Higher harmonic flow of $\phi$ meson in STAR at RHIC

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OUTLINE:

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✓ STAR Detector and Data set
✓ Analysis Method
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Introduction: Azimuthal anisotropy

Azimuthal anisotropy is a phenomenon observed in high-energy particle collisions, where the particles produced tend to be emitted in specific azimuthal directions. The azimuthal angle, denoted by $\psi_R$, is the angle of the reaction plane (spanned by impact parameter and beam direction) with respect to the beam axis. The particle distribution in the pseudorapidity $\eta$ and azimuthal angle $\phi$ is described by the reaction plane direction $\psi_R$. The anisotropy coefficients $v_2$, $v_3$, and $v_4$ are called elliptic, triangular, and quadrangular flow, respectively.

The probability distribution of particles with respect to the azimuthal angle $\phi$ can be expressed as:

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

where $\phi = \tan^{-1}\left(\frac{p_y}{p_x}\right)$ and $v_n = \langle \cos[n(\phi - \psi_R)] \rangle$.

- $\psi_R$ is the azimuthal angle of the reaction plane (spanned by impact parameter and beam direction).
- $v_2$, $v_3$, and $v_4$ are called elliptic, triangular, and quadrangular flow.


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Motivation

- $\phi$ meson has small hadronic interaction cross section. Thus $\phi$ meson $v_n$ is less affected by later stage hadronic interaction. Hence $\phi$ meson is a clean probe to study the medium created in the early stage of collisions.

- The ratios between various harmonics can be used to understand the properties of the system created in heavy-ion collisions.

**Coalescence Model**

$$\frac{v_{4,M}(2p_T)}{v_{2,M}(2p_T)} \approx \frac{1}{4} + \frac{1}{2} \frac{v_{4,q}(p_T)}{v_{2,q}(p_T)}$$

Where $v_{n,q}(p_T) = kv_{n/2,q}(p_T)$

If $k=1$

$$\frac{v_{4,M}(2p_T)}{v_{2,M}(2p_T)} \approx 0.75$$

**Hydro Model**

$$\frac{v_4}{v_2} = 0.5$$

$$\frac{v_3}{v_2} = \text{Constant at high } p_T$$


*J. Adams et al. (STAR Collaboration), Nucl. Phys. A 757, 102 (2005).*


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**Data Set**  |  **Vertex Cut**  |  **Trigger**  |  **No. of events**  
--- | --- | --- | ---  
AuAu 200 GeV (Run 11)  | \(|V_z| < 30 \text{ cm}\)  | MinBias  | 560 Million  

Magnetic field 0.5 Tesla  
Full azimuthal coverage (0, 2\(\pi\))  
\(|\eta| < 1.0\) for TPC and \(|\eta| < 0.9\) for TOF
Particle Identification with STAR TPC and TOF

- **TPC**
  - Full azimuthal coverage (0, 2π)
  - Identifies kaon upto p = 0.65 GeV/c
  - **Bethe Bloch Formula**
    \[
    -\left\langle \frac{dE}{dx} \right\rangle \sim A \left( 1 + \frac{m^2}{p^2} \right)
    \]
  - Particle identifies using
    \[
    N\sigma = \frac{1}{R} \times \log \left( \frac{dE/dx_{measured}}{dE/dx_{theory}} \right)
    \]

- **TOF**
  - Full azimuthal coverage (0, 2π)
  - Kaon can be identified for p > 0.65 GeV/c
  - **Time of Flight**
    \[
    \langle t \rangle = \frac{L}{\beta} \quad \frac{1}{\beta} = \sqrt{1 + \frac{m^2}{p^2}}
    \]


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Event Plane Resolution

- Event Plane defined as:
  \[ \Psi_n = \left( \tan^{-1} \left[ \frac{\sum_i w_i \sin(n\phi_i)}{\sum_i w_i \cos(n\phi_i)} \right] \right) / n \]

- Event Plane angle calculated in two different windows ‘west’ (\( \eta > 0.075 \)) and ‘east’ (\( \eta < -0.075 \))

- Event Plane Resolution then given by:
  \[ R = \sqrt{< \cos[n(\Psi_n^{\text{west}} - \Psi_n^{\text{east}})]}> \]

- Event- by- event resolution correction
  \[ \langle v_n \rangle = \langle \frac{v_{n,\text{obs}}}{R} \rangle \]

- $\phi$ meson decay -> $K^+K^-$ (B.R 48.9 %)
- Background reconstructed from mixed events
- $\phi$ signal is fitted with BW +1\textsuperscript{st} order polynomial

$\langle \cos(n(\Phi - \Psi)) \rangle$

$= \frac{v_{n}^{Sig}}{Sig + Bg} (m_{inv}) + \frac{v_{n}^{Bg}}{Sig + Bg} (m_{inv})$

$\chi^2 / ndf = 95.67 / 105$

$v3 = 0.0199 \pm 0.0032$
$p1 = 0.003943 \pm 0.000109$
$p2 = 0.02477 \pm 0.00111$
$p3 = 0.01239 \pm 0.00150$
$p4 = -0.02408 \pm 0.00086$

$\frac{\text{Counts}}{1 \text{ MeV}}$

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The magnitude of $v_2(\psi_2)$ is greater than $v_3(\psi_3)$ and $v_4(\psi_4)$ for all centralities.

- $v_n$ increases with $p_T$ and has a maximum value in 2-3 GeV/c.
\( v_n : \) Centrality dependence

- \( v_2(\psi_2) \) shows strong centrality dependence
- No centrality dependence for \( v_3(\psi_3) \) and \( v_4(\psi_4) \) within statistical uncertainties
The $v_3/v_2$ ratio is constant for $p_T > 1.5$ GeV/c.
$v_4/v_2^2$ vs $p_T$

$0$-$80\%$

$v_4(\psi_4)/v_2^2 = 1.90 \pm 0.37$

$0$-$30\%$

$v_4(\psi_4)/v_2^2 = 2.84 \pm 0.60$

$30$-$80\%$

$v_4(\psi_4)/v_2^2 = 0.56 \pm 0.42$
Summary

- We have presented $v_3(p_T)$ and $v_4(p_T)$ of $\phi$ meson in Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV.
- $v_n$ increases with $p_T$ and has a maximum value in 2-3 GeV/c.
- No centrality dependence for $v_3(\psi_3)$ and $v_4(\psi_4)$ within statistical uncertainties.
- $v_3/v_2$ and $v_4(\psi_4)/v_2^2$ ratios are calculated in Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV.
- $v_3/v_2$ ratio is constant for $p_T > 1.5$ GeV/c.
Thank you
Back up Slides

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• Corrected by Recentre + Shift method
• Fitted with $p0(1+p1\cos[n\Psi_n] + p2\sin[n\Psi_n])$
• $\eta$ gap between east & west event plane is 0.1