Effect of nuclear structure on particle production in heavy-ion collisions using AMPT model

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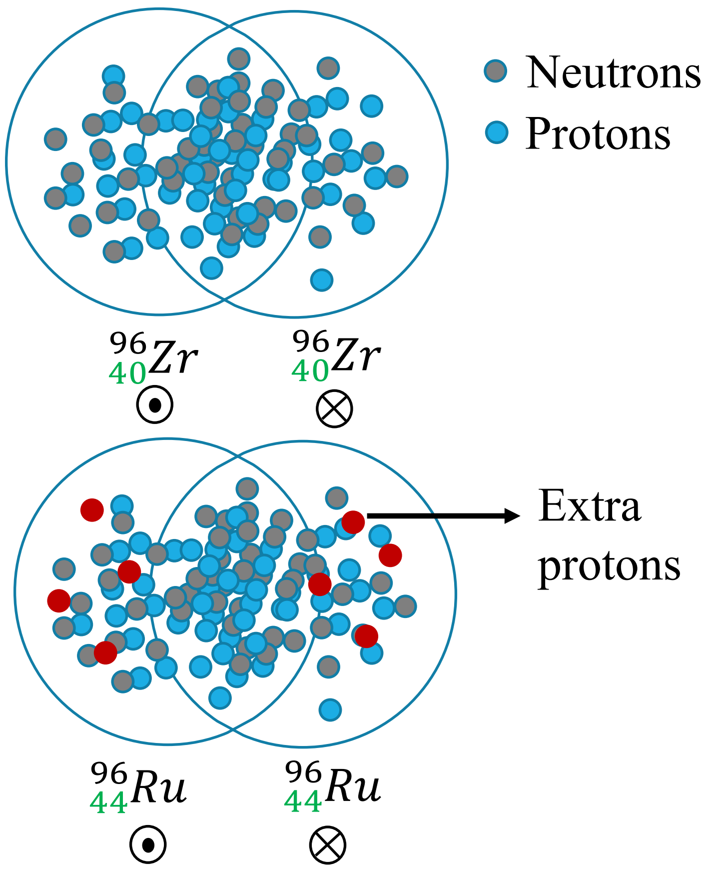
arXiv:2305.13950 [hep-ph]

Motivation

- Isobars, ${}^{96}_{44}$Ru and ${}^{96}_{40}$Zr, have the same nucleon number
  - → Similar initial geometry and dynamical evolution
  - → Produces a medium with same properties
- Isobar collisions performed at RHIC-STAR experiment in the year 2018
- Collective flow and charged particle multiplicity different between the two isobar species
- Different nuclear structure impacting the initial state and final state particle production



M. S. Abdallah et al. (STAR Collaboration), Phys. Rev. C **105**, 14901 (2022)

Motivation

- Nucleon density distributions described by deformed Woods-Saxon (WS) form

$$\rho(r,\theta) = \frac{\rho_0}{\{1+e^{[(r-R(\theta,\varphi))/a]}\}}$$

ρ_0 → normal nuclear density

a → surface diffuseness parameter

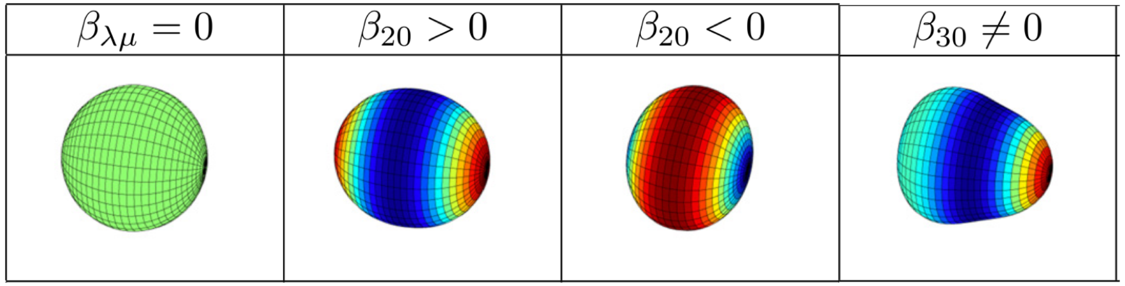
$$R(\theta,\varphi) = R_0[1 + \beta_{20}Y_{20}(\theta,\varphi) + \beta_{30}Y_{30}(\theta,\varphi)]$$

R_0 → Radius of nucleus

β_{20} → Quadrupole deformity

β_{30} → Octupole deformity

- Study of deformation effects is needed to understand properties of partonic matter
  → bridging low energy nuclear physics to high energy collisions



Deformation parameters, $\beta_{\lambda\mu}$ of order λ $[2, \infty)$, $\mu[-\lambda, +\lambda]$

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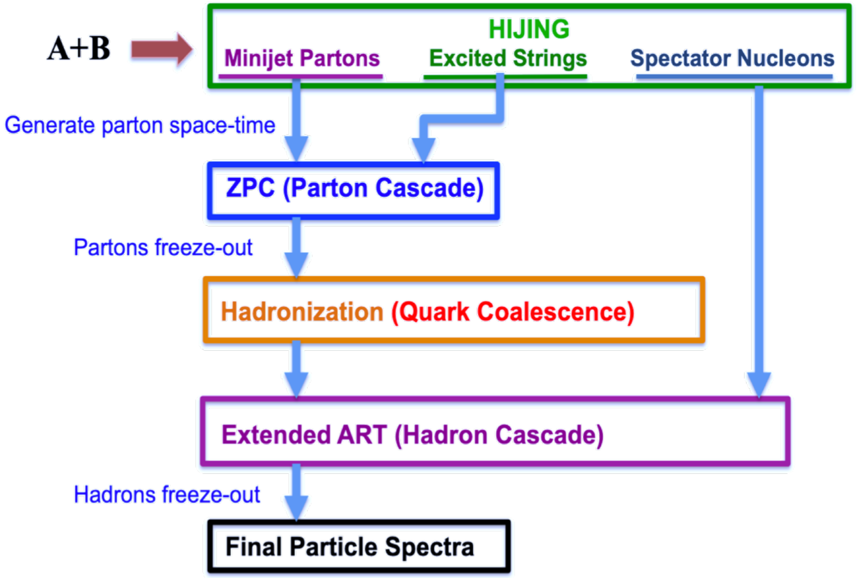
AMPT model



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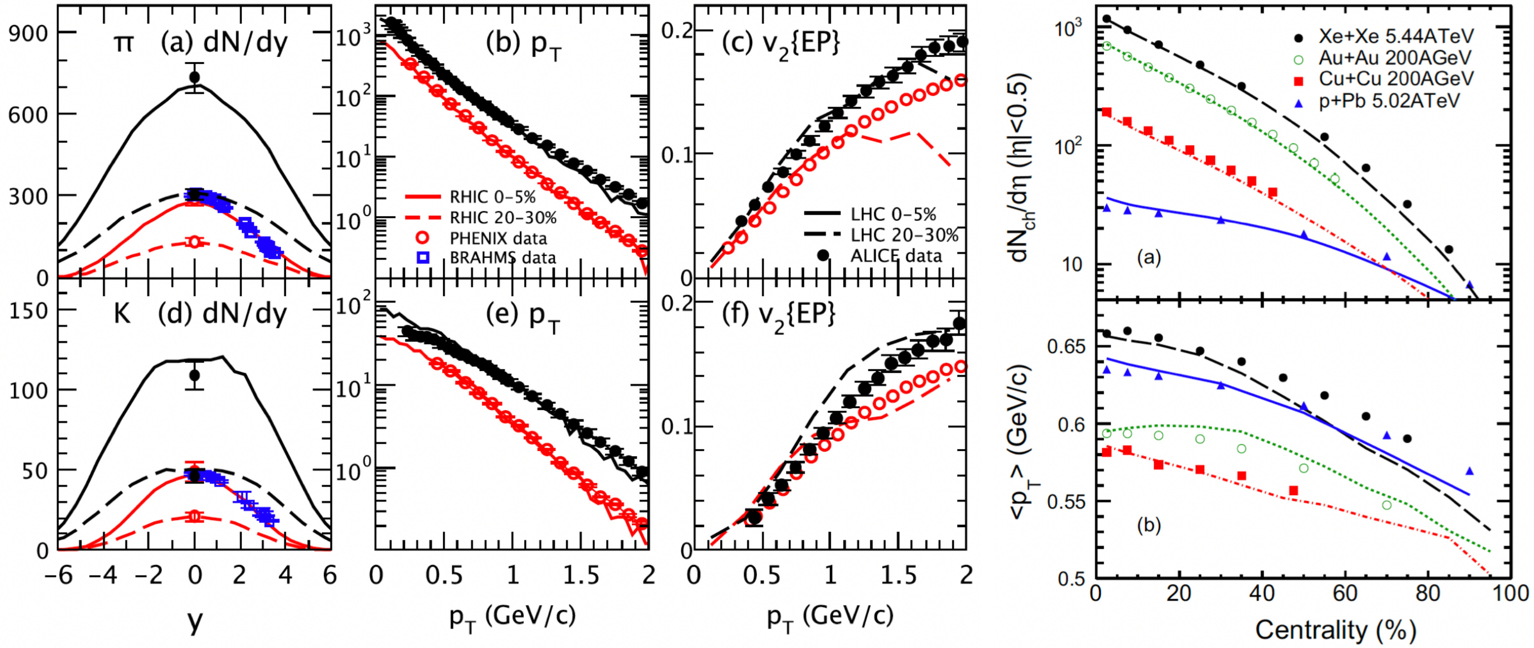
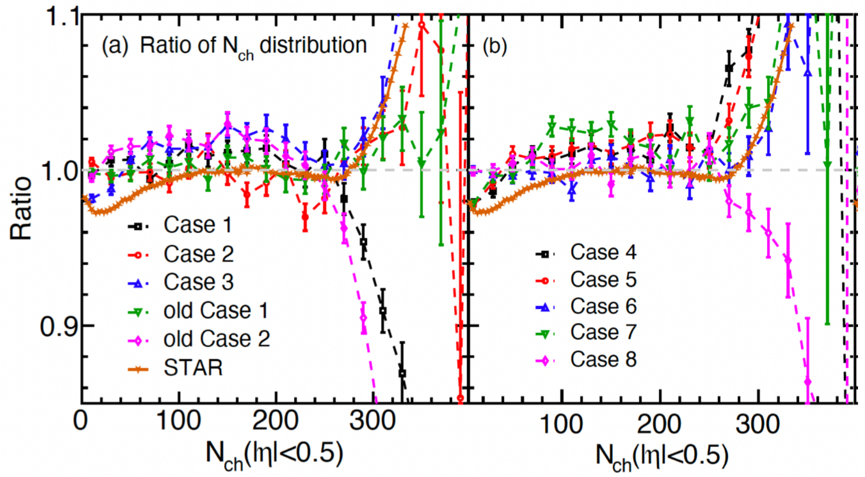


Zi-Wei Lin and Liang Zheng, Nucl. Sci. Tech. **32**, 113 (2021)

- A multi-phase transport model (AMPT) used extensively to study relativistic heavy-ion collisions
- Used AMPT string melting model version 2.26t9 with partonic cross-section of 3mb

AMPT model

- Different parameterization of Woods-Saxon distribution in AMPT model used to study multiplicity and $v_{2,3}$ for charged hadrons in Ru+Ru and Zr+Zr collisions
- Studies using parameterization as $\beta_{2,Ru} > \beta_{2,Zr}$ & $\beta_{3,Ru} < \beta_{3,Zr}$



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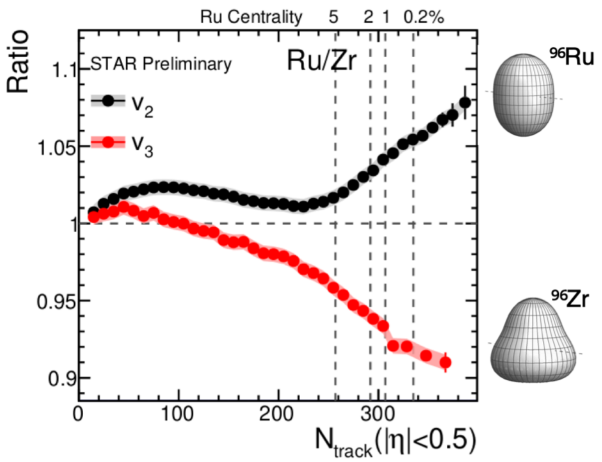

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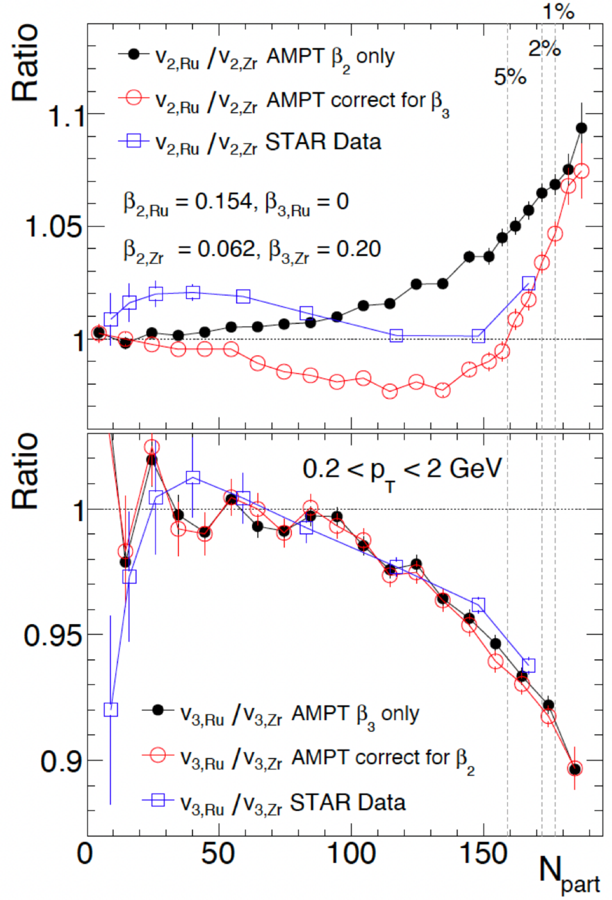


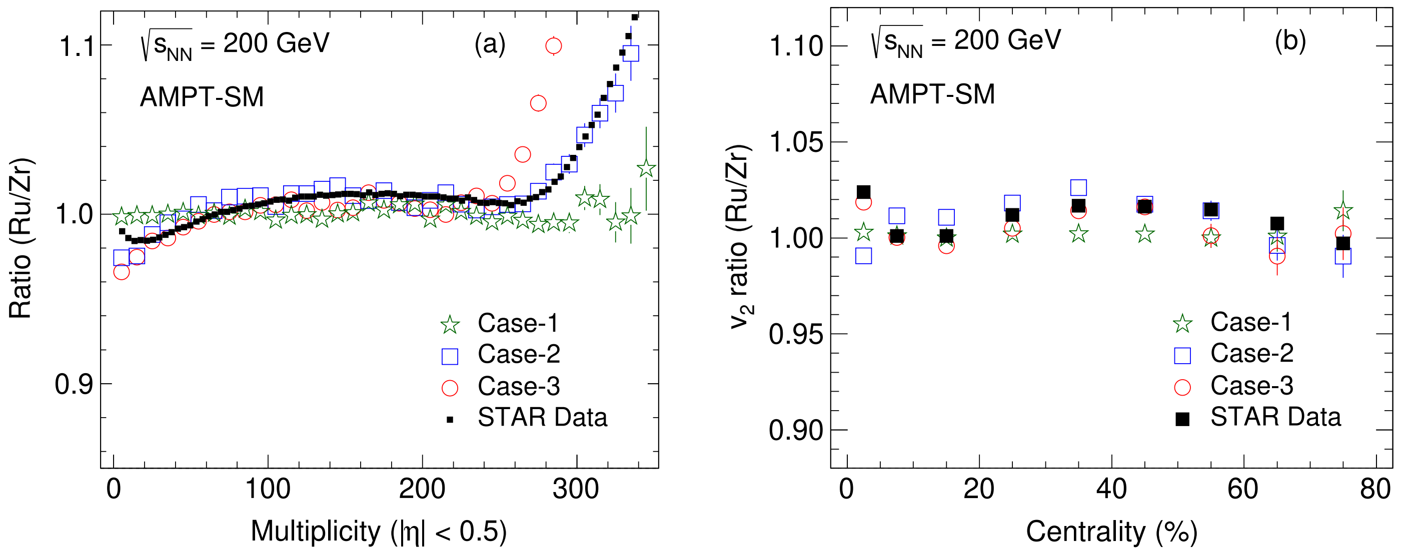
Chunjian Zhang and Jiangyong Jia, Phys. Rev. Lett. **128**, 022301 (2022)

Analysis

Case-1	R_0	a	β_2	β_3
Ru	5.096	0.54	0.0	0.0
Zr	5.096	0.54	0.0	0.0

Case-2	R_0	a	β_2	β_3
Ru	5.067	0.500	0.0	0.0
Zr	4.965	0.556	0.0	0.0

Case-3	R_0	a	β_2	β_3
Ru	5.09	0.46	0.162	0
Zr	5.09	0.52	0.060	0.2



U	R_0	a	β_2	β_3
Case-1	7.115	0.54	0.0	0.0
Case-2	6.810	0.550	0.28	0.0

Au	R_0	a	β_2	β_3
Case-1	6.380	0.535	0.162	0

- Three different cases of isobar nuclear structure studied
- Nuclei involving difference in size and structure describes the isobar data from STAR better

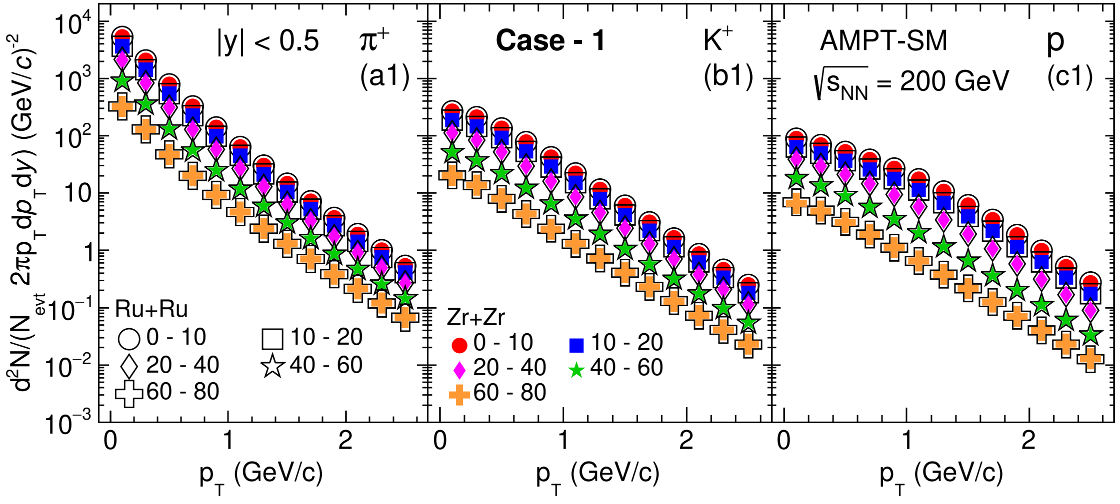
Zi-Wei Lin et. al., Phys. Rev. C **72**, 064901 (2005)
G. Giacalone et. al., Phys. Rev. Lett. **127**, 242301 (2021)

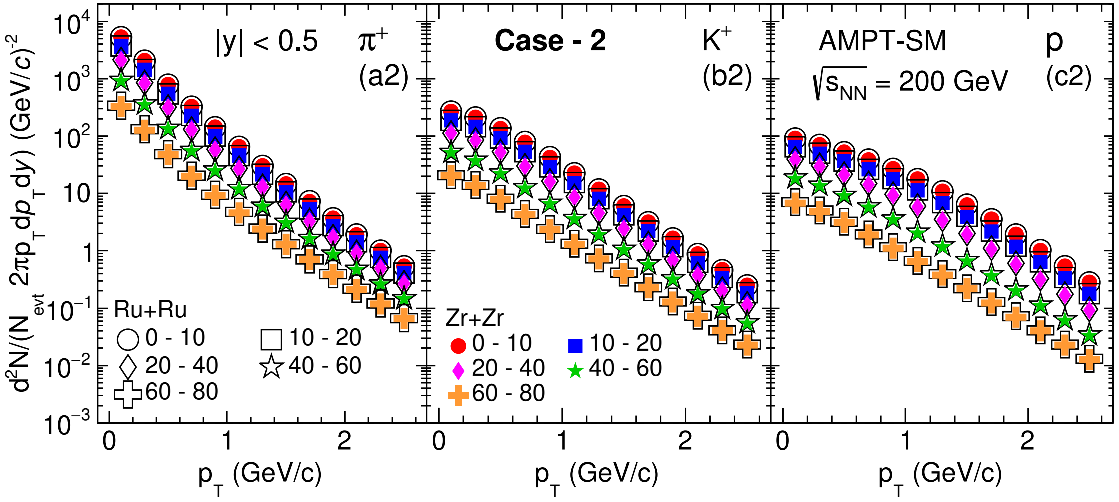
Effect of nuclear deformation

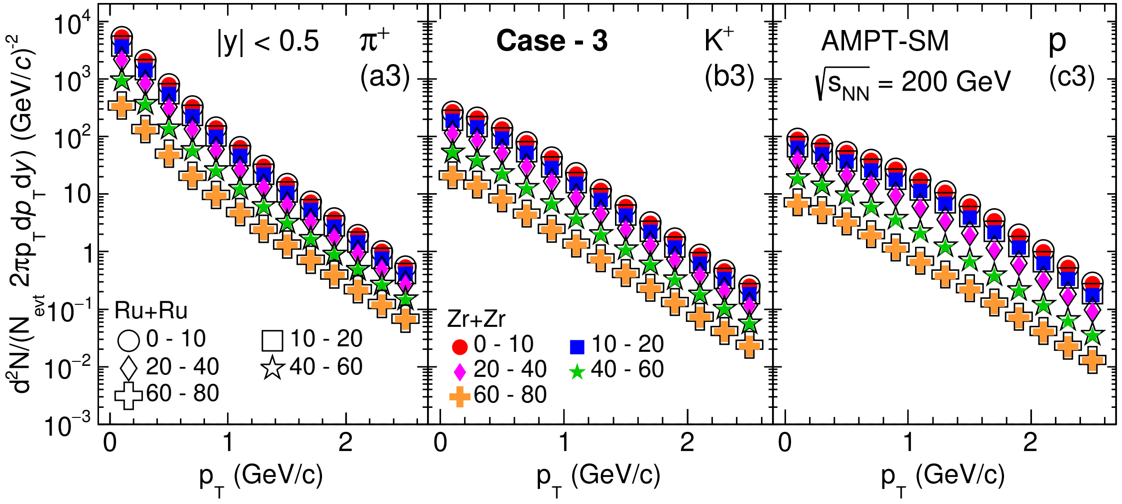
Transverse momentum spectra

❖ Transverse momentum dependence shows a systematic centrality dependence for identified hadrons

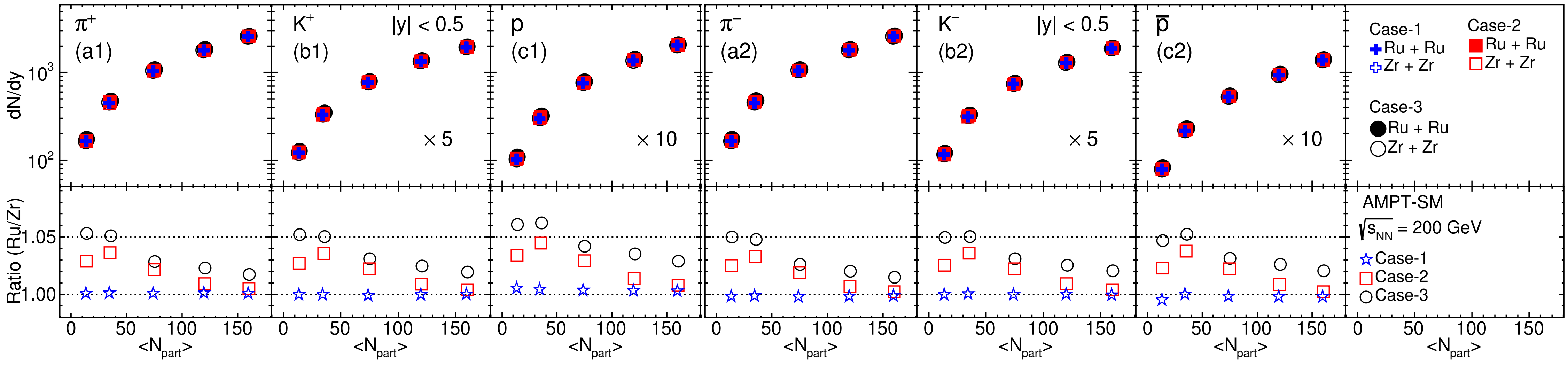
❖ Hardening of p_T spectra towards central collisions particularly protons → radial flow







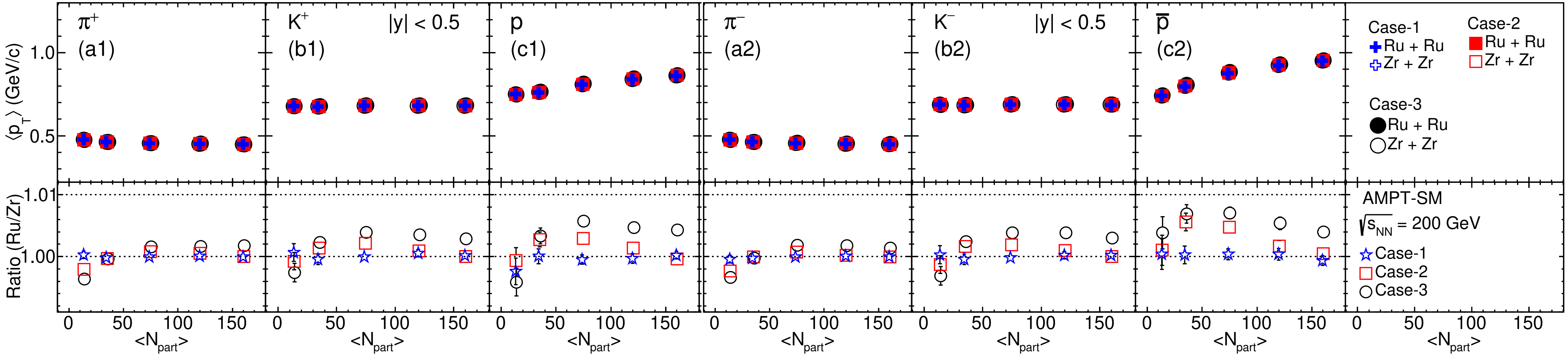
Particle yield



❖ More significant deviation in the ratio of particle yields which could be attributed to the inclusion of deformation along with different nuclear sizes

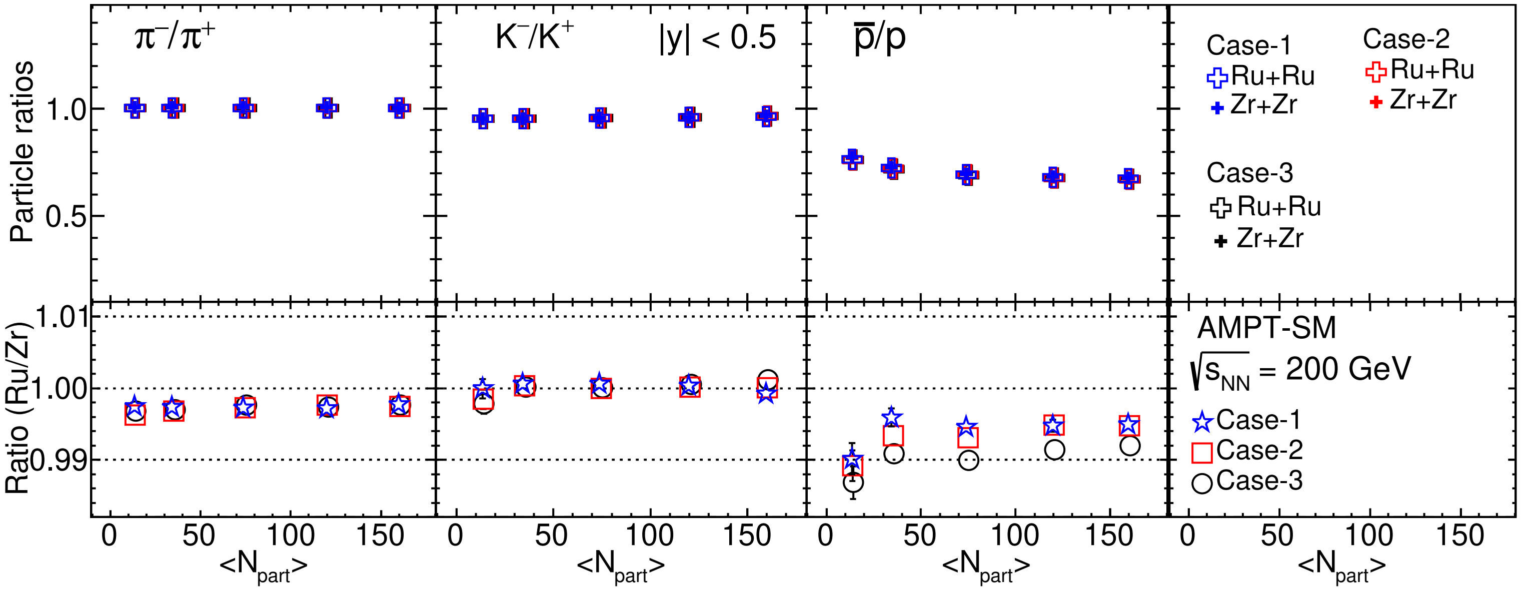
- Clear centrality dependence
- Deviation up to 5% in peripheral collisions

Average transverse momentum



- No significant difference in $\langle p_T \rangle$ between isobar nuclei having the same nuclear size
- Deviation from unity within 1% in nuclei with different nuclear sizes and deformations
- Deviation increasing with particle mass
  - Increased radial flow in central collisions

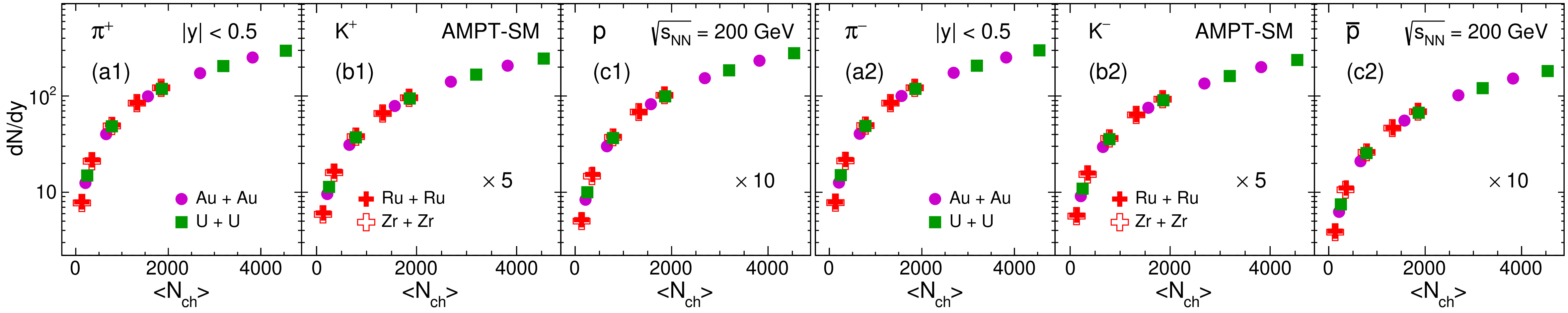
Particle ratios



- ❖ In same system: cancellation of effects of nuclear geometry
- ❖ Higher π^-/π^+ ratio in Zr+Zr collisions compared to Ru+Ru → higher d/u ratio in the Zr nucleus
- ❖ Higher $\bar{p}/p$ ratio in Zr+Zr compared to Ru+Ru collisions → lower number of protons in Zr nucleus
- ❖ Kaon production dominated by pair production

Effect of nuclear size

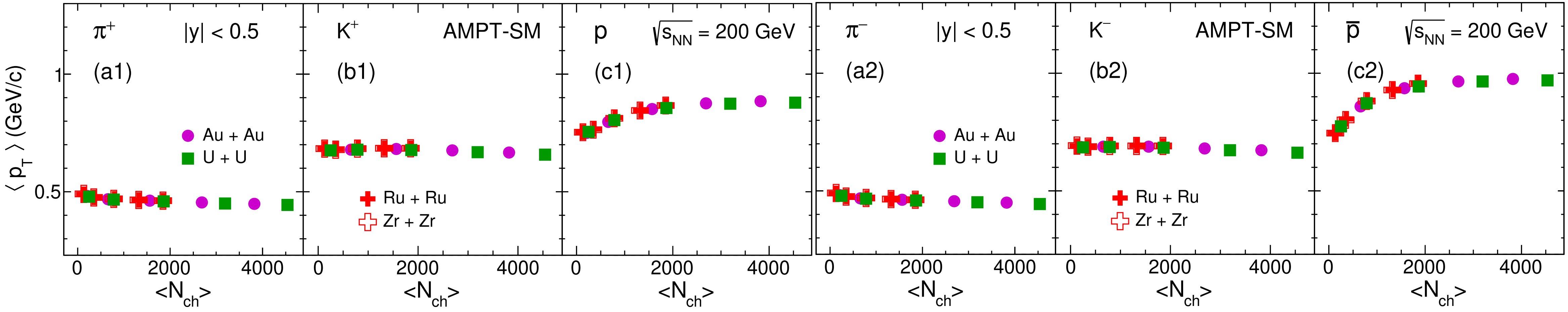
Yield



❖ Increase in dN/dy with increasing $\langle N_{ch} \rangle$ for all the particle species

❖ Particle yields for different colliding systems show a smooth variation

Mean p_T



❖ $\langle p_T \rangle$ increases with increasing particle mass

→ stronger radial flow

❖ Shows a smooth variation with $\langle N_{ch} \rangle$

❖ Pions and kaons show a weak centrality dependence than protons

Conclusion

- Predictions of the transverse momentum spectra for pions, kaons, and protons in Ru+Ru and Zr+Zr collisions at $\sqrt{s_{NN}}$ = 200 GeV using AMPT model

- Effect of nuclear deformation
  - Difference in dN/dy and $\langle p_T \rangle$ due to a different nuclear size and deformation for the two isobars
  - Centrality dependence in yield ratios between isobar collisions
  - Antiparticle to particle ratio between the two isobars for pions and protons indicates isospin effect; ratio for kaons indicates dominance of pair production

- Effect of nuclear size
  - dN/dy and $\langle p_T \rangle$ varies smoothly with multiplicity for all collision systems

Thank you for your attention!

Back-up

Transverse momentum spectra