Проявление начальных условий и ядерной структуры в столкновении тяжёлых ионов по таблице изобар

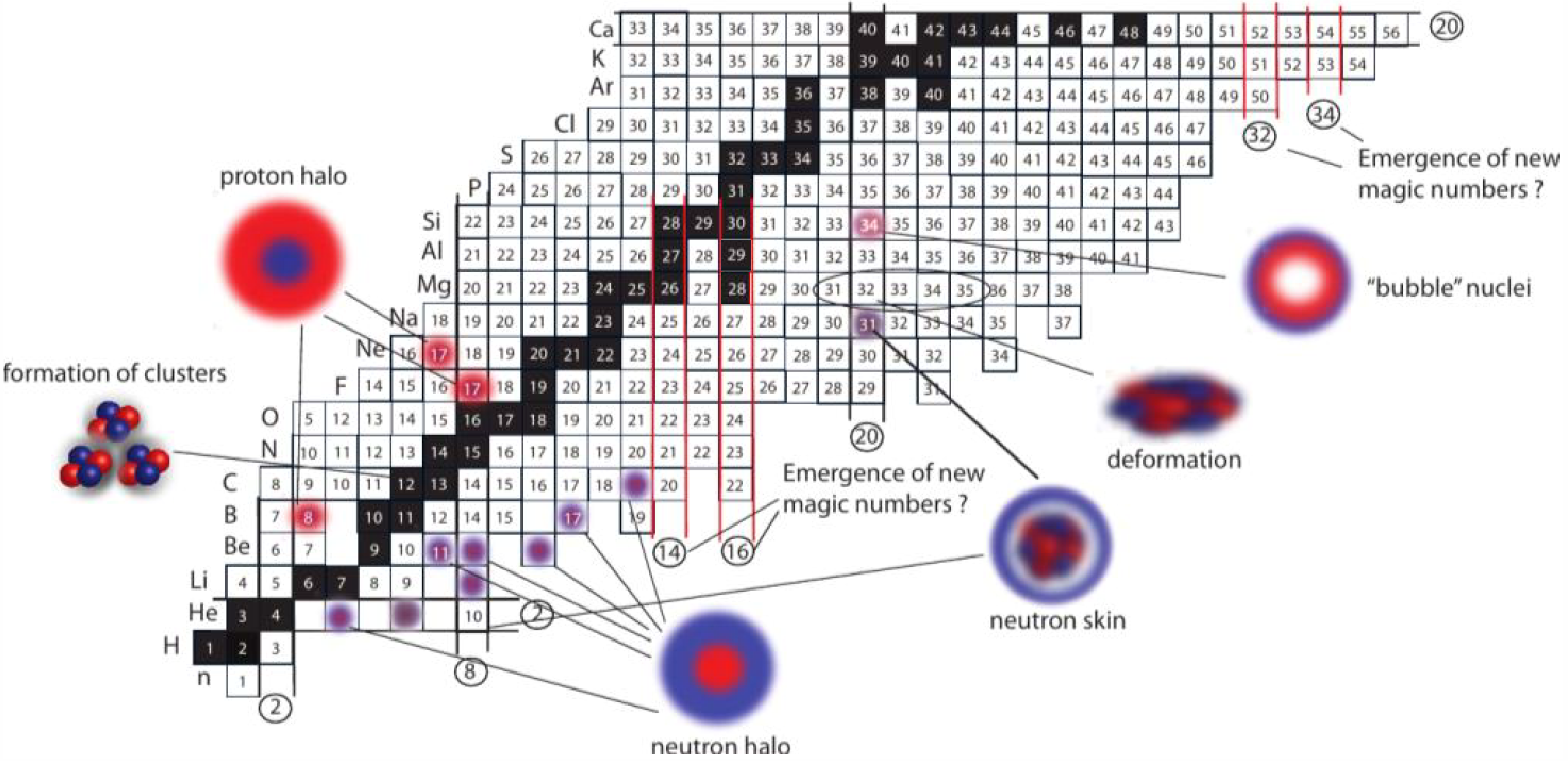
В.Л. Коротких

(новое направление HIC)

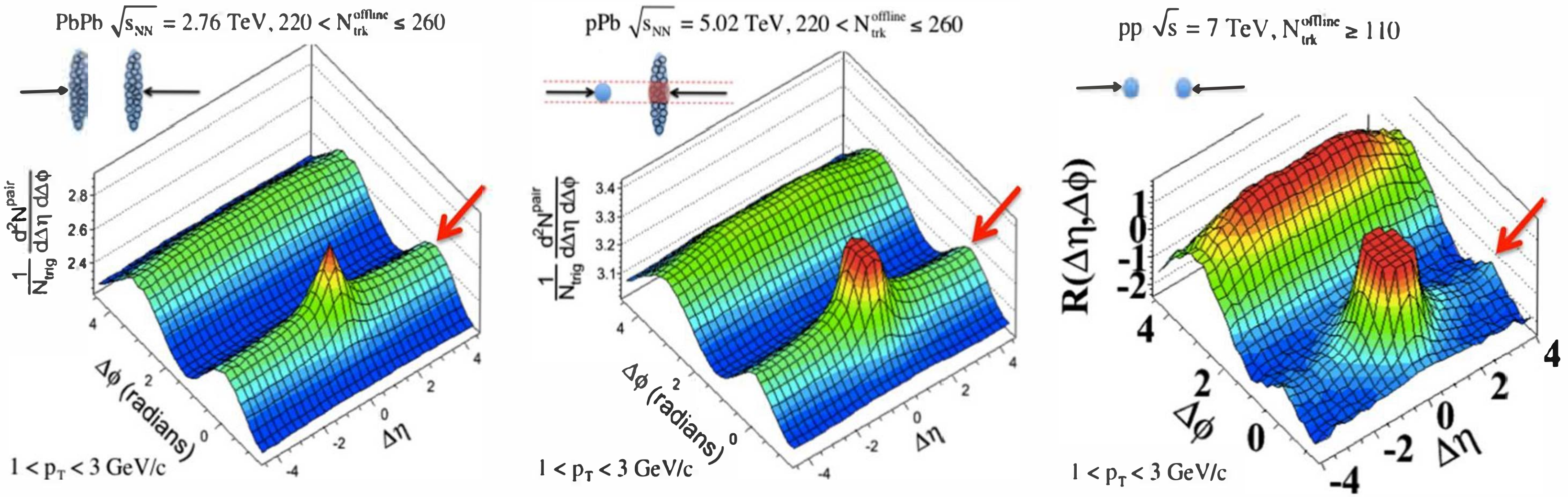
1. Presentation of Jia “JiangyongJia_qcdtownhall_final.pdf” (in Hot and Cold QCD conf at 24/09/2022 BNL)
   “Initial condition and emergence of collectivity”
1. arXiv:2209.11042, Imaging the initial condition of heavy-ion collisions
2. arXiv:2102.08158, Accessing the shape of atomic nuclei
3. 2111.15559_Jia_AMPT.pdf, Scaling approach to nuclear structure in high-energy heavy-ion collisions
4. M. Abdallah et al. (STAR), http://arxiv.org/abs/2109.00131, Isobar Collisions at 200 GeV

Giuliano Giacalone, Ulrich Heinz, Jiangyong Jia, Shengli Huang, Wei Li, Constantin Loizides, Matthew Luzum, Jacquelyn Noronha-Hostler, Jacquelyn Noronha-Hostler, …..

Таблица изотопов и изобар



Длинно-действующие корреляции в PbPb, pPb, pp



Длинно-действующая коллективность вездесуща: в АА-, pA-, pp- и gamma-A столкновениях!!! Кажется, мы не можем выключи это. С другой стороны, мы не знаем, что движет этой коллективностью: первоначальная анизотропия импульса, гидродинамика, обусловленная геометрией, и какова роль нуклонной структуры ядер?

Длинно-действующие корреляции в столкновениях малых систем

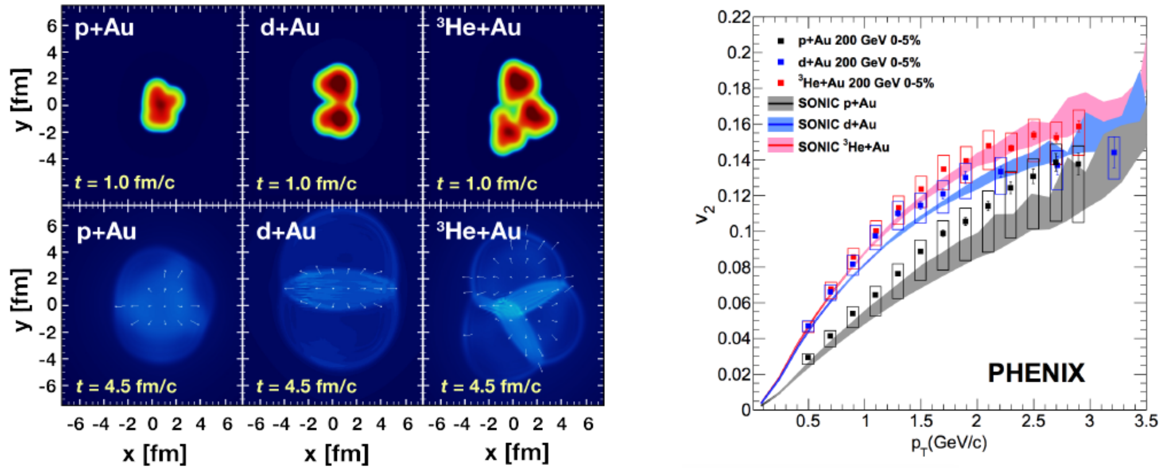


Figure 4

(*a*) Calculations of (*top*) the initial energy density in *p*+Au, *d*+Au, and ^{3}He+Au collisions at RHIC and (*bottom*) the resulting hydrodynamic evolution utilizing Monte Carlo Glauber initial conditions (75). (*b*) Comparison between hydrodynamic calculations (75) and data from *p*+Au, *d*+Au, and ^{3}He+Au collisions at $\sqrt{s_{NN}} = 200$ GeV (78).

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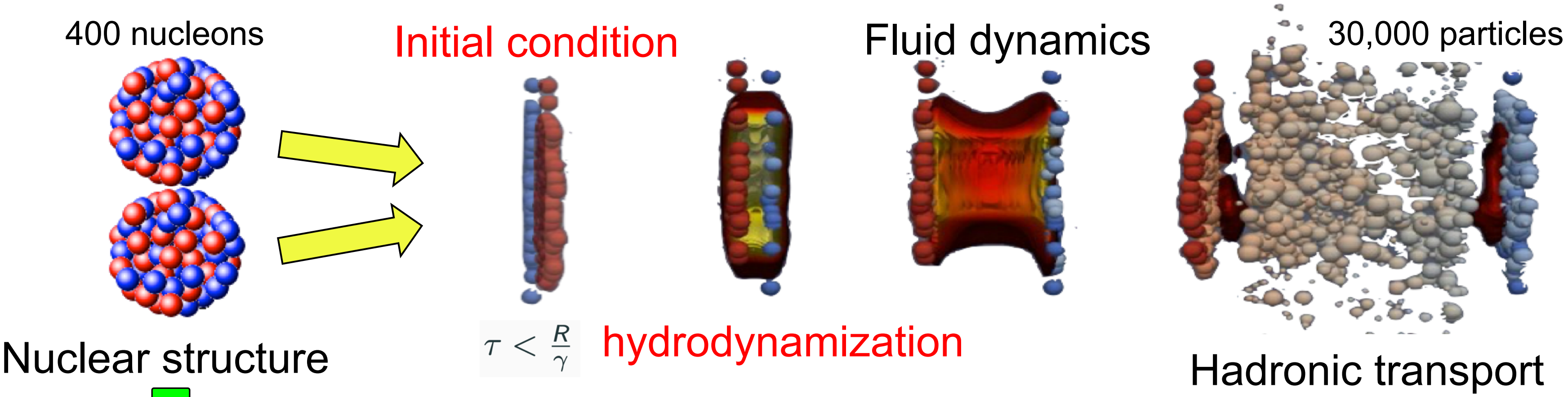
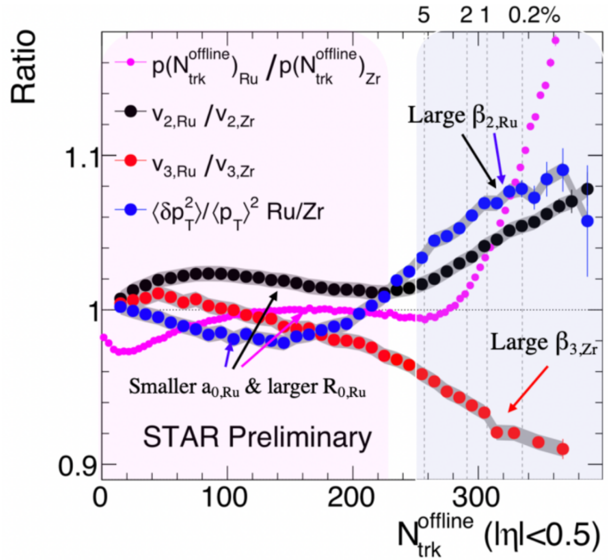
Initial condition and emergence of collectivity

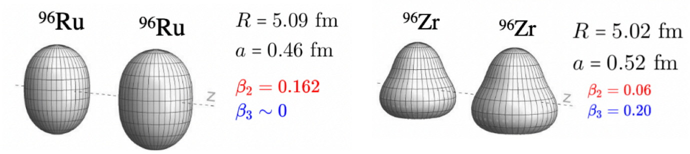


Challenge: A lack of control on the **initial condition** and **hydrodynamization** process from which collectivity emerges, limits the precision on the extraction of QGP transport properties and exploration of QCD phase diagram. Proposal: Collisions of carefully-selected species across nuclear charts to 1) understand how heavy-ion initial condition is shaped from structure of nuclei, and in turn improve constraints on QGP properties and provide new insights on nuclear structure, 2) stress-test the emergence of collectivity by going to small systems in a more systematic way. 3) Future data from a well-motivated system scan, isobars in particular, is necessary for precision heavy ion physics.

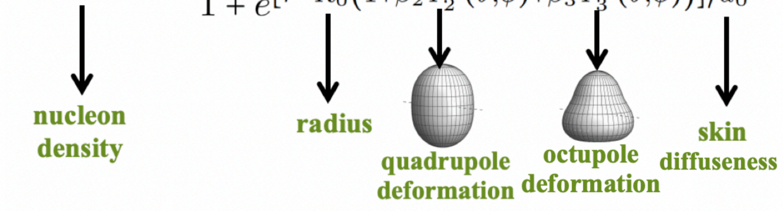
How impact of nuclear structure shows up?

Nuclear structure influences show up ubiquitously in comparison of data between different collision species. Best example: Isobars collisions (96Ru vs 96Zr) are a precision tool to access nucleon distributions.





$$\rho(r,\theta,\phi) \propto \frac{1}{1+e^{[r-R_0(1+\beta_2 Y_2^0(\theta,\phi)+\beta_3 Y_3^0(\theta,\phi))]/a_0}}$$



X and Y are isobars, O is an obervable:

$$\frac{\mathcal{O}_{X+X}}{\mathcal{O}_{Y+Y}} \stackrel{?}{=} 1 \longrightarrow$$ **Departure from unity from nuclear structure.**

Access structure differences: $R_{\mathcal{O}} \equiv \frac{\mathcal{O}_{Ru}}{\mathcal{O}_{Zr}} \approx 1 + c_1\Delta\beta_2^2 + c_2\Delta\beta_3^2 + c_3\Delta R_0 + c_4\Delta a$

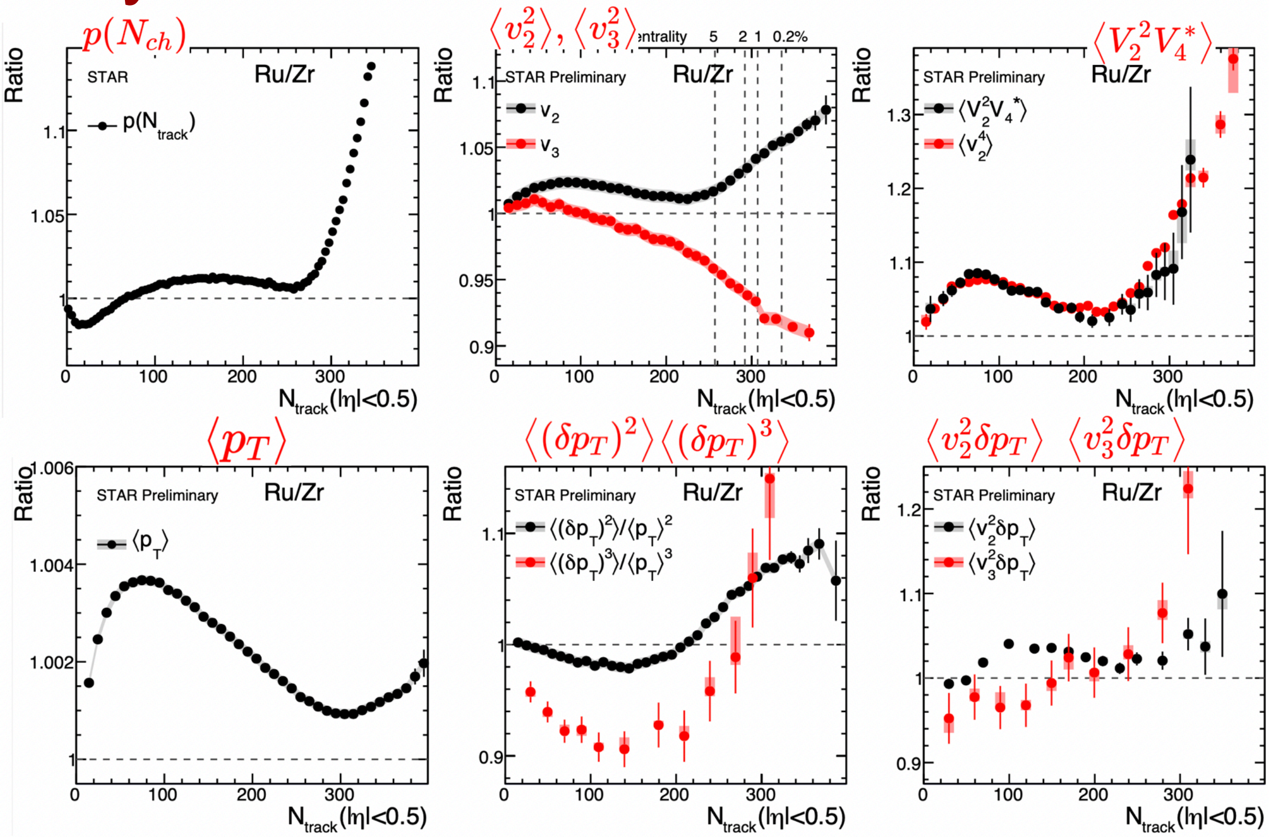
Access neutron skin: $\Delta r_{np} = \langle r_n\rangle^{1/2} - \langle r_p\rangle^{1/2}$

$$\Delta r_{np,Ru} - \Delta r_{np,Zr} \propto \underbrace{(R_0\Delta R_0 - R_{0p}\Delta R_{0p}) + 7/3\pi^2(a\Delta a}_{\text{mass}} - a_p\Delta a_p)$$

charge

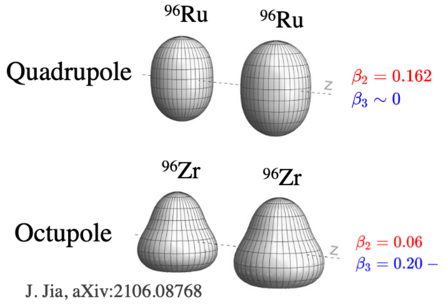
mass

Many more observables show sensitivity



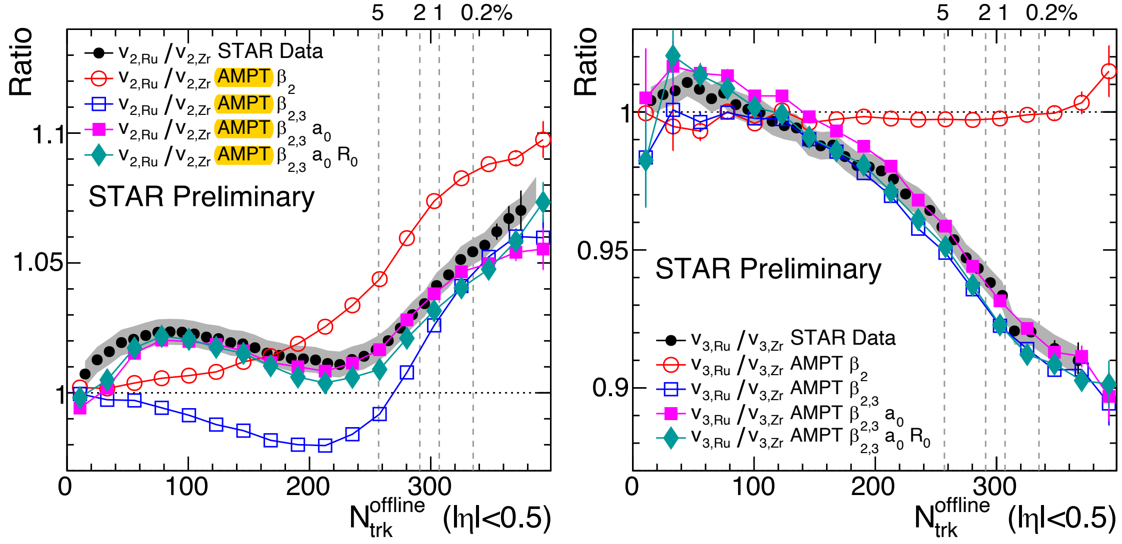
We can ask the same question for isobar ratios for hard probes

Nuclear structure via v_n-ratio



- β_{2Ru}~0.16 increase v_2, no influence on v_3 ratio
- β_{3Zr}~0.2 decrease v_2 in mid-central, decrease v_3 ratio
- Δa_0= -0.06fm increase v_2 mid-central, small influ. on v_3.
- Radius ΔR_0=0.07fm only slightly affects v_2 and v_3 ratio.

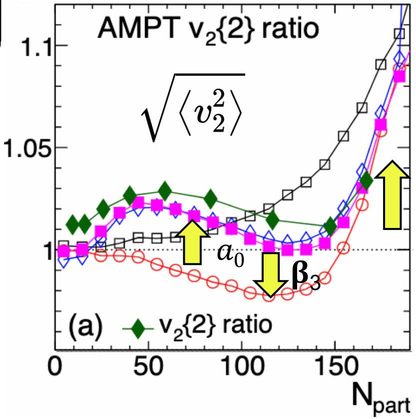
$$R_{\mathcal{O}} \equiv \frac{\mathcal{O}_{\mathrm{Ru}}}{\mathcal{O}_{\mathrm{Zr}}} \approx 1 + c_1\Delta\beta_2^2 + c_2\Delta\beta_3^2 + c_3\Delta R_0 + c_4\Delta a$$

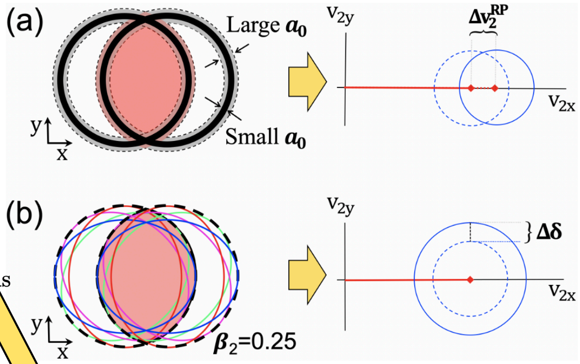


Simultaneously constrain these parameters using different N_{ch} regions

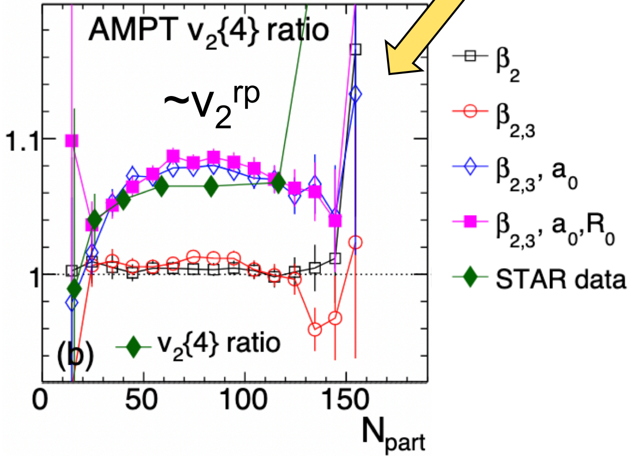
Separating shape and size effects

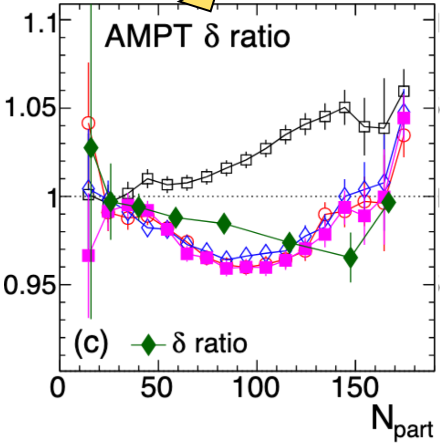
Nuclear skin contributes to $v_2^{rp} \sim v_2\{4\}$,
deformation contribute to fluctuations





$$\langle v_2^2 \rangle = \underbrace{(v_2^{rp})^2}_{\text{mean}} + \underbrace{\delta^2}_{\text{fluctuations}}$$





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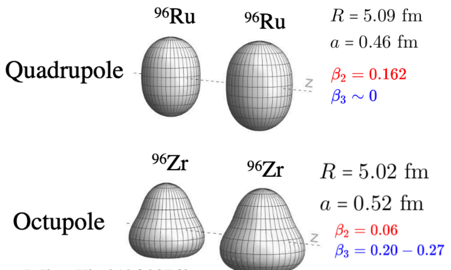
Nuclear structure via $p(N_{ch})$, <pT>-ratio

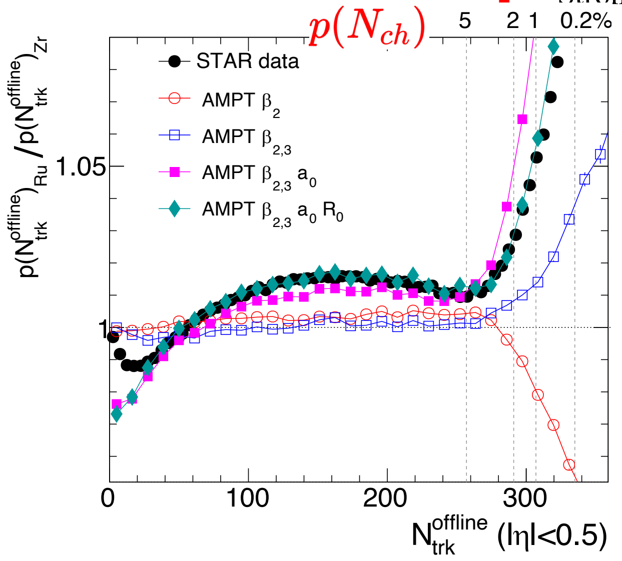
Earlier studies on this from H.Li, H.J Xu, PRL125, 222301 (2020) arXiv:2111.14812



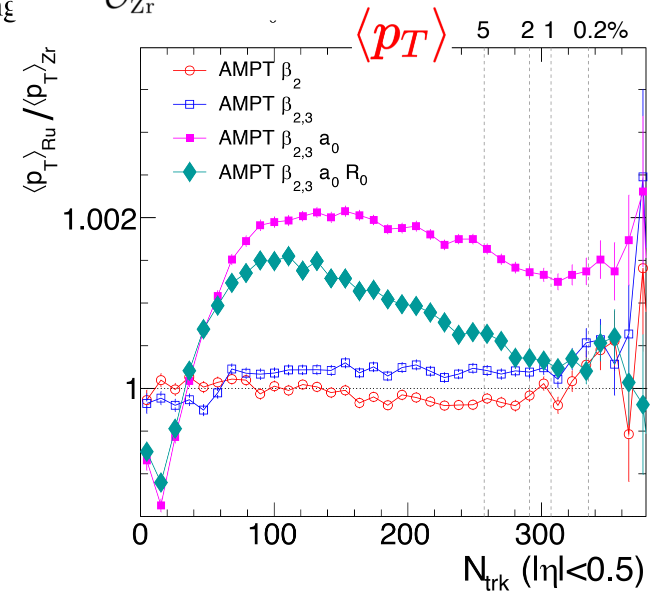
J. Jia, aXiv:2106.08768

- For Nch ratio:
  - β_{2Ru}~0.16 decrease ratio, increase after considering β_{3Zr}~0.2
  - The bump structure in non-central region from Δa_0 and ΔR_0
- For <pT>
  - Strong

$$R_{\mathcal{O}} \equiv \frac{\mathcal{O}_{\mathrm{Ru}}}{\mathcal{O}_{\mathrm{Zr}}} \approx 1 + c_1\Delta\beta_2^2 + c_2\Delta\beta_3^2 + c_3\Delta R_0 + c_4\Delta a$$



Δa_0 and ΔR_0 influences add up



Δa_0 and ΔR_0 influences cancel

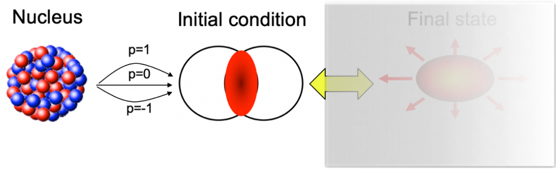
Isobar ratios not affected by final state

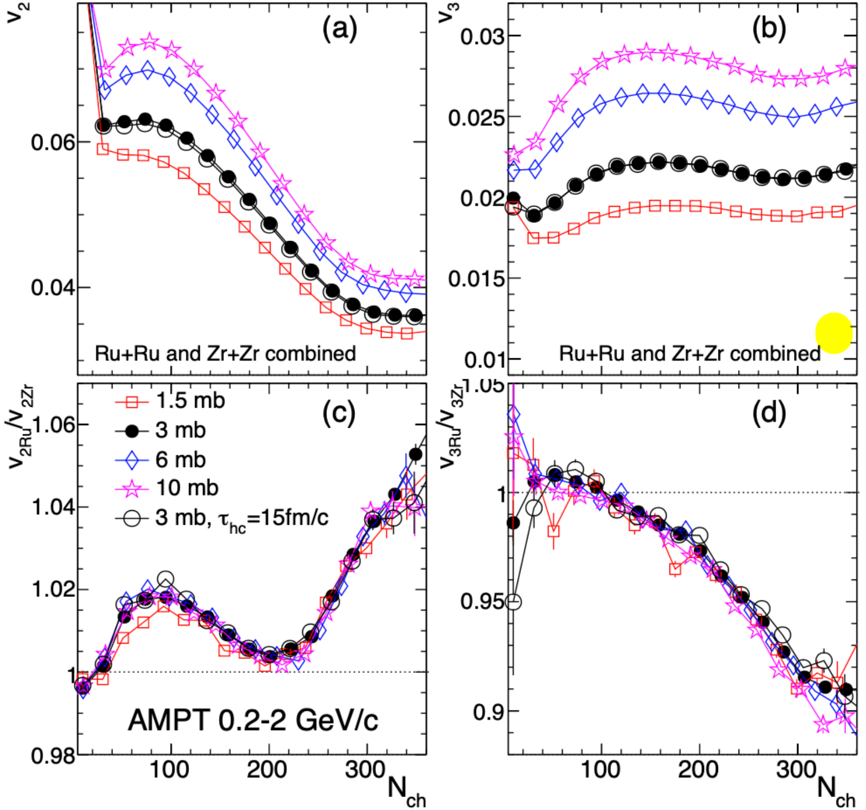
- Vary the shear viscosity via partonic cross-section

$$v_n = k_n \varepsilon_n$$

$$\frac{v_{n,\mathrm{Ru}}}{v_{n,\mathrm{Zr}}} \approx \frac{\varepsilon_{n,\mathrm{Ru}}}{\varepsilon_{n,\mathrm{Zr}}}$$

Robust probe of initial state!

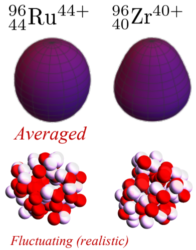


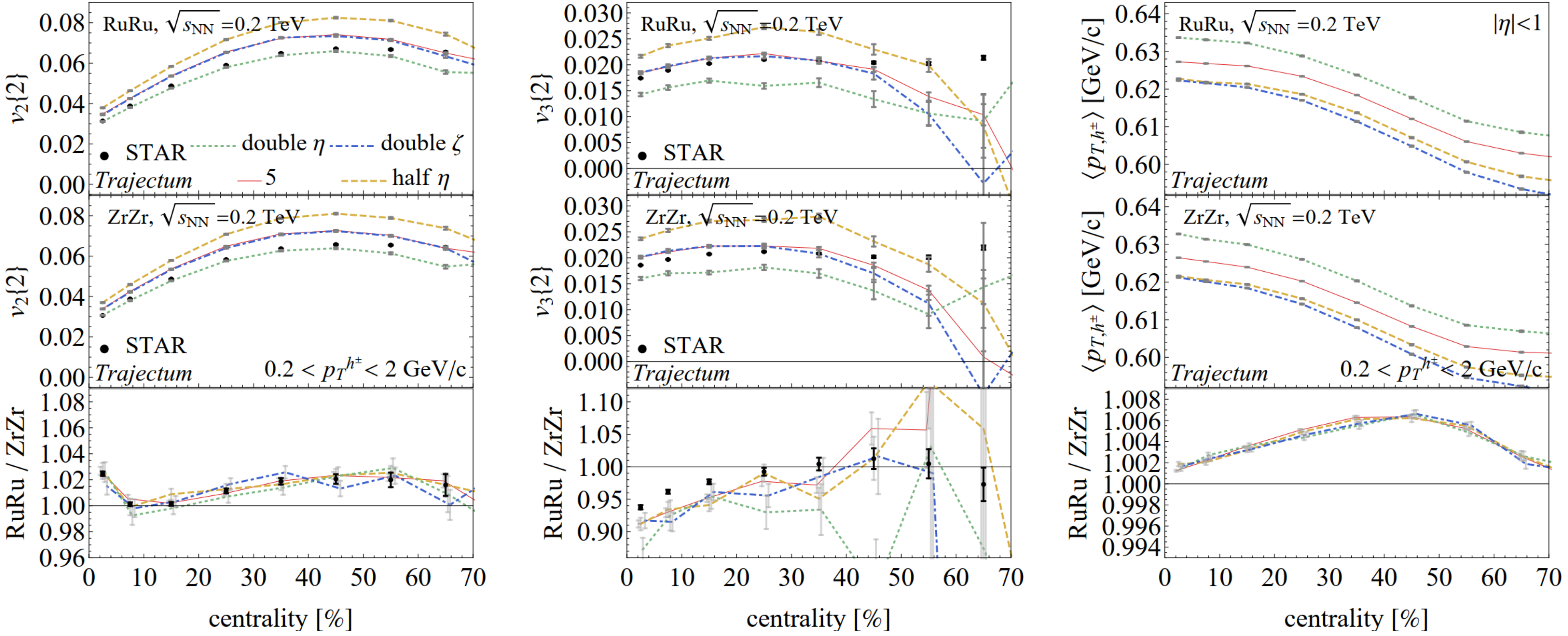


Effect of viscosity on observables

Significant effects, but cancel in the ratio

Wilke van der Schee, CERN





Заключение

1. Освоить новое направление "Исследование физики столкновения ионов, используя таблицу изотопов при высоких энергиях"
2. Модифицировать HYDJET для столкновения деформированных ядер
3. Использовать AMPT и HYDJET
4. Исследовать возможности столкновения ионов малых масс