Neutrinoless Double-beta Decay Experiment NνDEx

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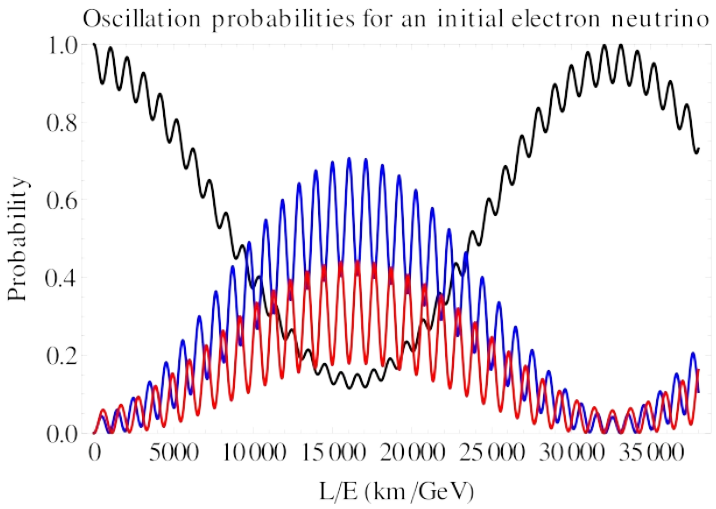
Institute of Modern Physics, CAS

Neutrinos



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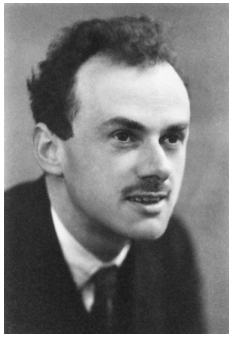

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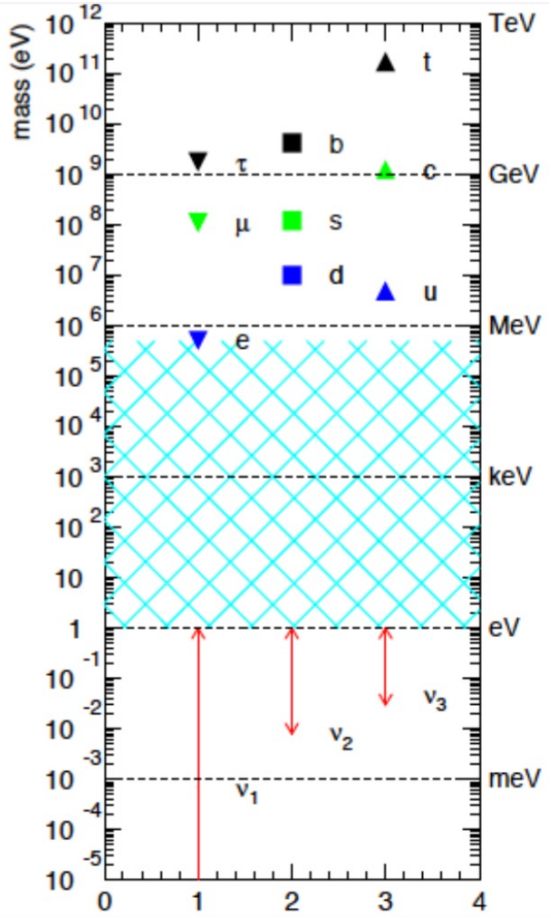
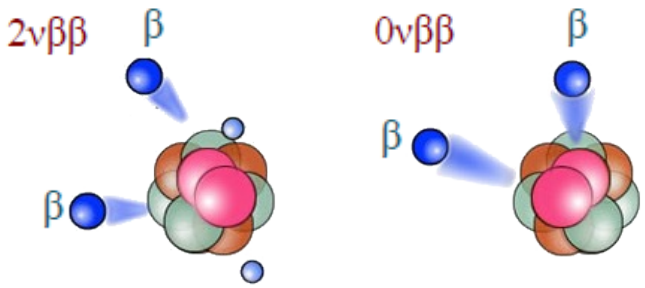
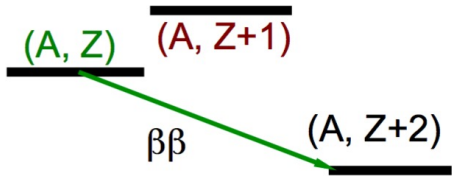


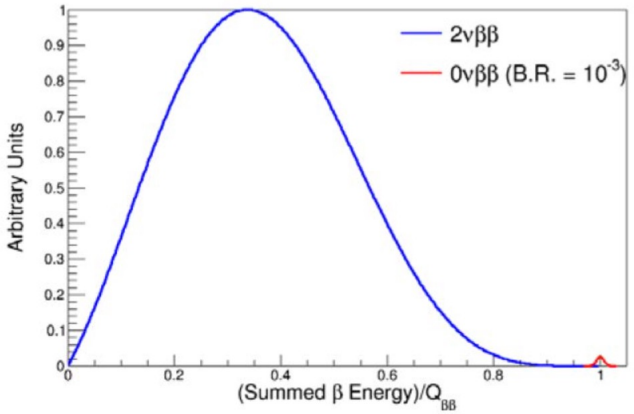
- Neutrinos oscillate ⇒ they have finite mass ⇒ beyond Standard Model
- Could be Majorana or Dirac fermions (could be their own anti-particle)
- Have “unnaturally” tiny mass

⇒ Could be a key to new physics beyond Standard Model

0νββ Decay

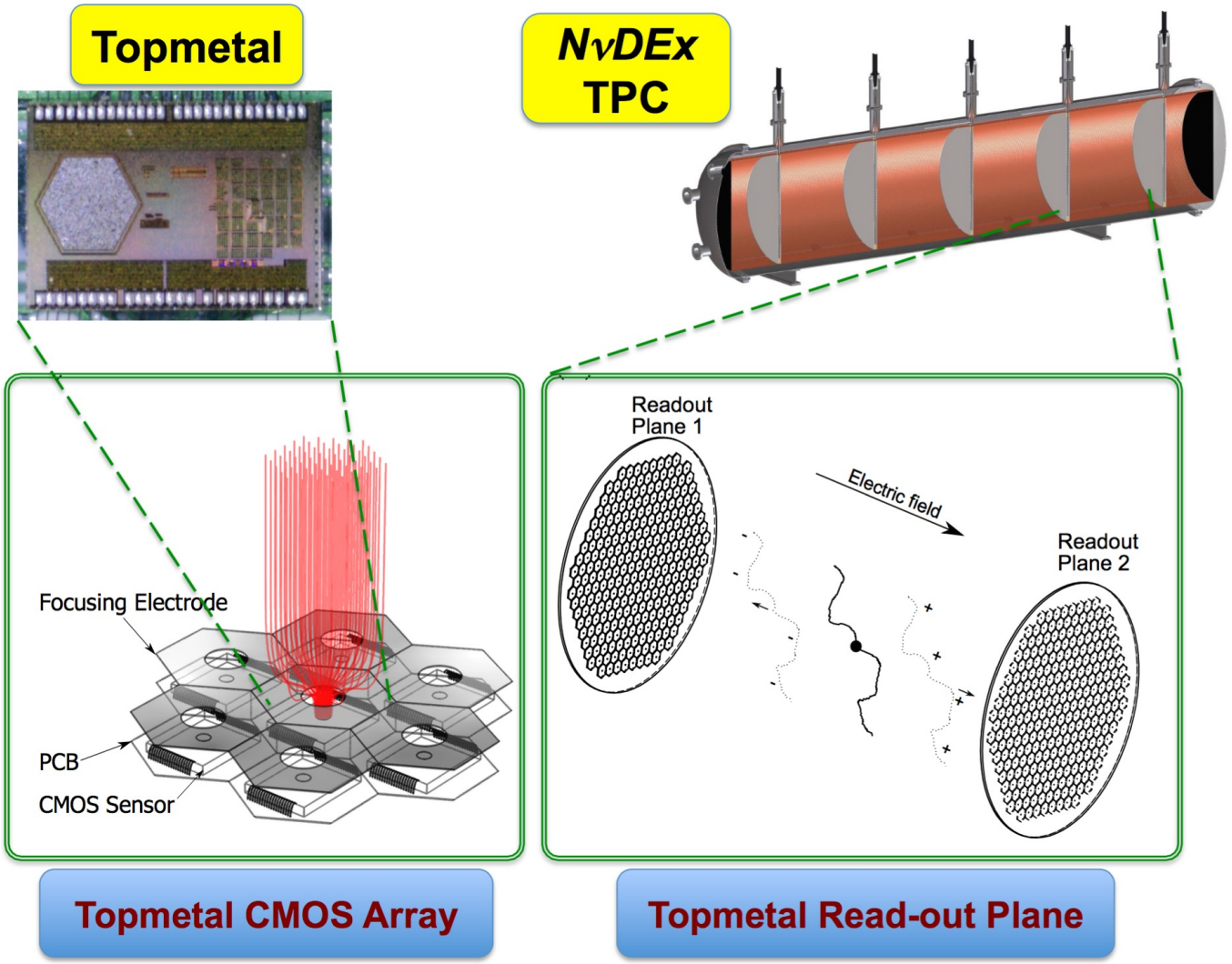






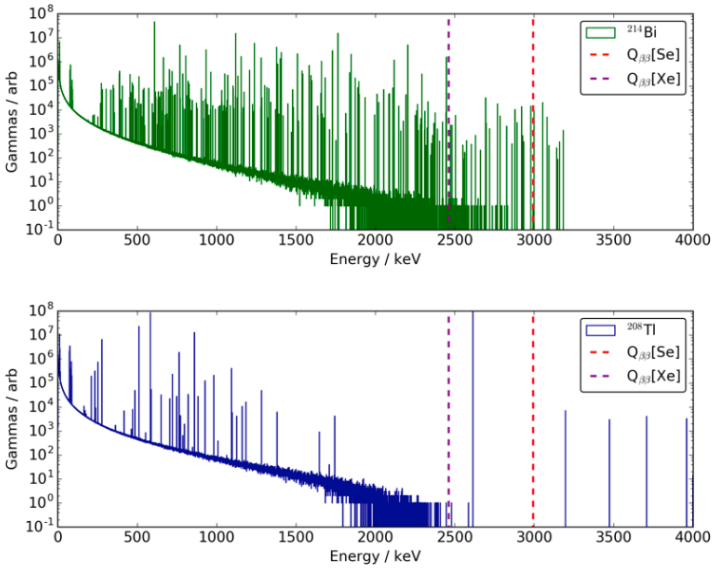
- If 0νββ decay is observed, it
  - will prove that ν is a Majorana particle ⇒ beyond Standard Model
  - may explain the finite but tiny ν masses, by see-saw mechanism with an extended Standard Model
  - will constrain absolute ν mass, and ν mass hierarchy
  - may explain matter-antimatter asymmetry in the universe, since it violates CP symmetry and lepton number conservation
- $T_{1/2} > 10^{26}$ y ⇒ very difficult to observe

NνDEx Concept

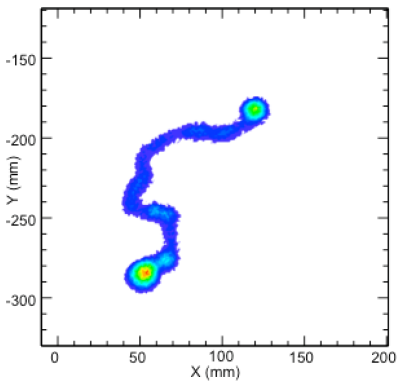


- High pressure $^{82}SeF_6$ gas TPC, with direct read-out by topmetal CMOS sensors

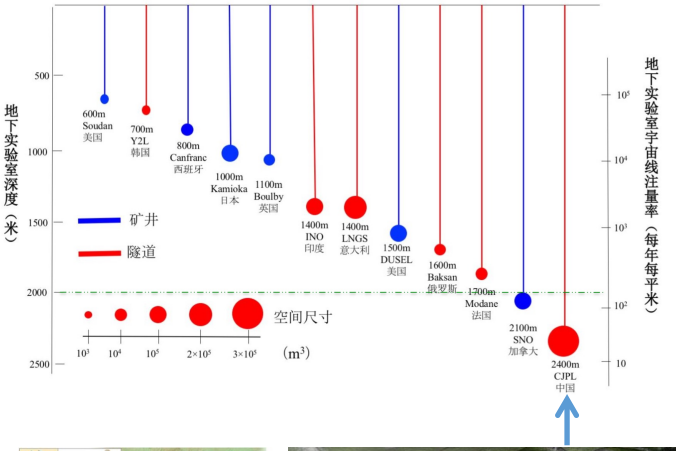
NνDEx Advantages

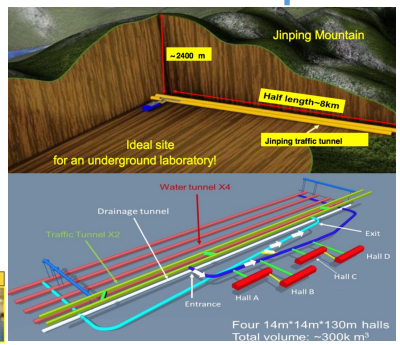


γ background energy spectra from natural radiations



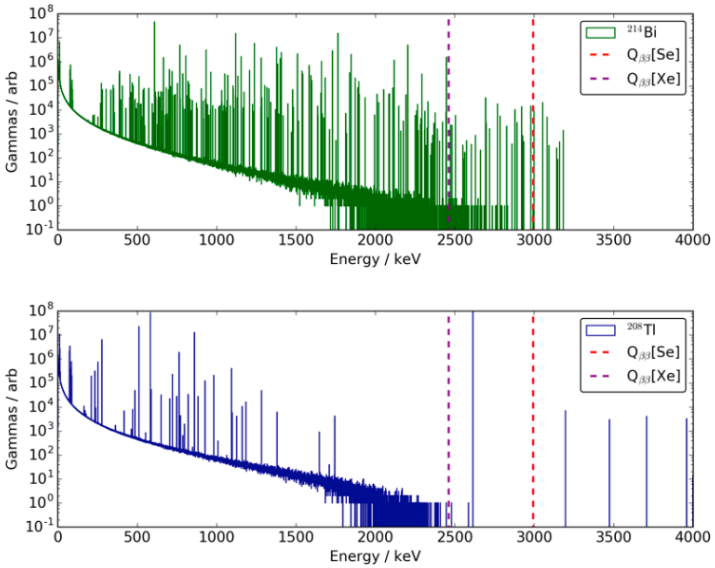
energy deposition for a 0νββ event





- Low background level is crucial for 0νββ experiments to reach high sensitivity
  - High Q value of ^{82}Se (2.996 MeV) – above most natural radiation background
  - Distinguish signal and background with event topology by TPC
  - Better energy resolution without avalanche amplification (~1% FWHM)
  - CJPL - deepest underground lab

NνDEx Advantages



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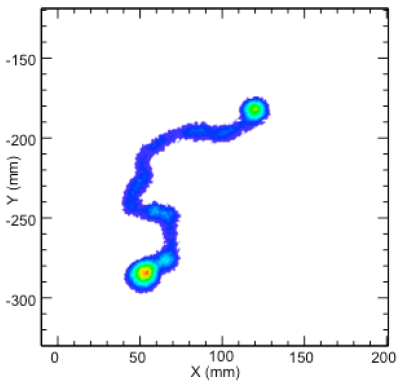

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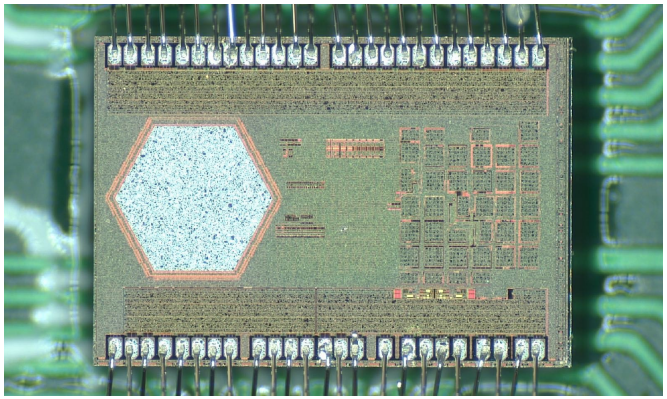
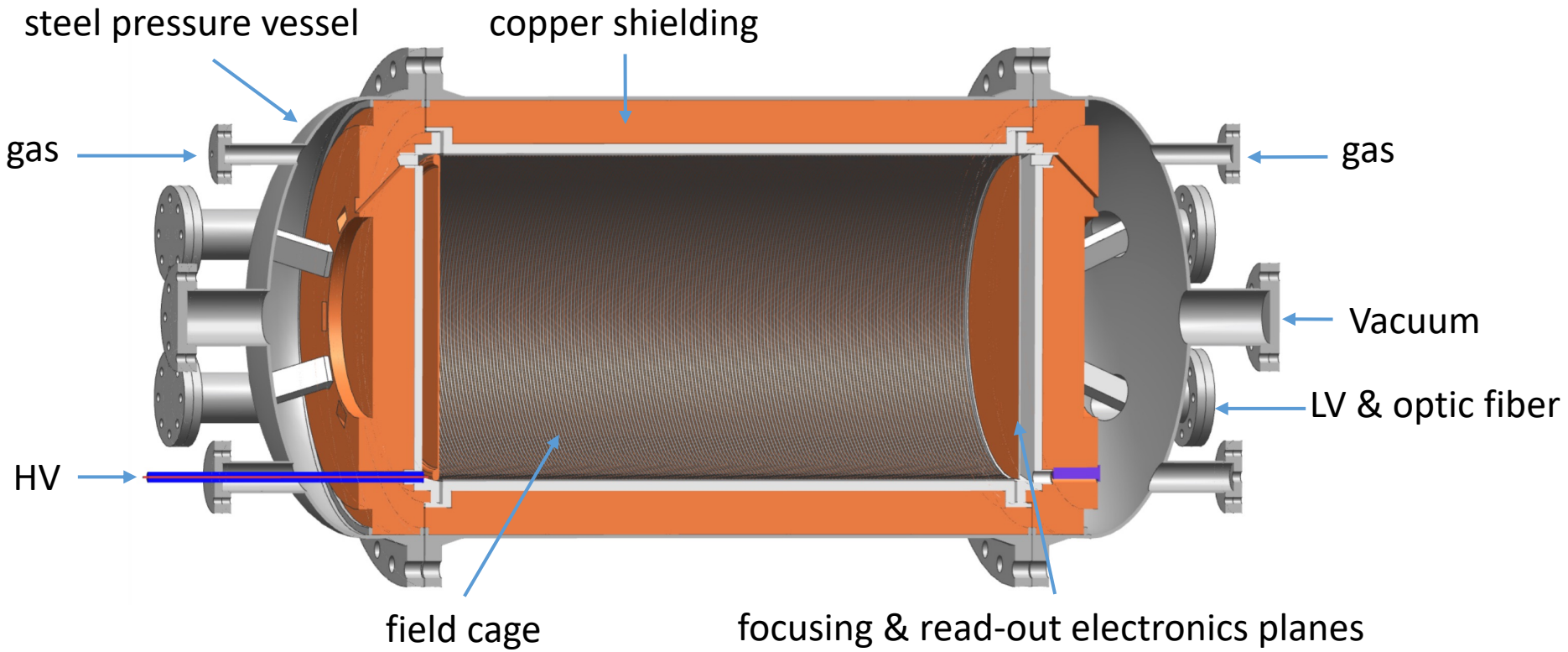


Topmetal-S silicon sensor

PLAC
Pixel Laboratory at CCNU

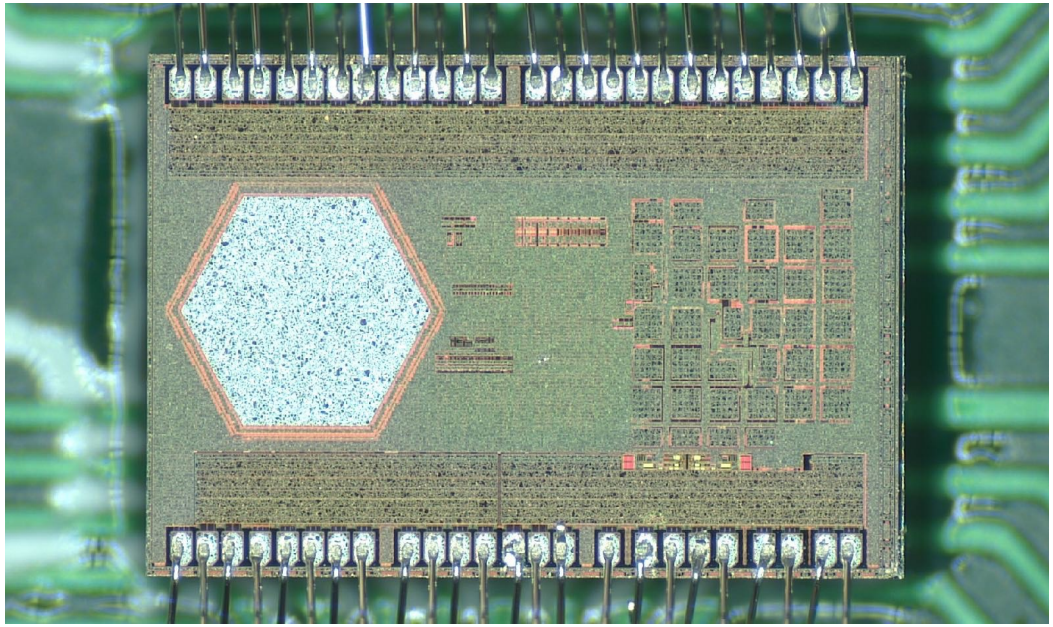
- SeF_6 is electronegative. Amplification by electron avalanche is not possible with it.
- The combination of advantages from the high Q value of ^{82}Se and TPC's ability to see event topology, is only possible with low-noise direct charge read-out.
- Topmetal-S sensor, specifically for 0νββ detection, is made by Pixel Lab of CCNU.

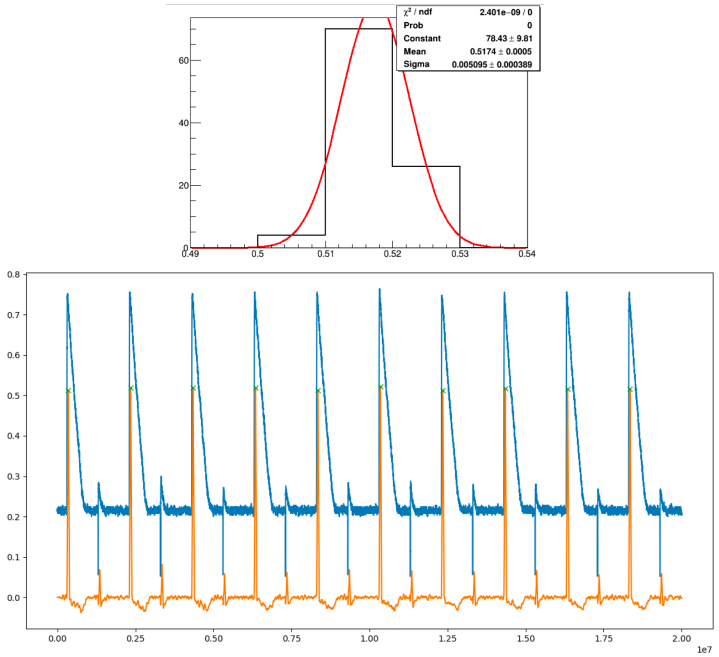
NνDEx-100



- 100kg SeF_6 gas at 10 atm in the sensitive volume
- barrel part length: 160 cm, pressure vessel inner diameter: 120 cm
- start with non-poisonous SF_6 gas
  - test for gas tightness - SeF_6 is poisonous: <0.05 ppm in environment
- then switch to SeF_6 gas, finally use $^{82}SeF_6$ gas if getting enough funding in the future

Topmetal-S Sensor

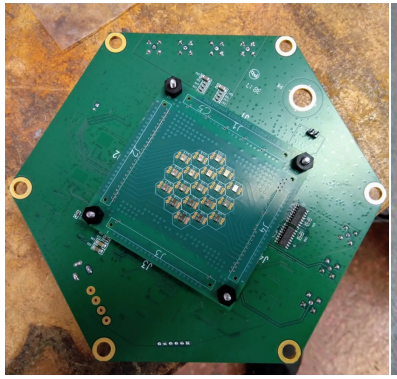


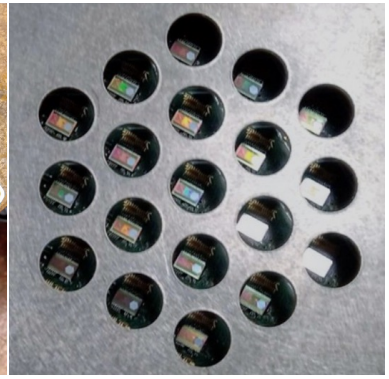


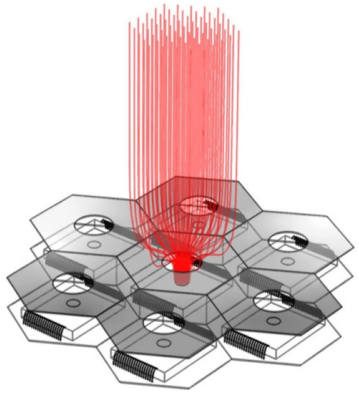
- Two tapeouts have been conducted.
- The 2nd tapeout of sensors are being tested. There are still some issues to be understood / resolved.
- The configuration of the sensor is still being optimized.
- An equivalent input noise <130e- has been achieved so far (NνDEx goal: 45e-).

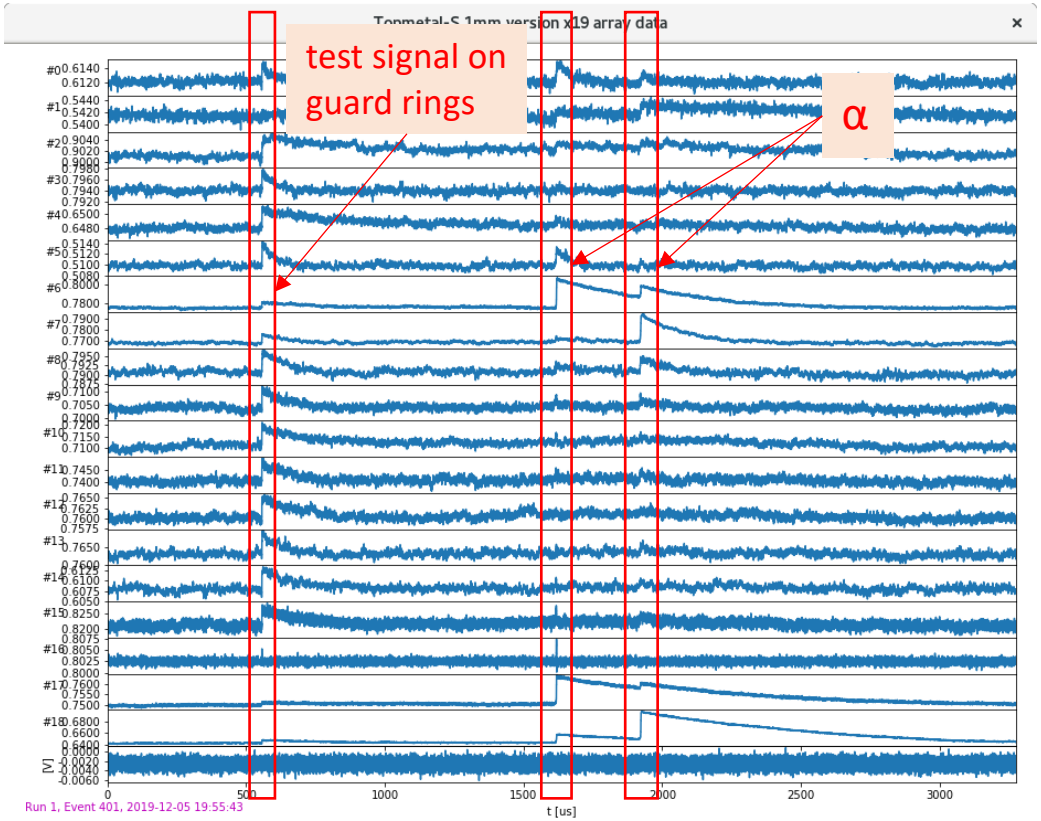
more details: poster by Dongliang Zhang et. al. Parallel Session IX (5), Aug 11, 2:00 PM

Array of 19 Topmetal-S Sensors



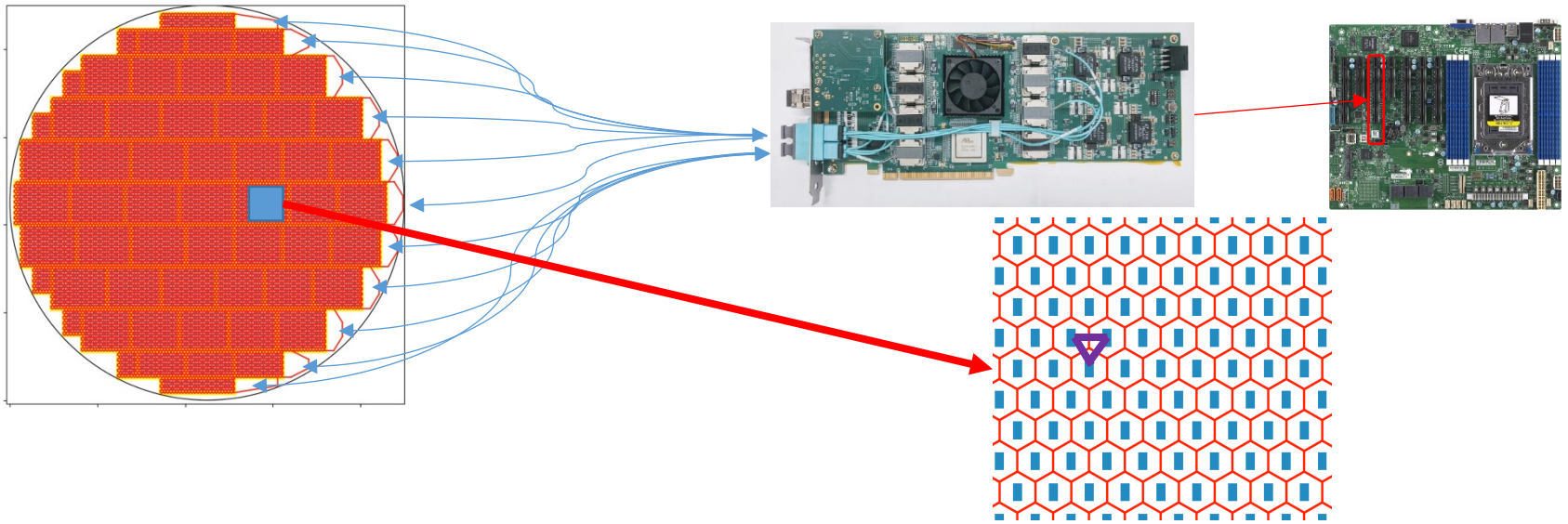






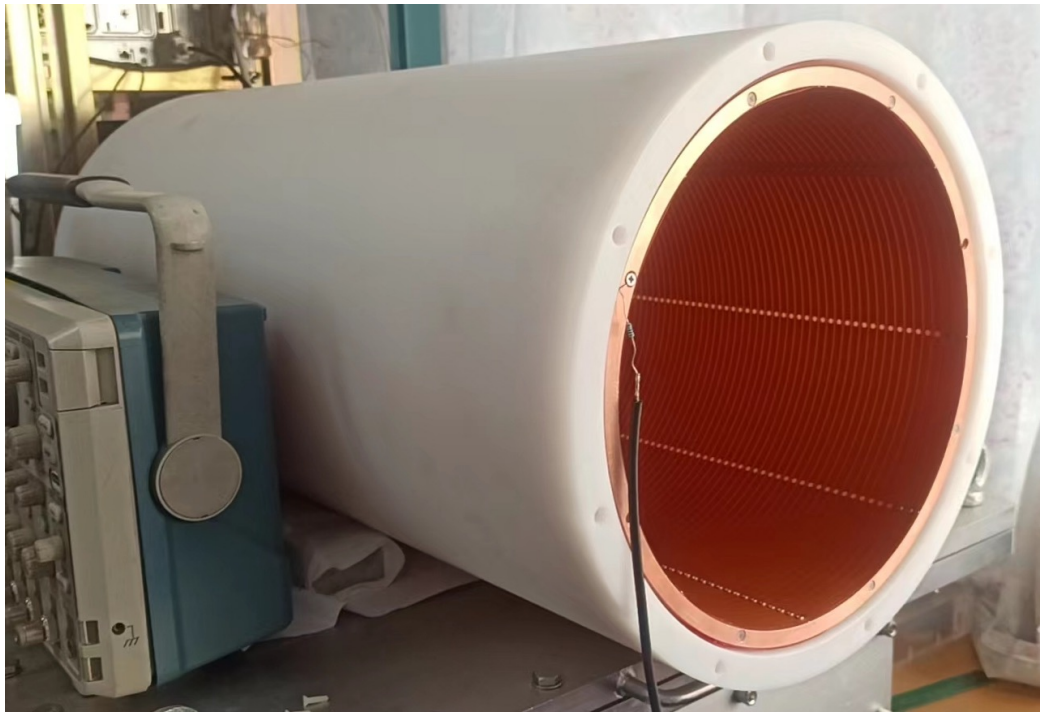
- An array of 19 Topmetal-S sensors (1st tapeout) was tested with ^{241}Am α source
- Signals from the α source observed, but the magnitude is only 5% of expected value.
- The magnification in the CSA is not high enough, because the bias voltage cannot work stably when the magnification is increased.
- Redesigned and solved in the 2nd tapeout – to be tested with α source again

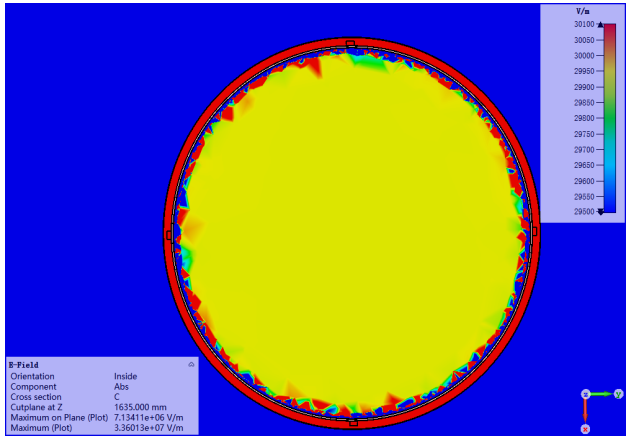
Readout & DAQ

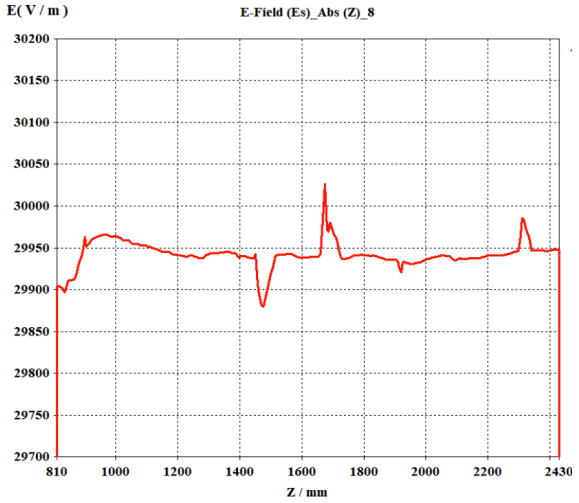


- Sensor pitch: 8mm
- Sampling rate is 0.5~20 kSps
- PCIe based DAQ system: FELIX (used in ATLAS, DUNE, sPHENIX and CBM).
  - The first prototype has been fabricated
- Firmware and software developments ongoing

TPC Field Cage

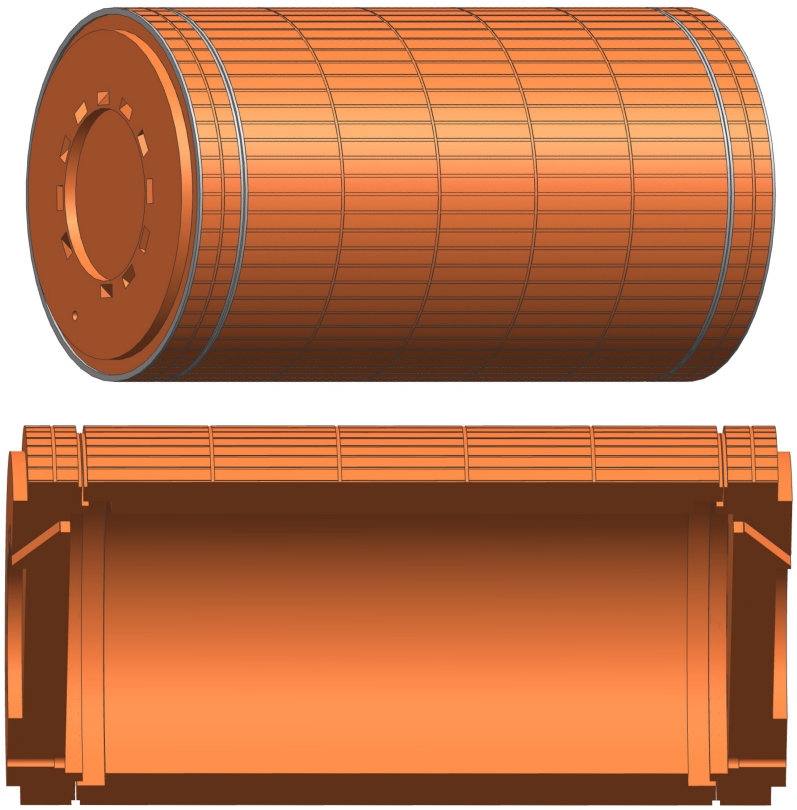






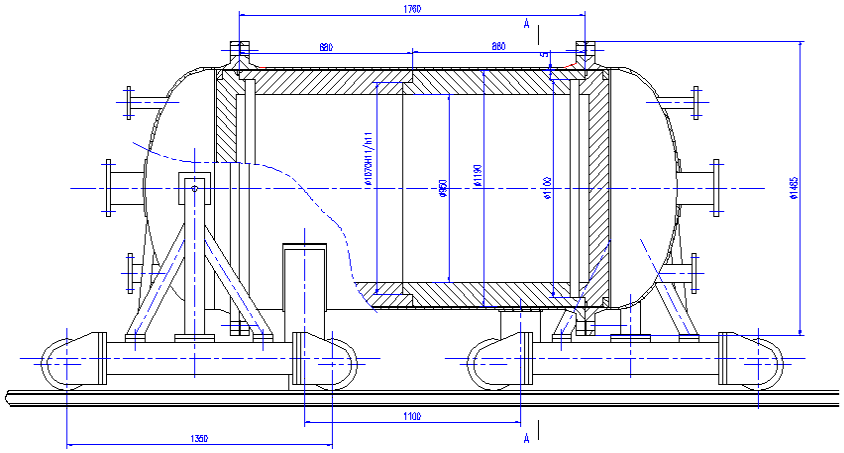
- 2.5cm thick POM insulator layer + POM supporting structure + FPCB
- Finished with an initial design, a 30cm-diameter prototype is made and being tested

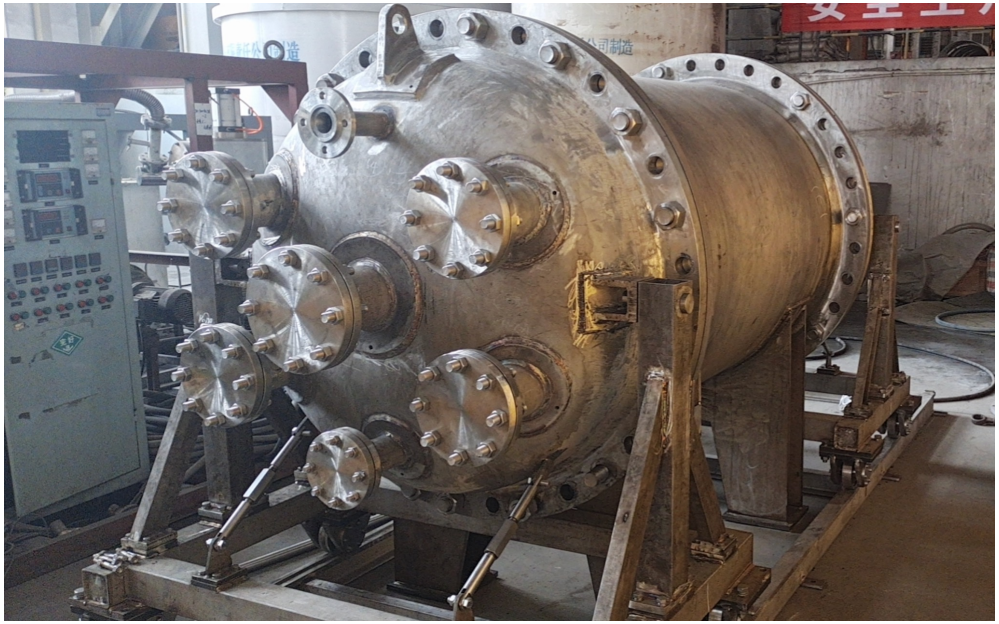
Inner Copper Shielding



- Low-radiation oxygen-free copper
- 12 cm thick
- Finished with manufacture

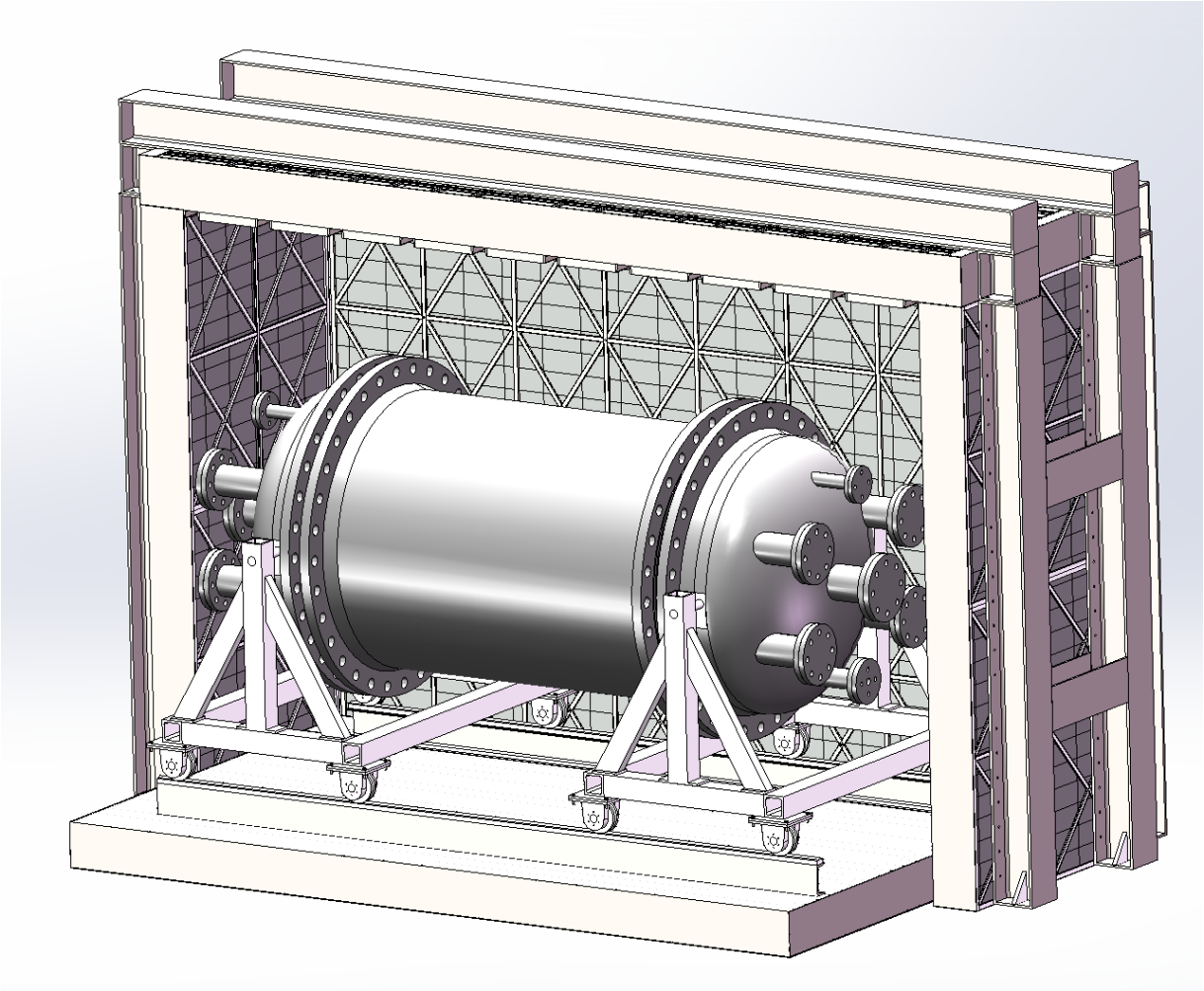
Pressure Vessel





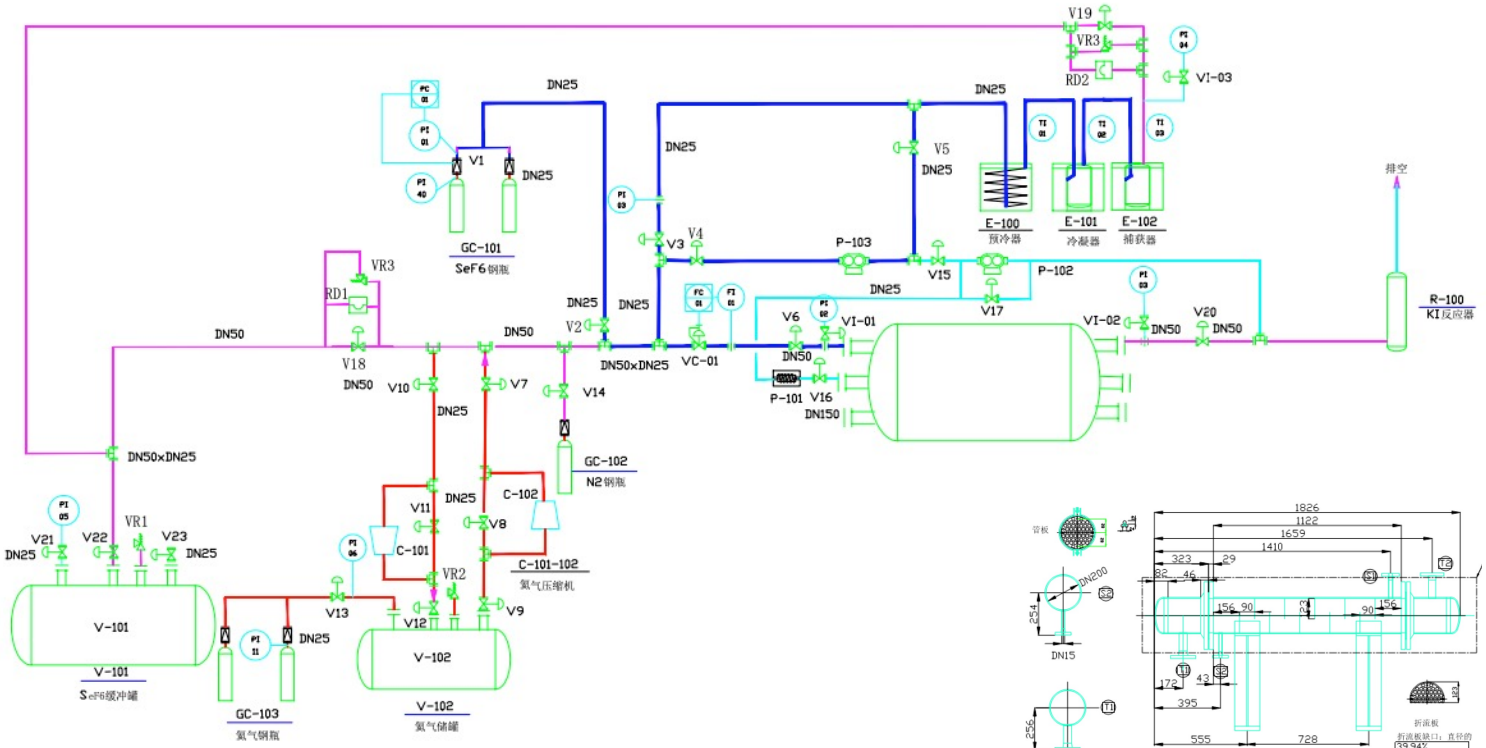
- 316L alloy
- Maximum pressure: 15 atm
- Being manufactured

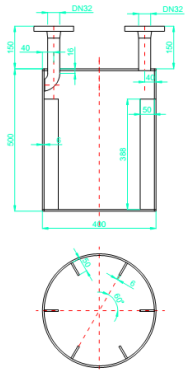
External Shielding



- 25 cm thick of Pb
- Being designed

Gas System





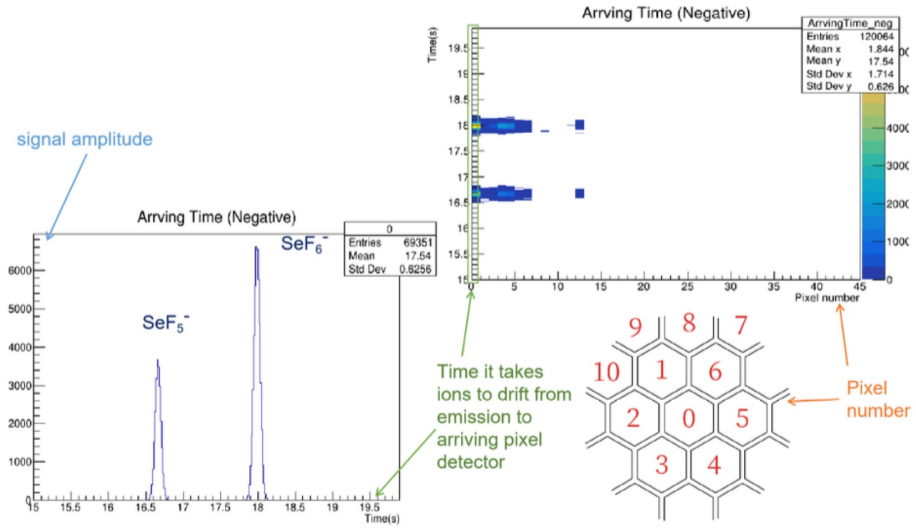
condenser

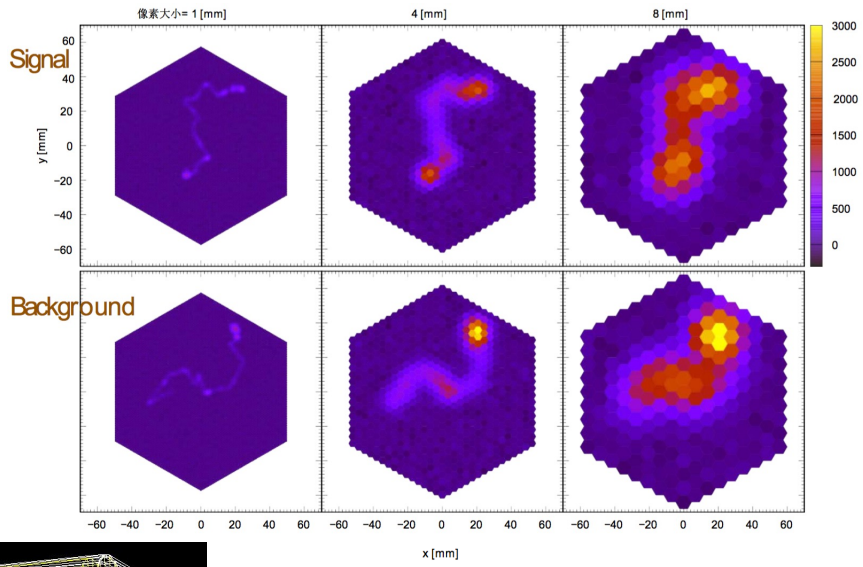
pre-cooler

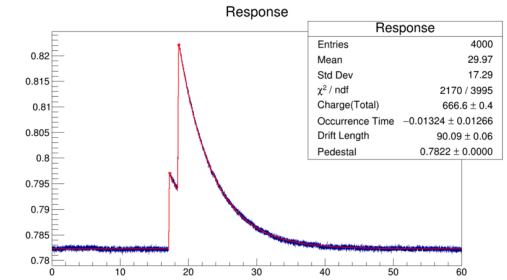
chiller

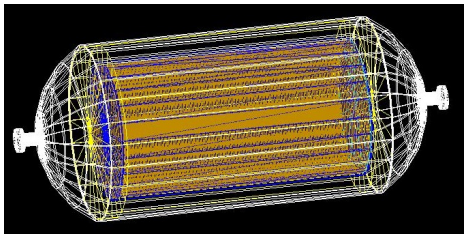
- A cold trap for SeF_6 storing
- An emergency tank for emergent SeF_6 releasing
- A negative pressure room with gas monitor & SeF_6 reactor: second line of safty
- Test with SF_6 gas before filling SeF_6 each time
- Finished with design and being assembled

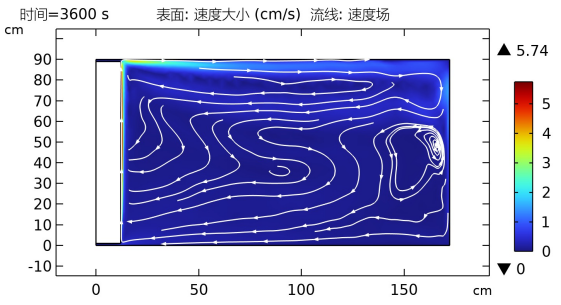
Simulations

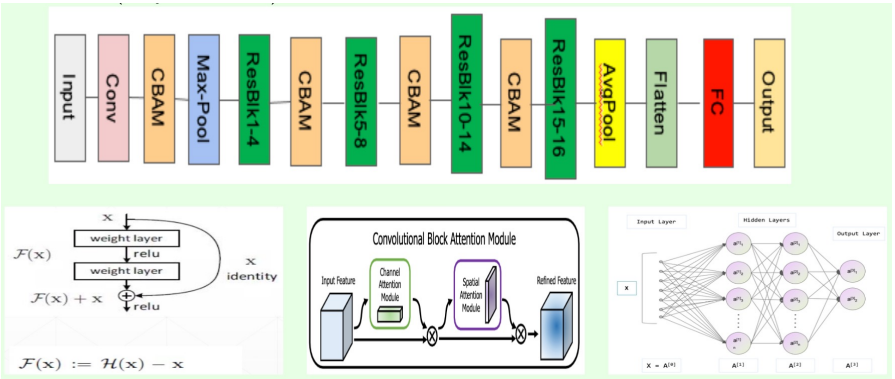


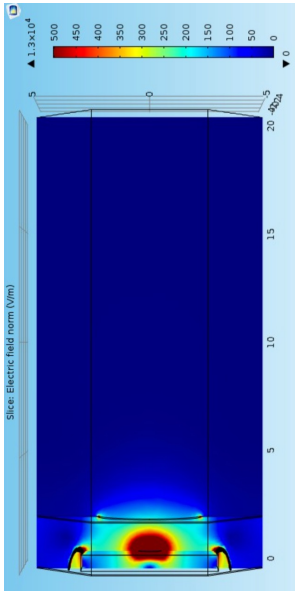






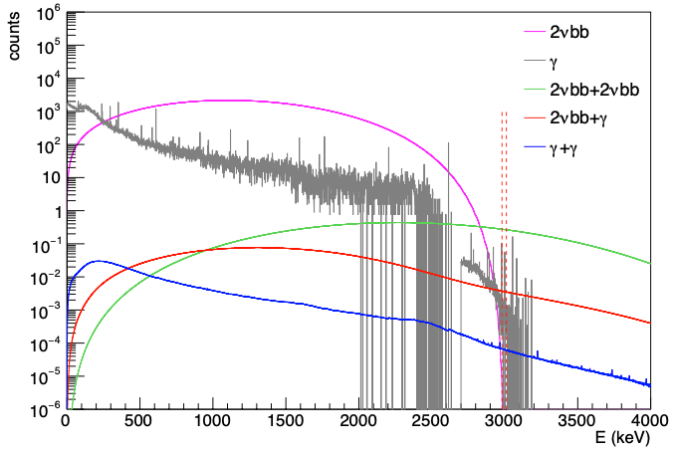


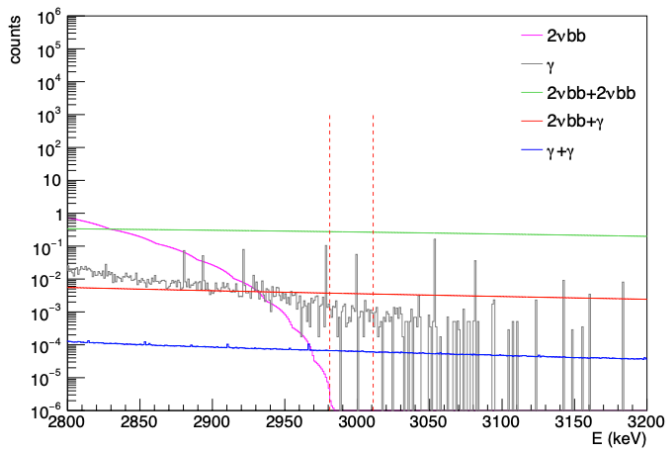


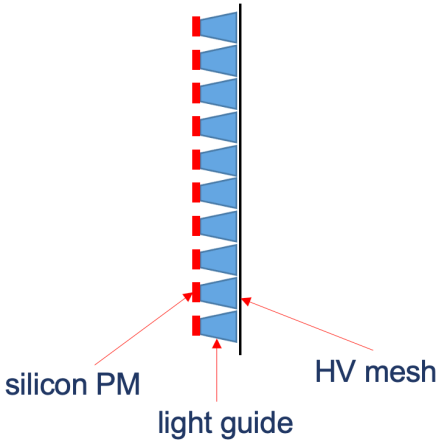


- Various simulations have been carried out

Background & Sensitivity Estimations







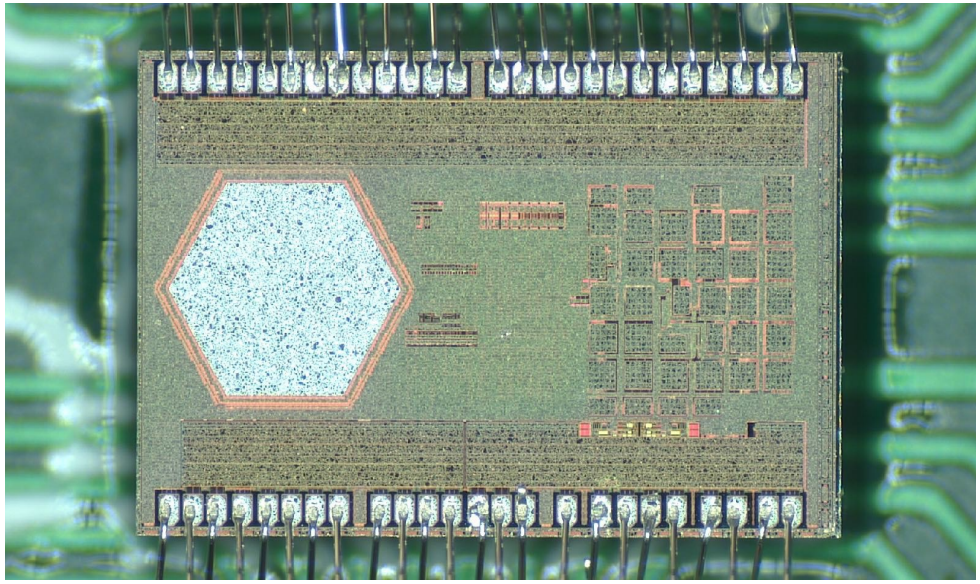
- Assuming the same natural radiation contaminations as NEXT, ~0.5 counts / year background in ROI for 100kg gas, without suppression using event topology
  - ~0.05 counts / year with suppression using event topology ⇒ ~10^{26} y sensitivity
- Due to slow drift velocity of ions, pile-up backgrounds could be an issue
  - considering adding scintillation light read-out with silicon PM at the HV end
- Cosmic-generated ^{56}Co, ROI background ~3400 / y, half life 77 d, need ~3 years to cool down underground
- Other background sources being / to be studied: neutron, Radon, μ, ν…

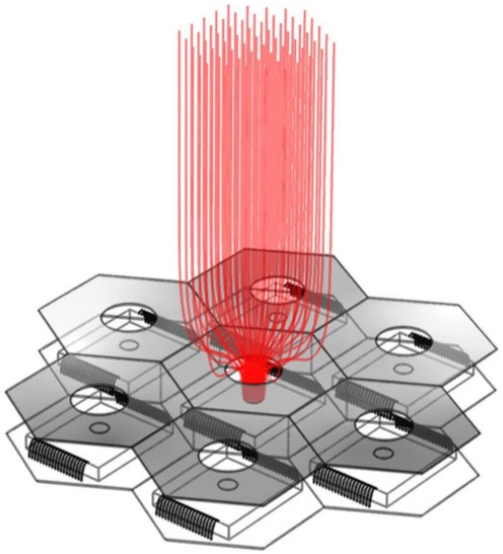
Summary and future plan

- NνDEx concept combines advantages from the high Q value of ^{82}Se and TPC's ability to see event topology, using noval topmetal sensor technology.
- NνDEx-100 is being built.
- ~10^{26} y sensitivity expected, with only 3.6kg ^{82}Se in 100kg natural SeF_6 gas.

- Plan:
  - 2022: Demonstrate topmetal sensor array TPC readout; CDR
  - 2023: TDR
  - 2024: move down to CJPL
  - 2025: assembling the whole system, begin data-taking
  - 2026: get physics results

Outlook – TPC with Topmetal Sensors





- TPC read out by topmetal sensors will be revolutionary
  - Enabling a wide range of working media (gas / liquid) – like NνDEx
  - 50 μm level pixel size ⇒ high position resolution
  - No fluctuations due to avalanche amplification ⇒ better energy resolution
  - No space charge from avalanche ions
  - No gate grid dead-time
  - No nonuniformity from GEM etc.

Thanks ☺