Quark Matter 2004

Oakland – January 11-17

Measurement of Jet Fragmentation at RHIC

Spectra of charged hadrons associated with a large p_T leading particle

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for the STAR Collaboration

– OUTLINE –

Physics motivation

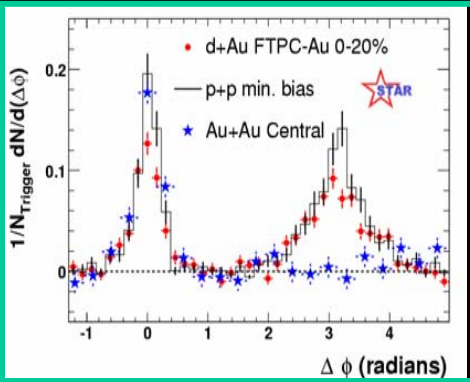
Analysis techniques

Preliminary results

Summary and open questions

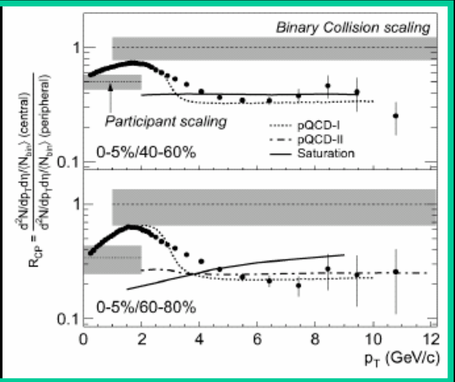
Physics motivations

The goal of RHIC is to create QGP – a thermalized partons state



RHIC AA + pp + dAu results:

Hard-scatterings are initially present;
Suppression phenomena in central Au+Au
are due to final-state interactions.
(consistent with jet quenching)



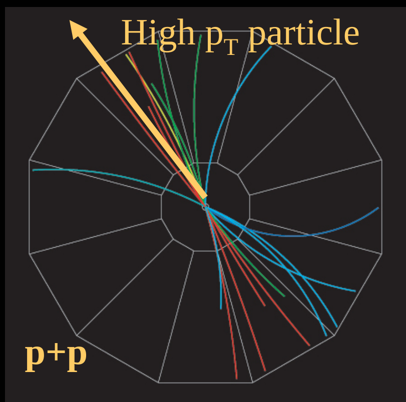
…through interactions with what medium?

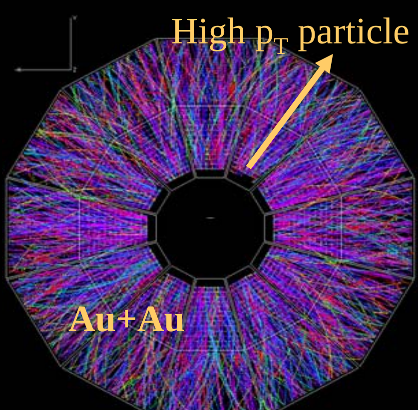
- Study how the energy is distributed.
- Investigate equilibration between the energy and the surrounding medium.
- Measure the amount of energy loss.

S. Pal, S. Pratt, PLB574 (2003) 21.
X.-N. Wang, PLB 579 (2004) 299, nucl-th/0307036.
C.A. Salgado, U.A. Wiedemann, hep-ph/0310079.
M. Gyulassy, I. Vitev, X.-N. Wang, B.-W. Zhang, nucl-th/0302077.
……

…by reconstructing hadrons associated with a large p_T particle.

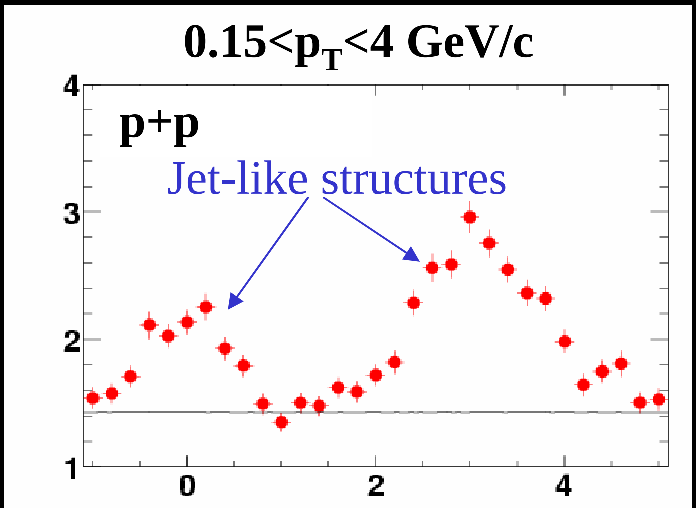
Reconstructing associated particles

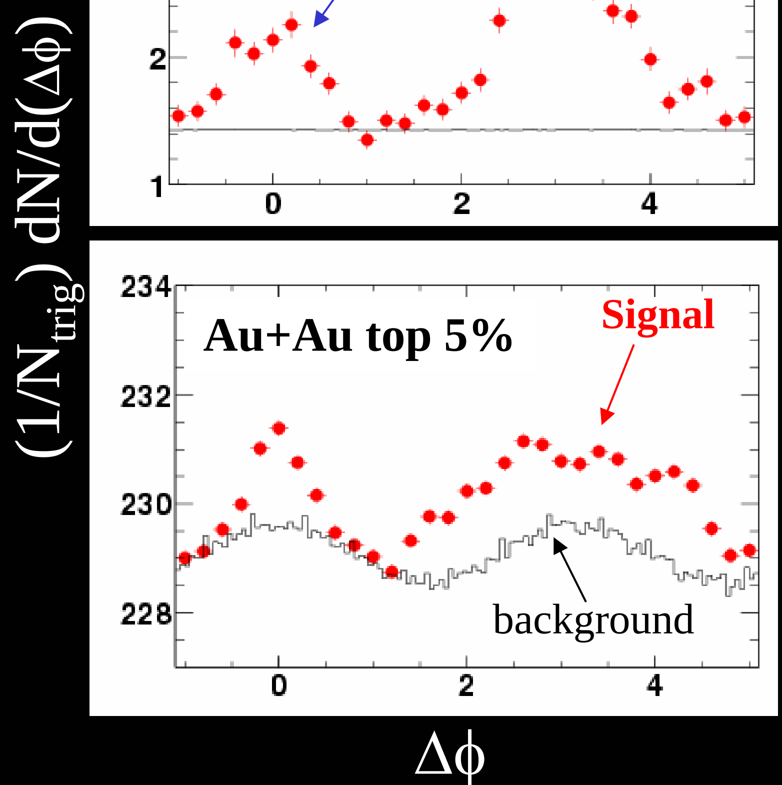




- Select a leading particle $4<p_T<6$ GeV/c, $|\eta|<0.75$.
- Associate all other particles ($0.15<p_T<4$ GeV/c, $|\eta|<1.1$) with the leading particle. Form $\Delta\phi$,$\Delta\eta$ correlation.
- Background from mix-events. v_2 modulation on background. Normalize in $0.9<|\Delta\phi|<1.3$.
- Efficiency corrections are applied to associated particles.
- Take difference and normalize per trigger.

STAR Preliminary





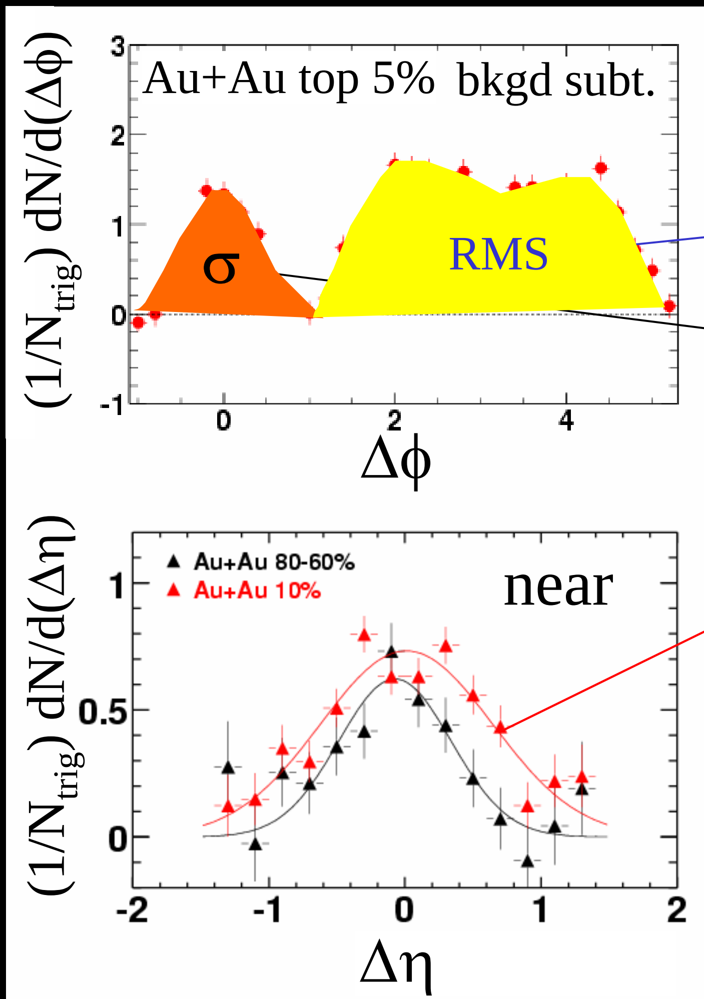
“Jet” sizes

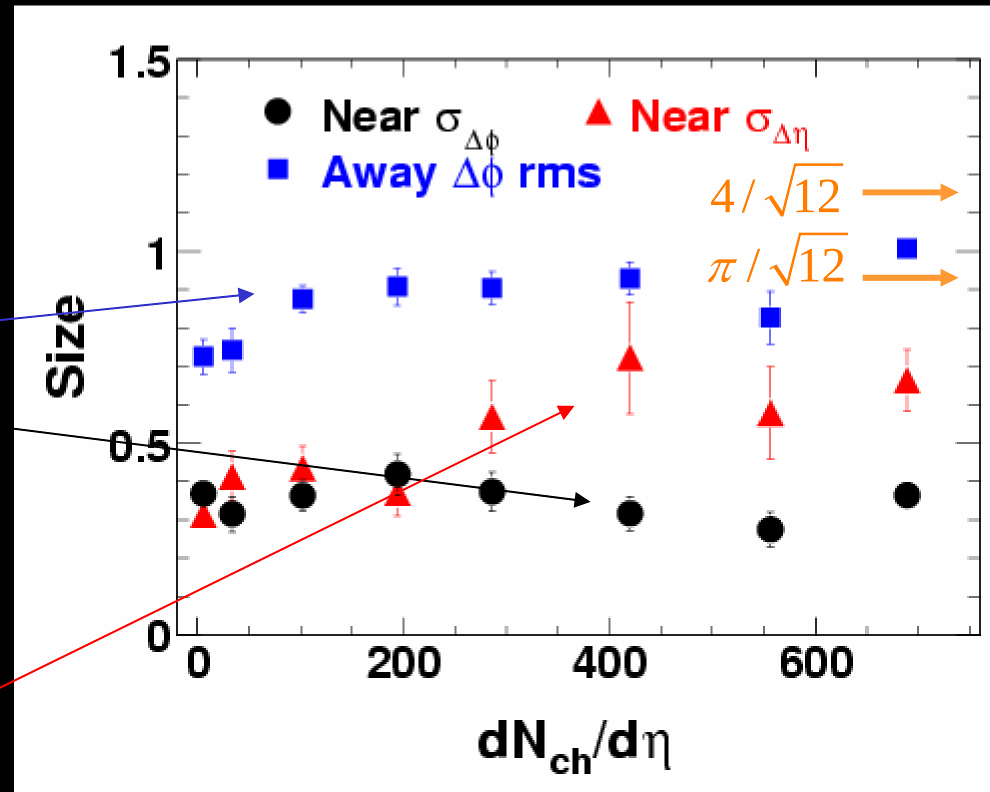
$4 < p_T^{trig} < 6$ GeV/c, $0.15 < p_T^{assoc} < 4$ GeV/c

near: $|\Delta\phi|<1.1$, $|\Delta\eta|<1.4$

away: $|\Delta\phi-\pi|<2$, $|\eta|<1.1$

STAR Preliminary



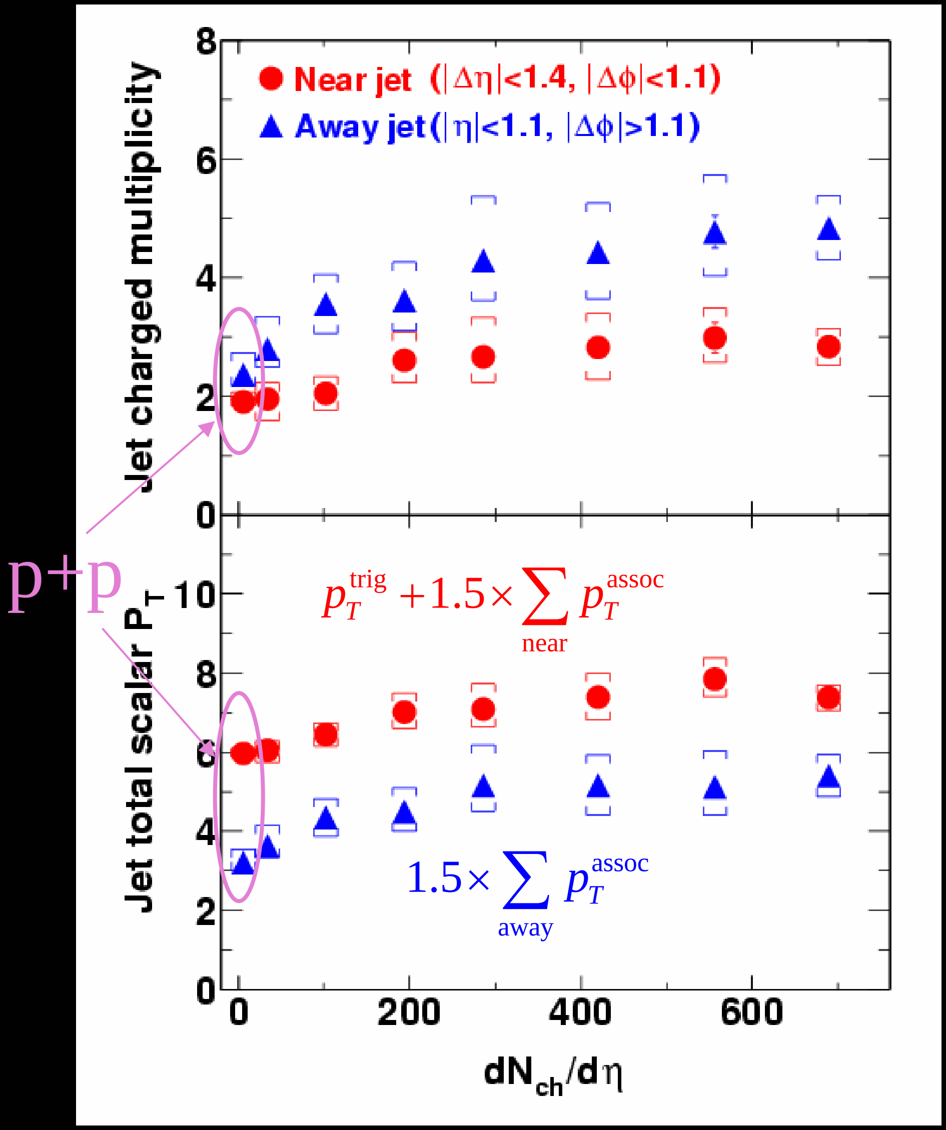


With increasing centrality:

- Near side broadens in η but not φ.
- Away side modest increase in size.

"Jet" charge multiplicity and "energy"

STAR Preliminary



Leading particle: $4 < p_T^{trig} < 6$ GeV/c

$\langle p_T^{trig} \rangle = 4.5$ GeV/c

Associated particle: $0.15 < p_T < 4$ GeV/c

With the same final leading particle, we are selecting a larger energy jet in central AA than in pp.

For the same final leading particle ($4 < p_T^{trig} < 6$ GeV/c):

near side "jet" energy difference:

$E_{AA} - E_{pp} \approx 1.4 \pm 0.2 \pm 0.2$ GeV

away diff. in TPC $\approx 2.2 \pm 0.2 \pm 0.3$ GeV

Associated particles p_T distributions

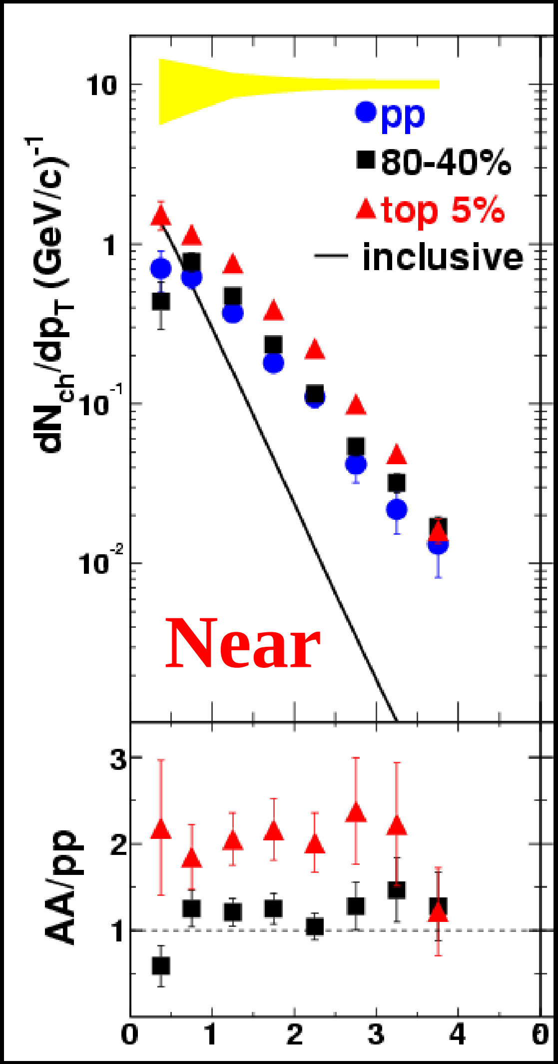
$4 < p_T^{trig} < 6$ GeV/c **STAR Preliminary**

Near side:

Overall enhancement from pp to AA

⬇

larger initial parton energy (and modest energy loss)?

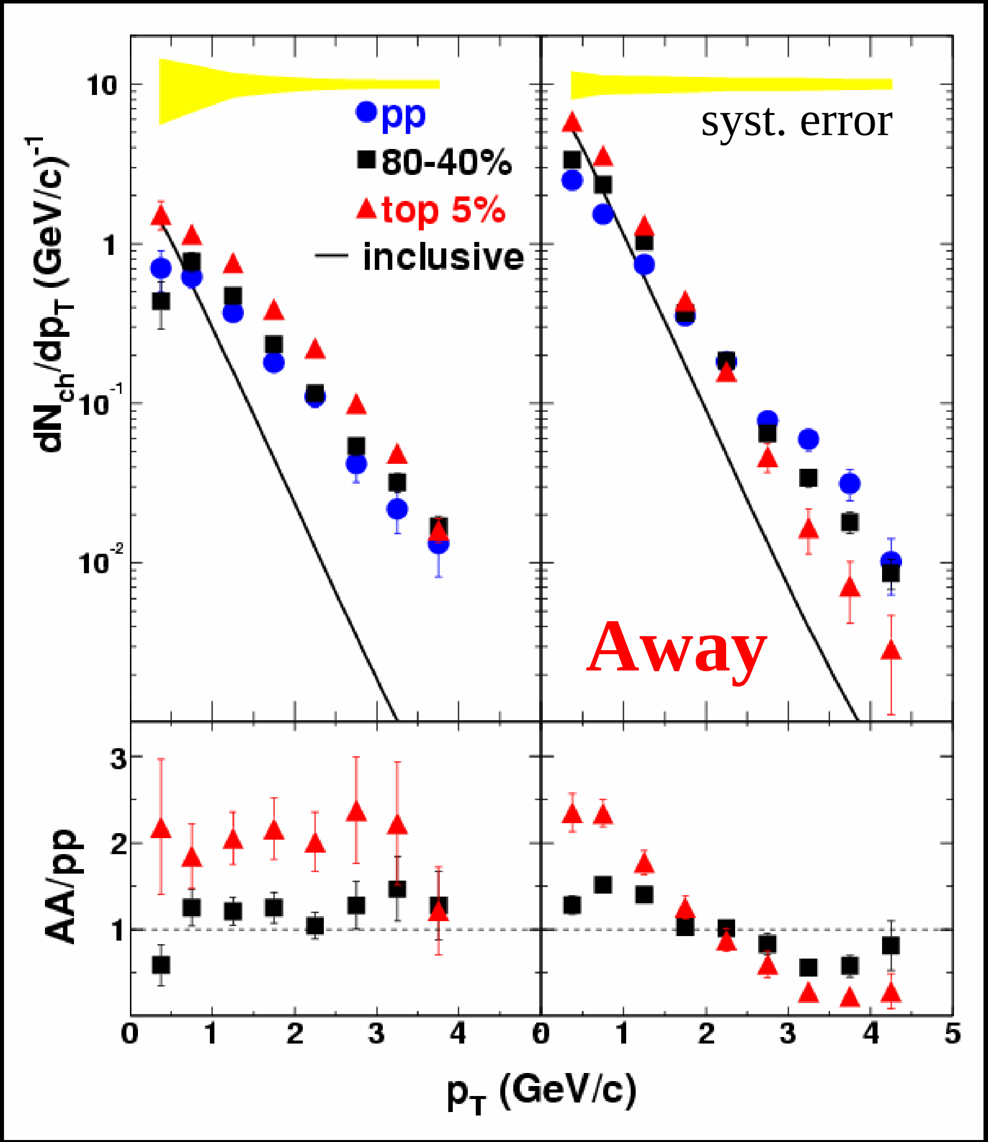


p_T (GeV/c)

Associated particles p_T distributions

$4 < p_T^{trig} < 6$ GeV/c

STAR Preliminary



Near side:

Overall enhancement from pp to AA

⬇

larger initial parton energy (and modest energy loss)?

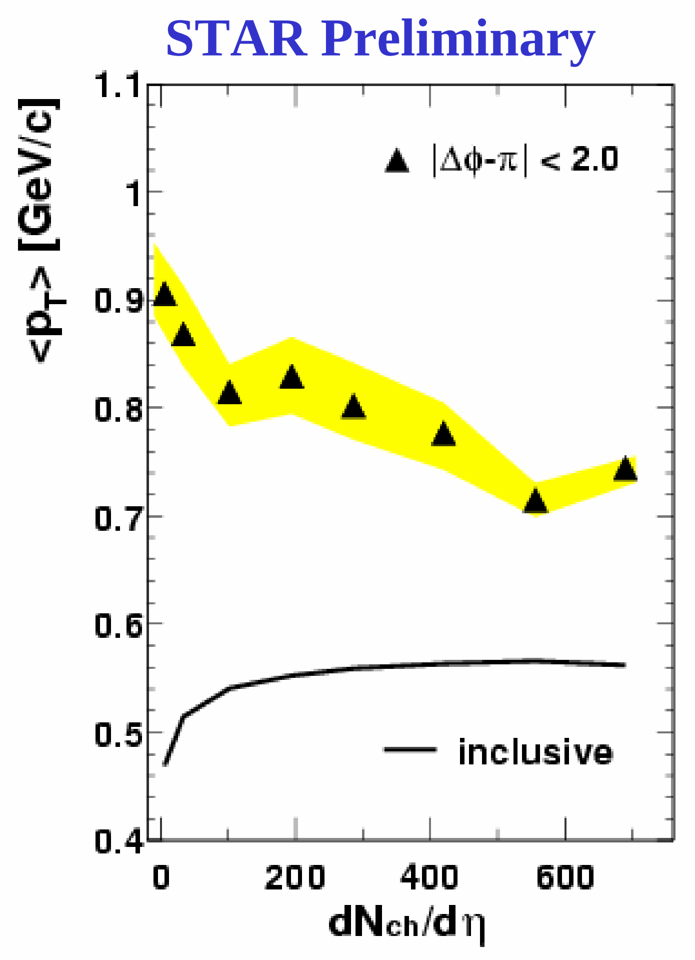
Away side:

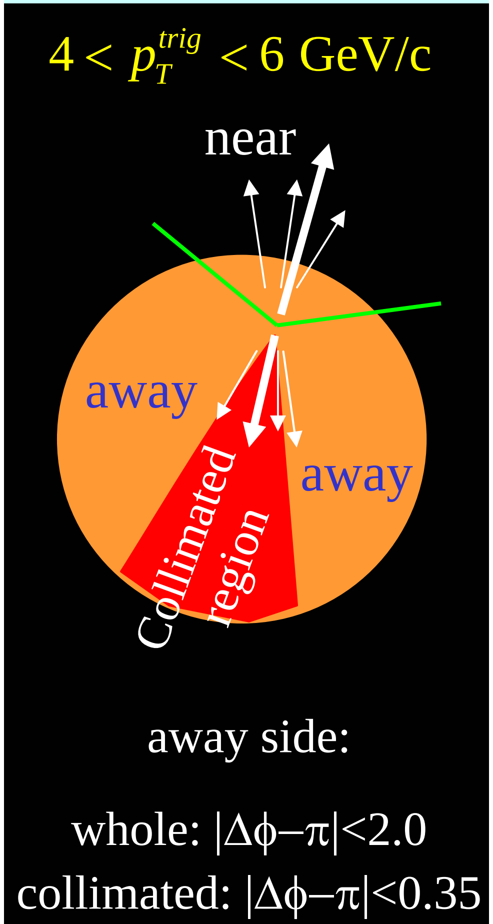
energy from the initial parton has been converted to lower p_T particles

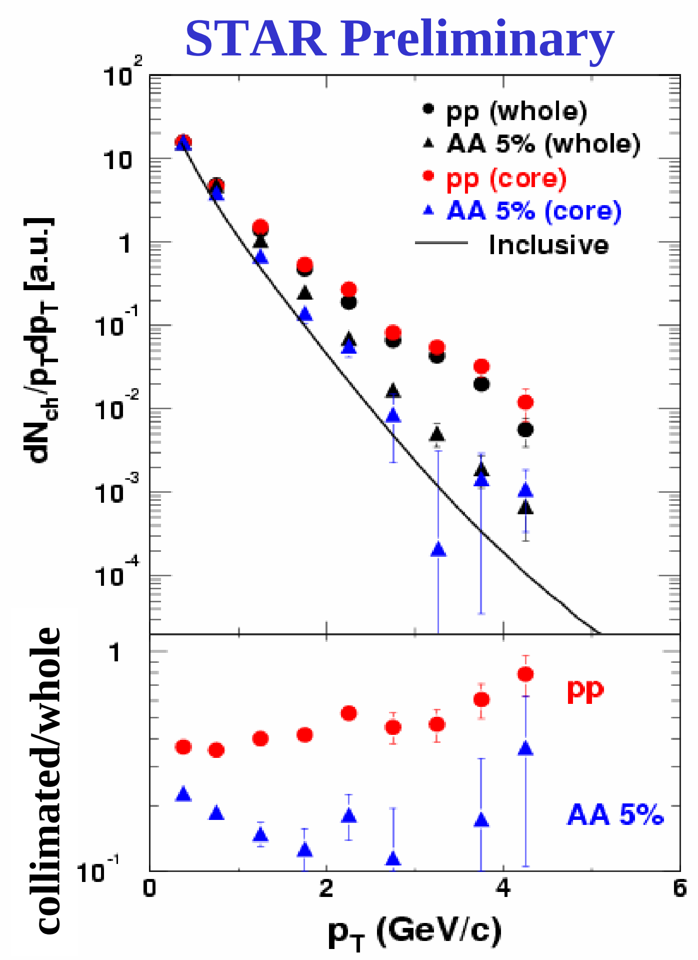
⬇

energy loss in medium!

Energy loss and thermalization

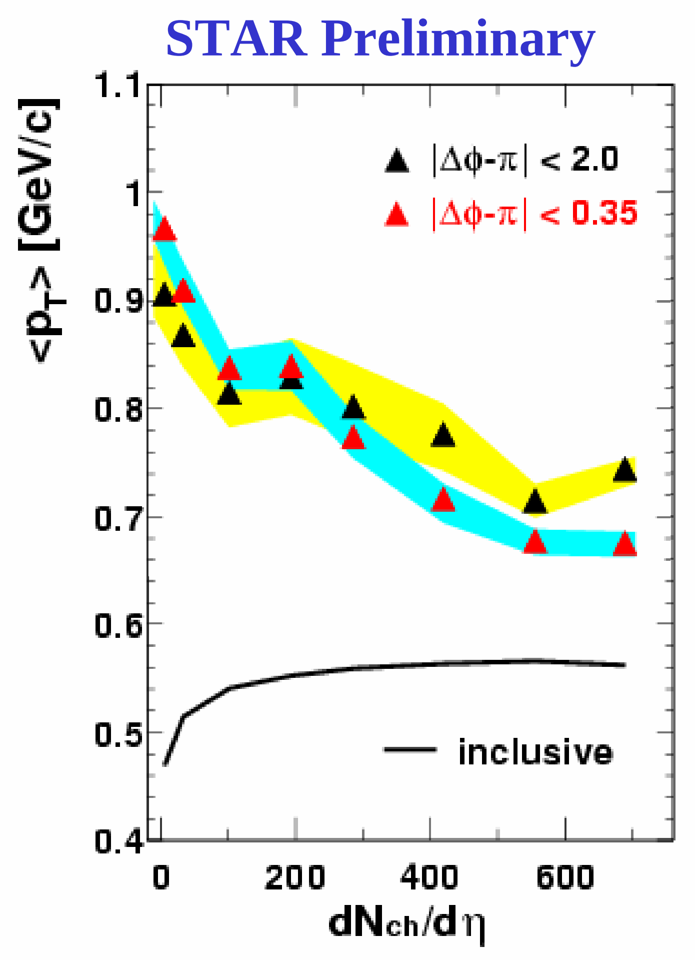


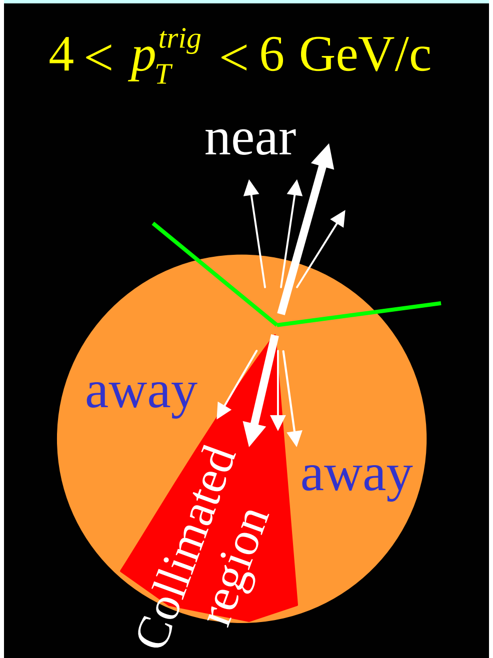




- Away side $\langle p_T \rangle$ decreases with centrality.

Energy loss and thermalization

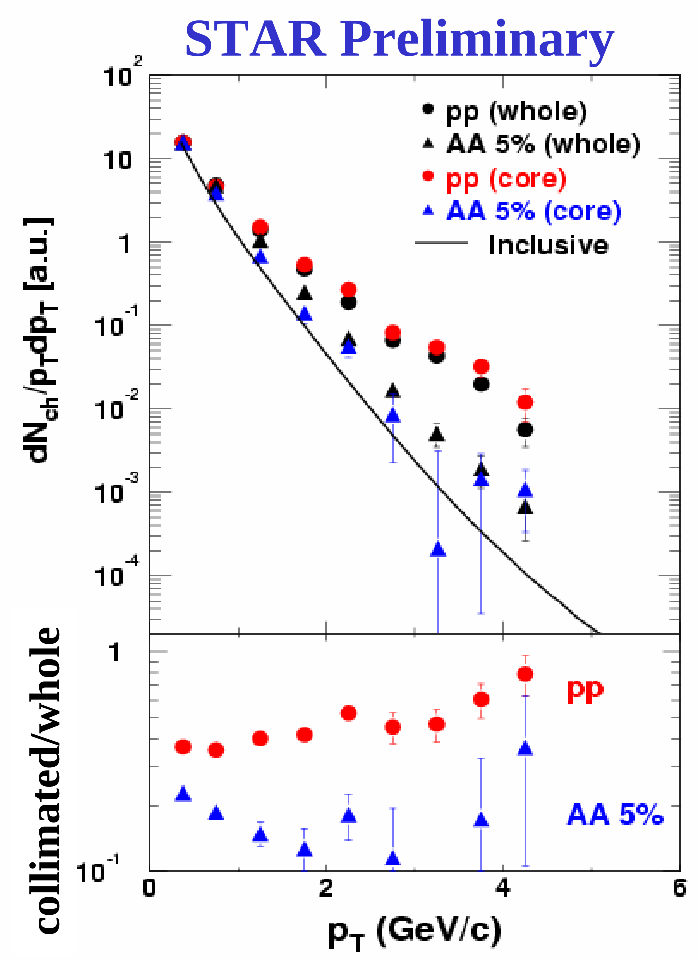




away side:

whole: |Δϕ−π|<2.0

collimated: |Δϕ−π|<0.35



- Away side $\langle p_T \rangle$ decreases with centrality.
- Away side collimated region is harder in pp and peripheral AA – jet property.
  But the collimated region is softer in central AA! Effect appears gradually with centrality.
- Away side $\langle p_T \rangle$ is still larger than that from the inclusive result.

→ Towards thermalization in more central collisions!

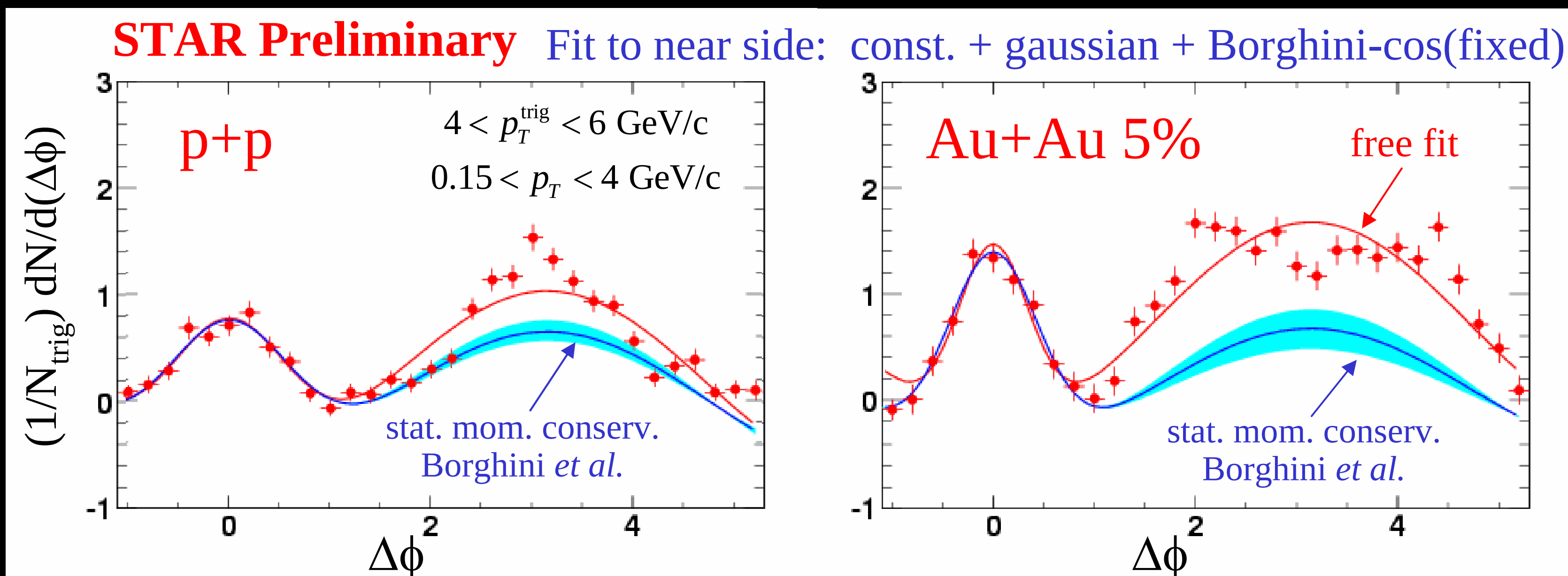
Broadened distribution and thermalization

e.g. a thermal fluctuated large p_T particle (or a mono-jet) would produce an away side excess due to momentum conservation.

Borghini *et al.* PRC 62, 034902 (2000):

$$C^{\Sigma p_T} = -\frac{2\vec{p}_{T1}\cdot\vec{p}_{T2}}{N_{\text{all}}\langle p_T^2\rangle_{\text{all}}} \rightarrow \frac{dN}{d(\Delta\phi)} = -\frac{N_{\text{meas}}}{2\pi}\frac{2P_T^{\text{jet}}\langle p_T\rangle_{\text{meas}}}{N_{\text{all}}\langle p_T^2\rangle_{\text{all}}}\cos(\Delta\phi)$$

$\langle p_T^2\rangle$ [GeV/c]^2	HIJING all η	STAR |η| < 0.5
p+p	0.23	0.26
Au+Au 5%	0.31	0.50



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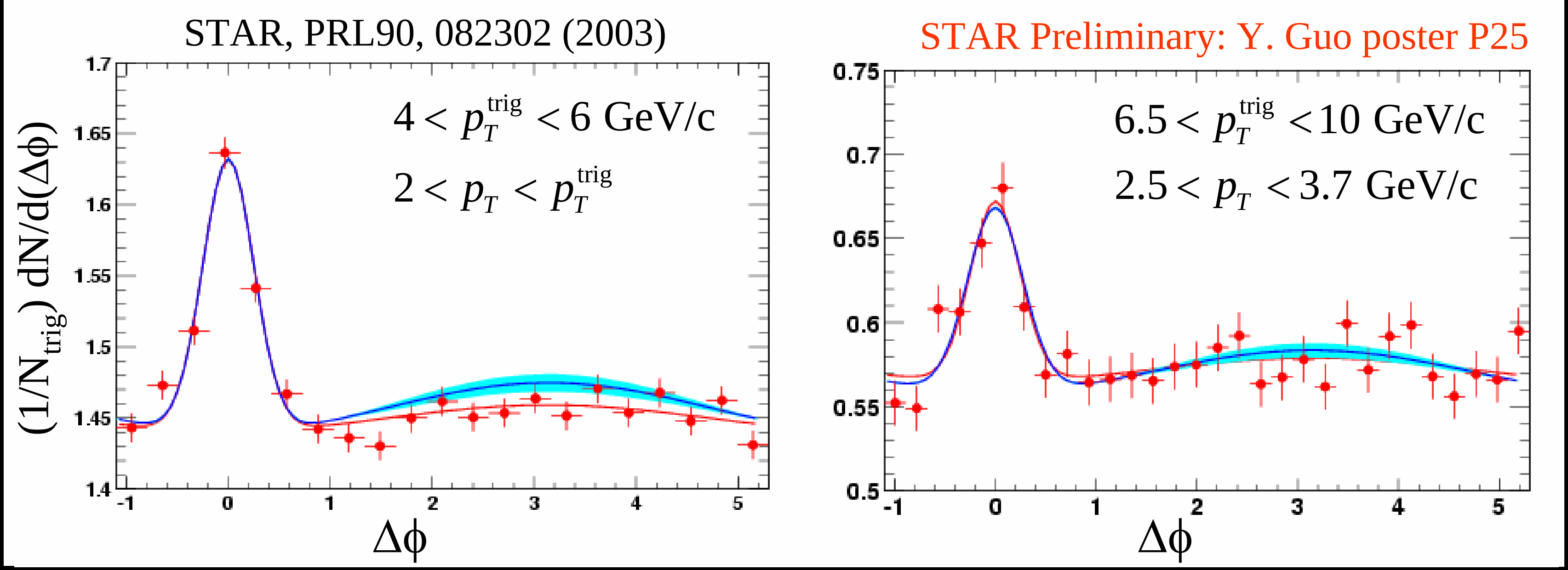

No punch-through for $6 < p_T^{\mathrm{trig}} < 10$ GeV/c.

Broadened distribution and thermalization

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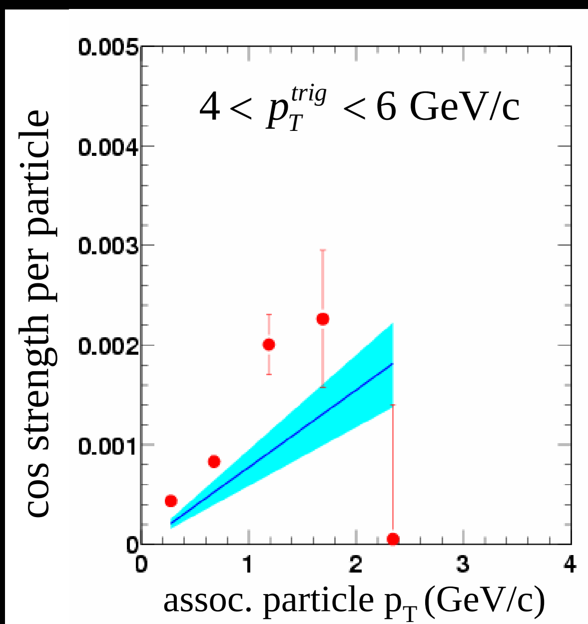
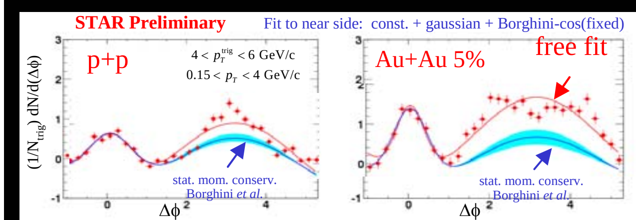
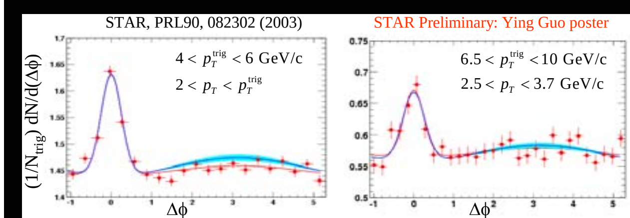
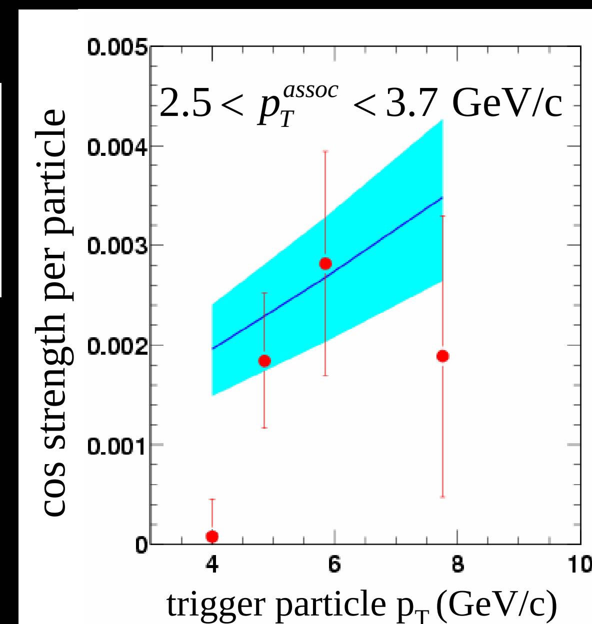








- the final state away excess has a similar shape to a stat. distr. from momentum conservation.
- near side is mostly a jet, and initially no mono-jet at mid-rapidity.

→ the away side excess is approaching equilibration with the medium, consistent with the p_T spectra results.

Summary and Open Questions

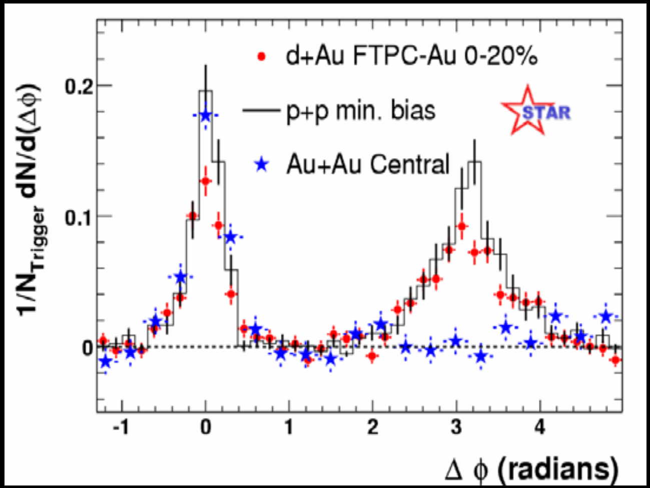
- Statistical reconstruction of jets in pp and AA collisions.
- Same p_T leading particles come from larger initial energy in central AA than in pp.
- Near side: overall increase in multiplicity.
- Away side: increase in multiplicity as well as softening in p_T.
- Away side: towards thermalization in more central collisions.
- How does jet lose energy? In what medium?
  How & to what extent are they equilibrated with the medium?

  Statistical jet reconstruction opens up opportunities to answer these questions experimentally.

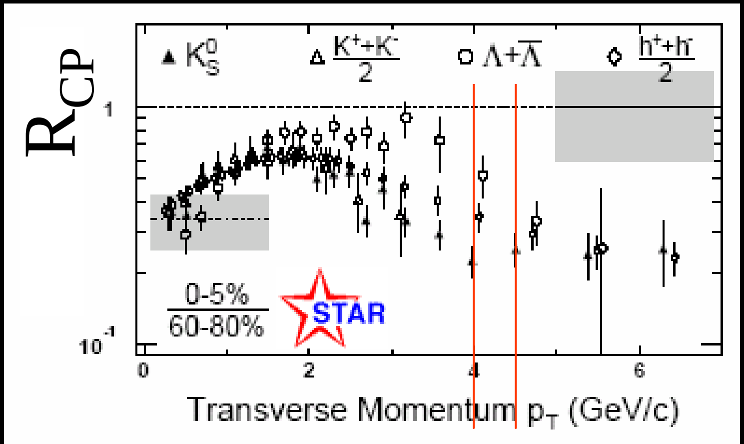
---Backup slides---

Backup Slides

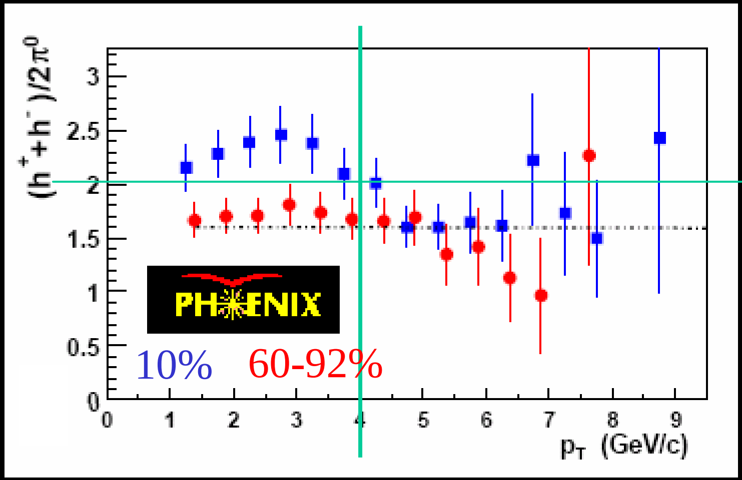
What we know from previous measurements…



Suppression phenomena in central Au+Au are due to final-state interactions. Parton-parton hard-scatterings are initially present.



p_T > 4 GeV/c region is mainly from jet fragmentation.



$4 < p_T < 4.5$ GeV/c region:

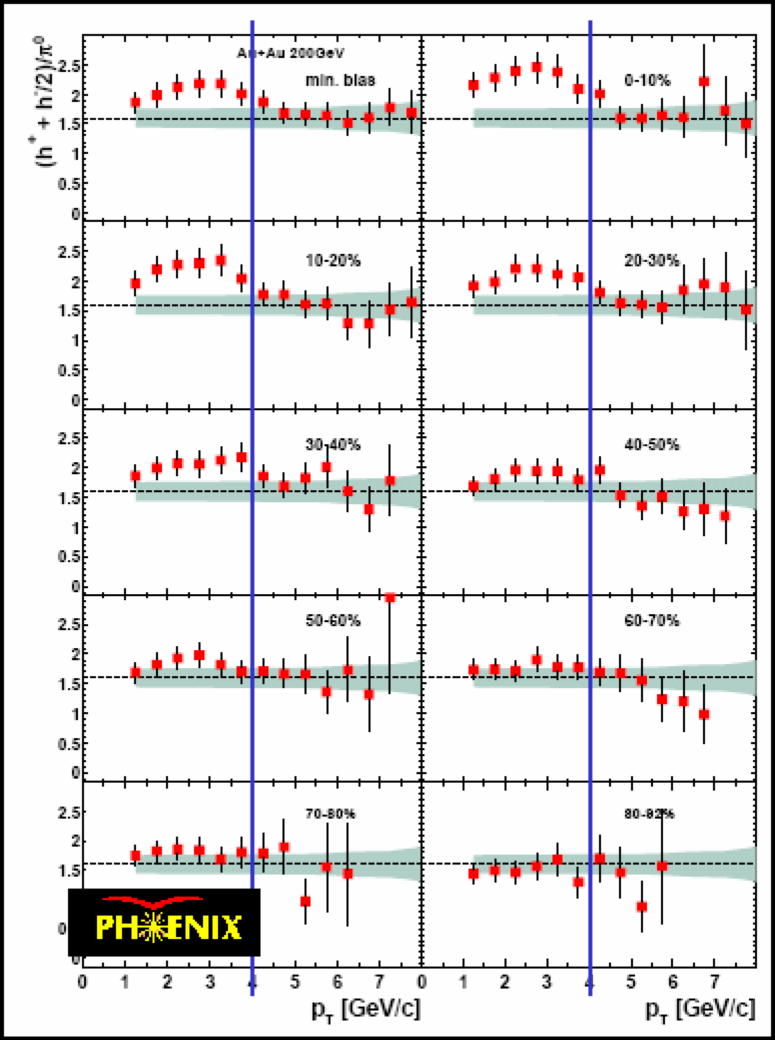
π, K are dominated by jet fragmentation.

pp, peripheral: $(\pi_{\text{frag}} + K_{\text{frag}} + p_{\text{frag}})/\pi^0 = 1.6$

central: $(\pi_{\text{frag}} + K_{\text{frag}} + p_{\text{frag}} + p_{\text{non-frag}})/\pi^0 = 2.0 \pm 0.2$

$\Rightarrow$ central: $p_{\text{non-frag}}/(\pi + K + p)_{\text{all}} = 0.2 \pm 0.1$

Baryon/meson



$4 < p_T < 4.5$ GeV/c:

pp, peri.: $(p+K)/\pi = 1.6$

central: $(p+K)/\pi = 2.0 \pm 0.2$

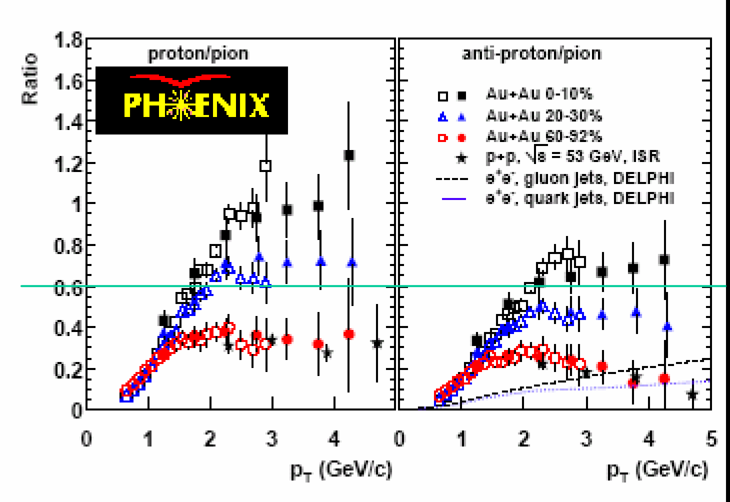
$p_{\text{non-frag}} / \pi = 0.4$

$p_{\text{frag}} / \pi = 0.2$

$4 < pt < 4.5$ GeV/c:

$$R_{CP}^{\pi} = \frac{\pi^{cent} / N_{coll}^{cent}}{\pi^{peri} / N_{coll}^{peri}} = \frac{1}{3}$$

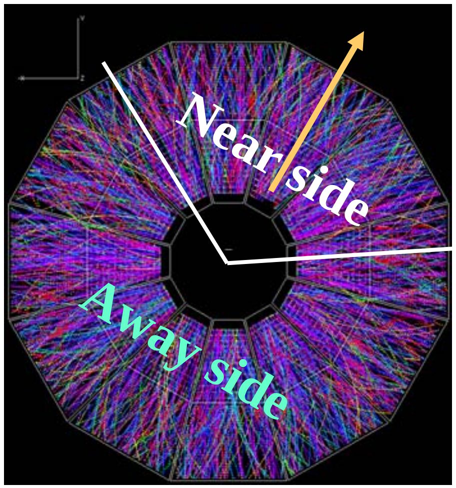
$$R_{CP}^{p} = \frac{0.6\pi^{cent} / N_{coll}^{cent}}{0.2\pi^{peri} / N_{coll}^{peri}} = 1$$

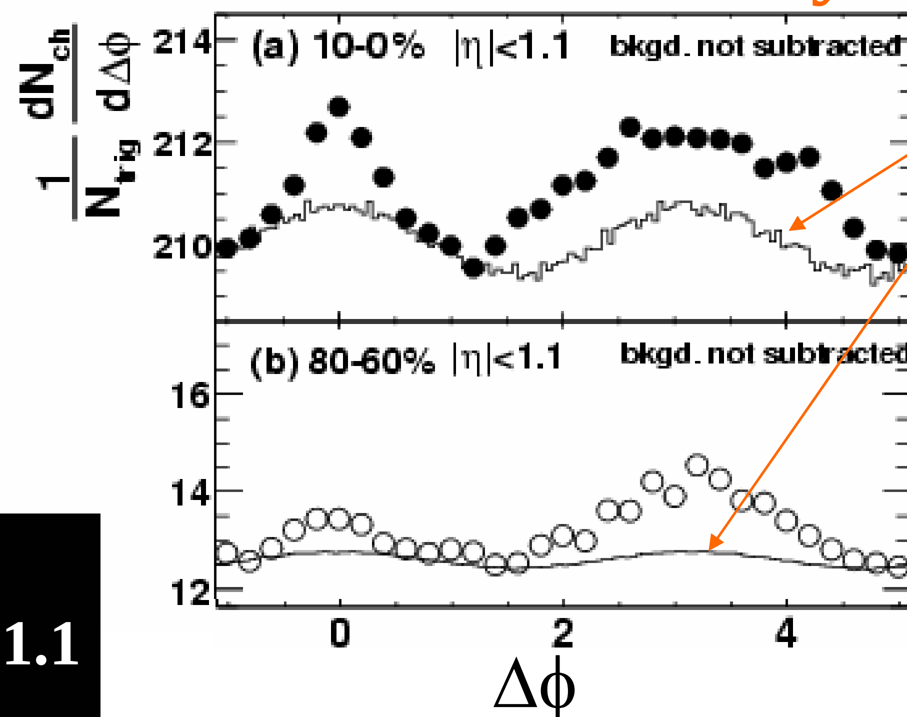


Analysis Technique II

Leading particle: $|\eta|<0.75$, $4<p_T<6$ GeV/c Associated particle: $|\eta|<1.1$, $0.5<p_T<4$ GeV/c

STAR Preliminary





Background with v_2 modulation. Normalized to $0.9<|\Delta\phi|<1.3$

Central:
N_{trig}=103K, S/B=2/200

Peripheral:
N_{trig}=5K, S/B=1/13

Near side:
$|\Delta\eta|<1.4$, $|\Delta\phi|<1.1$

Away side:
$|\eta|<1.1$, $|\Delta\phi|>1.1$

Significance of signal:

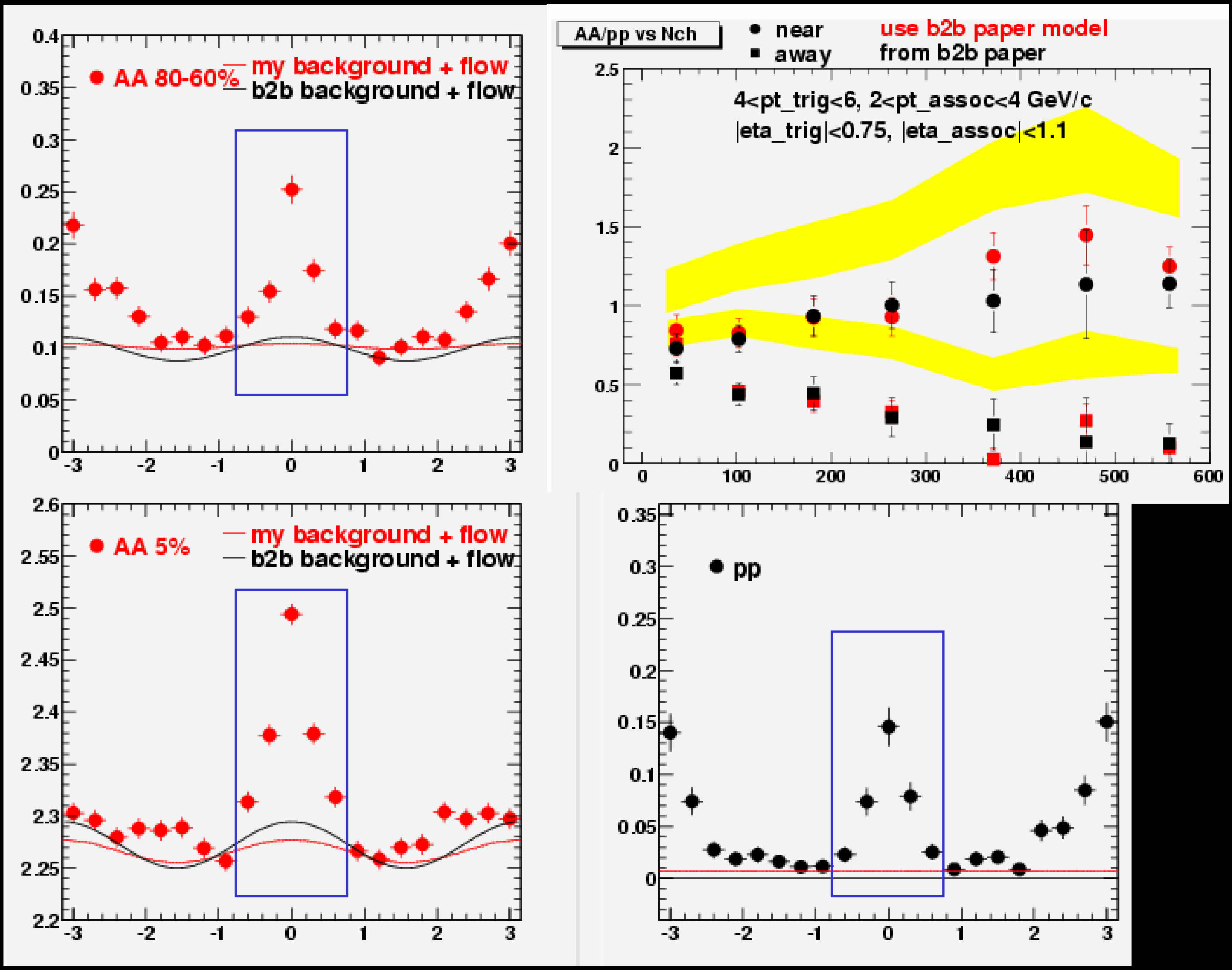
$$S\sqrt{\frac{N_{trig}}{B}} = \begin{cases} 2\sqrt{\frac{10^5}{200}} = 45 & \text{central} \\ 1\sqrt{\frac{5000}{13}} = 20 & \text{peripheral} \end{cases}$$

AA/pp vs I_{AA}

Peripheral:
AA/pp=1.01
I_{AA}=0.84

- broadening in η
- pp reference
- v_2
- model difference

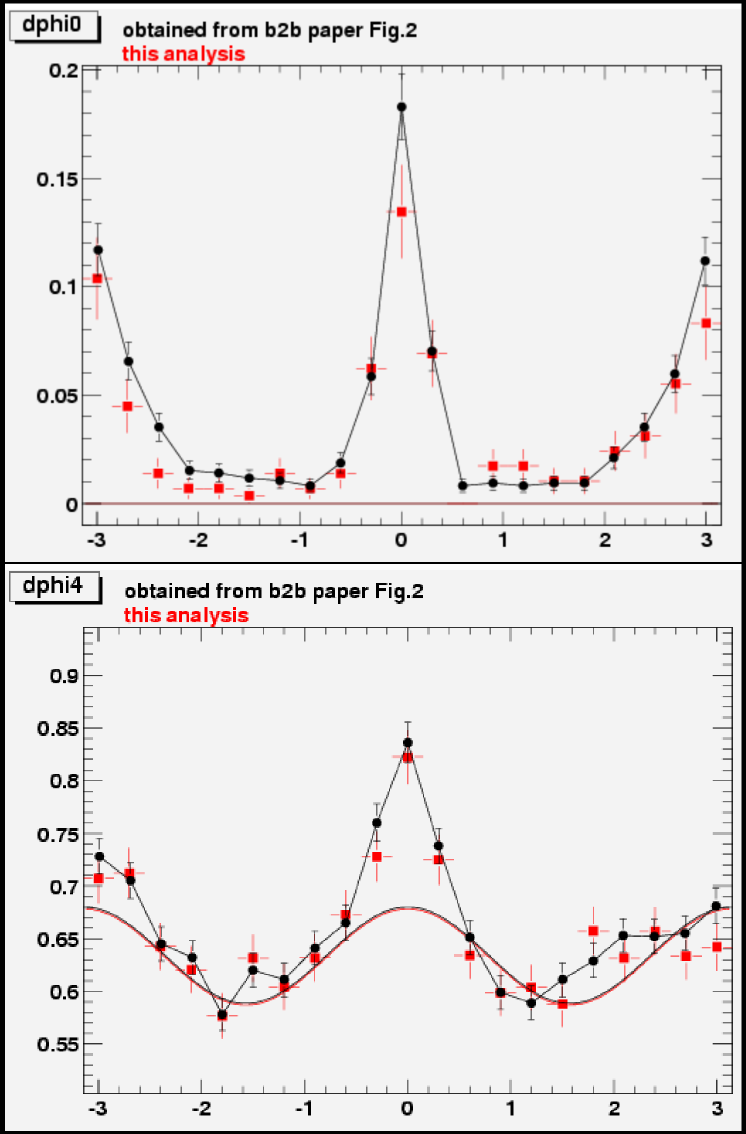
Central:
AA/pp=1.66
I_{AA}=1.25

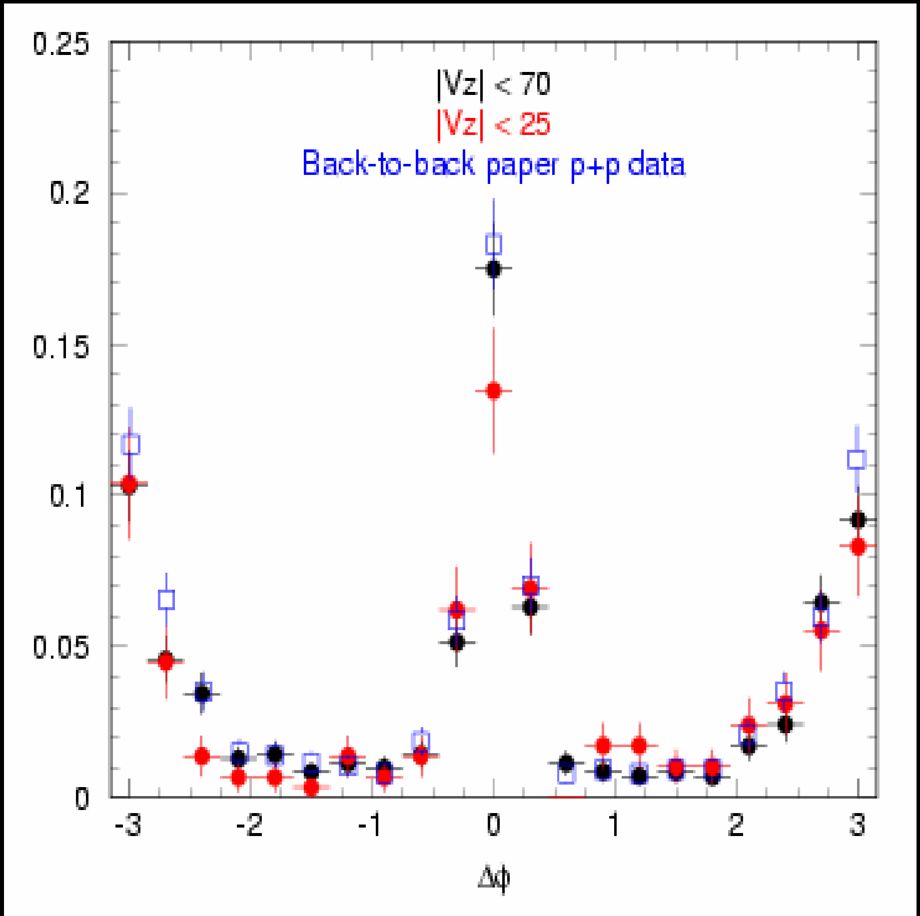


$\Delta\phi$ $\Delta\phi$

$I_{AA} < 1$ in peripheral ?

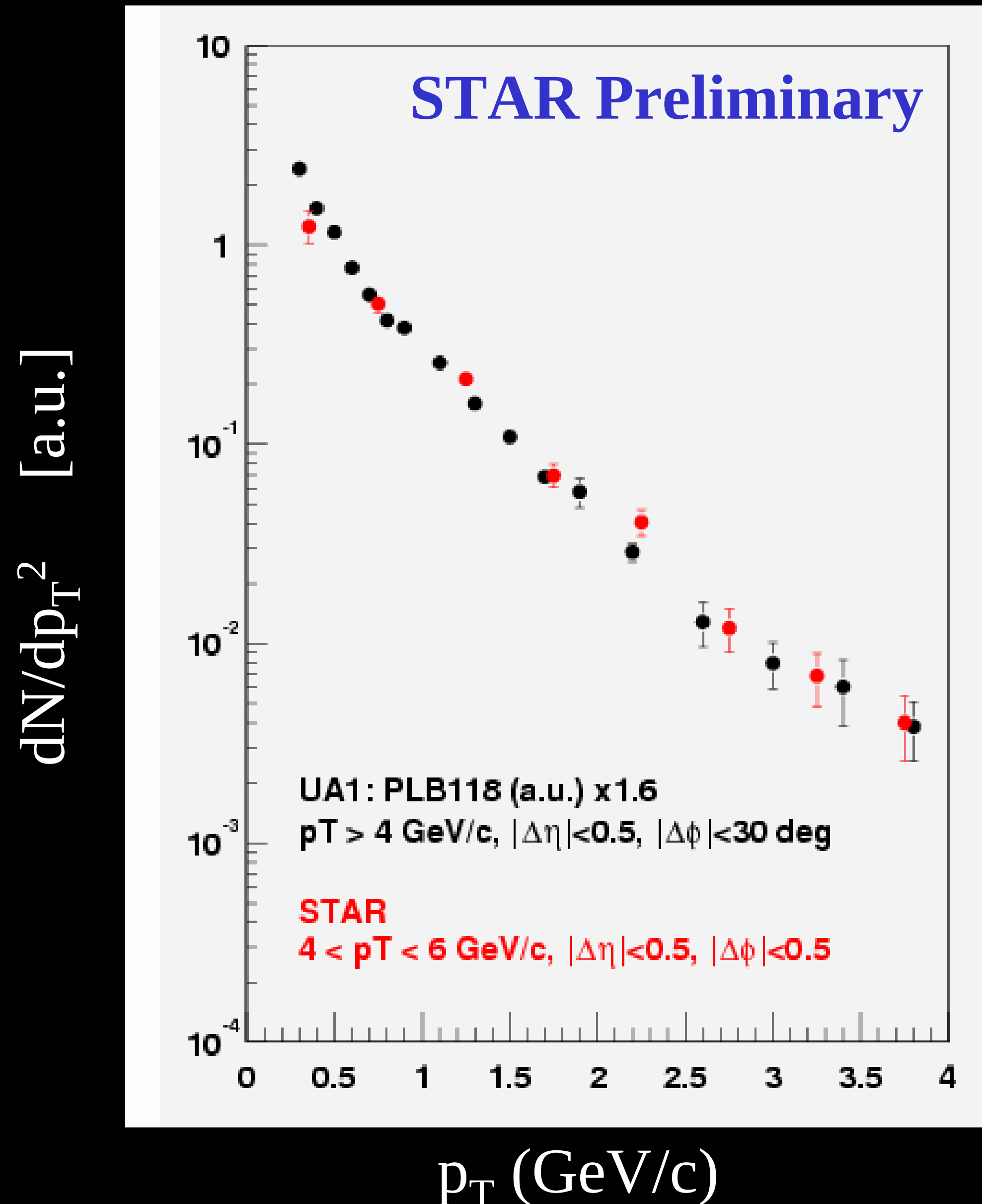
STAR Preliminary





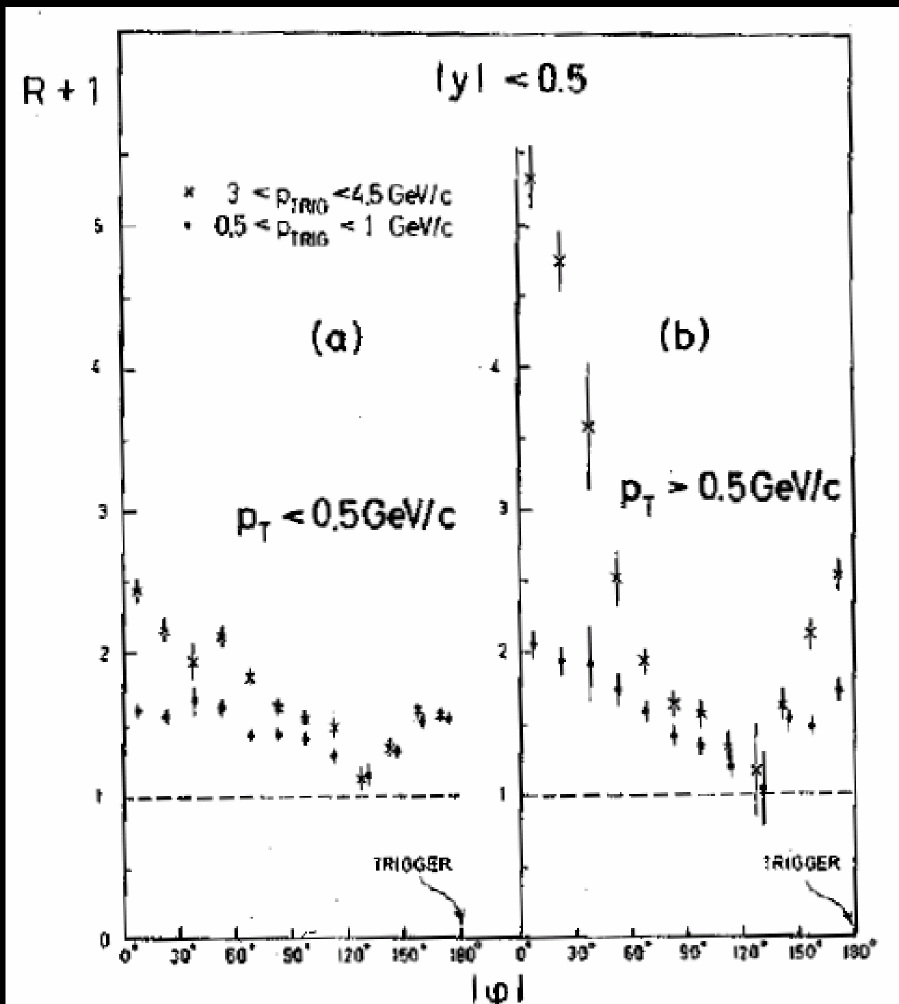
pp reference

Compare to UA1

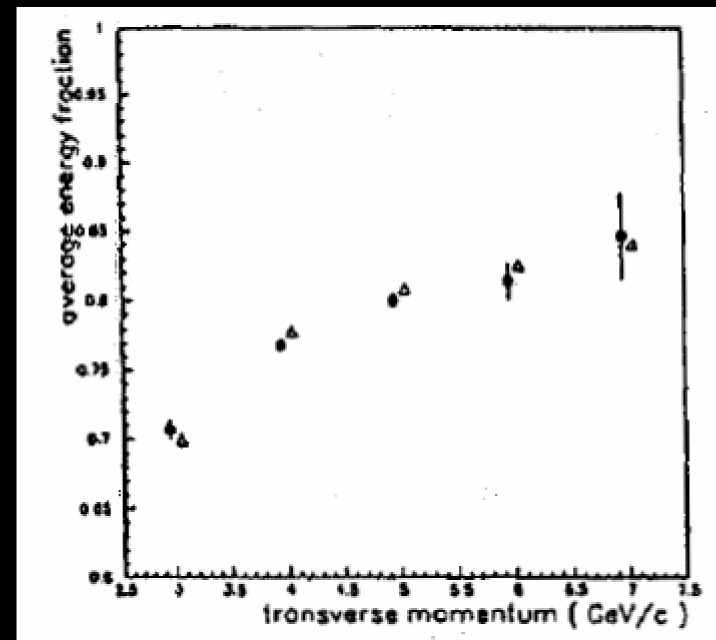


Existing pp, pA results

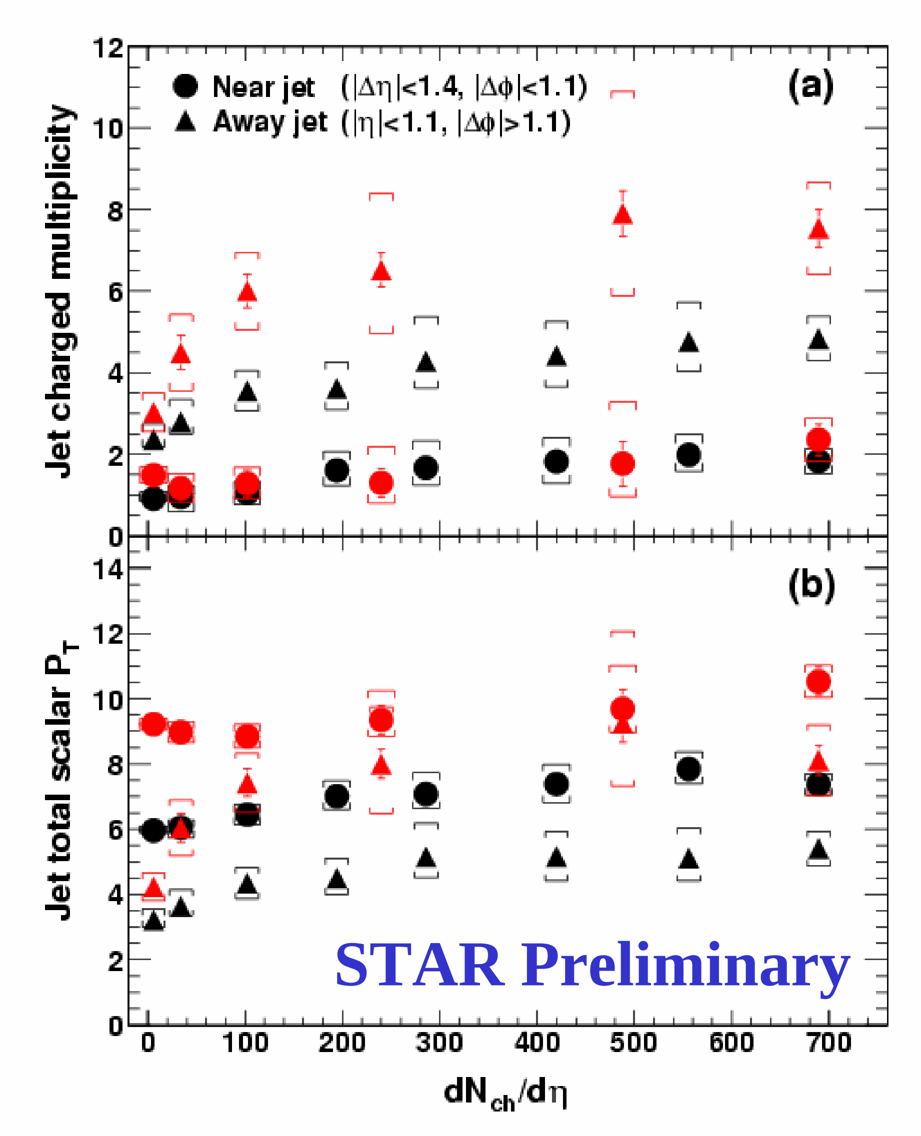
M.G. Albrow *et al.* NPB145, 305 (1978)



G. Boca *et al.* ZPC49, 543 (1991)



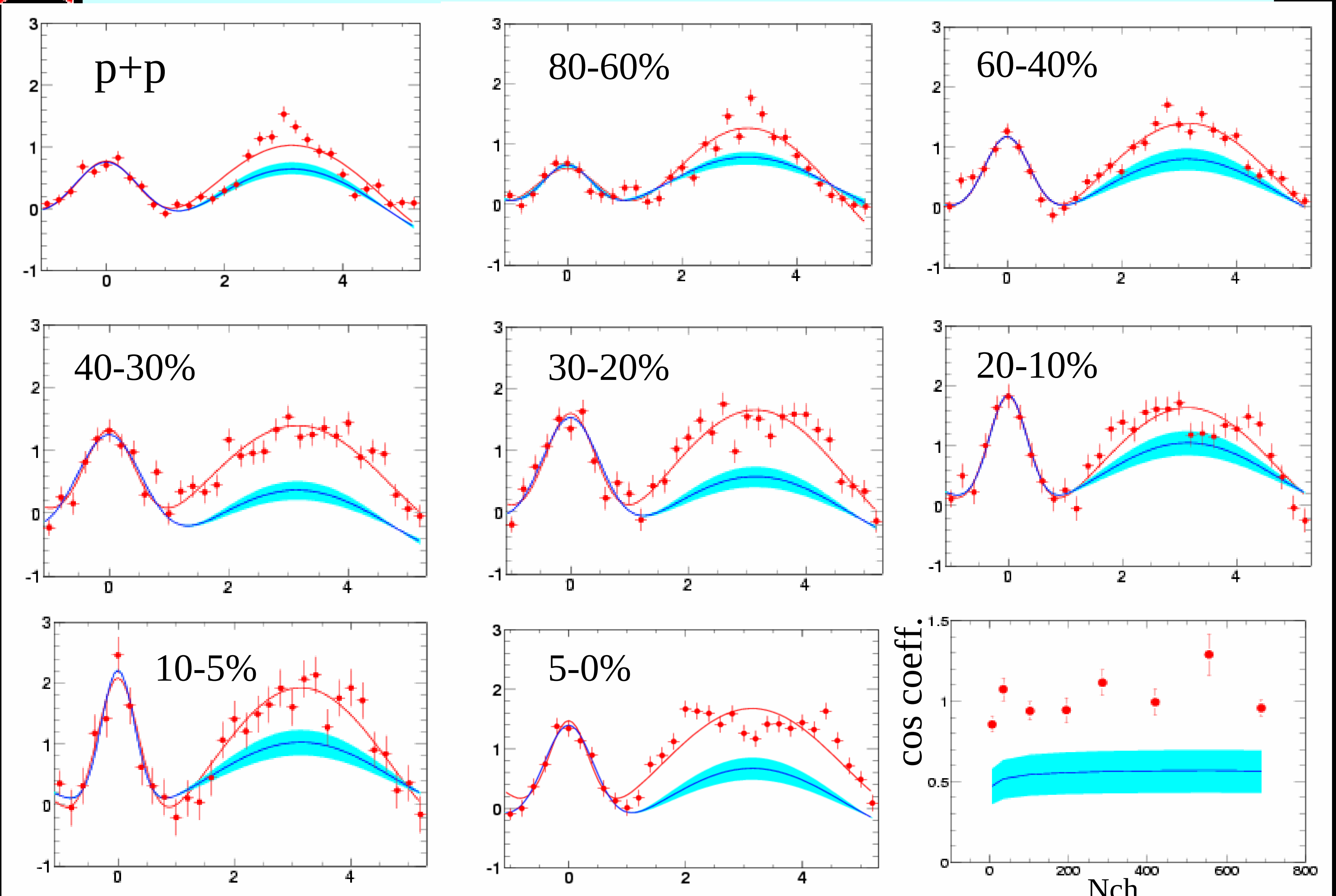
Higher trigger p_T



$4 < p_T^{trig} < 6$ GeV/c

$6 < p_T^{trig} < 10$ GeV/c

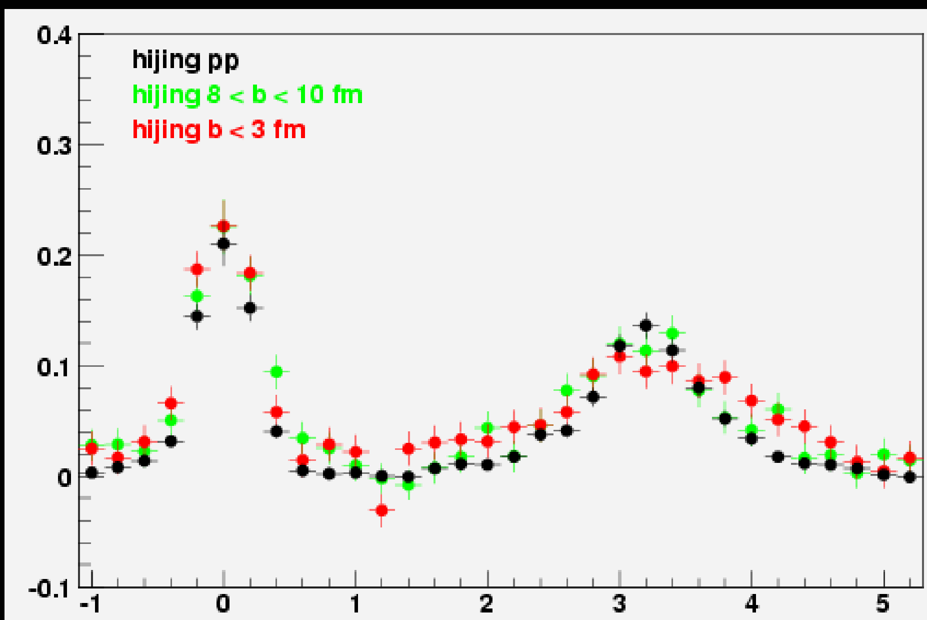
Cos-coefficient vs centrality



Hijing (no quenching)

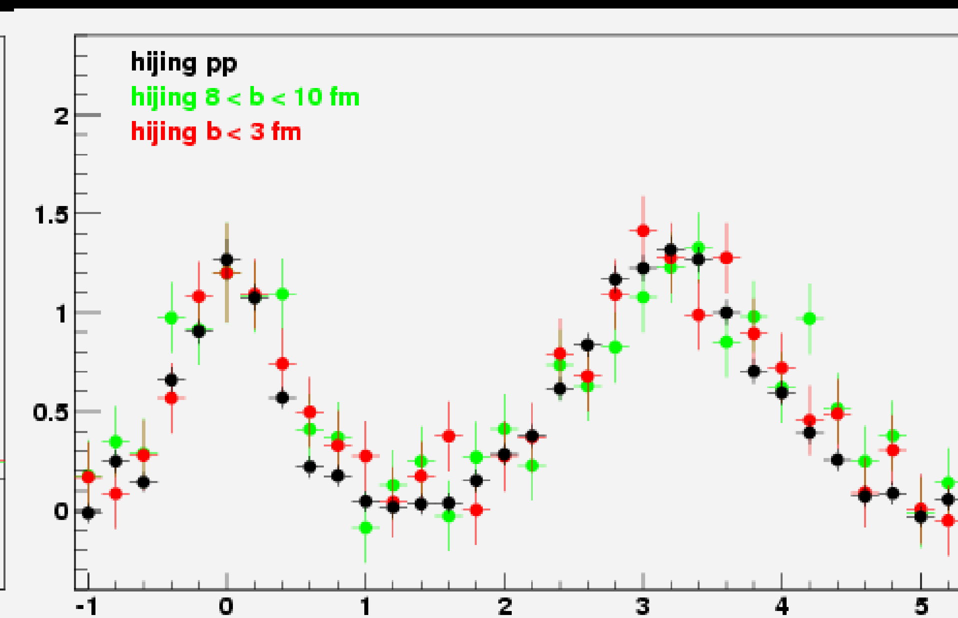
$4 < p_T^{trig} < 6$ GeV/c

$2 < p_T < 4$ GeV/c



$\Delta\phi$

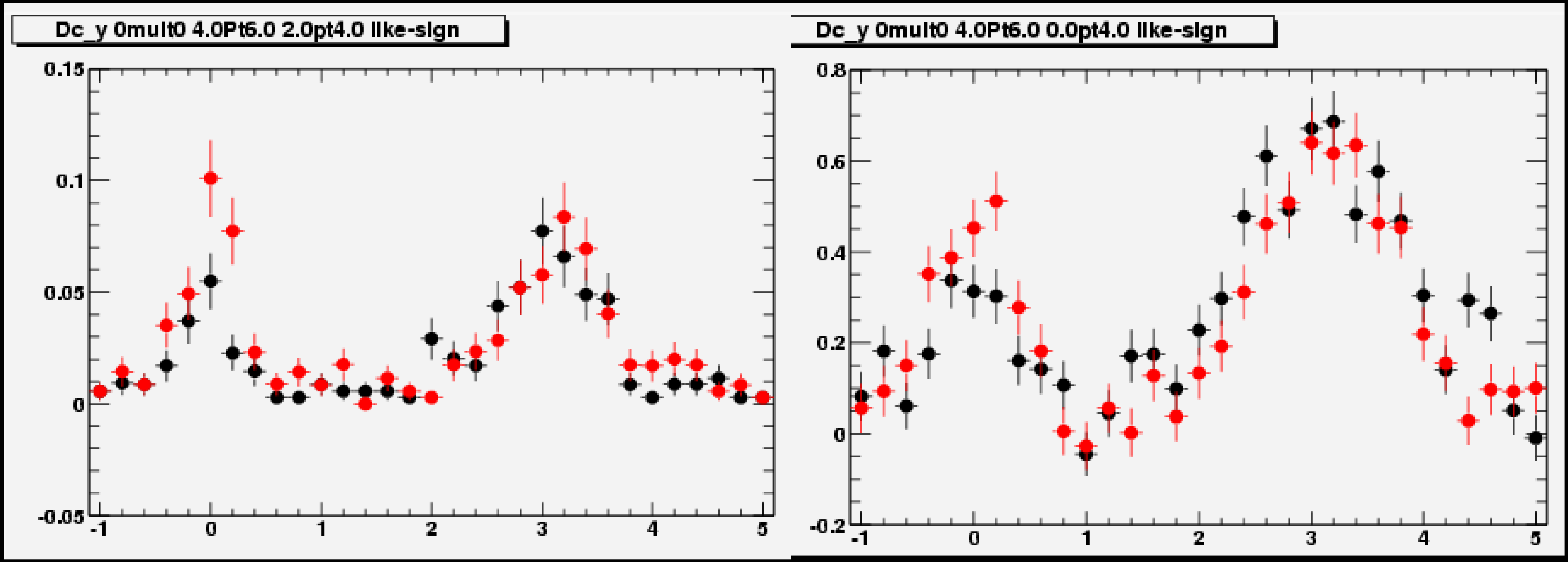
$0.15 < p_T < 4$ GeV/c



$\Delta\phi$

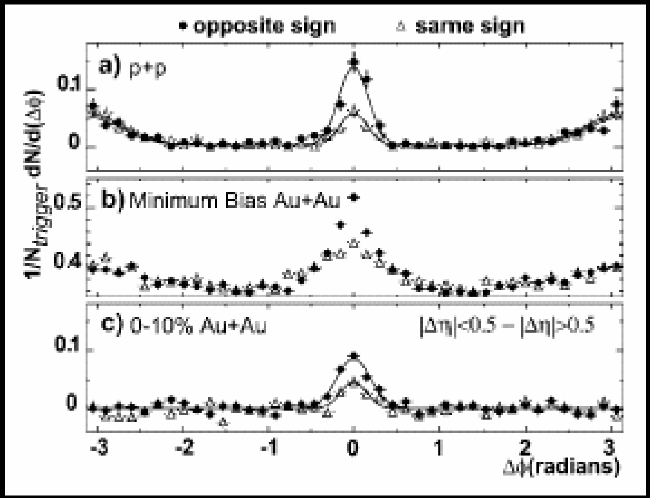
Like-sign and unlike-sign

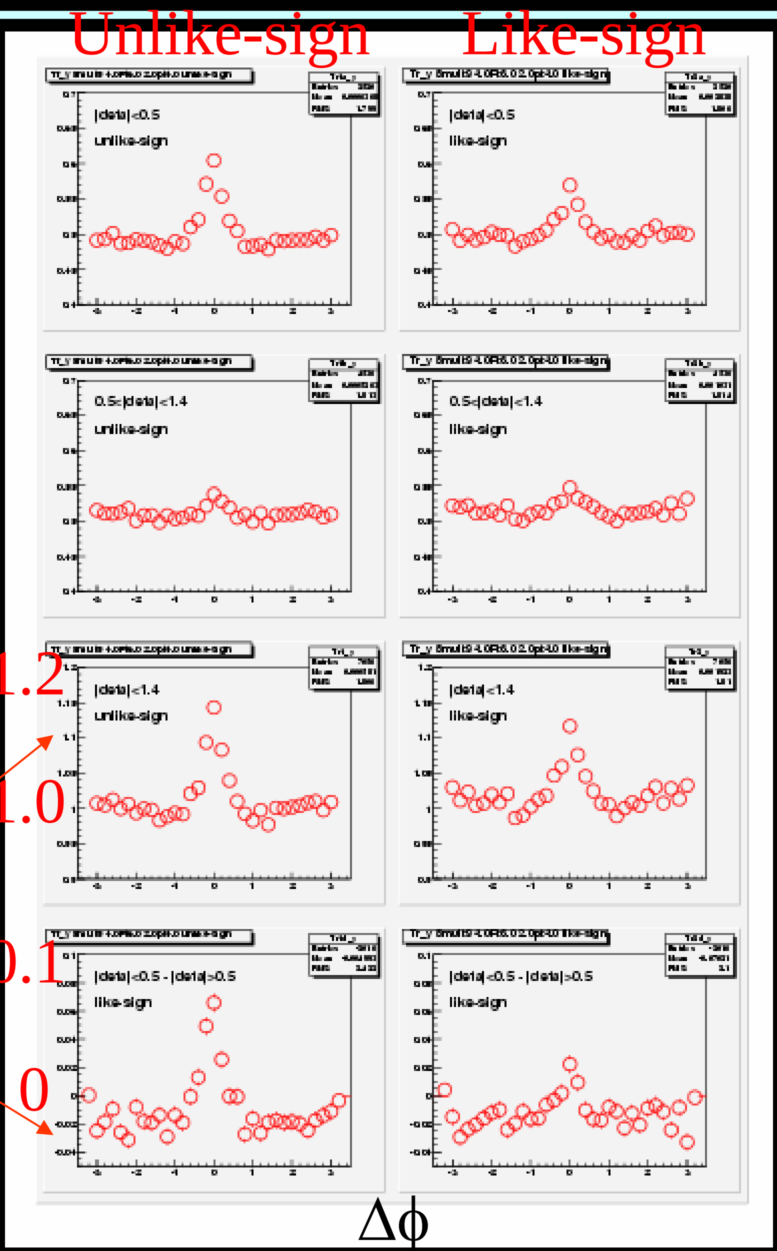
STAR Preliminary



Unlike vs like (top 10%)

Back-to-back paper





$|\Delta\eta|<0.5$

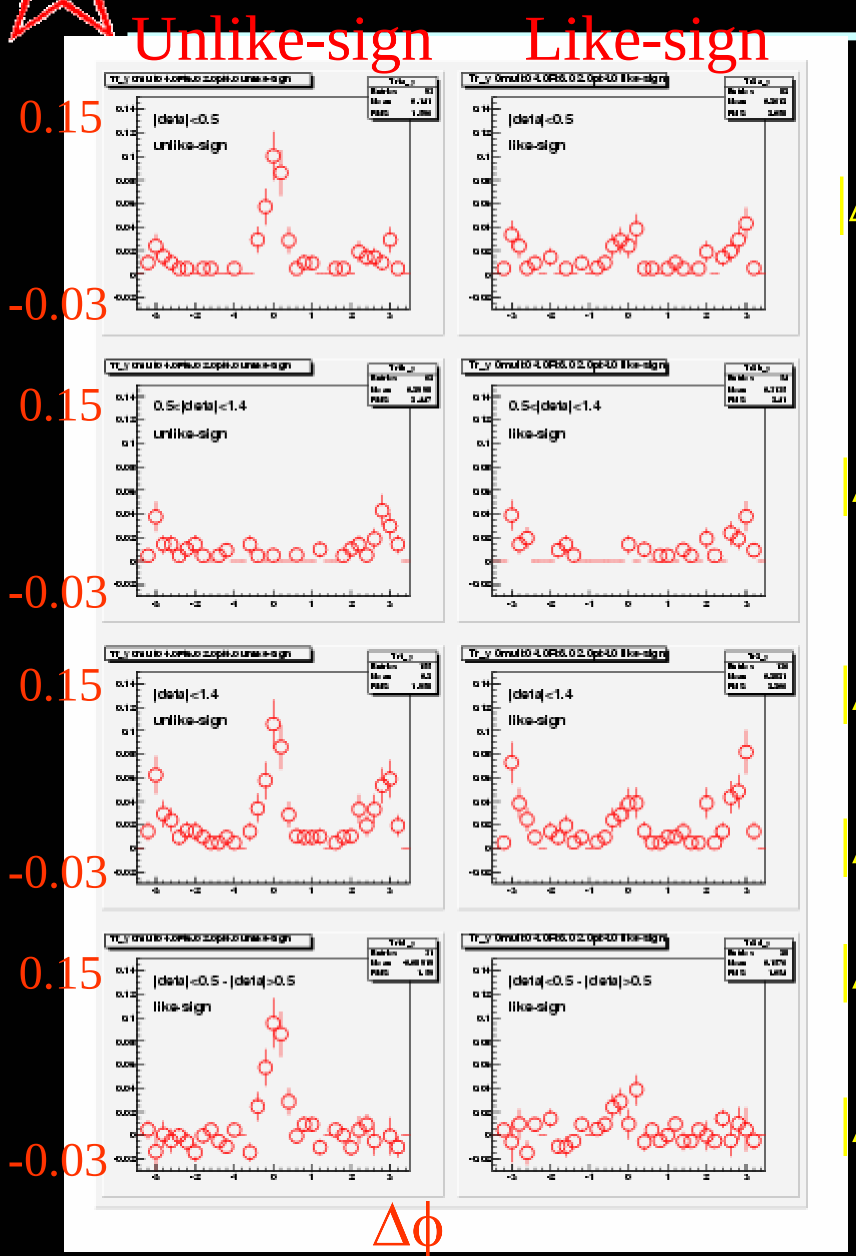
$|\Delta\eta|>0.5$

$|\Delta\eta|<0.5$ + $|\Delta\eta|>0.5$

$|\Delta\eta|<0.5$ – $|\Delta\eta|>0.5$

(Unlike-like)/unlike = 0.2-0.3 / 1-1.5

pp (left) AuAu top 5% (right)



|Δη|<0.5

|Δη|>0.5

|Δη|<0.5
+
|Δη|>0.5

|Δη|<0.5
–
|Δη|>0.5