Measurement of collective flow
via Two-particle correlation method in $\sqrt{s_{NN}} = 200\text{GeV}$
$^3\text{He}+\text{Au}$ collisions at RHIC-PHENIX

筑波大学
数理物質科学研究科 物理学専攻
塩谷 知弘 for the PHENIX collaboration
Anisotropic Flow

In heavy ion collision, distribution of emitted particles is anisotropic in azimuthal direction.

**Anisotropic Flow**

**Probe sensitive to the properties of the system**

**Understanding QGP properties using hydrodynamics**

Distribution of emitted particles can be written as Fourier formula.

\[
\frac{dN}{d\phi} \propto 1 + \sum_n 2v_n \cos[n(\phi - \Psi_n)] \quad v_n = \langle \cos[n(\phi - \Psi_n)] \rangle
\]

**ψₙ**: Azimuthal angle of Event Plane

**Φ**: Azimuthal angle of emitted particles

**vₙ**: Flow harmonics (measured parameters)

Second order flow harmonics is known as **elliptic flow (v₂)**
Flow in small collision systems

The collective flow has not initially been expected in small collision systems.

Elliptic flow and long-range angular correlation structure have been observed in small systems at RHIC and LHC.

Measured $v_2$ is expected to include contributions of high momentum particles and elastic scattering. $\Rightarrow$ non-flow effect

How much do non-flow effects contribute to $v_2$ in small systems?

Motivation

(1) Measure $v_2$ by conventional method (two particle correlation method)
(2) Remove non-flow effect and measure $v_2$ (Future plan)
(3) Comparison between (1) and (2) (Future plan)
PHENIX (the Pioneering High Energy Nuclear Interaction eXperiment)

- **Central Arm Detectors (CNT)** \(|\eta| < 0.35\)
  - Particle identification, 3D tracking, momentum measurement

- **Forward Silicon Vertex Tracker (FVTX)** \(1.5 < |\eta| < 2.5\)
  - Silicon strip detector, it can track by detected points.

- **Beam Beam Counter (BBC)** \(3.0 < |\eta| < 3.9\)
  - BBC has 64 elements (PMT and quartz Cherenkov radiator) for each side.
  - Measured signals are used as Centrality, collision point, and Event trigger.
Two-particle correlation method and Event mixing

Correlation function is measured as the azimuthal pair distribution. $\phi_{\text{Trig.}}$ and $\phi_{\text{Asso.}}$ are azimuthal angle of trigger and associate particle.

$$\Delta \phi = \phi_{\text{asso}} - \phi_{\text{trig}}$$

Event mixing

$\Rightarrow$ Event mixing is done to reduce acceptance and efficiency.

$$C'(\Delta \phi) = \frac{S(\Delta \phi)}{B(\Delta \phi)} \cdot \frac{\int B(\Delta \phi) d\Delta \phi}{\int S(\Delta \phi) d\Delta \phi}$$

mix event: B

efficiency

(2 particle from other event)

real event: S

signal + efficiency

(2 particle from same event)
\( \nu_n \) extraction (Fourier fitting and 3-sub method)

- Fit correlation function with 4th Fourier formula and obtain \( C_n \)
  \[
  F(\Delta \phi) = N_0 (1 + \sum_{n=1}^{4} 2C_n \cos(n\Delta \phi))
  \]
- Obtained \( C_n \) can be written as below, \( \nu_n^a \) and \( \nu_n^b \) are \( \nu_n \) for each detectors.
  \[
  C_n = \nu_n^a \cdot \nu_n^b
  \]
- \( \nu_n \) parameters are extracted by 3-sub method with 3 type correlations.
  \[
  \nu_n^a = \sqrt{\frac{C_n^{ab} C_n^{ac}}{C_n^{bc}}}
  \]
  \[
  C_n^{ab} = \nu_n^a \cdot \nu_n^b
  \]
  \[
  C_n^{bc} = \nu_n^b \cdot \nu_n^c
  \]
  \[
  C_n^{ac} = \nu_n^a \cdot \nu_n^c
  \]
  \( a,b,c = \text{detectors} \)

In this analysis, used 3-sub combinations have symmetric eta-gap.

CNT-BBCs-BBCn
CNT-FVTXs(1-4)-FVTXn(1-4)
Correlation functions in CNT-BBCs-BBCn

\[ C_2(\Delta \phi) \]

| CNT - BBCn | 0-5% | 5-10% | 10-20% | 20-40% | 40-60% | 60%-
|------------|------|-------|--------|--------|--------|------
| \(^3\text{He-going}\) | ![Graph](image1.png) | ![Graph](image2.png) | ![Graph](image3.png) | ![Graph](image4.png) | ![Graph](image5.png) | ![Graph](image6.png)
| 2.65<\Delta \eta<4.25 | clearly difference at Central | ![Graph](image7.png) | ![Graph](image8.png) | ![Graph](image9.png) | ![Graph](image10.png) | ![Graph](image11.png)

\[ CNT \text{ pT 1.0- 2.0 GeV/C} \]

\[ \text{CNT pT 1.0- 2.0 GeV/C} \]

\[ \text{BBCs - BBCn} \]

\[ 6.0<\Delta \eta<7.8 \]

-4.25<\Delta \eta<-2.65

\[ \text{it is similar to south side} \]

\[ \text{data - Fourier} \]

\[ \text{almost no difference at peripheral} \]

\[ \text{Work in Progress} \]
$p_T$ Dependence of $v_2$ at $|\eta|<0.35$ (Centrality:0-5%)

- $v_2$ from this work is consistent with previous publication. (blue symbols, measured by Event plane method)
- Is the Usual Fourier $v_2$ extraction strongly biased by different eta-gap (and $p_T$)?
Reference fitting method

Reference fitting is done to reduce effect of non-flow and to elucidate centrality dependence of $v_2^{\text{Ref}}$. Distribution of non-flow effect should have constant parameters ($\varepsilon_2$, $v_2$...). Peripheral correlations are used as reference function.

$$C_{2\text{Cent}}(\Delta \phi) = \text{soft + non-flow}$$
$$C_{2\text{Ref}}(\Delta \phi) \simeq \text{non-flow}$$

A difference of $c_2(\Delta \phi)$ shape from reference function can be taken as evolution of $v_2, \text{ref}$.

$$F(\Delta \phi) = a \times C_{2\text{Ref}}(\Delta \phi) + b$$

$F(\Delta \phi)$ defined by peripheral event is subtracted from central correlation function. (peripheral v2 is subtracted.)

$$C_{2\text{sub}}(\Delta \phi) = C_{2\text{Cent}} - F(\Delta \phi) + 1$$

Fit subtracted correlation function with Fourier formula and extract $v_2^{\text{ref}}$ by 3-sub method.

$$F(\Delta \phi) = N_0(1 + \sum_{n=1}^{4} 2C_n \cos(n\Delta \phi))$$

$$v_n^{\text{Ref}} = \sqrt{\frac{C_n^{ab} C_n^{ac}}{C_n^{bc}}}$$
Comparison with reference function and $C_{2,\text{sub}}(\Delta \phi)$

BBCs - BBCn correlation

$F(\Delta \phi) = a \times C_{2\text{ref}}(\Delta \phi) + b$ — Reference function

Centrality 0 - 5% 5 - 10% 10 - 20% 20 - 40% 40-60% Ref. (>60%)

$C_{2\text{cent}}$ and $C_{2\text{ref}}$

Subtraction

$C_{2\text{sub}}(\Delta \phi) = C_{2\text{cent}} - F(\Delta \phi) + 1$

$v_2^{\text{Ref}}$ will be extracted with using subtracted correlations
Summary and Outlook

• $v_2$ via two-particle correlation method is consistent with previous publication.
• Is the Usual Fourier $v_2$ extraction strongly biased by different eta-gap (and pT)?
• After Reference Fitting,
  • Subtracted correlation functions show double peak.

Outlook
• Extract $v_2$ from subtracted correlation by Reference fitting
• Compare $v_2$ extracted by Reference fitting with previous results
Back up
Analysis flow

- 2 particle correlation
- event mixing

\[ C(\Delta \phi, \Delta \eta) = \frac{\int N_{\text{mix}} \Delta \phi \Delta \eta}{\int N_{\text{real}} \Delta \phi \Delta \eta} \frac{N_{\text{real}}(\Delta \phi, \Delta \eta)}{N_{\text{mix}}(\Delta \phi, \Delta \eta)} \]

- Fit by Fourier function.
- Obtain Fourier coefficients \( C_n \)

\[ F(\Delta \phi) = N_0 (1 + \sum_{n=1}^{4} 2C_n \cos(n\Delta \phi)) \quad C_n = v_n^a \times v_n^b \]

- Calculate \( v_n \) by 3-sub method

\[ v_n^a = \sqrt{\frac{C_n^{ab} C_n^{ac}}{C_n^{bc}}} \]

3-sub combinations

**CNT - south - north** (symmetric eta gap)
Data Set

RHIC-PHENIX Run14 $^3$He+Au collisions $\sqrt{S_{NN}} = 200$GeV

**Event Cut**: BBC$_z \neq 0.0$, $|BBCz| < 10$ [cm], $|BBCz - FVTXz| < 2.0$cm

**Centrality**: BBCsouth multiplicity (MB+High-Mul.Trig)

**Detectors**
- CNT($|\eta|<0.35$) BBC($3.0<|\eta|<3.9$)
- FVTX($1.5<|\eta|<2.5$): FVTX tracks are divided to 8 region by eta (0.25 step)

**Event Mixing Class**
- 10 classes about BBCz
- 6 classes about centrality
  (0-5, 5-10, 10-20, 20-40, 40-60, 60-%)
Track cut

- **CNT Track**
  0.2 < mom< 5.0 , |pc3dphi|<3σ , |pc3dz|<3σ (tracking quality = 31 or 63) , |zed|<70

- **BBC PMT**
  cut hit time >0, charge >0

- **FVTX track**
  $\chi^2 < 5.0$, nhits $\geq 3$
  $\sqrt{(\sigma_{DCA_x}^2 + \sigma_{DCA_y}^2)} < 2.0$;

  **Eta acceptance cut**
  -0.025*BBC$_Z$ - 2.45 < $\eta$ < -0.025*BBC$_Z$ - 1.5
  -0.025*BBC$_Z$ + 2.45 > $\eta$ > -0.025*BBC$_Z$ + 1.5
$p_T$ Dependence of $v_2^{\text{Fourier}}$ (Cent:0-5%)