Jet Medium Interactions with Identified Particles

Anne Sickles

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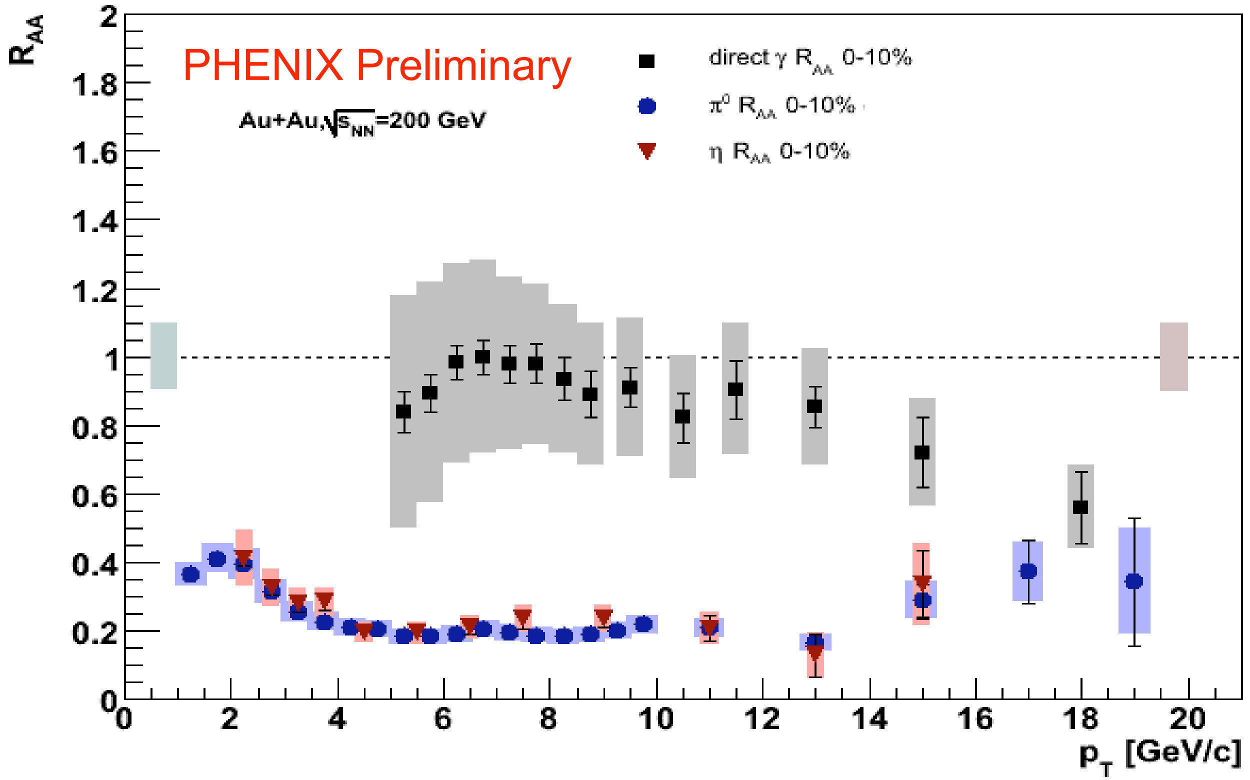
BROOKHAVEN
NATIONAL LABORATORY

Jets @ RHIC



- γ_{direct}: initial hard scattering (relatively) unmodified
- colored partons lose (a lot of) energy
  - how? where does it go?

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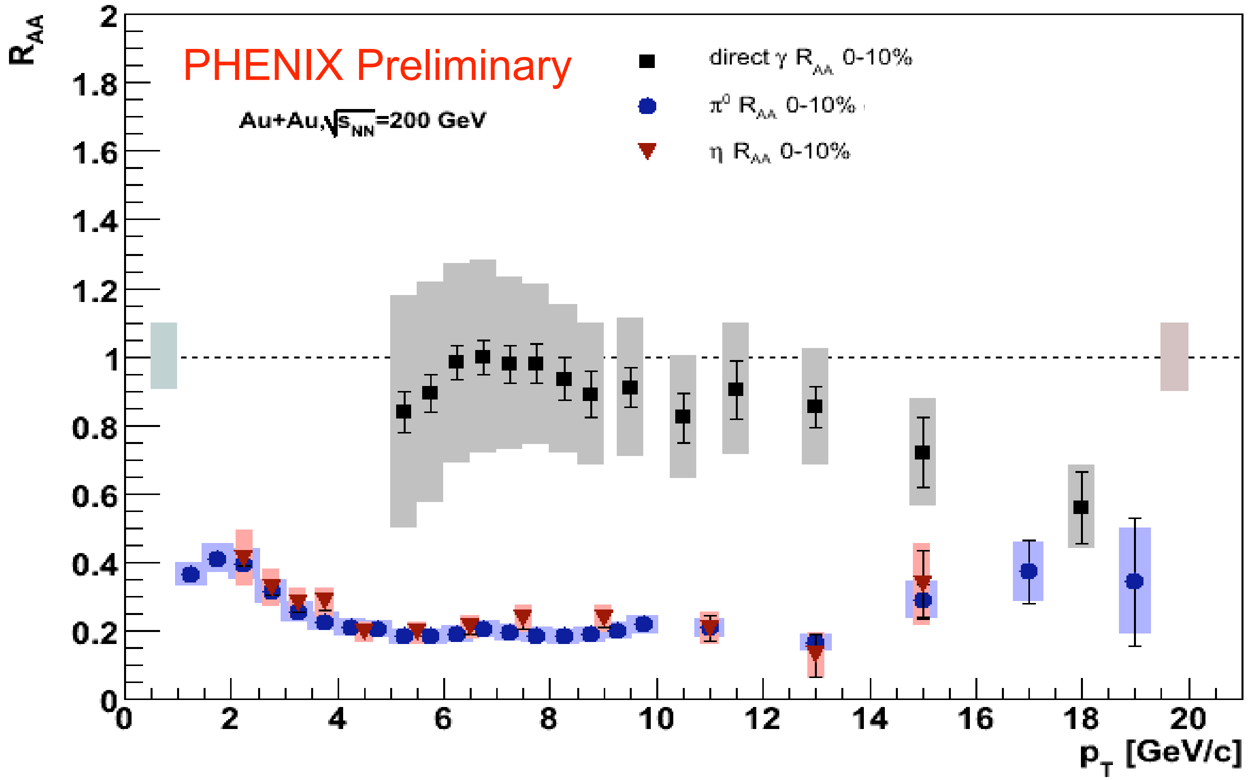

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how can we address these questions with the data in hand?

Jet Modifications

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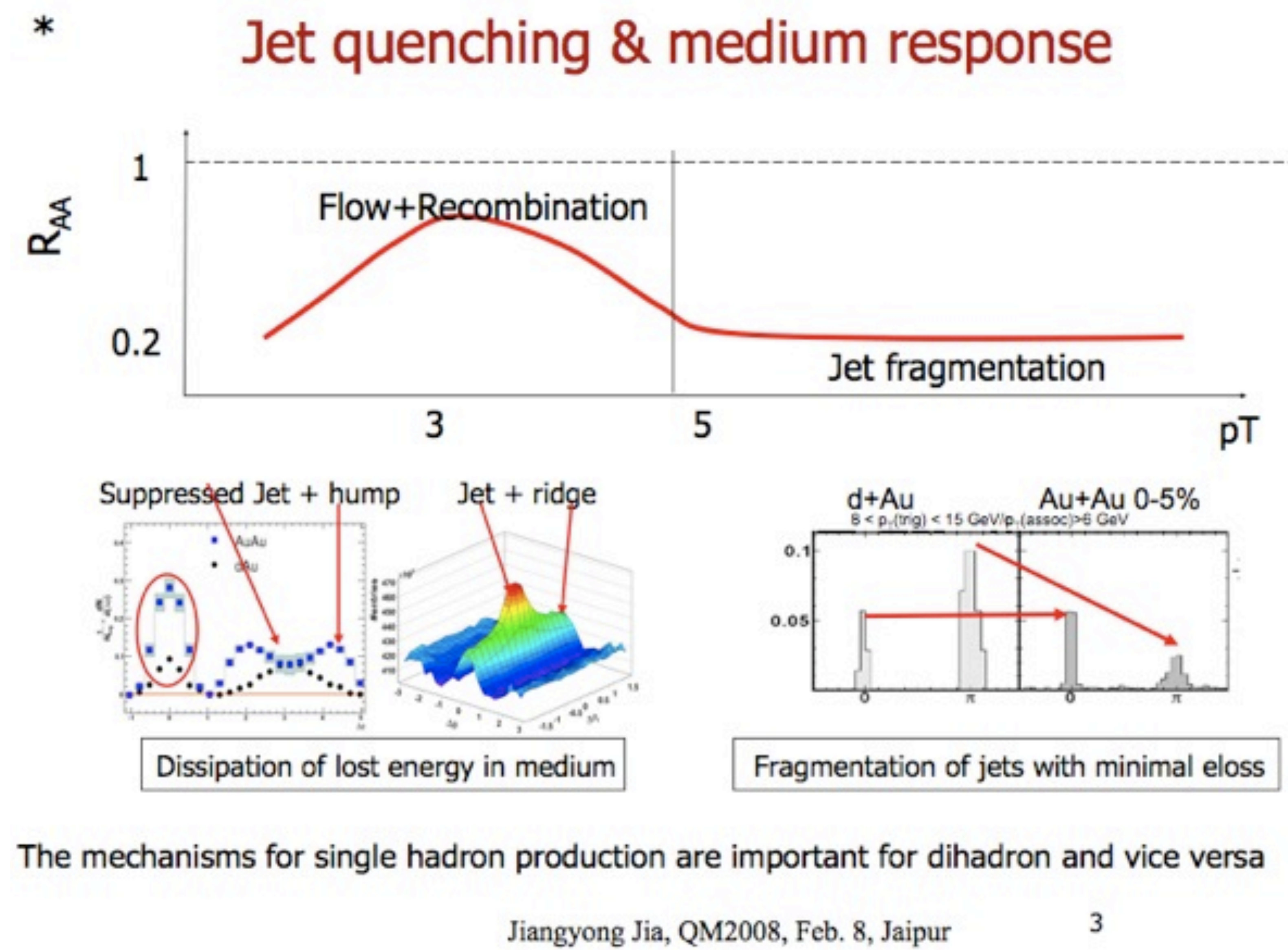
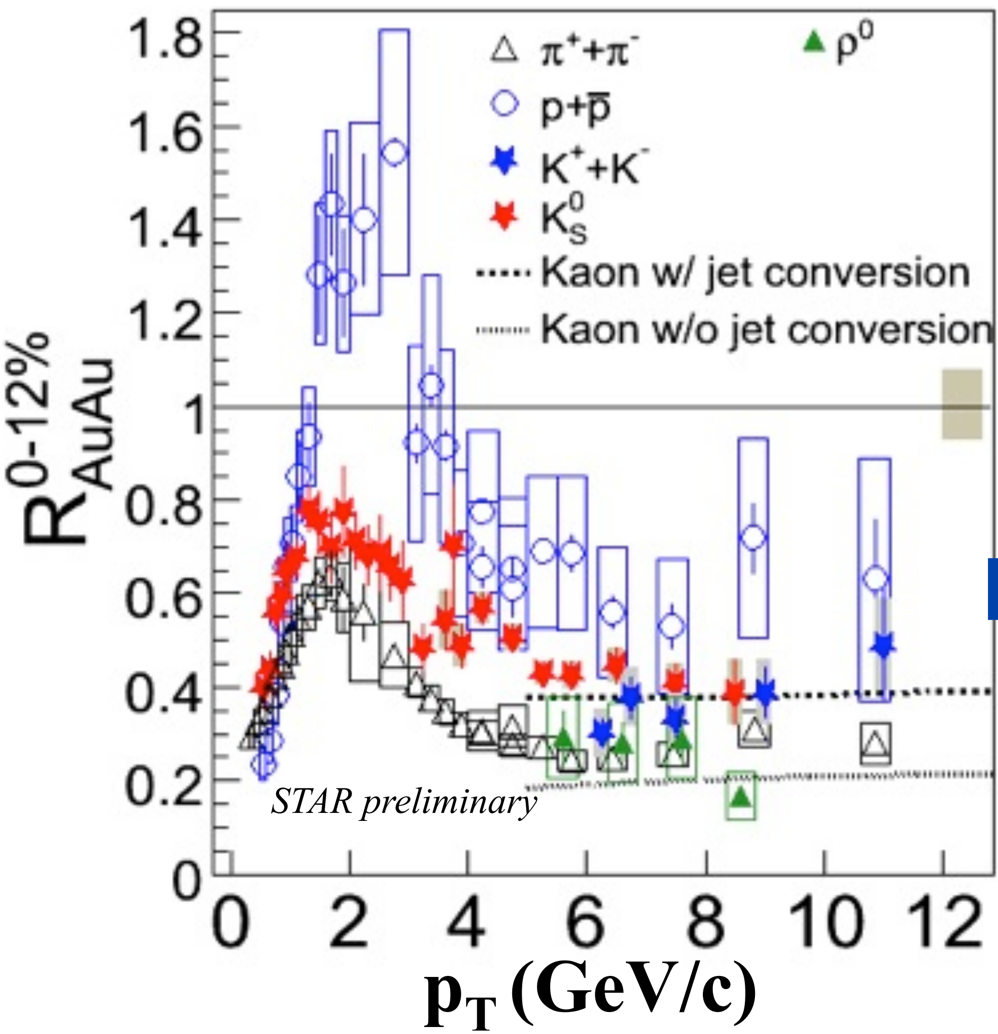
wealth of experimental data of a wide range of observables with reasonable precision

A simple separation?



high p_T: fragmentation modifications



protons

π

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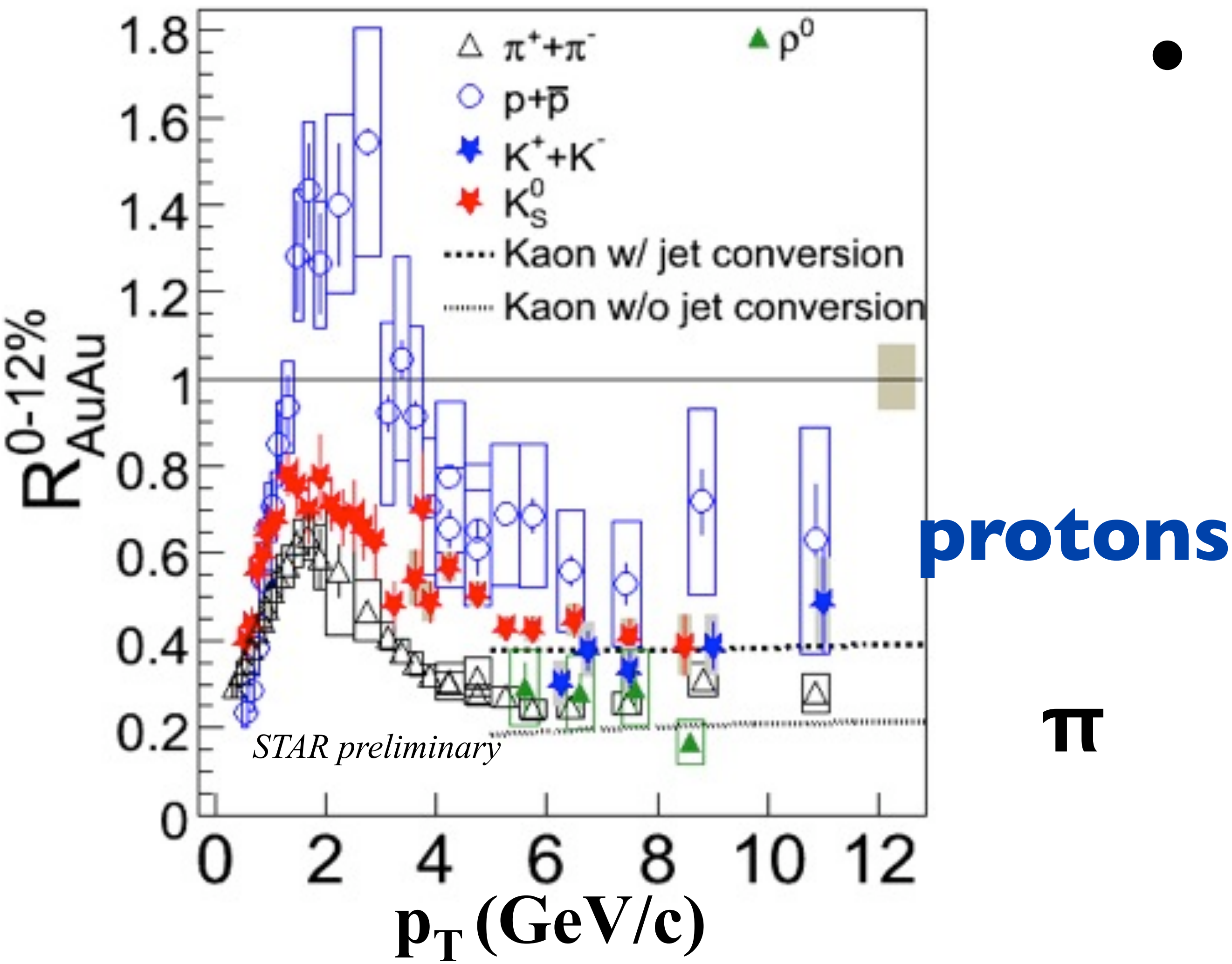

- R_{AA} differences remain even at high p_T

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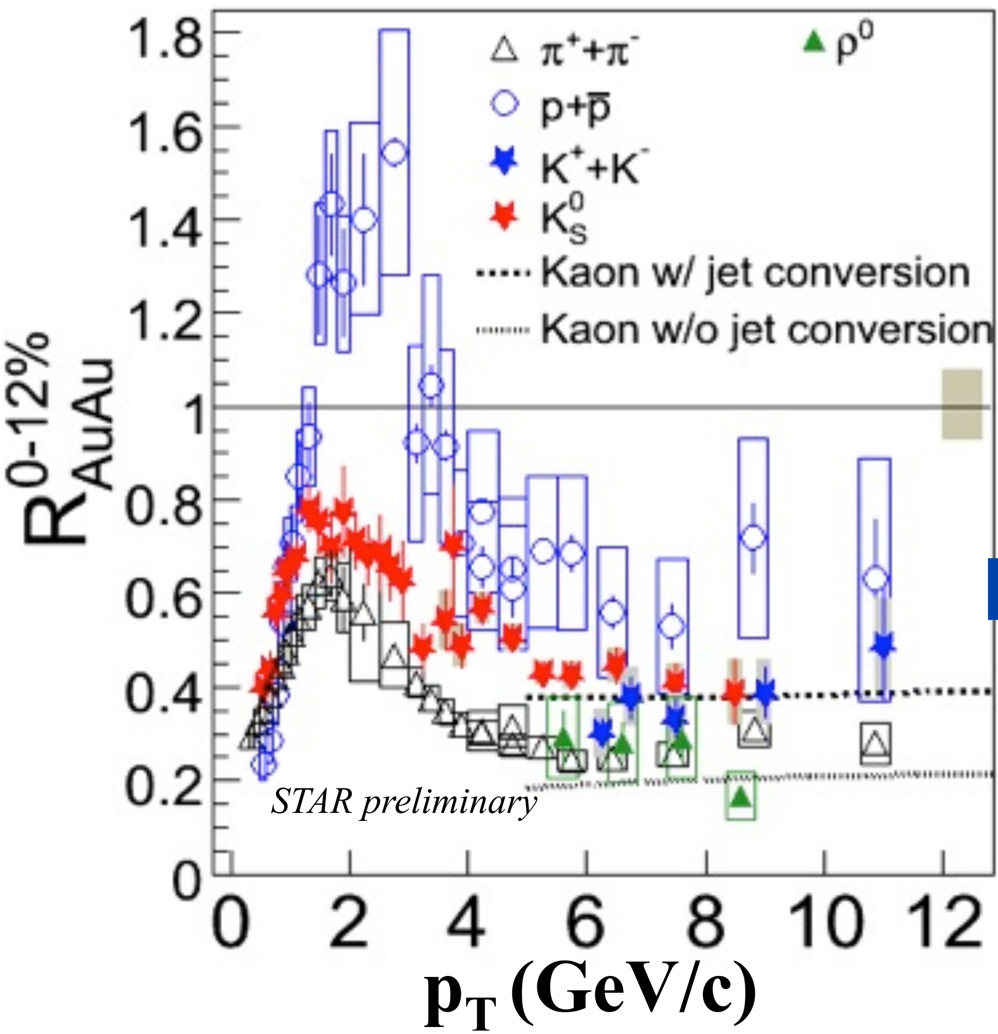

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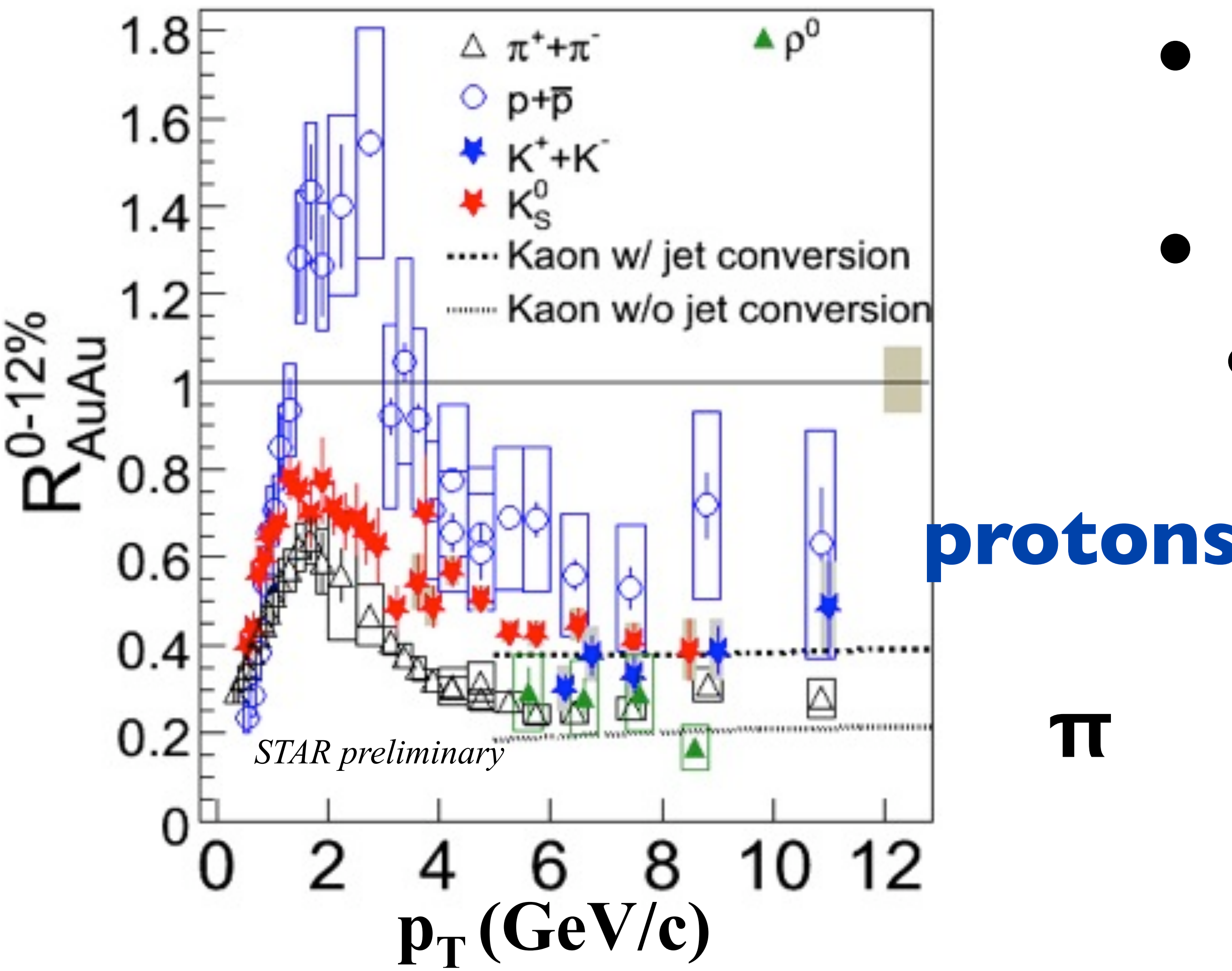

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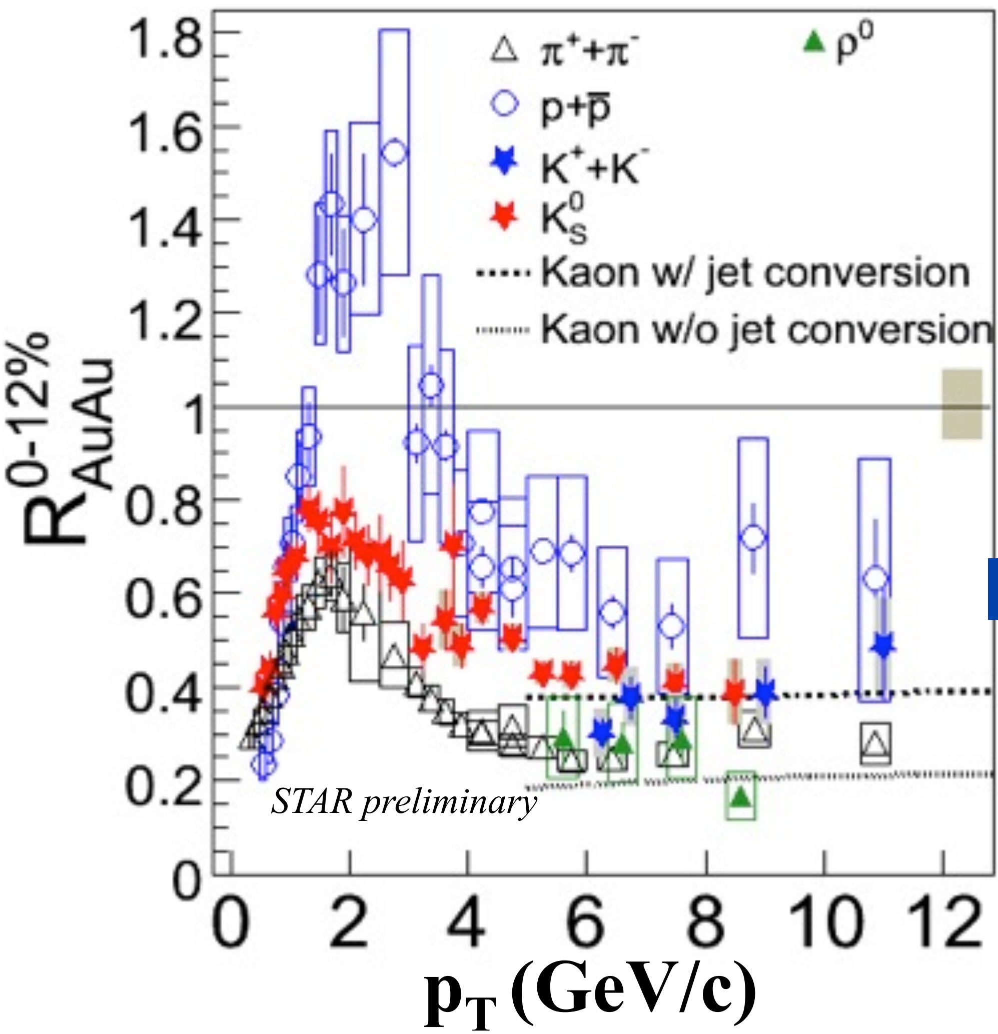

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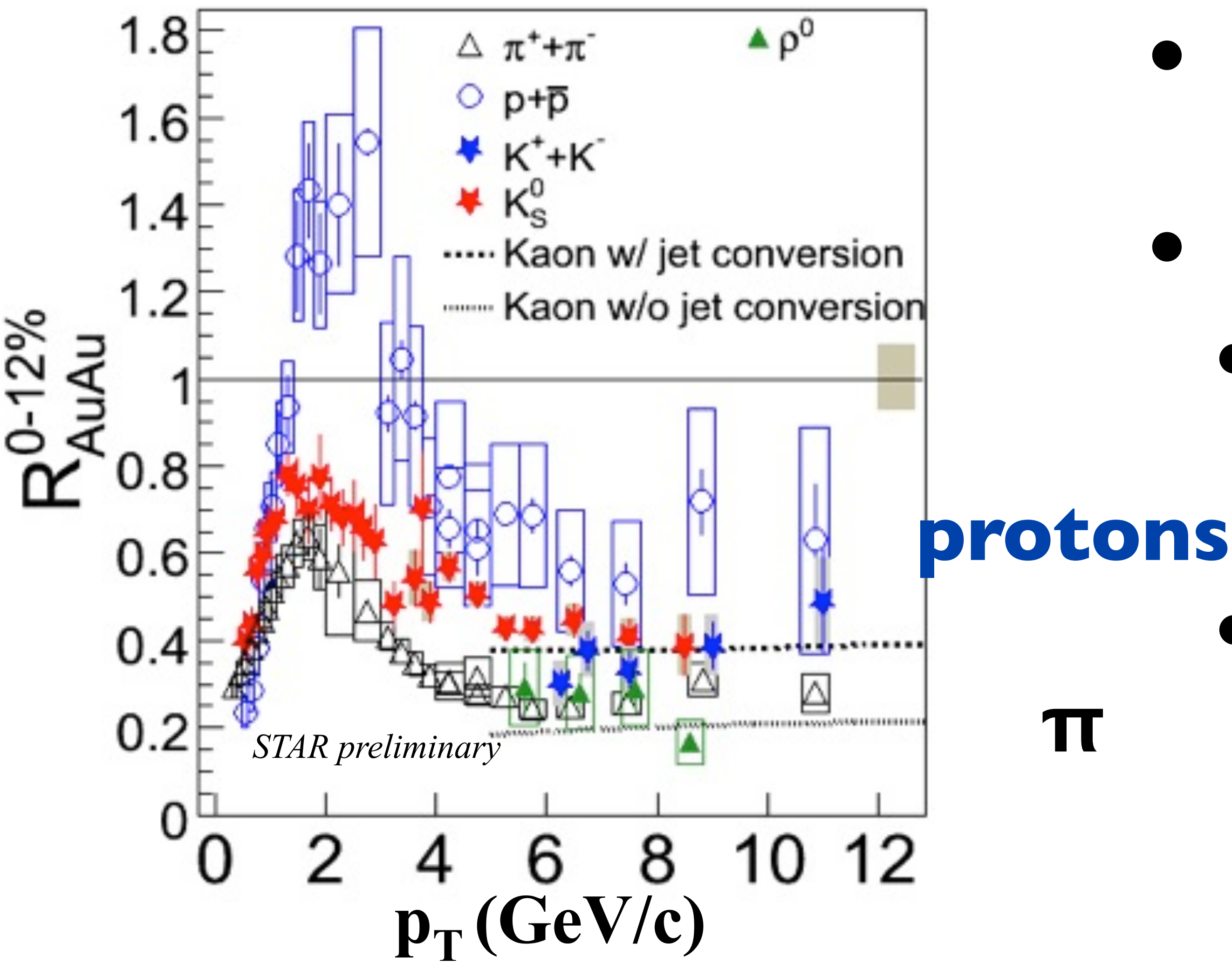

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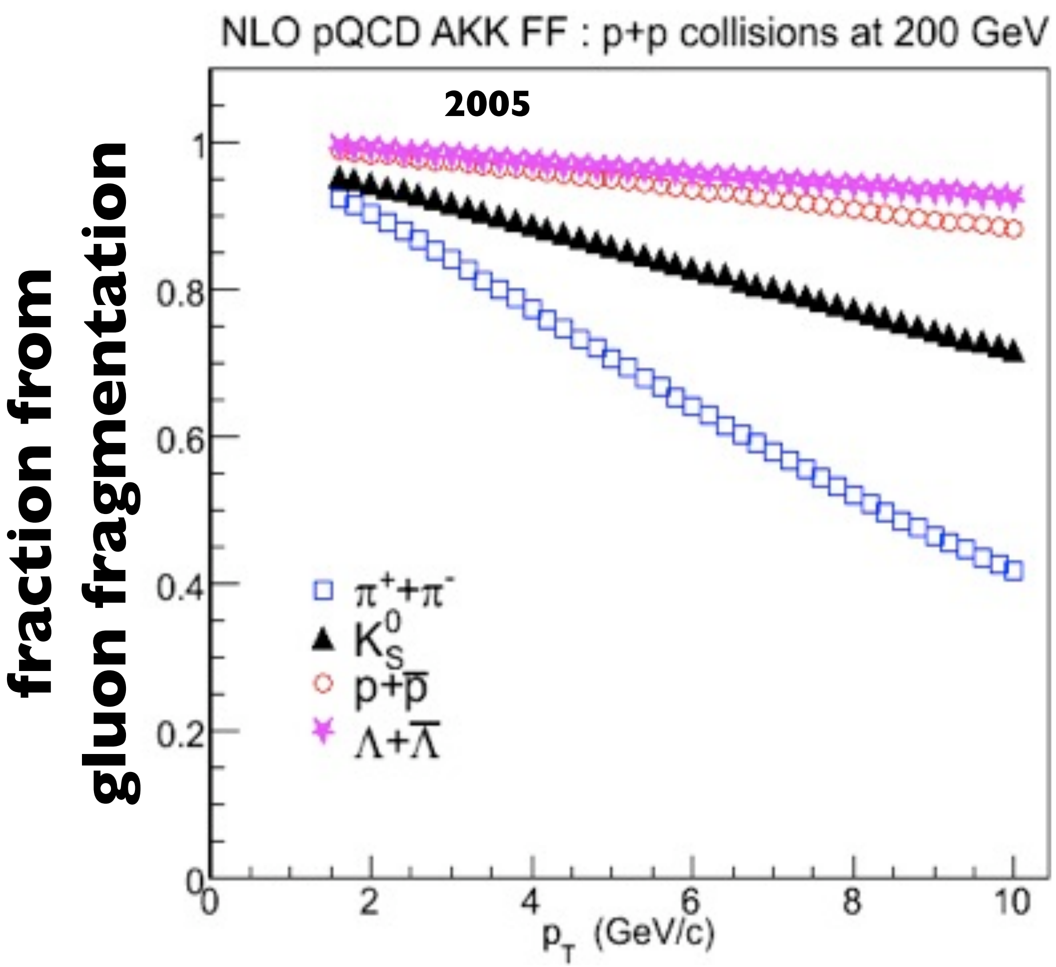
however the story is not quite so clear...

uncertainties in proton FF



uncertainties in proton FF

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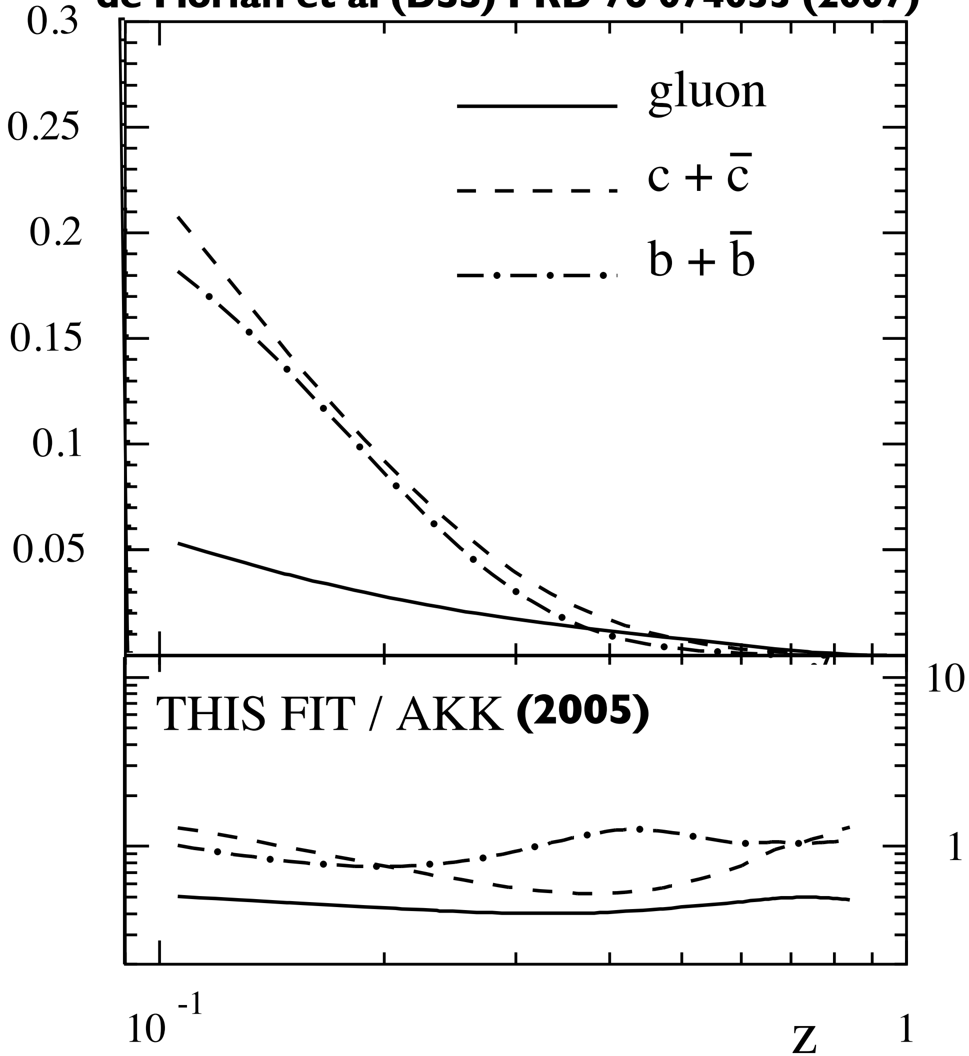

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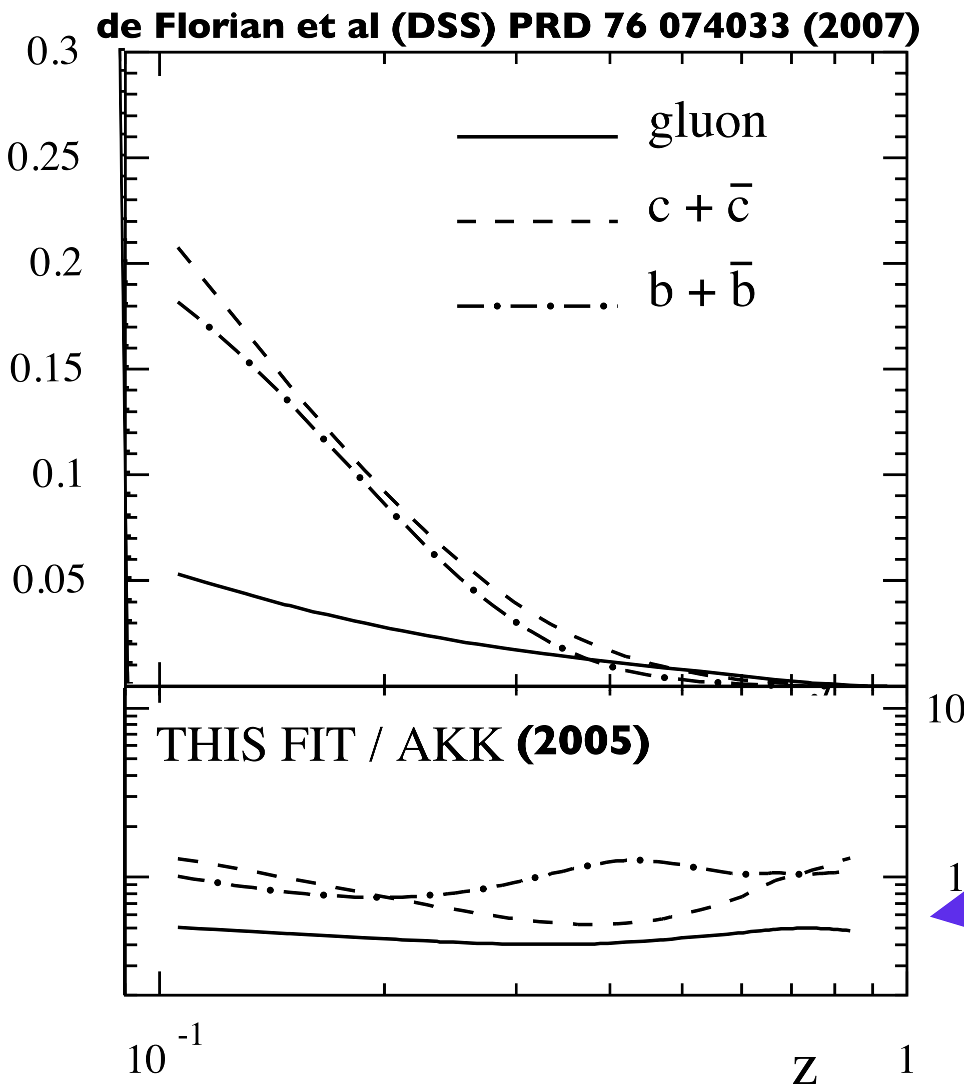

$\frac{g \to p\ (DSS)}{g \to p\ (AKK)}$

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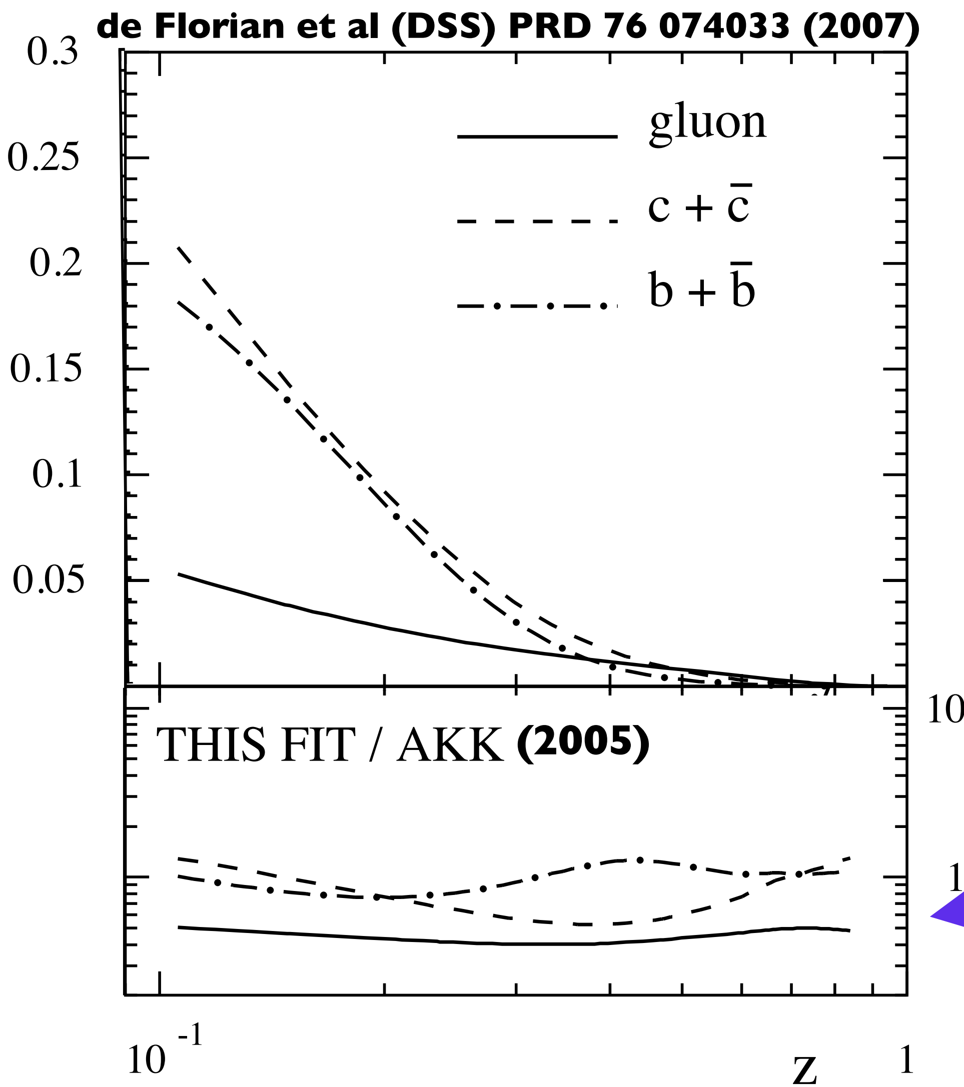
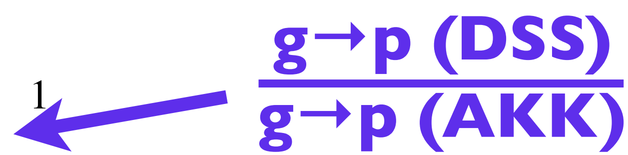


- **factor of three** differences in gluon → proton FF!
- DSS fragmentation functions reproduce STAR p+p results (they were used in the constraint)



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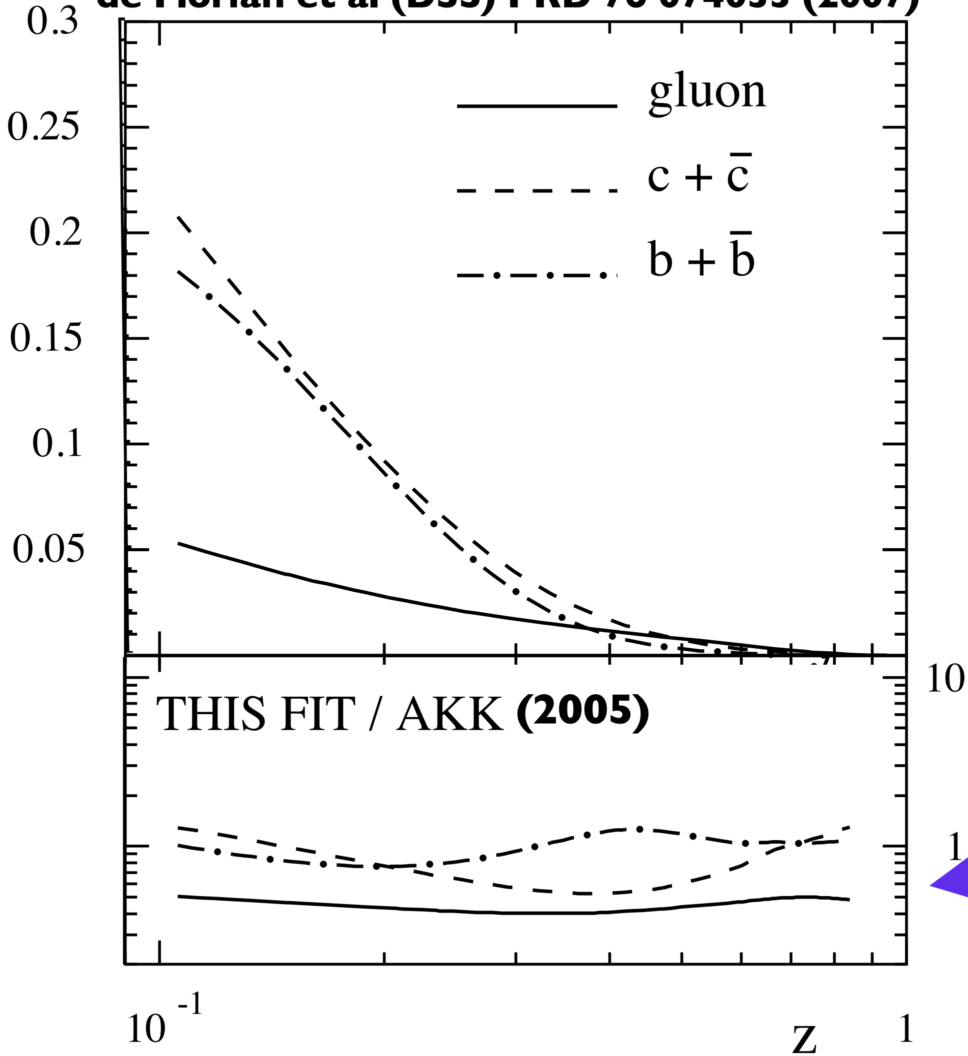

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g→p (DSS) / g→p (AKK)

still unclear why $R_{AA}(p) > R_{AA}(\pi)$

jet conversions

idea: jet parton scatters on medium parton and changes flavor

$$q + \overline{q} \leftrightarrow g + g$$

$$q + g \leftrightarrow g + q$$

Ko et al. PRC 75 051901 (2007)
Liu & Fries PRC77 054902 (2008)

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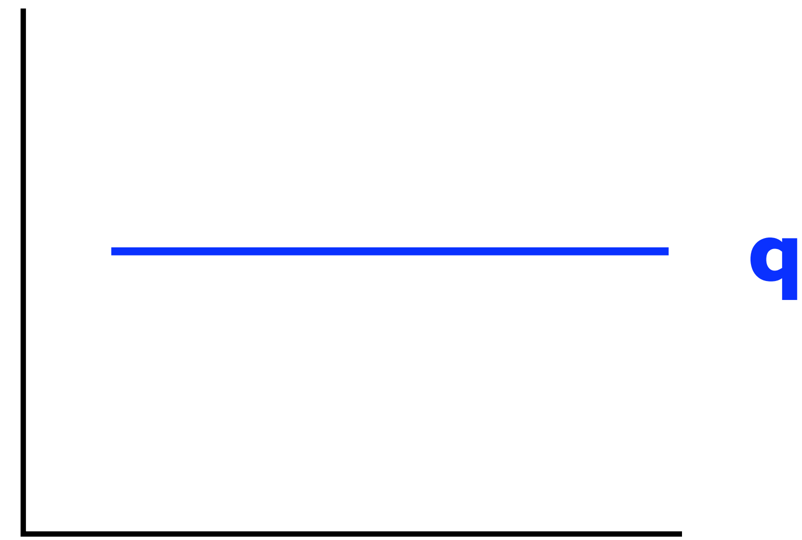

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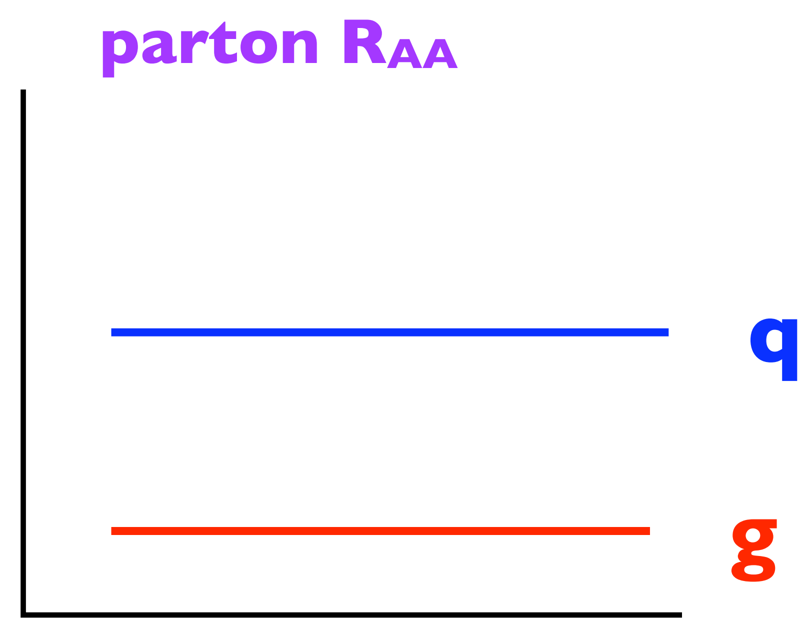

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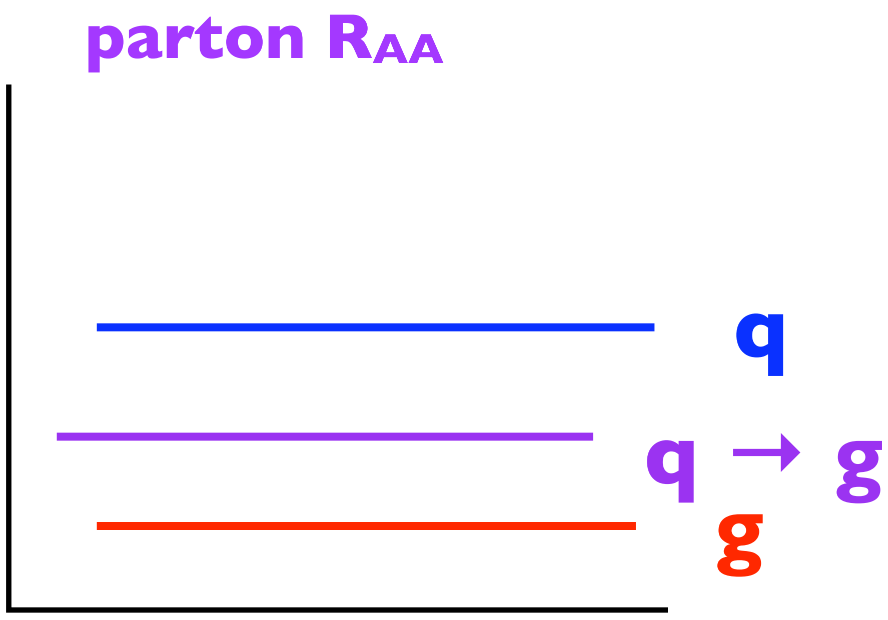

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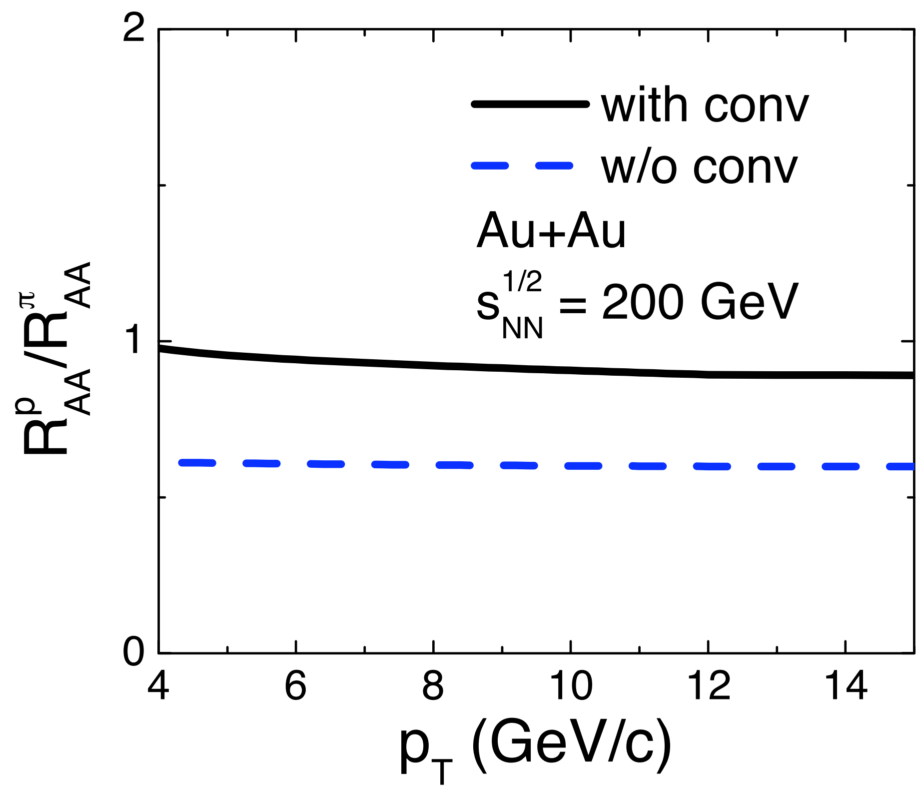

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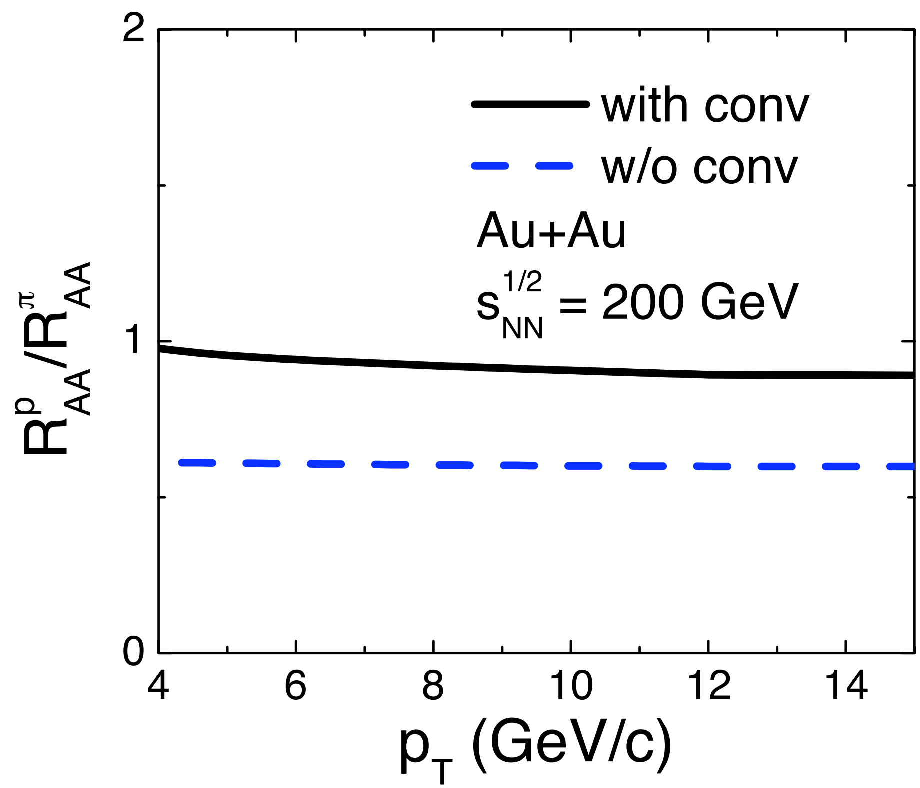

- could increase R_{AA}(protons)/R_{AA}(π), but not beyond 1

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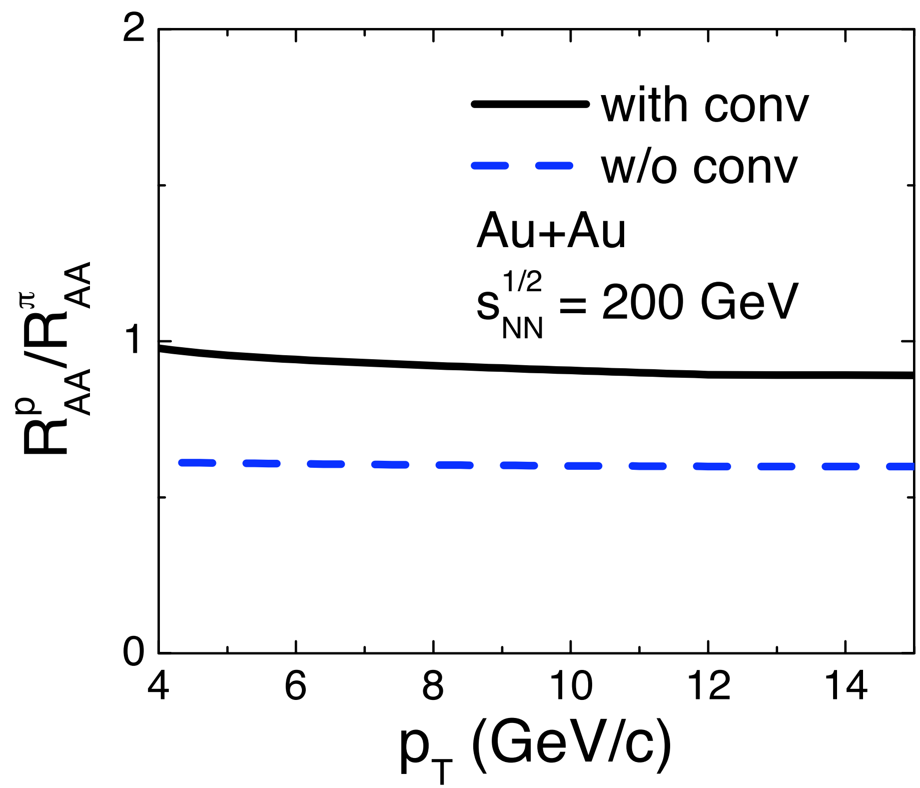

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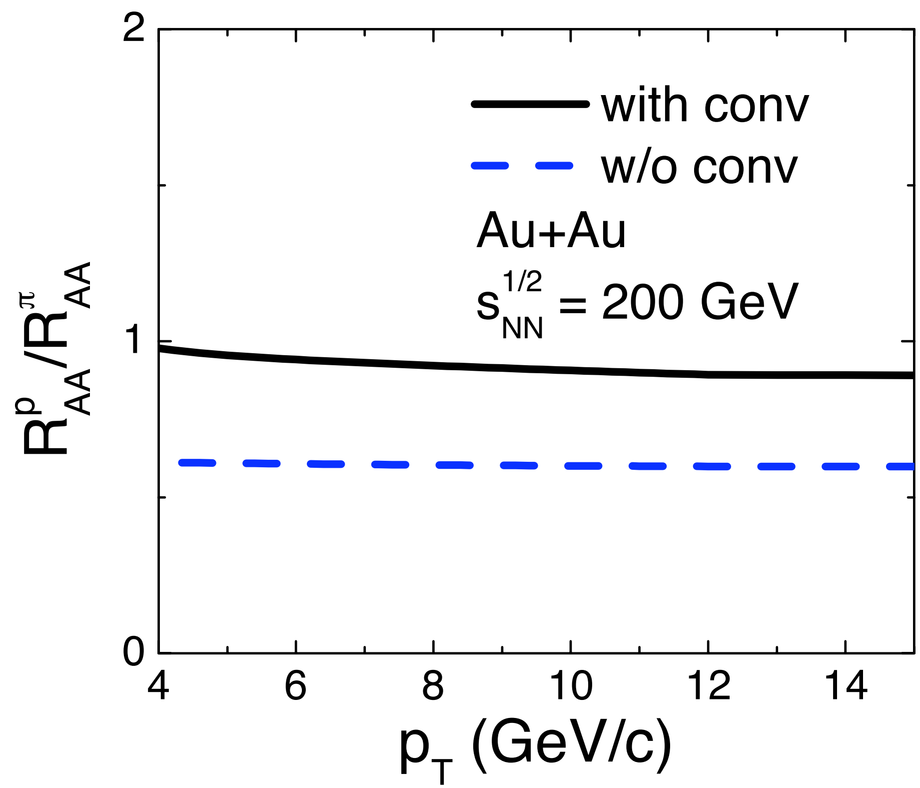

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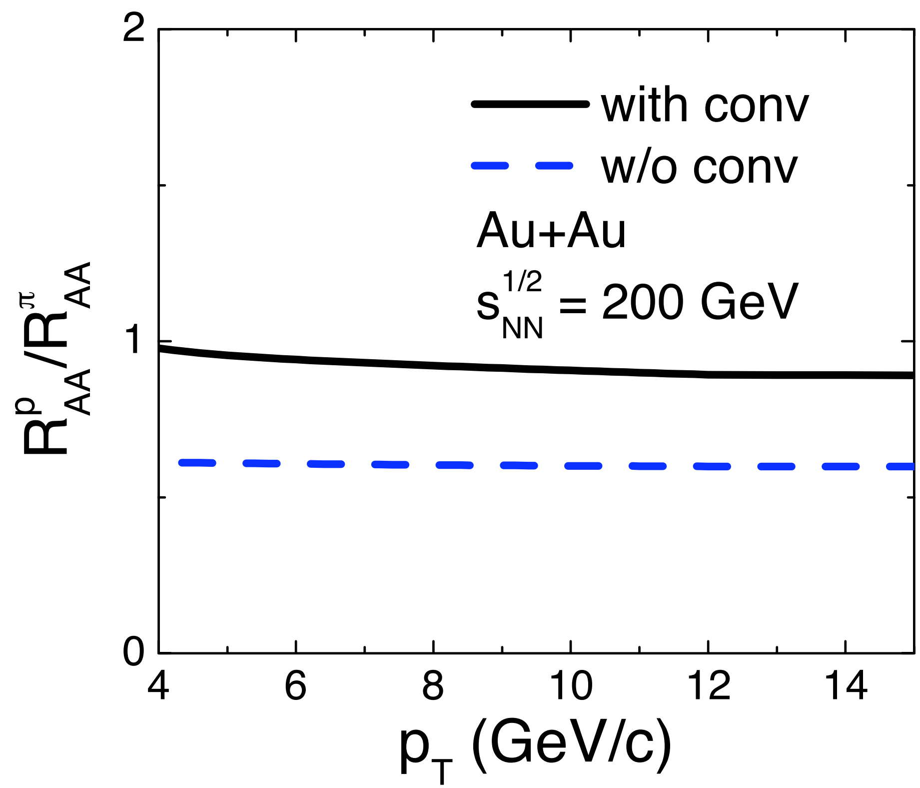

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    - however need to understand FF

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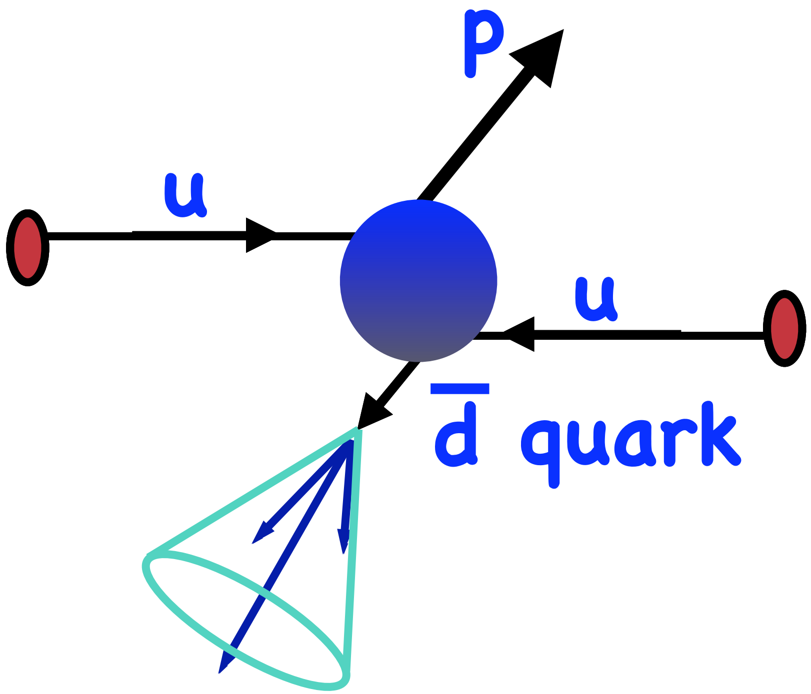
direct proton production?



$uu \rightarrow p\bar{d}$

Brodsky & AMS PLB 668 111 (2008)

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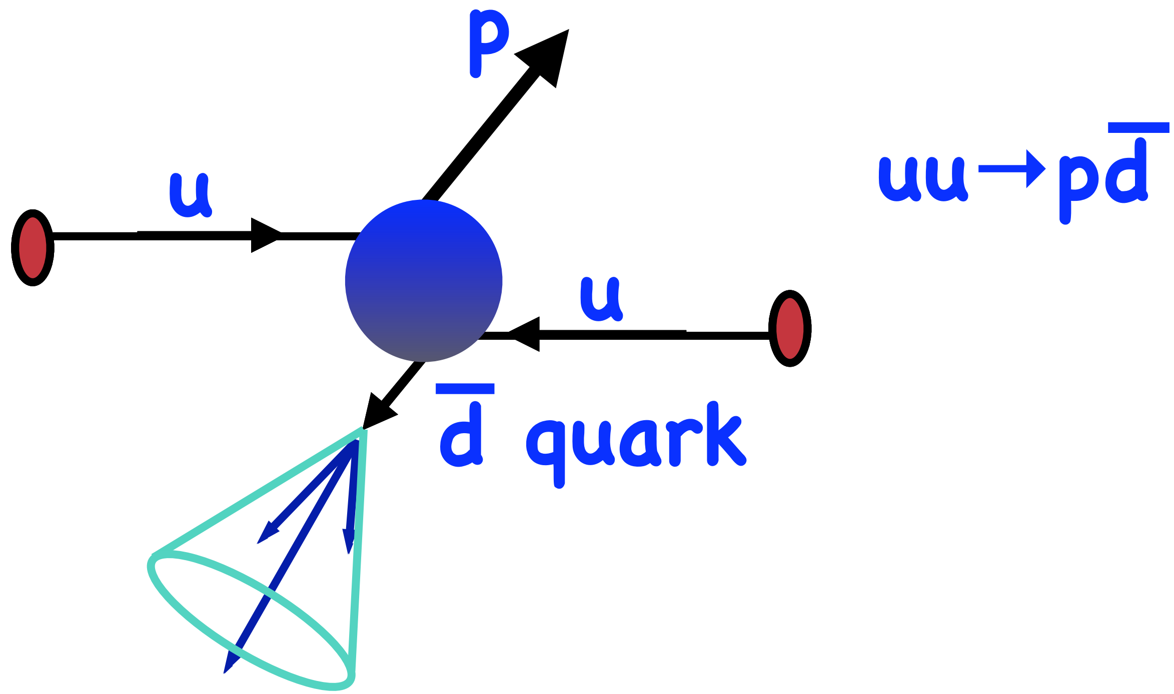

- color singlet proton directly produced within hard scattering

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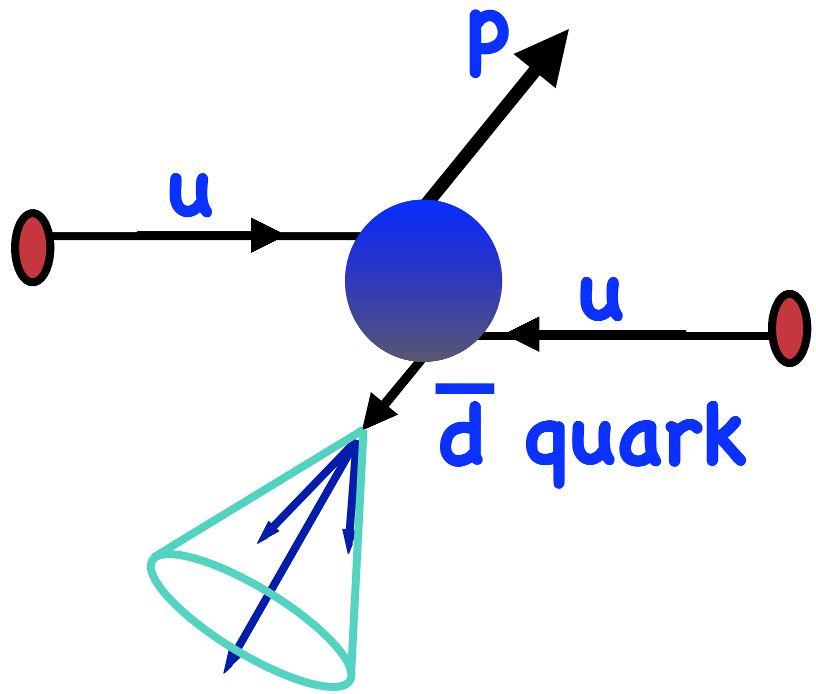

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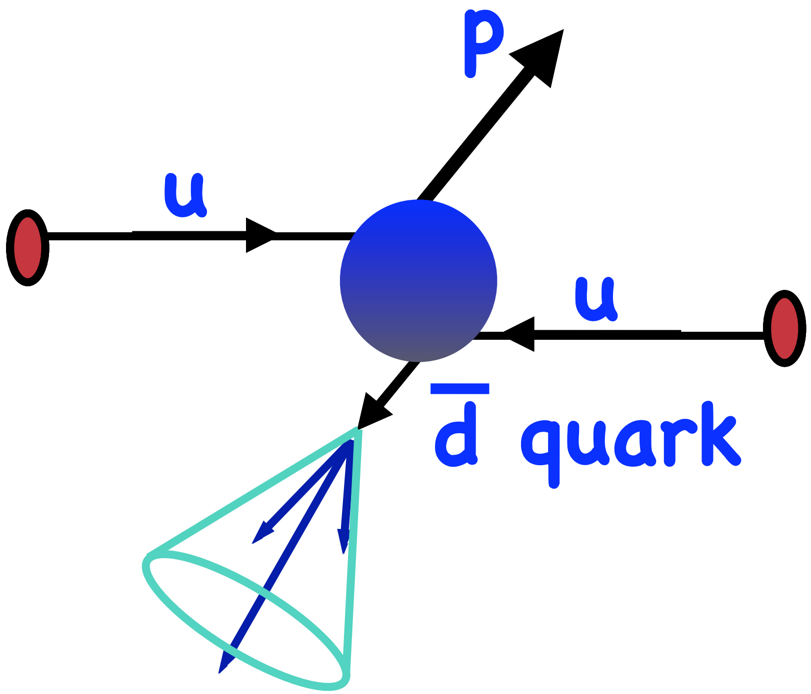

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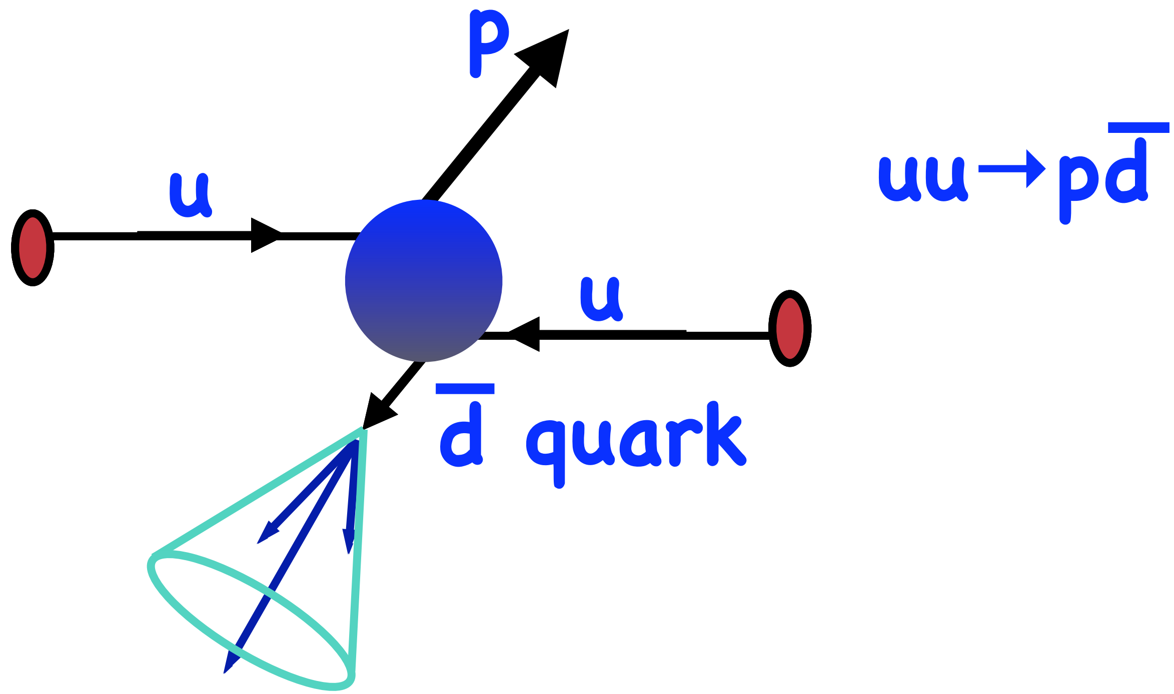

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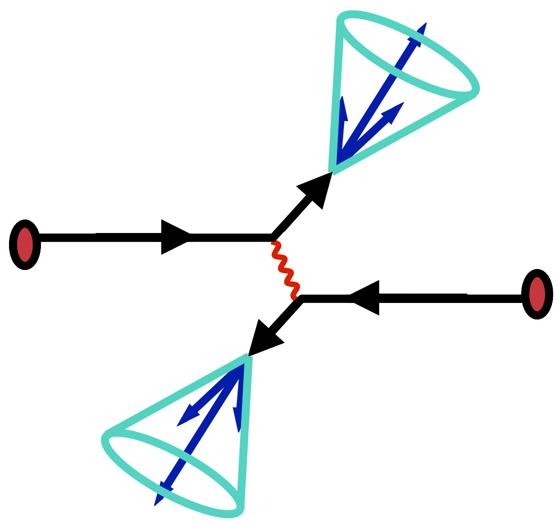
2 particle correlations



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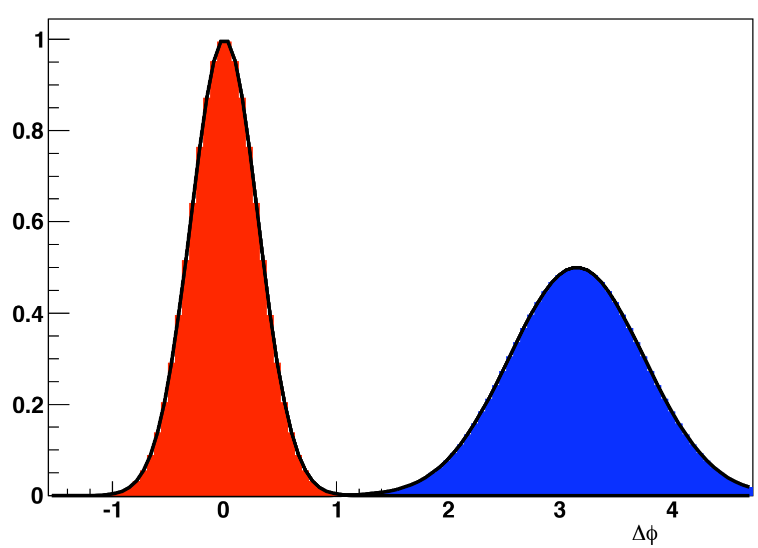
- different sensitivity to geometry



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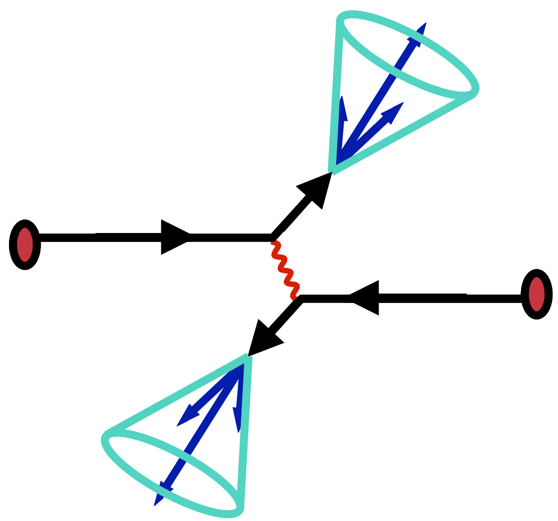

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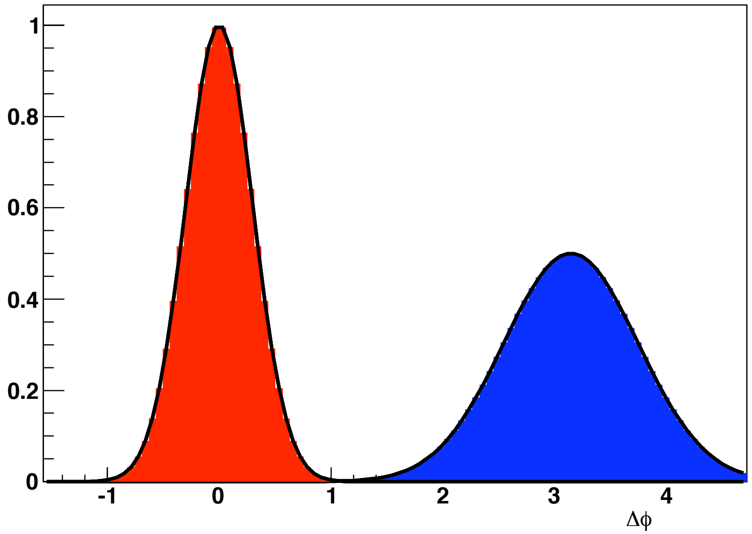
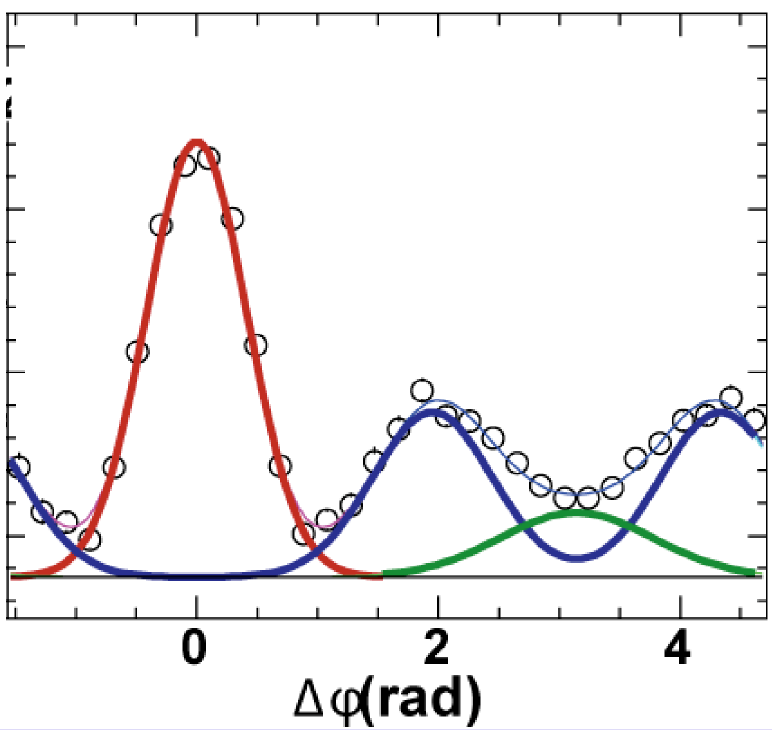
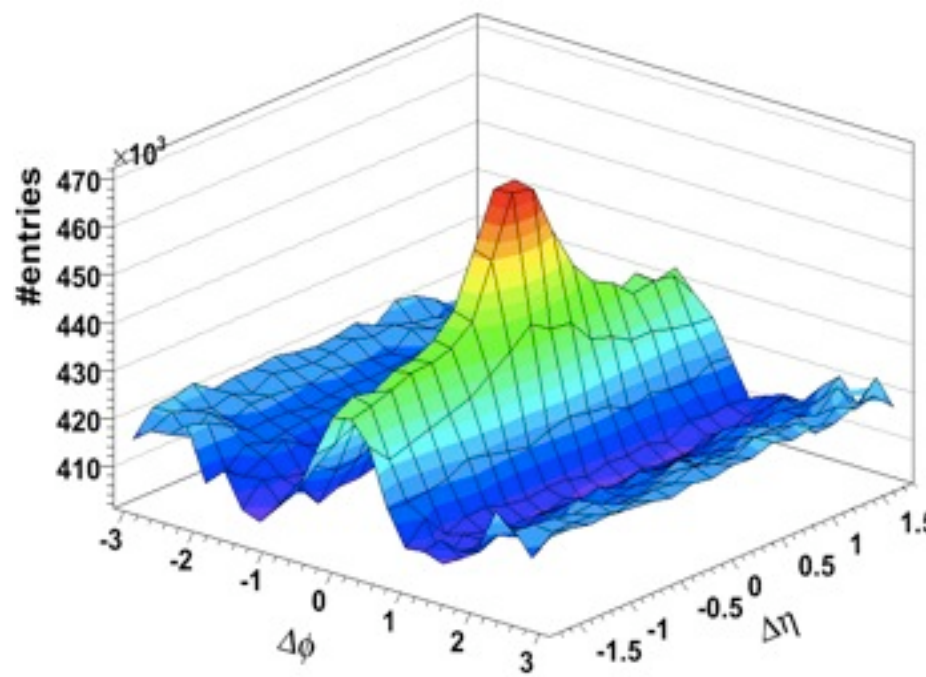


$$I_{AA} = \frac{\text{conditional yield in AuAu}}{\text{conditional yield in pp}}$$

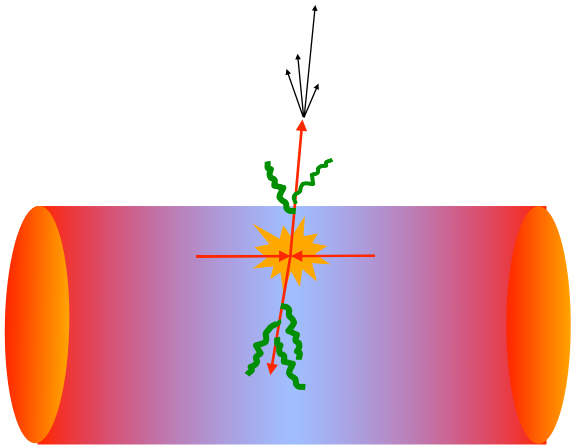
what are we looking for?

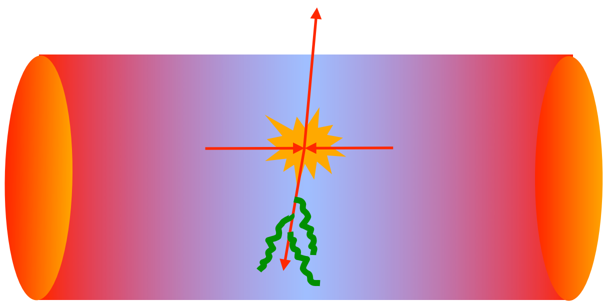
- yields: complementary to R_{AA} measurements
- shapes: ridges? shoulders?
  - measurements with identified particles discriminate between production mechanisms





π^0-h v γ_{direct}-h





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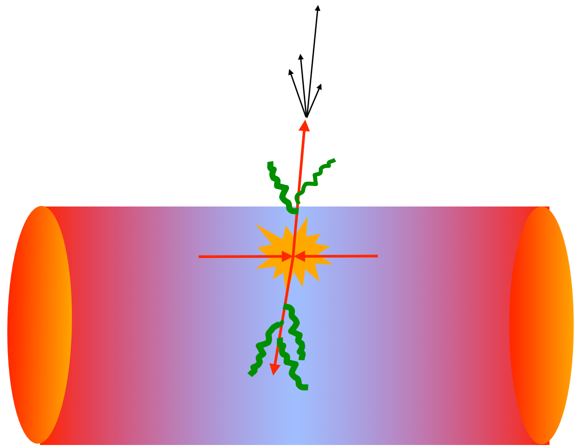

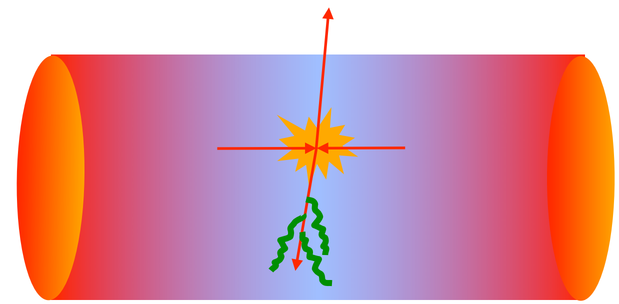

π^0-h	γ_{direct}-h
g,q interact strongly	γ don't interact strongly

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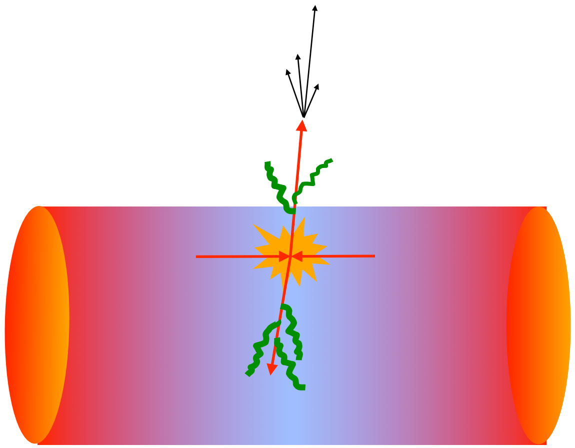

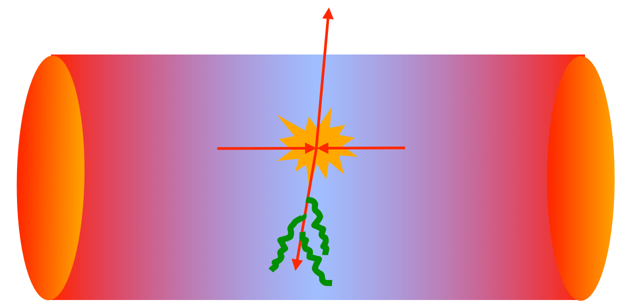

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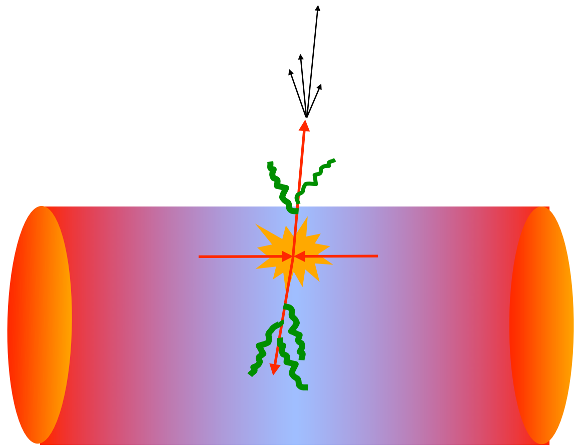

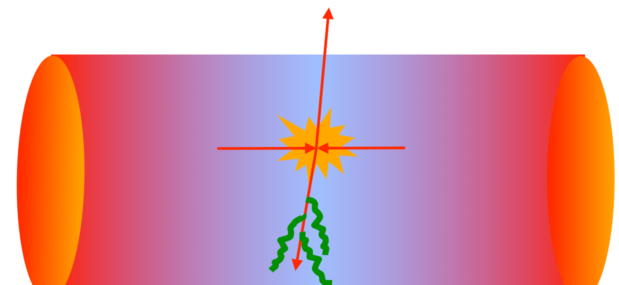

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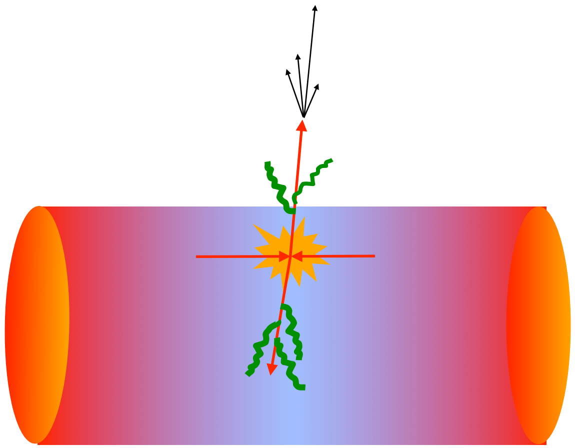

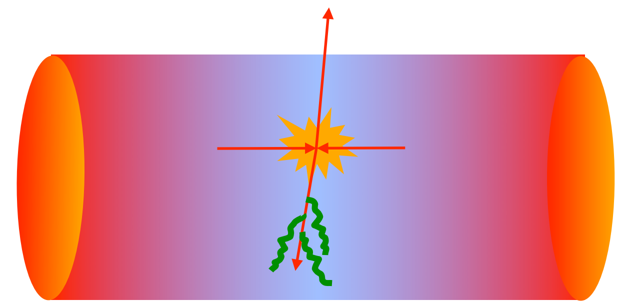

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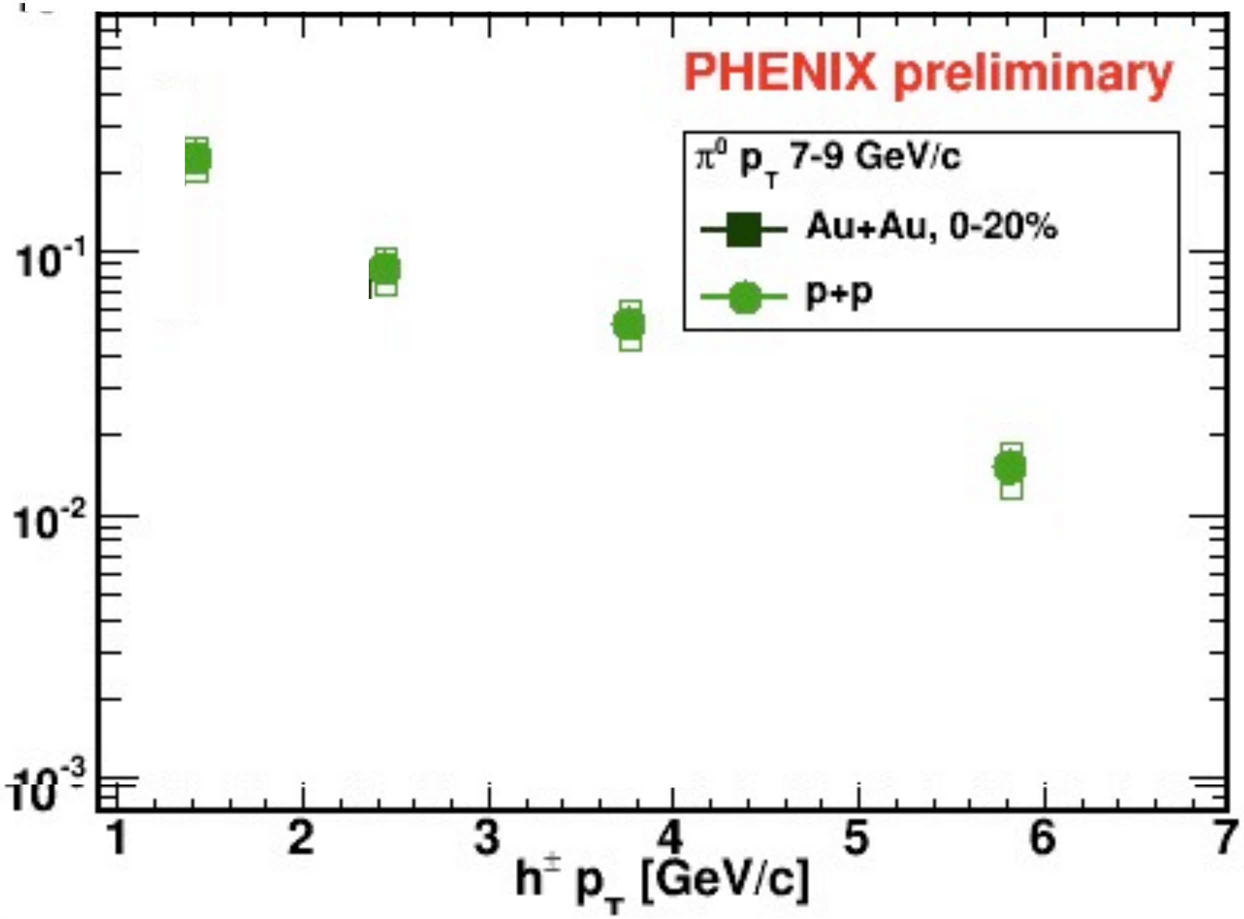
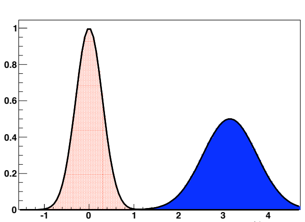
$p_{T,\pi 0} < p_{T,jet}$	$p_{T,\gamma} \sim p_{T,jet}$
	away side more likely to be quark: $q + g \rightarrow q + \gamma$

π^0-h: away side suppression

$1/N_{trig}\, dN/dp_T$





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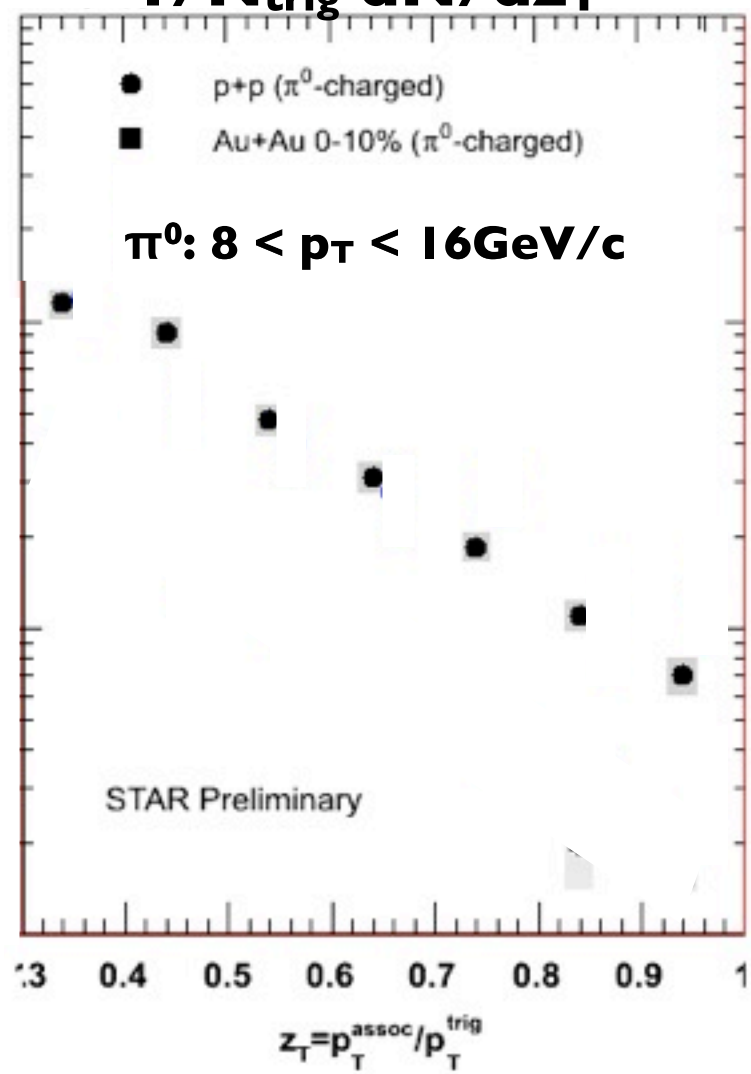

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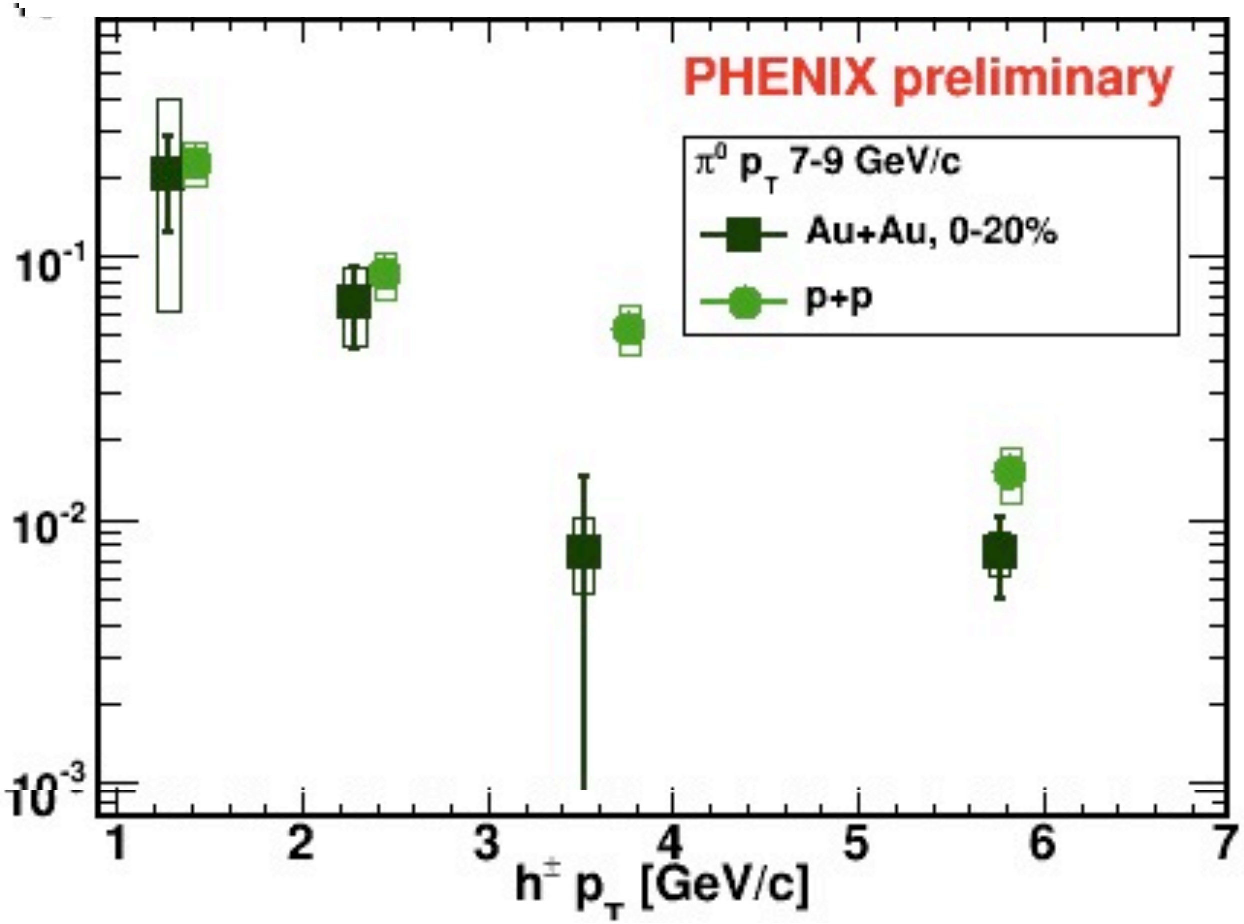

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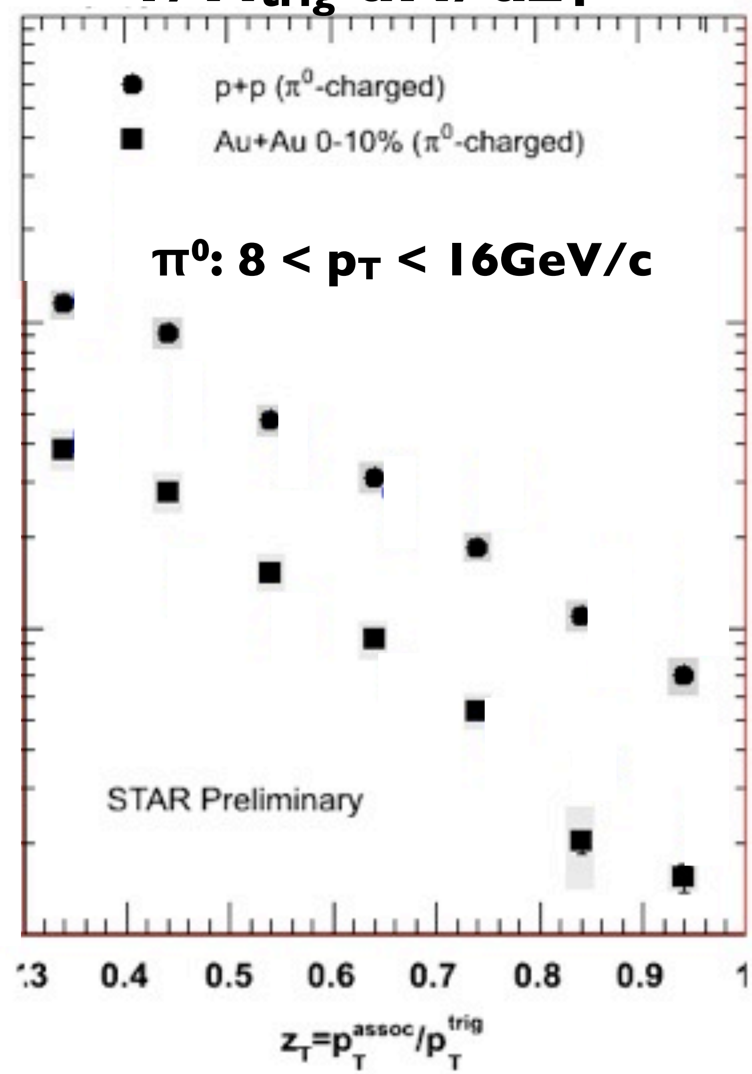
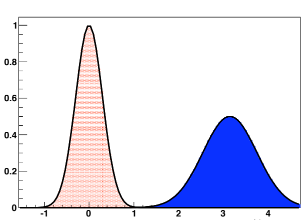
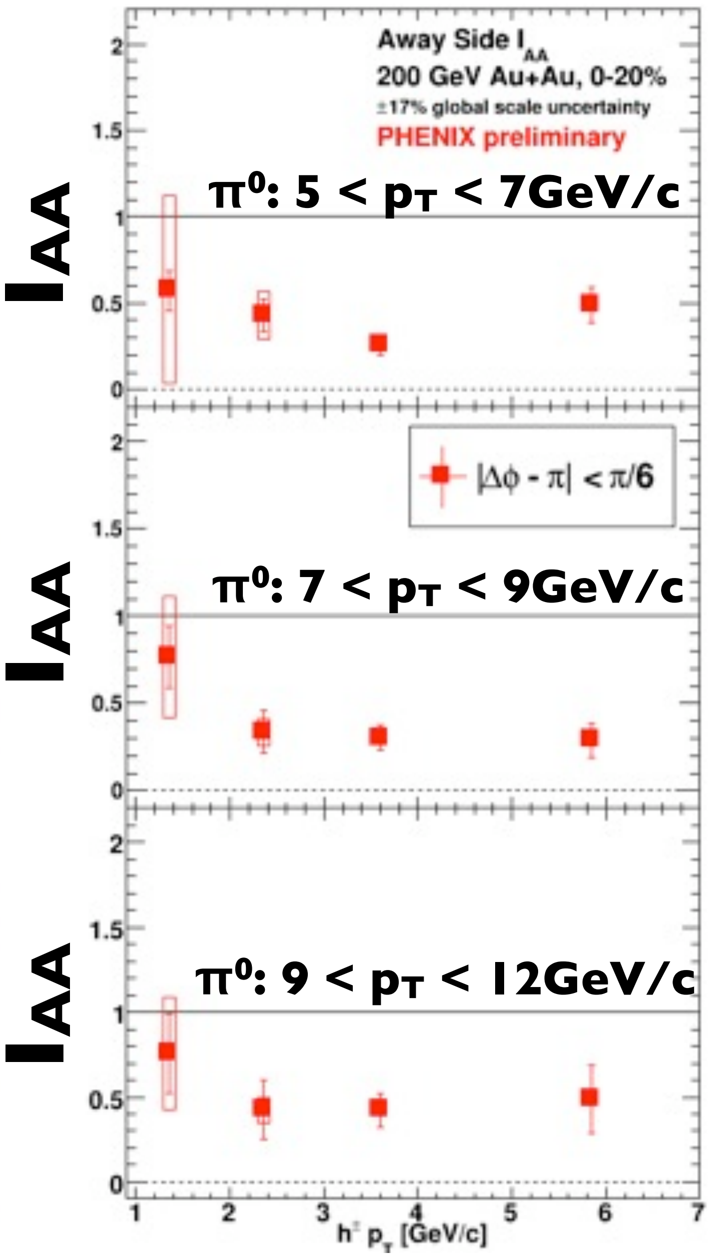
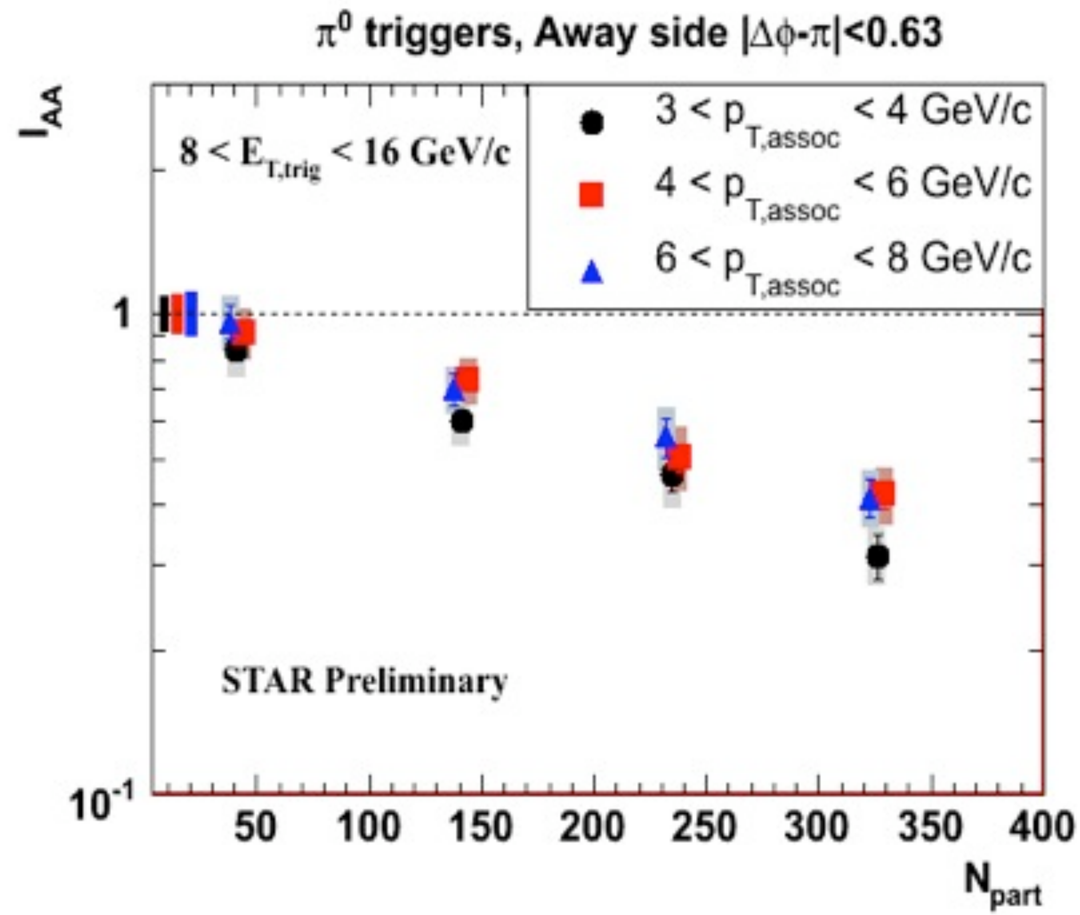
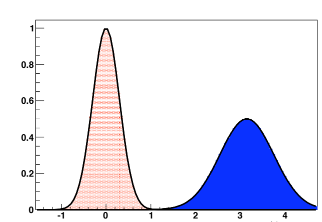




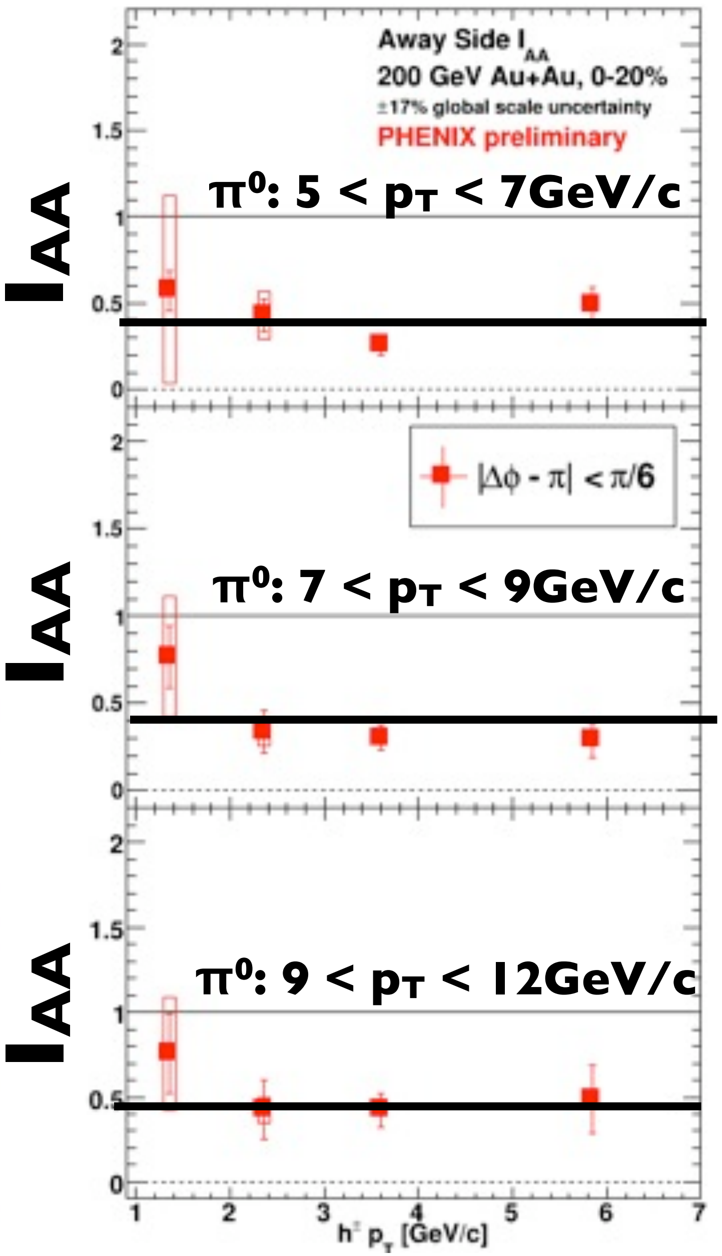
π^0-hadron: away side suppression

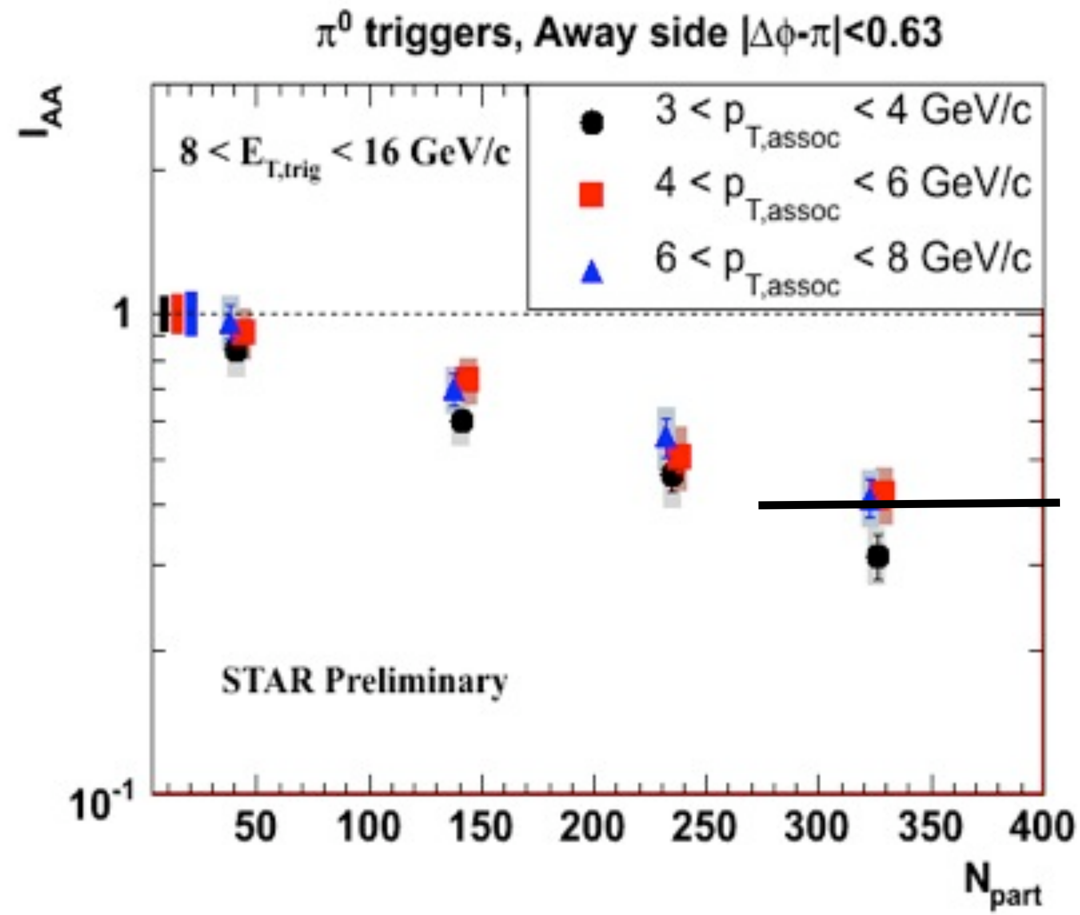




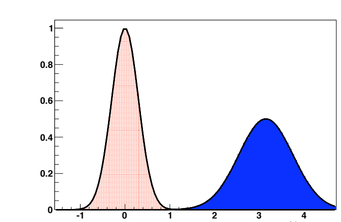


π^0-hadron: away side suppression





suppression nearly constant with $p_{T,trig}$ $p_{T,h}$

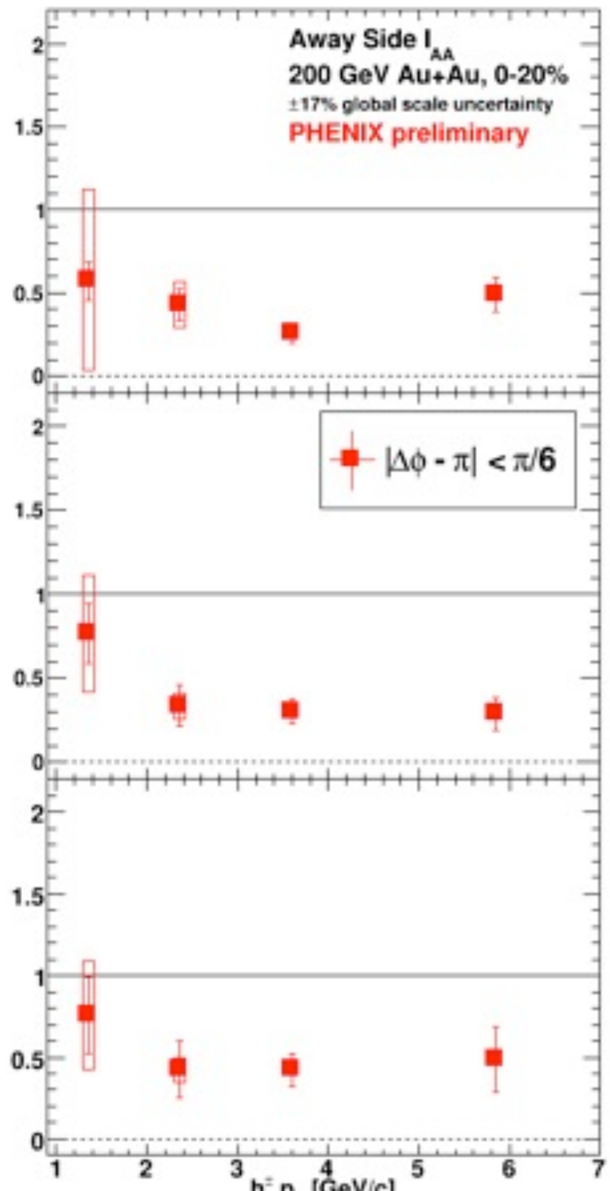


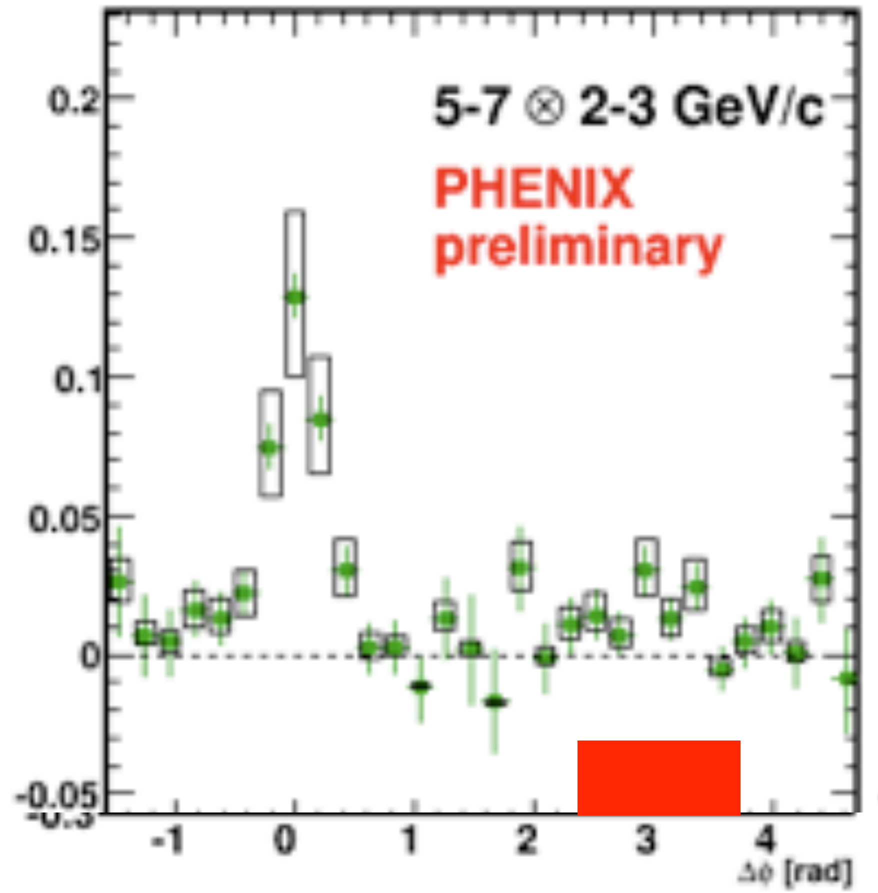
π^0-h: away side shape?

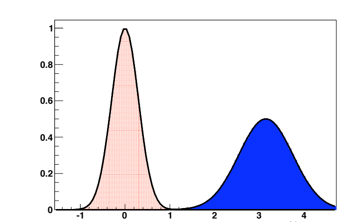
I_{AA}

I_{AA}

I_{AA}





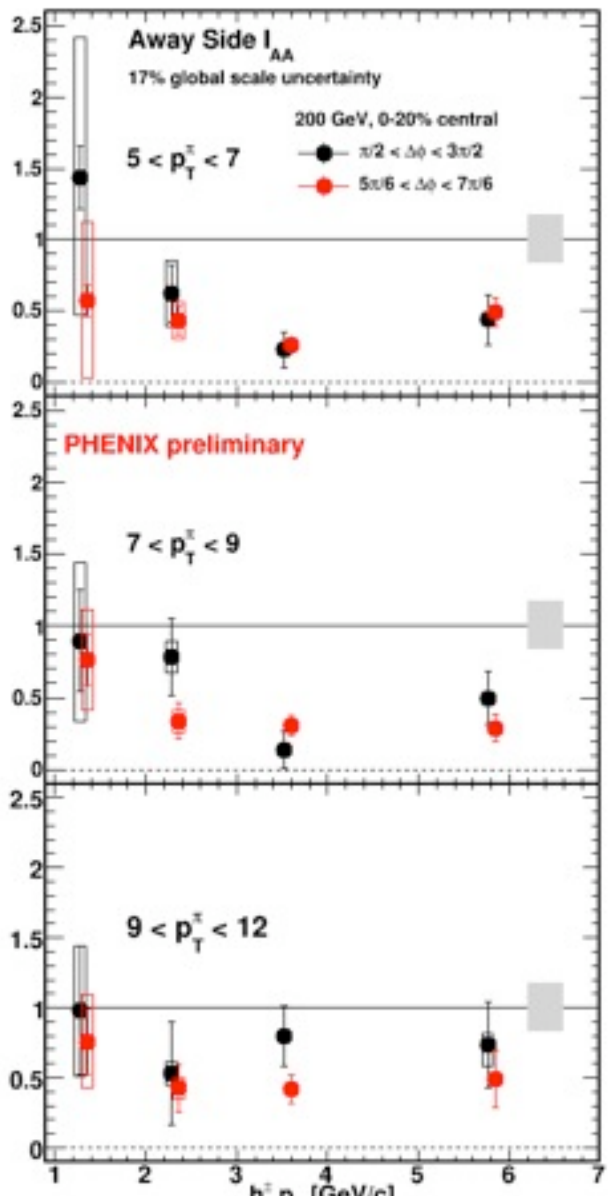


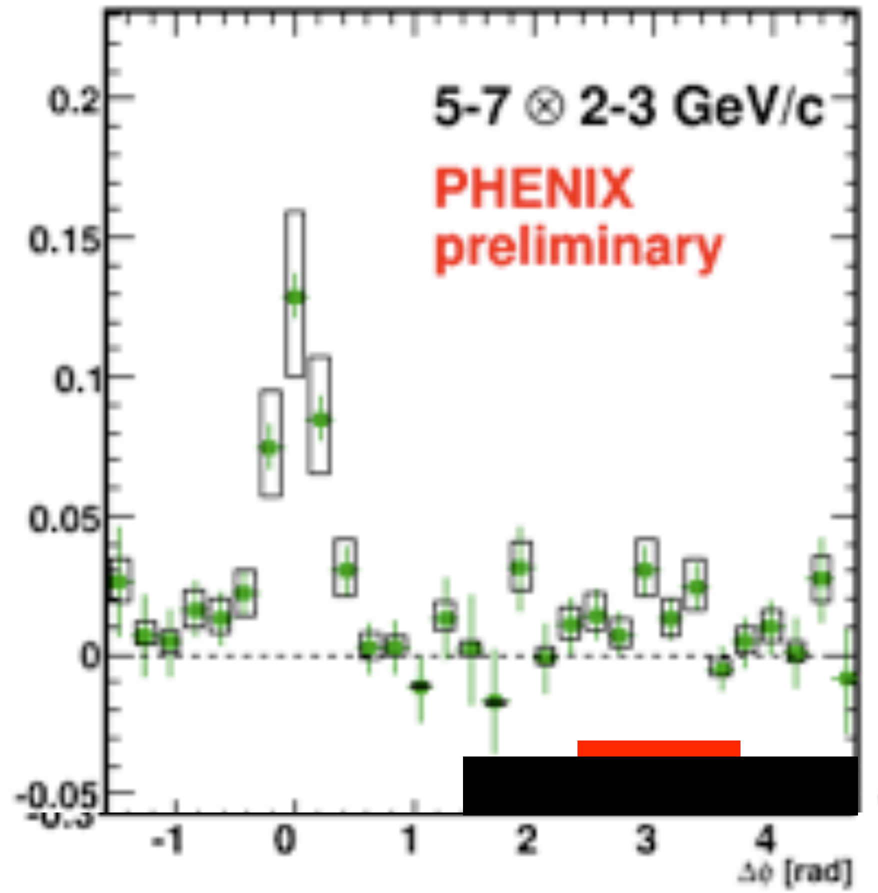
π^0-h: away side shape?

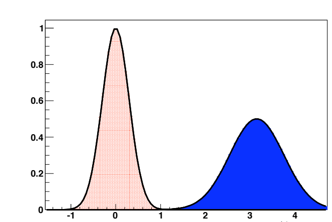
IAA

IAA

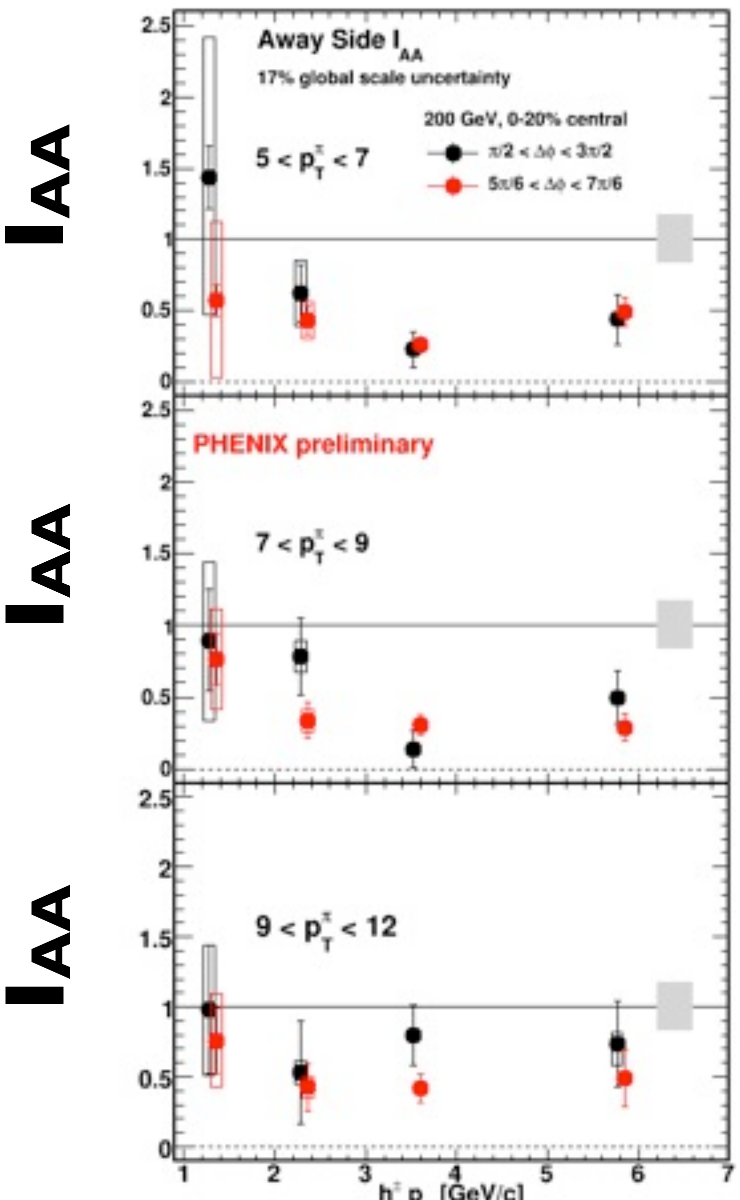
IAA

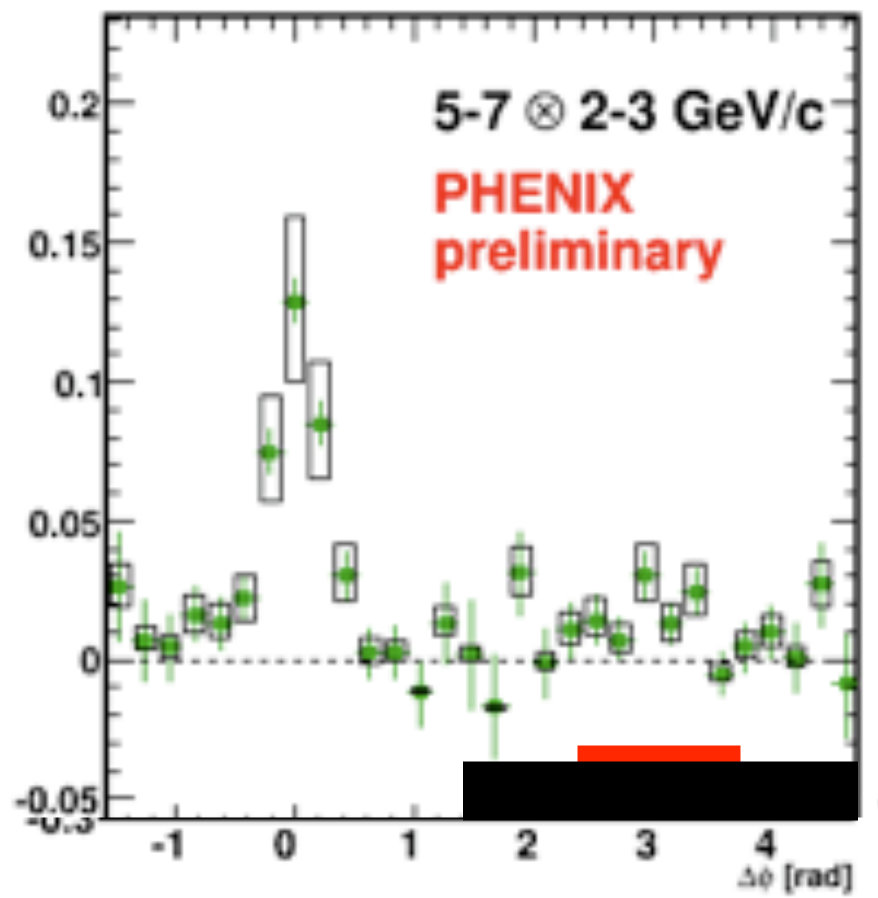




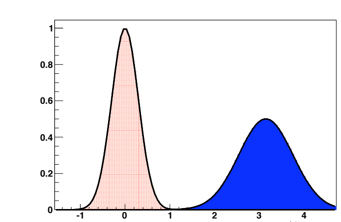


π^0-h: away side shape?





- dominated by punch through jets



measuring γ_{direct}-h

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challenge: γs from π^0 decay

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measure γ_{incl}-h:
$$Y_{\gamma_{incl}-h} = \frac{N_{direct}}{N_{incl}} Y_{\gamma_{direct}-h} + \frac{N_{decay}}{N_{incl}} Y_{\gamma_{decay}-h}$$

measuring γ_{direct}-h

challenge: γs from π^0 decay

measure γ_{incl}-h: $$Y_{\gamma_{incl}-h} = \frac{N_{direct}}{N_{incl}} Y_{\gamma_{direct}-h} + \frac{N_{decay}}{N_{incl}} Y_{\gamma_{decay}-h}$$

	PHENIX	STAR

measuring γ_{direct}-h

challenge: γs from π^0 decay

measure γ_{incl}-h:

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	PHENIX	STAR
$R_\gamma = 1 + N_{direct} / N_{decay}$	measured γ_{direct} spectra (PRL 232301 (2005))	adjusted by requiring no near side yield

measuring γ_{direct}-h

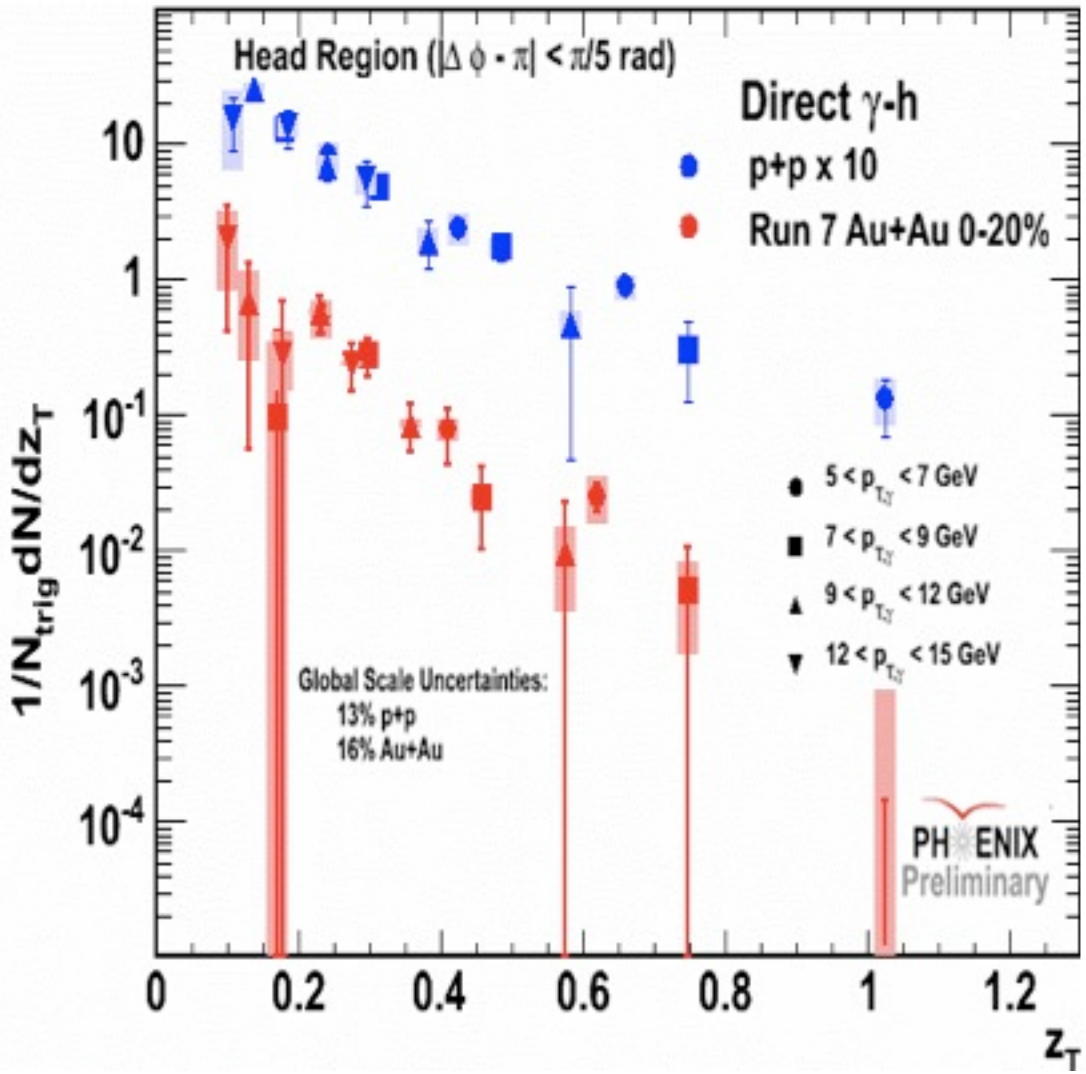
challenge: γs from π^0 decay

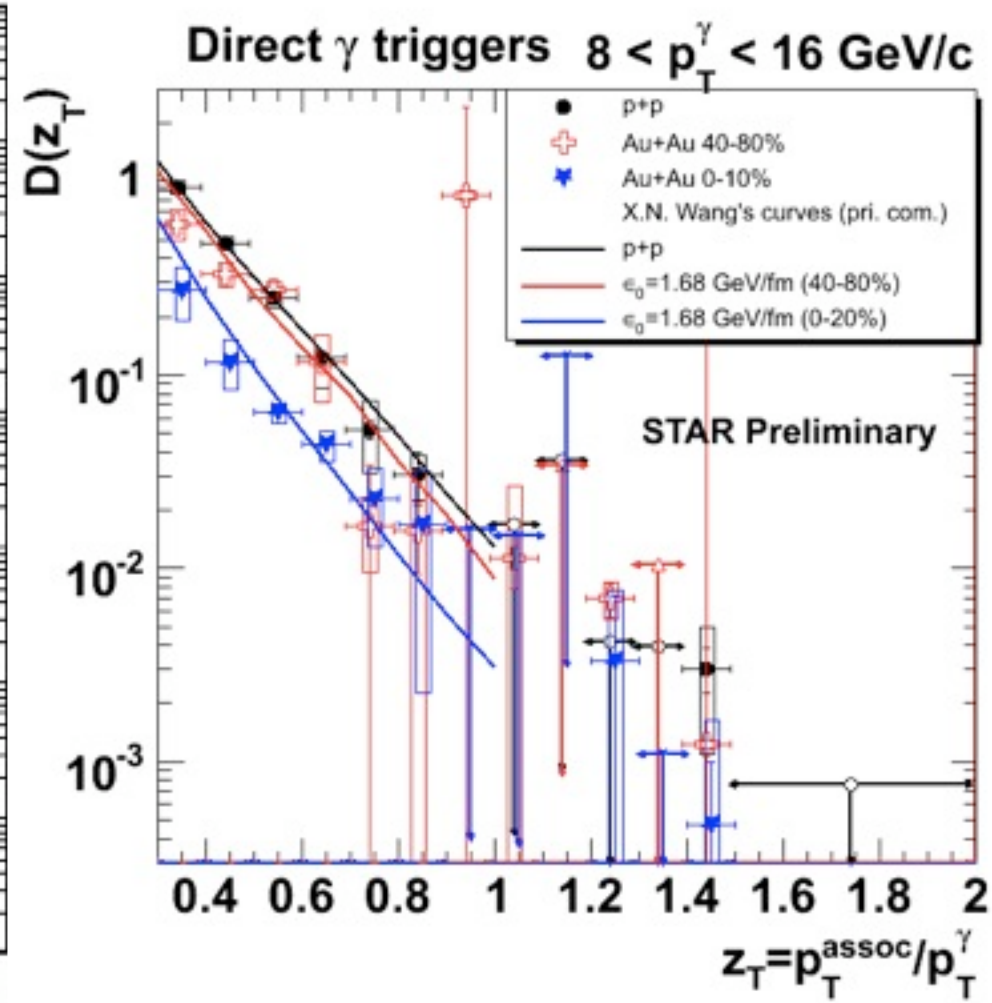
measure γ_{incl}-h:

$$Y_{\gamma_{incl}-h} = \frac{N_{direct}}{N_{incl}} Y_{\gamma_{direct}-h} + \frac{N_{decay}}{N_{incl}} Y_{\gamma_{decay}-h}$$

	PHENIX	STAR
$R_\gamma = 1 + N_{direct} / N_{decay}$	measured γ_{direct} spectra (PRL 232301 (2005))	adjusted by requiring no near side yield
γ_{decay}-h	π^0-h + Monte Carlo π^0 decay kinematics	π^0-h (merged π^0s identified w/ shower shape cut)

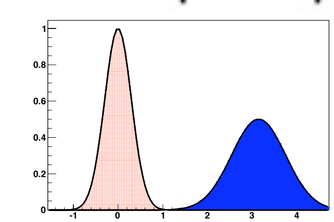
γ-h: away side suppression



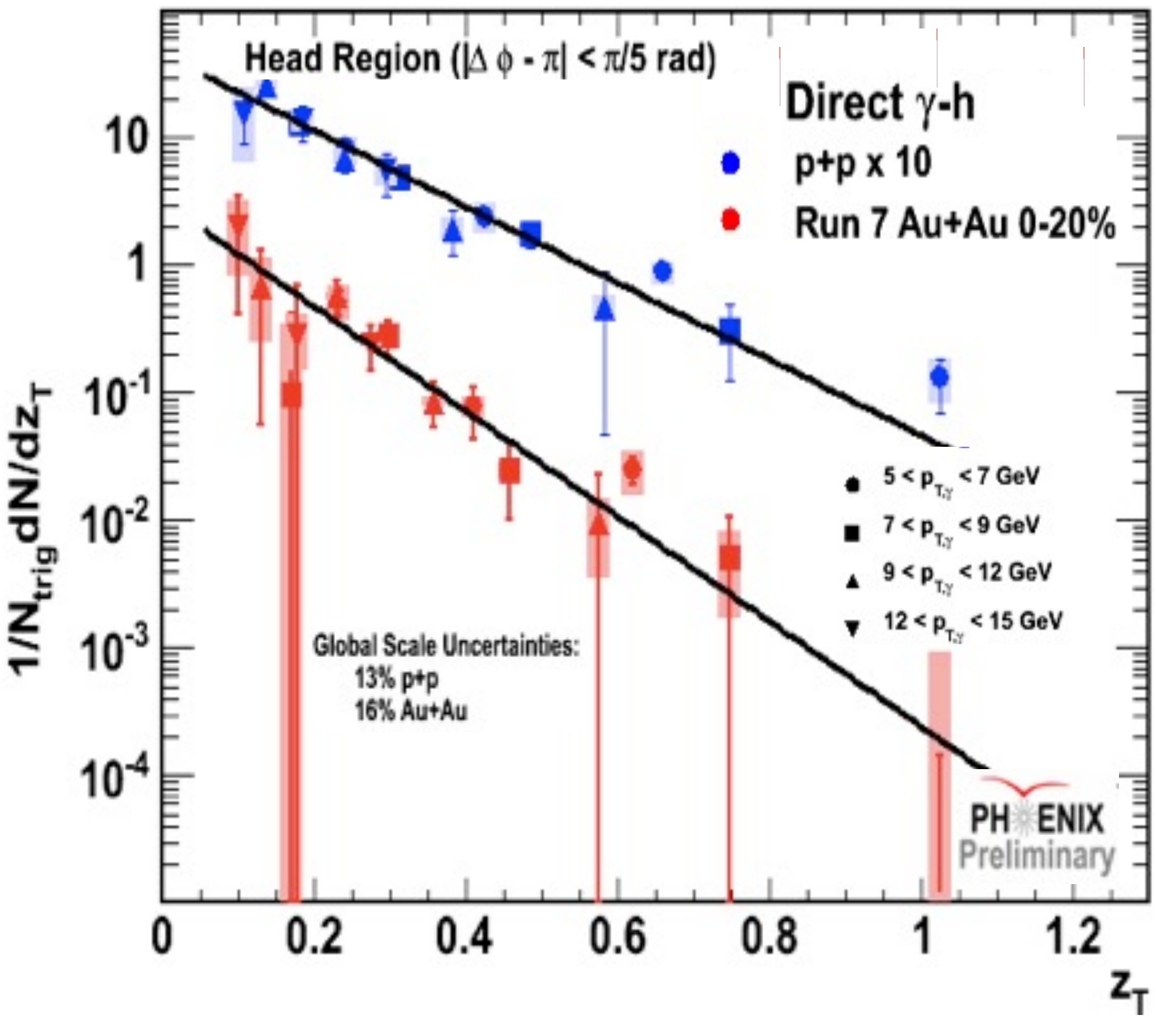


$z_T = p_{T,hadron} / p_{T, trig}$

γ_{dir}: $p_{T,trig} \sim p_{T,jet}$

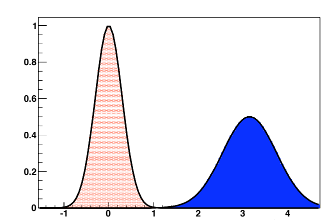


in medium fragmentation function

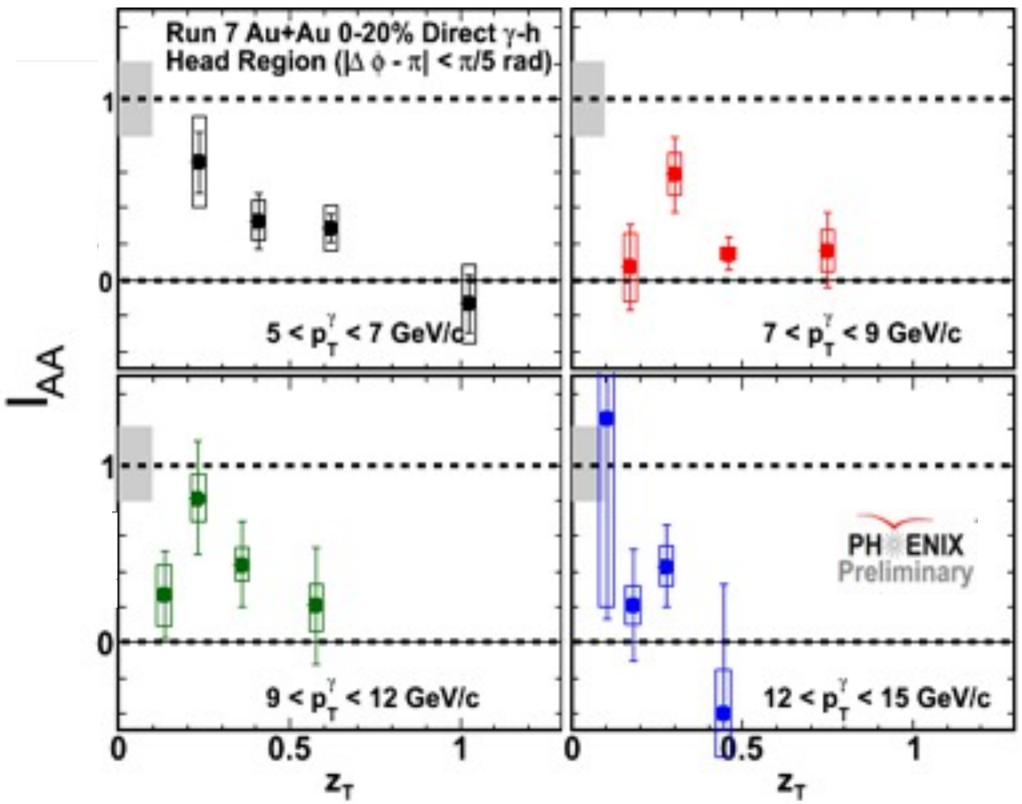


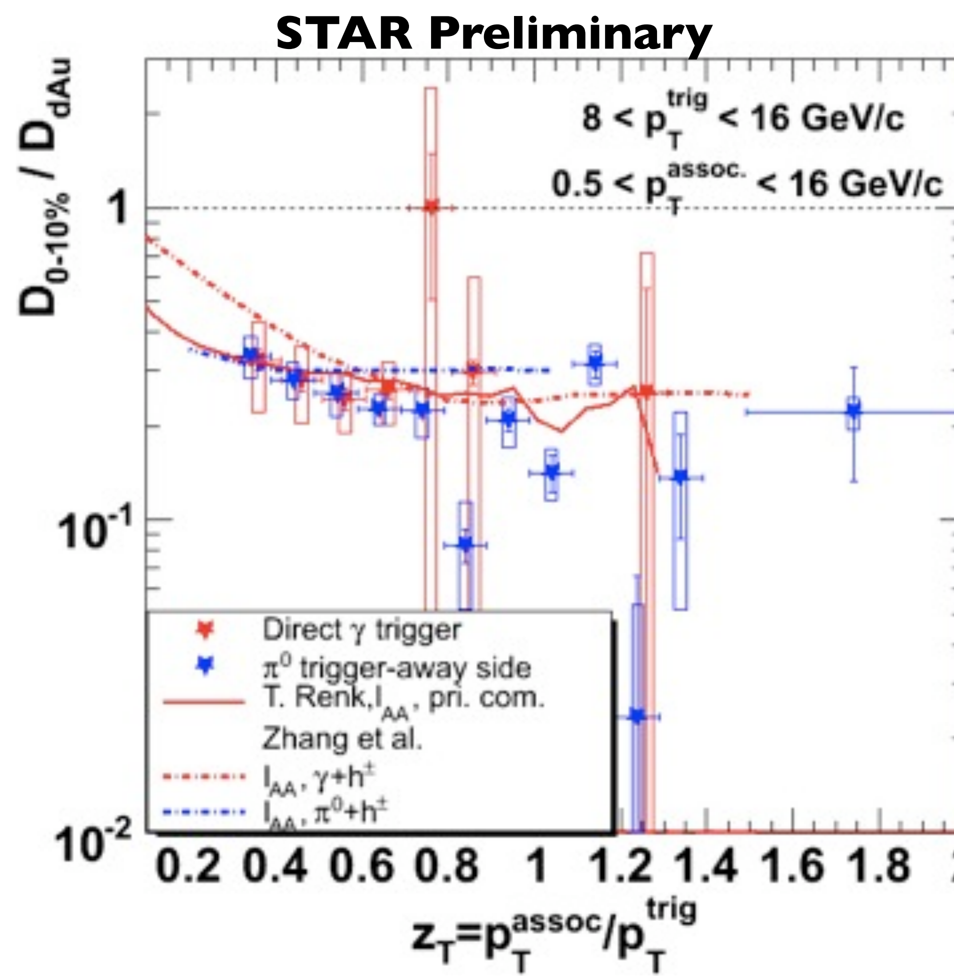
$$\frac{dN}{dz_T} = Ne^{-bz_T}$$

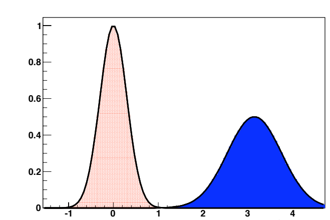
- p+p: b= 6.89 ± 0.64
  - consistent with quark fragmentation (b=8)
- Au+Au: b = 9.49 ± 1.37



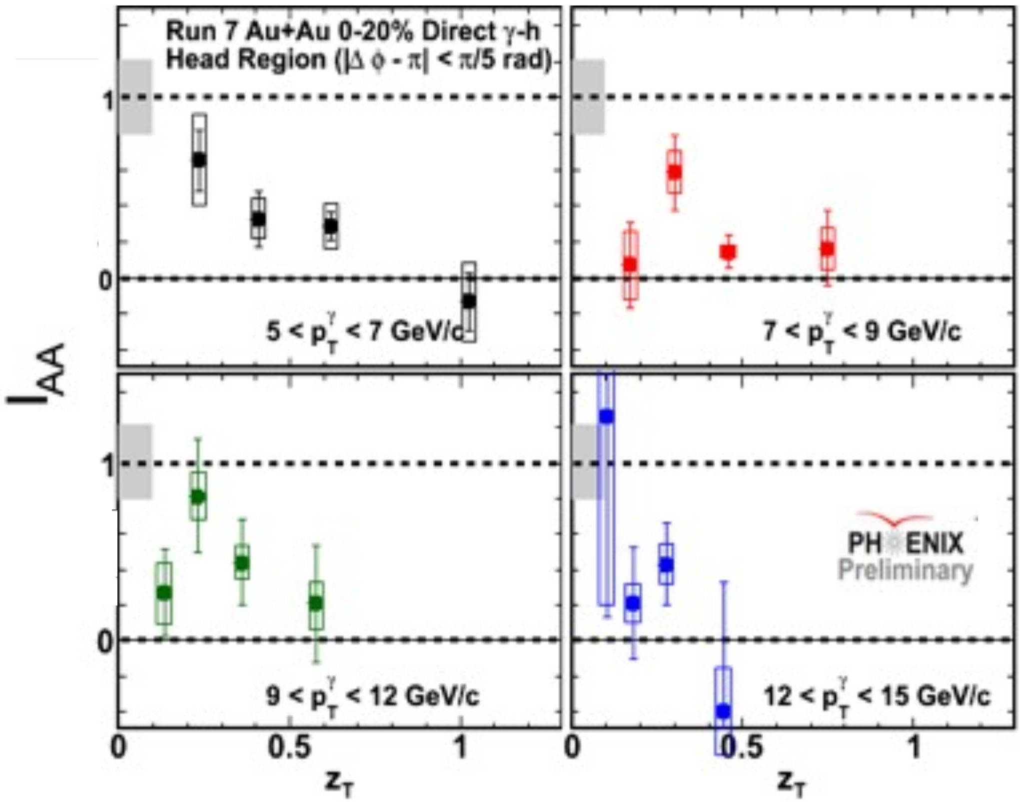
γ_{direct}-h: Au+Au

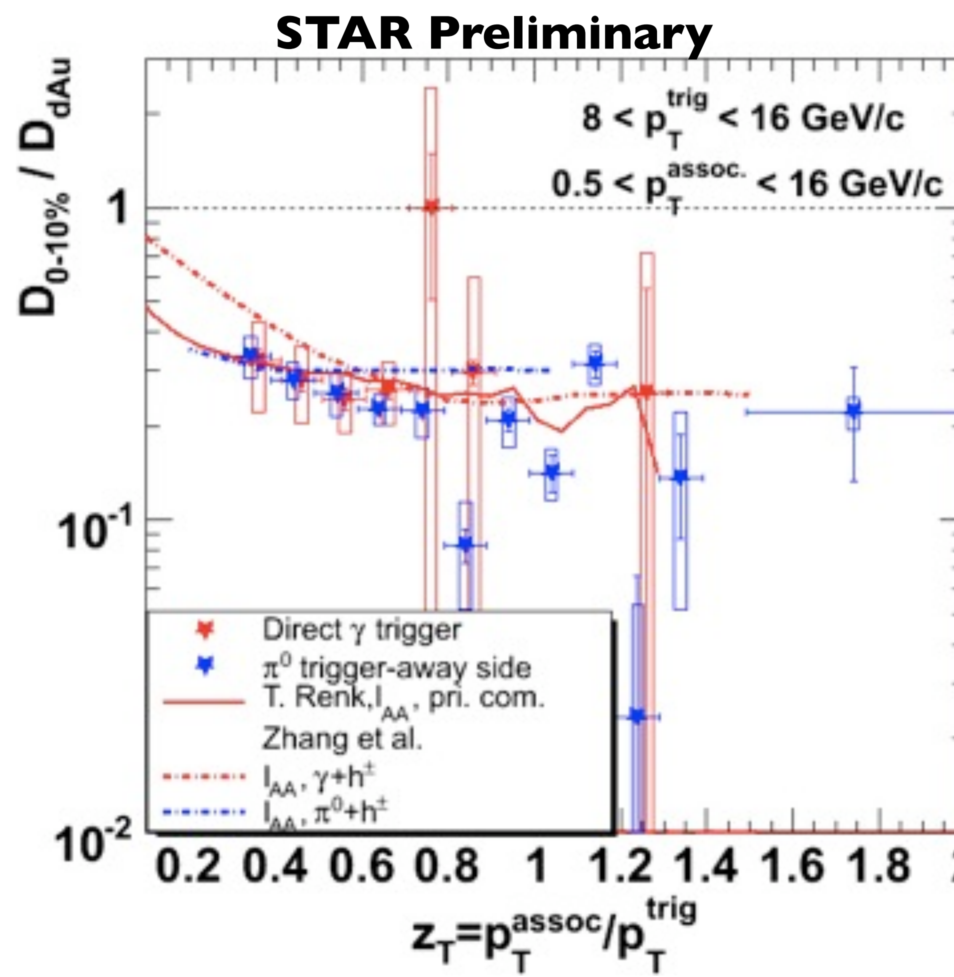




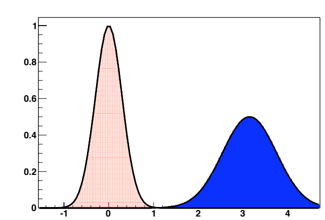


γ_{direct}-h: Au+Au

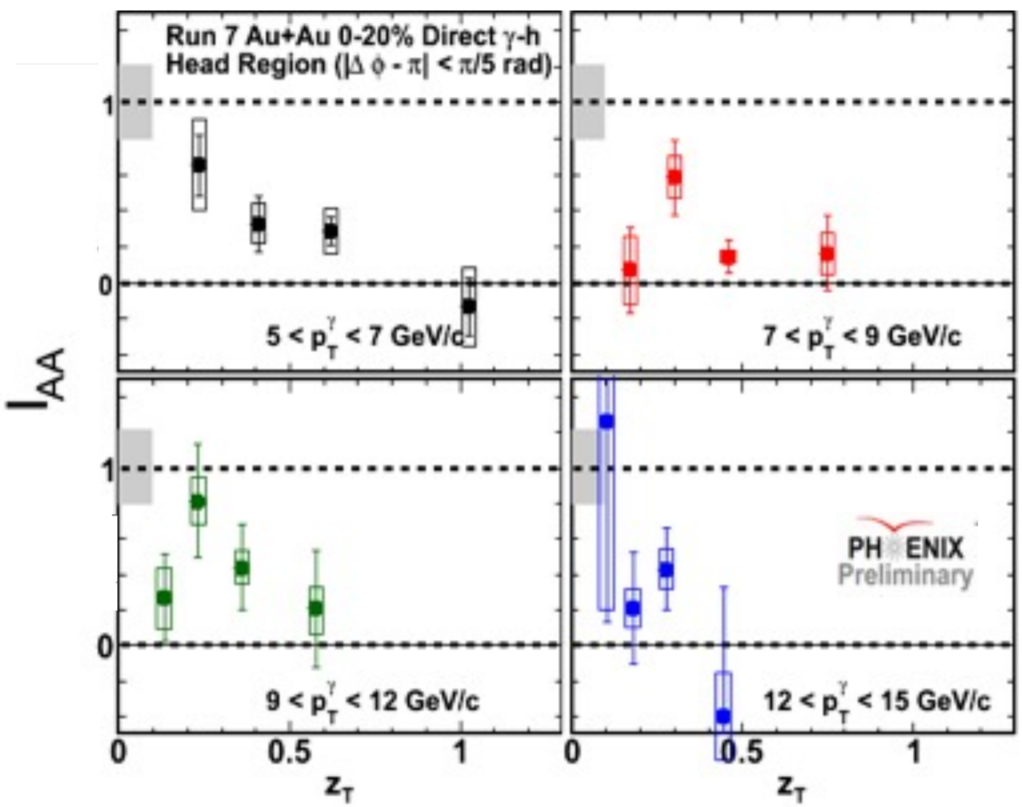


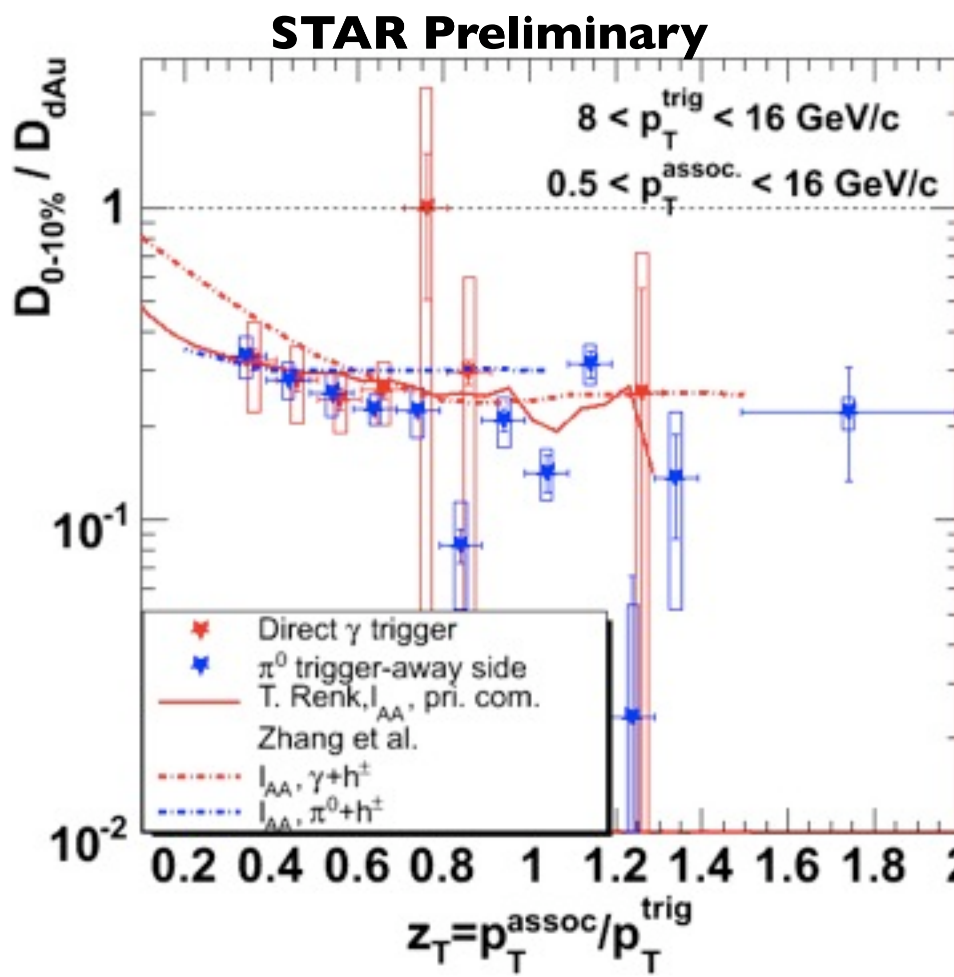


- I_{AA} nearly flat with z_T

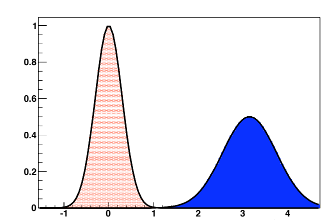


γ_{direct}-h: Au+Au

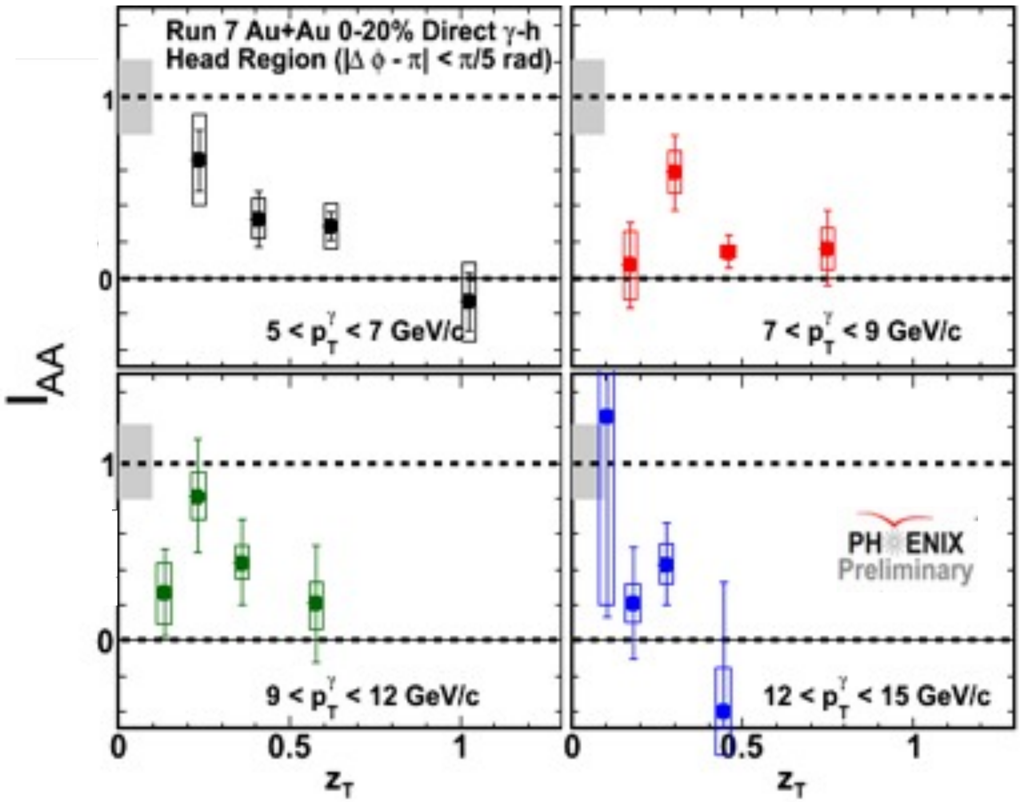


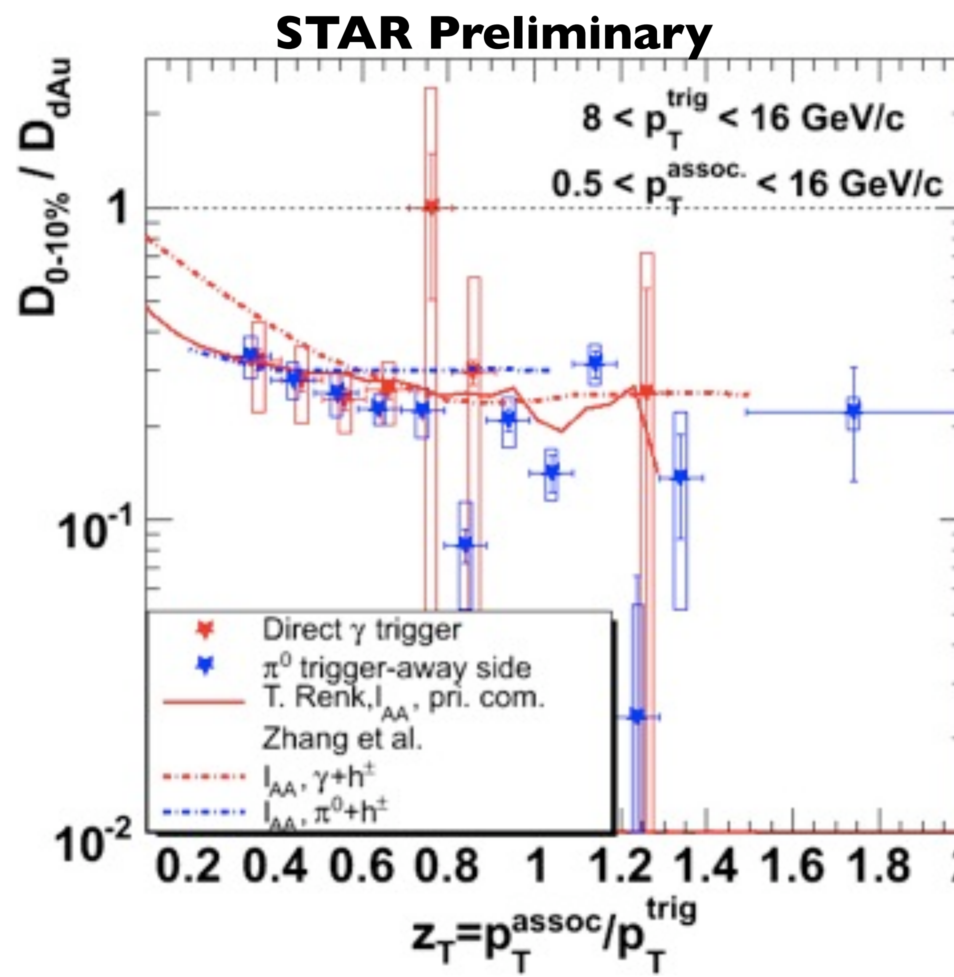


- I_{AA} nearly flat with z_T
- slight softening at lower z_T

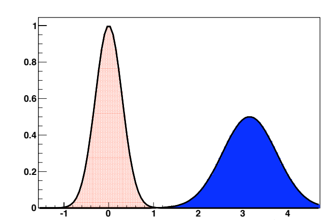


γ_{direct}-h: Au+Au

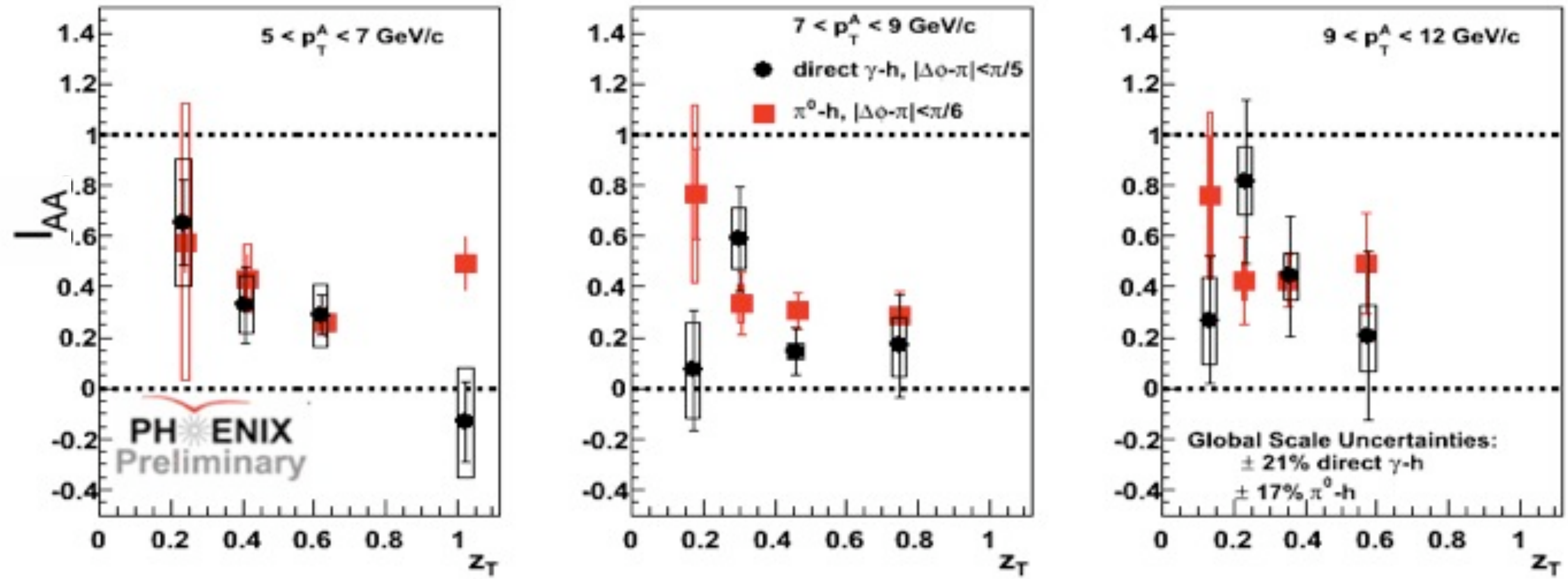


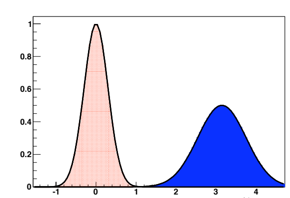


- I_{AA} nearly flat with z_T
- slight softening at lower z_T
  - better low z_T data needed

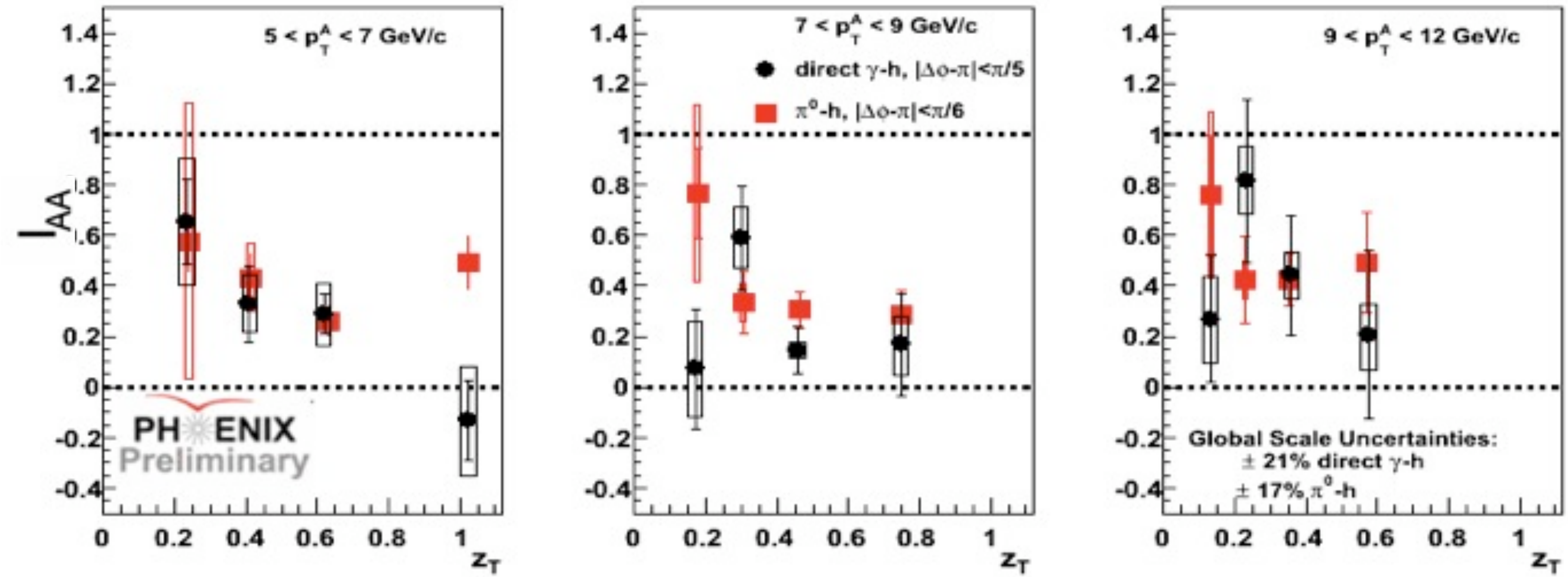


I_{AA}: π^0-h & γ_{direct}-h

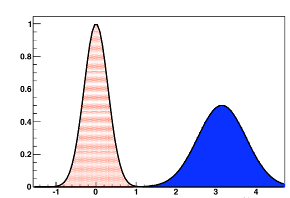




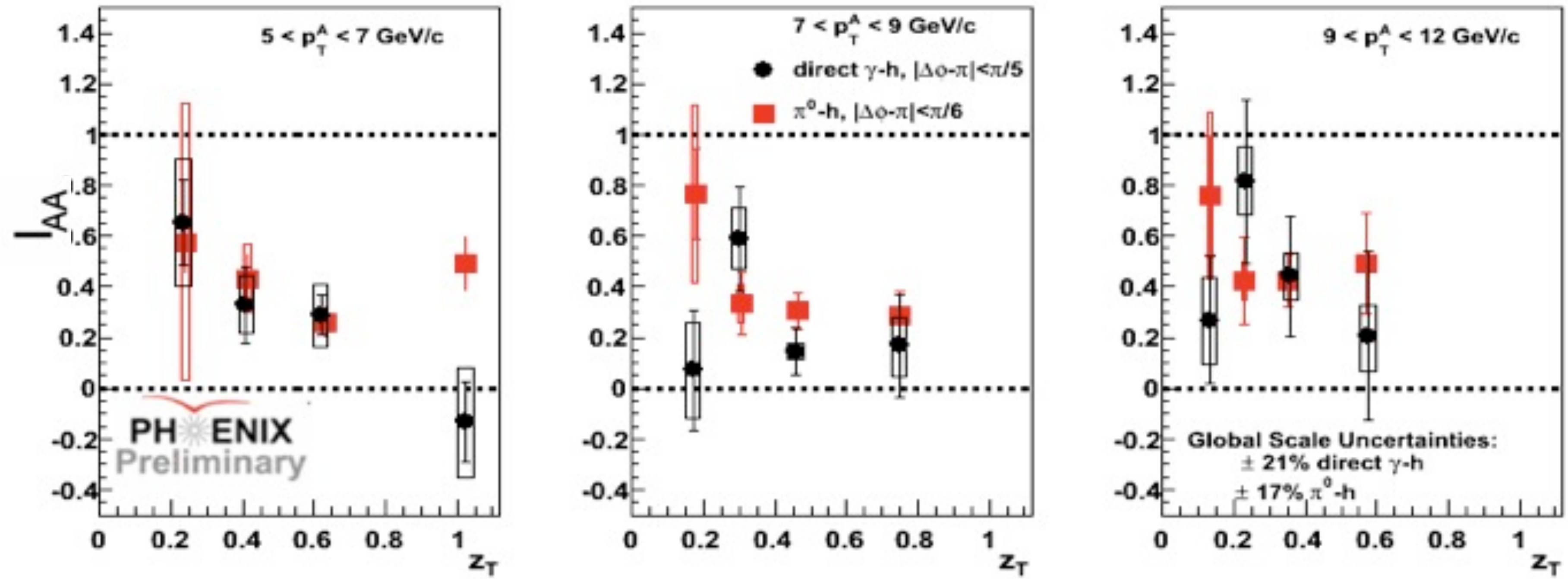
I_{AA}: π^0-h & γ_{direct}-h



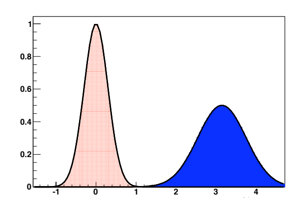
- no significant difference between π^0-h and γ_{dir}-h suppression



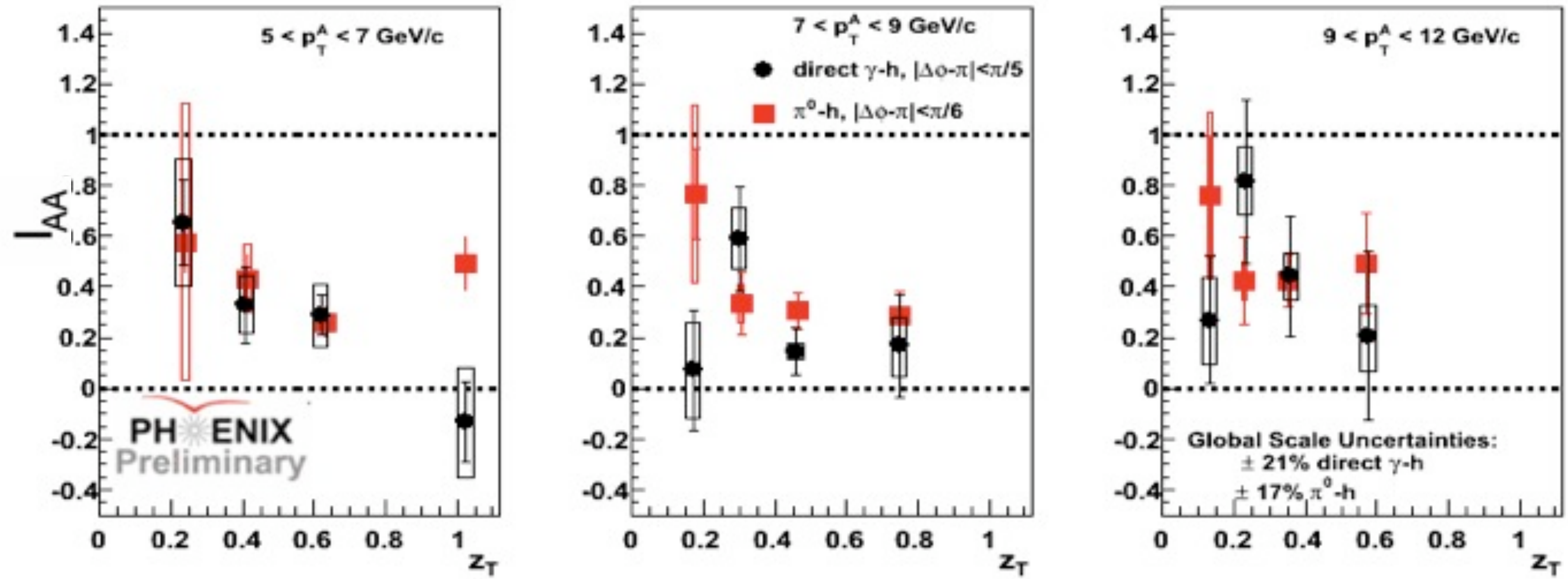
I_{AA}: π^0-h & γ_{direct}-h



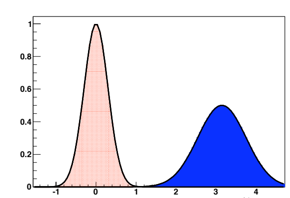
- no significant difference between π^0-h and γ_{dir}-h suppression
  - just how important is the π^0 surface bias?



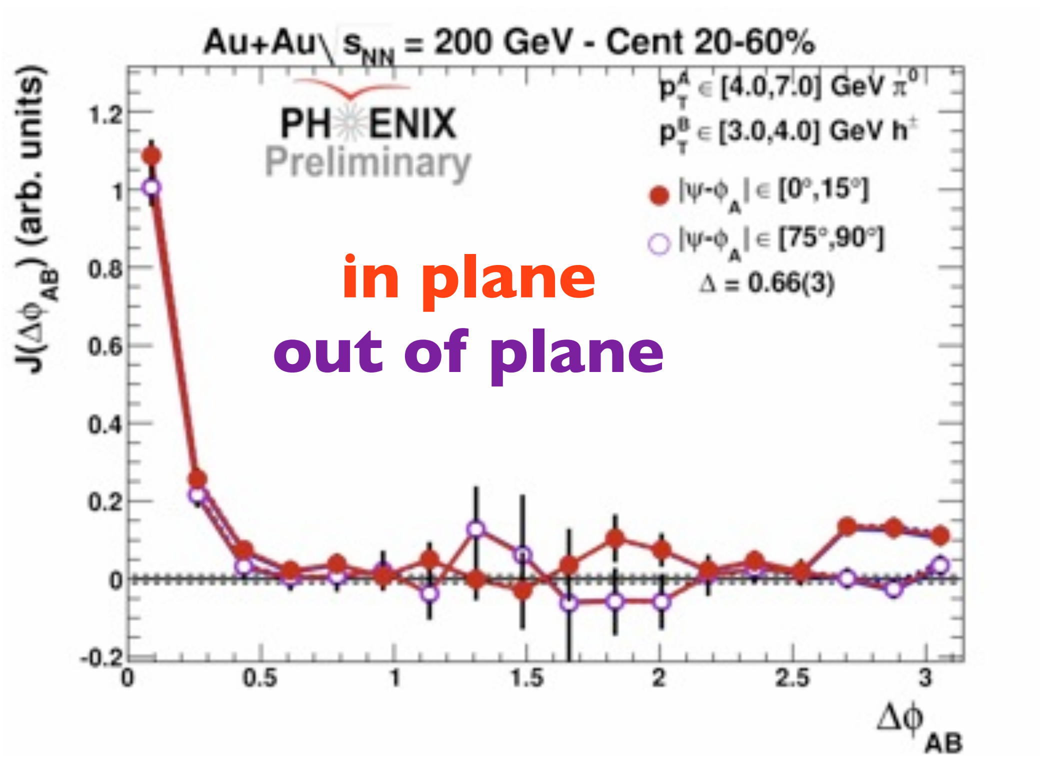
I_{AA}: π^0-h & γ_{direct}-h

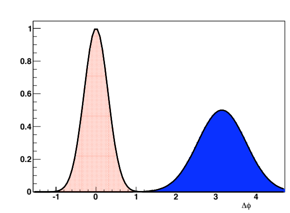


- no significant difference between π^0-h and γ_{dir}-h suppression
  - just how important is the π^0 surface bias?
- z_T>1 is potentially very interesting, not allowed at leading order

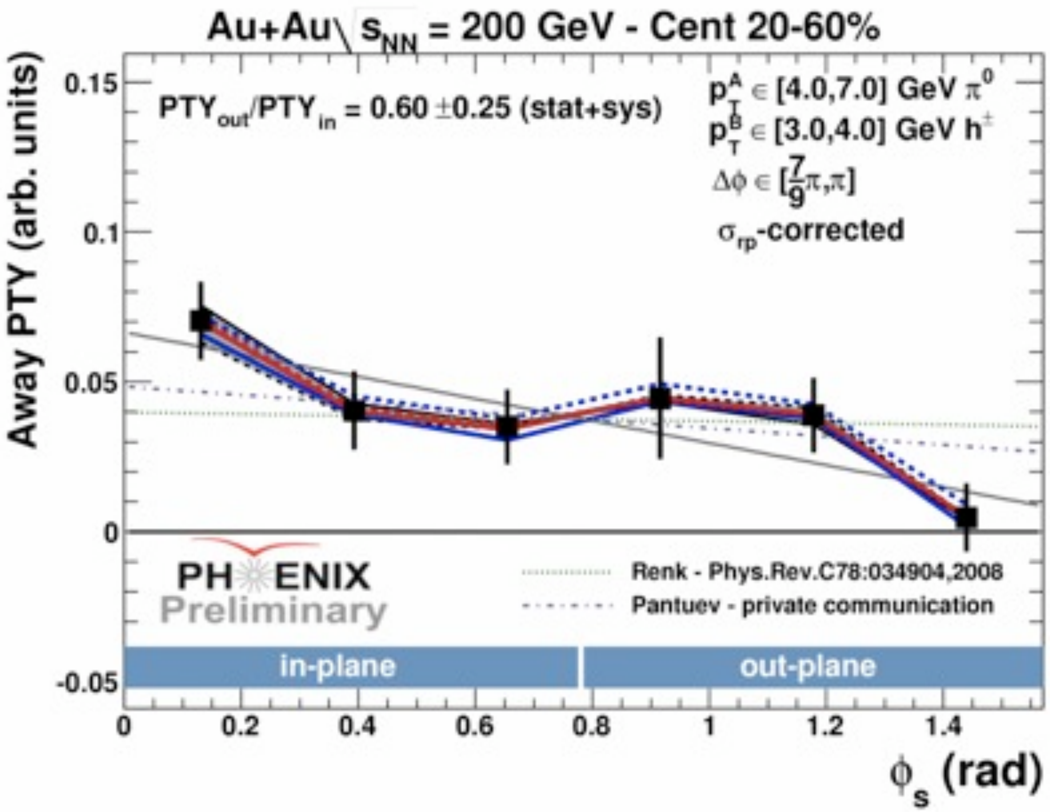


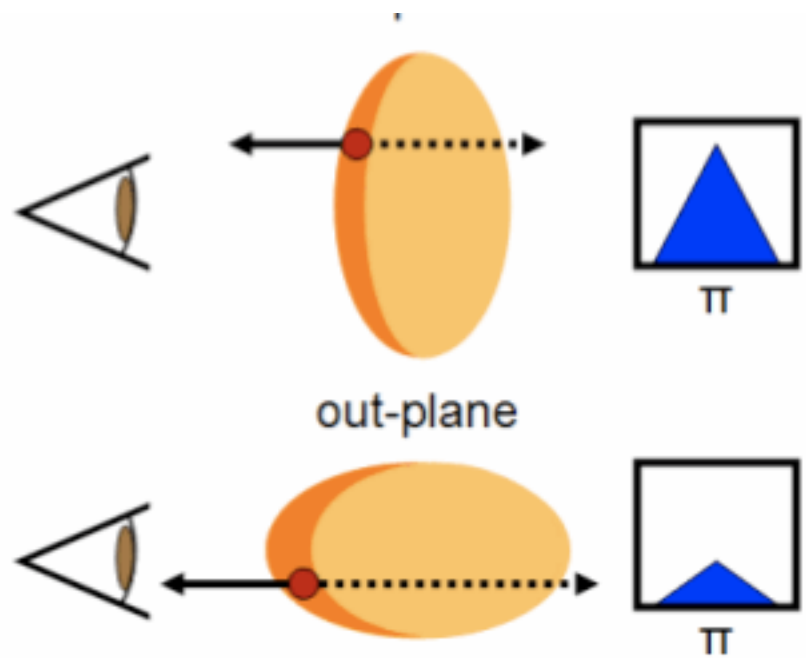
π^0-h: varying the geometry

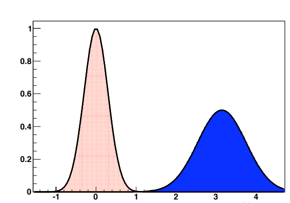




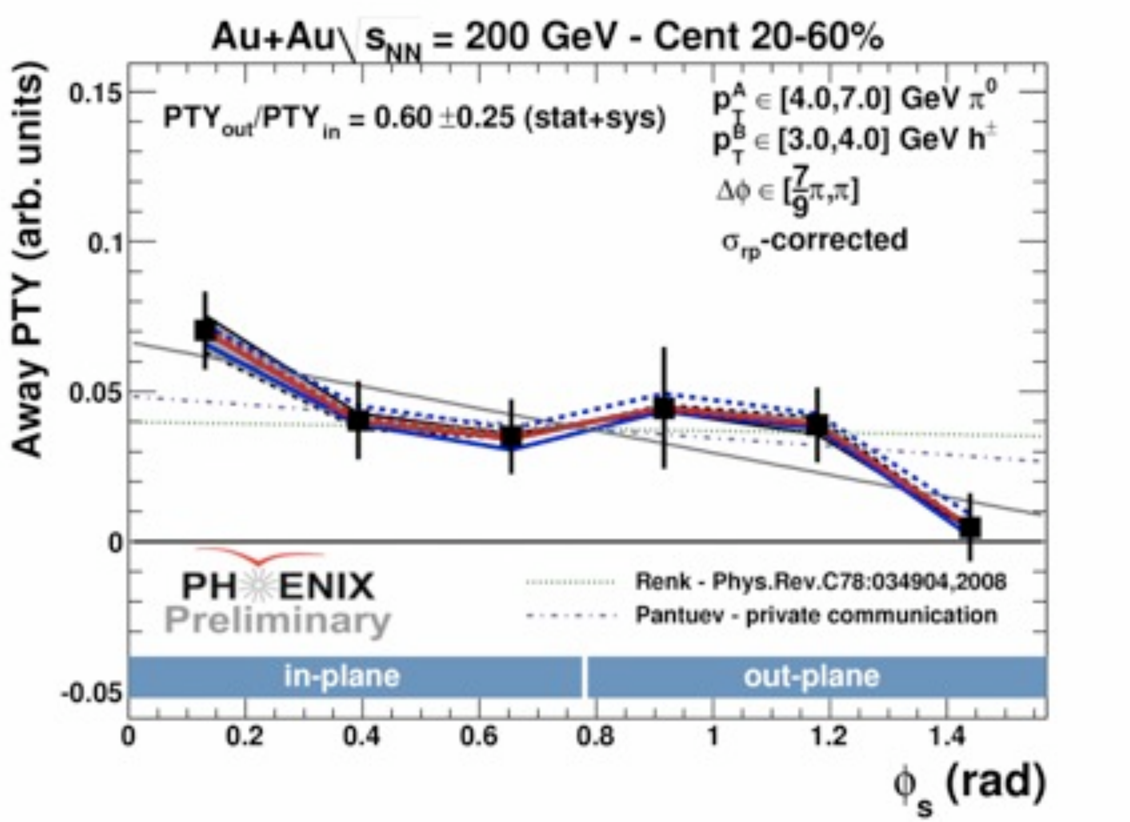
π^0-h: varying the geometry

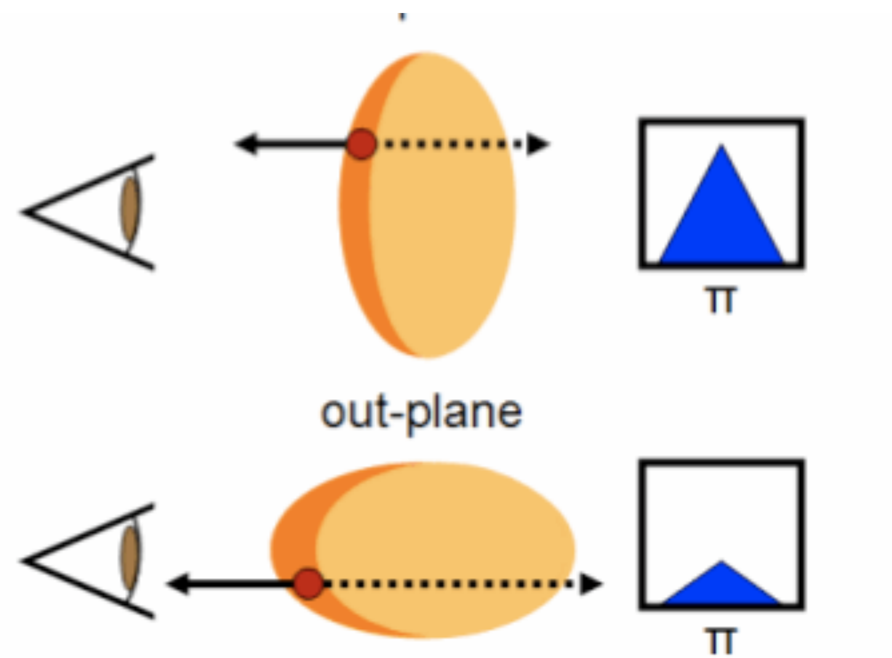




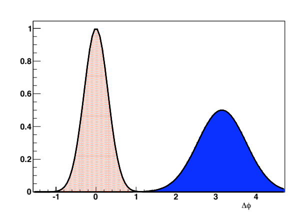


π^0-h: varying the geometry

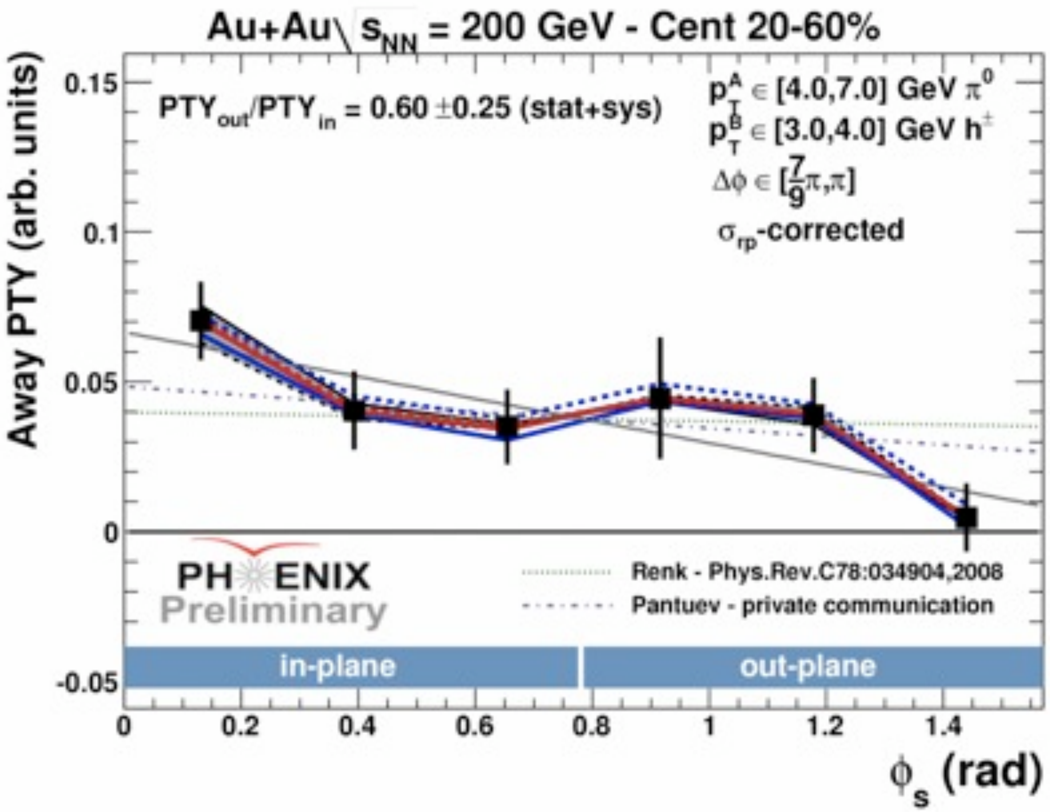


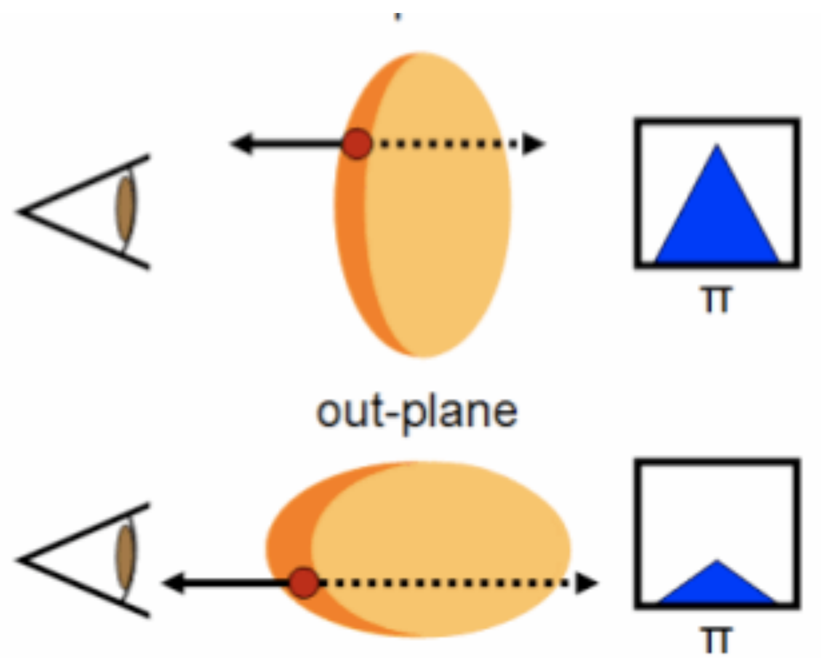


- high p_T di-jet cross the nuclear overlap

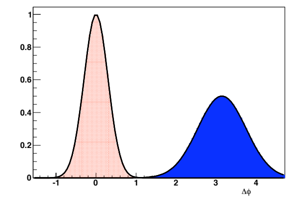


π^0-h: varying the geometry

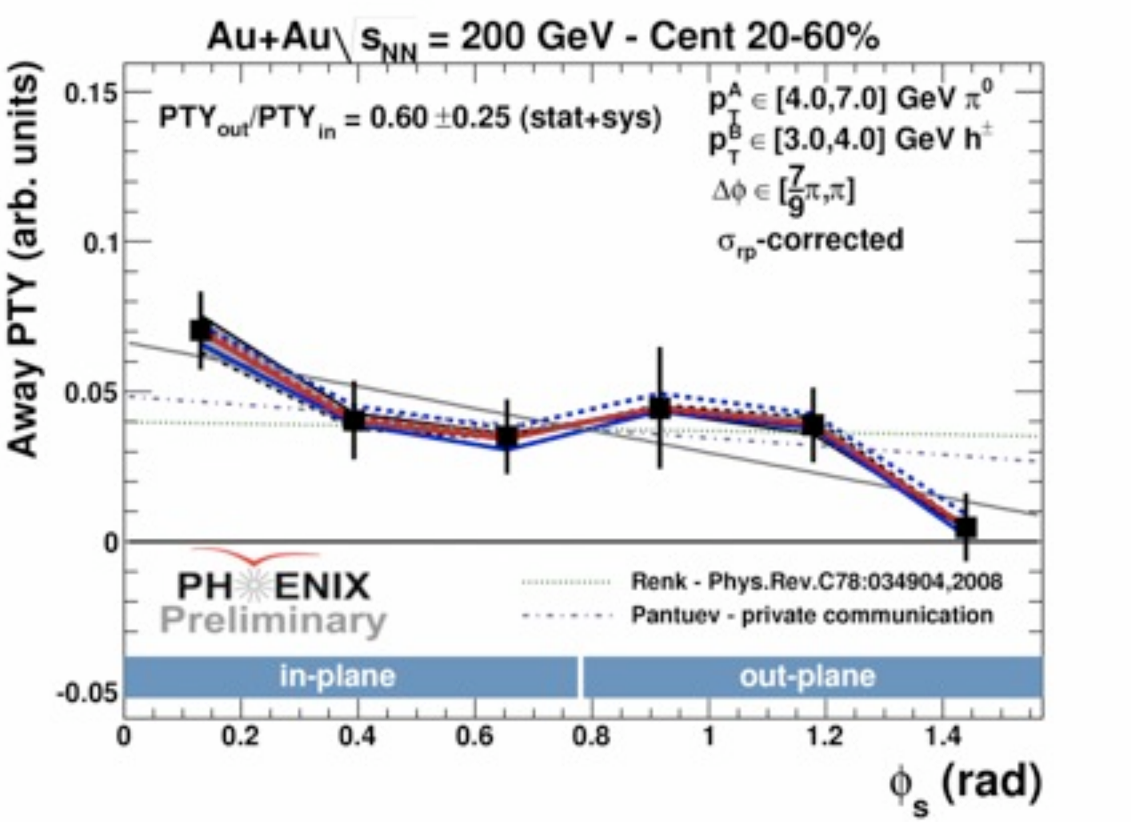


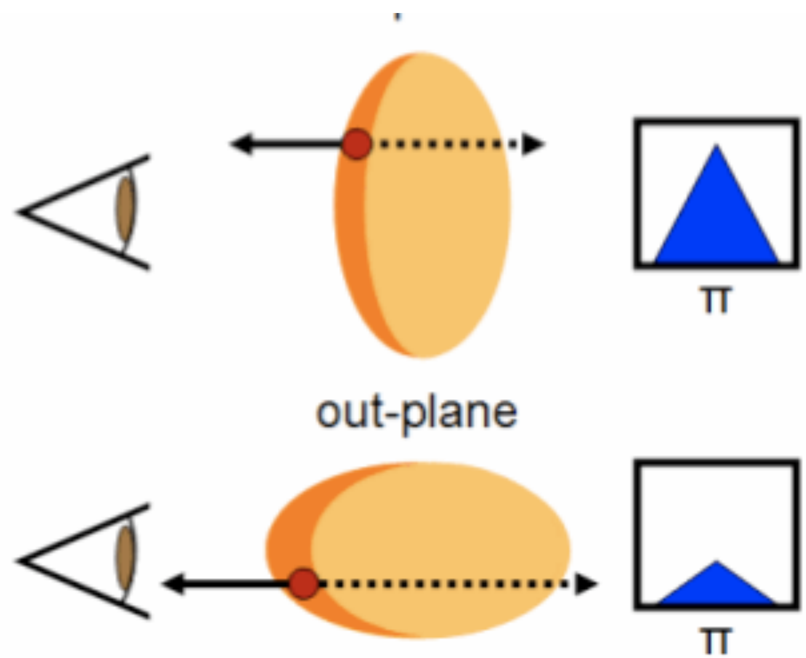


- high p_T di-jet cross the nuclear overlap
  - not a completely black core

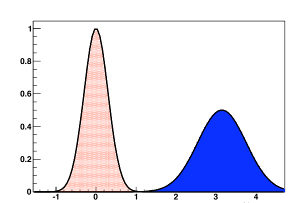


π^0-h: varying the geometry



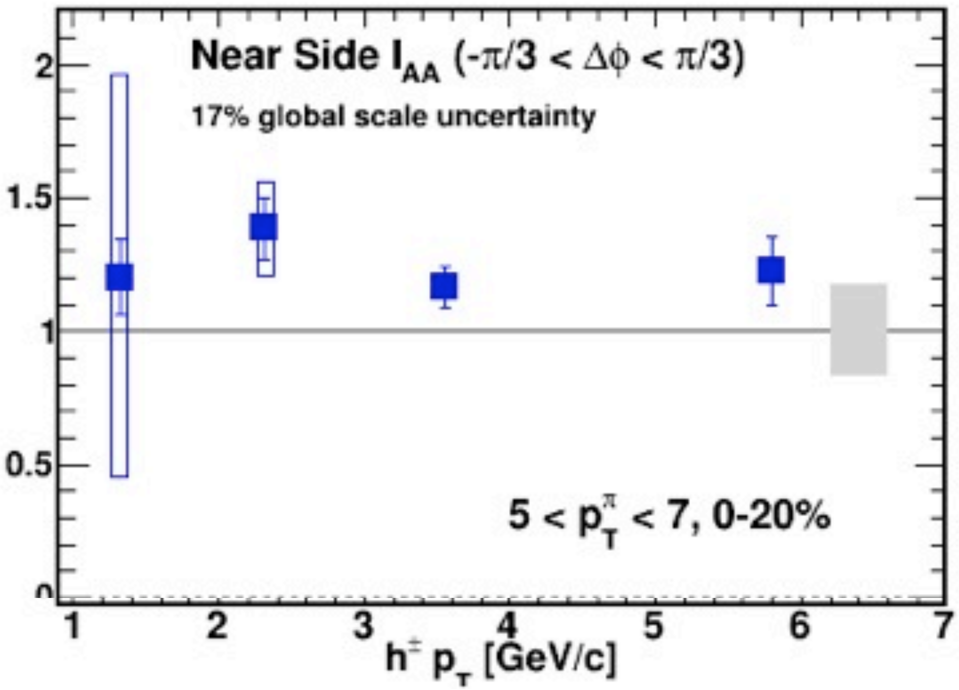


- high p_T di-jet cross the nuclear overlap
  - not a completely black core
- role of fluctuations in energy loss?

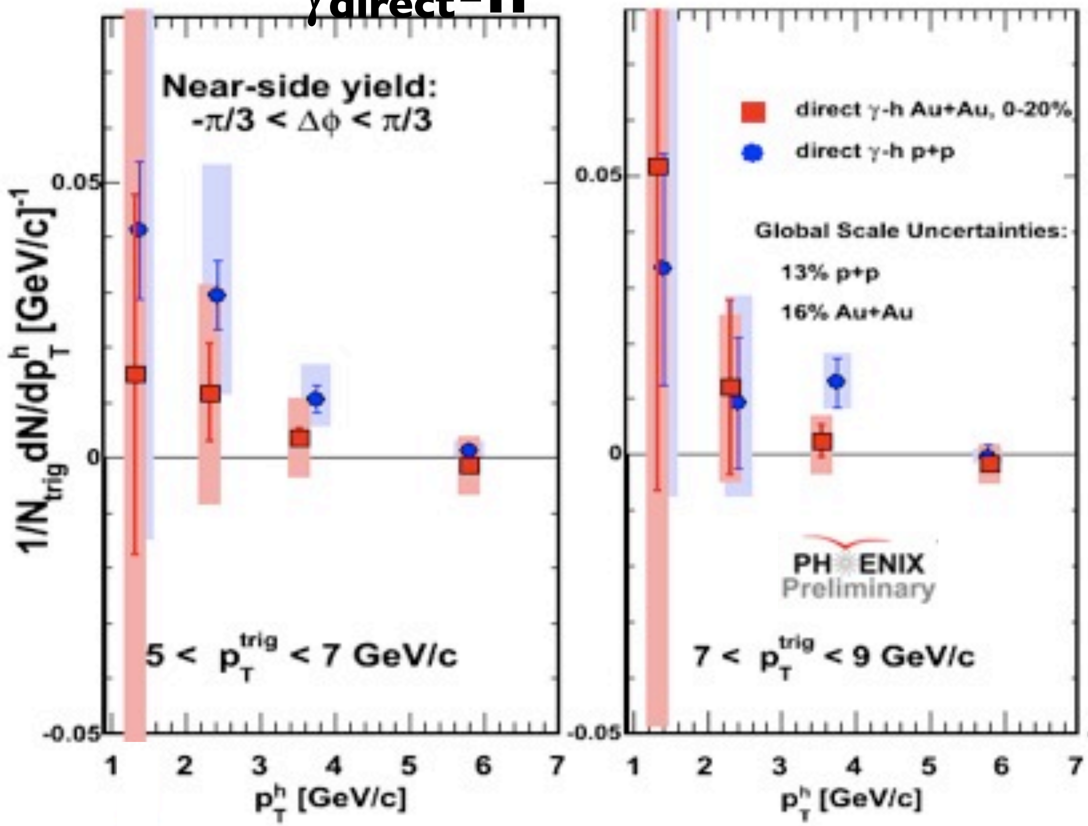


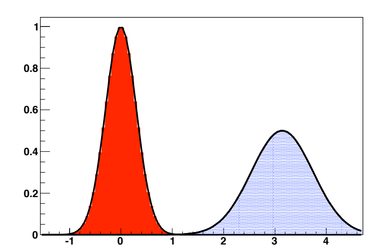
near side

π^0-h



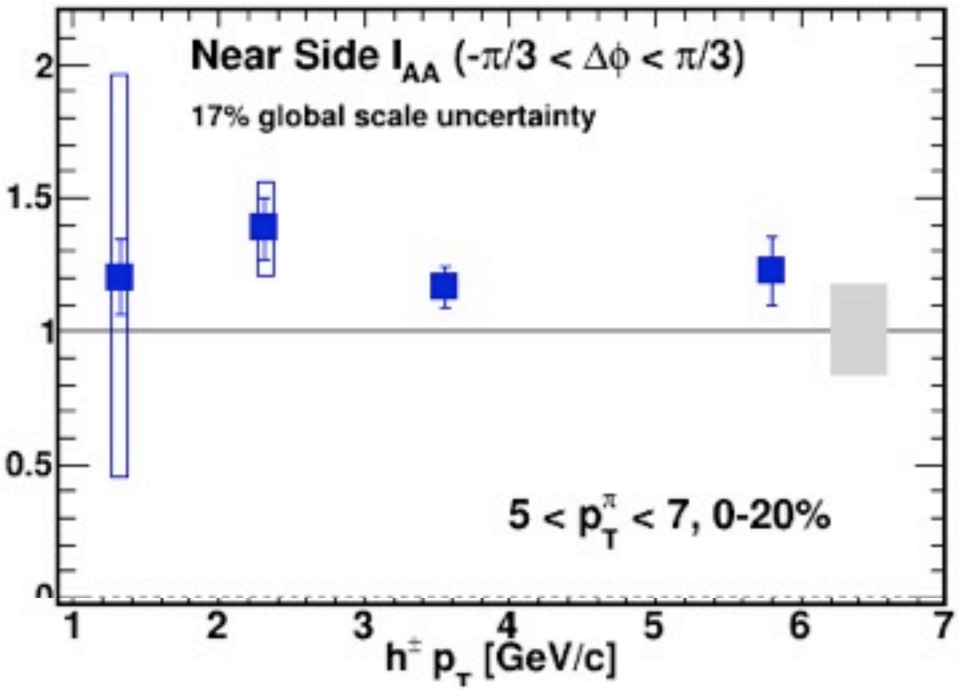
γ_{direct}-h



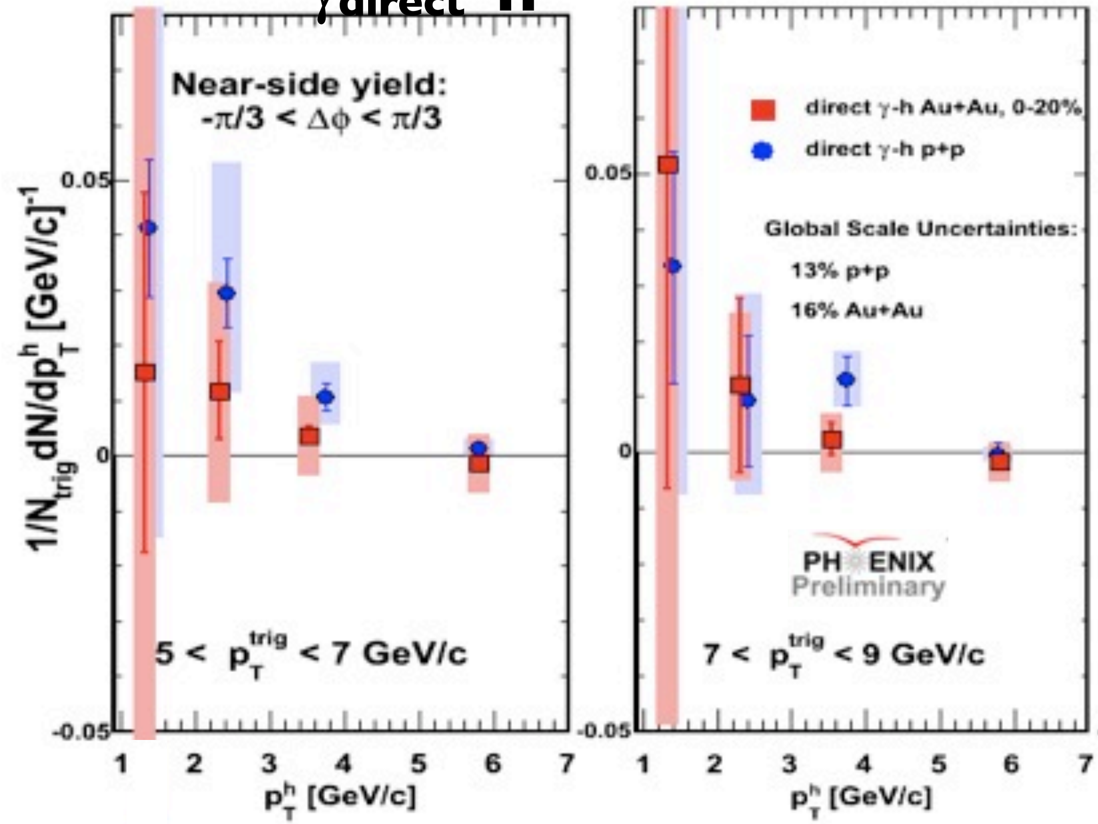


near side

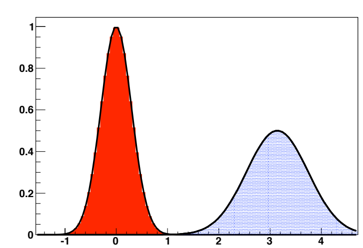
π^0-h



γ_{direct}-h

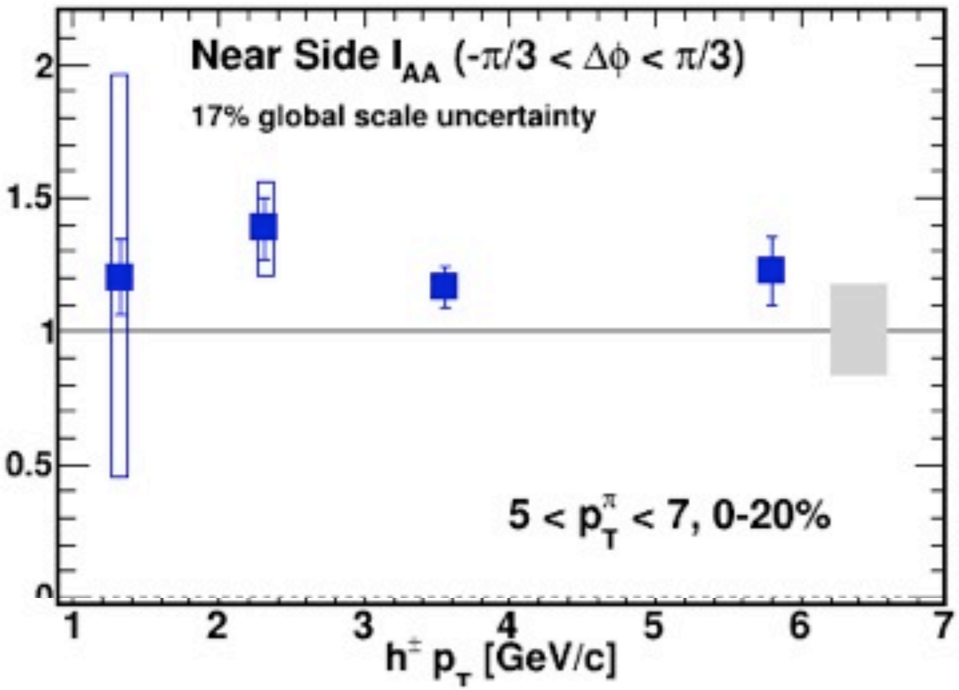


- for both π^0-h and γ_{direct}-h near side consistent between p+p and Au+Au

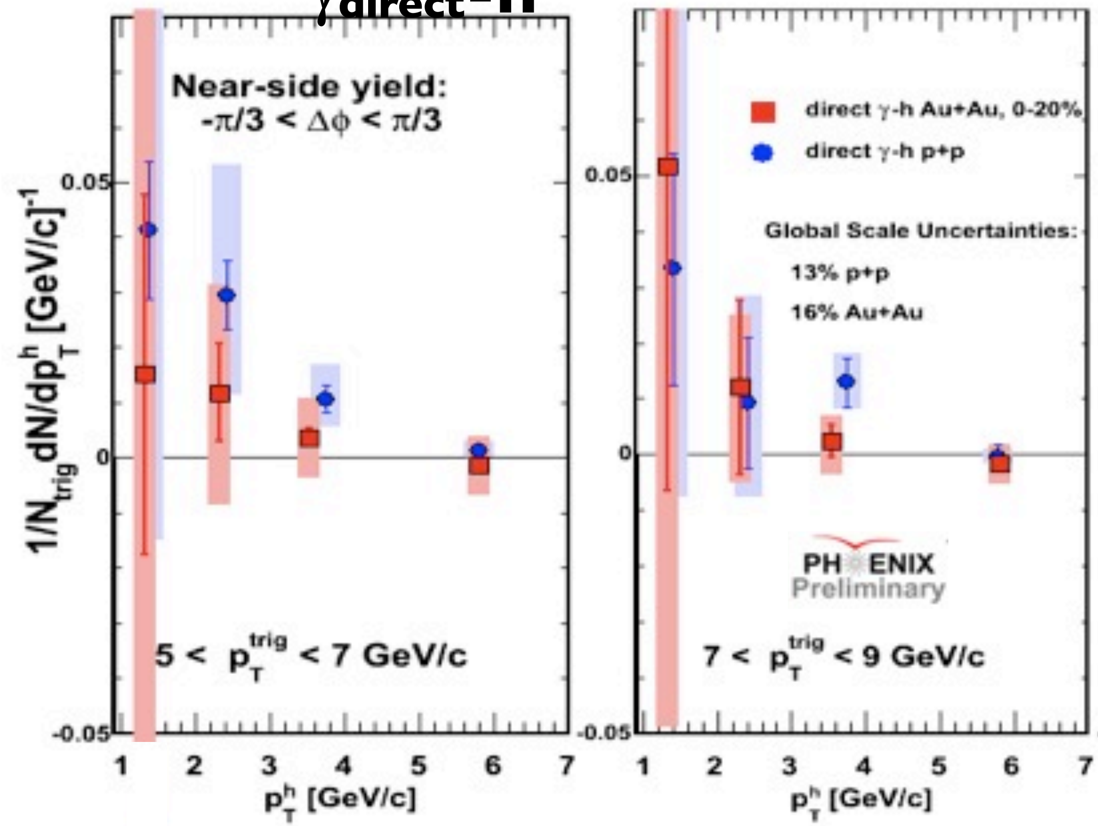


near side

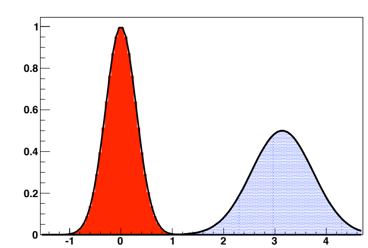
π^0-h



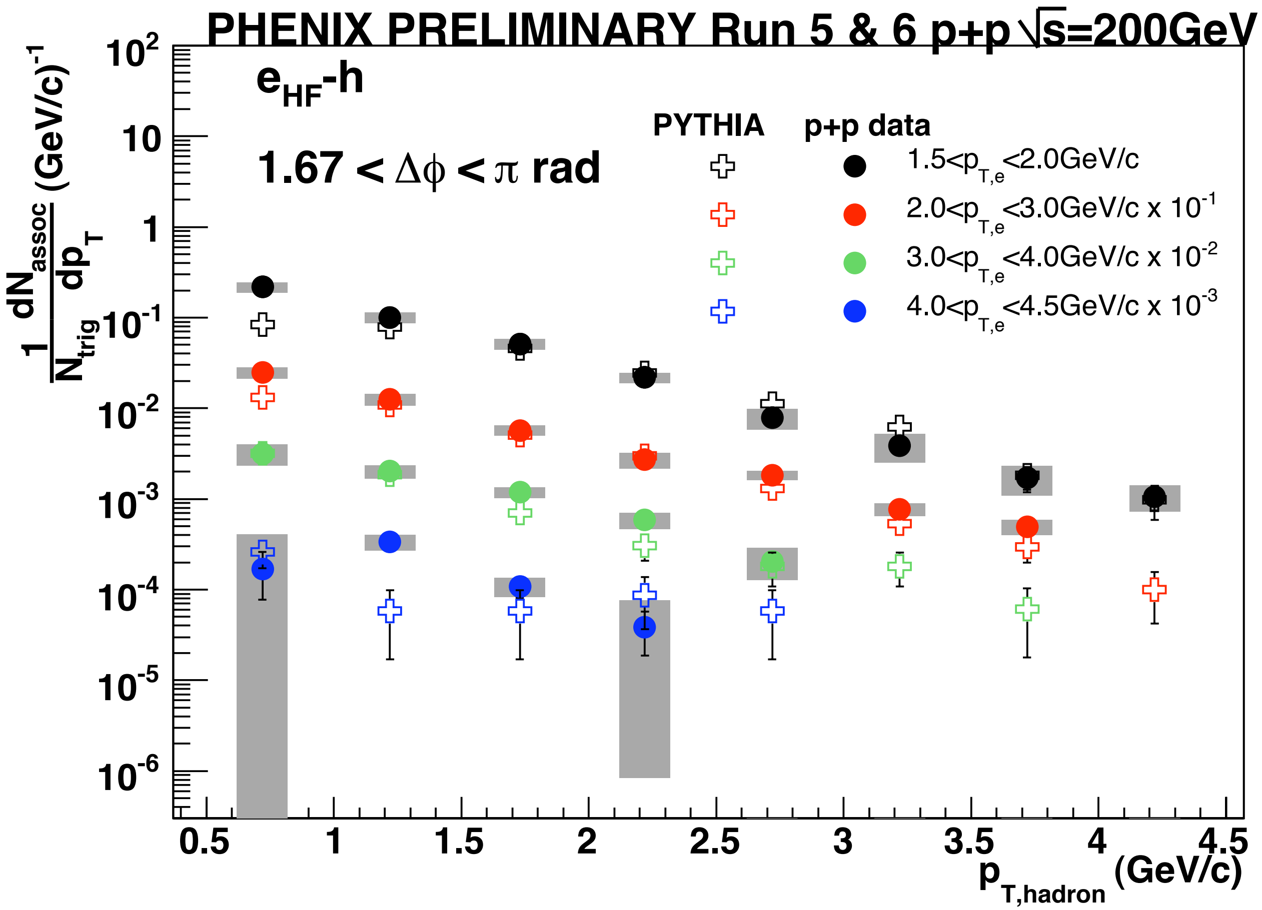
γ_{direct}-h



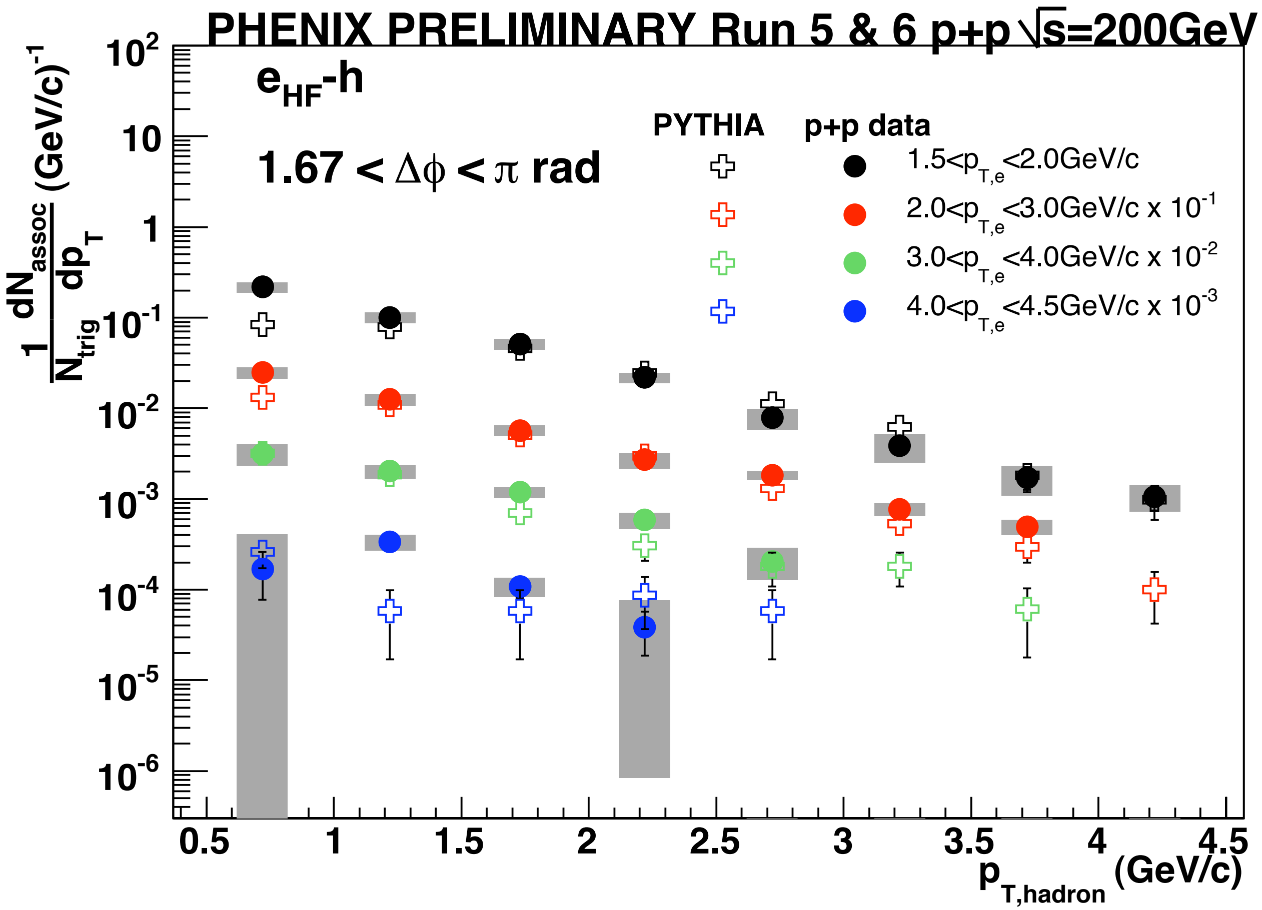
- for both π^0-h and γ_{direct}-h near side consistent between p+p and Au+Au
- room for slight excess in π^0-h

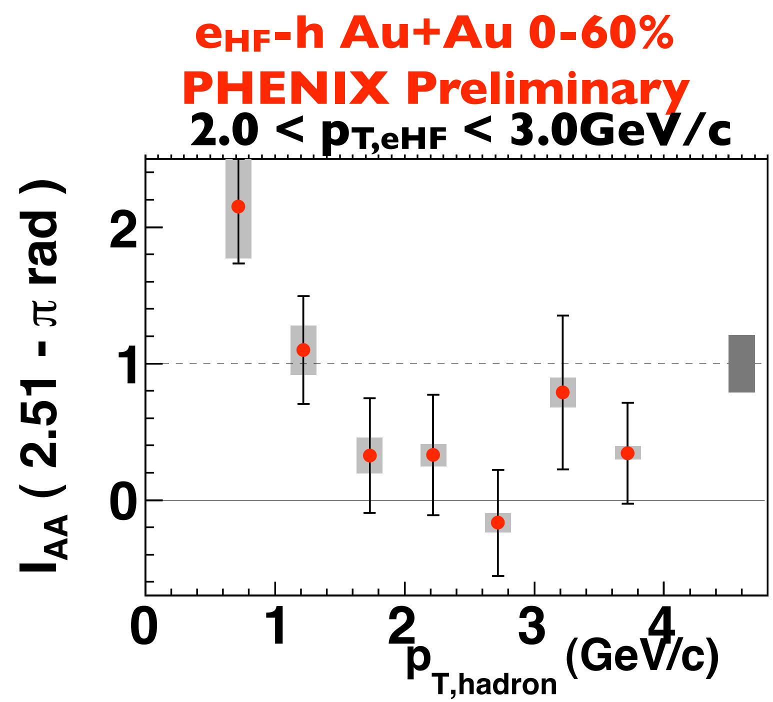


jet physics with heavy flavor

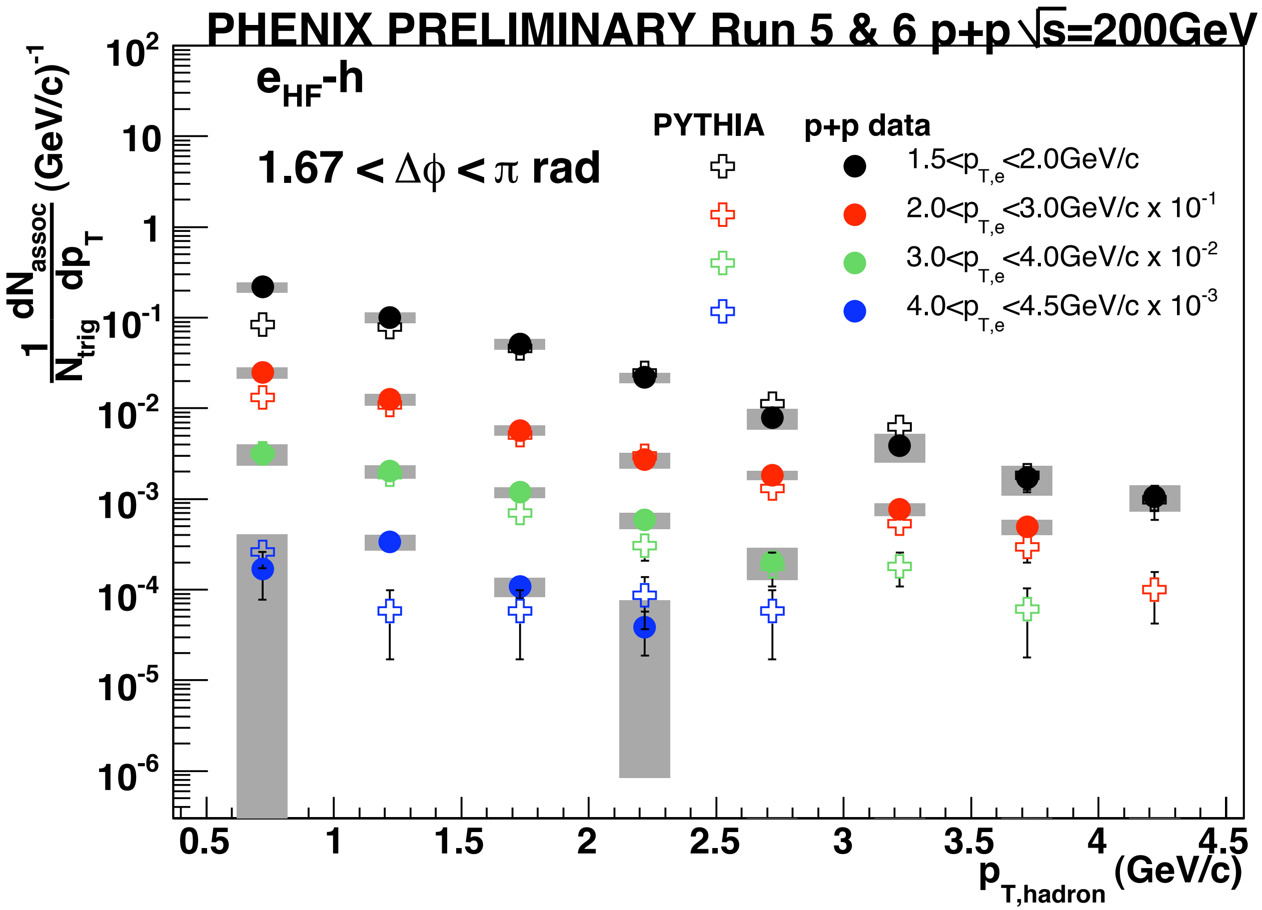


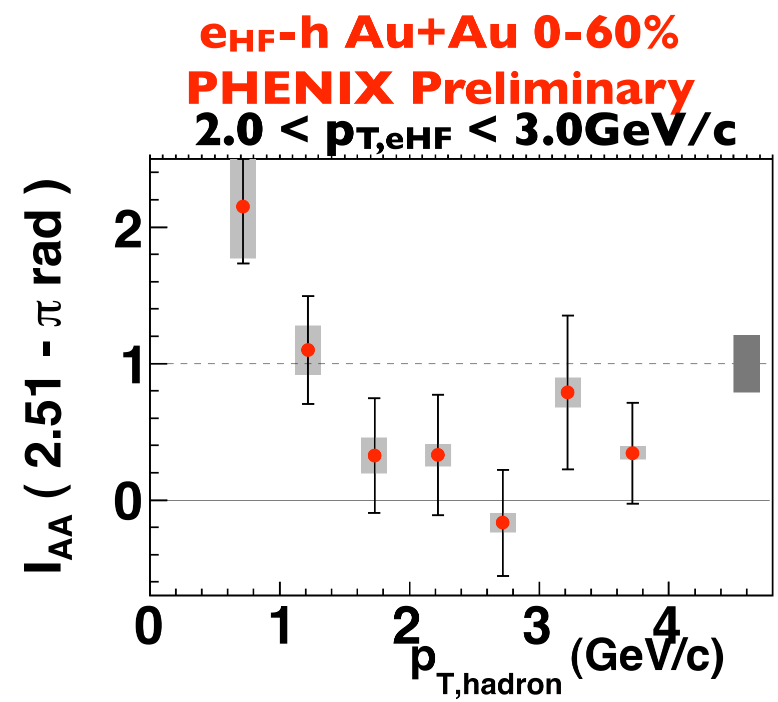
jet physics with heavy flavor





jet physics with heavy flavor



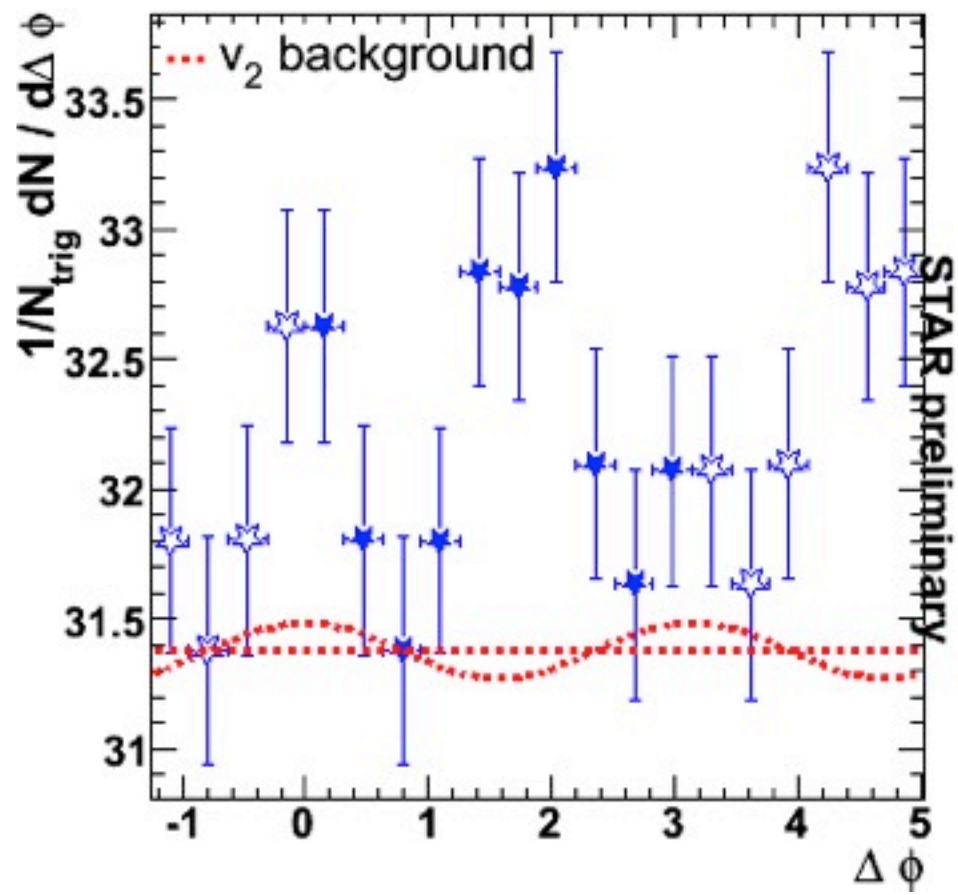


- heavy flavor tagged jet production: NLO important e_{HF} not necessarily balanced by back-to-back heavy quark

a warning!

- jet signal in heavy ion sits on a large combinatoric background
  - S/B ~ as low as1% or less
- with low statistics ZYAM has large uncertainties
- worse: biased toward downward fluctuations

Cu+Cu 0-20% eHF-h
3<p_{Te}<6GeV/c
0.15 < p_{Th} < 0.5GeV/c



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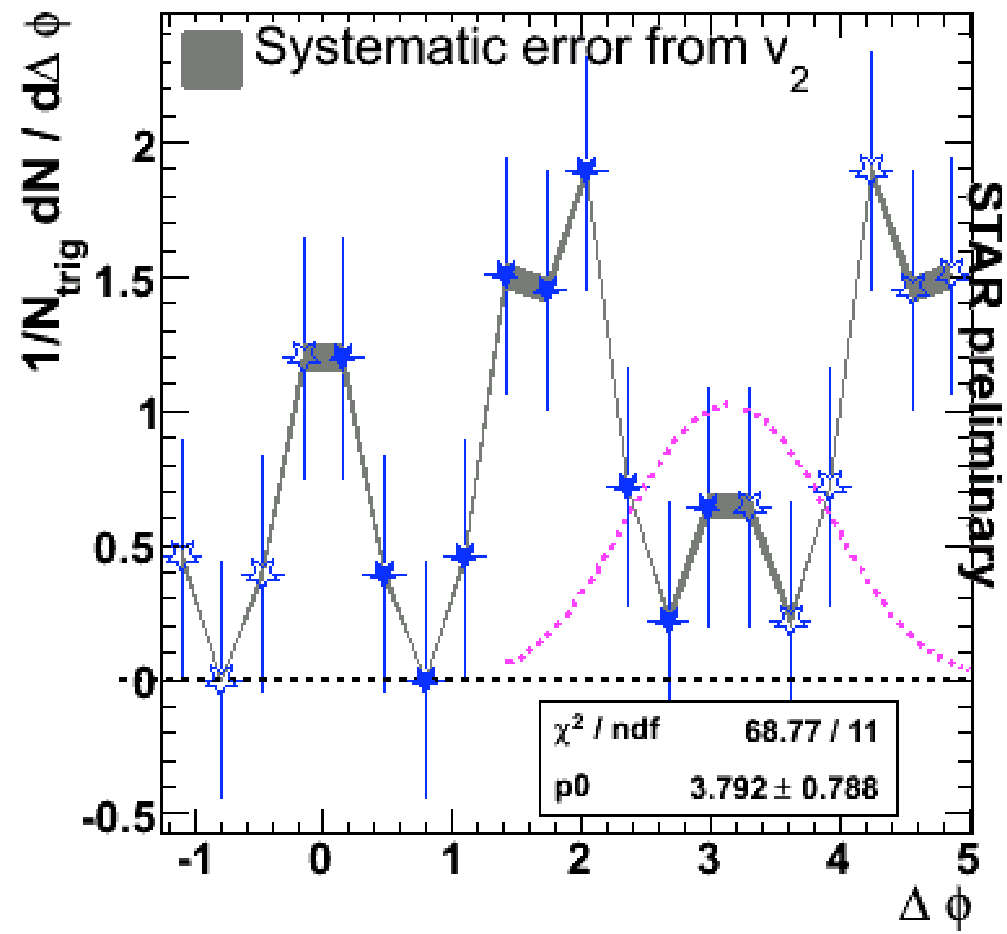

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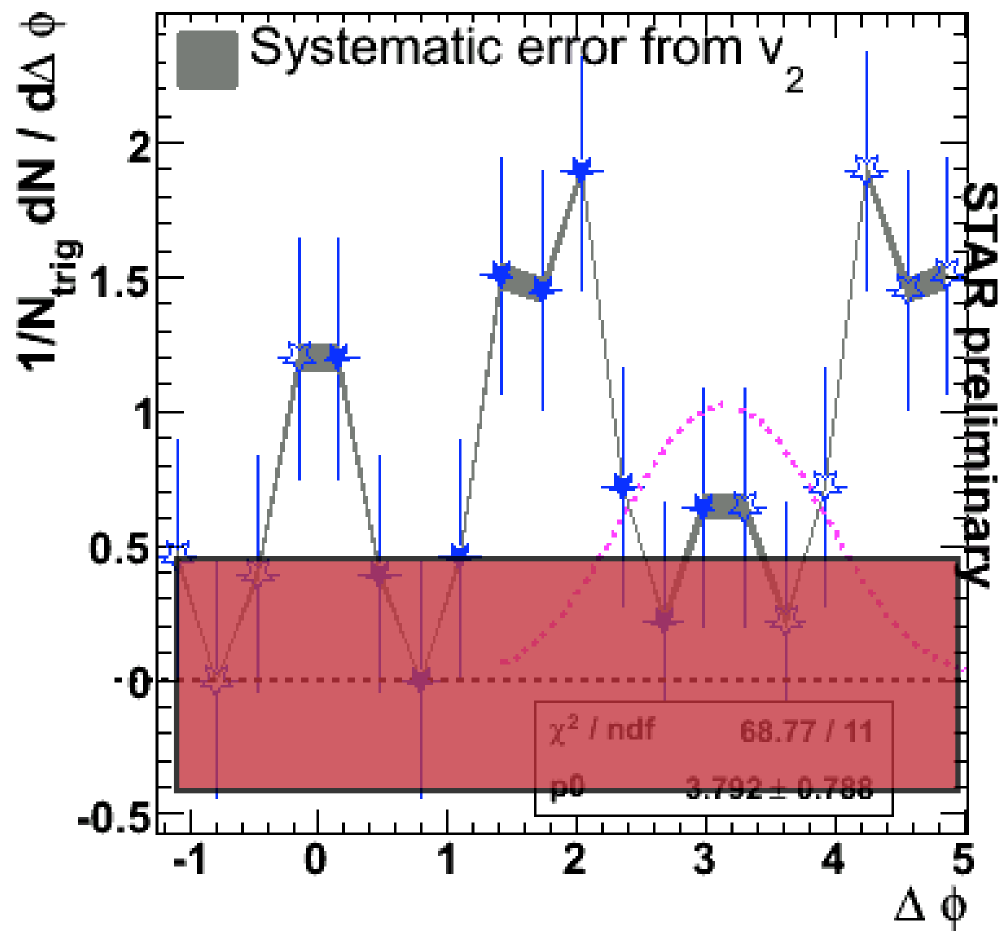

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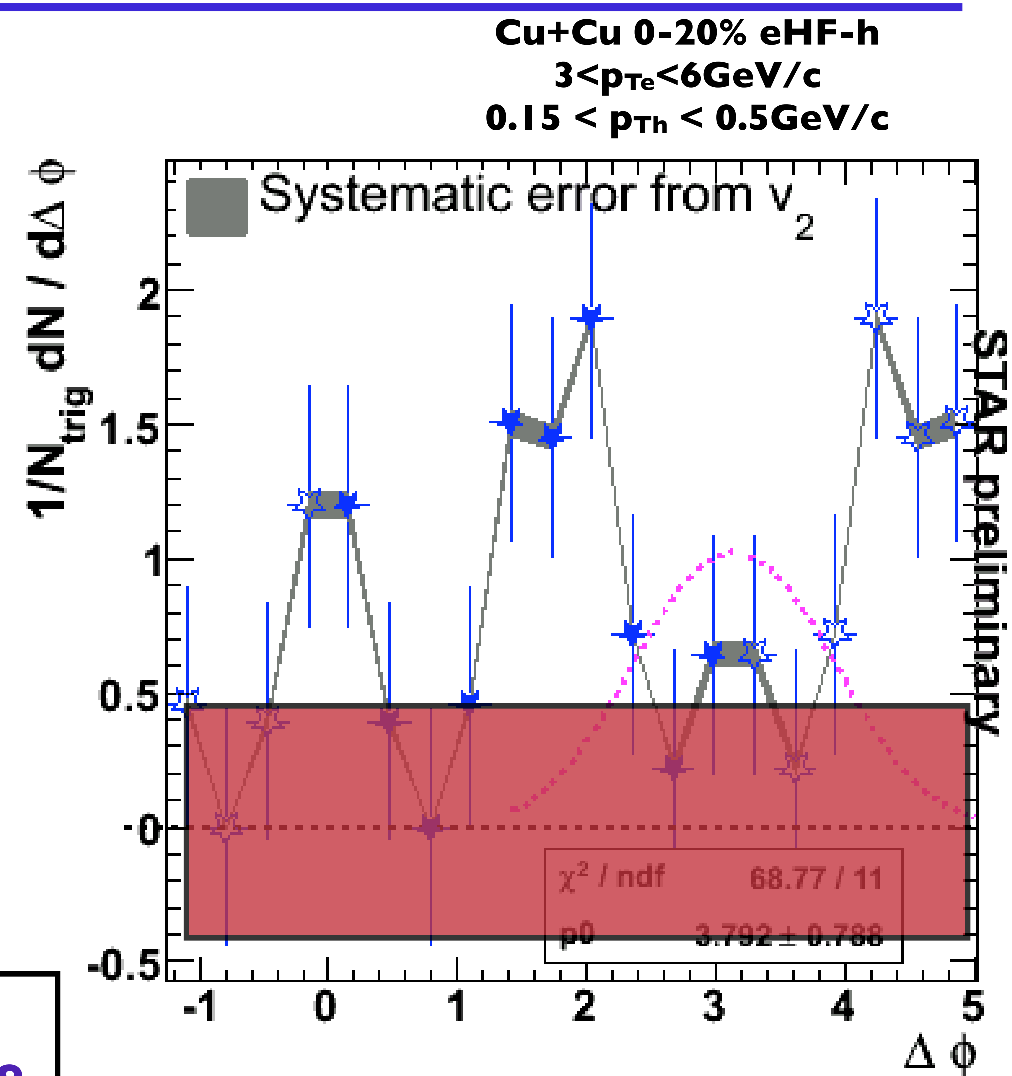

better way: absolute background subtraction (PRC 71 051902 (2005) & PHENIX Au+Au results shown here)

<1σ ZYAM error

summary

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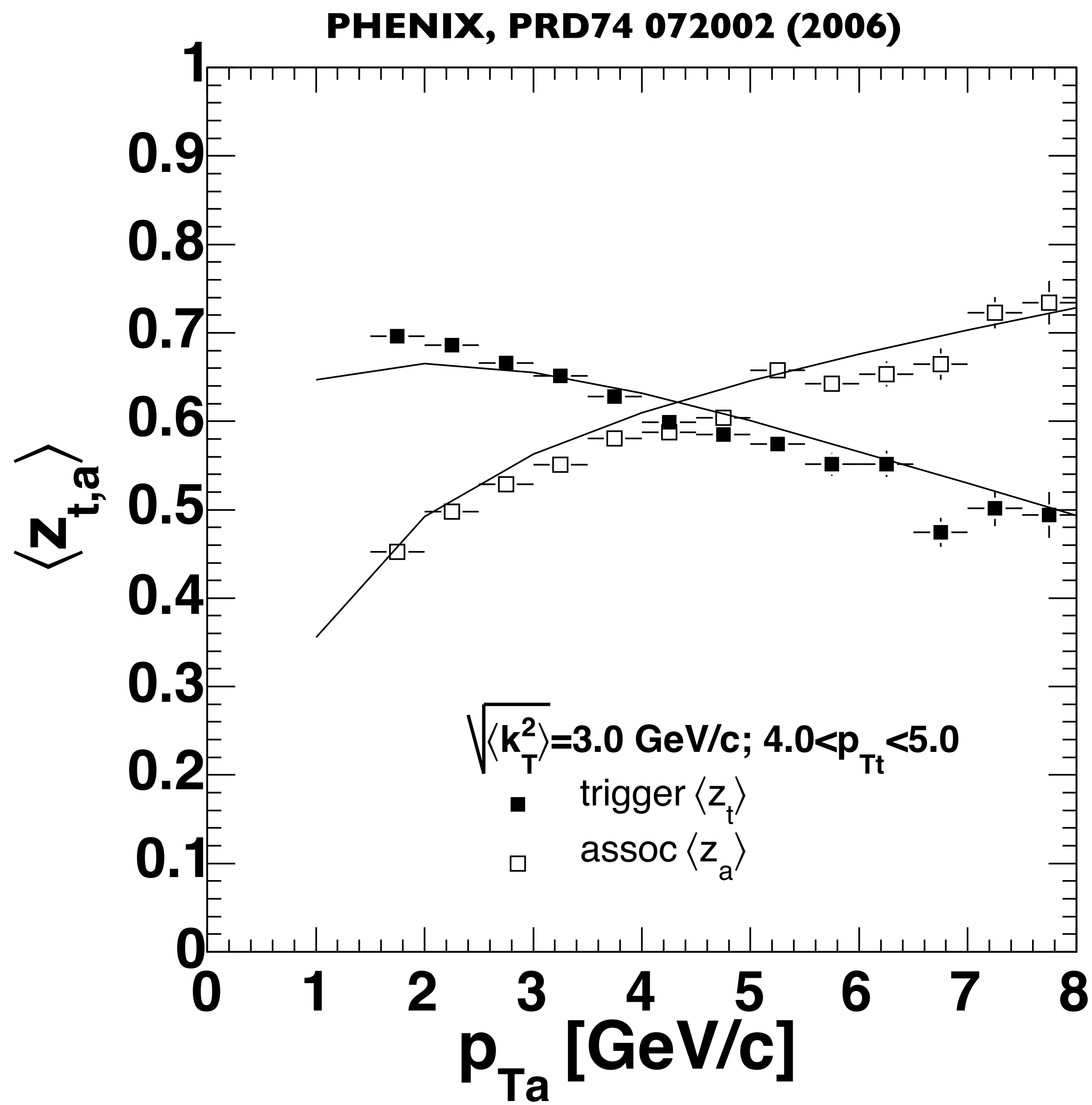
- heavy flavor jets, first results

experimental parallel talks

- C. Chen: Jet Correlation Observations from the PHENIX Experiment to Provide Information on Energy Lost by High-p_T Partons
- R. Wei: High p_T Measurements of Reaction Plane Dependent Jet-suppression and Azimuthal Anisotropy in Au+Au Collisions at sqrt(sNN) = 200 GeV at PHENIX
- M. Connors: Direct Photon-Hadron Correlations Measured with the PHENIX Detector
- A. Hamed: Direct Gamma - Charged Hadron Azimuthal Correlation Measurements from STAR
- A. Hanks: Measurements of Photon Fragmentation and the Flavor Dependence of Jet Fragmentation with the PHENIX Detector
- Y. Xu: Measurements of K0 and K+/- Production at High p_T up to 15 GeV/c at STAR as a Probe for Jet Flavor Conversion at RHIC
- A. Timmins: Strangeness Production in Heavy-Ion Collisions at STAR
- T. Engelmore: Heavy Flavor Production and Energy Loss with Two-Particle Correlations at RHIC-PHENIX
- B. Biritz: Non-photonic Electron-Hadron Azimuthal Correlation for AuAu, CuCu, and pp Collisions at sqrt(sNN) = 200 GeV
- A. Adare: High p_T jet correlations as a probe of the QGP (poster)

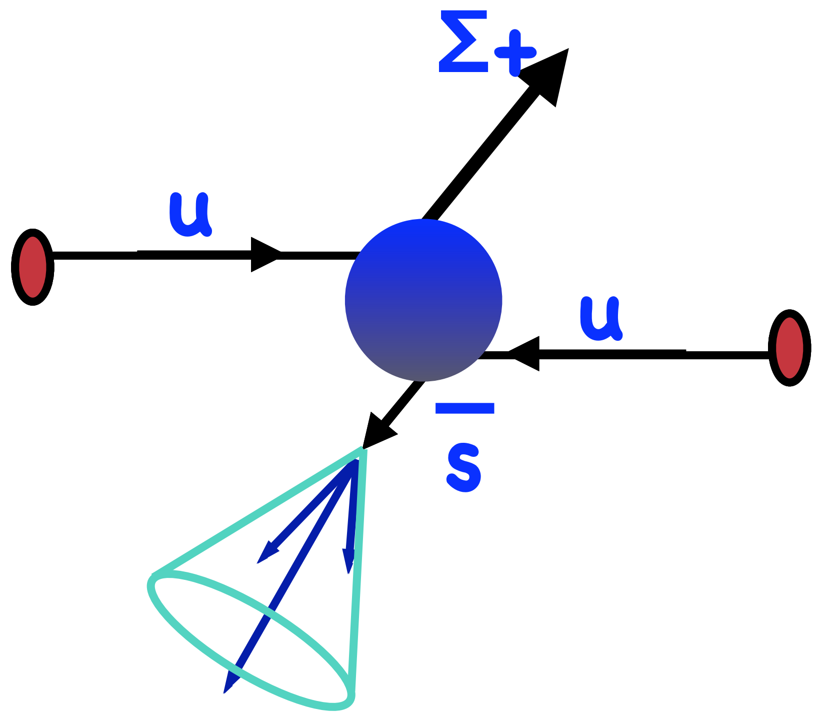
<z> from PYTHIA



how would you test this?

Brodsky, AS
PLB 668 111 (2008)

how would you test this?



$uu \rightarrow \Sigma^{+}\bar{s}$

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PLB 668 111 (2008)

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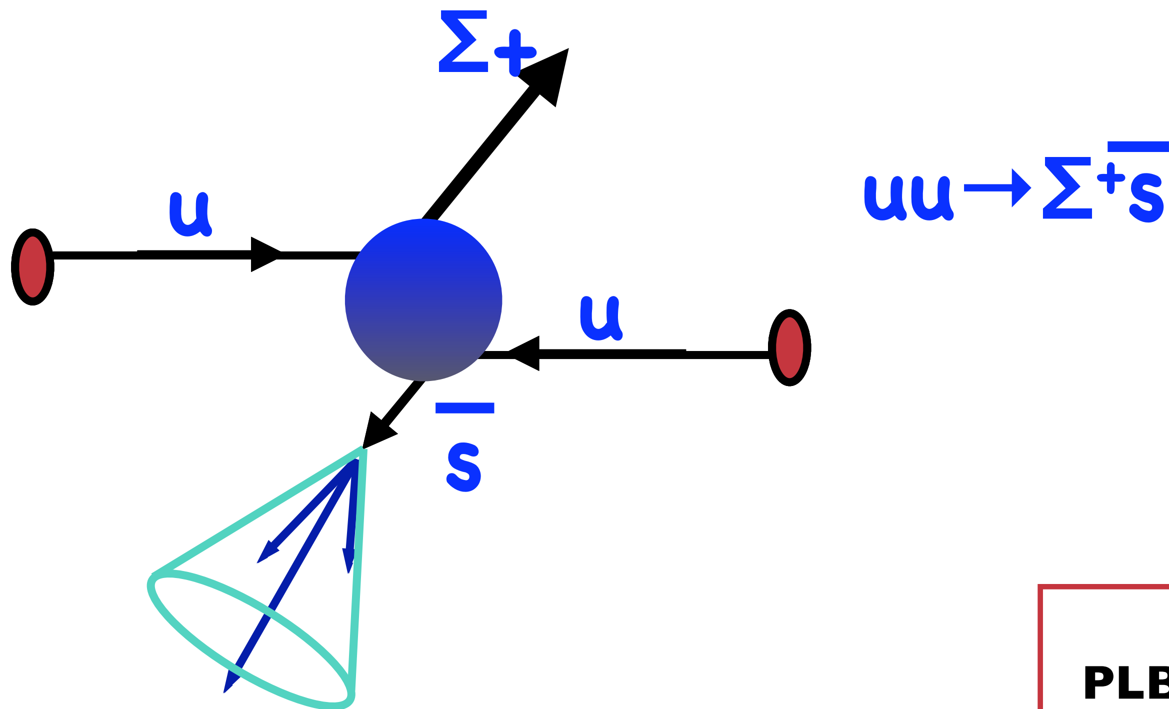

Brodsky, AS
PLB 668 111 (2008)

- can also make strange baryons: signature balancing strangeness will be on in recoil jet

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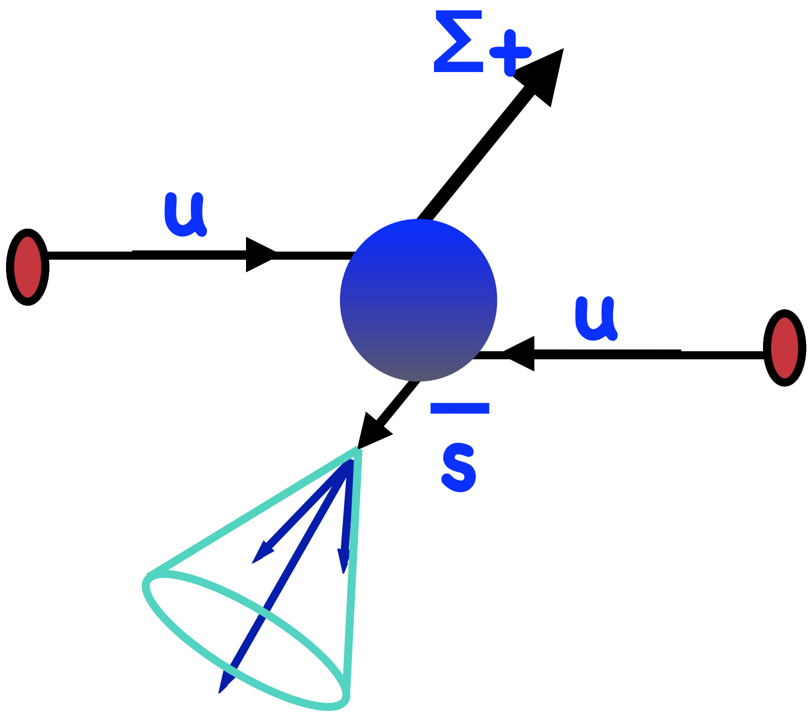


$uu \to \Sigma^+ \bar{s}$

Brodsky, AS
PLB 668 111 (2008)

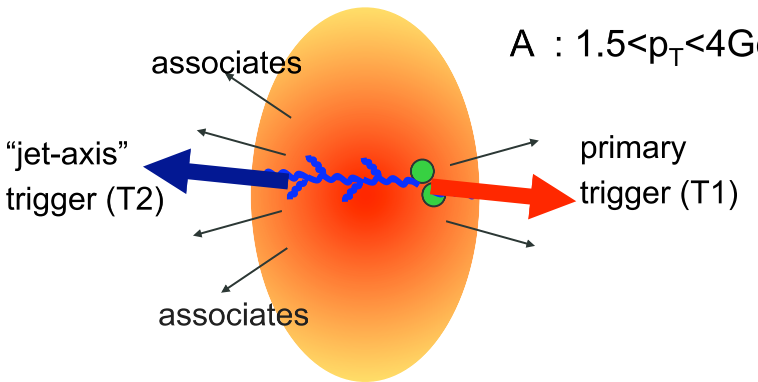
- can also make strange baryons: signature balancing strangeness will be on in recoil jet
- in contrast, in hard fragmentation picture: balancing strangeness will be close, in same jet

Di-jet triggered (2+1) multi hadron correlations

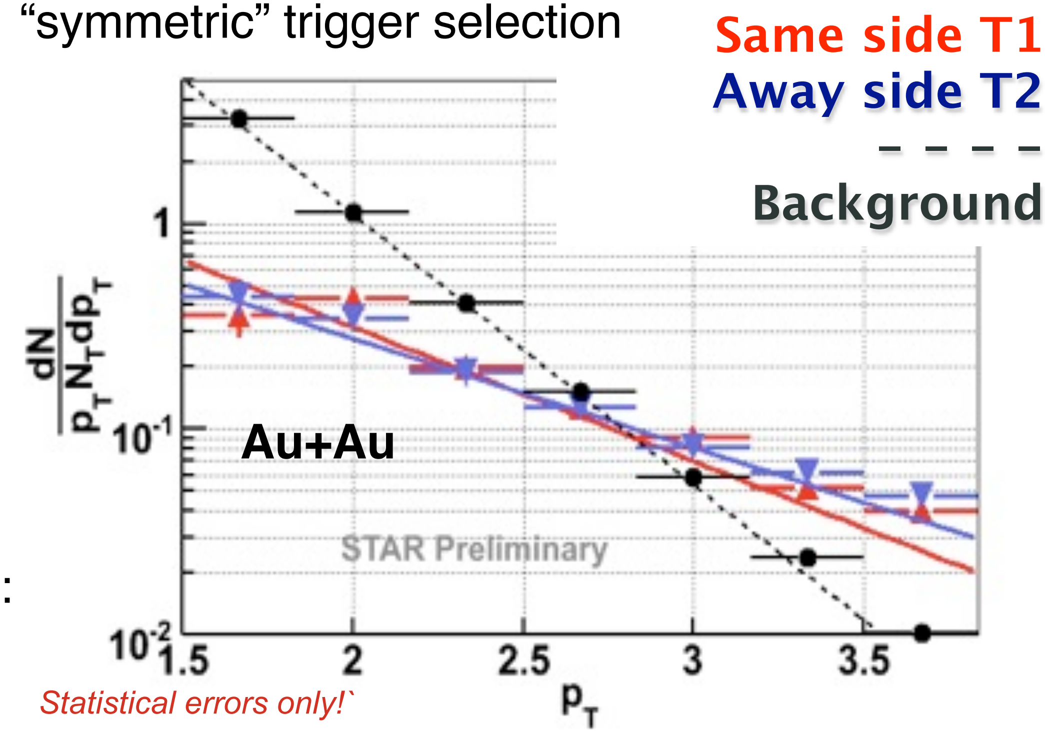
T1: p_T>5GeV/c

T2: 4<p_T<5GeV/c

A : 1.5<p_T<4GeV/c



"symmetric" trigger selection



Transverse charged hadron momentum sum:

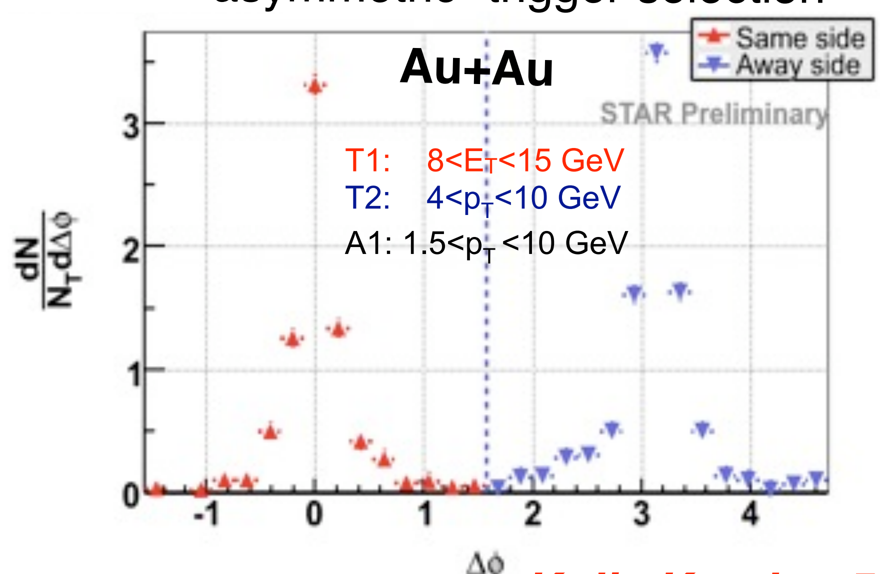
$$\sum p_T = \sum p_{T,assoc} + p_{T,trig}$$

$$\Delta = \sum p_T(\text{near}) - \sum p_T(\text{away})$$

Δ(AuAu)=1.50±0.31 GeV

Δ(dAu)=1.64±0.35 GeV

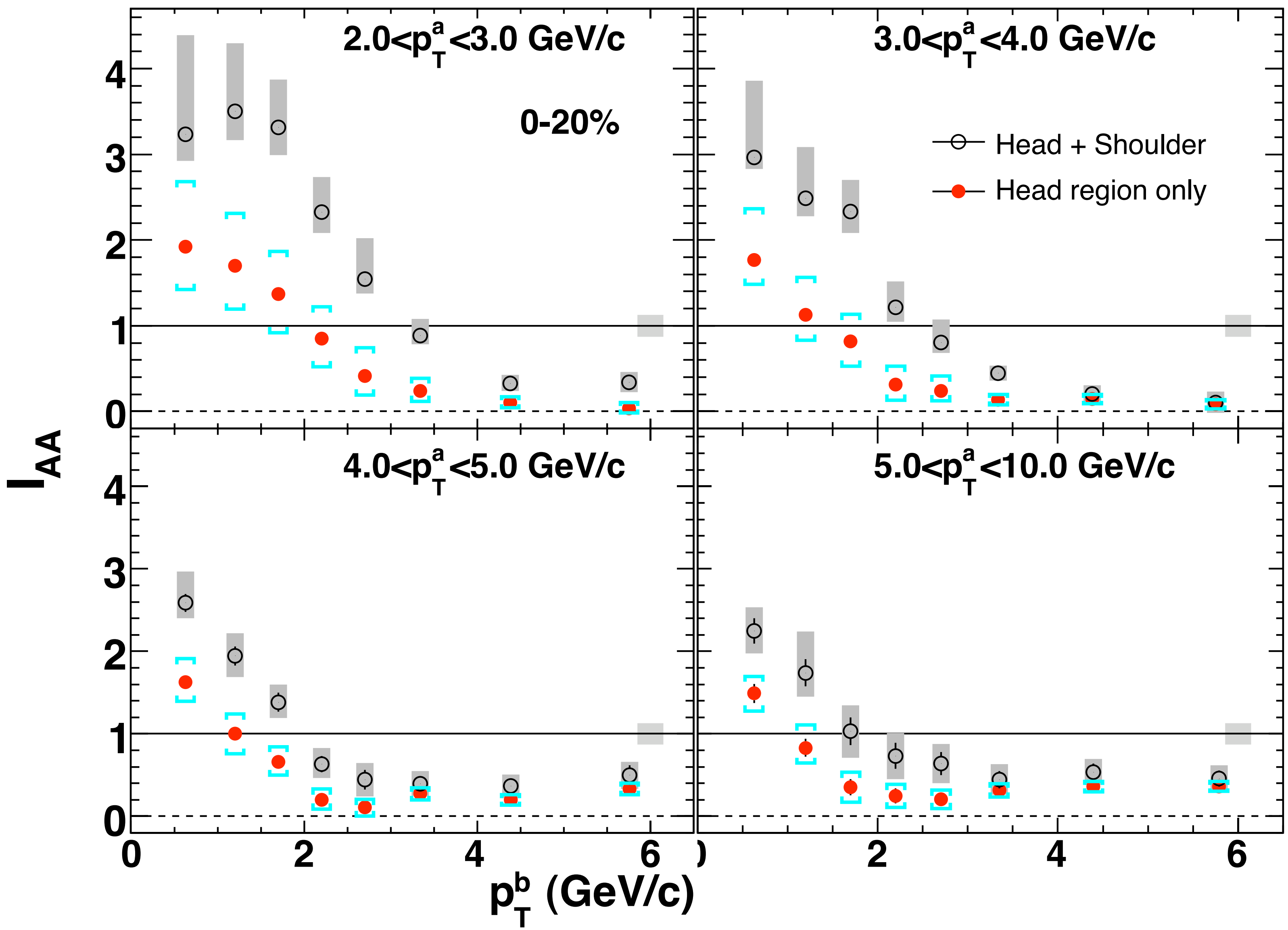
"asymmetric" trigger selection



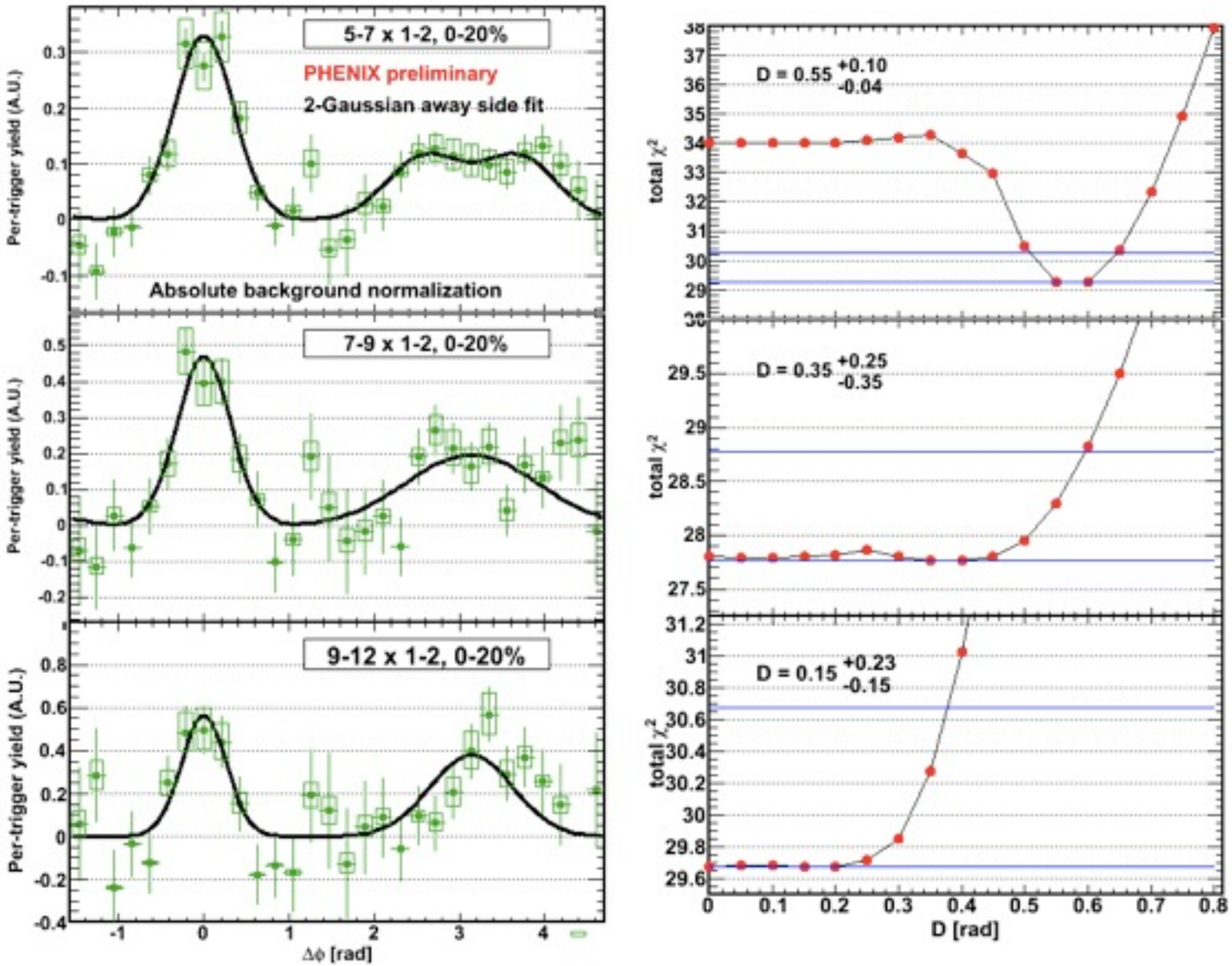
- No energy loss in AuAu for "symmetric" 2+1 correlations beyond kinematic observed
- Yields and $\Delta\eta$, $\Delta\phi$ widths comparable for "asymmetric" 2+1 correlations

Kolja Kauder, 5A

dihadron correlations

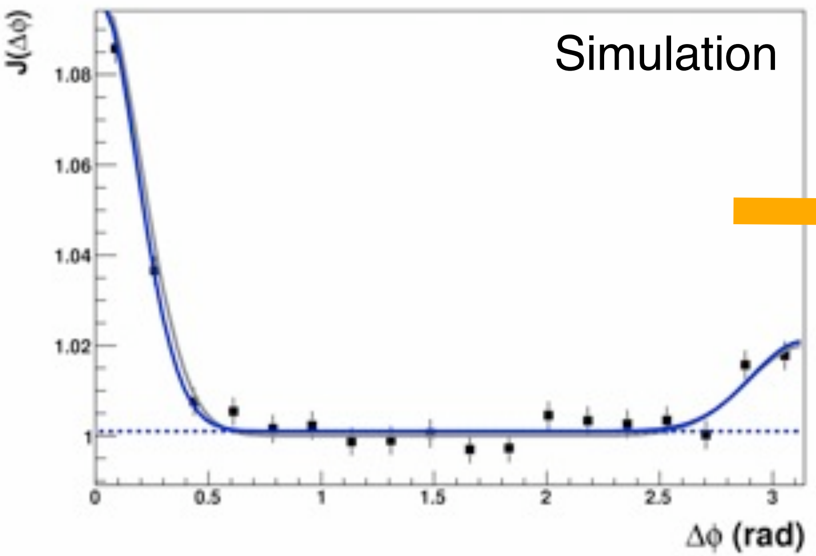


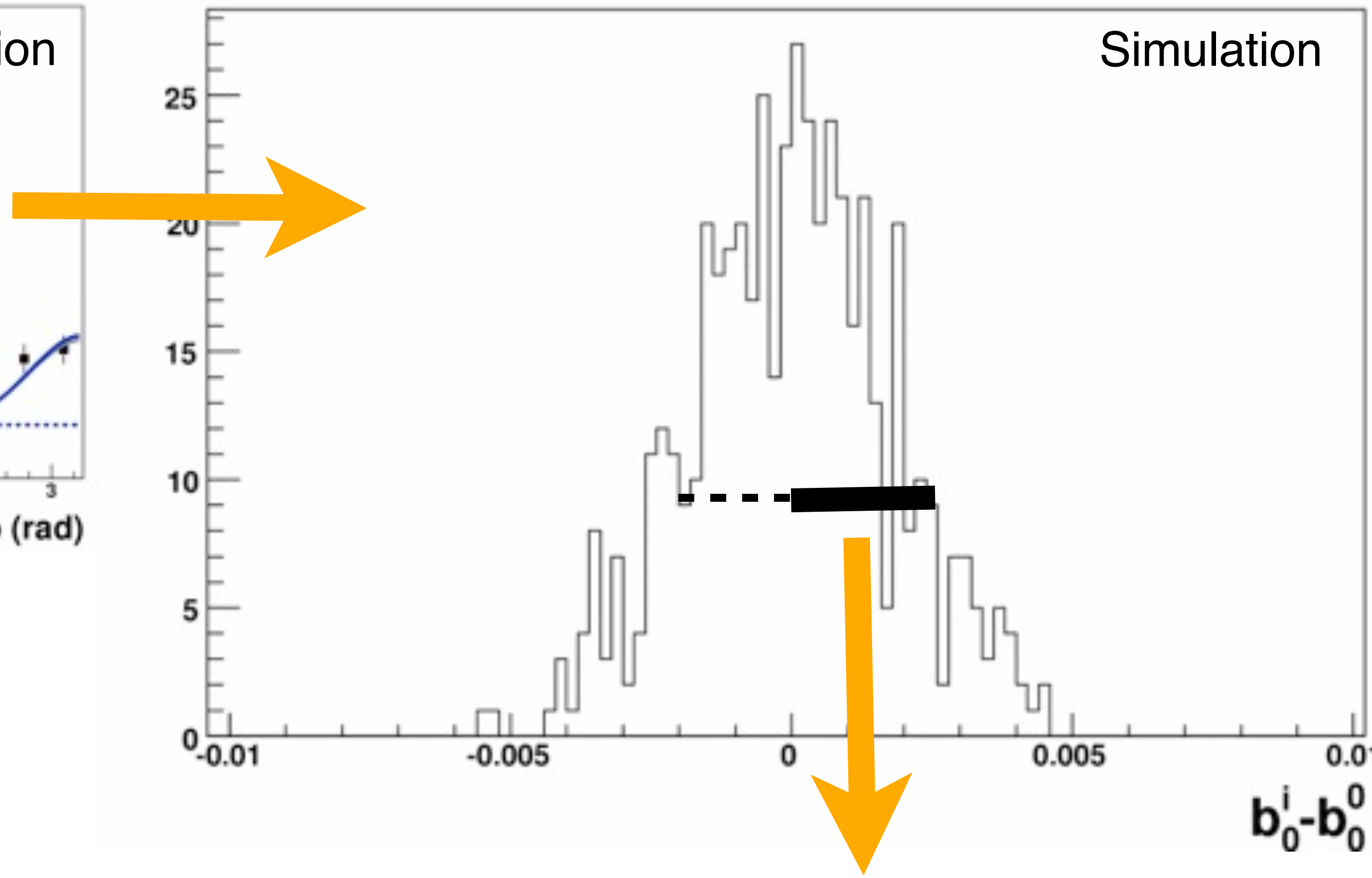
PHENIX, PRC78 014901 (2008)


5-7 x 1-2, 0-20%
PHENIX preliminary
2-Gaussian away side fit
Absolute background normalization
7-9 x 1-2, 0-20%
9-12 x 1-2, 0-20%
Per-trigger yield (A.U.)
Δφ [rad]
D = 0.55 +0.10 -0.04
D = 0.35 +0.25 -0.35
D = 0.15 +0.23 -0.15
total χ²
D [rad]

ZYAM Statistical Uncertainty

M. McCumber February 2008





Bin Methods typically use statistical error of points (not a real estimate)

Proper Error Calculation:
- Toss new C(Δϕ) against measurement(fit)
- Fit new C(Δϕ) (fit method only)
- Extract b_0, & repeat

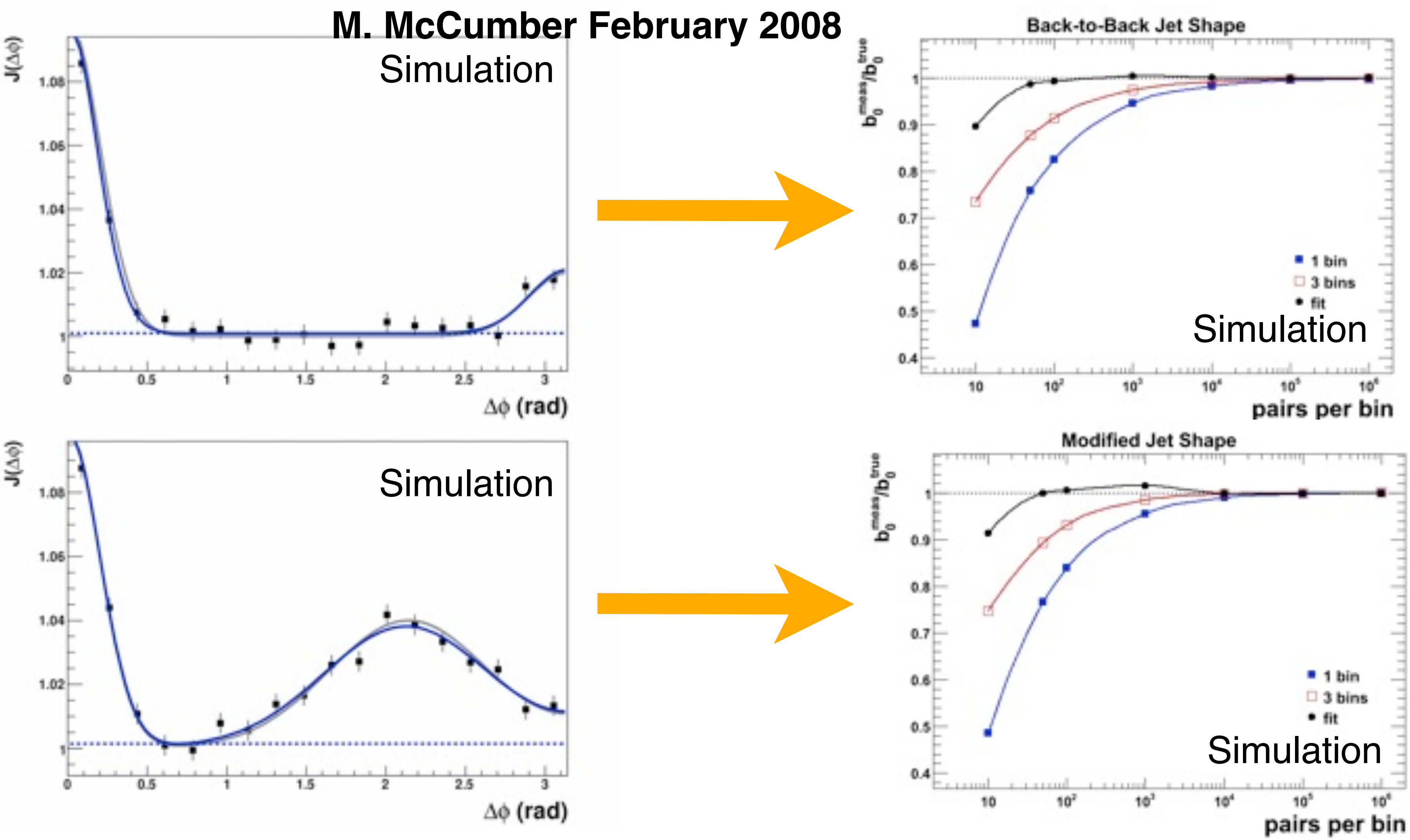
Scatter of b_0 in tossed C(Δϕ)s is the estimation of statistical error

σ_{b0}

Don’t trust ZYAM yields without this error bar!

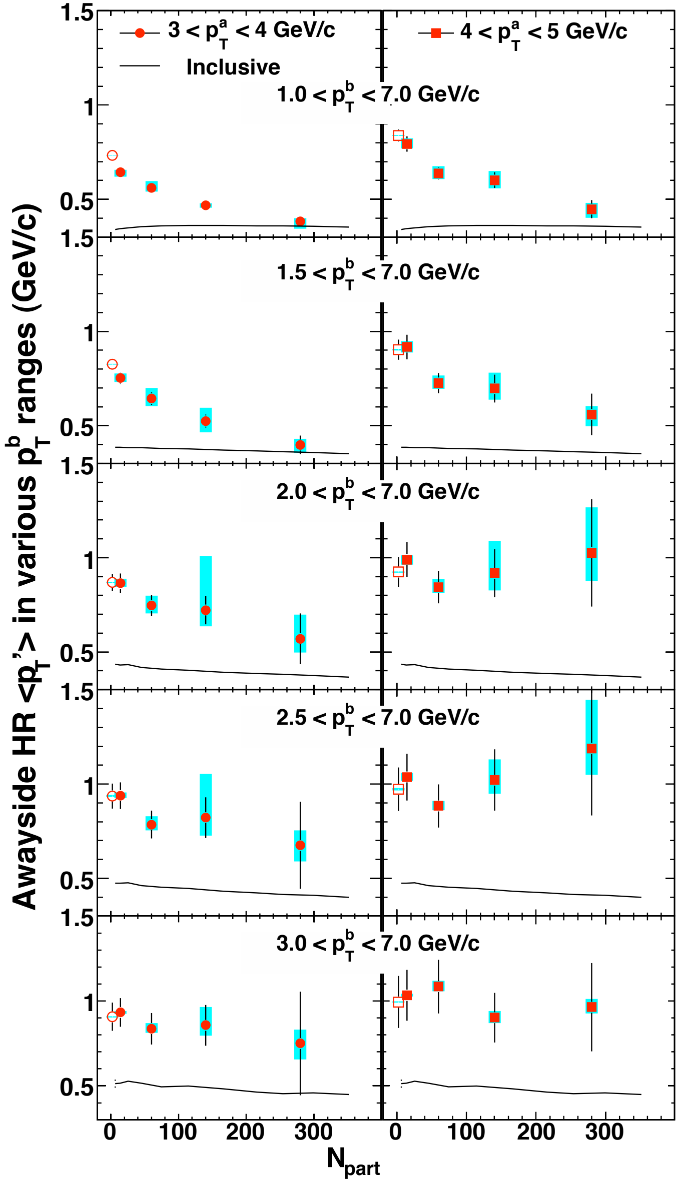
ZYAM Systematic Uncertainty

M. McCumber February 2008



Binned ZYAMs deviate significantly from true value at low sampling rates
Fit method deviates most slowly (no effort to recover failed fits made here)
These jet shapes show only minor effects on

ZYAM applied at sufficiently low statistics requires an additional systematic!
(this is ~~usually not~~ never done)


3 < p_T^a < 4 GeV/c
Inclusive
4 < p_T^a < 5 GeV/c
1.0 < p_T^b < 7.0 GeV/c
1.5 < p_T^b < 7.0 GeV/c
2.0 < p_T^b < 7.0 GeV/c
2.5 < p_T^b < 7.0 GeV/c
3.0 < p_T^b < 7.0 GeV/c
Awayside HR <p_T'> in various p_T^b ranges (GeV/c)
N_{part}