

Constraining the symmetry energy with the $S\pi RIT TPC$

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Nuclear equation of state describes the relations among pressure, energy, temperature, density, and isospin asymmetry of nuclear systems

$$E(\rho, \delta) = E(\rho, \delta = 0) + \frac{\delta^2 \cdot S(\rho)}{Symmetric}$$

Symmetry Energy
nuclear matter

where δ = ($\rho_n\text{-}~\rho_p)/$ ($\rho_n\text{+}~\rho_p)$ = (N-Z)/A

What is the symmetry energy (SE)?

"The symmetry energy describes the response of the force on protons and neutrons in a nuclear system with excess neutrons or protons. It reduces the nuclear binding energy in nuclei with N \neq Z and is critical to understanding the properties of nuclei, including the existence of rare isotopes with extreme proton to neutron ratios" - PRC **86** (2012) 015803



Why do we study the symmetry energy?

- To probe fundamental questions on the nature of nuclear matter especially the isospin asymmetric matter
- To recreate and study astrophysical environments (i.e. SE and pressure in neutron stars)



Above saturation energy ($\rho > \rho_0$) the extrapolation of the symmetry energy shows strong model dependence...



In neutron stars, balance of gravity and SE pressure \rightarrow masses vs. radii





pBUU (P. Danielewicz)

- Transport model that relates motion through mean field and collisions

- Simple parameterization of SE

$$S(\rho) = S_{kin}(\rho_o) \left(\frac{\rho}{\rho_o}\right)^{\frac{2}{3}} + S_{int}(\rho_o) \left(\frac{\rho}{\rho_o}\right)^{\gamma}$$

- Production of pions via Δ resonances
- π^{-}/π^{+} ratio biggest sensitivity to SE
- Need data to constraint symmetry energy and develop and verify theoretical models
- What do we need?
- Large coverage detector
- Track and reconstruct many particles in a B field $\rightarrow \pi$:(p,d,t)~1:300
- Resolve and distinguish different particle species by mass and charge
 → SπRIT TPC





The $S\pi RIT$ Campaign @ RIKEN

Primary	Secondary	Target	δ _{CN}
²³⁸ U	¹³² Sn	¹²⁴ Sn	0.22
	¹²⁴ Sn	¹¹² Sn	0.15
¹²⁴ Xe	¹¹² Sn	¹²⁴ Sn	0.15
	¹⁰⁸ Sn	¹¹² Sn	0.09

Total of 33M collision events @ 300 MeV/A for the four systems (total of 230 TB of data)







The Sπ**RIT Time Projection Chamber**





The Sπ**RIT Time Projection Chamber**



Time bucket (0 ~ 270)



The $S\pi RIT TPC$: Trigger Arrays





$S\pi RITROOT$: the Analysis Software

- High-density environment(~50 tracks/event)
- Reconstruct low momentum tracks (i.e. pions at ~50 MeV/c)
- Distinguish between collision on target and on gas events
- Identification of pi⁺ in the positively charged background
- We adapted tools from High Energy Physics but still need to develop tools for our needs





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SπRITROOT: Tracking Algorithm



2) Clustering/Track finding





4) Track fitting

- Riemann fit method

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SπRITROOT: Tracking Algorithm

- 4) Track fitting
- Riemann fit

1. Track hits

- 2. Track hits are connected to the north pole with a straight line. Intersection of line and surface of the sphere defines mapped hits.
- 3. Plane fit is performed with mapped hits.
- 4. Cross section of sphere and fit plane defines the cicle on sphere.
- 5. Circle on sphere is inverse mapped to the pad plane which becomes fitted circle of track hits.

5) Hit-Track correlation









SπRITROOT: Tracking Algorithm

6) GENFIT: a generic toolkit for track reconstruction for experiments in particle and nuclear physics \rightarrow for extraction of the momentum with different hypothesis

7) PID Matching: for each fitted track, the momentum and measured dE/dx are used as input to determine what particle is the most probably to be following the Bichsel dE/dx curves (add segment length w.r.t. BB)

8) Vertex finding by RAVE package (Reconstruction in an Abstract Vertices Environment)

The optimization of the code is still ongoing \bigcirc



Sπ**RITROOT: Preliminary Results**





Summary

- The $S\pi RIT$ experimental campaign was a success
- Calibrations and software development are still ongoing
- Lots of results will be extracted within the next few months
 Stay tuned ⁽³⁾
- Ideas for future experiment proposals (also using the TPC as active target) are under way



SπRIT Collaboration

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Sπ**RIT** Collaboration



