Particle-particle correlation functions as an experimental probe of the nuclear symmetry energy

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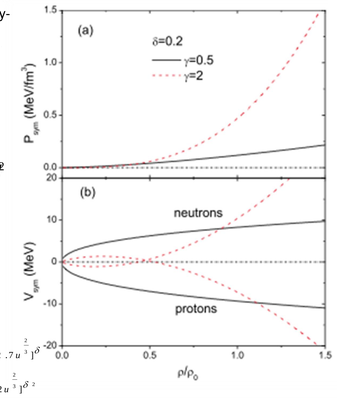
Motivation

- Transport Model (isospin-dependent Boltzmann-Uehling-Uhlenbeck: IBUU) studies have shown that correlation functions are sensitive to the density-dependence of the symmetry energy.
- Sensitivity is related to timescales of emission
- Correlation functions are sensitive to:
  - Size of the source
  - Timescale of particle emission.
- These are related to the symmetry pressure
  - Effects neutrons and protons differently

•Isospin asymmetry (δ): 0.2
•Central collisions
•^{52}Ca + ^{48}Ca: 80 MeV/A

$$\delta = \frac{N - Z}{A}$$

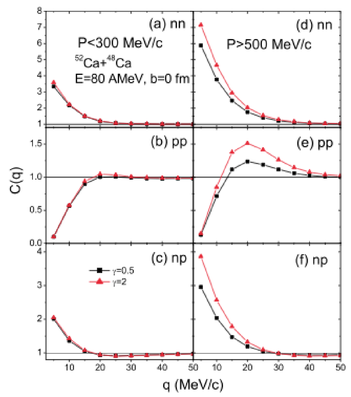
γ = 0.5 "soft" Density-dependence
γ = 2 "Stiff" Density-dependence



$$P_{sym} = (r^2 \frac{\P E_{sym}}{\P r}) d^2$$

$$u \equiv \frac{\rho}{\rho_0}$$

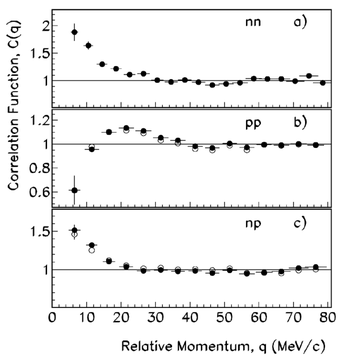
$$V_{sym} = \pm 2[E_{sym}(\rho_0)u^{\gamma} - 12.7u^{\frac{2}{3}}]\delta^2 + [E_{sym}(\rho_0)(\gamma - 1)u^{\gamma} + 4.2u^{\frac{2}{3}}]\delta^2$$



Chen, L. *PRL*, **90,** 2003.
Henzl, V. *PRC,* **85,** 2012

Correlation Functions

Koonin-Pratt formalism:
•Quantum Nature (fermions)
•Final-state Interactions of Particle pairs
•Pauli exclusion
•Spatial & Temporal Information
•Correlated Protons (N_c): Same Event
•Non-Correlated (N_c): Different Events
•Effected by
  •Total Momentum of Pair
  •Impact Parameter
•Protons & Neutrons differ, Coulomb



$$C(\vec{q}, \vec{P}_{tot}) = K \bullet \frac{N_c(\vec{q}, \vec{P}_{tot})}{N_{nc}(\vec{q}, \vec{P}_{tot})}$$

$$\vec{q}_{Rel} = \frac{\vec{p}_1 - \vec{p}_2}{2}$$

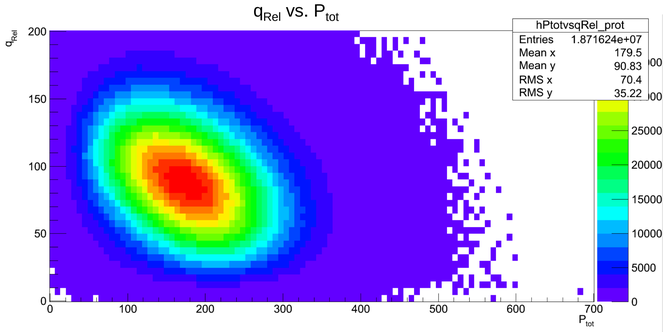
$$\vec{P}_{Tot} = \vec{p}_1 + \vec{p}_2$$

•Isospin Asymmetry (δ): 0.073
•Central collisions
•^{58}Ni + ^{27}Al: 45 MeV/A
•Open Circles: "Event-Mixing"
•Black Dots: "Singles-Product"

Pratt, S. *PRC,* **36,** 1987.
Koonin, S. *Phys. Lett.,* **70B,** 1977.
Ghetti, *NPA,* **674,** 2000, 277-297.

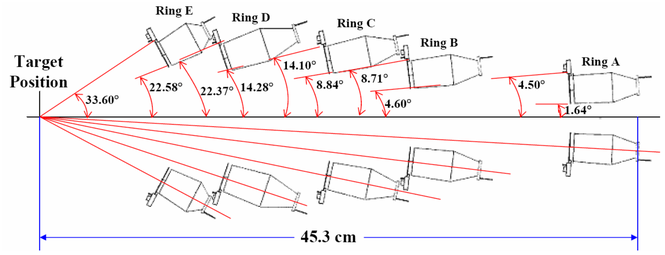
Constrained Molecular Dynamics (CoMD)

•Investigate if a MD Simulation gives similar result to IBUU for the Correlation Functions.
•Dealing with Fermions
•Calcium systems
•Multiple E(ρ)
•Heavier Systems, Lower E

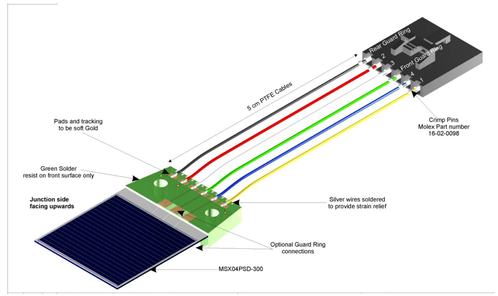


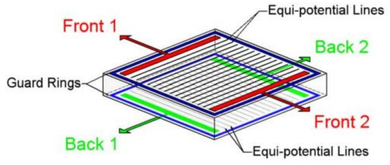
Papa, M., *PRC,* **64,** 2001.

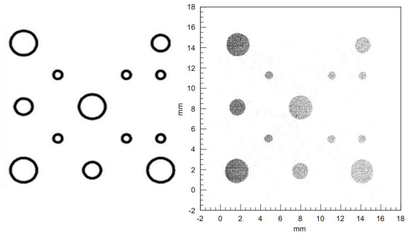
Experimental: FAUST Upgrade



•TAMU Cyclotron Institute: Forward Array Using Silicon Technology (FAUST)
•Detection from 1.6° to 33.6°
•Dual-Axis Dual-Lateral (DADL) Si Detectors
  •Uniform Resistance
  •Position resolution to 200 μm
  •Angular Resolution
•Protons resolved with E-ΔE from Si-CsI telescopes

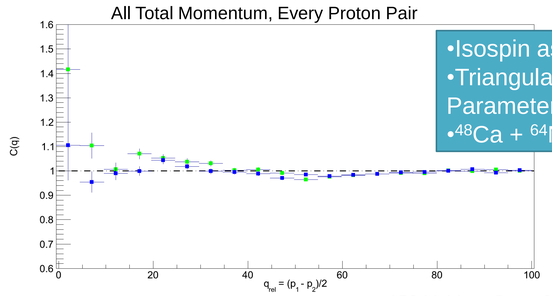






Gimeno-Nogues, F., *NIMA,* **399,** 1997.
Soisson, S.N. *NIMA,* **613,** 2010

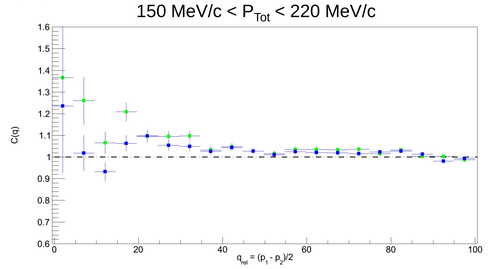
Preliminary CoMD Correlation Functions



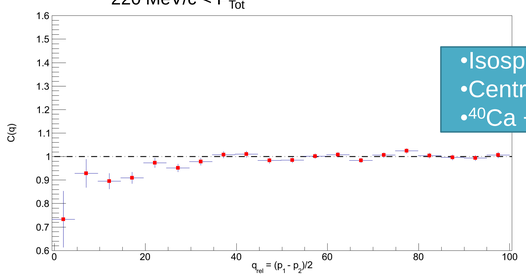
•Isospin asymmetry: 0.33
•Triangular Impact Parameter Distribution
•^{48}Ca + ^{64}Ni: 30 MeV/A

150 MeV/c < P_{Tot} < 220 MeV/c

"Soft" Density Dependence of E_{sym}
"Stiff" Density Dependence of E_{sym}
"Super-Stiff" Density Dependence of E_{sym}



220 MeV/c < P_{Tot}



•Isospin asymmetry: 0
•Central collisions
•^{40}Ca + ^{40}Ca: 31 MeV/A

Conclusions

•Basic shape of known Correlation Functions (Coulomb bump & fermion dip) can be reproduced by CoMD
•There is some difference between the different density-dependences of the symmetry energy in CoMD
•Need more statistics to say anything definitive
•Neutron-proton C(q) "should" be more sensitive to E_{sym}
•Run some BNV/transport code for these new systems at Lower Energies (30 MeV/A)

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