Elliptic flow of identified particles in Au + Au collisions at $\sqrt{s_{NN}} = 14.6$ GeV in BESII

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CPOD 2022 - Critical Point and Onset of Deconfinement
Outline

• Motivation
• Experimental Setup
• Analysis Method
• Results and Discussion
• Summary
Motivation

Initial spatial anisotropy in coordinate space exists in non-central heavy-ion collisions.

Pressure gradient and interaction among constituents lead to conversion from initial spatial anisotropy to final momentum-space anisotropy.

Elliptic flow is sensitive to the degree of freedom and thermalization of the medium

\[ E \frac{d^3N}{d^3p} = \frac{1}{2\pi p_T dp_T dy} \left( 1 + \sum_{n=1}^{\infty} 2v_n \cos(n(\phi - \psi_{RP})) \right) \]

\[ v_2 = \langle \cos(2(\phi - \psi_{RP})) \rangle \]

The artistic view of the STAR detector

**Time Projection Chamber (TPC)**

- Particle identification from ionization energy loss \( dE/dx \)
- Charged Particle Tracking

**Time-of-Flight (TOF)**

- Particle identification using \( m^2 \)
Event Plane Method

\[
E \frac{d^3 N}{d^3 p} = \frac{1}{2\pi p_T dp_T dy} \left( 1 + \sum_{n=1}^{\infty} 2\nu_n \cos(n(\phi - \Psi_{RP})) \right)
\]

Sub-event method:

\[
\begin{align*}
q_x &= \sin(n\phi_i) \\
q_y &= \cos(n\phi_i)
\end{align*}
\]

\[
\begin{align*}
Q_{n,x} &= \sum_i w_i \cos(n\phi_i) = Q_n \cos(n\Psi_n) \\
Q_{n,y} &= \sum_i w_i \sin(n\phi_i) = Q_n \sin(n\Psi_n)
\end{align*}
\]

Shift: \( n\Delta\psi_{n,\text{shift}} = \sum_{i=1}^{\text{im}_\text{ax}} \frac{2}{i} \left( \langle \sin(i\psi_{n,rc}) \rangle \cos(i\psi_{n,rc}) + \langle \cos(i\psi_{n,rc}) \rangle \sin(i\psi_{n,rc}) \right) \)

Recentering:

\[
Q_{x,n,rc} = \sum_i (q_{n,i,x} - \langle q_x \rangle), \quad \Psi_{n,rc} = \frac{1}{n} \left[ \tan^{-1} \left( \frac{Q_{x,n,rc}}{Q_{y,n,rc}} \right) \right],
\]

\[
Q_{y,n,rc} = \sum_i (q_{n,i,y} - \langle q_y \rangle),
\]

A uniform event plane distribution obtained by recentering and shift calibration
The observed $v_2$ corrected by event plane resolution
π and K Identification

1.8<p_T<2.0 GeV/c, 0-80%

Shift and scale:

\( (\mu_\pi(n\sigma_\pi), \mu_\pi(m^2)) = (0, 0.019) \)

\[ f_{scale} = \sigma_\pi(n\sigma_\pi/n\sigma_\pi(m^2)) \]

\[ \alpha = -\tan^{-1}\left(\frac{y_k}{x_k}\right) = -\tan^{-1}\left(\frac{\mu_k(m^2) - \mu_\pi(m^2)}{\mu_k(n\sigma_\pi) - \mu_\pi(n\sigma_\pi) \ast f_{scale}}\right) \]

Rotation:

\[
\begin{pmatrix}
    x' \\
    y'
\end{pmatrix} = \begin{pmatrix}
    \cos \alpha & -\sin \alpha \\
    \sin \alpha & \cos \alpha
\end{pmatrix} \begin{pmatrix}
    x \\
    y
\end{pmatrix} = \begin{pmatrix}
    \cos \alpha & -\sin \alpha \\
    \sin \alpha & \cos \alpha
\end{pmatrix} \begin{pmatrix}
    n\sigma_\pi \ast f_{scale} \\
    m^2 - \mu_\pi(m^2)
\end{pmatrix}
\]

2022/ 11/ 30

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The goal of this transformation is to have a maximal separation between pion and kaon distribution.

Projection on x-axis of 2D distribution after excluding proton contamination

Using the student-t function to fit the distribution
Proton Identification

Protons are identified by $m^2$ up to $p_T$ 3.2 GeV/c

Systematic Uncertainties

We use the maximum deviation from default value and assume these sources are uncorrelated for nHitsFit, dca, nσ

\[ sys_{total} = \sqrt{(y_{dca} - y_{def})^2 + (y_{nHit} - y_{def})^2 + (y_{n\sigma} - y_{def})^2} \]

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<thead>
<tr>
<th>Cuts</th>
<th>Default</th>
<th>var1</th>
<th>var2</th>
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<tr>
<td>nHitsFit(&gt;)</td>
<td>15</td>
<td>12</td>
<td>18</td>
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<tr>
<td>Dca(&lt;)</td>
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<td>0.7</td>
<td>1.3</td>
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<tr>
<td>nσ_{particles}</td>
<td>2.5</td>
<td>2</td>
<td>3</td>
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Comparison to BESI

The results are consistent with BESI
The statistical errors are reduced by a factor of ~3 compared to BES-I
Centrality Dependence of $v_2$

Clear centrality dependence: $v_2$ driven by initial anisotropy of the participants
Proton $v_2 >$ anti-Proton $v_2$
Centrality Dependence of $v_2$

Clear centrality dependence: $v_2$ driven by initial anisotropy of the participants $v_2$ difference between particles and anti-particles observed
NCQ Scaling: Centrality Dependence

Fit function: \( f(x) = \frac{a}{1.0 + \exp\left(-\frac{x-b}{c}\right)} - d \)

NCQ scaling holds at 20% level except low \( p_T \) anti-proton and anti-\( \Lambda \)

P. Dixit, Wed, 11/30 for strangeness
NCQ Scaling: Centrality Dependence

NCQ scaling holds at 20% level

NCQ scaling works in all centralities
Centrality dependence $v_2$ of pions, kaons and protons at 14.6 GeV

The statistical errors are reduced by a factor of ~3 compared to BES-I

$v_2$ is driven by initial geometry of participants

NCQ scaling test at 14.6 GeV

Scaling holds for light, strange and multi-strange particles within 20%

Medium produced at 14.6 GeV

Partonic collectivity is built-up

Thank you!