# Conditional h-h and 3-particle correlations

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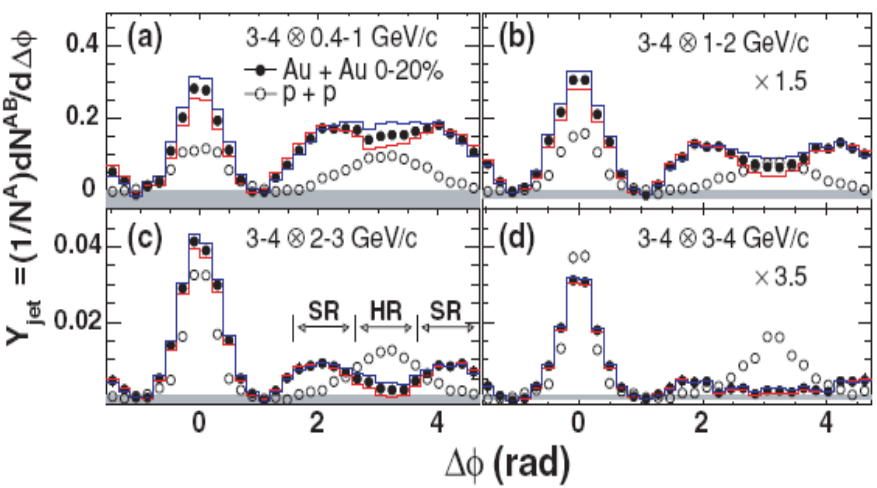
# Outline

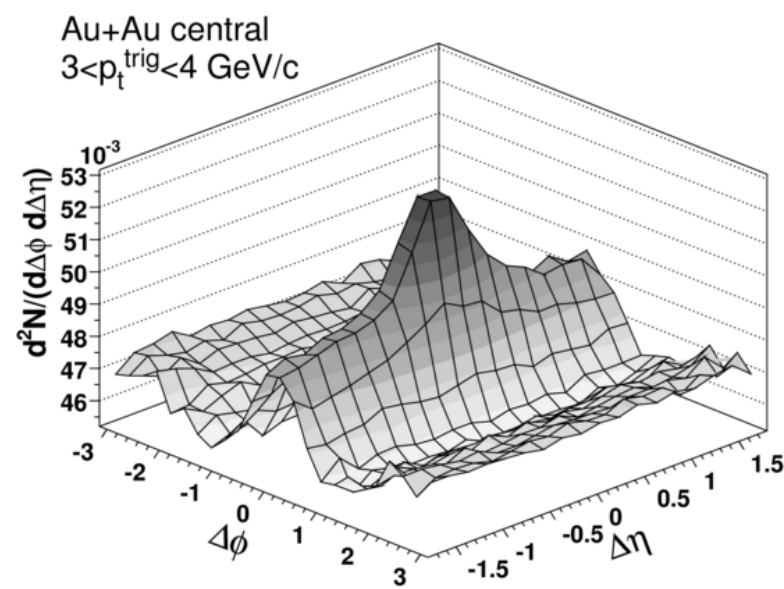
- 2-particle correlation results and questions
- Multi-particle correlations add more power on:
  - Conical structure (emission ?)
  - Absorption (Surface-bias) vs. Suppression ?
  - Ridge: where are you from ?
- Summary and future outlook.

# 2-particle correlations

- We have learned a lot from 2-particle correlation:
  - Head-shoulder shape on the away-side
  - Ridge at near-side



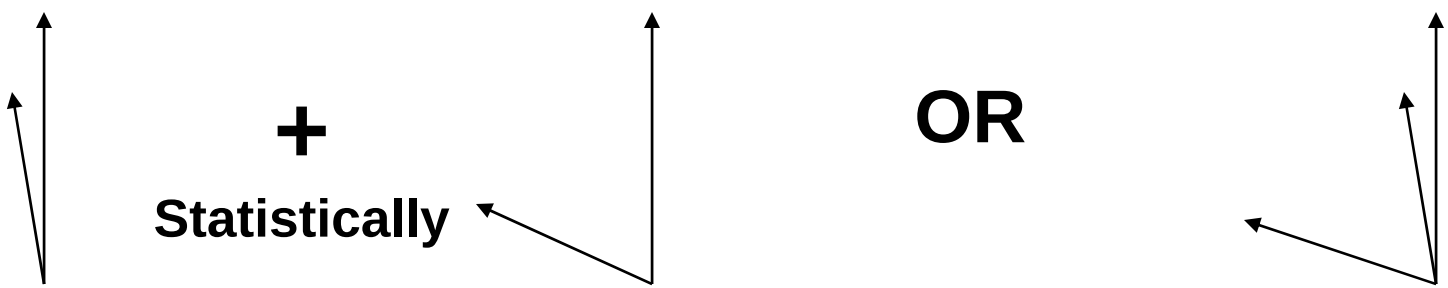

Phys. Rev. C **77**, 011901(R) (2008)




Phys. Rev. C **80** (2009) 64912

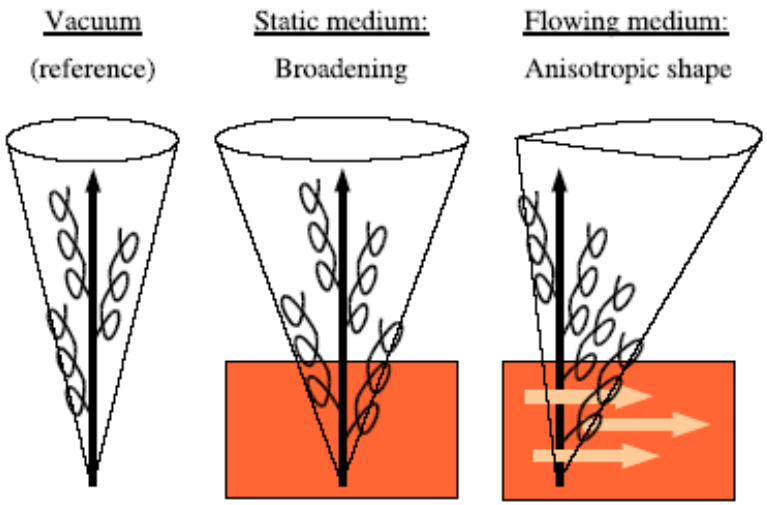
# Now 2-particle correlation has raised more questions to answer

- The correlation shape may be induced by different physics. Which is the true (or biggest contribution) one?
  - Ridge: is the “ridge” particles of the same source of jet? Do the associates particles appear in the jet and ridge shape come from the same source?



# Now 2-particle correlation has raised more questions to answer

- The correlation shape may be induced by different physics. Which is the true (or biggest contribution) one?
  - Away-side: is the “bump” shape real, or it’s a stack-up of another physics? Adding up deflected away-side jets statistically can also give a similar “bump” as Mach-cone does.

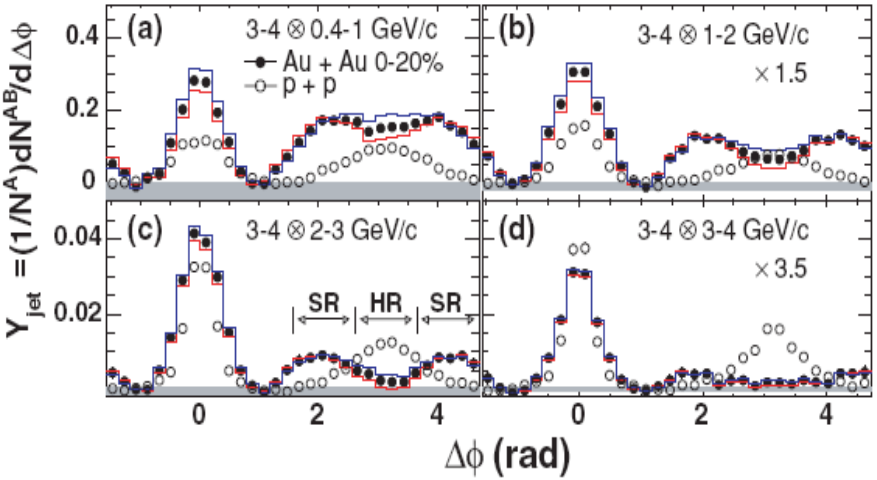


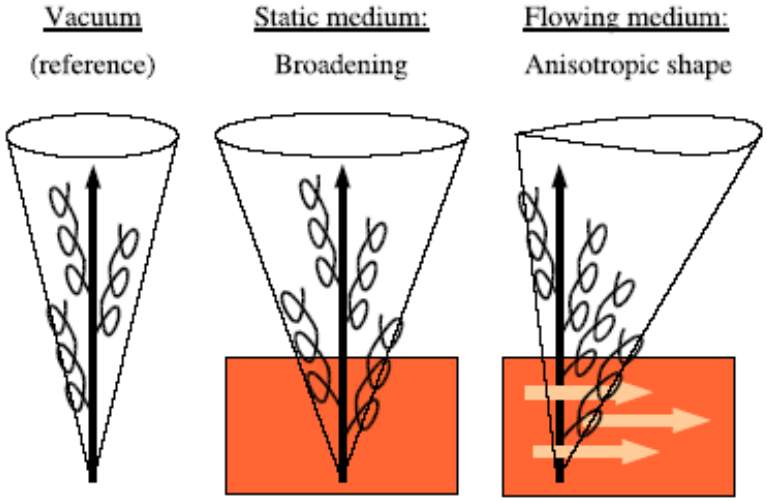
# Why multi-particle correlation

- One ideal method is to reconstruct jet event-by-event, and measure their shape/spectra one-by-one.
- However this can be difficult at RHIC energy level
  - Particle at $p_T$ ~ a few GeV can still be from thermal flow instead of jets, since the flow obeys quark-number scaling.
  - The mean $E_T$ of central Au+Au at RHIC makes a shift >20GeV in a typical jet-cone resolution of R ~ 0.4. This makes jet reconstruction challenging with fluctuation and smearing effects.
- The multi-particle correlation method is introduced to give better insight on correlation topology than the traditional 2-particle correlation, and is less event-by-event fluctuated than full-jet reconstruction.

# The long “Mach-cone” legend

- At specific kinetic regimes we observe this “cone-like” structure.
- Real cone or stack-up of deflected jets? The 2-particle correlation has done many useful tests on which scenario is closer to the reality.




Phys. Rev. C **77**, 011901(R) (2008)

# Is that a “Mach-cone” ?

- At specific kinetic regimes (intermediate $p_T$ regime) we observe this “cone-like” structure.
- Real cone or stack-up of deflected jets? The 2-particle correlation has done many useful tests on which scenario is closer to the reality.

- Now a 3-particle correlation, $\Delta\phi$–$\Delta\phi$ of two associates in the same event relative to the trigger particle, shall give us more robust evidence:
  - Are the two associates together or separated on the away-side axis of trigger?

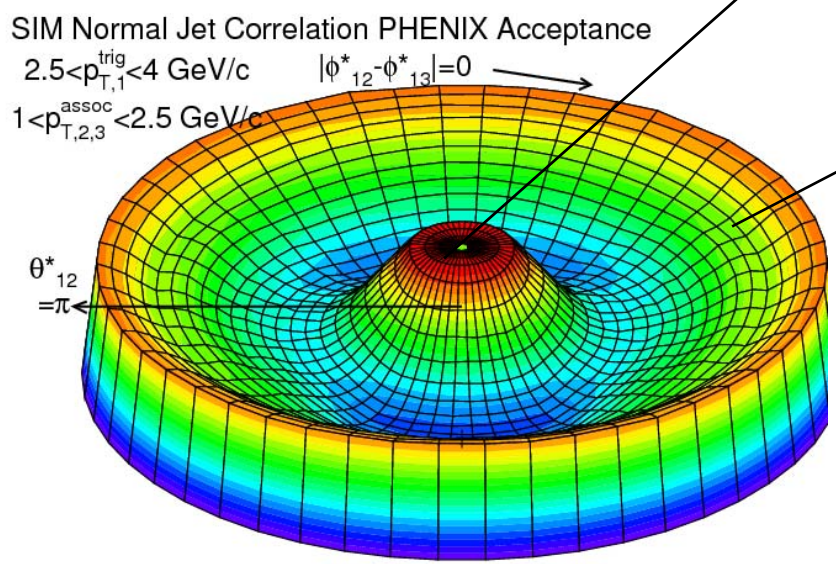
# 3-p correlation in high-$p_T$ (polar) framework

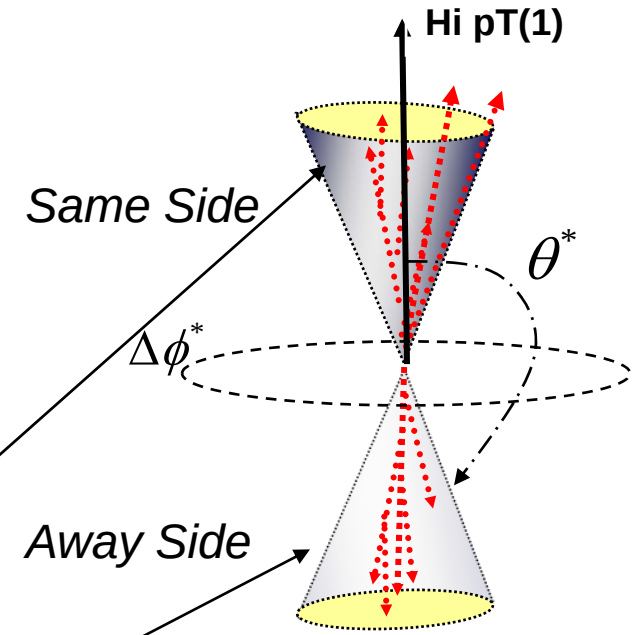
**along azimuth**

$$\Delta\phi^* = \phi^*_{12} - \phi^*_{13}$$

**along radius**

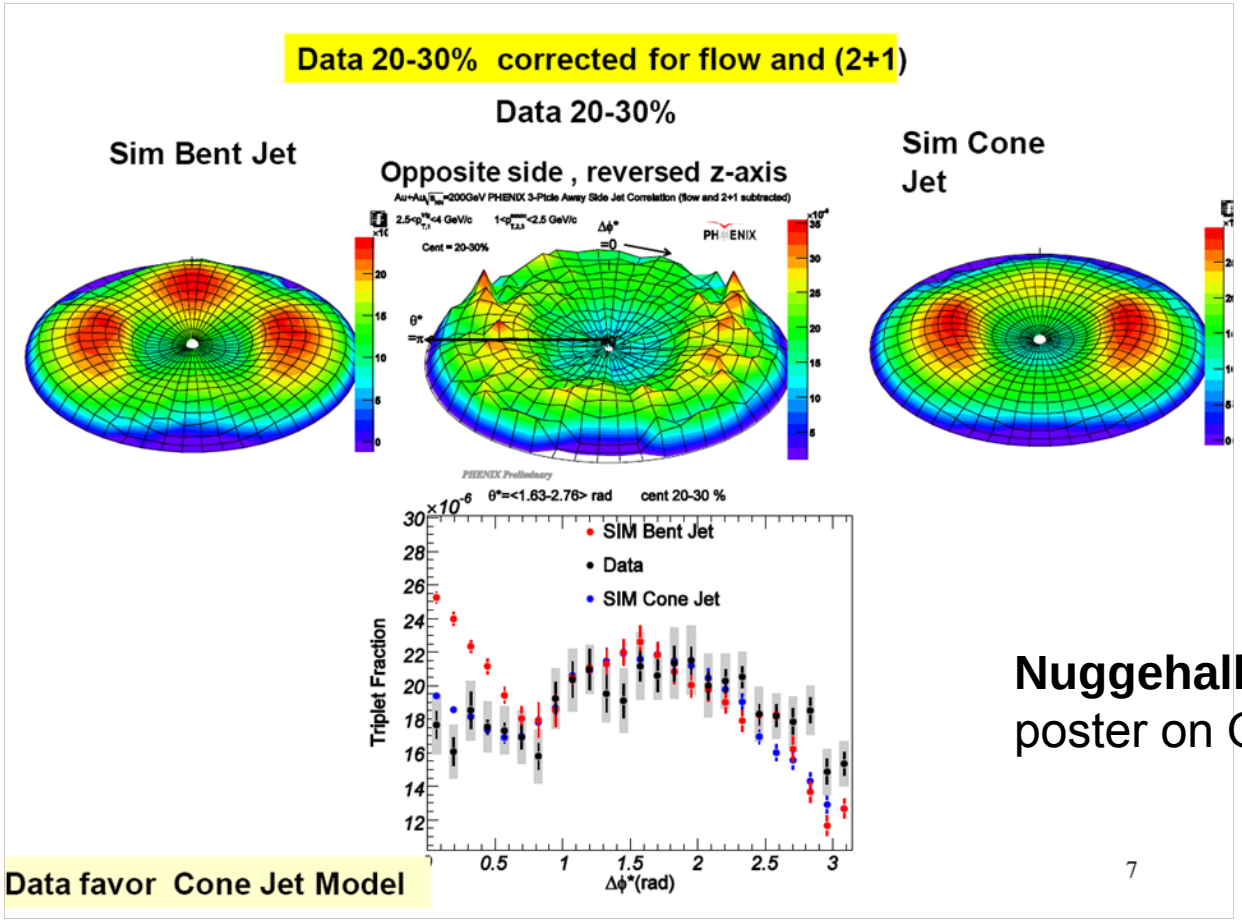
$$\theta^* = \theta^*_{12}$$




First shown by **Nuggehalli Ajitanand** on QM05

# 3-p correlation in high-$p_T$ (polar) framework




**Nuggehalli Ajitanand**
poster on QM09

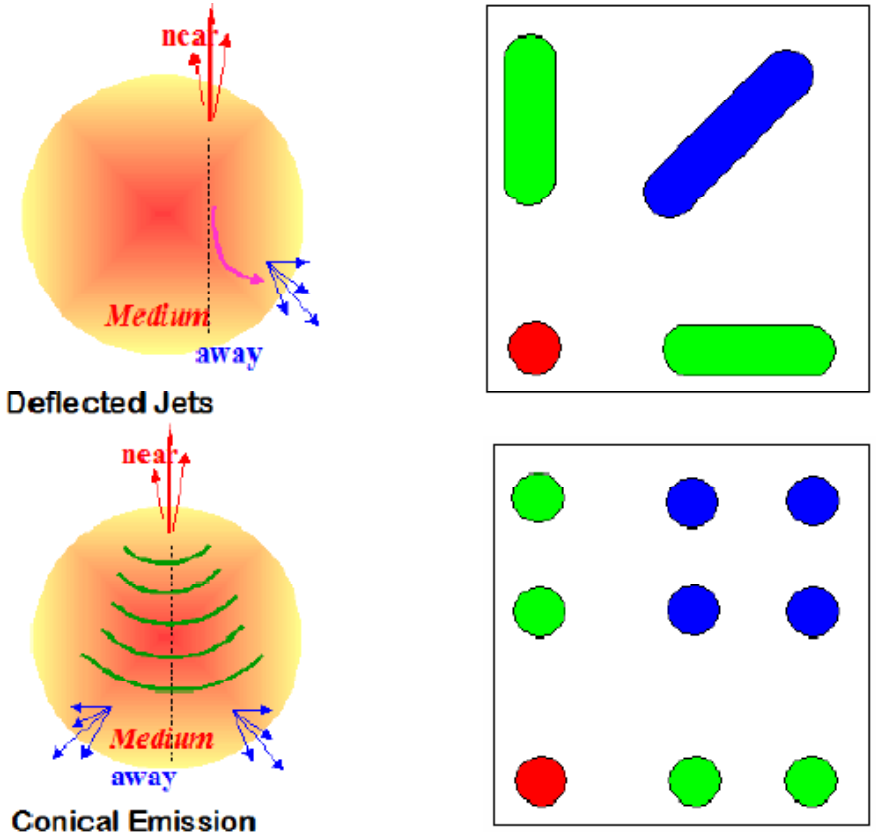
(Quote from Ajit's poster) True 3-particle jet correlations validate presence of Mach Cone jets but do not rule out small contributions from other topologies.

Can this Mach-cone angle yield a sound speed?

# 3-p correlation: $\Delta\phi$–$\Delta\phi$ correlation

The 3-particle correlation has a deeper insight on the modification of the away-side peak, to distinguish conical emission from deflected jets.

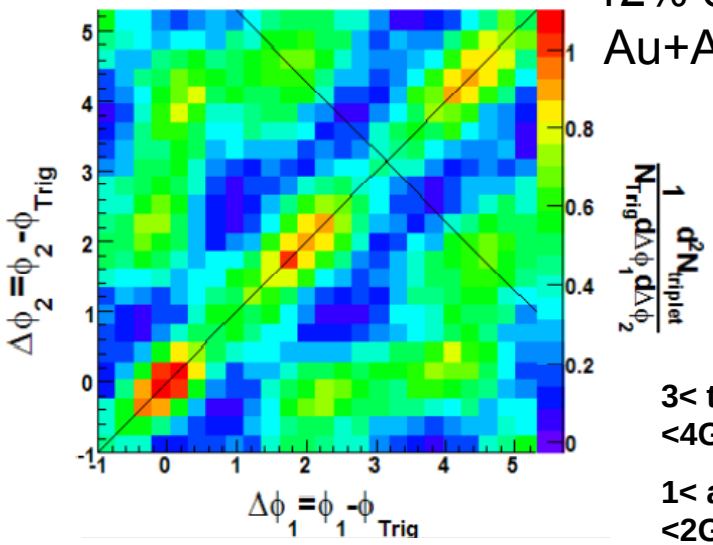
From Jason Glyndwr Ulery at Cathie-Riken workshop



# Published $\Delta\phi$–$\Delta\phi$ correlation result

Phys. Rev. Lett. **102** (2009) 52302

12% central Au+Au.




**3< trig pT <4GeV**

**1< assoc pT <2GeV**

- The conclusions: (quote from of this paper)
  - Distinct peaks at =1.37 ± 0.02(stat)+0.06 −0.07(syst) from are observed on the away side in central Au+Au collisions, with correlated hadron pairs far apart, symmetric about $\pi$.
  - **These structures are evidence of conical emission of hadrons correlated with high $p_T$ particles.**
  - **The conical emission angle is measured to be independent of the associated particle $p_T$. ---- anything to extrapolate?**

# The “cone” legend is not over yet

- Even if we confirm the shape is “cone-like”, the physical source is not fully understood yet.
- *It’s already argued that the away-side “cone” can be due to artifact of analysis method such as ZYAM, or we shall see it elsewhere ---- instead of specific centrality/$p_T$ bins.*
- New analysis has been done to understand whether this “cone” is not directly from jet or its energy loss, but rather due to jet correlation with flow (reaction-plane).
- These issues will be further discussed in the following talks from Michael McCumber (correlation w.r.t. reaction-plane) and Andrew Adare (ZYAM and v2).

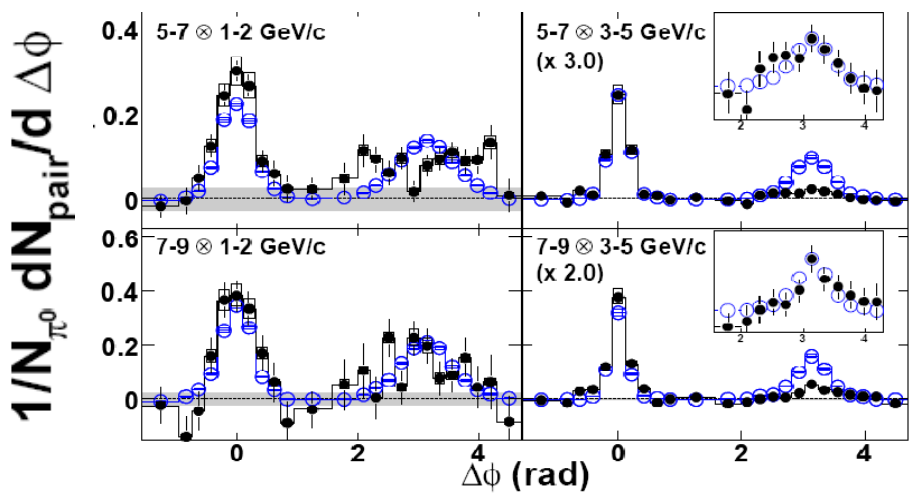
# Now let's move to higher $p_T$

- We know with high-$p_T$ triggers, the away-side peak re-appear even if in central Au+Au.

- *And it's argued that the "cone" we saw at intermediate-pT can be "artifact".*

- But does this re-appearance mean everything is back to as in p+p?
  - **The per-trigger yields has changed (even if shapes scale).**
  - **We connect this fact to the suppression of single high-pT spectra**.

arXiv: 1002.1077



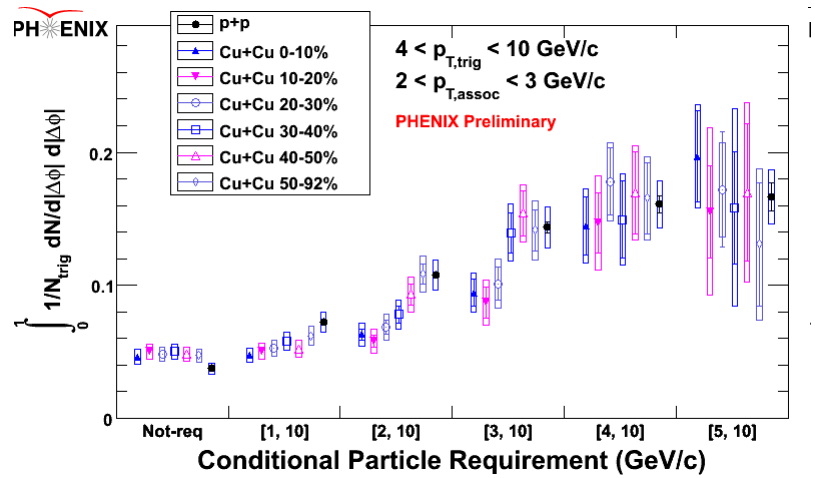
# Introduction of “2+1” correlation

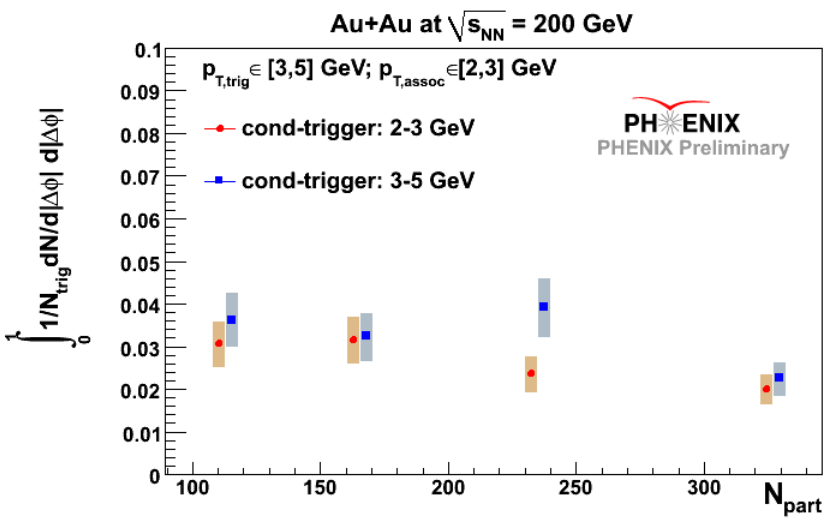
- If we already observe high and low-$p_T$ associates each forming a peak on the away-side of a high-pT trigger, do they form the same peak in the same event?

- Both PHENIX and STAR reported their “2+1” work on QM08, using a second high-$p_T$ (“conditional”) particle in addition to the first high-$p_T$ trigger particles to tag events, then plot the low-$p_T$ associates around the pair of high-$p_T$ particles.

# First result of “2+1” correlation

- Cu+Cu and Au+Au at sqrt(s_NN) = 200 GeV
- Patterns of moving toward higher $Q^2$ even before background subtraction



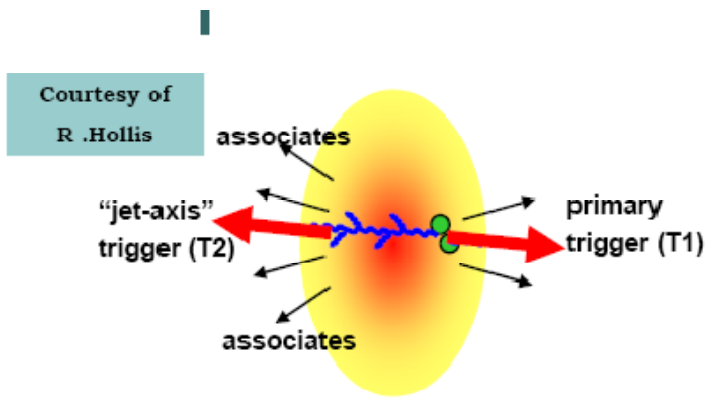



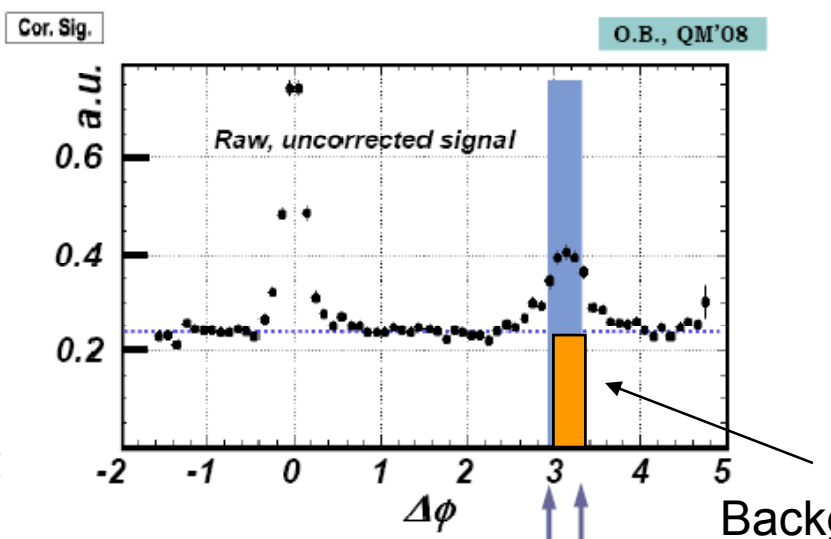

PHENIX QM08 and DNP09 result.

The 2nd high-pT is selected on the whole back-side hemisphere of 1st trigger.

# More specific “2+1” correlation

- The away-side high-pT may not physically correlated with the 1st high-pT trigger, but due to random combinations.
- Thus it’s natural to confine the 2nd trigger to be the back-to-back side of 1st trigger where the S/N is best.




T1: $p_T$>5GeV/c
T2: $p_T$>4GeV/c

$\pi \pm 0.2$

Background estimated by 2-p correlation

- Use di-jets to study jet-mediur effects
  - “pin” the jet axis selecting back-to-back triggers

# Direct view of "2+1" correlation

Kinematic constraints:

T1: 5 GeV/$c$ < $p_T$ < 10 GeV/$c$

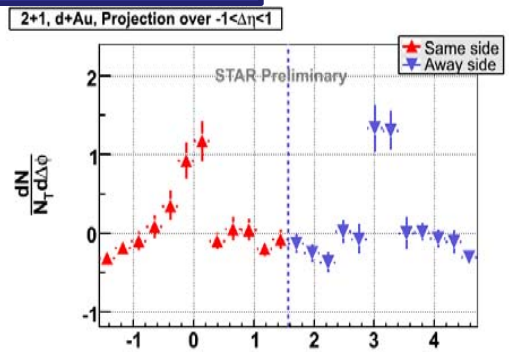
T2: 4 GeV/$c$ < $p_T$ < $p_T^{T1}$

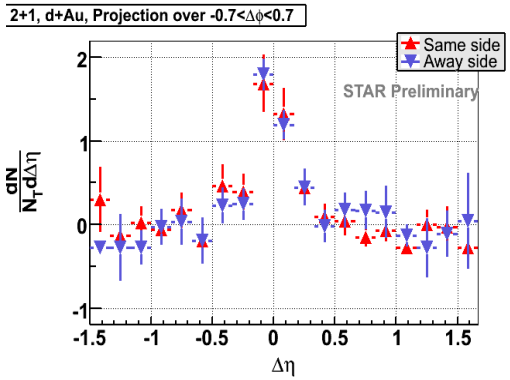
A1: 1.5 GeV/$c$ < $p_T$ < 4 GeV/$c$

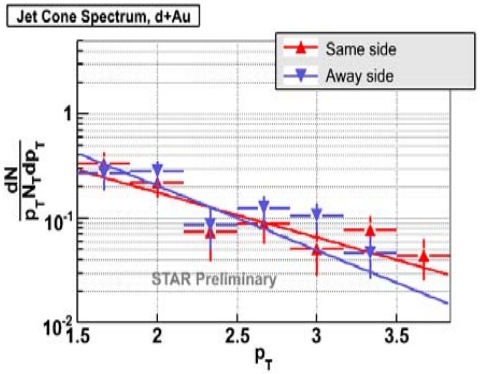
**Kolja Kauder**

**QM09**

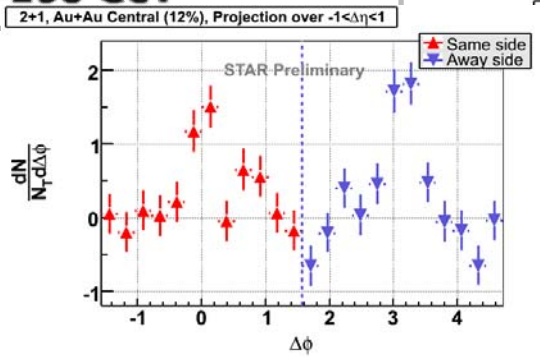
**d+Au**
**$\sqrt{S_{NN}}$=200 GeV**

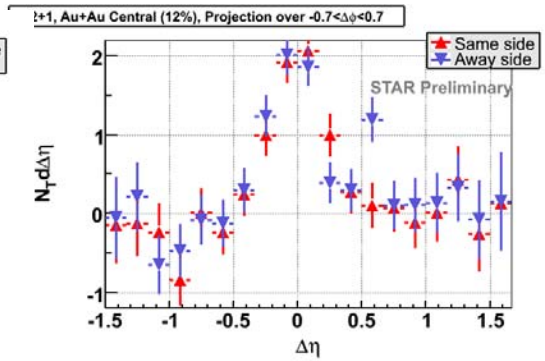


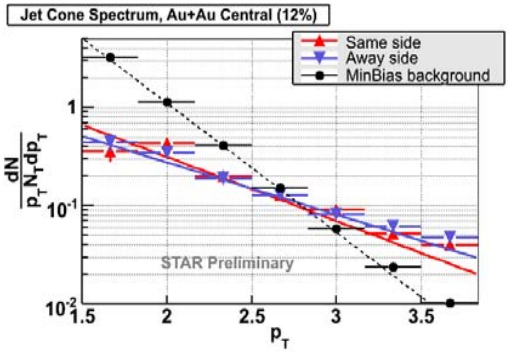




**Au+Au 12% Central**
**$\sqrt{S_{NN}}$=200 GeV**




- **Significantly harder than uncorrelated background**
- **No appreciable difference between same side and away side**

# Further PHENIX/STAR "2+1" correlation

- An obvious question is:
- if away-side is expected to lose energy due to path-length dependence, isn't there "man-made" surface-bias by selecting two similar high-$p_T$ triggers and/or forcing them back-to-back?

- We can change the conditions to check, by doing:

- Selecting two trigger with "asymmetric high-pT", and compare the near/away-side: No evident change. (see next slide).

# "2+1" correlation from asymmetric triggers

**Hua Pei at DNP09**

T1
8 GeV < $E_T$ < 15 GeV

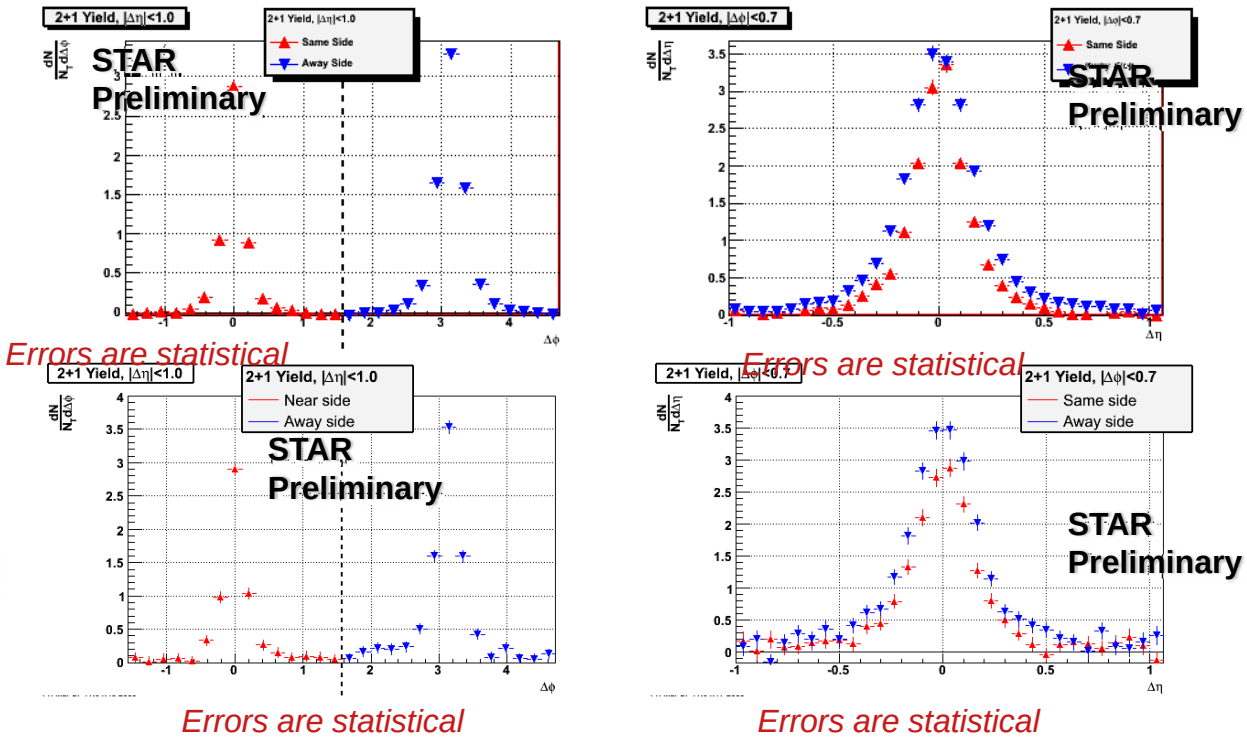
**d+Au**

T2
4 GeV/*c* < $p_T$ < 10 GeV/c

**Vs.**

Assoc
1.5 GeV/c < $p_T$ < 10GeV/c

**Au+Au**




**Projection at Δφ (radian) and Δη plane**

**Even with very asymmetric trigger pairs:**

**The correlations functions are still comparable between near/away-side, and stay close from d+Au to central Au+Au collisions**

# Further PHENIX/STAR "2+1" correlation

- An obvious question is:
- if away-side is expected to lose energy due to path-length dependence, isn't there "man-made" surface-bias by selecting two similar high-$p_T$ triggers and/or forcing them back-to-back?

- We can change the conditions to check, by doing:

- Selecting two trigger with "asymmetric high-pT", and compare the near/away-side: No evident change. (see next slide).

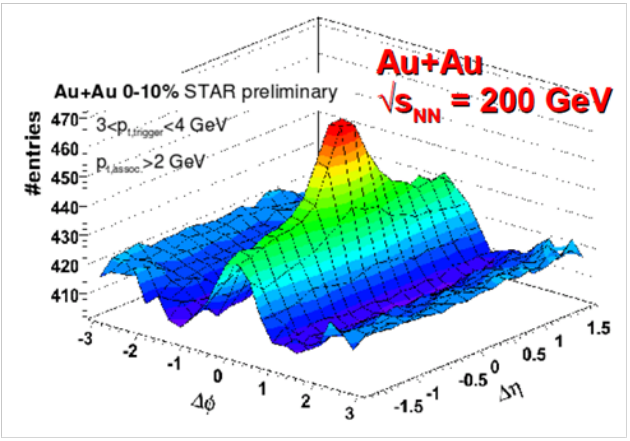
- Selecting the 2nd trigger at a specific azimuthal direction relative to 1st trigger, say 90 degrees or 135 degrees. By doing this we select possibly those "deflected" jets. Doe this "no-change" conclusion still stand?
  - Possible output: associates still follows Trigger 2 (away-side jets survive), with risk of relatively more random T1T2 at region away from $|\phi_T1 - \phi_T2| \sim \pi$.

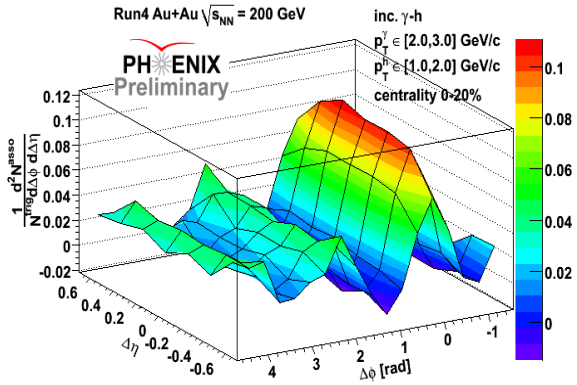
- Lowering the pT cuts: will we include too many thermal particles? ($q_n$ scaling of flow stands until $p_T$ ~2GeV)

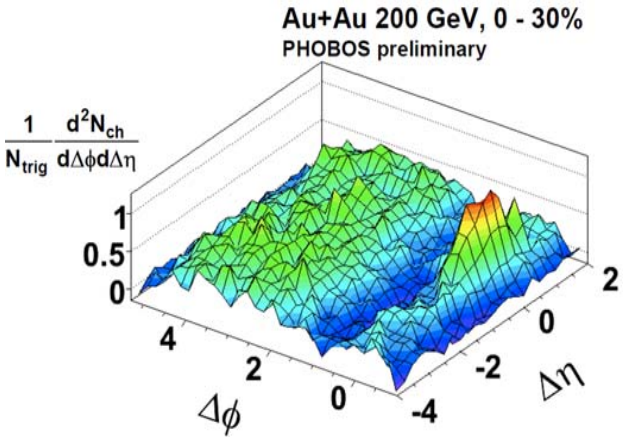
# Now we turn to the near-side

- Ridge is reported by RHIC everywhere

Central Au+Au



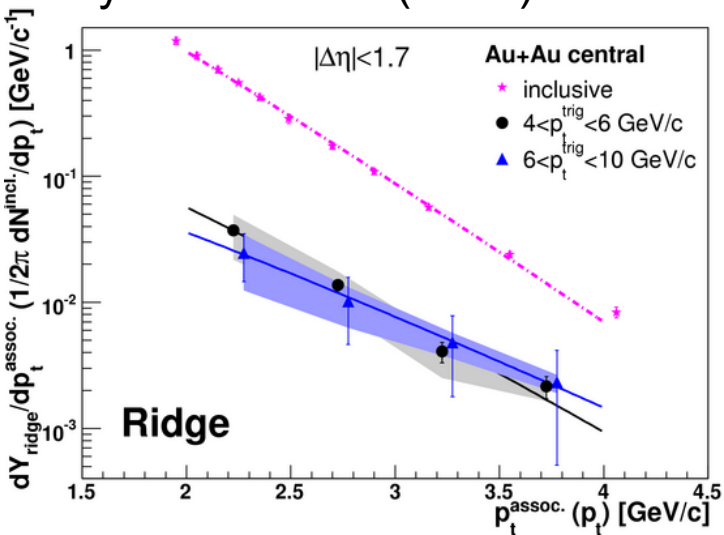




- The ridge pT spectra is similar to that of inclusive spectra and independent of trigger pT. Is this indication of ridge source?

- A 3-particle correlation shall help.

Phys. Rev. C **80** (2009) 64912



# STAR long-range pseudo-rapidity correlation

*Pawan Kumar Netrakanti*

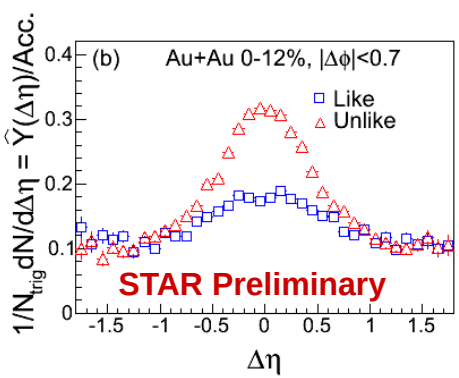
$3<p_T^{trig}<10$ GeV/c  $1<p_T^{assoc}<3$ GeV/c  $|\Delta\phi|<0.7$

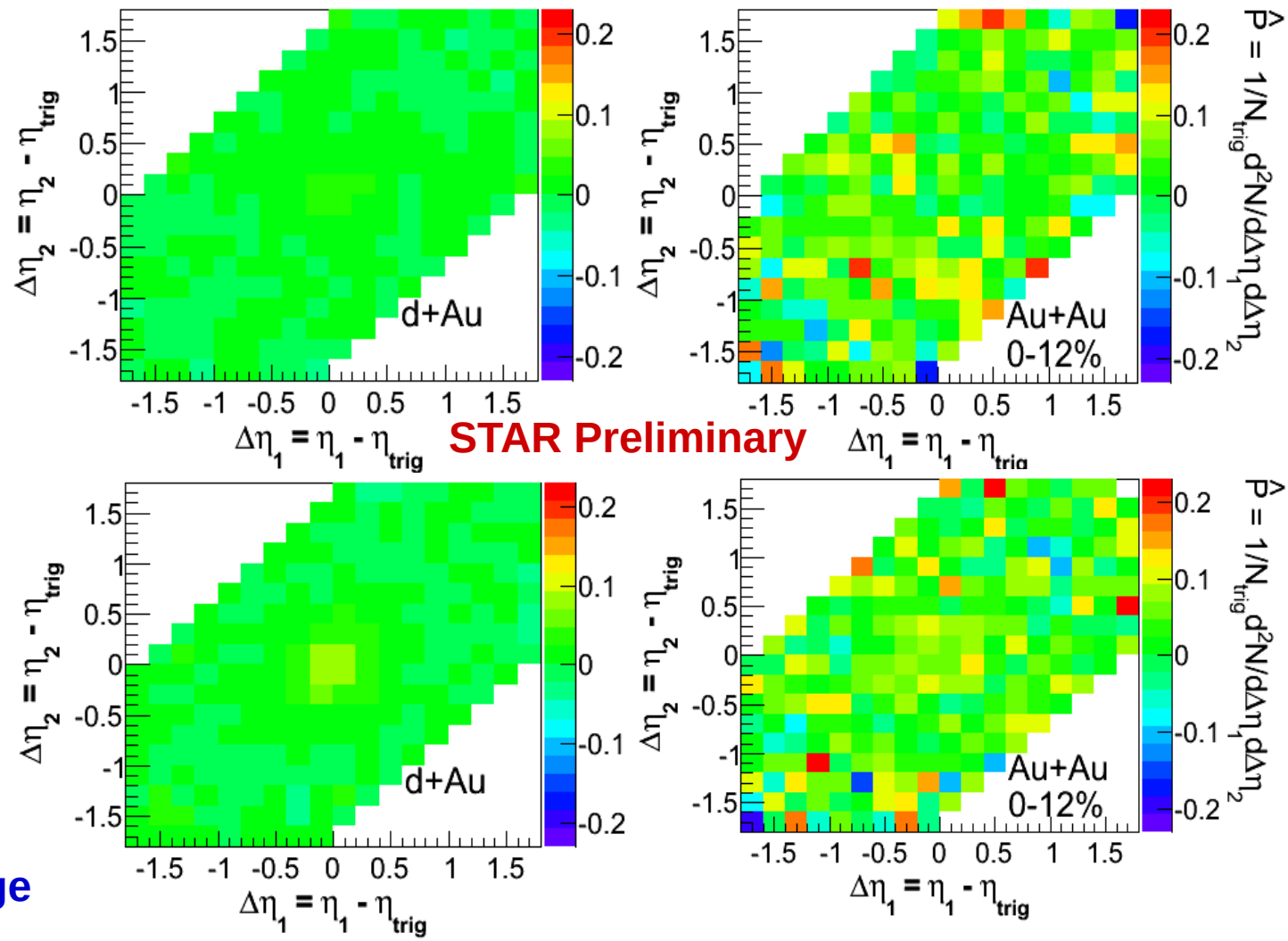
*CGC workshop*

Same-sign triplets

**($A^{\pm}A^{\pm}T^{\pm}$)**

**Ridge : 4* $A^{\pm}A^{\pm}T^{\pm}$**




Same-sign associated pair and opposite sign trigger particle **($A^{\pm}A^{\pm}T^{\mp}$)**

**Jet-like: Total - Ridge**

Like-sign triplets : Dominated by ridge

# $\Delta\eta-\Delta\eta$ pair densities: ridge, jet-like, and the cross-item

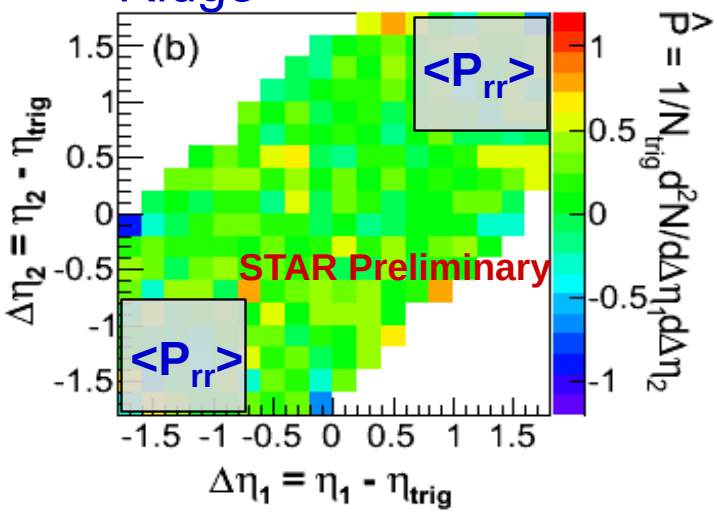
*Pawan Kumar Netrakanti*

*CGC workshop*

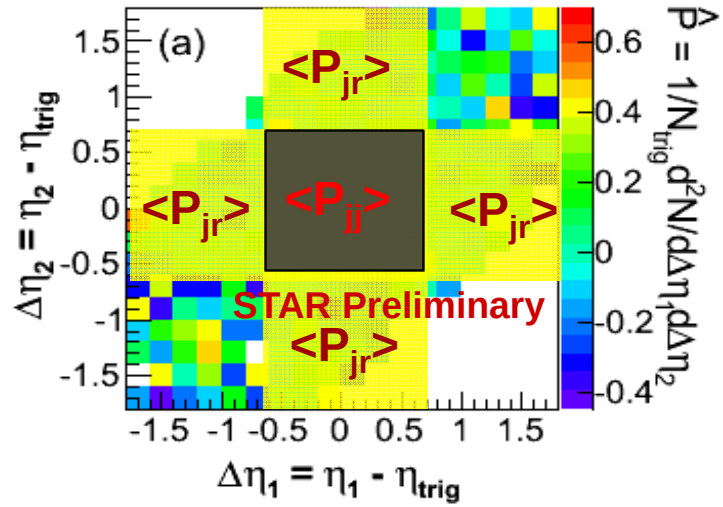
Au+Au 0-12%

$3<p_T^{trig}<10$ GeV/c
$1<p_T^{assoc}<3$ GeV/c
$|\Delta\phi|<0.7$

Ridge




Jet-like




$\langle P_{rr}\rangle$ : **0.114 ± 0.039**

$\langle P_{jj}\rangle$ : **0.077 ± 0.026**

Jet-ridge cross pairs
$\langle P_{jr}\rangle$ : **-0.004 ± 0.025**

Ridge production appears to be uncorrelated with the presence of jet.

# STAR long-range pseudo-rapidity correlation

(Quote from STAR $\Delta\eta-\Delta\eta$ correlation paper: arXiv 0912.3977):

- Except for the correlations at $\Delta\phi\sim0$, the particles from the ridge appear to be uncorrelated in not only with the trigger particle, but also between themselves.
- They are uniform in our measured $\Delta\eta$ range event-by-event. No correlation is found between production of the ridge and production of the jet-like particles
- This fact suggests the ridge may be formed from the bulk medium itself.

# Summary

- 3-p correlation of $\Delta\phi$–$\Delta\phi$ confirms the "cone-like" structure on the away-side.
  - Further work: why we see it at inter-mediate $p_T$, and why cone angle is independent of pT. Sound speed?

- "2+1" correlation shows that not only the back-to-back peak re-appears at high-$p_T$, but also a "unchanged" CF when high-$p_T$ pairs are back-to-back.
  - Further work: if high-pT pairs are at other angles, will CF still comparable 1) near vs away-side 2) p+p vs. central Au+Au? Random combinatorics will be chanllenging.
  - We need to plot the $\Delta\phi$–$\Delta\eta$ of associated particles to both hadrons simultaneously, since the pair of hadrons are not necessarily back-to-back anymore.

- Long-range $\Delta\eta$–$\Delta\eta$ correlation at near side indicates the mechanism of "ridge" may be independent of jets.

# Outlook in the (near) future

- The near/away-side is often considered to be different because their different average path-length <L>.
- This implies an assumption: “ridge” and “cone” are both created through energy-loss.
- *If this is true* (Thorsten’s words on CATHIE workshop):
  - Either ridge and cone are the same phenomenon, i.e. the ridge is a cone which had too little time to develop (the bow shock). In this case, varying <L> should turn the ridge into the cone.
  - Or ridge and cone are separate phenomena. In this case, the ridge is hidden on the away side by the fact that the rapidity position of the away side parton is not known. In addition, there must be a minimum length <L> for the cone to develop, because it is not seen on the near side.
- Either way, the associated particle distribution in those multi-hadron tagged events, high or low $p_T$, shall allows us to control <L> on near and away side. *Multi-particle correlation are “helpful” and “necessary”.*