Status of LAMPS at RAON

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On behalf of LAMPS Collaboration

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Contents

Part 1.

Introduction to the LAMPS system

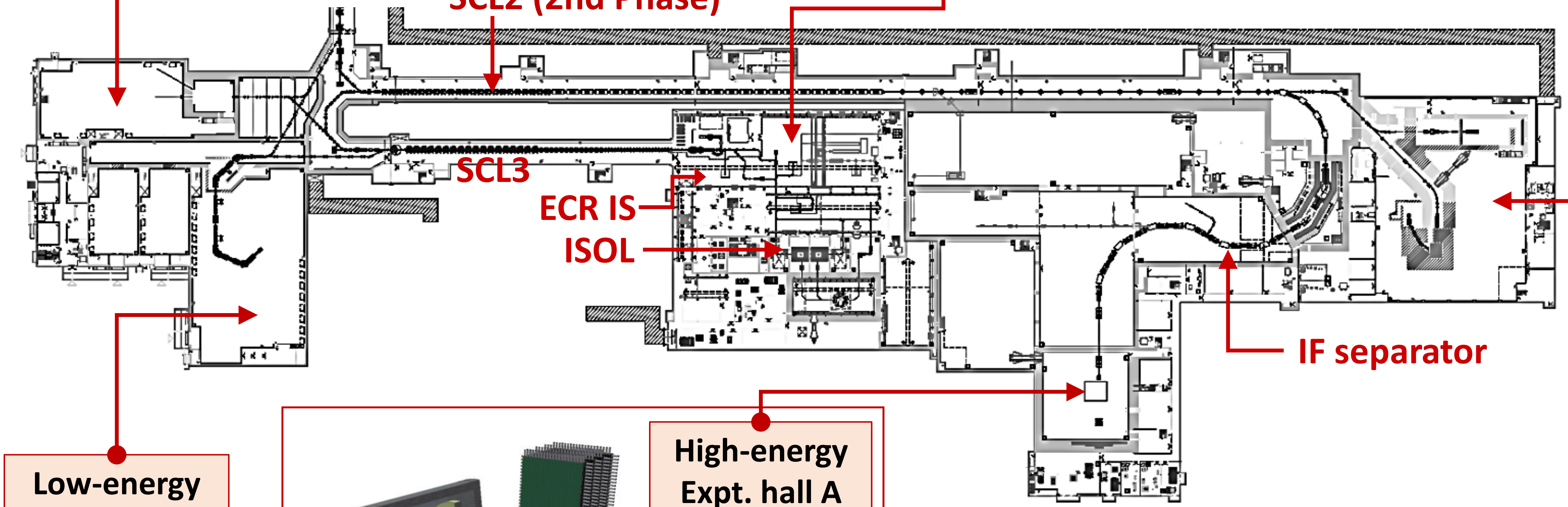
Location of LAMPS @ RAON

Low-energy Expt. hall B (NDPS)

(Session 4) Taeksu Shin
5 October 2022

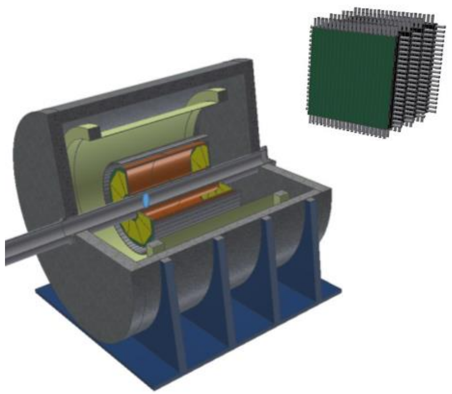
Ultra low-energy Expt. hall (MMS, CLS)

High-energy Expt. hall B (BIS, μSR)



Low-energy Expt. hall A (KoBRA)

High-energy Expt. hall A



LAMPS can take all available beams at RAON!

- SIB: ECR IS→SCL3→SCL2→IF(w/o target)
- RIB (ISOL): ISOL→SCL3→SCL2→IF(w/o target)
- RIB (IF): ECR IS→SCL3→SCL2→IF
- RIB (ISOL+IF): ISOL→SCL3→SCL2→IF

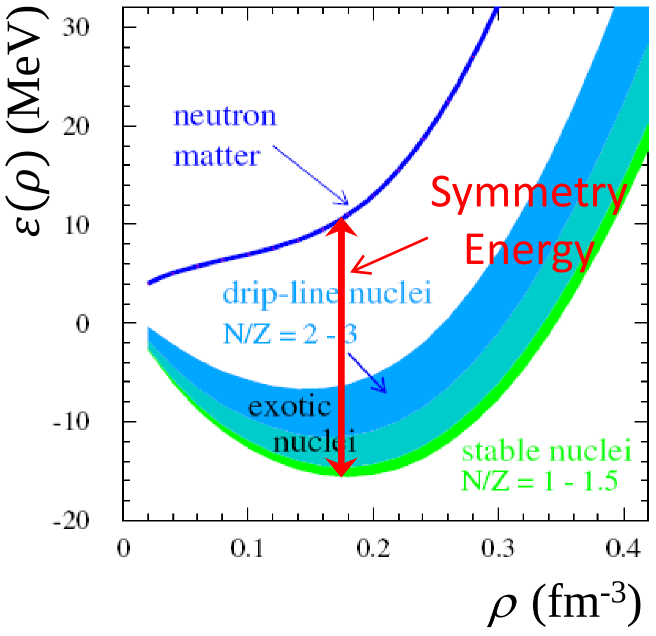
Physics objectives

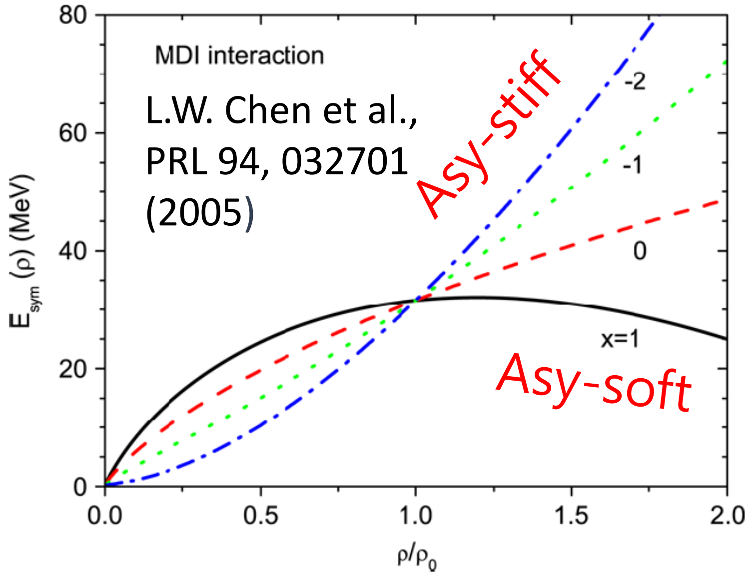
- Comprehensive understanding of the Equation of State (EoS) & symmetry energy of nuclear matter:

$$E/A = \varepsilon(\rho,\delta) = \varepsilon(\rho,\delta=0) + E_{sym}(\rho)\delta^2 + \mathcal{O}(\delta^4) + \cdots$$

with $\delta = (N-Z)/(N+Z)$

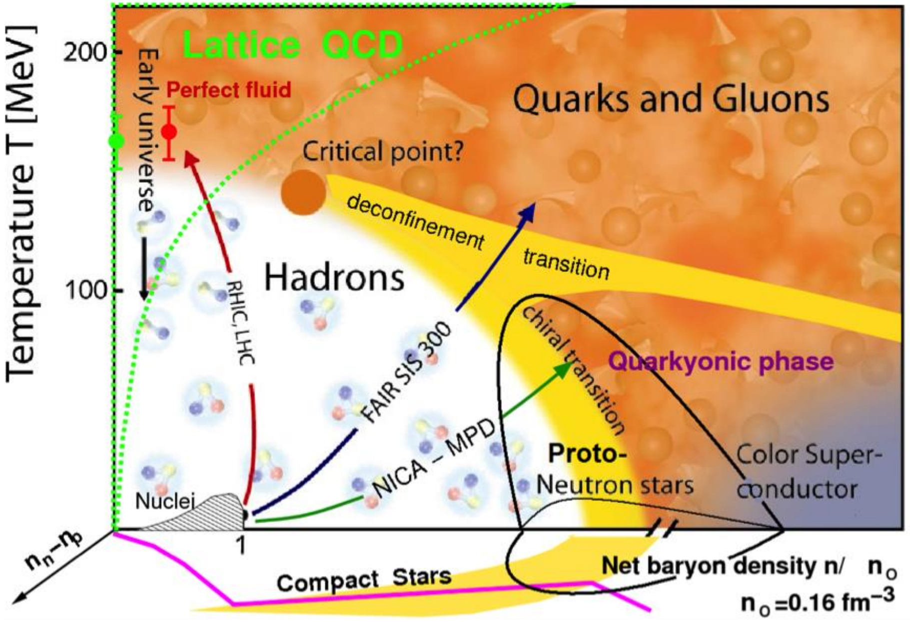
- General approach
  - Investigate $\varepsilon(\rho,\delta)$ as functions of baryon density ρ and isospin asymmetry δ
- Theoretical approach
  - Estimate of $\varepsilon(\rho,\delta)$ by some density functionals or variational calculations
- Experimental approach
  - Constrain EoS using controlled laboratory Expts. at specific densities (determined largely by the beam energy and less effectively by the system size)

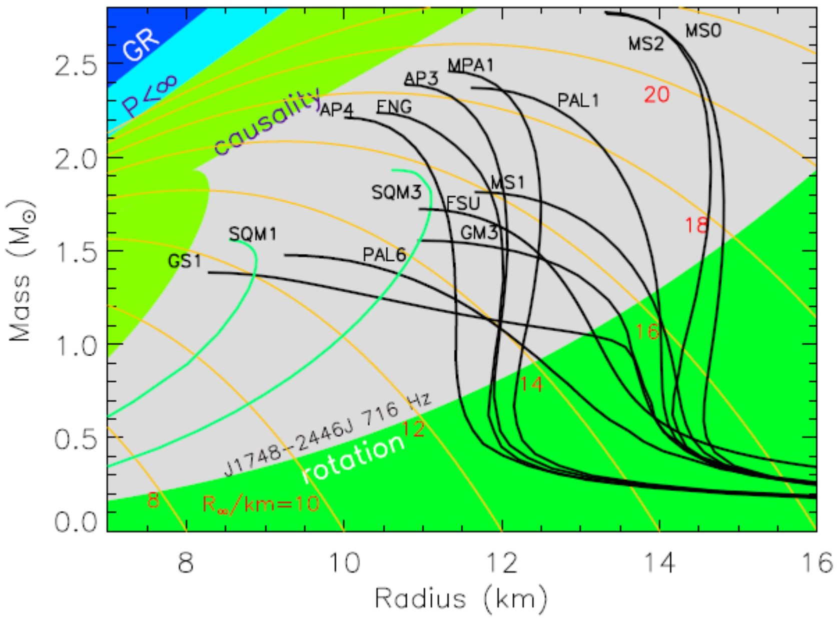




Physics objectives

- Necessity of heavy-ion collisions
  - It is the only way to create dense nuclear matter in the laboratories.
- Necessity of RIB
  - RIB enables us to access a wide range of the isospin axis ($n_n - n_p$ or N/Z).
- Essential to understand
  - Structure of the nuclear phase diagram
  - Stability of neutron stars against gravitational collapse
  - Mass and radius relation of neutron stars
  - Determination of the stella density profile and internal structure
  - Cooling rate of proto-neutron stars
  - Stella masses, radii, and moments of inertia from temperatures and luminosities of the X-ray bursters



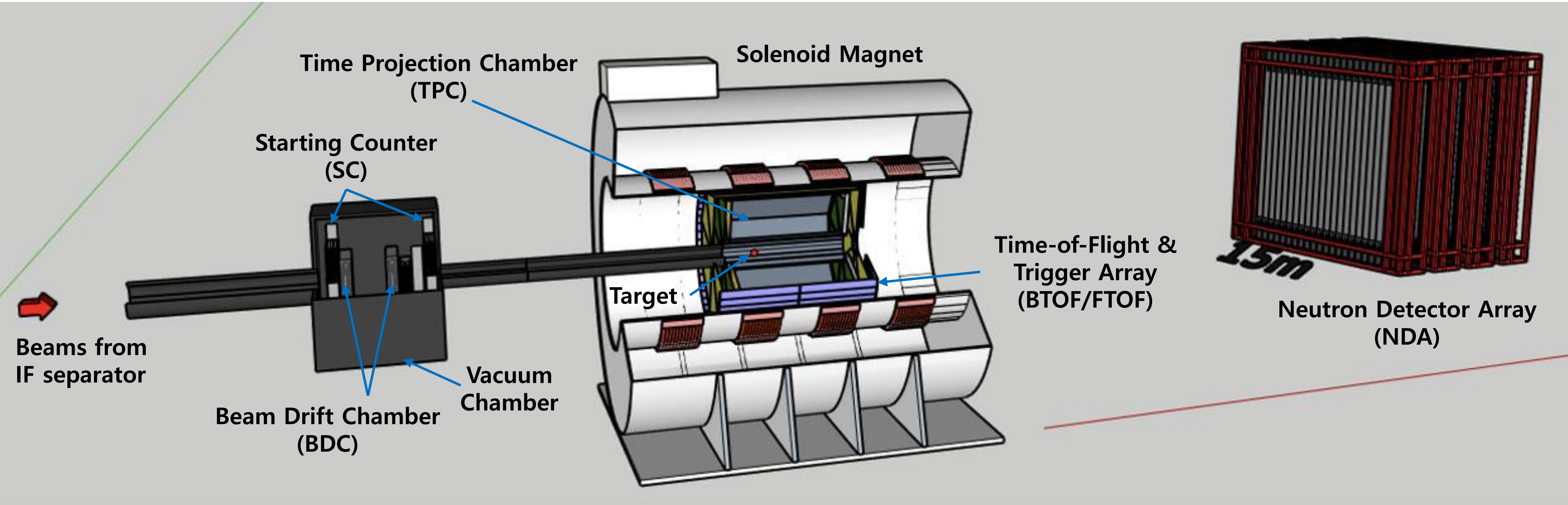


Observables

- Requirements for EoS experiments
  - Systematic change of the system size and N/Z of the collision system
  - Systematic change of the beam energy to cover a wide range of ρ/ρ_0
  - Systematic analysis as functions of the collision centrality and momentum (or kinetic energy)
- Observables
  - Particle spectra and yield ratios for *n/p*, ^{3}H/^{3}He, ^{7}Li/^{7}Be, 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
  - $E1$ transitions (giant and pygmy dipole resonances): peak position and magnitude
    (Some theories suggest that PDR is sensitive to the radius of the neutron skin for unstable nuclei.)
  - Angular dependence of the gamma emission
- Detectors needed
  - Beam diagnostic detectors for tracking and timing
  - Large acceptance charge particle tracking (from pions to fragments)
  - Neutron (and/or gamma) detector
  - Event characterization detector for centrality and the reaction plane

Overall configuration of LAMPS

- **LAMPS**: **L**arge **A**cceptance **M**ulti-**P**urpose **S**pectrometer
  - TPC with ~3π sr acceptance for tracking charged particles
  - Beams with energies up to 250 MeV/u for ^{132}Sn and intensity as large as 10^8 pps
  - Useful detector system not only for nuclear EoS, but also for nuclear structure studies

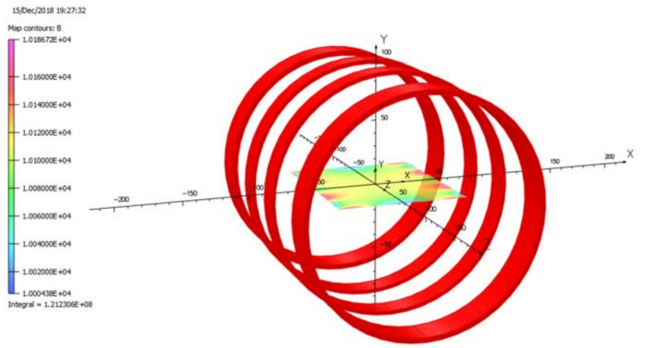


Part 2.

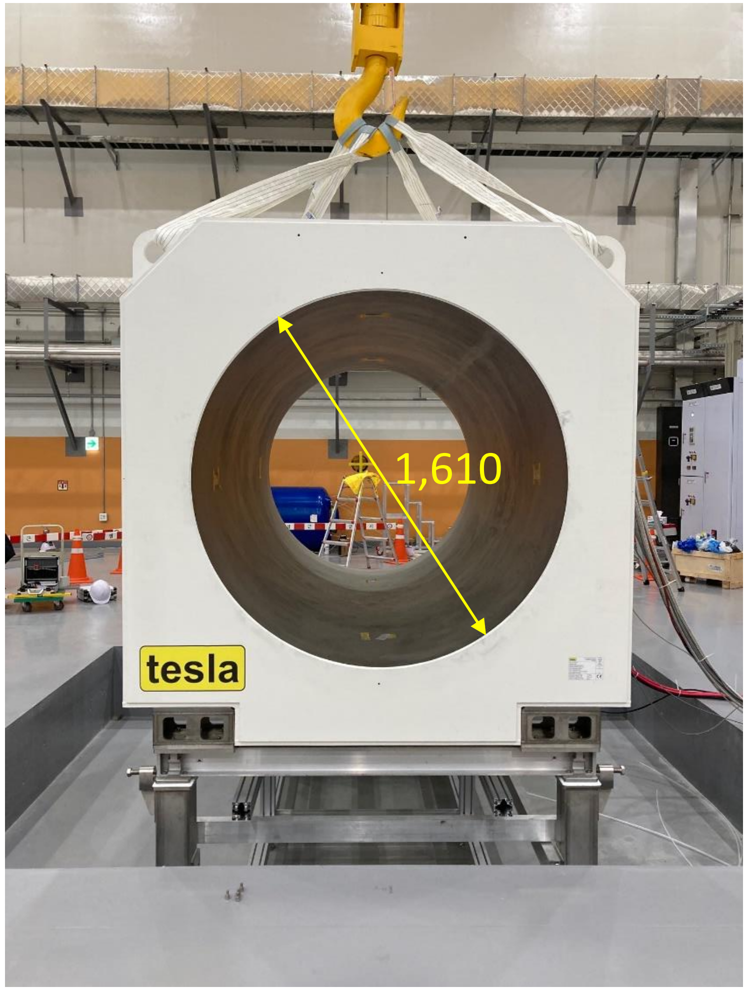
Status of each detector component

Magnet

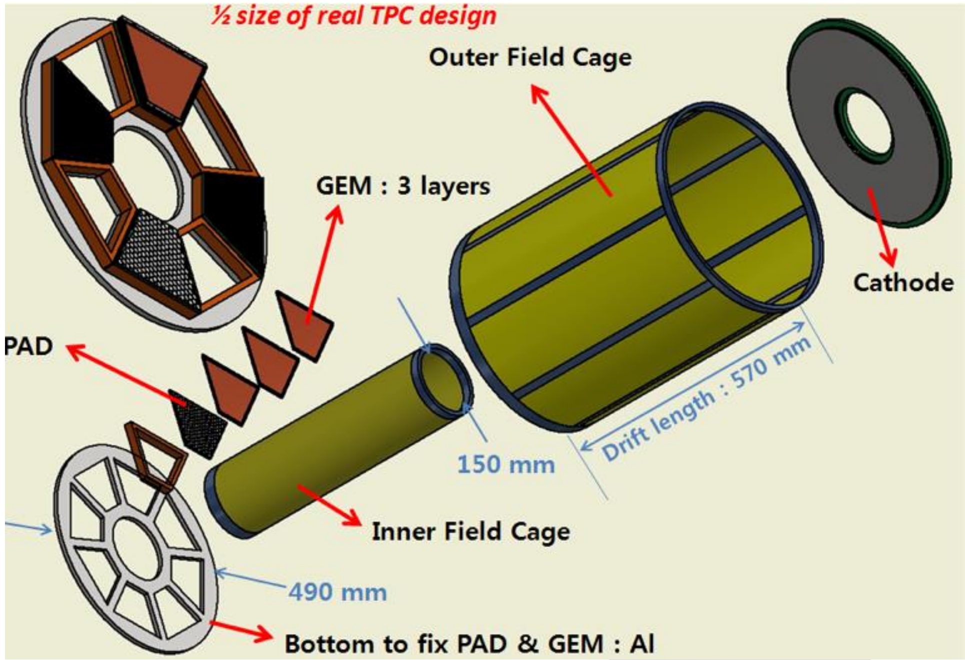
- Design parameters
  - Superconducting solenoid magnet
  - Dim.: 3,300(L) X 2,100(W) X 2,600(H) mm^3
  - Diameter of bore: 1,610 mm
  - Max. field: 1 Tesla
  - Variation of field over TPC volume: $\pm$0.94%

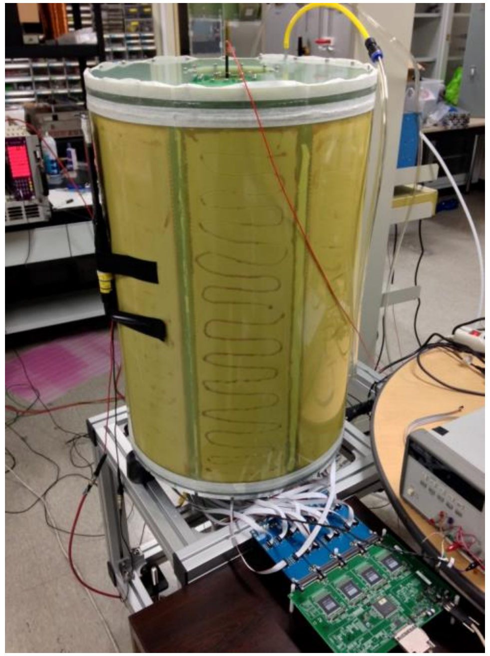


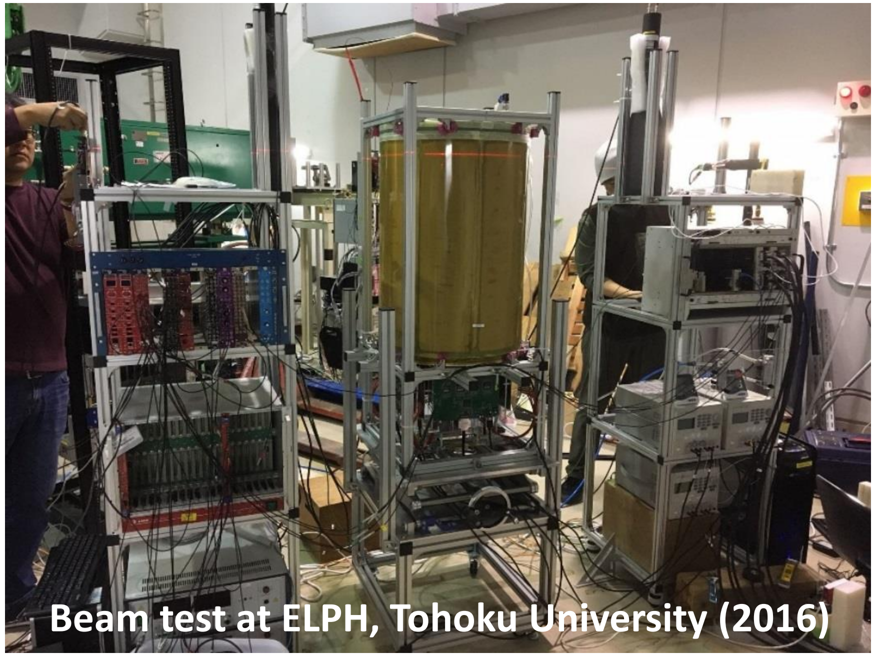
  - Passive quench protection
  - Conduction cooling with 4 K vessel thermal shield and vacuum vessel
- Construction
  - Vendor: Tesla Engineering Ltd., UK
  - Contracted in Feb. 2019
  - Installation completed at RAON in 2021

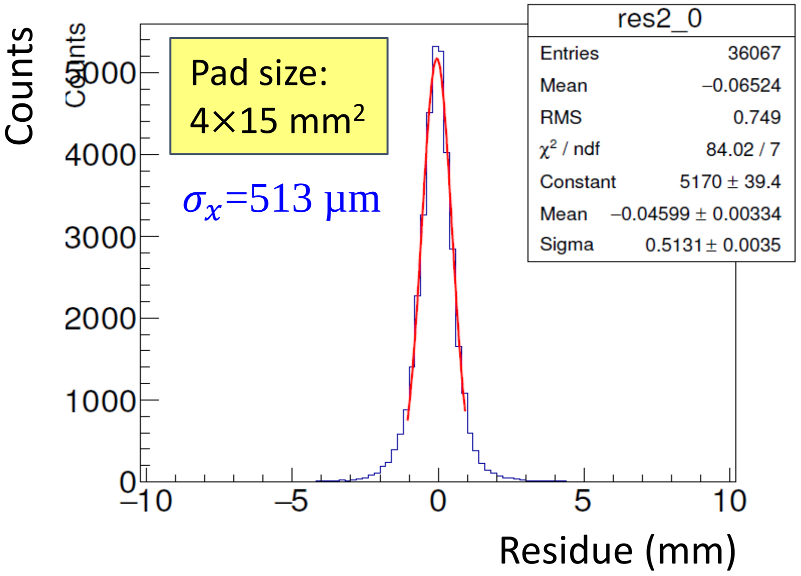


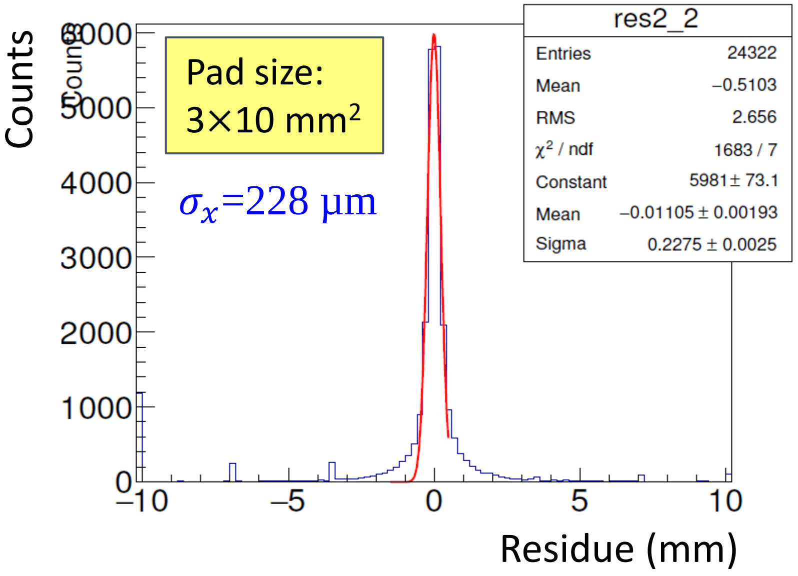
TPC: Performance test with prototype

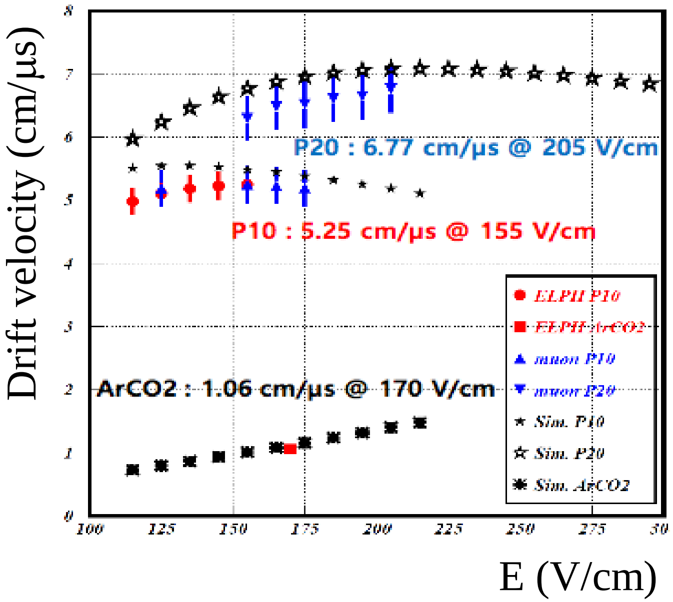




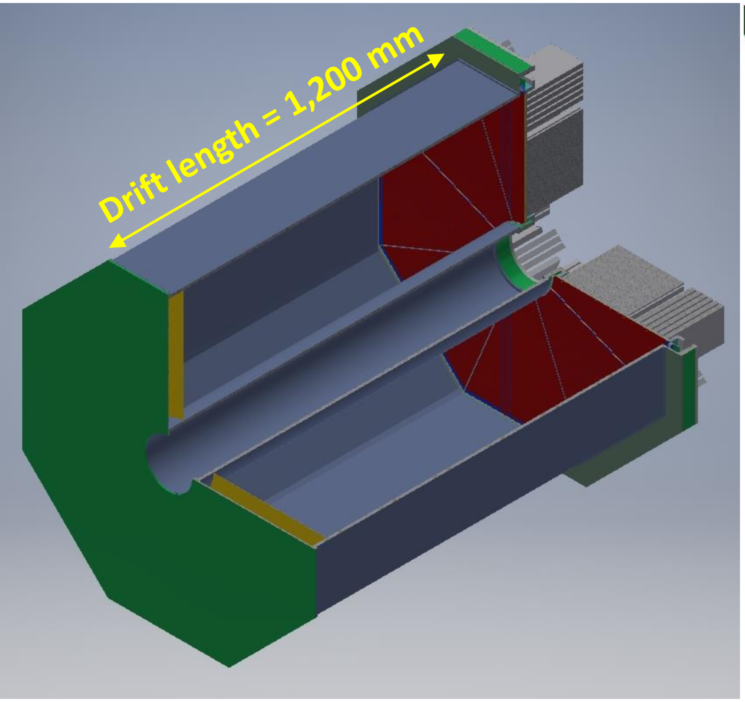


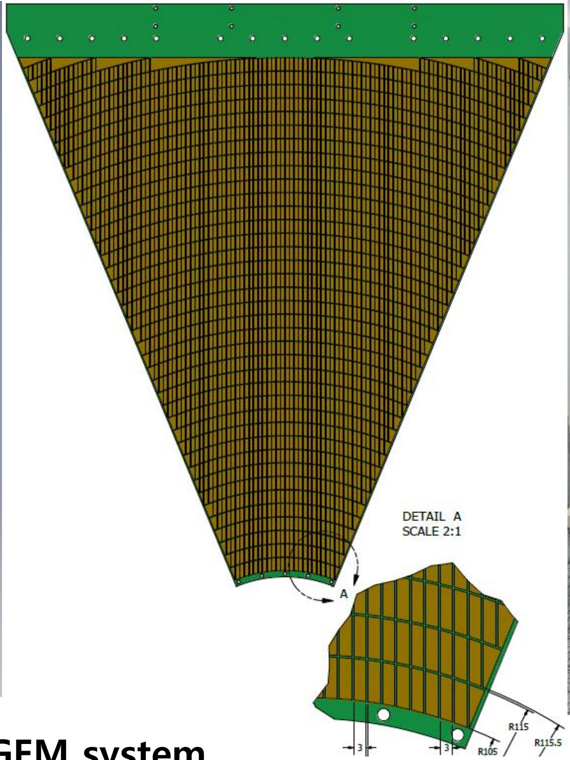


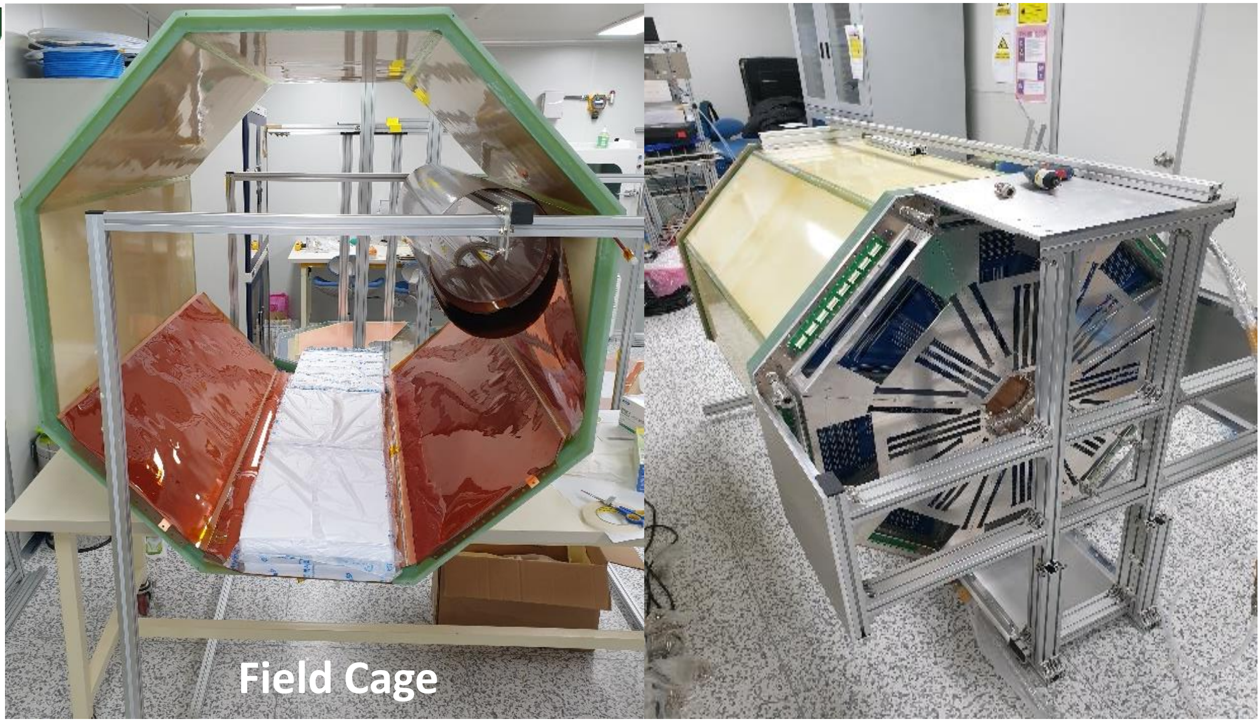




TPC: Construction of real detector

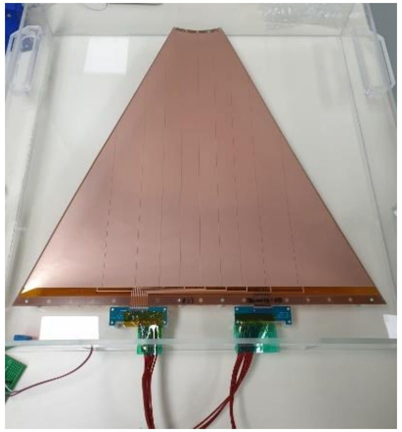


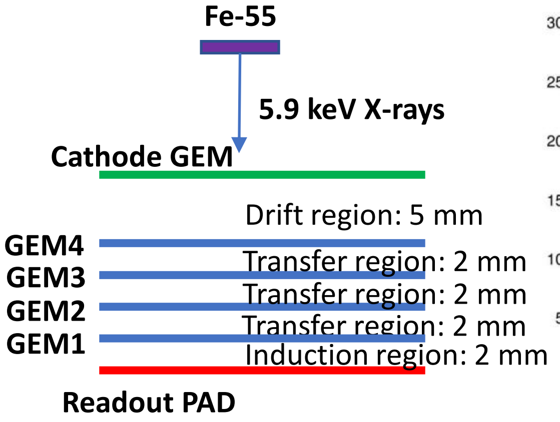


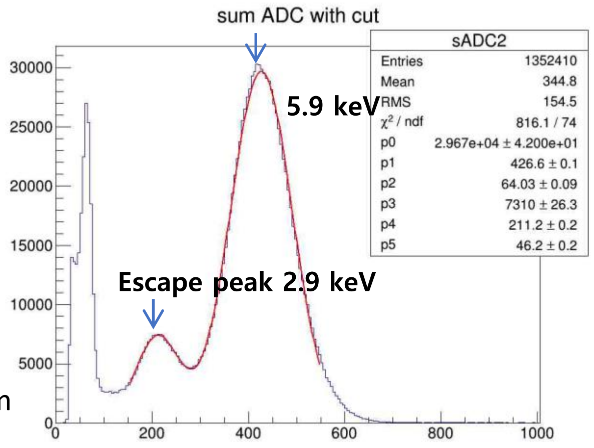


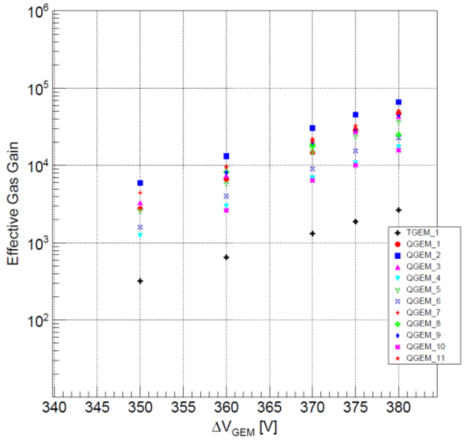
- Pad Dim.: 3×10 mm^2
- Ch. #: 2,618/sector $\times$ 8 sectors = 20,944
- FEE (GET electronics): 11 AsAD/sector $\times$ 8 sectors = 88 AsAD

Quadruple GEM system

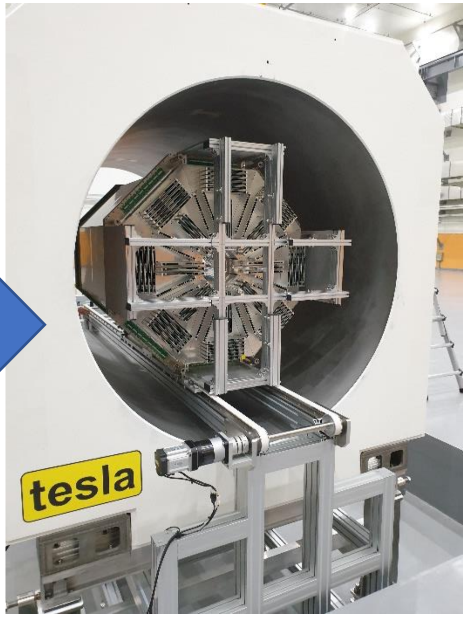


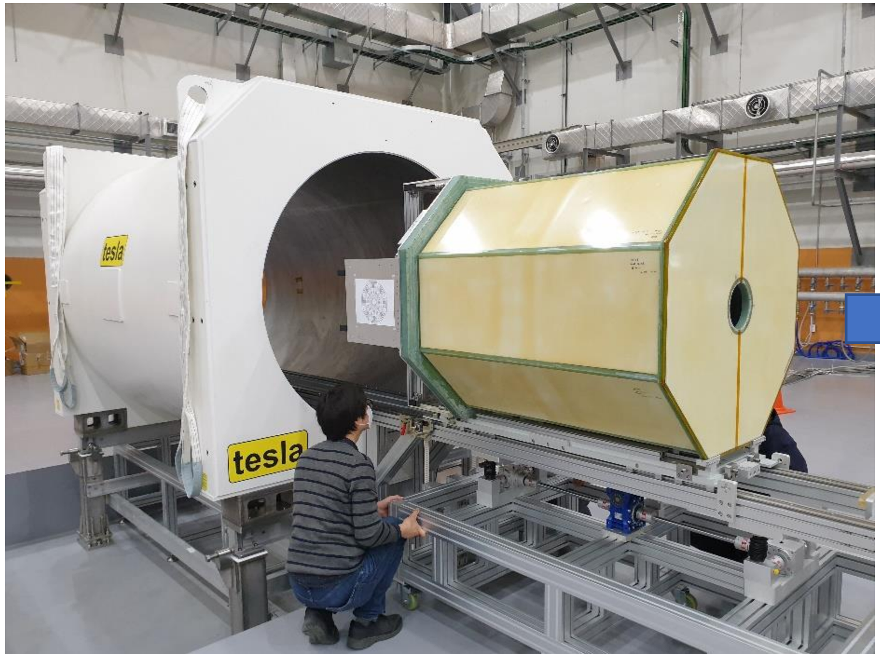


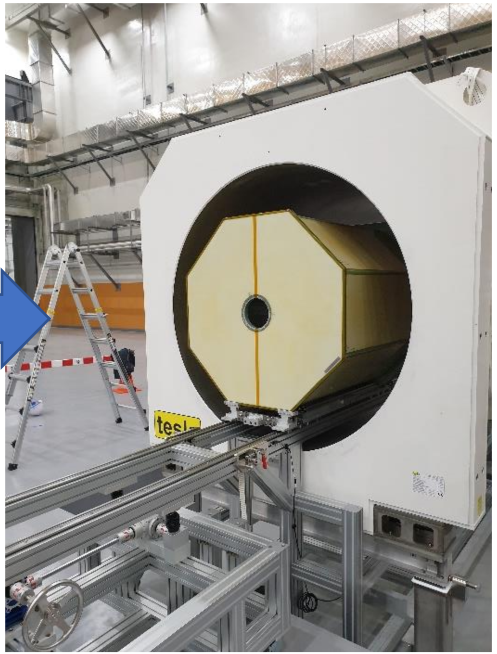




TPC: Transportation system

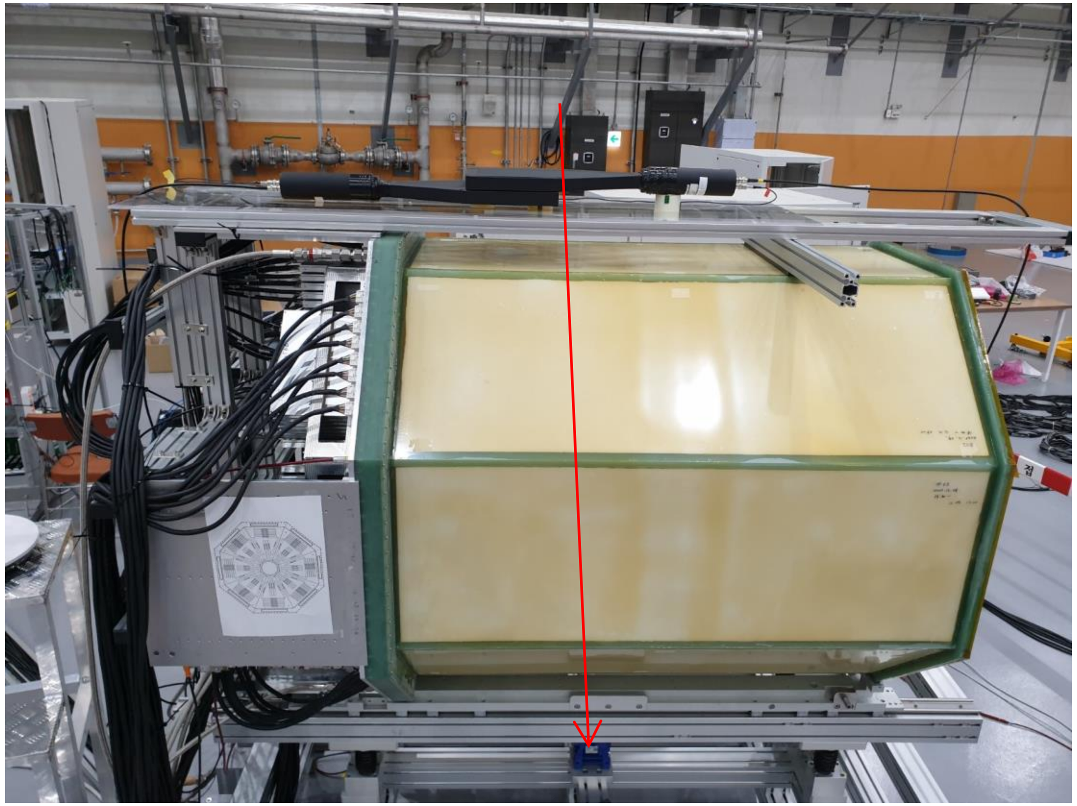




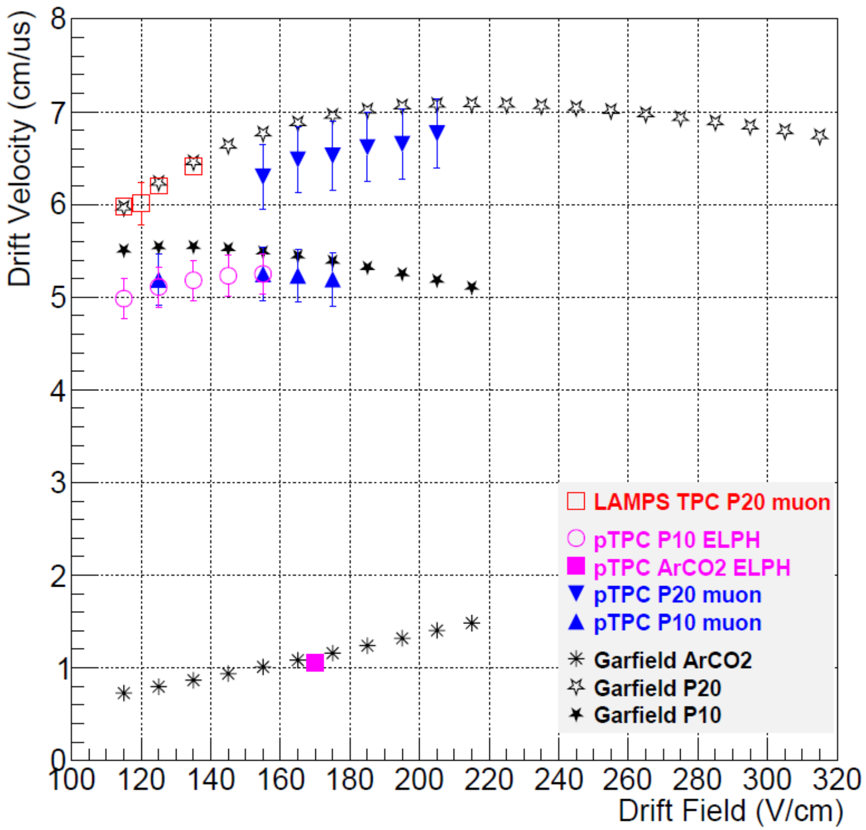


TPC: Drift velocity measurement by cosmic ray

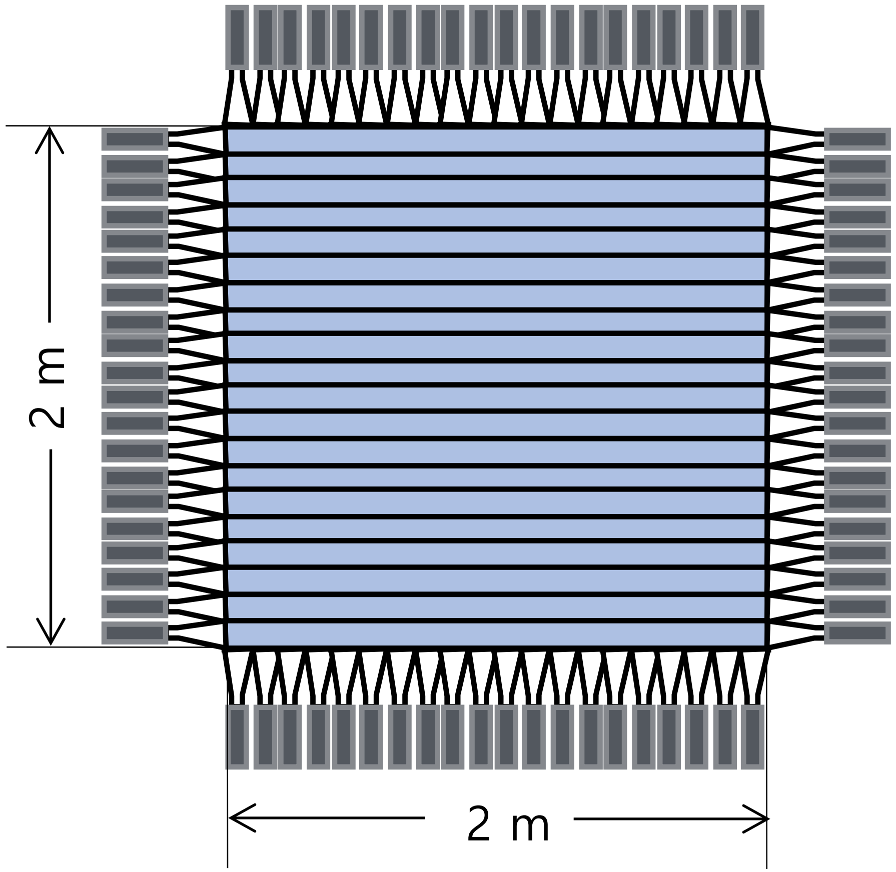
- Cosmic muon trigger
  - Coincidence of two scintillators (scintillator size: 20 x 20 cm^2 each)
  - Trigger position : 30, 60 and 90 cm
  - Measured drift field points: 115, 125 and 135 V/cm

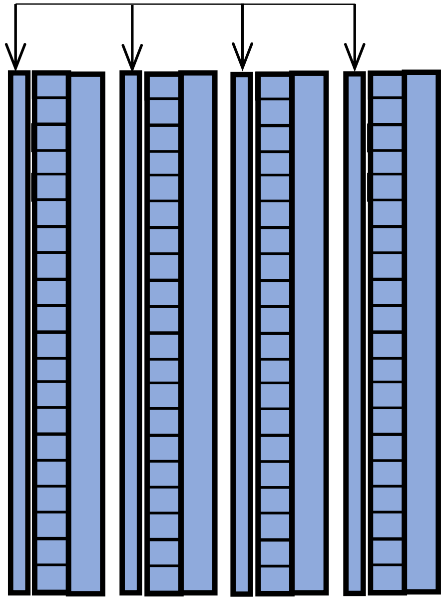


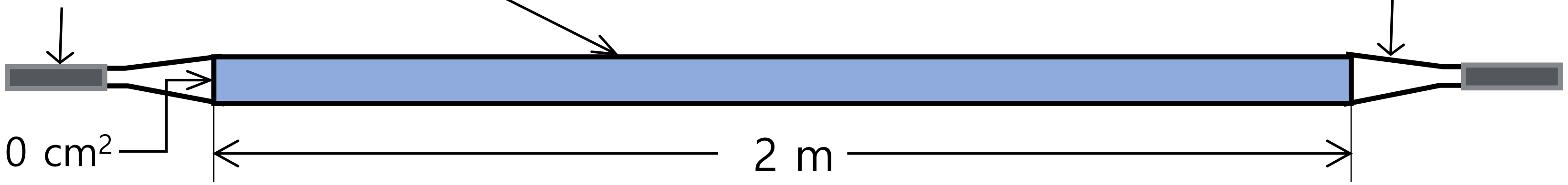
Drift velocity data (preliminary)



Neutron Detector Array (NDA): Structure

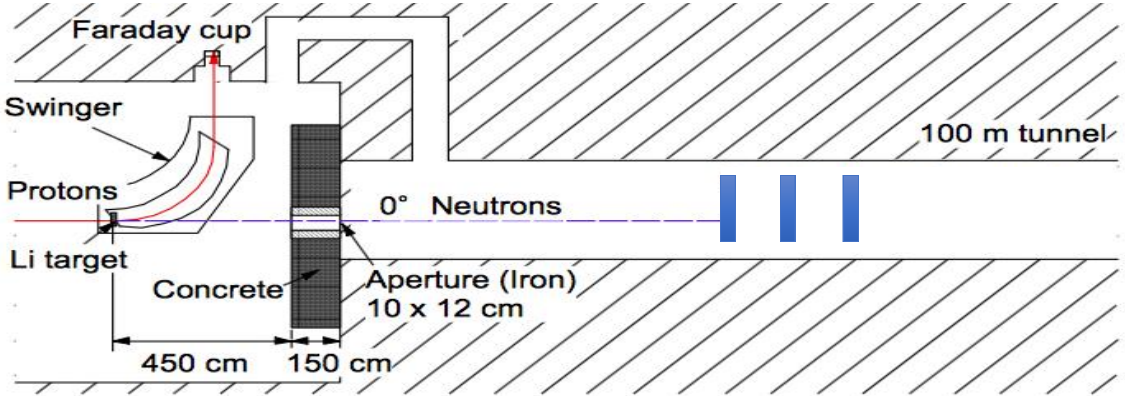




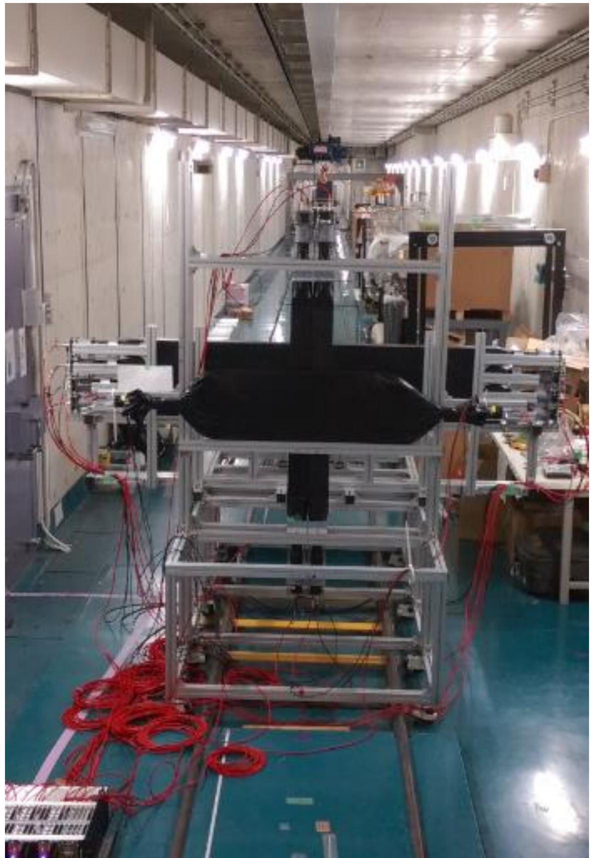


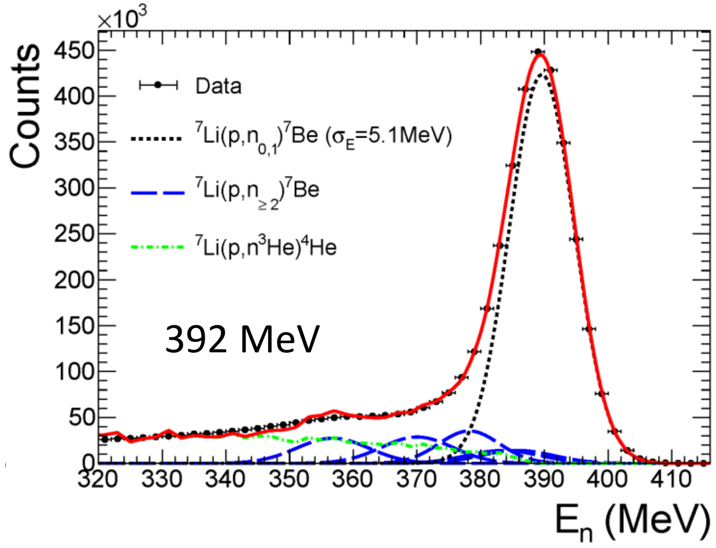
NDA: Performance test with prototype

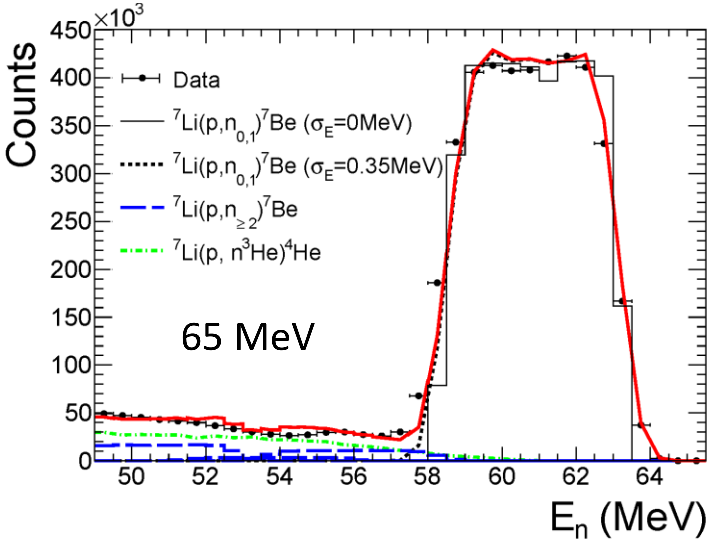
Beam test at RCNP (2016)



- Beam specifications
  - Production reaction: p+^{7}Li → n + ^{7}Be
  - Neutron beam flux: 1×10^{10} n/sr/μC
  - Neutron energy: 65 and 392 MeV
  - Background neutrons above 3 MeV is < 1% [NIMA 629, 43 (2011)]

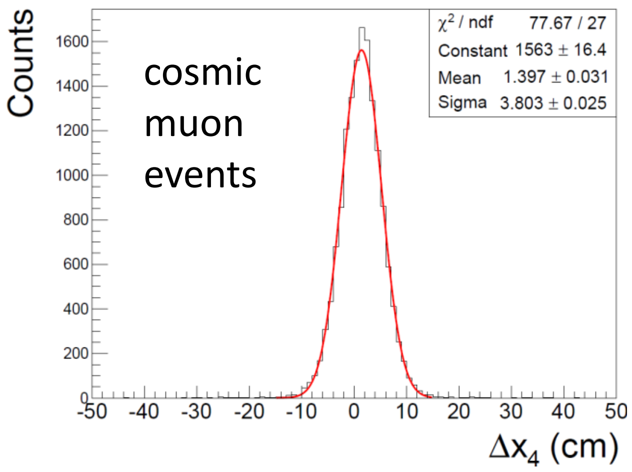






- Significant energy-loss effect in the Li target at 65 MeV
- Low-energy background dominated by the 3-body decays $^7\mathrm{Li}(p,n\ ^3\mathrm{He})\ ^4\mathrm{He}$
- Energy resolution (FWHM): 3.1% @ 392 MeV, 1.3% @ 65 MeV

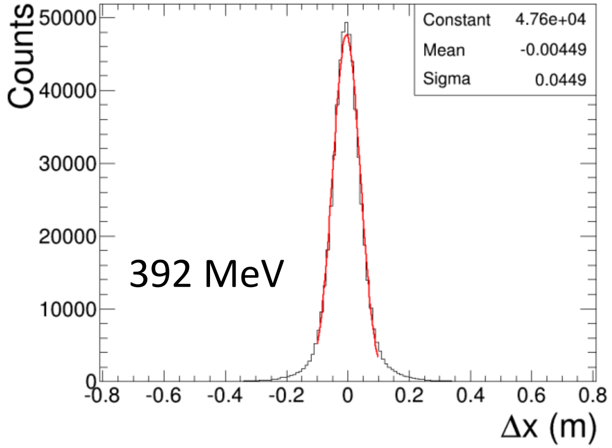
NDA: Performance with prototype



← Position difference between the projected hit position and the detected hit position for cosmic muons: $\Delta x_4 \equiv x_{D4,proj} - x_{D4,hit}$

← Relative position resolution for cosmic muons for one bar:

$$\sigma_x = \frac{\sigma(\Delta x_4)}{1.87} = 2.0\ \text{cm}: R_x(\mu) = 4.8\ \text{cm (FWHM)}$$



→ Hit position difference between neighboring scintillators for neutrons with simultaneous hits: $\Delta x_{S1} \equiv x_{D1} - x_{D2}$ for 10 MeV threshold and $\delta t < 3$ ns

→ Relative position resolution for neutrons for one bar:

$$\sigma_n = \frac{\sigma(\Delta x_{S1})}{\sqrt{2}} = 4.5\ \text{cm}: R_x(n) = 7.5\ \text{cm (FWHM)}$$

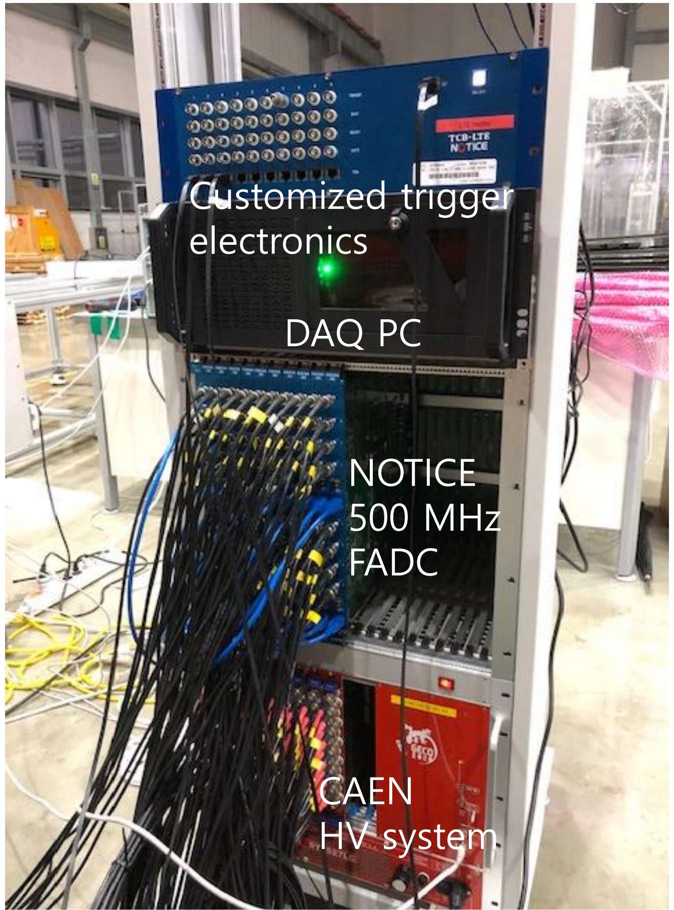
Comparison of performances by cosmic rays for similar configuration of neutron detectors [NIMA 927, 280 (2019)]

	LAMPS (this work)	MoNA [13]	NEBULAR [14]	LAND [15]
Dimensions (cm^3)	10 × 10 × 200	10 × 10 × 200	12 × 12 × 180	10 × 10 × 200
Time resolution (ps)	309	423	376	588
Position resolution (cm)	4.8	5.2	6.1	7.1

NDA: Construction

- Installation of all modules in the frame was completed at the Sejong campus of Korea University in Dec. 2018 to test the performance.
- The whole system was dissembled and transported to the RAON site in Sindong in March and assembled again with the three additional veto walls in September in 2022.
- The fully assembled system will take the cosmic muon data at the RAON site very soon.

Assembled detector system at the Sejong Campus of Korea Univ.



First station assembled at the high-energy experimental hall of the RAON site

Time-Of-Flight/Trigger Array (BTOF/FTOF)

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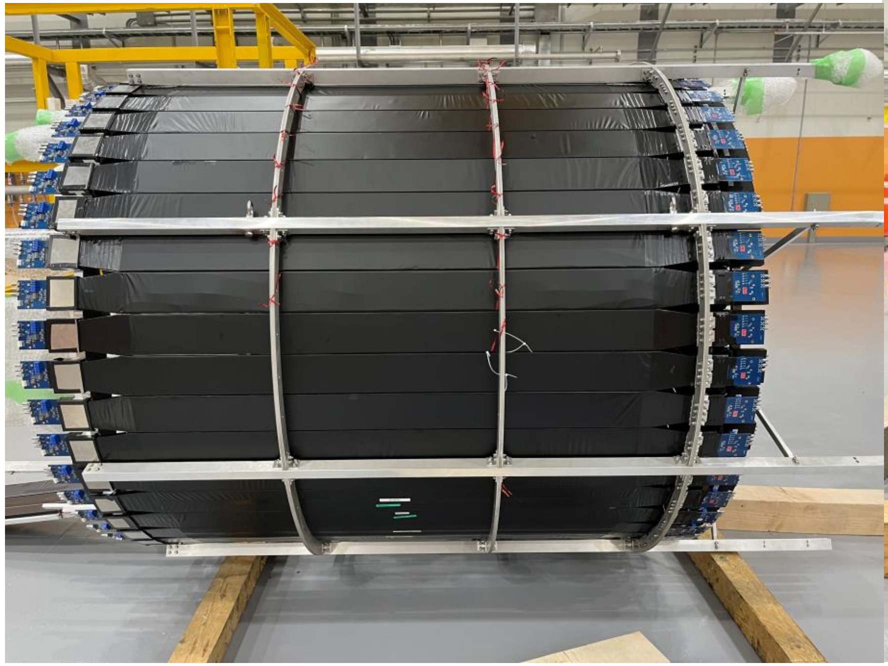
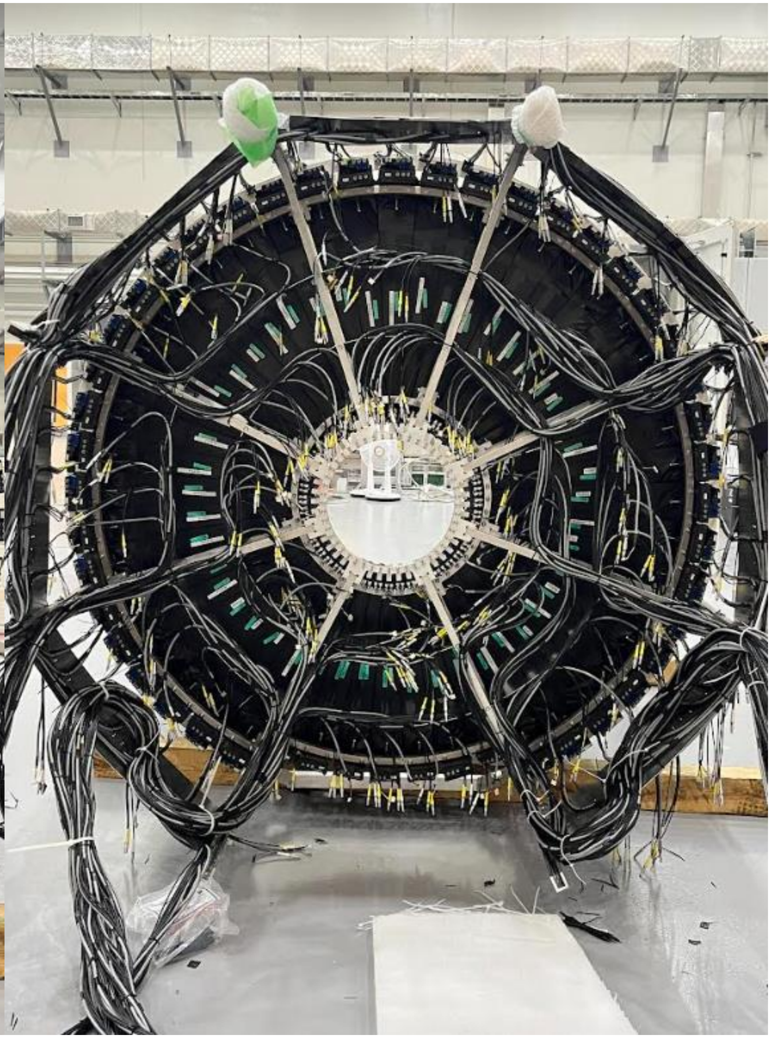
- Number of scintillators & dimensions:
  - BTOF: (48) 1500 X 90 X 10 mm^3 each
  - FTOF: (48) 500 X (90, 25) X 5 mm^3 each
- MPPC readout from both ends
- Installation completed in 2022
- The performance test with cosmic muons is in progress.





Beam Drift Chamber (BDC): Test with prototype

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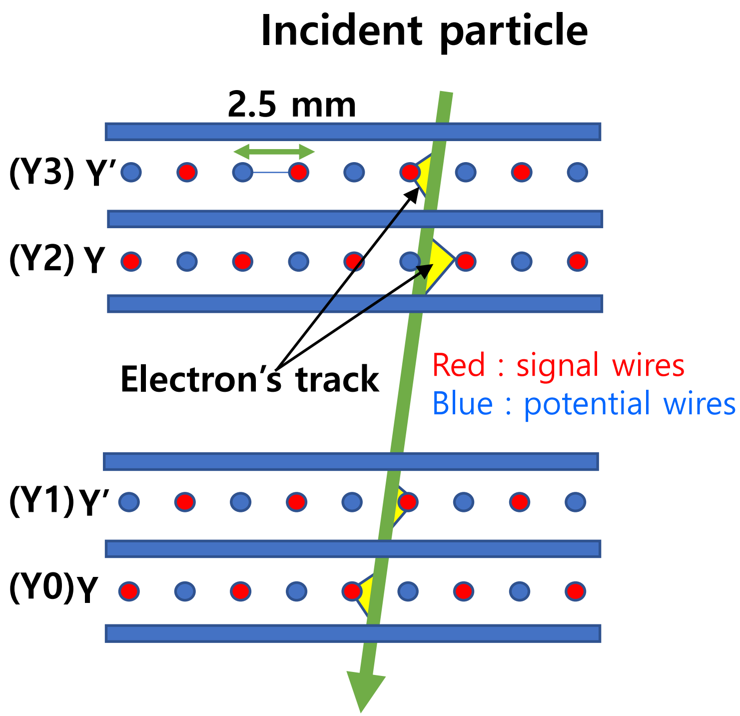
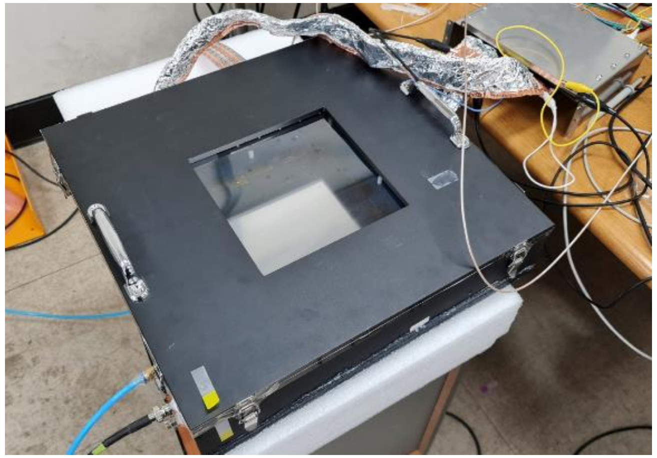
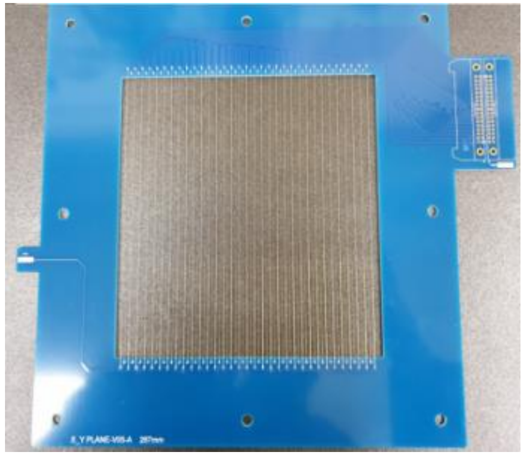
- Schematic design
  - Active area: 160 X 160 mm^2
  - 32 channels for each plane
  - Gas: P10





Cathode plane

Signal plane



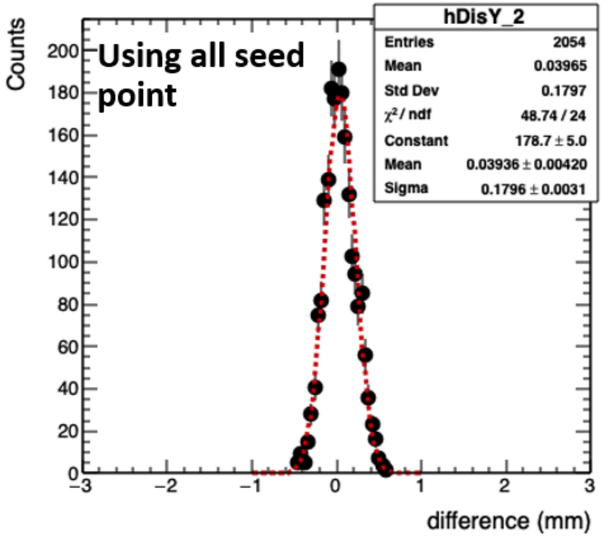
Then, intrinsic resolution of layer Y2 $\boldsymbol{\sigma}$:

$$\sigma = \sqrt{\sigma_1 \sigma_2} = 253.7\ \mu m$$

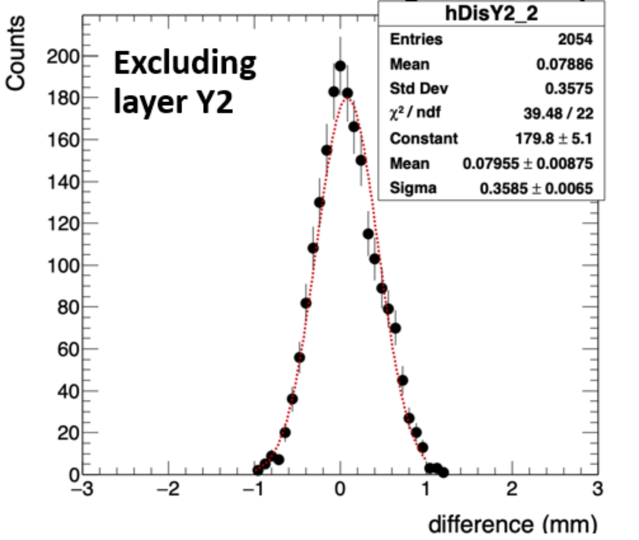
ATLAS Collaboration, JINST14, P09011 (2019)

Final goal: σ = 100 μm

Inclusive resolution: $\sigma_1 = 179.6\ \mu m$



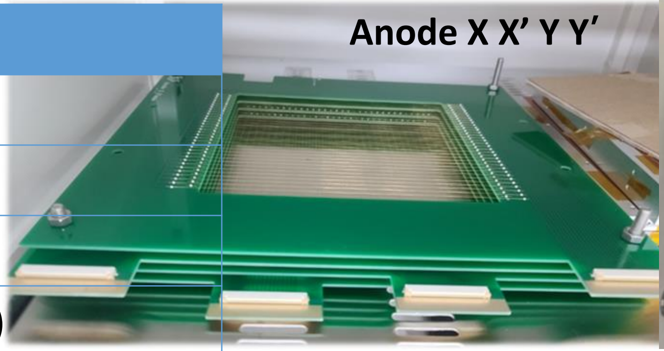
Exclusive resolution: $\sigma_2 = 358.5\ \mu m$

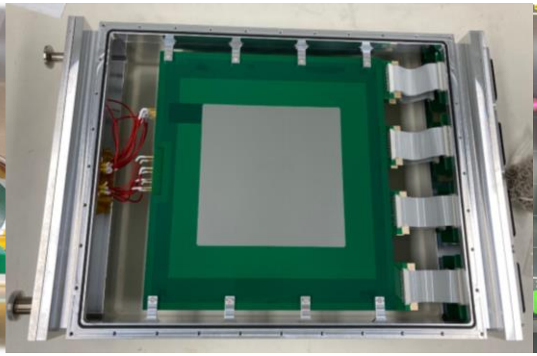


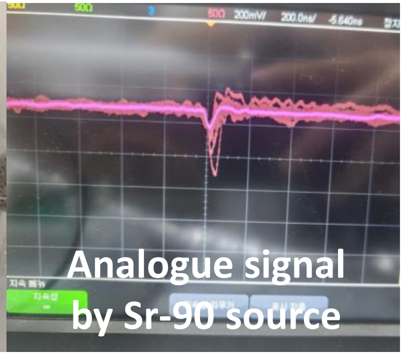
BDC: Construction of real detector

Parameter	Value
Anode wire	ϕ 20 µm Au-W
Potential wire	ϕ 80 µm Cu-Be or Au-W
Cathode	2 µm-thick Al-mylar, 9 layers
Cell size	5 mm (max. drift length 2.5 mm)
Active area	170 x 170 mm^2
Anode configuration	XX'YY'XX'YY', 8 layers
Number of channel	256 (32 wires/plane, 8 planes)
Operation gas	i-C_4H_{10} below 1 atm P10 (Ar 90% + CH_4 10%) at 1 atm
High voltage	2 channels for cathode & potential wires
Readout	ASD(RP-2125)+TDC(V1190A)+QDC(V792)
Body dimension	490(L) x 360(H) x 100(W) mm^3
Beam window (variable)	12 µm Al-mylar (up to 20 kPa) 50 µm Al-mylar (up to 50 kPa)

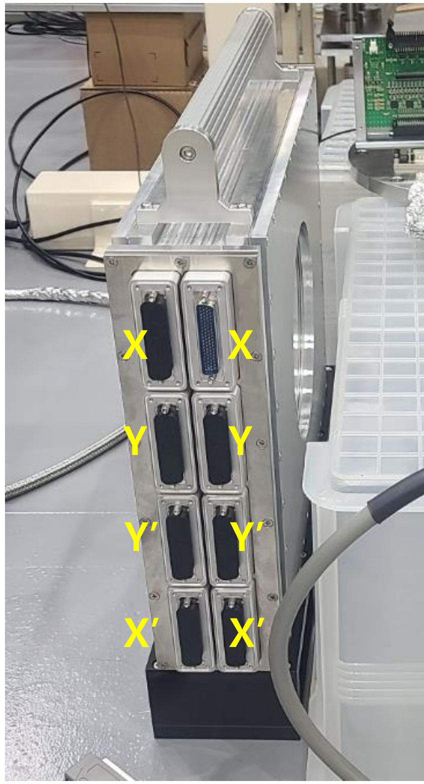
- HV & vacuum tests completed
- Performance test with electronics in progress





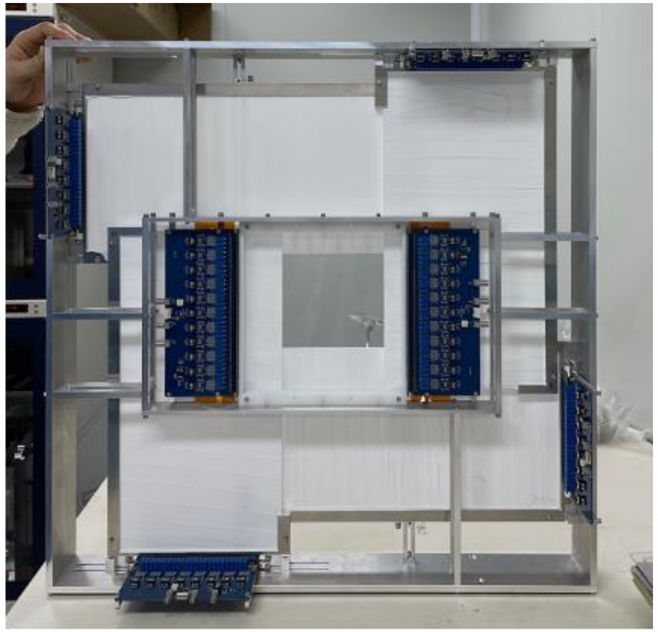


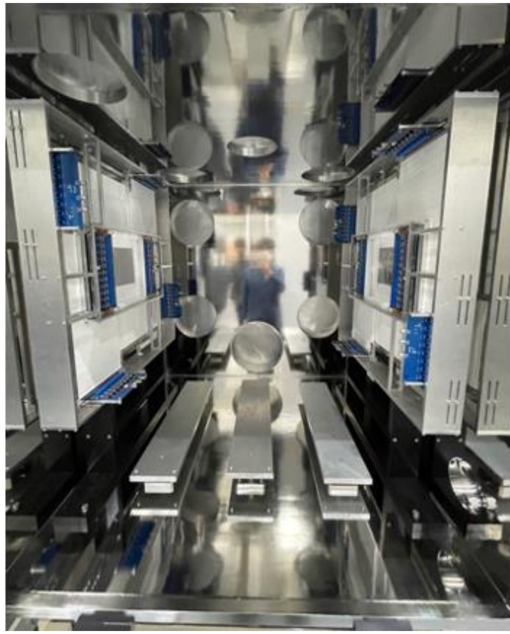
BDCs in the beam diagnostic chamber

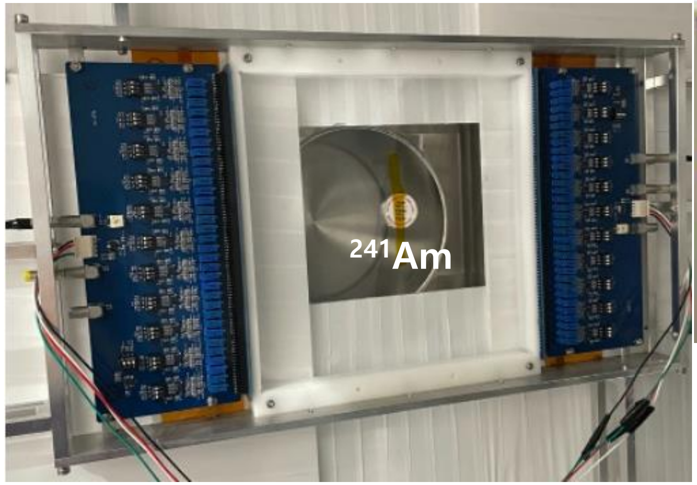


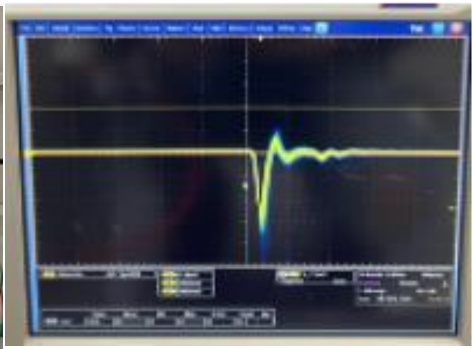
Starting Counter (SC)

- Primary function
  - Providing an accurate reference time ($\sigma_t \lesssim 100$ ps) for entire experiment when actual beams arrive.
- Structure & dimensions
  - Two sets of (1 SC + 4 Veto counters)
  - SC: 210 X 210 X 0.2 mm^3 (Active area: 200 X 200 mm^2)
  - Veto: 410 X 210 X 5 mm^3 (Adjustable area)
- Material
  - SC & Veto: EJ-230 polytoluene-based scintillator
  - Lights collected by MPPC on a sensor board
    - 2 sensor boards on a SC scintillator & 1 board for Veto
    - 33 MPPCs on a sensor board for SC & 24 MPPCs for Veto
- Electronics
  - Conventional CAEN TDC, QDC for the time and charge information
- Installation & α source (^{241}Am) test
  - Full system installed in the vacuum chamber
  - σ_t ~130 ps → Using two SC's, ~92 ps is achievable.









Part 3.

Preparation of the low-energy experiments

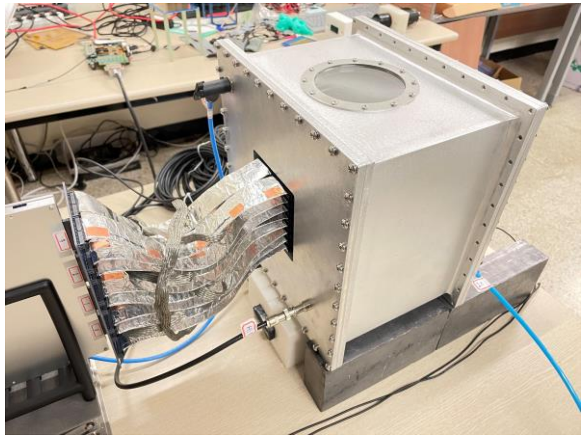
by Center for Extreme Nuclear Matters

CENuM

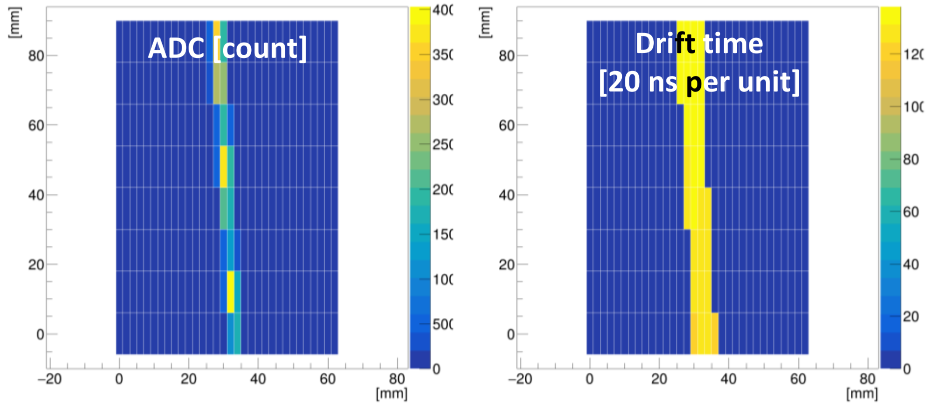
AT-TPC and SC magnet

- Superconducting magnet
  - B_{max} = 1.5 T
  - Diameter & length of the detector space = 60 cm each
  - Conductive cooling
  - Construction done in 2019

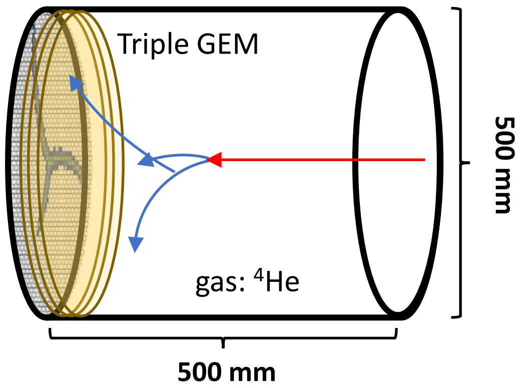
- AT-TPC: Construction of prototype
  - # of pads: 64 X 16 = 1024
  - Pad size: 1.9 X 11.9 mm^2 (gap between pads: 0.1 mm)
  - Performance test is on going using cosmic muons & alpha source.
  - Beam test using (α, p) reaction at CRIB is forseen in 2023.

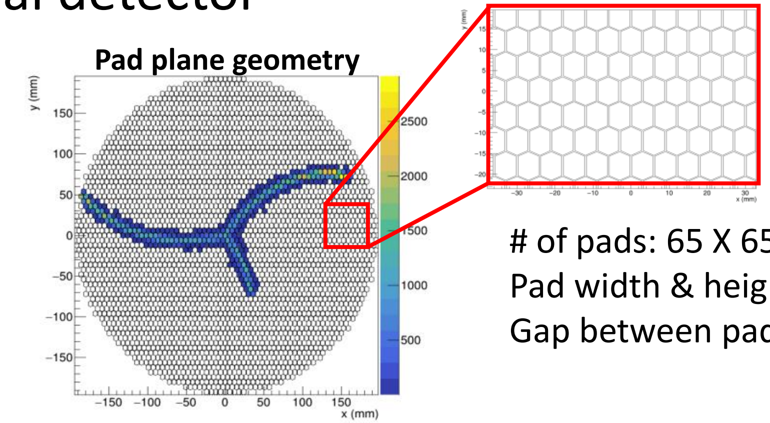


Event display for cosmic muon events



- AT-TPC: Design of real detector





# of pads: 65 X 65 = 3,300
Pad width & height: 6 mm each
Gap between pads: 0.5 mm

KHALA: $LaBr_3$ γ-detector array

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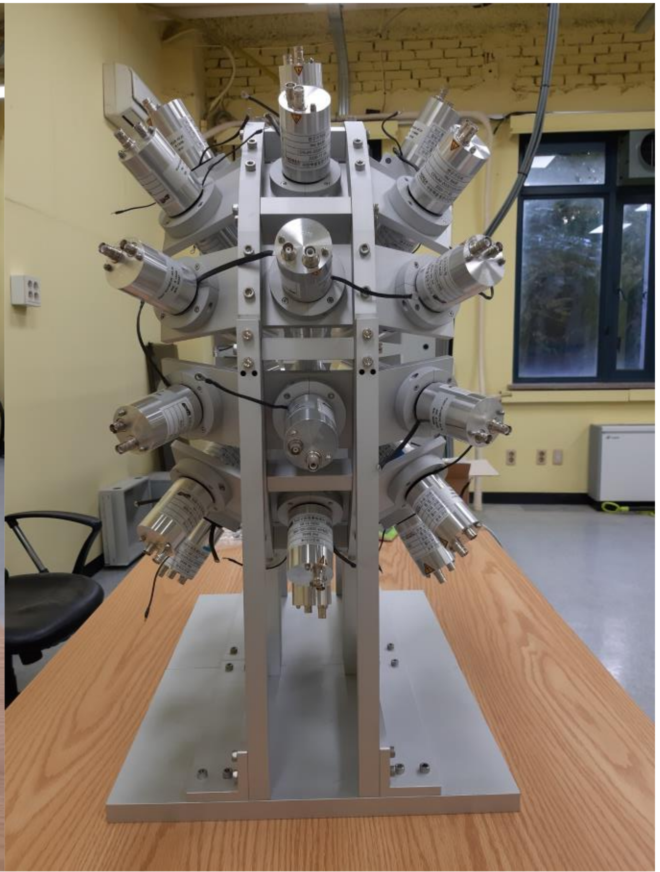
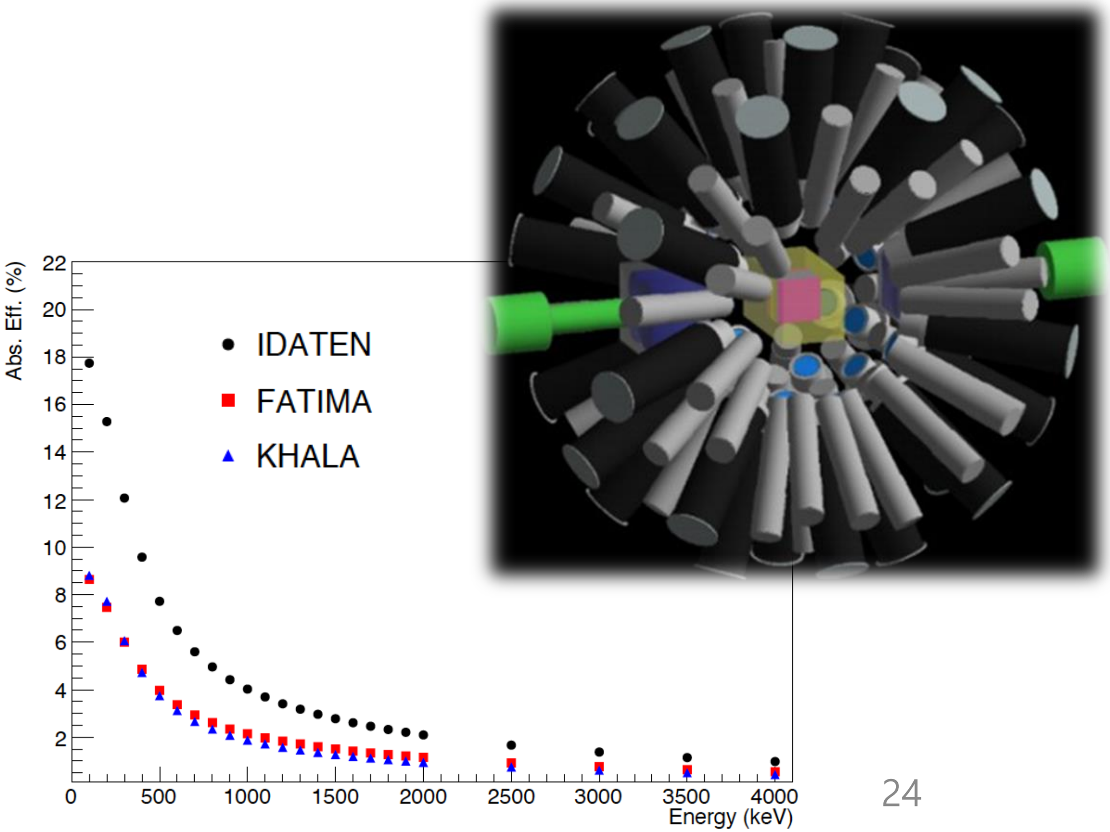
- KHALA: Korea High-resolution Array of $LaBr_3$(Ce)
- Characteristics
  - R_t < 150 ps (fast timing measurement), R_E< 3.5%
- Total 36 [$LaBr_3$(Ce)+PMT] modules
- Formed IDATEN Collaboration = KHALA at CENuM + FATIMA in Europe.
  - IDATEN will perform extensive campaign experiments at RIBF in 2023.

Talk by B. Moon in 11:10 on Friday (Session 8)

Poster by J. Lee (PS8-9)



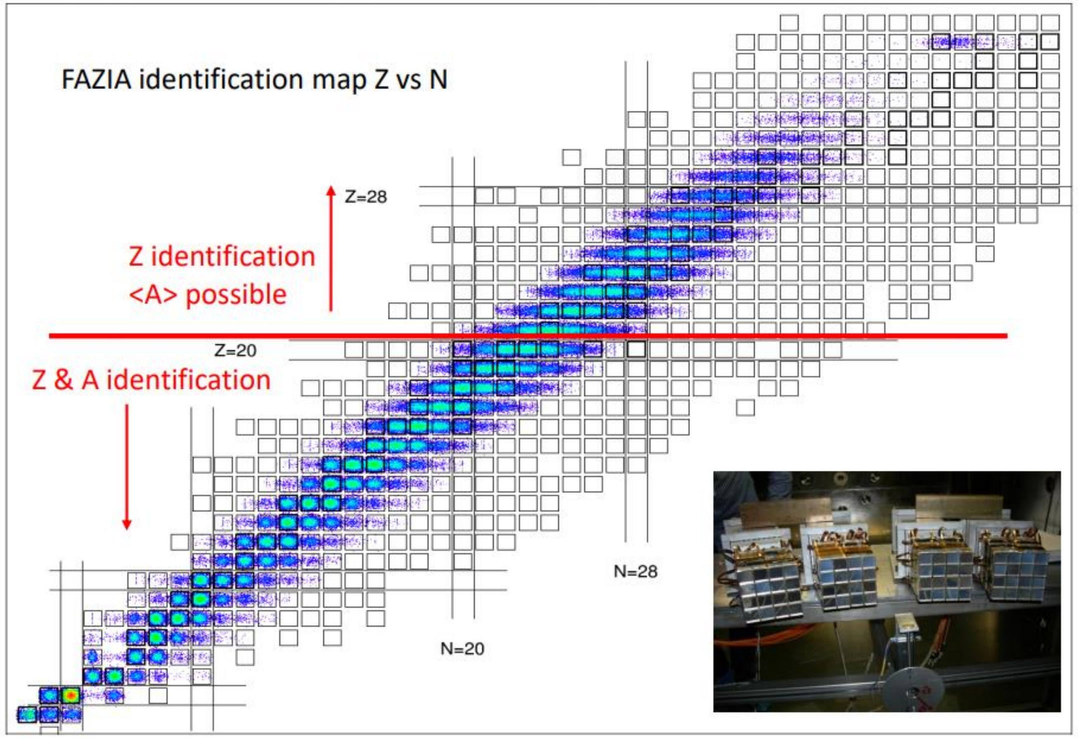


Si+CsI charged particle detector

- FAZIA: A charged-particle detector for heavy-ion collisions at intermediate beam energies
- One FAZIA block consists of 16 Si_1+Si_2+CsI telescopes with a cross-sectional area of 2 X 2 cm^2.
- Development of new Si detectors in Korea

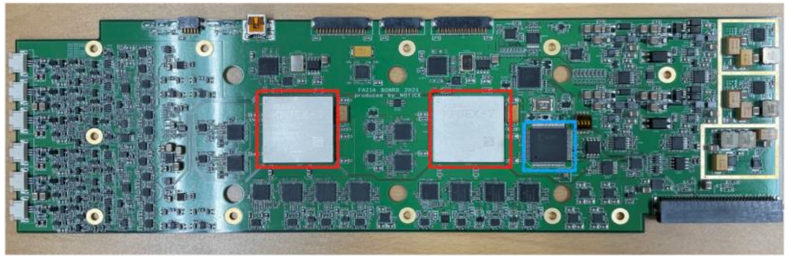
Talk by M. Kweon in 14:30 today (Session 14)

PID from ^{80}Kr+$^{40\text{-}48}$Ca at 35 AMeV in the IsoFAZIA experiment @ LNS, Catania in 2015



New 750 μm thick Si detector modules

New FEE card made in Korea



Summary

- Purpose of LAMPS
  - Detailed investigation of *nuclear equation of state (EoS)*
  - Precise measurement of *symmetry energy* as a function of the baryon density
  - *Structure of exotic nuclei*
- Status of the LAMPS detector system
  - All detector systems were developed, manufactured and assembled.
  - The performance tests with cosmic muons and radiation sources are in progress.
  - *Machine commissioning of the integrated LAMPS system with the trigger electronics is expected in the end of 2022.*
- Plan
  - In the beginning we will concentrate on the low-energy experiments because the high-energy beams from RAON will be available in 2029 or later.
  - We want to exploring the possibility to use the low-energy beams at the high-energy experimental hall.

LAMPS Collaboration

- Status of Collaboration (7 Universities & 2 Institutes)
  - *Chonnam National University*
  - *Institute for Basic Science (IBS)*
  - *Inha University*
  - *Jeonbuk National University*
  - *Korea University*
  - *Korea Research Institute of Standards and Science (KRISS)*
  - *Pusan National University*
  - *Sejong University*
  - *Sungkyunkwan University*
- Number of active collaborators
  - 8 Professors, 9 Ph.D. researchers, ~15 students
- *We are looking forward to the globalization!*


Thank you very much for your attention
and welcome to Korea!
光化門

Backups

LAMPS

Run plan without SCL2

- SCL2 postponed to the second phase
  - No high-energy beams for LAMPS until ~2027
  - LAMPS may explore the step-by-step approach to reach the normal operational mode:
    - (Step 1) Use the low-energy stable ion beams (e.g., O or Ar) from the ECR ion source
    - (Step 2) Ca isotopes from IF, e.g., for ^{40,50,54}Ca + ^{40}Ca
    - (Step 3) ^{70}Zn, ^{78}Kr and ^{238}U primary beams from SCL2 after the 2nd stage: ^{58,68,70,72,78,79}Ni + ^{58}Ni and ^{100,106,112,124,130,132}Sn + $^{112\text{-}124}$Sn

14.5 GHz ECS ion source stable beam list

Ions/Q	1+	2+	4+	6+	8+	9+	11+	14+	20+	23+	25+	26+	27+	30+	31+	32+
H	2000															
H_2	1000															
H_3	700															
He	2000	1000														
C	500	350	200	3												
N	1000	300	100	10												
O	1000	400	300	200												
Ne	1000	300	200	160	25											
Ar	1000	350	250	200	200	90	30	1								
Kr	1000						25	15								
Ag			250	250	200	90	30		4							
Xe	500				220				15	14	10	5				
Ta									4	0.8						
Au												10	6	1	0.7	0.2
Pb									10		5	3	1			

Table 4: Maximum beam intensities (eμA)

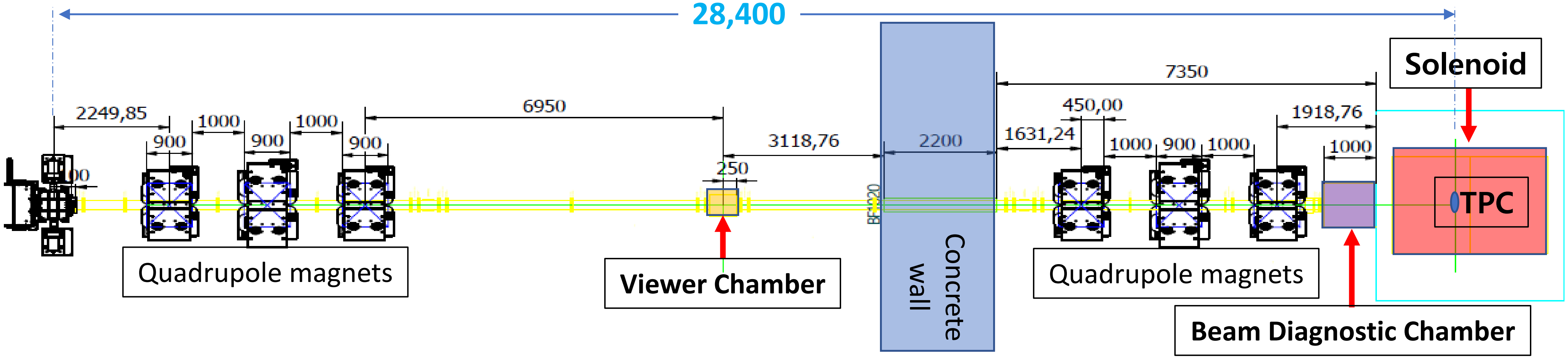
IF RI beam list (400 kW primary beam condition)

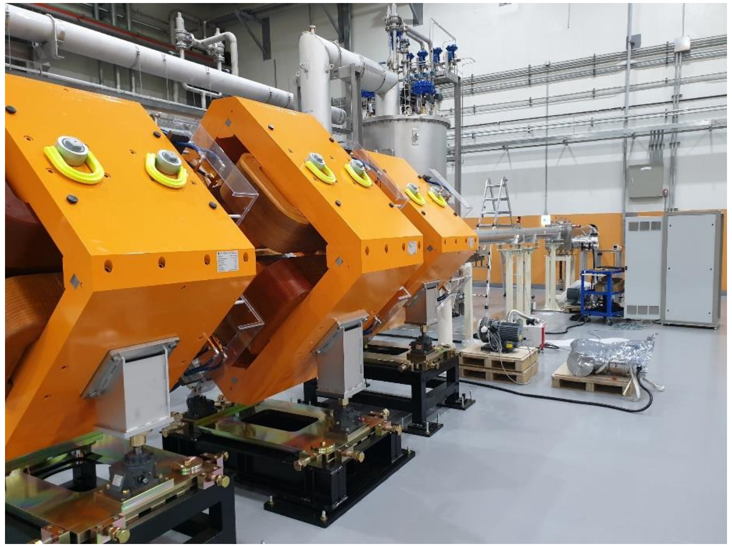
Fragment	Decay Type	Primary beam (400 kW)		Production Reaction	RI beam eneryg	RI beam Intensity	RI Beam purity
		Type	에너지 (MeV/u)		(MeV/u)	(pps)	(%)
132Sn	Beta- decay	238U	200	in-flight fission	133.2	8.21E+06	1.4661
130Sn	Beta- decay	238U	200	in-flight fission	133.1	3.74E+08	13.6
124Sn	stable	124Sn	230	transmission	230	8.77E+13	100
112Sn	stable	112Sn	263	transmission	263	8.49E+13	100
106Sn	Beta+ decay	124Xe	252	fragmentation	155.9	5.31E+08	18.5
100Sn	Beta+ decay	112Sn	263	fragmentation	161.1	1.41E+01	0.0128
96Zr	stable	96Zr*	248	transmission	248	1.05E+14	100
82Cu	Beta- decay	96Zr	248	fragmentation	166.8	2.72E-03	1.2557
81Cu	Beta- decay	238U	200	in-flight fission	140	5.91E+00	0.000012
80Cu	Beta- decay	238U	200	in-flight fission	139.9	6.17E+01	0.0002
79Ni	Beta- decay	96Zr	248	fragmentation	167.1	2.64E-03	1.3223
78Ni	Beta- decay	238U	200	in-flight fission	140.3	8.99E+00	0.000045
72Ni	Beta- decay	82Se	256	fragmentation	167.5	5.63E+06	77.8
70Ni	Beta- decay	76Ge	260	fragmentation	169.4	2.57E+08	15.7
68Ni	Beta- decay	76Ge	260	fragmentation	168.4	2.65E+09	18.6
77Co	Unknown	86Kr	258	fragmentation	172.2	1.87E-02	97.59
76Co	Beta- decay	82Se	256	fragmentation	164.3	5.80E-01	99.93
76Fe	Unknown	86Kr	258	fragmentation	173.5	1.05E-04	99.8
75Fe	Beta- decay	82Se	256	fragmentation	165.1	6.13E-03	100
74Fe	Beta- decay	82Se	256	fragmentation	170.4	6.24E-01	99.82
54Ca	Beta-decay	82Se	256	fragmentation	173.4	1.07E+03	96.2
50Ca	Beta-decay	48Ca	264	fragmentation	155	2.11E+07	100
44Si	Beta- decay	48Ca	264	fragmentation	163	2.73E-02	100
43Si	Beta- decay	48Ca	264	fragmentation	171.3	1.42E+01	100
42Si	Beta- decay	48Ca	264	fragmentation	180.5	1.50E+03	100
40Mg	Beta- decay	48Ca	264	fragmentation	184.8	1.45E-02	100
33Na	Beta- decay	48Ca	264	fragmentation	181.9	2.66E+03	100
32Na	Beta- decay	48Ca	264	fragmentation	181.5	3.70E+04	100
31Na	Beta- decay	48Ca	264	fragmentation	181.1	4.36E+05	100
32Ne	Beta- decay	48Ca	264	fragmentation	183.2	1.77E+01	100
31F	Beta- decay	48Ca	264	fragmentation	184.8	5.57E-02	100
29F	Beta- decay	48Ca	264	fragmentation	183.3	4.34E+01	100
12N	Beta+ decay	16O	333	fragmentation	214.4	1.33E+11	100
22C	Beta- decay	48Ca	264	fragmentation	185.7	2.91E+00	100
20C	Beta- decay	48Ca	264	fragmentation	185.8	2.60E+03	100
16C	Beta- decay	48Ca	264	fragmentation	186.3	7.91E+07	99.997
14C	Beta- decay	18O	299	fragmentation	200.3	1.00E+12	100
11C	Beta+ decay	16O	333	fragmentation	219.4	7.85E+11	100
10C	Beta+ decay	16O	333	fragmentation	215.8	7.75E+10	100
12B	Beta+ decay	18O	299	fragmentation	203	3.61E+11	100
12Be	Beta- decay	18O	299	fragmentation	208.3	3.63E+09	80.67
11Be	Beta- decay	18O	299	fragmentation	206.5	3.07E+10	100
10Be	Beta- decay	18O	299	fragmentation	205.7	1.35E+11	100
8He	Beta- decay	18O	299	fragmentation	212.3	7.29E+07	100
3H	Beta- decay	16O	333	fragmentation	235.8	8.74E+09	100

(yellow)	Neutron rich
(pink)	Proton rich
(green)	Stable

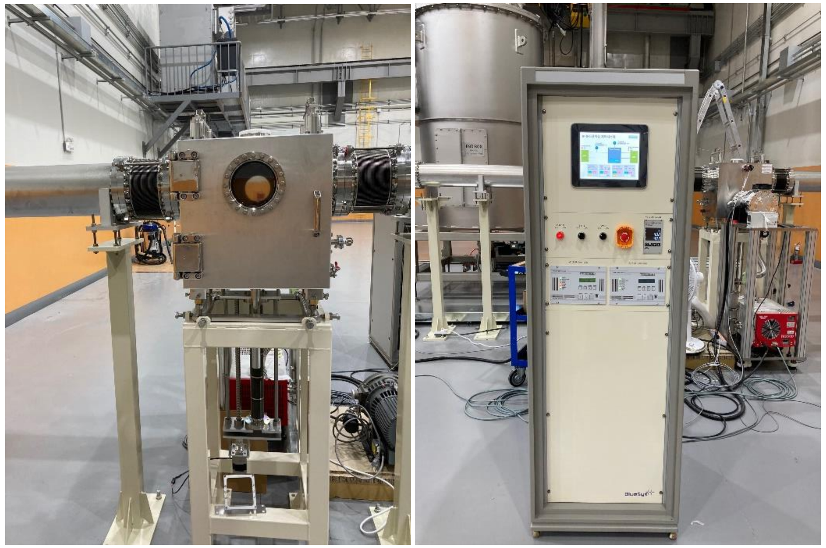
IF-LAMPS beamline

Length of beamline (from F8 to the LAMPS target) : 28.4 m





Beamline on the IF side



Viewer chamber & control system

Beamline on the LAMPS side

Si+CsI charged particle detector

Talk by Minjung Kweon in 14:30 this afternoon (Session 14).

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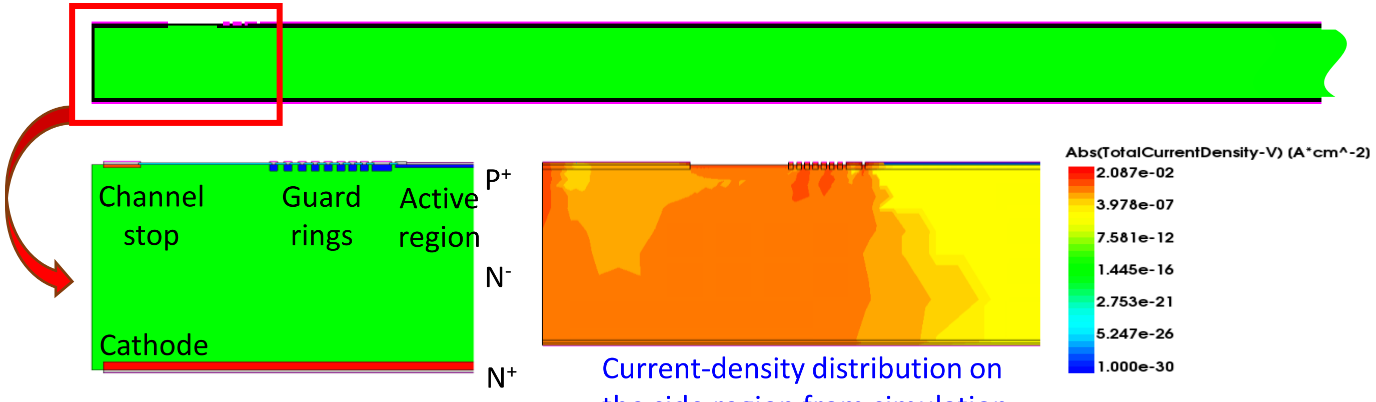
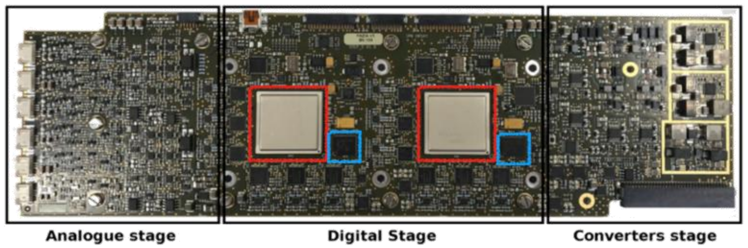
- Design and construction of the new thick Si detectors
  - The detailed structure, dimensions, and doping profiles are finalized by intense simulations.
  - Low total current, $\mathcal{O}(10\ \mathrm{nA})$, is expected in the working-voltage range.
  - Si wafers will be processed at ETRI & NNFC in Korea.
- Development of the new FEE card
  - Original schematics were provided by the FAZIA Collaboration.
  - But several changes were applied for more effective functioning.
- The next step is to design and produce the 150 μm thick detectors.



Current-density distribution on the side region from simulation

FAZIA / FEE(Front-End Electronics) Old Card



The FAZIA setup. NIMA. Volume 930. 2019. Pages 27-36

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Assembly of quartetto