Review of Hard Scattering and Jet Analysis

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Correlations and Fluctuations in Relativistic Nuclear Collisions,
Galileo Galilei Institute,
Arcetri, Florence, Italy
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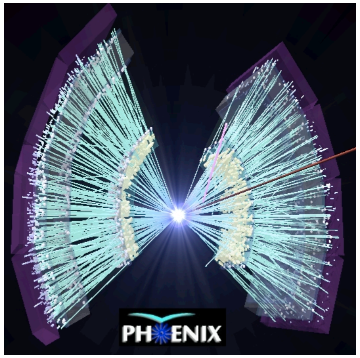


LO-QCD in 1 slide

Cross Section in p-p collisions c.m. energy $\sqrt{s}$

The overall p-p reaction cross section
is the sum over constituent reactions

$$a + b \rightarrow c + d$$

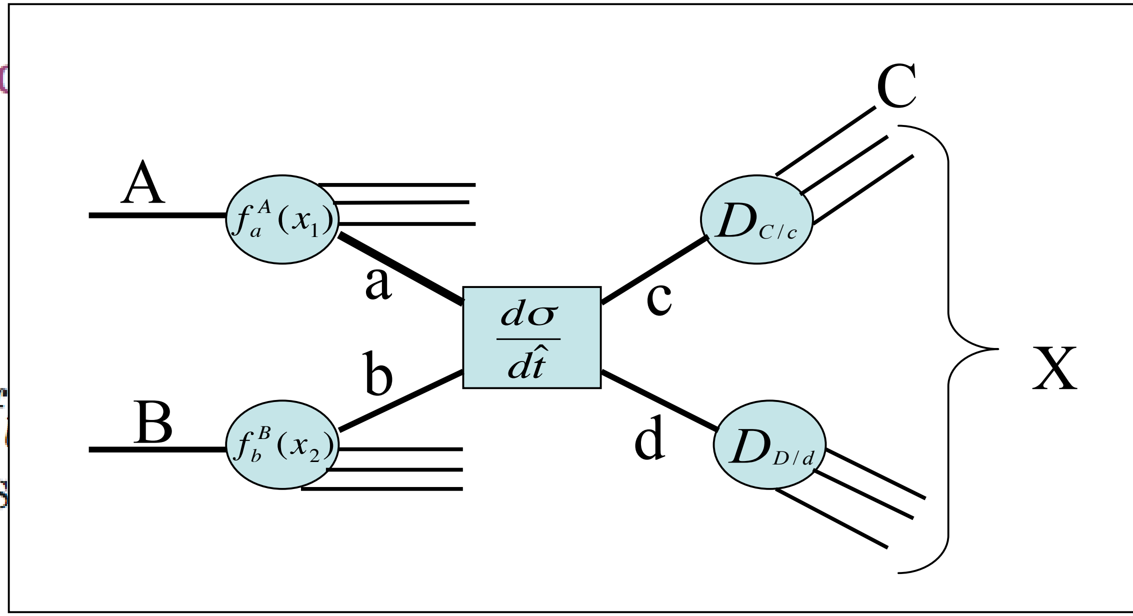
$f_a^A(x_1)$, $f_b^B(x_2)$, are structure functions, the differential probabilities
for constituents a and b to carry momentum fractions x_1 and x_2
of their respective protons, e.g. $u(x_1)$,

$$\frac{d^3\sigma}{dx_1 dx_2 d\cos\theta^*} = \frac{1}{s}\sum_{ab} f_a^A(x_1) f_b^B(x_2) \frac{\pi\alpha_s^2(Q^2)}{2x_1x_2}\Sigma^{ab}(\cos\theta^*)$$

$\Sigma^{ab}(\cos\theta^*)$, the characteristic subprocess angular distributions
and $\alpha_s(Q^2) = \frac{12\pi}{25\ln(Q^2/\Lambda^2)}$ are predicted by QCD

LO-QCD in 1 slide

Cr... y $\sqrt{s}$



$f_a^A(x_1)$, f... probabilities

for cons... x_1 and x_2

$$\frac{d^3\sigma}{dx_1 dx_2 d\cos\theta^*} = \frac{1}{s}\sum_{ab} f_a^A(x_1) f_b^B(x_2) \frac{\pi\alpha_s^2(Q^2)}{2x_1x_2}\Sigma^{ab}(\cos\theta^*)$$

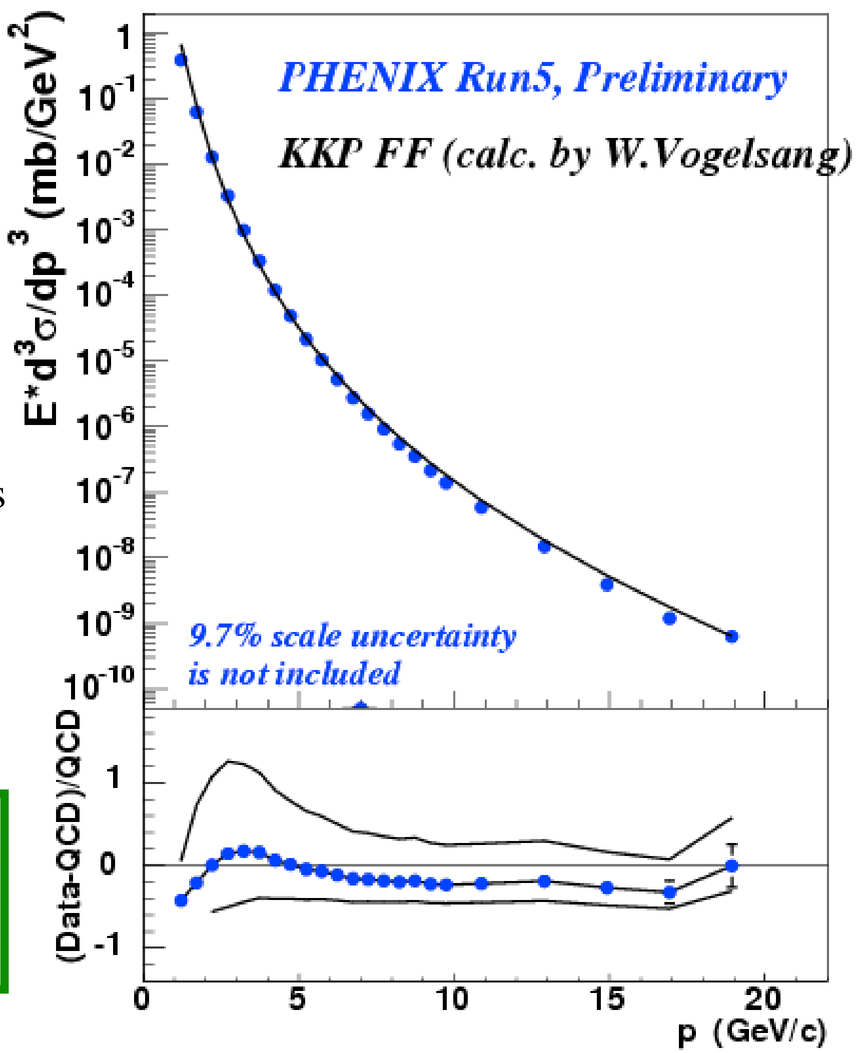
$\Sigma^{ab}(\cos\theta^*)$, the characteristic subprocess angular distributions and $\alpha_s(Q^2) = \frac{12\pi}{25\ln(Q^2/\Lambda^2)}$ are predicted by QCD

π^0's in p+p: Data vs. pQCD

- Result from run2 published-a classic
  - ✓ PRL91 (2003) 241803
- New result from run5
  - ✓ preliminary
- Comparison of π^0 cross section
  - ✓ Next-to-leading order(NLO) pQCD
    - CTEQ6M + KKP or Kretzer
    - Matrix calculation by Aversa, et. al.
    - Renormalization and factorization scales are set to be equal and set to

      $1/2p_T$, p_T, $2p_T$

    - Calculated by W.Vogelsang



NLO-pQCD described very well down even to $p_T \sim 1$ GeV/c

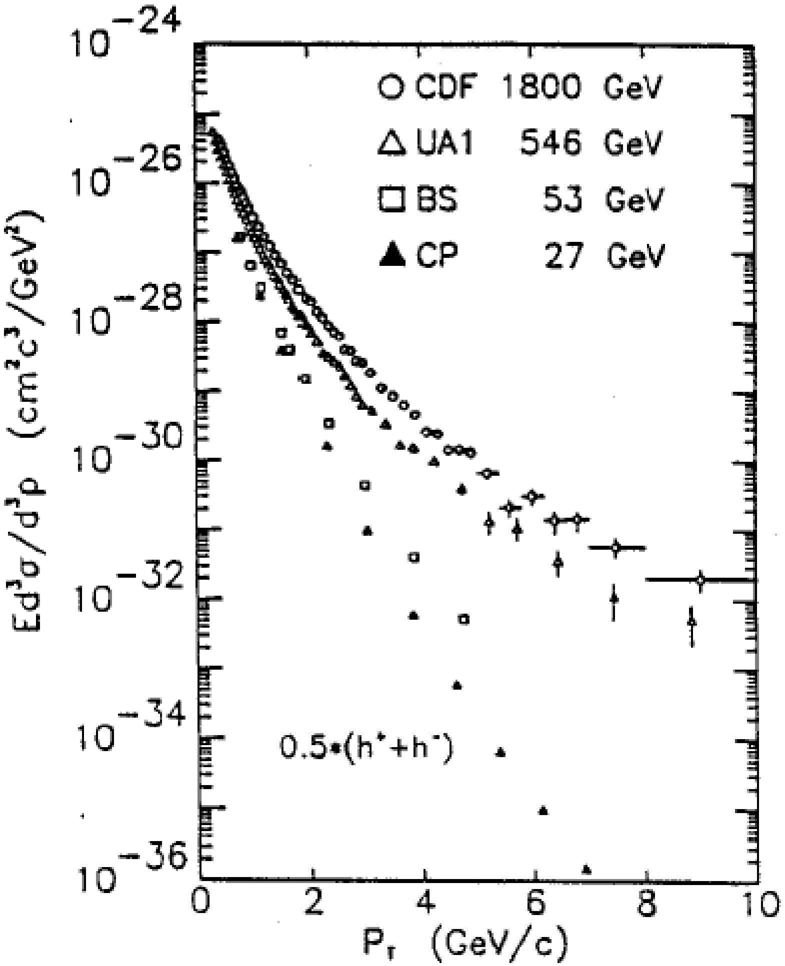
Theorists have a tough job---Experimentalists can use scaling rules

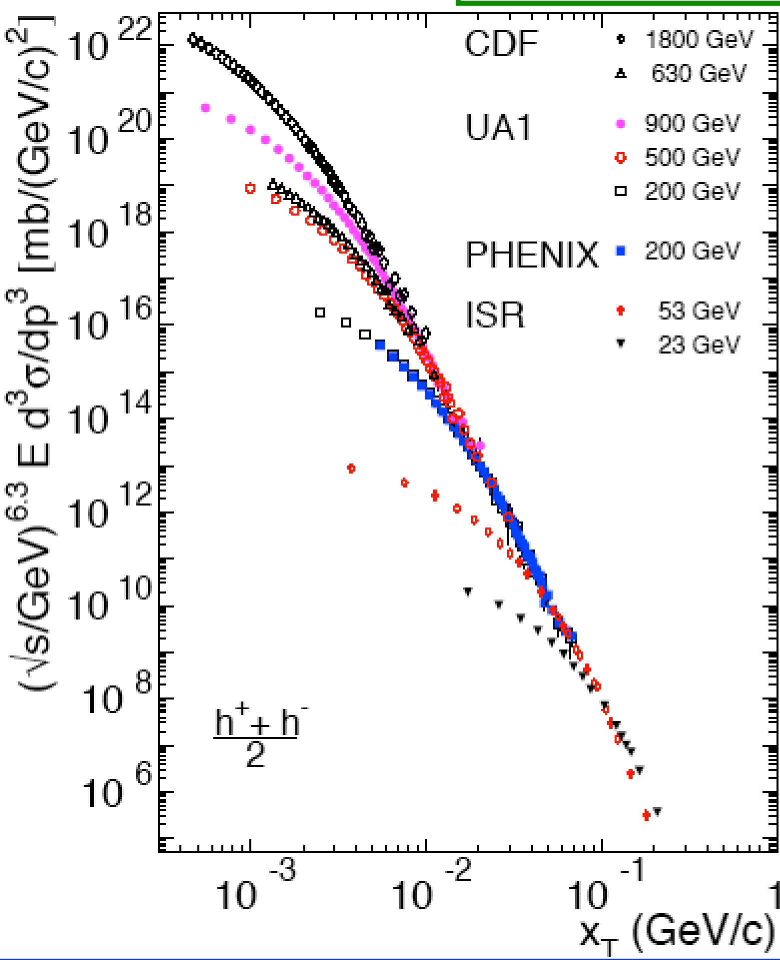
QCD follows x_T scaling-very powerful tool

$$E\frac{d^3\sigma}{d^3p} = \frac{1}{p_T^n}F\left(\frac{p_T}{\sqrt{s}}\right) = \frac{1}{\sqrt{s}^{\,n}}G(x_T) \qquad x_T = \frac{2p_T}{\sqrt{s}}$$

LOQCD, QED: n=4

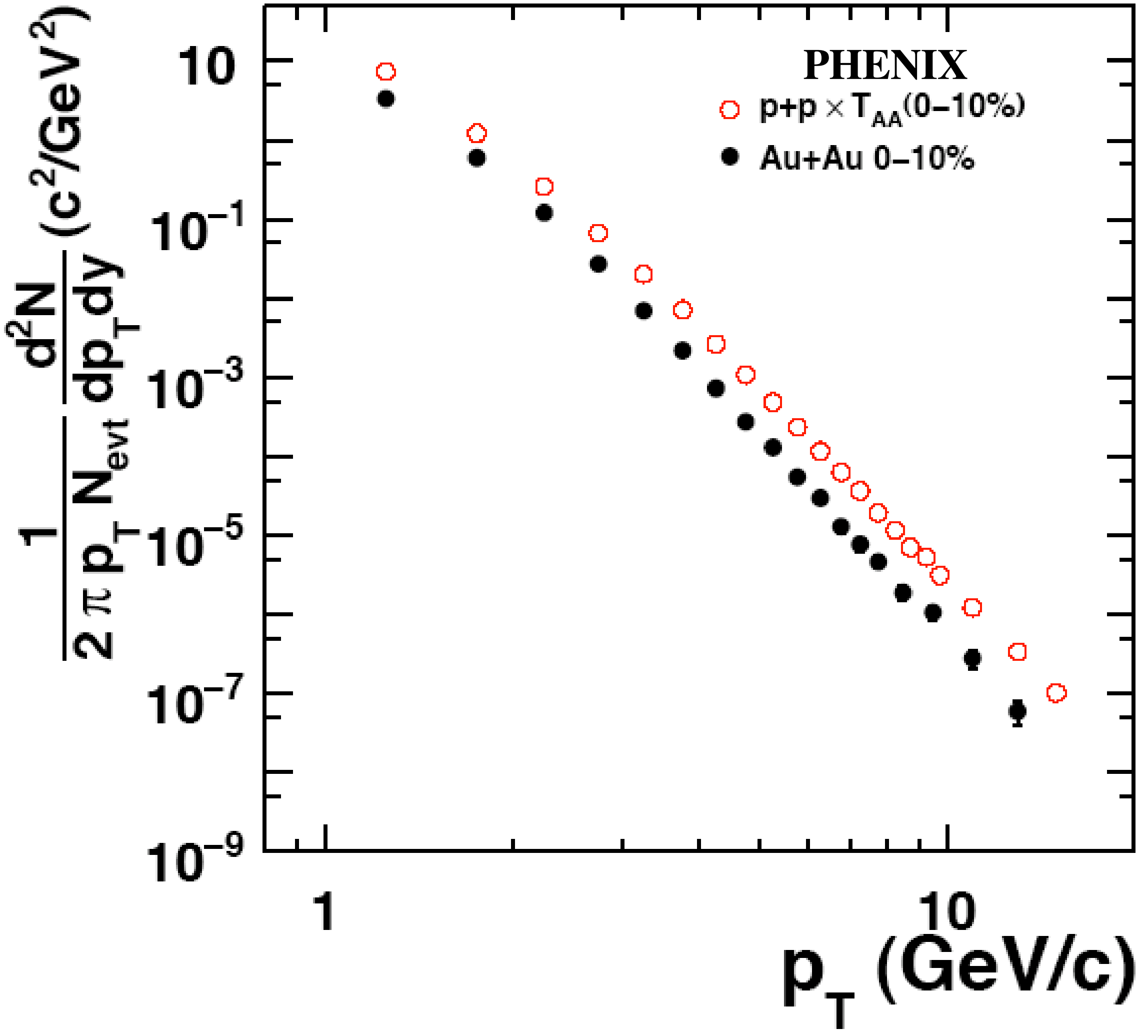
QCD $n(x_T, \sqrt{s}) = 4^{++}$





Structure and Fragmentation fns., which `scale', i.e. are functions only of ratios of momenta, are in F (G)

Inclusive invariant π^0 spectrum is power law for $p_T \geq 3$ GeV/c n=8.1±0.1 in p+p and Au+Au



Nuclear Modification Factor

$$R_{BA} = \frac{\left[d^2N^{\pi}_{BA} / dp_T dy dN^{inel}_{BA}\right]}{\langle T_{BA} \rangle \times \left[d^2\sigma^{\pi}_{pp} / dp_T dy\right]}$$

$$R_{BA} = \frac{\left[d^2N^{\pi}_{BA} / dp_T dy dN^{inel}_{BA}\right]}{\langle N_{coll} \rangle / \sigma^{inel}_{pp} \times \left[d^2\sigma^{\pi}_{pp} / dp_T dy\right]}$$

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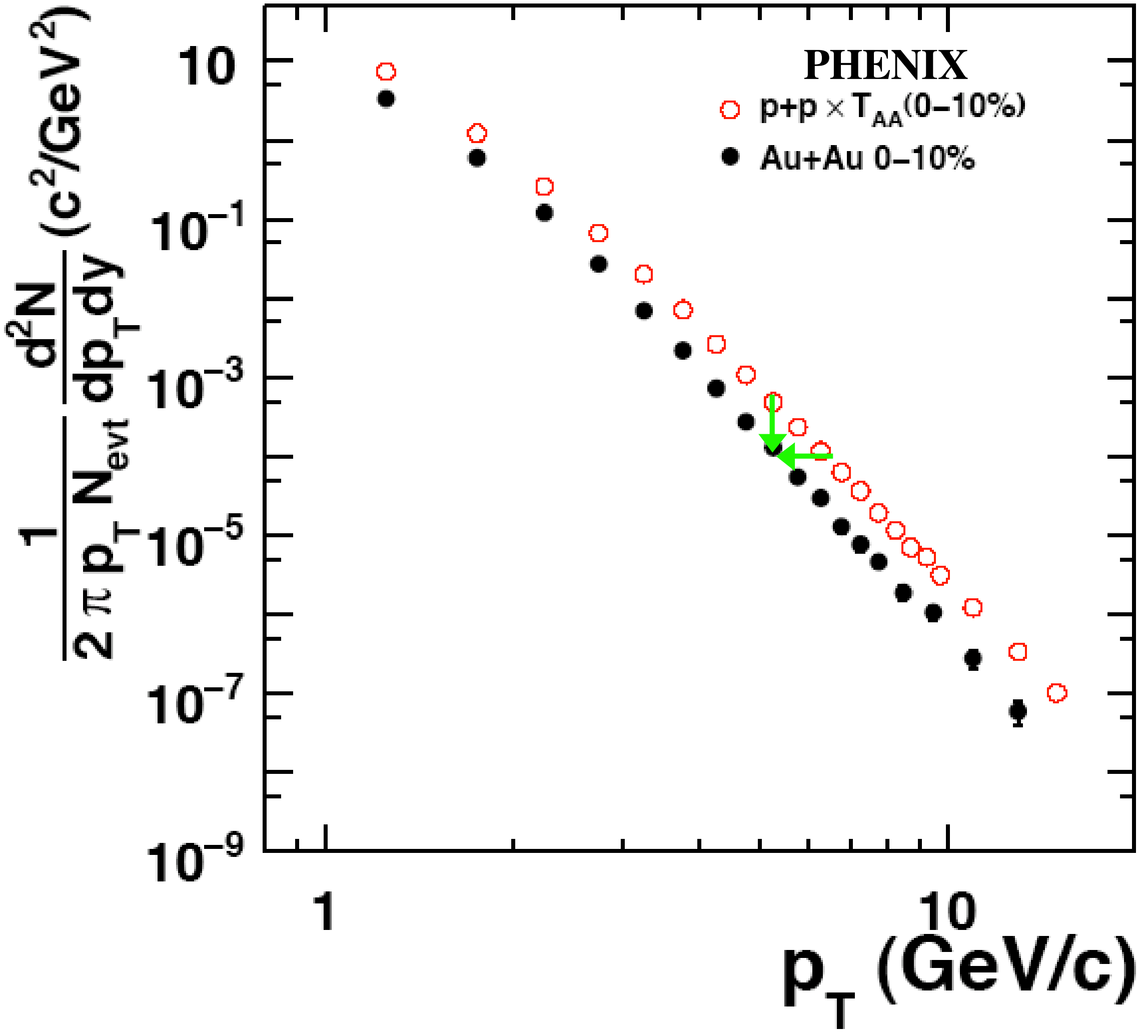

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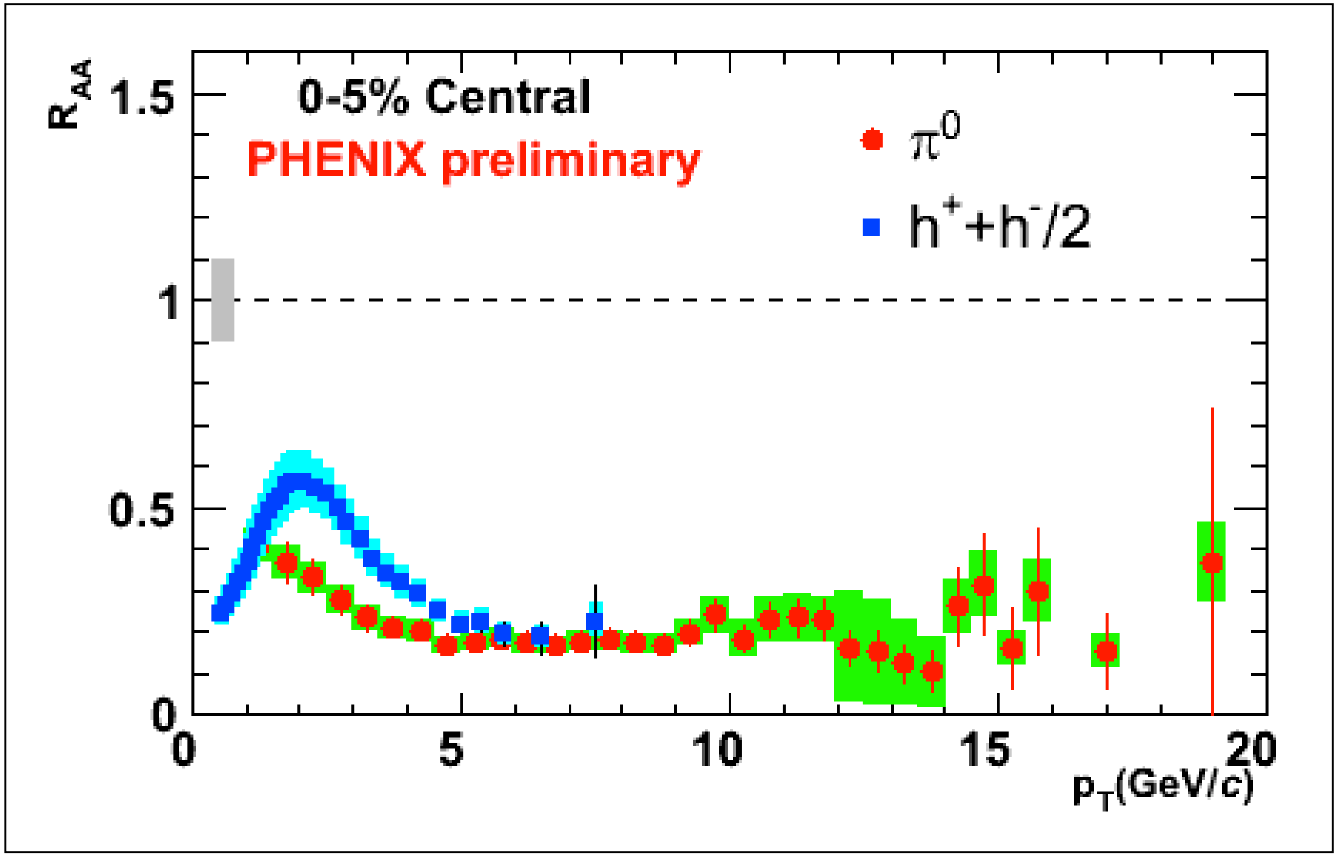
Impossible to distinguish reduction in the number of partons (due to e.g. stopping in medium) from fractional downshift in spectrum (due to e.g. energy loss of parton in medium)

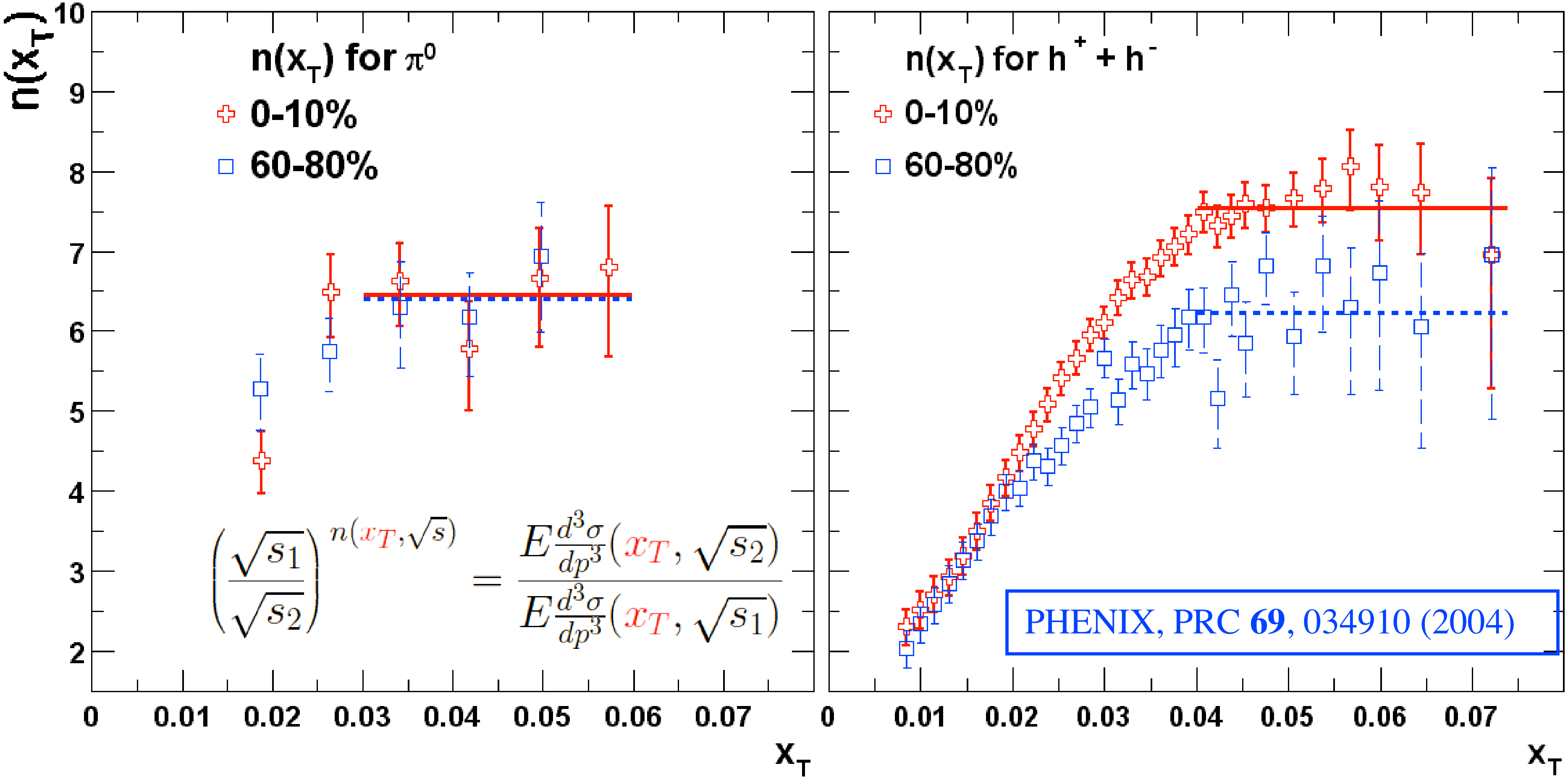
R_{AA}: π^0 and non-identified charged are different

Au Au 200-run 4



Does either obey QCD? We tried x_T scaling AuAu 200 cf 130 GeV

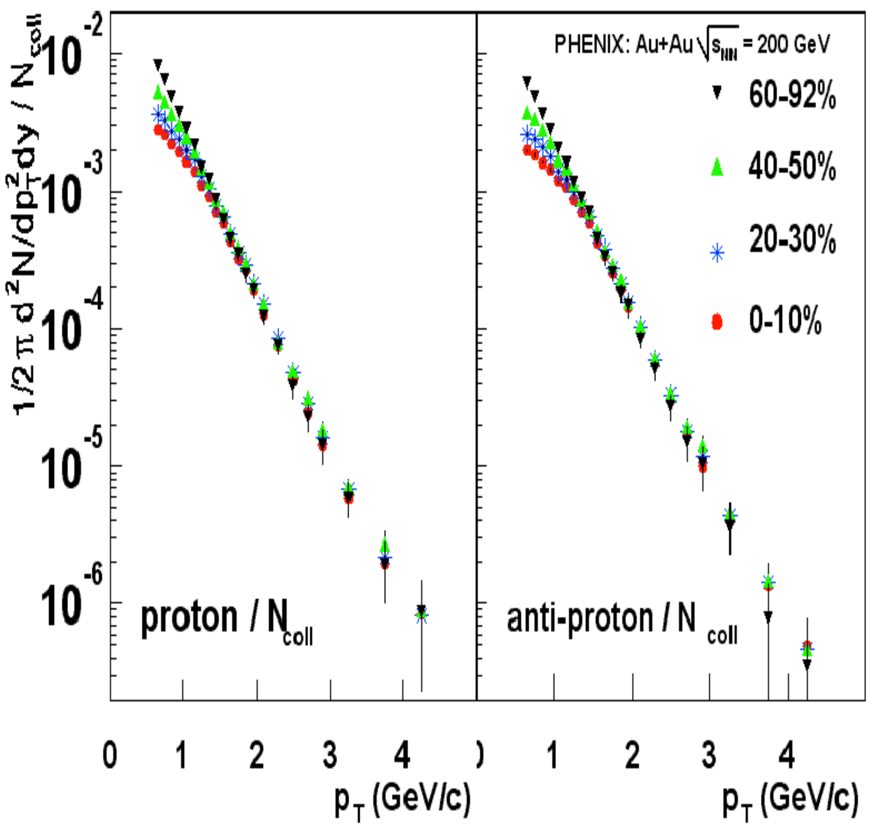
x_T scaling 200/130 AuAu shows $h^{\pm}$ are anomalous

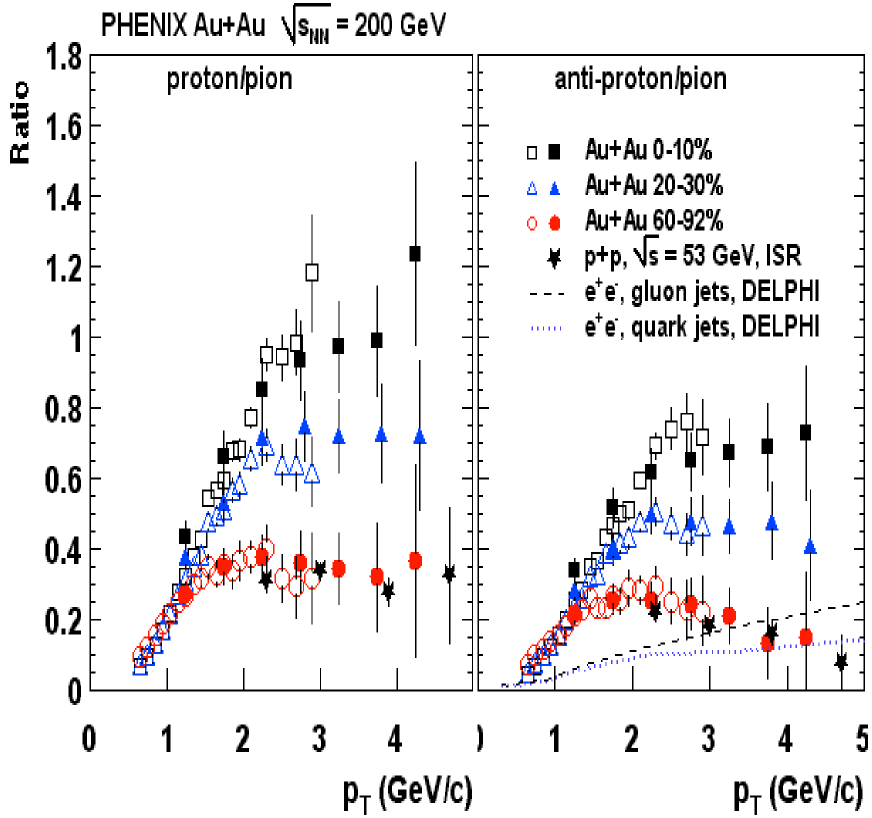


- π^0 x_T scales in both peripheral and central Au+Au with same value of n=6.3 as in p-p indicates that structure and fragmentation fns. (including any energy loss) scale in AuAu i.e. energy loss is fractional
- $(h^+ + h^-)/2$ x_T scales in peripheral same as p-p but difference between central and peripheral is significant

This is the Baryon Anomaly $2<p_T<4.5$ GeV/c

PHENIX PRL 91(2003) 172301



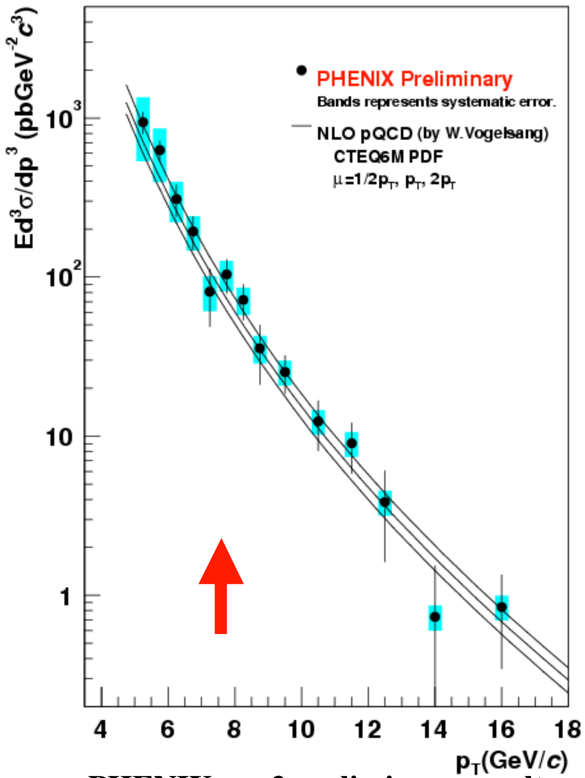


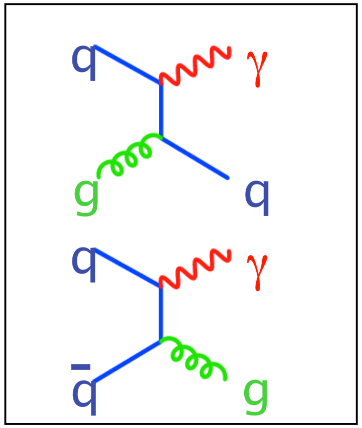
$p^{\pm}$ are not suppressed

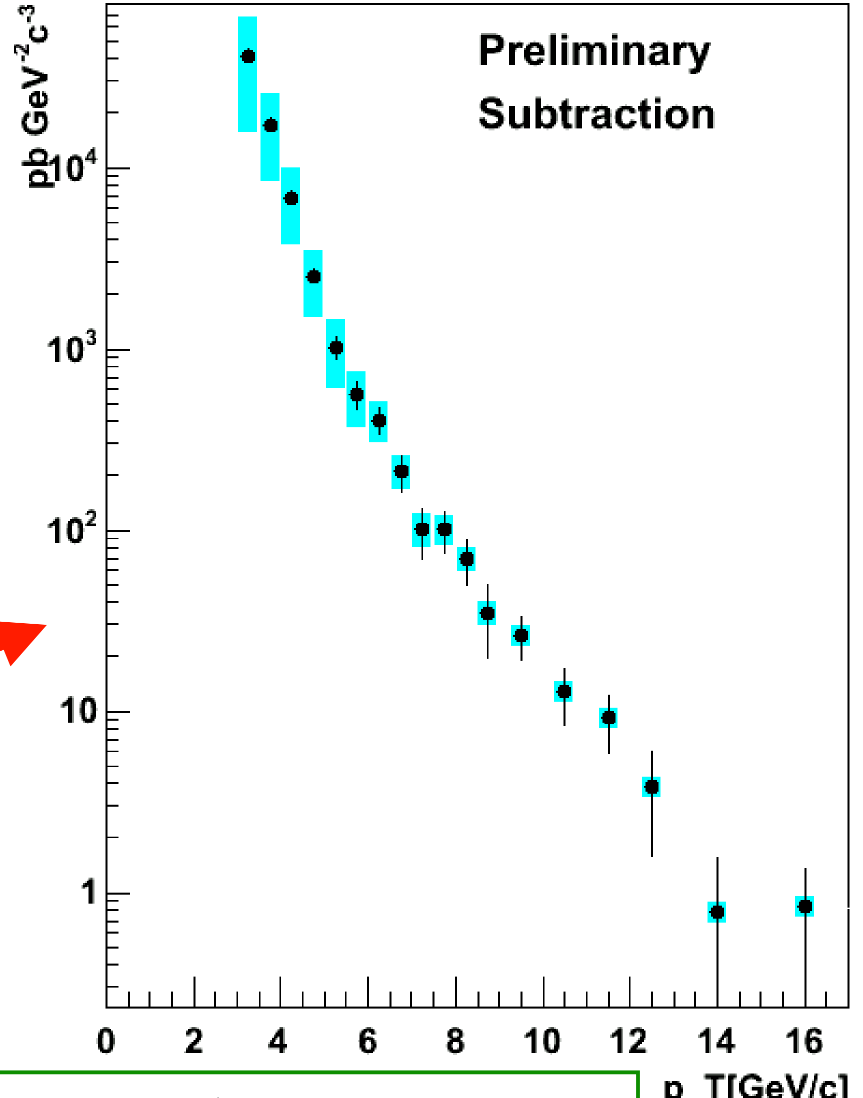
$p^{\pm}/\pi^{\pm}$ ratio much larger than from jet fragmentation

Is this 'recombination' ⇒ QGP: Fries,Muller, Nonaka PRL **90** 202303 (2003)

New direct γ's in p+p: Data vs. pQCD





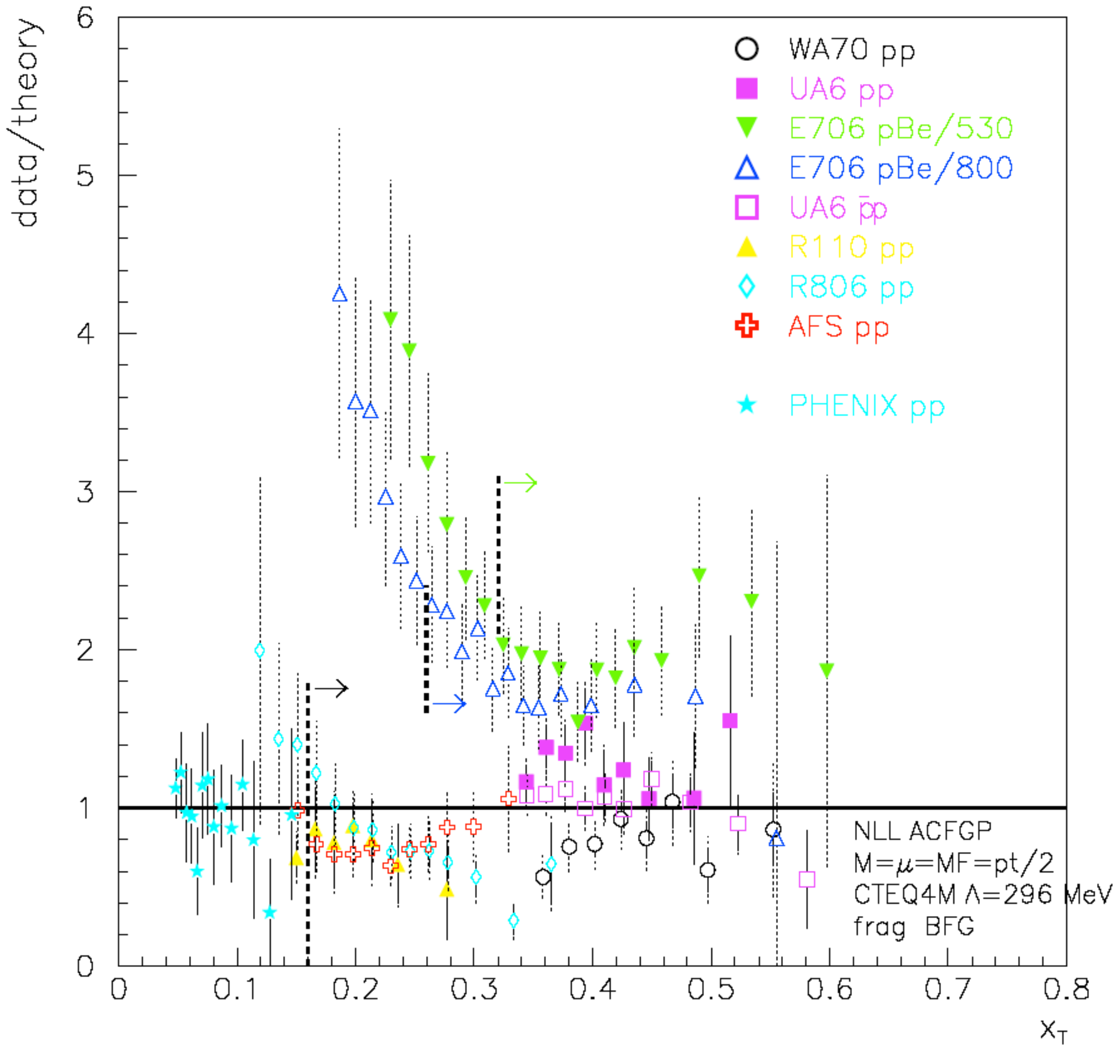


- PHENIX run3 preliminary result.
  - ✓ Recent Update down to 3GeV/c
  - ✓ Publication is coming soon.
- NLO-pQCD calculation
  - ✓ Private communication with W.Vogelsang
  - ✓ CTEQ6M PDF.
  - ✓ Sum of direct γ + Bremsstrahlung γ
  - ✓ 3 scales (1/2pT,1pT,2 pT)

Previous results for p_T> 5GeV/c new results p_T>3 GeV/c

Comparison with other data and pQCD

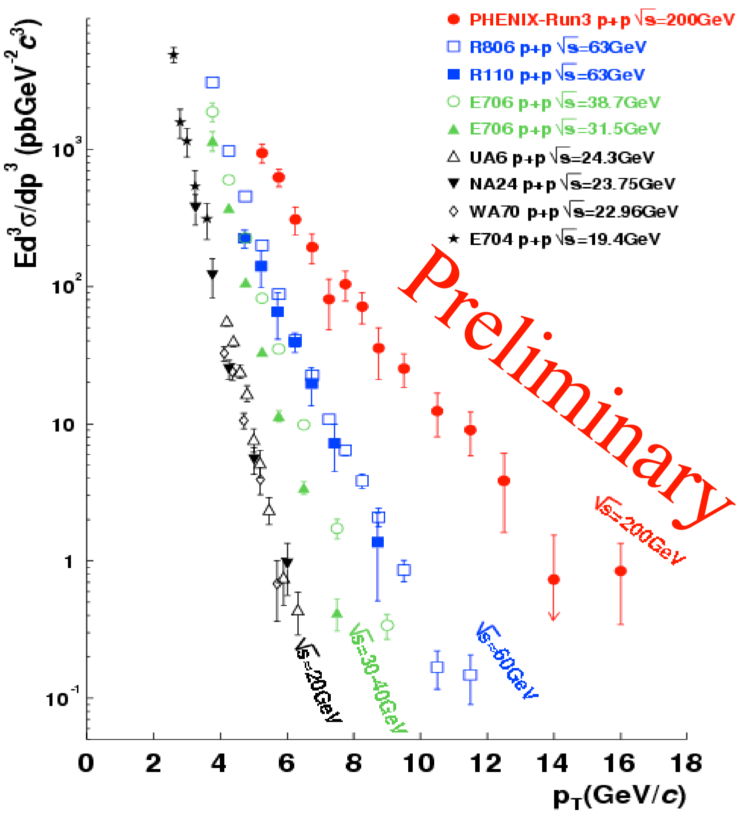
Aurenche et al Eur. Phys. JC9,10(1999)

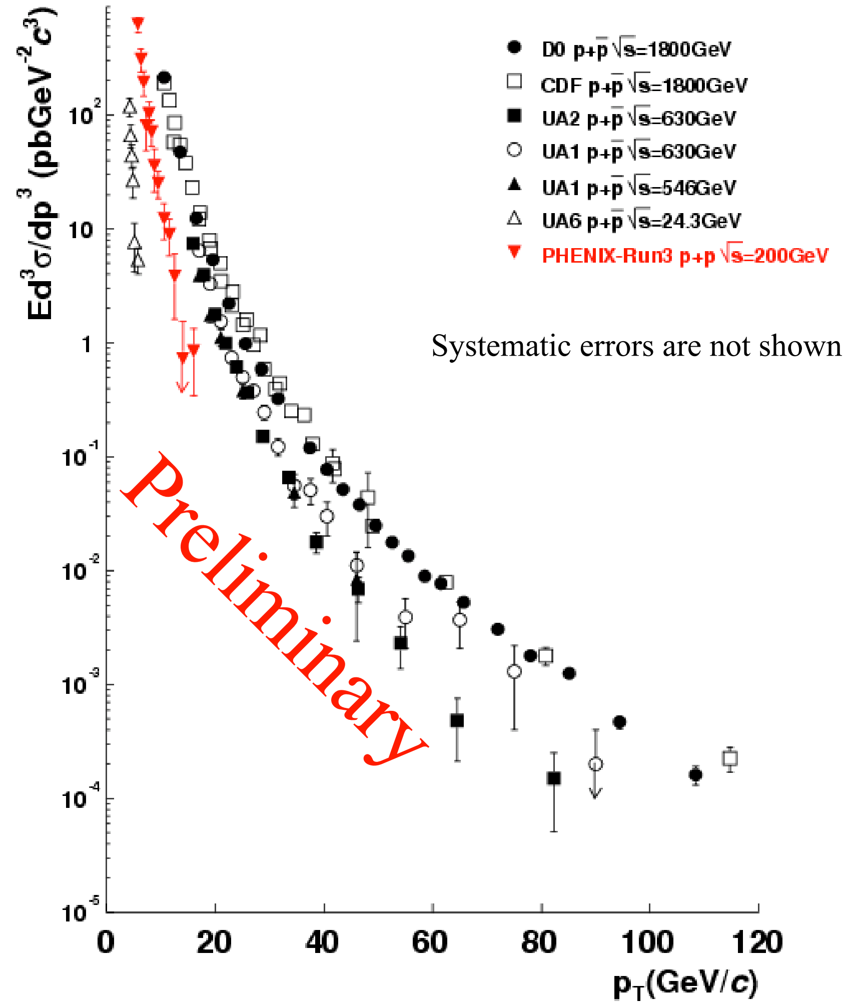


Talk by Monique Werlen at RHIC&AGS users meeting 2005

Phenix data clarifies the data/theory puzzle

Comparison with Other Experiments

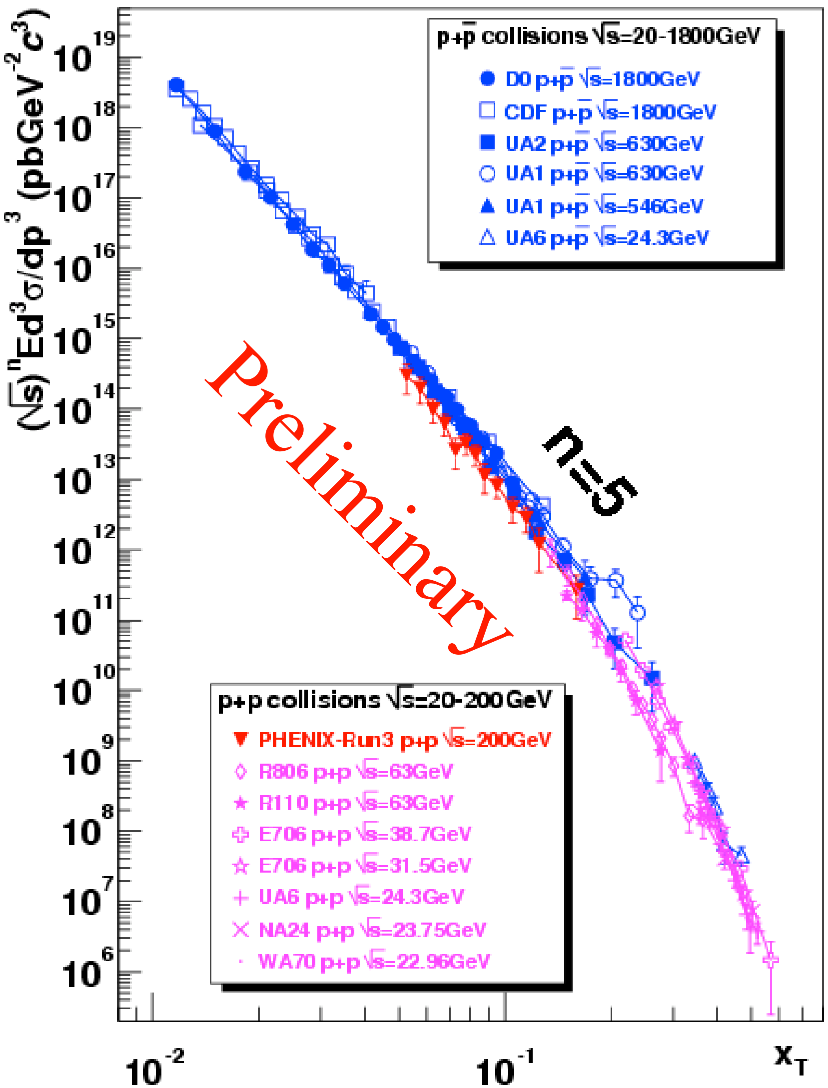




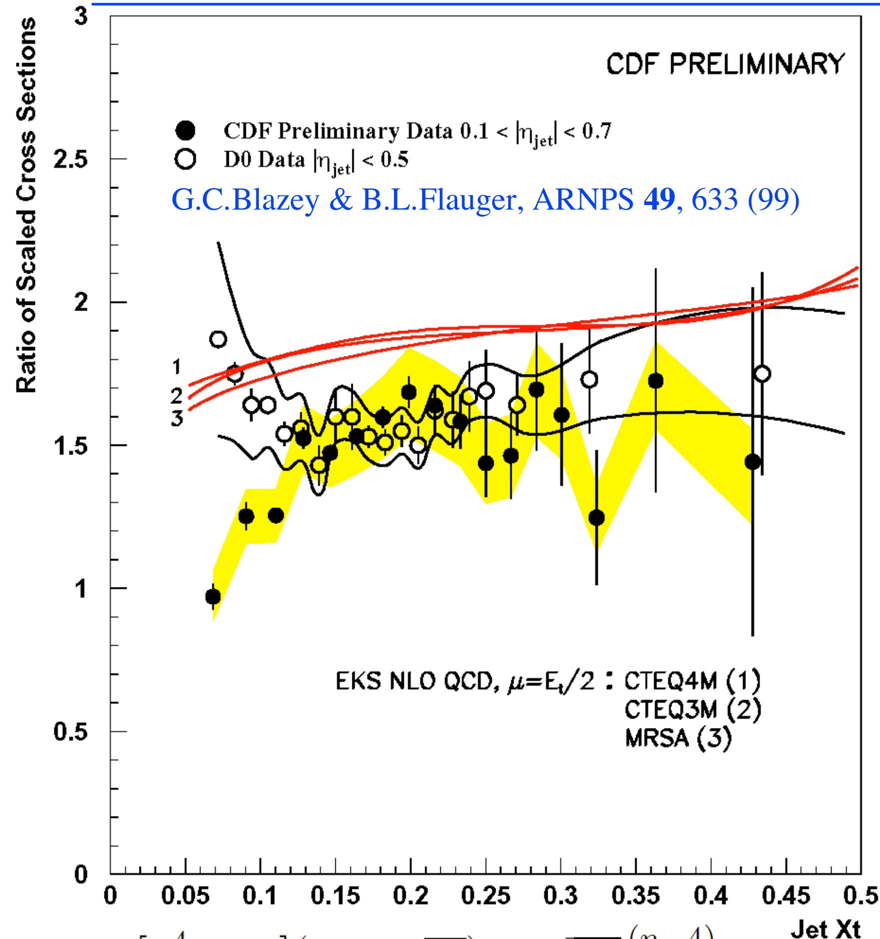
proton-proton collisions

proton-antiproton collisions

x_T scaling: a) Direct-γ b) Jets



Jets-Ratio of Scaled Cross Sections 630/1800

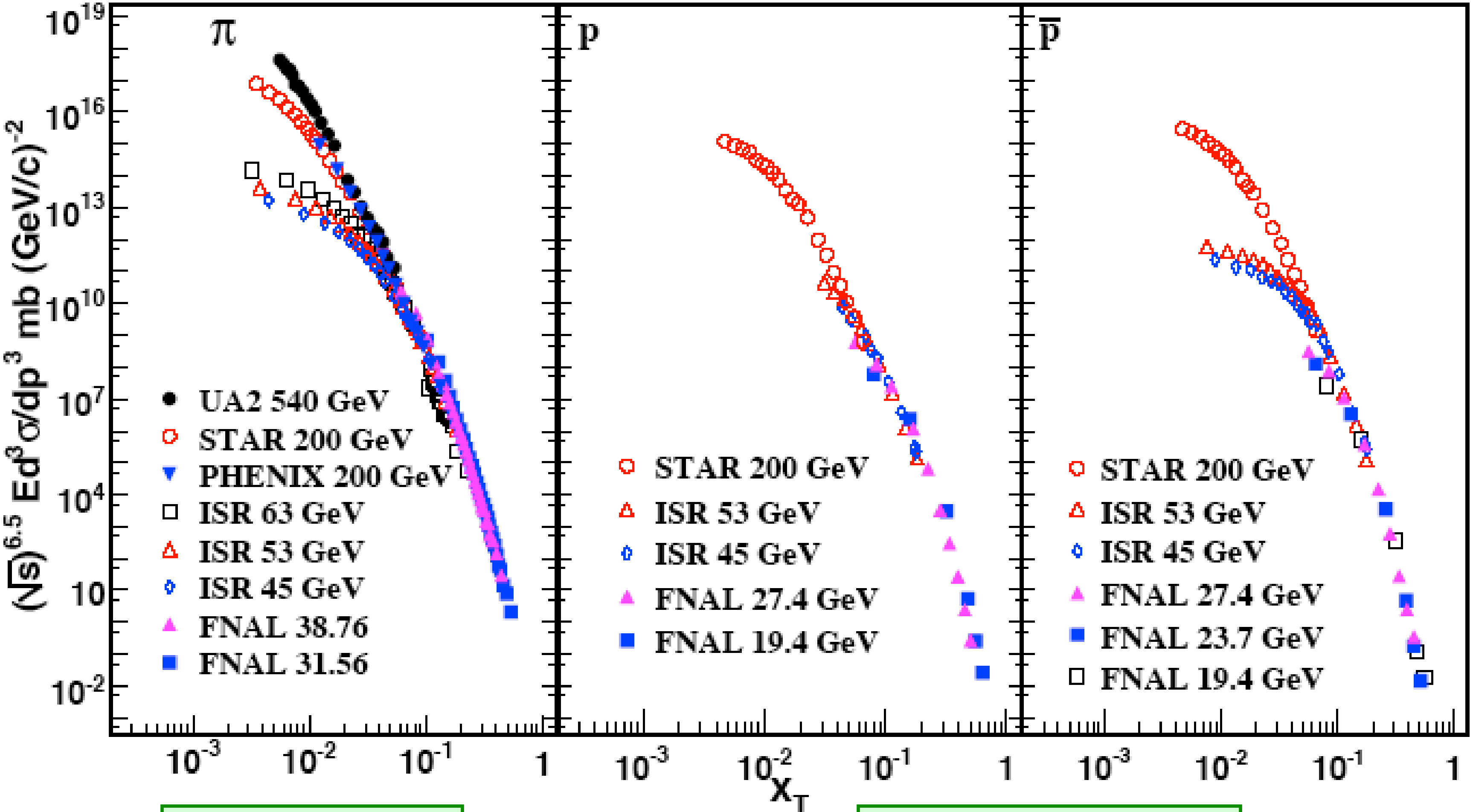


$$\frac{[p_T^4\,\sigma_{\rm inv}](x_T,\sqrt{s_1})}{[p_T^4\,\sigma_{\rm inv}](x_T,\sqrt{s_2})}=\sqrt{\frac{s_2}{s_1}}^{(n-4)}$$

Direct γ n≈5

Jets n≈4.5

New: STAR x_T scaling result for (anti-)protons in p+p collisons $\sqrt{s_{NN}}$=200 GeV

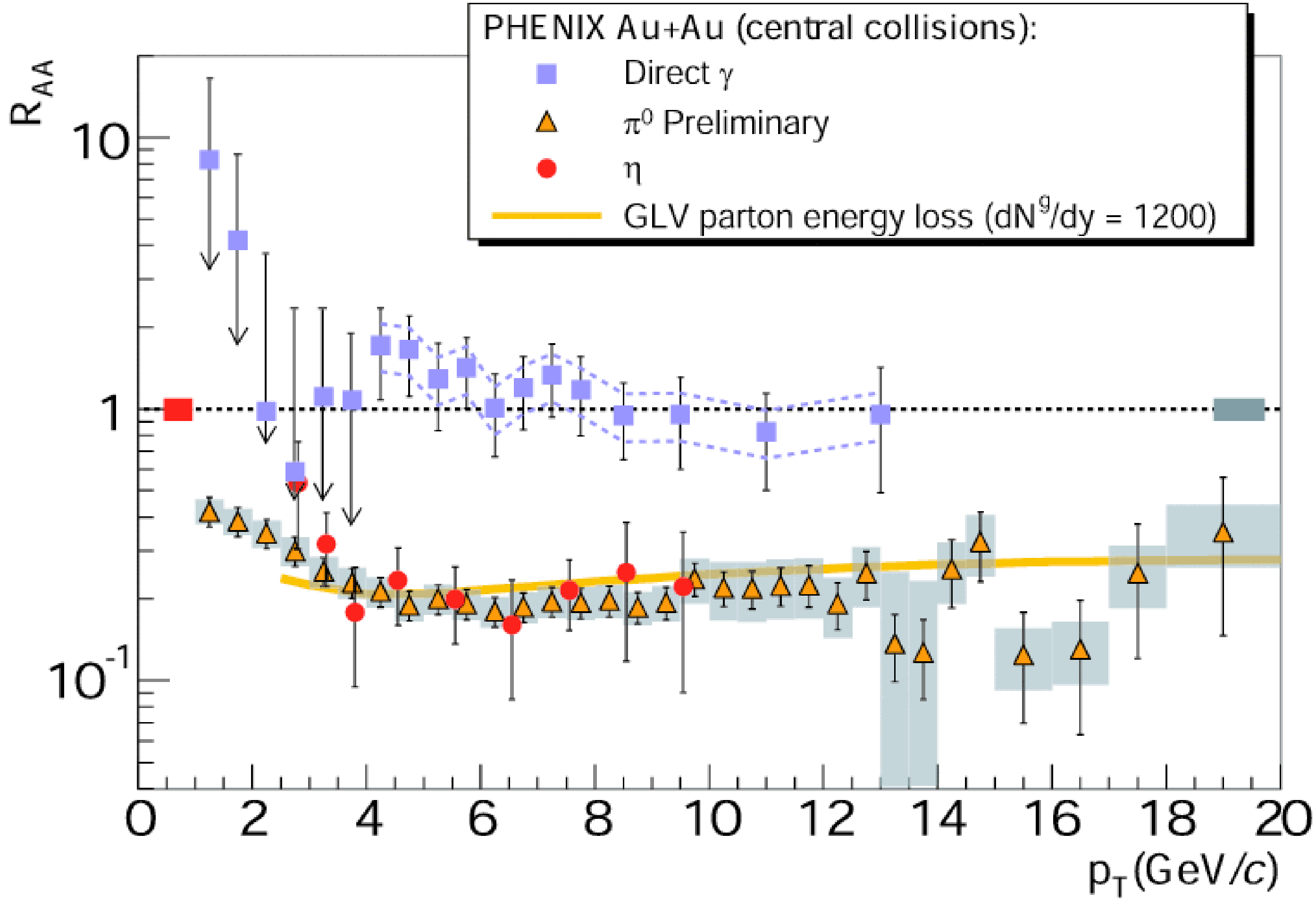


$\pi^{\pm}$ n=6.8 ± 0.5

$p, \bar{p}$ n =6.5 ± 1.0

STAR, nucl-ex/0601033. It appears that Brodsky, et al PLB**637**, 58 are likely wrong

State of R_{AA} in AuAu at $\sqrt{s_{NN}}$=200 GeV



Direct γ are not suppressed. π^0 and η suppressed even at high p_T
Implies a strong medium effect since γ not affected.
Suppression is flat at high p_T. Are data flatter than theory?

To test details of Theory⇒$R_{AA}(\Delta\phi, p_T)$

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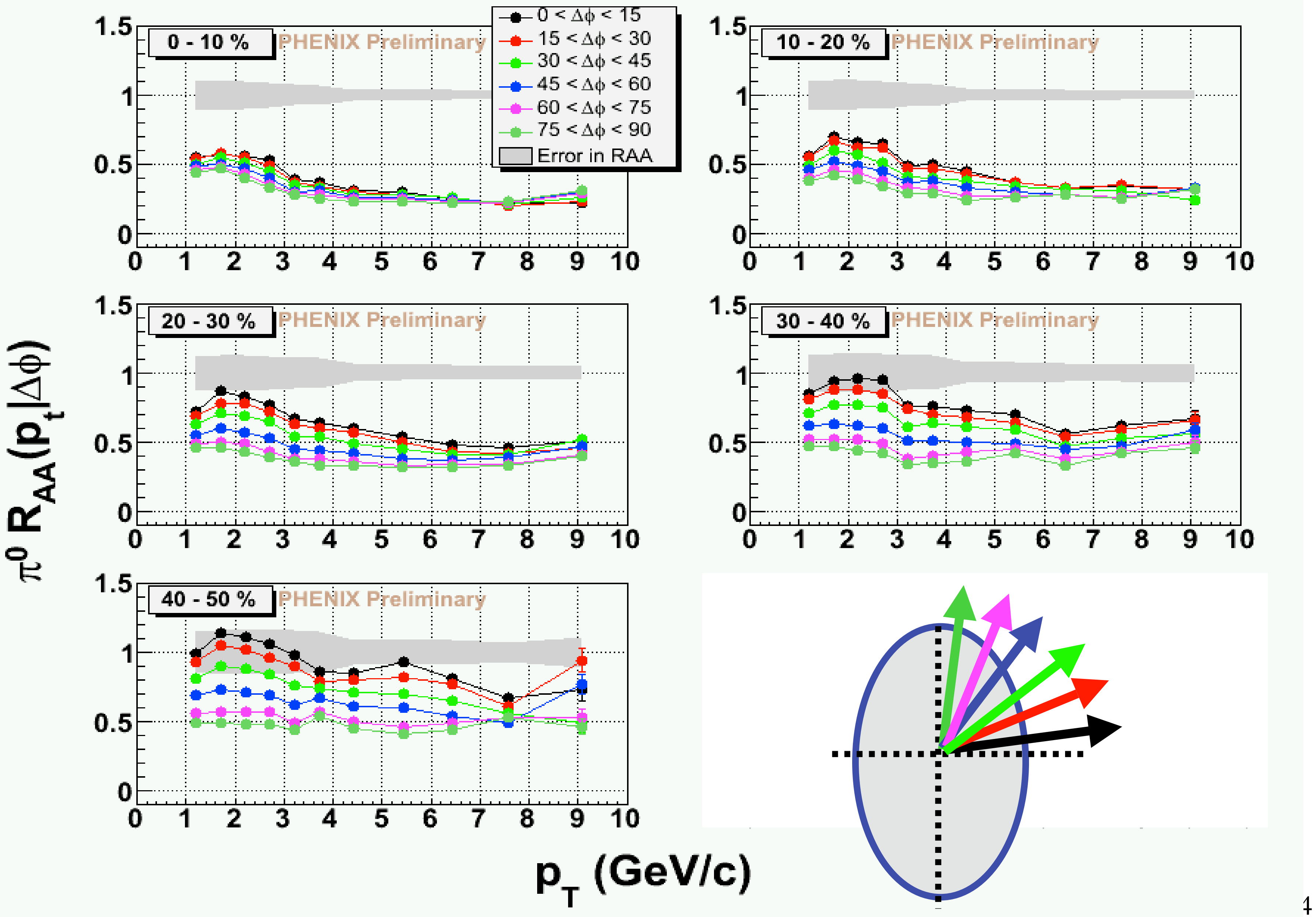
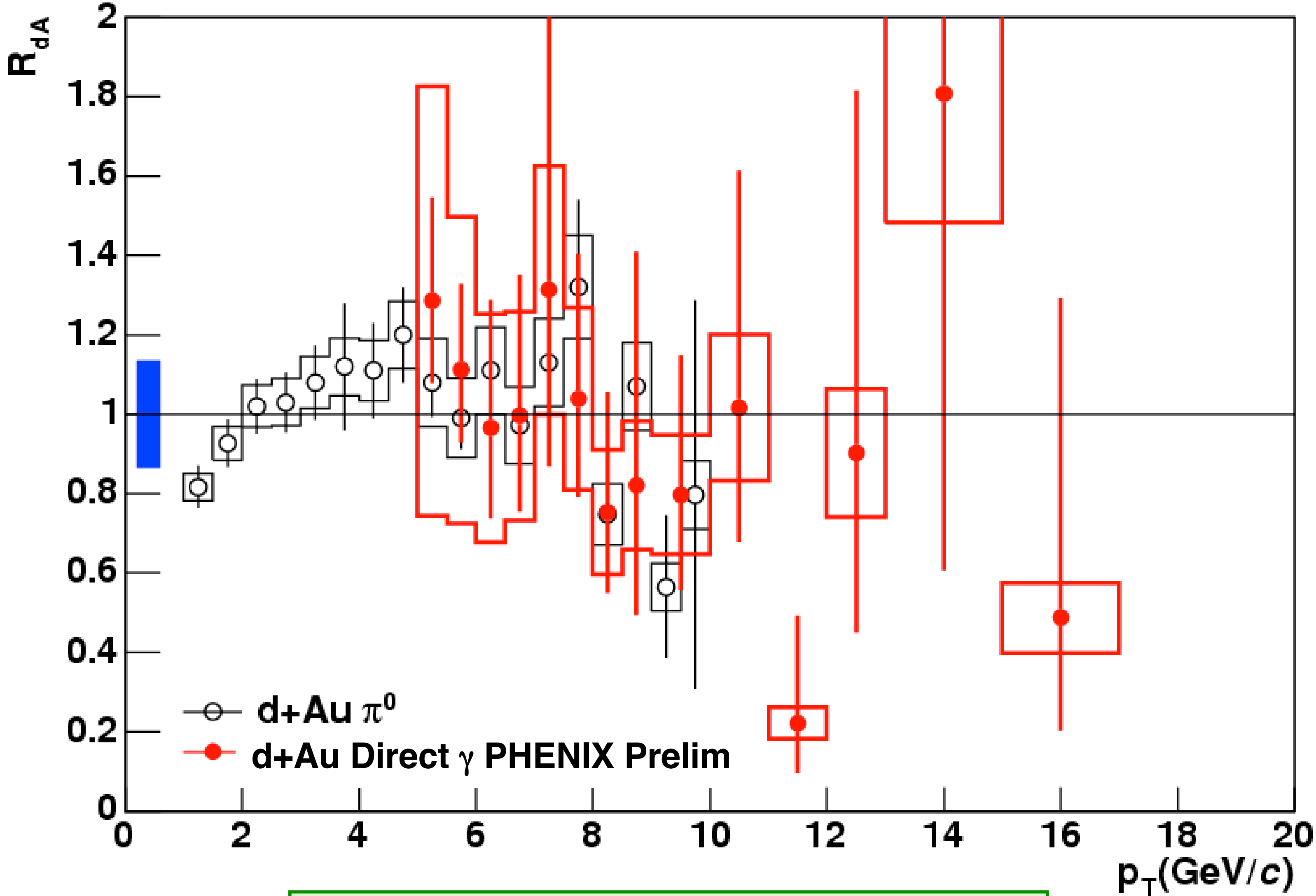


State of R_{dA} in d+Au at $\sqrt{s_{NN}}$=200 GeV



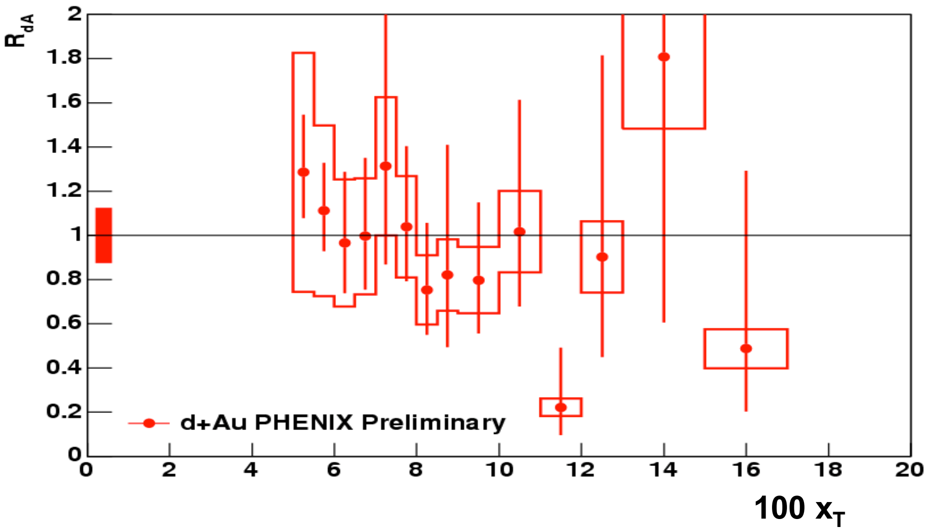
Both Direct γ and π^0 consistent with 1

Direct γ is "EMC effect" for gluons

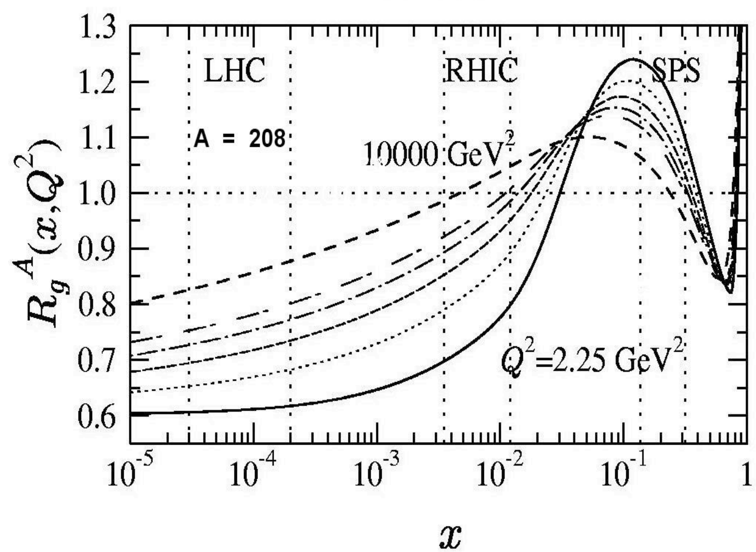
Nuclear Modification Factor-Min Bias

$$R_{dA} = \frac{d\sigma_\gamma^{dA}(p_T)/dp_T}{(2 \times A) \times d\sigma_\gamma^{pp}(p_T)/dp_T}$$

$$\boxed{R_{dA} \approx \frac{1}{2}\left(\frac{F_{2A}(x_T)}{AF_{2p}(x_T)} + \frac{g_A(x_T)}{Ag_p(x_T)}\right)}$$



Eskola, Kolhinen, Vogt hep-ph/0104124



Consistent with 1 ➔ No modification within the error

This is first measurement of 'EMC effect' for gluons

Correlations

The leading-particle effect a.k.a. trigger bias

- Due to the steeply falling power-law spectrum of the scattered partons, the inclusive particle p_T spectrum is dominated by fragments biased towards large z. This was unfortunately called trigger bias by M. Jacob and P. Landshoff, Phys. Rep. **48C**, 286 (1978) although it has nothing to do with a trigger.

$$\frac{d^2\sigma_\pi(\hat{p}_{T_t}, z_t)}{d\hat{p}_{T_t} dz_t} = \frac{d\sigma_q}{d\hat{p}_{T_t}} \times D^q_\pi(z_t)$$

Fragment spectrum given $\hat{p}_{T_t}$

$$= \frac{A}{\hat{p}_{T_t}^{n-1}} \times D^q_\pi(z_t)$$

let $\hat{p}_{T_t} = p_{T_t}/z_t \qquad d\hat{p}_{T_t}/dp_{T_t}|_{z_t} = 1/z_t$

$$\frac{d^2\sigma_\pi(p_{T_t}, z_t)}{dp_{T_t} dz_t} = \frac{1}{z_t}\frac{A}{(p_{T_t}/z_t)^{n-1}} \times D^q_\pi(z_t)$$

$$= \frac{A}{p_{T_t}^{n-1}} \times z_t^{n-2} D^q_\pi(z_t)$$

Fragment spectrum given p_{T_t}

where $z_{t\min}|_{p_{T_t}} = x_{T_t} \qquad D^q_\pi(z_t) = Be^{-6z_t}$

From MIT 2005

2 particle Correlations

$$\frac{d^2\sigma_\pi(\hat{p}_{T_t}, z_t)}{d\hat{p}_{T_t} dz_t} = \frac{d\sigma_q}{d\hat{p}_{T_t}} \times D^q_\pi(z_t)$$

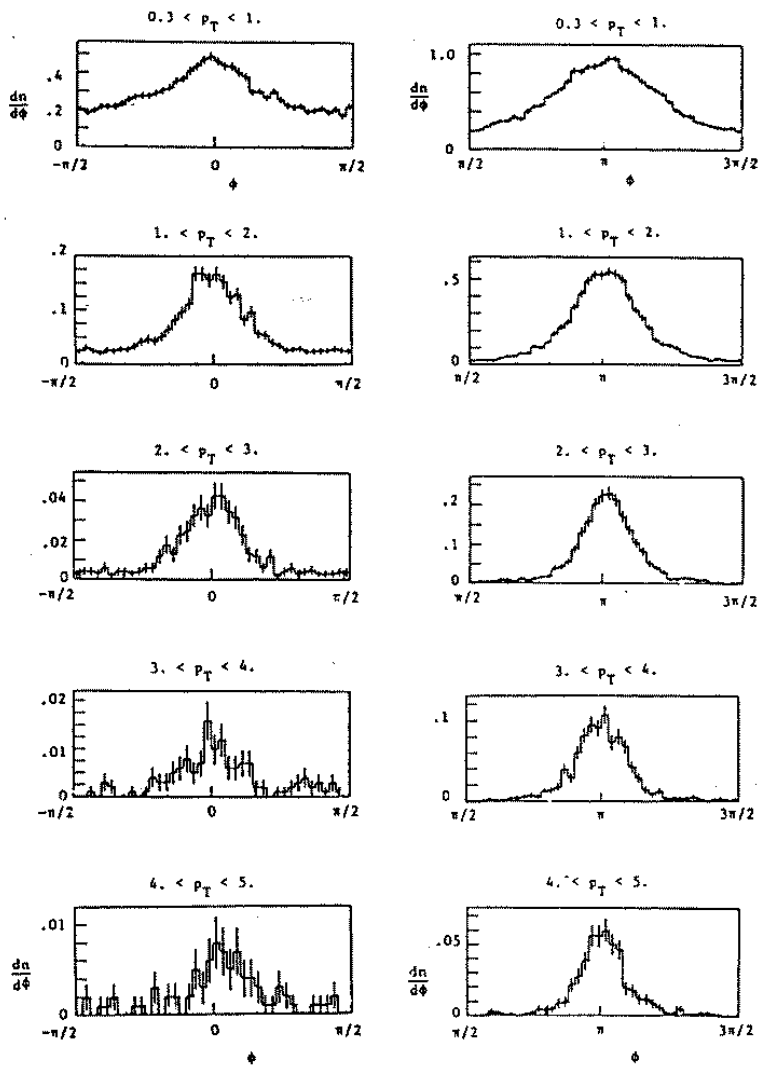
Also detect fragment with $z_a = p_{T_a}/\hat{p}_{T_a}$
from away jet with $\hat{p}_{T_a}/\hat{p}_{T_t} \equiv \hat{x}_h$

$$\frac{d^3\sigma_\pi(\hat{p}_{T_t}, z_t, z_a)}{d\hat{p}_{T_t} dz_t dz_a} = \frac{d\sigma_q}{d\hat{p}_{T_t}} \times D^q_\pi(z_t) \times D^q_\pi(z_a)$$

$$z_{\mathrm{a}} = \frac{p_{T\mathrm{a}}}{\hat{p}_{T\mathrm{a}}} = \frac{p_{T\mathrm{a}}}{\hat{x}_{\mathrm{h}}\hat{p}_{T\mathrm{t}}} = \frac{z_{\mathrm{t}} p_{T\mathrm{a}}}{\hat{x}_{\mathrm{h}} p_{T\mathrm{t}}}$$

(1) $$\boxed{\frac{d\sigma_\pi}{dp_{T_t} dz_t dp_{T_a}} = \frac{1}{\hat{x}_{\mathrm{h}}\, p_{T_t}} \frac{d\sigma_q}{d(p_{T_t}/z_t)} D^q_\pi(z_t) D^q_\pi(\frac{z_t p_{T_a}}{\hat{x}_{\mathrm{h}} p_{T_t}})}$$

How everything you want to know about JETS was measured with 2-particle correlations



CCOR, A.L.S.Angelis, et al
Phys.Lett. **97B**, 163 (1980)
PhysicaScripta **19**, 116 (1979)

$p_{Tt} > 7$ GeV/c vs p_T

From MIT 2005

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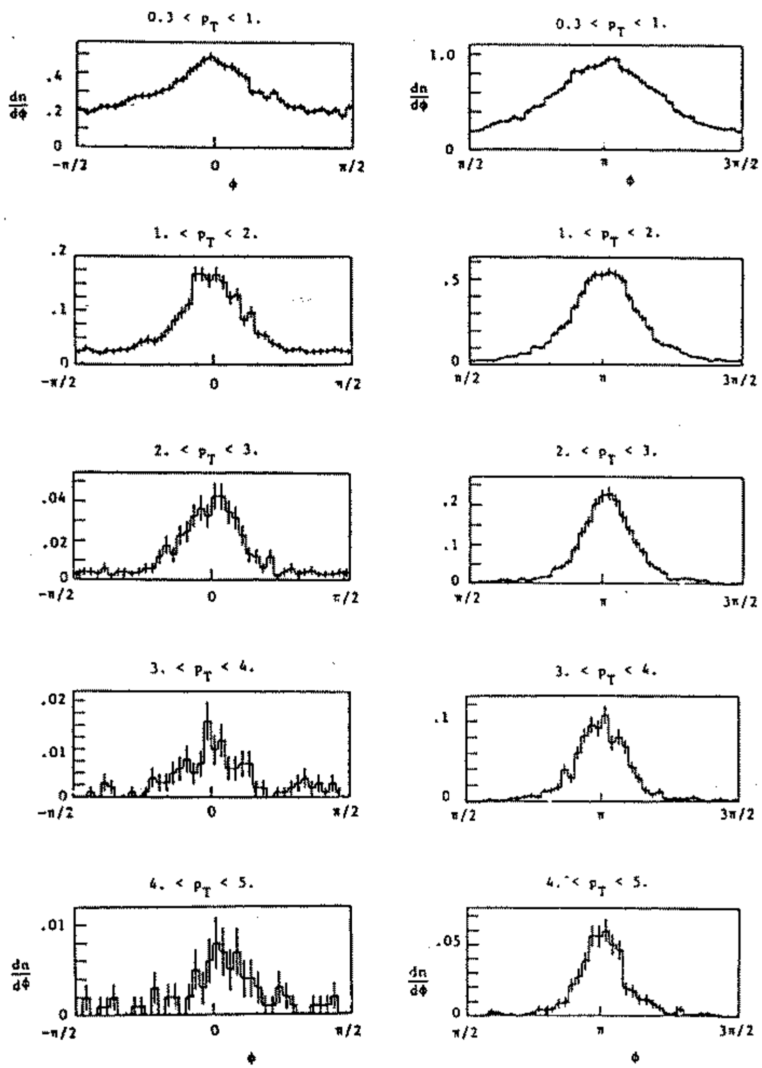

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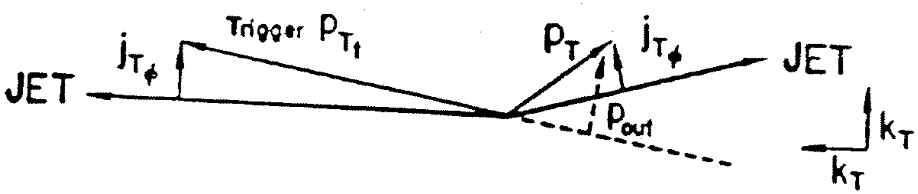

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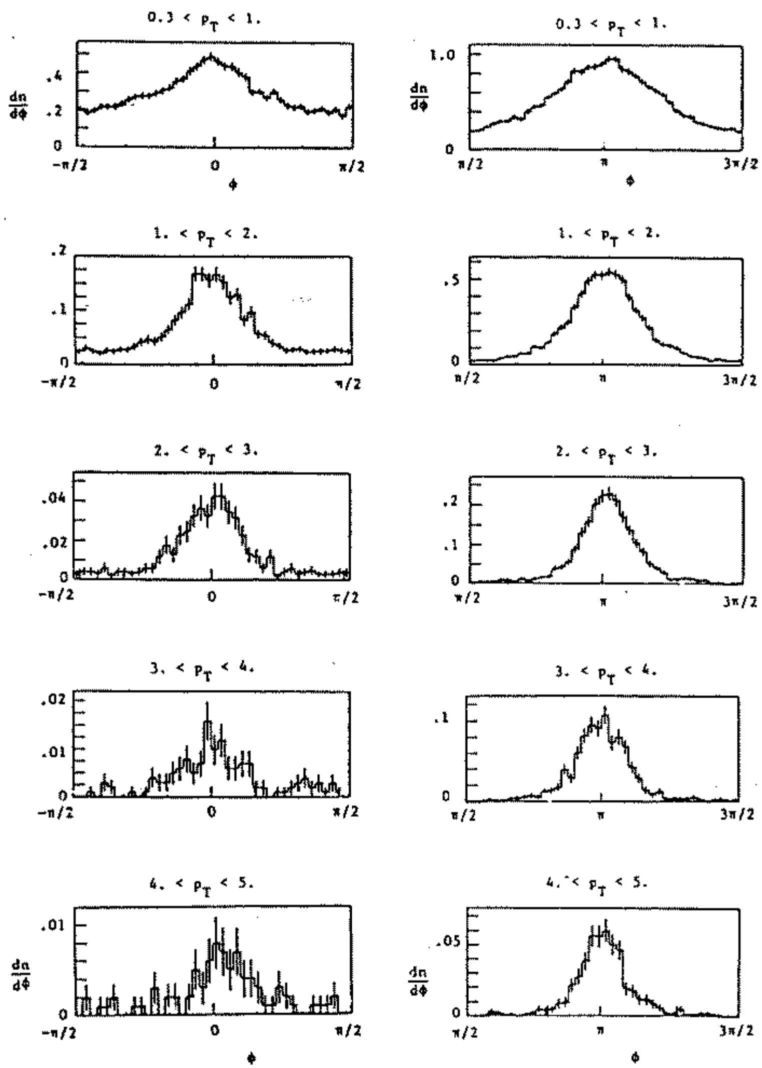

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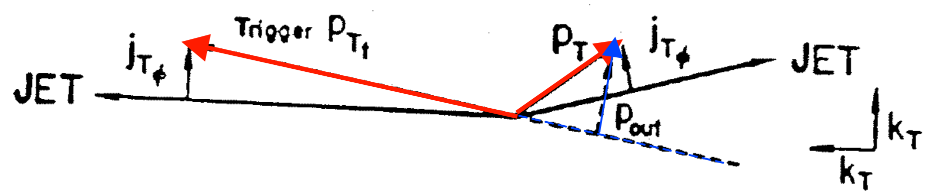

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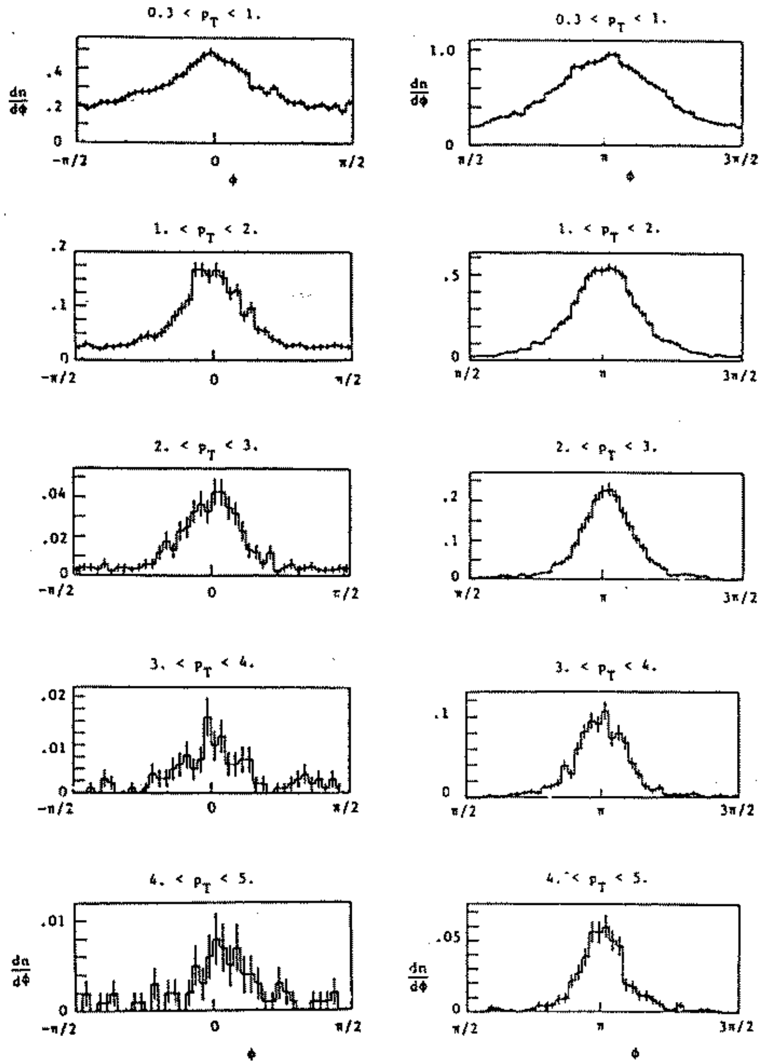

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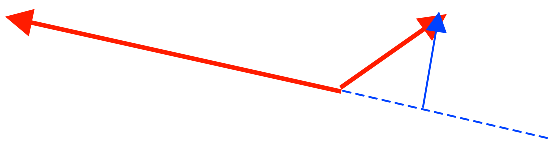

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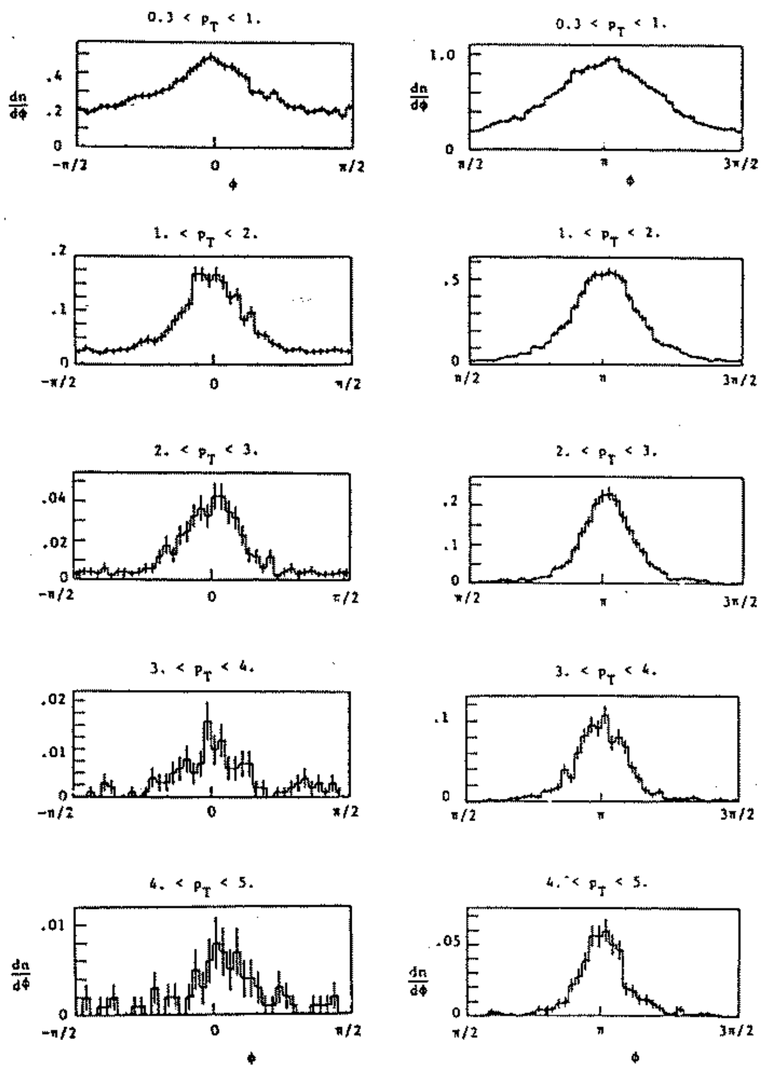

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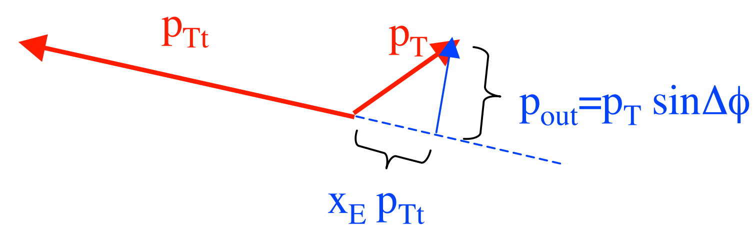
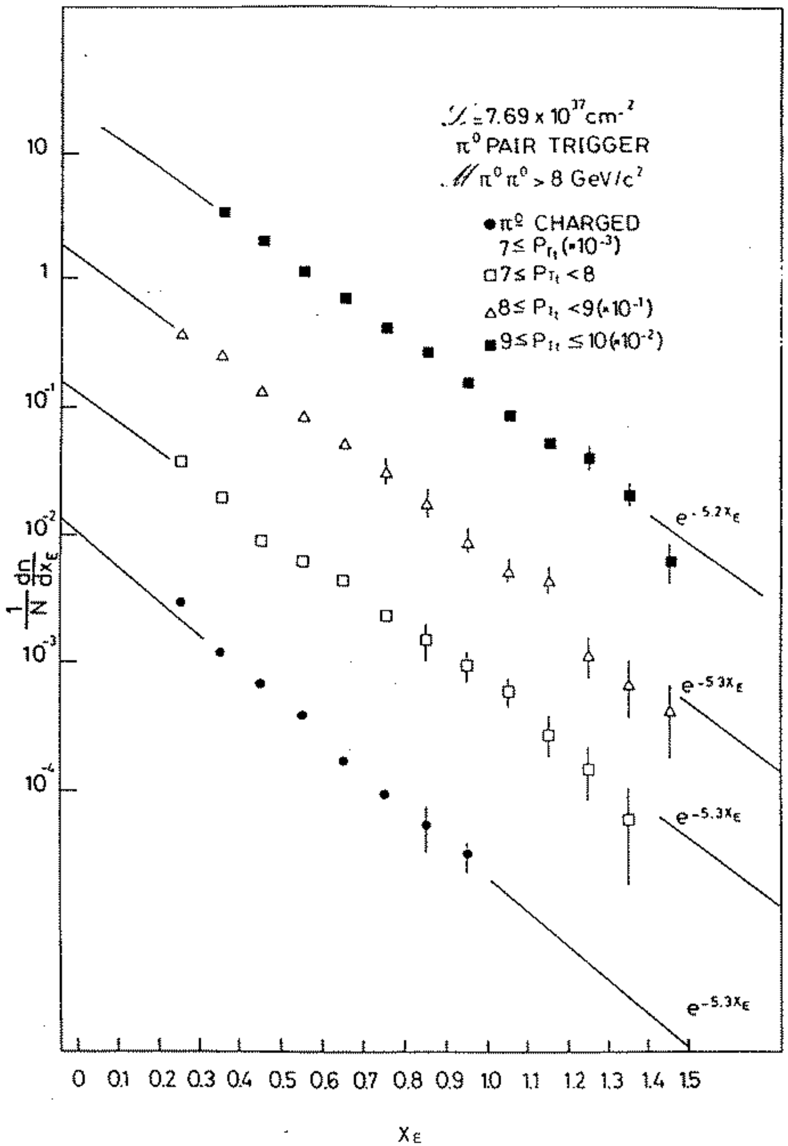


$p_{Tt} > 7$ GeV/c vs p_T

x_E distribution measures fragmentation fn.



$x_E \sim z/\langle z_{trig}\rangle$

$\langle z_{trig}\rangle$=0.85 measured

$\Rightarrow D^q_\pi(z) \sim e^{-6z}$

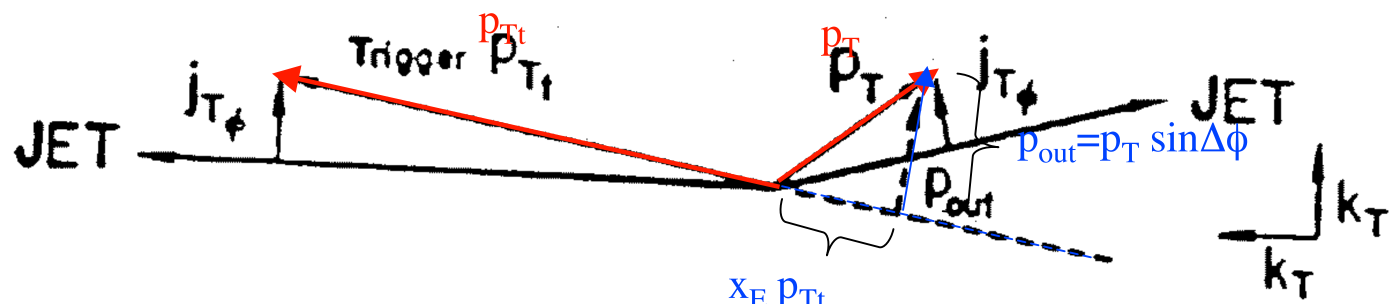
- independent of p_{Tt}

See M. Jacob's talk EPS 1979 Geneva

From MIT 2005

PHENIX (hep-ex/0605039) found this is wrong

Following FFF and CCOR PLB**97**(1980)163-168 we were trying to measure the net transverse momentum of the di-jet ($\sqrt{2}$ x $\langle k_T \rangle$)

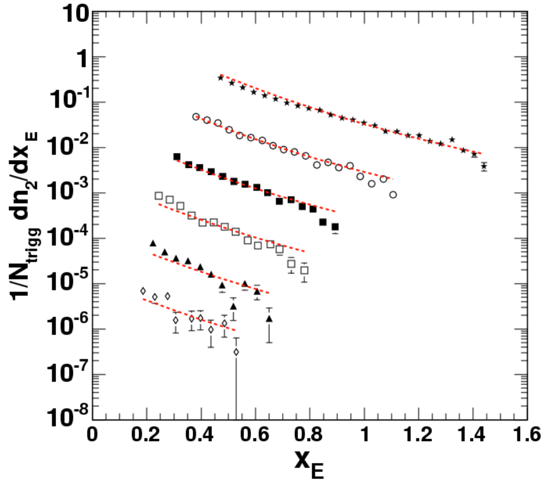


$$\frac{\langle z_t(k_T,x_h)\rangle\sqrt{\langle k_T^2\rangle}}{\hat{x}_h(k_T,x_h)} = \frac{1}{x_h}\sqrt{\langle p_{out}^2\rangle - \left\langle j_{Ty}^2\right\rangle(1+x_h^2)} \qquad x_h \equiv \frac{p_{T_a}}{p_{T_t}} \qquad \hat{x}_h \equiv \frac{\hat{p}_{T_a}}{\hat{p}_{T_t}}$$

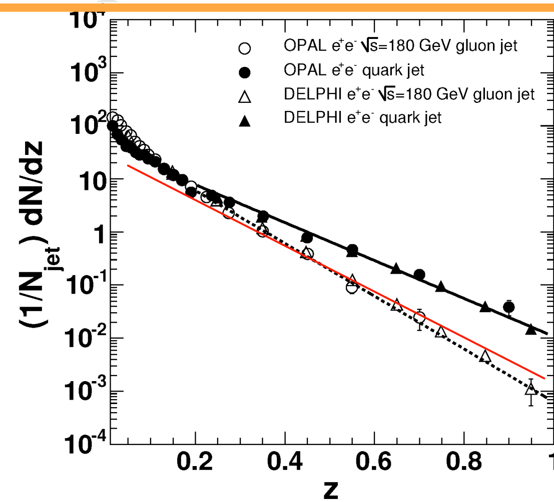
- j_T is parton fragmentation transverse momentum
- k_T is transverse momentum of a parton in a proton (2 protons)
- $x_E = -p_T \bullet p_{Tt}/|p_{Tt}|^2$ represents away jet fragmentation z
- p_{out} is component of away p_T perpendicular to trigger p_{Tt}

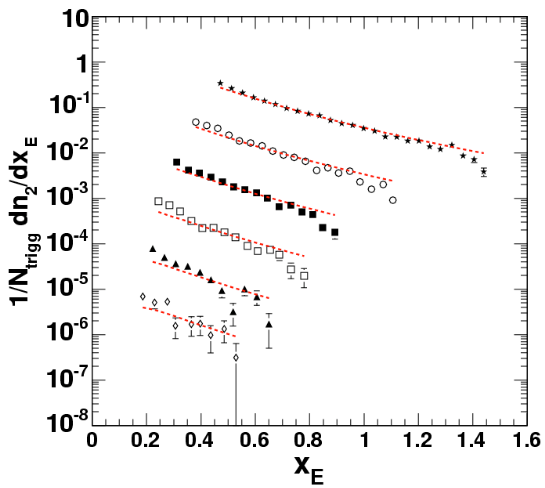
We needed $\langle z_t \rangle$ to solve for k_T. Tried to get it from x_E dist.

Fit x_E distributions to form of D(z) used by LEP measurements by integrating Eq (1) numerically

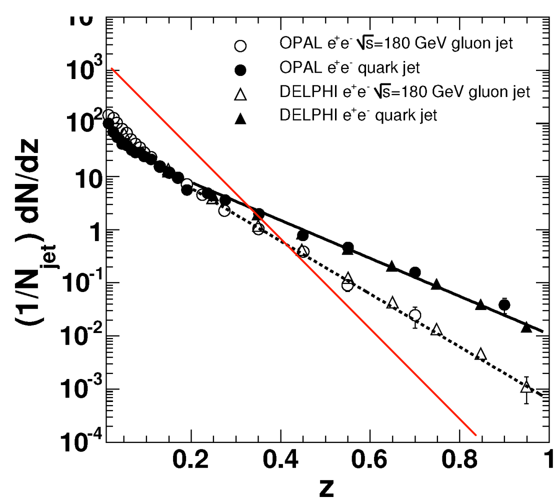


$D(z)=\exp(-10z)$





$D(z)=\exp(-20z)$



After many convergence difficulties, Jan Rak gets desperate and tries two vastly different frag. Functions$\Rightarrow$No effect on calculated x_E distributions---Mike, can you check this analytically?!

Amazingly, I could; and got a neat result

$$\boxed{\frac{d\sigma_\pi}{dp_{T_t} dz_t dp_{T_a}} = \frac{1}{\hat{x}_h\, p_{T_t}} \frac{d\sigma_q}{d(p_{T_t}/z_t)} D^q_\pi(z_t) D^q_\pi(\frac{z_t p_{T_a}}{\hat{x}_h p_{T_t}})} \quad (1)$$

Take: $D(z) = B\, \exp(-bz)$ $\quad \dfrac{d\sigma_q}{d(p_{T_t}/z_t)} = \dfrac{A}{(p_{T_t}/z_t)^{(n-1)}}$

(2) $$\frac{d\sigma_\pi}{dp_{T\mathrm{t}} dp_{T\mathrm{a}}} = \frac{B^2}{\hat{x}_\mathrm{h}} \frac{A}{p^n_{T_t}} \int_{x_{T_t}}^{\hat{x}_\mathrm{h} \frac{p_{T\mathrm{t}}}{p_{T\mathrm{a}}}} dz_\mathrm{t}\, z_\mathrm{t}^{n-1} \exp -bz_\mathrm{t}(1 + \frac{p_{T\mathrm{a}}}{\hat{x}_\mathrm{h} p_{T\mathrm{t}}})$$

$$\frac{d\sigma_\pi}{dp_{T\mathrm{t}}} = \frac{AB}{p^{n-1}_{T_t}} \int_{x_{T_t}}^{1} dz_\mathrm{t}\, z_\mathrm{t}^{n-2} \exp -bz_\mathrm{t}$$

Using: $\Gamma(a,x) \equiv \int_x^\infty t^{a-1}\, e^{-t}\, dt$ $\quad$ Where Γ(a,0)= Γ(a)=(a-1) Γ(a)

The final result

$$\frac{d^2\sigma_\pi}{dp_{T\mathrm{t}}dp_{T\mathrm{a}}} \approx \frac{\Gamma(n)}{b^n}\frac{B^2}{\hat{x}_\mathrm{h}}\frac{A}{p_{T_t}^n}\frac{1}{(1+\frac{p_{T\mathrm{a}}}{\hat{x}_\mathrm{h}p_{T\mathrm{t}}})^n}$$

$$\frac{d\sigma_\pi}{dp_{T\mathrm{t}}} \approx \frac{\Gamma(n-1)}{b^{n-1}}\frac{AB}{p_{T_t}^{n-1}} \quad ,$$

$$\left.\frac{dP_\pi}{dp_{T\mathrm{a}}}\right|_{p_{T\mathrm{t}}} \approx \frac{B(n-1)}{b p_{T\mathrm{t}}}\frac{1}{\hat{x}_\mathrm{h}}\frac{1}{(1+\frac{p_{T\mathrm{a}}}{\hat{x}_\mathrm{h}p_{T\mathrm{t}}})^n} \quad . \qquad (42)$$

In the collinear limit, where $p_{T\mathrm{a}}=x_\mathrm{E}p_{T\mathrm{t}}$:

$$\left.\frac{dP_\pi}{dx_\mathrm{E}}\right|_{p_{T\mathrm{t}}} \approx \frac{B(n-1)}{b}\frac{1}{\hat{x}_\mathrm{h}}\frac{1}{(1+\frac{x_E}{\hat{x}_\mathrm{h}})^n} \quad . \qquad (43)$$

Where B/b≈<m>≈b is the mean charged multiplicity in the jet

Why dependence on the Frag. Fn. vanishes

- The only dependence on the fragmentation function is in the normalization constant B/b which equals <m>, the mean multiplicity in the away jet from the integral of the fragmentation function.

- The dominant term in the x_E distribution is the Hagedorn function $1/(1+x_E/\hat{x}_h)^n$ so that at fixed p_{Tt} the x_E distribution is predominantly a function only of x_E and thus exhibits x_E scaling, as observed.

- The reason that the x_E distribution is not sensitive to the shape of the fragmentation function is that the integral over z_t in (1, 2) for fixed p_{Tt} and p_{Ta} is actually an integral over jet transverse momentum $\hat{p}_{T_t}$. However since the trigger and away jets are always roughly equal and opposite in transverse momentum (in p+p), integrating over $\hat{p}_{T_t}$ simultaneously integrates over $\hat{p}_{T_a}$. The integral is over z_t, which appears in both trigger and away side fragmentation functions in (1).

Where did I (and everybody in HEP) get this idea?---from Feynman, Field and Fox

38 *R.P Feynman et al. / Large transverse momenta*

FFF Nucl.Phys. **B128**(1977) 1-65

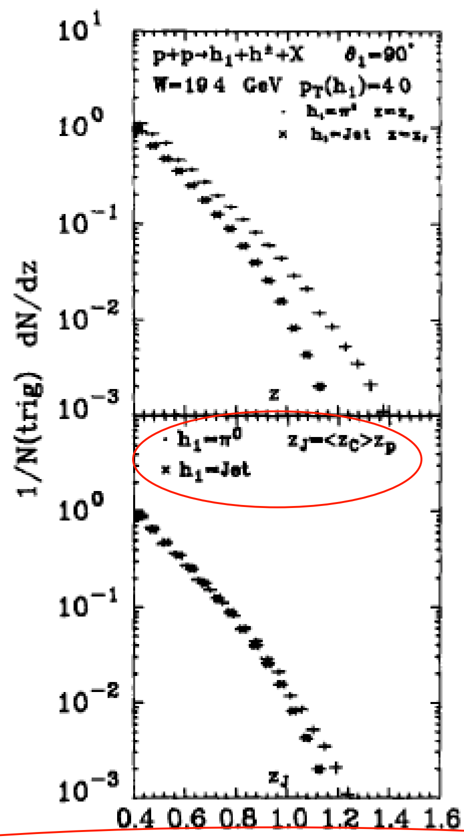


Fig. 23. Comparison of the π^0 and jet trigger away-side distribution of charged hadrons in pp collisions at $W = 19.4$ GeV, $\theta_1 = 90°$, and $p_\perp$ (trigger) = 4.0 GeV/c from the quark-quark scattering model. The upper figure shows the single-particle (π^0) trigger results plotted *versus* $z_p = -p_x(h^\pm)/p_\perp(\pi^0)$ and the jet trigger plotted *versus* $z_J = -p_x(h^\pm)/p_\perp(\text{jet})$ (see table 1). In the lower figure, we plot *both versus* z_J, where for the jet trigger $z_J = z_J$ but for the single-particle trigger $z_J = \langle z_c \rangle z_p$. The away hadrons are integrated over all rapidity Y and $|180° - \phi| \leqslant 45°$ and the theory is calculated using $\langle k_\perp \rangle_{h\to q} = 500$ MeV. ● $h_1 = \pi^0$, × h_1 = jet.

"There is a simple relationship between experiments done with single-particle triggers and those performed with jet triggers. The only difference in the opposite side correlation is due to the fact that the 'quark', from which a single-particle trigger came, always has a higher $p_\perp$ than the trigger (by factor $1/z_{trig}$). The away-side correlations for a single-particle trigger at $p_\perp$ should be roughly the same as the away side correlations for a jet trigger at $p_\perp$ (jet)= $p_\perp$ (single particle)/ $<z_{trig}>$".

As measured at the ISR by Darriulat, etc.

P. Darriulat, et al, Nucl.Phys. **B107** (1976) 429-456

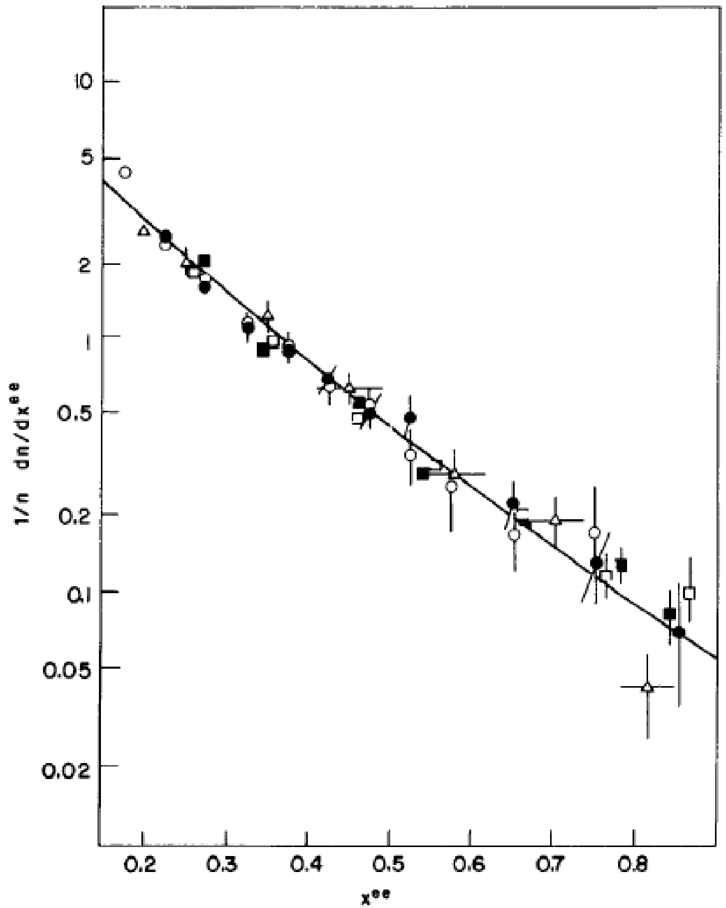


Figure 21 Jet fragmentation functions measured in different processes: ν-p interactions (*open triangles*, Van der Welde 1979); e^+e^- annihilations (*solid line*, Hanson et al 1975); and pp collisions (*full circles* CS, $p_T < 6$ GeV/c, *open circles* CS, $p_T > 6$ GeV/c, *full squares* CCOR, $p_T > 5$ GeV/c, *open squares* CCOR, $p_T > 7$ GeV/c).

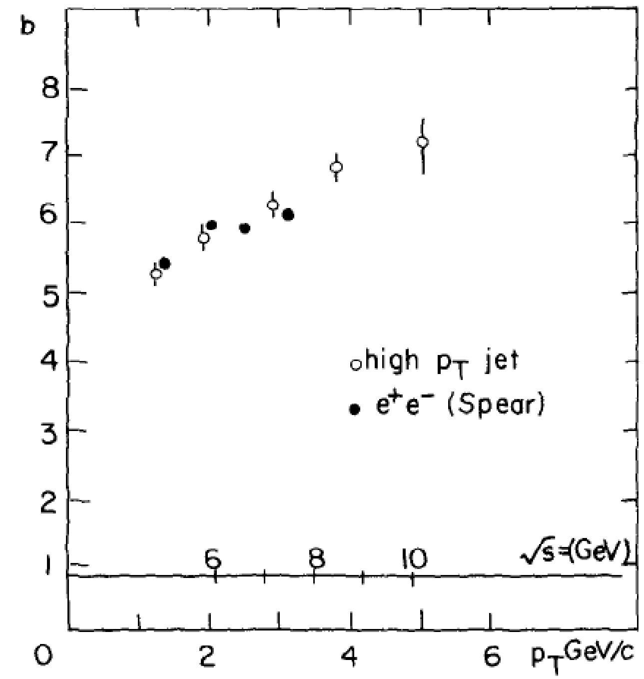
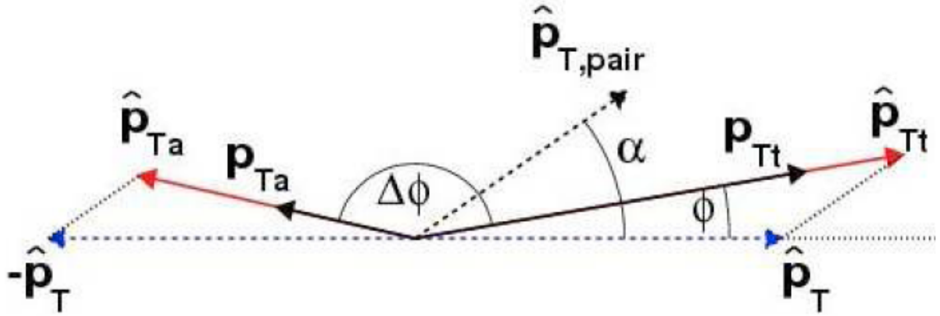


Figure 19 The slopes *b* obtained from exponential fits to the jet fragmentation function in the interval $0.2 < z < 0.8$ in e^+e^- annihilation (*full circles*) and LPTH data of the BS Collaboration (*open circles*).

Figures from P. Darriulat, ARNPS **30** (1980) 159-210 showing that Jet fragmentation functions in νp, e^+e^- and pp (CCOR) are the same with the same dependence of *b* (exponential slope) on "$\hat{s}$"

A very interesting formula

$$\left.\frac{dP_\pi}{dx_{\rm E}}\right|_{p_{T{\rm t}}} \approx \langle m\rangle (n-1)\frac{1}{\hat{x}_{\rm h}}\frac{1}{(1+\frac{x_E}{\hat{x}_{\rm h}})^n}$$

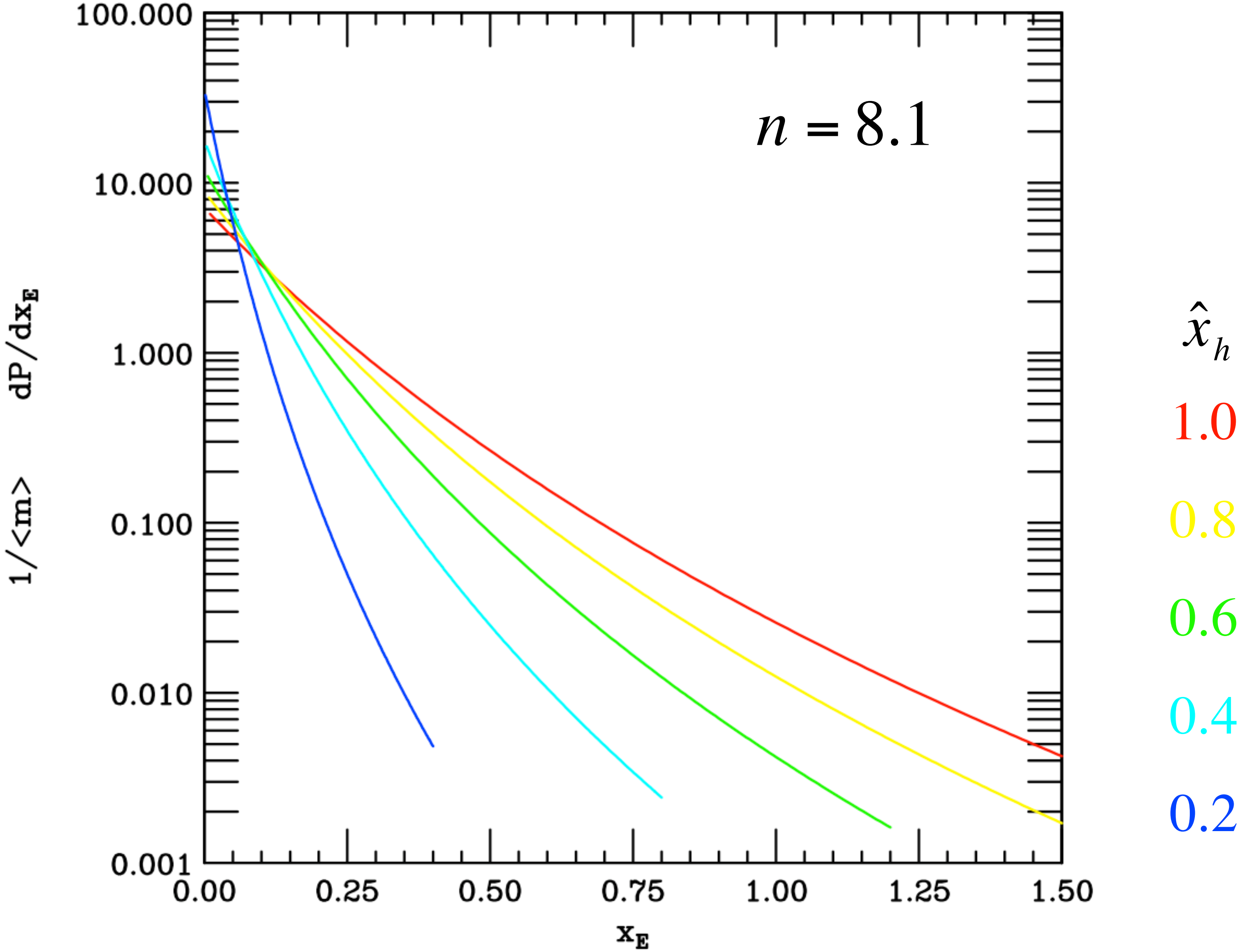


$$x_E = \frac{-p_{T_a}\cos\Delta\phi}{p_{T_t}} \simeq \frac{p_{T_a}}{p_{T_t}} \longrightarrow \hat{x}_h = \frac{\hat{p}_{T_a}}{\hat{p}_{T_t}}$$

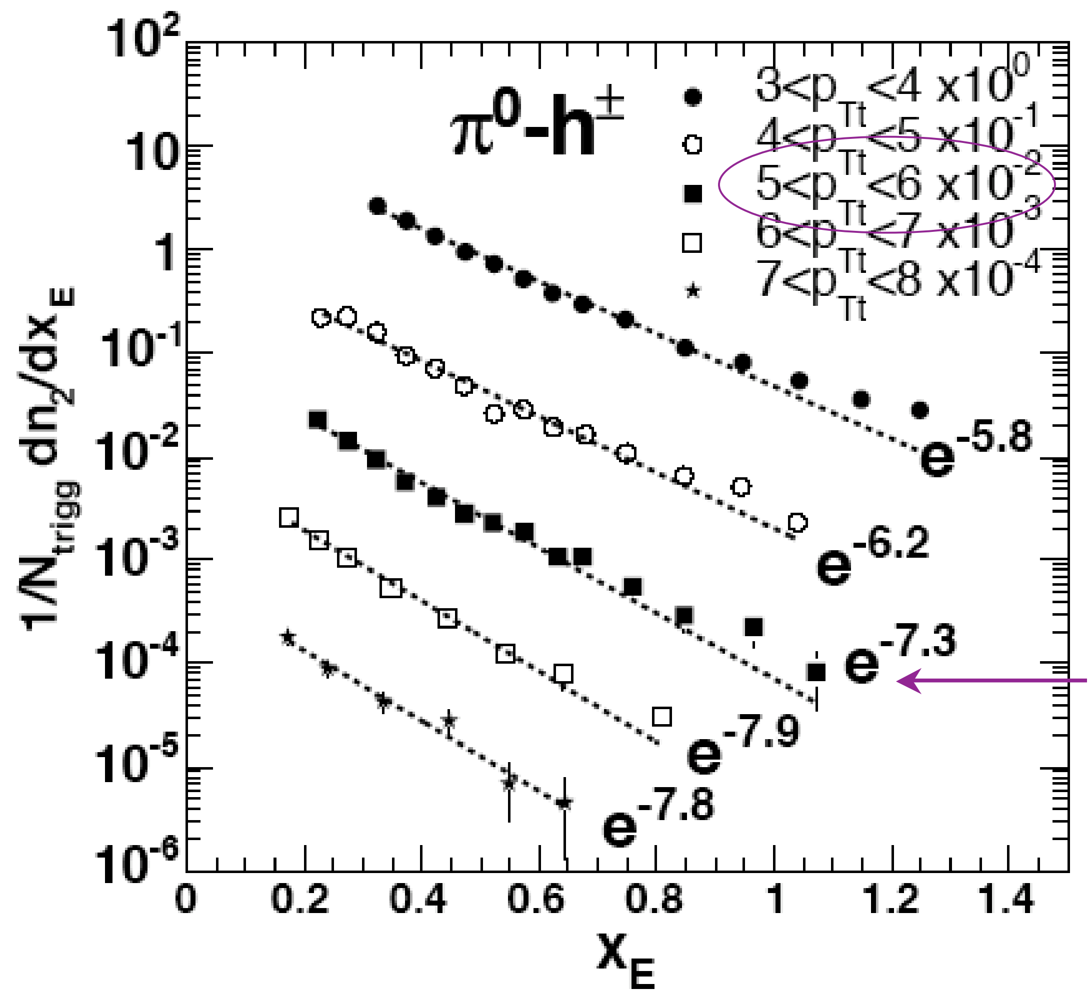
measured

Ratio of jet transverse momenta

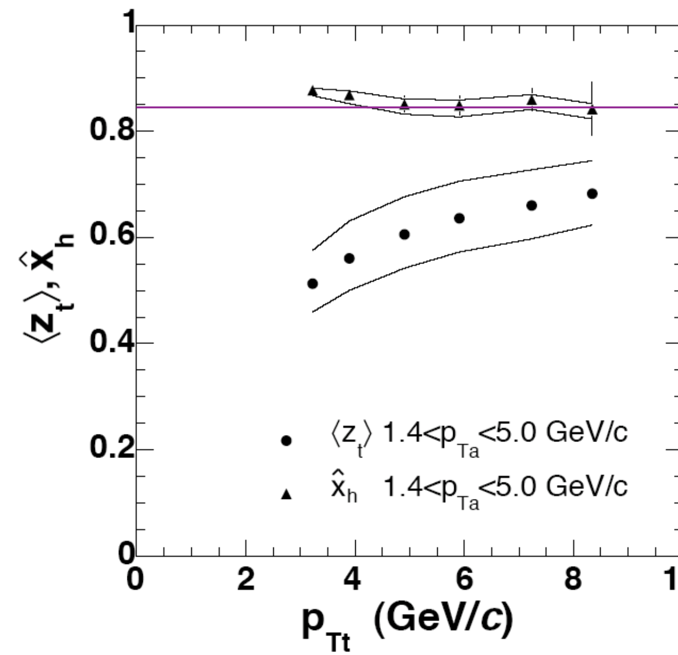
Shape of x_E distribution depends on $\hat{x}_h$ and n but not on b



Does the formula work?

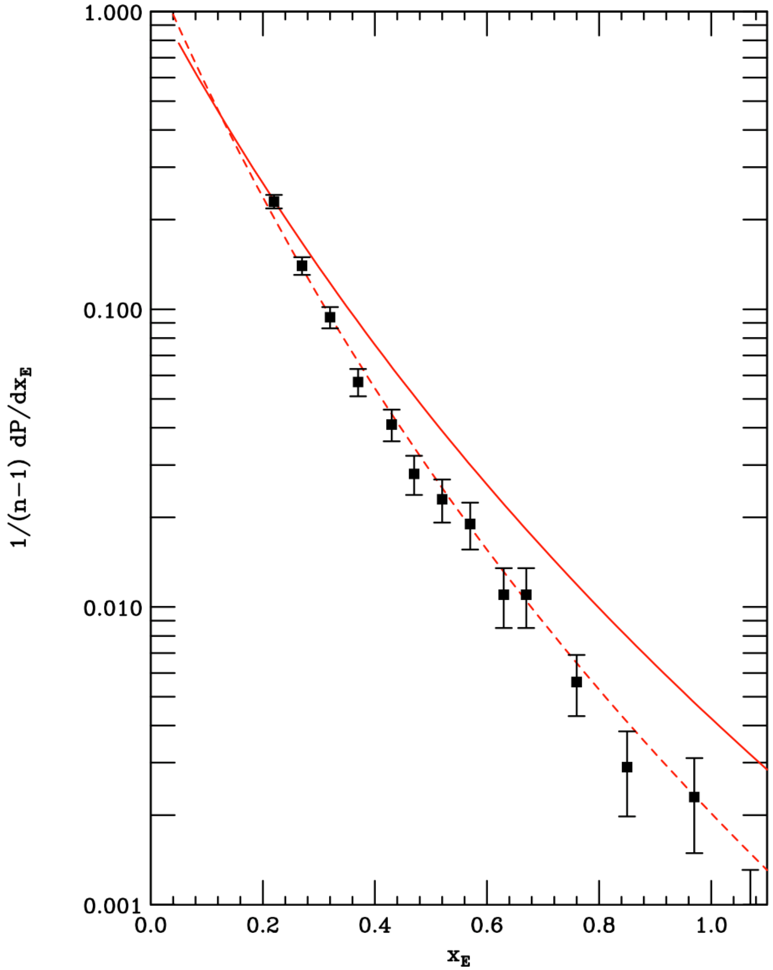


PHENIX p+p
hep-ex/0605039



$\hat{x}_{\rm h} \approx 0.8$ due to k_T smearing

It works for PHENIX p+p hep-ex/0605039



$$f(y) = \frac{1}{(1+y)^{8.1}}$$

$x_E = y$ (solid line)

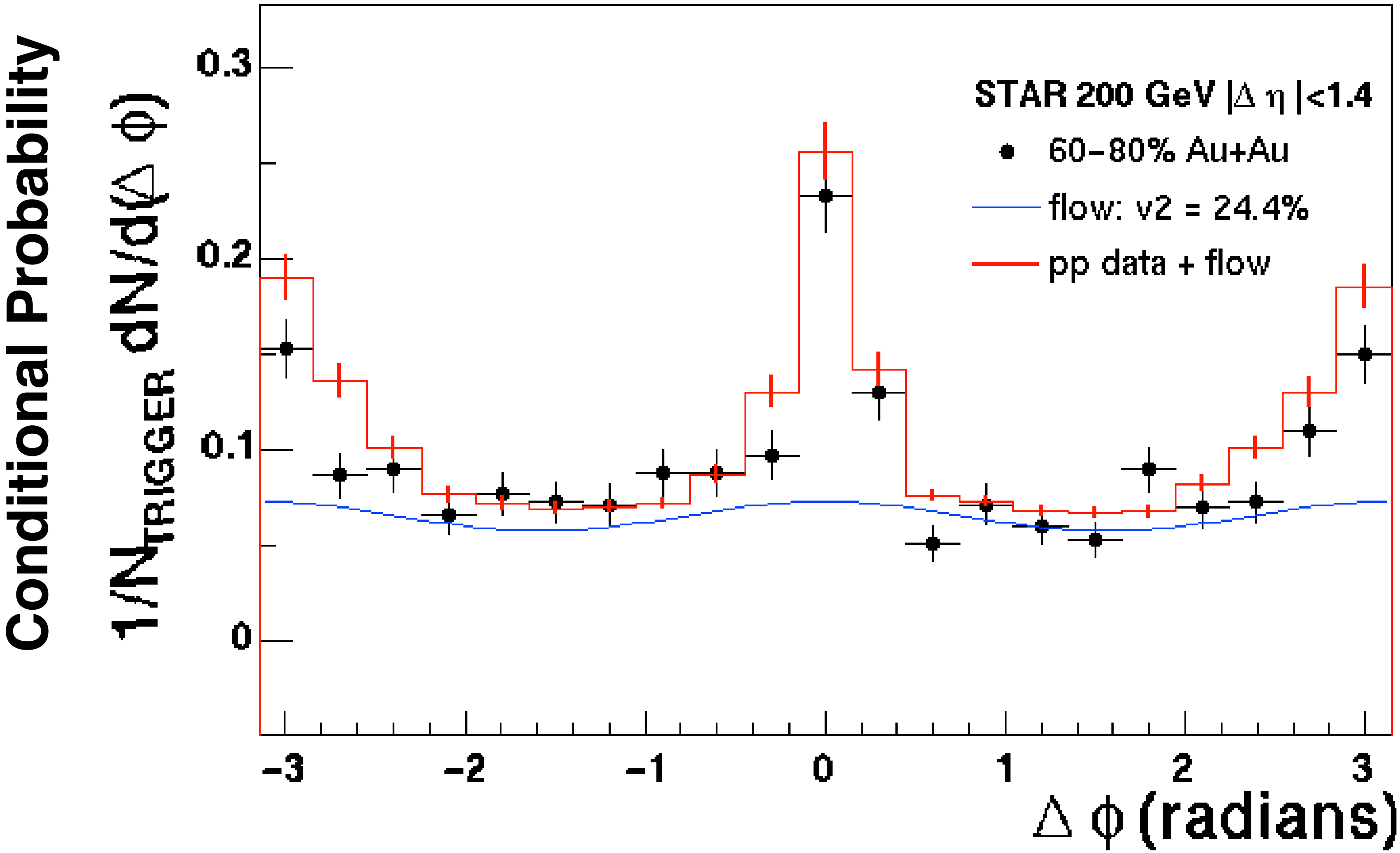
$x_E = \hat{x}_h\, y = 0.8\, y$ (dashed line)

nb: vertical scale labels on this and following similar plots should be multiplied by 10

Application 2-particle correlations in Au+Au

STAR-Peripheral Au+Au data vs. pp+flow

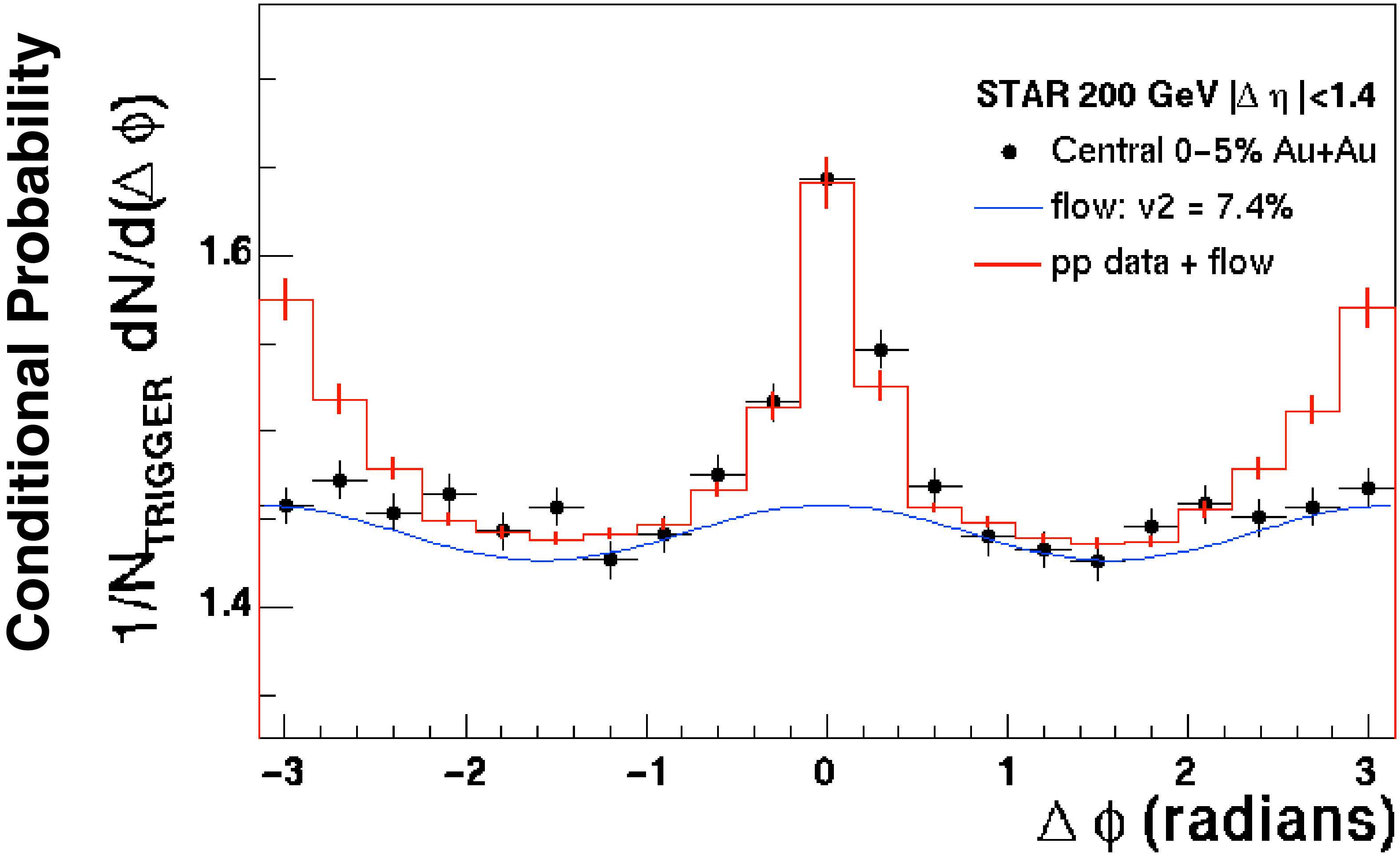
$$C_2(Au+Au) = C_2(p+p) + A*(1+2v_2(p_{Tt})v_2(p_{Ta})\cos(2\Delta\phi))$$



STAR-QM2002-Hardke 4< p_{Tt}< 6 GeV/c 2<p_{Ta}<p_{Tt}

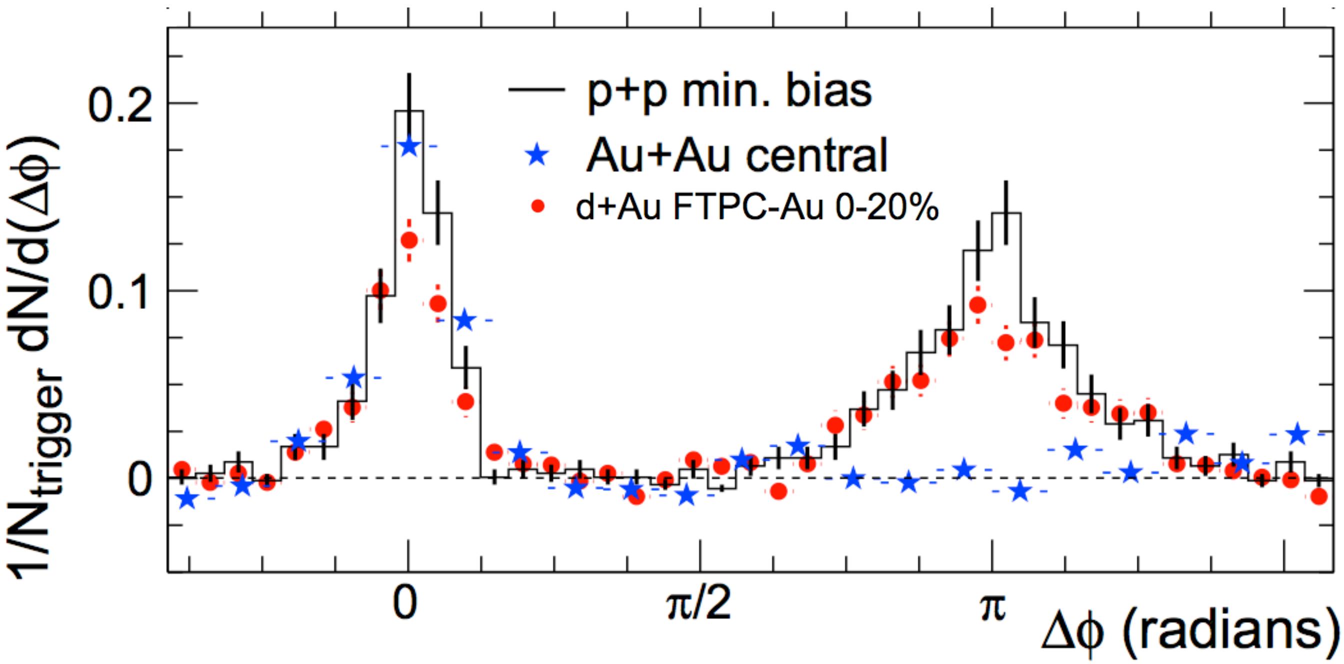
STAR-Central Au+Au data vs. pp+flow

$$C_2(Au+Au) = C_2(p+p) + A*(1+2v_2(p_{Tt})v_2(p_{Ta})\cos(2\Delta\phi))$$



STAR-QM2002-Hardke 4< p_{Tt}< 6 GeV/c 2<p_{Ta}<p_{Tt}

Great PR-Not such good Science

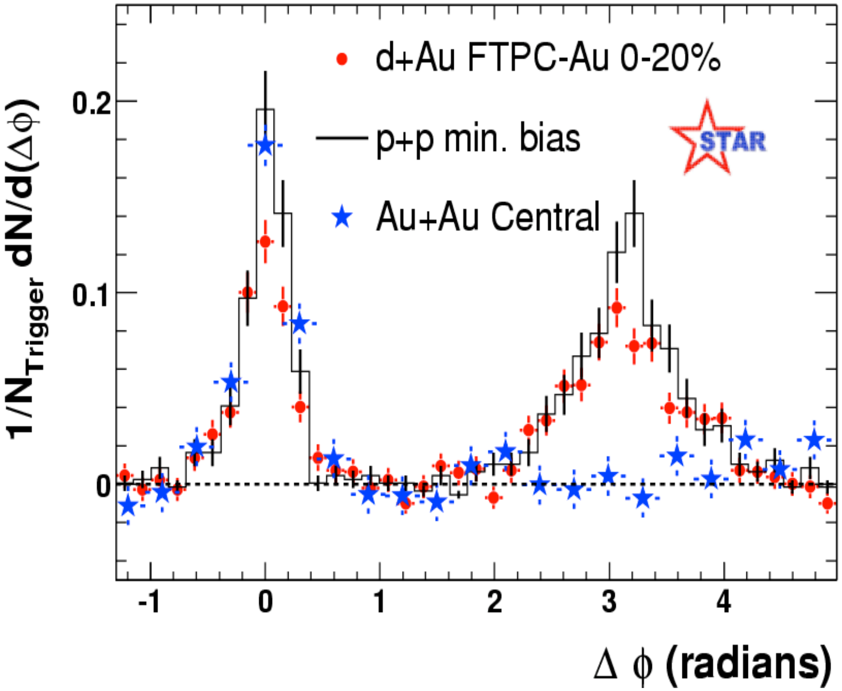


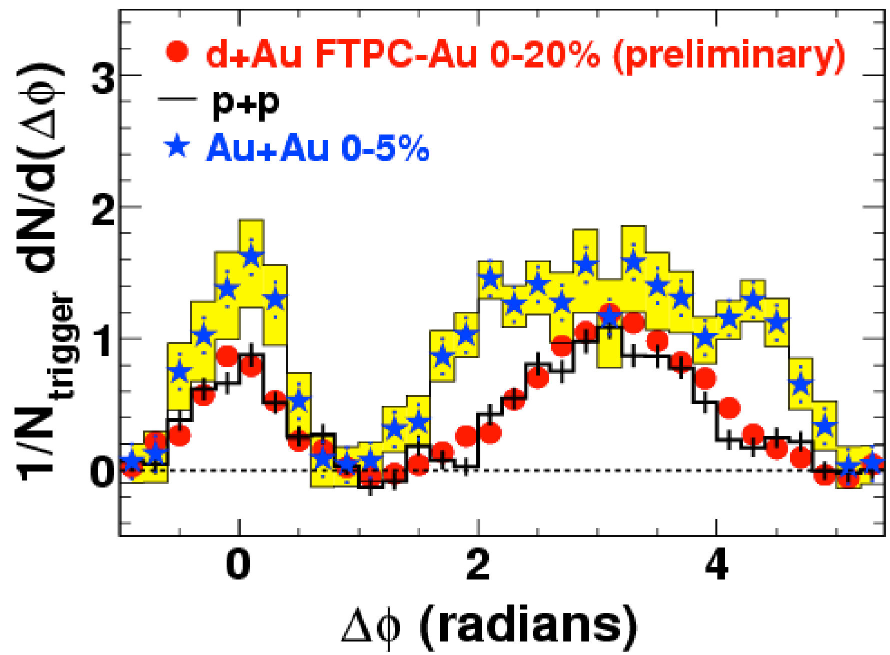
Did the away jet vanish in Au+Au?

STAR-PRL **91**(2003)072304 4< p_{Tt}< 6 GeV/c 2<p_{Ta}<p_{Tt}

Also serious issues with exact v_2 to use, and exact background level

The away jet didn't disappear it just lost energy and widened





STAR-PRL**91**(2003)072304
$4 < p_{Tt} < 6$ GeV/c $2 < p_{Ta} < p_{Tt}$
$x_h = p_{Ta}/p_{Tt} \sim 0.5$

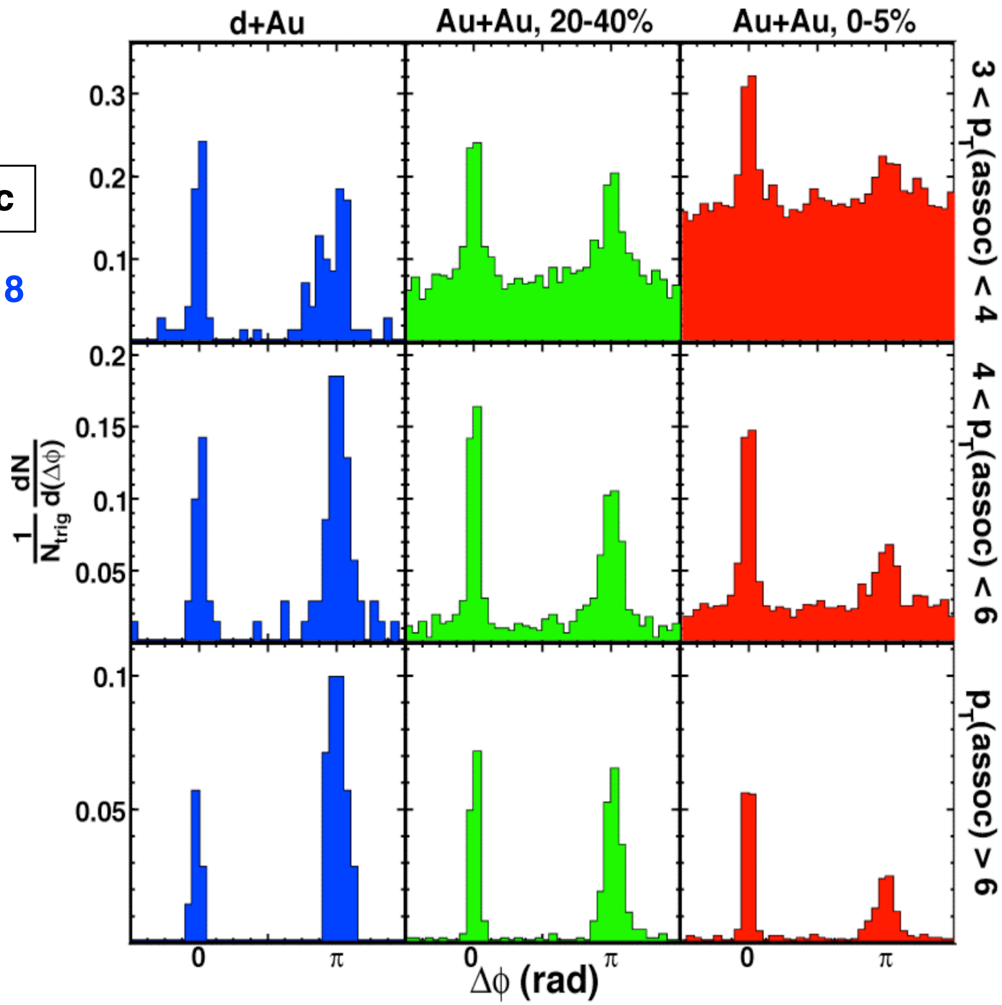
STAR-PRL**95**(2005)152301
$4 < p_{Tt} < 6$ GeV/c $0.15 < p_{Ta} < 4$ GeV/c
$x_h = p_{Ta}/p_{Tt} \sim 0.04$

Emergence of narrow Di-Jets p_{Ta}>3 GeV/c--- Is the trick p_{Tt}>8 GeV/c or $x_h=p_{Ta}/p_{Tt}$~0.375?

STAR

8 < p_T(trig) < 15 GeV/c

STAR nucl-ex/0604018



$$x_h = p_{Ta} / p_{Tt}$$

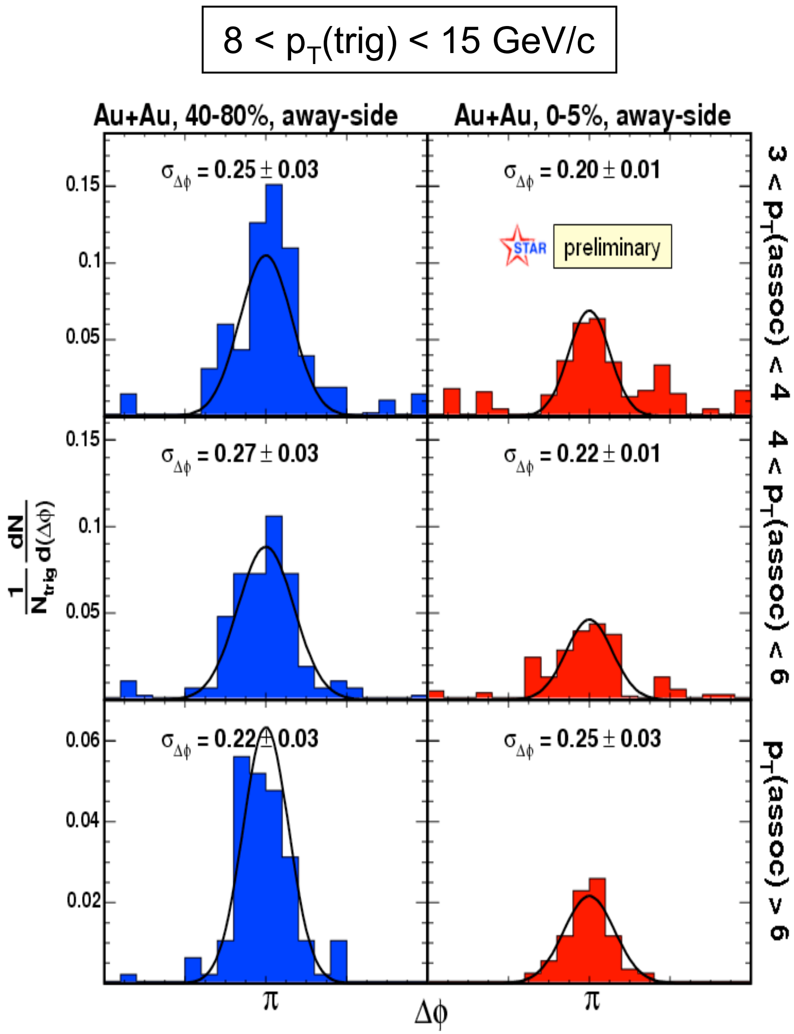
~0.375

~0.5

~0.75

Could it be simply that away-jets lose 1/2 their energy?

Width of Away-Side Peaks

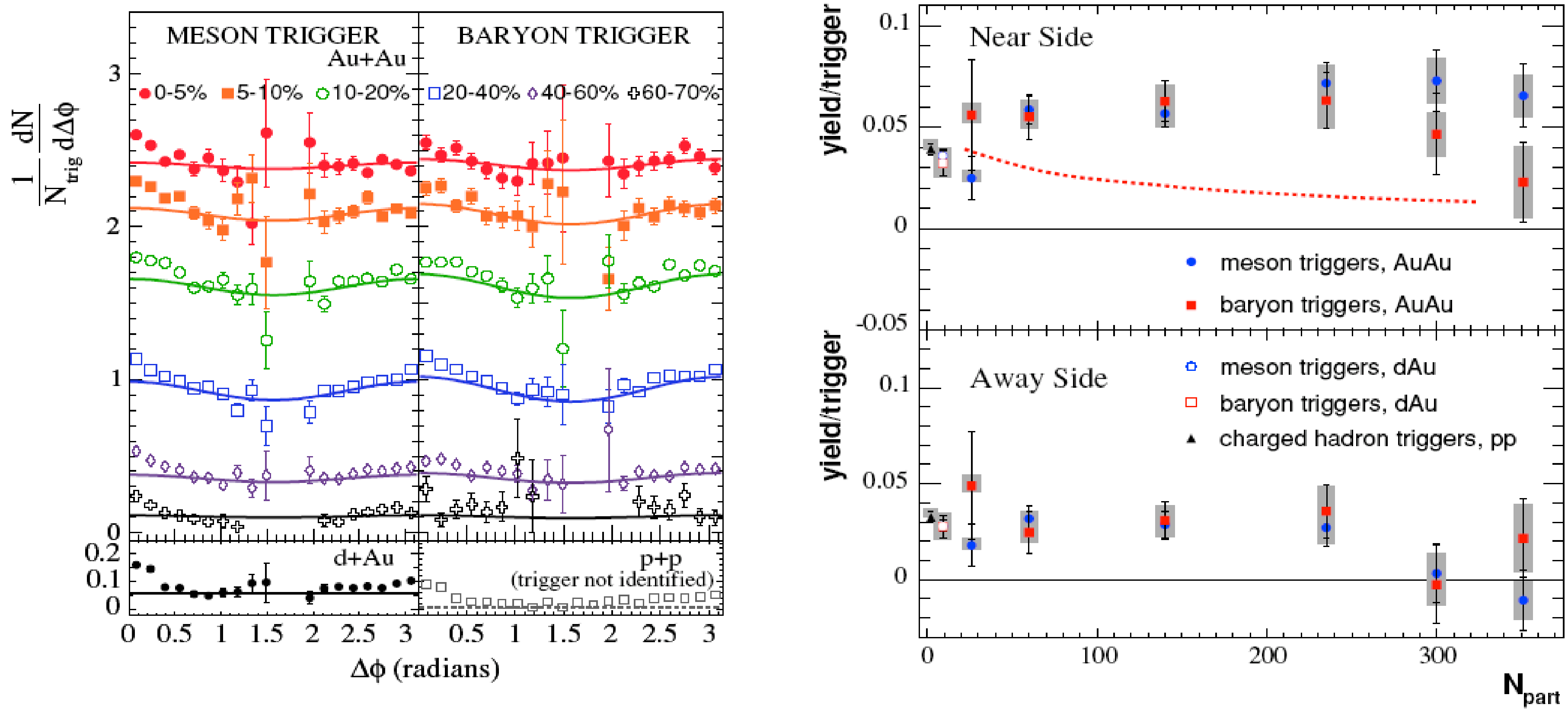


STAR nucl-ex/0604018

- away-side widths similar for central and peripheral
- Away-side width INCREASES with increasing p_{Ta}??!!!

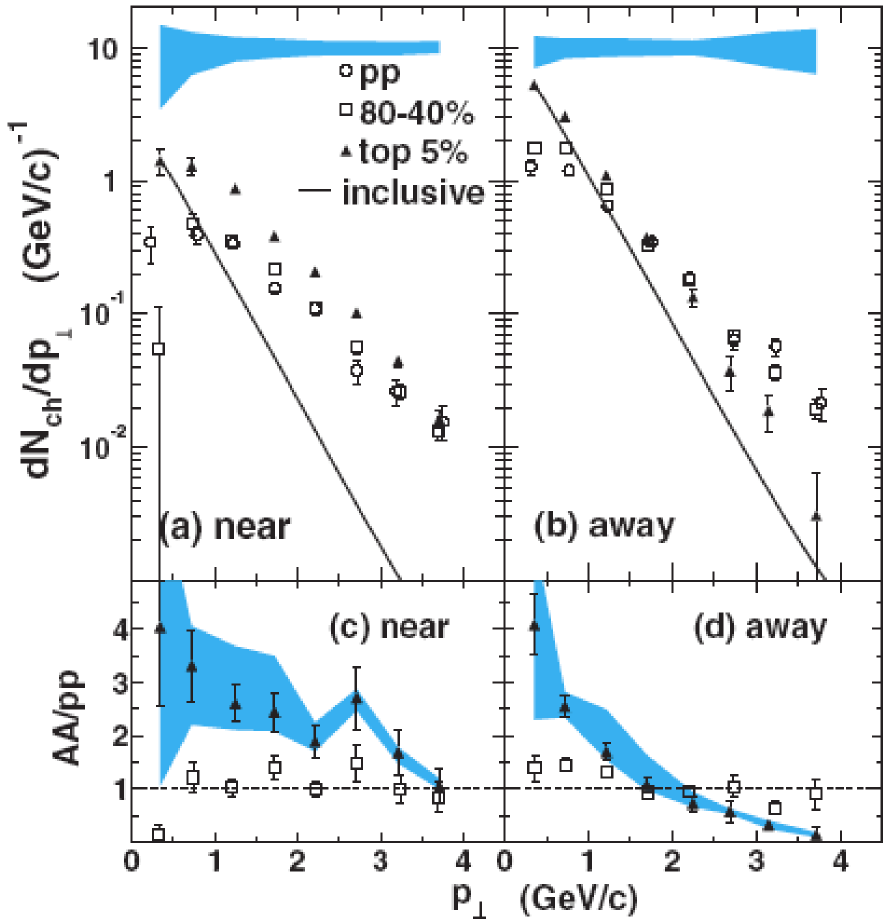
One of the few definitive results

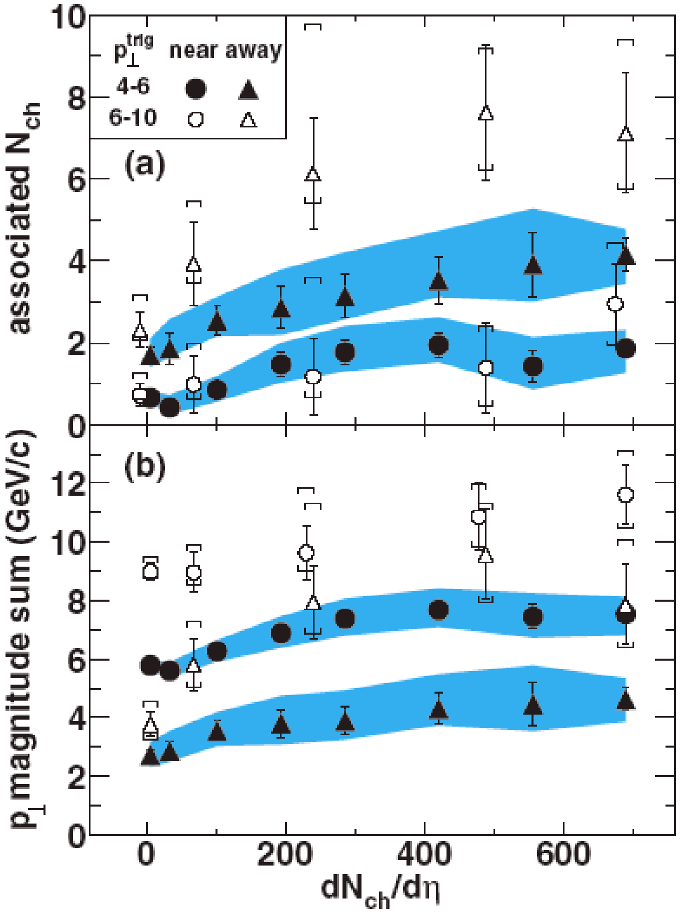
PHENIX PRC **71** 051902 $2.4<p_{Tt}<4$ GeV/c $1.7< p_{Ta}<2.5$ GeV/c



Trigger mesons and baryons in the region of the baryon anomaly both show the same trigger (near) side and away side jet structure. This 'kills' the elegant recombination model of the baryon anomaly

Now Apply Eq. To (STAR) Au+Au data



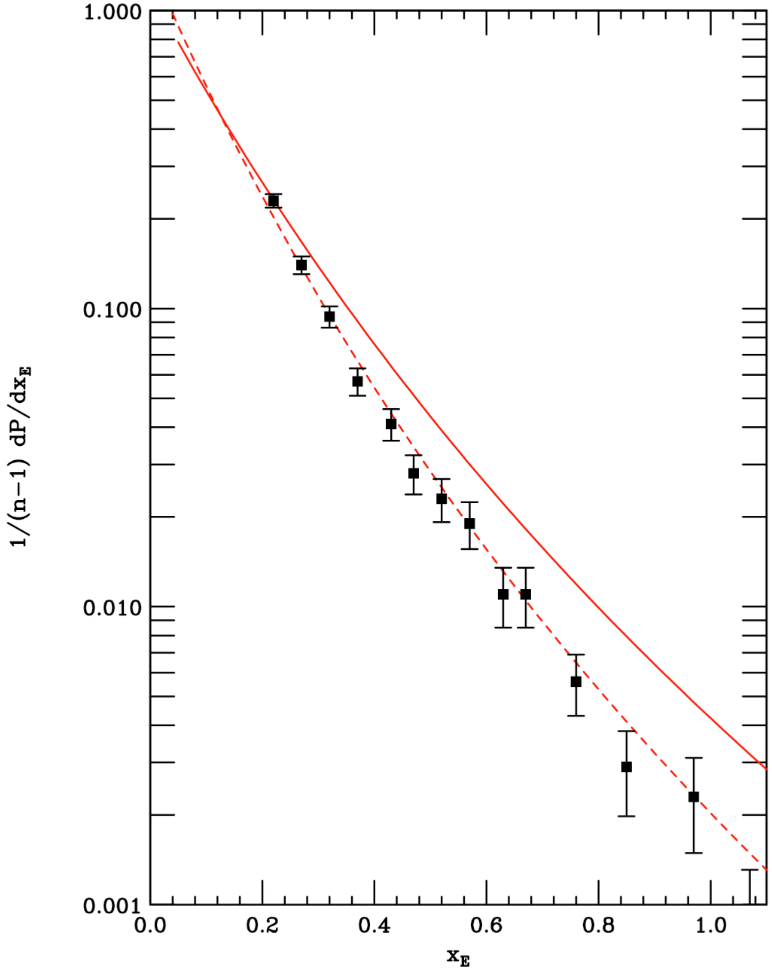


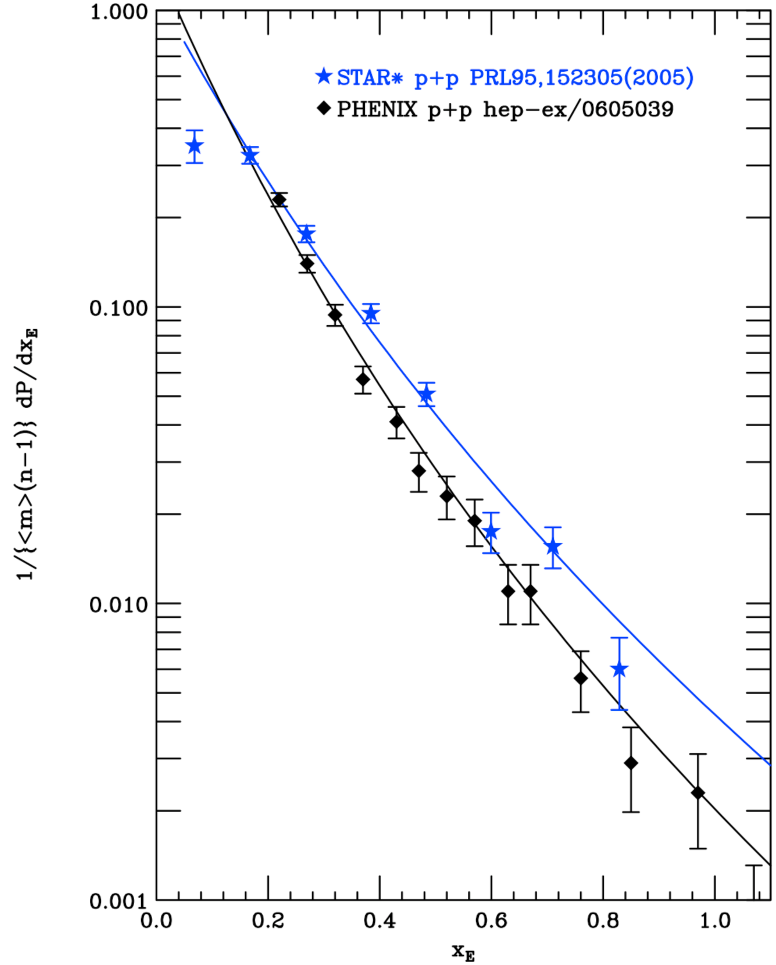
$4 < p_{Tt} < 6$ GeV/c $\langle p_{Tt}\rangle$=4.56 GeV/c

pp, AuAu $\sqrt{s_{NN}}$=200 GeV

STAR, J. Adams, Fuqiang Wang, et al PRL **95**, 152301 (2005)

It works for STAR p+p and:

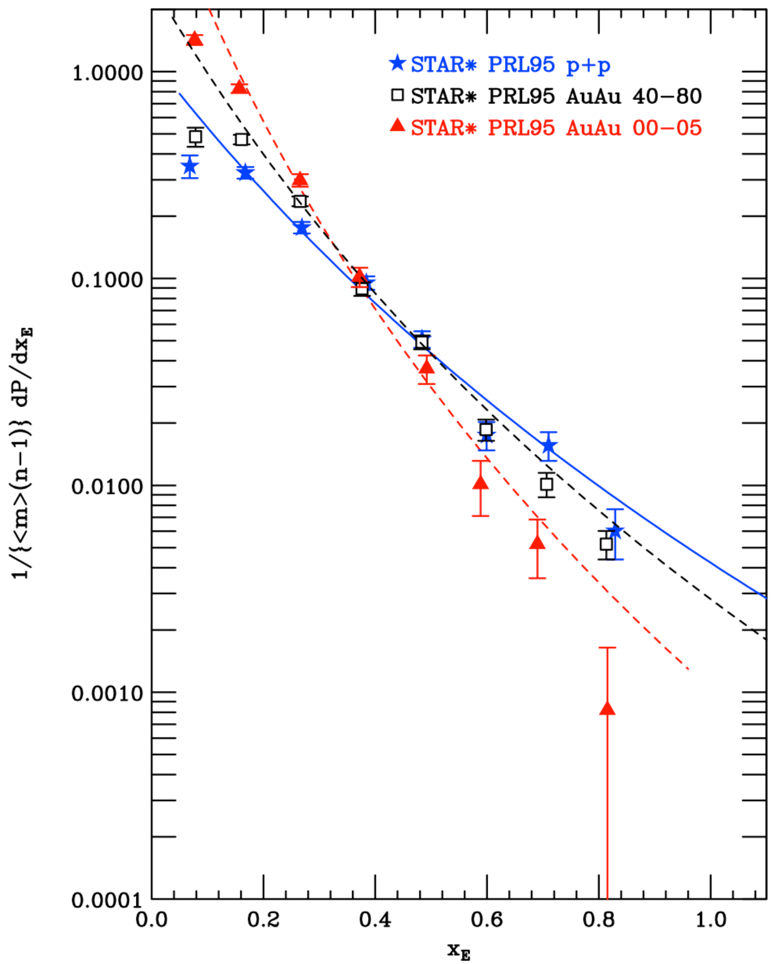




a) * means data normalized w.r. to hep-ex/0605039

b) $\hat{x}_h = 1.0$

Clear effect with centrality

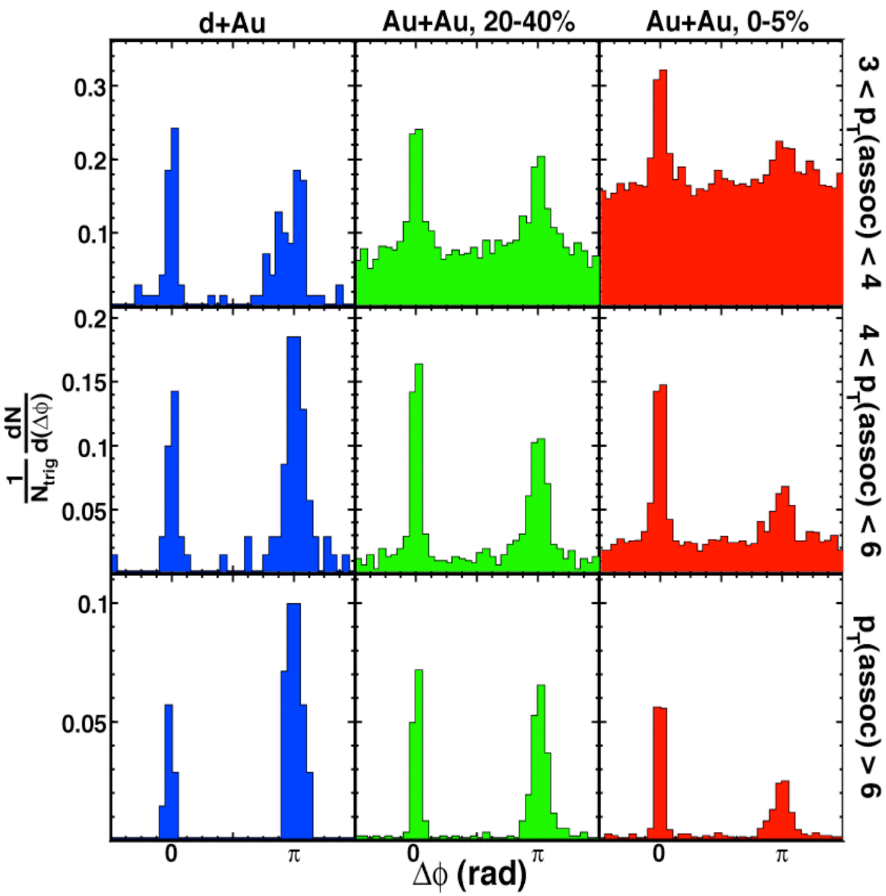


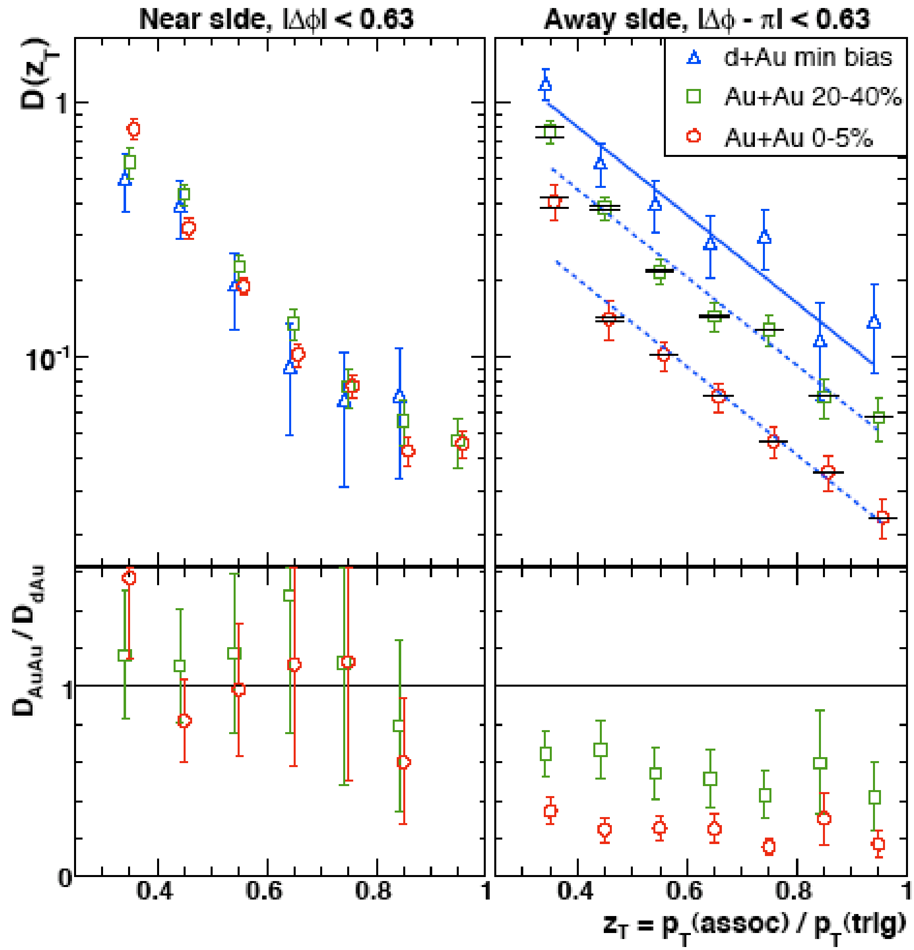
p+p	data*0.6	fit*1.0	$\hat{x}_h$ =1.0
AuAu40-80	data*0.6	fit*1.75	$\hat{x}_h$ =0.75
AuAu00-05	data*0.6	fit*4.0	$\hat{x}_h$ =0.48

- Away jet p_{Ta}/trigger jet p_{Tt} decreases with increasing centrality
- consistent with increase of energy loss with distance traversed in medium

STAR, J. Adams, Fuqiang Wang, et al PRL **95**, 152301 (2005)

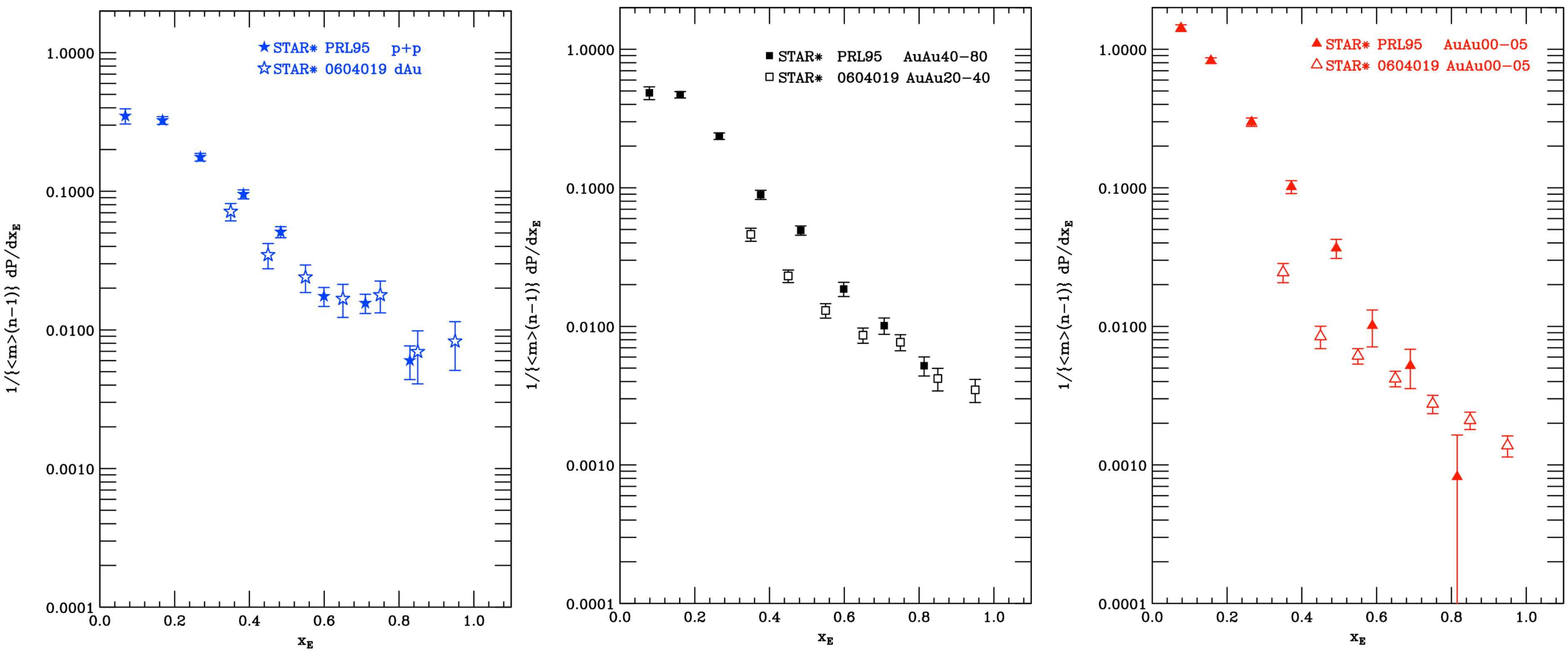
New STAR data AuAu: nucl-ex/0604018





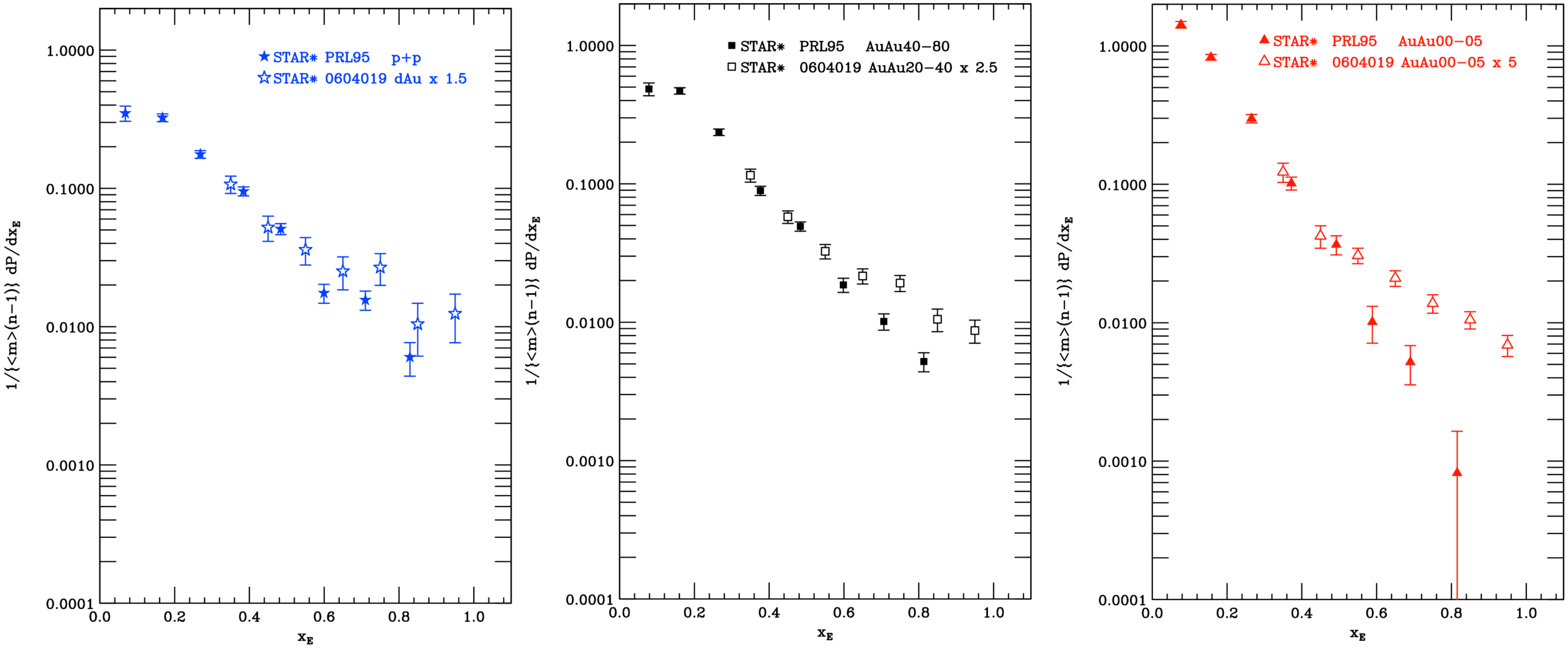
$8 < p_{Tt} < 15$ GeV/c $\langle p_{Tt} \rangle = 9.38$ GeV/c Thanks to Dan Magestro for table of data points

STAR(nucl-ex/0604018) differs from STAR (PRL95) in normalization and SHAPE

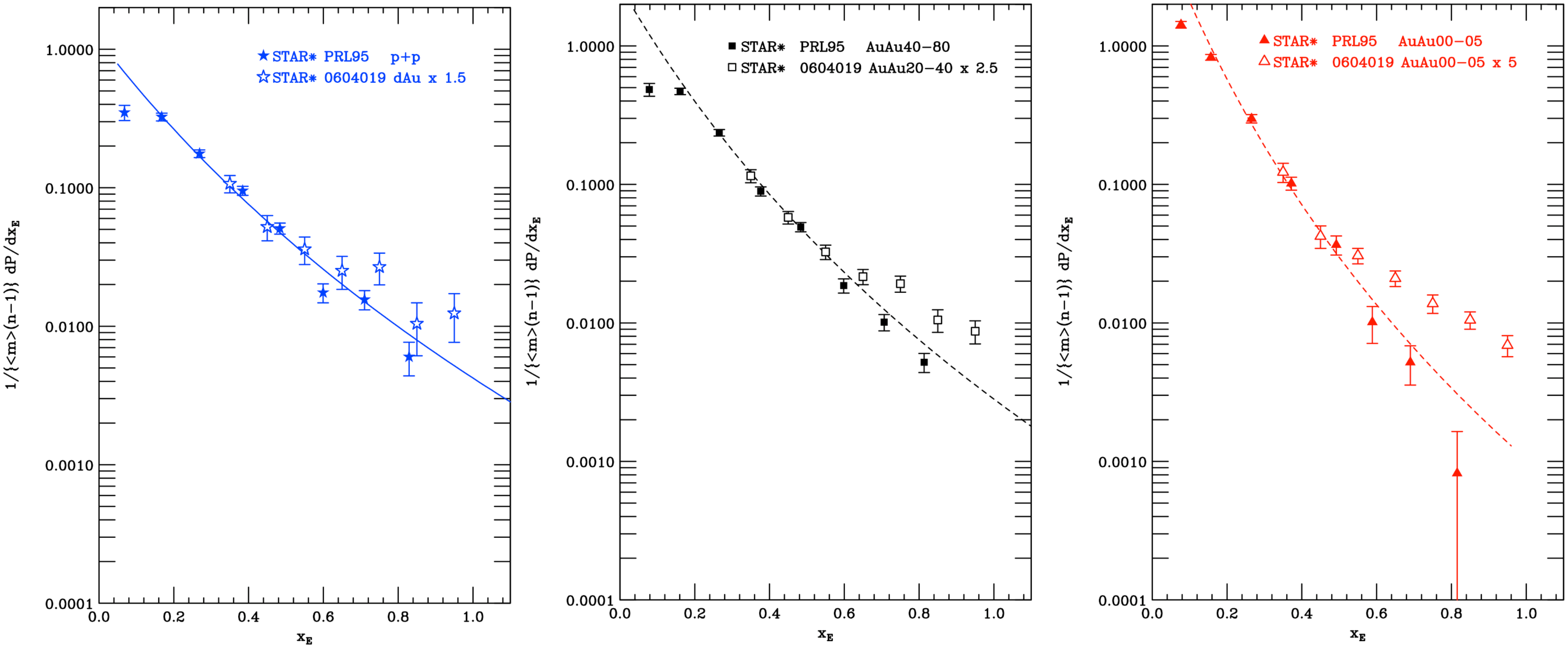


nb: vertical scale labels on these and following similar plots should be multiplied by 10
STAR* 0604019 label should be STAR* 0604018

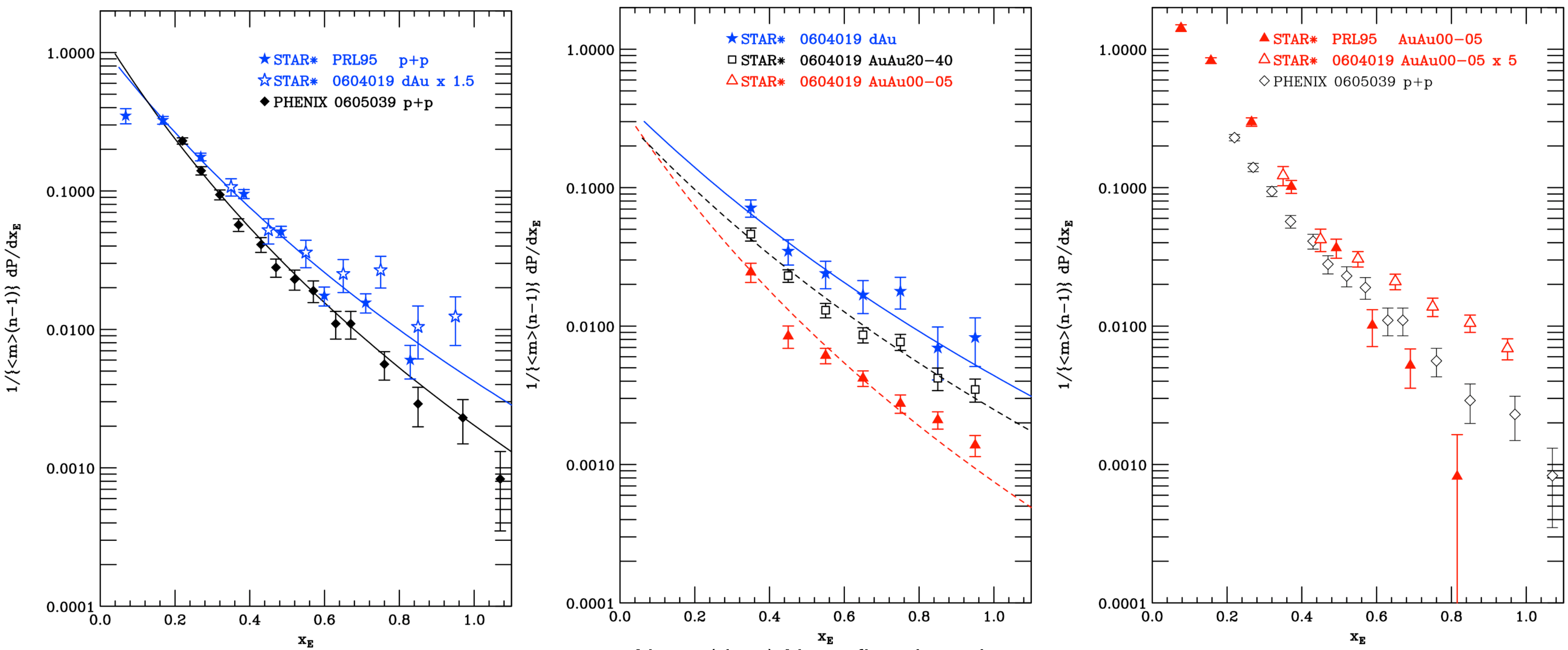
Normalize 064018 to PRL95 by eye



Normalized data with PRL95 curve



STAR 0604018 AuAu central flatter than PHENIX 0605039 p+p for x_E>0.5!

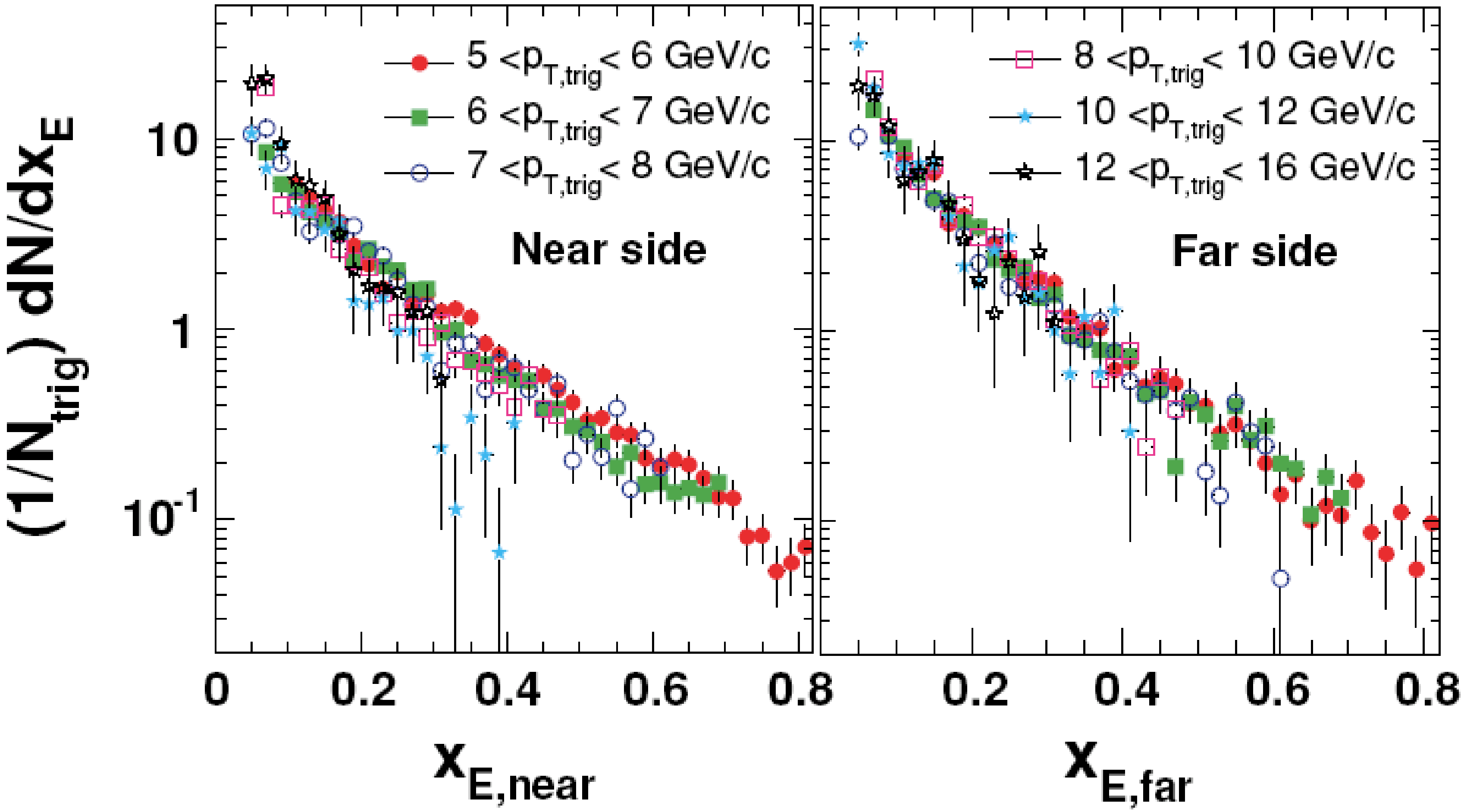


Norm (data)	Norm fit	hatx_h
Data*0.6	Fit*0.500	1.300
Data*0.6	Fit*0.350	1.200
Data*0.6	Fit*0.300	0.850

Can still fit, but curves too flat x_h>1, but still decreases with increasing centrality

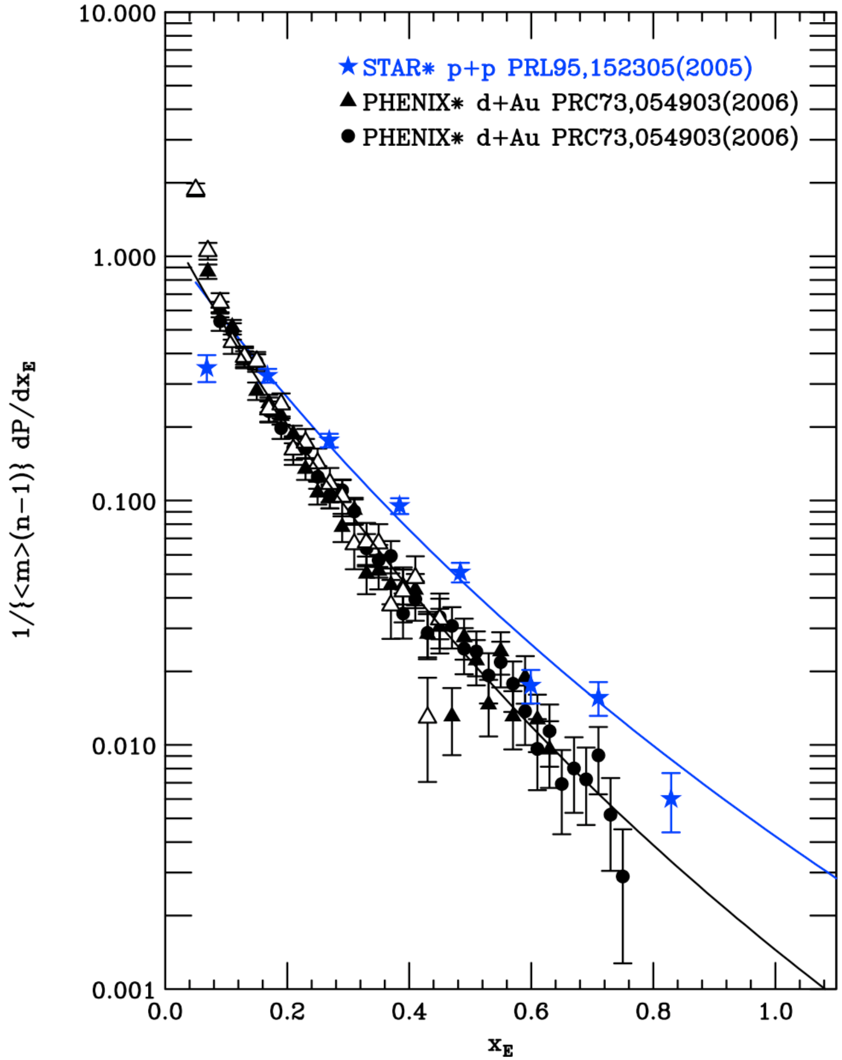
PHENIX d+Au results

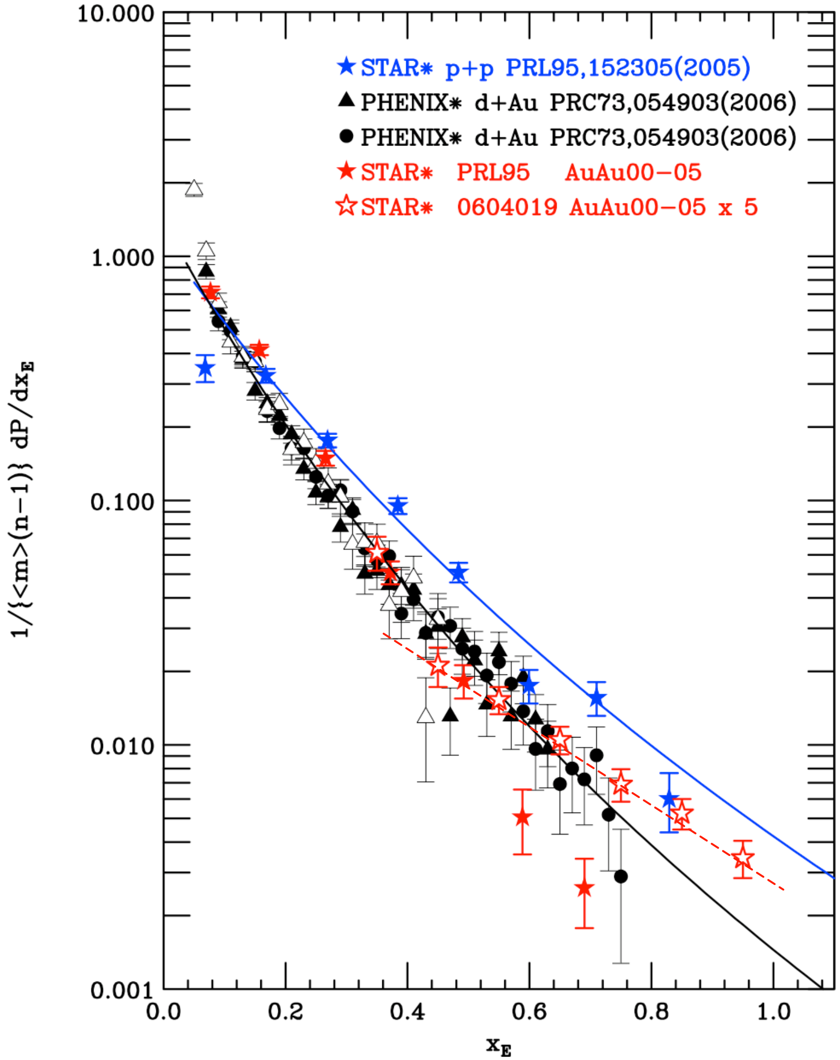
PHENIX, PRC 73, 054903 (2006)



- Beautiful p+p and dAu results with pTt in STAR punchthrough range.

PHENIX d+Au PRC73





$\hat{x}_h = 0.75$ $\hat{x}_h = 1.0$

- STAR 0604018 AuAu0-5 flatter than all published p+p and d+Au data ????

Conclusions

- Nice `fit' of $1/(1+y)^{n=8.1}$ with $x_E = \hat{x}_h\, y$ to PHENIX hep-ex/0605039 and PRC73; and STAR PRL95 x_E distributions. But STAR nucl-ex/0604018 d+Au much flatter than PHENIX d+Au PRC73,054903 (2006)

- Both STAR Au+Au measurements show a decrease in the ratio of the transverse momentum of the away jet relative to the trigger jet with increasing centrality. For both data sets $\hat{x}_h$ decreases by a factor of ~2 from p+p (dAu) to Au+Au central collisions. Much more info than I_{AA}.

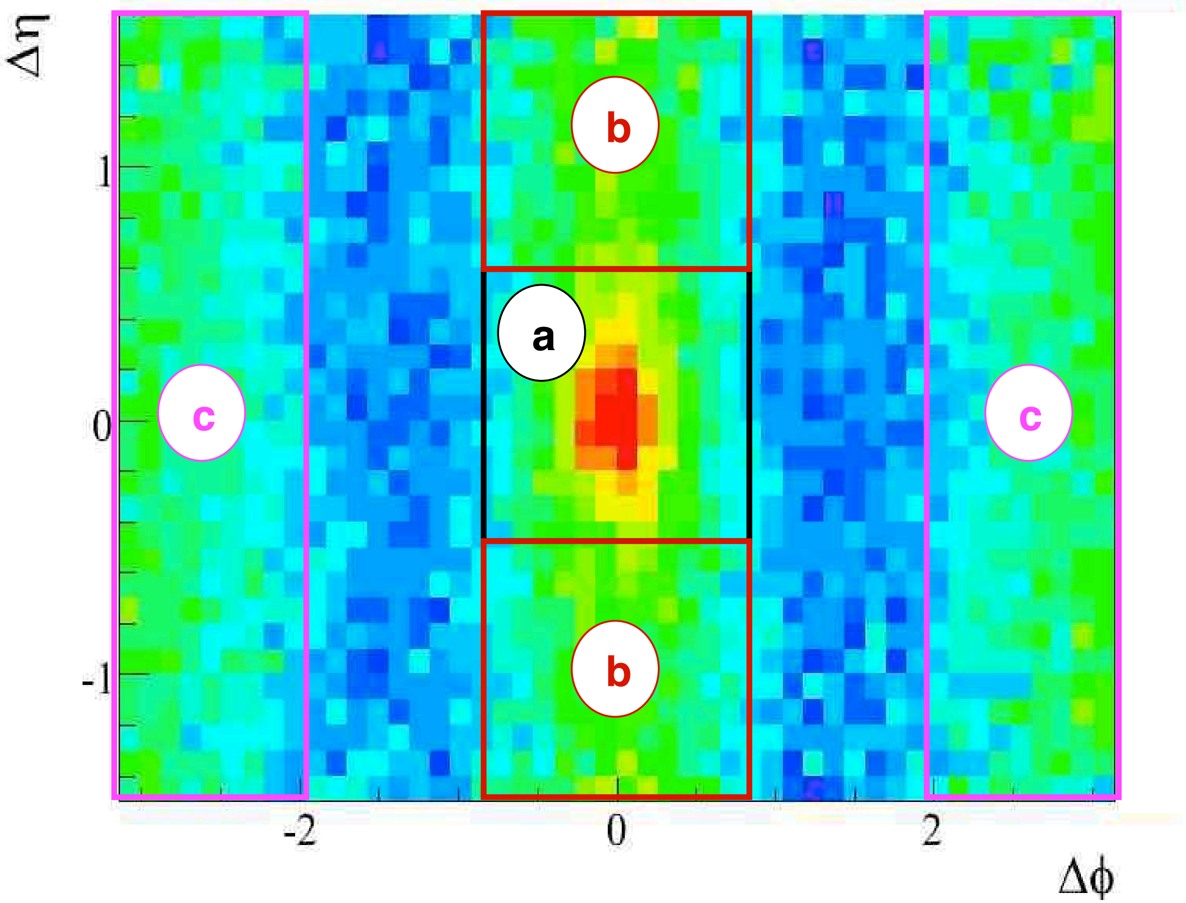
- New STAR `punchthrough' data has much too flat shape, an apparent sharp break, and disagrees in normalization with STAR PRL95.

- Comparison of two STAR data sets would benefit by going lower in p_{Ta} (z_T) for the data of nucl-ex/0604018 to see whether slope is really steeper at low z_T, with dramatic break and (unreasonable in my opinion) flattening of the z_T distribution for $z_T \geq 0.5$

Interaction with medium
Where does the lost energy go?
Mach Cone?

Near-Side Long-Range $\Delta\eta$ Correlation: the Ridge

Au+Au 20-30%



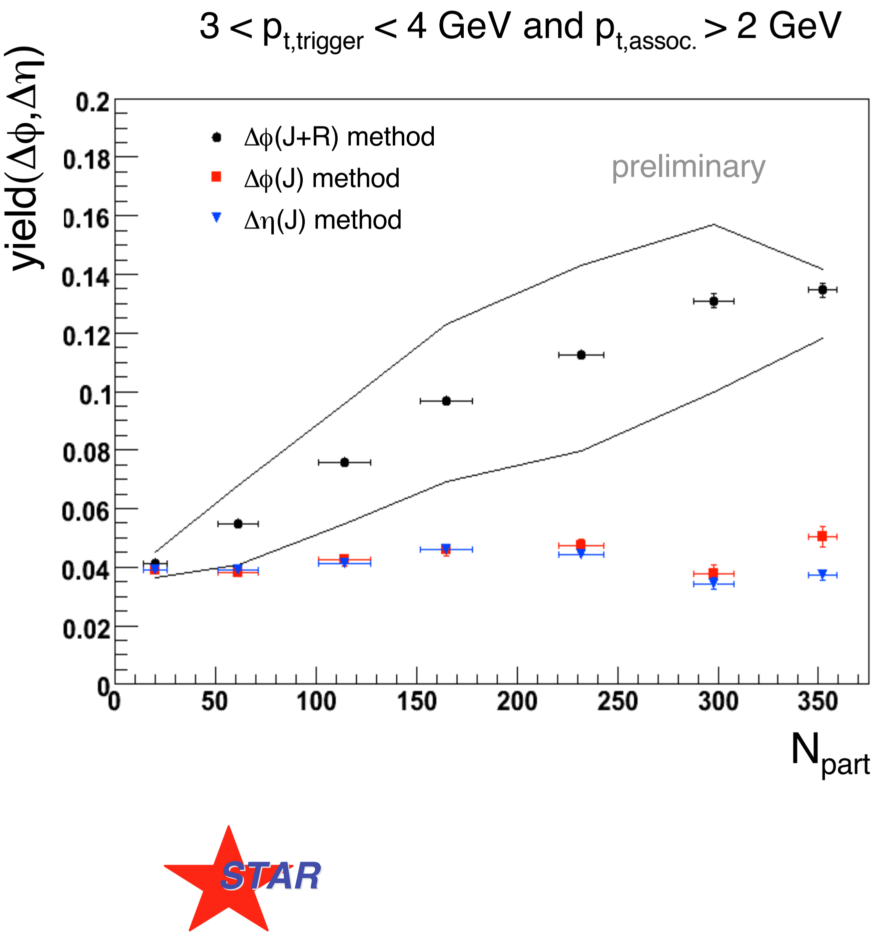
a) Near-side jet-like corrl. + ridge-like corrl. + v_2 modulated bkg.

b) Ridge-like corrl. + v_2 modulated bkg.

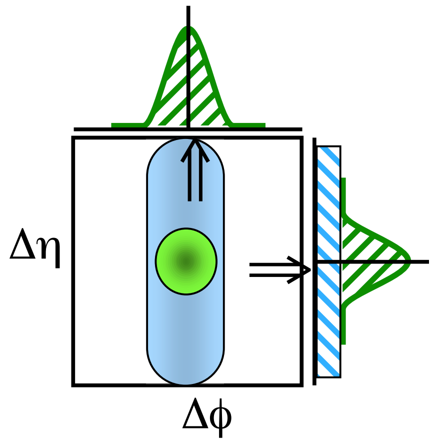
c) Away-side corrl. + v_2 modulated bkg.

STAR-HardProbes 06

Centrality Dependence of the Ridge

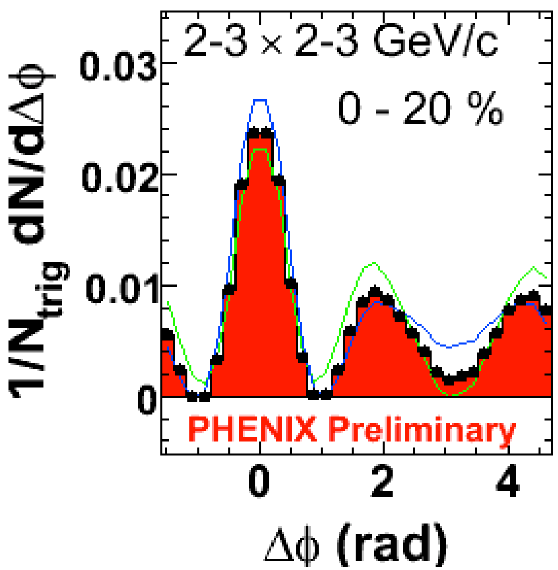


- yield of associated particles can be separated into a jet-like yield and a ridge yield
  - ✓ jet-like yield consistent in η and ϕ and independent of centrality
  - ✓ ridge yield increases with centrality



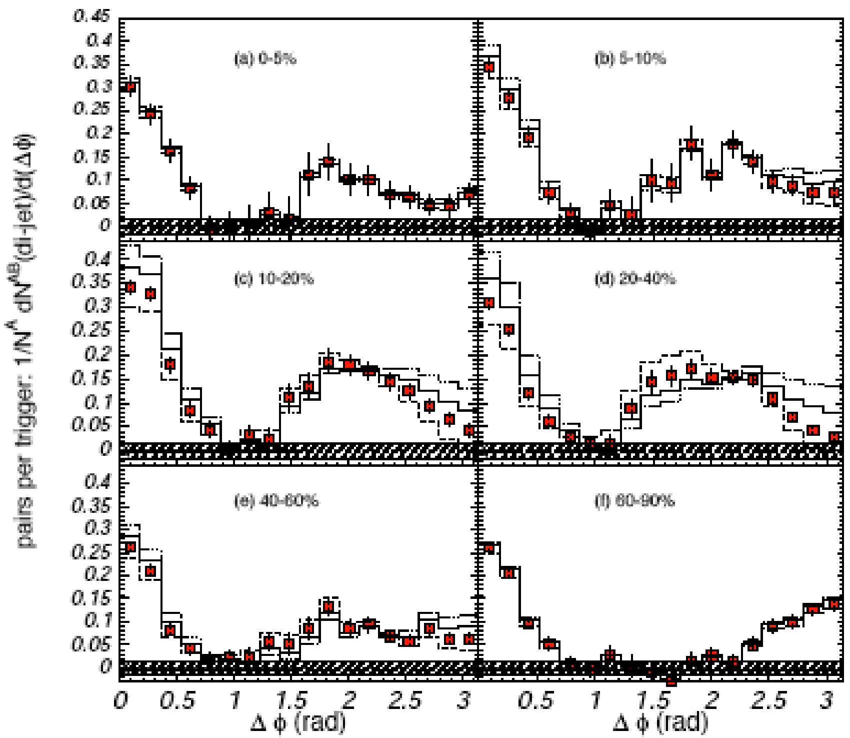
2-particle correlations AuAu at intermediate p_T

Status at QM05:
PHENIX



$2.5 < p_{T,trigger} < 4.0$ GeV
$1.0 < p_{T,assoc} < 2.5$ GeV

PHENIX
nucl-ex/0507004



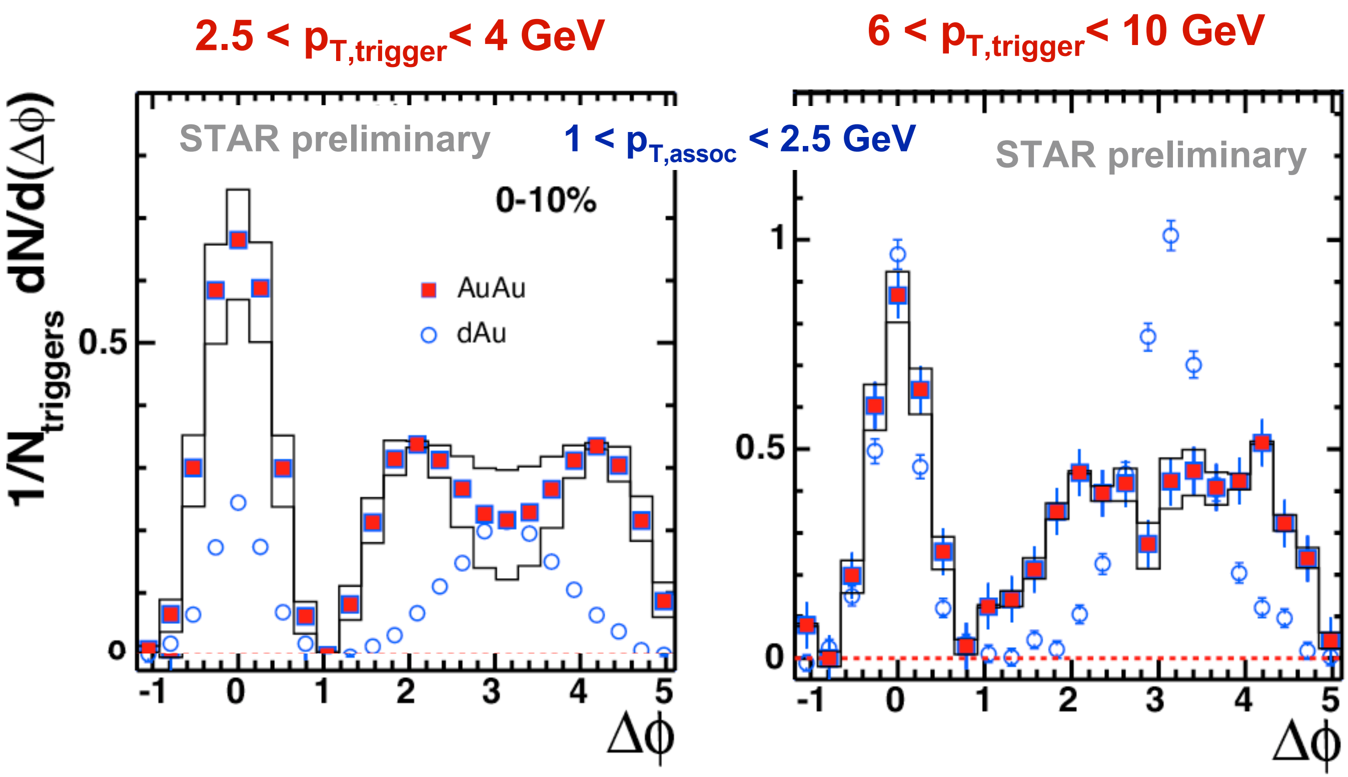
Strong away-side broadening seen at low $p_{T,assoc}$

Is there a 'dip' at the away-side?

Conical emission: Mach cone? Cherenkov? Other mechanisms?

Also note: systematic uncertainties should not be disregarded

STAR-New 2-particle results-HP2006



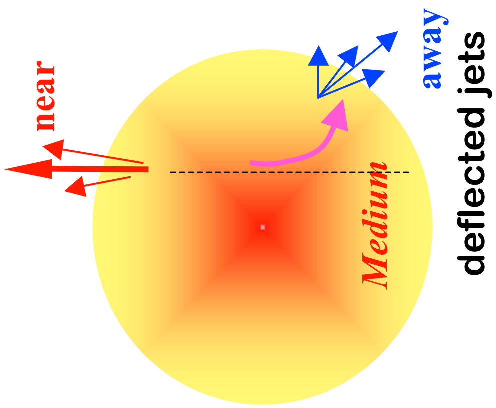
Systematic study of intermediate $p_{T,assoc}$ under way

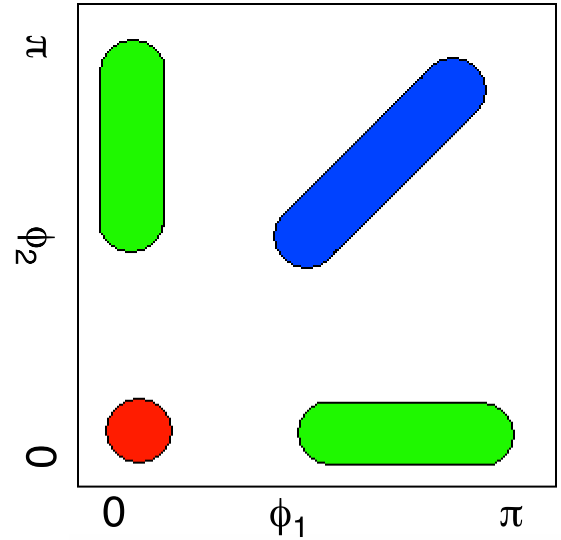
Broadening persists to higher $p_{T,trigger}$, but not 'dip'

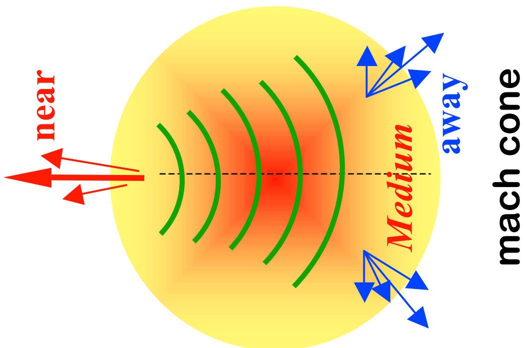
What happens to the away-side at intermediate p_T?

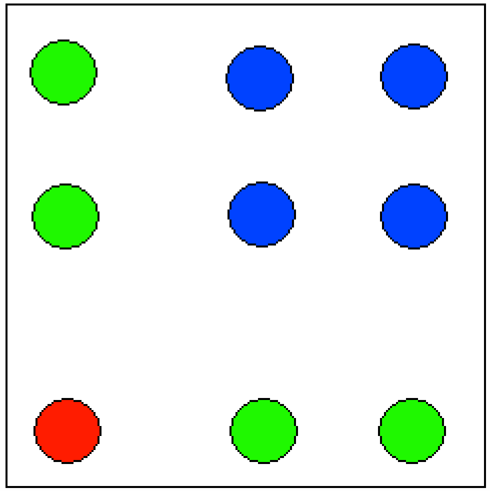
Conical Flow vs Deflected Jets

STAR 3 particle : Given a trigger, plot plot ϕ_1 vs ϕ_2 for 2 away particles









STAR Preliminary

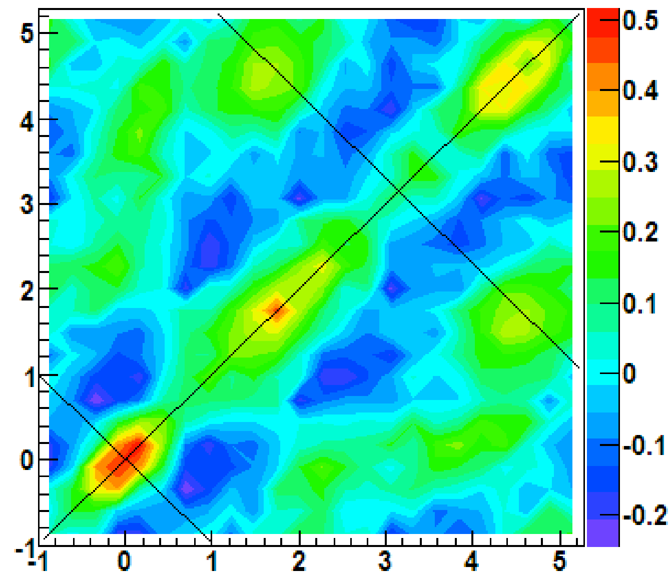
HP2006≠QM2005

Central Au+Au

0-12% triggered

ZYAM/Purdue normalization

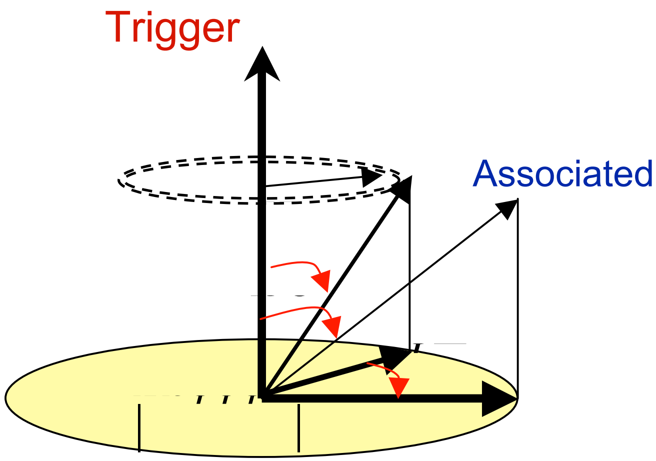
$3 < p_{T,trigger} < 4$ GeV
$1 < p_{T,assoc} < 2$ GeV



Not obviously the best projection-difficult to understand

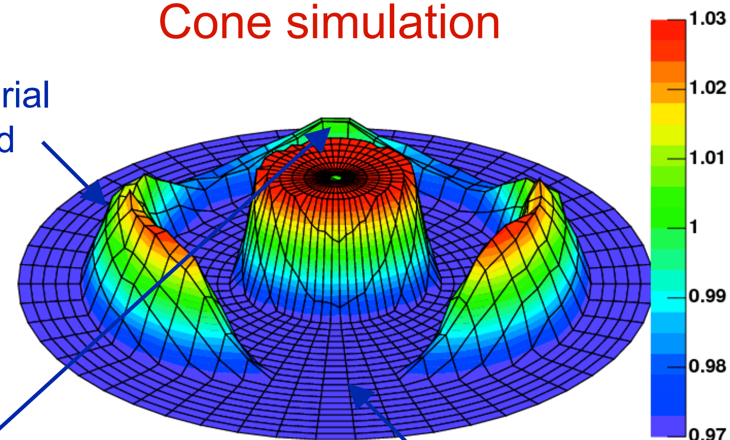
PHENIX-Polar co-ordinates-wrt Cone

Method being developed in PHENIX-Better Projection?



Cone simulation

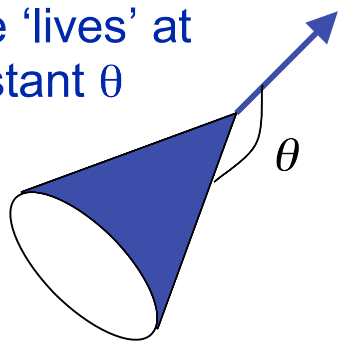
Combinatorial background



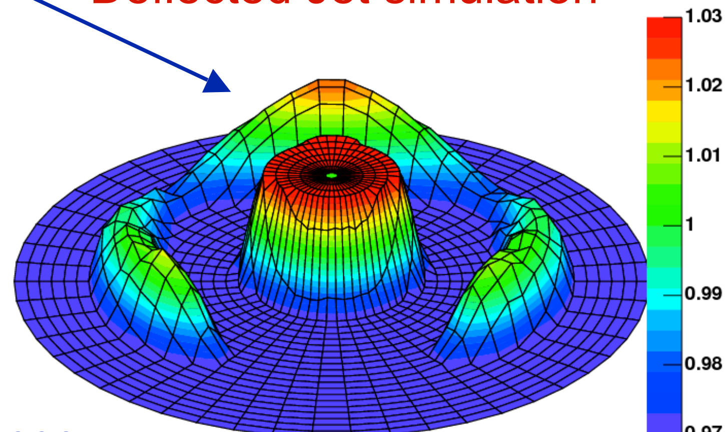
More strength at $\Delta\phi$ =0 for deflected

$\Delta\phi$=180° swamped?

Motivation: cone ‘lives’ at constant θ



Deflected Jet simulation



Cone is not back-to-back with trigger in 3-space
Must distinguish hollow from solid moving cone

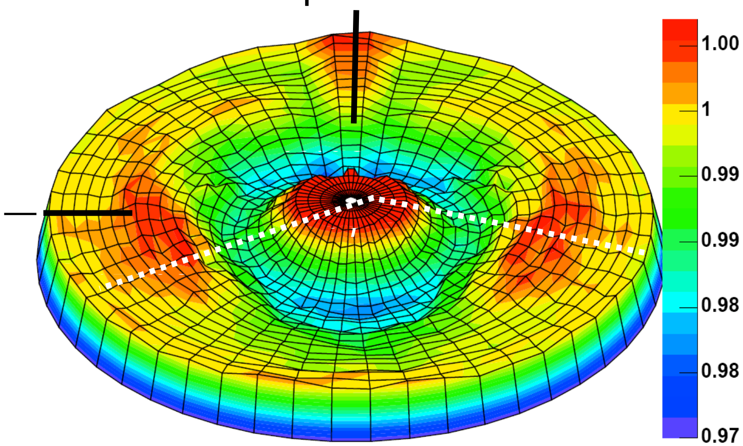
VanLeeuwen-Ajitnand-HP2006

Experimental results: PHENIX

PHENIX Acceptance

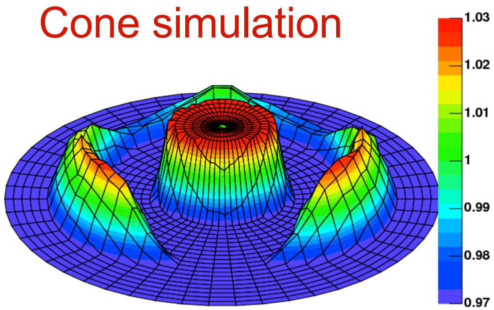
PHENIX *Preliminary*

$3 < p_{T,trigger} < 4$ GeV
$1 < p_{T,assoc} < 2$ GeV



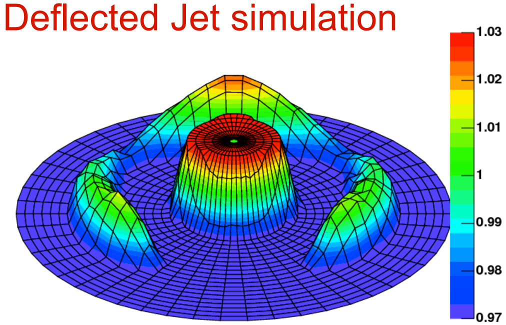
Uncorrected,
no v_2 subtraction

Cone simulation



Middle of
Long Learning Curve

Deflected Jet simulation



N.N. Ajitanand's Hard Probes 2006