Measurement of anisotropic radial flow in relativistic heavy ion collisions

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Lin Li, Na Li and Yuanfang Wu CPC,2012,36(5):423-428
Peng Yang, Lin Li and Yuanfang Wu arXiv:1405.0686

Outline

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2. Measurements of radial expansion
3. Physics of measured $d\langle\langle y_T \rangle\rangle / d\phi$
4. Extracted ρ_2 and measured y_{T2}
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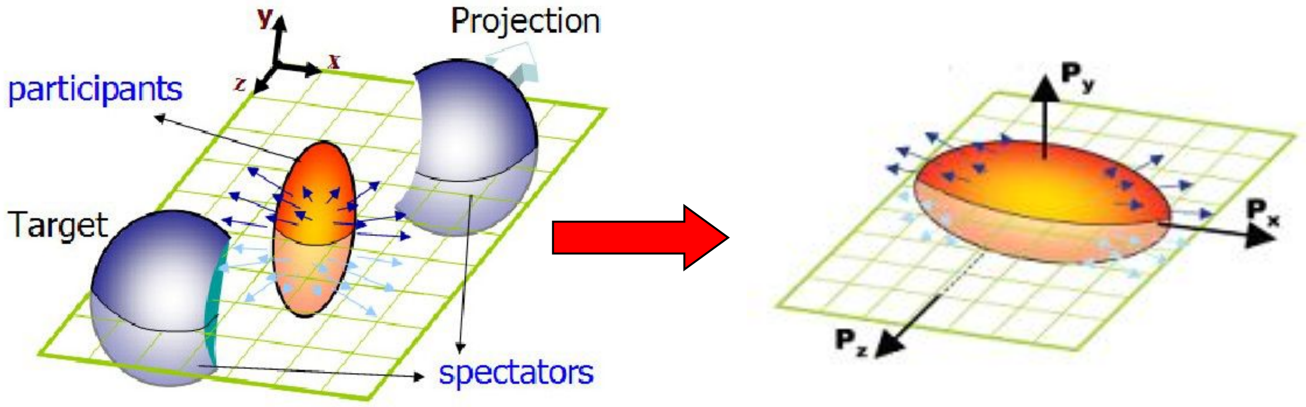
1. Motivation

Coordinate-Space **Momentum-Space**



◆ Elliptic flow:

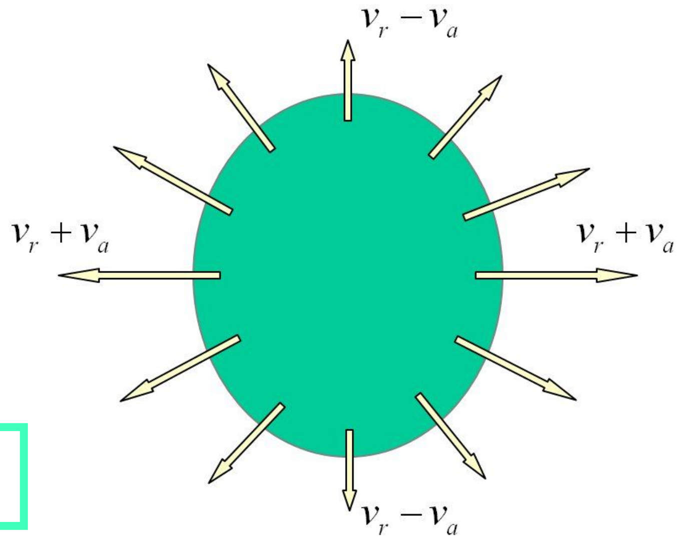
Azimuthal multiplicity distribution:

$$\frac{dN}{d\phi} \propto 1 + \sum_{n=1}^{\infty} 2\underline{v_n(N)}\cos\left[n\left(\phi - \psi_r\right)\right] \qquad \phi = \tan^{-1}\left(\frac{p_y}{p_x}\right)$$

Define elliptic flow: $\boxed{v_2(N) = \left\langle \cos\left[2\left(\phi - \psi_r\right)\right]\right\rangle}$

- ➢ **It measures the anisotropy of azimuthal multiplicity distribution !**

◆ Radial expansion



3 velocities:

- Average radial expansion velocity (v_r)
- Anisotropic velocity (v_a)
- Thermal velocity

Radial expansion + Elliptic flow

⇩

Particle mass splitting of differential elliptic flow at low transverse momentum region.

Sergei A. Voloshin, Arthur M. Poskanzer, and Raimond Snellings arXiv: 0809.2949

- **Radial velocities are important parameters of hydrodynamic calculations !**

◆ Generalized Blast-wave parameterization

Radial flow: $$\rho = \tilde{r}\left(\rho_0 - \rho_2 \cos(\phi_m)\right)$$

ρ_0 : the isotropic radial flow rapidity;

ρ_2 : the anisotropic radial flow rapidity

ρ_0, ρ_2 are determined by fitting:

(1) Transverse momentum spectrum

(2) Differential elliptic flow

E. Schnedermann, et.al, PRC 48, 2462(1993);
W.Broniowski et.al, PRL 87 272302(2001);
P. Huovinen, et.al, PLB 503, 58(2001).

- **Such extracted parameters are model dependent !**

2. Measure of radial expansion

- **Transverse rapidity:**

$$y_T = \ln\left(\frac{m_T + p_T}{m_0}\right) \qquad m_T = \sqrt{m_0^2 + p_T^2}$$

m_0 : the particle mass in the rest frame.

p_T : transverse momentum.

m_T : the transverse mass.

- **Total transverse rapidity in an azimuthal angle bin:**

$$\langle Y_T(\phi_m)\rangle = \frac{1}{N_{event}} \sum_{j=1}^{N_{event}} \left(\sum_{i=1}^{N_m} y_{T,i}(\phi_m) \right) \quad \Rightarrow \quad \frac{d\langle Y_T\rangle}{d\phi}$$

$y_{T,i}$: transverse rapidity of the ith particle in the mth angular bin.

N_m : total number of particles in the mth angular bin.

Li Lin, Li Na and Wu Yuanfang J. Phys. G: Nucl. Part. Phys. 40 (2013) 075104

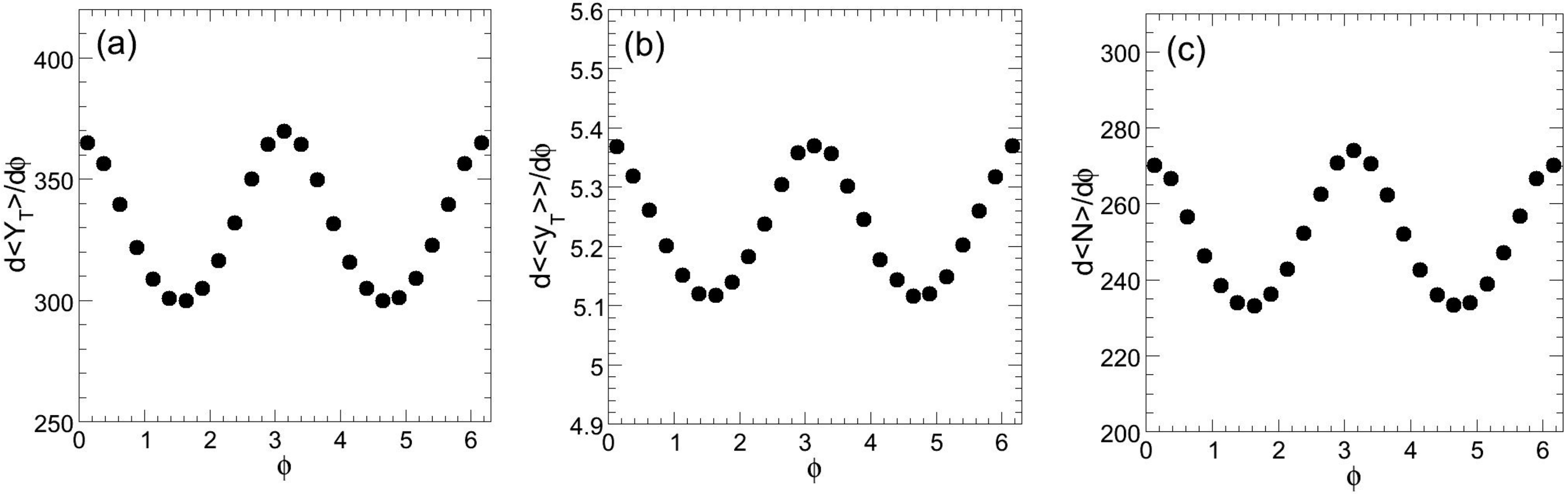
- **It contains the information of kinetic expansion and multiplicity distribution!**

✧ **Mean transverse rapidity** **in an azimuthal angle bin:**

$$\langle\langle y_T(\phi_m)\rangle\rangle = \frac{1}{N_{event}}\sum_{j=1}^{N_{event}}\left(\frac{1}{N_m}\sum_{i=1}^{N_m} y_{T,i}(\phi_m)\right) \Rightarrow \boxed{\frac{d\langle\langle y_T\rangle\rangle}{d\phi}}$$

➢ **It measures the transverse (radial) kinetic expansion only!**

AMPT with string melting for Au+Au coll. at 200GeV



◆ Definitions of various flows:

Azimuthal multiplicity distribution:

$$\frac{dN}{d\phi} = v_0(N)\left(1+\sum_{n=1}^{\infty}\underline{2v_n(N)}\cos\left[n(\phi-\psi_r)\right]\right)$$

Azimuthal total transverse rapidity distribution:

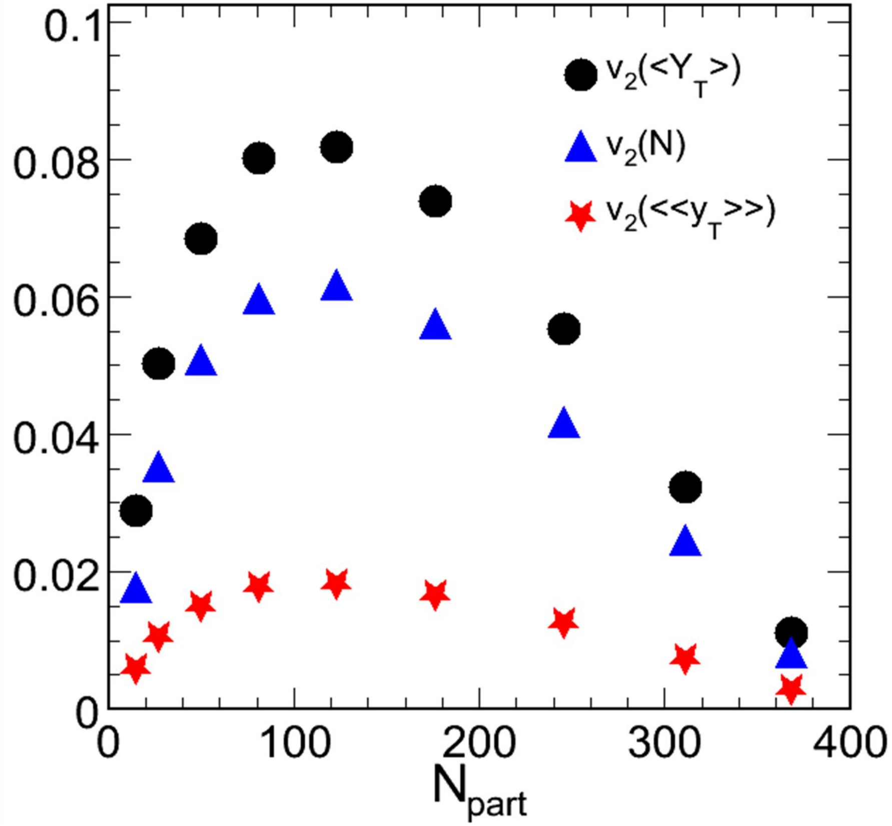
$$\frac{d\langle Y_T\rangle}{d\phi} = v_0(\langle Y_T\rangle)\left(1+\sum_{n=1}^{\infty}\underline{2v_n(\langle Y_T\rangle)}\cos\left[n(\phi-\psi_r)\right]\right)$$

Azimuthal mean transverse rapidity distribution:

$$\frac{d\langle\langle y_T\rangle\rangle}{d\phi} = v_0(\langle\langle y_T\rangle\rangle)\left(1+\sum_{n=1}^{\infty}\underline{2v_n(\langle\langle y_T\rangle\rangle)}\cos\left[n(\phi-\psi_r)\right]\right)$$

◆ Centrality dependence of various anisotropic flows

AMPT with string melting
for Au+Au coll. at 200GeV



- They show similar centrality dependence.
- $v_2(<<y_T>>)$ is smallest, $v_2(N)$ is in the middle, and $v_2(<Y_T>)$ is largest, as it counts the anisotropy from both multiplicity and transverse rapidity distributions.

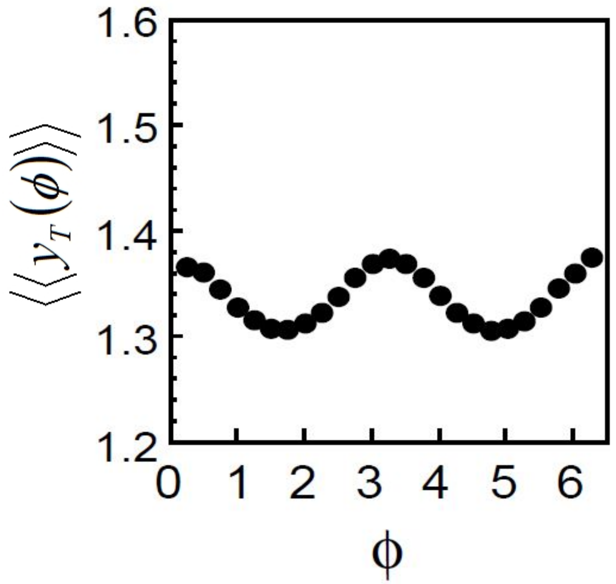
- **Azimuthal distribution of mean transverse rapidity presents the anisotropy of radial expansion.**

3. The physics of measured $d\langle\langle y_T \rangle\rangle / d\phi$

Mean transverse rapidity in an azimuthal angle bin:

$$\langle\langle y_T(\phi_m)\rangle\rangle = \frac{1}{N_{event}} \sum_{j=1}^{N_{event}} \left(\frac{1}{N_m} \sum_{i=1}^{N_m} y_{T,i}(\phi_m) \right)$$

AMPT with string melting for Au+Au coll. at 200GeV



It is well described by:

$$\boxed{\langle\langle y_T(\phi)\rangle\rangle = y_{T0} + y_{T2}\cos(2\phi)}$$

with $\boxed{y_{T0} = 1.3371 \pm 0.0001}$

Isotropic mean transverse rapidity:

isotropic expansion + thermal motion

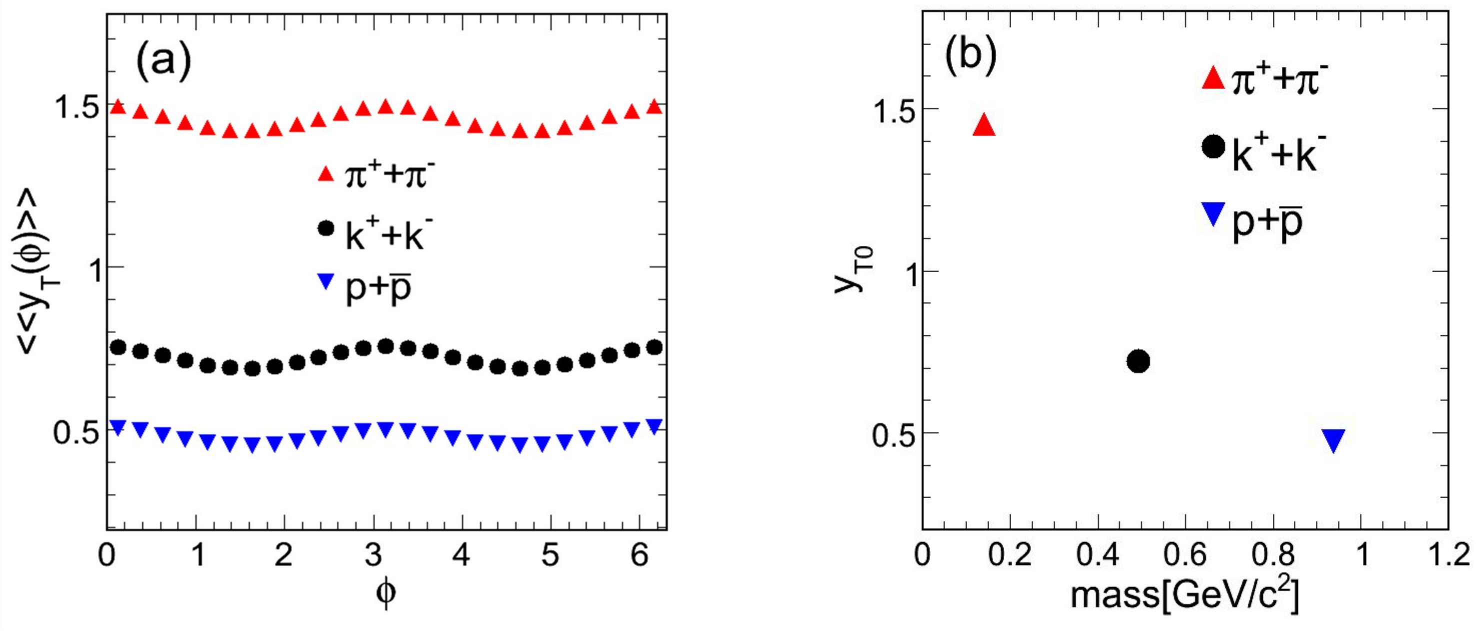
and $\boxed{y_{T2} = 0.0334 \pm 0.0002}$

anisotropy mean radial rapidity:

➔ **anisotropic rapidity.**

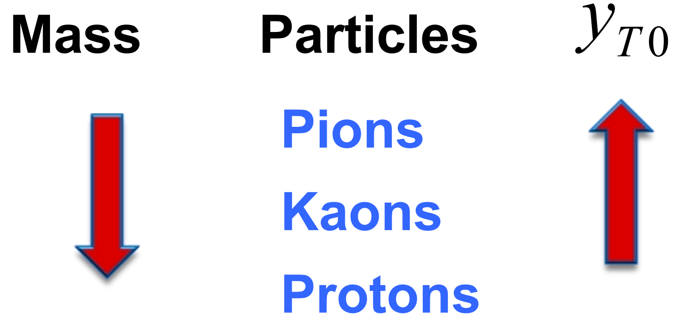
◆ Particle mass dependence of isotropic mean rapidity

AMPT with string melting for Au+Au coll. at 200GeV



Thermal motion: temperature
particle mass

At fixed T: lighter particle,
larger thermal velocity

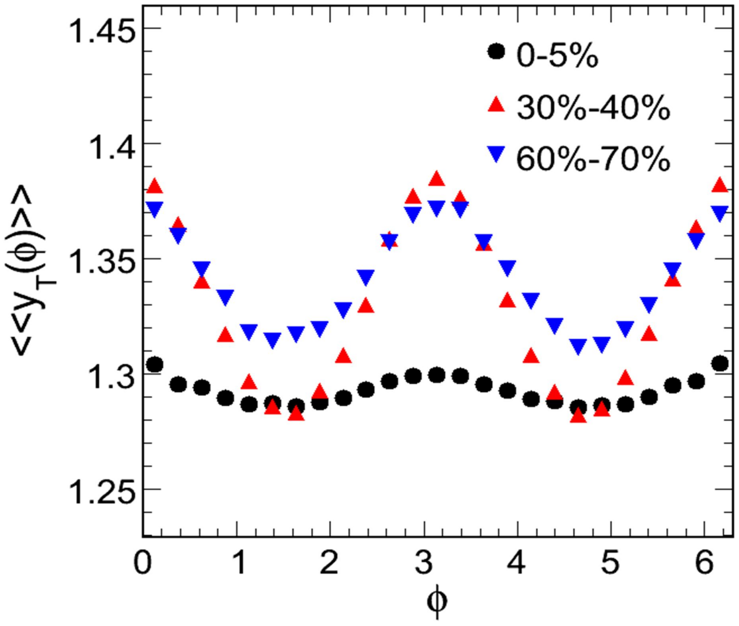


Mass	**Particles**	y_{T0}
↓	Pions Kaons Protons	↑

➢ **They are ordered as expected from random thermal motion !**

◆ Centrality dependence of measured distribution:

AMPT with string melting
for Au+Au coll. at 200GeV



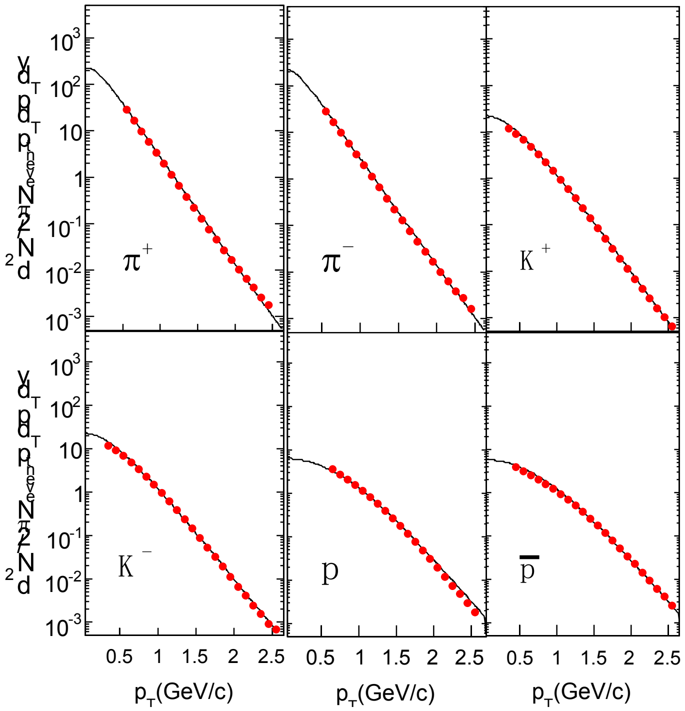
- The distribution is almost azimuthal angle independent in central collisions, but dependent in non-central coll.
- Large anisotropy in mid-central collisions, and small anisotropy in peripheral collisions.

- **Consistent with the fact that anisotropic expansion appears in non-central collisions, and is the largest in mid-central collisions !**

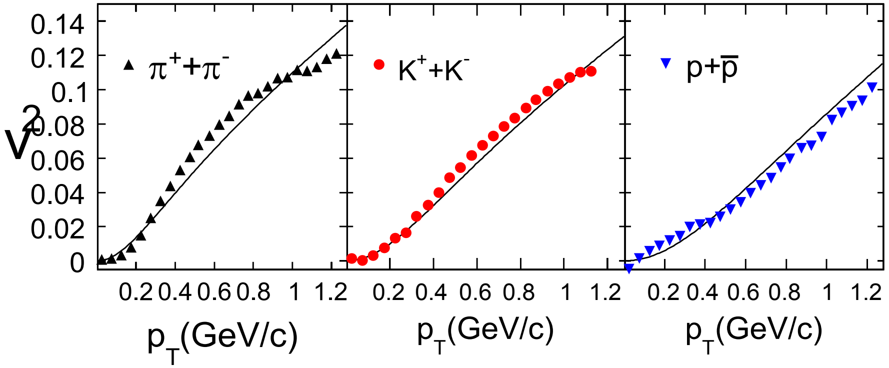
4.Extracted ρ_2 and measured y_{T2}

◆ **Extracted ρ_2 by blast-wave parameterization:**

Fitting p_t spectrum of 6 particles



Fitting differential elliptic flow



Extracted parameters:

$$T = 96.1 \pm 1.0$$

$$\rho_0 = 0.73 \pm 0.01$$

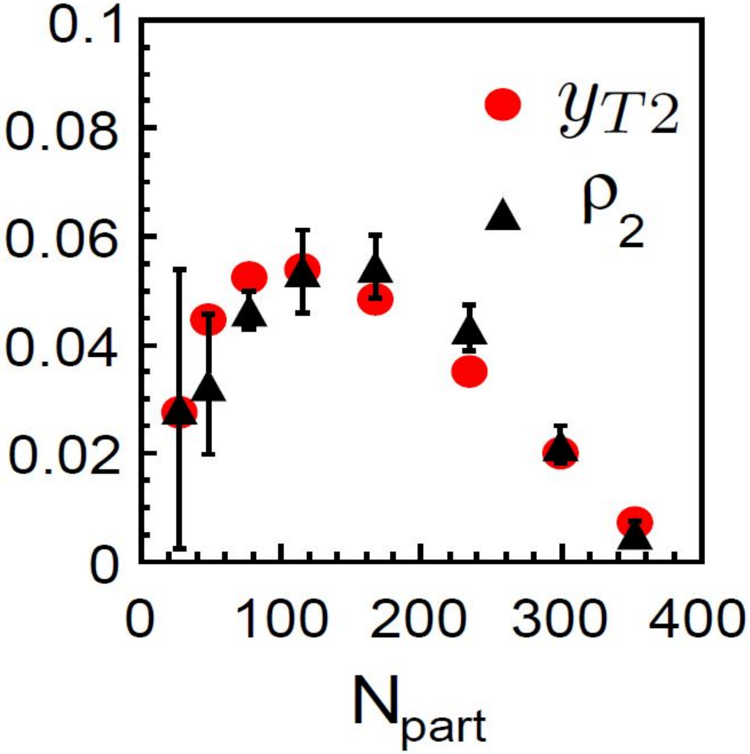
$$\rho_2 = 0.035 \pm 0.003$$

Measured: $y_{T2} = 0.0334 \pm 0.0002$

➢ **Extracted anisotropic rapidity parameter is consistent with measured anisotropic part of mean transverse rapidity!**

◆ Centrality dependence of extracted ρ_2 and measured y_{T2}

AMPT with string melting for Au+Au coll. at 200GeV



- At each of centrality, the extracted anisotropic radial flow parameter is close to that from measured anisotropic part of mean transverse rapidity.
- They show consistent centrality dependence.

- **So suggested measure provides a model independent way to get the anisotropic radial rapidity.**

5. Summary

- We suggest the measurement of azimuthal distribution of mean transverse rapidity.
- It consists of two parts: isotropic, and anisotropic mean transverse rapidity.

  Isotropic part: isotropic radial expansion + thermal motion

  Consistent with the mass ordering

  Anisotropic part: anisotropic radial expansion

  Centrality dependence is consistent with extracted anisotropic radial rapidity
- It provides a model independent way to get anisotropic rapidity parameter. It is helpful for hydrodynamic calculations.

Thanks !