Measuring Parton Energy Loss at RHIC Compared to LHC

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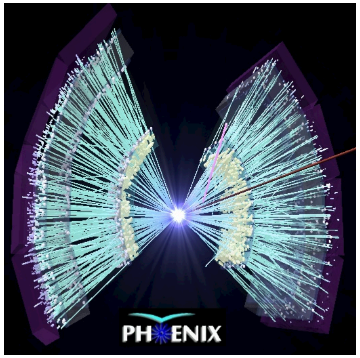
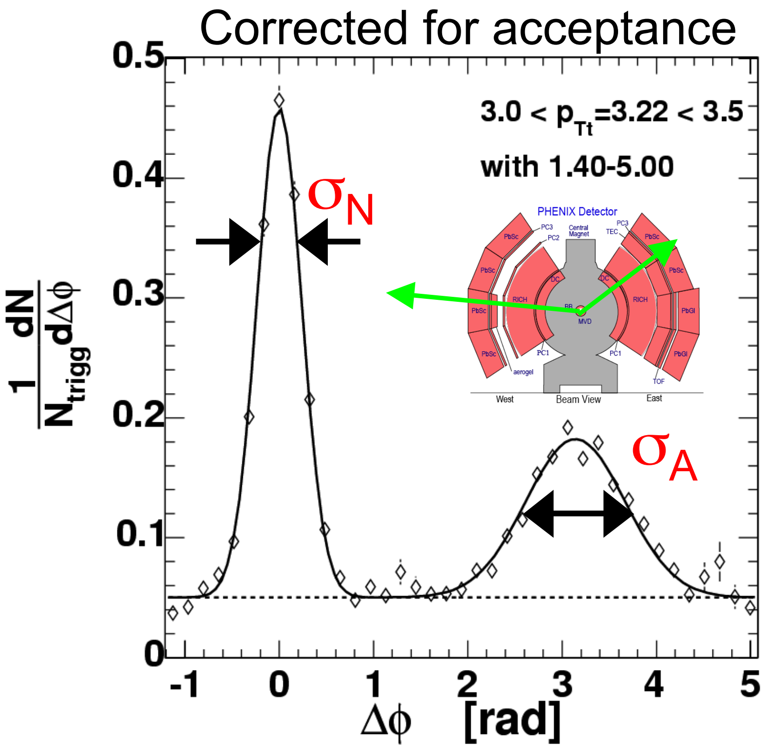
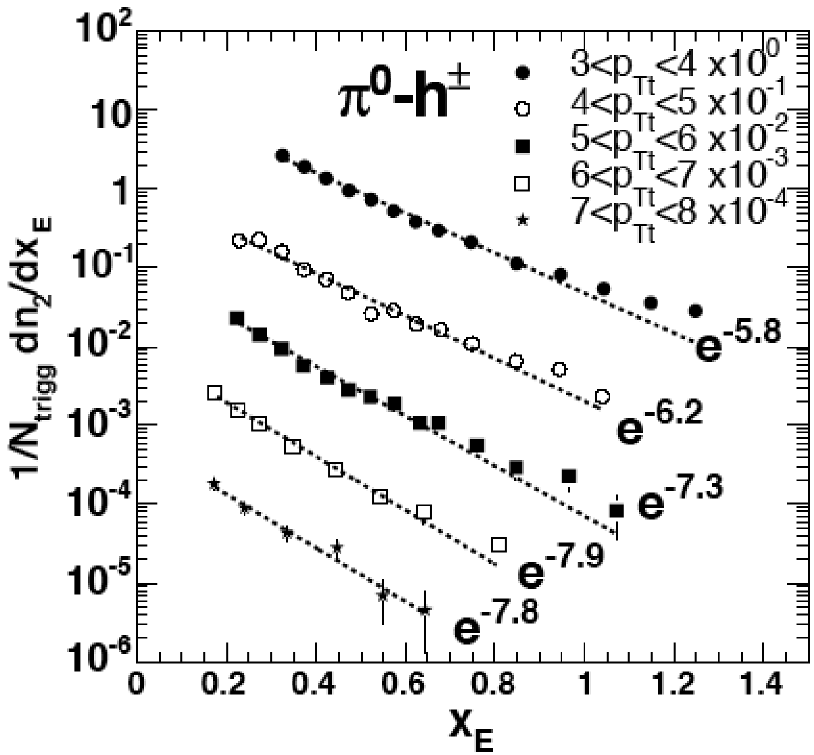


22nd International Conference on
Ultrarelativistic Nucleus-Nucleus Collisions
Quark Matter 2011
Annecy, France
May 23--28, 2011

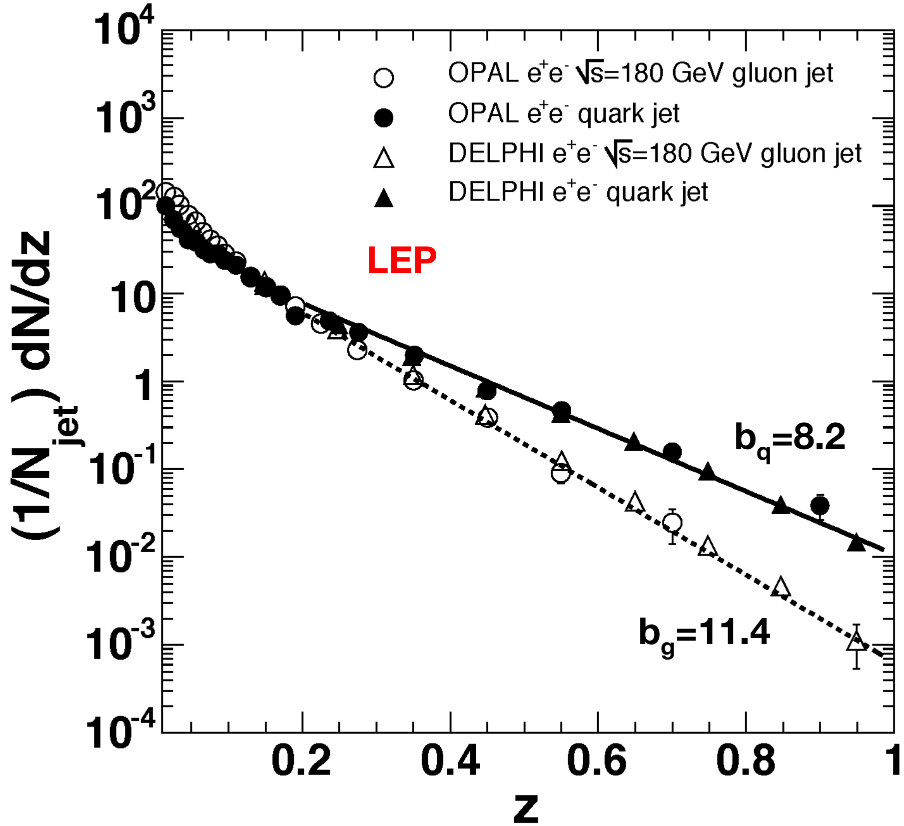
PHENIX π^o - $h^\pm$ correlation functions p+p $\sqrt{s}$=200 GeV: PRD **74**, 072002 (2006)

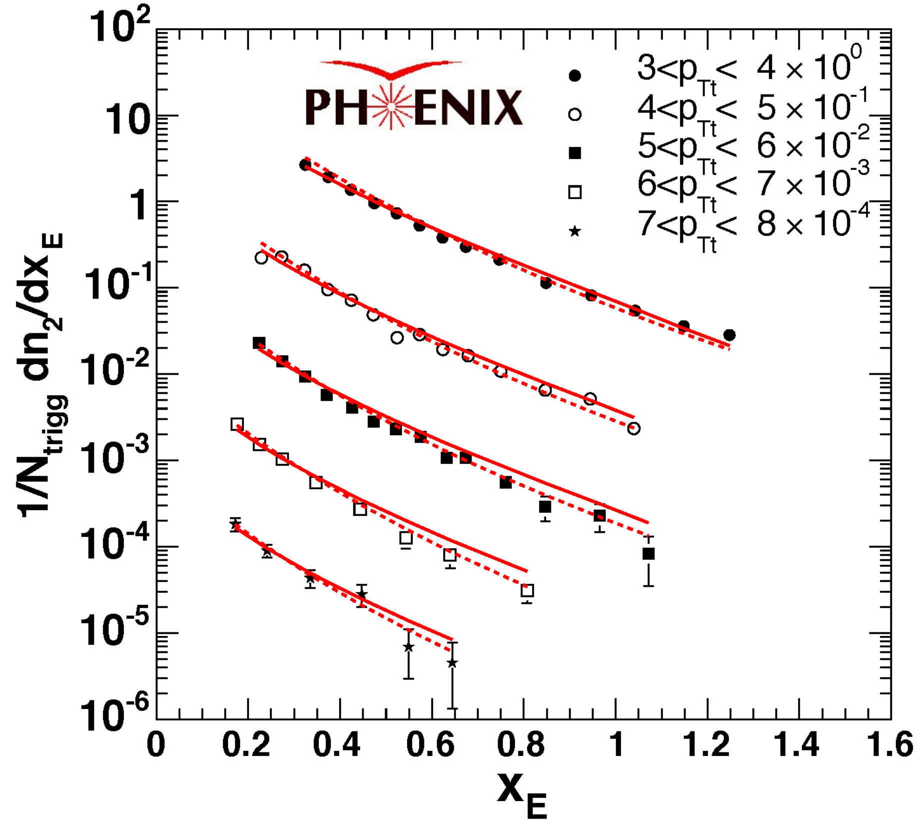




Trigger on a particle e.g. π^0 with transverse momentum p_{Tt}. Measure azimuthal angular distribution w.r.t the trigger azimuth of associated (charged) particles with transverse momentum p_{Ta}. The strong same and away side peaks in p-p collisions indicate di-jet origin from hard-scattering of partons. For the away distribution calculate the conditional yield in the peak as a function of $x_E \sim p_{Ta}/p_{Tt}$

PHENIX-compared measured x_E distribution in p-p to numerical integral using LEP fragmentation functions

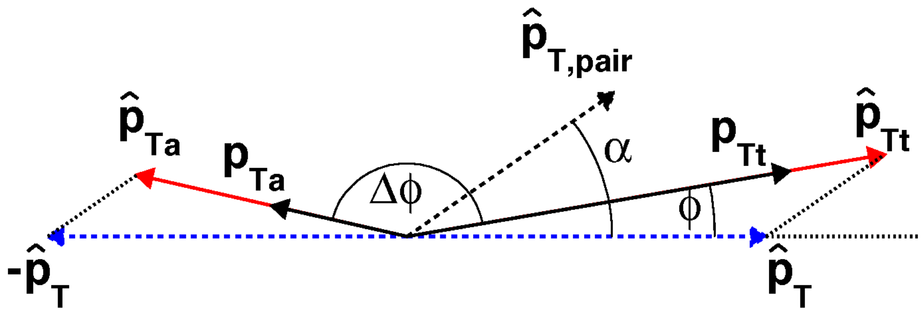




PHENIX PRD **74** (2006) 072002. The x_E distribution triggered by a leading fragment (π^0) is not sensitive to the shape of the fragmentation function!!! Disagrees with Feynman, Field&Fox NPB**128** (1977) 1

A very interesting new formula for the x_E distribution was derived by PHENIX in PRD74

$$\left.\frac{dP_\pi}{dx_E}\right|_{p_{T_t}} \approx \langle m\rangle\,(n-1)\frac{1}{\hat{x}_h}\frac{1}{(1+\frac{x_E}{\hat{x}_h})^n}$$



Relates ratio of particle p_T

$$x_E = \frac{-p_{T_a}\cos\Delta\phi}{p_{T_t}} \simeq \frac{p_{T_a}}{p_{T_t}}$$

measured

aka Z_T

Ratio of jet transverse momenta

$$\hat{x}_h = \frac{\hat{p}_{T_a}}{\hat{p}_{T_t}}$$

Can be determined

If formula works, we can also use it in Au+Au to determine the relative energy loss of the away jet to the trigger jet (surface biased by large *n*)

Exponential Frag. Fn. and power law crucial

$$\frac{d^2\sigma_\pi(\hat{p}_{T_t}, z_t)}{d\hat{p}_{T_t} dz_t} = \frac{d\sigma_q}{d\hat{p}_{T_t}} \times D^q_\pi(z_t) = \boxed{\frac{A}{\hat{p}_{T_t}^{n-1}}} \times D^q_\pi(z_t)$$

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

Power law spectrum of parton $\hat{p}_{T_t}$

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

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

Fragment spectrum given p_{Tt} is weighted to high z_t by z_t^{n-2}

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

$$\boxed{\frac{1}{p_{T_t}} \frac{d\sigma_\pi}{dp_{T_t}} = \frac{AB}{p_{T_t}^n} \int_{x_{T_t}}^1 dz_t \; z_t^{n-2} \exp -bz_t}$$

Incomplete gamma function

Good approximation $x_{T_t} \rightarrow 0$ upper limit $\rightarrow \infty$

$$\boxed{\frac{1}{p_{T_t}} \frac{d\sigma_\pi}{dp_{T_t}} \approx \frac{\Gamma(n-1)}{b^{n-1}} \frac{AB}{p_{T_t}^n}}$$

Bjorken parent-child relation: parton and particle invariant p_T spectra have same power n, etc.

Latest π^0 Au+Au PHENIX n=8.1±0.05

Power Law p_T>3GeV/c all centralities n=8.10±0.05

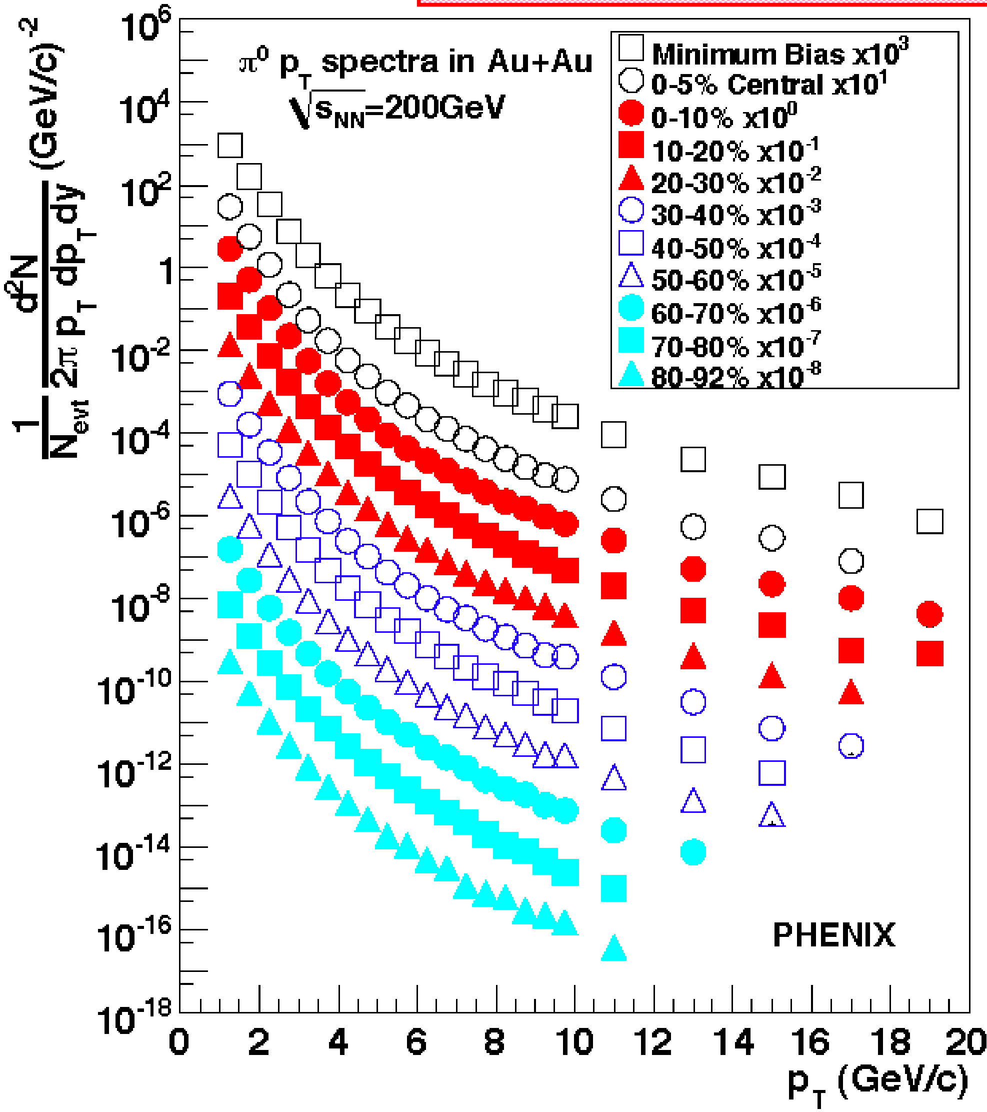
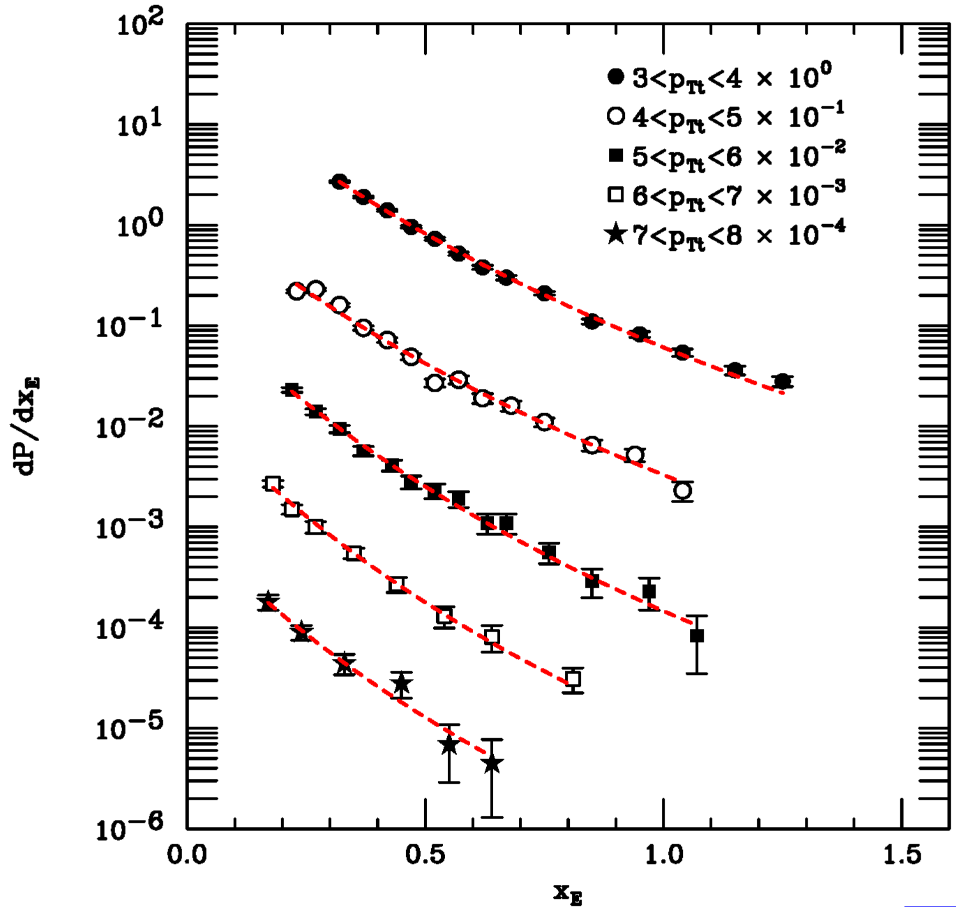


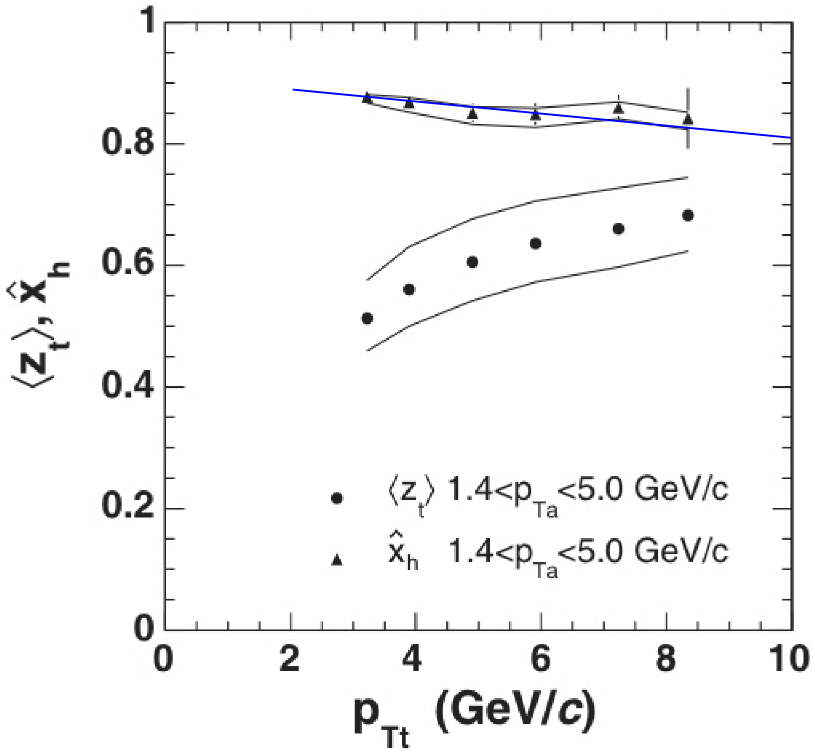
Table 5: Fit parameters for p_T>3 GeV/c

System	A	n	χ^2/NDF
p+p	14.61±1.45	8.12±0.05	5.68/17
Au+Au 0-5 %	81.18±10.30	8.20±0.07	9.66/16
Au+Au 0-10 %	75.28±8.89	8.18±0.06	10.62/17
Au+Au 10-20 %	64.62±7.64	8.19±0.06	10.04/17
Au+Au 20-30 %	49.33±5.78	8.18±0.06	6.63/16
Au+Au 30-40 %	30.85±3.53	8.10±0.06	10.63/16
Au+Au 40-50 %	22.58±2.61	8.13±0.06	3.50/15
Au+Au 50-60 %	12.40±1.48	8.06±0.07	8.09/15
Au+Au 60-70 %	6.25±0.78	8.03±0.07	2.89/14
Au+Au 70-80 %	3.38±0.45	8.12±0.08	8.42/13
Au+Au 80-92 %	1.19±0.18	8.03±0.09	9.84/13
Au+Au 0-92 %	29.31±3.07	8.17±0.05	6.83/17

PHENIX, PRL 101,232302 (2008)

Fit works for PHENIX p+p PRD **74**, 072002

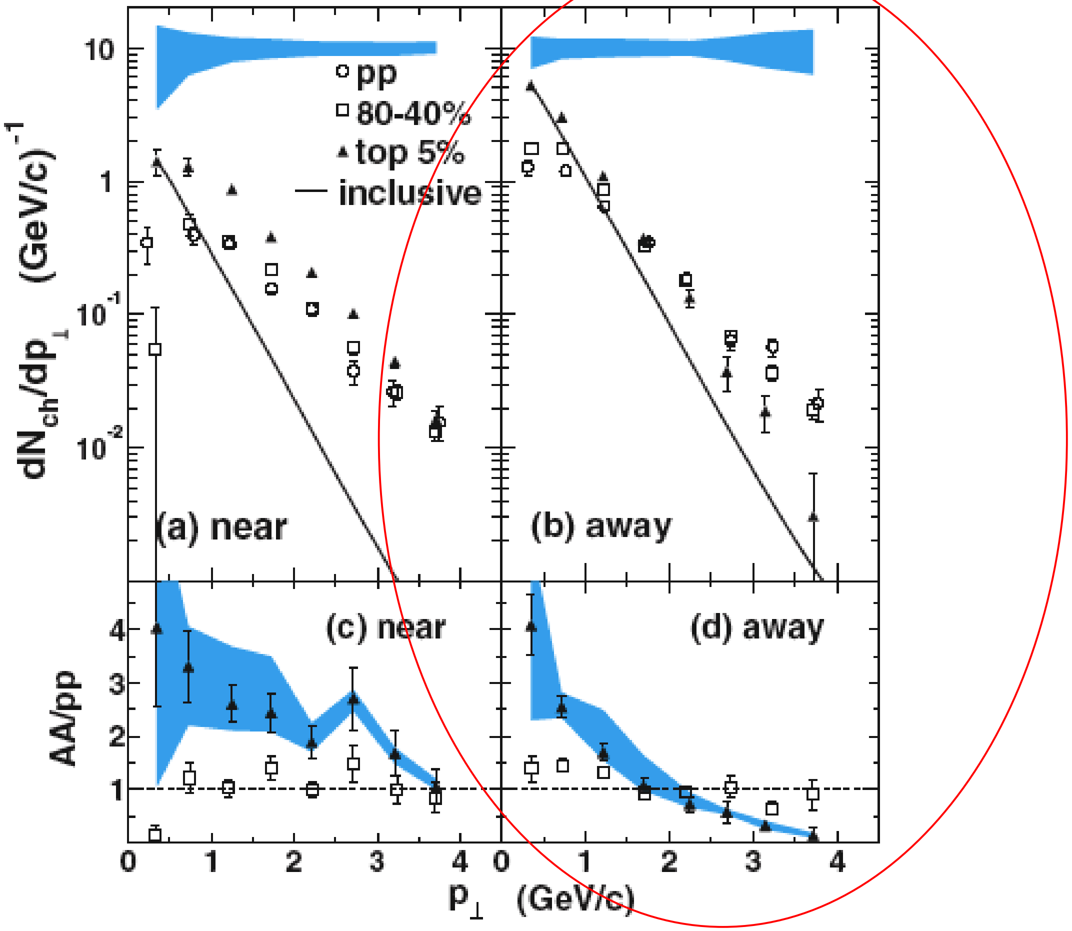


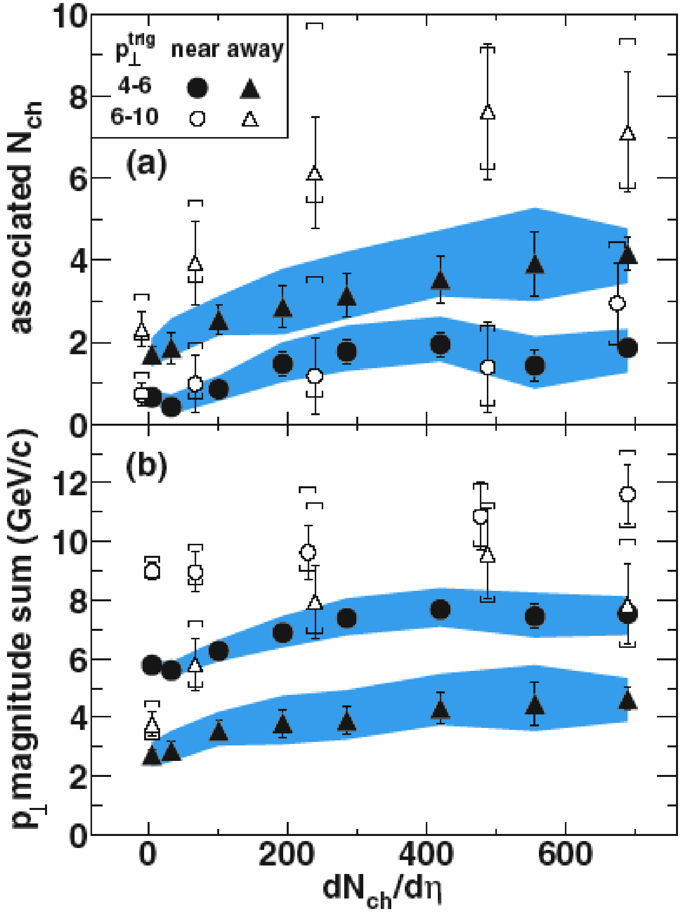


New fits. Very nice!

$\hat{x}_h \approx 1.0 - 0.8$ due to k_T smearing
Depends on x_E range

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



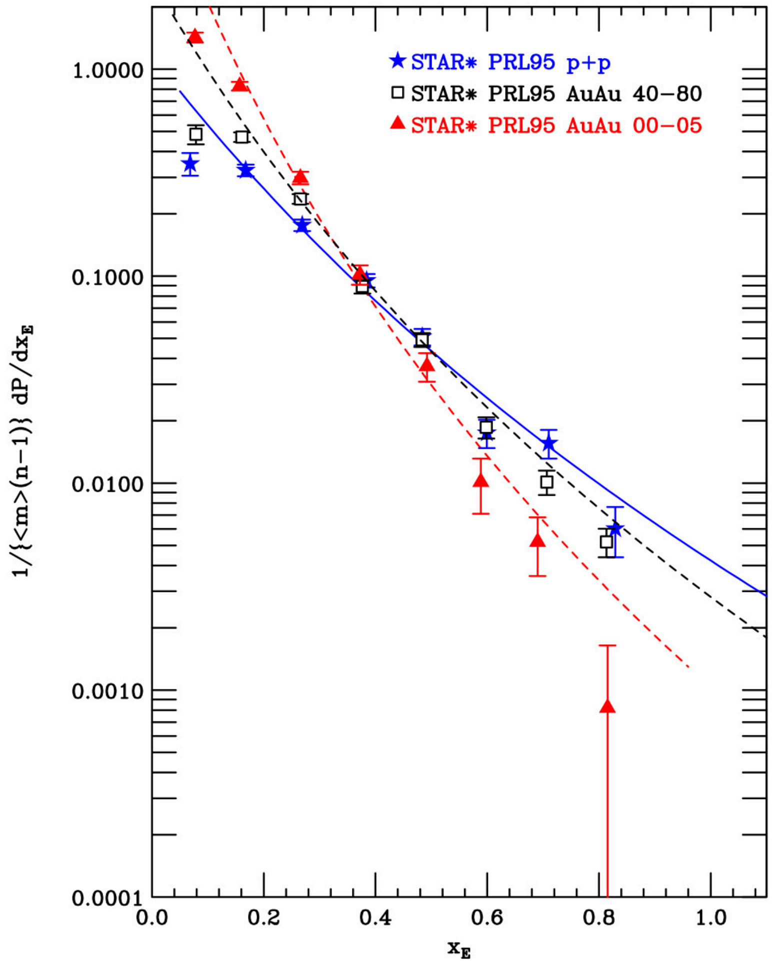


$4 < p_{Tt} < 6$ GeV/c $<p_{Tt}>=4.56$ GeV/c

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

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

Clear effect with centrality



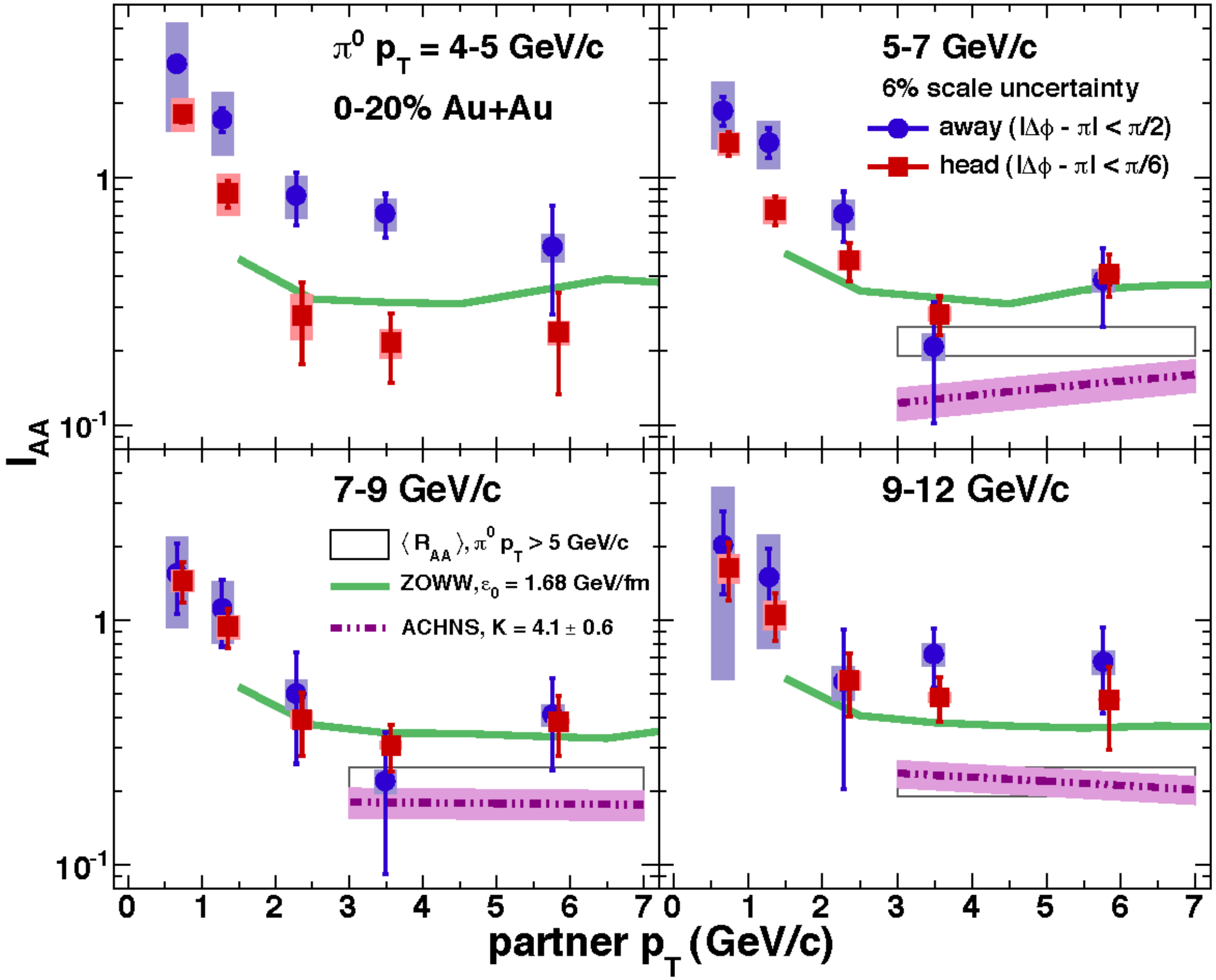
p+p	data*0.6	fit*1.0	$\hat{x}_h$ =1.0
AuAu40-80	data*0.6	fit*1.75	$\hat{x}_h$ =0.75
AuAu00-05	data*0.6	fit*4.0	$\hat{x}_h$ =0.48

$$\hat{x}_h^{AA} / \hat{x}_h^{pp} = 0.48$$

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

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

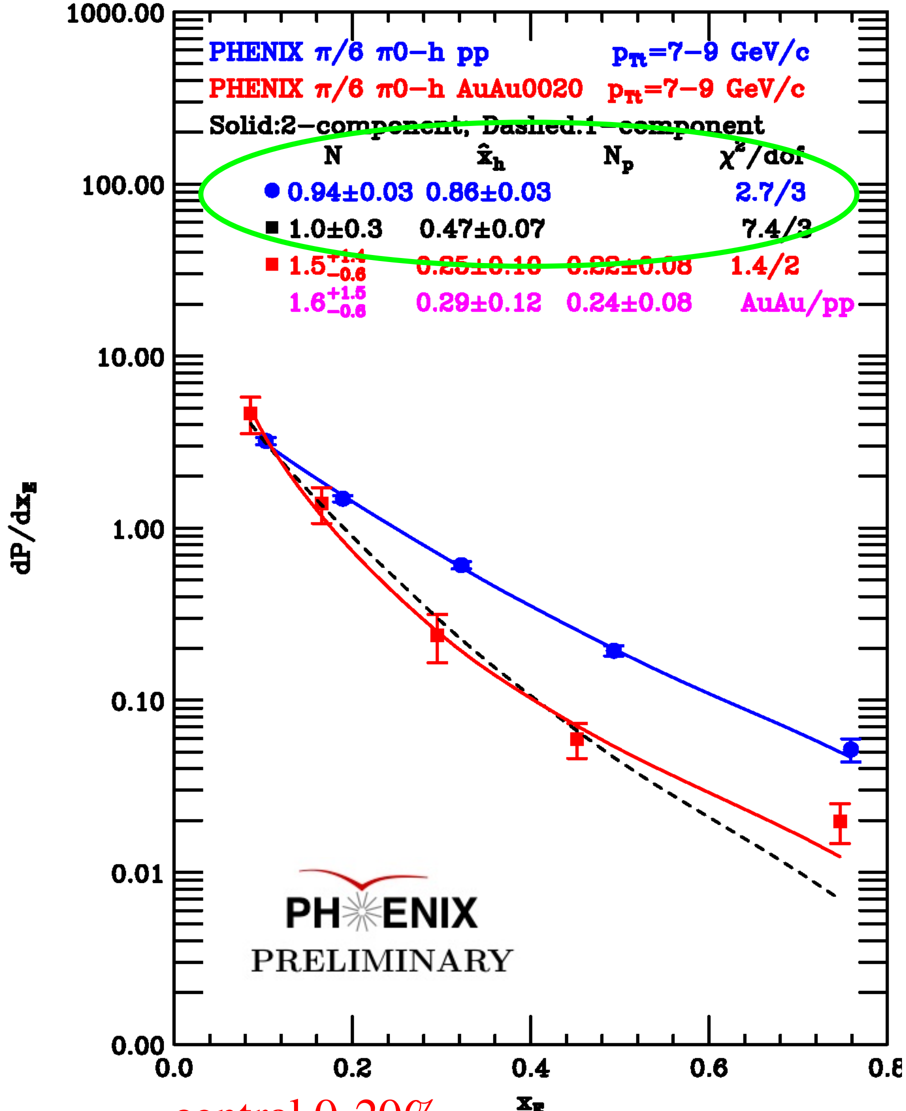
PHENIX π^0-h-I_{AA} PRL**104**,252301(2010)



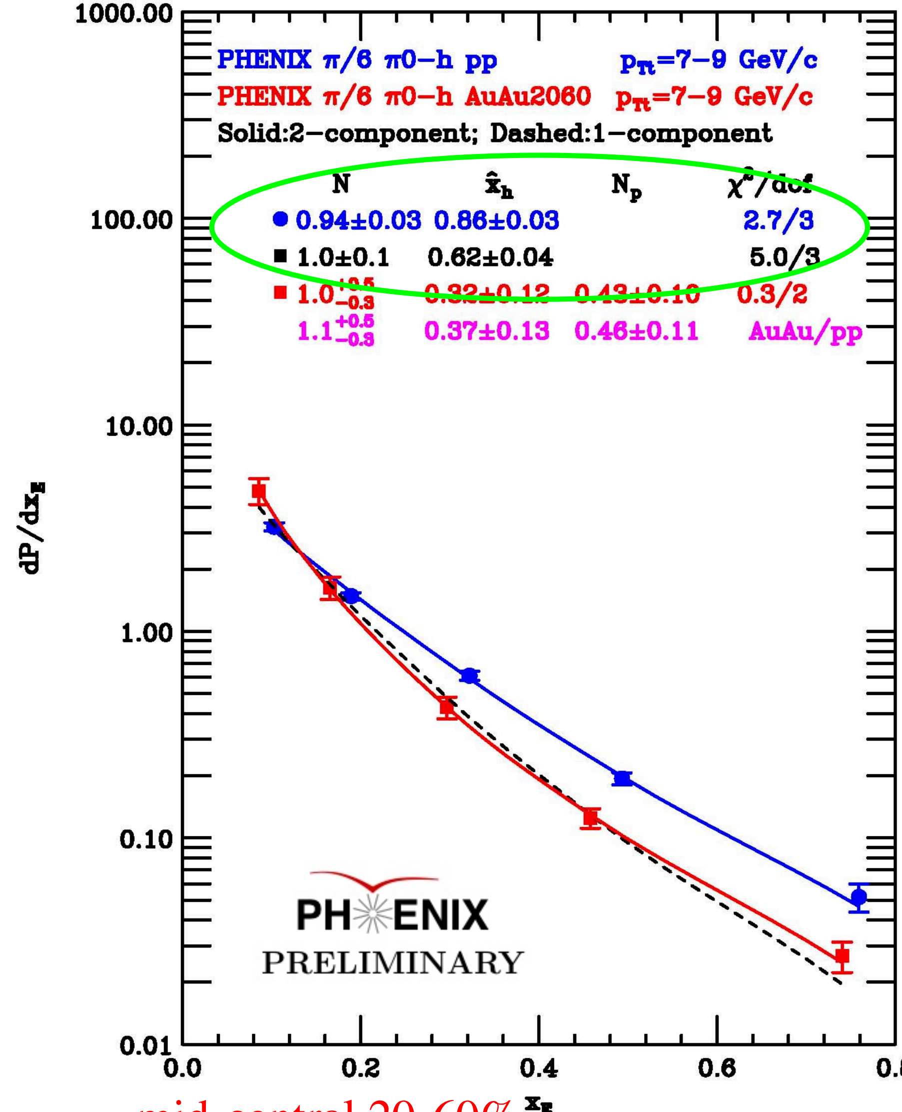
$$I_{AA}=[dN^{AA}/dx_E]/\ [dN^{pp}/dx_E] \approx [dN^{AA}/dz_T]/\ [dN^{pp}/dz_T]$$

Separately fit pp and AuAu $x_E(z_T)$ distributions

First, use 1 component fit



central 0-20%



mid-central 20-60%

$$\left.\frac{dP_\pi}{dz_T}\right|_{p_{T_t}} = N_{pp}\,(n-1)\,\frac{1}{\hat{x}_h^{pp}}\,\frac{1}{(1+\frac{z_T}{\hat{x}_h^{pp}})^n}$$

$$\left.\frac{dP_\pi}{dz_T}\right|_{p_{T_t}} = N_{1AA}\,(n-1)\,\frac{1}{\hat{x}_h^{AA}}\,\frac{1}{(1+\frac{z_T}{\hat{x}_h^{AA}})^n}$$

Separately fit pp and AuAu $x_E(z_T)$ distributions

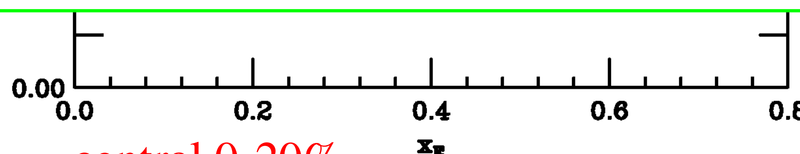
First, use 1 component fit

p_{T_t}	N_{1AA}/N_{pp}	$\hat{x}_h^{AA}/\hat{x}_h^{pp}$	$AA\chi^2$/dof
4-5 GeV/c	2.1 ± 0.7	0.44 ± 0.06	3.0/3
5-7 GeV/c	1.1 ± 0.2	0.58 ± 0.06	10.1/3
7-9 GeV/c	1.1 ± 0.3	0.54 ± 0.08	7.4/3
9-12 GeV/c	1.0 ± 0.4	0.65 ± 0.14	5.2/3

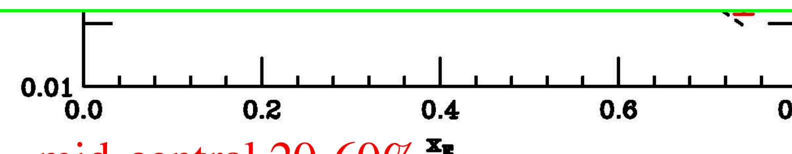
Table 2: 00-20 Centrality. 1 component fits to Au-Au data (Eq. 1). Fitted parameters N_{1AA}/N_{pp} $\hat{x}_h^{AA}/\hat{x}_h^{pp}$

p_{T_t}	N_{1AA}/N_{pp}	$\hat{x}_h^{AA}/\hat{x}_h^{pp}$	$AA\chi^2$/dof
4-5 GeV/c	1.2 ± 0.2	0.68 ± 0.06	7.7/3
5-7 GeV/c	1.0 ± 0.1	0.72 ± 0.05	11.1/3
7-9 GeV/c	1.1 ± 0.1	0.72 ± 0.05	5.0/3
9-12 GeV/c	1.0 ± 0.1	0.74 ± 0.07	3.8/3

Table 3: 20-60 Centrality. 1 component fits to Au-Au data (Eq. 1). Fitted parameters N_{1AA}/N_{pp} $\hat{x}_h^{AA}/\hat{x}_h^{pp}$



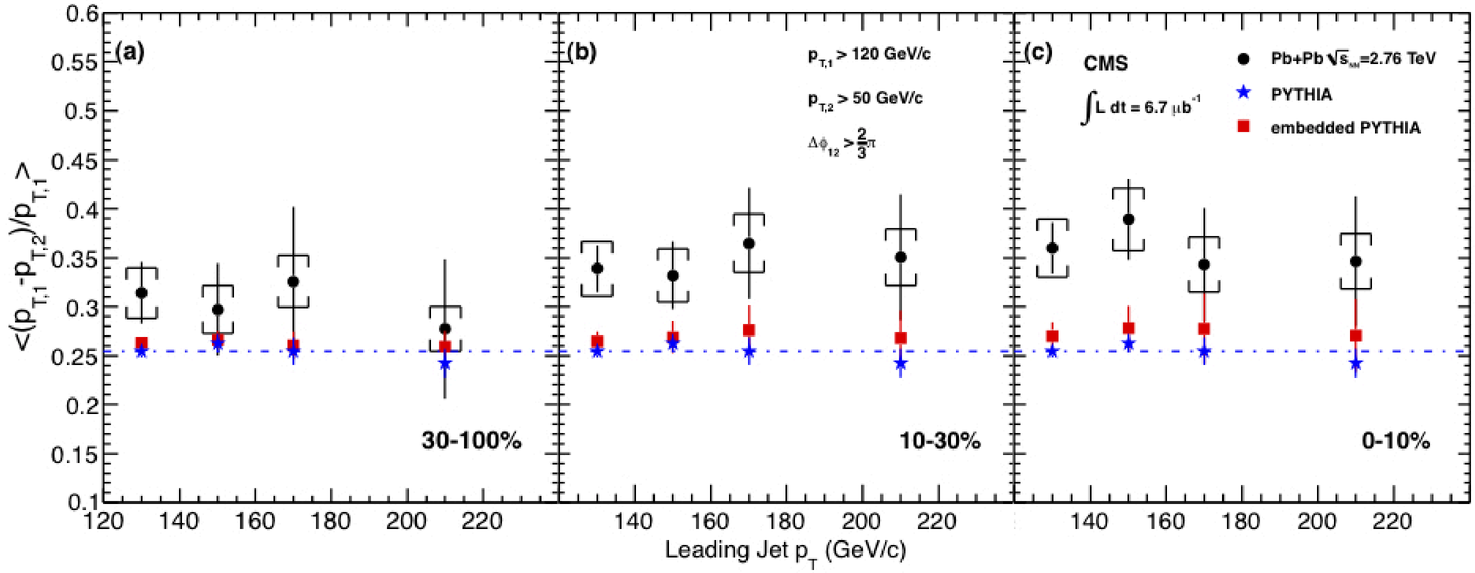
central 0-20%



mid-central 20-60%

Comparison with CMS-fractional jet imbalance

arXiv:1102.1957v2



Need to correct for the large non-zero effect in p-p collisions

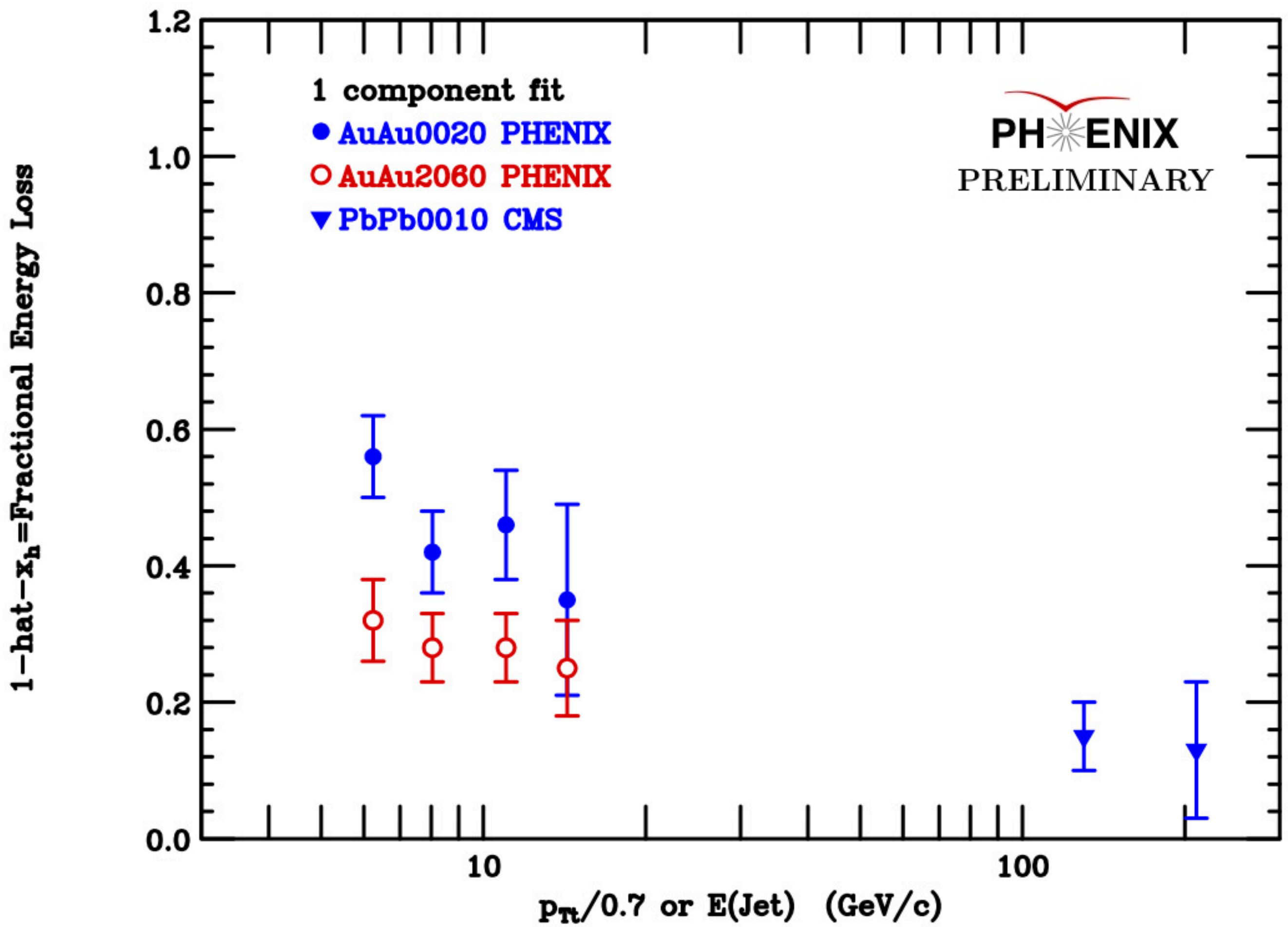
$$(p_{T1} - p_{T2})/p_{T1} = 1 - \hat{x}_h$$

$$\hat{x}_h = 1 - (p_{T1} - p_{T2})/p_{T1}$$

130: pp = 0.255, PbPb=0.36 $\Rightarrow$ $\hat{x}_h$: pp = 0.745, PbPb=0.64

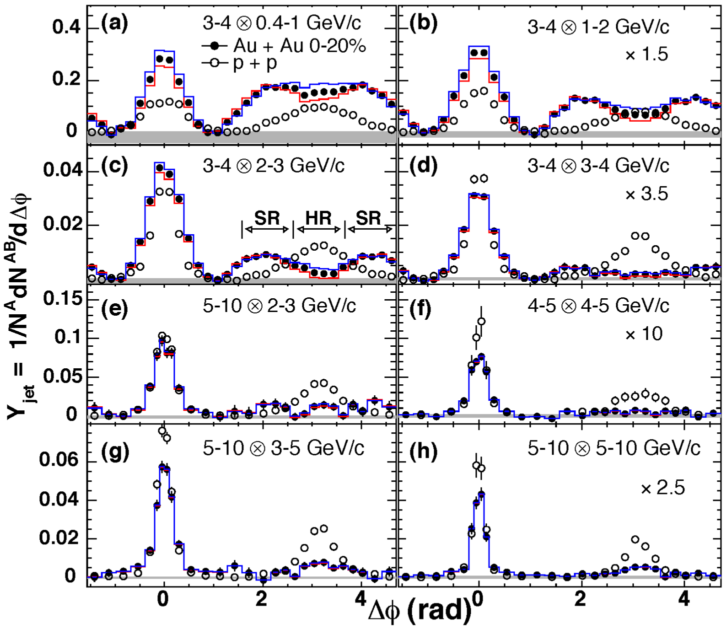
$$1 - \hat{x}_h^{AA} / \hat{x}_h^{pp} = 0.141 \Leftarrow \hat{x}_h^{AA} / \hat{x}_h^{pp} = 0.64/0.745 = 0.859$$

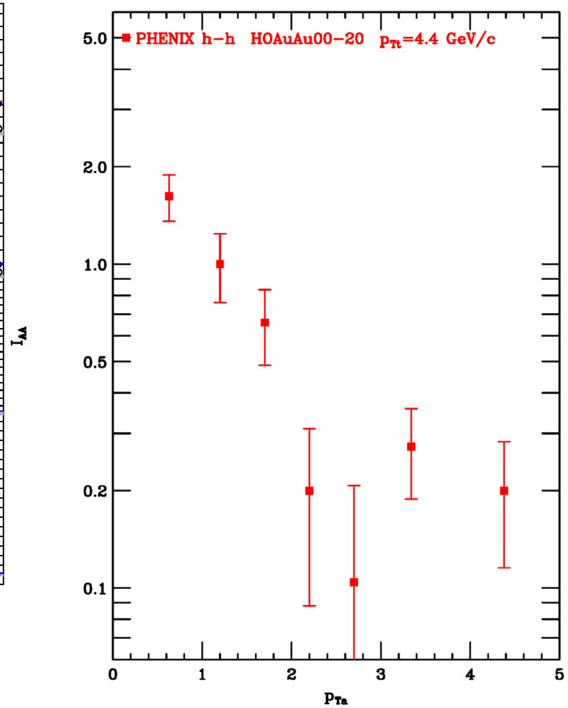
PHENIX 00-20, 20-60 cf CMS central

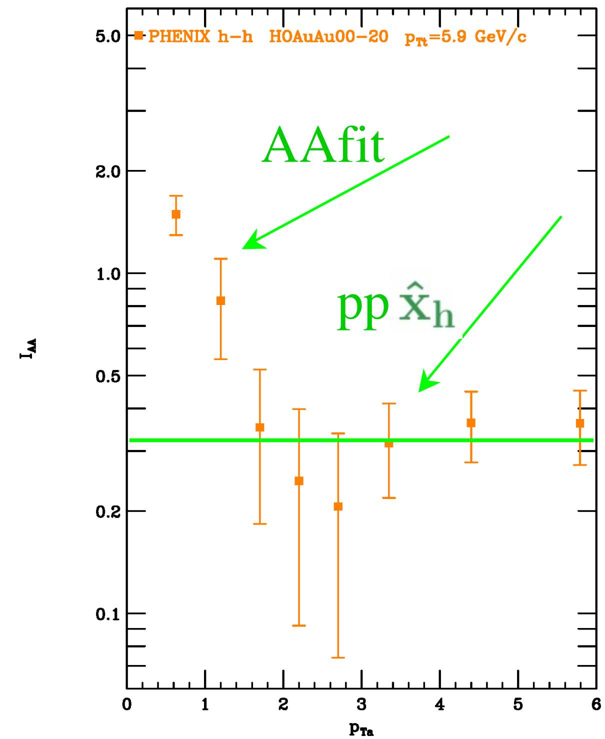


Big difference between RHIC and LHC in this analysis

2 component fit to dP/dx_E c.f. I_{AA}







Head $|\Delta\phi-\pi|<\pi/6$
Shoulder $\pi/6< |\Delta\phi-\pi|<\pi/2$

punchthrough not significant

punchthrough IS significant

PHENIX AuAu PRC**77**,011901(R)(2008)

$$\left.\frac{dP_\pi}{dz_T}\right|_{p_{T_t}} = N_{AA}\,(n-1)\frac{1}{\hat{x}_h^{AA}}\frac{1}{(1+\frac{z_T}{\hat{x}_h^{AA}})^n} + N_p\,(n-1)\frac{1}{\hat{x}_h^{pp}}\frac{1}{(1+\frac{z_T}{\hat{x}_h^{pp}})^n}$$

Two component fit to π0-h

p_{T_t}	N_{AA}/N_{pp}	$N_{AA}/(N_{pp}-N_p)$	$\hat{x}_h^{AA}/\hat{x}_h^{pp}$	$f_{\rm punchthrough}=N_p/N_{pp}$
4-5 GeV/c	$3.1^{+3.4}_{-1.1}$	$3.5^{+3.9}_{-1.3}$	0.32 ± 0.11	0.13 ± 0.09
5-7 GeV/c	$1.6^{+1.4}_{-0.6}$	$1.7^{+1.5}_{-0.6}$	0.32 ± 0.11	0.06 ± 0.07
7-9 GeV/c	$1.6^{+1.5}_{-0.6}$	$2.1^{+2.0}_{-0.8}$	0.29 ± 0.12	0.24 ± 0.08
9-12 GeV/c	$1.5^{+3.6}_{-0.6}$	$2.5^{+5.9}_{-1.2}$	0.27 ± 0.17	0.39 ± 0.13

Table 4: 00-20 Centrality. 2-Component fitted parameters N_{AA}/N_{pp} $\hat{x}_h^{AA}/\hat{x}_h^{pp}$, $f_{\rm punchthrough}$

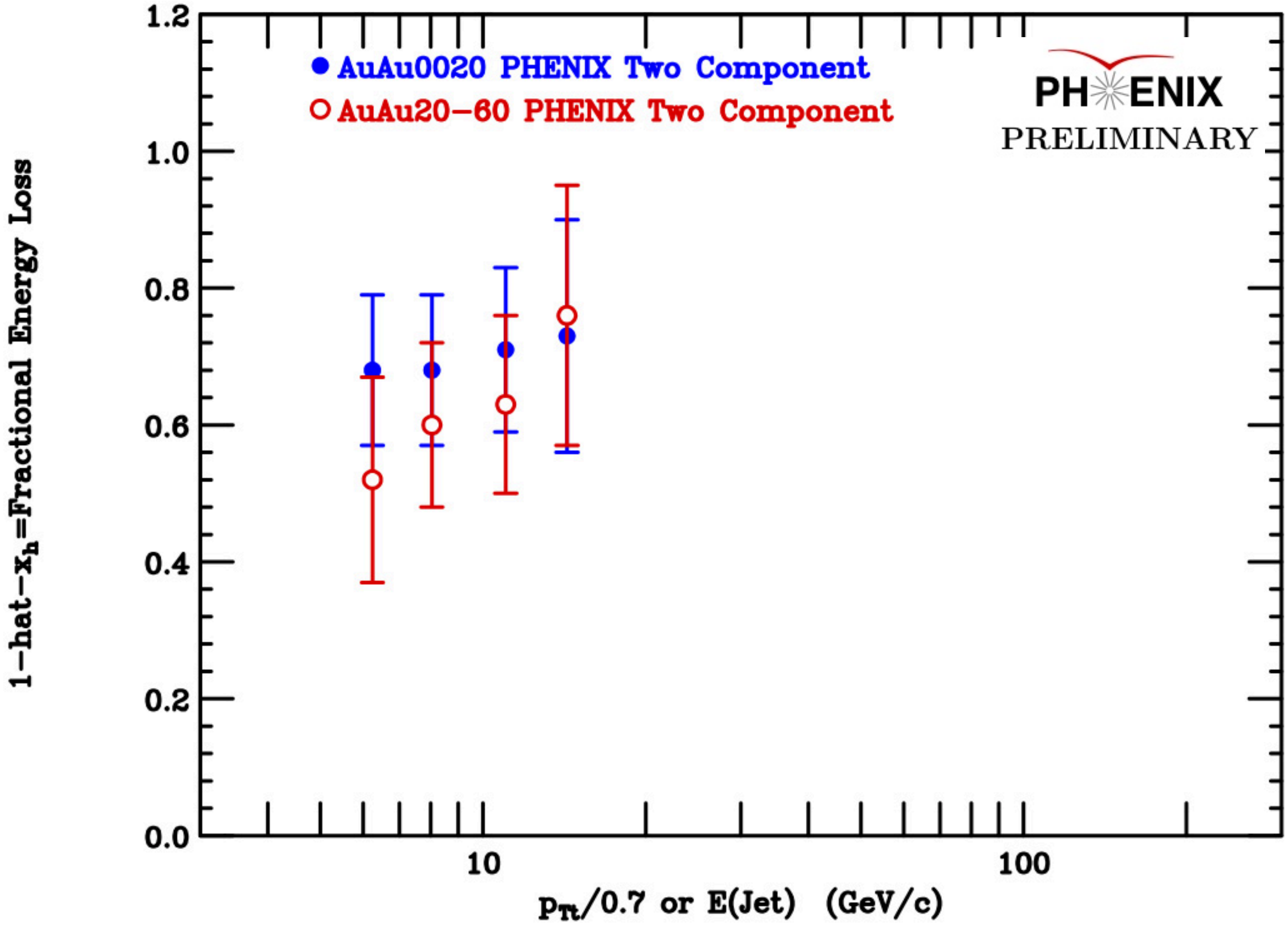
p_{T_t}	N_{AA}/N_{pp}	$N_{AA}/(N_{pp}-N_p)$	$\hat{x}_h^{AA}/\hat{x}_h^{pp}$	$f_{\rm punchthrough}=N_p/N_{pp}$
4-5 GeV/c	$1.2^{+0.6}_{-0.4}$	$1.7^{+0.8}_{-0.6}$	0.48 ± 0.15	0.27 ± 0.18
5-7 GeV/c	$1.1^{+0.6}_{-0.3}$	$1.7^{+1.0}_{-0.5}$	0.40 ± 0.12	0.38 ± 0.09
7-9 GeV/c	$1.1^{+0.5}_{-0.3}$	$2.0^{+1.0}_{-0.6}$	0.37 ± 0.13	0.46 ± 0.11
9-12 GeV/c	$1.5^{+6.3}_{-0.7}$	$3.5^{+15}_{-1.6}$	0.24 ± 0.19	0.58 ± 0.12

Table 5: 20-60 Centrality. 2-Component fitted parameters N_{AA}/N_{pp} $\hat{x}_h^{AA}/\hat{x}_h^{pp}$, $f_{\rm punchthrough}$

central 0-20%

mid-central 20-60%

2 component fit gives larger imbalance for AA-fit component at RHIC



LHC

?

Conclusion

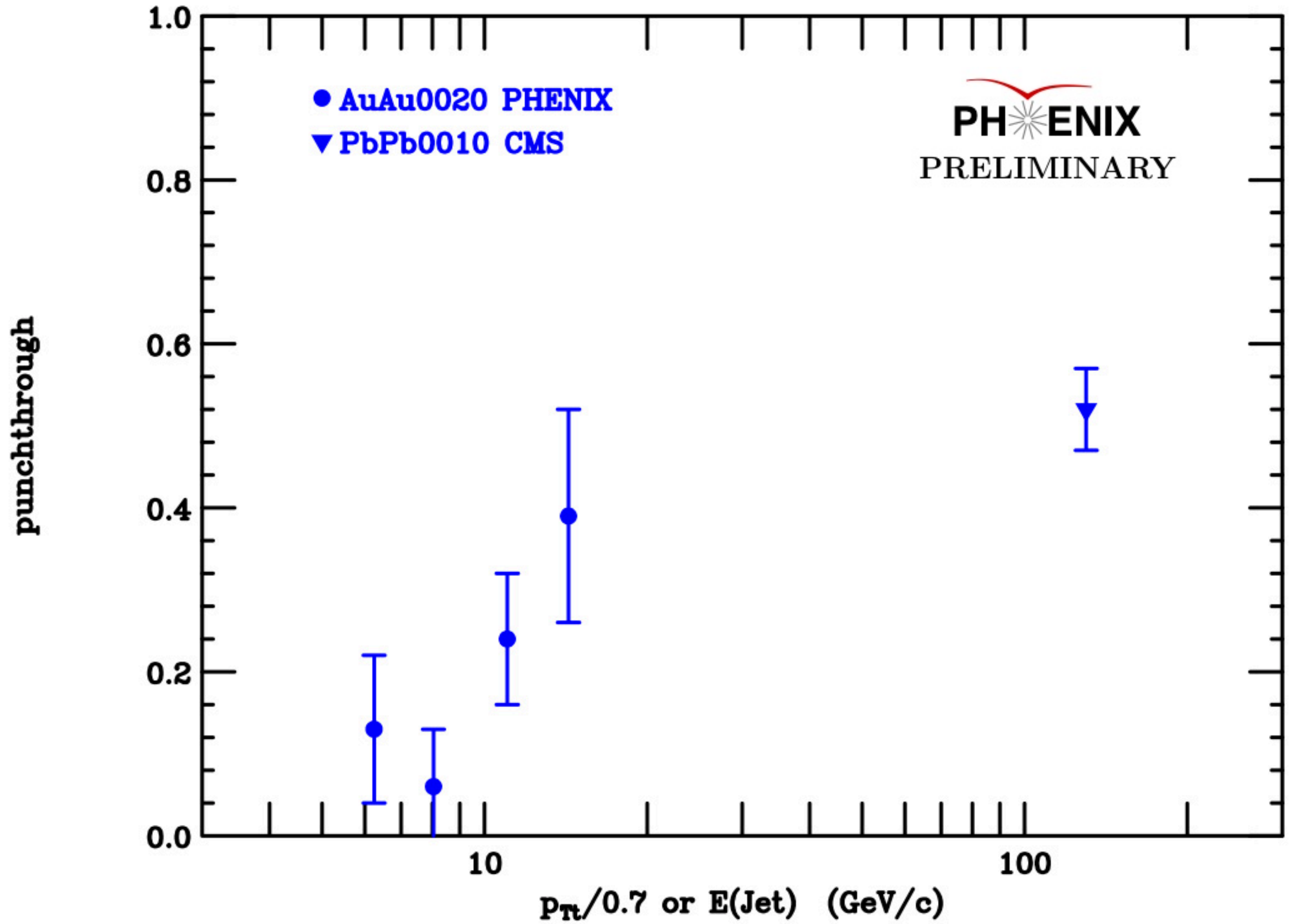
RHIC and LHC jet imbalance

(= fractional energy loss?)

Appear to be different in this analysis.

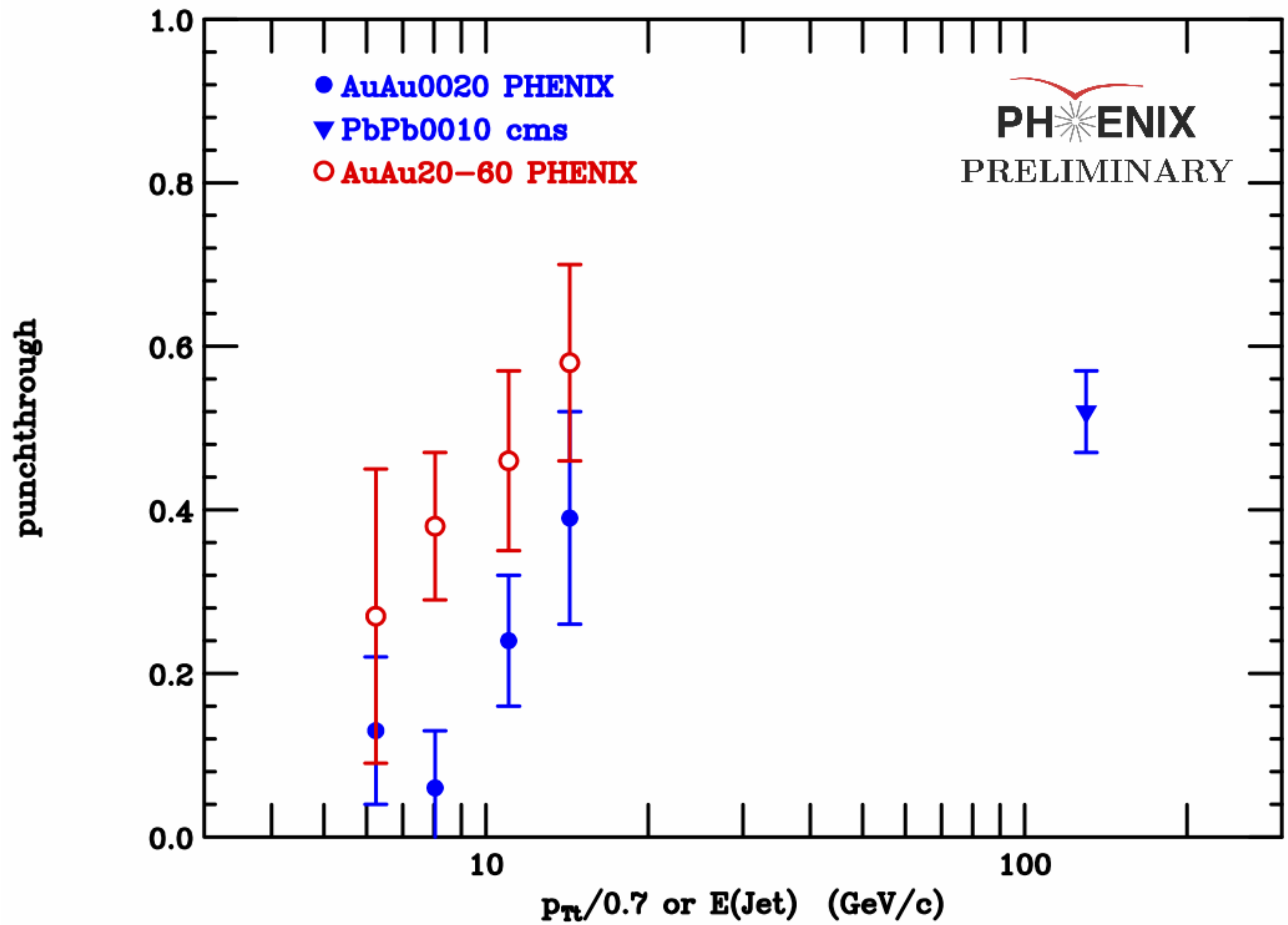
Is it due to a difference in the medium or to the different p_T range?

Comparison with CMS-balanced



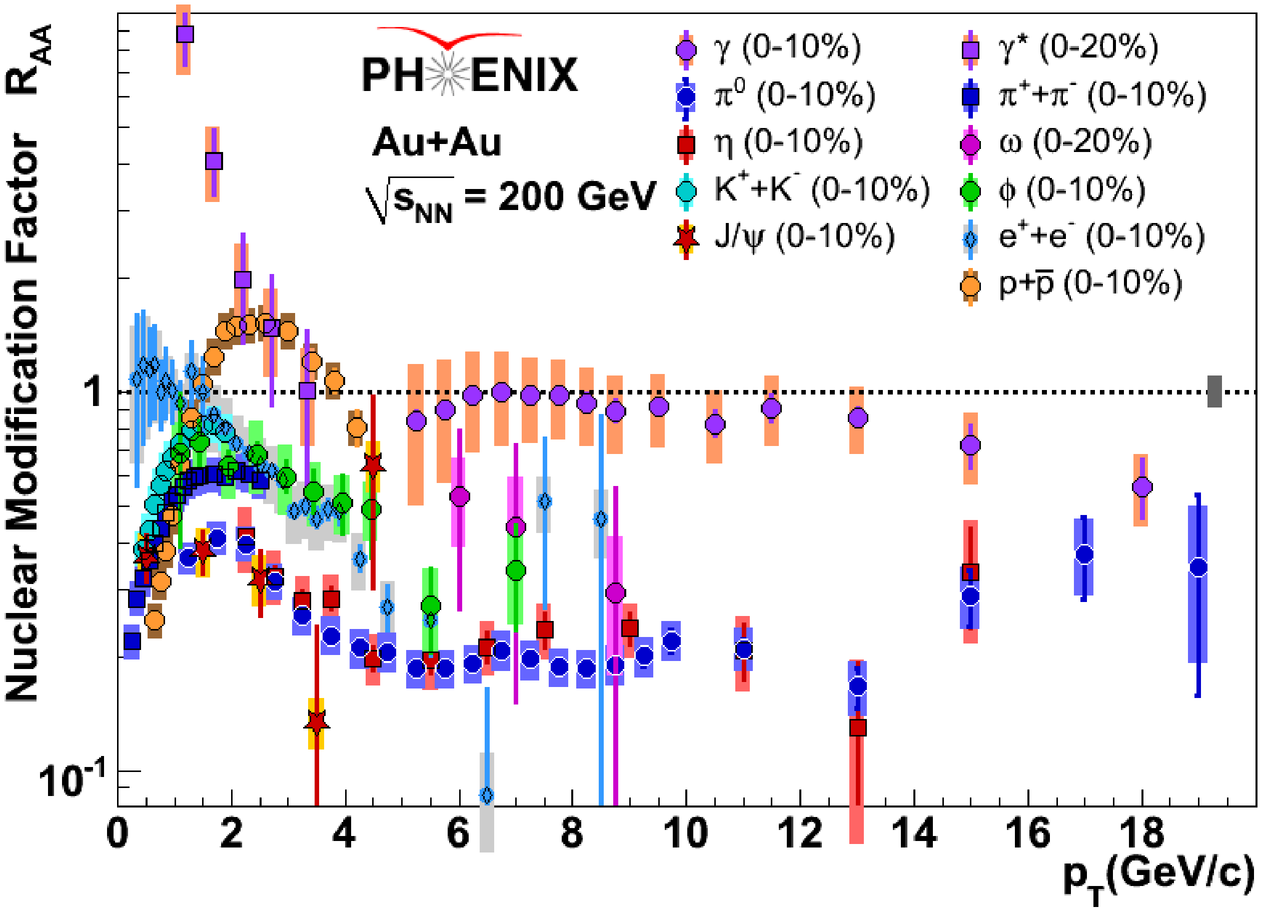
Punchthrough or balanced jets

Comparison with CMS-balanced



Punchthrough or balanced jets

Status of R_{AA} in AuAu at $\sqrt{s_{NN}}$=200 GeV QM09



particle ID is crucial different particles behave differently

Exponential enhancement of direct-γ as $p_T \rightarrow 0$ is unique. No other particle is enhanced except in the region of the 'baryon anomaly'. This suggests new physics, *i.e*. thermal photons.