

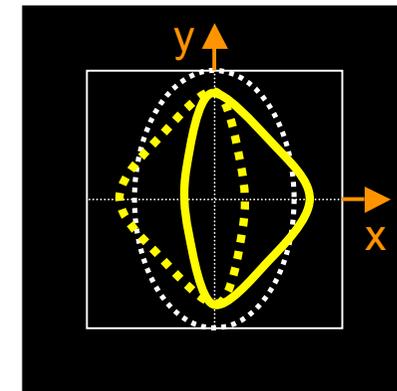
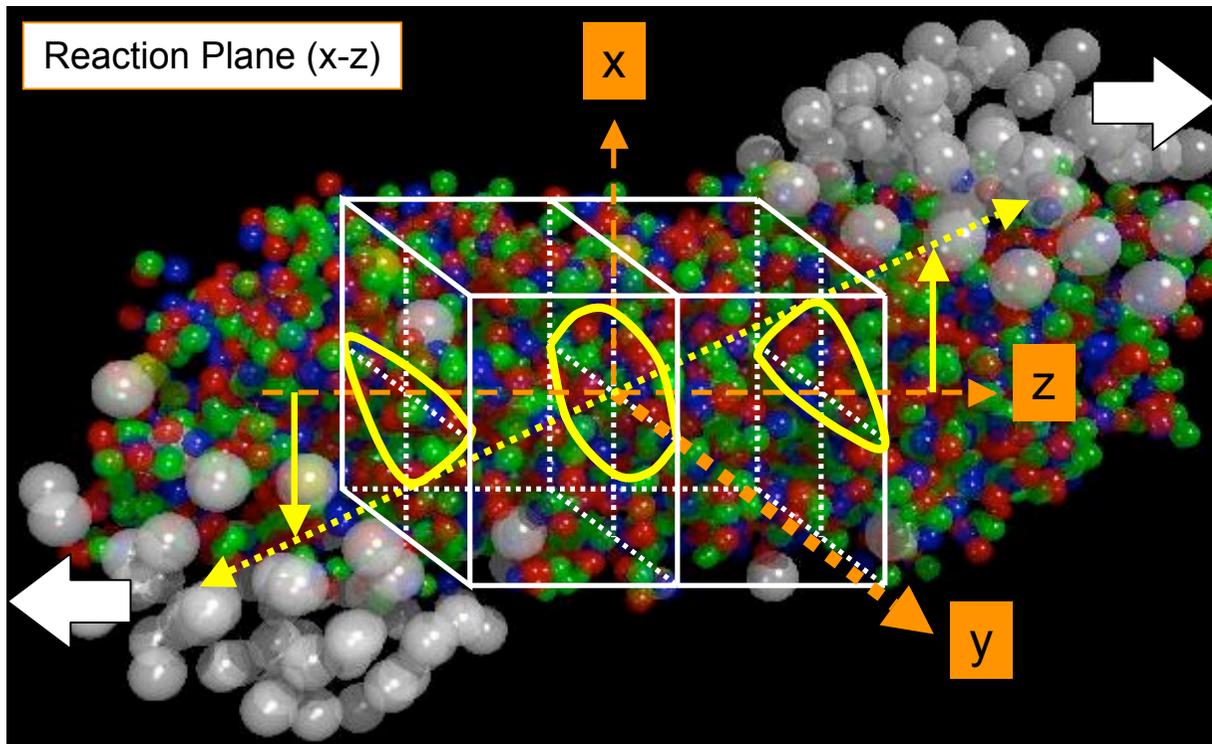
$v_n\{\text{EP}\}$ measurements with forward rapidity Φ_n in 200GeV Au+Au collisions at RHIC-PHENIX

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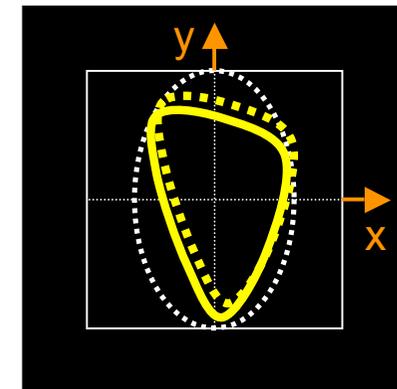
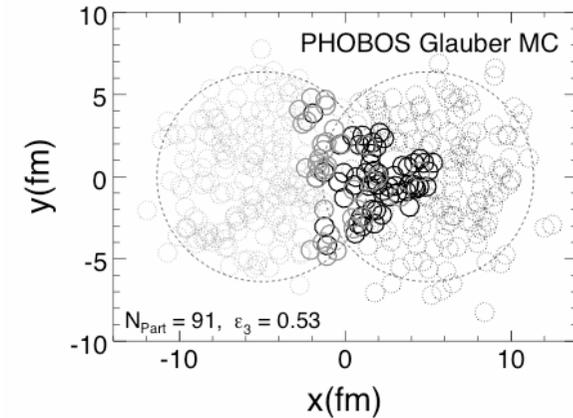
introduction
higher order event plane correlations
2-particle correlations with rapidity gap
 $v_n\{\text{EP}\}$ results and comparisons
summary

Higher order event anisotropy --- v_3 ---

black-disk collision, sign-flipping v_3 like v_1
 initial geometrical fluctuation, no-sign-flipping v_3

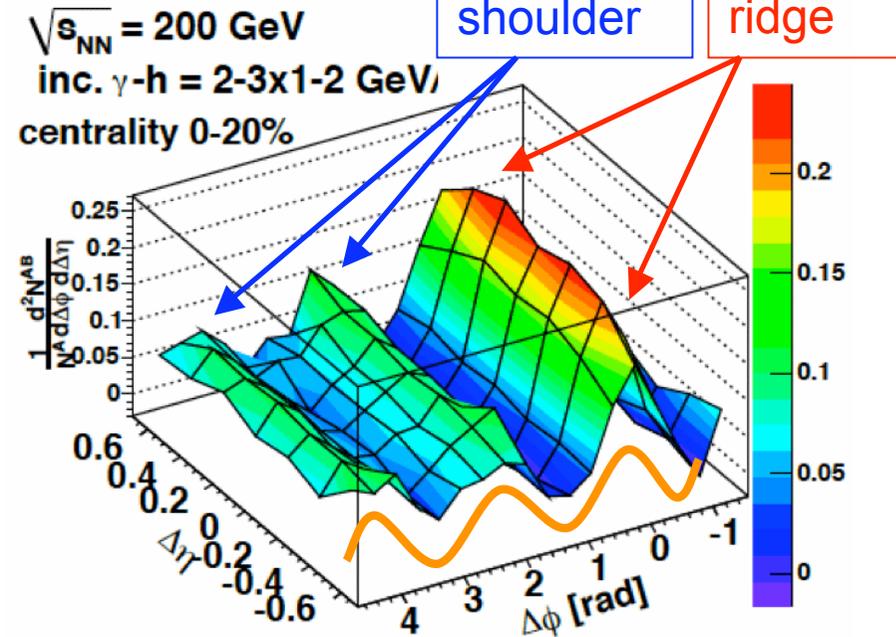
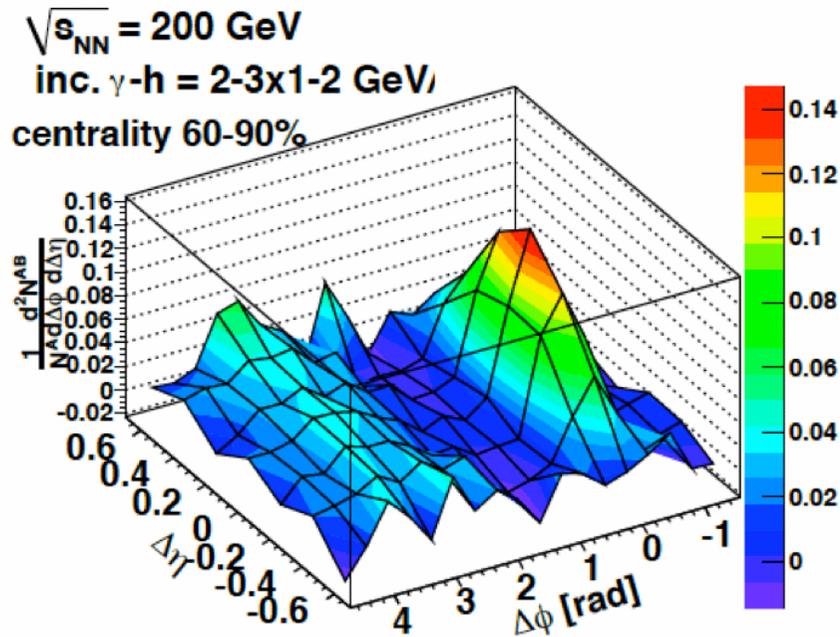
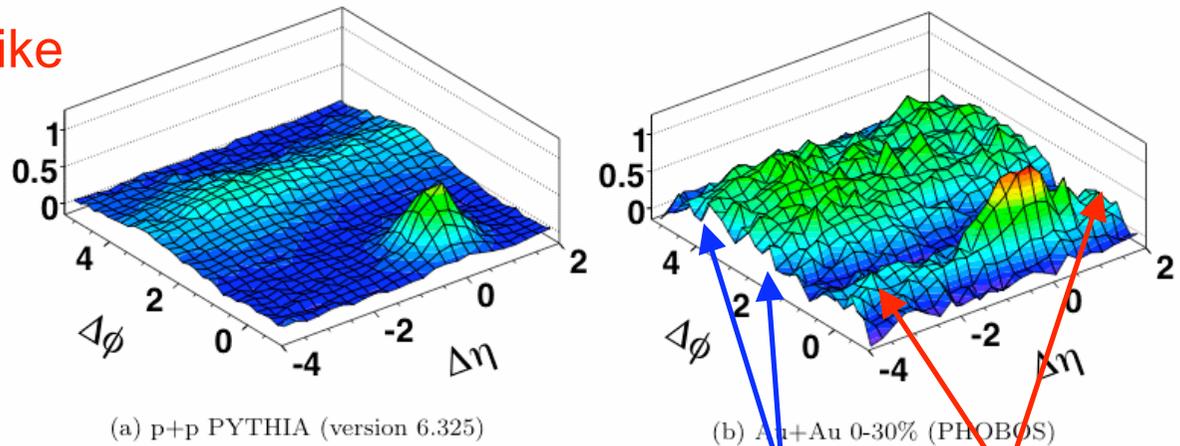


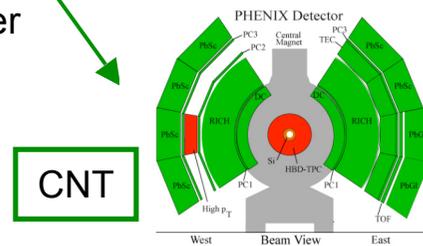
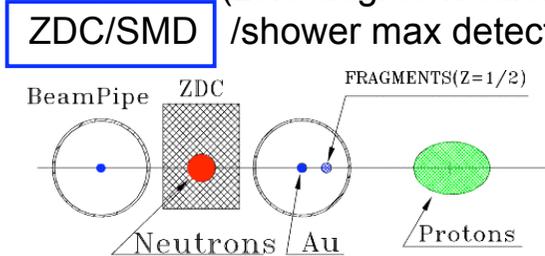
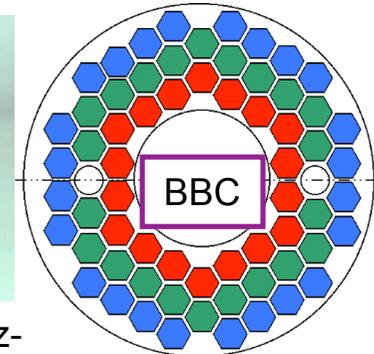
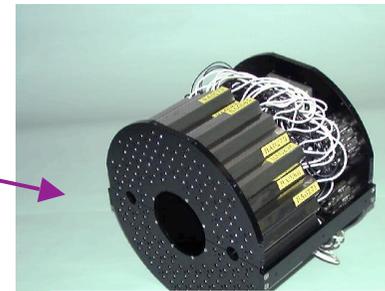
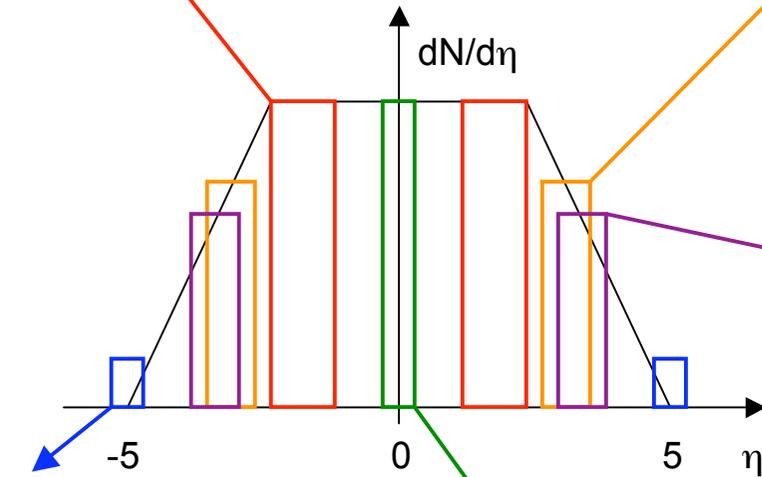
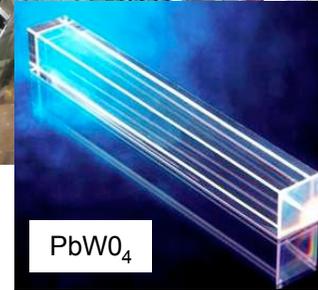
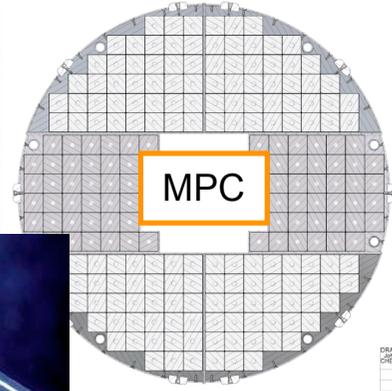
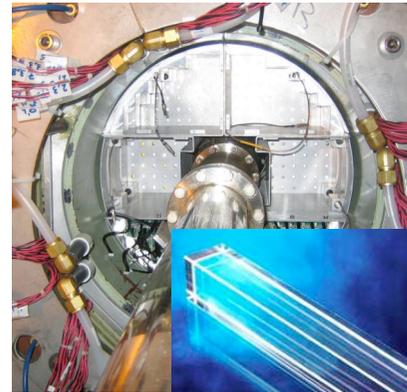
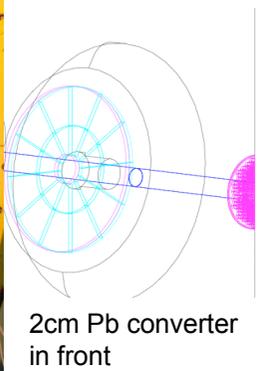
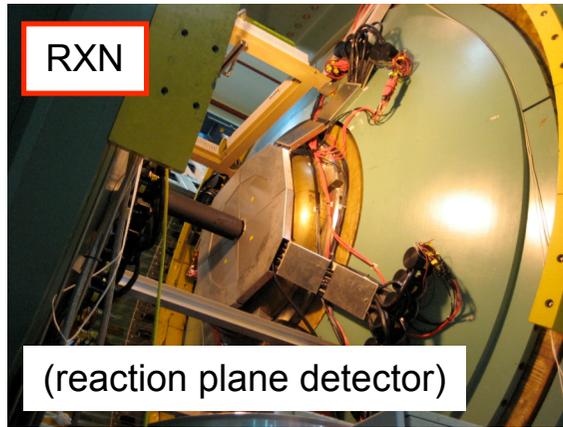
arXiv:1003.0194



Some couplings between “mach-cone-like and ridge-like emissions” and v_3 are expected to be there!

What is the origin and what is the consequence?





Method of event plane determination

(1) Detector calibration / cell-by-cell calibration

(2) Q-vector, re-centering, normalization of width

$$Q_{\{n\}x} = \sum_i \{ w_i \cos(n \phi_i) \} \quad Q'_{\{n\}x} = (Q_{\{n\}x} - \langle Q_{\{n\}x} \rangle) / \sigma_{Q_{\{n\}x}}$$

$$Q_{\{n\}y} = \sum_i \{ w_i \sin(n \phi_i) \} \quad Q'_{\{n\}y} = (Q_{\{n\}y} - \langle Q_{\{n\}y} \rangle) / \sigma_{Q_{\{n\}y}}$$

$$Q_{\{1\}x}^{\text{ZDC}} = \sum_i \{ w_i x_i \} / \sum_i \{ w_i \}$$

$$Q_{\{1\}y}^{\text{ZDC}} = \sum_i \{ w_i y_i \} / \sum_i \{ w_i \}$$

(3) n-th harmonics reaction plane

$$\Phi_{\{n\}} = \text{atan2}(Q'_{\{n\}y}, Q'_{\{n\}x}) / n$$

(4) Fourier flattening (Sergei's+Art's method paper)

$$n \Phi'_{\{n\}} = n \Phi_{\{n\}} + \sum_i (2/i) \{ - \langle \sin(i n \Phi_{\{n\}}) \rangle \cos(i n \Phi_{\{n\}}) + \langle \cos(i n \Phi_{\{n\}}) \rangle \sin(i n \Phi_{\{n\}}) \}$$

(5) measure v_n w.r.t. Φ_n and correct for E.P. resolution

2-particle correlation among 3-sub detectors

Forward^{Hit} (F), Backward^{Hit} (B), Central^{Track} (C)

(1) measure $d\phi$ distribution between 2 detectors weighting by the hit amplitude

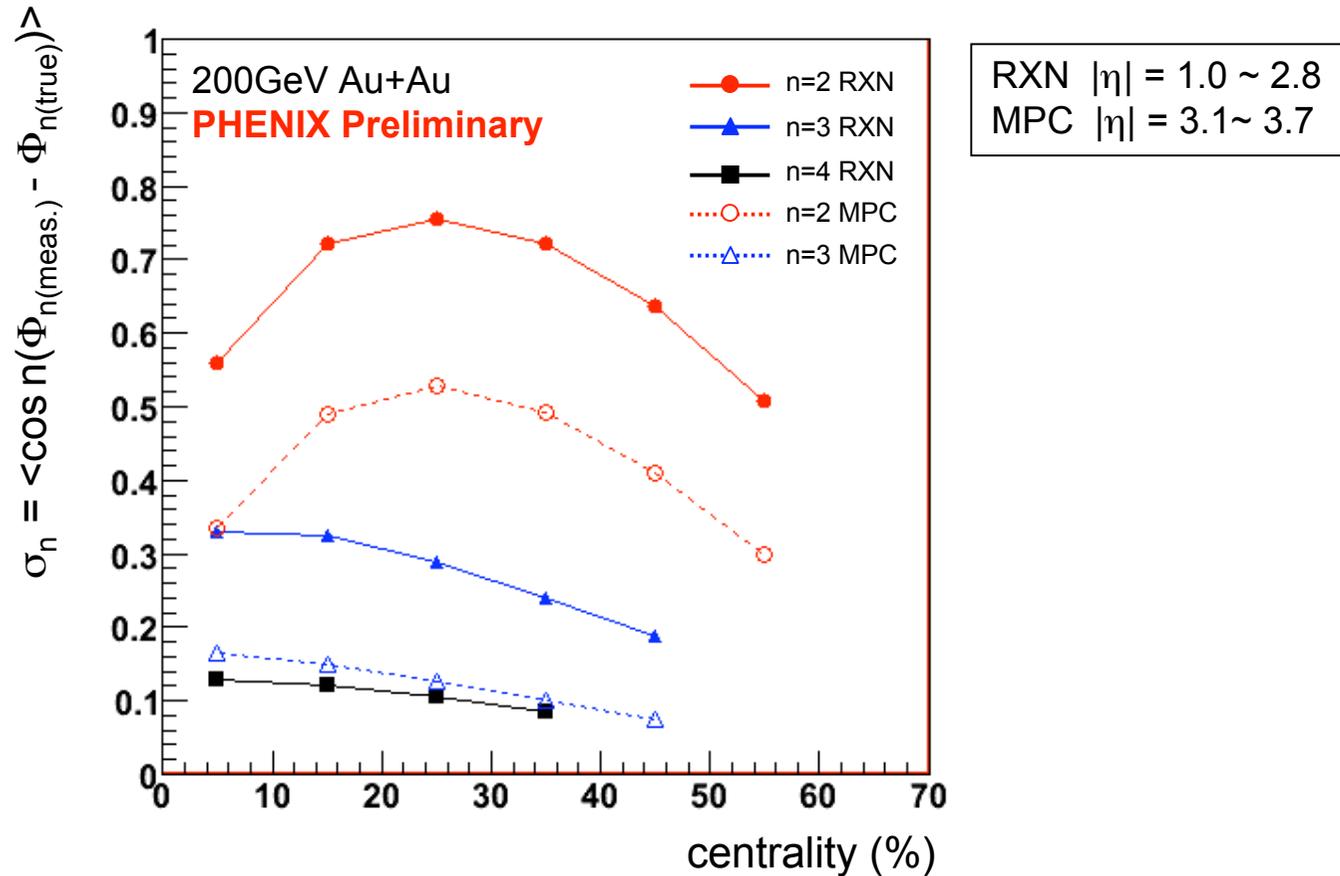
(2) normalize by the event mixing to make correlation functions for 3 combinations

(3) fit the correlation with Fourier function to extract $v_n^F v_n^B$, $v_n^F v_n^C$ and $v_n^B v_n^C$

(4) $v_n^F(\text{Hit})$ and $v_n^B(\text{Hit})$ can be determined as a function of centrality

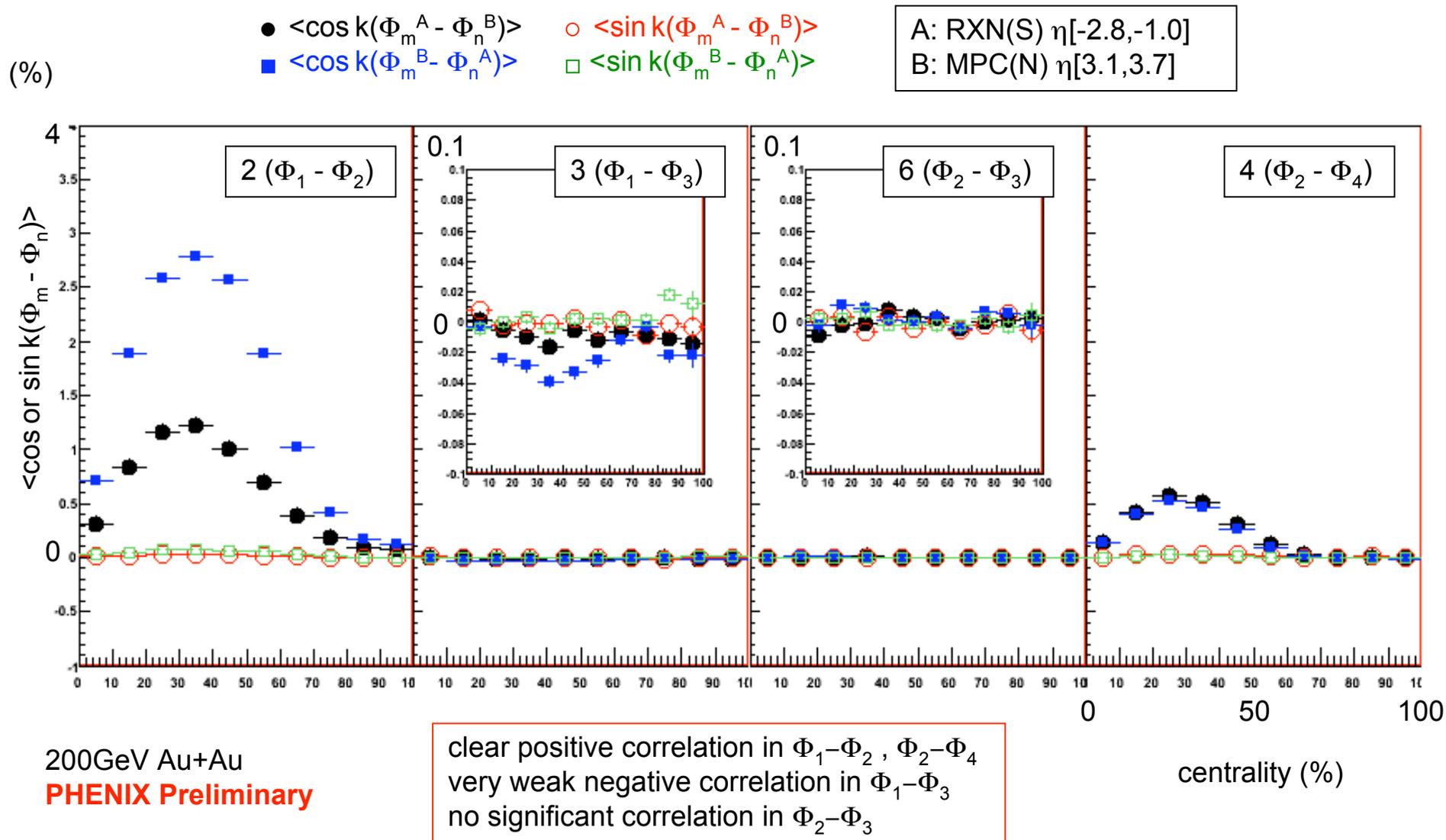
(5) $v_n^C(\text{Track})$ can be determined as a function of centrality and p_T

E.P. resolution of n-th order plane

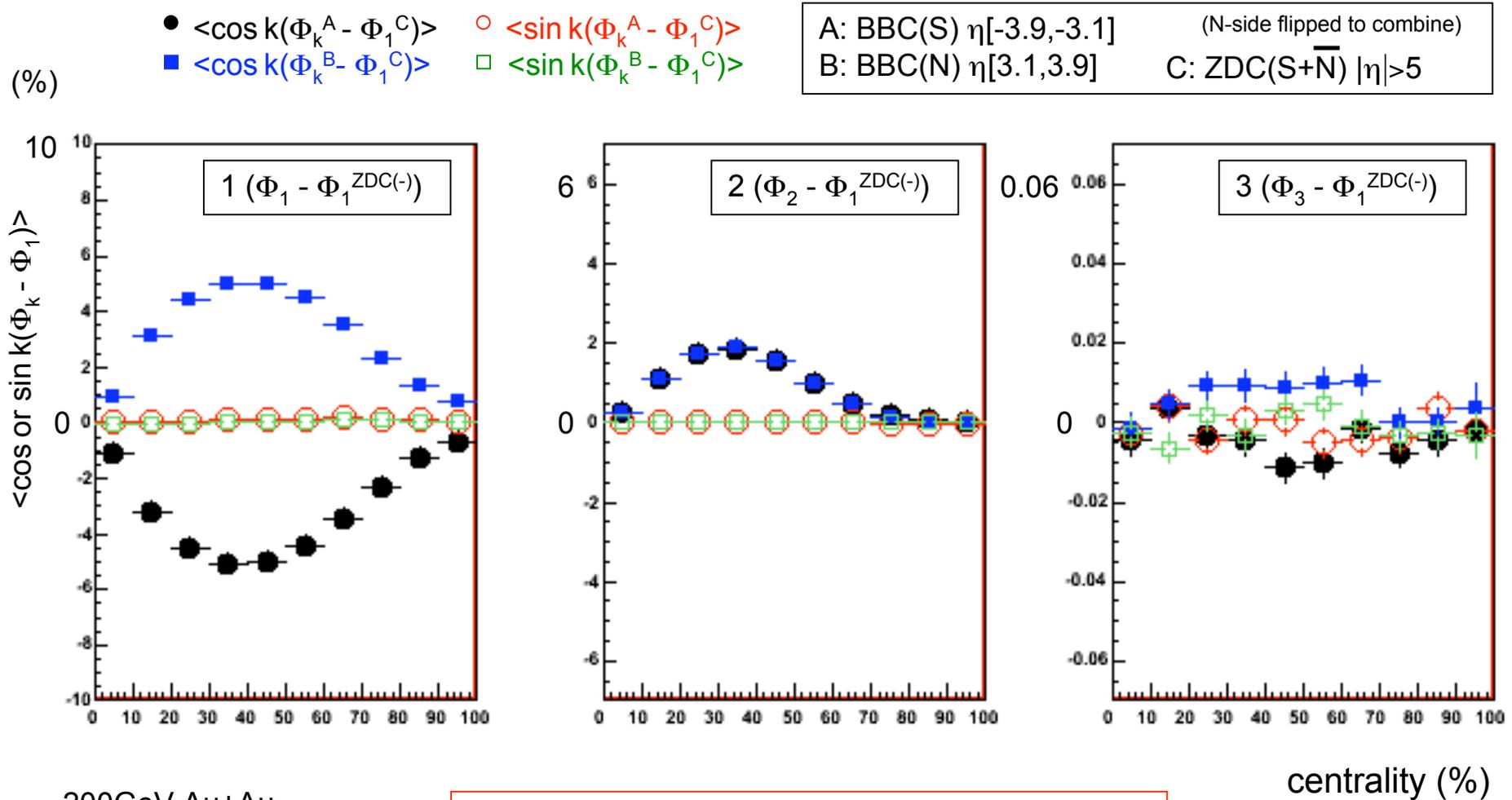


positive correlation in Φ_3 between opposite η up to $\pm 3 \sim 4$
 no-sign flipping in Φ_3 , which is an indication initial geometrical fluctuation
 Φ_n resolution estimated from Forward-Backward correlation
 $\Phi_{n\{\text{true}\}}$ can be different for different order

Correlation between different harmonics #1 (opposite arms)



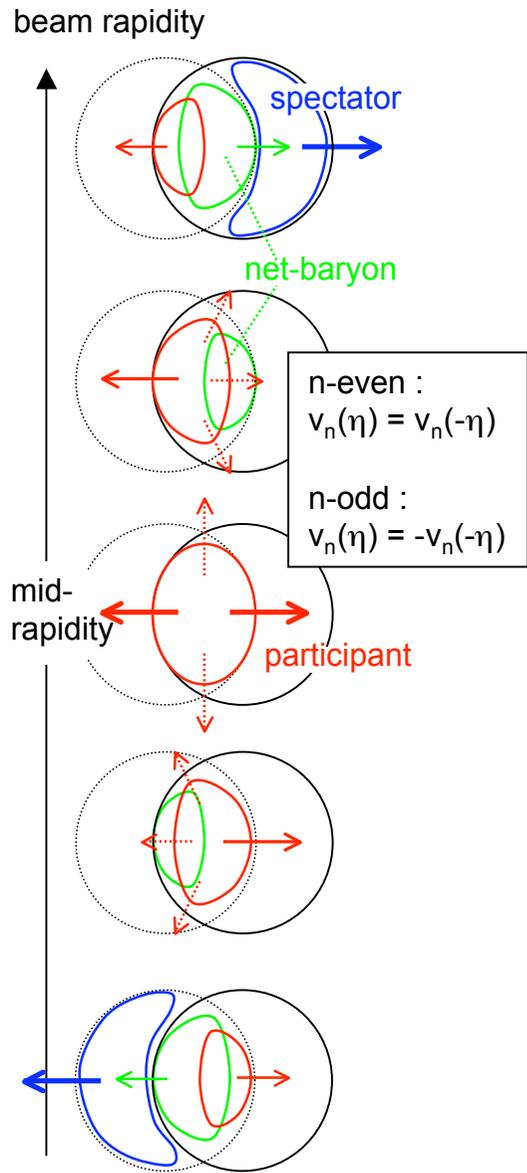
Correlation between different harmonics #2 (w.r.t spectator Φ_1)



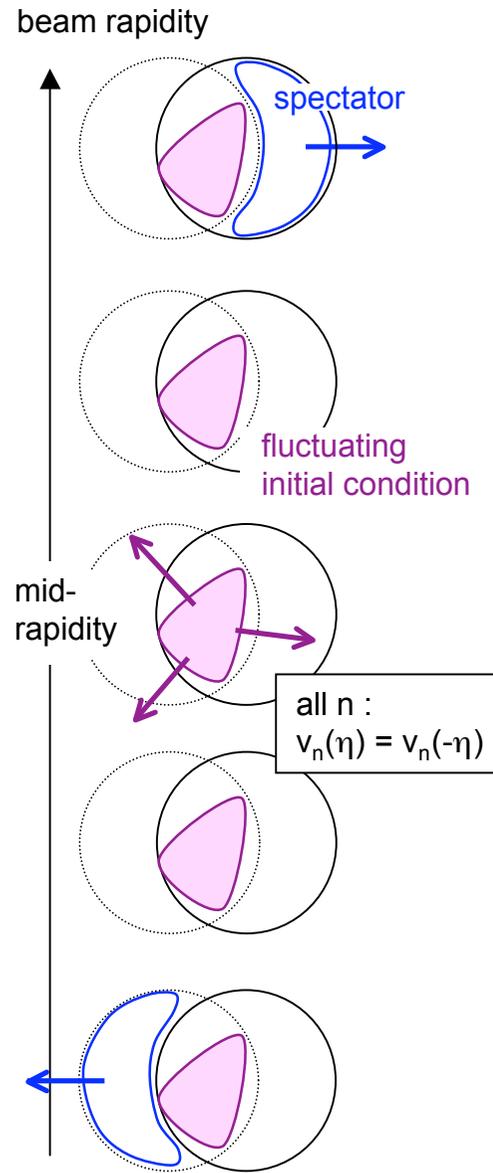
200GeV Au+Au
PHENIX Preliminary

clear sign-flipping in v_1 , clear positive v_2
 indication of sign-flipping in v_3 , $\text{sign}(v_1) = \text{sign}(v_3)$

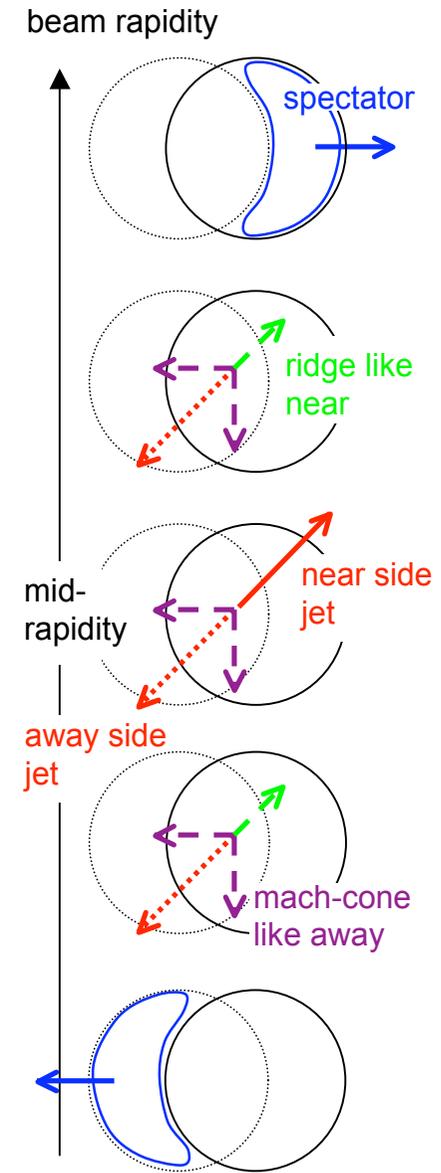
case1



case2



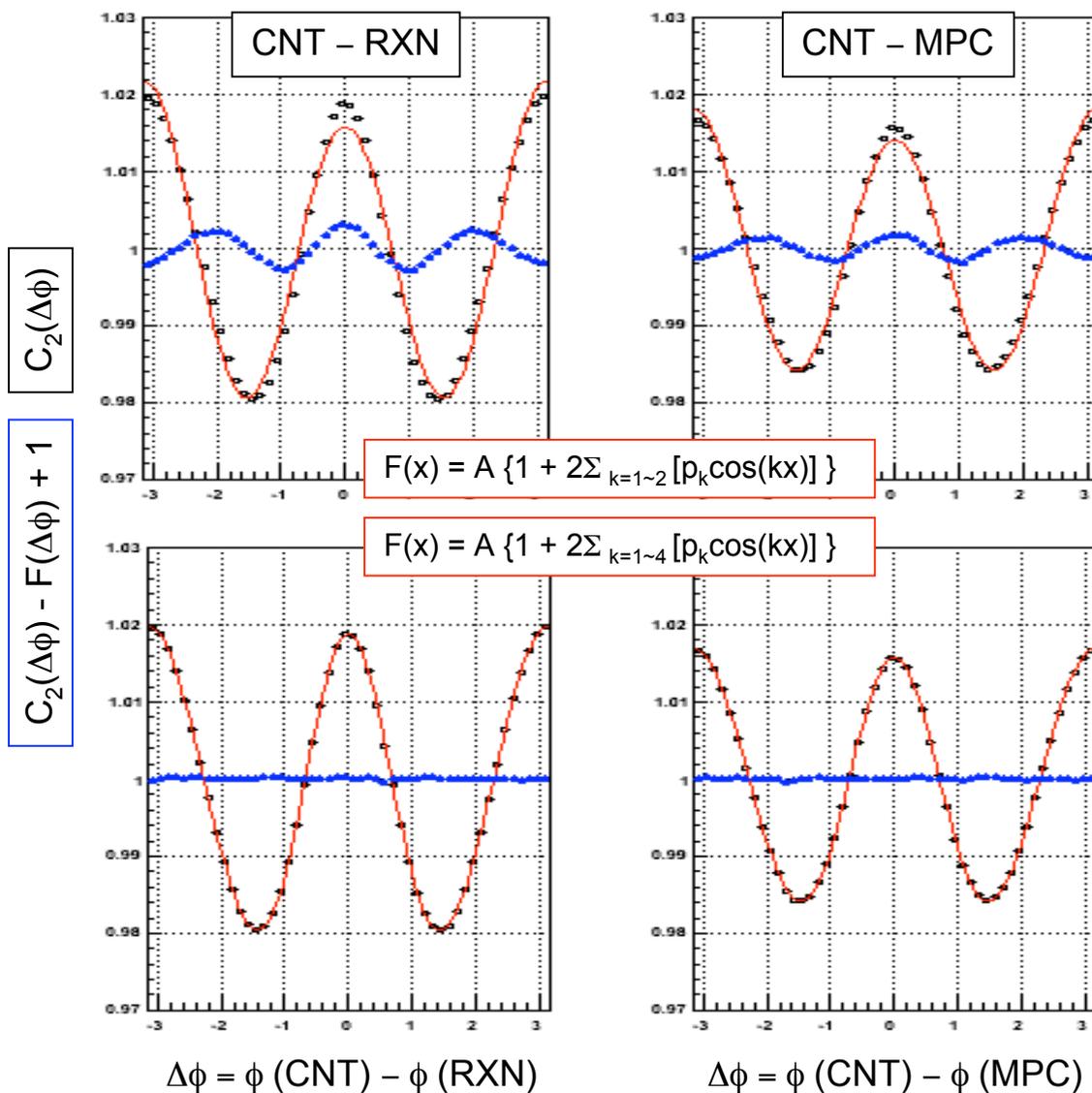
case3



What we have observed with Φ_n

- (1) clear correlation between Φ_1 and Φ_2 as well as Φ_2 and Φ_4 , where $v_{2,4}$ have also been measured with lower order harmonic planes
- (2) participant (pion dominant) v_1 is opposite with respect to spectator v_1 as expected (already seen at RHIC and other energies)
- (3) weak correlation between Φ_1 and Φ_3 is seen as a signature of true v_3 with sign-flipping at mid-rapidity, same sign for both v_1 and v_3
- (4) no significant correlation between Φ_2 and Φ_3 is seen within current statistical accuracy
- (5) clear correlations of same order $\Phi_{3,(4)}$ are seen between detectors with wide rapidity gap, which is consistent with initial geometrical participant fluctuation commonly over wide rapidity space
- (6) The origin can also be jet-medium correlation, which can spread over wide rapidity space (coupled with earlier stage)

2-part. correlation between central and forward



200GeV Au+Au 20~30%

PHENIX Preliminary

CNT: central tracks
mid-rapidity ($|\eta| < 0.35$)
charged hadrons
 $p_T = 2 \sim 4$ (GeV/c)

RXN: reaction plane detector
forward $|\eta| = 1.0 \sim 2.8$
all cells/hits (charge weighting
with Pb converter)

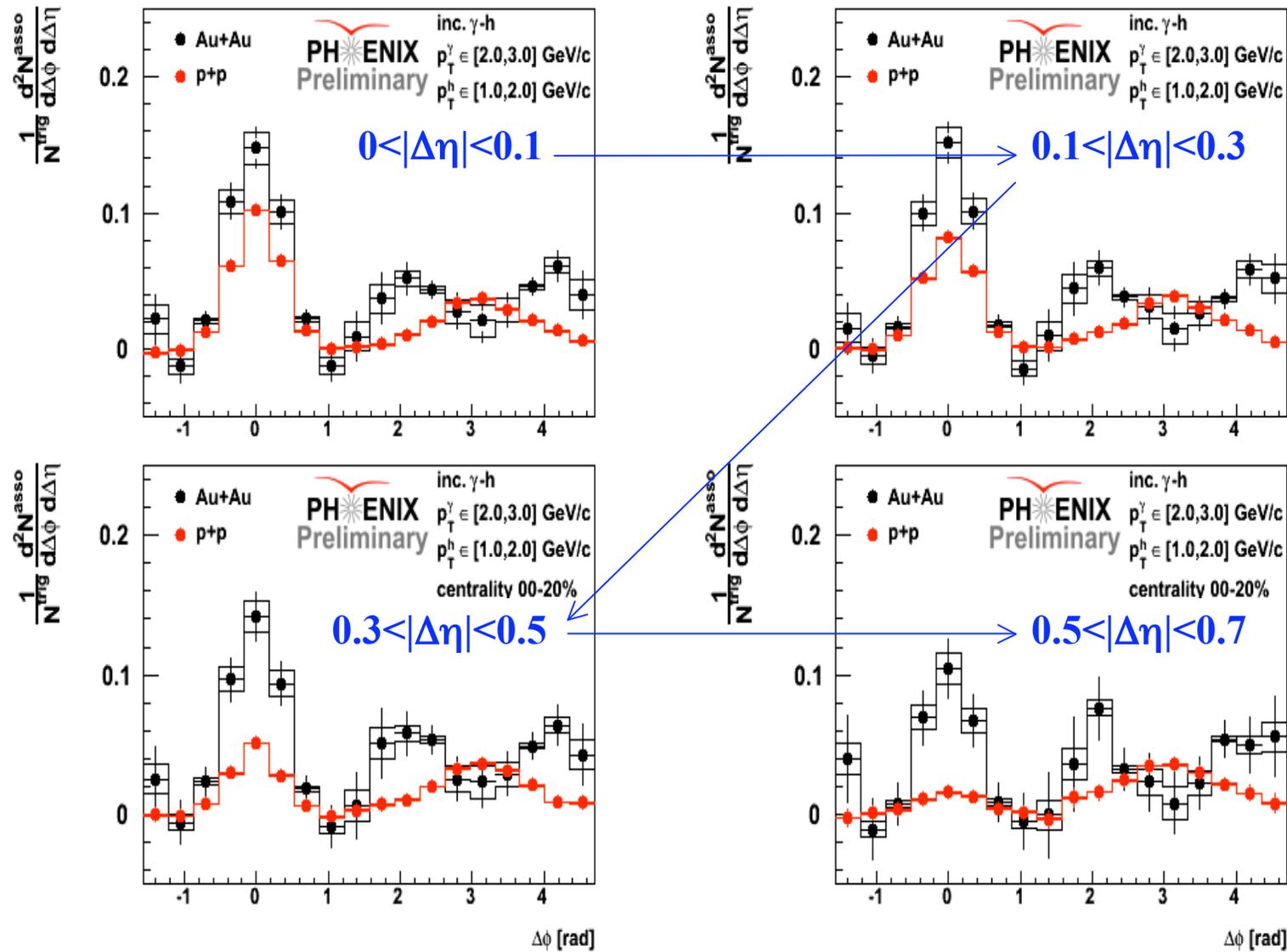
MPC: muon piston calorimeter
forward EM-cal $|\eta| = 3.1 \sim 3.7$
all cells/towers (eT weighting)

$$\rho_n = v_n^A \times v_n^B$$

clear 3rd moment in
two-particle correlation
with large η gap

central-central 2-part. correlation with $\Delta\eta$ dependence

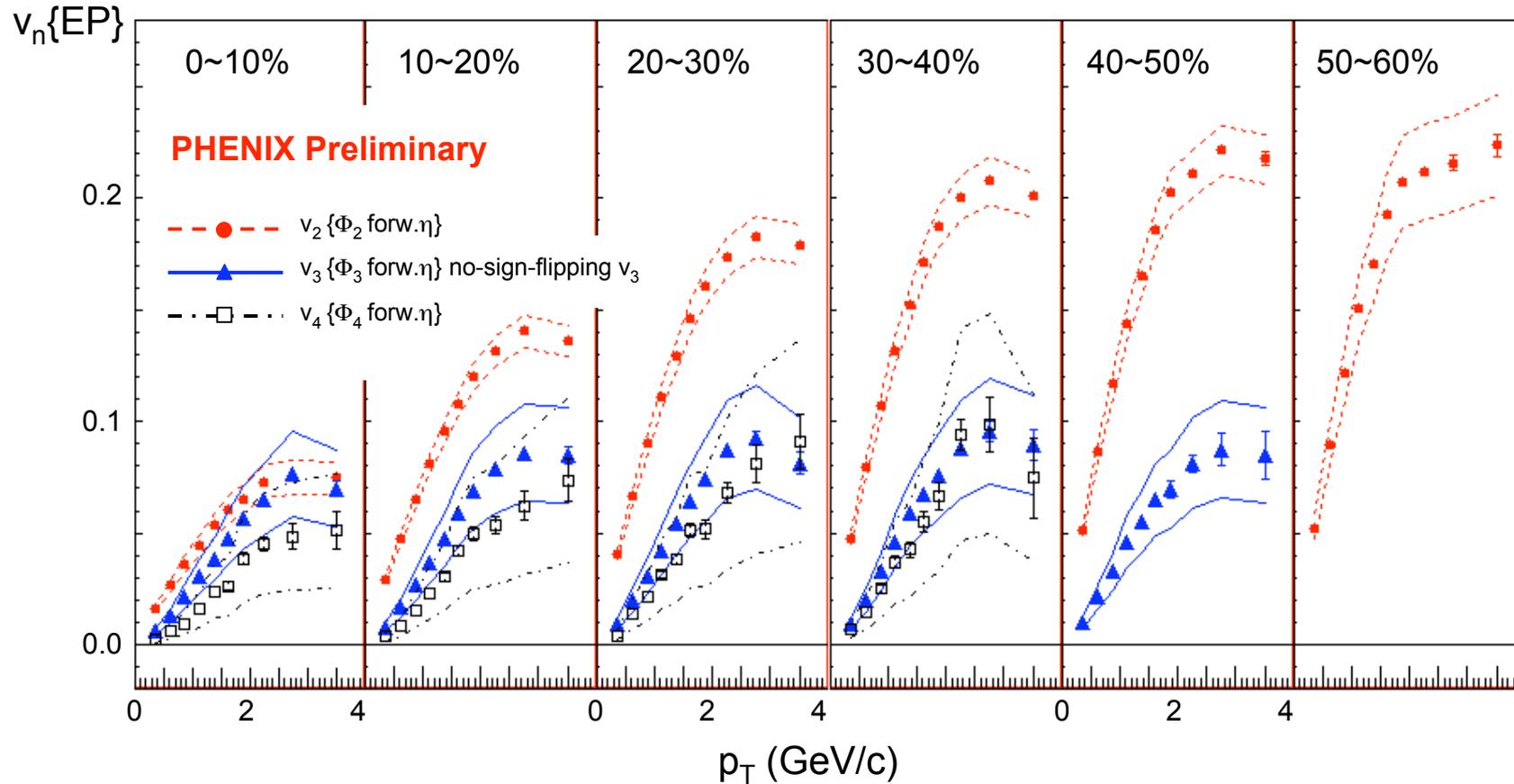
200GeV Au+Au
0-20%, inc. γ -had.



$v_n\{EP\}$ at mid-rapidity with forward Φ_n

200GeV Au+Au \rightarrow charged particles ($|\eta| < 0.35$)

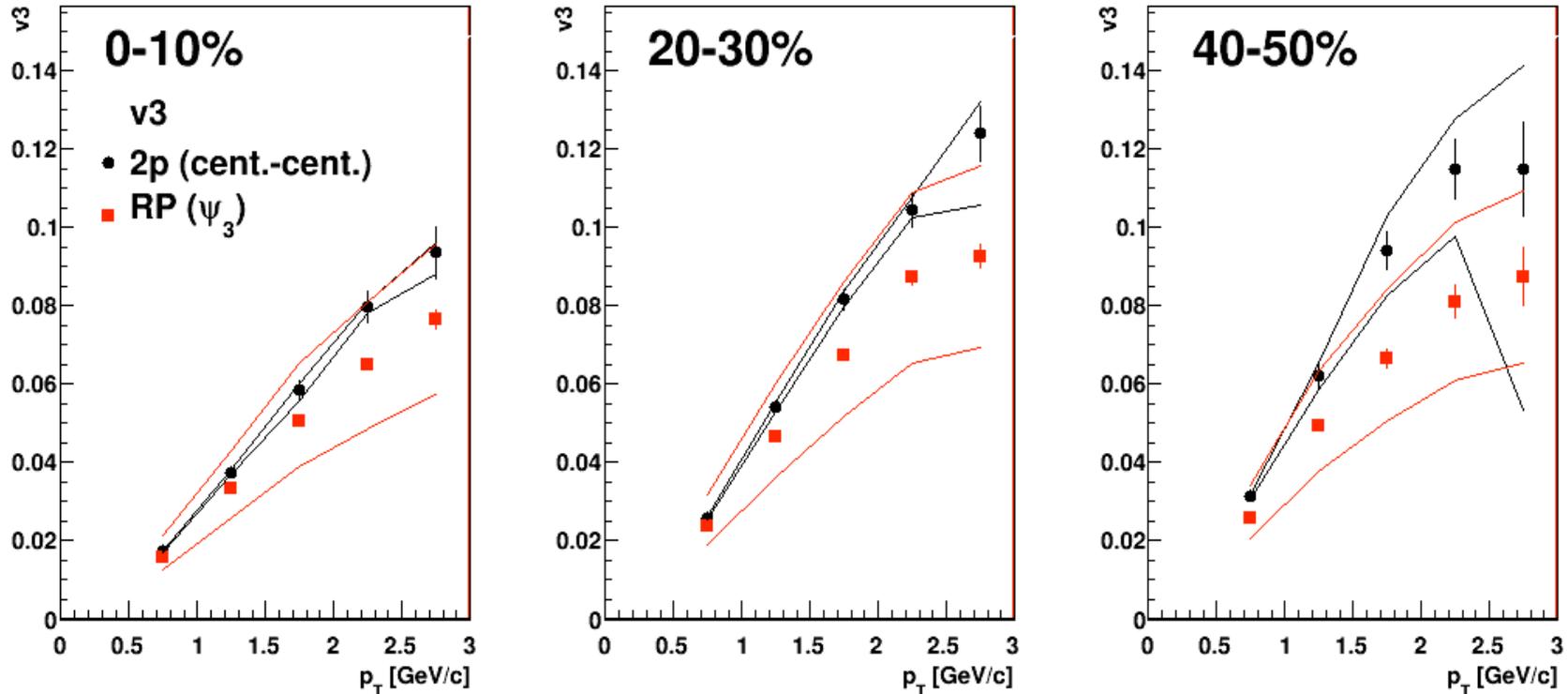
Φ_n RXN ($|\eta| = 1.0 \sim 2.8$)
 MPC ($|\eta| = 3.1 \sim 3.7$)
 BBC ($|\eta| = 3.1 \sim 3.9$)



systematic errors are defined by the variations with Φ_n from different η and from different methods including central-forward 2-particle correlation. Therefore it could include some physics biases.

comparison between $v_3\{\psi_3 \text{ forward}\}$ vs $v_3\{2\text{-part. cent.-cent.}\}$

PHENIX PRELIMINARY

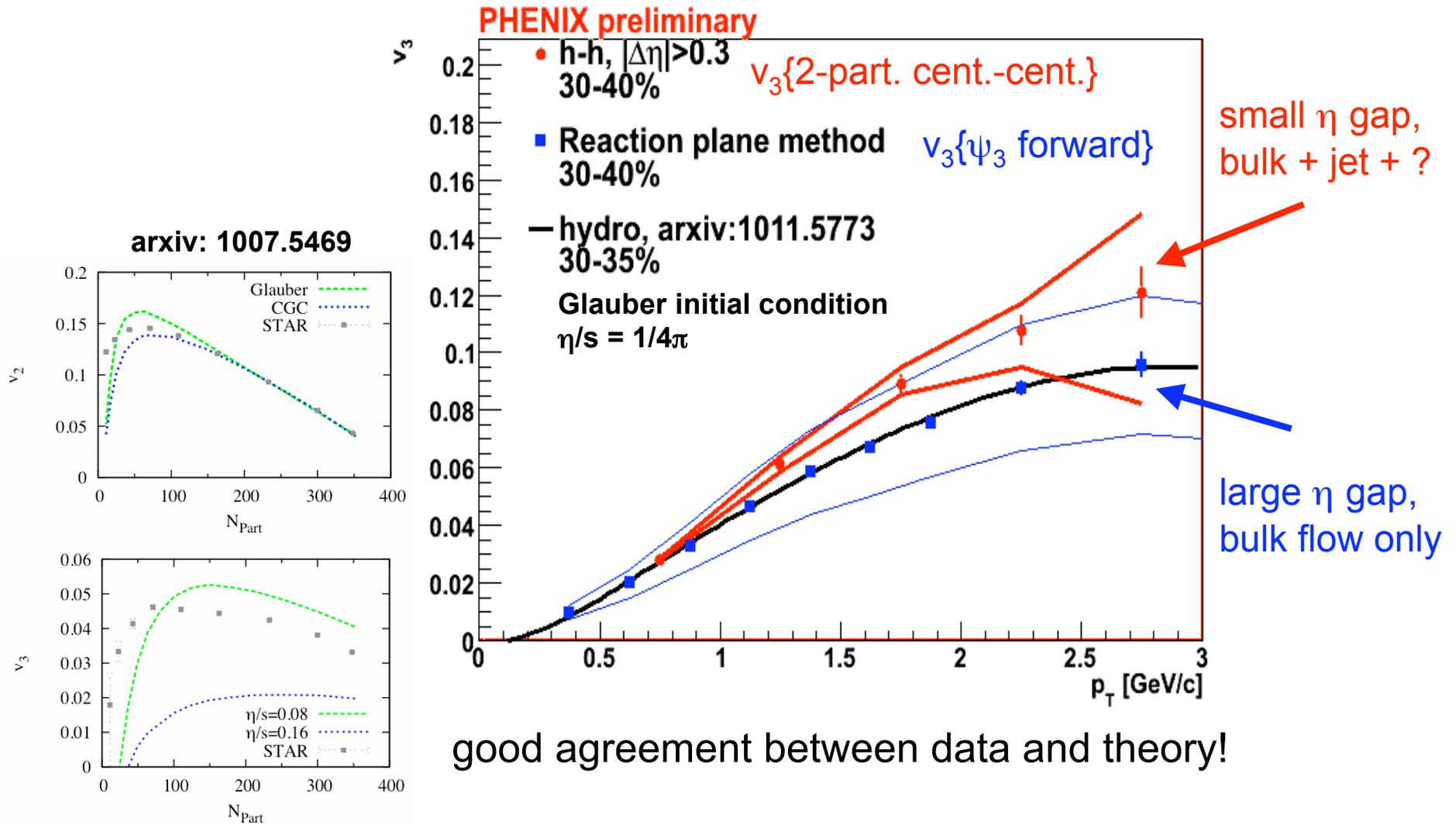


black • : 2-particle correlation (cent.-cent.)

red ■ : event plane method (ψ_3 forward)

agree at low p_T , non-flow (i.e jet) effects at high p_T

Comparison with Hydro calculation



Summary and outlook

$v_n\{\text{EP}\}$ are measured at mid-rapidity with Φ_n defined at forward η and with 2 particle correlation between forward-central.

Long range clear positive correlation of Φ_3 (non-sign-flipping v_3) is observed over several units of η .

There is an indication of sign-flipping v_3 in forward rapidity.

$v_3\{\text{EP}\}$ at mid-rapidity measured with various forward detectors has similar p_T dependence as $v_2\{\text{EP}\}$, much smaller centrality dependence (but significant in central collisions).

Further multi-particle correlation study including Φ_n (with and without η gap) would answer the origin of this long range correlation; initial state geometrical fluctuation alone or jet-medium interaction at initial stage...