Systematic measurement of charged pion production in HIC with RI beams at RIKEN-RIBF

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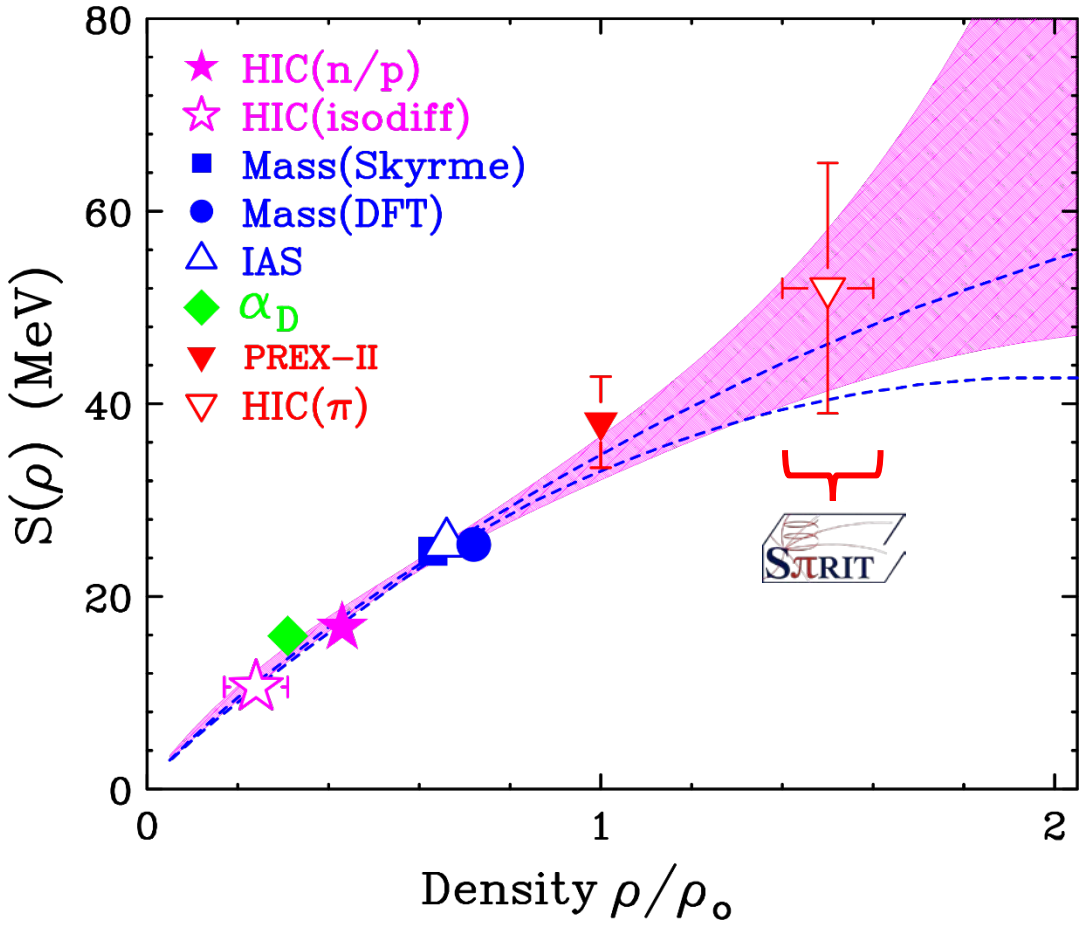
Density dependent Symmetry Energy (SE) constraints obtained from structure and HI collisions

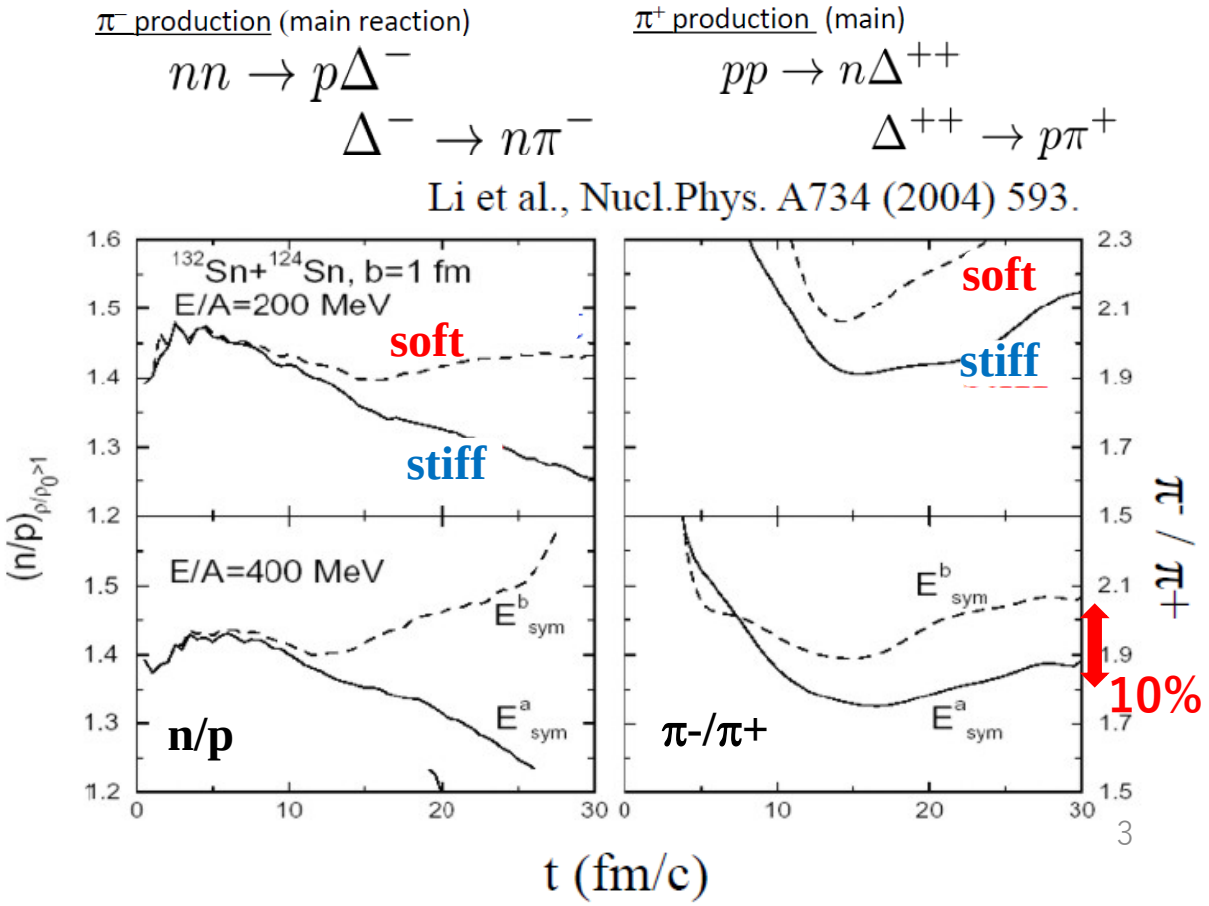
- Plotting constrain on SE at the sensitive density for each observables.
  - Skin thickness, nuclear mass, electric dipole polarizability.
- HIC for proving SE of high dense region
  - Based on charged pion spectra ratio
  - SPiRIT pion data point at $\rho \sim 1.5\rho_0$
- For making stronger constraint based on charged pion data:
  - We want systematic data
  - We want high precision data

W.G. Lynch and M.B. Tsang PLB 830, 137098 (2022)



Pion production from HIC to constrain the symmetry energy

- Difference of symmetry energy is appeared as n/p ratio in bulk matter.
- n/p ratio in dense region can be investigated through charged pion ratio as pions have the information mainly of dense region.



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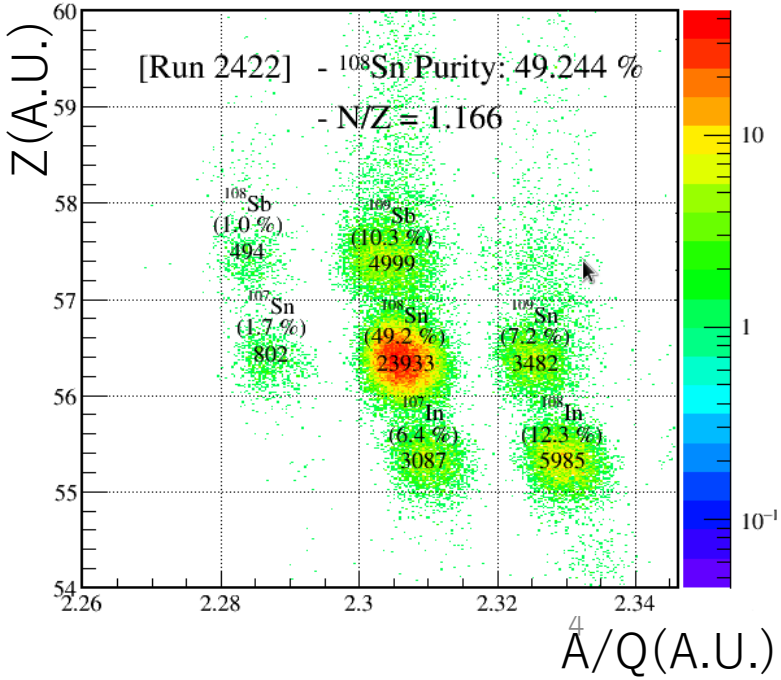
Heavy RI Collision program @RIBF

- Experimental project to give a constrain on the density dependent symmetry energy mainly for higher dense region.
- Systematic measurements in same *Z* but different *N* systems realized with heavy RI beam.
  - Additional parameter we can control. (Control nuclear effect.)
  - $\rho \sim 2\rho_0$ nuclear matter at RIBF energy.
- Effect of symmetry energy on each observables is expected to be largest around this energy region. (especially pion emission)
- 1st experimental campaign using Sn (Z=50) isotopes in 2016 spring.
  - Data taken for 4 systems.

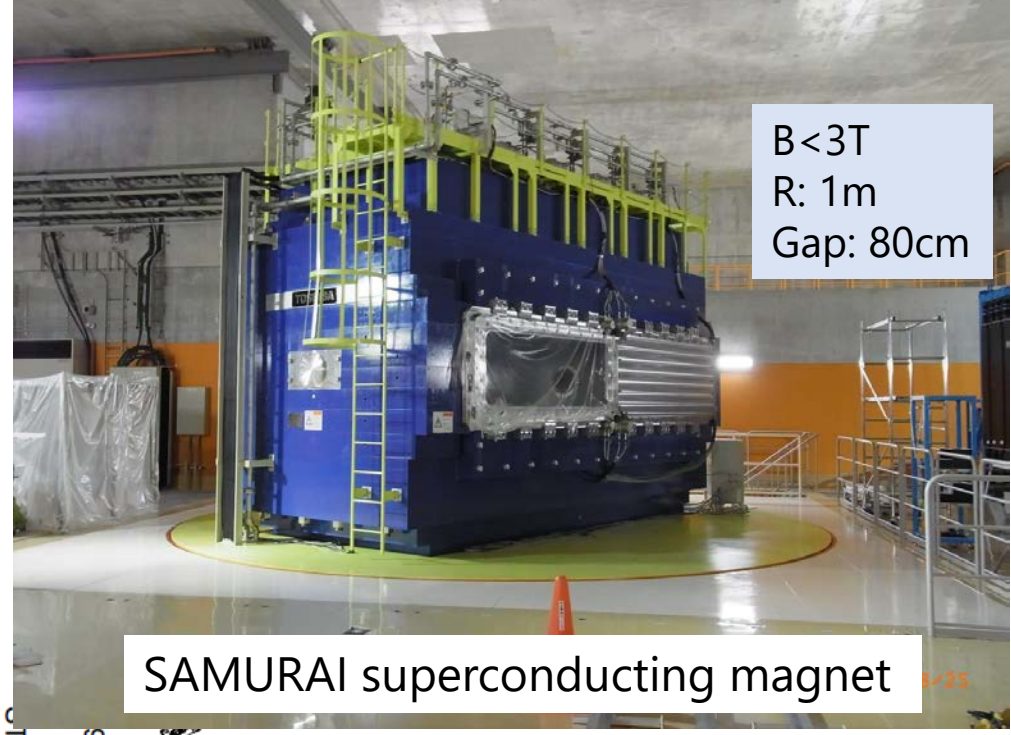
Primary	Beam	Target	E_{beam}/A	$(N-Z/A)_{sys}$
^{238}U	**^{132}Sn**	**^{124}Sn**	270	0.22
	^{124}Sn	**^{112}Sn**	270	0.15
^{124}Xe	**^{108}Sn**	**^{112}Sn**	270	0.09
	^{112}Sn	**^{124}Sn**	270	0.15



RIKEN-RIBF: RI production at world leading RI facility

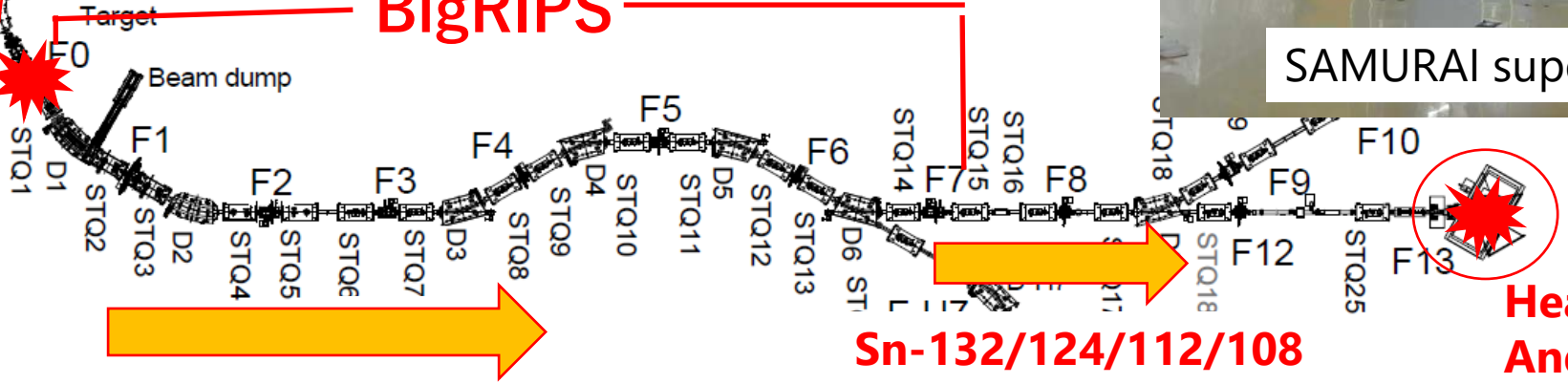
U-238 345 MeV/u beam
Z=92、N=146

SRC
Accelerator



SAMURAI superconducting magnet

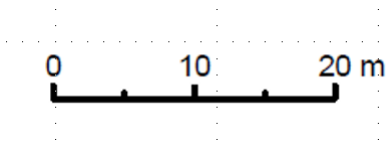
BigRIPS

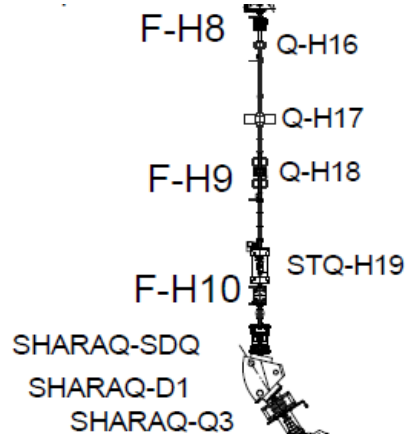


Neutron rich ion separator
Purification & identification of ion

Sn-132/124/112/108

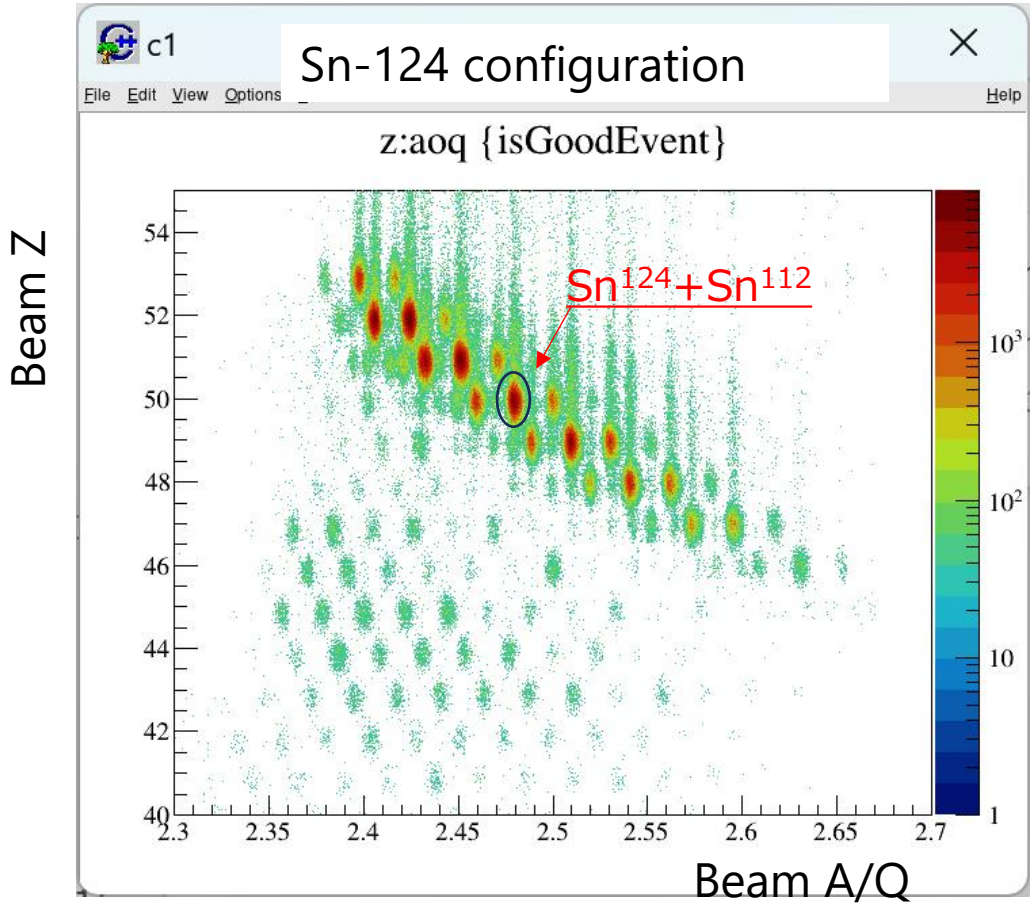
Heavy ion collision!
And create dense matter!



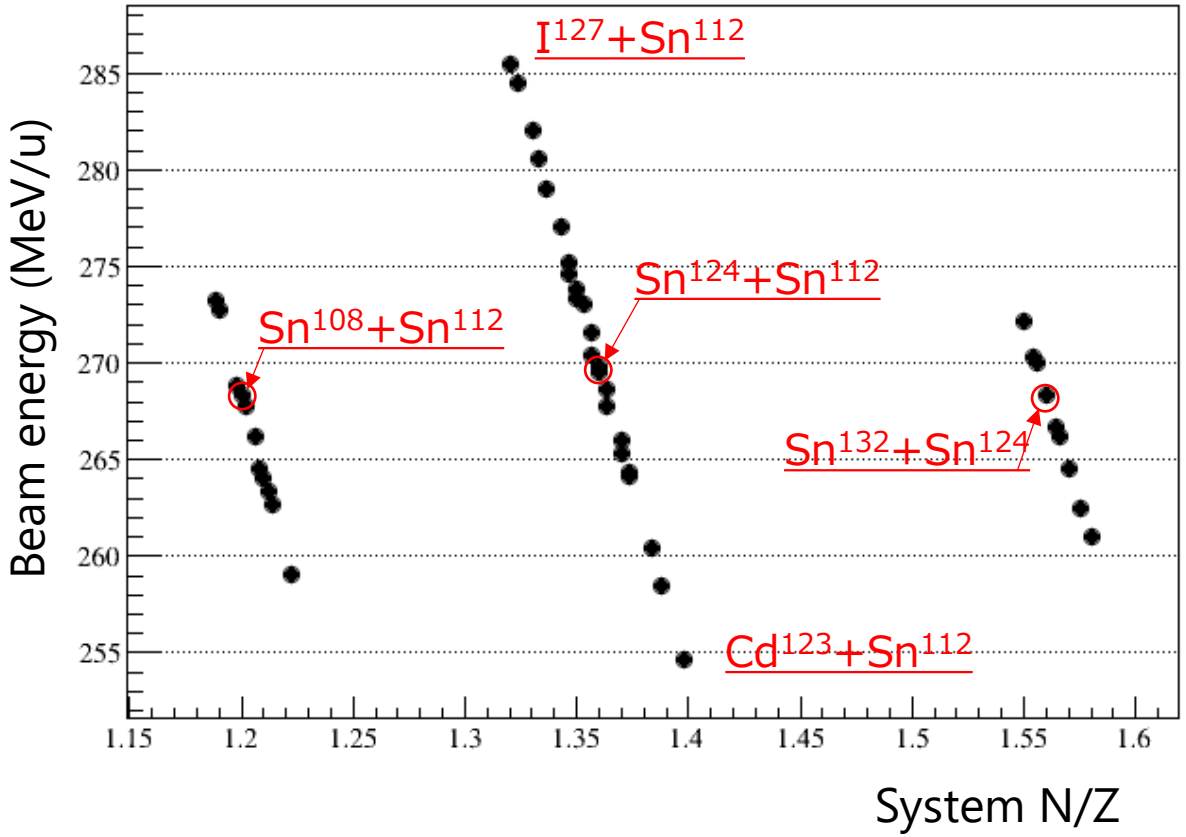


HI collision data is not only Sn+Sn

- Purity of produced RI beam is not 100%.
- Purity depends on the requirement on the 2ndary beam property.
  - Z, N, Q and Beam energy.

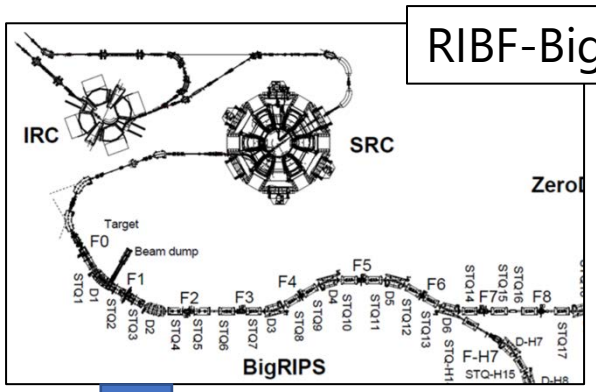


Reactions N(π+)>10 && N(π-)>10



- Why don't we analyze those data?

SPiRIT experimental setup top view: beam line+TPC+trigger+neutron detector



RIBF-BigRIPS

Sn RI beam

STQ

Chamber in SAMURAI magnet B=0.5T

Beam Tracker

scintillator

Field cage

Beam

target

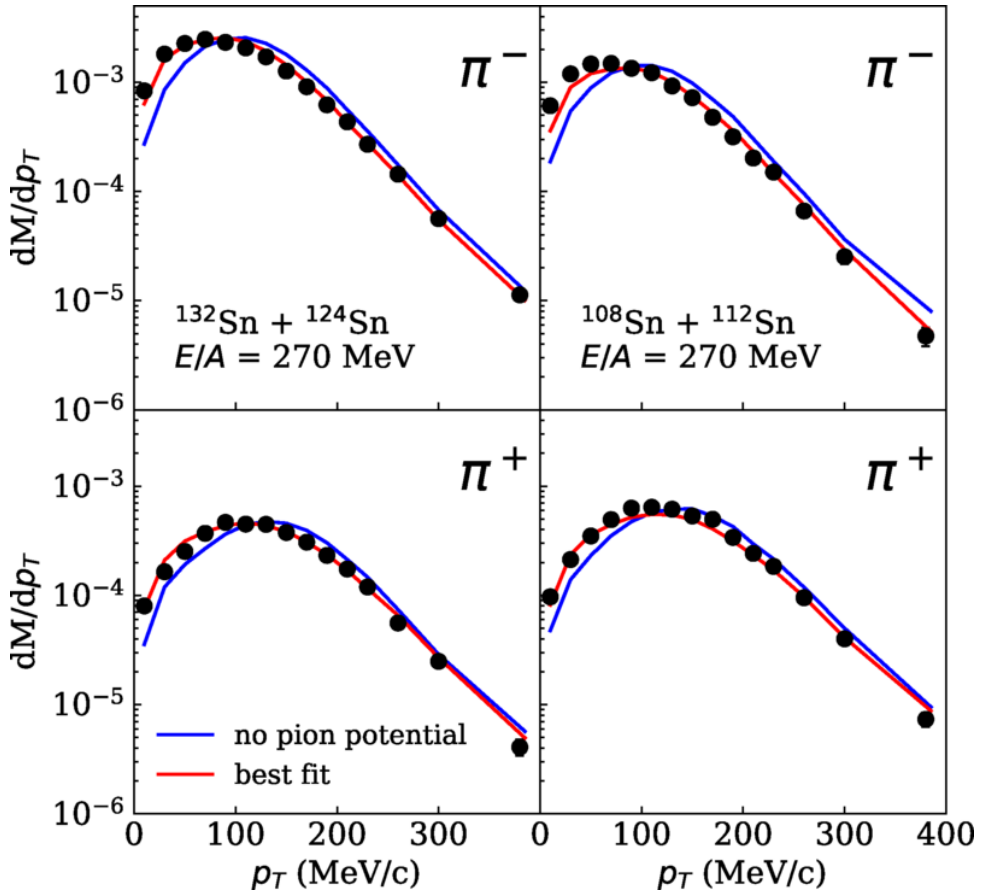
trigger array

MWPC type Time Proj. Chamber 12k channel

NeuLAND

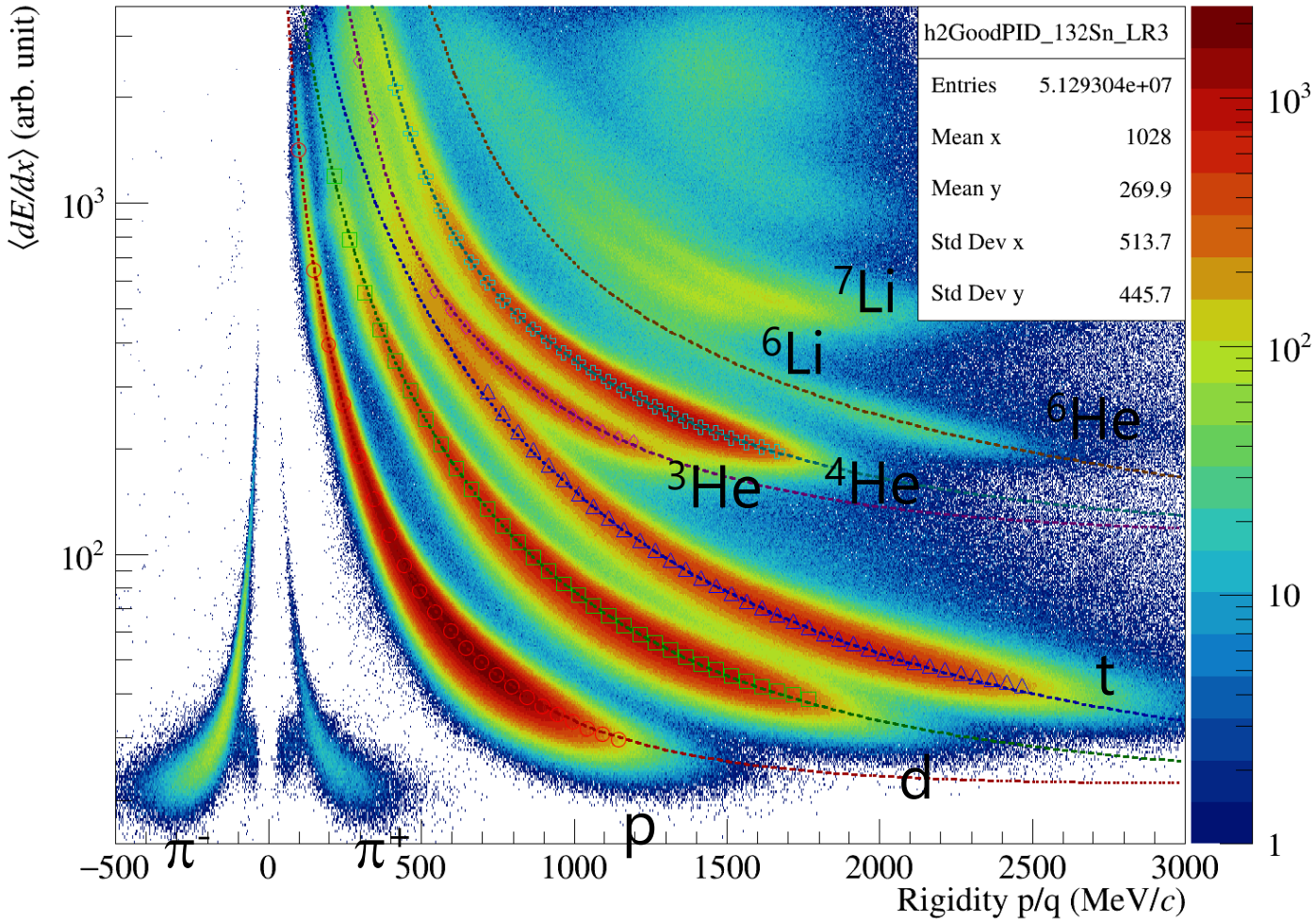
Charged particle measurement with Time Projection Chamber

Measure all of particles produced in a HIC
Particle ID based on rigidity-dE/dx ($dE/dx \propto Z^2$)
Rigidity → particle momentum



Estee et al., PRL 126 (2021) 162701

TPC ParticleID for ^{132}Sn+^{124}Sn



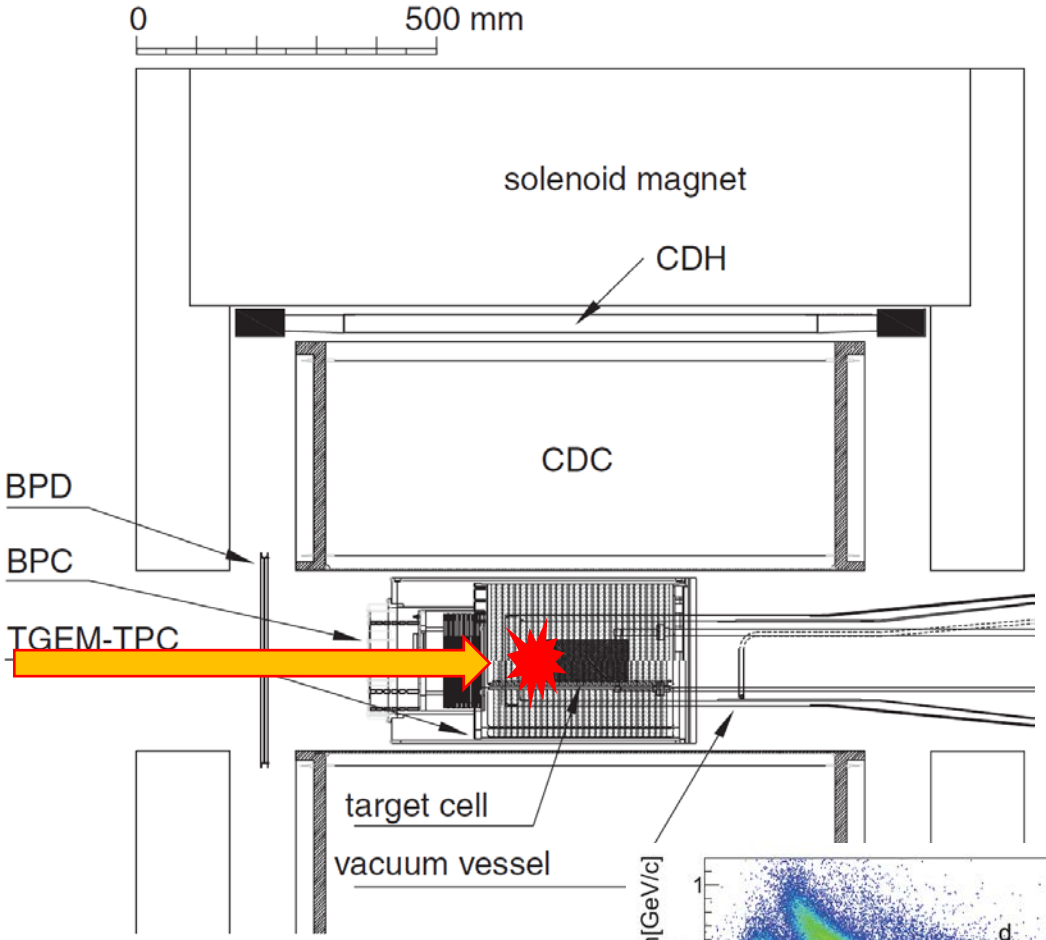
One of the next steps: Solenoid type system at RIBF

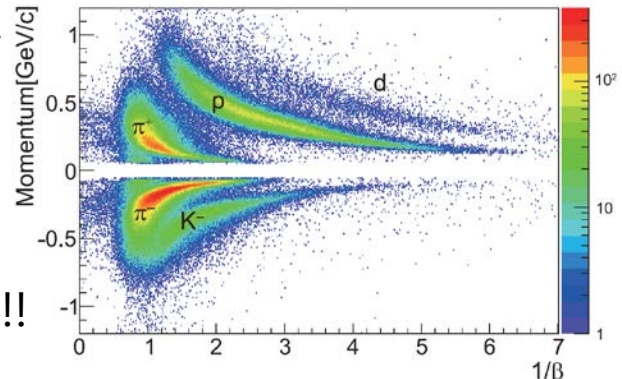
- Solenoid type magnet
  - 1.2m inside diameter
  - 1.2m in beam direction
  - Up to 0.7T
- Moving from J-PARC to RIBF in 2025.
- Replaceable HODO and DC are already installed

- Higher rate beam can be accepted.
- Appropriate geometry to measure particle flow.

→Measurement of high pT pion.

→Measurement of charged pion flow.

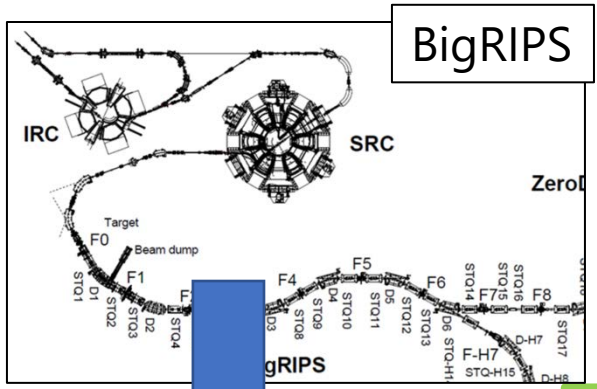




Nice PID!!

2023/11/01@ JPARC

Experimental setup with solenoid type system



BigRIPS

RI beam

STQ

Doraemon magnet B=0.5T

Beam Tracker

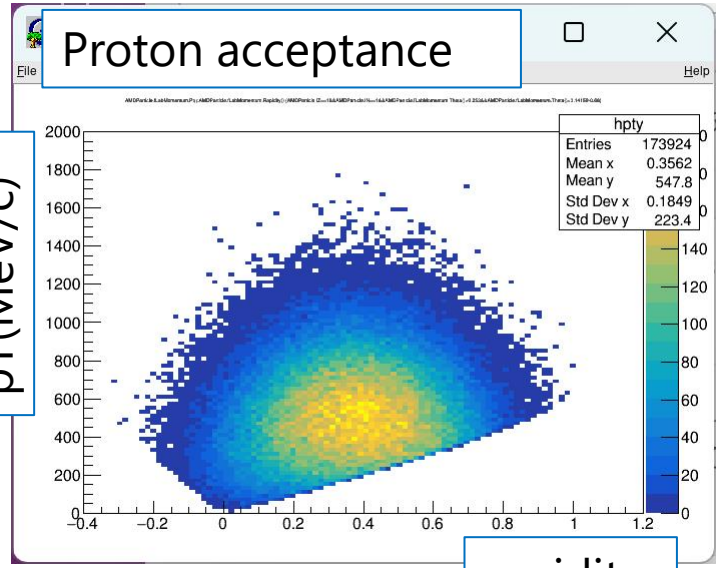
~60cm : 0.3Bρ=90MeV

target

Start Counter

Position Sensitive Counter for HI

Proton acceptance



Summary

- Heavy RI collision experiment was conducted at RIKEN-RIBF to give constraint on EoS for high dense regime.
- Systematic charged pion data with different beam energy and reaction systems were taken.
- Charged pion ratio data shows less dependence on beam energy while it depends on N/Z.
  - FOPI shows dependence on beam energy.
  - Main production mechanism of charged pion is different? Range of beam energy is too small to see the tendency?
  - 2024 spirit Xe+Sn data may give some hints.
- New projects to utilize solenoid type spectrometer are on-going.
  - Expected to utilize for taking high-pT pion data with higher rate beam.