Azimuthal Correlation in p+p, d+Au and Au+Au System

Aihong Tang for STAR

Outline

- **Refresh STAR's old results[1,2] on scalar product in p+p, d+Au and Au+Au systems.**

- **Present STAR's recent studies[3] on two particle correlation in light of recent discussions of "flow in small systems".**

[1] STAR, PRC 72 014904 (2005)
[2] STAR, PRL 93 252301 (2004)
[3] Y. Li for STAR, QM2014. F. Wang for STAR arXiv:1403.5851

Choosing the Right Scaling Variable

v_2 does not scale --- need to find a multiplicity (or Nbinary) independent quantity to compare azimuthal correlations between two different systems.

The most elegant choice is

$$M^2\left\langle e^{in(\phi_1-\phi_2)}\right\rangle = M \bullet M\left\langle e^{in(\phi_1-\phi_2)}\right\rangle = M \bullet \underbrace{\left\langle uQ^*\right\rangle}_{\text{Multiplicity independent correlations}} = M\,\tilde{\delta}_2$$

Scaling !

Multiplicity independent correlations

$$Q = \sum u_i; \quad u_i = e^{i2\phi_i}$$

The Scalar Product

$$\langle u_b Q^* \rangle = (v_b v_p + \delta_{bp}^{AA}) M^{AA}$$

$$\delta_{bp}^{AA} \approx \frac{\delta_{bp}^{pp}}{N_{coll}} \approx \frac{\delta_{bp}^{pp} M^{pp}}{M^{AA}}$$

$$\longrightarrow \quad \langle u_b Q^* \rangle^{AA} \approx v_b v_p M^{AA} + \langle u_b Q^* \rangle^{pp}$$

$$Q = \sum_{i \in \text{"pool"}} u_i; \quad u_i = e^{i2\phi_i}$$

v_p - Flow in a particle pt/eta "bin"

v_b - Average flow for particles used ("pool particles") to define RP

δ_{bp}^{pp} - Azimuthal correlations in pp ($\langle u_a u_b^* \rangle$, $u = e^{i2\phi}$)

Then non-flow/flow contribution ratio in AA would be:

$$\frac{\delta_{bp}^{pp}}{N_{coll}} : v_2^2$$

Could be significant for peripheral ($N_{coll} \sim 5, v \sim 0.08$) or very central ($N_{coll} \sim 200, v \sim 0.01$) collisions

S. Voloshin, 2003

In a Formal Language

Consider the generating function for cumulants

$$G_n(z) = \prod_{j=1}^{M} (1 + z^* e^{in\phi_j} + z e^{-in\phi_j})$$

For a system that is superposition of two independent system 1 and 2, and only "nonflow" correlations are present, we have

$$G(z) = G1(z)G2(z)$$

So if a Nucleus-Nucleus collision is a simple superposition of N independent pp collisions, then

$$G(z) = [G_{pp}(z)]^N$$

Log(G(z)) then should scale linearly with the number of pp collisions, so should cumulants, which is the coefficient of z of Log(G(z)).

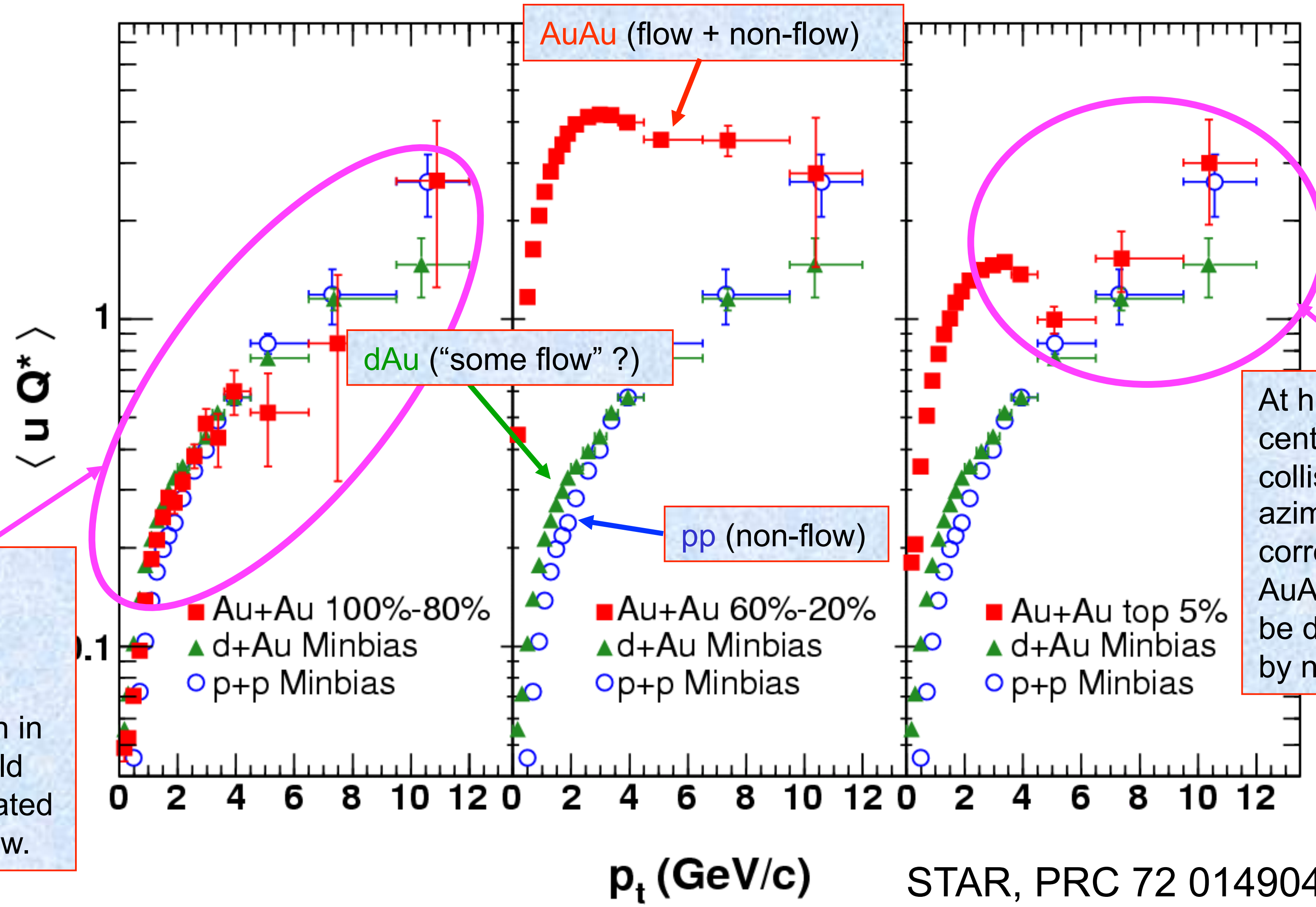
In the case of a second order cumulant, this is

$$M^2 \left\langle e^{in(\phi_1 - \phi_2)} \right\rangle = M \bullet M \left\langle e^{in(\phi_1 - \phi_2)} \right\rangle = M \bullet \langle uQ^* \rangle = M \tilde{\delta}_2$$

J-Y Ollitrault, 2003

Scalar Product in pp, dAu, and AuAu Collisions

$$\left\langle u_b Q^* \right\rangle^{AA} \approx v_b v_p M^{AA} + \left\langle u_b Q^* \right\rangle^{pp}$$



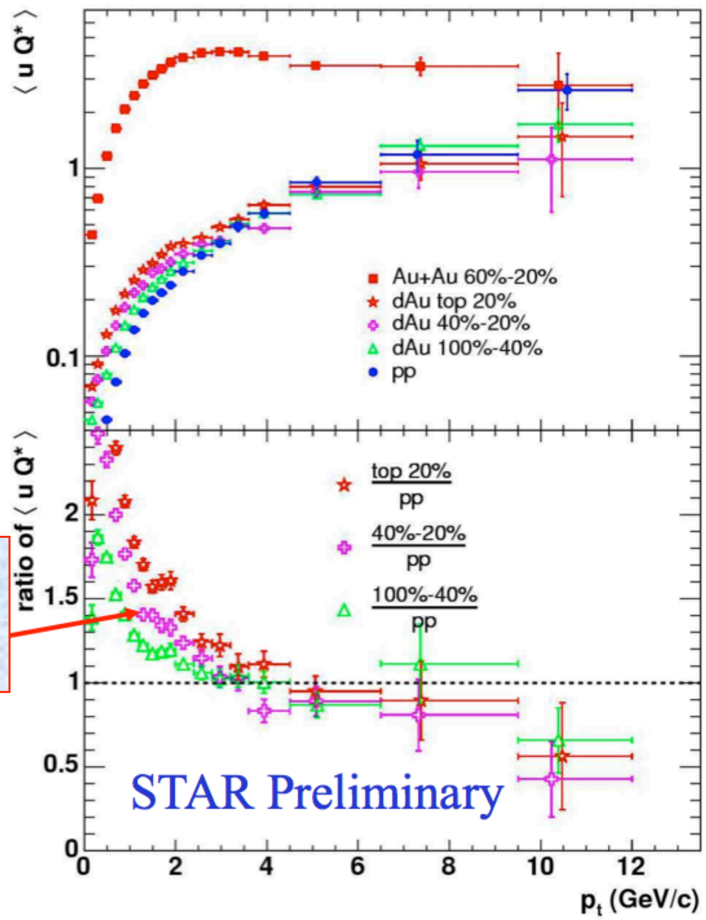
In VERY peripheral collisions, azimuthal correlation in AuAu could be dominated by non-flow.

At high pt in central collisions, azimuthal correlation in AuAu could be dominated by nonflow.

STAR, PRC 72 014904 (2005)

Scalar Product in pp, dAu, and AuAu Collisions

Is there " elliptic flow " in dAu collisions ?



Collective motion at low pt or other physics ?

The scalar product in dAu collisions is relatively close to that from p+p collisions but there is a finite difference at low p_t

The scalar product in dAu keeps increasing as a function of multiplicity class, which is contradictory to AuAu collisions, where the difference rise and fall as a function of centrality

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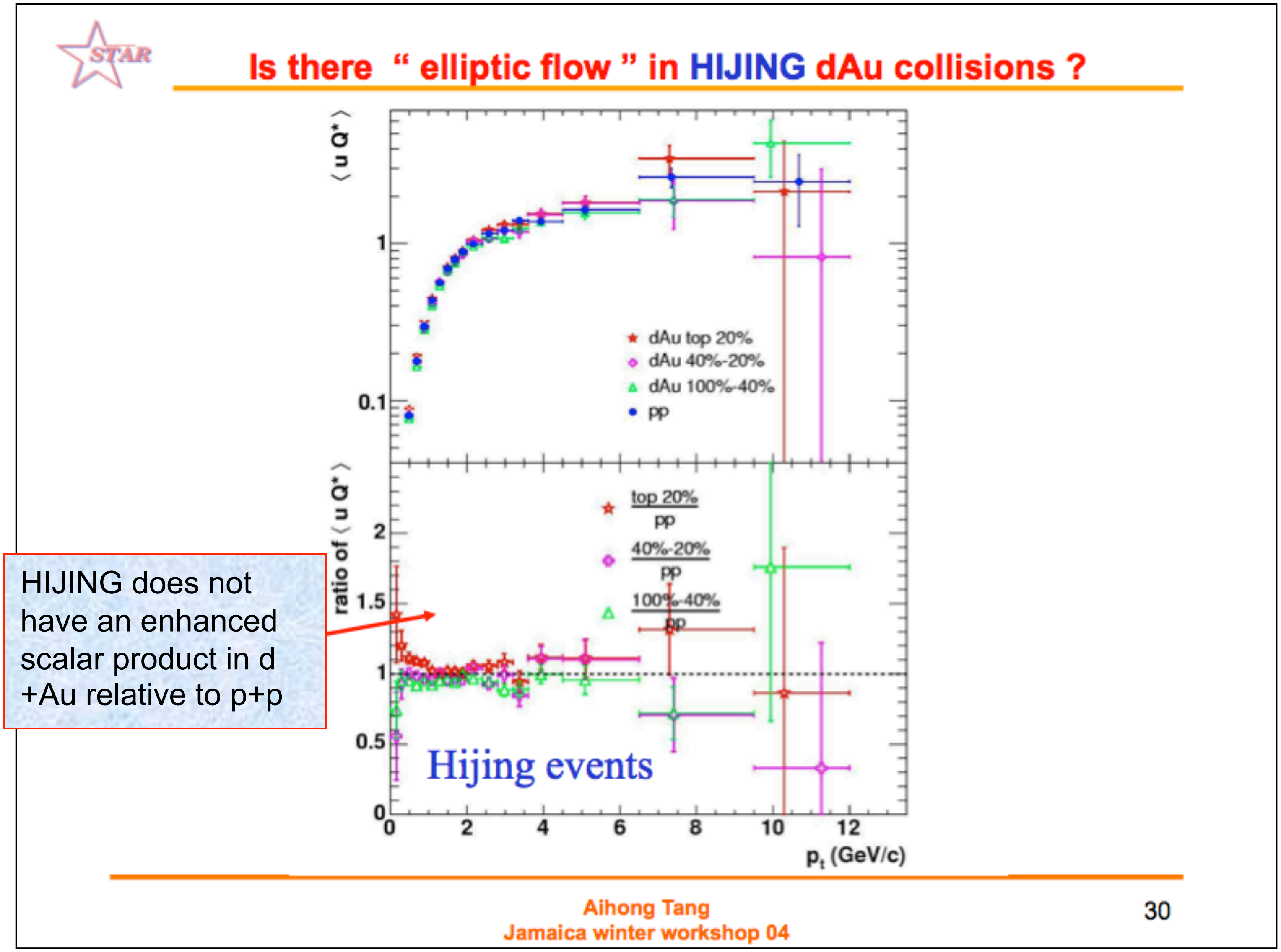
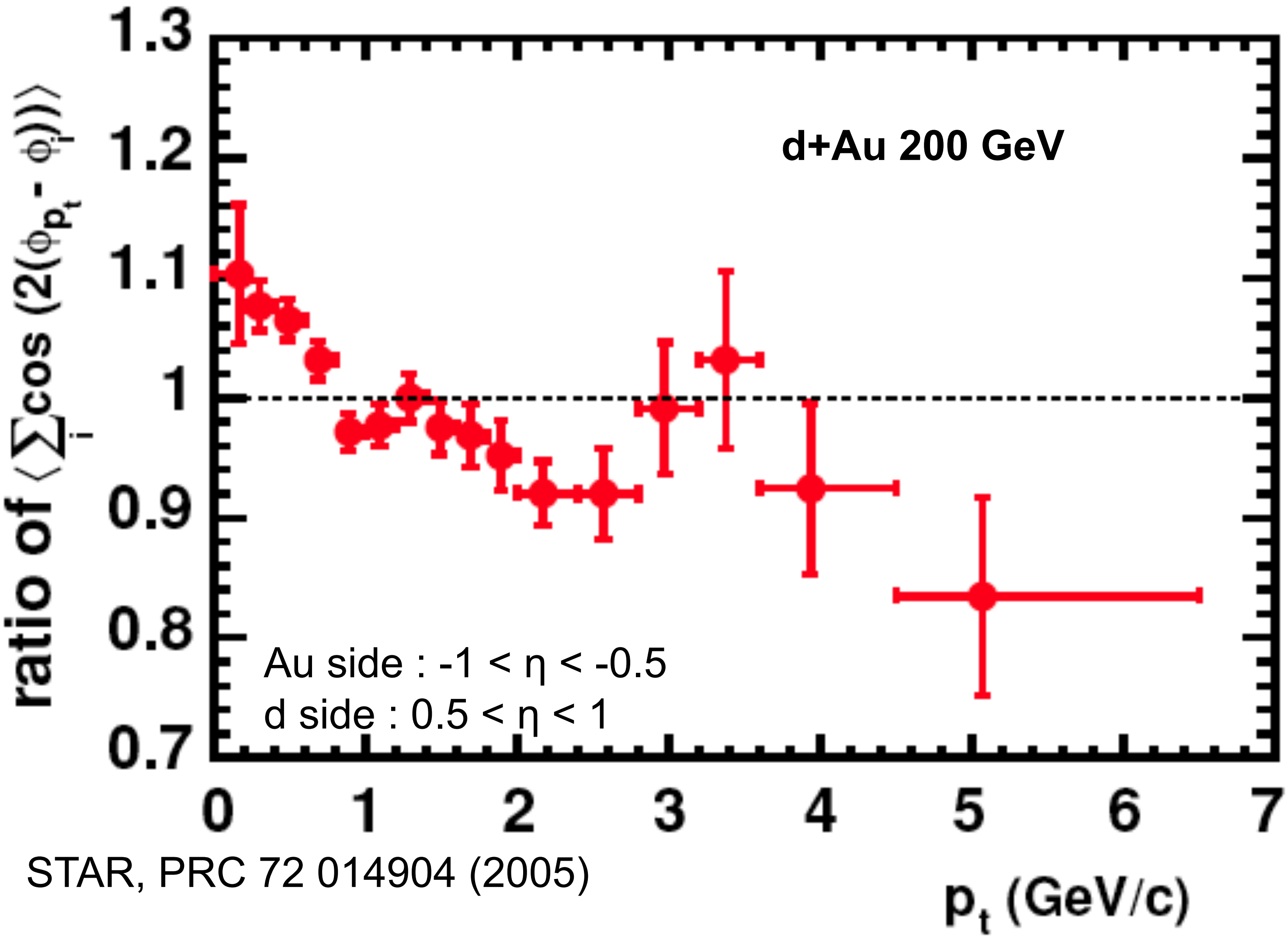
29

Scalar Product in pp, dAu, and AuAu Collisions



HIJING does not have an enhanced scalar product in d+Au relative to p+p

Scalar Product, Au-side/d-side



STAR, PRC 72 014904 (2005)

What We Learned from Previous Studies

• **The azimuthal correlation (scalar product) in dAu exhibits a deviation from pp, while the magnitude is very small if compared to the deviation in non-ultrapheripheral AuAu collisions.**

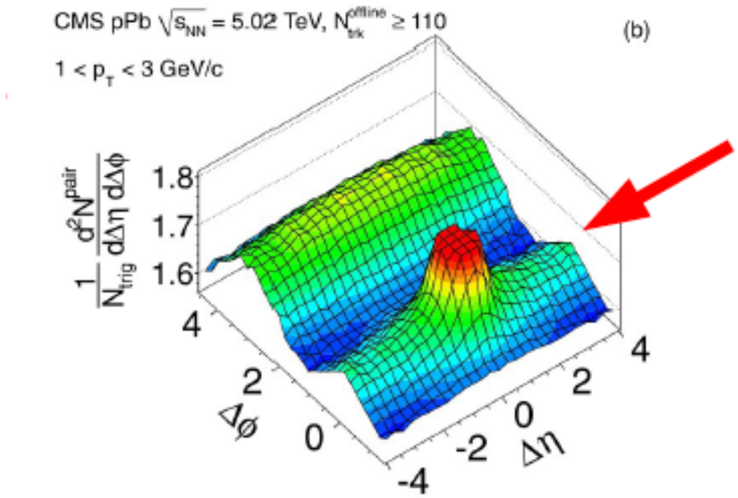
• **The deviation has features like flow*, but it also has features that are not like flow**.**

*Flow-like features :
more prominent at low pt than large pt,
more prominent at Au-side than d-side.
**Not-flow-like features :
magnitude very small,
monotonic multiplicity dependence instead of rise-and-fall,
4-part cumulant v_2 does not work (due to either M being small or flow being small or both).

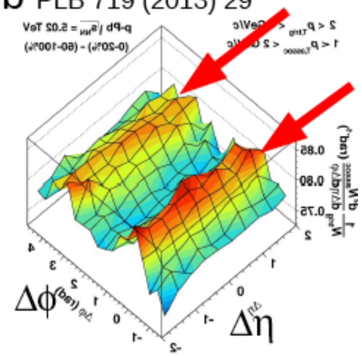
Let's add another dimension (Δη) and re-examine dAu correlations

Setting the Scene of Ridge in Small Systems

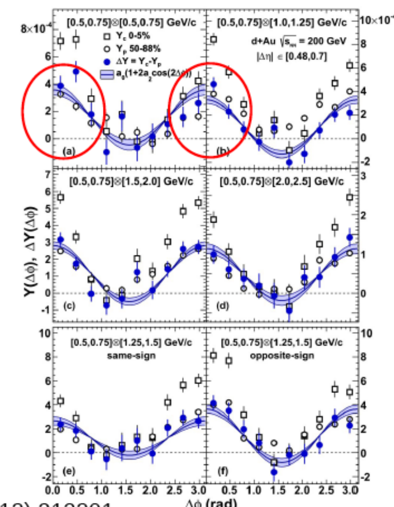
CMS pPb PLB 718 (2013) 795



ALICE pPb PLB 719 (2013) 29

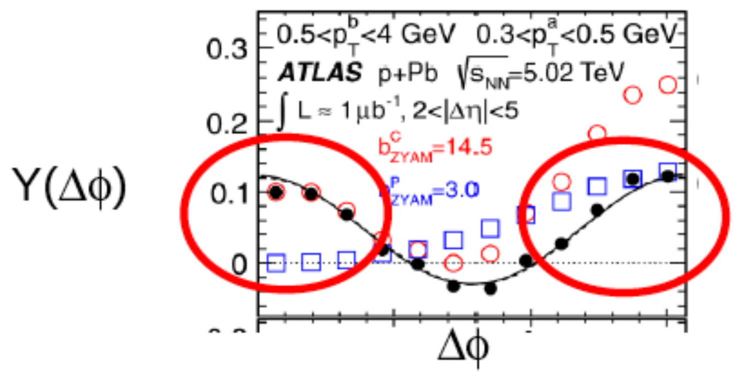


PHENIX d+Au Double Ridge



PRL 111 (2013) 212301

ATLAS pPb PRL 110 (2013) 182302



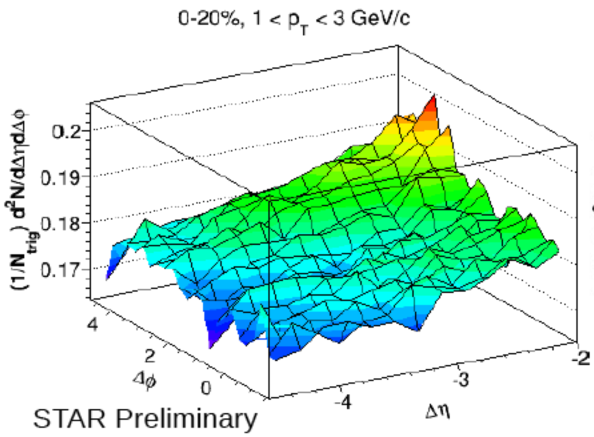
DiHadron Δη-Δφ Correlations in d+Au Collisions

d+Au@200 GeV Run3

p_T: [1,3]x[1,3] GeV/*c*

Trigger-Associate

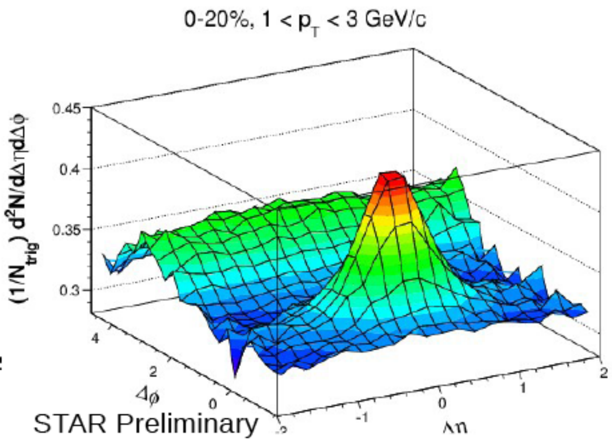
Normalized by number of trigger particles



TPC-FTPC (Au-going)

$-4.5<\Delta\eta<-2$

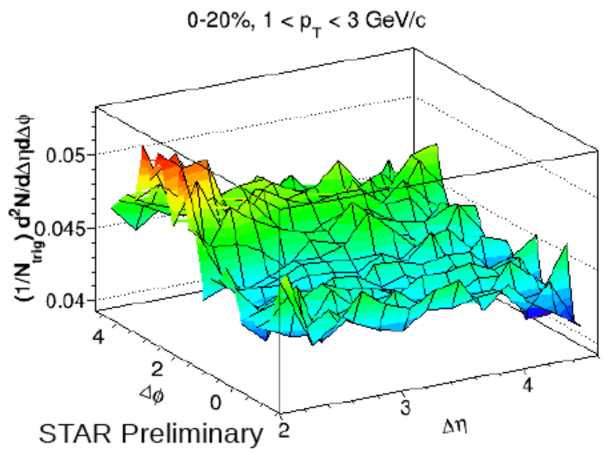
ZDC Energy



TPC-TPC

$-2<\Delta\eta<2$

FTPC Multiplicity



TPC-FTPC (d-going)

$2<\Delta\eta<4.5$

ZDC Energy

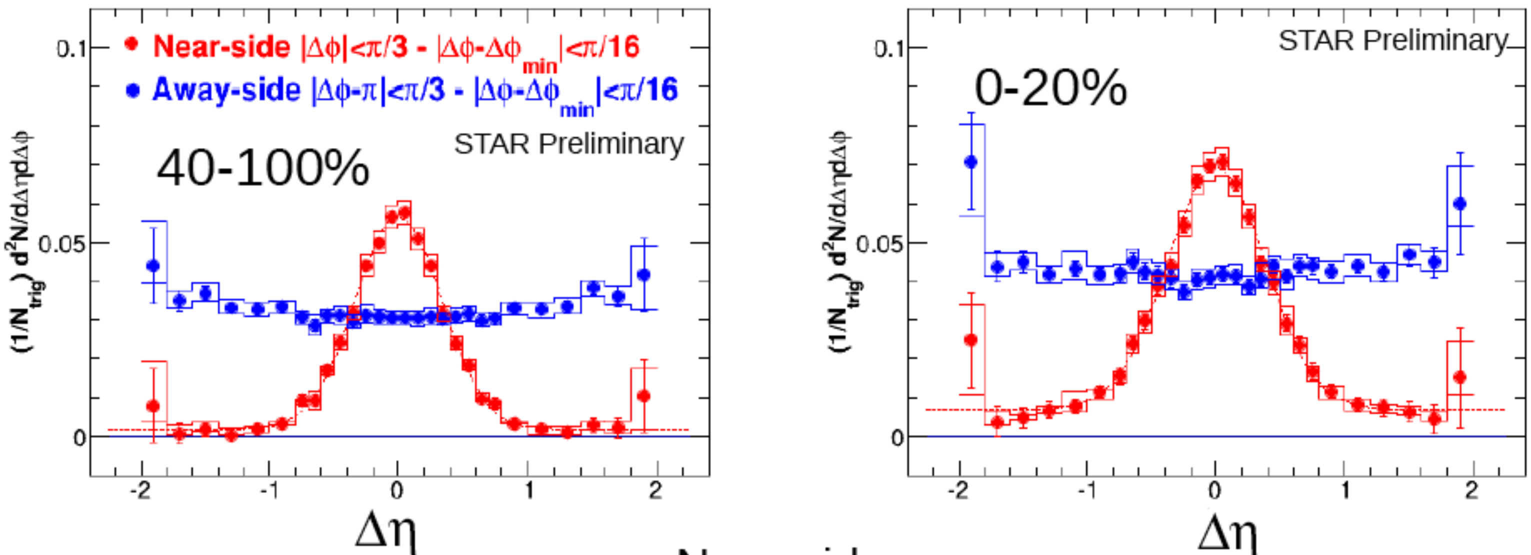
Background subtracted by Δη-dependent Zero-Yield-At-Minimum (ZYAM) method

Large Δη window allows STAR to study the diharon correlation comprehensively

Near-side Ridge in High-multiplicity

d+Au@200 GeV

p_T: [1,3]x[1,3] GeV/c
FTPC Multiplicity



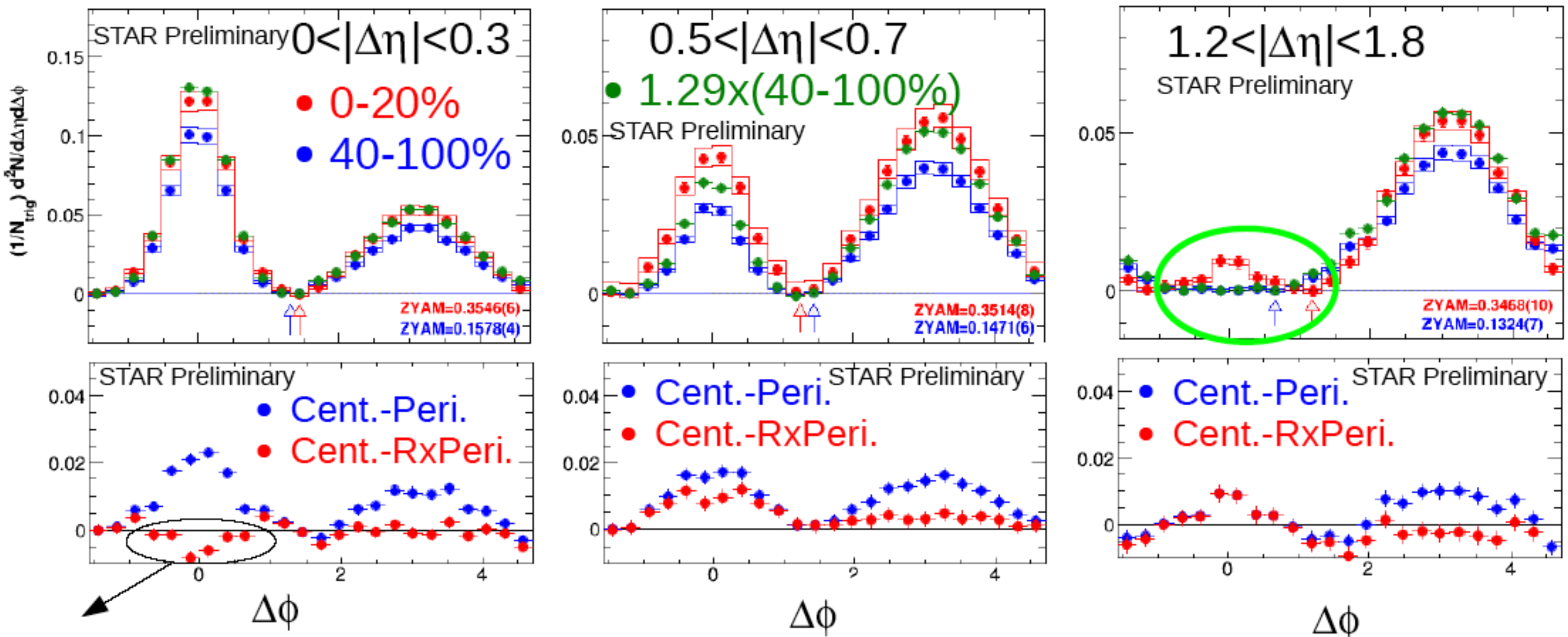
Y = 0.0459(10)	Near-side Gaussian + Pedestal Fit	Y = 0.0594(18)	Gaus. area
σ = 0.336(6)		σ = 0.382(9)	Gaus. width
Ped = 0.0019(4)		Ped = 0.0070(8)	Pedestal
χ^2/ndf = 19/25		χ^2/ndf = 19/25	

Details matter : Jet shape and yield change with centrality
Careful with subtraction !

TPC-TPC Δφ Correlations High- vs. Low-Mult.

d+Au@200 GeV

p_T: [1,3]x[1,3] GeV/c
FTPC Multiplicity



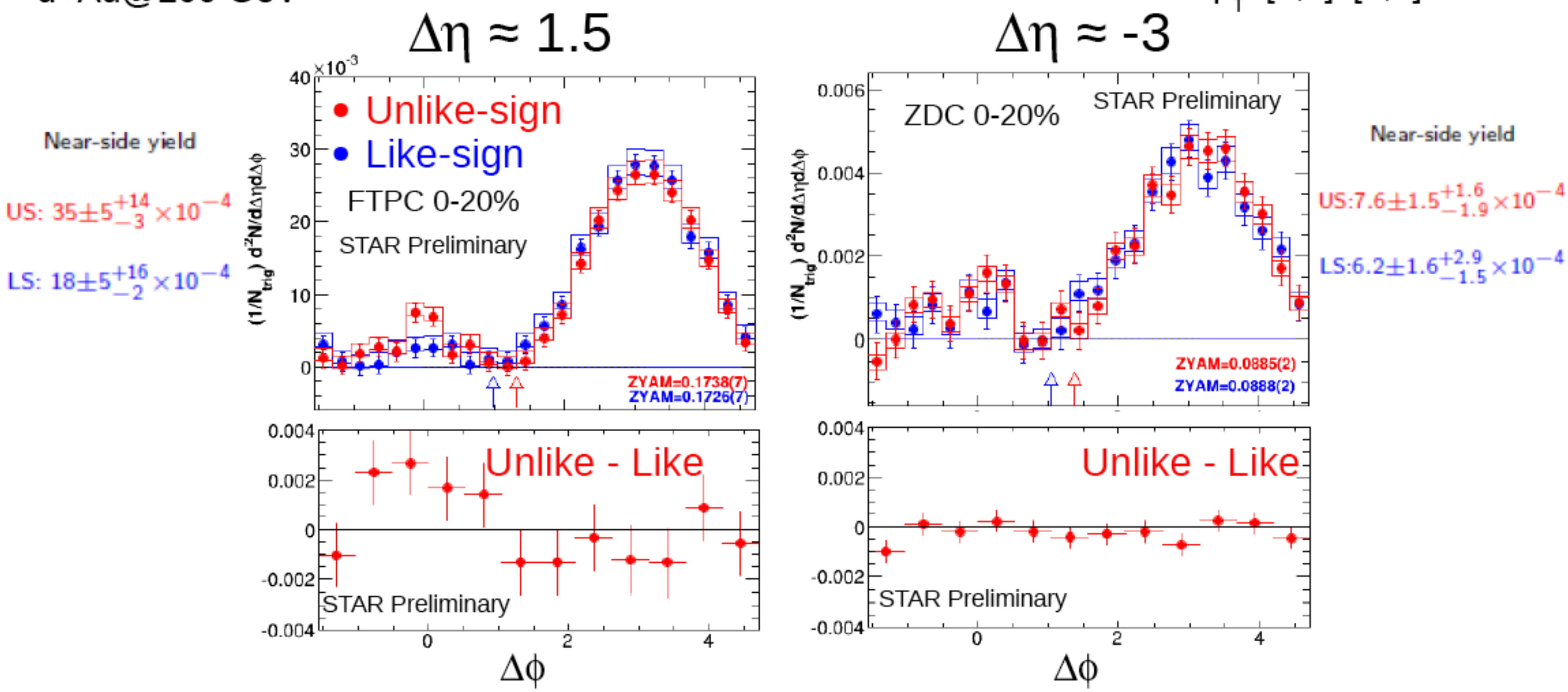
Jet shape difference

With a simple scale to take into account the difference in jet correlated yield between central and peripheral collisions, after subtraction, away-side disappears while near-side remains finite.

Near Side in Close-look : Different Charge Combinations

d+Au@200 GeV

p_T: [1,3]x[1,3] GeV/c

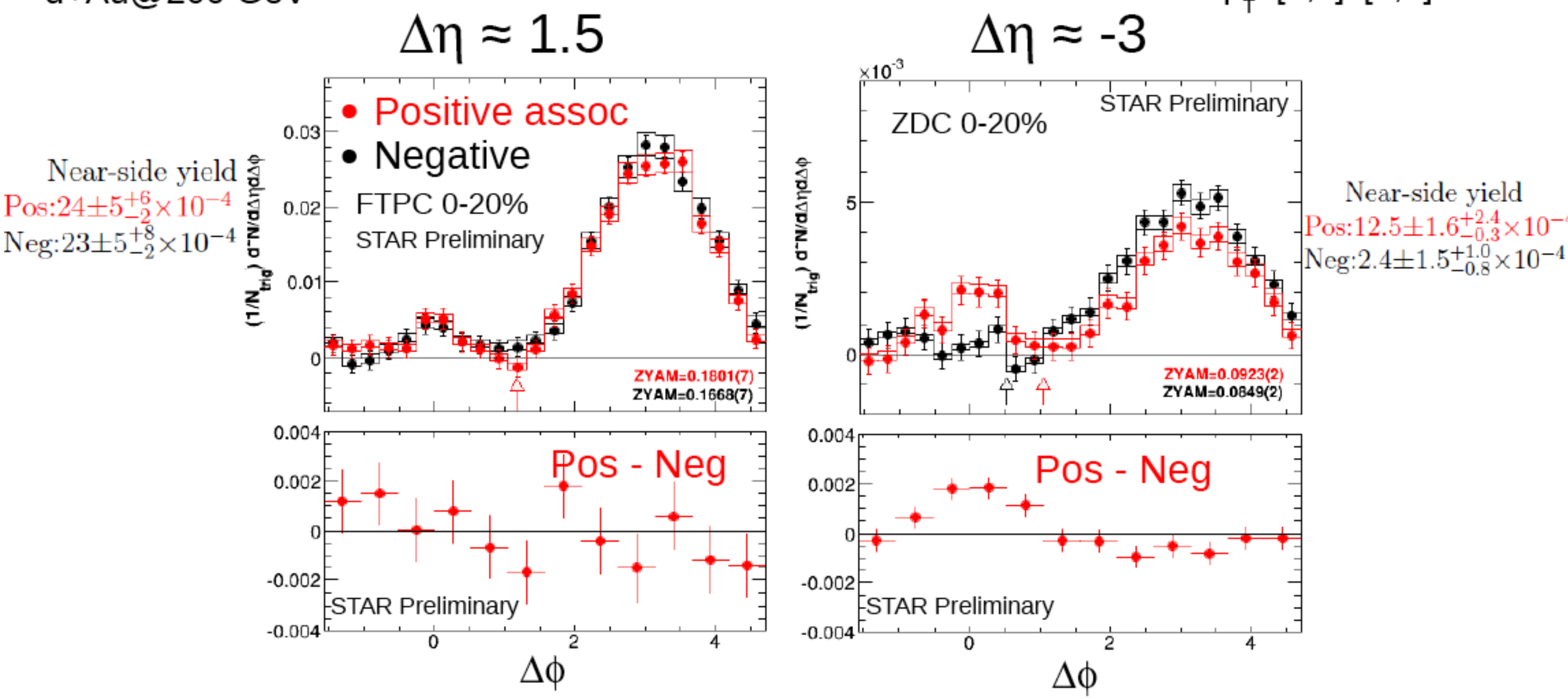


Charge combination dependence seen for Δη=1.5
No dependence seen for Δη=-3.

Near Side in Close-look : Different Charge of Associated Particles

d+Au@200 GeV

p_T: [1,3]x[1,3] GeV/c



Near side at Δη=-3 is mainly from positive particles

Summary

• The azimuthal correlation (scalar product) in dAu collisions at 200 GeV exhibits a deviation from pp, while the magnitude is very small if compared to the deviation in non-ultrapheripheral AuAu collisions.

• Early studies show that the deviation has features like flow, but it also has features that are not like flow.

• Recent studies with two particle correlation suggest that such deviation is more likely to be jet-related instead of flow.