UIC UNIVERSITY OF ILLINOIS AT CHICAGO

Experimental status and new results on 2- and 3- particle correlations

Olga Barannikova

Outline

- Jet quenching in heavy ion collisions
  - The beginning of the Era
- 2-particle correlations:

  the Jet, the Ridge, and the Humps
  - Systematic studies in momentum space
  - System-size & path-length effects
- 3-particle-correlations
  - $\Delta\phi$-$\Delta\phi$, $\Delta\eta$-$\Delta\eta$, di-jets
- Outlook

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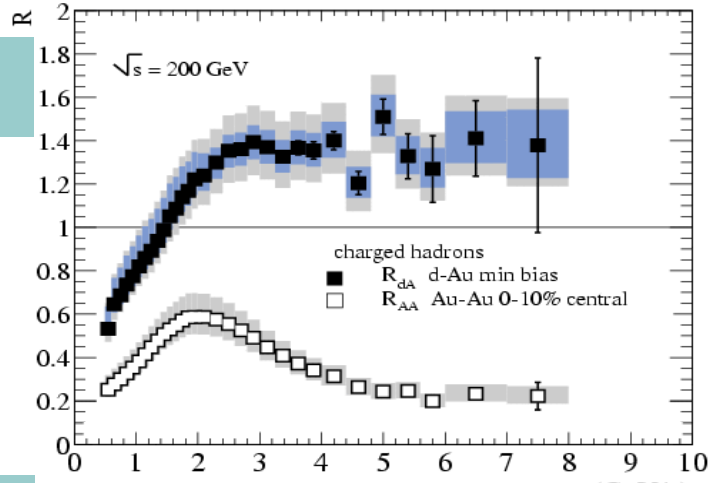
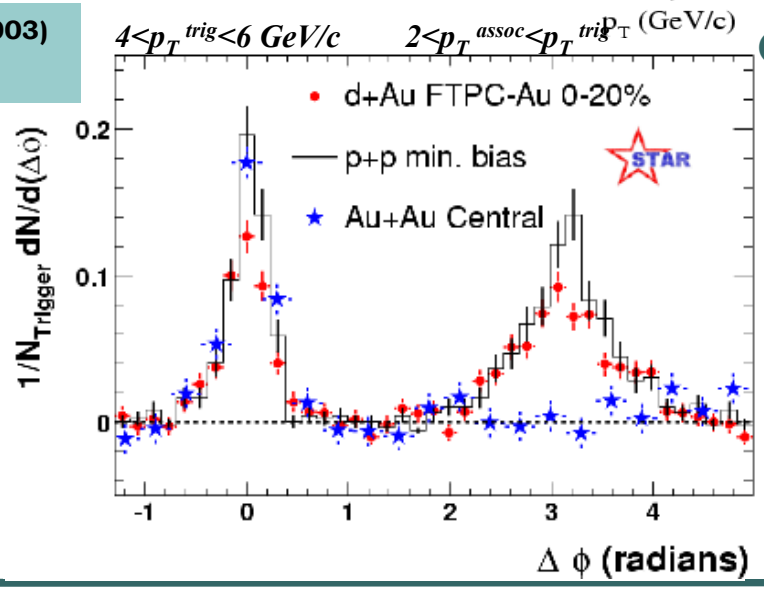
Jet quenching – first glimpse

PRL 91 (2003) 072303



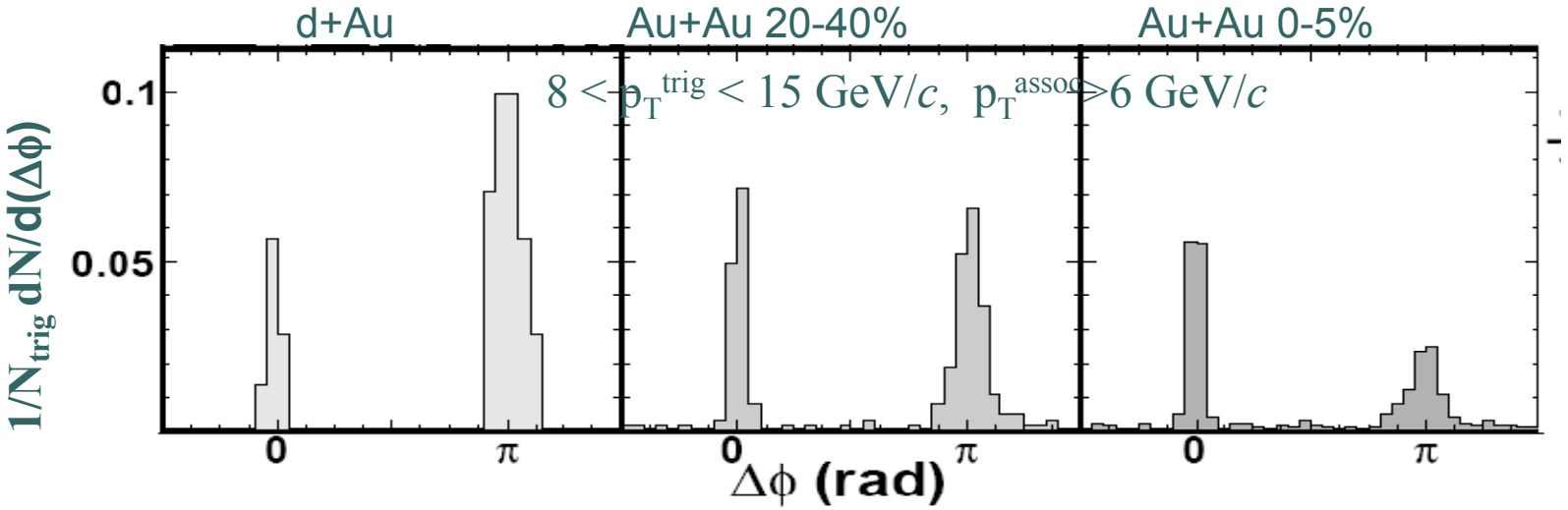
PRL 91 (2003) 072304



- High p_T hadron suppression:
  - Final state effect in Au+Au collisions
  - Observation extends to all accessible p_T range
- Signature two-particle correlation result:
  - Disappearance of the away side jet in central Au+Au collisions
  - Effect vanishes in peripheral/d+Au collisions

Are there jets?

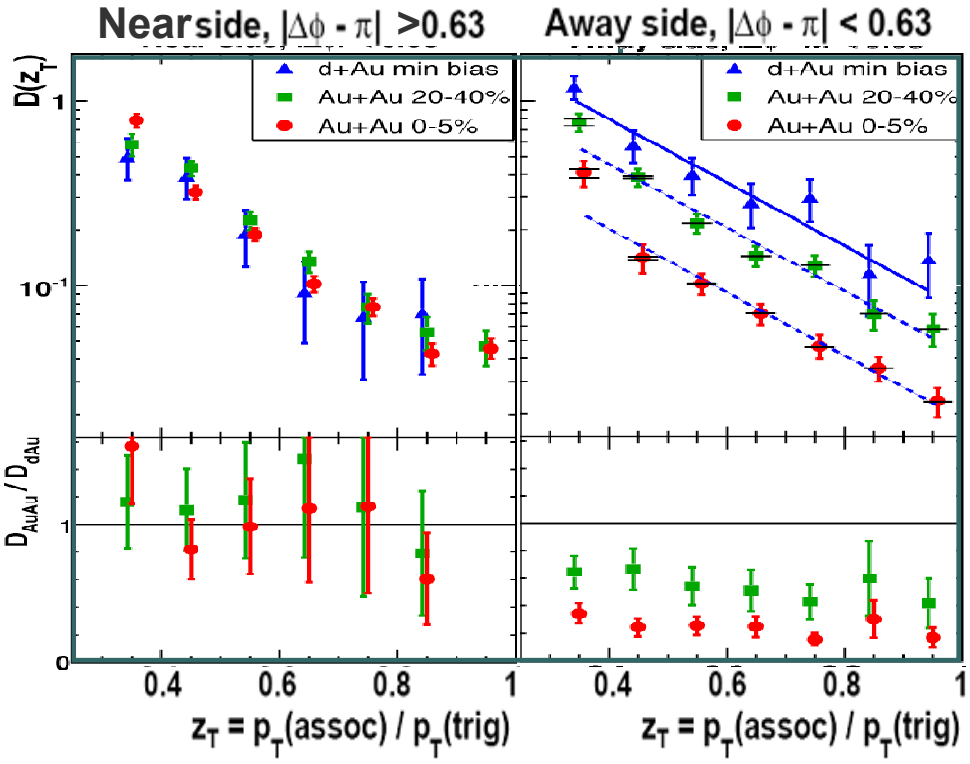
PRL 97 (2006) 162301



- Recovering the away side:
  - Away-side yield suppression
  - Little modification of the Near-side yields
  - No broadening on Near- or Away-sides

High-p_T – vacuum fragmentation?

PRL 97 (2006) 162301

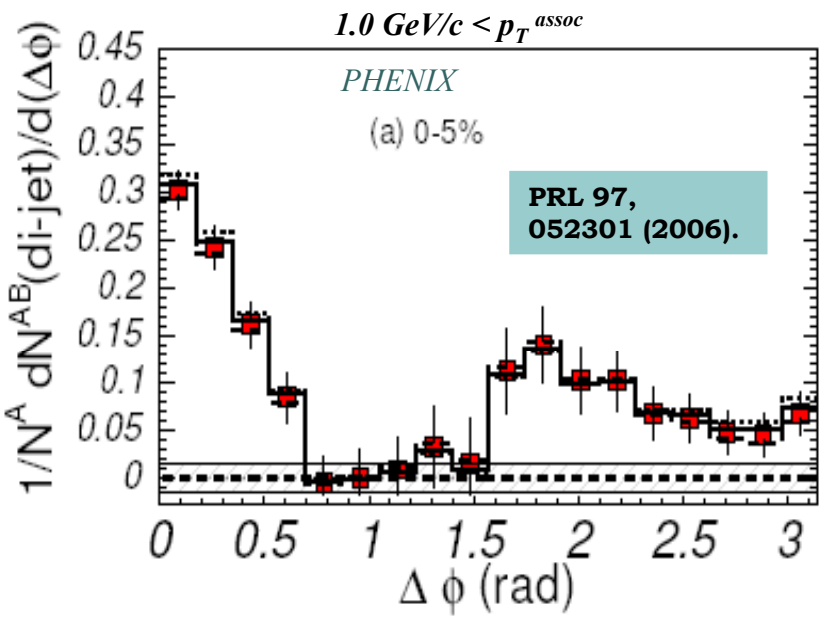


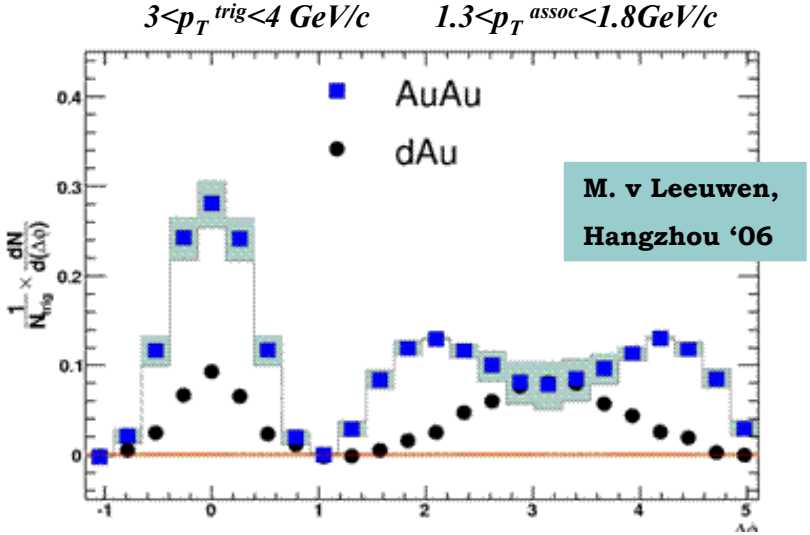
$$D^{h_1h_2}\left(z_T, p_T^{trig}\right) = p_T^{trig}\,\frac{d\sigma_{AA}^{h_1h_2}/dp_T^{trig}dp_T}{d\sigma_{AA}^{h_1}/dp_T^{trig}}$$

$$z_T \equiv \frac{p_T^{assoc}}{p_T^{trig}}$$

- Near-side:
  - No dependence on z_T in the measured range – no modification
- Away side:
  - Suppression ~ level of R_{AA}
  - No dependence on z_T in the measured range – no modification

Jet modifications: $p_T \downarrow$

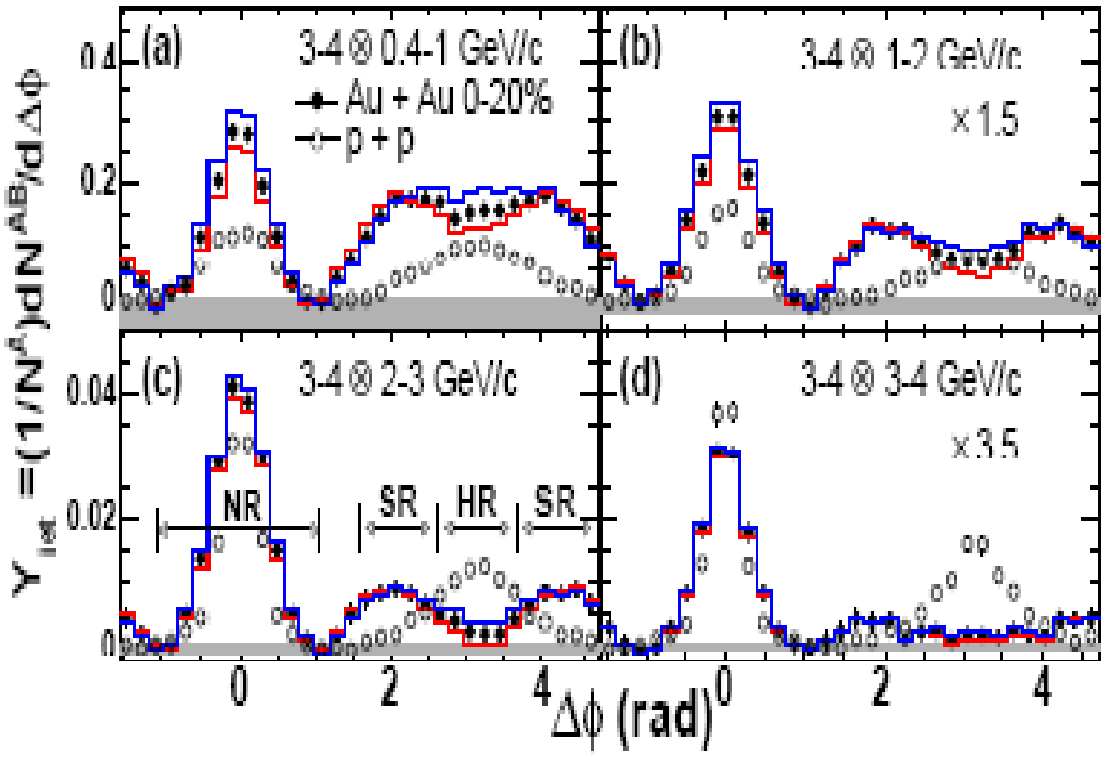




- One high-p_T, one low-p_T trigger
  - Reappearance of the away-side jet
  - Double-hump structure hints at additional physics phenomena

Away-side scan

PHENIX
PRC 78, 014901 (2008)



Associated p_T dependence:

- Recovering the away side
- Development of "double-humps" or "shoulders"

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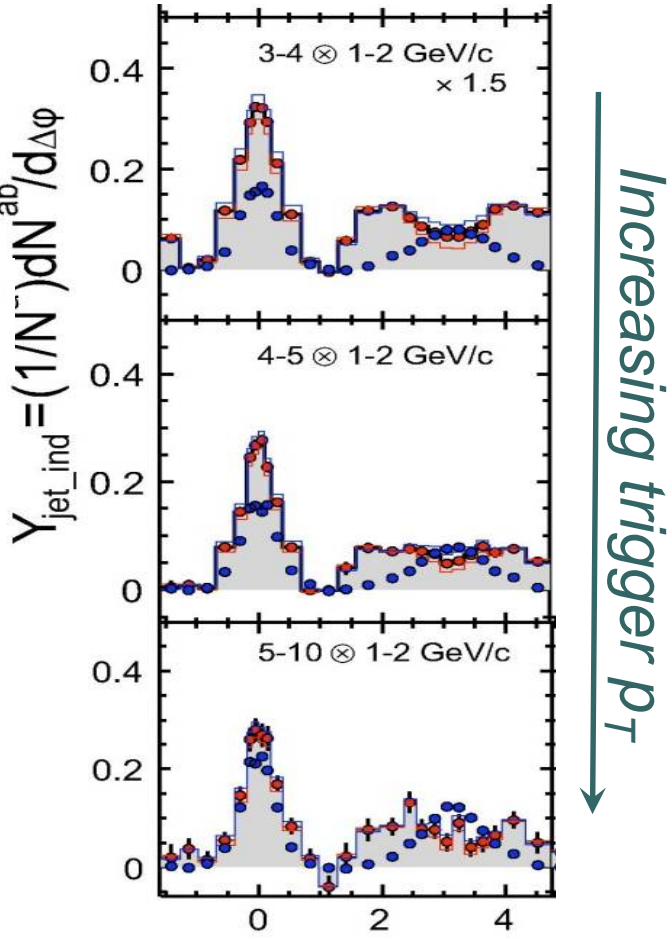
Trigger p_T dependence

PHENIX

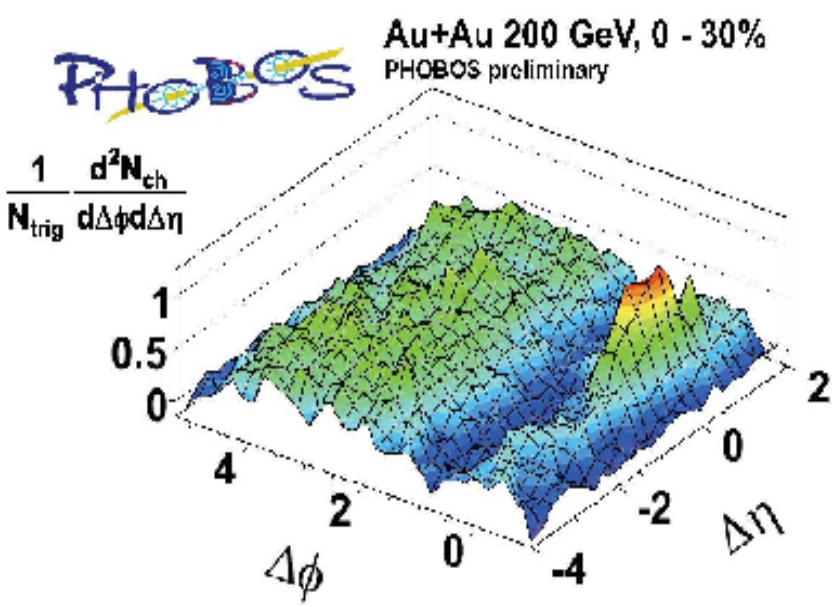
Phys. Rev. C 78, 014901 (2008)

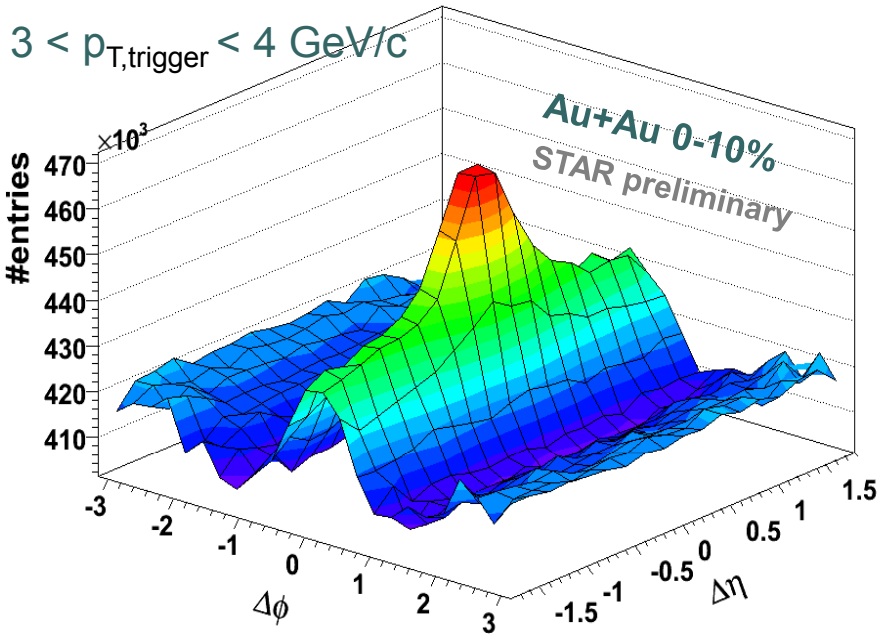
- Au+Au 0-20 %
- p+p



- Away-side
  - shape - stable
  - shoulders magnitude ↓
- Excess yield on the same-side

Intermediate p_T : the ridge



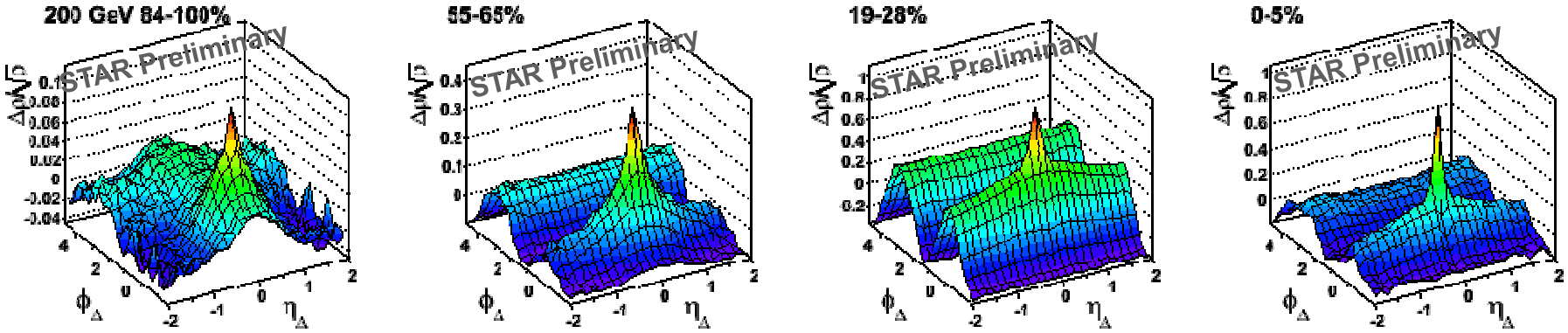


- Near-side correlation structure:
  - Central Au+Au: cone-like + ridge-like
  - Ridge extends to very high Δη

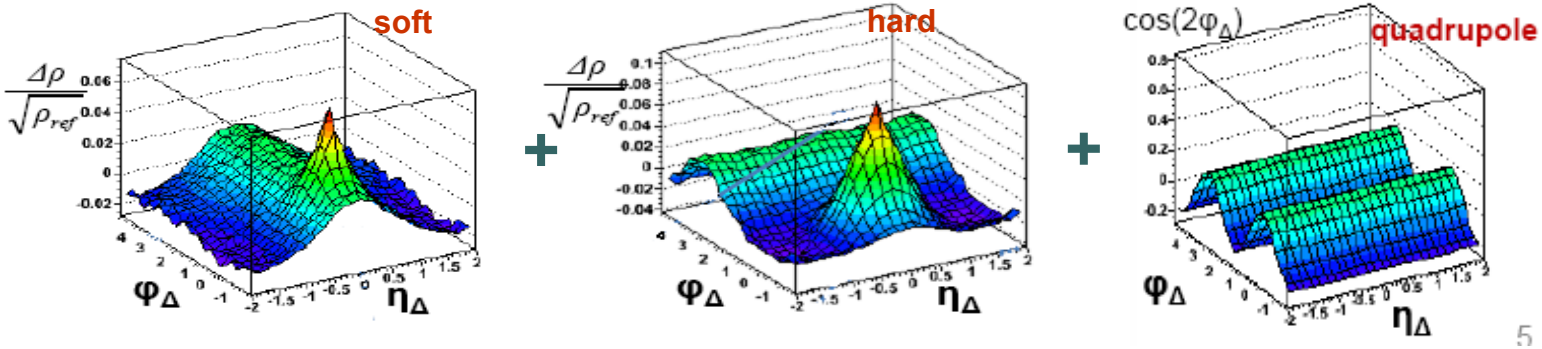
Angular pair correlations

M Daugherity, QM08

Au+Au 200 GeV



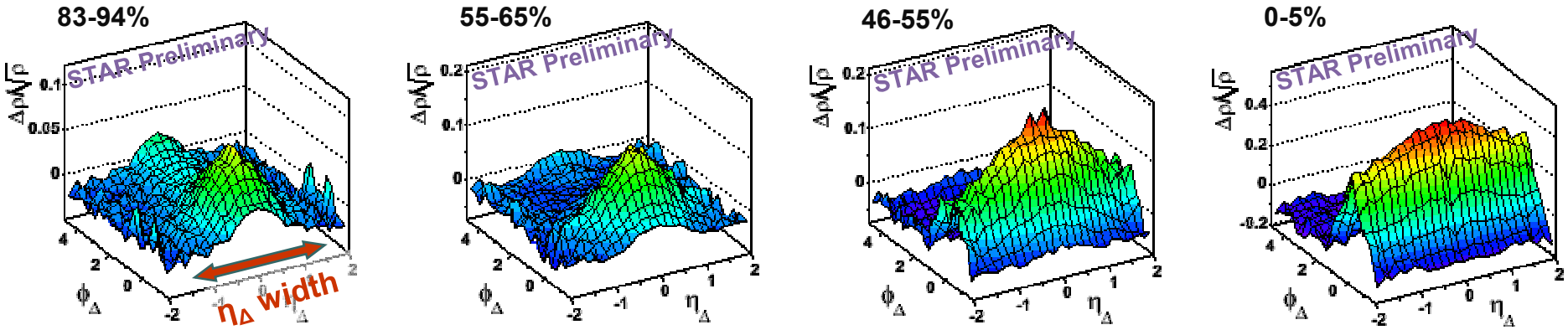
Fit function =

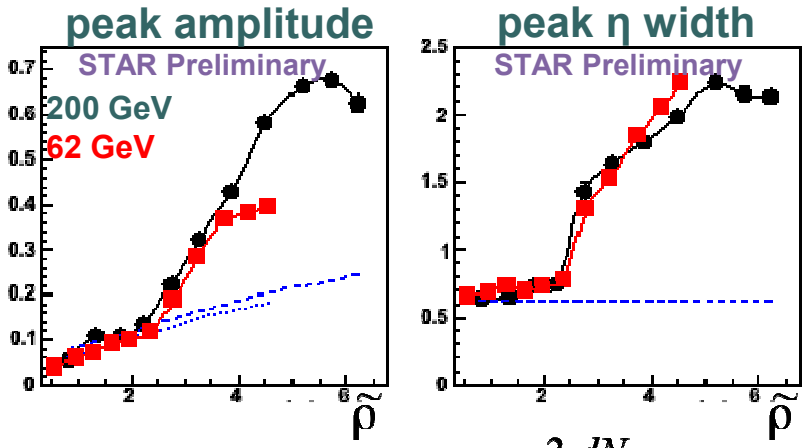


Low p_T ridge

M Daugherity, QM08

Same-side evolution





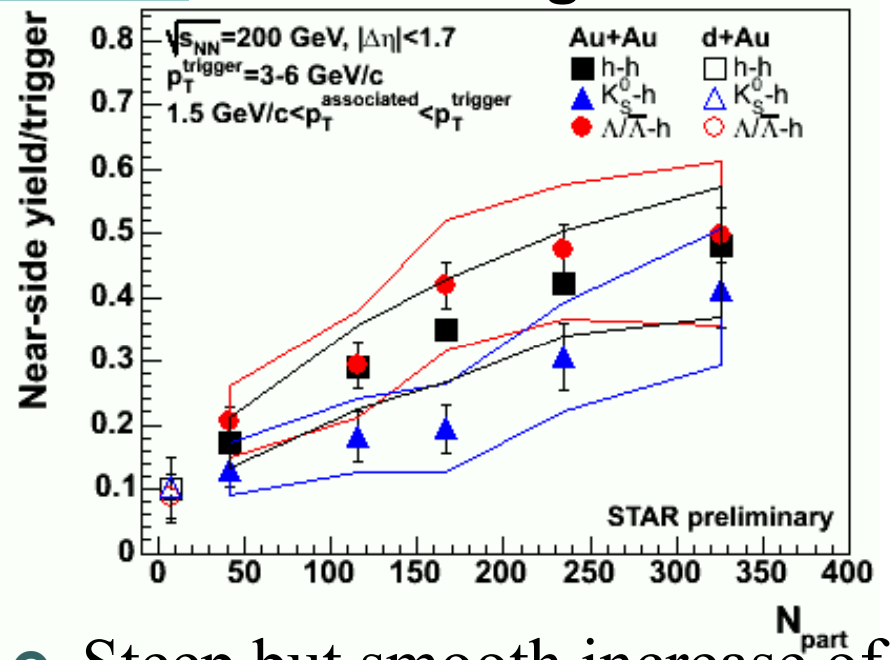
Transverse particle density $\frac{3}{2}\frac{dN_{ch}}{d\eta}/S$

- Sharp transition in both amplitude and width at $\rho \sim 2.5$
- Similar ρ-trends at 62 and 200GeV

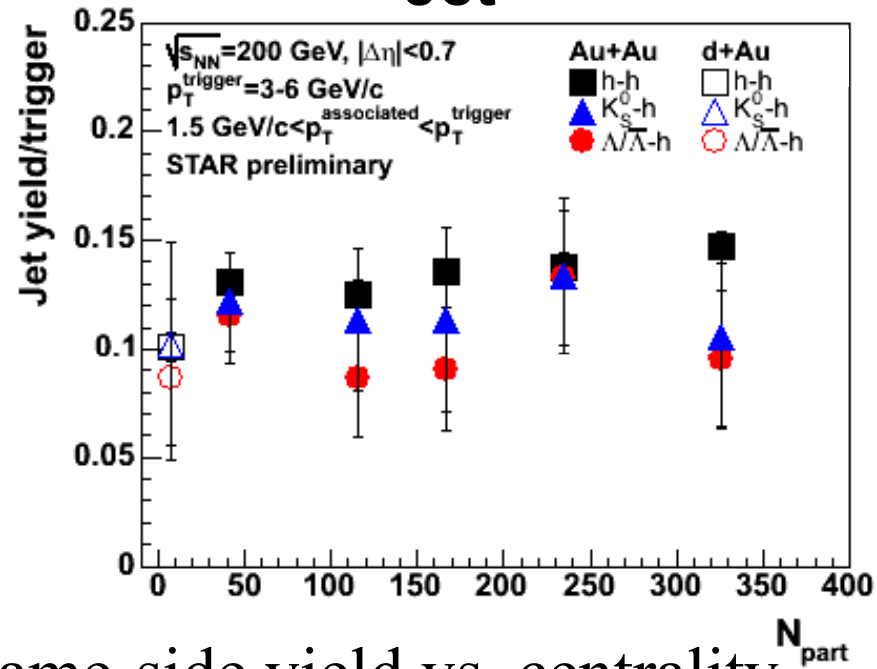
More on centrality dependence:

J Bielcikova WWND07

Jet + Ridge



Jet

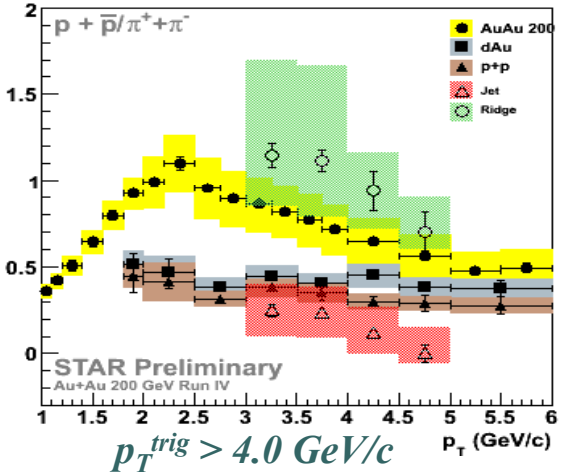


- Steep but smooth increase of same-side yield vs. centrality
- Associated yields ration of ~5 for Au+Au/d+Au
- No changes to "Jet" part

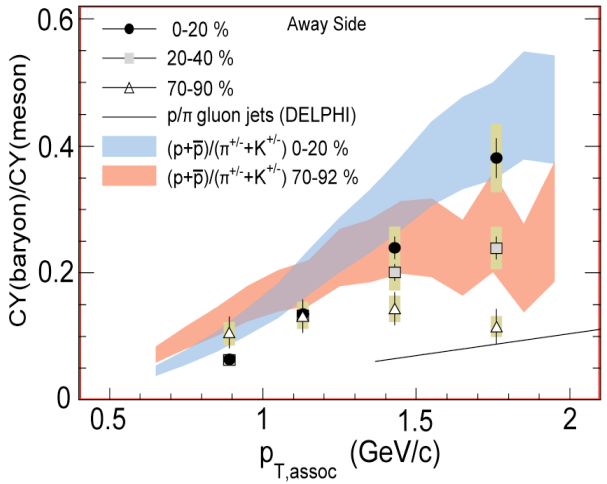
Ridge flavor

Production mechanisms

C Suarez, QM08

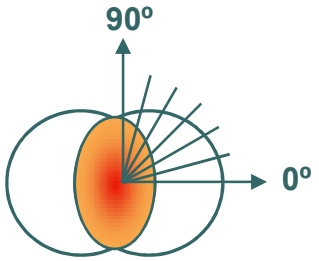


PHENIX, PRL101.082301



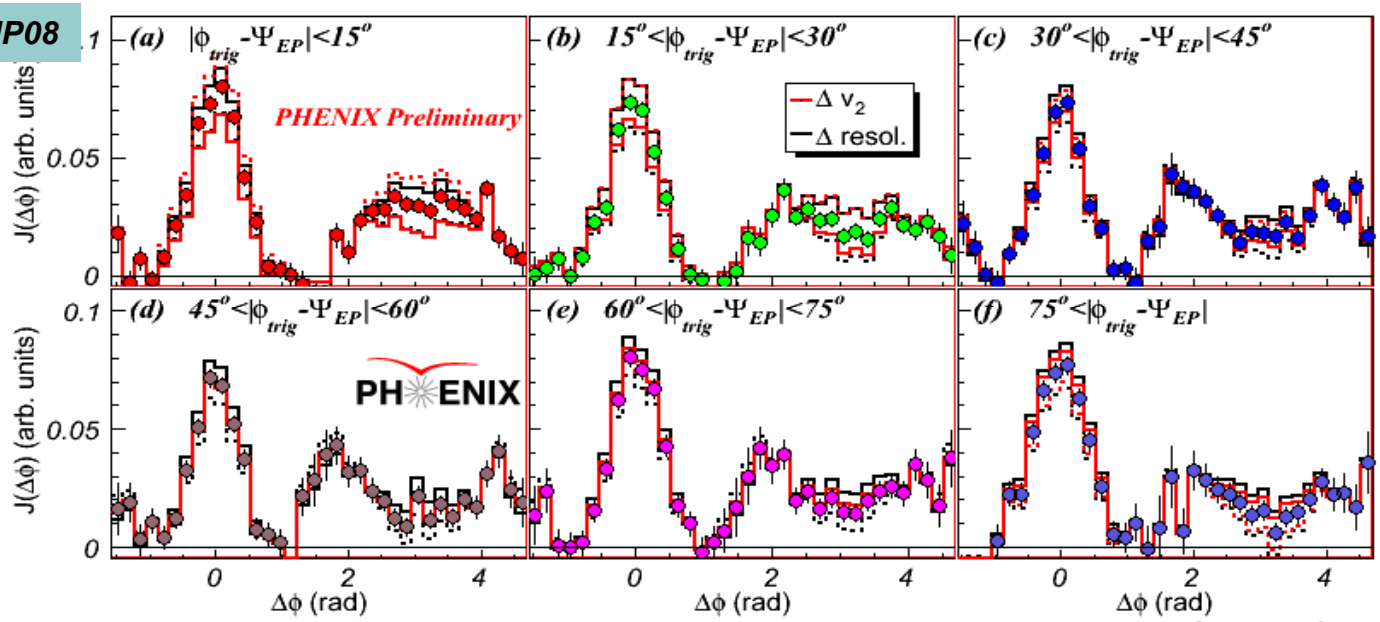
- Jet ~ pp,d+Au , Ridge ~ Bulk ~ Away
- Production mechanisms for jet and ridge are different

Path-length effects



In-Plane Au+Au $\sqrt{s_{NN}}$=200GeV, Cent=30-40%, $1<p_{T,assoc}<2$ GeV/c, $3<p_{T,trig}<4$ GeV/c

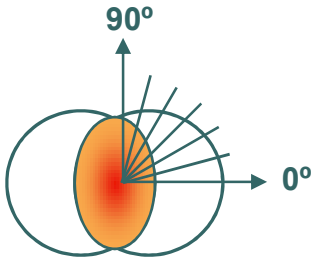
A Sickles, HP08



Out-of-Plane

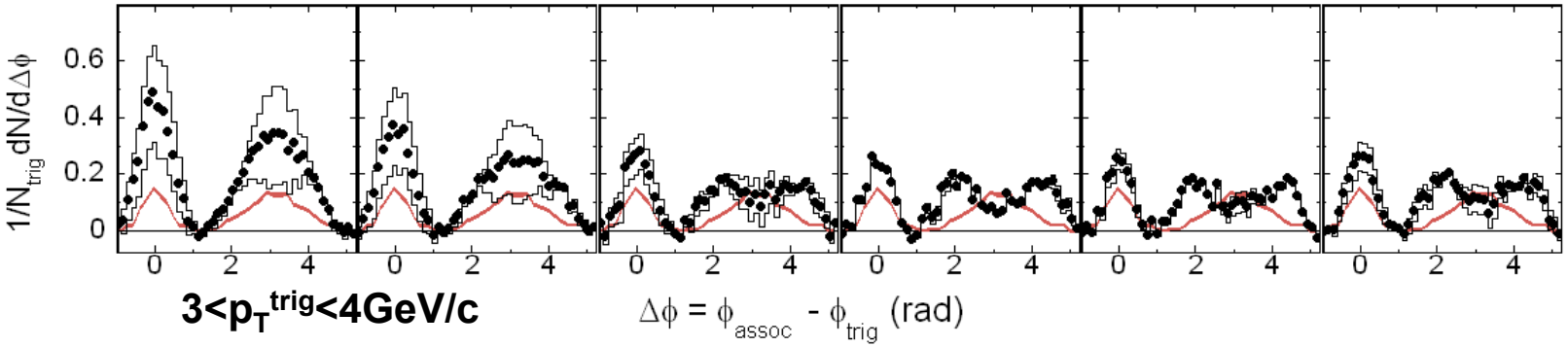
- Away-side: double-hump becomes more pronounced out-of-plane
- Same-side?

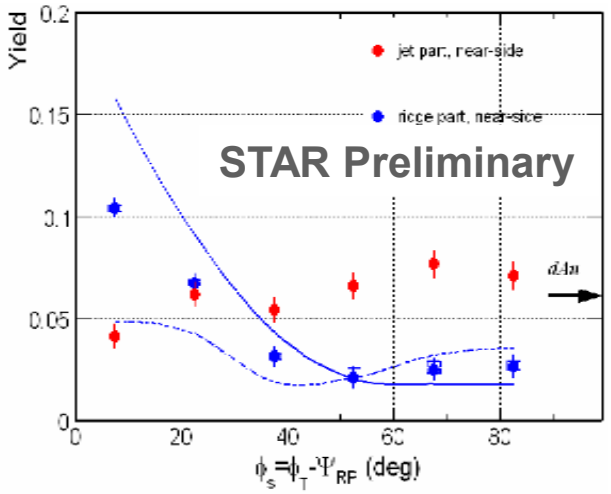
Path-length effects



A Feng, QM08

in-plane ϕ_S=0 ⟶ **out-of-plane ϕ_S=90º**



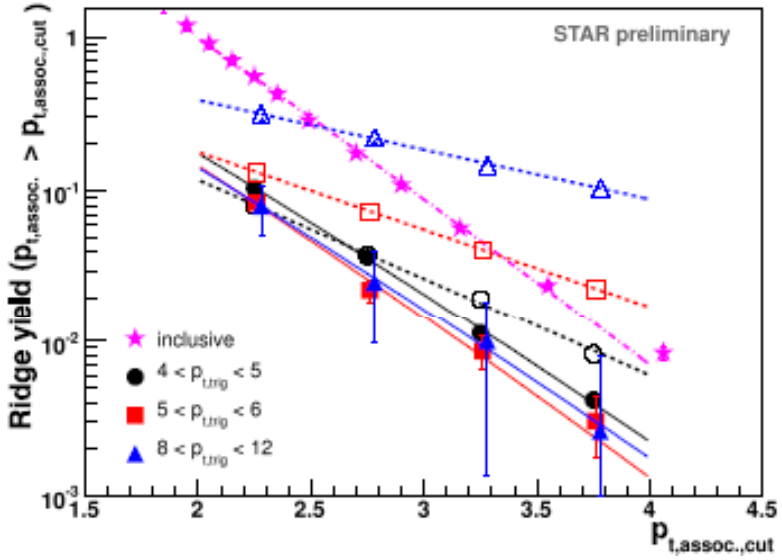


- Same-side yield
  - Jet: d+Au ~ Au+Au
- Ridge decreases from in-plane to out-of-plane

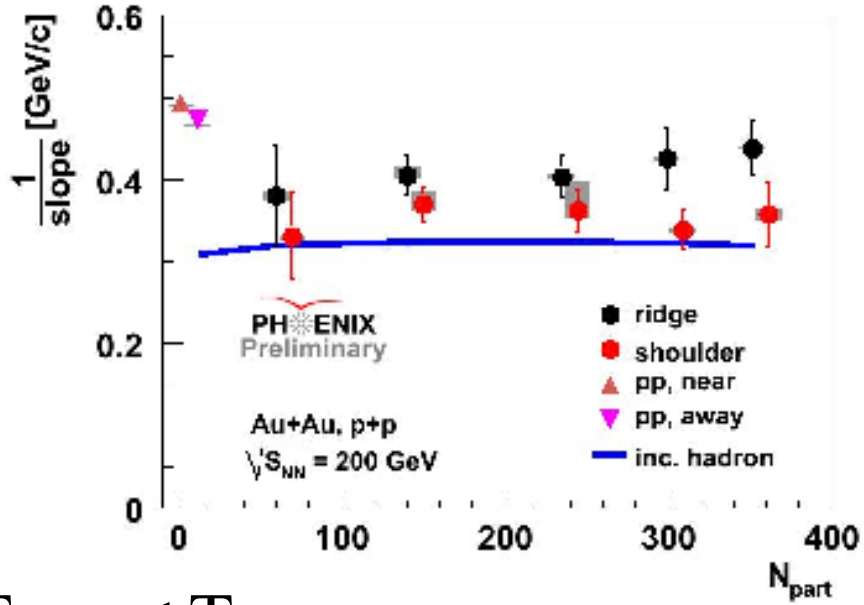
Elliptic flow effects?

Medium effects or medium?

J. Putschke, QM06



J. Chen, HP08



- Ridge: $T_{Ridge} \sim T_{Bulk} < T_{Jet}$
- Shoulder ~ Ridge
- Similar centrality dependence for S. and R.

Energy Loss in QCD Medium

Quantitative measures energy loss…

- Double-hump Away-side
  - Mach Cone

    Stoecker, Nucl. Phys. A750(2005)121
    Casalderrey-Solana, Shuryak, Teaney, J. Phys. 27(2005)22
    Ruppert, B. Muller, PLB 618 (2005)123
    Renk, Ruppert, PRC 76 (2007) 014908
  - Parton mult. scattering, recombination

    Chiu, Hwa, PRC 74(2006) 064909
  - Radial flow boost + jet quenching

    Armesto, Salgado, Wiedemann, PRL 93 (2004) 242301
  - Parton + longitudinal flow coupling
  - …

- Long-range Ridge on Same-side
  - Mach Cone

    Possible "splash back"
  - Parton mult. scattering, recombination

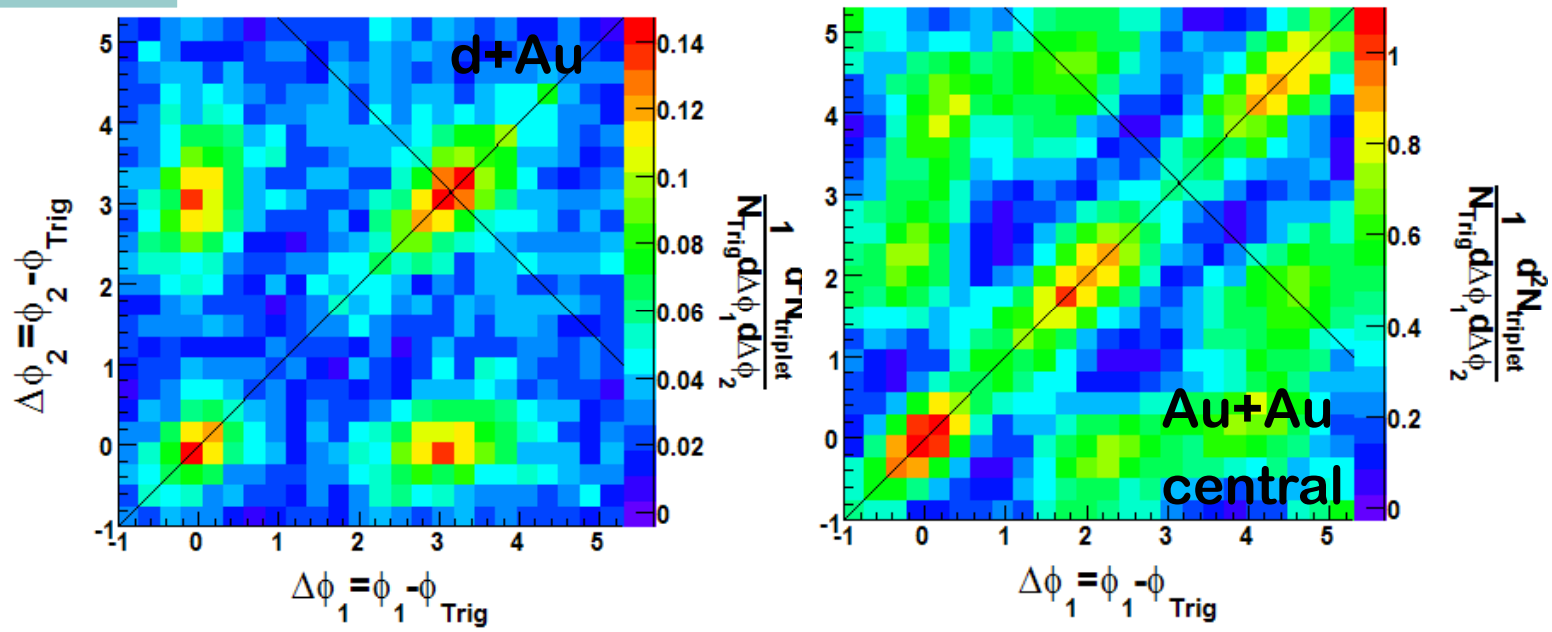
    Chiu, Hwa PRC72:034903,2005
  - Radial flow + jet-quenching

    S.A.Voloshin, Phys.Lett.B. 632(2006)490
    E.Shuryak, hep-ph:0706.3531
  - Parton + longitudinal flow coupling

    Armesto et.al PRL93(2004) 242301
  - …

Away side: $\Delta\phi$-$\Delta\phi$ correlation

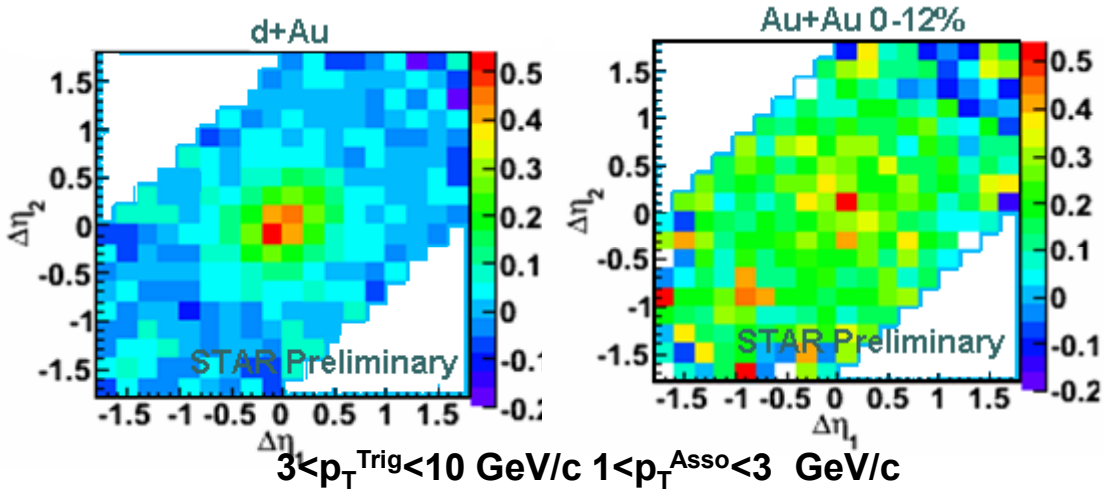
STAR, PRL102.052302



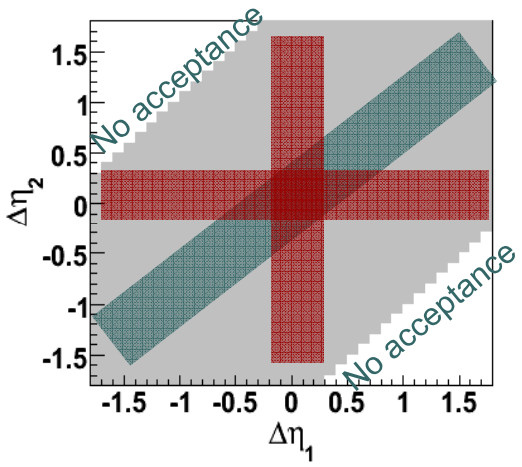
- Experimental observation of conical emission
  - θ_M = 1.37 ± 0.02 (stat.)± 0.06 (syst.)
  - Constrains the speed of sound $c_S \sim 0.2$

Near-side: $\Delta\eta$-$\Delta\eta$ correlations

P. Netrakanti
QM'08

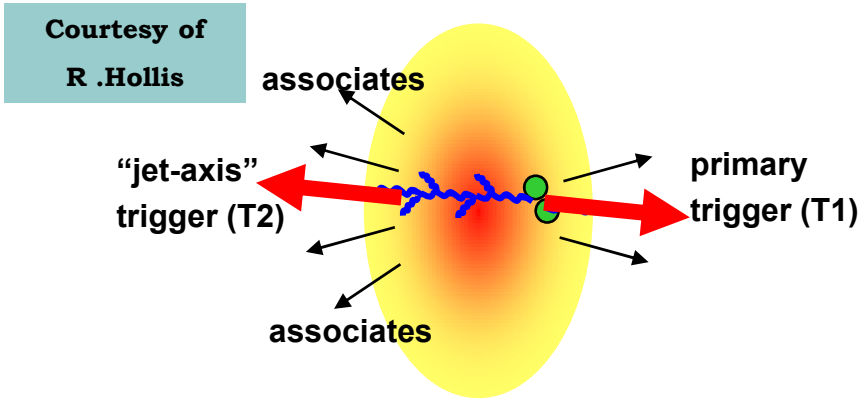


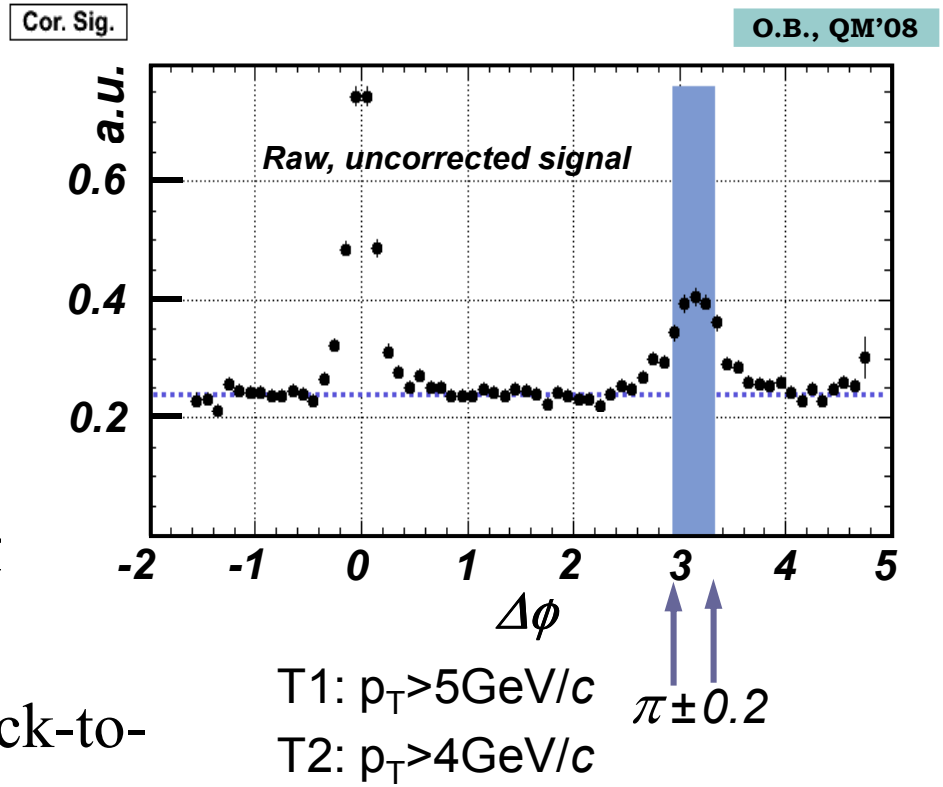
$3<p_T^{Trig}<10$ GeV/c $1<p_T^{Asso}<3$ GeV/c



- No apparent substructure – no gluon fragments/flow coupling?
- No cross-like term – ridge and cone decoupled?

2+1 Correlation Technique

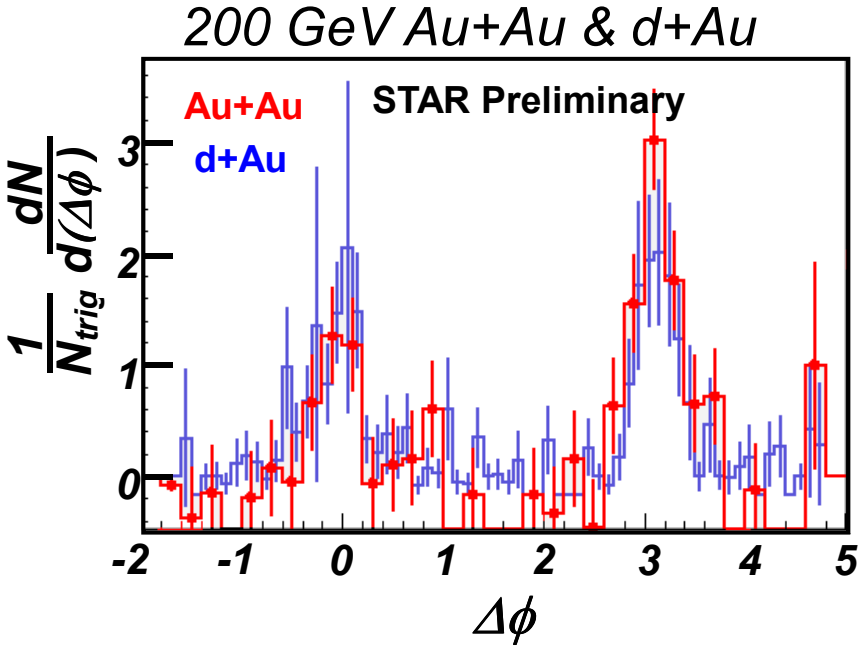


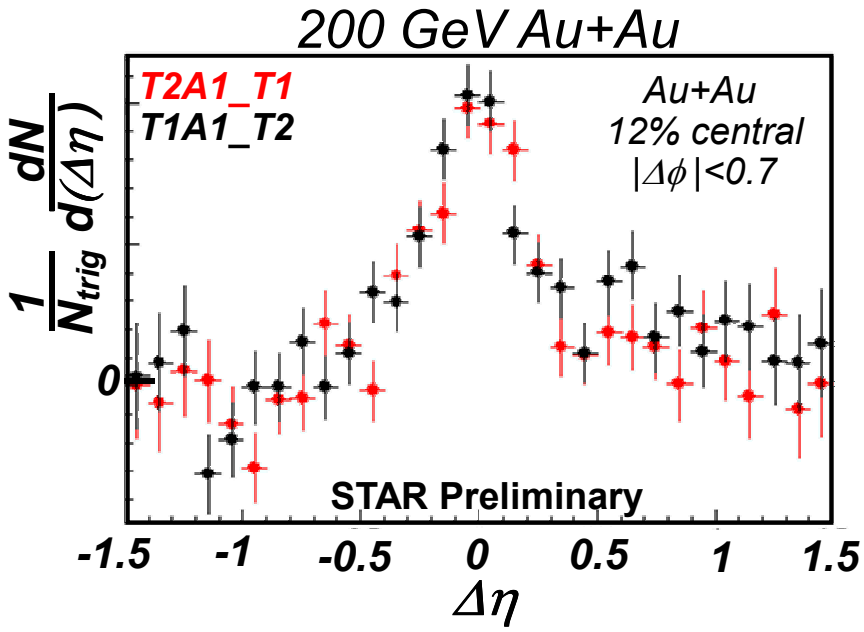


- Use di-jets to study jet-mediur effects
  - "pin" the jet axis selecting back-to-back triggers
  - study correlation w.r.t. this axis

Di-Jets in Au+Au Collisions

O.B., QM'08





- Central Au+Au ~ d+Au. No away-side suppression!
- Shapes of near- and away-sides are similar
  - $\Delta\phi$ projection: no significant shape/yield modifications
  - $\Delta\eta$ projection: no apparent ridge

Summary &Outlook:

- Medium-induced jet modifications
  → Jet induced medium modifications
  - Double-hump away side
  - Ridge
- Differential studies are afforded by multi-particle correlation techniques
  - 3particle $\Delta\phi$-$\Delta\phi$ → consistent with mach cone
  - 3 particle $\Delta\eta$-$\Delta\eta$ → no substructure in ridge
  - 2+1 correlations – unmodified di-jet observation