PHENIX results on flow observables in asymmetric Cu+Au collisions

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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

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

$$v_n = \left\langle \cos[n(\phi - \psi_n)] \right\rangle$$

anisotropic flow harmonics – event plane method

- reflect properties of initial state and evolution
- probe different length scales
- sensitive to EoS and η/s

*tracks reconstructed with DC
and matched to PC3, EMCal*

PID: TOFE, TOFW

ψ_1 - Shower Maximum Detector
spectator plane

$\psi_{2,3}$ - Beam Beam Counter
participant plane

v_1 sign conventions used

- v_1 is defined to be positive at positive η (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:

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

Ψ_1 : SMDS, $\Psi_{2,3}$: BBCS+BBSN

centrality dependence

V_1
magnitude
decreases

V_2
magnitude
increases

centrality dependence

V_3

weak

dependence

V_2

magnitude

increases

v_2 system size dependence

Cu+Au falls between Cu+Cu and Au+Au

v_2 (ε_2 scaled)

ε_2 scaling reorders the results by system size

v_2 ($\epsilon_2 N_{\text{part}}^{1/3}$ scaled)

universal behavior in all centralities and systems:
Cu+Cu, Cu+Au, Au+Au

centrality bin	Au+Au 200 GeV ϵ_3	Cu+Au 200 GeV ϵ_3
0%–10%	0.087 ± 0.0018	0.130 ± 0.004
10%–20%	0.122 ± 0.0035	0.161 ± 0.005
20%–30%	0.156 ± 0.0047	0.208 ± 0.007

for the same centrality Glauber- ϵ_3 is larger in the smaller system due to increased fluctuations

v_3 system size dependence

$$v_3 \text{ Cu+Au} > v_3 \text{ Au+Au}$$

v_3 (ε_3 scaled)

close agreement at low-intermediate p_T
within systematics at high p_T

v_3 ($\epsilon_3 N_{\text{part}}^{1/3}$ scaled)

agreement within systematics at all p_T

identified particle v_2

mass ordering at low p_T for v_2

identified particle $v_{1,3}$

v_1

v_3

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

comparison to viscous hydro

$$|\eta| < 0.35$$

$$|\eta| < 1.0$$

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

backup

Number of participant and the participant eccentricity (ε_2 , ε_3) from Glauber Monte-Carlo calculations for Au+Au, Cu+Cu, and Cu+Au collisions at 200 GeV

centrality bin	Au+Au 200 GeV			Cu+Cu 200 GeV		Cu+Au 200 GeV		
	N_{part}	ε_2	ε_3	N_{part}	ε_2	N_{part}	ε_2	ε_3
0%–10%	325.2 ± 3.3	0.103 ± 0.003	0.087 ± 0.0018	98.2 ± 2.4	0.163 ± 0.003	177.2 ± 5.2	0.138 ± 0.011	0.130 ± 0.004
10%–20%	234.6 ± 4.7	0.200 ± 0.005	0.122 ± 0.0035	73.6 ± 2.5	0.241 ± 0.007	132.4 ± 3.7	0.204 ± 0.008	0.161 ± 0.005
20%–30%	166.6 ± 5.4	0.284 ± 0.006	0.156 ± 0.0047	53.0 ± 1.9	0.317 ± 0.006	95.1 ± 3.2	0.280 ± 0.008	0.208 ± 0.007
30%–40%	114.2 ± 4.4	0.356 ± 0.006	0.198 ± 0.0083	37.3 ± 1.6	0.401 ± 0.008	65.7 ± 3.4	0.357 ± 0.010	0.266 ± 0.010
40%–50%	74.4 ± 3.8	0.422 ± 0.006	0.253 ± 0.0111	25.4 ± 1.3	0.484 ± 0.008	43.3 ± 3.0	0.436 ± 0.013	0.332 ± 0.013
50%–60%	45.5 ± 3.3	0.491 ± 0.005	0.325 ± 0.0179	16.7 ± 0.9	0.579 ± 0.008	26.8 ± 2.6	0.523 ± 0.019	0.412 ± 0.019

backup

Systematic uncertainties given in percent on the v_n measurements.

v_n	Uncertainty Sources	10%–20%	40%–50%	Type
v_1	Event plane resolution	20%	12%	C
	Event plane detectors	3%	4%	B
	Background	2%	2%	A
	Acceptance	10%	10%	C
v_2	Event plane resolution	2%	2%	C
	Event plane detectors	3%	4%	B
	Background	2%	2%	A
	Acceptance	8%	3%	C
v_3	Event plane resolution	2%	2%	C
	Event plane detectors	3%	7%	B
	Background	2%	2%	A
	Acceptance	2%	10%	C

backup

Systematic uncertainties for particle identification

species	$p_T \leq 2\text{GeV}/c$	$p_T \geq 2\text{GeV}/c$	Type
pion	3%	5%	A
kaon	3%	10%	A
proton	3%	5%	A