

# Jet-h 2p Correlations Update & PHENIX d+Au 200 Away to Nearside Yield Ratios

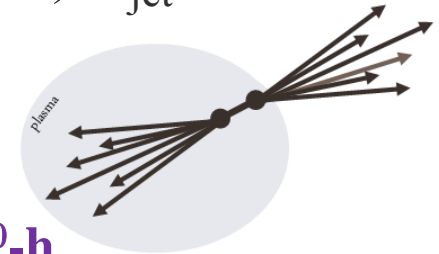
Justin Frantz

WWND15 Keystone, CO



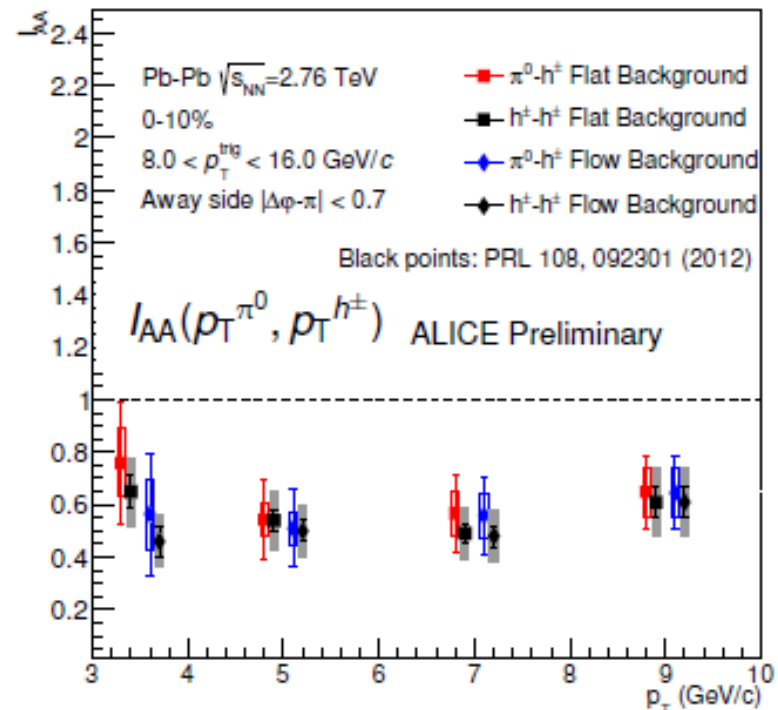
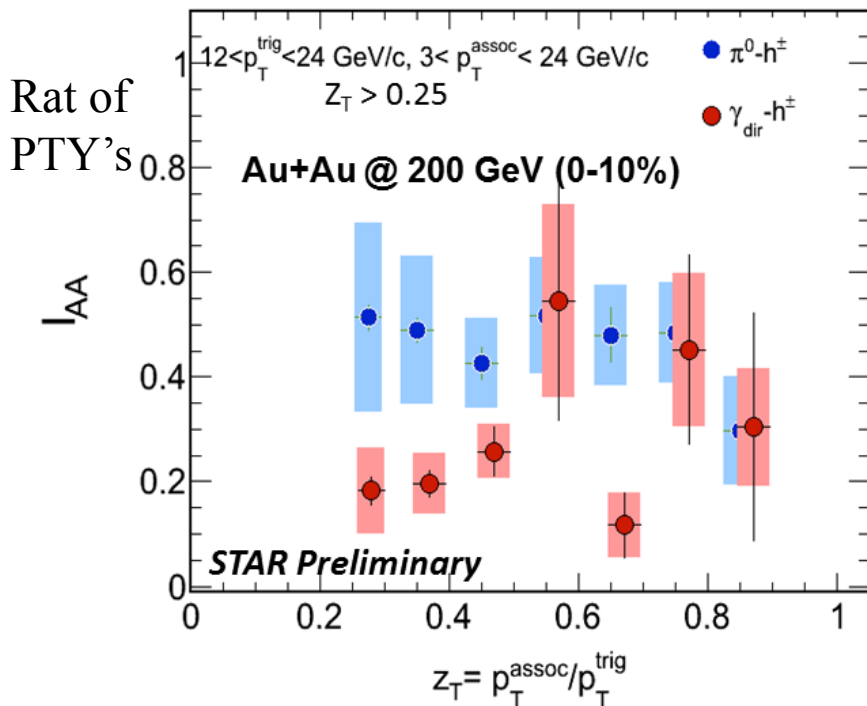
# Using 2-p Correlations for $E_{loss}$

- As a tool for studying jet Eloss, “high” (mid)  $p_T$  2PC remain important
- Allows for study of lowest  $Q^2$  possible (a la sPHENIX)  $E_{jet} = 5-20$  GeV (Jet Reco systematics large there)
- Two recent results  $\rightarrow$  These reflect the FF mods
- Reminders of some features



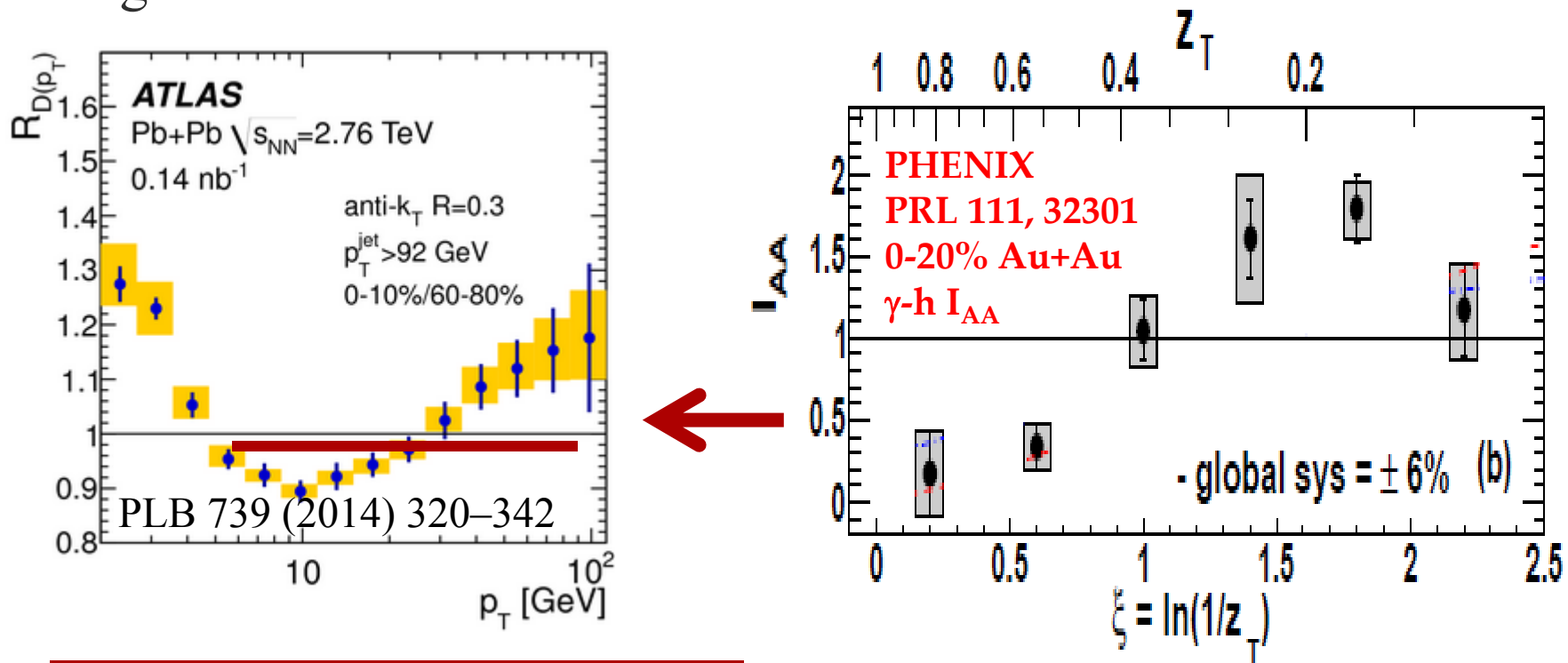
QM '14  $\gamma$ -h

QM'14  $\pi^0$ -h



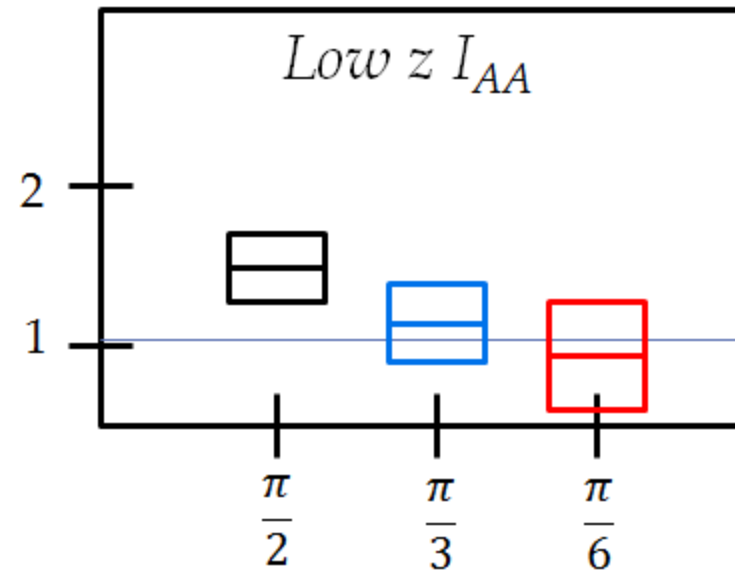
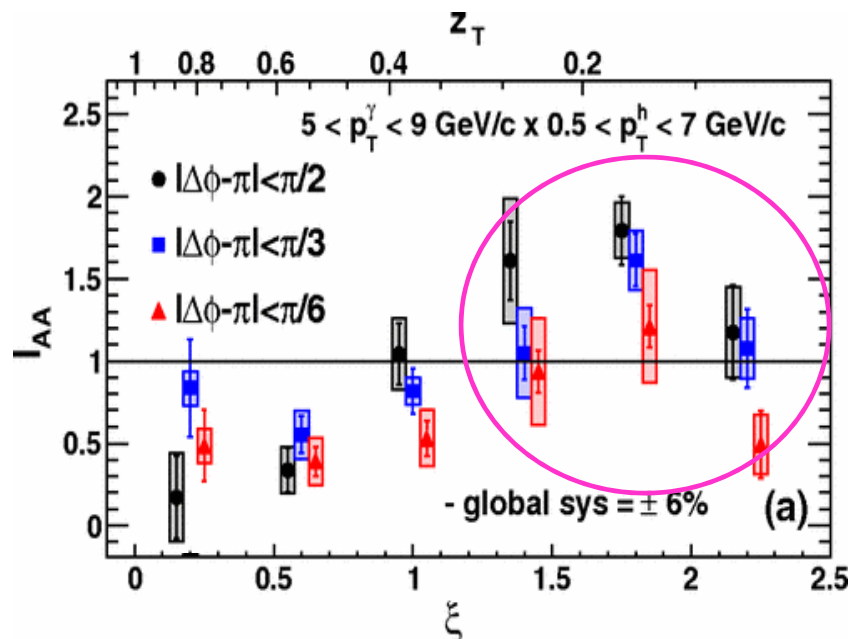
# Enhancement at Low $z$

- We know there's enhancement at low  $z$ 
  - LHC FF's (note Normalization! high  $z/p_T = \sim 1$ )
- Interpreted as recovered Eloss E
- 2pc  $I_{AA}$  Enhancement should be measured relative to suppressed high  $z$



# Example: No Significant Enhancement in Small Cones?

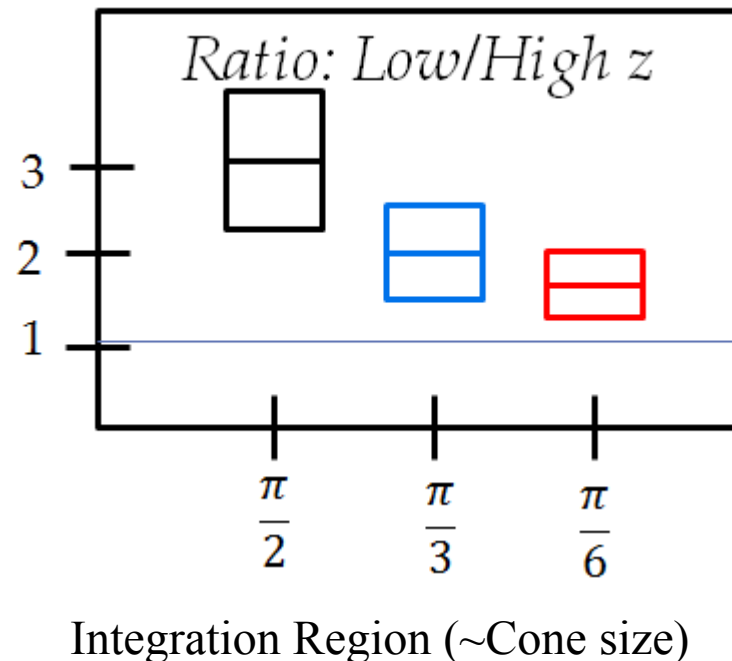
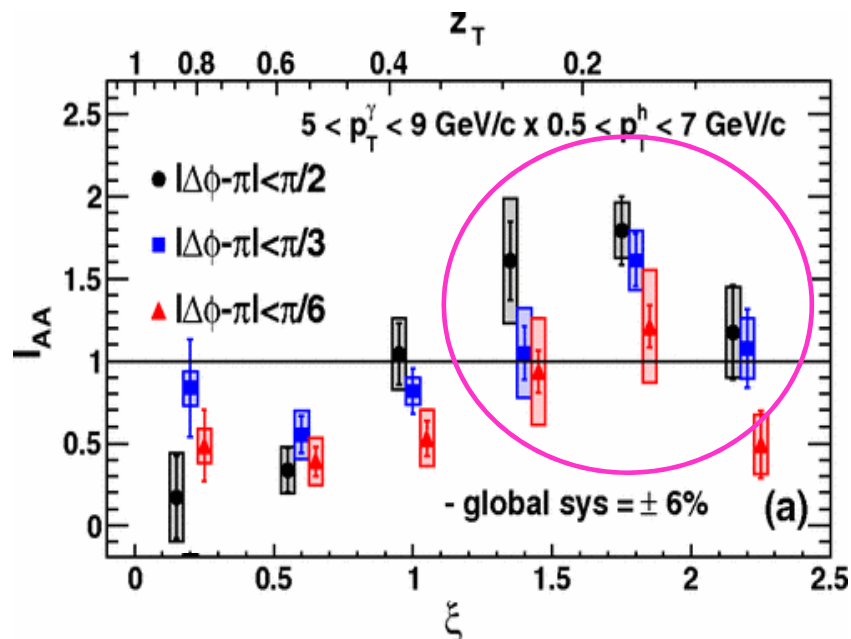
- Judging enhancement only by  $I_{AA} > 1$  is misleading
- No enhancement in the core?



Integration Region ( $\sim$ Cone size) **4**

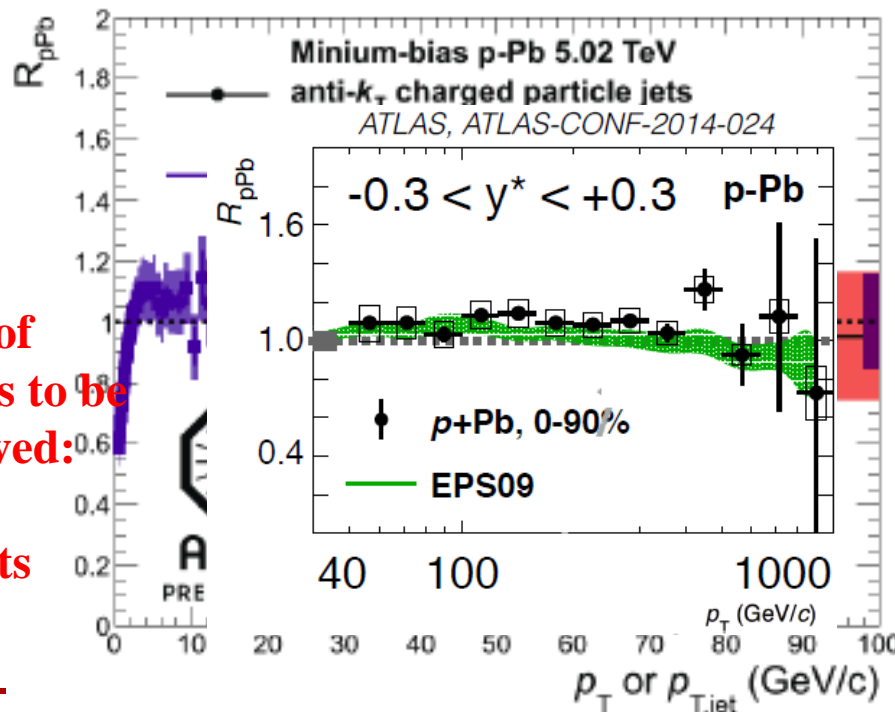
# Example: No Significant Enhancement in Small Cones?

- Judging enhancement only by  $I_{AA} > 1$  is misleading
- Must look at size of  $I_{AA}$  relative to suppressed jet level—
- enhancement in all parts, “jet core” included



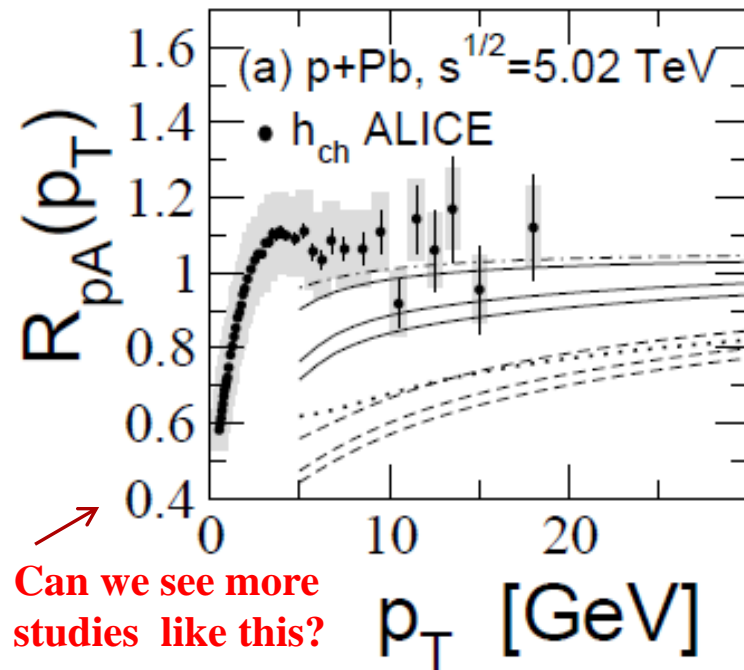
# Switch to p+A Medium? Eloss?

- We've seen the soft observables: *Small Medium At Large*
- The obvious associated question: is there Jet  $E_{loss}$ ?
- Single particle/jet  $R_{pA} / R_{dA}$  suffer from "Ncoll" systematics
- Warning: can't conclude there are no jet  $E_{loss}$  effects in p+Pb, without knowing the size we would expect given AuAu  $E_{loss}$ !



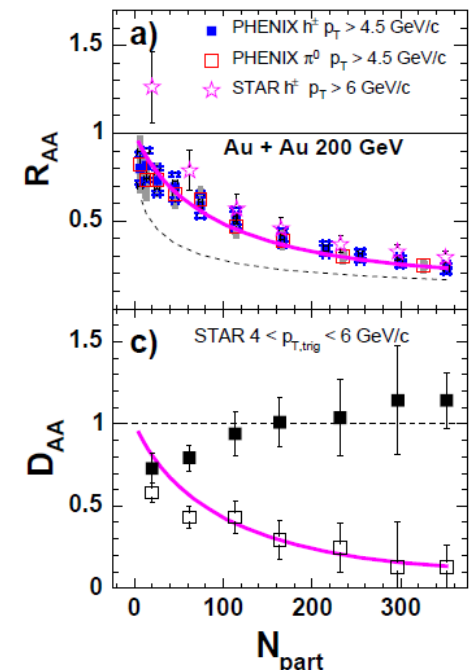
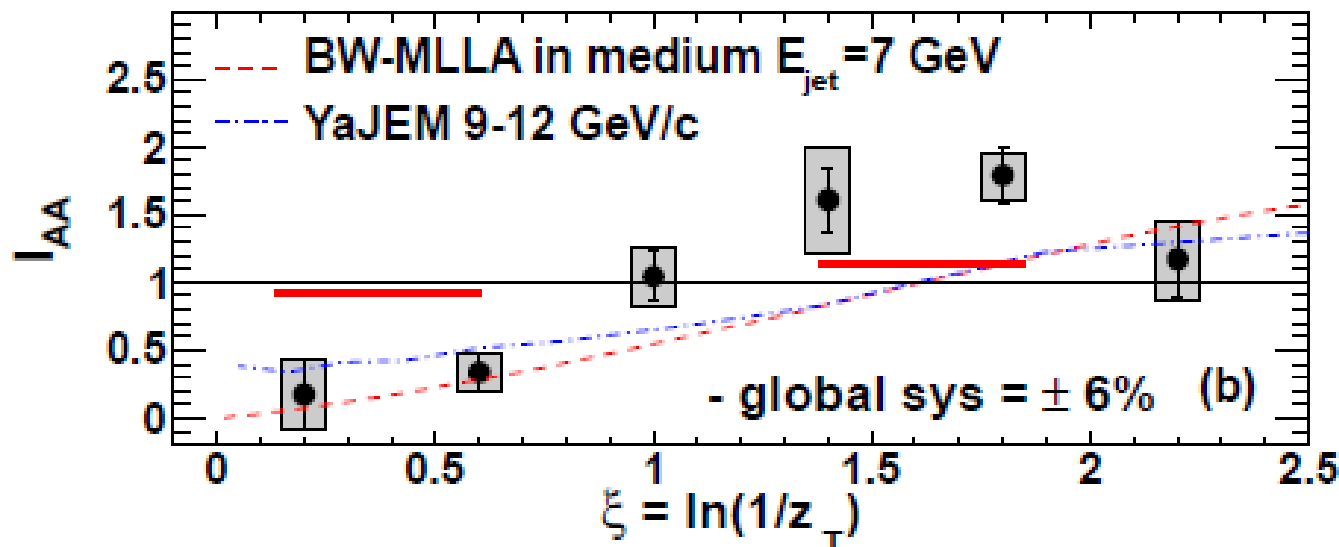
Lots of things to be resolved:  
Cold Effects +Hot

Zakarov 1311.1159



# How small could $E_{\text{loss}}$ in pA be?

- ...in 2PC: **Suppression** AND **Enhancement**
- Simple (upper bound) empirical estimate: assume *suppression and enhancement* scale with  $\sim L N_{\text{part}}^{1/3}$
- Suppression =  $1 - N_{\text{part}}^{1/3}/350^{1/3} * R_{AA}$  (high pt jet) = 0.4
- Enhancement:  $1 + N_{\text{part}}^{1/3}/350^{1/3} * D_{\gamma-h}^{\text{excess}}$  (low  $z$ ) = 0.5
- In Central d+Au: **Supp = 0.9 Enh = 1.1**



# Precision in d+Au Observables

- Rewind Circa ~2005

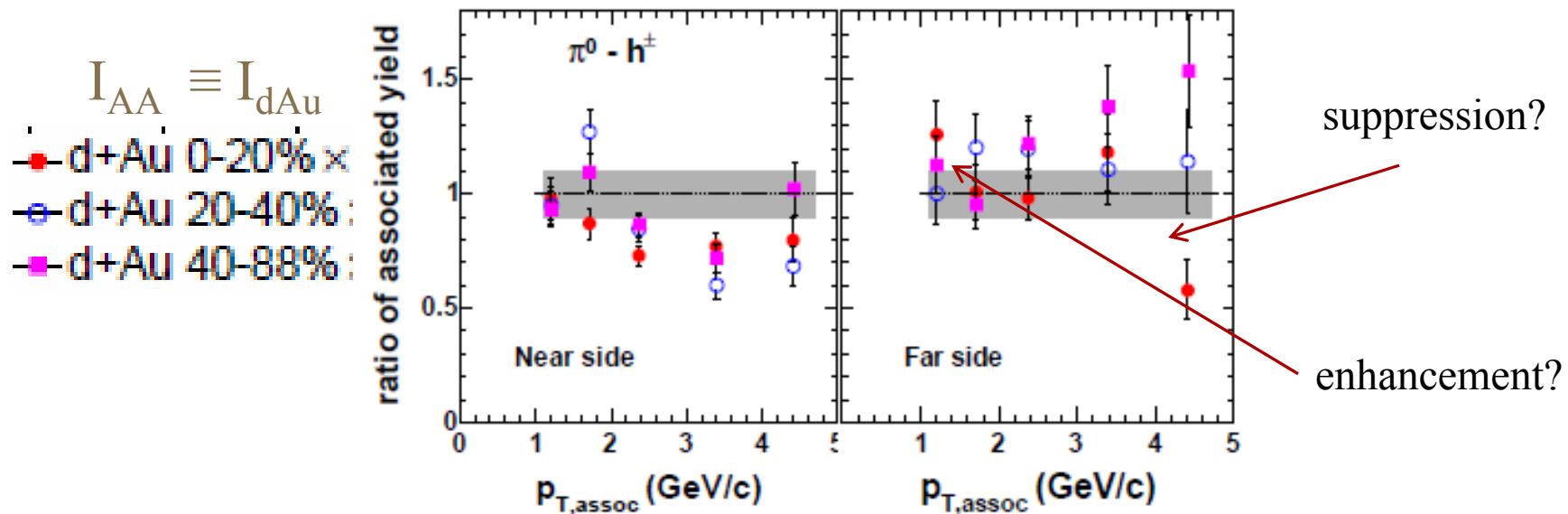
PHENIX Phys. Rev. C 73, 054903 (2006) ,

## Jet Structure from Dihadron Correlations in d+Au collisions at $\sqrt{s_{NN}}=200$ GeV

S.S. Adler,<sup>5</sup> S. Afanasiev,<sup>20</sup> C. Aidala,<sup>10</sup> N.N. Ajitanand,<sup>44</sup> Y. Akiba,<sup>21,40</sup> A. Al-Jamel,<sup>35</sup> J. Alexander,<sup>44</sup> K. Aoki,<sup>25</sup> L. Aphecetche,<sup>46</sup> R. Armendariz,<sup>35</sup> S.H. Aronson,<sup>5</sup> R. Averbeck,<sup>45</sup> T.C. Awes,<sup>36</sup> V. Babintsev,<sup>17</sup> A. Baldisseri,<sup>11</sup> K.N. Barish,<sup>6</sup> P.D. Barnes,<sup>28</sup> B. Bassalleck,<sup>34</sup> S. Bathe,<sup>6,31</sup> S. Batsouli,<sup>10</sup> V. Baublis,<sup>39</sup> F. Bauer,<sup>6</sup> A. Bazilevsky,<sup>5,41</sup> S. Belikov,<sup>19,17</sup> M.T. Bjorndal,<sup>10</sup> J.G. Boissevain,<sup>28</sup> H. Borel,<sup>11</sup> M.L. Brooks,<sup>28</sup> D.S. Brown,<sup>35</sup> N. Bruner,<sup>34</sup> D. Bucher,<sup>31</sup> H. Buesching,<sup>5,31</sup> V. Bumazhnov,<sup>17</sup> G. Bunce,<sup>5,41</sup> J.M. Burward-Hoy,<sup>28,27</sup> S. Butsyk,<sup>45</sup> X. Camard,<sup>46</sup> P. Chand,<sup>4</sup> W.C. Chang,<sup>2</sup> S. Chernichenko,<sup>17</sup> C.Y. Chi,<sup>10</sup> J. Chiba,<sup>21</sup> M. Chiu,<sup>10</sup> I.J. Choi,<sup>53</sup> R.K. Choudhury,<sup>4</sup> T. Chujo,<sup>5</sup> V. Cianciolo,<sup>36</sup> Y. Cobigo,<sup>11</sup> B.A. Cole,<sup>10</sup> M.P. Comets,<sup>37</sup> P. Constantin,<sup>19</sup> M. Csanád,<sup>13</sup> T. Csörgő,<sup>22</sup> J.P. Cussonneau,<sup>46</sup> D. d'Enterria,<sup>10</sup> K. Das,<sup>14</sup> G. David,<sup>5</sup> F. Deák,<sup>13</sup> H. Delagrangé,<sup>46</sup> A. Denisov,<sup>17</sup> A. Deshpande,<sup>41</sup> E.J. Desmond,<sup>5</sup> A. Devismes,<sup>45</sup> O. Dietzsch,<sup>42</sup> J.L. Drachenberg,<sup>1</sup> O. Drapier,<sup>26</sup> A. Drees,<sup>45</sup> A. Durum,<sup>17</sup> D. Dutta,<sup>4</sup> V. Dzhordzhadze,<sup>47</sup> Y.V. Efremenko,<sup>36</sup> H. En'yo,<sup>40,41</sup> B. Espagnon,<sup>37</sup> S. Esumi,<sup>49</sup> D.E. Fields,<sup>34,41</sup> C. Finck,<sup>46</sup> F. Fleuret,<sup>26</sup> S.L. Fokin,<sup>24</sup> B.D. Fox,<sup>41</sup> Z. Fraenkel,<sup>52</sup> J.E. Frantz,<sup>10</sup> A. Franz,<sup>5</sup> A.D. Frawley,<sup>14</sup> Y. Fukao,<sup>25,40,41</sup> S.-Y. Fung,<sup>6</sup> S. Gadrat,<sup>29</sup> M. Germain,<sup>46</sup> A. Glenn,<sup>47</sup> M. Gonin,<sup>26</sup>

# Precision Limitations to these small effects 2-p

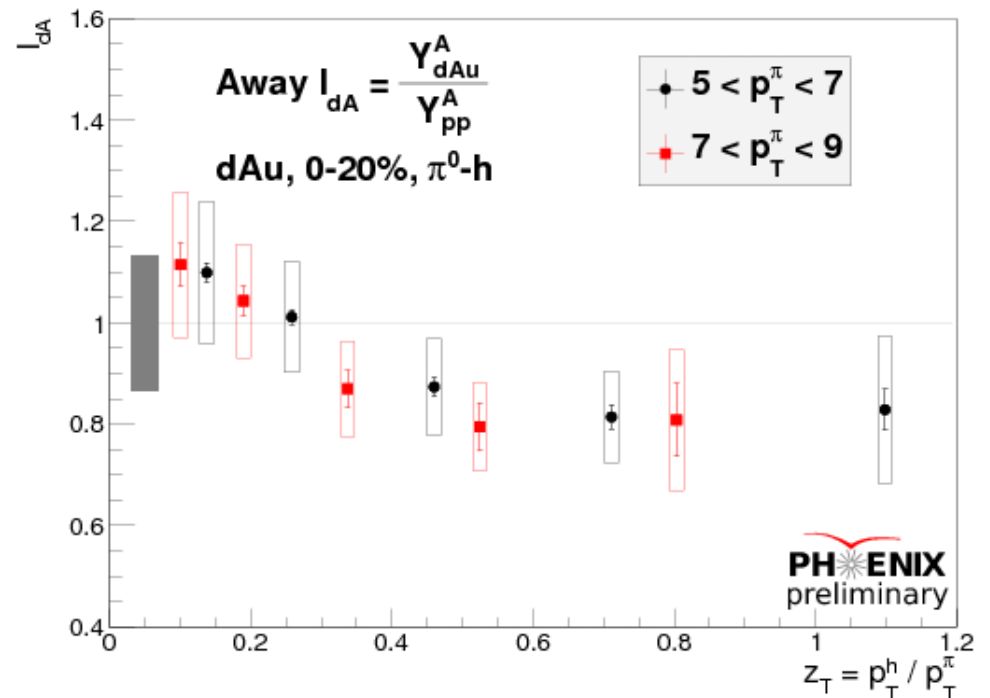
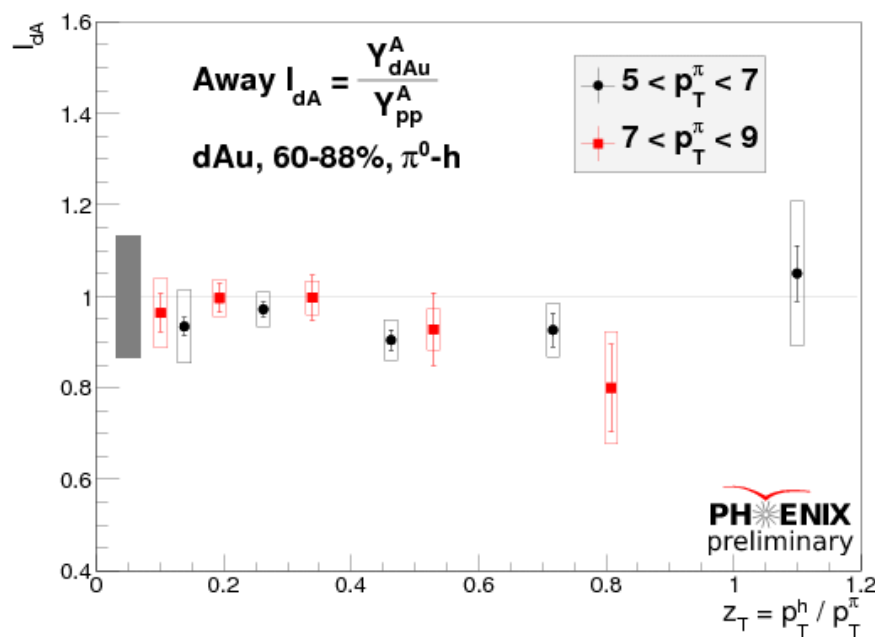
- Direct Photon Statistics/Systematics Limit for d+Au
- Di-Hadron have better statistics/systematic control: 5-10 GeV/c trigger → Lowest Jet Energies looked at: (much lower than LHC)



- But efficiency uncertainties limit:
- Need to find observable

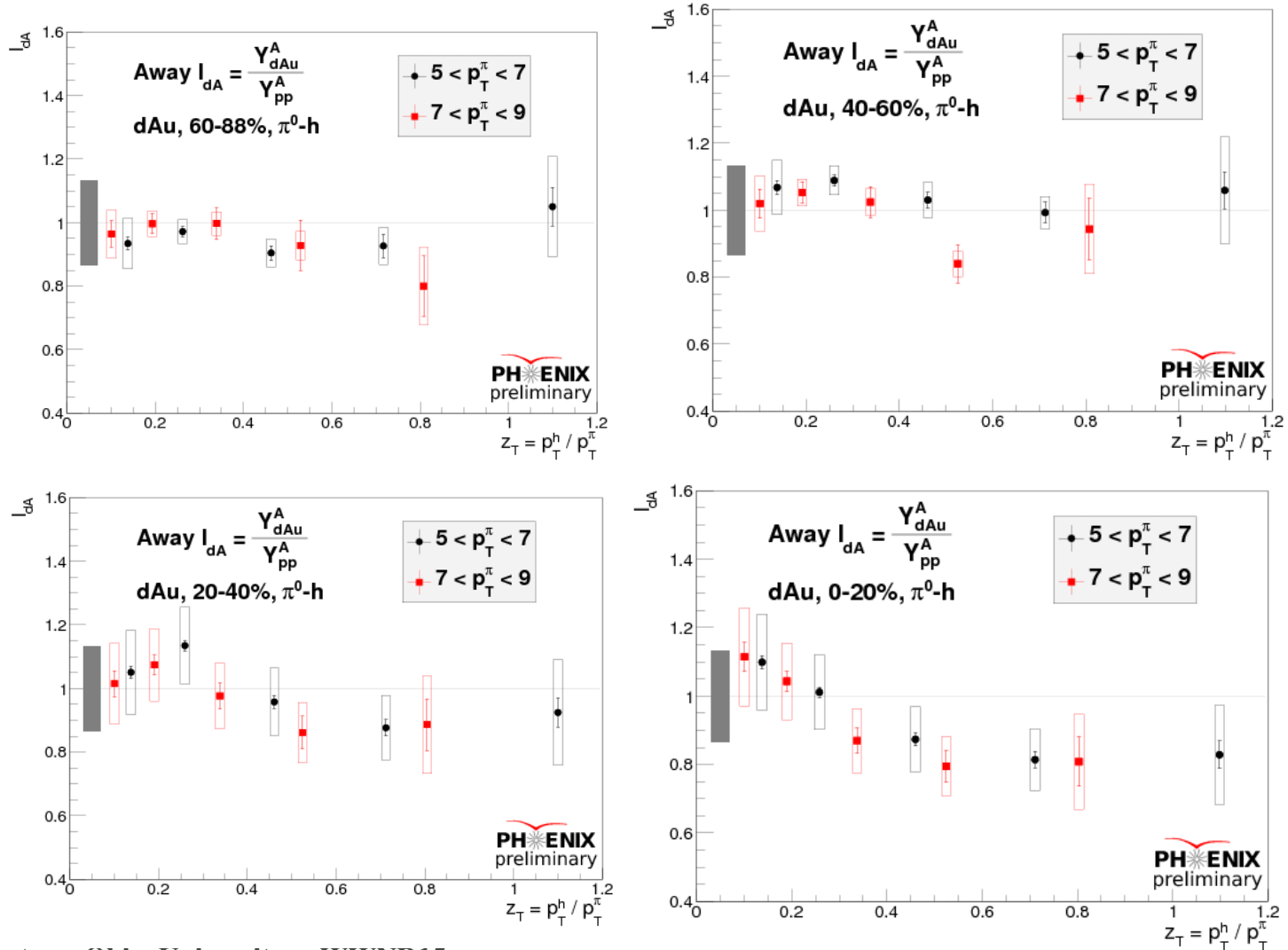
# 2008 Statistics Improvement

- NEW DATA (QM14 Preliminary)
- Statistics does allow a better view of centrality dependence
- But efficiency systematics are still too big to resolve



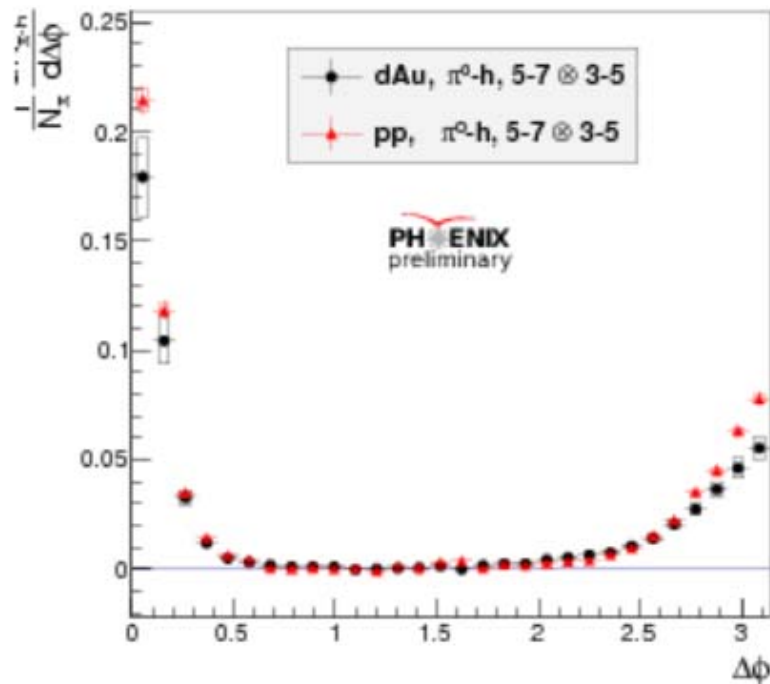
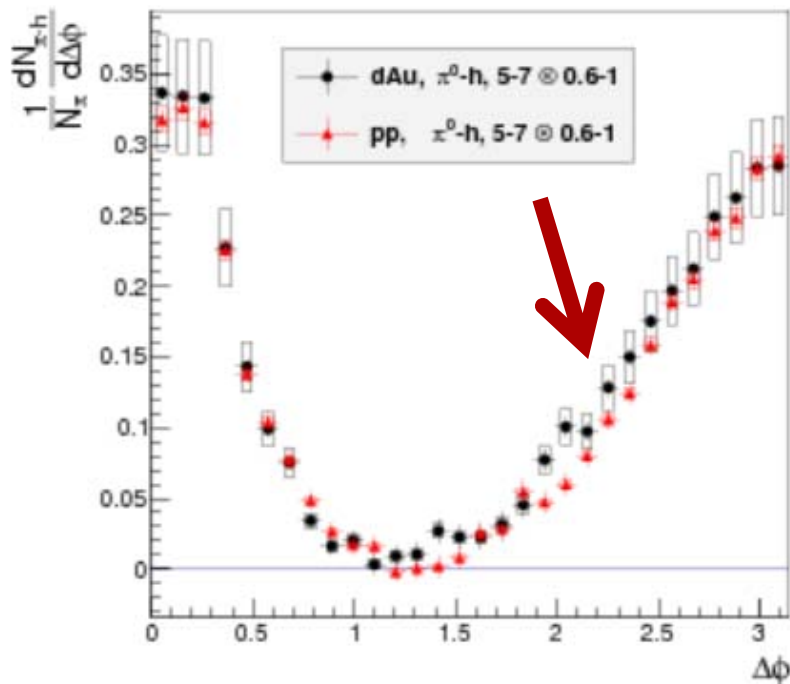
# 2008 Statistics Improvement

- All Centralities: Centrality Dependence



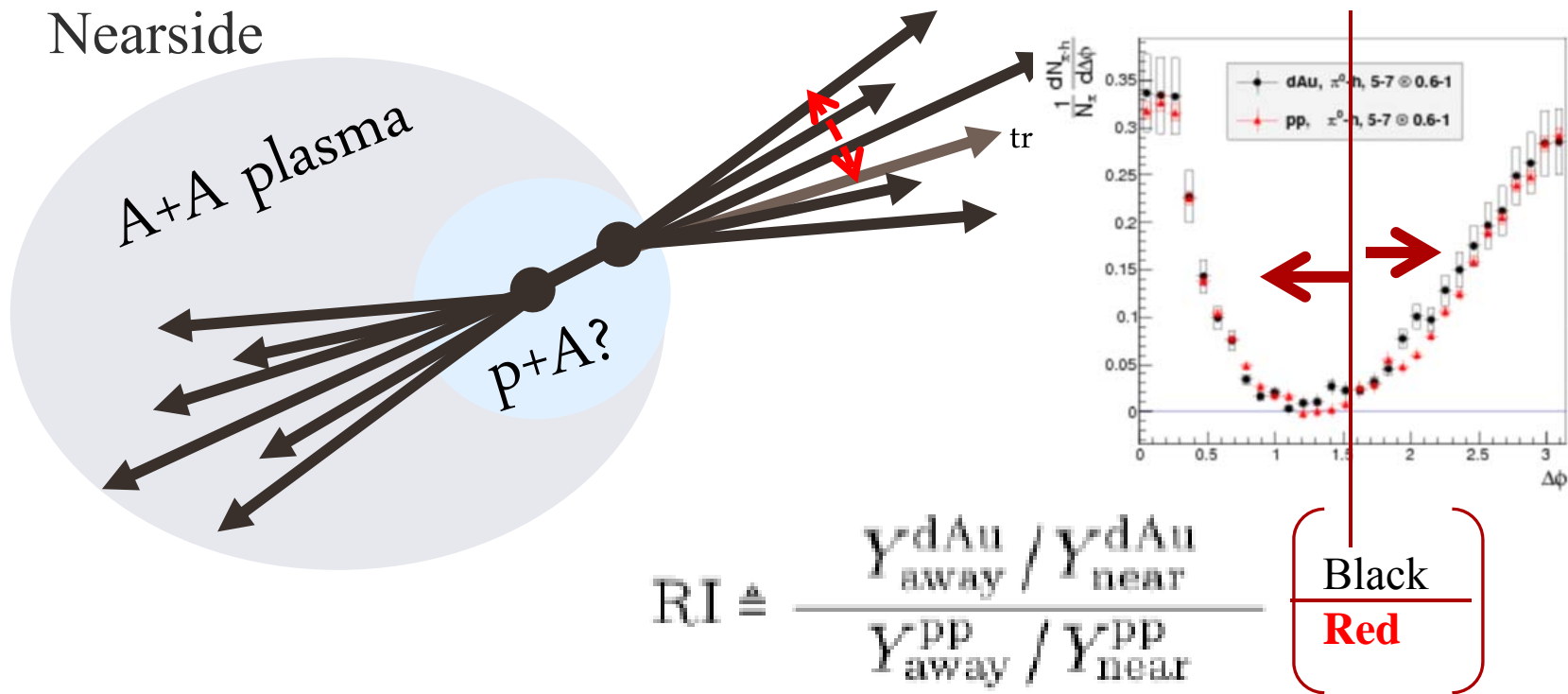
# Qualitatively Similar Features to AA

- Run 8 high precision data allows us to see delicate features
- Enhancement/Suppression
- Efficiency Systematics not shown  $\rightarrow$  same (const) for all  $\Delta\phi$



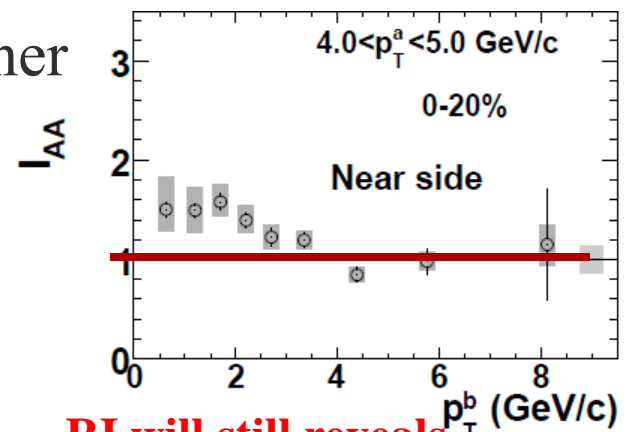
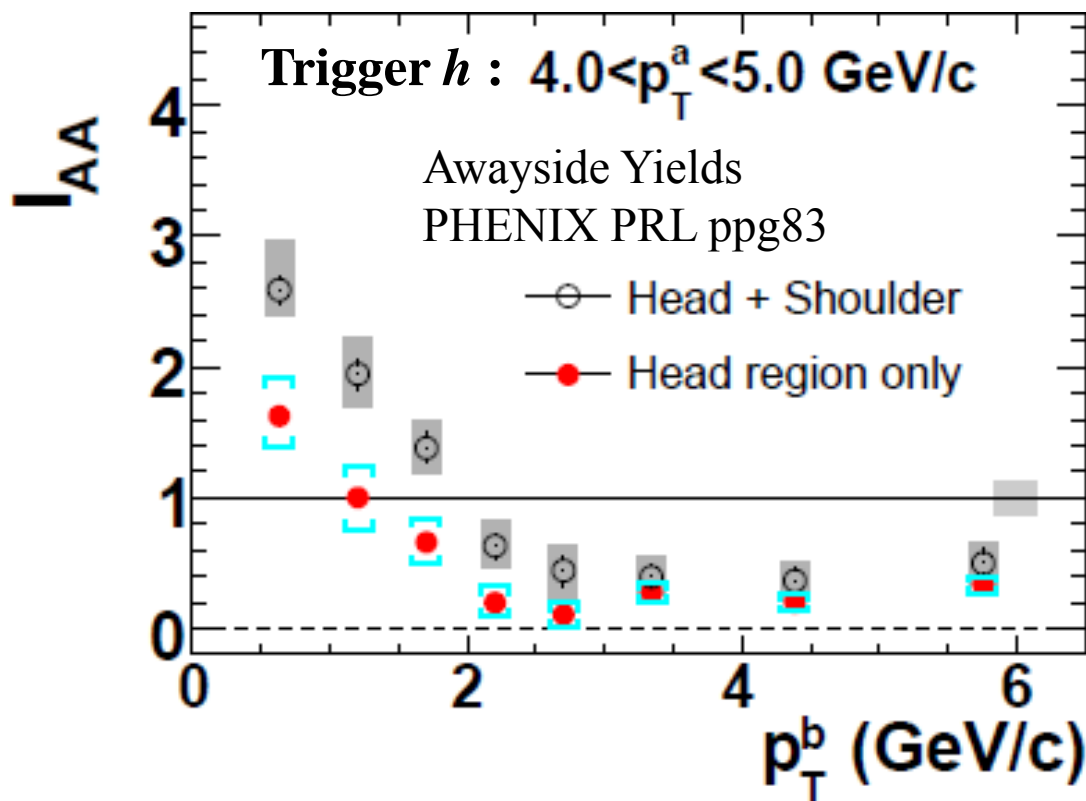
# NS/AS Ratios: A Nice Observable for searching for $E_{\text{loss}}$ in small systems?

- Assume well-known surface bias picture for Au+Au should apply to a smaller d+Au
- Look for Differences in Awayside Modification compared to Nearside

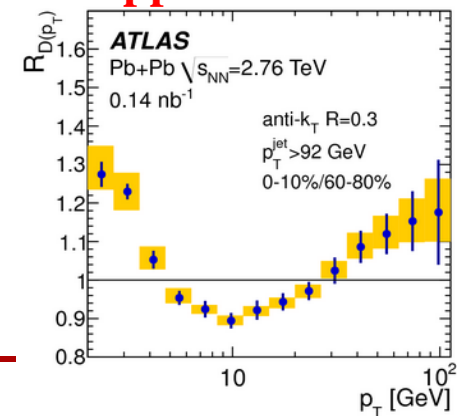


# IAA $\rightarrow$ RI AuAu: Enhance/Suppress

- Example Au+Au IAA NOTE not  $v_3$  subtracted (but  $v_3$  does not change the (large!) qualitative trend
- Dividing by the NS doesn't change trend either
- We've checked with AA RI including full  $v_n$  subtraction



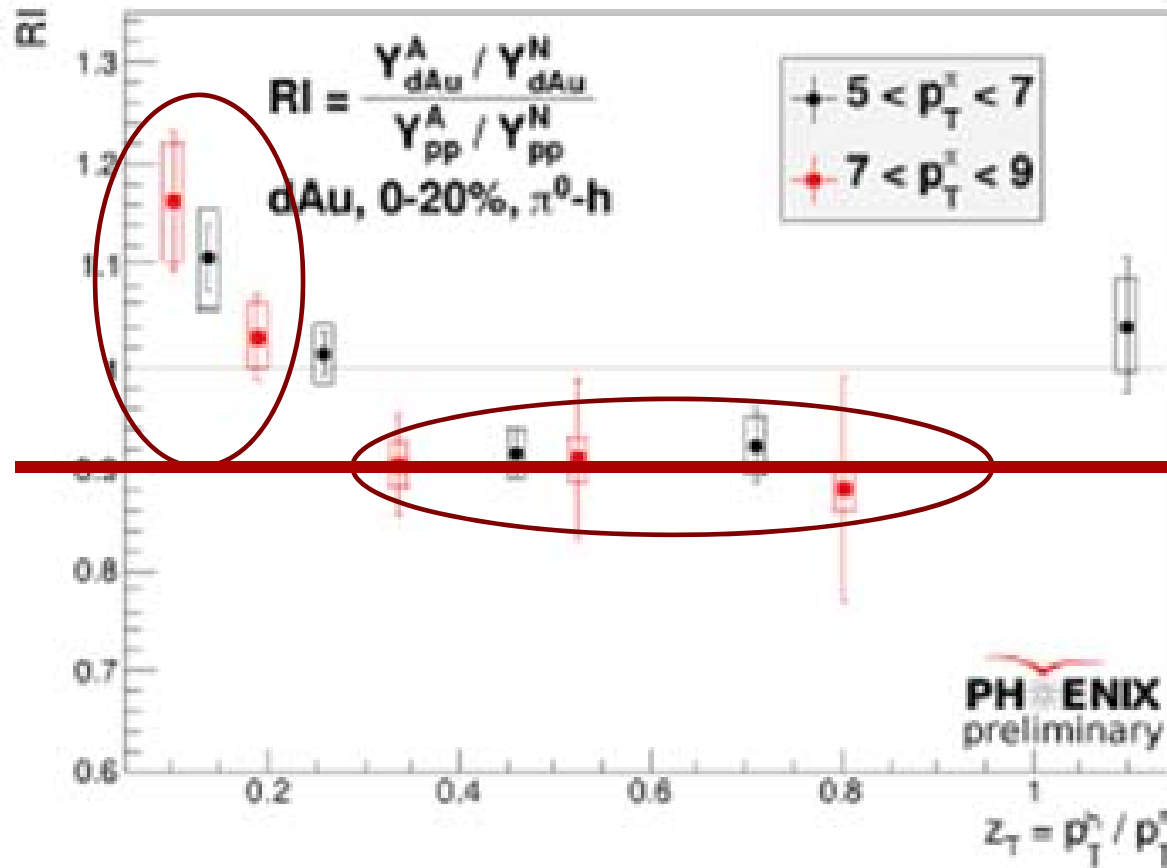
**RI will still reveals  
the qualitative  
features of the FF +  
Jet Suppression**



PLB 739 (2014) 320-342

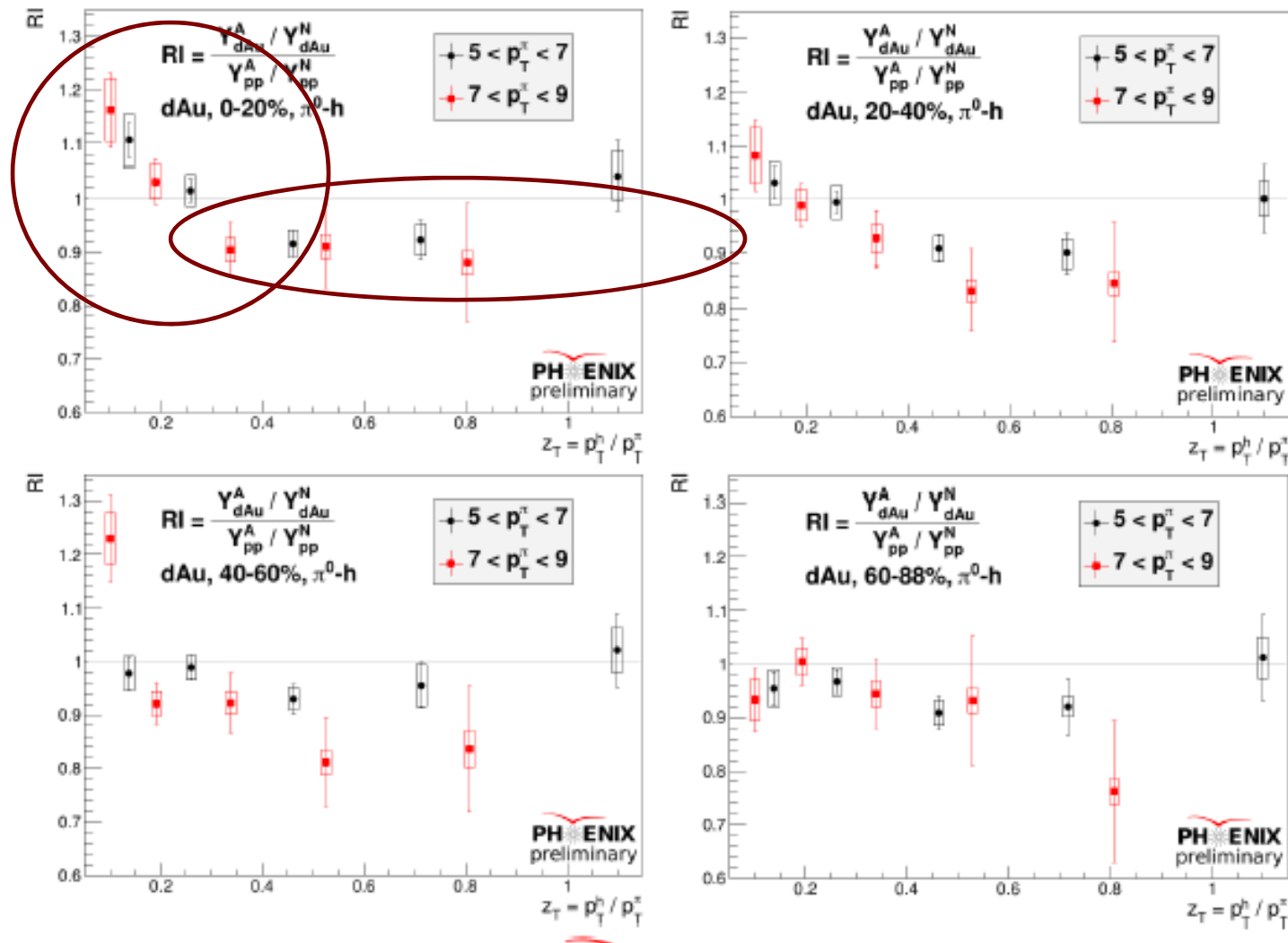
# RI in Central Events

- Reminiscent of Au+Au behavior but much smaller.
- RI uncertainty cancellations allows statistical significance for small effect
- Chi2 of constant fit is large: many sigma significance



Remember  
Look here

# RI Ratio Centrality Dependence

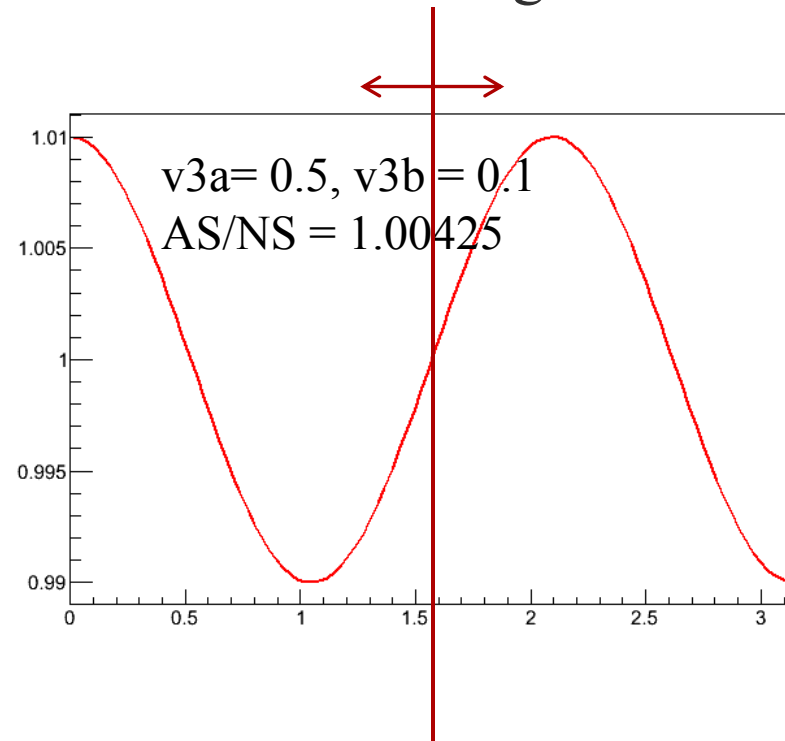
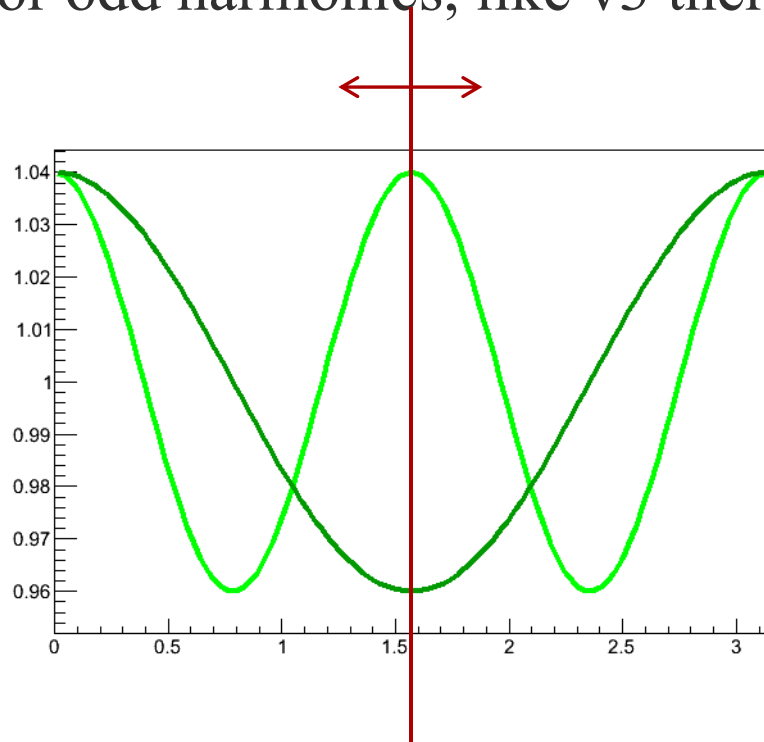


# “Trivial” Causes?

- Maybe it’s not Eloss, but in any case what is it?!
- Strategy: address all “trivial” explanations we can test:
  - “Hydro” v3, v1
  - Enhanced Nuclear  $k_T$
  - Initial State nPDF effects
  - Trivial Rapidity Distributions Mismatching p+p vs d+Au?
  - HIJING show anything like this?
- If none of above → INTERESTING
  - Looking for other ideas?

# "Soft" (Hydro?) v1, v3?

- Because we divide full AS ( $D\phi \pi/2$ ) by full NS even harmonics such as v2 cancel perfectly after ZYAM
- in AS/NS yields themselves ZYAM level systematic evaluated, given separately
- For odd harmonics, like v3 there is a residual affecting  $RI=AS/NS$

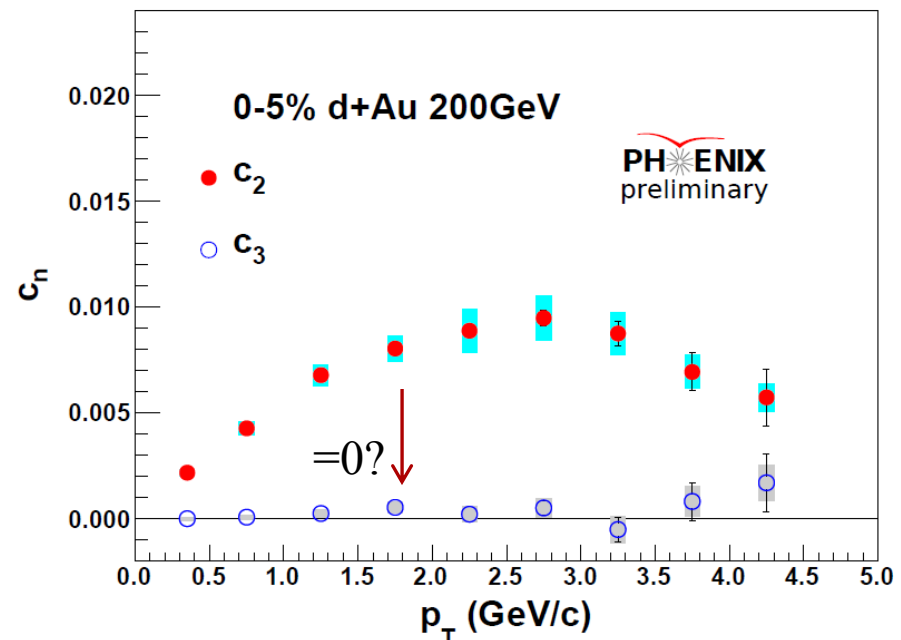
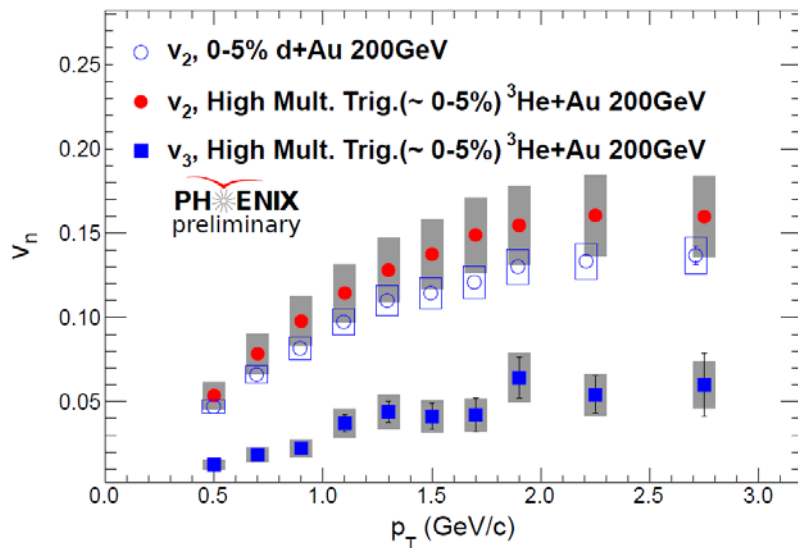


# v3 in d+Au? Probably

- Note there is no d+Au PHENIX  $v_3$  measurement **nor upper limit**
- Previously shown  $c_3 = 0$  does not constrain  $v_3$  very much
  - (depends on multiplicity/acceptance/ $v_3$ (large eta) which may be small)
- Something compatible with He+Au is likely given fluctuations dominance

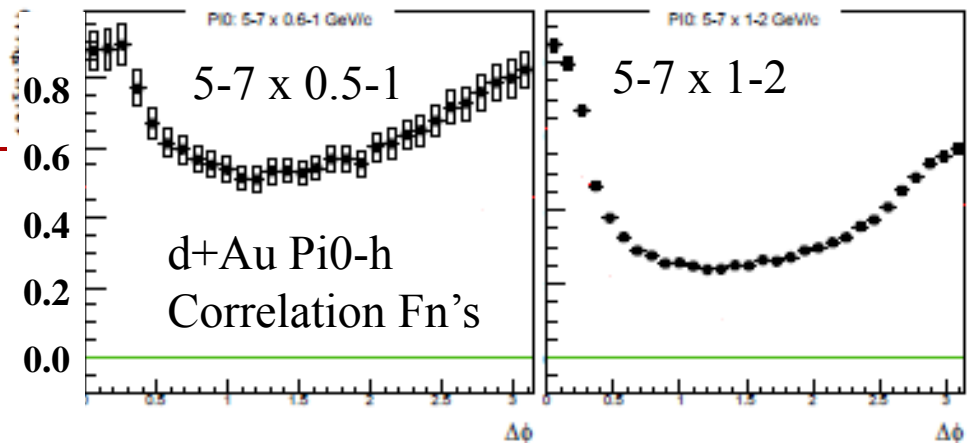
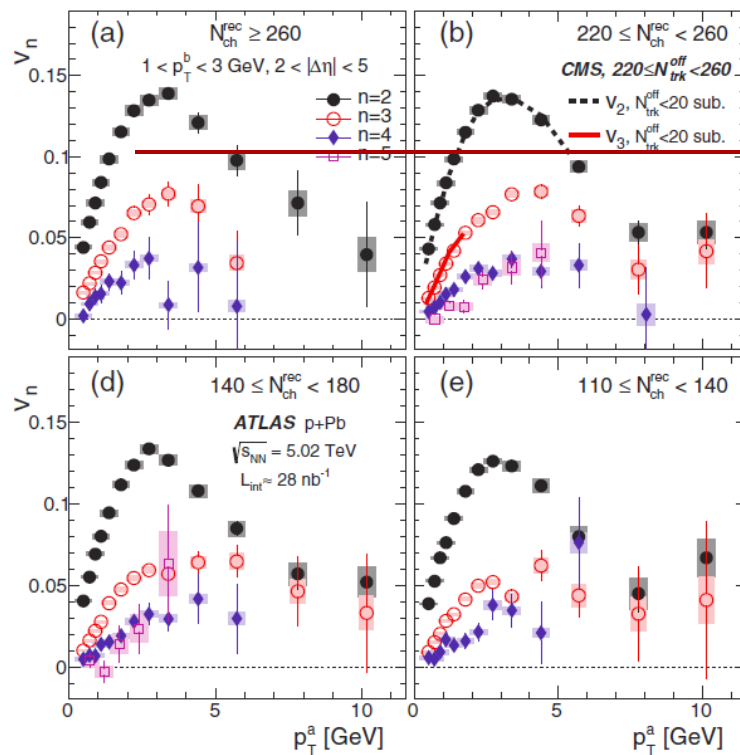
These are  $c_n$ 's = ( $\propto v_n^2$ ) not  $v_n$ s!!!

Recent non-zero  $v_3$  in He+Au !!!!



# LHC Estimate for $V_3$

- [Remember other than the recent PHENIX He, there are no RHIC d+Au  $v_3$  measurements]
- Thus we estimate it as being the same size as at the LHC. (Judging by 200 GeV He+Au probably overestimate! )



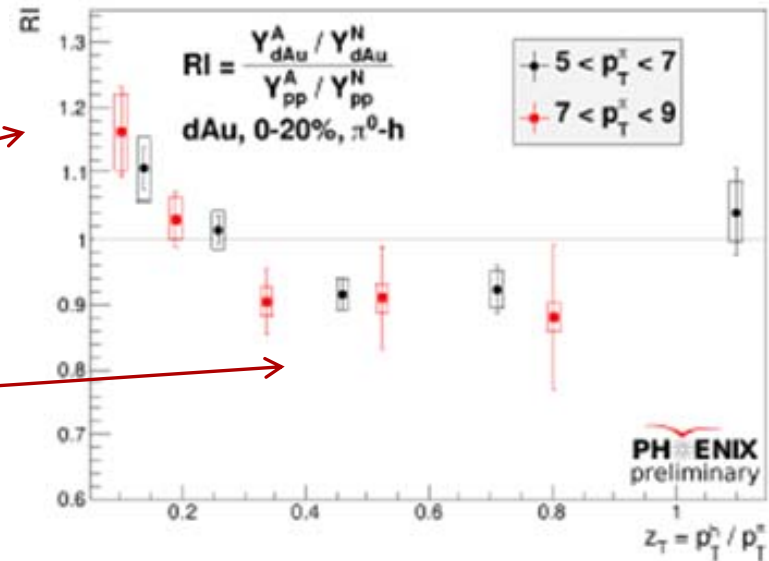
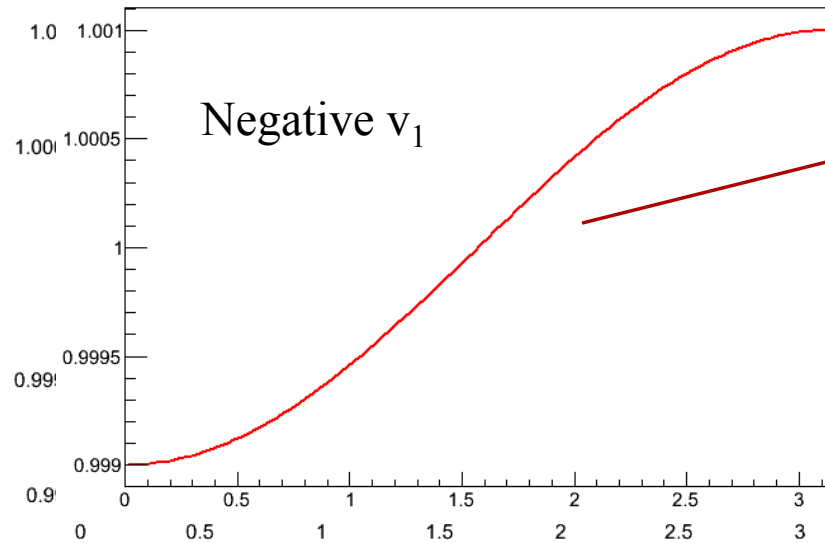
Still this is still d+Au & high  
 $p_T \rightarrow$  jet still has good S/B

**$\sim \leq 1\%$  Effect**

(included in RI systematics)

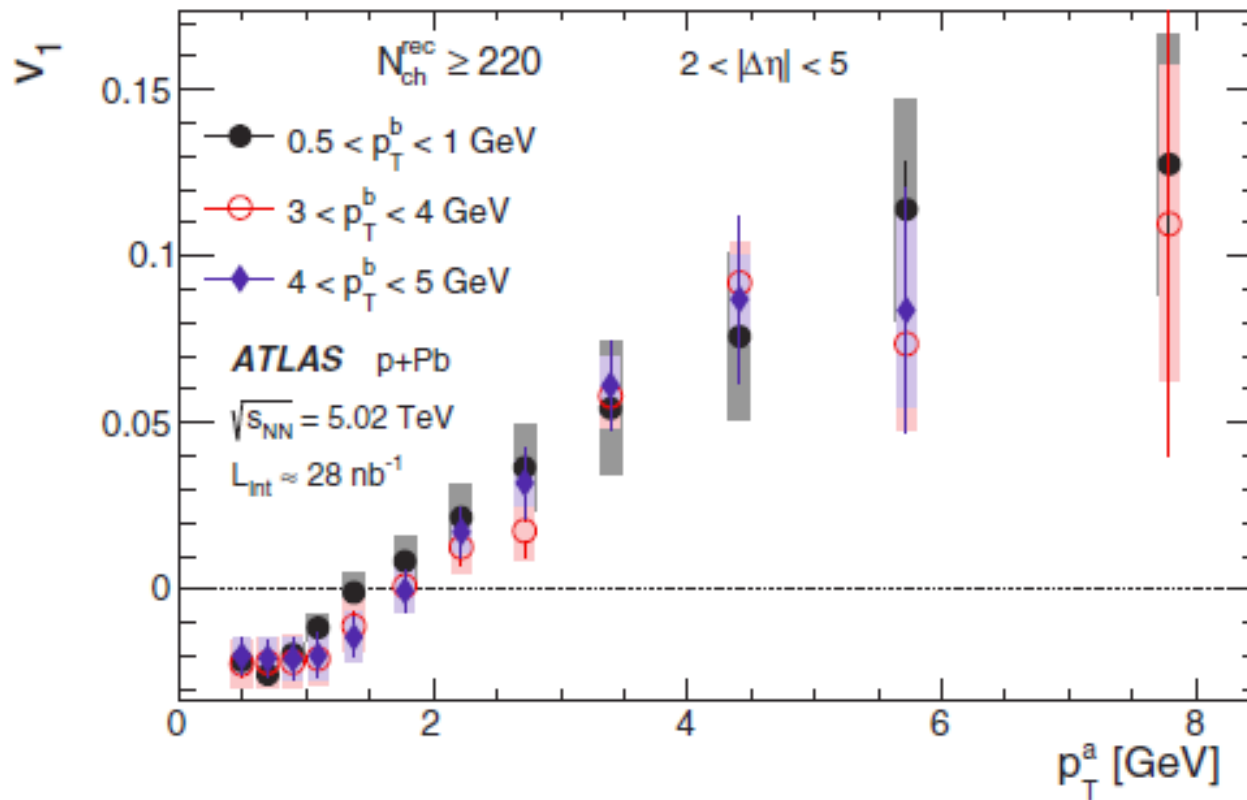
# $v_1$ is Stickier

- We don't need to consider higher odds because “residuals” become small due to oscillations and the  $v_n$ 's get even smaller
- However, if we use LHC as estimate,  $v_1$  may not be negligible:
  - Big enough positive  $v_1$  would “subtract” lowering AS/NS
  - Low pt would make enhancement *bigger* than measured!
- But big enough negative  $v_1$  at low pt would go in right direction for enhancement!



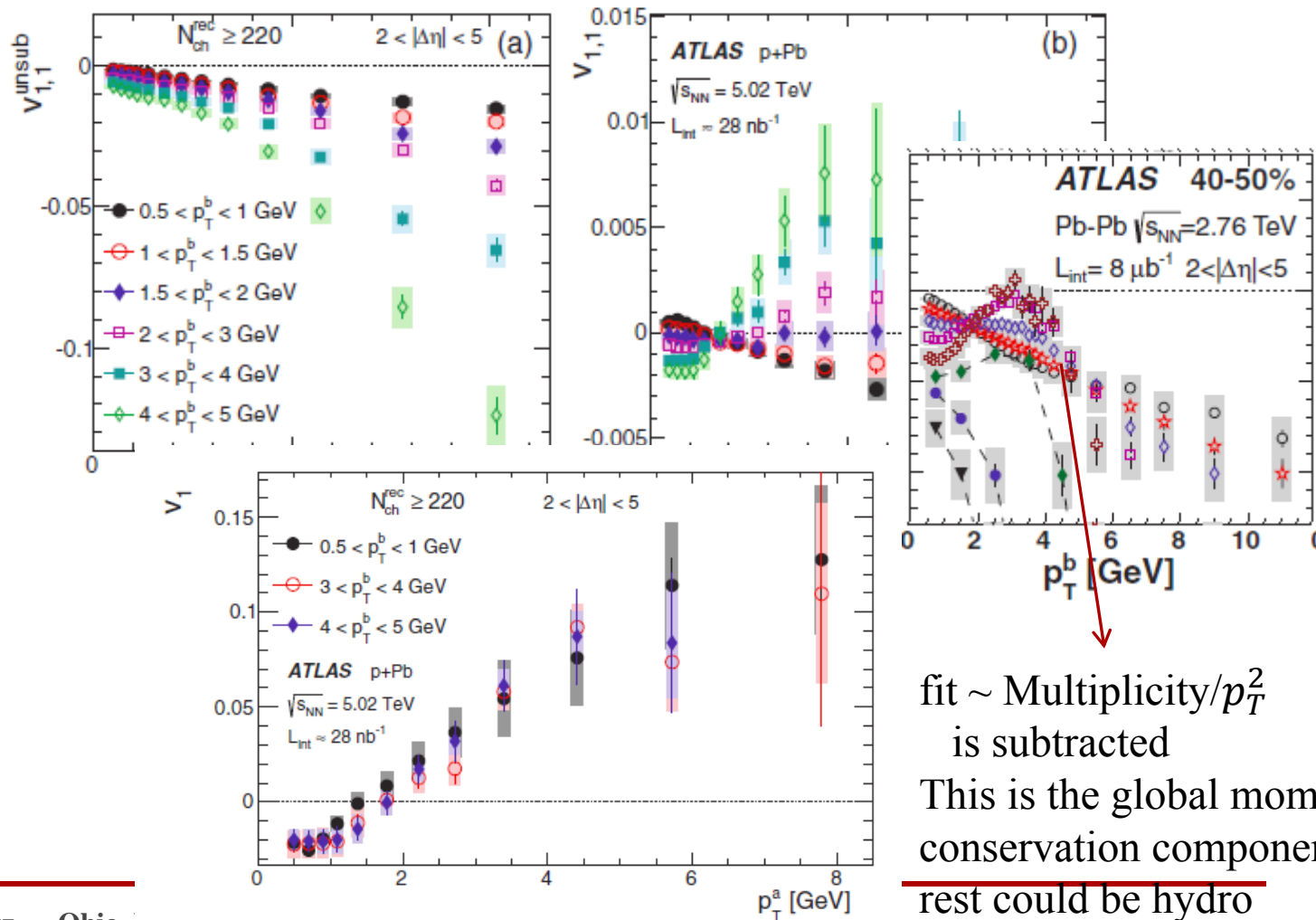
# Negative $v_1$ @ Low $p_T$ , You Ask?

- In fact a negative  $v_1$  is indeed observed in this  $p_T$  region at the LHC by ATLAS



# Which $v_1$ are we talking about?

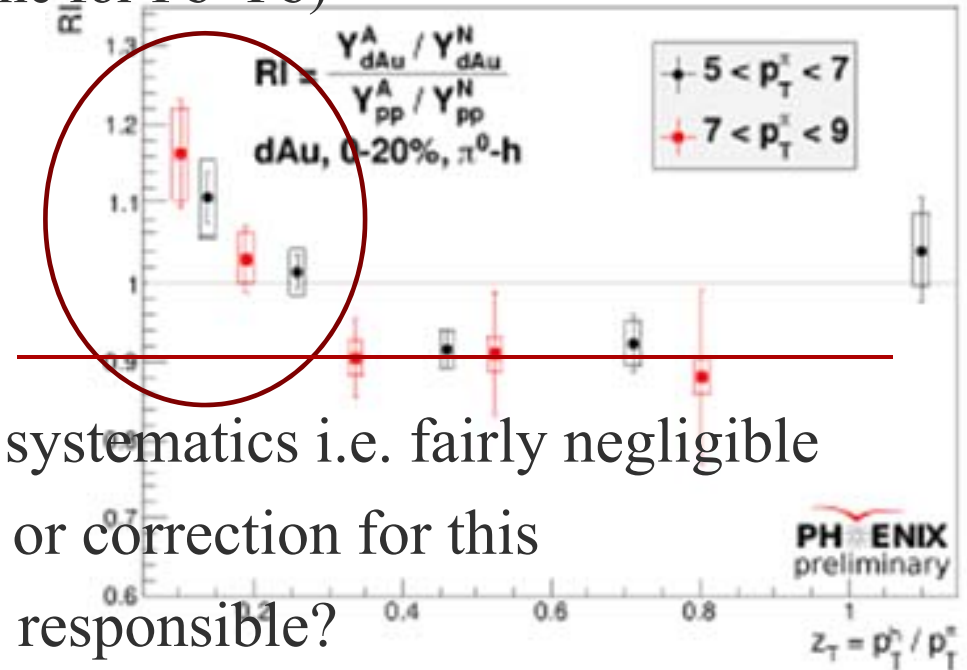
- However the  $v_1$  which can enter the 2pc ( $v_{1,1}$ ) is modeled as having two components



# Implication

- Using the ATLAS estimate of the p+Pb hydro part
- (similar size to v3 and v2, same for Pb+Pb)

$$\Delta R_{I_{v1}}(\text{low } p_T) \sim 2-3 \%$$

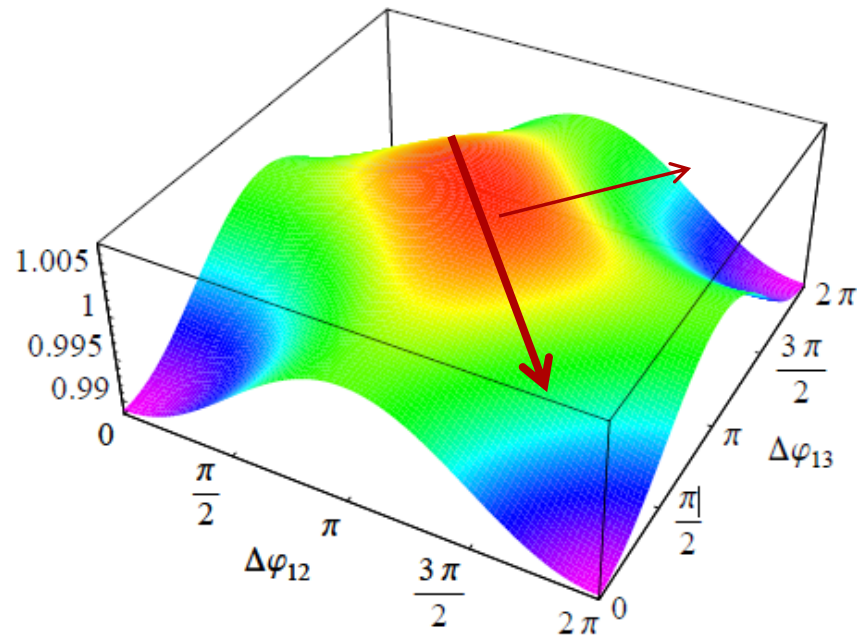


- about half of the current total systematics i.e. fairly negligible
- Currently no extra systematic or correction for this
- GlobalMomConsv and/or jets responsible?
  - if jets  $\rightarrow E_{loss}$ ?
  - GMC: hard to disentangle from the jets,
  - if GMC is modified separately it would be interesting!
  - GMC would still not explain the suppression at high  $z_T$

**CURRENTLY STUDYING  
AMPT**

# Digression

- Cumulant Discussion this morning about Global Correlation
- Borghini: Thought I remembered GMC explanation of Mach Cone (v3)  
Borghini nucl-th/0612093v1



Project certain  $\Delta\phi_{13}$   
regions in 2+1 type  $\Delta\phi_{12}$   
projection ?

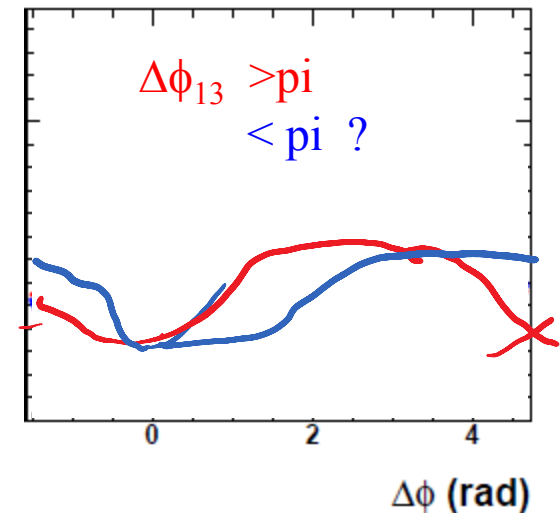


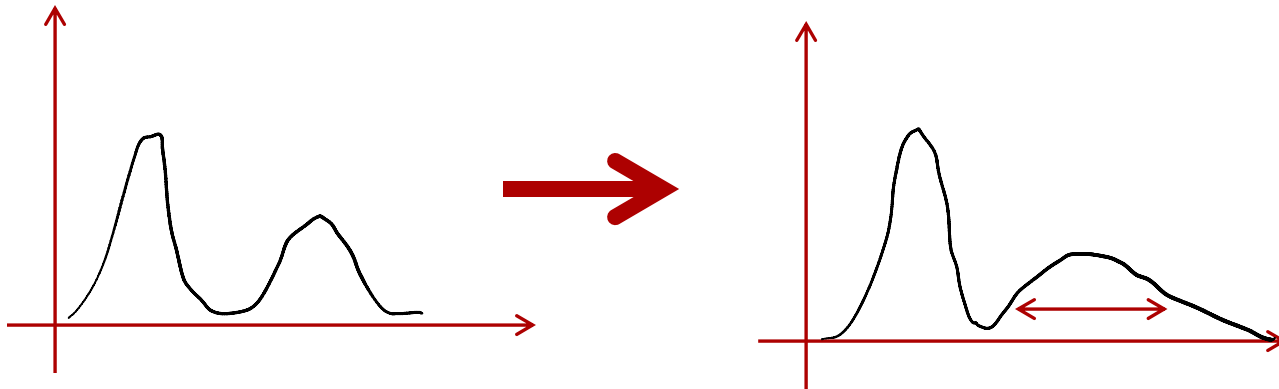
FIG. 2: (Color online) Three-particle correlation due to global transverse-momentum conservation vs. the relative angles  $\Delta\varphi_{12}$ ,  $\Delta\varphi_{13}$ , assuming  $N = 8000$  particles per event with a rms transverse momentum  $\langle p_T^2 \rangle^{1/2} = 0.45$  GeV/ $c$ , for particles of transverse momentum  $p_{T1} = 3.2$  GeV/ $c$  and  $p_{T2} = p_{T3} = 1.2$  GeV/ $c$ , respectively.

# “Trivial” Causes?

- Maybe it’s not Eloss, but in any case what is it?!
- Strategy: address all “trivial” explanations we can test:
- ~~“Hydro” v3, v1~~
- Enhanced Nuclear  $k_T$
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- Trivial Rapidity Distributions Mismatching p+p vs d+Au?
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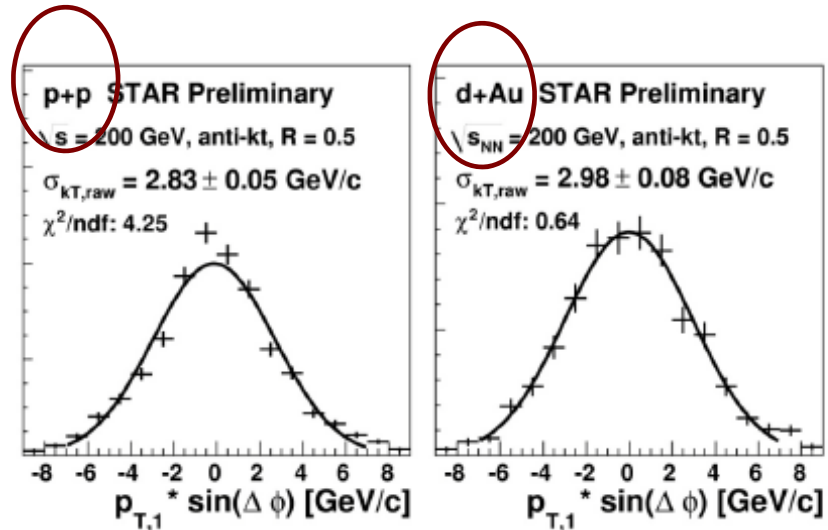
# Enhanced Nuclear $k_T$ ?

- $k_T \equiv$  Acoplanarity of di-jets
- Smears *Awayside*  $\rightarrow$  Known part of the 2pc AS width
- If d+Au had long sought after enhanced nuclear  $k_T$ , could this cause this effect in RI?



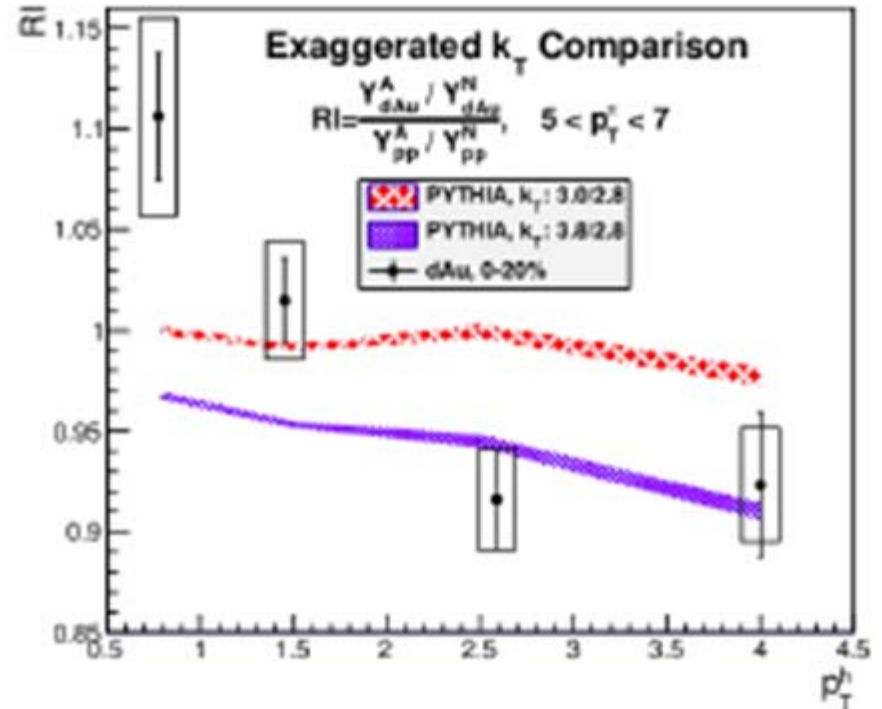
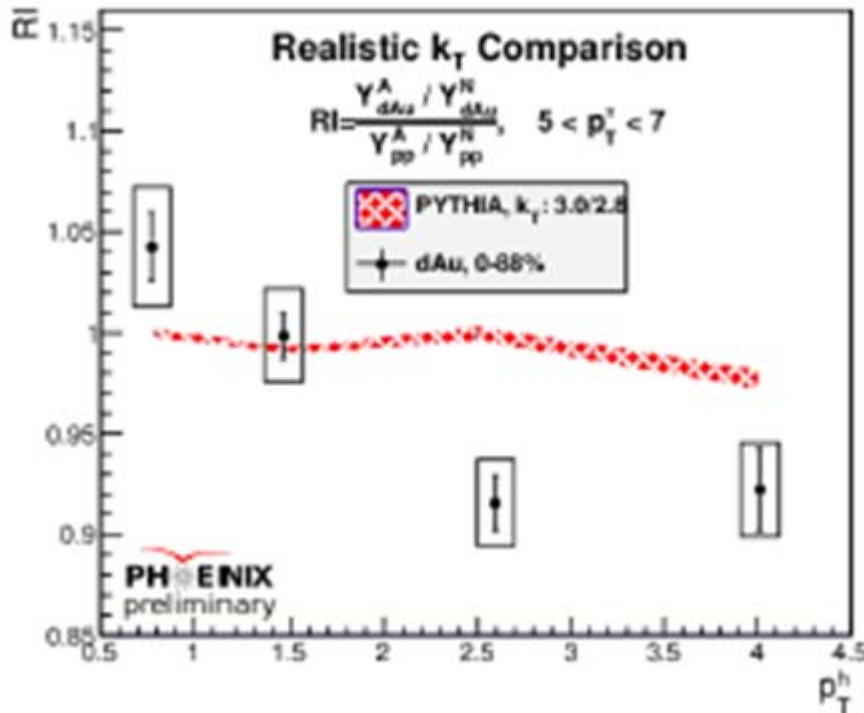
# PYTHIA Nucl $k_T$ Test

- Using  $k_T$  constraints from STAR jet measurements  $\rightarrow$  No effect for 0-100% Minbias
- However,  $k_T$  smear larger in Central?



J. Kapitan (STAR), arXiv:1012.1804

## Using STAR $k_T$ Increase (Minbias)



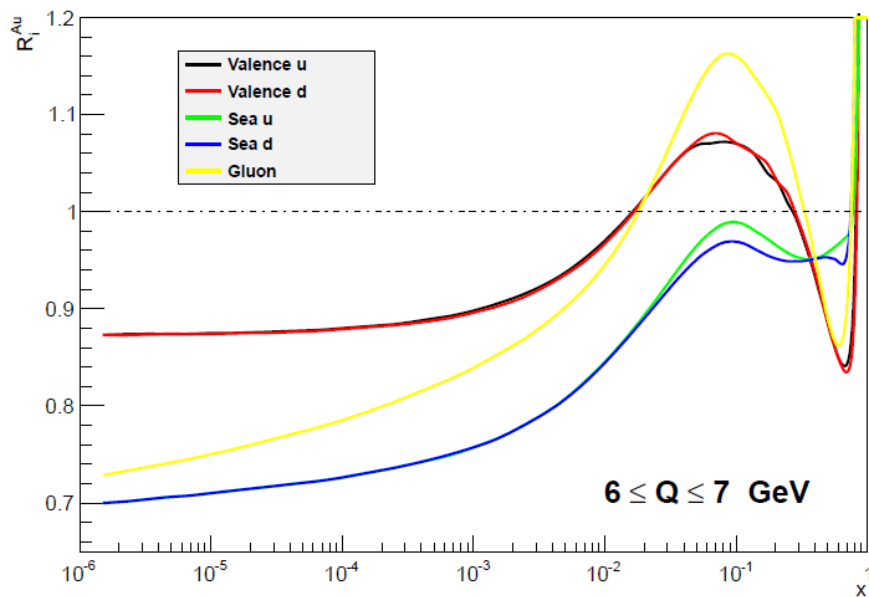
# “Trivial” Causes?

- 
- Strategy: address all “trivial” explanations we can test:
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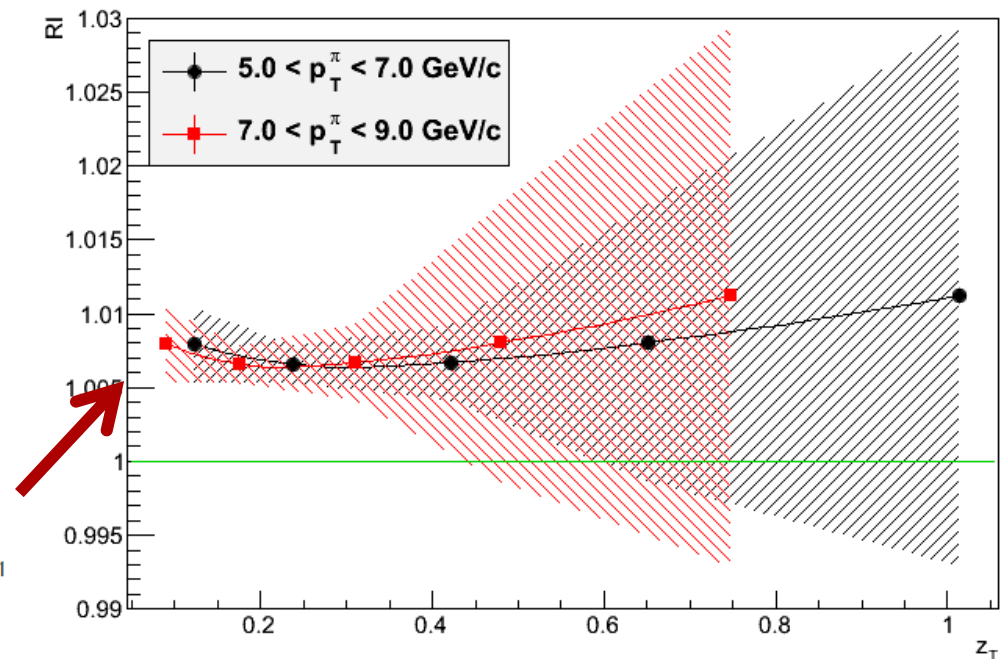
# Initial State Nuclear PDF's?

- nPDF effects would seem unlikely to cause this, since they probably often affect *both* jets in a di-jet
- Studies with EPS09 (and 09s) confirm this expectation
  - NOTE UNITS:  $\ll 1\%$  negligible effect

nPDF extracted from EPS09 code



RI Extracted from EPS09 Study

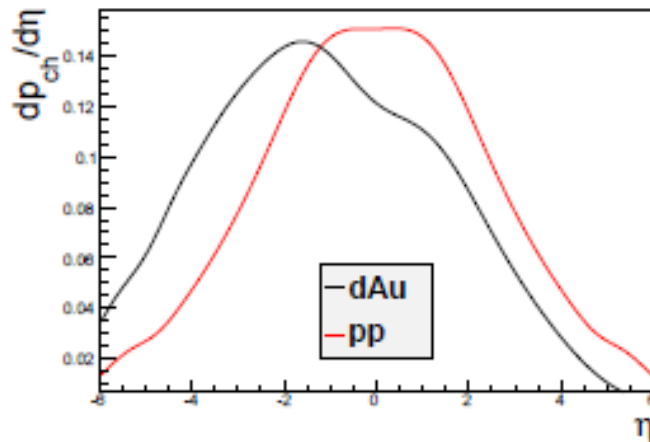


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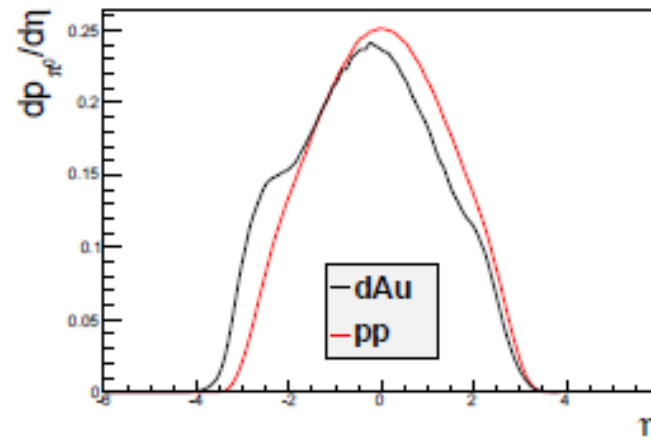
- 
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# HIJING

- We ran HIJING with default settings
- First, this can test for *very* trivial effects e.g. due to the 2p method and to the mismatch in rapidity distributions
- More importantly any other “cold” nuclear physics embedded in HIJING (mini-jets, momentum conservation (?), etc...)



(a) Charged hadrons in central HIJING

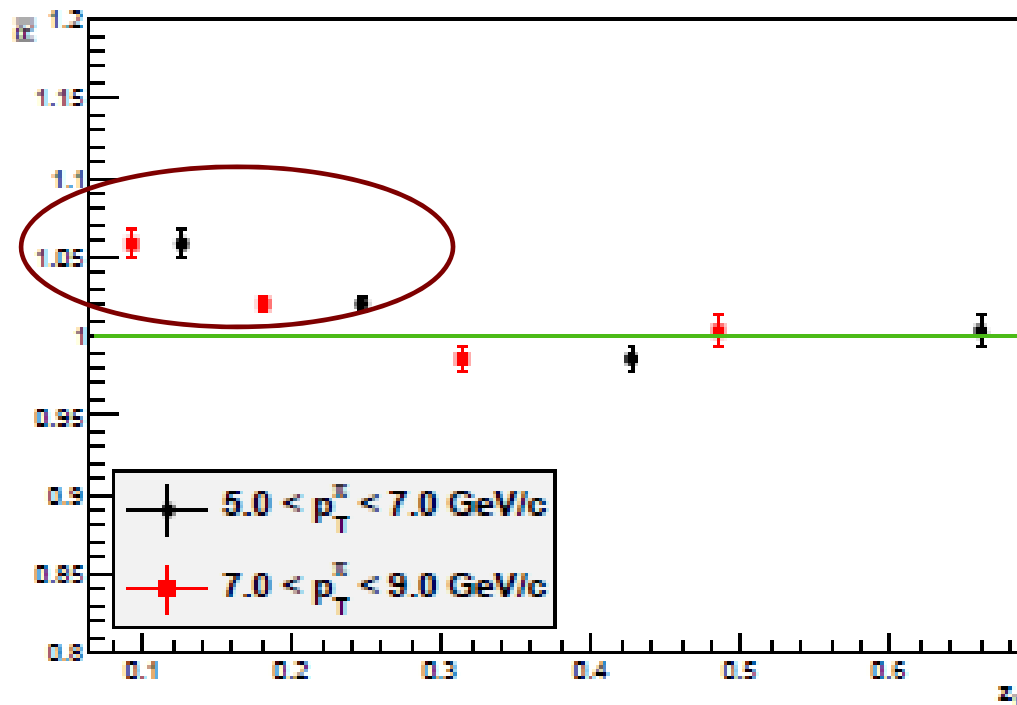


(b)  $\pi^0$  triggers in central HIJING

# HIJING RI

- With default settings, HIJING does not reproduce the effect
- Small enhancement at low  $z_T$  appears to be due to default nuclear  $k_T$  in HIJING consistent with PYTHIA study

*RI* from HIJING simulation with  $k_T = 0.44$  GeV/c.



# “Trivial” Causes?

- 
- Strategy: address all “trivial” explanations we can test:
- ~~“Hydro”  $v_3$ ,  $v_1$~~
- ~~Enhanced Nuclear  $k_T$~~
- ~~Initial State nPDF effects~~
- ~~Trivial Rapidity Distributions Mismatching p+p vs d+Au?~~
- ~~HIJING show anything like this?~~

- **Yes this looks INTERESTING!**
  - Looking for other ideas?

# Conclusions

- By canceling systematics, the RI ratio reveals a modification in the traditionally jet interpreted  $p_T$  regions that is qualitatively similar to A+A  $E_{loss}$  but *much smaller*
- No “easily available” initial state or other “trivial” explanation appears to explain this modification
- **Calling Theorists!:** Looking for predictions for this observable. And general guidance for “hot” Eloss in pA: RpA/2PC Is there still room for hot Eloss in LHC data?
  - Cold calculations of interesting other types of RI modifications ?
- Either way this observable should tell us something interesting



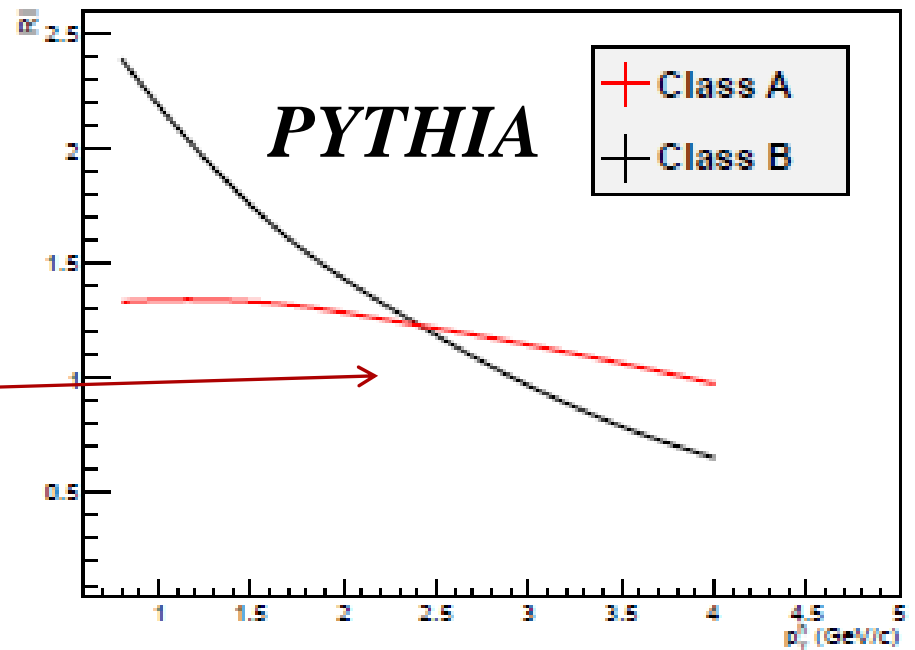
# Backup

# Another PYTHIA study: $q$ vs $g$ jets

- Gluon jets known to be softer than quark jets
- Demonstrated below for a couple different processes
  - Class A: All  $gg$  final states to  $qq(q\bar{q})$  final states

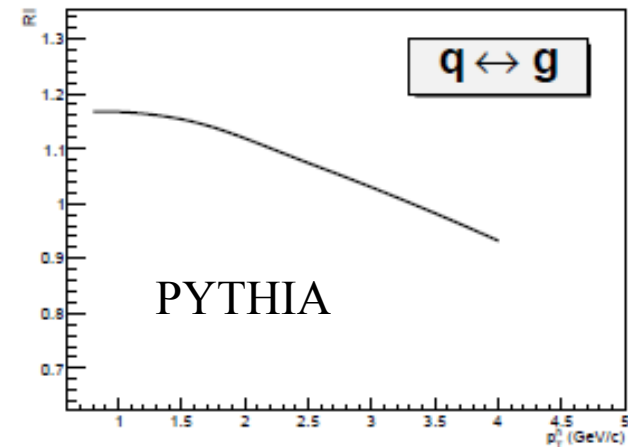
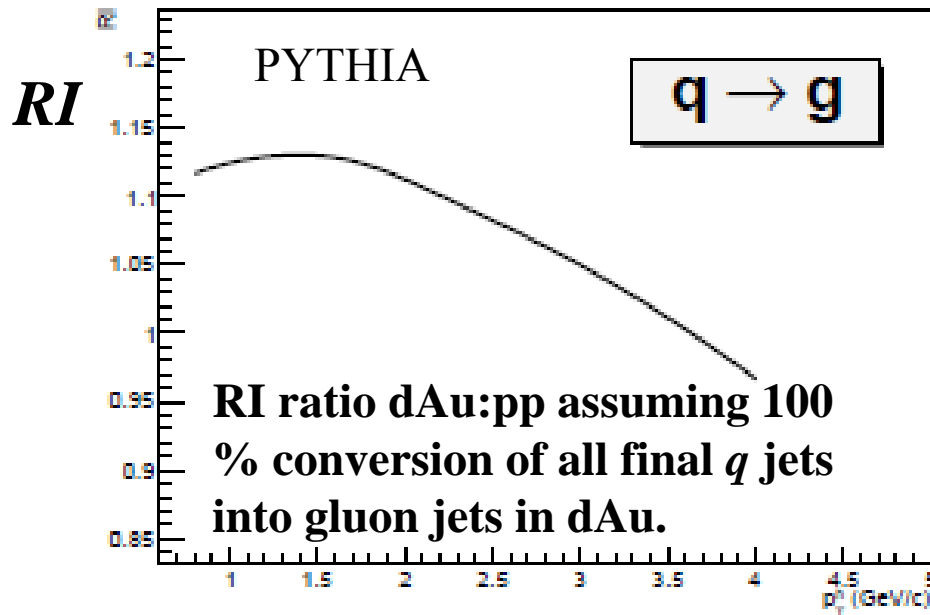
– Class B:  $qg \rightarrow qq$  /  $qg \rightarrow gq$   
(Compton with glue on awayside divided by w/ quark on AS)

-First think of these curves as  $g$  to  $q$  Fragmentation Function Ratios  
-(They are actually  $RI$ -like Away/Near double ratios: A:N for gluon AS final states divided by A:N for quark AS jets)



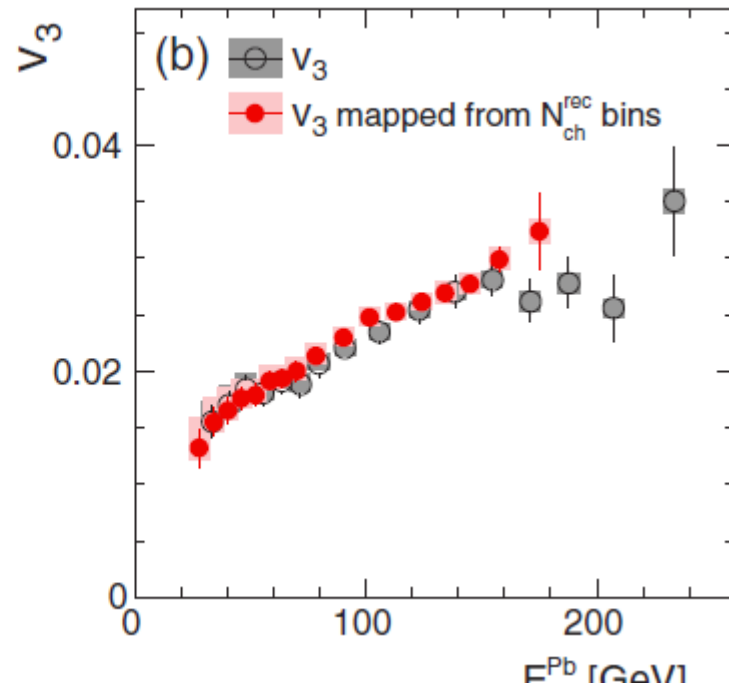
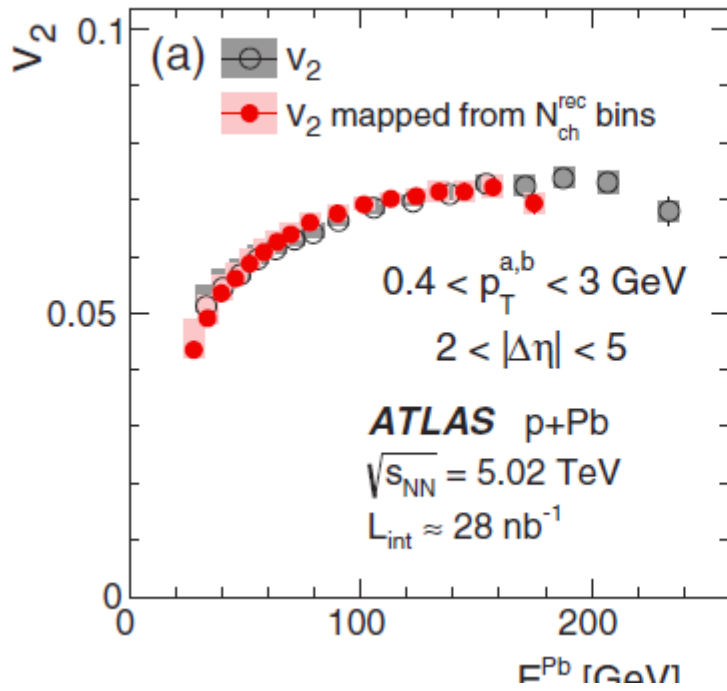
# Couple Scenarios

- Changes to the mix of final state jets: even extreme scenarios don't reproduce the effect



However we note that bigger effects can be generated by changing the mixture in different ways, *e.g.* of putting higher weight on Compton processes

- Shapes also not consistent with effect we see
-

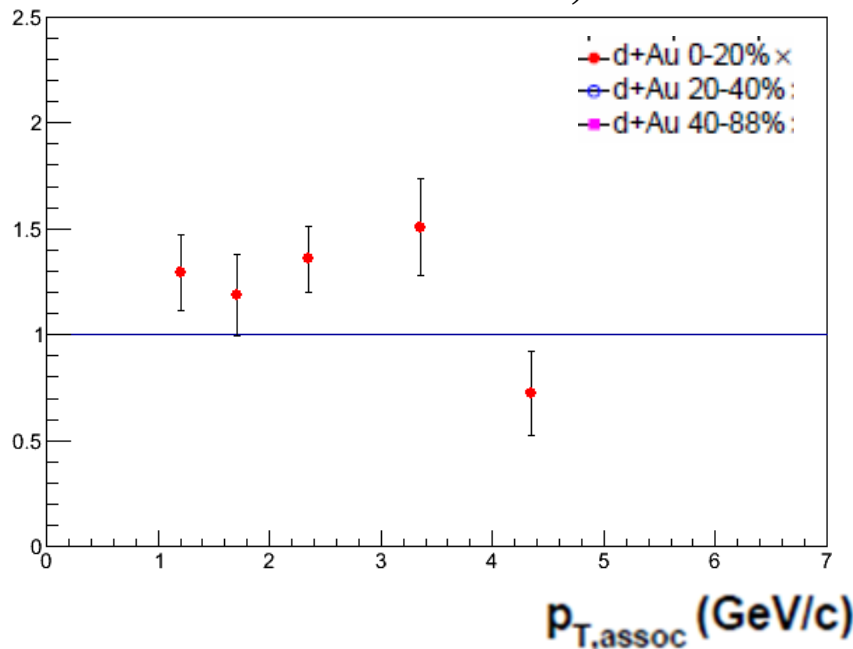


# Old data Awayside/Nearside

## Ratio

- Taking the ratio of nearside to awayside cancels efficiency systematics

PHENIX PRL Data C 73, 054903



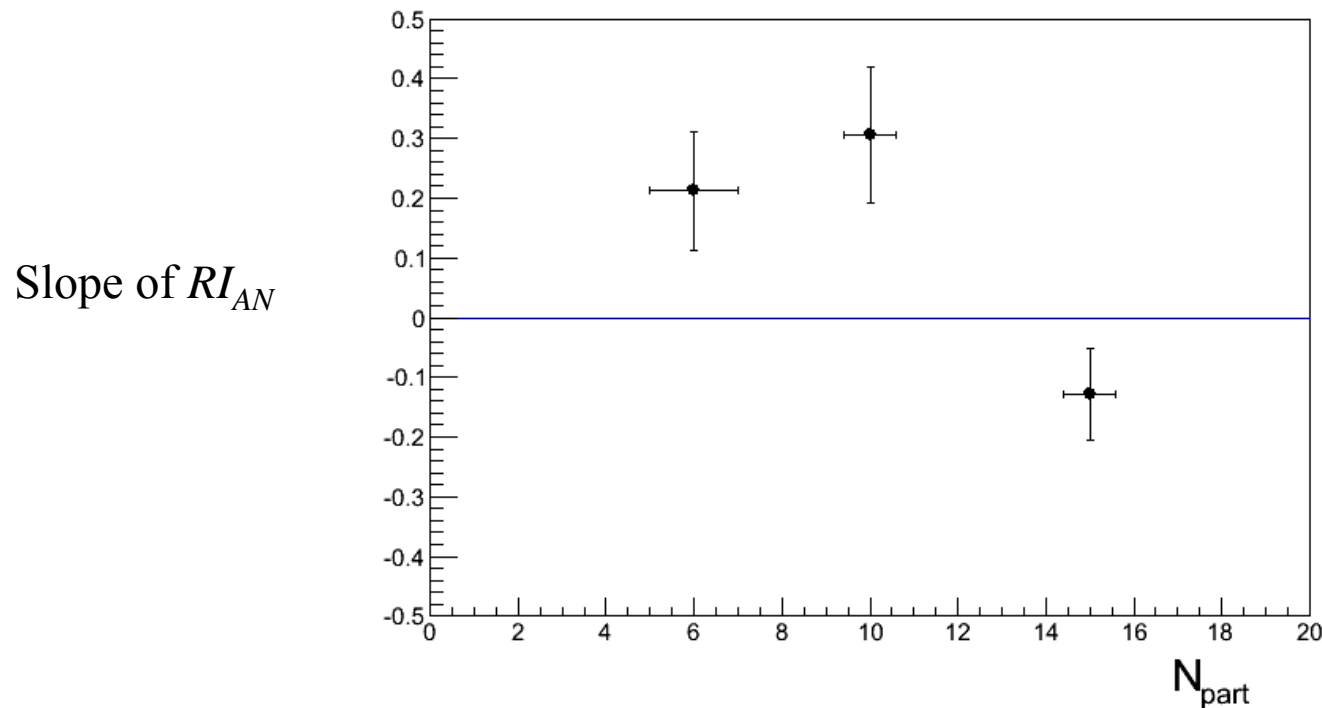
Slope of fit line like for direct photon-h FF fit.

$$\frac{AS_{dAu} / NS_{dAu}}{AS_{p+p} / NS_{p+p}} = \frac{I_{dAu \text{ Away}}}{I_{dAu \text{ Near}}}$$

- Choosing Full  $\pi/2$  range cancels  $v_{2n}$  contributions!
- Only left with vodd:  $v_3$  small in d+Au

# $RI_{AN}$ Slope Centrality Dependence

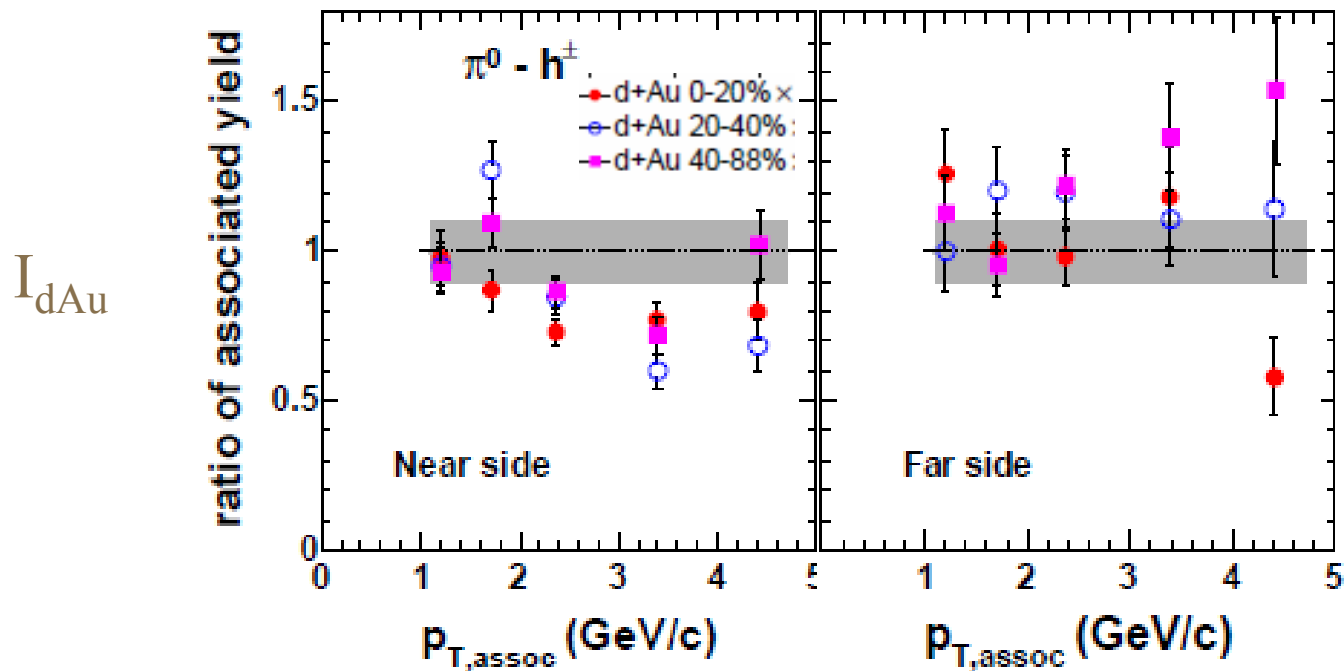
- Slope Change in most central?



- Limited only by statistics?: this is Run3! (Stay tuned for Run8!)

# Awayside/Nearside Ratio $RI_{AN}$

- Taking the ratio of nearside to awayside cancels efficiency systematics



$$RI_{NA} = \frac{AS_{dAu}/NS_{dAu}}{AS_{p+p}/NS_{p+p}} = \frac{I_{dAu \text{ Away}}}{I_{dAu \text{ Near}}}$$

- Choosing Full  $\pi/2$  range cancels  $v_{2k}$  contributions!
- Only left with  $v_{odd}$ :  $v_3$  small in d+Au