ISMD2021 50th International Symposium on Multiparticle Dynamics (ISMD2021)

Constraining nuclear quadrupole deformation in relativistic heavy-ion collisions from a multiphase transport model

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Based on preprints 2102.05200, 2105.01638, 2105.05713

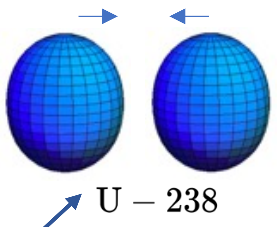
Plenary: Flash-talk (July 14, 2021 12:20 - 12:25)

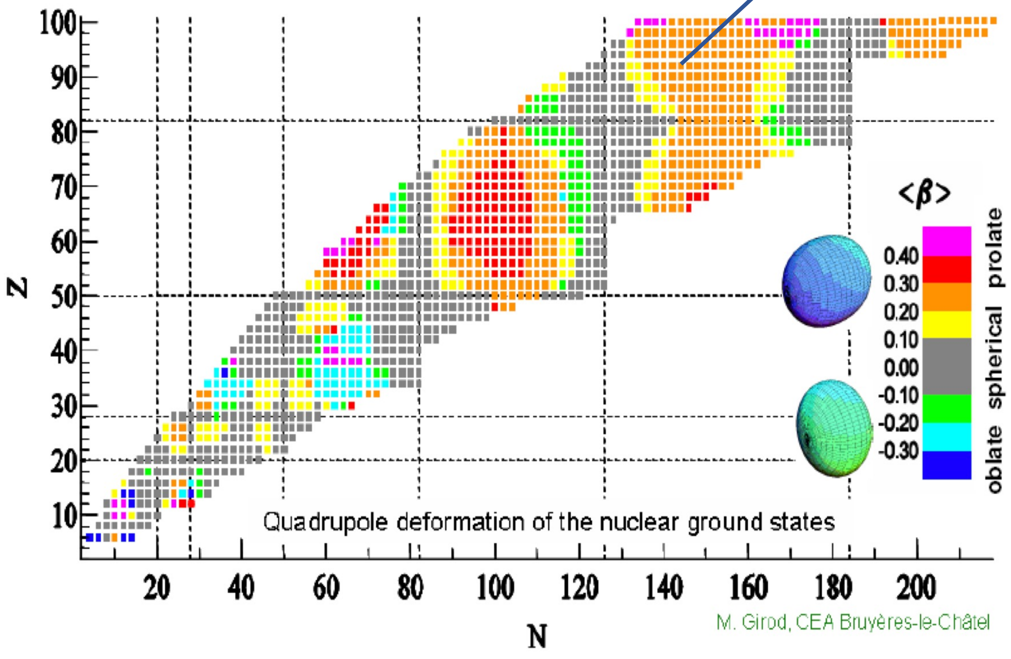
Stony Brook University

Connecting the initial state to the nuclear geometry

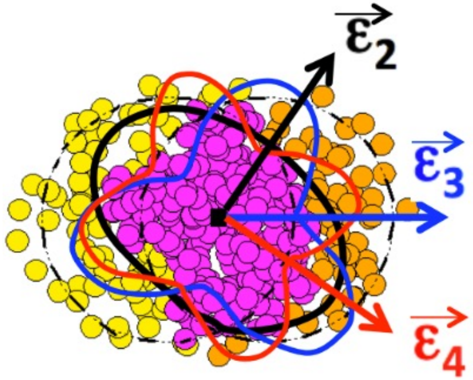
A. Gorgen, Tech. Rep. 051, 019(2015)

$$\rho(r,\theta) = \frac{\rho_0}{1+e^{(r-R_0(1+\beta_2 Y_{20}(\theta))/a}}$$





Hartree-Fock-Bogolyubov (Gogny D1S effective interaction)



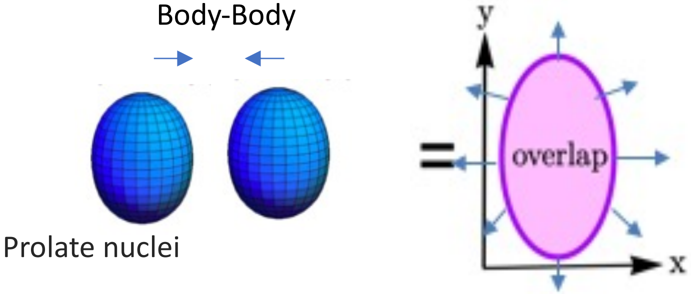
$$\vec{\epsilon}_n \equiv \epsilon_n e^{in\Phi_n^*} \equiv -\frac{\langle r^n e^{in\phi}\rangle}{\langle r^n\rangle}$$

Hydro-response

$$v_n \propto \epsilon_n, n = 2, 3$$

Shape and size fluctuation affects v_n and $\langle p_T \rangle$

Body-Body

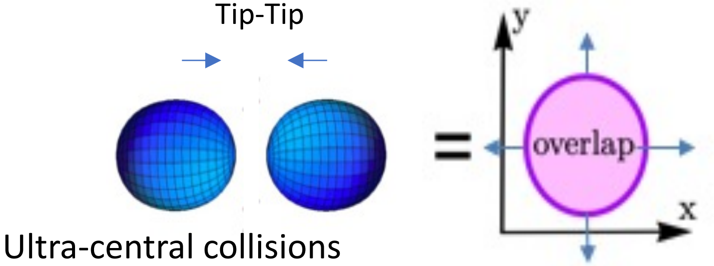


large *R*, small $\langle p_T \rangle$

large $\boldsymbol{\varepsilon}_2$

$$\left\langle \epsilon_n^2 \frac{1}{R} \right\rangle \rightarrow \langle v_n^2\, p_T \rangle$$

Tip-Tip



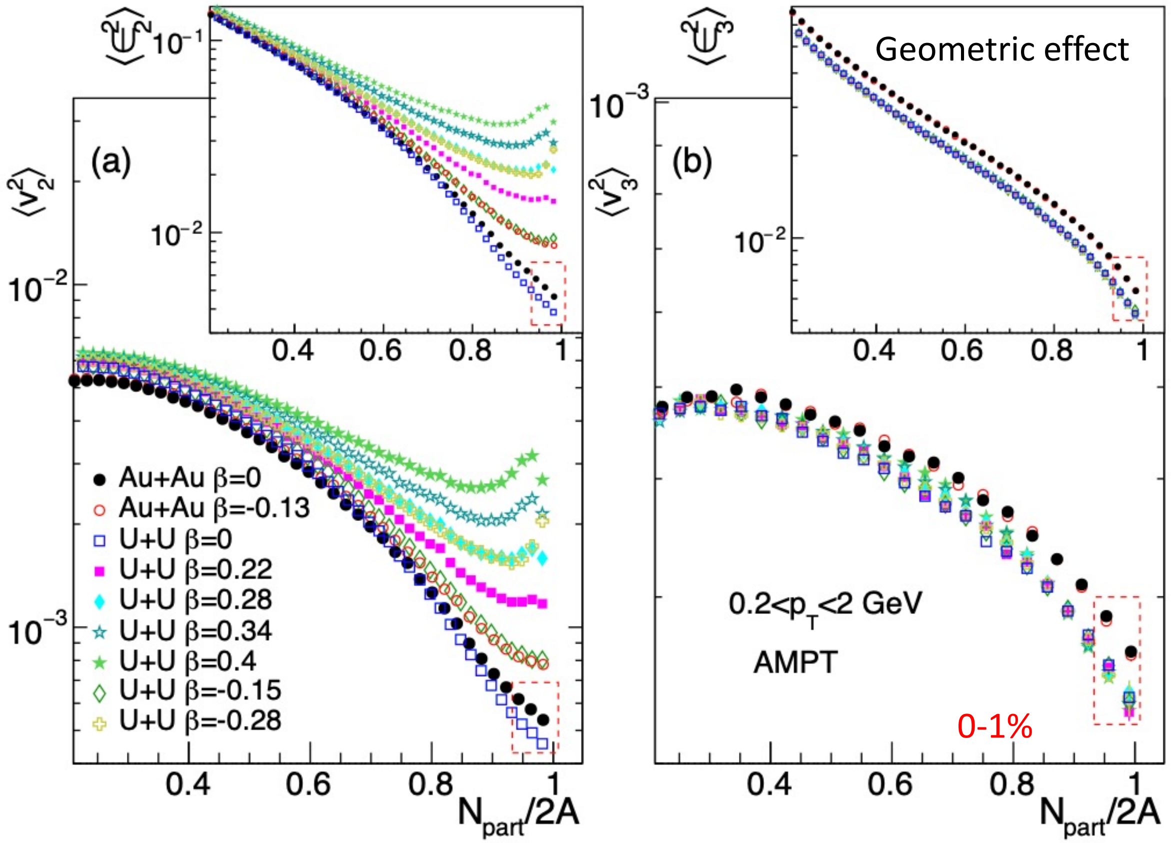
small *R*, large $\langle p_T \rangle$

small $\boldsymbol{\varepsilon}_2$

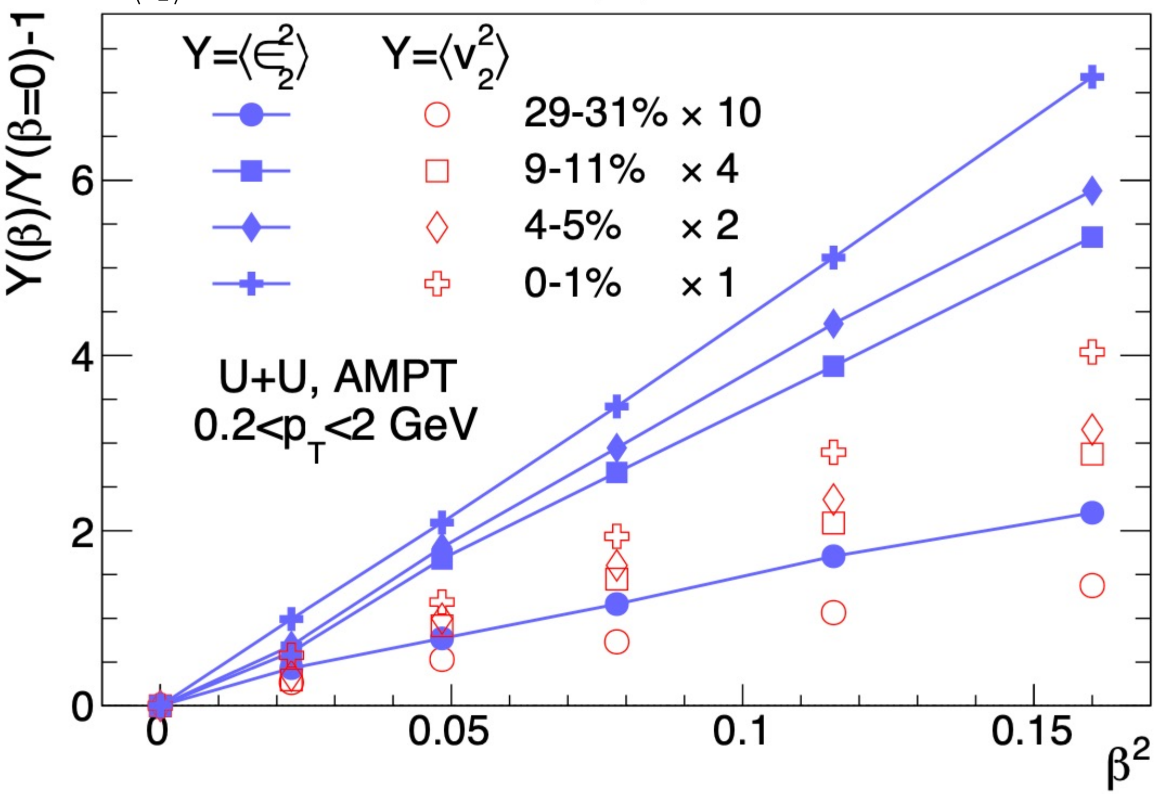
Study the deformation β_2 effect on $p(v_n)$ and $p(v_n, [p_T])$ in heavy ion collisions.

J. E. Bernhard et al., Nature Physics 15, 1113(2019); F.G. Gardim et al., arXiv:2002.07008v1;
G. Giacalone, PRC102, 024901(2020); W. Broniowski et al., PRC80, 051902(R)(2009).

Constrain the β_2 using $\mathrm{p}(\mathrm{v_n})$



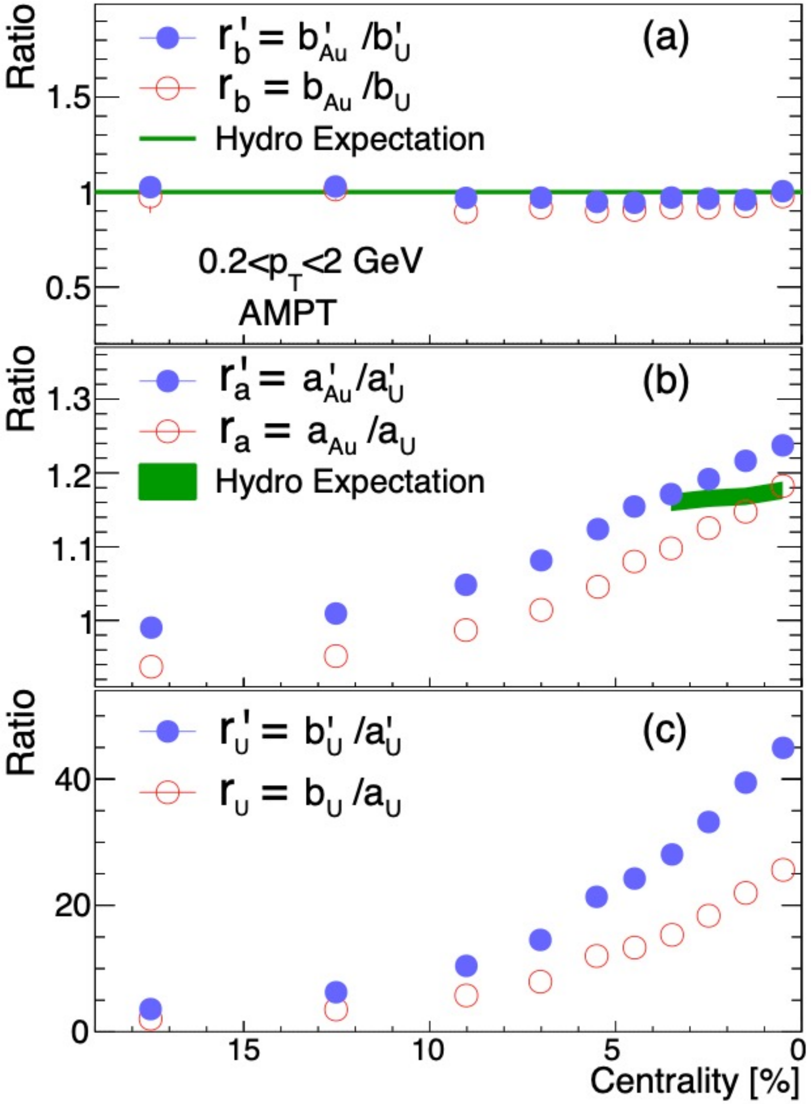
$\langle \epsilon_2^2 \rangle = a' + b'\beta^2$ $\quad v_2\{2\}^2 \equiv \langle v_2^2 \rangle = a + b\beta^2$



- $\langle v_2^2 \rangle$ strongly depends β_2 in central collisions.
- $\langle v_3^2 \rangle$ is independent of β_2 .
- $\langle v_2^2 \rangle$ and $\langle \epsilon_2^2 \rangle$ are indeed linear in β_2^2 .

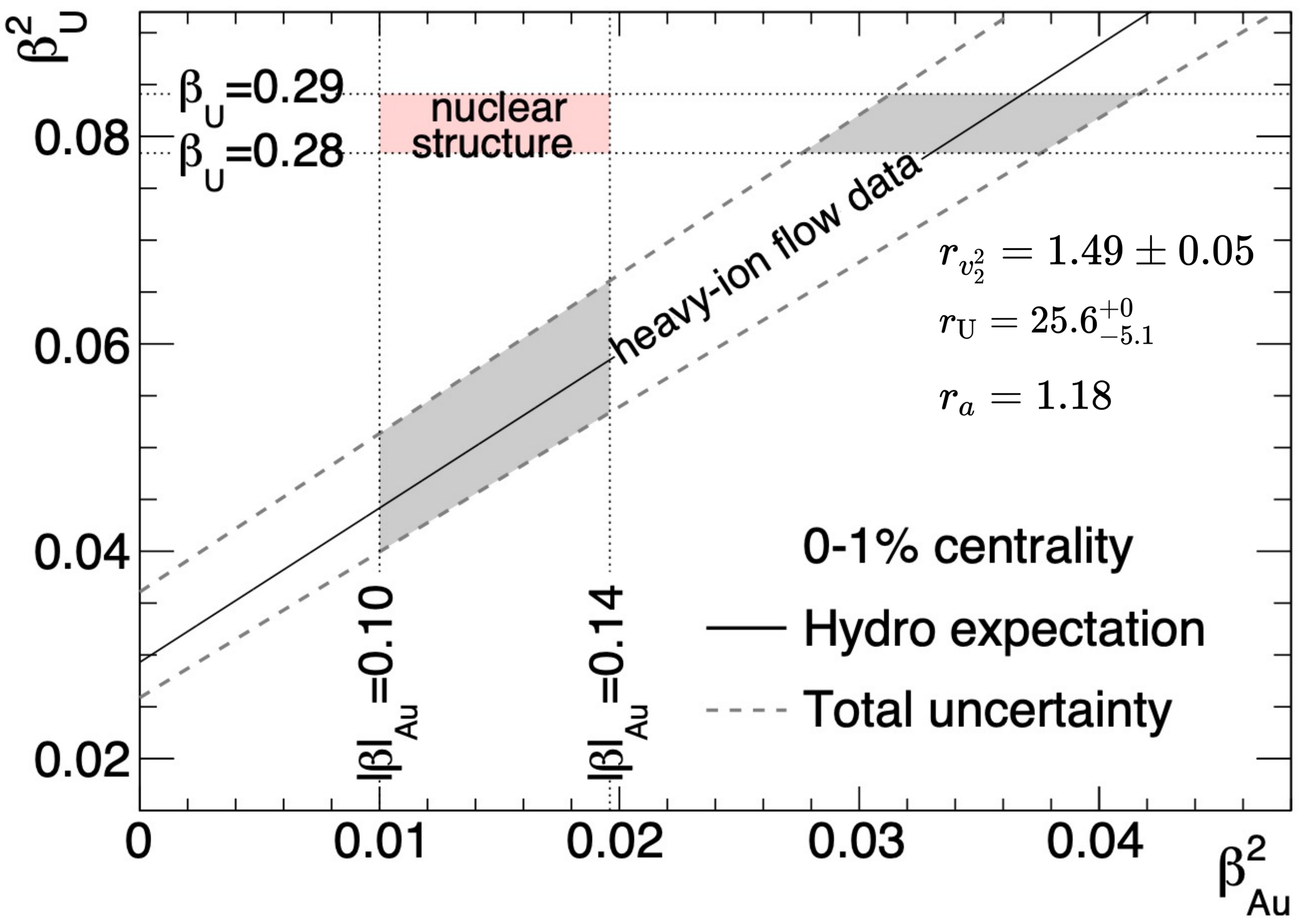
Clear geometric effect and the linear β_2 dependence.

Constrain the β_2 using $\mathrm{p}(\mathrm{v_n})$



- A minor role of the hydrodynamic response.
- Numerical results are confirmed.

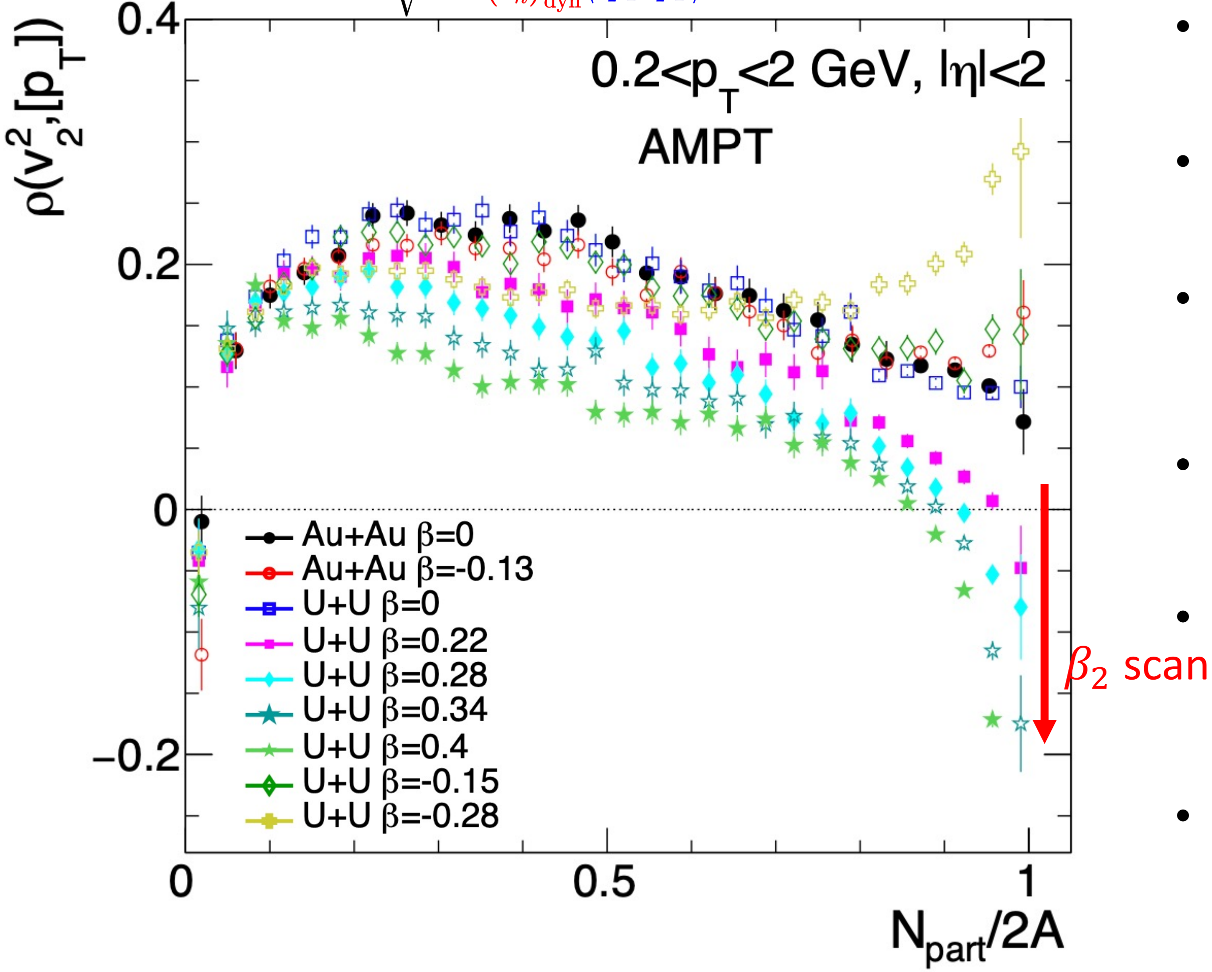
$$\beta^2_{\mathrm{Y}} = \left(\frac{r_{v_2^2} r_a - 1}{r_{\mathrm{Y}}}\right) + \left(r_{v_2^2} r_b\right) \beta^2_{\mathrm{X}}$$



Intrinsic connection between the phenomenology of heavy-ion collisions and the structure of the atomic nuclei.

Constrain the β_2 using $\mathrm{p}(\mathrm{v_n}, [\mathrm{p_T}])$

$$\rho(v_n^2,[p_T]) = \frac{\mathrm{cov}(v_n^2,[p_T])}{\sqrt{\mathrm{Var}(v_n^2)_{\mathrm{dyn}}\langle\delta p_T \delta p_T\rangle}}$$



- v_2 is an even function of β_2, while $\rho(v_2^2,[p_T])$ isn't.
- Deformation influence collisions from mid-central to central.
- Further confirm the deformation effect with TRENTo and IP-Glasma+MUSIC+UrQMD calculations.
- Comparison with STAR data in future
  STAR talk by Shengli Huang, July 15, 09:10-09:30
- Double check the volume fluctuations (centrality bias) effect:
  UCC region is a sweet spot.
- Non-flow are negligible in UCC region in HIJNG and PYTHIA study.

New way to constrain β_2 of uranium at a much shorter time scale (~10^{-23}s) in heavy-ion collisions.

TRENTo: G. Giacalone PRC102, 024901(2020),PRL124, 202301(2020)

IP-Glasma+MUSIC+UrQMD: B. Schenke, C. Shen, P. Tribedy, PRC102, 044905(2020), 2102.11189

C.J. Zhang et al., arXiv:2102.05200v1; S.H. Lim and J.L. Nagle. PRC103, 064906(2021); G. Aad et al. (ATLAS), EPJC79, 985(2019)

Conclusions and Outlooks

1. Numerically calculate the intrinsic connection between the phenomenology heavy-ion collisions and the structure of atomic nuclei:

    - Clear geometric effect and the linear β_2 dependence in central collisions.
    - $\langle v_2^2 \rangle$ strongly depends β_2 in central collisions. $\langle v_3^2 \rangle$ is independent of β_2 .
    - $\langle v_2^2 \rangle$ and $\langle \epsilon_2^2 \rangle$ are indeed linear in β_2^2.

2. AMPT β_2 scan could qualitatively describe the STAR Preliminary $\rho(v_2^2, [p_T])$ results.

3. A new experimental test to study nuclear shape in heavy-ion collisions.

    - UCC region is an sweet spot.

4. Decipher the puzzle of nuclear deformation in Ru and Zr in future.

Many thanks to ISMD2021 conference and also thank you for listening.