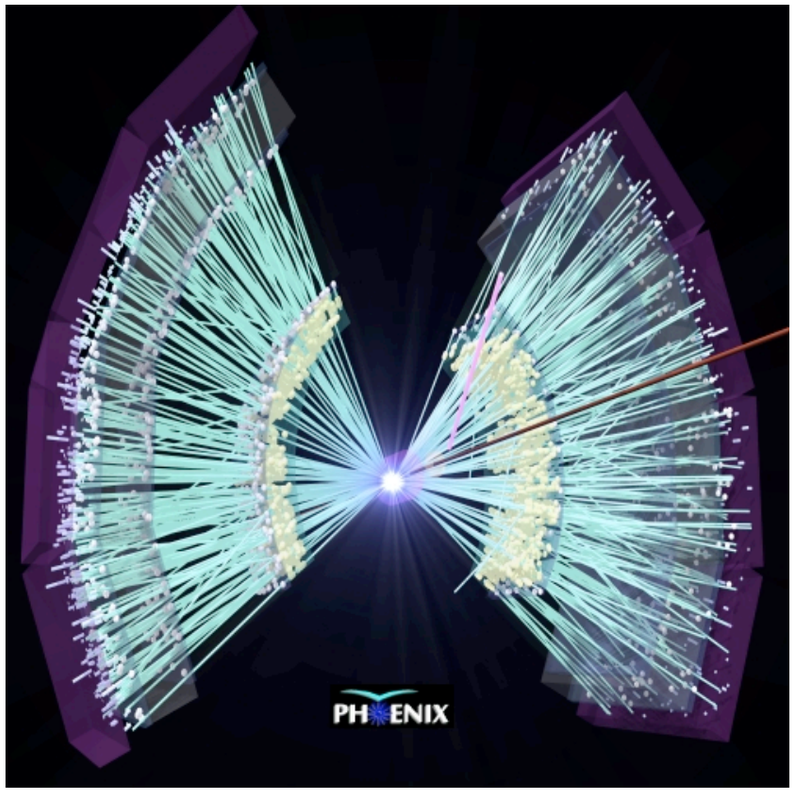
Direct-photon hadron correlations at $\sqrt{s}$ = 200 GeV with PHENIX



Ali Hanks

for the PHENIX Collaboration

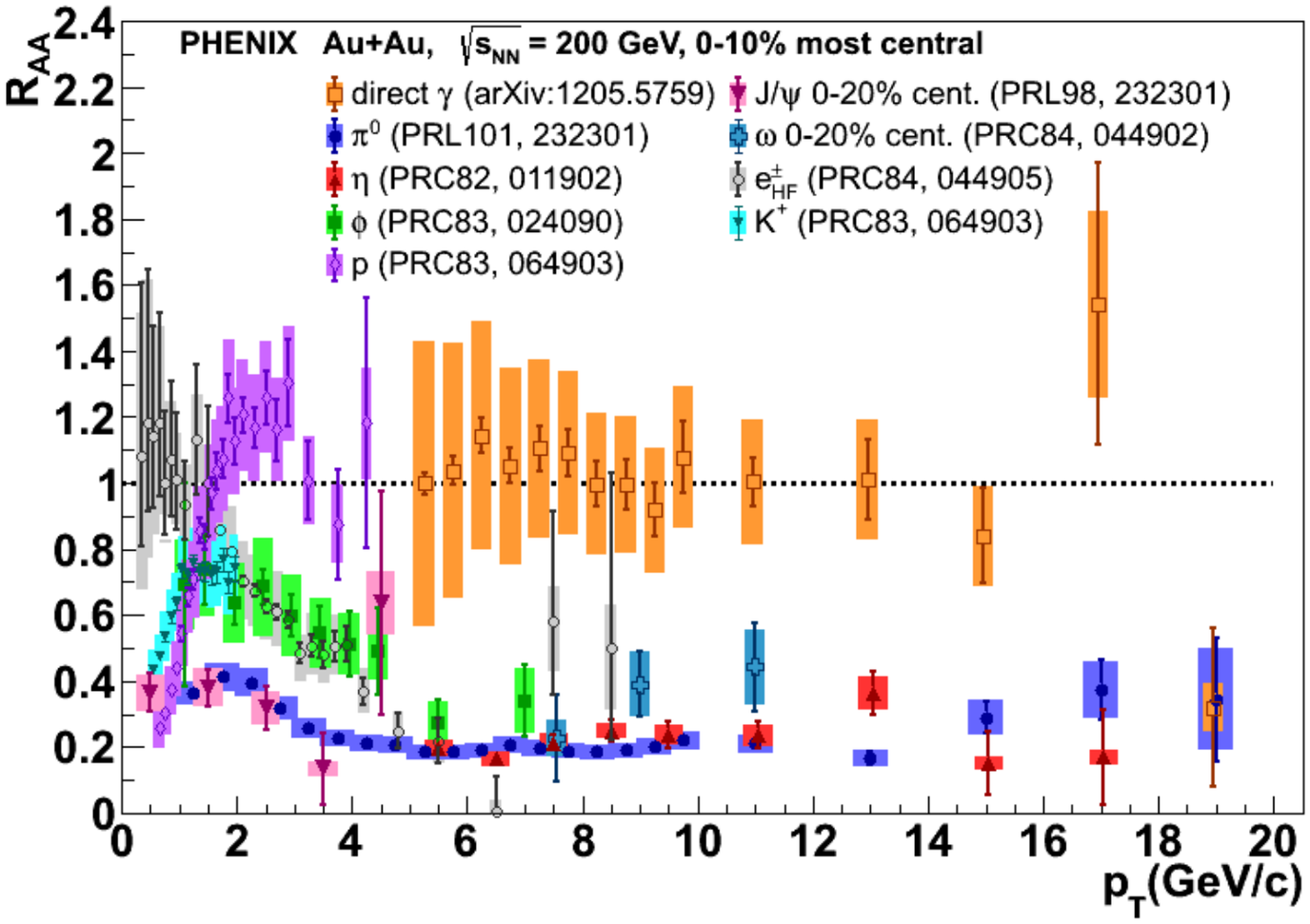
XXI International Workshop on Deep-Inelastic Scattering and Related Subjects

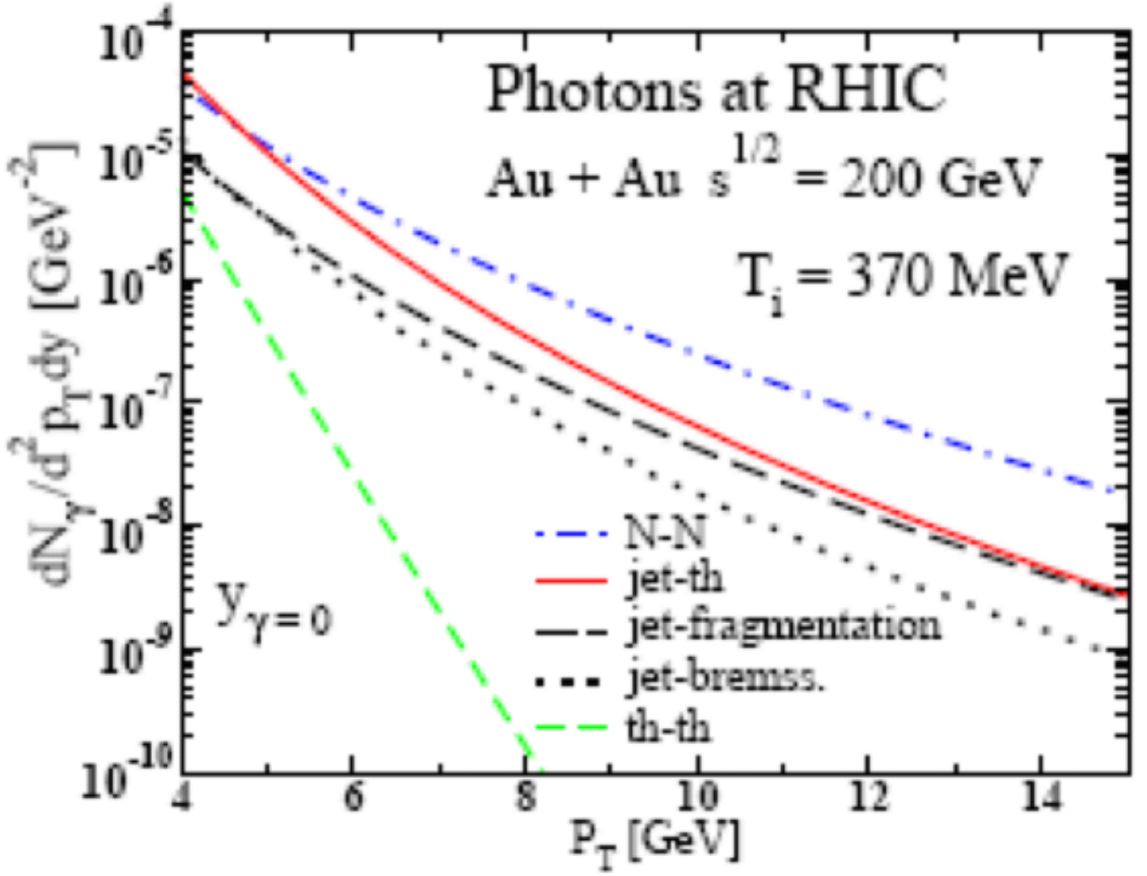
Marseille, France

April 23rd, 2013

Stony Brook University | The State University of New York

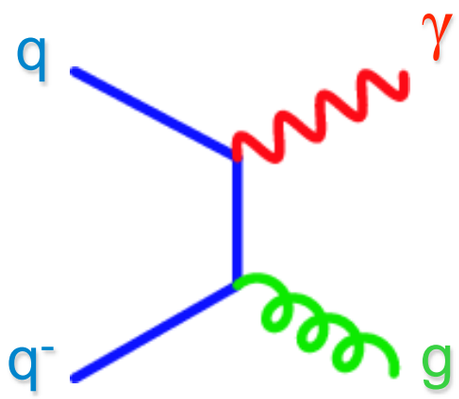
Why direct photons?



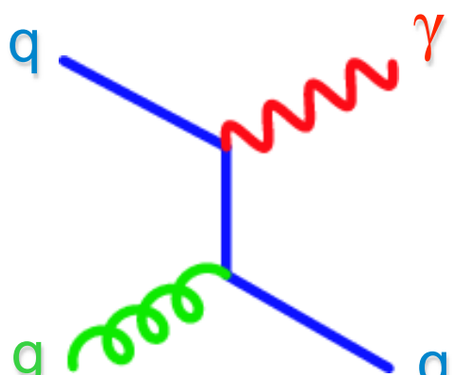


- Calibrated probe: largely insensitive to medium
  - photons do not interact strongly with the medium
  - at high p_T yield is dominated by hard processes
- Produced back-to-back with parton

$\Longrightarrow$ calibrated measure of initial parton energy

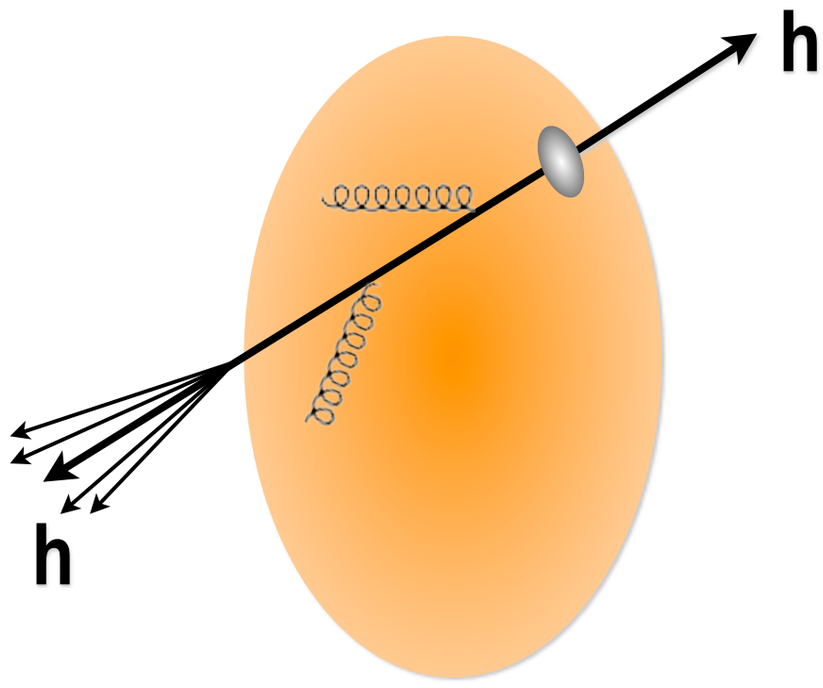


Annihilation



Compton

Probing energy loss with correlated particles



- **h-h correlations:**
  - most straight forward experimentally
- surface bias for trigger
- trigger poorly constrains **modified** parton p_T

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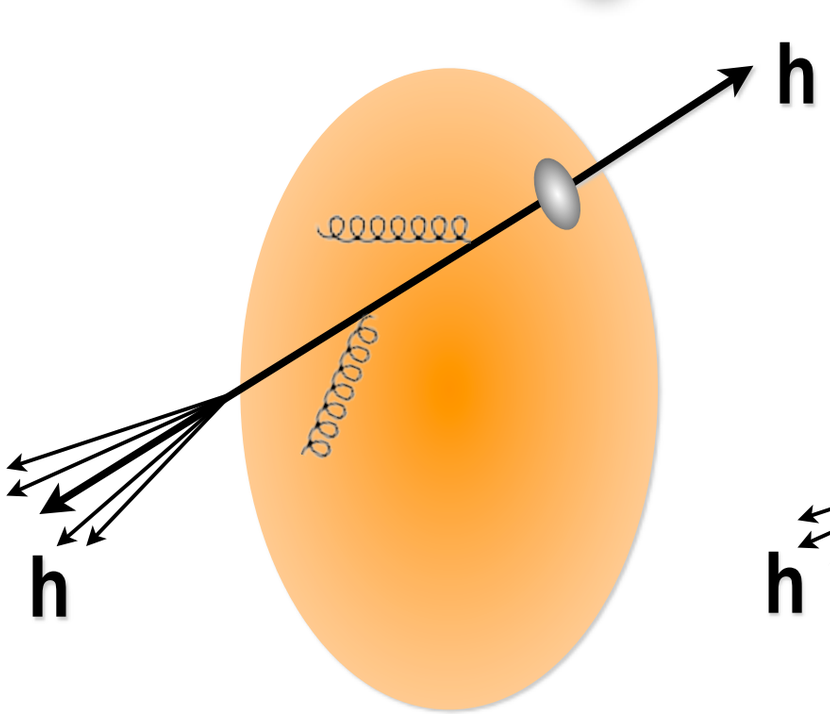

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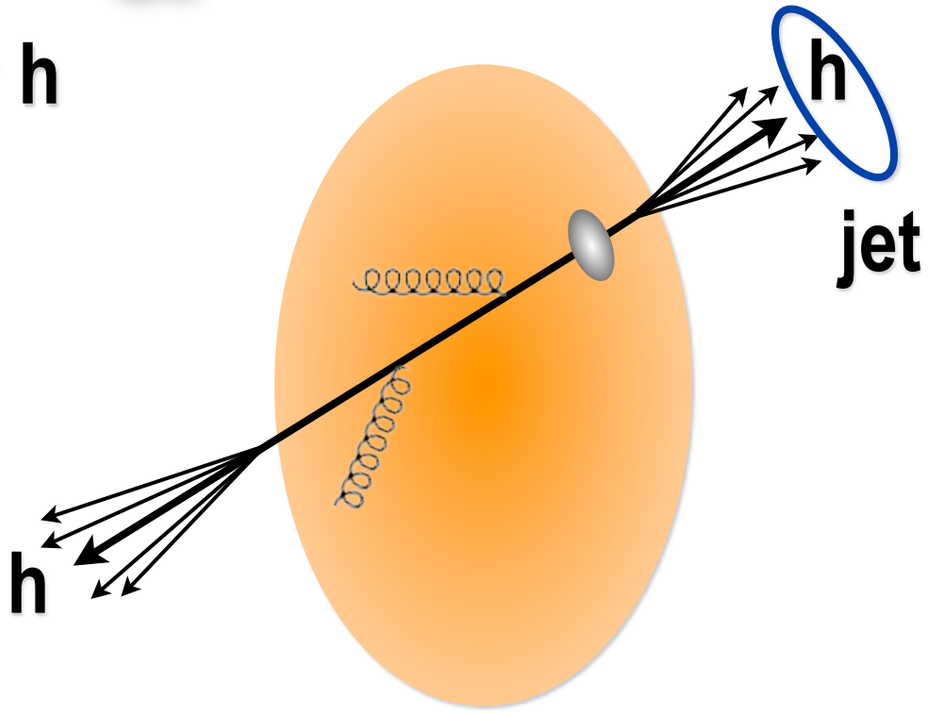

- **jet-h and jet FF:**
  - HI background + flow presents challenge
- some surface bias
- most direct measure of **modified** parton p_T
  - requires unfolding

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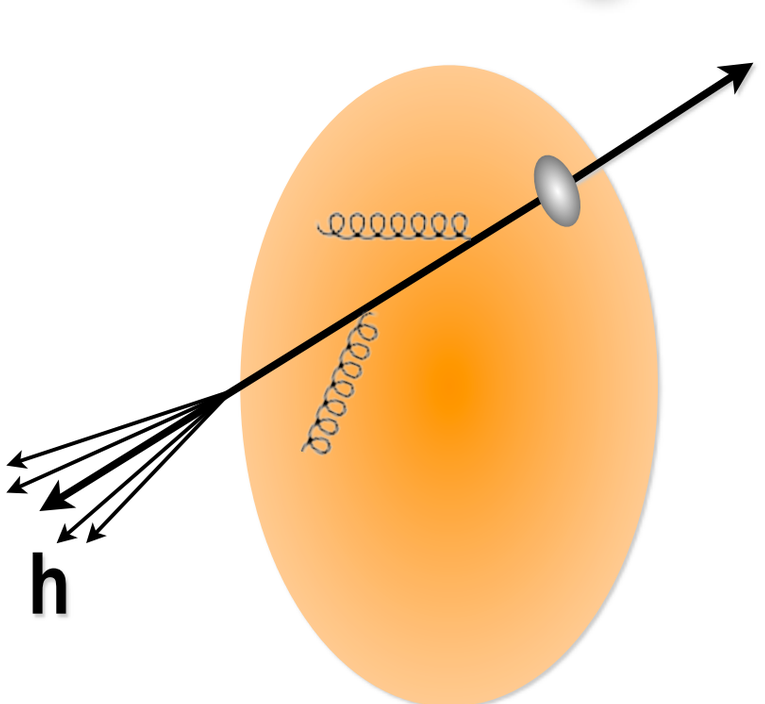

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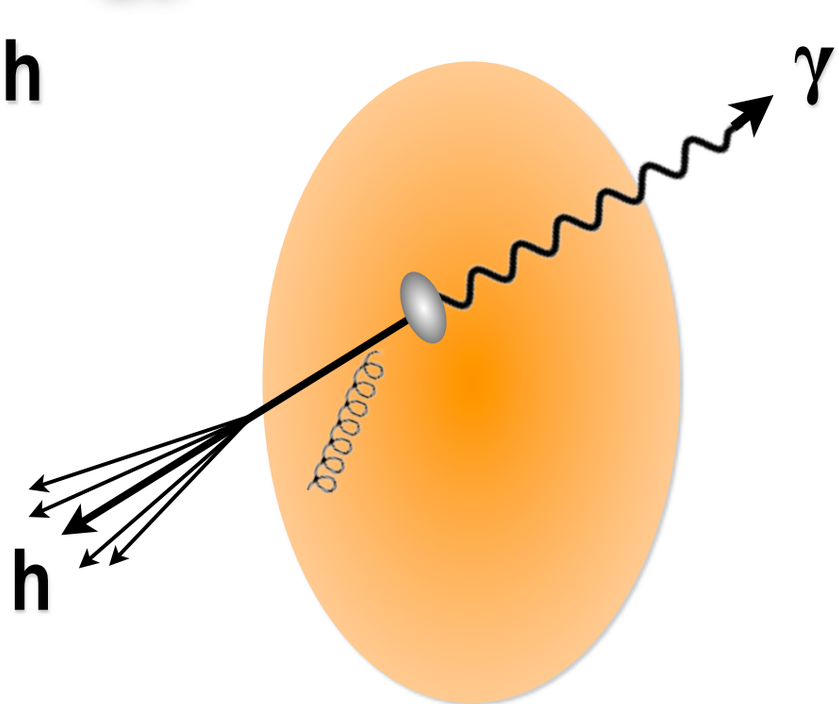
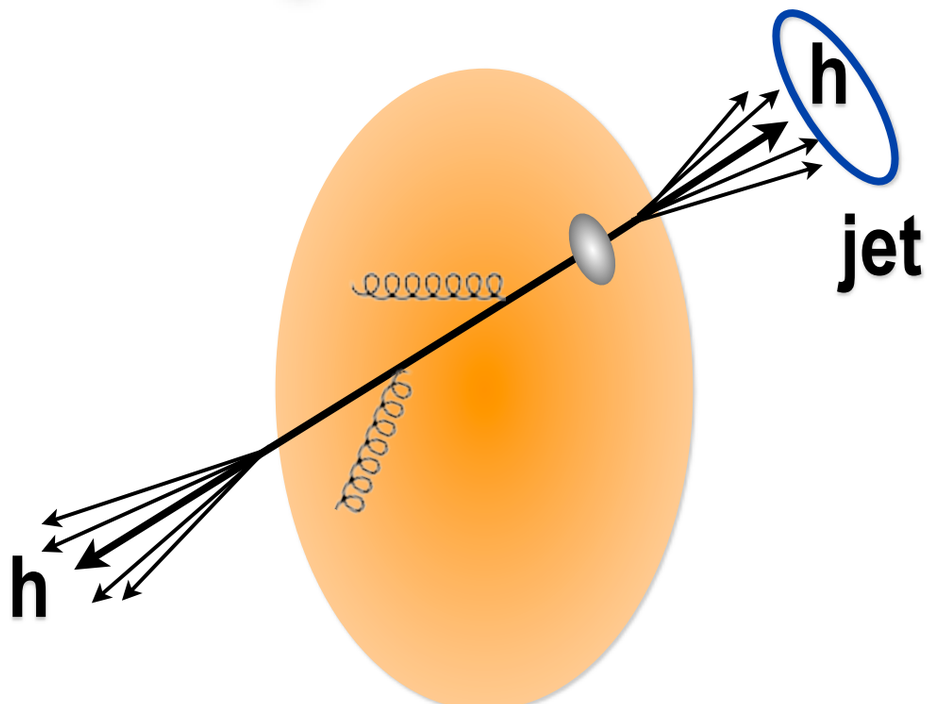


- **γ-h (and γ-jet):**
  - low signal rate
  - large decay background
- no trigger surface bias
- $p_{T,\gamma}$ most direct measure of **initial** parton p_T

dominated by quark jet



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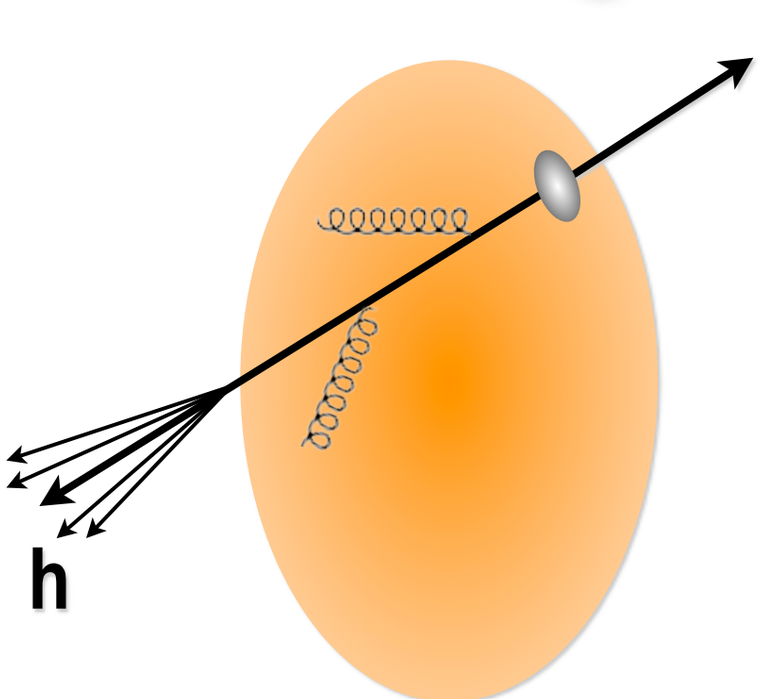

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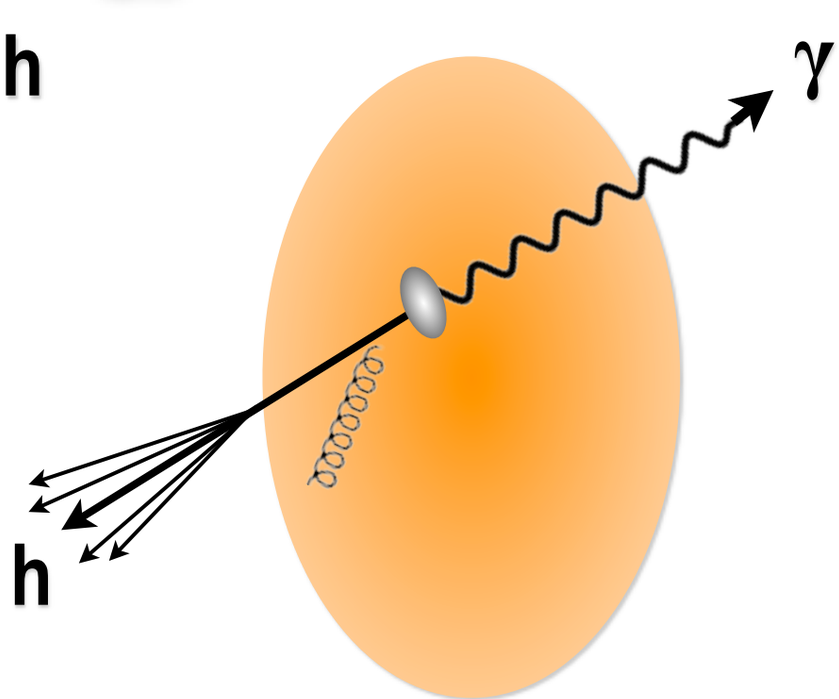

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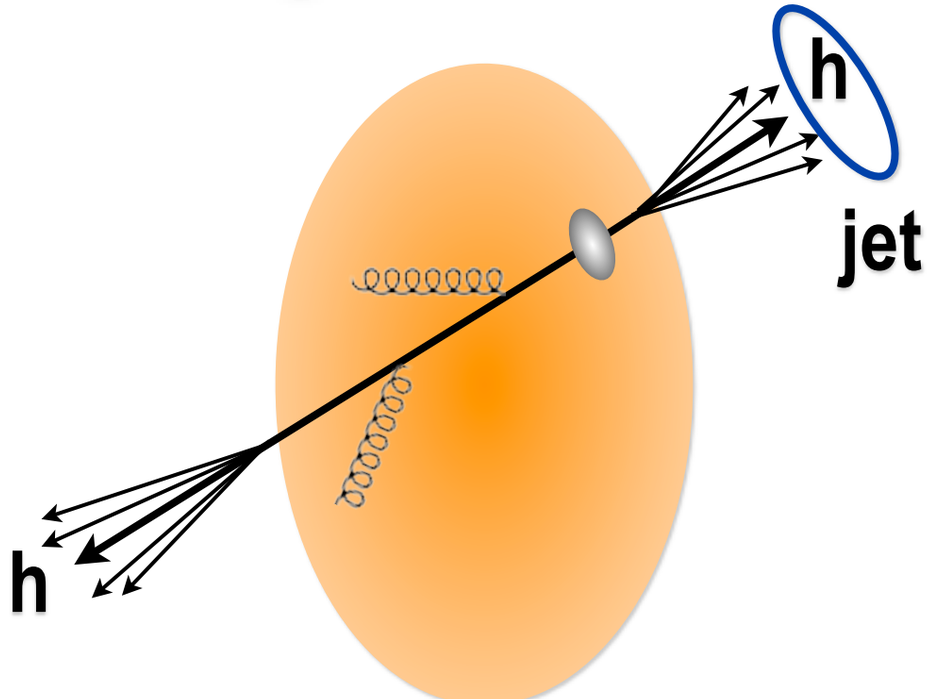

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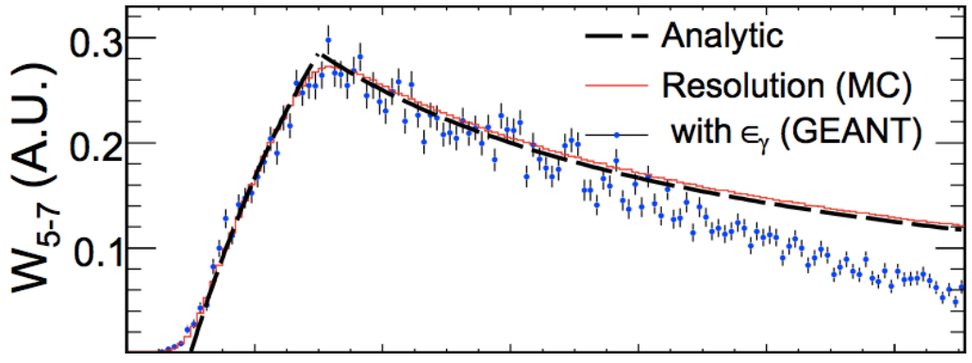
complementary measurements with different sensitivities

The γ_{dir}-h signal in p+p

$$Y_{direct} = \frac{R_\gamma Y_{incl} - Y_{decay}}{R_\gamma - 1}$$

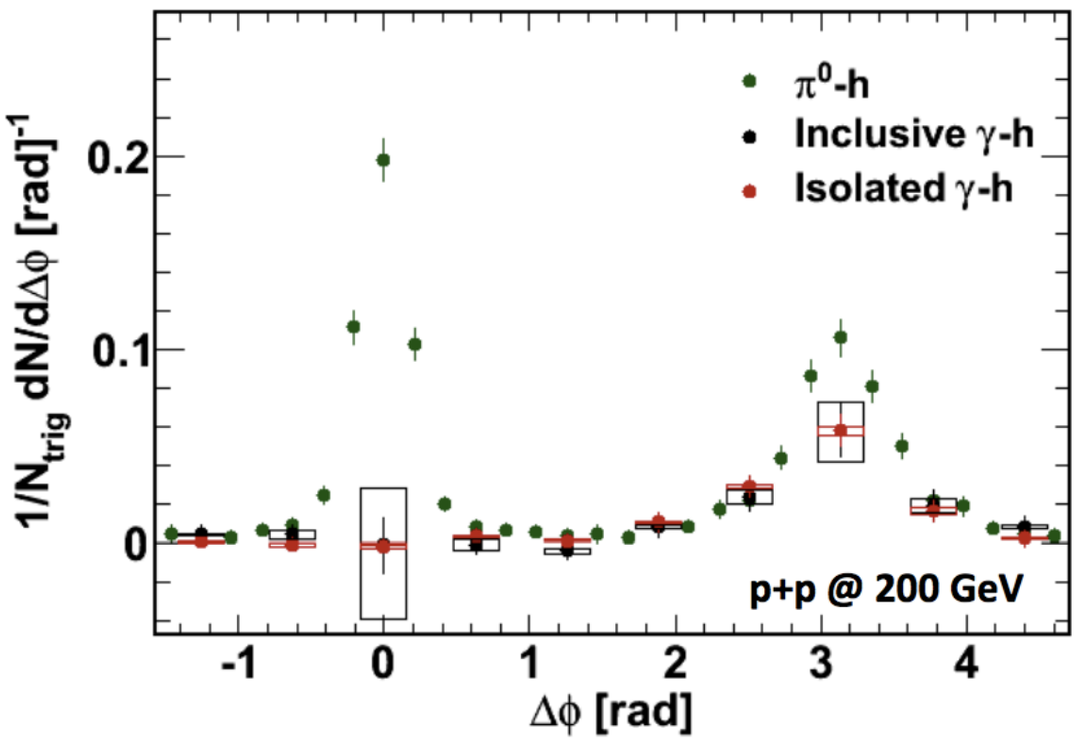
- ZYAM subtraction of pedestal for Y_{inc} and Y_{decay}
  - only important for lowest p_T bins
- isolation cut to improve systematic uncertainties

$$Y_{\pi 0} \rightarrow Y_{decay}$$



A. Adare et al, Phys. Rev. C 80, 024908 (2009)

$$R_\gamma = \frac{N_{incl}}{N_{decay}}$$



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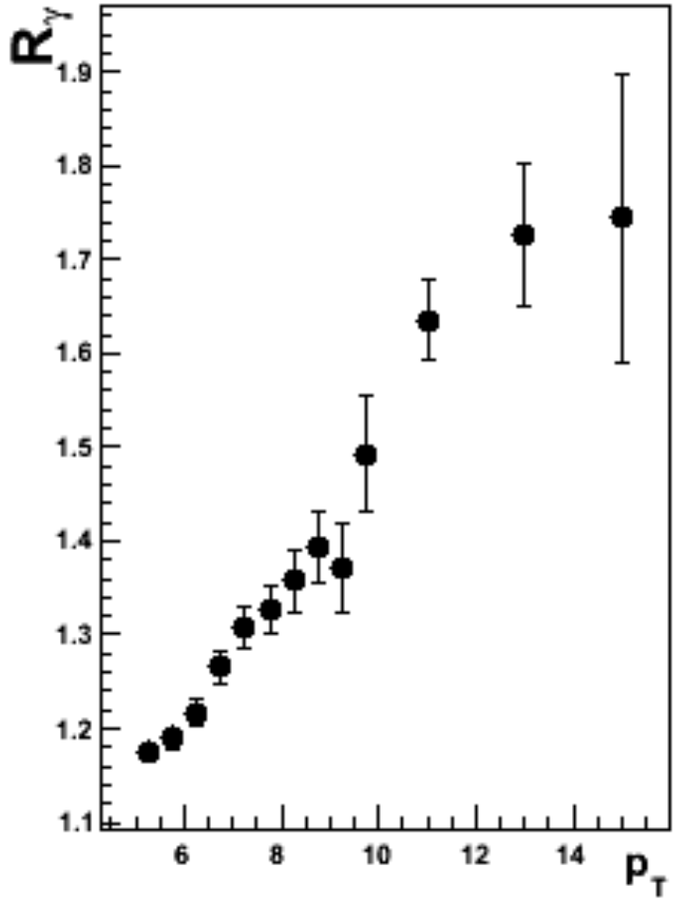


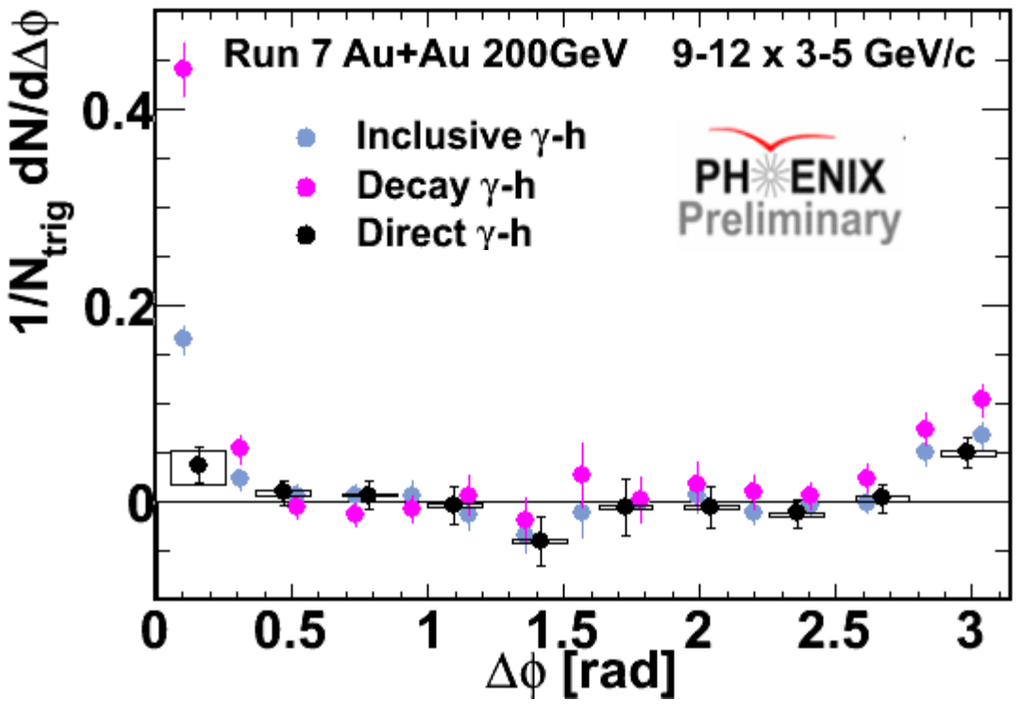
The γ_{dir}-h signal in Au+Au

$$Y_{direct} = \frac{R_\gamma Y_{incl} - Y_{decay}}{R_\gamma - 1}$$

$$Y_x \propto C(\Delta\phi) - \xi(1 + 2\langle v_2^\gamma \rangle \langle v_2^h \rangle \cos 2\Delta\phi)$$

Norm **Bkg(Flow)**

- UE (Abs. Norm.) and flow(v_2) subtracted from Y_{inc} and Y_{decay} separately



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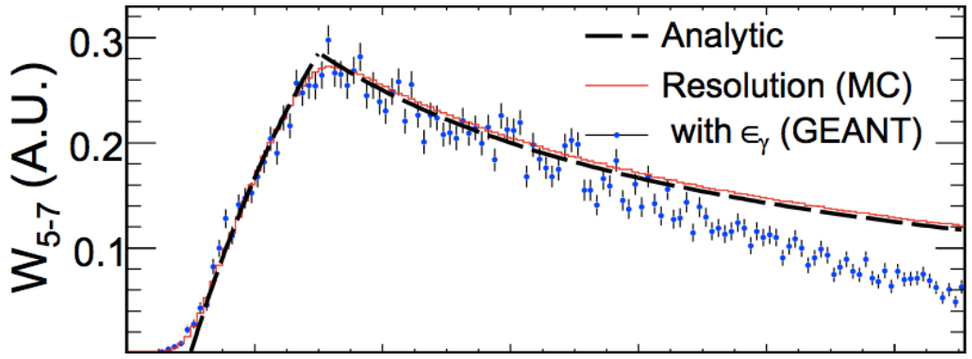

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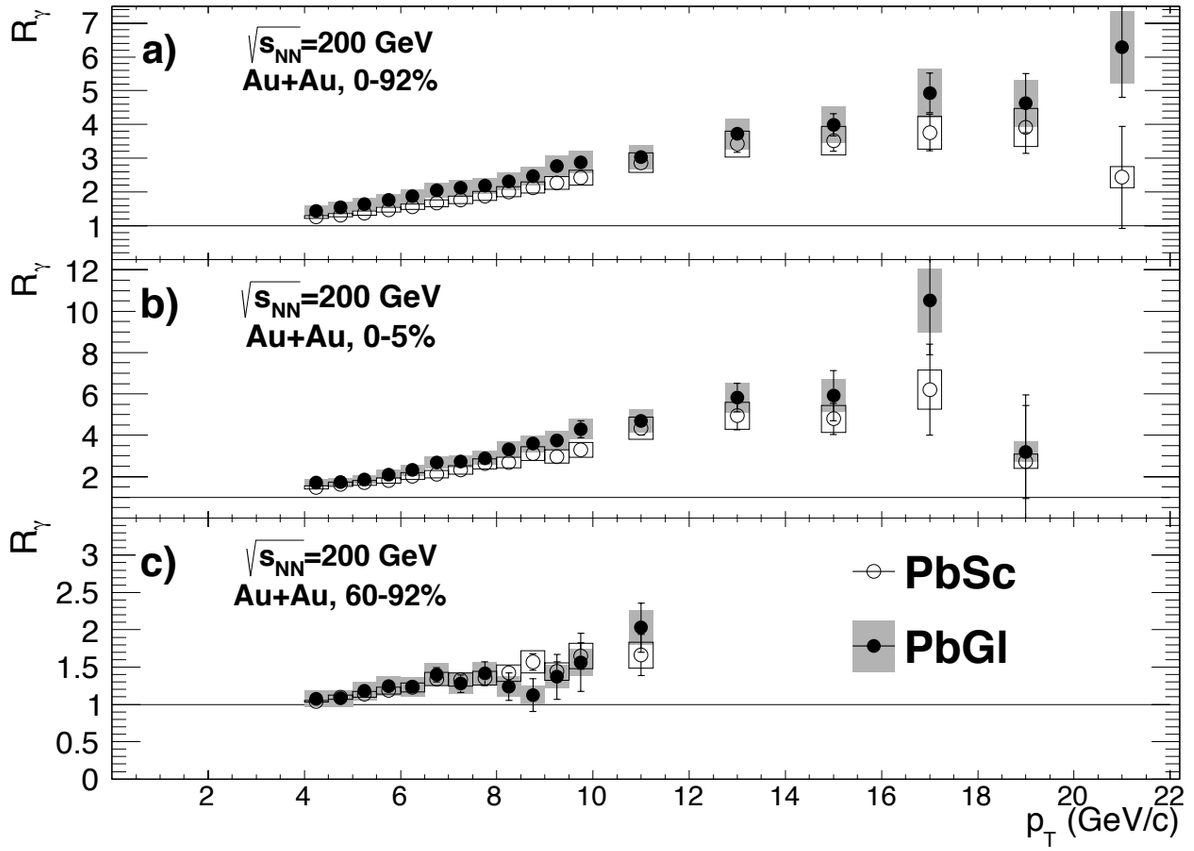
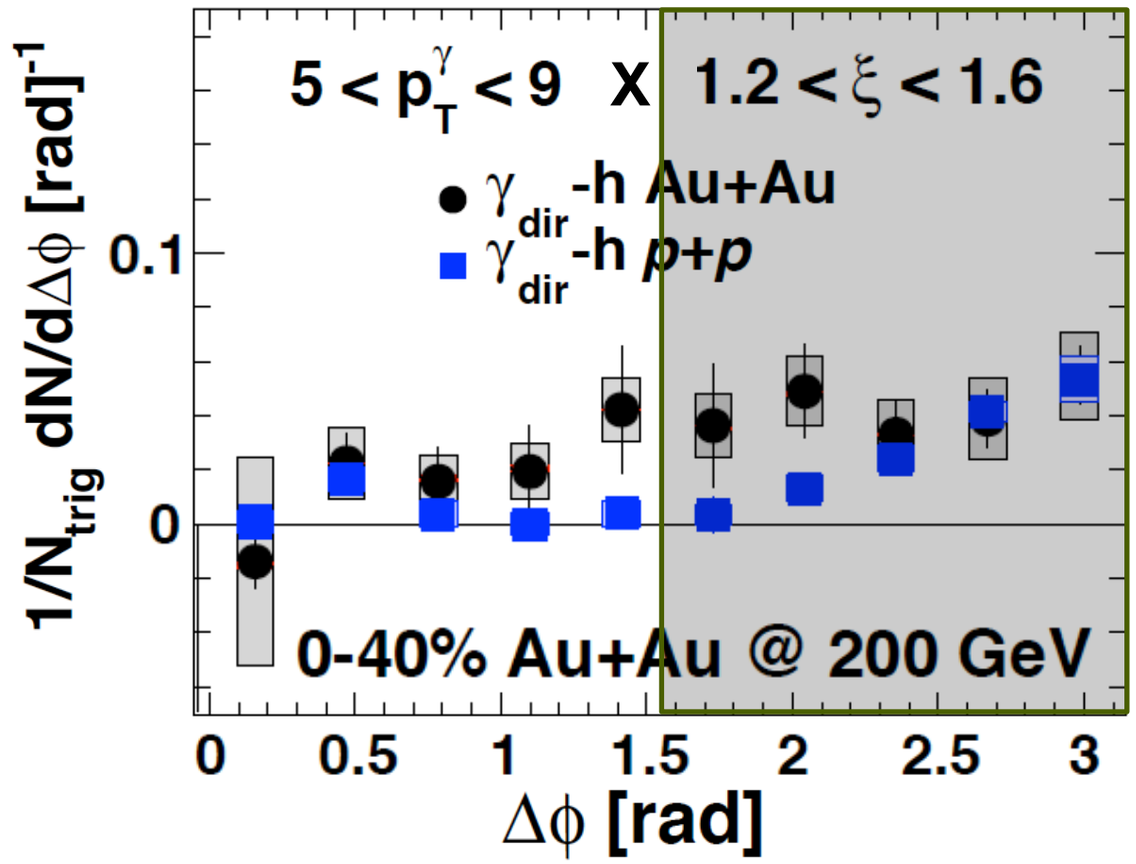


S. Afanaev et al, Phys. Rev. Lett. 109, 152302 (2012)

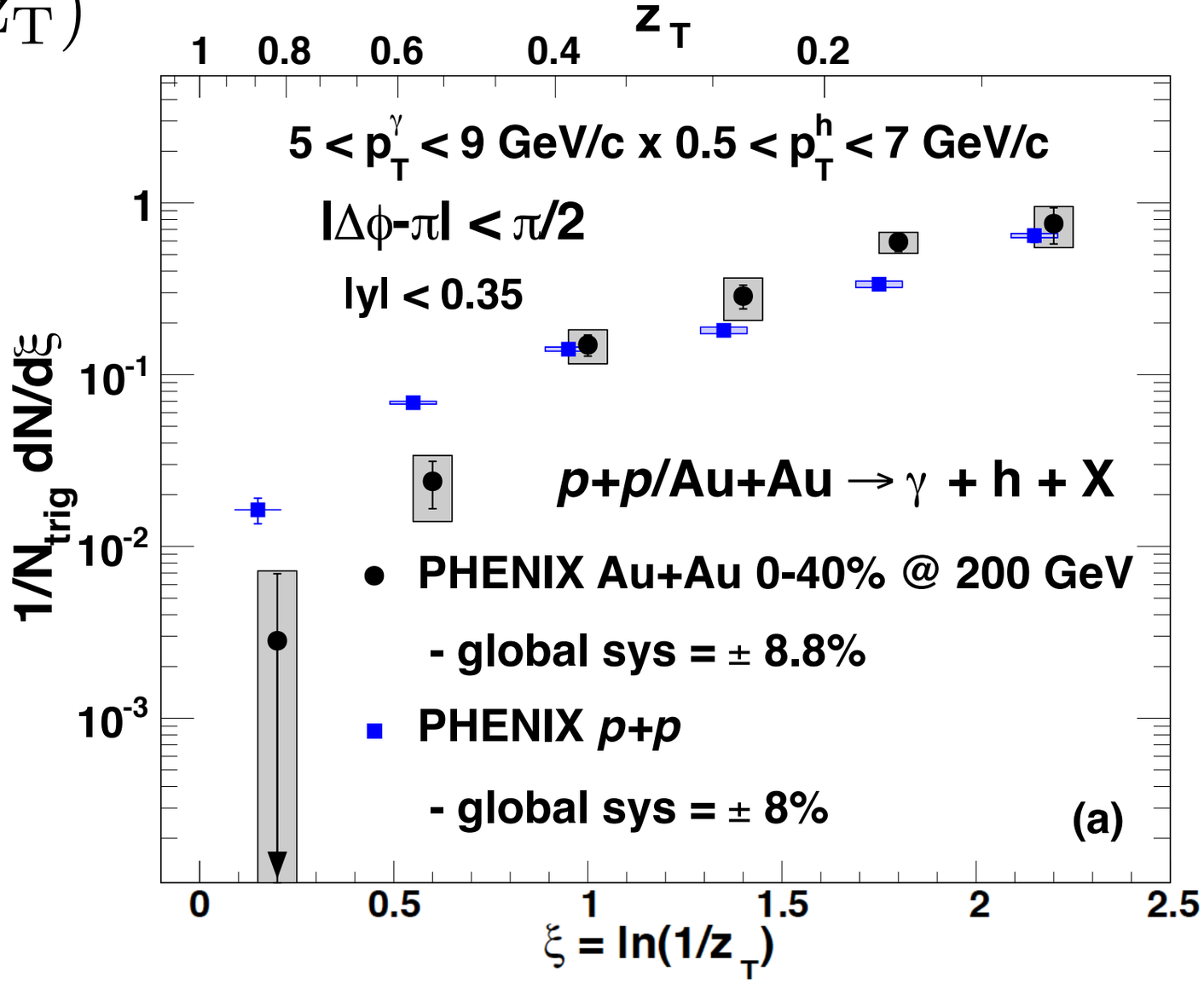
Meauring the effective fragmentation function

$$p_T^{\gamma} \approx p_T^{jet} \qquad z_T = \frac{p_T^h}{p_T^{\gamma}} \qquad \Longrightarrow \qquad D_q(z_T) = \frac{1}{N_{evt}} \frac{dN(z_T)}{dz_T}$$

- measure away-side yield to get effective fragmentation function
- focus on low $z_T \rightarrow \xi = \ln(1/z_T)$

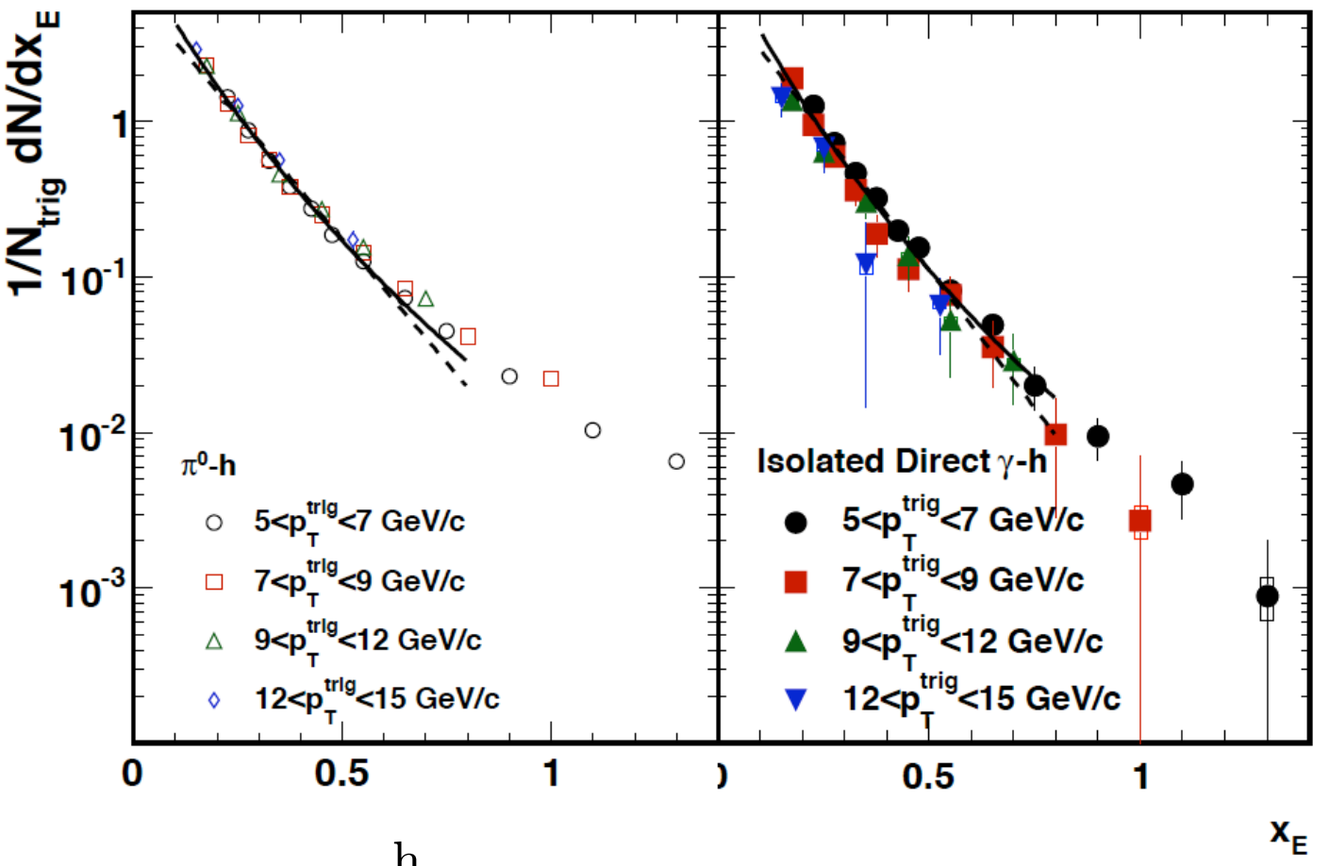


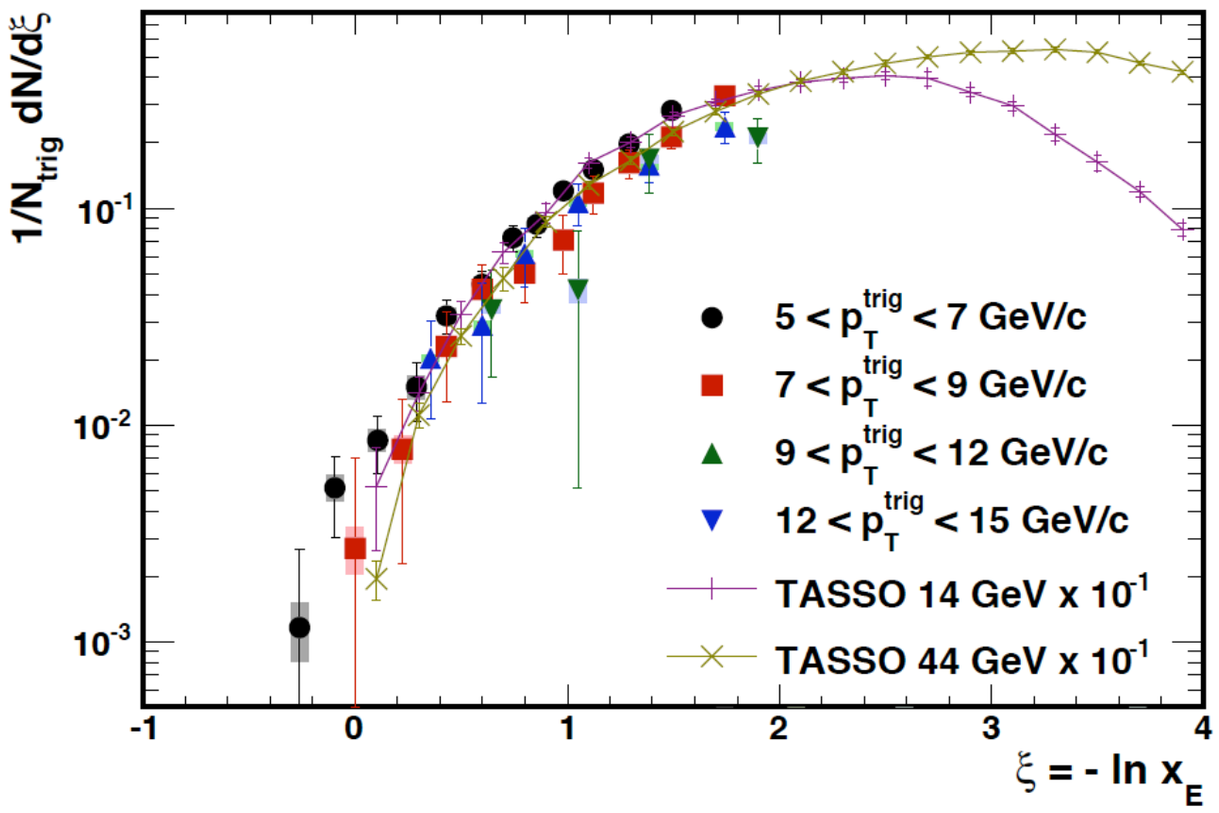
arXiv:1212.3323



Establishing the p+p baseline

A. Adare et al, Phys. Rev. D 82, 072001 (2010)



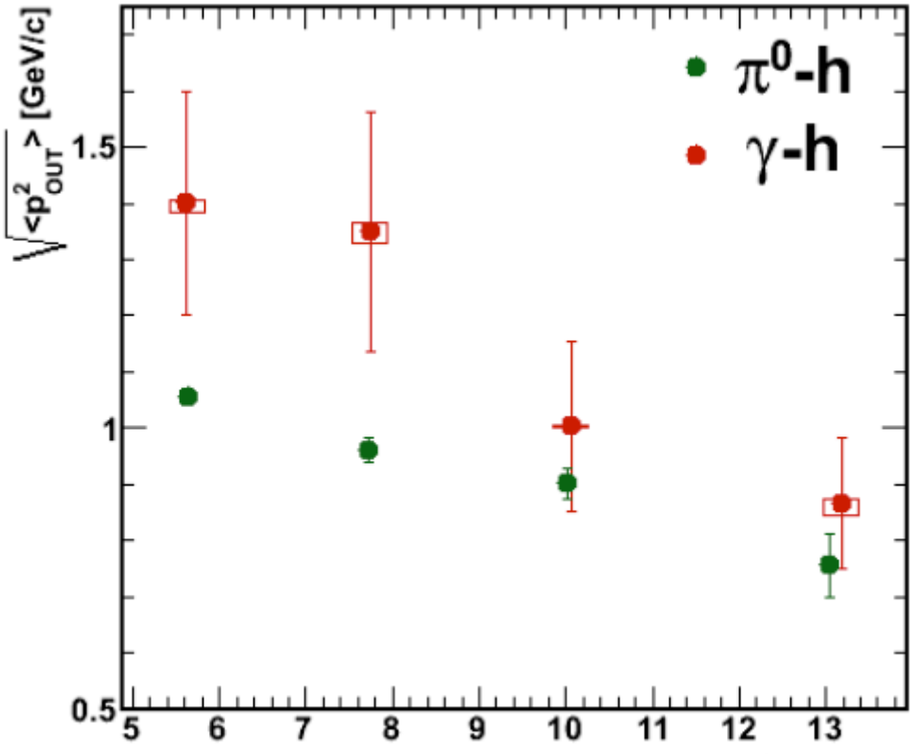


$$x_E = -\frac{p_T^h}{p_T^\gamma}\cos(\Delta\phi) \sim z_T$$

$$\frac{dN}{dx_E} = Ne^{-bx_E}$$

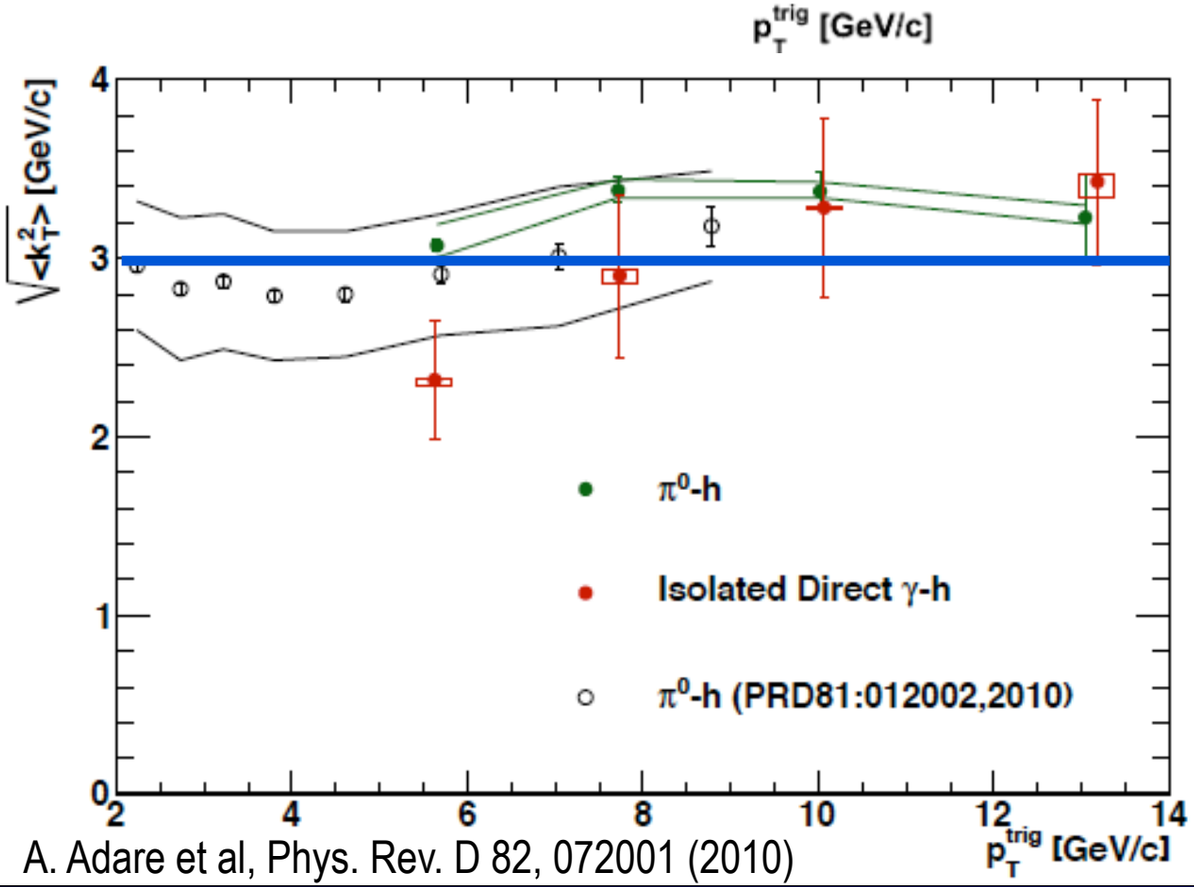
- approximate universal scaling
- b = 8.2 ± 0.3 → consistent with quark fragmentation
- good agreement with TASO measurement (e^+e^-)

How approximate is $p_{T,\gamma} \sim p_{T,q\text{-jet}}$



- obtain p_{out} from C($\Delta\phi$)
- extract k_T using LO+k_T smearing model
- consistent with other jet measurements
- no significant variation in k_T observed

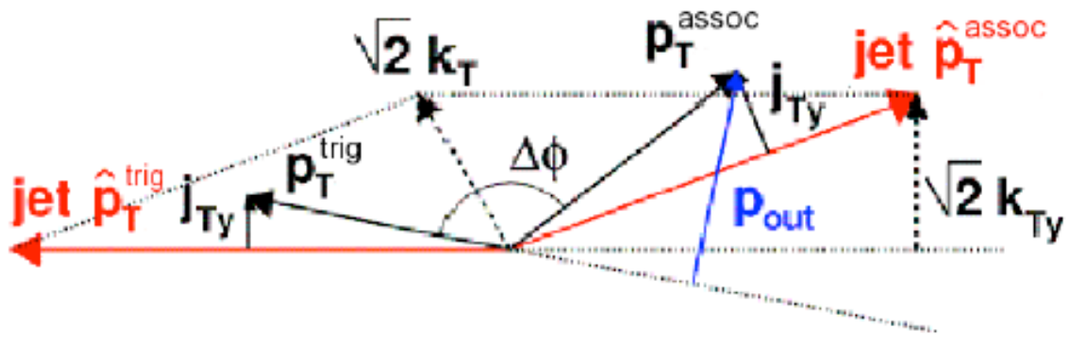
(Adler et al, Phys.Rev.C73:054903,2006)



A. Adare et al, Phys. Rev. D 82, 072001 (2010)

$$|p_{\rm out}| = |p_{\rm T}^{\rm assoc}|\sin\Delta\phi$$

$$|p_{\rm out}|^2 = x_{\rm E}^2[2\langle|k_{Ty}|\rangle^2 + \langle|j_{Ty}|\rangle^2] + \langle j_{Ty}\rangle^2$$



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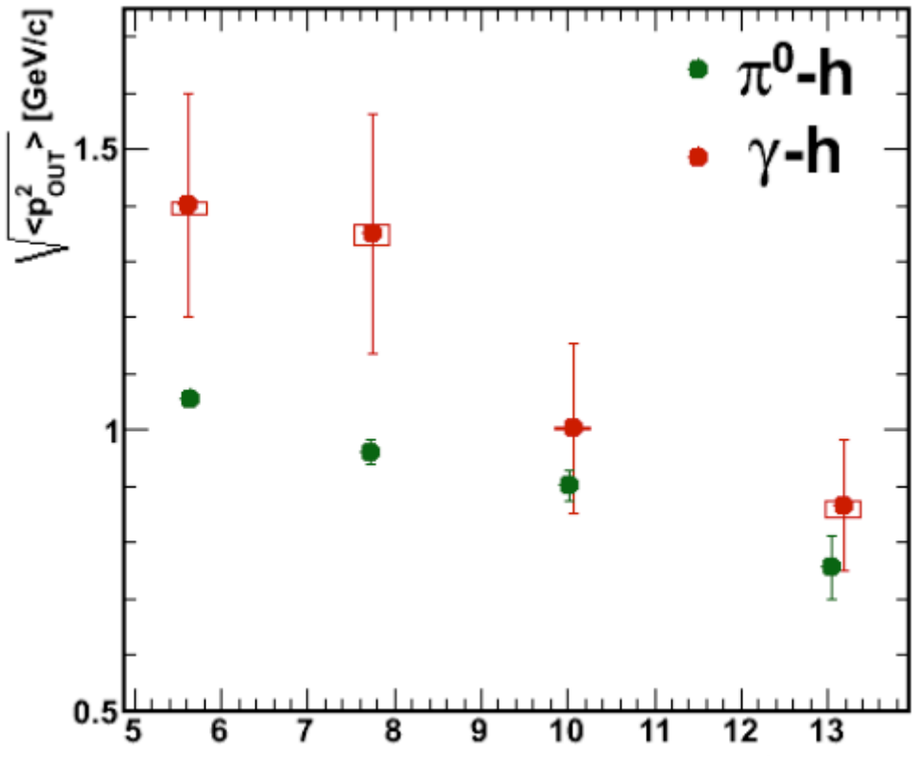

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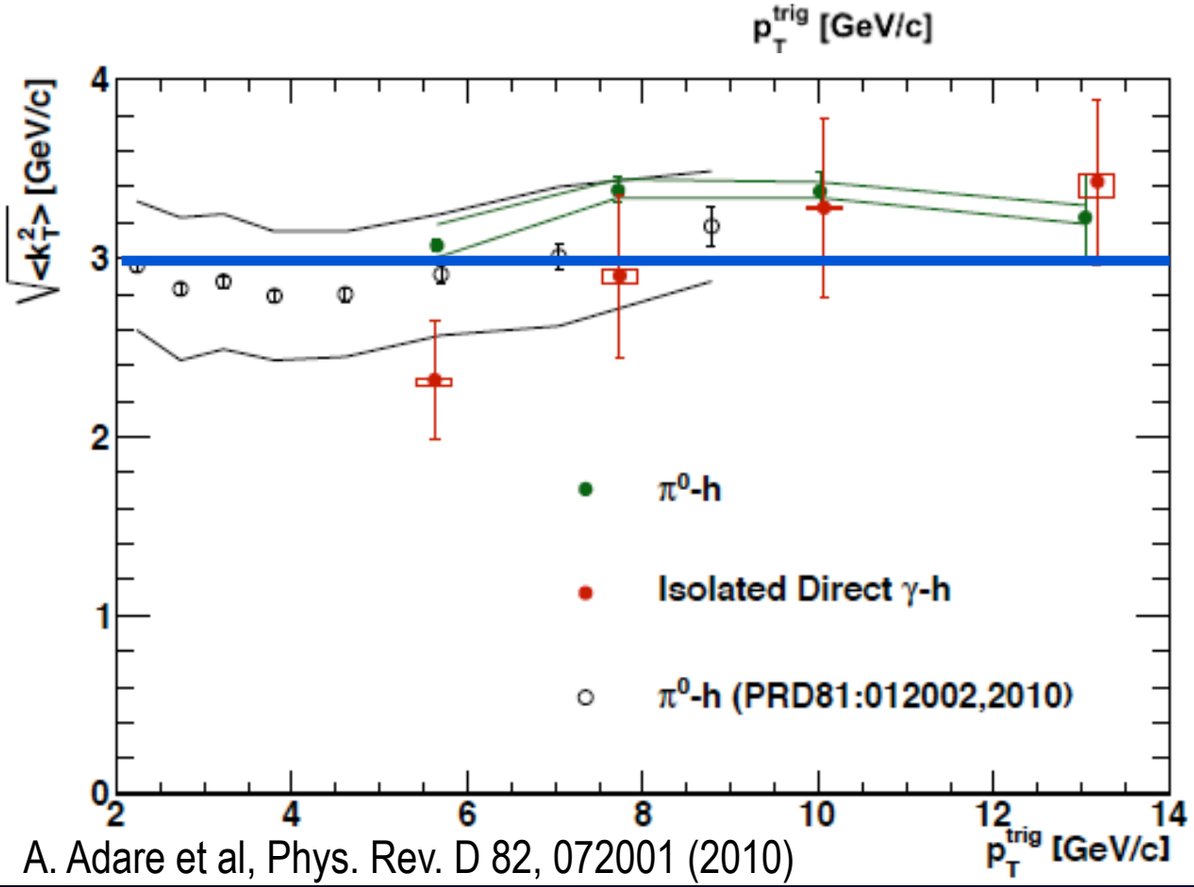

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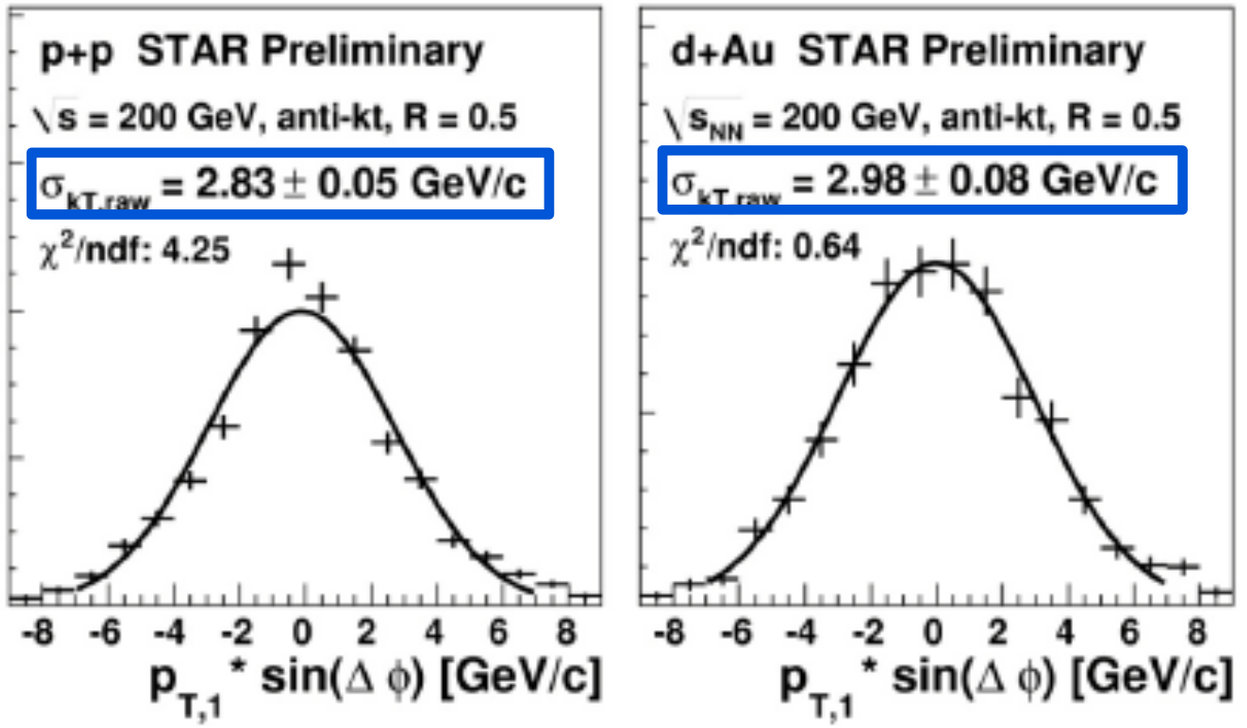
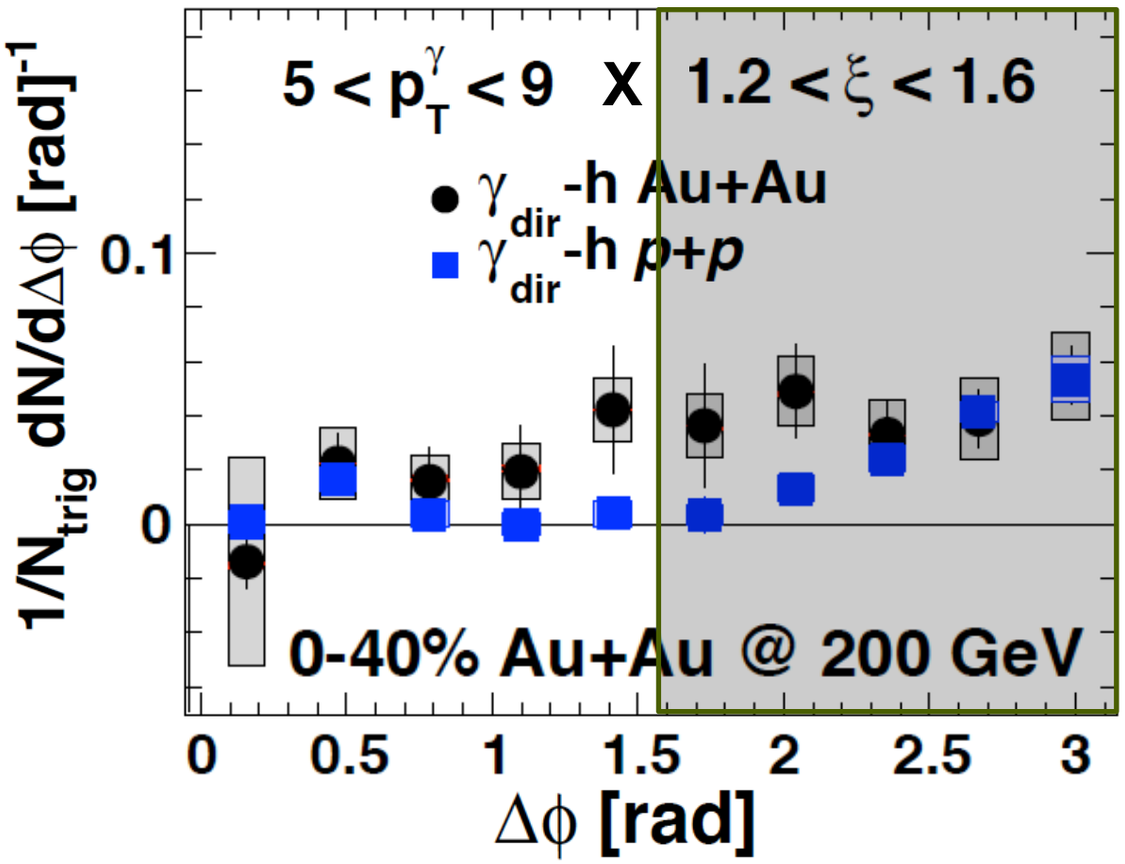
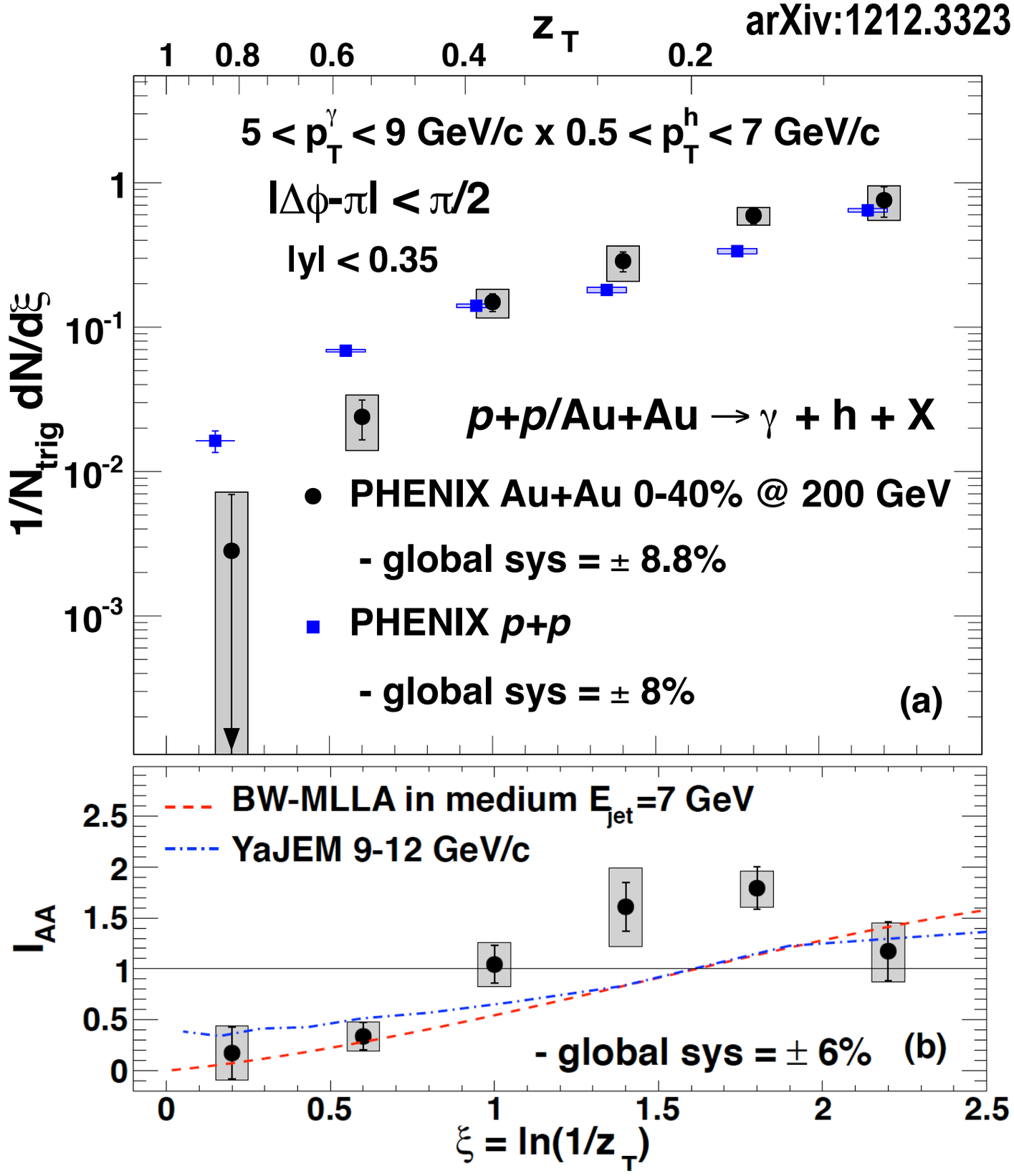
p_T(jet): 10-20 GeV/c



We see modification!

$$I_{AA} = \frac{Y_{AA}}{Y_{pp}} \sim \frac{D_{AA}(z_T)}{D_{pp}(z_T)}$$





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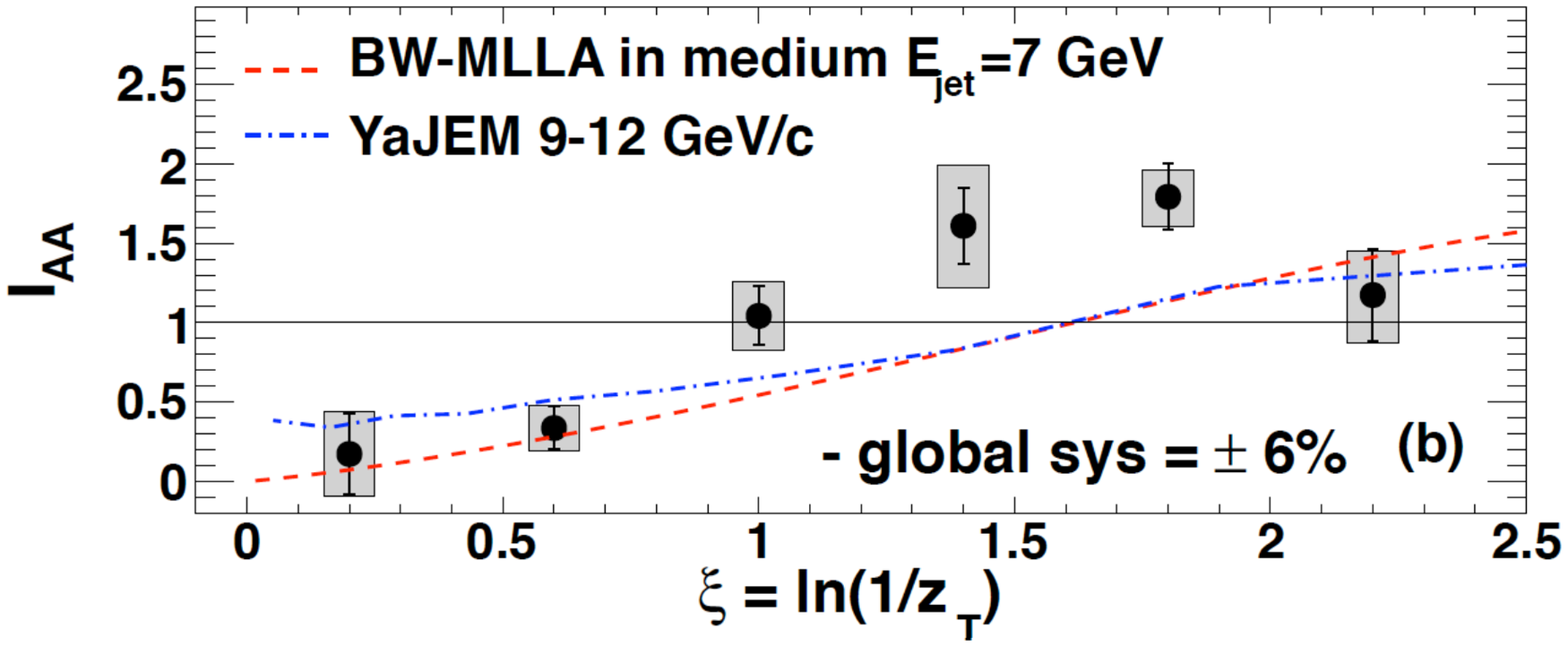
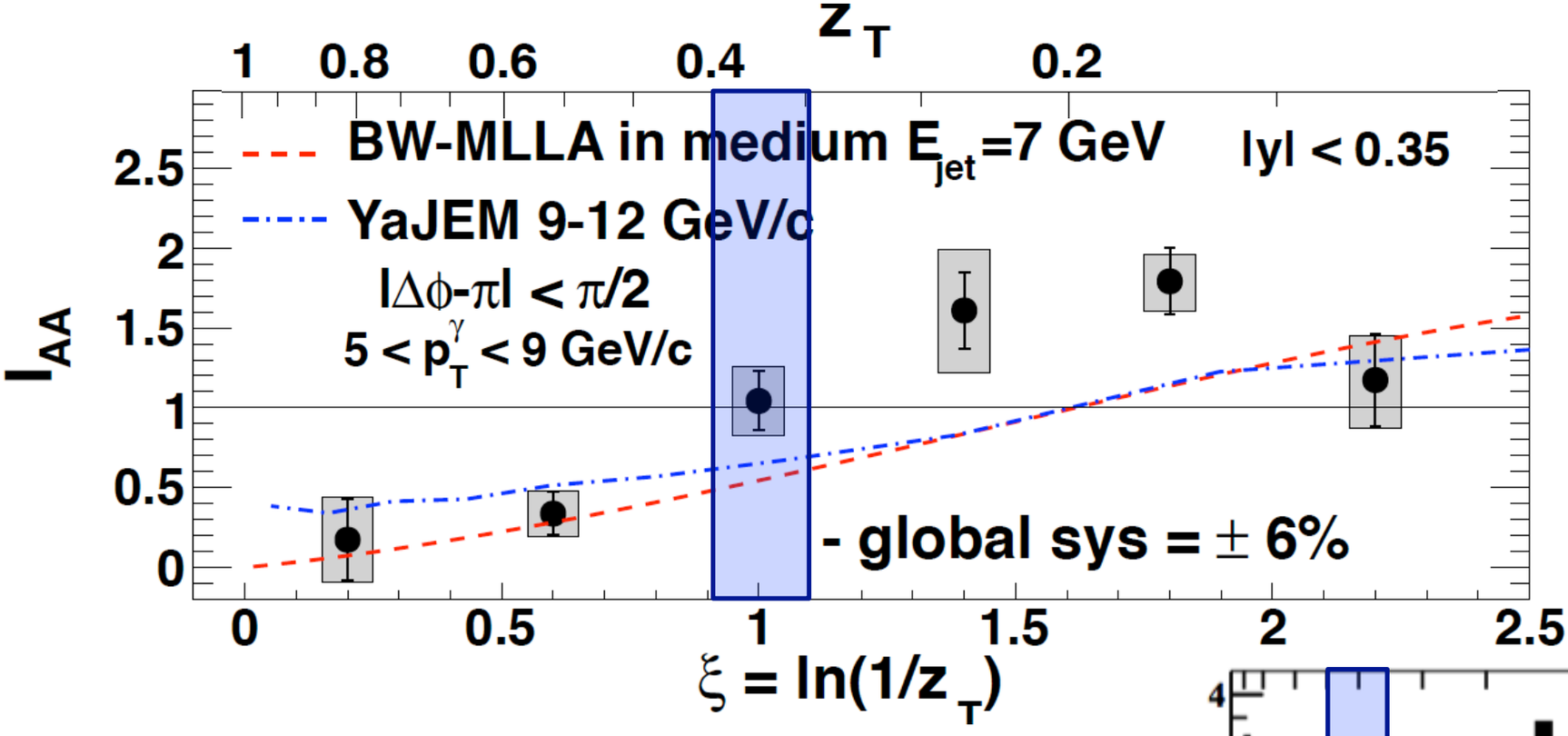
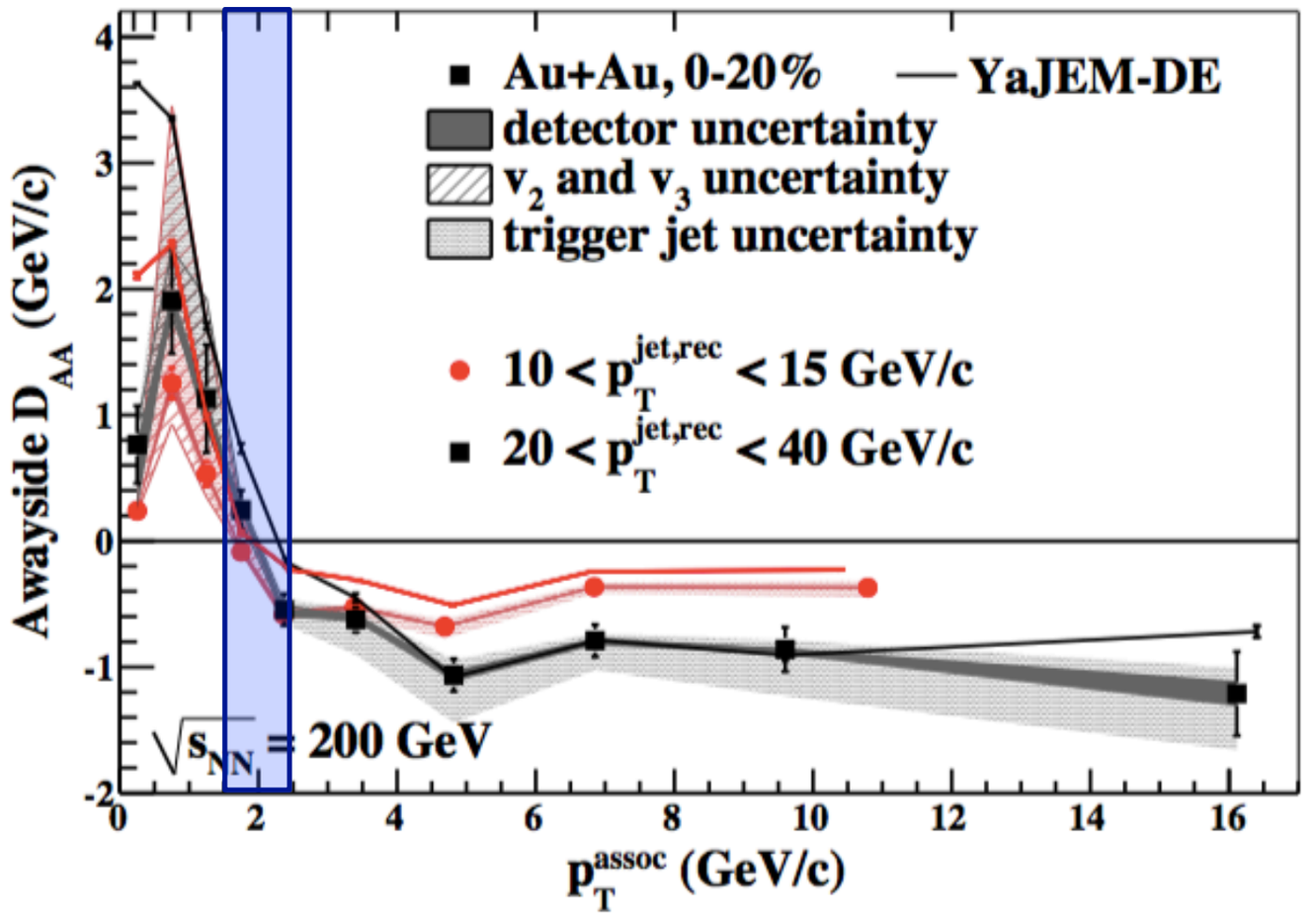
arXiv:1212.3323



- See modification to effective fragmentation function (shape)
- Qualitative agreement with expectations from models that track the redistribution of energy from leading parton to soft particle production

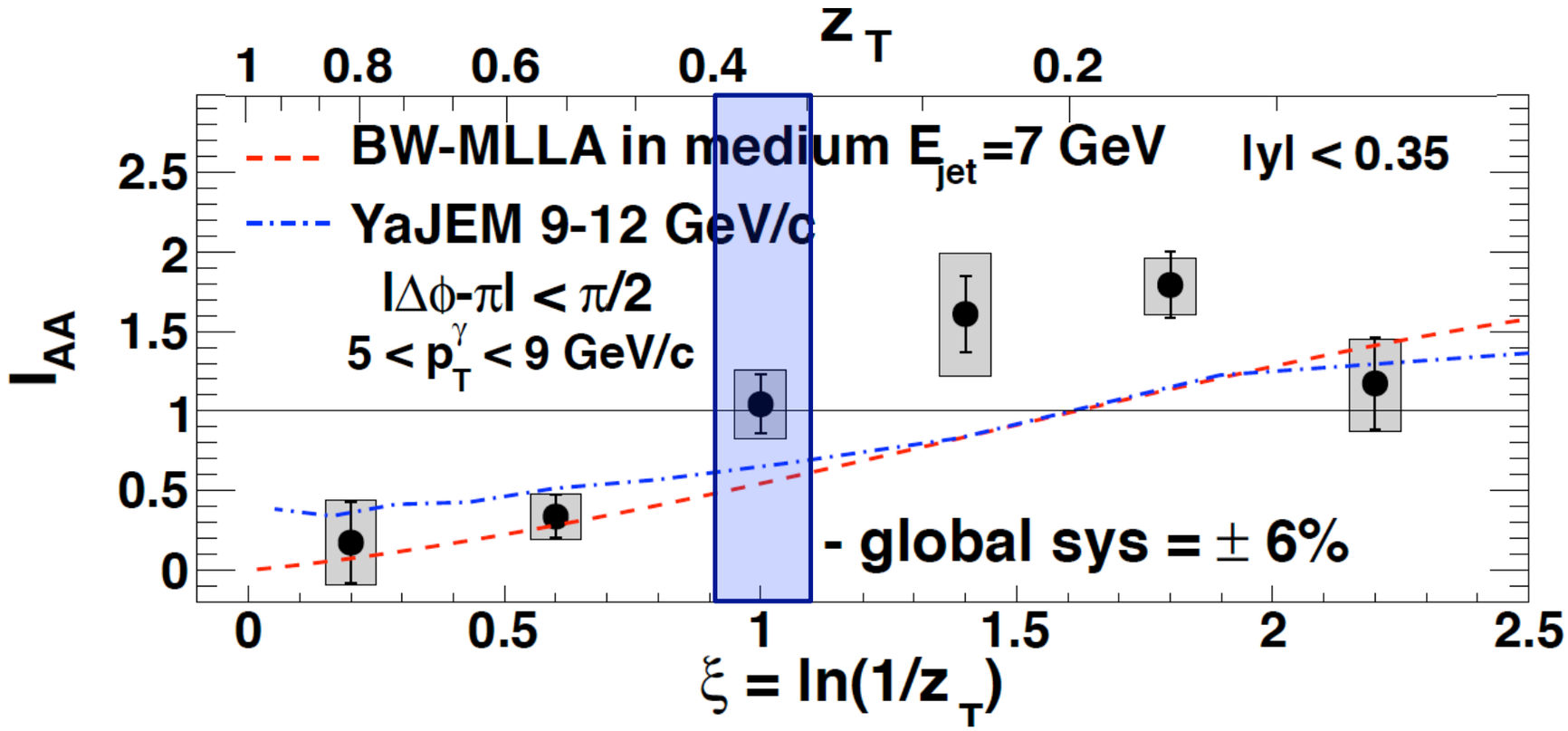
Comparison to similar RHIC results





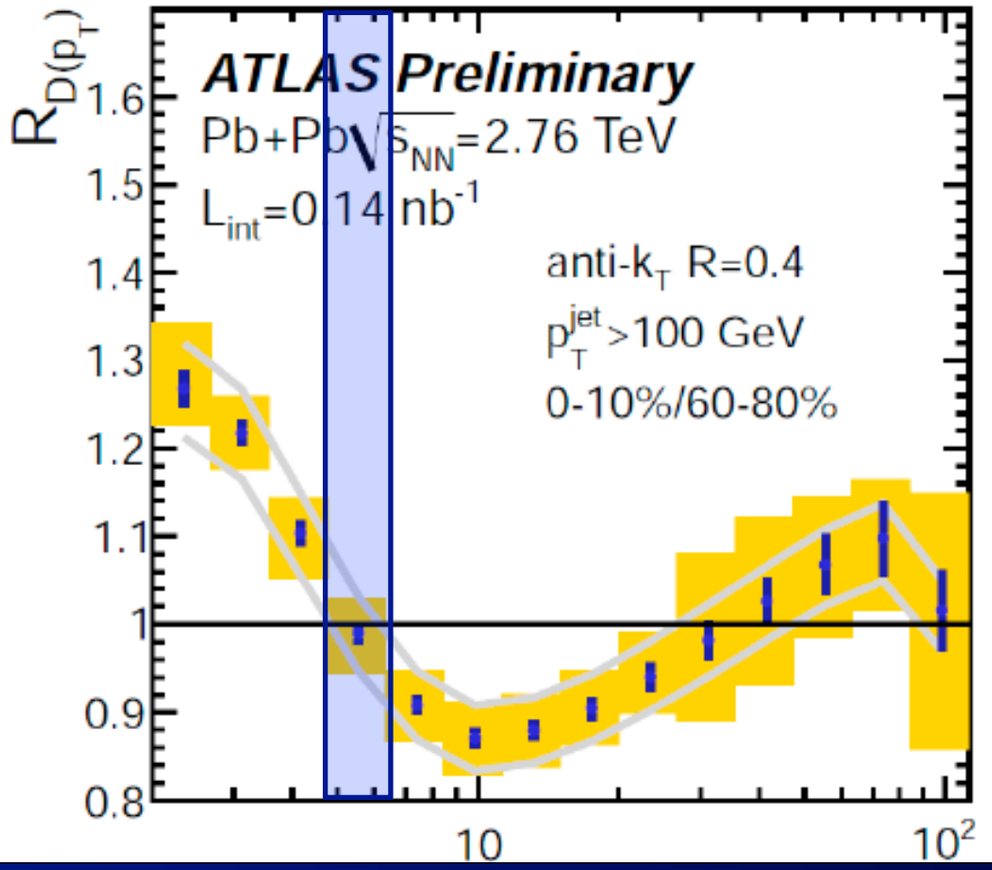
- Transition from suppression to enhancement at $p_{T,assoc}$ ~ 2 GeV/c

Comparison to similar LHC results



- Transition from suppression to enhancement
  - ~ 2 GeV/c at RHIC
  - ~ 3-5 GeV/c at LHC

What determines the constituent p_T at which enhancement appears?



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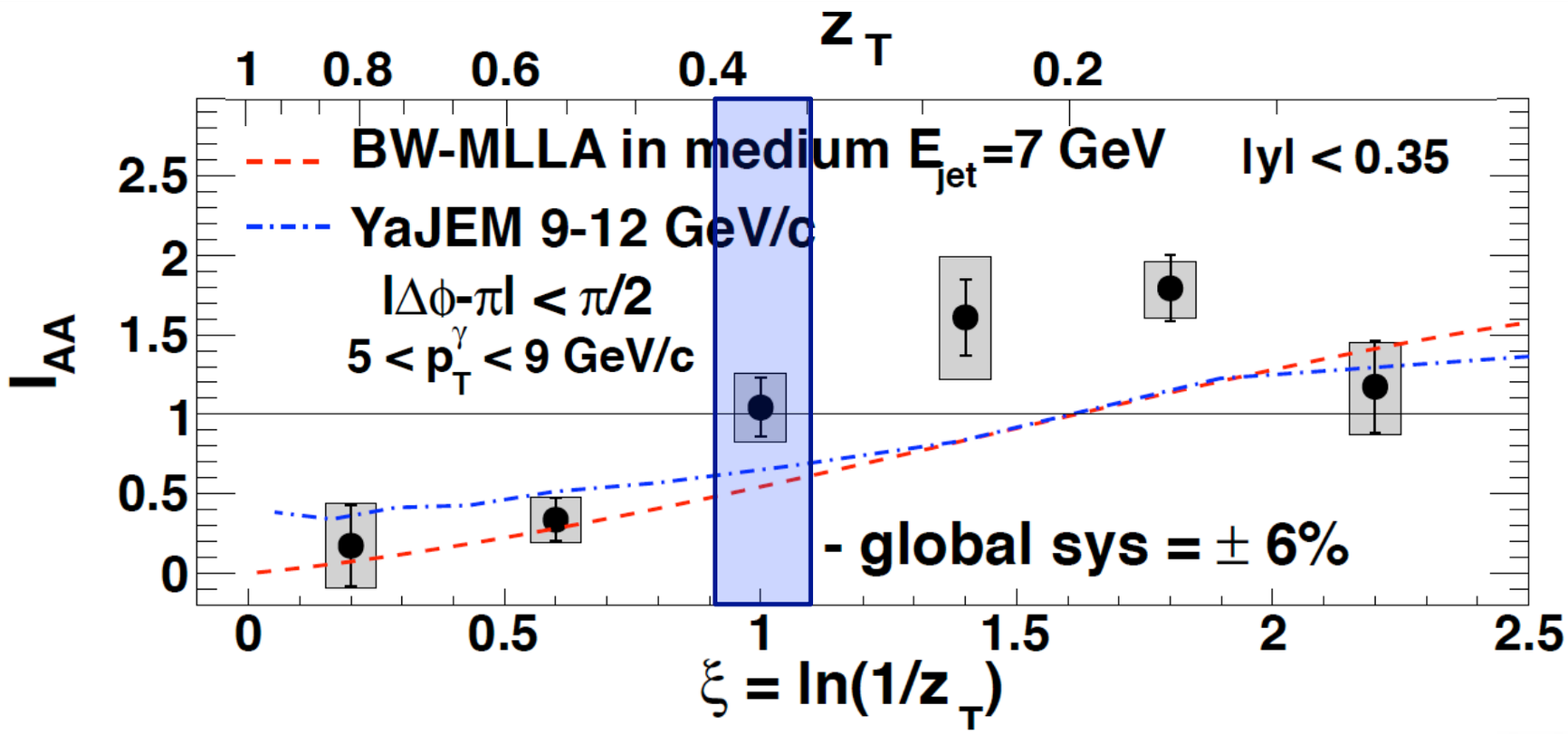

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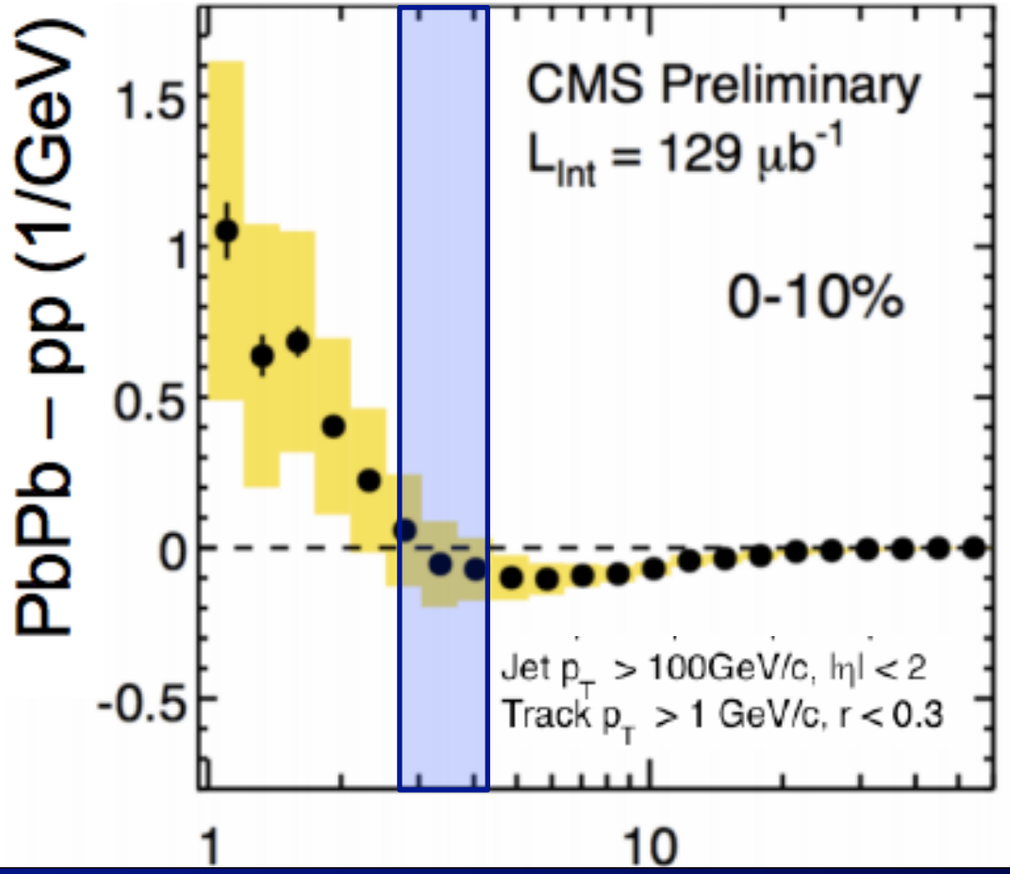
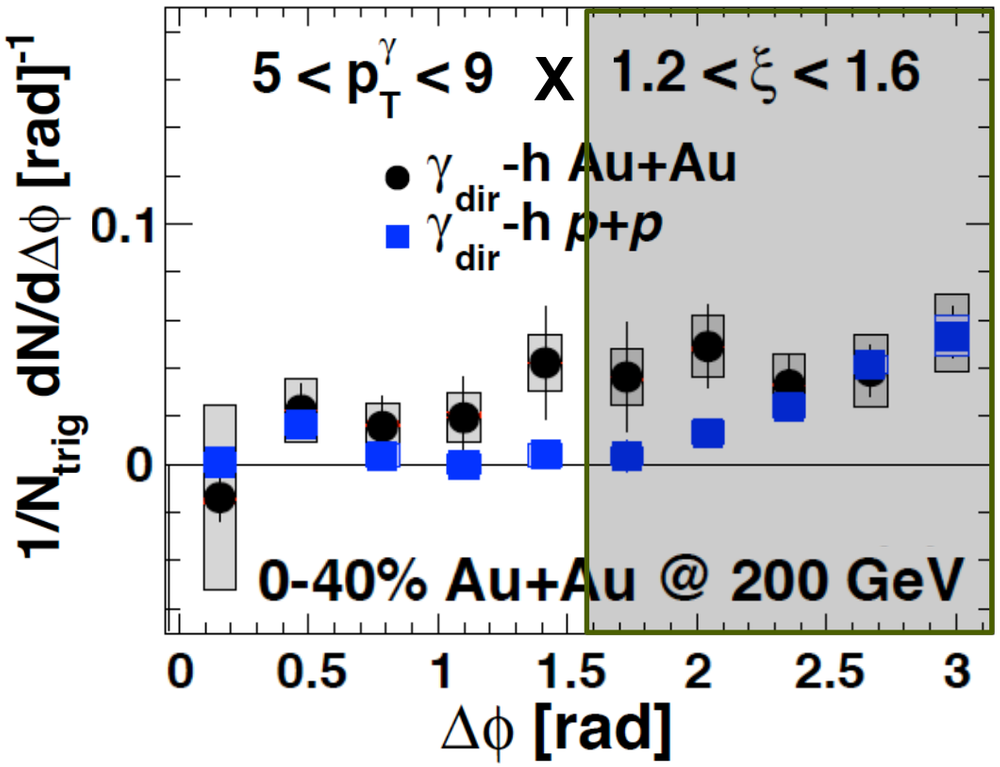
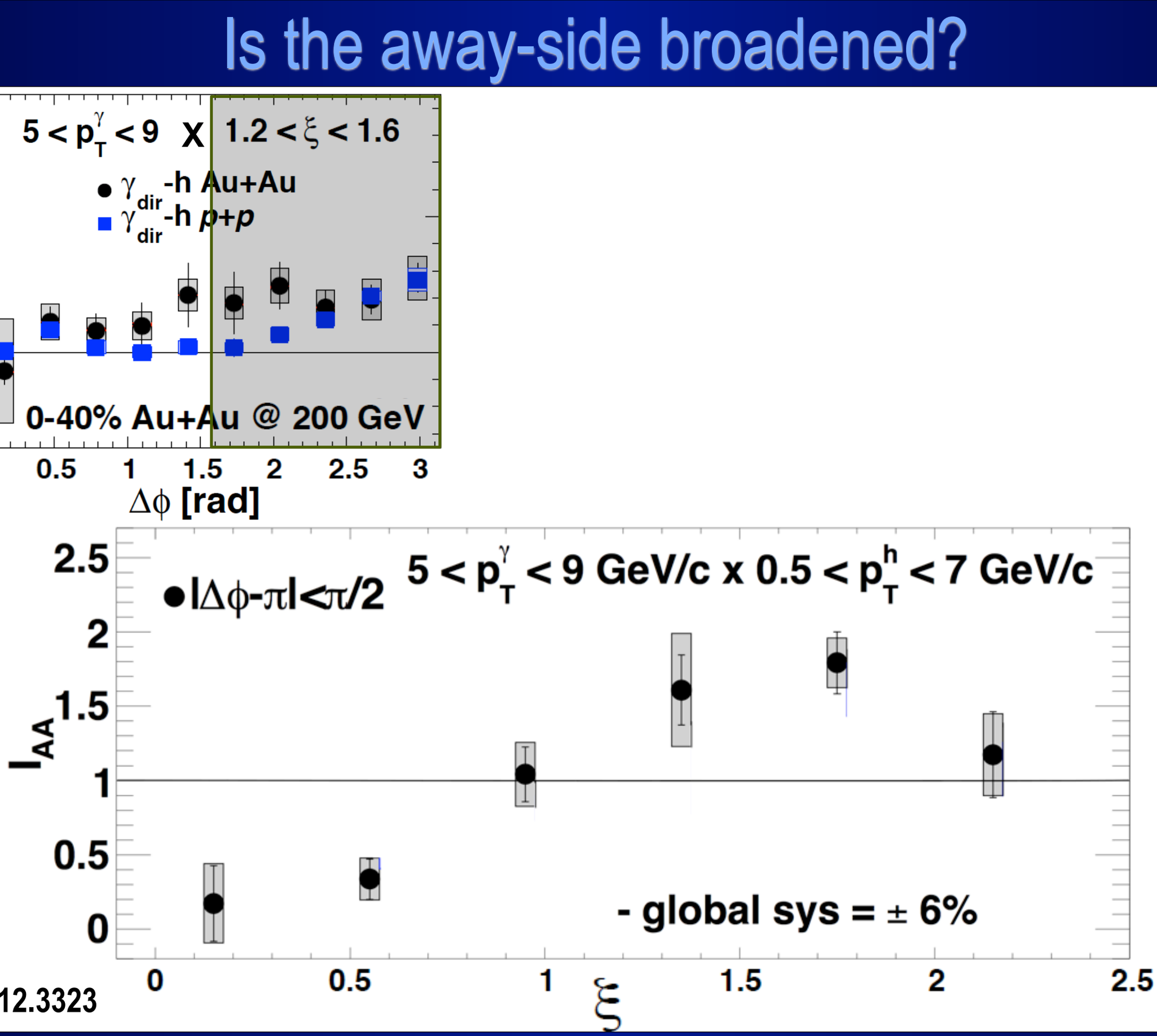


Is the away-side broadened?





arXiv:1212.3323

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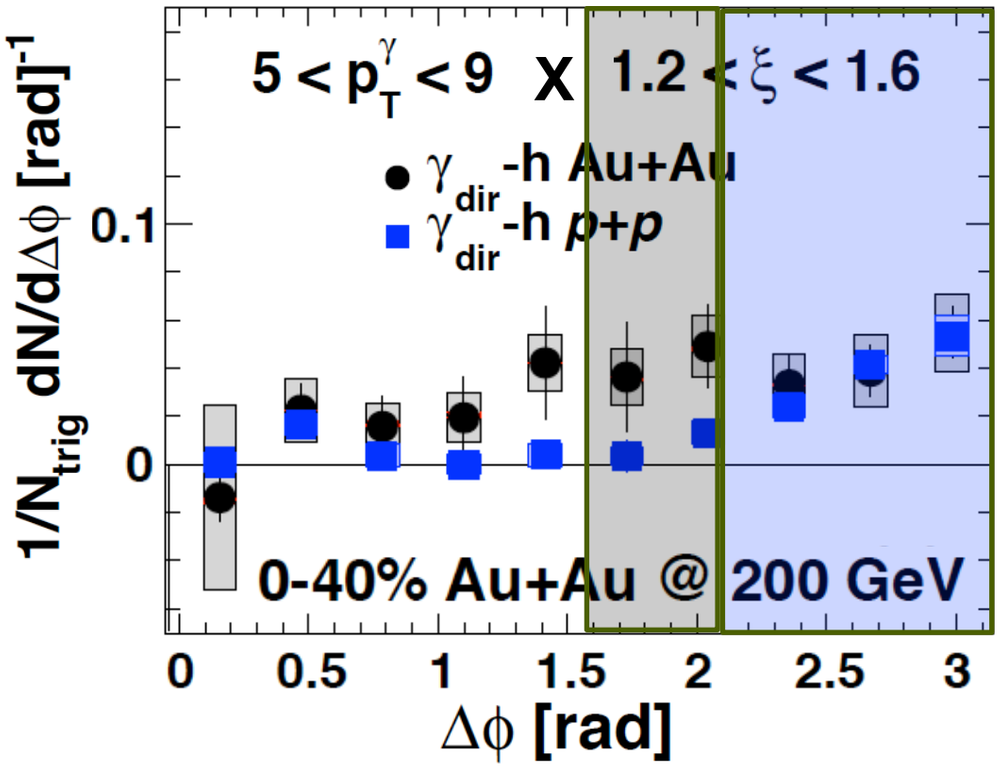

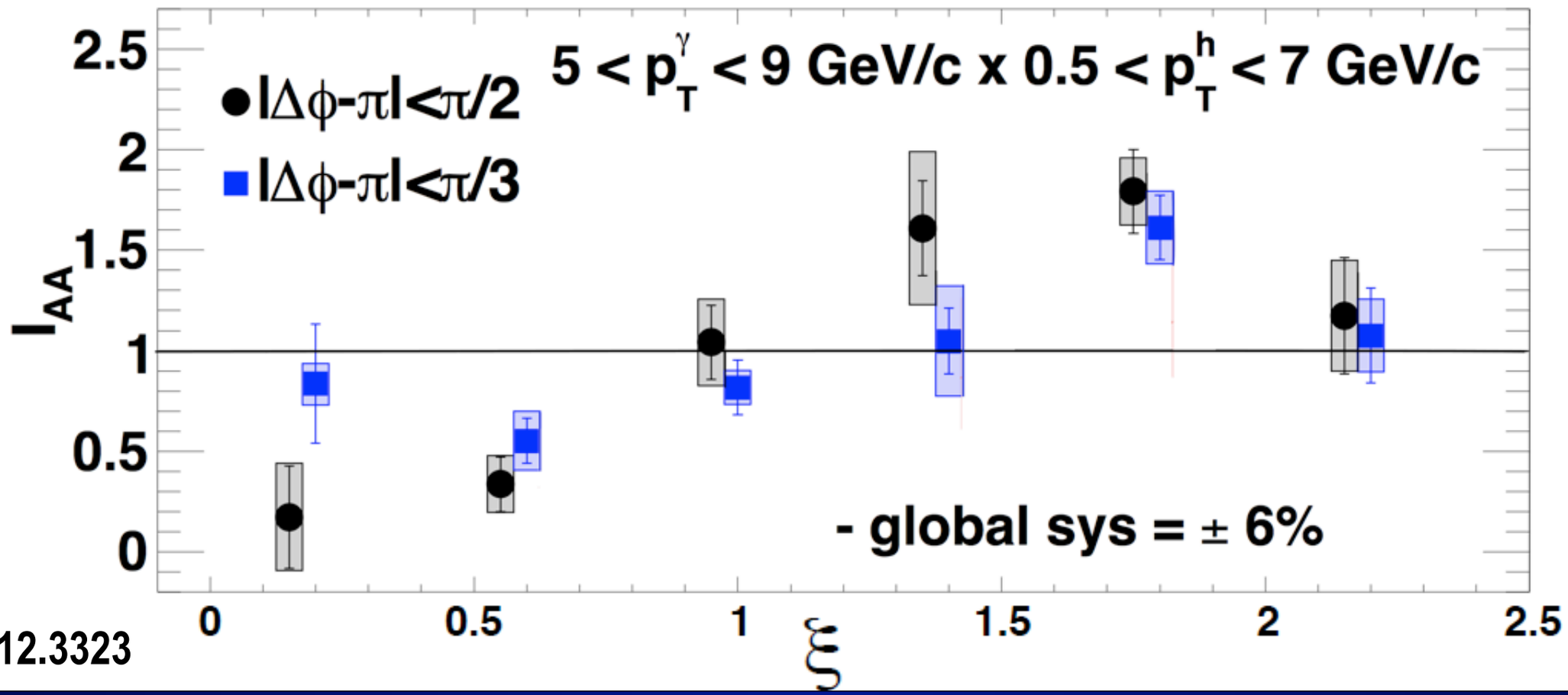

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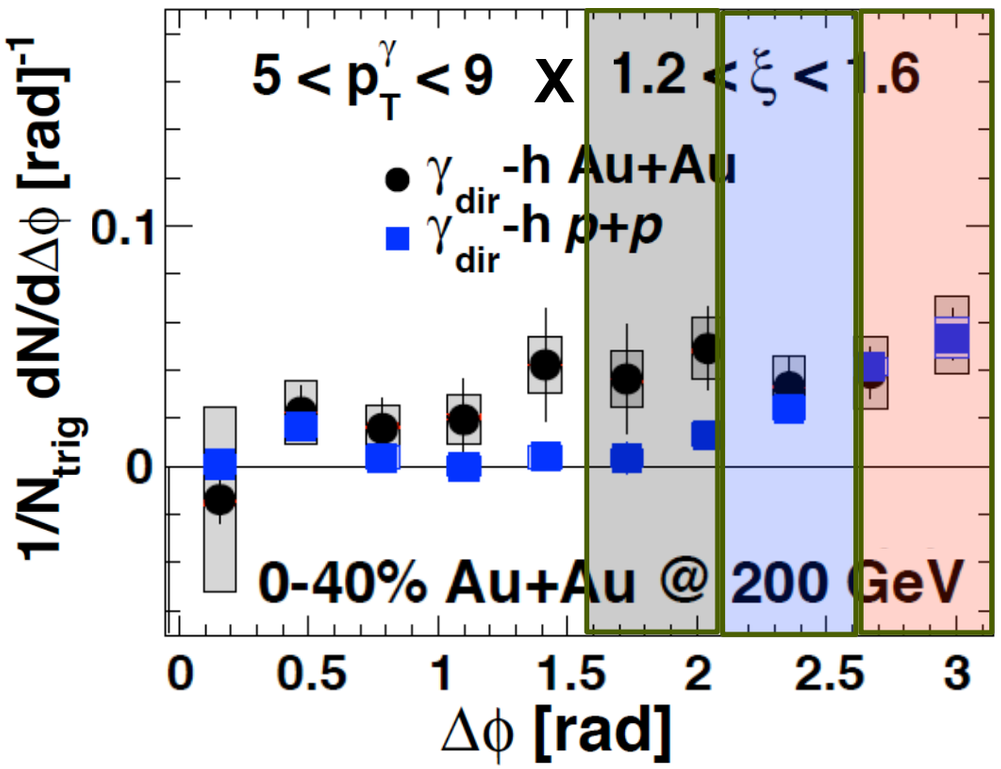

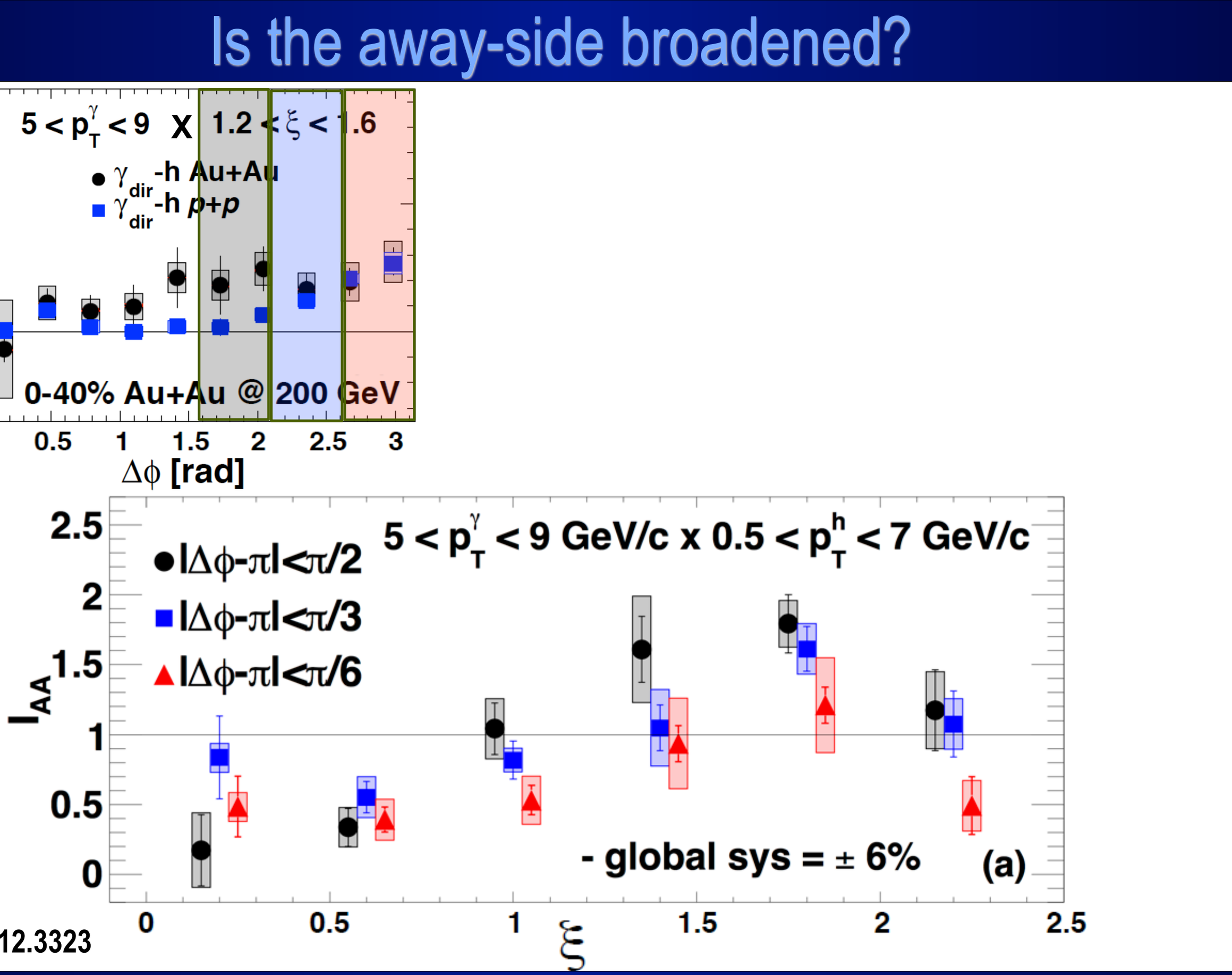

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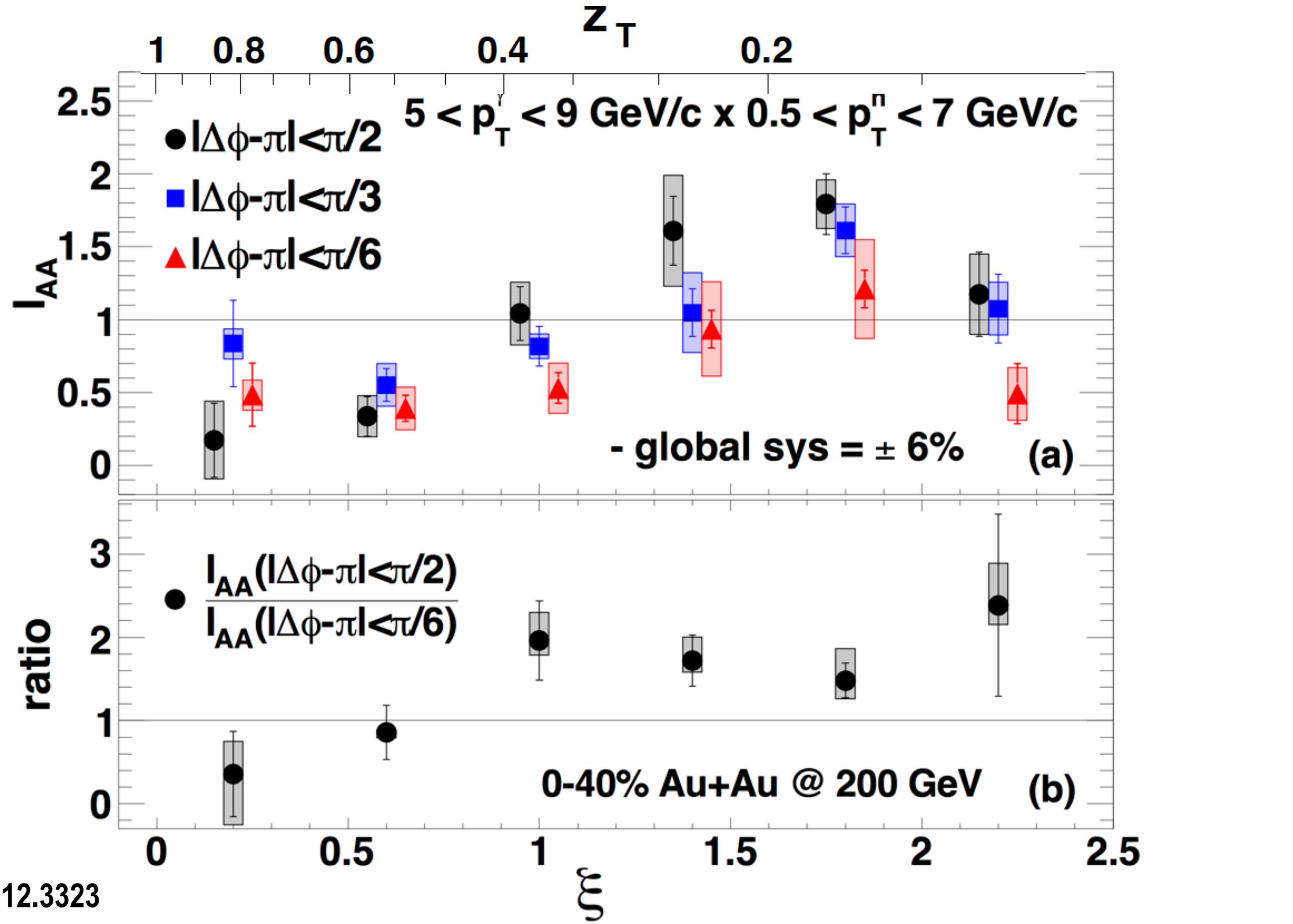

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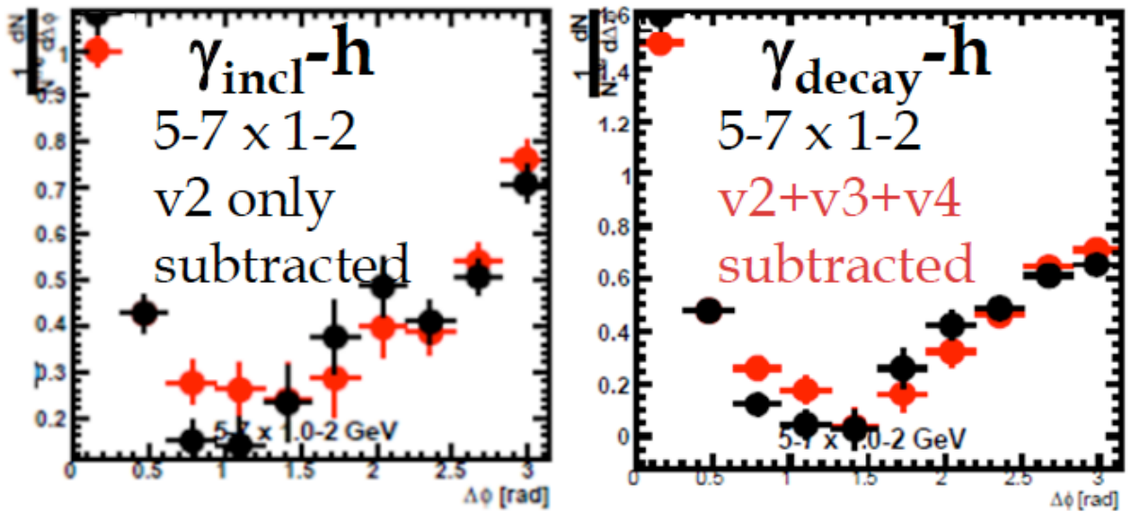
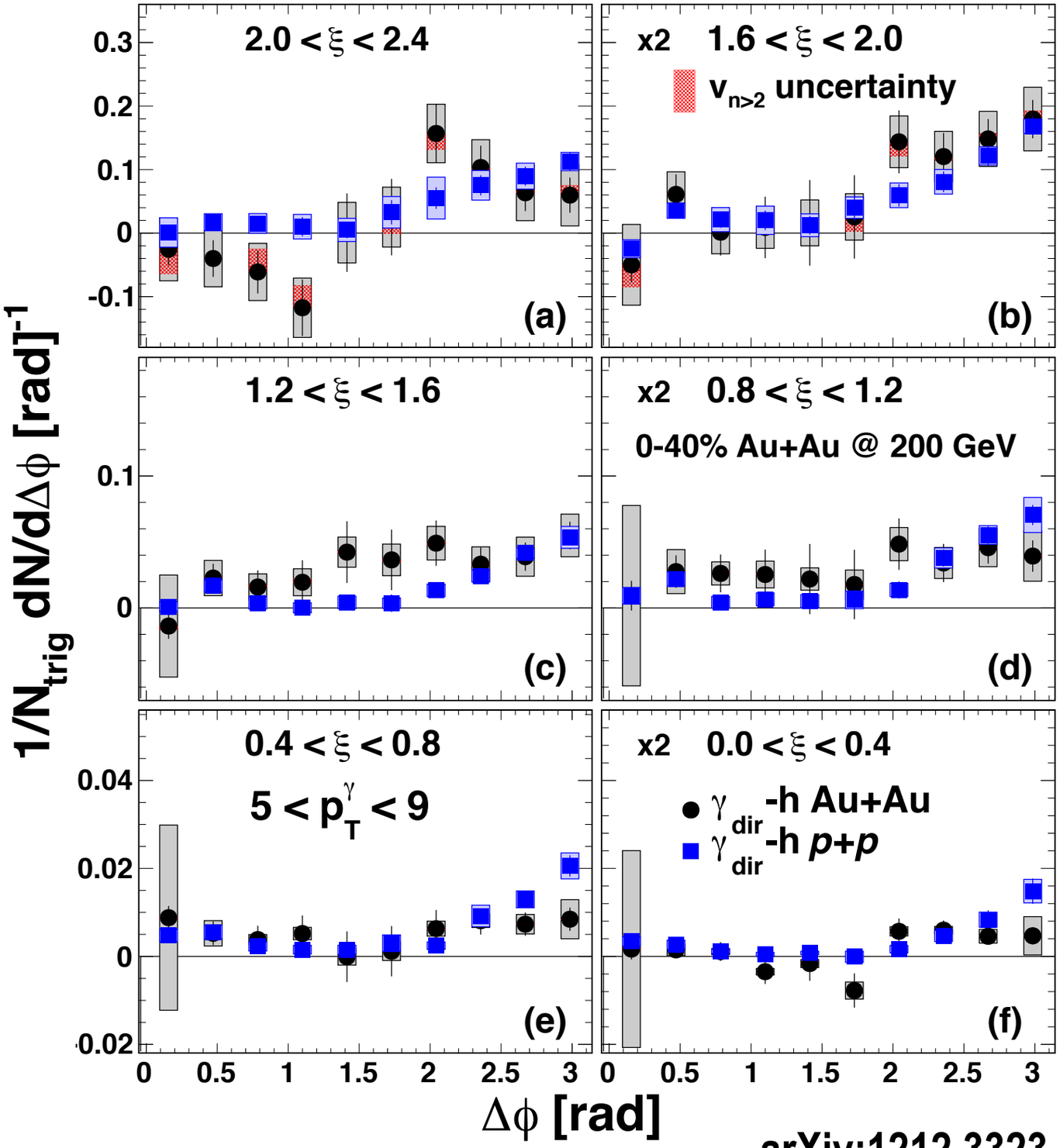
Could this simply be v_n again?

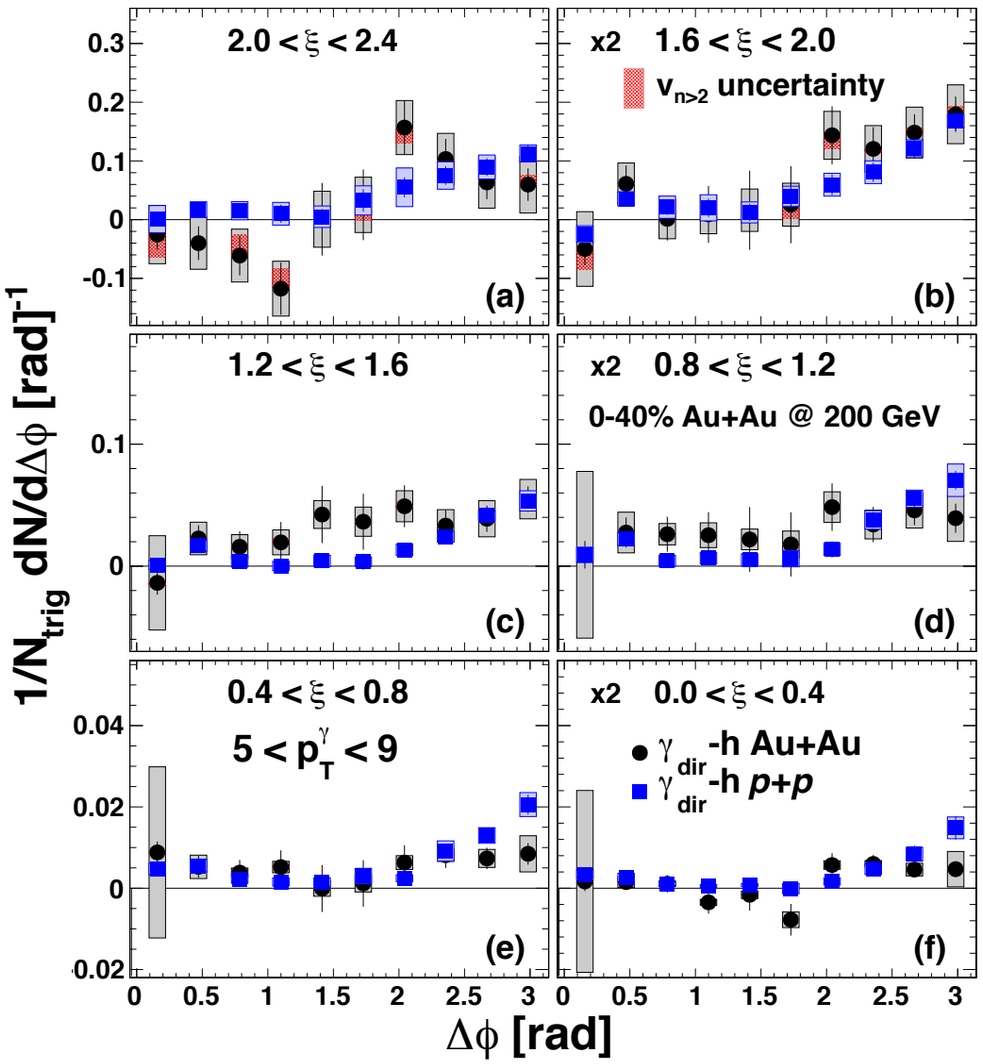


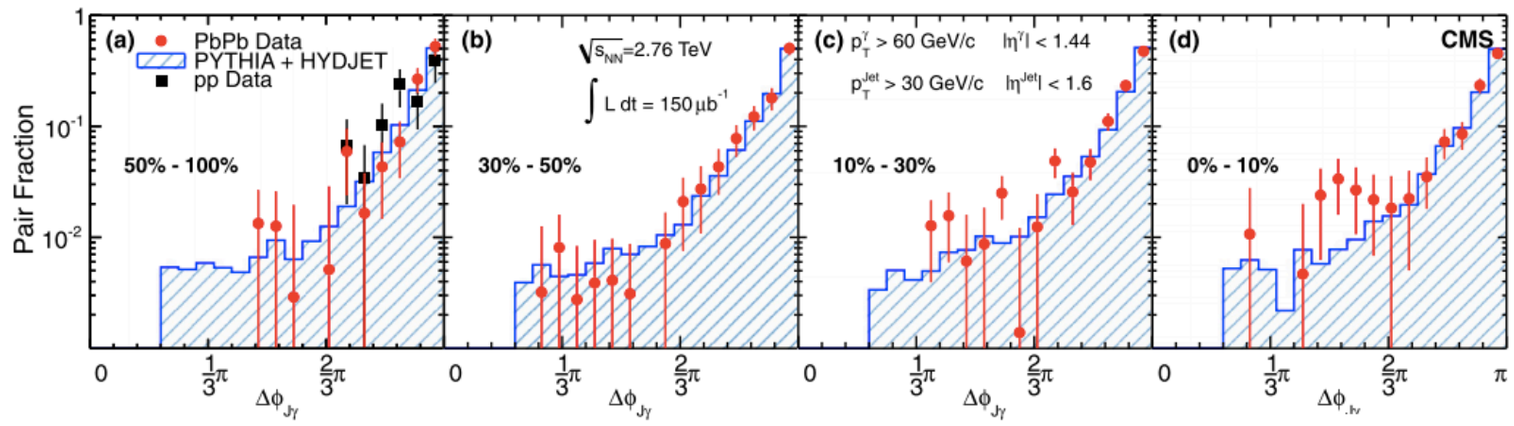
- No high p_T γ $v_{3,4}$ measurement
- Conservative estimate based on π^0
  - assume direct photon $v_n = 0.5 v_n^{\pi 0}$
- Uncertainties shown separately in $\Delta\phi$ distributions
- Additional source of systematic uncertainty in I_{AA} measurement

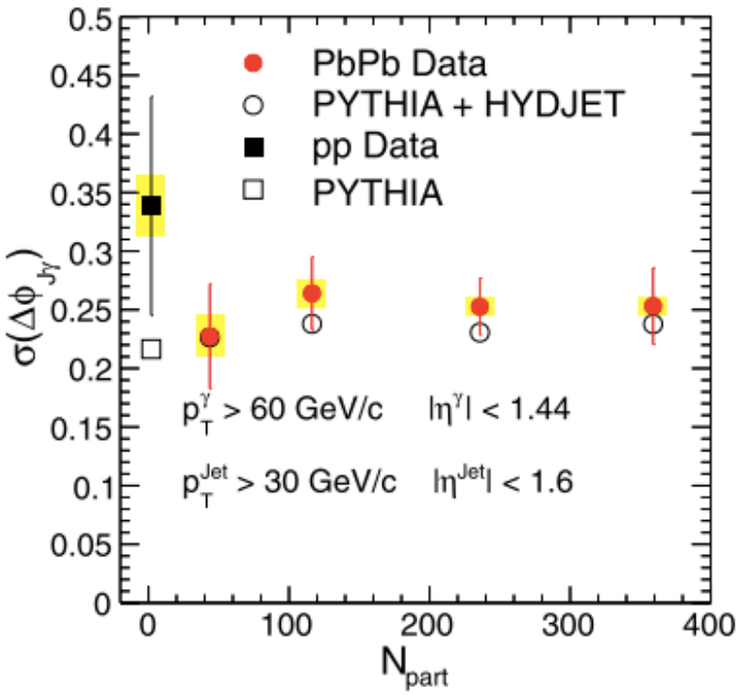


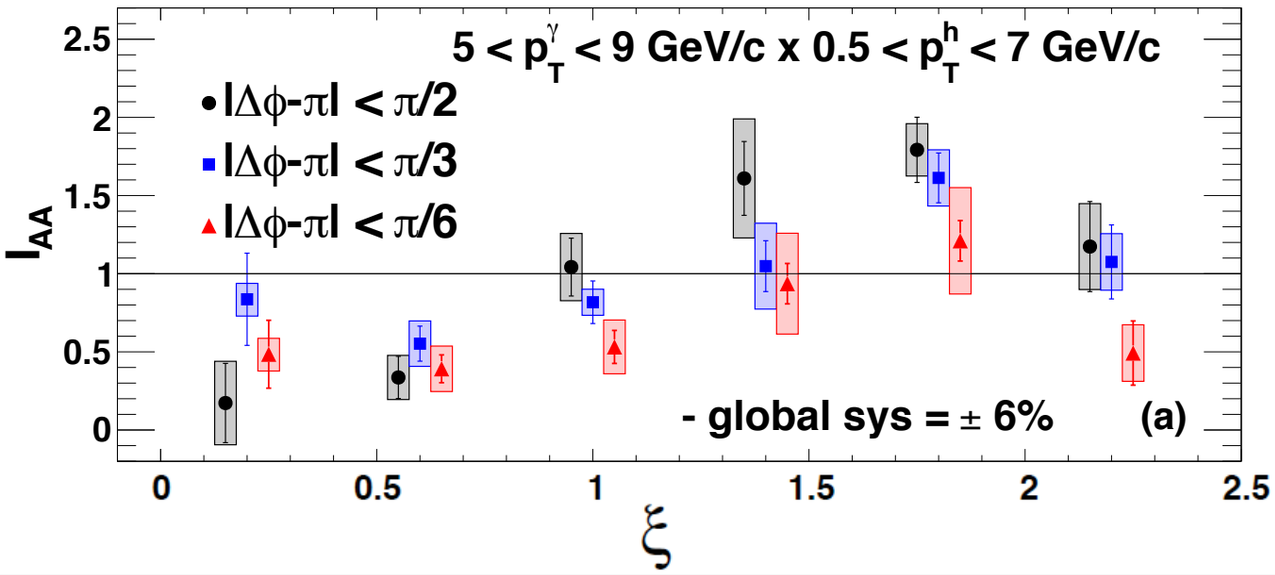
arXiv:1212.3323

What does γ-h away-side broadening imply?



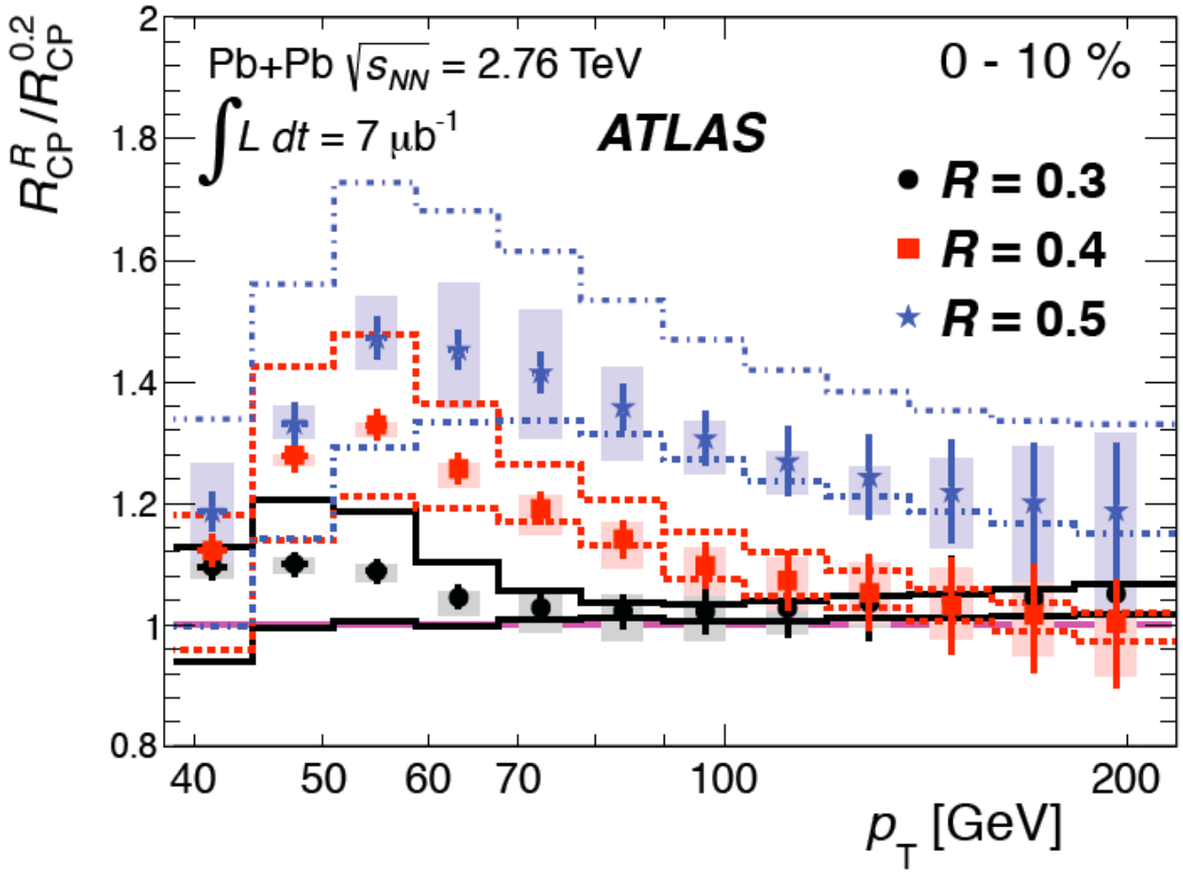


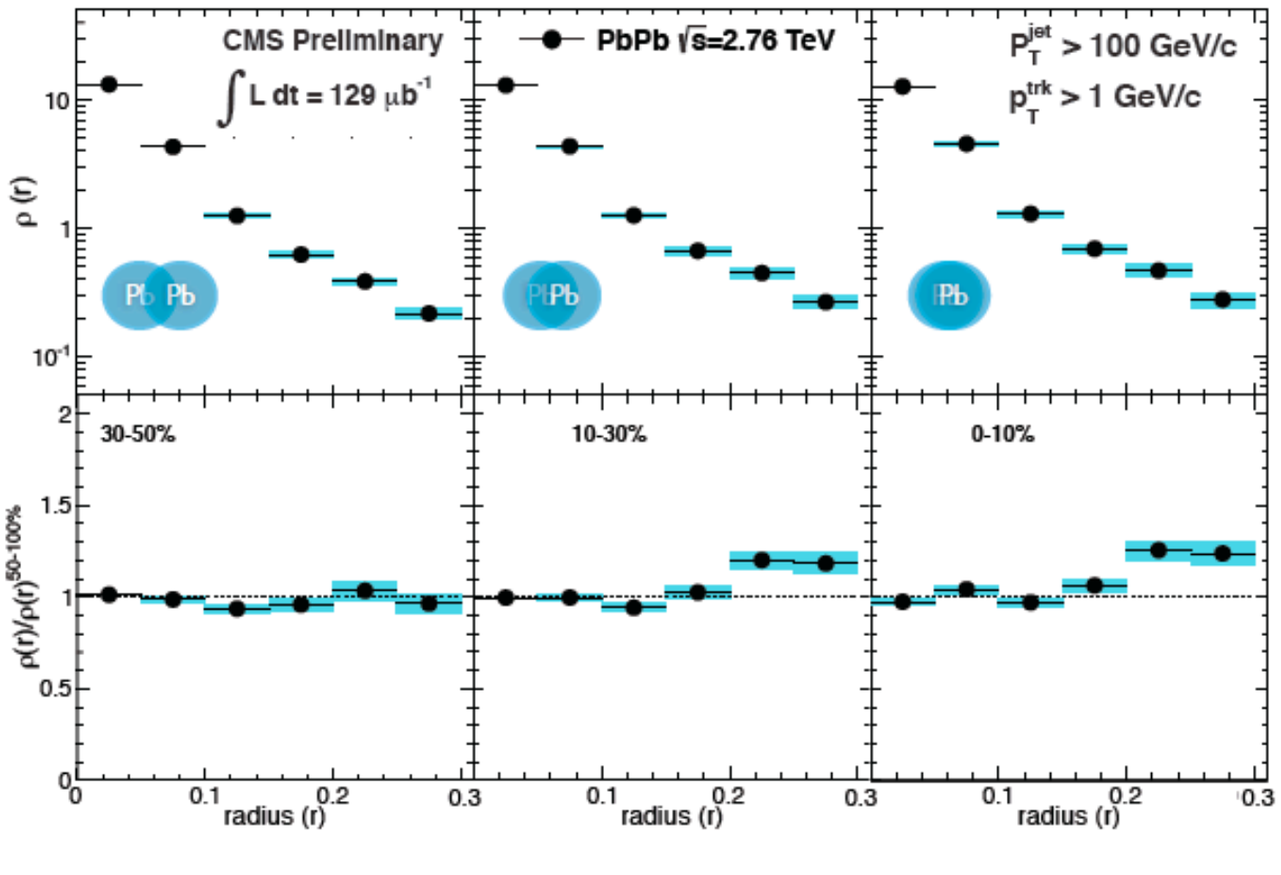


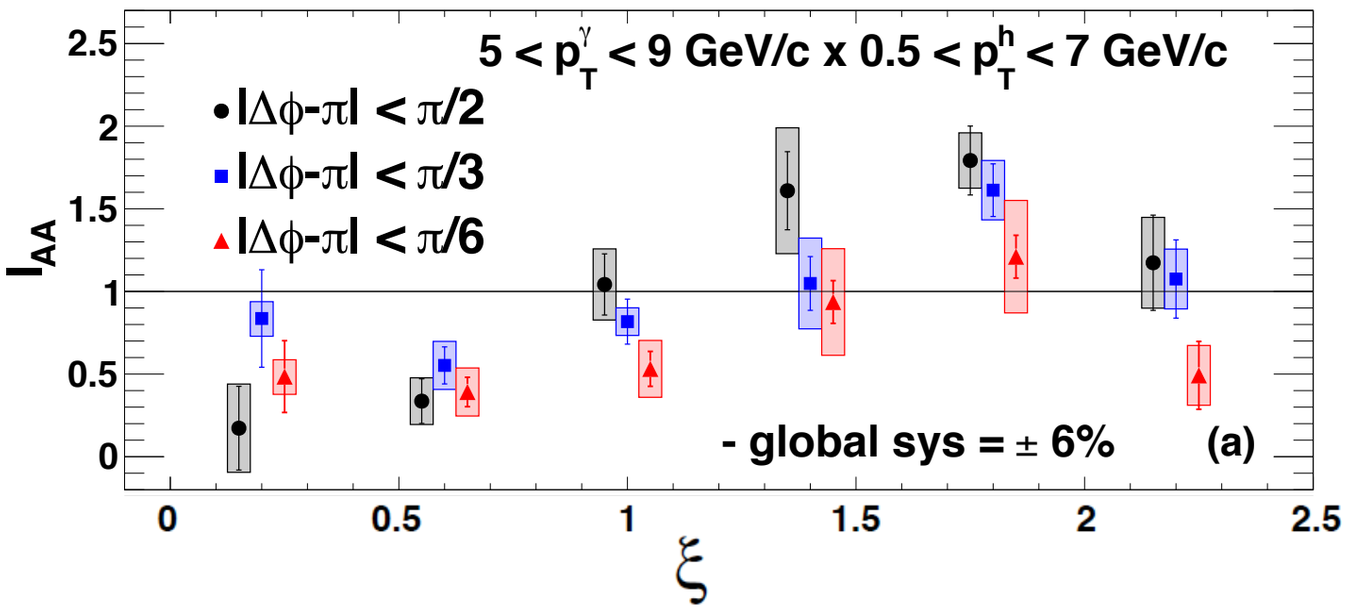


- γ-h Δφ variation results from either
  - variation in underlying γ-quark balance
  - broadening of away-side jet
- no broadening in γ-jet at CMS
  - different jet p_T and energies

What does γ-h away-side broadening imply?







- γ-h Δφ variation results from either
  - variation in underlying γ-quark balance
  - broadening of away-side jet
- broadening of jet seen at LHC
  - inclusive jet measurements
  - different jet p_T and energies

Summary

- p+p baseline well established
- k_T effect seen but likely similar in p+p and Au+Au

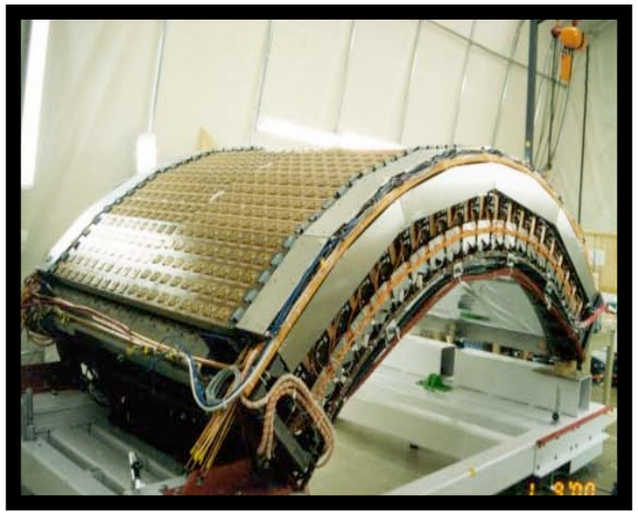
- modification to effective fragmentation function observed using γ-h correlations
  - consistent with similar studies using fully reconstructed jets
  - similar effect seen at LHC looking at fragmentation function of reconstructed jets
- variation of away-side integration range suggests jet broadening in addition to enhancement at low $p_{T,h}$
  - similar effect seen at LHC
- Qualitatively consistent with expectations from models

- Further study looking at $p_{T,\gamma}$ and centrality dependence and potential modifications to p_{out} and charge asymmetry ongoing

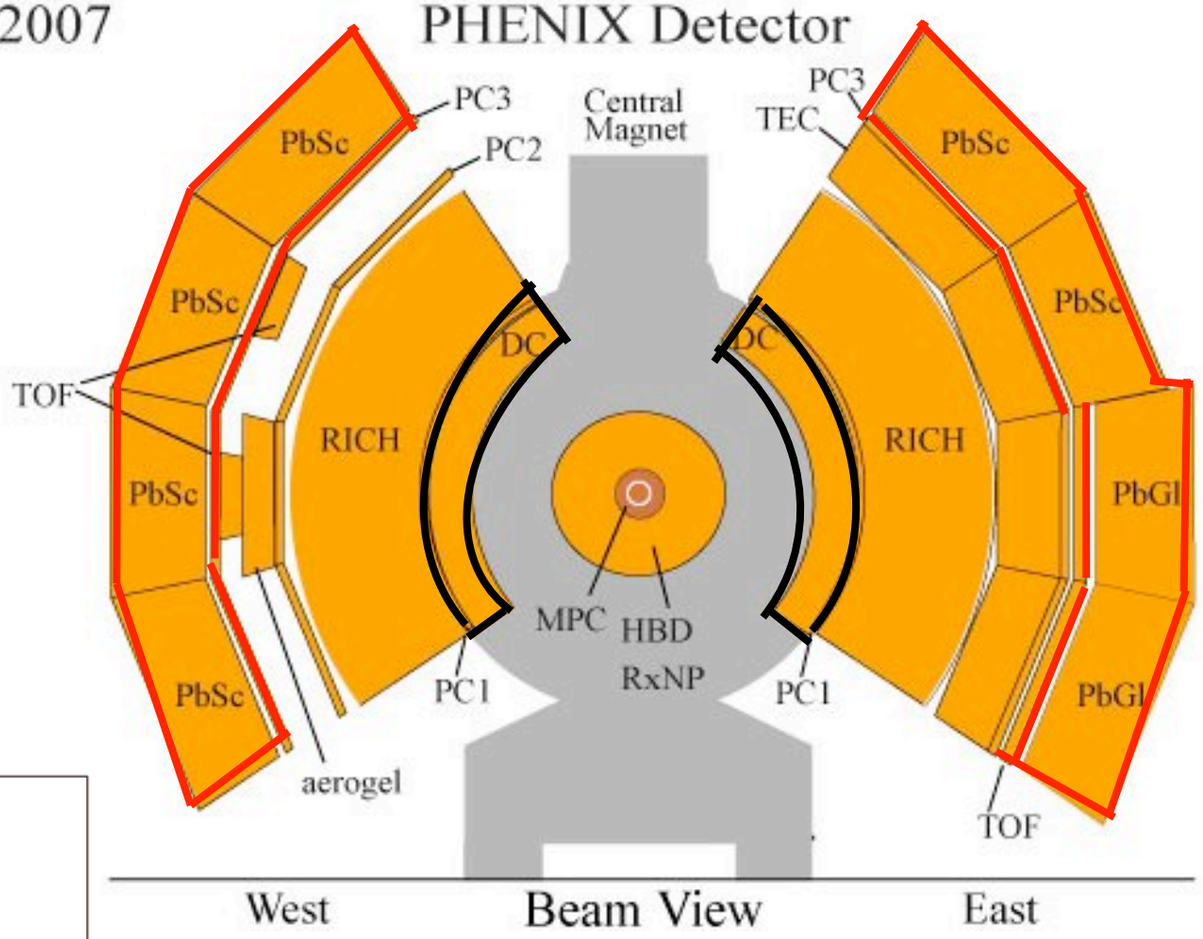
Backup

γ-h correlations in PHENIX

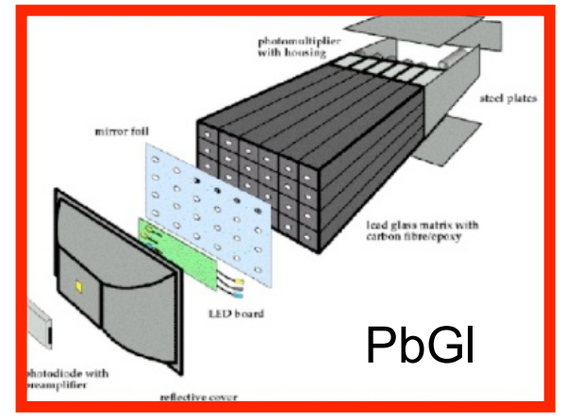
Drift Chamber

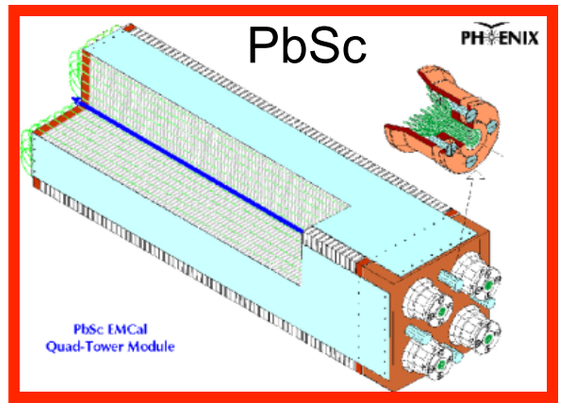


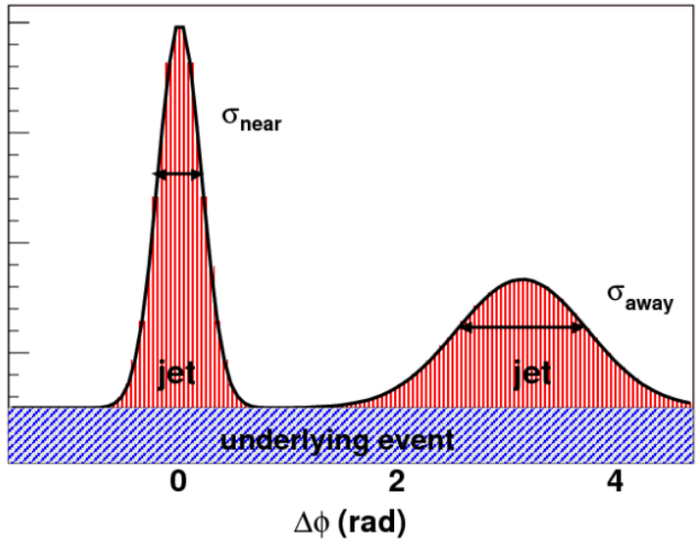
2007 PHENIX Detector

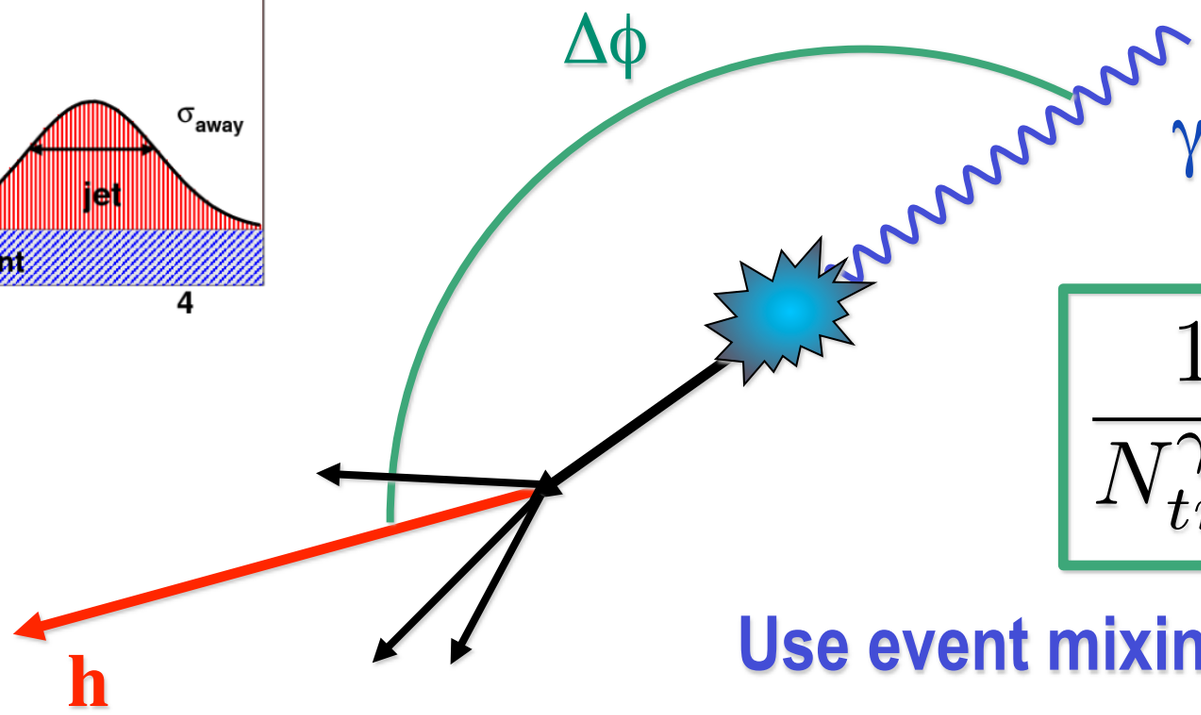


Electromagnetic Calorimeters







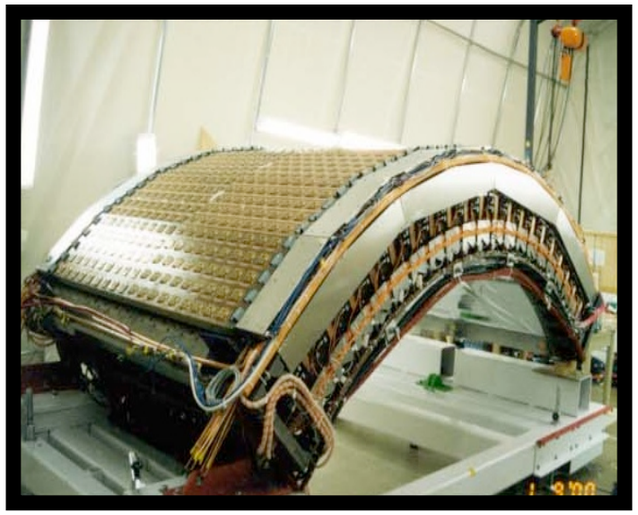


$$\frac{1}{N^{\gamma}_{trig}}\frac{dN^{\gamma-h}}{d\Delta\phi} = Y(\Delta\phi)$$

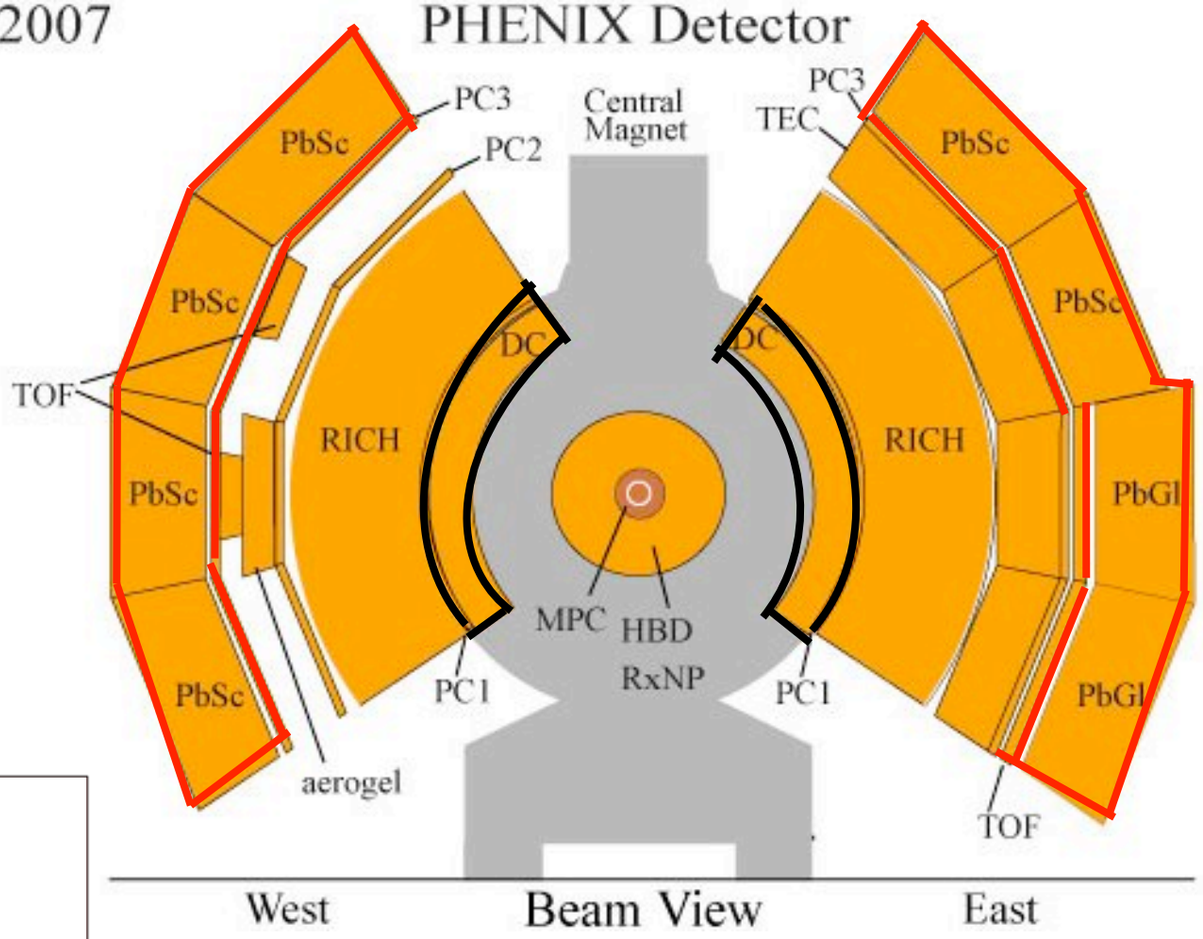
Use event mixing to correct for acceptance

γ-h correlations in PHENIX

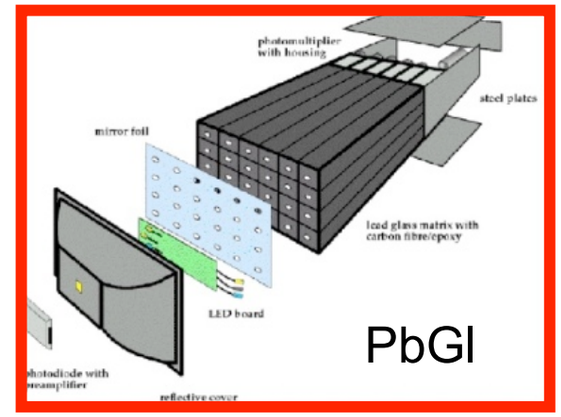
Drift Chamber

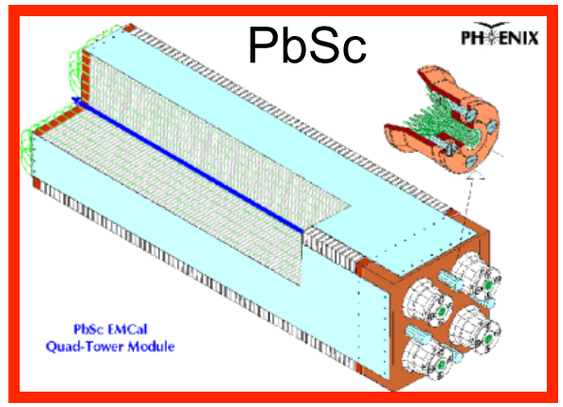


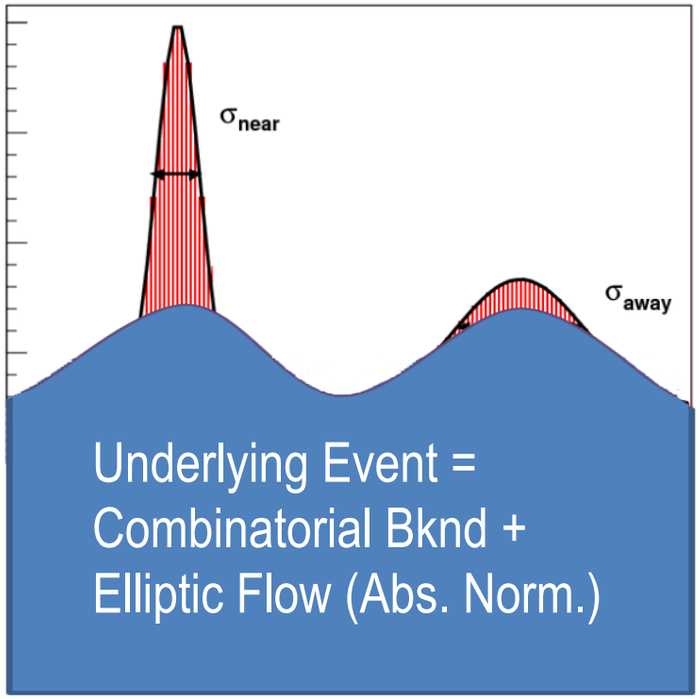
2007 PHENIX Detector

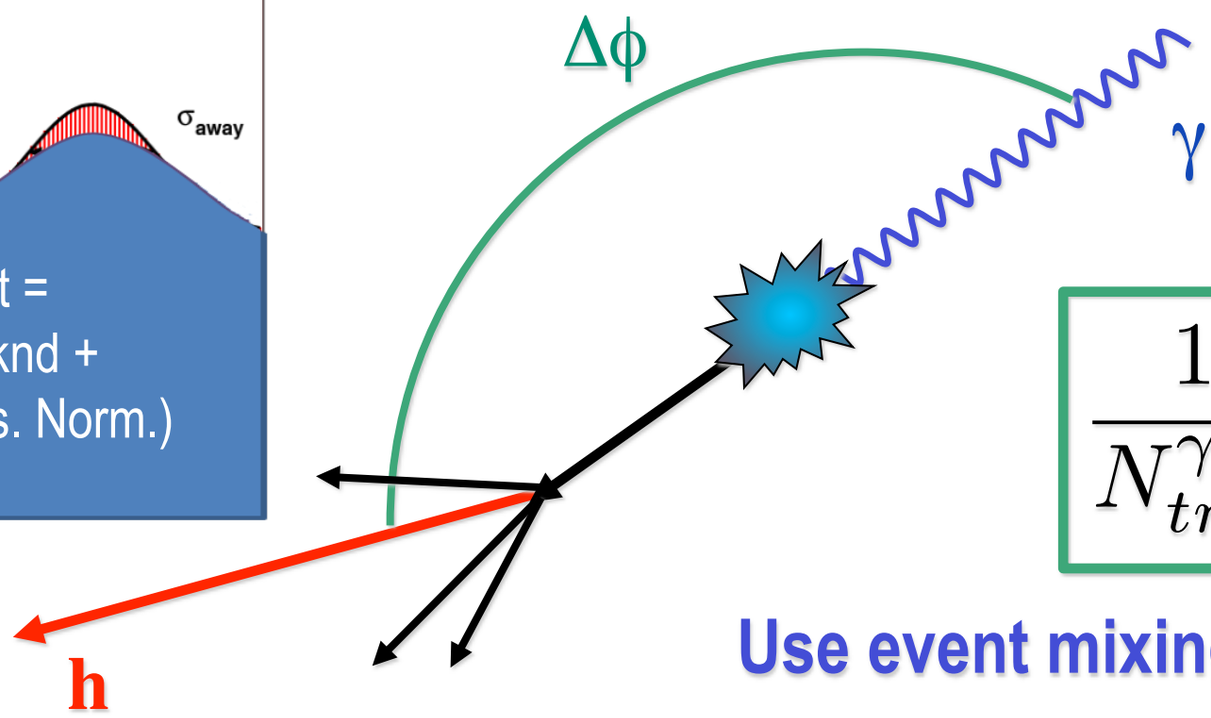


Electromagnetic Calorimeters





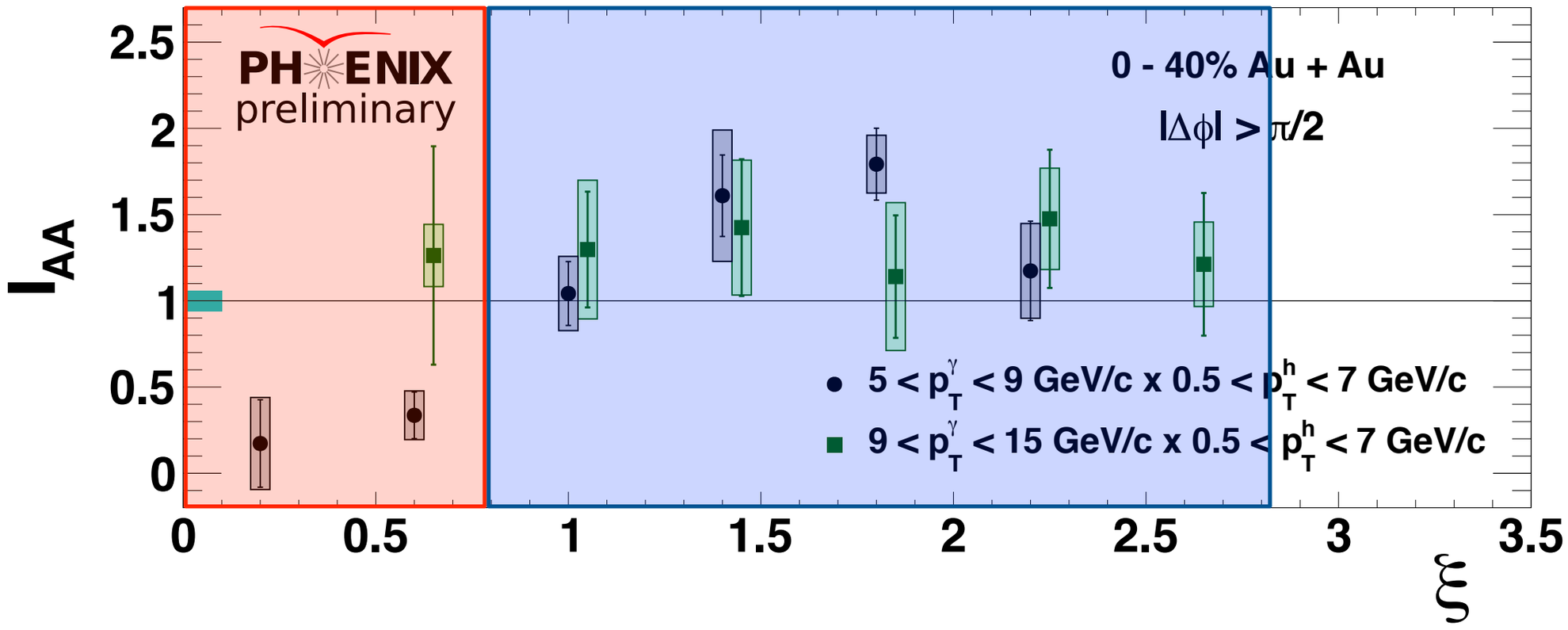




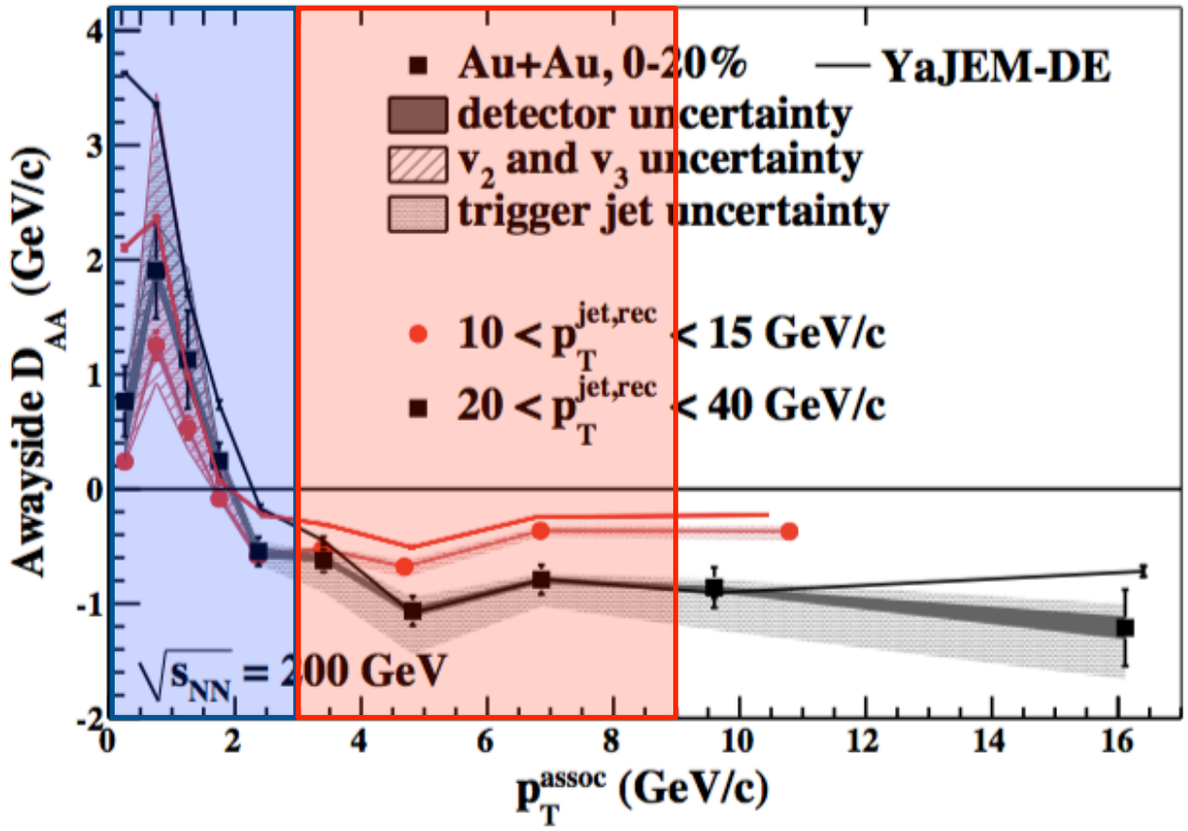
$$\frac{1}{N^{\gamma}_{trig}}\frac{dN^{\gamma-h}}{d\Delta\phi} = Y(\Delta\phi)$$

Use event mixing to correct for acceptance

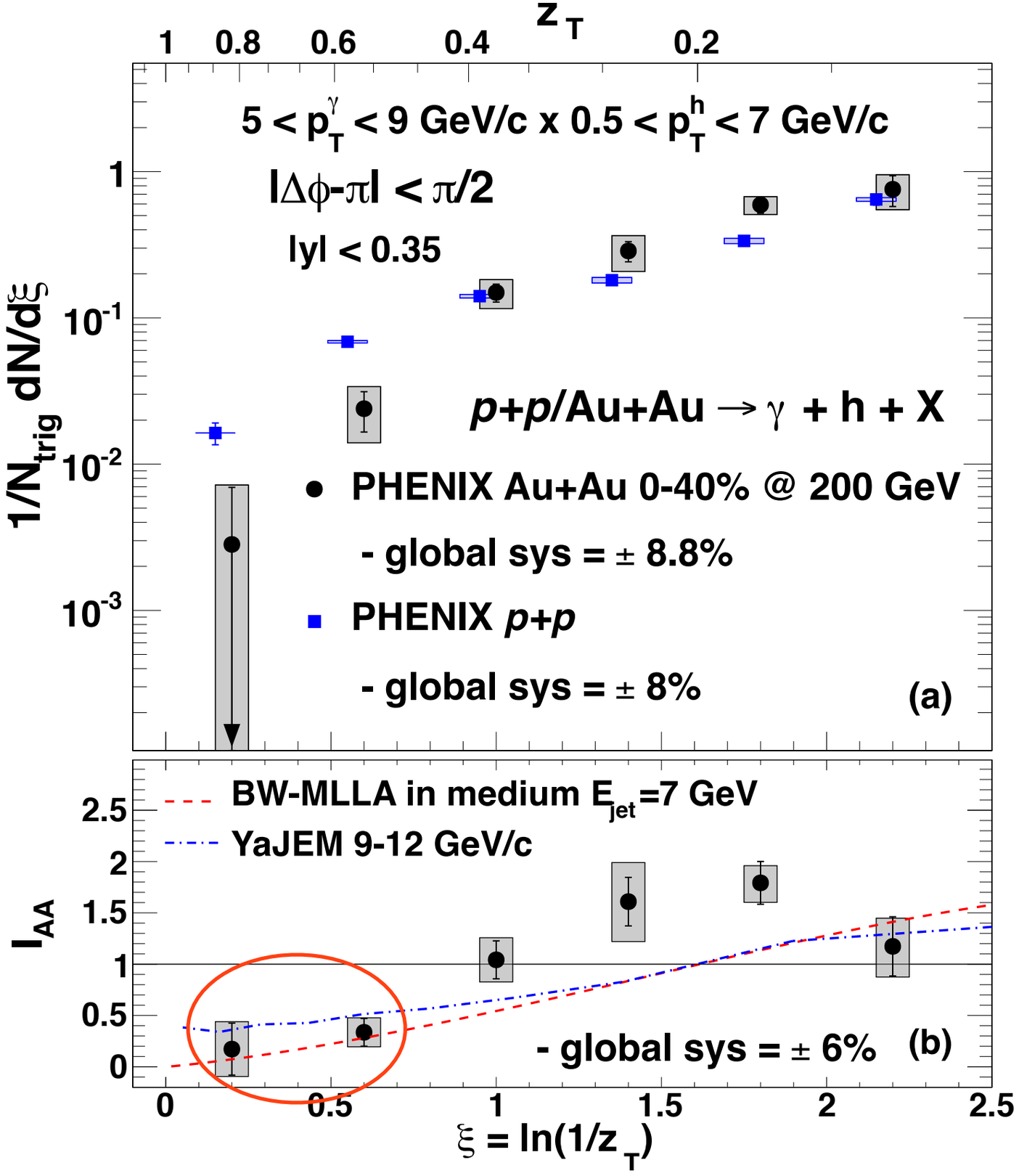
A look at trigger p_T dependence

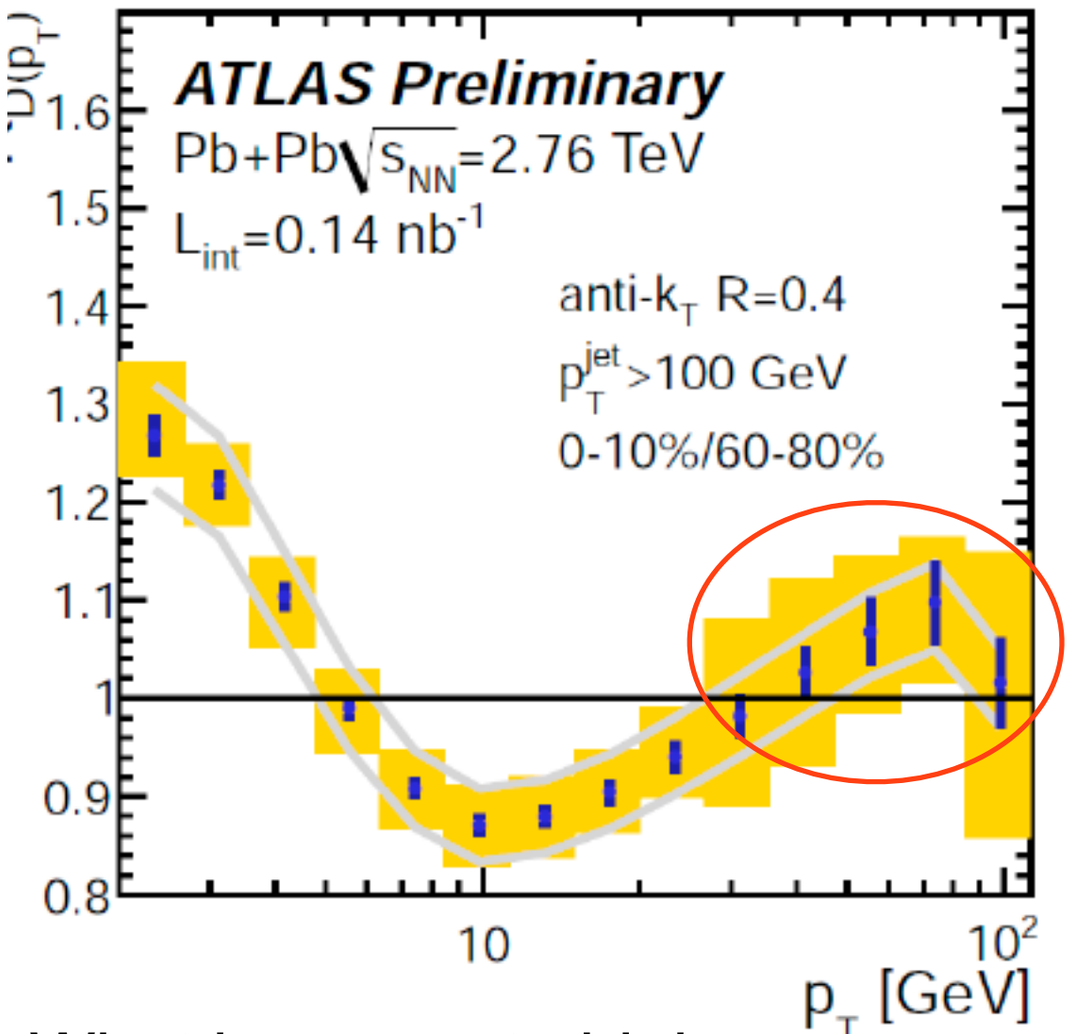


- **Low $p_{T,assoc}$:** lack of jet p_T dependence would show up as a shift in ξ
- **High $p_{T,assoc}$:** different path-length dependence → may see different effect



Consistency with LHC?





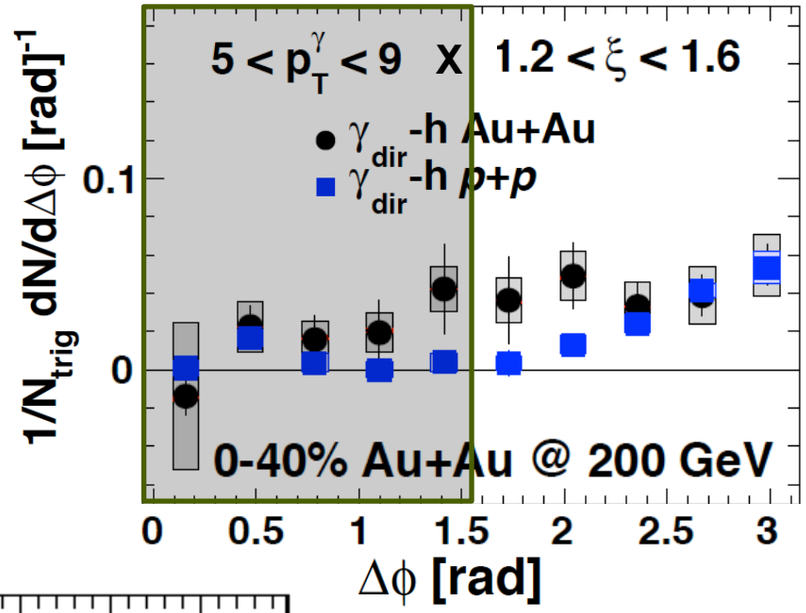
What happens to high z_T suppression?

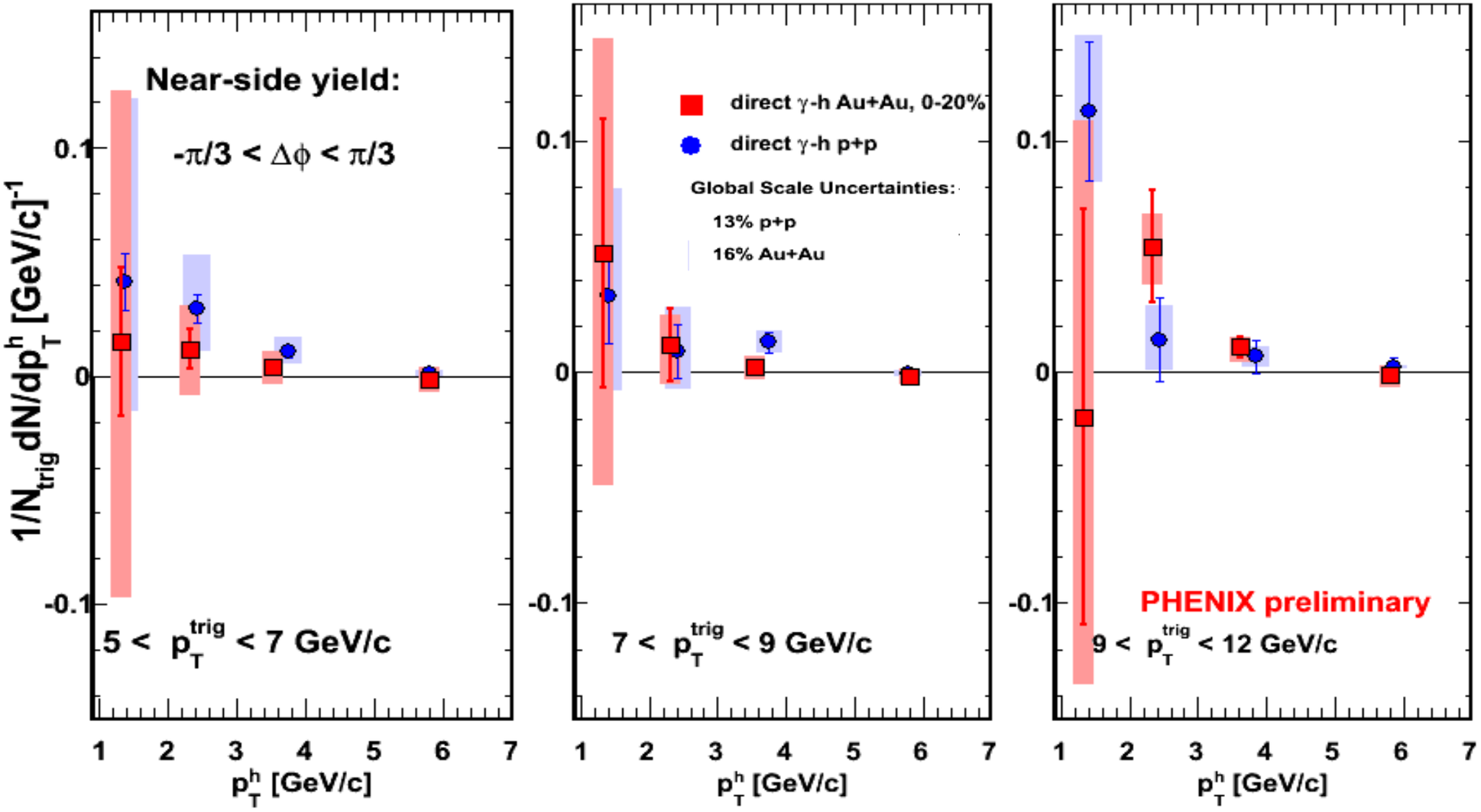
- not really measuring same thing
- comparing associated hadrons to **reco-jet** (has lost energy) vs **direct photon** (unmodified)

The near-side

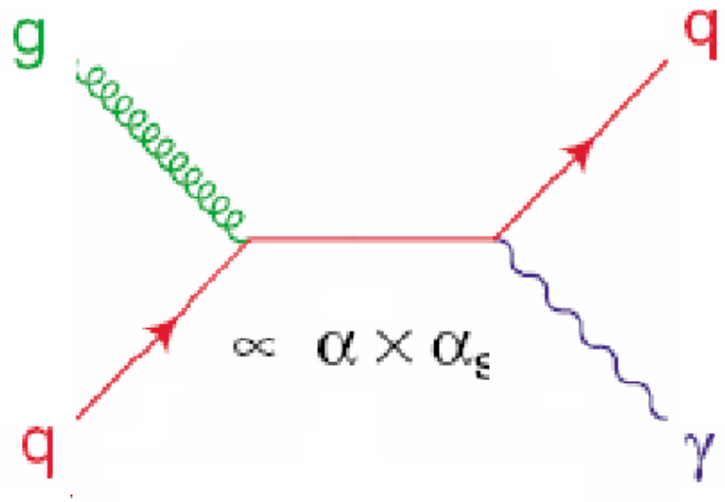
$$p_T^{\gamma} \approx p_T^{jet} ?$$

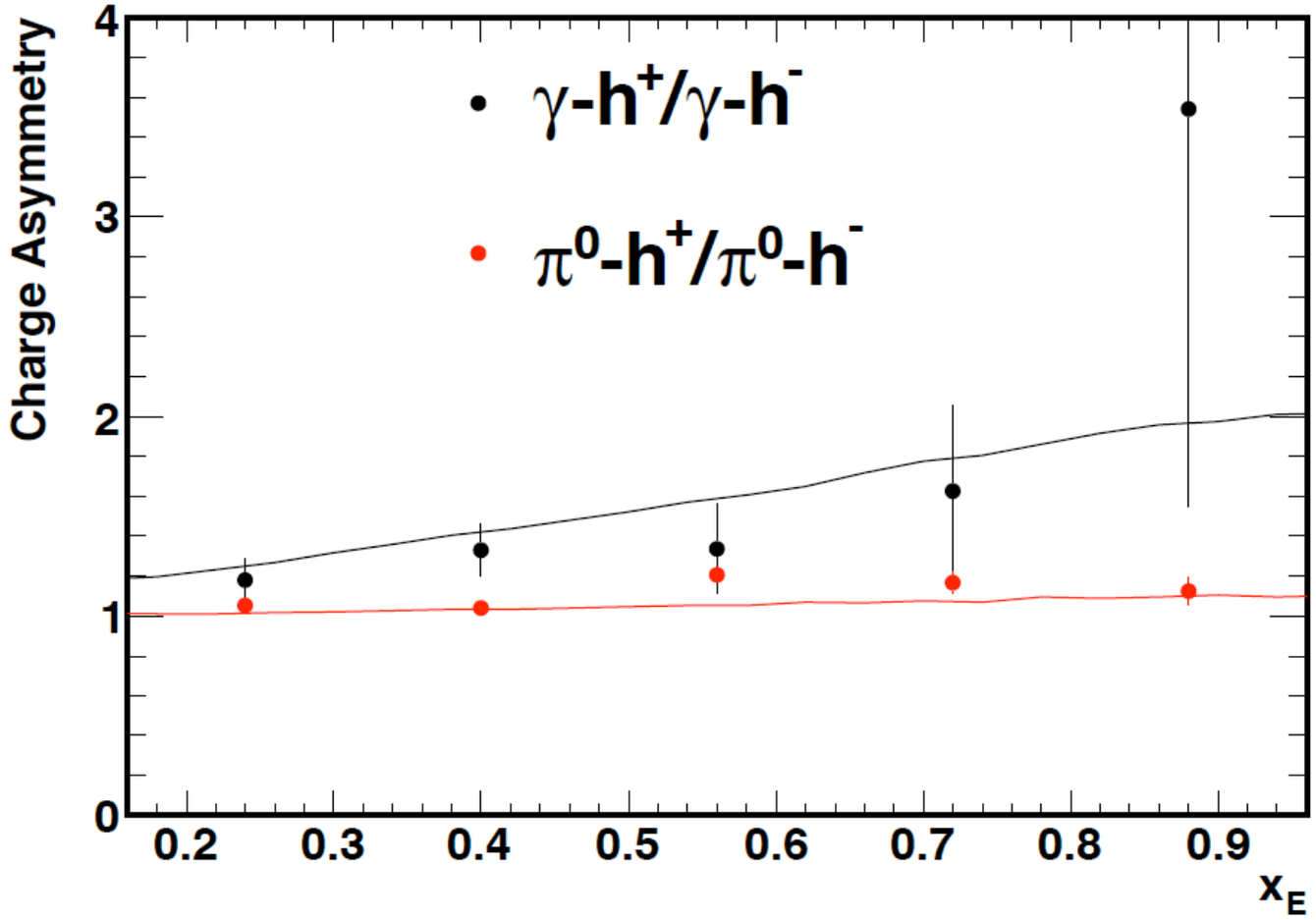
- near-side yield consistent with zero
- no significant variation between p+p and Au+Au



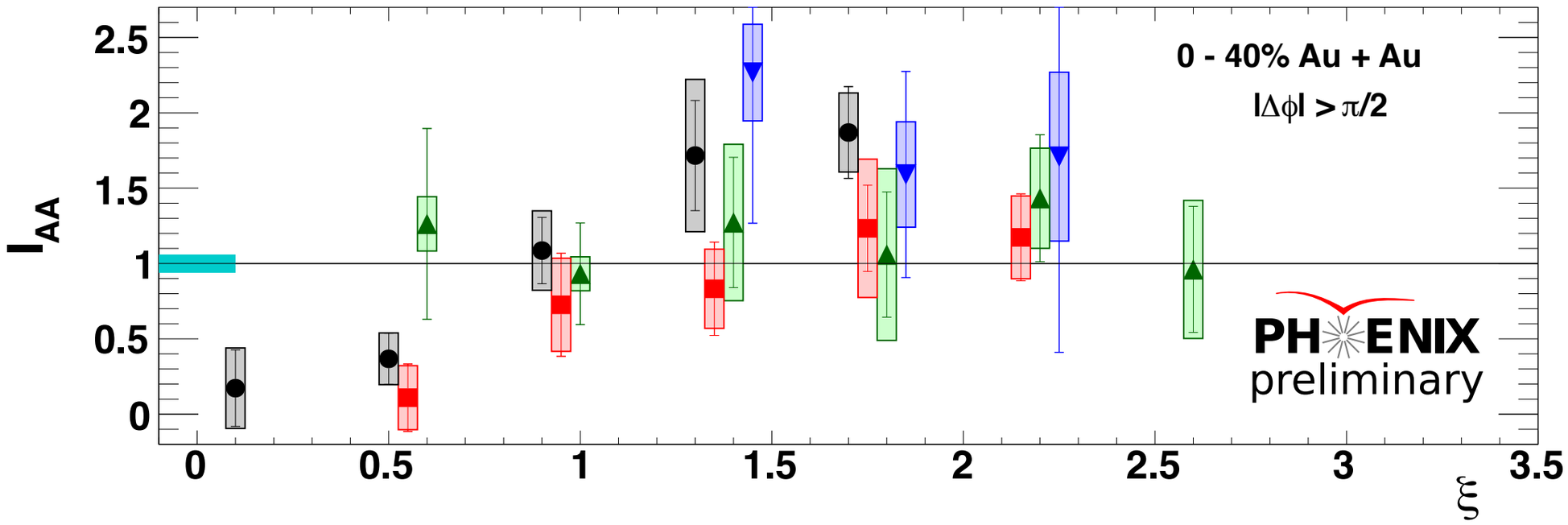


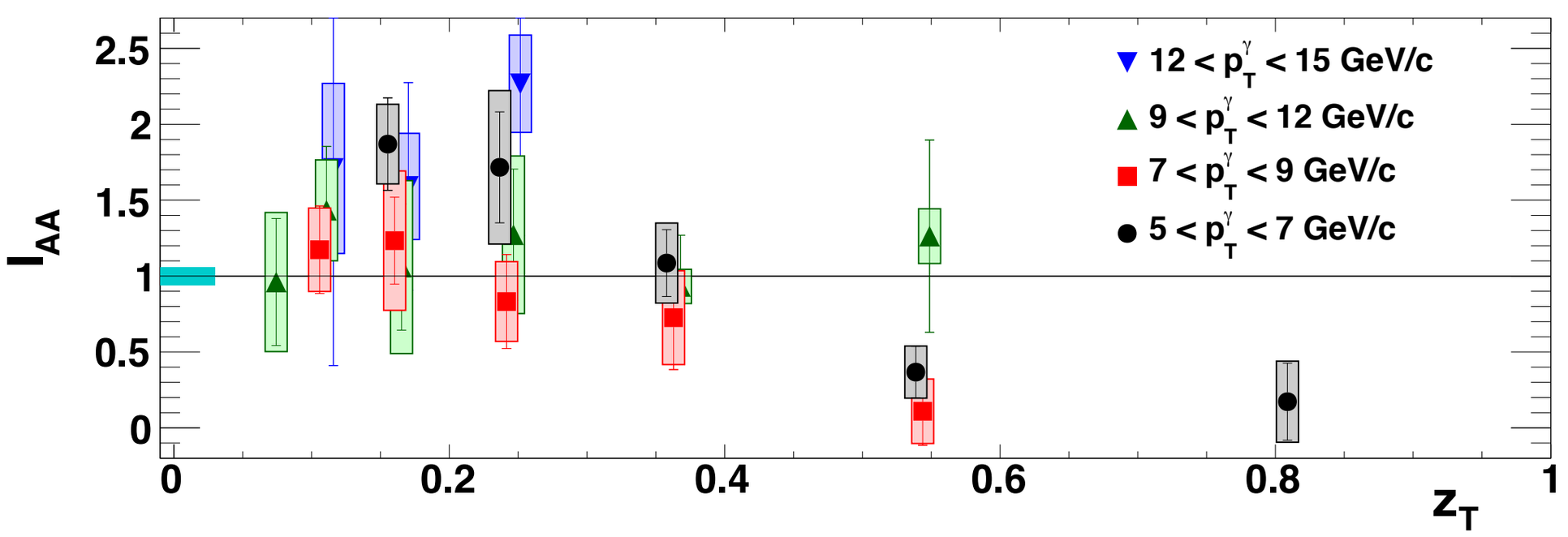
Charge asymmetry ⟶ quark fragmentation

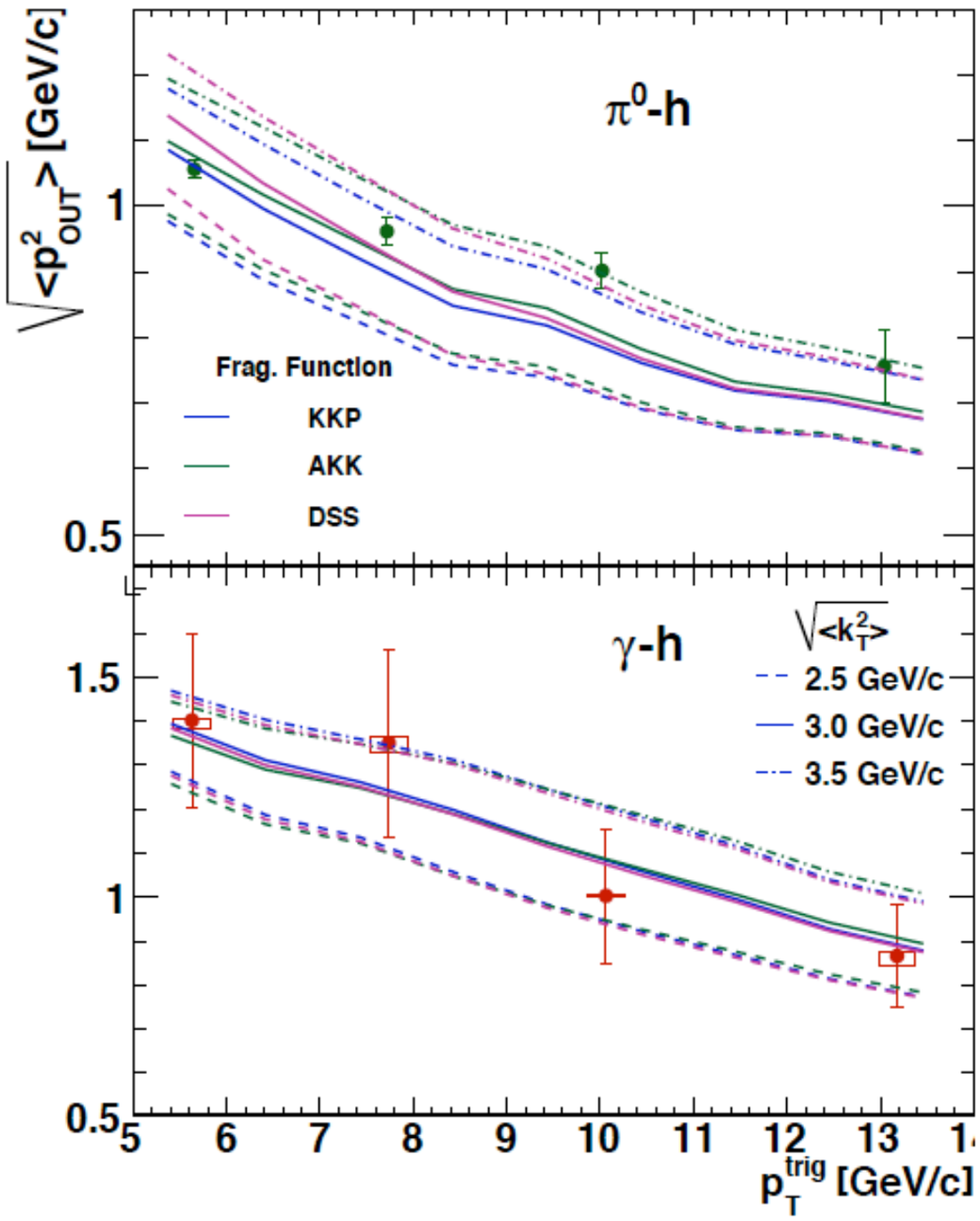


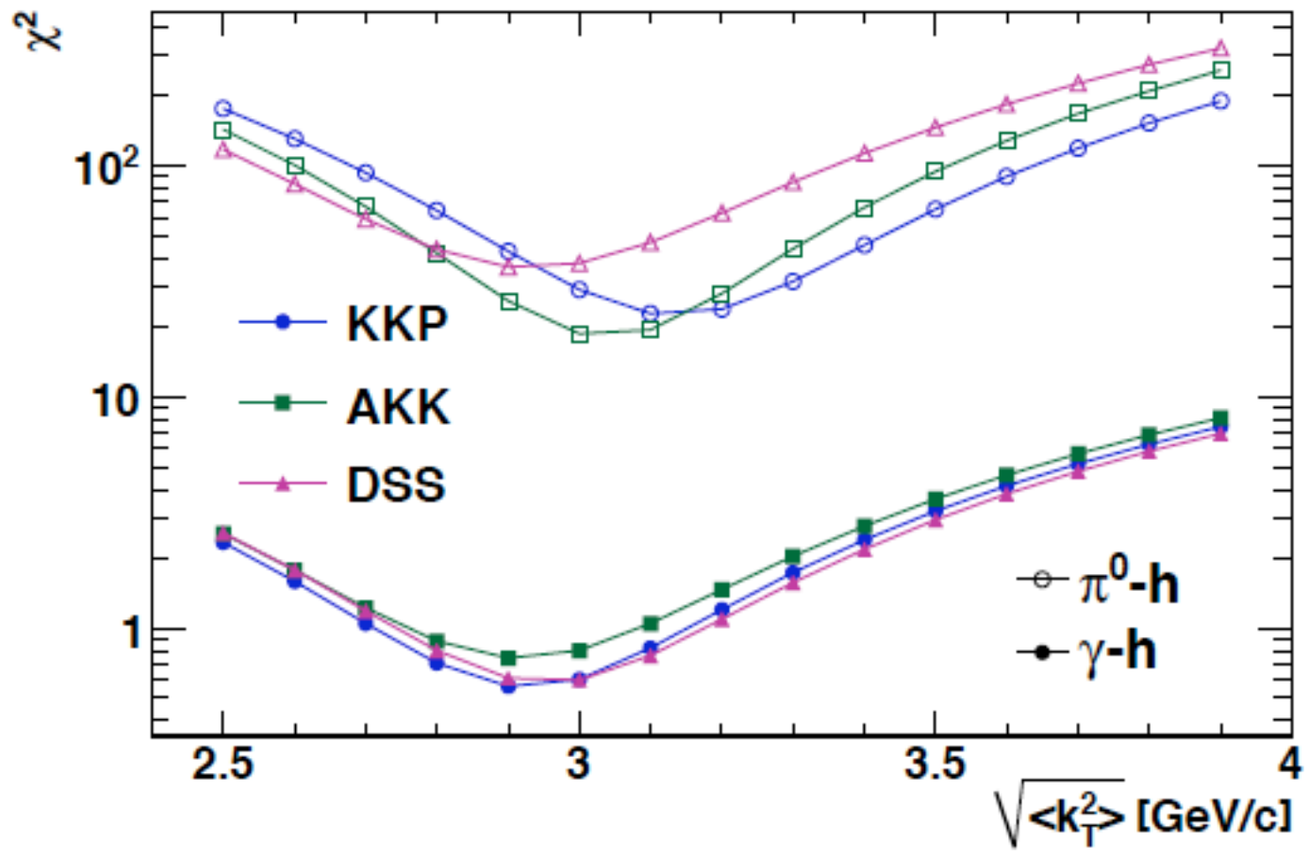


- Dominate direct photon process at RHIC is QCD Compton
- Valence quark (u:d = 2:1) charge asymmetry leads to final state charged hadron asymmetry
- Observe an excess of positive charge consistent with LO+k_T model predictions
  - supports claim that recoil jet in γ-h correlations is dominated by quark fragmentation in p+p


0 - 40% Au + Au
|Δφ| > π/2
PHENIX
preliminary
I_AA
ξ
0
0.5
1
1.5
2
2.5
3
3.5

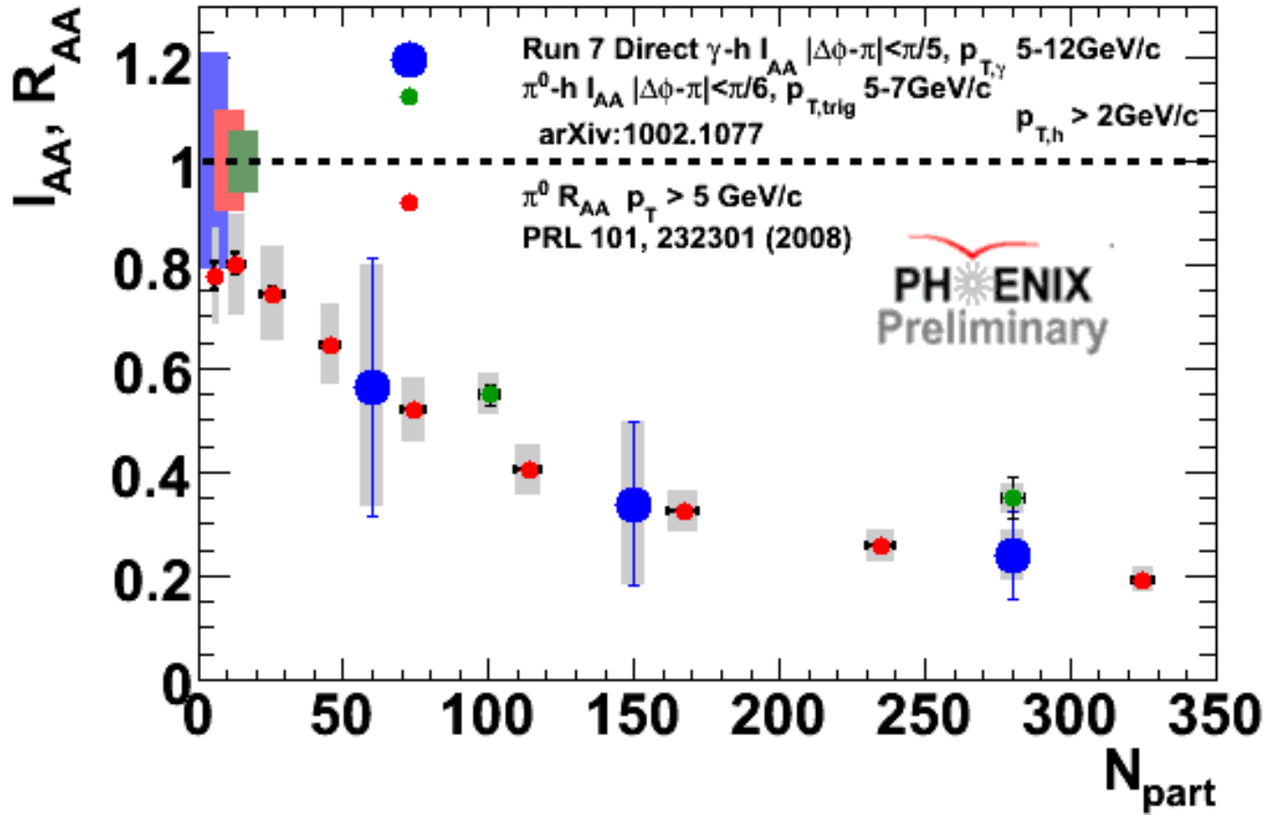

12 < p_T^γ < 15 GeV/c
9 < p_T^γ < 12 GeV/c
7 < p_T^γ < 9 GeV/c
5 < p_T^γ < 7 GeV/c
I_AA
z_T
0
0.2
0.4
0.6
0.8
1

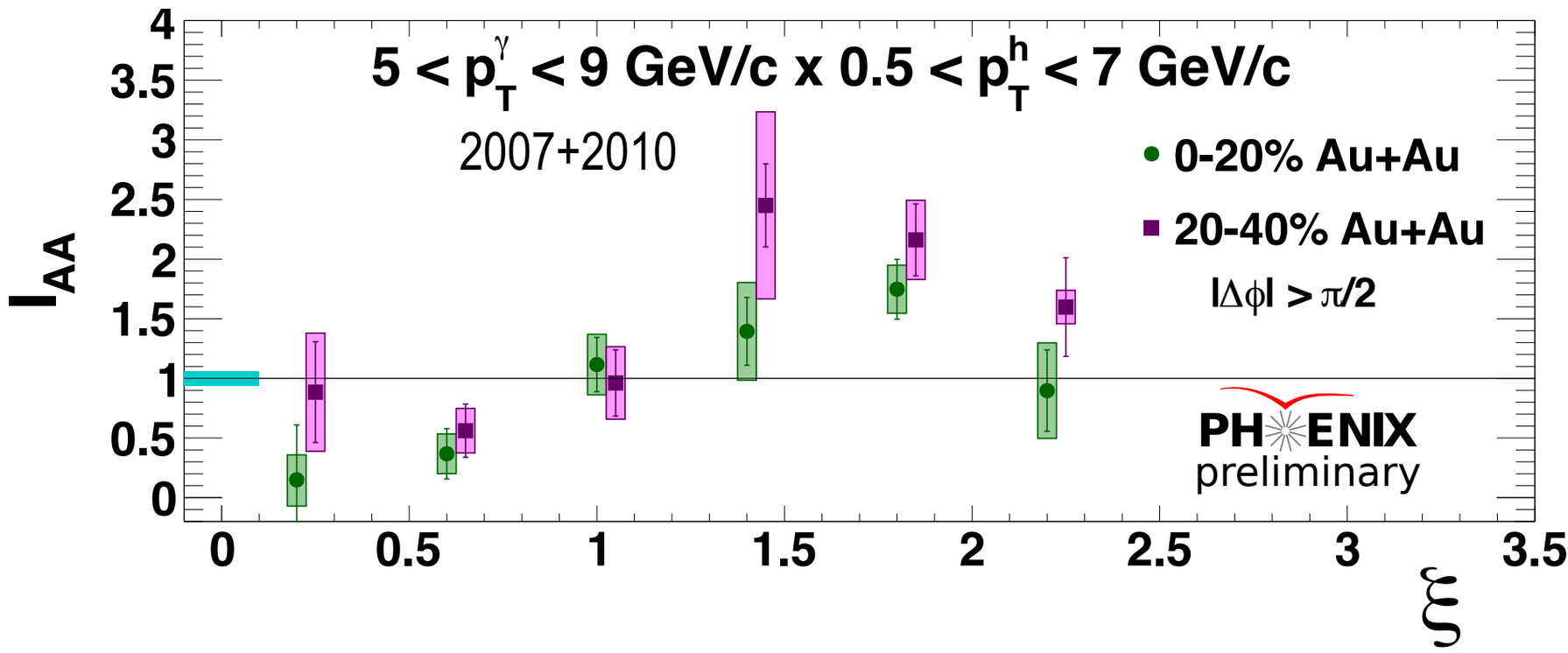

$\sqrt{<p_{OUT}^2>}$ [GeV/c]
π^0-h
Frag. Function
KKP
AKK
DSS
γ-h
$\sqrt{<k_T^2>}$
2.5 GeV/c
3.0 GeV/c
3.5 GeV/c
p_T^{trig} [GeV/c]


χ^2
KKP
AKK
DSS
π^0-h
γ-h
$\sqrt{<k_T^2>}$ [GeV/c]

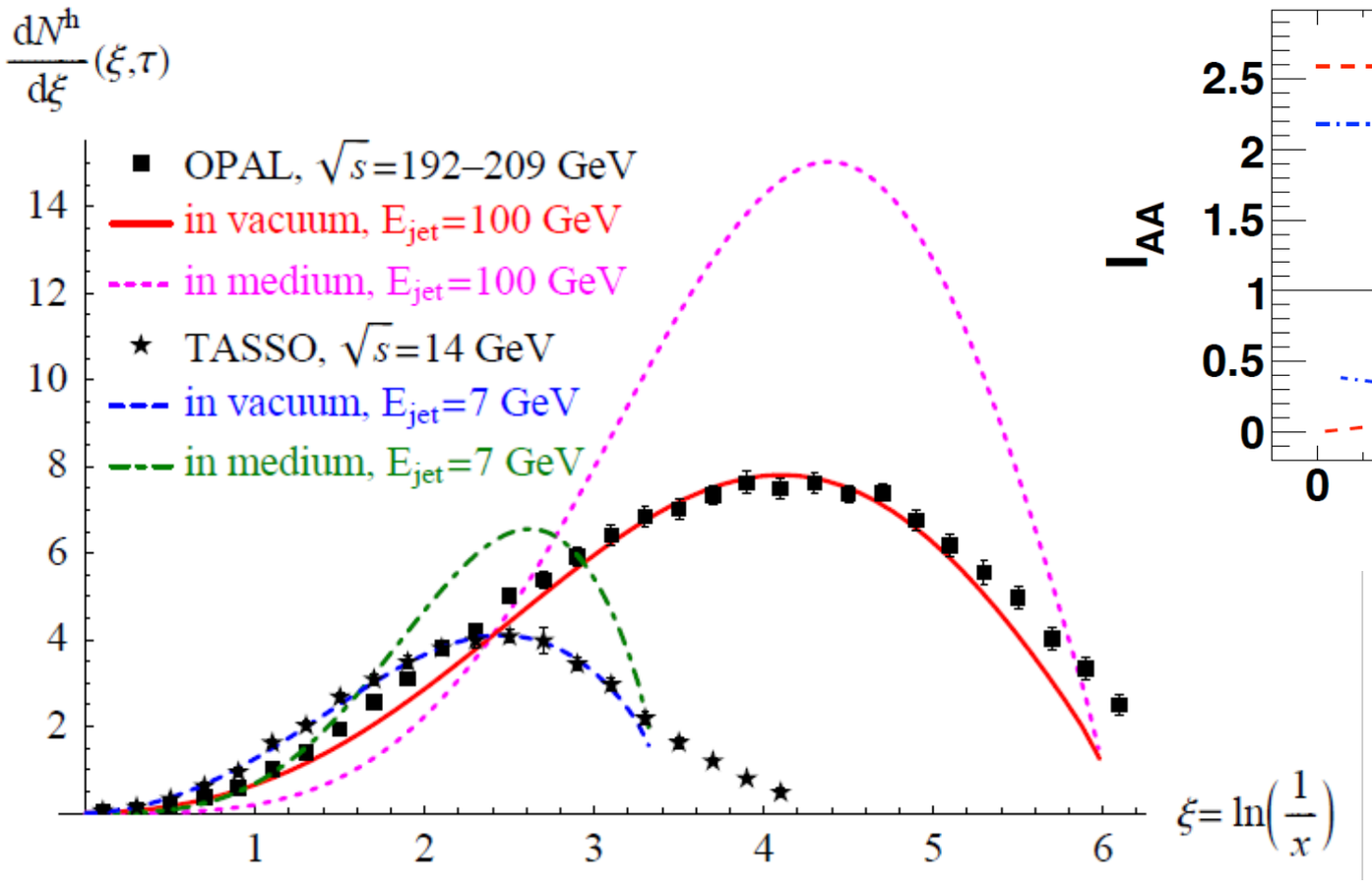
Centrality dependence

- Current large uncertainties
  - → γ-h I_{AA} consistent with π^0 R_{AA} and I_{AA}
- Previous result focus on $p_{T,h}$ >2 GeV/c and $|\Delta\phi-\pi|<\pi/5$
- Improved statistics may allow for more detailed study

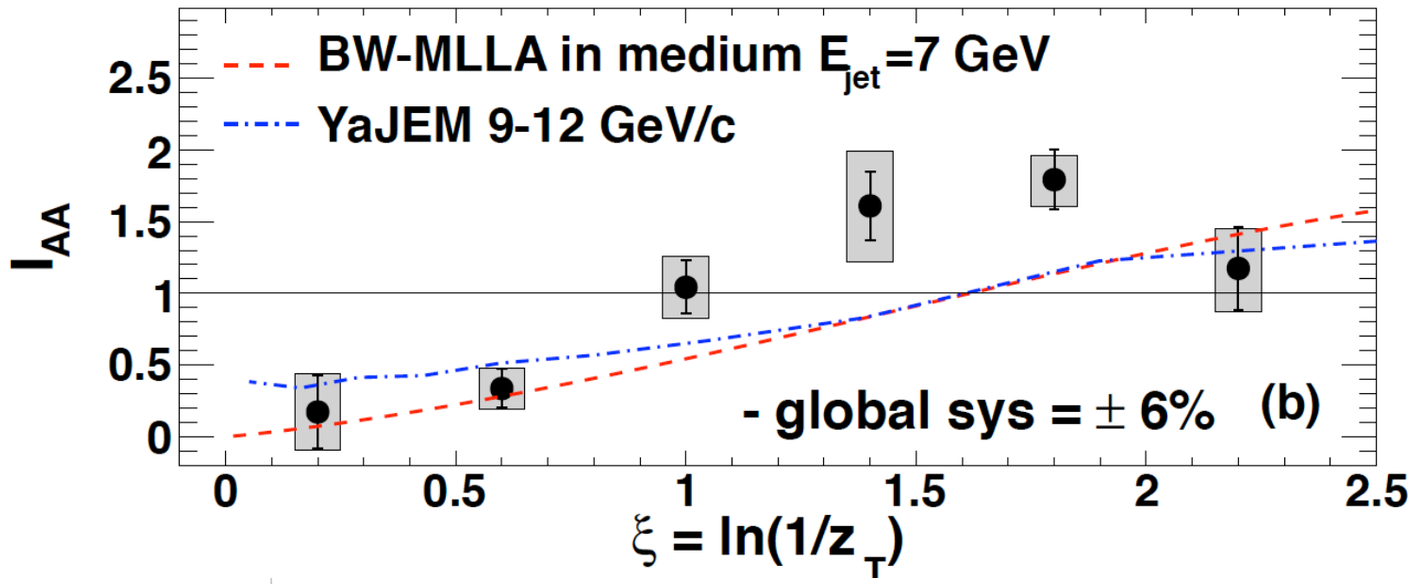




The MLLA prediction

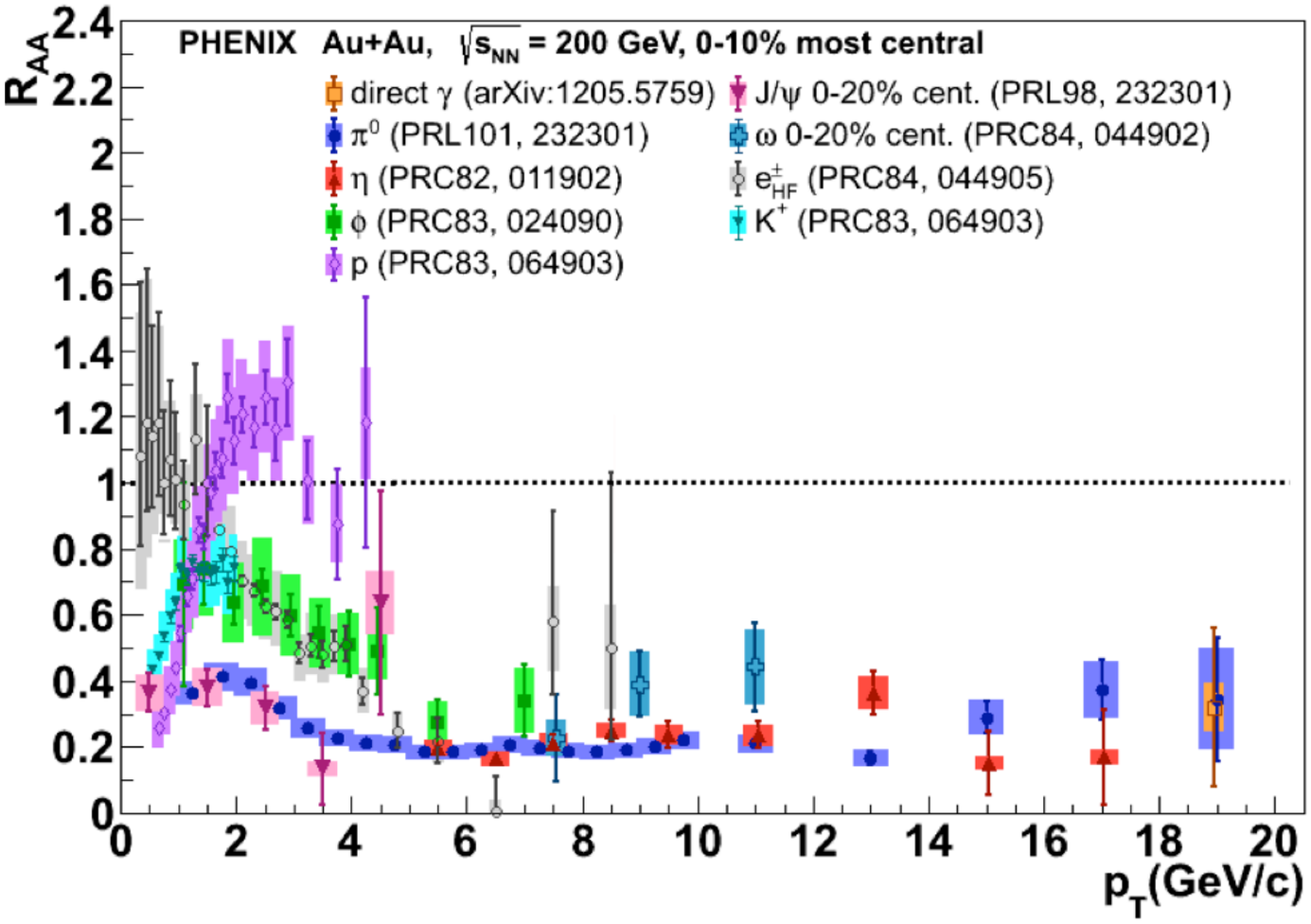


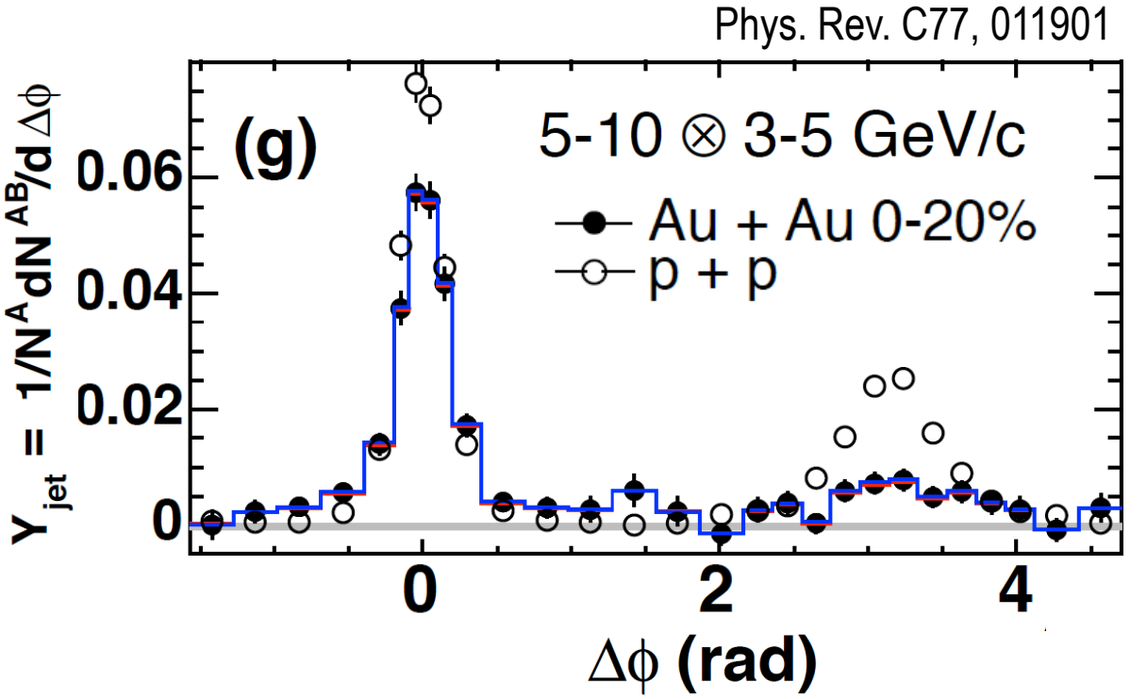
Borghini and Wiedemann arXiv:hep-ph/0506218



- implements parton splitting
- reproduce central π^0 R_{AA}

The basic picture of energy loss





Key signatures of partonic energy loss

- Single particle (hadron) production suppressed at high p_T
- Di-hadron correlations show suppression of away-side

leave details of energy loss mechanism poorly constrained