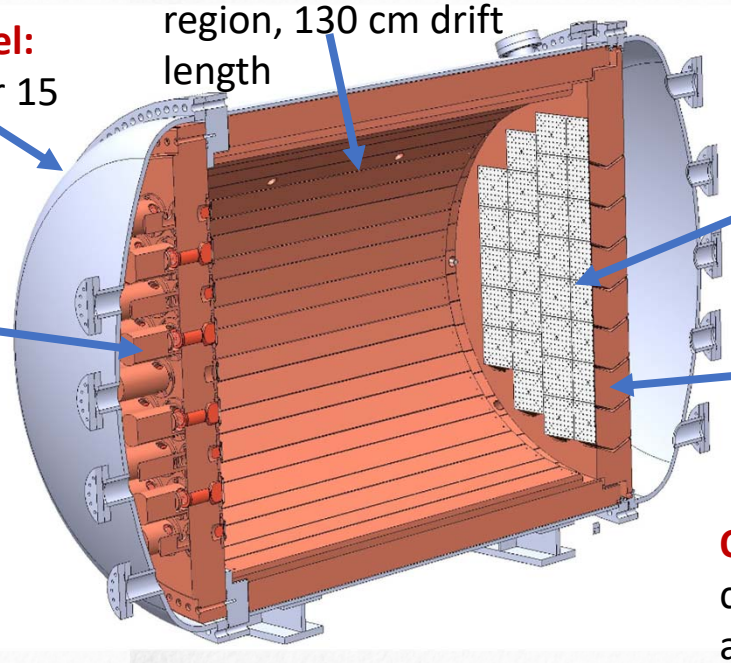
NEW status



$\beta\beta 2\nu$ data taking started Feb 2019 with 90%-enriched ^{136}Xe

Prospect

- NEXT-100 will be assembled in one year
  - Similar sensitivity as KamLAND-ZEN after ~4 years
- aiming ton-scale detector
- R&D's
  - Low-diffusion gas (Xe-He, or Xe doped with <1% CH4)
  - PMT → SiPM



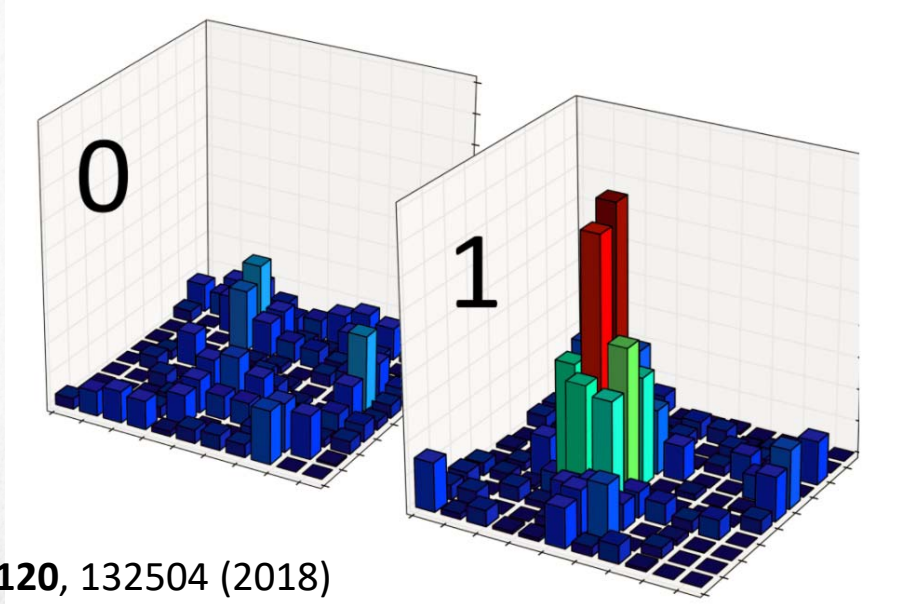
J. Martín-Albo, et al. (NEXT collaboration), JHEP (2016) 2016 159, arXiv:1511.09246

Barium Tagging: towards "background free" experiment

identifying the ^{136}Ba daughter

Single Molecule Fluorescence Imaging (SMFI)

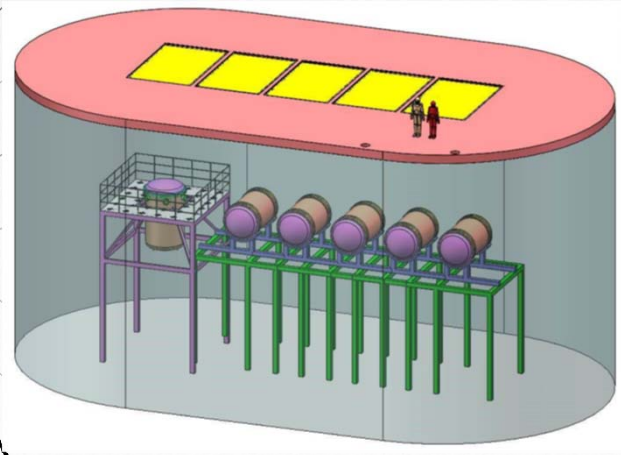
- coat cathode with chelating molecules selective for barium ions (but not Xe).
- The molecules are non fluorescent in isolation and become fluorescent upon chelation.
- Interrogate cathode surface with a laser: a single molecule holding Ba fluoresces at a longer wavelength.



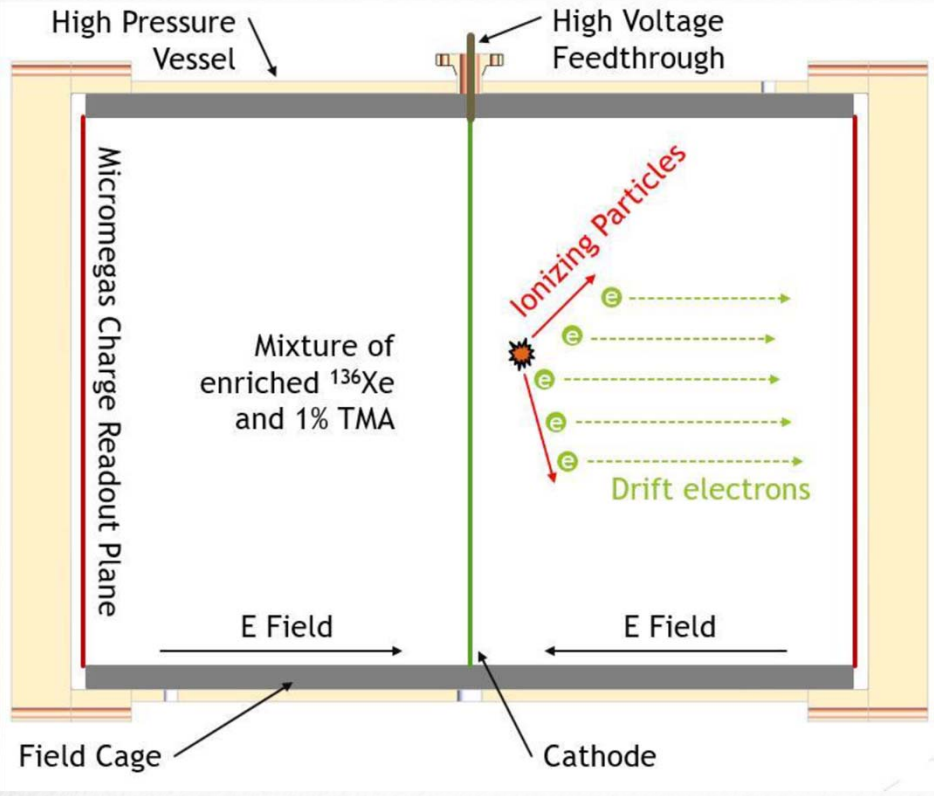
A. D. McDonald *et al.* (NEXT Collaboration), PRL **120**, 132504 (2018)

PANDA X
PARTICLE AND ASTROPHYSICAL XENON TPC

PandaX-III

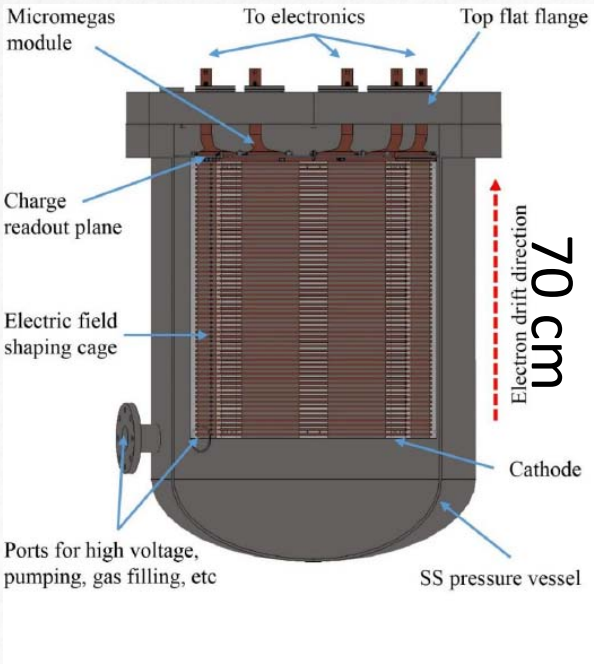


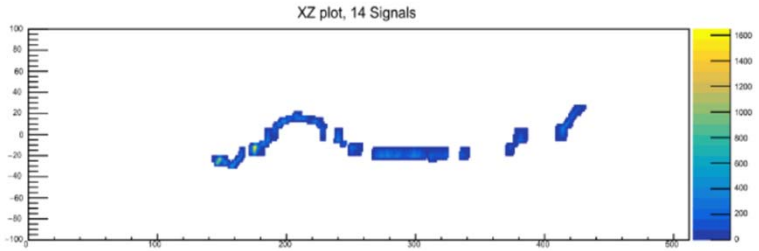
- at Jin Ping underground Lab, China
- one module = 200 kgx90%-^{136}Xe
  increase mass by adding modules
- 10 bar Xe-(1%)TMA (trimethylamine)
- double-end charge readout with cathode in the middle
- MicrobulkMicromegas and strips (x, y) for charge readout
- expected energy resolution : 3%(FWHM)

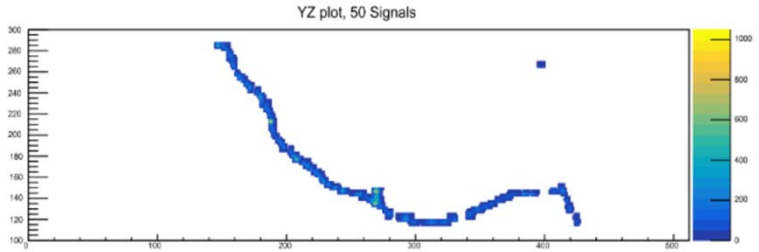


Prototype

PANDA X
PARTICLE AND ASTROPHYSICAL XENON TPC





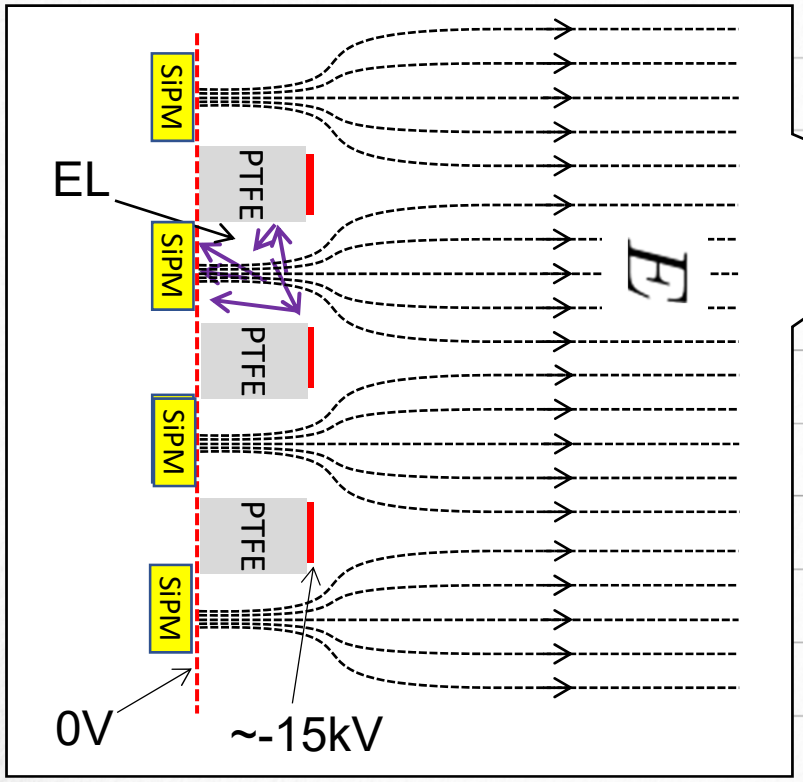


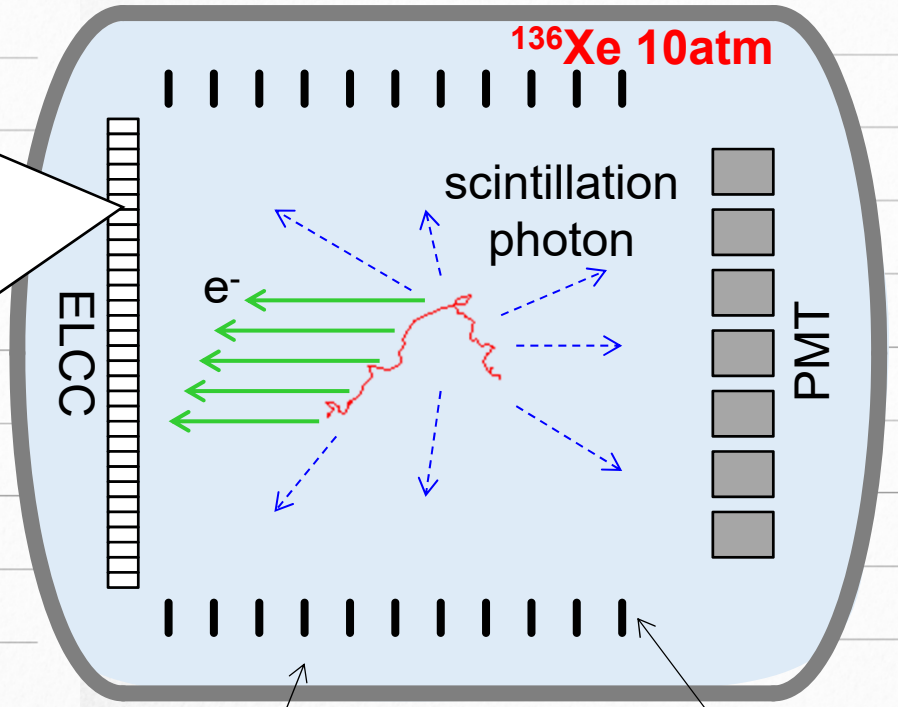
- Vessel: 600L(20kg Xeat 10bar in active region)

A Xenon ElectroLuminescence detector

R&D phase

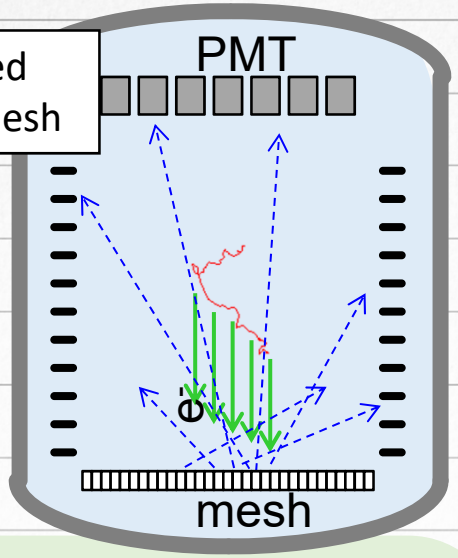
- pure Xe
- T_0 by detecting Scinti. w/ PMT's
- Energy and topology by measuring EL w/ 'ELCC'
- target energy resolution : 0.5%(FWHM)



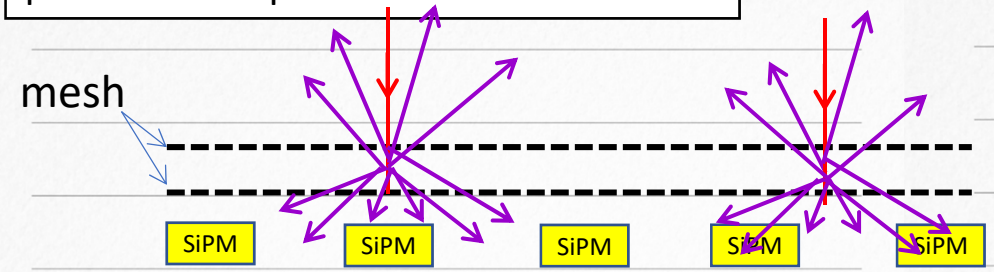


ELCC
– Electronluminescence Light Collection Cell -
Why?

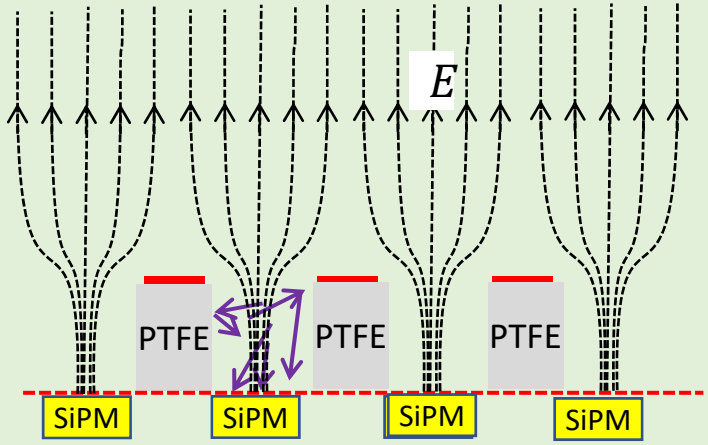
Photosensors placed far away from EL mesh

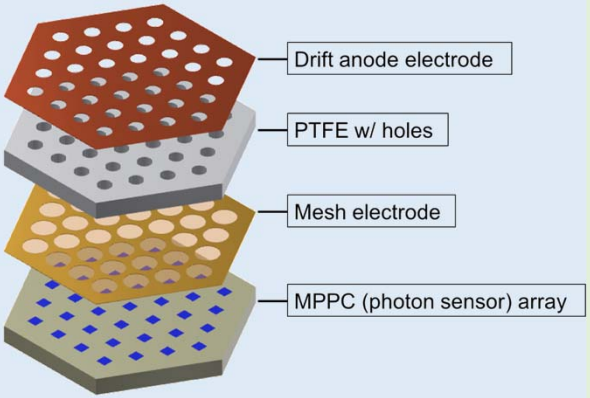


photosensors placed close to EL mesh



ELCC

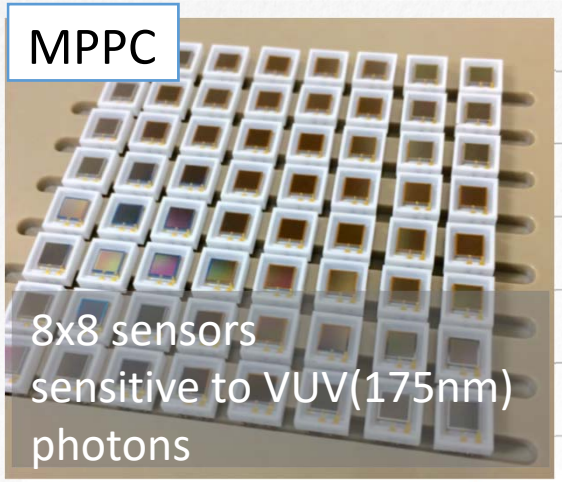




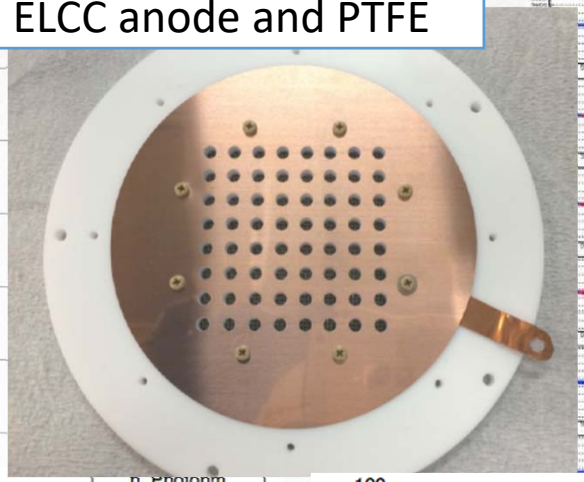
ELCC can have uniform gain.

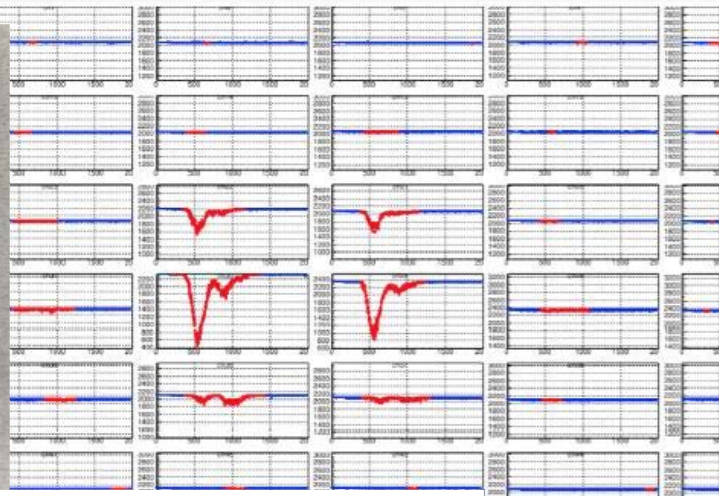
10L prototype for proof-of-principle of ELCC

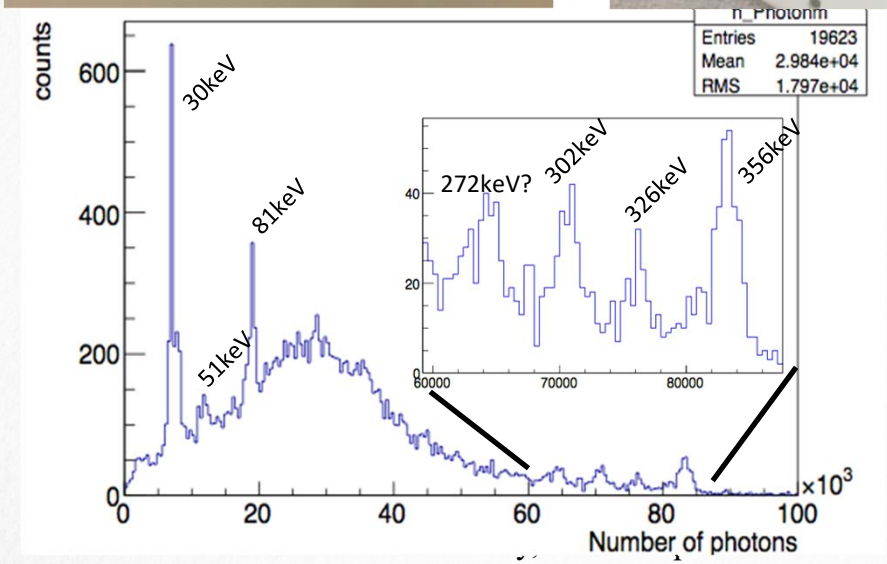
MPPC

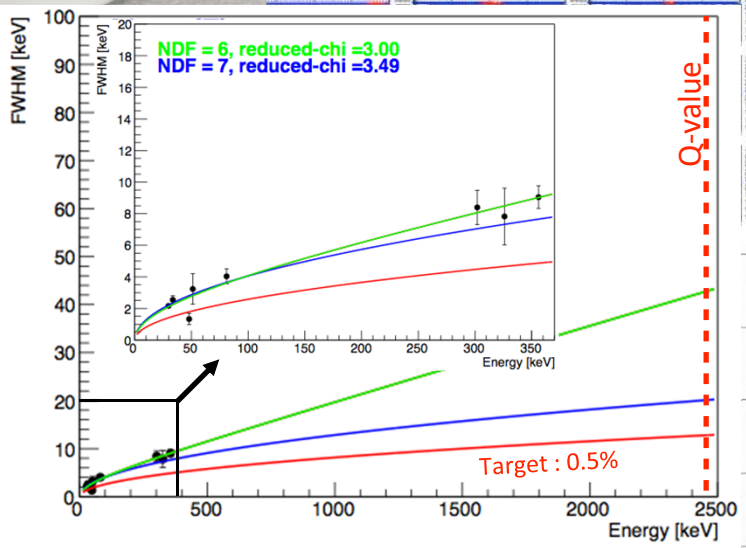


ELCC anode and PTFE





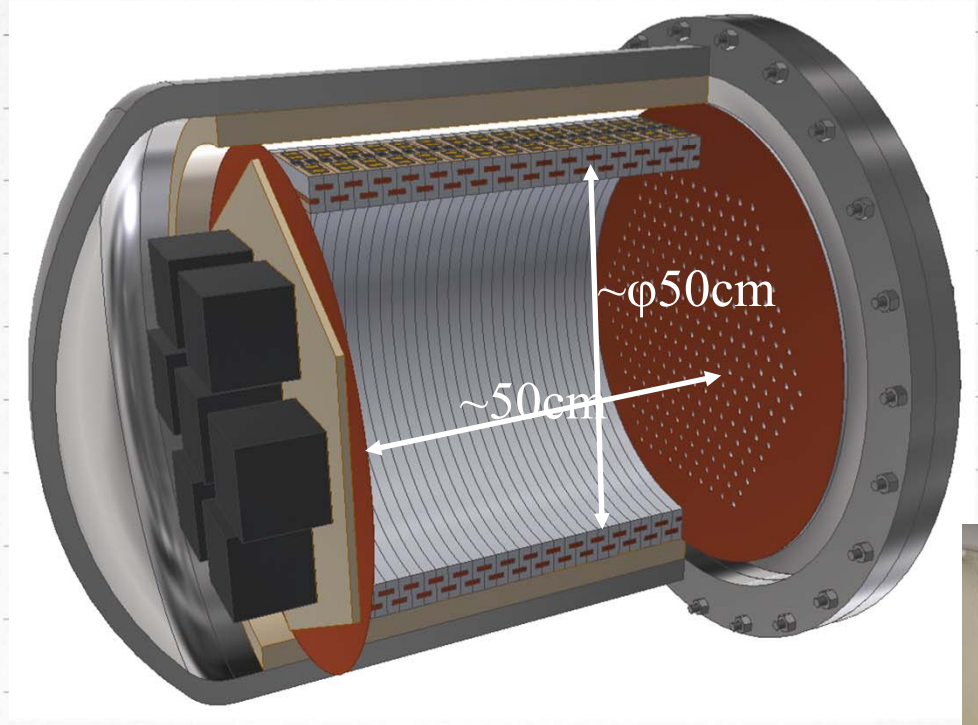


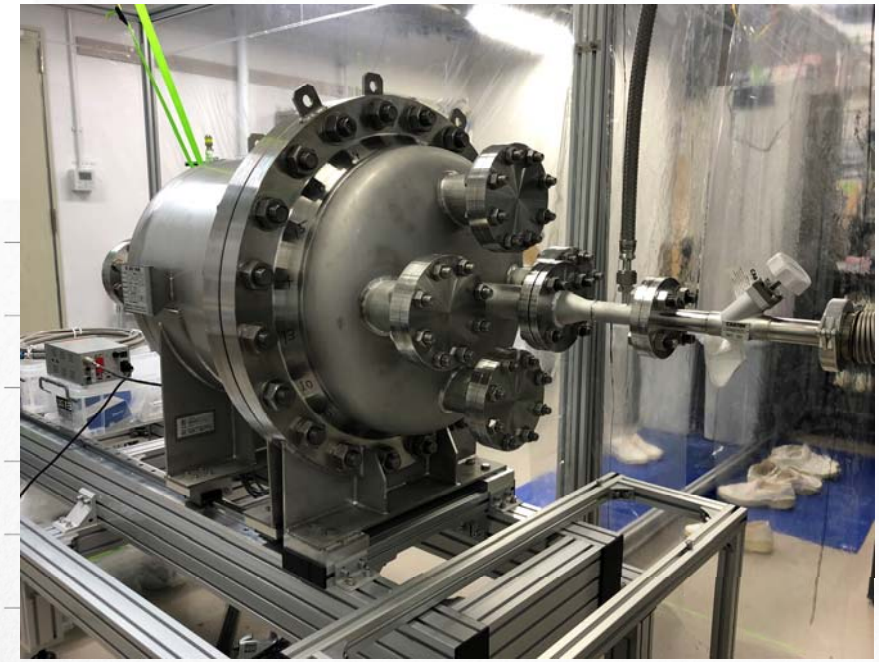


Energy resolution(FWHM) at Q-value(2.5 MeV)

current : 0.82 ~ 1.74 % (target: 0.5%)

180L prototype



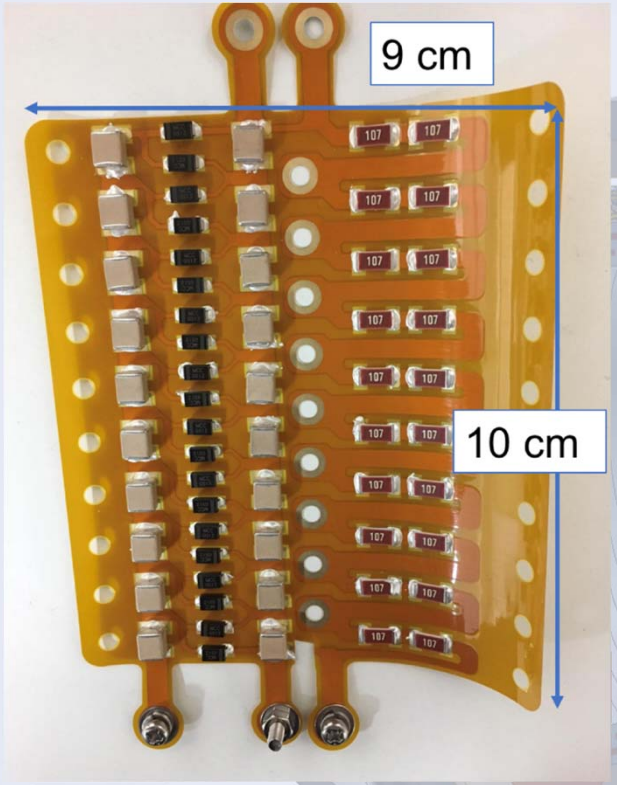


Purpose

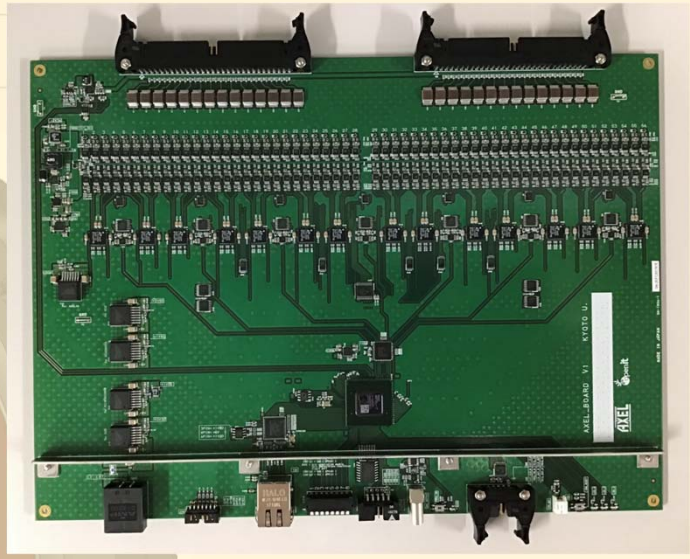
- demonstrate performance at Q-value
- establish techniques for large detectors
- R&D for new technologies

180L prototype

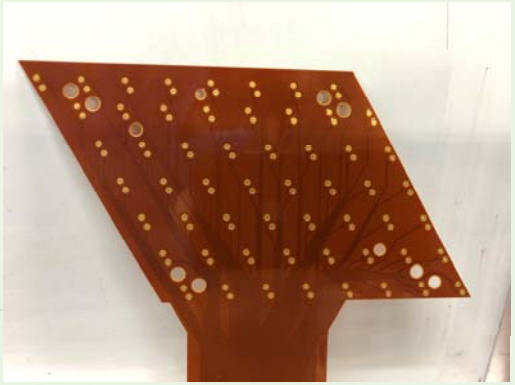
Cockcroft-Walton w/ polyimide board to generate 10kV/unit



dedicated digitization board
56ch/board



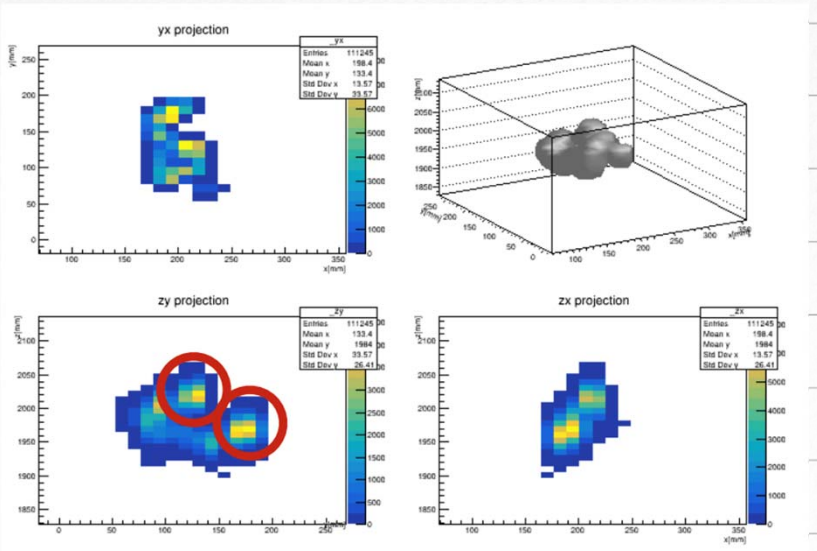
FPC for 56ch MPPC readout



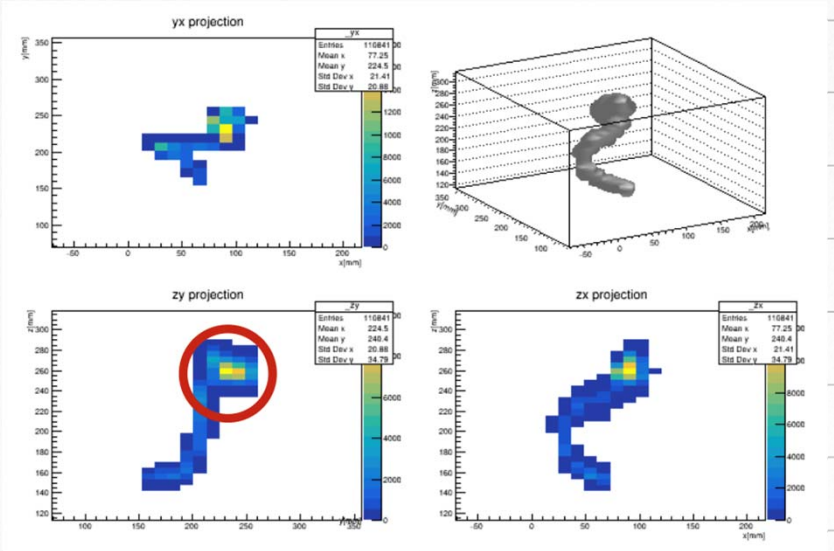
First signal expected in May, 2019.

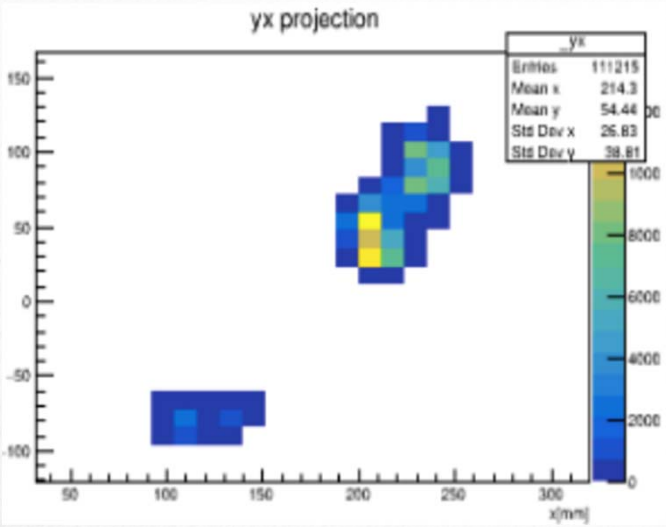
Signal discrimination by machine learning

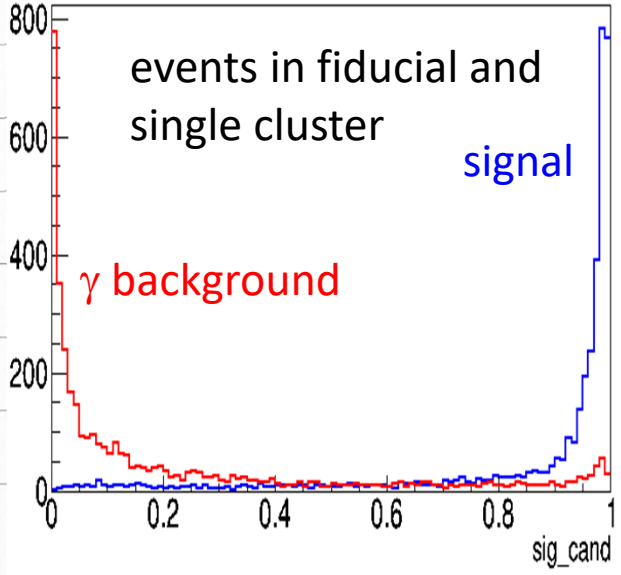
$0\nu\beta\beta$



γ-ray





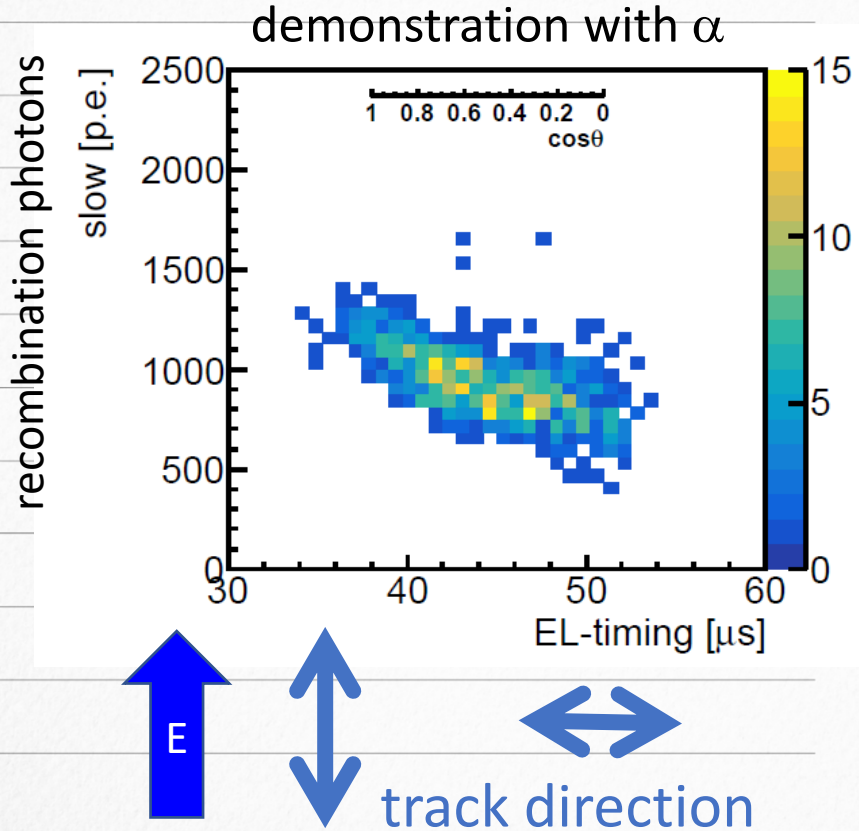


~1/2,000 reduction by topology

Towards ton-scale background-free experiment

R&D's are on going:

- ✓ Ionization positive-ion detection
  - Less diffusion → (possibly) clear image
  - → poster presentation by S. Obara
- ✓ thin or active chamber surrounded by water/liq.scinti
- ✓ Scintillation timing profile
- ✓ columnar recombination for direction sensitive dark matter search
  - Supported by this Scientific Research on Innovative Areas



Summary

- neutrinoless double beta search by **high pressure Xenon gas TPC**
  high energy resolution, event topology
- NEXT
  - ✓pure Xe, EL readout, <1% energy resolution
  - ✓started physics-data taking with NEW(~10kg) detector
  - ✓construction of ~100 kg detector in a coming year
- PandaX-III
  - ✓Xe+TMA and MPGD readout, ~3% energy resolution, good track resolution
  - ✓600L prototype
- AXEL
  - ✓pure Xe, EL readout, <1% energy resolution
  - ✓10L prototype → 180L prototype
- all groups are pursuing R&D for further reduction of background.