Plan and Status of Rare Isotope Accelerator and Facility for the Study of Symmetry Energy in Korea

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Institute for Basic Science (IBS)

NUSYM15
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RISP and RAON

- RISP = Rare Isotope Science Project (2011. December - 2021. December)
  - Plan & build Rare Isotope accelerator and experimental facilities in Korea
- RAON (라온) = Name of Rare Isotope accelerator complex
  - Pure Korean word: meaning "delightful", "joyful", "happy"
  - It will be located at the northern part of Daejeon where is in the middle of S. Korea
  - Budge: US $ 1.44 B (US $ 1 B ~ KR₩ 1 T)
    - Accelerators & Experimental Apparatus : US $ 0.46 B
    - Conventional Facilities & Construction : US $ 0.98 B
      (include the land of the RAON site purchasing)

- Brief History

-Institute for Basic Science (IBS) established (Nov. 2011)

-Rare Isotope Science Project (RISP) launched (Dec. 2011)

✓Rare Isotope accelerator complex is the representative facility of IBS

-Baseline Design Summary Report (Aug. 2012)

-Technical Design Report (Jun. 2013)

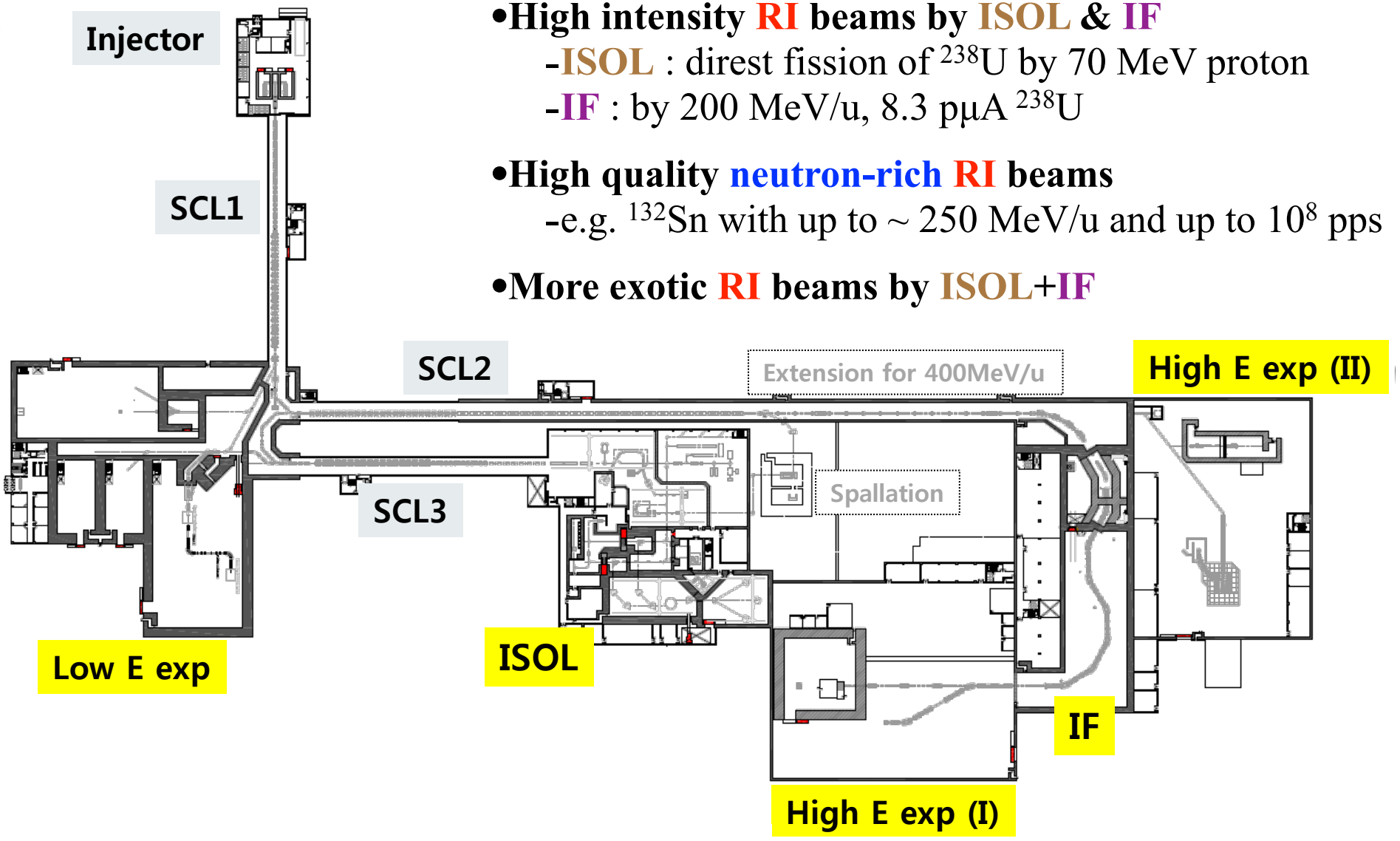
-1st Director resigned (Jun. 2014)

-New director selected and he has been working since Jan. 2015

-Complete the project by the end of 2021

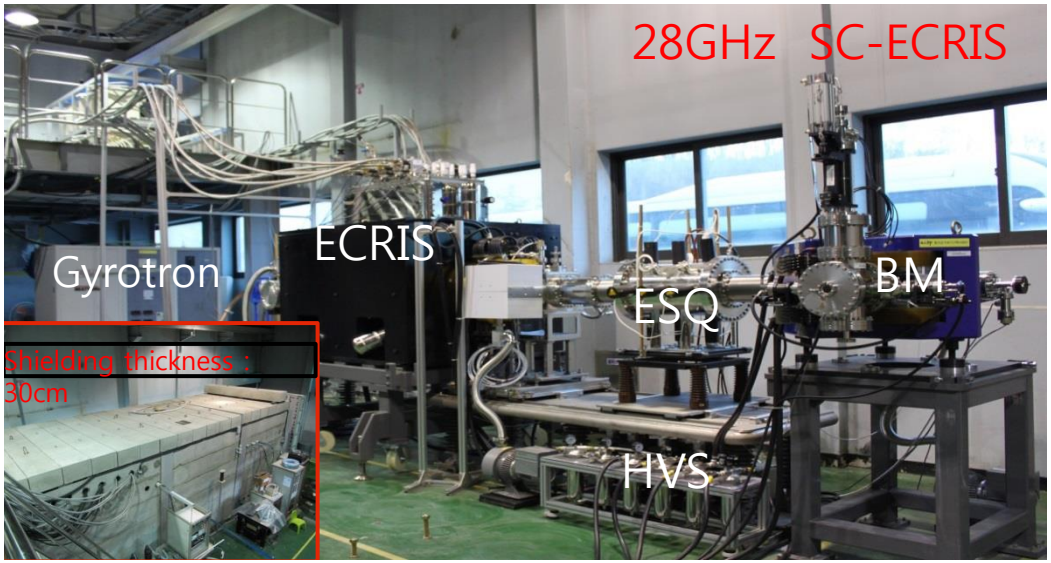
RAON site Bird's-eye view

RAON Accelerator & Experimental Facilities

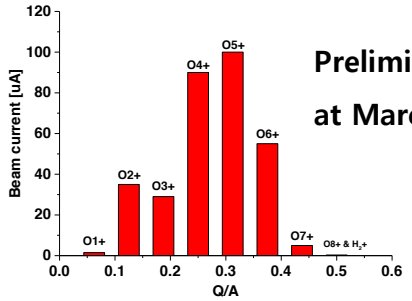


- **High intensity RI beams by ISOL & IF**
  - -ISOL : direst fission of ^{238}U by 70 MeV proton
  - -IF : by 200 MeV/u, 8.3 pμA ^{238}U
- **High quality neutron-rich RI beams**
  - -e.g. ^{132}Sn with up to ~ 250 MeV/u and up to 10^8 pps
- **More exotic RI beams by ISOL+IF**

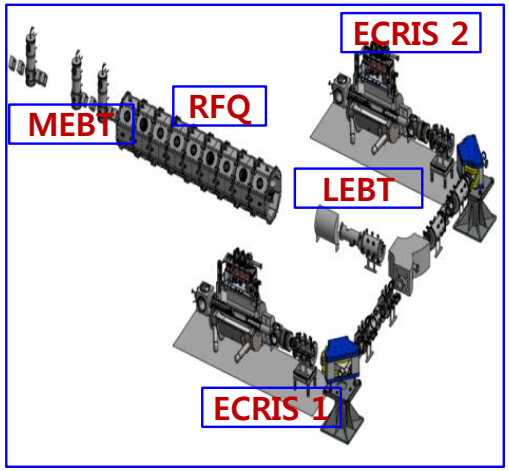
RAON Accelerator Injector System



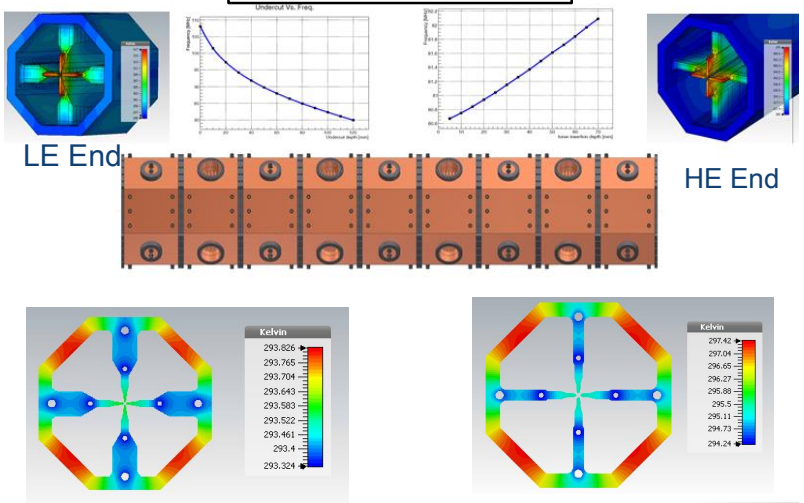
- **ECR-IS**
  - -Output emittance: 0.12 π mm-mrad
  - -Beam current: 400eμA for $^{238}U^{33+}$ + $^{238}U^{34+}$
  - -Output beam energy: 10 keV/u
  - -RF frequency: 28 GHz
  - -Magnets: Fully superconducting NbTi

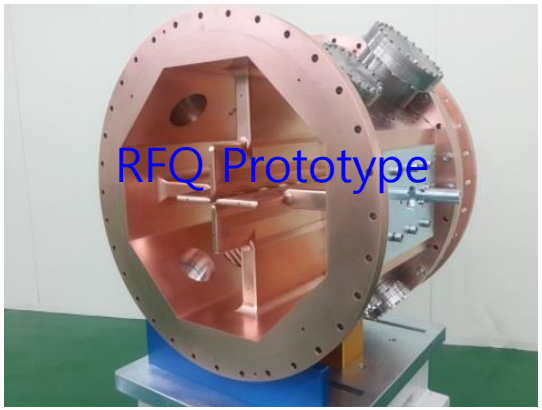


Injector layout



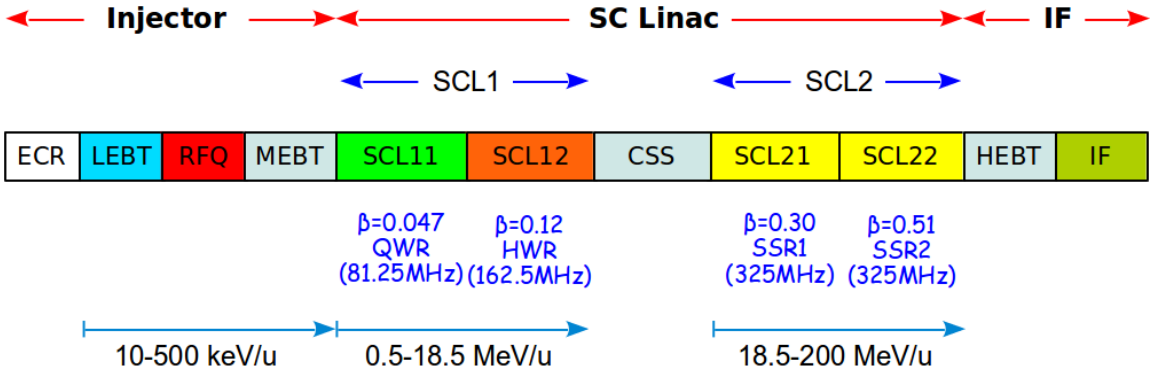
RFQ Engineering Design

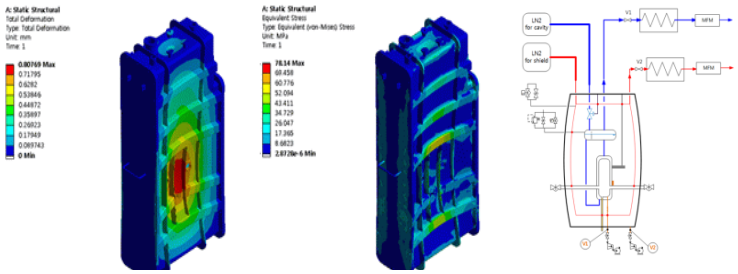




- **RFQ**
  - -RF frequency: 81.25 MHz
  - -Output beam energy: 500 keV/u
  - -4 Vane types

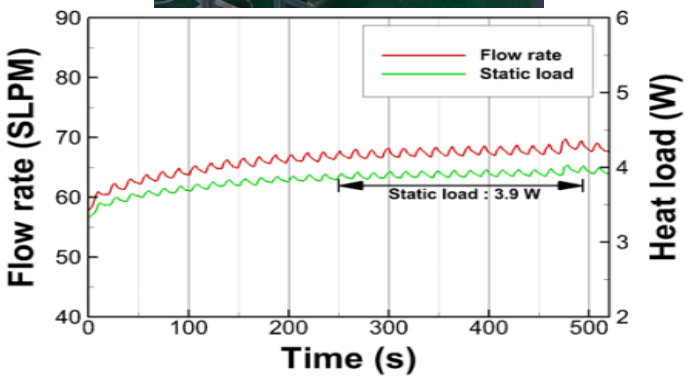
RAON Superconducting Linac (SCL)



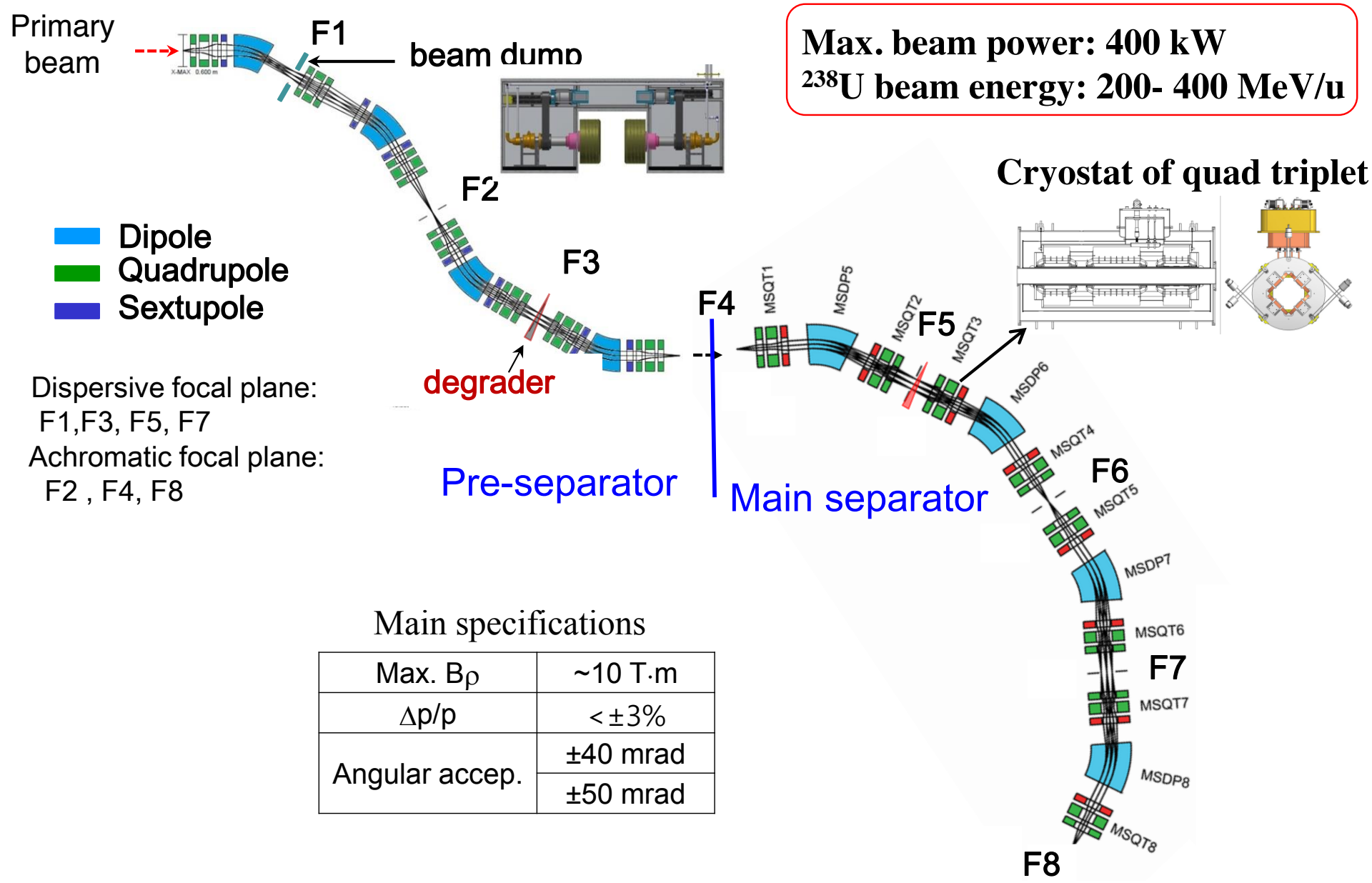


- **SCL**

-Baseline frequency: 81.25 MHz
-Ni cavities operating at 2 K
-Focusing by normal conducting quad doublets
-Optimized geometric beta of SC cavities (0.047, 0.12, 0.3, 0.51)
-Large aperture to reduce beam loss (4 cm and 5 cm)



RAON In-Flight Separator



Max. beam power: 400 kW
^{238}U beam energy: 200- 400 MeV/u

Cryostat of quad triplet

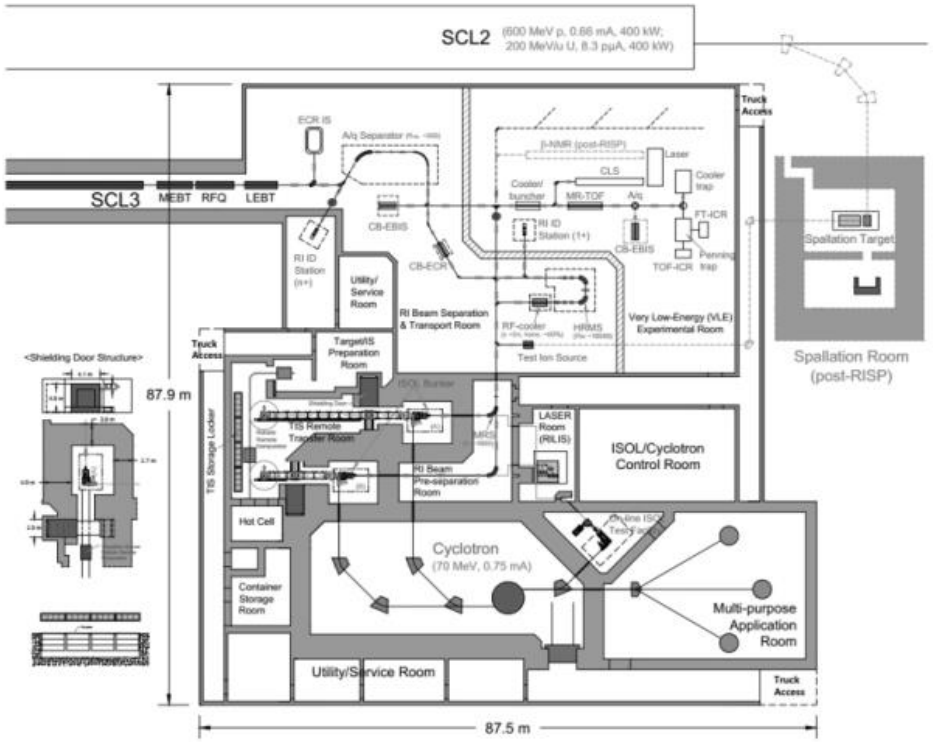
Dispersive focal plane:
F1,F3, F5, F7
Achromatic focal plane:
F2 , F4, F8

Main specifications

Max. Bρ	~10 T·m
Δp/p	< ±3%
Angular accep.	±40 mrad
	±50 mrad

RAON ISOL System

ISOL Driver: 35-70 MeV, H^- 1 mA cyclotron



The layout still evolving

	TIS	EBIS
Ion	1+	A/q < 4
E	40 keV	10 keV/u

Separator
$m/\delta m = 300$

↓

MR-TOF

↓

RFQ Cooler/Buncher
3π mm mrad, 1 eV

↓

EBIS

↓

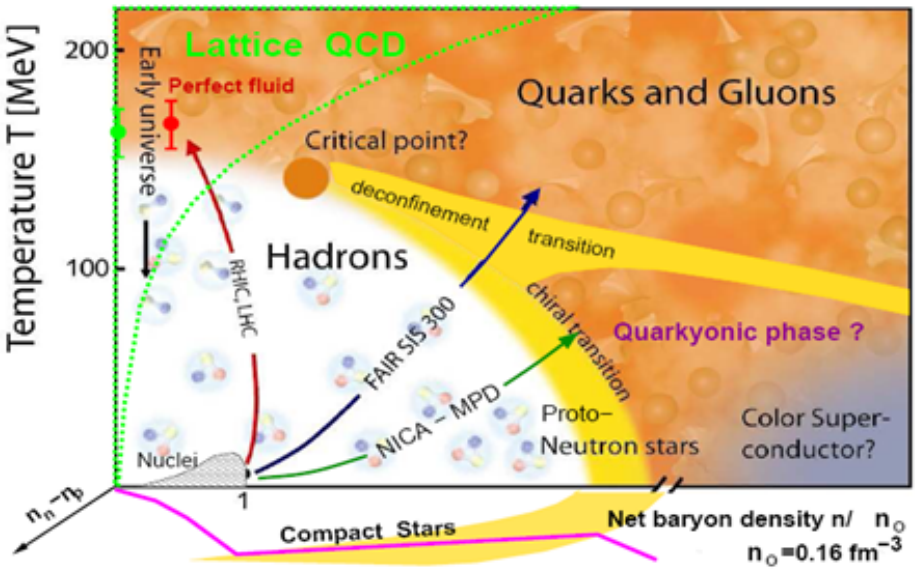
Post linac

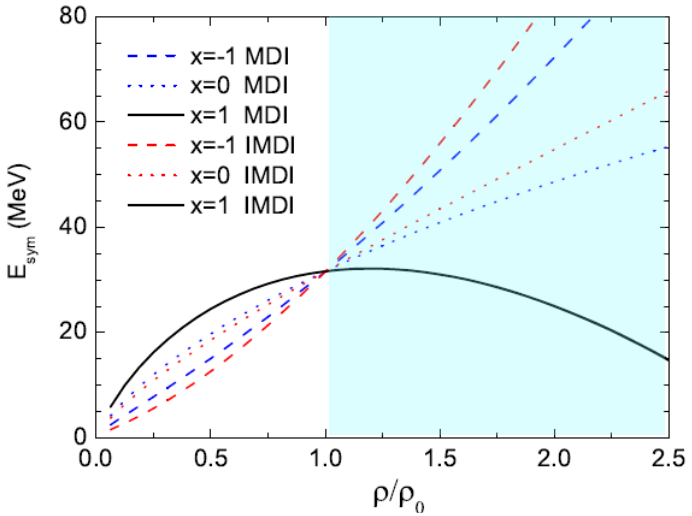
UCx target: 10 kW (Dia. 5 cm, 1.3 mm 19 disks)

Off-line test stand for target ion source, front-end mass separator on HV platform

Symmetry Energy Study at RAON

- **Exploring the nuclear phase diagram including the isospin axis**
- **Role of isospin dof in strong interaction**
  - **-Nuclear symmetry energy from sub- to supra-saturation densities**
  - **-Characterization of the core of neutron stars**

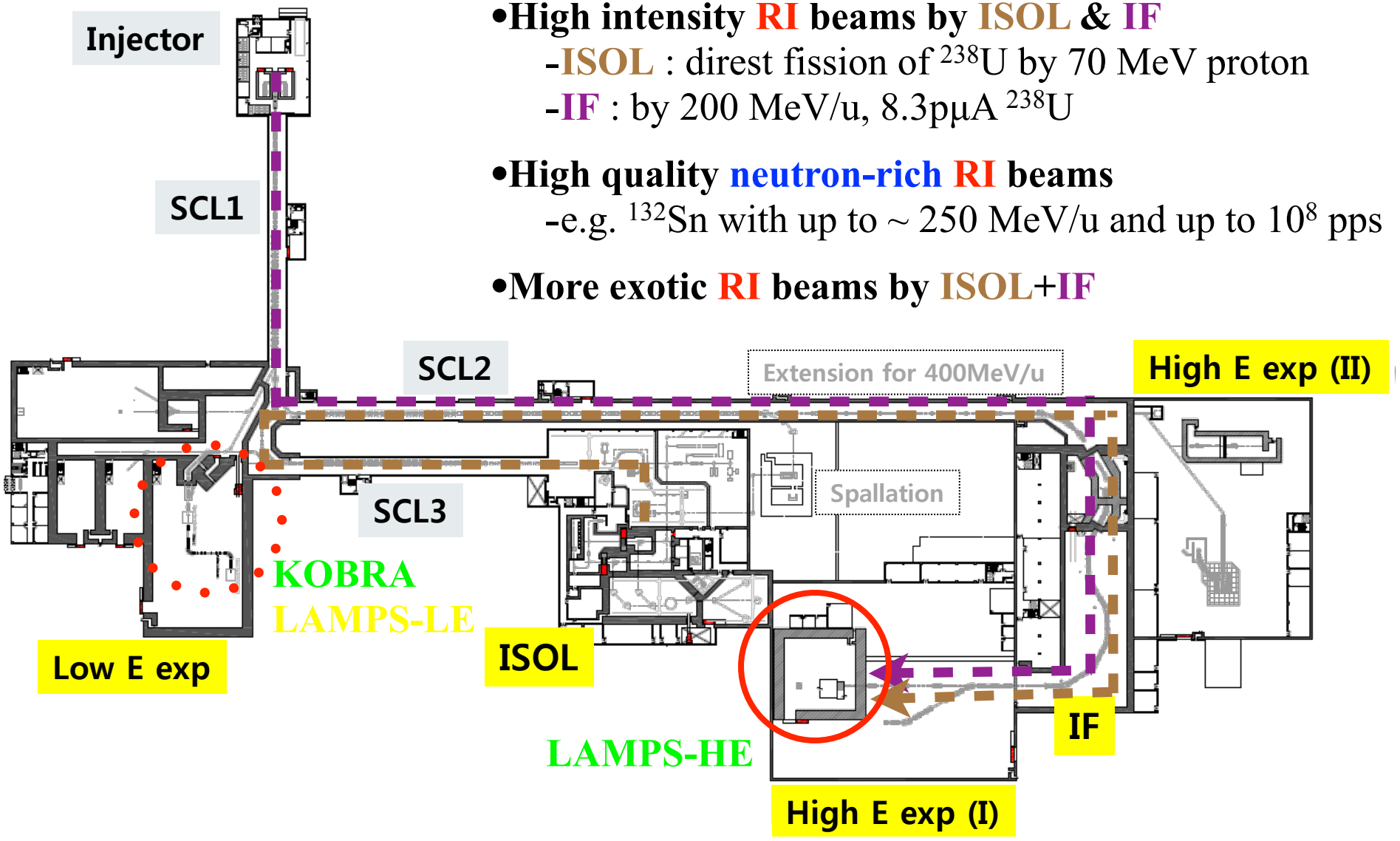




C. Xu and B. A. Li, PRC 81, 044603(2010)

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

LAMPS Experimental Facility



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- **More exotic RI beams by ISOL+IF**

LAMPS Experimental Setup

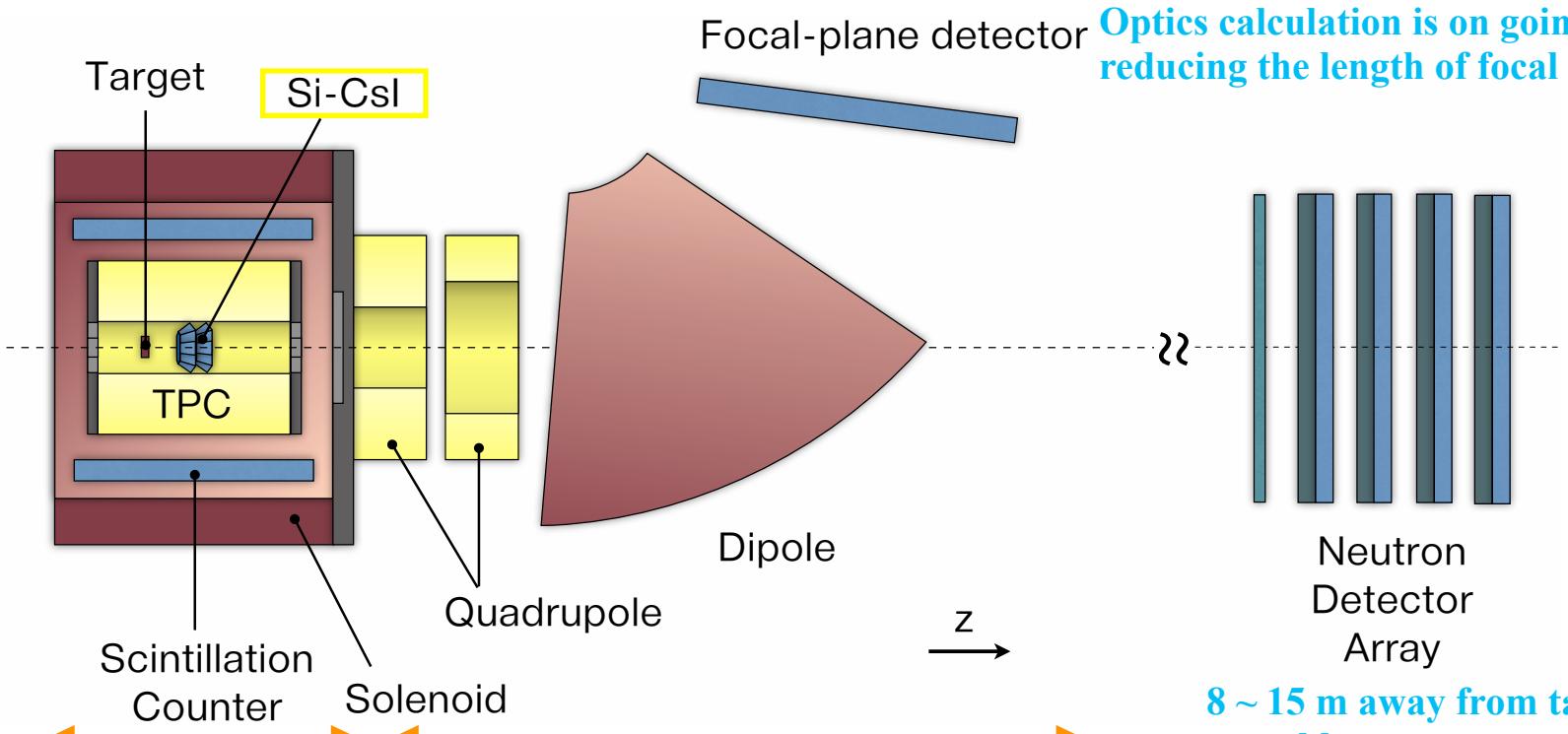
E_{beam} < 250 MeV/u for ^{132}Sn

For Symmetry Energy Study via Heavy-Ion Collision Experiments and Nuclear Reaction Study

-Example of Reactions for Symmetry Energy Study:

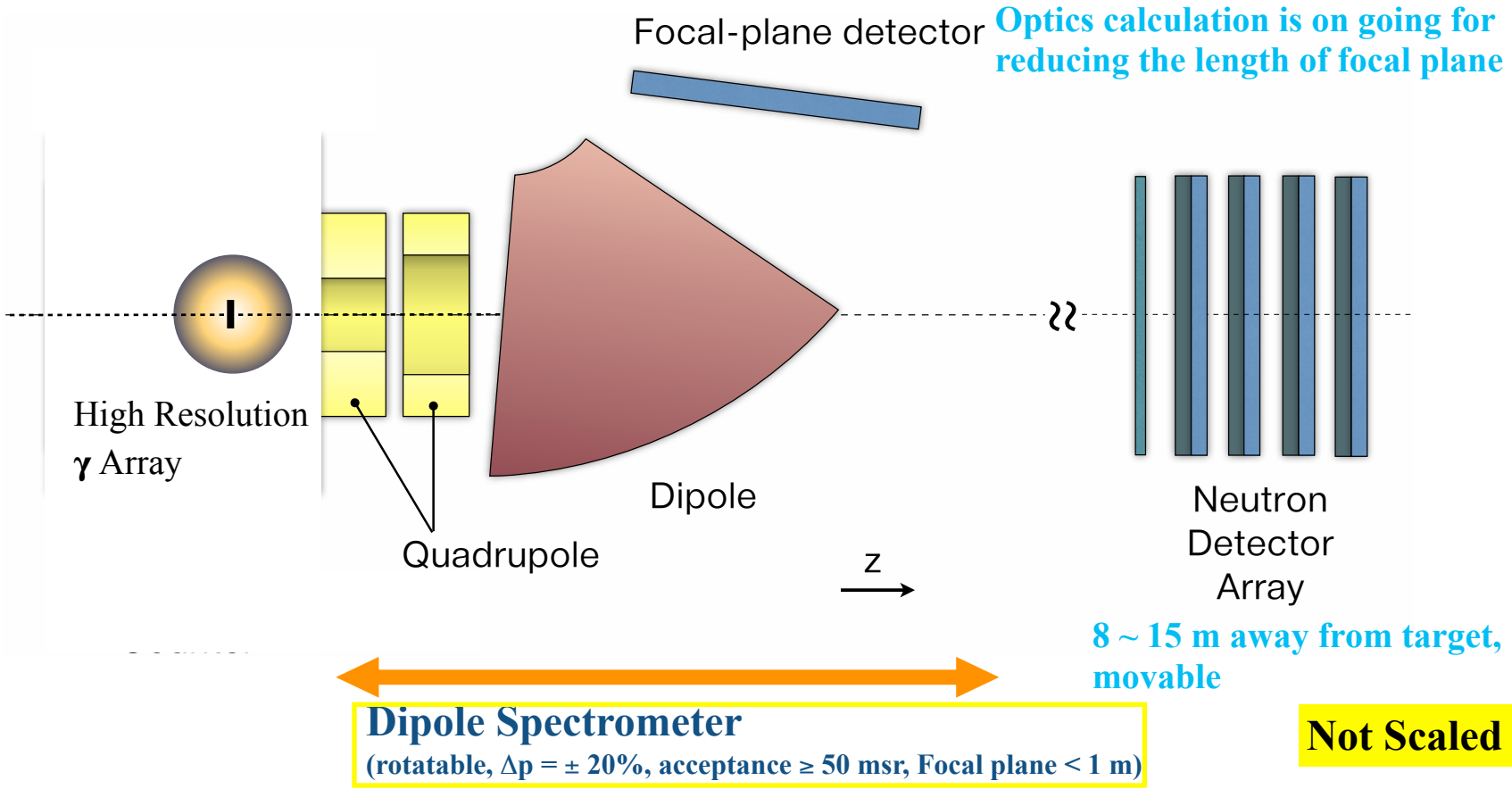
Central and peripheral collisions

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



LAMPS Experimental Setup

Other experimental configuration



- PDR/GDR measurements
  $^{124,130,132}Sn+^{208}Pb$, $^{68,70,72}Ni+^{208}Pb$, $^{50,54,60}Ca+^{208}Pb$, etc.
- Photoabsorption measurements
  Various $1n$ and $2n$ removal cross sections for unstable nuclei
- Measurement of E^* from gamma, beam fragments, and neutrons

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

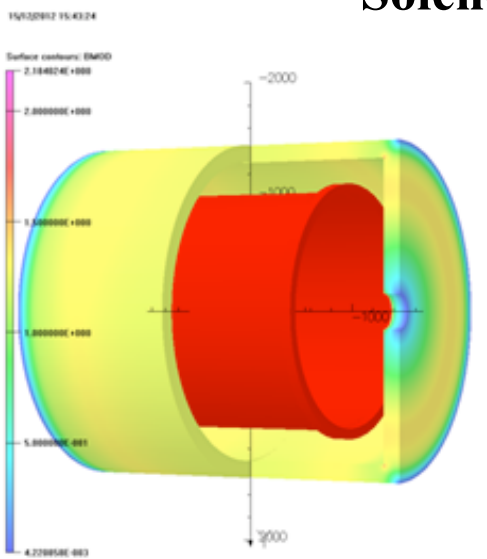
2.Collective flow
- v_1 & v_2 of n, p, and heavier clusters
- Azimuthal angle dependence of n/p ratio w.r.t the reaction plane

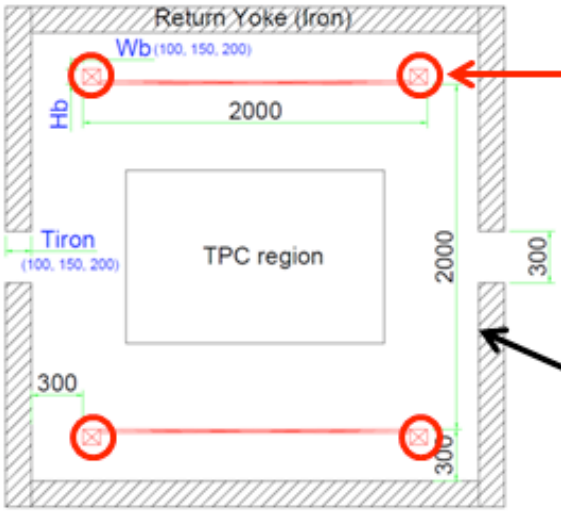
3.Various isospin dependent phenomena
- Isospin fractionation and isoscaling in nuclear multifragmentation
- Isospin diffusion (transport)
- Etc.

4.Pygmy and Giant dipole resonances
- Energy spectra of gammas
- Related to the radius of n-skin for unstable nuclei

LAMPS Solenoid Magnet

Solenoid design

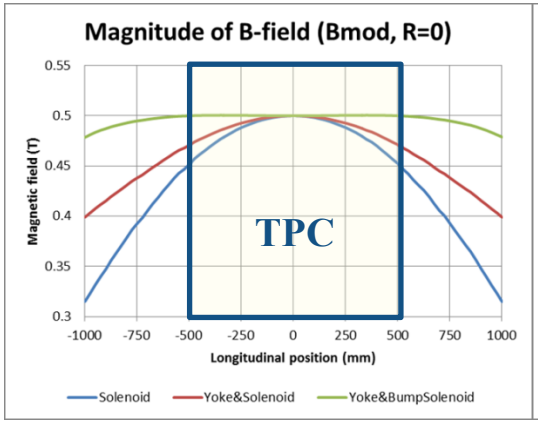


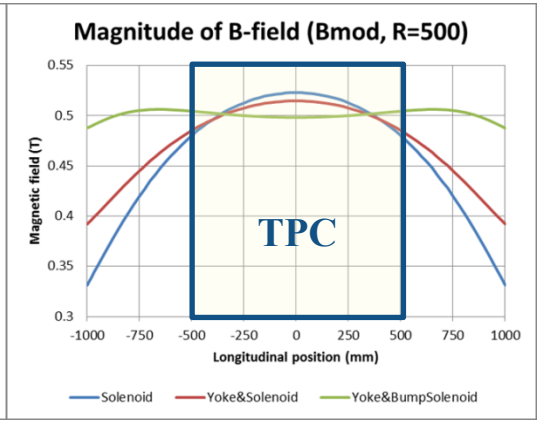


Bump coil

Return yoke

Total size: 3 x 3 m²
- **Coil: 2 x 2 m²**
- **Cylindrical shape**
- **To cover TPC (r = 0.5 m, l = 1.2 m) with homogeneous B-field**
- **Boperation: ~ 0.5 T**
- **Bmax.: ~ 1T**
- **ΔB/B < 2 %**

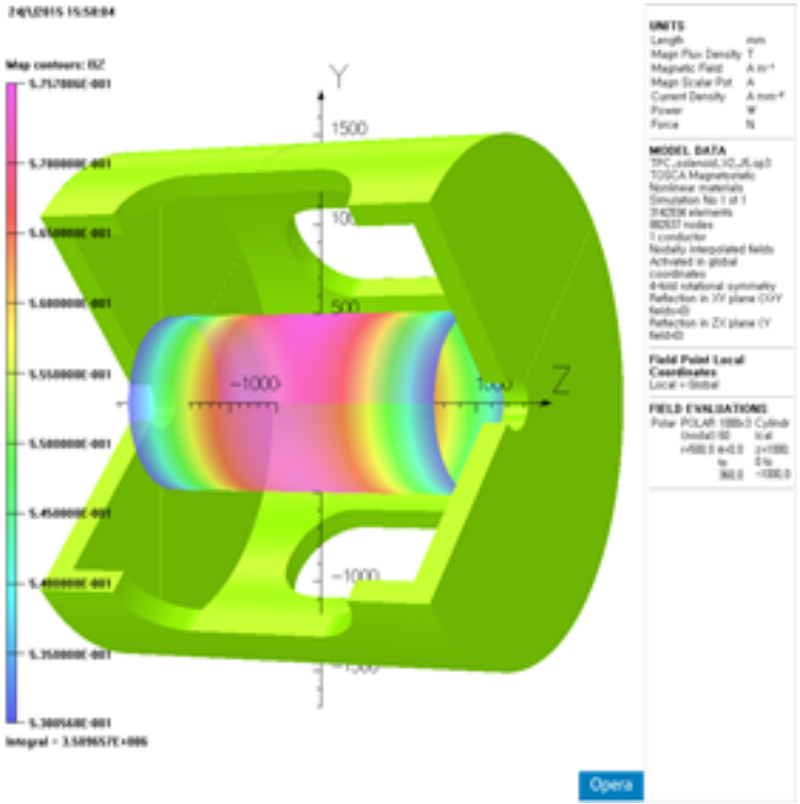


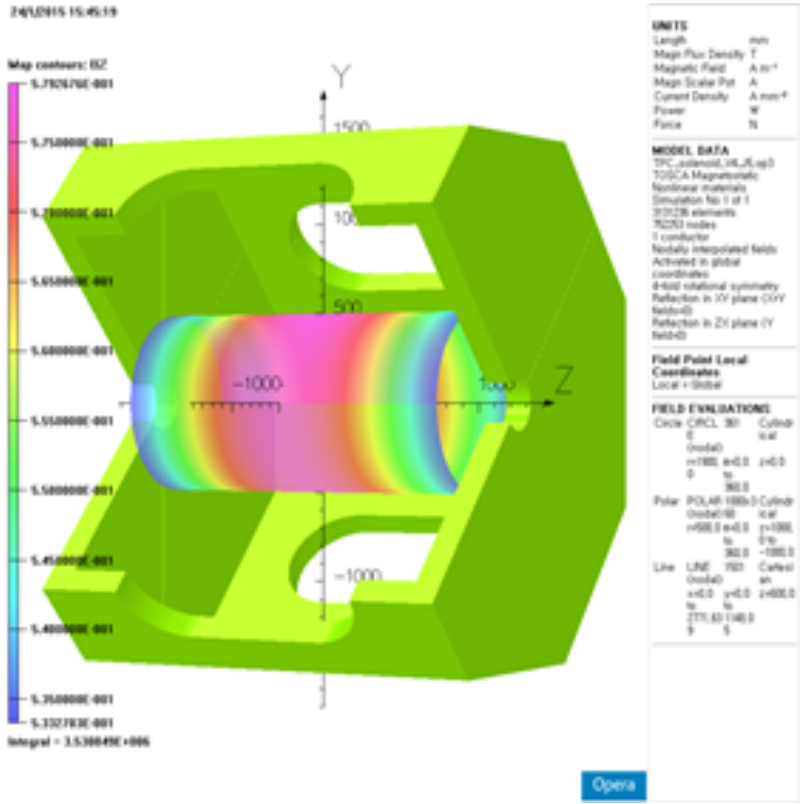


Deviation of magnetic field

-75 ~ 75 cm	Solenoid Coil	Solenoid with Return Yoke	Solenoid with Return Yoke & Bump Coil
ΔB_{mod} (R = 0 cm)	0.107 T	0.062 T	0.006 T
ΔB_{mod} (R = 50 cm)	0.103 T	0.070 T	0.008 T
ΔB_z (R = 50 cm)	0.110 T	0.072 T	0.008 T
ΔB_r (R = 50 cm)	±0.076 T	±0.043 T	±0.008 T

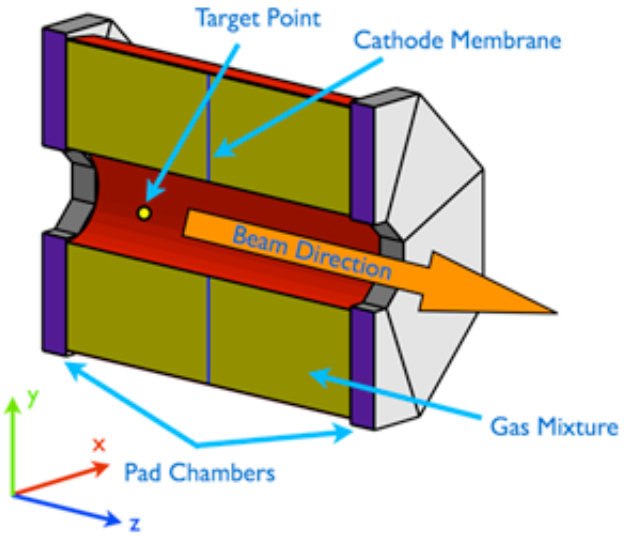
LAMPS Solenoid Magnet

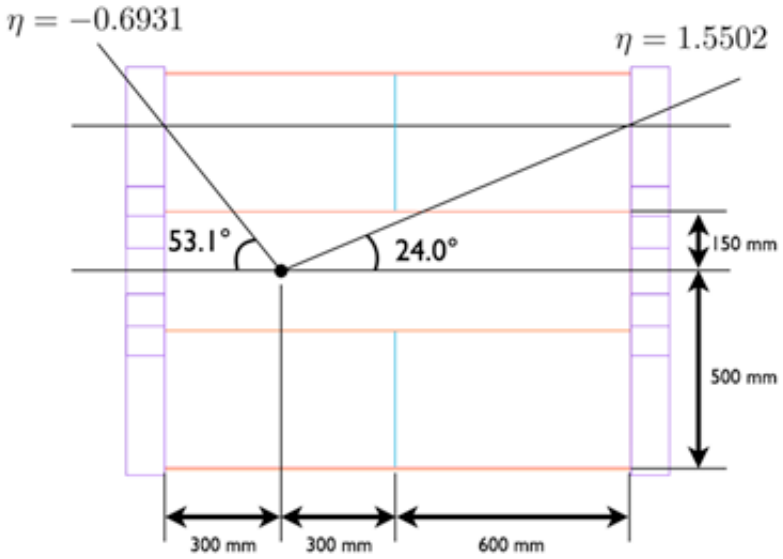




- **Solenoid magnet design is being modified**
  - **For better neutron measurement**
  - **Higher order harmonics occurs but the influence is only < 0.5% in addition to the deviation of magnetic field from previous design**
  - **Further improvement is in progress**

LAMPS TPC

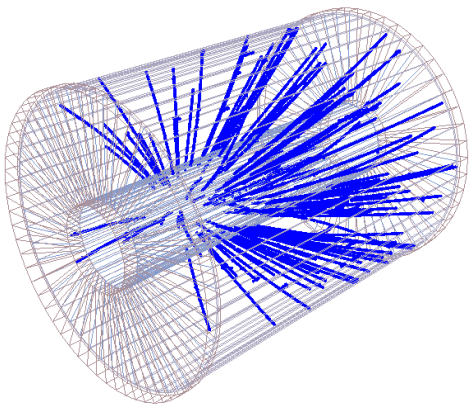


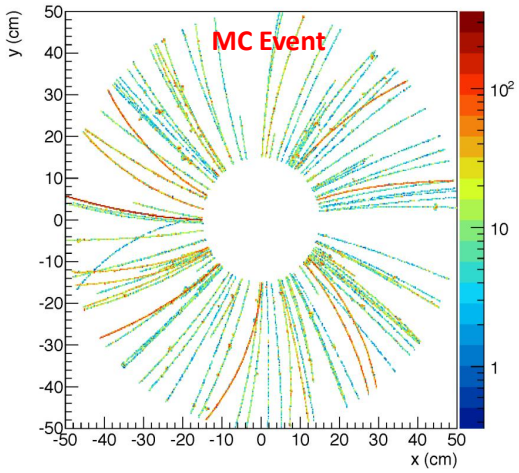


Time Projection Chamber (TPC)

-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

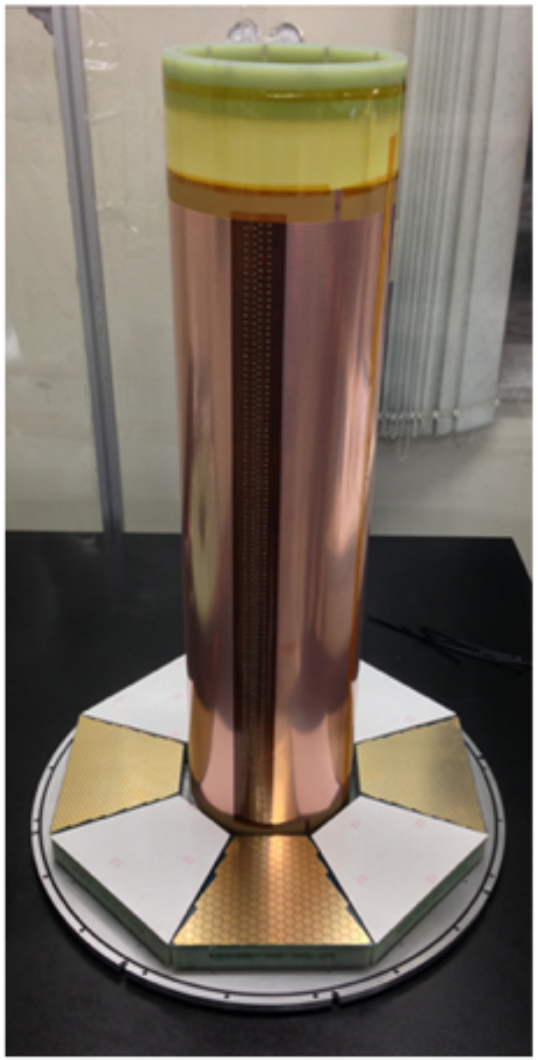
- **IQMD Au+Au @ 250 *A* Mev is used for event generator.**
- **Gas : Argon (90%) + CO_2 (10%) mixture.**
  - Density : 1.78 g/cm^3
- **Field : 0.5 Tesla**



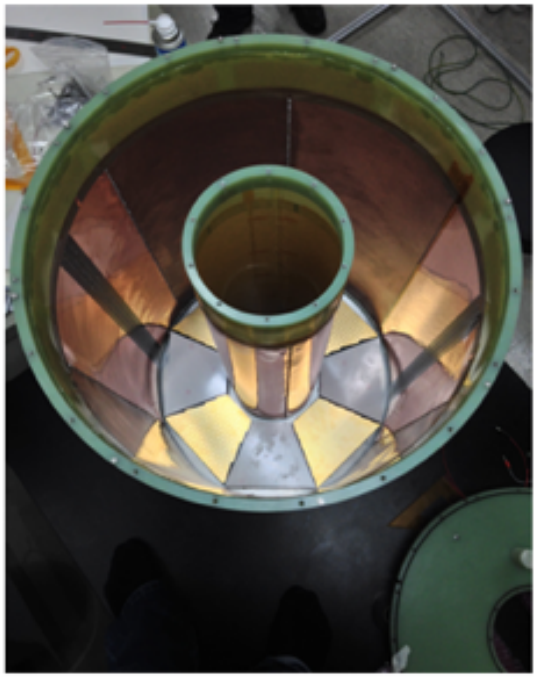


LAMPS TPC Prototype R&D

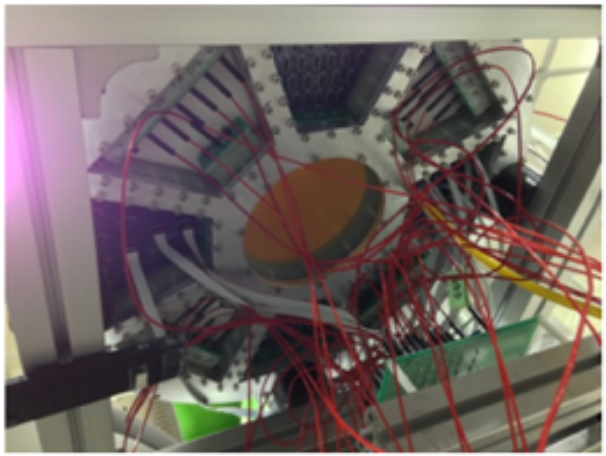
Inner Field Cage install



Outer Field Cage install

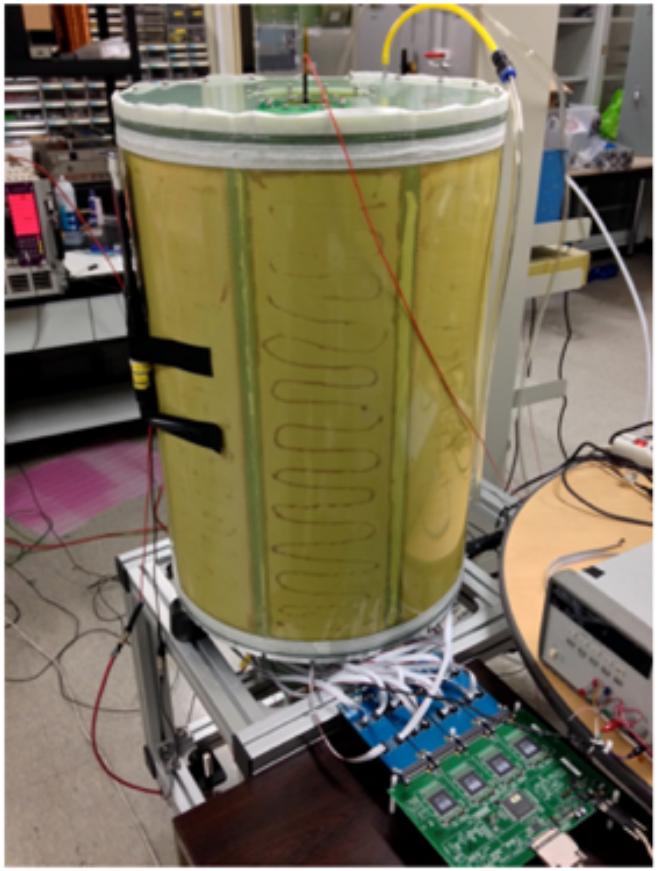


Prototype TPC : back



same drift length as final TPC

Prototype TPC

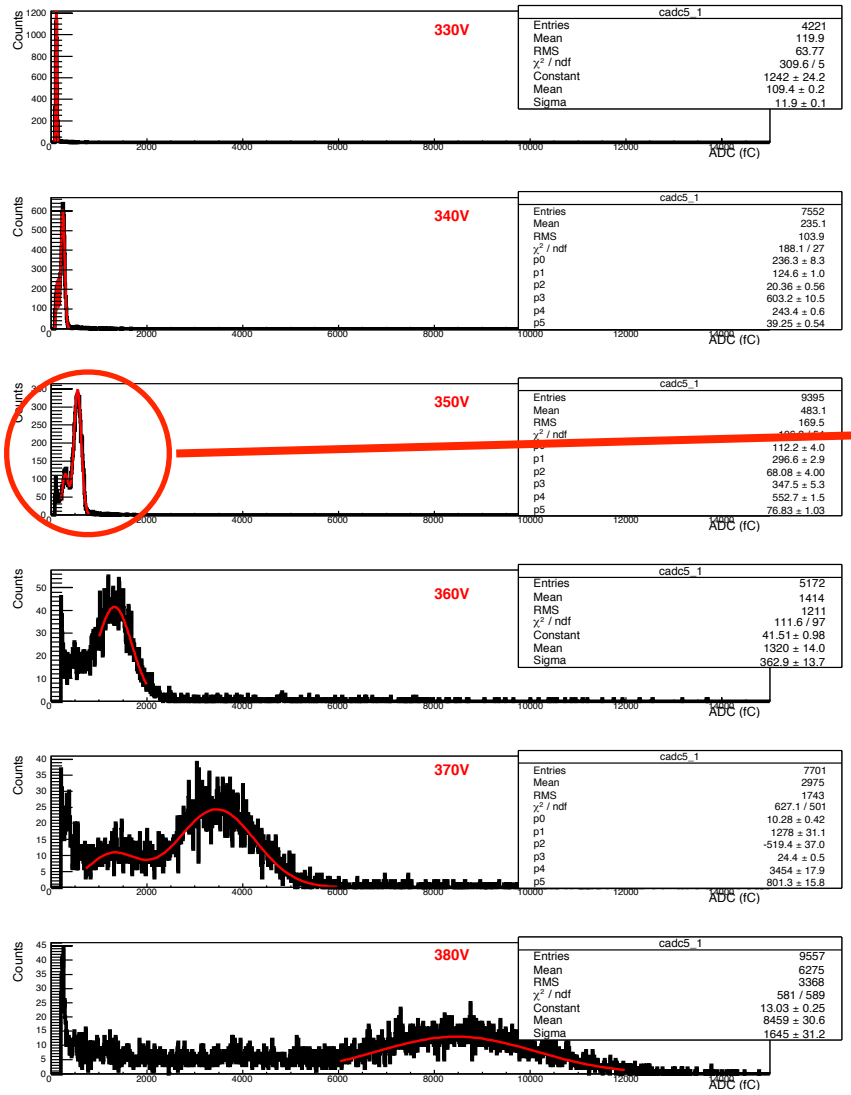


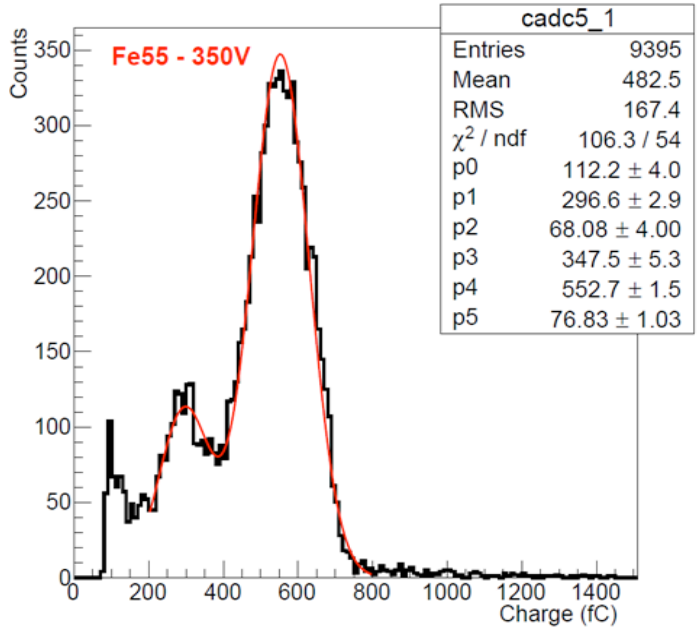
- Problem with GEM foils

-Found new GEM manufacture in Korea (produce GEM foil for CMS upgrade project)

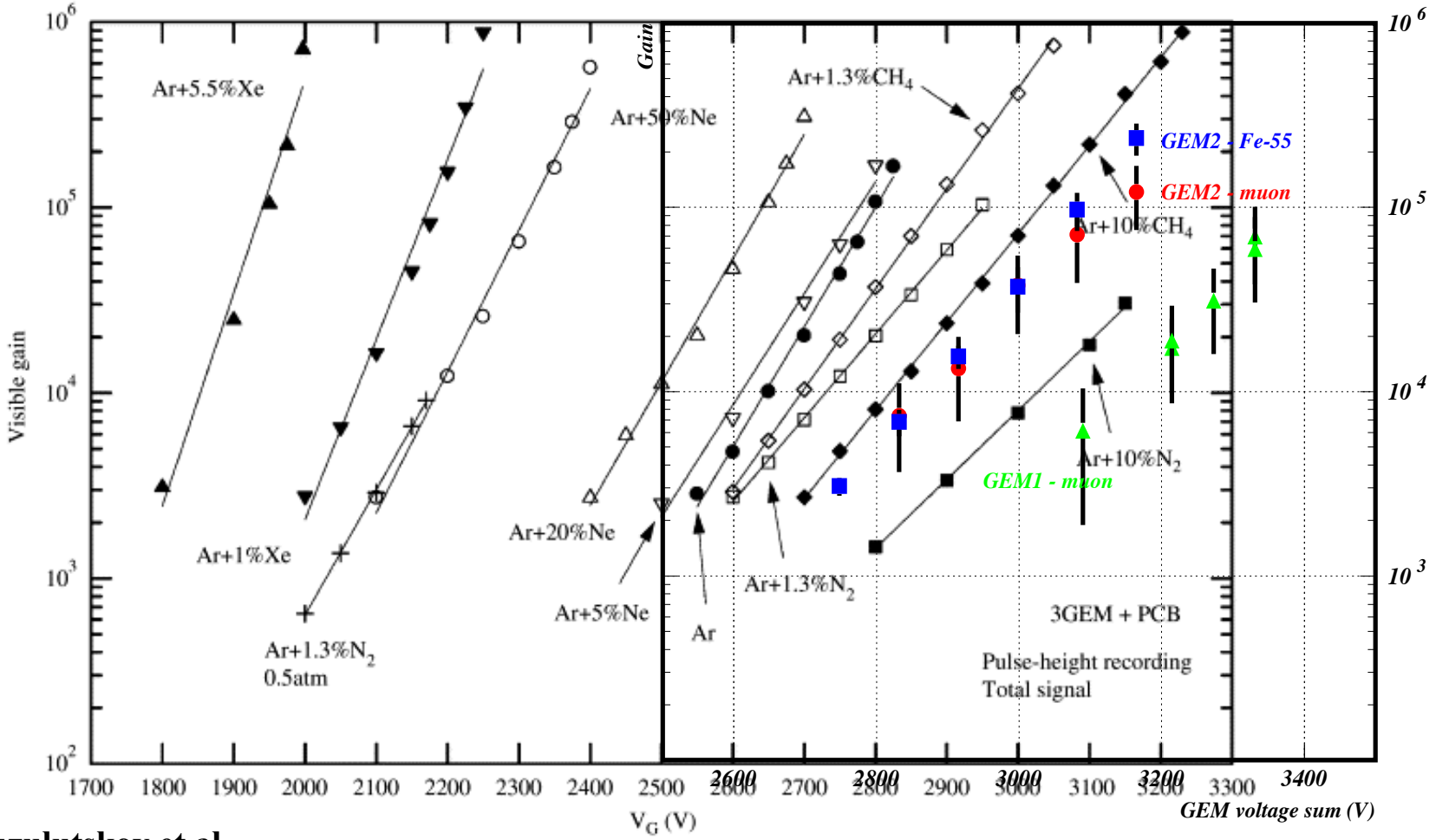
LAMPS TPC GEM Foil R&D

GEM2(Mecharonics) - Fe55





Comparison between data and ref.



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

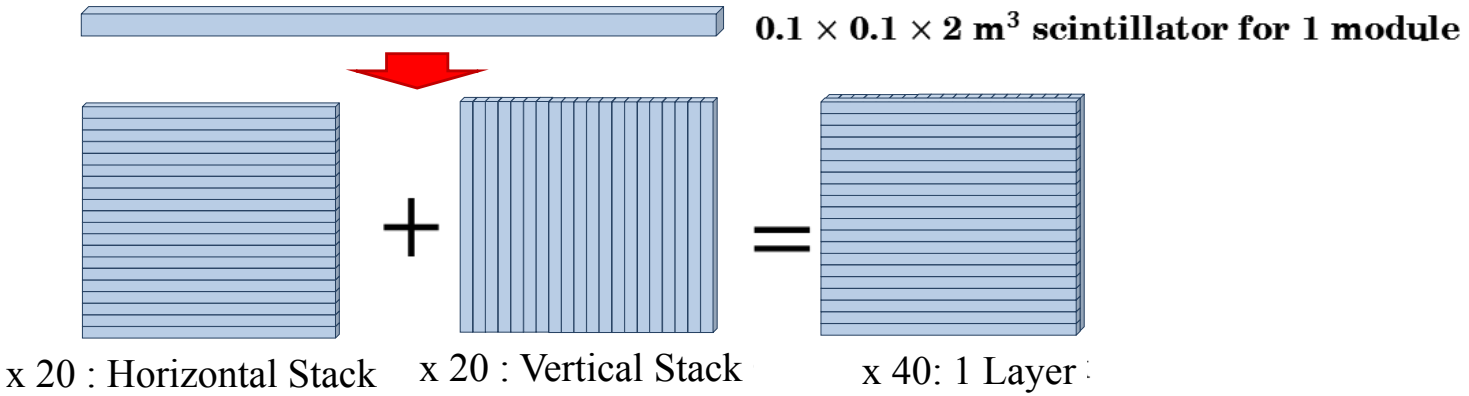
Different test setup and gap distances between GEMs

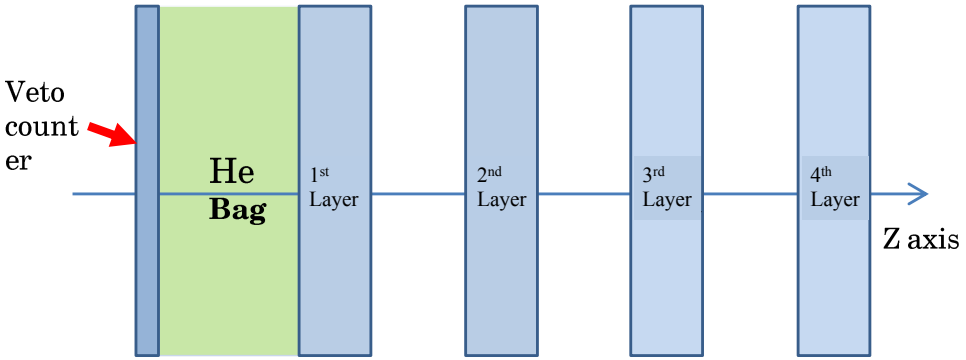
LAMPS Forward Neutron Detector Array

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

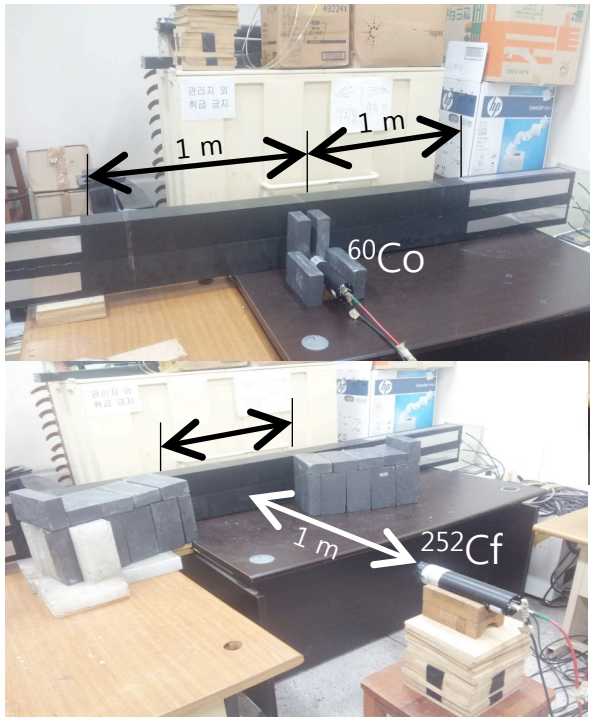
+ 1 Veto plastic layer for charged particle rejection

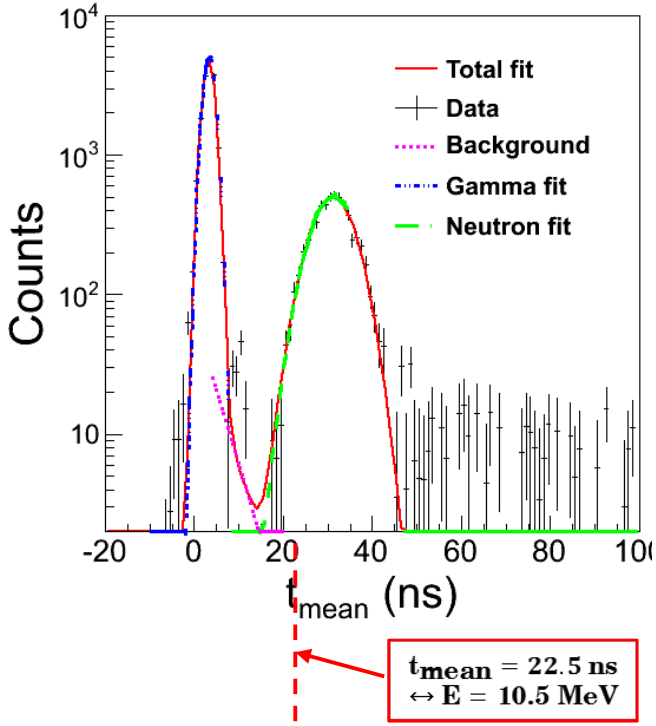
- ✓ Energy range to measure: 30 ~ 300 MeV
- ✓ Time resolution < 500 ps for ToF measurements
- ✓ $\Delta E/E \sim 2 \times 10^{-2}$ via TOF measurements
- ✓ $\varepsilon = 0.60$ for single-neutrons @ maximum 300 MeV (GEANT4)





LAMPS Neutron Detector R&D

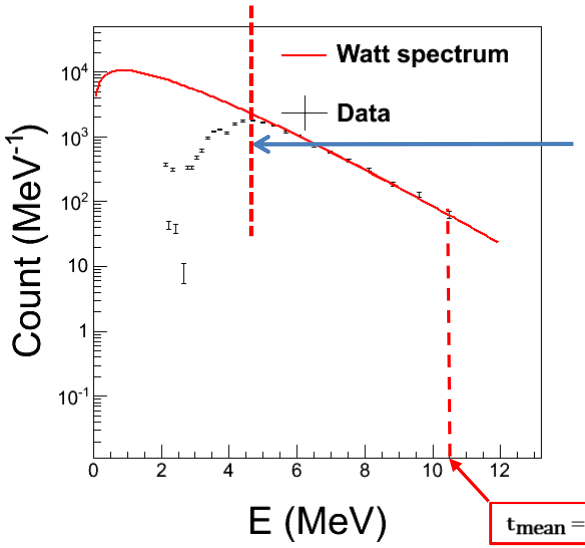




Real size prototypes are tested with cosmic and radioactive sources

- -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



Energy of neutrons to be measured with ε = 0.5 ~ 4.5-MeV

LAMPS Collaboration

- **RISP**
  - **LAMPS Experimental Facility**
  - **TPC R&D**
  - **Solenoid Magnet**
  - **DAQ System**
- **Korea University**
  - **Neutron detector R&D**
  - **TPC Software Development**
  - **GEANT-4 simulation**
- **Chonbuk National University**
  - **GEANT-4 simulation**
- **Chonnam National University**
  - **CsI(Tl) detector R&D**
- **Kyungpook National University**
  - **Si detector R&D**
- **Inha University**
  - **TPC tracking algorithm**

- **TPC GET electronics**
- **NARVAL DAQ**

~ 20 people from 6 domestic institutes

Looking for more collaborators from both domestic and international

➢ **To form international collaboration**

LAMPS Schedule