

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

Aihong Tang for 



# Outline

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- Refresh STAR's old results<sup>[1,2]</sup> on scalar product in p+p, d+Au and Au+Au systems.
- Present STAR's recent studies<sup>[3]</sup> 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

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$v_2$  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

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

Scaling !

Multiplicity independent correlations

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



# The Scalar Product

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

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



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

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

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

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

$\delta_{bp}^{pp}$  - 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

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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

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

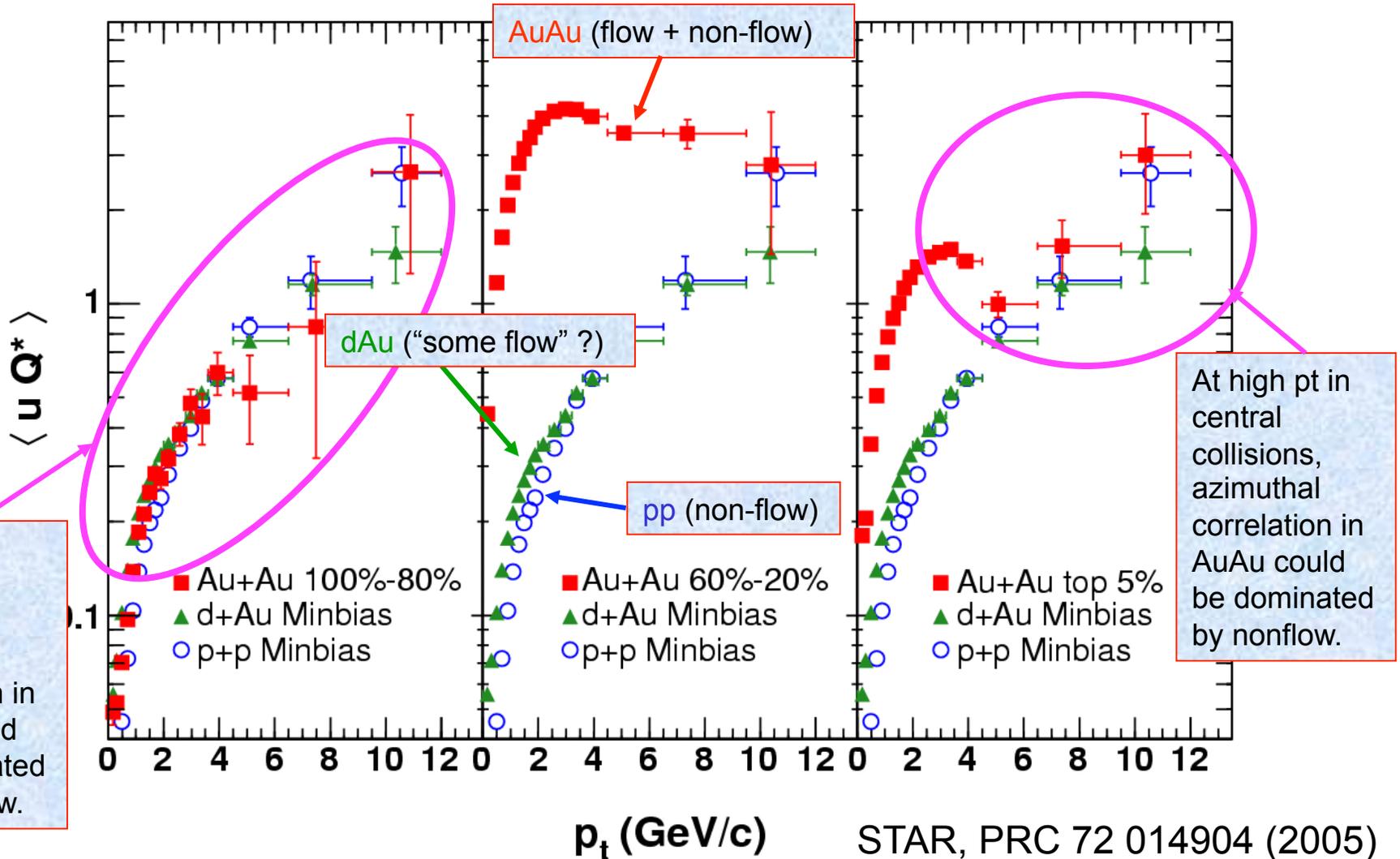
J-Y Ollitrault, 2003

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# Scalar Product in pp, dAu, and AuAu Collisions

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

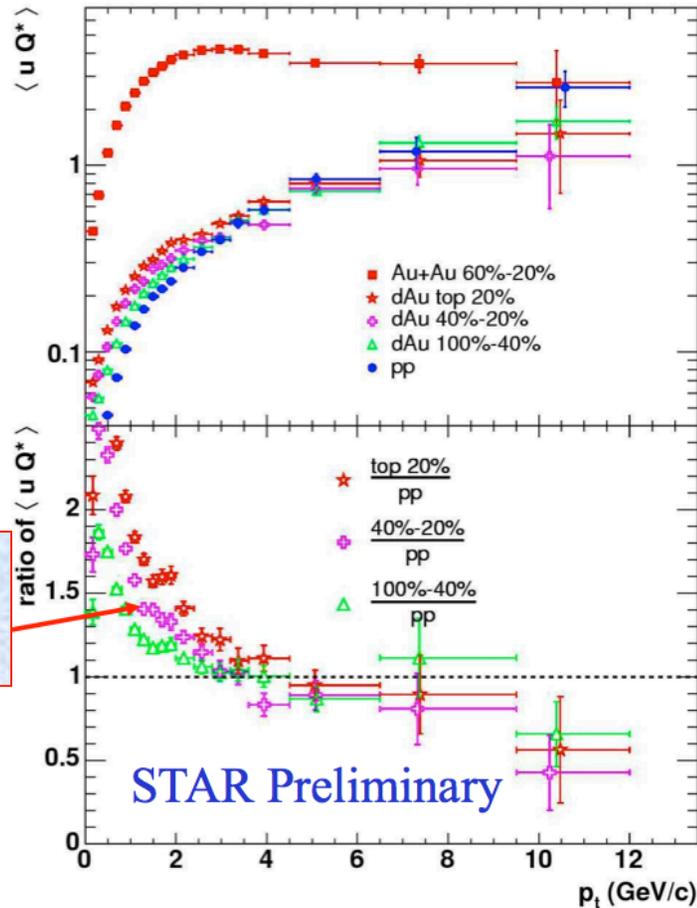




# Scalar Product in pp, dAu, and AuAu Collisions



Is there “elliptic flow” in dAu collisions ?



Collective motion at low  $p_t$  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

Aihong Tang  
Jamaica winter workshop 04

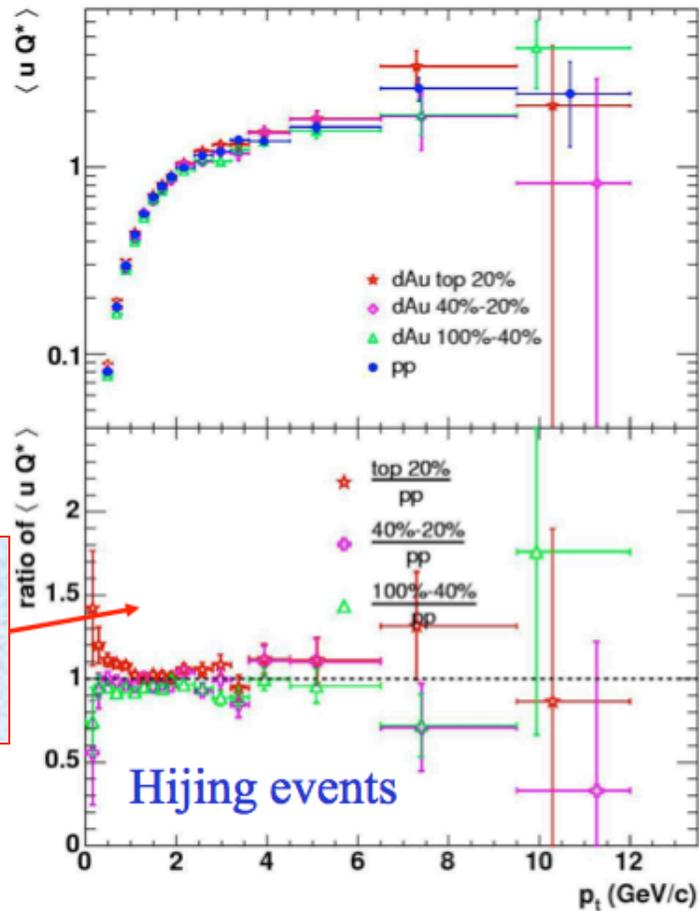
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# Scalar Product in pp, dAu, and AuAu Collisions



Is there "elliptic flow" in HIJING dAu collisions ?



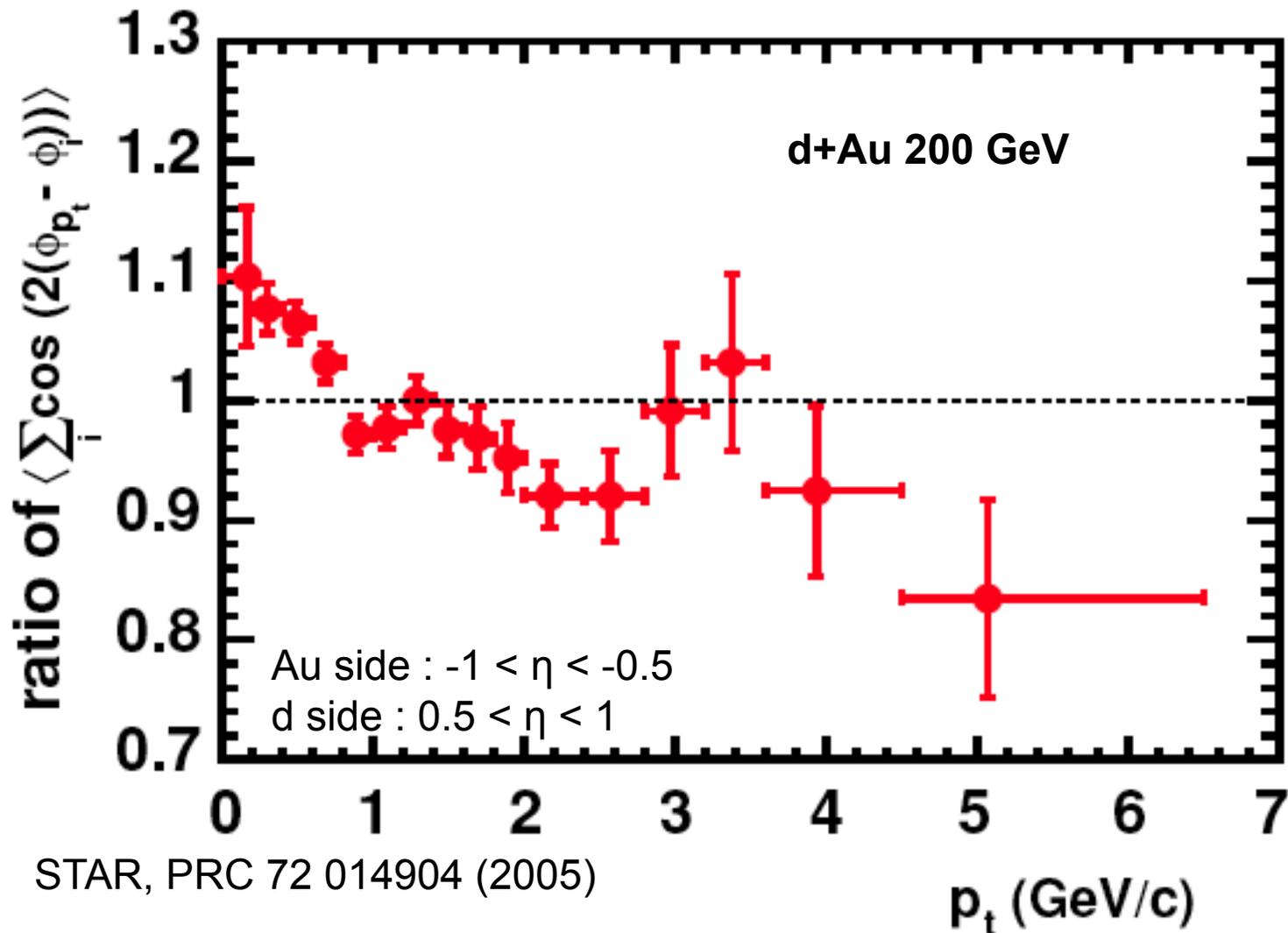
HIJING does not have an enhanced scalar product in d+Au relative to p+p

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Jamaica winter workshop 04

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## Scalar Product, Au-side/d-side





## What We Learned from Previous Studies

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- 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  $p_t$  than large  $p_t$ ,  
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 ( $\Delta\eta$ ) and re-examine dAu correlations**

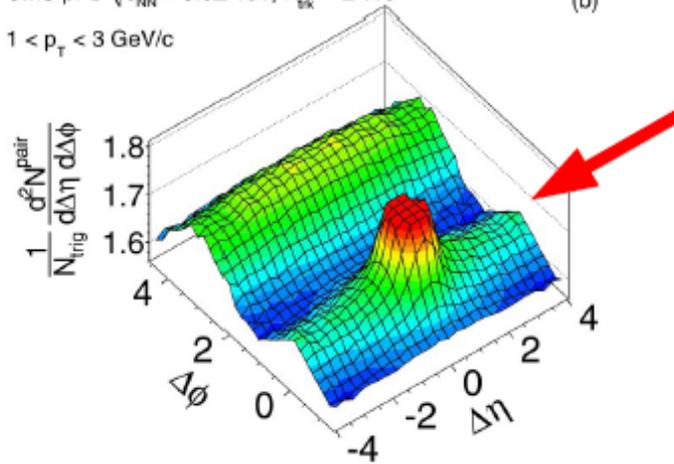
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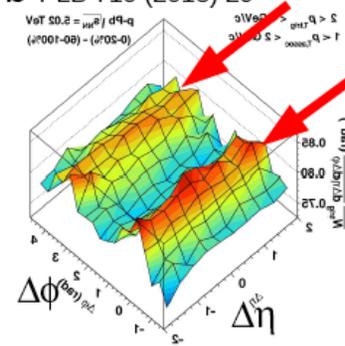
# Setting the Scene of Ridge in Small Systems

## CMS pPb PLB 718 (2013) 795

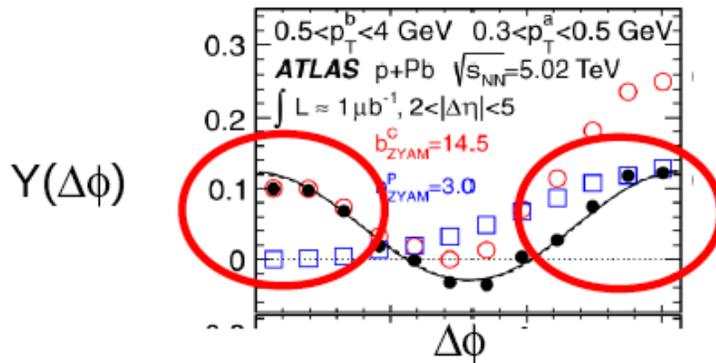
CMS pPb  $\sqrt{s_{NN}} = 5.02$  TeV,  $N_{ch}^{offline} \geq 110$   
 $1 < p_T < 3$  GeV/c



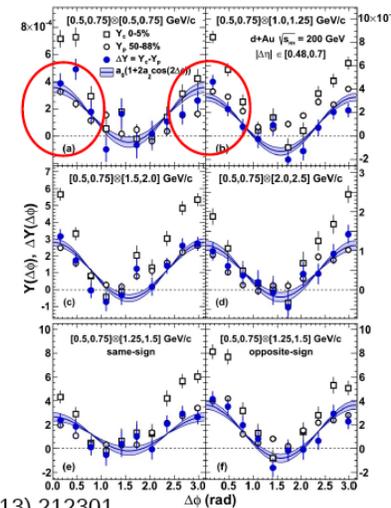
## ALICE pPb PLB 719 (2013) 29



## ATLAS pPb PRL 110 (2013) 182302



## PHENIX d+Au Double Ridge



PRL 111 (2013) 212301



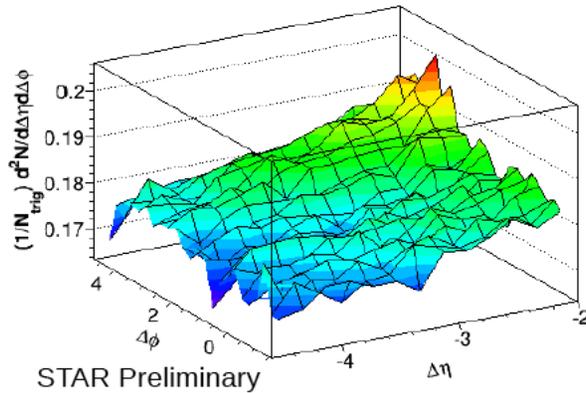
# DiHadron $\Delta\eta$ - $\Delta\phi$ Correlations in d+Au Collisions

d+Au@200 GeV Run3

## Trigger-Associate

Normalized by number of trigger particles

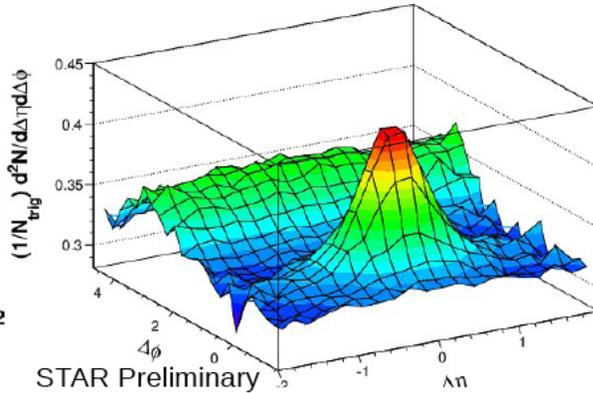
0-20%,  $1 < p_T < 3$  GeV/c



TPC-FTPC (Au-going)

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

0-20%,  $1 < p_T < 3$  GeV/c

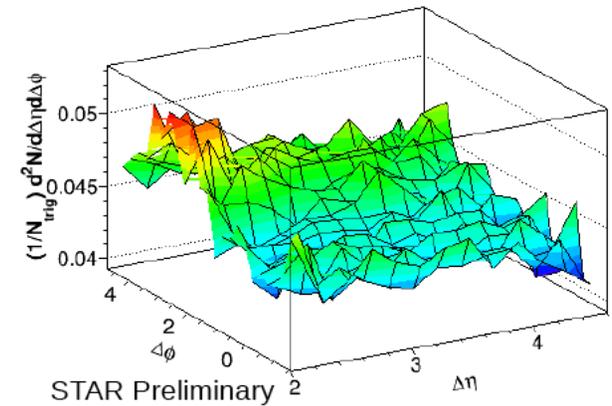


TPC-TPC

$-2 < \Delta\eta < 2$   
FTPC Multiplicity

$p_T$ :  $[1,3] \times [1,3]$  GeV/c

0-20%,  $1 < p_T < 3$  GeV/c



TPC-FTPC (d-going)

$2 < \Delta\eta < 4.5$   
ZDC Energy

Background subtracted by  $\Delta\eta$ -dependent Zero-Yield-At-Minimum (ZYAM) method

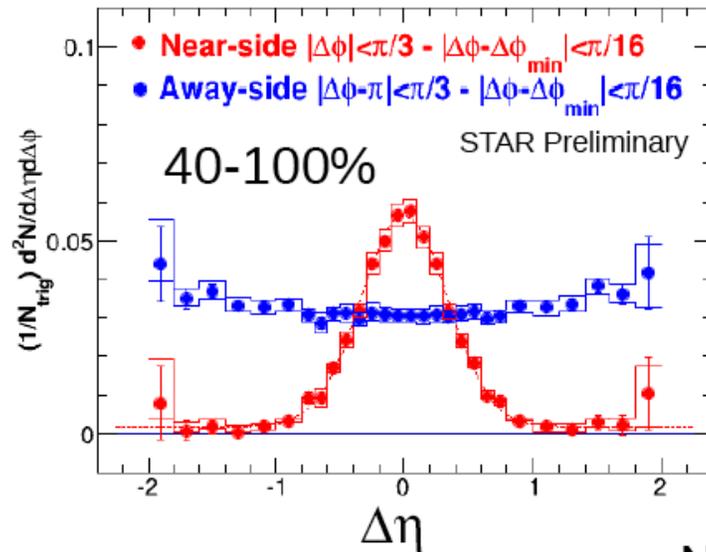
Large  $\Delta\eta$  window allows STAR to study the dihadron correlation comprehensively



# Near-side Ridge in High-multiplicity

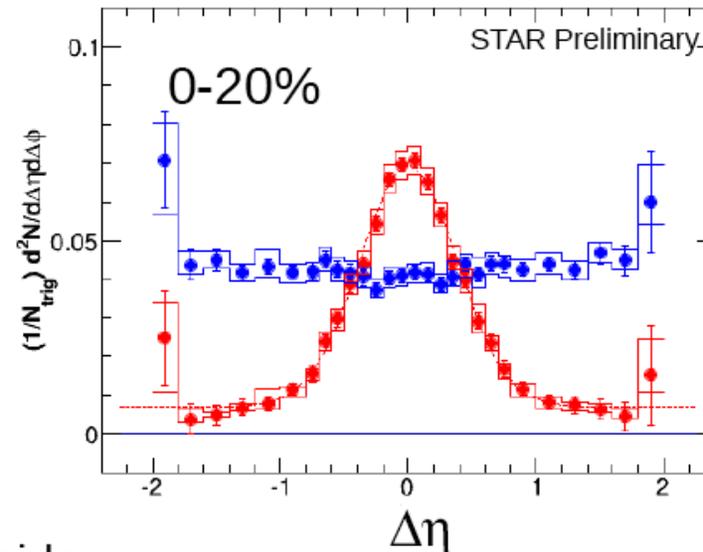
d+Au@200 GeV

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



$Y = 0.0459(10)$   
 $\sigma = 0.336(6)$   
 Ped = 0.0019(4)  
 $\chi^2/ndf = 19/25$

Near-side  
Gaussian + Pedestal Fit



$Y = 0.0594(18)$  Gaus. area  
 $\sigma = 0.382(9)$  Gaus. width  
 Ped = 0.0070(8) Pedestal  
 $\chi^2/ndf = 19/25$

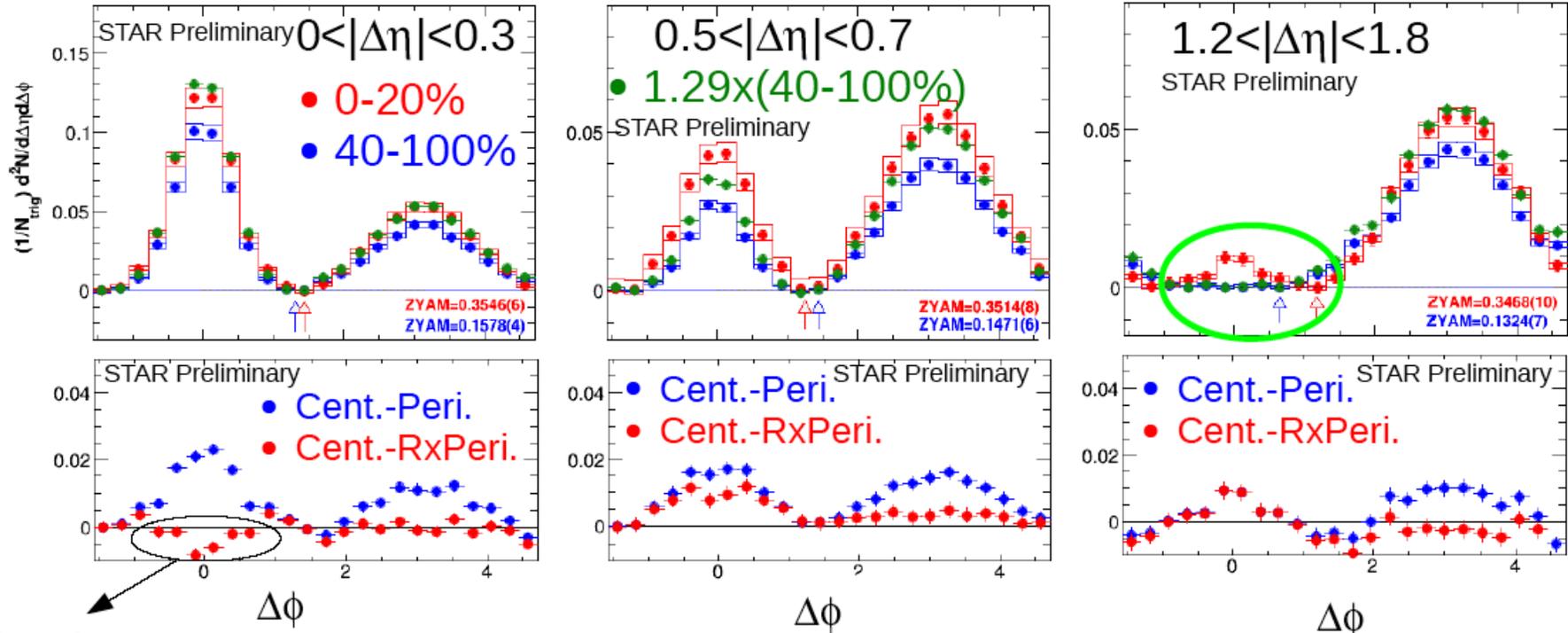
**Details matter : Jet shape and yield change with centrality  
 Careful with subtraction !**



# TPC-TPC $\Delta\phi$ Correlations High- vs. Low-Mult.

d+Au@200 GeV

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



Jet shape  
difference

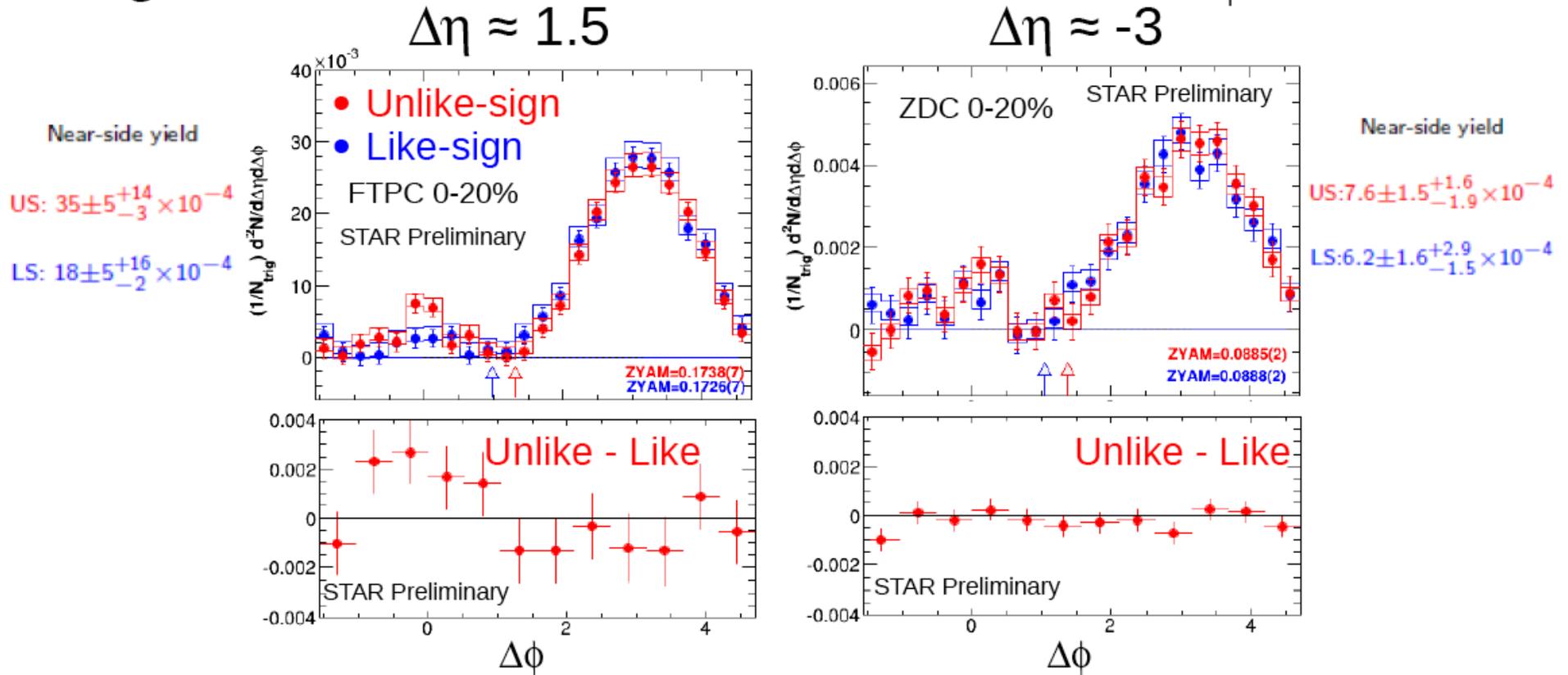
With a simple scale to take into account the difference in jet correlated yield between central and peripheral collisions, after subtraction, away-side disappears while near-side remains finite.



# 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  $\Delta\eta=1.5$   
No dependence seen for  $\Delta\eta=-3$ .**



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

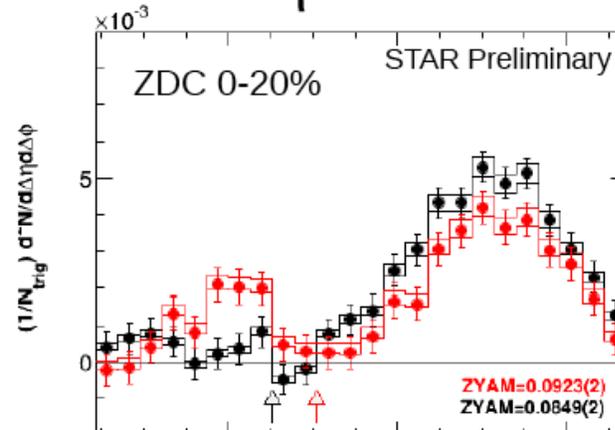
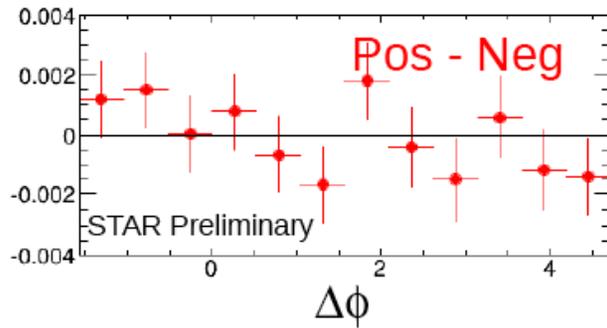
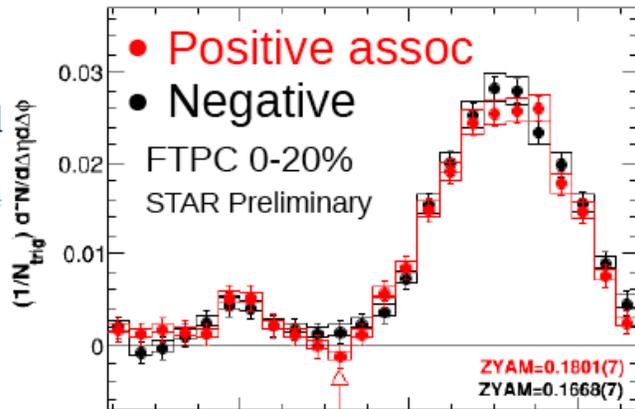
d+Au@200 GeV

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

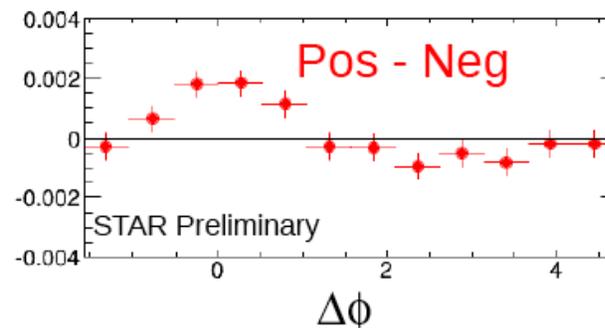
$\Delta\eta \approx 1.5$

$\Delta\eta \approx -3$

Near-side yield  
Pos:  $24 \pm 5_{-2}^{+6} \times 10^{-4}$   
Neg:  $23 \pm 5_{-2}^{+8} \times 10^{-4}$



Near-side yield  
Pos:  $12.5 \pm 1.6_{-0.3}^{+2.4} \times 10^{-4}$   
Neg:  $2.4 \pm 1.5_{-0.8}^{+1.0} \times 10^{-4}$



Near side at  $\Delta\eta=-3$  is mainly from positive particles



# Summary

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- **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.**