Local parity violation - measurement, new observable and alternative contributions

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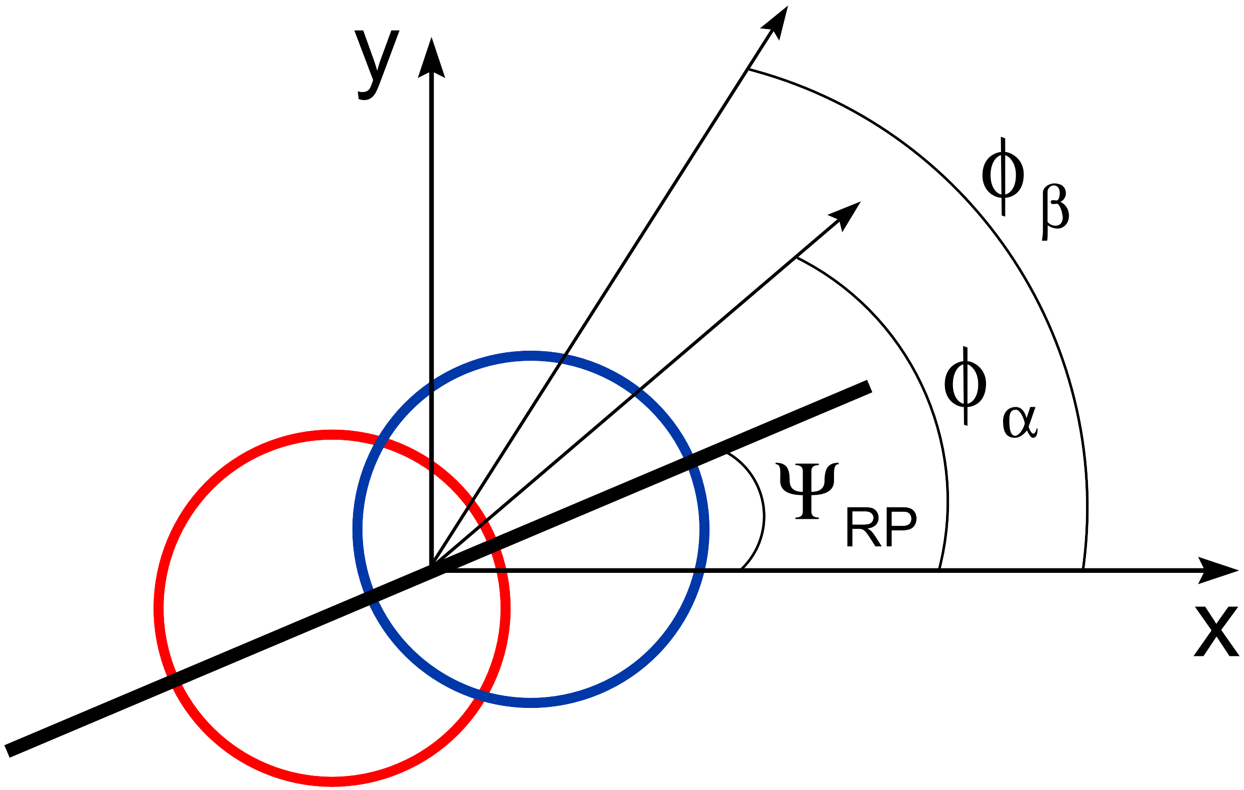
arXiv:0912.5050 [nucl-th] (PRC), 1005.5380 [nucl-th], tbs [nucl-th]

Outline

- introduction
- STAR data: integrated signal, p_t and η distributions
- v_2 contribution
- new dipole analysis
- transverse momentum contribution
- conclusions

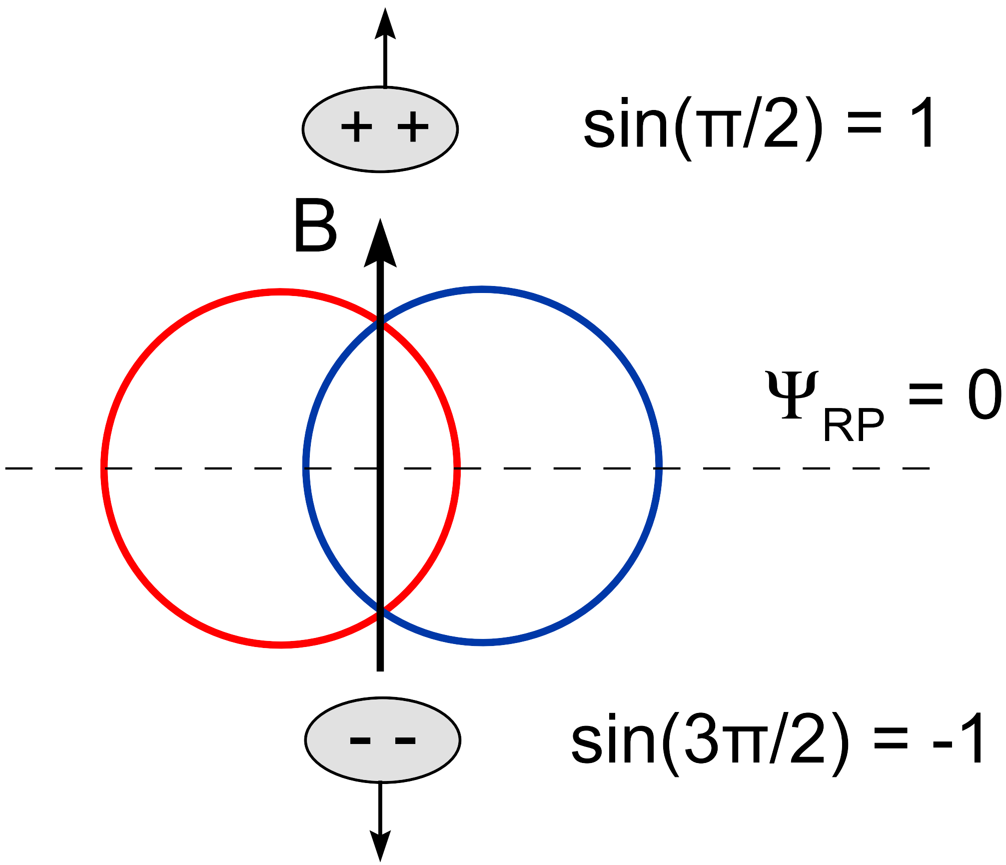
Introduction

Reaction plane



We work in the frame where $\Psi_{RP} = 0$

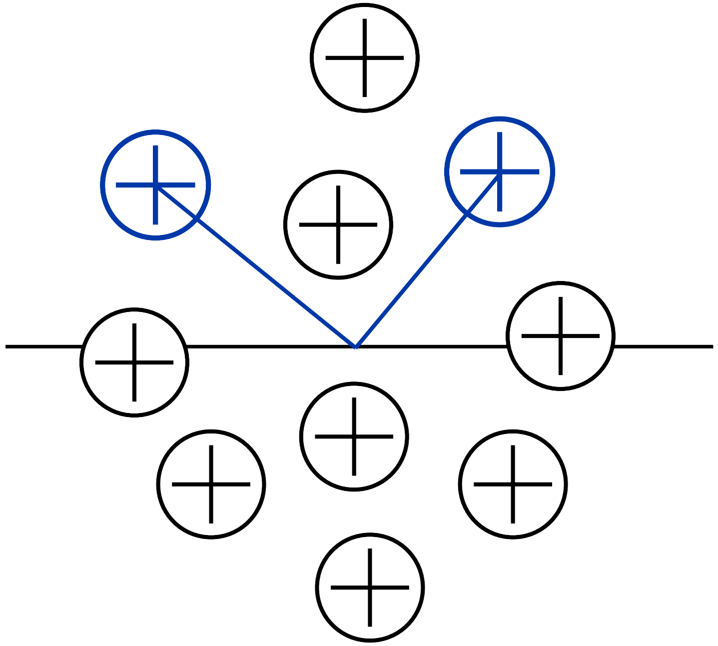
Chiral Magnetic Effect



$$\boxed{\left\langle \sin(\phi_\alpha)\sin(\phi_\beta)\right\rangle_{same} > 0, \qquad \left\langle \cos(\phi_\alpha)\cos(\phi_\beta)\right\rangle_{same} = 0}$$

$$\left\langle \cos(\phi_\alpha + \phi_\beta)\right\rangle_s = \left\langle \cos(\phi_\alpha)\cos(\phi_\beta)\right\rangle_s - \left\langle \sin(\phi_\alpha)\sin(\phi_\beta)\right\rangle_s < 0$$

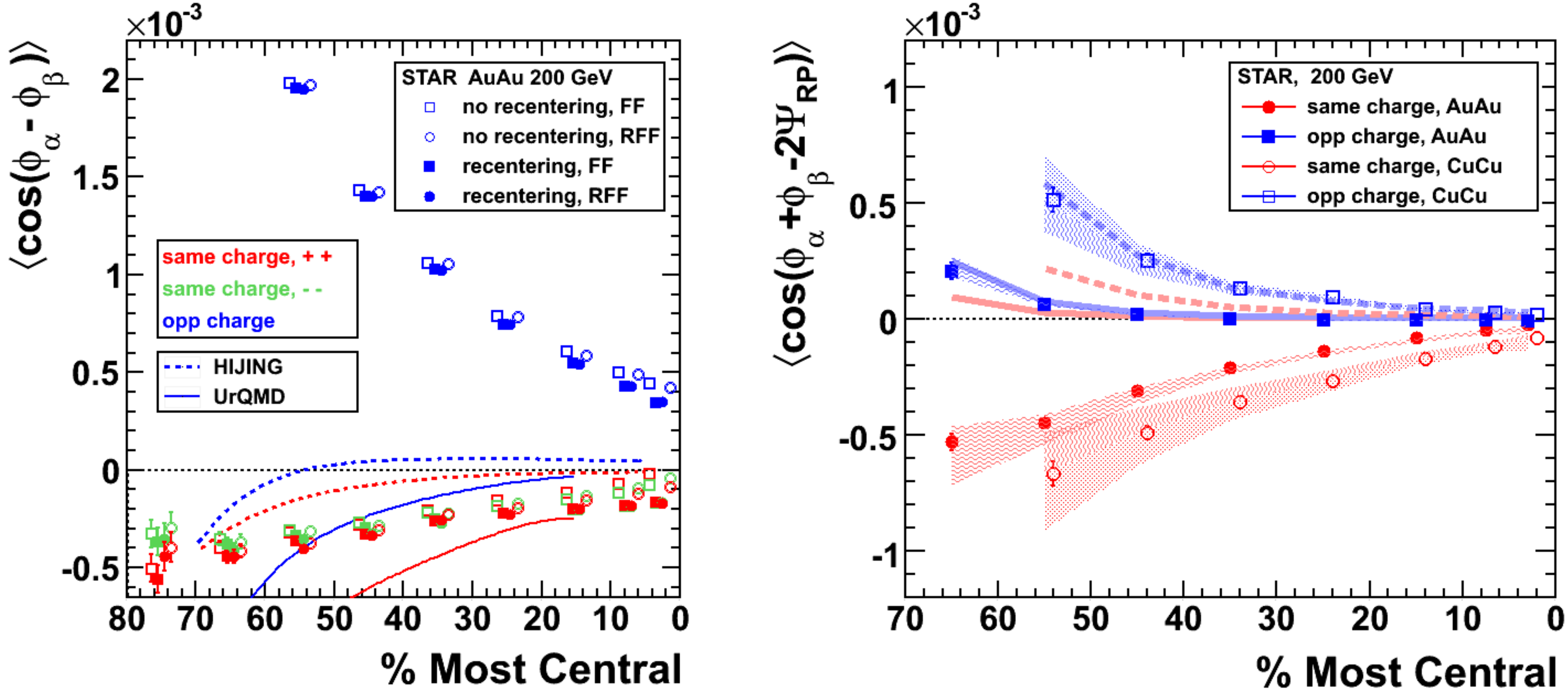
Definition:



$$\left\langle \cos(\phi_\alpha - \phi_\beta) \right\rangle_{same} = \left\langle \frac{\sum\limits_{i \neq k} \cos(\phi_i - \phi_k)}{\sum\limits_{i \neq k} 1} \right\rangle$$

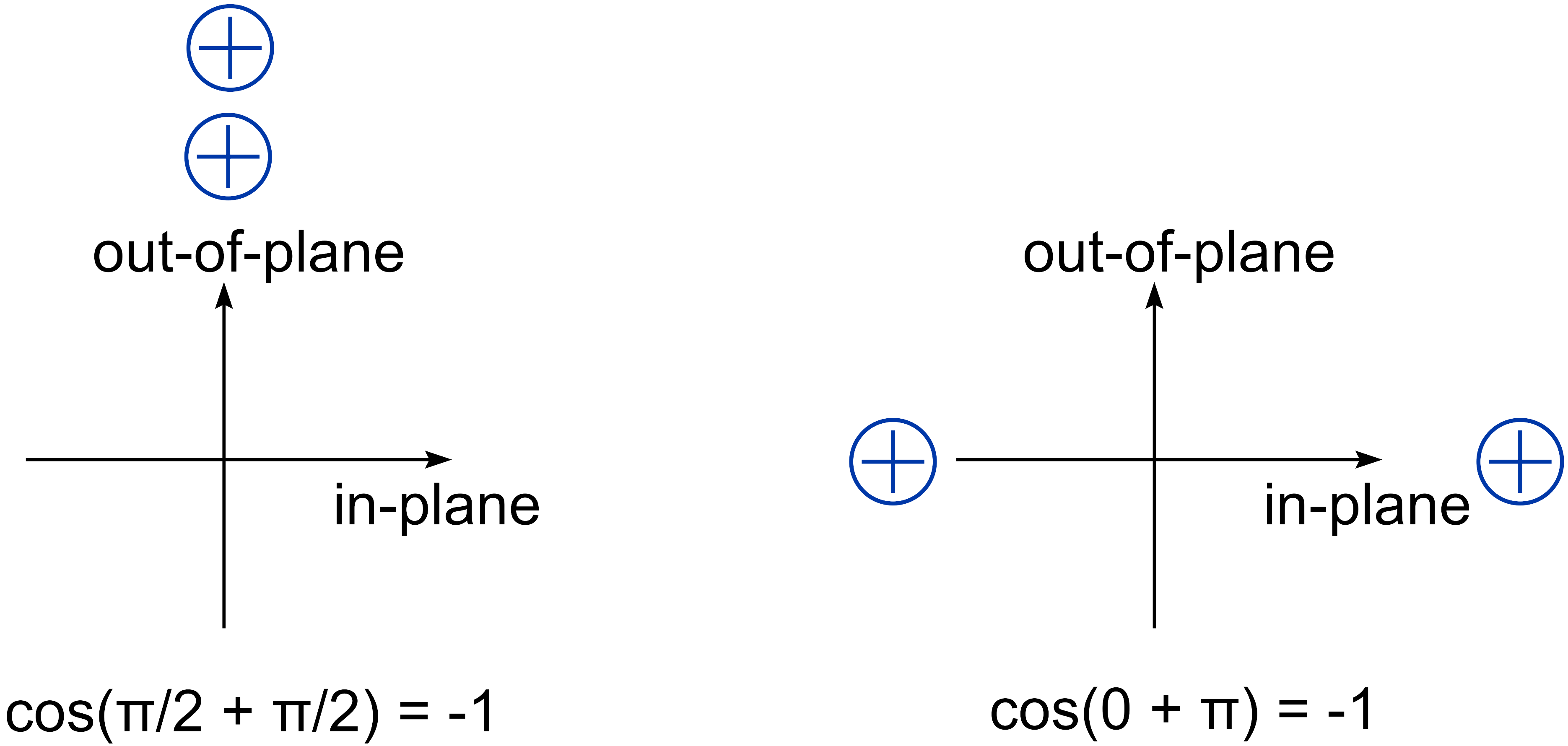
Integrated signal

STAR data: PRL 103 (2009) 251601; PRC 81 (2010) 54908



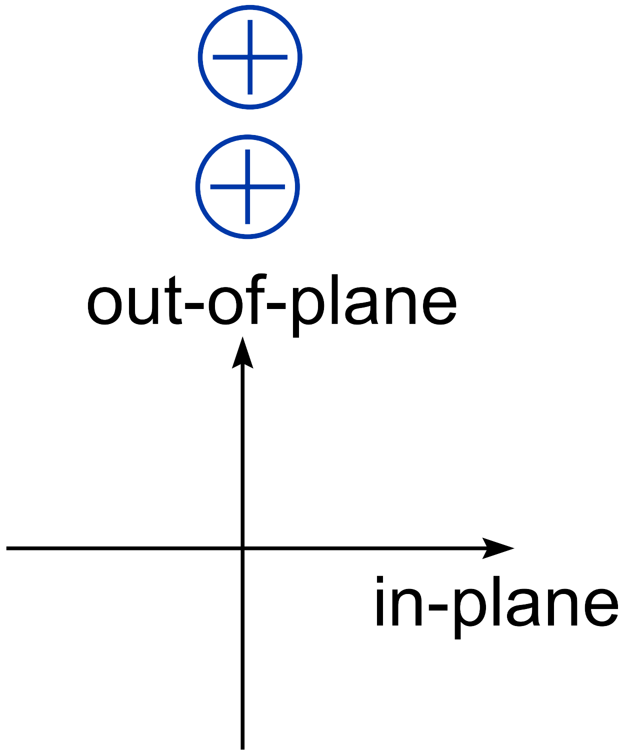
$$\langle \cos(\phi_\alpha + \phi_\beta) \rangle_{same} < 0$$

Chiral Magnetic Effect vs 'Trouble' Effect



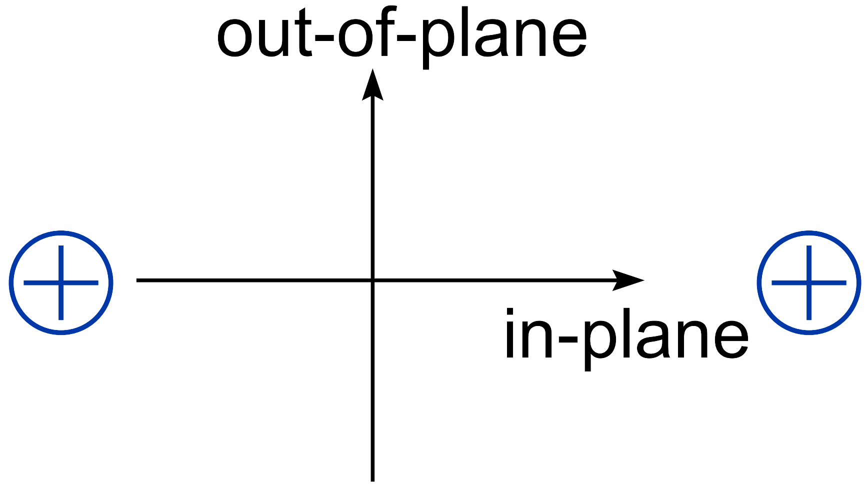
How to distinguish between the two?

Chiral Magnetic Effect vs 'Trouble' Effect



$\cos(\pi/2 + \pi/2) = -1$

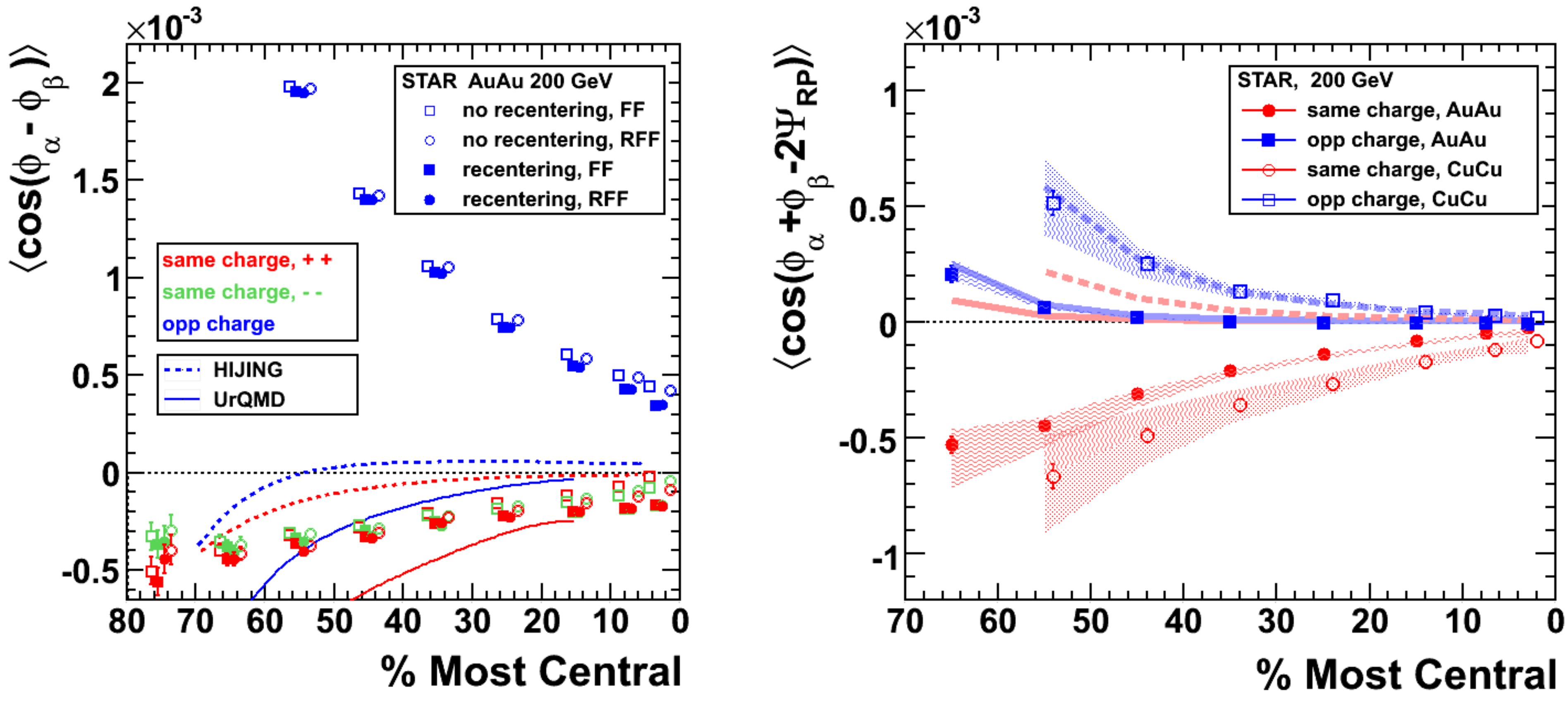
$\cos(\pi/2 - \pi/2) = +1$



$\cos(0 + \pi) = -1$

$\cos(0 - \pi) = -1$

STAR data



$$\left\langle \cos(\phi_\alpha - \phi_\beta) \right\rangle_{same} \simeq \left\langle \cos(\phi_\alpha + \phi_\beta) \right\rangle_{same} < 0$$

$$\left\langle \cos(\phi_\alpha - \phi_\beta) \right\rangle_{opposite} > 0; \quad \left\langle \cos(\phi_\alpha + \phi_\beta) \right\rangle_{opposite} \approx 0$$

from

$$\left\langle \cos(\phi_\alpha - \phi_\beta) \right\rangle = \left\langle \cos(\phi_\alpha)\cos(\phi_\beta) \right\rangle + \left\langle \sin(\phi_\alpha)\sin(\phi_\beta) \right\rangle$$

$$\left\langle \cos(\phi_\alpha + \phi_\beta) \right\rangle = \left\langle \cos(\phi_\alpha)\cos(\phi_\beta) \right\rangle - \left\langle \sin(\phi_\alpha)\sin(\phi_\beta) \right\rangle$$

we obtain

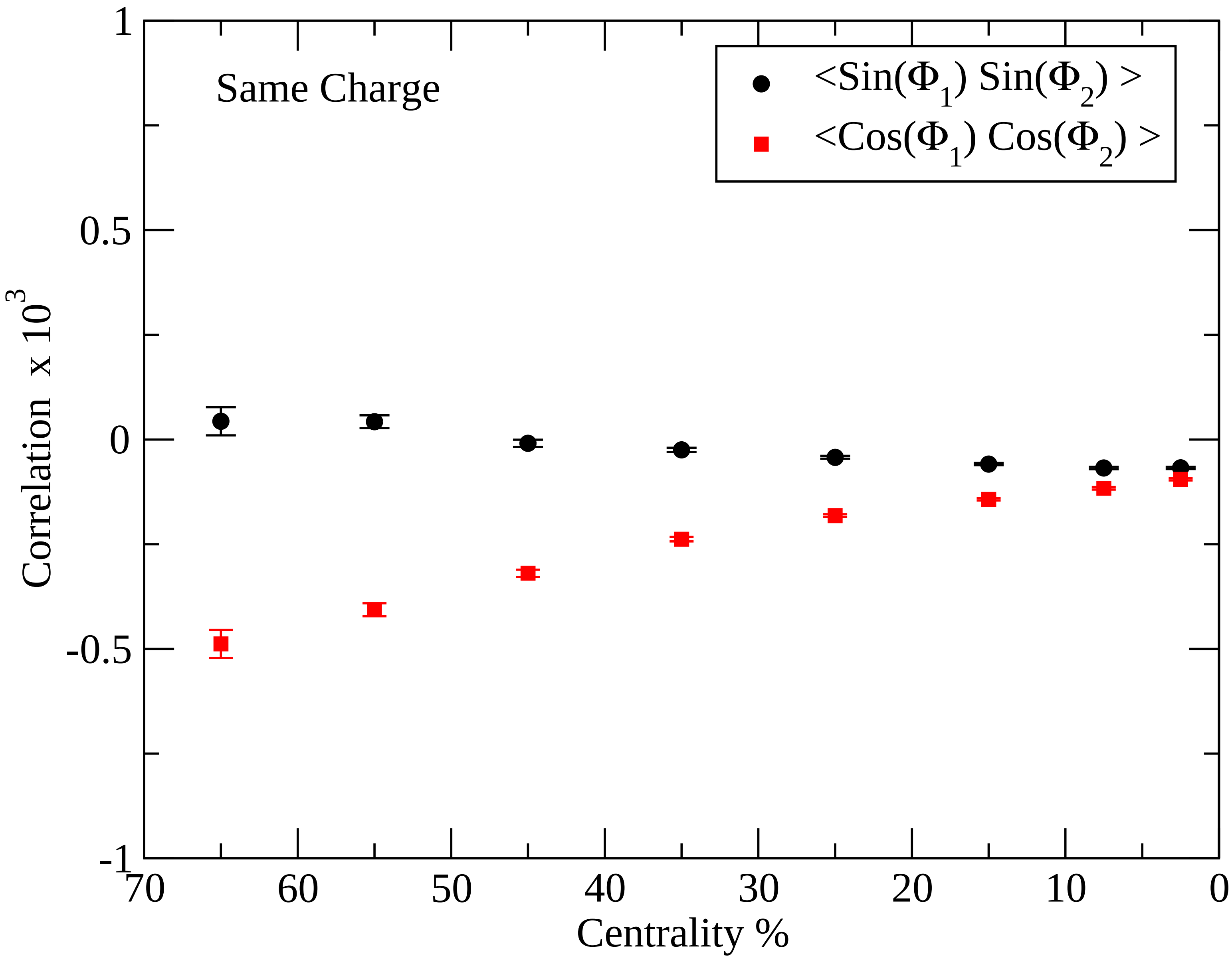
$$\left\langle \sin(\phi_\alpha)\sin(\phi_\beta) \right\rangle_{same} \simeq 0$$

$$\left\langle \cos(\phi_\alpha)\cos(\phi_\beta) \right\rangle_{same} < 0$$

and

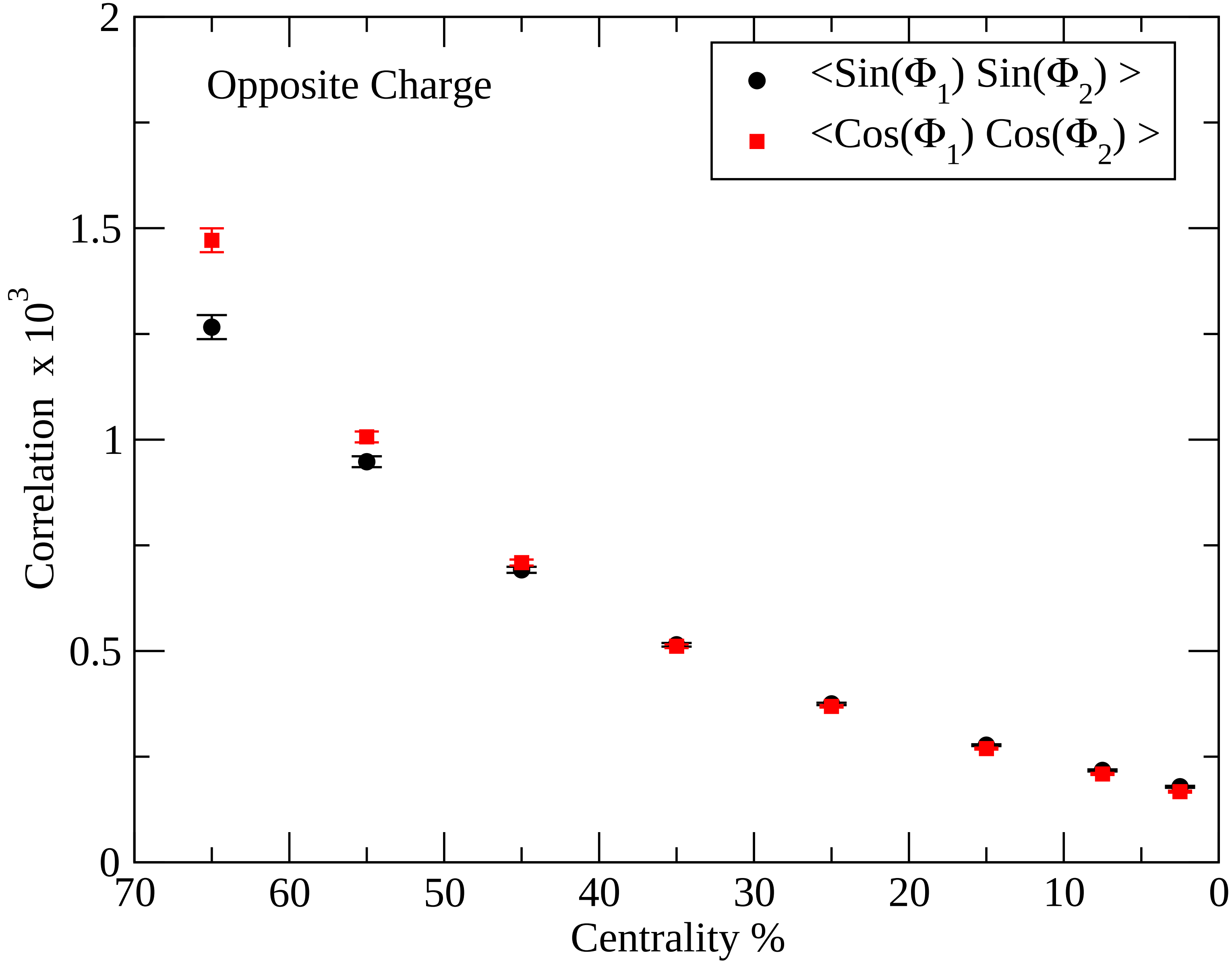
$$\left\langle \sin(\phi_\alpha)\sin(\phi_\beta) \right\rangle_{opposite} \simeq \left\langle \cos(\phi_\alpha)\cos(\phi_\beta) \right\rangle_{opposite} > 0$$

Same sign



Same Charge
<Sin(Φ1) Sin(Φ2) >
<Cos(Φ1) Cos(Φ2) >
1
0.5
0
-0.5
-1
70
60
50
40
30
20
10
0
Correlation x 10^3
Centrality %

Opposite sign



where is the parity?

$$\left\langle \sin(\phi_\alpha)\sin(\phi_\beta)\right\rangle_{same} \simeq 0$$

$$\left\langle \sin(\phi_\alpha)\sin(\phi_\beta)\right\rangle_{same} \equiv P + B_{out}$$

in consequence:

$$\boxed{\mathbf{P \simeq -B_{out}}}$$

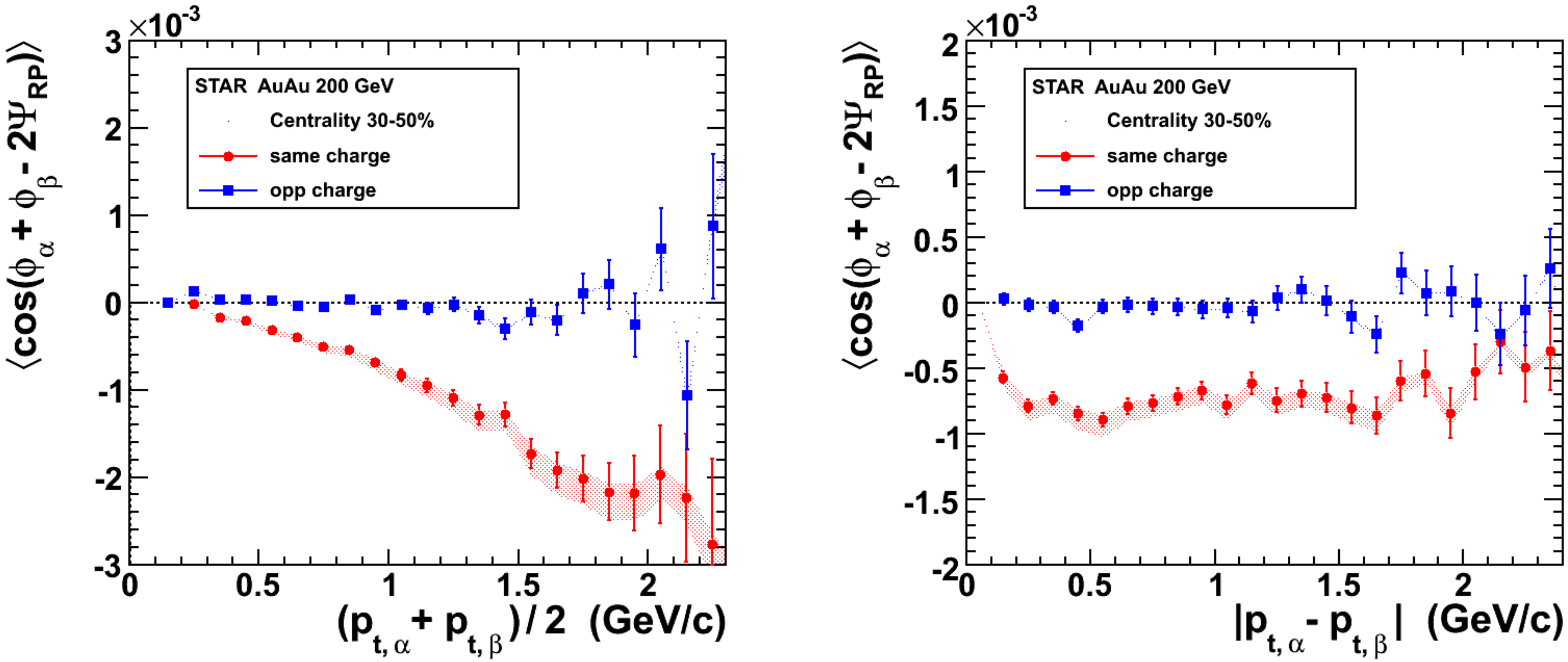
This is an unexpected relation ...

maybe it is a lucky coincidence?

in order to answer that question we need differential (p_t, η) $\left\langle \cos(\phi_\alpha + \phi_\beta)\right\rangle$ and $\left\langle \cos(\phi_\alpha - \phi_\beta)\right\rangle$

p_t distribution

STAR data



$\langle \cos(\phi_\alpha + \phi_\beta) \rangle \propto p_{t,\alpha} + p_{t,\beta}$ and very weak dependence on $|p_{t,\alpha} - p_{t,\beta}|$

We will show that the 'true' signal is located at low p_t

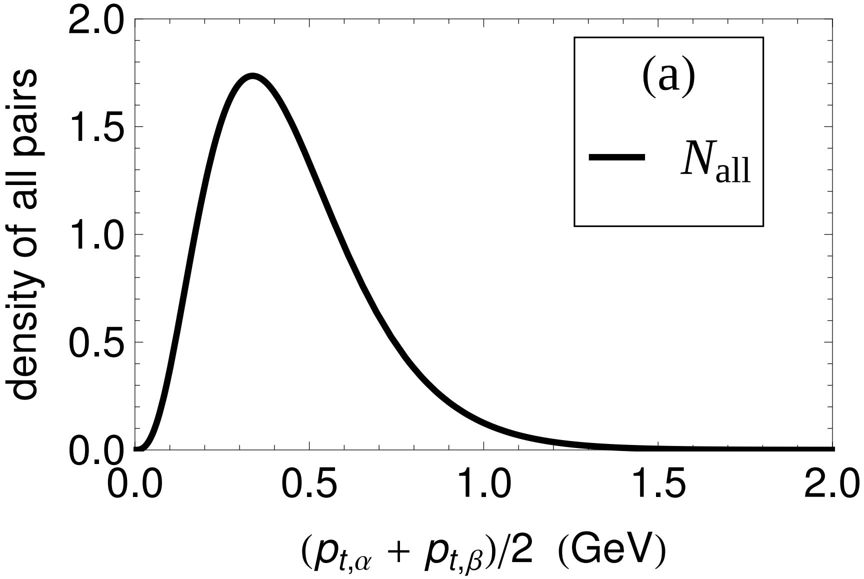
Definition

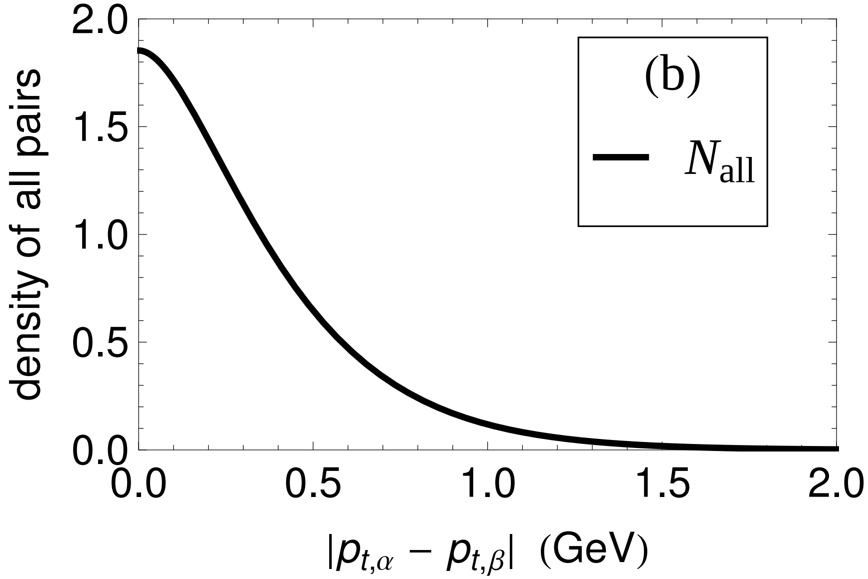
$$\left\langle \cos(\phi_\alpha + \phi_\beta) \right\rangle = \frac{\text{No. of correlated pairs}\left[\cos(\phi_\alpha + \phi_\beta)\right]}{\text{No. of all pairs}} \sim \frac{1}{1000}$$

We can calculate the (differential) number of all pairs

$$\int \exp\left(\frac{-p_{t,\alpha}}{T}\right) \exp\left(\frac{-p_{t,\beta}}{T}\right) \, d^2\vec{p}_{t,\alpha} d^2\vec{p}_{t,\beta} \quad (\text{fixed } p_{t,\alpha} + p_{t,\beta})$$

The number of all pairs vs $(p_{t,\alpha} + p_{t,\beta})$ and $\left|p_{t,\alpha} - p_{t,\beta}\right|$



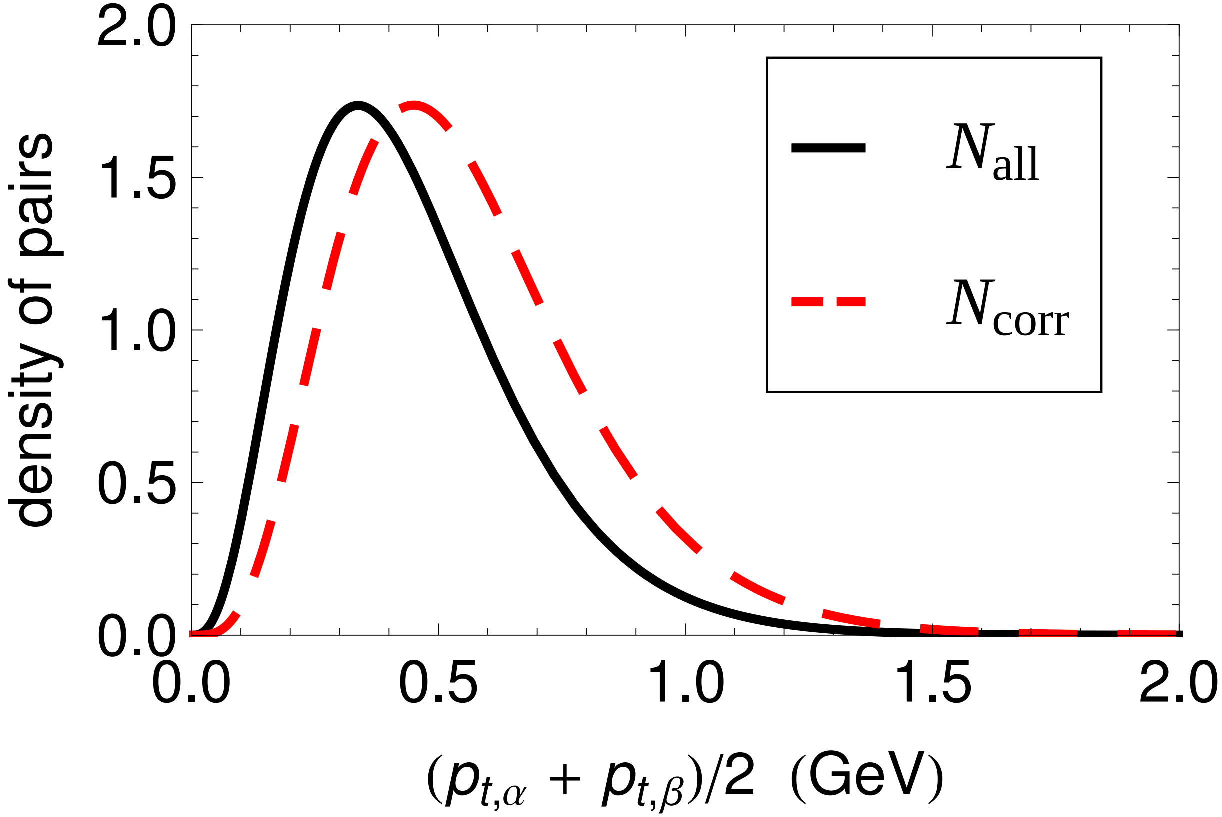


From that we can obtain p_t dependence of the number of correlated pairs:

– $\left|p_{t,\alpha} - p_{t,\beta}\right|$ distribution is as above (right plot)

– and multiply the left plot by $(p_{t,\alpha} + p_{t,\beta})$ ...

… we obtain [all pairs (black), correlated pairs (red)]



The observed signal is NOT inconsistent with the Chiral Magnetic Effect

v_2 contribution

$$\left\langle \sin(\phi_\alpha)\sin(\phi_\beta)\right\rangle_{same} \equiv P + B_{out}$$

$$\left\langle \cos(\phi_\alpha)\cos(\phi_\beta)\right\rangle_{same} \equiv B_{in}$$

STAR hope: $B_{in} \simeq B_{out}$ so that $|B_{in} - B_{out}| << P$, then

$$\left\langle \cos(\phi_\alpha + \phi_\beta)\right\rangle = \left\langle \cos(\phi_\alpha)\cos(\phi_\beta)\right\rangle - \left\langle \sin(\phi_\alpha)\sin(\phi_\beta)\right\rangle \approx -P$$

$$\left\langle \cos(\phi_\alpha - \phi_\beta)\right\rangle = \left\langle \cos(\phi_\alpha)\cos(\phi_\beta)\right\rangle + \left\langle \sin(\phi_\alpha)\sin(\phi_\beta)\right\rangle \approx 2B_{in} + P$$

How to define correlation that does not depend on the reaction plane?

Are there correlations that do not depend on the reaction plane?

Let us fix the reaction plane Ψ_{RP}

$$p_2(\phi_1, \phi_2, \Psi_{RP}) = p(\phi_1, \Psi_{RP}) p(\phi_2, \Psi_{RP}) \left[1 + C\left(\phi_1 - \phi_2\right)\right]$$

thus for ALL 2-particle correlations that do not depend on the reaction plane we obtain

$$\boxed{B_{in} - B_{out} \propto v_2 \quad \Rightarrow \quad \left\langle \cos(\phi_\alpha + \phi_\beta) \right\rangle \propto v_2}$$

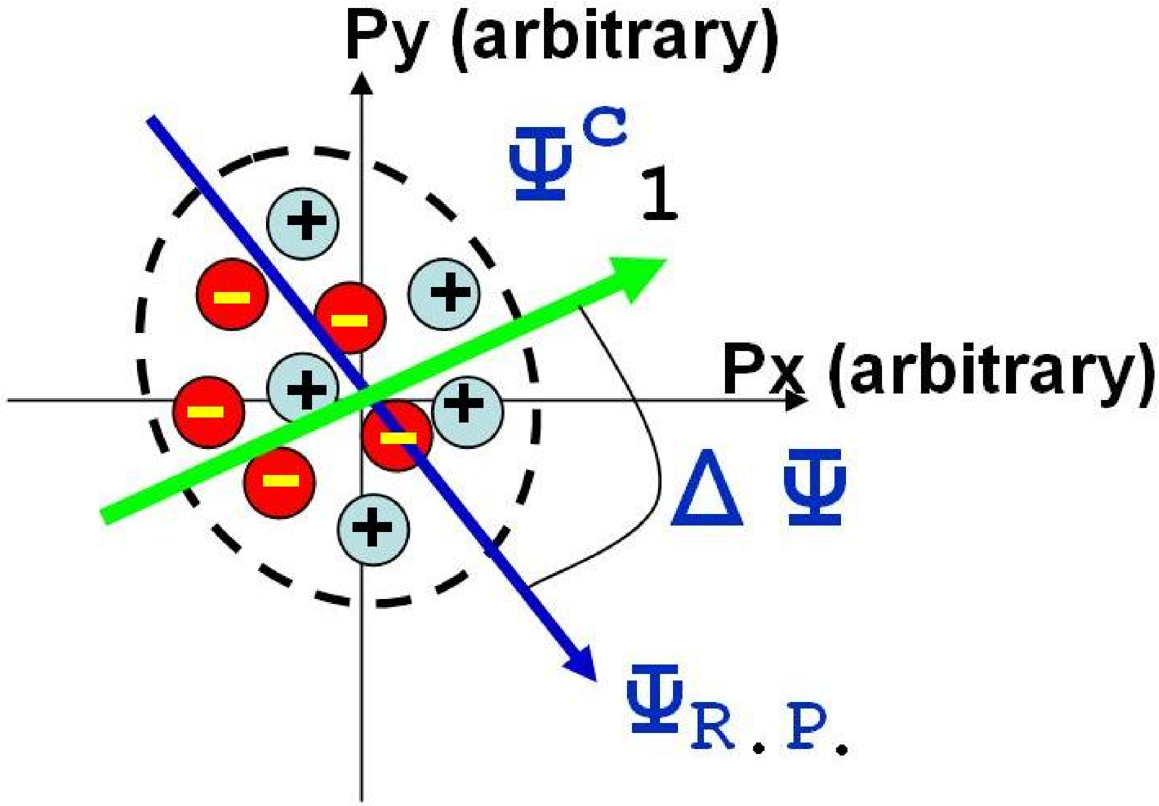
This is also true for correlations depending on $\left|\vec{k}_1 - \vec{k}_2\right|$ or $\left|\vec{k}_1 + \vec{k}_2\right|$

Indeed: $\left|\vec{k}_1 \pm \vec{k}_2\right|^2 \sim \vec{k}_1 \cdot \vec{k}_2 \sim \cos\left(\phi_1 - \phi_2\right)$

It is clear that we have to study all sources of correlations!

Dipole analysis

In each event we can measure size and orientation Ψ_1^c of the dipole



We can also determine orientation of the particle reaction plane Ψ_2 and study the relation between Ψ_1^c and Ψ_2

well known Q_2 analysis for elliptic flow:

$$Q_2 \cos(2\Psi_2) = \sum_i \cos(2\phi_i)$$

$$Q_2 \sin(2\Psi_2) = \sum_i \sin(2\phi_i)$$

new Q_1^c dipole analysis:

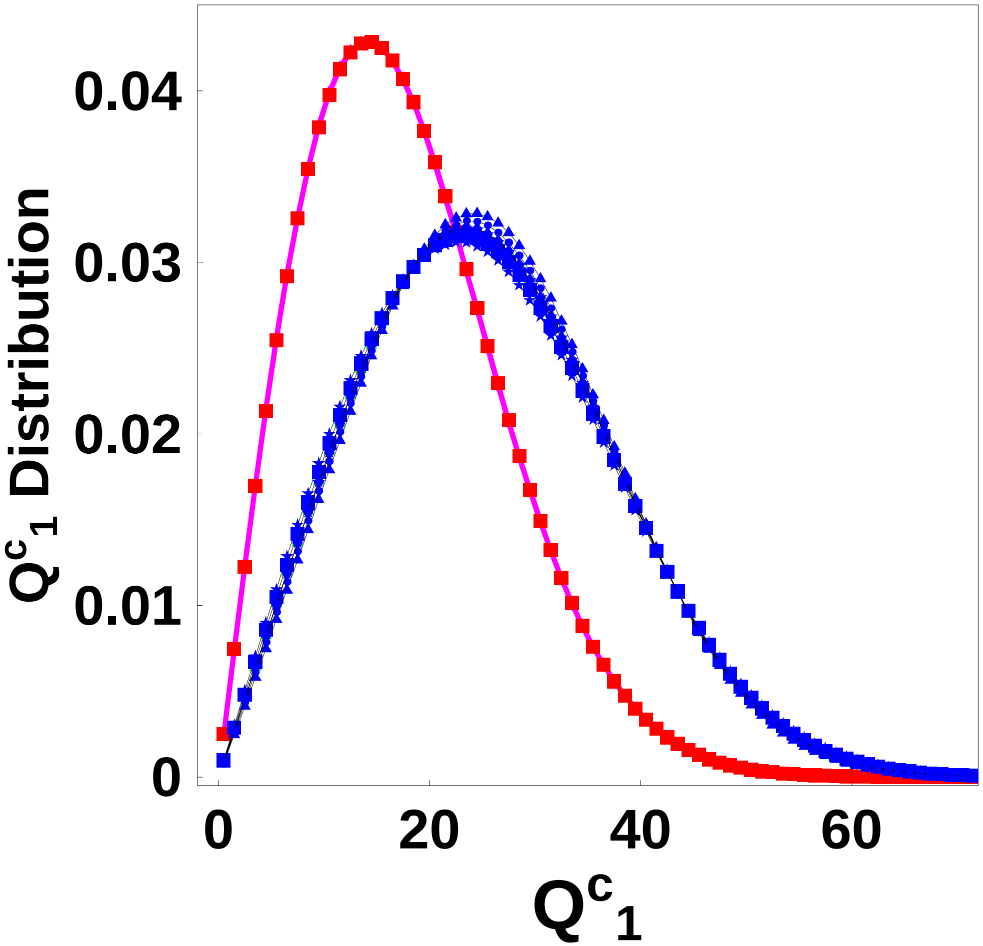
$$Q_1^c \cos\left(\Psi_1^c\right) = \sum_i q_i \cos(\phi_i)$$

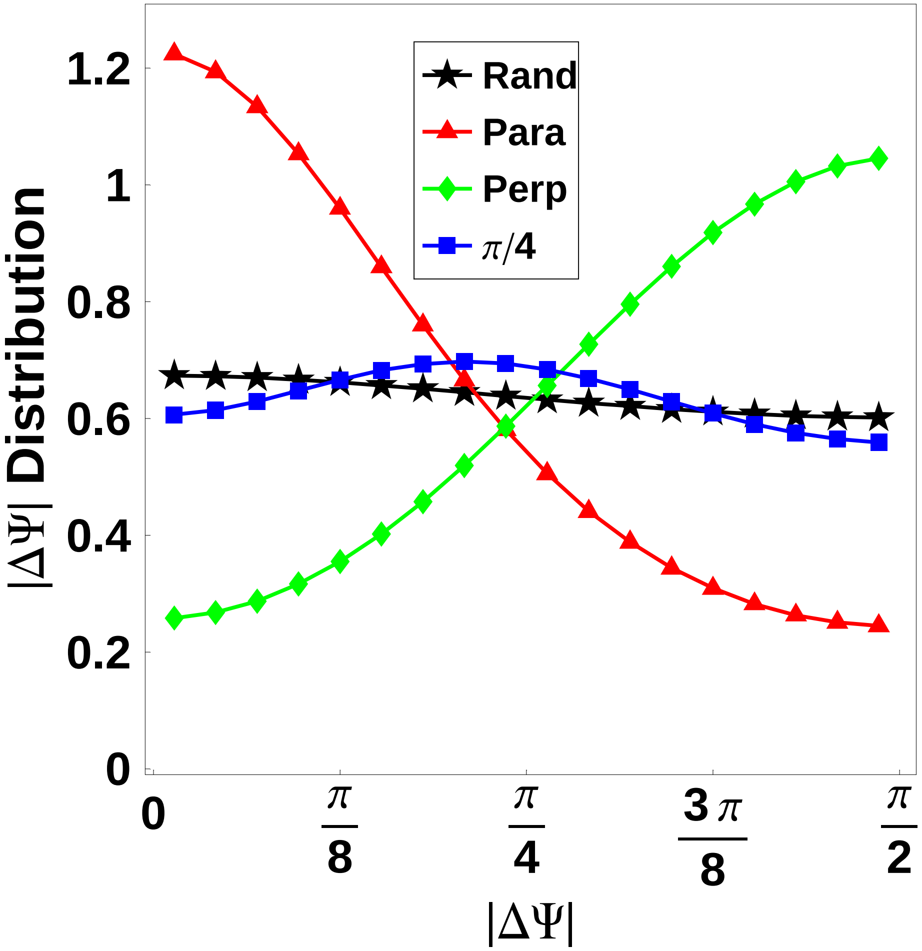
$$Q_1^c \sin\left(\Psi_1^c\right) = \sum_i q_i \sin(\phi_i)$$

In each event: (Q_2, Ψ_2) and $\left(Q_1^c, \Psi_1^c\right) \quad \Rightarrow \quad \boxed{\left\langle \cos\left(2\Psi_1^c - 2\Psi_2\right)\right\rangle}$

Monte Carlo: $f \propto 1 + 2v_2 \cos(2\phi - 2\Psi_{R.P.}) + 2q\chi d_1 \cos(\phi - \Psi_{C.S.})$

200+, 200−, $v_2 = 0.1$, $d_1 = 0.05$, $\chi = \pm 1$

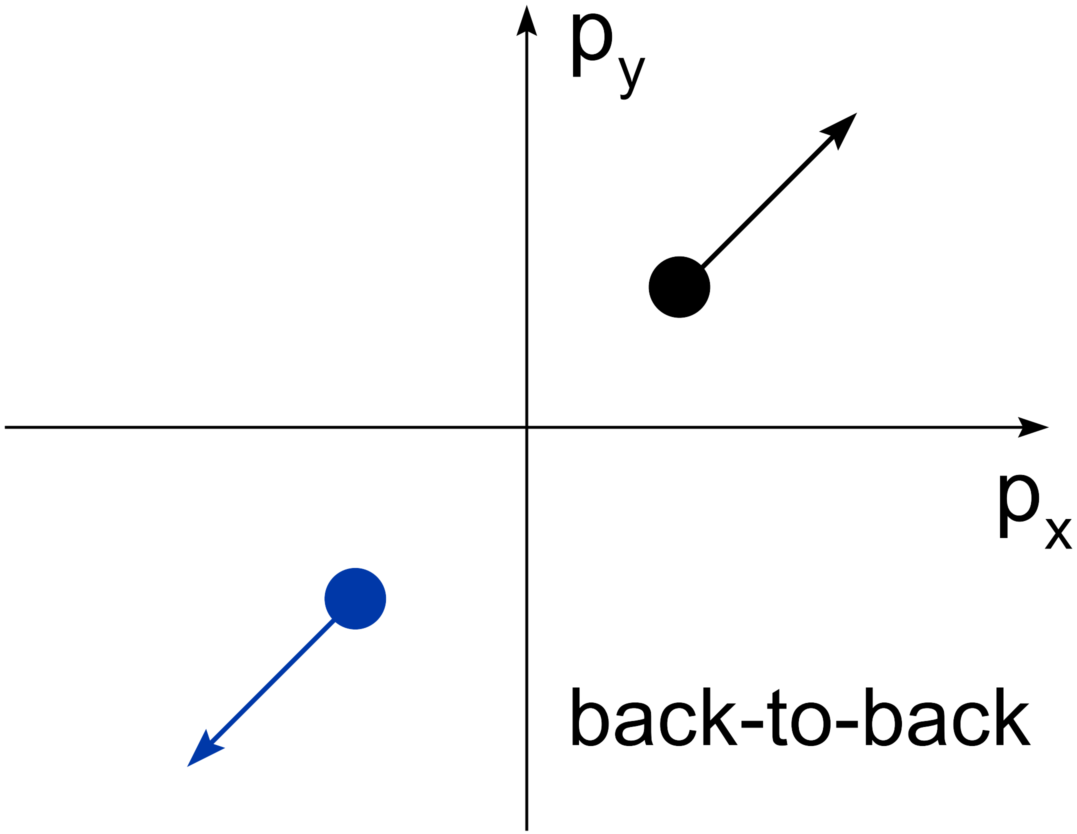




Good discriminating power, may clarify the situation

Transverse momentum conservation

$\sum p_x = \sum p_y = 0 \quad \rightarrow \quad$ natural back-to-back correlations



Blind to particle charge

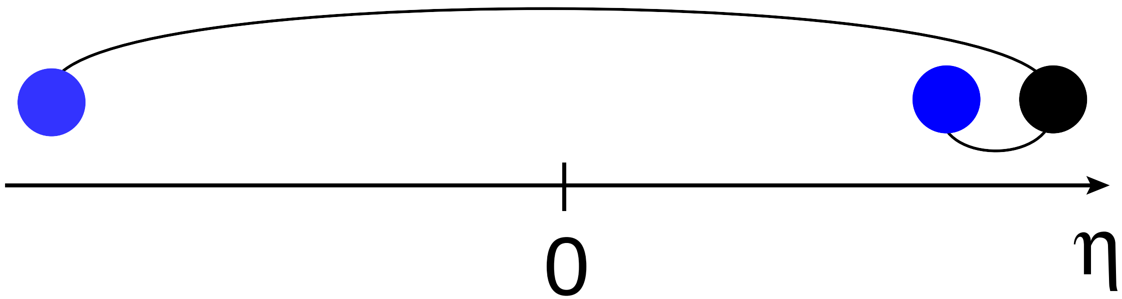
Let us produce N particles and construct N-particle density:

$$f_N(\vec{p}_1, ..., \vec{p}_N) \propto \delta^2 \left(\vec{p}_{1,t} + ... + \vec{p}_{N,t}\right) \cdot f(\vec{p}_1) \cdot ... \cdot f(\vec{p}_N)$$

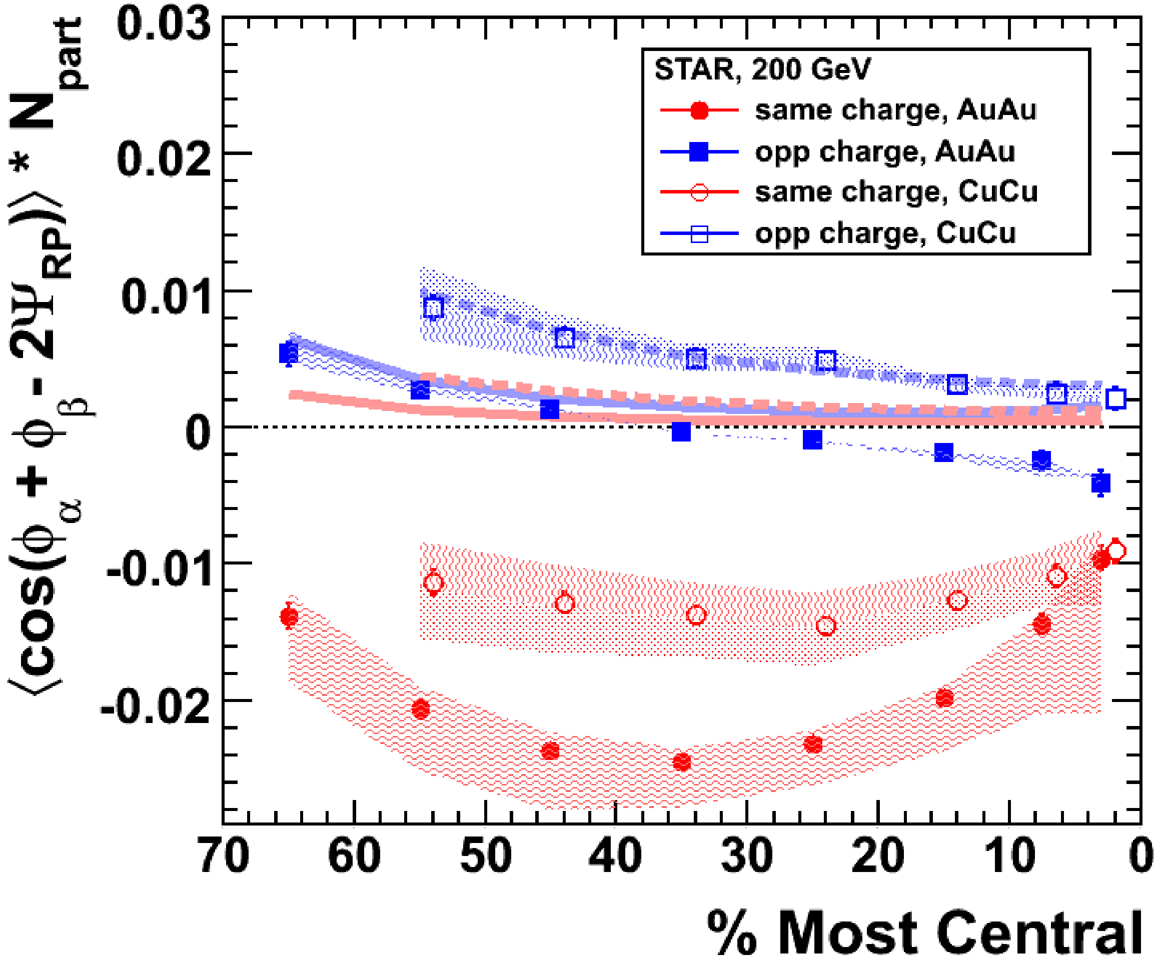
From that we can calculate $f_2(\vec{p}_1, \vec{p}_2)$ (central limit theorem):

$$f_2(\vec{p}_1, \vec{p}_2) \simeq f(\vec{p}_1) f(\vec{p}_2) \left(1 + \frac{2}{N} - \frac{(p_{1,x} + p_{2,x})^2}{2N \left\langle p_x^2 \right\rangle_F} - \frac{(p_{1,y} + p_{2,y})^2}{2N \left\langle p_y^2 \right\rangle_F}\right)$$

and calculate $\langle \cos(\phi_1 + \phi_2) \rangle$ or $\langle \cos(\phi_1 - \phi_2) \rangle$ (lower limit?)

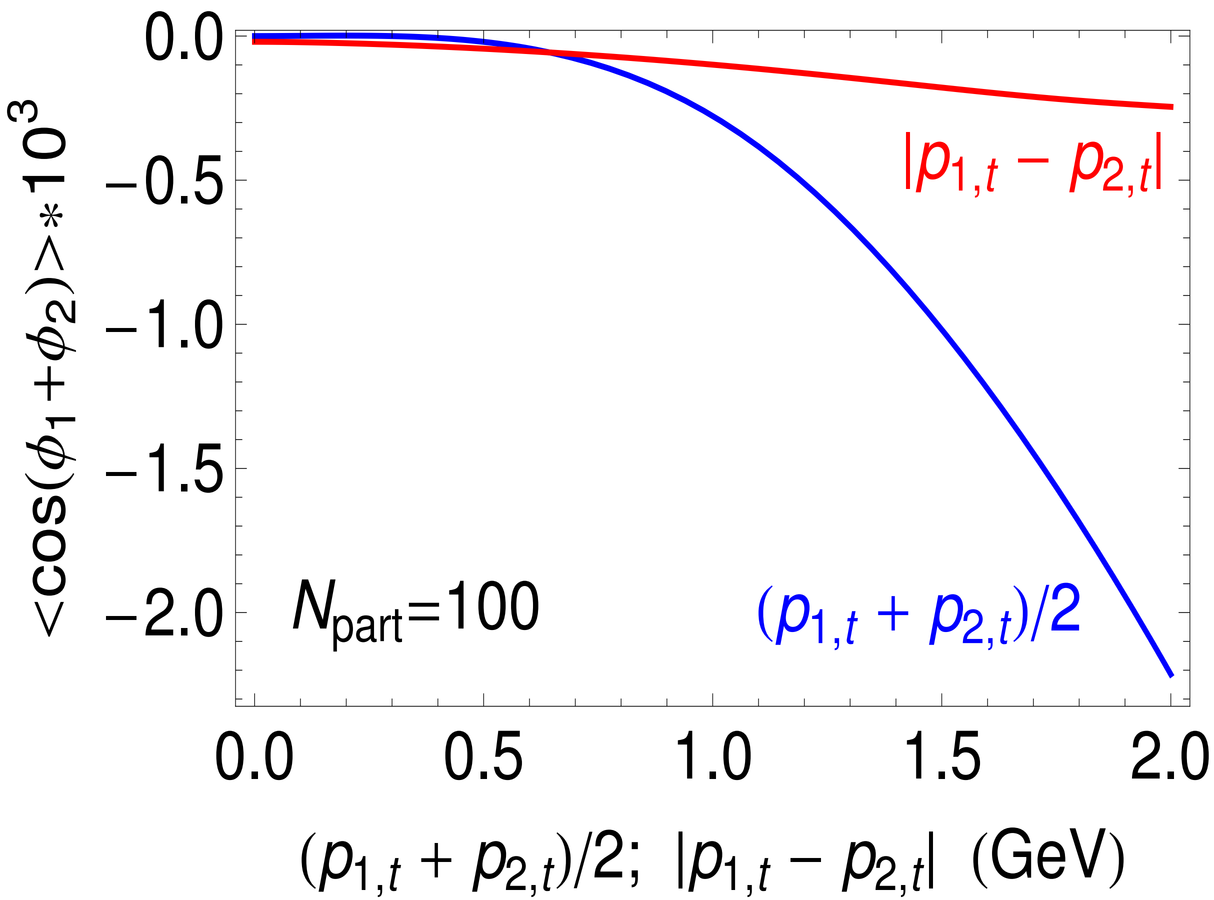


Our result: $\langle\cos(\phi_1+\phi_2)\rangle \approx -2v_2/N$; $\langle\cos(\phi_1-\phi_2)\rangle \approx -1/N$



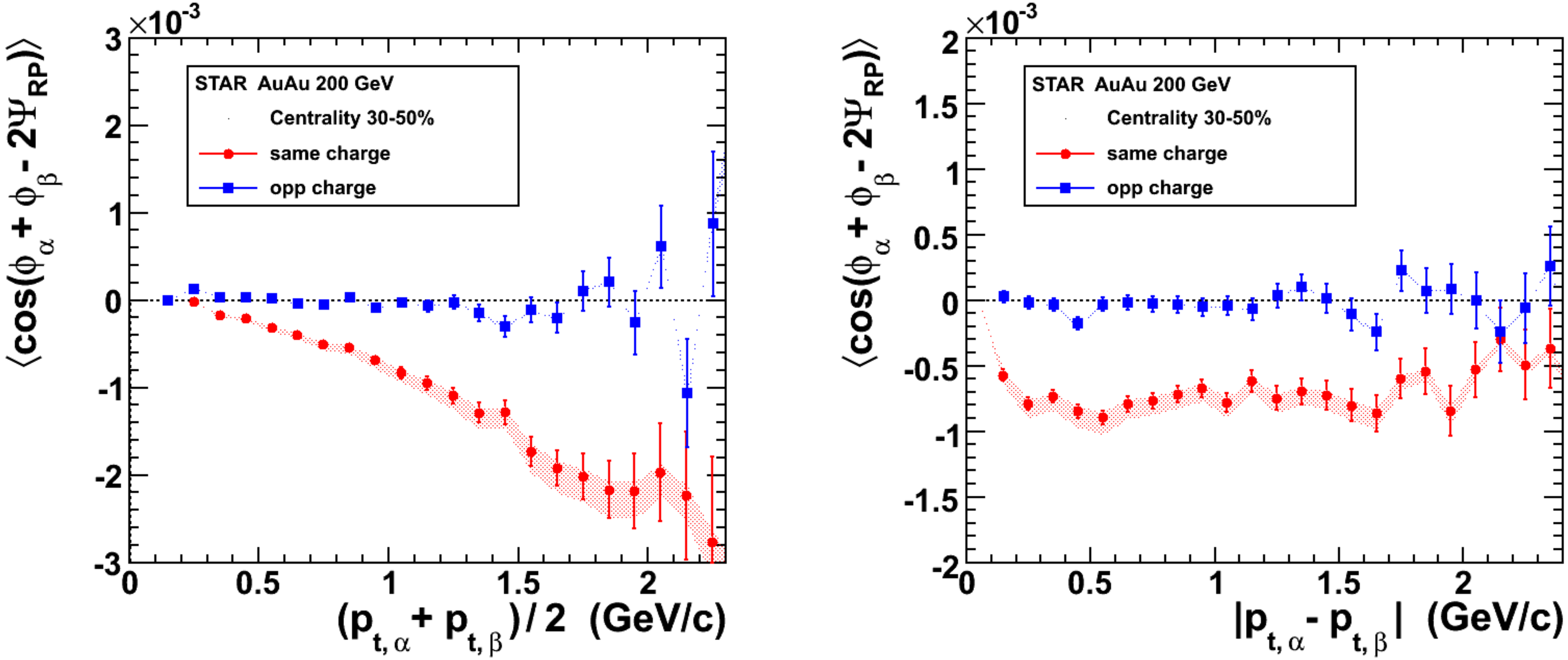
we obtain: $\langle\cos(\phi_1+\phi_2)\rangle \cdot N_{part} = -0.005$ (lower limit)

p_t differential distributions:

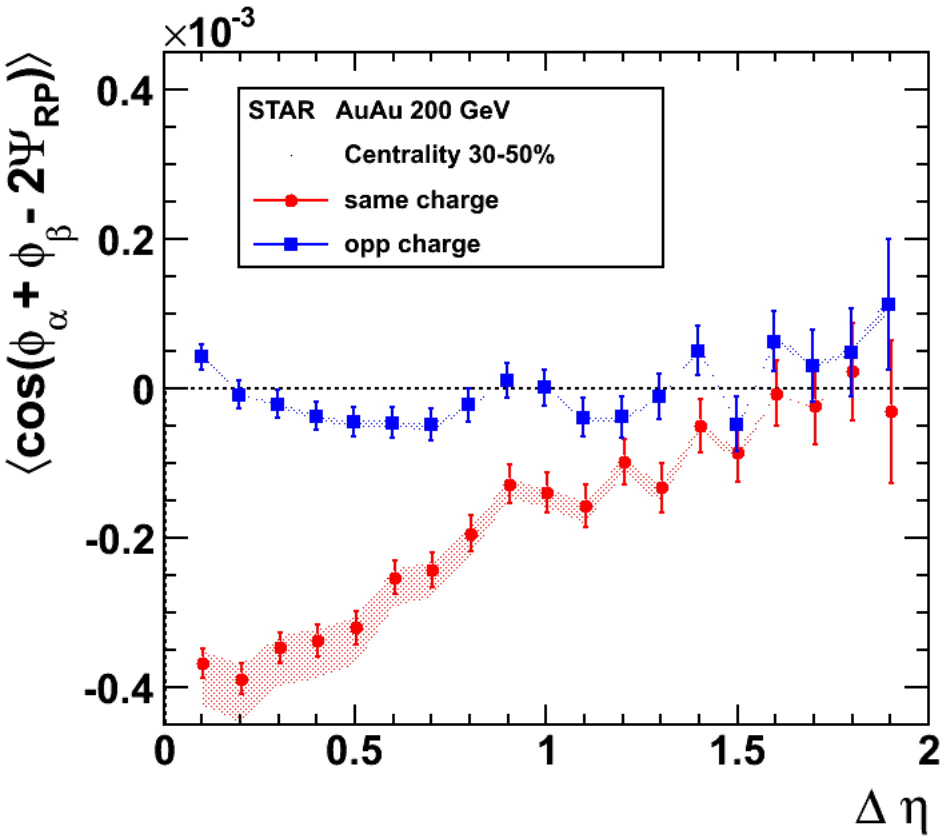


in good agreement with STAR data

STAR data:


STAR AuAu 200 GeV
Centrality 30-50%
same charge
opp charge
$\times 10^{-3}$
$\langle\cos(\phi_\alpha + \phi_\beta - 2\Psi_{RP})\rangle$
$(p_{t,\alpha} + p_{t,\beta})/2$ (GeV/c)
$|p_{t,\alpha} - p_{t,\beta}|$ (GeV/c)

Speculation - "local" transverse momentum conservation



With only global transverse momentum conservation this distribution is approximately flat.

With "local" t.m.c. we can easily make the signal stronger $(1/N)$

Conclusions

- for the same sign STAR sees large signal in-plane and very week signal out-of-plane
- if there is a parity signal it must almost exactly cancel out-of-plane background
- maybe this is (un)lucky coincidence? We need differential $\langle \cos(\phi_\alpha - \phi_\beta) \rangle$ (p_t, η) to answer that question
- signal is dominated by $p_t < 1$ GeV and this is not inconsistent with the Chiral Magnetic Effect
- all two-particle correlations that do not depend on the reaction plane orientation contribute to the signal (v_2)

- we proposed direct dipole analysis that may help to clarify the situation
- we calculated the contribution from transverse momentum conservation and found it surprisingly large - the same order of magnitude as the observed signal
- see also M.Asakawa, A.Majumder, B.Muller [PRC 81 (2010) 064912] and S.Schlichting, S.Pratt [arXiv:1005.5341 nucl-th] for different mechanisms