PHENIX results on flow observables in asymmetric Cu+Au collisions

Brennan Schaefer for the PHENIX Collaboration
Vanderbilt University
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Collision Systems at BNL-RHIC

- Au+Au
- p+p
- d+Au
- Cu+Cu
- U+U
- Cu+Au
- He+Au
- p+Au
- p+Al

PHENIX data in this analysis

- Run 12 (2012)
- 200 GeV
- 5 weeks
- 7.6 B events
- $|\eta| < 0.35$
anisotropic flow harmonics – event plane method

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

\[v_n = \left\langle \cos[n(\phi - \psi_n)] \right\rangle\]
anisotropic flow harmonics – event plane method

- reflect properties of initial state and evolution
- probe different length scales
- sensitive to EoS and $\eta/s$
tracks reconstructed with DC and matched to PC3, EMCal

**PID**: TOFE, TOFW

ψ₁ - Shower Maximum Detector spectator plane

ψ₂,₃ - Beam Beam Counter participant plane
\( \nu_1 \) sign conventions used

- \( \nu_1 \) is defined to be positive at positive \( \eta \) (Cu-going)
- \( x \) is positive if spectators flow outwards
- measurements use Au spectators, signs are flipped
event plane resolution

three sub-event method used to determine the resolution:

\[
\text{Res}(\Psi_n^A) = \sqrt{\frac{\langle \cos n (\Psi_n^A - \Psi_n^B) \rangle \langle \cos n (\Psi_n^A - \Psi_n^C) \rangle}{\langle \cos n (\Psi_n^B - \Psi_n^C) \rangle}}
\]

\[\Psi_1 : \text{SMDS, } \Psi_{2,3} : \text{BBCS+BBSN}\]
centrality dependence

$\mathbf{v_1}$ magnitude decreases

$\mathbf{v_2}$ magnitude increases
centrality dependence

$\nu_3$
weak
dependence

$\nu_2$
magnitude
increases
$v_2$ system size dependence

Cu+Au falls between Cu+Cu and Au+Au
$v_2$ ($\varepsilon_2$ scaled)

$\varepsilon_2$ scaling reorders the results by system size
$v_2 \left( \varepsilon_2 N_{\text{part}}^{1/3} \right.$ scaled $)$

universal behavior in all centralities and systems:
Cu+Cu, Cu+Au, Au+Au
for the same centrality Glauber-$\varepsilon_3$ is larger in the smaller system due to increased fluctuations
$v_3$ system size dependence

$\nu_3 \text{ Cu+Au} > \nu_3 \text{ Au+Au}$
$v_3 \ (\varepsilon_3 \text{ scaled})$

close agreement at low-intermediate $p_T$
within systematics at high $p_T$
$v_3 \ (\varepsilon_3 N_{\text{part}}^{1/3 \text{ scaled}})$

agreement within systematics at all $p_\text{T}$
identified particle $v_2$

mass ordering at low $p_T$ for $v_2$
identified particle $v_{1,3}$

mass ordering at low $p_T$ for $v_{1,3}$
comparison to viscous hydro

\[ |\eta| < 0.35 \quad \text{and} \quad |\eta| < 1.0 \]

indirect comparison shows qualitative agreement, assuming spectators curl outward from the z-vertex
comparison to viscous hydro

$v_2$

$v_3$
comparison to AMPT

$V_2$

$V_3$
conclusions

- in Cu+Au the magnitude of $v_1$ decreases from central to peripheral, opposite to $v_2$ behavior
- $v_{2,3}$ in different systems scale with $\varepsilon_{2,3} N_{\text{part}}^{1/3}$
- mass ordering is seen for all harmonics
- $v_{2,3}$ is consistent with viscous hydro $\eta/s = (1-2)/4\pi$
- AMPT with $\sigma = 3.0$ mb describes $v_{2,3}$ for $p_T < 2$ GeV
Number of participant and the participant eccentricity ($\varepsilon_2$, $\varepsilon_3$) from Glauber Monte-Carlo calculations for Au+Au, Cu+Cu, and Cu+Au collisions at 200 GeV

<table>
<thead>
<tr>
<th>centrality</th>
<th>Au+Au 200 GeV</th>
<th>Cu+Cu 200 GeV</th>
<th>Cu+Au 200 GeV</th>
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<tr>
<td></td>
<td>$N_{\text{part}}$</td>
<td>$\varepsilon_2$</td>
<td>$\varepsilon_3$</td>
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<tr>
<td>0%–10%</td>
<td>325.2</td>
<td>0.103</td>
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<td>234.6</td>
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<td>±5.4</td>
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<td>±0.006</td>
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### Systematic uncertainties given in percent on the $v_n$ measurements.

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<tr>
<th>$v_n$</th>
<th>Uncertainty Sources</th>
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<th>40%–50%</th>
<th>Type</th>
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<td>Background</td>
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<td>Acceptance</td>
<td>2%</td>
<td>10%</td>
<td>C</td>
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## Systematic uncertainties for particle identification

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<tr>
<th>species</th>
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<th>$p_T \geq 2\text{GeV}/c$</th>
<th>Type</th>
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<td>A</td>
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<tr>
<td>proton</td>
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<td>5%</td>
<td>A</td>
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