# Measurement of radial flow in relativistic heavy ion collisions

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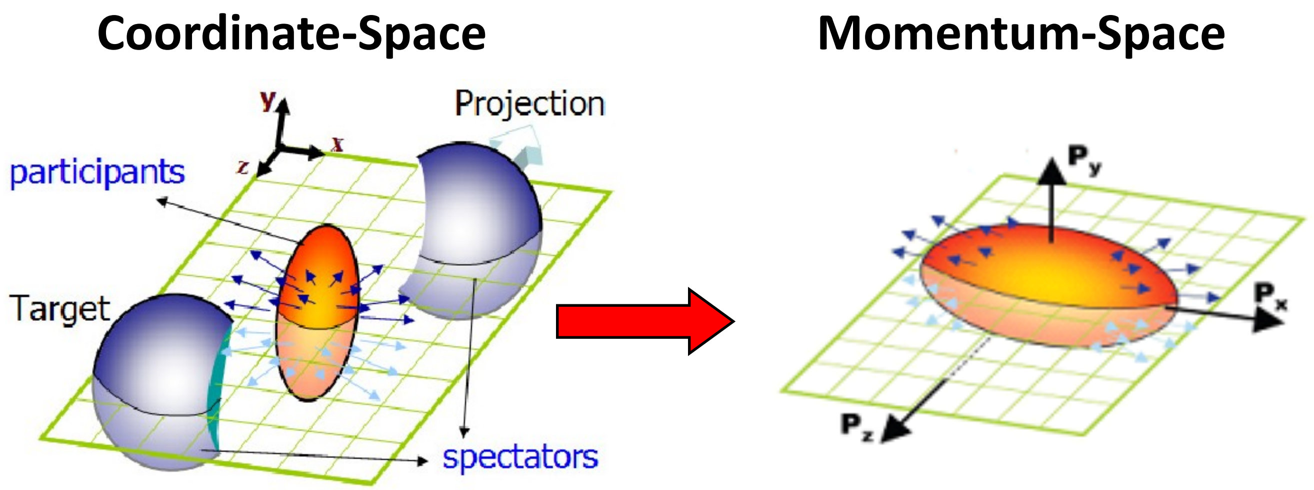
# Outline

1. Motivation
2. Azimuthal distributions
3. The features of the distributions
4. Summary

# 1. Motivation

◆ **Elliptic flow:**




**Azimuthal multiplicity distribution:**

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

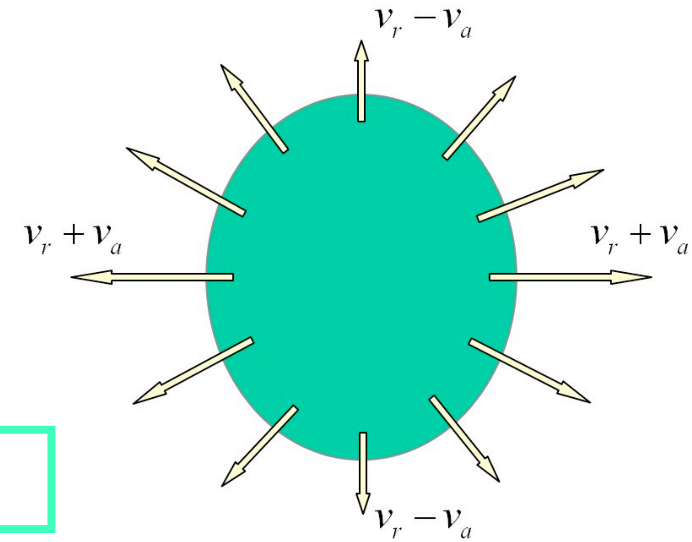
**Define elliptic flow:** $\boxed{v_2(N) = \langle \cos[2(\phi - \psi_r)] \rangle}$

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

## ◆ Radial expansion

3 velocities:

- Average radial expansion velocity
- Anisotropic velocity
- Thermal velocity




Radial expansion + Elliptic flow

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

P. Huovinen, P. F. Kolb, U. W. Heinz, P. V. Ruuskanen and S. A. Voloshin, Phys. Lett. B 503, 58

- ➢ Radial velocities are important parameters of hydrodynamic calculations !
- ➢ Anisotropic velocity directly relates to the shear viscosity.

# 2. Azimuthal distributions

## ✧ 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:

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

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

$N_m$ : total number of particles in the $m$th angular bin.

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

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

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

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

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

## ◆ Definitions of various flows:

**Azimuthal multiplicity distribution:**

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

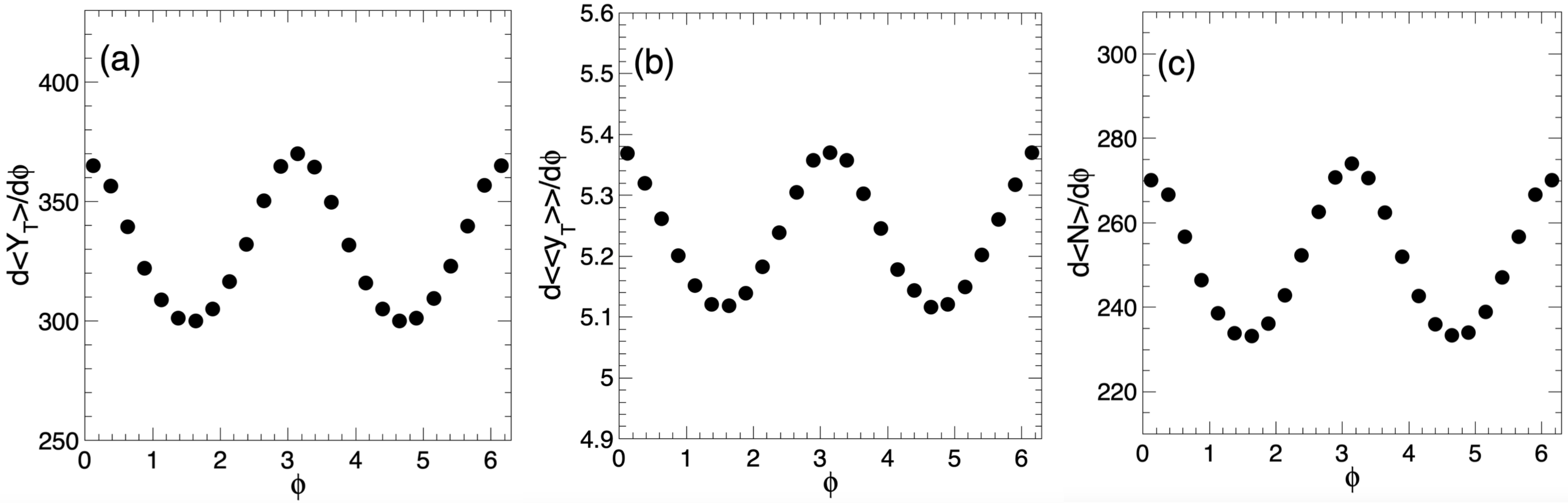
**Azimuthal total transverse rapidity distribution:**

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

**Azimuthal mean transverse rapidity distribution:**

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

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

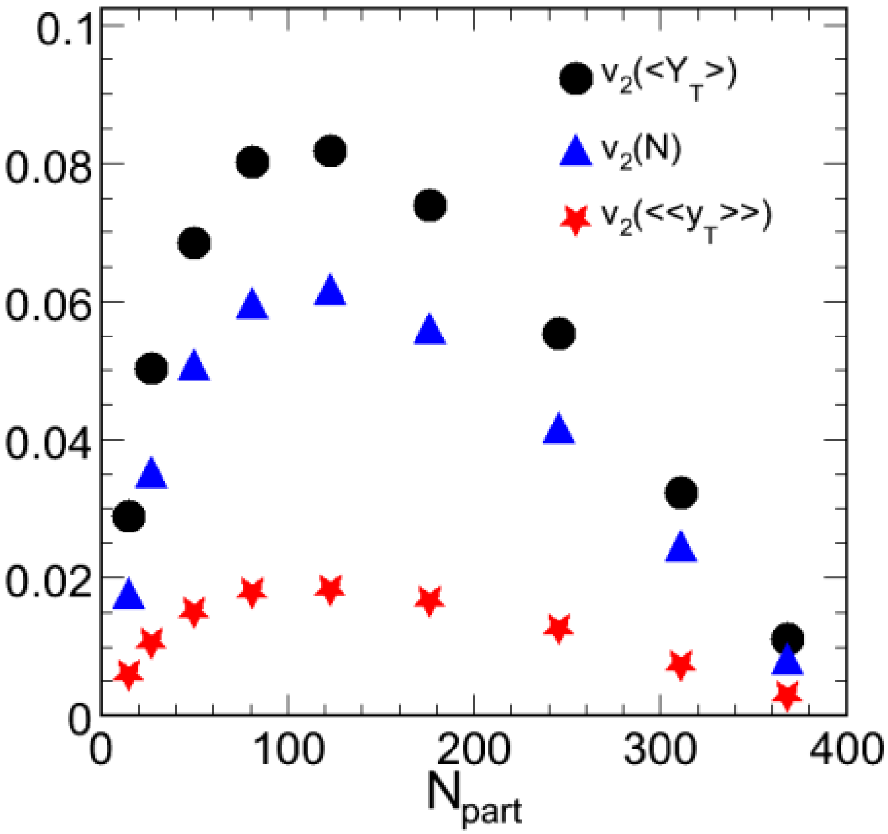



The azimuthal distributions of (a) total transverse rapidity, (b) mean transverse rapidity, and (c) multiplicity of minimum bias sample.

- Although their amplitudes are quite different, they are same periodic function.
- Their maximums and minimums appear in the in-plane and out-plan directions, respectively.
- It shows that the radial expansion has the same anisotropy as that of multiplicity distribution.

# 3.The features of the distributions

## ◆ Centrality dependence of various anisotropic flows



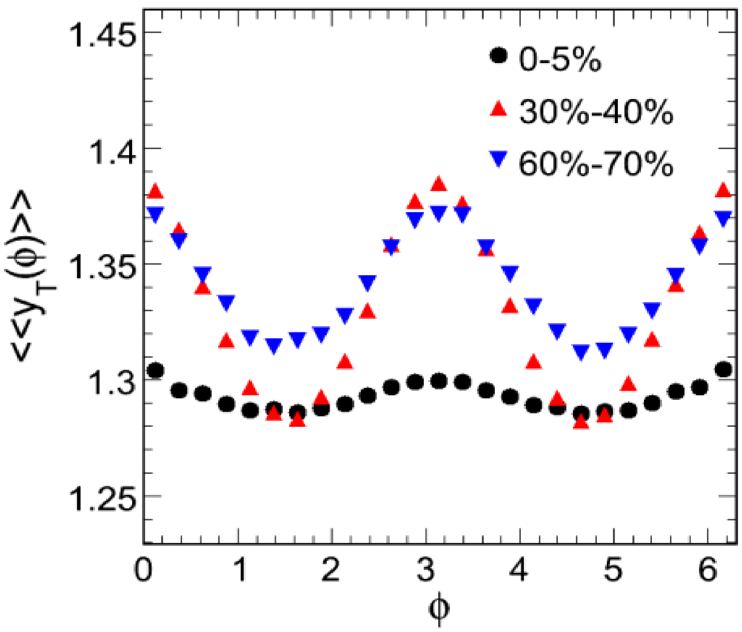

Peng Yang, Lin Li and Yuanfang Wu, arXiv:1405.0686v1

- 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 can present the anisotropy of radial expansion.**

## ◆ Centrality dependence of measured distribution:

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

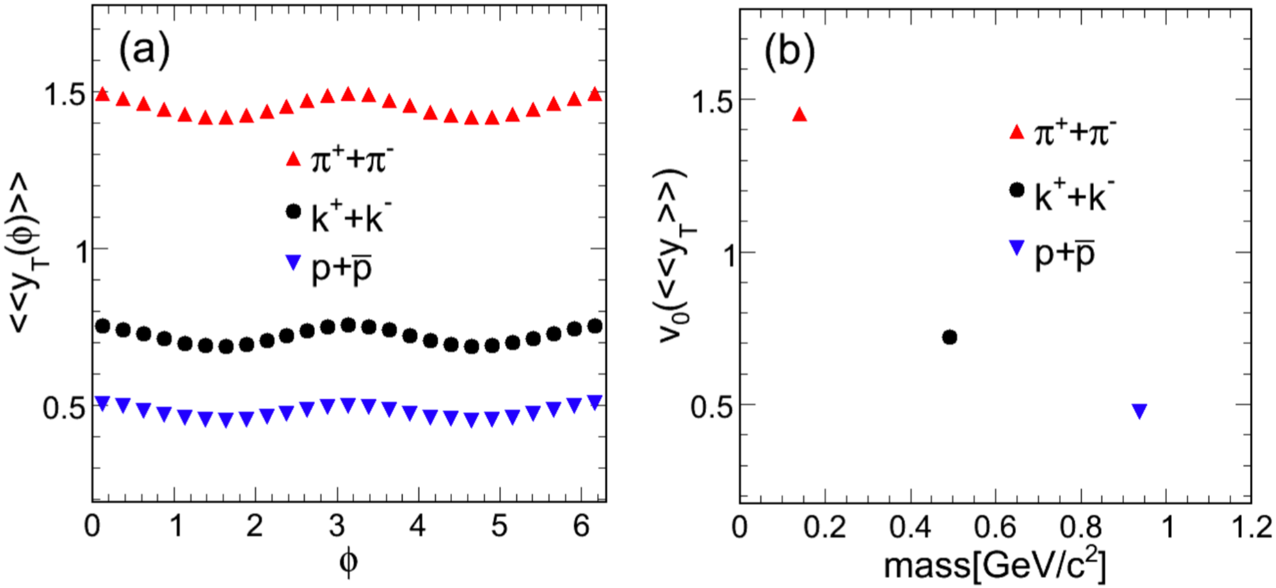



- The distributions is almost azimuthal angle independent in central collisions, but dependent in non-central coll.
- Large anisotropy in mid-central collisions, and small anisotropy in peripheral collisions.

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

## ◆ 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(MeV/$c^2$) | $y_{T0}$ |
| --- | --- | --- |
| ↓ | Pions(140) | ↑ |
| | Kaons(494) | |
| | Protons(938) | |

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

# 4. 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. It is helpful for hydrodynamic calculations, and a model independent determination of shear viscosity.