Flow or Flux Tubes or Both

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What causes the Ridge?

There are two possibilities flow or flux tubes

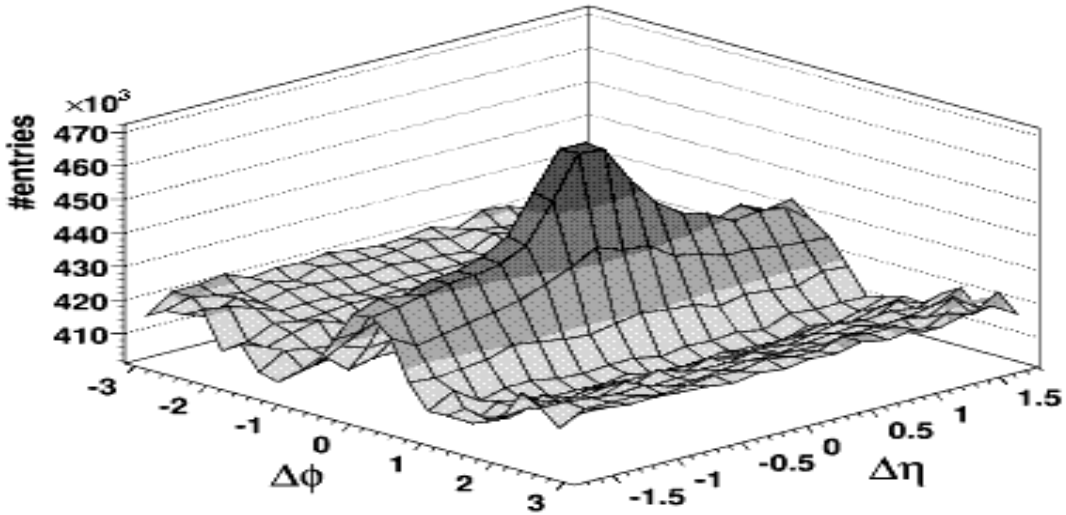


FIG. 7:

Glauber Monte Carlo

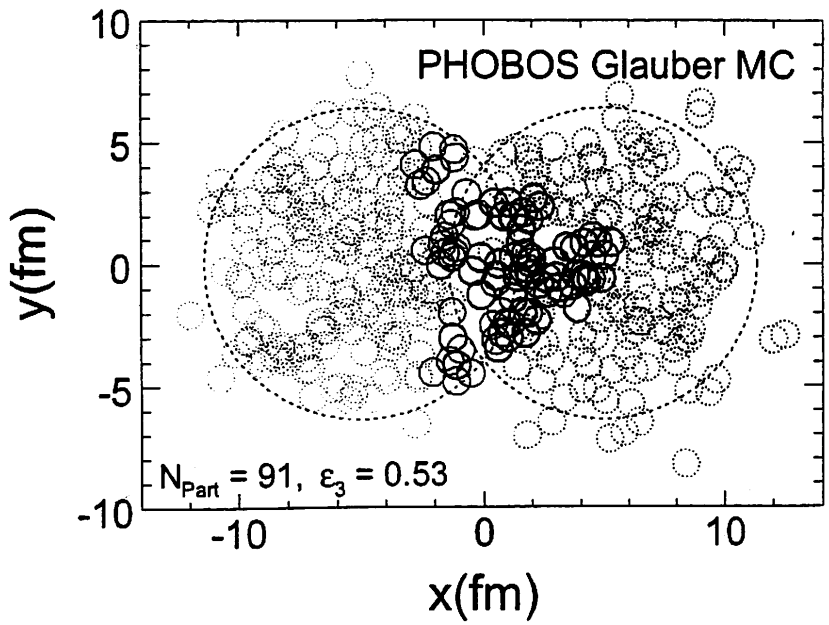


FIG. 3: Distribution of nucleons on the transverse plane for a $\sqrt{s_{NN}}$ = 200 GeV Au+Au collision event with ε_3=0.53 from Glauber Monte Carlo. The nucleons in the two nuclei are shown in gray and black. Wounded nucleons (participants) are indicated as solid circles, while spectators are dotted circles.

Flow from Harmonic Deformations

III. FLOW FROM HARMONIC DEFORMATIONS

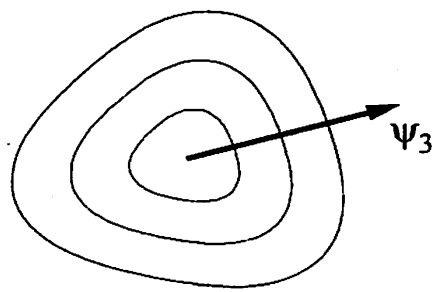


FIG. 1: (Color online) Contour plots of the energy density (4) for $n = 3$ and $\varepsilon_3 = 0.2$.

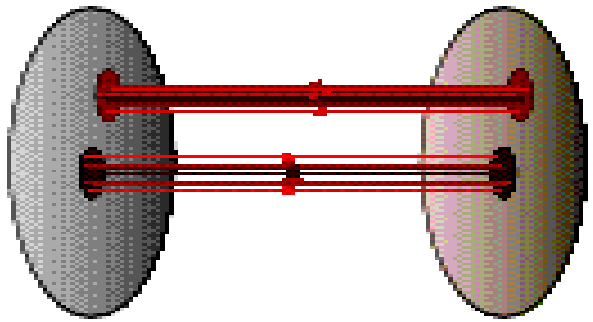


Figure 4: Glasma flux tubes. The transverse size of the flux tubes is of order $1/Q_s$.

note that there are several other models of the ridge [30]–we will not attempt to discuss these here. A key difference between the dominant particle production mechanism we will describe here and other mechanisms described in the literature is that our correlation is not formed from a a daughter particle splitting off a parent particle. Instead, the dominant QCD contribution to the long range rapidity correlation comes from particles that are produced independently along the length of flux tube of color electric and magnetic fields, localized in a region of size $1/Q_s$ in the transverse plane of the colliding nuclei.

2 Computing the Glasma 2-particle correlation

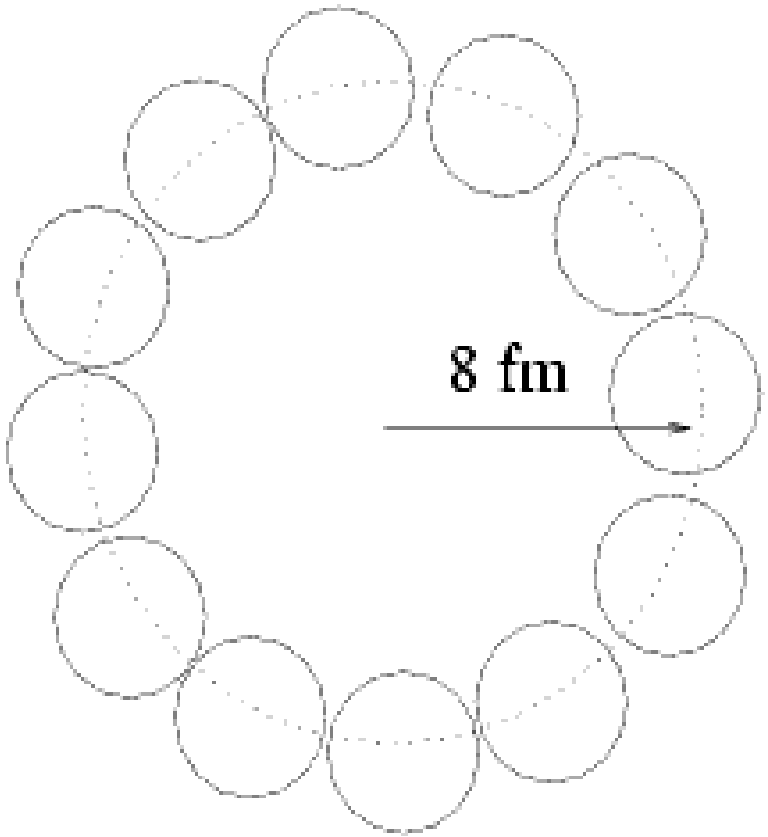
We now turn to a quantitative analysis of two particle correlations in the Glasma and their role in forming the near side ridge in A–A collisions. The variance of the two particle multiplicity distribution, for two particles with momenta $\boldsymbol{p}$ and $\boldsymbol{q}$, is defined as

$$C(\boldsymbol{p},\boldsymbol{q}) \equiv \left\langle \frac{dN_2}{dy_p d^2\boldsymbol{p}_\perp dy_q d^2\boldsymbol{q}_\perp} \right\rangle - \left\langle \frac{dN}{dy_p d^2\boldsymbol{p}_\perp} \right\rangle \left\langle \frac{dN}{dy_q d^2\boldsymbol{q}_\perp} \right\rangle \ , \tag{6}$$

where the brackets $\langle \cdots \rangle$ denote an average over events. Also, see footnote 3.

The contributions to $C(\boldsymbol{p},\boldsymbol{q})$ have distinct origins. If we compute emission in a fixed configuration of the color sources, there are connected and disconnected

Plane section of tube geometry perpendicular to the beam at eta = 0



What about the Ridge?

- Let us consider 0-5% centrality.
- Let us use the Glasma flux tube Model.
- Let us consider a trigger 3-4 GeV/c Pt.
- We need to add jets to the model.
- We will use HIJING jets.
- 80% of the jets are quenched away.
- Second particle Pt > 2.0 GeV/c.

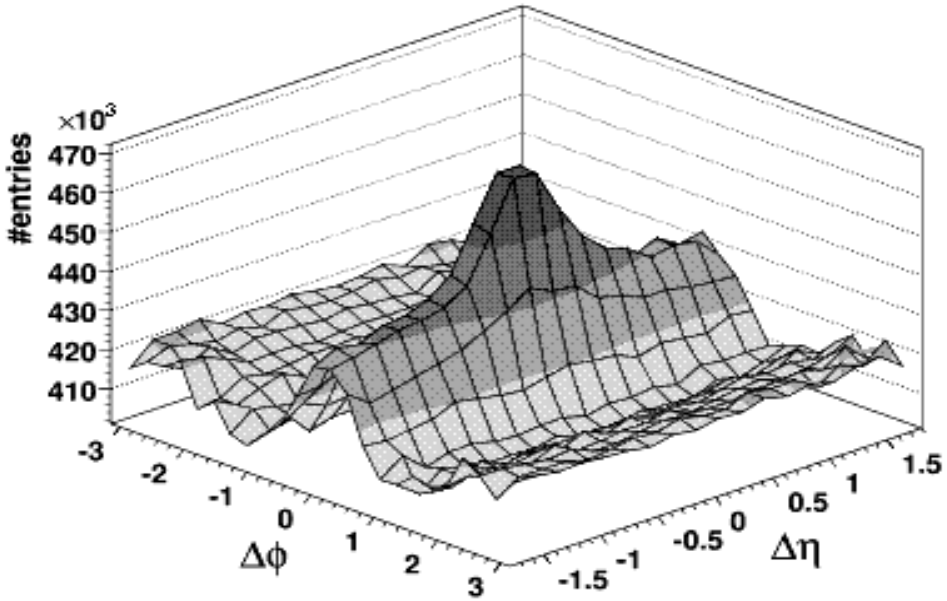

#entries
×10^3
470
460
450
440
430
420
410
-3
-2
-1
0
1
2
3
Δφ
-1.5
-1
-0.5
0
0.5
1
1.5
Δη

FIG. 7:

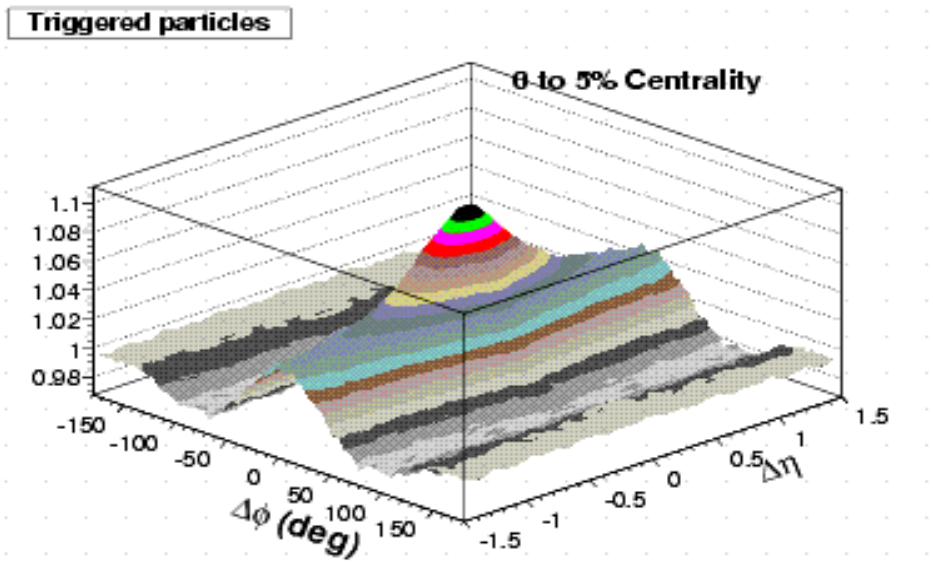
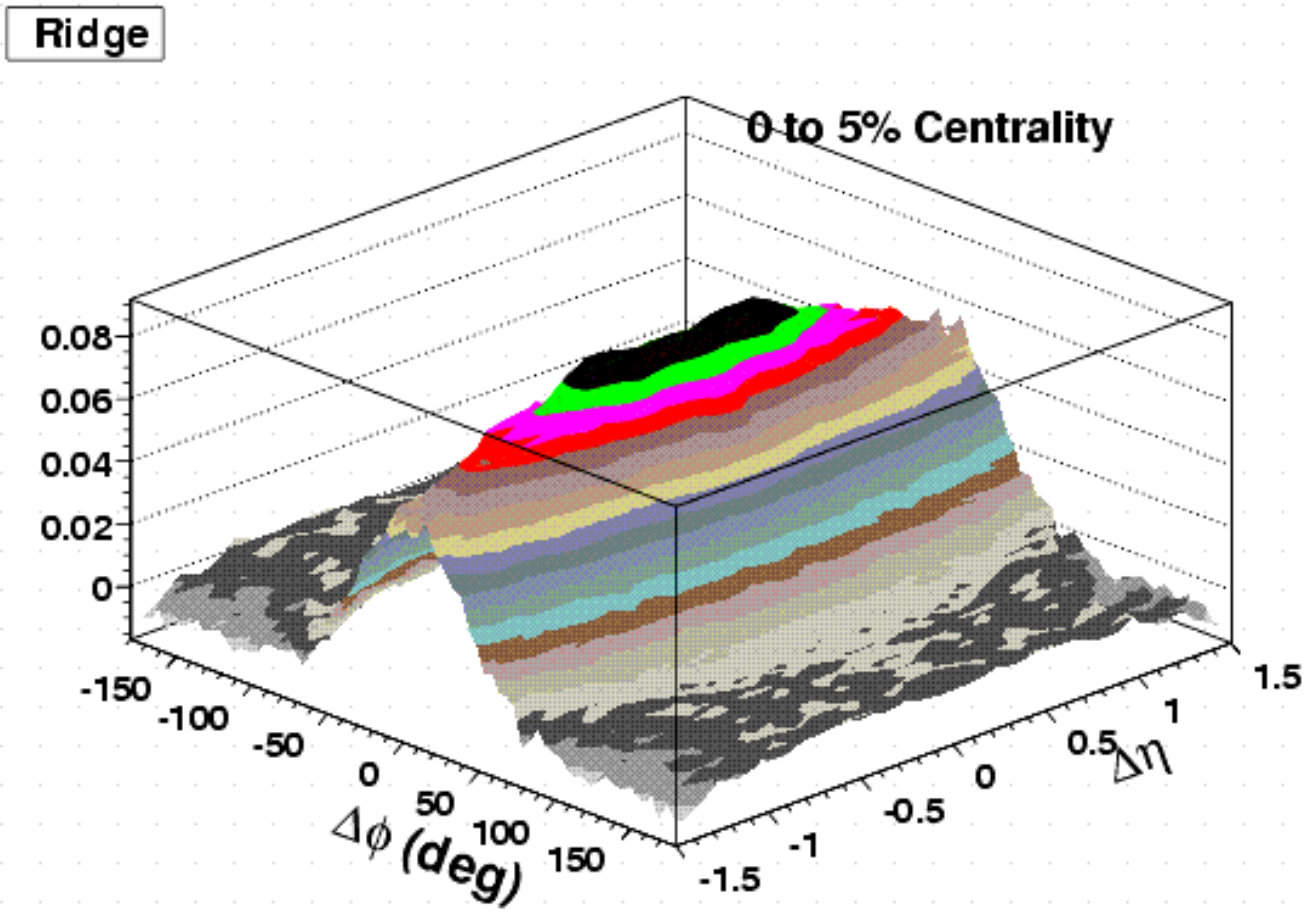
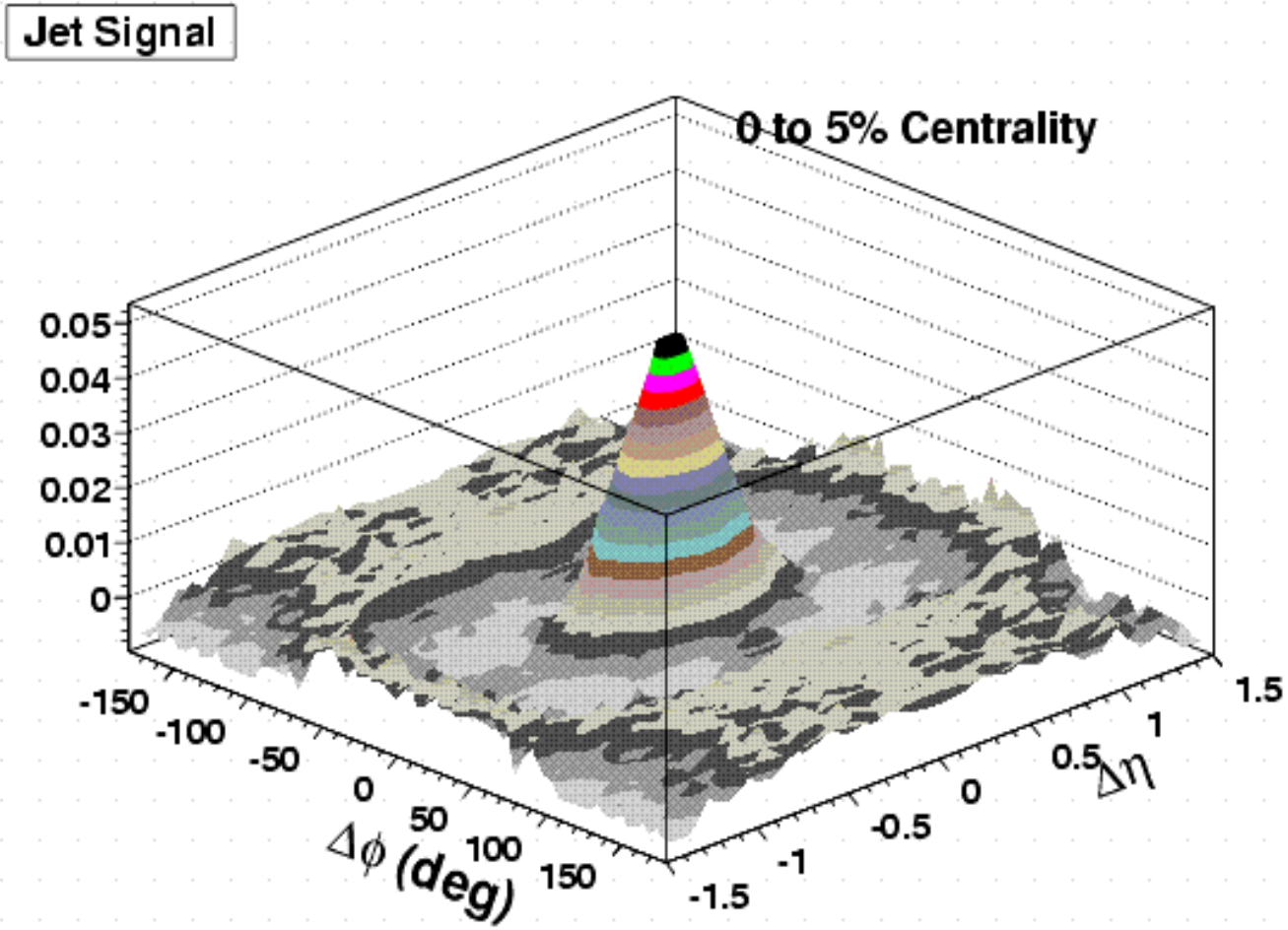

Triggered particles
0 to 5% Centrality
1.1
1.08
1.06
1.04
1.02
1
0.98
-150
-100
-50
0
50
100
150
Δφ (deg)
-1.5
-1
-0.5
0
0.5
1
1.5
Δη

FIG. 8:


Ridge
0 to 5% Centrality
0.08
0.06
0.04
0.02
0
-150
-100
-50
0
50
100
150
Δφ (deg)
-1.5
-1
-0.5
0
0.5
1
1.5
Δη


Jet Signal
0 to 5% Centrality
0.05
0.04
0.03
0.02
0.01
0
-150
-100
-50
0
50
100
150
Δφ (deg)
-1.5
-1
-0.5
0
0.5
1
1.5
Δη

PHOBOS has measured the ridge in Au Au

for central collisions at $\sqrt{s_{NN}}$ =200 GeV

for trigger $P_t > 2.5$ GeV/c

Phys. Rev. Lett. 104 (2009) 044901.

Trigger particle η 0.0 to 1.5

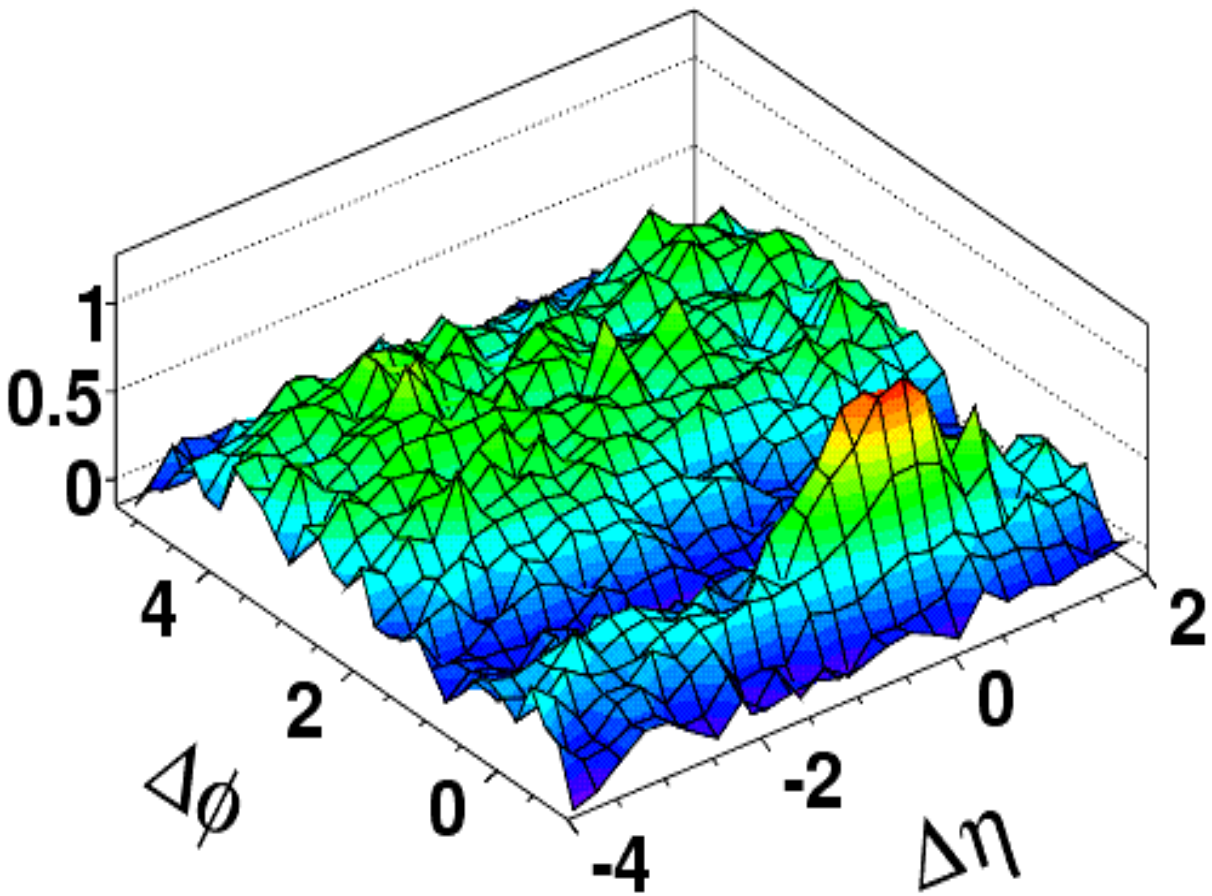
Soft particles $|\eta| < 3.0$

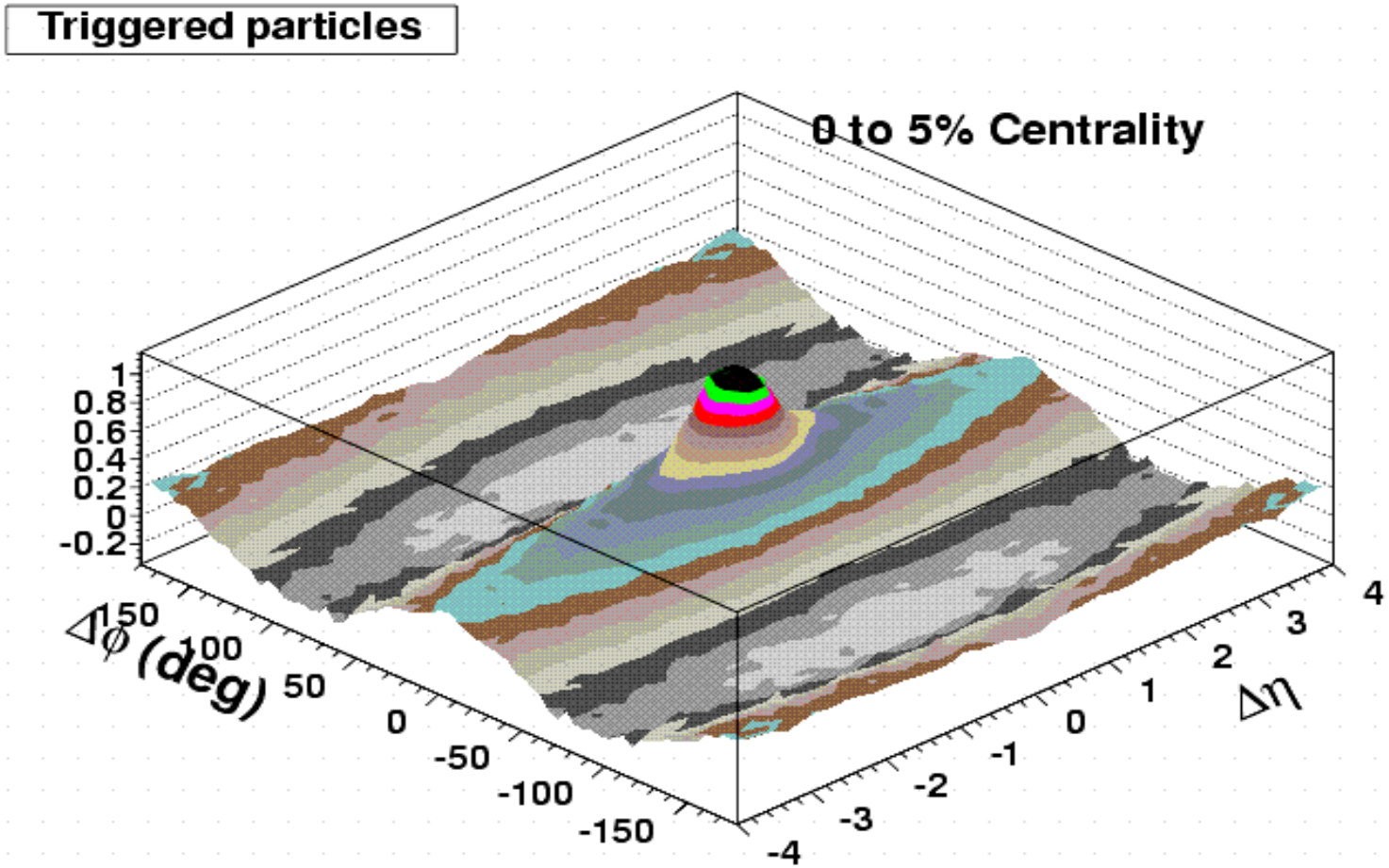
Glasma Flux Tube model

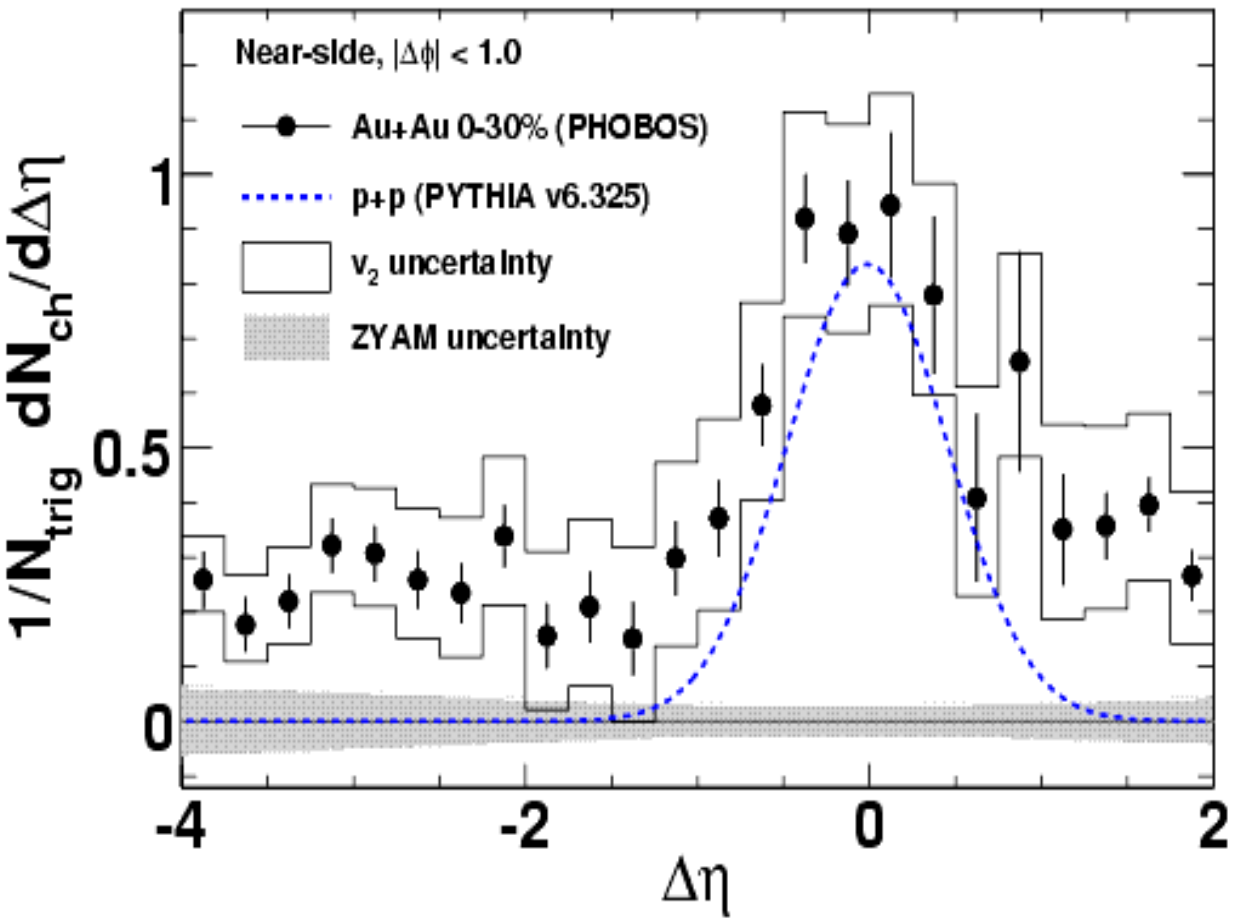
for trigger $P_t > 2.5$ GeV/c

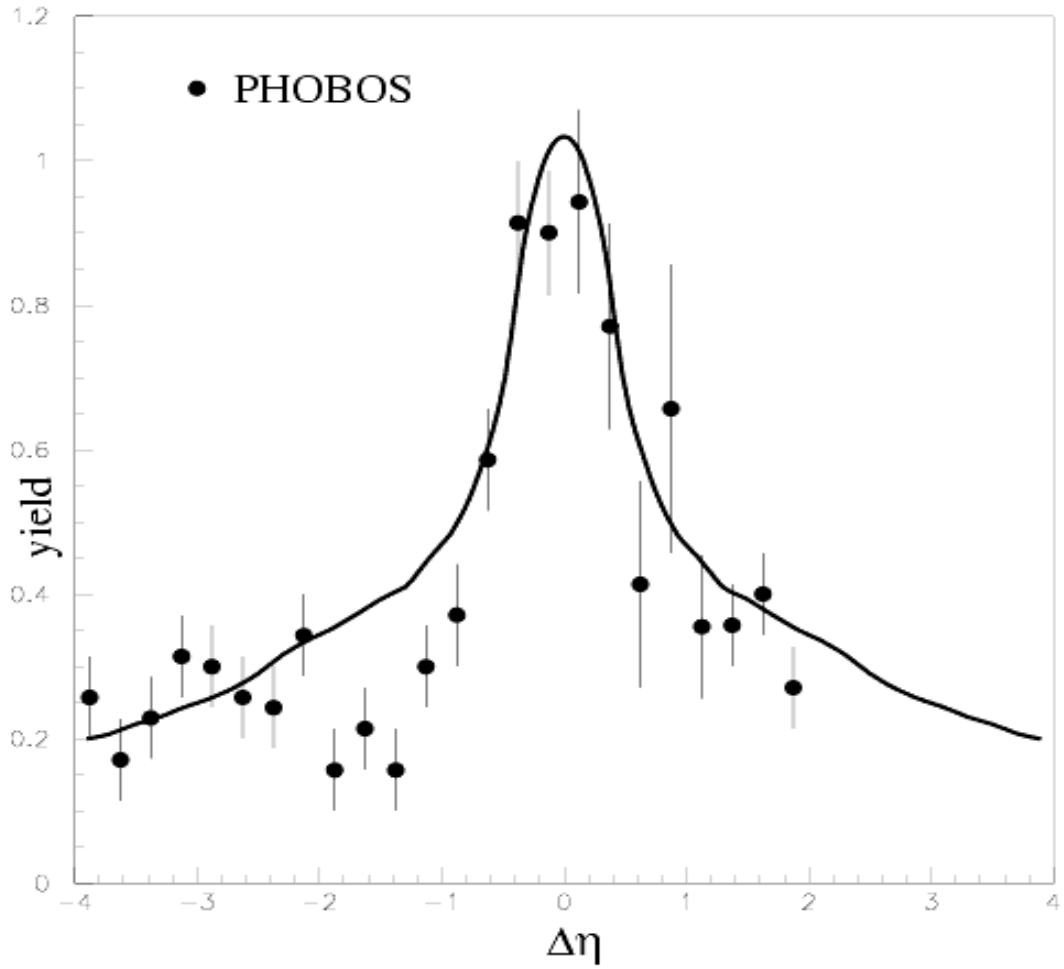
Trigger particle η -0.75 to 0.75

All Soft particles are used


1
0.5
0
4
2
0
Δφ
-4
-2
0
2
Δη

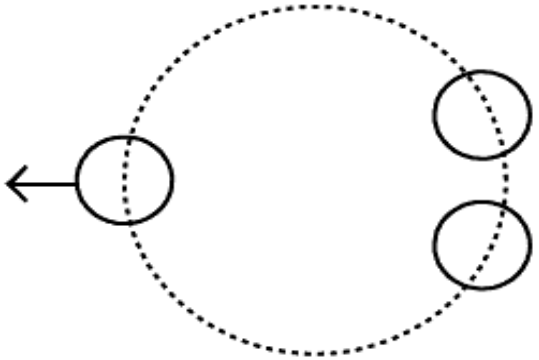

Triggered particles
0 to 5% Centrality
1
0.8
0.6
0.4
0.2
0
-0.2
150
100
50
0
-50
-100
-150
Δφ (deg)
-4
-3
-2
-1
0
1
2
3
4
Δη


Near-side, |Δφ| < 1.0
Au+Au 0-30% (PHOBOS)
p+p (PYTHIA v6.325)
v2 uncertainty
ZYAM uncertainty
1/Ntrig dNch/dΔη
1
0.5
0
-4
-2
0
2
Δη

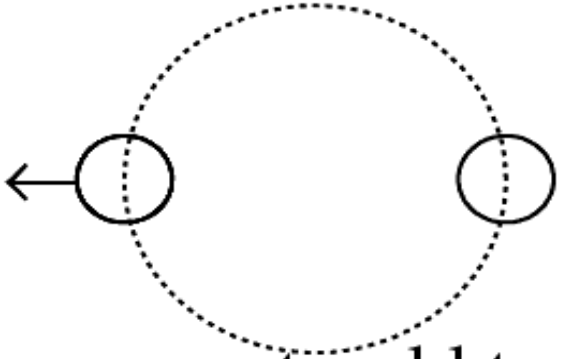

PHOBOS
yield
Δη
1.2
1
0.8
0.6
0.4
0.2
0
−4
−3
−2
−1
0
1
2
3
4

What about the Mach Cone?

Mach Cone from trigger particle



These events add to Mach Cone



These events add to v_2

These are substracted away

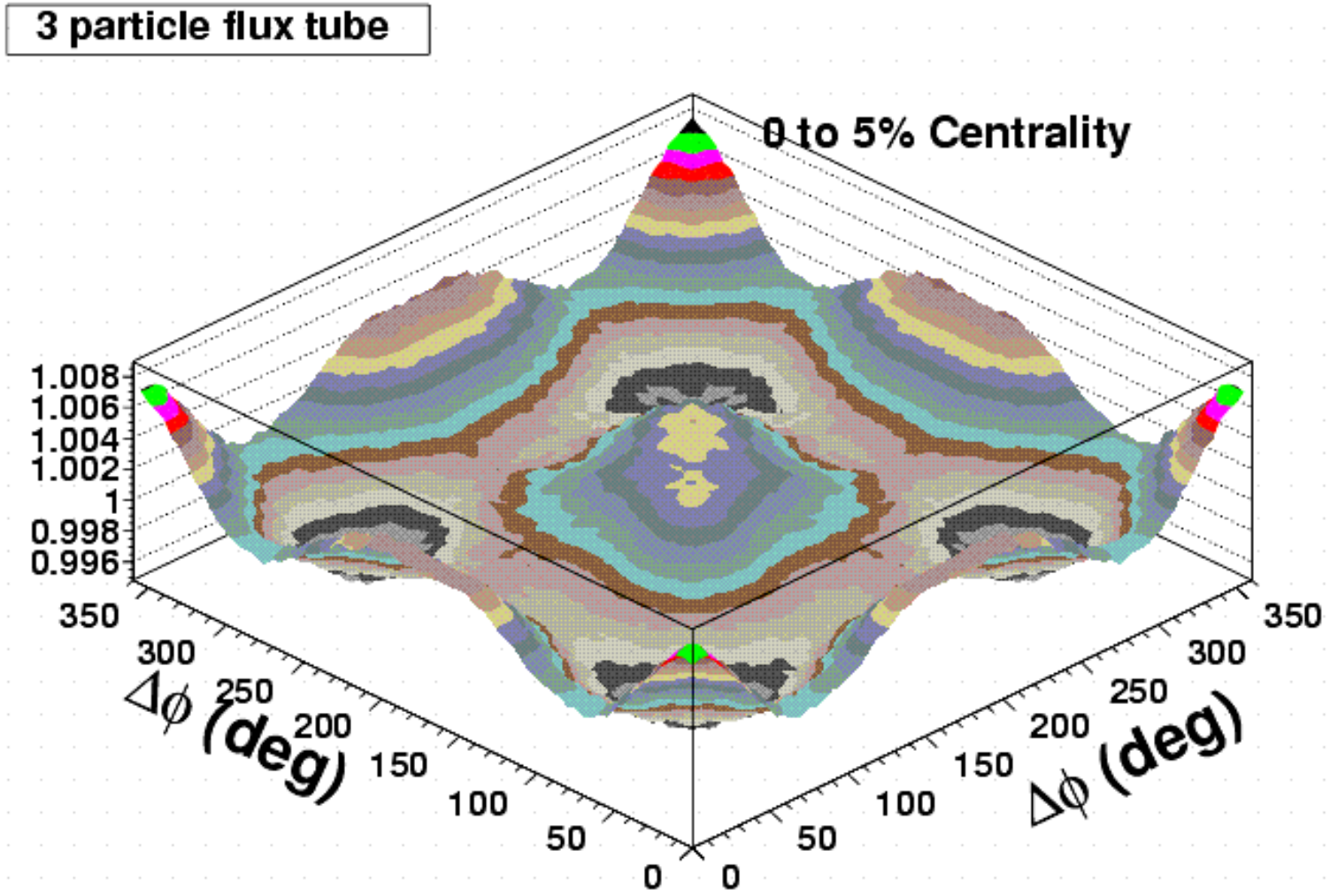
Three Particle correlation

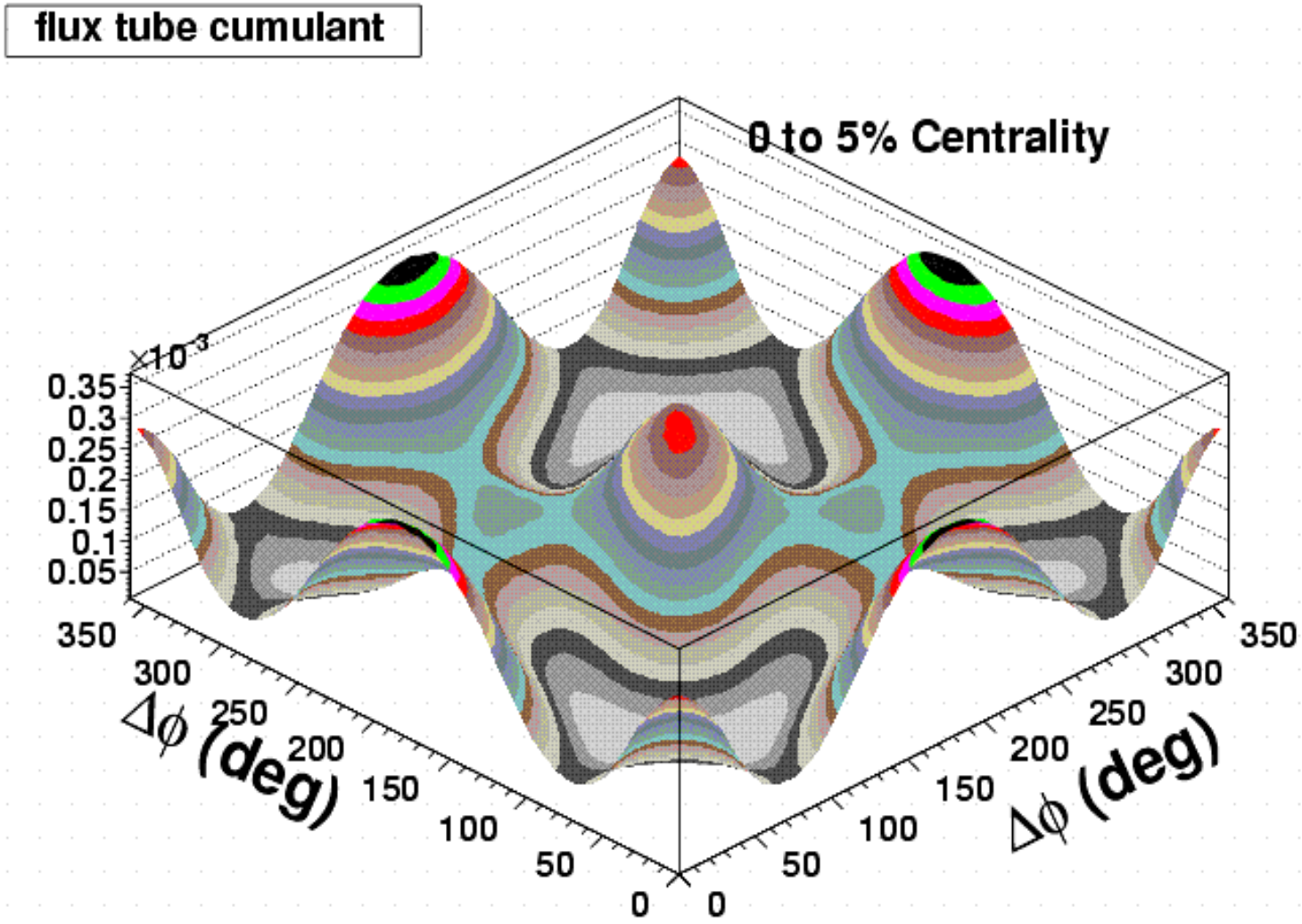
1. First particle $P_t > 1.1$ GeV/c.
2. Second particle $P_t < 1.1$ GeV/c.
3. Third particle $P_t < 1.1$ GeV/c.

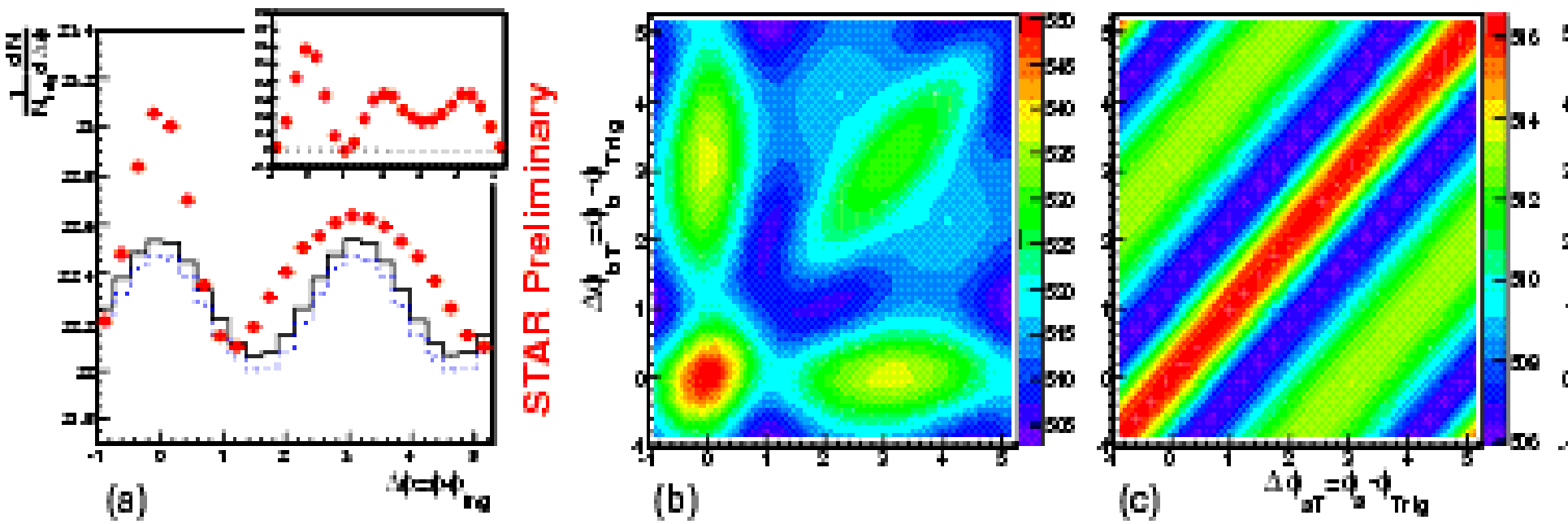
We will consider the ϕ angles between

1. and 2. and 1. and 3.

$$\Delta\phi_{12} \quad \text{vs} \quad \Delta\phi_{13}$$


3 particle flux tube
0 to 5% Centrality
1.008
1.006
1.004
1.002
1
0.998
0.996
350
300
250
200
150
100
50
0
Δφ (deg)
0
50
100
150
200
250
300
350
Δφ (deg)


flux tube cumulant
0 to 5% Centrality
×10⁻³
0.35
0.3
0.25
0.2
0.15
0.1
0.05
350
300
250
200
150
100
50
0
Δφ (deg)
0
50
100
150
200
250
300
350
Δφ (deg)


STAR Preliminary
(a)
(b)
(c)

Let us divide up the central Au Au into 7 transverse momentum bins

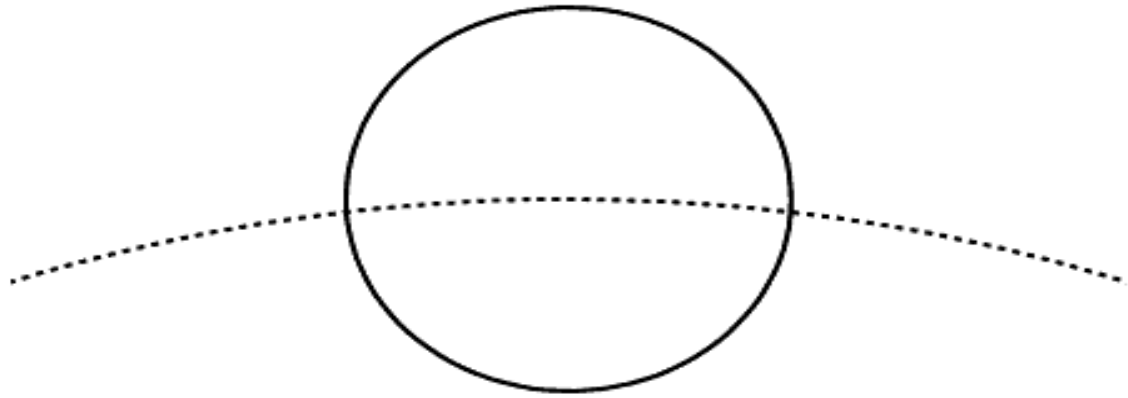
- P7 1.1 GeV/c < Pt < 4.0 GeV/c
- P6 0.8 GeV/c < Pt < 1.1 GeV/c
- P5 0.65 GeV/c < Pt < 0.8 GeV/c
- P4 0.5 GeV/c < Pt < 0.65 GeV/c
- P3 0.4 GeV/c < Pt < 0.5 GeV/c
- P2 0.3 GeV/c < Pt < 0.4 GeV/c
- P1 0.2 GeV/c < Pt < 0.3 GeV/c

40% of charged particle come from surface flux tubes

Table 2. Parameters of surface flux tube model charged particle

Variable	Amount	Fluctuations
flux tubes	12	0
Particles	49	10
Soft	873	30

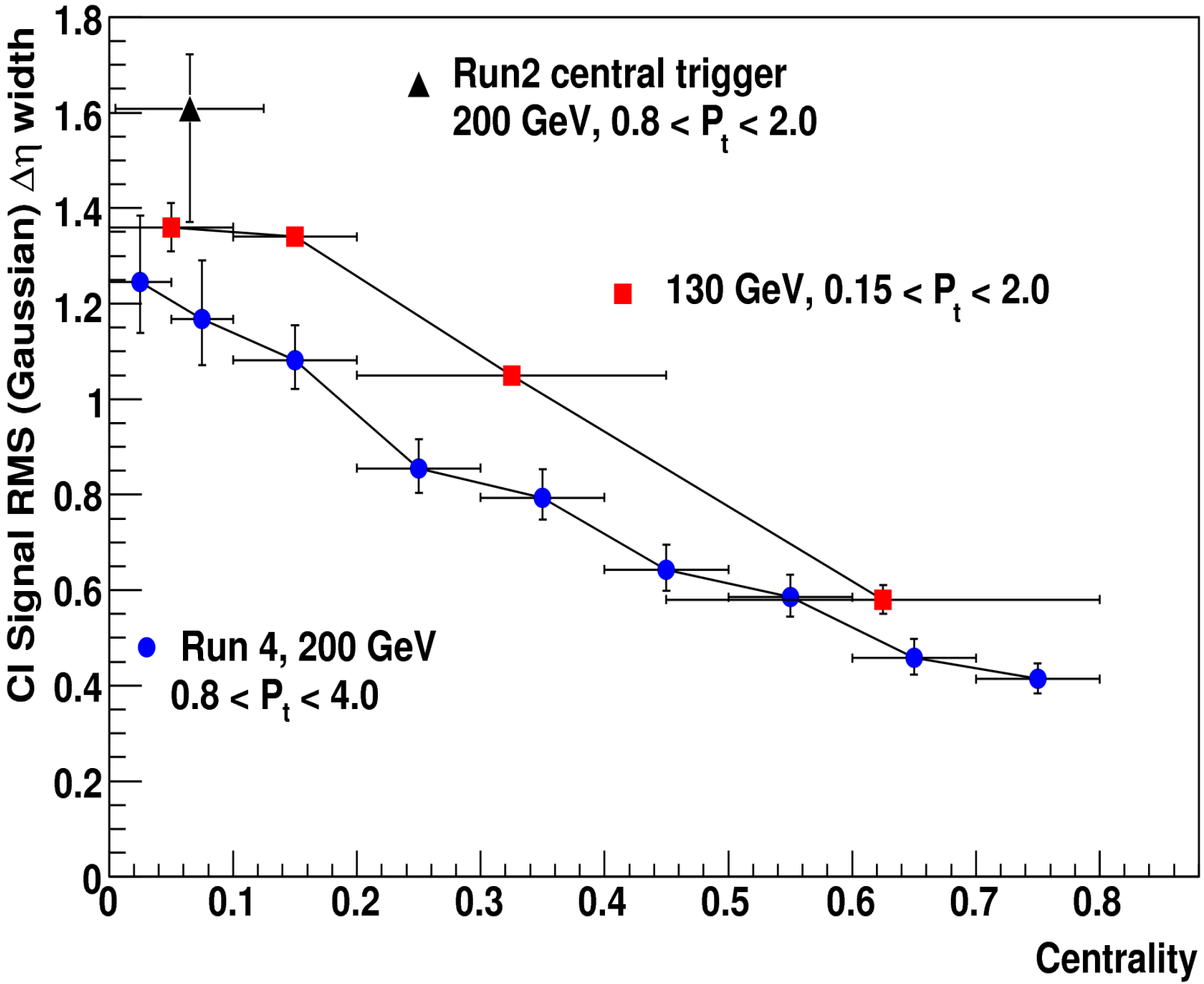
In the rest frame of the tube 1/2
of the particles are emitted away
from the fireball surface

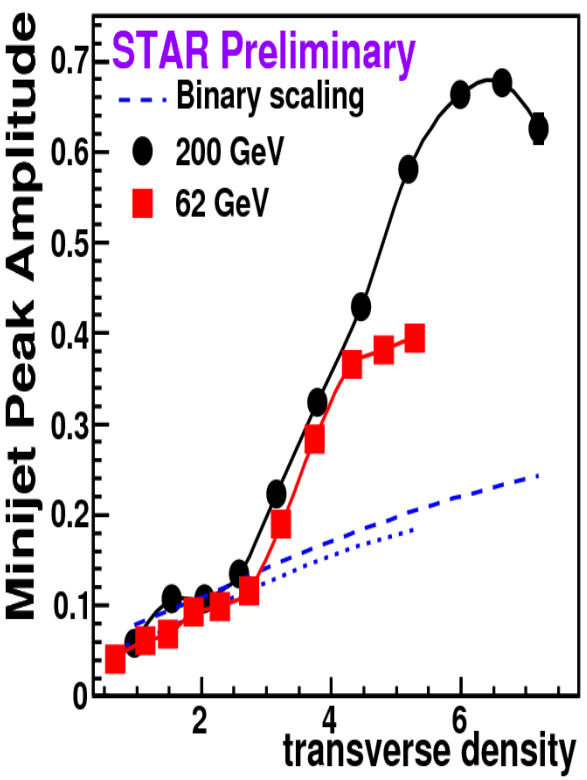


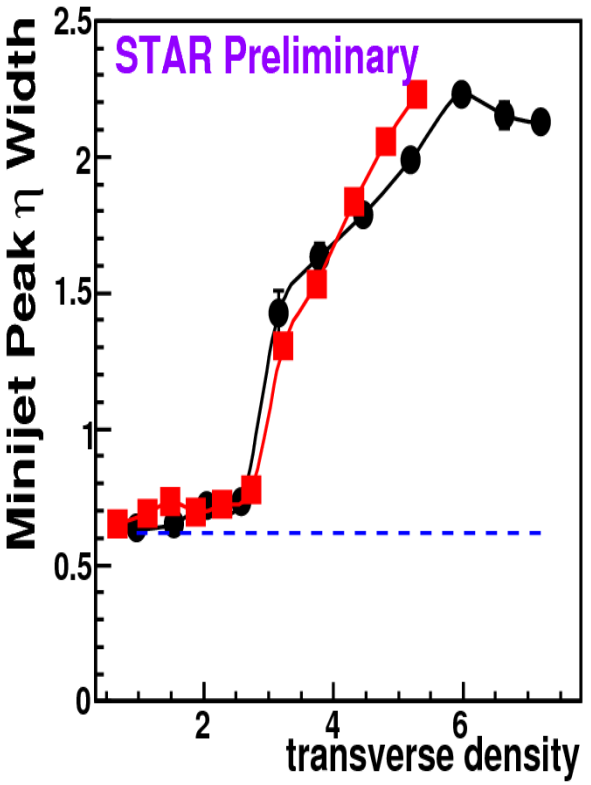
average of 49 particles 24.5 go outward

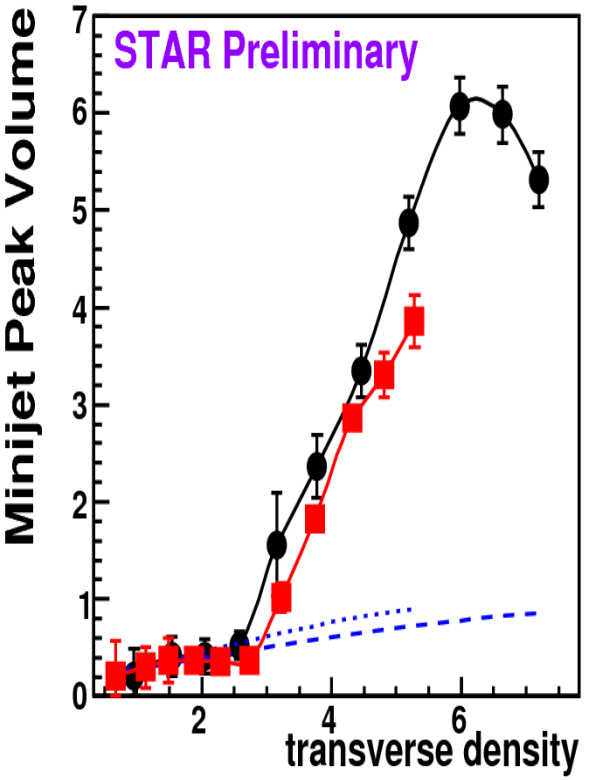
Average particle per tube per Pt becomes 20% of charged particles

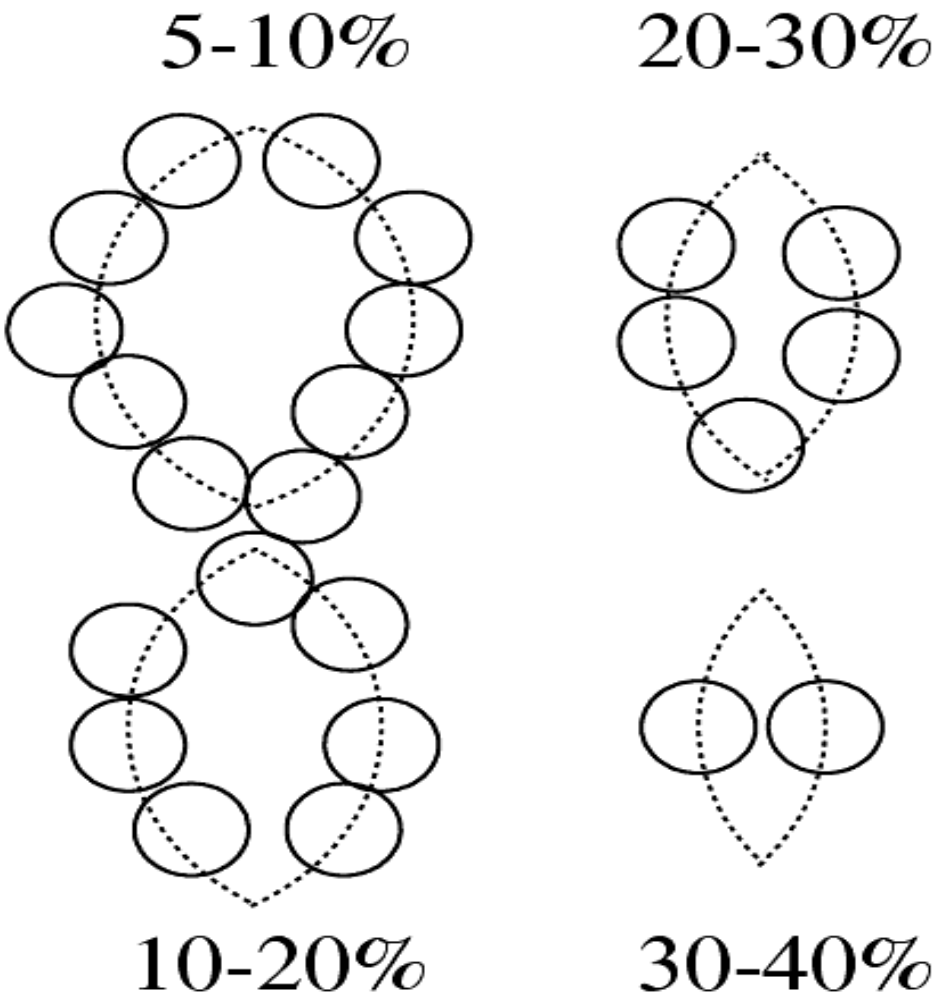
- P7 4.2 particles 100% survive
- P6 3.8 particles 76% survive
- P5 3.2 particles 65% survive
- P4 4.2 particles 54% survive
- P3 3.2 particles 43% survive
- P2 3.3 particles 35% survive
- P1 2.6 particles 25% survive


Run2 central trigger
200 GeV, 0.8 < P_t < 2.0
130 GeV, 0.15 < P_t < 2.0
Run 4, 200 GeV
0.8 < P_t < 4.0
CI Signal RMS (Gaussian) Δη width
Centrality
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8


STAR Preliminary
Binary scaling
200 GeV
62 GeV
Minijet Peak Amplitude
transverse density


STAR Preliminary
Minijet Peak η Width
transverse density


STAR Preliminary
Minijet Peak Volume
transverse density


5-10%
20-30%
10-20%
30-40%

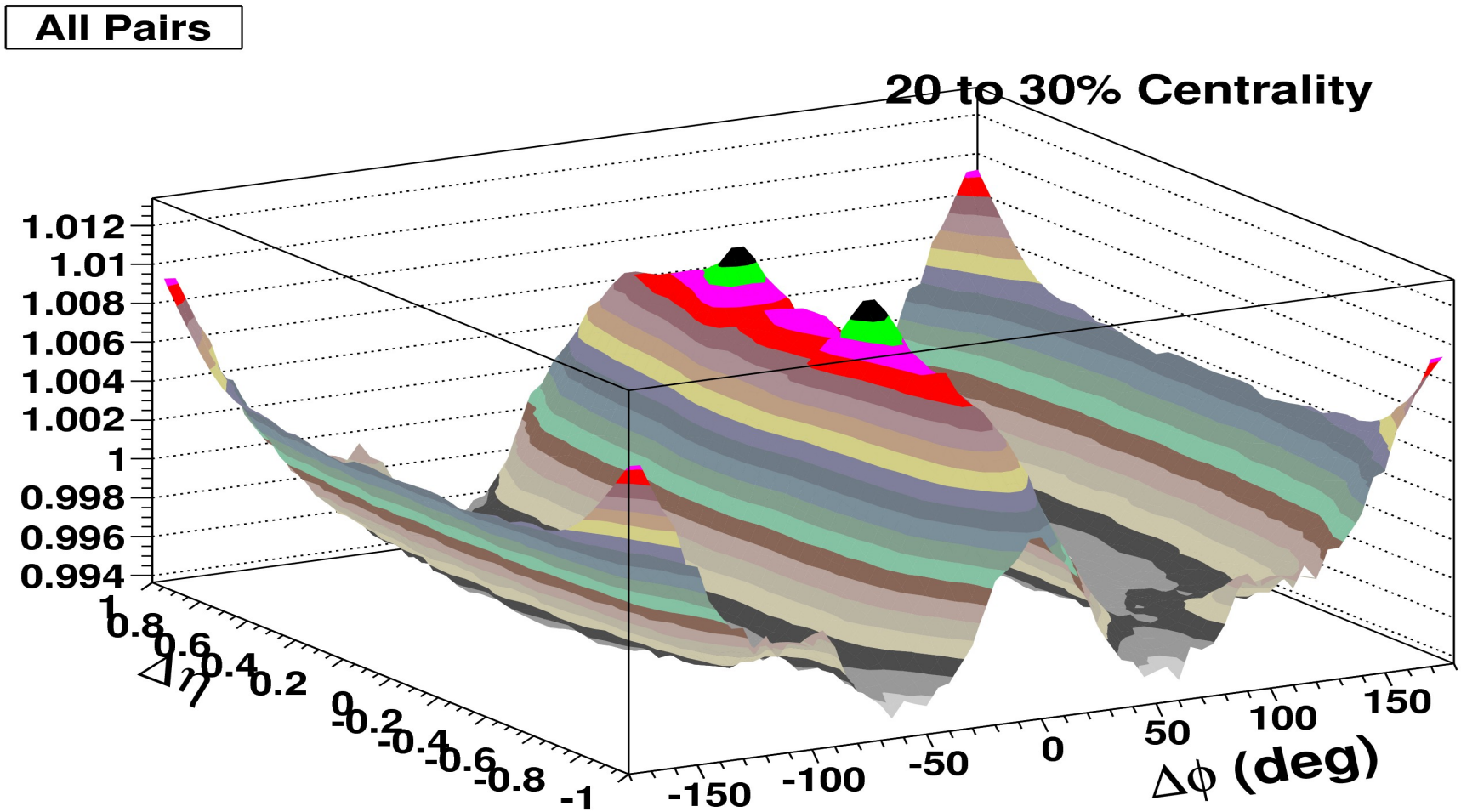
Surface vs Bulk

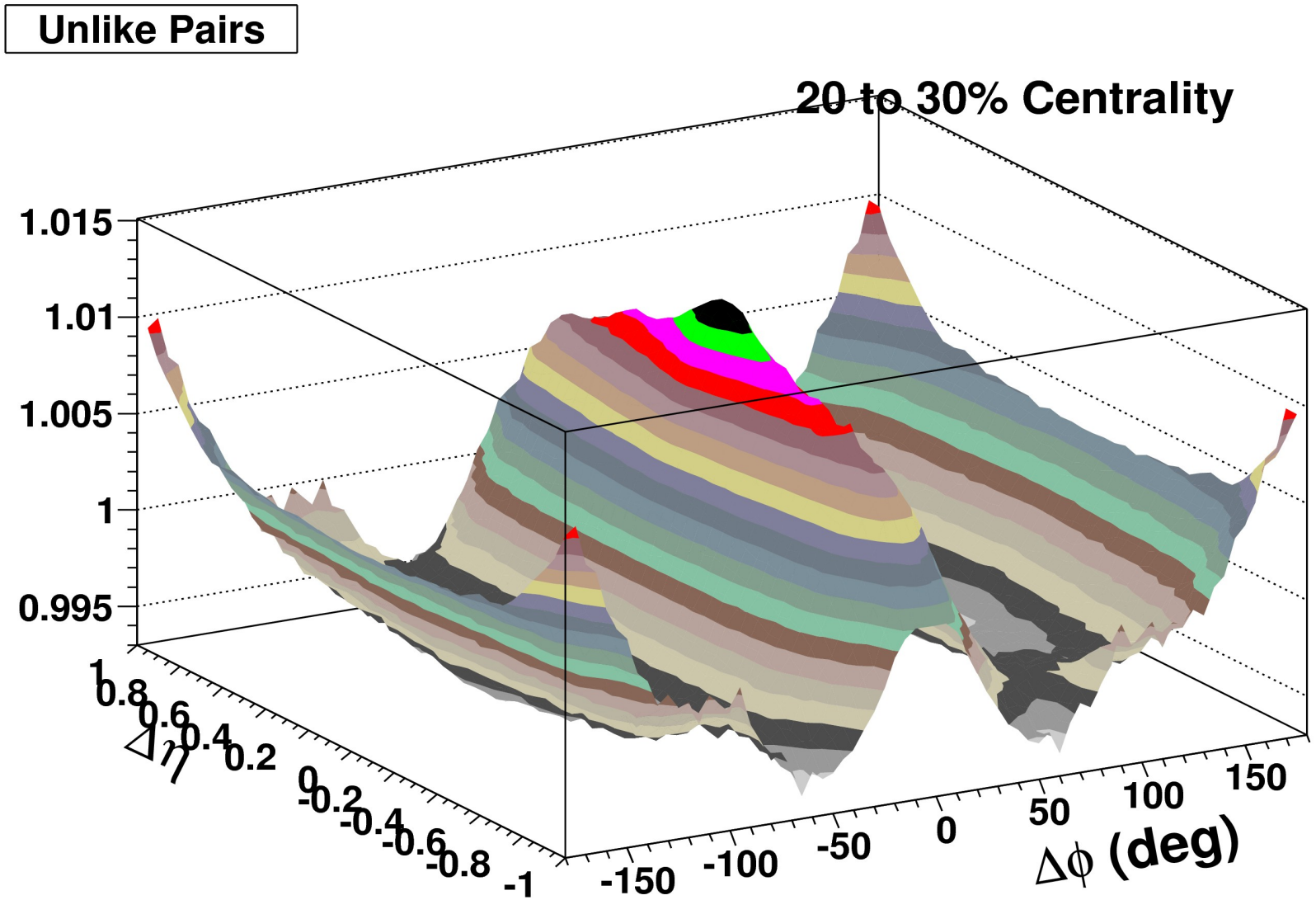
20% to 30%

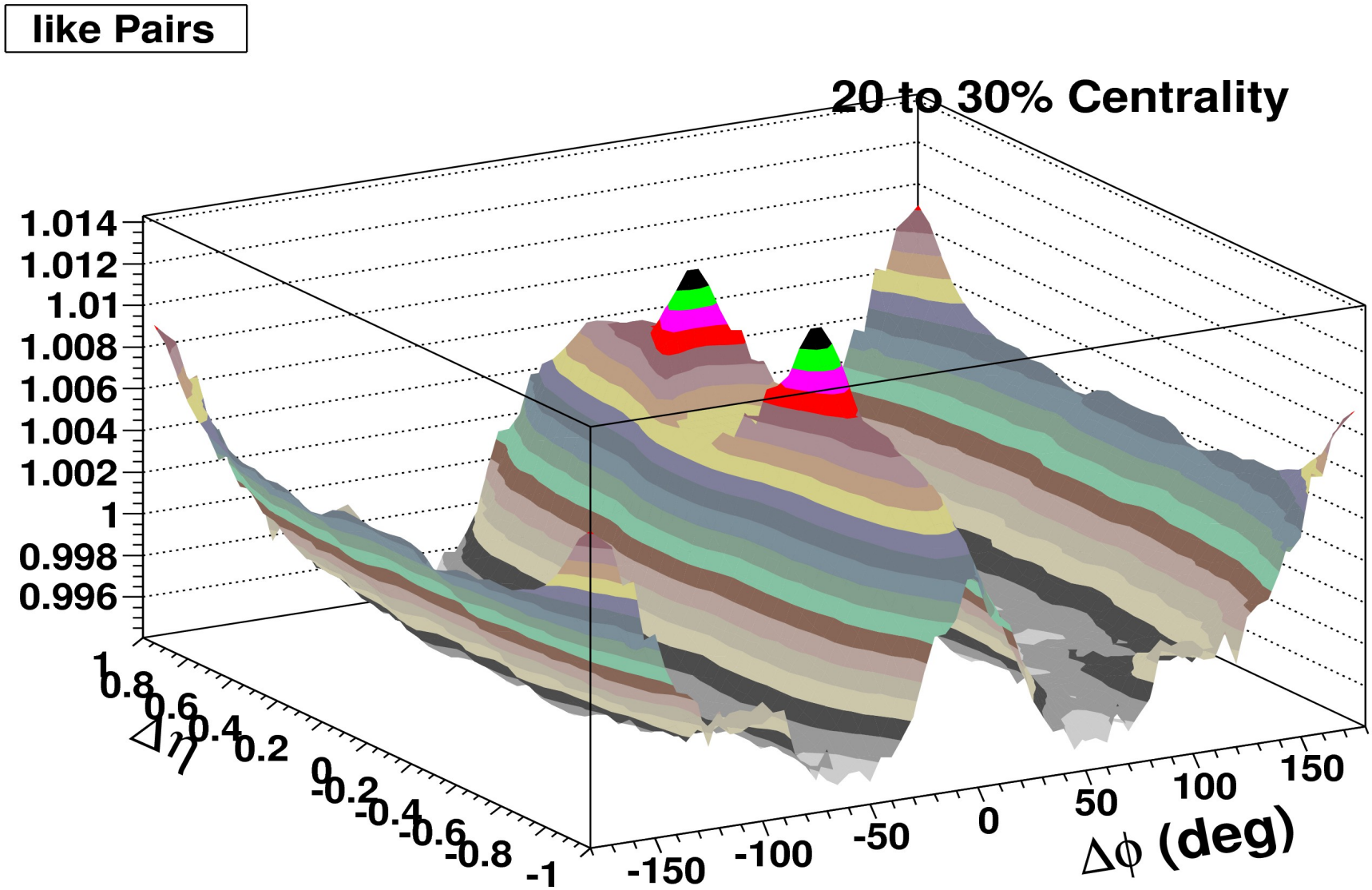
Surface flux tubes 5 in number

Bulk flux tubes 9 in number

# of particles 4.0 > Pt > 0.8 GeV/c equals 131
# of particles 4.0 > Pt > 0.2 GeV/c equals 598


All Pairs
20 to 30% Centrality
1.012
1.01
1.008
1.006
1.004
1.002
1
0.998
0.996
0.994
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
Δη
-150
-100
-50
0
50
100
150
Δφ (deg)


Unlike Pairs
20 to 30% Centrality
1.015
1.01
1.005
1
0.995
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
Δη
-150
-100
-50
0
50
100
150
Δφ (deg)


like Pairs
20 to 30% Centrality
1.014
1.012
1.01
1.008
1.006
1.004
1.002
1
0.998
0.996
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
Δη
-150
-100
-50
0
50
100
150
Δφ (deg)

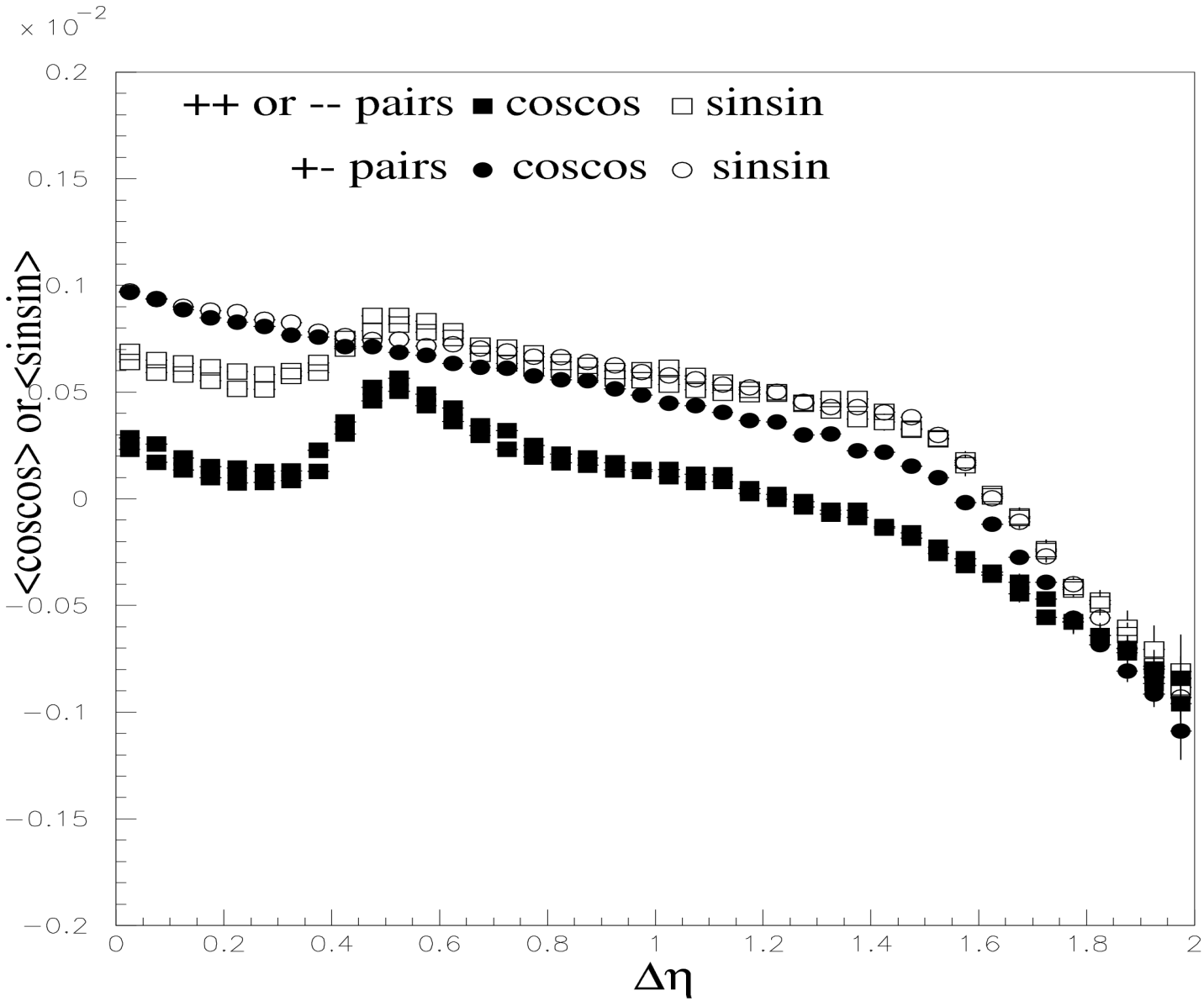
Three Particle Correlation

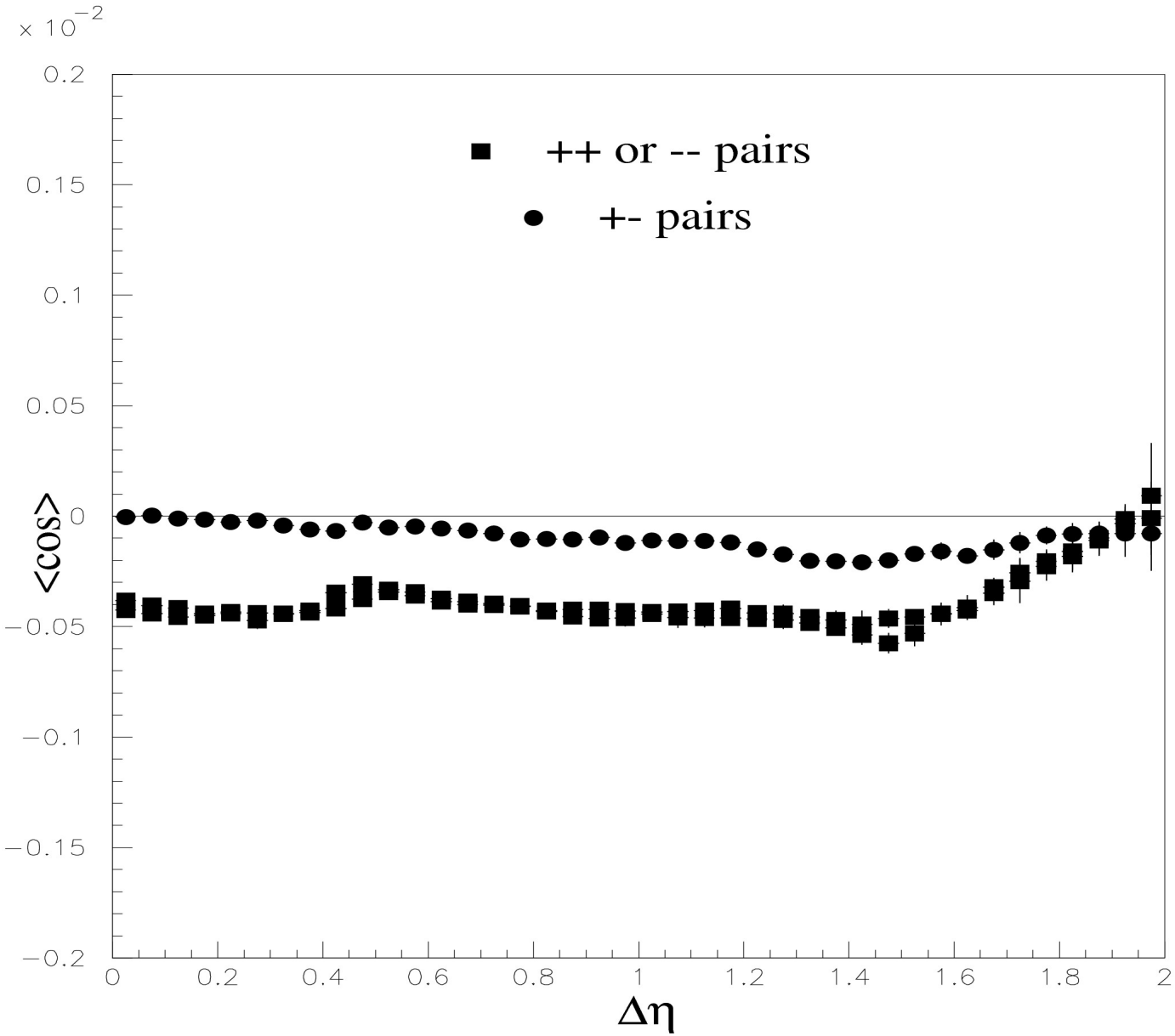
$$\langle\cos(\phi_1(\eta_1) + \phi_2(\eta_2) - 2\phi_3)\rangle$$

$$\Delta\eta = \eta_1 - \eta_2$$

If ϕ_3 = reaction plane and ϕ_1 & ϕ_2 are measured in the rotated frame then $\phi_3 = 0$

$$\langle\cos(\phi_1(\eta_1) + \phi_2(\eta_2))\rangle = \langle\cos\phi_1\cos\phi_2\rangle - \langle\sin\phi_1\sin\phi_2\rangle$$


× 10^−2
0.2
0.15
0.1
0.05
0
−0.05
−0.1
−0.15
−0.2
<coscos> or <sinsin>
++ or -- pairs ■ coscos □ sinsin
+- pairs ● coscos ○ sinsin
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Δη


× 10^−2
0.2
0.15
0.1
0.05
0
−0.05
−0.1
−0.15
−0.2
<cos>
++ or -- pairs
+- pairs
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Δη

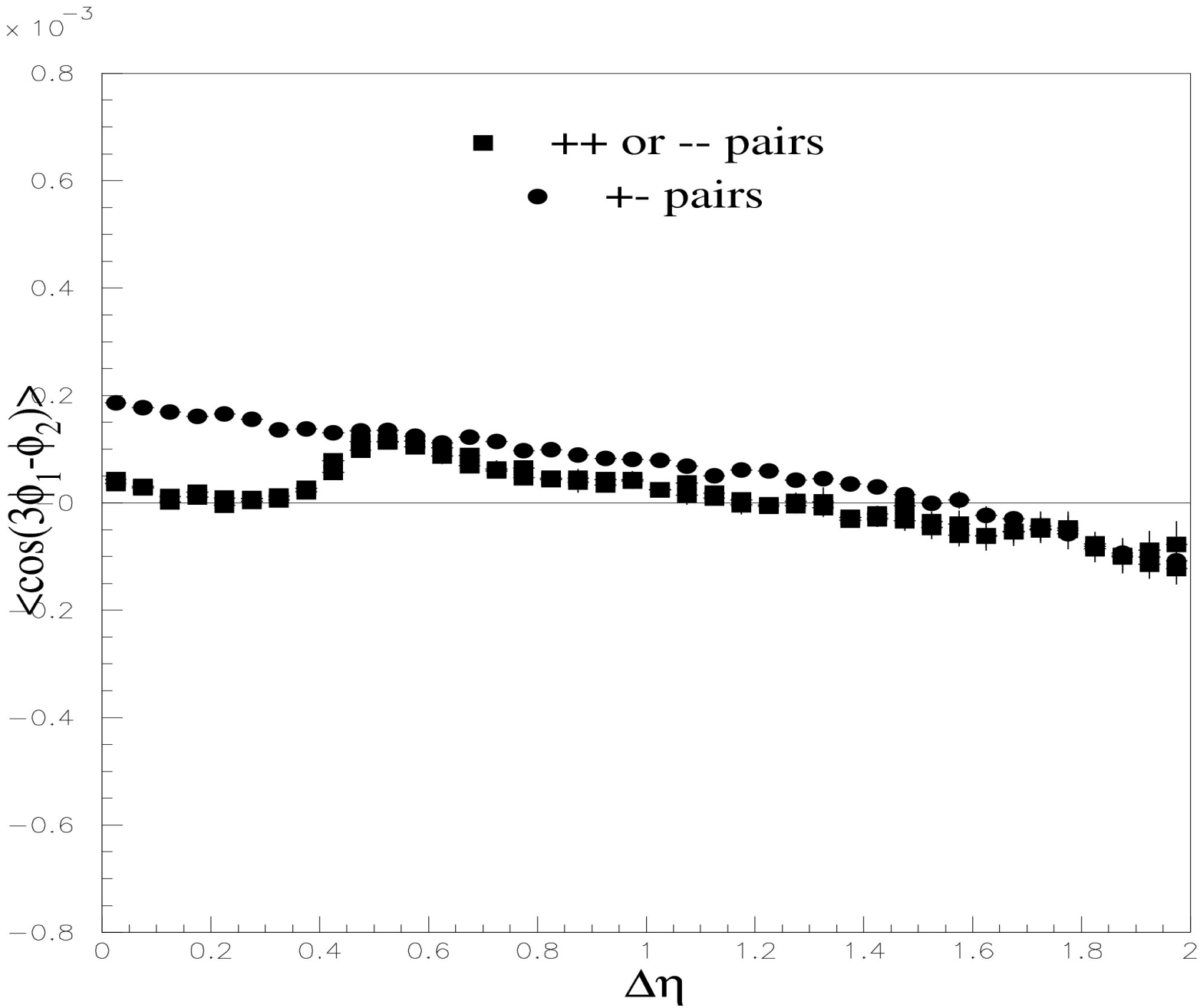
Another Three Particle Correlation

$$\langle\cos(3\phi_1(\eta_1) - \phi_2(\eta_2) - 2\phi_3)\rangle$$

$$\Delta\eta = \eta_1 - \eta_2$$

If ϕ_3 = reaction plane and ϕ_1 & ϕ_2 are measured in the rotated frame then $\phi_3 = 0$

$$\langle\cos(3\phi_1(\eta_1) - \phi_2(\eta_2))\rangle$$


× 10^−3
0.8
0.6
0.4
0.2
0
−0.2
−0.4
−0.6
−0.8
<cos(3φ1-φ2)>
++ or -- pairs
+- pairs
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Δη

Flux Tubes are 3D

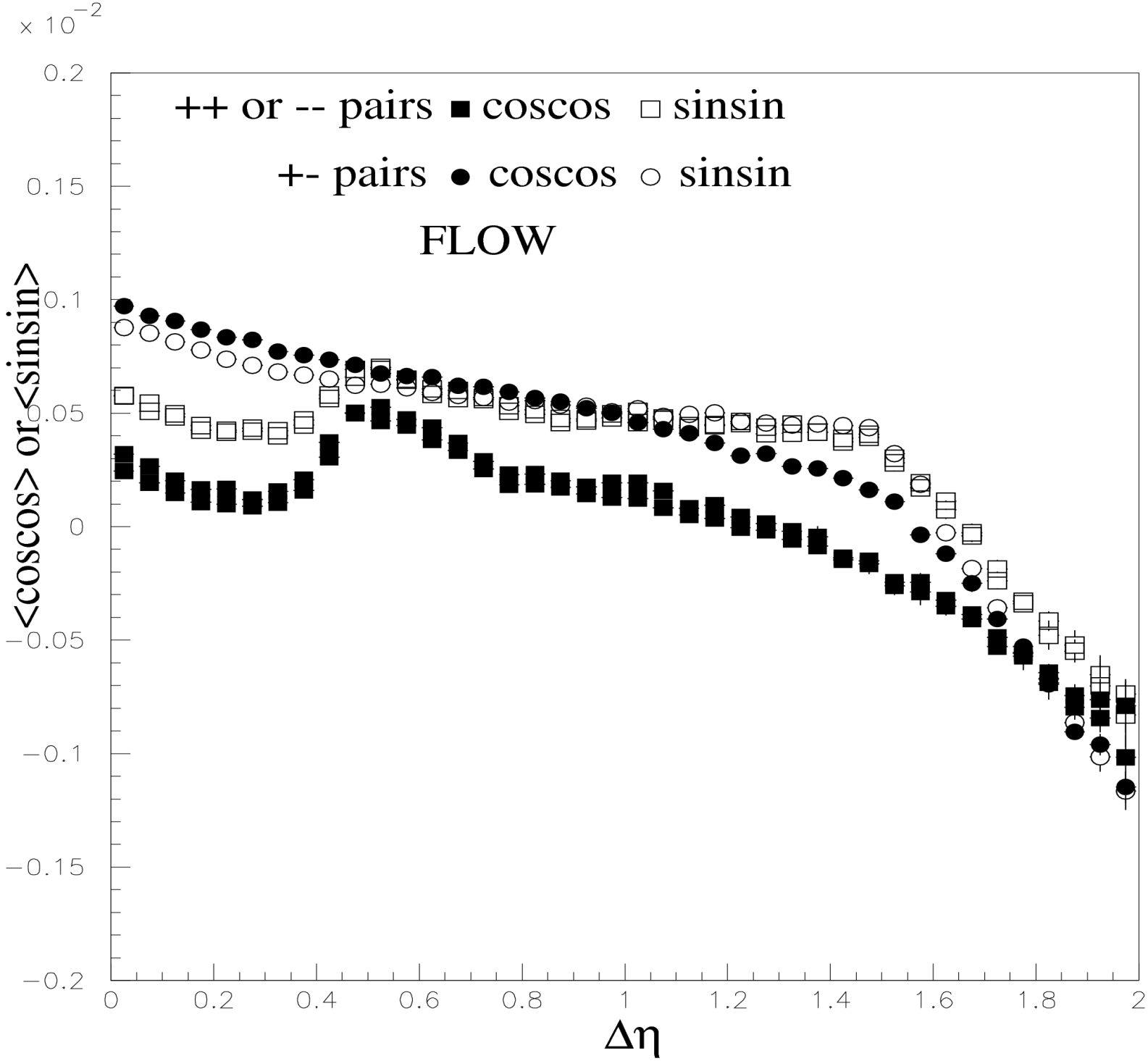
1. They occur at different X, Y and η.
2. Momentum Conservation between Tubes.
3. Thus a $-\cos\phi$ between Tubes.
4. This an initial condition of the system.
5. Large $\Delta\eta$ is between different tubes.

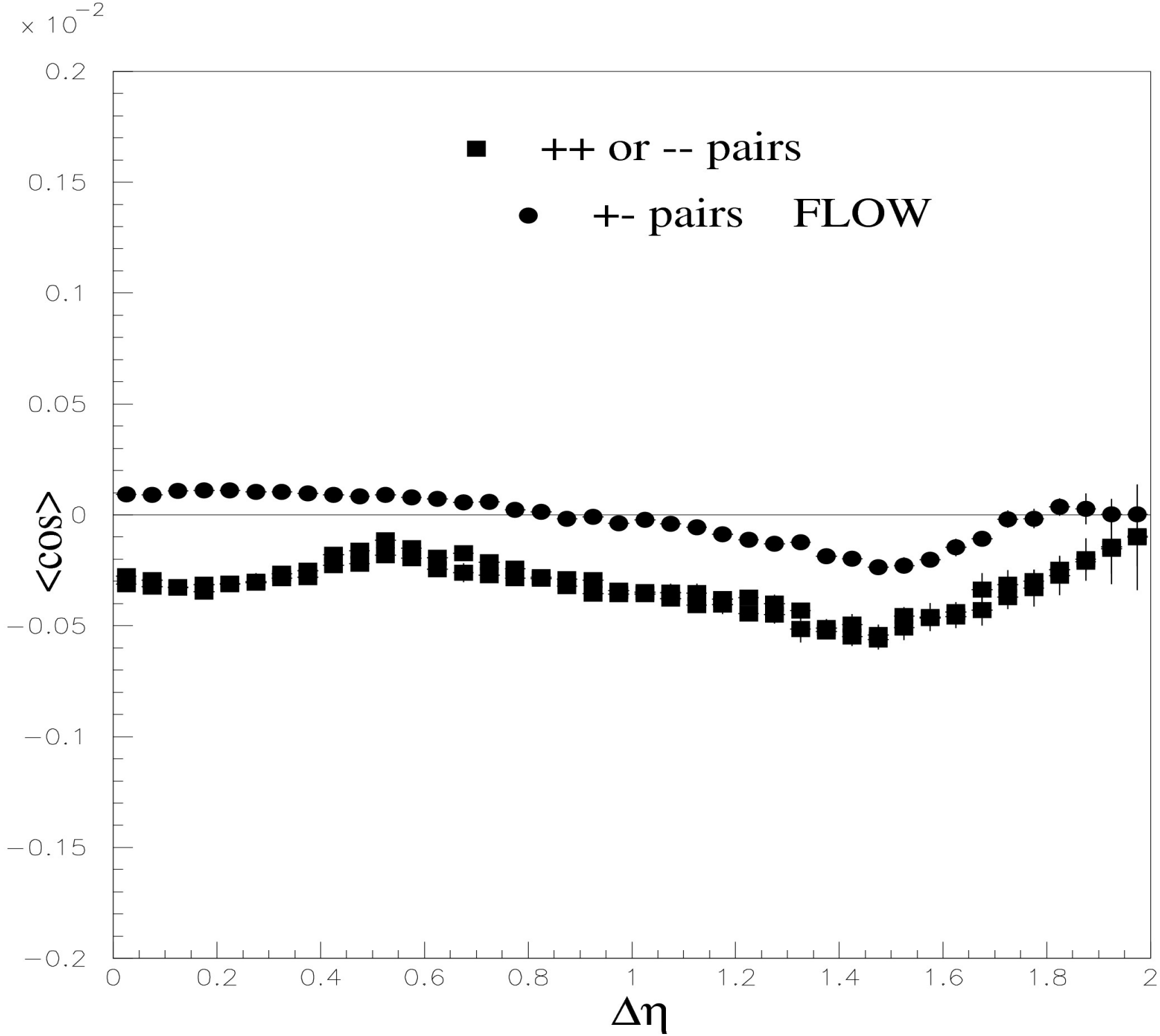
Glauber is 2D which spreads in η.

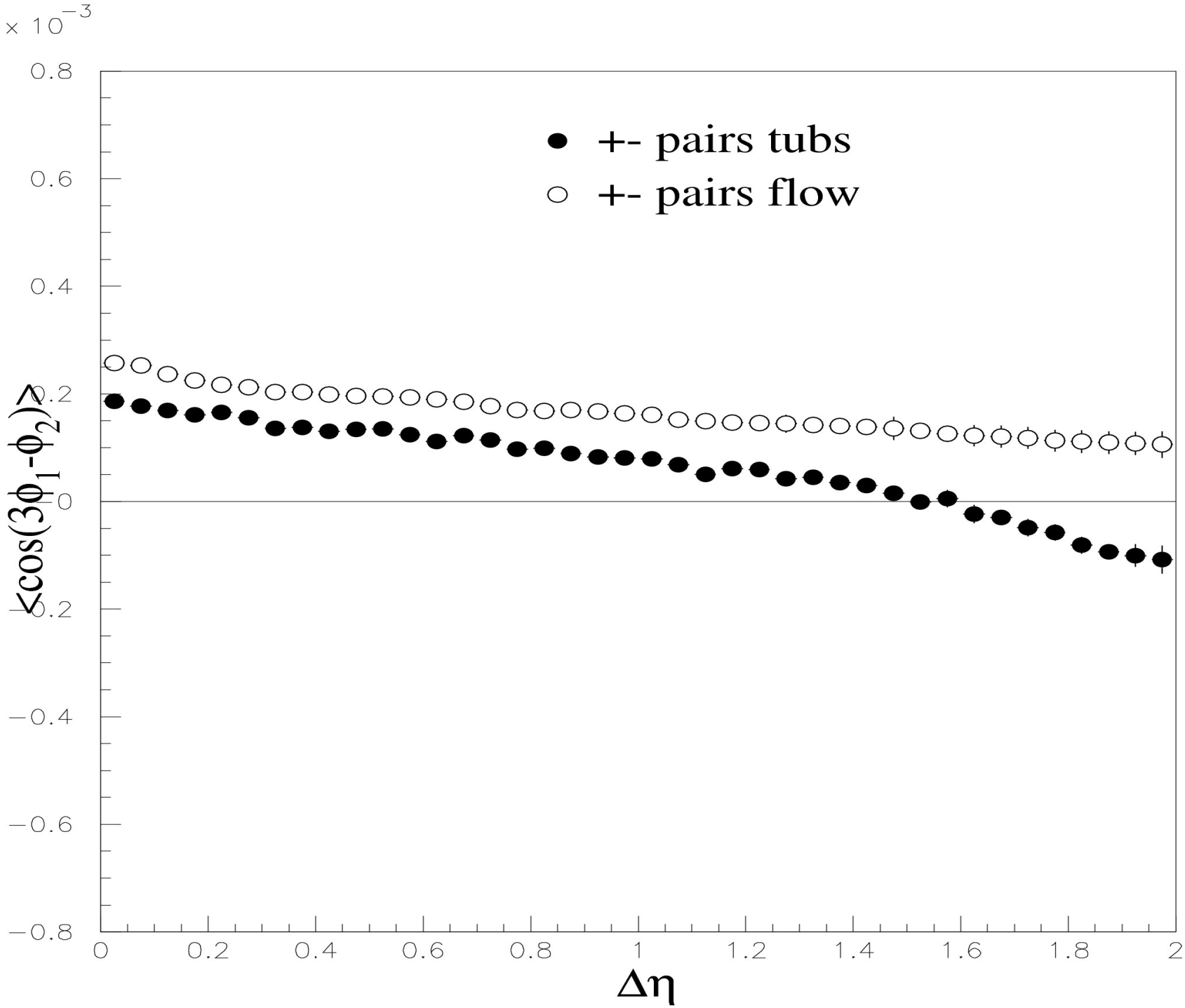
1. Initial ϕ effect spreads in η.

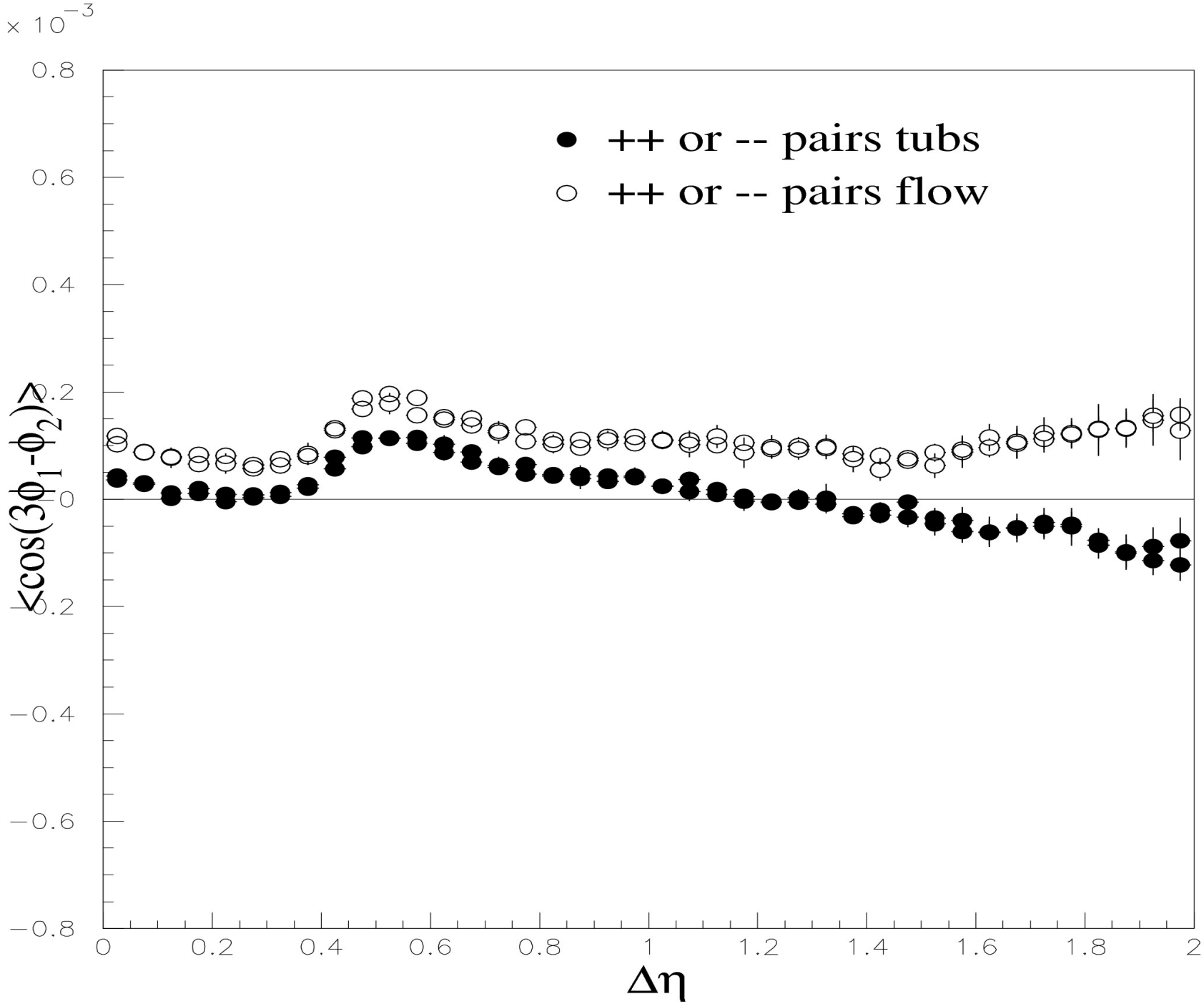
2. Momentum Conservation is shared by all.

3. Large $\Delta\eta$ correlation is from same Glauber effect spread in η.

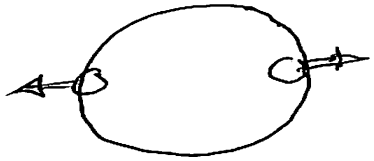

× 10^−2
0.2
0.15
0.1
0.05
0
−0.05
−0.1
−0.15
−0.2
<coscos> or <sinsin>
++ or -- pairs ■ coscos □ sinsin
+- pairs ● coscos ○ sinsin
FLOW
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Δη


× 10^−2
0.2
0.15
0.1
0.05
0
−0.05
−0.1
−0.15
−0.2
<cos>
++ or -- pairs
+- pairs FLOW
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Δη

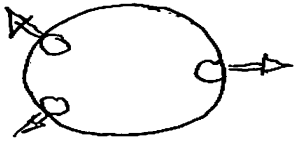

× 10^−3
0.8
0.6
0.4
0.2
0
−0.2
−0.4
−0.6
−0.8
+- pairs tubs
+- pairs flow
<cos(3φ1-φ2)>
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Δη


× 10⁻³
0.8
0.6
0.4
0.2
0
−0.2
−0.4
−0.6
−0.8
<cos(3φ1-φ2)>
++ or -- pairs tubs
++ or -- pairs flow
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Δη

Central Collisions



v_2 Tubes

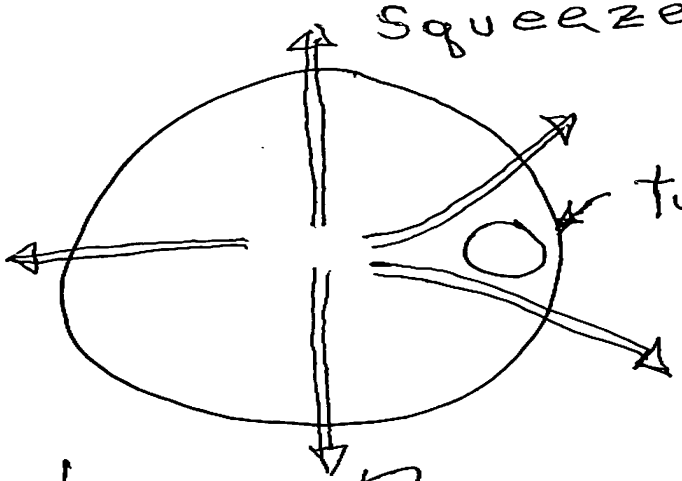


v_3 Tubes

High P_t both v_2 v_3 positive 0°

In the center particle flow

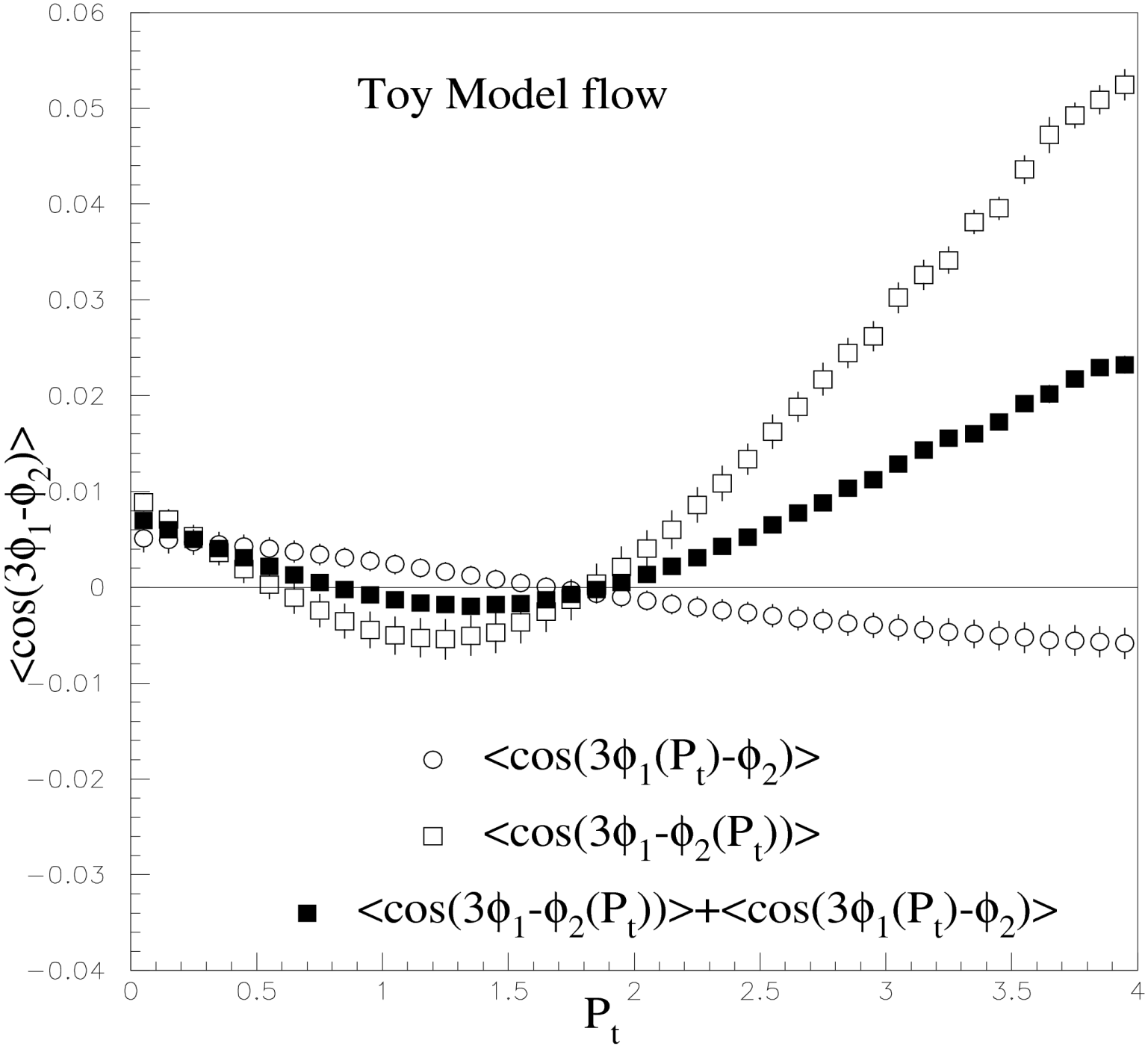
Squeeze Out

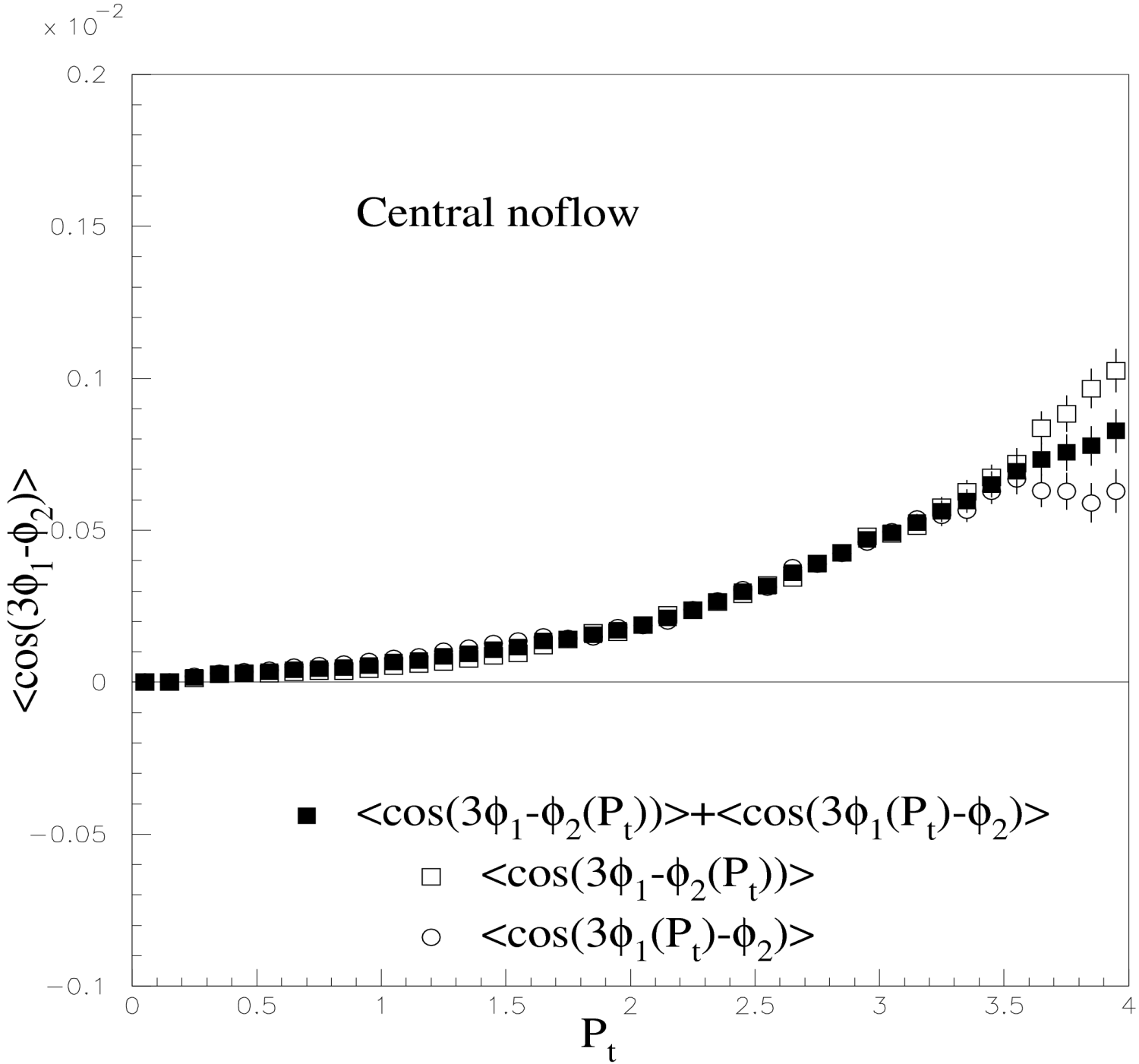


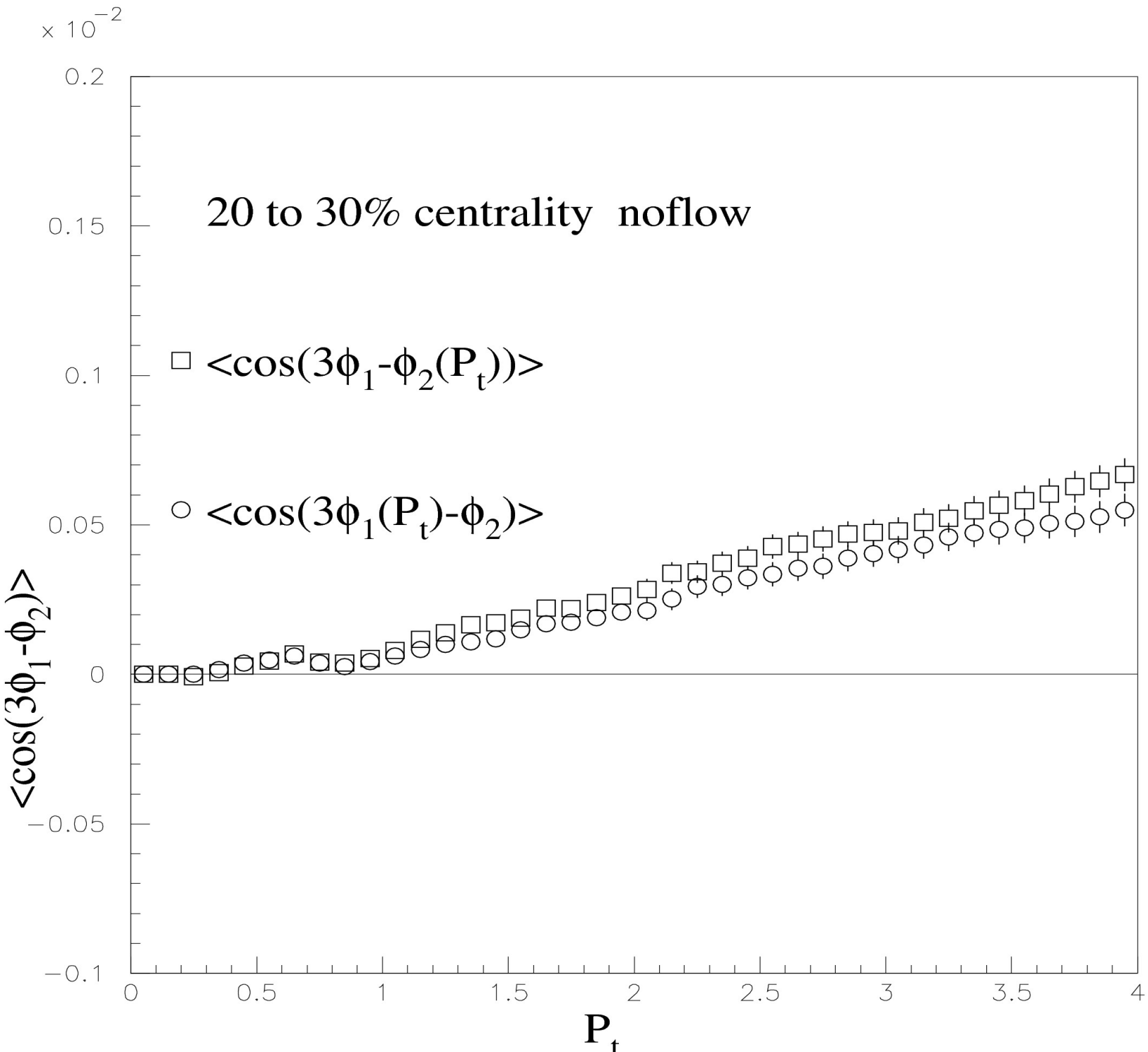
tube

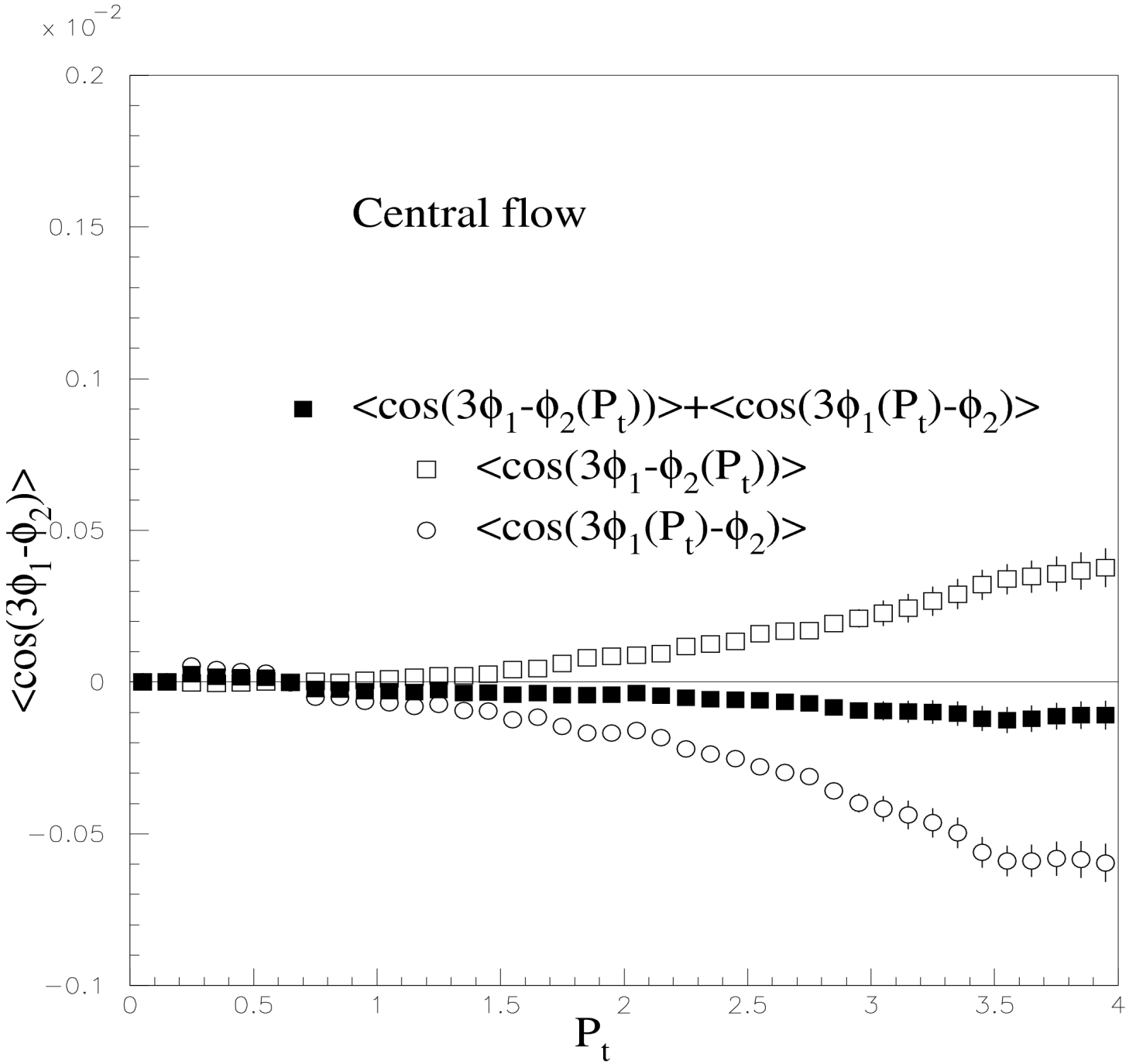
Low P_t

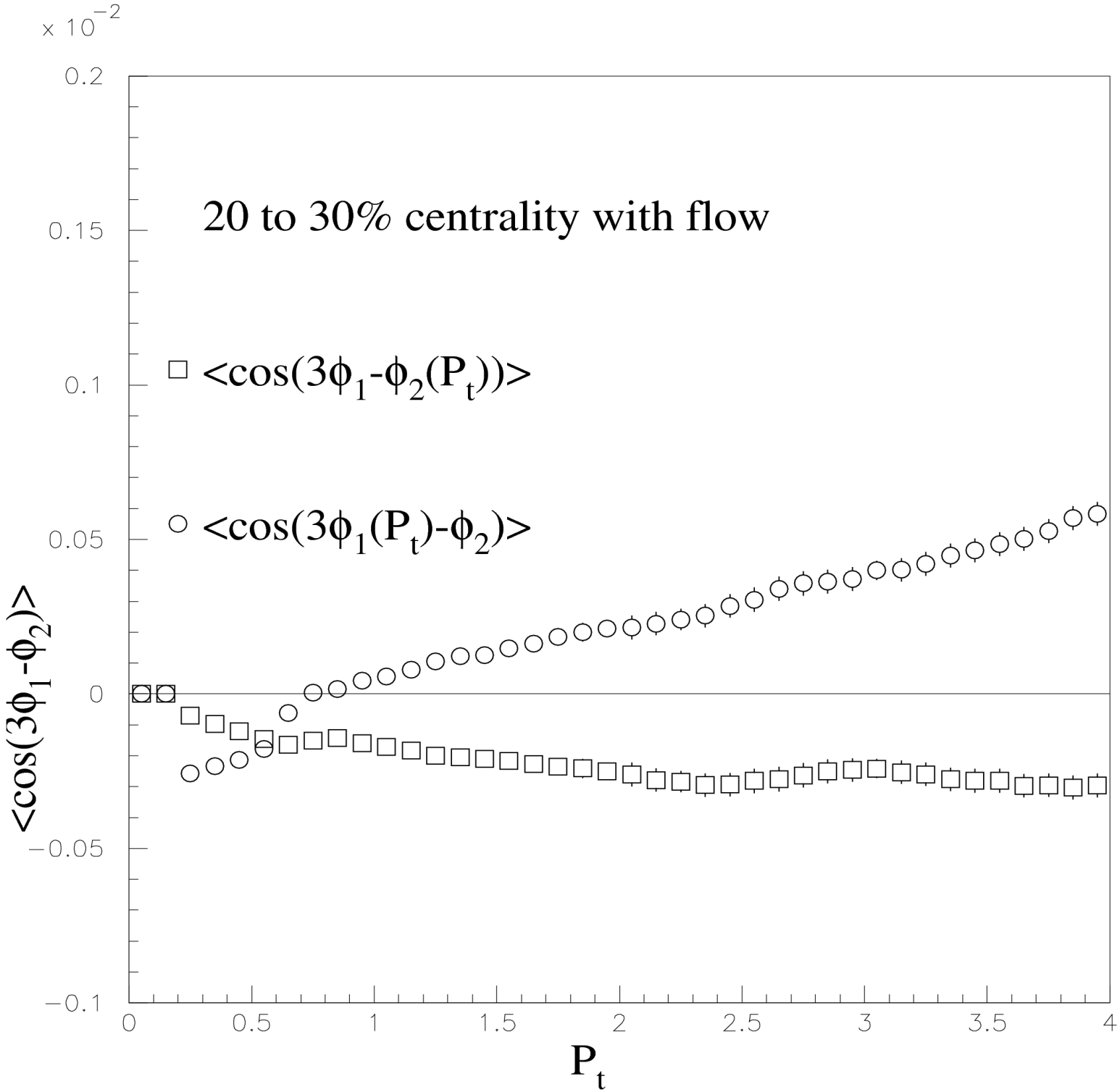
v_2 at 90° v_3 at 180°


Toy Model flow
<cos(3φ1-φ2)>
Pt
<cos(3φ1(Pt)-φ2)>
<cos(3φ1-φ2(Pt))>
<cos(3φ1-φ2(Pt))>+<cos(3φ1(Pt)-φ2)>
0.06
0.05
0.04
0.03
0.02
0.01
0
−0.01
−0.02
−0.03
−0.04
0
0.5
1
1.5
2
2.5
3
3.5
4


x 10^-2
0.2
0.15
0.1
0.05
0
−0.05
−0.1
Central noflow
<cos(3φ1-φ2)>
<cos(3φ1-φ2(Pt))>+<cos(3φ1(Pt)-φ2)>
<cos(3φ1-φ2(Pt))>
<cos(3φ1(Pt)-φ2)>
0
0.5
1
1.5
2
2.5
3
3.5
4
Pt


× 10^−2
0.2
0.15
0.1
0.05
0
−0.05
−0.1
20 to 30% centrality noflow
□ <cos(3φ1-φ2(Pt))>
○ <cos(3φ1(Pt)-φ2)>
<cos(3φ1-φ2)>
0
0.5
1
1.5
2
2.5
3
3.5
4
Pt


× 10^−2
0.2
0.15
0.1
0.05
0
−0.05
−0.1
0
0.5
1
1.5
2
2.5
3
3.5
4
P_t
<cos(3φ_1-φ_2)>
Central flow
<cos(3φ_1-φ_2(P_t))>+<cos(3φ_1(P_t)-φ_2)>
<cos(3φ_1-φ_2(P_t))>
<cos(3φ_1(P_t)-φ_2)>


x 10^-2
0.2
0.15
0.1
0.05
0
−0.05
−0.1
0
0.5
1
1.5
2
2.5
3
3.5
4
20 to 30% centrality with flow
<cos(3φ1-φ2(Pt))>
<cos(3φ1(Pt)-φ2)>
<cos(3φ1-φ2)>
Pt

Conclusions

Three particle correlations using the third particle as a measure of the reaction plane maybe able to determine the nature of the quark gluon plasma evolution.

The existence of Glasma Flux Tubes and how they form and interact with the flowing plasma maybe imprinted on these correlations.

These correlations should differ from initial Glauber with a 3D hydo evolution.