LAMPS for Nuclear Symmetry Energy Study at RISP

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Rare Isotope Science Project (RISP)

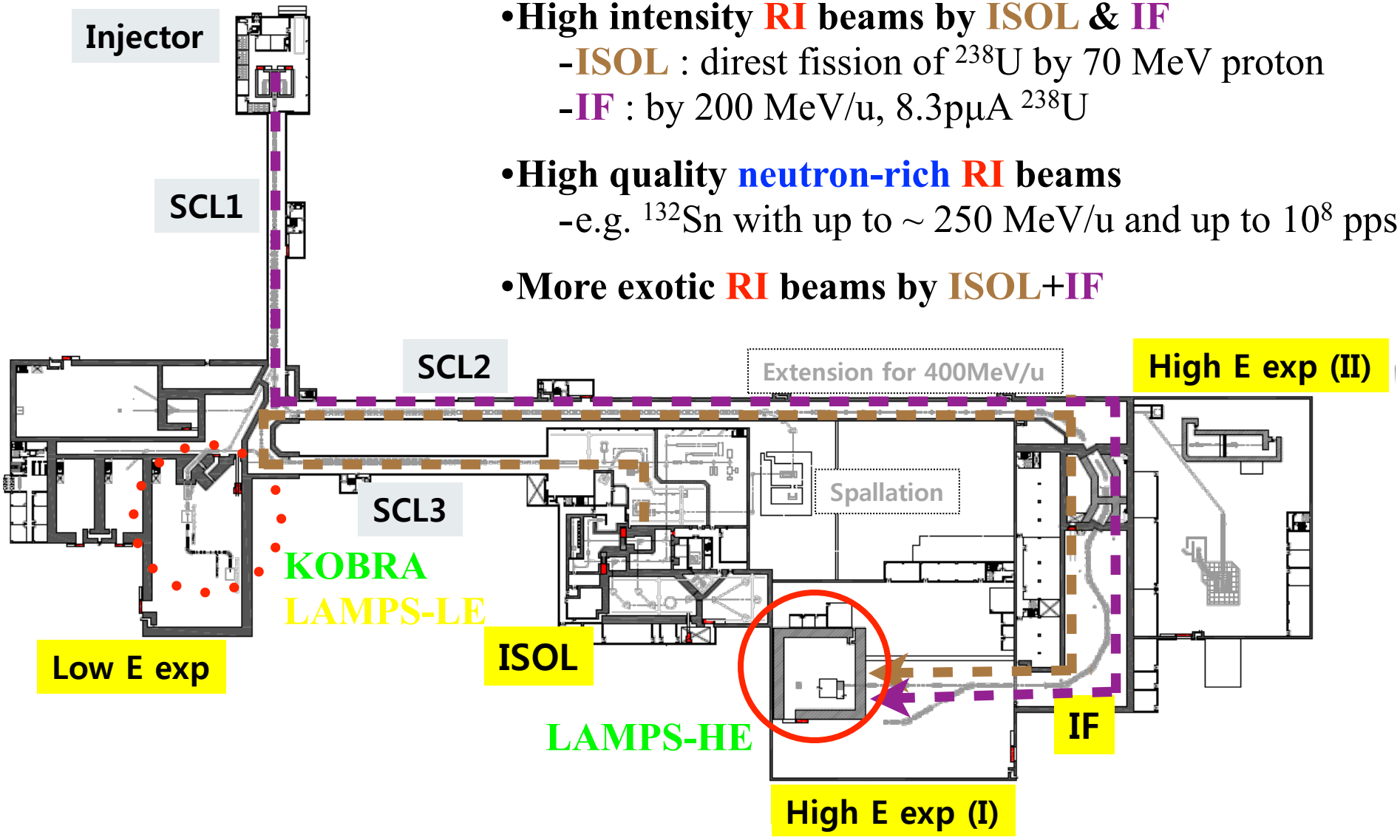
Institute of Basic Science (IBS)

Korean Physical Society 2015 Fall Meeting

Pioneering Symposium: Nuclear Physics with Rare Isotope Beams (ANPhA Symposium)

October 23rd, 2015

RAON Accelerator Facility



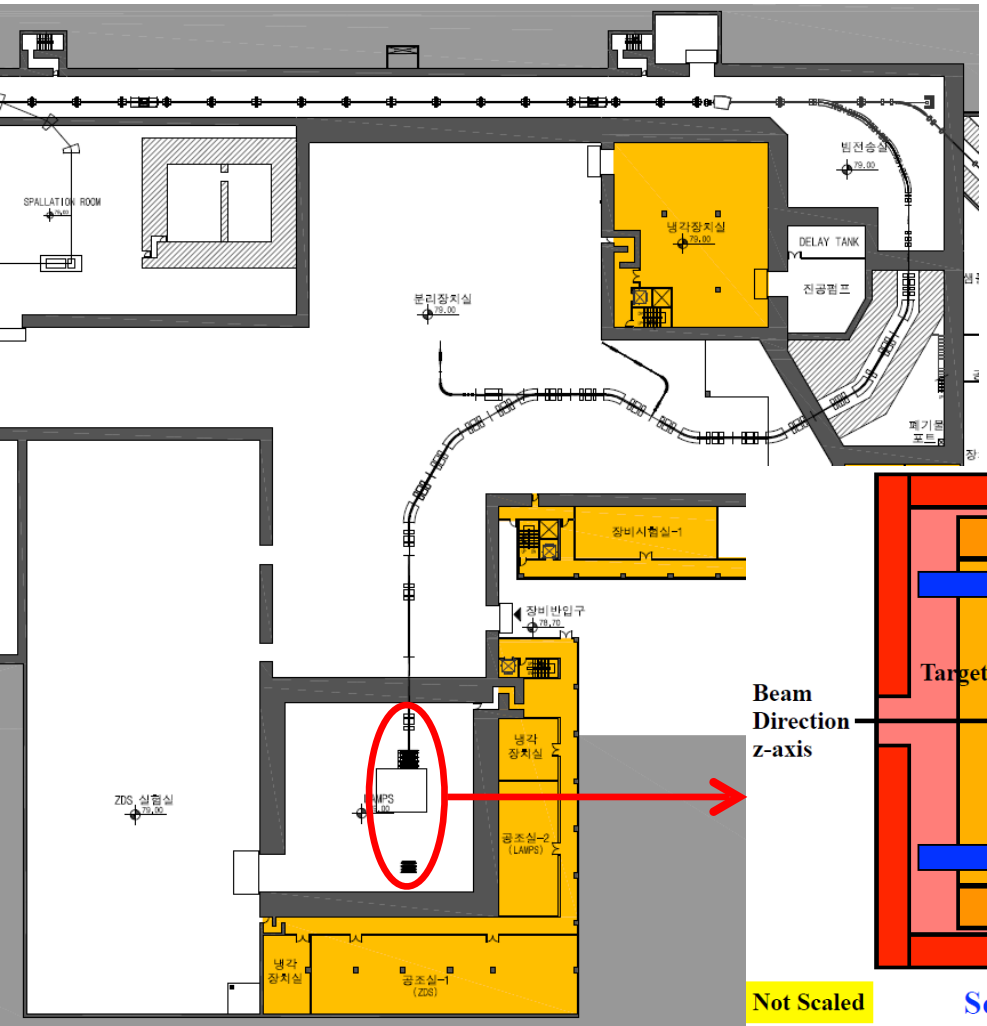
- **High intensity RI beams by ISOL & IF**
  - -ISOL : direst fission of ^{238}U by 70 MeV proton
  - -IF : by 200 MeV/u, 8.3pμA ^{238}U
- **High quality neutron-rich RI beams**
  - -e.g. ^{132}Sn with up to ~ 250 MeV/u and up to 10^8 pps
- **More exotic RI beams by ISOL+IF**

Large Acceptance Multi-Purpose Spectrometer (LAMPS)

•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

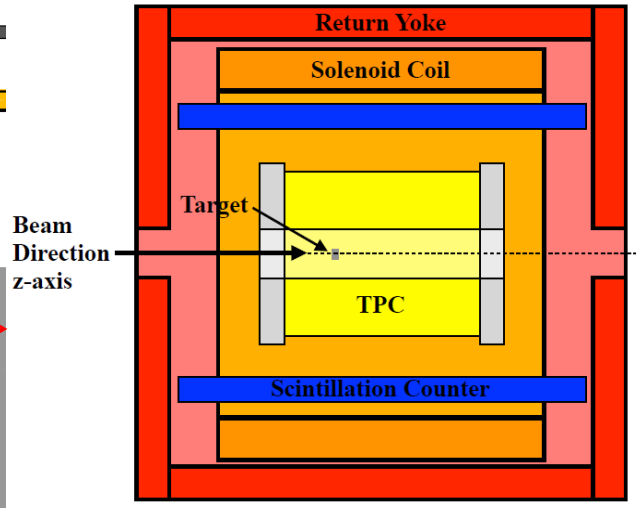


•Beam Energy: up to 250 MeV/u

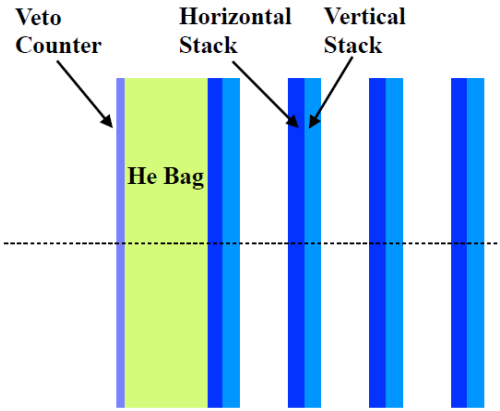
•Solenoid Spectrometer

- Max. 1T solenoid magnet
- TPC (~ 3π sr acceptance, charged particle tracking)
- Scintillation counter (trigger & ToF)

•Neutron Wall (neutron tracking)



Solenoid Spectrometer



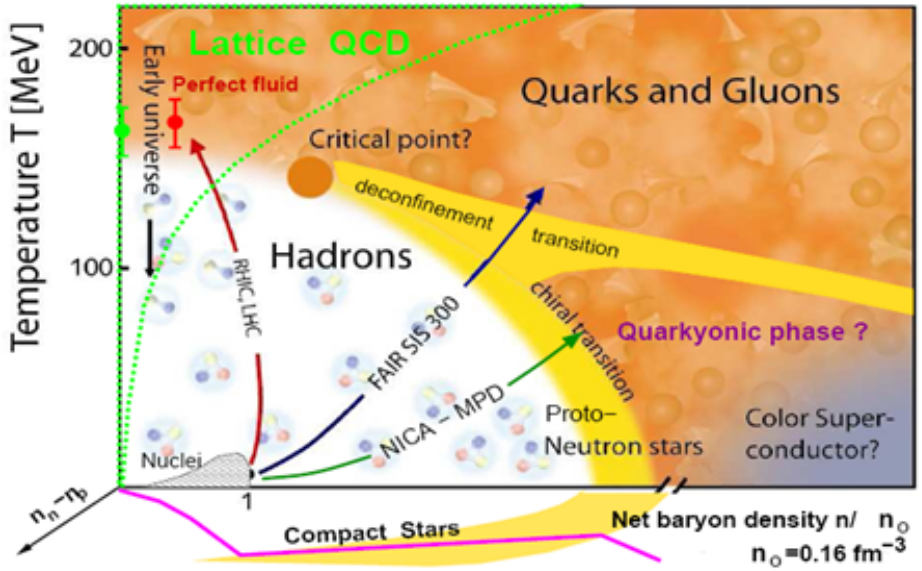
Neutron Detector Array

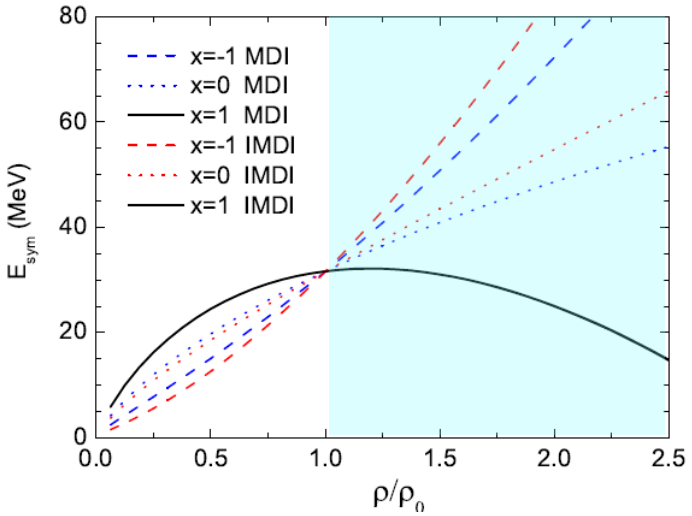
8 ~ 15 m away from target

movable for experiments

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 from sub- to supra-saturation densities**
  - **-Characterization of the core of neutron stars**

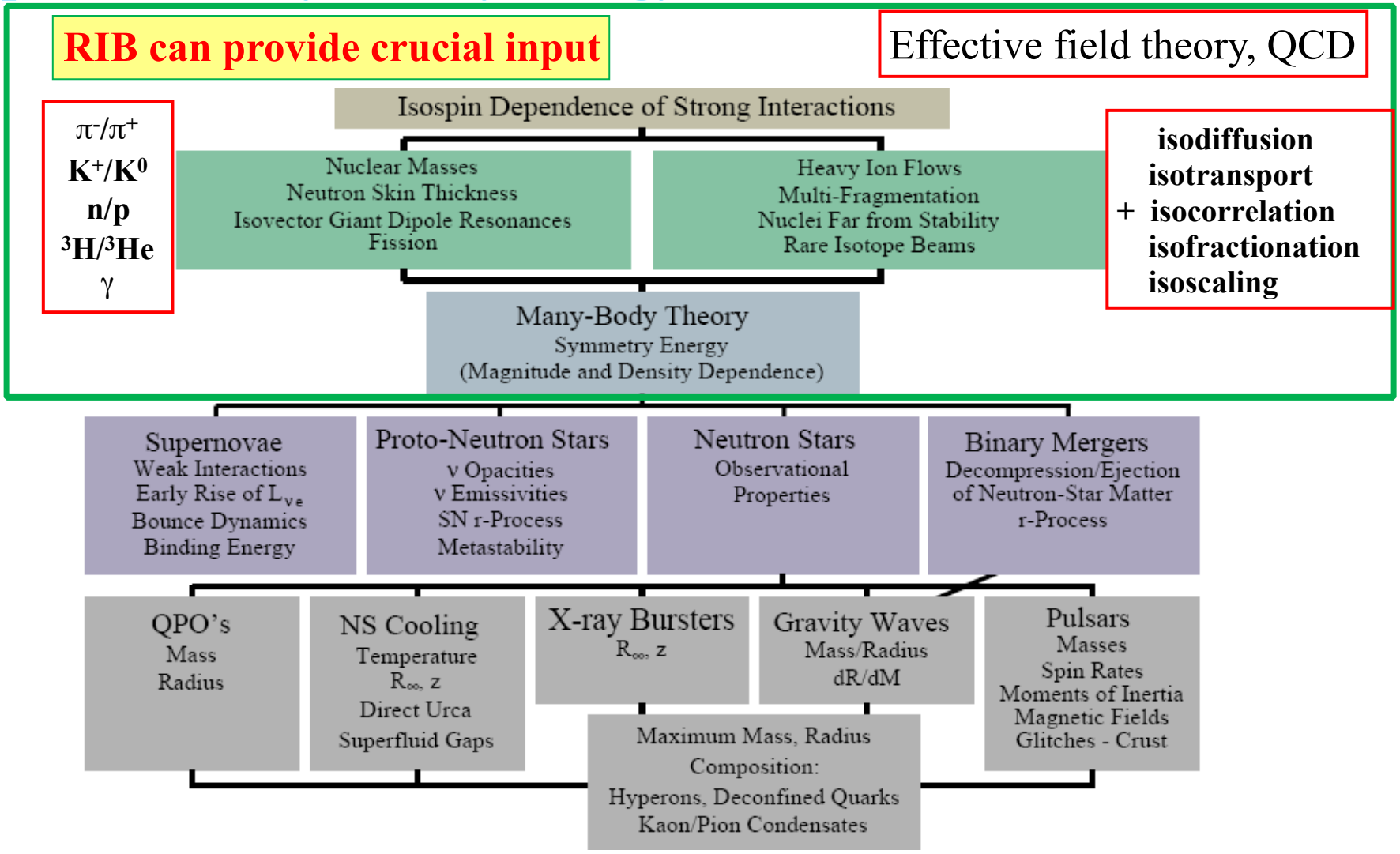




C. Xu and B. A. Li, PRC 81, 044603(2010)

LAMPS(Large Acceptance Multi-Purpose Spectrometer) is going to study of nuclear symmetry energy at supra-saturation density via heavy-ion collision experiment at RAON

Importance of Symmetry Energy



- **A.W. Steiner, M. Prakash, J.M. Lattimer and P.J. Ellis, Physics Report 411, 325 (2005)**
- **Red boxes: added by B.-A. Li**

Importance for understanding

- **–Supernovae and neutron stars**
- **–Nuclear synthesis and exotic nuclei near neutron drip lines**

Physics Observables

Important to measure

system size (Ca, Ni, Ru, Zr, Sn, Xe, Au, U),
energy (lowest to top energies),
centrality, rapidity & transverse momentum dependence

1.Particle spectrum, yield, and ratio

- n/p, ^{3}H(pnn)/^{3}He(ppn), ^{7}Li(3p4n)/^{7}Be(4p3n), $\pi^-(d\bar{u})/\pi^+(u\bar{d})$, etc

2.Collective flow

- v_1 & v_2 of n, p, and heavier clusters
- Azimuthal angle dependence of n/p ratio w.r.t the reaction plane

3.Various isospin dependent phenomena

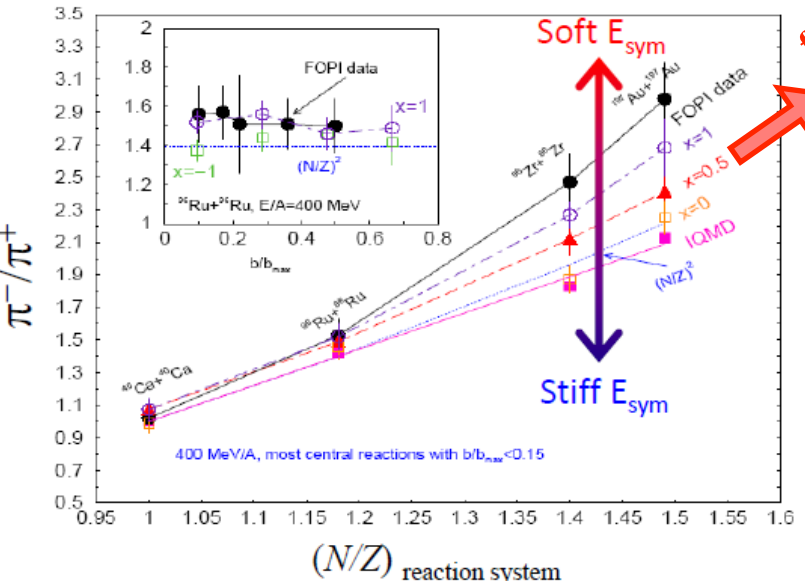
- Isospin fractionation and isoscaling in nuclear multifragmentation
- Isospin diffusion (transport)
- Etc.

4.Giant and Pygmy dipole resonances

- Energy spectra of gammas
- Related to the radius of n-skin for unstable nuclei

LAMPS Physics Cases

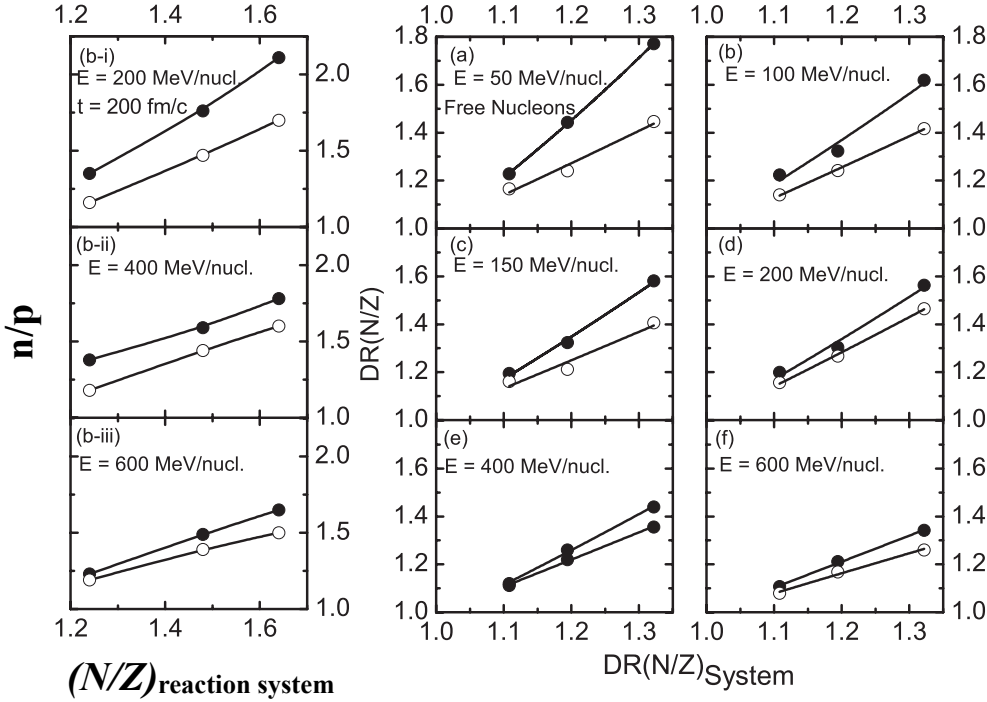
System & Beam Energy Dependence



future RI beam experiments

Z. Xiao *et al.*, PRL 102, 062502(2009)

S. Kumar *et al.*, PRC 85, 024620(2012)



solid = asy-soft
open = asy-stiff

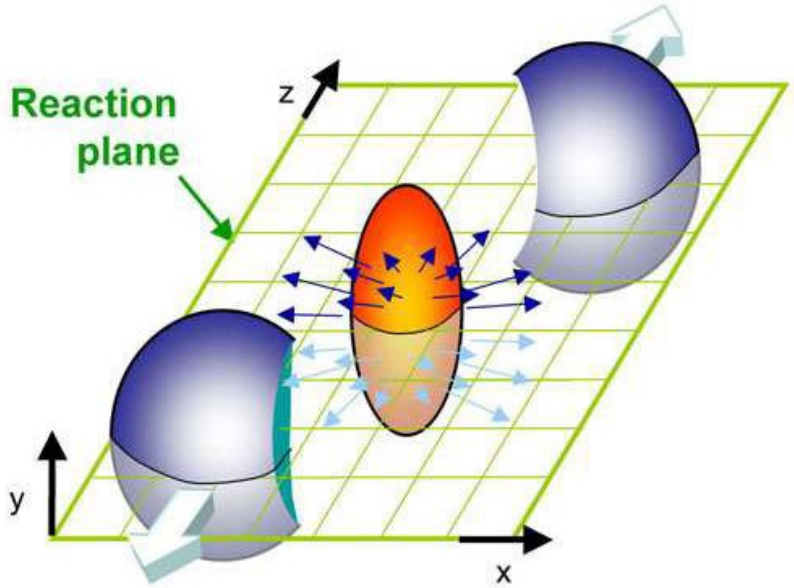
Examples for Sn at RAON
$N/Z(^{106}Sn + ^{112}Sn) = 1.18$
$N/Z(^{132}Sn + ^{124}Sn) = 1.56$

$N/Z(^{112}Sn + ^{112}Sn) = 1.24$
$N/Z(^{124}Sn + ^{124}Sn) = 1.48$
$N/Z(^{132}Sn + ^{132}Sn) = 1.64$

DR(N/Z) = $(N/Z)^{neutron\ rich}/(N/Z)^{neutron\ weak}$

$DR(^{132}Sn/^{124}Sn) = 1.11$
$DR(^{124}Sn/^{112}Sn) = 1.19$
$DR(^{132}Sn/^{112}Sn) = 1.32$

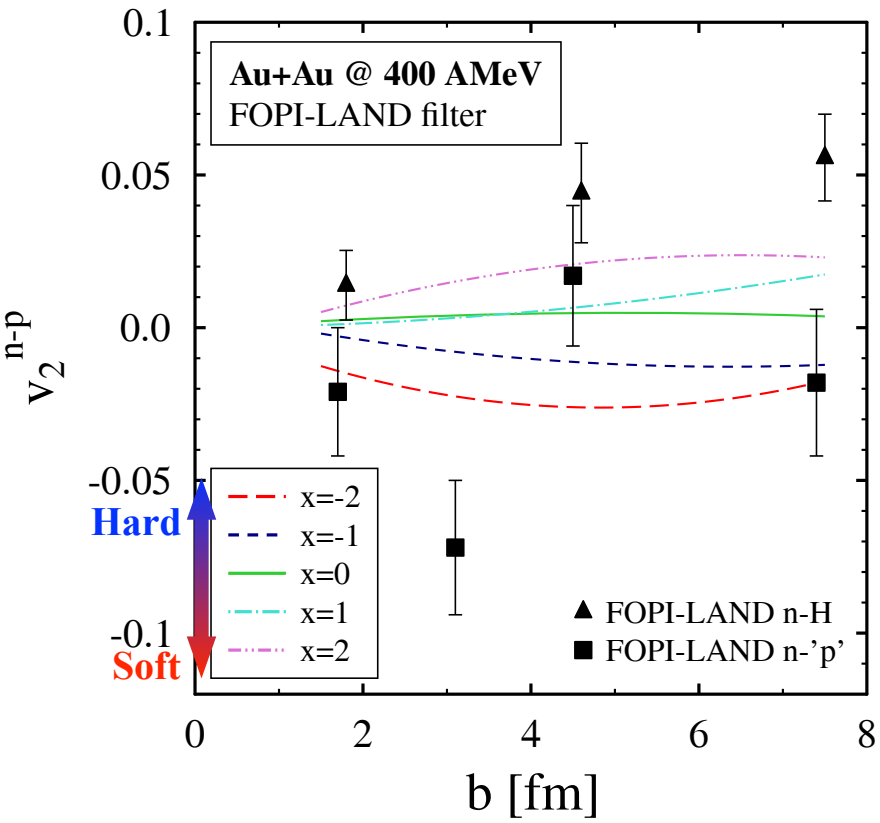
LAMPS Physics Cases



$$E\frac{d^3N}{dp^3} = \frac{d^3N}{2\pi p_t dp_t dy} \cdot (1 + 2v_1 cos(\Phi - \Phi_R^{(n)}) + 2v_2 cos(2 \cdot (\Phi - \Phi_R^{(n)})) + \cdots)$$

$$v_n = < cos(n \cdot (\Phi - \Phi_R^{(n)})) >$$

P. Russotto *et al.*, EPJA 50, 38 (2014)



LAMPS Collaboration

- **RISP**
  - **LAMPS Experimental Facility**
  - **TPC R&D**
  - **Solenoid Magnet**
  - **DAQ System**

- **Adopt & Use**
  - **TPC GET electronics**
  - **NARVAL DAQ**

- **Korea University**
  - **Neutron Detector and Trigger/ToF Detector R&D**
  - **TPC Software Development**
  - **GEANT-4 simulation**

- **Customized electronics by NOTICE**

- **Chonbuk National University**
  - **GEANT-4 simulation**
  - **Neutron Detector R&D**

- **Chonnam National University**
  - **CsI(Tl) detector R&D**

- **Kyungpook National University**
  - **Si detector R&D**

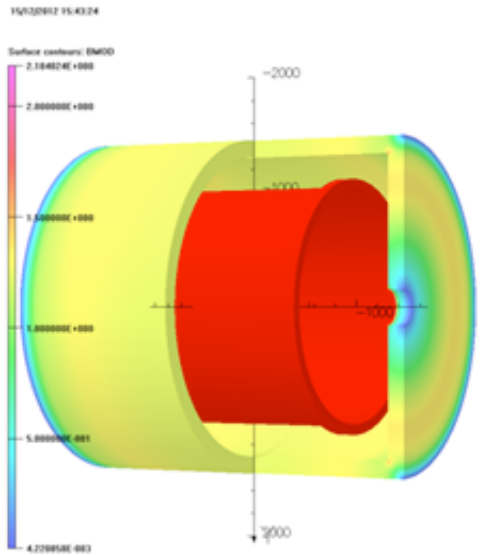
- **Inha University**
  - **TPC tracking algorithm**

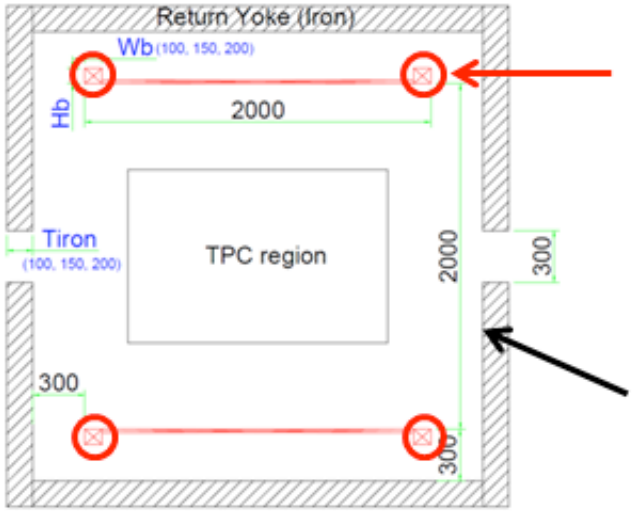
18 people from 6 domestic institutes

Looking for more collaborators from both domestic and international

➢ **To form international collaboration**

LAMPS Solenoid Magnet

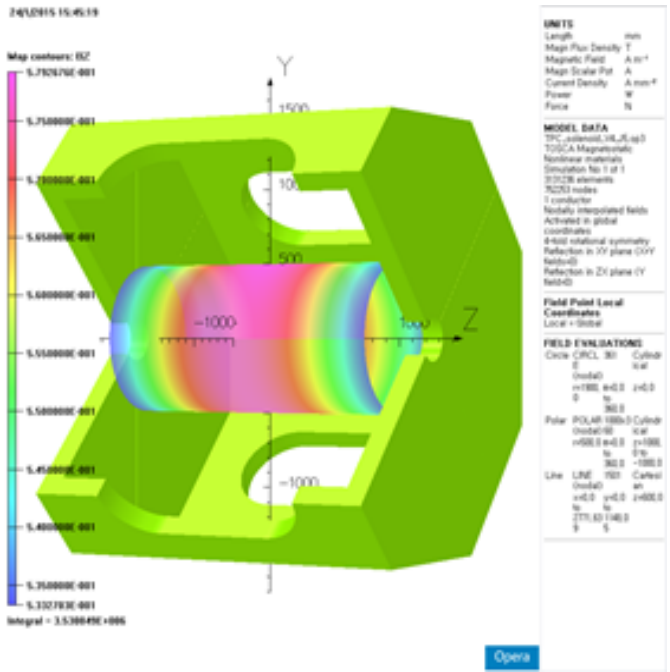




Bump coil

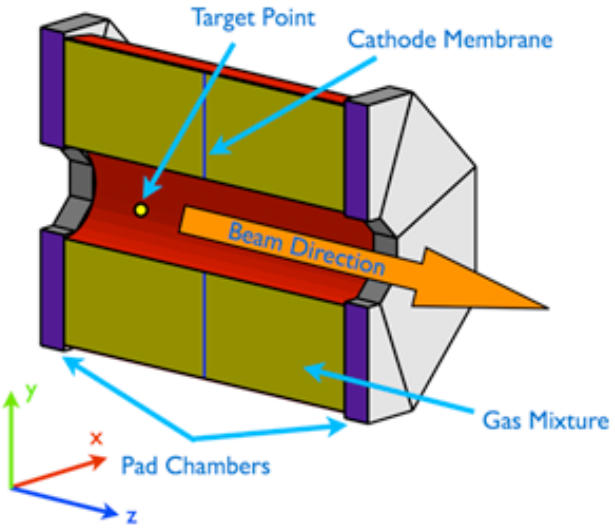
Return yoke

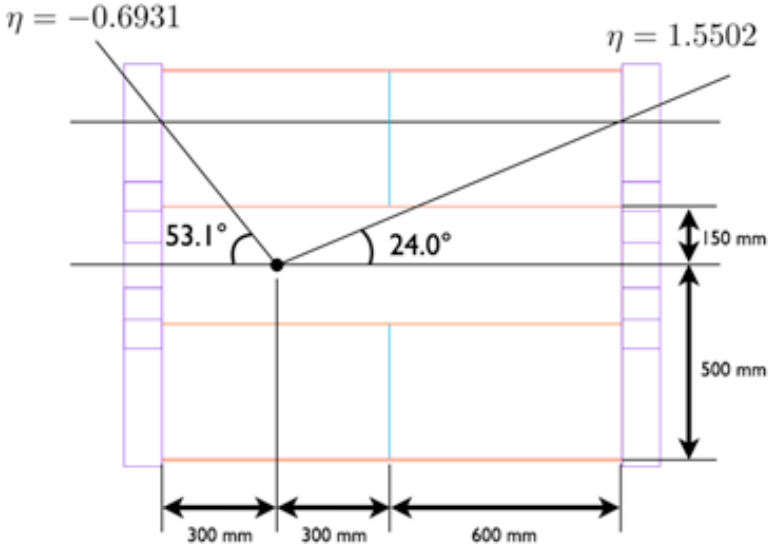
- Cylindrical shape
- Coil: 2 x 2 m^2
- Total size: 3 x 3 m^2
- Boperation: ~ 0.5 T
- Bmax.: ~ 1T
- To cover TPC (r = 0.5 m, l = 1.2 m) with homogeneous B-field
- $\Delta B/B < 2$ %

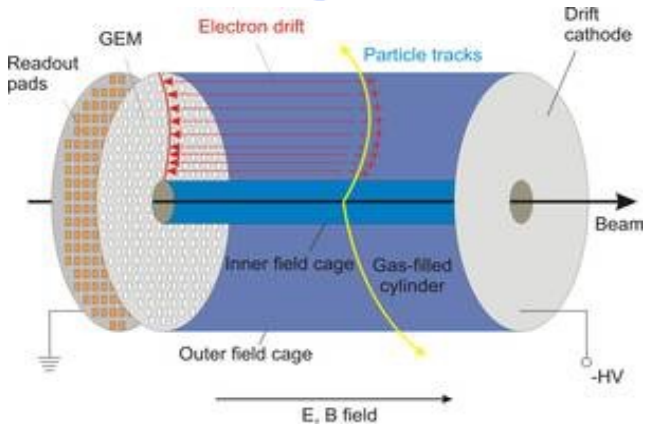


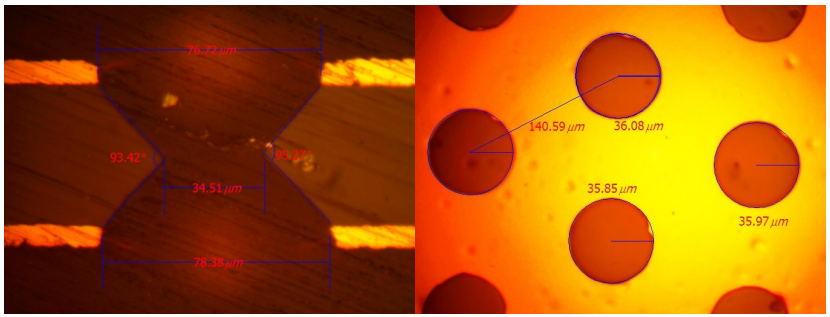
- **Solenoid magnet design modification**
  - For better neutron measurement
  - Higher order harmonics occurs but the influence is only < 0.5% in addition to the deviation of magnetic field from previous design
  - Further improvement is in progress
  - After modification, GEANT-4 simulation is required

LAMPS Time Projection Chamber (TPC)



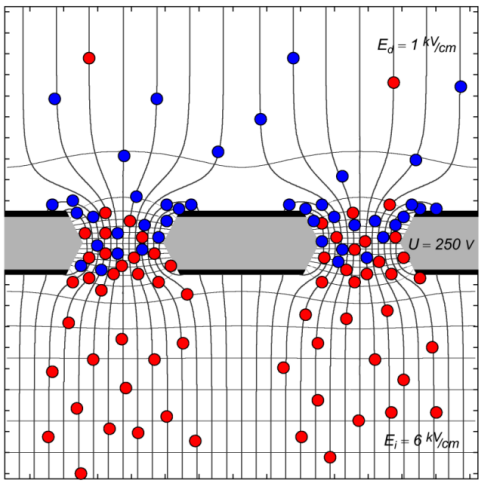


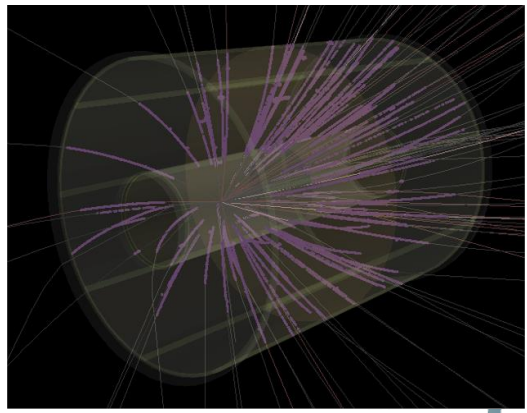




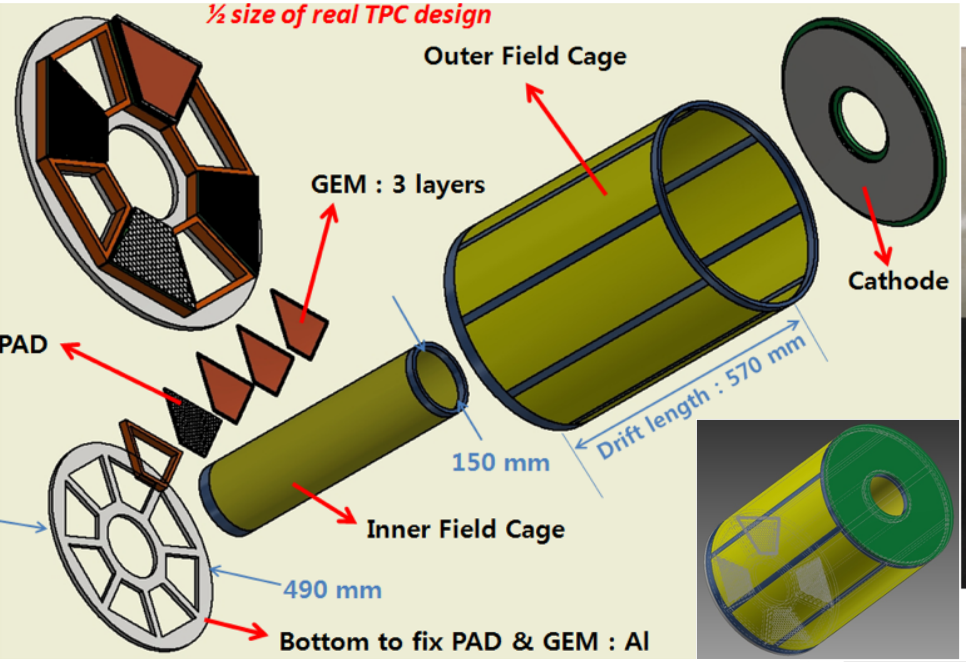
Time Projection Chamber (TPC)

- -1 x 1.2 m^2 cylindrical shape
- -Triple GEM based & pad readout in end-caps
- -Large acceptance (~ 3π sr)
- ★Complete 3D charged particle tracking
  - ➡Particle identification and momentum reconstruction

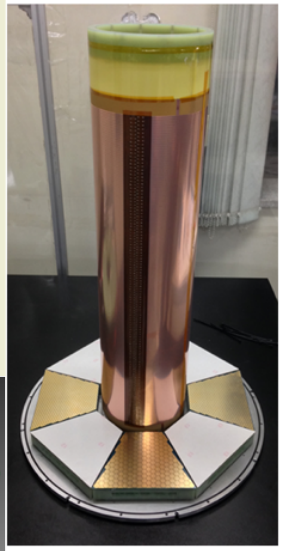




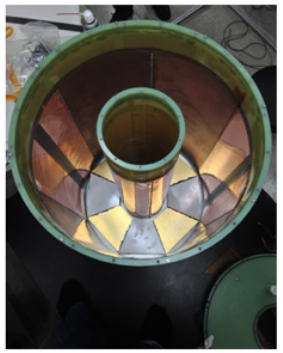
LAMPS TPC Prototype R&D



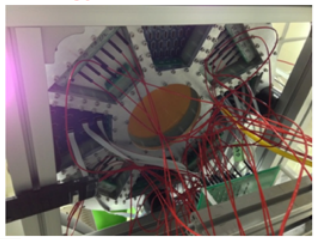
Inner Field Cage install



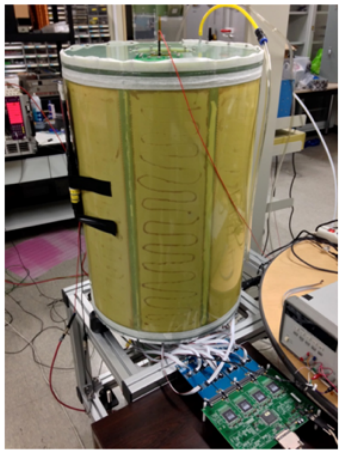
Outer Field Cage install



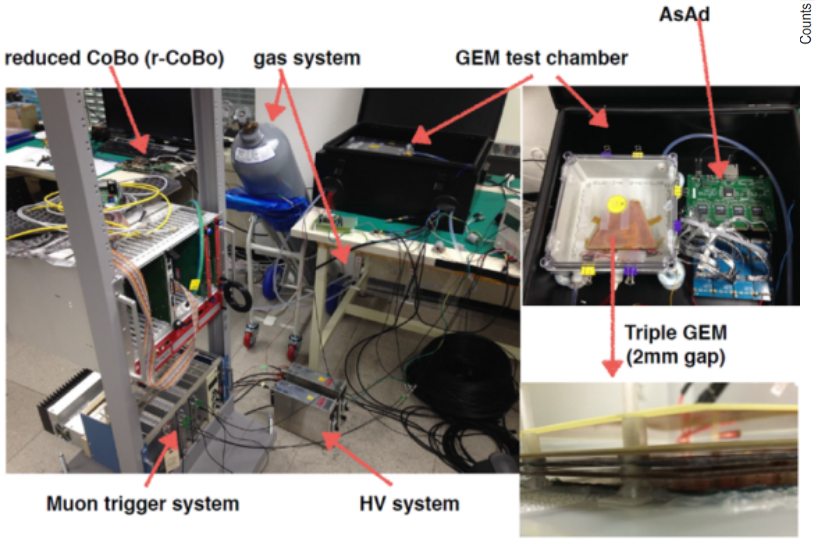
Prototype TPC : back

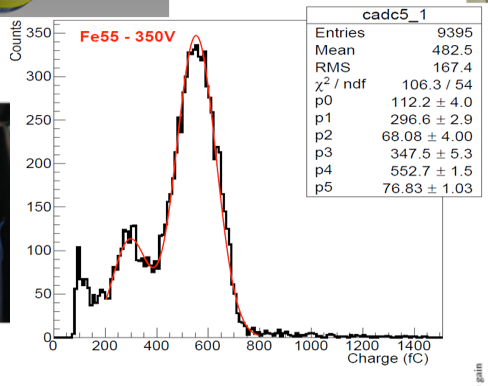


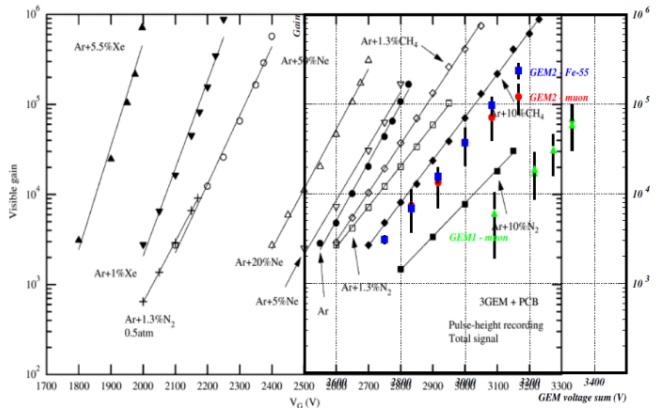
Prototype TPC



same drift length as final TPC





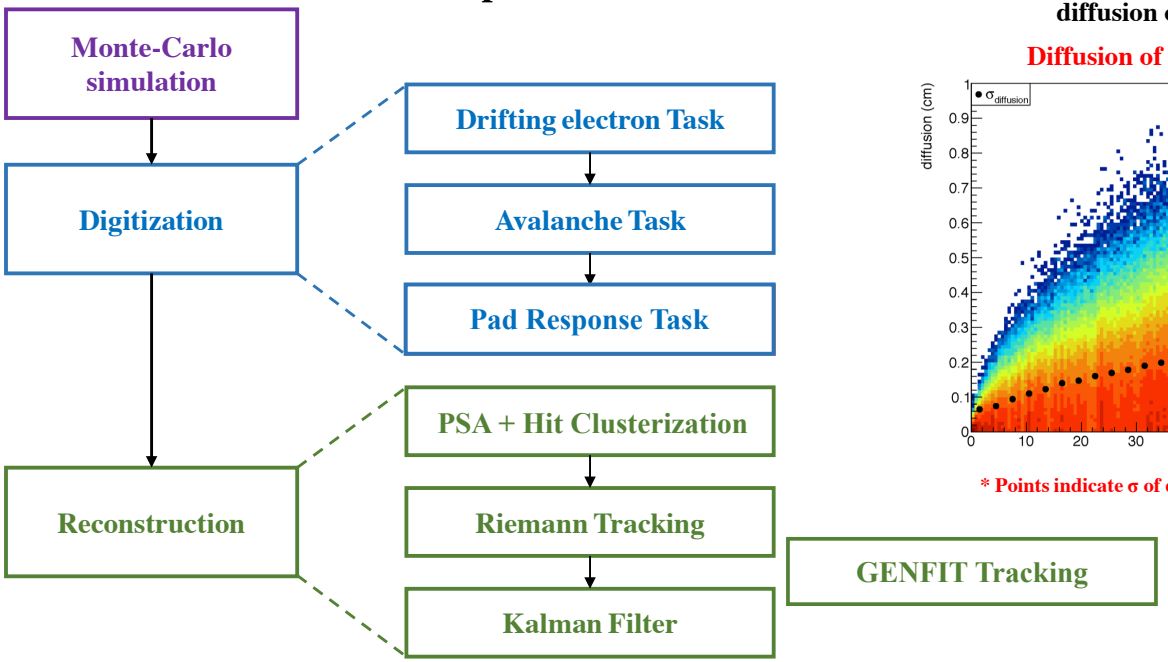


A. Buzulutskov et al., NIMA 443(2000) 164

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

LAMPS TPC Software Development

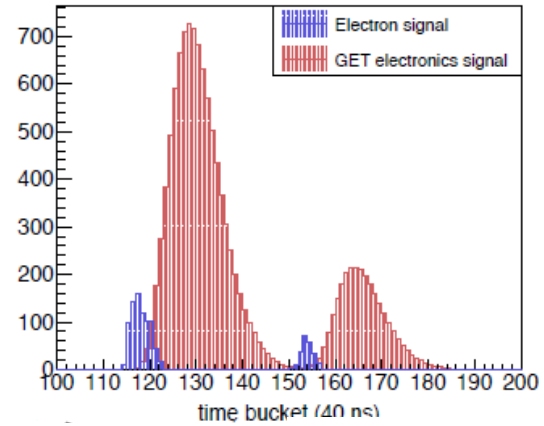
- **LAMPSROOT is developed based on FAIRROOT.**



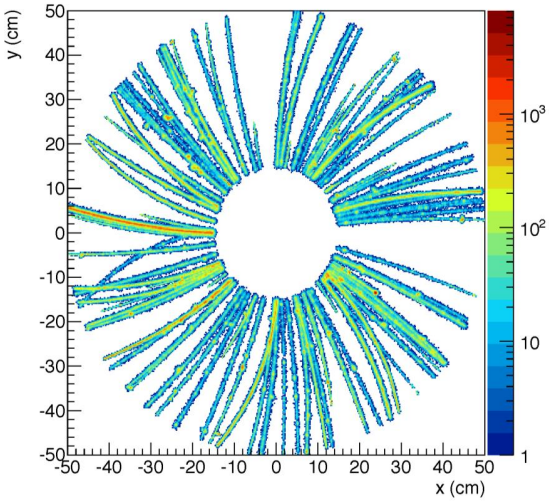
- **Digitization process is developed to simulate ionization, diffusion of electrons and response of GEM and pad.**

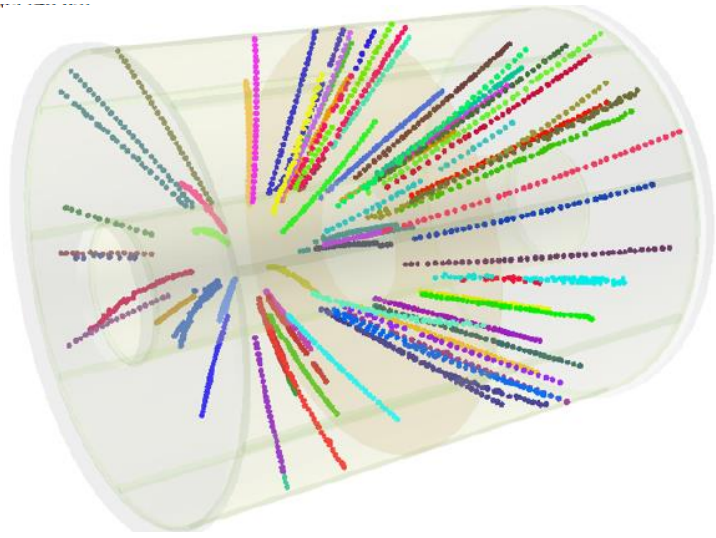
Diffusion of electron

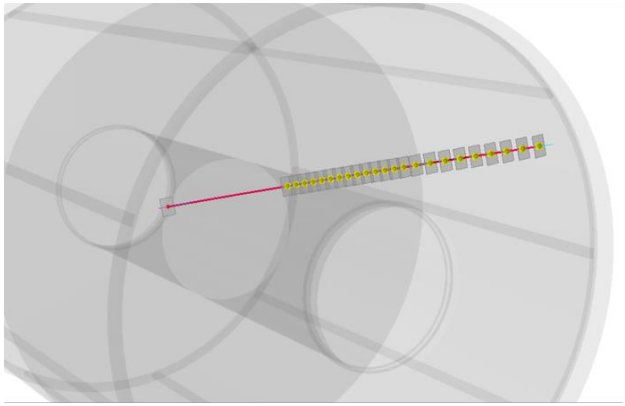
* Points indicate σ of diffusion



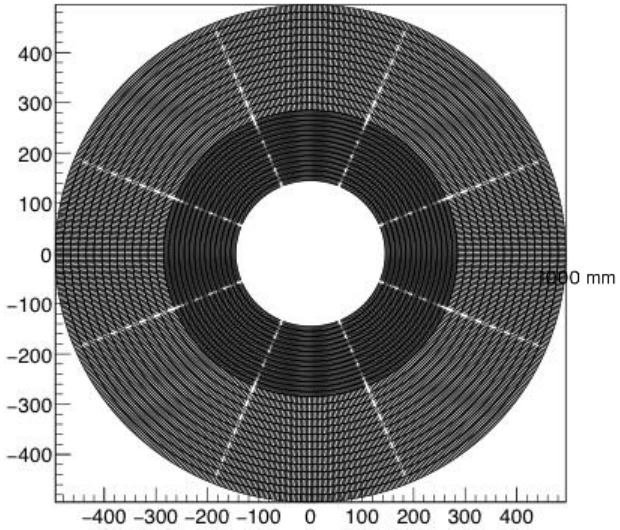
Digitized Event



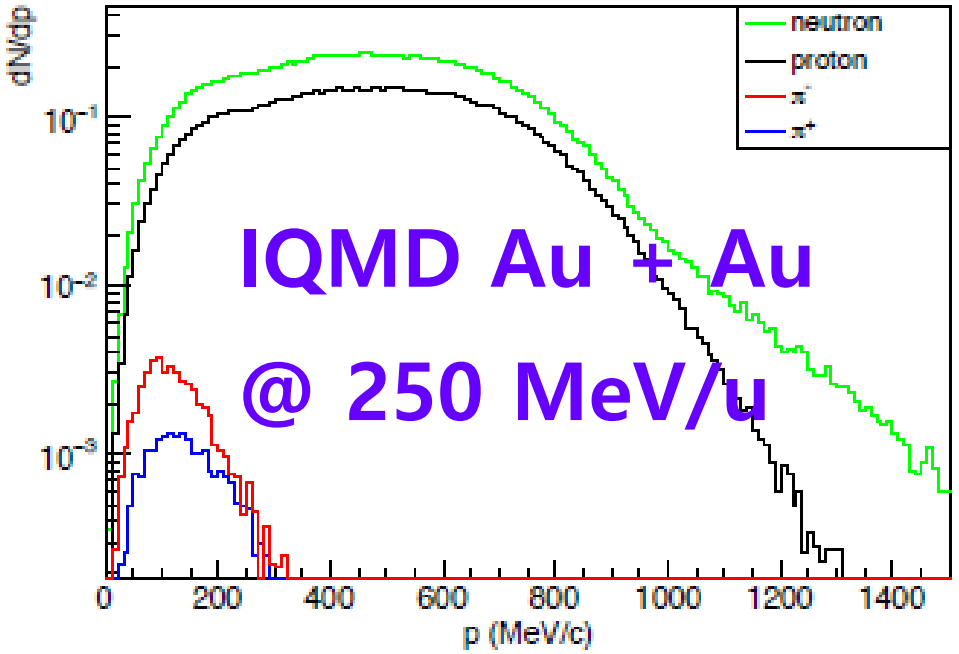




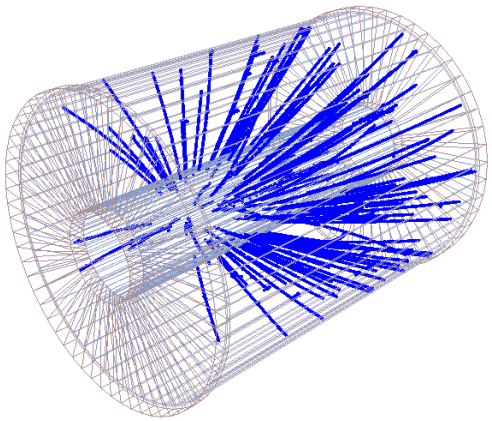
LAMPS TPC Simulation

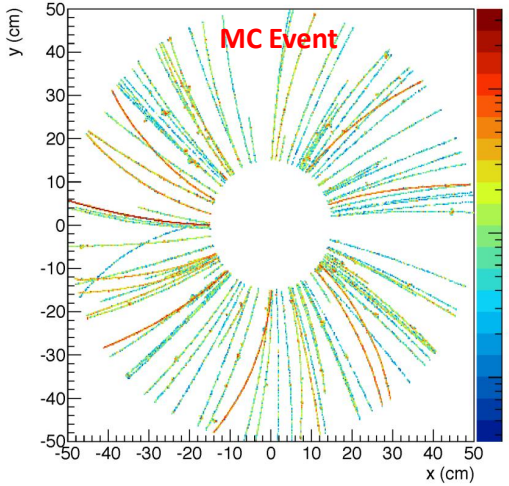


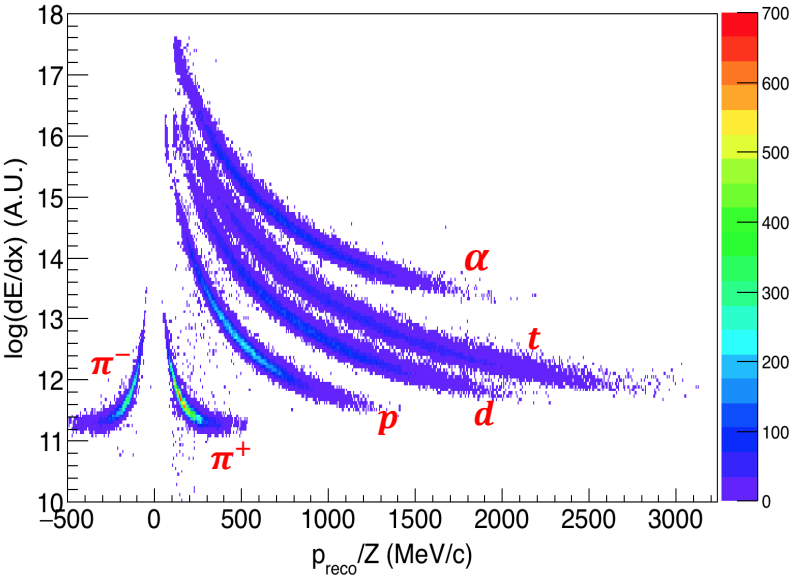
Fan-type readout pad
inner radius = 3 x 10 mm²
outer radius = 4 x 15 mm²



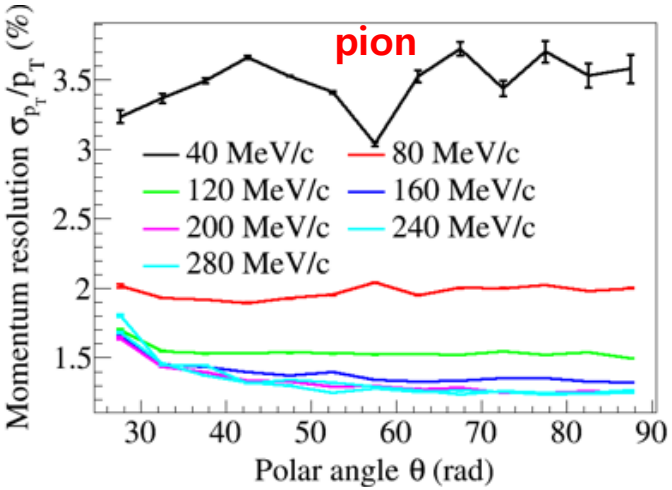
- **IQMD Au+Au @ 250 *A* Mev is used for event generator.**
- **Gas : Argon (90%) + CO_2 (10%) mixture.**
  - Density : 1.78 g/cm³
- **Field : 0.5 Tesla**

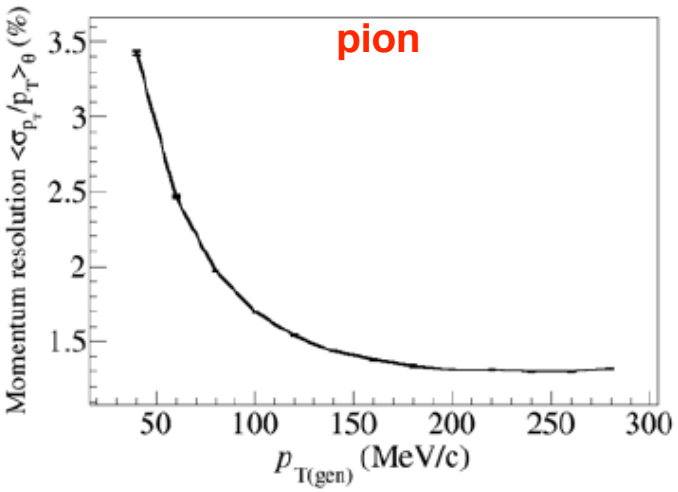


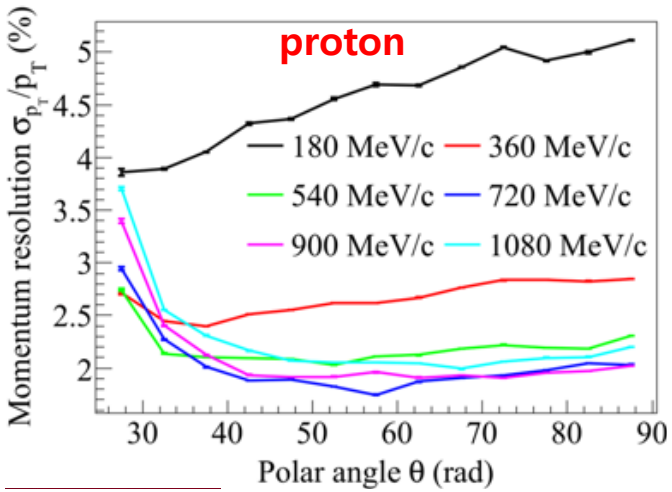


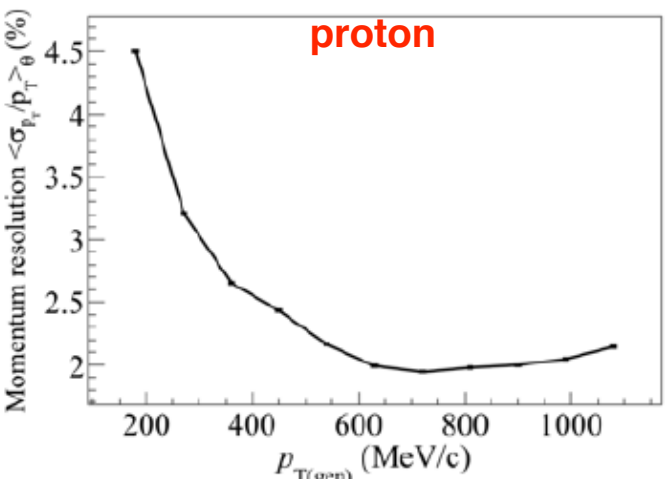


LAMPS TPC Simulation









Transverse momentum resolution as a function of polar angle

Transverse momentum resolution as a function of transverse momentum

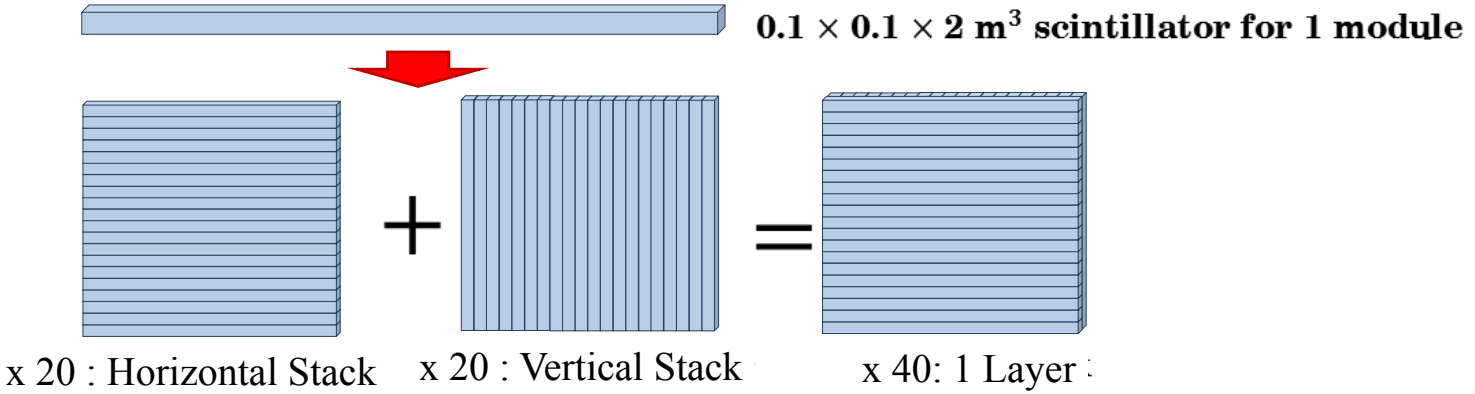
Detail simulation for performance estimation of LAMPS TPC is on-going

LAMPS Neutron Detector Array

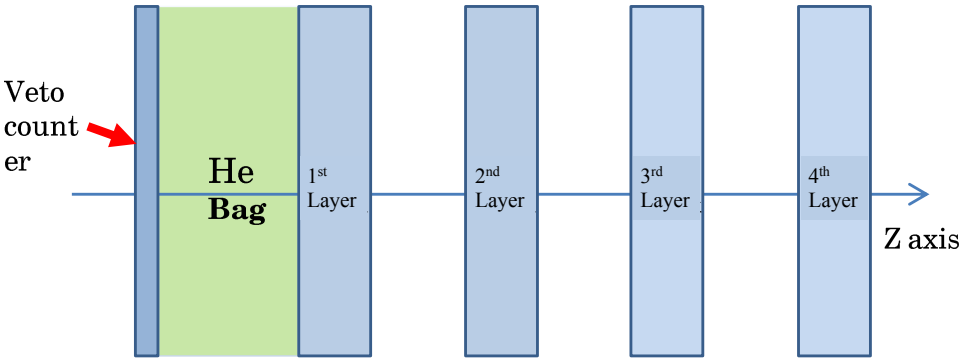
Proposed structure: 4 layers of plastic scintillators (2-m long)

+ 1 Veto plastic layer for charged particle rejection

- ✓ Energy range to measure: 30 ~ 300 MeV
- ✓ Time resolution < 500 ps for ToF measurements
- ✓ $\Delta E/E \sim 2 \times 10^{-2}$ via TOF measurements
- ✓ $\varepsilon = 0.60$ for single-neutrons @ maximum 300 MeV (GEANT4)

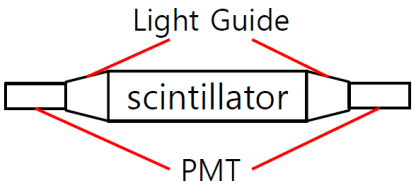


Multi-hit performance
Capability for neutron tracking

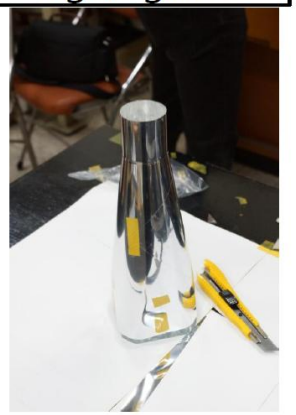


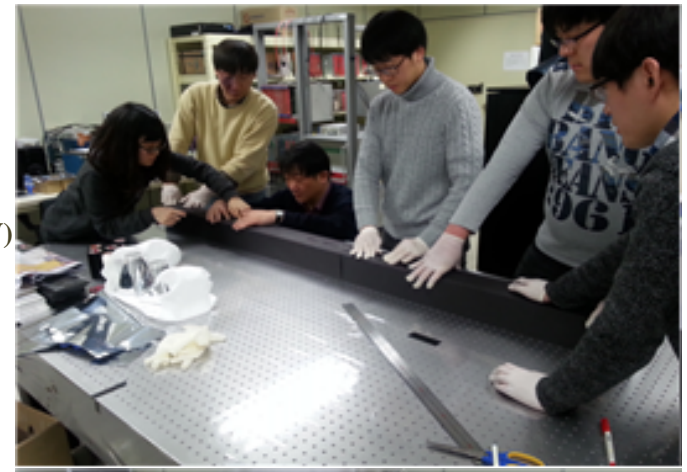
LAMPS Neutron Detector R&D

Single detector module

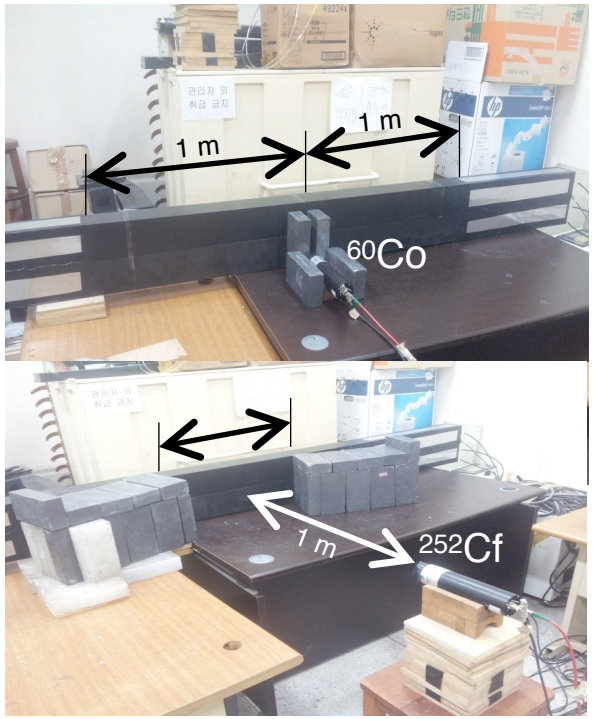


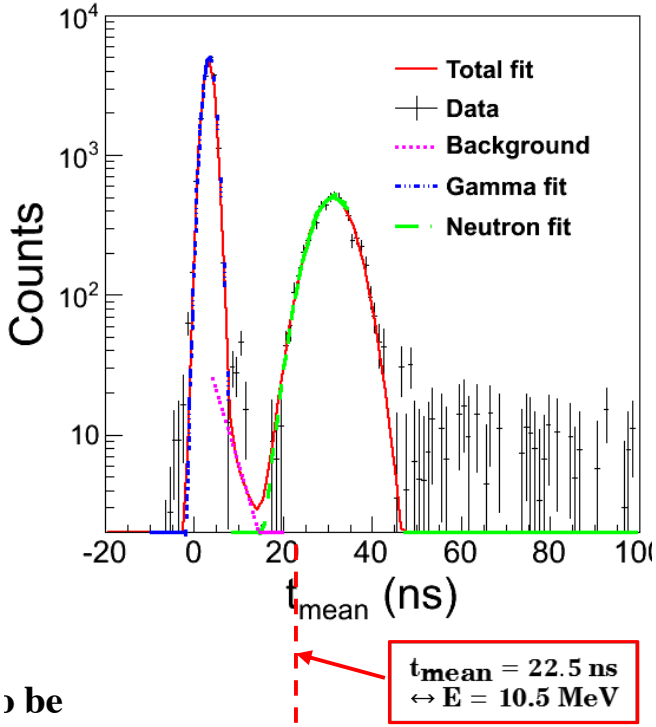
- *n-p* elastic scattering
- *n*-^{12}C elastic scattering
- $n+p \rightarrow d+\gamma$ (neutron capture, E_γ = 2.23 MeV)
- $n+^{12}C \rightarrow {}^{13}C+\gamma$ (neutron capture, E_γ = 1.2, 3.6, 4.9 MeV)

scintillator	Light guide	PMT
		
Bicron BC-408 Decay constant: 2.1 ns Bulk light attenuation length: 380 cm Refractive index: 1.58 H:C ratio: 1.104 Density: 1.032 Softening point: 70 ℃₩	**Arcrylic** Density: 1.18 g/cm3 Refractive index: 1.4914	**H2431-50** Wavelength short: 300 nm Wavelength long: 650 nm Transit time: 16 ns Gain: 2.5e+6



LAMPS Neutron Detector Array R&D

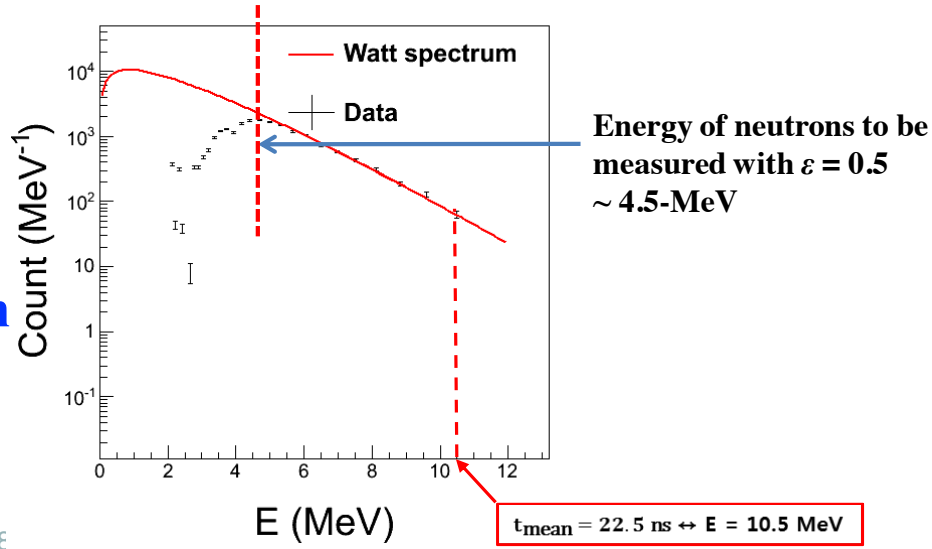




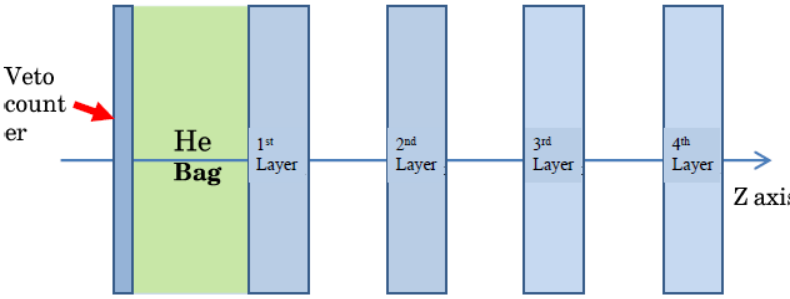
Real size prototypes with commercial electronics are tested with cosmic and radioactive sources

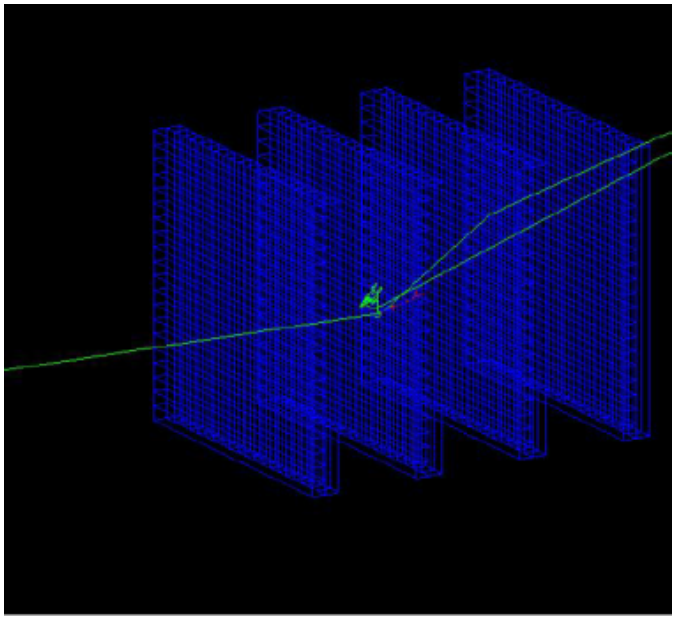
- **-intrinsic time resolution = 392 ps**
- **-position resolution = 6.62 cm**
- **-good separation of gamma and neutron**

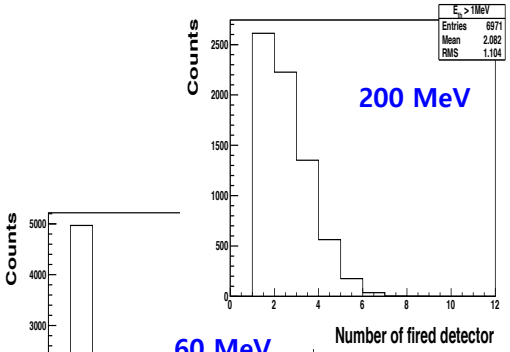
Plan to test them again with customized electronics & beam test



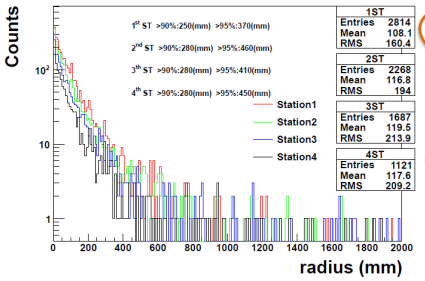
LAMPS Neutron Detector Simulation

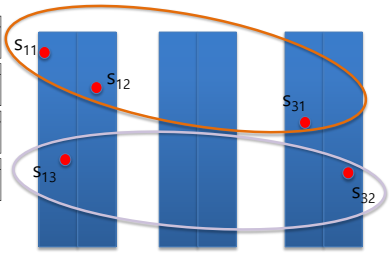






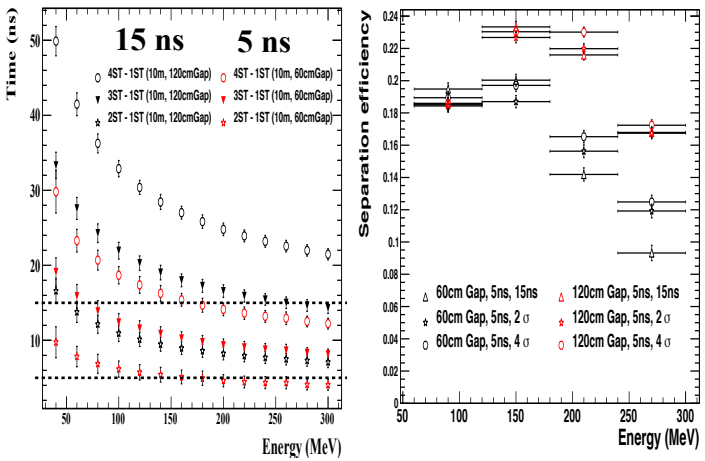
- Radial hit distribution < 50-cm for the same track



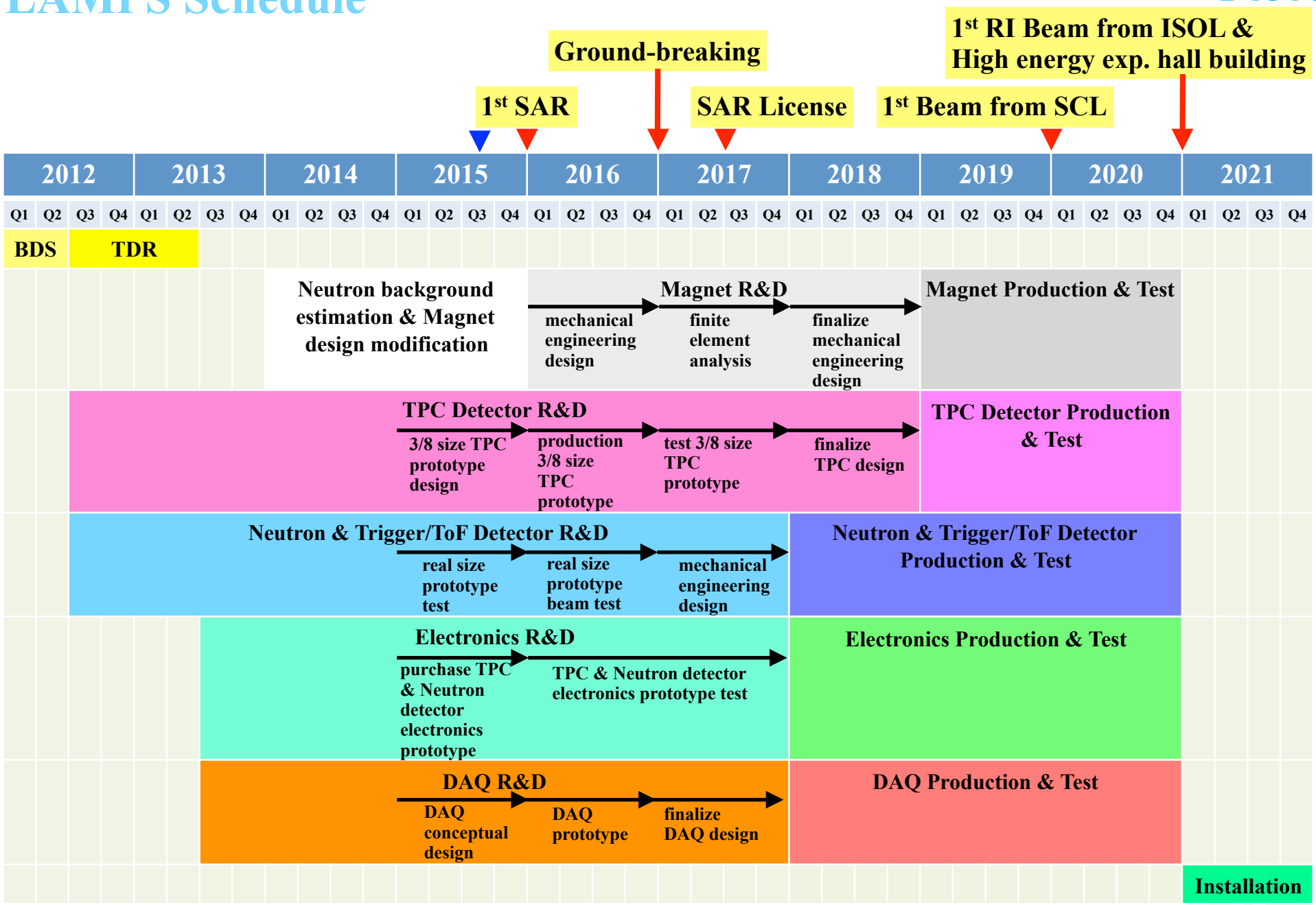


- Hit Digitization (from Response Simulation)
- Grouping : Time difference, Radial distribution, Velocity constraint.

GEANT-4 simulation is under development



LAMPS Schedule



LAMPS Experimental Setup

E_{beam} < 250 MeV/u for ^{132}Sn

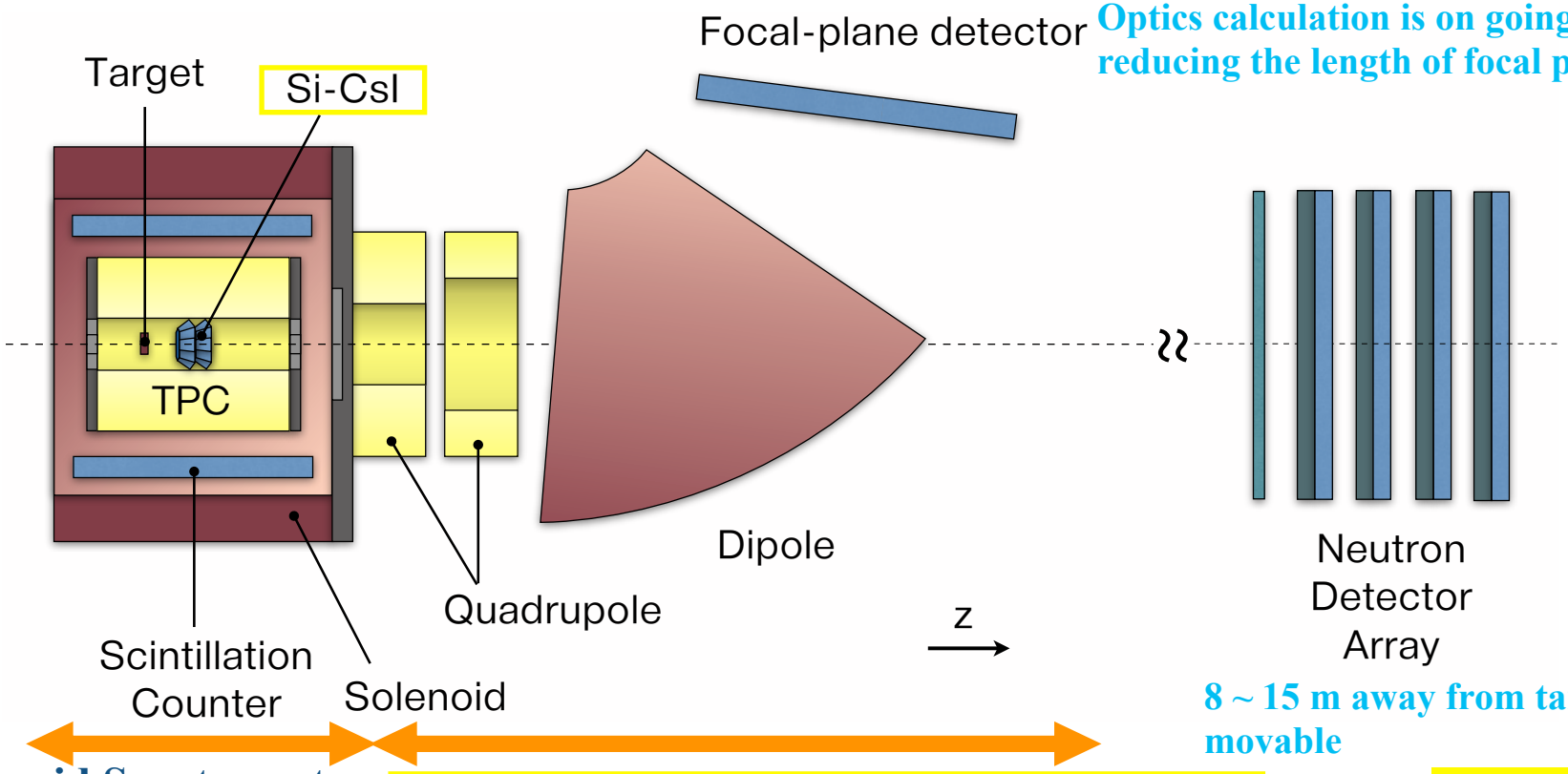
For Study of Symmetry Energy at Supra-saturation Density via Heavy-Ion Collision Experiments and Nuclear Reaction Study

-Example of Reactions for Symmetry Energy Study:

Central and Peripheral Collisions

$^{50,54}Ca + ^{40}Ca$, $^{68,70,72}Ni + ^{58}Ni$, $^{106,112,124,130,132}Sn + ^{112,118,124}Sn$

Si-CsI Array at Solenoid Spectrometer & Dipole Spectrometer are for future upgrade



Summary

- **Large Acceptance Multi-Purpose Spectrometer (LAMPS) at RAON**
  - **-Study of nuclear symmetry energy with RI and stable beam**
  - **-Particle yield, spectrum, ratio, collective flow, and other observables for charged particles and neutron**
  - **-Solenoid spectrometer (solenoid magnet + TPC + plastic scintillators for trigger & ToF + Si-CsI detector※)**
  - **& neutron detector array**
  - **& dipole spectrometer (magnet system + focal plane detector)※**
  - **※for future upgrade**
  - **✓To cover entire energy range of RAON with complete event reconstruction within large acceptance**
  - **-Design of experimental setups is almost complete**
  - **-Detector R&D is ongoing**
  - **-Getting more collaborators from not only both domestic and foreign but also nuclear structure**
    - **Forming international collaboration**