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# Exploring system size dependence of directed flow in heavy-ion collisions through the transport model

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*Based on: arXiv:2506.17763 (2025)*

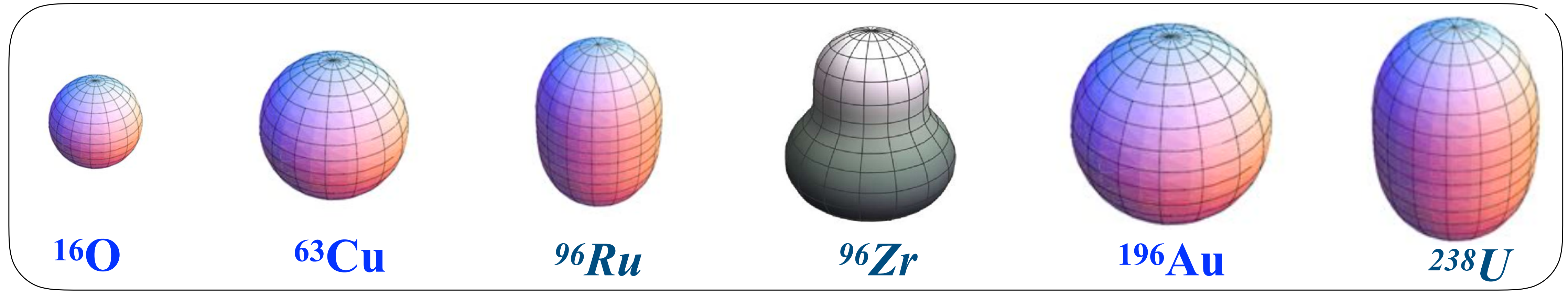


# Outline

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- Motivation**
- New Coalescence AMPT Model**
- Analysis details**
- Results**
- Summary**

# Motivation

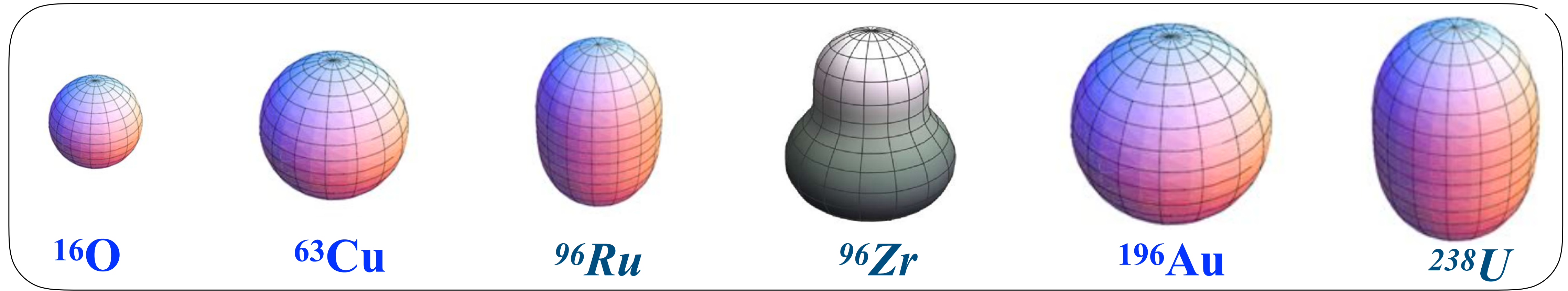


✓ System size dependence  $v_1$  study

→ Help to estimate the participant-spectator contribution

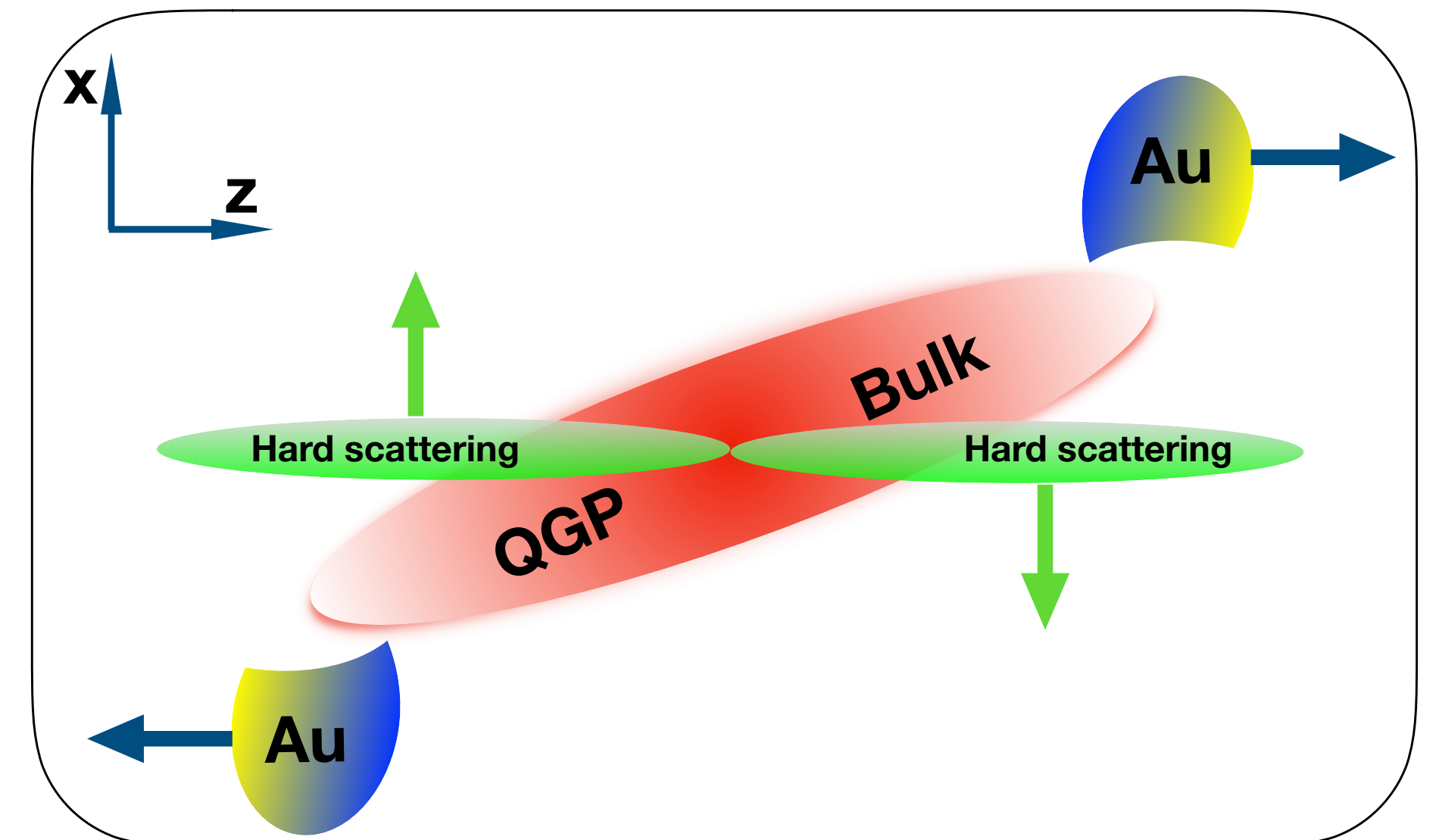
→ Improve understanding of EoS for symmetric nuclear matter

# Motivation



- ✓ System size dependence  $v_1$  study
  - Help to estimate the participant-spectator contribution
  - Improve understanding of EoS for symmetric nuclear matter

- ✓ QGP bulk (mostly soft particles) tilted in rapidity, unlike the hard scattering profile (symmetric)
  - Hard-soft asymmetry in initial state
  - Induces (negative)  $v_1$  for hard partons



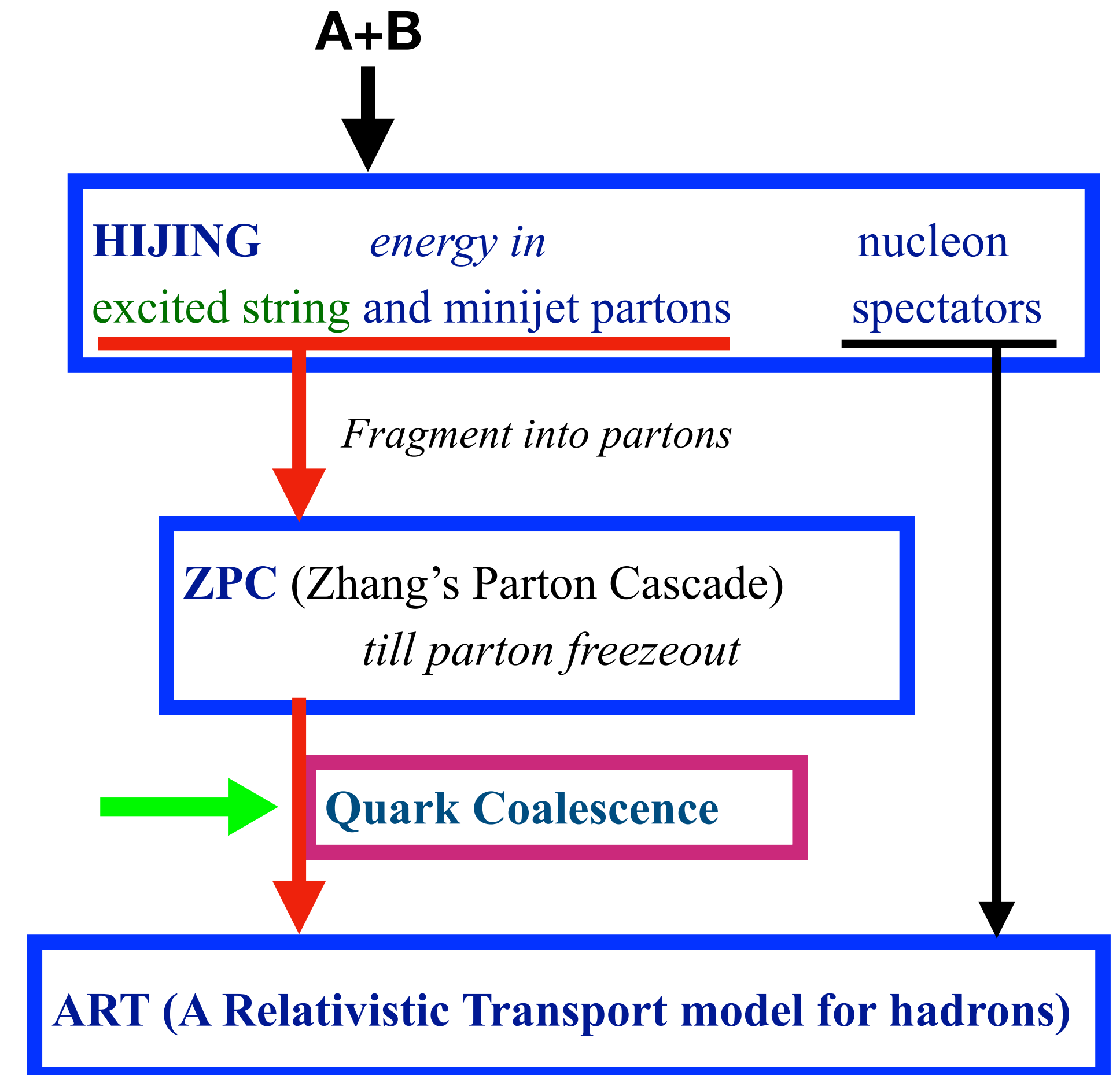
*Phys. Rev. Lett.* 120, 192301 (2018); *Phys. Rev. C* 72, 034907 (2005)

# New Coalescence AMPT Model

- New quark coalescence model in the AMPT searches for a meson partners before searching for baryon or anti-baryon partners.
- Some changes in the quark coalescence model are:
  - ▶ Mesons and (anti)baryons are formed under the competition
  - ▶ “co-ordinate coalescence” but with momentum limit  $\Delta p_0$

$$\begin{cases} \Delta r_{\text{new}} < \Delta r_{\text{old}} \\ \Delta p_{\text{new}} < \Delta p_0 \end{cases}$$

- A quark has the freedom to form either a meson or a baryon (depending on the distance to potential coalescence partners)



Structure of the AMPT model with string melting

*Y. He and Z.-W. Lin, Phys. Rev. C 96, 014910 (2017)*

# Implementation of Nuclear Deformation

✓ Spherical Nuclei: O, Cu, Au

✓ Deform Nuclei: Zr, Ru, U

Input Parameters for Nuclei

Parameter	O	Cu	Zr	Ru	Au	U
$Z$	8	29	40	44	79	92
$A$	16	63	96	96	197	238
$R_0$	2.608	4.214	5.090	5.090	6.380	6.810
$a$	0.513	0.586	0.520	0.460	0.535	0.550
$\beta_2$	0	0	0.060	0.162	0	0.280
$\beta_3$	0	0	0.200	0	0	0

✓ Woods-Saxon function:

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

▶  $\rho_0$  is the normal nuclear density

▶  $a$  is the surface diffuseness parameter

▶  $R(\theta, \phi)$  is the parameter characterizing the deformation of the nucleus:

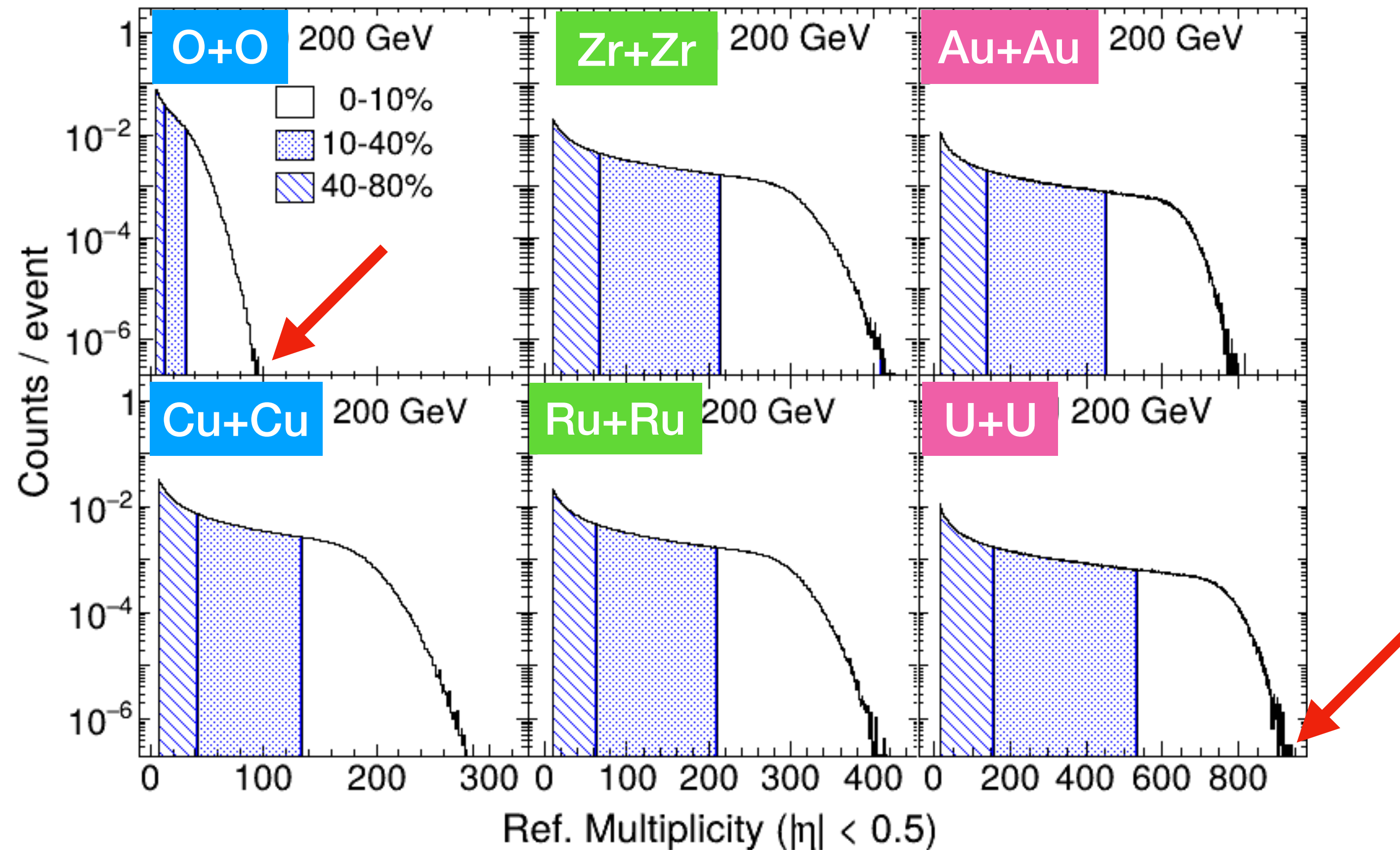
$$R(\theta, \phi) = R_0[1 + \beta_2 Y_{2,0}(\theta, \phi) + \beta_3 Y_{3,0}(\theta, \phi)]$$

•  $R_0$  represents the radius parameter

•  $\beta_2$ : quadrupole,  $\beta_3$ : octupole deformities

•  $Y_{l,m}(\theta, \phi)$  are the spherical harmonics

# Analysis Method: Centrality



System	Mass No.	#Events (M)
O+O	16	50
Cu+Cu	63	15
Zr+Zr	96	9
Ru+Ru	96	9
Au+Au	197	6
U+U	238	6

- ✓ Multiplicity coverage is from 100 (O+O) to 900 (U+U)
- ✓ Mass number from 16 (O+O) to 238 (U+U)

# Analysis Method

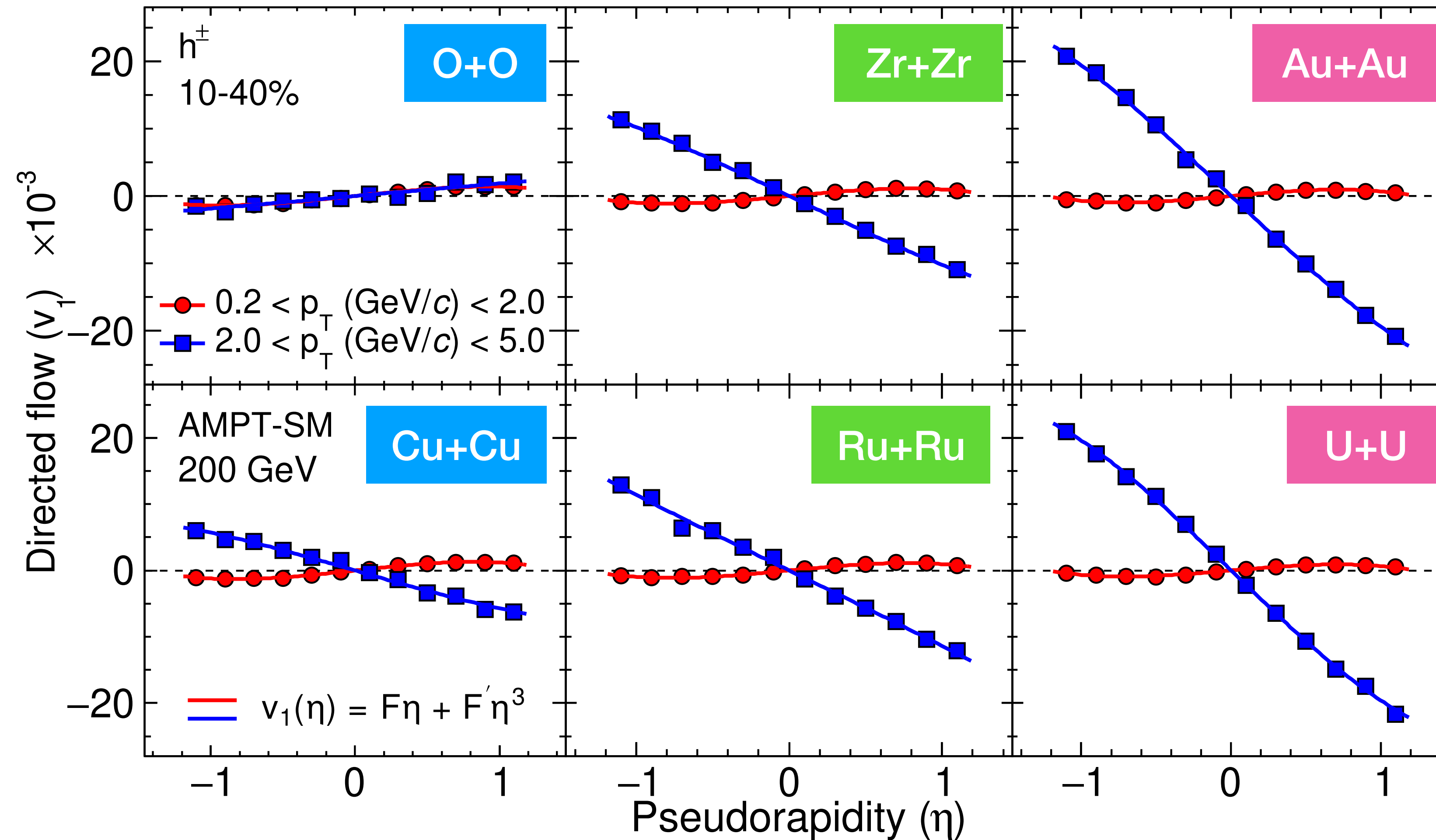
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- ✓ Directed flow,  $v_1 = \langle \cos(\phi - \Psi_R) \rangle$ , where  $\phi = \tan^{-1}\left(\frac{p_y}{p_x}\right)$
- ✓ In this analysis we have taken  $\Psi_R = 0$
- ✓ In the AMPT-SM, particles are identified from their Pythia ID (PID)

## What is the best way to compare $v_1$ of different colliding systems?

- ➔ The scaled impact parameter  $b_0$  ( $= b/b_{\max}$ ) as a measure of centrality,  $b_{\max} = 1.15(A_p^{1/3} + A_T^{1/3})$
- ➔ Symmetric collisions systems ( $A_T = A_P = A$ ), then  $b_0$  ( $\sim \langle b \rangle / A^{1/3}$ )

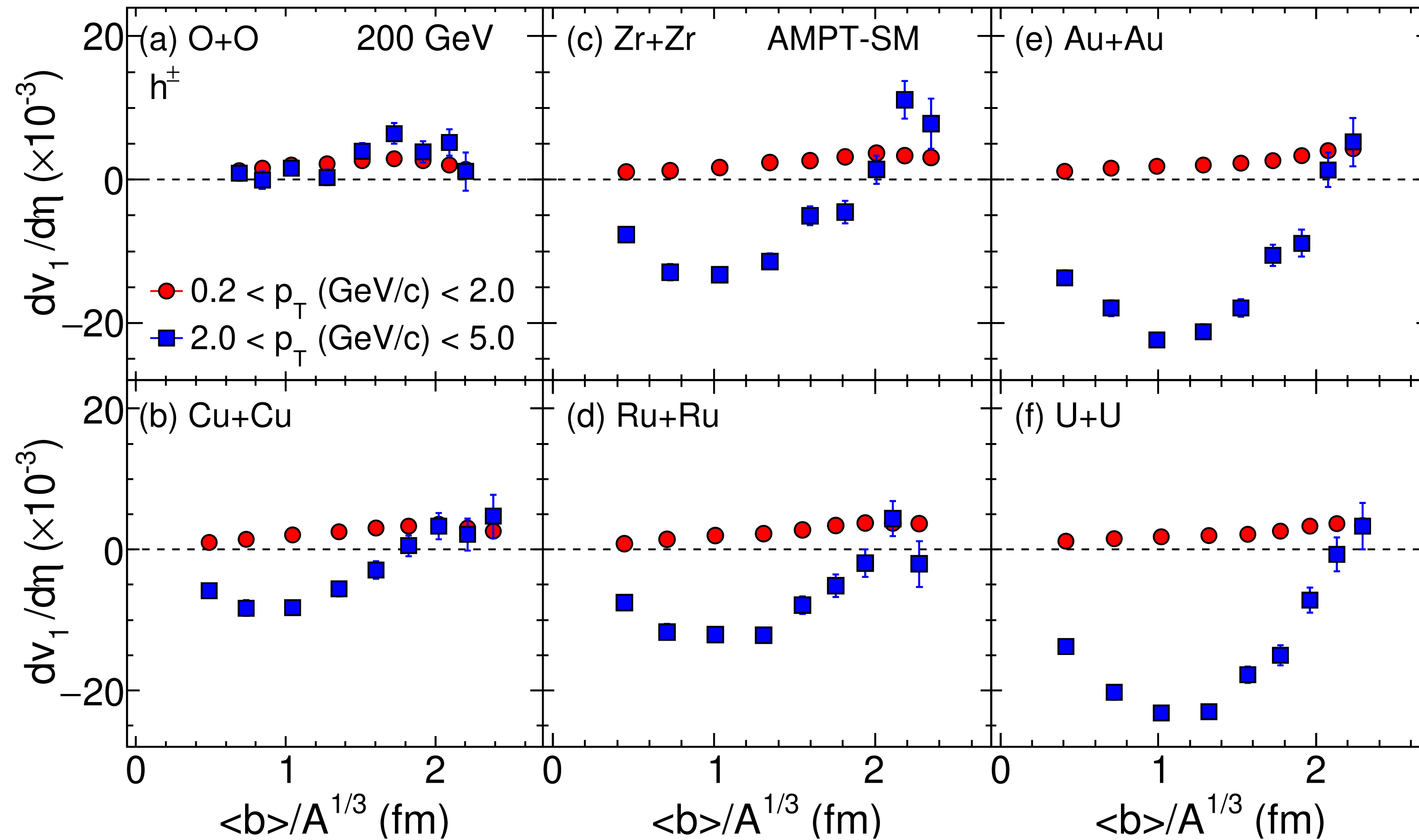
# Directed Flow of Charged Hadrons



- $v_1$  vs  $\eta$  are fitted in the  $\eta = 0$  region ( $|\eta| < 1.2$ ) with a cubic function to extract slope  $F = dv_1/d\eta$

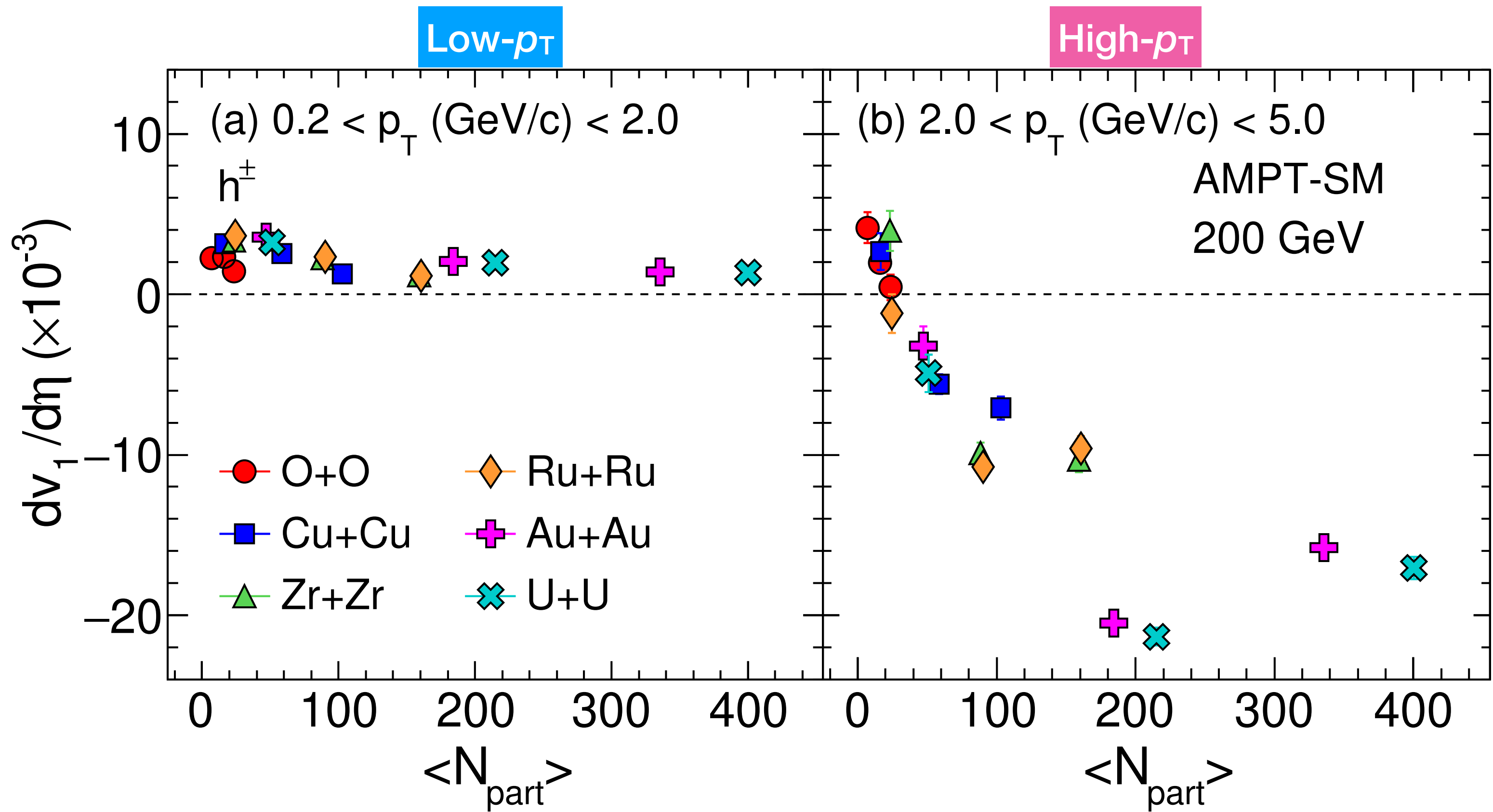
$$v_1(\eta) = F\eta + F'\eta^3$$

# $v_1$ -slope $F = dv_1/d\eta$ : Low- $p_T$ & high- $p_T$



- **Low- $p_T$ :** Flow ( $F > 0$ ) is dominant
  - **High- $p_T$ :** Anti-flow ( $F < 0$ ) with larger slope magnitude (except for O+O)
- **Hard-soft asymmetry**

# System Size Dependence: $dv_1/d\eta$ vs $\langle N_{\text{part}} \rangle$



## At low- $p_T$ :

- A very weak centrality dependence
- System size independence

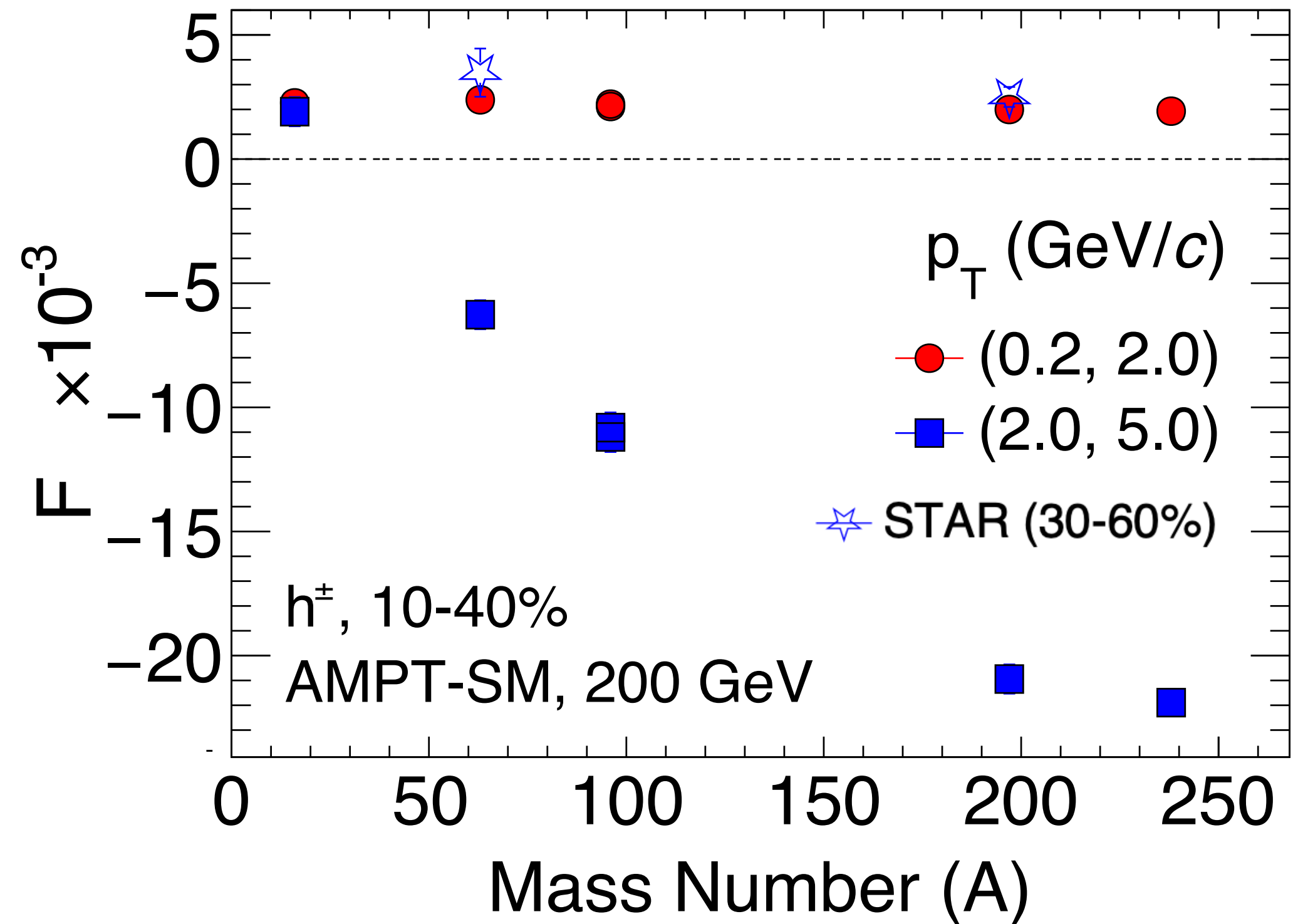
## At High- $p_T$ :

- Both centrality and system size dependence of  $v_1$ -slope is found
- Higher slope magnitude might be due to less interactions with the medium

- A system size independence is observed at low- $p_T$  in Cu+Cu & Au+Au,  $\sqrt{s_{\text{NN}}} = 200$  GeV at RHIC  
 → QGP bulk for all these systems are driven by multiplicity

# System Size Dependence

$dv_1/d\eta$  vs A



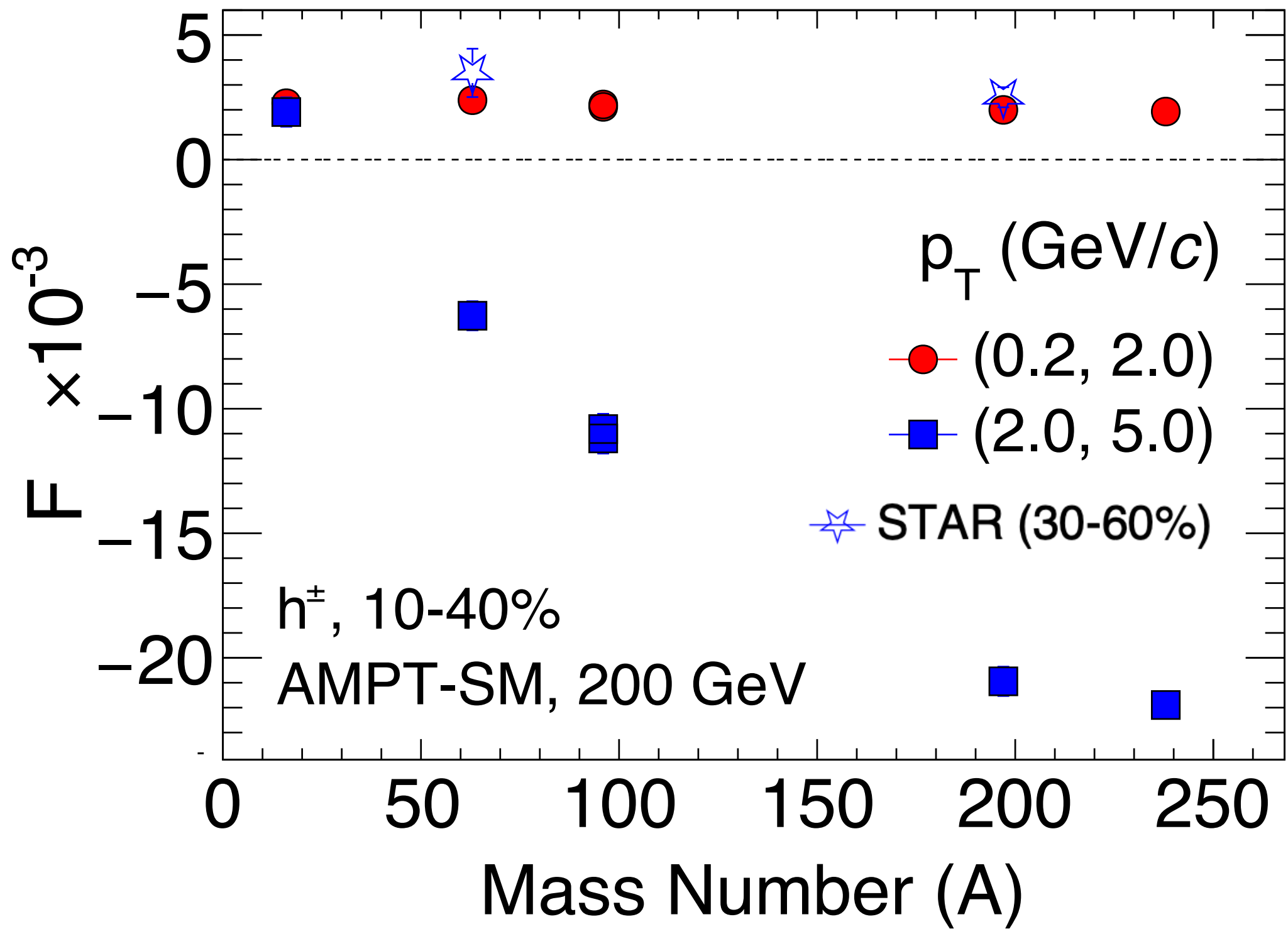
•  $F = dv_1/d\eta$

☑ **Low- $p_T$ :** The magnitude of  $dv_1/d\eta$  measured in STAR for Cu+Cu and Au+Au are in good agreement with our AMPT-SM calculations

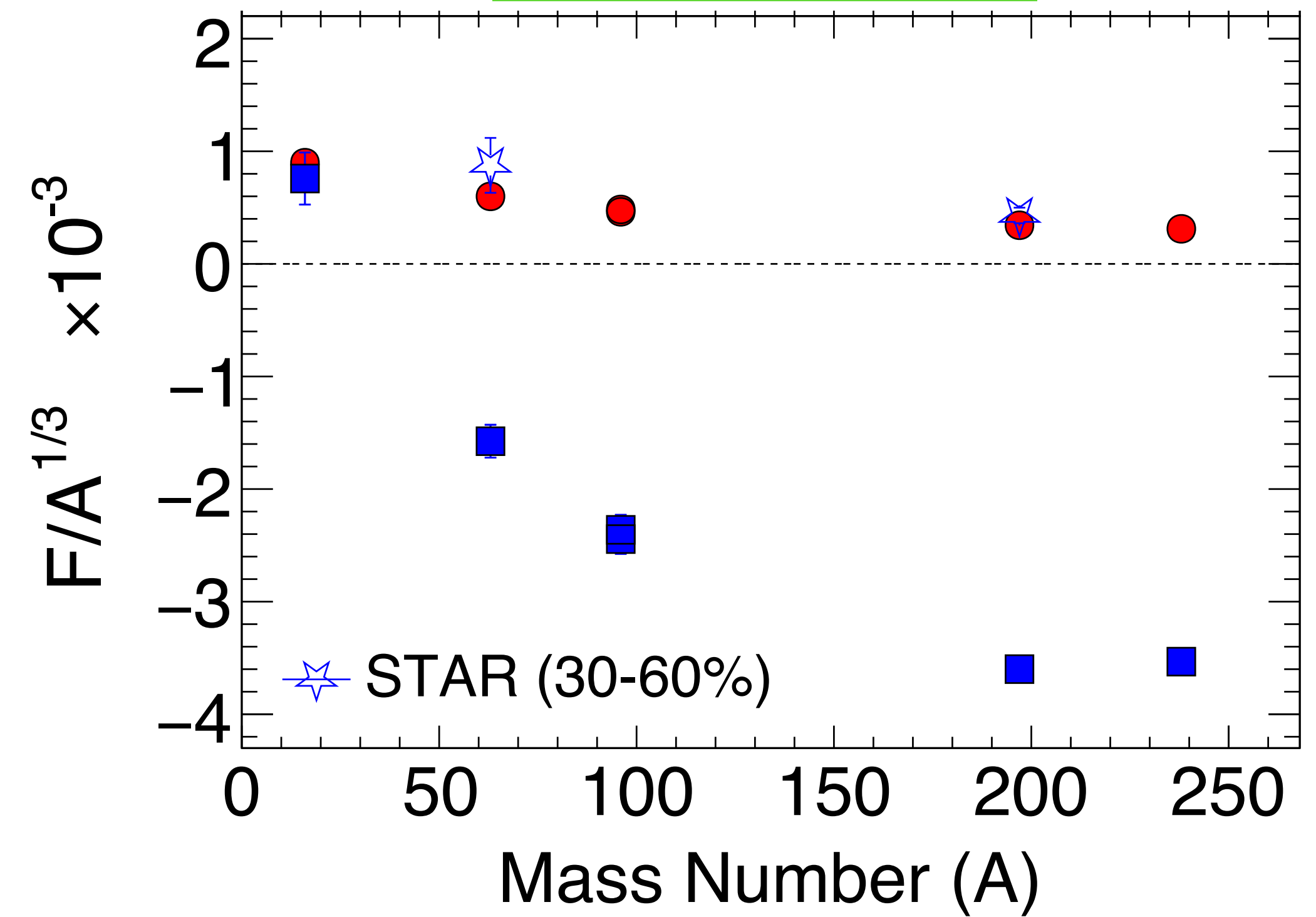
STAR Collaboration, Phys. Rev. Lett 101, 252301 (2008)

# System Size Dependence

$dv_1/d\eta$  vs A



$(dv_1/d\eta)/A^{1/3}$  vs A



•  $F = dv_1/d\eta$

☑ **Low- $p_T$** : The magnitude of  $dv_1/d\eta$  measured in STAR for Cu+Cu and Au+Au are in good agreement with our AMPT-SM calculations

% change of  $F/A^{1/3}$  between Cu+Cu & Au+Au:

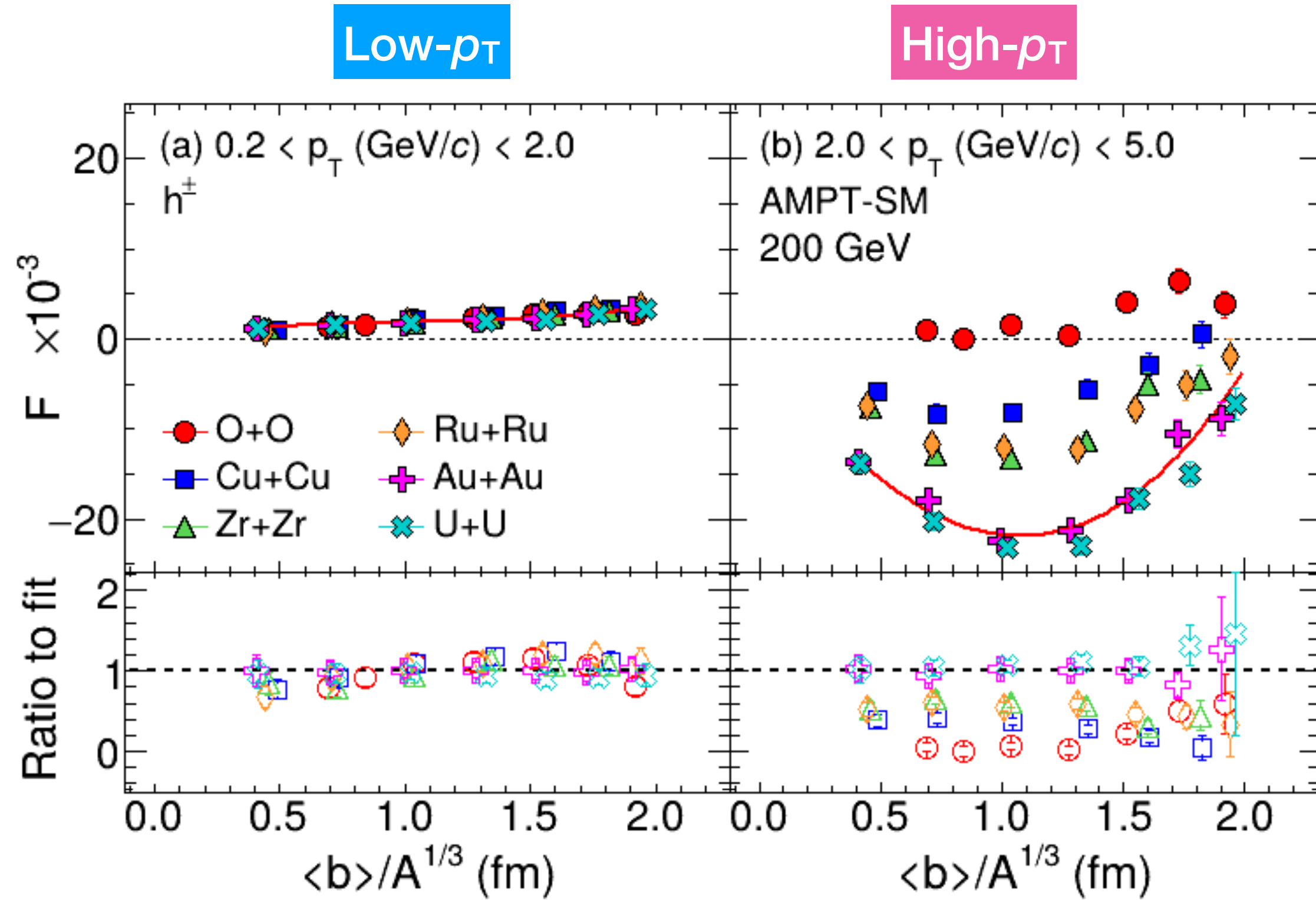
☑ STAR :  $28.1 \pm 9.05$  (low- $p_T$ )

☑ AMPT-SM:  $42.3 \pm 1.90$  (low- $p_T$ )

:  $128.5 \pm 12.5$  (high- $p_T$ )

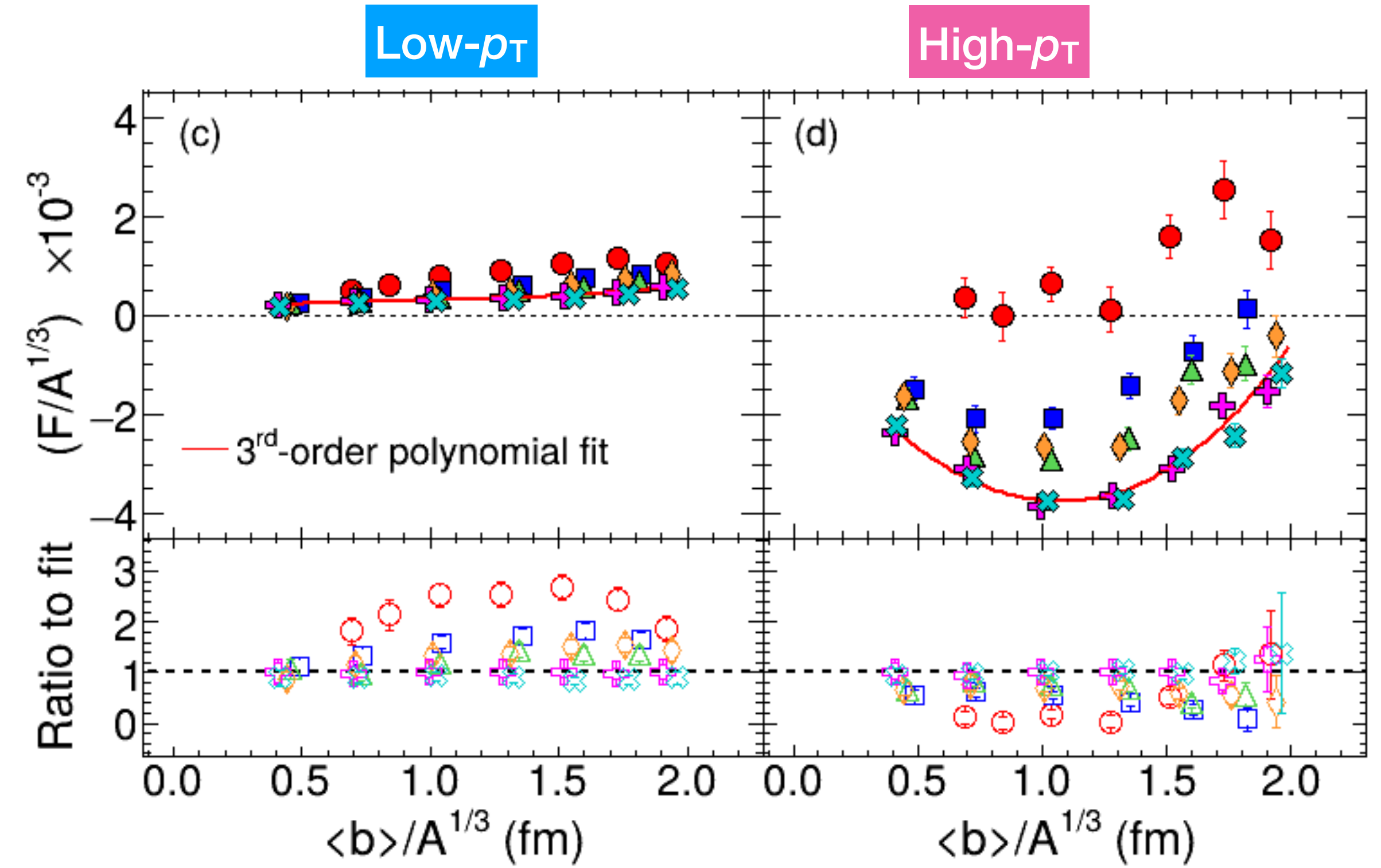
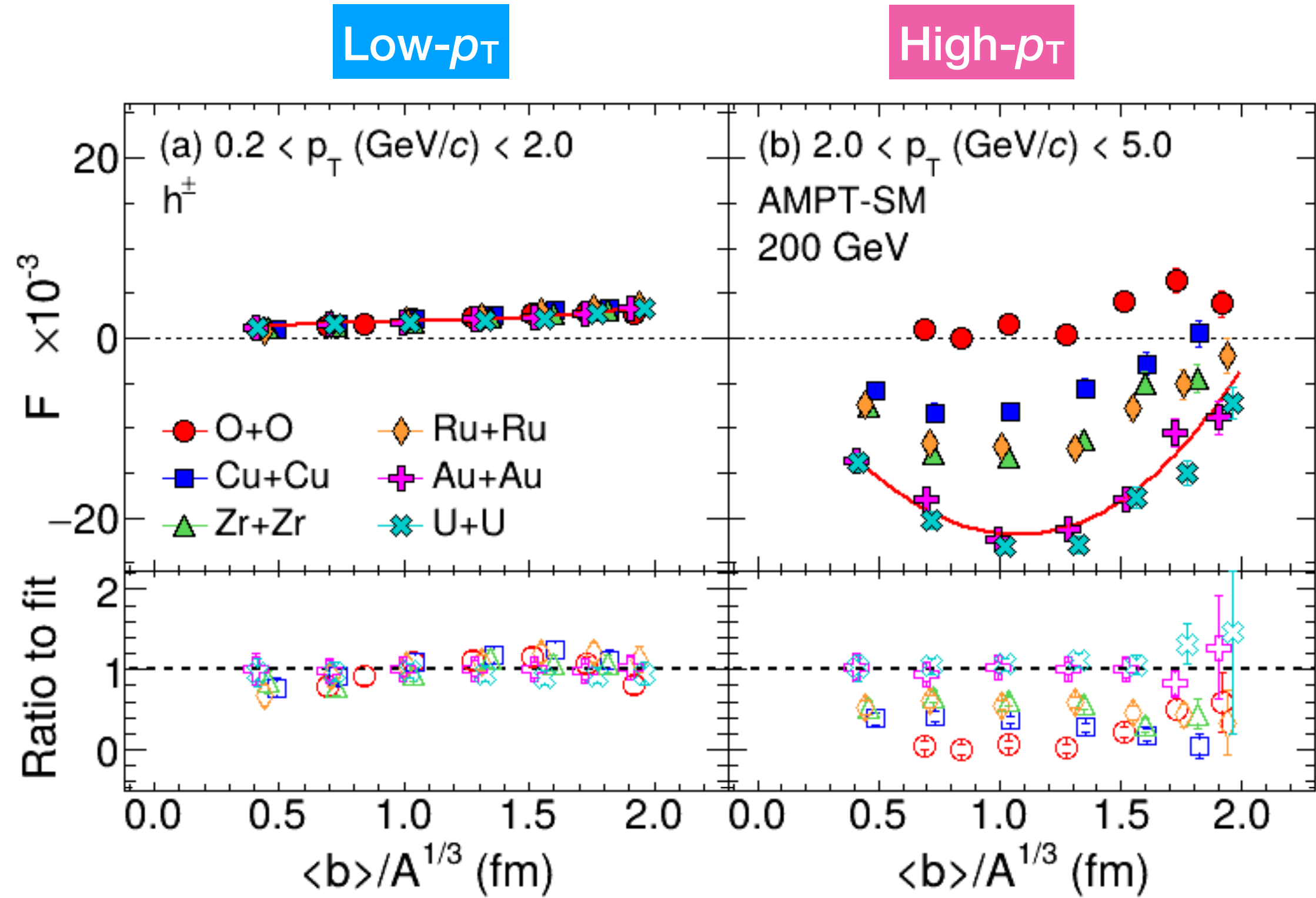
STAR Collaboration, Phys. Rev. Lett 101, 252301 (2008)

# Testing the Scaling Property of $dv_1/d\eta$



- QGP bulk is low- $p_T$  dominated and a prominent positive flow is seen unlike the high- $p_T$
- $v_1$ -slope ( $F$ ) scaling is relatively better in low- $p_T$  as compared to high- $p_T$

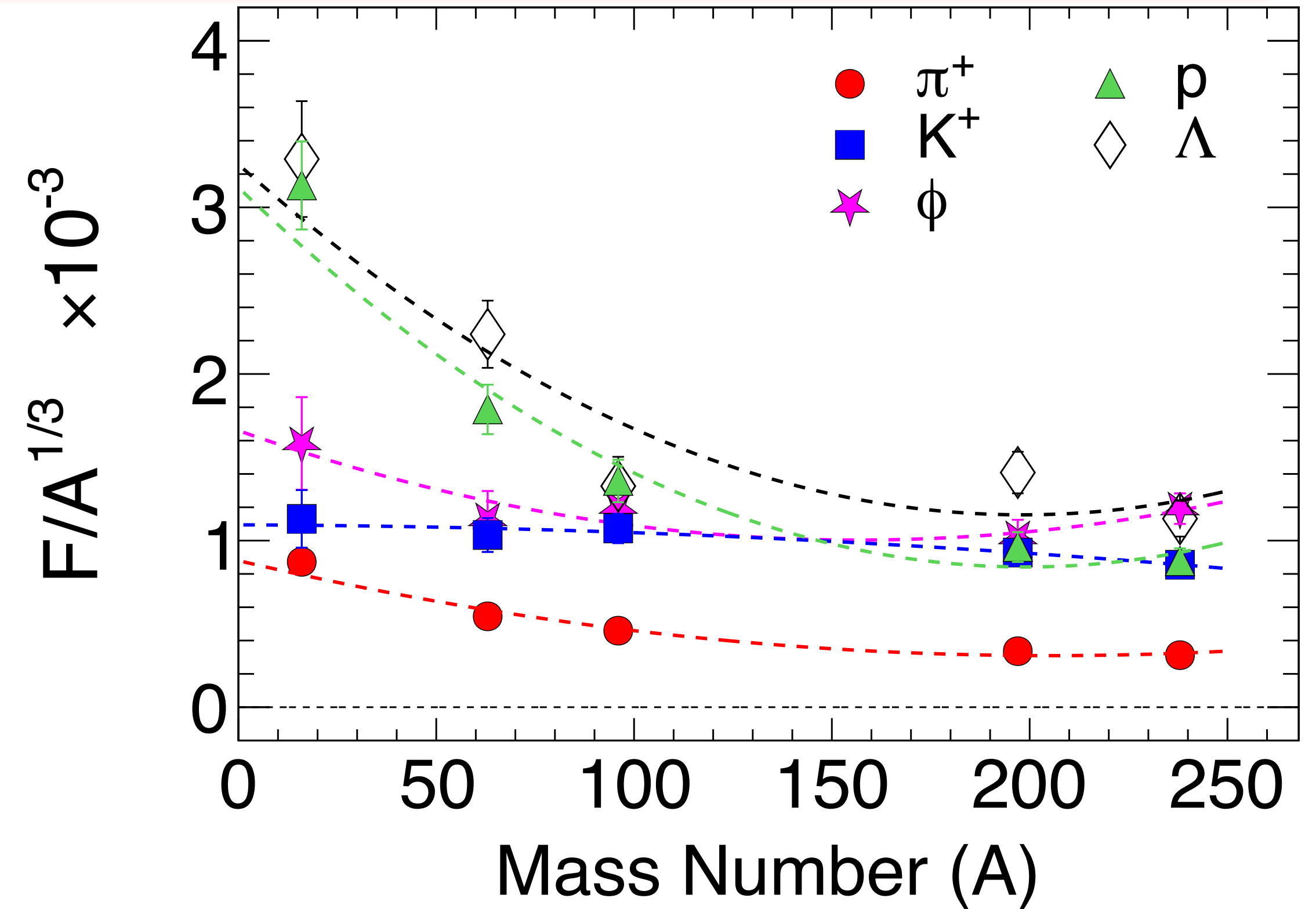
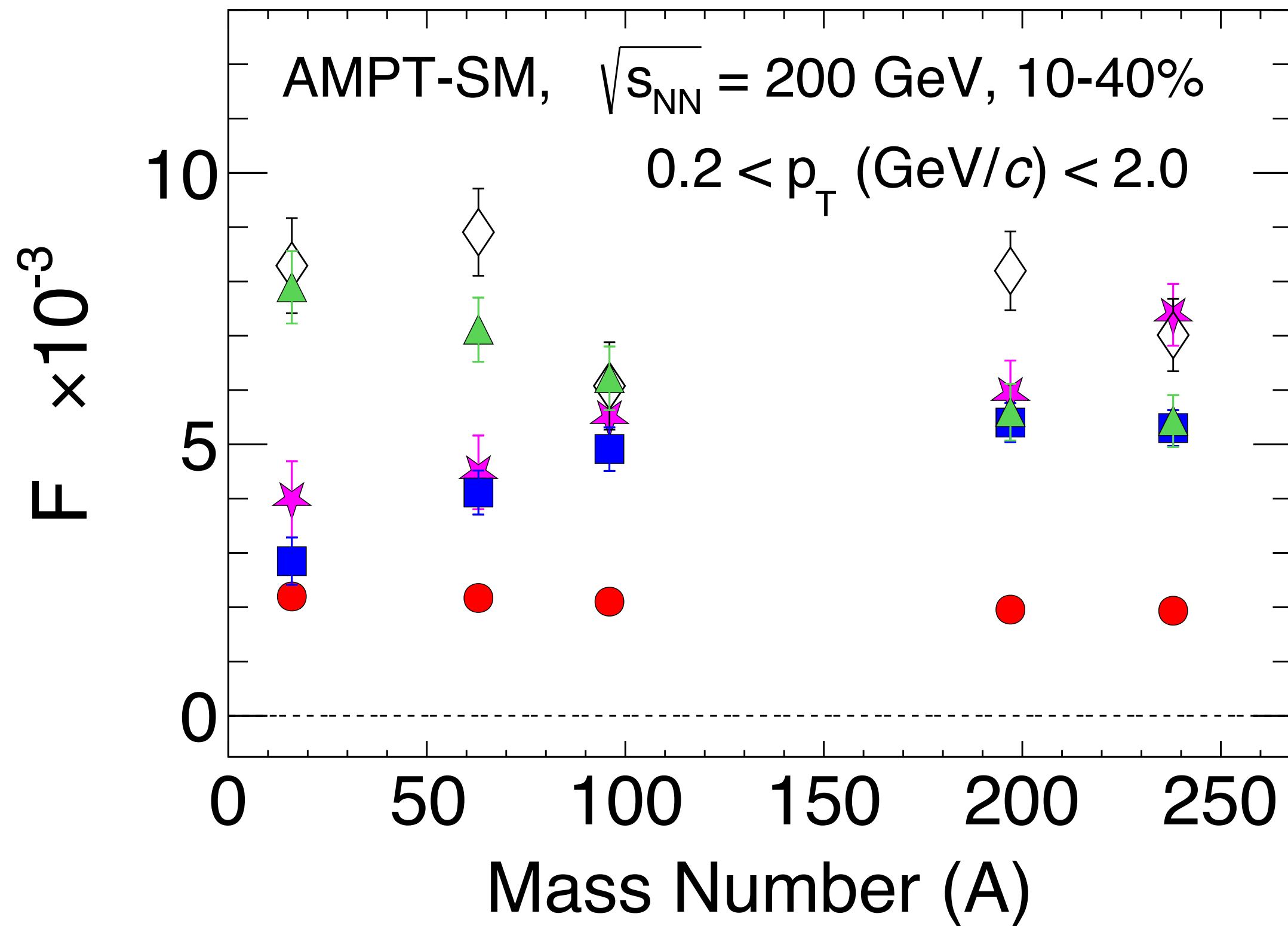
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- $F/A^{1/3}$  scaling violation of charged hadron in both low- $p_T$  and high- $p_T$
- The violation increases from heavier (U+U) to lighter (O+O) collision systems

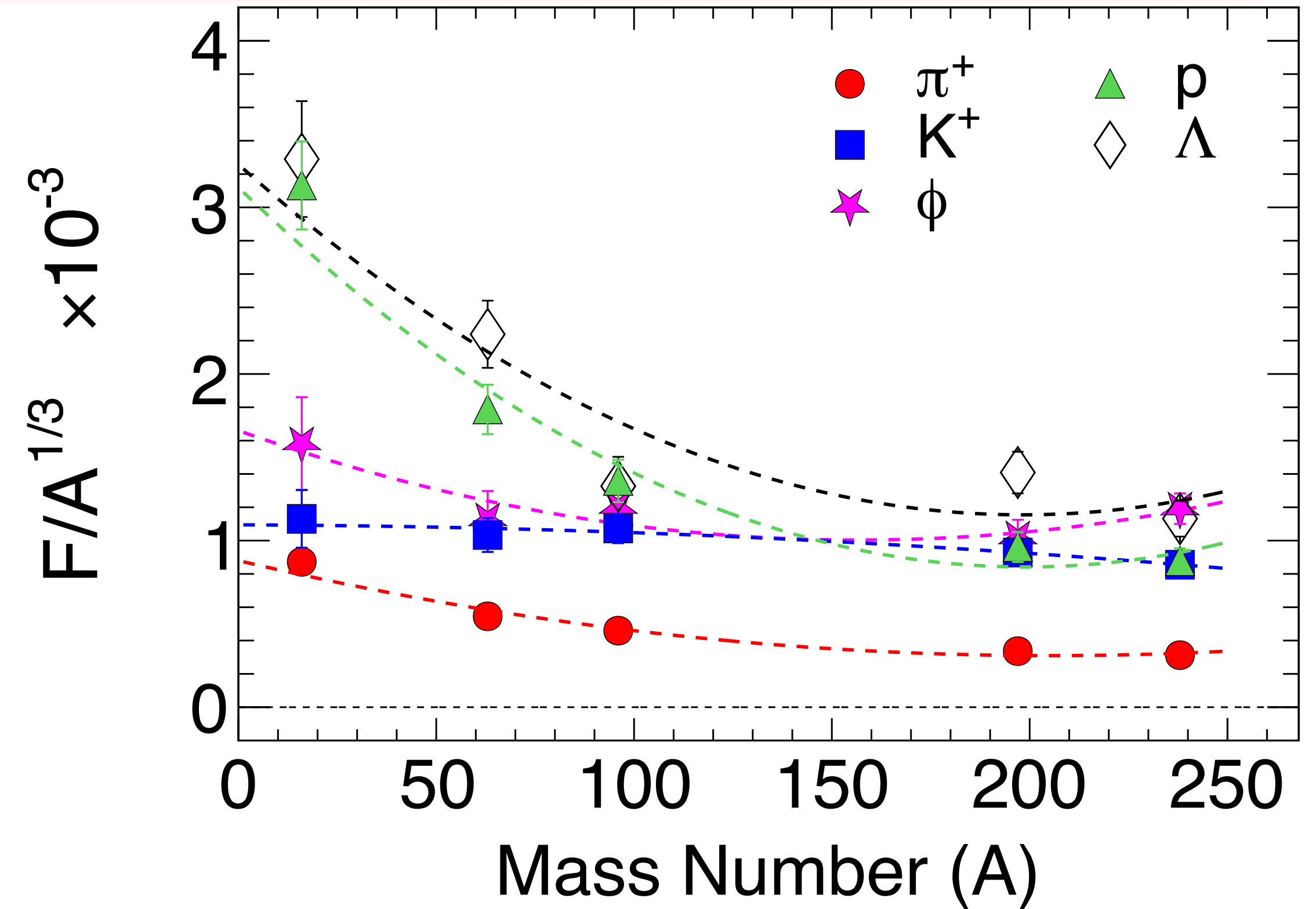
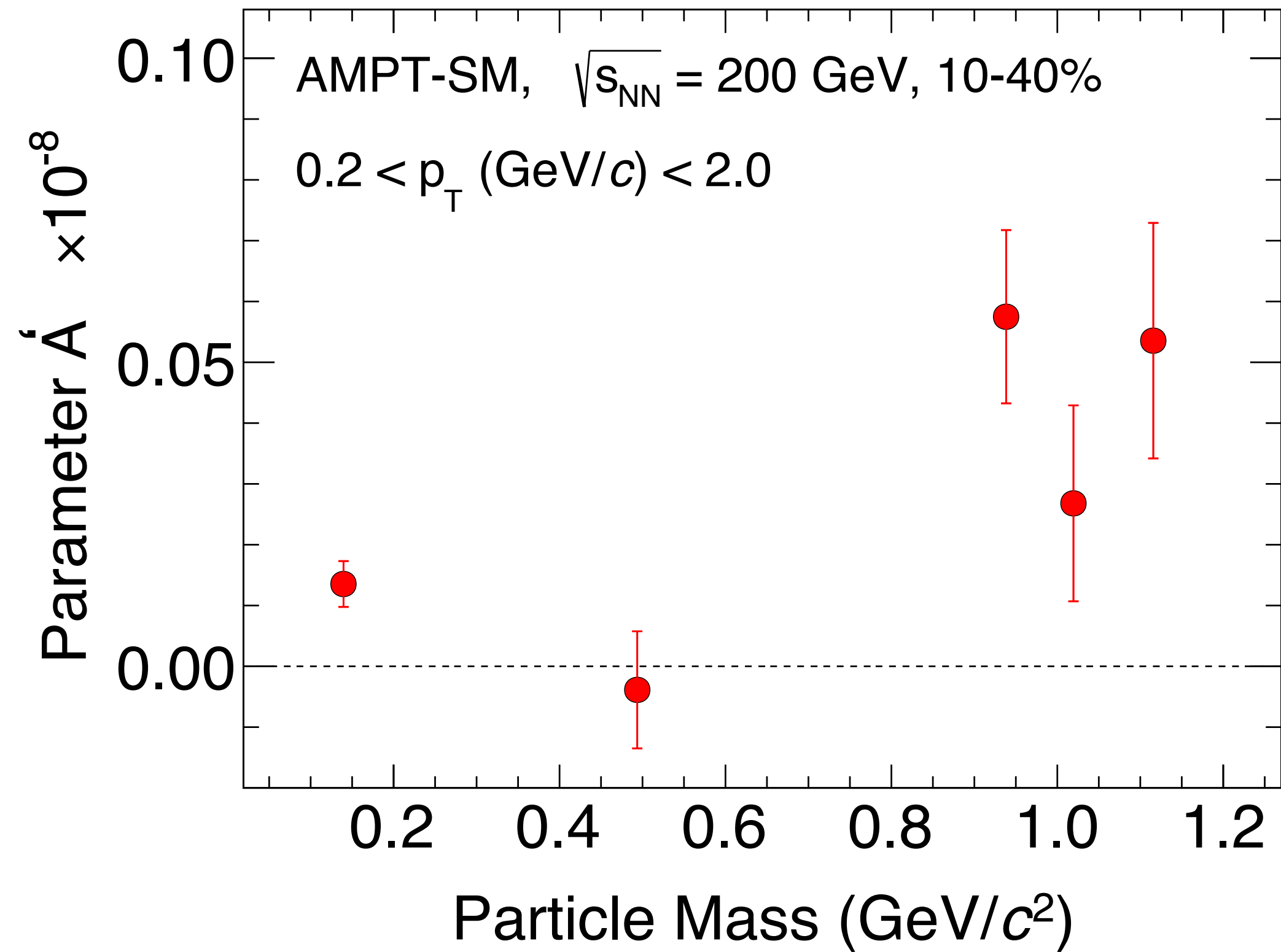
# System Size Dependence: PID



- A clear particle type dependence of  $v_1$ -slope ( $F$ ) is seen in the region of lower mass number ( $A$ )
- A characteristic baryon-meson separation in the region of lower mass number ( $A$ )

- $F/A^{1/3}$  is fitted with a quadratic polynomial  $A'x^2 + B'x + C'$
- Rate of change of slope ( $A'$ ) is calculated

# System Size Dependence: PID



- Rate of change of slope ( $A'$ ) for proton and  $\Lambda$  is higher than the mesons ( $\pi, K, \phi$ )
- A similar observation of system size dependence of proton is reported in STAR

- $F/A^{1/3}$  is fitted with a quadratic polynomial  $A'x^2 + B'x + C'$
- Rate of change of slope ( $A'$ ) is calculated

# Summary

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- ✓ Directed flow ( $v_1$ ) study is performed in O+O, Cu+Cu, Zr+Zr, Ru+Ru, Au+Au & U+U collisions at  $\sqrt{s_{NN}} = 200$  GeV to understand the system size dependence via AMPT model
- ✓ A system size independence of  $v_1$ -slope ( $dv_1/d\eta$ ) is found for charged hadron at low- $p_T$
- ✓ Centrality and  $p_T$ -dependent  $v_1$ -slope suggests the effect of initial hard-soft asymmetry
- ✓ System size dependence is prominent for baryon as compared to mesons

**Thank you!**

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# Backup

# v<sub>1</sub> vs y: PID

