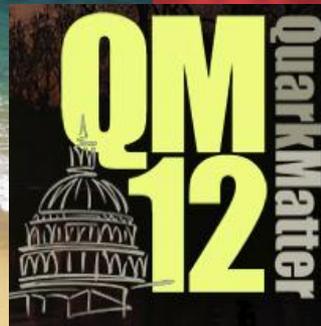


# STEPS FROM QUALITATIVE TO QUANTITATIVE: PROMPT PHOTON PRODUCTION AND PHOTON-JET $\gamma$ -HADRON CORRELATIONS IN PHENIX



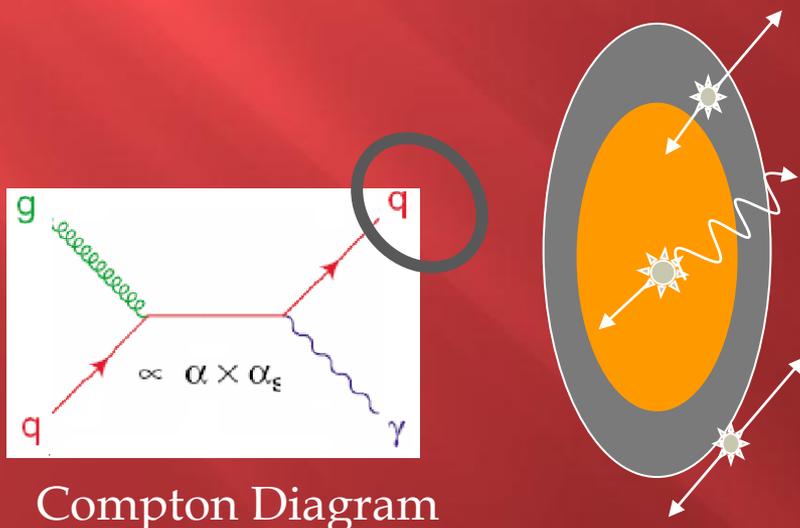
Justin Frantz  
Ohio University

For the PHENIX Collaboration

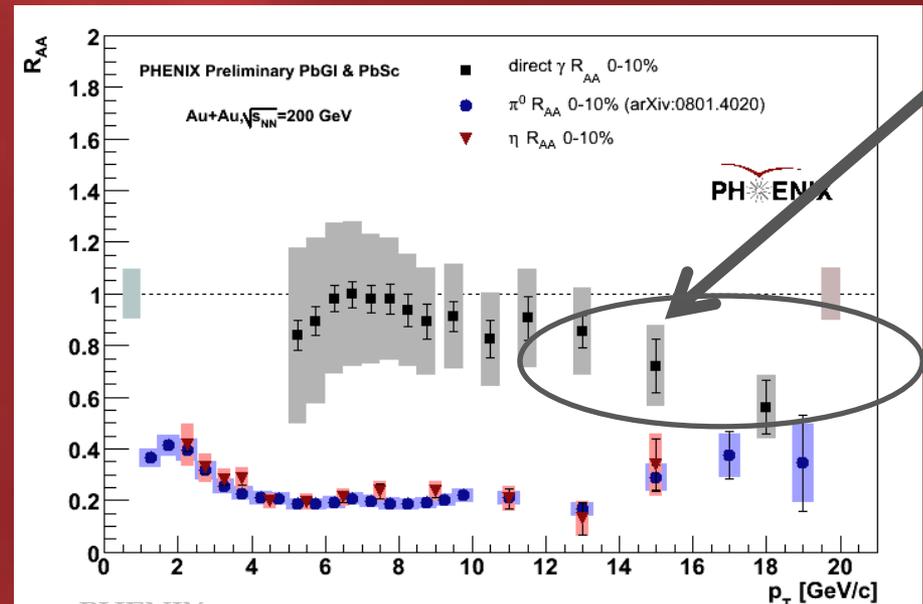


# A “golden” HI jet $E_{\text{loss}}$ channel: $\gamma$ -Jet

- Trigger  $\gamma$  E calibrates the partner jet to leading order
- Purely jet/hadronic observables clouded  $\rightarrow$  triggers themselves are modified
  - Geometric *surface bias* of the single jet, *di-jet* ?
  - Direct  $\gamma$  production unmodified by medium: **no surface bias for  $\gamma$  vertices**
- Plus dominant partonic type becomes purely *q-jets* compared mainly  $\gamma$ -jet/mix in jet-jet ( $q$  vs  $g$   $E_{\text{loss}}$  differs)



Compton Diagram



# How to make direct photon results more quantitative

- ▣ Step 1: strengthen baseline from elementary p+p collisions

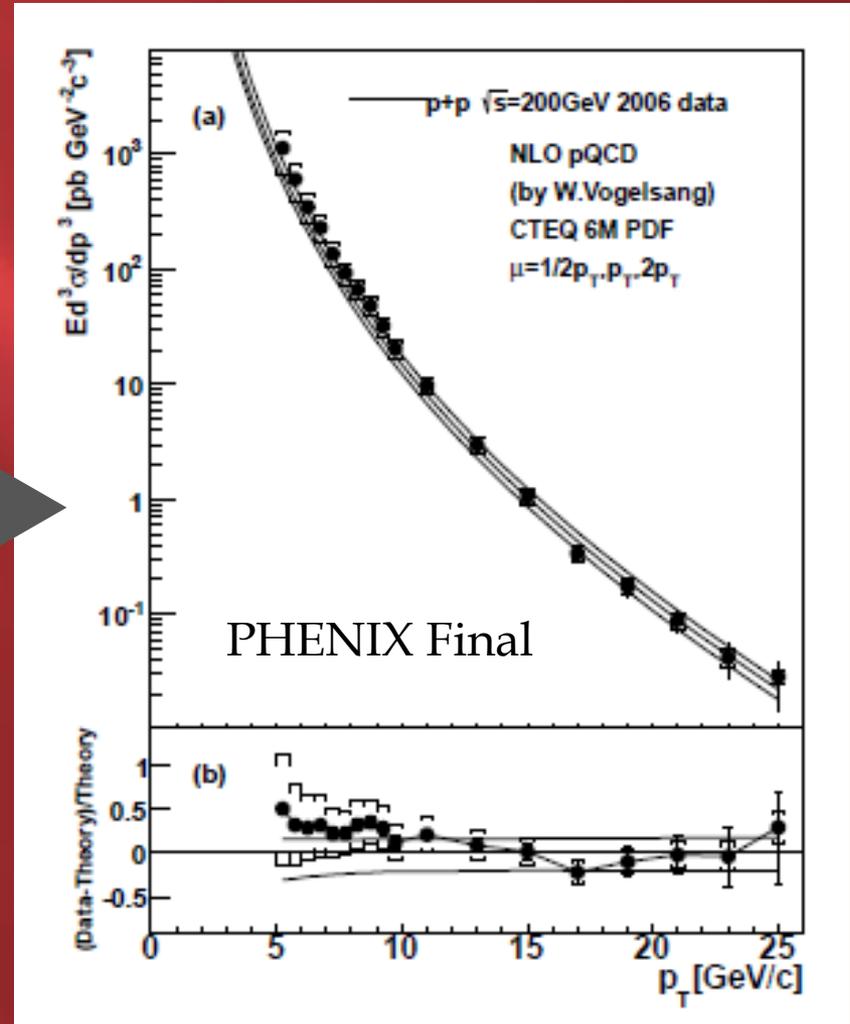
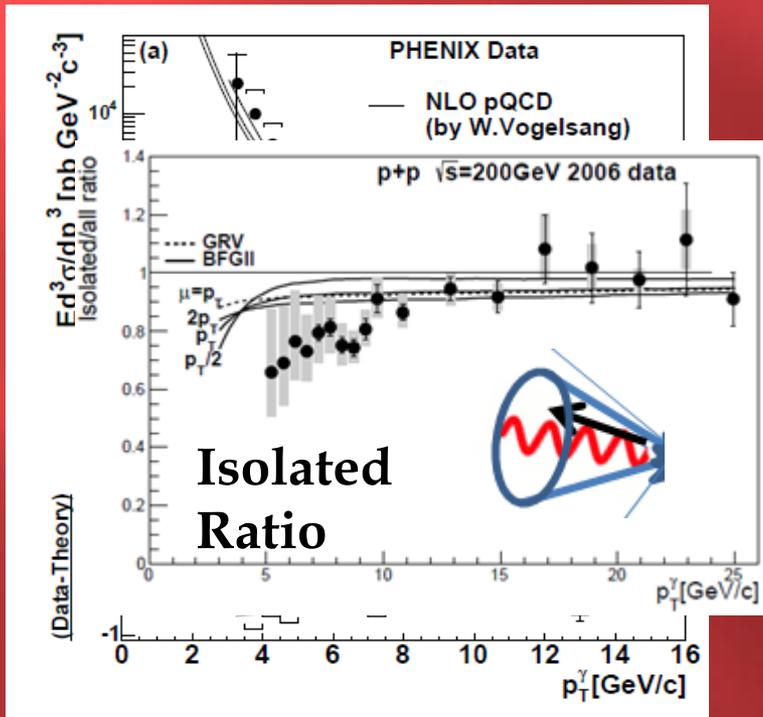


# Strong New p+p measurement!

- ▣ New high statistics dataset
  - $p_T$  range  $\times 2$
  - Precision Improved  $> \times 2$
- ▣ More precise isolated fraction
- ▣  $\sim 90\%$  Iso in  $R = 0.5$  cone

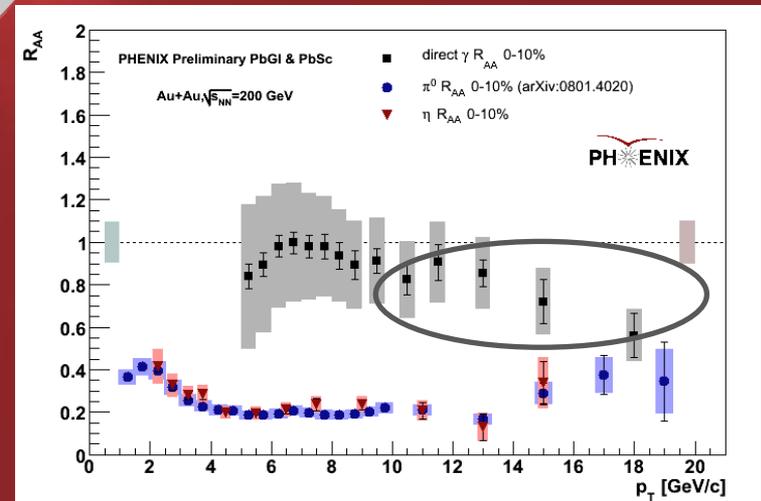


Submitted PRD arXiv:1205.5533



# How to make direct photon results more quantitative

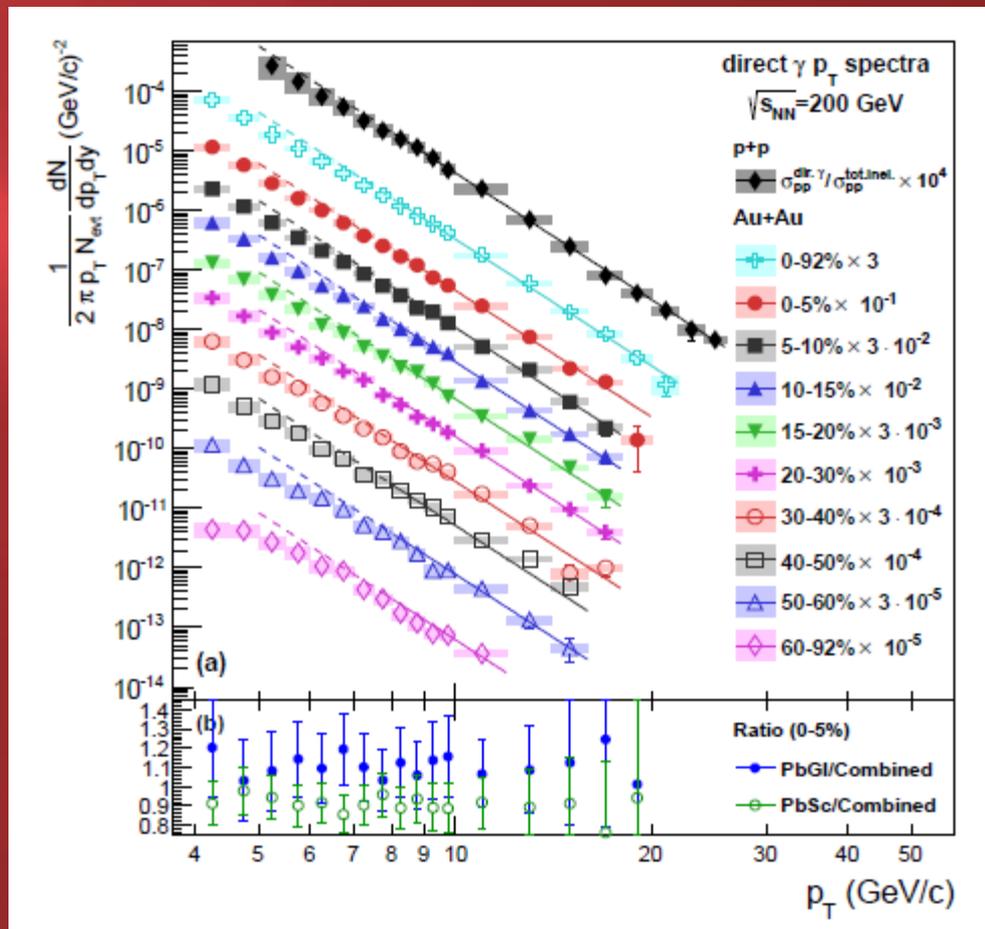
- Step 2: Master your systematics and finalize 2004 golden dataset analysis



# Moving Forward...Finalized Au+Au

- More precise spectra measurement published!
- 2004 Dataset systematics (e.g.  $\pi^0$  merging) studied in great detail

[Submitted PRL arXiv:1205.5759](#)

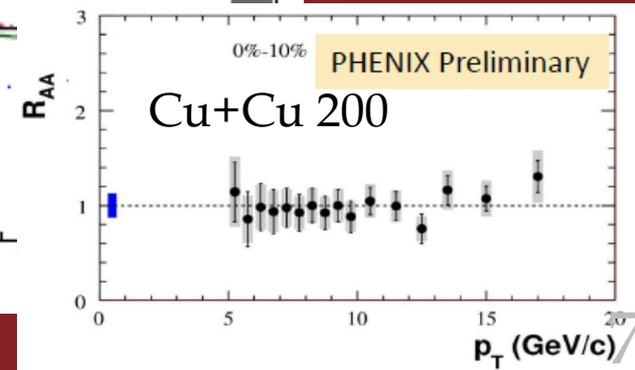
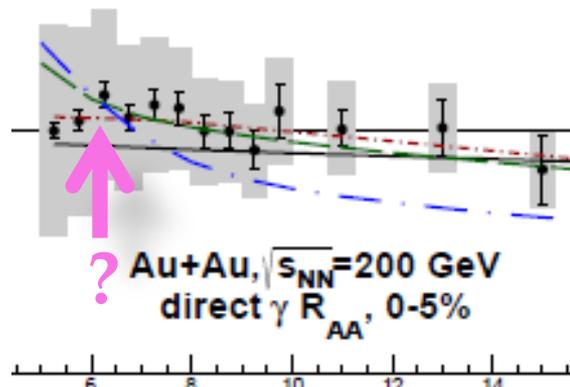
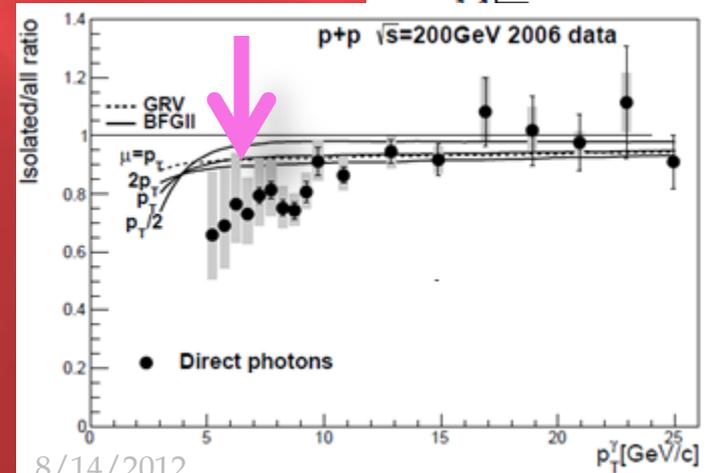
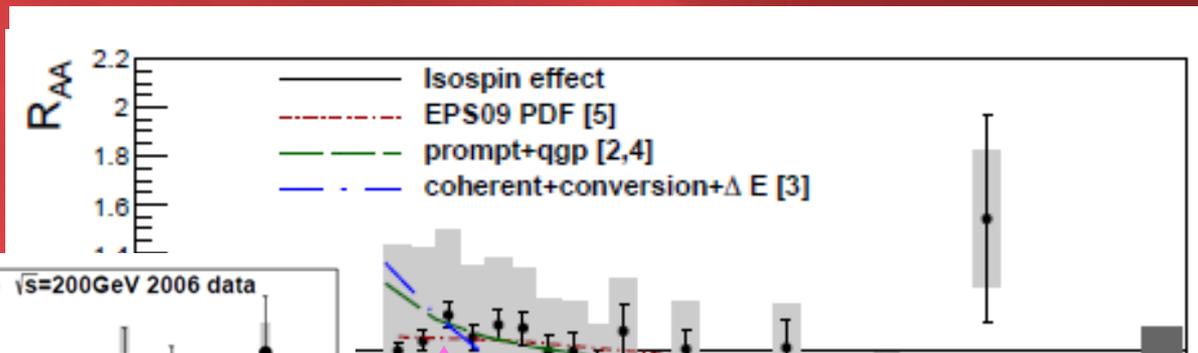


# Final Au+Au $R_{AA}$

- ❑ Lack of suppression re-confirmed
- ❑ Substantial high  $p_T$  suppression in prompt photon no longer looking viable (esp. combining with other data)
- ❑ Should we be using iso component as p+p reference?
  - More Jet-Medium-like enhancement?

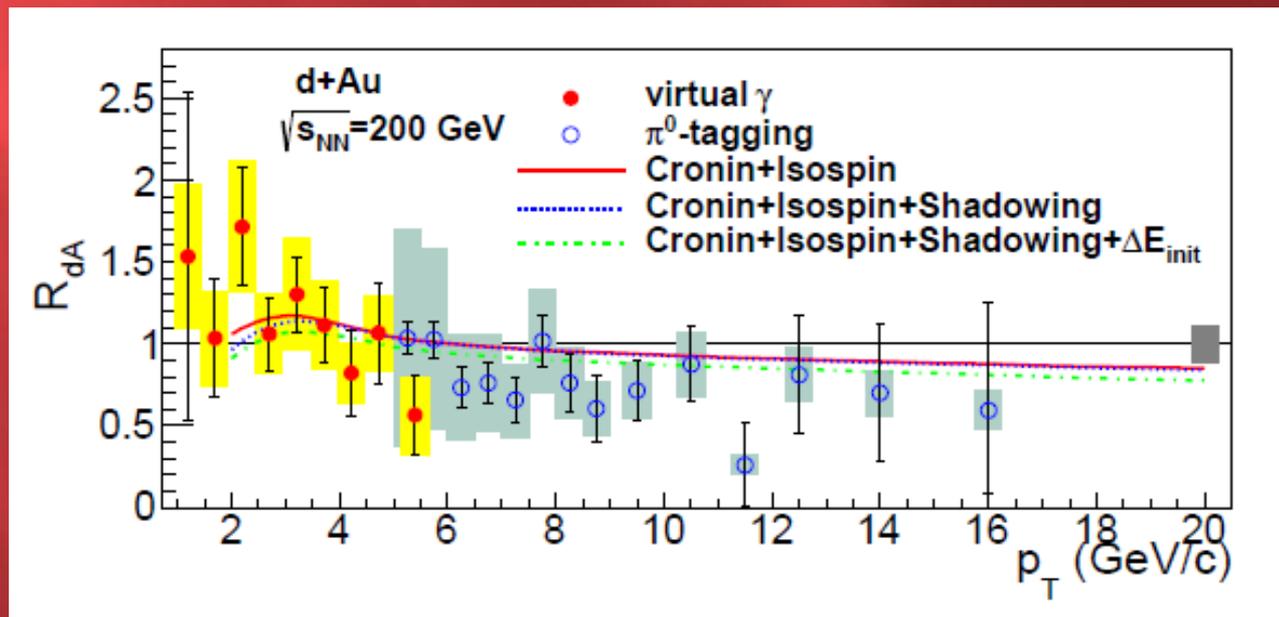
Submitted PRL arXiv:1205.5759

See poster 24  
B. Sahlmueller



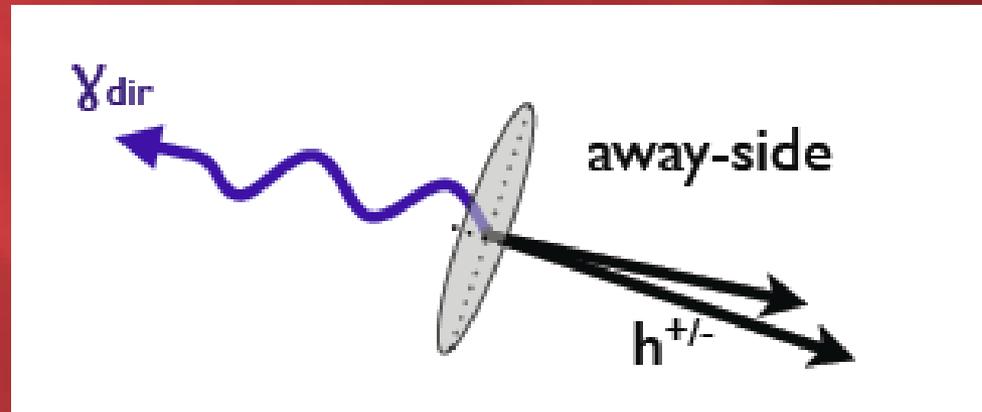
# “New” d+Au Direct $\gamma$ Result: High $p_T$

- Direct photons: d+Au, A+A initial state effect tester!
- At low  $p_T$  using PHENIX-invented virtual  $\gamma$  di-electron method (yellow error bars)
  - Up to moderate  $p_T$  – not just soft! Confirmation of method
- High  $p_T$  newly finalized 2003 Calorimeter data
- 2003 d+Au  $R_{dA}$  made more precise by new p+p
- Consistent dAu  $R_{dA}$  vs AuAu  $R_{AA}$



# From control to hot medium modification observable: Photon-Hadron results

- Use the “unmodified” photon as calibration for the modified away-side jet

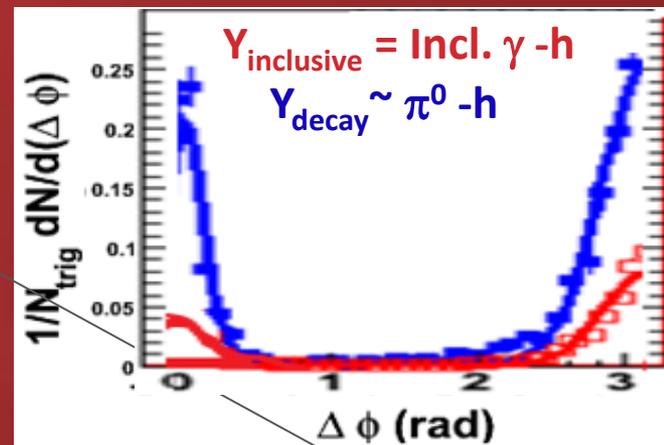


# 2-particle Statistical Method

$\gamma$ -h: subtraction of 2-p  $\Delta\phi_{12}$  measurements

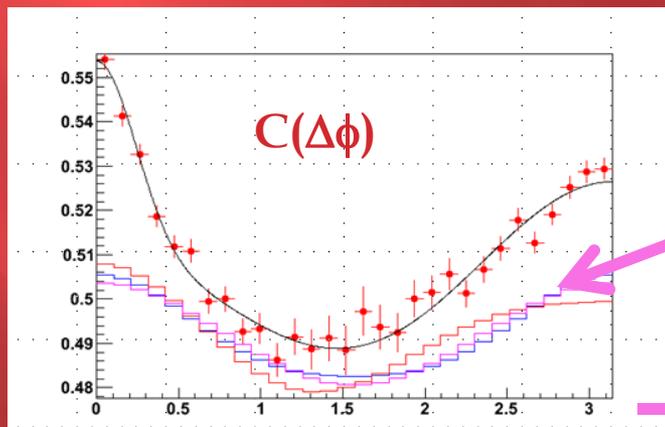
→  $R_\gamma$  directly from new single direct  $\gamma$  analysis

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



$$Y_{direct} \propto C_{incl} - Bkg_{incl}(Flow) - [C_{decay} - Bkg_{decay}(Flow)]$$

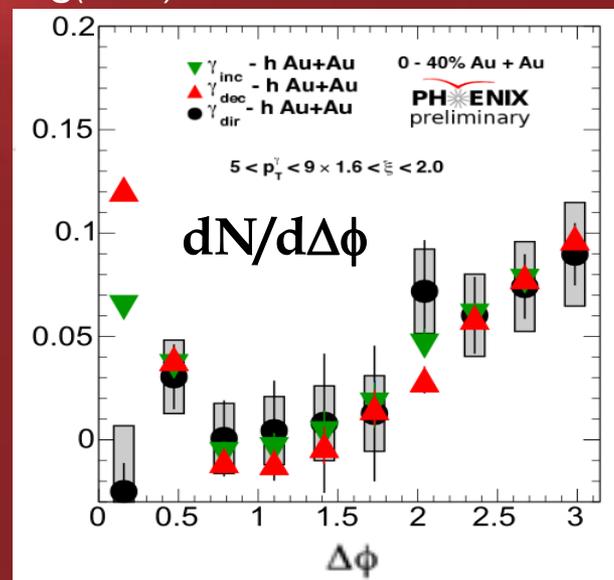
$$\equiv C(\Delta\phi) - \xi(1 + 2\langle v_2^\gamma \rangle \langle v_2^h \rangle \cos 2\Delta\phi)$$



Norm

Bkg(Flow)

$+v_3 + v_4 \dots$



- Subtraction w/ flow modulation included

- → Abs. Norm subtraction

# Pre-QM12: 2007 Result

- $\Delta\phi$ -Integrated yield plotted *vs.*  $z_T$

$$z_T = p_{Th}/p_{T\gamma}$$

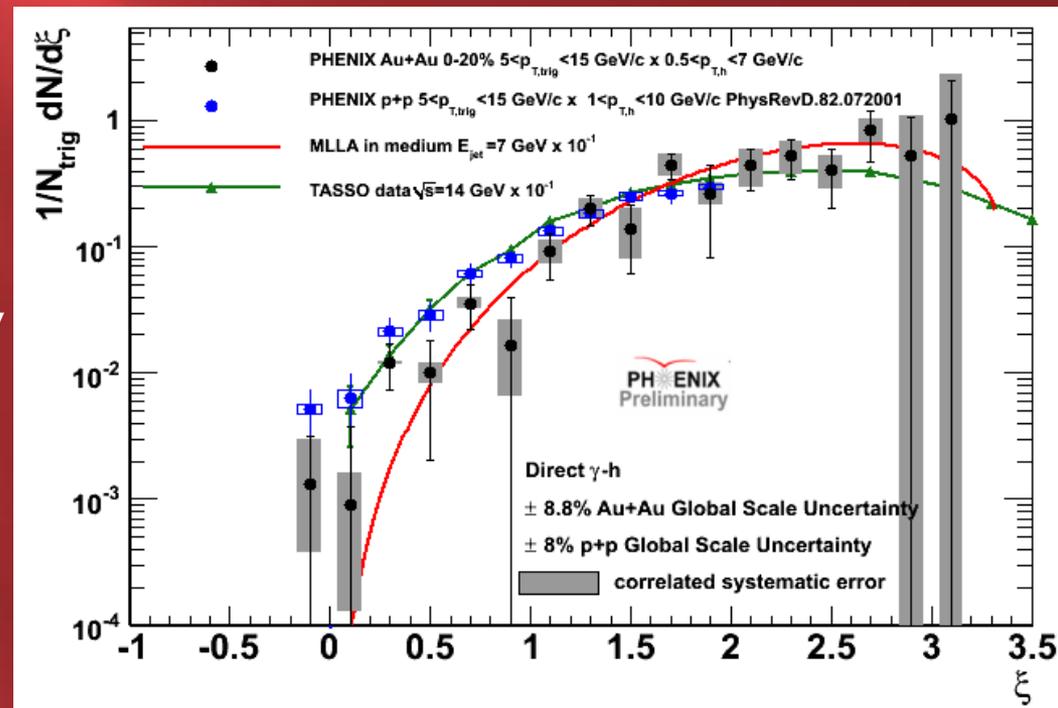
$$\text{or } \xi = \ln(1/z_T)$$

- $\rightarrow$  Frag Fn !

$$D(z_T) \text{ or } D(\xi)$$

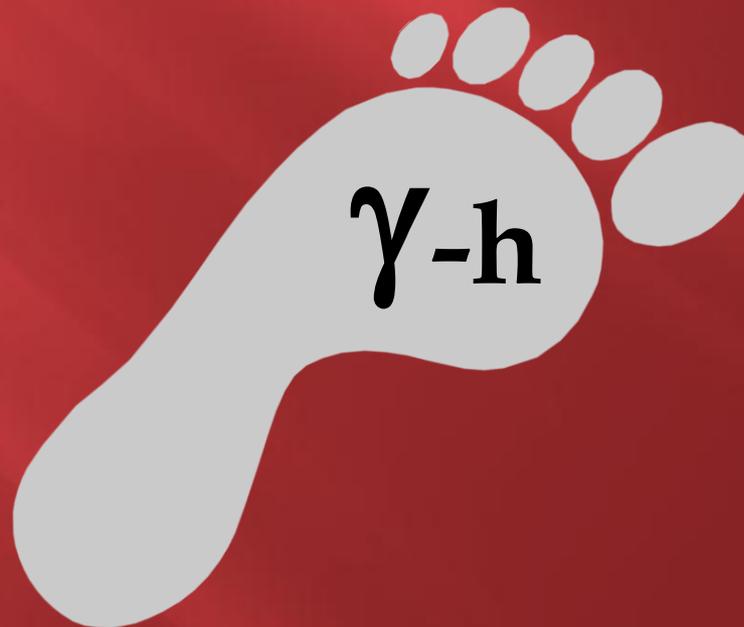
- Suppression signal: clear at low  $z$  (high  $\xi$ )
- Hint at rise in shape/enhancement
- **(Qualitative!)**

## $\gamma$ -h Fragmentation Function



# How to make *this result* more quantitative

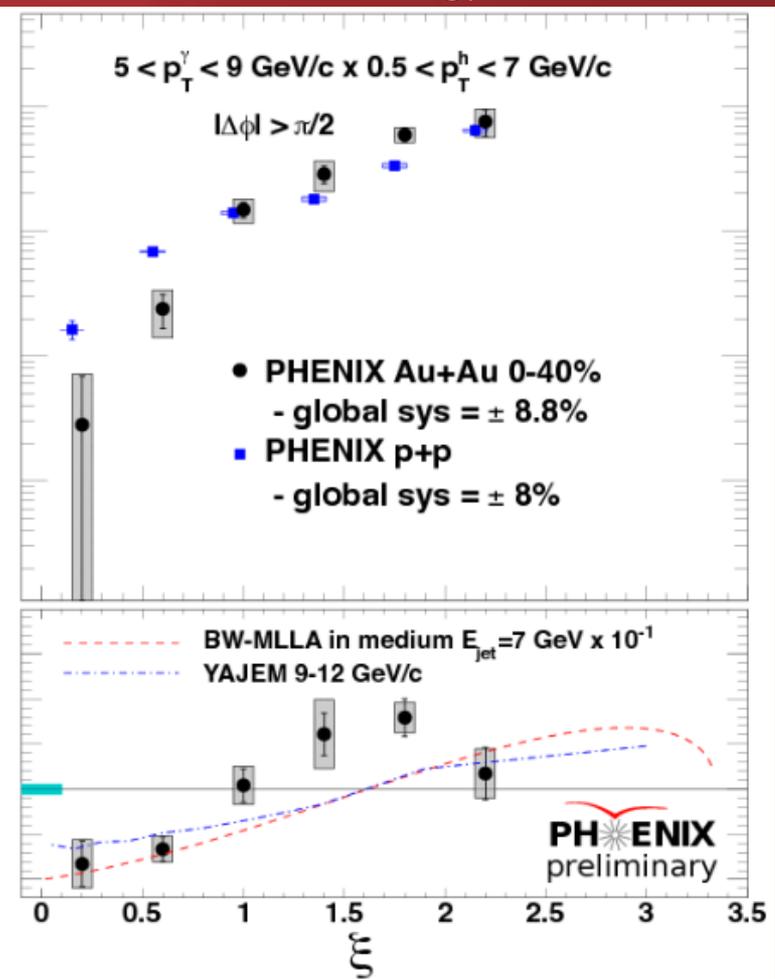
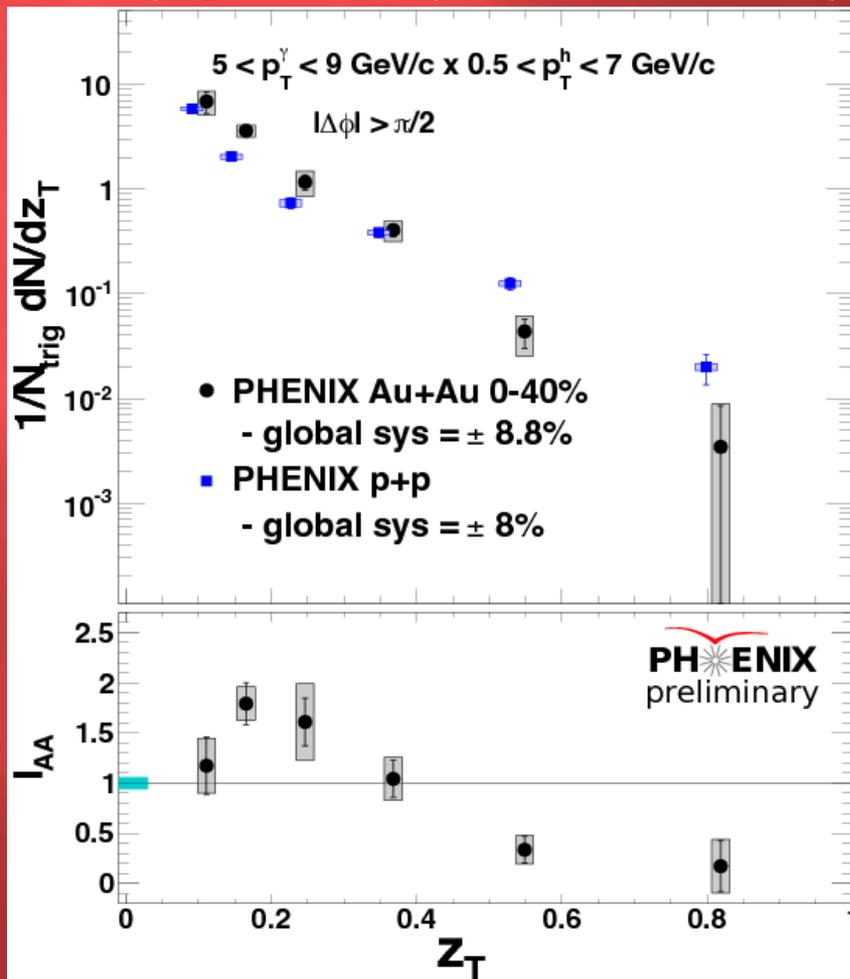
- ▣ Add 2010 dataset
  - Combined statistics of 2007 + 2010 datasets
- ▣ Combine centrality 0-20% + 20-40%



# Pied de Resistance!

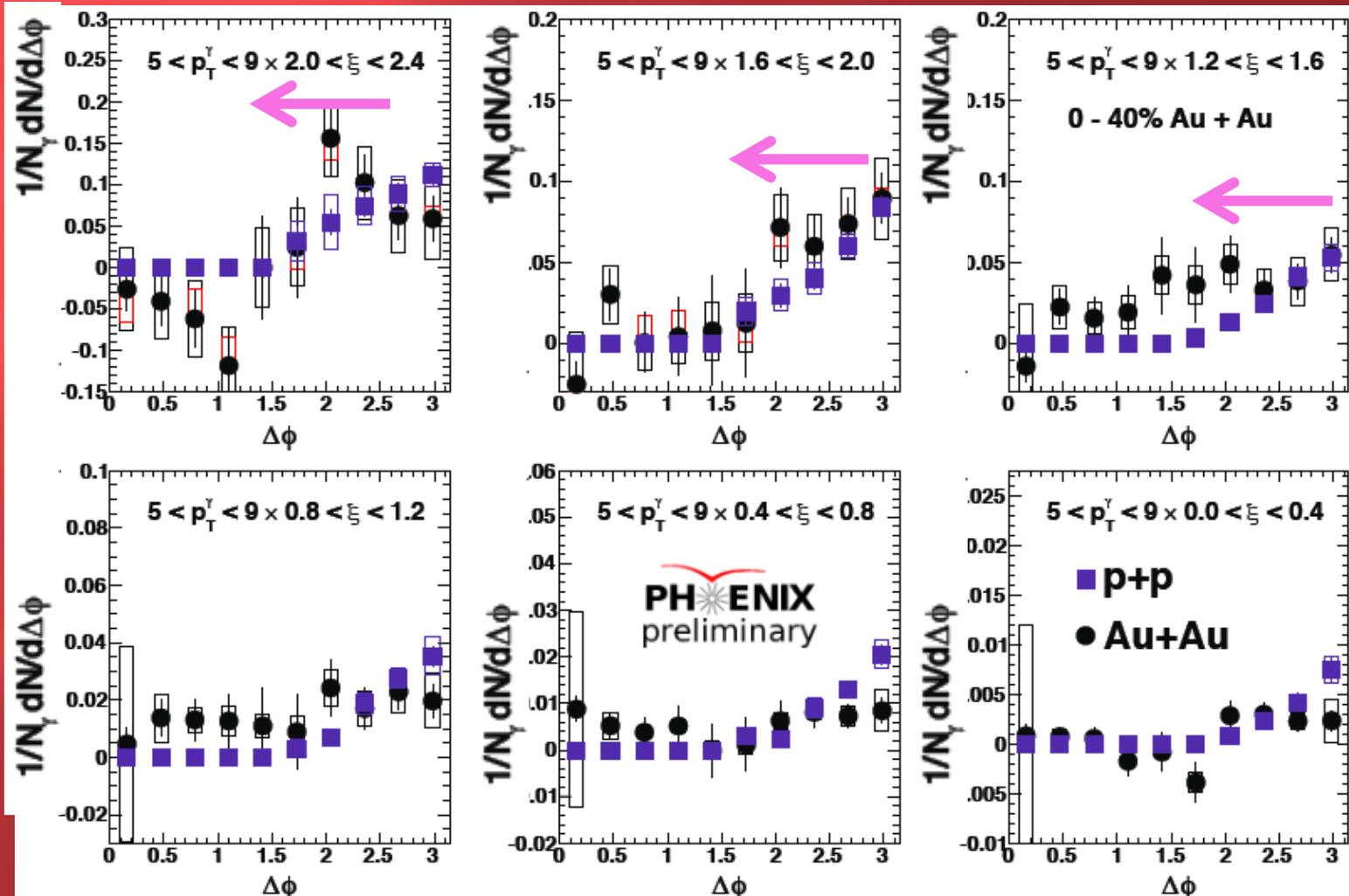


- Suppression at high  $z$ , low  $\xi$  -- universal 2-p phenomenon
  - LHC non-effect at  $z = 1$  is **only within** ID'd jets
  - 2-p method  $I_{AA}$  includes/accounts for "lost" jets and particles
- **Enhancement signal at low  $z$ , high  $\xi$  now statistically significant!**
- Theory qualitatively similar : recovery of lost/radiated energy



# Where is this enhancement?

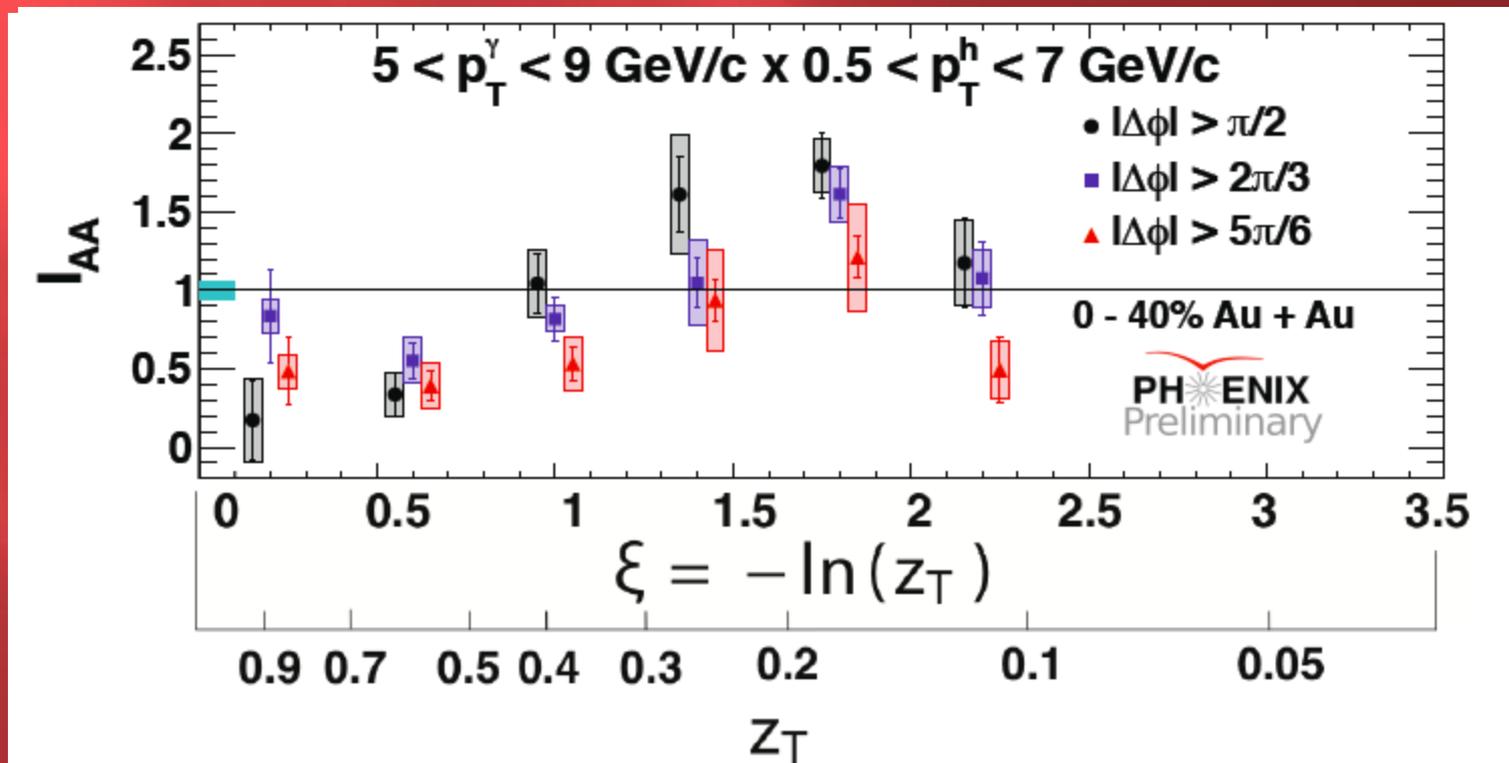
- Low  $z \rightarrow$  Low associated hadron  $p_T$
- Enhancement increasing at larger angles from away jet



# Integrations in different $\Delta\phi$ ranges

## Quantitative-ness

- Integrating in different ranges shows **quantitative** evolution with away-side angle
- Qualitatively consistent: Rise from low  $\xi$  to high  $\xi$  present in all integration ranges
- Less in the “head” region!
- Broadening of the away-side fragmentation!

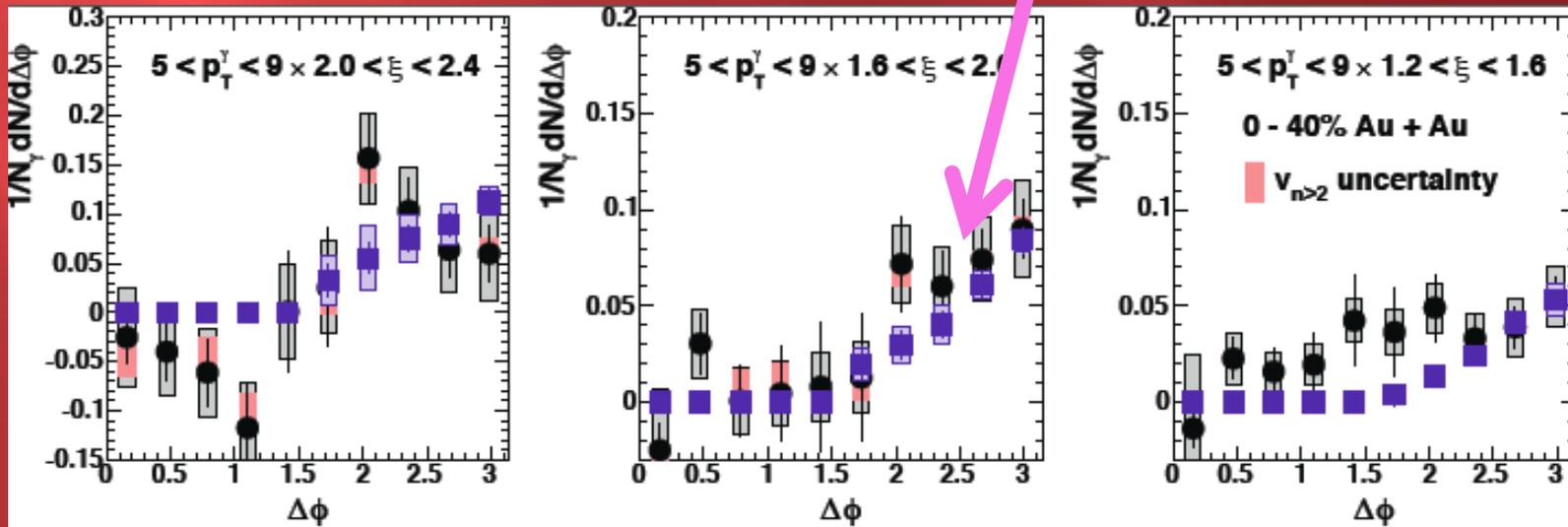
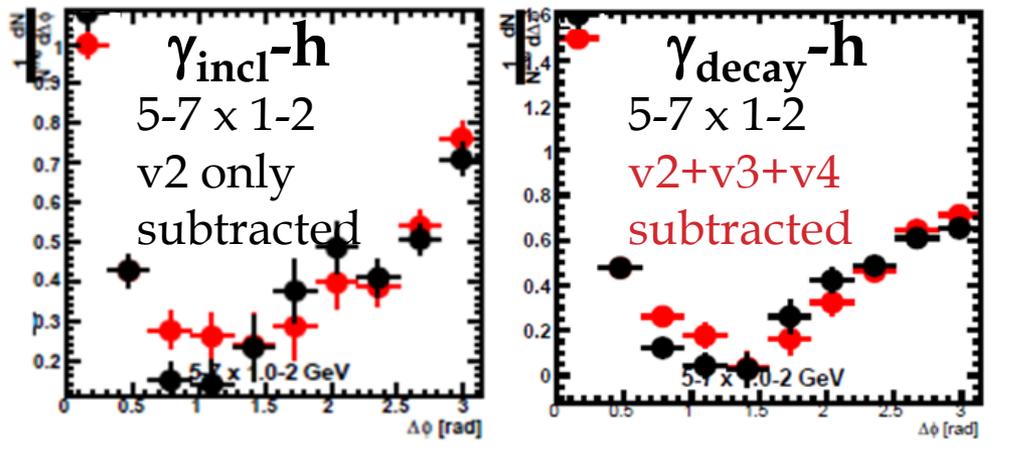


Posters:  
N. Riveli  
21  
B. Xia -  
23

# Just Effect of $v_n$ ?

All of broadening due to  $v_3$  ?  
No!

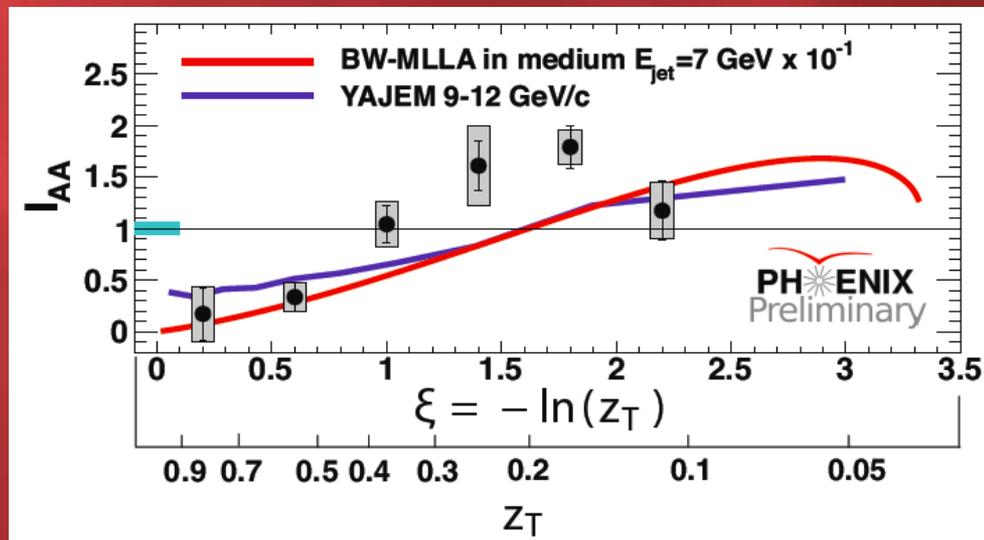
- Test: Conservatively large guestimate for high  $p_T$   $v_{3,4}$  (RHIC measure unavailable)
- Visible change for  $\gamma_{dec}-h$  and  $\gamma_{incl}-h$  but broadening still present
- Mostly cancels in  $\gamma$  subtraction
  - Assuming direct  $\gamma$   $v_n = 0.5 v_n$  of  $\pi^0$  chosen as max  $v_n$  RHIC
  - Integrated yields difference generally much less ( $v_3$  effect in  $\Delta\phi$  of  $2\pi/3 \rightarrow \sim 0!$ )



$v_1$  effect should be small too. e.g. see T. Todoraki parallel talk 6D

# Conclusions

- ▣ Au+Au single Direct  $\gamma$  non-suppression re-confirmed w/ more precise finalized p+p and Au+Au data
  - ▣ Isolated reference for p+p: enhancement in the Jet-Medium area?
- ▣ New d+ Au, A+A single direct  $\gamma$  interesting to compare initial state/CNM effects seen in jets
- ▣ Fragmentation Function modification seen with statistical significance!
  - ▣ Enhancement at low  $z$ /high  $\xi$ : recovery of lost energy?
  - ▣ Increasing at wide angles from away jet direction



# Backups

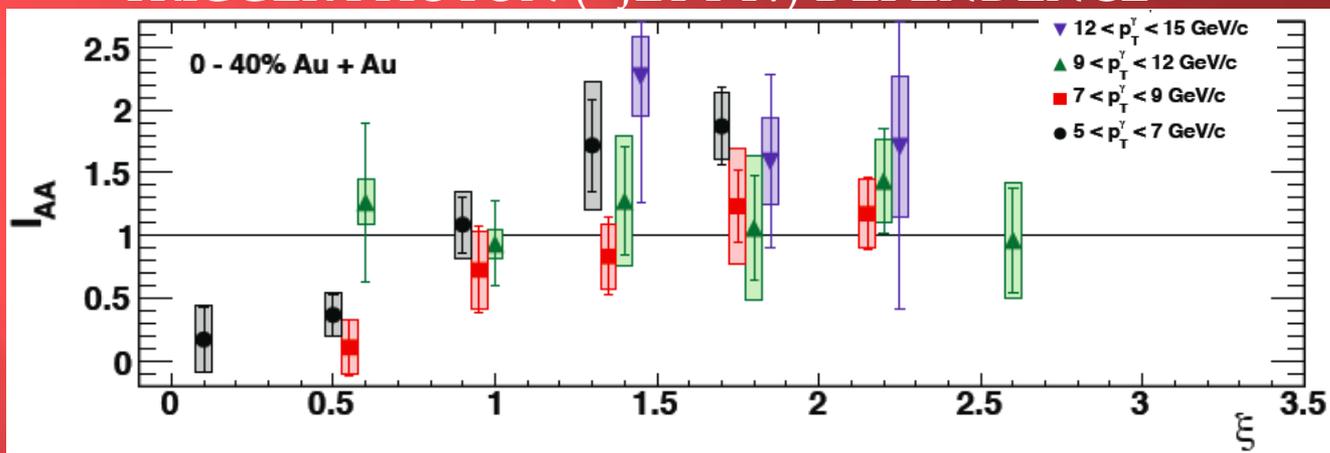
"Hate and the killer were not successful. He wanted to divide and we have come together."  
PRABHJOT SINGH, co-founder of the Sikh Coalition, at a memorial service for six worshipers slain at a Sikh temple in Oak Creek, Wis.

-NYT

# Jet pt, angular ranges, and centrality?

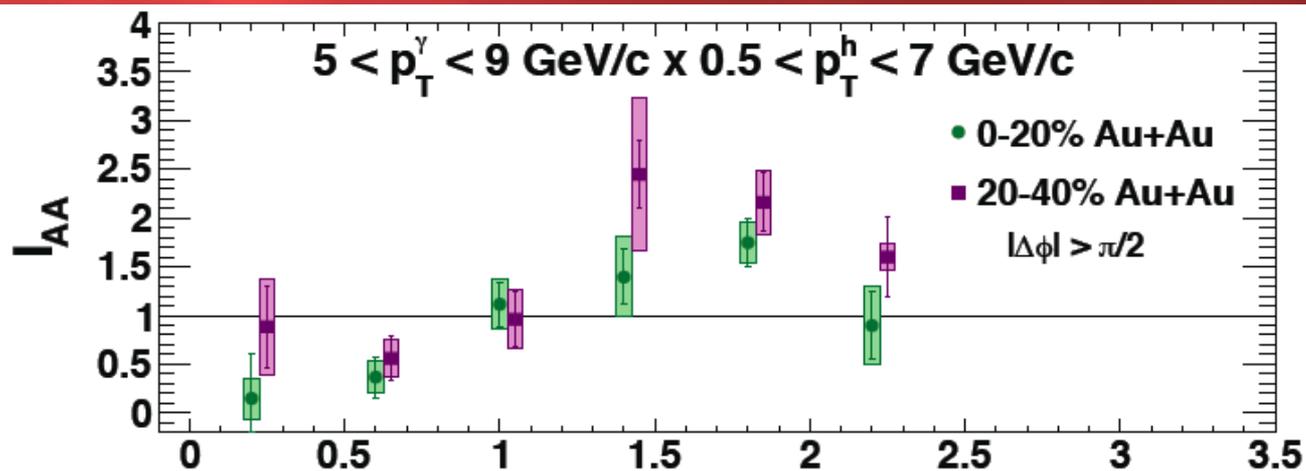
- With more statistics try to study various differential dependences...

## TRIGGER PHOTON (~JET PT?) DEPENDENCE

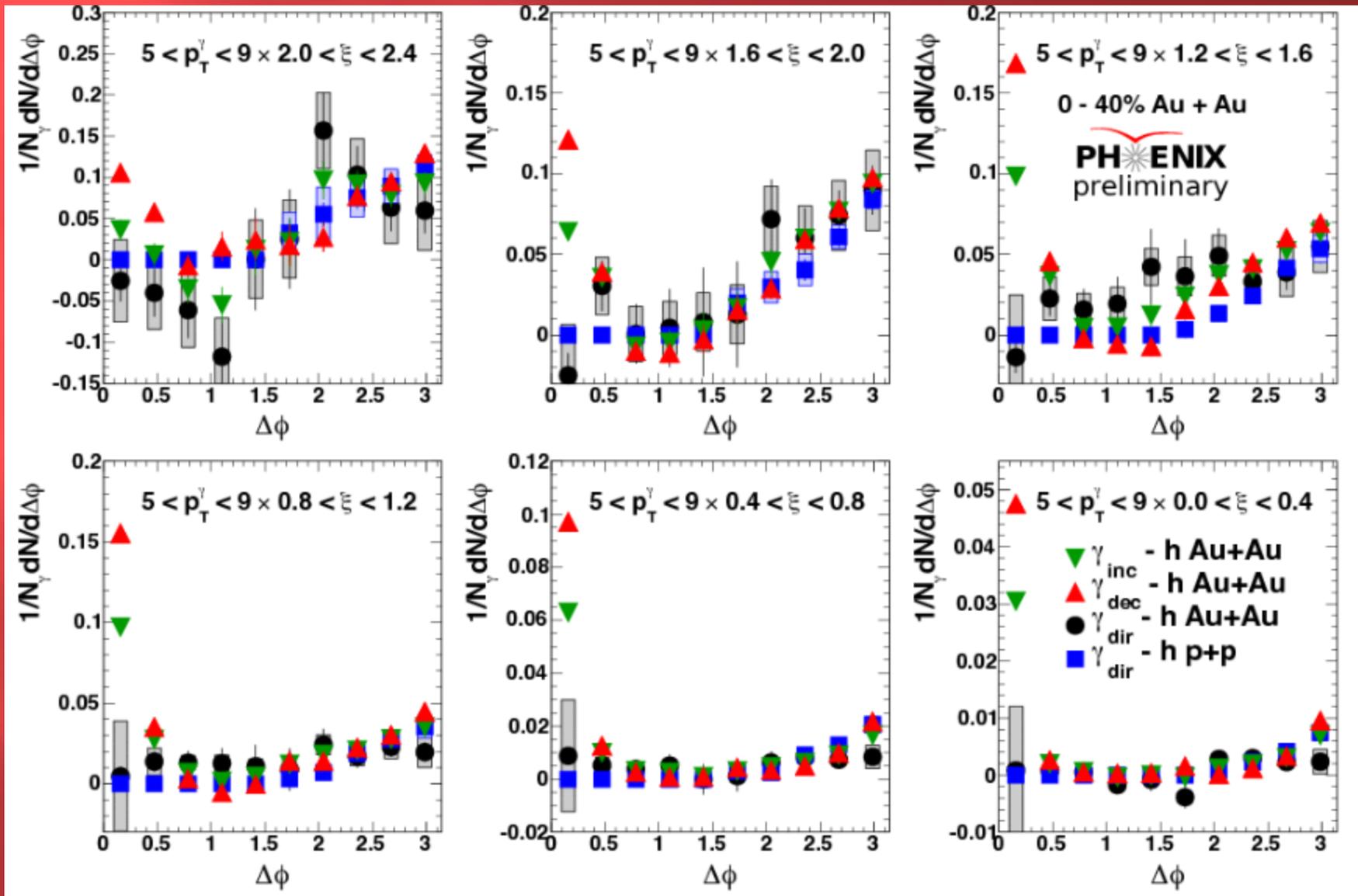


- Consistent qualitative trends
- Hint of enhancement at diff  $\xi$  ( $p_{Ta}$ ,  $p_{Tt}$  dep)?

## CENTRALITY DEPENDENCE

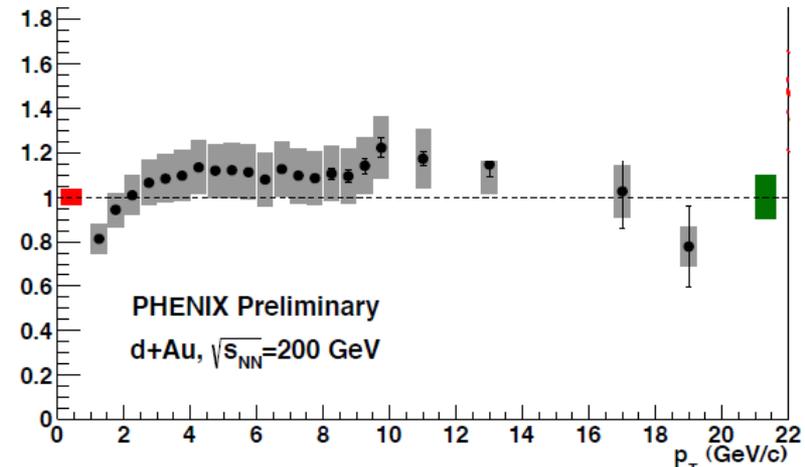
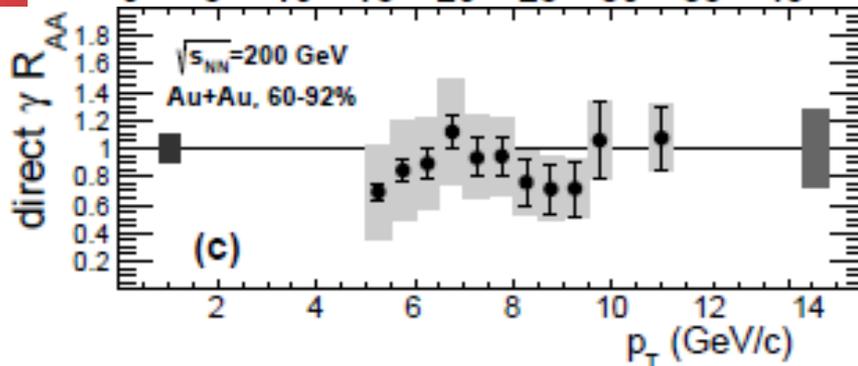
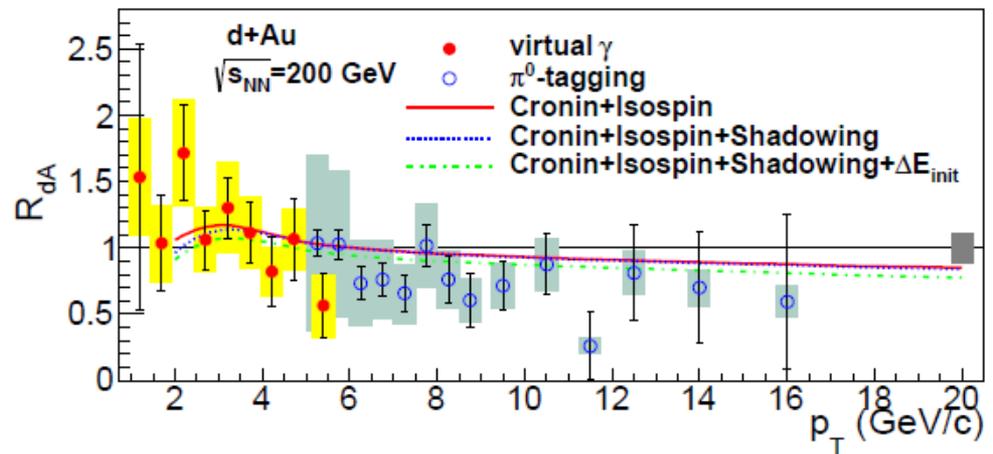
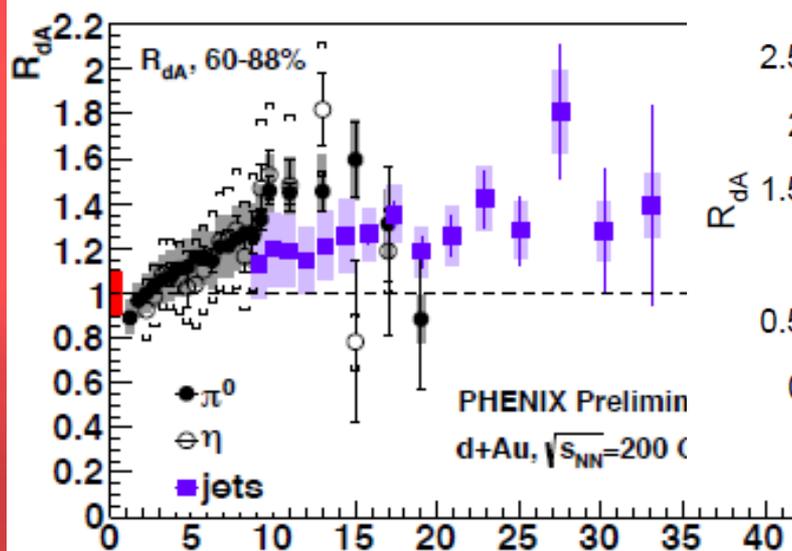


- Low  $z$ /high  $z$  suppression dependence consistent w/ expectations?
- Hint of enhancement at diff  $\xi$  ( $p_{Ta}$ ,  $p_{Tt}$  dep?)
- Enhancement persists



# Initial state effect? Like jets?

- Looking for initial state effects in  $\gamma$  is especially interesting given jet sector results
- 2003  $\rightarrow$  2008 dataset will allow for centrality dependence for  $\gamma_{\text{dir}} R_{\text{dAu}}$ . Different than surprising jet dependence?



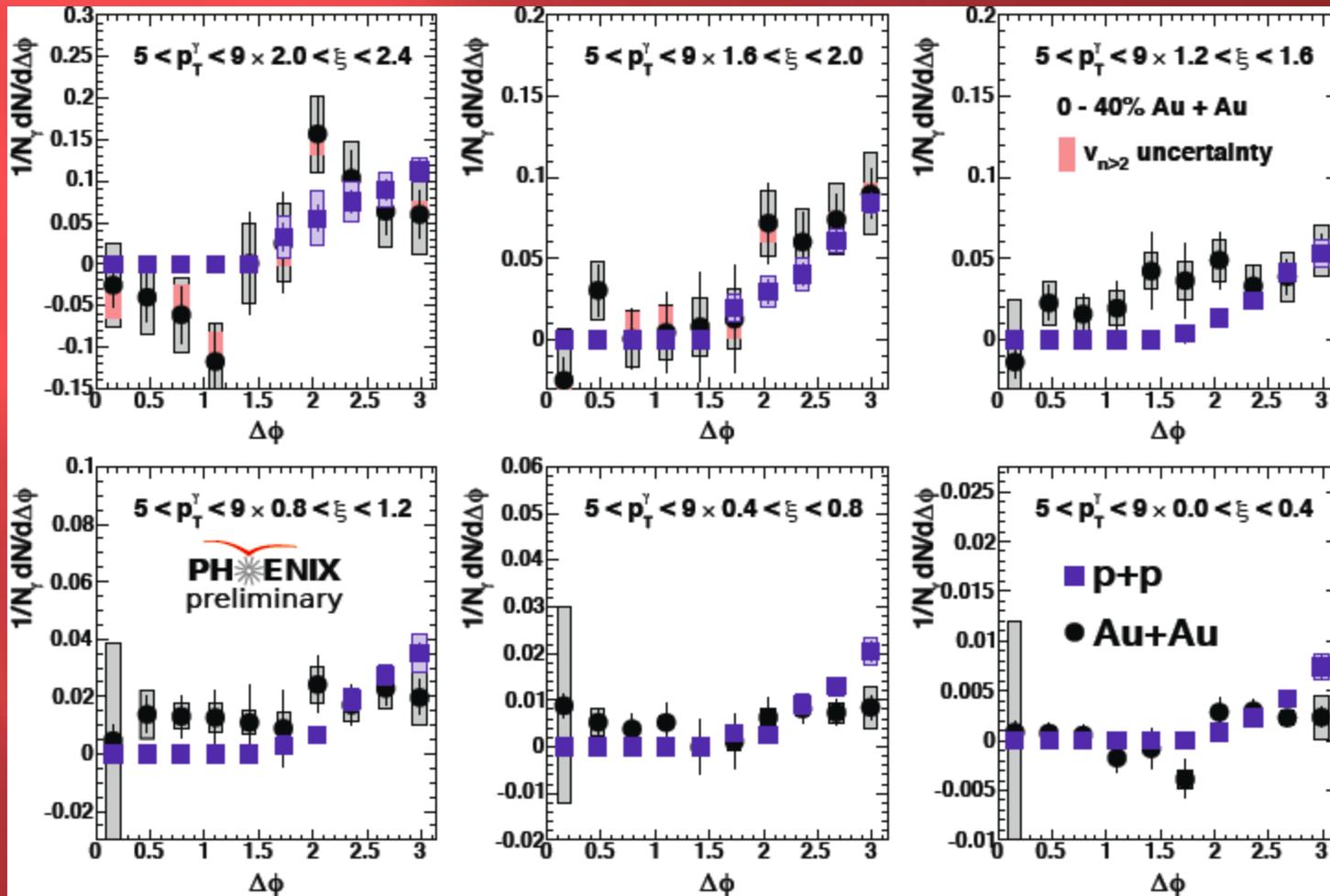
# Direct $\gamma$ Motivation II

- ▣ A+A Initial state effect tester!
- ▣ In A+A this is the only modification possible (for Compton/Iso component)!
- ▣ Big step: understand initial state/ CNM effects for jets

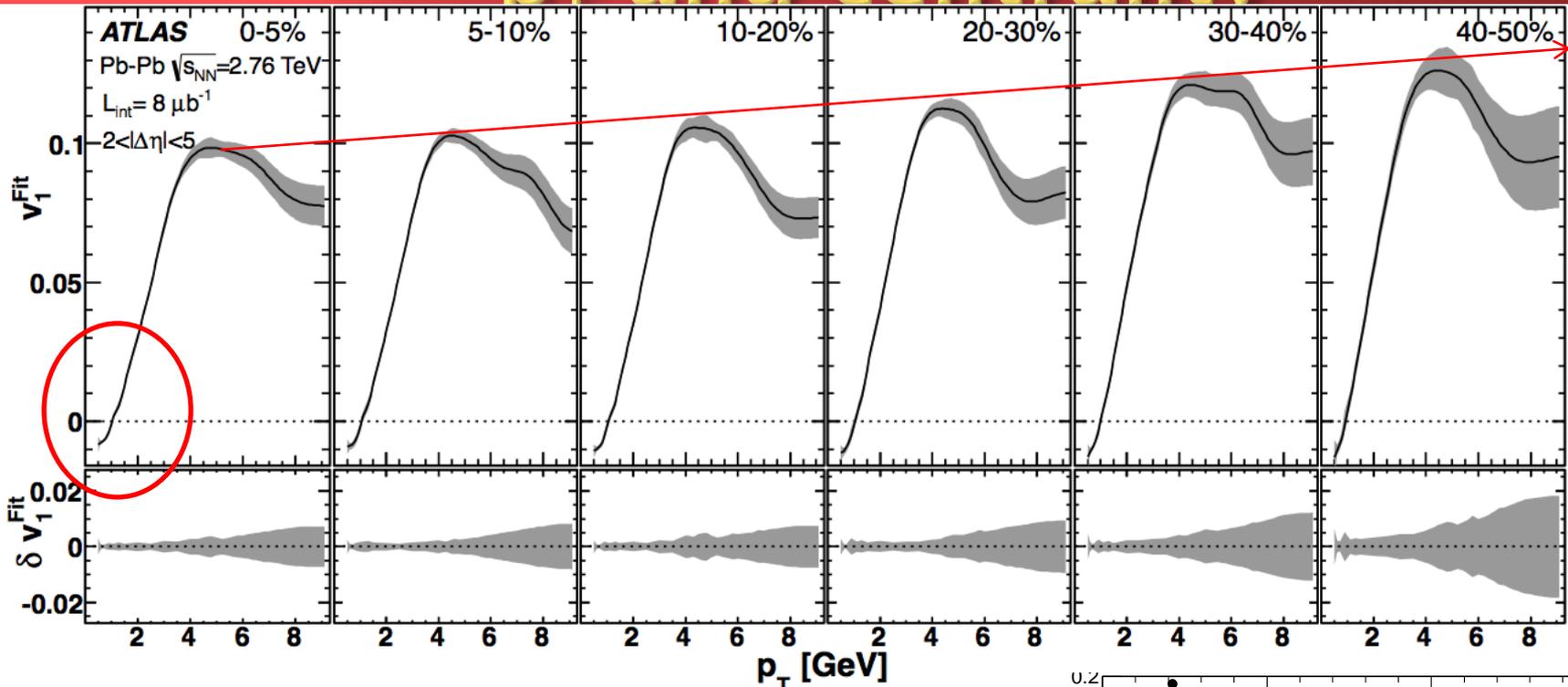


- ▣ To understand CNM effects in A+A start with to p+A, d+A

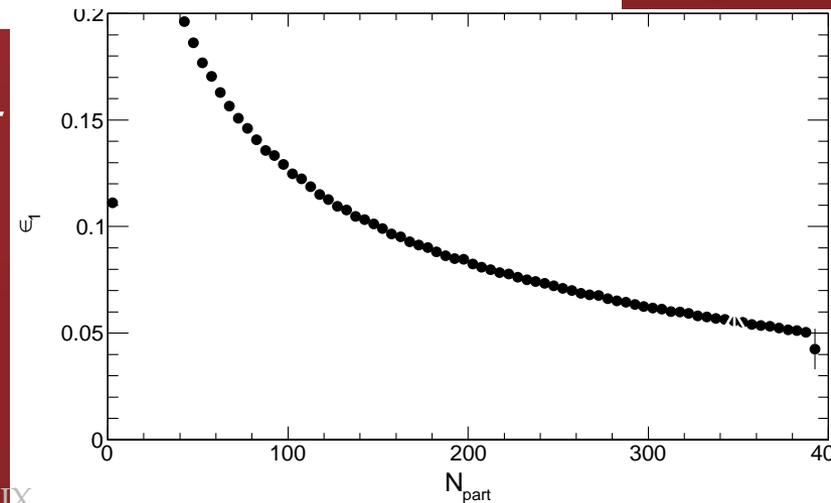
# Jet Fn's



# Jia: wwnd12: v1 slide: Fit result vs $p_T$ and centrality



- $v_1^{\text{Fit}}(p_T)$  peaks around 4-5 GeV, peak-value increases with centrality by about 20%.
  - Less viscosity damping, reflecting the increase in  $\varepsilon_1$ ?



# sPHENIX (?)

- ▣ Rates for Direct  $\gamma$  are 1/1000 of Jets  $\rightarrow$  But still sufficient statistics at RHIC for good overlap of jet, leading particle results
- ▣ Because of spectral shapes RHIC  $\rightarrow$  has better S/B for Direct Gamma ( $/\pi^0$ ) than LHC: better high  $p_T$  stats than  $\pi^0$  !

...from sPHENIX Proposal 2012:

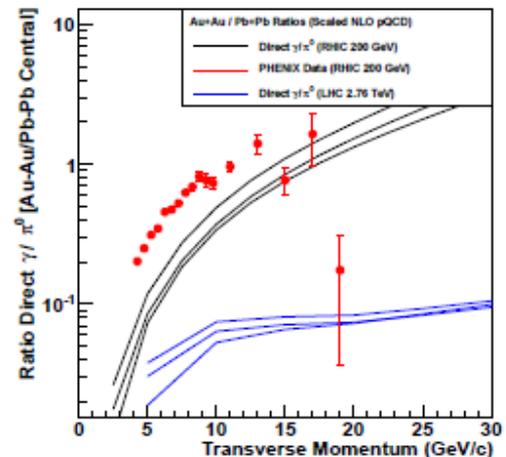
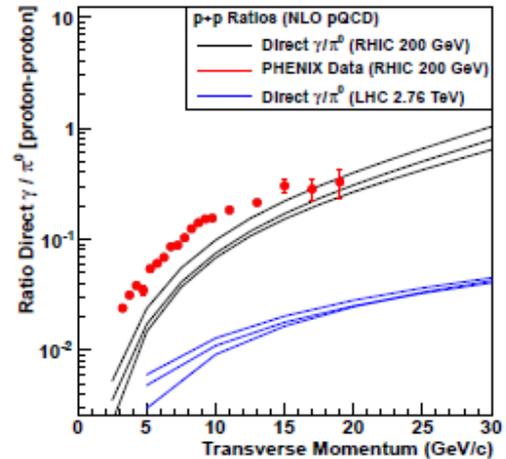
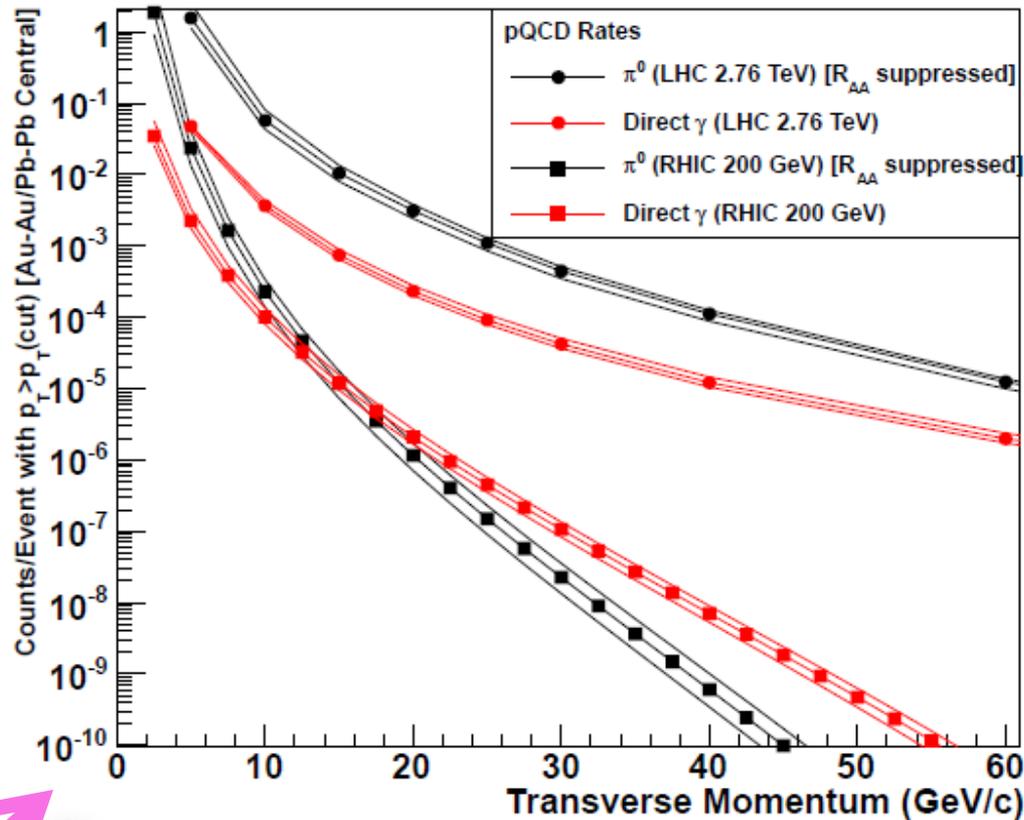
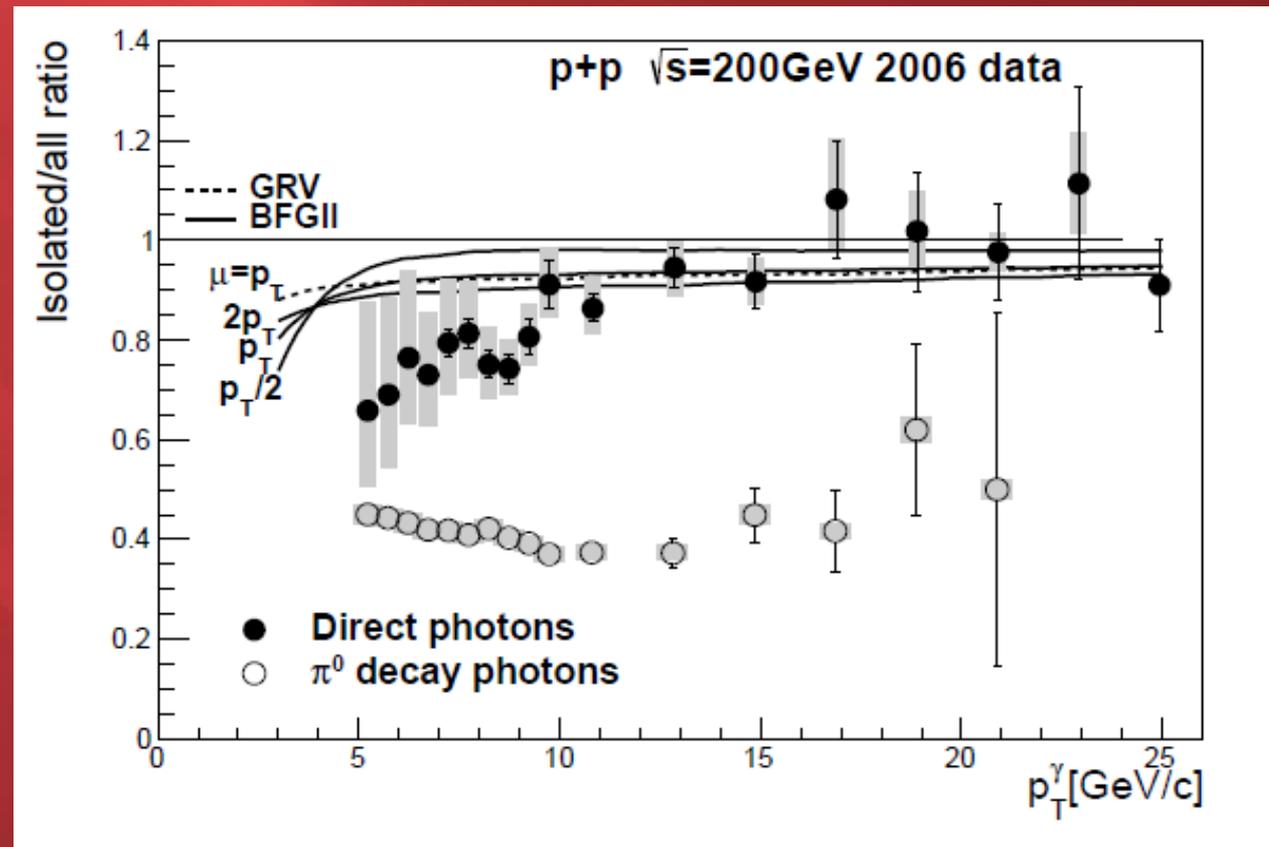


Figure 1.22: NLO pQCD calculations of direct photons and  $\pi^0$  for RHIC and LHC. The

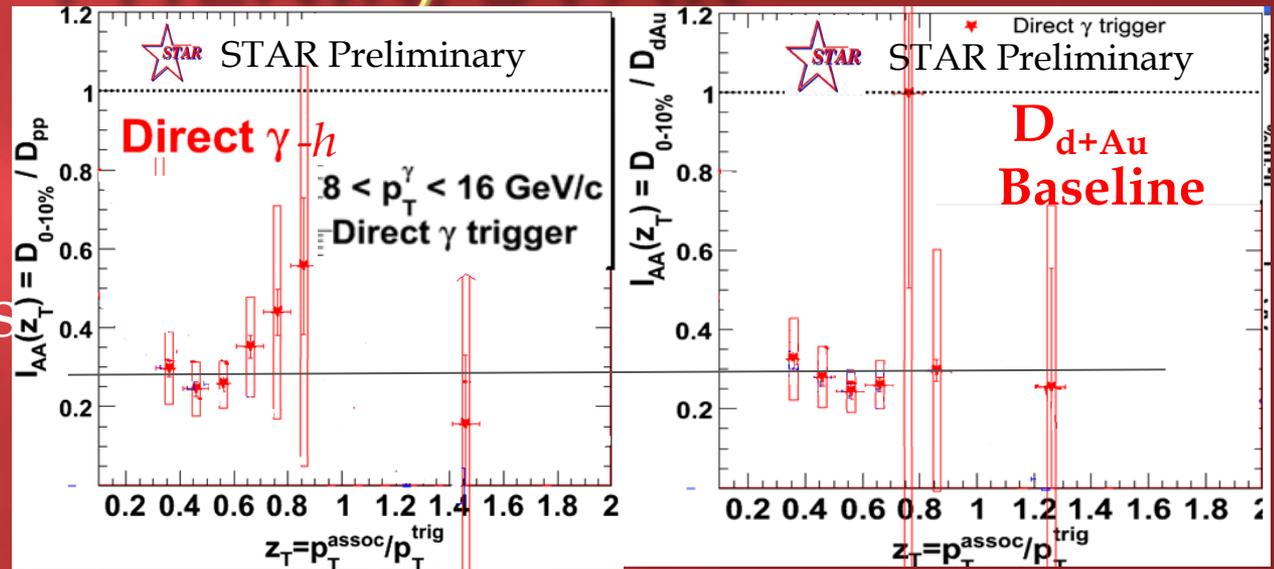
# Isolation cut

- Isolation cuts in p+p
- New cone size 0.3  $\rightarrow$  0.5



# Good Agreement PHENIX/STAR

- Strong Suppression Signal both collaborations
- At about  $\sim 0.3$



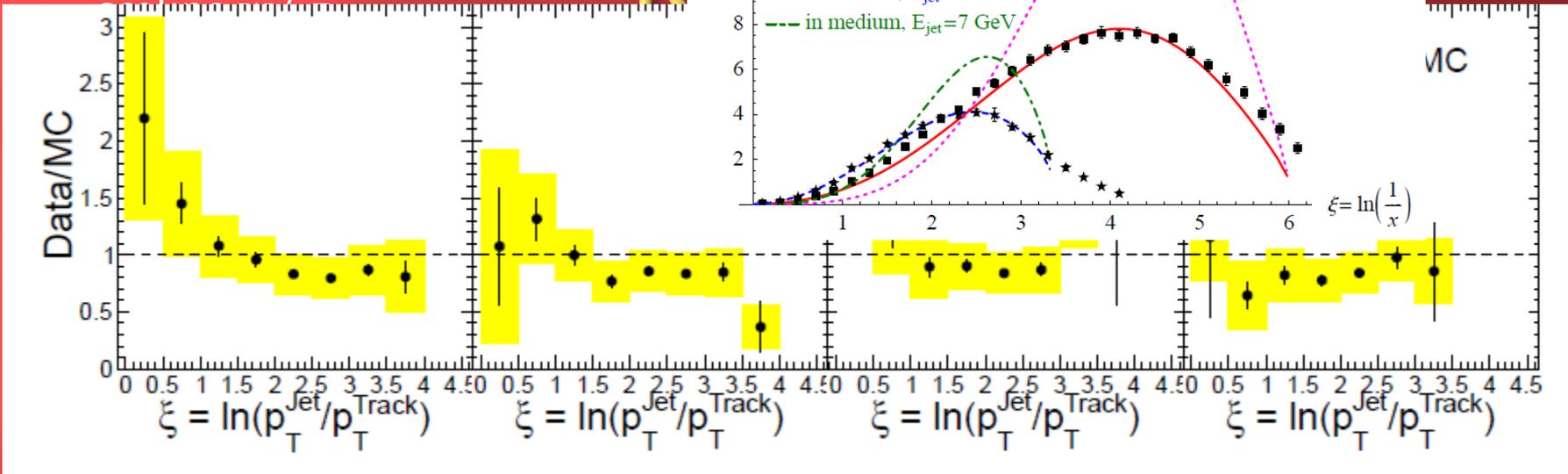
PHENIX split into smaller trigger bins

$I_{AA}$

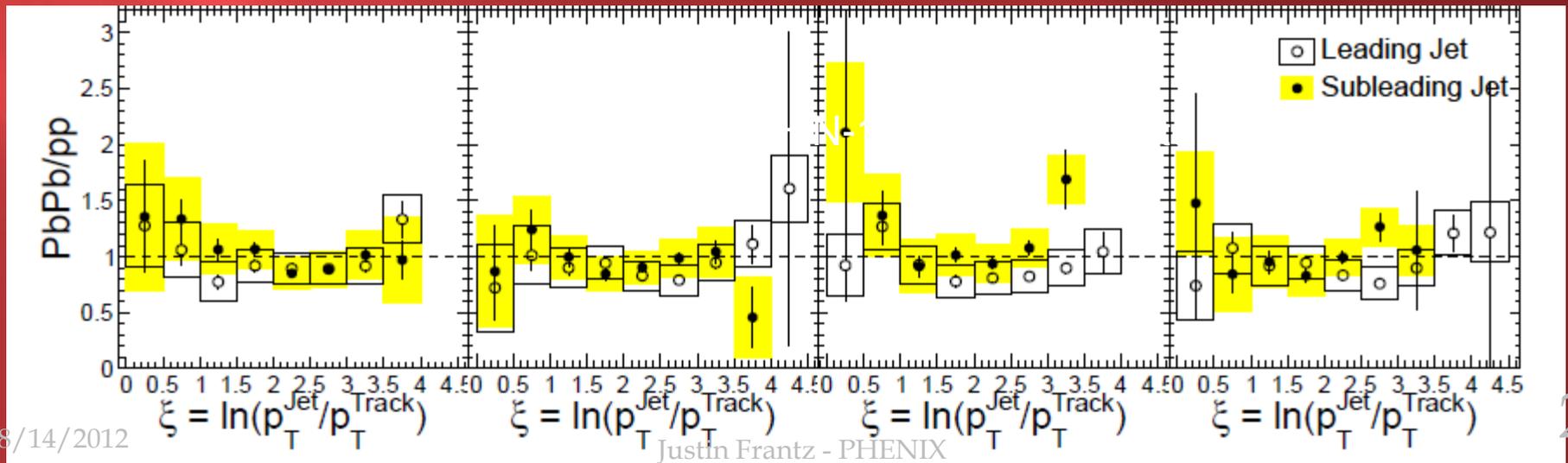
$$z_T = \frac{p_T^h}{p_T^{trig}}$$

# Compare to CMS

Comparing to the CMS data



Also apparent in STAR jet-h ...

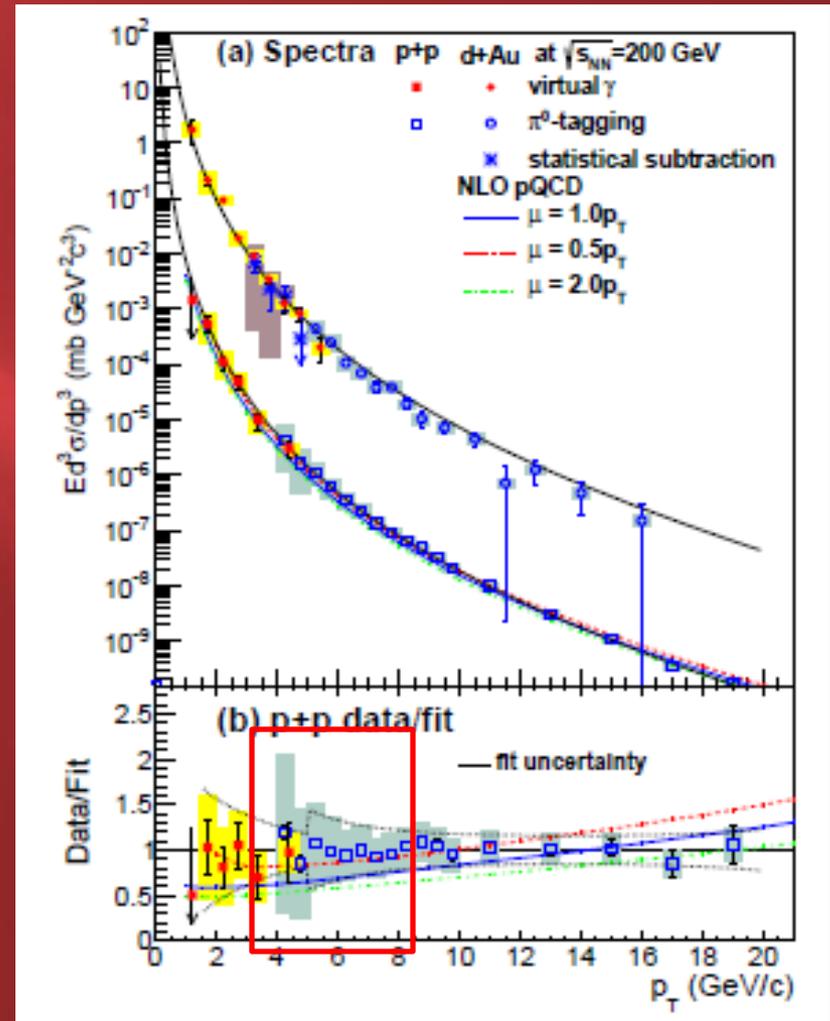


# New d+Au Direct Photon

Submitted PRL [arXiv:1208.1234](https://arxiv.org/abs/1208.1234)

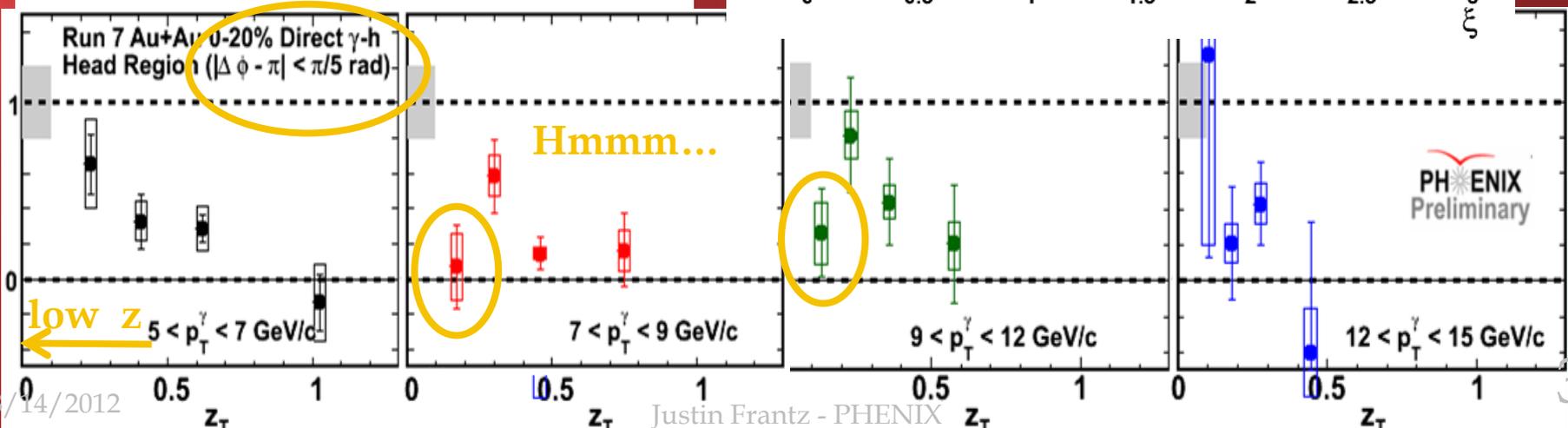
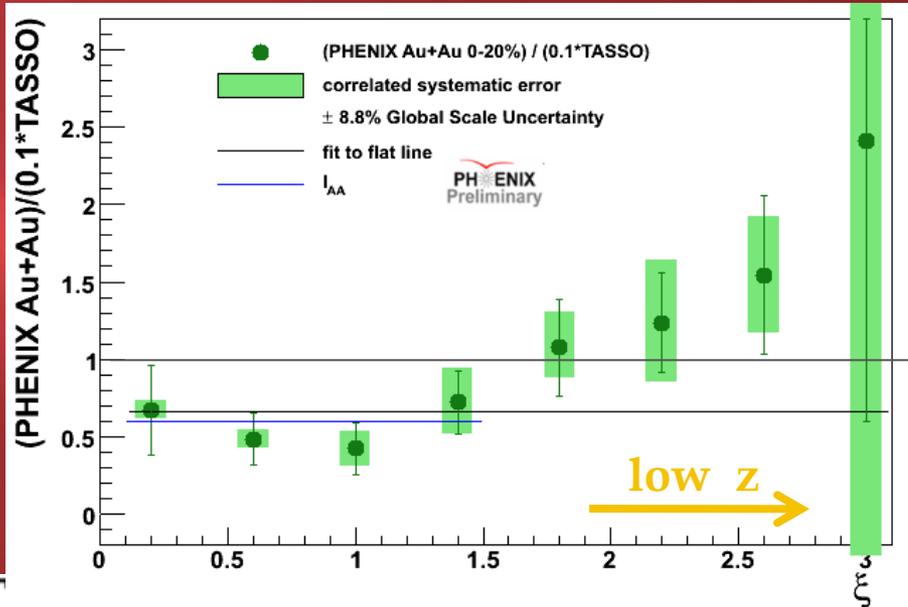
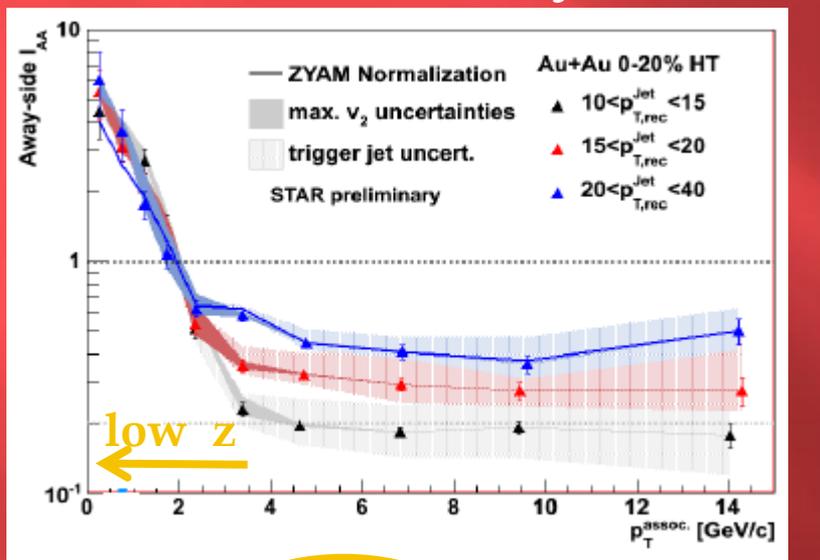


- At low  $p_T$  using virtual di-electron method
  - Up to moderate  $p_T$  — not just soft!
- High  $p_T$  newly finalized 2003 Calorimeter data
  - Newly relevant due to much better p+p data



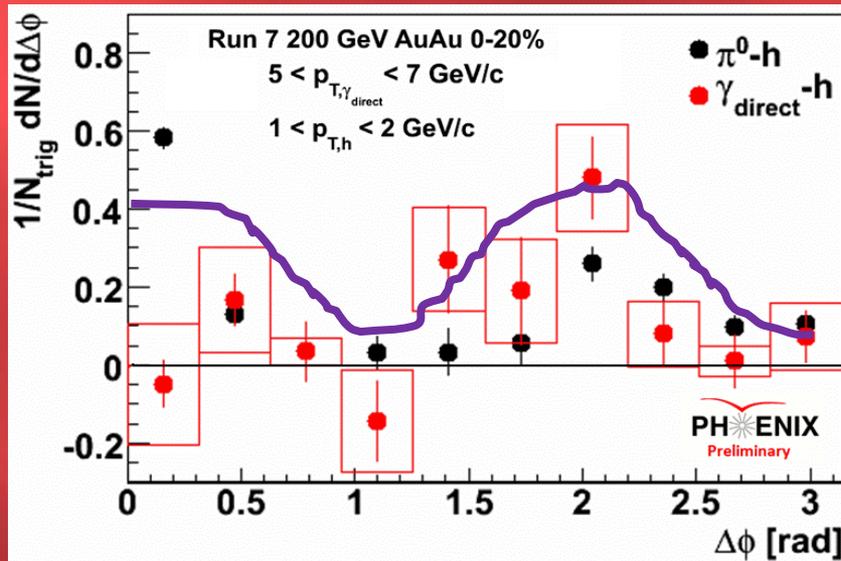
# Compare to Reco'd Jet-h RHIC TO RHIC

- Interesting to compare results to jet reco
- Qualitatively similar  $\rightarrow$  Same conclusions



# Don't forget $\Delta\phi$ Shapes Themselves

- Some of Reco Jet  $I_{AA}$  enhancement is coming in  $\sim$ same  $\Delta\phi$  region as "ridge"/"shoulder"/ (probably) "v3" ? Needs further investigation
- Direct  $\gamma$ -h too? I know for both analyses work is well underway...



v3?

