Two particle correlations with respect to higher harmonic plane in Au+Au 200 GeV collisions at RHIC-PHENIX

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Outline

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   ✓ Higher harmonic event plane ($\Phi_n$) & flow ($v_n$)
   ✓ Backgrounds from $v_n$ in correlations
   ✓ $v_n$ subtracted correlations

2. Physics Motivation

3. Analysis Overview

4. Results
   ✓ $\Phi_2$ & $\Phi_3$ dependence

5. Summary
Higher harmonic event plane & flow

- Previous picture; Assumed a “reaction plane” defined by impact parameter vector and beam axis vector
- Recent picture; Higher harmonic deformation due to fluctuations of collision geometry
  - Deformation transferred to momentum space by collective expansion \( \rightarrow \) higher harmonic flow \( v_n \)

\[
\frac{dN}{d\phi} \propto 1 + 2v_2 \cos 2(\phi - \Phi_2) + 2v_3 \cos 3(\phi - \Phi_3) + 2v_4[\Phi_4] \cos 4(\phi - \Phi_4)
\]
Backgrounds from $v_n$ in 2 particle correlations

$$Jet(\Delta \phi) = CF(\Delta \phi) - b_0 Flow(\Delta \phi)$$

- Backgrounds from $v_n$ (especially $v_3$) subtraction reduce “Ridge” and “Shoulder”
- $v_n$ subtractions help to see more “real” correlation shape

Ridge: near side long range $\Delta \eta$ correlations

Shoulder: double hump at away side of $\Delta \phi$ correlations (also long in $\Delta \eta$)

Jet($\Delta \phi$) = $C_F(\Delta \phi) - b_0 Flow(\Delta \phi)$

$\sim b_0 2 v_n^{trig} v_n^{asso} \cos n \Delta \phi$
\( v_n \) subtracted correlations

- Shoulder is described by \( v_n \) in central collisions
- Shoulder is still seen in mid-central collisions

Au+Au\( \sqrt{s_{NN}} = 200\text{GeV} \)
h\(^+\)-h\(^-\): \( p_t = 2-4 \odot 1-2 \text{ GeV} \)
Sliced within |\( \Delta \eta \)|<0.7

\[ V_2 \text{ & } V_4(\Phi_2) \text{ ZYAM subtracted} \]
Physics Motivations

- $v_n$ subtracted correlations still show double-hump structure in ways side in mid-central collisions
  - Average of jets flying to various direction in bulk
- Detailed survey of away side peaks
  - Two particle correlations with trigger selection relative to $\Phi_2$ & $\Phi_3$
    - Modification of away side w.r.t. $\Phi_2$ & $\Phi_3$
    - Difference between $\Phi_2$ & $\Phi_3$
Analysis Overview

- $v_n$ measurements
  - Forward Event Plane ($RXN$) - Charged Hadrons in mid-rapidity
    - To exclude autocorrelations by jet
- Selection of Trigger Directions
  - Forward Event Plane ($RXN$)-Charged Hadron Trigger in mid-rapidity
- 2 particle charged hadron correlations in azimuth
  - Mid-rapidity Trigger – Mid-rapidity Associate, $p_T: 2-4 \& 1-2$ [GeV/c]
- Subtract $v_n$ modulated backgrounds by ZYAM Method
**$\Phi_2$ dependent correlations**

- **Two competitive effects**
  - Away-side peak shift to in/out of plane with in/out of plane trigger

Flow subtracted yield is shown radially with base line.

Trigger angle selection w.r.t. $\Phi_2$ for left(up) / right(down)

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200GeV Au+Au -> h-h, 20-50% ($p_T^{\text{Trig}}=2\sim4$, $p_T^{\text{Asso}}=1\sim2\text{GeV/c}$)

$v2$, $v3$ & $v4\{\Phi_4\}$ subtraction

PHENIX work in progress
\( \Phi_3 \) dependence before \( v_n \) subtractions

- Subtraction shows no evident dependence
- Difference b/w \( \Phi_2 \) & \( \Phi_3 \)
  - \( \Phi_2 \) dominated by almond shape
  - \( \Phi_3 \) dominated by fluctuations
  - Would be related to differences
Summary

• Measured two particle correlations with trigger selection relative to $\Phi_2$ & $\Phi_3$

• $\Phi_2$ dependent correlations show two competitive effects
  ✓ Away-side peak shift to in/out of plane with in/out of plane trigger

• $\Phi_3$ harmonic plane dependence wouldn’t be seen
  ✓ $\Phi_2$ dominated by almond shape
  ✓ $\Phi_3$ dominated by fluctuations
Back Up Slides
Charged hadron $v_n$ Centrality and $p_T$ dependences

- $v_3$ is comparable to $v_2$ at 0~10%
- $v_2$ rises up when centrality goes up, but $v_3$ hardly does
- $v_4\{\Phi_4\} \sim 2 \times v_4\{\Phi_2\}$
Degeneracy among models disentangled by $v_3$

- $v_3$ seems to prefer low viscosity
  - Glauber + $4\pi\eta/s = 1$ works better
  - CGC-KLN + $4\pi\eta/s = 2$ failed

- $v_n$ provides more constraints to hydrodynamics calculations
Compare with the Event Plane method

QM2011, ATLAS

ATLAS Preliminary 1-2 GeV
\[ \int L dt = 8 \mu b^{-1} \]
Stat. Error only

\[ V_n \]

2-3 GeV

Open Symbols: correlation method for fixed-p_T and 2<|\Delta\eta|<5.
Solid Symbols: full FCal EP method for |\eta|<2.5

Consistent between the 2PC and full FCal EP method (Similar for FCal_{P(N)}).
Fourier decomposition of flow subtracted correlations

\[ \text{Au+Au} \sqrt{S_{NN}} = 200 \text{GeV}, \ h^+ - h^- \text{ correlations at } |\Delta \eta| < 0.7, \ p_T: 2-4 < 1-2 \text{GeV} \]

\[ J(\Delta \phi) = \sum_{n=0}^{9} J_n \cos(n^+ \Delta \phi) \]

- \( J_n: \text{ZYAM v2 v4(} \Phi_2 \text{) subtracted} \)
- \( J_n: \text{ZYAM v2 v3 v4(} \Phi_4 \text{) subtracted with } <\cos(4(} \Phi_4 - \Phi_2 \text{))> = {v4(} \Phi_2 \text{)}/v4(} \Phi_4 \text{) } \)

\[ J_n \]

\[ n \text{ th order harmonic} \]
\( \Phi_2 \) dependence with \( v_2 \) & \( v_4(\Phi_2) \) subtraction

200GeV Au+Au -> h-h (run7) \( (p_T^{\text{Trig}}=2-4\text{GeV/c, } p_T^{\text{Asso}}=1-2\text{GeV/c}) \)

- out-of-plane
  - \( \phi_s=[3,4]\pi/8 \)
  - \( \phi_s=[-4,-3]\pi/8 \)

- in-plane
  - \( \phi_s=[2,3]\pi/8 \)
  - \( \phi_s=[-3,-2]\pi/8 \)
  - \( \phi_s=[1,2]\pi/8 \)
  - \( \phi_s=[-2,-1]\pi/8 \)
  - \( \phi_s=[0,1]\pi/8 \)
  - \( \phi_s=[-1,0]\pi/8 \)

average

mid-central: 20-50%
Trigger dependence relative to event plane

200GeV Au+Au -> h-h, 20-50%
($p_T^{\text{Trig}}=2\sim 4$, $p_T^{\text{Asso}}=1\sim 2\text{GeV/c}$)

$v_2, v_4 \{\Phi_2\}$ only subtraction

PHENIX preliminary

Trigger angle selection w.r.t.
$\Phi_2$ separately for
left(up) / right
(down)

Trigger angle selected 2-part.
corr. data are
plotted in polar
coordinate by
rotating $\Phi_2$ R.P.
angle as X-axis.

Flow subtracted
yield is shown
radially with base
line.

RHIC-PHENIX
Flow plenary
S.E.

Two competing processes seen
\( \Phi_2 \) dependence with \( v_2 \) & \( v_3 \) & \( v_4 \) subtraction

200GeV Au+Au \( \rightarrow \) h-h, 20-50% 
\( (p_T^{\text{Trig}}=2\sim4, \ p_T^{\text{Asso}}=1\sim2\)GeV/c) 
\( v2,v3,v4\{\Phi_4\} \) subtraction

PHENIX Work in progress

\[
\frac{1}{N_{\text{trig}}} \frac{dN_{\text{pair}}}{d\Delta \phi}
\]

\( \Delta \phi \) [rad]
Au+Au, $\sqrt{s_{\text{NN}}}=200\text{GeV}$, $h^+-h^-$ $C_2$ & Flow with respect to $\Phi_3$ at $|\Delta\eta|<0.7$, $p_T$:2-4$\oplus$1-2GeV, Cent.0-10%