

# Centrality dependence of $v_2$ with respect to the ZDC-SMD event plane in Au + Au at $\sqrt{s_{NN}} = 200$ GeV

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Aspen Lodge at Estes Park, Colorado*

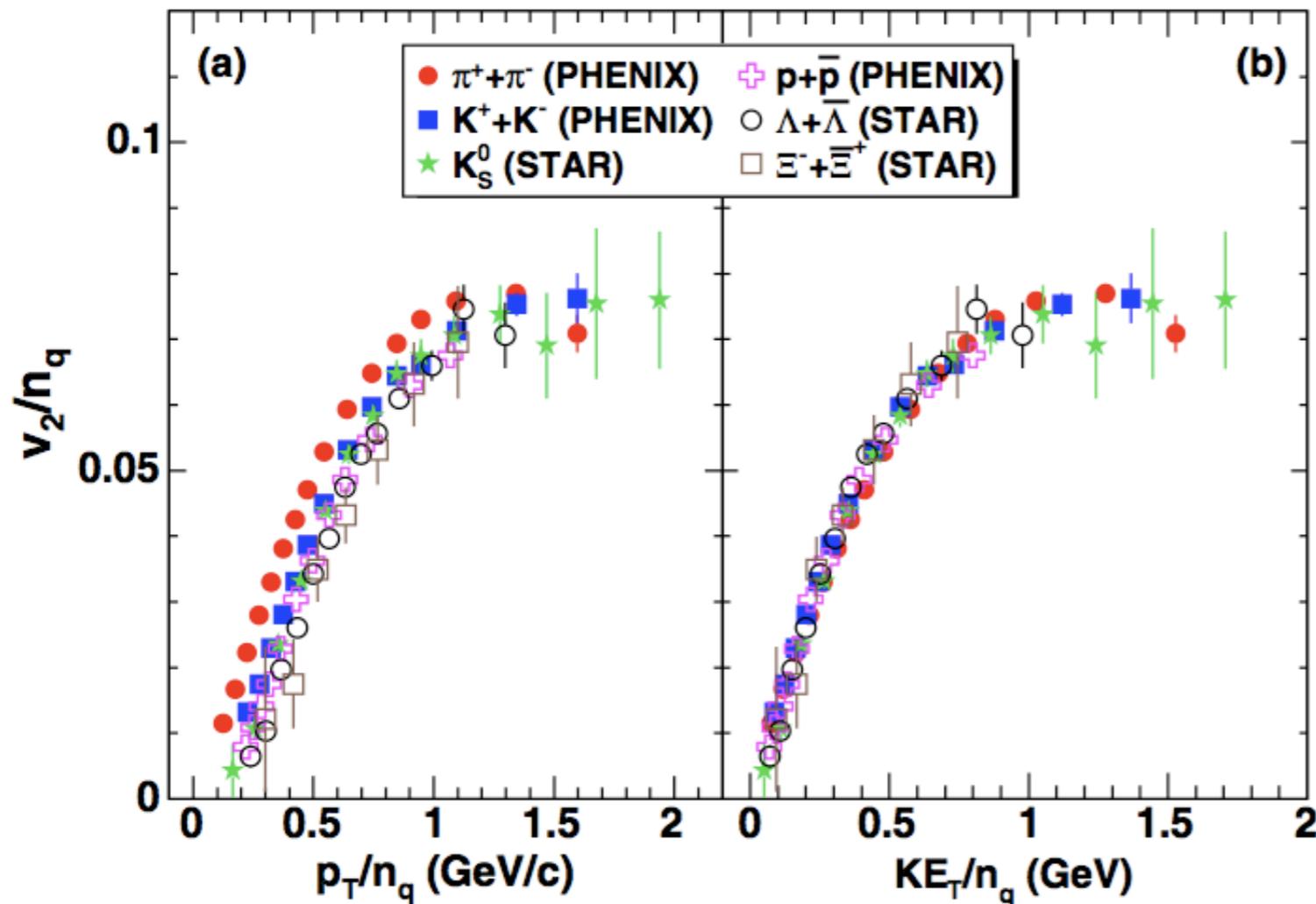
# Outline

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- Introduction
  - ✓ Elliptic flow ( $v_2$ ) at RHIC
  - ✓ Why ZDC-SMD event plane ?
- PHENIX experiment
  - ✓ Event plane at Shower Maximum Detector (SMD)
- Event plane method
- Results in 20 - 60 % centrality
  - ✓ Comparison of  $v_2\{\text{BBC}\}$  with  $v_2\{\text{ZDC-SMD}\}$
- Conclusions

# Elliptic flow at RHIC

PHENIX: PRL98, 162301 (2007)



- Elliptic flow ( $v_2$ )
  - ✓ Second harmonic azimuthal correlation with respect to the reaction plane
- Sensitive probe to early stage
  - ✓ Speed of sound
  - ✓ Shear viscosity
- Dominant Background
  - ✓ “Non-flow” effect, correlations not originate from reaction plane
    - ex. di-jets, resonance decay
    - Flow fluctuations

$$v_2 = \langle \cos(2[\phi - \Psi_{RP}]) \rangle$$

$\phi$  : azimuthal angle of emitted particles

$\Psi_{RP}$  : azimuthal angle of reaction plane

# How to remove non-flow ?

## ▶ Proposed methods:

### ● q distribution method<sup>[1]</sup>

- ✓ Fitting flow vectors with flow + non-flow terms

### ● Multi-particle cumulant method<sup>[2]</sup>

- ✓ n-th particle correlation, typically 4-th order cumulant is used

### ● Lee-Yang zero method<sup>[3]</sup>

- ✓ Correlation of all particles

- ➔ Require a large number of particles for a given event
- ➔ Huge statistical errors due to the limited acceptance at midrapidity in PHENIX

Are there any other methods to minimize non-flow ?

Yes.

Event plane from directed flow at the Zero Degree Calorimeter (ZDC) and the Shower Maximum Detector (SMD)

[1] Nucl. Phys. **A590**, 561c (1995); Z. Phys. **C70**, 665 (1996)

[2] Phys. Rev. **C64**, 054901 (2001)

[3] Nucl. Phys. **A727**, 323 (2003)

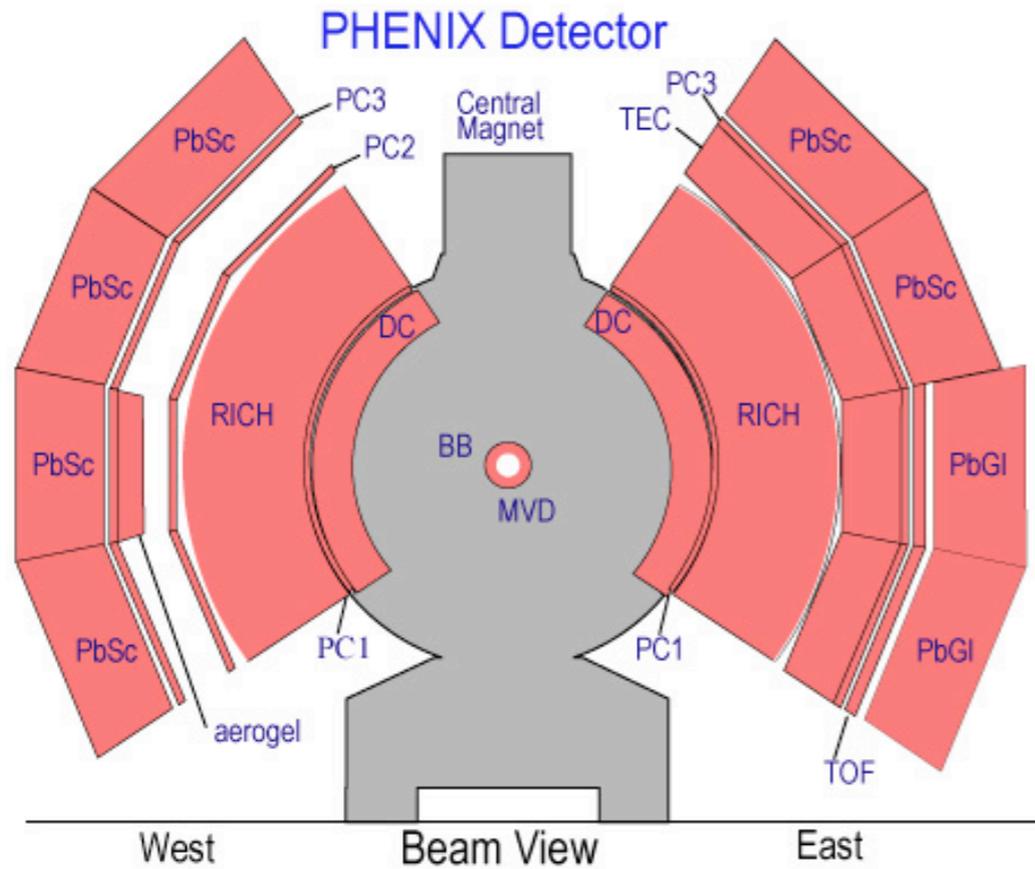
# Why ZDC-SMD ?

- **Event plane from directed flow at ZDC-SMD\***
  1. Wide rapidity gap  $|\Delta\eta| \sim 6$  from midrapidity ( $|\Delta\eta| \sim 3 - 4$  at the BBC)  $\rightarrow$  short range correlations do not contribute
  2. Spectator neutrons, event-by-event fluctuations in nucleon positions are small  $\rightarrow v_2$  fluctuations are negligible
  3. Event plane by directed flow ( $v_1$ ) = Mixed harmonic method  $\rightarrow$  Direct two particle correlations do not contribute to  $v_2\{\text{ZDC-SMD}\}$

**Non-flow contributions are minimal in  $v_2\{\text{ZDC-SMD}\}$**

\* Nucl. Phys. **A774**, 515 (2006); Phys. Lett. **B641**, 260 (2006)

# PHENIX experiment



- PHENIX Run 4

- ✓ Au + Au 200 GeV, ~650 M events

- Trigger, z-vertex, centrality, event plane

- ✓ Beam-Beam Counter (BBC),  $|\eta| = 3.1 - 3.9$ , full azimuth

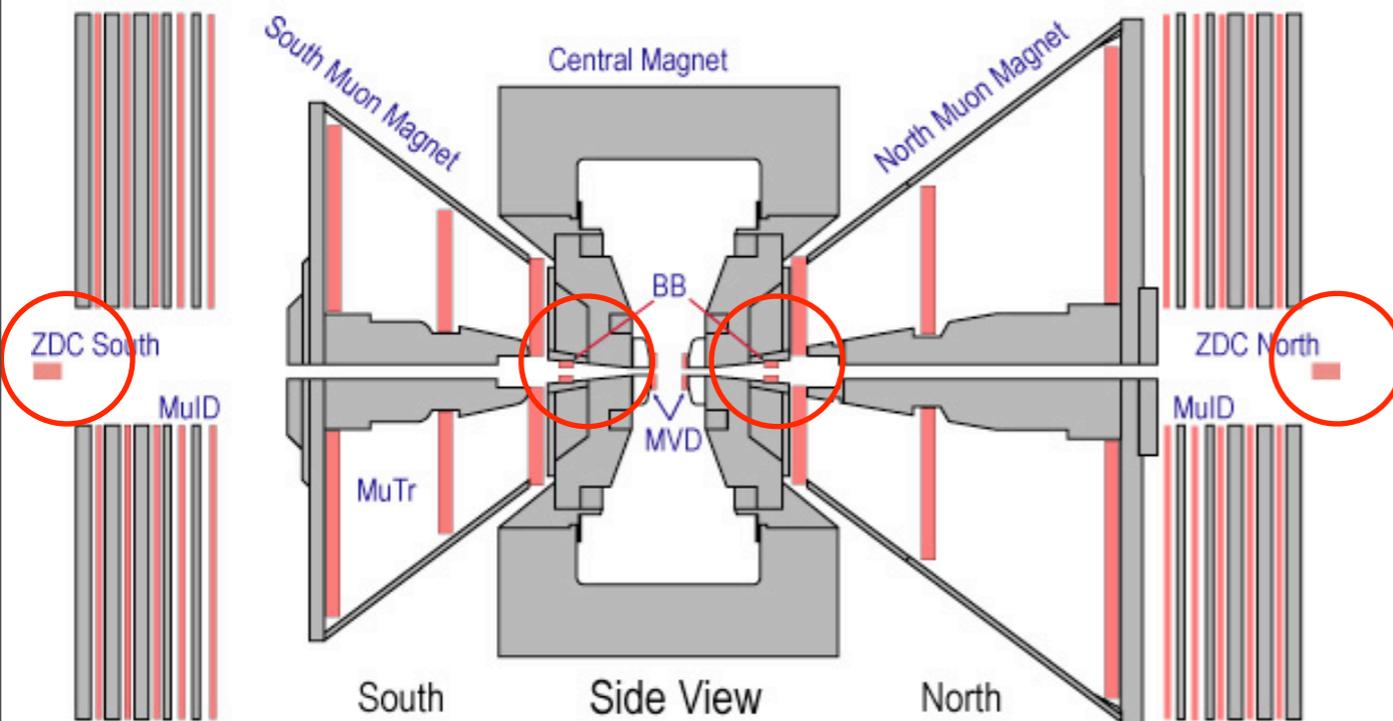
- ✓ Zero Degree Calorimeter (ZDC) and Shower Maximum Detector (SMD),  $|\eta| > 6$ , full azimuth

- also use the central arm to determine the reference event plane

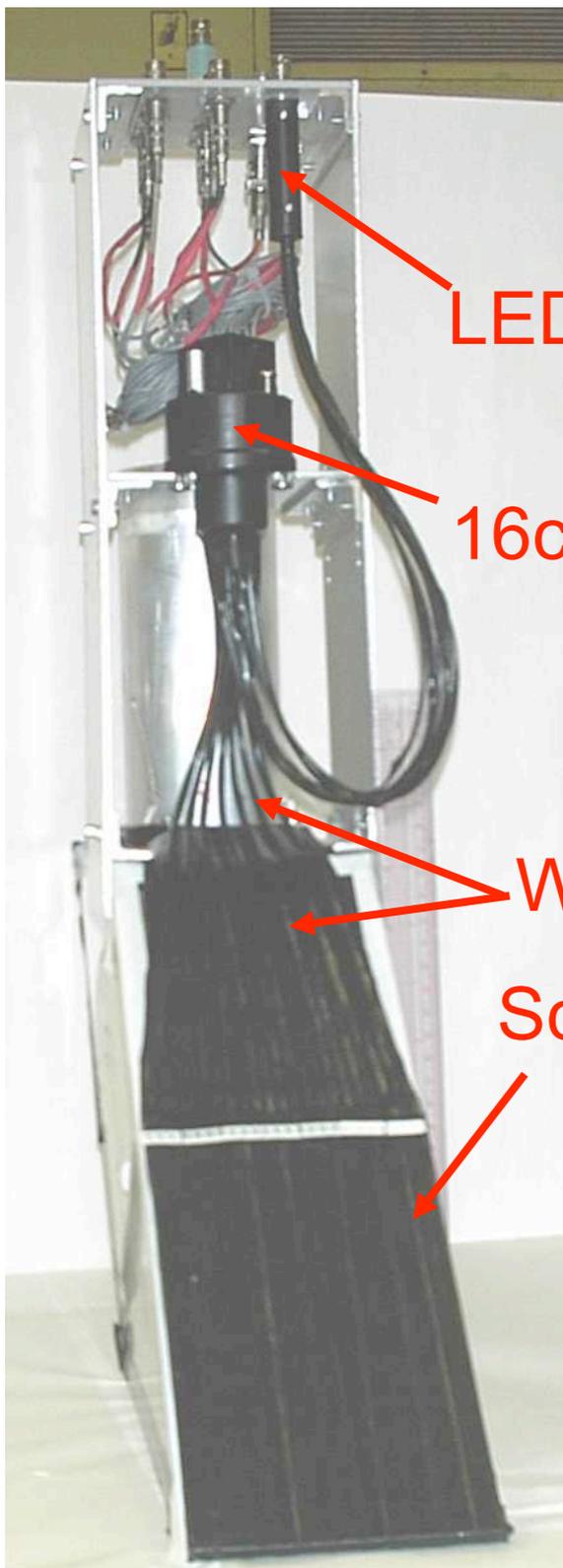
- Tracking

- ✓ Central arm (CNT),  $|\eta| < 0.35$ , half of full azimuth

- $E/p > 0.2$  to improve S/B ratio at high  $p_T$



# Shower Maximum Detector

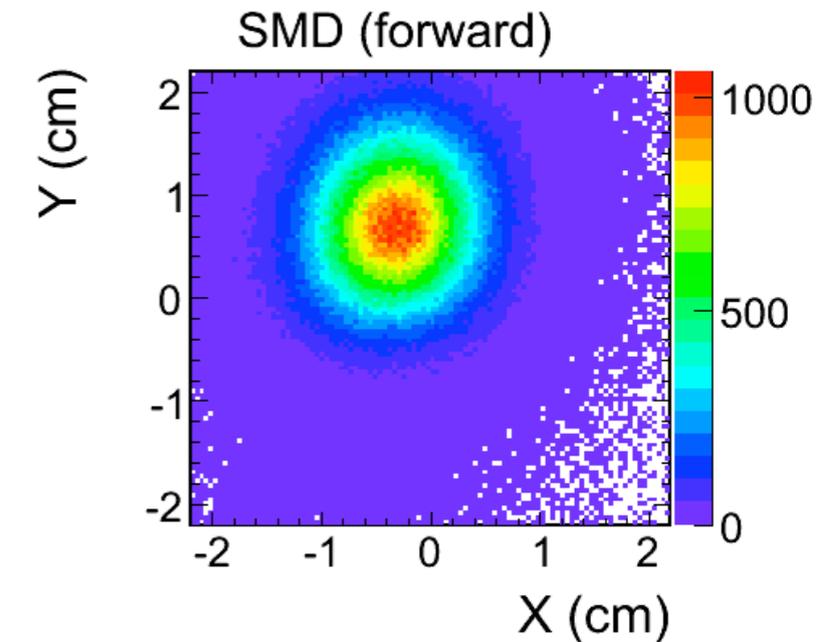
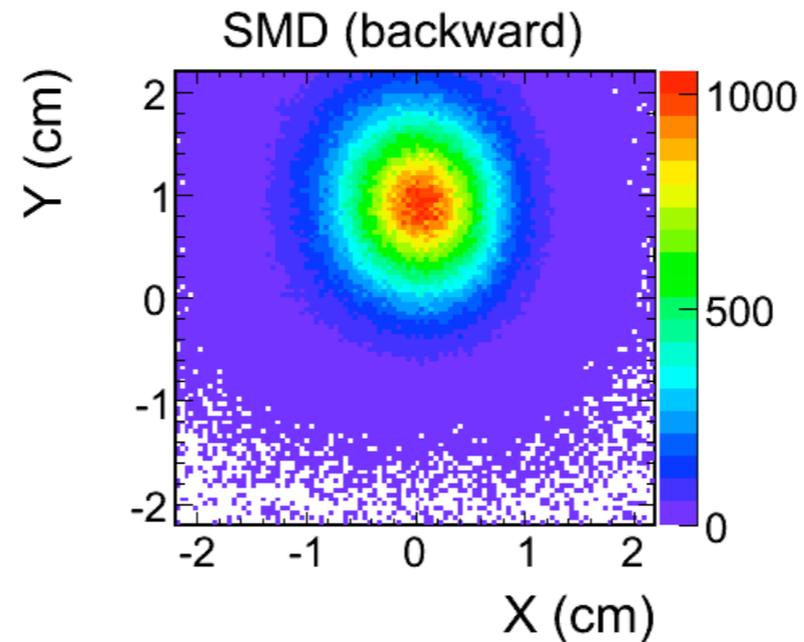


LED flasher

16ch. PMT "M16"

WLS fibers

Scintillator strips



- Active area of SMD

- ✓ 105 mm × 110 mm (horizontal × vertical)

- ✓ 7 × 8 bins in (x, y) space

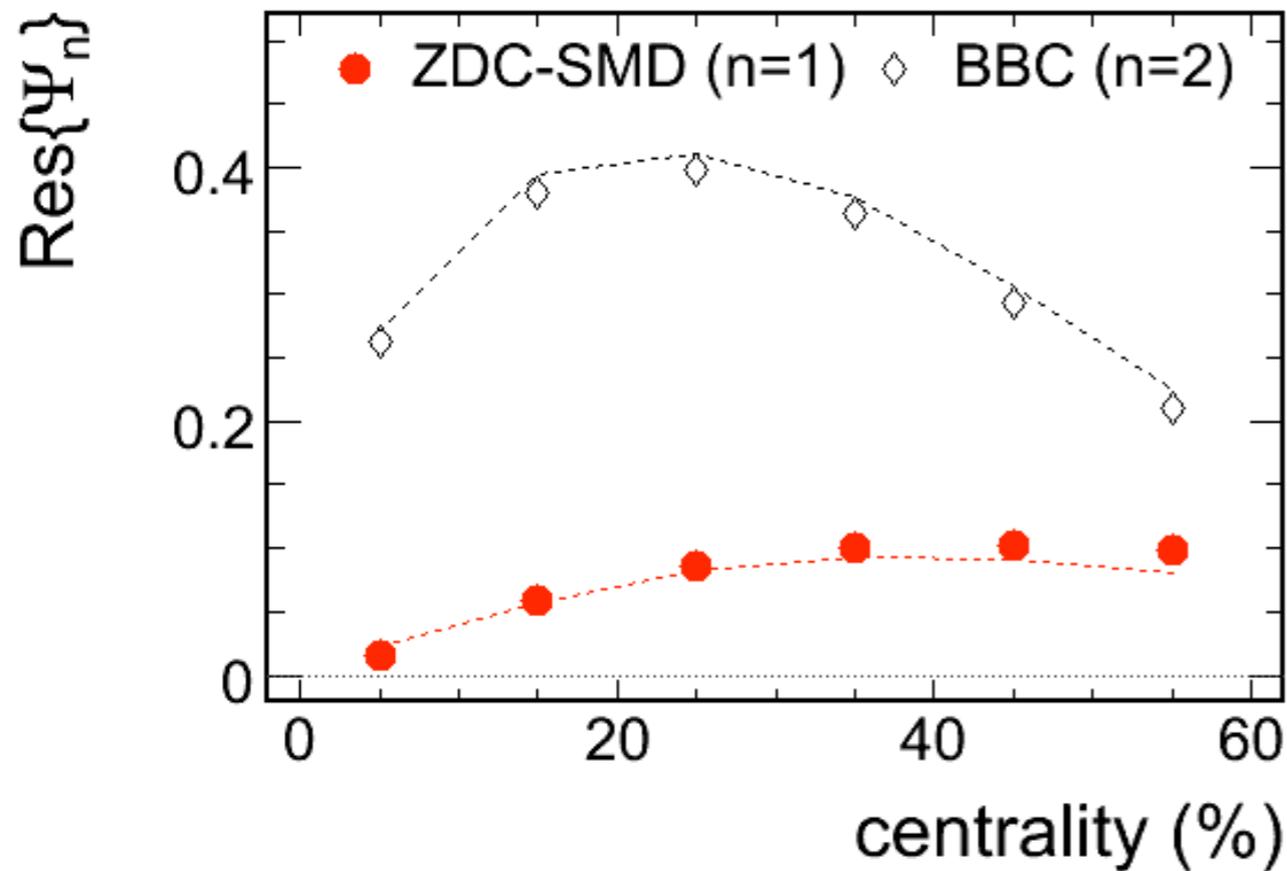
- Position resolution

- ✓ 3 - 10 mm

- Raw event flow vectors

- ✓ Weighted sum of (x, y) with energy deposit in SMD

# Event plane resolution



- Backward - Forward (south - north, S - N) correlation (symbols)
- ZDC - BBC - CNT correlation (dashed lines)

$$v_2 = \frac{v_2^{obs}}{\text{Res}\{\Psi_n\}} = \frac{\langle \cos(2[\phi - \Psi_n]) \rangle}{\langle \cos(2[\Psi_n - \Psi_{RP}]) \rangle}$$

$$\text{Res}\{\Psi_n\} \approx \sqrt{2 \langle \cos(2[\Psi_n^S - \Psi_n^N]) \rangle}$$

$$\text{Res}\{\Psi_n\} = \sqrt{\langle \cos(2[\Psi_n^B - \Psi_n]) \rangle}$$

$$\times \sqrt{\frac{\langle \cos(2[\Psi_n - \Psi_n^A]) \rangle}{\langle \cos(2[\Psi_n^A - \Psi_n^B]) \rangle}}$$

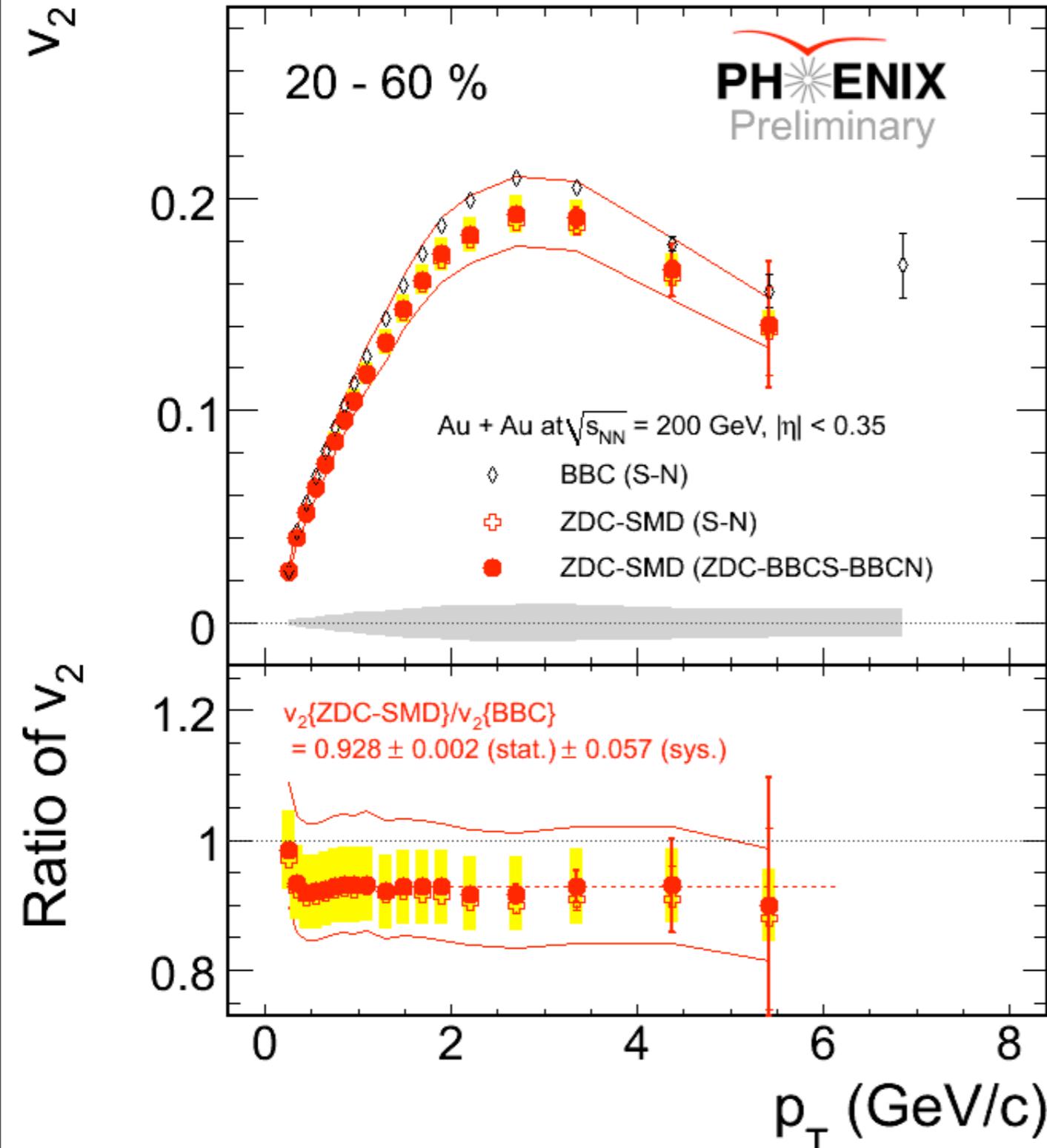
# Results

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- $v_2\{\text{BBC}\}$  vs  $v_2\{\text{ZDC-SMD}\}$
- PHENIX vs STAR
- $v_2\{\text{ZDC-SMD}\}$  with and without CNT (central arm) event plane resolution

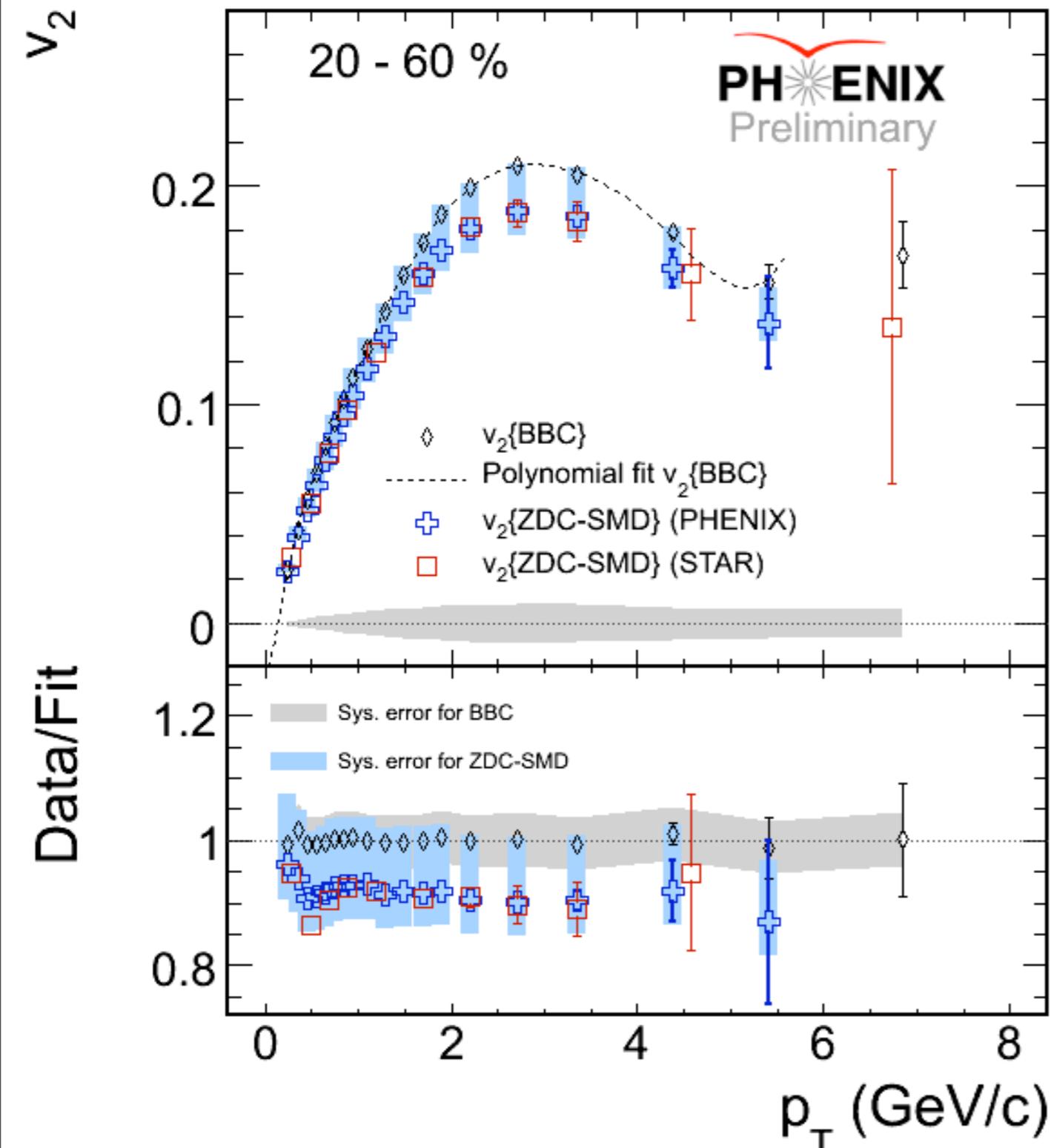
✓ NOTE: South and north combined event plane are used

# $v_2\{\text{ZDC-SMD}\}$ vs $v_2\{\text{BBC}\}$



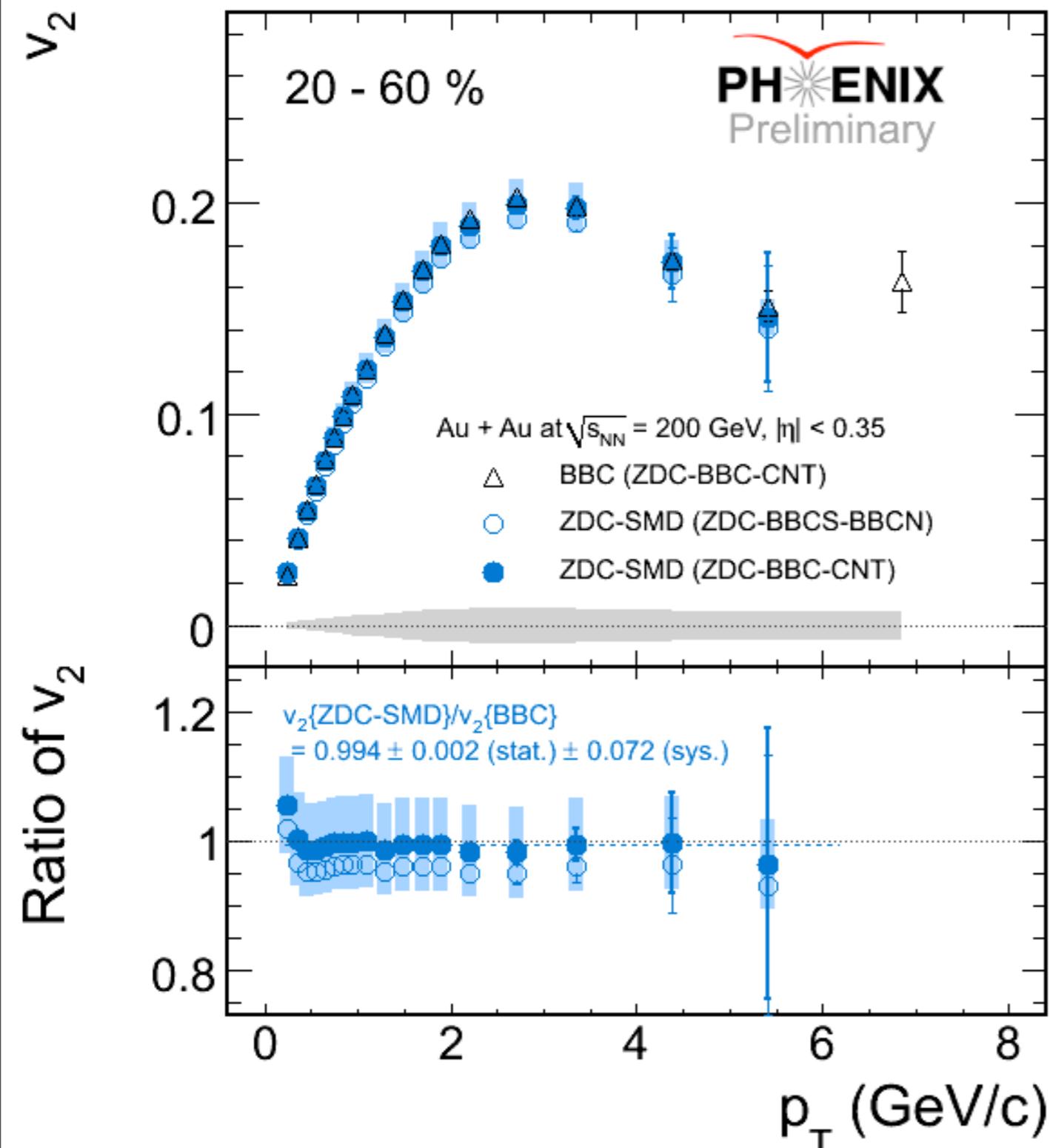
- $v_2\{\text{BBC}\}$ 
  - ✓ Increase up to  $p_T \sim 3$  GeV/c
  - ✓ Start decreasing for higher  $p_T$
- $v_2\{\text{ZDC-SMD}\}$ 
  - ✓ Consistent with  $v_2\{\text{BBC}\}$  within systematic errors
    - Dominant source of systematic errors is event plane determination
  - ✓  $v_2$  from ZDC-BBCS-BBCN resolution
    - Better systematic error
    - consistent with  $v_2$  from S-N resolution
- Ratio (ZDC-SMD/BBC)
  - ✓  $= 0.93 \pm 0.06$ , no  $p_T$  dependence

# PHENIX vs STAR



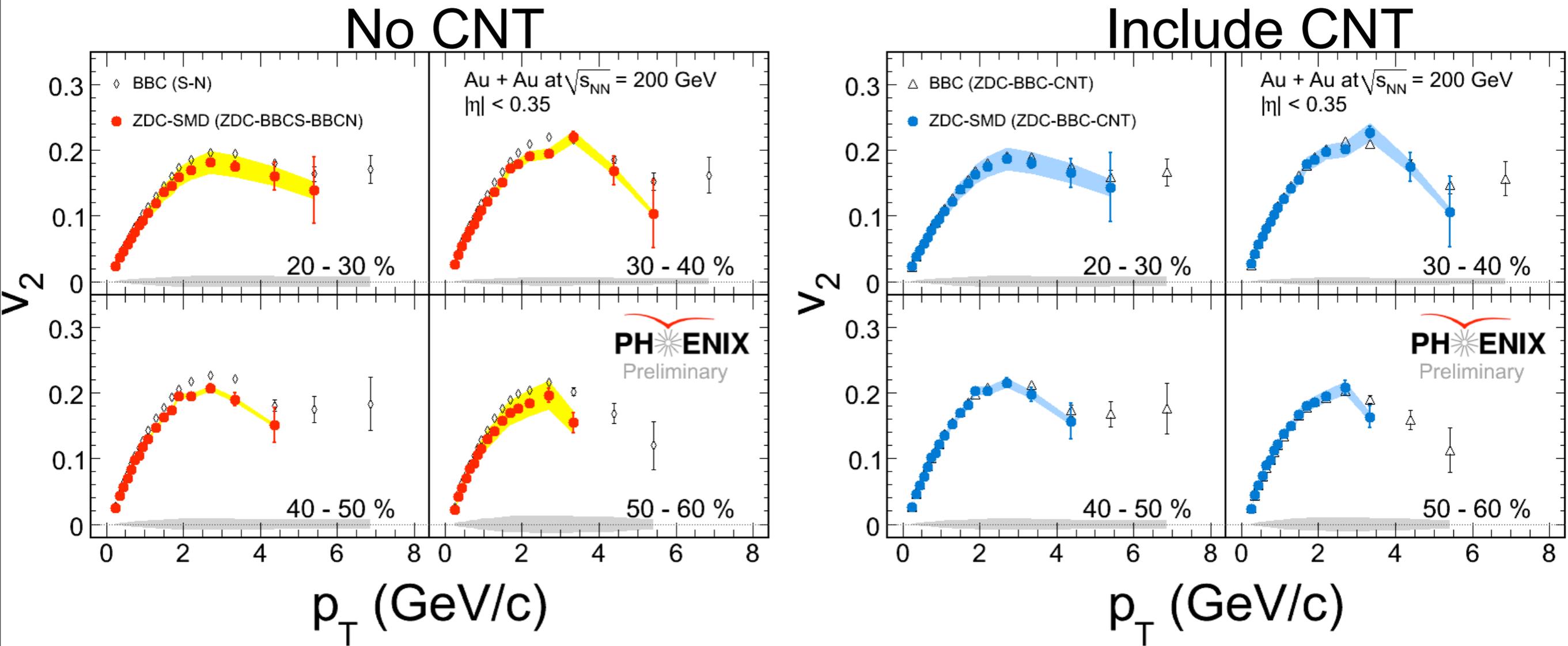
- $v_2\{\text{ZDC-SMD}\}$  in PHENIX and STAR
  - ✓ Resolution by S-N correlation
    - Same method
  - ✓ Ratio of  $v_2\{\text{ZDC-SMD}\}$  to polynomial fit of  $v_2\{\text{BBC}\}$
- Good agreement with STAR preliminary  $v_2\{\text{ZDC-SMD}\}$  within systematic errors

# $v_2$ with CNT resolution



- $v_2$  from ZDC-BBC-CNT resolution
  - CNT event plane has maximal sensitivity to non-flow
- ✓ Consistent with  $v_2\{\text{ZDC-SMD}\}$  from S-N as well as ZDC-BBCS-BBCN
- $v_2\{\text{ZDC-SMD}\}$  is more consistent with  $v_2\{\text{BBC}\}$ 
  - ✓ Because  $v_2\{\text{BBC}\} \downarrow$ ,  $v_2\{\text{ZDC-SMD}\} \uparrow$  with the CNT resolution
  - ✓ Non-flow from the CNT event plane ?

# Centrality dependence



- 10 % centrality bin in 20 - 60 %
- $v_2\{\text{ZDC-SMD}\}$  is consistent with  $v_2\{\text{BBC}\}$  within systematic error
- ✓  $v_2\{\text{ZDC-SMD}\} < v_2\{\text{BBC}\}$  at peripheral (left figure); non-flow effects ?

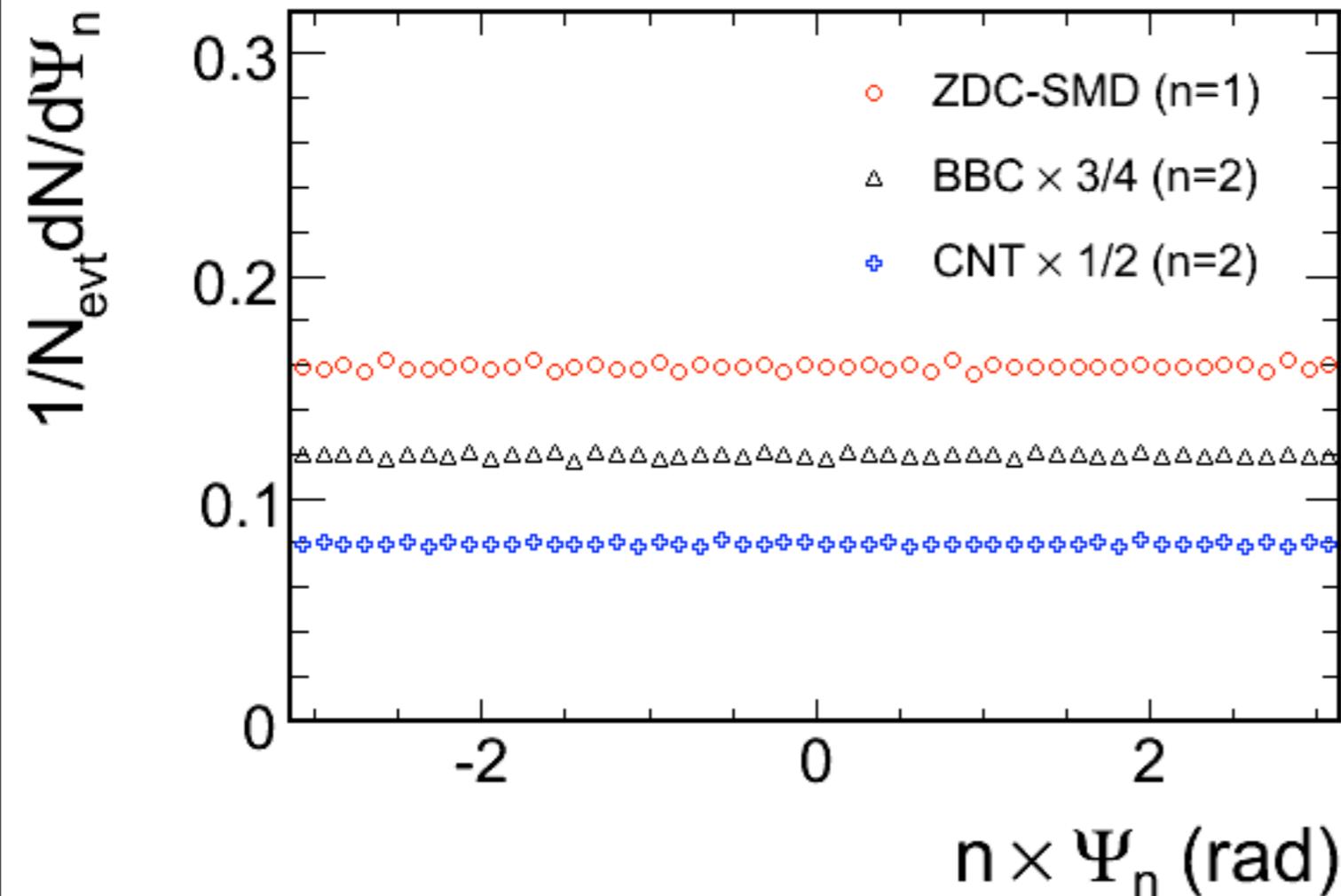
# Conclusions

- Measurement of charged hadron  $v_2$  with respect to the ZDC-SMD event plane from directed flow
- $v_2\{\text{ZDC-SMD}\}$  is consistent with  $v_2\{\text{BBC}\}$  within systematic uncertainties in 20 - 60 % centrality bins
  - ✓ Study several different event plane resolution corrections
  - ✓ Results are not so sensitive to the different resolutions
    - even we use CNT event plane resolution which has maximal sensitivity to non-flow
- Results indicate that non-flow contributions on  $v_2\{\text{BBC}\}$  could be minimal
  - ✓ because  $v_2\{\text{ZDC-SMD}\}$  is expected to be unbiased by non-flow effects
- Small difference of  $v_2$  between BBC and ZDC-SMD at peripheral 40 - 60 % may be due to the non-flow effects

# Extra slides

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# Flattening of event plane

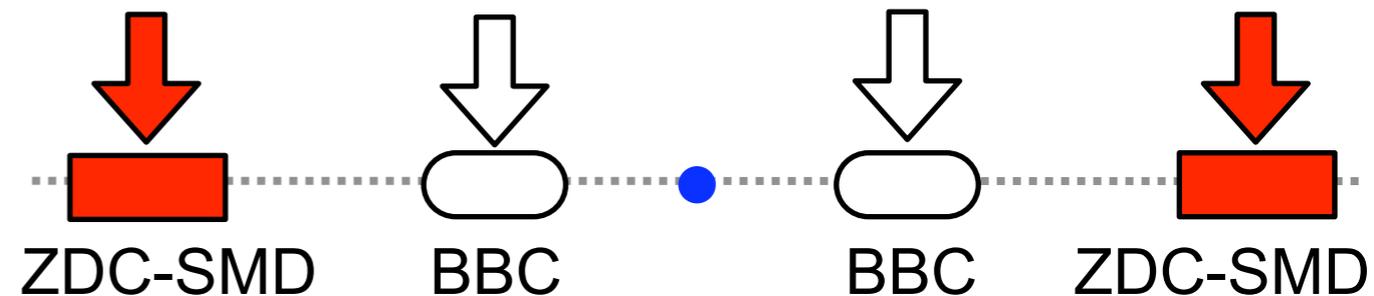
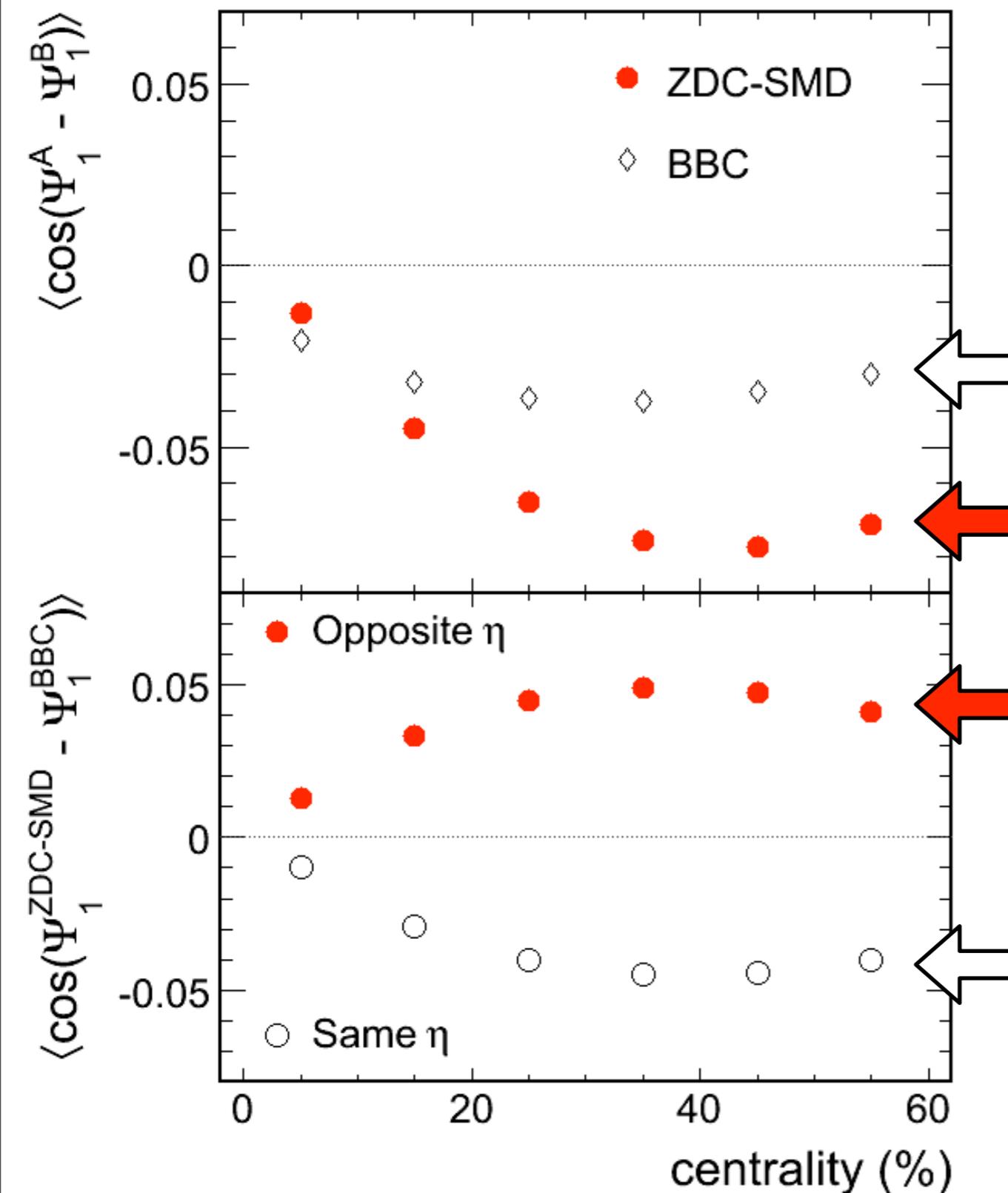


- Remove biases due to the finite acceptance of the detector
  - Flattening of the event planes
1. Re-centering correction
  2. Shift correction

$$1. \quad Q'_x = \frac{Q_x - \langle Q_x \rangle}{\sigma_x}, \quad Q'_y = \frac{Q_y - \langle Q_y \rangle}{\sigma_y}$$

$$2. \quad n\Delta\Psi_n = \sum_{k=1}^{k_{max}} \frac{2}{k} \left[ \langle \cos(kn\Psi_n) \rangle \sin(kn\Psi_n) - \langle \sin(kn\Psi_n) \rangle \cos(kn\Psi_n) \right]$$

# Event plane correlation



- ZDC-SMD > BBC

- ✓  $|v_1\{\text{ZDC-SMD}\}| > |v_1\{\text{BBC}\}|$

- and/or  $M_{\text{ZDC-SMD}} > M_{\text{BBC}}$

- Correlation between ZDC-SMD and BBC

- Opposite  $\eta$  (forward - backward) → Positive

- Same  $\eta$  (Forward - Forward or Backward - Backward) → Negative

- ✓ Opposite sign of  $v_1$  at the ZDC-SMD compared to that at the BBC