

Extracting ground-state nuclear deformations from RHIC-BNL and LHC-CERN type of physics experiments.

Balraj Singh, McMaster University. NSDD-2022, April 4-7 virtual meeting

Presentation of literature survey (mostly in the last 6 months) of seemingly new topic of research.

Topic: connection between low-energy nuclear physics and relativistic heavy-ion physics experiments and analysis at BNL-RHIC and LHC-CERN.

In NSR, articles in PRC on relativistic heavy-ion physics have not been keyworded since ~2007.

Observables in RHI experiments such as **Elliptic flow fluctuations** and **centrality** from analysis of quark-gluon plasma (QGP) data in relativistic nuclear collisions: strongly affected by the deformation of the colliding ions.

Description of nomenclature: see R. Snellings, New J. of Phys. 13, 055008 (2011).

Analysis of data by Glauber model. Extensions to more modern Monte Carlo Glauber model: see C. Loizides: PRC 94, 024914 (2016). Also, TRENTO, URQMD, and multi-phase transport (**AMPT**) models.

Perhaps a more direct way of determining ground-state deformation parameters: β_2 , β_3 , β_4 and γ in contrast to low-energy nuclear physics methods.

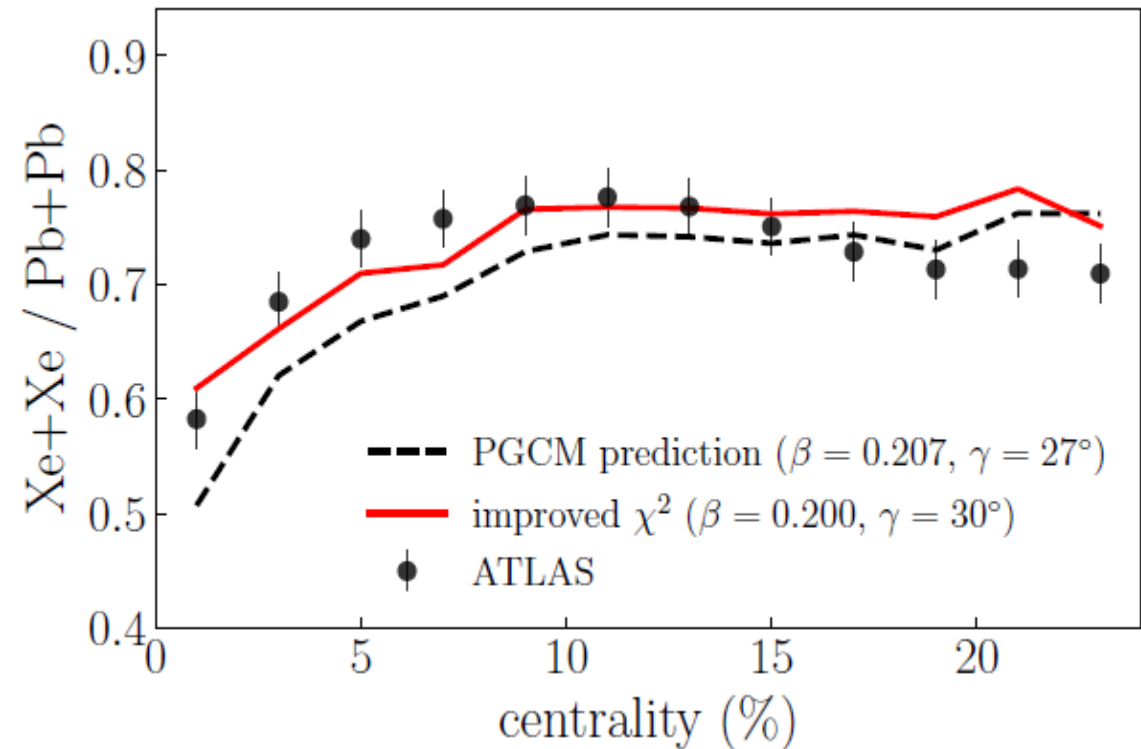
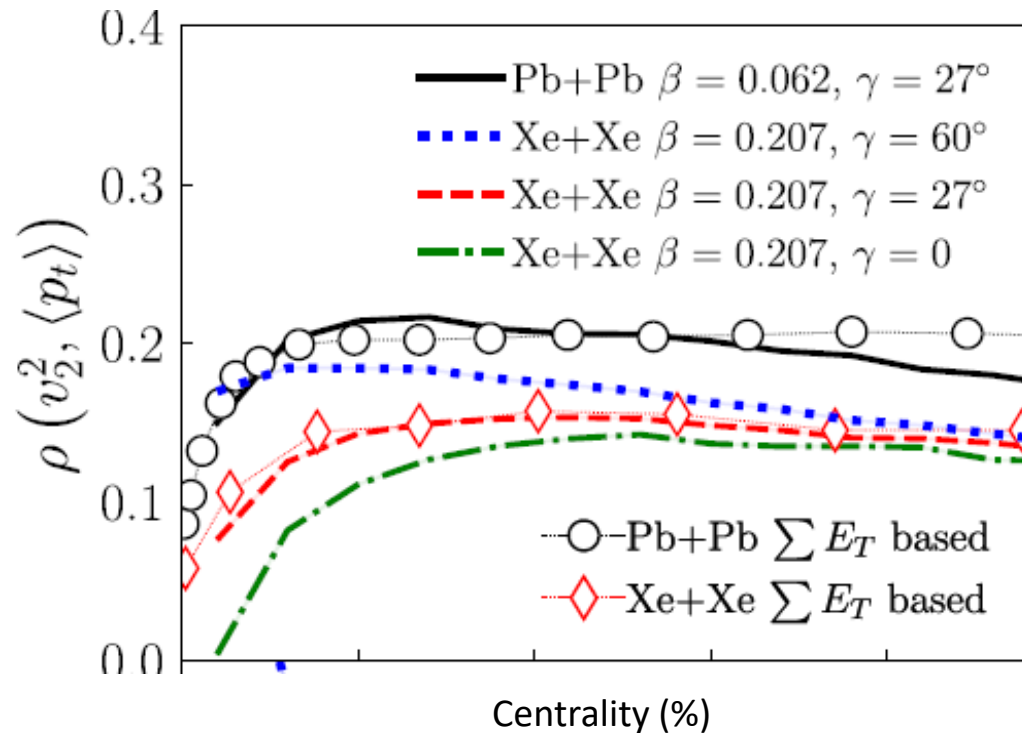
Relevant articles: RHI physics and low-energy nuclear structure

1. G. Giacalone, PRC **99**, 024910 (2019): **Elliptic flow fluctuations in central collisions of spherical and deformed nuclei**: analysis of quadrupole deformation of ^{197}Au : $\beta_2 = (-)0.11$ in ENSDF (taken from 1989Wa11), and **-0.125** in 2016Mo08 theoretical calculations.
2. G. Giacalone, Jiangyong Jia, Chunjian Zhang: PRL **127**, 242301 (2021): **Impact of Nuclear Deformation on Relativistic Heavy-Ion Collisions: Assessing Consistency in Nuclear Physics across Energy Scales**. $^{197}\text{Au}+^{197}\text{Au}$ and $^{238}\text{U}+^{238}\text{U}$ collisions: RHIC data implies $0.16 \lesssim |\beta| \lesssim 0.20$ for ^{197}Au nuclei, significantly more deformed than reported in the literature.
3. G. Giacalone, Jiangyong Jia, V. Somà: PRC **104**, L041903 (2021): **Accessing the shape of atomic nuclei with relativistic collisions of isobars**: analysis of data for ^{96}Ru , ^{96}Zr , ^{154}Sm , ^{154}Gd . Octupole deformation indicated for ^{96}Zr from analysis of data from STAR collaboration (arXiv-210900313 (2021)) at BNL-RHIC, consistent with experimental B(E3) value (2019Is03: PL-B 788, 396), but a challenge for some theoretical calculations.
4. Chunjian Zhang, Jiangyong Jia: PRL **128**, 022301 (2022): **Evidence of Quadrupole and Octupole Deformations in $^{96}\text{Zr} + ^{96}\text{Zr}$ and $^{96}\text{Ru} + ^{96}\text{Ru}$ Collisions at Ultrarelativistic Energies**: analysis of STAR collaboration data of 2021: Using a transport model simulation, and from differences in between the two collisions, authors conclude large quadrupole deformation β_2 of ^{96}Ru and large octupole deformation β_3 of ^{96}Zr . Authors' say: "Our analysis demonstrates that isobaric heavy-ion collisions can be used as a precision tool to image the shape and radial structures of the nuclei."

Relevant articles

- 5. B. Bally, M. Bender, G. Giacalone, V. Som`a: PRL **128**, 08321 (2022): **Evidence of the Triaxial Structure of ^{129}Xe at the Large Hadron Collider (CERN)**: authors point out difficulty in obtaining intrinsic deformations for odd-A and odd-odd nuclei in low-energy physics experiments. Comparison of $^{129}\text{Xe}+^{129}\text{Xe}$ and $^{208}\text{Pb}+^{208}\text{Pb}$ collisions from experiments at LHC. Authors perform Monte Carlo simulations of millions of these collisions to produce the results below.

(PGCM=Projected Generator Coordinate Method)



Relevant articles

6. Jiangyong Jia: PRC **105**, 014905 (2022): **Shape of atomic nuclei in heavy ion collisions**: “In these collisions, two Lorentz-contracted nuclei, by a factor of 100 at RHIC and more than a factor of 1000 at the LHC, cross each other over a timescale $\tau < 0.1 \text{ fm}/c \approx 3 \times 10^{-24} \text{ s}$, forming a hot and dense quark-gluon plasma (QGP) [8] in the overlap region, **whose initial shape is correlated with the deformed shape of the nuclei**”. “...at a time scale much shorter than $\sim 10^{-21} \text{ s}$ probed by low-energy nuclear structure.”

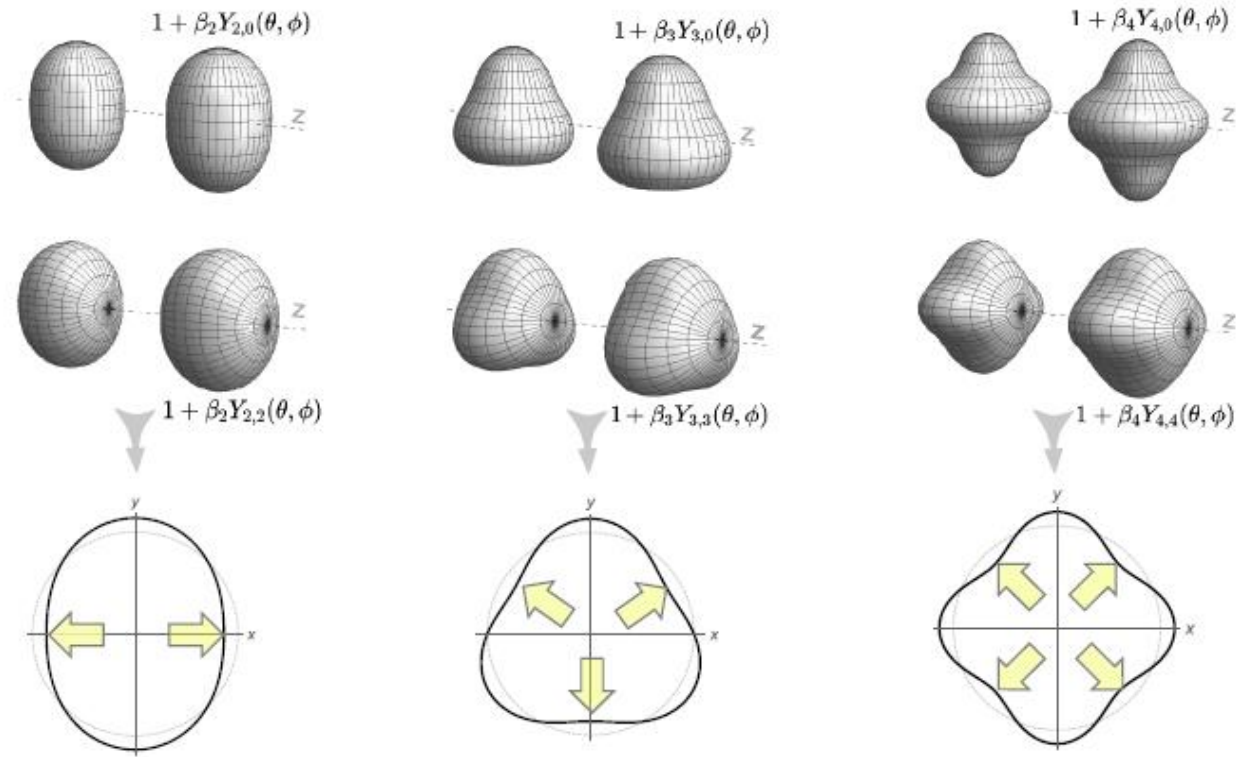


FIG. 1. A diagram of the collision of nuclei with quadrupole (left), octupole (middle), and hexadecapole (right) deformations including either the $Y_{n,0}$ mode (top row) or the $Y_{n,n}$ mode (middle row) and with $\beta_n = 0.25$. The Lorentz contractions in the z direction, by factor of 100 at RHIC and more than a factor of 1000 at the LHC, are not shown. The bottom row represents the initial conditions of the QGP formed after the collision in the transverse plane. The hollow arrows indicate the direction of maximum pressure gradients along which the medium expands with largest velocity, leading to final state harmonic flow v_n with n -fold symmetry.

Other related articles:

7. Jiangyong Jia: PRC **105**, 014906 (2022): **Probing nuclear quadrupole deformation from correlation of elliptic flow and transverse momentum in heavy ion collisions:** $^{238}\text{U}+^{238}\text{U}$ and $^{197}\text{Au}+^{197}\text{Au}$ collisions, focused on quadrupole deformation of ^{238}U .
8. Junjie He, Wan-Bing He, Yu-Gang Ma, Song Zhang: PRC **104**, 044902 (2021): **Machine-learning-based identification for initial clustering structure in relativistic heavy-ion collisions:** $^{12}\text{C}+^{197}\text{Au}$ and $^{16}\text{O}+^{197}\text{Au}$ collisions at $E(\text{c.m.})=200$ GeV: α -clustering structure in light nuclei; three- α triangular for ^{12}C and four- α tetrahedral structure for ^{16}O .
9. Hao-jie Xu, Hanlin Li, Ying Zhou, Xiaobao Wang, Jie Zhao, Lie-Wen Chen, Fuqiang Wang: PRC **105**, L011901 (2022): **Measuring neutron skin by grazing isobaric collisions:** Neutron skin thickness of nuclei nuclear symmetry energy are of importance to nuclear physics and astrophysics; analysis of $^{96}\text{Ru}+^{96}\text{Ru}$ and $^{96}\text{Zr}+^{96}\text{Zr}$ data from BNL-RHIC.

Conclusion: we may need to pay attention to articles in relativistic heavy-ion physics, and, it may be useful to enter such articles in the NSR database with keywords. Until January-2022 PRC issue, I keyworded above articles. Hope the practice continues, as after 15 years of keywording PRC articles for NSR, I have taken leave from this work after Jan-2022 PRC issue.

Perhaps Dr. Jiangyong Jia (BNL-Physics) could be requested to give a presentation at the next US-NDP meeting.