ASY-EOS 2012: International Workshop on Nuclear Symmetry Energy and Reaction Mechanisms
Siracusa, Sicily, Italy, September 4-6, 2012

New Opportunity for Nuclear Symmetry Energy using LAMPS in Korea Rare Isotope Accelerator

Byungsik Hong (Korea University)

Outline

- Introduction to RISP (Rare Isotope Science Project)
- Plan for the symmetry-energy study with LAMPS
- Summary

Brief History of RISP

1. International Science-Business Belt (ISBB) plan (Jan. 2009)
2. Preliminary Design Report (Mar. 2009-Feb. 2010)
3. Conceptual Design Report (Mar. 2010-Feb. 2011)
4. International Advisory Committee (Jul. 2011)
5. Institute for Basic Science (IBS) established (Nov. 2011)
6. Rare Isotope Science Project (RISP) launched (Dec. 2011)
   - *Rare isotope accelerator complex is the representative facility of IBS*
7. Technical Advisory Committee (May 2012)
8. Baseline Design Summary (Jun. 2012)
9. International Advisory Committee (Jul. 2012)
10. Technical Design Report (present)

Site Plan

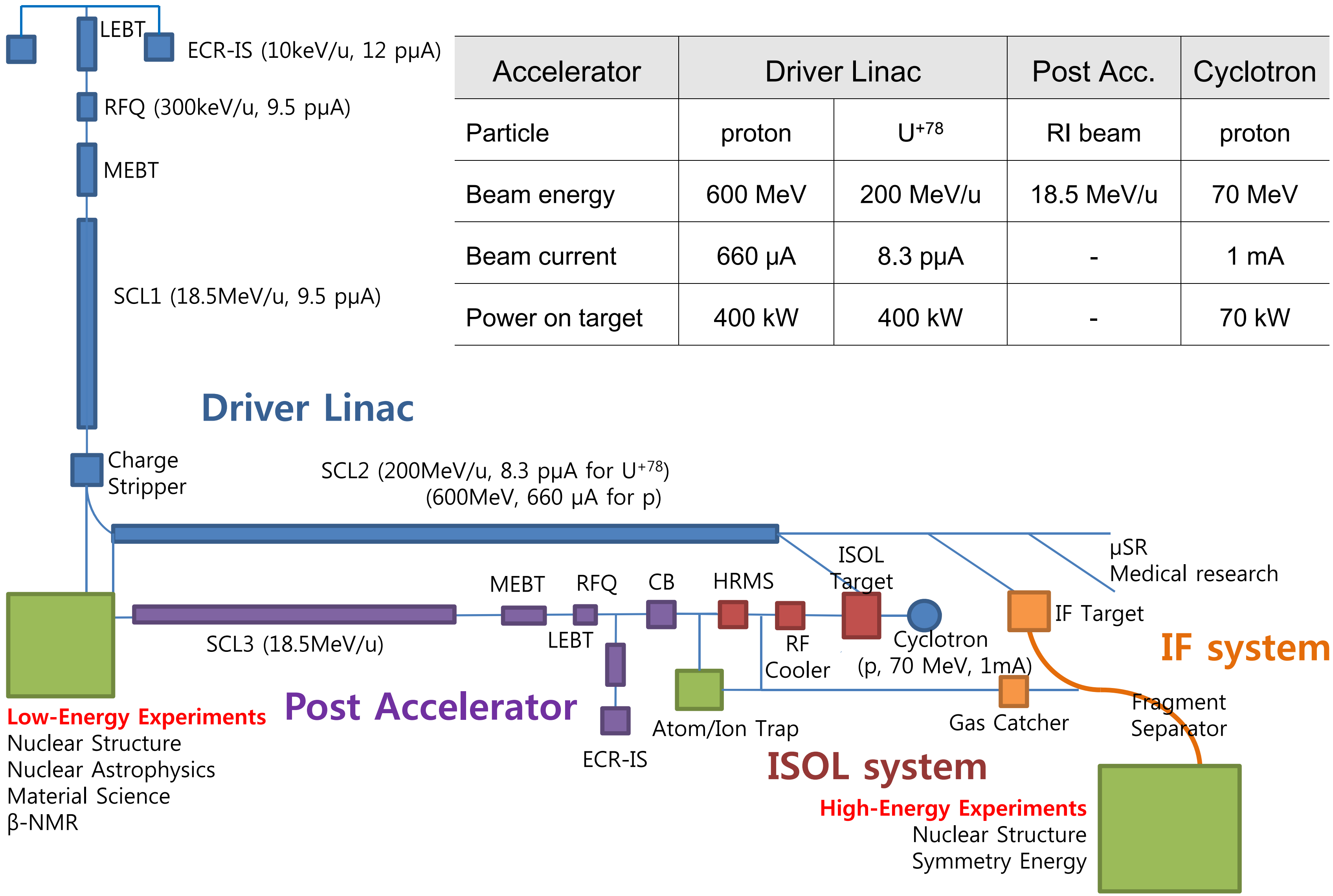

In Daejeon city, ~150 km south of Seoul
Rare Isotope Accelerator Complex

Technical Specification

1. High-intensity RI beams by ISOL & IF
   - 70kW ISOL from direct fission of ^{238}U target induced by high-current proton beams (70 MeV, 1 mA)
   - 400kW IF by high-current ^{238}U beams (200 MeV/u, 8 pμA)
2. High-energy, high-intensity & high-quality neutron-rich RI beams
   - ^{132}Sn up to ~10^8 pps at 250 MeV/u
3. More exotic RI beams by combining ISOL & IF
4. Multiple operation modes for maximum use of the facility

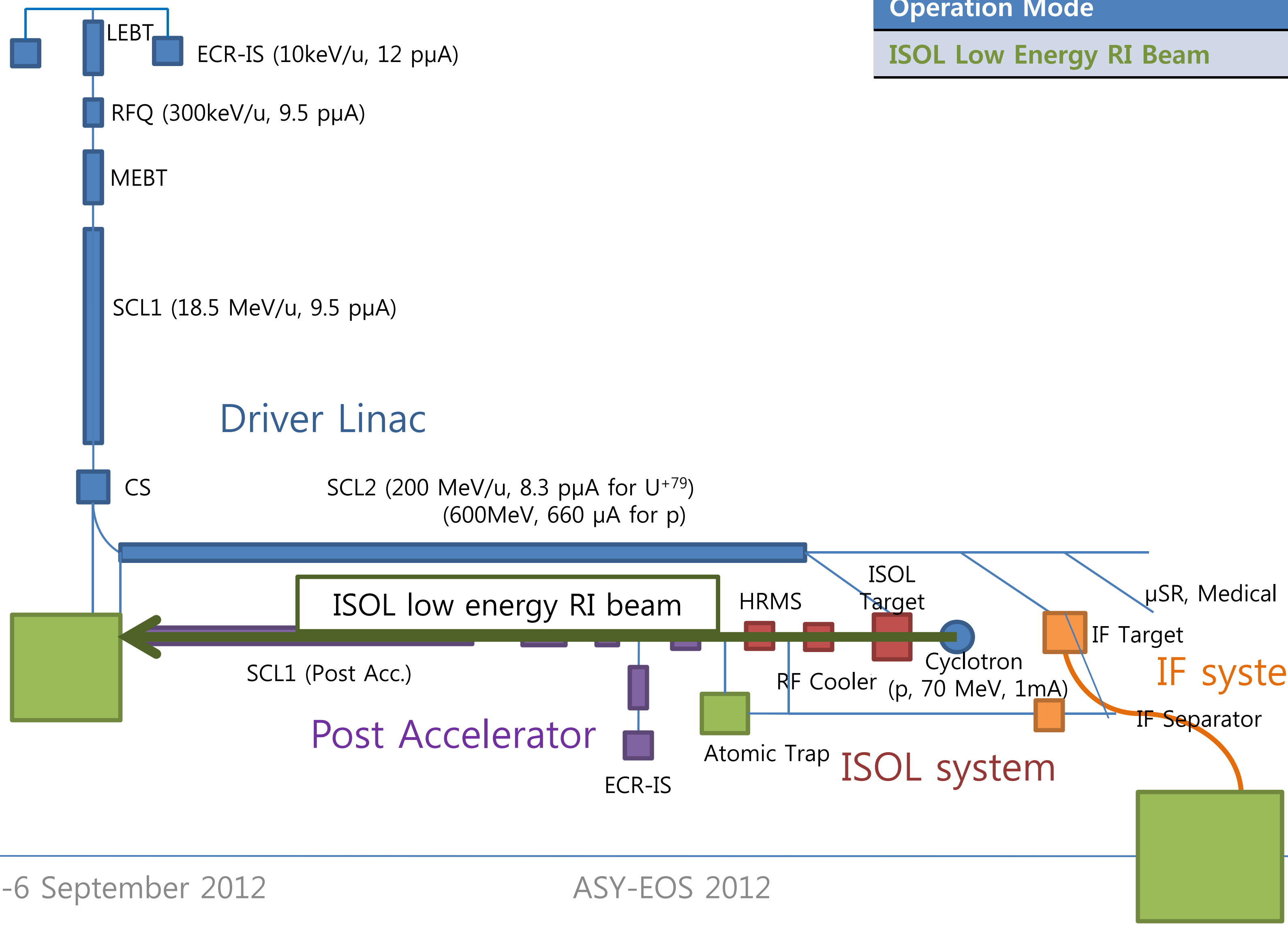
RISP Accelerator Complex

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



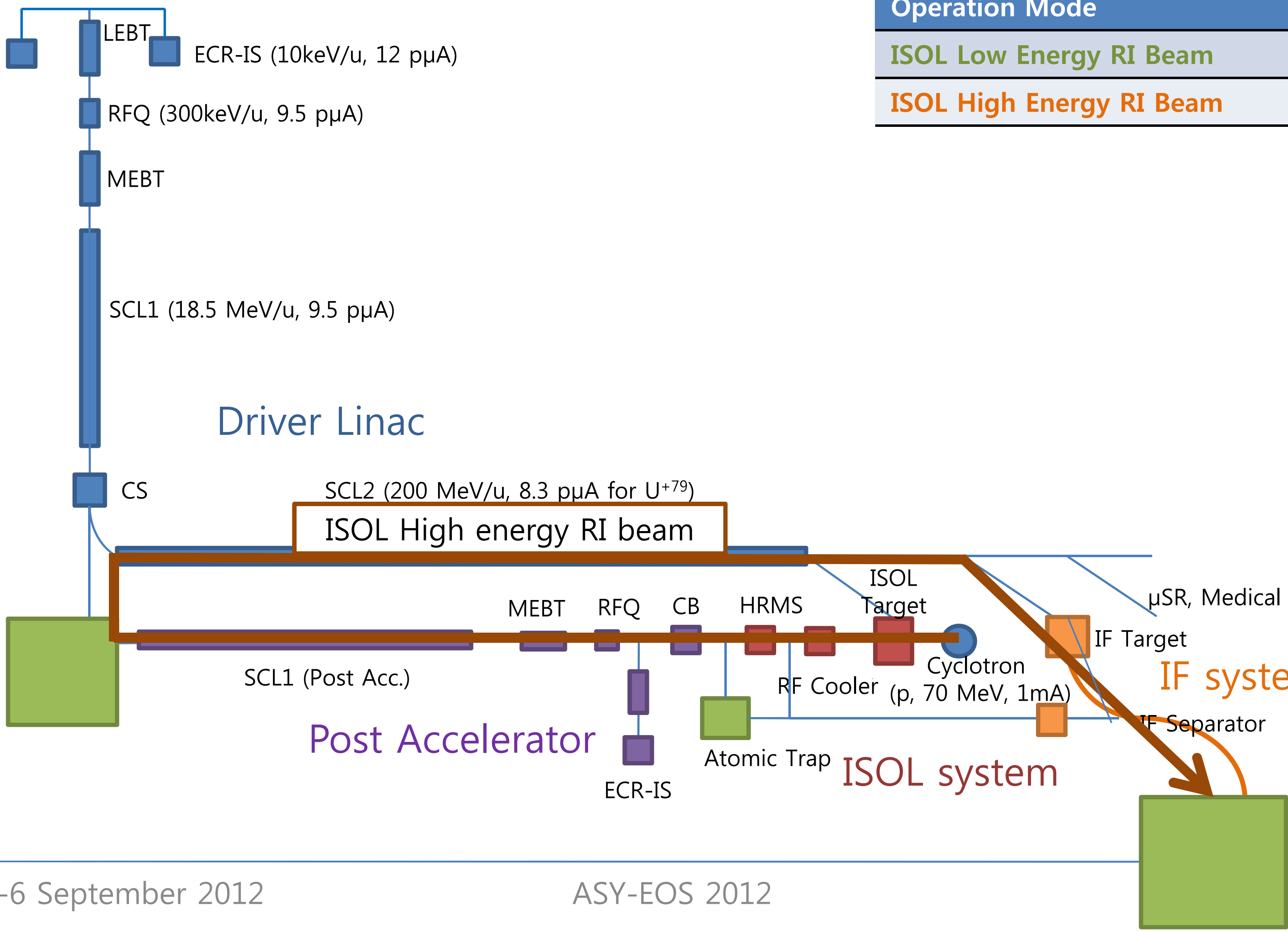
Operation Mode

Operation Mode
ISOL Low Energy RI Beam



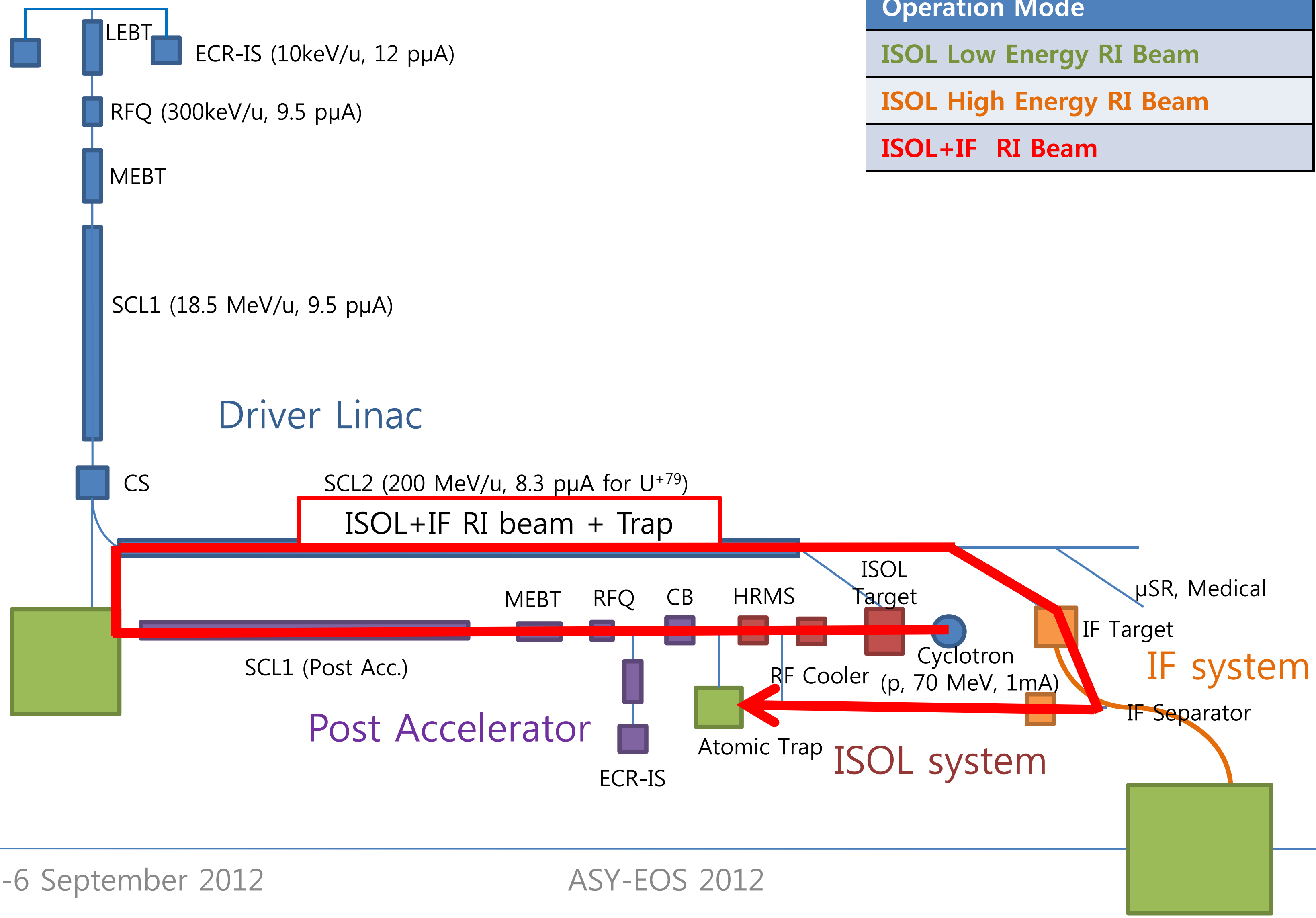
Operation Mode

Operation Mode
ISOL Low Energy RI Beam
ISOL High Energy RI Beam



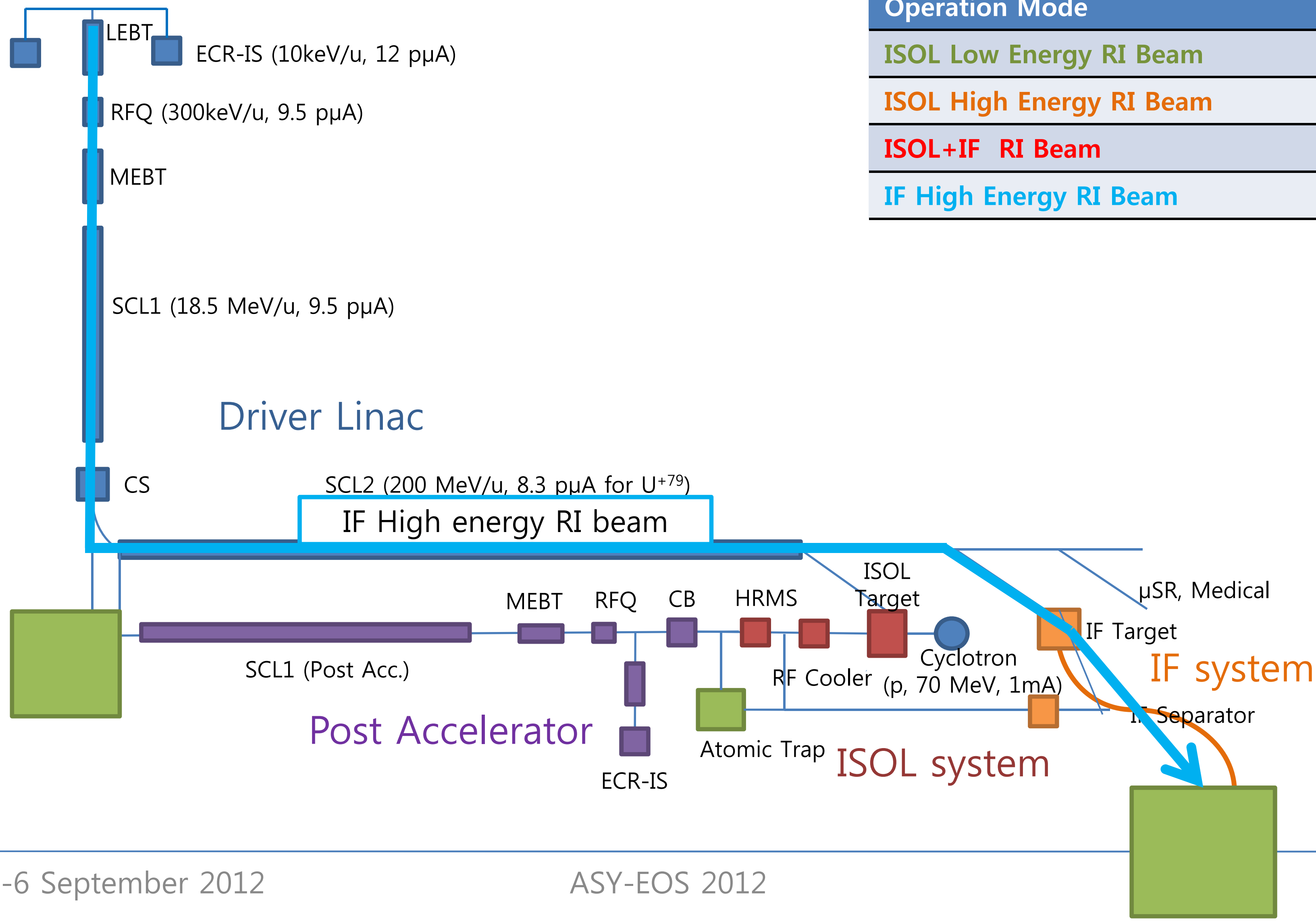
Operation Mode

Operation Mode
ISOL Low Energy RI Beam
ISOL High Energy RI Beam
ISOL+IF RI Beam



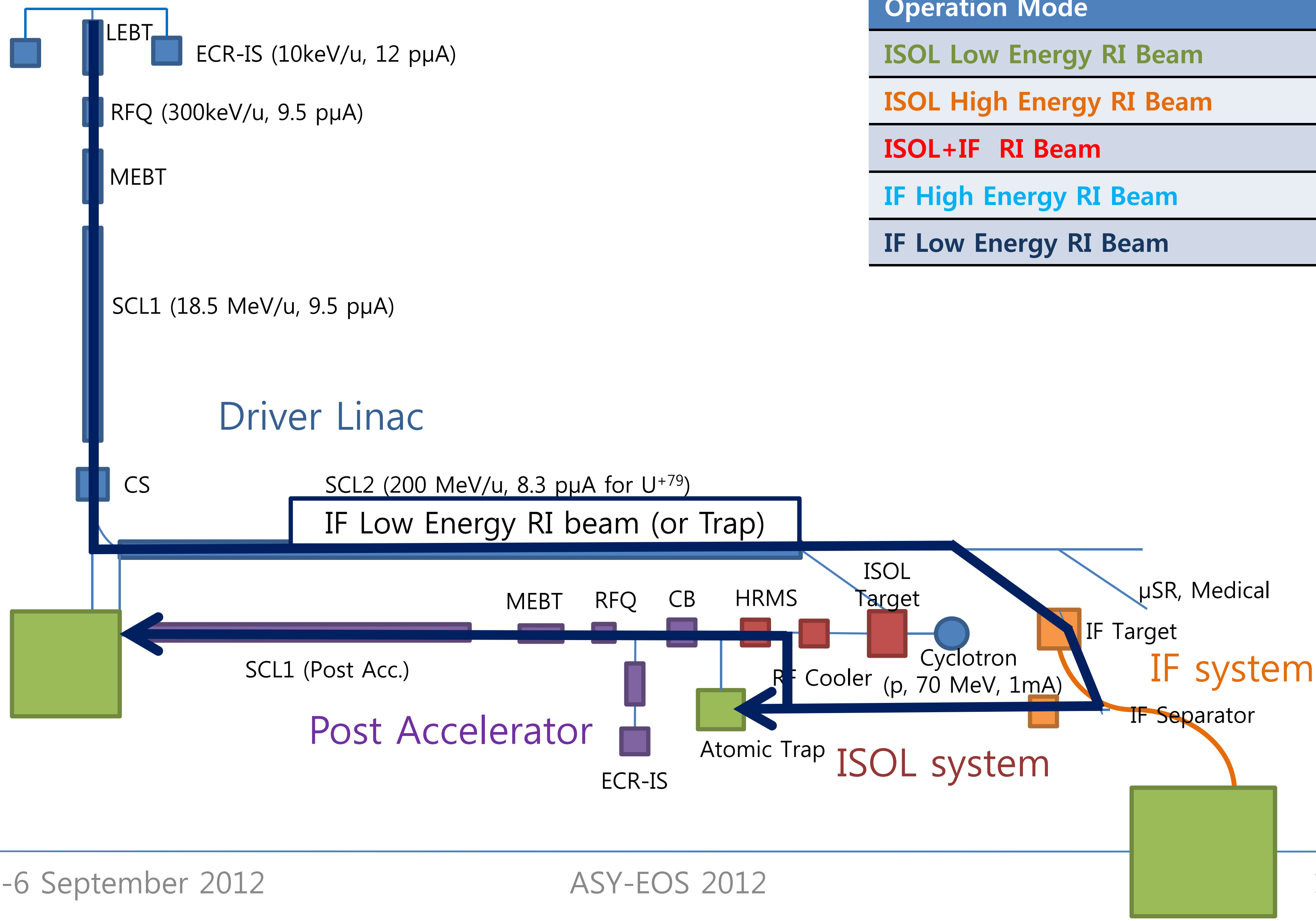
Operation Mode

Operation Mode
ISOL Low Energy RI Beam
ISOL High Energy RI Beam
ISOL+IF RI Beam
IF High Energy RI Beam



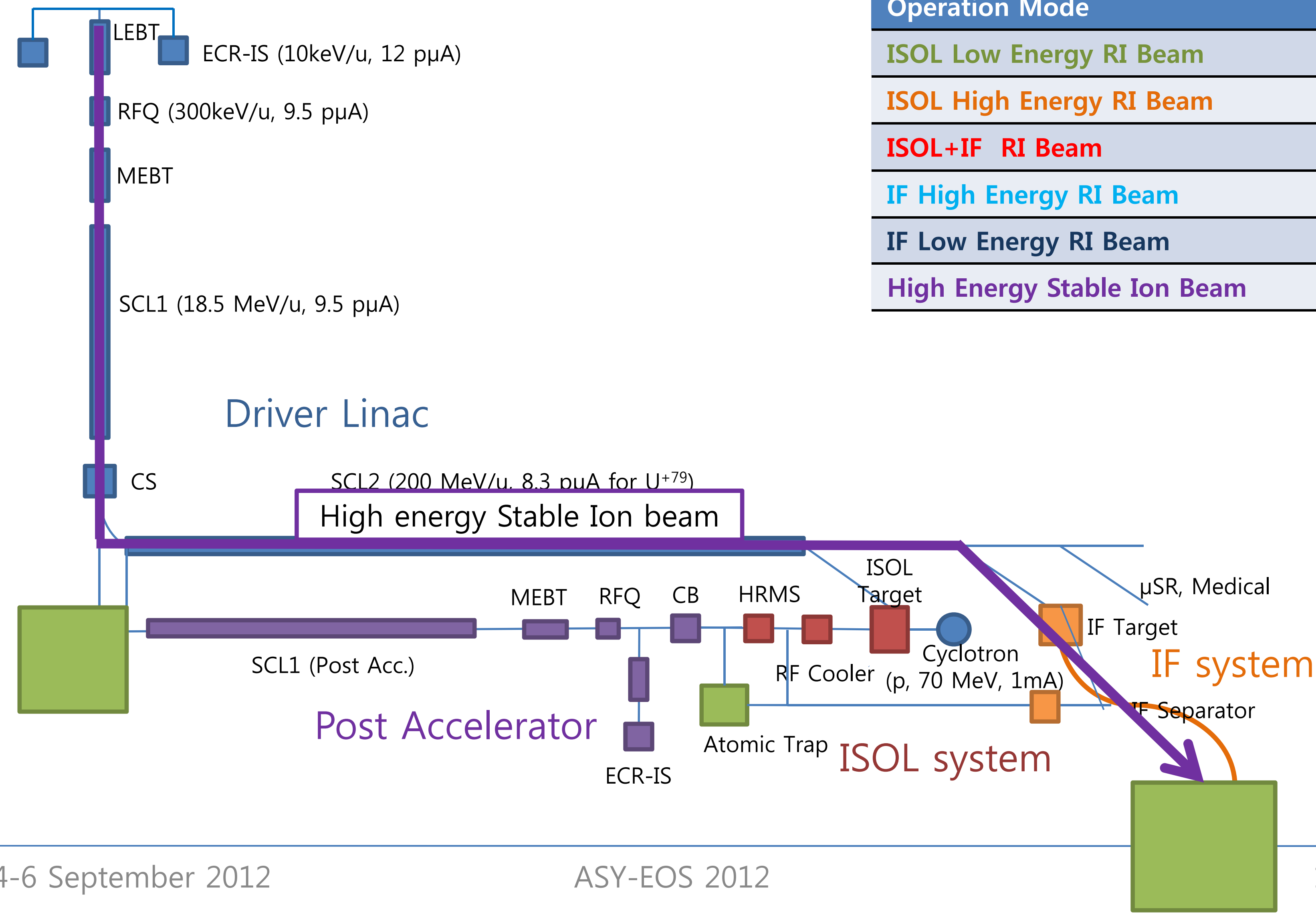
Operation Mode

Operation Mode
ISOL Low Energy RI Beam
ISOL High Energy RI Beam
ISOL+IF RI Beam
IF High Energy RI Beam
IF Low Energy RI Beam



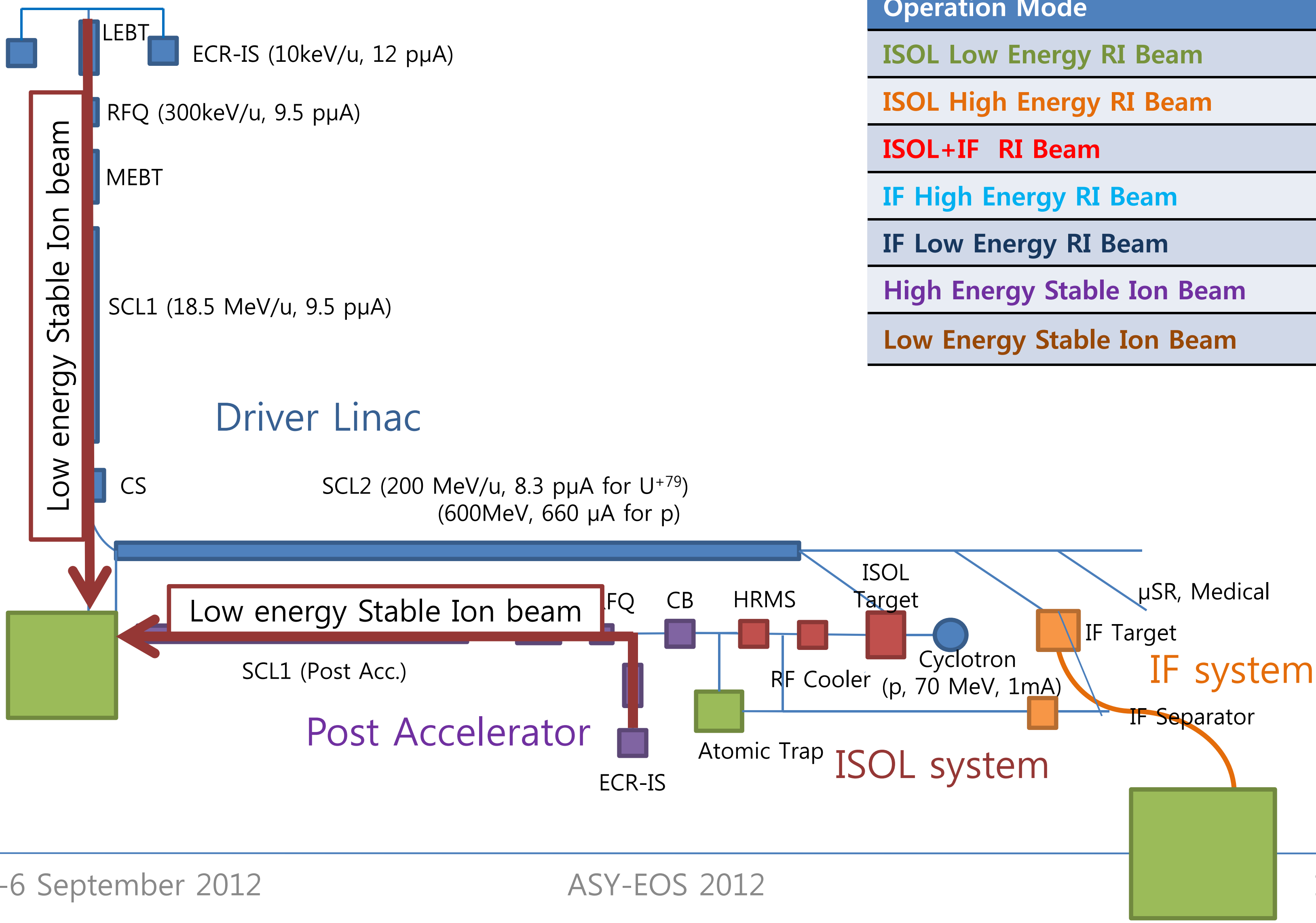
Operation Mode

Operation Mode
ISOL Low Energy RI Beam
ISOL High Energy RI Beam
ISOL+IF RI Beam
IF High Energy RI Beam
IF Low Energy RI Beam
High Energy Stable Ion Beam

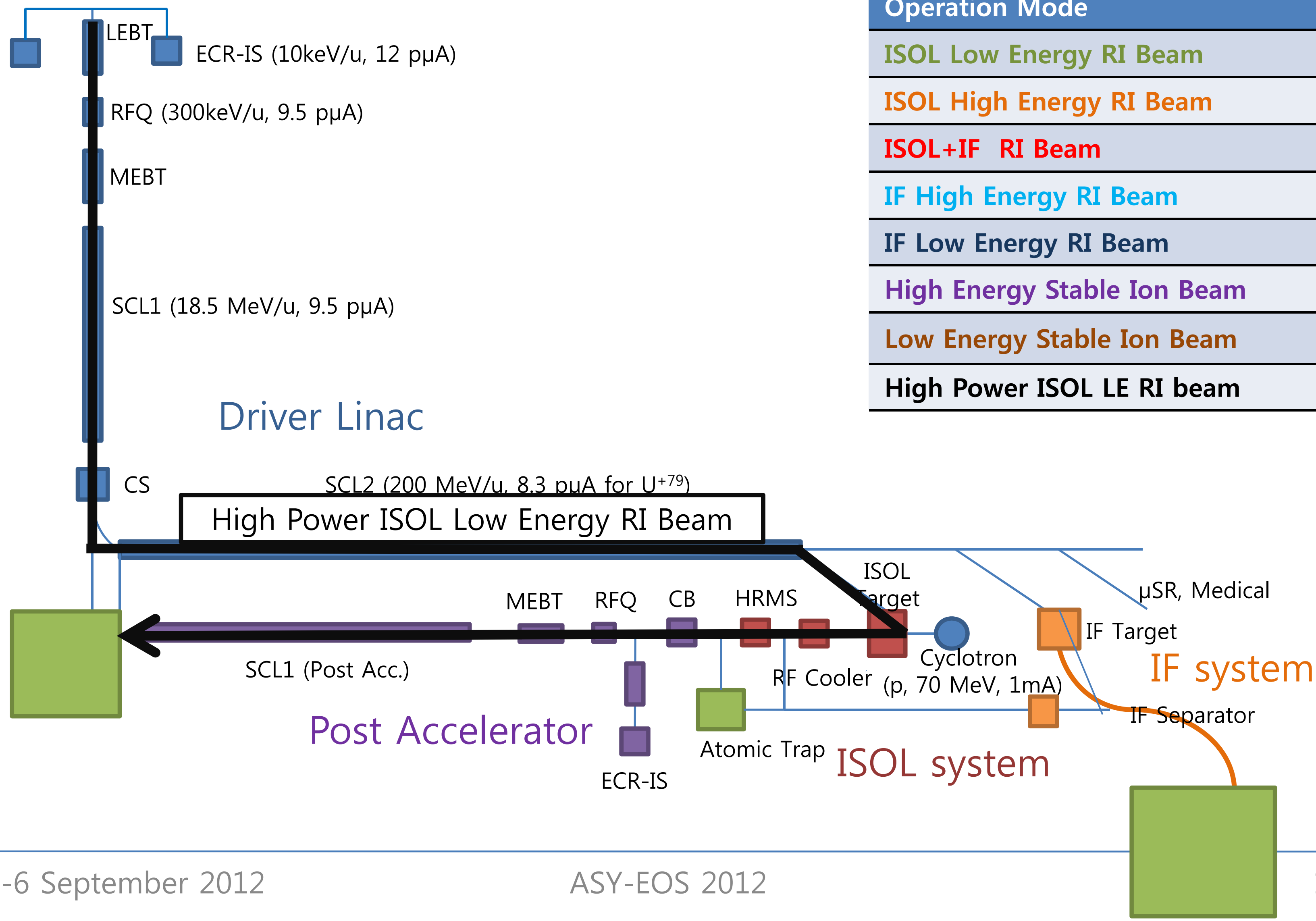


Operation Mode

Operation Mode
ISOL Low Energy RI Beam
ISOL High Energy RI Beam
ISOL+IF RI Beam
IF High Energy RI Beam
IF Low Energy RI Beam
High Energy Stable Ion Beam
Low Energy Stable Ion Beam

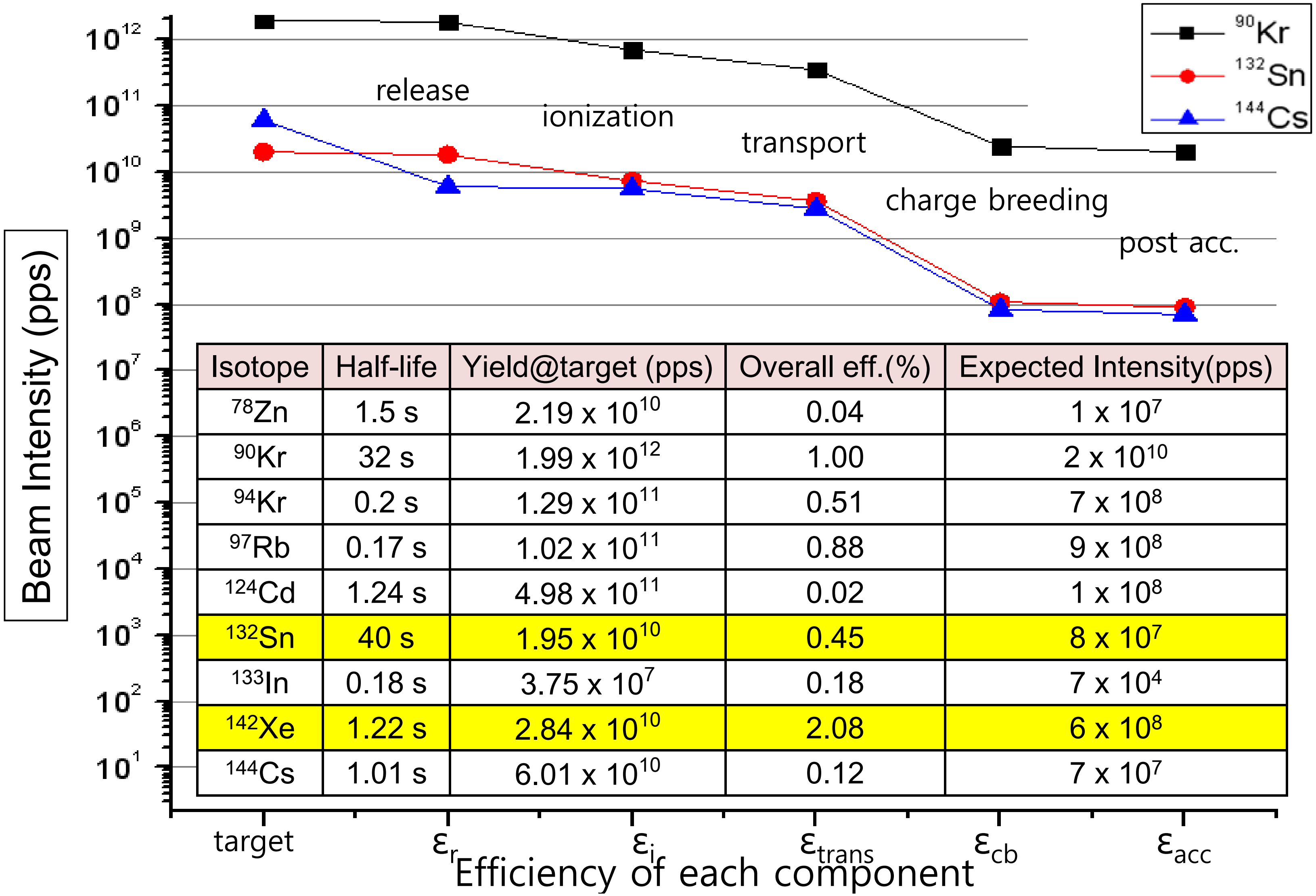


Operation Mode



Operation Mode
ISOL Low Energy RI Beam
ISOL High Energy RI Beam
ISOL+IF RI Beam
IF High Energy RI Beam
IF Low Energy RI Beam
High Energy Stable Ion Beam
Low Energy Stable Ion Beam
High Power ISOL LE RI beam

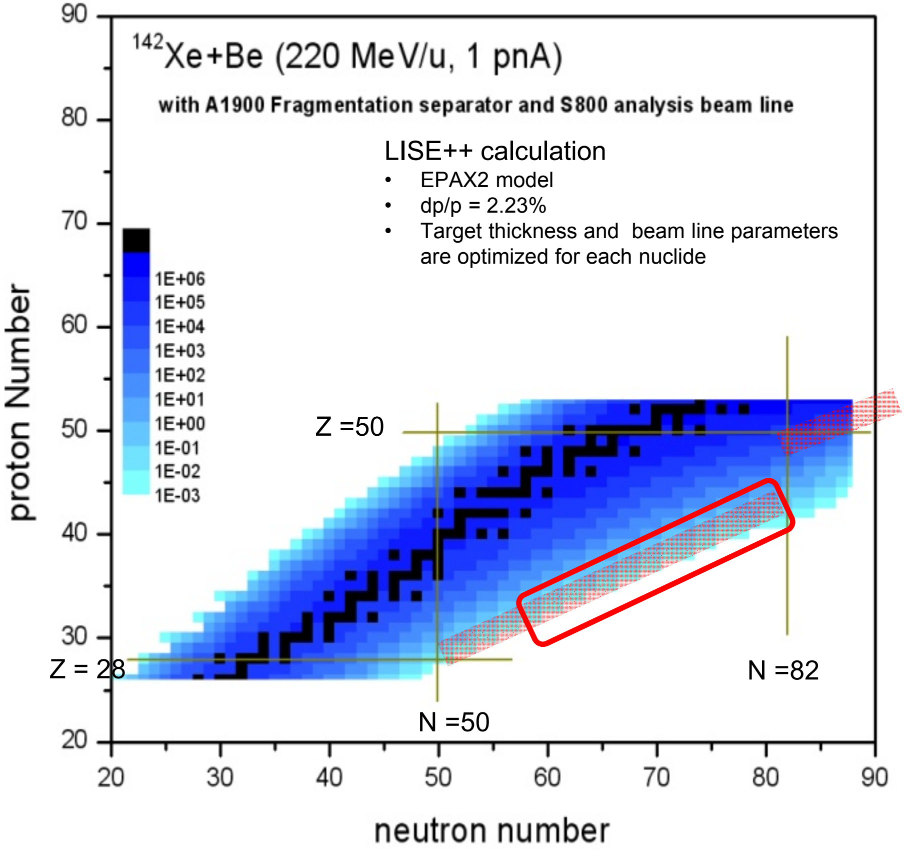
ISOL Yield Estimation

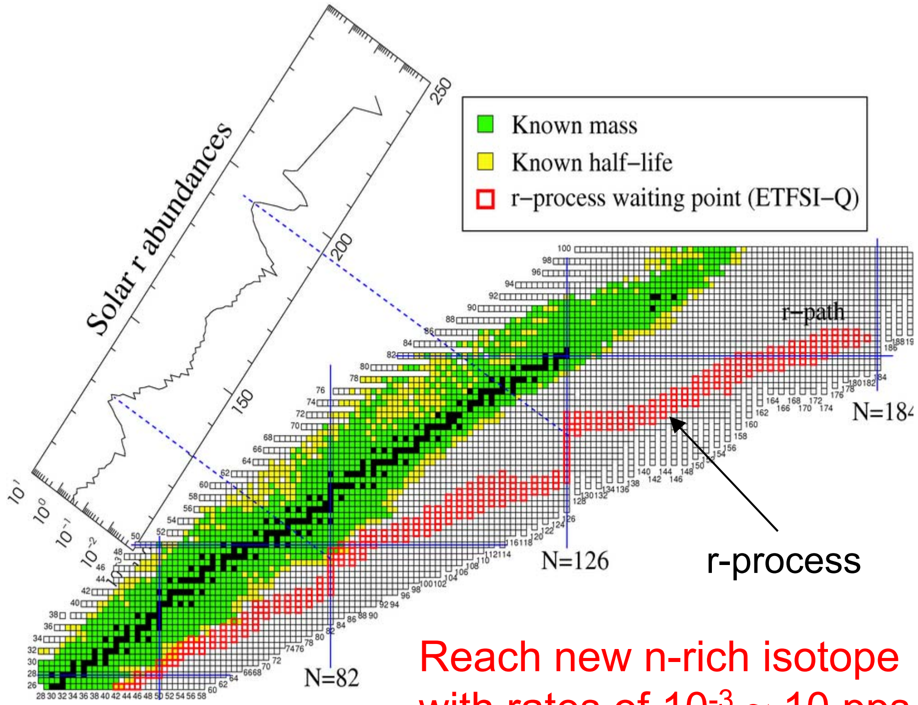


Isotope	Half-life	Yield@target (pps)	Overall eff.(%)	Expected Intensity(pps)
^{78}Zn	1.5 s	2.19×10^{10}	0.04	1×10^{7}
^{90}Kr	32 s	1.99×10^{12}	1.00	2×10^{10}
^{94}Kr	0.2 s	1.29×10^{11}	0.51	7×10^{8}
^{97}Rb	0.17 s	1.02×10^{11}	0.88	9×10^{8}
^{124}Cd	1.24 s	4.98×10^{11}	0.02	1×10^{8}
^{132}Sn	40 s	1.95×10^{10}	0.45	8×10^{7}
^{133}In	0.18 s	3.75×10^{7}	0.18	7×10^{4}
^{142}Xe	1.22 s	2.84×10^{10}	2.08	6×10^{8}
^{144}Cs	1.01 s	6.01×10^{10}	0.12	7×10^{7}

* Overall efficiency was estimated using the information from existing ISOL systems. (HRIBF, CERN-ISOLDE, KEK-ISOL, etc.)

More Exotic RI Beams





Reach new n-rich isotope with rates of 10^{-3} ~ 10 pps

nuclide	Estimated Intensity (pps)
^{110}Y	1.8
^{110}Zr	1.8
^{114}Nb	1.1
^{116}Mo	3.8
^{118}Tc	1.4

Operational mode: ^{142}Xe (ISOL) → Post-Accelerator → Driver Linac → IF target → Fragment Separator → Experiments

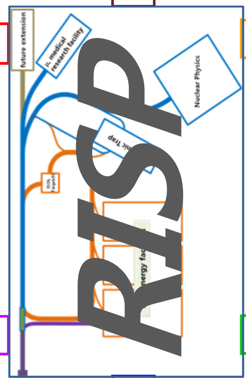
Note that ~10^3 times higher than ^{136}Xe (350 MeV/u, 10 pnA)+Be

Research Topics

➢ **Nuclear Physics**
- Exotic nuclei near the neutron drip line
- Equation-of-state (EoS) of nuclear matter

➢ **Nuclear Astrophysics**
- Origin of nuclei
- Neutron stars and supernovae
- Nucleosynthesis Superheavies

➢ **Atomic/Particle Physics**
- Atomic trap
- Fundamental symmetries



➢ **Medical & Biosciences**
- Advanced therapy technology
- Mutation of DNA
- New isotopes for imaging

➢ **Nuclear data with fast neutrons**
- Basic nuclear reaction data for future nuclear energy
- Nuclear waste transmutation

➢ **Material science**
- Production & Characterization of new materials
- β-NMR / μSR

Research Topics

Origin of Elements
Stella Evolution
Formation of Matter

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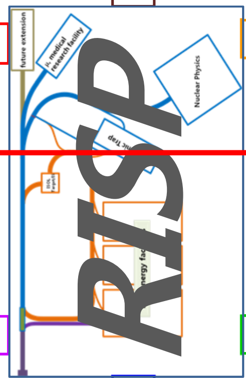

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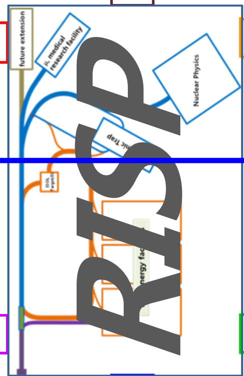

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  - Production & Characterization of new materials
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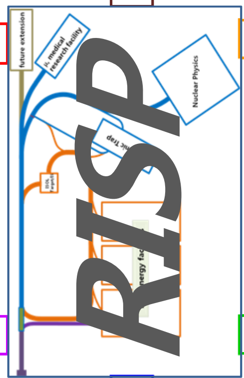
Application of RI Isotopes

Experimental Systems

- **Nuclear Physics**
  - Large-Acceptance Multipurpose Spectrometer (LAMPS)

- **Nuclear Astrophysics**
  - Korea Recoil Spectrometer (KRS)
  - Gas-Filled Separator for SHE

- **Atomic/Particle Physics**
  - Atom & Ion Trap System



- **Medical & Biosciences**
  - Heavy-Ion Therapy Unit
  - Irradiation Facility

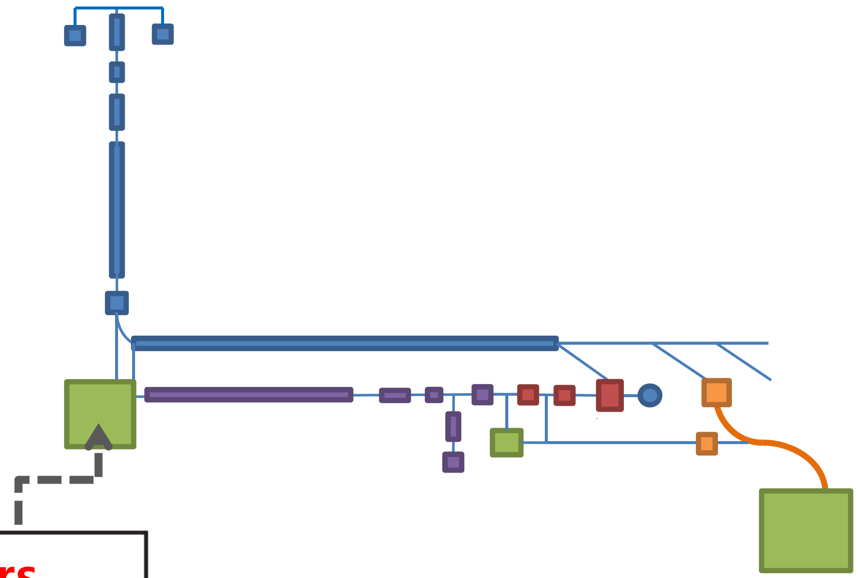
- **Nuclear data with fast neutrons**
  - Neutron Time-of-Flight System (n-TOF)

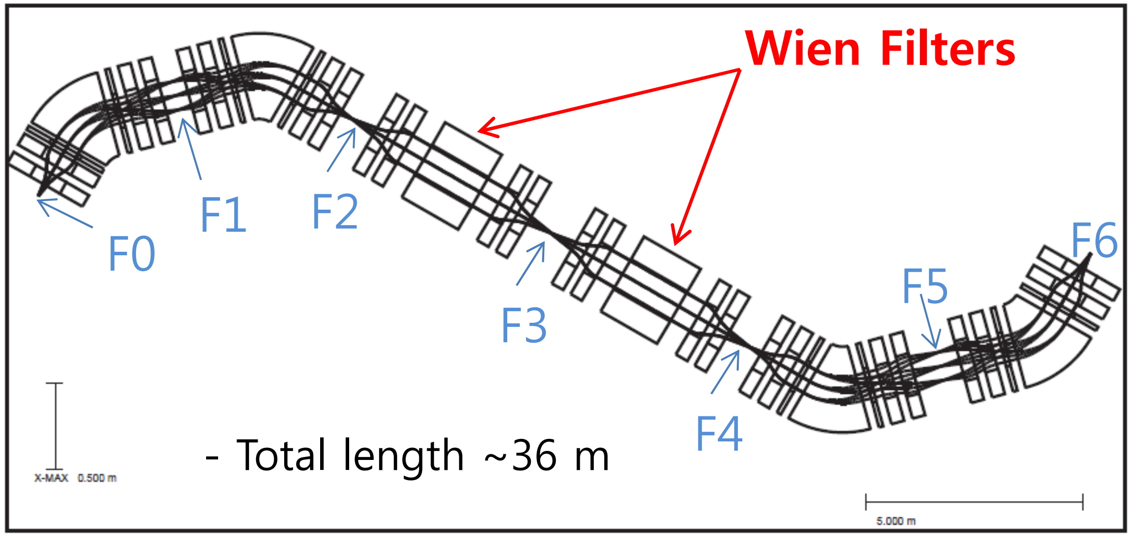
- **Material science**
  - β-NMR /NQR, μ-SR
  - Laser Selective Ionizer

Recoil Spectrometer (KRS)

- **Specification**

Maximum magnetic rigidity	~1.5 T·m
Mass resolution (ΔM/M)	< 0.5 %
Momentum resolution (Δp/p)	~0.05 %
Angular acceptance	< ±100 mrad
Background reduction	< 10^{-15}

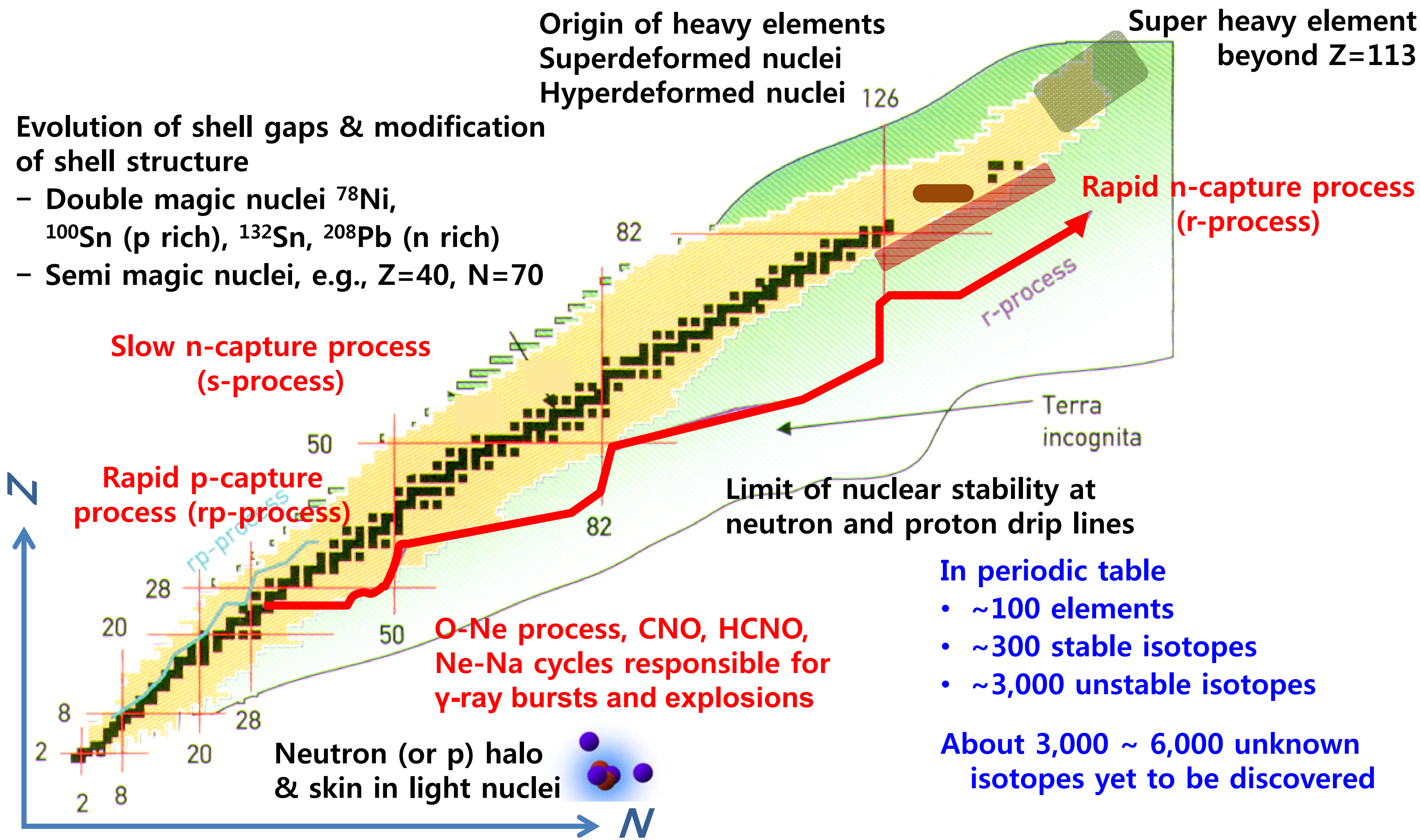




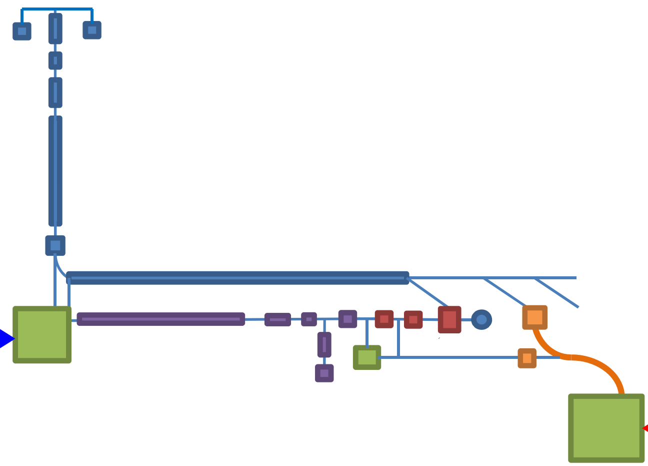
4 dipoles +
24 quadruples +
8 multipoles +
2 Wien filters

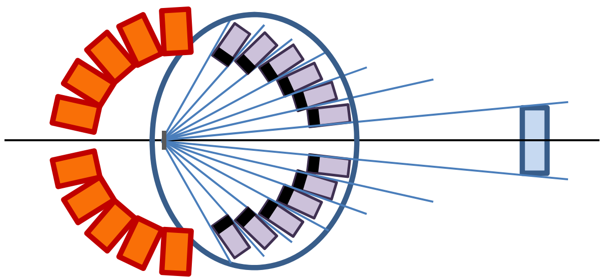
Double achromatic with
electrostatic components

Physics Program with KRS

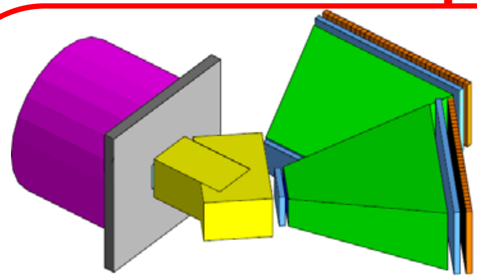


Large-Acceptance Multipurpose Spectrometer (LAMPS)

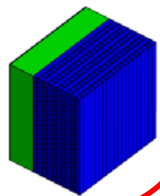




LAMPS at low-energy exp. hall
(LAMPS-L)



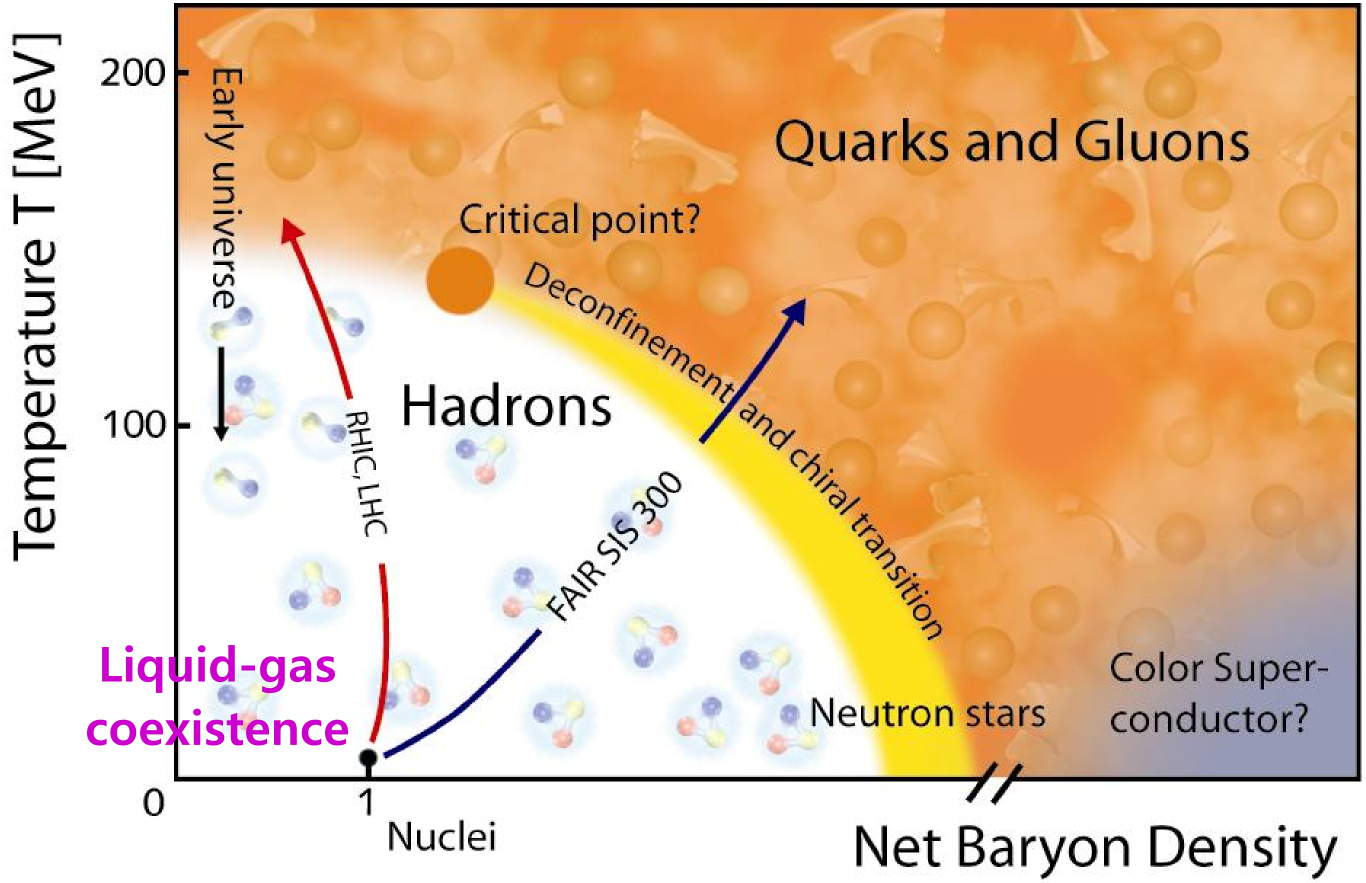
LAMPS at high-energy exp. hall
(LAMPS-H)



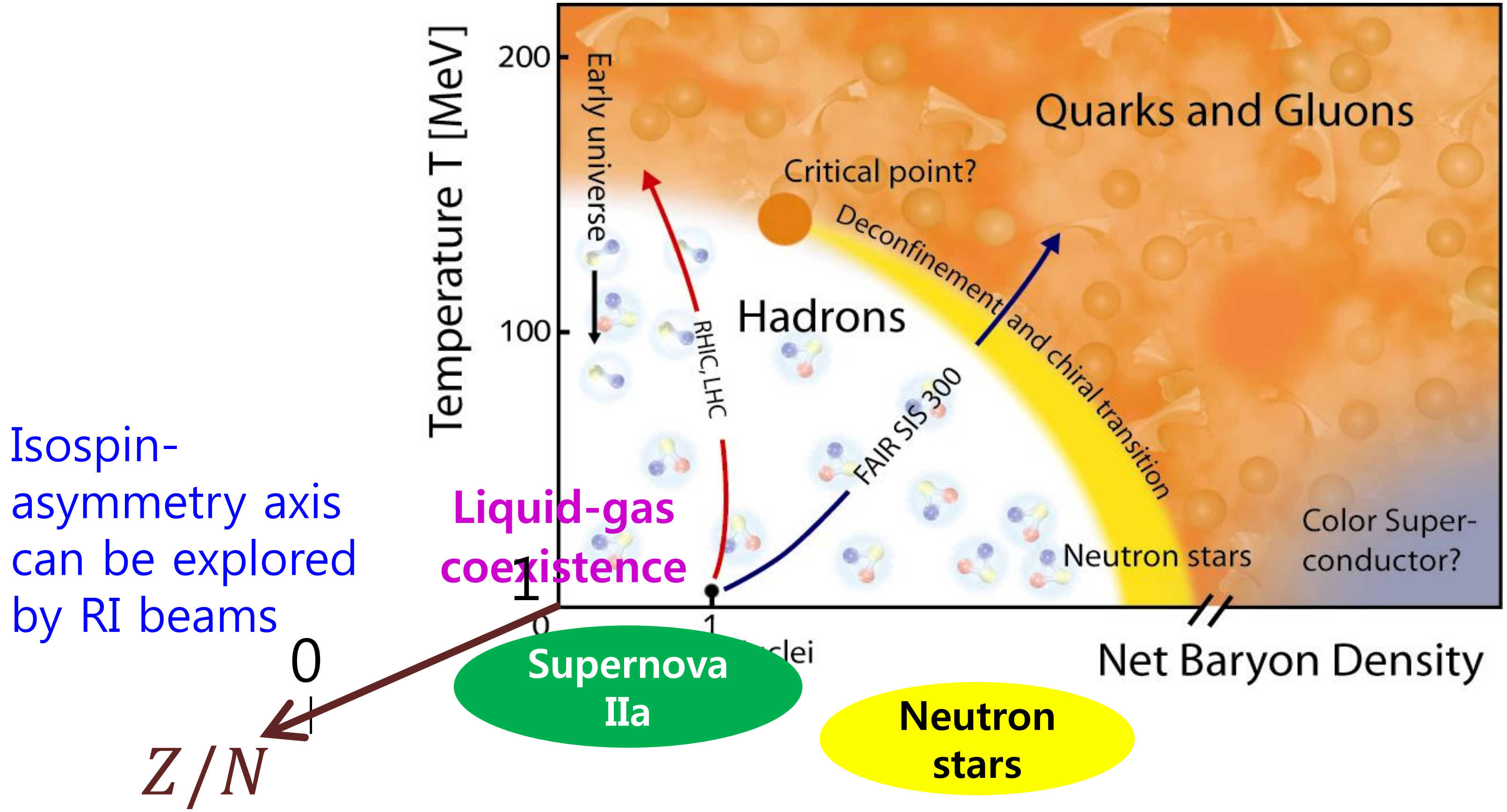
Purpose of Nuclear Matter Study

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 densities
3. Modification of hadronic properties in dense medium
4. Important for astrophysics
   - Supernovae
   - Neutron stars

Nuclear Phase Diagram



Nuclear Phase Diagram



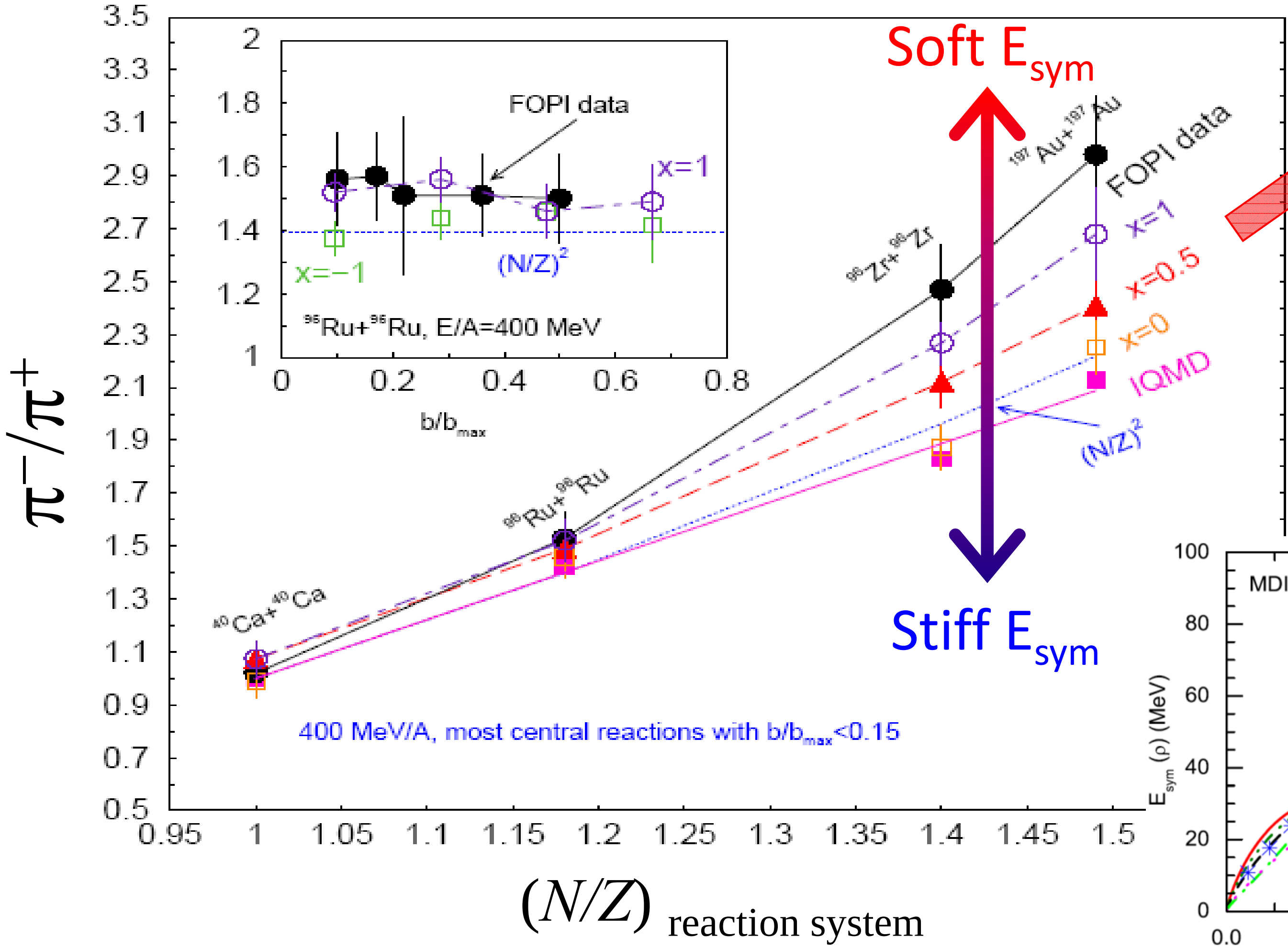
For the isospin dependence of EOS, nuclear symmetry energy will play an important role!

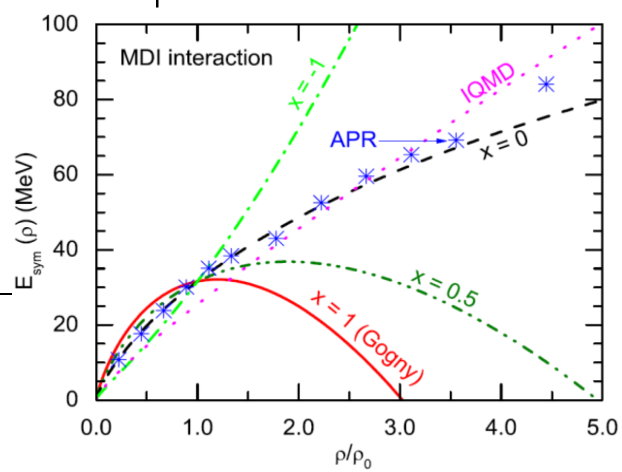
Experimental Observables for E_{sym}

1. Particle ratios
    - n/p, $^3H/^3He$, $^7Li/^7Be$, etc.
    - π^-/π^+
2. Collective flow
    - v_1 & v_2 of n, p, and heavier clusters
    - Azimuthal angle dependence of n/p ratio w.r.t. the R.P.
3. Pygmy dipole resonance
    - Energy spectra of gammas
    - Sizes of n-skins for unstable nuclei
4. Various isospin-dependent phenomena
    - Isospin fractionation and isoscaling in nuclear multifragmentation
    - Isospin diffusion (transport)

π^-/π^+ Ratio

Data: FOPI Collaboration, Nucl. Phys. A 781, 459 (2007)





Directed Flow

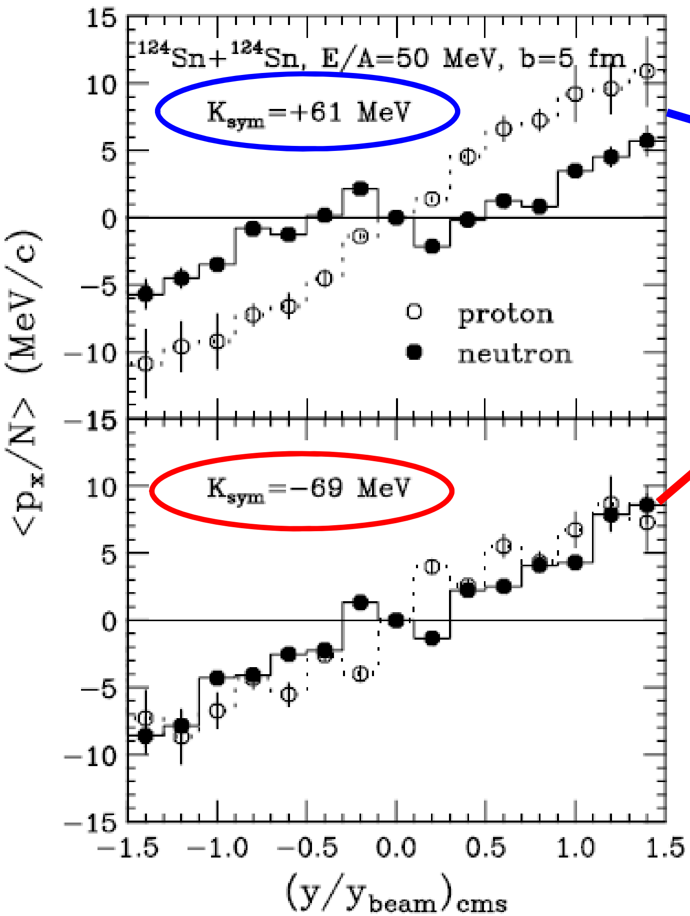
B.-A. Li,
PRL 85, 4221
(2000)

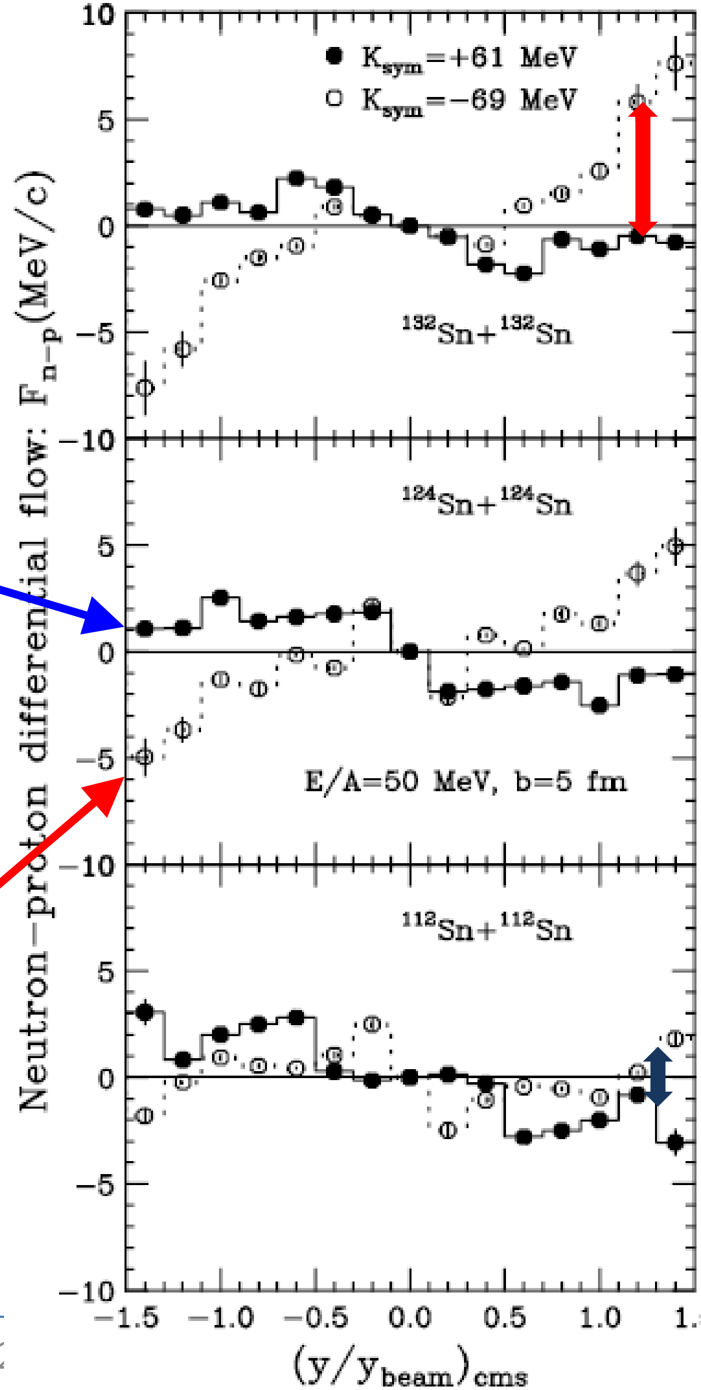
$$K_{sym} \equiv 9\rho_0^2 \frac{\partial^2 E_{sym}(\rho)}{\partial \rho^2}\bigg|_{\rho=\rho_0}$$

Stiff

Also known as v_1

Super
Soft





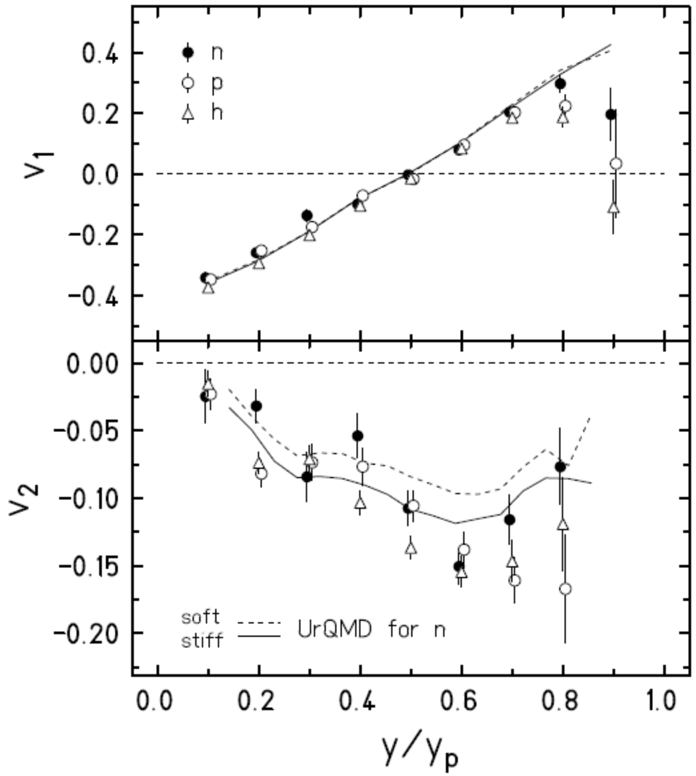
Large
N/Z

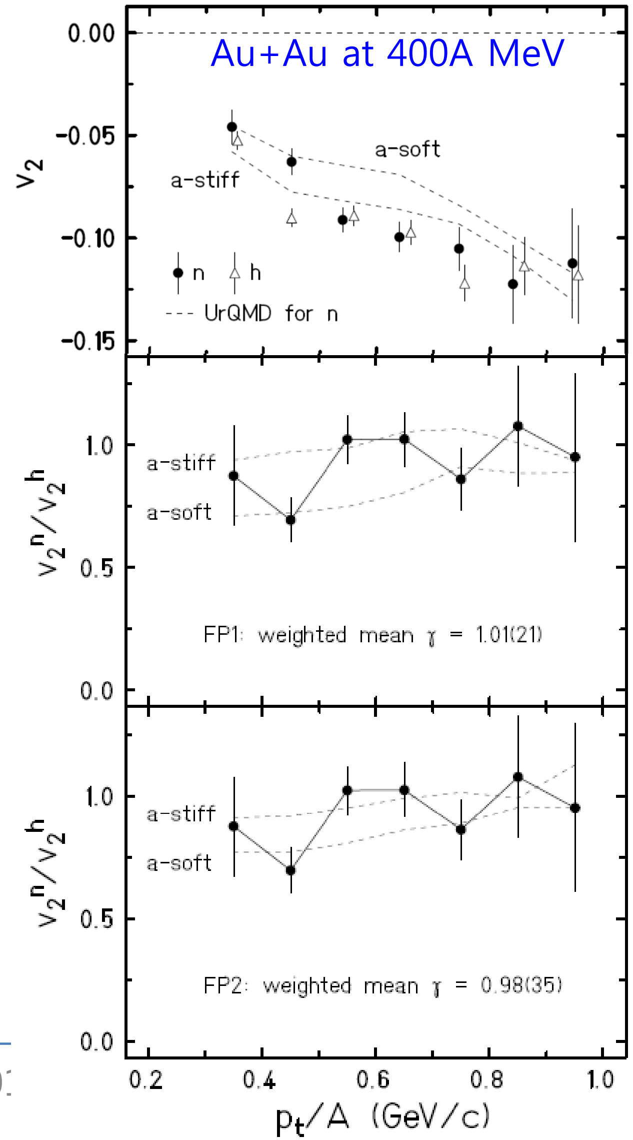
Small
N/Z

Elliptic Flow

But, ...

P. Russotto et al., PLB 697, 471 (2011)





v_2 may be more sensitive!

Isospin Diffusion Parameter: Isospin Tracer

Isospin diffusion occurs only in asymmetric systems A+B

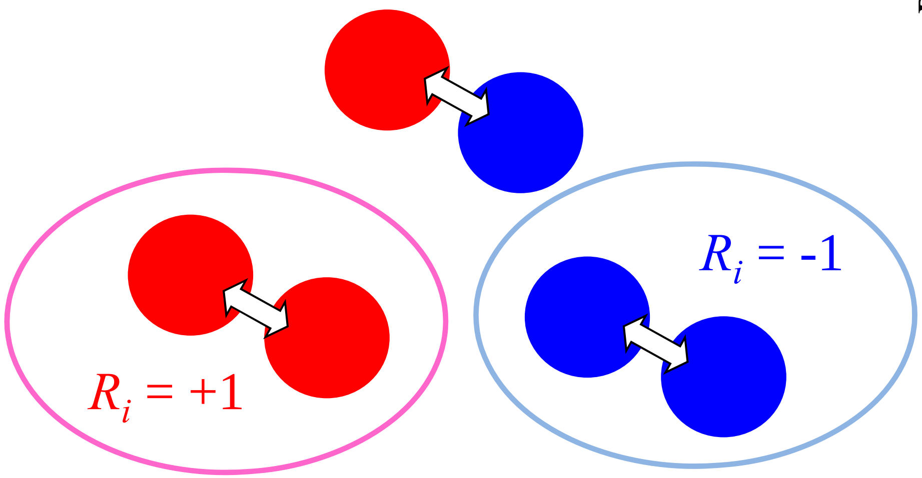
(No isospin diffusion between symmetric systems)

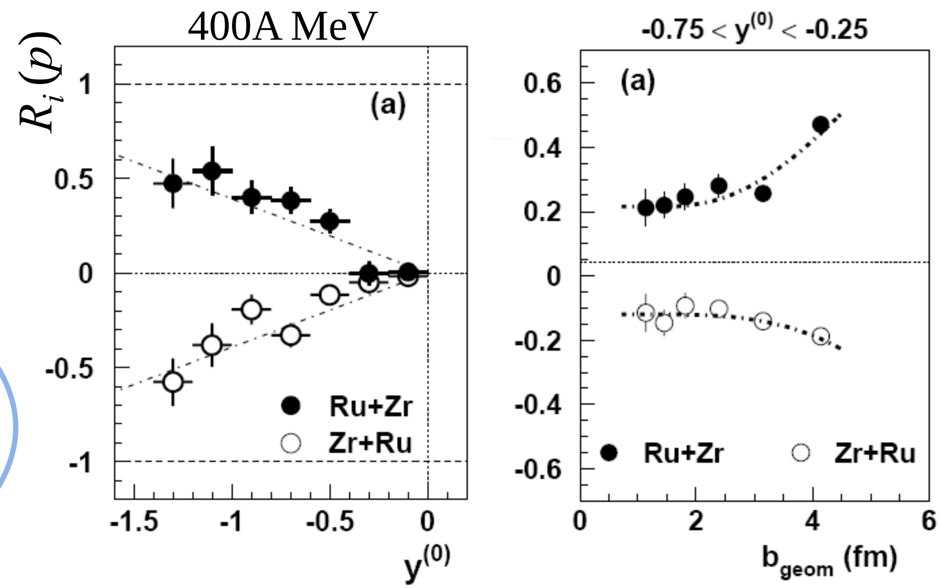
$$R_i = 2\frac{N^{AB} - (N^{AA} + N^{BB})/2}{N^{AA} - N^{BB}}$$

F. Rami et al., FOPI, PRL 84, 1120 (2000)

B. Hong et al., FOPI, PRC 66, 034901 (2002)

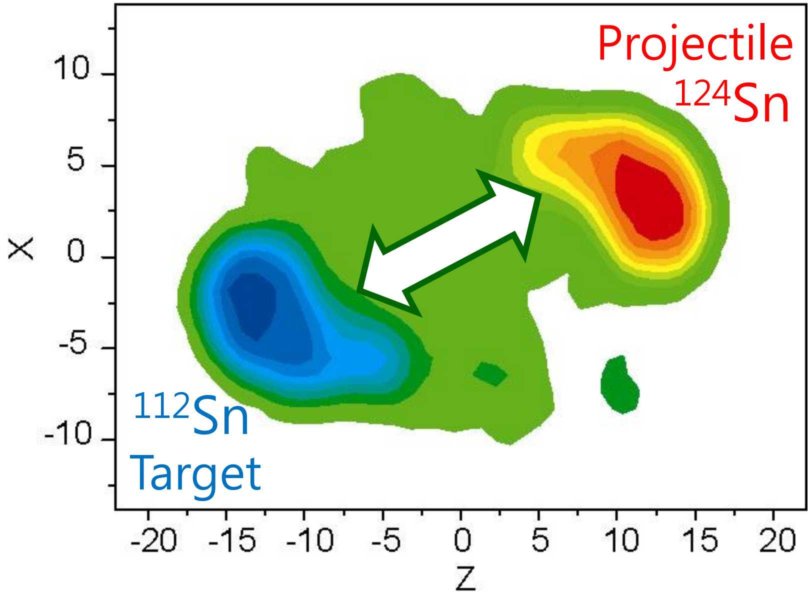
R_i = 0 for complete isospin mixing

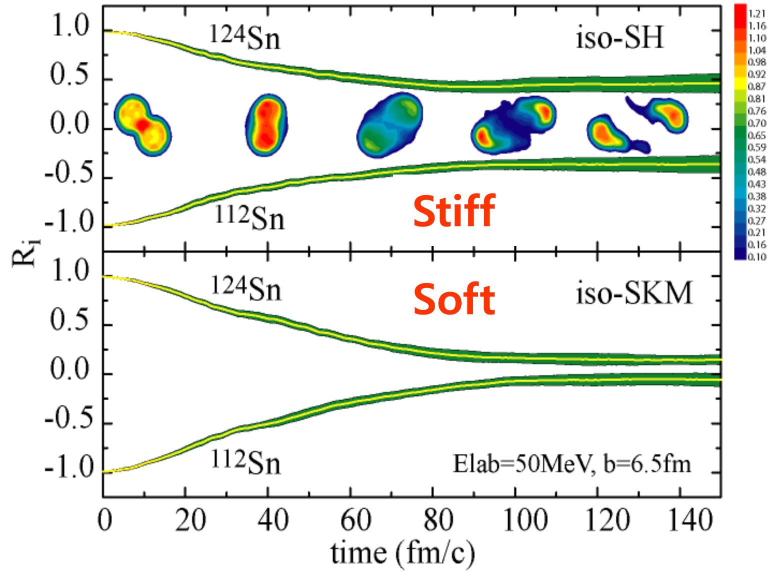




Isospin Diffusion Parameter

M.B. Tsang et al., PRL 92, 062701 (2004)





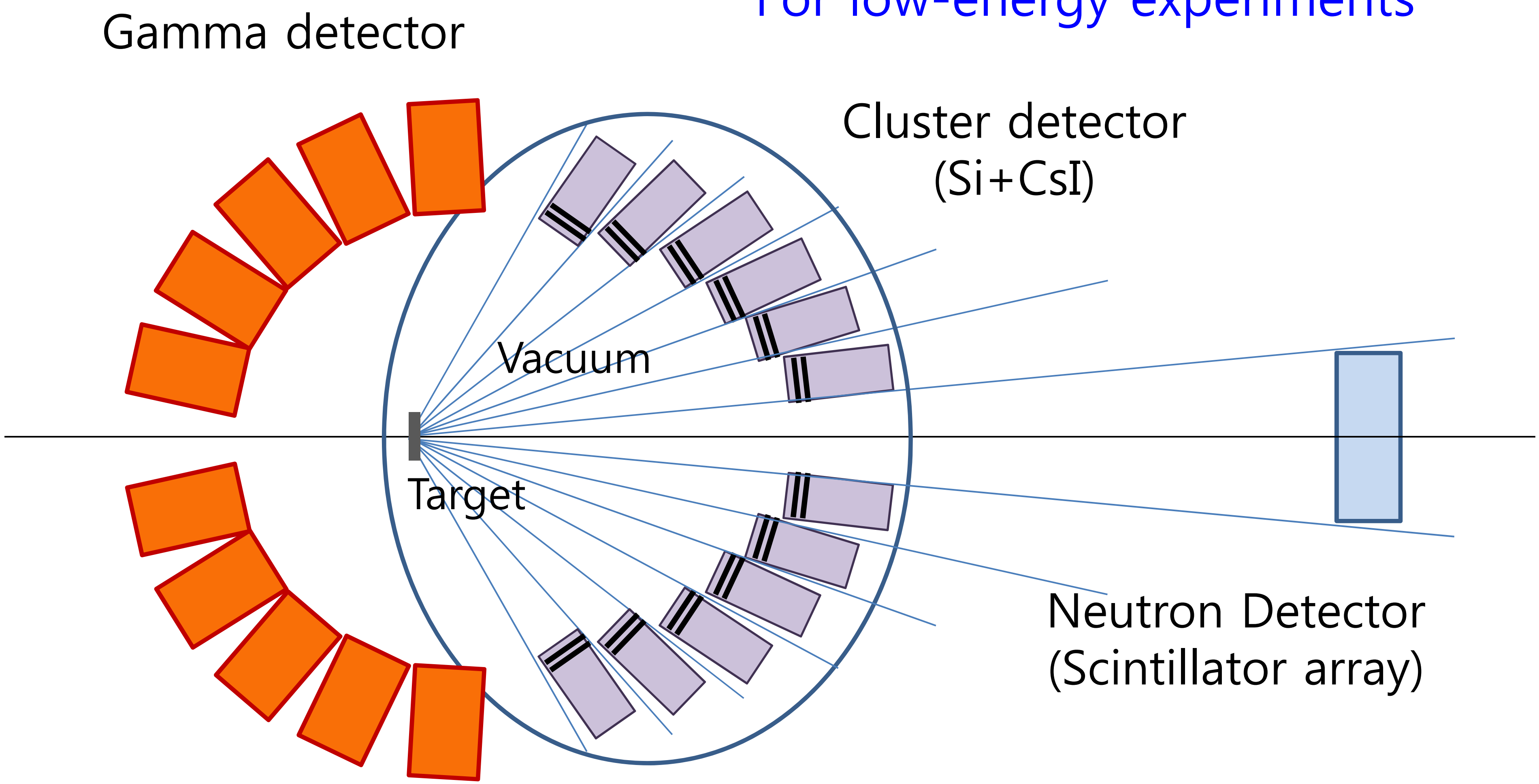
- Symmetry energy drives system towards equilibrium
  - stiff EOS : small diffusion ($|R_i| \gg 0$)
  - soft EOS : large diffusion & fast equilibrium ($R_i \rightarrow 0$)

Design of Detector System

1. 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 PDR
   - Keep flexibility for other physics topics
2. This leads to the design of **LAMPS**
   - **L**arge-**A**cceptance **M**ulti**p**urpose **S**pectrometer
3. Current plan for construction
   - Low-energy LAMPS system: LAMPS-L
     - Also important for the day-1 experiment
   - High-energy LAMPS system: LAMPS-H

Conceptual Design of LAMPS-L

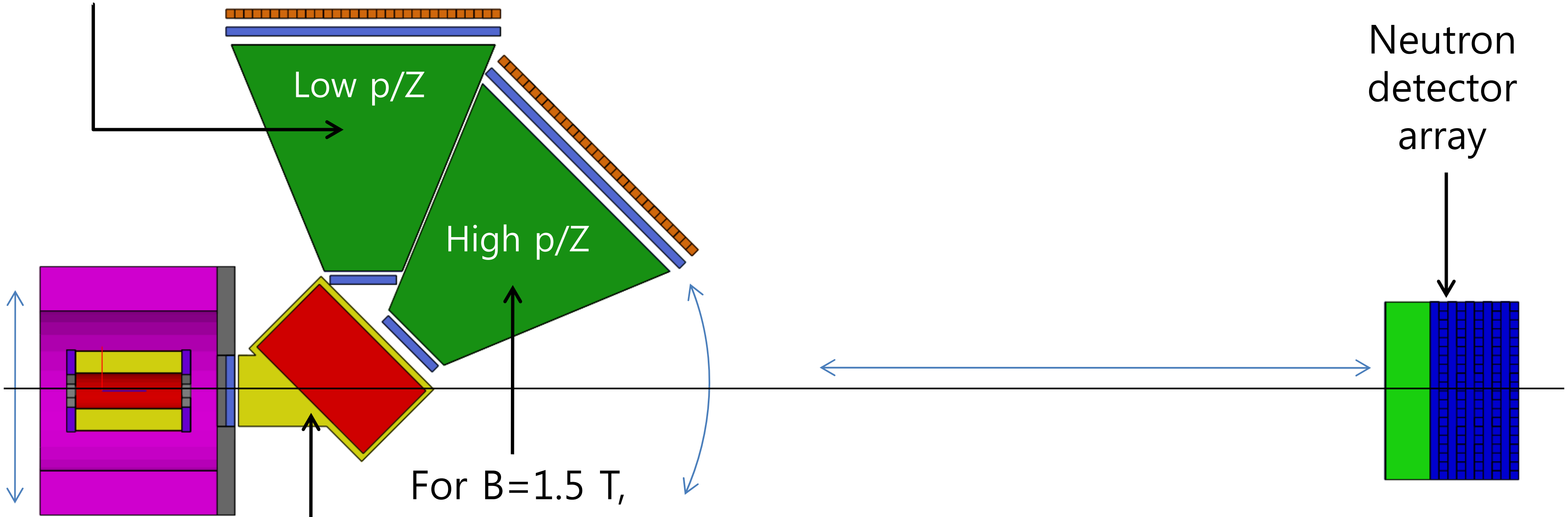
For low-energy experiments



Conceptual Design of LAMPS-H

For B=1.5 T,
p/Z ≈ 0.35 GeV/c
at 110°

- Magnets: Q for better resolution →
  Focal plane for low energy particles



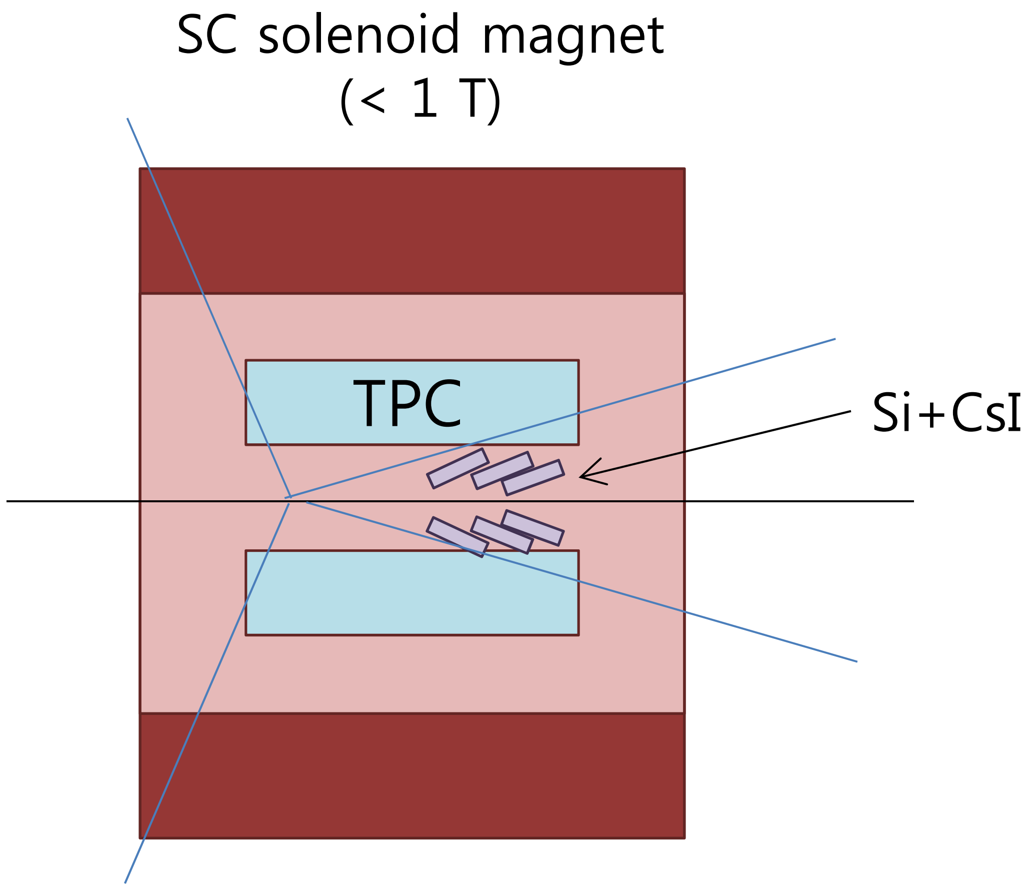
For B=1.5 T,
p/Z ≈ 1.5 GeV/c at 30°

Solenoid
magnet

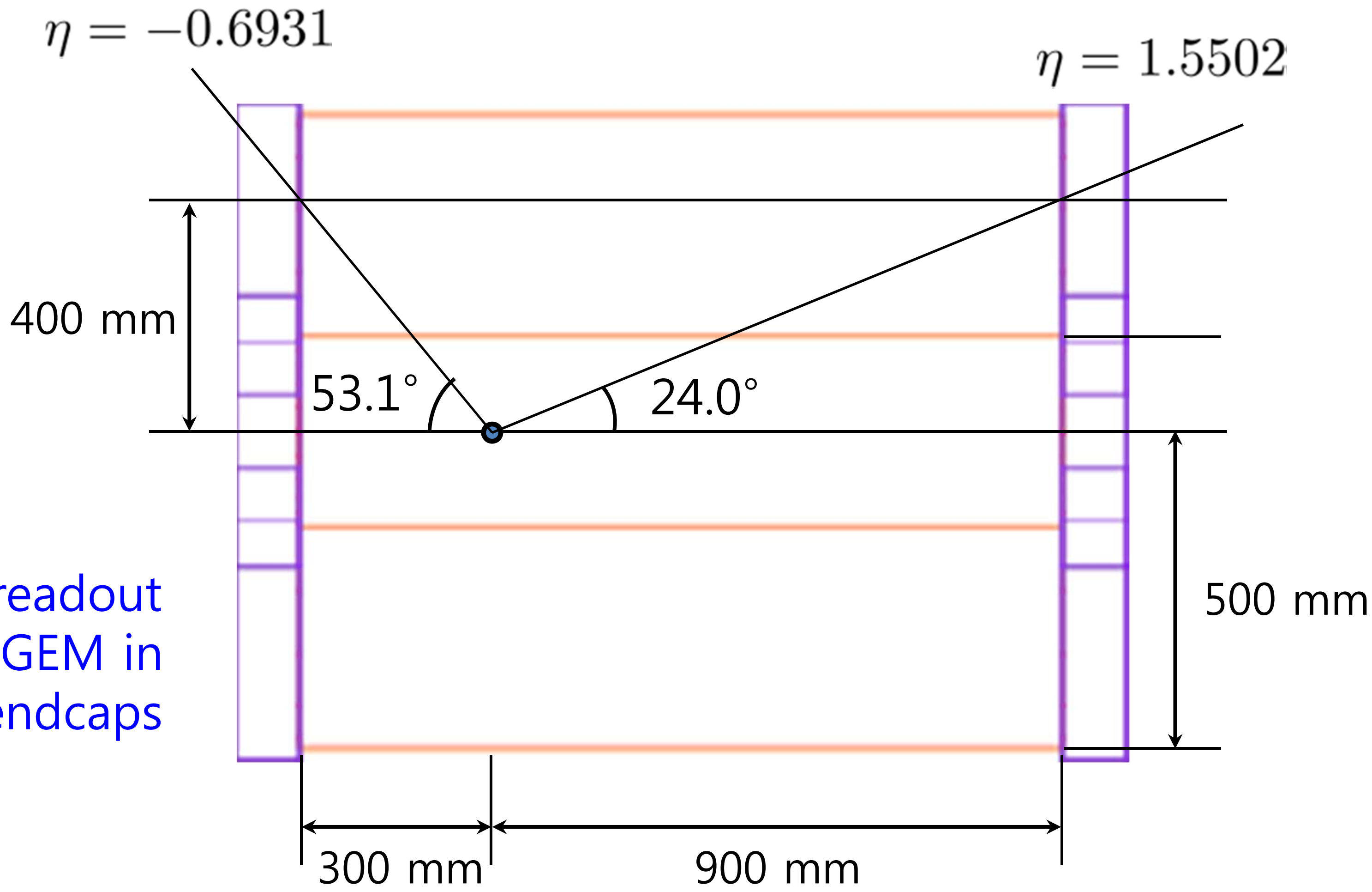
Dipole magnet: Considering the large aperture (rotational) superconducting dipole magnet (SAMURAI type).

Solenoid Spectrometer

- TPC
  - Large acceptance (~3π Sr)
  - $\pi^{+/-}$
  - Light fragments
- Si+CsI
  - Si layers for ΔE
  - CsI(Tl) for E
  - Fragments
  - Also useful for event characterization



Time Projection Chamber

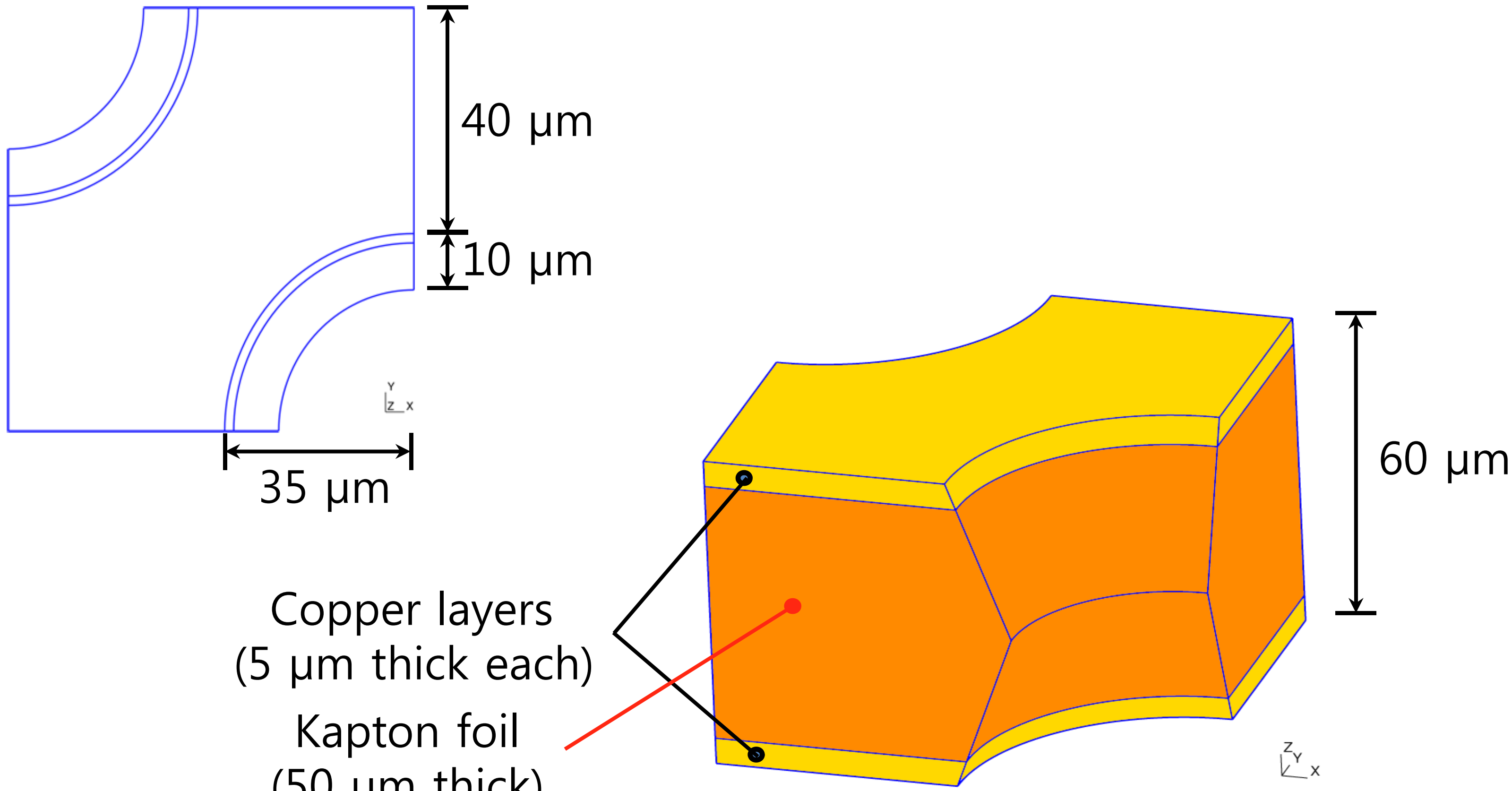


Pad readout with GEM in the endcaps

Time Projection Chamber

Genie Jhang (Korea Univ.)

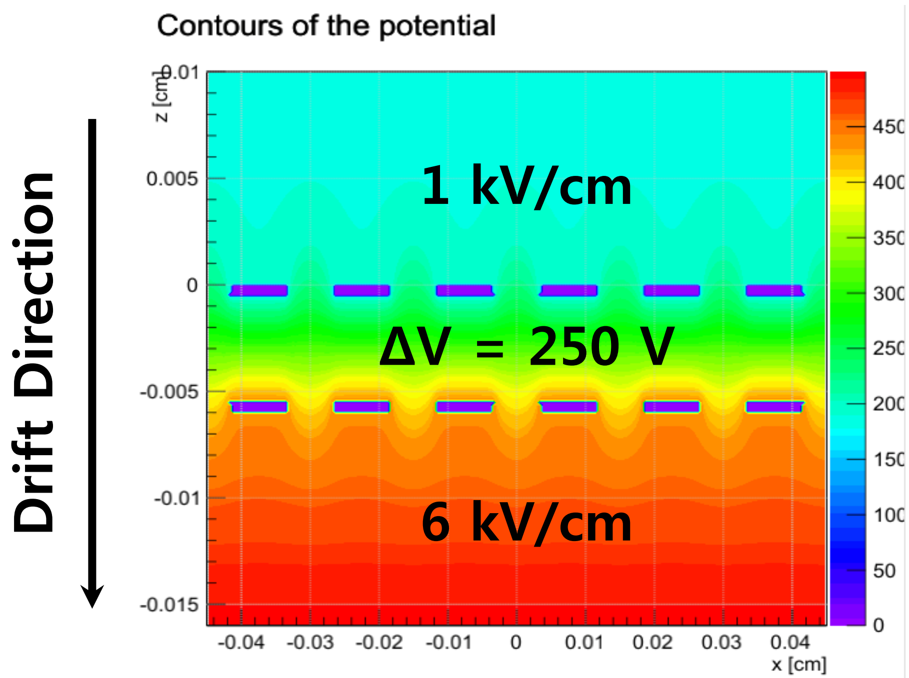
- GEM Simulation (geometry of the GEM hole)

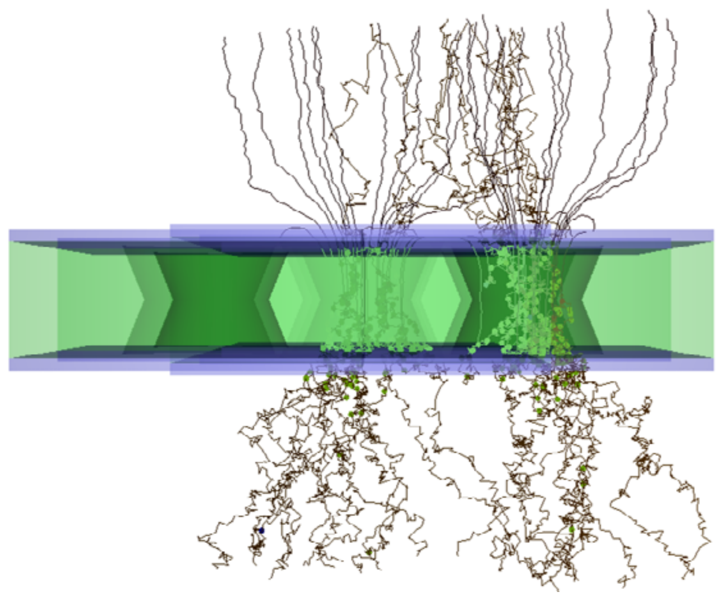


Time Projection Chamber

Genie Jhang (Korea Univ.)

- GEM Simulation
  - E-field is approximated by the finite element method in Garfield++
  - Determination of gain and dispersion for fast TPC simulation





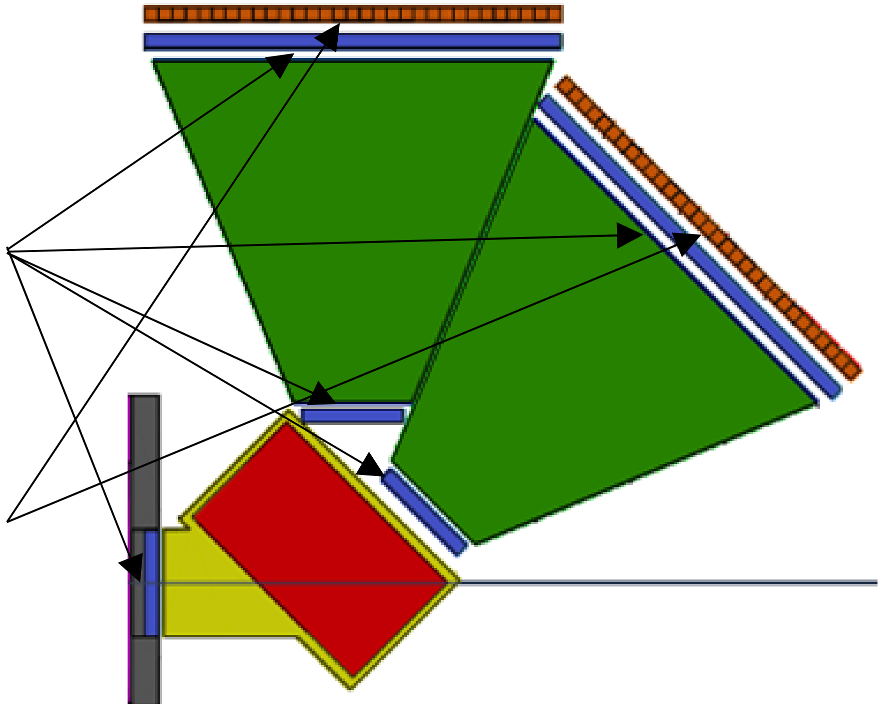
No B-field

Dipole Spectrometer

- Multiparticle tracking capability
  - Isotopes for p, He, and heavier elements.

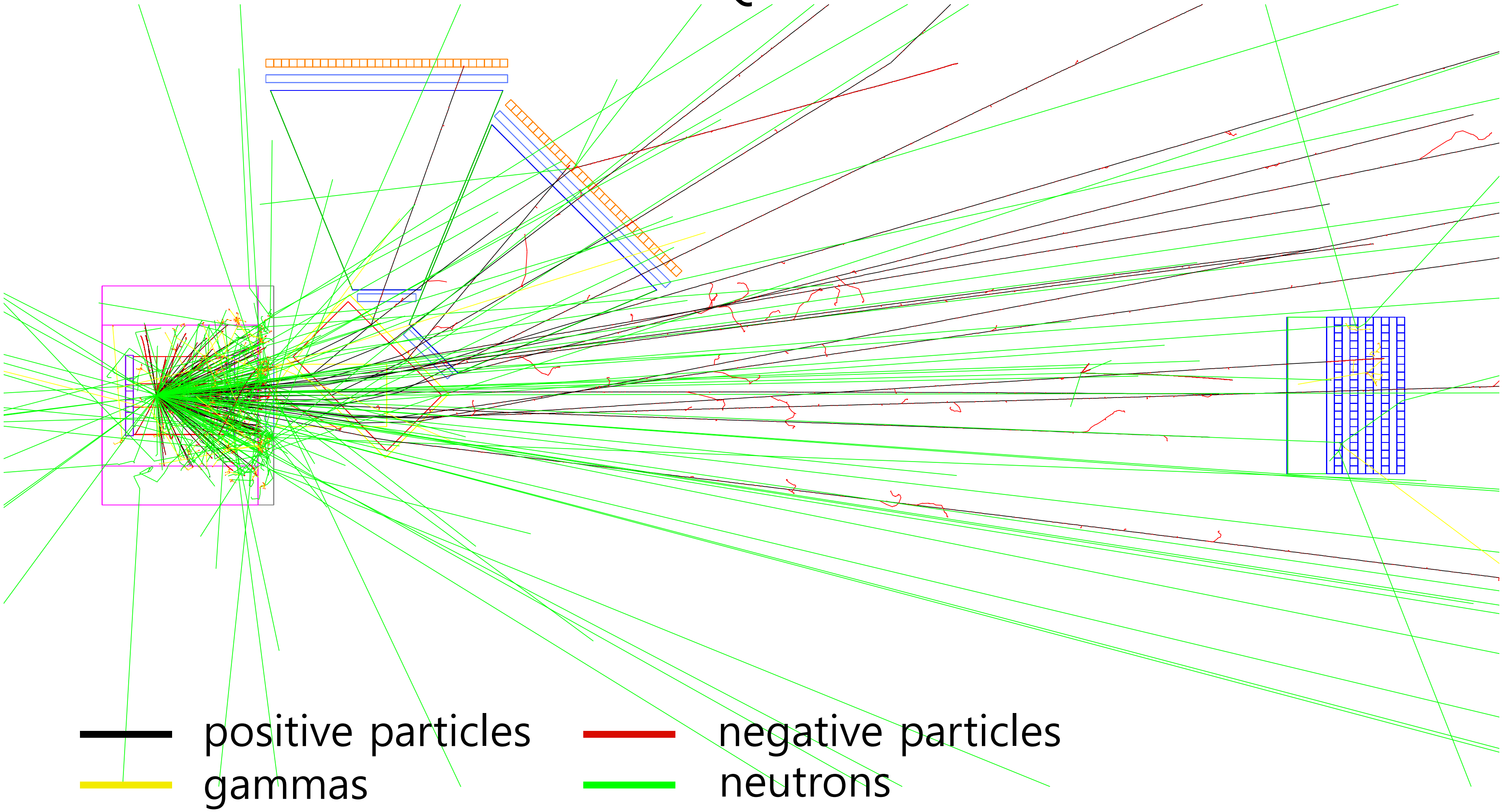
- Tracking chambers
  - ≥ 3 drift chamber stations for each arm

- ToF
  - Conventional plastic scintillator detectors
  - $\sigma_t < 100$ ps, which is essential for $\Delta p/p < 10^{-3}$ @ $\beta=0.5$



Event Simulation

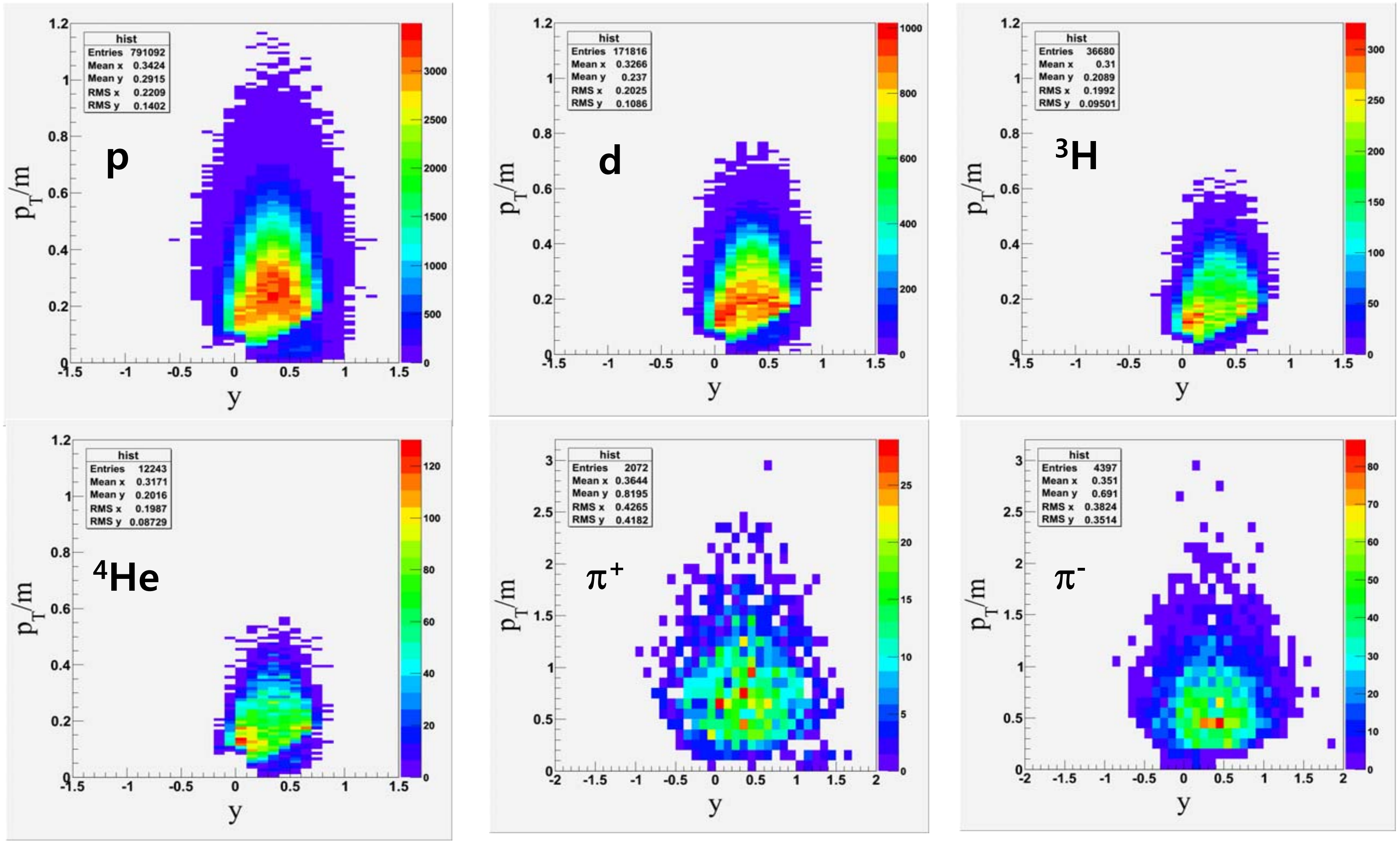
IQMD for Au+Au at 250A MeV



Acceptance of LAMPS-H

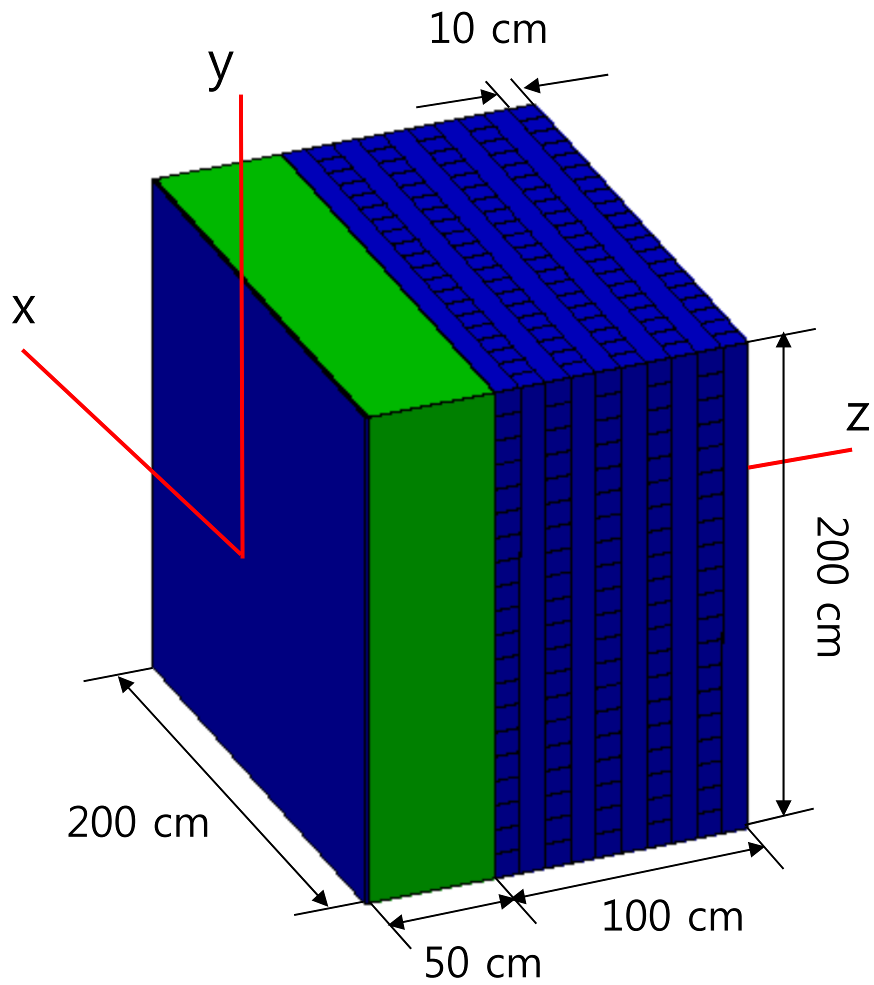
Au+Au @ 250A MeV

Genie Jhang (Korea Univ.)



Neutron-Detector Array

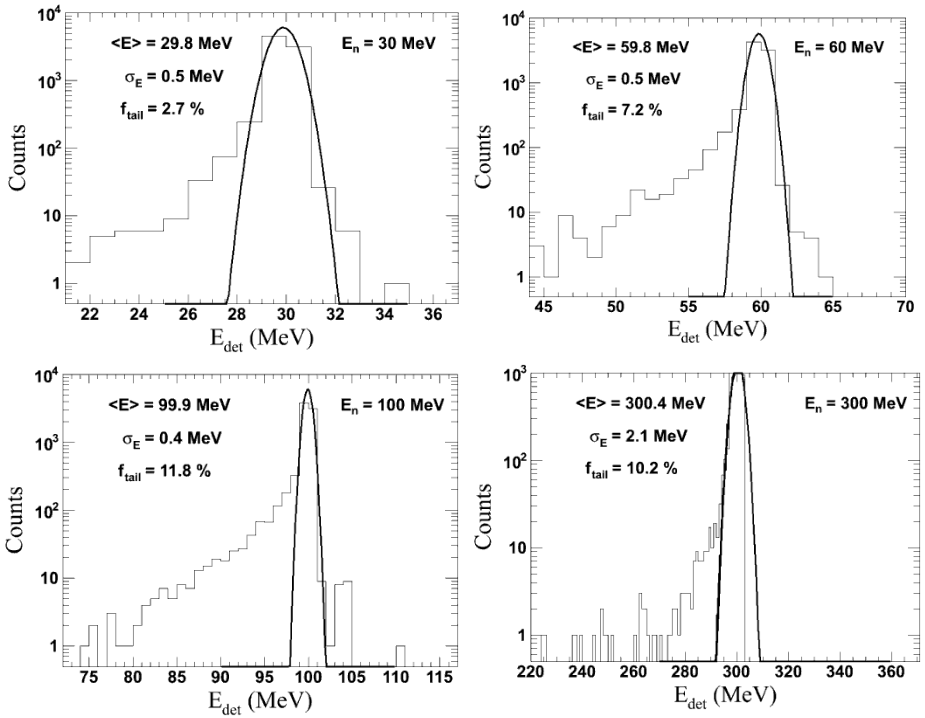
- Important to measure neutrons for the nuclear symmetry energy
- Important to measure wide neutron-energy range
- Large veto and neutron detector array are composed of scintillator slats



Simulation: Neutron Detector

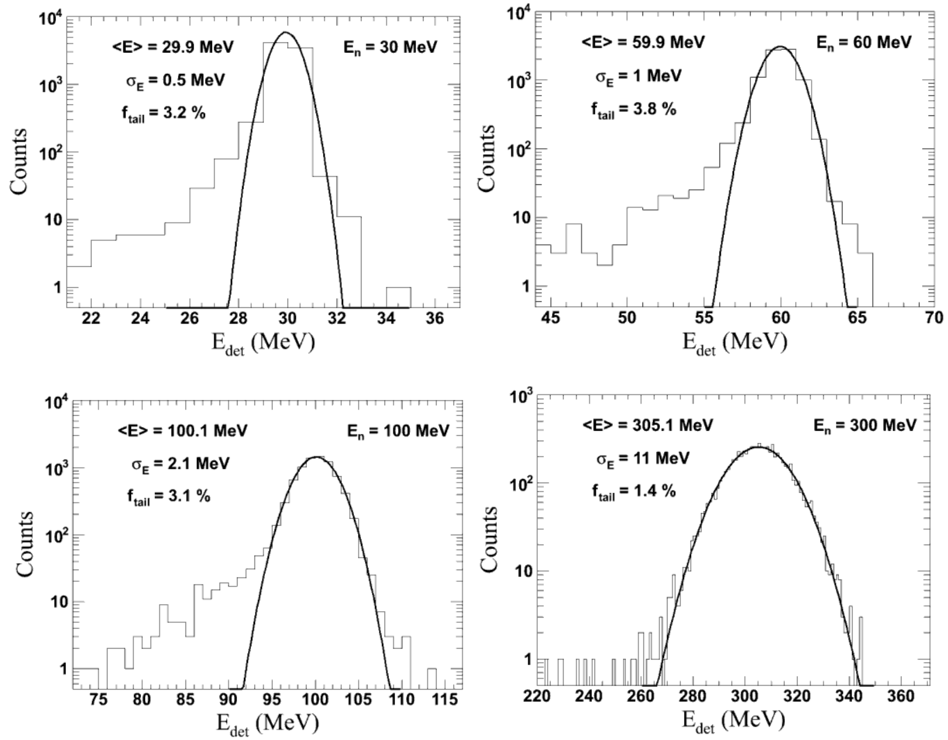
Assuming Perfect Time Resolution

Eunah Joo & Hyunha Shim (Korea Univ.)



E_n estimated by ToF

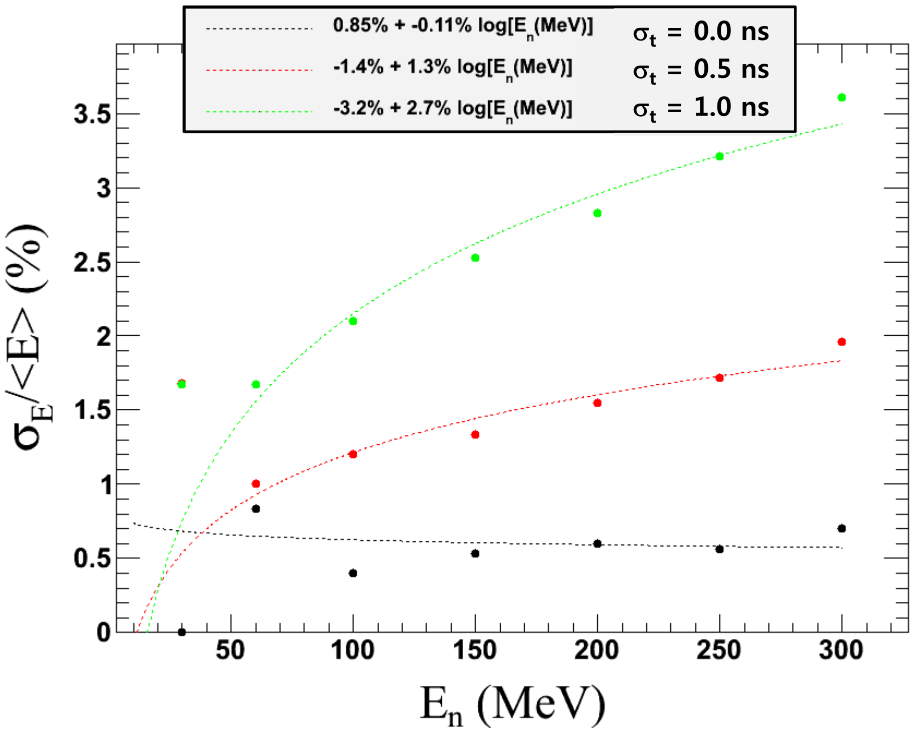
Assuming σ_t = 1.0 ns



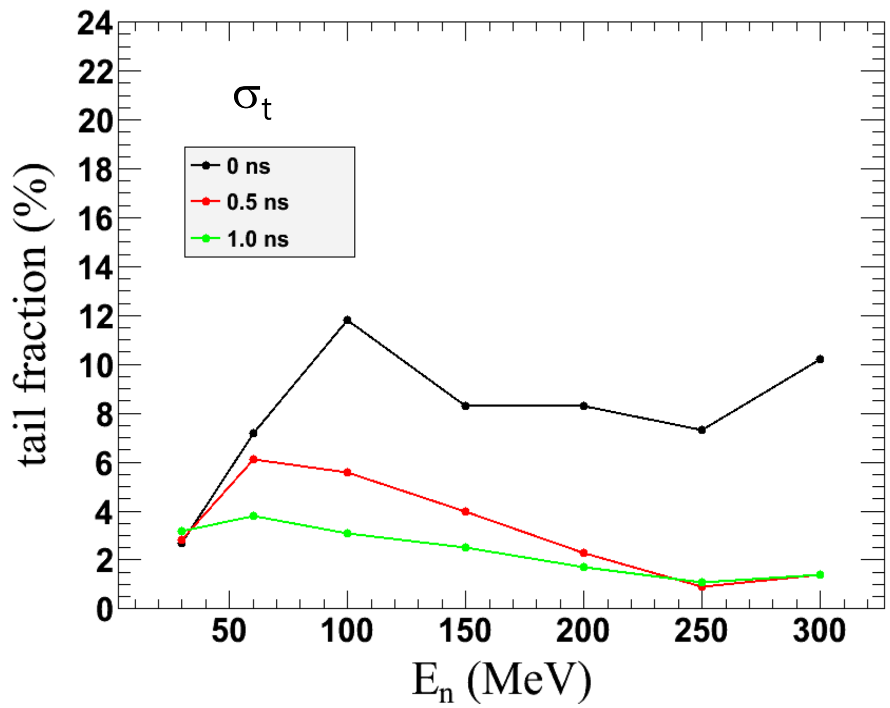
Simulation: Neutron Detector

Eunah Joo & Hyunha Shim (Korea Univ.)

Energy Resolutions



Tail Fractions



Summary

1. Future Rare Isotope Accelerator in Korea
   - Plan to deliver more exotic high-current RI beams by combining ISOL and IF technologies
   - Keep the diverse operational modes
2. Symmetry Energy in EoS
   - Crucial to understand the neutron-rich matter & several astrophysical objects
   - Long-standing unsolved problem in nuclear physics
3. Large-Acceptance Multipurpose Spectrometer (LAMPS)
   - Low-energy system: important for day-1 experiment
   - Full high-energy system: combination of solenoid and dipole spectrometers with movable arms

4. We hope you can join us!