# d+Au dihadron correlations from STAR


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# Outline

- Physics motivations
- Analysis details
- Results (extensive systematics)
  - 2D correlations and $\Delta\phi$ and $\Delta\eta$ projections
  - Concentrate on $1<p_T^{trig}$, $p_T^{assoc}<3$ GeV/c bin, but have $p_T$ dependence
  - Fourier Coefficients
- Summary

# Motivations: pp,p+Pb ridge@LHC; d+Au@RHIC?

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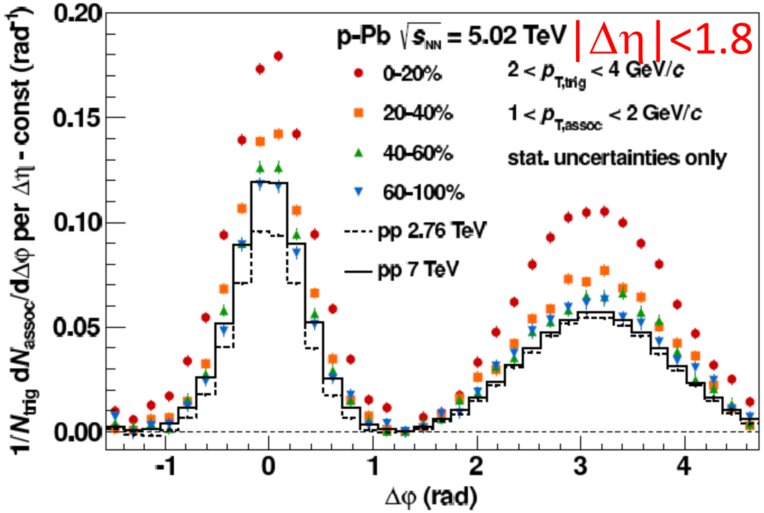
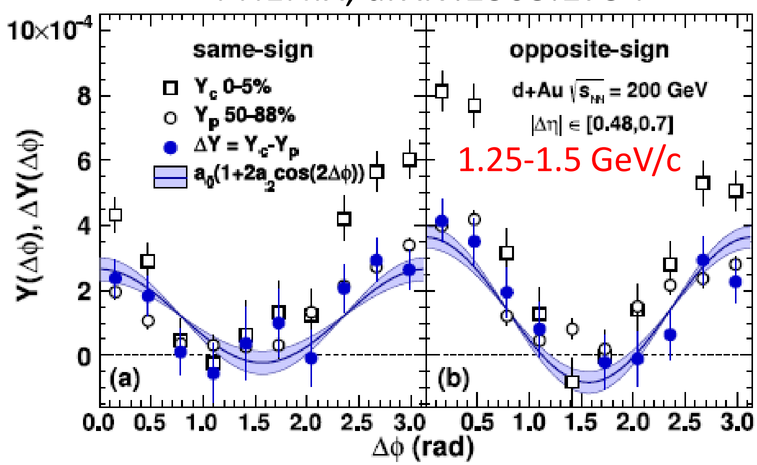
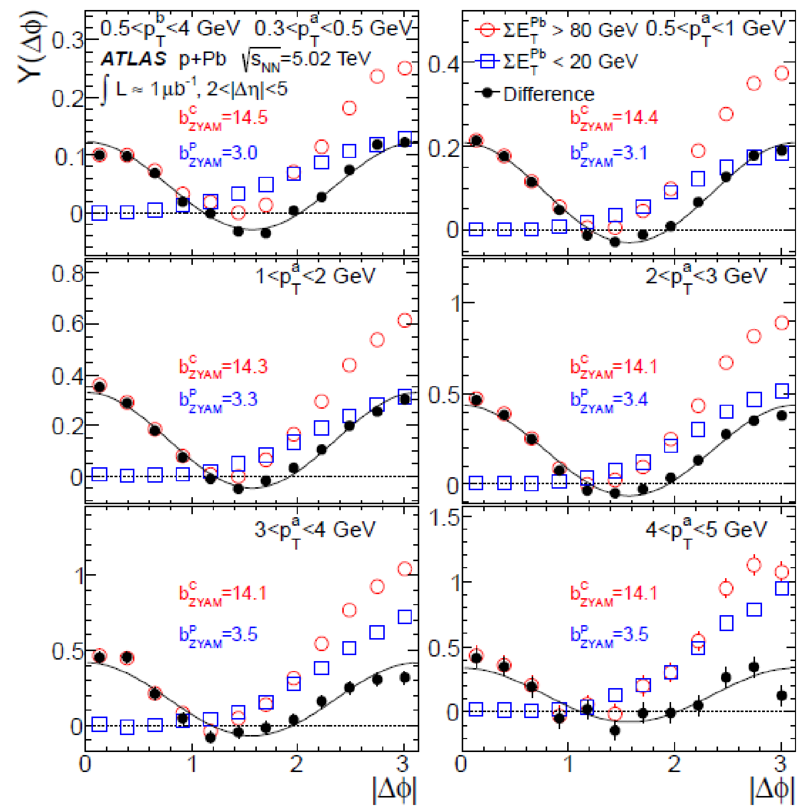
ALICE, arXiv:1212.2001




PHENIX, arXiv:1303.1794




ATLAS, arXiv:1212.5198




- Ridge in small systems
- Double-ridge from central – peripheral technique

# Motivations: to kill or learn from models

PHENIX, 1303.1794; P. Bozek, Phys. Rev. C 85, 014911 (2012).

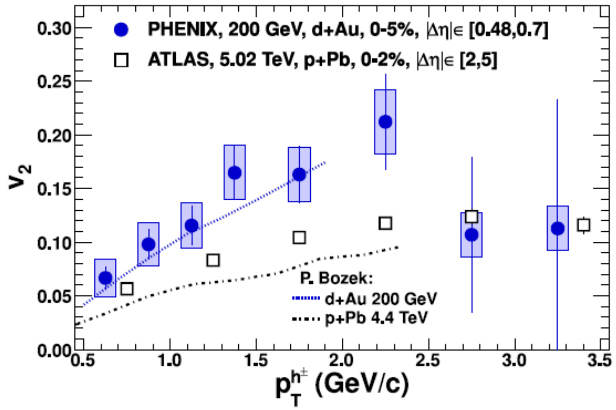



FIG. 4: (color online) Charged hadron second-order anisotropy, $v_2$, as a function transverse momentum for (filled [blue] circles) PHENIX and (open [black] circles) ATLAS [9]. Also shown are a hydrodynamic calculation [14, 25] for (upper [blue] curve) $d$+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV and (lower [black] curve) 0–4% central $p$+Pb collisions at $\sqrt{s_{NN}}$ = 4.4 TeV.

Kevin Dusling and Raju Venugopalan, 1302.7018

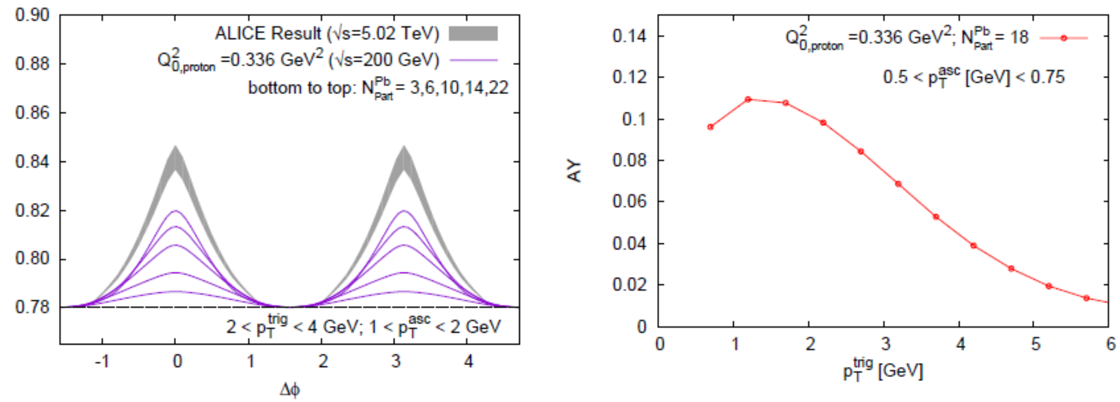


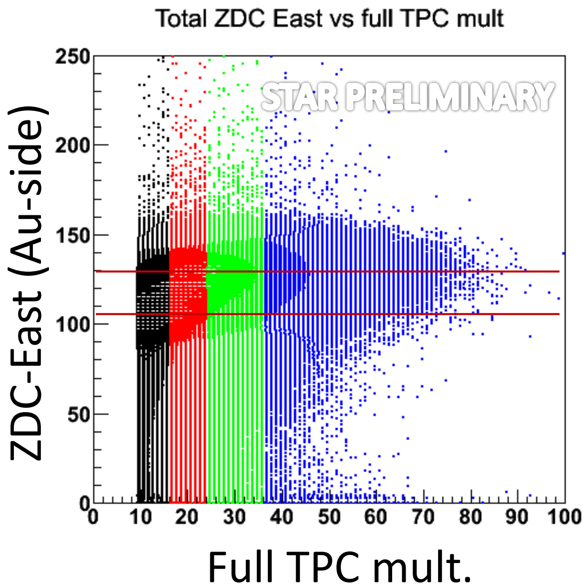

FIG. 11. Predictions for the associated yield versus $\Delta\phi$ (left figure) and the $\Delta\phi$ integrated associated yield $p_T^{trig}$ (right) figure from Glasma graphs for RHIC energies. The result from Fig. 10 for the ALICE experiment is show for comparison.

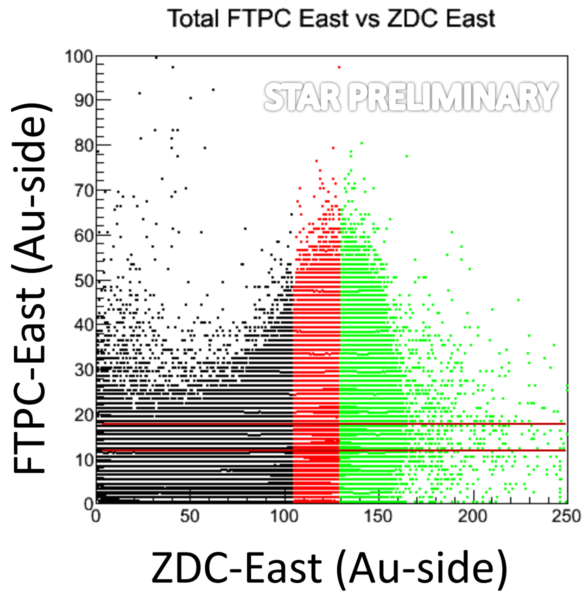
- Ridge in high-mult. pp and p-Pb at LHC. Very large $\Delta\eta$.
- PHENIX claims ridge in d+Au at 0.5<$|\Delta\eta|$<0.7 by central – peripheral.
- Hydro models (curves in the left plot) reproduce data.
- CGC (middle & right plot) reproduces LHC data. RHIC unclear.

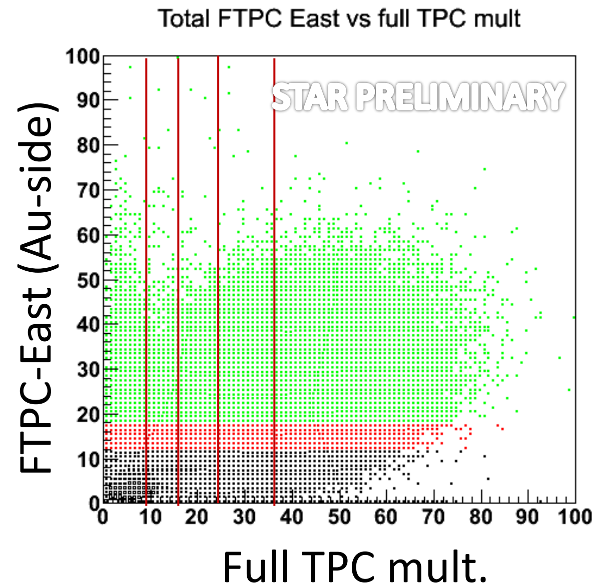
# Analysis details

- STAR d+Au data taken in 2003
- **Three centrality definitions**: TPC, FTPC-E, ZDC-E
- Vertex z matching in mixed-events
- Discrete multiplicity match in mixed-events with TPC and FPTC centrality definitions; For ZDC centrality, ZDC-E-sum 10-size bins
- Correlation functions: various trigger and assoc. pT bins; normalize per trigger; efficiency corrected for assoc. particle
  - Both trigger and assoc. in **TPC**
  - **TPC(trig)-FTPC(assoc)** correlations

# Centrality definitions




- Three different centrality definitions
- Correlations are broad

# 2D TPC-TPC correlation functions

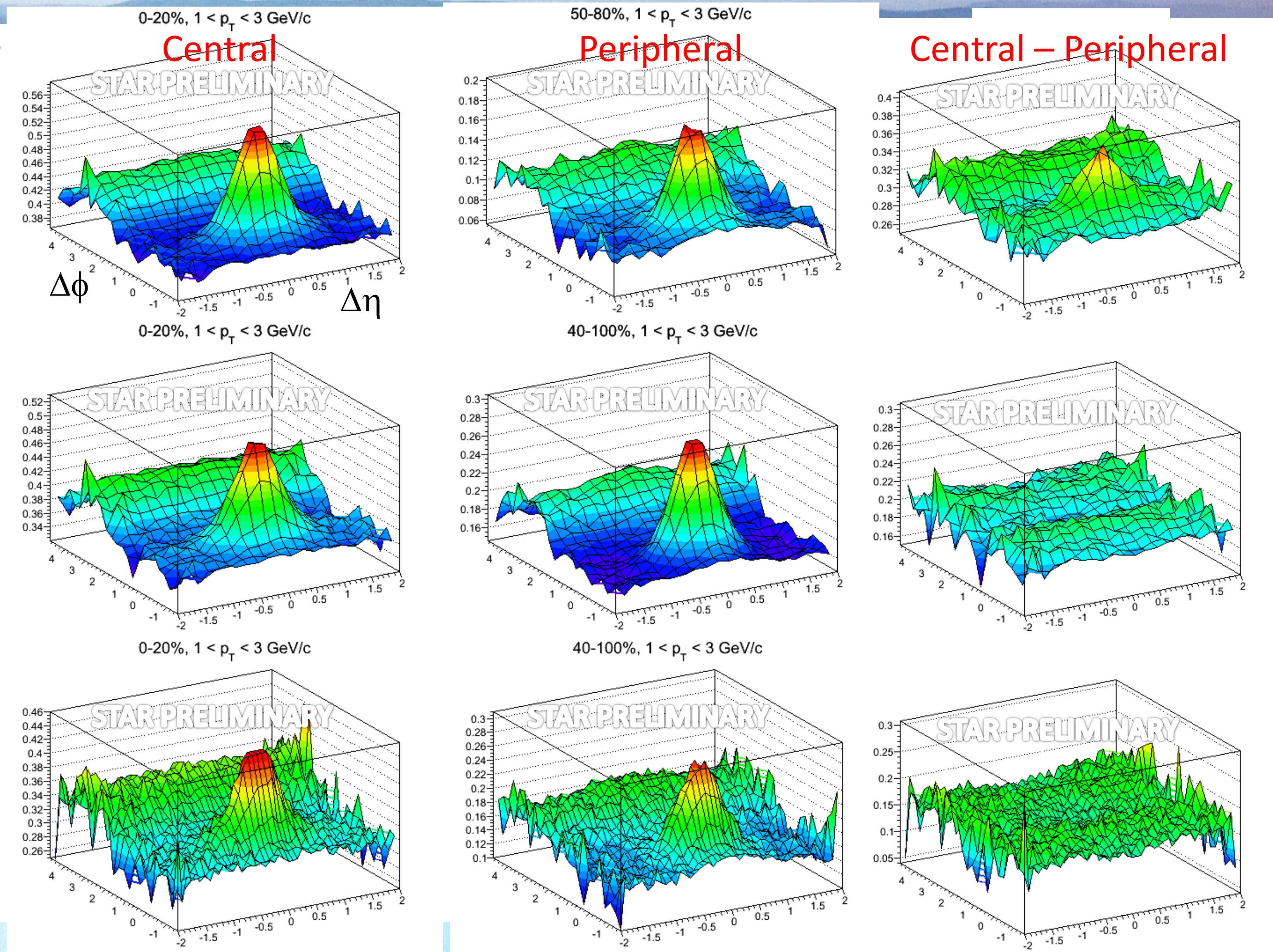
$1 < p_T^{trig}, p_T^{assoc} < 3$ GeV/c

Centrality def.

TPC mult. $|\eta|<1$

FTPC-E (Au-side) $-3.8<\eta<-2.8$

ZDC-E (Au-side)



# Δϕ projections vs Δη (TPC as centrality)

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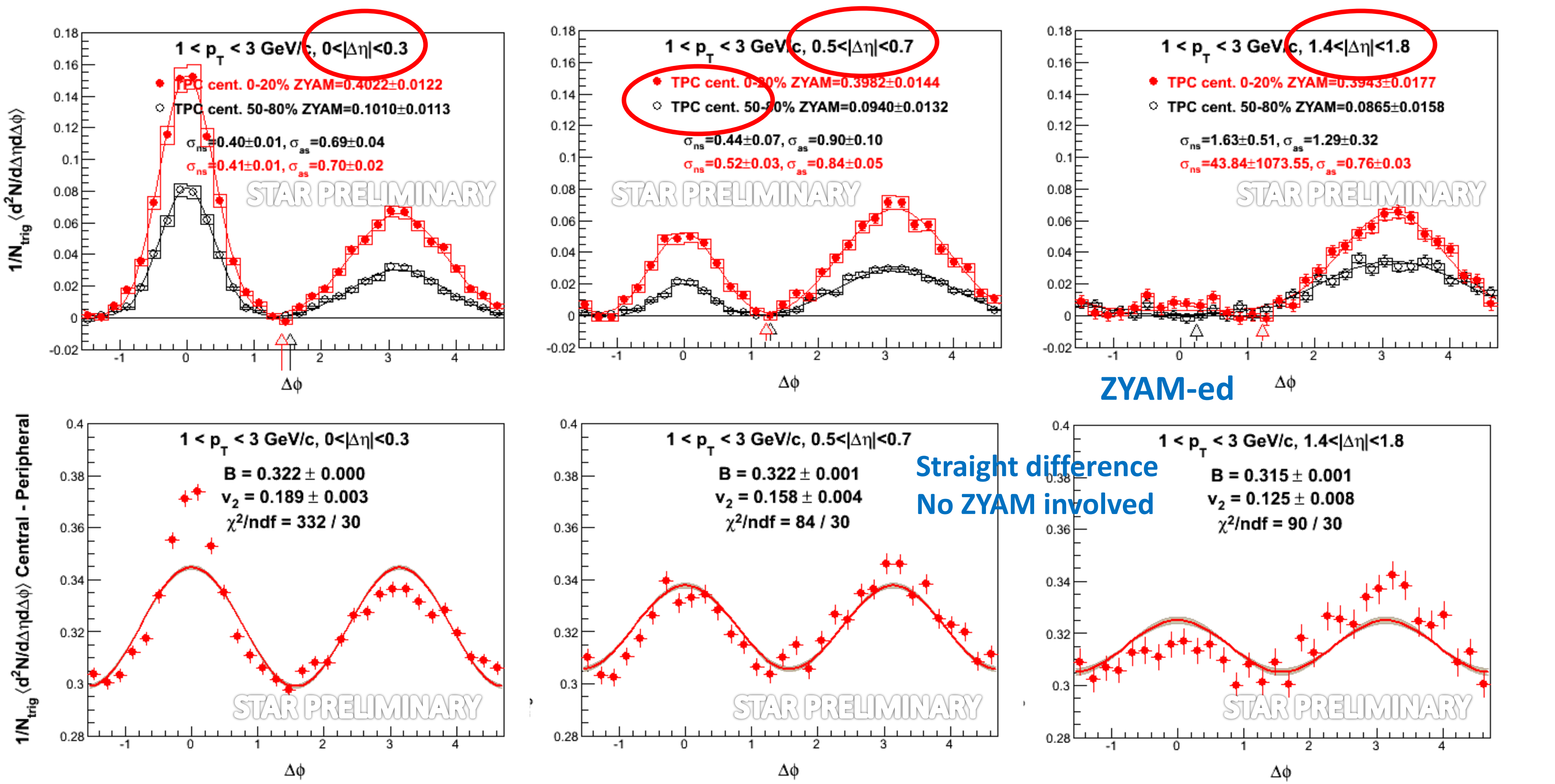
$1 < p_T^{trig}, p_T^{assoc} < 3$ GeV/c

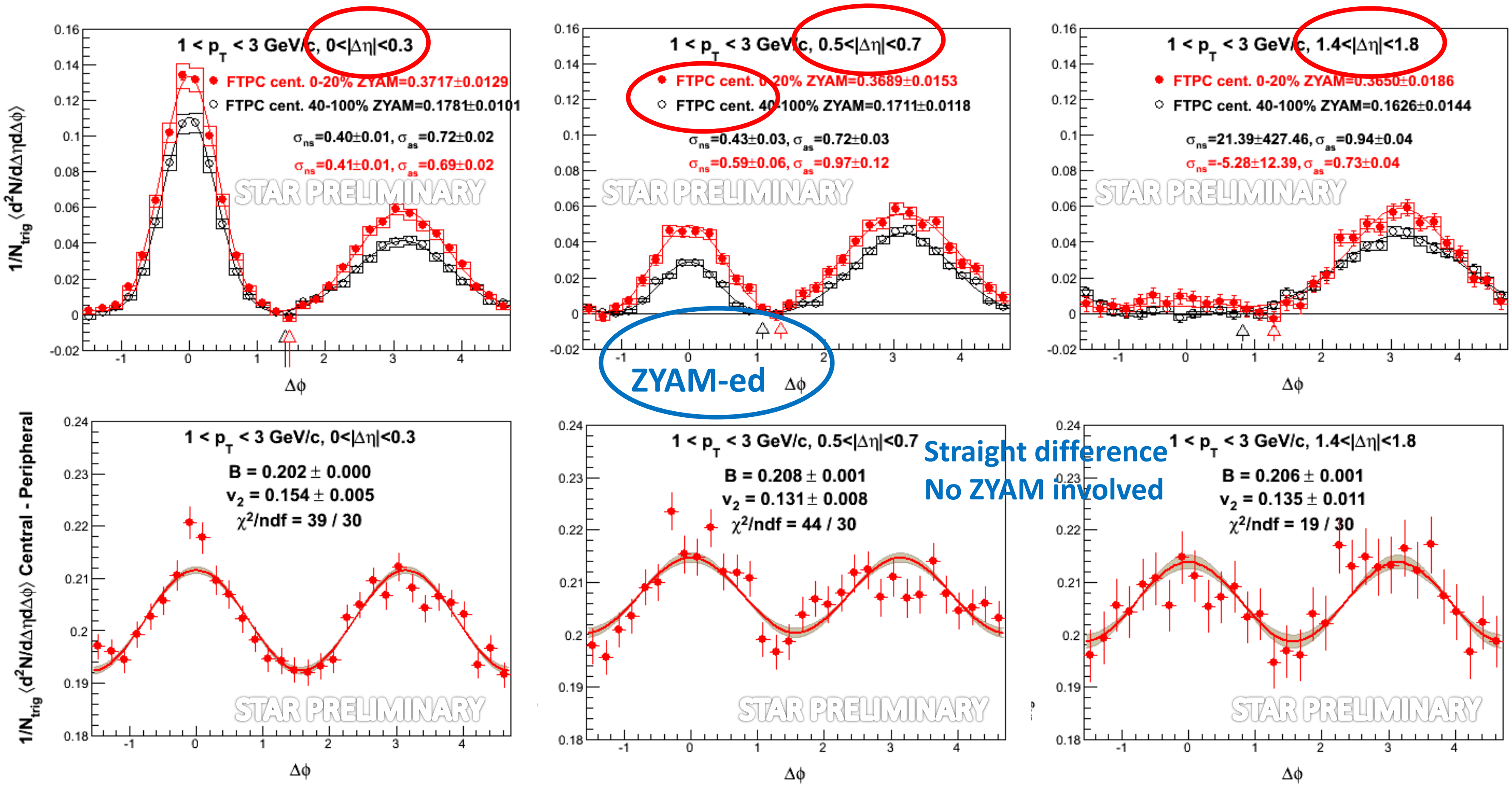



- ZYAM syst. error from different sizes of Δϕ region for ZYAM.
- Efficiency corrected: 85 ± 5% .

Multiplicity biases jets

# $\Delta\phi$ projections vs $\Delta\eta$ (FTPC as centrality)

$1 < p_T^{trig}, p_T^{assoc} < 3$ GeV/c




- ZYAM syst. error from different sizes of $\Delta\phi$ region for ZYAM.
- Efficiency corrected: 85 ± 5% .

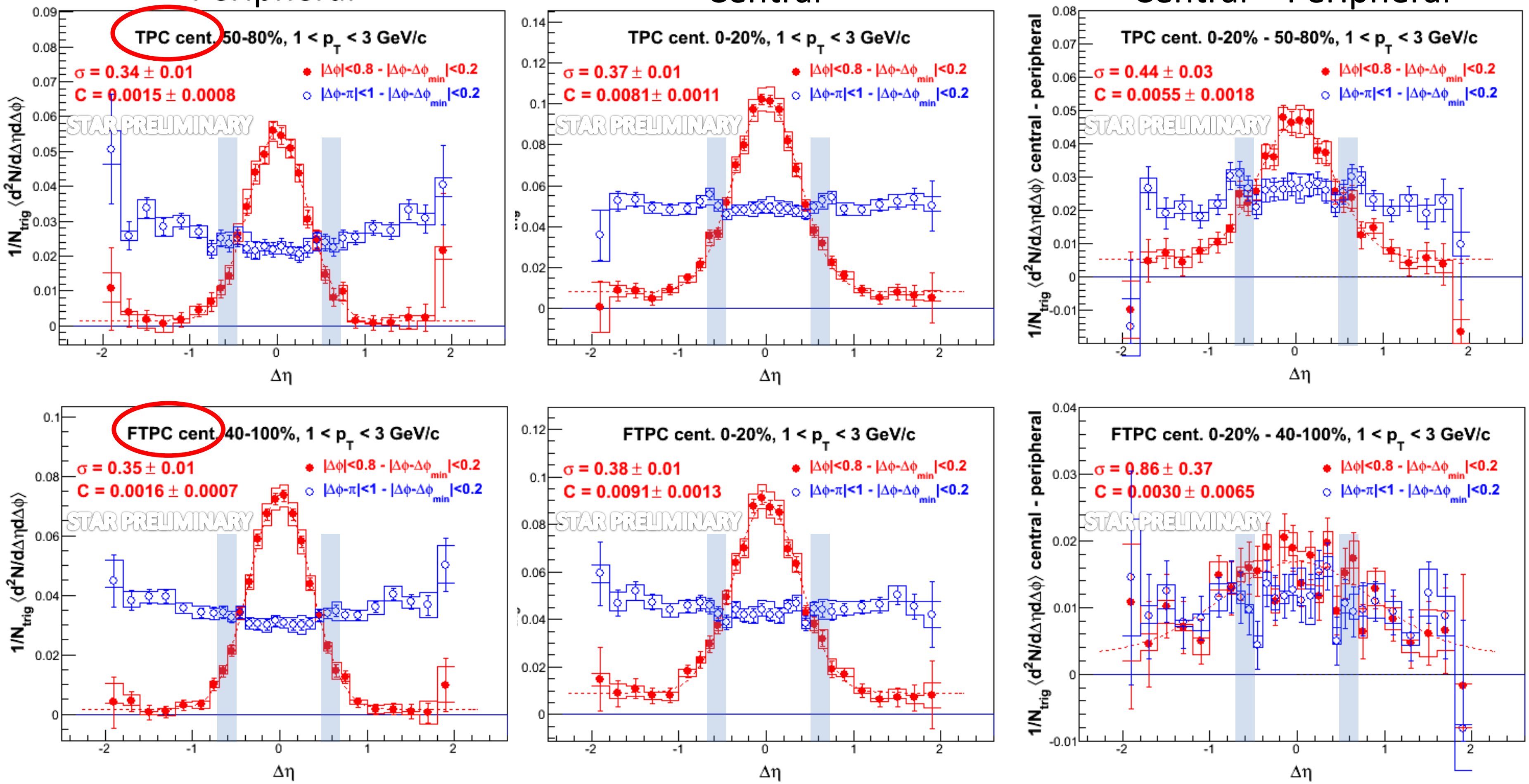
- Multiplicity biases jets.
- Remaining back-to-back structure at large $\Delta\eta$.

# ZYAM-ed Δη correlations, ZYAM'ed

$1 < p_T^{trig}, p_T^{assoc} < 3$ GeV/c

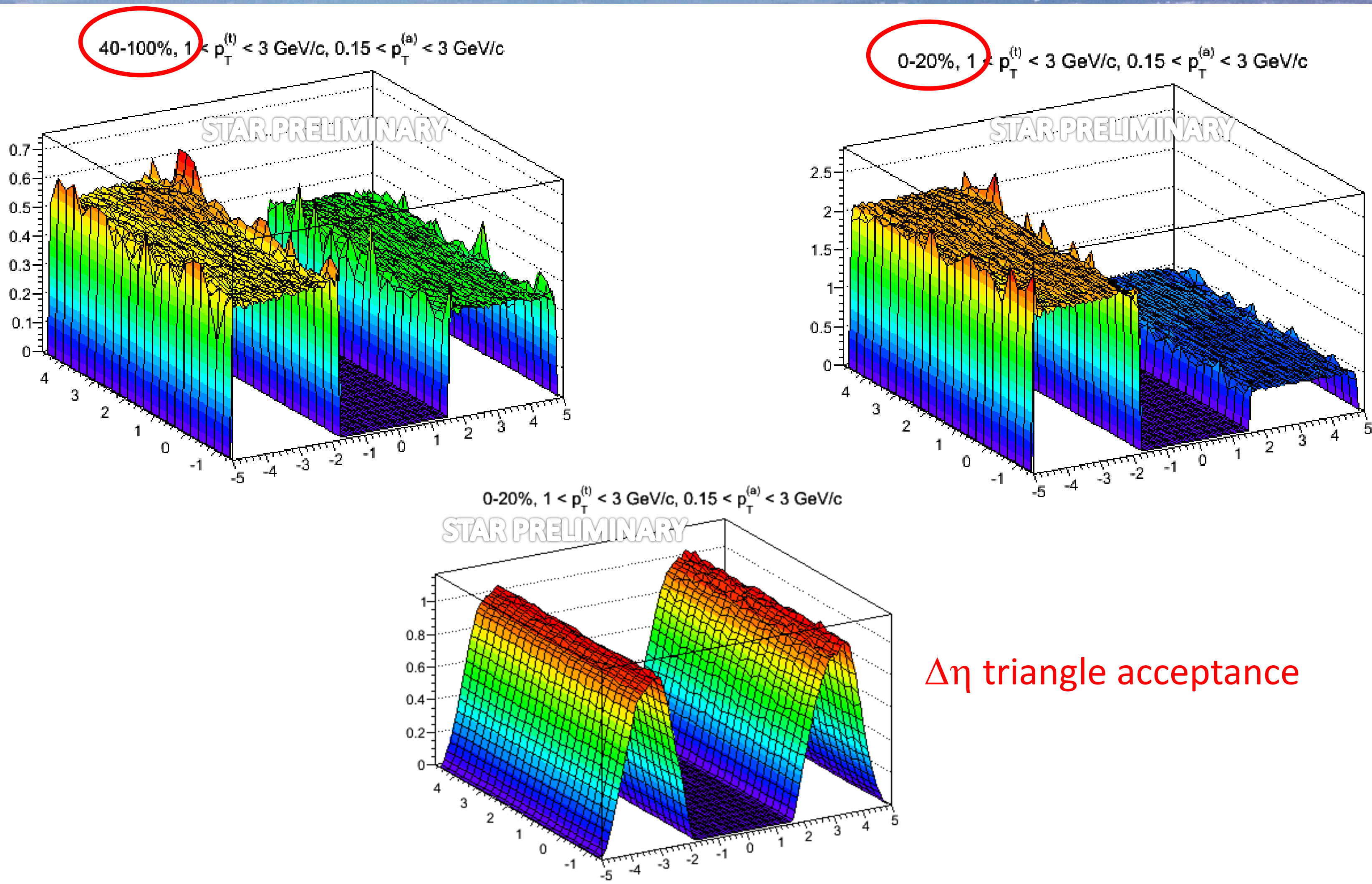
Shaded: PHENIX acceptance

Peripheral | Central | Central – Peripheral




- ZYAM syst. error from different sizes of Δϕ region for ZYAM.
- Efficiency corrected: 85 ± 5% .

# TPC-FTPC correlations

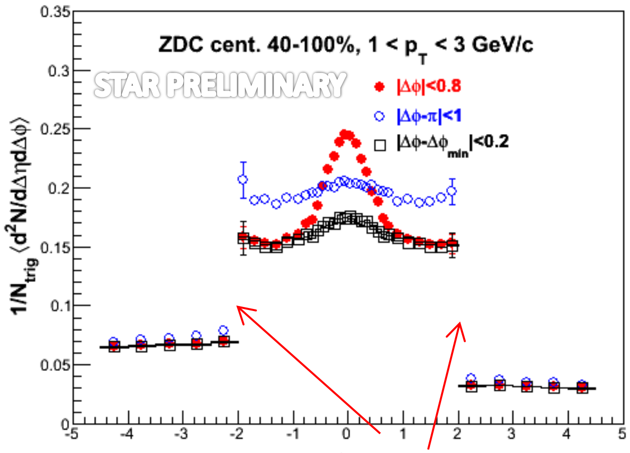


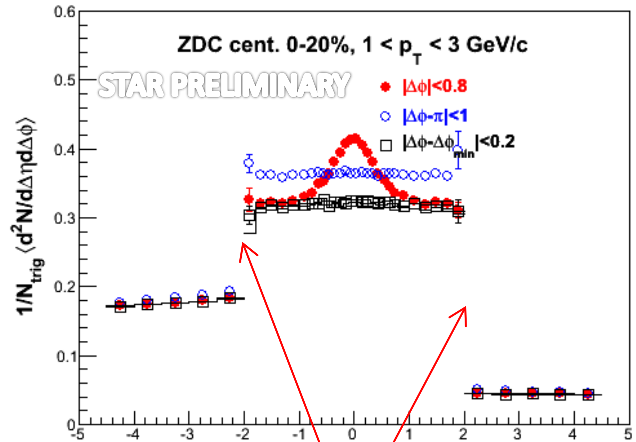

Δη triangle acceptance

# Raw and ZYAM'ed Δη Correlations

ZDC centrality, $1 < p_T^{trig}, p_T^{assoc} < 3$ GeV/c

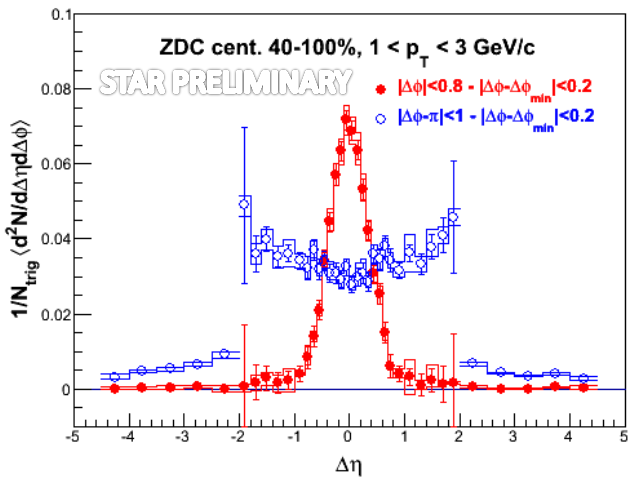
Raw correl.

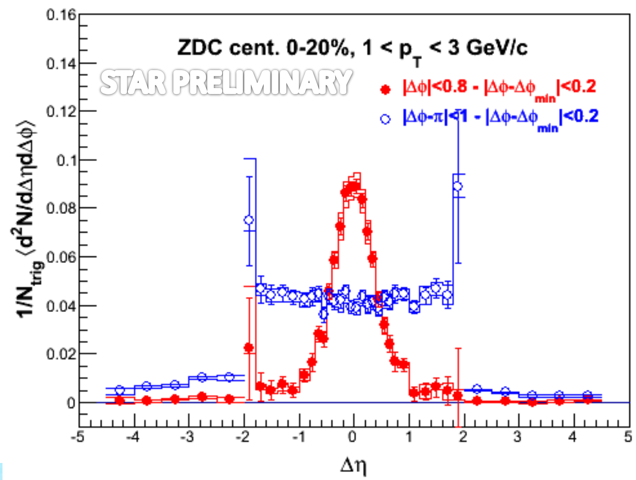


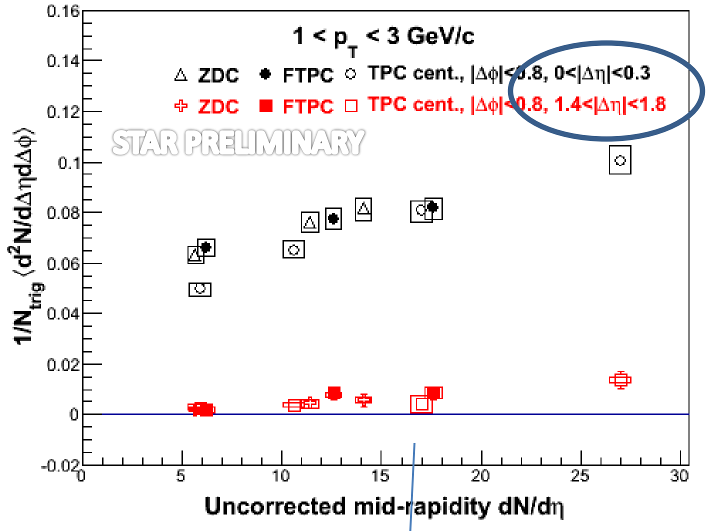

Discontinuity because it's Δη not η distribution.
At Δη=2, TPC-TPC and TPC-FTPC pairs come form different η's.

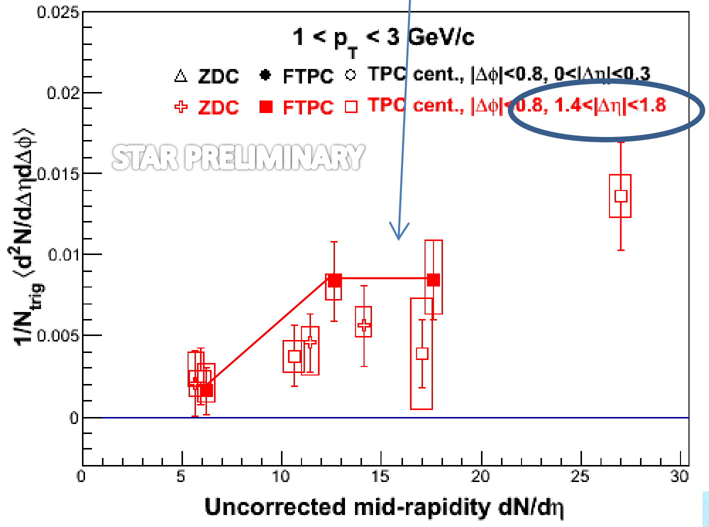
ZYAM'ed



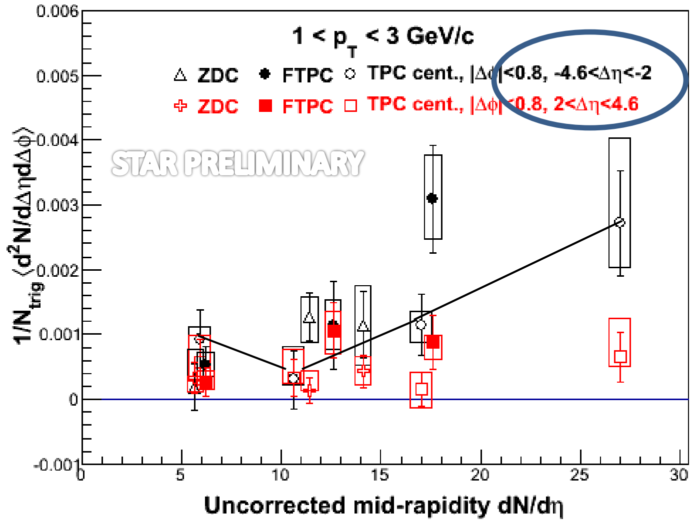



# ZYAM'ed yield vs multiplicity




$1 < p_T^{trig}, p_T^{assoc} < 3$ GeV/c



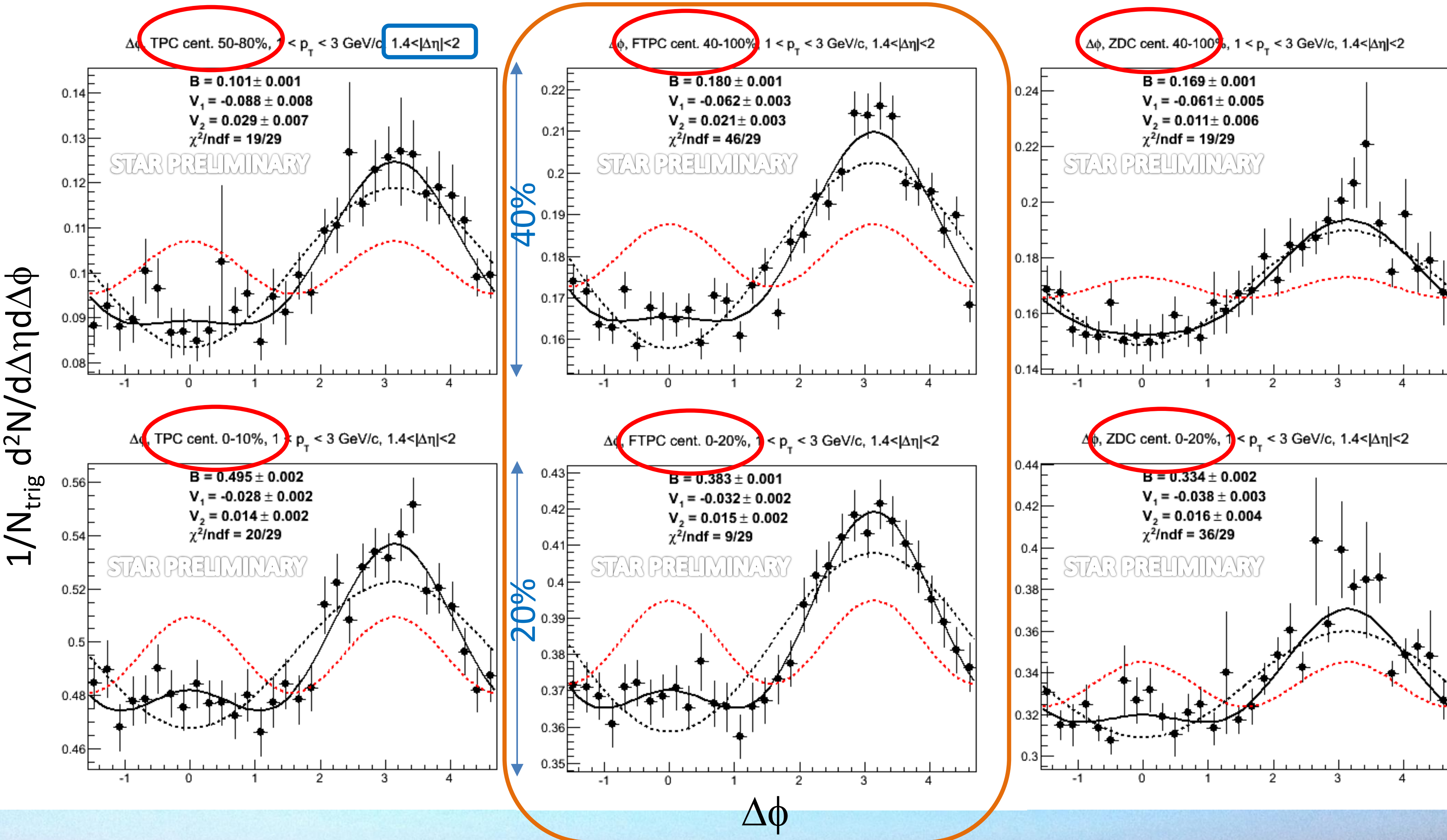

- Jets are biased by multiplicity
- Small ridge yield after ZYAM at large Δη; 2-3σ effect

# Fourier coefficients

- Fourier decomposition of correlation functions
- No ZYAM
- No central – peripheral

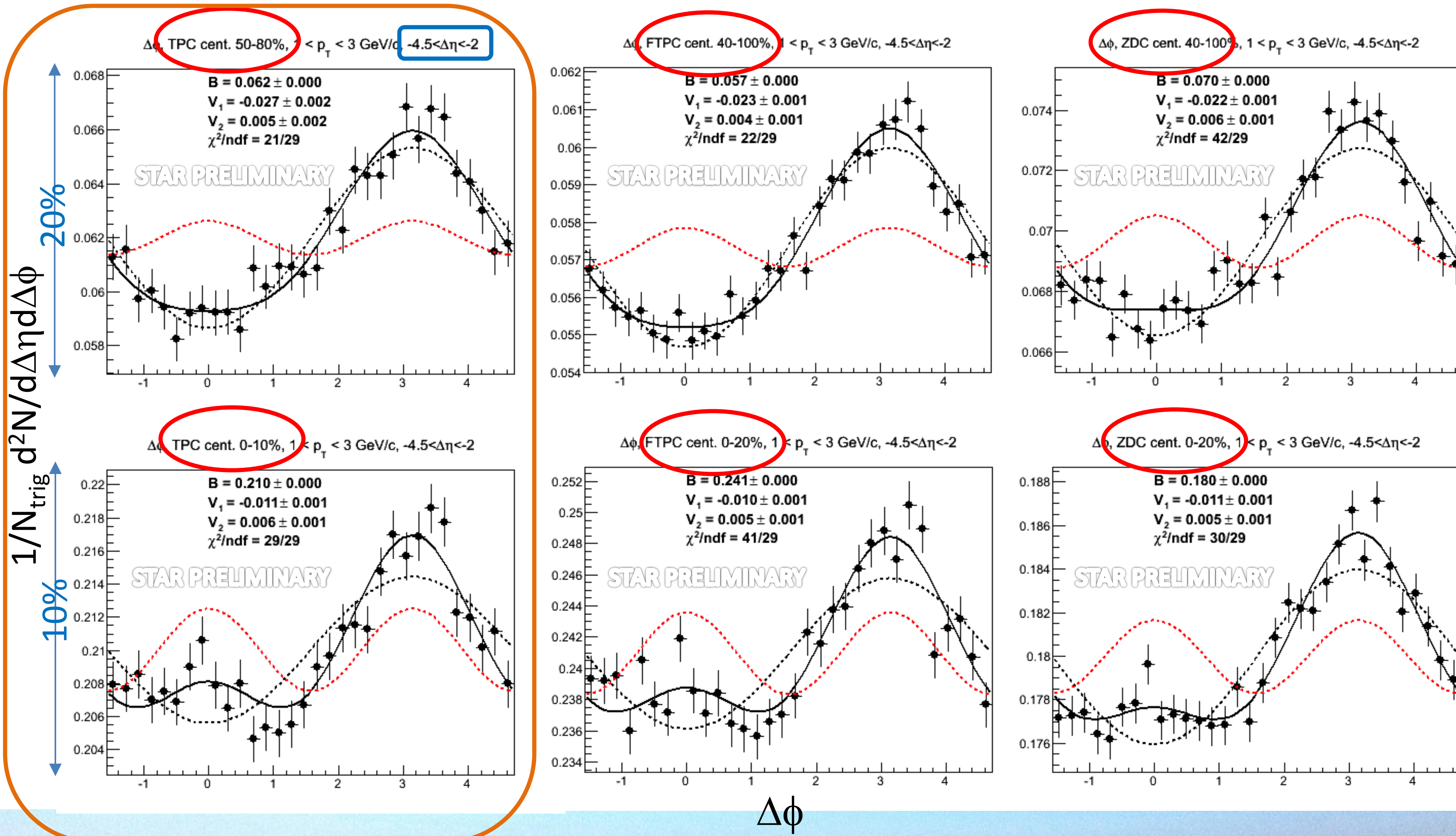
# TPC-TPC correlations Fourier decomposition

$1 < p_T^{trig}, p_T^{assoc} < 3$ GeV/c



# TPC-FTPC correlations Fourier decomposition

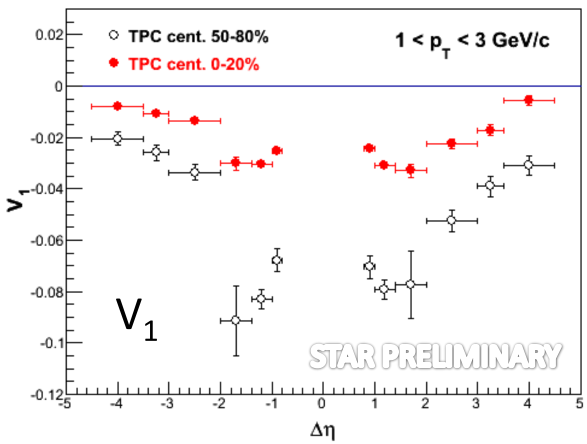
$1 < p_T^{trig}, p_T^{assoc} < 3$ GeV/c

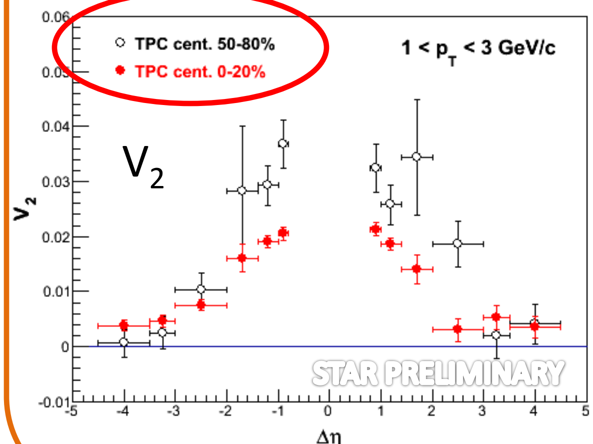


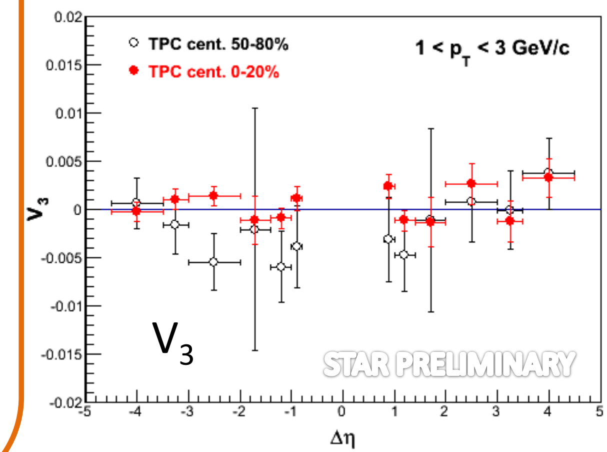
# Calculated Fourier coefficents vs Δη

$$V_n = \langle \cos(n\Delta\phi) \rangle$$

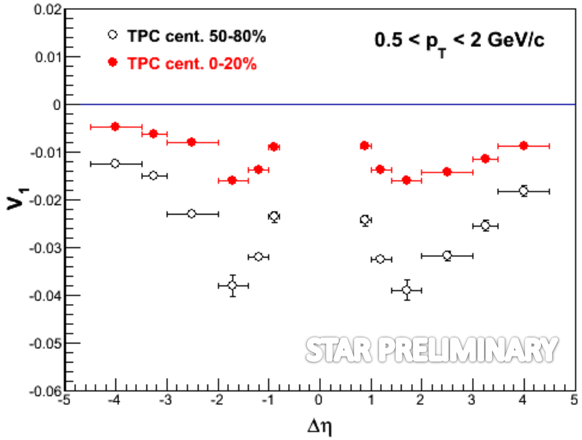
$1 < p_T^{trig}, p_T^{assoc} < 3$ GeV/c

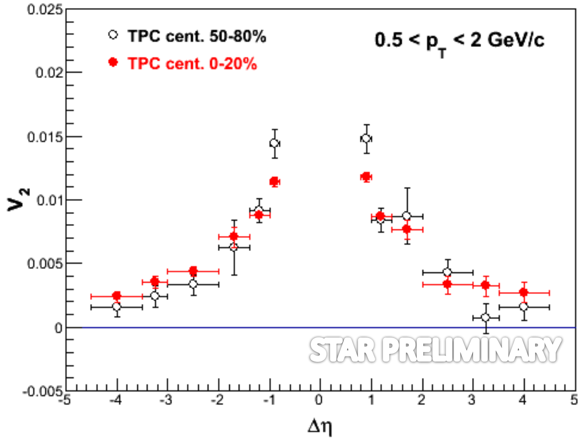


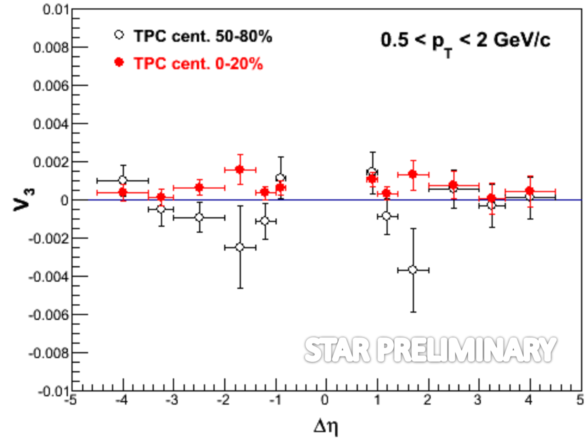




$0.5 < p_T^{trig}, p_T^{assoc} < 2$ GeV/c



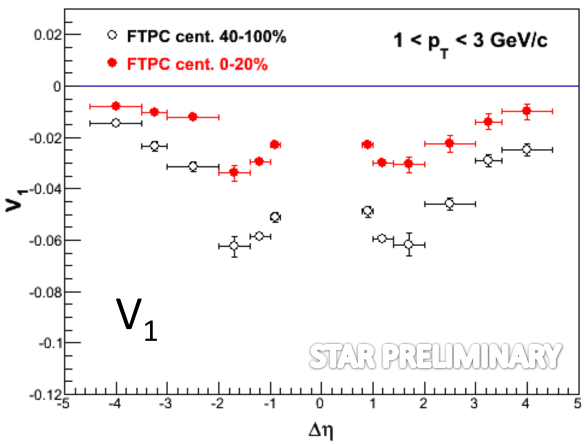



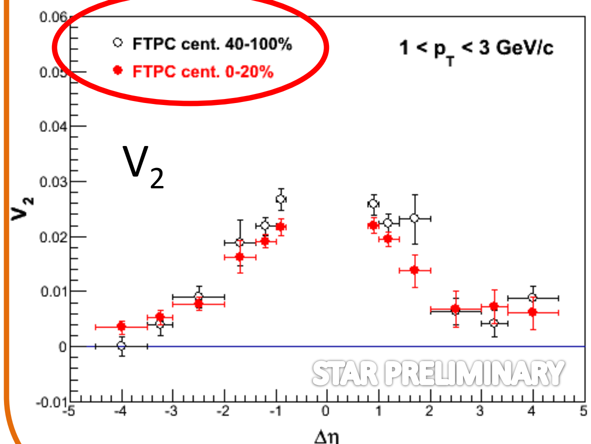



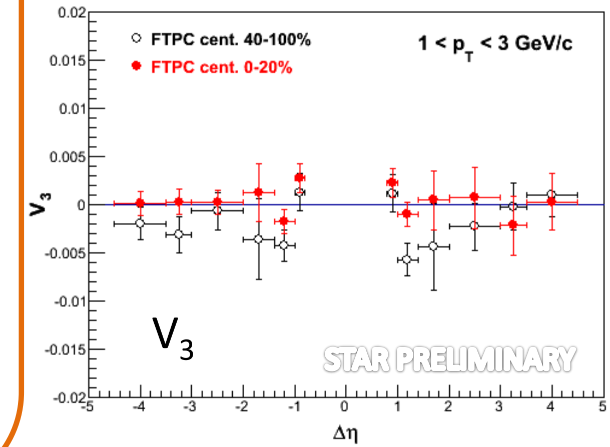
# Calculated Fourier coefficents vs Δη

$$V_n = \langle \cos(n\Delta\phi) \rangle$$

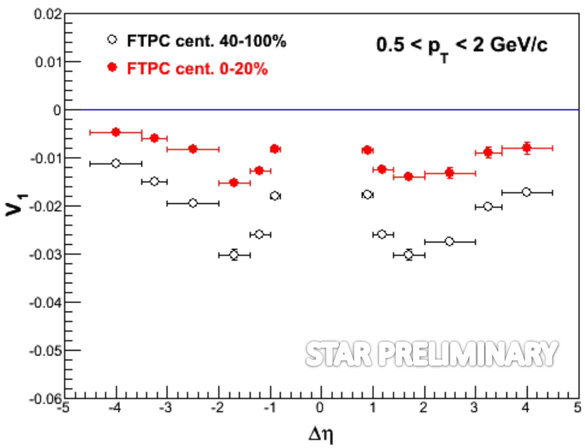
$1 < p_T^{trig}, p_T^{assoc} < 3$ GeV/c

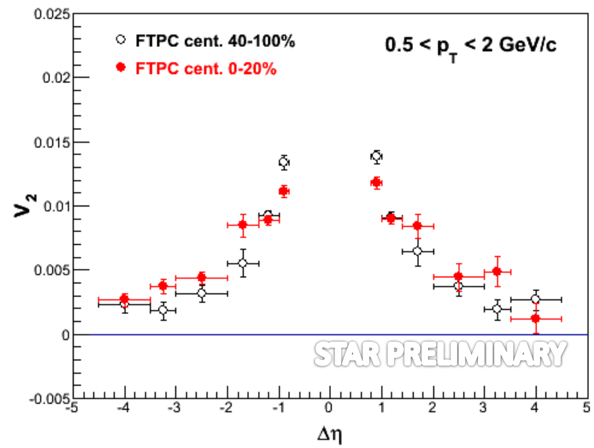


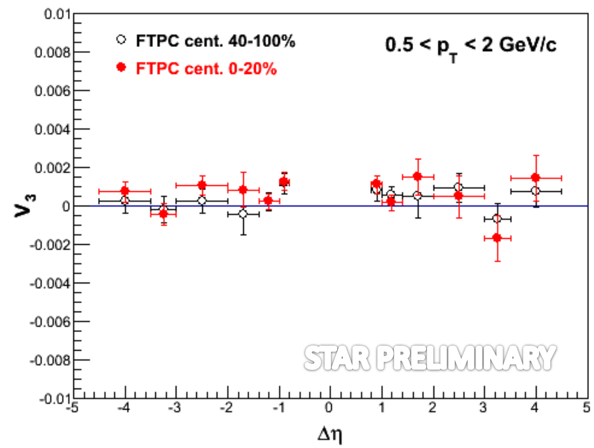




$0.5 < p_T^{trig}, p_T^{assoc} < 2$ GeV/c

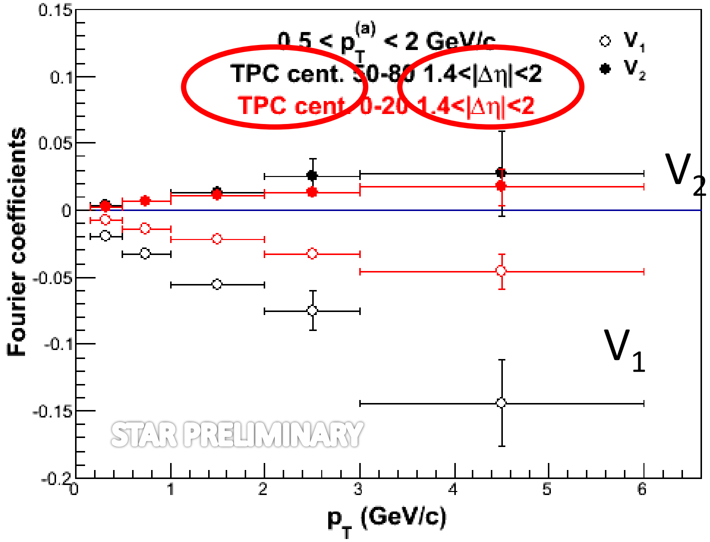


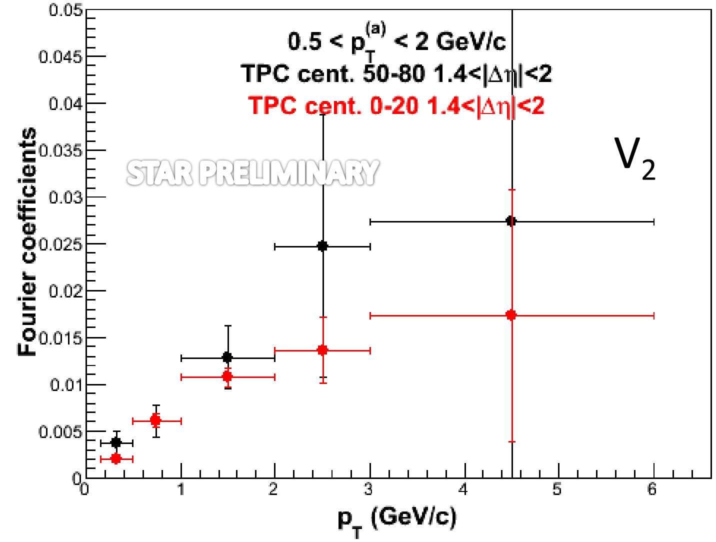



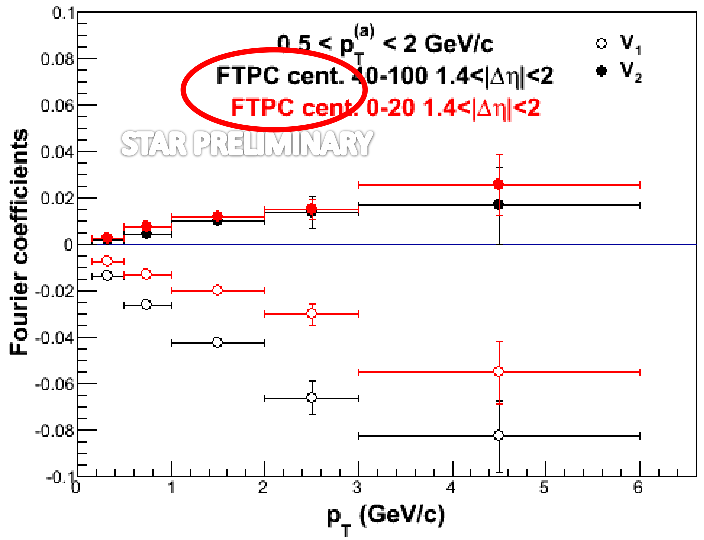



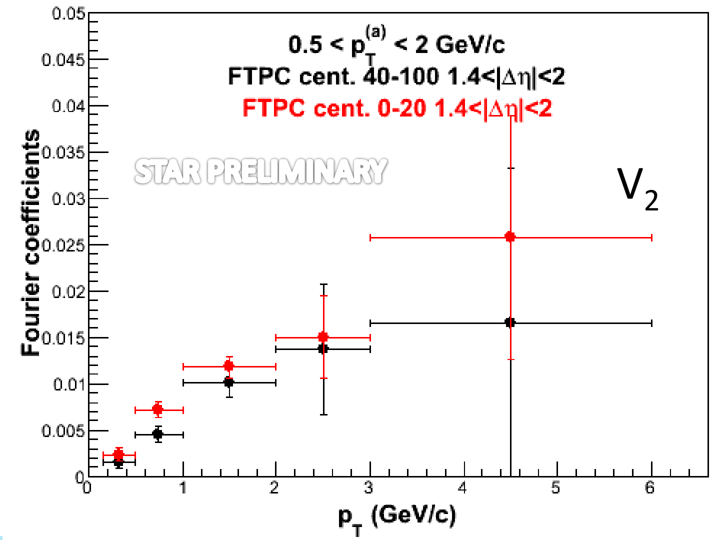
# Calc. Fourier coefficients vs $p_T$

One particle $p_T$ is fixed 0.5-2 GeV/c



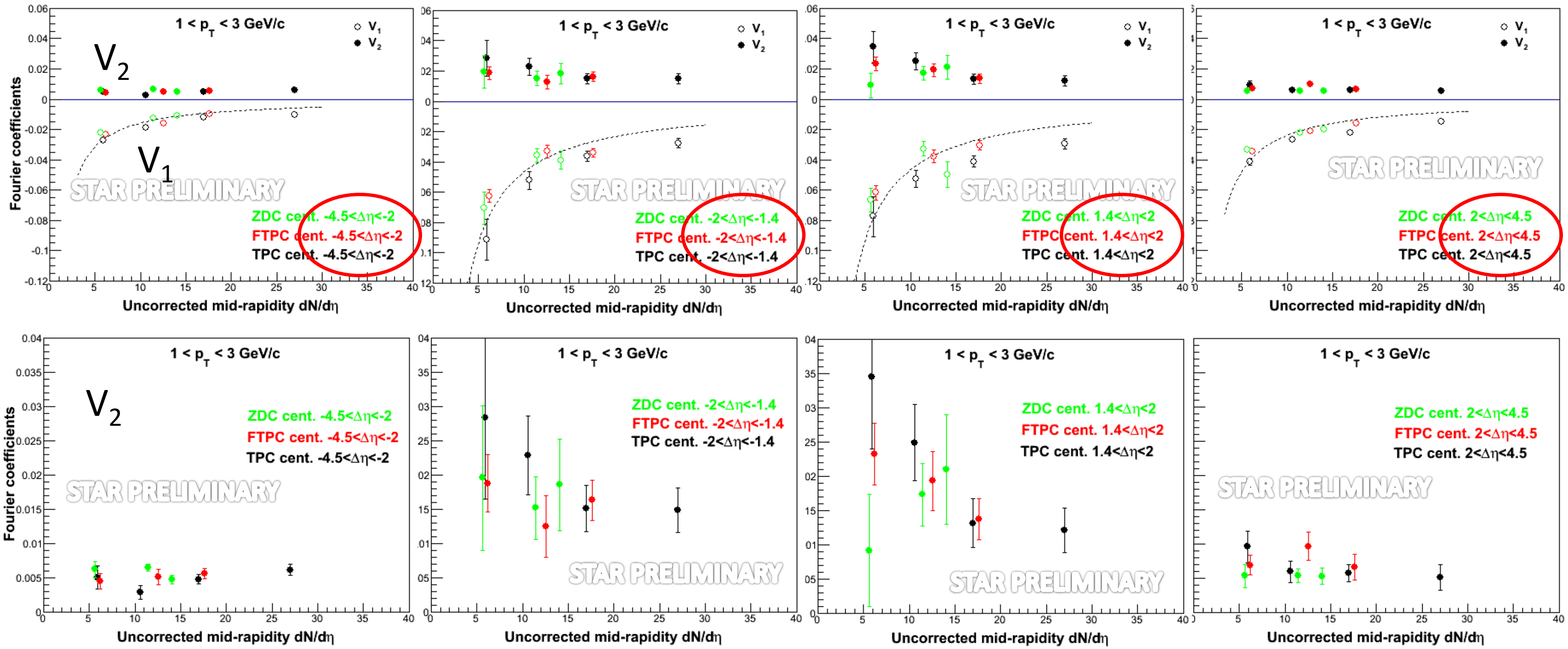



# Calc. Fourier coefficients vs multiplicity

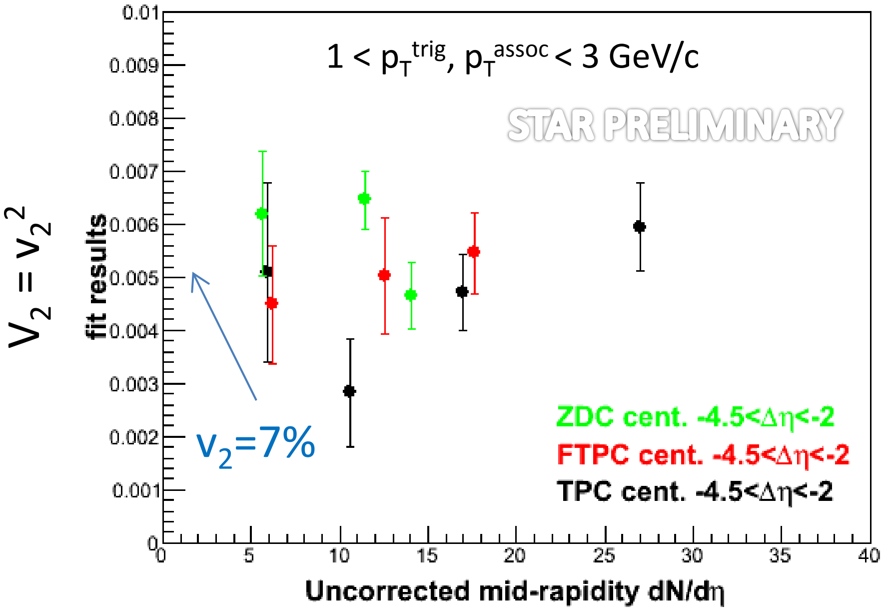
$1 < p_T^{trig}, p_T^{assoc} < 3$ GeV/c

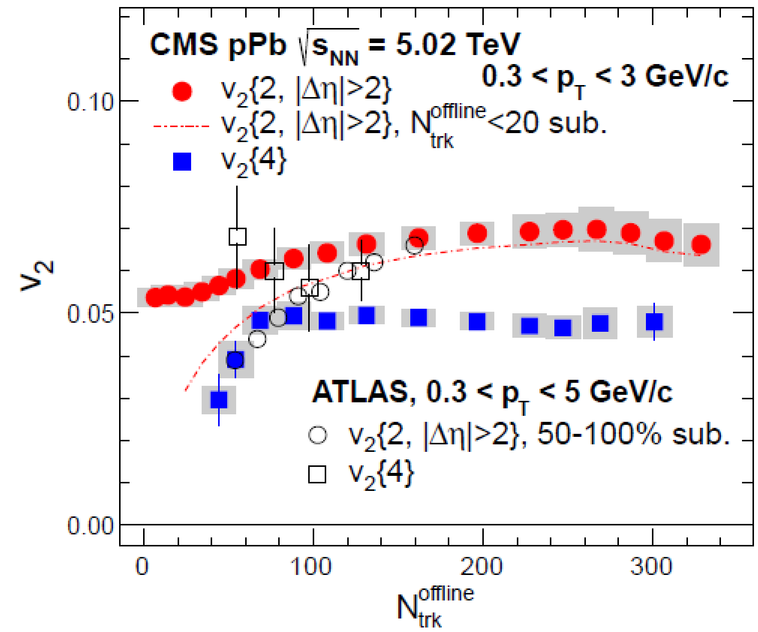



**Au-side** ⟷ **d-side**

- Correlations have $V_1$ and $V_2$ components
- $V_1$ appears ~1/N. $V_2$ ~constant over multiplicity
- Even at very forward d-side, $V_2$ component is large (maybe even larger than Au-side).

# RHIC/LHC $v_2$ vs multiplicity



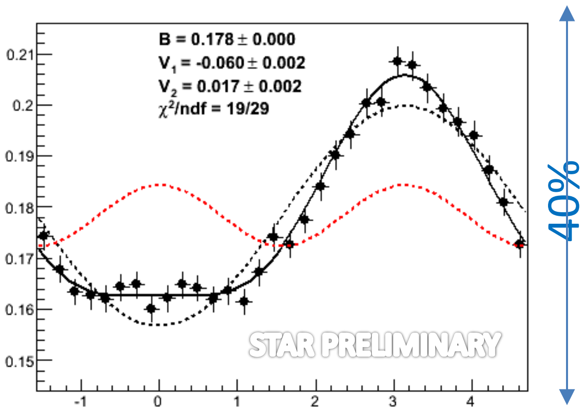




- LHC $v_2\{2\}$ is also relatively insensitive to multiplicity.
- LHC $v_2\{4\}$ is independent of multiplicity except peripheral. Nonflow or flow?
- **Hydrodynamic flow**: In peripheral? No increase with multiplicity?
- **CGC**: No increase with multiplicity?

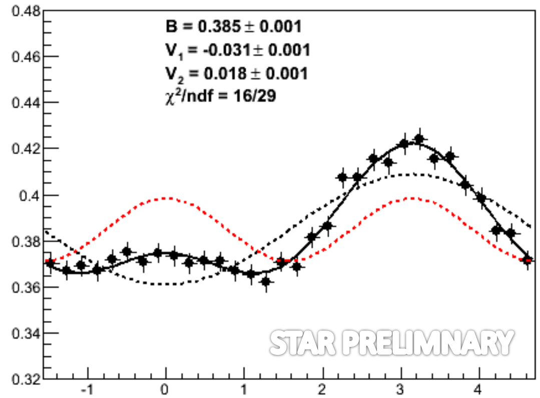
# Simple math, general remarks

$1 < p_T^{trig}, p_T^{assoc} < 3$ GeV/c; $1.4 < |\Delta\eta| < 1.8$

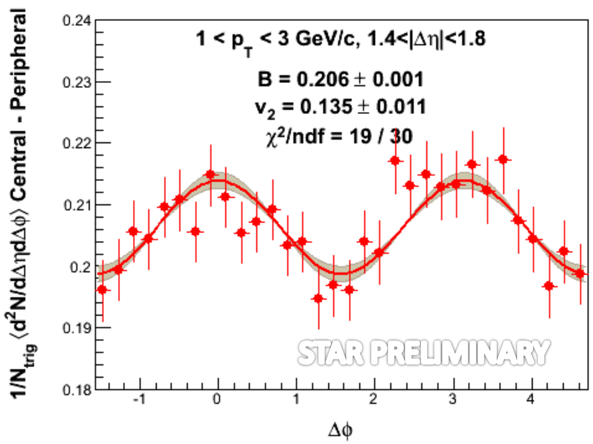
FTPC peripheral 40-100%




FTPC central 0-20%




central – peripheral




$$\text{Peripheral} = N_{peri}\left(1 - 2V_1^{peri}\cos\Delta\phi + 2V_2\cos 2\Delta\phi\right)$$

$$\text{Central} = N_{cent}\left(1 - 2V_1^{cent}\cos\Delta\phi + 2V_2\cos 2\Delta\phi\right)$$

$$\text{Central} - \text{Peripheral} = \left(N_{cent} - N_{peri}\right)\left(1 + 2V_2\cos 2\Delta\phi\right)$$

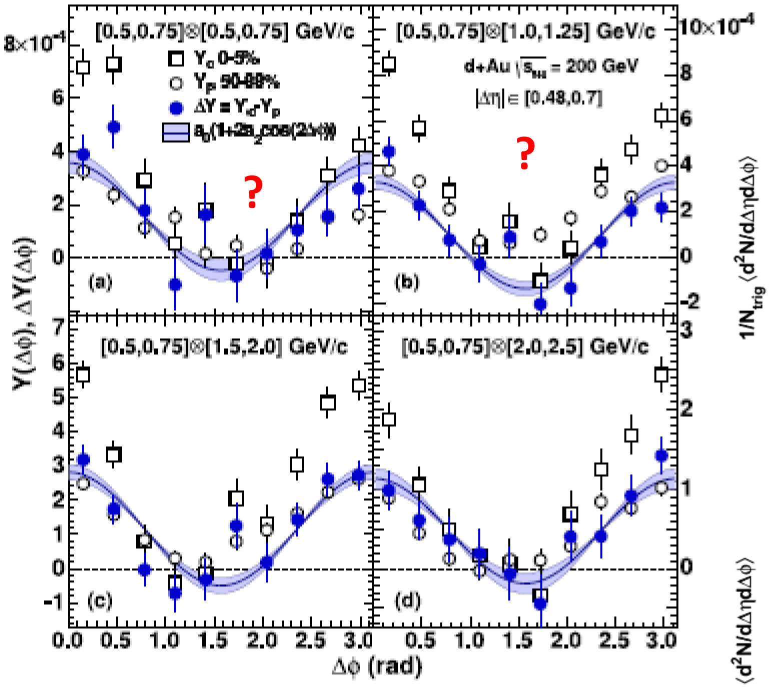
- ZYAM may give distorted information.
- Central=peripheral jets and anisotropic triggers do not go hand-in-hand naturally.

# Summary

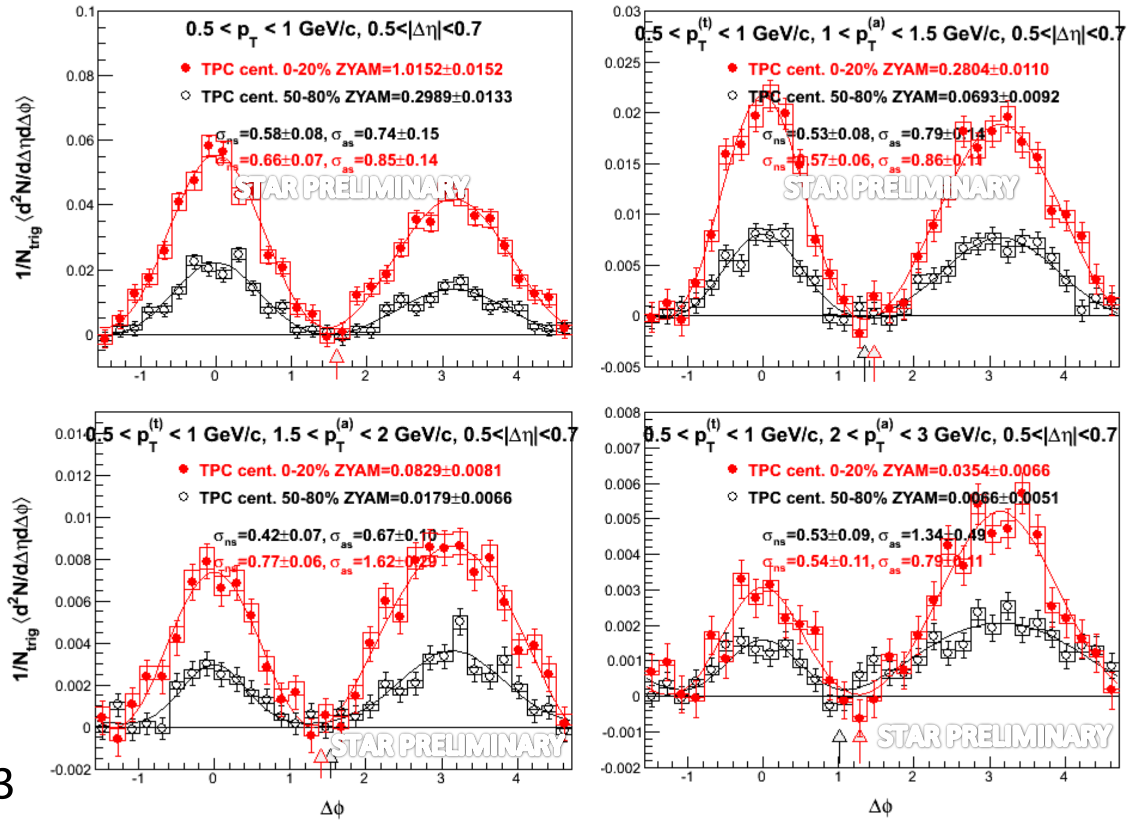
- Near-side Gaussian peak in $\Delta\eta$. Away-side approximately flat.
- Central – peripheral excess resembles near- and away-side jet shapes and charge ordering.
  - STAR large acceptance allows detailed investigation.
- d+Au data mainly consistent with jet phenomenology.
  - Large multiplicity events → larger-energy jets?

- Near-side large-$\Delta\eta$ yield is small, 2-3$\sigma$ at 1-3 GeV/c.
- There seems a similar v2 component in dihadron correlation function in peripheral and central, including deuteron-going forward rapidity.
- Not ready to rule out models.

# Compare to PHENIX results




Note: not exact $p_T$ matching




PHENIX not normalized by bin size?

Factor would be: 0.22x2x0.314=0.13

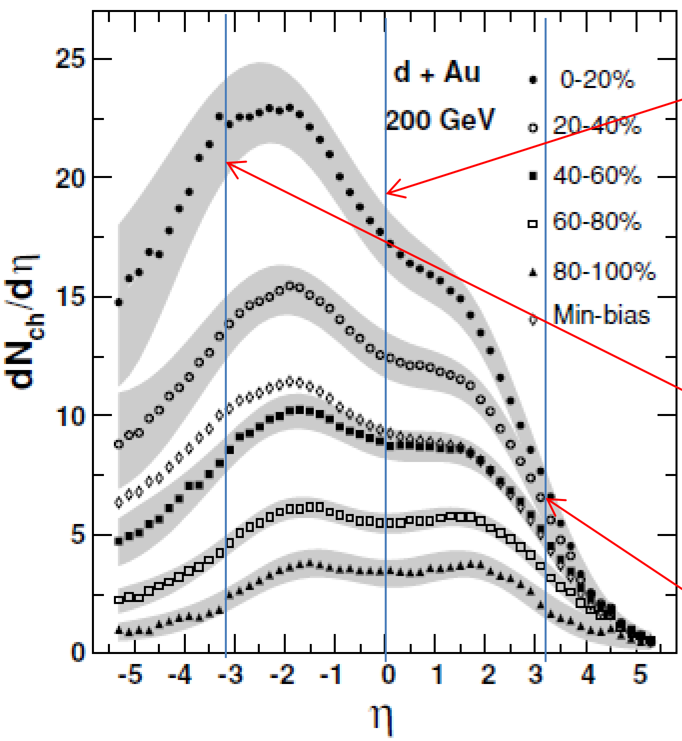
Then good consistency for the two high-pt bins.

Not so for the two low-$p_T$ bins.

# Sanity check

All charged hadrons

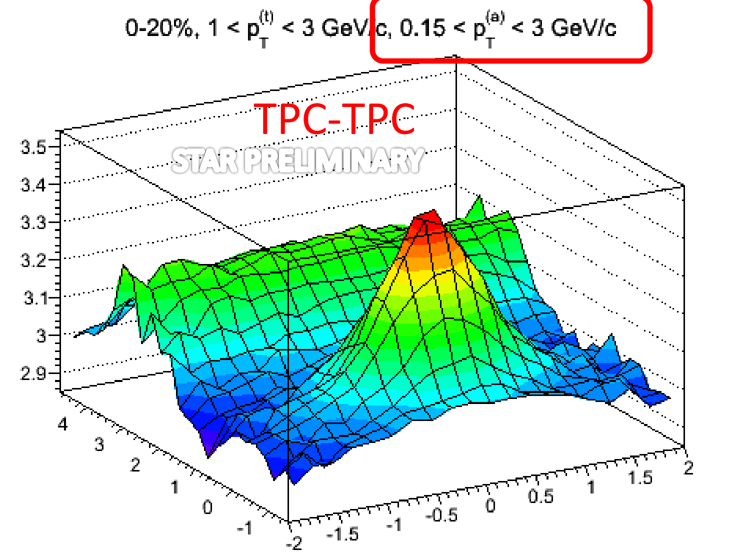
PHOBOS, PRC 72 (2005) 031901(R)

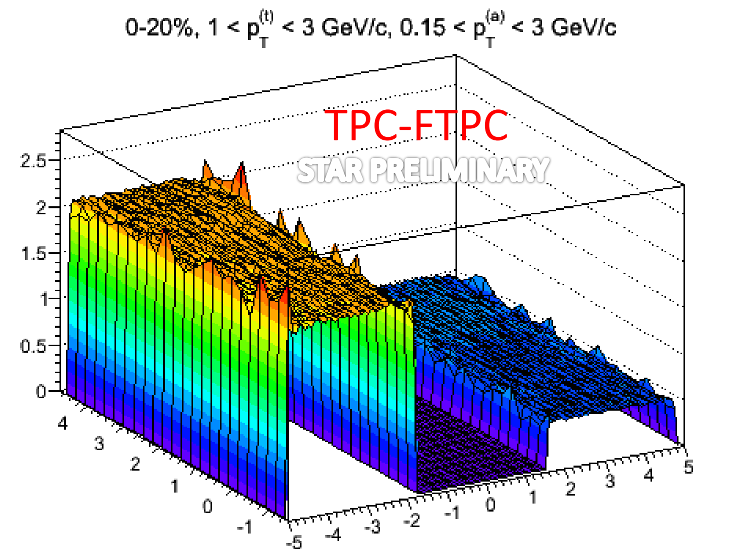



$$3\times\frac{4_{\Delta\eta}\times 2\pi}{2(acc.)\times 2_{\eta}}\approx 20$$

$$2\times\frac{3_{\Delta\eta}\times 2\pi}{2(acc.)\times 1_{\eta}}\approx 20$$

$$0.5\times\frac{3_{\Delta\eta}\times 2\pi}{2(acc.)\times 1_{\eta}}\approx 5$$



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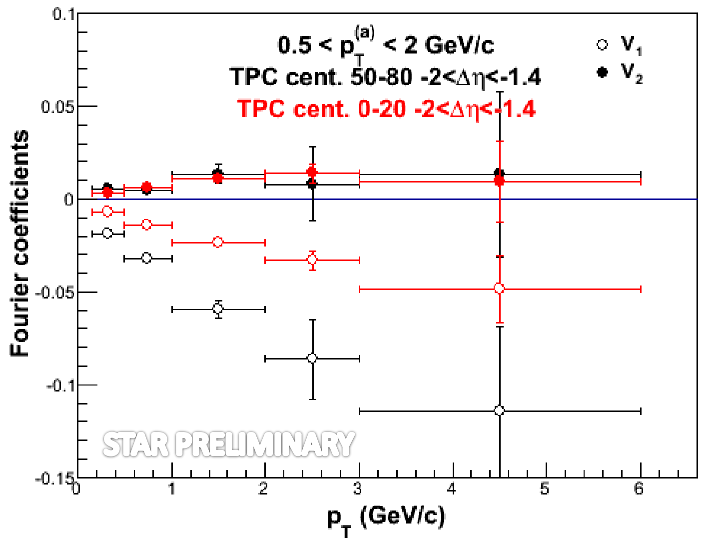
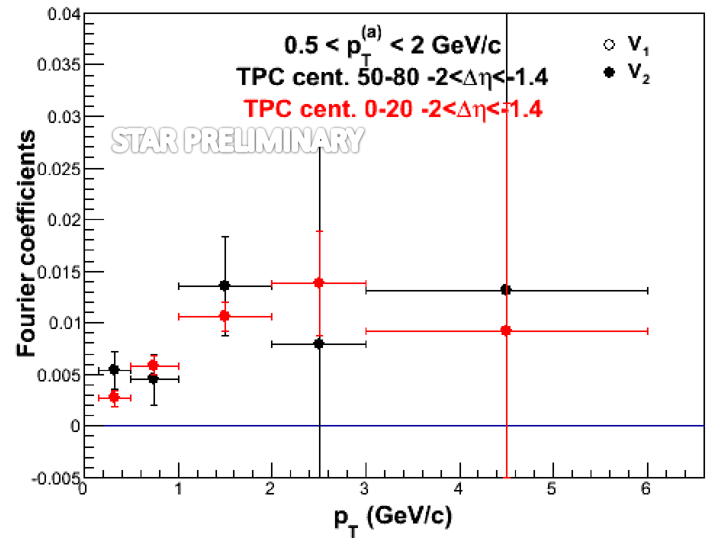
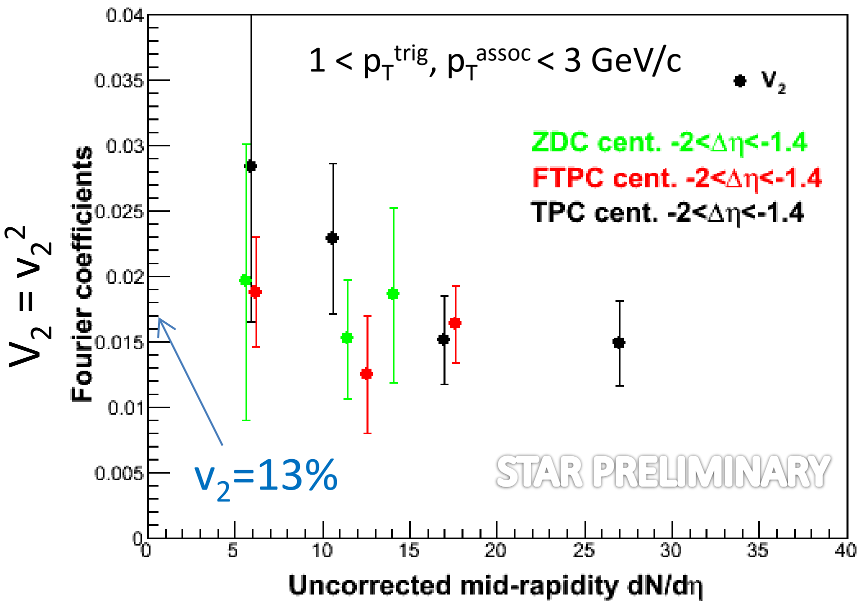
One particle $p_T$ is fixed 0.5-2 GeV/c

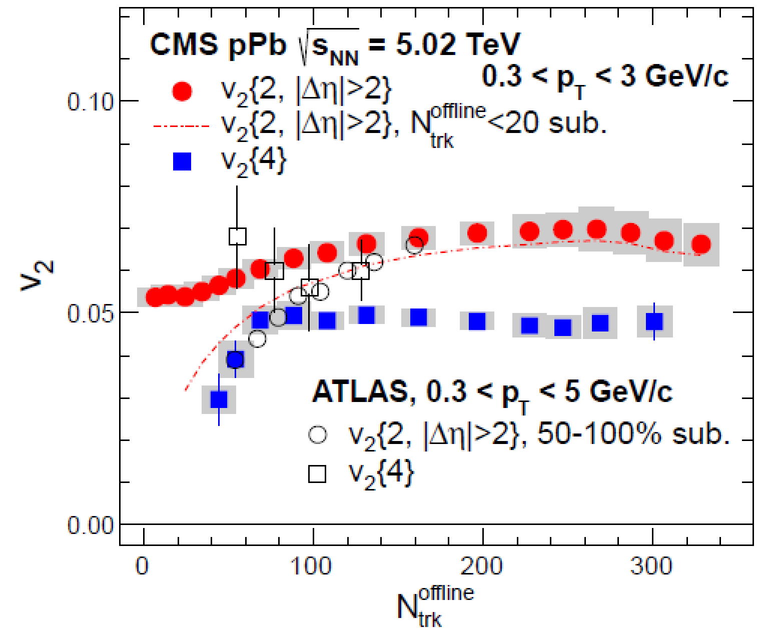



- V1 quite different between peripheral and central.
- V2 similar.

# LHC $v_2$ vs multiplicity




- LHC $v_2\{2\}$, i.e. Fourier $v_2$ of two-particle correlaiton, is also relatively insensitive to multiplicity.
- LHC $v_2\{4\}$ is independent of multiplicity except peripheral. Nonflow or flow?
- Hydrodynamic flow: In peripheral? No increase with multiplicity?
- CGC: No increase with multiplicity?