Pion Simulation and Heavy Ion Collision

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Cited Work:

Hong J, Danielewicz P.	Subthreshold pion production within a transport description of central Au+ Au collisions
Estee J.	Probing the Symmetry Energy with pions

Motivation

- Nuclear equation of state (EOS) is a long standing problem in nuclear physics.
- EOS for symmetric nuclear matter has been significantly constrained. The zero-temperature energy minimizes at -16 MeV per nucleon, at normal density ρ_0=0.16 fm^{-3}. The nuclear incompressibility K=240±20 MeV.
- EOS for asymmetric nuclear matter still has large uncertainties tied to the symmetry-energy term.

Motivation

$$\frac{E}{A}(\rho,\alpha)=\frac{E}{A}(\rho,0)+S(\rho)(\alpha^2-O(\alpha^4))$$

$$\alpha=\frac{\rho_n-\rho_p}{\rho_n+\rho_p}$$

$\frac{E}{A}$ Energy per nucleon

$S(\rho)$ symmetry energy

The density dependence of symmetry energy at $\rho < \rho_0$ has been constrained to some degree through various experimental measurements

At $\rho > \rho_0$, the knowledge is poor.

It is important to find a sensitive observable for experiments to constrain the behavior of symmetry energy at supranormal densities.

Motivation

- Different observables that could be used:
  - n/p ratio
  - $t/^3He$
  - π^-/π^+
- Pions are selected as:
  - n/p ratio is less sensitive to symmetry energy with increasing beam energies.
  - $t/^3He$ requires understanding of cluster formation.
  - π^-/π^+ currently the best observable, carry information about region of high-density in collision.

- So, our work is to employ pBUU transport model to simulate pion production in heavy ion collision (HIC).

Introduction to the pBUU model

- Dominant model of production is through delta resonances.

- pp -> Δ^{++} -> pn π^{+}
- nn -> Δ^{0} -> pn π^{-}

$$\pi^{-}/\pi^{+} \approx (\rho / \rho_0)^2$$

Introduction to the pBUU model

- pBUU is the theoretical model used here is Boltzmann-Uehling-Uhlenbeck (BUU) transport model developed by P. Danielewicz et al.
- BUU semi-classical equation for the phase space distrubutions of different particles is given by

$$\frac{\partial f_X}{\partial t} + \frac{\partial \epsilon_X}{\partial \vec{p}} \frac{\partial f_X}{\partial \vec{r}} - \frac{\partial \epsilon_X}{\partial \vec{r}} \frac{\partial f_X}{\partial \vec{p}} = \kappa_X^{<} (1 \mp f_X) - \kappa_X^{>} f_X$$

$f_X(\vec{p}, \vec{r}, t)$ Particle movement $\epsilon_X(\vec{p}, \vec{r}, t)$ Energy

$\kappa_X^{<}$ $\kappa_X^{>}$ The feeding and removal rates for specific momentum stats

L.H.S. of equation describes motion through mean field.
R.H.S. describes collisions.

Introduction to the pBUU model

- pBUU uses simple parameterization of symmetry energy.

$$S(\rho) = S_{kin}(\rho_0)(\frac{\rho}{\rho_0})^{\frac{2}{3}} + S_{\text{int}}(\rho_0)(\frac{\rho}{\rho_0})^{\gamma}$$

$S_{kin}(\rho_0) \simeq 12.3 MeV$ Symmetry energy in absence of interaction

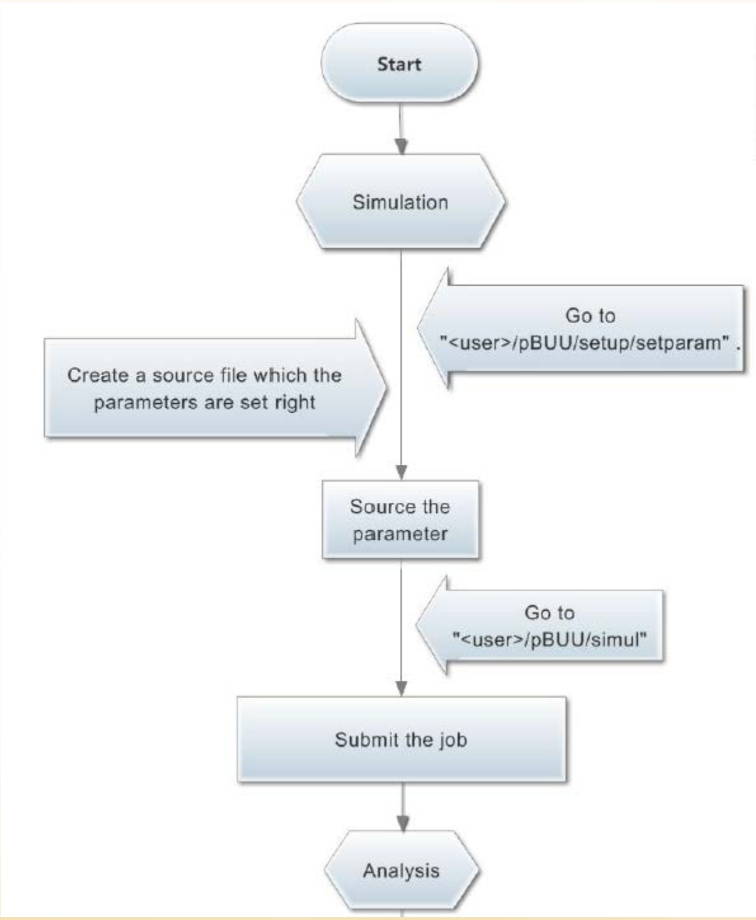
$S_{\text{int}}(\rho_0) \sim 0 MeV$ Interaction contribution

Larger γ stiff Smaller γ soft

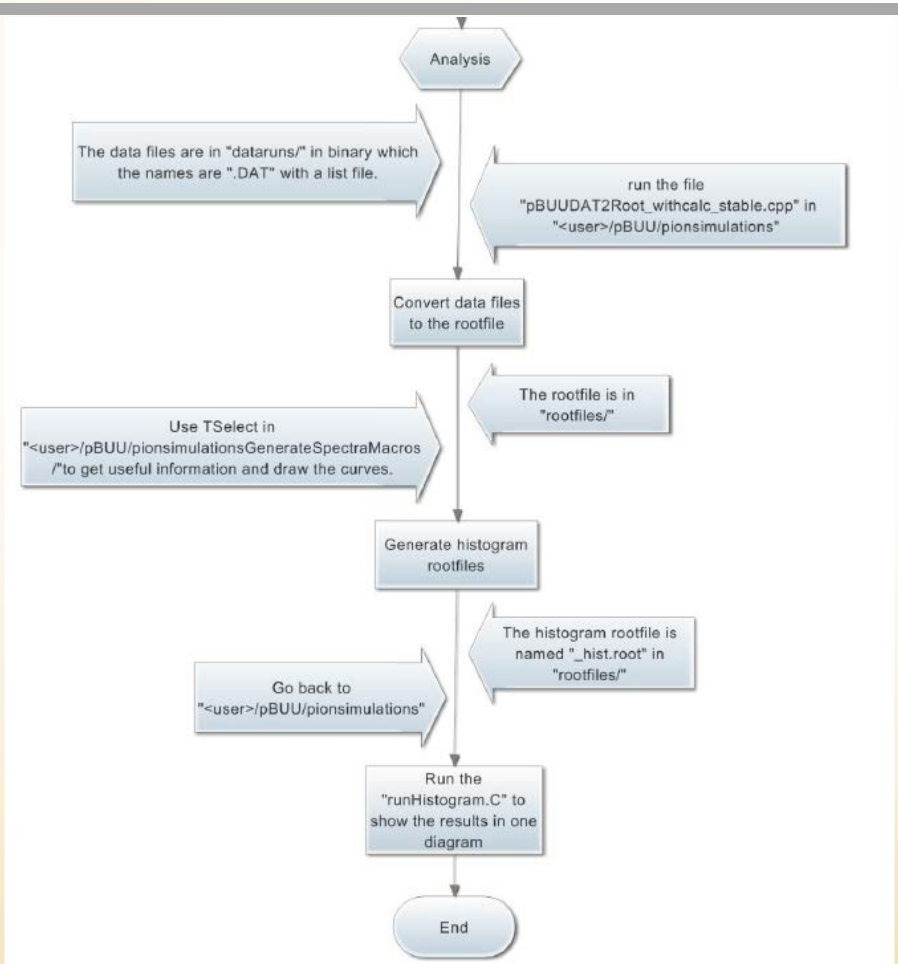
Asymmetry energy

$$\frac{E}{A}(\rho,\alpha) = \frac{E}{A}(\rho,0) + S(\rho)(\alpha^2 - \mathrm{O}(\alpha^4))$$

Method of simulation



Simulation



Analysis

Results and discussion

Goal	Neutron rich	Neutron poor
Collision	^{108}Sn(beam) + ^{112}Sn(target)	^{132}Sn(beam) + ^{124}Sn(target)
Energy density	200MeV/A & 300MeV/A	
Impact parameter	b=3fm	
gamma	0.5, 0.9 & 1.75	

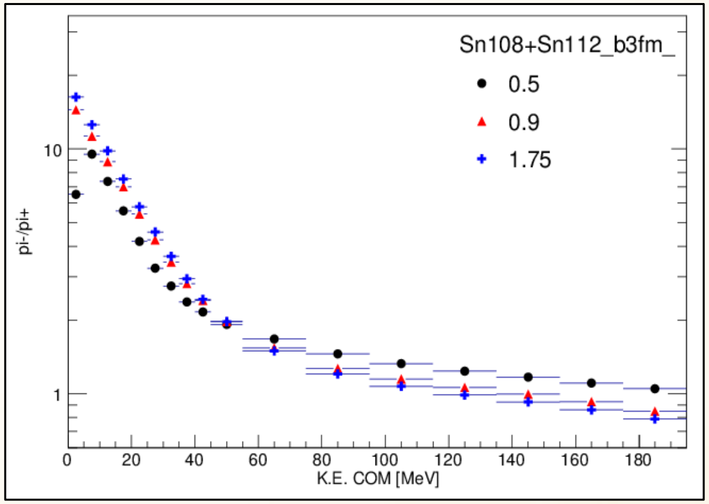
200Mev/A simulation isdone by Justin
300Mev/A ^{132}Sn(beam) + ^{124}Sn(target) simulation is done by Han
300Mev/A ^{108}Sn(beam) + ^{112}Sn(target) simulation is done by Mingbo

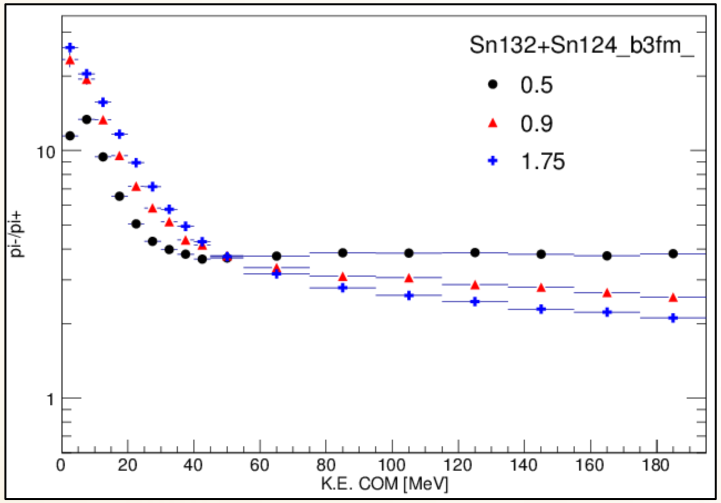
Results and discussion

^{108}Sn(beam) + ^{112}Sn(target)

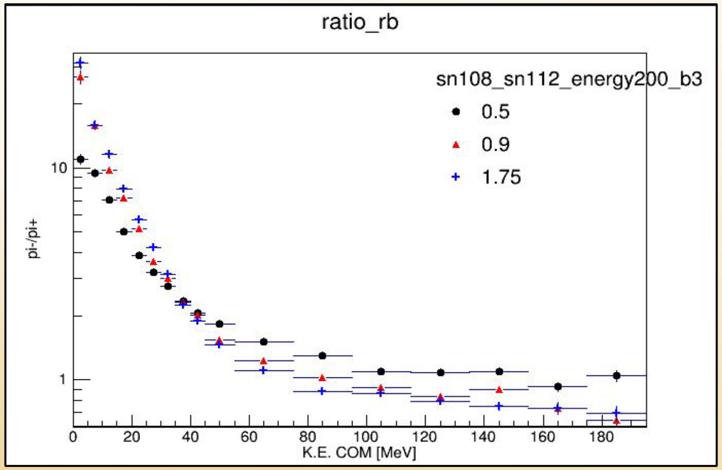
^{132}Sn(beam) + ^{124}Sn(target)

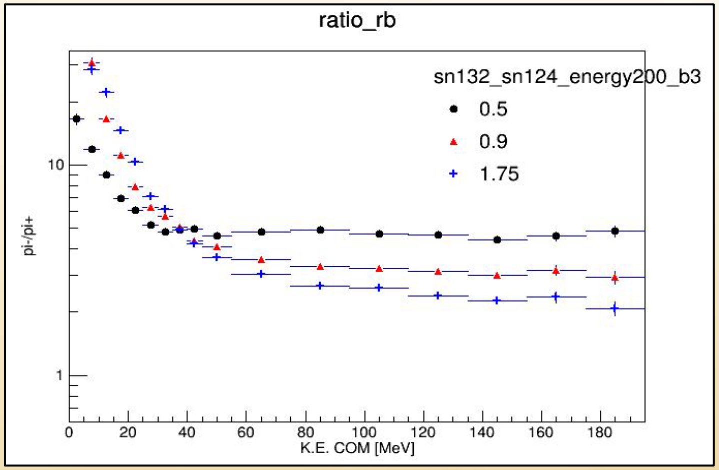
300 MeV/A





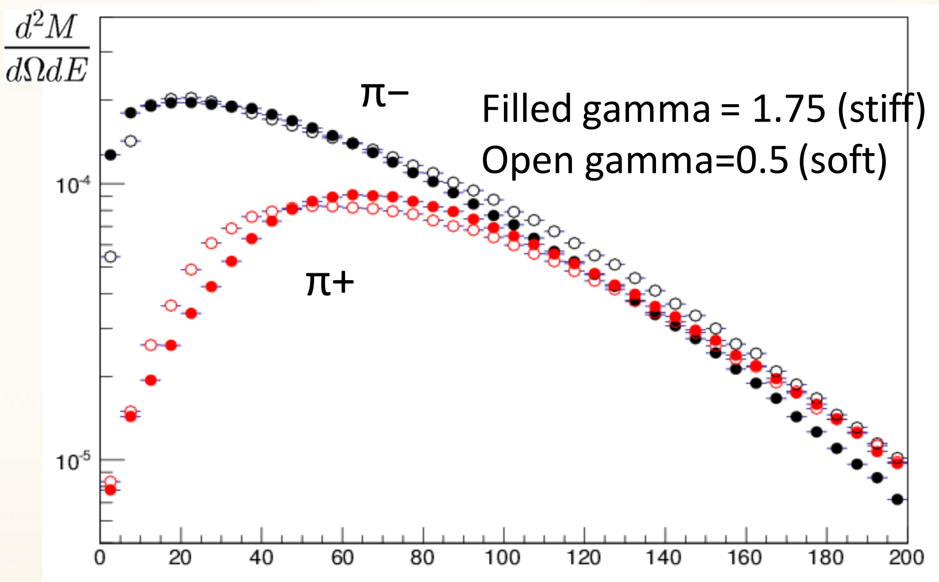
200 MeV/A





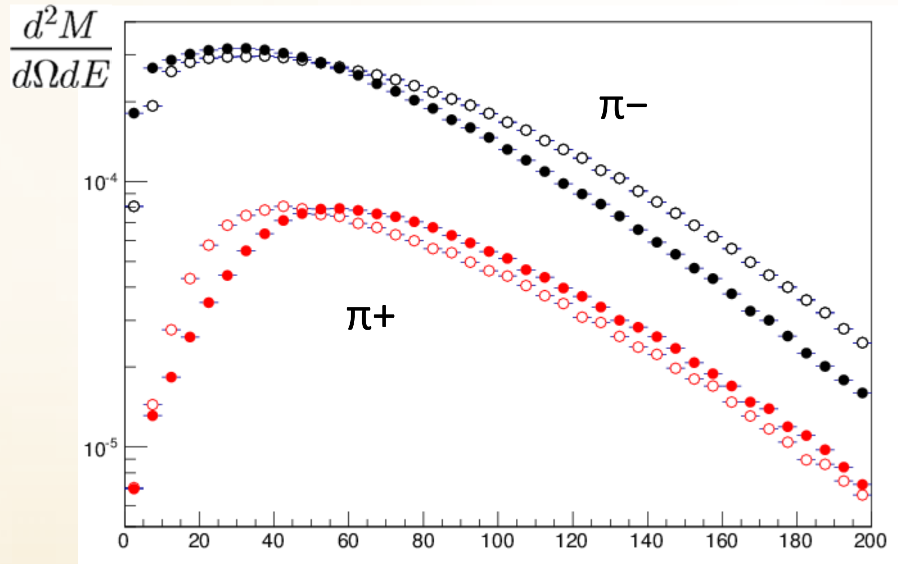
Results and discussion

$^{108}Sn+^{112}Sn$ 300MeV



KE_{COM} [MeV]

$^{132}Sn+^{124}Sn$ 300MeV

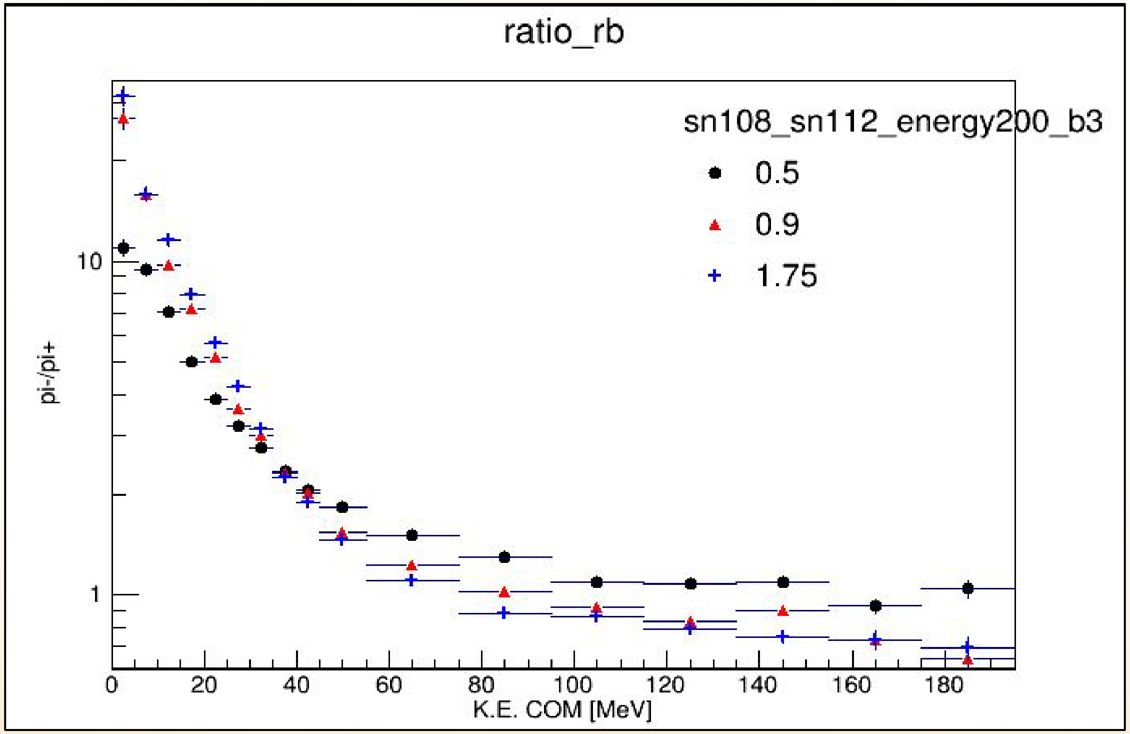


KE_{COM} [MeV]

- Rich neutron reaction makes π- more abundent than π+

Results and discussion

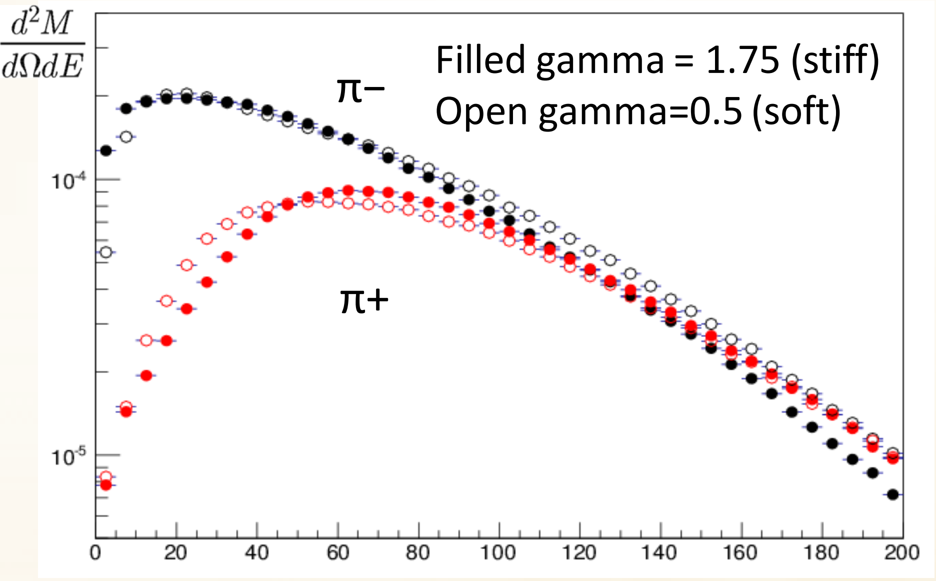
$^{108}Sn + ^{112}Sn$
200MeV/A

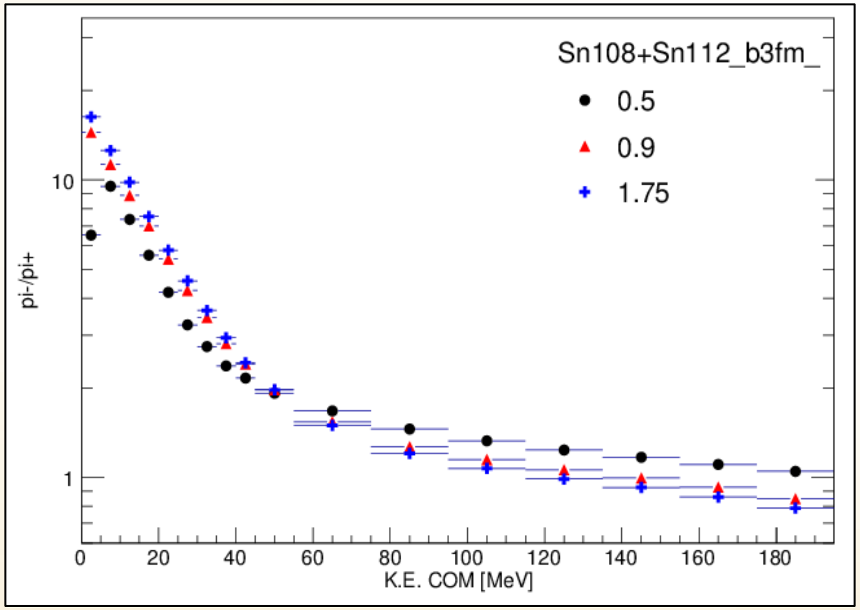


- Coulomb interactions accelerate π+ and decelerate π−. So π+/π- is big at low c.m. energies but small at high c.m. energies.

Results and discussion

$^{108}Sn+^{112}Sn$ 300MeV



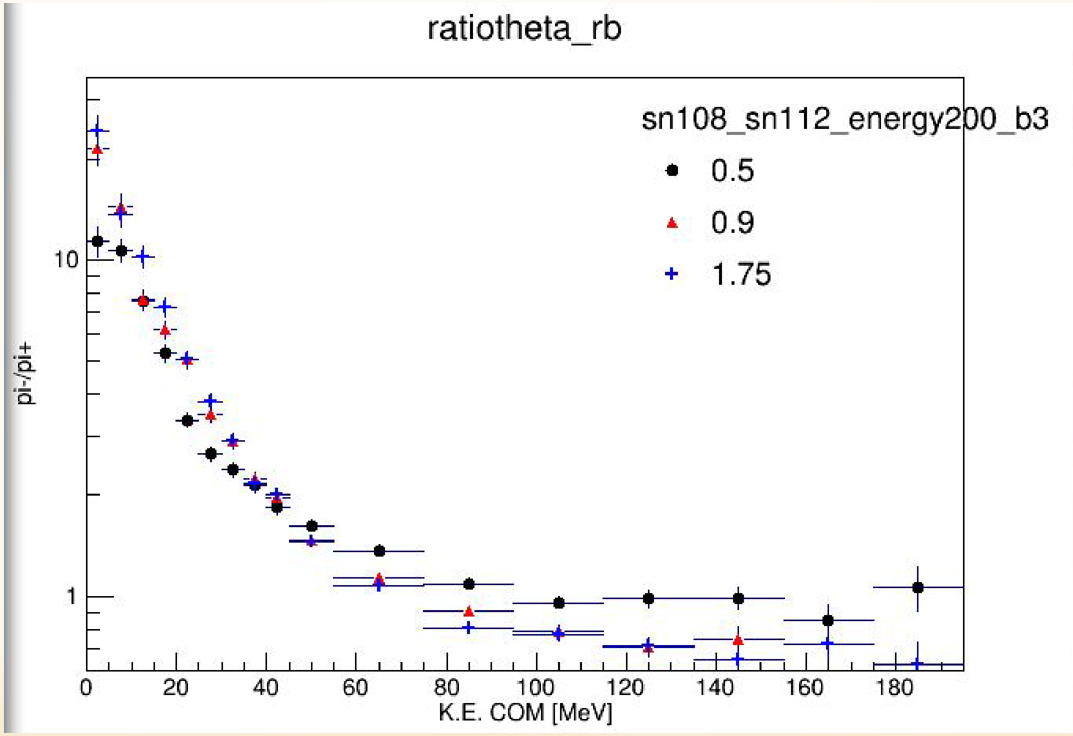


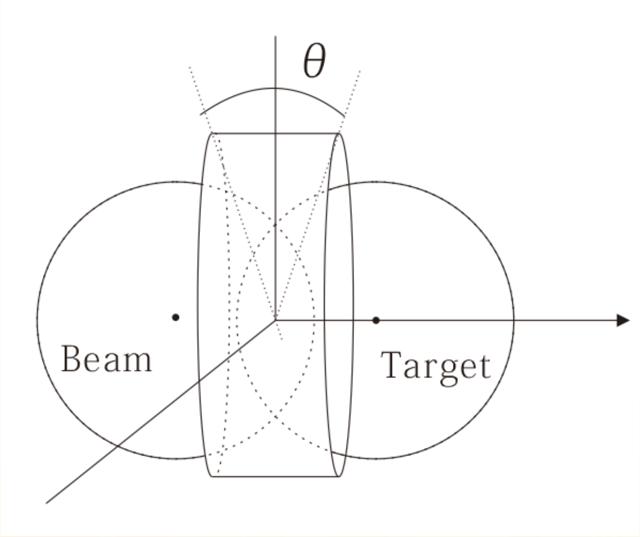
KE_{COM} [MeV]

- Stiff energy tends push away the coupled pions which makes π+ curve shift to higher energy and π- shift to lower energy when gamma gets bigger.

Results and discussion

$^{108}Sn+^{112}Sn$ 200MeV





- An angle of theta is cut to see whether there is special effect at certain direction. However, it doesn't look special.

Summary

- Spectral pion ratios are good observables to study symmetry energy.
- Pions provide critical constraints in high density regions
- There are competing effects of Coulomb interactions and of symmetry energy.
- The stiffness of the energy has an impact on the competitiveness of symmetry energy.
- The angle cut of the reaction doesn’t show big difference which may indicate other effects.

Acknowledge

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