# Prompt gamma-jet and di-jet via correlations in Heavy Ion Collisions in large and small systems

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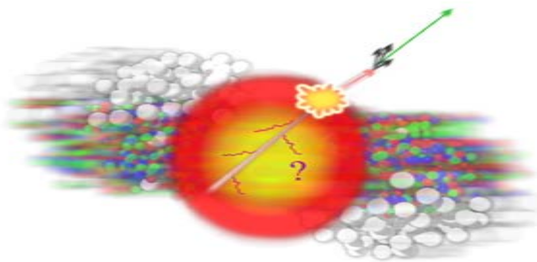
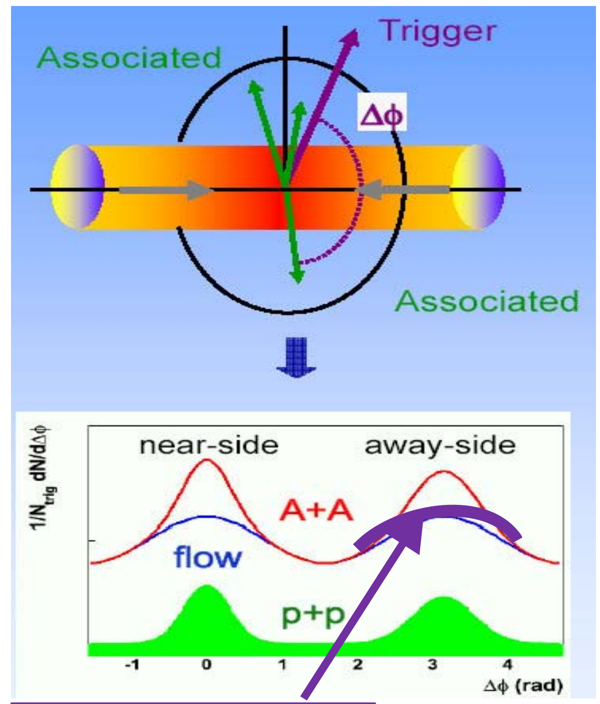
Jetscape Workshop 3/20/2020

# Two particle ANGULAR (mostly $\Delta\phi$ ) correlation

Jets must be produced in back to back pairs to conserve momentum



- Trigger particle → high momentum pi0 → proxy for jet
- Partner (Associated) particle → charged hadron from same jet or "awayside" jet
- Correlation function: C(ΔΦ)




Awayside suppression

Source: http://puma.uio.no/trine/ALICE-Oslo/angular_correlations.html

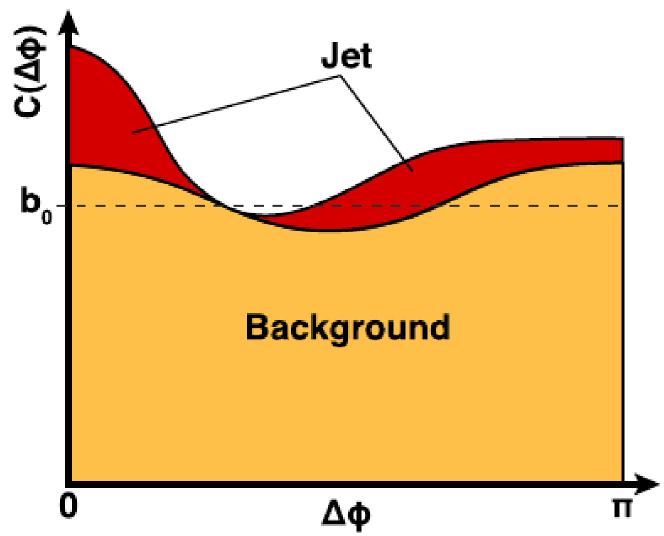
$$C(\Delta\phi) \propto \frac{N^{AB}_{same}(\Delta\phi)}{N^{AB}_{mixed}(\Delta\phi)}$$

← Corrects for imperfect detector

# 2-p Correlation Analyses - Methods

- Statistical Methods: subtraction: Not EvByEv
- Need to measure per-trigger yield function) $$C(\Delta\phi_{AB}) = J(\Delta\phi_{AB}) + b_0 \frac{dN^{AB}_{comb}}{d\Delta\phi_{AB}}$$
  - Correlation Function – bkgd (Flow)

$$\frac{dN^{AB}_{comb}}{d\Delta\phi_{AB}} \propto 1 + 2v_2^A v_2^B \cos(2\Delta\phi_{AB}) + v_{n>3}$$



# 2-particle Correlation Analyses – Methods -- Many Statistical Subtractions- not EvByEv

g-h: double subtraction of 2-particle measurements

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

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

$$Y_{xxx} \propto C_{xxx} - b_0\left(1 + 2\langle v_2^\gamma\rangle\langle v_2^h\rangle \cos 2\Delta\phi\right)$$

Norm ($b_0$)

*Bkgd(Flow)* ($\left(1 + 2\langle v_2^\gamma\rangle\langle v_2^h\rangle \cos 2\Delta\phi\right)$)

- For isolation cut - $Y_{inclusive} = Y_{isolated}$
- For p+p – no flow background subtraction
- No flow subtracted in small systems (e.g. p+Au and d+Au)

# Two-Particle vs Reco'd Jets

- Jet Reconstruction Observables Becoming More and More Varied and Sophisticated
  - "Jet Substructure" Observables with Found-jet Q/Jet E Scale   Good progress in theory/experiment exploring Jet & Jet Substr. relation
  - Fragmentation Function combine particles w/ jets
- Di-jet Two Particle Correlations Are Less Constrained
  - They are related to the above observables but integrate over possibly wide Jet E ranges – and lately revealed different shower properties
  - **Still they are still very useful where Jet Reco still cannot go:**
  - Particularly:
    - at the lowest jet E's   ~ 5-15 GeV
    - when prompt photons are one of particles is prompt $\gamma$ (provides jet scale)
    - at large angles w.r.t. jets
    - …which helps especially when viewing complex geometrical e.g. event plane, event engineering, peripheral dependences
- Lot's of theory development focused rightly on reco jets, but many theory frameworks can still address 2PC

# Example I

- Slide from Y.J. Lee at Santa Fe several months ago

Jet Imbalance $A_J$ @ RHIC rebalanced within $R \leq 0.4$?

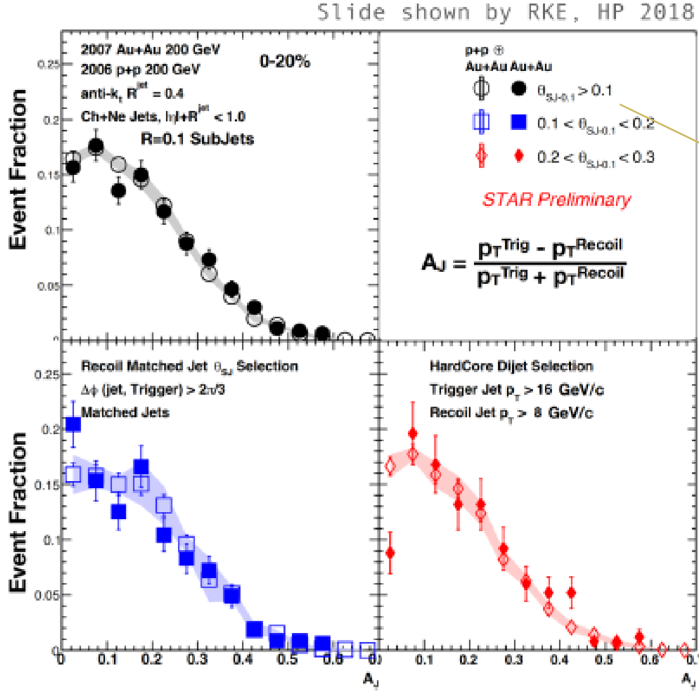
## Quenched Energy Flow at RHIC

Slide shown by RKE, HP 2018

**Matched $A_J$**

$p_T^{const} > 0.2$ GeV/c

**Matched jets of different $\theta_{SJ}$ selections are balanced at RHIC**




$$A_J = \frac{p_T^{Trig} - p_T^{Recoil}}{p_T^{Trig} + p_T^{Recoil}}$$

- STAR high tower triggered $A_J$ : lost energy recovered within R=0.4
- On the other hand, STAR h-Jet and PHENIX γ-hadron correlations (not shown): the quenched energy goes to large angle

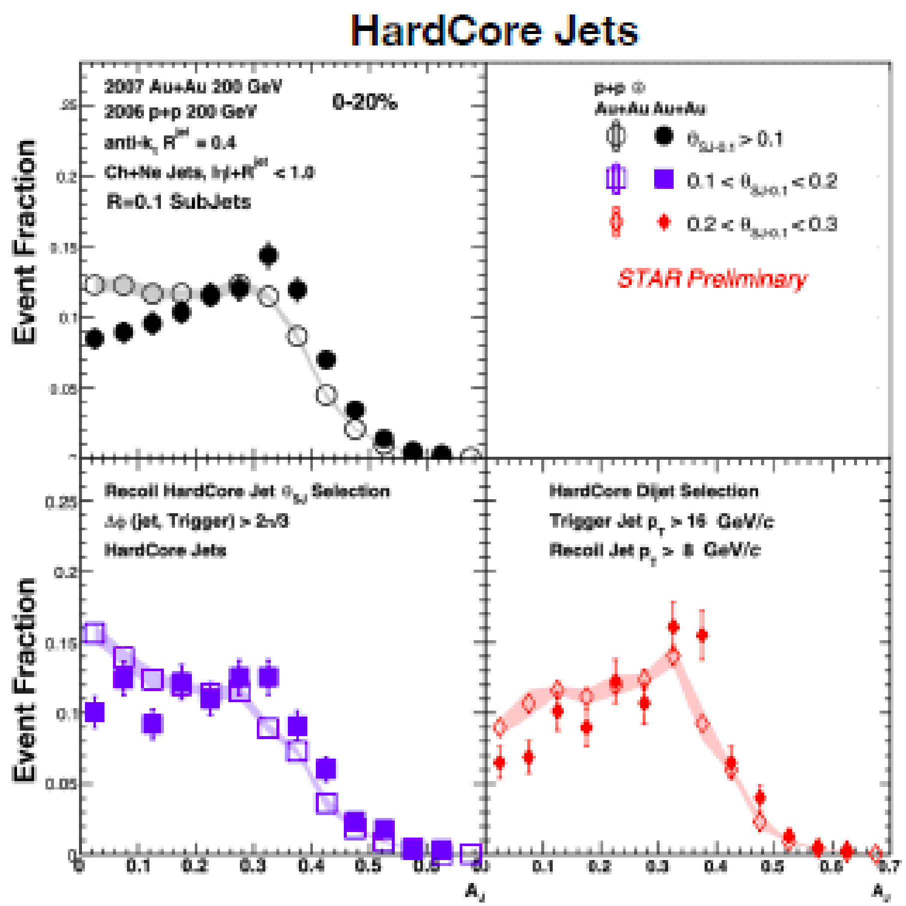
Yen-Jie Lee Jet Physics in Heavy Ion Collisions 22

**The shape parameters being varied here are still ~small angles < 0.4**

**Obviously AJ within this radius is not sensitive enough to feel this?**

# Example I (continued)

- The recovered STAR result is for matched jets, to be compared to Hard core jets– very subtle modification there

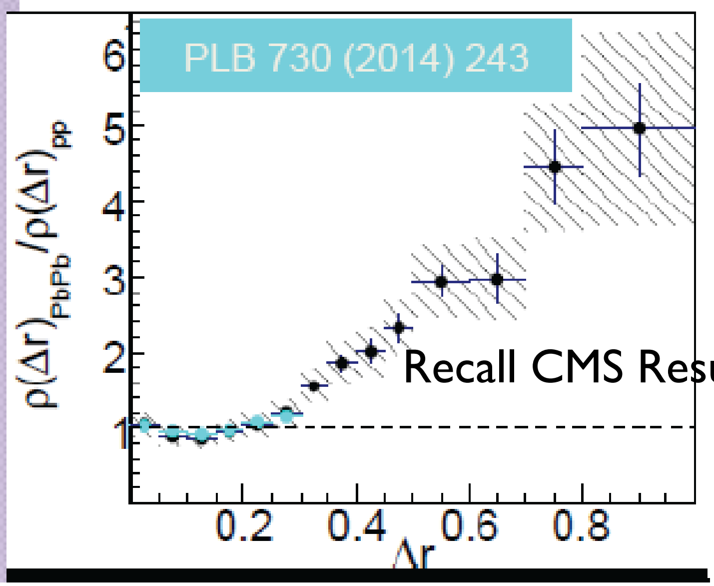


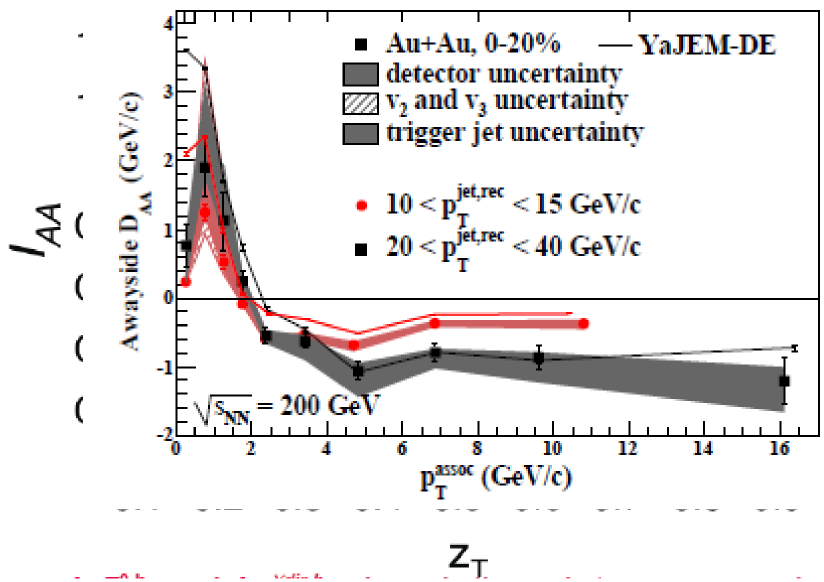

This is an example of why it will be great to get more precision and another independent check with sPHENIX!!!

# Energy flow @ large Angles

- As speaker pointed out, energy flow is well established out to very large angles/values
- Jet's (LHC) and at RHIC STAR Jet-h/$\gamma$-h…

STAR 1302.6184



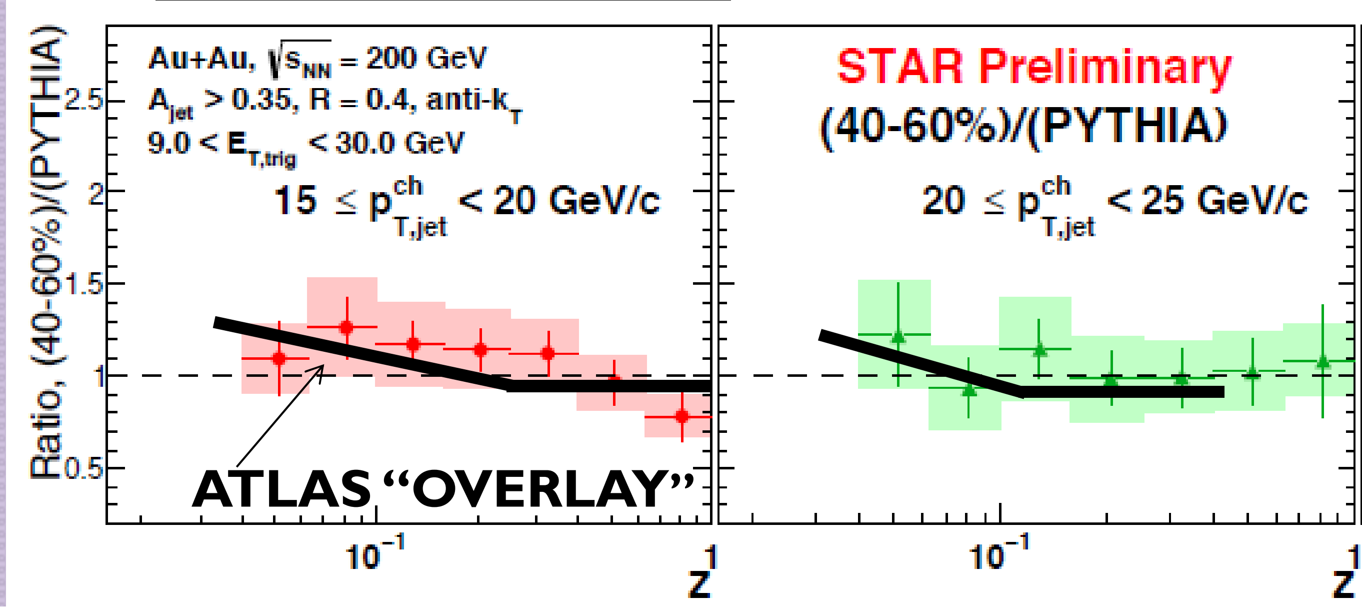



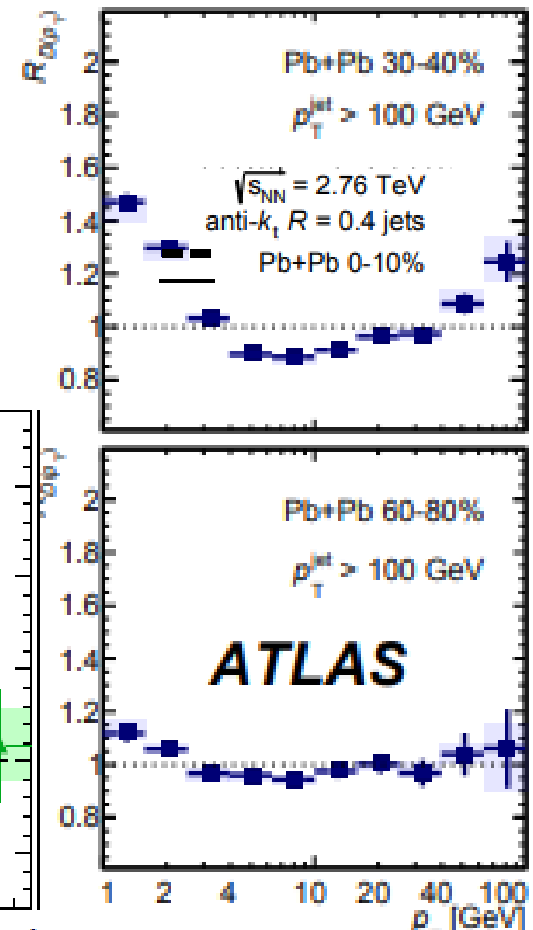
# (No) Disagreement Recent STAR data?

- Many caveats already stated by STAR when presented (recoil vs inclusive jets,  ratio to PYTHIA(!) etc.)
- But magnitude/pt of mods also

not large from LHC data

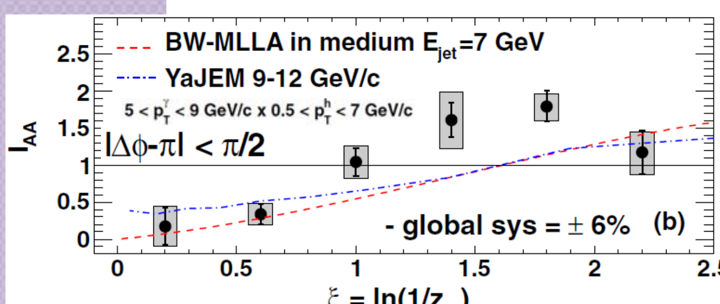
<u>-no tension here</u>



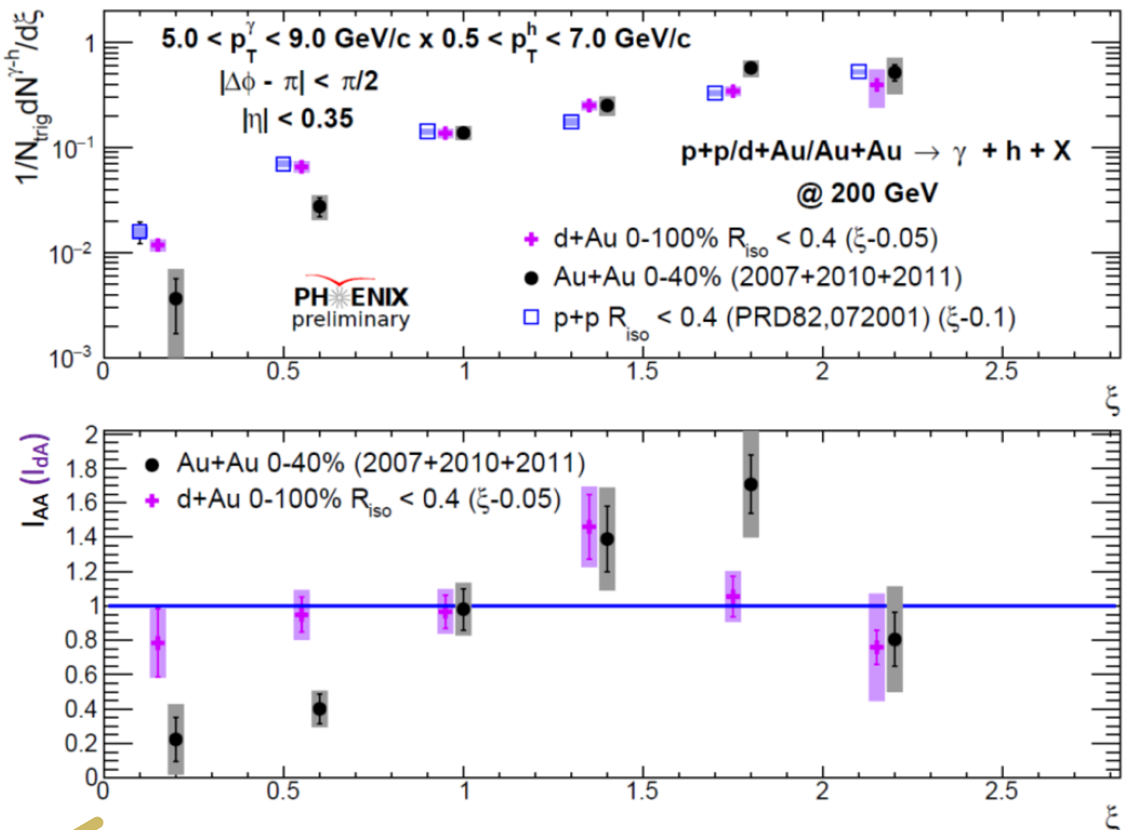



# In $\gamma$-h, PHENIX Measured/Reconfirmed Several Ways

- 0-40% events – Most central Au+Au
- No clear modification in d+Au
- Enhancement in Au+Au
- Run 7+10+11 Au+Au more precise than previous measurement (Run 7+Run 10)




PRL 111, 032301 (2013)




$\xi=\ln(1/z_T)$

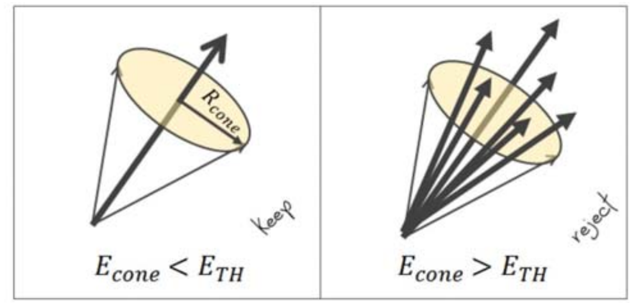
z increasing

How does enhancement behave with centrality?

# Updated Method - Isolation Cut in Au+Au

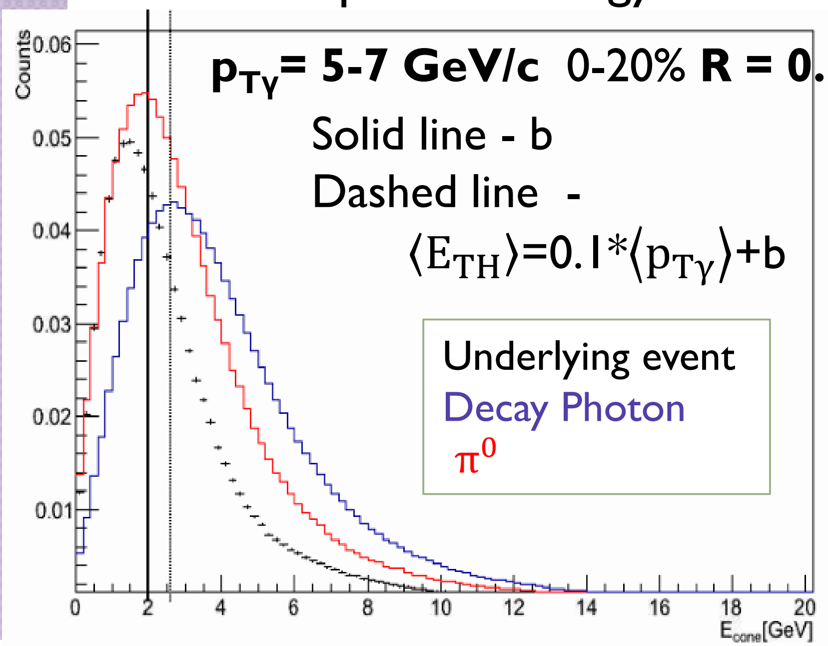
- Use cone method
  - Sum energy in cone around particle, if less than threshold, particle is isolated
  - Optimal threshold depends on centrality, background event energy, and central photon energy

$$R_{cone} = \sqrt{(\Delta\phi)^2 + (\Delta\eta)^2}$$
$$E_{TH} = aE_\gamma + b.$$




N. Riveli., Ph.D. thesis, Ohio University (2014).

| Centrality (%) | $R_{cone}$ | $a$ | $b$ (GeV) |
|---|---|---|---|
| 0 - 20 | 0.1 | 0.1 | 2.0 |
| 20 - 40 | 0.2 | 0.1 | 4.0 |
| 40 - 60 | 0.2 | 0.1 | 2.0 |
| 60 - 92 | 0.3 | 0.1 | 1.0 |

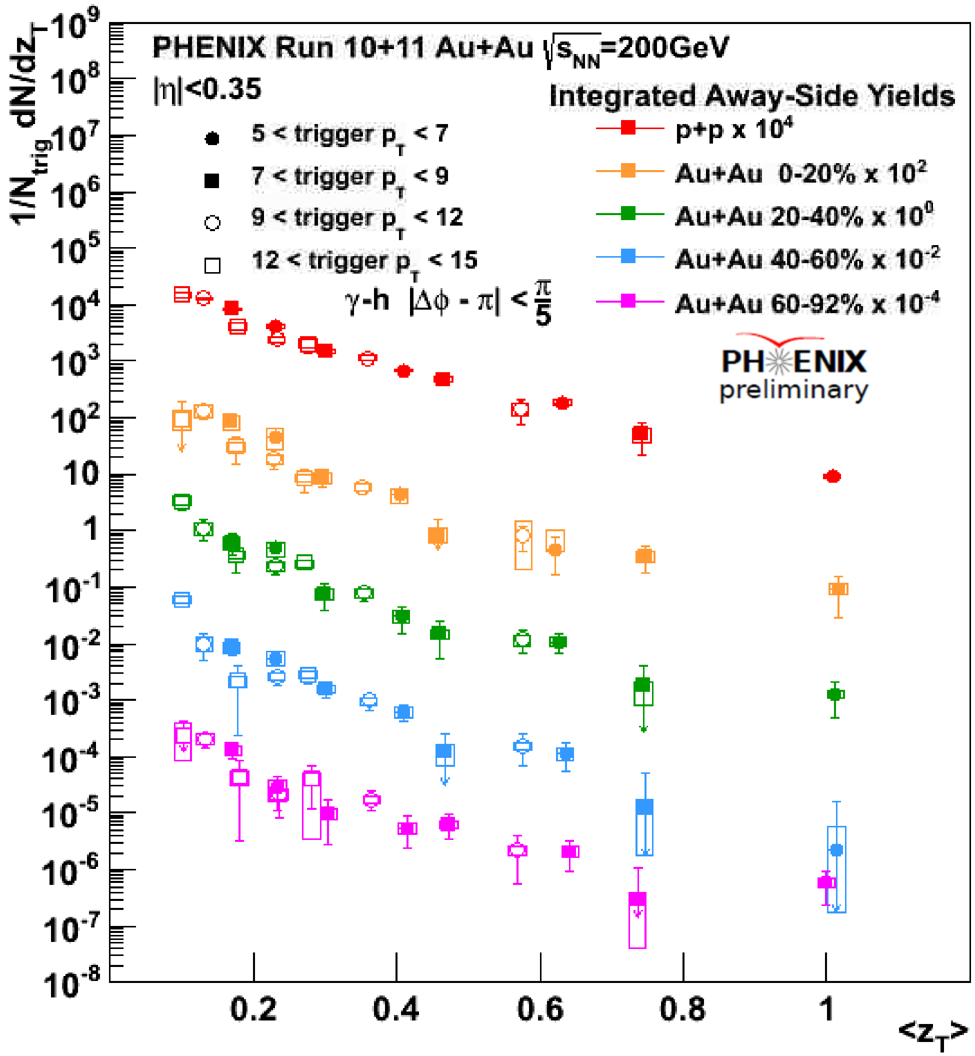



Causes complications

- Measuring isolated particle $v_2$ for 2-p background subtraction
- Background level – using abs norm method
- Decay photon statistical subtraction

# Away-side Prompt γ-h Yield

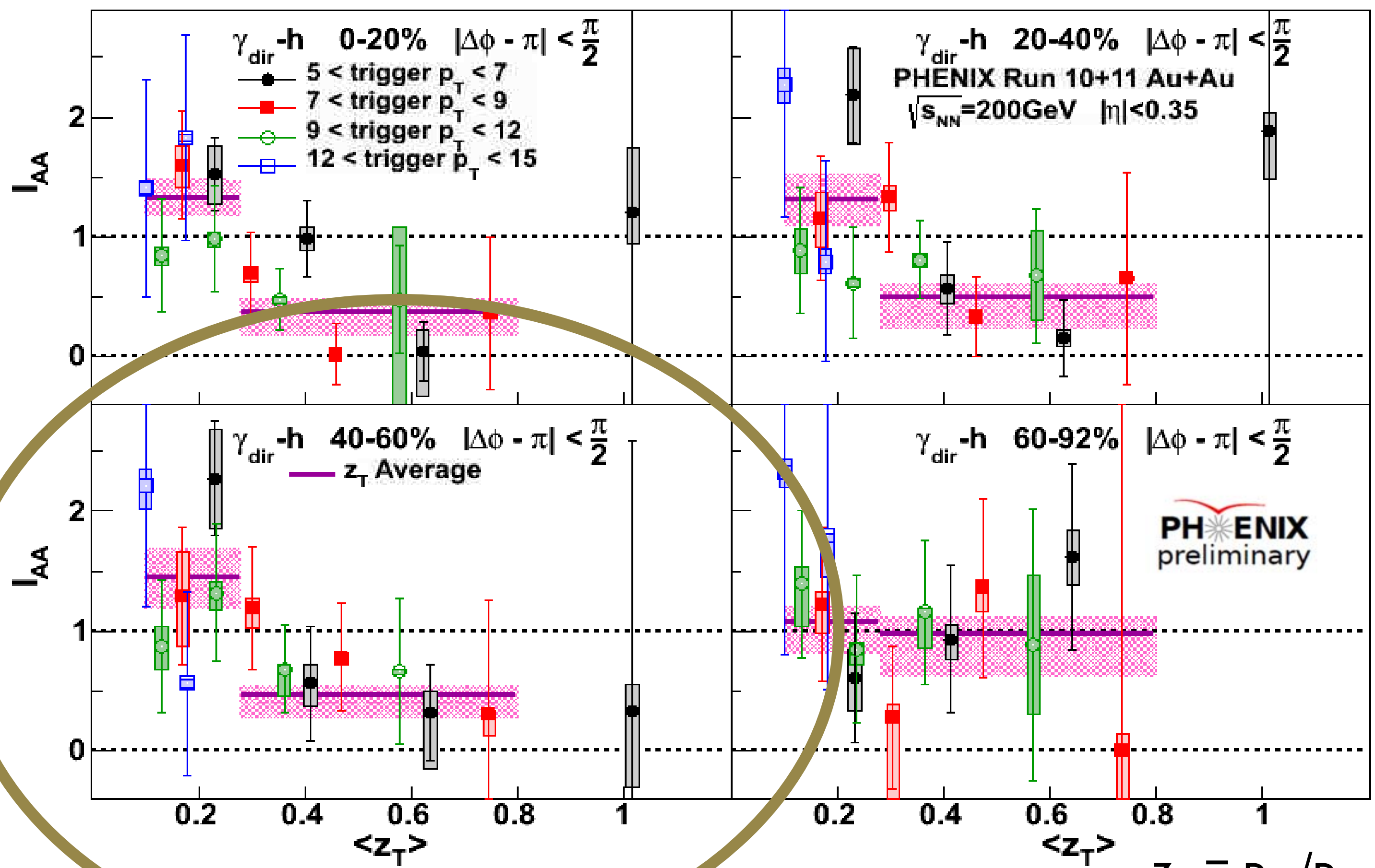
- Integrate away-side of per-trigger yield
- Seems to scale with $z_T = p_{Th}/p_{T\gamma}$



# $I_{AA}$ as a function of $z_T$

$$I_{AA}(p_T^\gamma, p_T^h) = \frac{Y^{Au+Au}(p_T^\gamma, p_T^h)}{Y^{p+p}(p_T^\gamma, p_T^h)}$$

- Fit all $I_{AA}$ points in two $z_T$ regions to a constant to extract the average $I_{AA}$ for each $z_T$ region and centrality bin

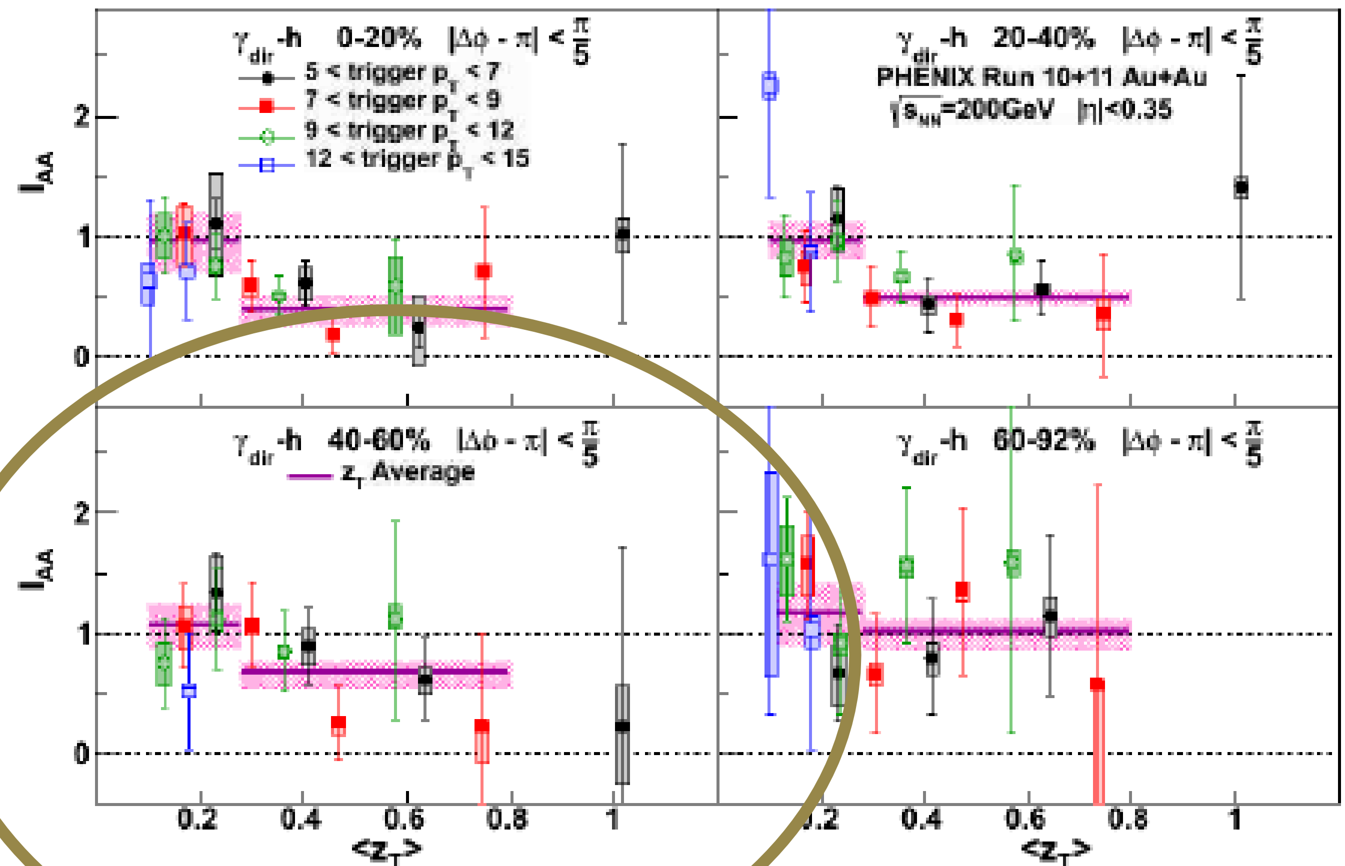



$z_T = p_{Th}/p_{T\gamma}$

# Better bin for STAR comparison : $I_{AA}$ as a function of $z_T$

$$I_{AA}(p_T^\gamma, p_T^h) = \frac{Y^{Au+Au}(p_T^\gamma, p_T^h)}{Y^{p+p}(p_T^\gamma, p_T^h)}$$

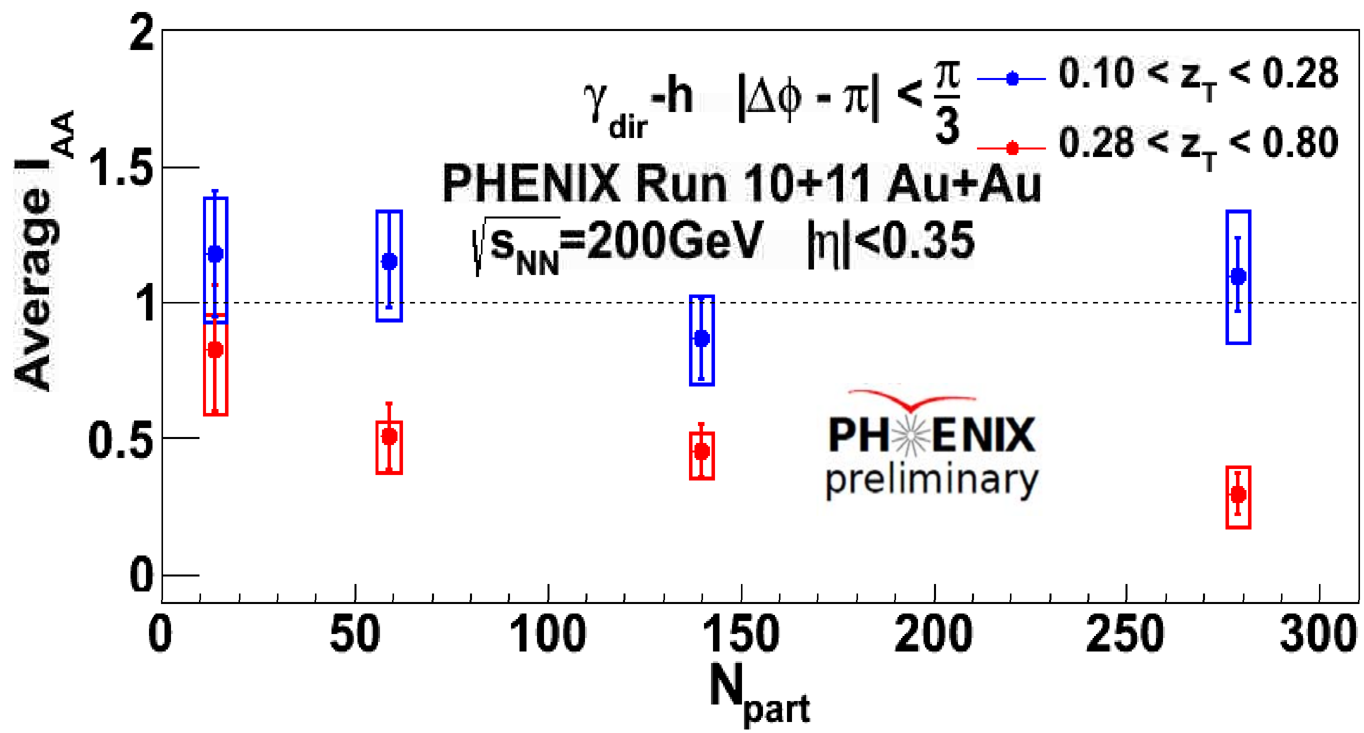
- **THIS BIN HAS AN INTEGRATION RANGE OF pi/5 ~ 0.6 cone size**




- **Note for 2PC must judge relative difference high vs low $z_T$**

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

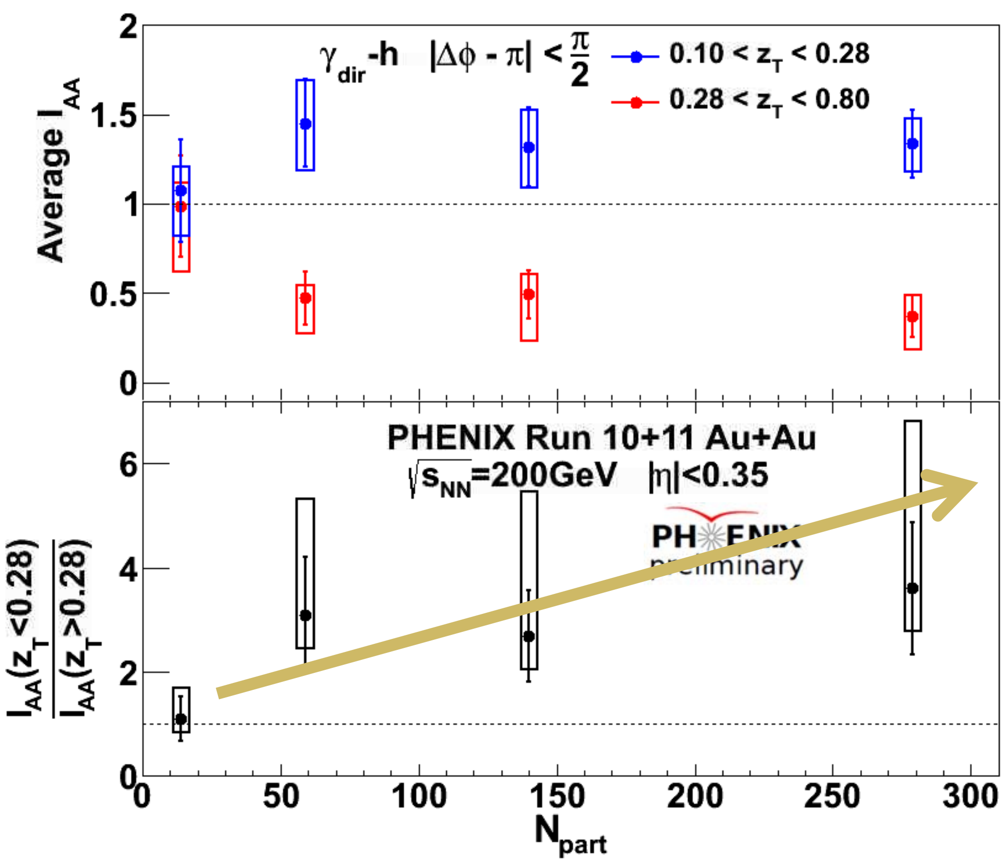
# Average $I_{AA}$ vs. Centrality




- Low $z_T$ and High $z_T$ behaviors different.
- High $z_T$ suppression for all centrality bins
- Low $z_T$ NOT SUPPRESSED, relatively flat with centrality-- $E_{loss}$ Recovery
- Isolation cut allows more precise analysis of the semi-peripheral and peripheral centralities

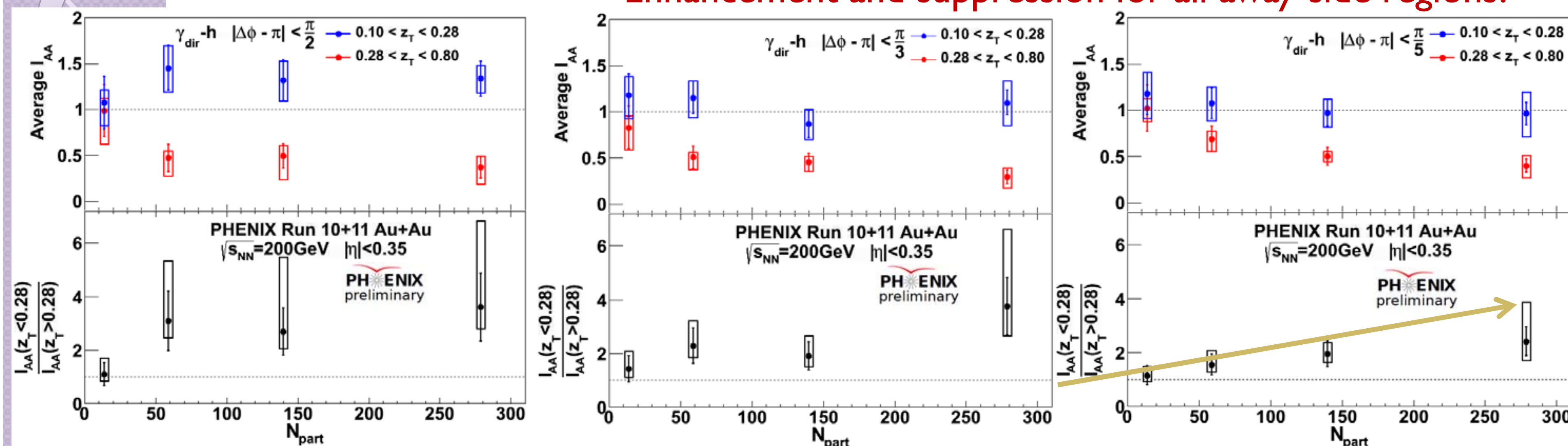
# Average $I_{AA}$ – π/2 away-side

- High $z_T$ energy loss enhances low $z_T$ production
- 1[st] measurement of centrality dependence of low $z_T$ enhancement
- To judge true centrality dependence of enhancement, must account for overall reduction of jets due to suppression
- Energy recovery factor – High $z_T$/ low $z_T$ ratio – shows monotonic increase toward central events



# Average $I_{AA}$

Enhancement and suppression for all away-side regions!

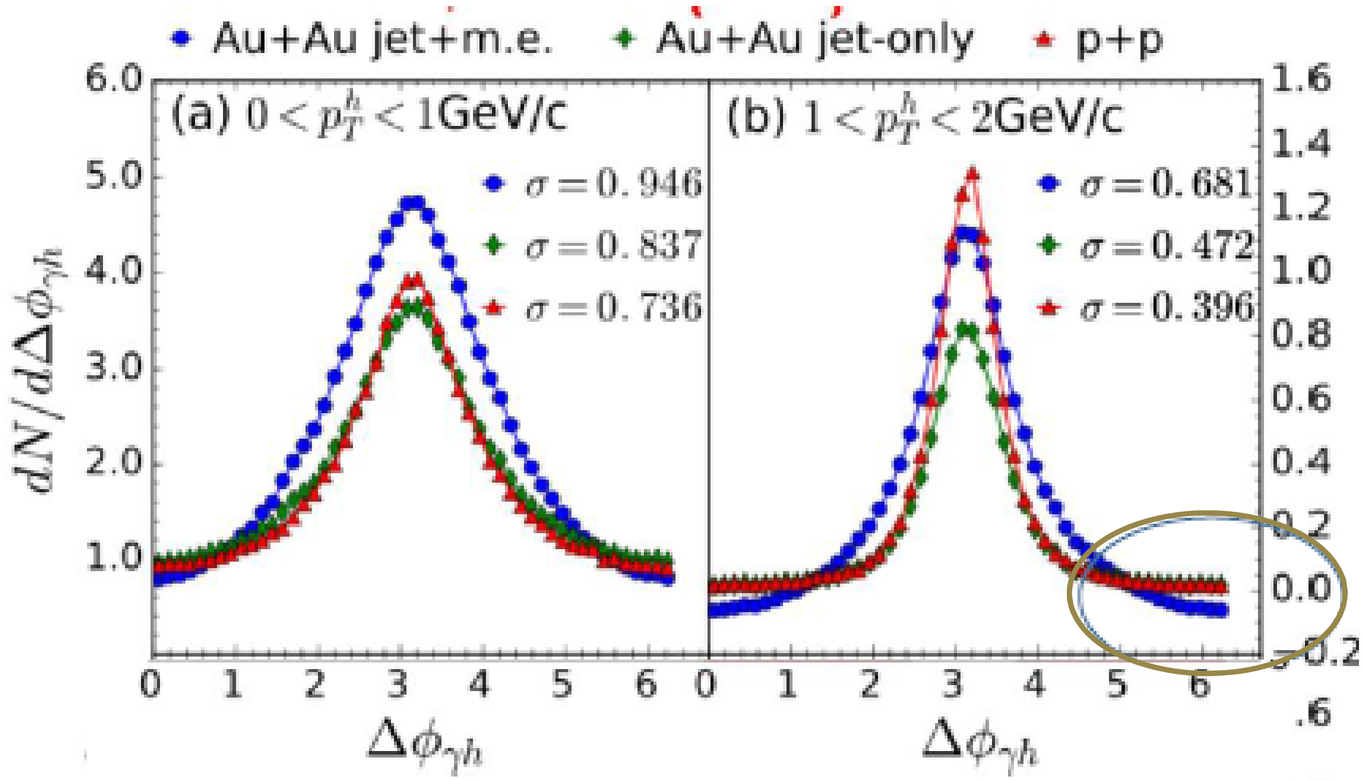



- Increasing low z enhancement for wider integration regions (blue points right to left)
  - Seen by previous gamma-jet and LHC jet reconstruction analyses
- Both high z suppression and low z enhancement
- Enhancement above suppressed jet level (black ratio) monotonically increasing towards central events for all away-sides

# Quick Aside What's Next?

- What's next here? Go WAY WIDER!!!!!
- Chen, XN Wang: et. al. Take awayside yield all the way to nearside!
  - This will be hard in small PHENIX acceptance
  - STAR → sPHENIX!

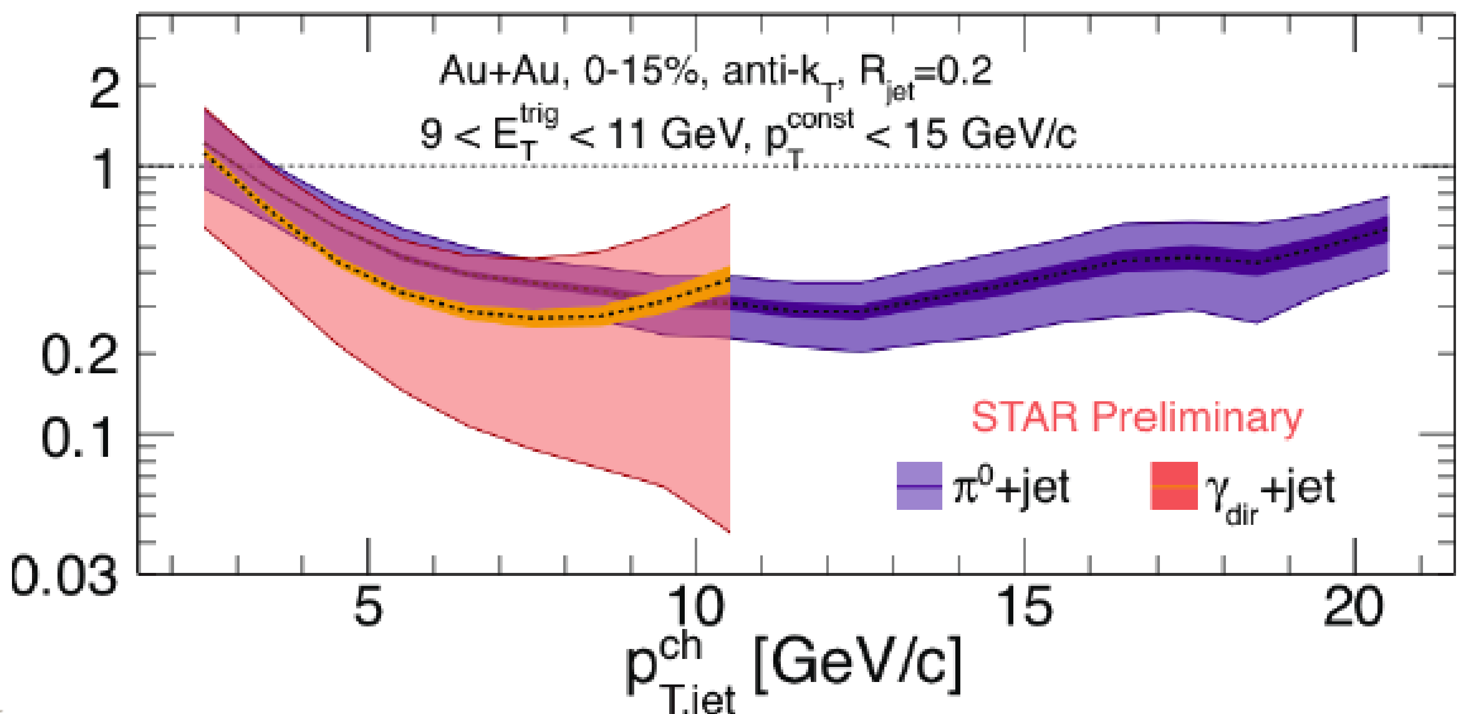
arXiv:1704.03648v4



# STAR h-Reco Jet, $\gamma$-Reco Jet: RECOIL

- STAR Prompt $\gamma$-h/jet Analyzers busy with first $\gamma$-Reco'd Jet Result at RHIC!
- Fragmentation Fn IAA (and other Substructure) Using Jet Angle will help with many of the previous studies

IAA of Number of Awayside Jets



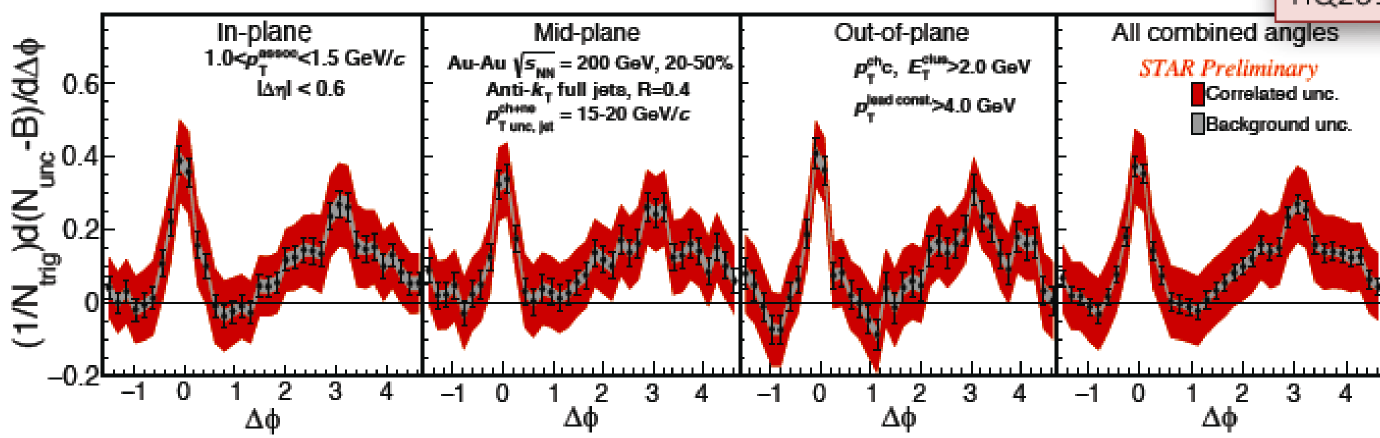
# The lesson

- With two particles in Au+Au, can access larger opening angles, lower jet E, where specifics of jet findings would be less important anyway
- …and thus we can still gain valuable insight into Jet Eloss

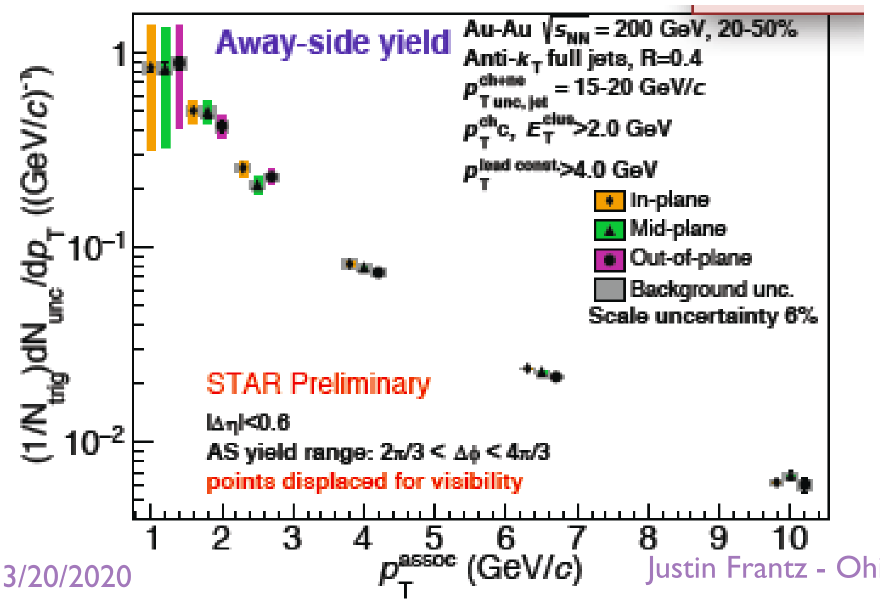
# Example II: STAR Event-Plane Dep. Jet-h "2PC"

- No event plane dependence?
  - (Similar results seen in regular 2PC also)

HQ2018

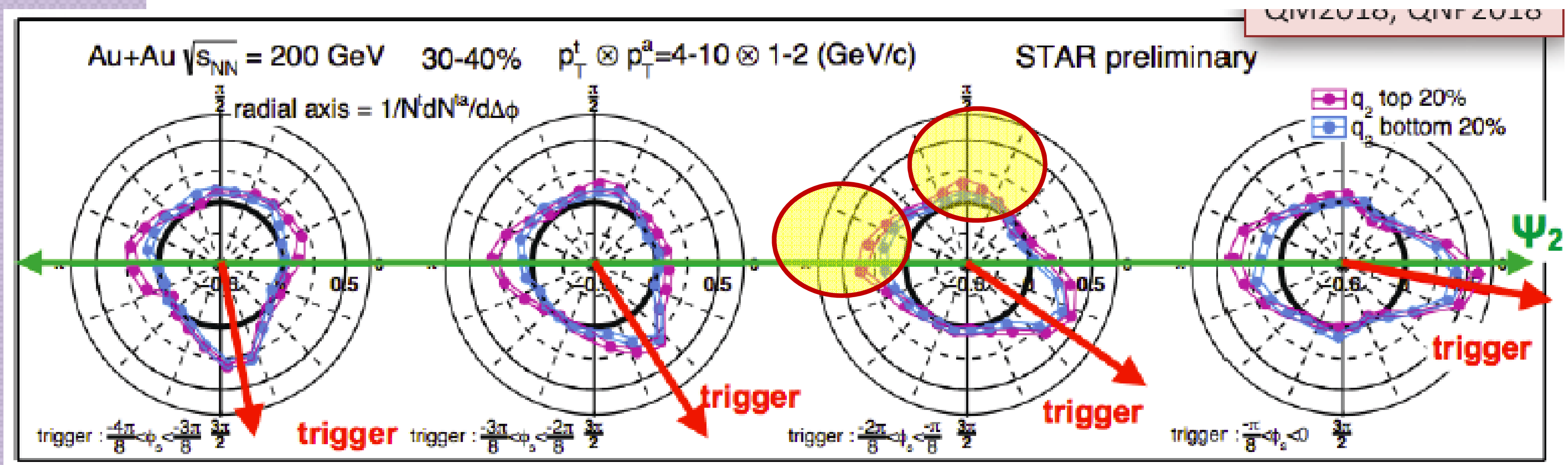



Talk by
S. Oh
WWND 19



# More Differential w/ 2PC

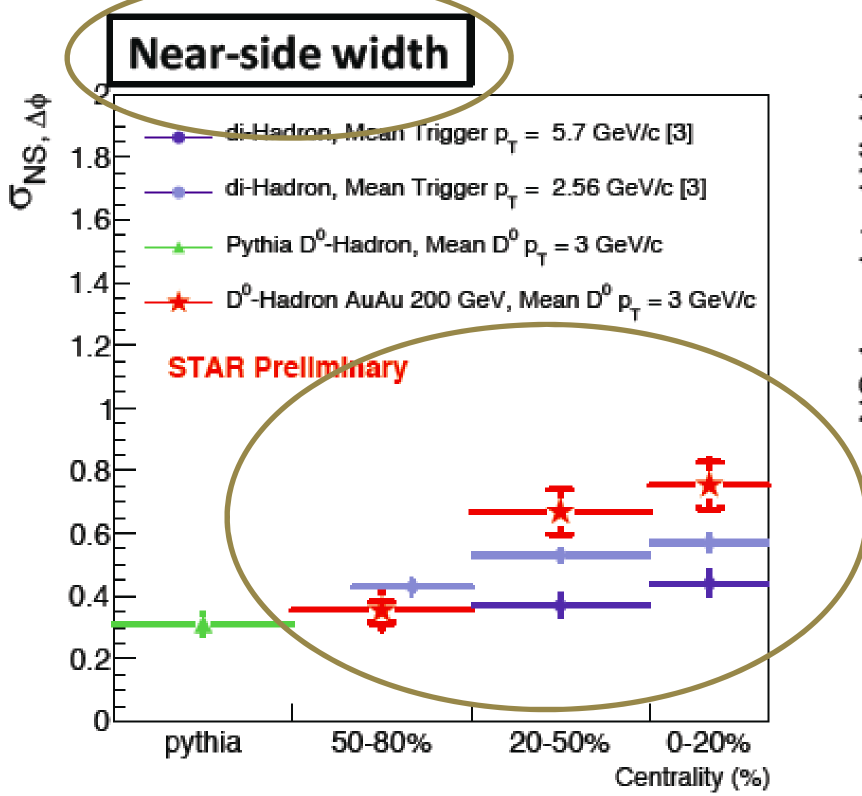
- 2PC correlations where trigger and partner NOT symmetrized and measured w.r.t "handed" direction reveals hidden dependence!

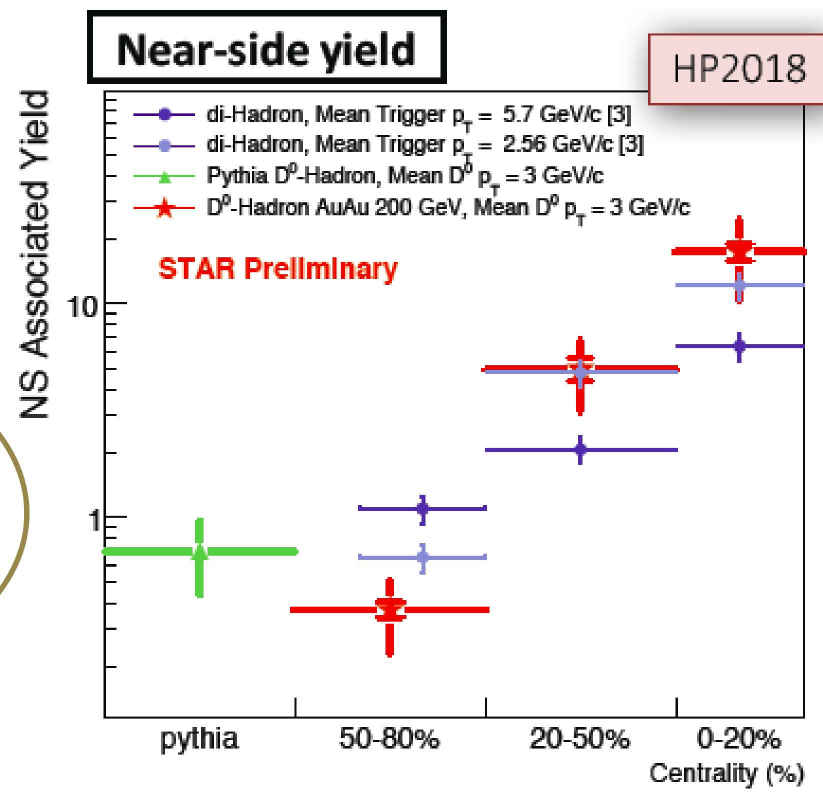



- **Awayside suppressed in direction of longer path length direction, which moves and thus washes out in inclusive**

# Example III: STAR $D_0$-h 2PC:

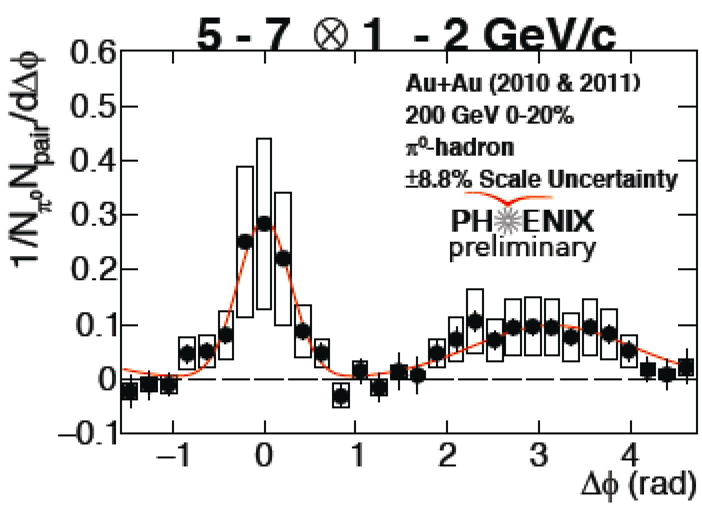
- Charm-jet 2PC have similar behavior to light di-hadrons
- Here, c quark, like for $\gamma$ provides interesting *momentum direction* / Scale even w/o Jet Reco

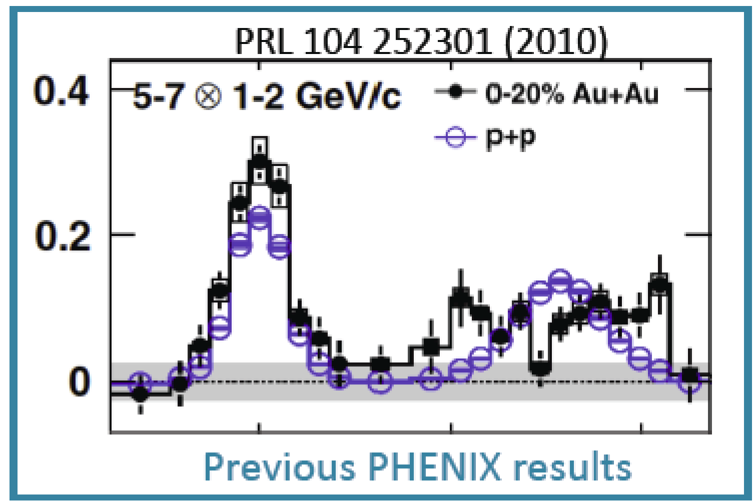


# Jet Corr. Widths from 2PC: A Recent focus (reason in a moment)

- Finally PHENIX re-analysis with full vn:

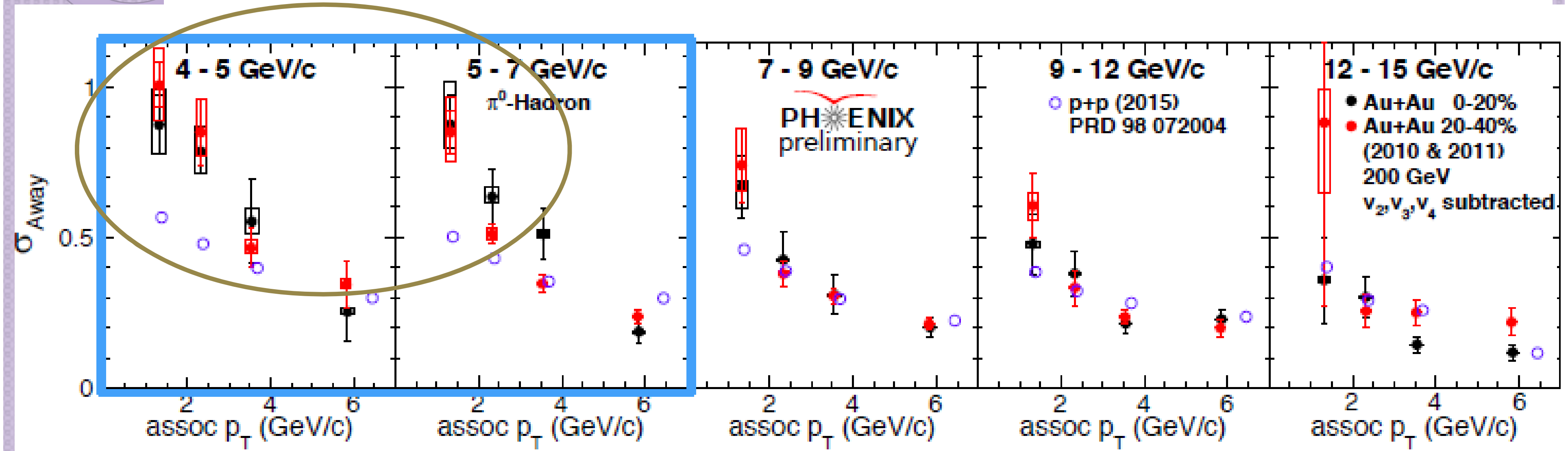



- Especially towards low pT (closely related to the enhancement)
- A serious width broadening is present even after vn

# Jet Corr. Widths from 2PC: A Recent focus (reason in a moment)

- Finally PHENIX re-analysis with full vn: (Run 10/11)




- A serious width broadening is present even after vn
- Centrality dependence
- This is the thing we are after –> go more peripheral…

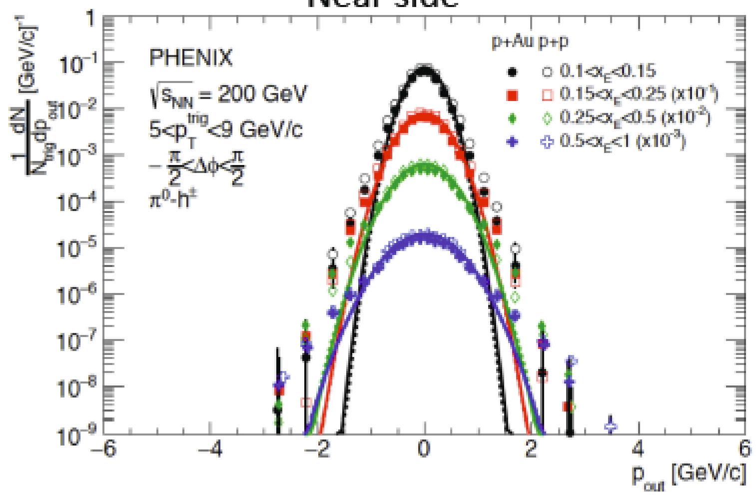
# …Because of small system results

- Width results: different variable:

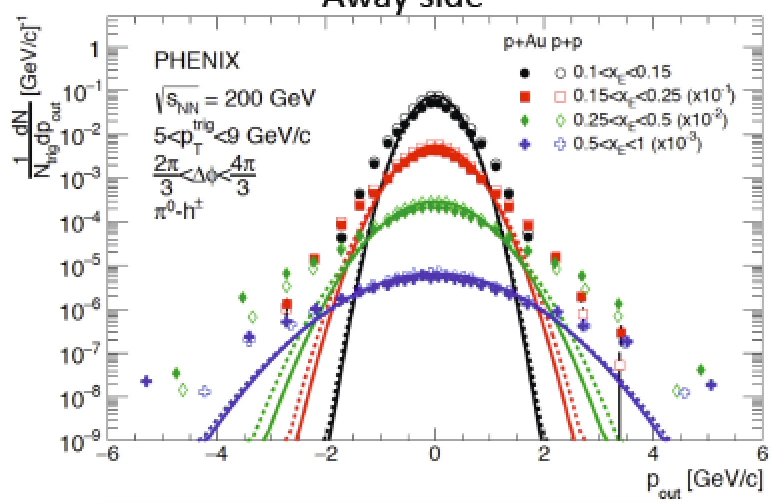
## $\bar{p}_{out}$ Distribution in p+A

arXiv:1809.09045v1

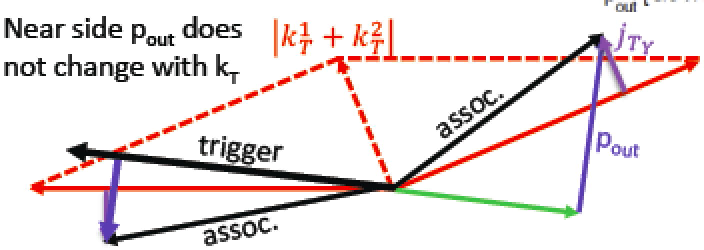
Near side




Away side




Near side $p_{out}$ does not change with $k_T$



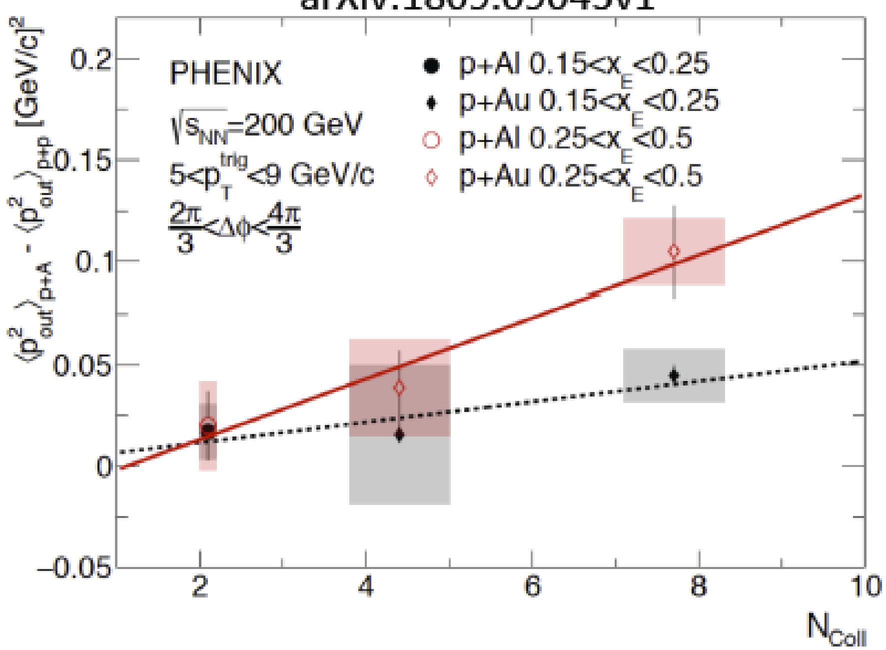

- Narrower near side $p_{out}$ distribution than the away side as $p_{out}^{near}$ depends on $j_T$ only
- $p_{out}^{away}$ depends on both $k_T$ and $j_T$

$x_E = -\frac{|\vec{p}_T^{assoc}|}{|\vec{p}_T^{trig}|} \cdot \cos(\Delta\phi)$ $\quad \vec{p}_{out} = \vec{p}_T^{assoc} \cdot \sin(\Delta\phi)$

# Small System Broadening of Jet Corr

- Of course this cannot be yet asserted to be due to Eloss, but we need to investigate

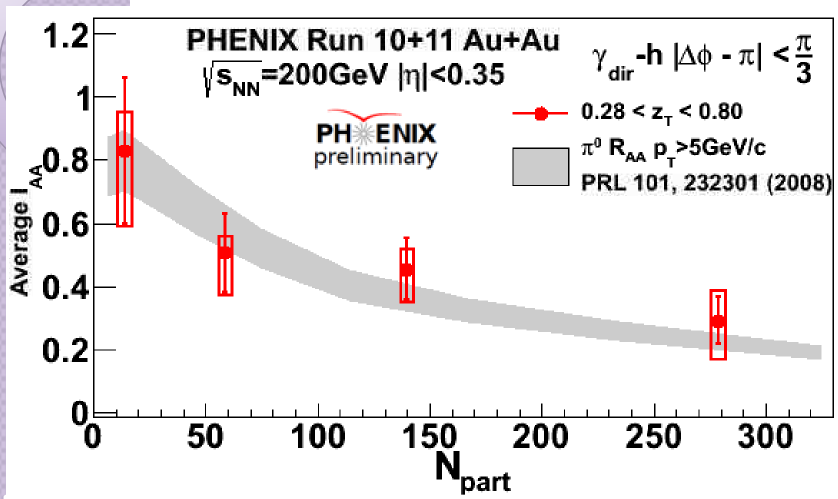
arXiv:1809.09045v1

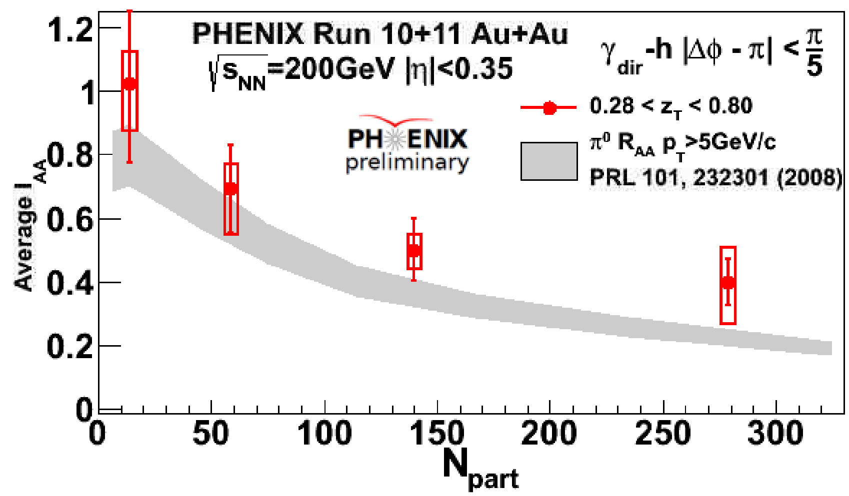



Centrality/$N_{coll}$ dependent: broader $\vec{p}_{out}^{\,p+A}$ as $N_{coll}$ increases

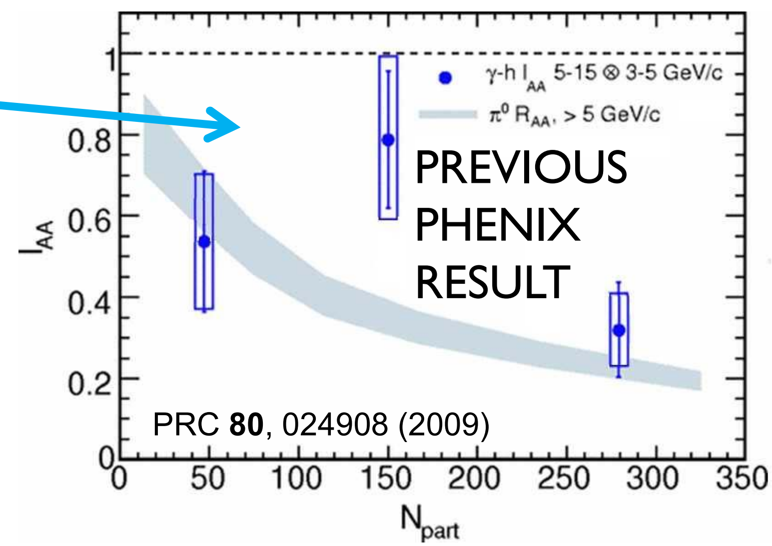
- ~~Underlying flow?~~ $v_2$ and $v_3$ are ruled out
- Higher $k_T$ for parton in nucleus?
- Energy loss?

# Back to $\gamma$-h Yields High $z_T$ Average $I_{AA}$ Centrality Dependence



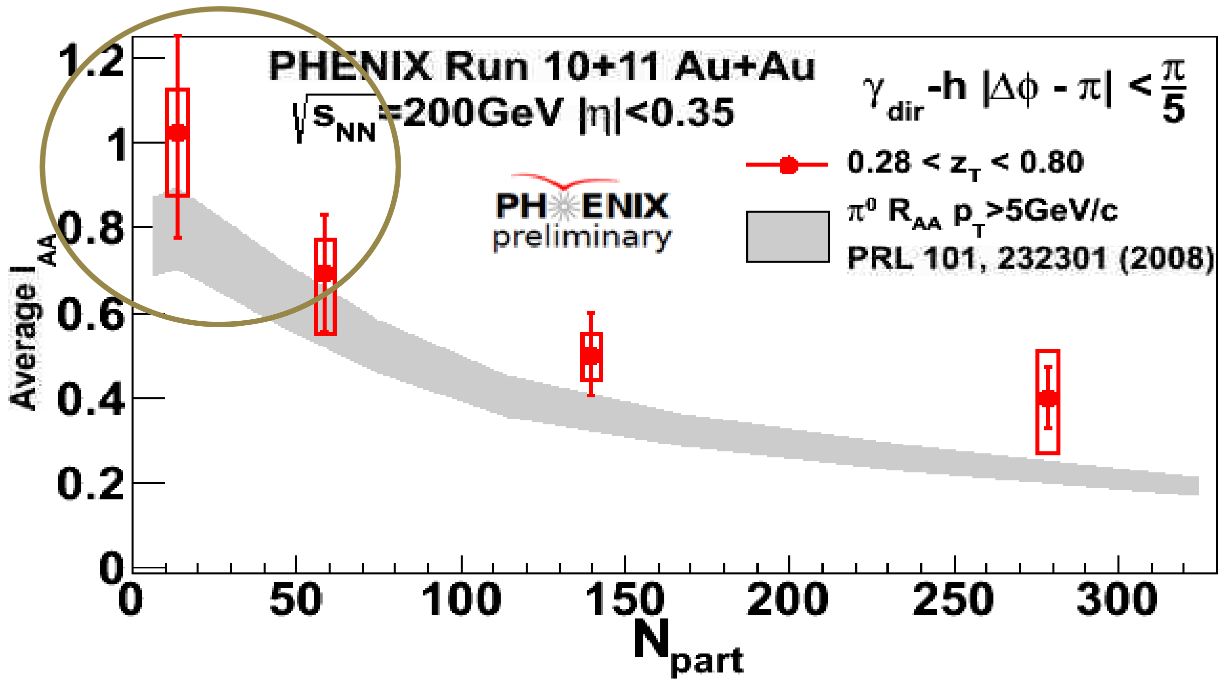




- Isolation cut/New stats substantial improvement in precision
- Detailed centrality shape of suppression
- High $z_T$ Average $I_{AA}$ and $\pi^0$ $R_{AA}$ approximately match
  - Photon tagged jet geometric distribution ($E_{loss}$ geometry) is exactly the same as single inclusive jet geometric distribution - so $R_{AA} \approx \gamma$-jet $I_{AA}$ expected



# Ultimate Goal Eloss Turn-off? Eloss in Small systems?

- We want to focus on region where Eloss is small in A+A to study whether it may be expected in small systems and how large does a system have to be?
- Isolation cut helps most in mid-central to periph: but low statistics we need analyze Run14/Run16 statistics to gain sufficient statistical precision



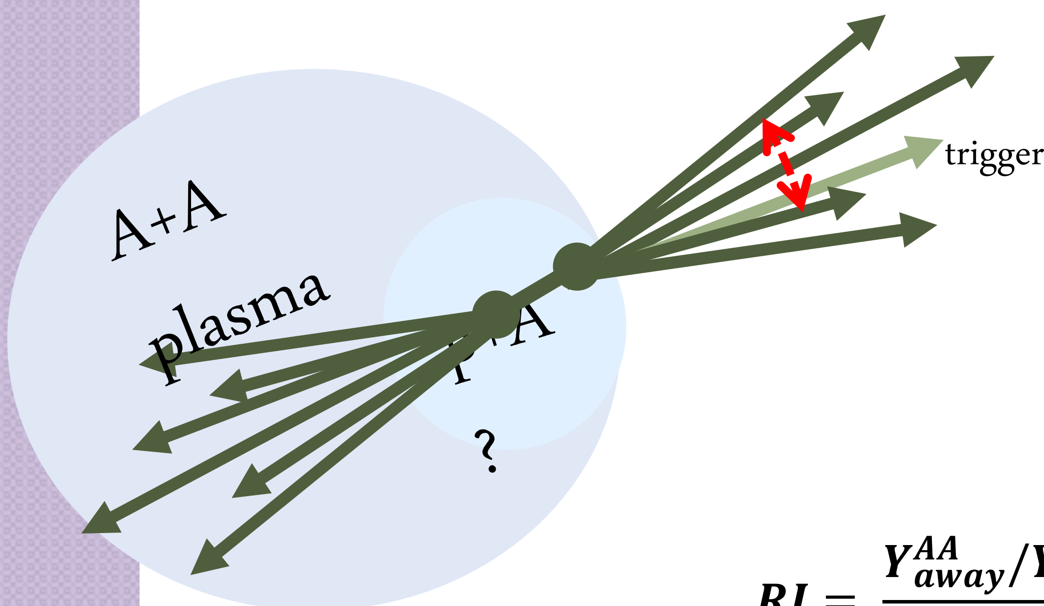
# Ultimate Goal Eloss Turn-off? Eloss in Small systems?

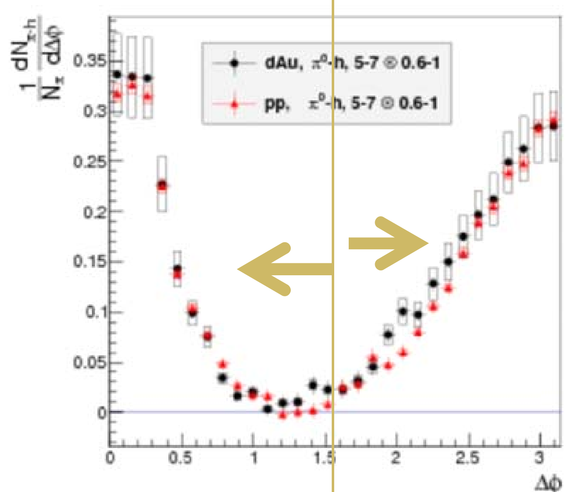
- Alternative solution:

1. Using pi0-h correlation to gain statistical precision.
2. Finding new observable other than IAA to take care of systematic errors.

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

- Assume well-known surface bias picture for Au+Au should apply as the system goes peripheral—possibly even in "small systems" p+Au, d+Au, He+Au
- Look for Differences in Awayside Modification compared to Nearside



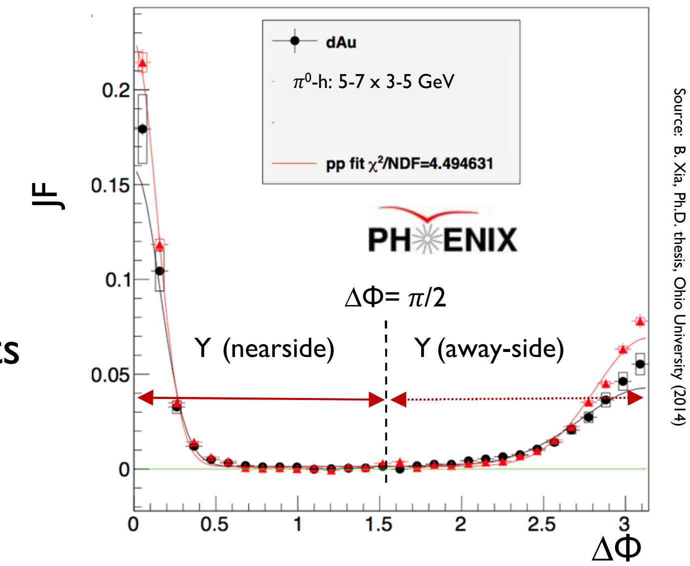

$$RI = \frac{Y_{away}^{AA}/Y_{near}^{AA}}{Y_{away}^{pp}/Y_{near}^{pp}}$$

Black
**Red**

# Jet Pair Quantification

**PTY Nuclear Modification Factor ($I_{AA}$) $= Y^{AA} / Y^{pp}$ (Away side)**

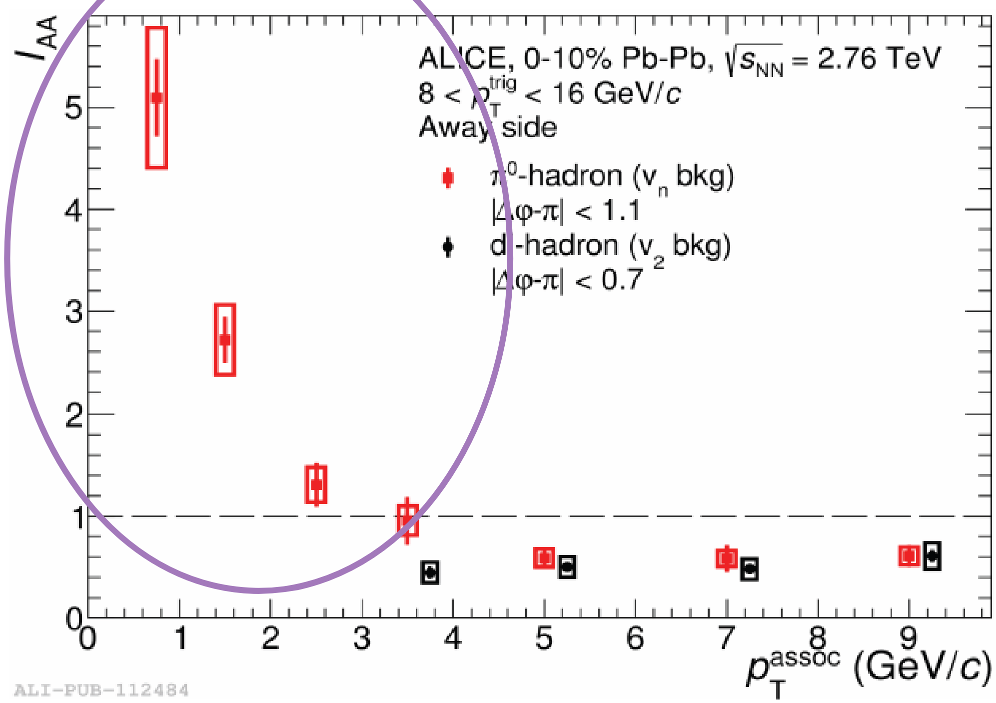
- Y roughly represents the number of particles produced per jet
- Y is Per Trigger: any deviation from unity represents modification
- AA/pp Partner $h^{\pm}$ SINGLES EFFICIENCIES vs $p_T$ NEEDED
- Uncertainty dominated by singles charge hadron efficiency




**Double Ratio:** $$RI = \frac{Y^{AA}_{away}/Y^{AA}_{near}}{Y^{pp}_{away}/Y^{pp}_{near}}$$

- **NO EFFICIENCIES NEEDED (Cancels in AS/NS)**
  - Dominant systematic errors due to single charge hadron efficiency are completely removed
- Surface Bias: levels of modification mostly unchanged (going from IAA to RI)
- Contribution of $v_{2n}$ even harmonics from hydrodynamic flow **is zero** (e.g. $v_2$)
- Contribution of higher order odd harmonics (>= $v_3$) can be neglected--only sensitive to $v_1$
- ZYAM systematic is also small since residual mis-subtraction contribute to both NS and AS.

# Energy loss + Suppress ?: IAA (/RI) Most Sensitive Observable?

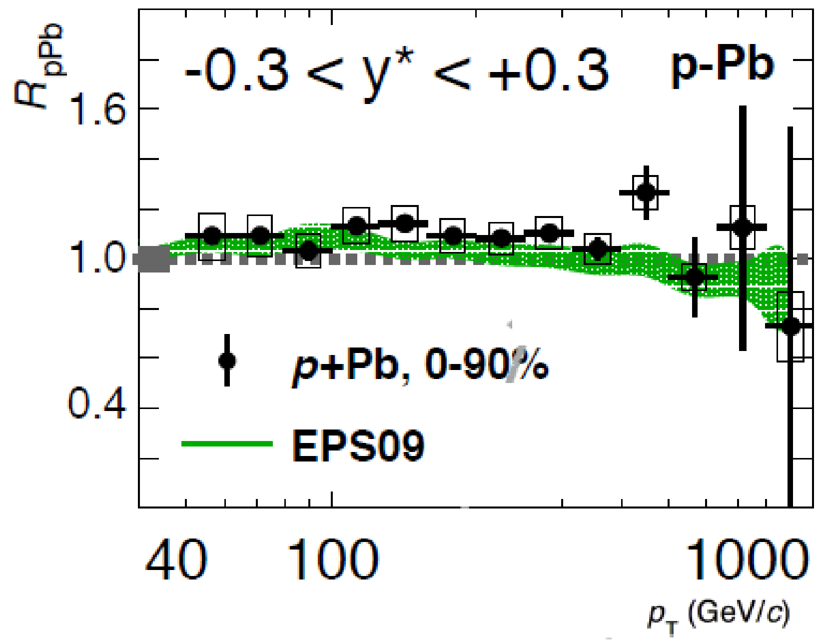



- **Reminder 2PC IAA (LHC)**:
  - relative rise from high pta (RI = ~0.5) to low pta (RI= 5) is factor of 10!
    - **MUCH BIGGER FACTOR THAN RAA SUPPRESSION!!! (better signature? )**
- **More sensitive then jet reco measurements because no "found-jet-only" bias**

# Other end of spectrum: Small Systems:?

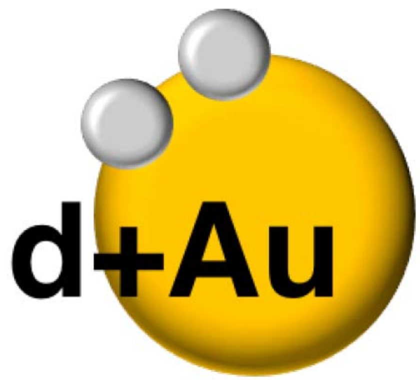
- No Eloss in p+Pb at LHC? –LHC only very high energy observables.
  - ndpfs account for ALL jet modifications?
- LHC focus on found jets, observables like x.s. excludes largest modification e.g. for A+A jets (ΔR > 1 enhancement)
- Greater sensitivity in low Ejet?
  - lowest possible "jet" pt: 5-15 GeV.
- Exploit enhancement—Exploit trigger bias for sensitivity: 2PC/RI can do both

ATLAS, ATLAS-CONF-2014-024



# d+Au: pi0-h correlation

In PHENIX we put all these ideas together a few years ago which can demonstrate

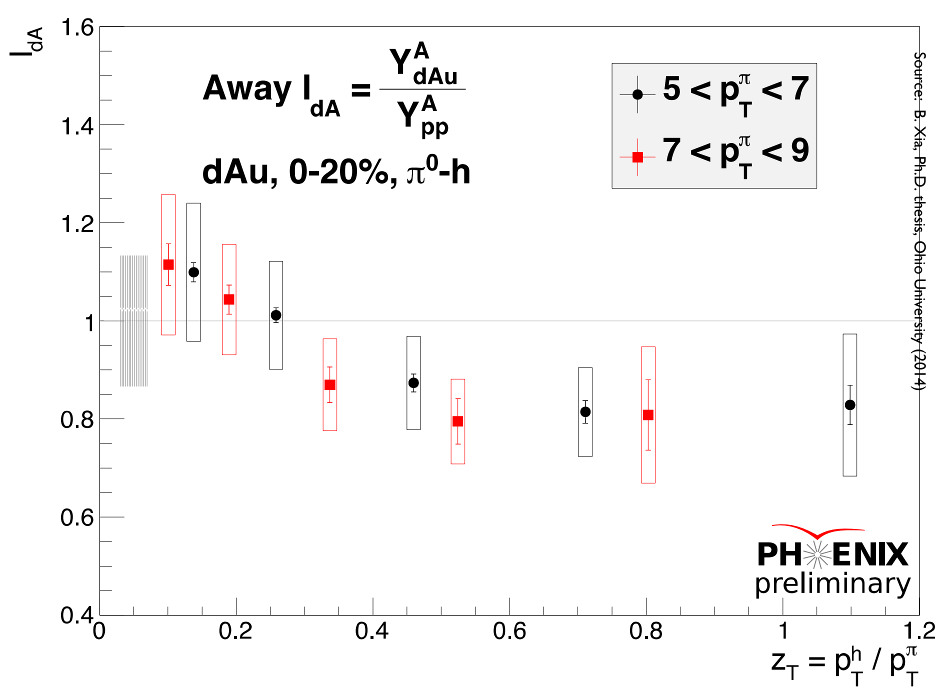



$\sqrt{s_{NN}} = 200$ GeV

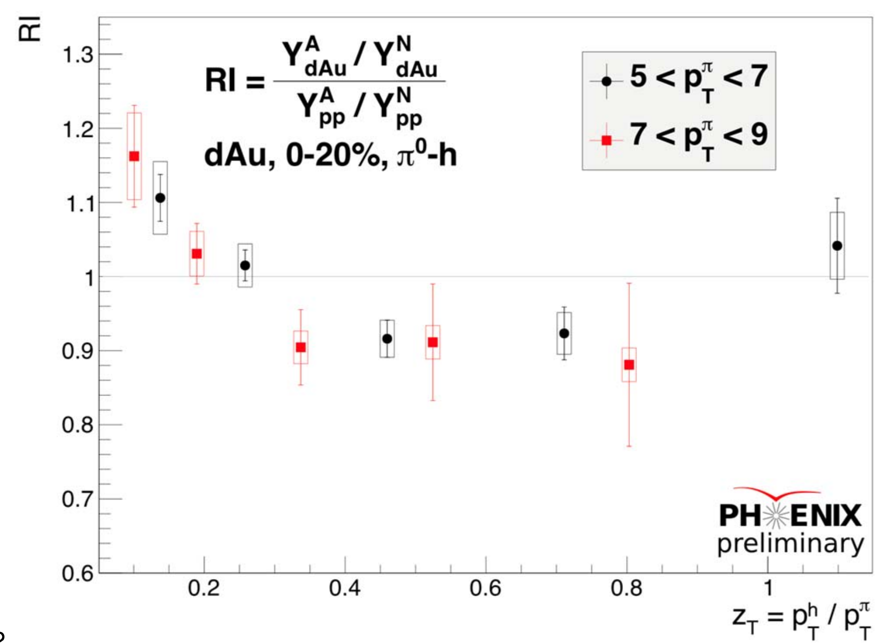
# $I_{AA}$ vs RI

- Clear improvement of uncertainties in RI compared to $I_{AA}$
- RI can be more sensitive to small levels of suppression or small cold nuclear effects
- Shows small high z suppression and low z enhancement in d+Au

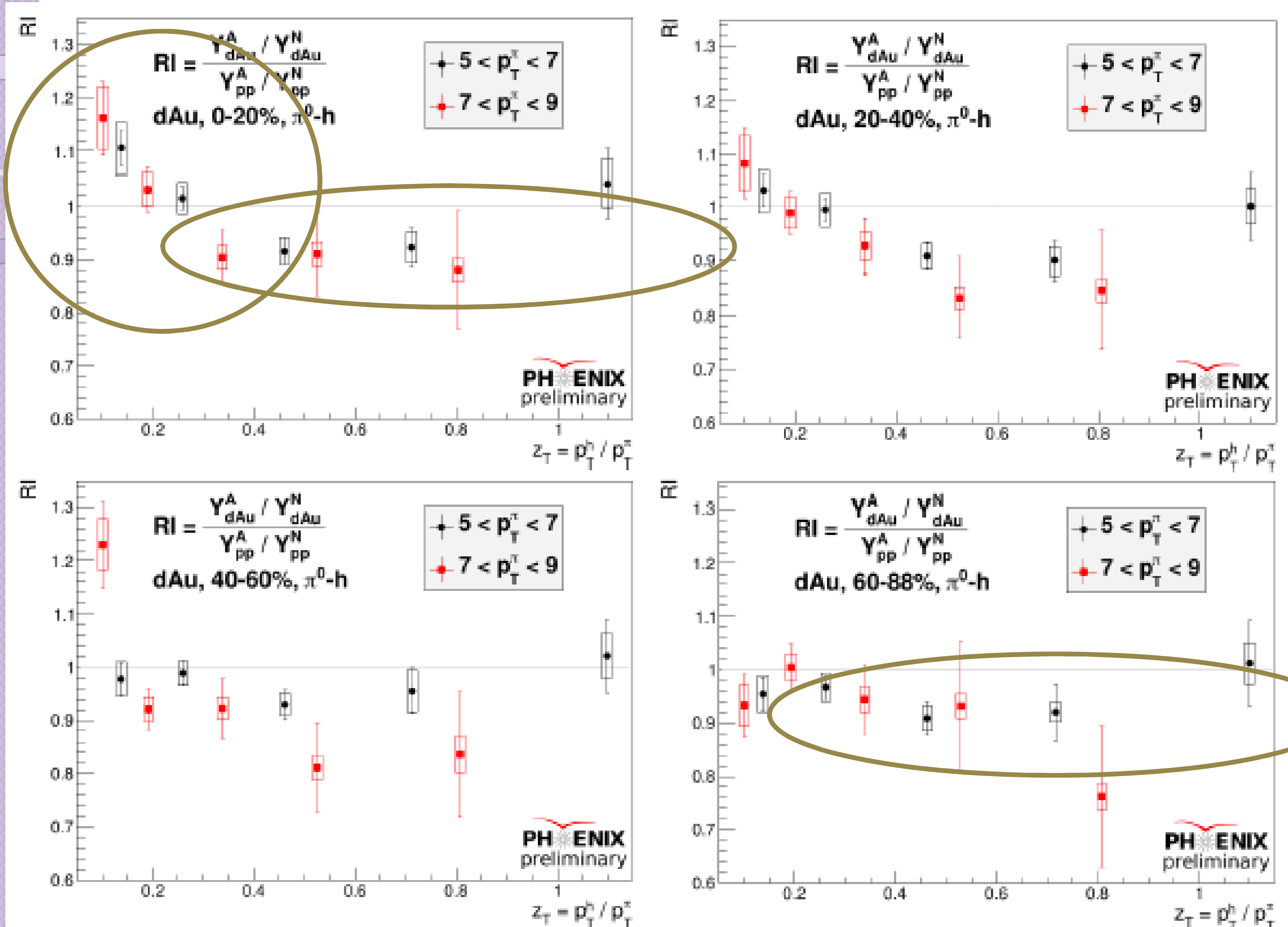
**Away Side $I_{dAu}$, 0-20 % centrality**
**Run8 d+A at $\sqrt{s_{NN}} = 200\ GeV$**




**RI, 0-20 % centrality,**
**Run8 d+A at $\sqrt{s_{NN}} = 200\ GeV$**



# dAu RI Ratio Centrality Dependence




System size evolution in d+Au? Peripheral to Central? More low z enhancement at low zT → High pt suppression? Not clear? Can we confirm this with another system?

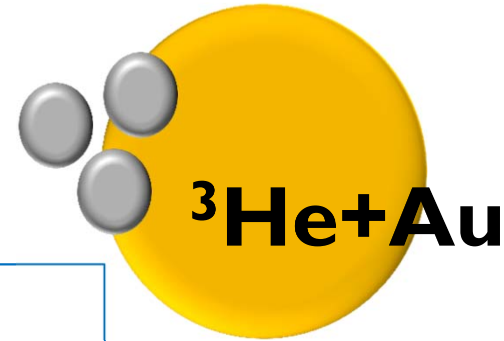
# Causes?

- We investigated a lot of trivial "COLD NUCLEAR" effects

✓None of these could reproduce the effect

**But this is (WAS) only one channel in one system, can we confirm the result in other data ?**

# Newer Datasets



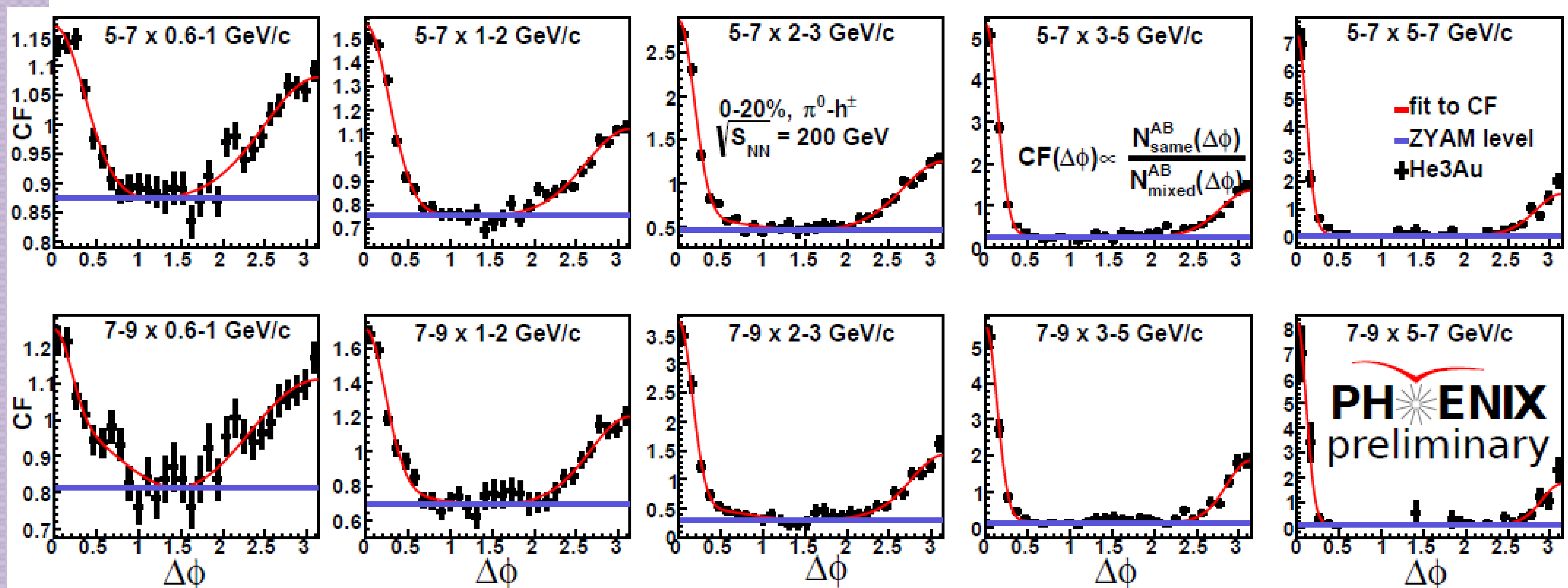

**2014 Run (He3+Au)**
**2015 Run (p+p)**
**2016 Run (new d+Au)**

- He3+Au
  - Centrality: 0-20%
  - $\sqrt{s_{NN}} = 200$ GeV
  - No. of pi0 triggers: **386 k** (vs. **Run8 d+Au: 5 m**)
    [386308 vs 4942516 ]
- Run 15 p+p improves statistics of previous d+Au result and HeAu result
  - No. of pi0 triggers in **Run 15 p+p: 6.9 m** (vs . **Run6 p+p: 1.5** m) [6883699 vs 1458711]
  - Thus better to use Run15 p+p for better statistics
- Run 16 d+Au data also available
  - Initial rough (pre-) re-analysis also confirms 2008 result TBA

# Correlation Functions

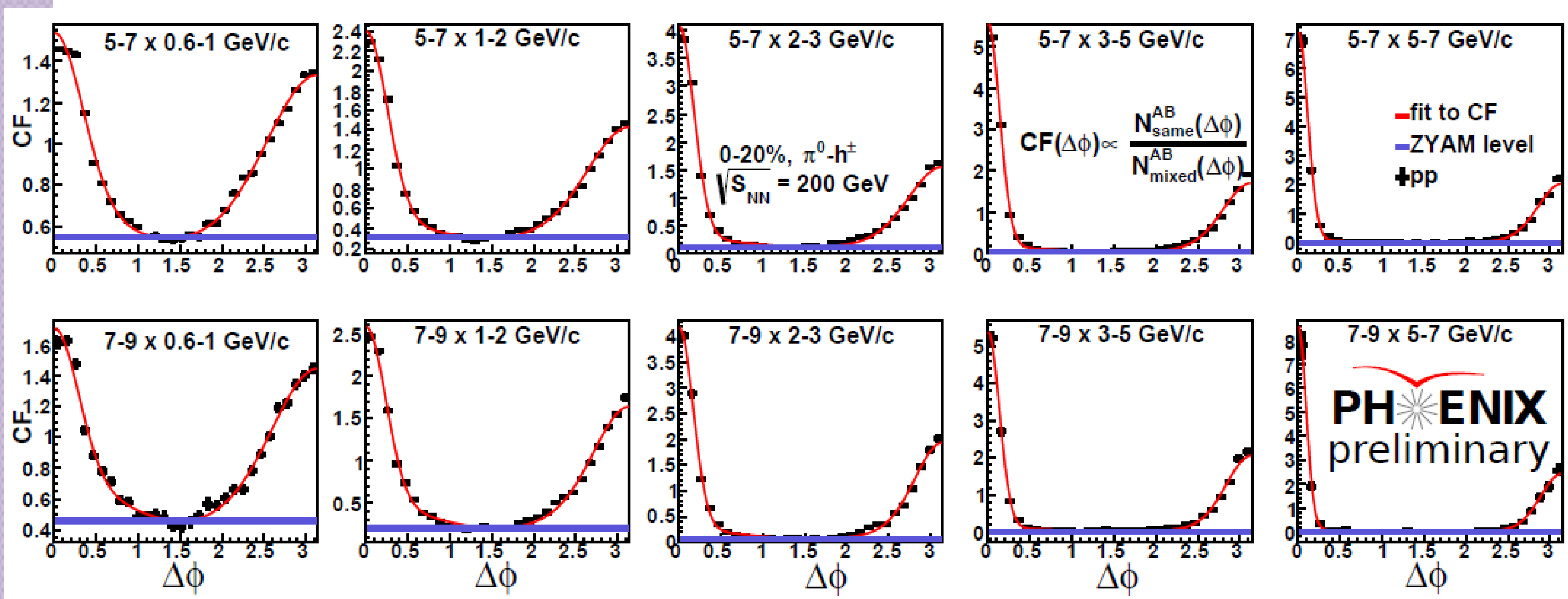
- As in 2008 d+Au Analysis:
- Run14 He3+Au at $\sqrt{s_{NN}} = 200$ GeV
- Background level: ZYAM method
- Trigger bins: [5-7, 7-9] GeV/c
- Partner bins:[ 0.6-1, 1-2, 3-5, 5-7] GeV/c

Abinash Pun: Recent Dissertation



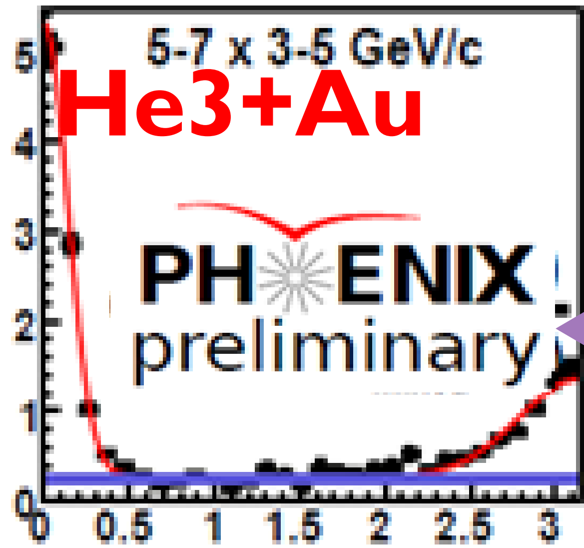
# Correlation Functions

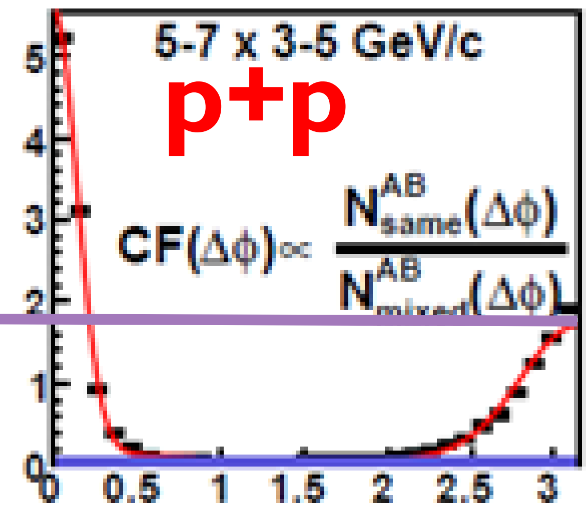
- As in 2008 d+Au Analysis:
- Run15 p+p at $\sqrt{s_{NN}} = 200$ GeV
- Background level: ZYAM method
- Trigger($\pi^0$) bins: [5-7, 7-9] GeV/c
- Partner($h^{\pm}$) bins:[ 0.6-1, 1-2, 3-5, 5-7] GeV/c
- Excellent p+p statistics for comparison in Run8 d+Au



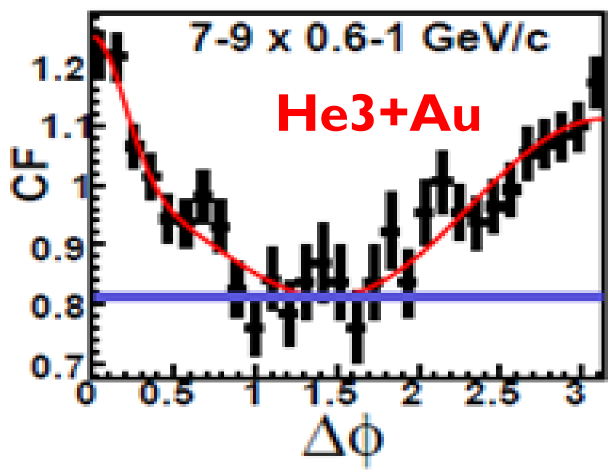
# Similar Modifications in HeAu?

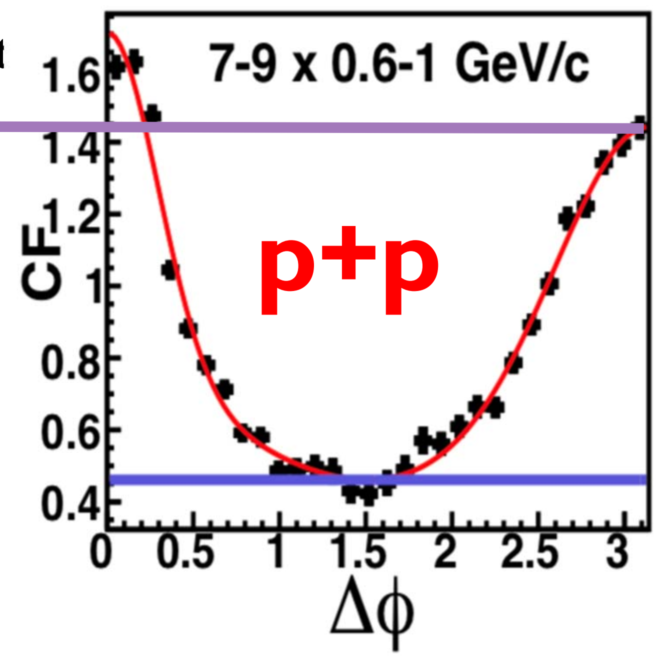
**By eye can see suppression in the AS Shape**



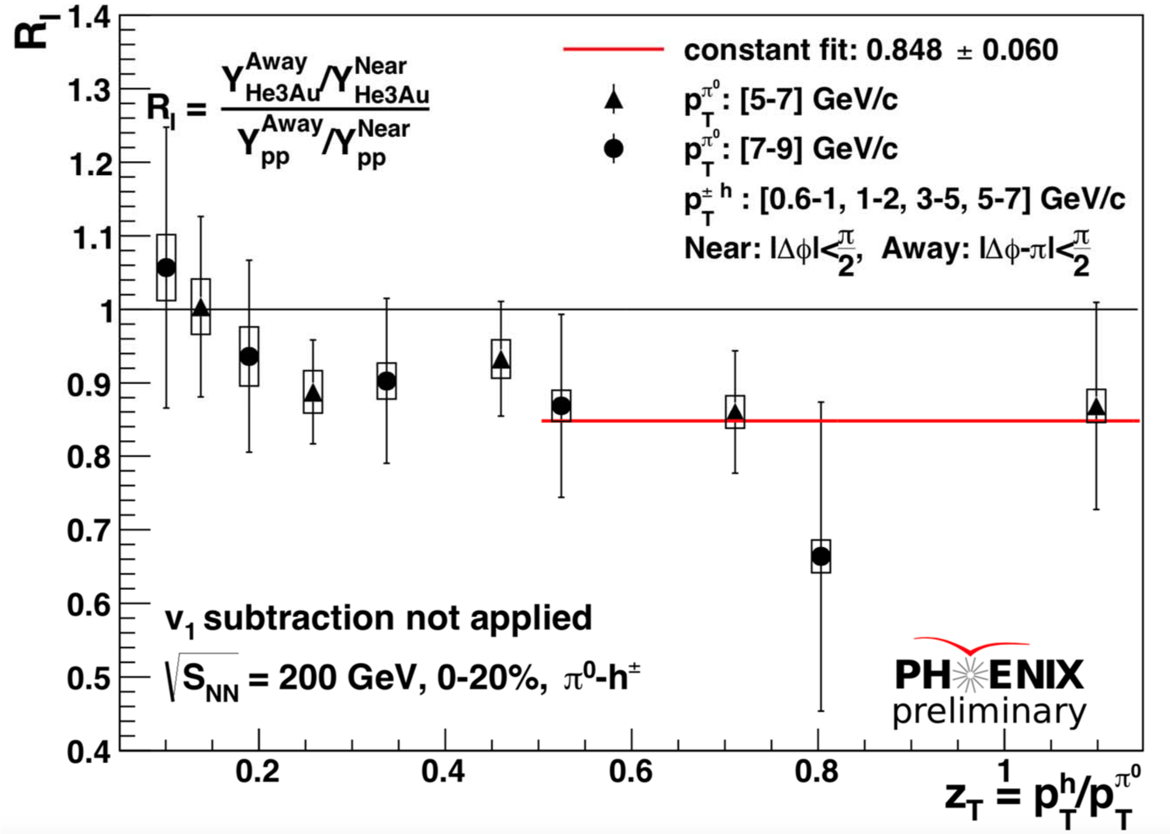




**At low z statistical precision of He+Au is limit**



# RI: He3+Au




- Significant Suppression at high $z_T$ in He3+Au
- Shape similar to d+Au, w/rise at low z, although unlike d+Au, uncertainties too large to confirm low z shape with significance

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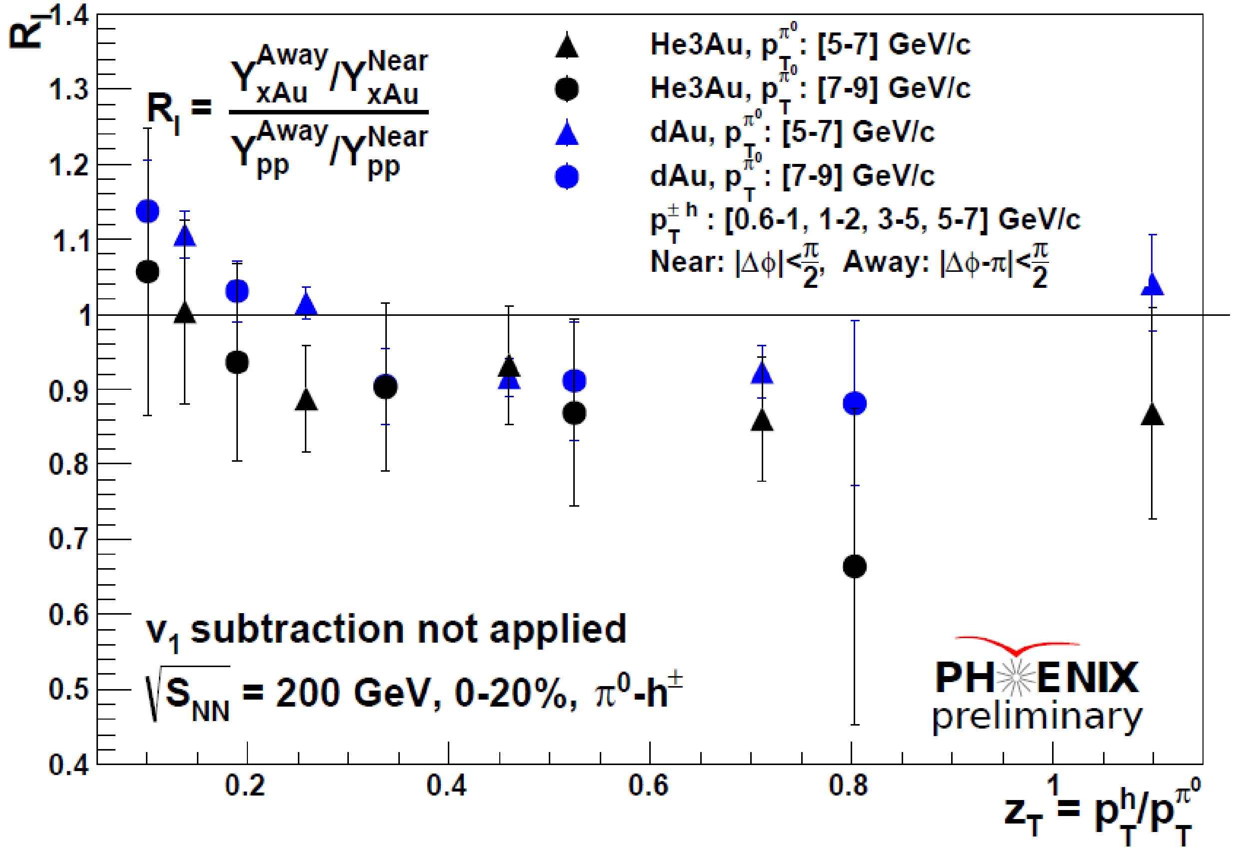
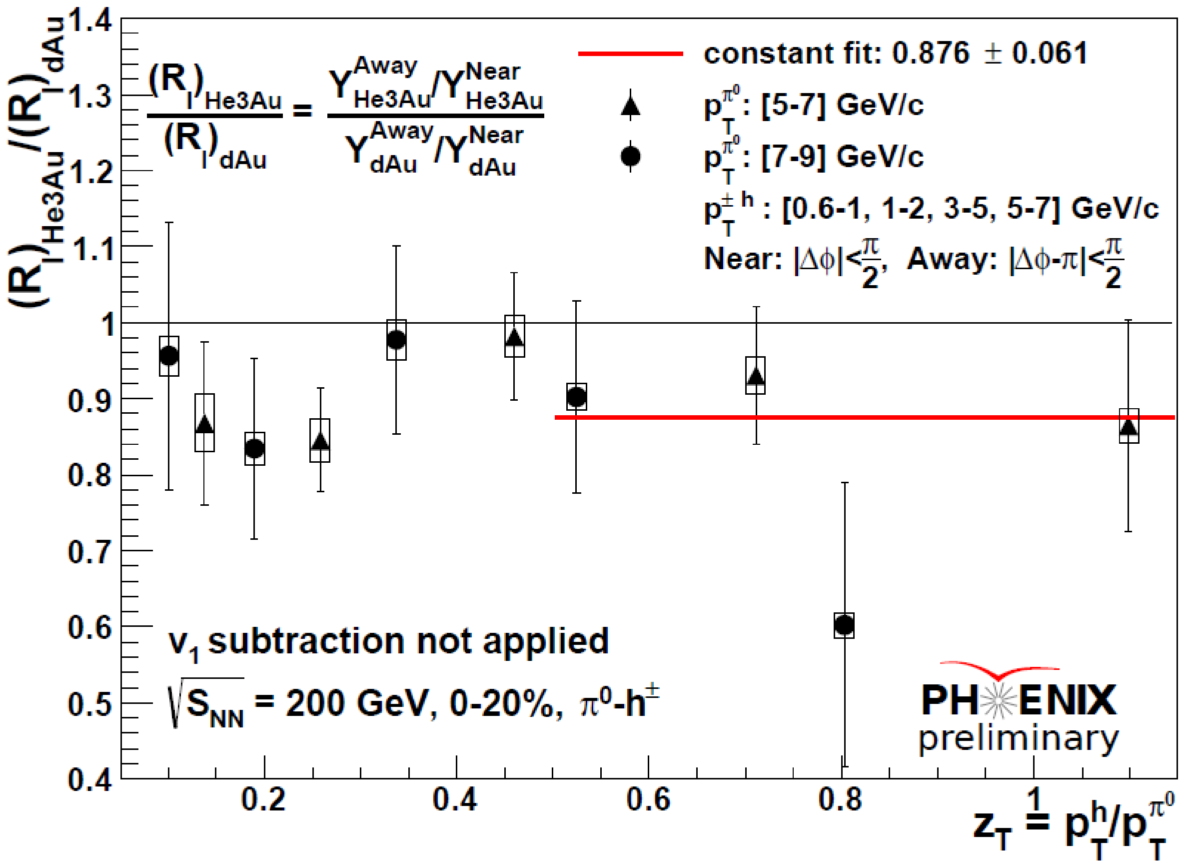
# Comparison of He3+Au and d+Au RI




- He+Au confirms behavior of d+Au: similar shape overall, and suppression at high $z_T$
- **How statistically significant is the suppression level?**

# Ratio of RI's of He3+Au to that of d+Au



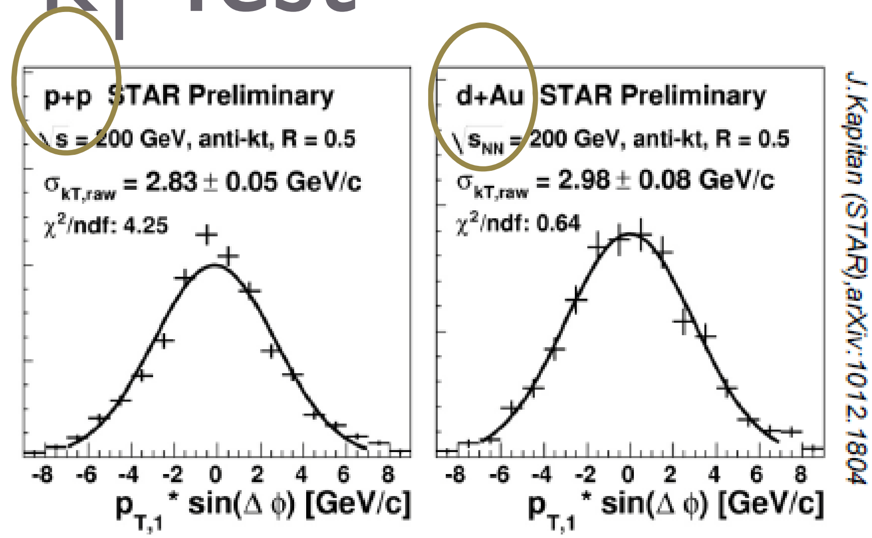

- High $z_T$ suppression in He+Au is about 12% larger than d+Au with at least 2-sigma significance.

# "Trivial" Causes?

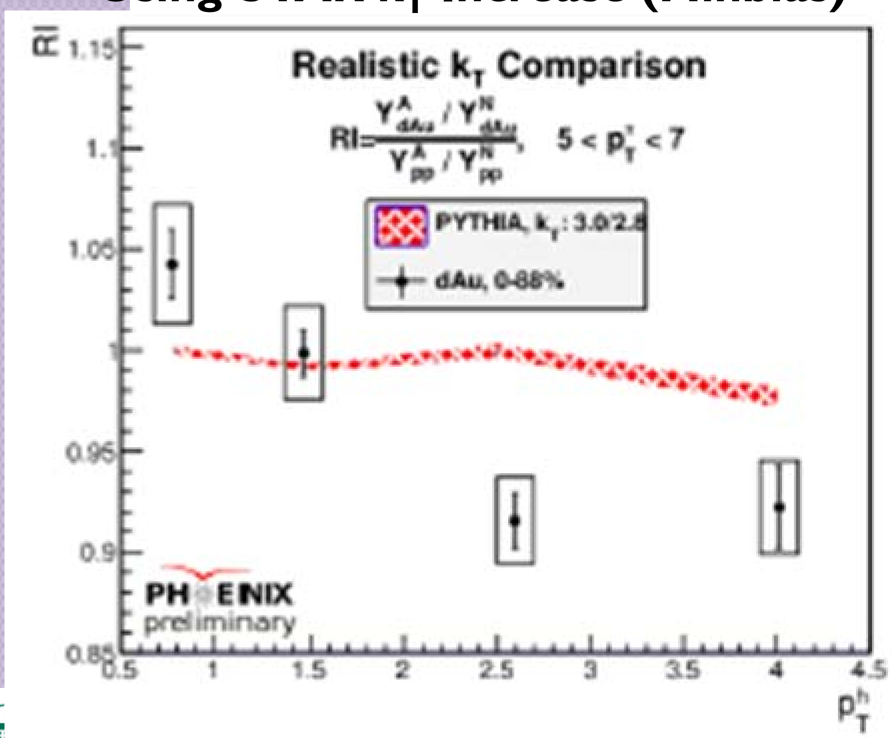
- Strategy: address all "trivial" explanations we can test:
- "Hydro" v3, v1 Jet S/B STILL TOO HIGH- NEGLIGIBLE
- ~~Enhanced Nuclear~~ $k_T$
- ~~Initial State nPDF~~ effects
- Trivial Rapidity Distributions Mismatching p+p vs d+Au?
- HIJING show anything like this?
- If none of above → INTERESTING
  - Looking for other ideas?

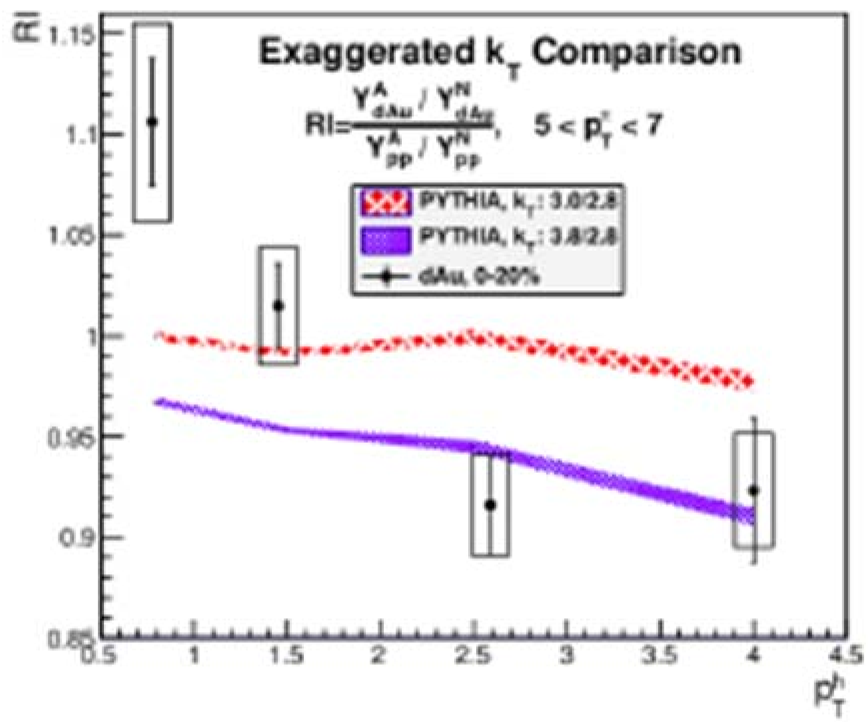
# OLD PYTHIA6 Nucl $k_T$ Test

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



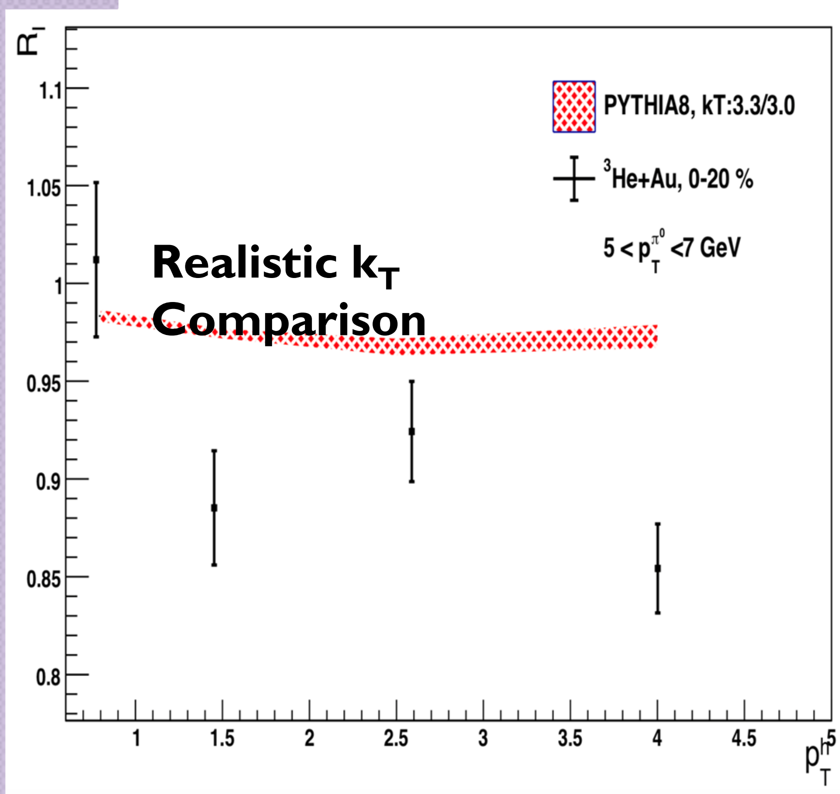

**Using STAR $k_T$ Increase (Minbias)**

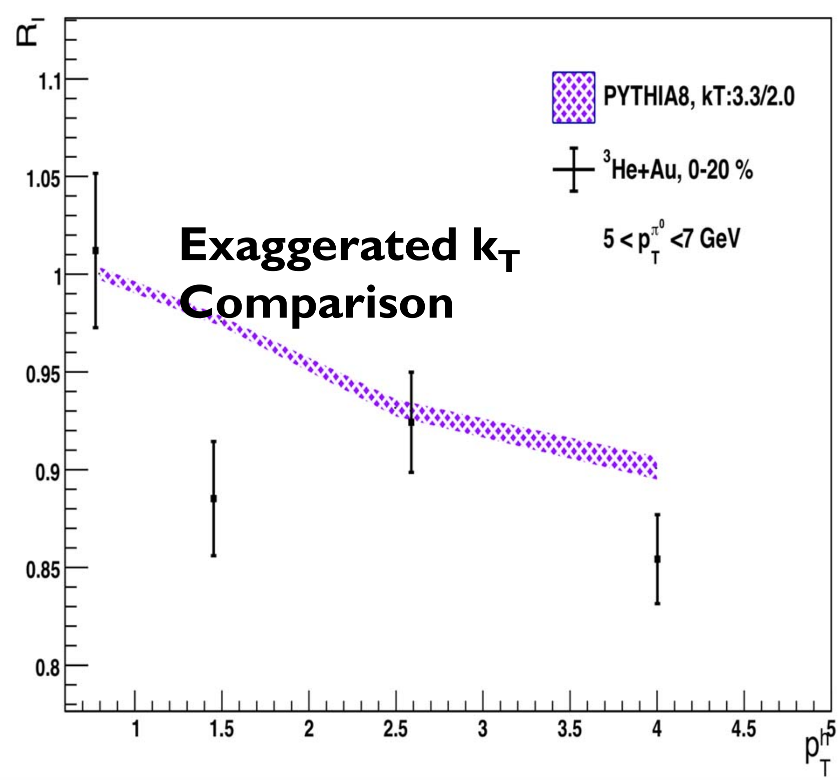


# UPDATED PYTHIA 8
## Nuclear $k_T$ test

- Using $k_T$ constraints from STAR jet measurements → No effect for 0-100% Minbias
- However, $k_T$ smear larger in Central HeAu→ Exaggerated has some shape similarity **but this is very large kT**

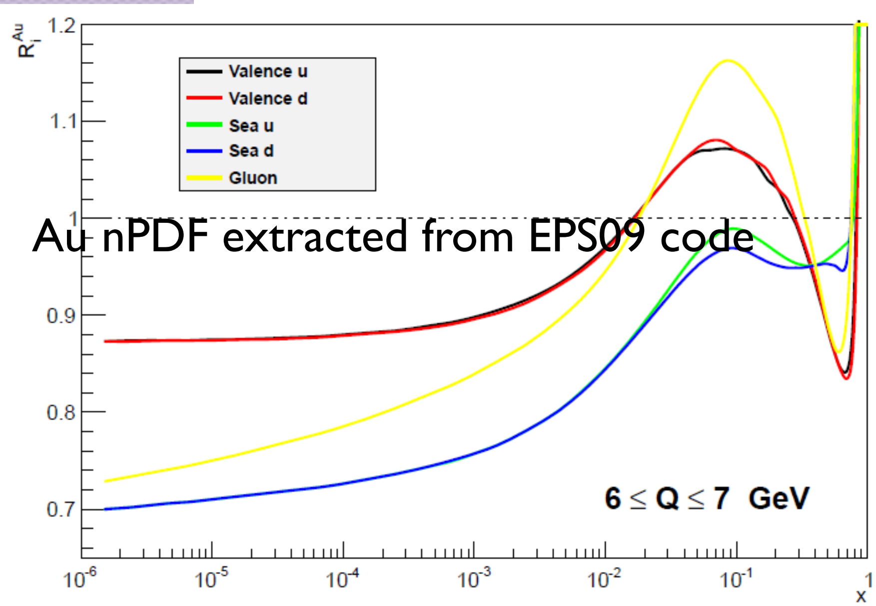


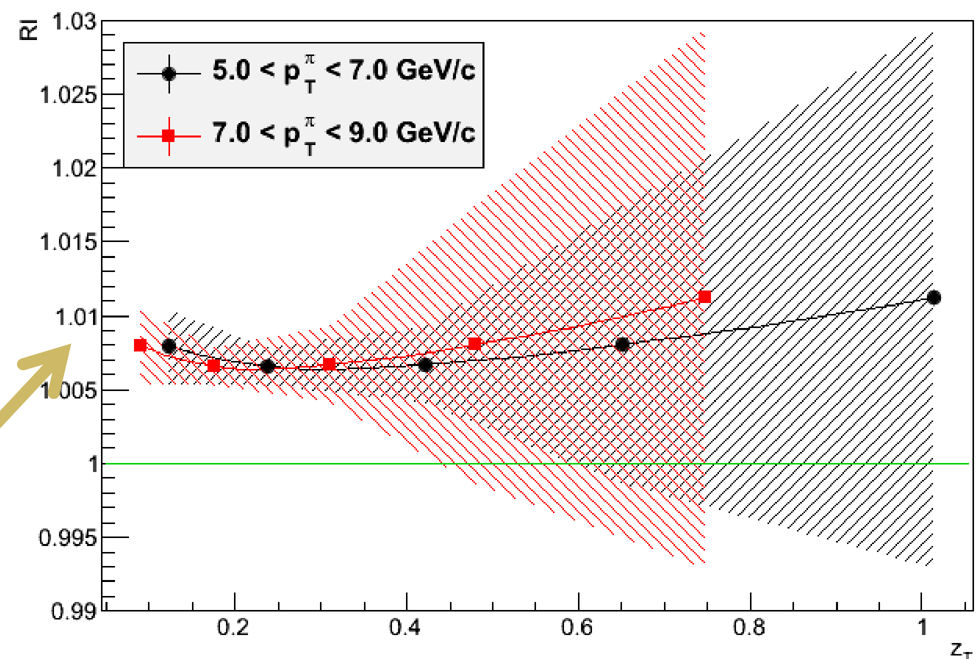
# OLD EPS09 Initial State Nuclear PDF's?

- 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: << 1% negligible effect

RI Extracted from EPS09 Study



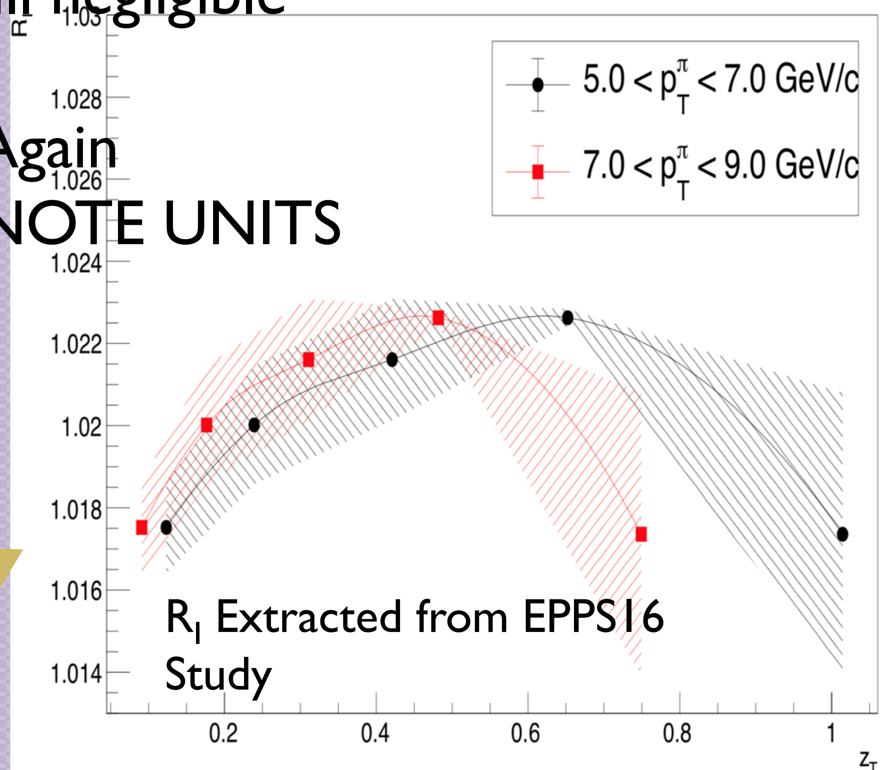

Au nPDF extracted from EPS09 code



# UPDATED EPPS16 & "Real" He+Au nPDF

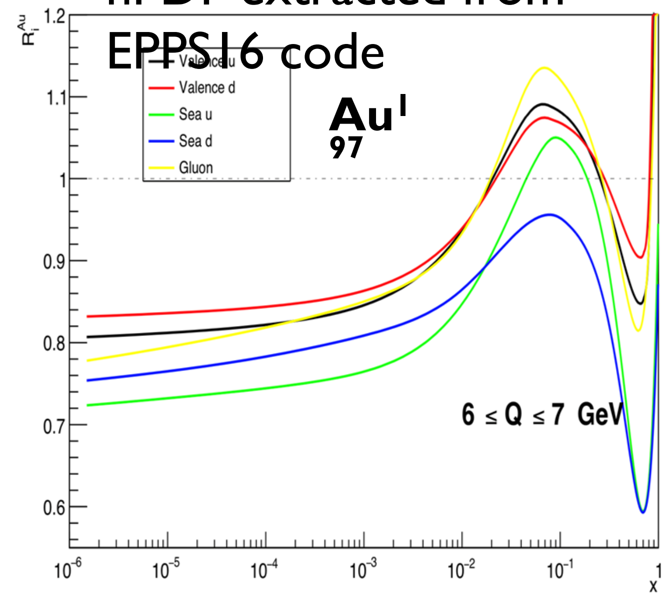
- Previously only p+Au test for scale – He Wave Fn make a difference?
- Studies with EPPS16 and full HeAu
- Still negligible

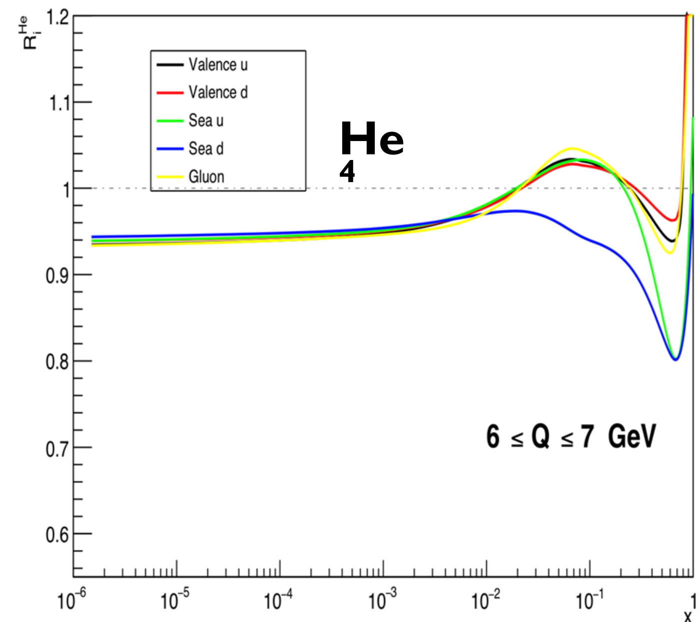
Again
NOTE UNITS




$R_I$ Extracted from EPPS16 Study

nPDF extracted from EPPS16 code



# Conclusion HeAu $I_{AA}$:

- He3+Au shows similar behavior to d+Au: Suppression at high zT and possible rise at low zT
- Ordering of increase in suppression with volume/system size is confirmed
  - HeAu RI is more suppressed than dAu RI in high zT
  - Ratio of HeAu to dAu at high $z_T$ (>0.48) is more than 2 sigma below the unity
- Motivations to theorists to determine possible explanations : whether they be Cold Nuclear to evaluate the likeliness whether could they also be consistent with Hot QGP Eloss?

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# Implication: Causes?

**Results are pretty well tested and confirmed in He+Au – Need Theory Input—Important Question!**

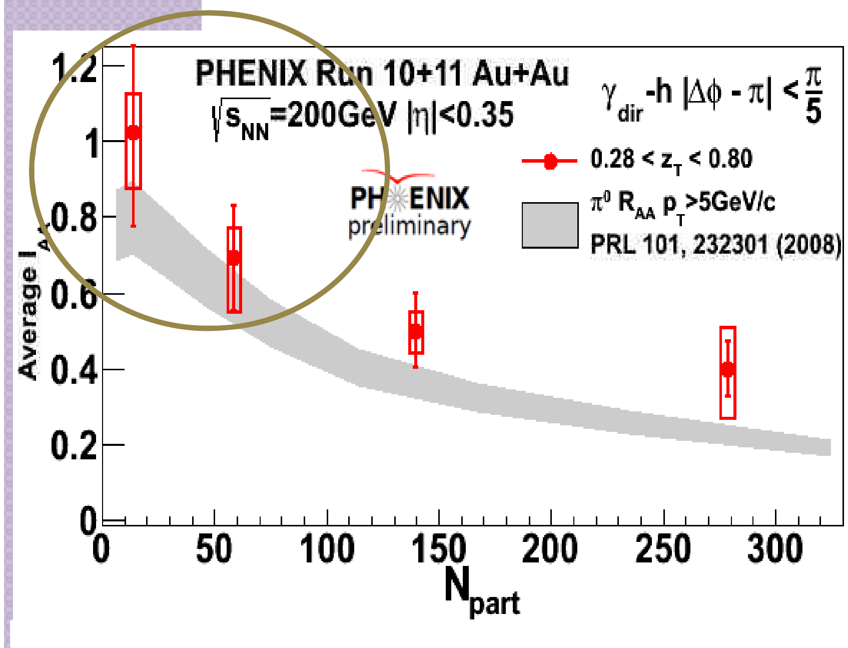
- Many potential Trivial or Cold Nuclear Explanations—but also shares qualitative features of Eloss
- "Trivial" explanations we could test:
  - ✓ "Hydro" v3, v1
  - ✓ Trivial Rapidity Distributions Mismatching p+p vs d+Au?
  - ✓ HIJING show anything like this?

None of these could reproduce the effect

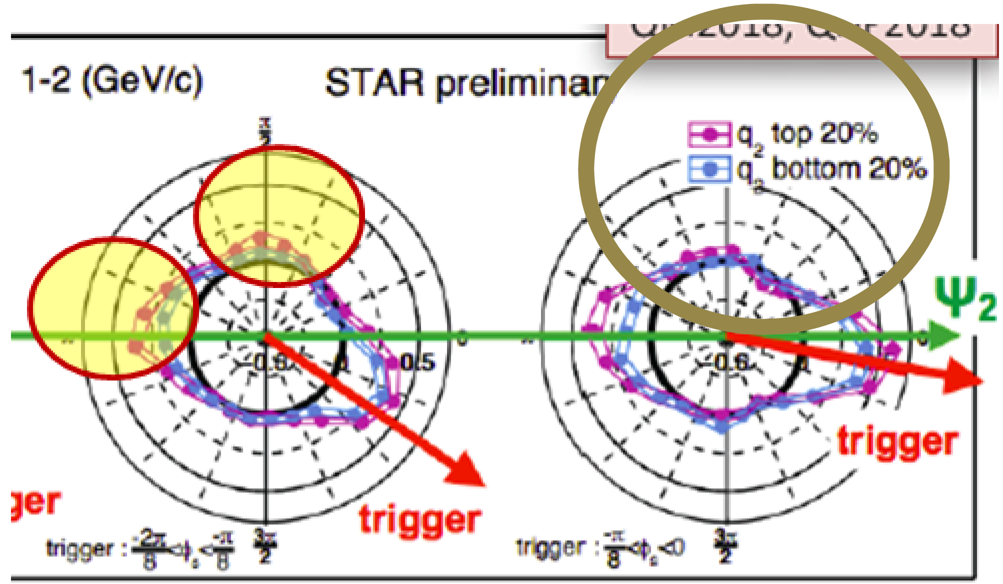
- "Cold Nuclear Effects":
  - ✓ Enhanced Nuclear $k_T$
  - ✓ Initial State nPDF effects (partial—EPS09(s) only checked)
  - Check other npdf's?
  - Get bonafide theory calcs from theorists (need input from theorists)
- Could QGP/Hot Eloss Cause This?
  - Get bonafide theory calcs from theorists (need input from theorists)

# Final Note Centrality Dep: **Event Engineering needed** in "turn on region"

- Something that Jet Reco will have a harder time doing than 2PC




STAR EVENT PLANE RESULT WAS ALSO EVENT ENGINEERED!

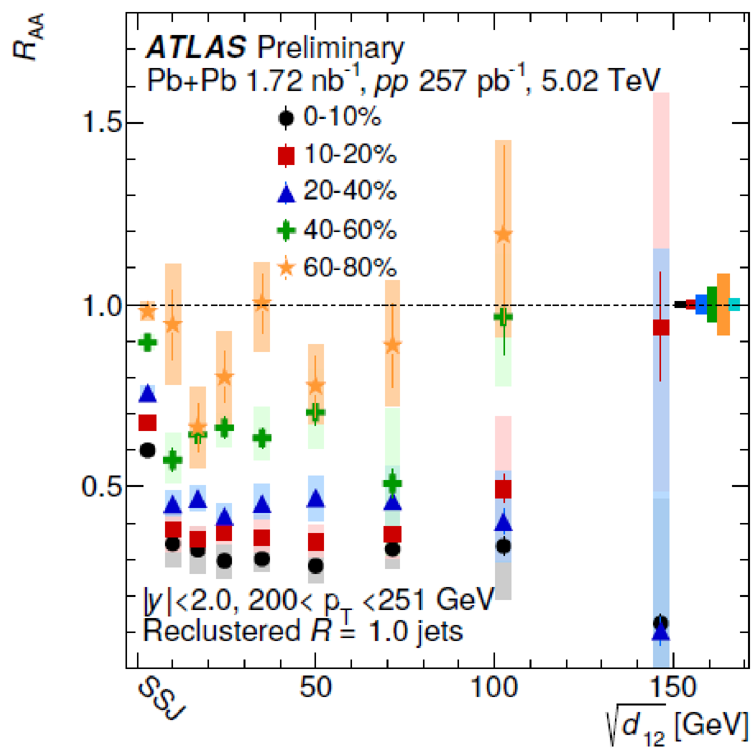


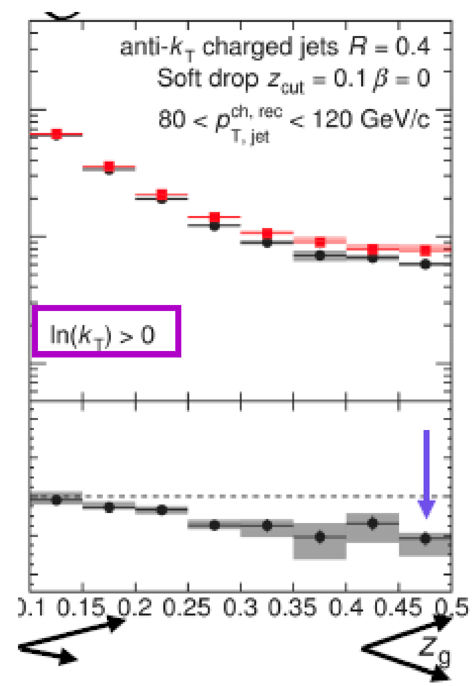

- For these small multiplicity, event fluctuations need controlled

# What about shower dependence of Eloss?

- Obviously this is one thing 2PC can't access
- However sophistocated MC tools like Jetscape can let us now assess sensitivity

Effects aren't huge so far? Should be studied for 2PC



# Conclusions

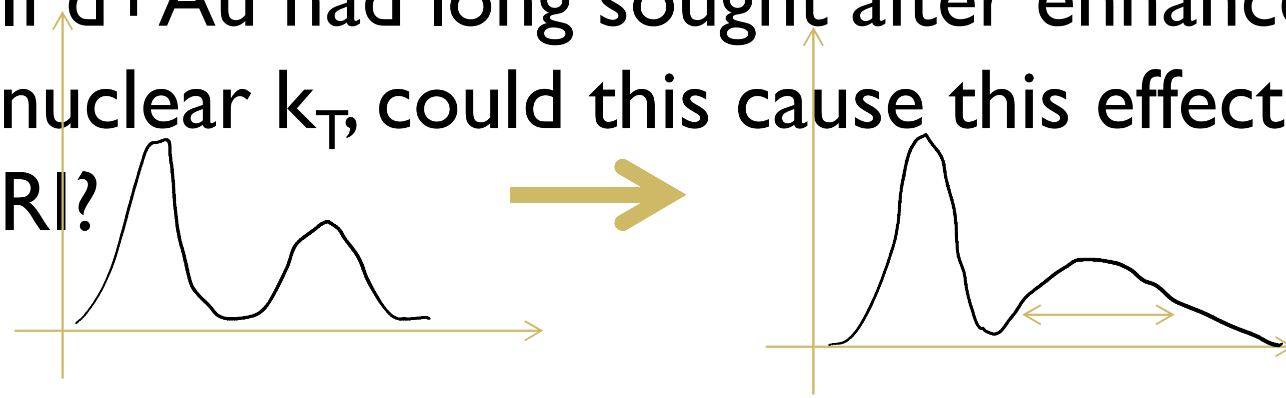
- Good progress being made in Jet-related 2PC at RHIC
- Still plenty of space that is complementary to reconstructed jet results and new jet observables
- $\gamma$-h : e.g. Studying Eloss E-flow at Large Angle/Smallest Jet E (Large Systems)
- Event Plane Dependent h-h: allows new tools such as event plane engineering
- h-jet, $\gamma$-jet, charm-h….
- Especially promising for sorting out Eloss and competing effects in Small Systems
  - He+Au RI result confirms d+Au Suppression/Enhancement – **need theory input!!! especially hot Eloss in Small System**

# BACKUP

- BACKUP

# Enhanced Nuclear $k_T$ ?

- kT == Acoplanarity of di-jets
- Smears Awayside → 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?



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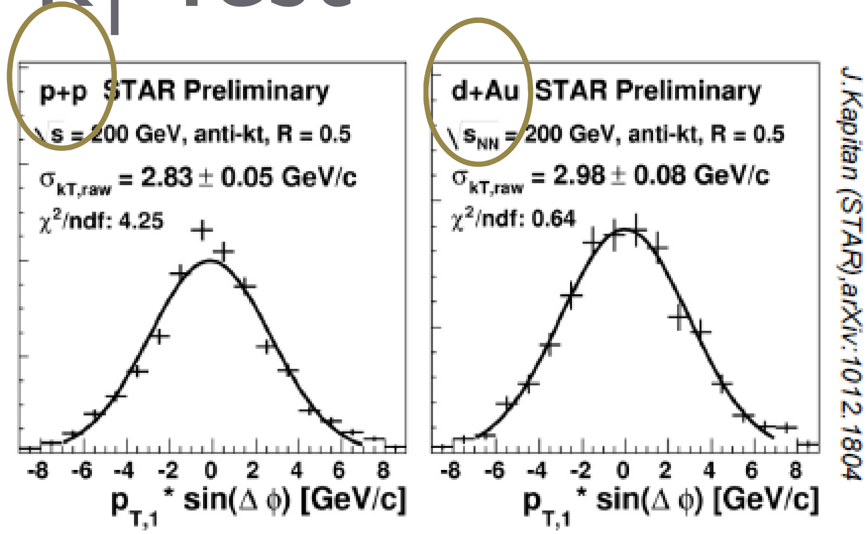


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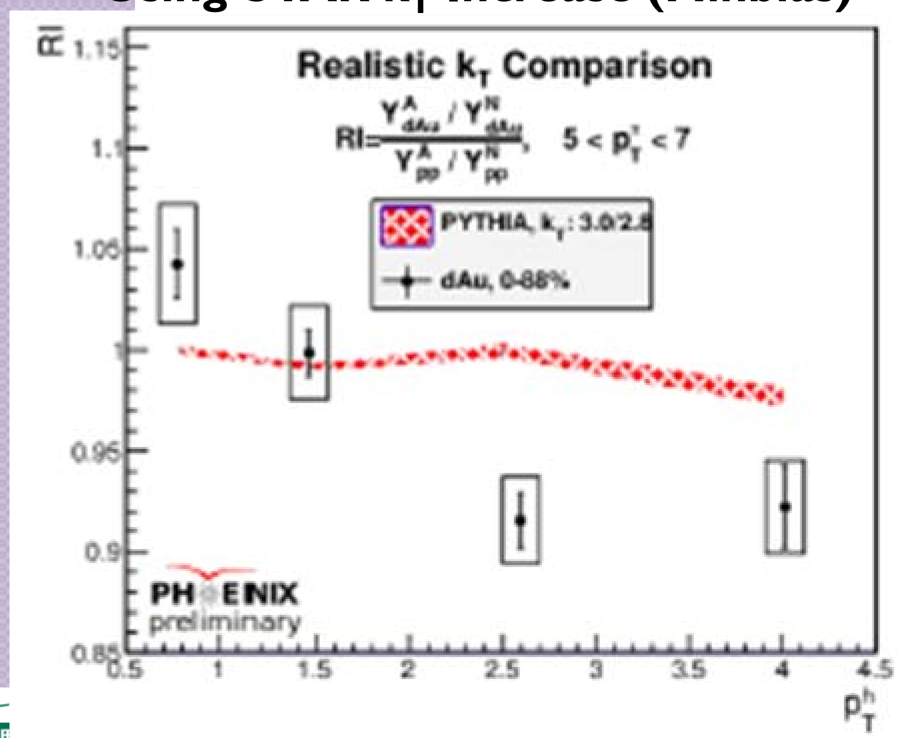
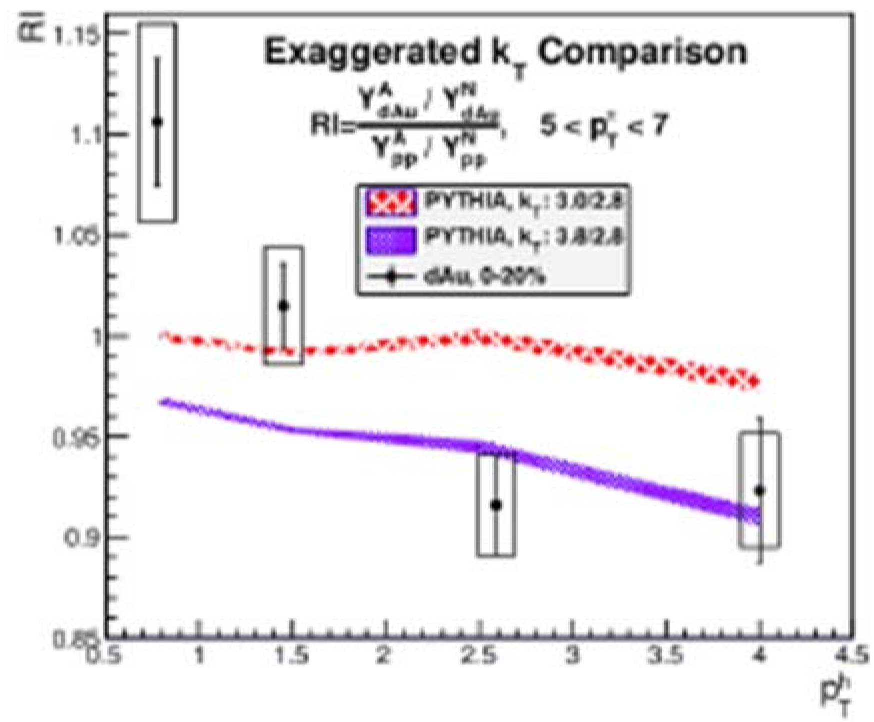
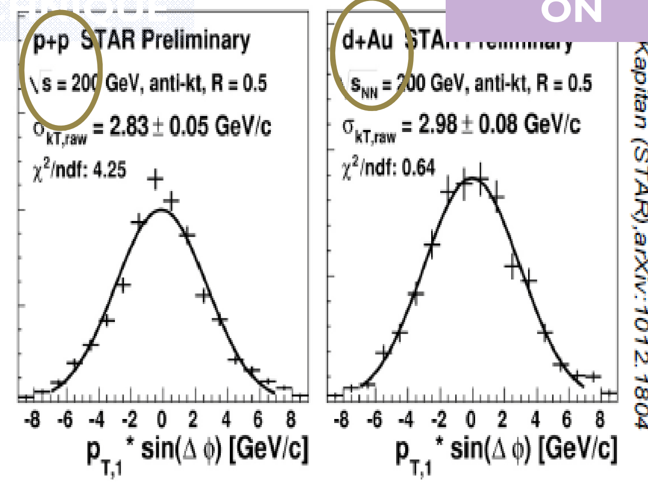


# UPDATED PYTHIA 8 Nuclear $k_T$ test

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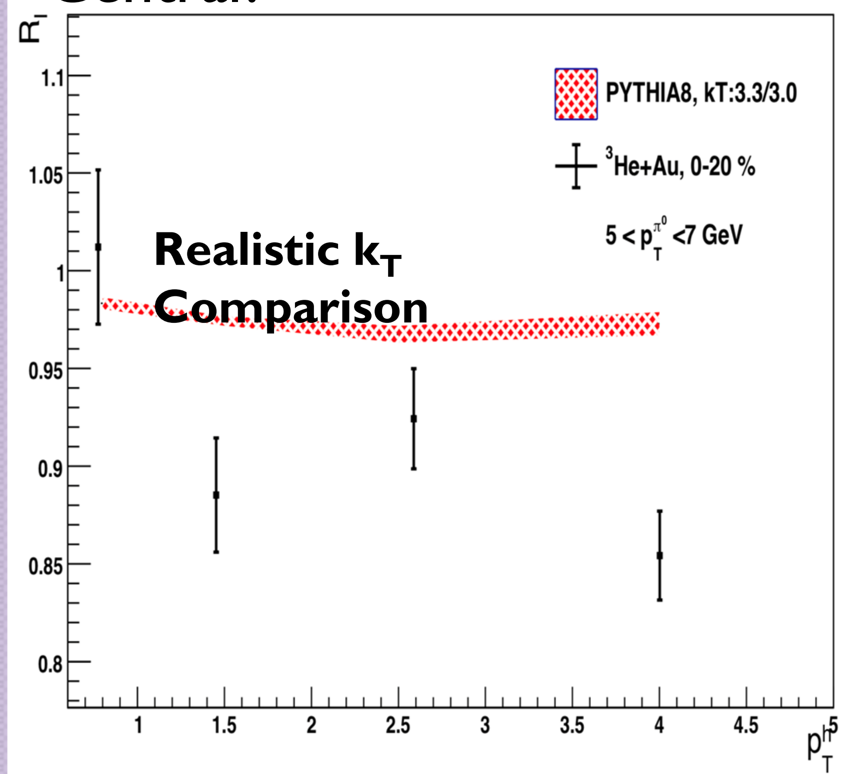


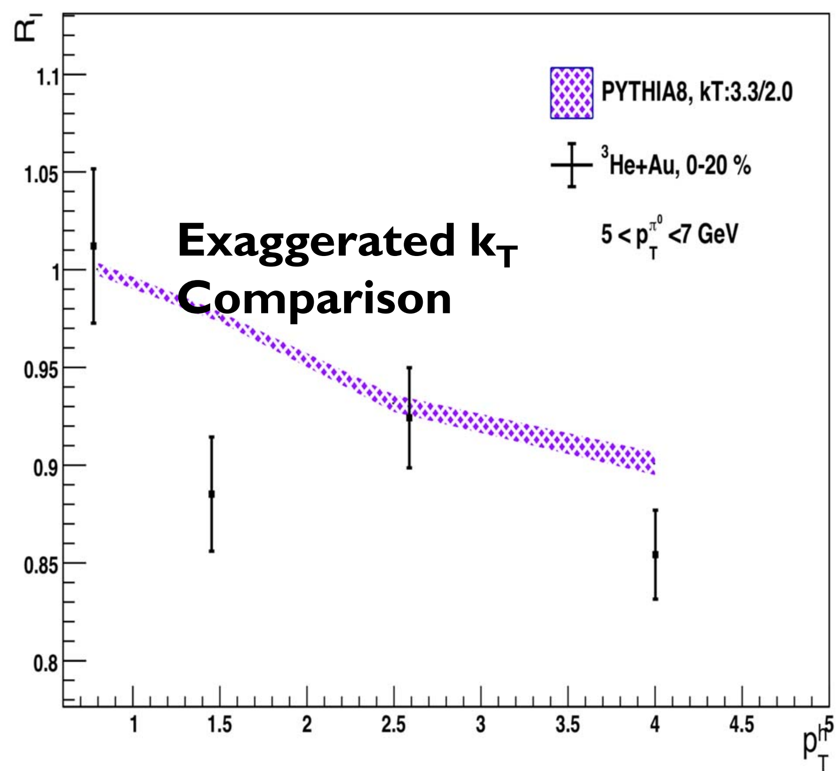

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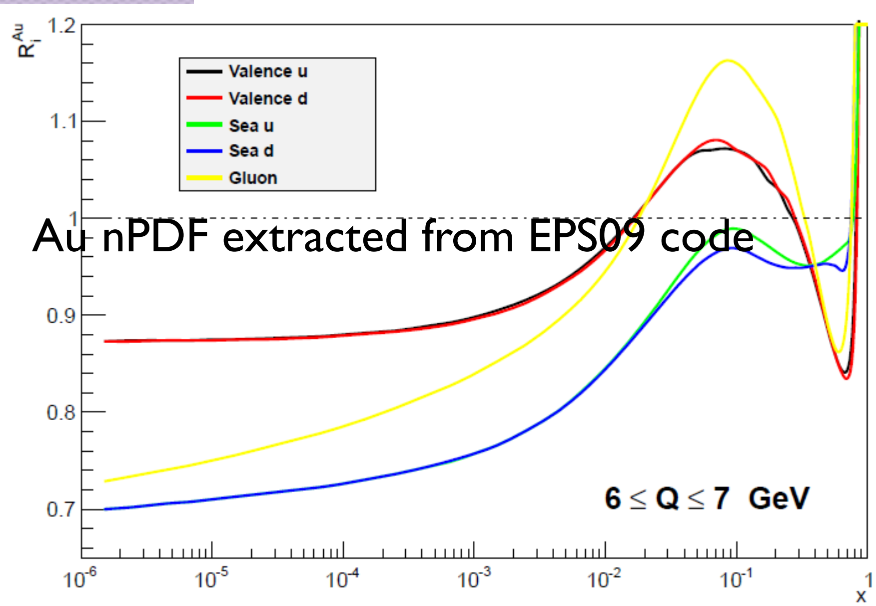


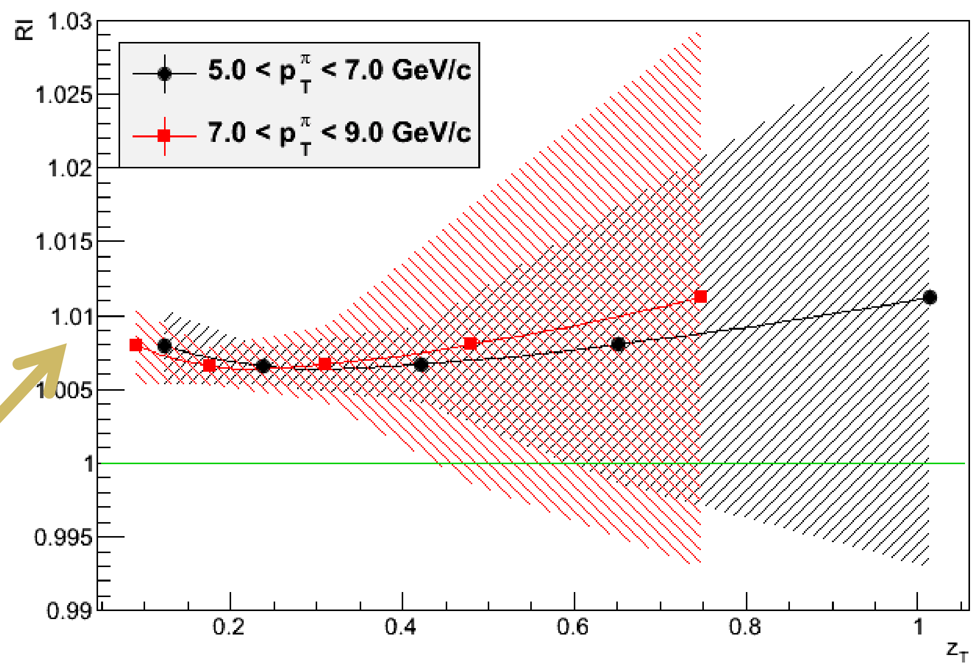

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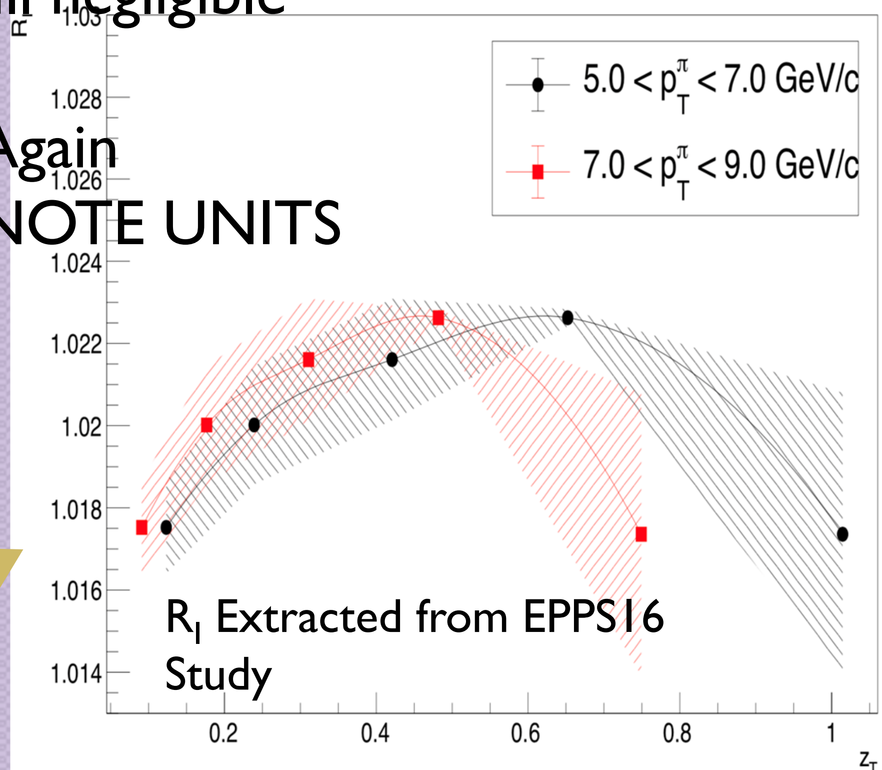
Again
NOTE UNITS

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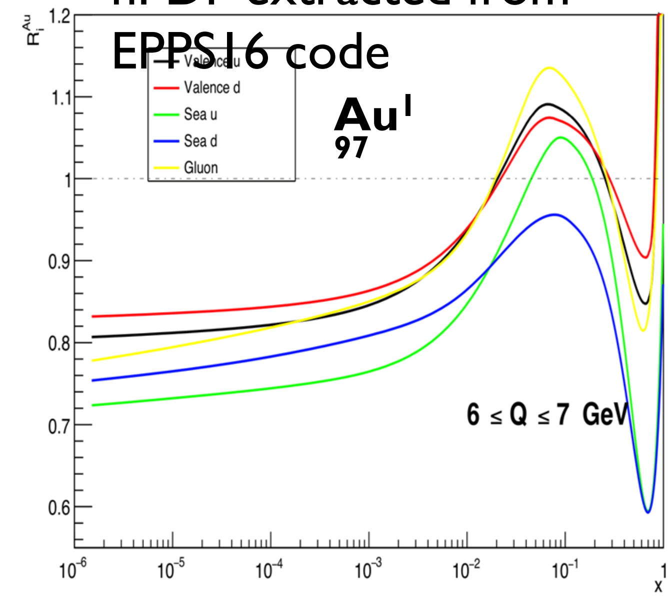


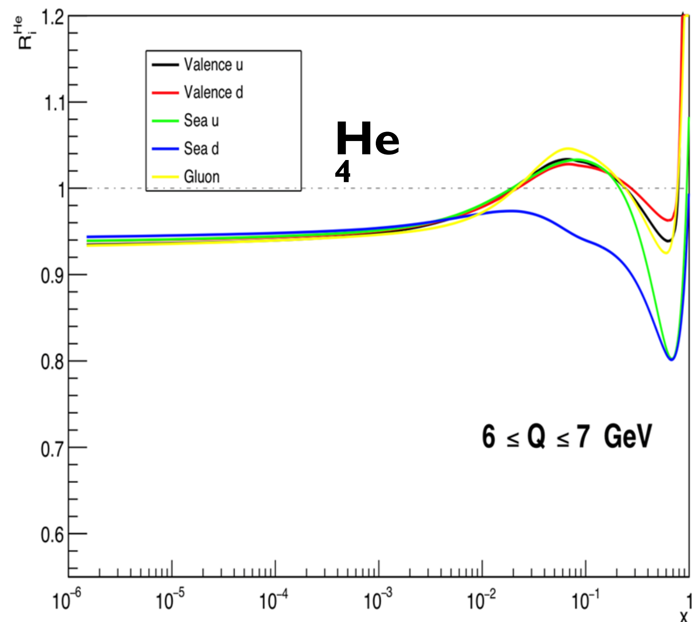

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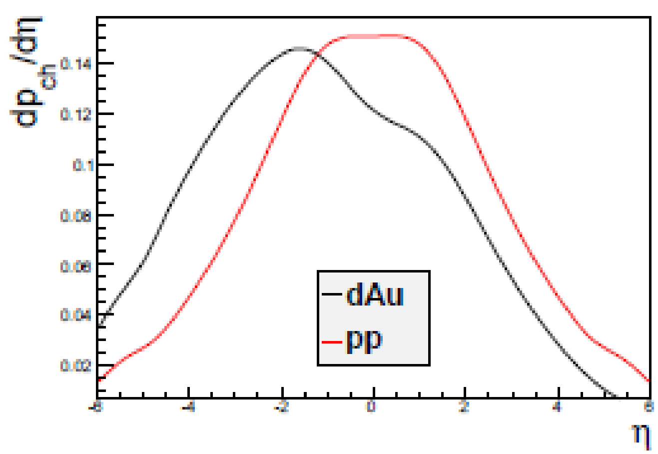
- Initial State nPDF effects
- Trivial Rapidity Distributions Mismatching p+p vs d+Au?
- HIJING show anything like this?

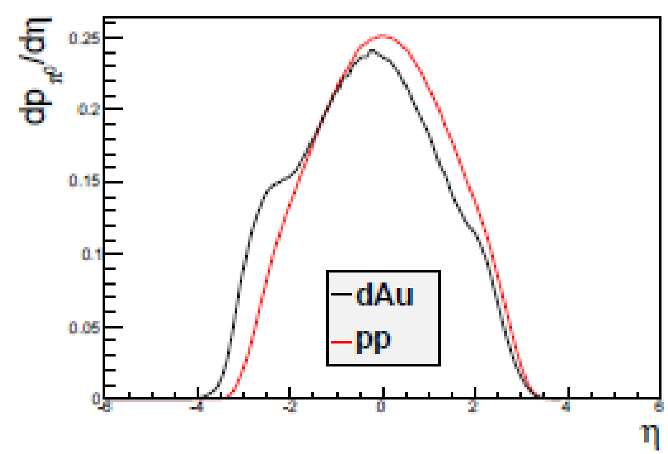
- If none of above → INTERESTING
  - Looking for other ideas?

# 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"




(a) Charged hadrons in central HIJING

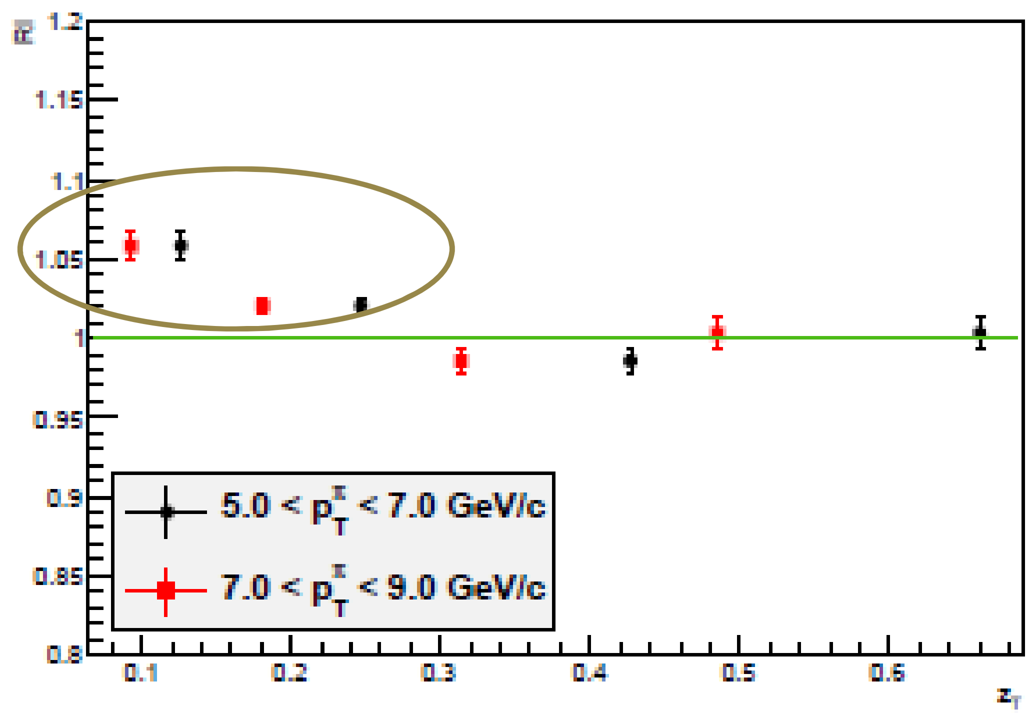



(b) $\pi^0$ triggers in central HIJING

# HIJING RI

- With default settings, HIJING does not reproduce the effect
- Small enhancement at low $z_T$ appears to be c… con…

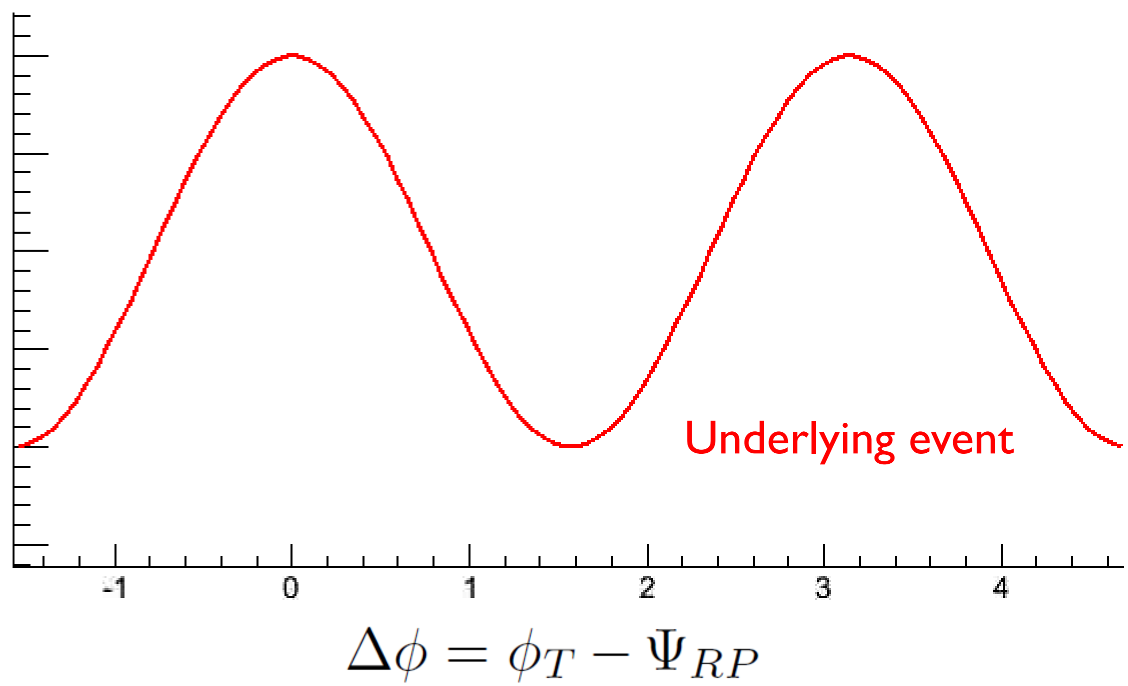
$RI$ from HIJING simulation with $k_T = 0.44$ GeV/$c$.



# Tyler’s Back up

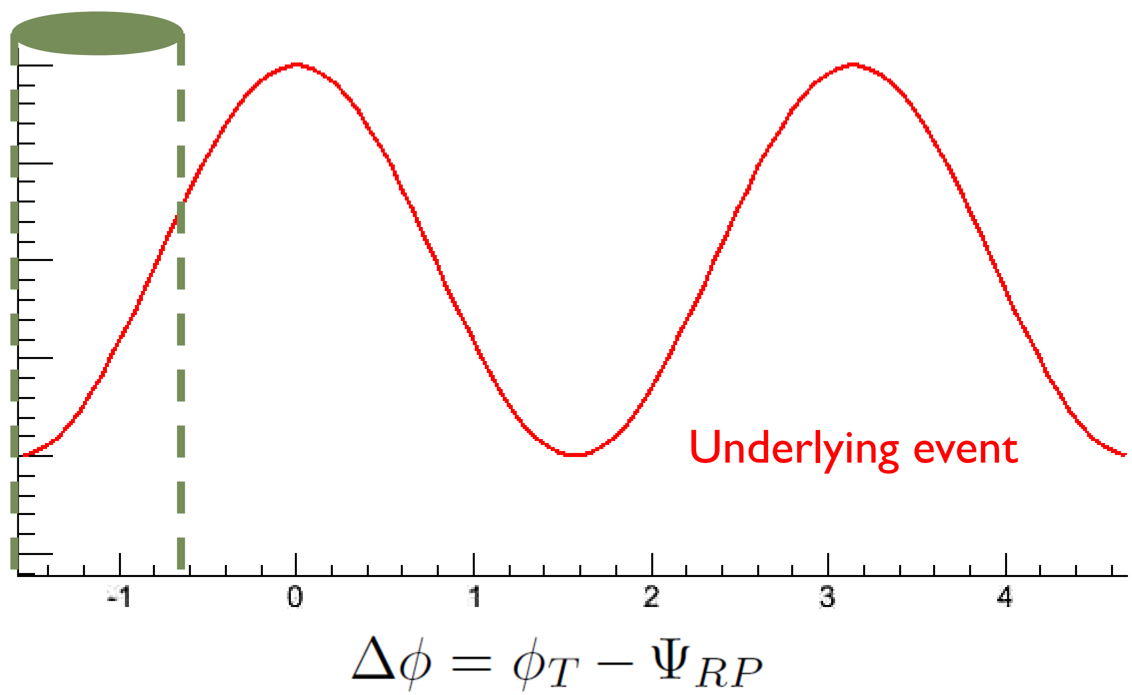
# Illustration of $v_2$ Measurement With Isolation Cone

- Underlying event shape



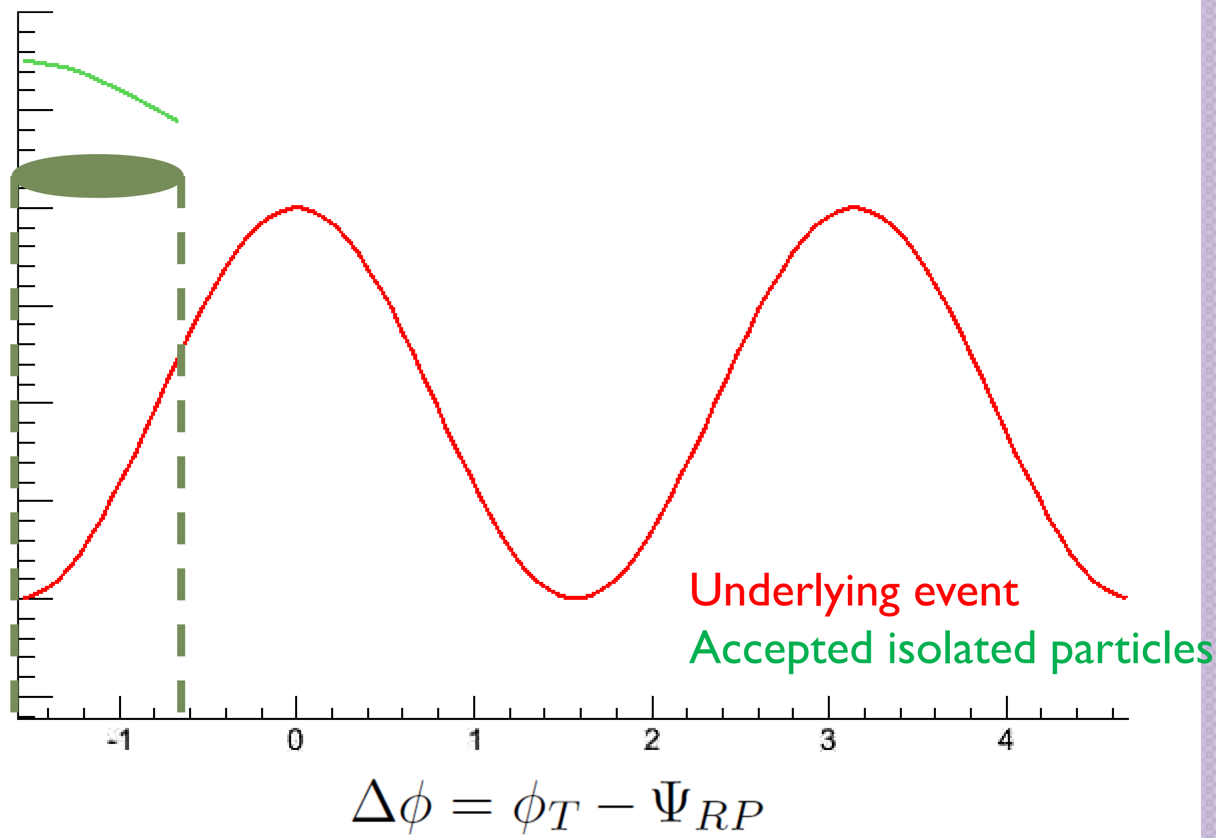
# Illustration of $v_2$ Measurement With Isolation Cone

- Underlying event shape
- Isolation cone



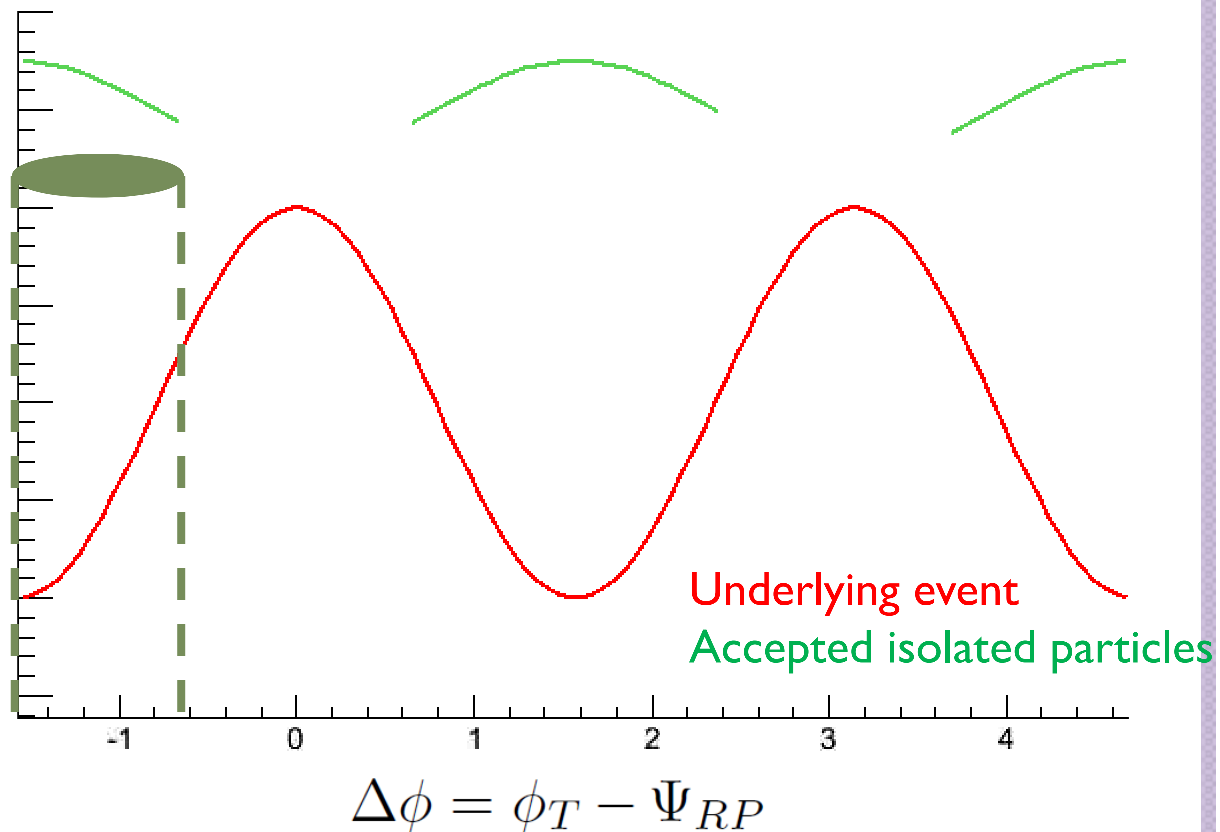
# Illustration of $v_2$ Measurement With Isolation Cone

- Underlying event shape
- Isolation cone
- Accept more particles when number of underlying event particles is low



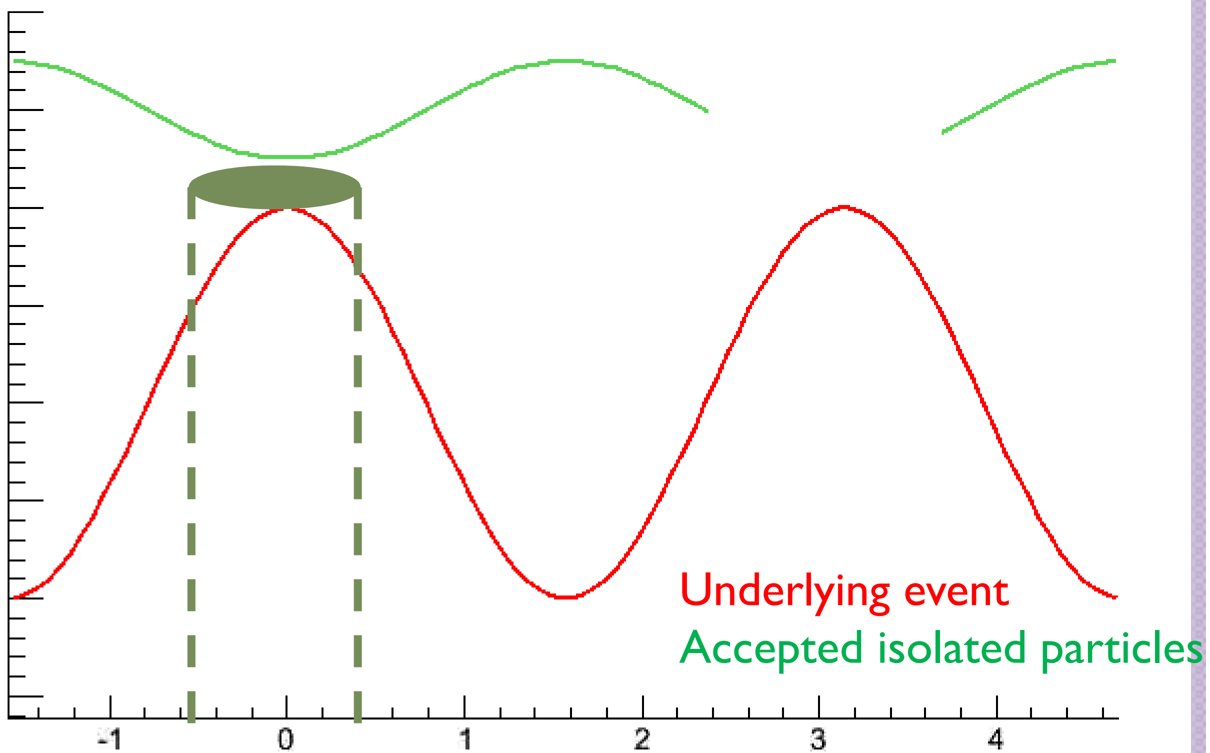
# Illustration of $v_2$ Measurement With Isolation Cone

- Underlying event shape
- Isolation cone
- Accept more particles when number of underlying event particles is low (out of event plane)



# Illustration of $v_2$ Measurement With Isolation Cone

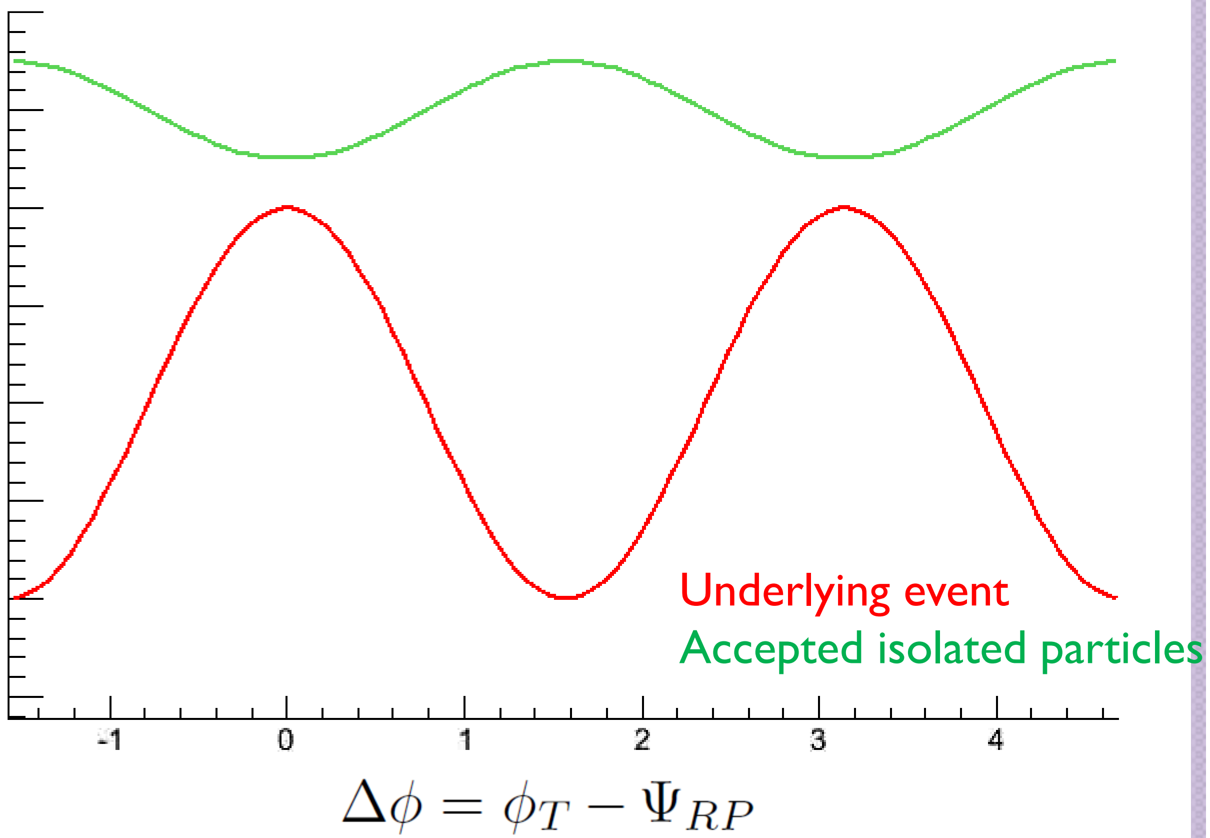
- Underlying event shape
- Isolation cone
- Accept less particles when number of underlying event particles is high




$$\Delta\phi = \phi_T - \Psi_{RP}$$

# Illustration of $v_2$ Measurement With Isolation Cone

- Underlying event shape
- Isolation cone
- Accept less particles when number of underlying event particles is high (in event plane)
- Must correct for this bias.



# Complications of $v_2$ Measurement with Isolation Cut

- Isolation cut efficiency

$$\epsilon = \epsilon_0\big(1 + 2v_{2E}\cos(2\Delta\phi)\big) \qquad \Delta\phi = \phi_T - \Psi_{RP}$$

- How does it effect the trigger particle's distribution?

$$\frac{dN_{TE}}{d\Delta\phi} = \mathcal{A}(1 + 2\mathcal{B}\cos(2\Delta\phi) + 4\mathcal{C}\cos^2(2\Delta\phi))$$

$$\mathcal{B} = v_{2T} + v_{2E}$$
$$\mathcal{C} = v_{2T}v_{2E}.$$

- How does the event plane resolution effect this distribution?

$$\frac{dN_{STSE}}{d\Delta\phi} = \mathcal{I}\Big(1 + 2\mathcal{J}\cos(2\Delta\phi) + \mathcal{K}\cos^2(2\Delta\phi) - 4\mathcal{L}\cos(4\Delta\phi)\Big)$$

$$\mathcal{J} = (v_{2T} + v_{2E})\langle\cos(2\delta\Psi)\rangle,$$
$$\mathcal{K} = v_{2T}v_{2E}, \quad \text{and}$$
$$\mathcal{L} \propto v_{2T}v_{2E}.$$

- How does it effect the correlation function background distributi

$$\frac{dN_{TA}}{d\Delta\phi} = \mathcal{F}(\mathcal{G} + 2\,\mathcal{H}\;\cos(2\Delta\phi_{TA}))$$

$$\Delta\phi_{TA} = \phi_T - \phi_A$$

$$\mathcal{G} = 1 + 2v_{2T}v_{2E},$$
$$\mathcal{H} = v_{2A}(v_{2T} + v_{2E})$$

- For 2 particle correlations, only need sum $v_{2iso} = v_{2T} + v_{2E}$ which is what is ~directly measured from isolated triggers using 'typical' event plane method
- These equations have been verified using toy MC simulation