IRIS 중이온가속기연구소
Institute for Rare Isotope Science

TPC for LAMPS Detector System at RAON

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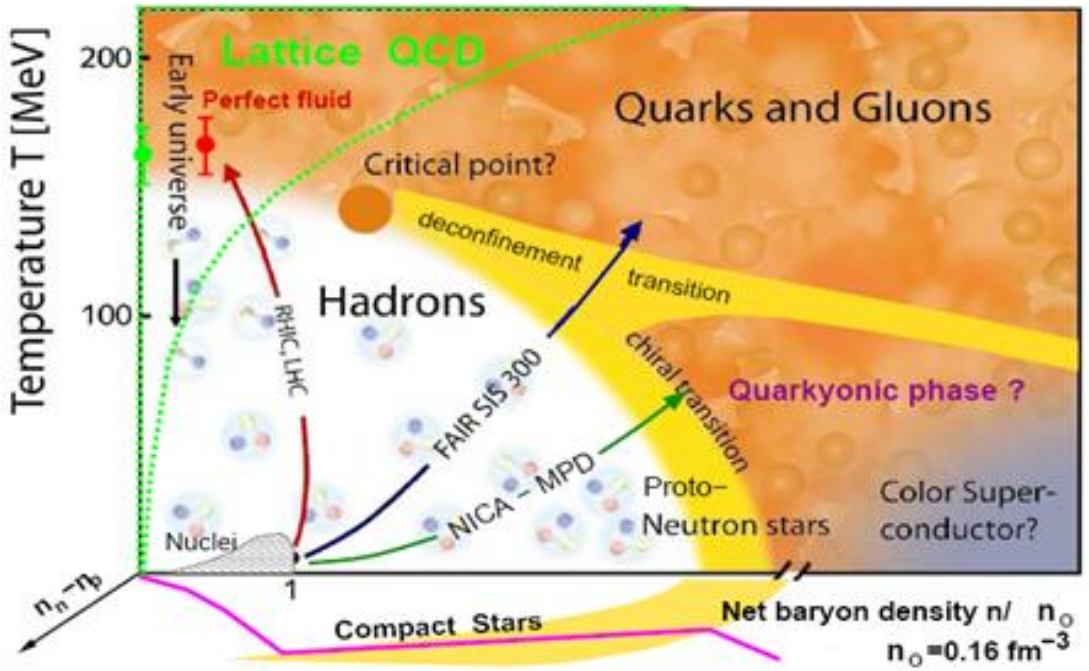
Nuclear Matter Symmetry Energy Study at RAON

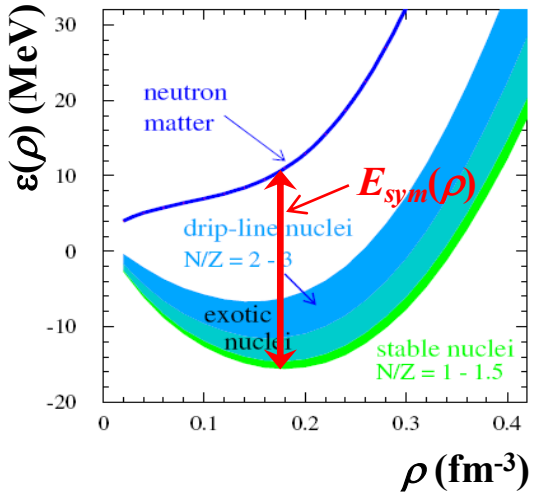
- **Exploring the nuclear phase diagram via heady-ion collisions including the isospin axis using RI beams**
- **Role of isospin degree of freedom in strong interaction**
  - **Nuclear symmetry energy study from sub- to supra-saturation baryon densities**
  - **Characterization of supernova and neutron stars**



- General approach
  - **Calculate the energy per nucleon $E/A = \varepsilon(\rho, \delta)$ as functions of baryon density ρ and isospin asymmetry δ**
- Theoretical approach
  - **Estimate of $\varepsilon(\rho, \delta)$ by some density functionals or variational calculations**
- Experimental approach
  - **Constrain EoS using controlled laboratory experiments at specific densities**

$$\varepsilon(\rho, \delta) = \varepsilon(\rho, \delta = 0) + E_{sym}(\rho)\delta^2 + \partial(\delta^4) + \cdots$$

with $E_{sym}(\rho)$ the symmetry energy & $\delta = (\rho_n - \rho_p)/(\rho_n + \rho_p)$



Why are we doing heavy-ion collision experiment?

→ **It is the only way to create dense, hot nuclear matter at laboratories.**

Why are we using RI beams for heavy-ion collision?

→ **We can control the isospin parameter (N/Z) of the collision systems.**

Observables

- Requirements for EoS experiments
  - Systematic change of the system size and N/Z of the collision system
  - Systematic change of the beam energy to change ρ/ρ_0
  - Systematic analysis as functions of the collision centrality and momentum (or kinetic energy)

- Observables
  - Particle yield, spectrum and ratio for n/p, $^3H/^3He$, $^7Li/^7Be$, π^-/π^+, etc.
  - Collective flow : v_1 & v_2 of n, p, and fragments
  - Azimuthal angle dependence of n/p ratio relative to the reaction plane
  - Isoscaling phenomenon in nuclear multi-fragmentation process
  - Isospin transportation (Isospin diffusion and drift)
  - Giant and Pygmy dipole resonances : peak position and magnitude
    (PDR could be sensitive to the radius of n-skin for unstable nuclei.)
  - Angular dependence of the gamma production

- Required detector system
  - beam diagnostic detectors
  - charged particle detectors
  - neutron detectors
  - gamma detectors

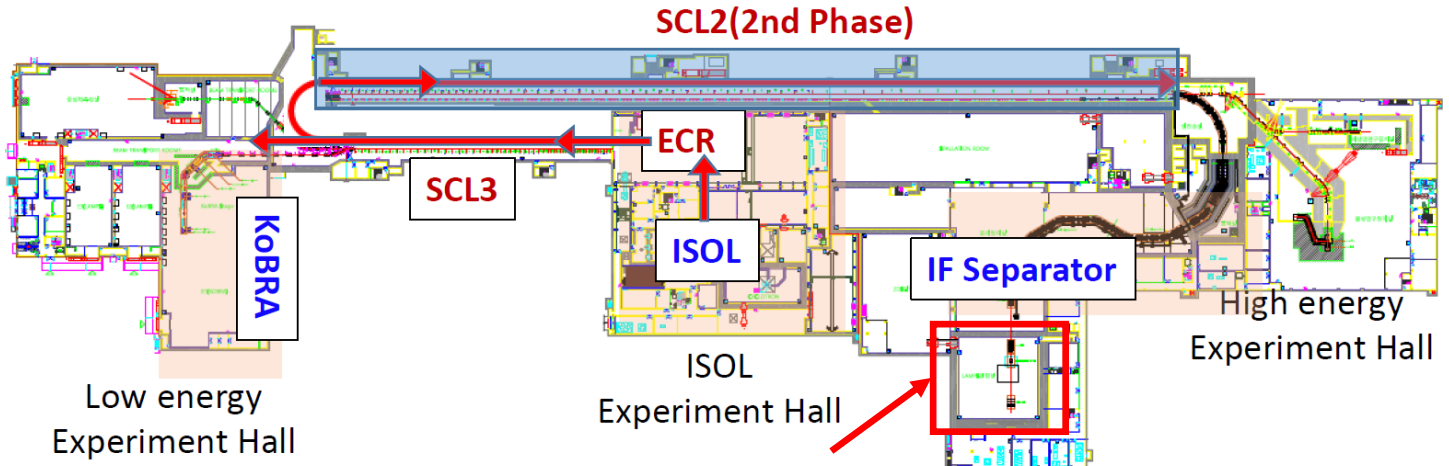
LAMPS (Large Acceptance Multi-Purpose Spectrometer)

Main facility for nuclear matter and nuclear reaction studies with intermediate energy stable and rare isotope beams

- **Main Research Subject**

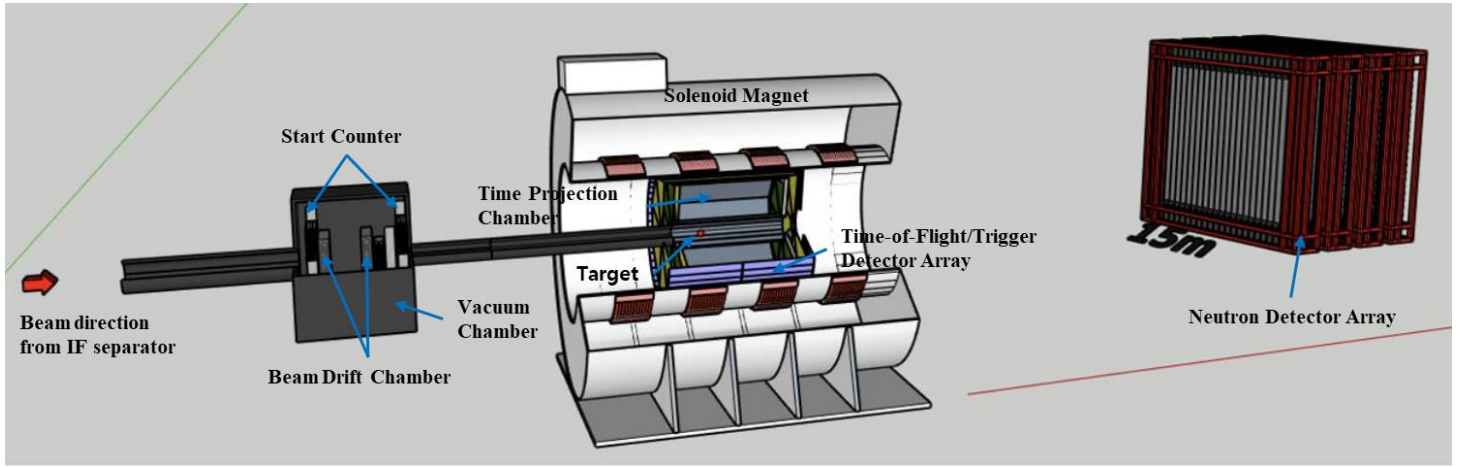
  Study of nuclear symmetry energy at supra-saturation density via heavy-ion collision experiment using rare isotope beam with varying beam energies and collision systems

  (e.g. measure *n/p* ratio & collective flow at the same time in the combination of $^{50,54}Ca+^{40}Ca$, $^{68,70,72}Ni+^{58}Ni$, $^{106,112,124,130,132}Sn+^{112,118,124}Sn$)



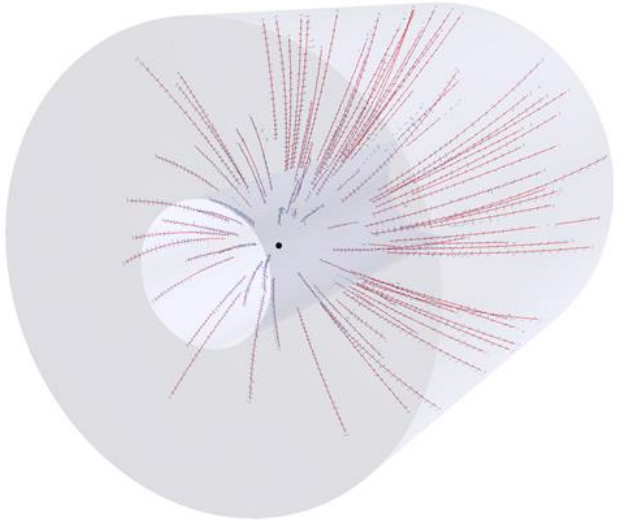
LAMPS Experimental Hall

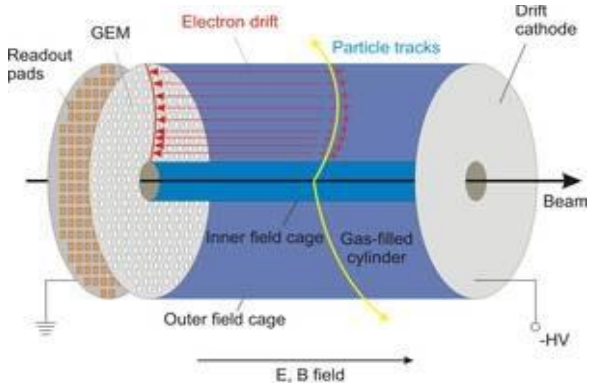
→ LAMPS can take all available beams at RAON

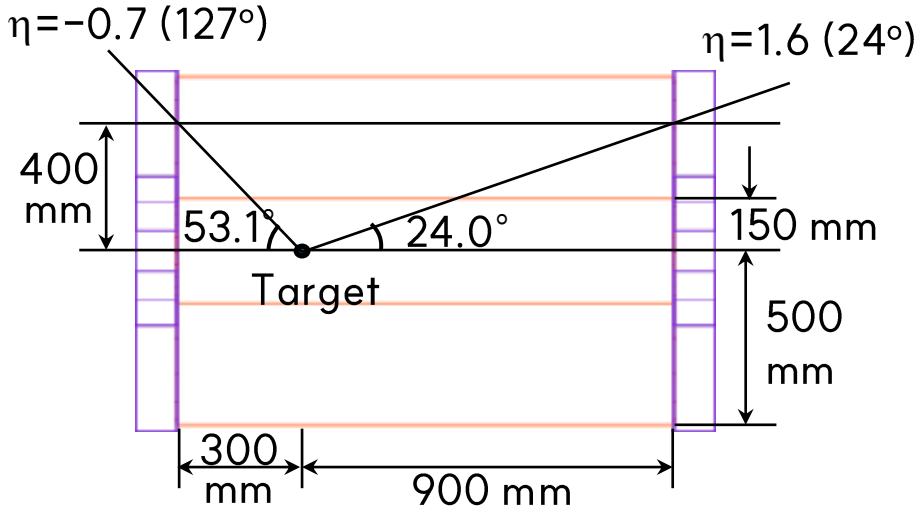


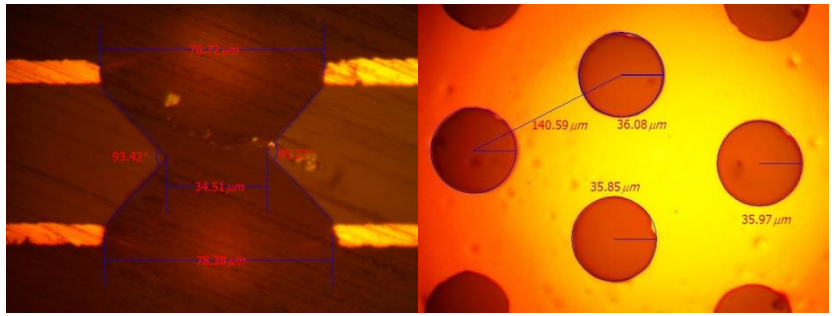
- **Designed to cover wide acceptance range with high detection efficiency and accuracy of charged particles and neutrons**
- **Beam Diagnostic Detectors : Two plastic start counters and two beam drift chambers**
- **Solenoid Spectrometer**
  - **Max. 1T solenoid magnet**
  - **TPC (~ 3π sr acceptance, charged particle tracking, complete information of momentum and PID)**
  - **Scintillation counters (ToF/Trigger Detector Array)**
- **Neutron Detector Array (neutron tracking)**

Time Projection Chamber : Conceptual Design



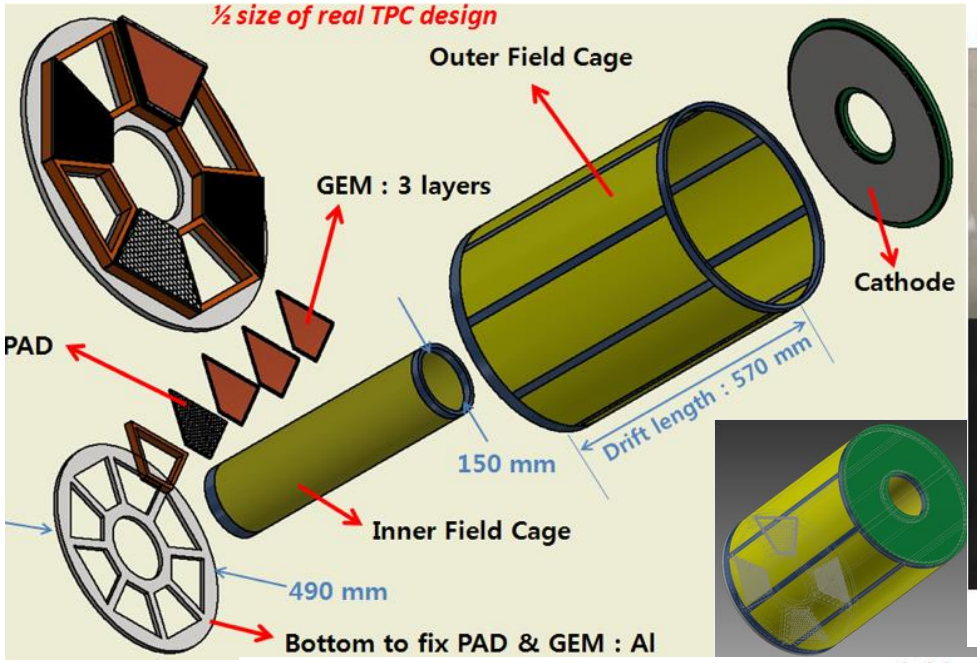


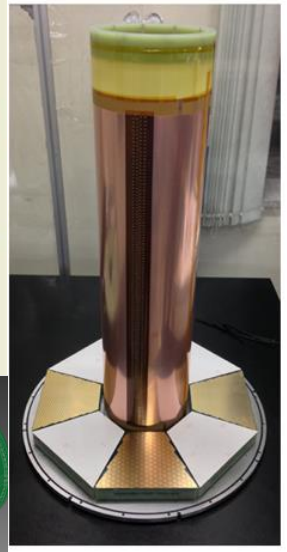


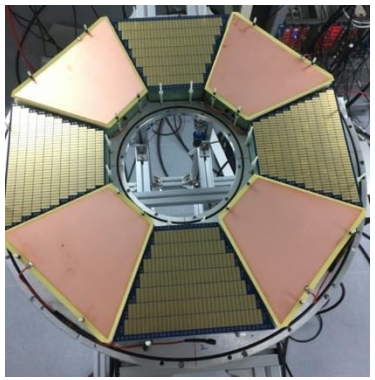


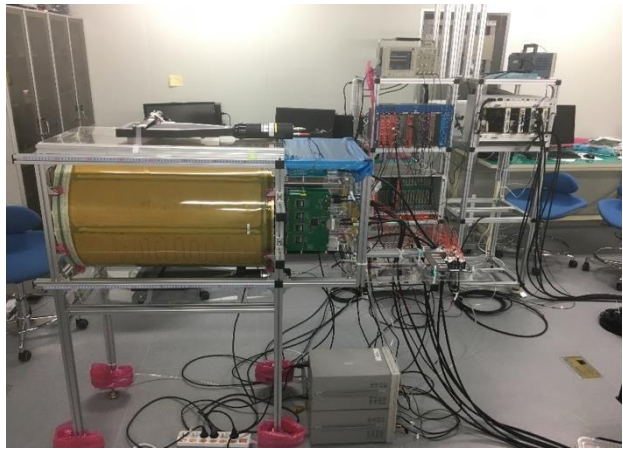
- TPC : Three-dimensional tracking for the charged particles
- Large acceptance (~ 3π sr)
- Dimensions : 1 (D) x 1.2 (L) m^2 (cylindrical hole along the beam path)
- Cathode placed in the middle of TPC
- Triple GEM based pad readout at both endcaps

Time Projection Chamber : Prototype R&D

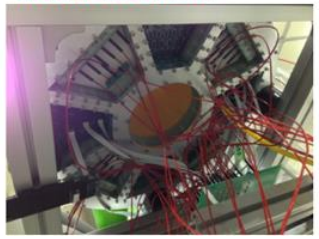


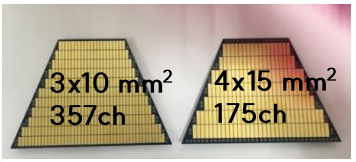


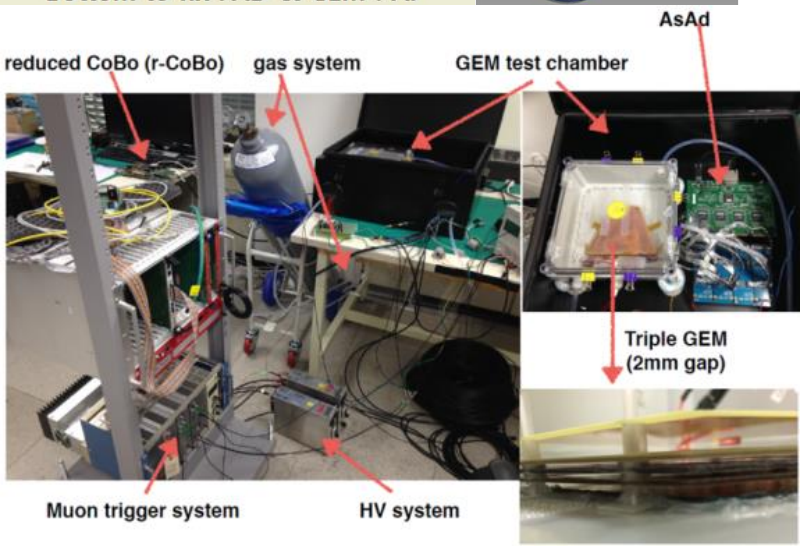


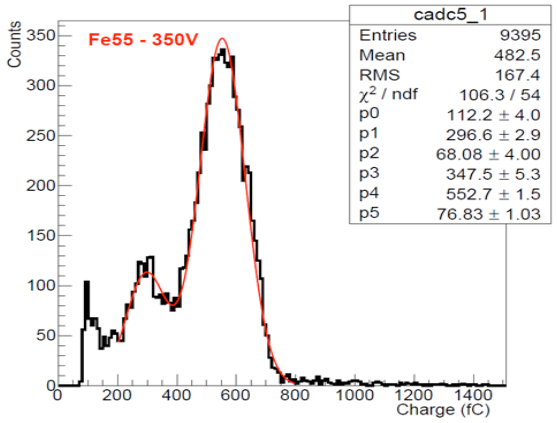


Same drift length as conceptual TPC

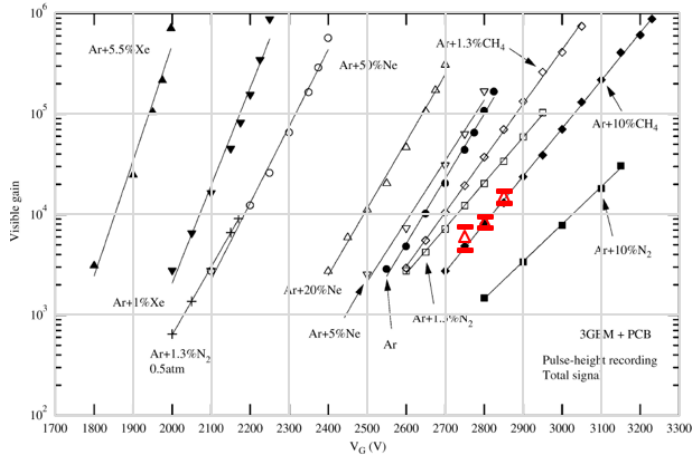








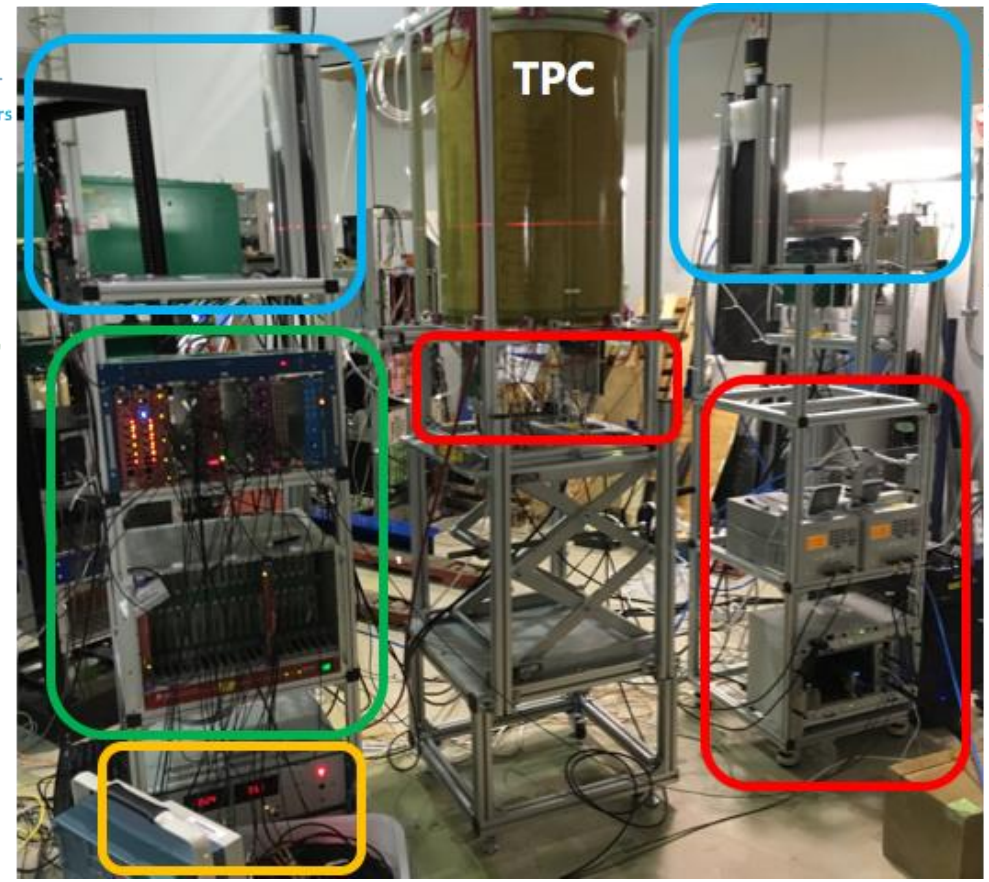
Gain of triple GEMs



Using cosmic muon & ^{55}Fe source with GET electronics

A. Buzulutskov *et al.*, NIMA 443, 164 (2000)

Time Projection Chamber : Prototype R&D (Position Resolution)



Trigger counter 1

Plastic scintillators
1cm x 1cm

Electronic & DAQ

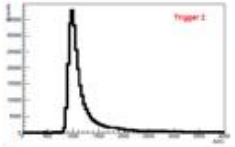
Trigger logic
VME DAQ

HV system

PNC 3500
PNC 60000

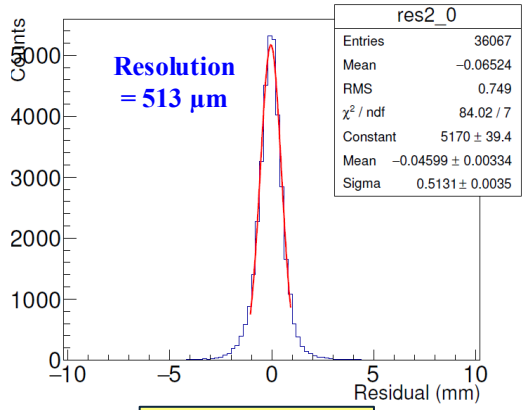
Trigger counter 2

4cm x 4cm

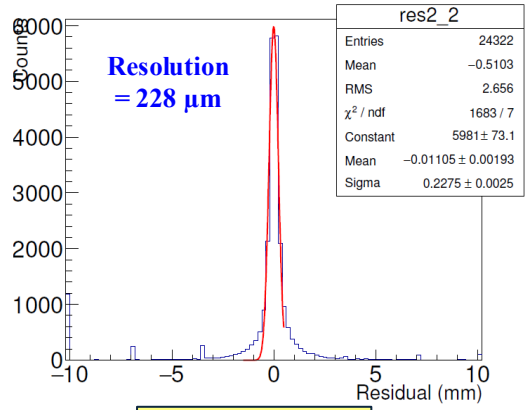


TPC readout

GET system
μ-TCA
AsAd board



4 x 15 mm² PAD



3 x 10 mm² PAD

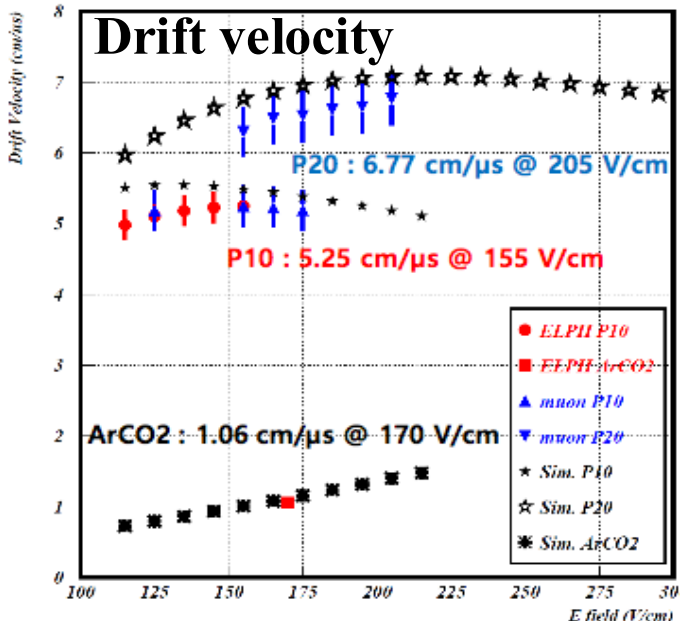
4 x 15 mm²
175 Ch.

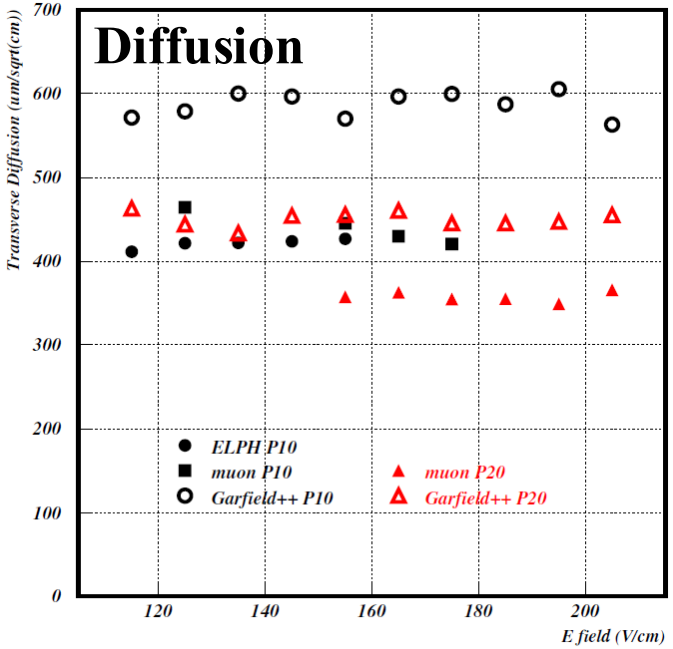
3 x 10 mm²
357 Ch.

e^+

Positron beam test at ELPH, Tohoku University (Nov. 1 ~ 2, 2016)

Time Projection Chamber : Prototype R&D (Drift Velocity & Diffusion)



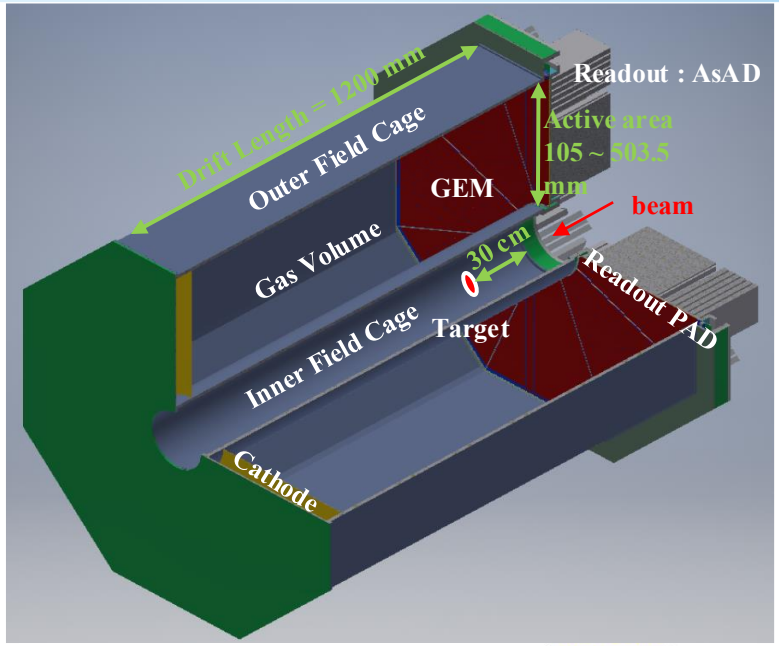


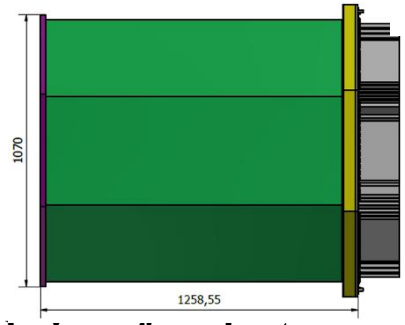
- **ELPH beam test**
  - Beam height : 20.24 cm, 35.24 cm, 50.24 cm
  - Electric field : 115 ~ 155 V/cm for Ar-CH_4(90:10)
    170 V/cm for Ar-CO_2(90:10)
- **Cosmic-ray muon test**
  - Trigger counter : 4 cm & 20 cm
  - Electric field : 155 ~ 175 V/cm for Ar-CH_4(90:10)
    155 ~ 205 V/cm for Ar-CH_4(80:20)

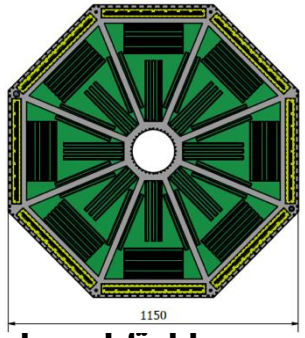
- $v_{drift} \leq 5.3$ cm/μs for P-10 : Maximum distance : 512 timing bins x 0.04 μs/bin x 5 cm/μs ≅ 100 cm
- Tested P-20 with cosmic muons : $v_{drift} > 6$ cm/μs that is suitable for LAMPS TPC if we want to read out signals from one end

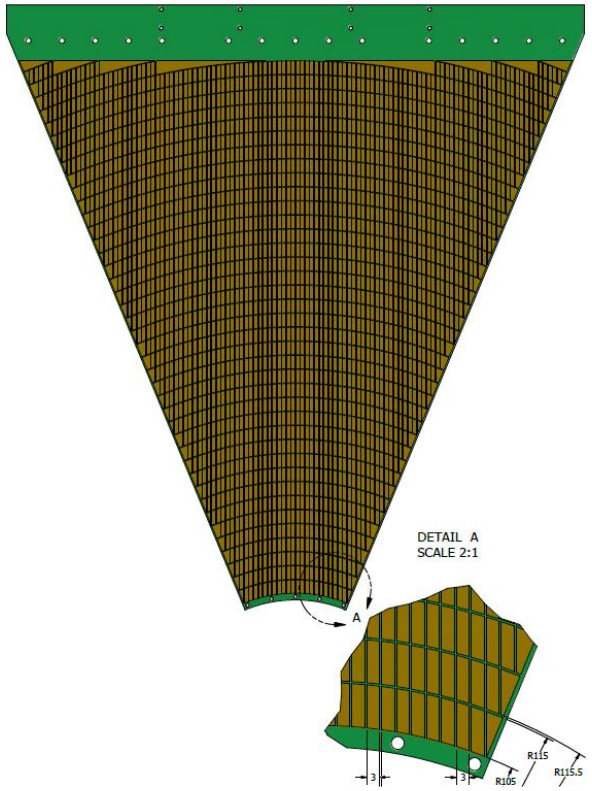
P10 : 420 $\mu m/\sqrt{cm}$ @ 155 V/cm

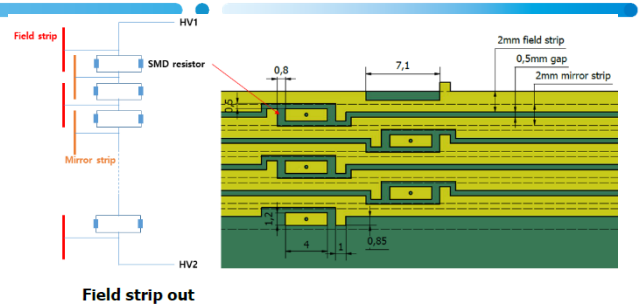
Time Projection Chamber : Final Design



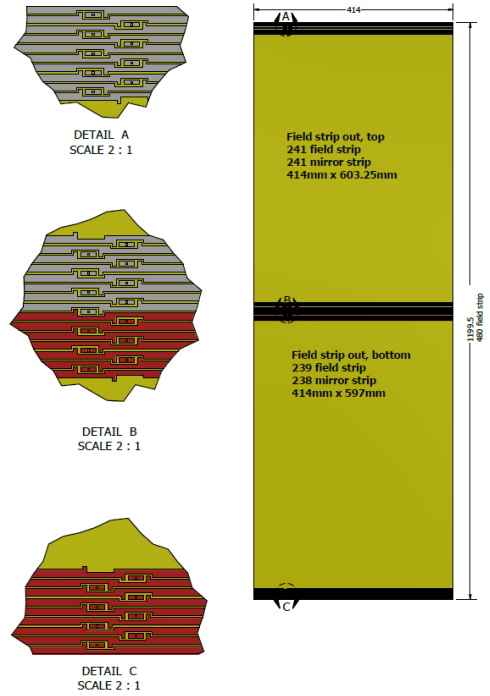








Field strip out

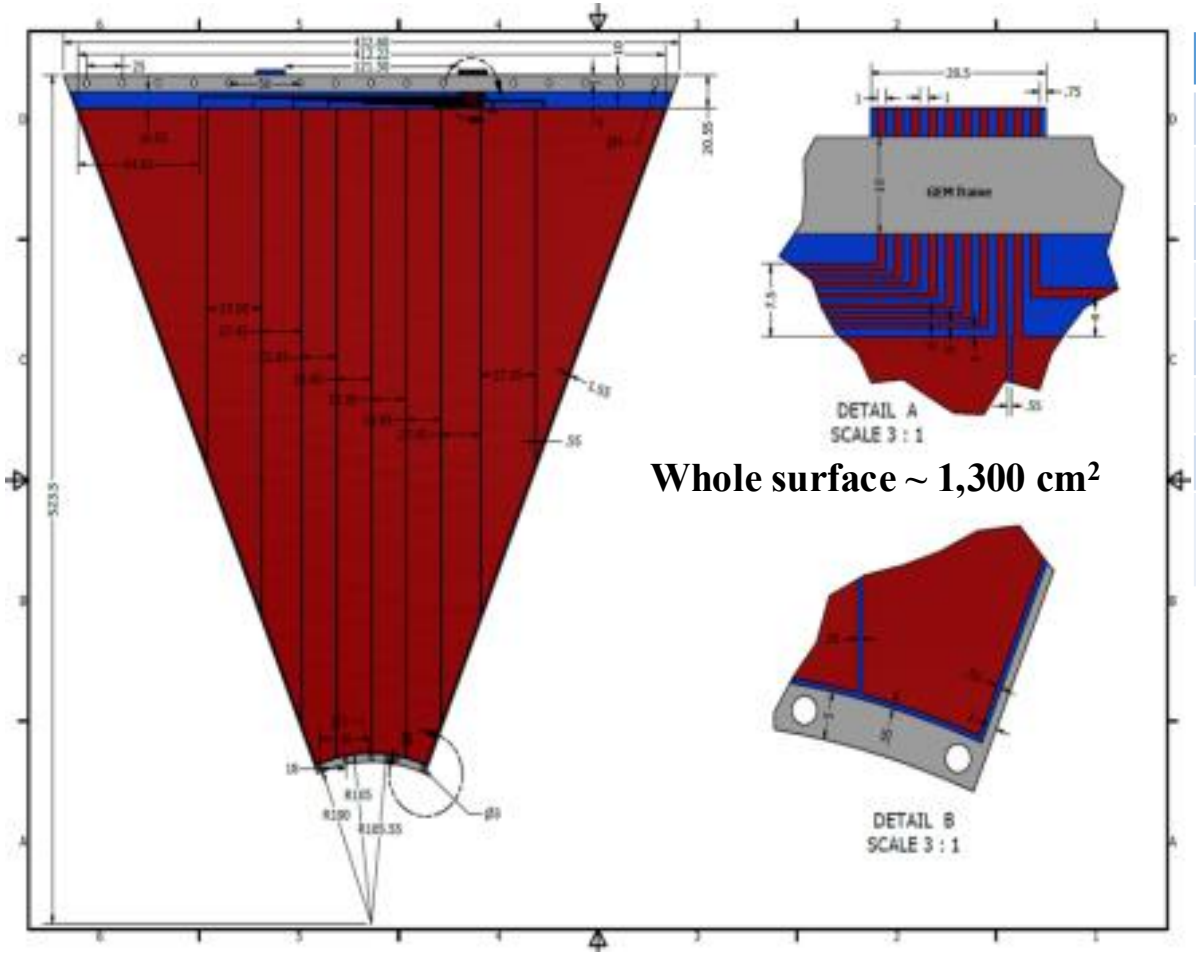


- Pad dim. : ~ 3 x 10 mm^2
- # of Ch. : 2,698/sector x 8 sectors = 21,584
- FEE : 11 AsAD/sector x 8 sectors = 88 AsAD

- Final design of readout, gas vessel, and field cage
  - Readout will be only at the upstream end.
  - P-20 gas with v_{drift} > 6 cm/μs meets entire readout time of GET electronics over full drift length (120 cm).
  - Octagonal outer barrel and circular inner barrel (X/X_0~1.55%), active gas volume ~ 1,200 Liter
  - Inner radius : 150 → 100 mm, Outer radius : 500 → 535 mm
  - Maximize the active region for R = 105 ~ 503.5 mm
  - Using Quadruple GEMs (effective gain ≥ 10^3)

- Pitch of Cu strips : 2.5 mm (2 mm strip + 0.5 mm gap)
- 480 field strips + 479 mirror strips
- 1MΩ SMD resistor
- Electric field strength : E_z = 200 V/cm

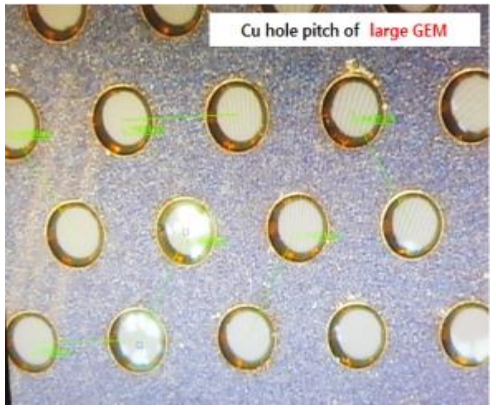
Time Projection Chamber : GEM Foil Design

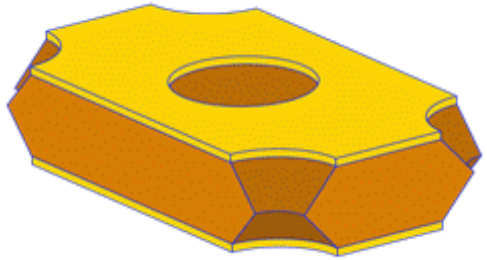


Whole surface ~ 1,300 cm²

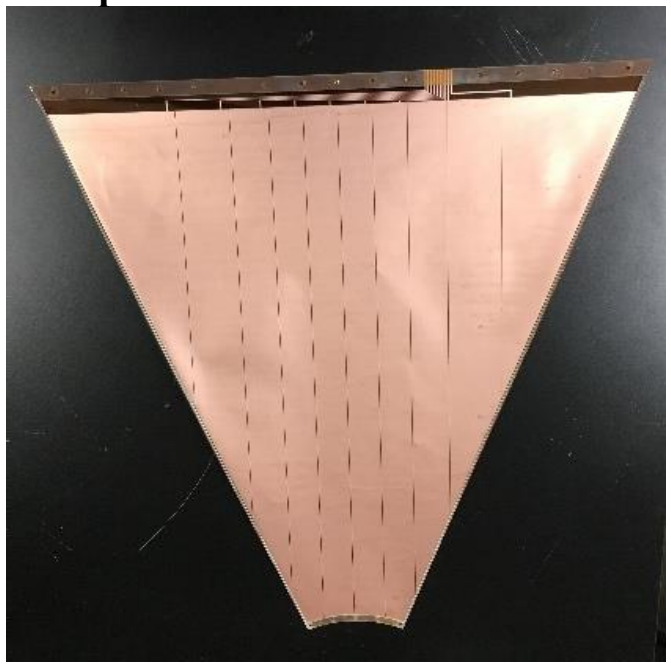
G10 frame(1 mm-thick) up & down
→ 2 mm gap between GEM layers

Gas Electron Multiplier for LAMPS TPC	
Thickness of PI	50 mm
Thickness of Cu	5 mm each
Hole size	70(2) mm
Shape of hole	Bi-conical
Pitch	140 mm
# of Segment	10
Capacity	≤ 6 nF/100 cm²
Leakage current (@500V bias)	≤ 5 nA/100 cm² ~≤ 5 nA/section





Sample of GEM foil for LAMPS TPC

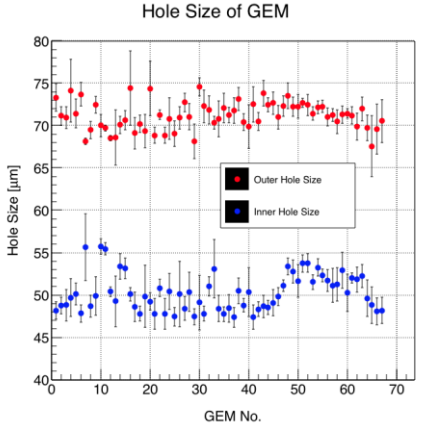


Number of sub HV sectors in a GEM foil : 10 on both top & bottom layers

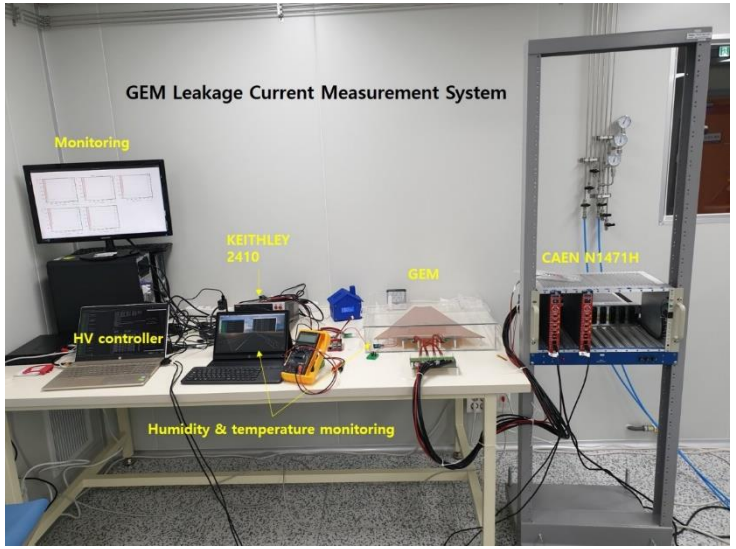
GEM Foil QA

GEM QA : 64 GEM

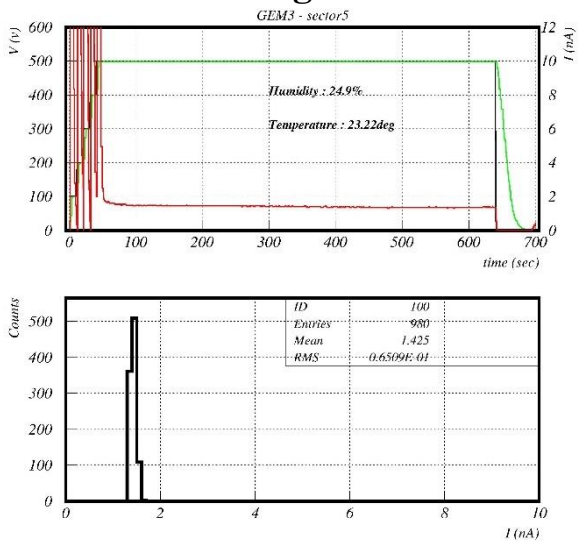
- check hole size
- check leakage current < 5nA/100cm^2
- check Capacitance < 6nF/100cm^2



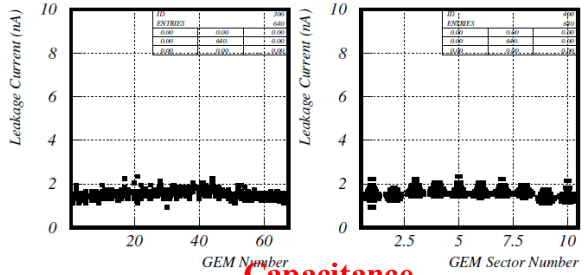
GEM Leakage Current Measurement System



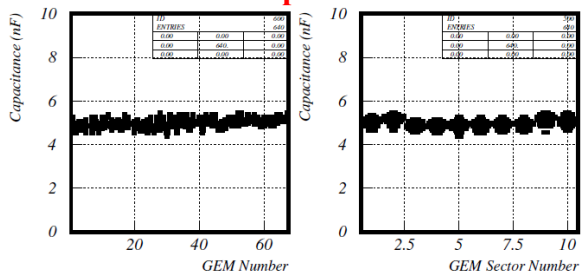
GEM Leakage Current



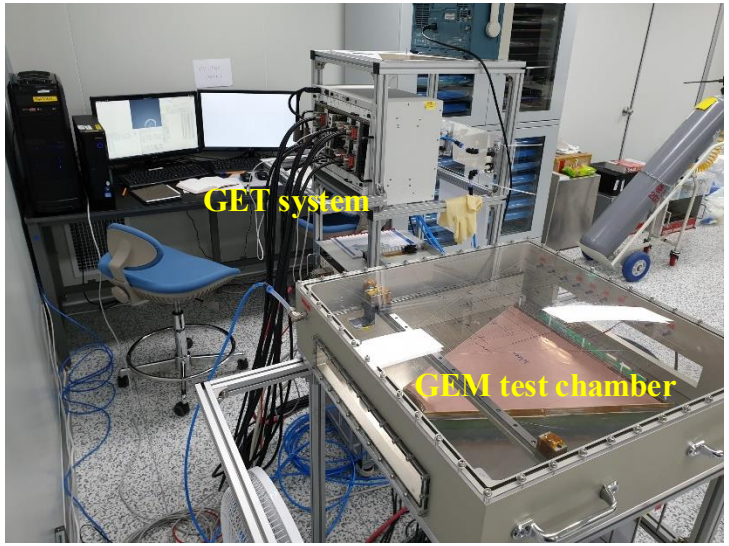
Leakage Current

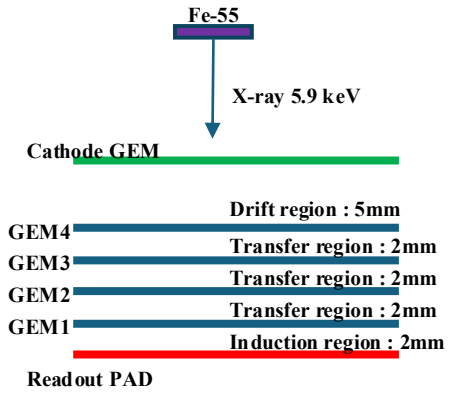


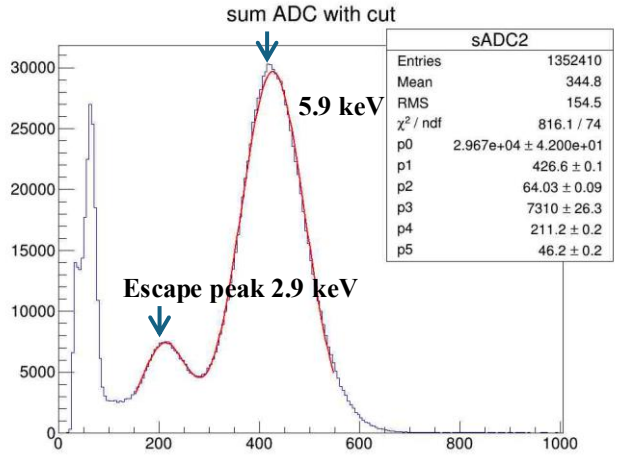
Capacitance

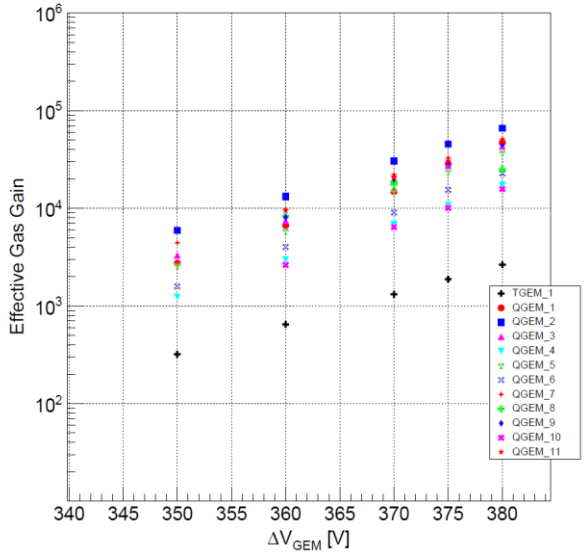


Quadruple GEM gain

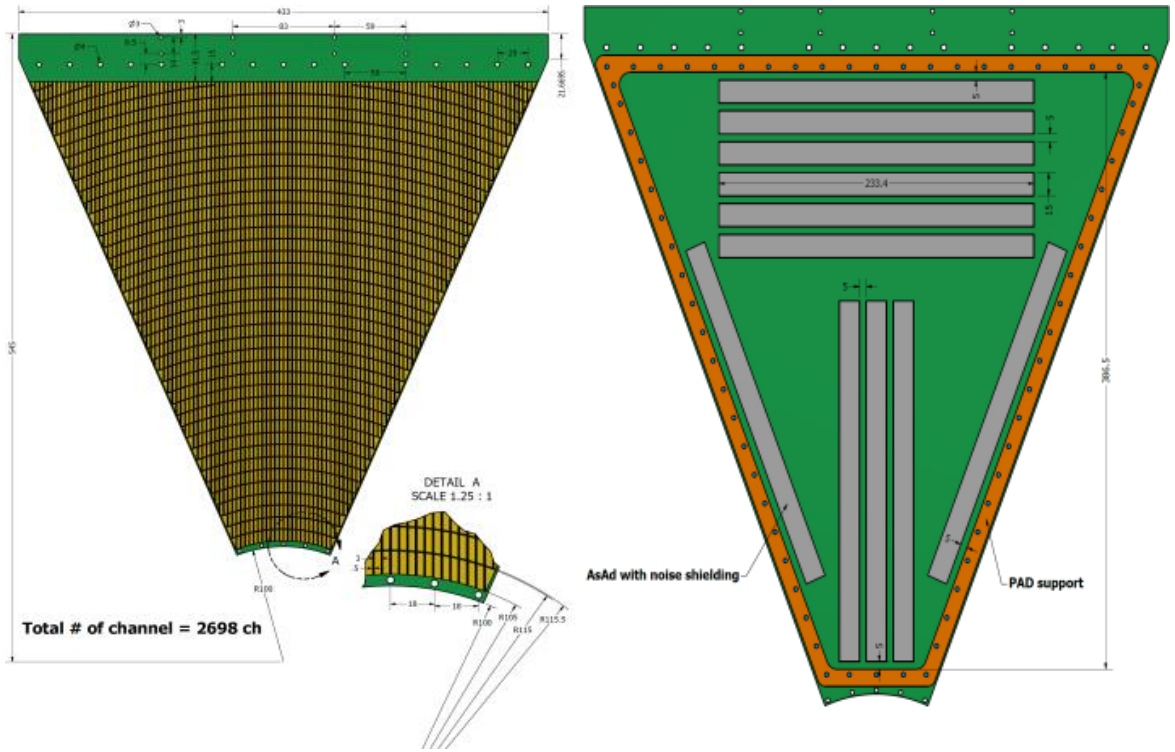








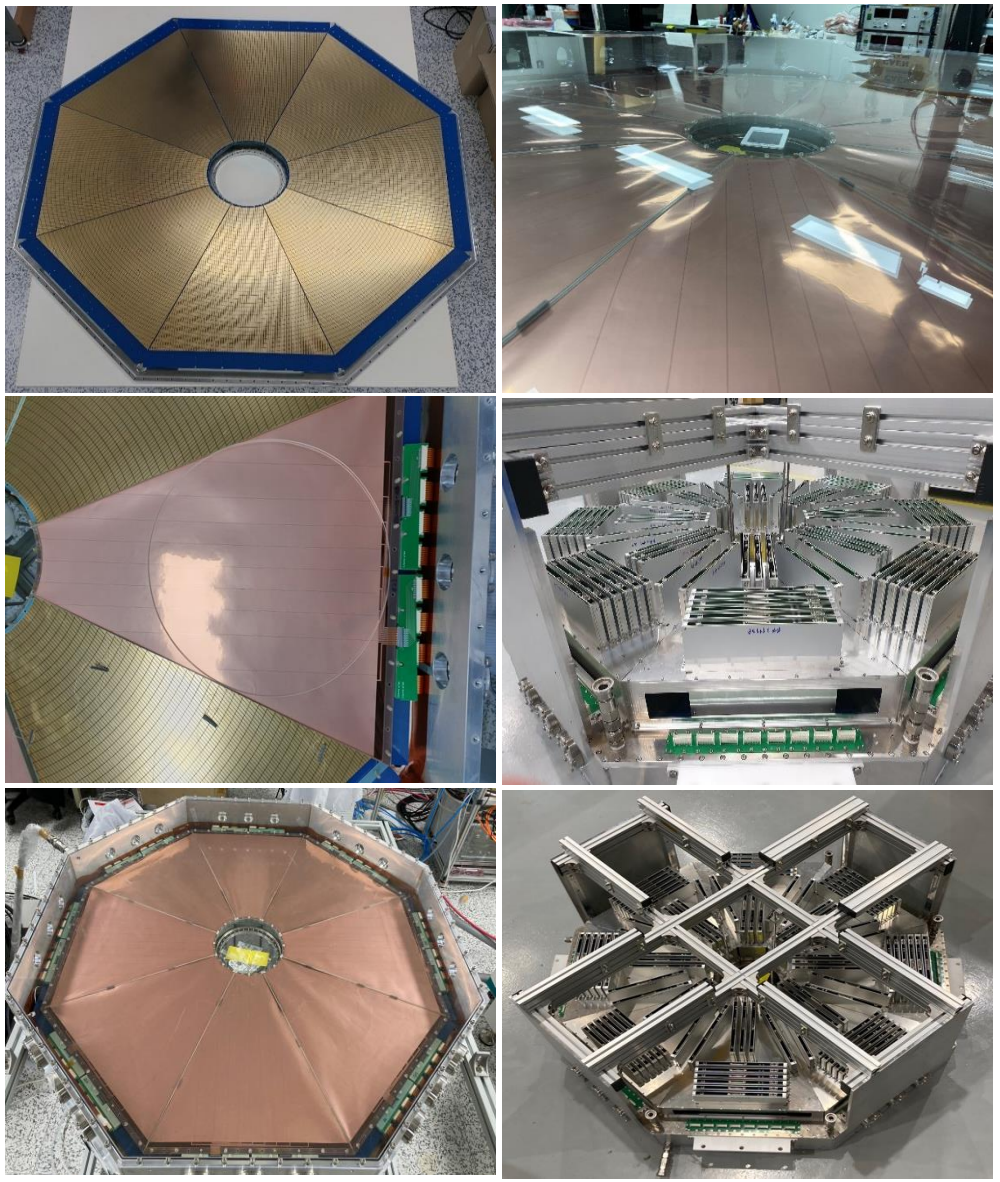
LAMPS TPC Readout Chamber



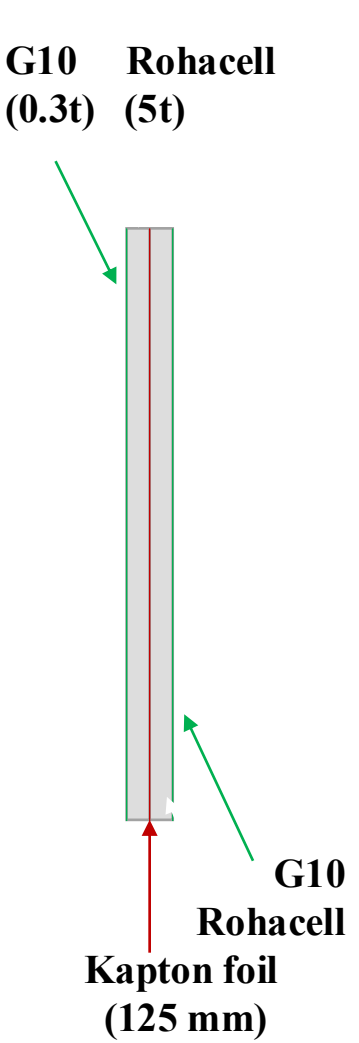
6 layered PCB
PAD/GND/Signal/Signal/GND/Connector

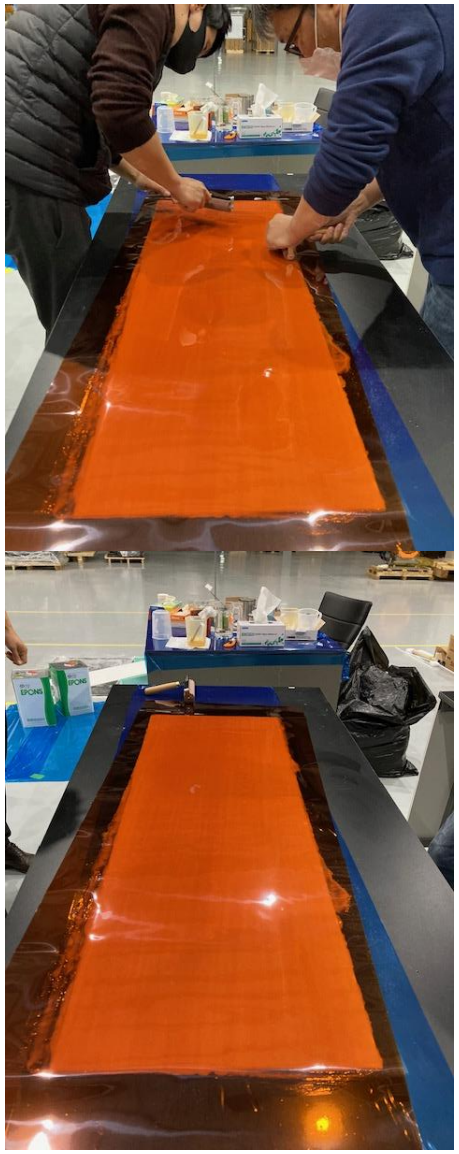
Readout chamber was divided into 8 sectors with quadruple GEM foils.

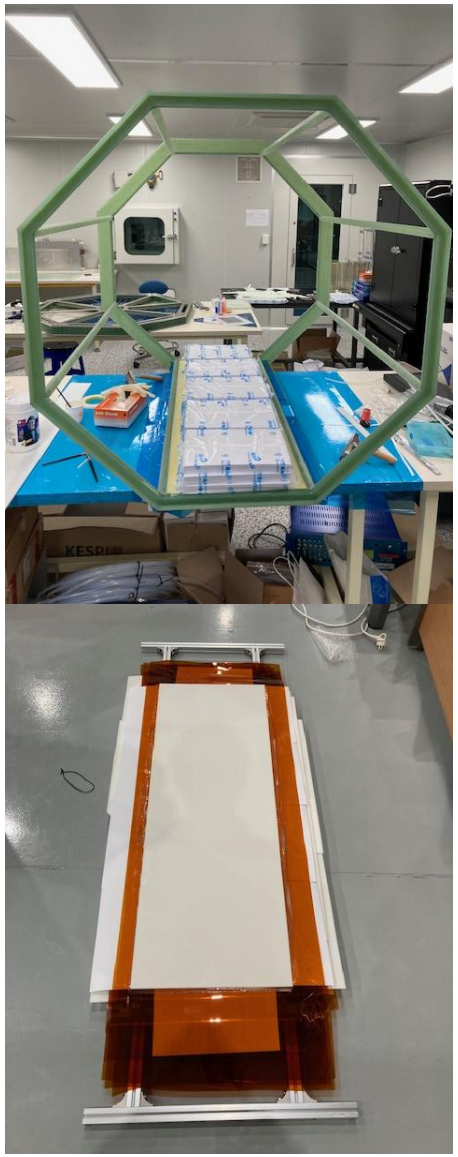
Readout Chamber

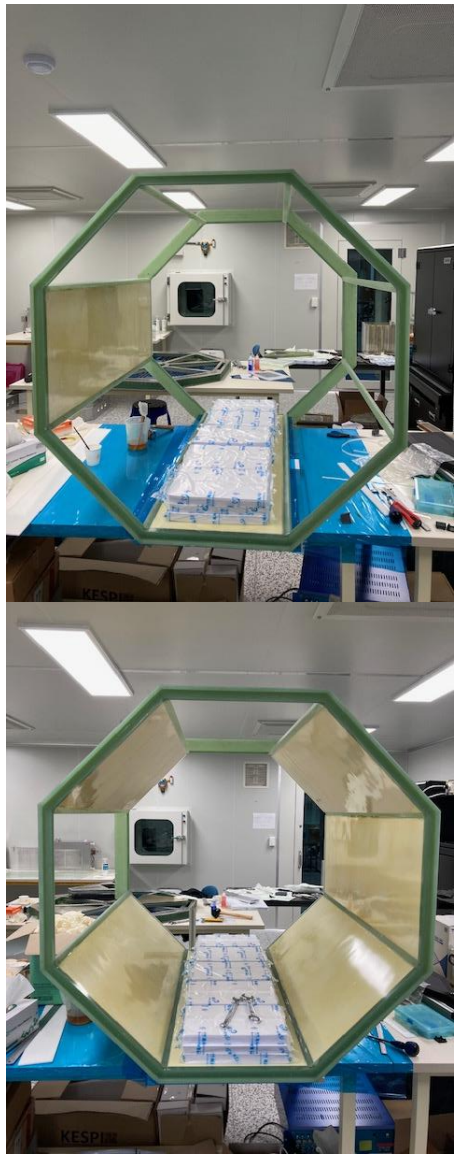


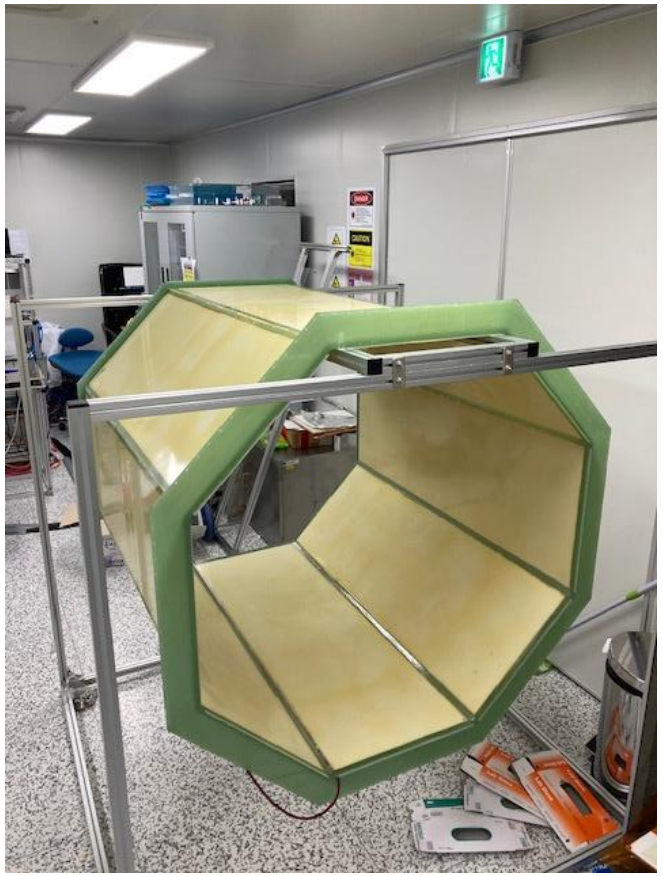
LAMPS TPC Outer Gas Vessel





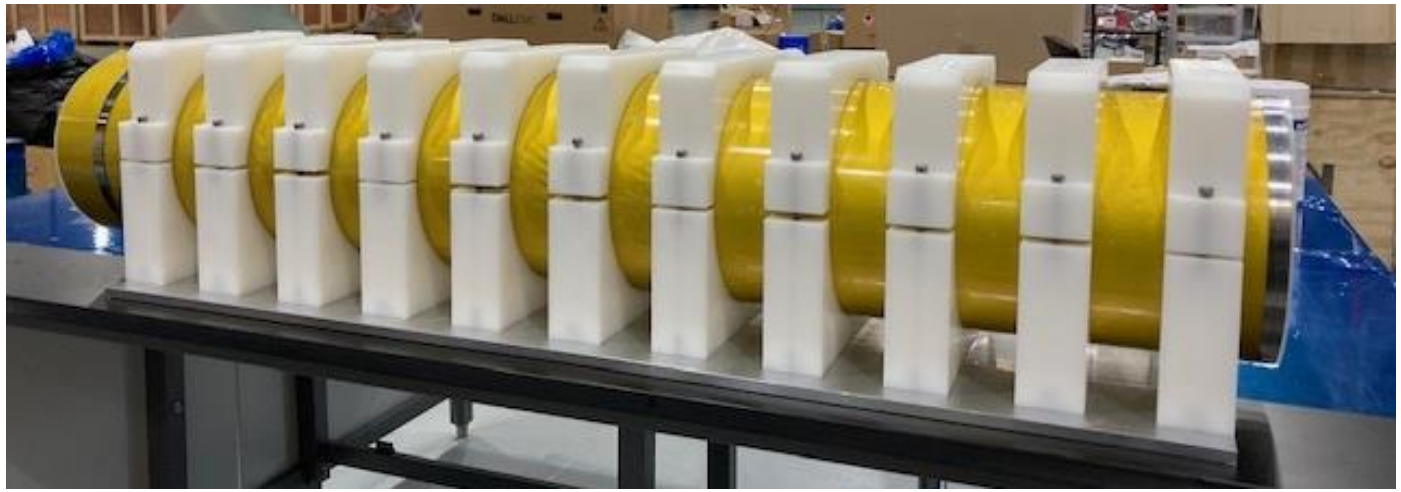






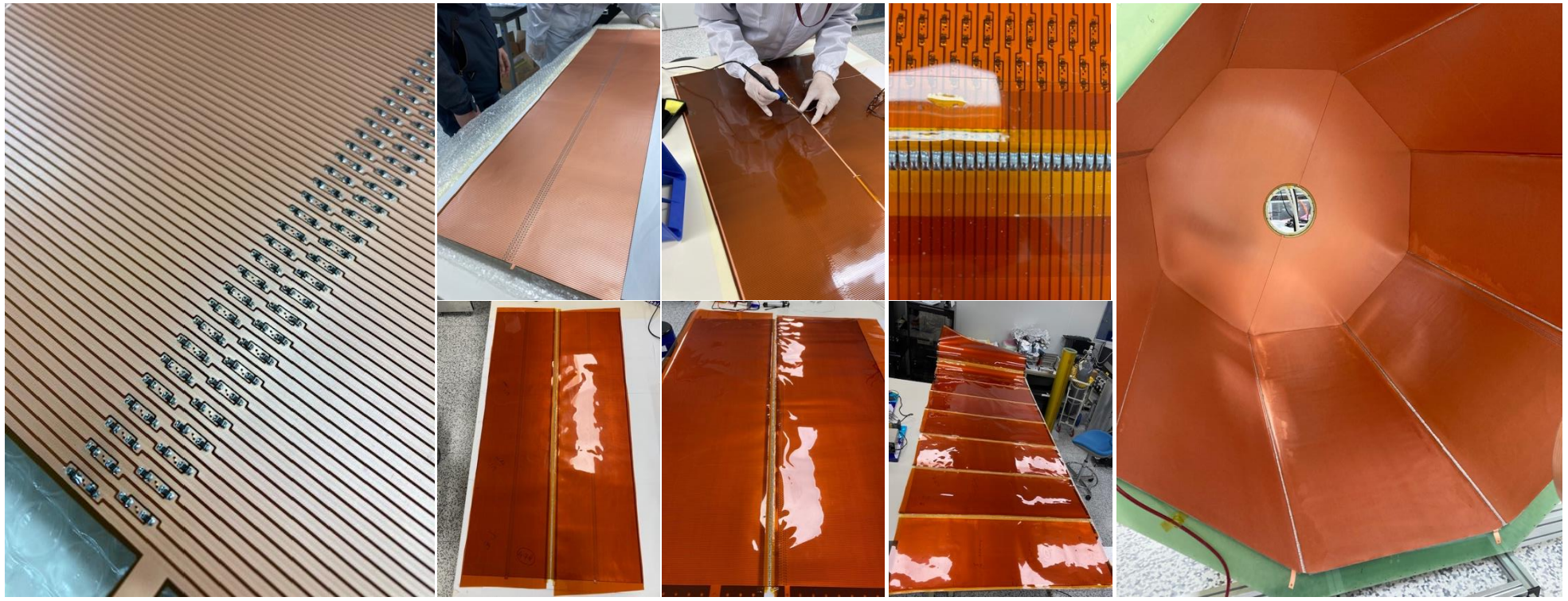
Cut Rohacell and Kapton gluing with Epoxy

LAMPS TPC Inner Gas Vessel



G10 sheet (0.3 mm) + Al-Kapton (50 mm)

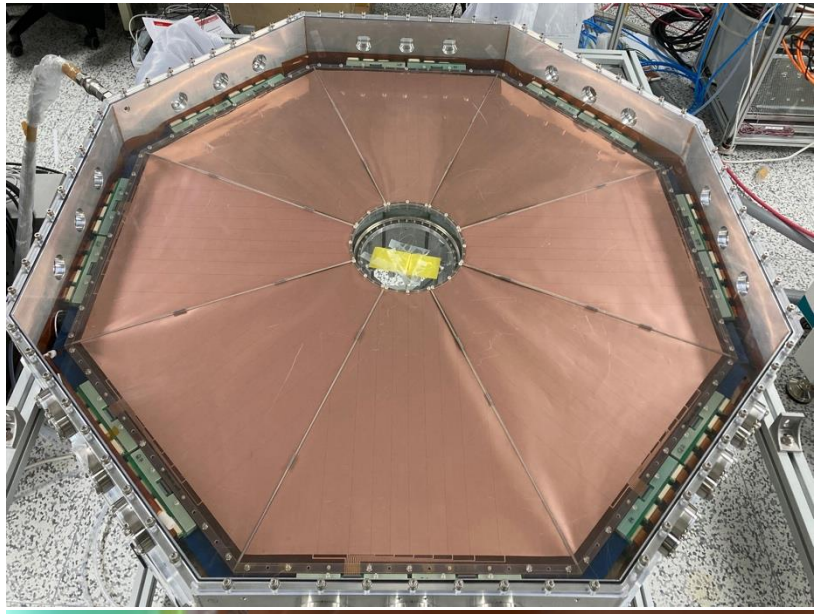
LAMPS TPC Field Cage

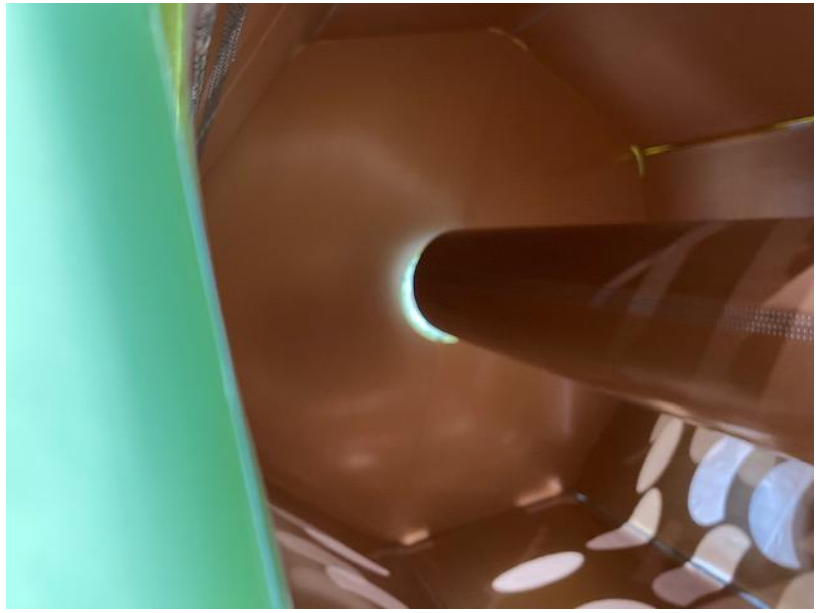


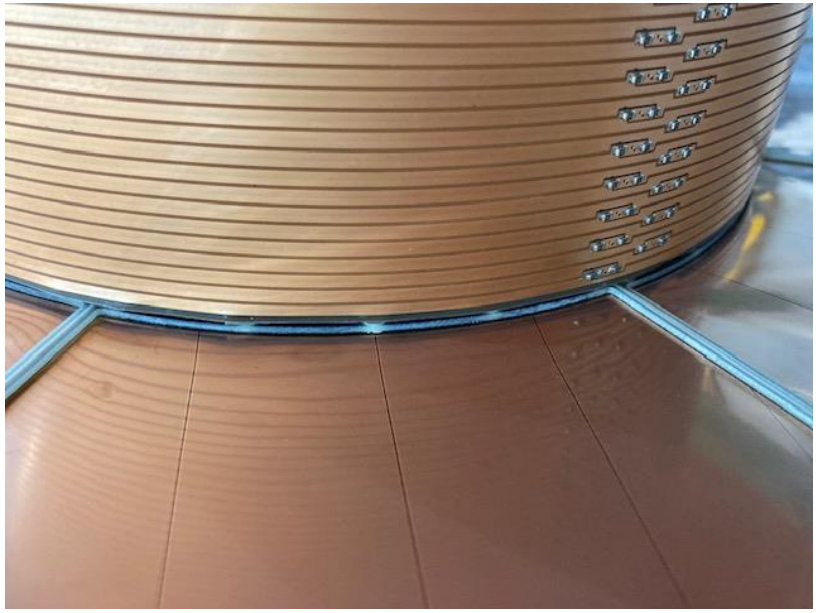
Due to limitation in flexible PCB board manufacturing technique, outer field cage is divided into 8 pieces.
Each piece of field strip board was connected by manual soldering, except the last one for 1MΩ resistor connection.

Inner field cage is made of 1 piece and connected with 1MΩ resistors.

LAMPS TPC Assembly

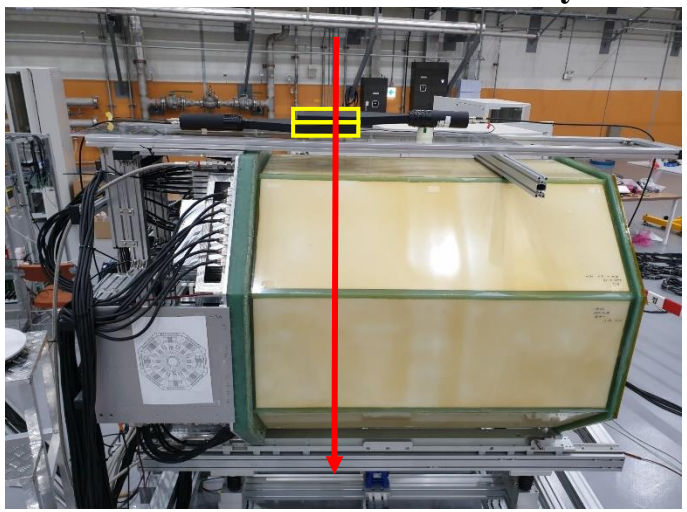






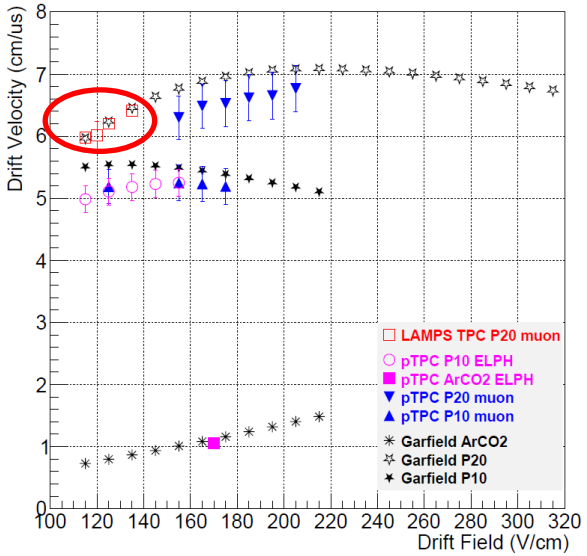
LAMPS TPC Test Results

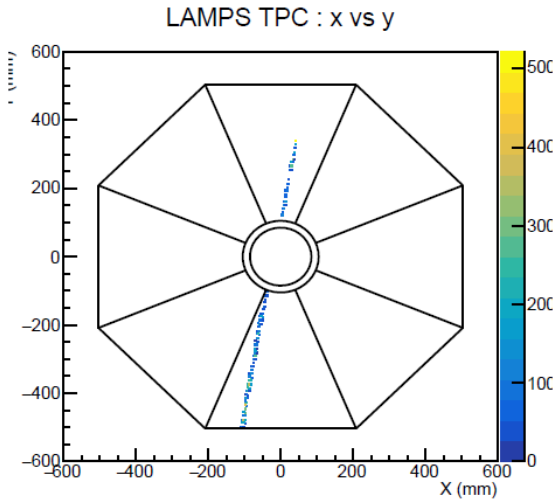
Muon Test for Drift Velocity

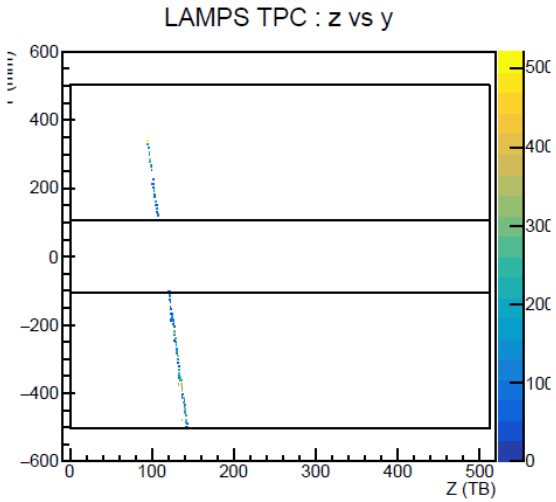


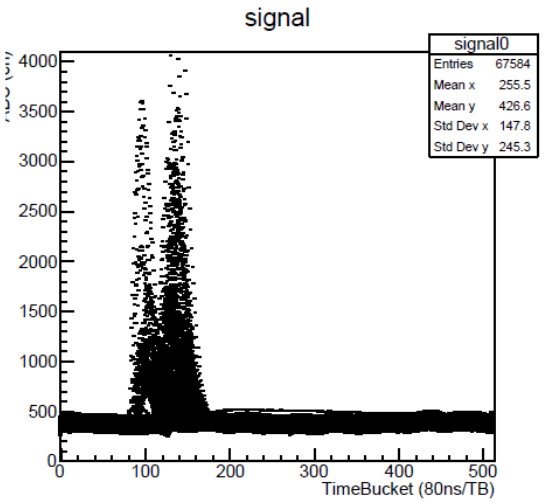
Muon trigger
- coincidence of two scintillators
- scintillator size : 20 x 20 cm^2
- trigger position : 30 cm, 60 cm, 90 cm

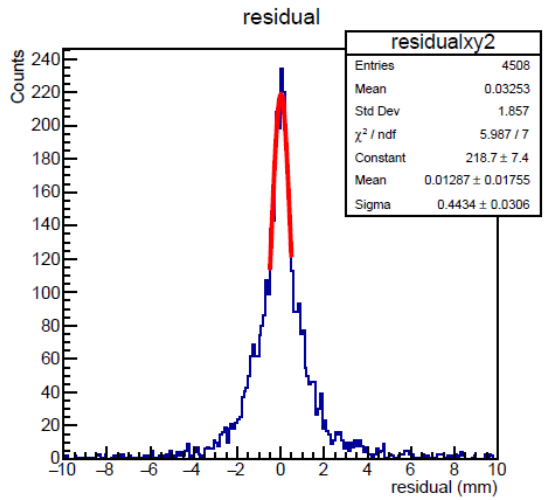
FC drift field : 115 V/cm, 125 V/cm, 135 V/cm

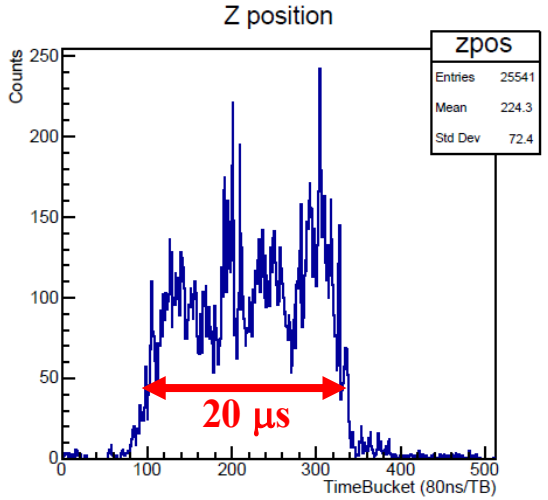


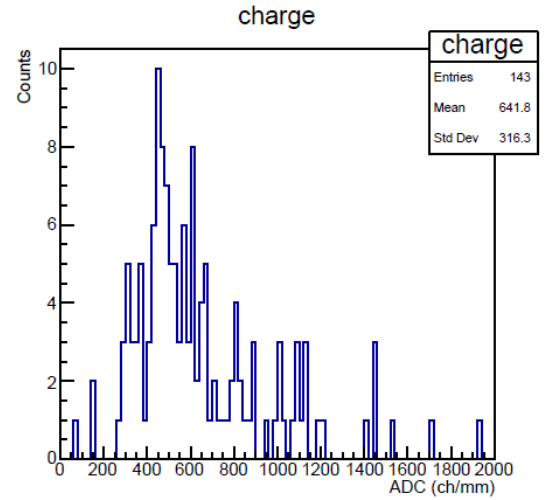




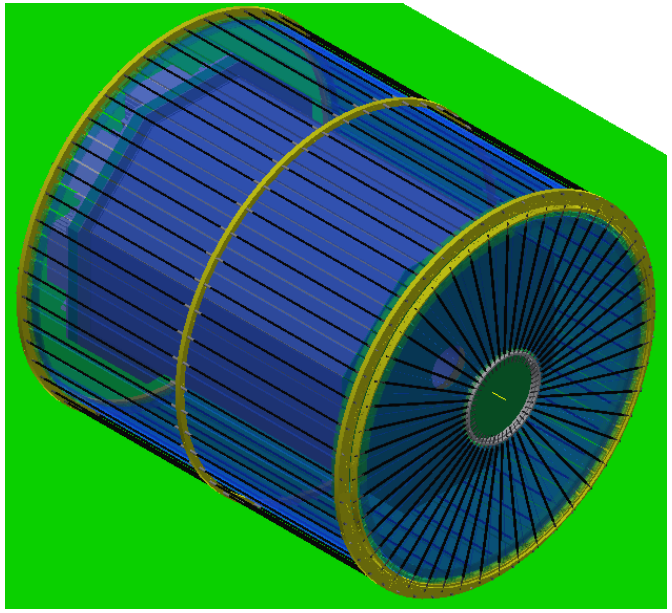
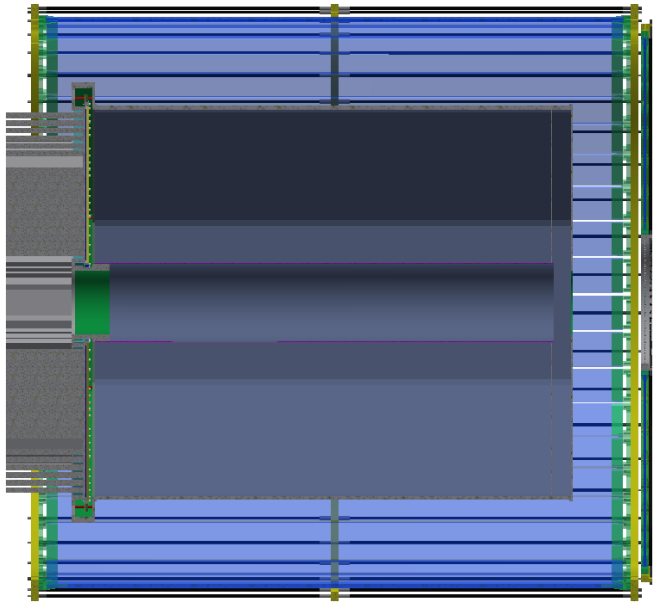
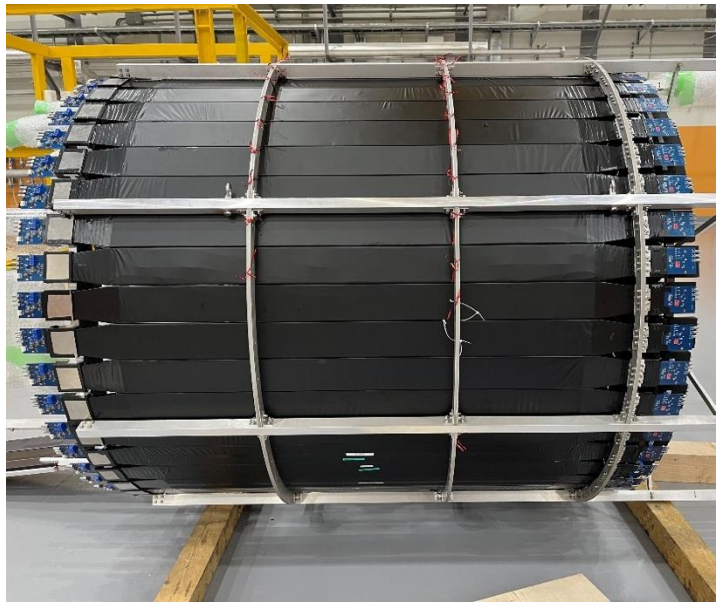






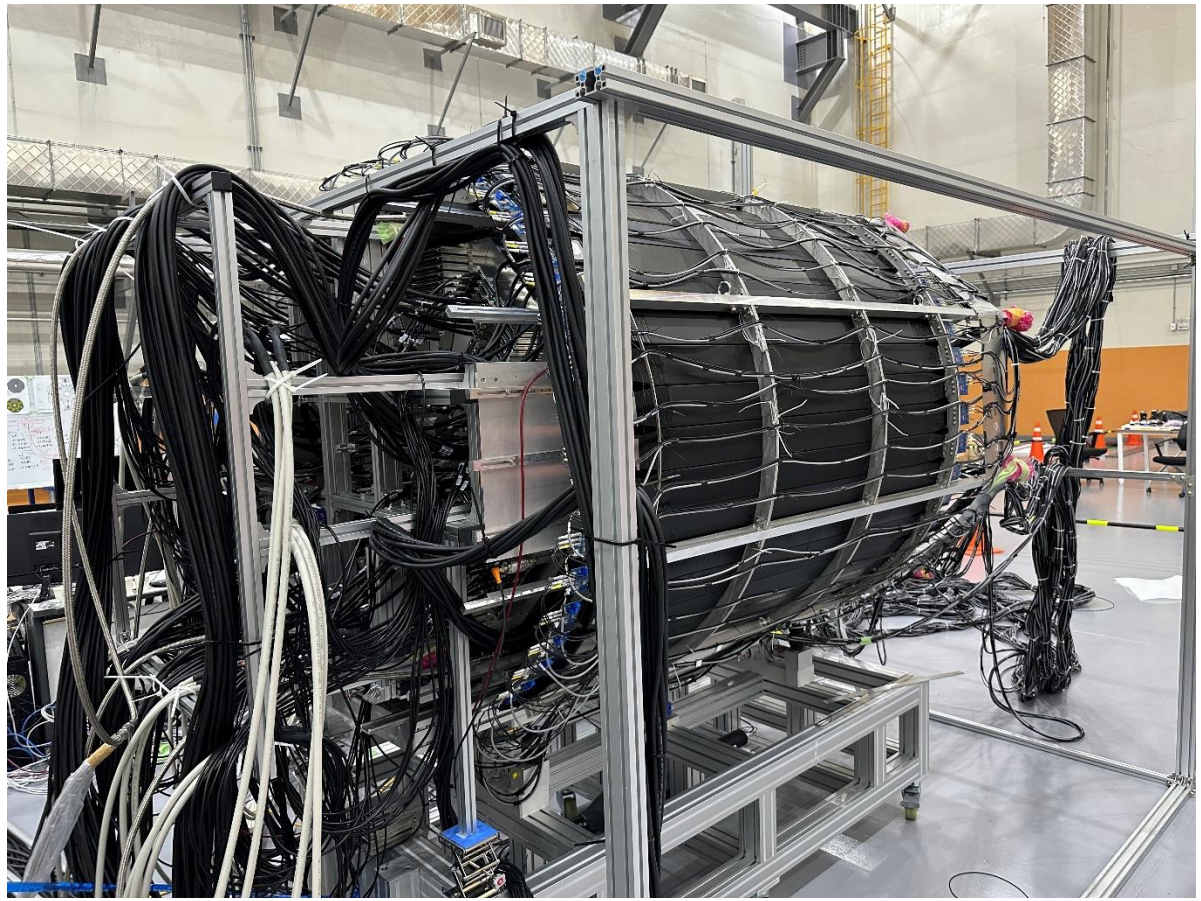


LAMPS ToF/Trigger Detector Array

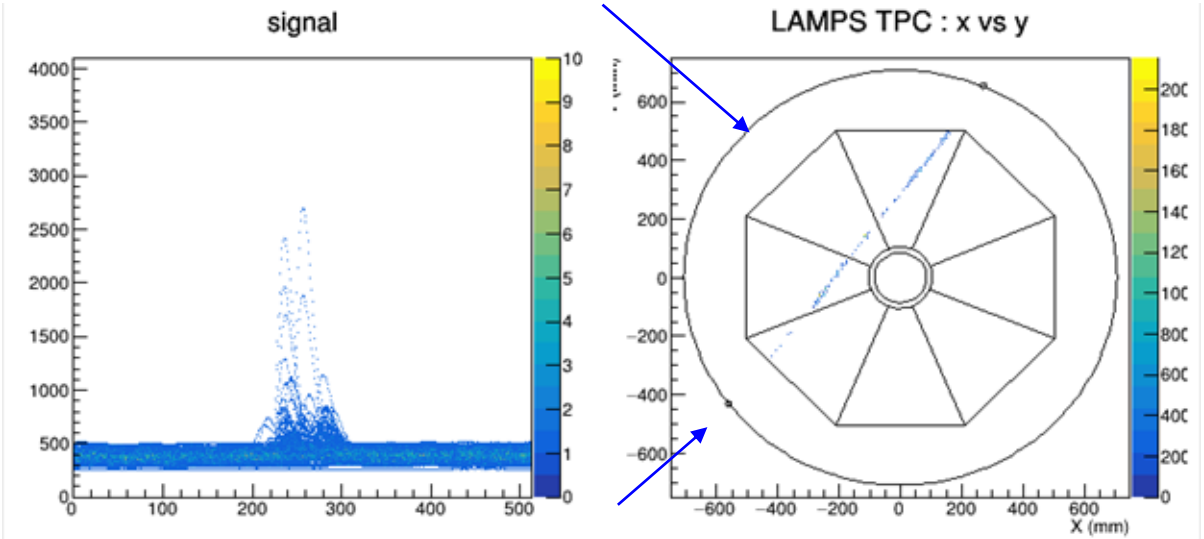





- **Time-of-Flight measurement of charged particle for PID and counting the number of charged particles for centrality selection (σ_t < 300 ps)**
  - **Barrel side : 46 x 150 (L) x 9 (W) x 1 (T) cm^3 EJ-230 scintillator with MPPC S13360-6050PE both ends**
  - **Downstream side : 48 x 50 (L) x 2.4 ~ 9 (W) x 0.5 (T) cm^3 EJ-232 scintillator with MPPC S14160-4050HS both ends**
  - **Time resolution σ_t = 150 ± 2.1 ps at bench test, σ_t = 236 ± 1.9 ps with ^{90}Sr,**
    σ_t = 163 ± 1.6 ps with cosmic muon for BToF & σ_t = 180 ± 2.7 ps with ^{90}Sr for FToF

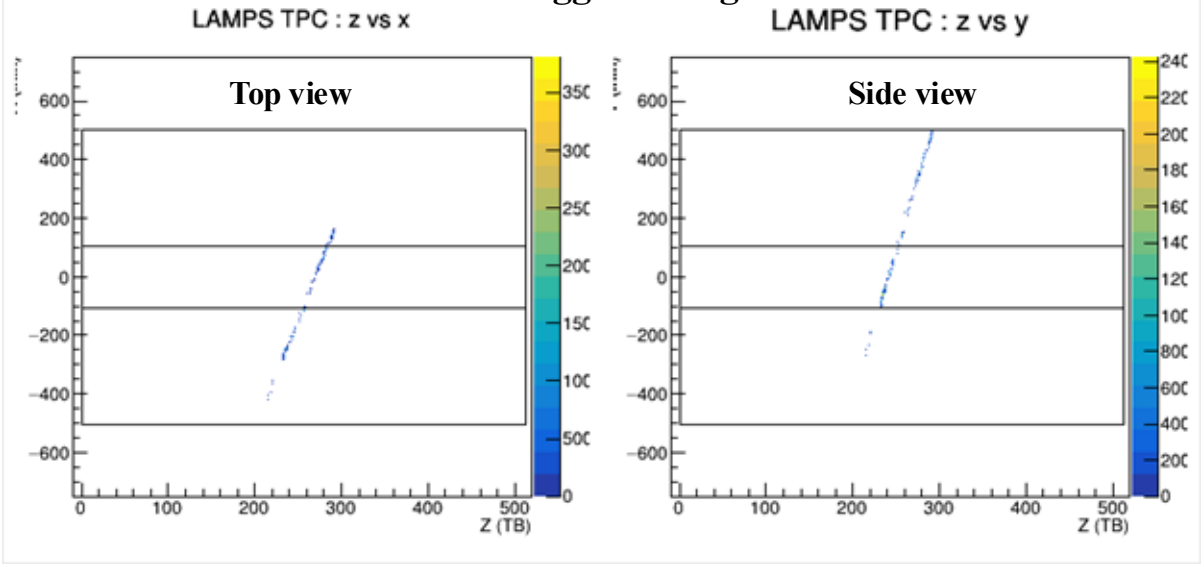
LAMPS TPC Test Results



ToF/Trigger position line



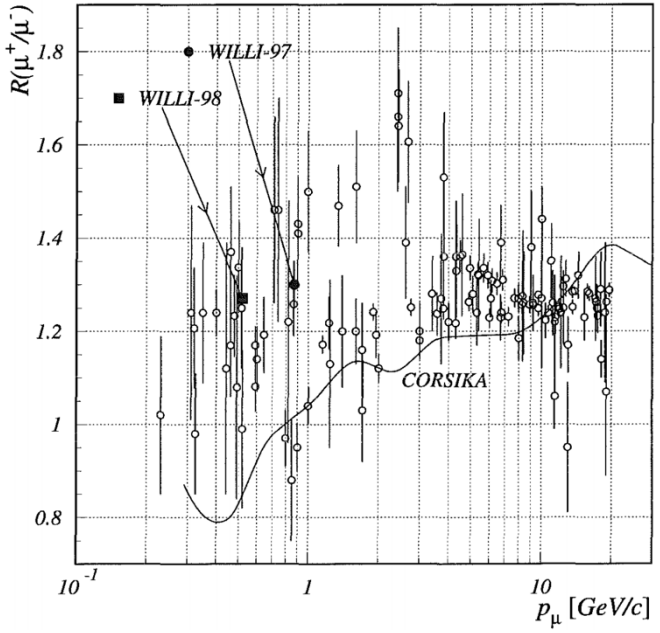
ToF/Trigger hit signal

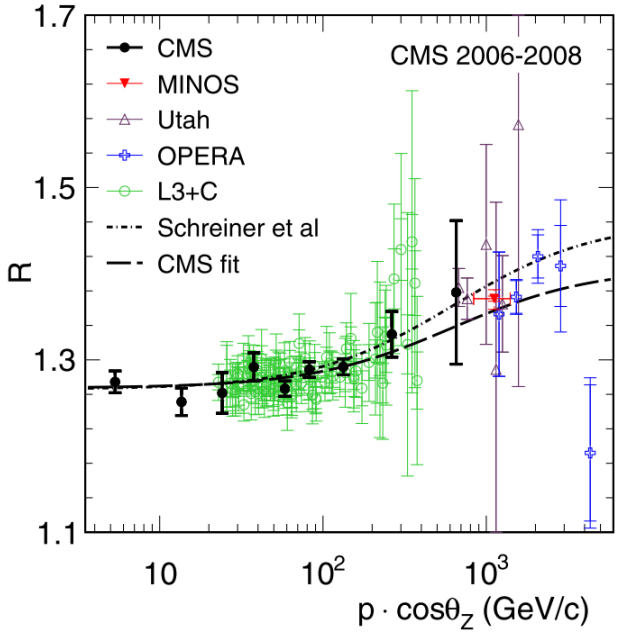


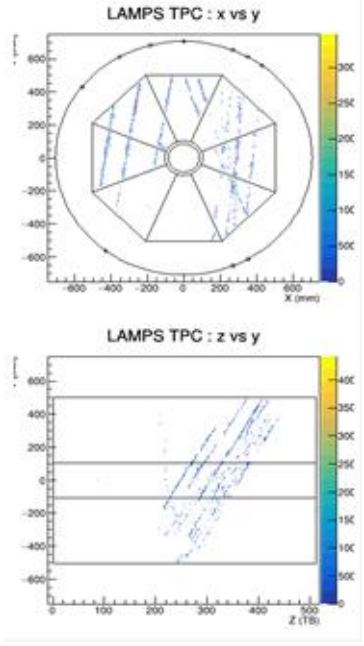
Summary

- **LAMPS is an experiment for investigating nuclear equation of state, especially symmetry energy from sub- to supra-saturation baryon densities.**
  - **LAMPS is going to use stable and rare isotope beams with varying beam energies and collision systems in intermediate energy at RAON in Korea**

- **LAMPS TPC is main charged particle tracking detector**
  - **Quadruple GEMs based without gating grid for continuous data read out**
  - **# of channels = 21,584**
  - **testing with cosmic muons is on going without magnetic field**
  - **plan to measure muon ratio in the momentum region below 1.5 GeV/*c* under magnetic field**

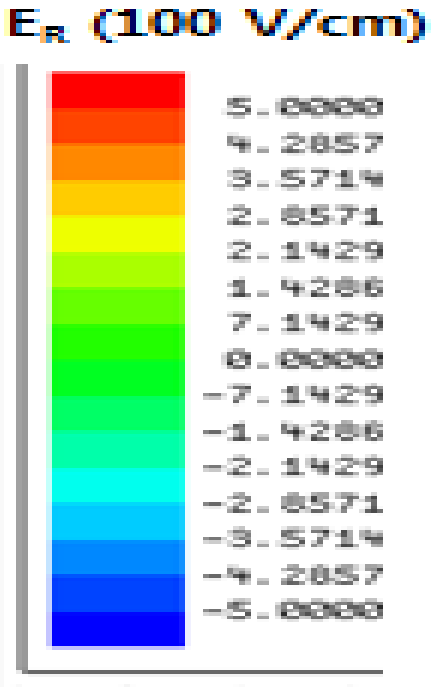


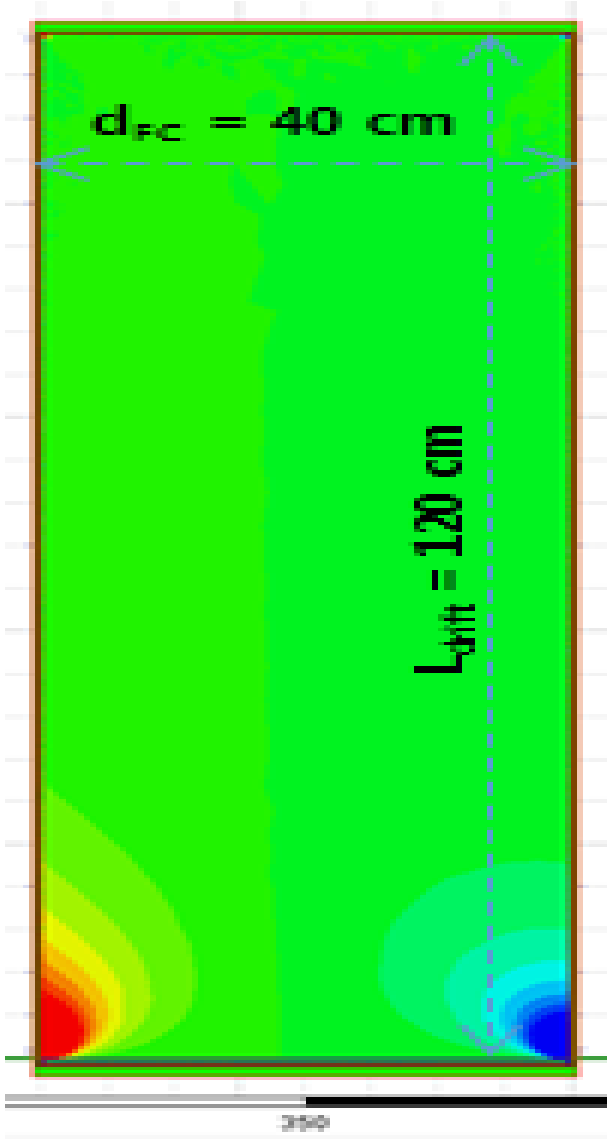


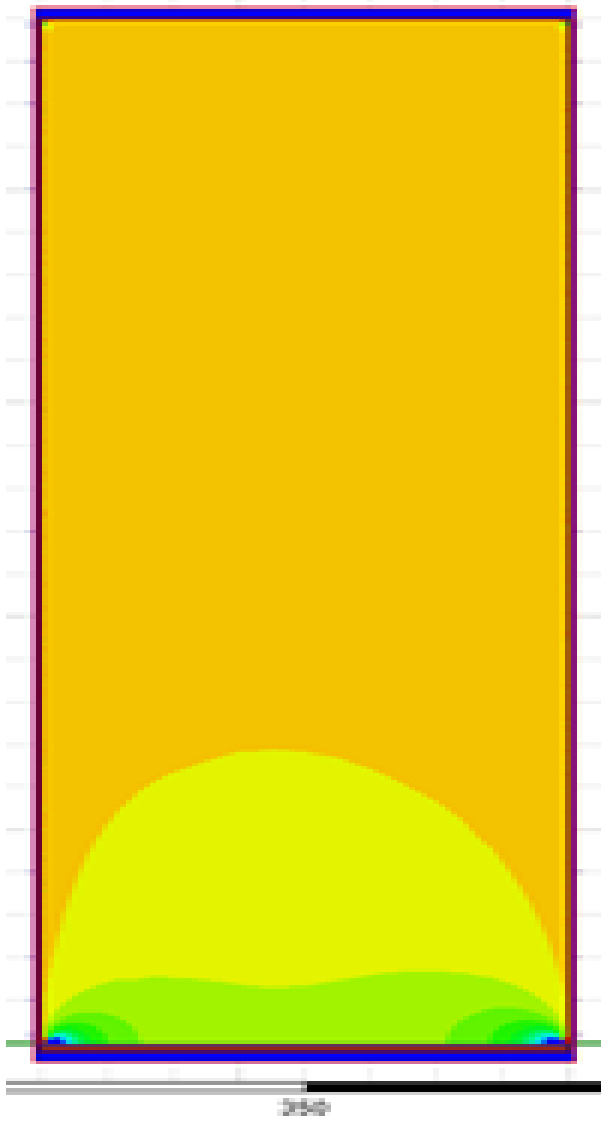


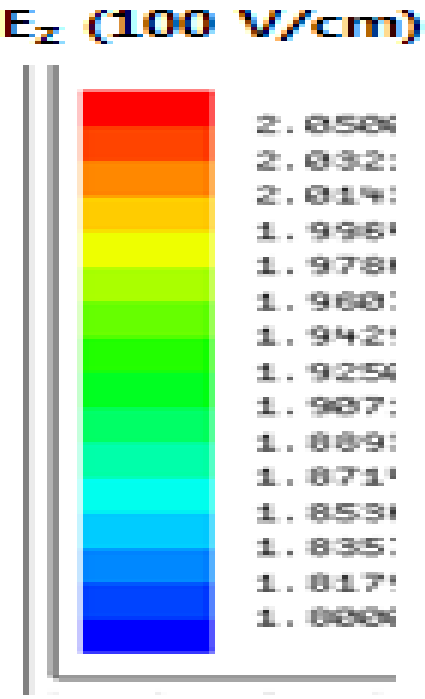
Backup

LAMPS TPC Field Cage Simulation









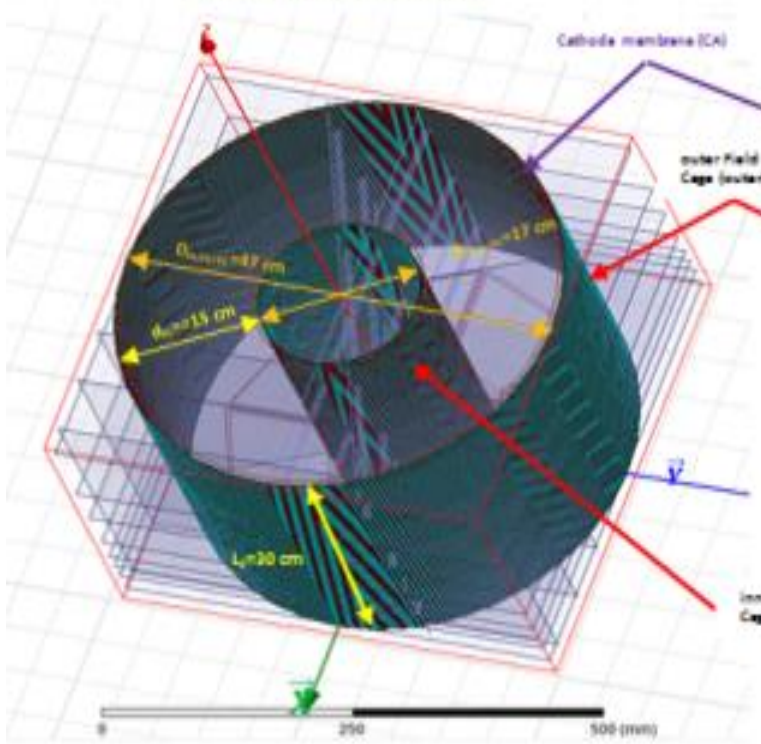
480 field strips + 479 mirror strips
Strip width = 2 mm
Strip gap = 0.5 mm

LAMPS TPC Field Cage Simulation

<Basic design concept>

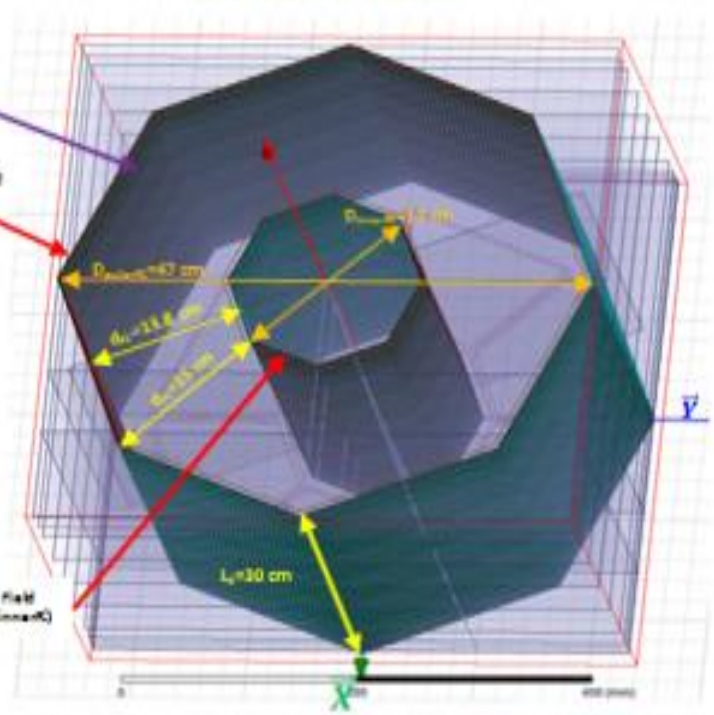
1. The drift length(L_d) is 30 cm.
2. The inner and outer diameters of field cage are 17 and 47 cm, respectively.

TPC 30[cylindrical]15



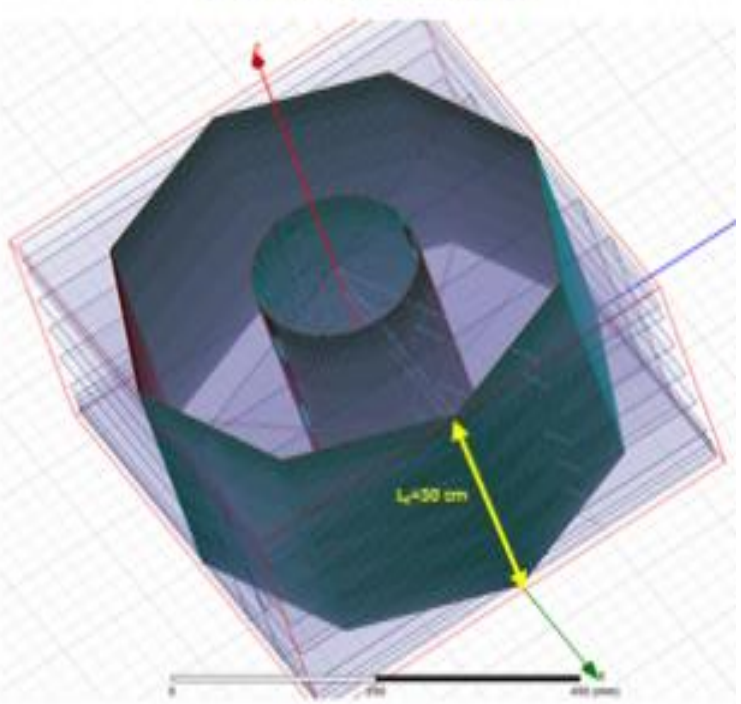
Each strip has 36 segments in Φ direction (10°/segment).

TPC 30[octagon]15



Each strip has 8 segments in Φ direction (45°/segment).

TPC 30[asymmetry]15



Each strip has 36 segments in Φ direction (10°/segment) for inner field cage.

Each strip has 8 segments in Φ direction (45°/segment) for outer field cage.

LAMPS TPC Field Cage Simulation