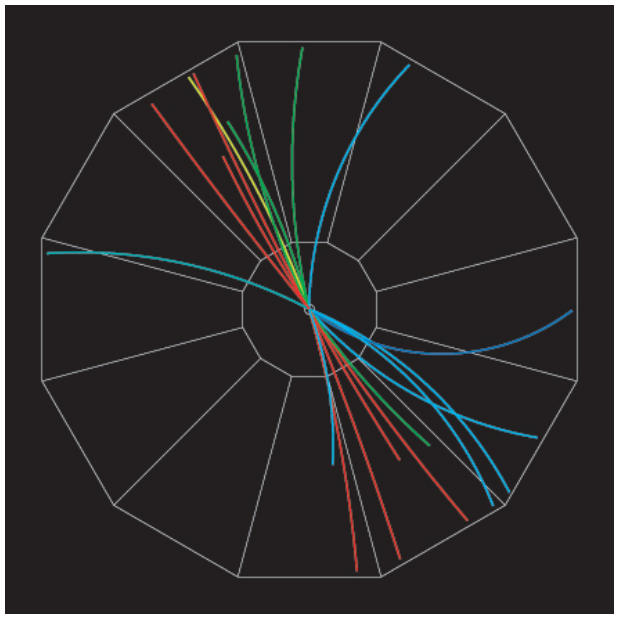
Jet Correlations



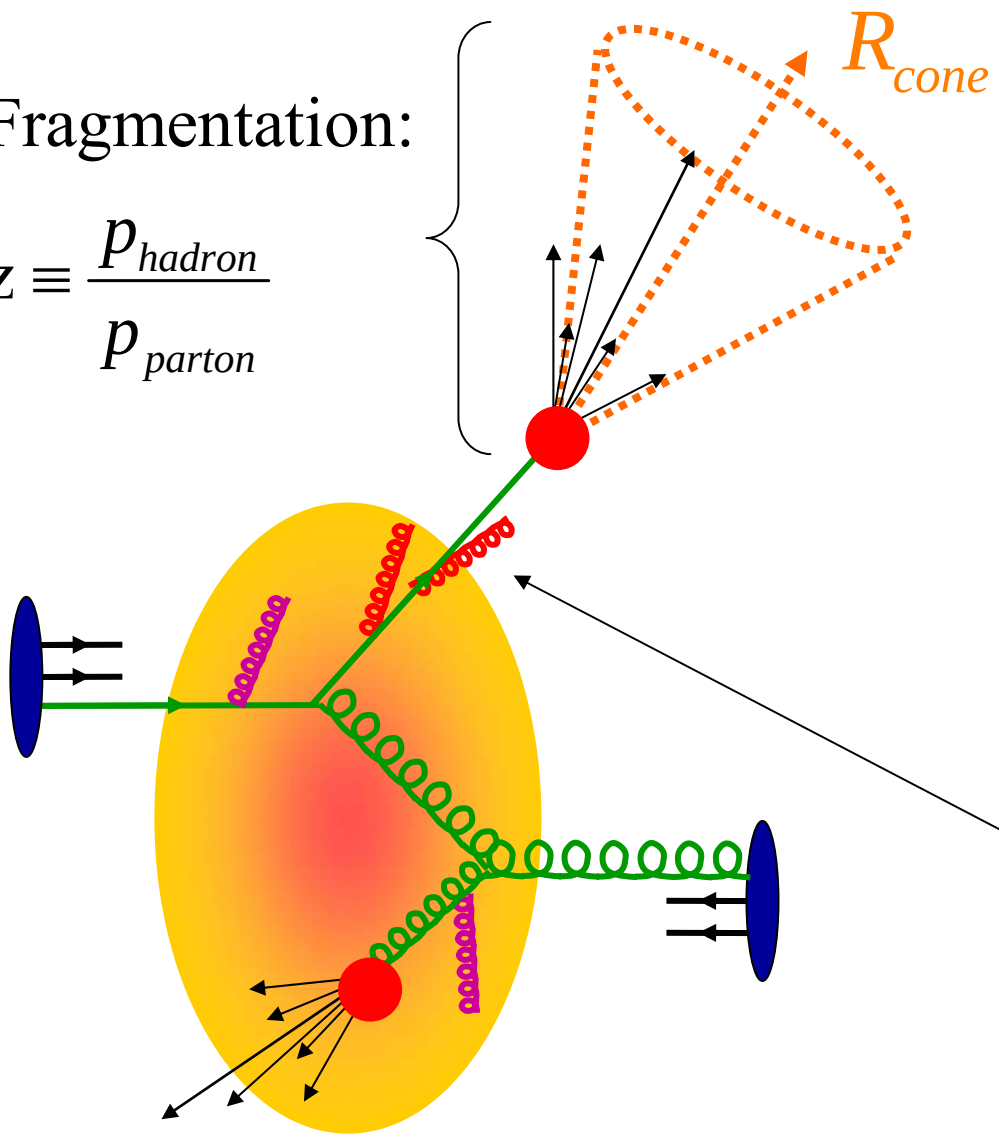
Mike Miller (Yale University)

Quark Matter 2004
Oakland – January 11-17

Why Jets?

Fragmentation:

$$z \equiv \frac{p_{hadron}}{p_{parton}}$$



- Hard probe⇒early time
- Calculable: pQCD
- Abundant at RHIC, LHC

k_T: "Radiative Corrections"

- pre- and post-scattering
- di-jet: $\Delta\phi \neq \pi$

In QCD Medium

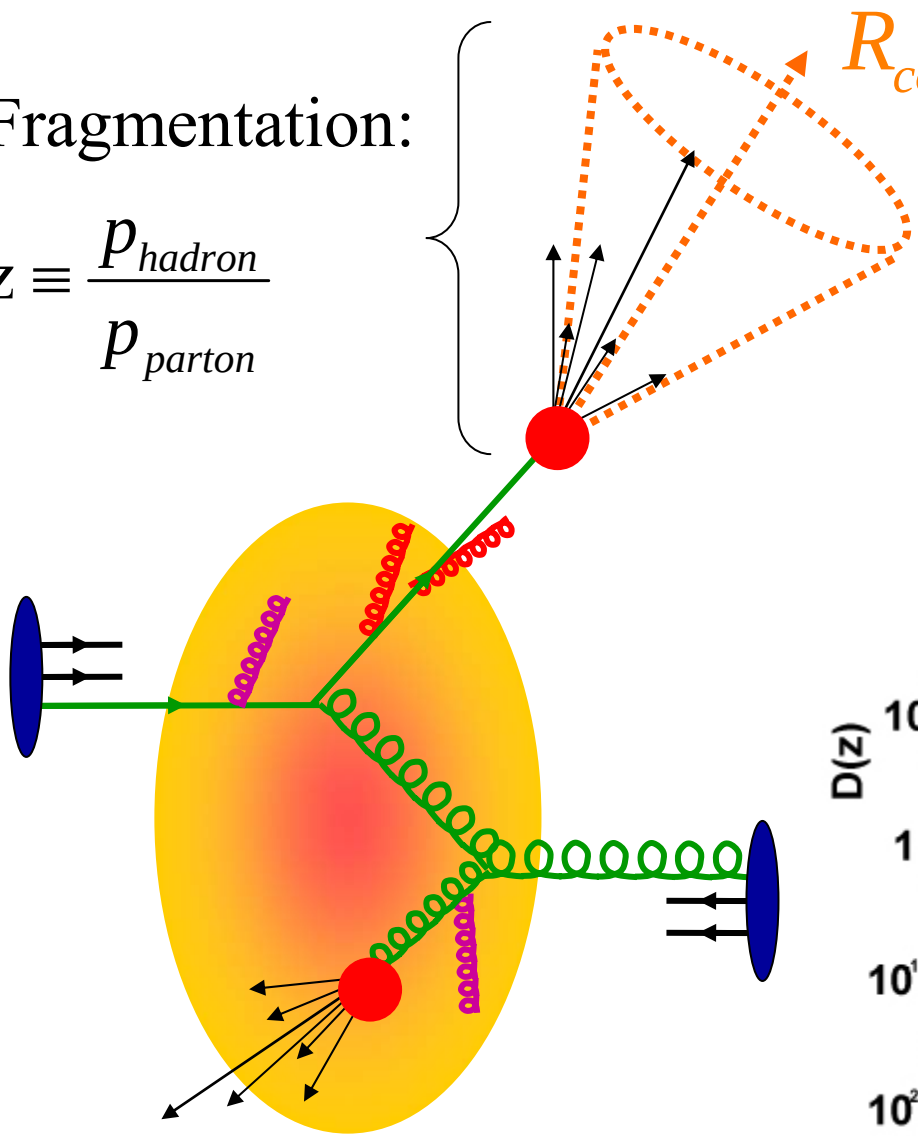
- Additional k_T
- Significant energy loss? ⇒high p_T suppression
- ***Sensitive to color properties of medium***

"So, why jets?"

Moment Analysis of QCD Matter

Fragmentation:

$$z \equiv \frac{p_{hadron}}{p_{parton}}$$



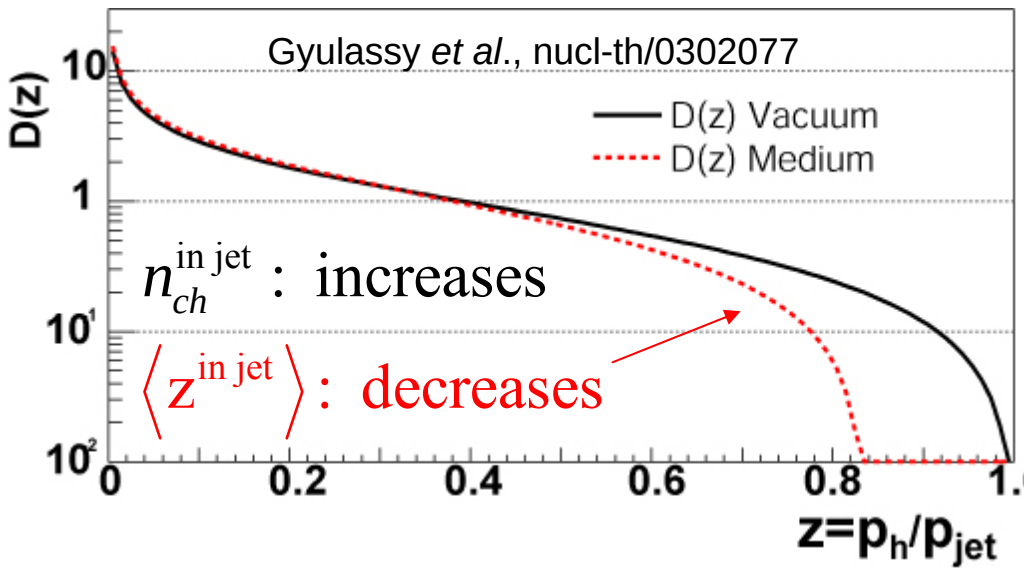
$$\left\langle \Delta k_T^2 \right\rangle \sim \int \rho_g(x)\, dx$$

$$\left\langle \Delta E \right\rangle \sim \int x\, \rho_g(x)\, dx$$

I. Vitev, nucl-th/0308028

Induced Gluon Radiation

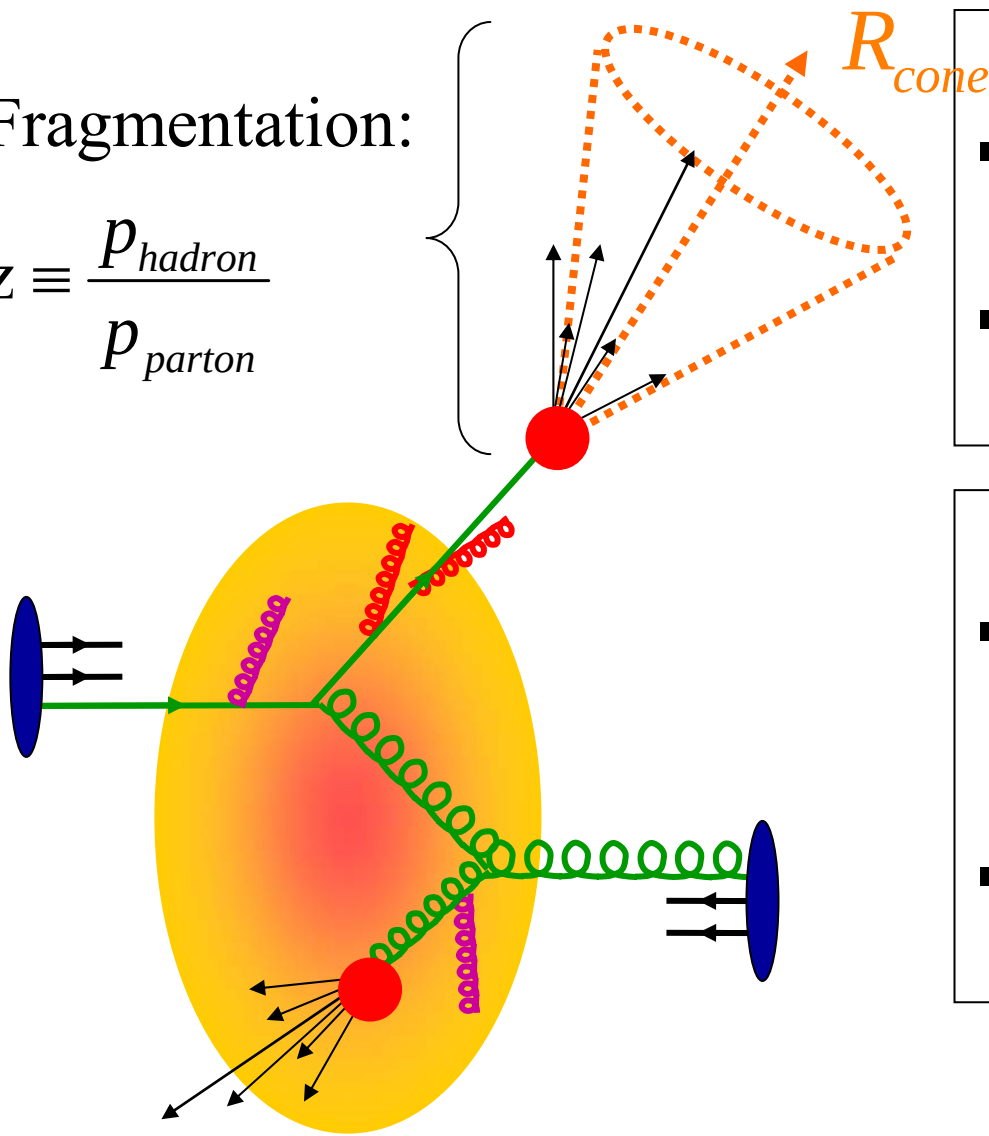
- ~collinear ⇒gluons in cone
- "Softened" fragmentation



Partonic vs. Hadronic Mechanisms

Fragmentation:

$$z \equiv \frac{p_{hadron}}{p_{parton}}$$



Hottest Questions:

- Fragment inside/outside of medium?
- Partonic vs. hadronic model of Final State interaction?

A Better Question:

- *To what degree* do partonic and hadronic interactions contribute to quenching?
- Discussion only recently started!

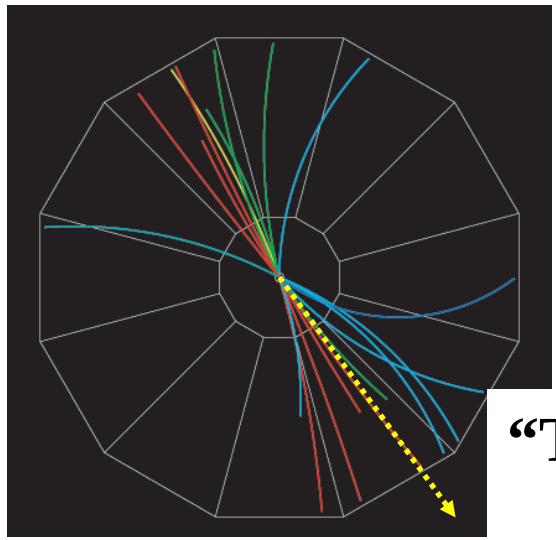
4 Ways to "Skin a ~~Cat~~ Jet"

1) Integral Distributions:
   $\langle p_T \rangle$, $\langle N_{ch} \rangle$

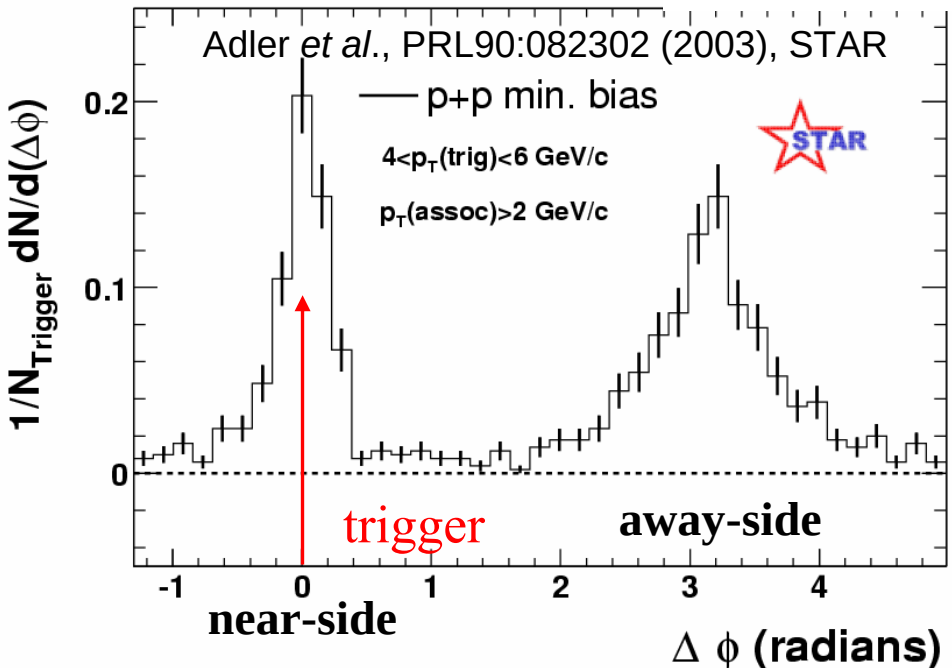
2) Single Particle Spectra:
   $d\sigma/dp_T \Rightarrow R_{AA}$, R_{dA}

3) 2-Particle Correlations:
   $dN/d(\Delta\phi)$

4) Jet Reconstruction:
   $d\sigma/dE_T$, *Frag. Func.*



"Trigger"
$\phi = 0$



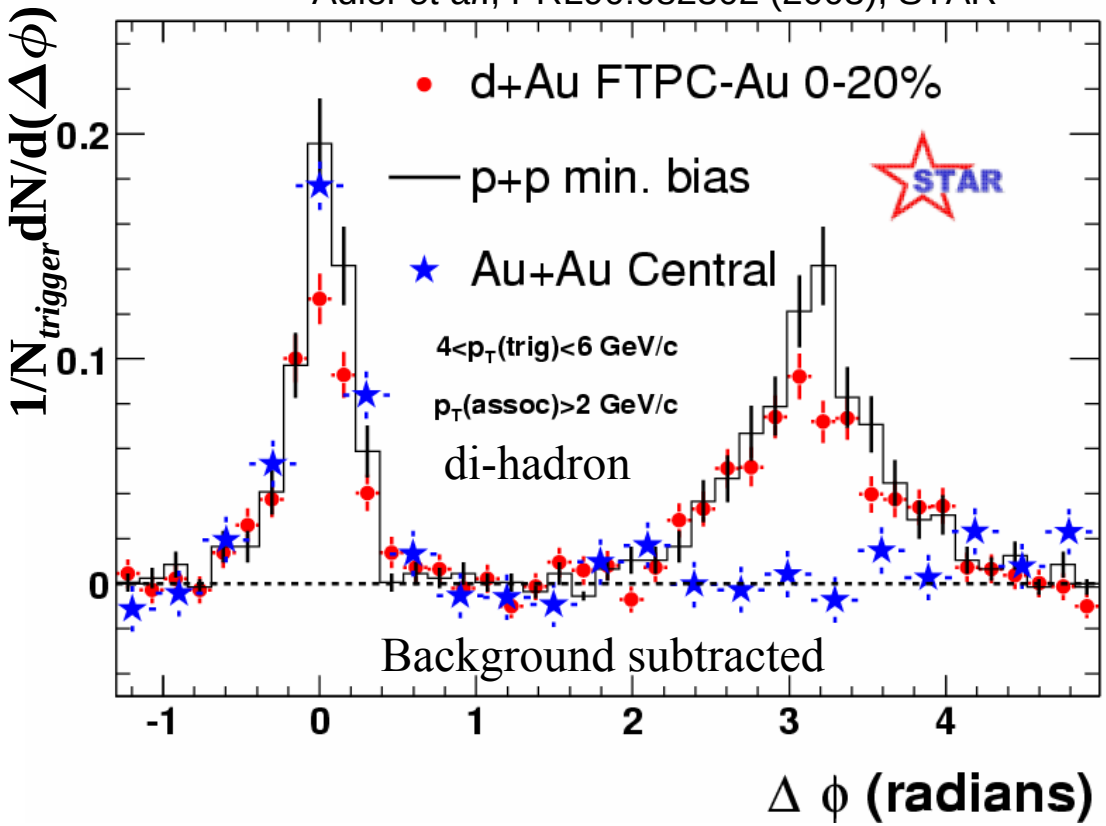
Disappearance of the away-side

2nd order correlations due to elliptic flow of entire event ⇒competing background

- p+p
  - ✓2-jets
- Peripheral Au+Au
  - ✓2-jets
- Central Au+Au
  - ? ***1-jet!***

$Au + Au, \quad \sqrt{s_{NN}} = 200$ GeV

Adams *et al.*, Phys. Rev. Let. 91 (2003)
Adler *et al.*, PRL90:082302 (2003), STAR



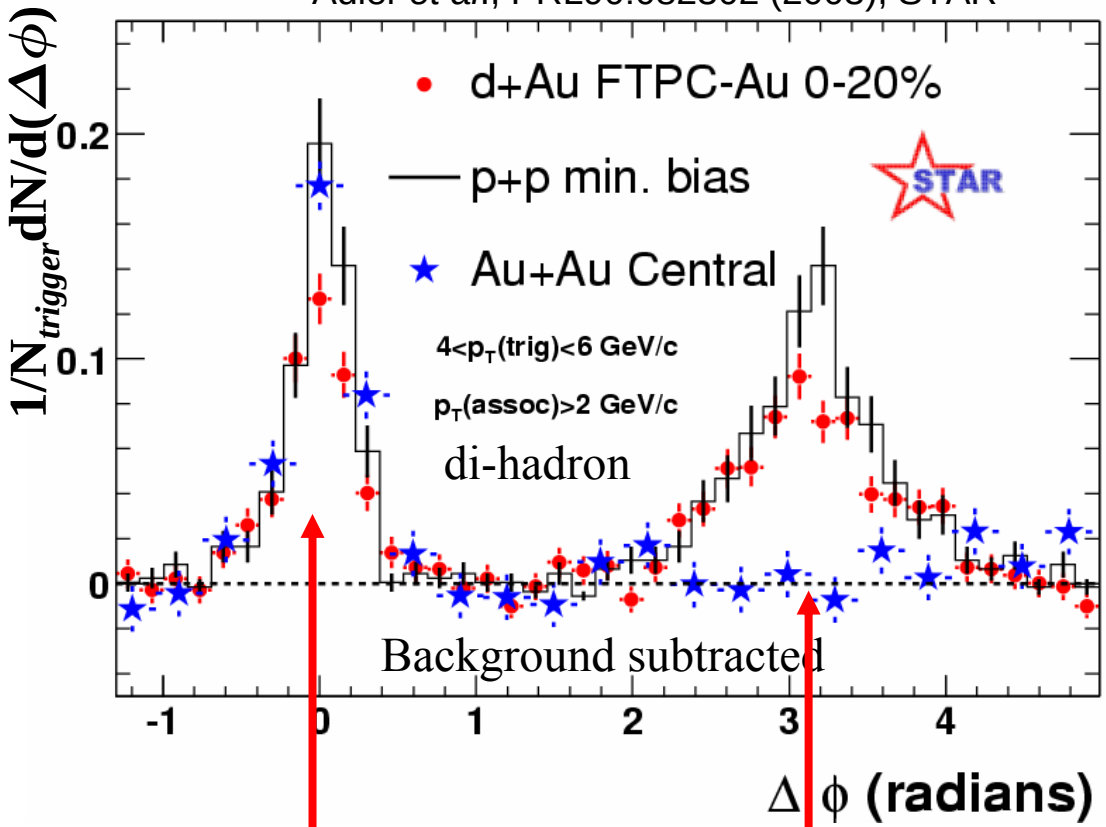
Disappearance (at mid-rapidity) is dominated by final state effect(s)! *Jet Quenching*

2nd order correlations due to elliptic flow of entire event ⇒competing background

- p+p
  - ✓2-jets
- Peripheral Au+Au
  - ✓2-jets
- Central Au+Au
  - ? ***1-jet!***
- d+Au
  - ✓2-jets

$Au + Au, \quad \sqrt{s_{NN}} = 200 \text{ GeV}$

Adams *et al.*, Phys. Rev. Let. 91 (2003)
Adler *et al.*, PRL90:082302 (2003), STAR



Near side jet "identical"

pp≈dAu≠AuAu

Questions Raised at QM02

- Initial state effects?
- What should 2-particle correlation look like?
  - Partonic/nuclear k_T
  - j_T
- Measurable at SPS?
- Final state energy loss?

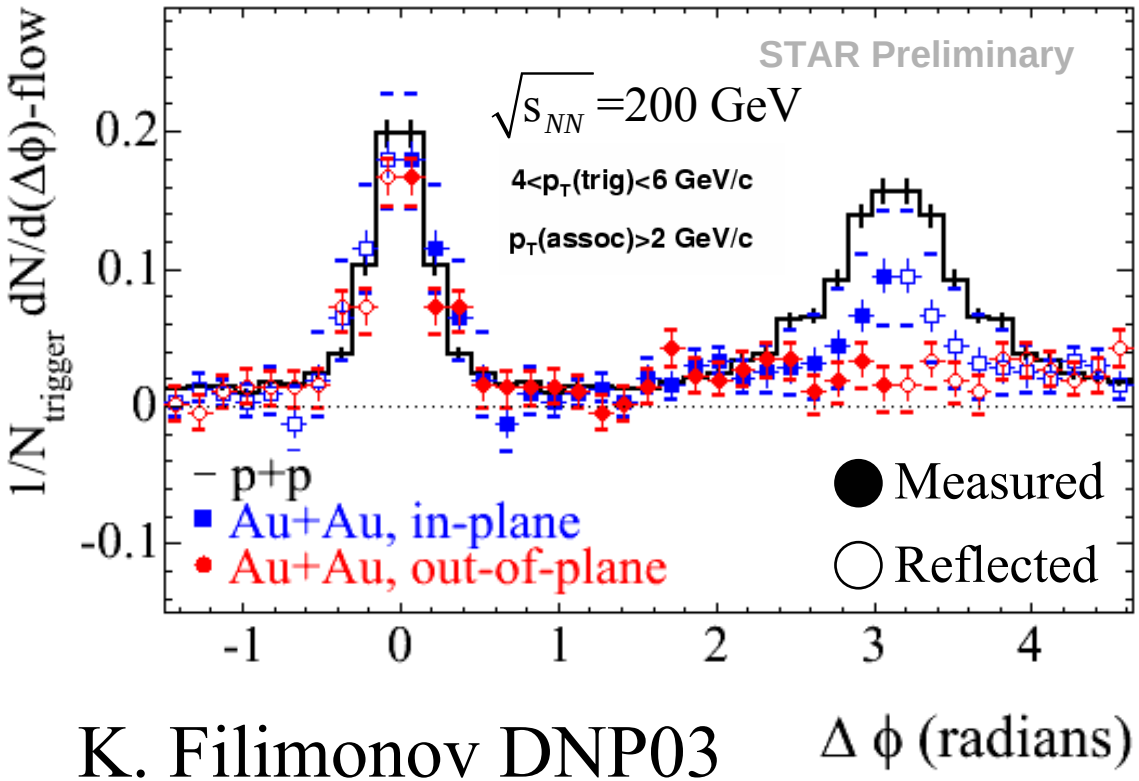
This talk

- Baryons vs. Mesons?
- PID?
- Background subtraction?
- Jets correlated with reaction plane?
- And many more…

Discussed in parallel

Path Length Dependence

di-hadron, 20-60% Central

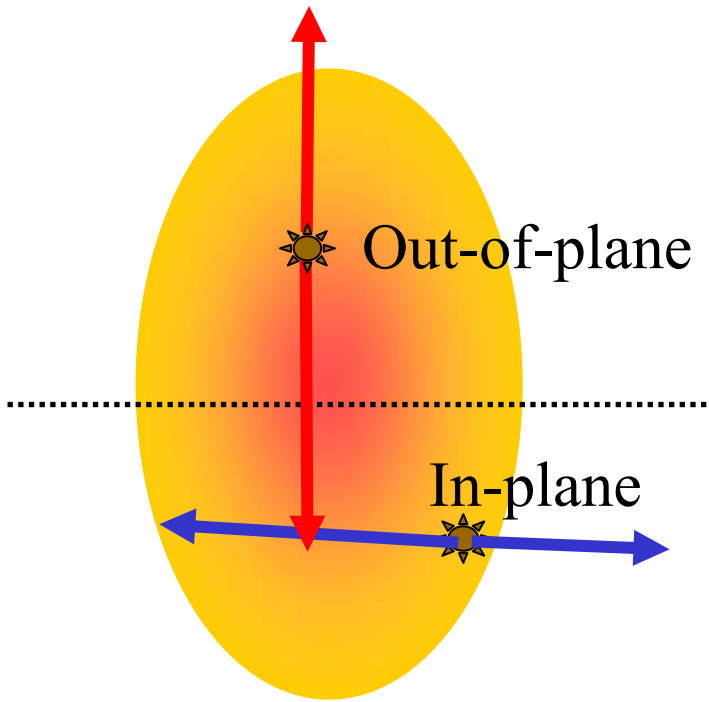


K. Filimonov DNP03

Suppression larger out-of-plane

Background Subtracted

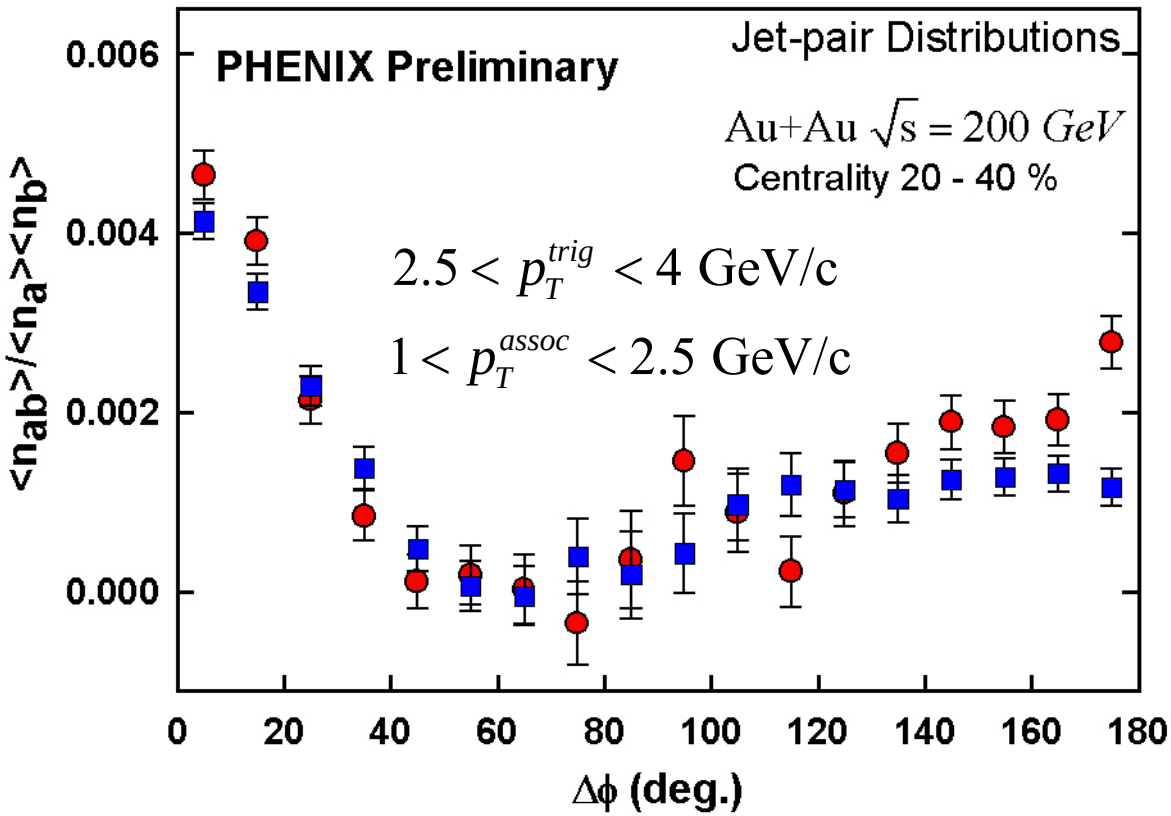
See J. Bielcikova *et al.*, (nucl-ex/0311007) for background derivation



$$\Delta E_{GLV} \sim L^n(\phi)$$

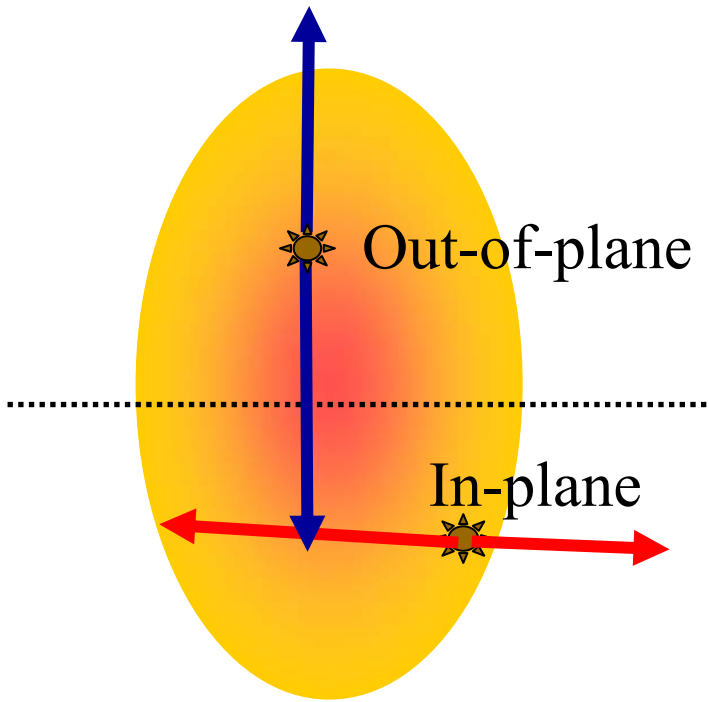
Path Length Dependence

di-hadron, 20-40% Central



Background Subtracted

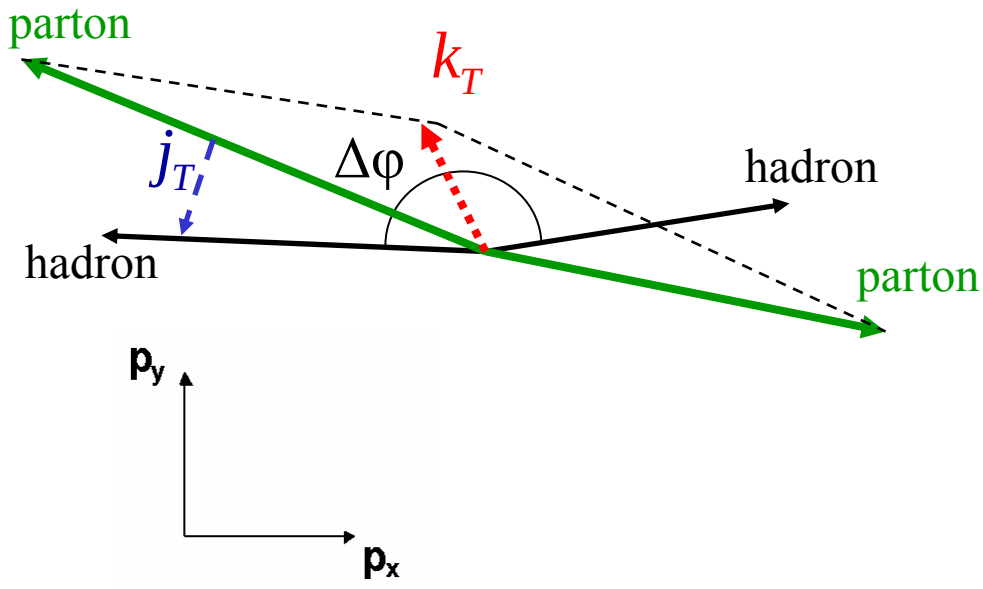
See J. Bielcikova *et al.*, (nucl-ex/0311007) for background derivation



$$\Delta E_{GLV} \sim L^n(\phi)$$

Quenching: Consistent with path length Dependence

Jet Fragmentation: "Shape"



$\left\langle \left| k_{Ty} \right| \right\rangle$: $\left\langle \vec{p}_T^{\,a} + \vec{p}_T^{\,b} \right\rangle$ of colliding partons

$\left\langle \left| j_{Ty} \right| \right\rangle$: $\left\langle p_T \right\rangle$ of hadron $\perp$ to jet axis

di-hadron

$$\left\langle \left| j_{\perp y} \right| \right\rangle = \left\langle p_\perp \right\rangle \sin \frac{\sigma_{Near}}{\sqrt{\pi}}$$

$$\left\langle \left| k_{Ty} \right| \right\rangle \approx \frac{\left\langle p_T \right\rangle}{\left\langle z \right\rangle} \sqrt{\sigma_{Far}^2 - \sigma_{Near}^2}$$

Jet "width"

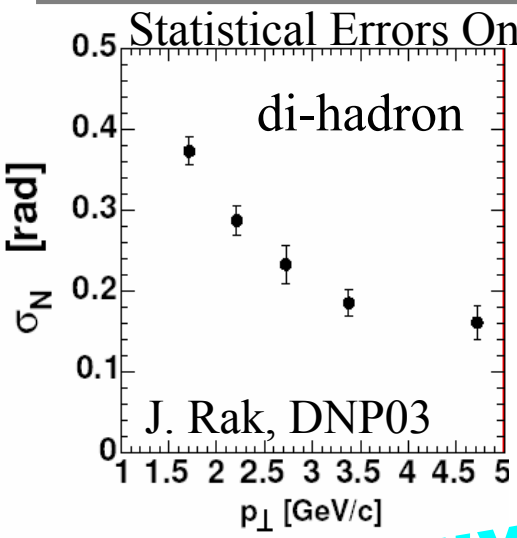
Jet-coplanarity

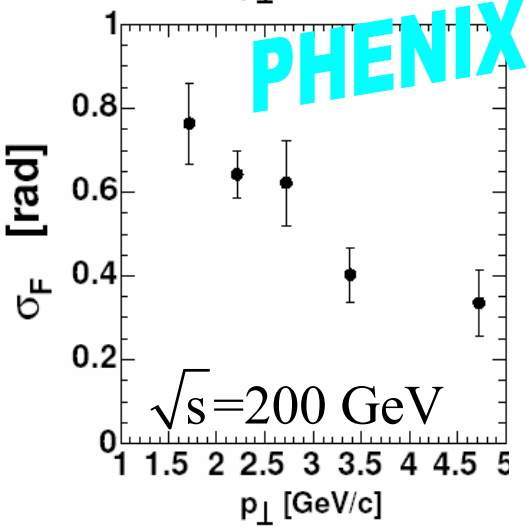
Reconstructed jets

$$j_T = p_T^{hadron} \sin\left(\theta_{jet-had}\right)$$

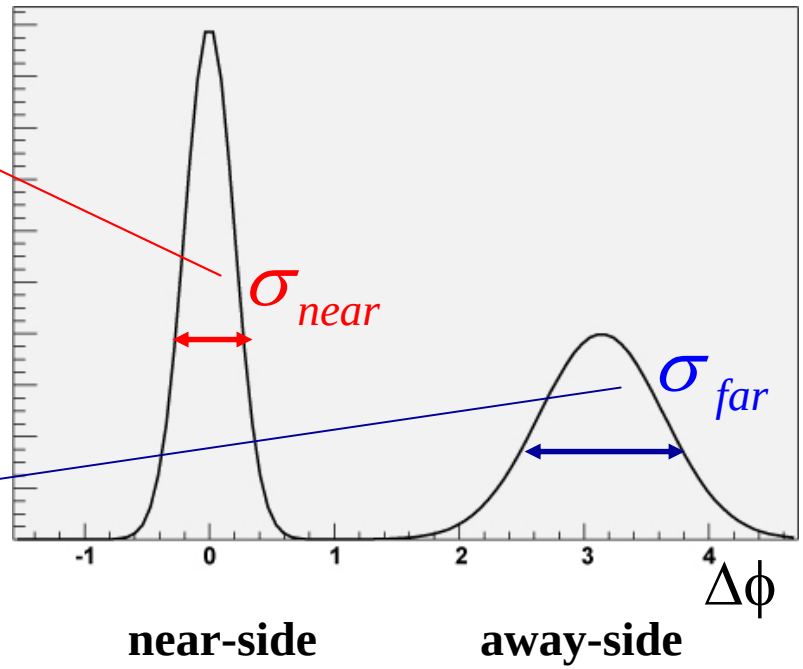
$$k_T = p_T^{jet} \sin\left(\Delta\phi_{jet-jet}\right)$$

k_T, j_T at RHIC from p+p Data

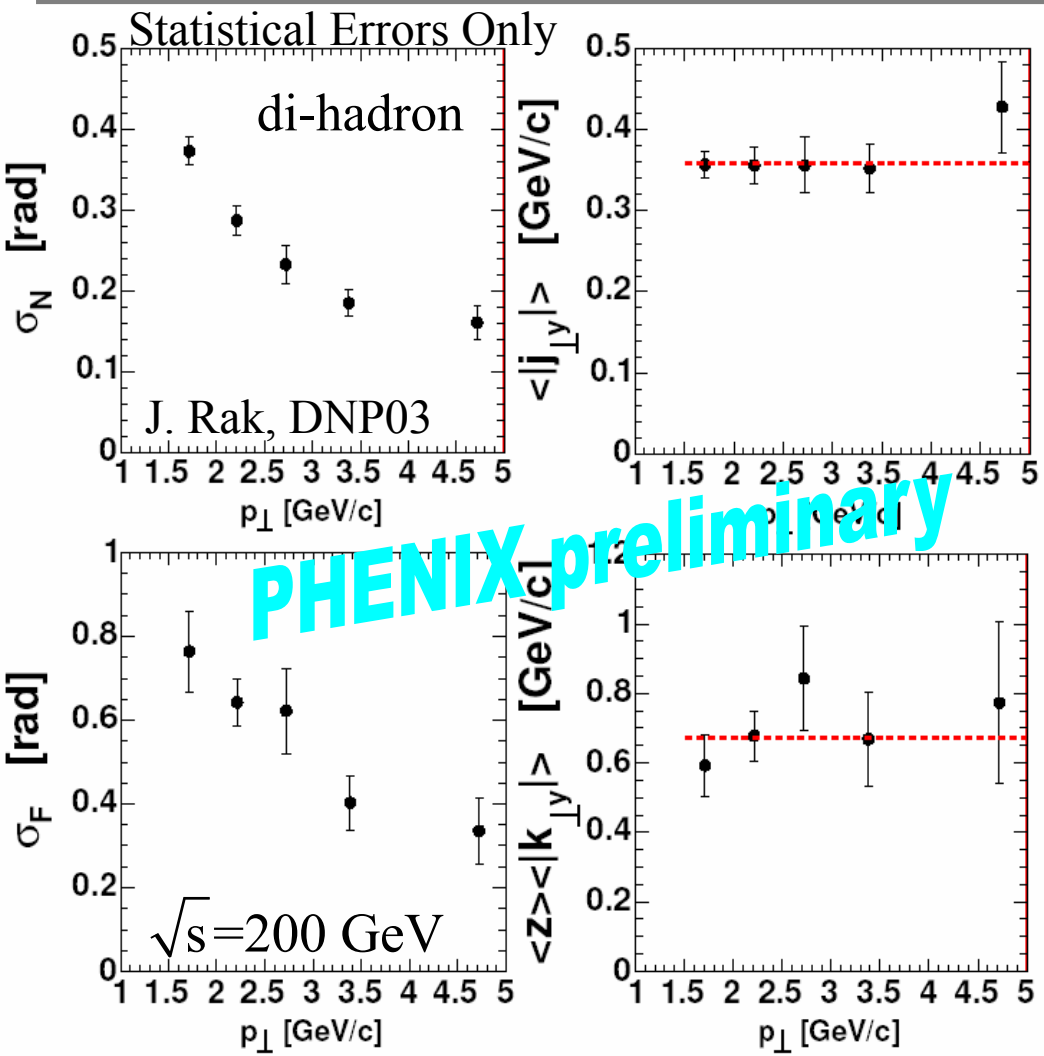




PHENIX preliminary



k_T, j_T at RHIC from p+p Data

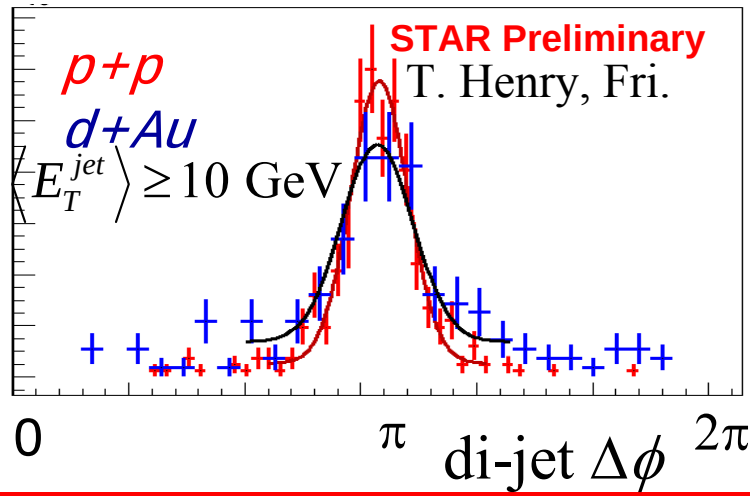


PHENIX preliminary

$\langle|j_{Ty}|\rangle = 359\pm11$ MeV/c

$\langle|k_{Ty}|\rangle = 964\pm49$ MeV/c

Good agreement with previous measurements: PLB97 (1980)163 PRD 59 (1999) 074007

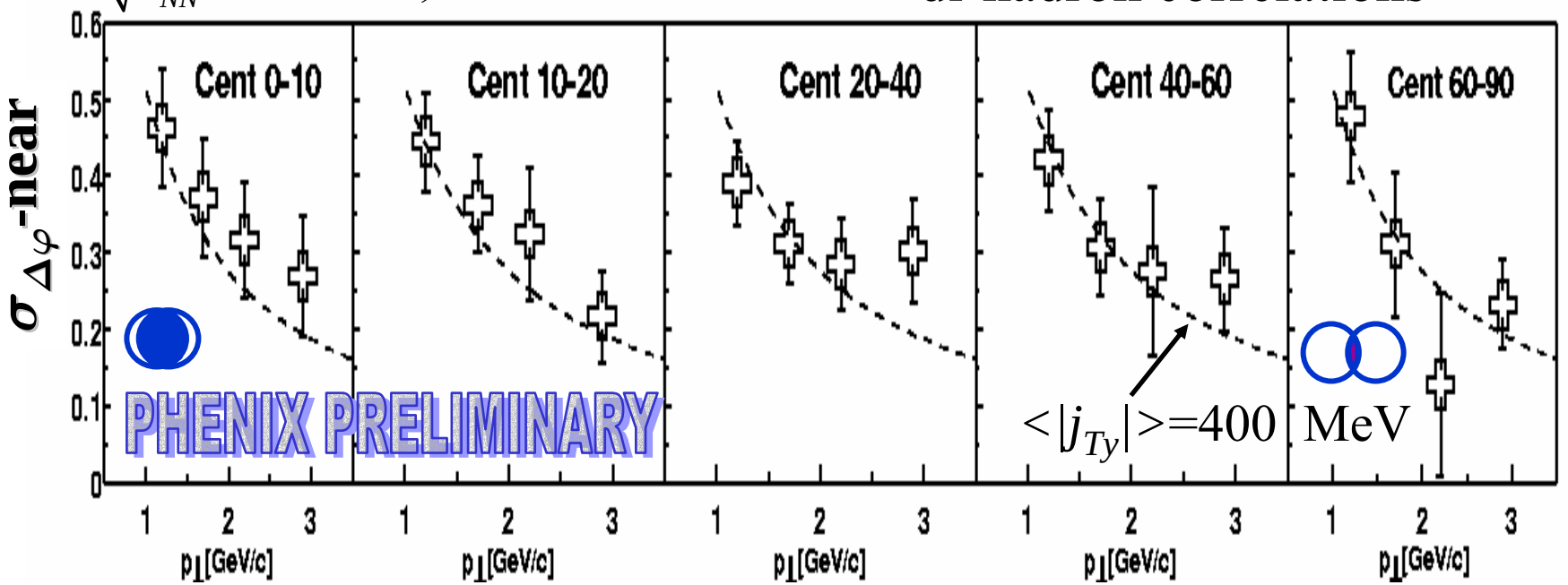


k_T, j_T from *p+p*, *d+Au*, *Au+Au* from "π^0"-hadron, di-hadron, jet, di-jet

⇒Friday: Completing the reference measurements!

Au+Au near-side: Jet-like at all centralities?

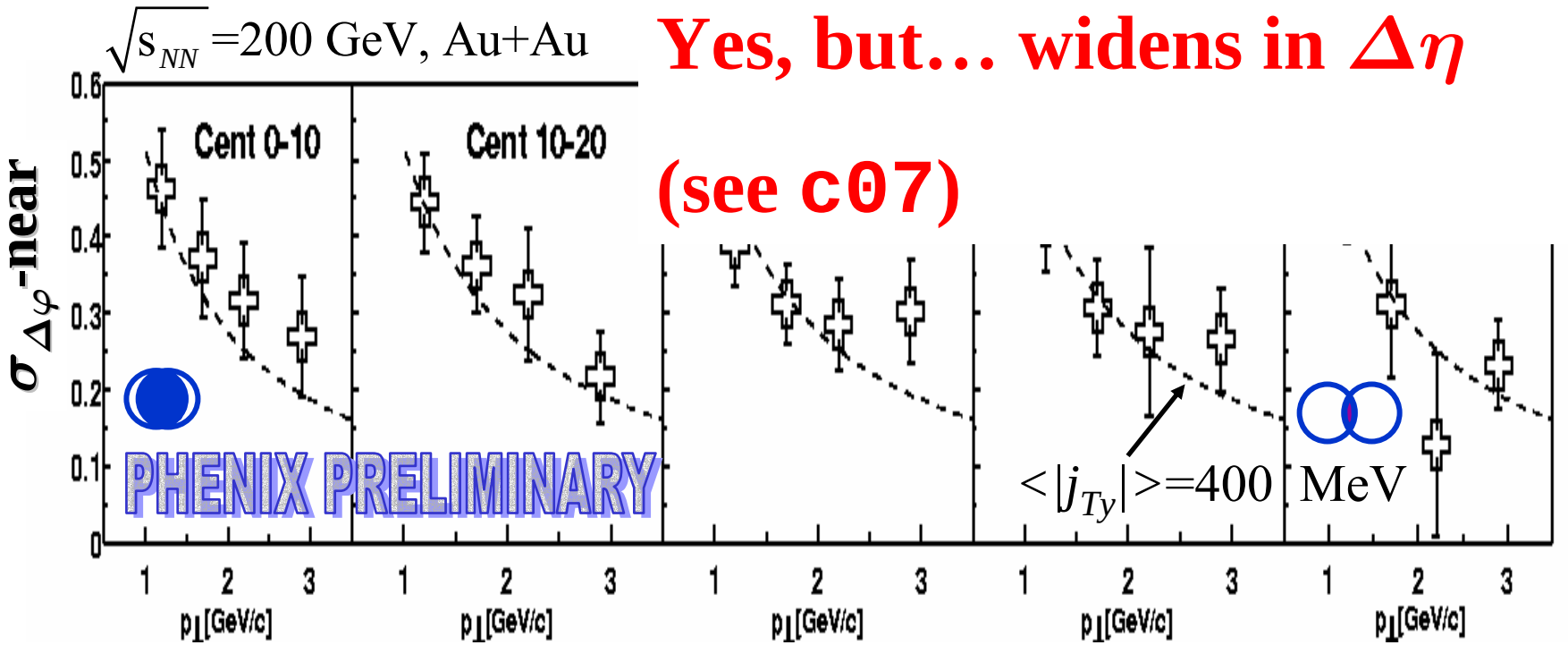
$\sqrt{s_{NN}}$=200 GeV, Au+Au di-hadron correlations



Follows fragmentation prediction:

$$\sigma = \sqrt{\pi}\,\sin^{-1}\frac{\left\langle \left| j_{Ty} \right| \right\rangle}{\left\langle p_T \right\rangle}$$

Au+Au near-side: Jet-like at all centralities?



Yes, but… widens in $\Delta\eta$

(see c07)

Follows fragmentation prediction:

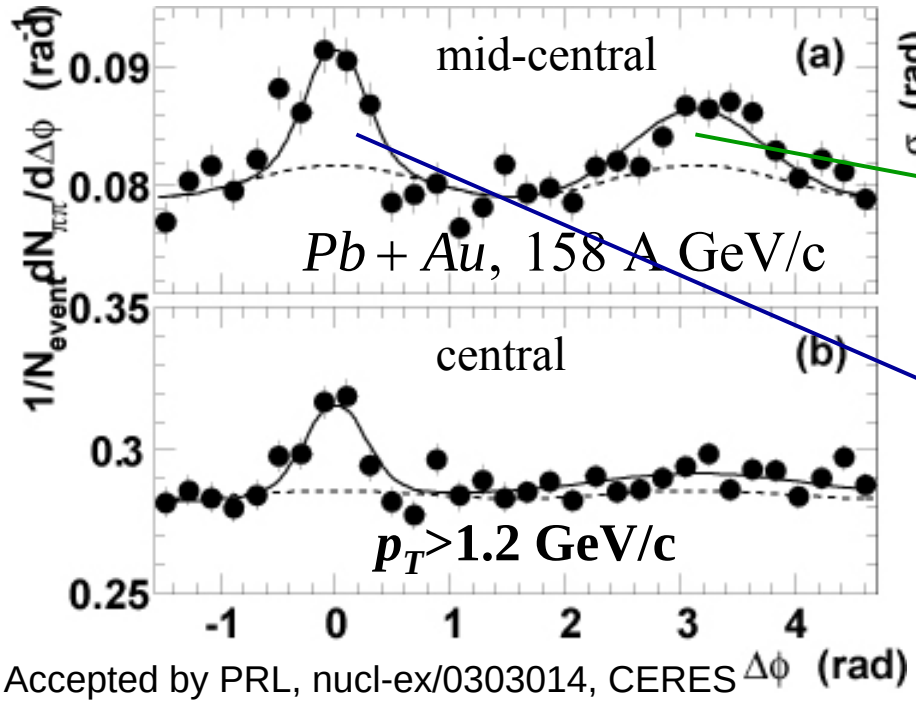
$$\sigma = \sqrt{\pi}\,\sin^{-1}\frac{\left\langle\left|j_{Ty}\right|\right\rangle}{\left\langle p_T\right\rangle}$$

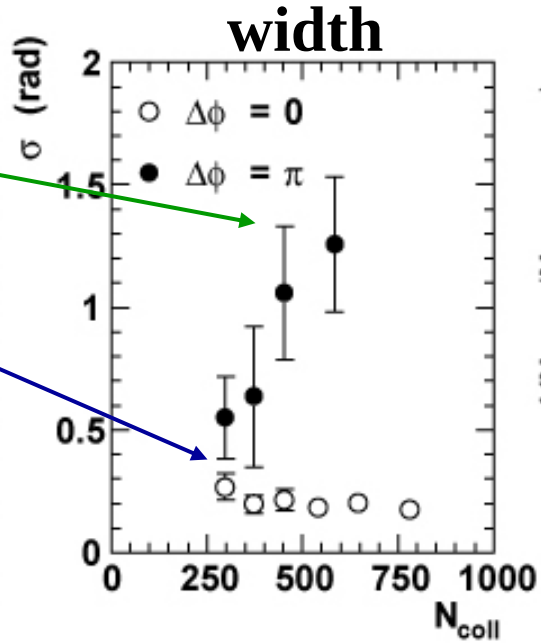
Quenching at SPS?

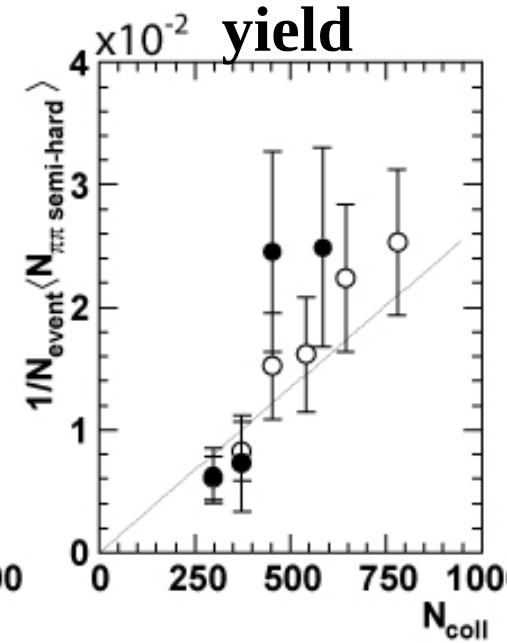
No, but…

Broadening at RHIC!

charged-pion pairs







Accepted by PRL, nucl-ex/0303014, CERES

Near angle correlations:

- Present at all centralities
- Consistent with fragmentation

Away side correlations:

- Present at all centralities
- Width broadens with centrality

+ WA98 Spectra: R_{AA}>1

See p36

~~Quenching at SPS?~~

Where is the enhancement at RHIC?

Di-Hadrons at "all" p_T

See F. Wang, Fri. QM04

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

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

$|\eta| < 1.1$

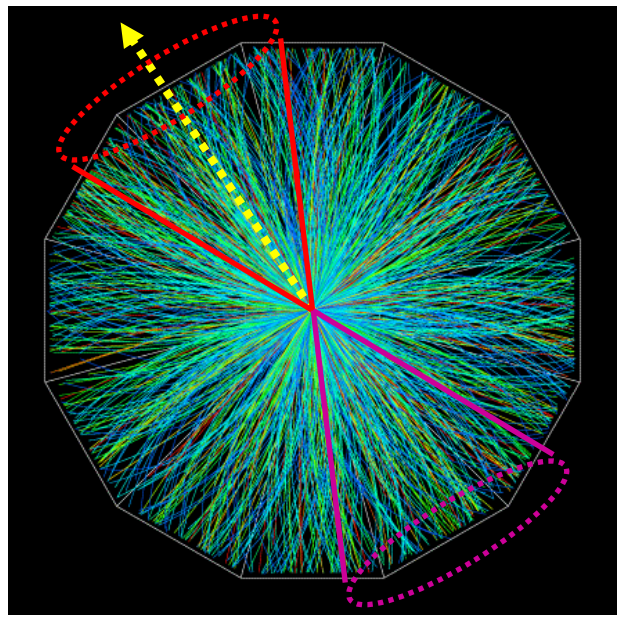
+ mixed event background subtraction

+ elliptic flow background subtraction

⇒Study "fragmentation" in p+p, Au+Au

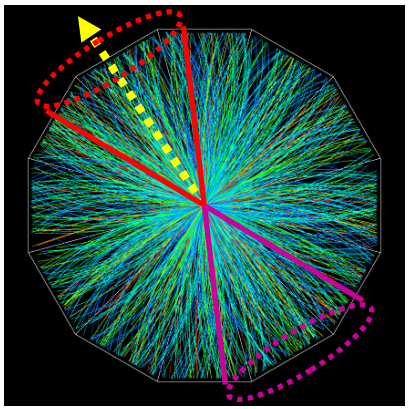
- Full range in p_T
- Transport from high-p_T to low-p_T?
- Change in jet "size"?

di-hadron correlations



Study p_T distribution in near- and away-side jet cones

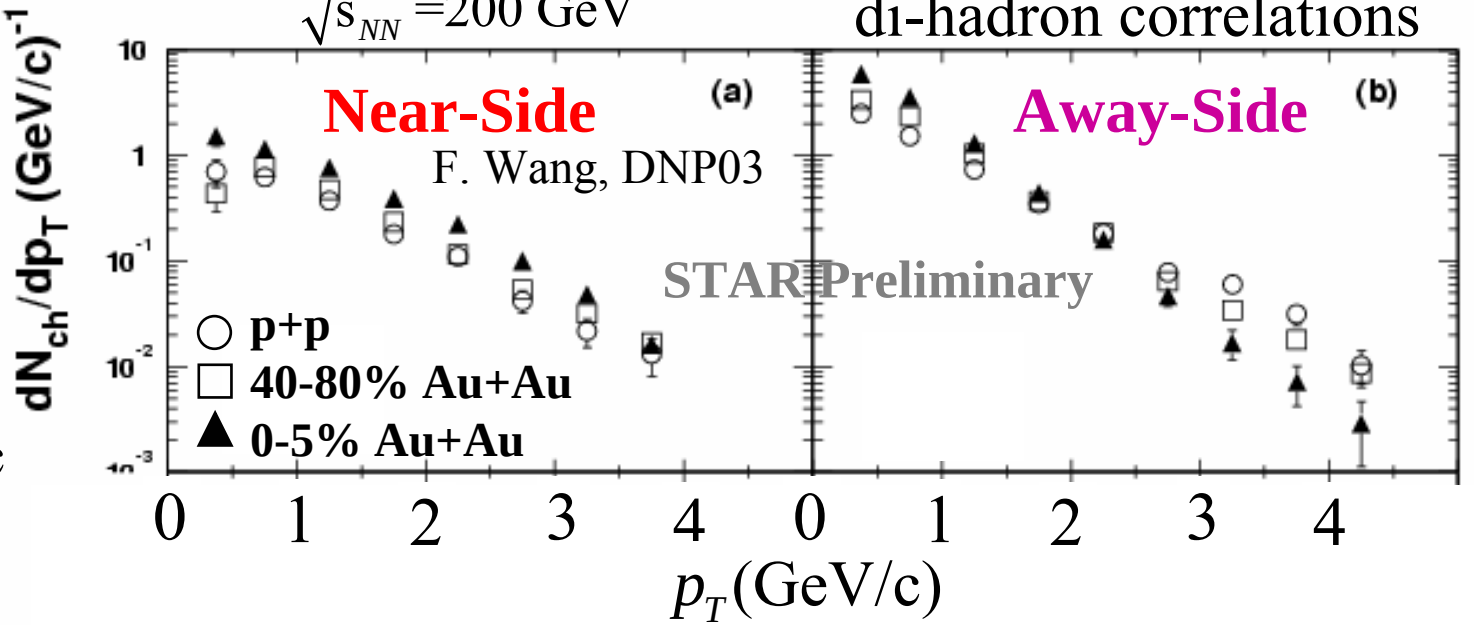
Di-Hadrons at "all" p_T



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

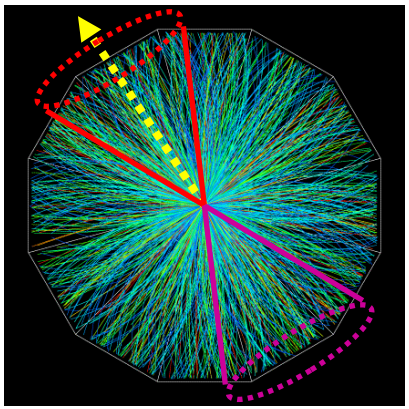
$\sqrt{s_{NN}}$ =200 GeV

di-hadron correlations



See F. Wang Friday

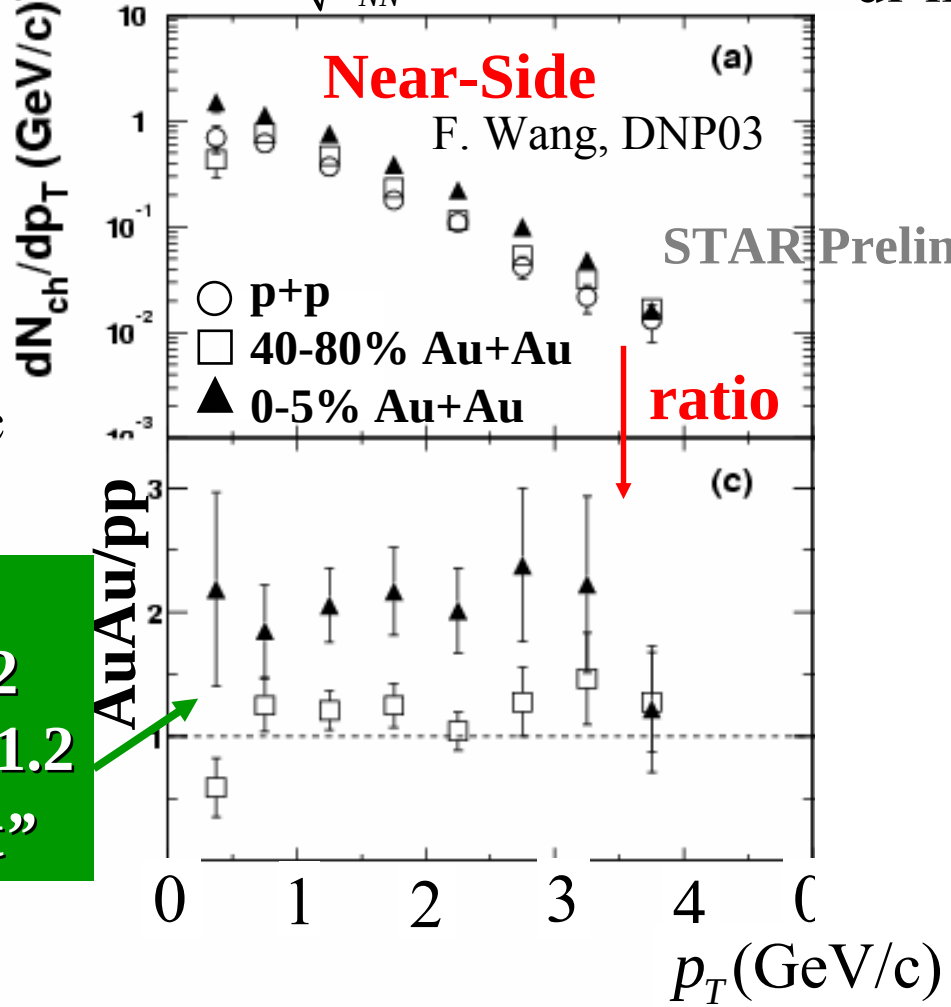
p_T Distribution in Near-Side Jet



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

$\sqrt{s_{NN}}$ =200 GeV

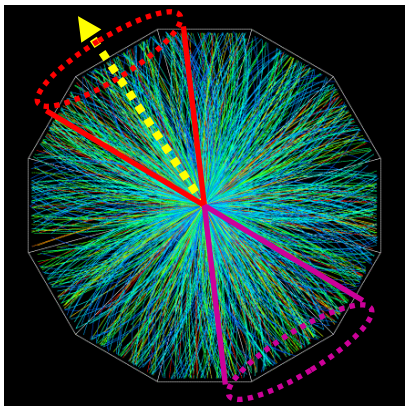
di-hadron correlations



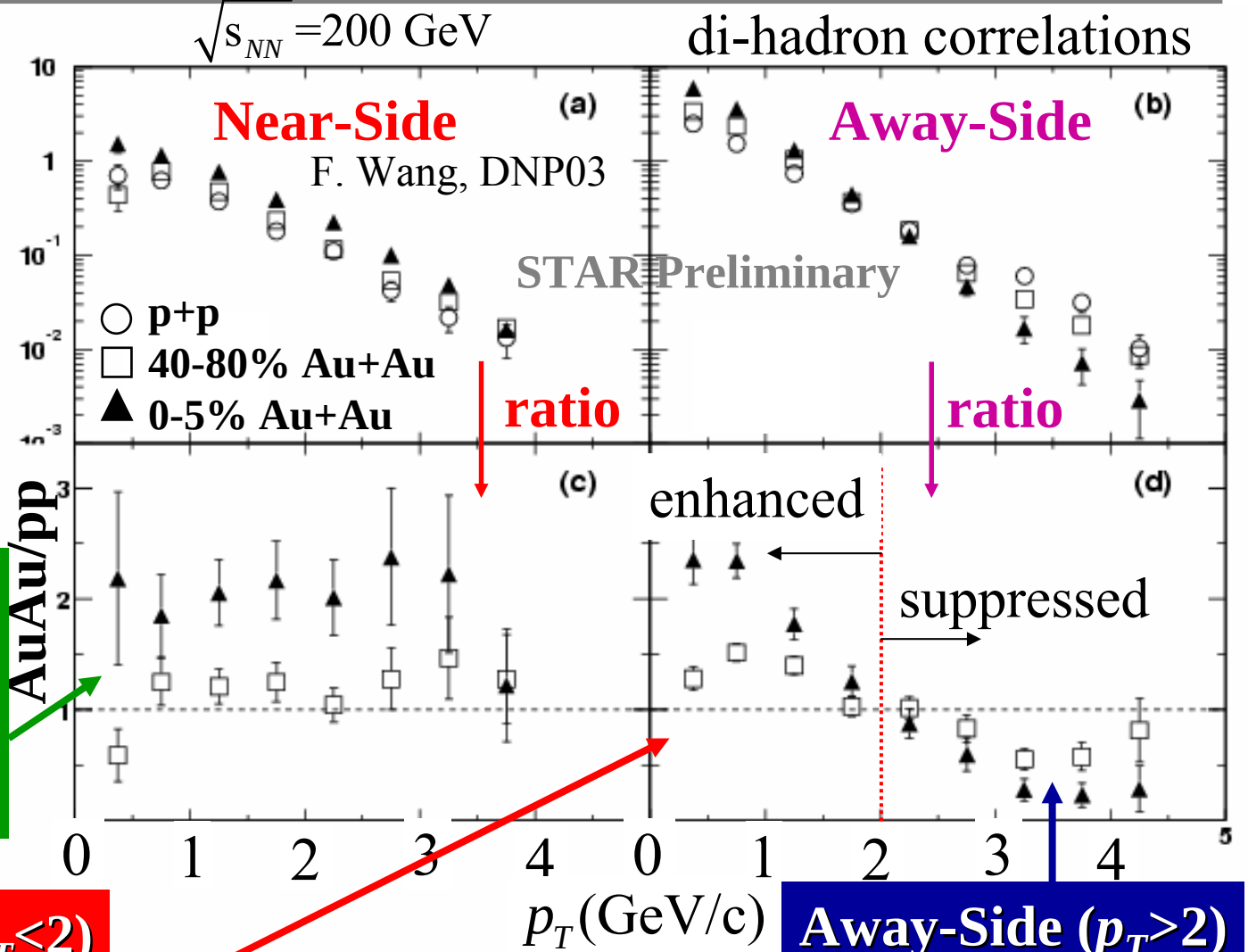
Near-Side
0-5% / pp ≈ 2
40-80% / pp ≈ 1.2
"enhancement"

See F. Wang Friday

p_T Distribution in Away-Side Jet



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



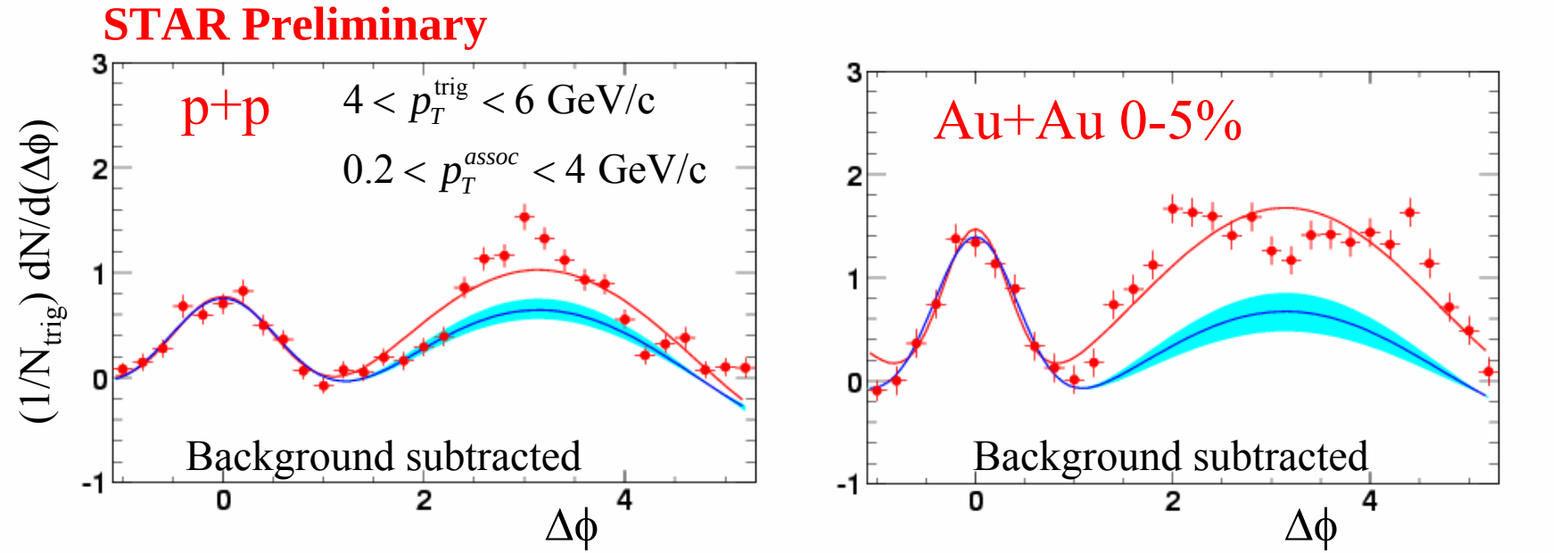
Near-Side
0-5% / pp ≈ 2
40-80% / pp ≈ 1.2
"enhancement"

Away-Side (p_T<2)
AuAu/pp >1
"Enhancement!"

See F. Wang Friday

Away-Side (p_T>2)
AuAu/pp <1
"Disappearance"

Is The Away-Side Jet-Like?

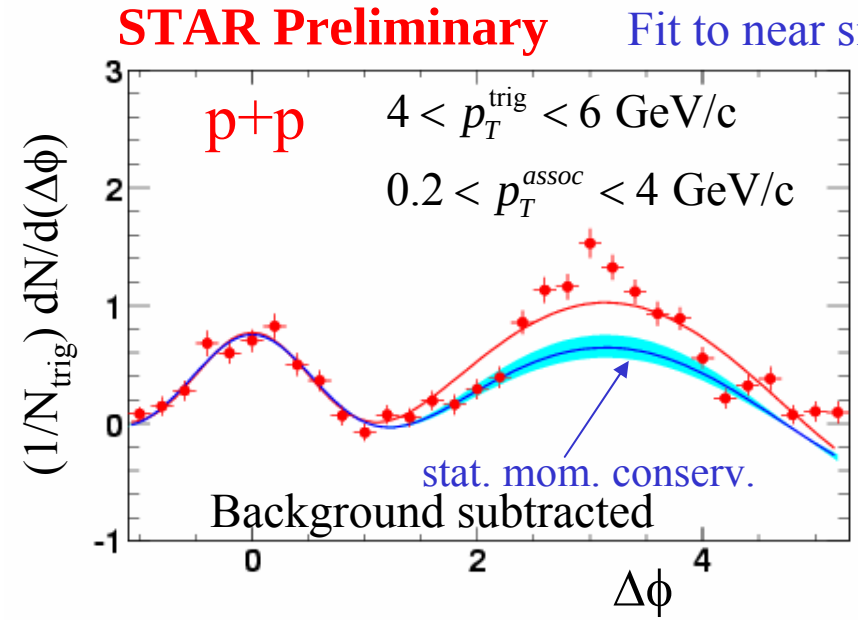


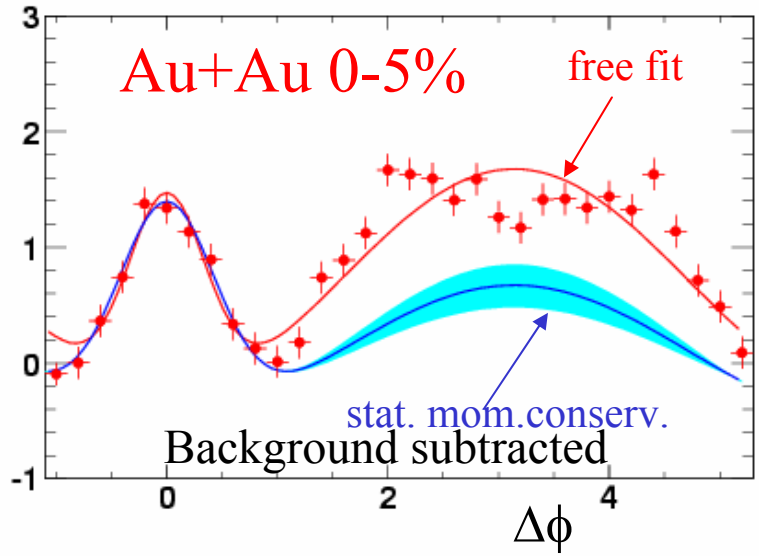
Away-side looks jet-like in p+p, not central Au+Au!

So what's going on?

See F. Wang Friday

Is The Away-Side Jet-Like?





Borghini *et al.*, nucl-th/0004026

Momentum conservation:

$$C_2\left(\vec{p}_1,\vec{p}_2\right) = -2\frac{p_{T1}p_{T2}\cos\left(\Delta\phi\right)}{N_{total}\left\langle p_T^2\right\rangle}$$

$$\int C_2\left(\vec{p}_1,\vec{p}_2\right)dp_{T2} \sim \frac{-N_{measured}}{N_{total}}\cos\left(\Delta\phi\right)$$

$\sim 1/10$

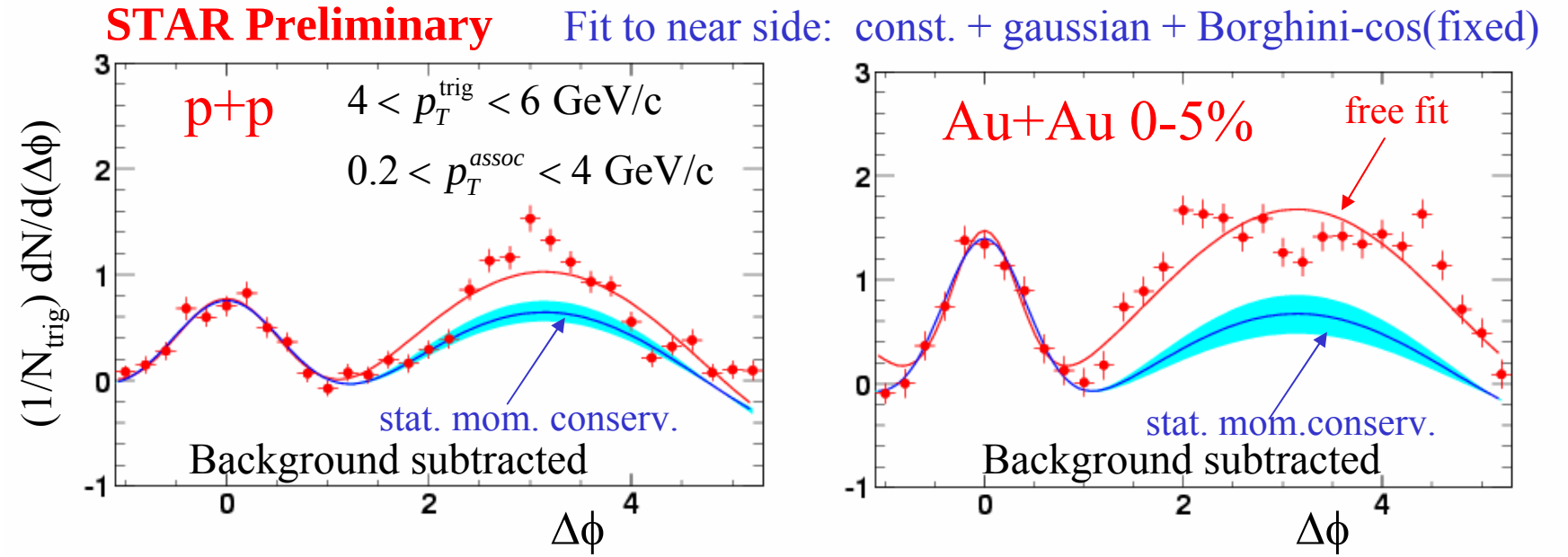
Amplitude:

- **Depends on p_T "window"**
- **Can be tested**
- **Work in progress**

(see)

See F. Wang Friday

What could this mean?



Pessimist:

A fundamentally boring result…*Another* background

Optimist:

Maybe the most exciting result yet!

⇒Away-side energy re-distributed over many particles, broad in angle, but it is still there!

See F. Wang Friday

Conclusions

- 2-particle correlations
  - Successful measure of hard-scattering, fragmentation
- Away-side quenching in central Au+Au
  - Indicative of strong final state interactions
  - In/out-of plane consistent with path length dependence
- Semi-hard scattering at SPS
  - Present at all centralities
  - Large away-side broadening
- Near-side correlations in Au+Au
  - Consistent with fragmentation at all centralities
- p_T distribution in near- and away-side jet cones
  - Consistent with modified fragmentation?

The *Real* Conclusions

- 2-particle correlations
  - Robust jet probe from p+p to central Au+Au
- QM02→Disappearance of away-side jet
- QM04→Finding the "lost-energy" on the away-side
  - Qualitative consistency between PHENIX and STAR
  - "Transport" from high p_T → low p_T
  - But… away-side has lost jet-like shape!

Future Directions at RHIC

- Minimize ambiguities, sensitivities
  - Higher trigger $p_T \rightarrow$ only jet production
  - higher trigger $p_T \rightarrow$ smaller k_T effects
- Higher statistics test of path length dependence
- Away-side p_T "transport"
  - d+Au?
  - Trigger-p_T dependence?
  - Punch through above momentum conservation?
- Calibrate the jet-energy scale: photon-jet
- Mass effect: heavy quarks vs. light quarks ΔE
- Color charge: quark vs. gluon jets?