Detector R&D for Nuclear Physics at RAON

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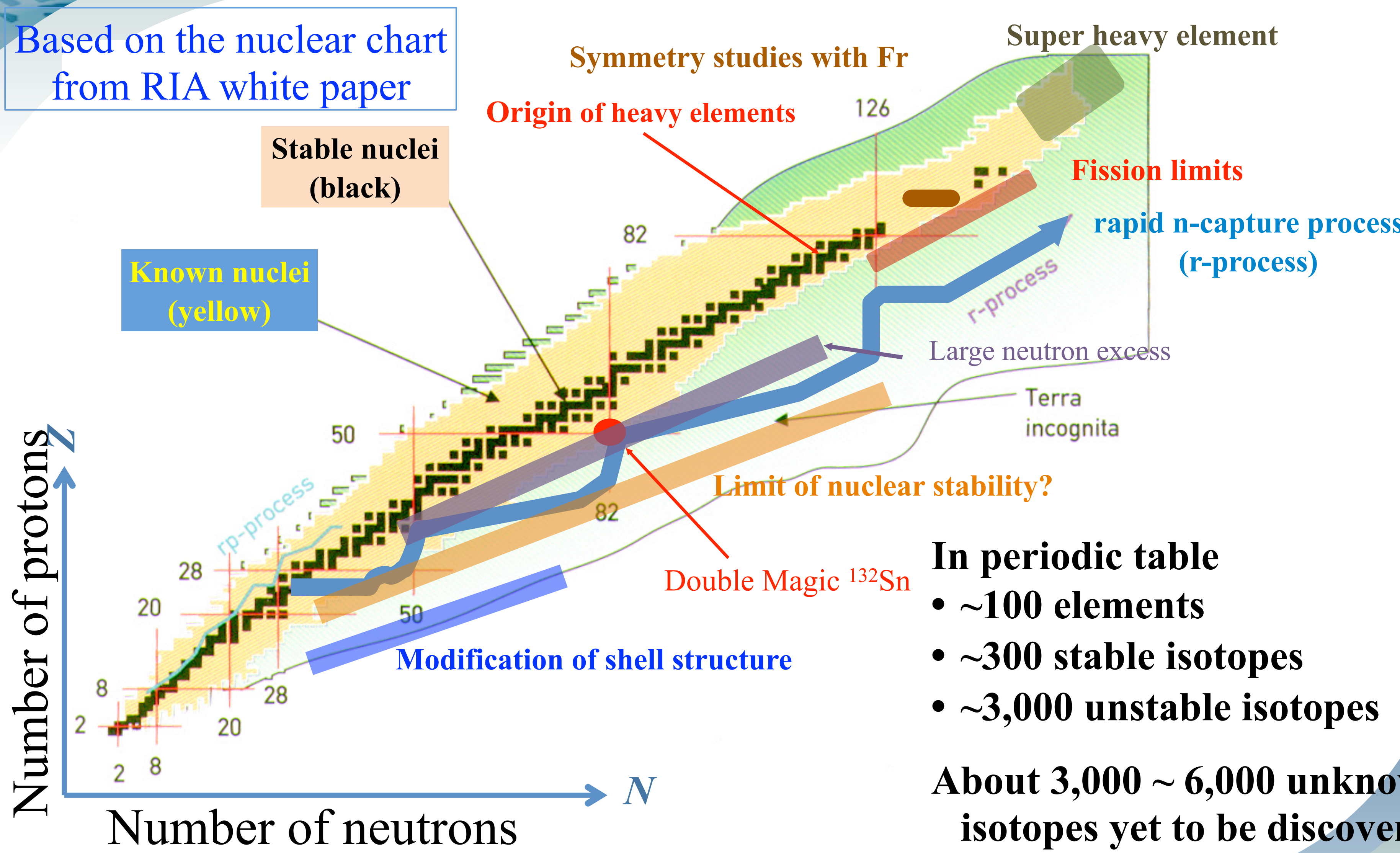
RIKEN-KOREA PHENIX Workshop
SKKU
November 05, 2013

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
  - -1st Technical Advisory Committee (May 2012)
  - -Baseline Design Summary (Jun. 2012)
  - -1st International Advisory Committee (Jul. 2012)
  - -2nd Technical Advisory Committee (May 2013)
  - -2nd International Advisory Committee (Jul. 2013)
  - -1st Program Advisory Committee (Oct. 2013)
  - -Technical Design Report (Present: Dec. 2013)

Why Rare Isotope Beam?



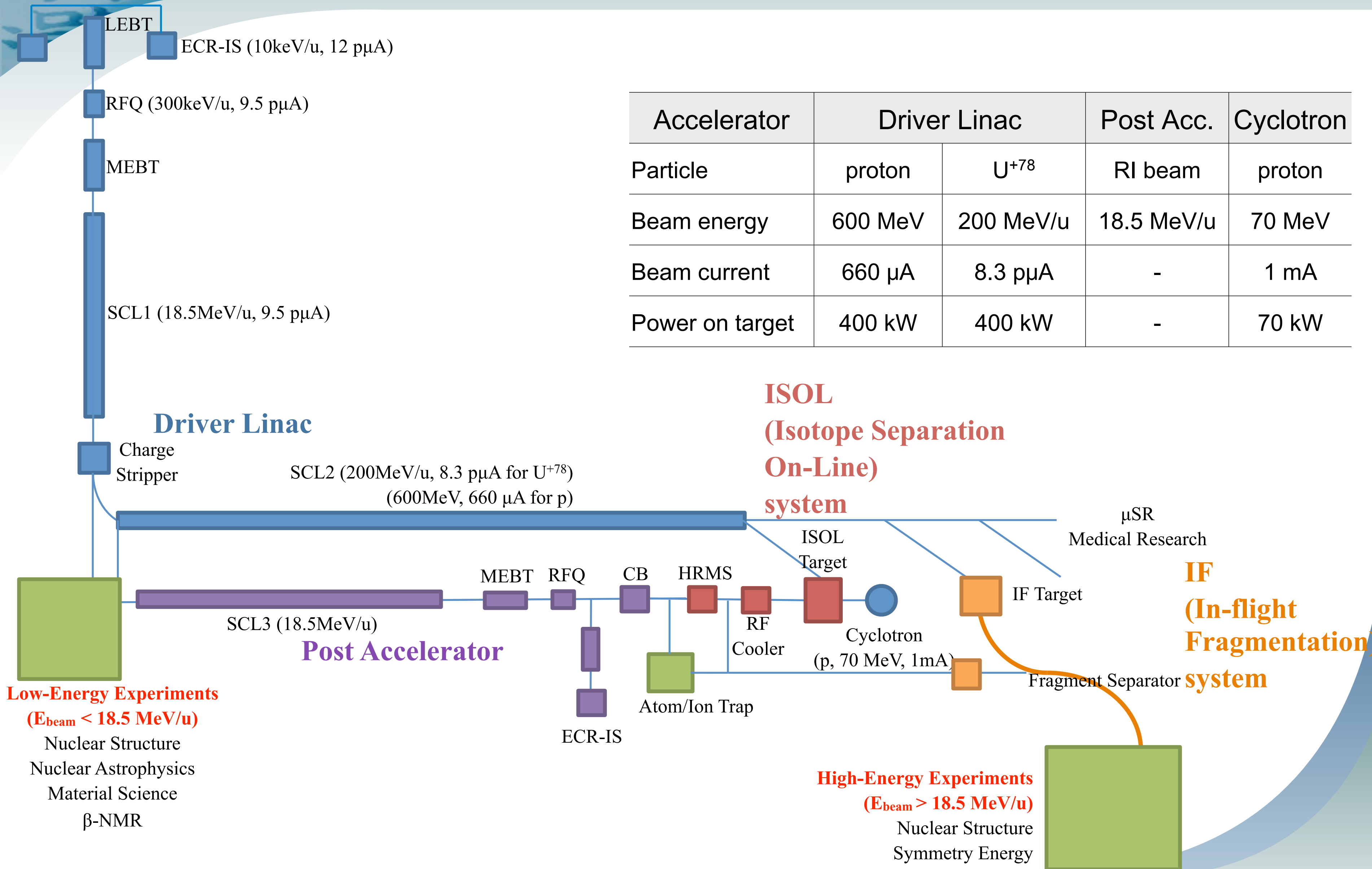
In periodic table

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

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

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

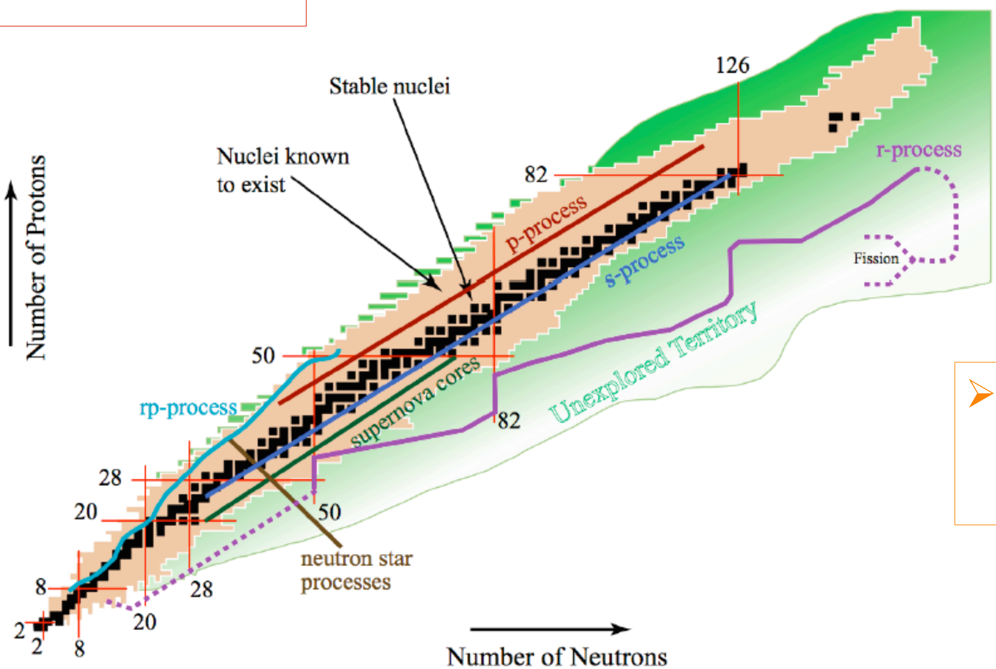


Science and Applications with Rare Isotopes

RAON

- **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



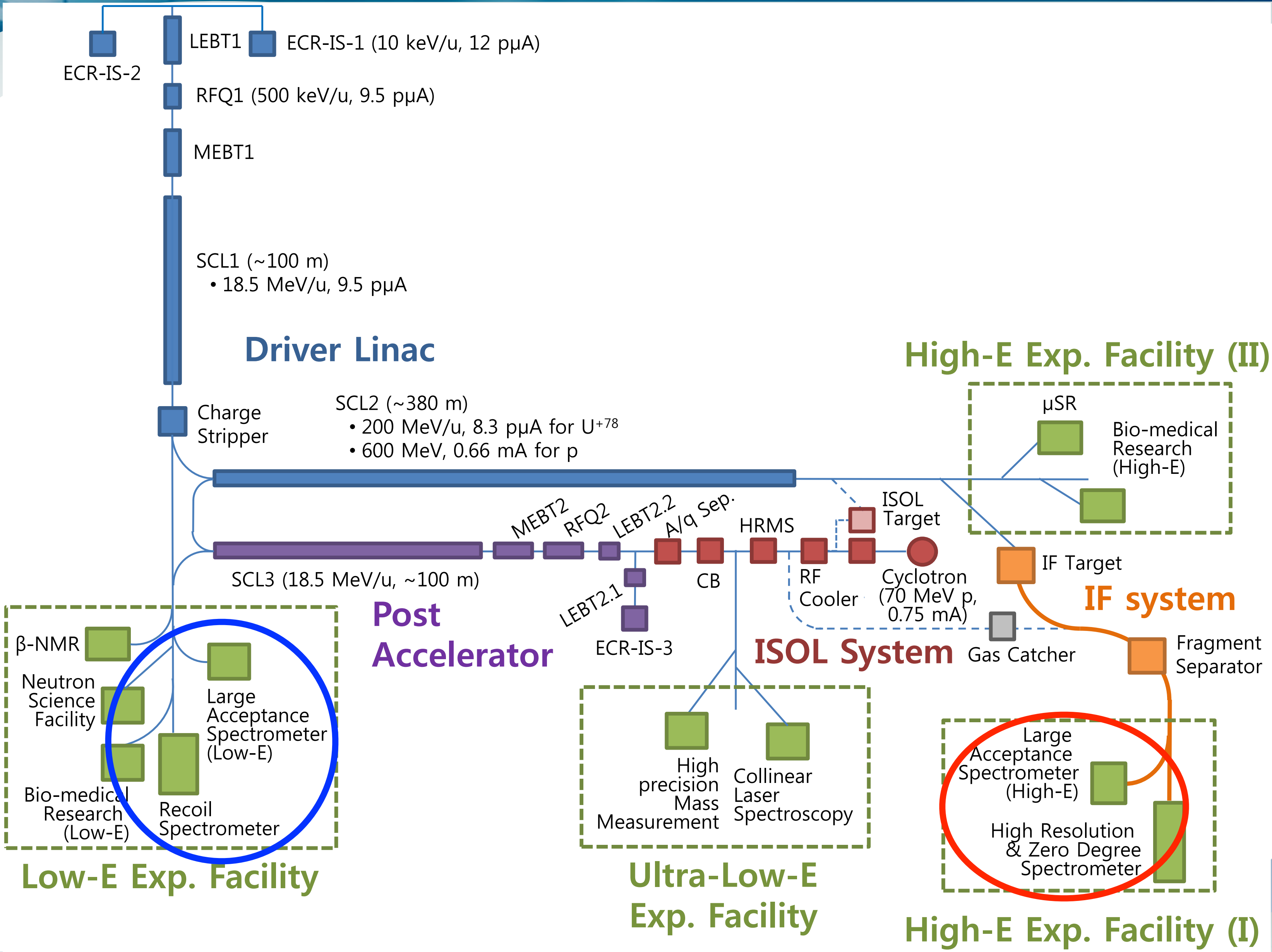
- **Atomic/Particle physics**
  - Atomic trap
  - Fundamental symmetries

- **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

Experimental Facilities



KOrea Broad Acceptance Recoil Spectrometer and Apparatus

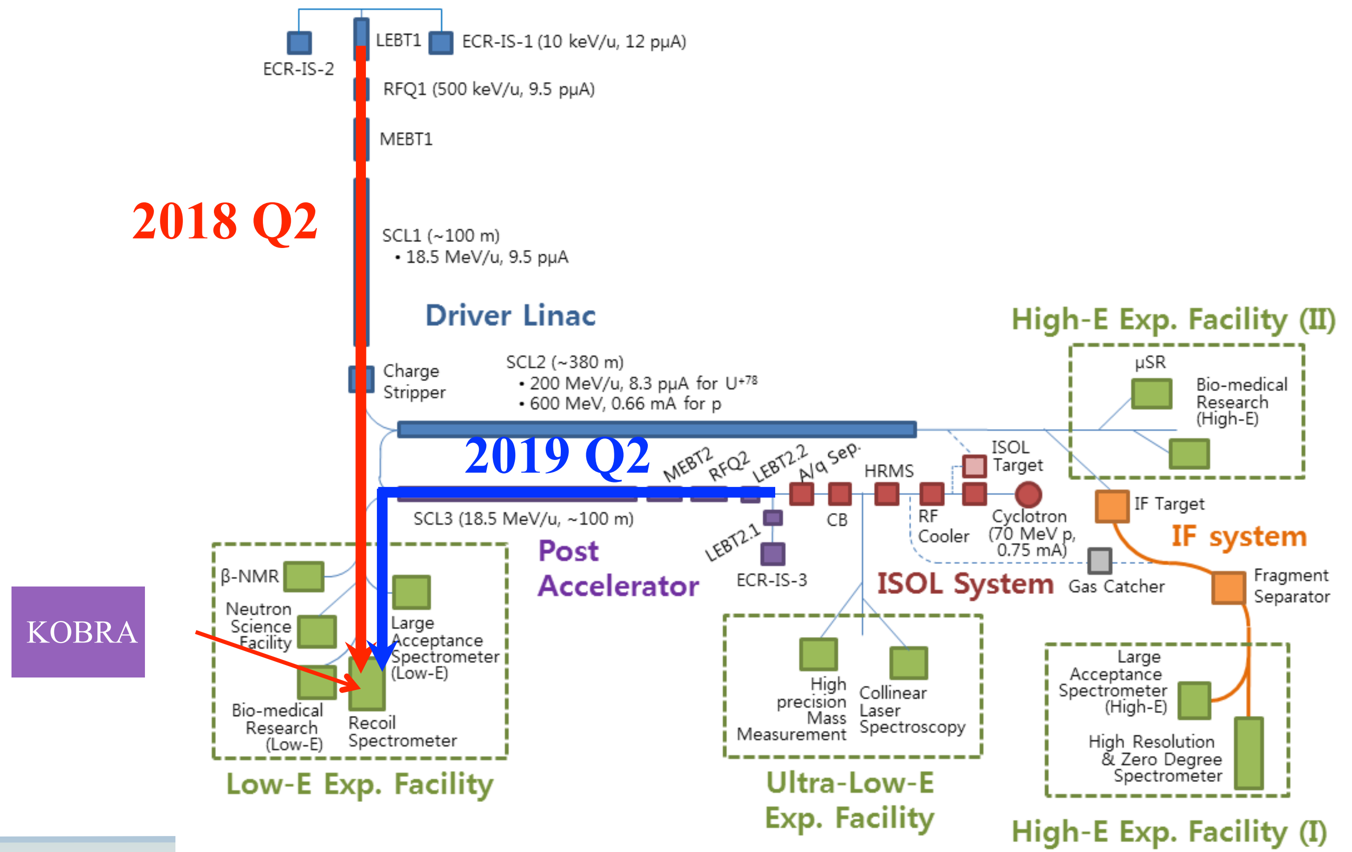
RAON

Main facility for nuclear structure and nuclear astrophysics studies with low-energy stable and rare isotope beams

KOBRA
High performance spectrometer

@

RAON
High quality & Low Energy stable and radioactive ion beams



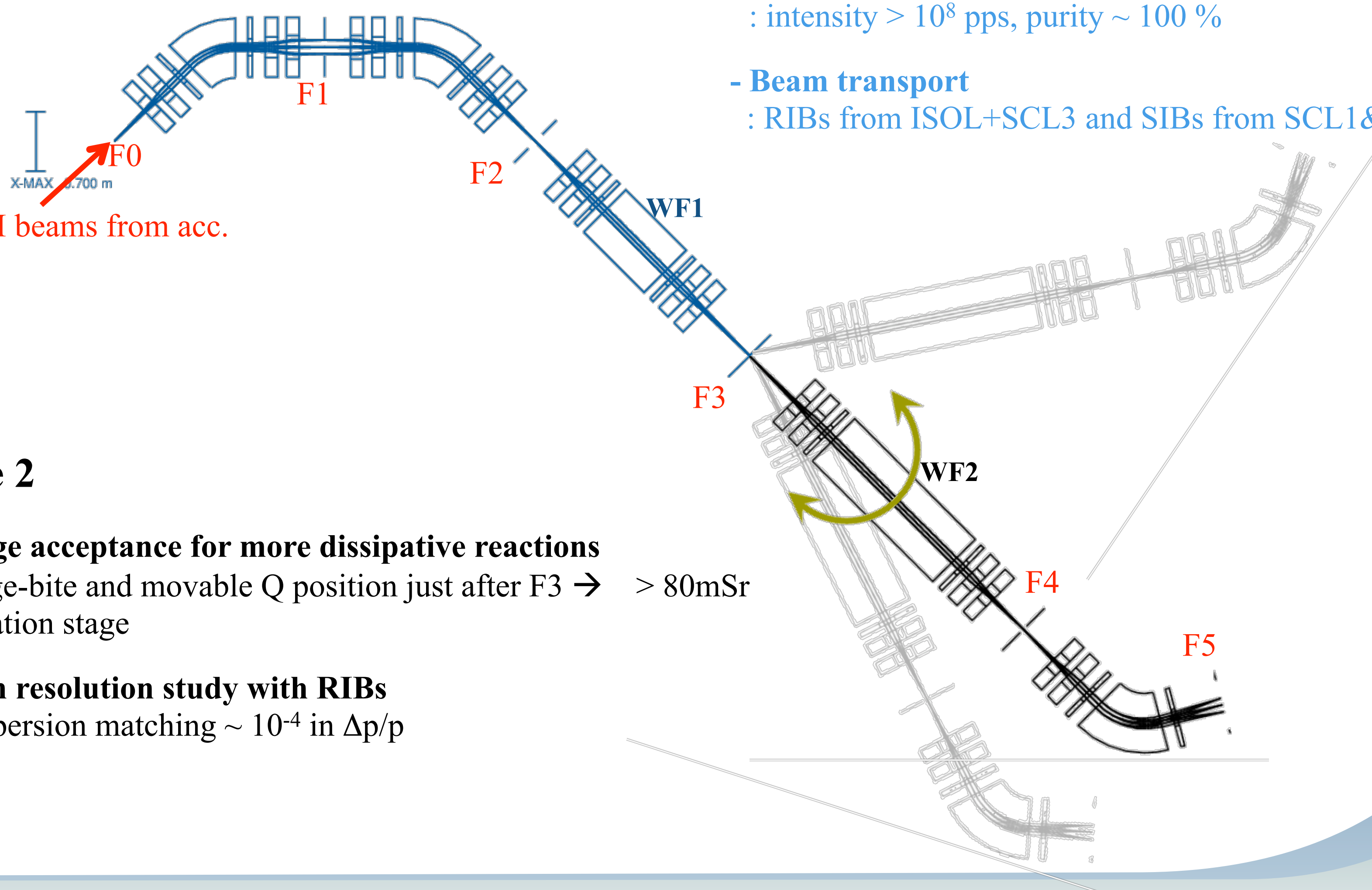
Main Features of KOBRA

- **Main Research Subject**
  - **Astrophysically important nuclear reactions**
  - **Rare event study**
    - Super Heavy Element (SHE), New isotopes
  - **Nuclear structure of exotic nuclei**

Stage 1

- Production of high-intense RIBs with in-flight method
: p-rich RIBs up to A~80
: intensity > 10^8 pps, purity ~ 100 %

- Beam transport
: RIBs from ISOL+SCL3 and SIBs from SCL1&SCL3

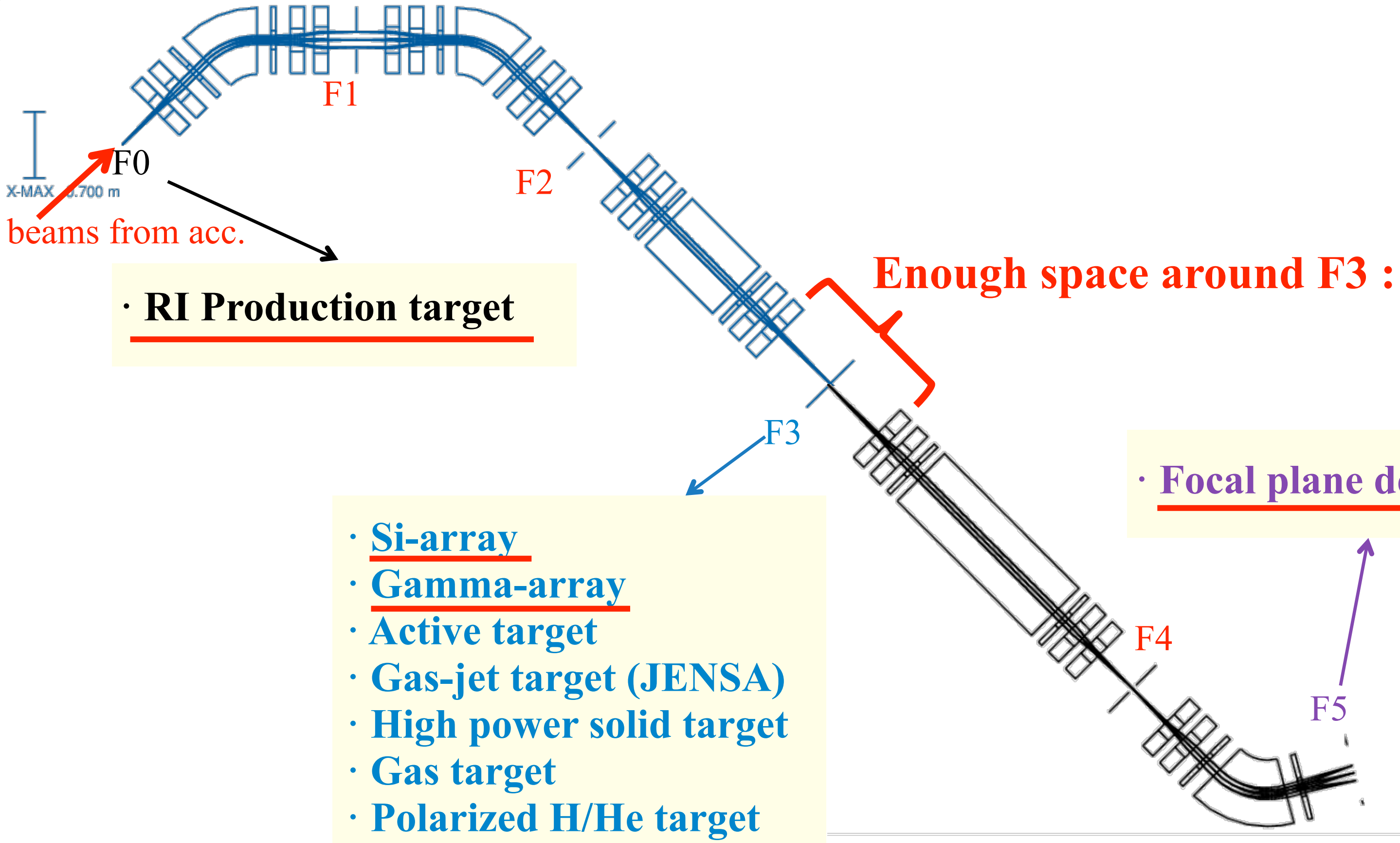


Stage 2

- Large acceptance for more dissipative reactions
: large-bite and movable Q position just after F3 → > 80mSr
: rotation stage

- High resolution study with RIBs
: dispersion matching ~ 10^{-4} in $\Delta p/p$

Associate Equipment in KOBRA



- RI Production target

- Si-array
- Gamma-array
- Active target
- Gas-jet target (JENSA)
- High power solid target
- Gas target
- Polarized H/He target

- Focal plane detection system

- Beam tracking detectors at F1~F5

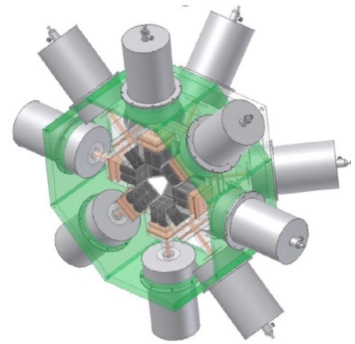
Associate Equipment – detector

RAON

Gamma-array

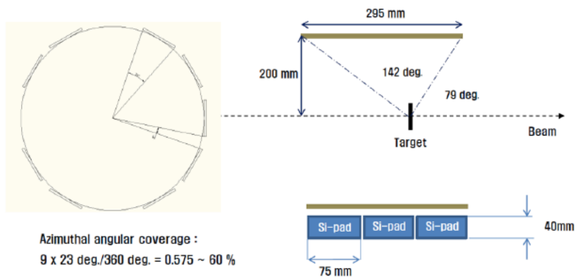
- 4-fold 32 segmented Clover HPGe X 16
- 3/8 array (6 clovers) : ~ 2015
- Half of full array : ~ 2018
- Last half of full array : 2019 ~
- International collaboration is under discussion

No of Clover	Full array
Distance from target to detector surface	107.5 mm
Angle coverage	85 % for 4 π
Digital electronics	TIGRESS



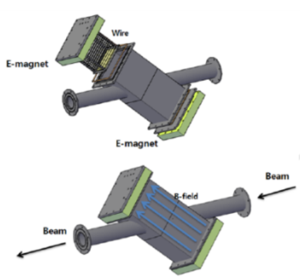
Si-array

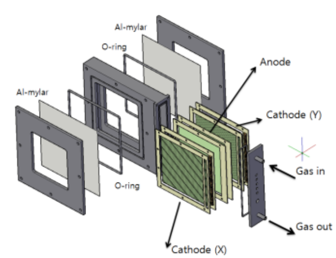
- barrel-type (# of position sensitive Si detectors = 27)
- Azimuthal angular coverage : 60%
- ΔE-E telescope : 60 μm + 1500 mm



Beam tracking detectors

- PPAC (Parallel Plate Avalanche Counter) : 100X100 mm^2, > 10^6 pps
- MCP (Multi-Channel Plate) : 70X70 mm^2, 0.3 mm (FWHM) of position resolution
- Diamond detector for the future





Focal plane detector

- Ion chamber + ΔE-E detector
- Effective length ~ 30 cm

Heavy-Ion Collision 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**

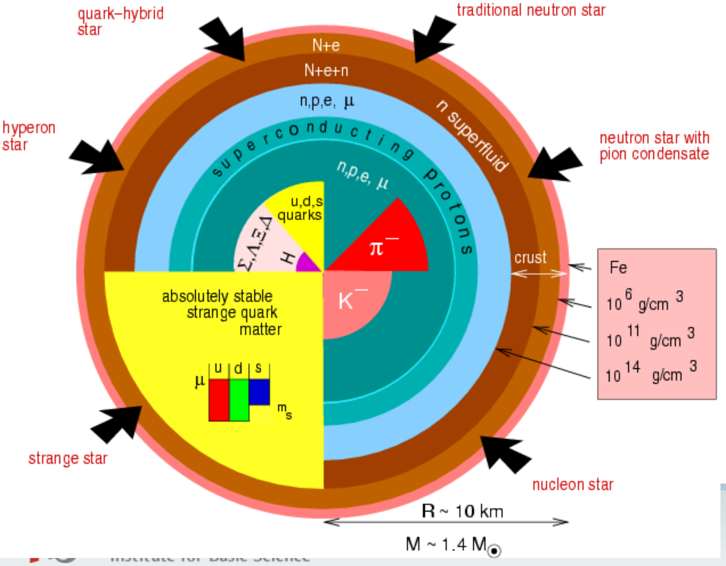
3.Modification of hadronic properties in dense medium

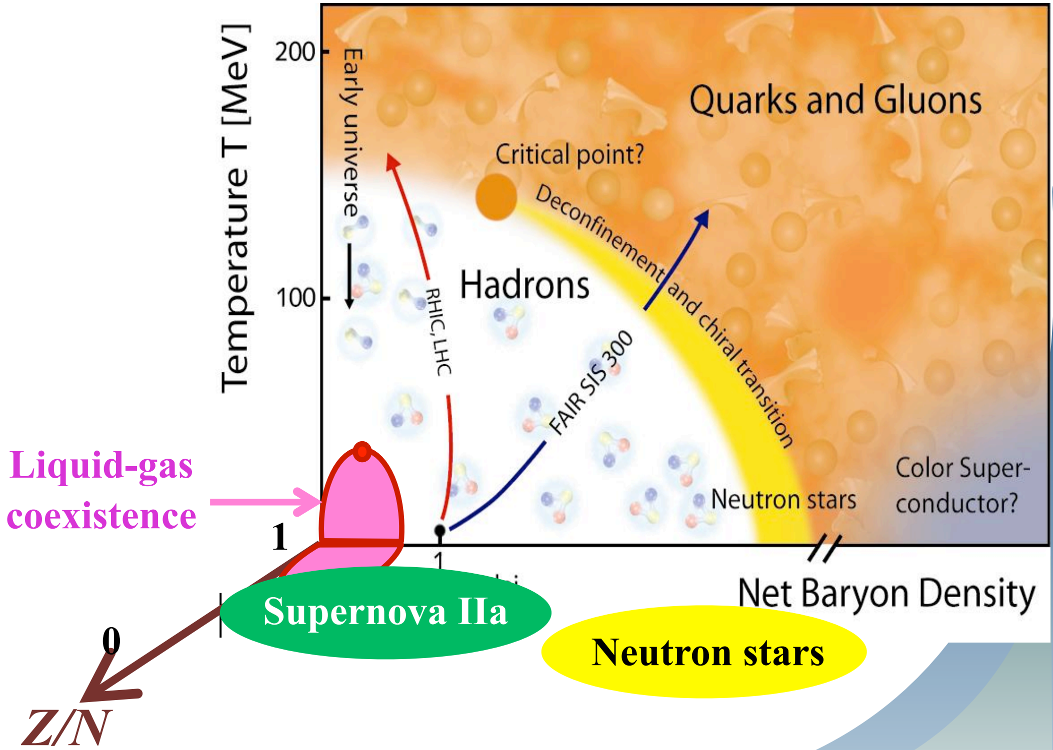
4.Importance for astrophysics

–**Supernovae and neutron stars**

–**Nuclear synthesis and exotic nuclei near neutron drip lines**

–QGP at colliders (not for RISP)





Physics Observables for Heavy-Ion Collision 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, $^3H(pnn)/^3He(ppn)$, $^7Li(3p4n)/^7Be(4p3n)$, $\pi^-(d\bar{u})/\pi^+(u\bar{d})$, 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)

Experimental Setup

- 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

☑ Large Acceptance Multi-Purpose Spectrometer (LAMPS)

- Two setups
  - Low-energy (E < 18.5*A* MeV) setup for the day-1 experiment
  - High-energy (E > 18.5*A* MeV) 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*A* MeV
  - RI beam: Ca, Ni, Ru, Zr, Sn, Xe, and more up to 250*A* MeV

  ∗for commissioning

  ❖when it is available

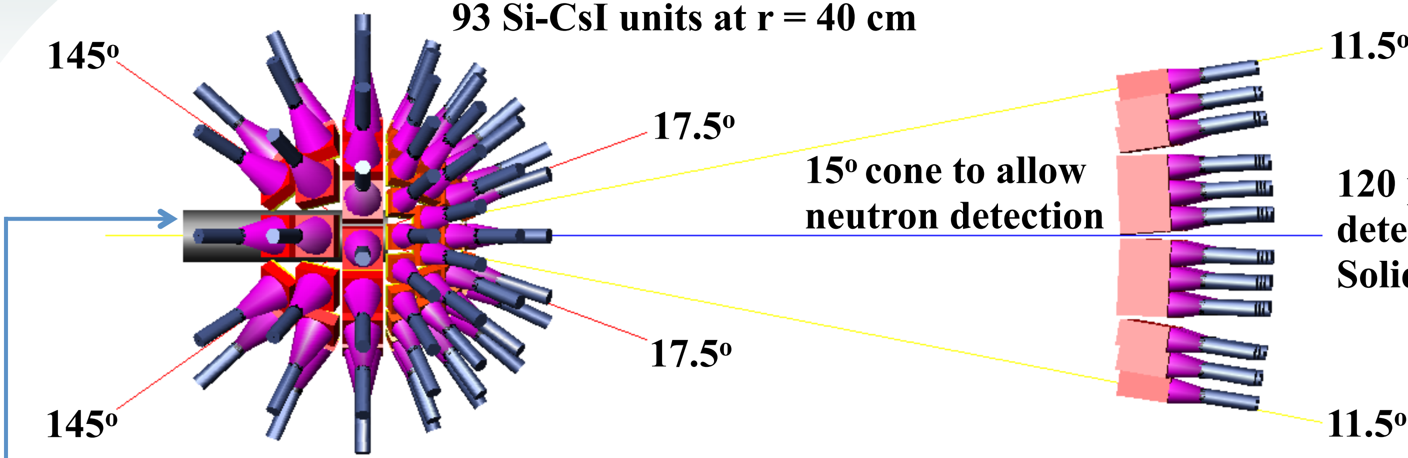
  ❖if it is possible

Low Energy LAMPS Experimental Setup

RAON

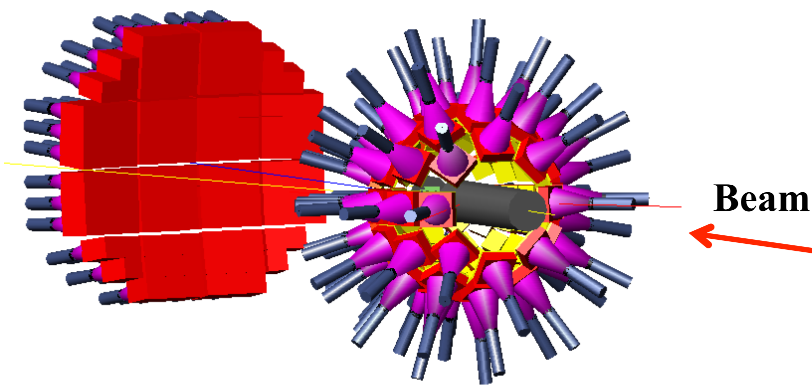
E_{beam} < 18.5*A* MeV

For GDR Experiments (to test PDR measurements as well)



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

25° cone to allow target installation



Si-CsI detector:

(ΔE-E technique for charged particle measurement as well as γ measurement)

- Energy resolution from simulation study
  - Si: 0.5% of FWHM
    (Energy resolution < 2% required for charged particle)
  - CsI: 2.0% of FWHM
    (Energy resolution < 5% required for max. 30 MeV γ-ray)

Neutron detector:

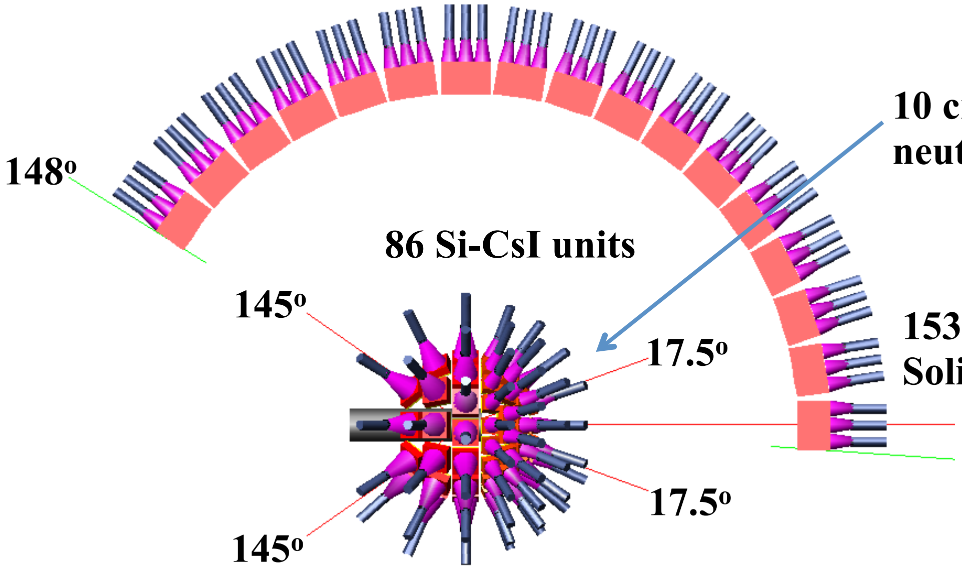
- Simulation study
  - Energy resolution: 2.6% for 10 MeV neutron
    (Energy resolution < 3.3% for 10 MeV neutron with time resolution ~ 500 ps)

Low Energy LAMPS Experimental Setup

RAON

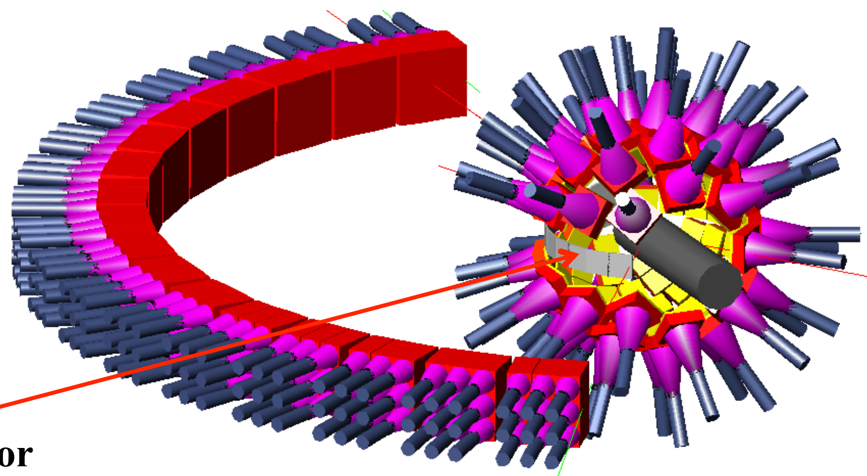
$E_{beam} < 18.5A$ MeV

For Heavy-ion Experiments



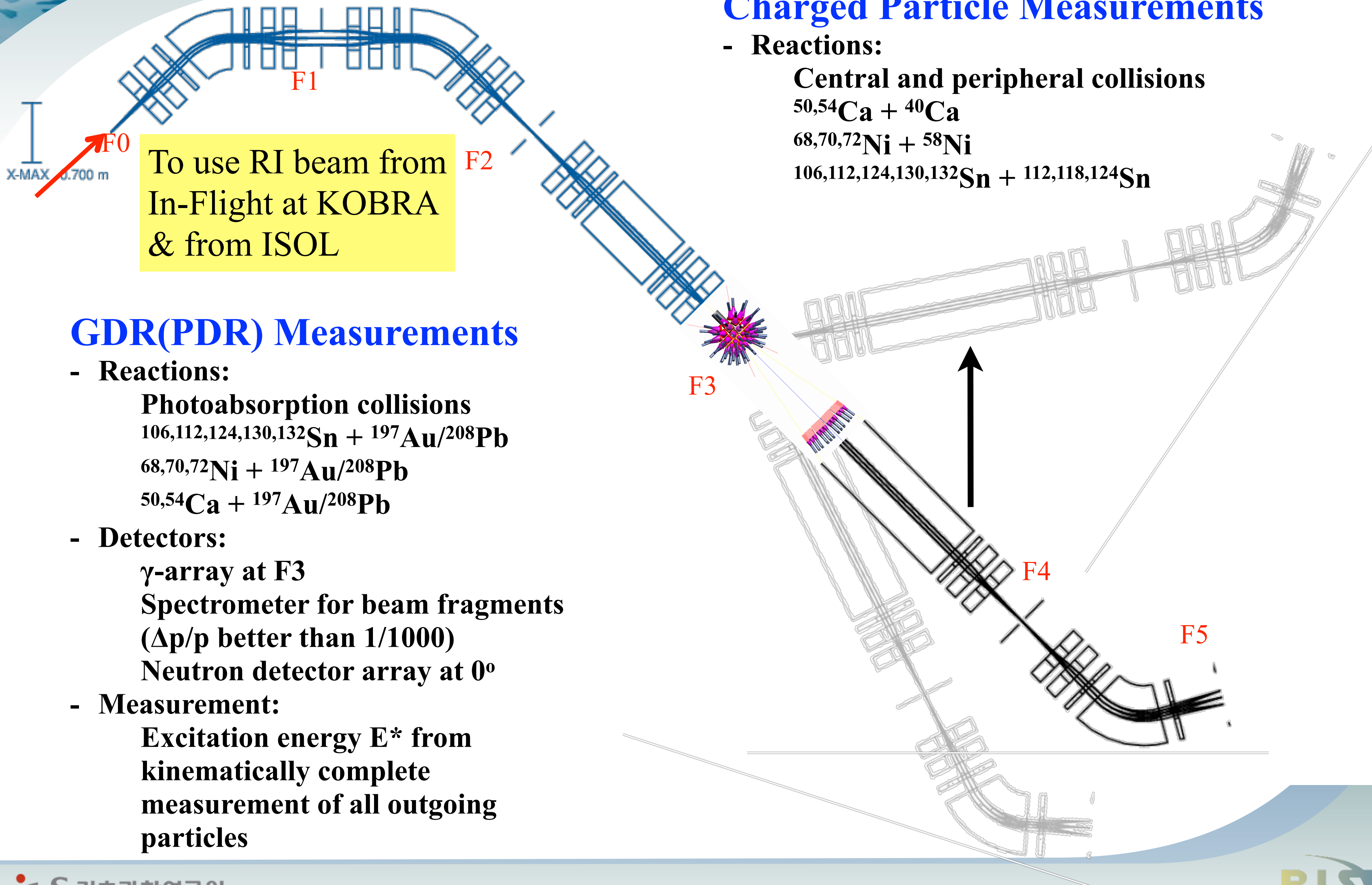
10 cm wide window to allow neutron detection along equator

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



10 cm wide window to allow neutron detection along equator

Cooperate with KOBRA



To use RI beam from In-Flight at KOBRA & from ISOL

Charged Particle Measurements

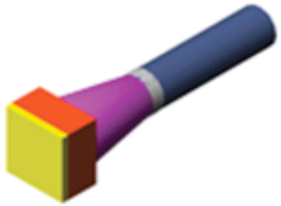
- Reactions:
  - Central and peripheral collisions
  - $^{50,54}Ca + ^{40}Ca$
  - $^{68,70,72}Ni + ^{58}Ni$
  - $^{106,112,124,130,132}Sn + ^{112,118,124}Sn$

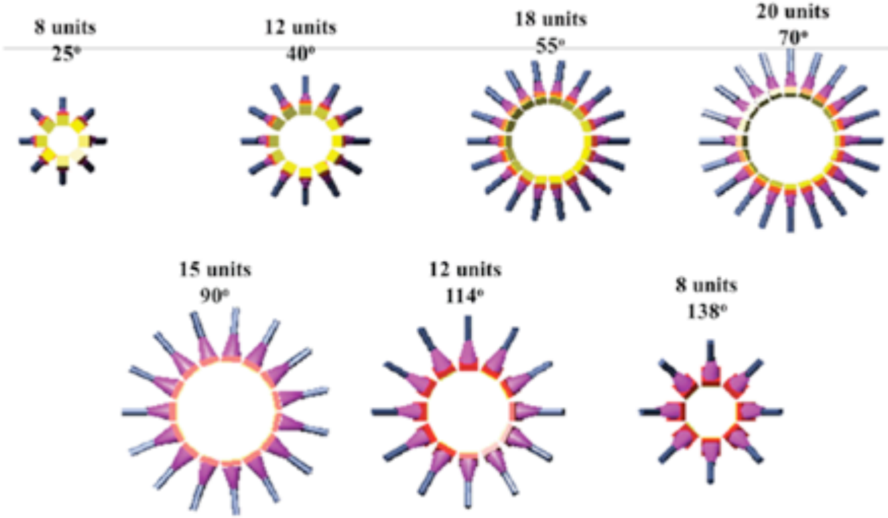
GDR(PDR) Measurements

- Reactions:
  - Photoabsorption collisions
  - $^{106,112,124,130,132}Sn + ^{197}Au/^{208}Pb$
  - $^{68,70,72}Ni + ^{197}Au/^{208}Pb$
  - $^{50,54}Ca + ^{197}Au/^{208}Pb$
- Detectors:
  - γ-array at F3
  - Spectrometer for beam fragments ($\Delta p/p$ better than 1/1000)
  - Neutron detector array at 0^o
- Measurement:
  - Excitation energy E* from kinematically complete measurement of all outgoing particles

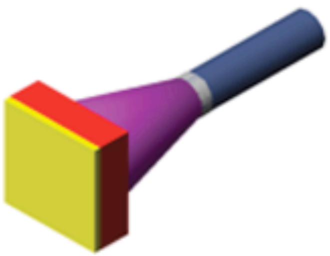
Si-CsI Detector R&D

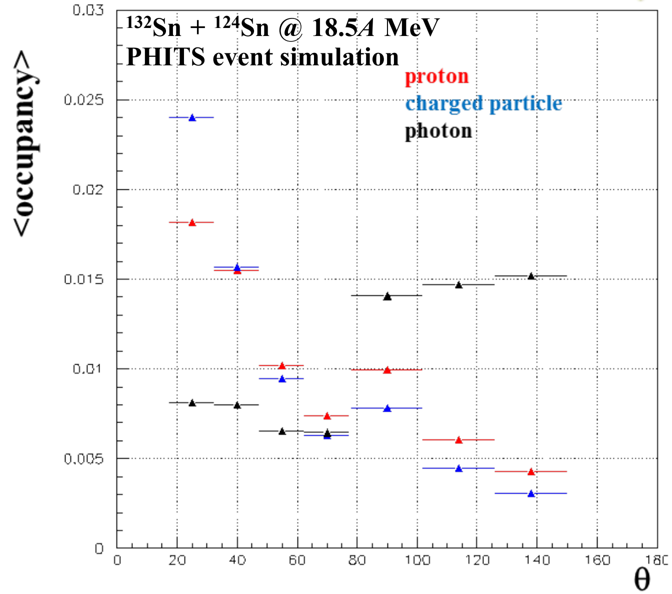
Total 58 detector units
($17.5^o < \theta_{lab} < 77.5^o$)
9 x 9 x 0.01 cm³ Si (3 x 3 Pad)
9 x 9 x 5 cm³ CsI (PMT readout)

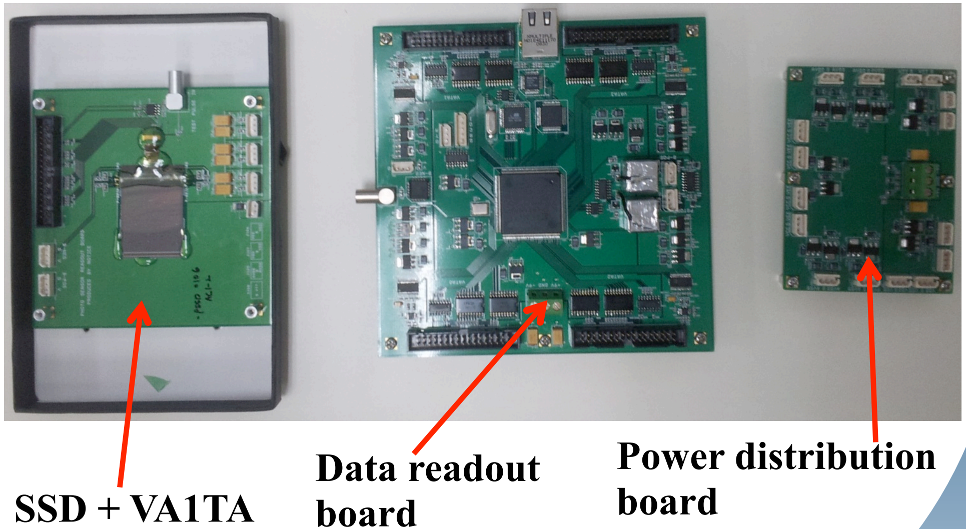




Total 35 detector units
($78^o < \theta_{lab} < 150^o$)
15 x 15 x 0.01 cm³ Si (3 x 3 Pad)
15 x 15 x 5 cm³ CsI (PMT readout)



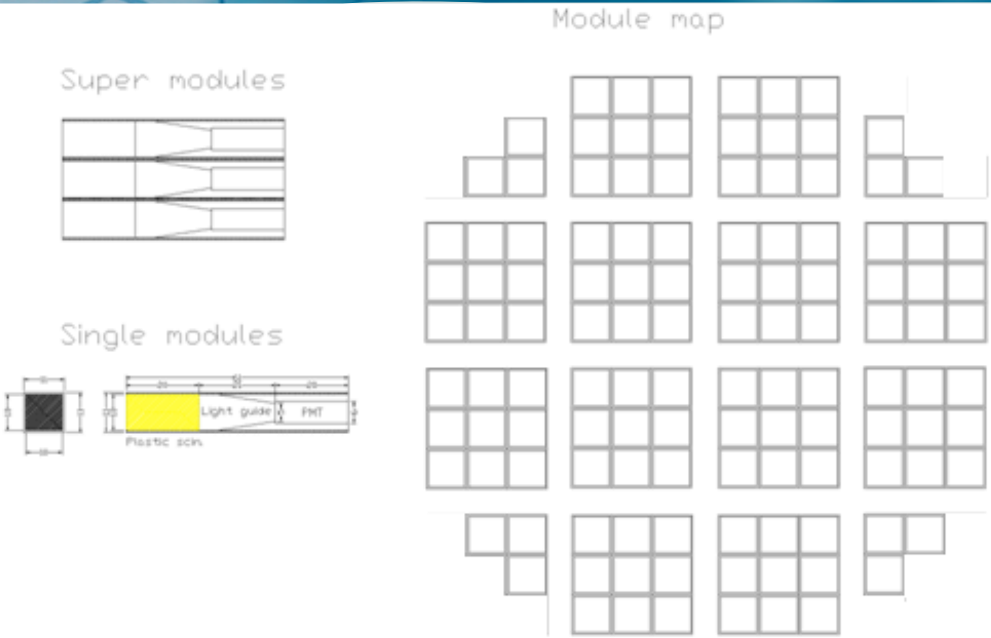




Si-CsI detector unit coverage of polar angle tuned to be <occupancy> < 0.1

Si detector: R&D with Kyungpook Natl. Univ.
CsI detector: 1st prototype in preparation

Neutron Detector



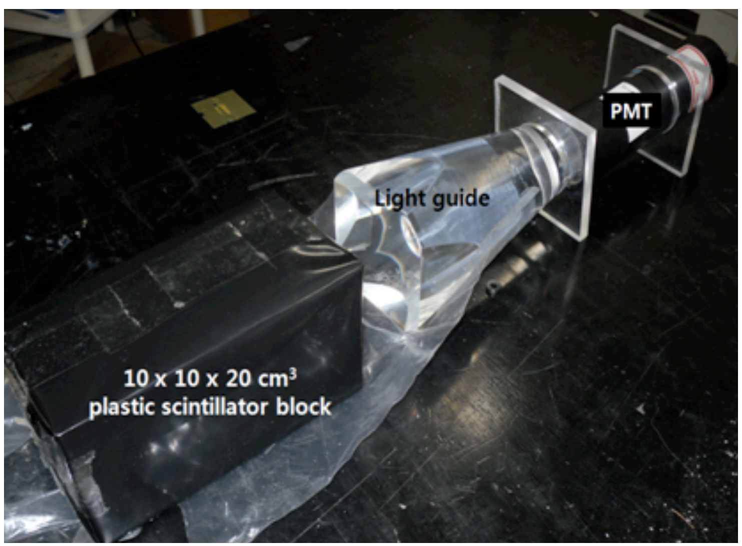
R&D with Korea Univ.

CFD & VTD electronics setups

^{60}Co & ^{252}Cf source tests

- **Bicron BC-408 & Rexon RP-408**
  - ➡**Better results with BC-408**
- **Tail-like fish & square frustum light guides**
  - ➡**Minimum measurable neutron energy is lower for square frustum light guide (~ 1.5 MeV)**
  - ➡**Beam test confirmed**

-Checking multi-hit performance by clusterization using at least 7 single modules is in preparation



High Energy LAMPS Experimental Setup

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

Heavy-ion Experiments

- Reactions:

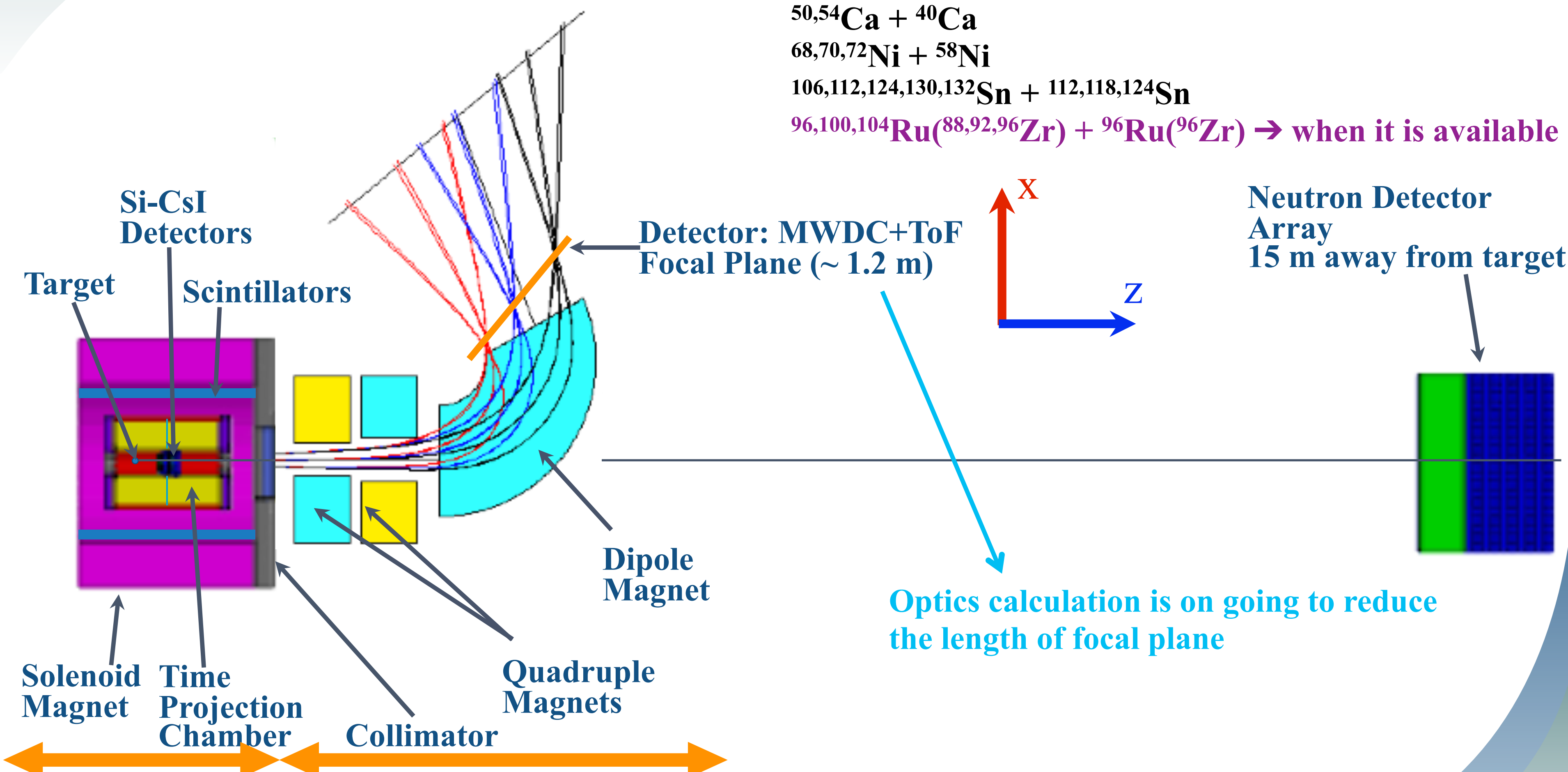
  Central and peripheral collisions

  ^{50,54}Ca + ^{40}Ca

  ^{68,70,72}Ni + ^{58}Ni

  ^{106,112,124,130,132}Sn + ^{112,118,124}Sn

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



Solenoid Spectrometer

Dipole Spectrometer

(rotatable, Δp = ± 20%, acceptance ≥ 50 msr, Focal plane < 1 m)

High Energy LAMPS Experimental Setup

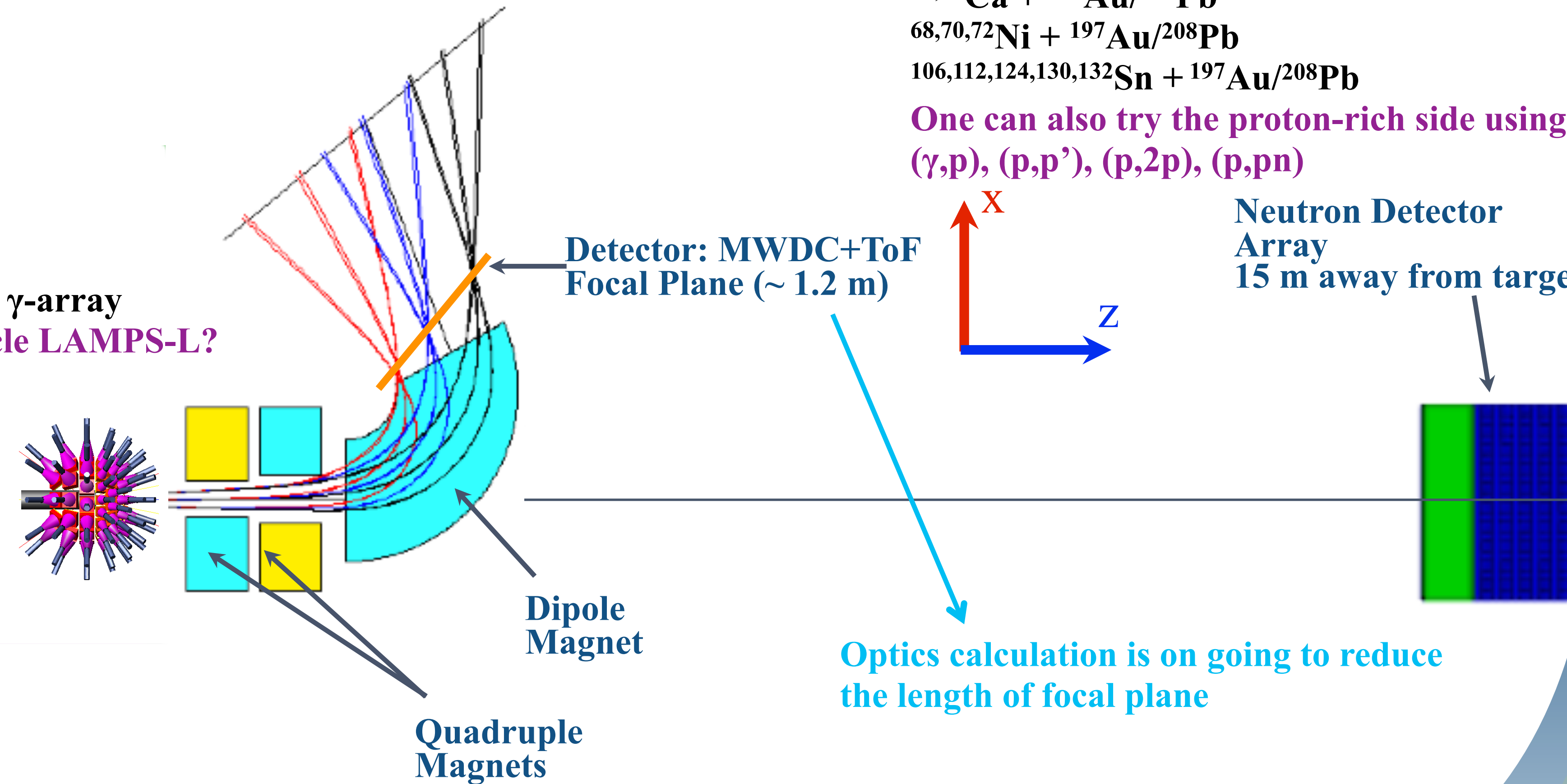
RAON

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

PDR/GDR Experiments

- Reactions:
  - Photoabsorption collisions
  - ^{50,54}Ca + ^{197}Au/^{208}Pb
  - ^{68,70,72}Ni + ^{197}Au/^{208}Pb
  - ^{106,112,124,130,132}Sn + ^{197}Au/^{208}Pb

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



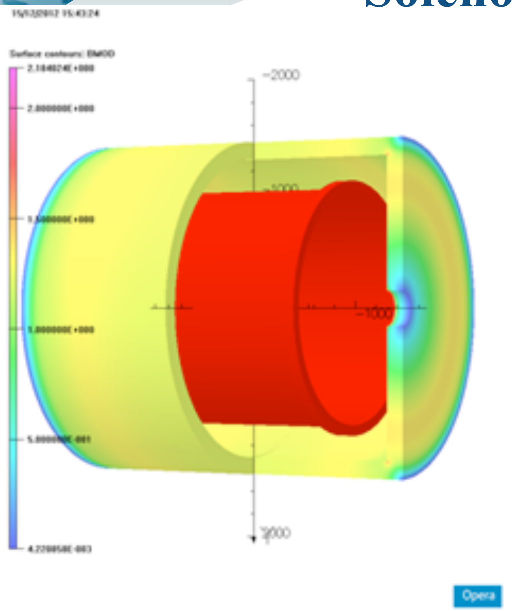
Optics calculation is on going to reduce the length of focal plane

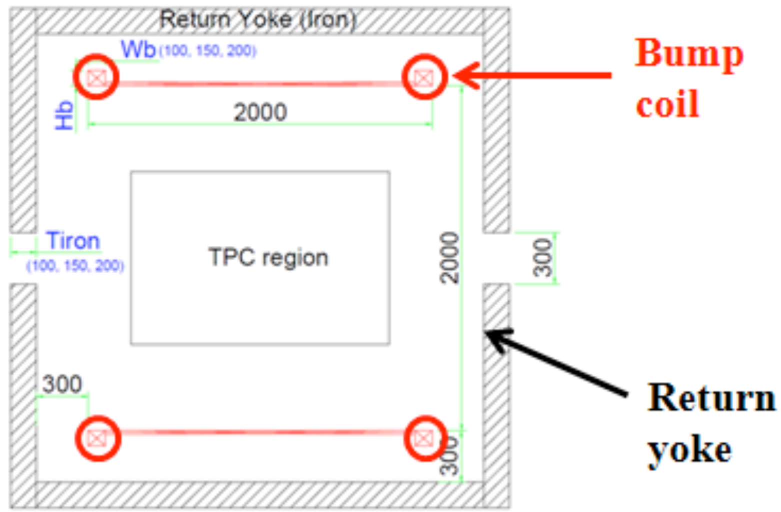
Dipole Spectrometer

(rotatable, Δp = ± 20%, acceptance ≥ 50 msr, Focal plane < 1 m)

Solenoid Magnet

Solenoid design





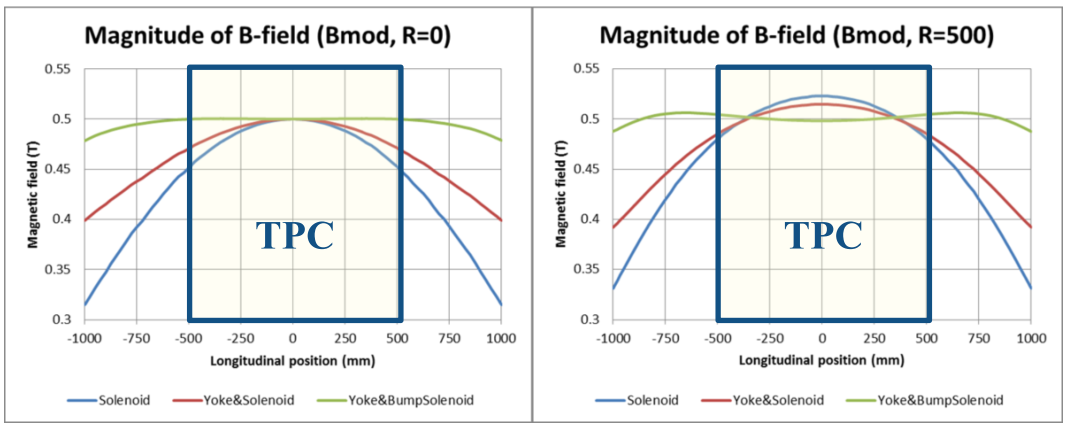
Total size: 2.6 x 2.6 m²

- **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 %

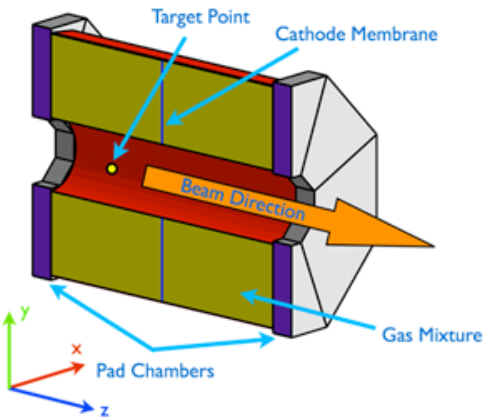


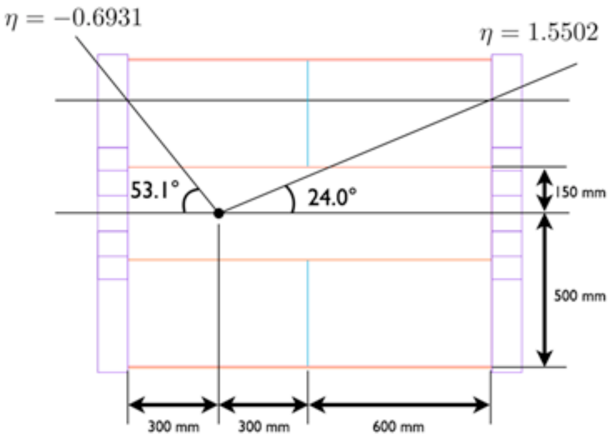
Deviation of magnetic field

-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

- **Solenoid magnet design is completed (Need to figure out production feasibility)**
  - **Communicate with domestic and foreign magnet companies**

Time Projection Chamber (TPC)





Time Projection Chamber (TPC)

R&D with Pusan Natl. Univ., Korea Univ., and Inha Univ.

-1 x 1.2 m² cylindrical shape

-GEM based & pad readout in end-caps (~100 k readout channels)

-Large acceptance (~ 3π sr)

-Complete 3D charged particle tracking

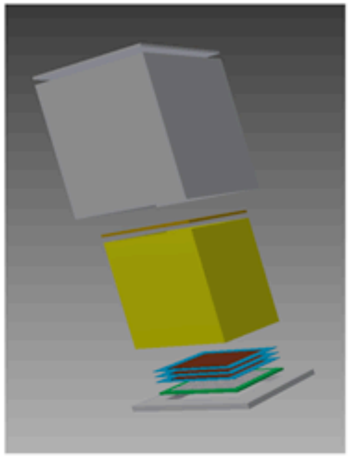
➡Particle identification and momentum reconstruction

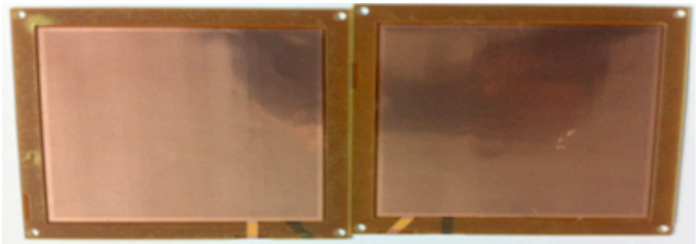
-Completed Garfield++ & GEANT-4 simulation

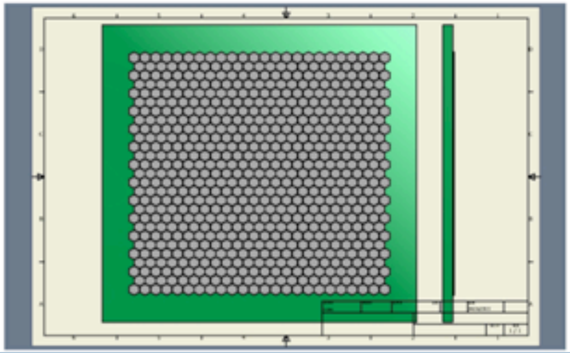
-Developing tracking algorithm

-1st Prototype test result is being analyzed

-Prepare to build 2nd Prototype







1st TPC Prototype

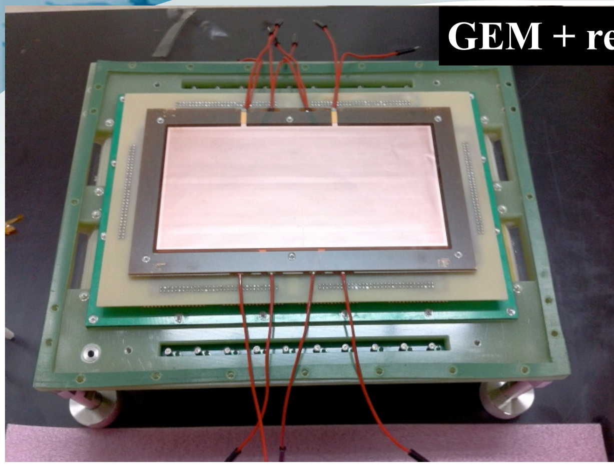
Active volume: 10 x 10 x 20 cm3

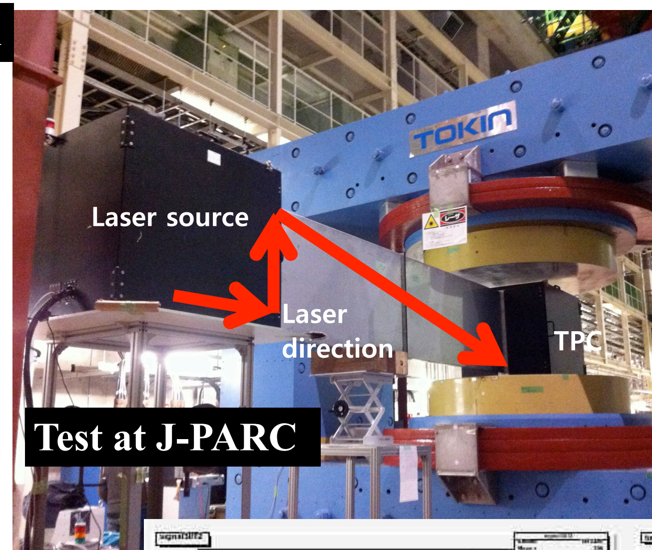
GEM based

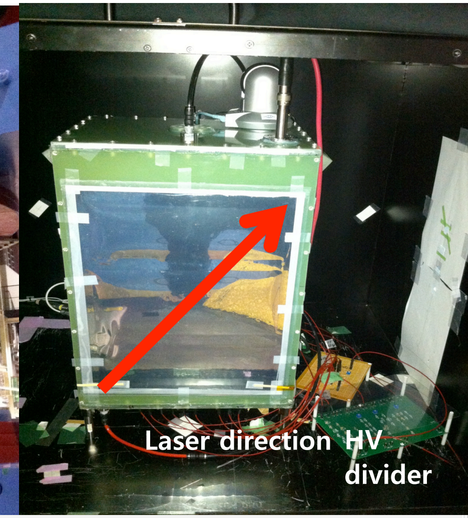
635 readout channels

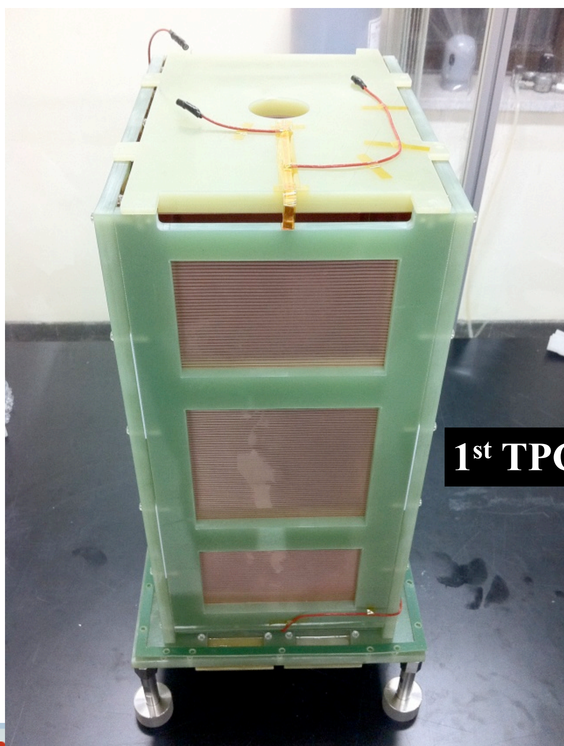
Analysis of test data is in progress

1st TPC Prototype Test

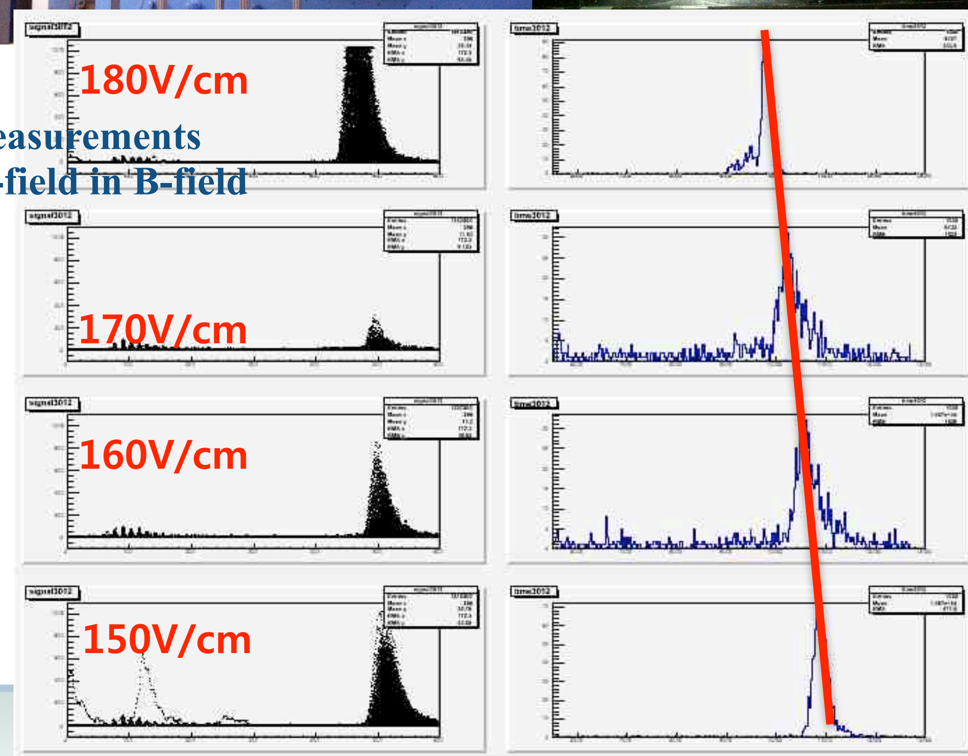




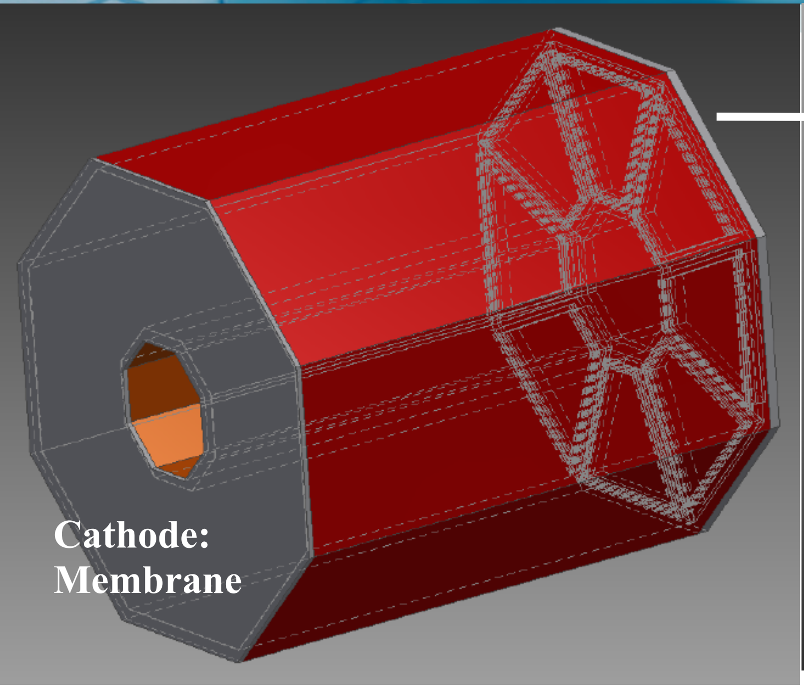


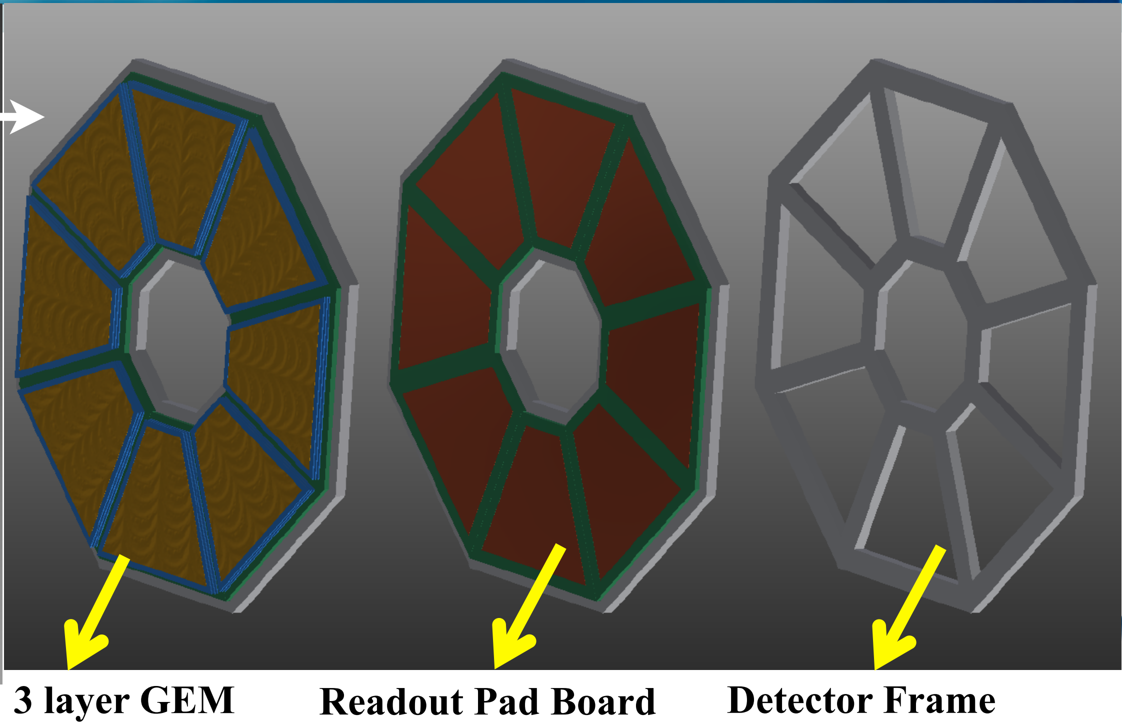


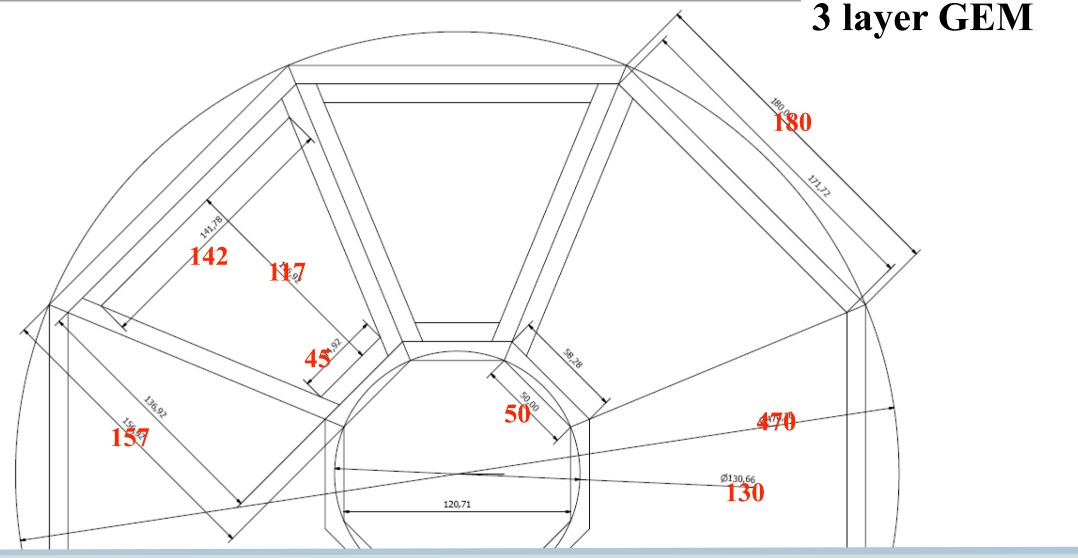
Drift velocity measurements with different E-field in B-field

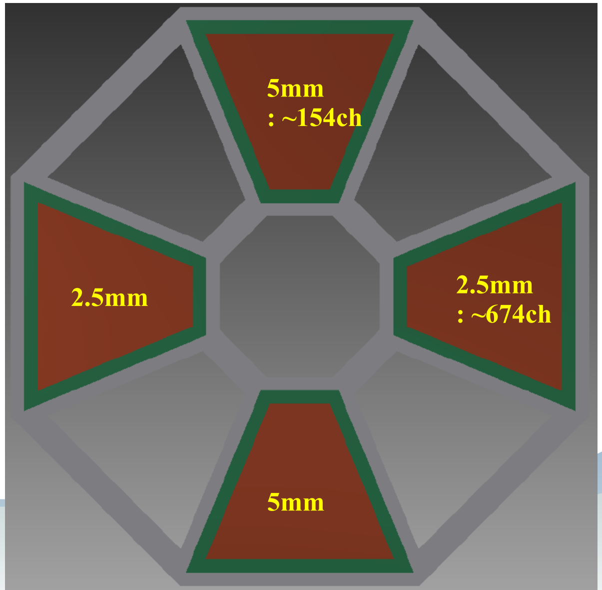


2nd TPC Prototype









TPC Simulation

RAON

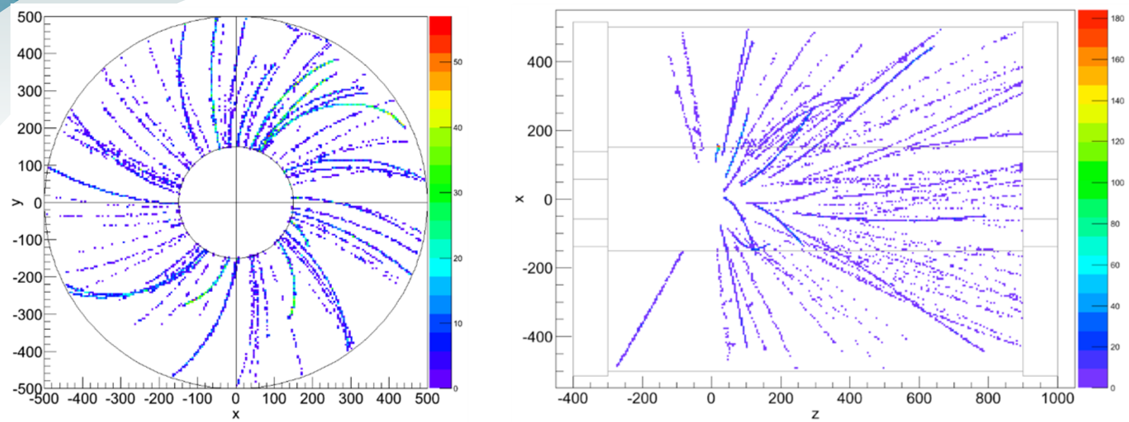
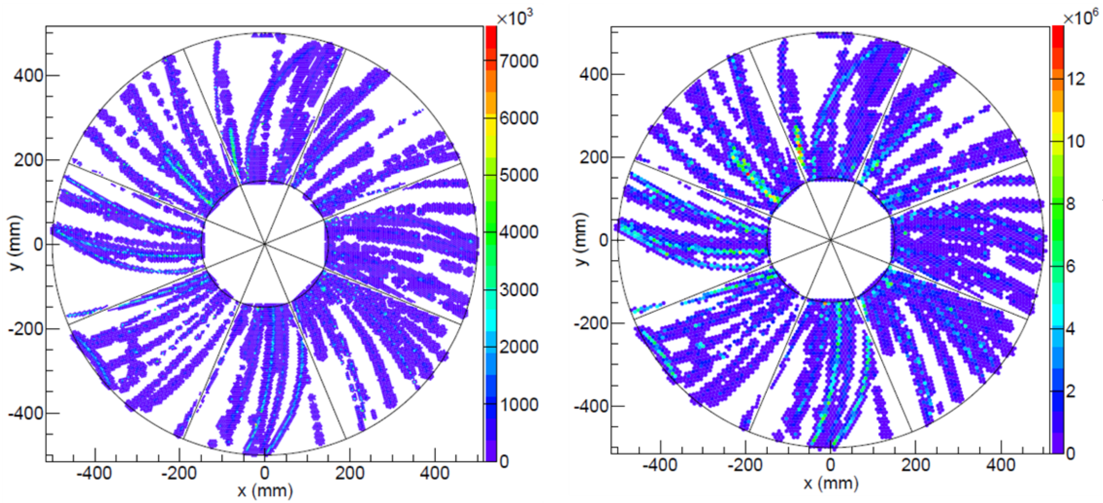


Figure 3.62 TPC hit information before digitization with P10 gas and single GEM.



Au + Au @ 250*A* MeV

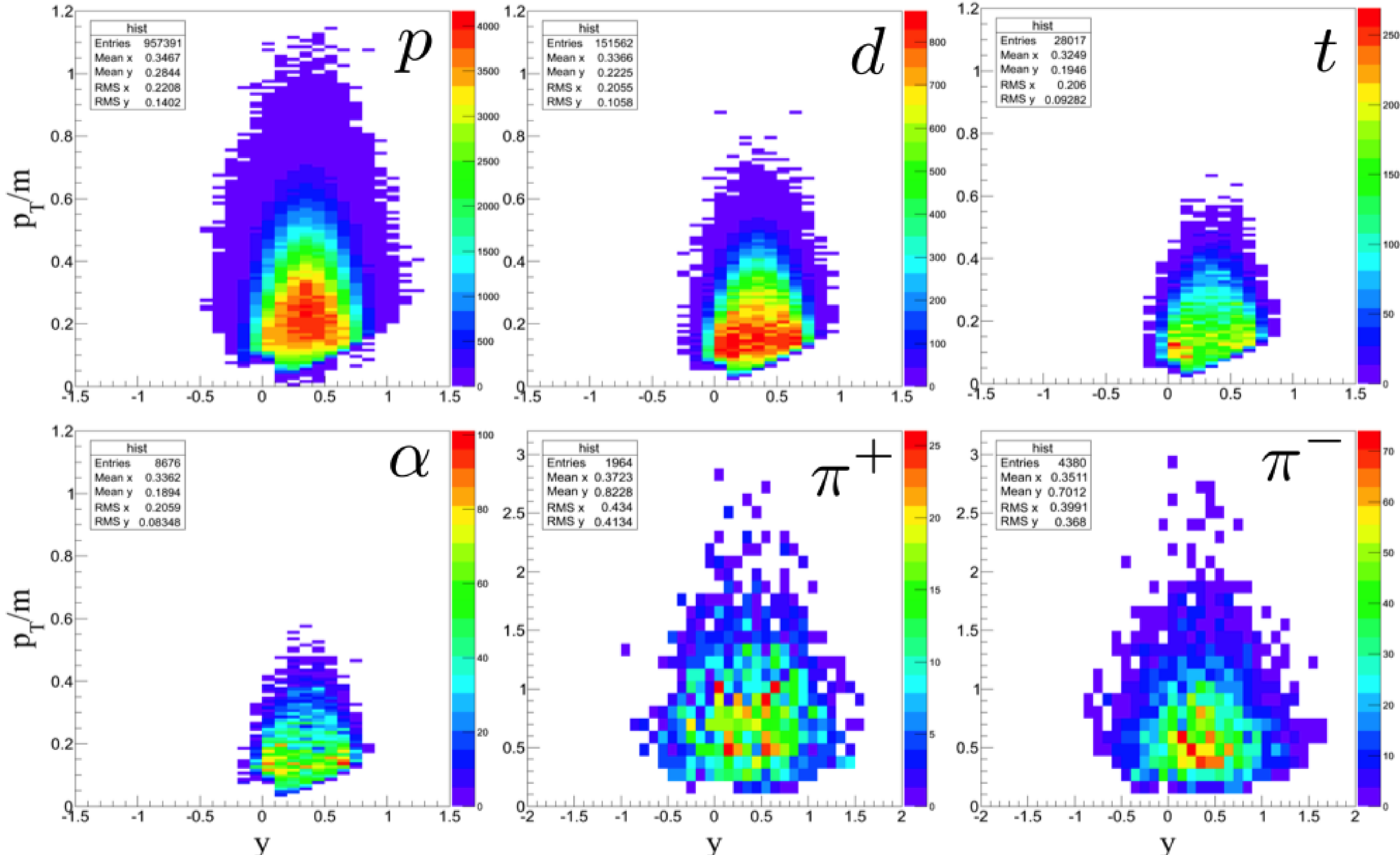
Isospin Quantum Molecular Dynamics Events

2.5 mm pad ~ 300 K readout channels

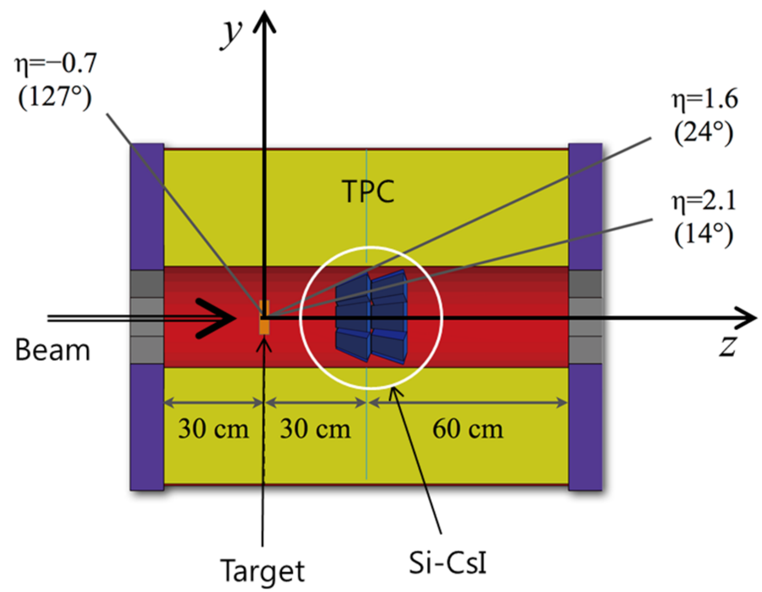
5 mm pad ~ 100 K readout channels

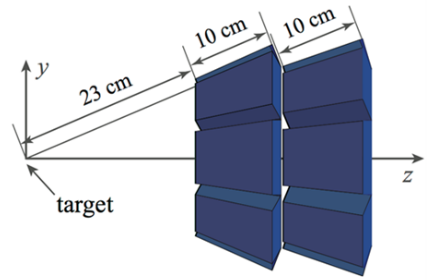
Figure 3.68 TPC hit information after digitization with Ar 90% + CO_2 10% gas and triple GEM. Left plot is with 2.5 mm hexagonal readout pads and right plot is with 5 mm hexagonal readout pads, respectively.

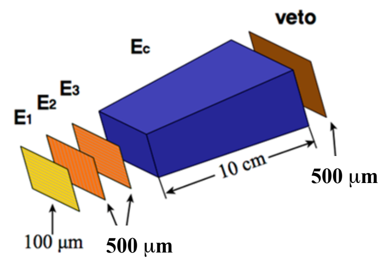
TPC Acceptance



Si-CsI Detector





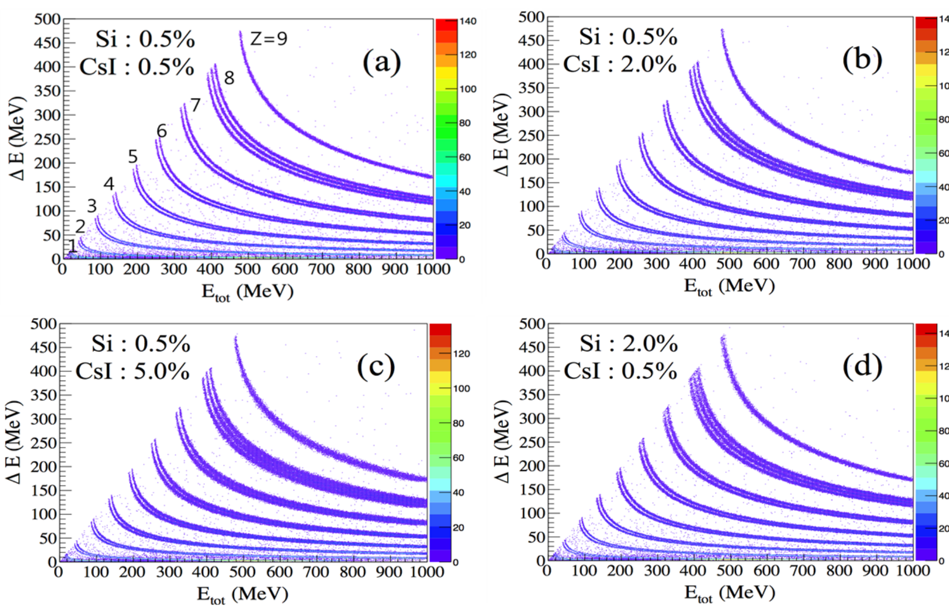


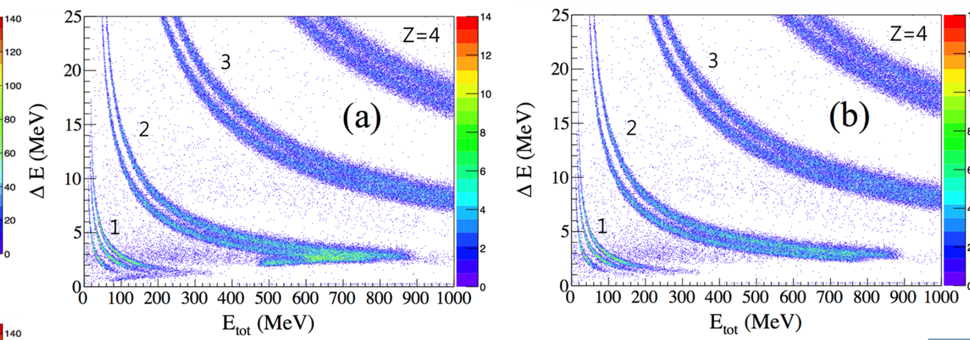
350 msr each		size (mm²)
inner ring (14° - 19°)	front	66.80 × 26.20
	rear	86.92 × 37.84
outer ring (19° - 24°)	front	62.09 × 20.08
	rear	89.17 × 28.84

Si-CsI module

Si: 2 x 8 pad readouts

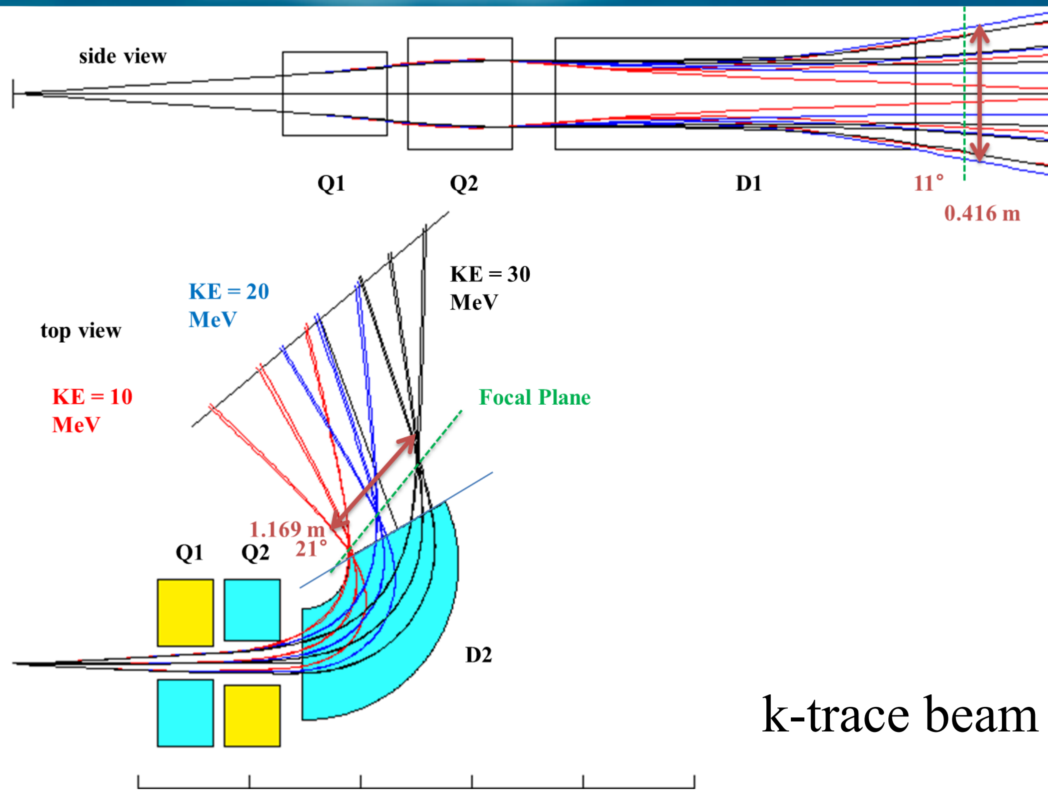
CsI: 4 x 4 APD readouts





veto Si detector can clean up unexpected correlation

Dipole Spectrometer



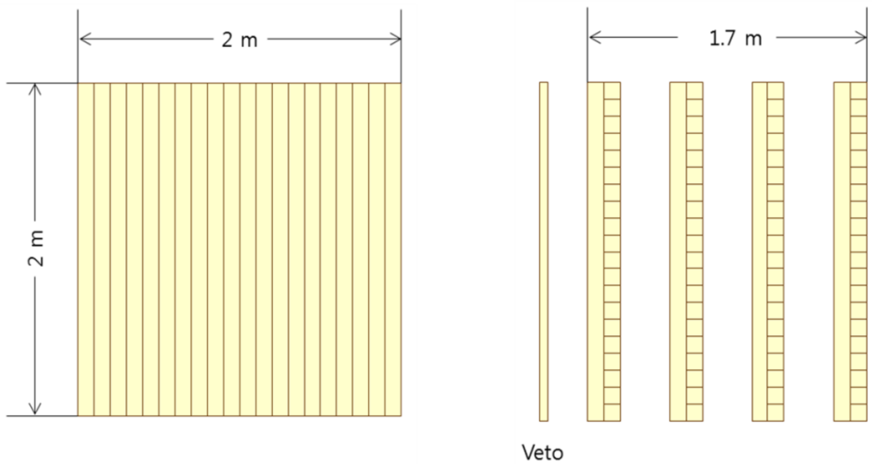
k-trace beam optics calculation

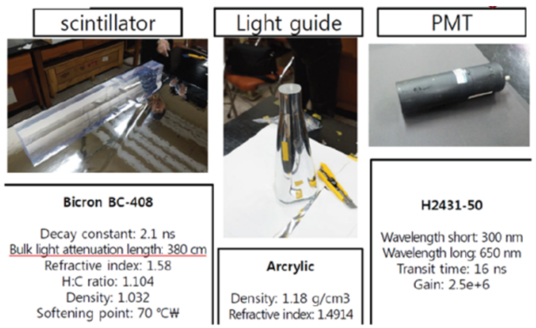
Magnet			Strength of Magnetic Field
Q1	length = 50 cm	aperture = 0.3 m	0.5 T/m
Q2	length = 50 cm	aperture = 0.4 m	1.1 T/m
D1	pole gap = 40 cm	radius = 0.9 m	0.82 T

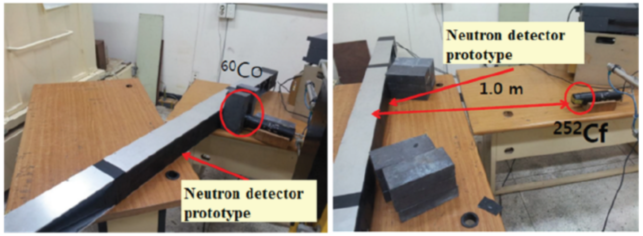
Multi particle tracking capability of isotopes for p, He, and heavier fragments

- **Rotatable, $\Delta p = \pm 20\%$, acceptance $\geq$ 50 msr, Focal plane < 1 m**
- **Optics calculation is on going to reduce the length of focal plane**
- **Focal Plane detector**
  - ✳**MWDC + Plastic scintillator ToF(σ_t < 100 ps, essential for $\Delta p/p < 10^{-3}$ @ $\beta = 0.5$)**

Neutron Detector Array







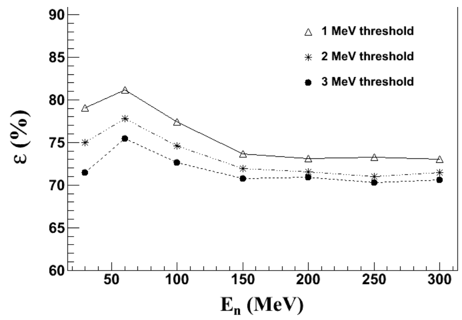
Charged particle veto: 5 x 5 x 200 cm^3

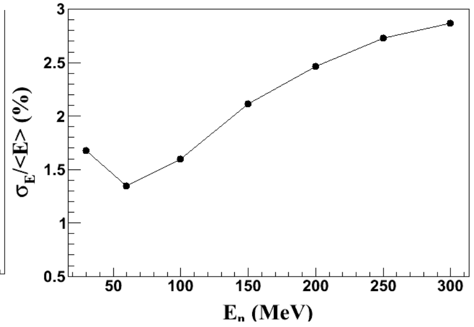
20 BC-408 10 x 10 x 200 cm^3/layer

4 – 5 coupled layers

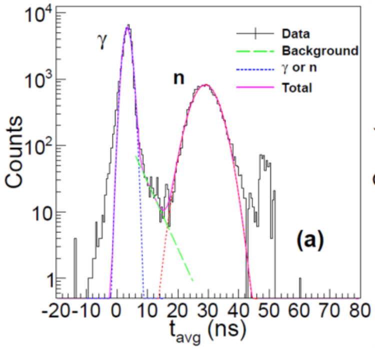
Possible Fe convertor in between layers

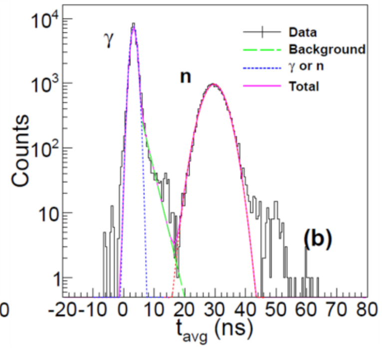
- **Covering wide neutron energy range (10 – 300 MeV)**

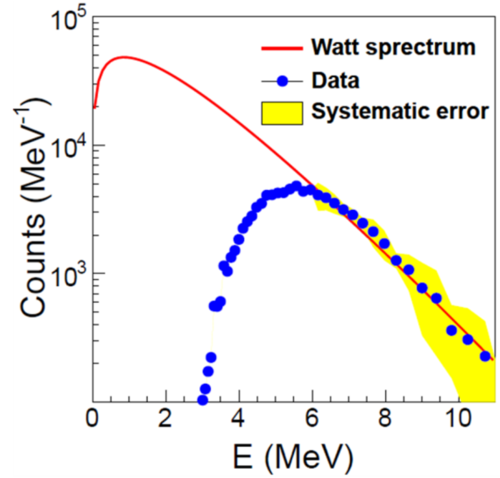




- **Capable for neutron tracking**







½ length prototype produced and tested with source

Beam test is planned

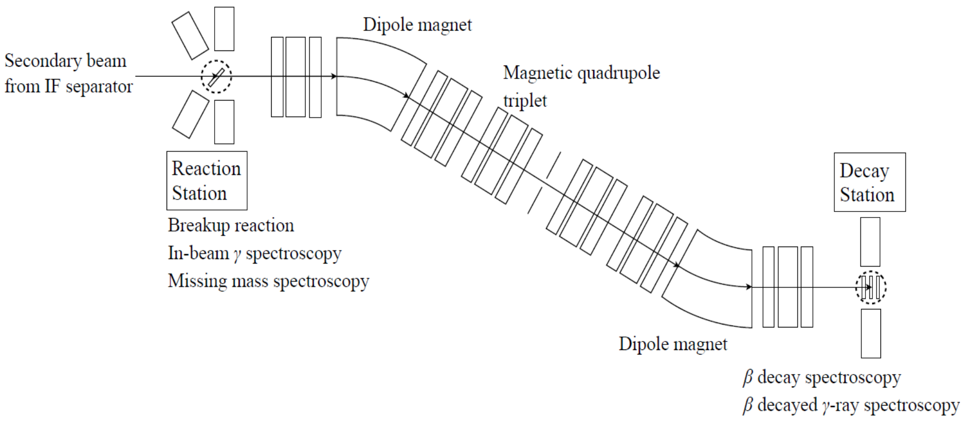
Real size prototype will be produced soon

Zero Degree Spectrometer (ZDS)

Spectroscopy of RI-bean at Zero Degree

Exotic RI beam → In-beam γ spectroscopy, Coulomb excitation, Nucleon knock out, Breakup reaction, Missing mass spectroscopy, Inverse kinematics → Nuclear Structure, Mass, Half-life, Excited states, Deformation & more

ZDS Conceptual Layout



Design Goals

Momentum resolution	$\Delta p/p$ = 1200–4000
Magnetic rigidity	~9 Tm
Angular acceptance (vertical)	± (20–50) mrad
Angular acceptance (horizontal)	± ~30 mrad
Momentum acceptance	± ~3%

R&D Plan, Production Plan

- Solenoid magnet design is completed
  - -Need to figure out production feasibility
  - -Communicate with domestic and foreign magnet companies

- Si-CsI detector & neutron detector are commonly used at both experimental setups
  - -Electronics also can be common
- TPC detector and electronics are quit complicated
  - -Need longer R&D time than other detectors

❖R&D and production of most of detectors will be done with domestic people
❖Adapt advanced electronics & DAQ system from foreign research institute and modify

◉For future upgrade

➡Longer optics calculation for better dipole spectrometer performance

-After optics calculation completed, magnet design will be started & focal plane detector design will be fixed

➡Build Si-CsI detector at high energy experimental setup

Thank for your attention!

Nuclear Equation of State

Bethe-Weizsäcker formula

$$B(A,Z)/A = a_V - a_s A^{-1/3} - a_c Z(Z-1)A^{-\frac{4}{3}} - a_s\frac{(N-Z)^2}{A^2} + \delta_{pair}$$

(Ref.) C. F. von Weizsäcker, Z. Physik 96, 431 (1935)
N. Bohr, Nature 137, 344 (1936)

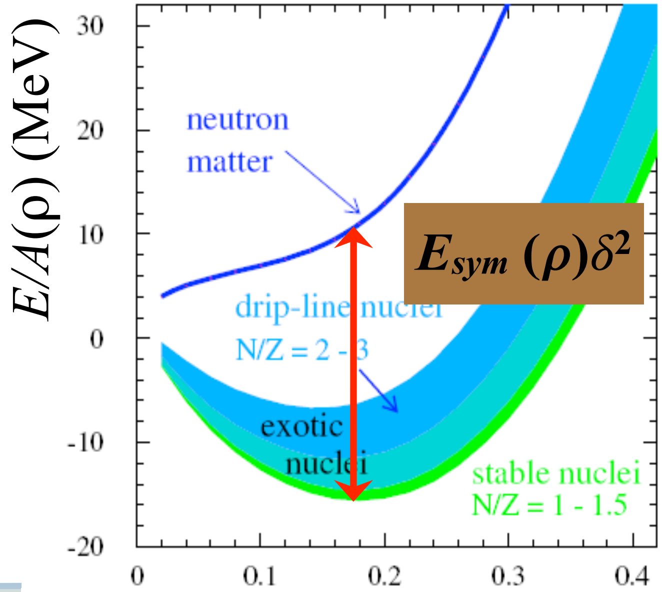
Symmetry energy
Difference between neutron and symmetric matter **(rather unknown)**

Energy of nuclear matter

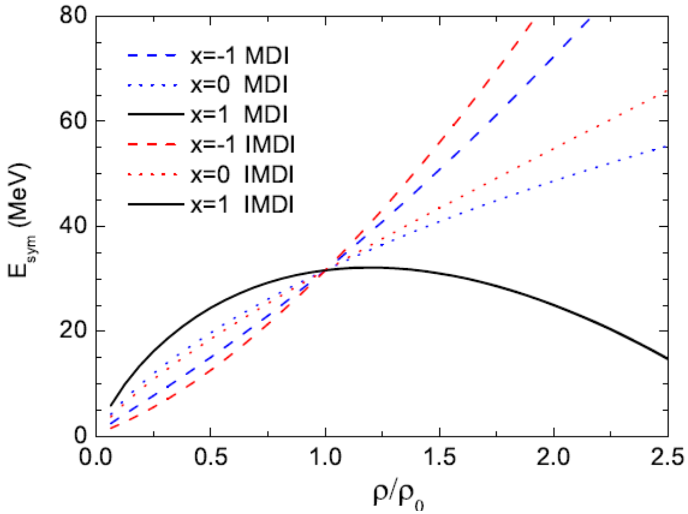
(density and isospin asymmetry dependence)

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

where $\rho = \rho_n + \rho_p$, $\delta = \frac{\rho_n - \rho_p}{\rho_n + \rho_p}$, $a_s \approx E_{sym}(0.6\rho_0)$

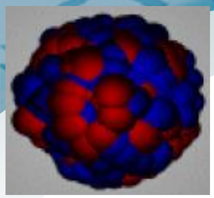


CDR, FAIR (2001) ρ (fm^{-3})

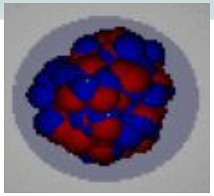


C. Xu and B. A. Li, PRC 81, 044603(2010)

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

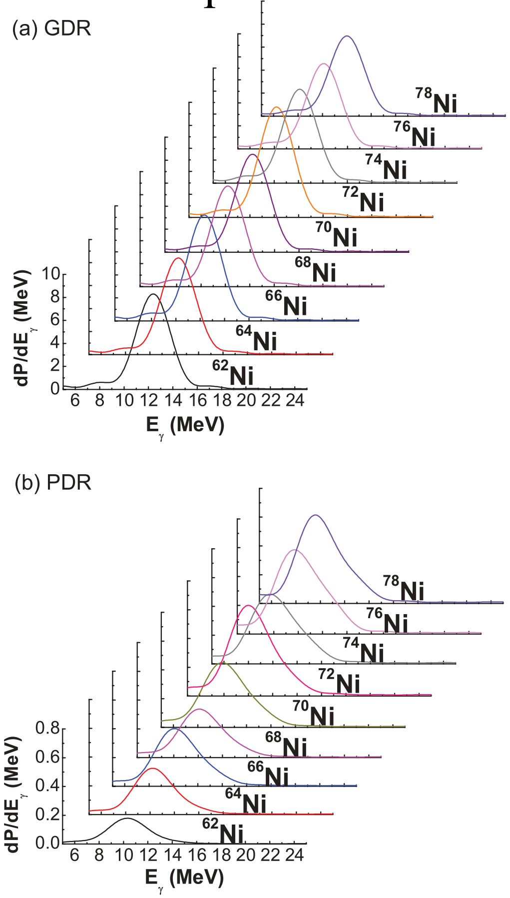


FIG. 10. (Color online) Mass number dependence of GDR (a) and PDR spectra (b) for Ni isotopes. In calculations, we use $E_{\rm in} = 100$ MeV/nucleon, $b = 24$ fm, $C_{\rm sym} = 32$ MeV, and the soft EOS without MDI.

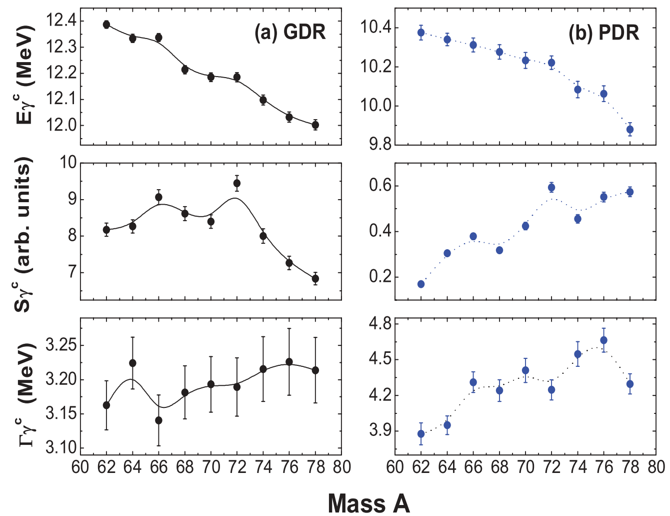


FIG. 11. (Color online) Mass number dependence of Ni isotopes of GDR (left panels) and PDR (right panels) parameters. In calculations, we use $E_{\rm in} = 100$ MeV/nucleon, $b = 24$ fm, $C_{\rm sym} = 32$ MeV, and the soft EOS without MDI.

System size dependence

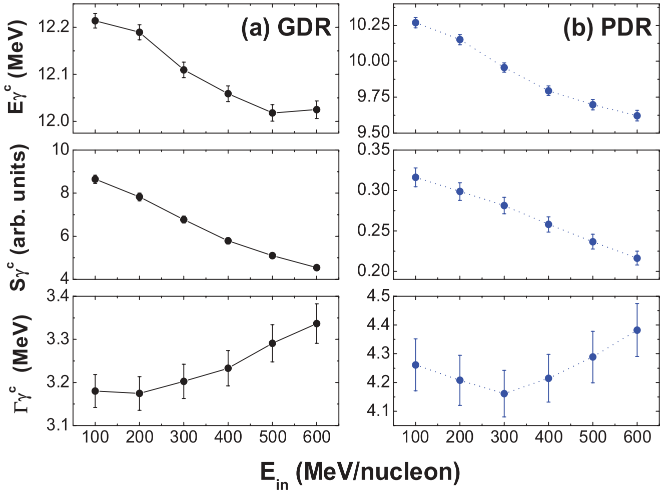


FIG. 5. (Color online) Incident energy dependencies of GDR (left panels) and PDR (right panels) parameters for ^{68}Ni. From the upper panel to bottom panel, it corresponds to the peak energy (E_γ^c), strength (S_γ^c), and FWHM (Γ_γ^c), respectively. In calculations, we use $b = 24$ fm, $C_{\rm sym}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

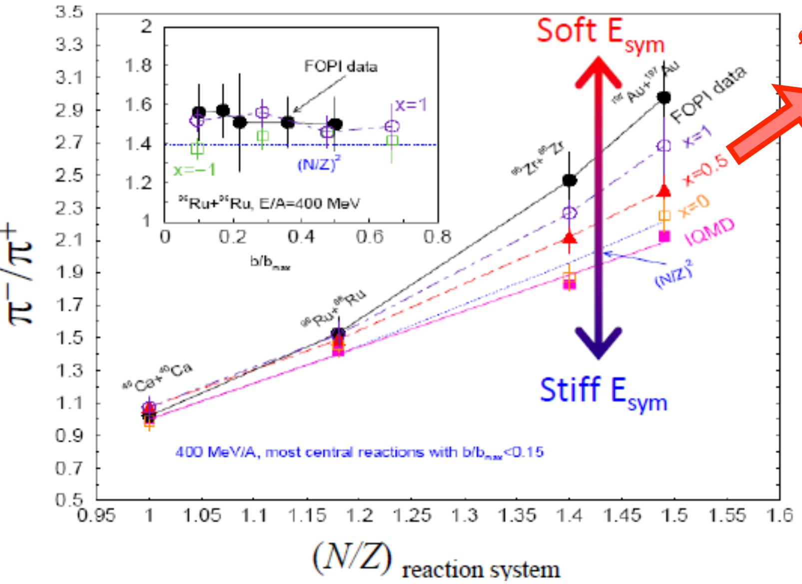
Energy dependence

Ni+Au collision

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

Particle Ratio

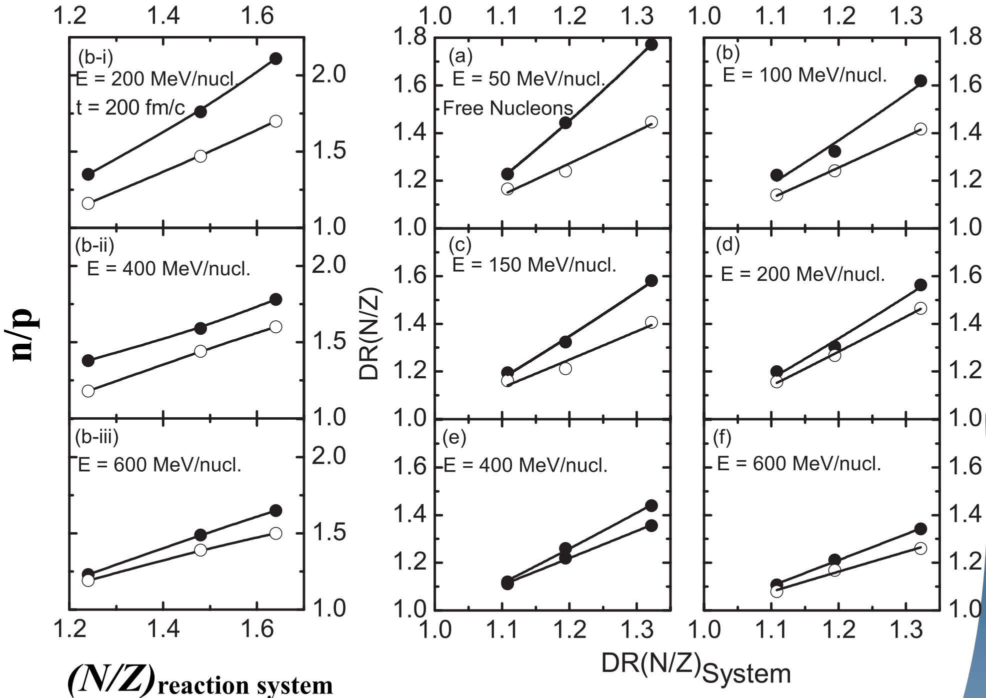
System & Beam Energy Dependence



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

future RI beam experiments

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



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

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

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

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

Collaboration

Domestic

- Korea University
  - Neutron detector R&D
  - TPC R&D
  - GEANT-4 simulation
- Chonbuk National University
  - Low energy physics
  - GEANT-4 simulation
- Pusan National University
  - TPC R&D
- Kyungpook National University
  - Si detector R&D
- Inha University
  - TPC tracking algorithm

International

- GSI
  - Triggerless DAQ
  - Diamond detector
- GANIL, Saclay, RIKEN, J-PARC
  - TPC electronics

23 people from 6 institutes

Looking for more collaborators from both domestic and international

➢ **To form international collaboration**

Budget

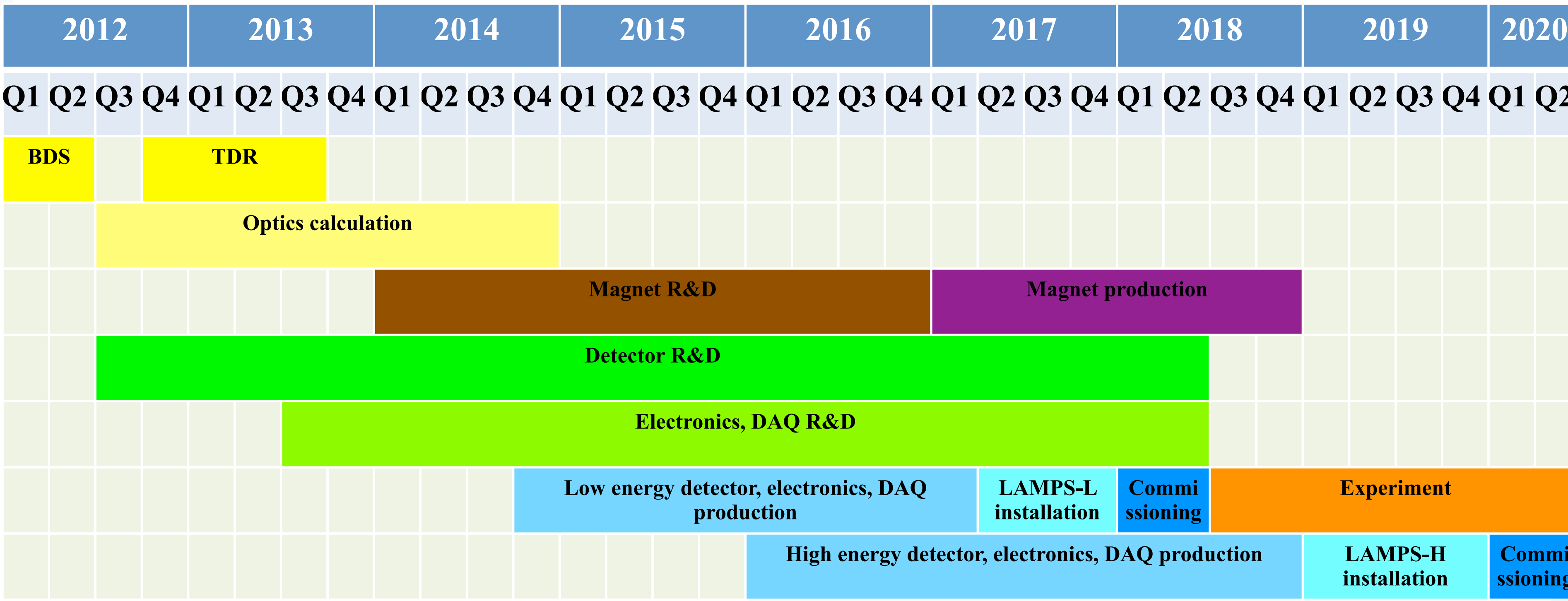
Item	Budget (M USD)
Low Energy Detector & Electronics	3.3
High Energy Detector & Electronics	26.7
Start Counter & Solid Target	0.6
DAQ & DAQ Electronics	2.2
Total	32.8 (-11.2)
Currently available budget	23.4 (21.6)

Item	Budget (M USD)
Dipole Spectrometer	8.9
Si-CsI	2.3
Total	11.2

In order to fit to currently available budget, dipole spectrometer and Si-CsI detecter at high energy experimental setup will be for the upgrade

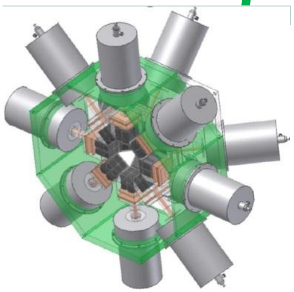
- Forward fragmentation measurement
- PDR/GDR resonance measurement
- Nuclear structure study (e.g. Coulomb breakup)

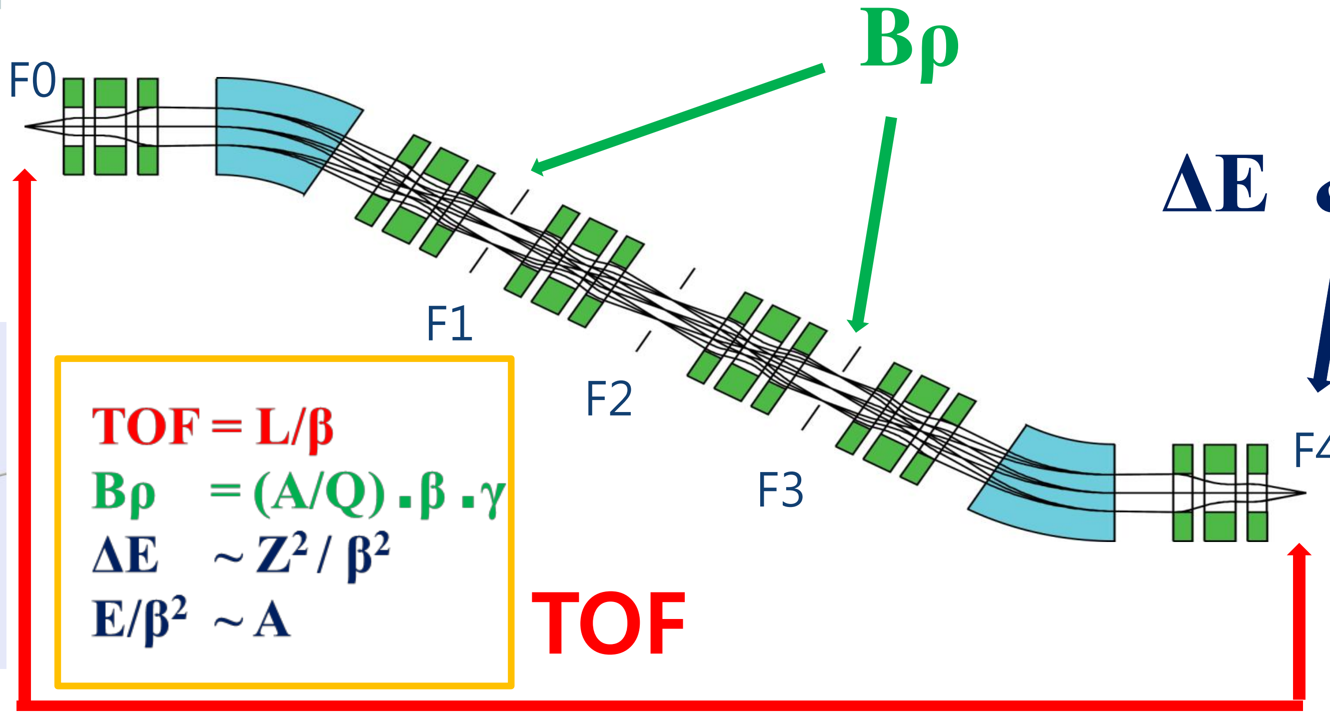
Schedule


2012
2013
2014
2015
2016
2017
2018
2019
2020
Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2
BDS
TDR
Optics calculation
Magnet R&D
Magnet production
Detector R&D
Electronics, DAQ R&D
Low energy detector, electronics, DAQ production
LAMPS-L installation
Commissioning
Experiment
High energy detector, electronics, DAQ production
LAMPS-H installation
Commissioning

Detectors in ZDS

- Particle identification of RI beam
  - Select nuclei of interest
  - Experiment with several nucleus at the same time
- **Bρ- ΔE-TOF** method





$$TOF = L/\beta$$
$$B\rho = (A/Q)\cdot\beta\cdot\gamma$$
$$\Delta E \sim Z^2/\beta^2$$
$$E/\beta^2 \sim A$$

$\sigma(x) < 0.33$ mm

$\sigma(timing) < 24$ ps

ZDS detector requirements

Institute for Basic Science
Rare Isotope Science Project

Summary

- **RAON is RI beam accelerator in Korea**
  - **-RAON will provide high purity, high intensity various RI beams (e.g. 10^7 pps ^{132}Sn at 250*A* MeV)**
- **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: Si-CsI detector & neutron detector**
    - **▸High energy: 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 both domestic and oversea**
    - **▸Forming international collaboration**

Any comments or suggestions are welcome!!!