Constraints on neutron skin thickness and nuclear deformations using relativistic heavy-ion collisions from STAR

Haojie Xu
Huzhou University

Chunjian Zhang
Stony Brook University

Speaker needs to be determined in talk committee (alphabetically)

RHIC's capability to perform relativistic collisions of various ion species provides a unique opportunity to explore and constrain neutron skin thickness and deformation parameters of nuclei.

The study of neutron skin thickness Δr_{np} of nuclei can help us directly infer nuclear symmetry energy. Such information is of critical importance to the equation of state of dense nuclear matter in neutron stars and the medium formed in heavy-ion collisions. The Δr_{np} has traditionally been measured in low-energy hadronic and nuclear scattering experiments over decades. An alternate recent measurement using parity-violating electroweak interactions by the PREX-II experiment has yielded a large neutron skin thickness of Pb nucleus [1] that is in tension with the world-wide data established in hadronic collisions. In isobar collisions at relativistic energies, the effect of neutron skin was predicted [2] to yield different multiplicities and elliptic flows. They, in turn, provide an unconventional but more precise method to probe the neutron skin [3]. The idea is to compare the produced hadron multiplicities ($N_{\rm ch}$) [3], the mean transverse momenta ($\langle p_T \rangle$) [4], and the net charge multiplicities (ΔQ) [5] to trace back to the neutron skin differences between the isobar nuclei.

Nuclear deformation, an ubiquitous phenomenon for most atomic nuclei, reflects collective motion induced by interaction between valence nucleons and shell structure. In most cases, the deformation has a quadrupole shape that is characterized by overall strength β_2 and triaxiality γ, and/or an octuple shape β_3. In relativistic collisions of two nuclei such deformations enhance the fluctuations of bulk observables that are sensitive to initial state geometry [6]. The deformation parameters can be constrained from the precision measurements of the ratios of harmonic anisotropy coefficients v_2, v_3, mean transverse momentum $[p_{\rm T}]$ fluctuations (mean, variance and skewness), and their Pearson correlation coefficient $\rho(v_n^2, [p_{\rm T}])$ between two isobar systems [7]. In Au+Au and U+U collisions the same can be done by performing measurement of v_2, cumulants of $[p_{\rm T}]$ distributions, and $\rho(v_n^2, [p_{\rm T}])$ [8].

In this talk we will discuss the aforementioned measurements in Au+Au, U+U and isobar ^{96}Ru+^{96}Ru and ^{96}Zr+^{96}Zr collisions at $\sqrt{s_{NN}}$ = 200 GeV using the STAR detector. We will discuss how we extract the neutron skin thickness and the symmetry energy slope parameter from these data. We will contrast our results in the context of the global data on symmetry energy and tension with the PREX-II data. We will discuss how the significant deviations of the ratios of v_2 and v_3 from unity in isobar collisions are indicative of large quadrupole and octuple deformations in Ru and Zr nuclei, respectively [9]. We will also discuss how the relative enhancement of $[p_{\rm T}]$-skewness, sign-change of $[p_{\rm T}]$-kurtosis and the suppression of $\rho(v_n^2, [p_{\rm T}])$ in U+U relative to Au+Au collisions are consistent with a large prolate deformation of the uranium nuclei.

[1] D. Adhikari *et al.* (PREX Collaboration), Phys. Rev. Lett. **126**, 172502 (2021), arXiv:2102.10767 [nucl-th].
[2] H. j. Xu, X. Wang, H. Li *et al.*, Phys. Rev. Lett. **121**, 022301 (2018), arXiv:1710.03086 [nucl-th].
[3] H. Li, H. j. Xu, Y. Zhou *et al.*, Phys. Rev. Lett. **125**, 222301 (2020) arXiv:1910.06170 [nucl-th].
[4] H. j. Xu, W. Zhao, H. Li *et al.*, arXiv:2111.14812 [nucl-th].
[5] H. j. Xu, H. Li, Y. Zhou *et al.*, Phys. Rev. C **105**, L011901 (2022), arXiv:2105.04052 [nucl-th].
[6] C. Zhang and J. Jia, Phys. Rev. Lett. **128**, 022301 (2022), arXiv:2109.01631 [nucl-th]
[7] J. Jia and C. J. Zhang, arXiv:2111.15559 [nucl-th].
[8] J. Jia, S. Huang and C. Zhang, Phys. Rev. C **105**, 014906 (2022), arXiv:2105.05713 [nucl-th].
[9] M. Abdallah *et al.* (STAR Collaboration), Phys. Rev. C **105**, 014901 (2022), arXiv:2109.00131 [nucl-ex].