Status RAON and LAMPS

Young Jin Kim

RISP/IBS

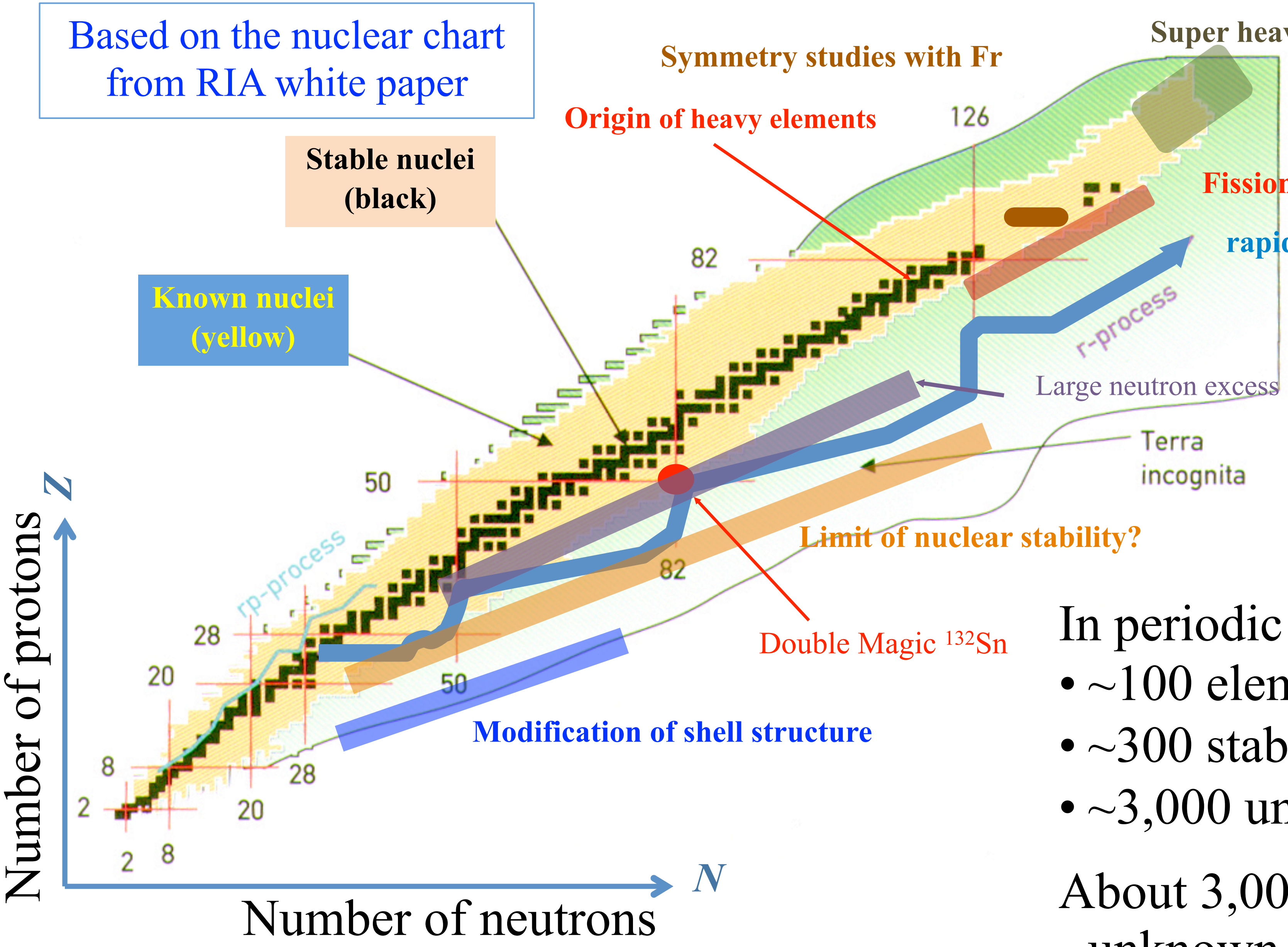
RISP and RAON

- RISP = Rare Isotope Science Project
  - 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"

- Brief History
  - -International Science-Business Belt (ISBB) plan (Jan. 2009)
  - -Preliminary Design Report (Mar. 2009 - Feb. 2010)
  - -Conceptual Design Report (Mar. 2010 - Feb. 2011)
  - -International Advisory Committee (Jul. 2011)
  - -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
  - -Technical Advisory Committee (May 2012)
  - -Baseline Design Summary (Jun. 2012)
  - -International Advisory Committee (Jul. 2012)
  - -Technical Advisory Committee (May 2013)
  - -Technical Design Report (Present: Sep. 2013)

Why Rare Isotope Beam?

Based on the nuclear chart from RIA white paper

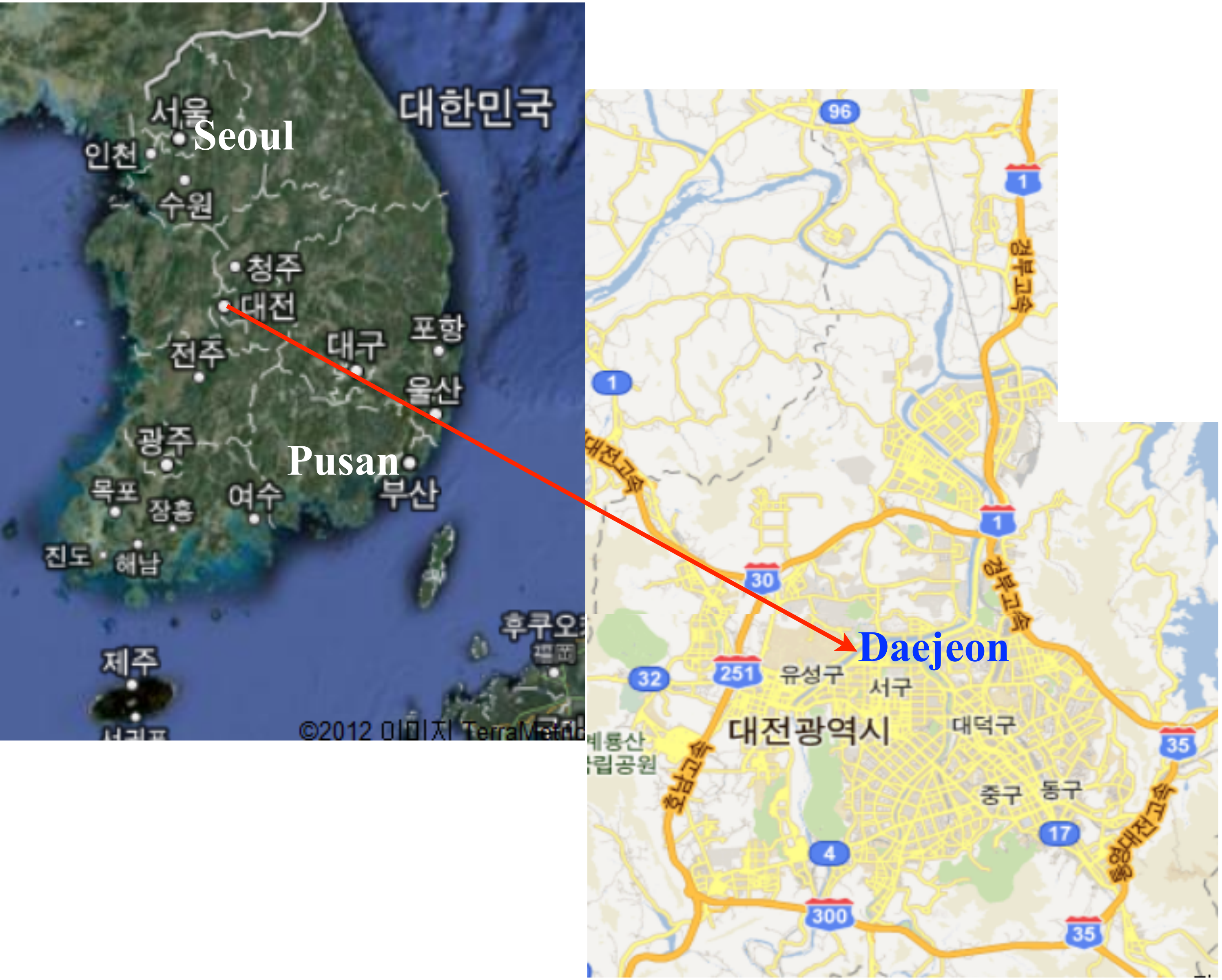


In periodic table

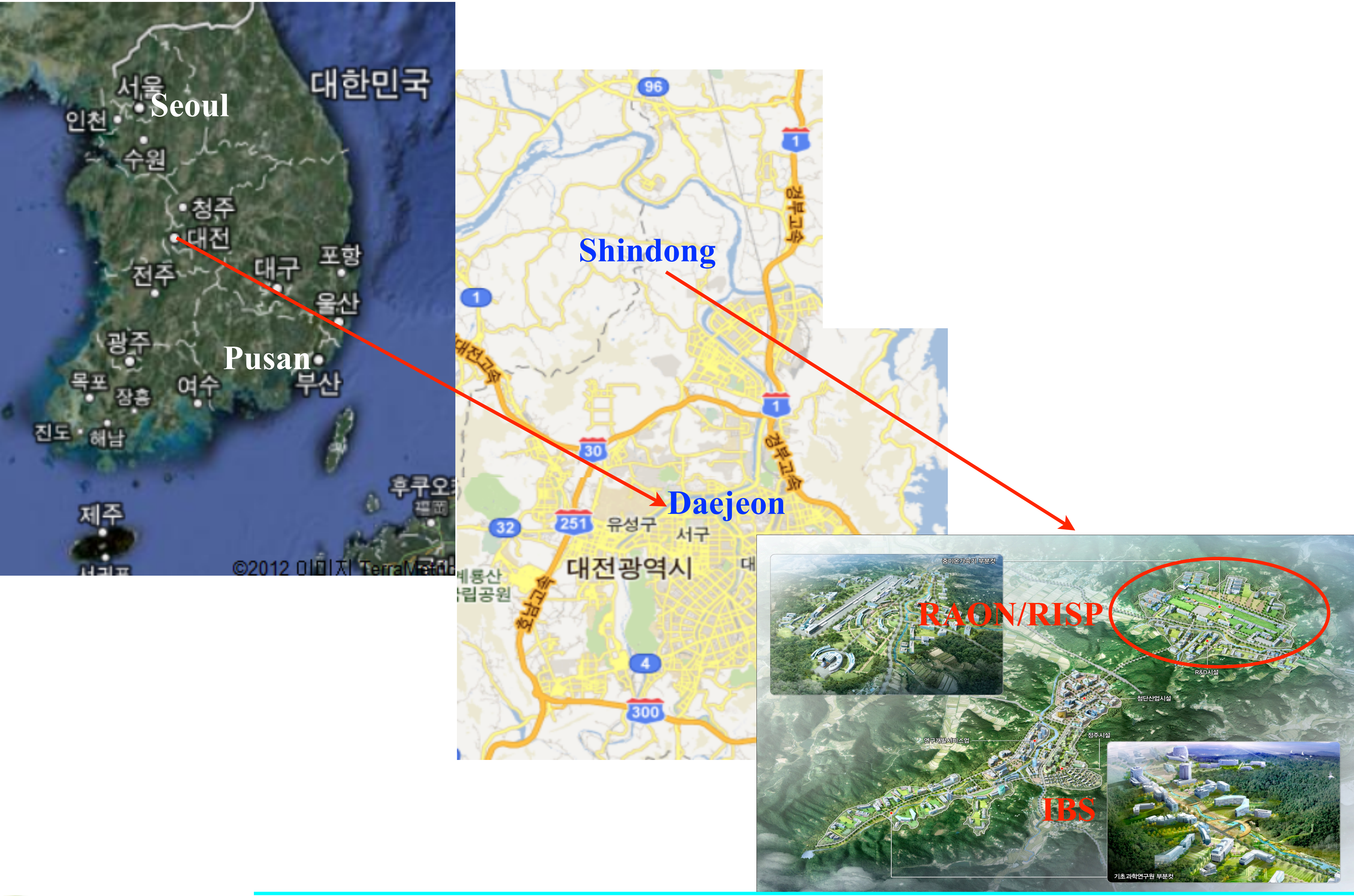
- ~100 elements
- ~300 stable isotopes
- ~3,000 unstable isotopes

About 3,000 ~ 6,000 unknown isotopes yet to be discovered

RAON Location



RAON Location

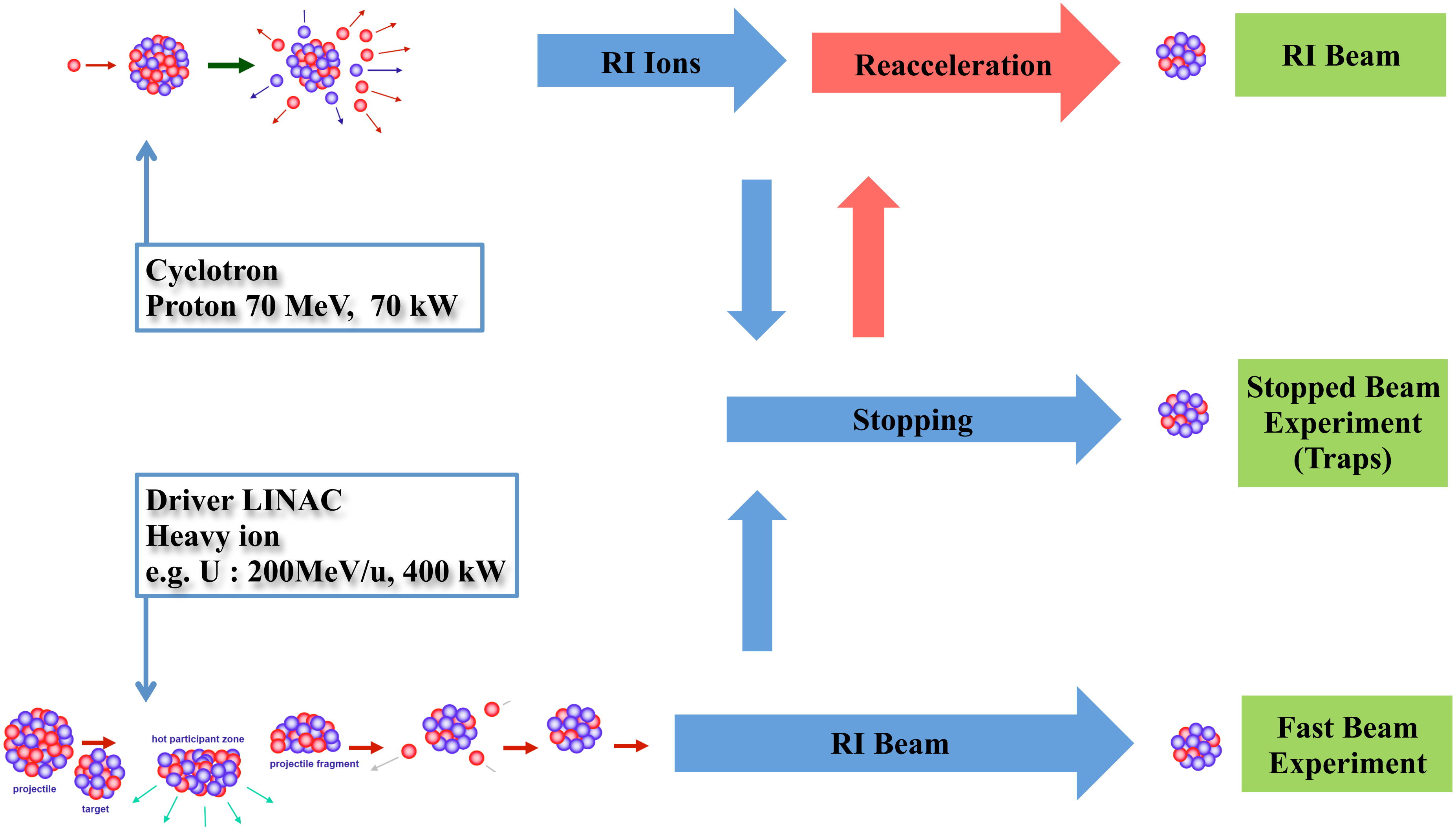


RAON/RISP Site

Rare Isotope Beam Production

ISOL(Isotope Separator On-Line)

proton ➣ thick target (e.g. Uranium Carbide) ➣ spallation or fission of target nuclei (low energy)



RI Ions

Reacceleration

RI Beam

Cyclotron
Proton 70 MeV, 70 kW

Stopping

Stopped Beam Experiment (Traps)

Driver LINAC
Heavy ion
e.g. U : 200MeV/u, 400 kW

RI Beam

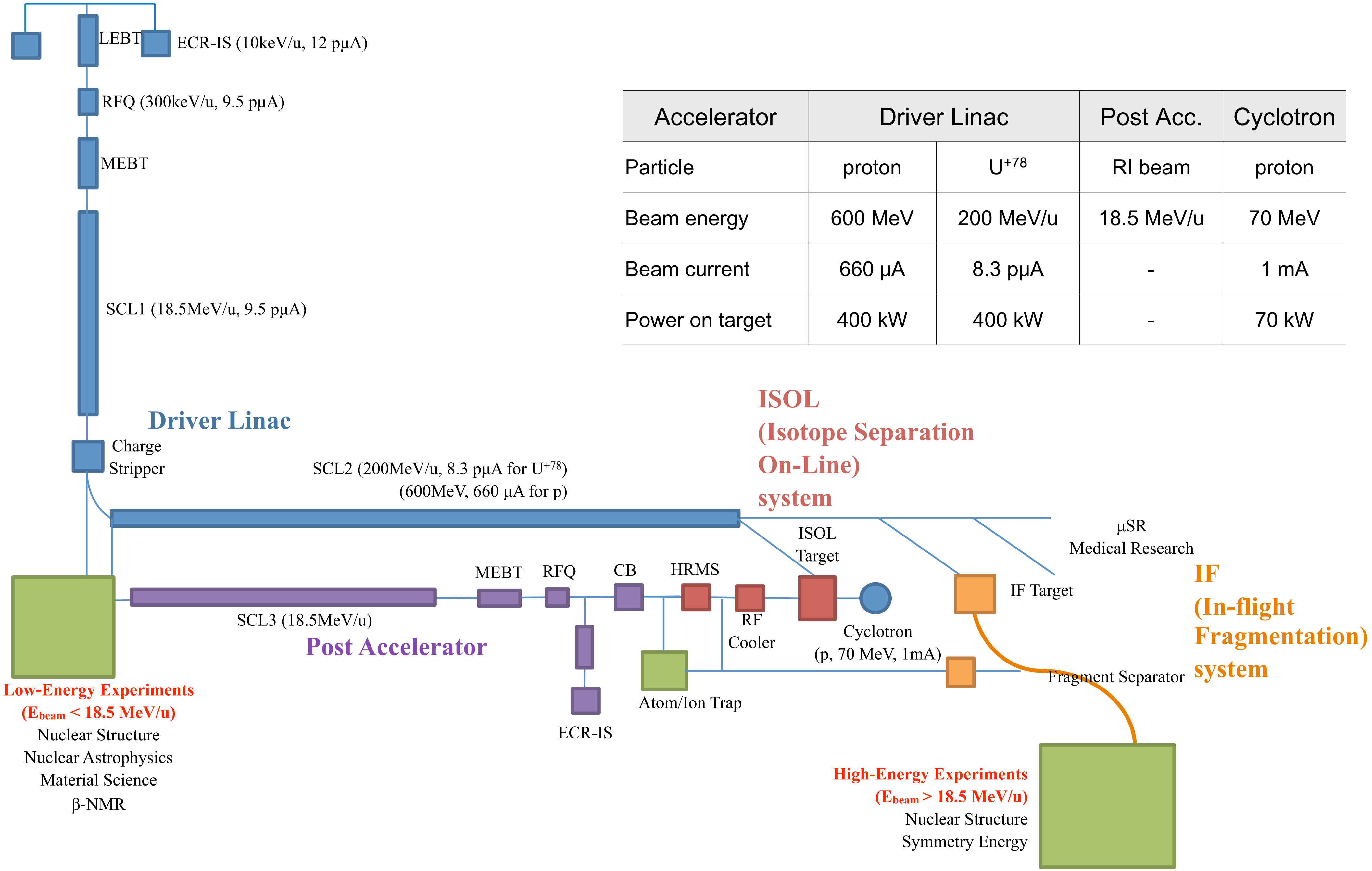
Fast Beam Experiment

IF(In-Flight Fragmentation)

Heavy stable isotope beam ➣ thin target (e.g. Carbon) ➣ fragmentation of projectile (high energy)

RAON Layout

Accelerator	Driver Linac		Post Acc.	Cyclotron
Particle	proton	U^{+78}	RI beam	proton
Beam energy	600 MeV	200 MeV/u	18.5 MeV/u	70 MeV
Beam current	660 μA	8.3 pμA	-	1 mA
Power on target	400 kW	400 kW	-	70 kW



Driver Linac

ISOL (Isotope Separation On-Line) system

IF (In-flight Fragmentation) system

Post Accelerator

Low-Energy Experiments
(E_{beam} < 18.5 MeV/u)
Nuclear Structure
Nuclear Astrophysics
Material Science
β-NMR

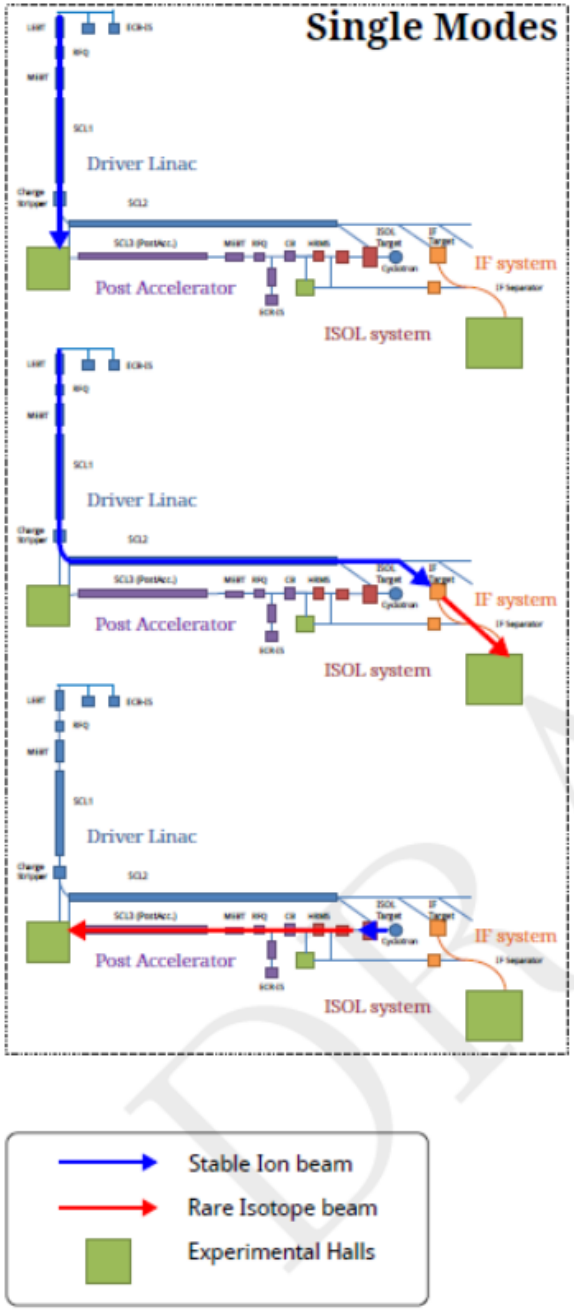
High-Energy Experiments
(E_{beam} > 18.5 MeV/u)
Nuclear Structure
Symmetry Energy

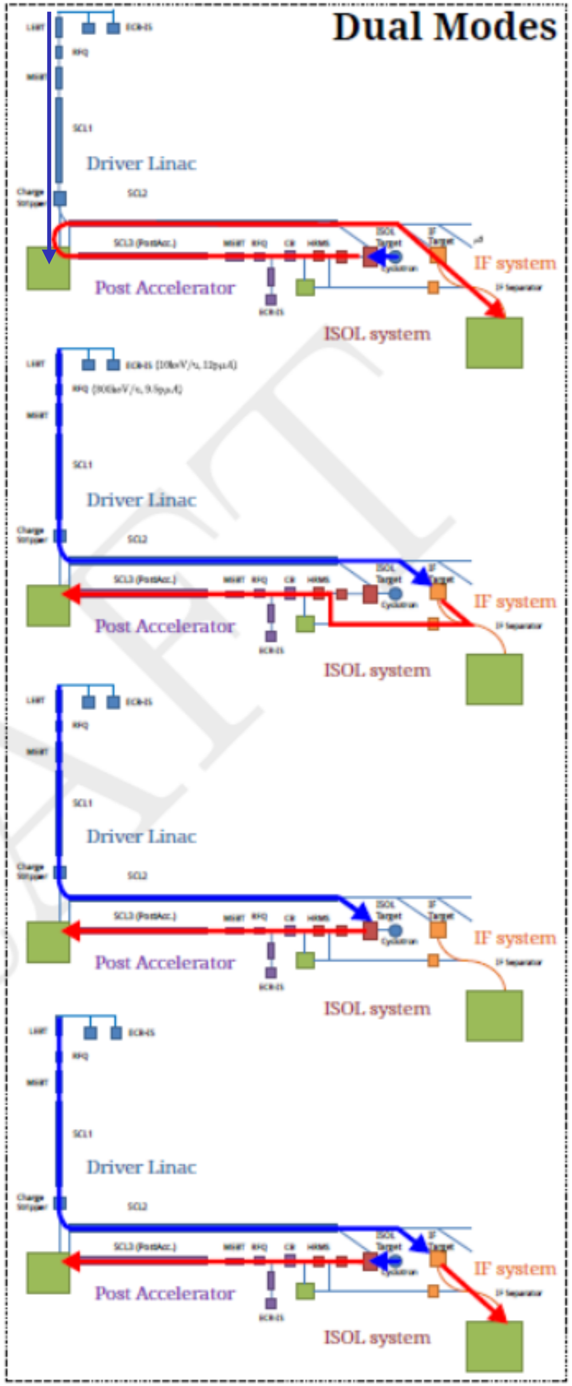
RAON Accelerator Operation Modes

Stable isotope beam
SHE search, …

IF mode
high energy RI beam, …

ISOL mode
low energy
high purity RI beam, …





ISOL+IF mode
high energy
exotic RI beams, …
(SI beam at the same time)

IF+ISOL mode
low energy
exotic RI beams, …

400 kW ISOL mode
(with 600 MeV p)

IF/ISOL independent mode

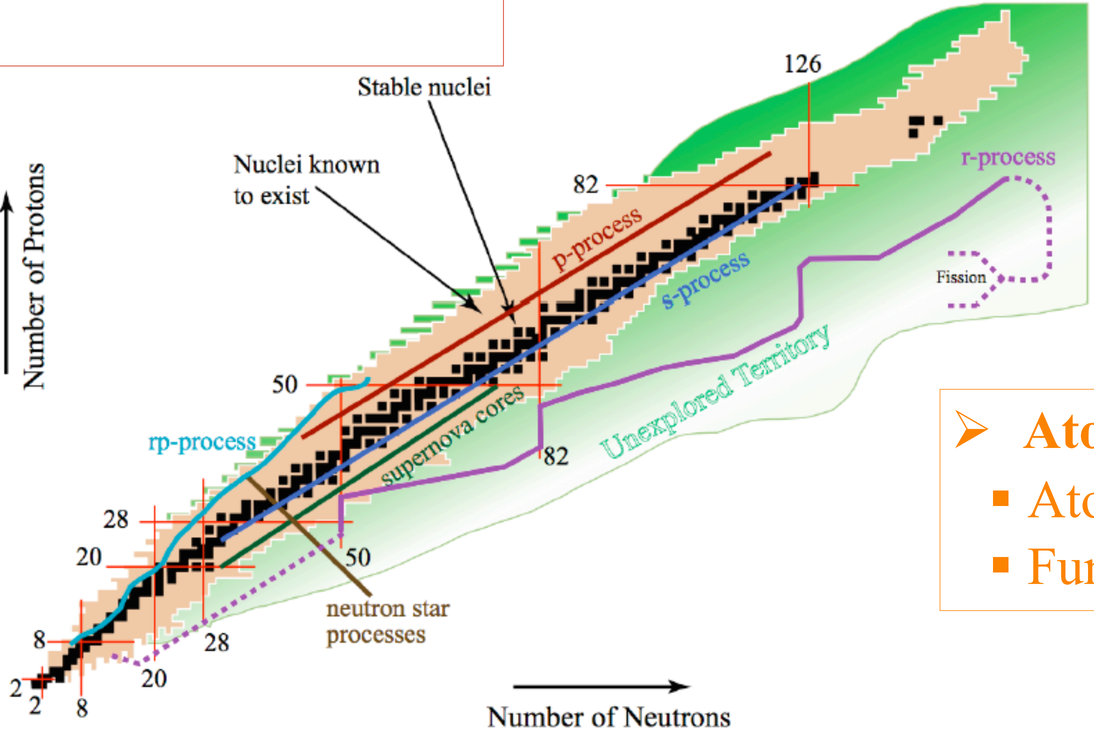
Science and Applications with Rare Isotopes

Nuclear Physics

- Exotic nuclei near the neutron drip line
- Superheavy Elements (SHE)
- Equation-of-state (EoS) of nuclear matter
- Nuclear structure

Nuclear Astrophysics

- Origin of nuclei
- Paths of nucleosynthesis
- Neutron stars and supernovae



Atomic/Particle physics

- Atomic trap
- Fundamental symmetries

Material science

- Production & Characterization of new materials
- β-NMR / μSR

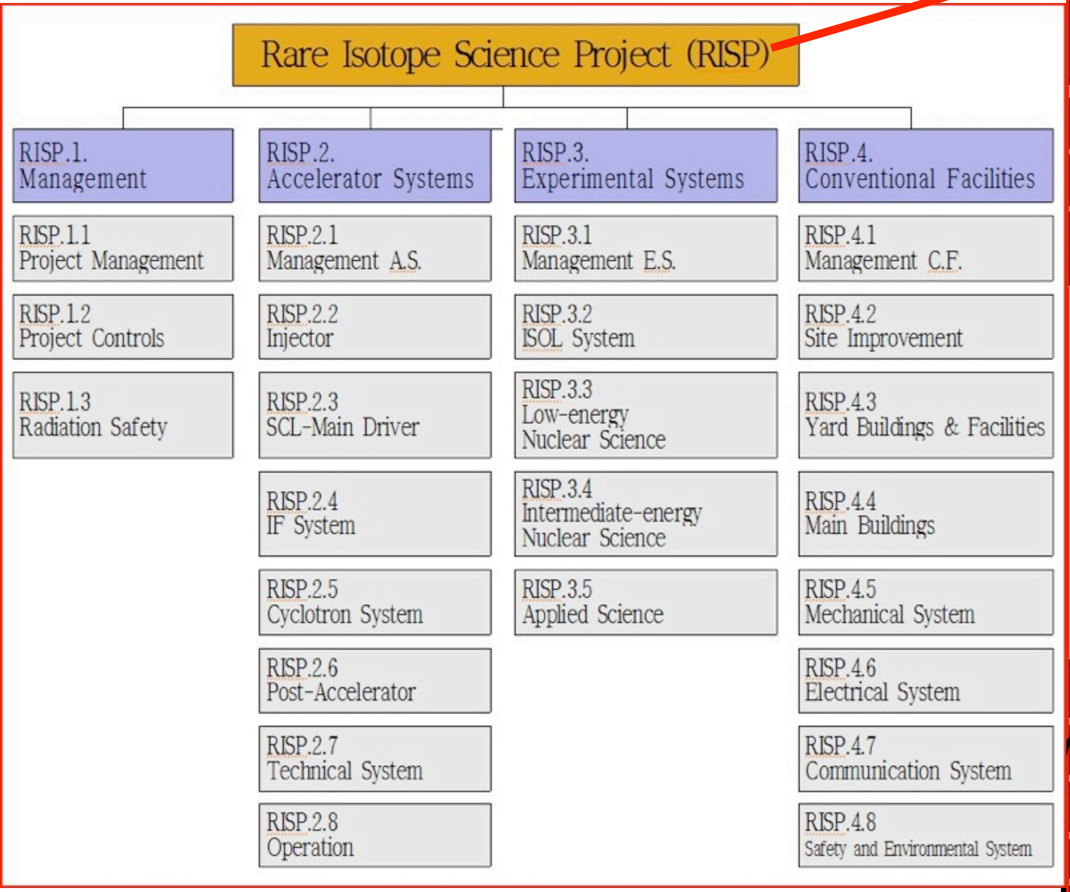
Nuclear data with fast neutrons

- Basic nuclear reaction data for future nuclear energy
- Nuclear waste transmutation

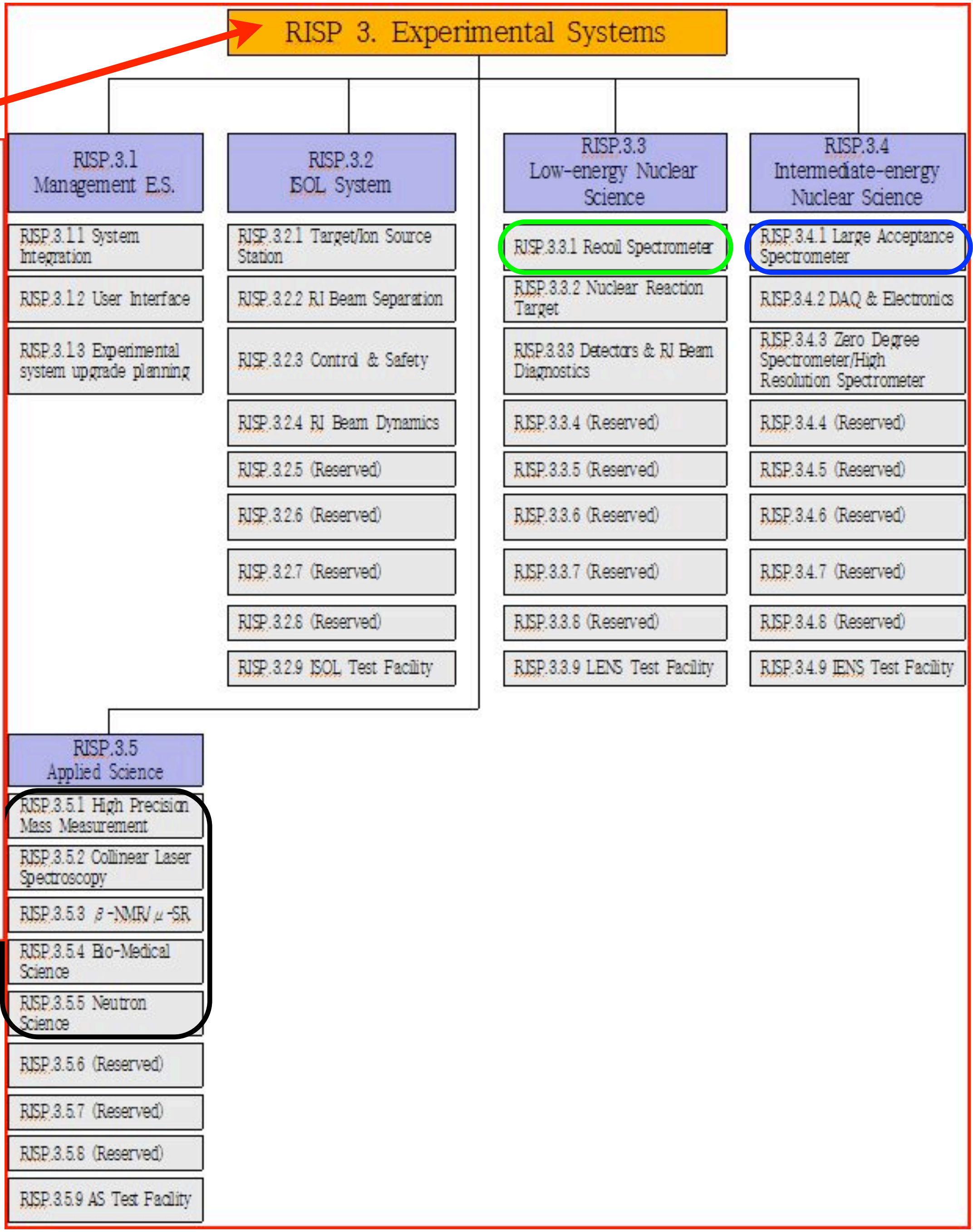
Medical and Bio sciences

- Advanced therapy technology
- Mutation of DNA
- New isotopes for medical imaging

RISP Project and Experiments at RAON



- Rare Isotope Science Project (RISP)
  - RISP.1. Management
    - RISP.1.1 Project Management
    - RISP.1.2 Project Controls
    - RISP.1.3 Radiation Safety
  - RISP.2. Accelerator Systems
    - RISP.2.1 Management A.S.
    - RISP.2.2 Injector
    - RISP.2.3 SCL-Main Driver
    - RISP.2.4 IF System
    - RISP.2.5 Cyclotron System
    - RISP.2.6 Post-Accelerator
    - RISP.2.7 Technical System
    - RISP.2.8 Operation
  - RISP.3. Experimental Systems
    - RISP.3.1 Management E.S.
    - RISP.3.2 ISOL System
    - RISP.3.3 Low-energy Nuclear Science
    - RISP.3.4 Intermediate-energy Nuclear Science
    - RISP.3.5 Applied Science
  - RISP.4. Conventional Facilities
    - RISP.4.1 Management C.F.
    - RISP.4.2 Site Improvement
    - RISP.4.3 Yard Buildings & Facilities
    - RISP.4.4 Main Buildings
    - RISP.4.5 Mechanical System
    - RISP.4.6 Electrical System
    - RISP.4.7 Communication System
    - RISP.4.8 Safety and Environmental System



- RISP 3. Experimental Systems
  - RISP.3.1 Management E.S.
    - RISP.3.1.1 System Integration
    - RISP.3.1.2 User Interface
    - RISP.3.1.3 Experimental system upgrade planning
  - RISP.3.2 ISOL System
    - RISP.3.2.1 Target/Ion Source Station
    - RISP.3.2.2 RI Beam Separation
    - RISP.3.2.3 Control & Safety
    - RISP.3.2.4 RI Beam Dynamics
    - RISP.3.2.5 (Reserved)
    - RISP.3.2.6 (Reserved)
    - RISP.3.2.7 (Reserved)
    - RISP.3.2.8 (Reserved)
    - RISP.3.2.9 ISOL Test Facility
  - RISP.3.3 Low-energy Nuclear Science
    - RISP.3.3.1 Recoil Spectrometer
    - RISP.3.3.2 Nuclear Reaction Target
    - RISP.3.3.3 Detectors & RI Beam Diagnostics
    - RISP.3.3.4 (Reserved)
    - RISP.3.3.5 (Reserved)
    - RISP.3.3.6 (Reserved)
    - RISP.3.3.7 (Reserved)
    - RISP.3.3.8 (Reserved)
    - RISP.3.3.9 LENS Test Facility
  - RISP.3.4 Intermediate-energy Nuclear Science
    - RISP.3.4.1 Large Acceptance Spectrometer
    - RISP.3.4.2 DAQ & Electronics
    - RISP.3.4.3 Zero Degree Spectrometer/High Resolution Spectrometer
    - RISP.3.4.4 (Reserved)
    - RISP.3.4.5 (Reserved)
    - RISP.3.4.6 (Reserved)
    - RISP.3.4.7 (Reserved)
    - RISP.3.4.8 (Reserved)
    - RISP.3.4.9 IENS Test Facility
  - RISP.3.5 Applied Science
    - RISP.3.5.1 High Precision Mass Measurement
    - RISP.3.5.2 Collinear Laser Spectroscopy
    - RISP.3.5.3 β-NMR/μ-SR
    - RISP.3.5.4 Bio-Medical Science
    - RISP.3.5.5 Neutron Science
    - RISP.3.5.6 (Reserved)
    - RISP.3.5.7 (Reserved)
    - RISP.3.5.8 (Reserved)
    - RISP.3.5.9 AS Test Facility

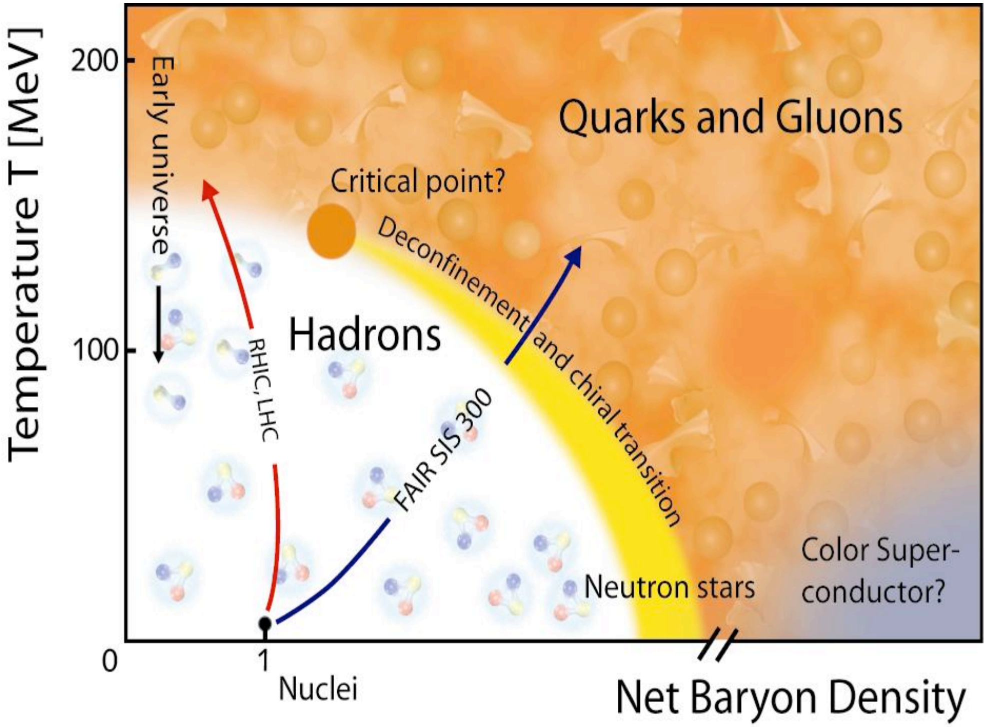
99 people
70 Researchers
23 in experimental systems

Heavy Ion Experiment

Study of Nuclear Matter

1. Exploring the phase diagram of strongly interacting matter

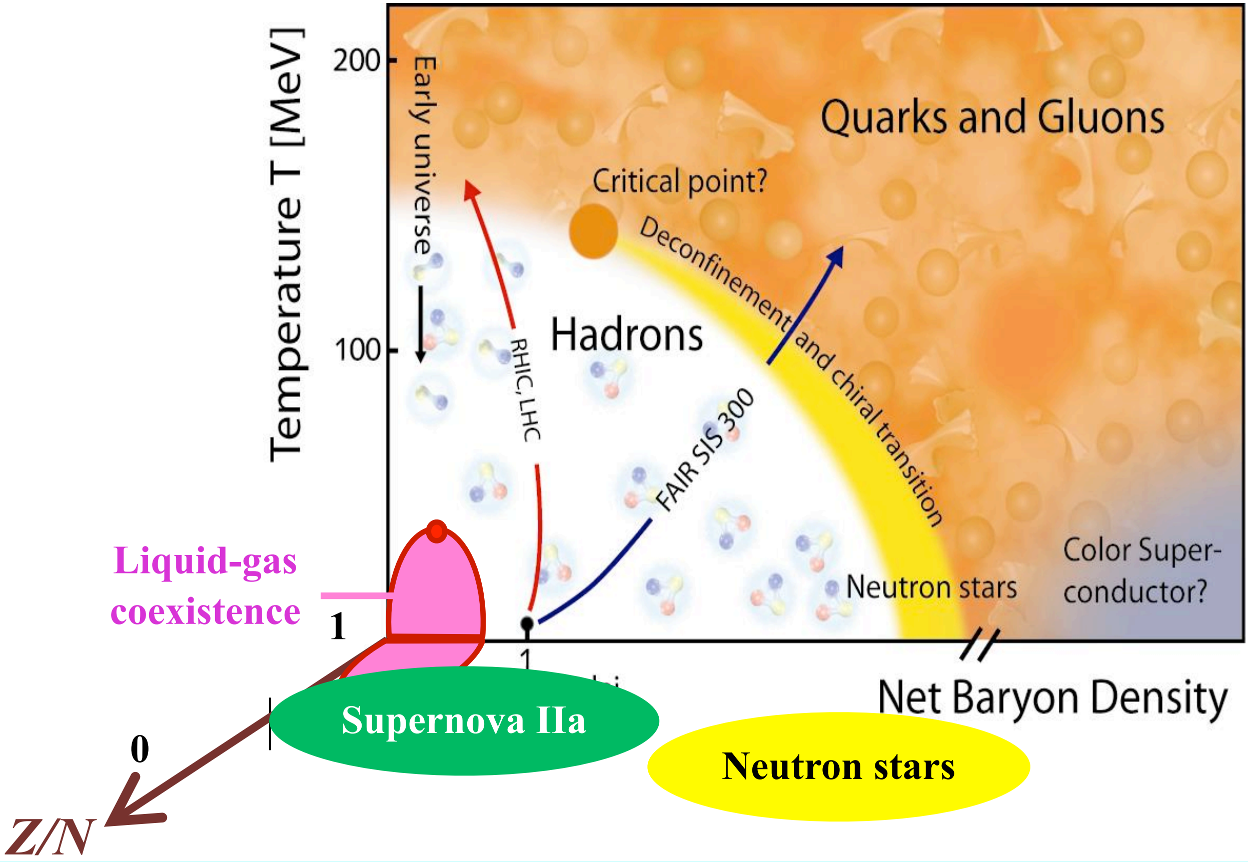
   –Phase transitions (liquid ↔ gas, hadron ↔ QGP)



Heavy Ion Experiment

Study of Nuclear Matter

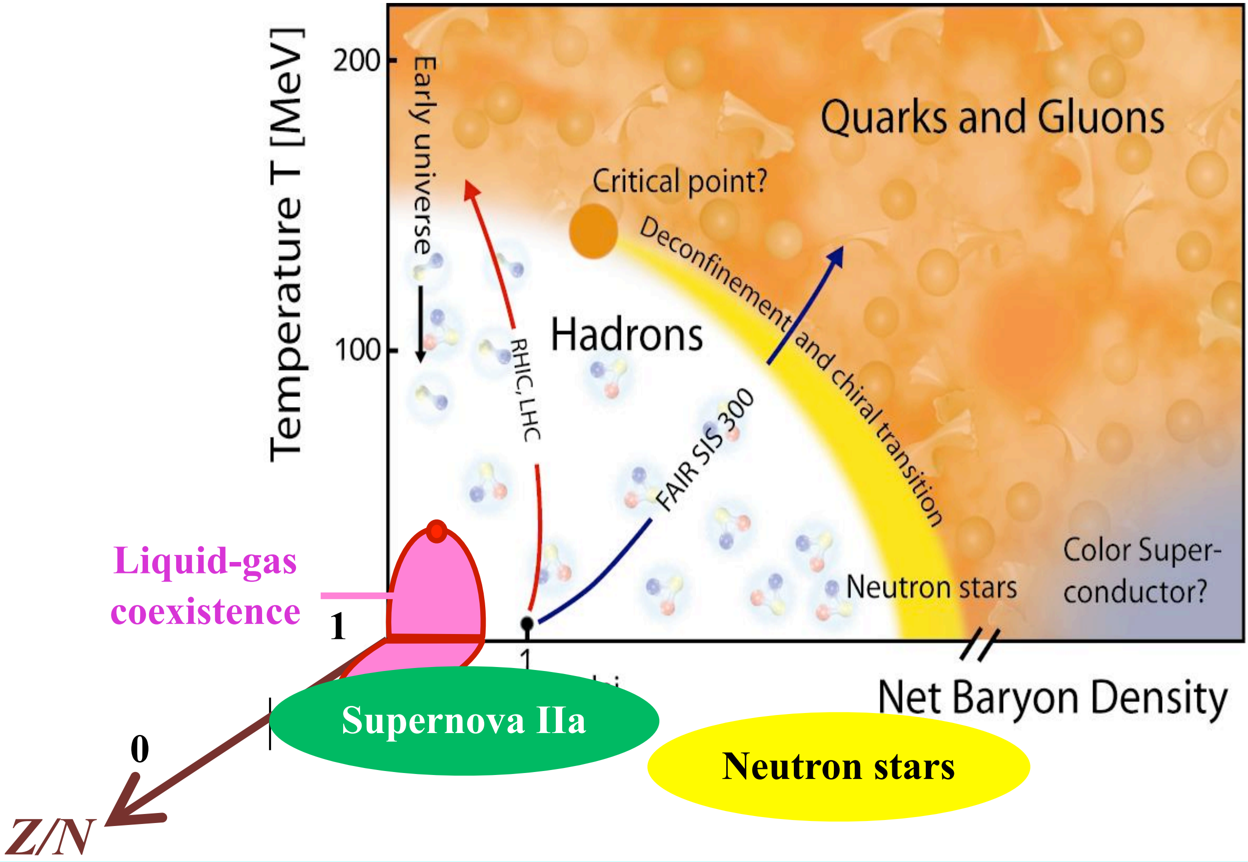
1. Exploring the phase diagram of strongly interacting matter
   - **Phase transitions (liquid ↔ gas, hadron ↔ QGP)**
2. Determining Equation of State (EOS) of the strongly interacting medium below and above the saturation density up to $\rho \sim 2\rho_0$
   - **Isospin dependence**



Heavy Ion Experiment

Study of Nuclear Matter

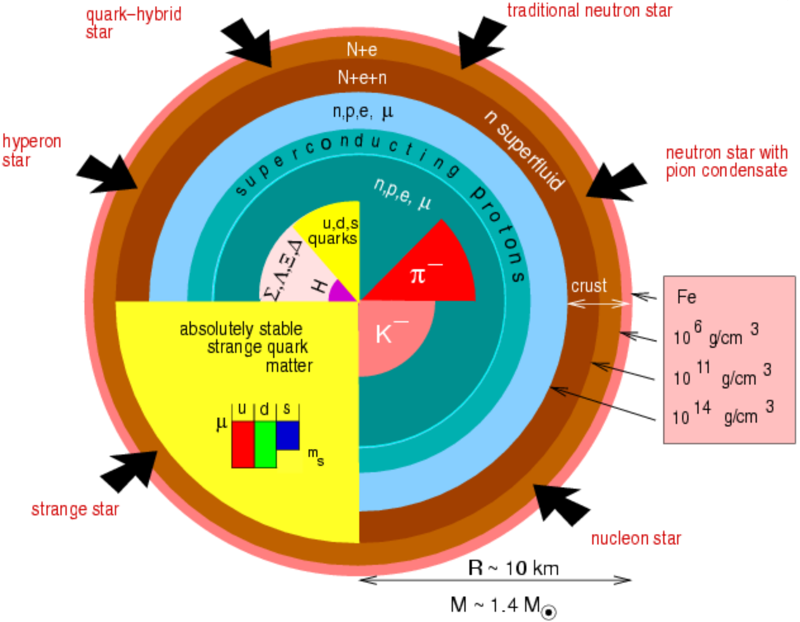
1. Exploring the phase diagram of strongly interacting matter
   - **Phase transitions (liquid ↔ gas, hadron ↔ QGP)**
2. Determining Equation of State (EOS) of the strongly interacting medium below and above the saturation density up to $\boldsymbol{\rho} \sim 2\boldsymbol{\rho}_0$
   - **Isospin dependence**
3. Modification of hadronic properties in dense medium

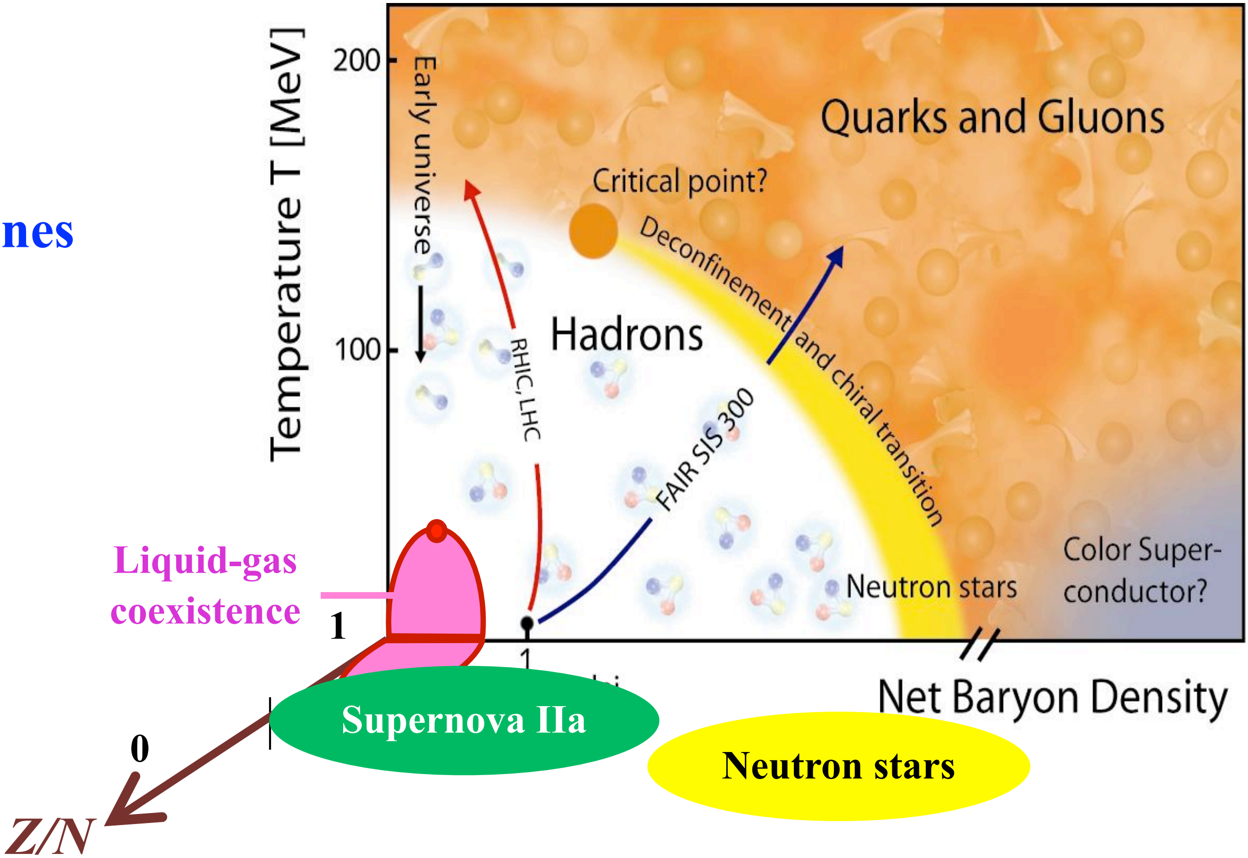


Heavy Ion Experiment

Study of Nuclear Matter

1. Exploring the phase diagram of strongly interacting matter
   - **Phase transitions (liquid ↔ gas, hadron ↔ QGP)**
2. Determining Equation of State (EOS) of the strongly interacting medium below and above the saturation density up to $\rho \sim 2\rho_0$
   - **Isospin dependence**
3. Modification of hadronic properties in dense medium
4. Importance for astrophysics
   - **Supernovae and neutron stars**
   - **Nuclear synthesis and exotic nuclei near neutron drip lines**
   - QGP at colliders (not for RISP)



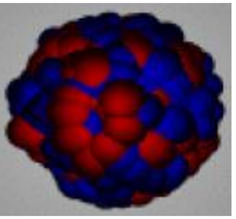


Physics Observables for Heavy-Ion Experiment at RAON

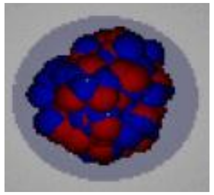
Important to measure system size (Ca, Ni, Ru, Zr, Sn, Xe, Au, U), energy (lowest to top energies), centrality, rapidity & transverse momentum dependence

1. Pygmy and Giant dipole resonances
   - Energy spectra of gammas
   - Related to the radius of n-skin for unstable nuclei
2. Particle spectrum, yield, and ratio
   - n/p, $^3H/^3He$, $^7Li/^7Be$, π^-/π^+, etc.
3. 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
4. Various isospin dependent phenomena
   - Isospin fractionation and isoscaling in nuclear multi fragmentation
   - Isospin diffusion (transport)

Pygmy and Giant Dipole Resonances



Giant dipole resonance:
oscillation between non-deformed, incompressible proton and neutron spheres



Pygmy dipole resonance:
neutrons at the nuclear surface (neutron skin) oscillating against the isospin neutral proton-neutron core

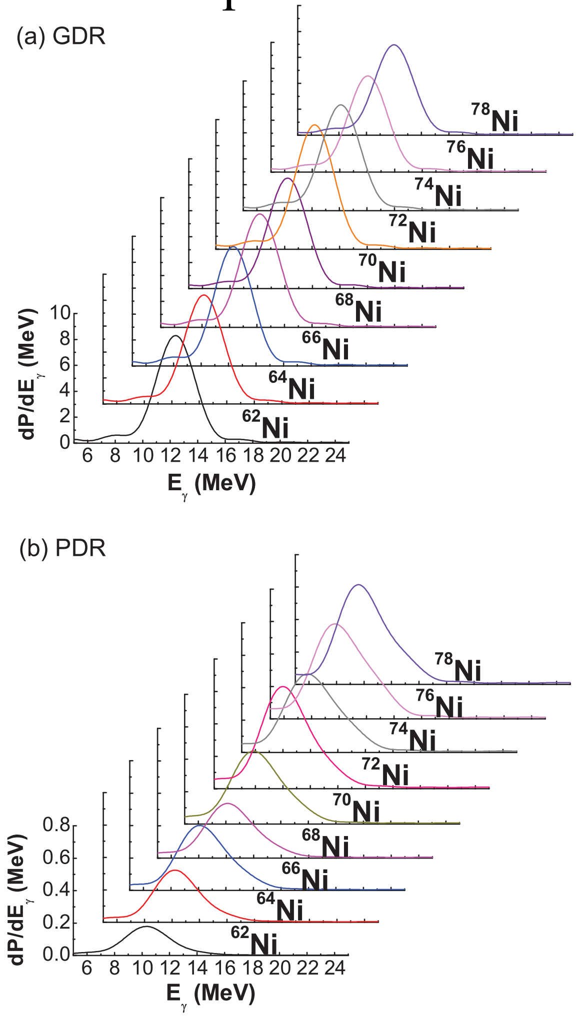


FIG. 10. (Color online) Mass number dependence of GDR (a) and PDR spectra (b) for Ni isotopes. In calculations, we use $E_{\rm in} = 100$ MeV/nucleon, $b = 24$ fm, $C_{\rm sym} = 32$ MeV, and the soft EOS without MDI.

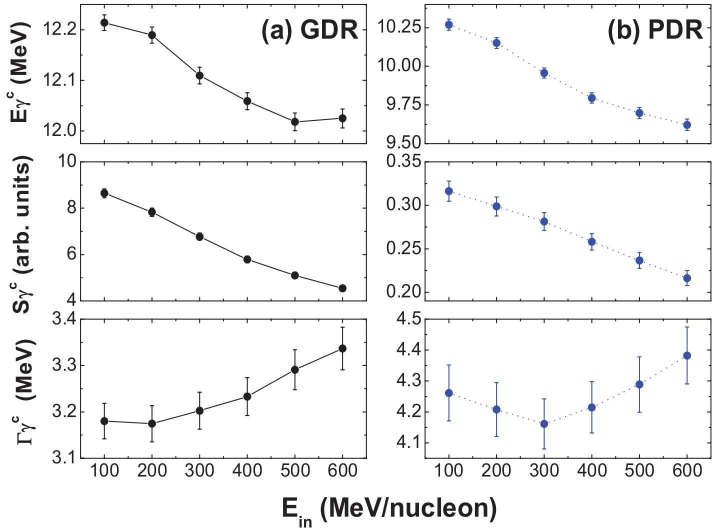


FIG. 5. (Color online) Incident energy dependencies of GDR (left panels) and PDR (right panels) parameters for ^{68}Ni. From the upper panel to bottom panel, it corresponds to the peak energy (E_γ^c), strength (S_γ^c), and FWHM (Γ_γ^c), respectively. In calculations, we use $b = 24$ fm, $C_{\rm sym} = 32$ MeV, and the soft EOS without MDI.

Energy dependence

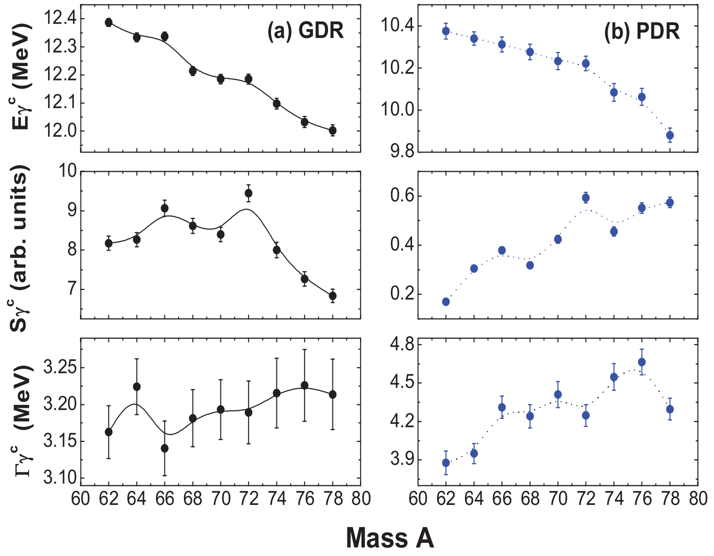


FIG. 11. (Color online) Mass number dependence of Ni isotopes of GDR (left panels) and PDR (right panels) parameters. In calculations, we use $E_{\rm in} = 100$ MeV/nucleon, $b = 24$ fm, $C_{\rm sym} = 32$ MeV, and the soft EOS without MDI.

System size dependence

Ni+Au collision

C. Tao *et al.*, PRC 87, 014621(2013)

Pygmy and Giant Dipole Resonances

PRL 95, 132501 (2005) PHYSICAL REVIEW LETTERS week ending 23 SEPTEMBER 2005

Evidence for Pygmy and Giant Dipole Resonances in ^{130}Sn and ^{132}Sn

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H. Emling,[1] H. Geissel,[1] M. Hellström,[1] K. L. Jones,[1] J. V. Kratz,[3] R. Kulessa,[4] Y. Leifels,[1] C. Nociforo,[3] R. Palit,[2]
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(LAND-FRS Collaboration)

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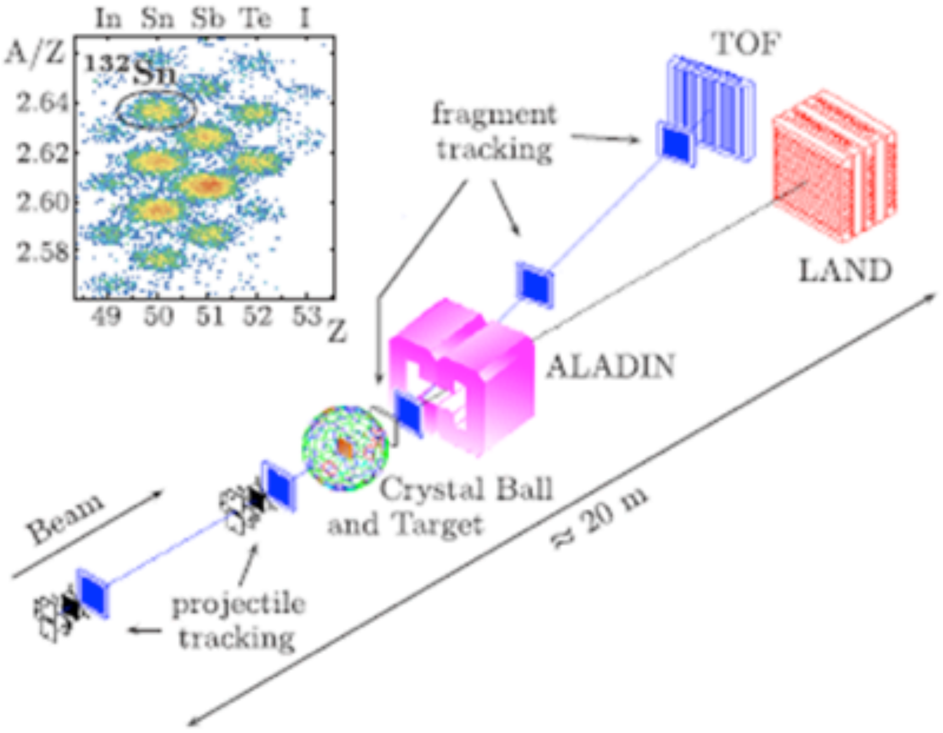
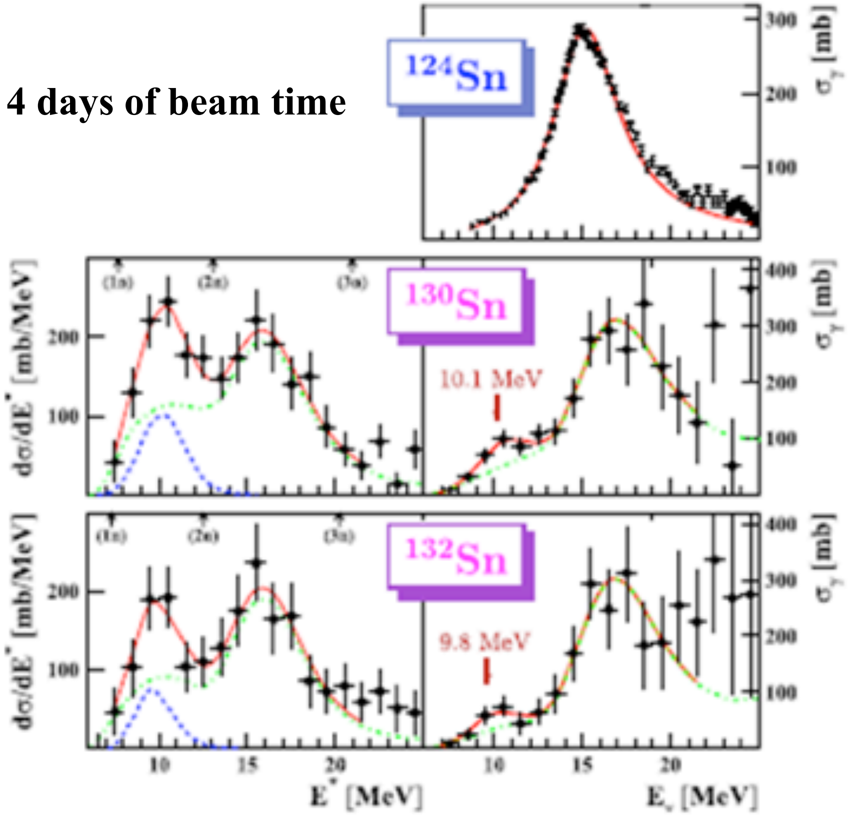
(Received 29 April 2005; published 21 September 2005)

The dipole strength distribution above the one-neutron separation energy was measured in the unstable ^{130}Sn and the double-magic ^{132}Sn isotopes. The results were deduced from Coulomb dissociation of secondary Sn beams with energies around 500 MeV/nucleon, produced by in-flight fission of a primary ^{238}U beam. In addition to the giant dipole resonance, a resonancelike structure ("pygmy resonance") is observed at a lower excitation energy around 10 MeV exhausting a few percent of the isovector $E1$ energy-weighted sum rule. The results are discussed in the context of a predicted new dipole mode of excess neutrons oscillating out of phase with the core nucleons.

The beam of ^{132}Sn and about 20 other isotopes of similar mass-to-charge (A/Z) ratio were produced by in-flight fission of a ^{238}U primary beam with an intensity of 1.4×10^8 ions/s incident on a Be target. Isotopes were selected according to their magnetic rigidity by the fragment separator FRS [14]. The secondary beams were delivered to the experimental setup with energies around 500 MeV/nucleon. For ^{132}Sn, the intensity amounted to about 10 ions/s on the target. The incoming projectiles were unambiguously identified event by event by determining their magnetic rigidity (with a position measurement in the dispersive midfocal plane of the FRS), time of flight, and energy loss. Projectiles were excited in a secondary ^{208}Pb target (468 mg/cm^2). Additional measurements were performed with a ^{12}C target (370 mg/cm^2) and without target. The results presented in this Letter were deduced from the data effectively collected for 4 days of beam time. The experimental setup and a beam-identification plot are shown in Fig. 1.



4 days of beam time



Pygmy and Giant Dipole Resonances

PRL **102,** 092502 (2009) PHYSICAL REVIEW LETTERS week ending 6 MARCH 2009

Search for the Pygmy Dipole Resonance in ^{68}Ni at 600 MeV/nucleon

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[4]*GSI, D-64291 Darmstadt, Germany*
[5]*Institut für Kernphysik, Universität zu Köln, D-50937 Köln, Germany*
[6]*Laboratori Nazionali di Legnaro, INFN, I-35020 Legnaro, Italy*
[7]*Dipartimento di Fisica, Universitá di Padova, I-35122 Padova, Italy*
[8]*INFN Sezione di Padova, I-35122 Padova, Italy*
[9]*Dipartimento di Fisica, Universitá di Camerino, I-62032 Camerino, Italy*
[10]*INFN Sezione di Perugia, I-06123 Perugia, Italy*
[11]*INFN Sezione di Genova, I-16146 Genova, Italy*
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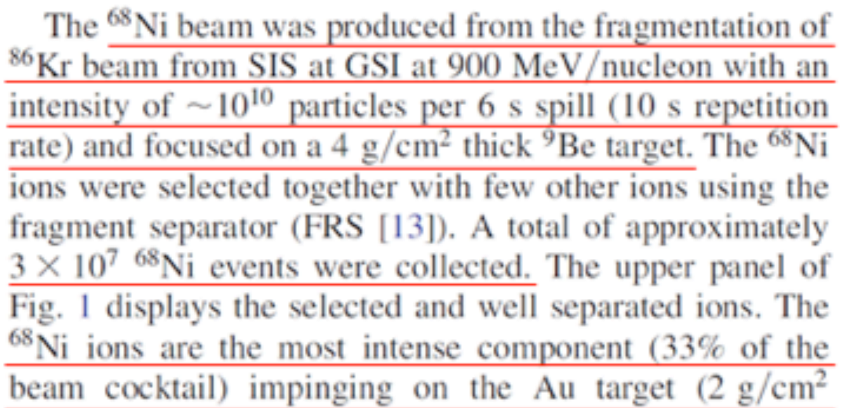
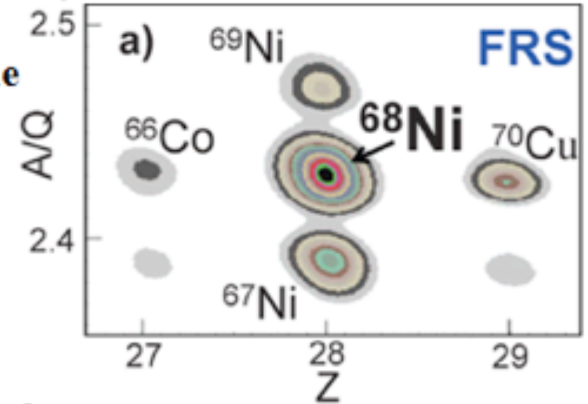
(Received 19 September 2008; published 4 March 2009)

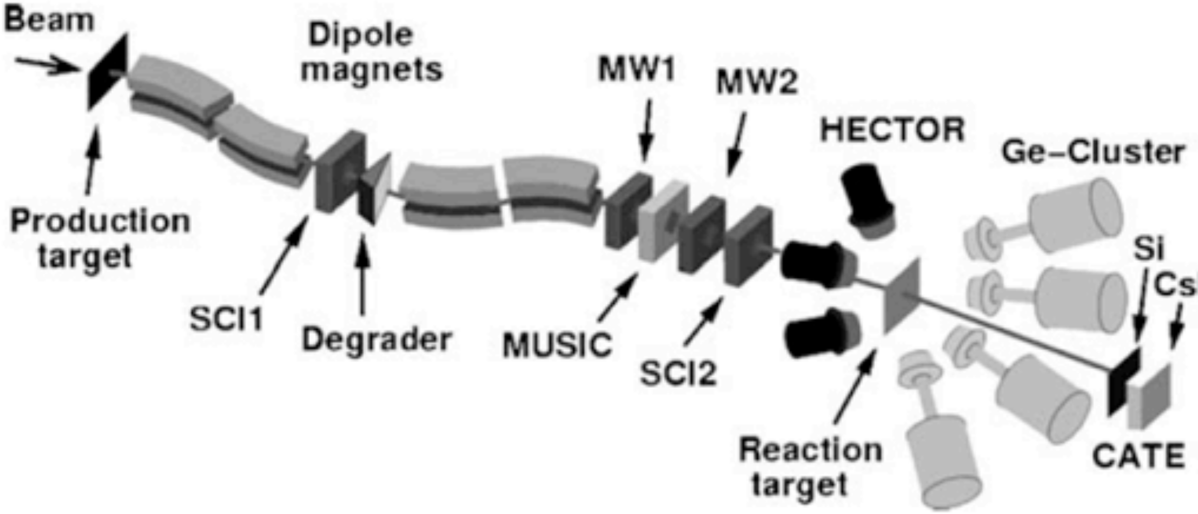
The γ decay from Coulomb excitation of ^{68}Ni at 600 MeV/nucleon on a Au target was measured using the RISING setup at the fragment separator of GSI. The ^{68}Ni beam was produced by a fragmentation reaction of ^{86}Kr at 900 MeV/nucleon on a ^{9}Be target and selected by the fragment separator. The γ rays produced at the Au target were measured with HPGe detectors at forward angles and with BaF$_2$ scintillators at backward angles. The measured spectra show a peak centered at approximately 11 MeV, whose intensity can be explained in terms of an enhanced strength of the dipole response function (pygmy resonance). Such pygmy structure has been predicted in this unstable neutron-rich nucleus by theory.

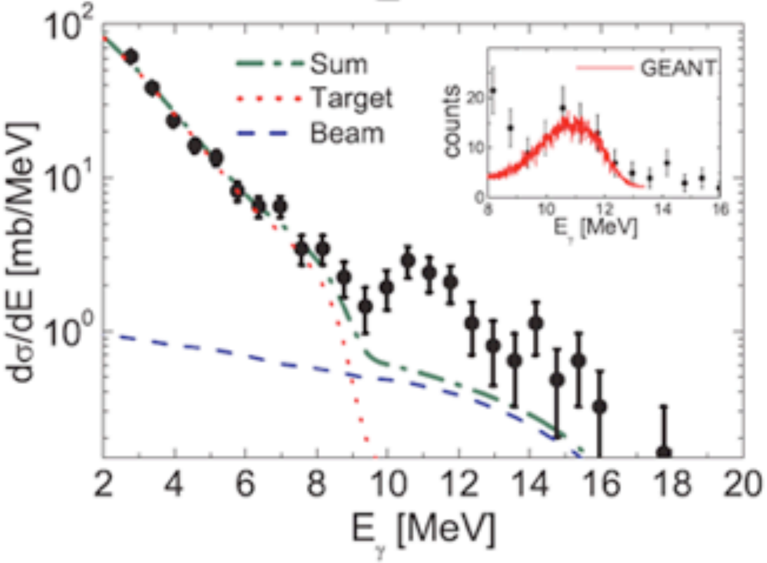


The ^{68}Ni beam was produced from the fragmentation of ^{86}Kr beam from SIS at GSI at 900 MeV/nucleon with an intensity of ~10^{10} particles per 6 s spill (10 s repetition rate) and focused on a 4 g/cm^2 thick ^{9}Be target. The ^{68}Ni ions were selected together with few other ions using the fragment separator (FRS [13]). A total of approximately 3×10^7 ^{68}Ni events were collected. The upper panel of Fig. 1 displays the selected and well separated ions. The ^{68}Ni ions are the most intense component (33% of the beam cocktail) impinging on the Au target (2 g/cm^2 thick). The particle identification after the Au target was

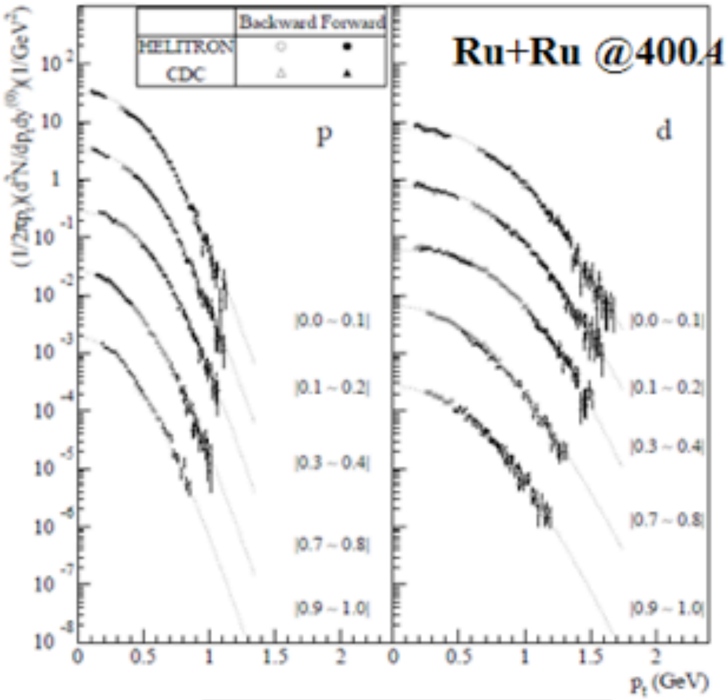
6 days of beam time



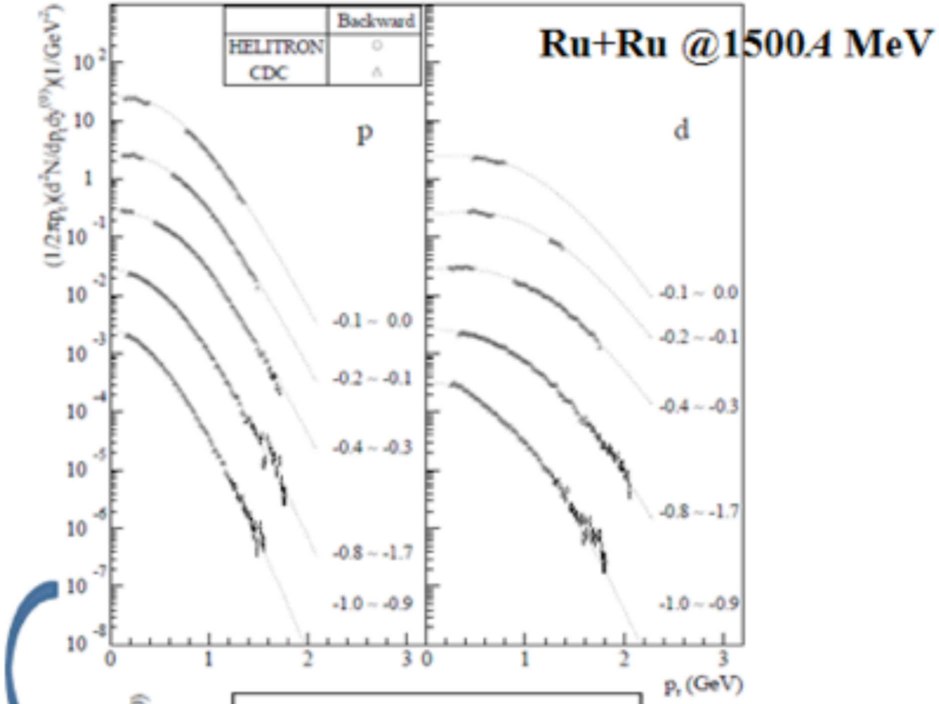


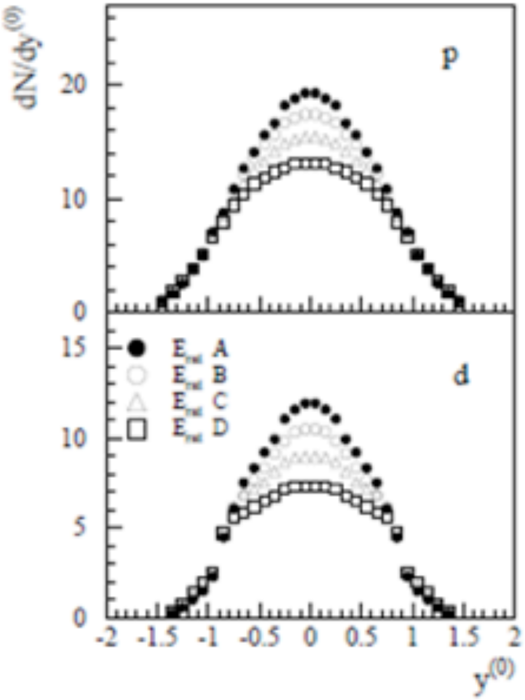


Particle Spectrum and Yield

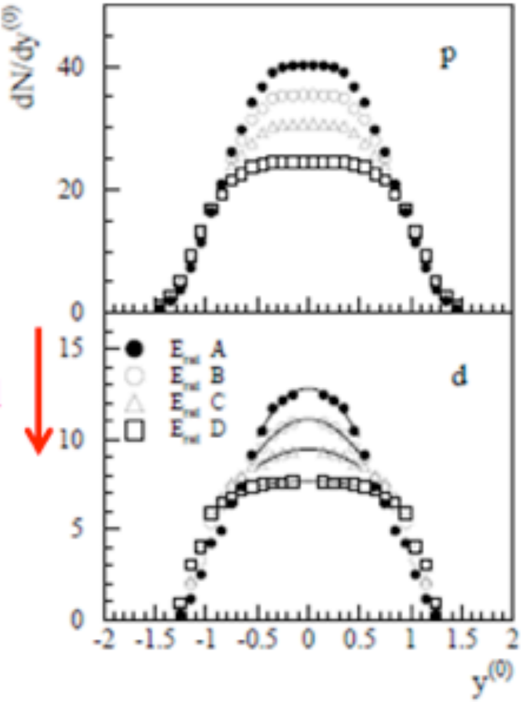


low to high energy

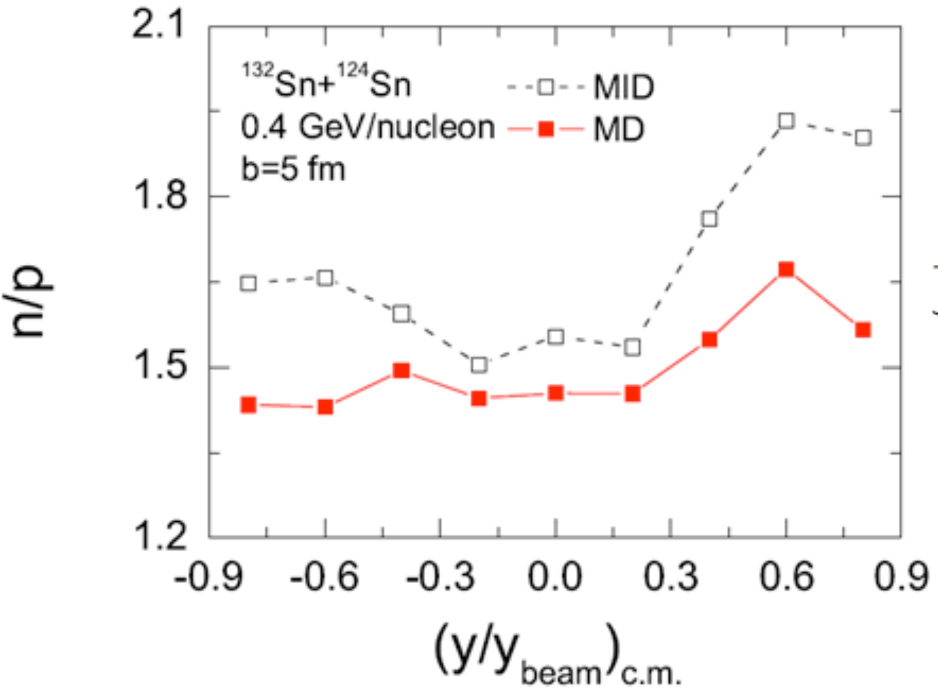


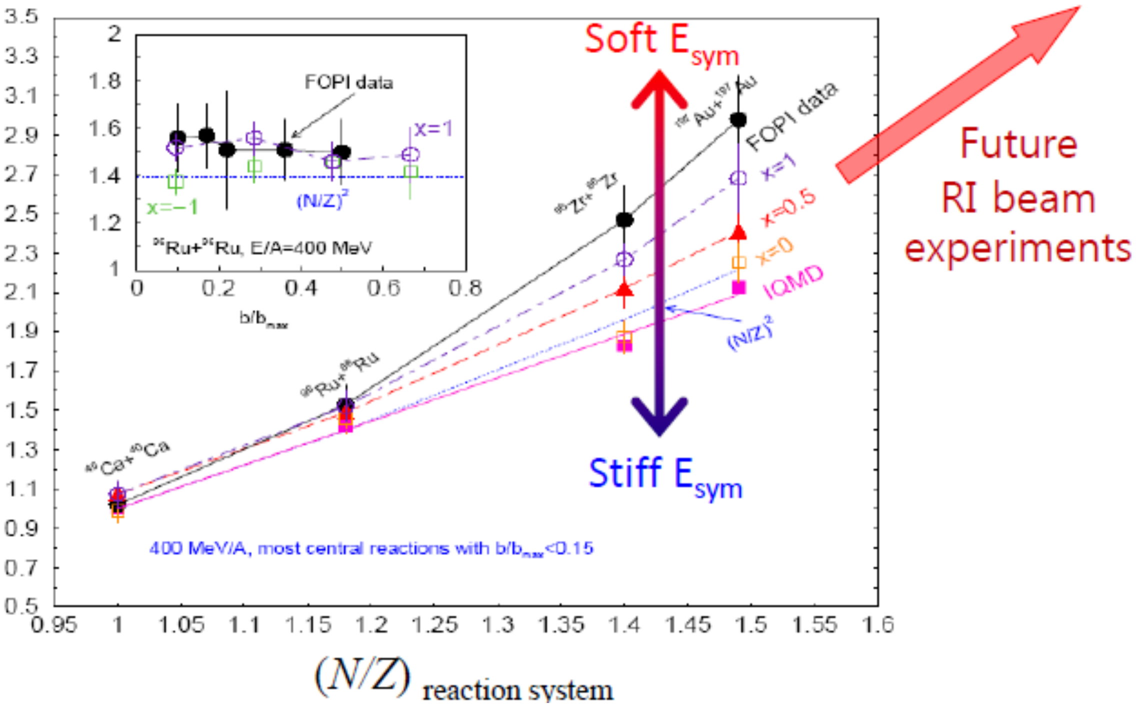


central to peripheral collisions



Particle Ratio



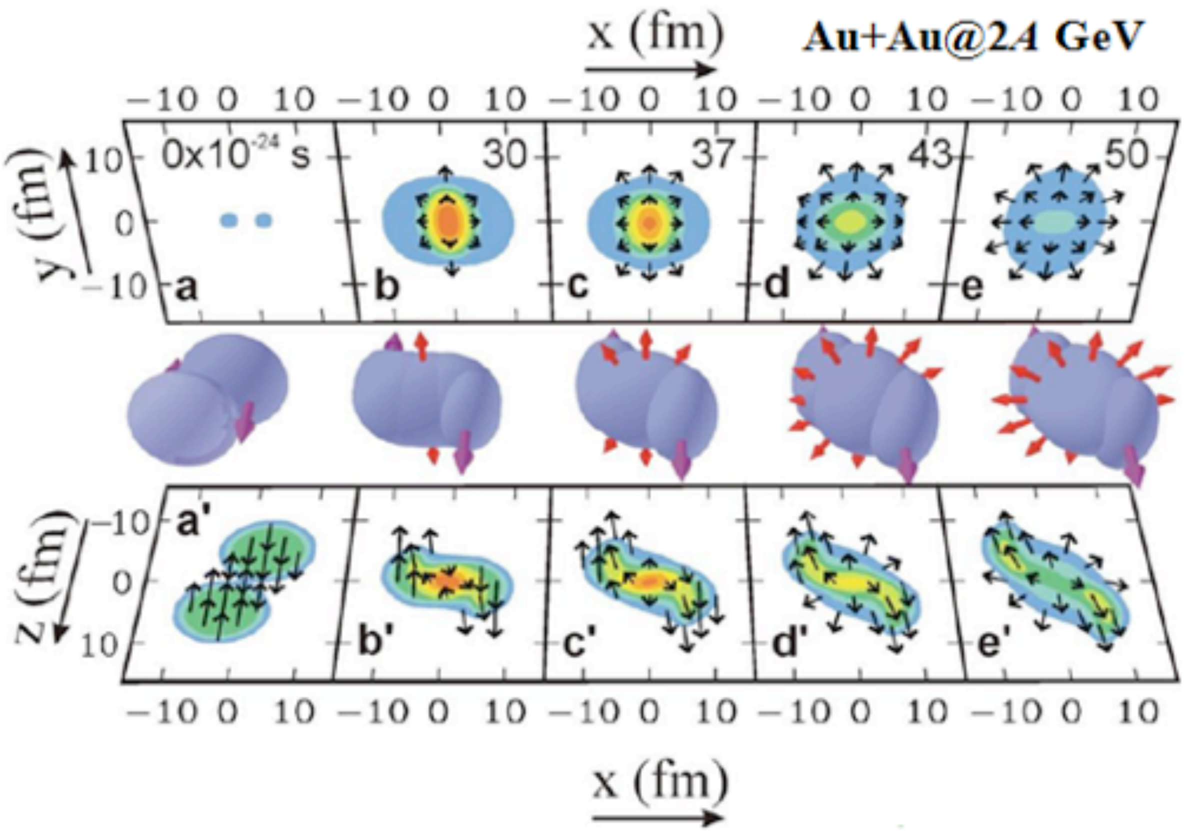


Example:

$N/Z(^{106}\mathrm{Sn} + {}^{112}\mathrm{Sn}) = 1.18$

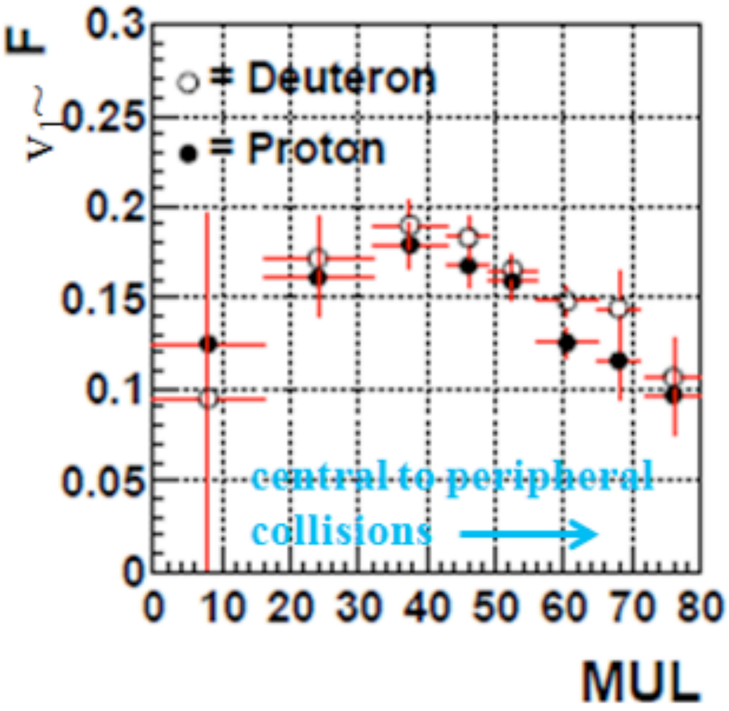
$N/Z(^{132}\mathrm{Sn} + {}^{124}\mathrm{Sn}) = 1.56$

Collective Flow

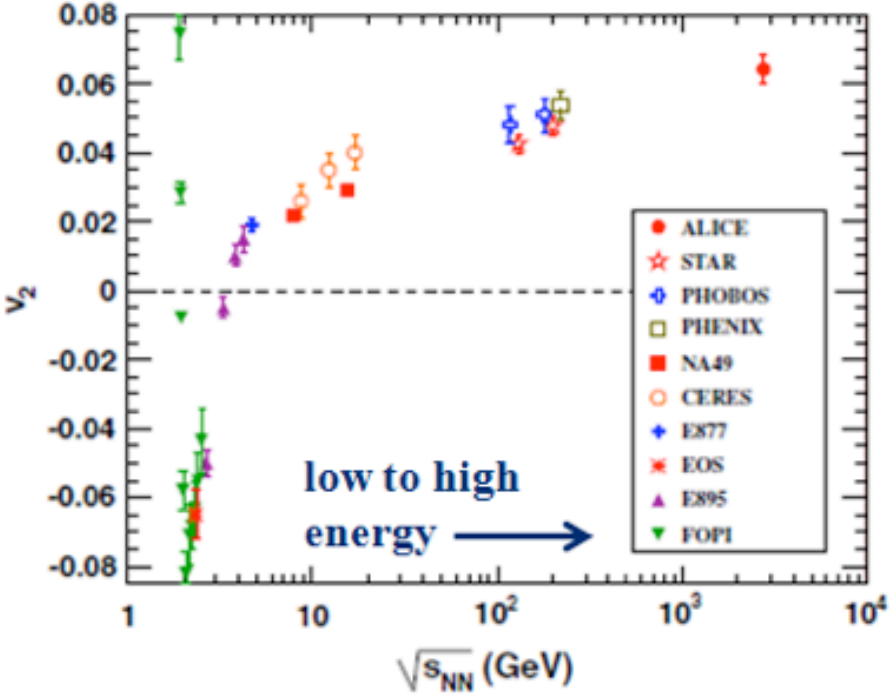


$$E\frac{dN}{d^3p} = \frac{dN}{2\pi p_t\,dp_t\,dy}\cdot\left(1+2v_1\cos\left(\Phi-\Phi_R^{(n)}\right)\right.$$
$$\left.+\,2v_2\cos\left(2\cdot\left(\Phi-\Phi_R^{(n)}\right)\right)+\cdots\right).$$

$$v_m = \langle\cos(m\cdot(\Phi-\Phi_R^{(n)}))\rangle$$

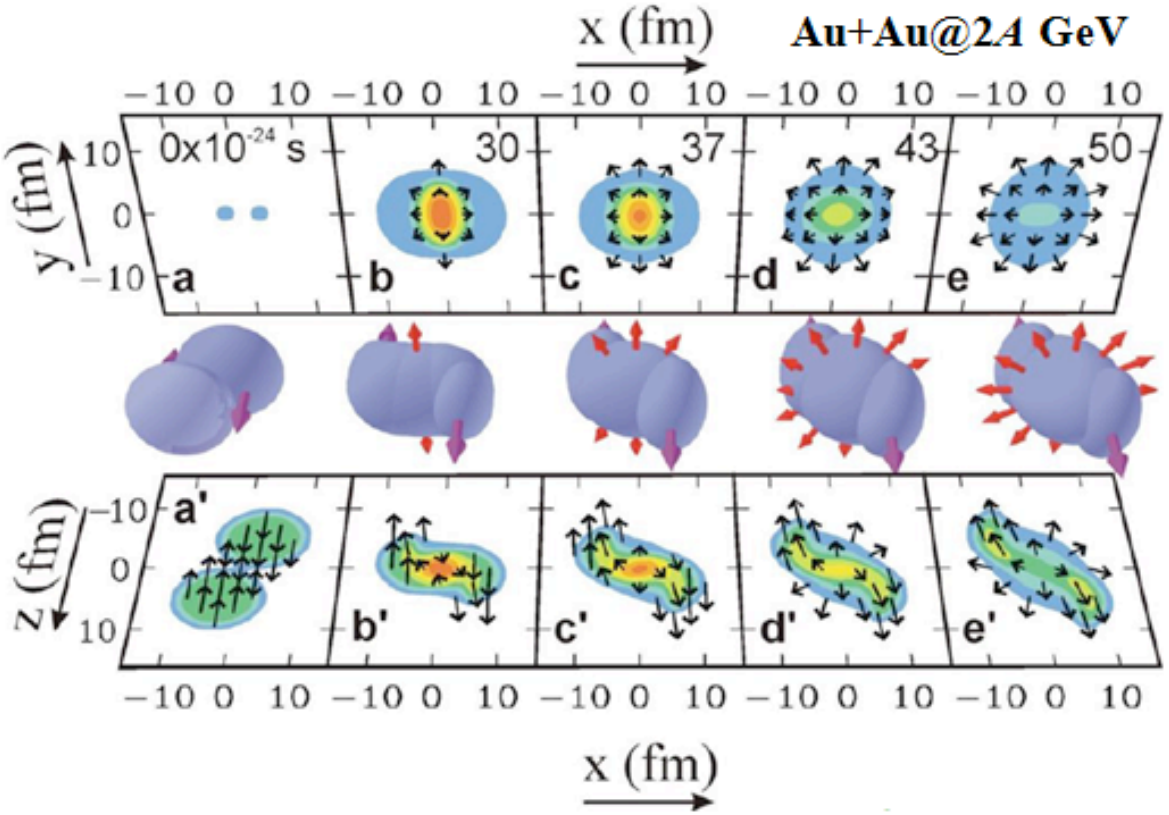


central to peripheral collisions →



low to high energy →

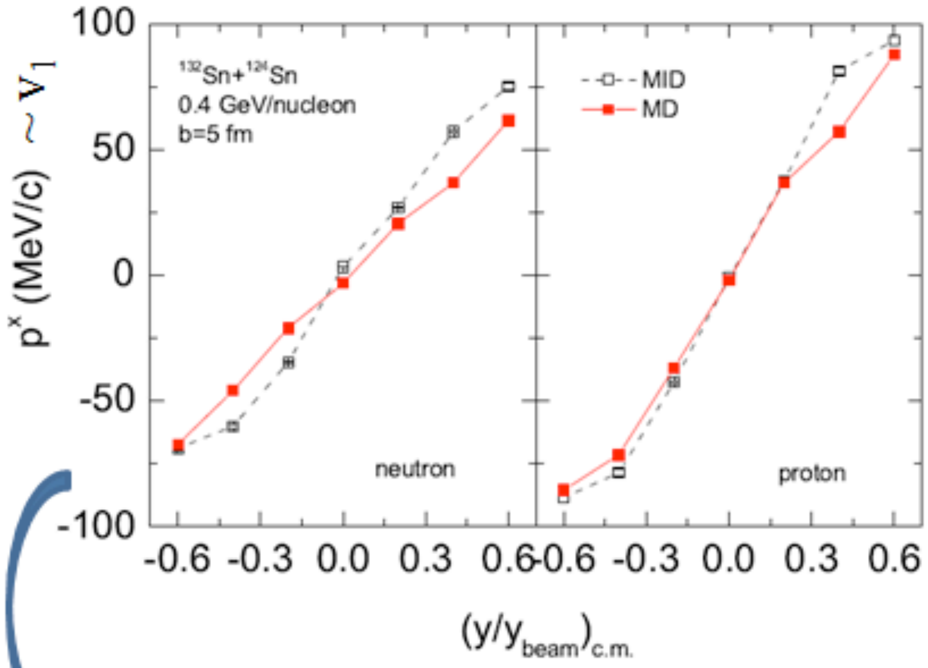
Collective Flow

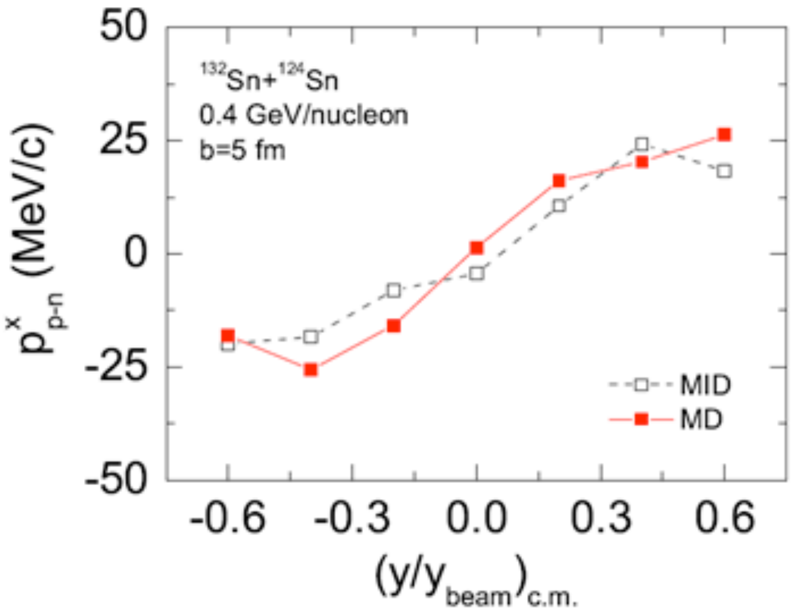


$$E\frac{dN}{d^3p} = \frac{dN}{2\pi p_t\, dp_t\, dy}\cdot\left(1 + 2v_1\cos\left(\Phi - \Phi_R^{(n)}\right)\right.$$

$$\left. + 2v_2\cos\left(2\cdot\left(\Phi - \Phi_R^{(n)}\right)\right) + \cdots\right).$$

$$v_m = \langle\cos(m\cdot(\Phi - \Phi_R^{(n)}))\rangle$$





Design of Detector System

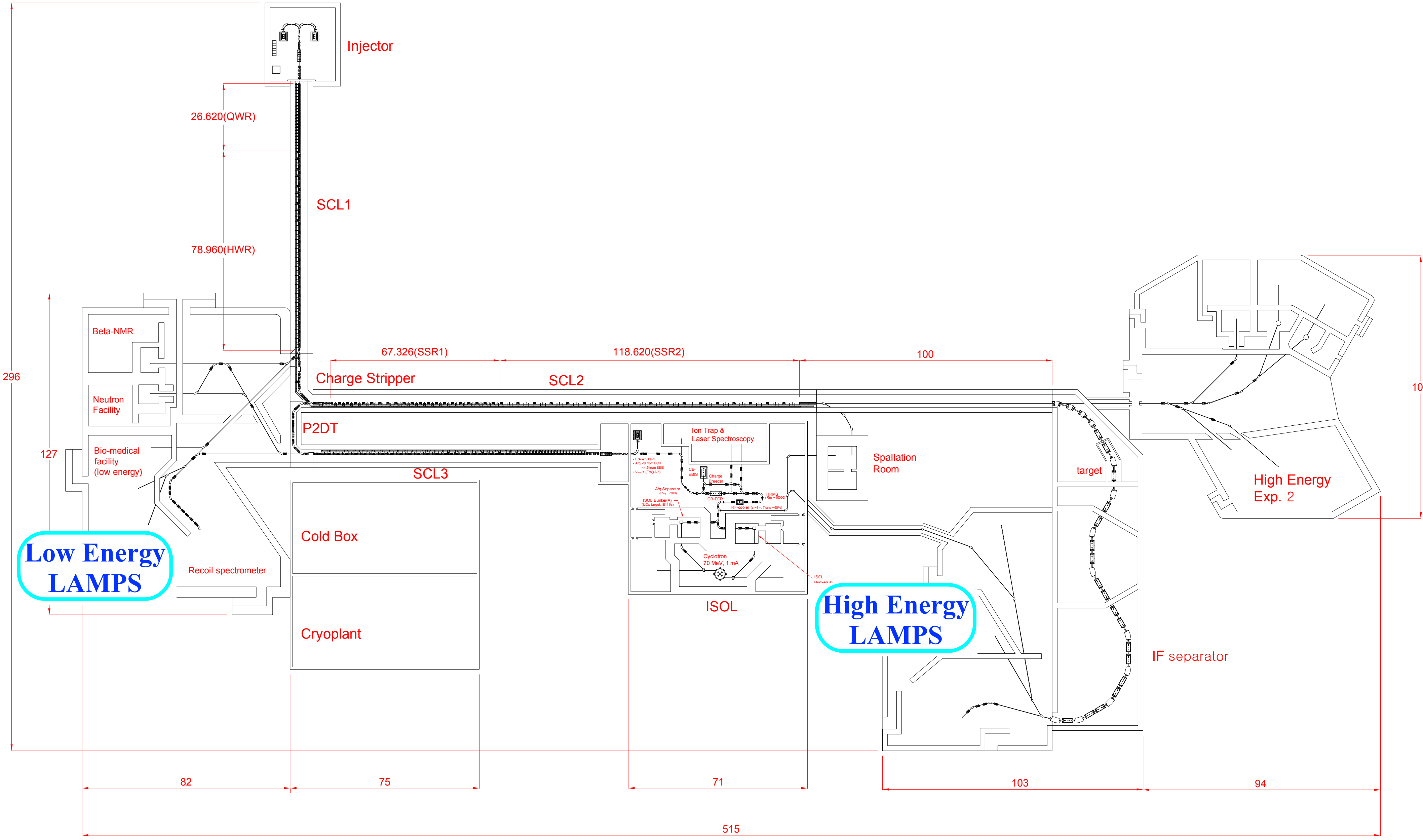
- We need to accommodate
  - Large acceptance
  - Precise measurement of momentum (or energy) for variety of particle species, including $\pi^{+/-}$ and neutrons, with high efficiency
  - Gamma detection for Pygmy and Giant dipole resonances
  - Keep flexibility for other physics topic
- Two setups
  - Low-energy (E < 18.5 MeV/u) setup for the day-1 experiment
  - High-energy (E > 18.5 MeV/u) setup
- Beam
  - State beam: p, ^{12}C, ^{40}Ca, ^{58}Ni, ^{96}Ru, ^{96}Zr, ^{112}Sn, ^{132}Xe, ^{158}Au, ^{238}U, and more up to 200 MeV/u
  - RI beam: Ca, Ni, Ru, Zr, Sn, Xe, and more up to 250 MeV/u

✴for commissioning

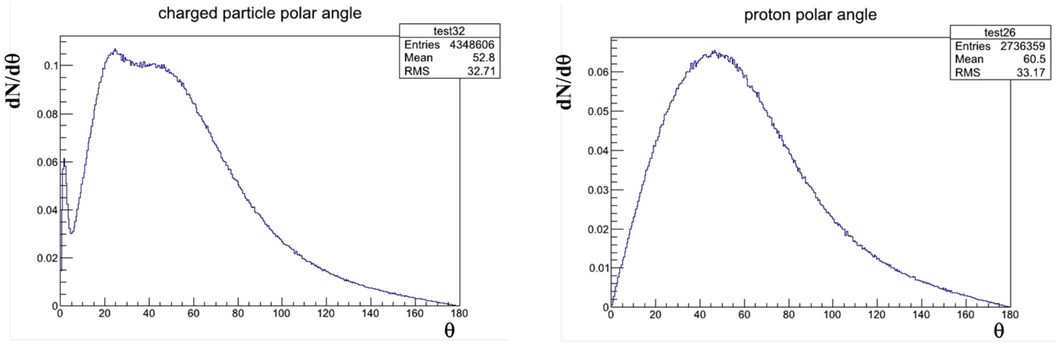
❖when it is available

❖if it is possible

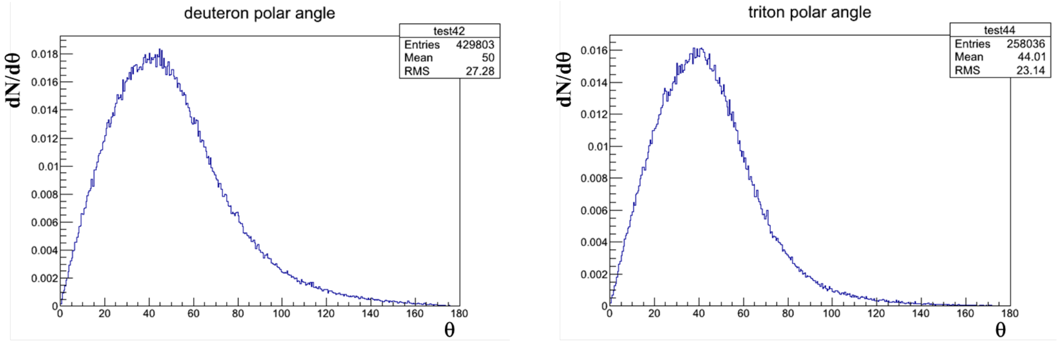
RAON Design (Accelerator and Experiments)



Low Energy LAMPS Experimental Setup

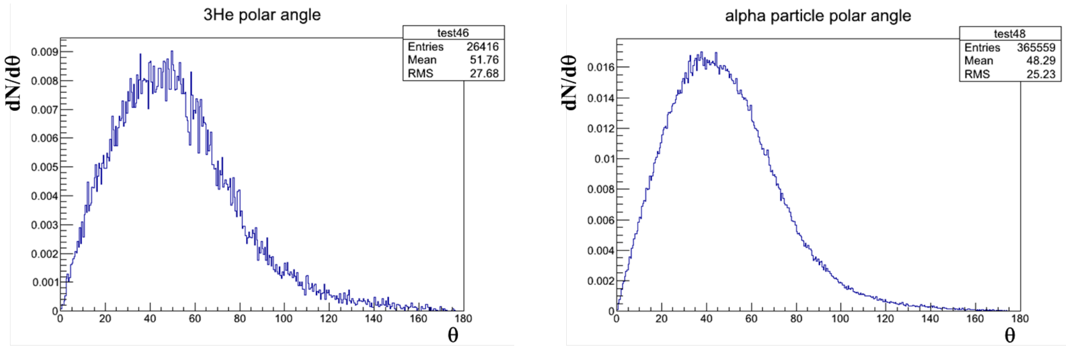


(a) Charged particle polar angle distribution. (b) Proton polar angle distribution.

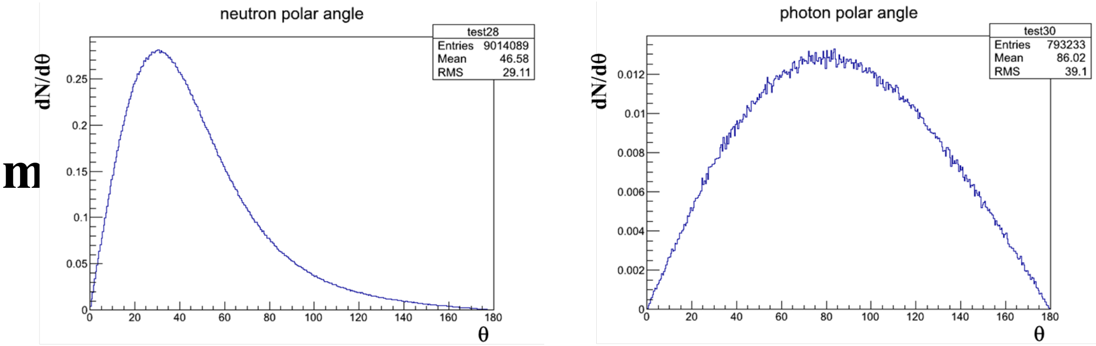


(c) Deuteron polar angle distribution. (d) Triton polar angle distribution.

Particle Species	Multiplicity per Event (4π)
charged particle	16
p	10
d	2
t	2
^3He	1
^4He	2
n	33
γ	3



(a) ^3He polar angle distribution. (b) ^4He angle distribution.



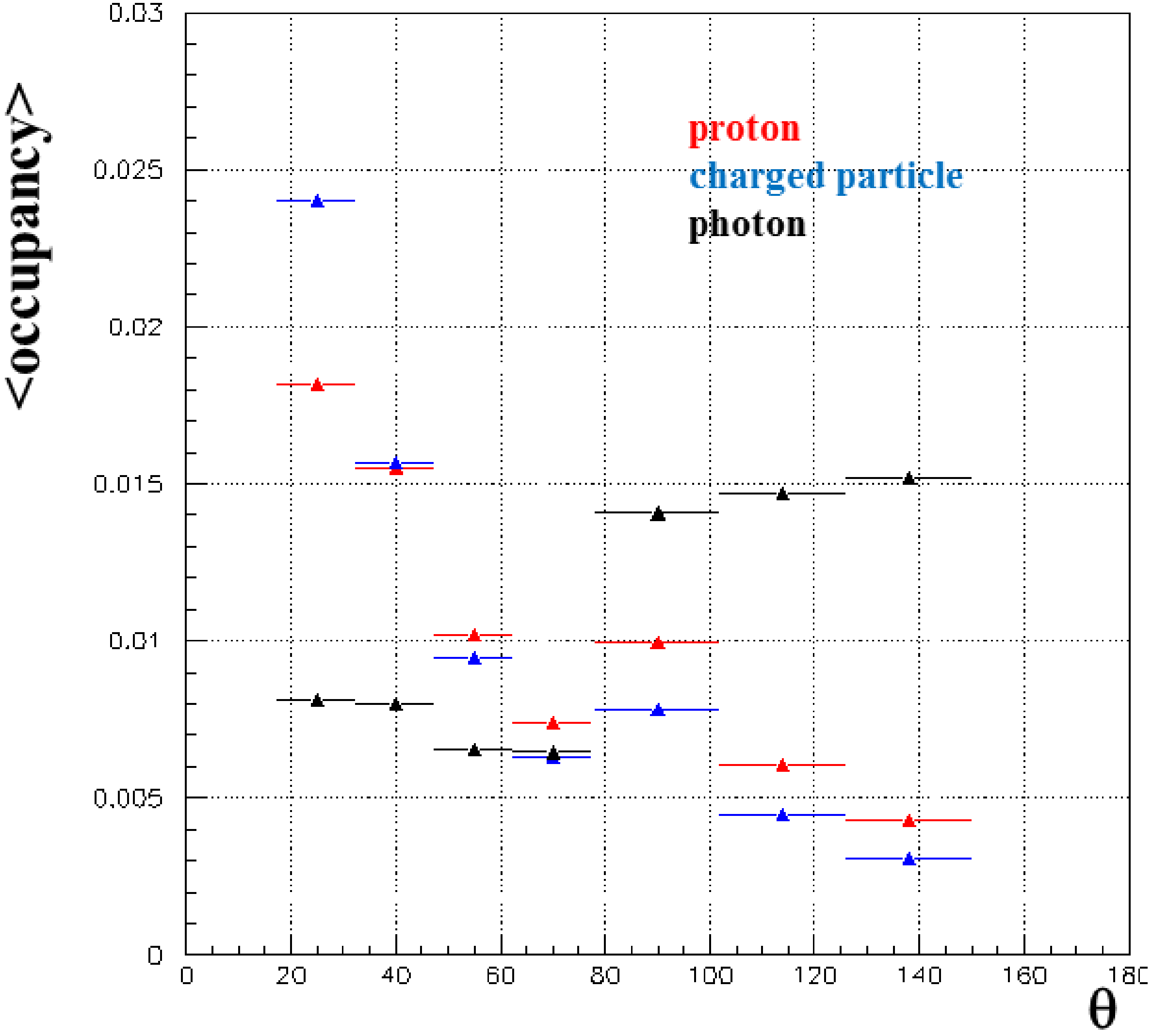
(c) Neutron polar angle distribution. (d) γ polar angle distribution.

^{132}Sn + ^{124}Sn @ 18.5*A* MeV

Particle and Heavy Ion Transport code System (PHITS) event simulation

Low Energy LAMPS Experimental Setup

^{132}Sn + ^{124}Sn @ 18.5*A* MeV PHITS event simulation

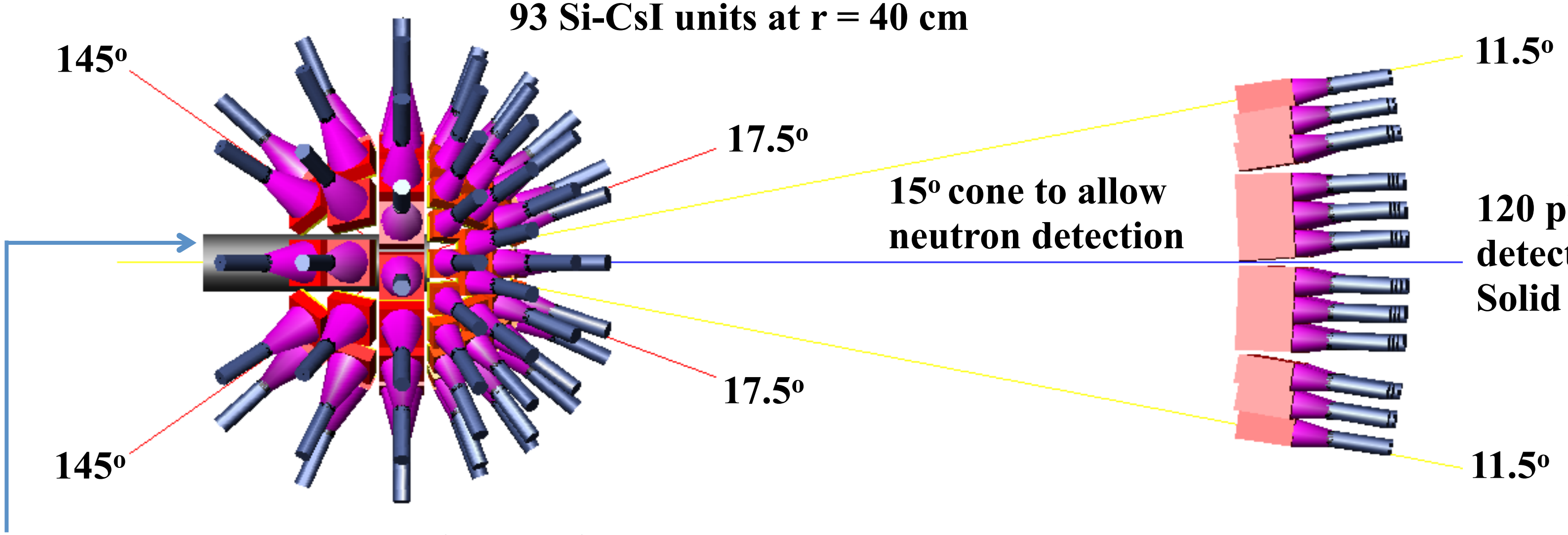


Si-CsI detector unit coverage of polar angle tuned to be <occupancy> < 0.1

Low Energy LAMPS Experimental Setup

$E_{beam} < 18.5A$ MeV

For PDR/GDR Experiments

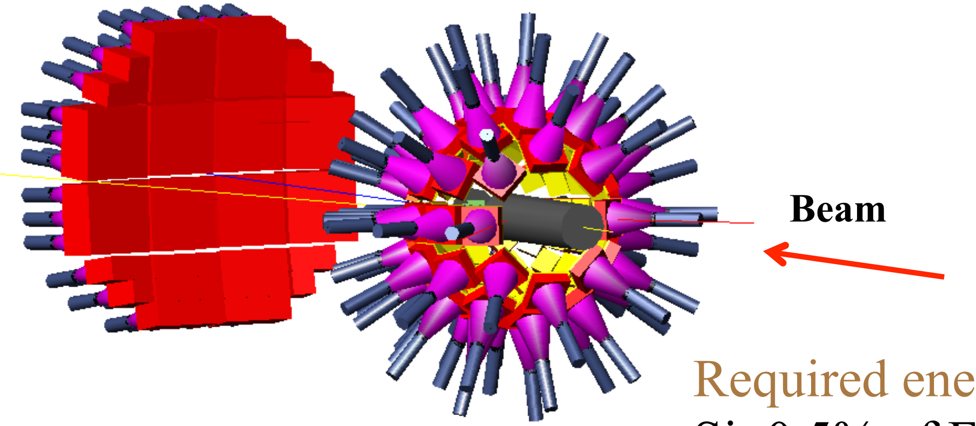


93 Si-CsI units at r = 40 cm

15° cone to allow neutron detection

120 plastic scintillator neutron detector units at z ~ 3.25 m
Solid angle = 133.3 mSr

25° cone to allow target installation



For PDR/GDR Experiments:

^{50,54}Ca, ^{68,70,72}Ni, ^{106,112,124,130,132}Sn RI beam
+ ^{197}Au/^{208}Pb (stable target)
+ ^{12}C/no target (background control)
❖could be possible from ISOL

Required energy resolution
Si: 0.5% of FWHM
CsI: 2.0% of FWHM

Low Energy LAMPS Experimental Setup

$E_{beam} < 18.5A$ MeV

For PDR/GDR Experiments

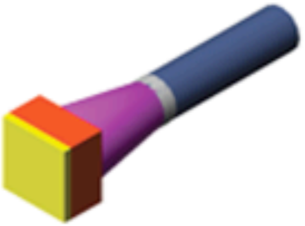
Geant4 simulation and detector R&D are ongoing

Total 58 detector units

($17.5^\circ < \theta_{lab} < 77.5^\circ$)

$9 \times 9 \times 0.01$ cm^3 Si (3 x 3 Pad)

$9 \times 9 \times 5$ cm^3 CsI (PMT readout)

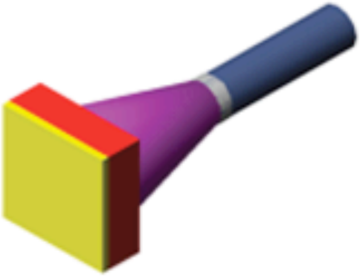


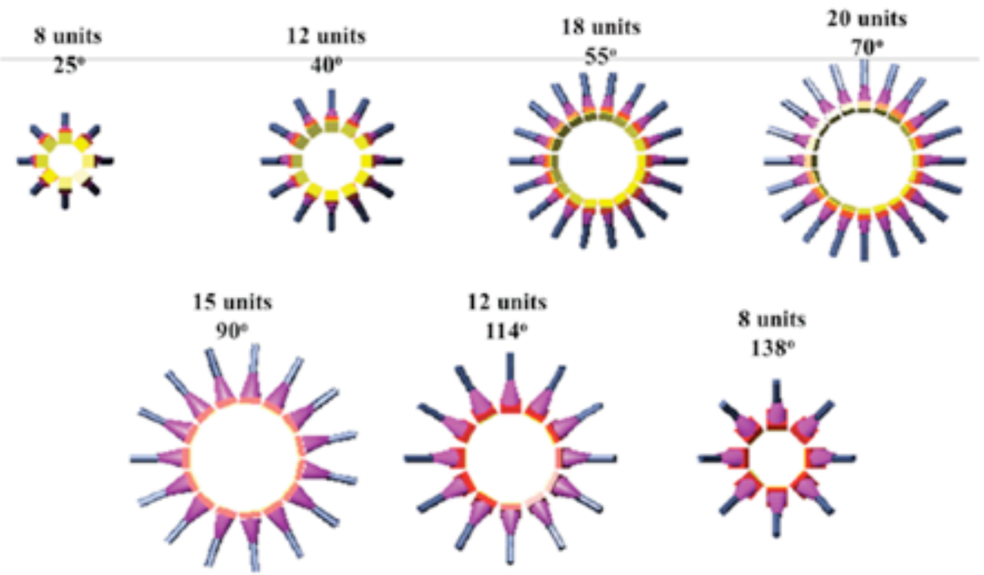
Total 35 detector units

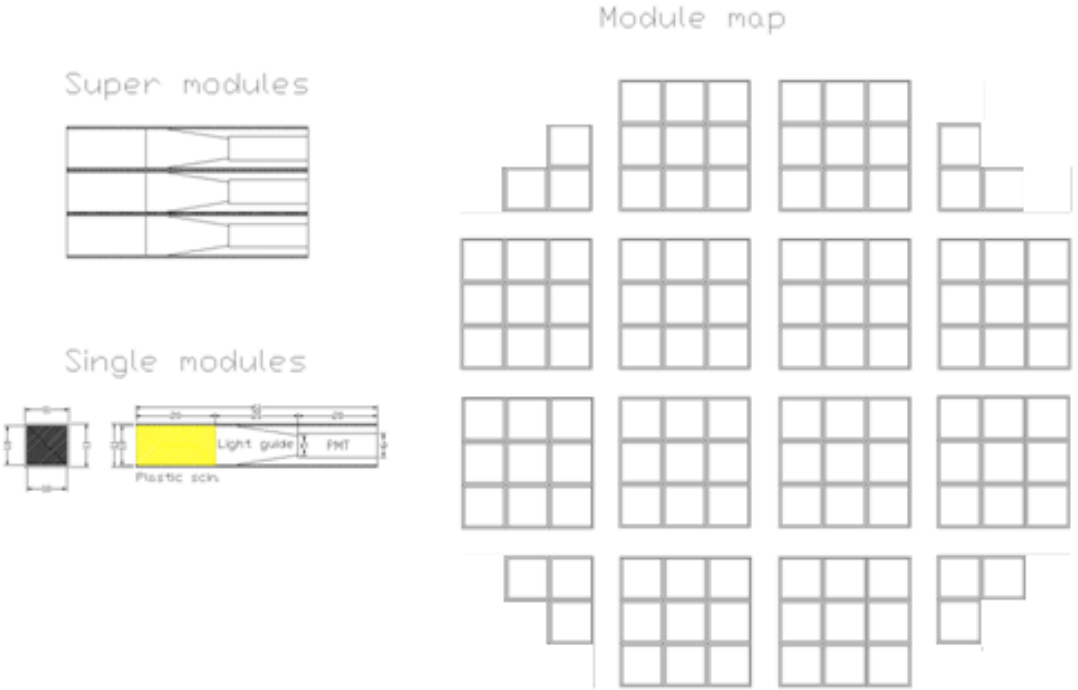
($78^\circ < \theta_{lab} < 150^\circ$)

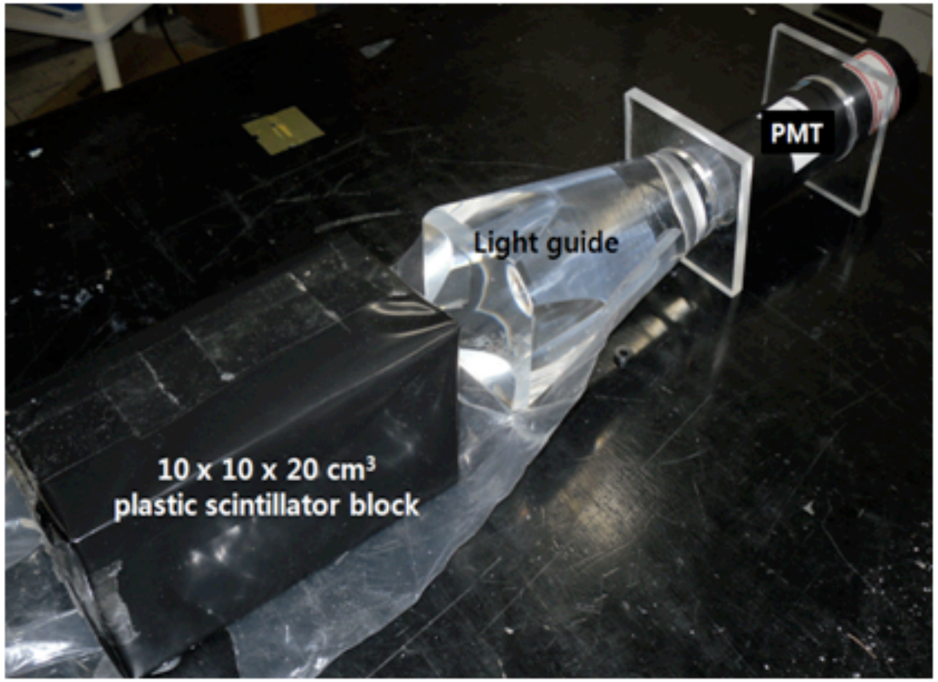
$15 \times 15 \times 0.01$ cm^3 Si (3 x 3 Pad)

$15 \times 15 \times 5$ cm^3 CsI (PMT readout)

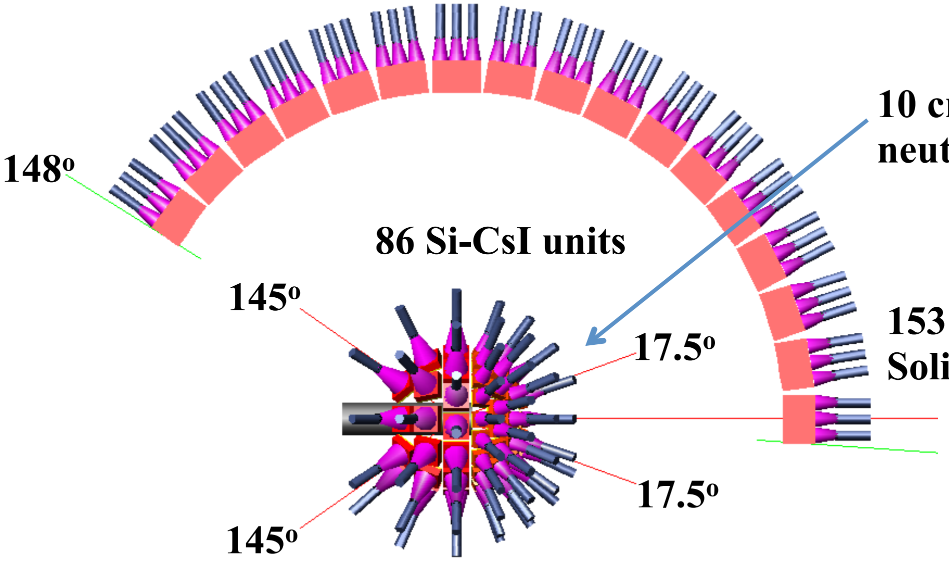








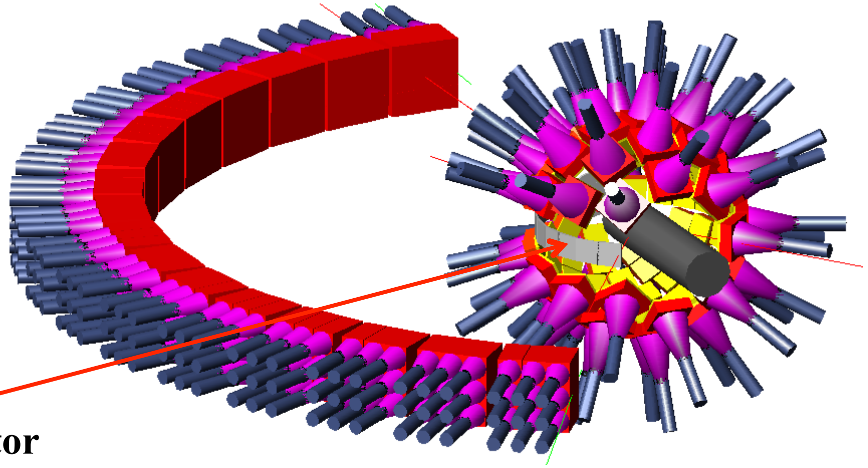
Low Energy LAMPS Experimental Setup



86 Si-CsI units

10 cm wide window to allow
neutron detection along equator

153 neutron detector units at r = 2.0 m
Solid angle = 382.5 mSr



10 cm wide window to allow
neutron detection along equator

$E_{beam} < 18.5A$ MeV

For HI Experiments:

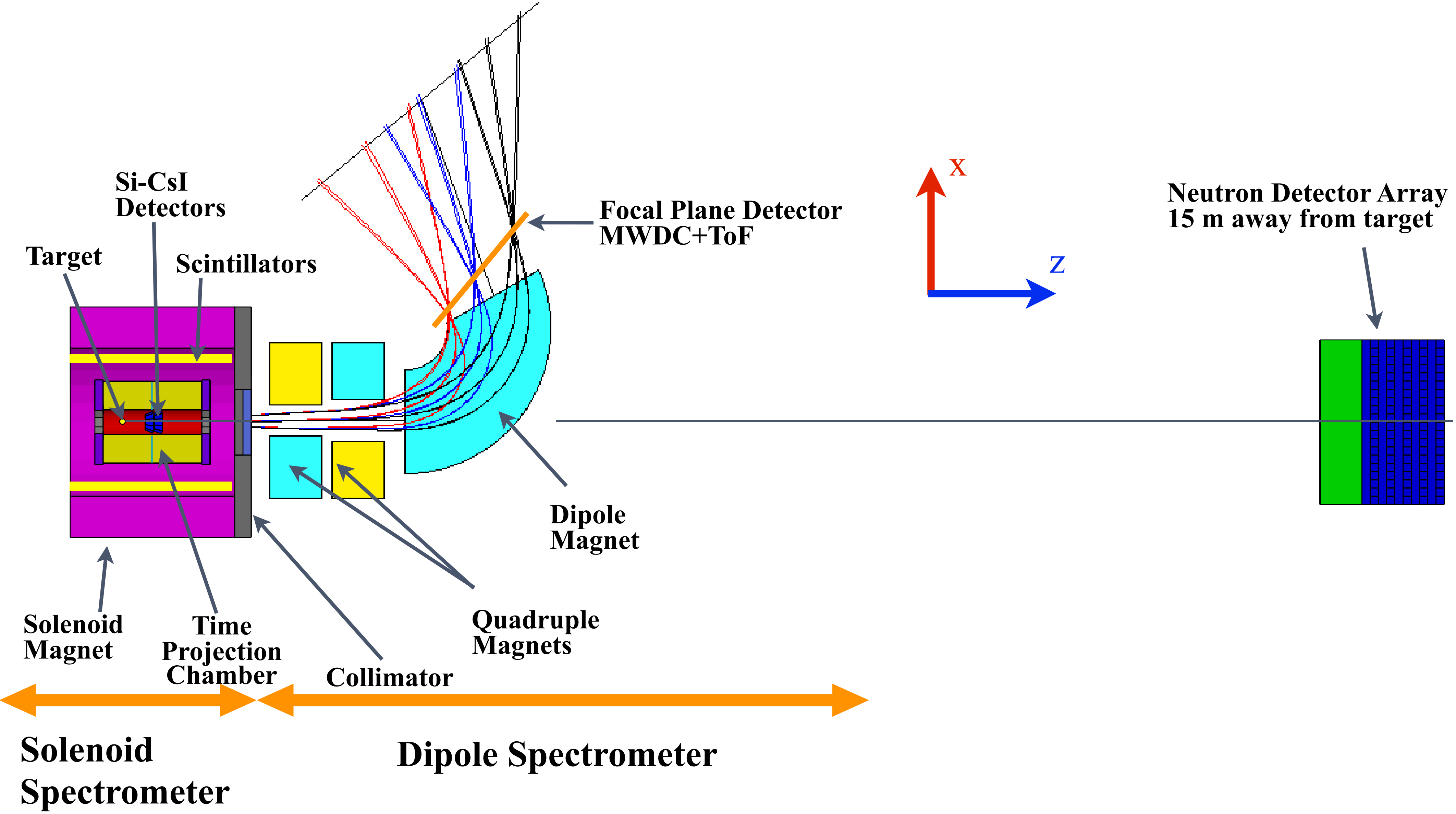
^{50,54}Ca, ^{68,70,72}Ni, ^{106,112,124,130,132}Sn RI beam
+ ^{40}Ca, ^{58}Ni, ^{112,118,124}Sn stable target

- could be possible from ISOL

Geant4 simulation is ongoing for the final tune

High Energy LAMPS Experimental Setup

$18.5A\ \text{MeV} < E_{\text{beam}} < 250A\ \text{MeV}$



Si-CsI
Detectors

Target

Scintillators

Focal Plane Detector
MWDC+ToF

Neutron Detector Array
15 m away from target

Dipole
Magnet

Solenoid
Magnet

Time
Projection
Chamber

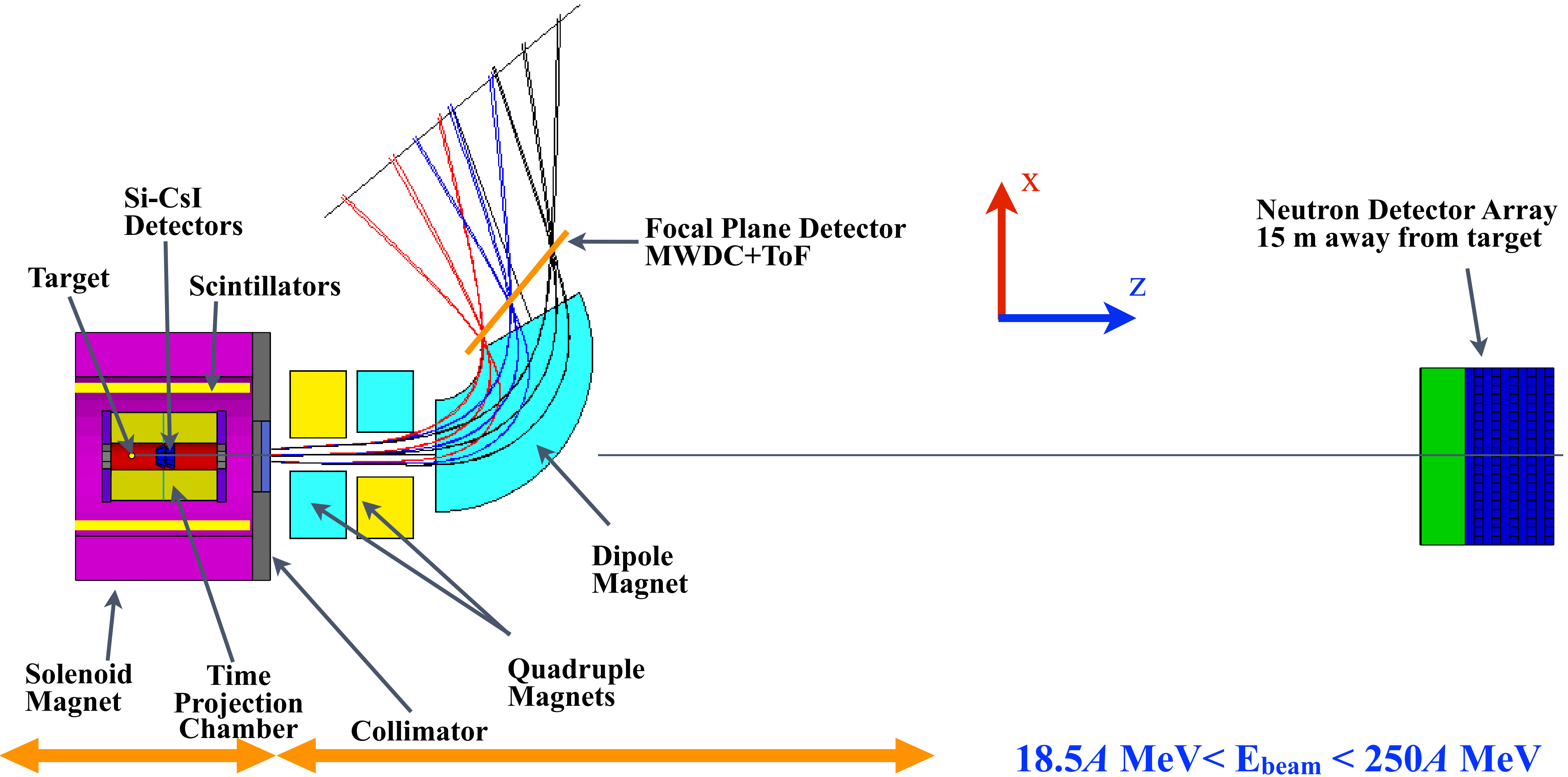
Collimator

Quadruple
Magnets

Solenoid
Spectrometer

Dipole Spectrometer

High Energy LAMPS Experimental Setup



Si-CsI Detectors

Target

Scintillators

Focal Plane Detector MWDC+ToF

X

Z

Neutron Detector Array 15 m away from target

Dipole Magnet

Solenoid Magnet

Time Projection Chamber

Collimator

Quadruple Magnets

$18.5A$ MeV$<$ E_{beam} $< 250A$ MeV

Solenoid Spectrometer

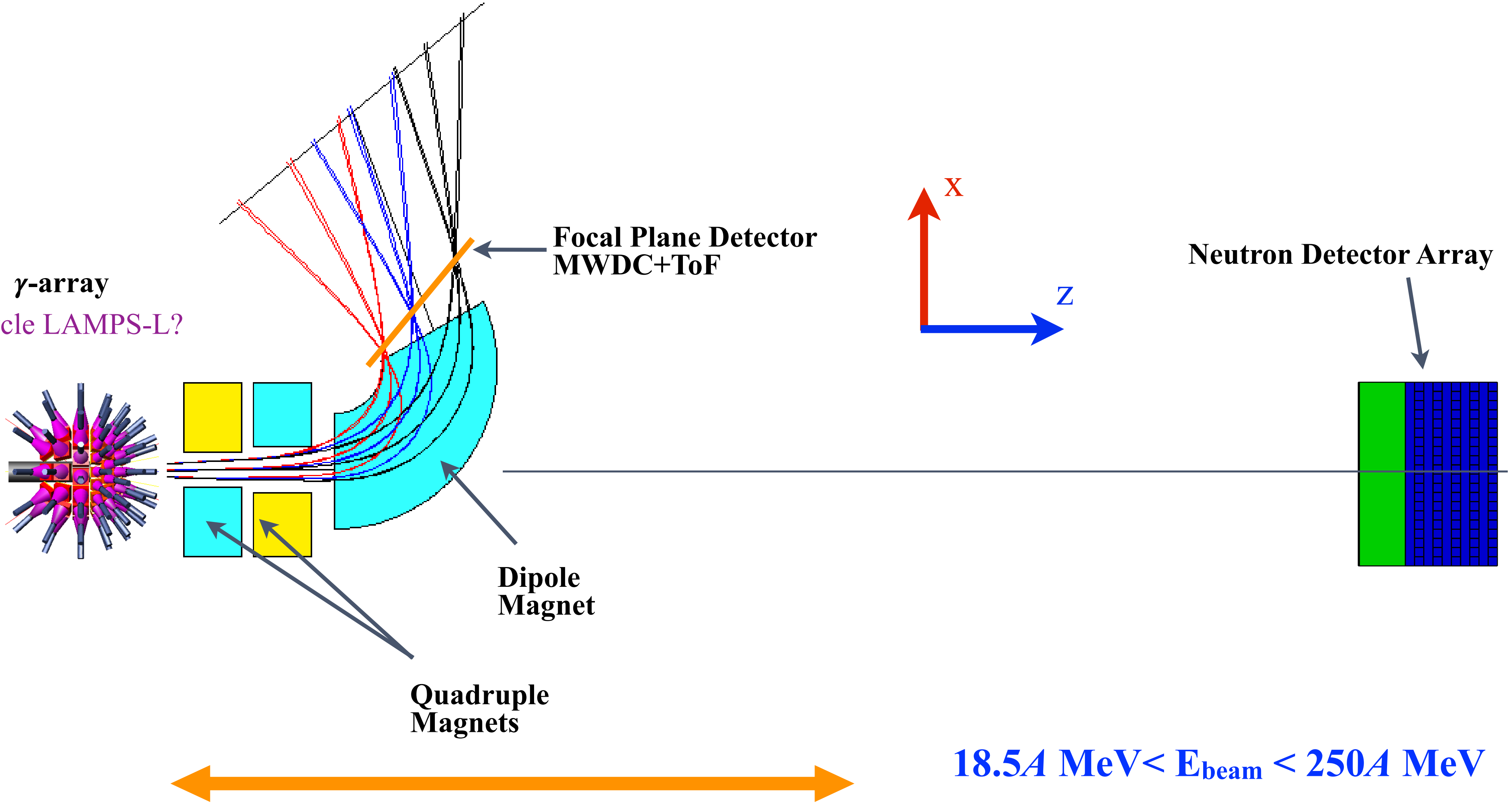
Dipole Spectrometer

For Symmetry Energy Experiments:

^{106,112,118,124,132}Sn + ^{112,118,124}Sn

^{96,100,104}Ru(^{88,92,96}Zr) + ^{96}Ru(^{96}Zr) ➔ when it is available

High Energy LAMPS Experimental Setup



γ-array

Recycle LAMPS-L?

Focal Plane Detector
MWDC+ToF

Neutron Detector Array

Dipole
Magnet

Quadruple
Magnets

$18.5A$ MeV< E_{beam} < $250A$ MeV

Dipole Spectrometer

For PDR/GDR Experiments:

^{50,54}Ca + ^{197}Au/^{208}Pb, ^{68,70,72}Ni + ^{197}Au/^{208}Pb, ^{124,130,132}Sn + ^{197}Au/^{208}Pb

One can also try the proton-rich side using (γ,p): (p,p'), (p,2p), (p,pn)

Solenoid Magnet

Requirement

Cylindrical shape

To cover TPC (r = 50 cm, l = 1.2 m)

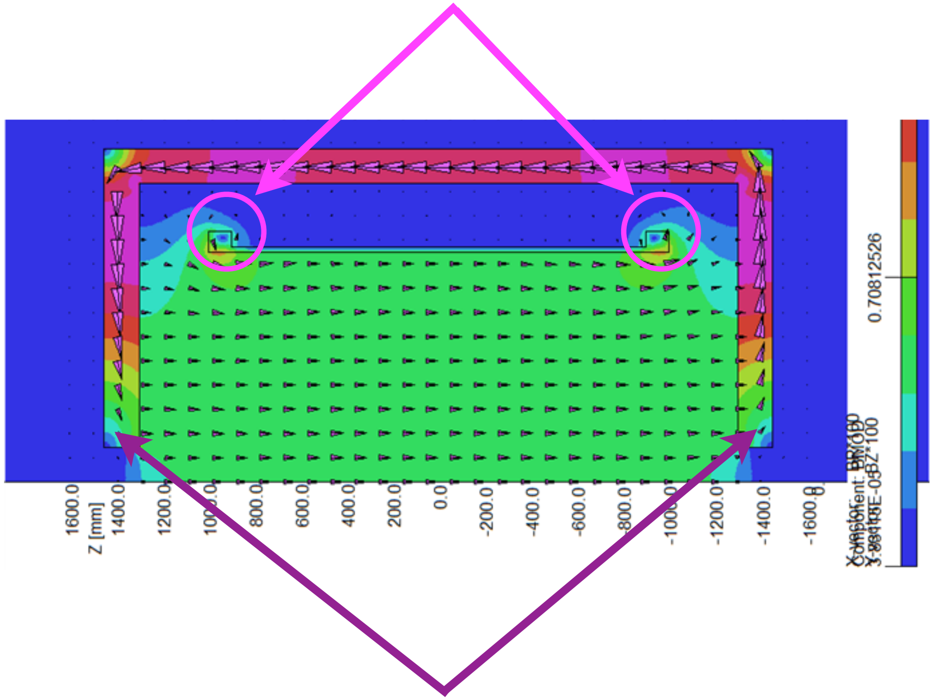
with homogeneous B-field

$B_{operation}$ = 0.5/0.6 T

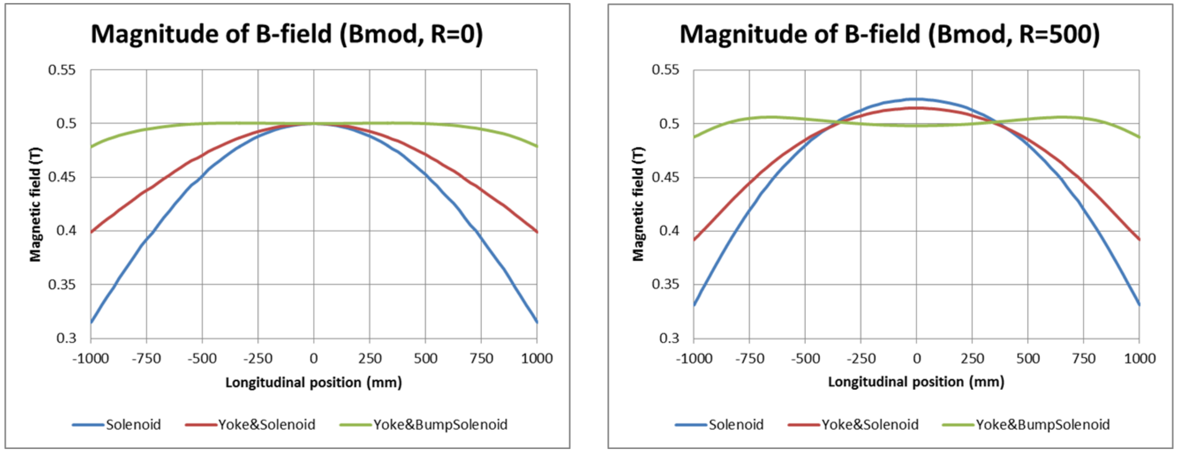
$B_{maximum}$ ~ 1 T

$\Delta B/B < 2$ %

bump coils

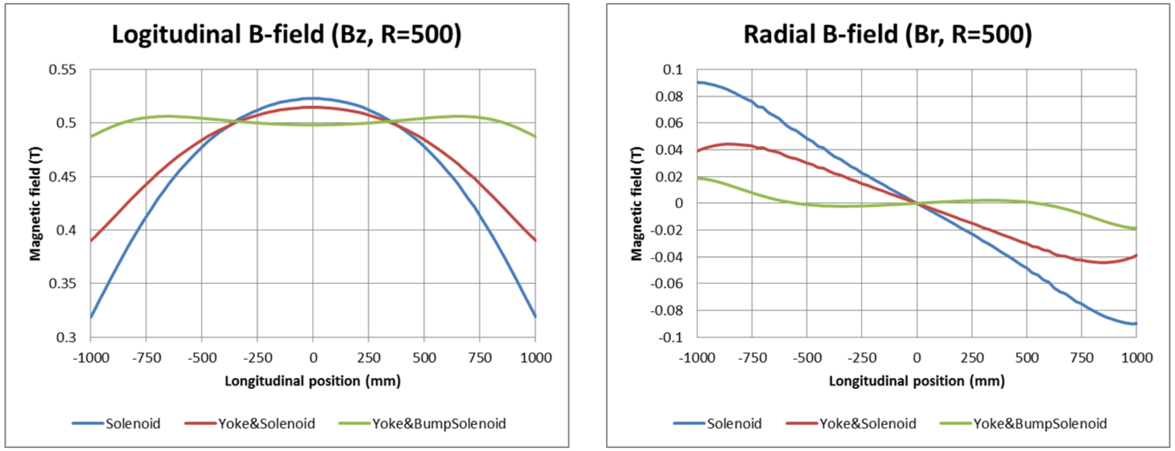


return yoke



(a) Modulated magnetic field distributions at R = 0 cm.

(b) Modulated magnetic field distributions at R = 50 cm.



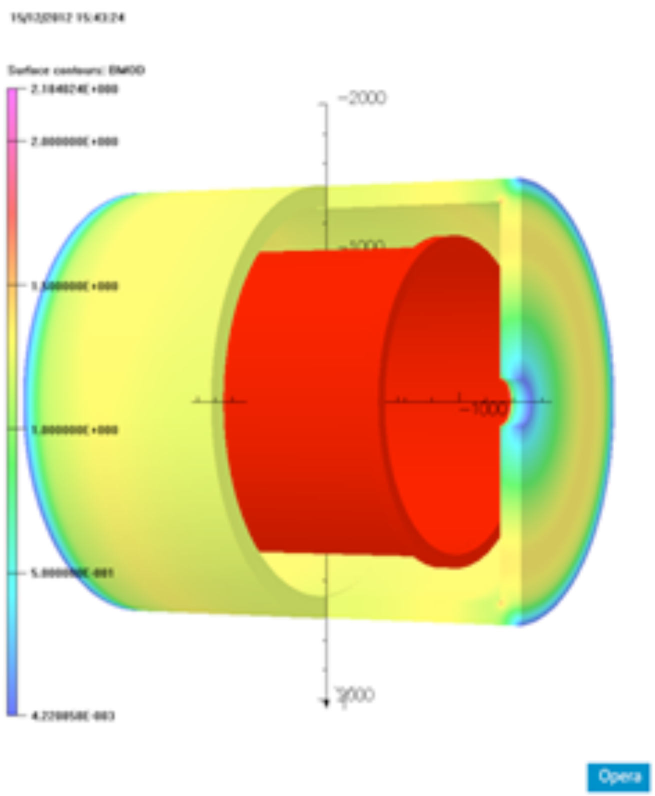
(a) Longitudinal magnetic field distributions at R = 50 cm.

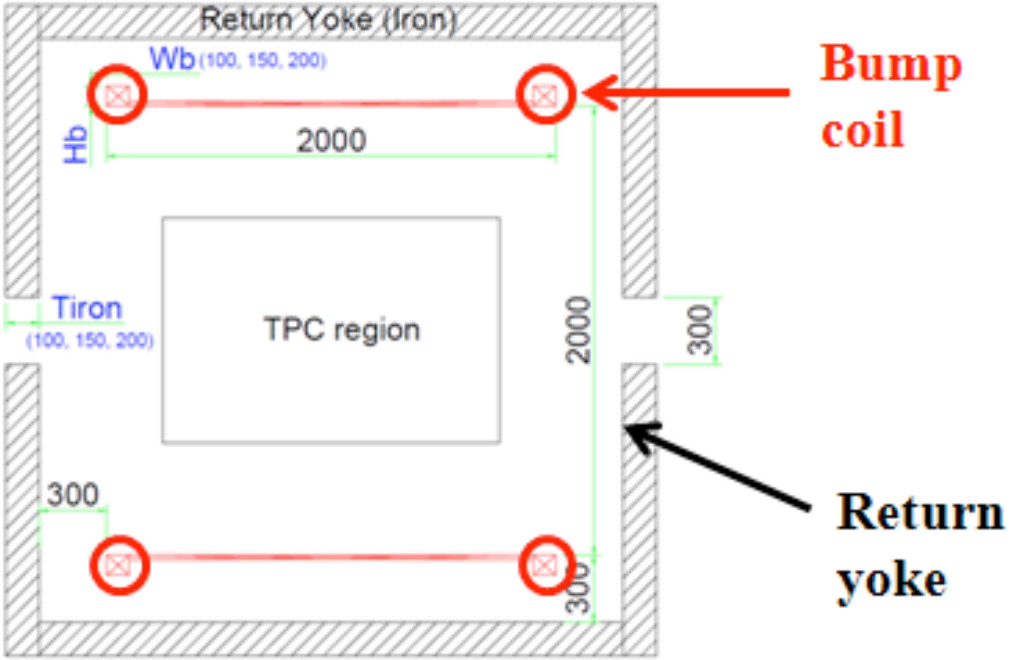
(b) Radial magnetic field distributions at R = 50 cm.

Table 3.6 Deviation of modulated 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

Solenoid Magnet Design





Bump coil

Return yoke

Cylindrical Solenoid Magnet

Total size 2.6 x 2.6 m^2

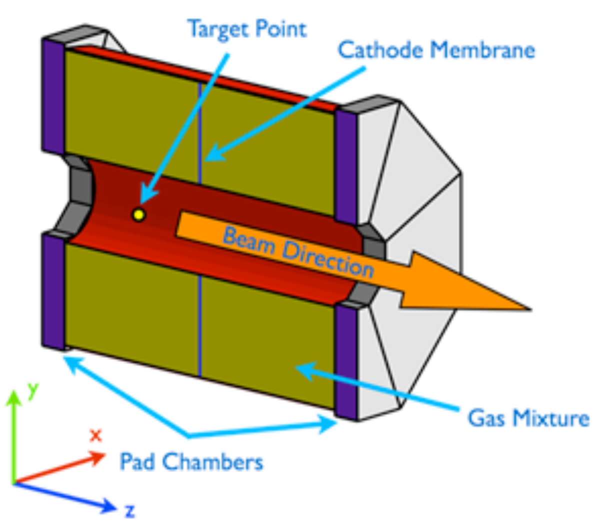
TPC size 1.0 x 1.2 m^2

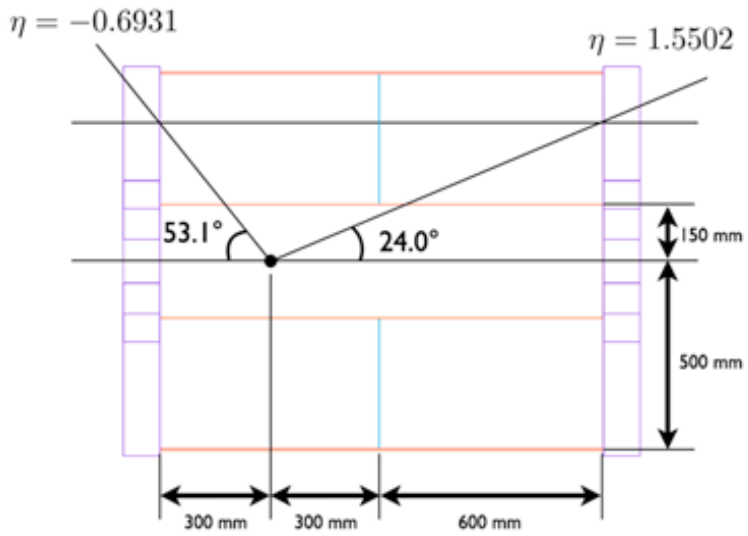
$B_{ope.}$ ~ 0.5T, $B_{max.}$ ~ 1 T

$\Delta B/B < 2\%$

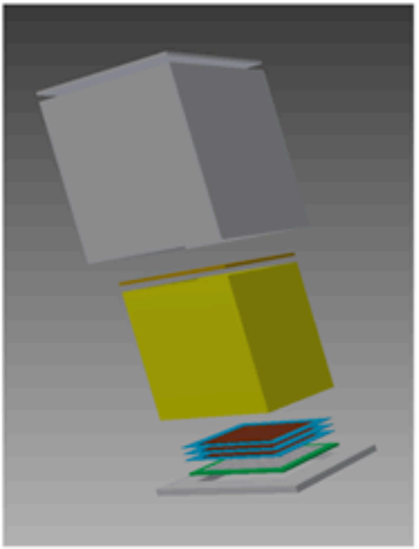
Getting suggestions and quotations from domestic companies

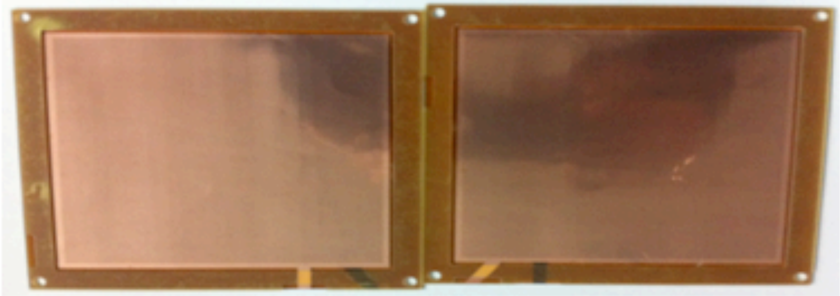
Time Projection Chamber (TPC)

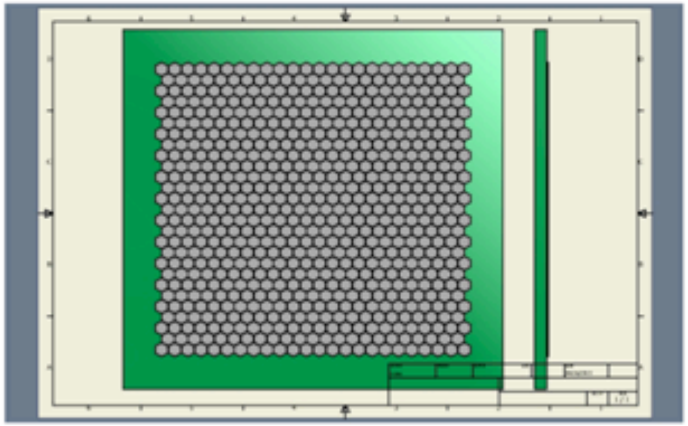




- **Time Projection Chamber (TPC)**
  - **-1 x 1.2 m^2 cylindrical shape**
  - **-GEM based & pad readout in end-caps**
    (~100 k readout channels)
  - **-Large acceptance (~ 3π Sr)**
  - **-Complete 3D charged particle tracking**
    - **➡Particle identification and momentum reconstruction**







1^{st} TPC Prototype

Active volume: 10 x 10 x 20 cm^3

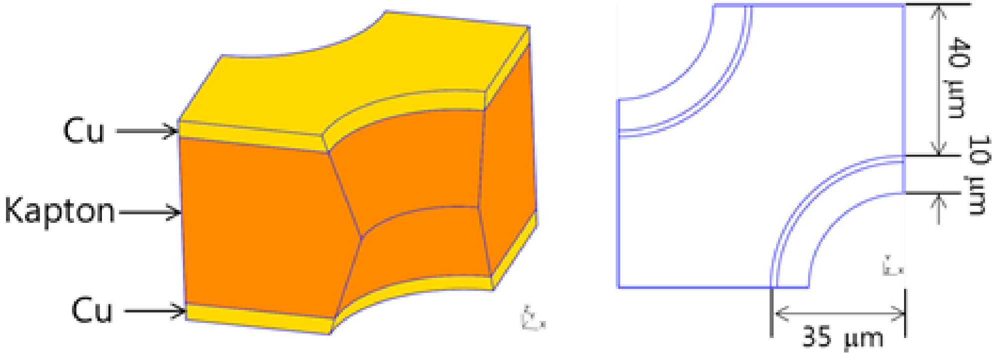
GEM based

635 readout channels

Study of test data is in progress

2^{nd} TPC Prototype design is ongoing (1/8 size of real)

TPC Simulation



Gas Electron Multiplier (GEM)

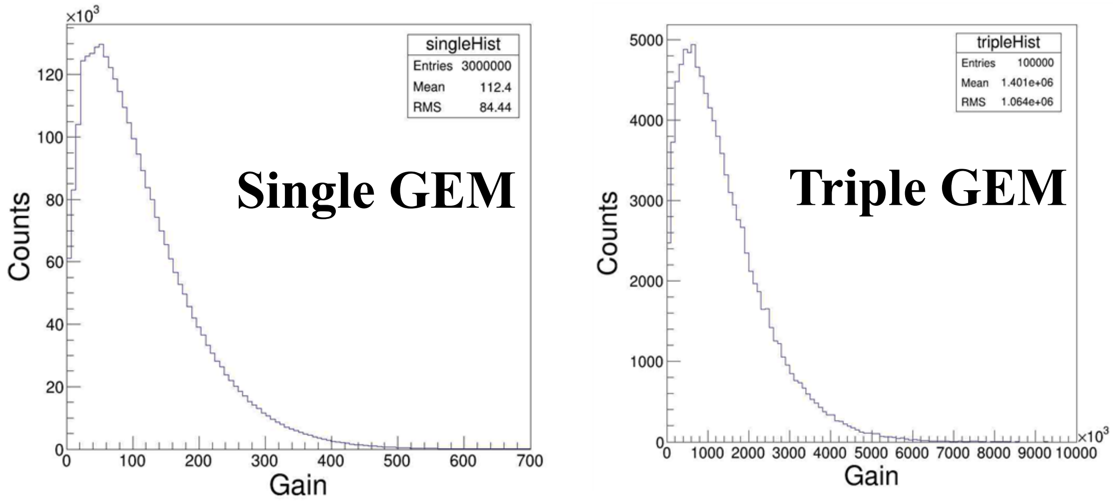


Figure 3.65 TPC gas gain simulation for single (left) and triple (right) GEM.

Single and triple GEM gain simulation with Garfield++

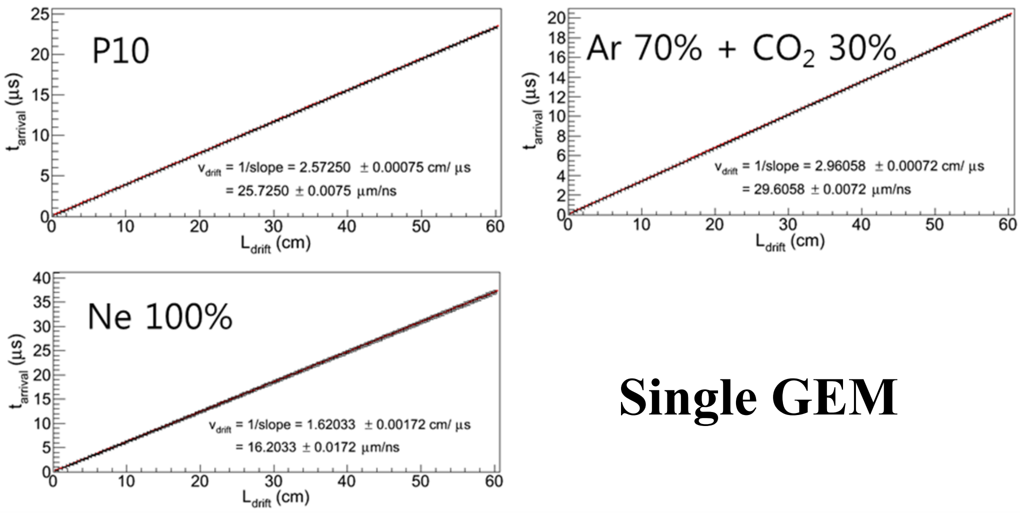


Figure 3.61 Drift time as a function of drift length with three different gas mixtures in Garfield++ simulation with single GEM.

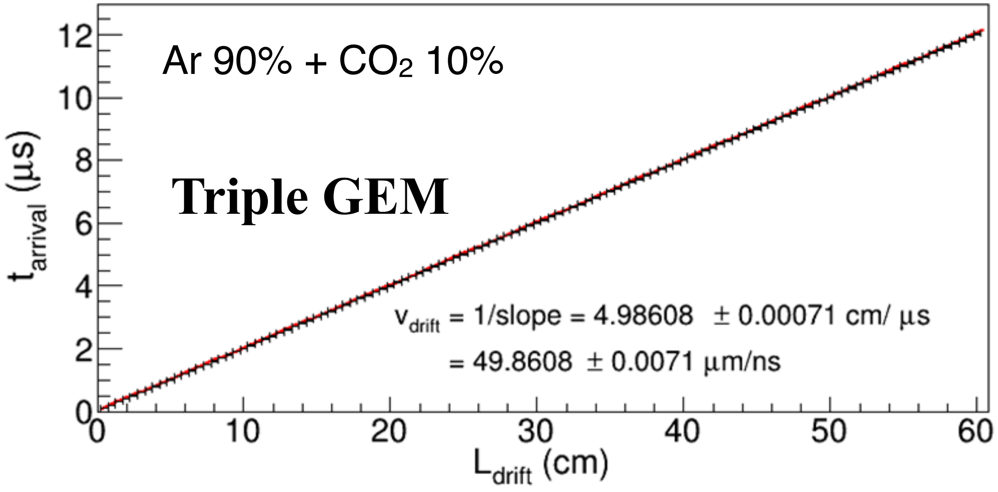


Figure 3.67 Drift time as a function of drift length with triple GEM.

TPC Simulation

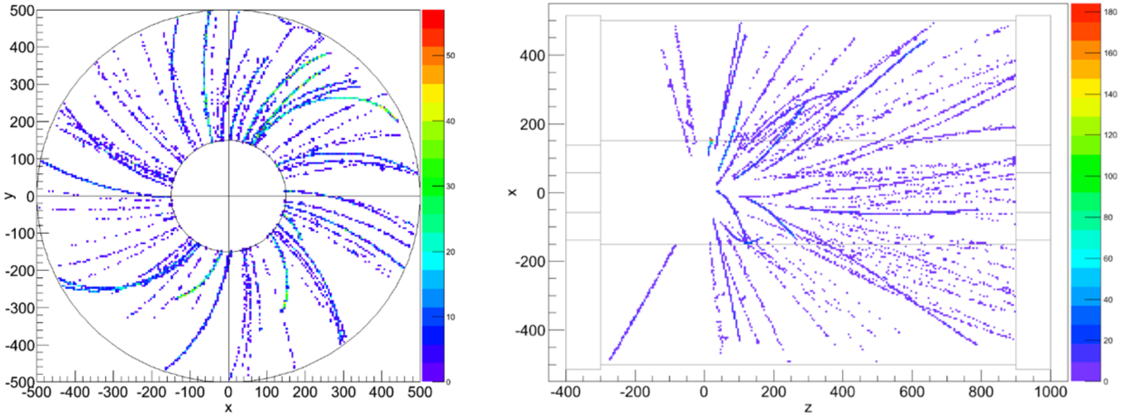


Figure 3.62 TPC hit information before digitization with P10 gas and single GEM.

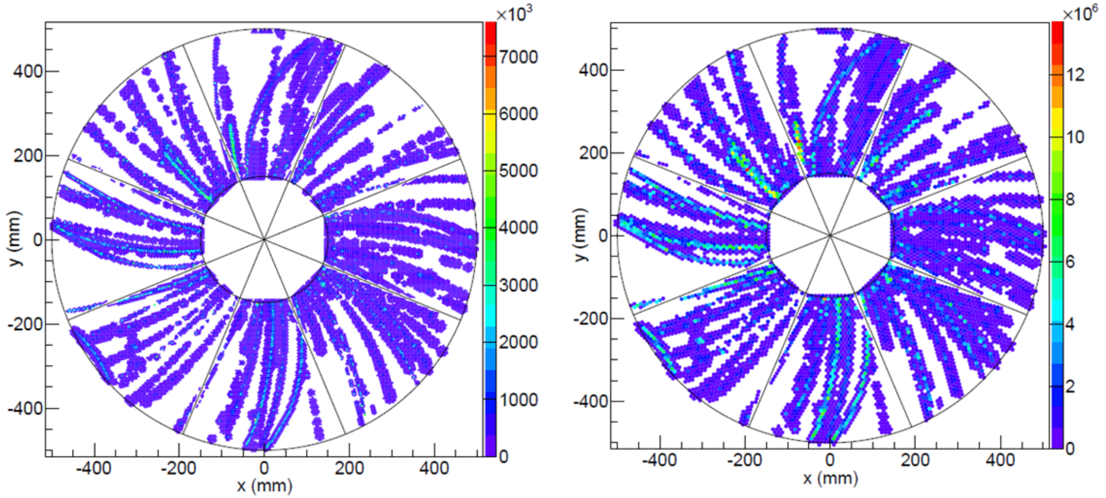


Figure 3.68 TPC hit information after digitization with Ar 90% + CO_2 10% gas and triple GEM. Left plot is with 2.5 mm hexagonal readout pads and right plot is with 5 mm hexagonal readout pads, respectively.

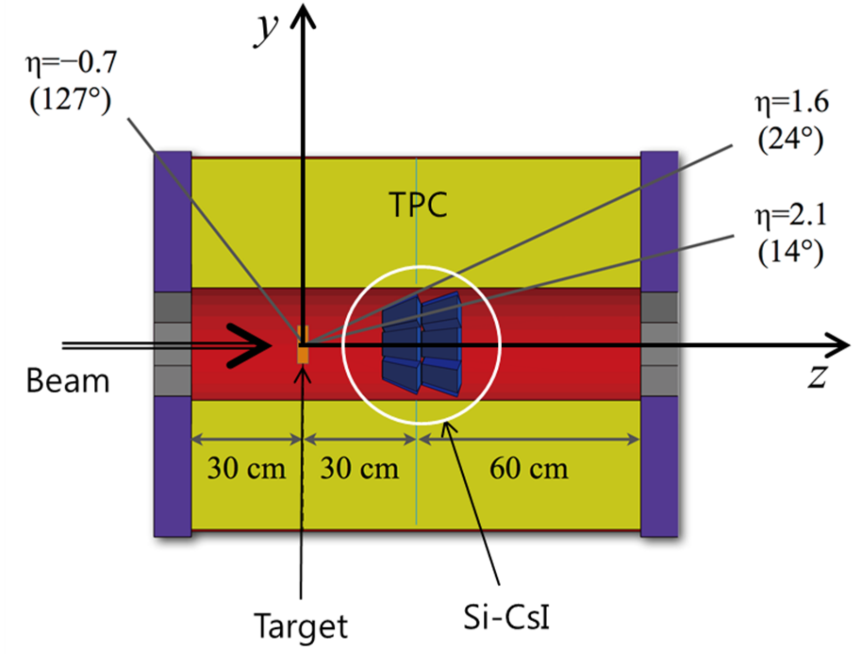
Au + Au @ 250*A* MeV

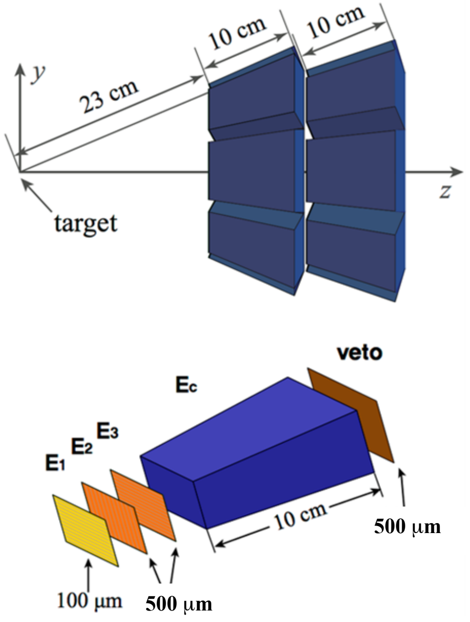
Isospin Quantum Molecular Dynamics Events

2.5 mm pad ~ 300 K readout channels

5 mm pad ~ 100 K readout channels

Si-CsI Detector



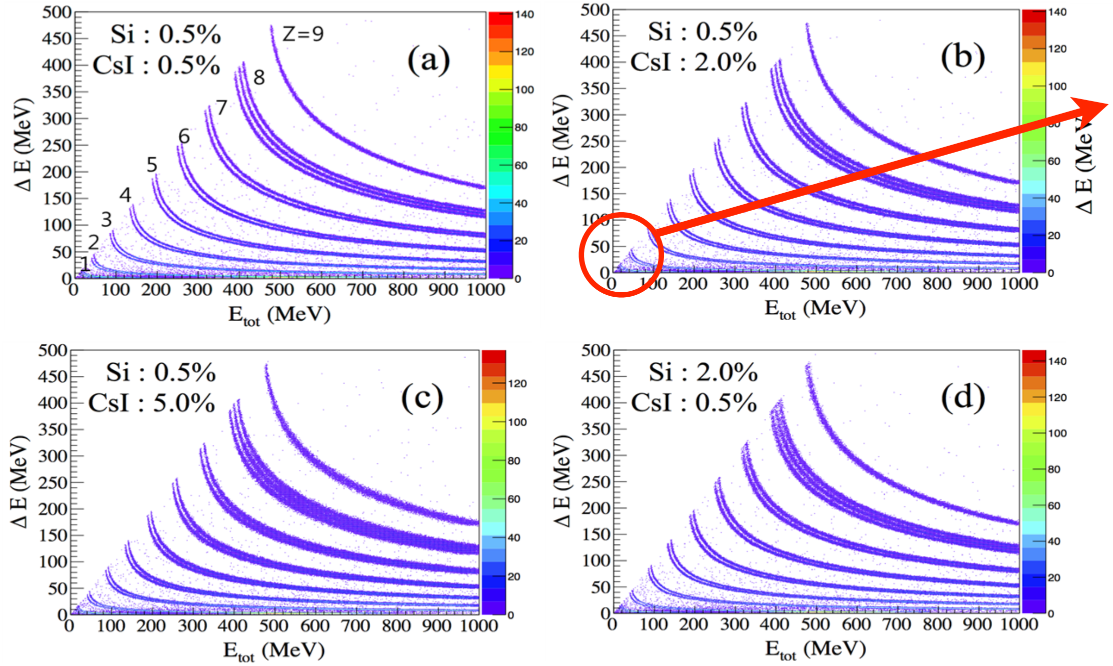


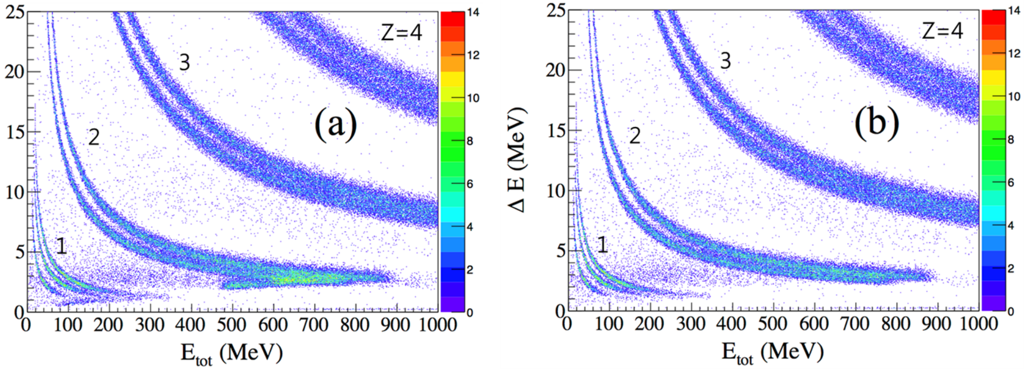
		size (mm²)
inner ring	front	66.80 × 26.20
	rear	86.92 × 37.84
outer ring	front	62.09 × 20.08
	rear	89.17 × 28.84

Si-CsI module

Si: 2 x 8 pad readouts

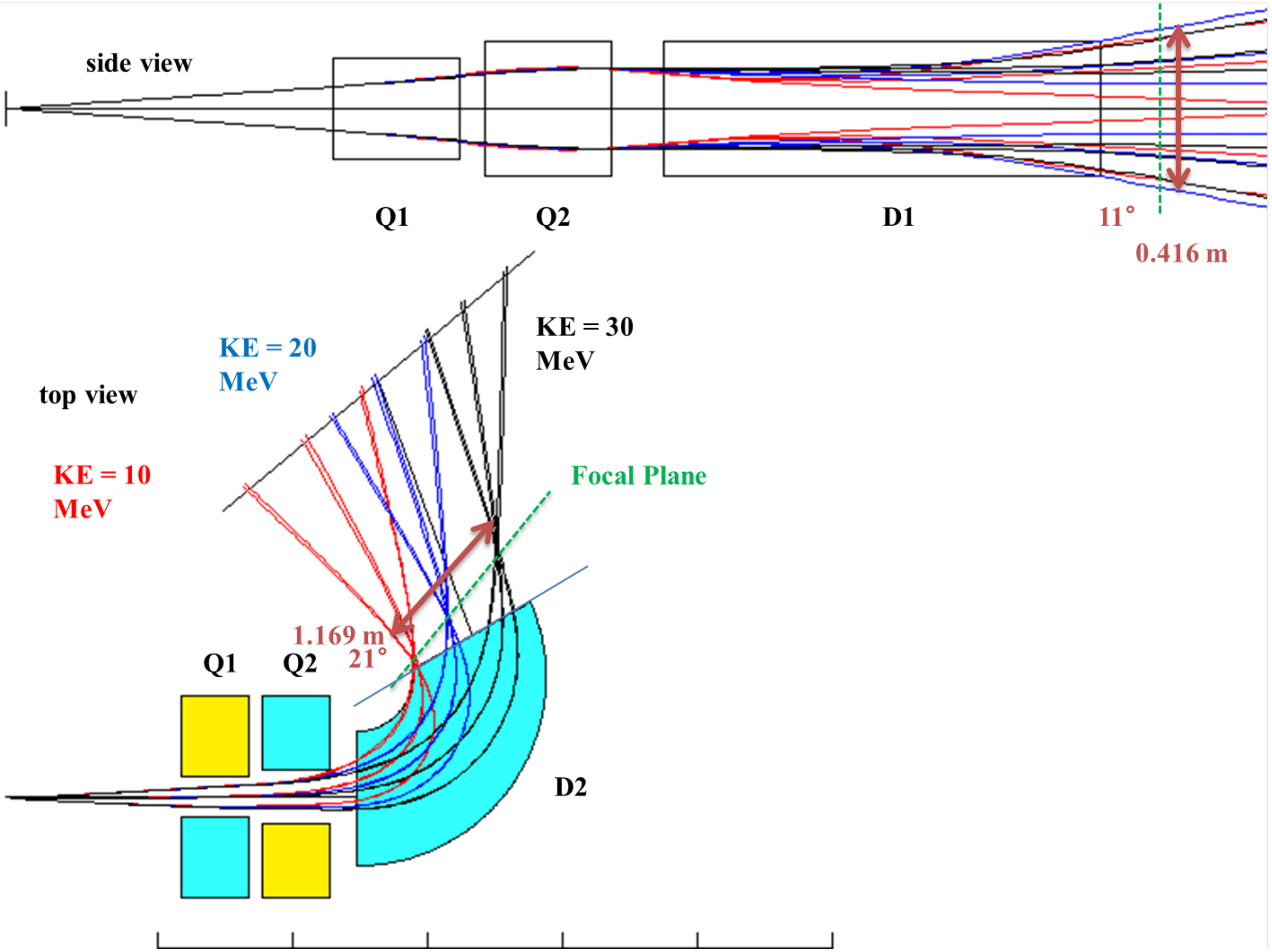
CsI: 4 x 4 APD readouts





veto Si detector can clean up unexpected correlation

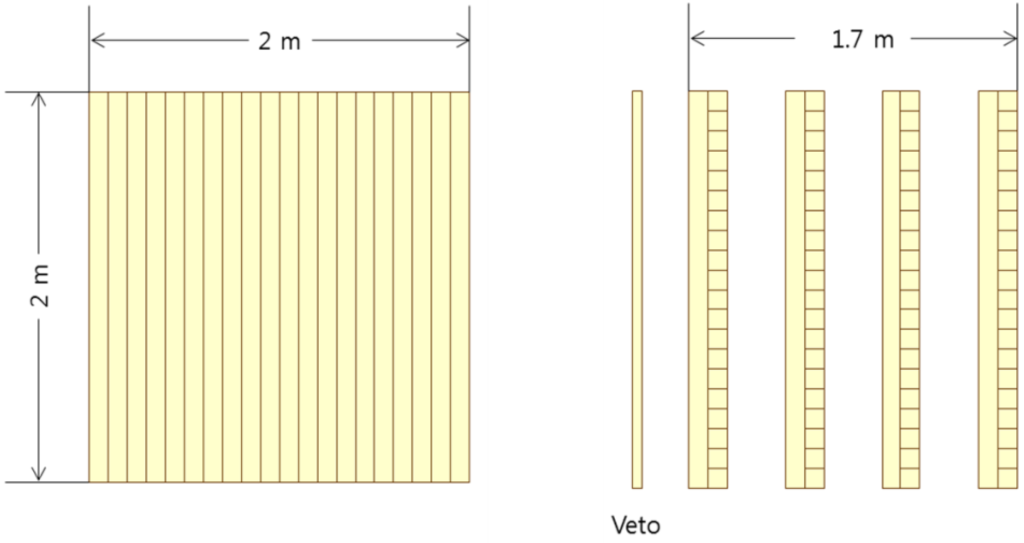
Dipole Spectrometer



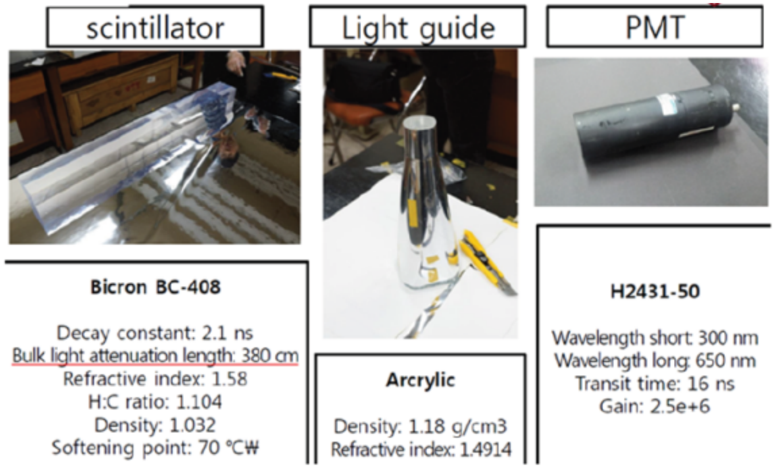
Magnet			Strength of Magnetic Field
Q1	length = 50 cm	aperture = 0.3 m	0.5 T/m
Q2	length = 50 cm	aperture = 0.4 m	1.1 T/m
D1	pole gap = 40 cm	radius = 0.9 m	0.82 T

- **Multi particle tracking capability of isotopes for p, He, and heavier fragments**
  - **Focal Plane detector for low momentum particles**
- **Plastic scintillator ToF**
  - **$\sigma_t < 100$ ps (essential for $\Delta p/p < 10^{-3}$ @ $\beta = 0.5$)**

Forward Neutron Detector Array



Charged particle veto: 5 x 5 x 200 cm^3
20 BC-408 10 x 10 x 200 cm^3/layer
4 – 5 coupled layers



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 °C₩

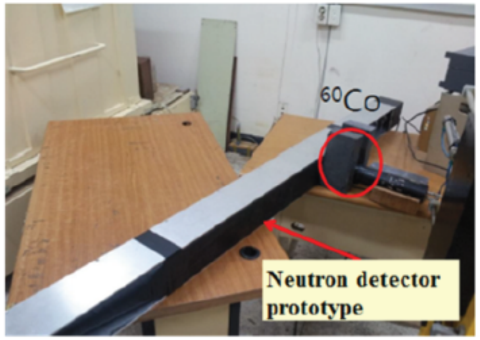
Arcrylic

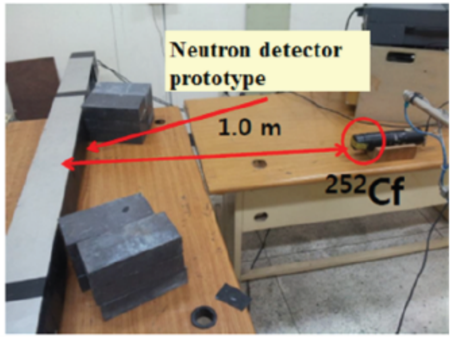
Density: 1.18 g/cm3
Refractive index: 1.4914

H2431-50

Wavelength short: 300 nm
Wavelength long: 650 nm
Transit time: 16 ns
Gain: 2.5e+6

½ length prototype produced and tested with source
Beam test is planed
Real size prototype will be produced





Forward Neutron Detector Test

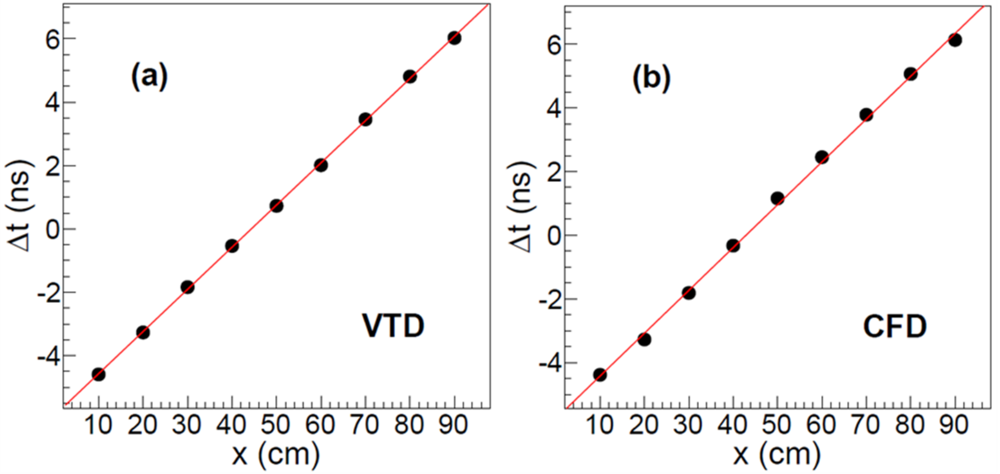


Figure 3.92 Time difference $\Delta t = t_L - tR$ as a function of photon incident position from neutron detector prototype with ^{60}Co source. Left plot is with VTD and right plot is with CFD

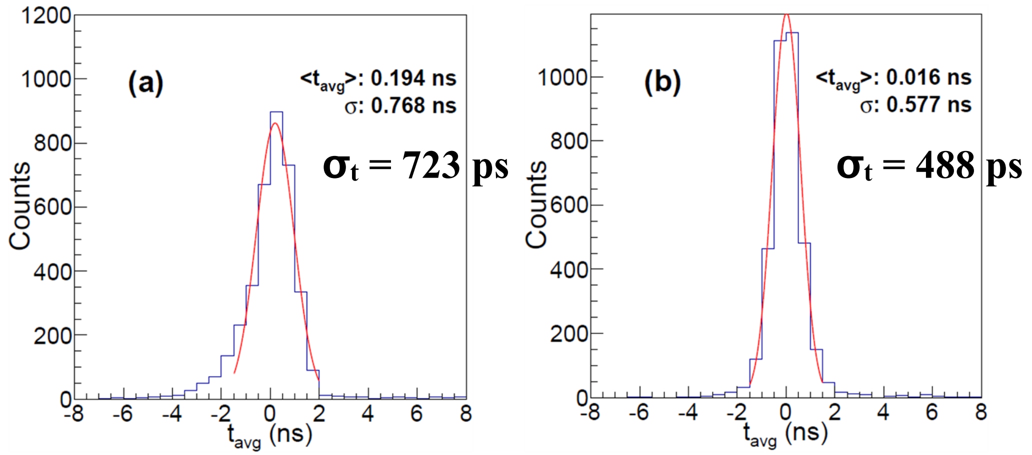


Figure 3.94 Time distribution of neutron detector prototype with ^{60}Co source. (a) is from VTD data and (b) is from CFD data. Solid line is indicated by Gaussian fitting.

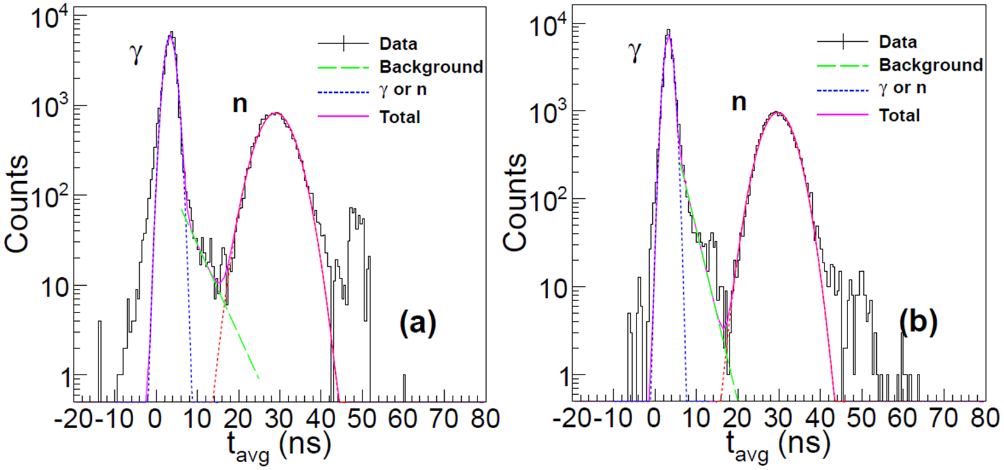


Figure 3.95 Time distribution of neutron detector prototype with ^{252}Cf source. (a) is from VTD data and (b) is from CFD data.

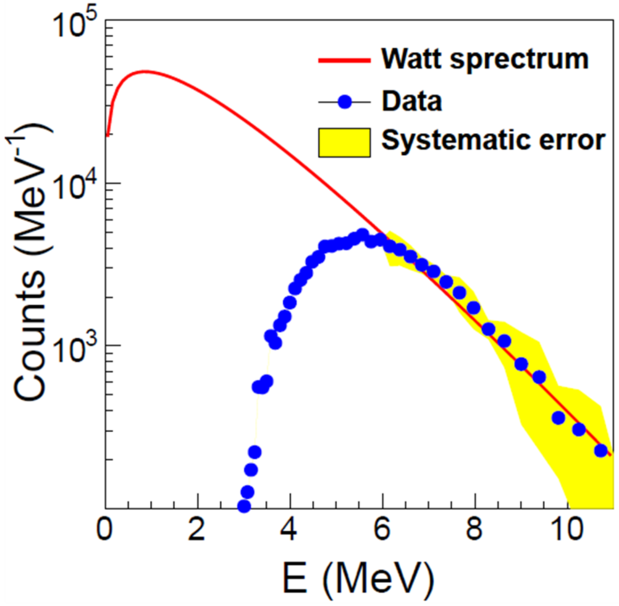
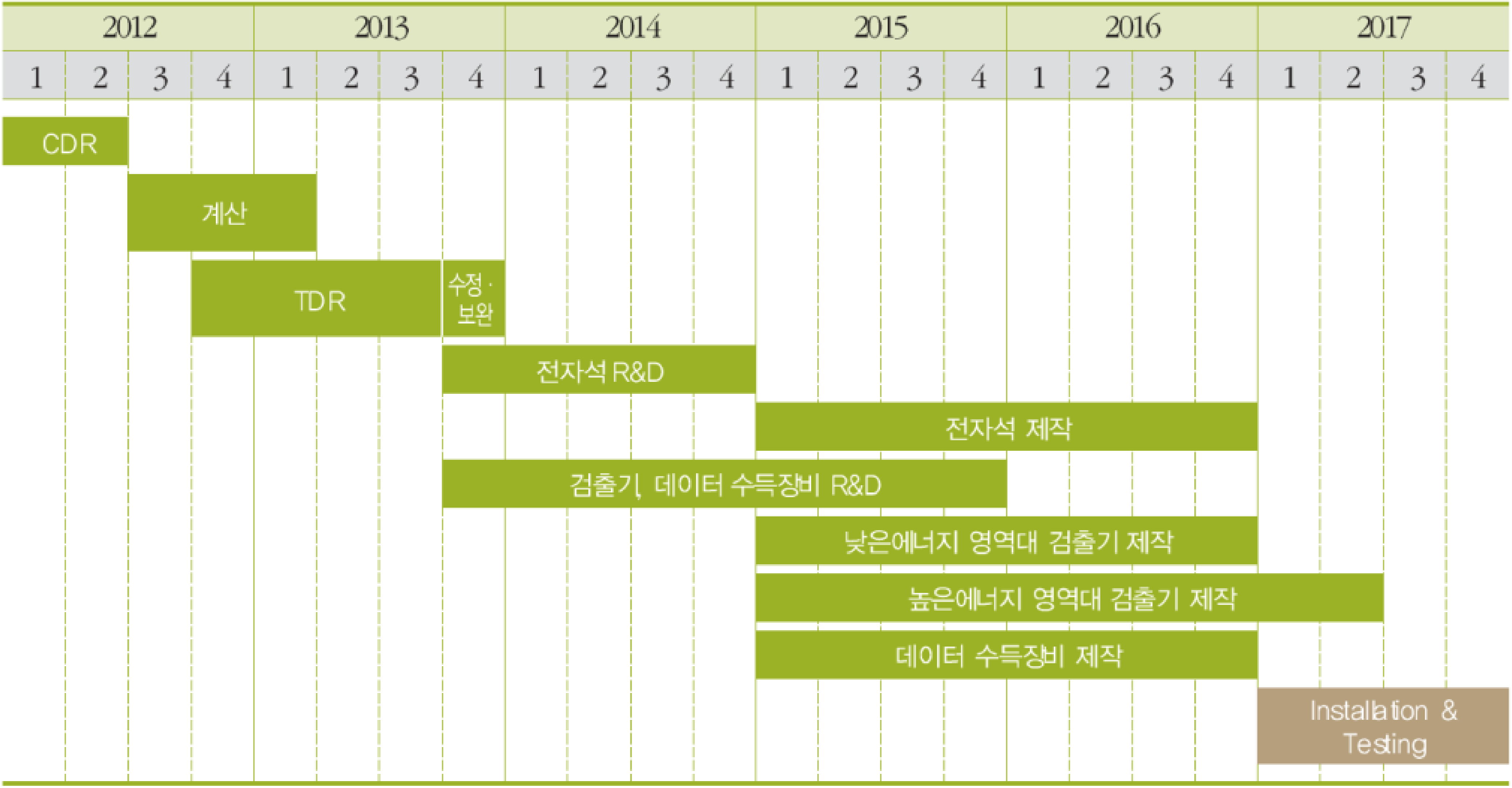


Figure 3.96 Neutron energy spectrum of neutron detector prototype. Solid line is empirical Watt spectrum.

LAMPS Schedule

II.3.2.2.2 Large Acceptance Spectrometer (WBS RISP.3.3.2)

추진 일정



	2012				2013				2014				2015				2016				2017			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
CDR	●	●																						
계산			●	●	●	●																		
TDR				●	●	●	●																	
수정·보완								●																
전자석 R&D								●	●	●	●	●												
전자석 제작													●	●	●	●	●	●	●	●				
검출기, 데이터 수득장비 R&D								●	●	●	●	●	●	●	●	●								
낮은에너지 영역대 검출기 제작													●	●	●	●	●	●	●	●				
높은에너지 영역대 검출기 제작													●	●	●	●	●	●	●	●	●	●		
데이터 수득장비 제작													●	●	●	●	●	●	●	●				
Installation & Testing																					●	●	●	●

LAMPS Collaboration

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and Chong Cheoul Yun

Rare Isotope Science Project/Institute for Basic Science

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Jung Woo Lee, Songkyo Lee, and Bernard Mulilo

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EunJu Kim and HyunHo Kim

Chonbuk National University

JungKeun Ahn and HyoSnag Lee

Pusan National University

Kyungpook National University for Si detector

Summary

- RAON is RI beam accelerator in Korea
  - RAON will provide high purity, high intensity various RI beams (e.g. 10^8 pps ^{132}Sn at 250 Mev/u)
- RISP is on going for establishment of RAON accelerator and experimental facilities

- Large Acceptance Multi-Purpose Spectrometer (LAMPS) at RAON
  - Study of nuclear symmetry energy with RI and stable beam
  - Two detector setup for low and high energy
    - ▸Low energy: gamma detector + Si-CsI detector + neutron detector
    - ▸High energy: TPC + Si-CsI detector + neutron detector + MWDC + ToF + Solenoid magnet + Dipole magnet
    - ✓To cover entire energy range of RAON with complete event reconstruction within large acceptance
  - Detail detector simulation and prototyping are in progress
  - Getting more collaborators from both domestic and oversea
    - ▸Forming International collaboration