Multi-phase transport model predictions of isobaric collisions with nuclear structures from density functional theory

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Based on

H.L. Li*, H.-J. Xu*, J. Zhao*, Z.-W. Lin, H. Z. Zhang, X. Wang, C. Shen, and F. Wang*. Phys. Rev. C 98, 054907 (2018).

Jie Zhao*, Hanlin Li, F. Wang*, Eur. Phys. J. C 79, 168 (2019).

Outline

Introduction

Isobaric collisions

★ Nuclear densities

★ The AMPT model

Model predictions

★ Multiplicity distribution

★ Glauber calculations

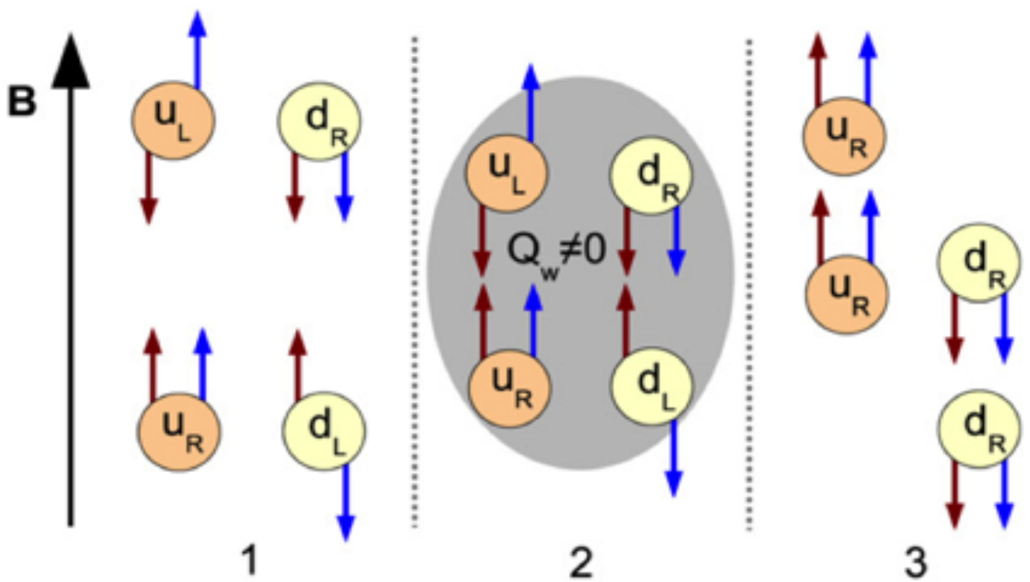
★ Particle production

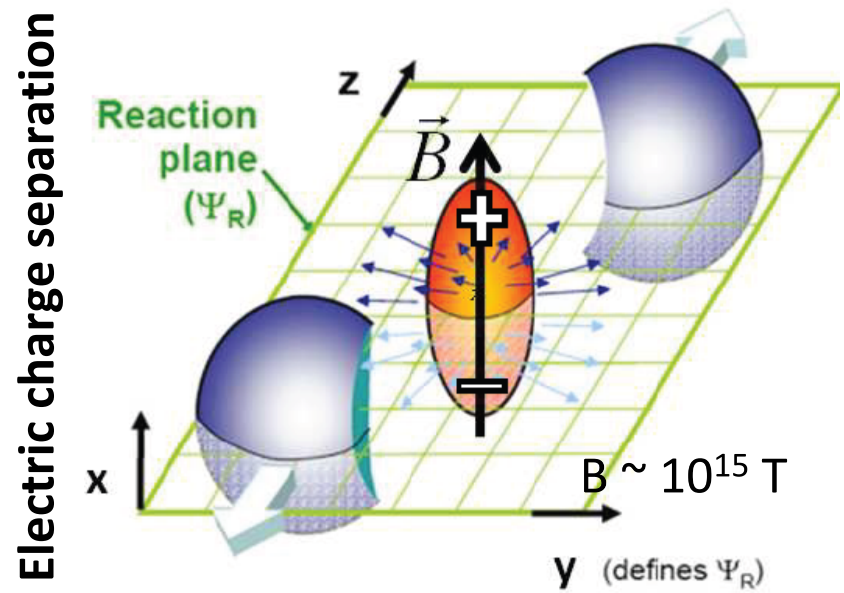
★ Elliptic anisotropy

Summary

Chiral Magnetic Effect (CME)

Kharzeev, Pisarski, Tytgat, PRL 81, 512, (1998) ; Kharzeev, et al. NPA 803, 227, (2008)





Non-conservation of axial currents

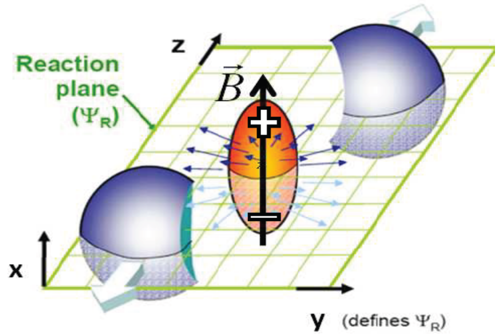
$$\partial^\mu j^5_\mu = 2\sum_f m_f \langle \bar{\psi}_f i \gamma_5 \psi_f \rangle_A - \frac{N_f g^2}{16\pi^2} F^a_{\mu\nu} \tilde{F}^{\mu\nu}_a$$

$$Q_\mathrm{w} = \frac{g^2}{32\pi^2} \int \mathrm{d}^4x\, F^a_{\mu\nu} \tilde{F}^{\mu\nu}_a$$

$$(N_L - N_R)_{t=\infty} = 2N_f Q_\mathrm{w}$$

- Quark degree of freedom, Approx. chiral sym. restoration
- QCD vacuum fluctuations, Topological gluon field, Qw≠0.
- Local P, CP violations
- Strong magnetic field

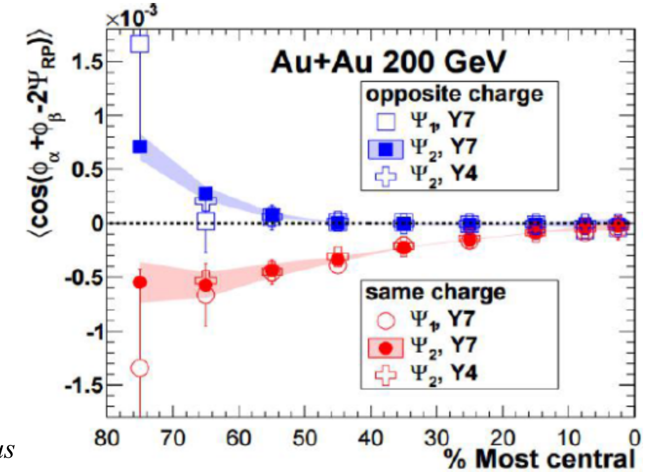
The Correlator & Background

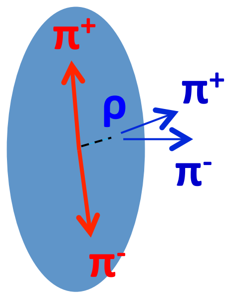


Voloshin, PRC 70, 057901, (2004)

$$\boxed{\gamma = \left\langle \cos(\varphi_\alpha + \varphi_\beta - 2\psi_{RP}) \right\rangle}$$

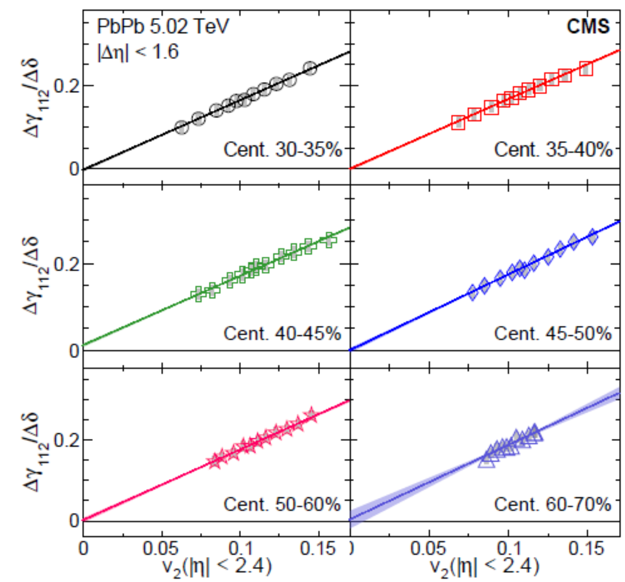
$$\Delta\gamma = \gamma_{OS} - \gamma_{SS}$$

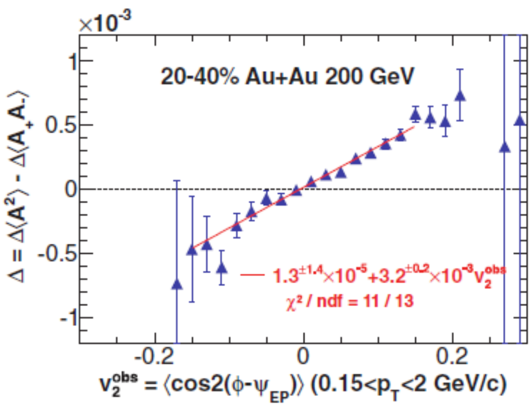


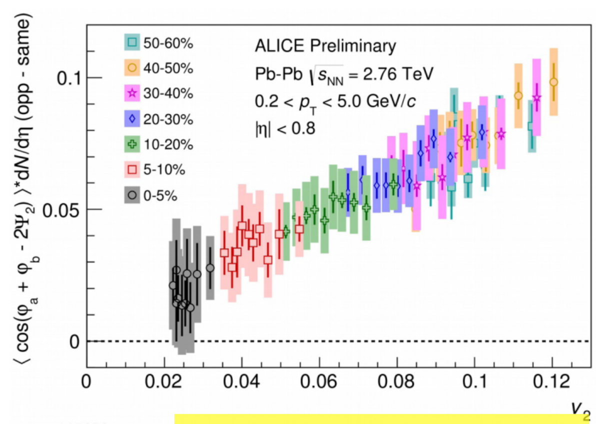


$$\Delta\gamma = \frac{N_\rho}{N_\alpha N_\beta} \left\langle \cos(\varphi_\alpha + \varphi_\beta - 2\varphi_{clus}) \right\rangle v_{2,clus}$$

FW, Jie Zhao, PRC 95, 051901(R), (2017)







PRC **89**, 044908 (2014)

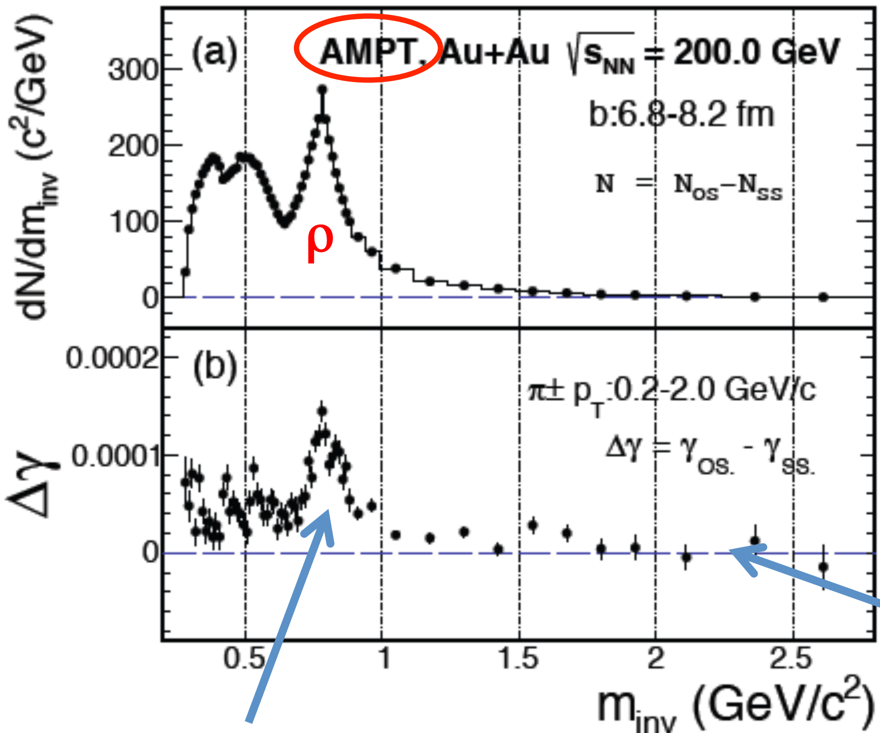
ALICE PLB777(2018)151

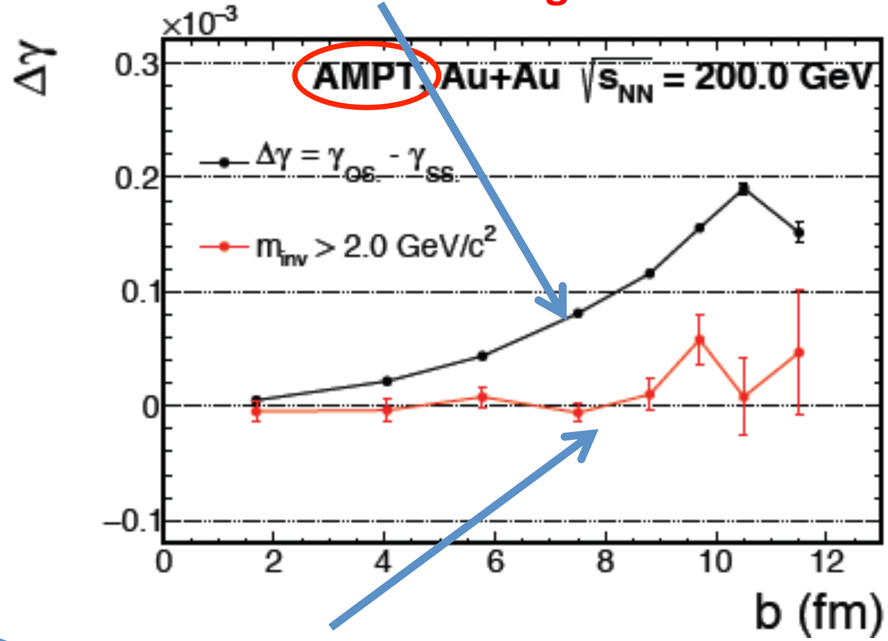
CMS PRC97(2018)044912

Background with AMPT

Jie Zhao, Hanlin Li, FW, Eur. Phys. J. C 79,168 (2019)

All are backgrounds





Resonance structure in Δγ as function of m_{inv}

High mass Δγ consistent with 0 as it should be

FW QM 2018

XHJ QM 2018

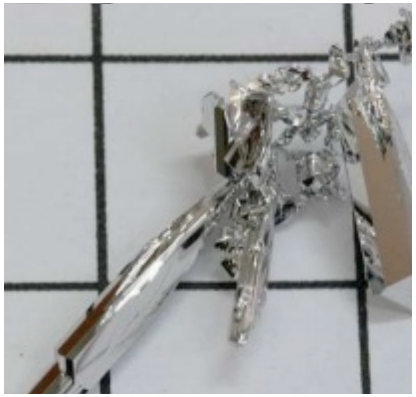
- Resonance background should be nearly zero at high mass
- CME at large mass may also be zero…

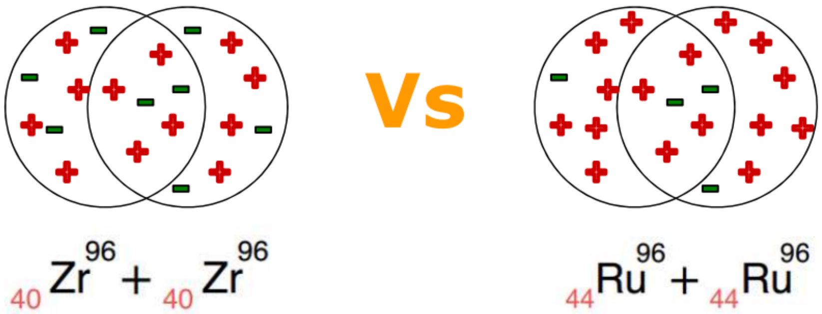
Isobaric collisions

Isobars are nuclides of different chemical elements that have the same number of nucleons.

- Examples: Ru and Zr

$^{96}_{44}$Ru+$^{96}_{44}$Ru vs $^{96}_{40}$Zr+$^{96}_{40}$Zr





Huang QM 2017

- Up to 10% variation in B field
- Flow(major source of background) magnitude will stay almost the same

Nuclear Densities-WS and DFT

Woods-Saxon (WS) density

$$\rho(r,\theta) = \frac{\rho_0}{1+\ \exp[(r - R_0 - \beta_2 R_0 Y_2^0(\theta)/a]}$$

Density functional theory (DFT)

$$\varepsilon = \varepsilon_{kin} + \varepsilon_{skyrme} + \varepsilon_{piaring} + \varepsilon_{Coulomb} + \varepsilon_{corr.}$$

Kinetic term

Skyrme energy function

Pair energy

Coulomb energy

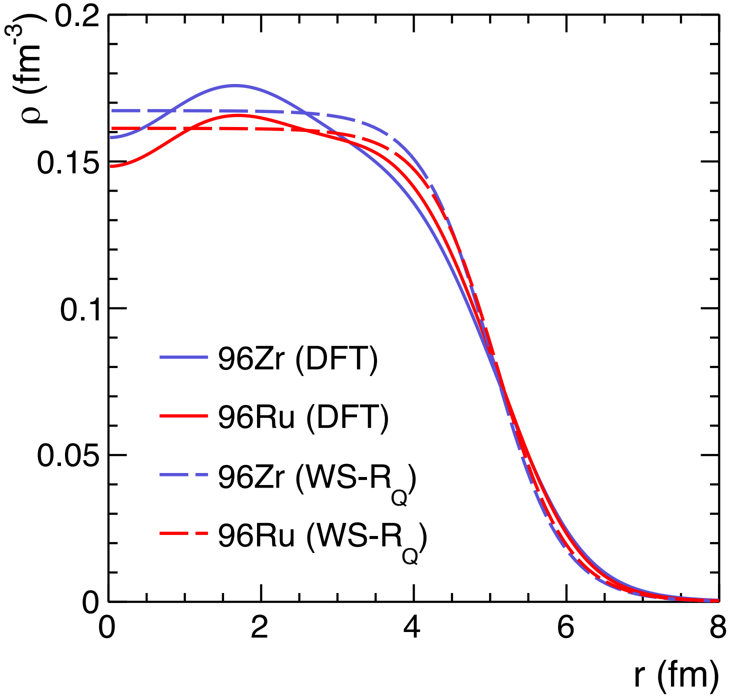
Corrections for spurious motion

$$\begin{aligned} V_{Skyrme} &= t_0(1+x_0P_\sigma)\delta(\mathbf{r}_1-\mathbf{r}_2) \\ &+\frac{1}{2}t_1(1+x_1P_\sigma)\left[\mathbf{k}^{\dagger 2}\delta(\mathbf{r}_1-\mathbf{r}_2)+\delta(\mathbf{r}_1-\mathbf{r}_2)\mathbf{k}^2\right] \\ &+t_2(1+x_2P_\sigma)\mathbf{k}^\dagger\delta(\mathbf{r}_1-\mathbf{r}_2)\mathbf{k} \\ &+\frac{1}{6}t_3(1+x_3P_\sigma)\delta(\mathbf{r}_1-\mathbf{r}_2)\rho^\alpha\left(\frac{\mathbf{r}_1+\mathbf{r}_2}{2}\right) \\ &+iW_0(\sigma_1+\sigma_2)\cdot\mathbf{k}^\dagger\times\delta(\mathbf{r}_1-\mathbf{r}_2)\mathbf{k}, \end{aligned}$$

E. Chabanat et al. Nucl. Phys. A, 643,1998.

Nucleon Densities of Ru and Zr

H.L. Li, et al. , PRC. 98, 054907, (2018)

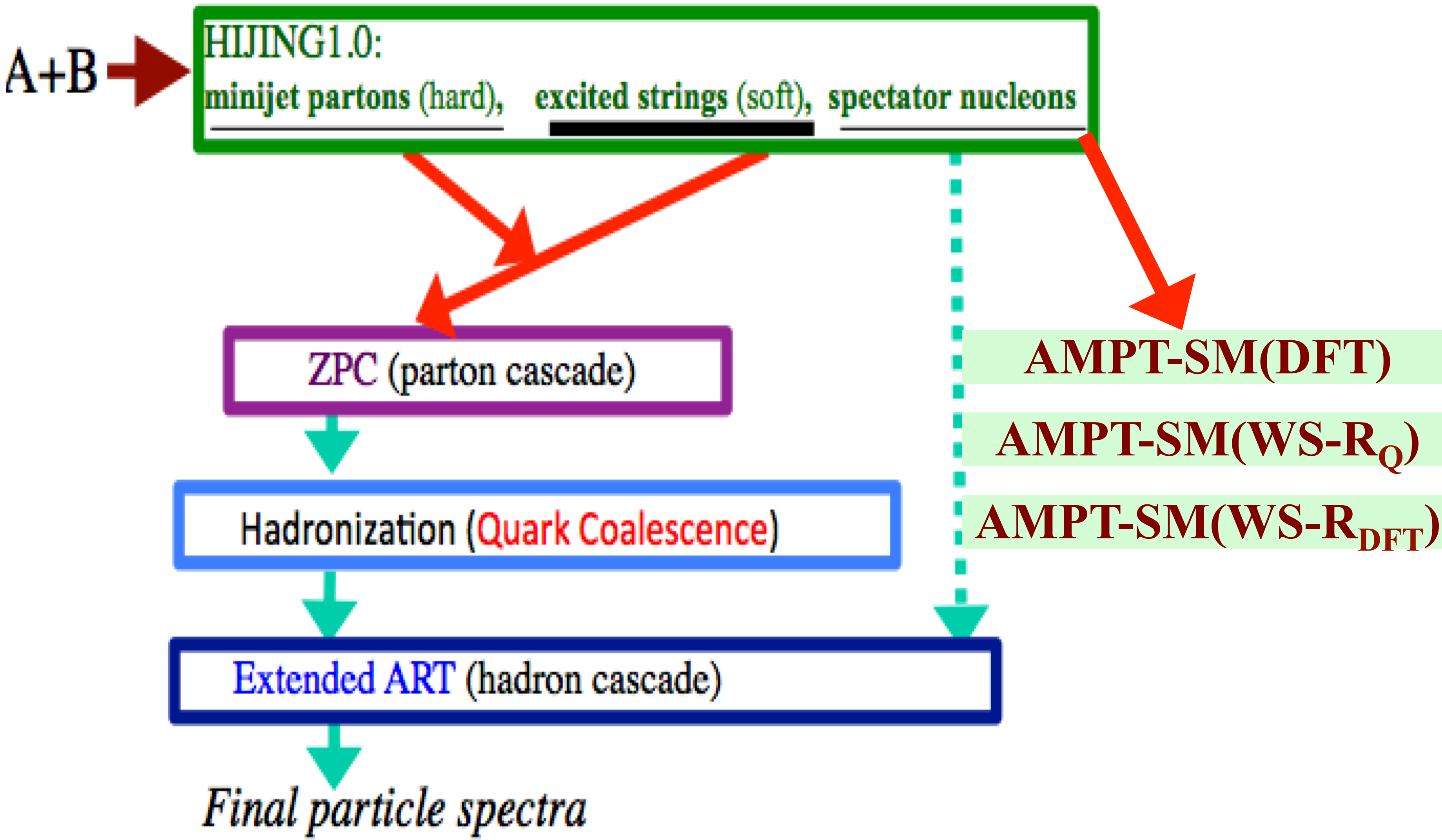


Effective nuclear radius parameters (in fm)

		$^{96}_{44}$Ru charge	mass	$^{96}_{40}$Zr charge	mass
WS-R$_Q$	R_0	5.085 [5]		5.020 [5]	
	$\sqrt{\langle r^2 \rangle}$	4.294		4.248	
DFT	$\sqrt{\langle r^2 \rangle}$	4.327	4.343	4.271	4.366
	$R_0 \equiv 1.183\sqrt{\langle r^2 \rangle}$	5.119	5.138	5.053	5.165

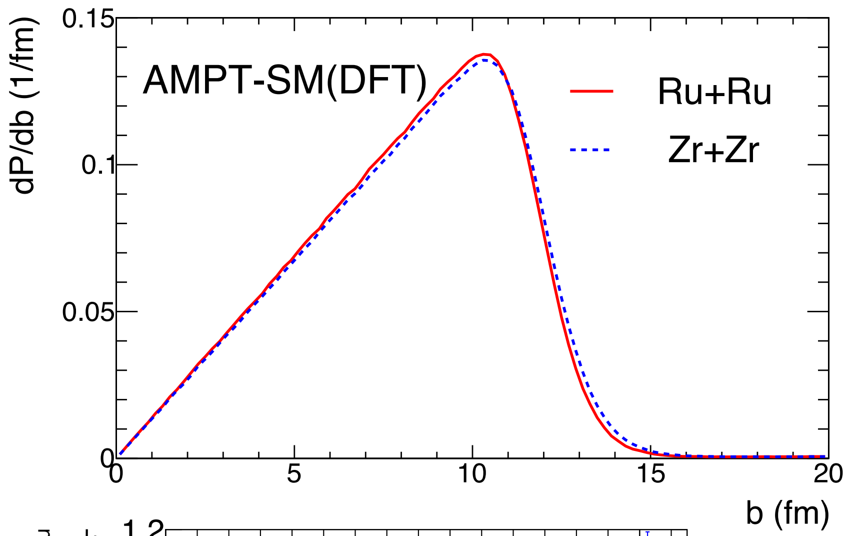
- The overall mass radius (i.e. of all nucleons) of Ru is slightly smaller than that of Zr from DFT. The relative mass radii between Ru and Zr are opposite for WS.

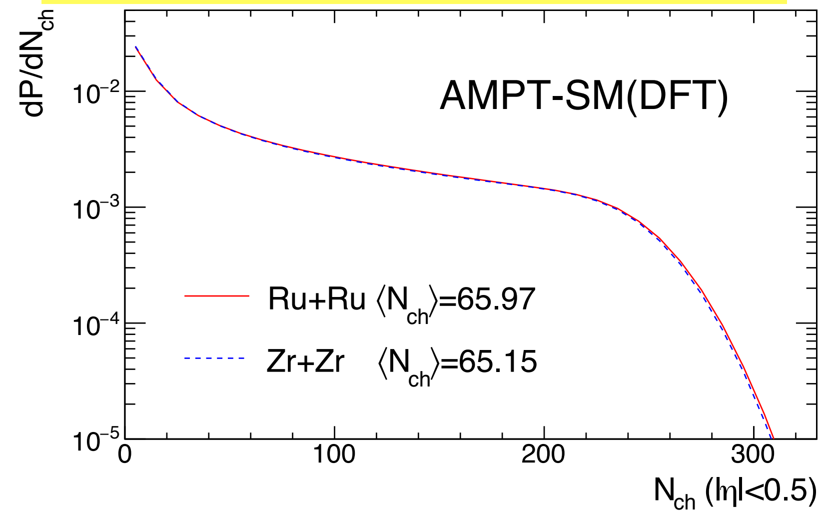
Structure of AMPT (String Melting version)

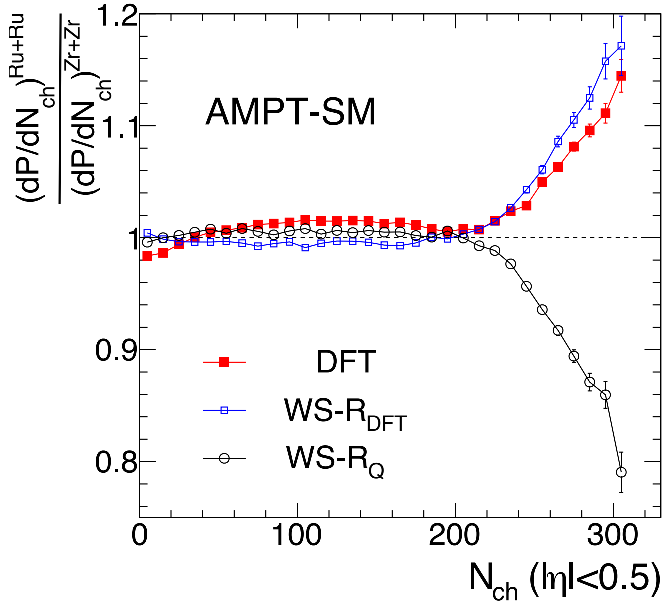


Multiplicity distribution

H.L. Li, et al. , PRC. 98, 054907, (2018)



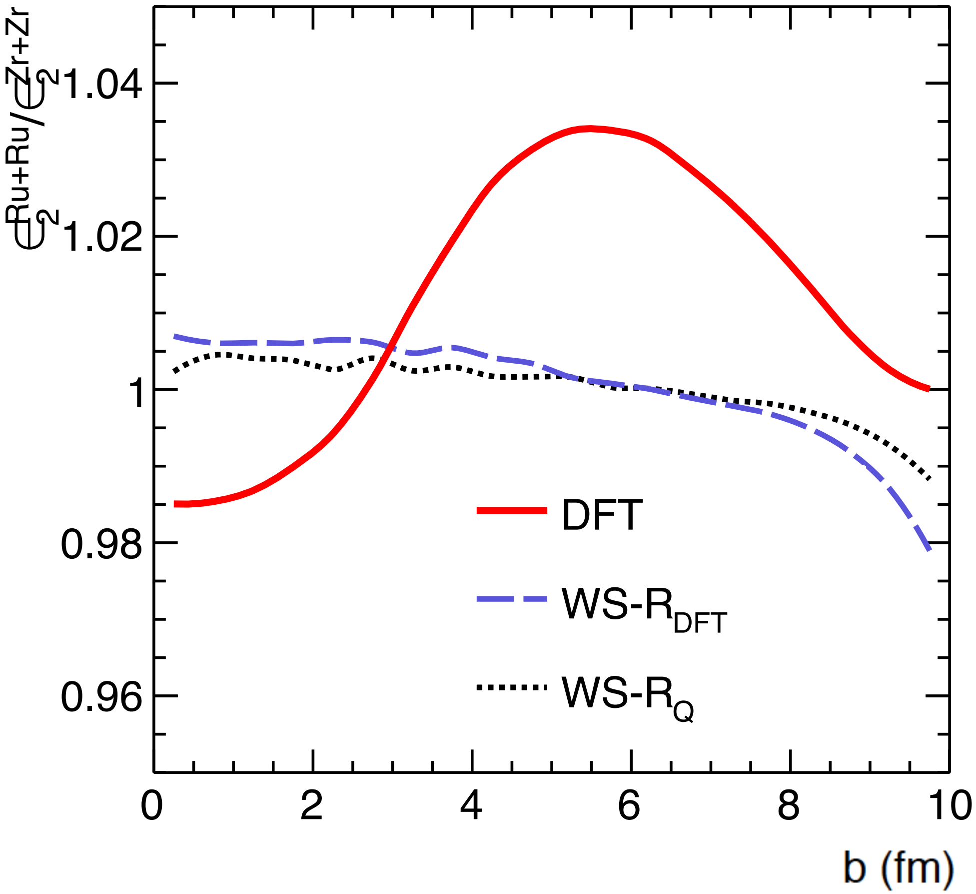




- The ratio curves up at large Nch because of the larger Nch tail in Ru+Ru.
- The trend of the ratio in the WS-RQ case is the opposite to the DFT case.
- The tail behavior in the ratio is mainly due to the ordering of the nuclear mass radii.

Glauber calculations

H.L. Li, et al. , PRC. 98, 054907, (2018)



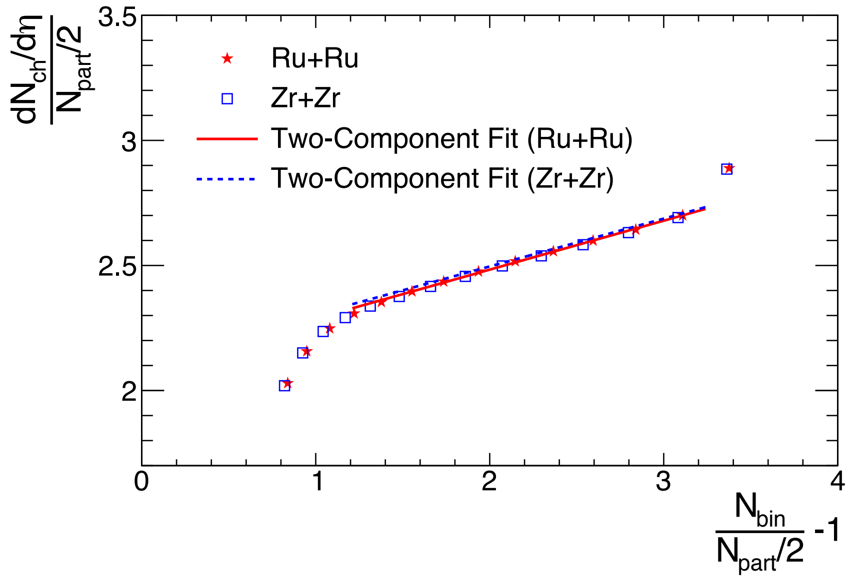
- The two WS density distributions give similar ratios. The DFT density gives quite different eccentricities for Ru+Ru and Zr+Zr;

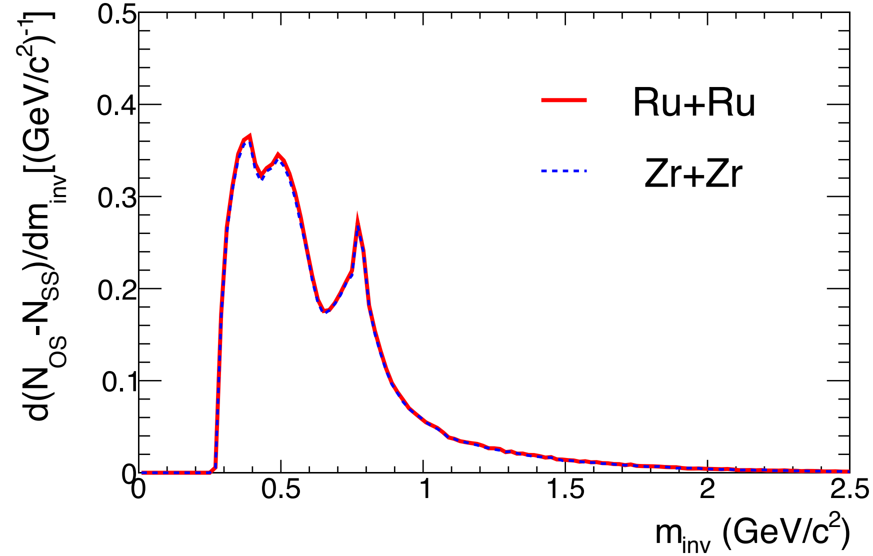
Particle production

Two-component model

$$\frac{dN_{ch}/d\eta}{N_{part}/2} = n_{pp}[1 + x(\frac{N_{bin}}{N_{part}/2} - 1)]$$

H.L. Li, et al. , PRC. 98, 054907, (2018)



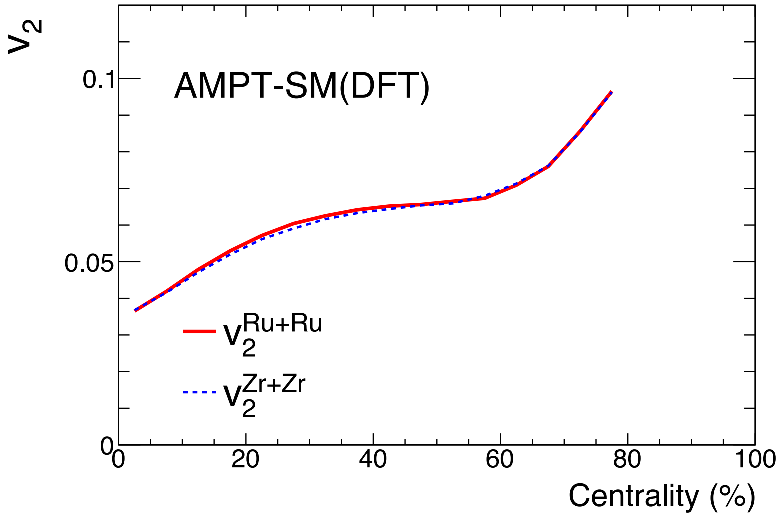


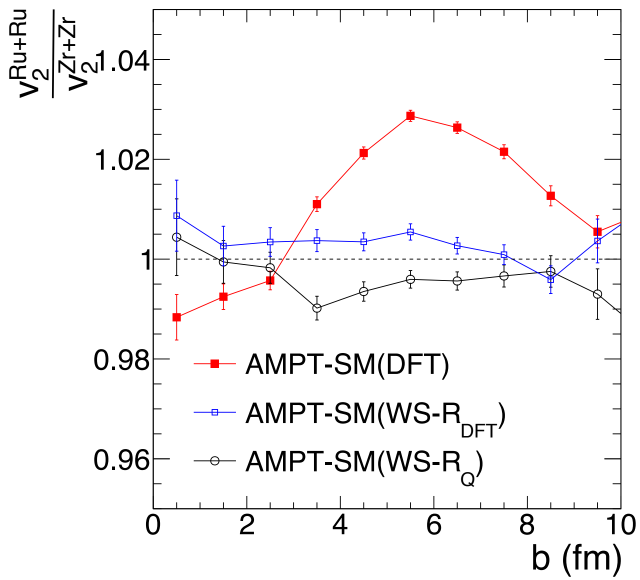
- The fit parameters are n_{pp}≈2.1 and x≈9% for both Ru+Ru and Zr+Zr.

- The m_{inv} distributions are nearly identical.

Elliptic anisotropy

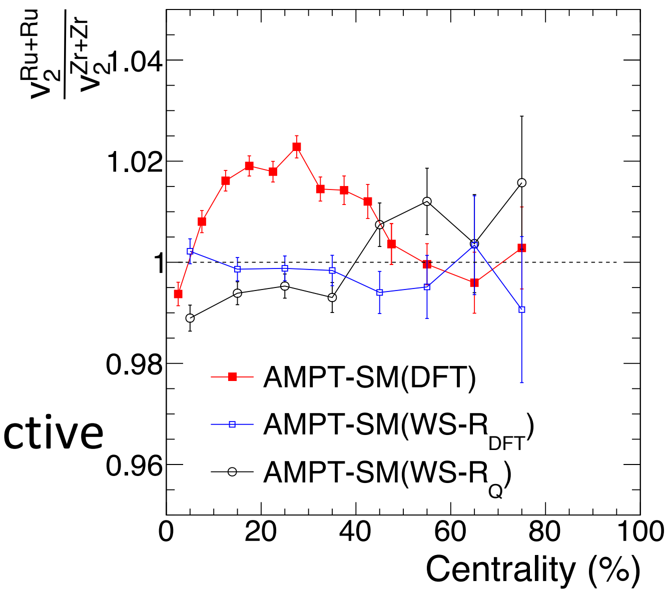
H.L. Li, et al. , PRC. 98, 054907, (2018)





$$\Psi_2 = \frac{1}{2} a\tan 2(\langle \sin 2\phi \rangle, \langle \cos 2\phi \rangle)$$

$$v_2 = \left\langle \cos\left(2\left(\phi - \Psi_r\right)\right)\right\rangle / R_2$$



- The v2 ratio in Ru+Ru to Zr+Zr has the distinctive feature between DFT and WS densities.

Summary

1. We make predictions of isobaric collisions using the string-melting version of the AMPT model with the nuclear density distributions calculated by the density functional theory.

2. For the reason of relative mass radii of the isobaric nuclei, the ratio of the N_{ch} distributions in Ru+Ru to Zr+Zr collisions curves up at large N_{ch} , opposite to the trend obtained using the common Woods-Saxon(WS) densities.

3. With the same radii, the centrality dependence of the v_2 ratio in Ru+Ru to Zr+Zr collisions can decisively determine whether DFT density is more realistic than WS or not.