Azimuthal Charge-Particle Correlations and Possible Local Strong Parity Violation at RHIC

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for the STAR Collaboration

Outline

- Motivation
- Observable
- STAR data Analysis and Results

- Plans and New Ideas

Motivation

Chiral Magnetic Effect

The theory suggested that within Heavy Ion collisions, meta stable q/q˜ domains may be formed in which P, CP are violated (net chirality) by the strong interaction.

Lee, Wick, PRD9, 2291 (1974)

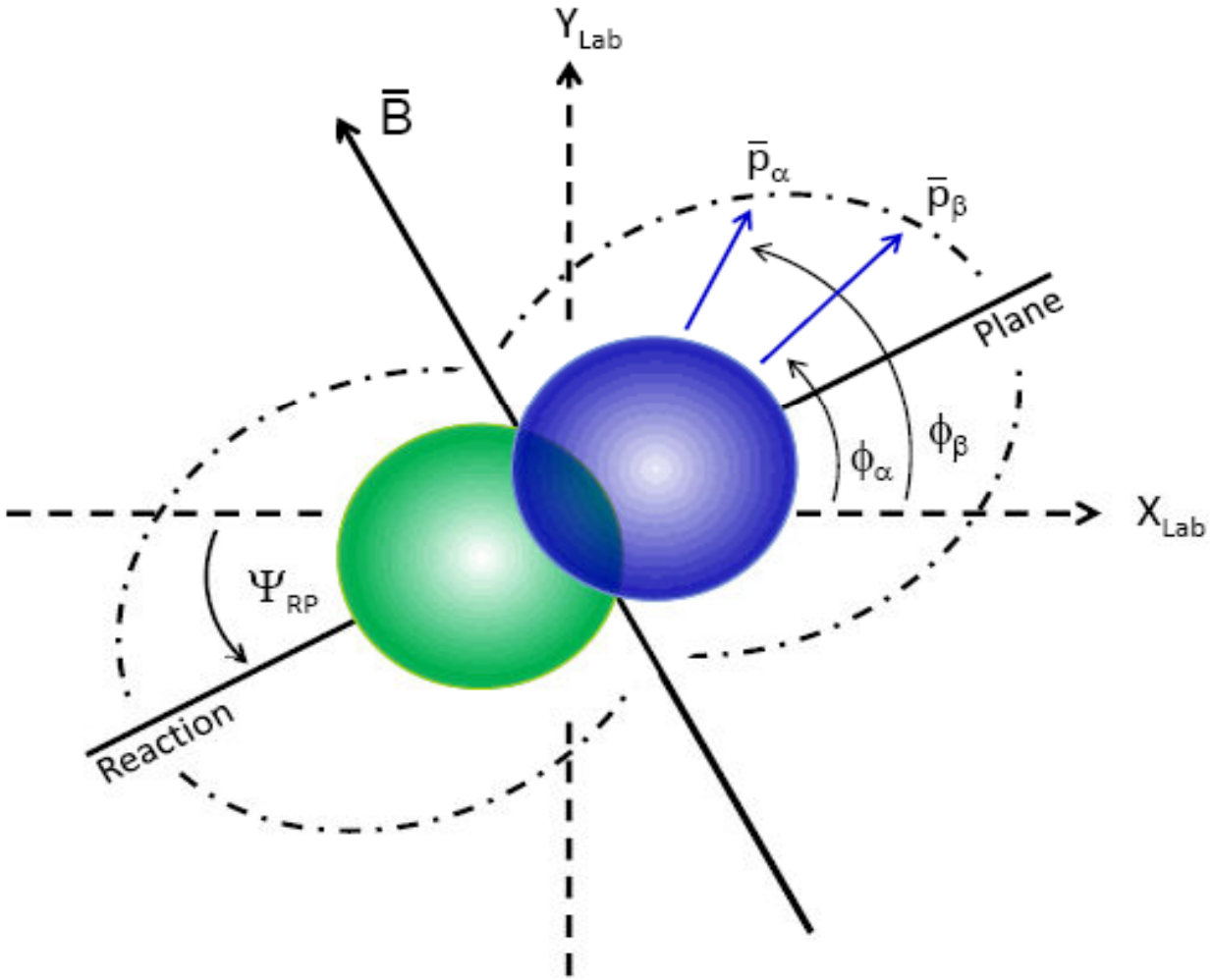
Morley and Schmidt, Z.Phyz. C26, 627 (1985)

Kharzeev, Pisarski and Tytgat, PRL81, 512 (1998)

Kharzeev, McLerran, Warringa, Nucl.Phys.A803,227(2008)

The strong Magnetic field of the collision induces Electric field, which leads to separation of charge along the angular momentum vector of the collision.

Collision geometry



JT

Event azimuthal distribution

$$dN_{\pm}/d\varphi \sim 1 + 2\cdot\Sigma_{n} v_n\cdot\cos(n\Delta\varphi) + 2\cdot a_{\pm}\cdot\sin(\Delta\varphi)$$

$\Delta\varphi = \varphi - \Psi_{RP}$ - particle azimuth relative to RP

Ψ_{RP} - Reaction Plane (RP) angle

v_n - symmetrical harmonic,

n=1 directed flow, n=2 elliptic flow

$a_{\pm}$ - asymmetrical first harmonic

Observable

For single event: $|a_{\pm}|$ << fluctuations.

For many events: $< a_+ > = < a_- > = 0$ (due to $<\mathbf{E}\cdot\mathbf{B}> = 0$).

Event by event correlation: $< a_+ a_+ > = < a_- a_- > = - < a_+ a_- > \; > \; 0$

Parity even observable but sensitive to CME was proposed by S.Voloshin, PRC70:057901 (2004)

Two-particles correlation:

$$<\cos(\varphi_\alpha+\varphi_\beta-2\Psi_{RP})> = <\cos\Delta\varphi_\alpha\cdot\cos\Delta\varphi_\beta> - <\sin\Delta\varphi_\alpha\cdot\sin\Delta\varphi_\beta>$$
$$= [<v_{1\alpha}v_{1\beta}> + BG^{in}] - [< a_\beta a_\alpha> + BG^{out}]$$

$<v_{1\alpha}v_{1\beta}>$ – directed flow (≈ 0)

RP independent background cancel out.

BG^{in}, BG^{out} – in, out of plane background.

Observable (cont.)

Three-particle correlation: α, β, c

Under the assumption that particle "c" is correlated with particles "α,β" only via common RP correlation, we have:

$$\langle\cos(\varphi_\alpha+\varphi_\beta-2\varphi_c)\rangle = \langle\cos(\varphi_\alpha+\varphi_\beta-2\Psi_{RP})\rangle\cdot\langle v_{2c}\rangle$$

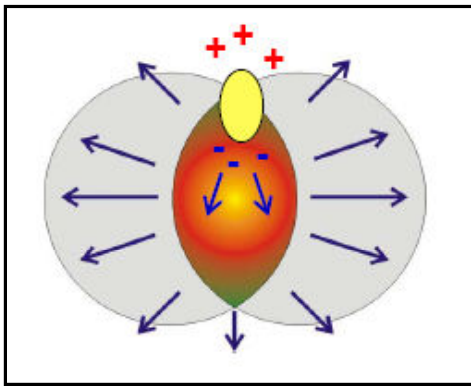
measured — observable — measured

ellipt. flow

The explicit determination of event plane is not required.

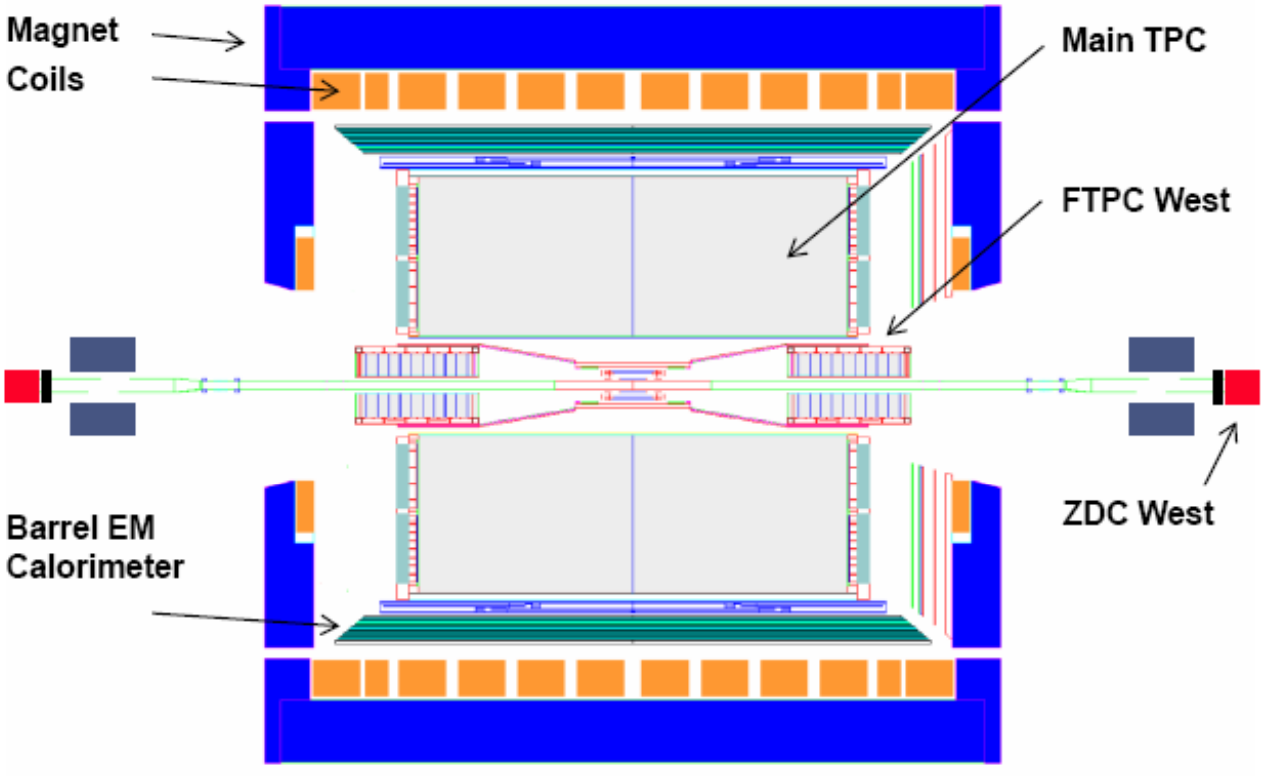
Expectations for correlations from Chiral Magnetic Effect.

- $|a_{\pm}| \approx 1\%$ for mid-central Au-Au collisions
- For given system $|\langle a_{\pm}a_{\pm}\rangle| \sim 1/N_{ch}$



- Quenching may cause $\langle a_{+}a_{-}\rangle$ suppression.
- *A* dependence would expect less quenching in smaller or less dense systems. For given *A*, expect $|a_{\pm}|$ to scale with *Z*.
- Effect expect at the range of $|\Delta\eta| < 1$ & $pt < 1$ GeV/c.

STAR detector at RHIC



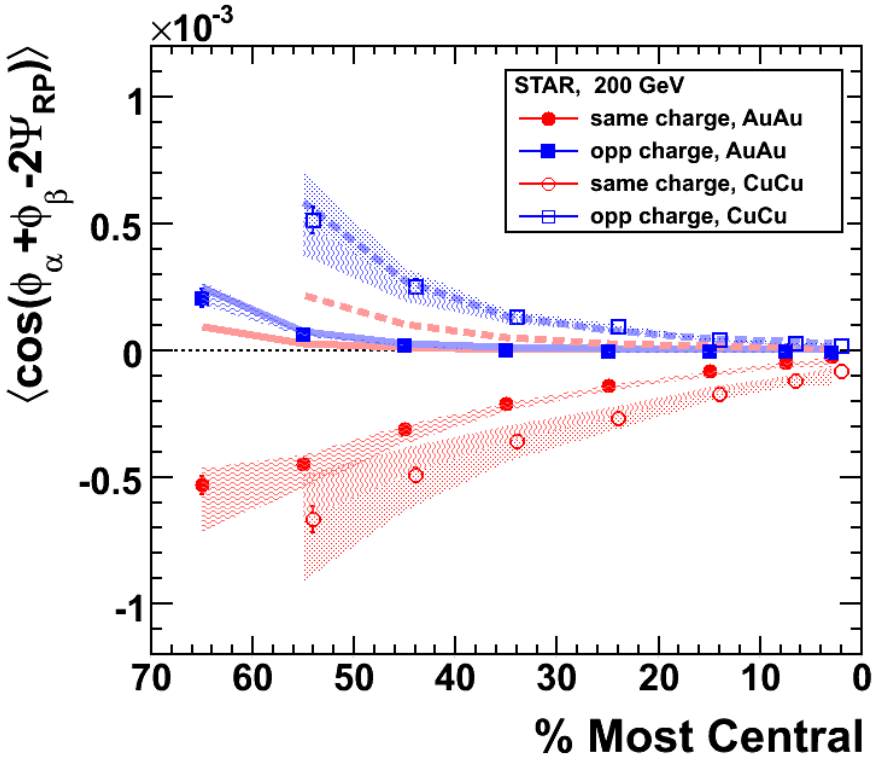
- Tracking is done by the Main TPC and independently by two Forward TPCs
- ZDC-SMD measures spectator neutrons and can be used to determine the first order reaction plane
- Tracking cuts:
  - $|\eta| < 1.0$ (Main TPC)
  - $-3.9 < \eta < -2.9$
    $3.9 < \eta < 2.9$ (FTPCs)
  - $0.15 < p_T < 2.0$ GeV/c

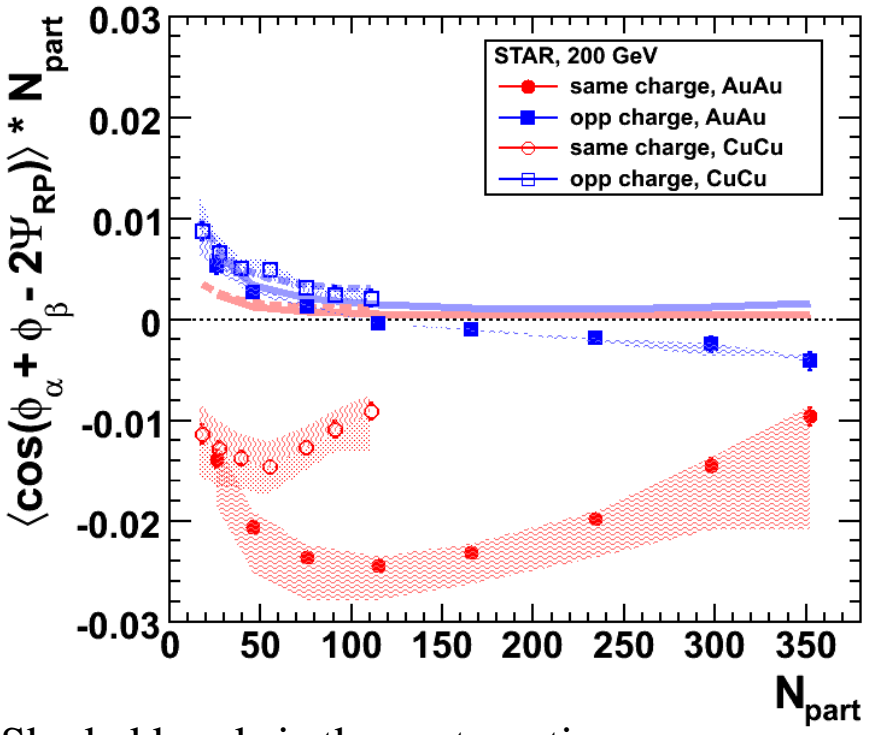
TI

Data from RHIC runs IV and V

Au+Au	200 GeV	~	10.6 M Minimum Bias events
Au+Au	62 GeV	~	7.0 M Minimum Bias events
Cu+Cu	200 GeV	~	30 M Minimum Bias events
Cu+Cu	62 GeV	~	19 M Minimum Bias events

200 GeV AuAu vs CuCu

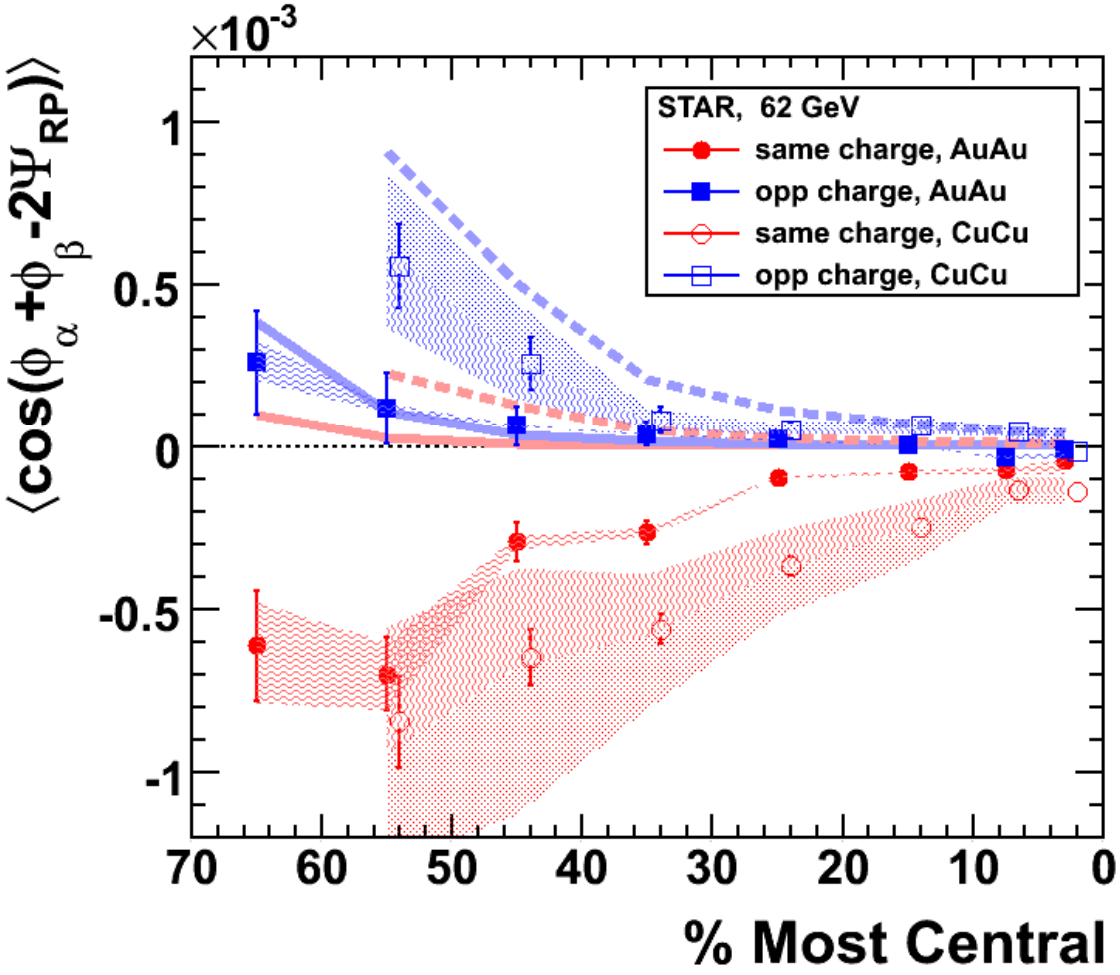




Shaded bands is the systematic error represent error in v2,c determination

1. Unlike sign in CuCu compared to AuAu consistent with the idea of less quenching in smaller system (there is a large potential background on all unlike-sign points)
2. In central AuAu, there is a significant “wrong” signal in the unlike-sign correlations.

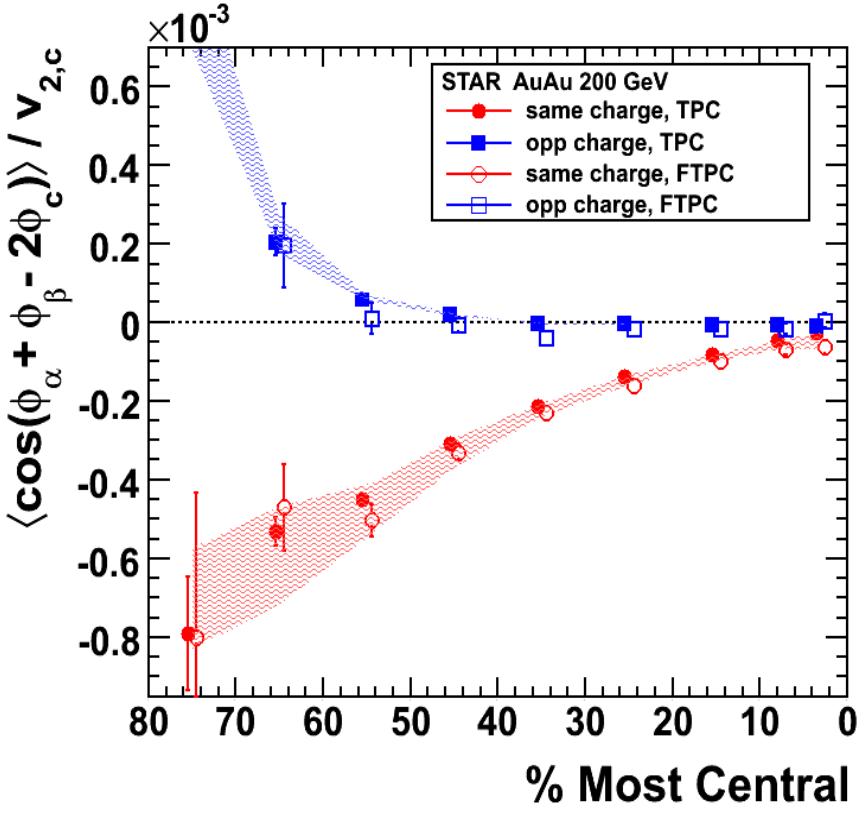
62 GeV AuAu vs CuCu

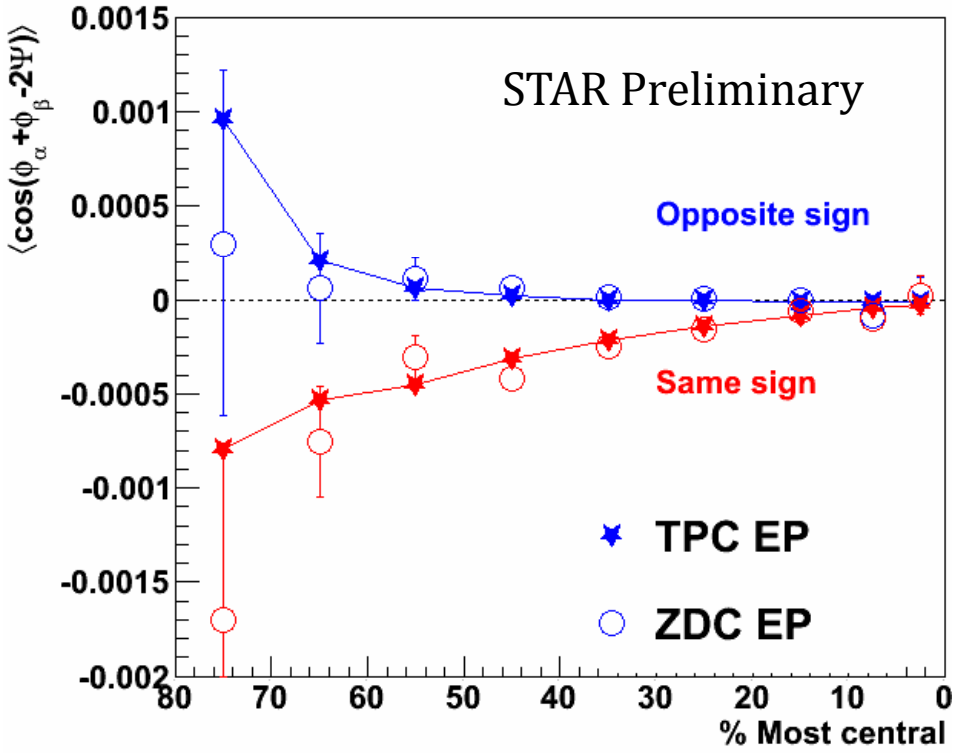


Similar to the 200 GeV results. Signal somewhat larger (less combinatoric dilution) and shows consistency with "less quenching in less dense systems"

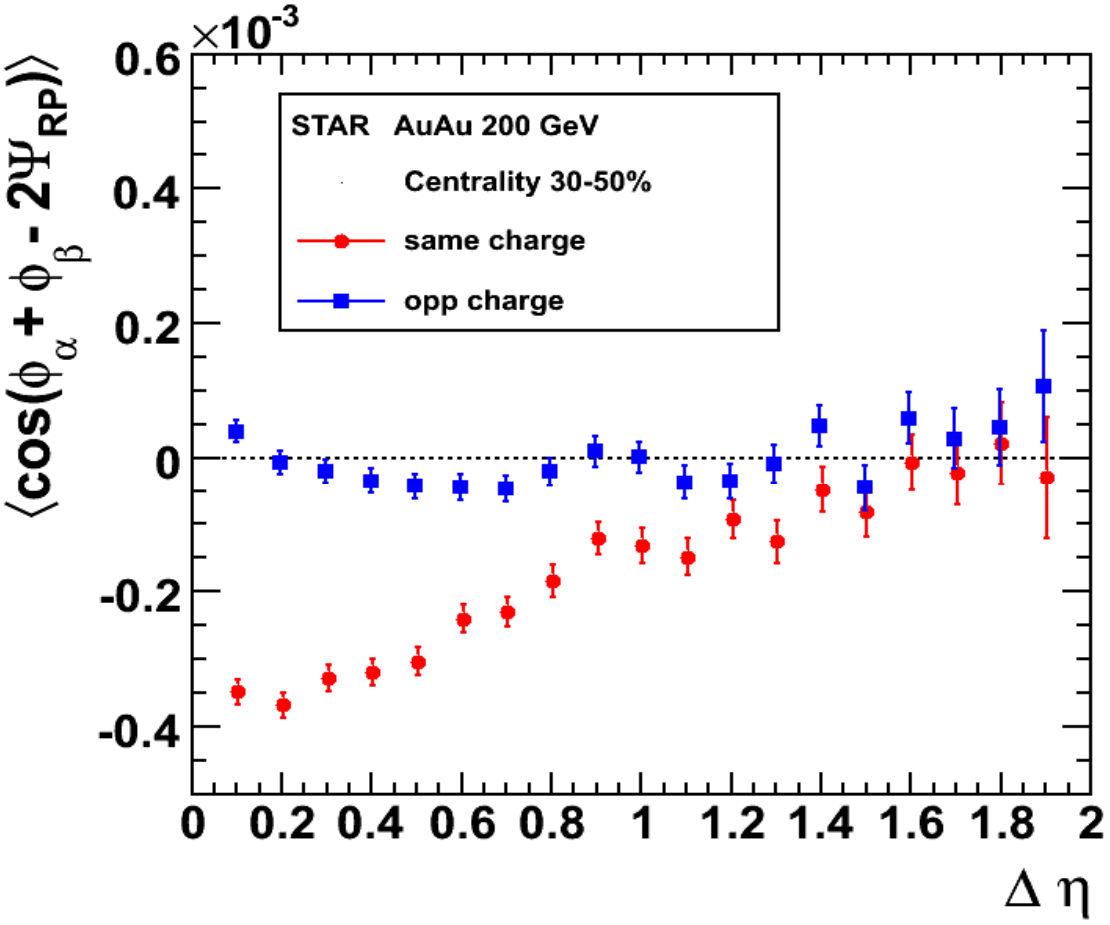
Checking factorization in data

A test of factorization (i.e. $\langle\cos(\varphi_a+\varphi_b-2\Psi_{r.p.})\rangle = \langle\cos(\varphi_a+\varphi_b-2\varphi_c)\rangle/v_{2,c}$) is that finding the reaction plane using different detectors gives consistent results.



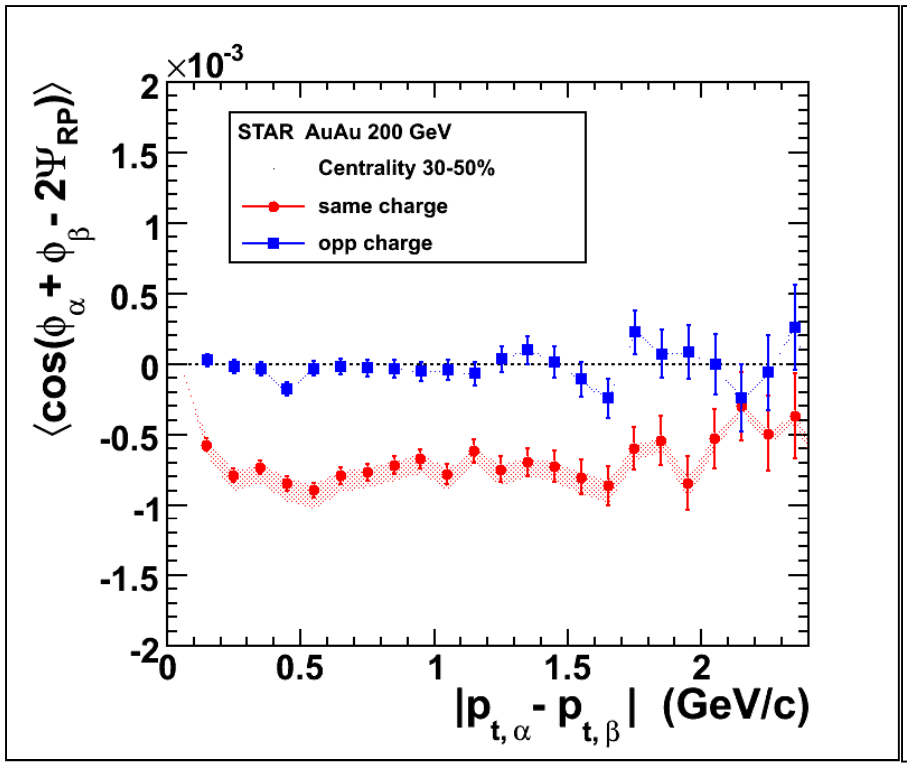


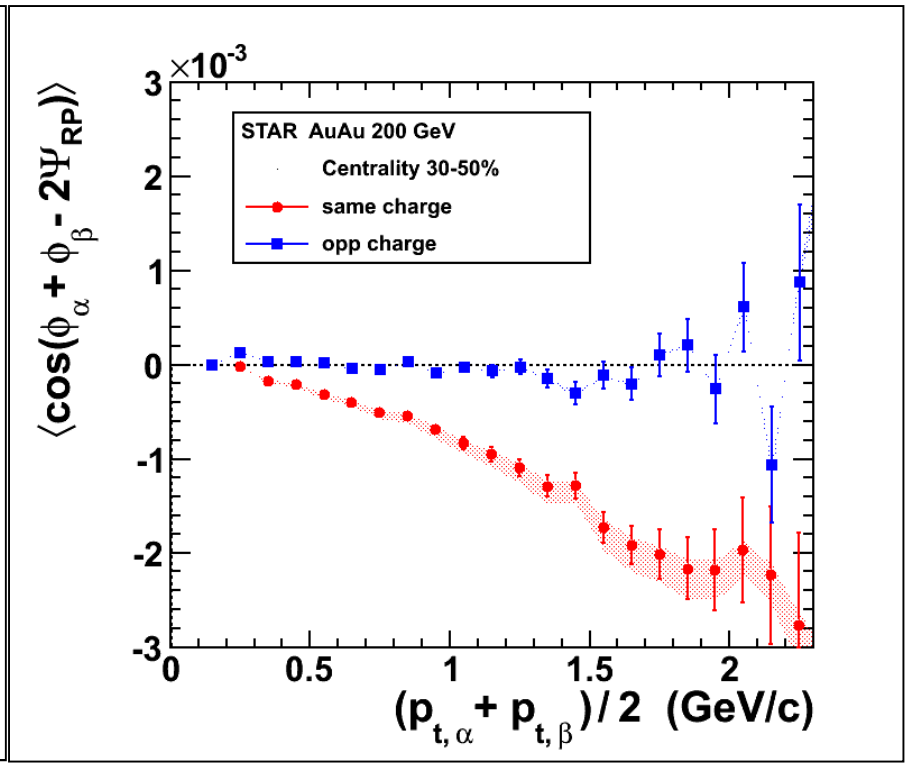
Δη dependence of signal



- Agrees roughly with expectations (there is no quantitative prediction from C.M.E. theory).

p_t dependence of signal





Signal is roughly constant for a p_t difference from 0 to 2 GeV/c. Would seem to rule out causes like HBT, Coloumb

Signal grows with average p_t up to 2 GeV/c Not as initially expected. (Can this be accommodated quantitatively by the C.M.E. theory?)

Physics Background

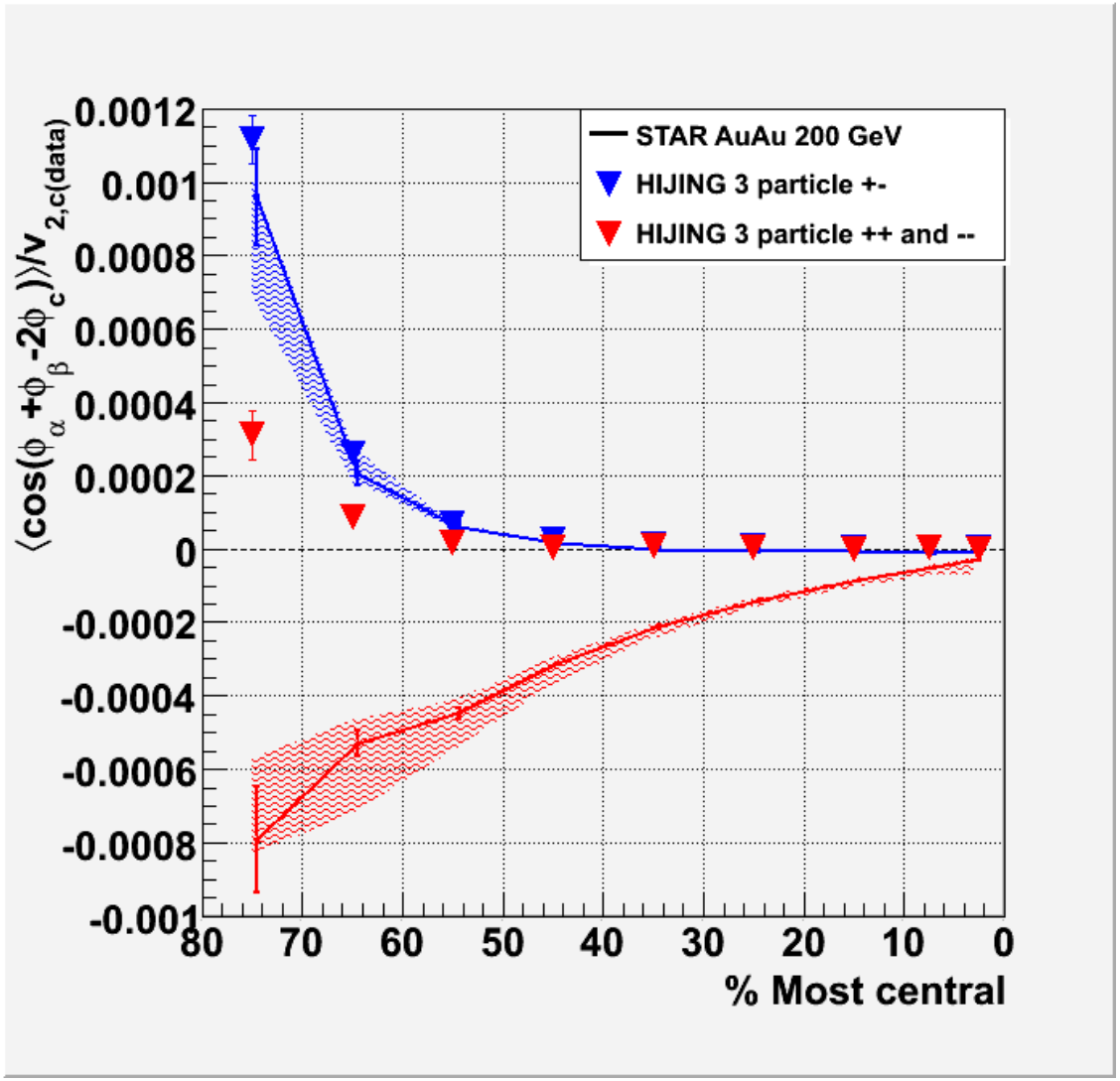
a) 3 (or more)-particle clusters, independent of reaction plane.

- Affect factorization $\langle\cos(\varphi_a + \varphi_b - 2\Psi_{r.p.})\rangle = \langle\cos(\varphi_a + \varphi_b - 2\varphi_c)\rangle / v_{2,c}$
- In principle, reducible if we can determine reaction plane in a way uncorrelated with 'signal' particles.
- Expected to scale as $1/N_{ch}^2$

b) 2 (or more)-particle clusters with reaction plane dependence.

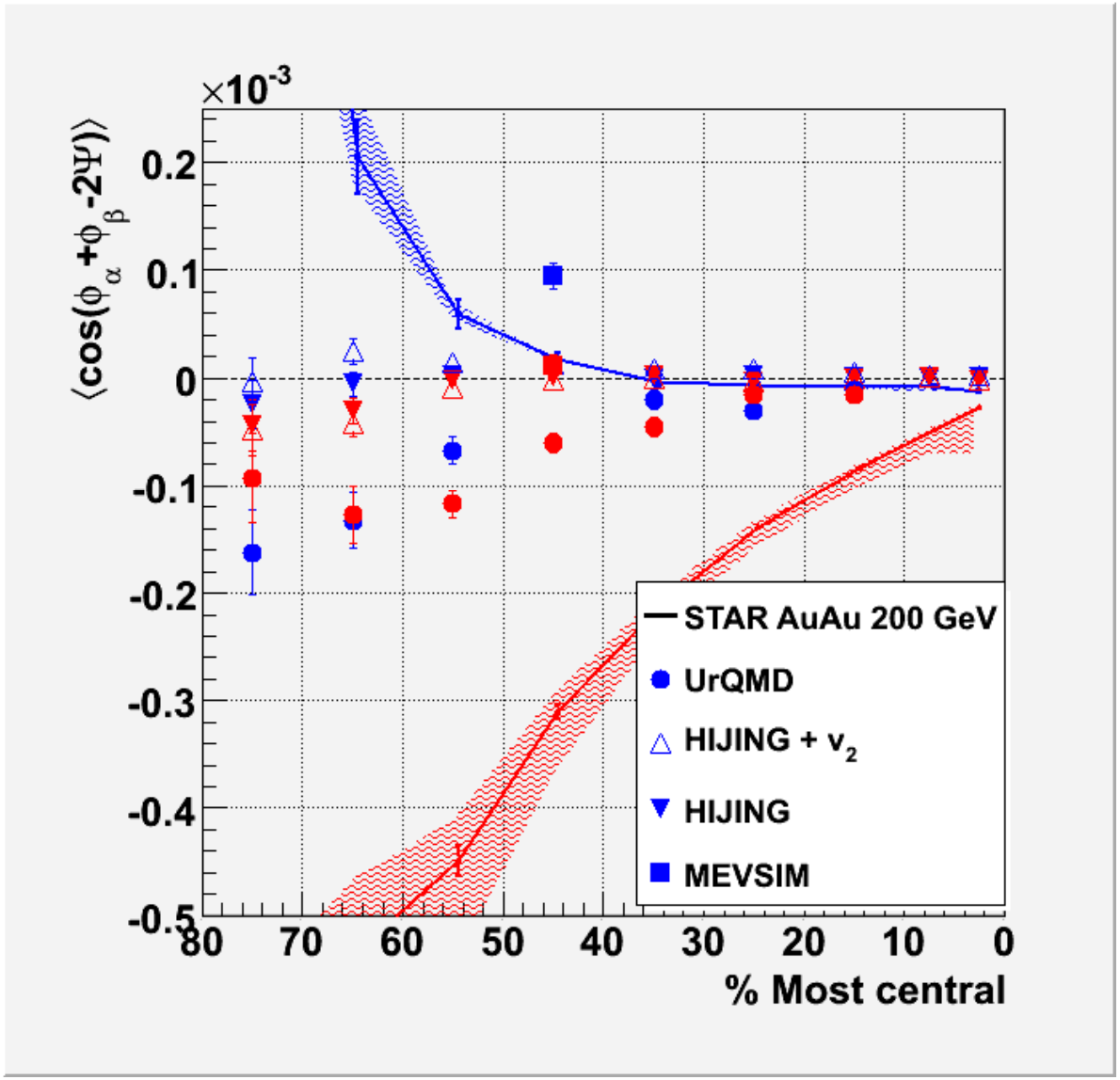
- Cannot disentangle just by better measurement of reaction plane.

Reaction-plane independent background



HIJING predicts that this background is about as large as measured signal for unlike-sign in several peripheral bins in all systems measured, but not significant background for like-sign correlations over most of centrality range. UrQMD predicts a considerably smaller 3-particle cluster background.

RP dependent background (with Ψ known)



Summary

- STAR has measured charge dependent azimuthal correlations which are sensitive to charge separation predicted as a result of local strong CP violation in the Chiral Magnetic Effect.
- Like-sign correlations:
  - Show rough agreement with expectations from chiral magnetic effect, p_t dependence is not what is naively expected.
  - No clear explanation from other physics backgrounds.
- Unlike-sign correlations
  - Much smaller than like-sign correlations and
  - Likely a very significant contribution to measured correlator from 3-particle clusters.
- Publications:

  Short version: arXiv: 0909, 1739 (accepted by PRL)

  Long version: arXiv: 0909, 1717 (submitted to PRC)

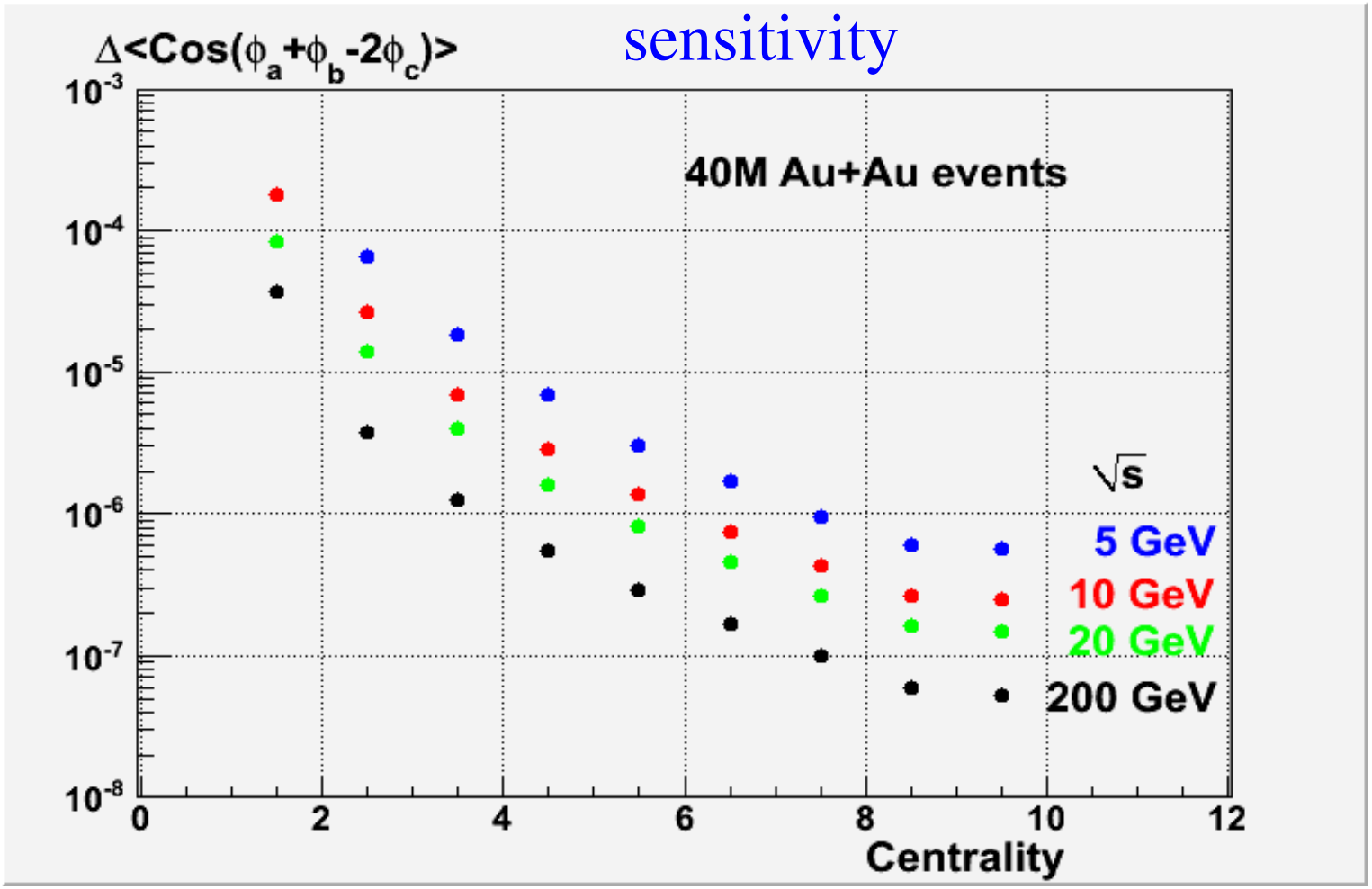
Plans & New Ideas

- Beam Energy Scan
- "Zero Signal" test: (π^0,π^0), (K^s,K^s), $(K^s,\pi^{\pm})$
- Magnetic Field effect on events in HIC

Beam Energy Scan (critical point search)

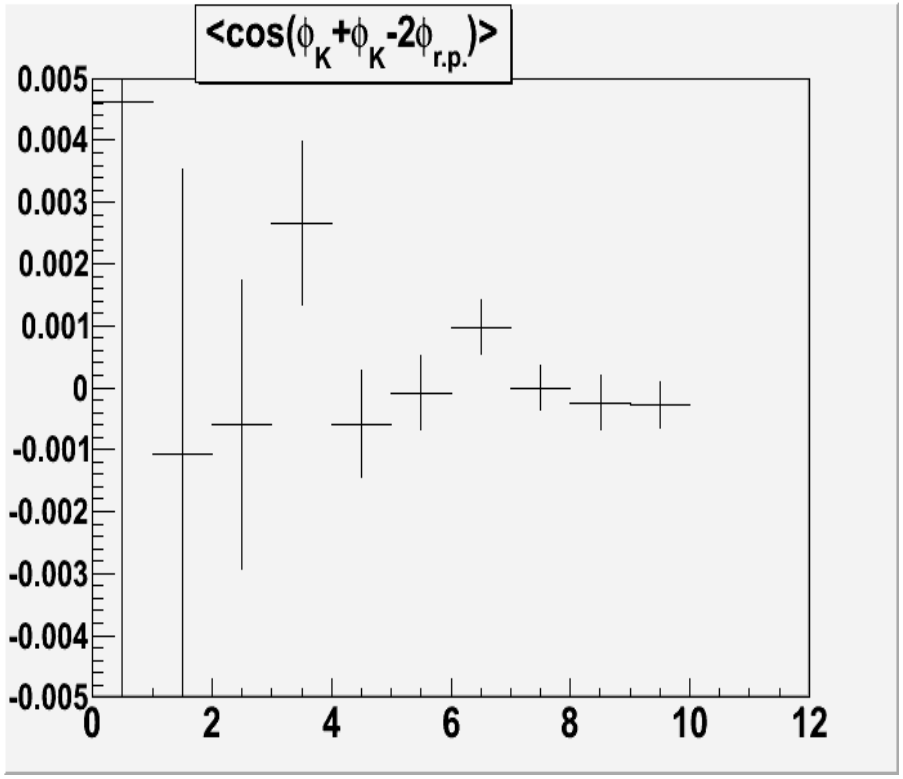
$\sqrt{s}$: 7.7, 11.5, 18, 27 GeV

expected # of events: 0.64, 3-5, 0-10, 45-80 M

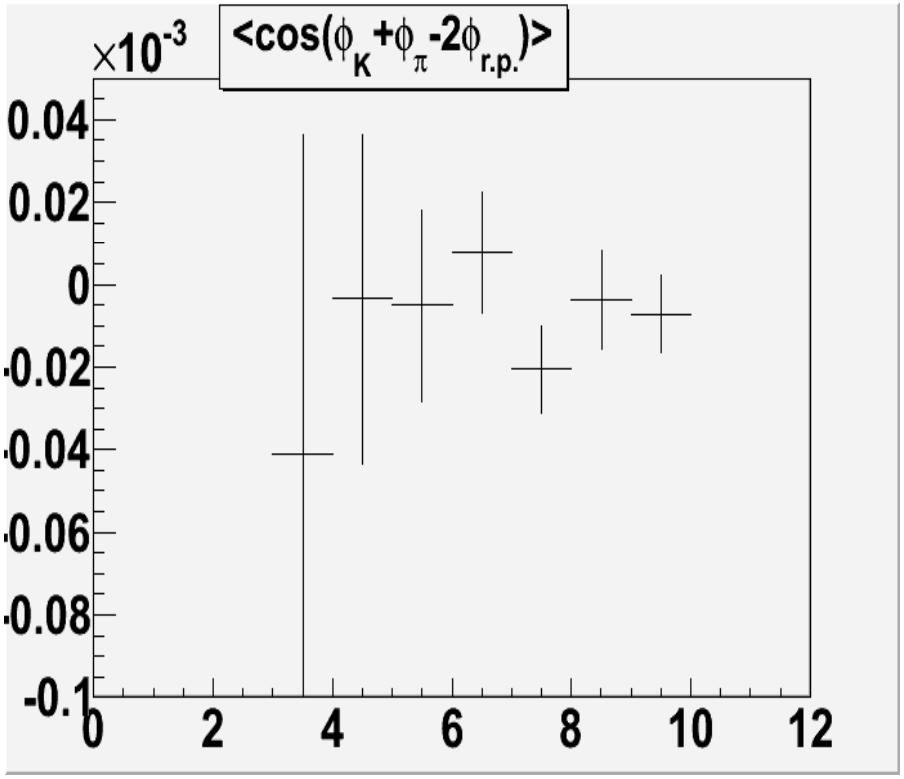


Statistical errors for (K^s,K^s) & $(K^s,\pi^{\pm})$ correlation

50 M 200 GeV Au+Au events (simulation)



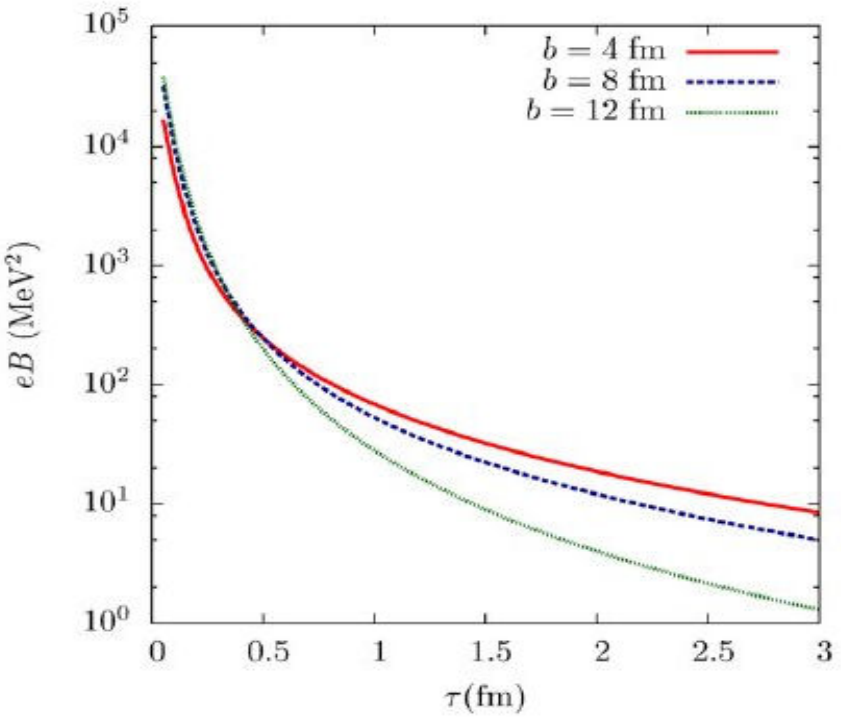
Centrality

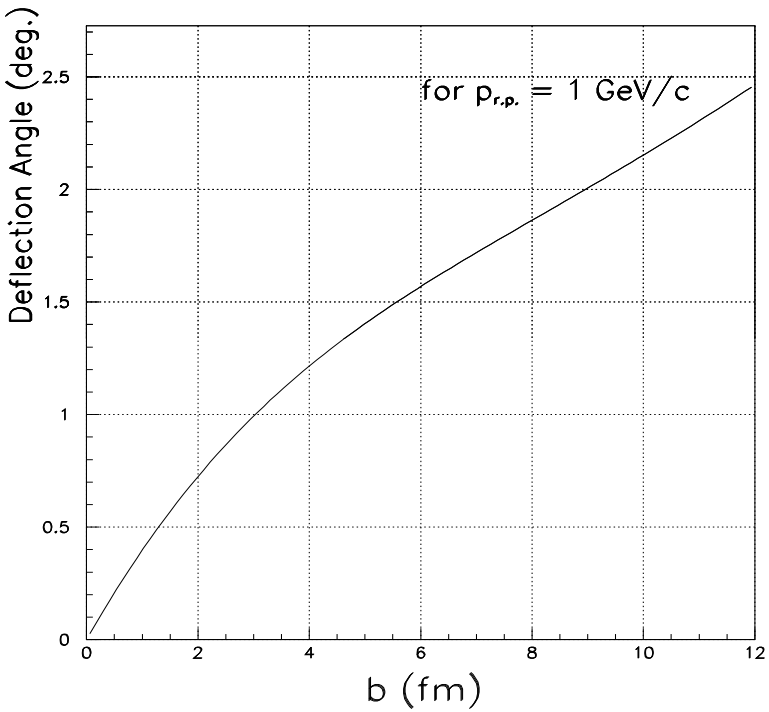


Centrality

Study of Magnetic Field effect on events in HIC

D.E. Kharzeev et al. / Nuclear Physics A 803 (2008) 227–253





First order reaction plane (ZDC-SMD) is necessary