Probing the Symmetry Energy with pions

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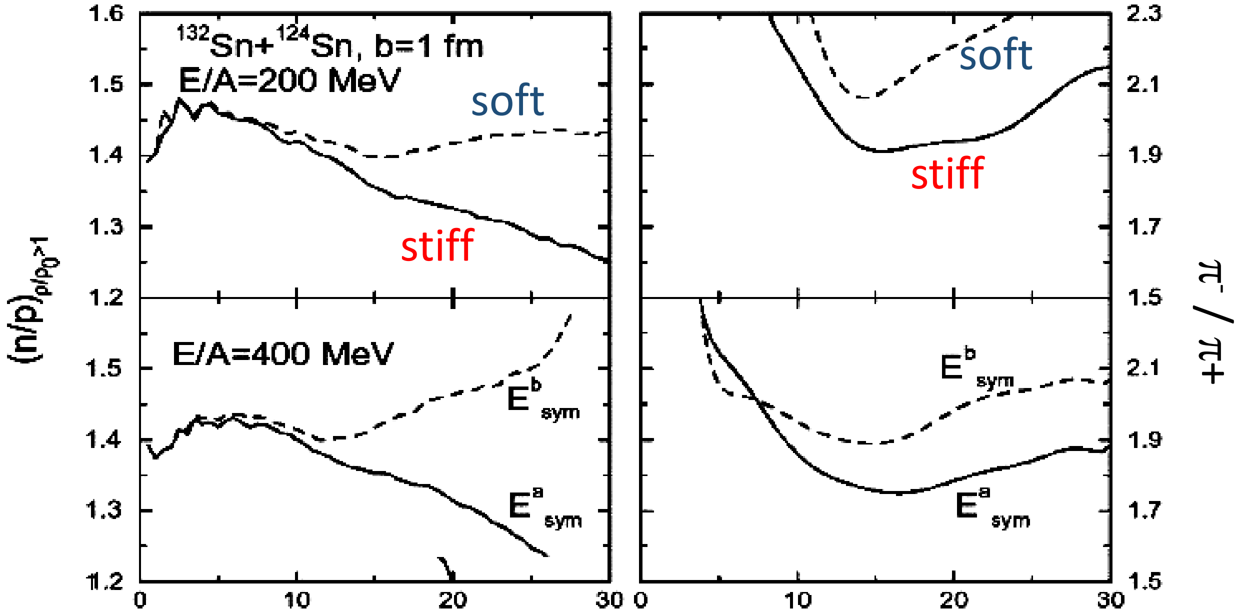
Motivation for the pion observable

- Observables around $\sim 2\rho_o$ (important for neutron –

ρ_o=.16 nucleons/fm^3

Pion production and Symmetry Energy



Li et al., Nucl.Phys. A734 (2004) 593.

Delta resonance reactions

$$pp \rightarrow \Delta^{++} \rightarrow pn\pi^{+}$$

$$\text{nn} \rightarrow \Delta^{o} \rightarrow pn\pi^{-}$$

…ect.

- Dominant mode of production is through delta resonances
- In delta resonance model, $Y(\pi^-)/Y(\pi^+) \approx (\rho_{n,}/\rho_p)^2$
- On average stiff symmetry expels more neutrons, less π^-
- High energy pions are of particular interest
  - Produced early at high density
  - Less likely to scatter and exchange charge

Transport equation

- BUU semi-classical equation governing the dynamics of phase space volume including collisions

$$\frac{\partial f_X}{\partial t} + \underbrace{\frac{\partial \varepsilon_X}{\partial \mathbf{p}}}_{\text{Local velocity}} \frac{\partial f_X}{\partial \mathbf{r}} - \underbrace{\frac{\partial \varepsilon_X}{\partial \mathbf{r}}}_{\text{Force from Mean field}} \frac{\partial f_X}{\partial \mathbf{p}} = \mathcal{K}_X^{<}(1 \mp f_X) - \mathcal{K}_X^{>} f_X . \qquad f_X \equiv f_X(\mathbf{p}, \mathbf{r}, t)$$

- L.H.S. of equation describes motion through mean field. R.H.S. describes collisions
- $\mathcal{K}_x^{<}$ and $\mathcal{K}_x^{>}$ are the feeding and removal rates of particles.

BUU by Danielewicz (pBUU)

- pBUU uses simple parameterization of symmetry energy.

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

$$\varepsilon = \varepsilon(\rho, \delta = 0) + S(\rho) \cdot \delta^2 \qquad \delta = (\rho_p - \rho_n)/\rho$$

- Stiff and soft symmetry energy dependence refers to larger and smaller γ respectively
- In this simulation pions are coupled not only through Coulomb interaction but also isospin.
- This isospin coupling is described by the pion optical potential

$$U_{\pi\pm} = \pm 8 S_{int}(\rho_o)\rho_T\left(\frac{\rho^{\gamma-1}}{\rho_o^{\gamma}}\right)$$

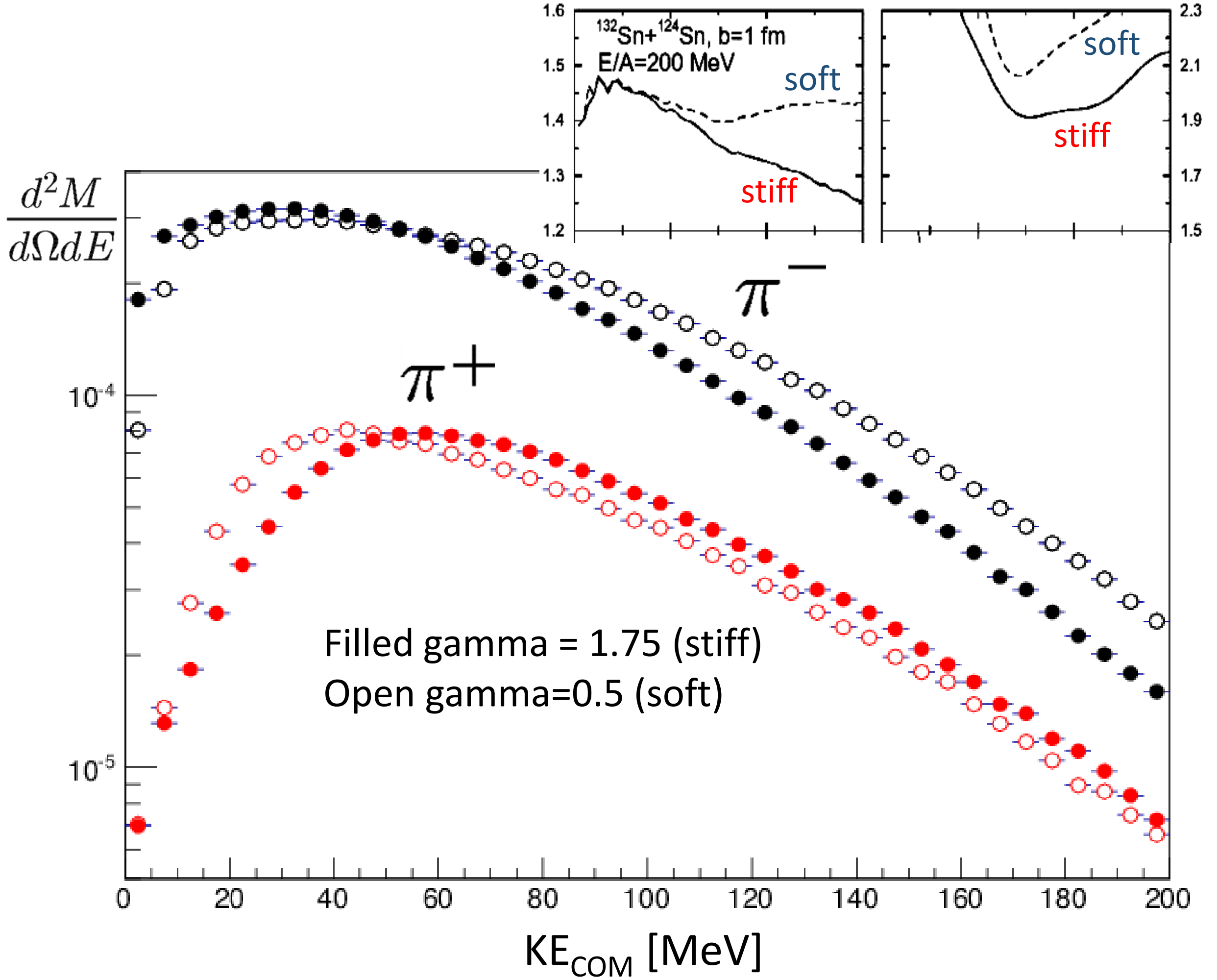
$\rho_T \sim \left(\frac{\rho_p - \rho_n}{2}\right)$ is isospin density

First Experiments to be done with SπiRIT TPC

- Radioactive beams produced at RIKEN
- ^{132}Sn(beam) + ^{124}Sn(target), neutron rich
- ^{108}Sn(beam)+^{112}Sn(target), neutron deficient
- E/A = 300MeV/A
- Perform pBUU simulations with several impact parameters and gammas.

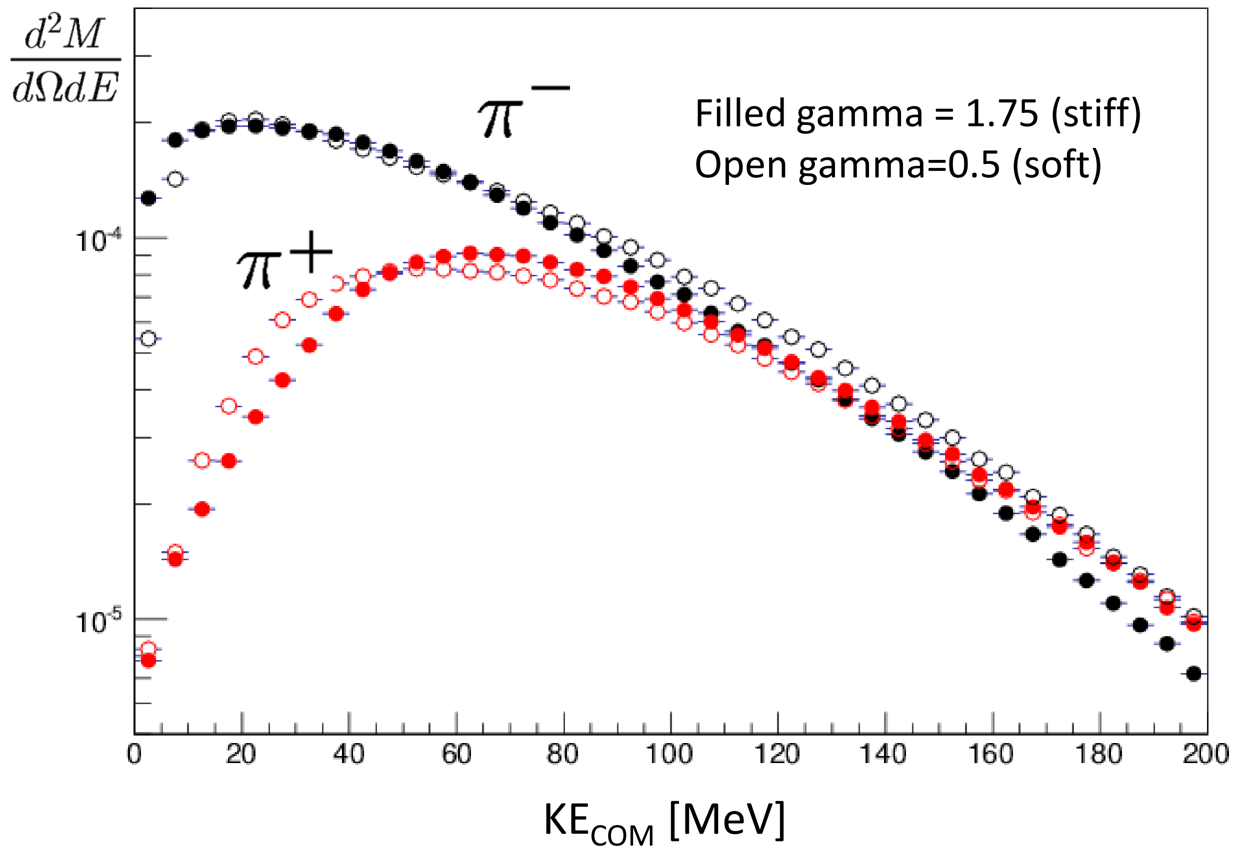
π - & π + spectra; $^{132}Sn + ^{124}Sn$ *and b=3fm*

- Difference in π^- & π^+, due to resonance model
- Stiffer symmetry energy, $\gamma = 1.75$, tends to expel neutrons more than $\gamma = .5$
- π^+ peak at ~ 50 MeV represents Coulomb peak.



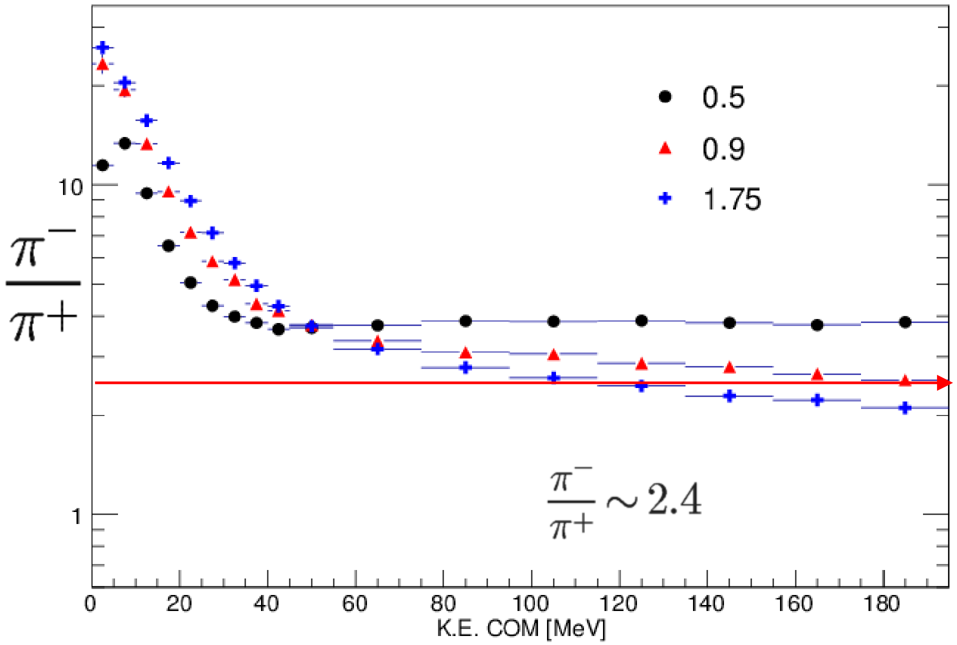
π - & π + spectra; $^{108}Sn+^{112}Sn$ *and b=3fm*

- Pion yields are similar at high energy
- expected since the system is neutron poor and is closer to isospin symmetry

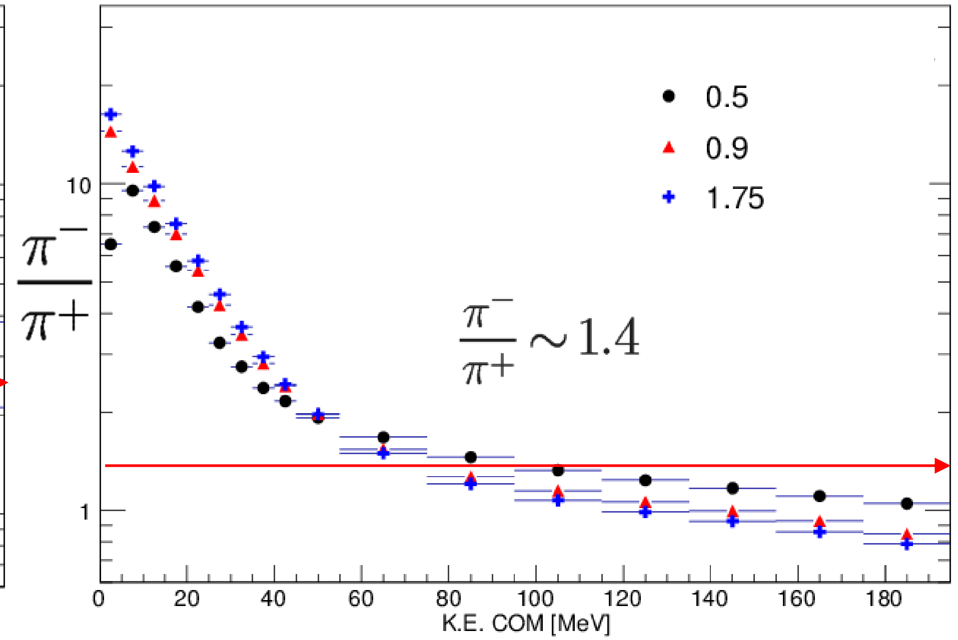


π^- / π^+ Ratios

***^{132}Sn+^{124}Sn* and b=3fm**



***^{108}Sn+^{112}Sn* and b=3fm**



- Coulomb interactions accelerate π^+ and decelerate π^- boosting ratio at lower K.E., Lowering the ratio at higher K.E. (> 50 MeV)
- Sensitivity to the symmetry energy at energies >50 MeV but the effects are small.

New comparison; Subtracted π^-/π^+ ratio

$$\Delta R_{(132+124)-(108+112)}\left(\pi^-/\pi^+\right) = R_{132+124}\left(\pi^-/\pi^+\right) - R_{108+112}\left(\pi^-/\pi^+\right)$$

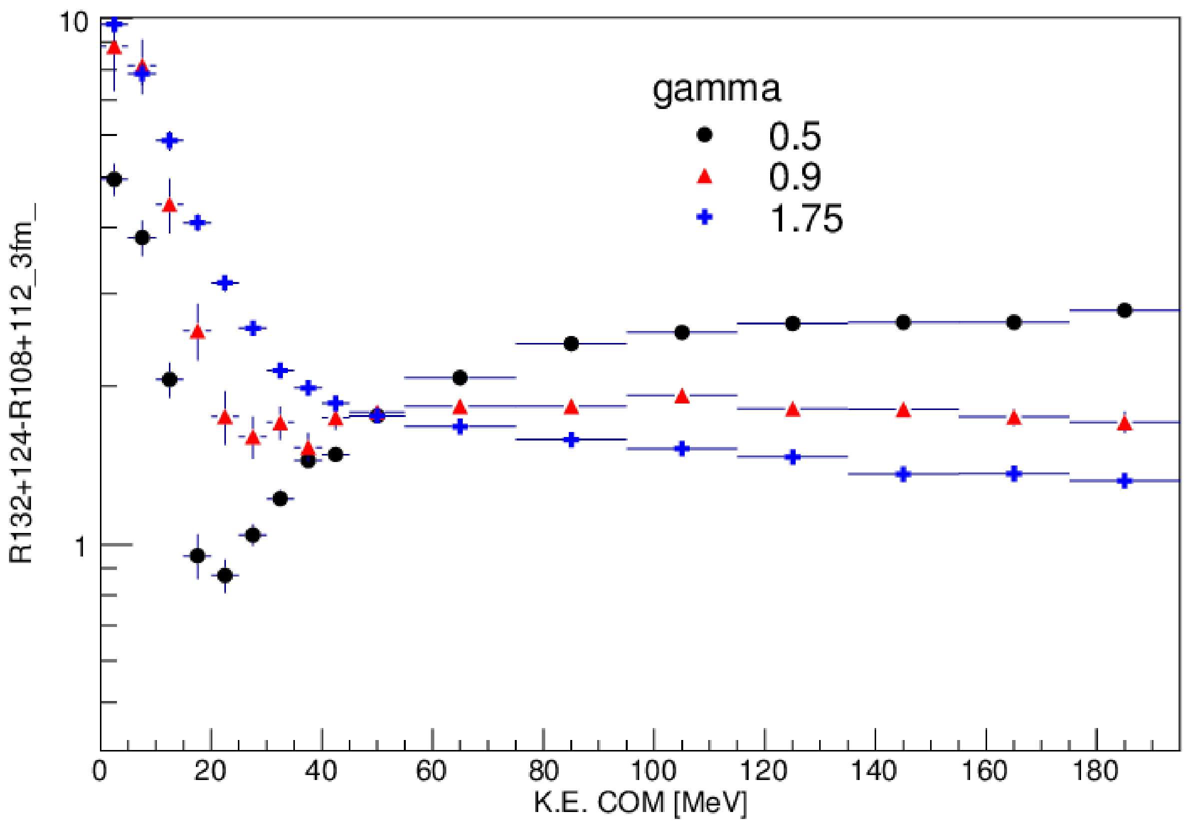
b=3fm

High energy pions
(Better understood)

- produced early in high density regions
- less likely to be absorbed and exchange charge

Low energy pions
(less understood)

- Pion ratios lack sensitivity in the Coulomb region < 50 MeV
- Complicated by Coulomb and pion optical potential effects.
- The soft EOS can act opposite to the Coulomb potential.



Summary

- Spectral pion ratios are better observables to study symmetry energy
- Pions will provide critical constraints in high density regions
- High energy pions provide clear sensitivity to different EOS.
- The Coulomb and optical potential effects may mask the sensitivity in the low energy pions.

Thank you!

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