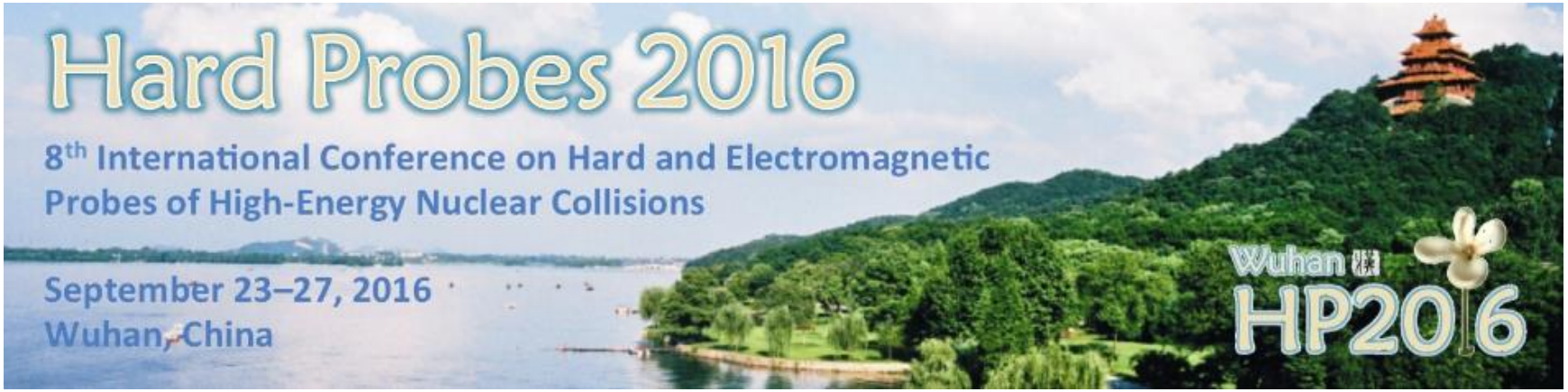
PHENIX results on direct photon-hadron correlations

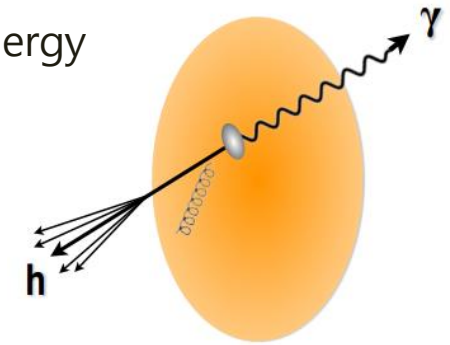
Huijun Ge

for the PHENIX Collaboration



Motivation: why Υ_{direct}-h?

- Υ_{direct}-h correlation measurement
  - No trigger surface bias
  - Trigger photon p_T - most direct measure of the initial parton energy
  - Important complement to other jet measurement
    - Different path length dependence
    - Different relative contribution from quark vs gluon jets

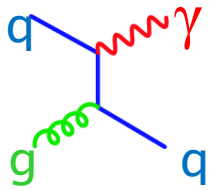


- Measure Υ_{direct}-h in Au+Au
  - Directly measure the modification of recoil jet fragmentation function
  - Important to understand in-medium energy loss mechanism
  - Constrain models in explaining soft particle production

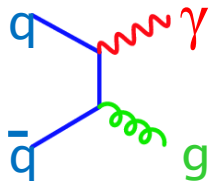
- Measure Υ_{direct}-h in p+p
  - Baseline measurement to compare with HI case

- Measure Υ_{direct}-h in d+Au
  - Probe cold nuclear matter effect
  - Test of initial state energy loss hypothesis

Direct Photon Processes at LO



QCD Compton Scattering



Annihilation

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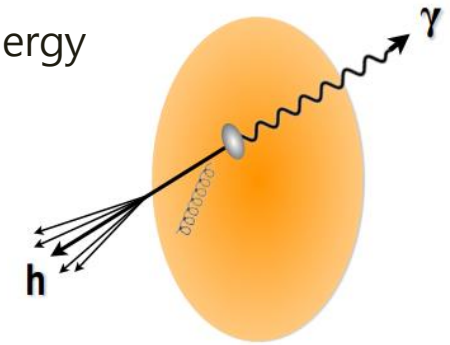

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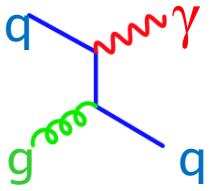

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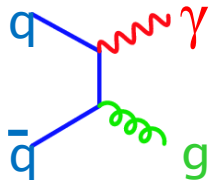
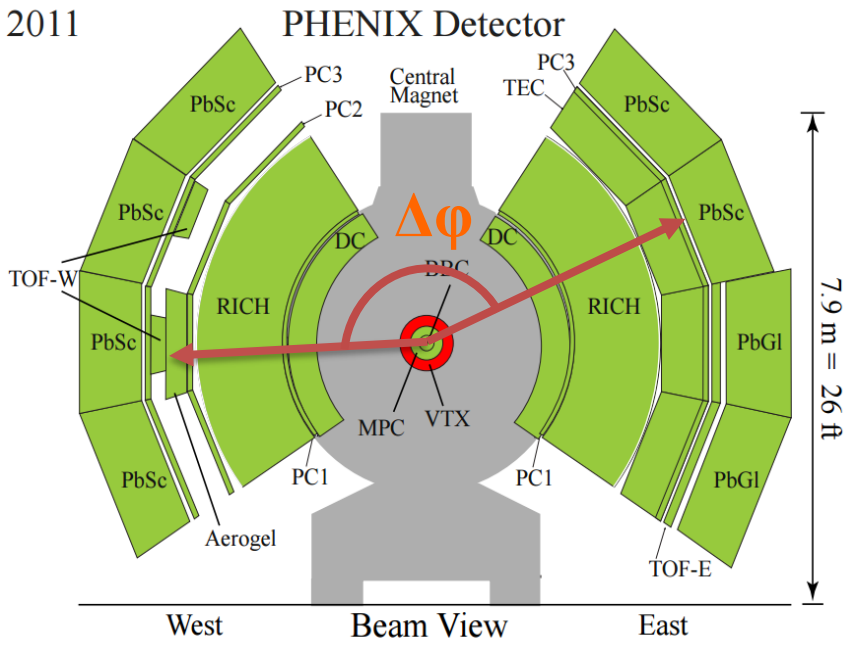
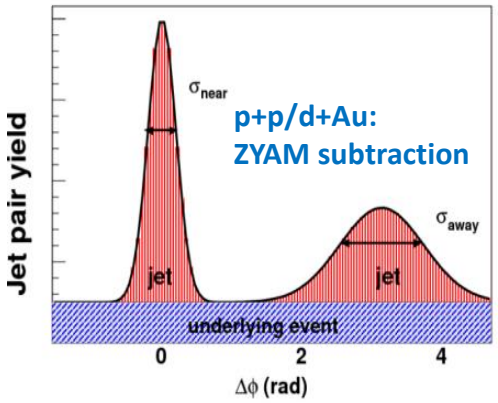
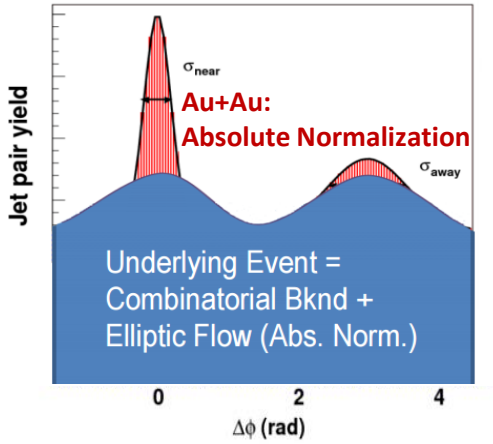


Annihilation

Measuring Υ_{direct}-h in PHENIX







- Central arm acceptance: $|\eta| < 0.35$, $\Delta\varphi$ – 2 x 90˚
- EMCals: measure Υ and π^{0}, merging effect minimal up to ~15 GeV
- Drift Chamber and Pad Chambers: measure $h^{\pm}$.
- Beam-Beam counters: determine collision centrality/vertex position

Event mixing method
- Correct for detector acceptance
- Determine background level

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

$$Y \propto C(\Delta\phi) - \boldsymbol{b}(1 + 2\langle v_2^{\gamma}\rangle\langle v_2^{h}\rangle \cos 2\Delta\phi)$$

Norm **Bkg(Flow)**

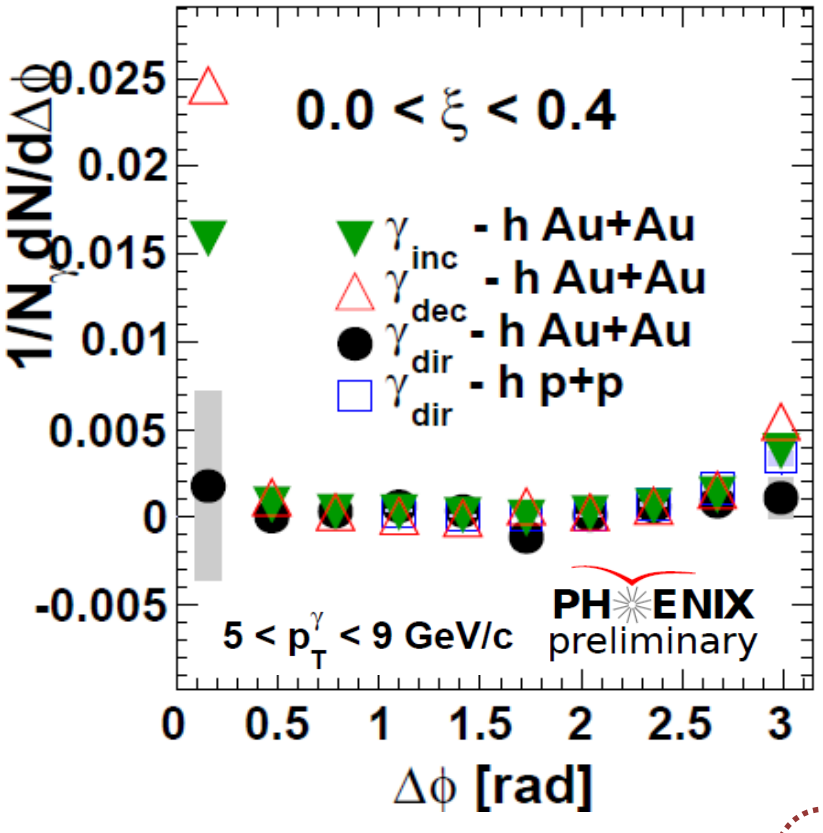
Measuring Υ_{direct}-h in PHENIX

- Background pairs are subtracted for both $Y_{inclusive}$ and Y_{decay}
- Subtract Y_{decay} from $Y_{inclusive}$ to get Y_{direct} using statistical subtraction

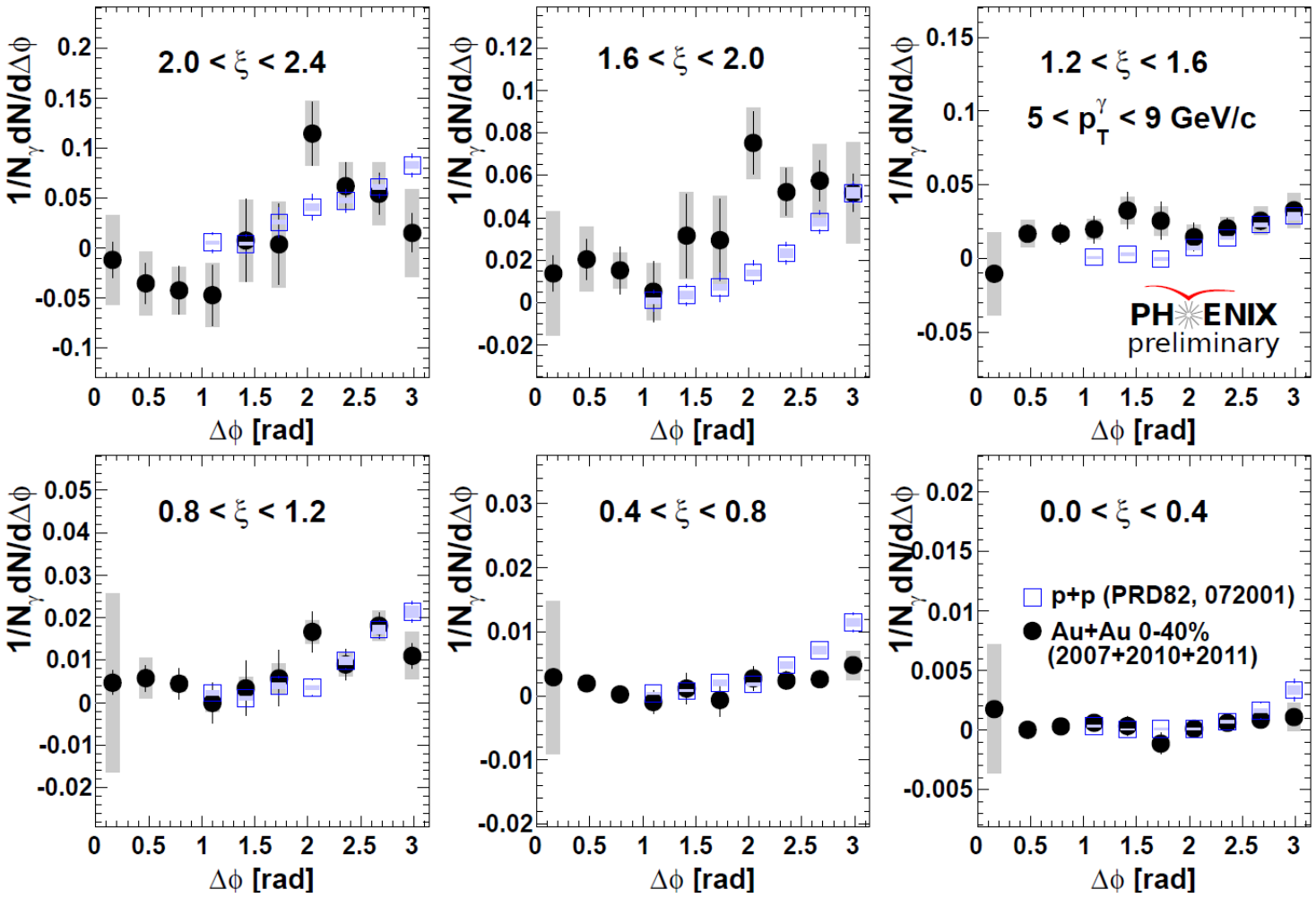
Statistical subtraction

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

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



Measuring Υ_{direct}-h in Au+Au



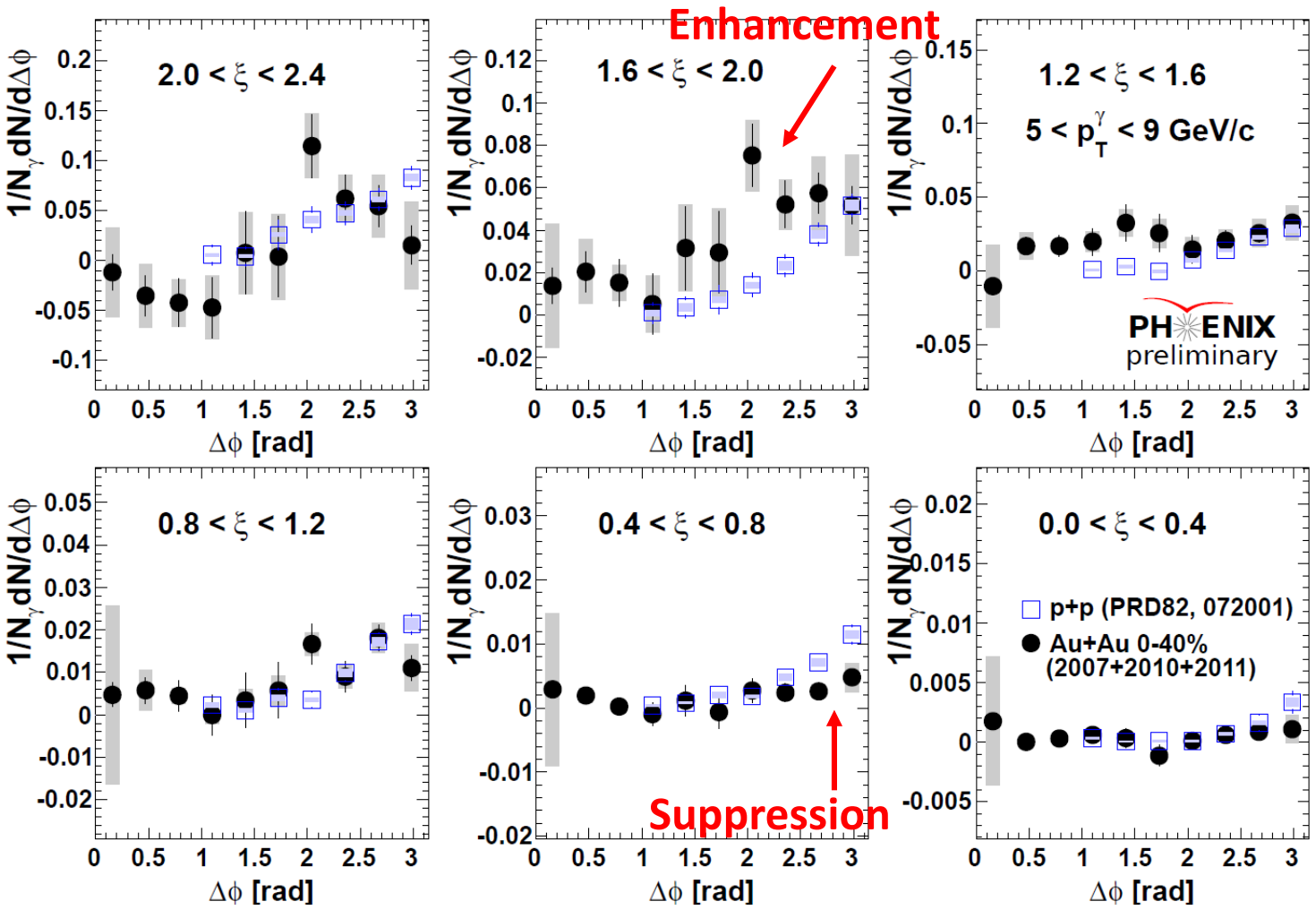
$$\xi = \ln(1/z_T)$$

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

- Combine 4.4 billion minimum bias Au+Au data from 2011 to previous measurement (from 2007 and 2010)

p+p points below Δφ < 1 rad are not shown, due to the photon isolation cut on the near-side.

Measuring Υ_{direct}-h in Au+Au



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

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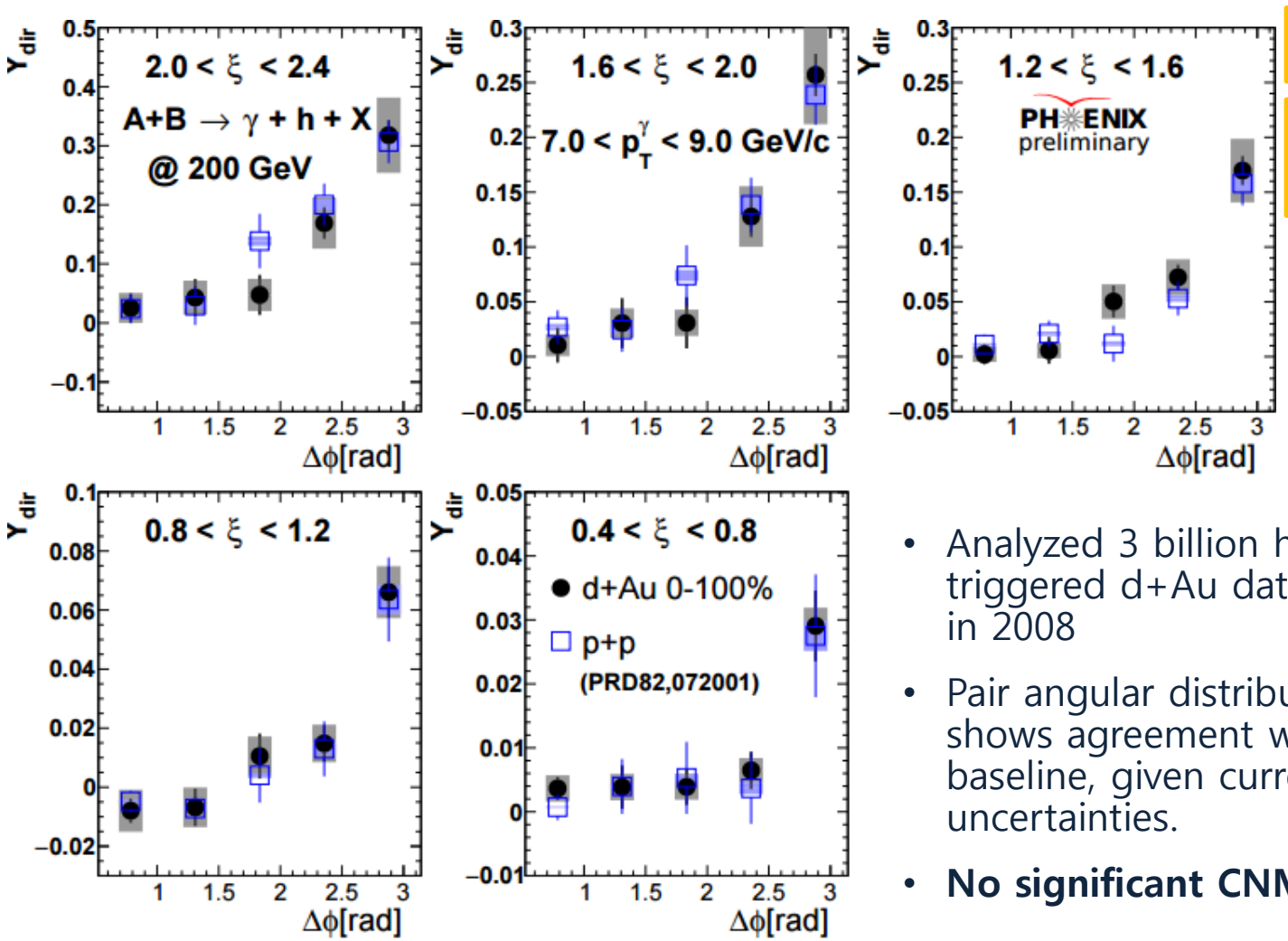
- **Away-side yield modification in Au+Au**

p+p points below Δφ < 1 rad are not shown, due to the photon isolation cut on the near-side.

How do things look in d+Au?



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

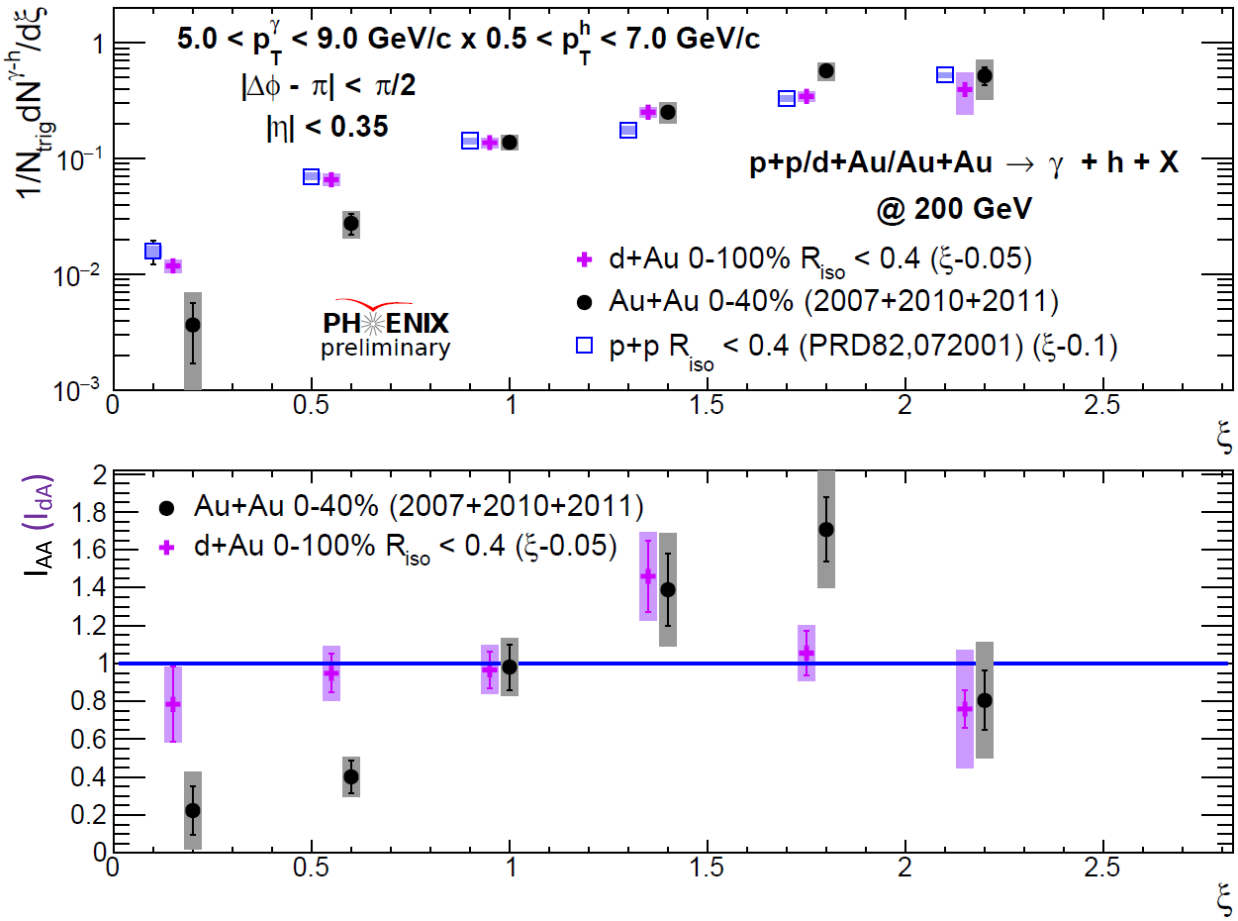
$$z_T = \frac{p_T^h}{p_T^\gamma}$$

- Analyzed 3 billion high p_T triggered d+Au data taken in 2008
- Pair angular distribution shows agreement with p+p baseline, given current uncertainties.
- **No significant CNM effect**

Measure effective jet fragmentation function

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

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



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

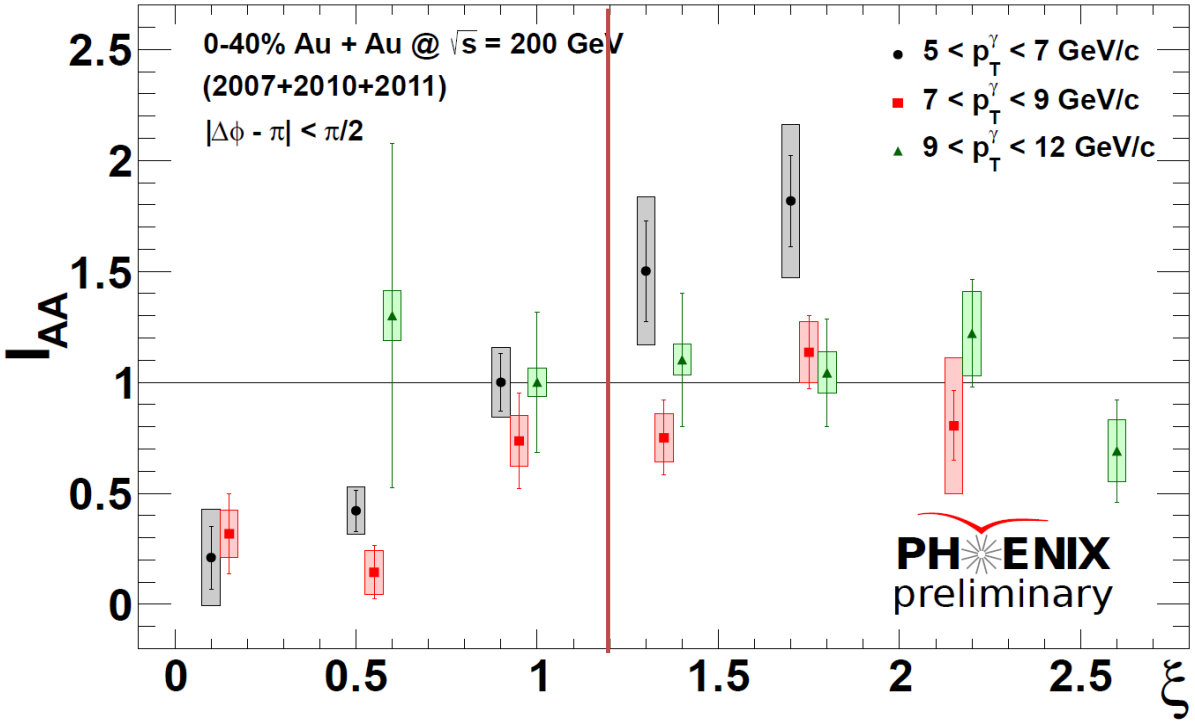
Modification in Au+Au! Suppression in low ξ and enhancement in high ξ

Transition from suppression to enhancement at ξ ~ 1

In d+Au, no significant modification

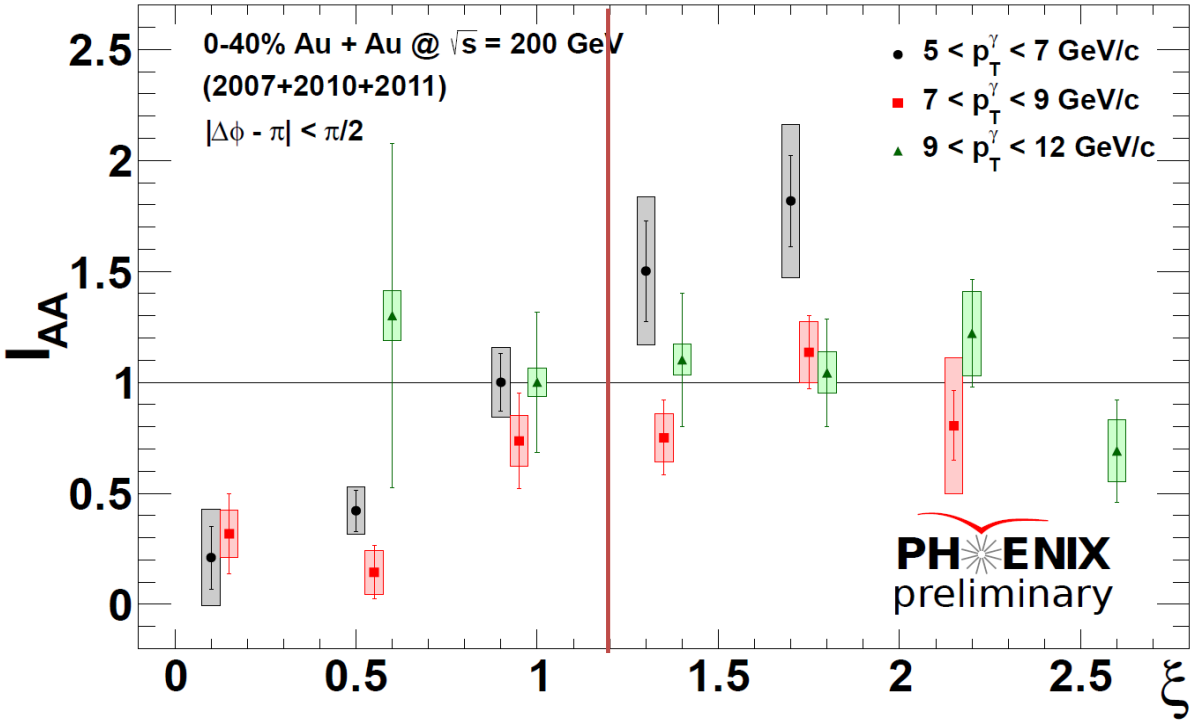
$$I_{dA} = \frac{Y_{dA}}{Y_{pp}}$$

Where does the transition occur?



Transition from suppression to relative enhancement:
$\xi \sim 1.2$ at RHIC?

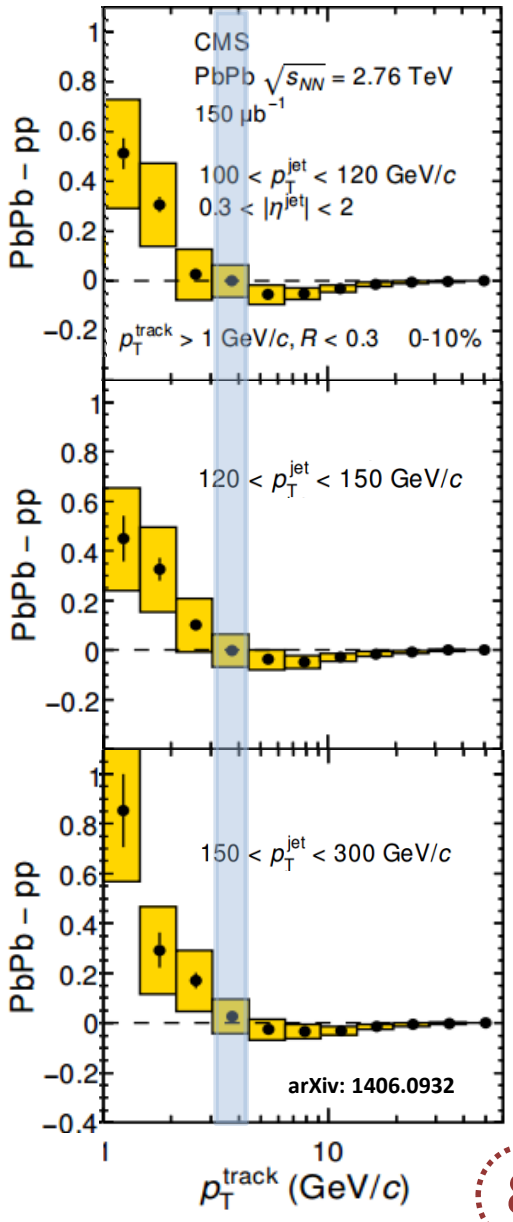
Where does the transition occur?



Transition from suppression to relative enhancement:

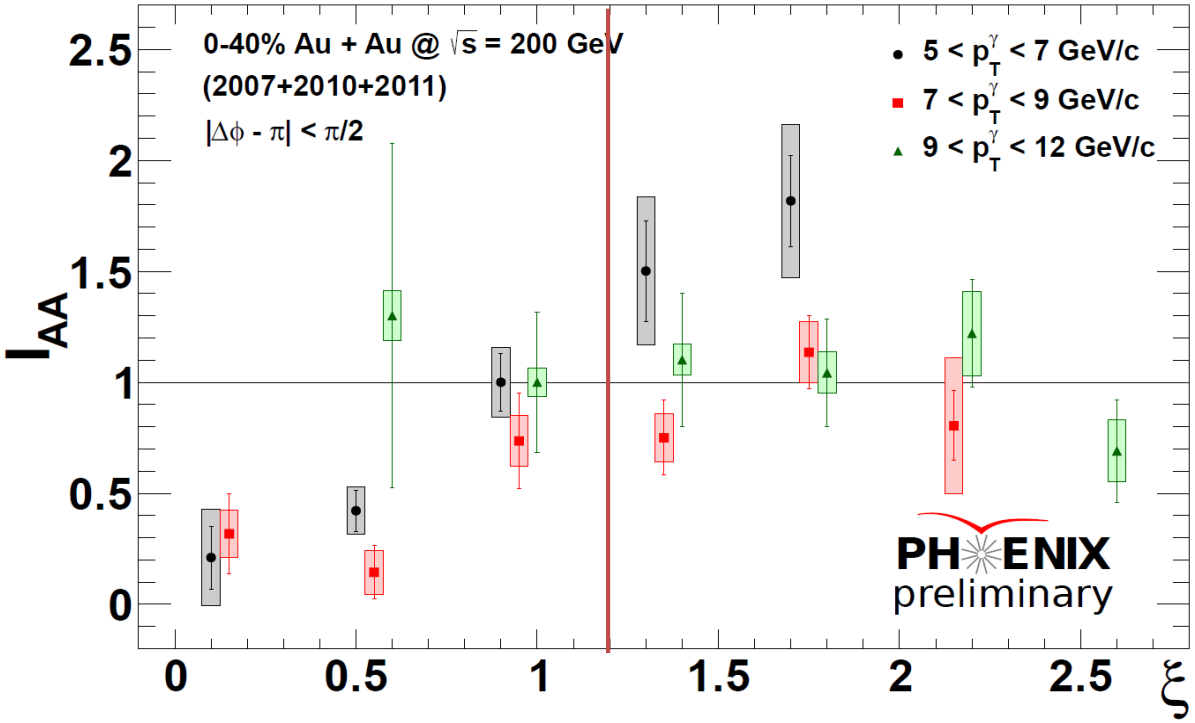
$p_{T,assoc}$ ~ 3 GeV/c at LHC

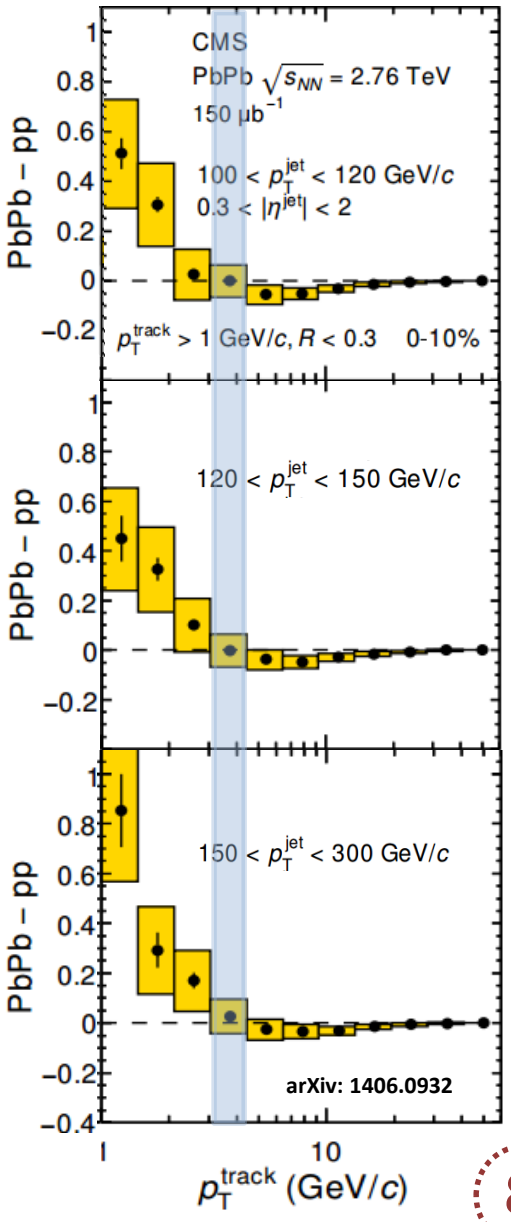
$p_{T,assoc}$ = ? at RHIC



Are we seeing a redistribution of energy within the jet or medium response?

Where does the transition occur?





Transition from suppression to relative enhancement:

$p_{T,assoc}$ ~ 3 GeV/c at LHC

$p_{T,assoc}$ = ? at RHIC

Fixed ξ or fixed $p_{T,assoc}$?

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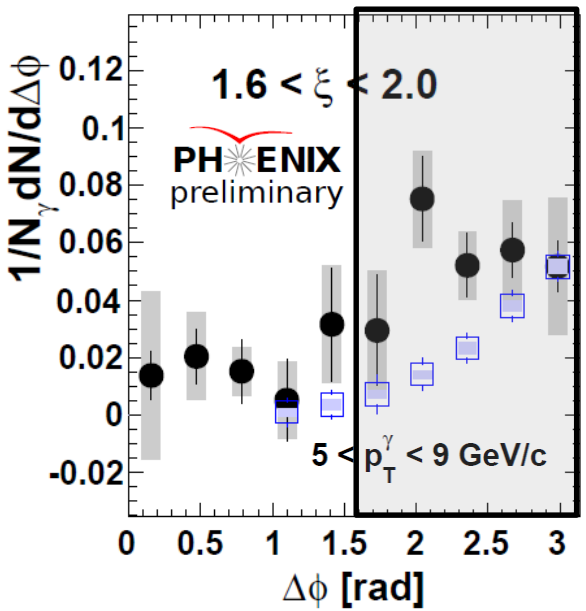
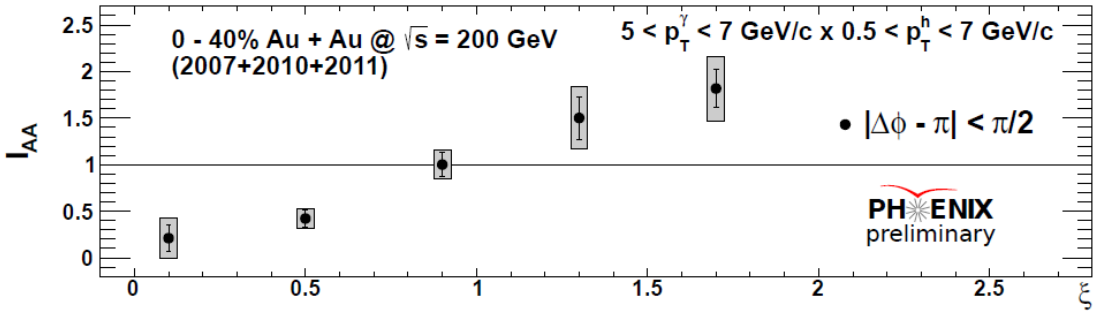
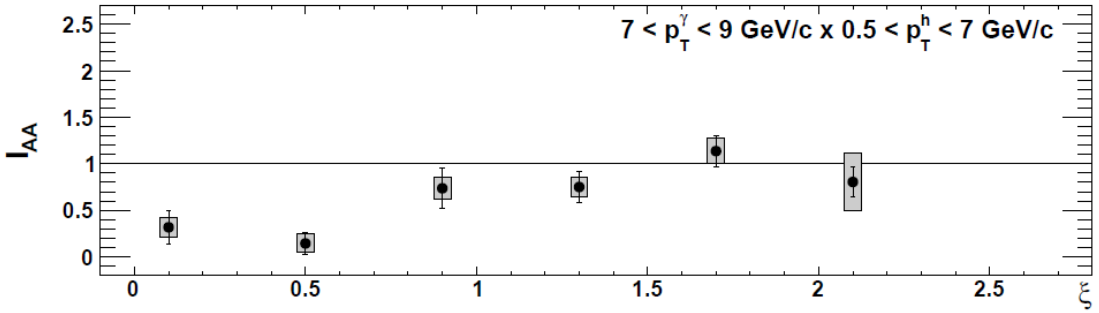
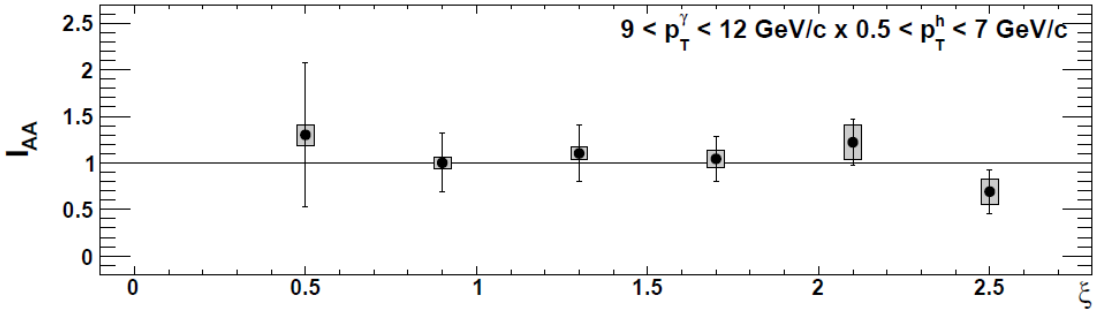




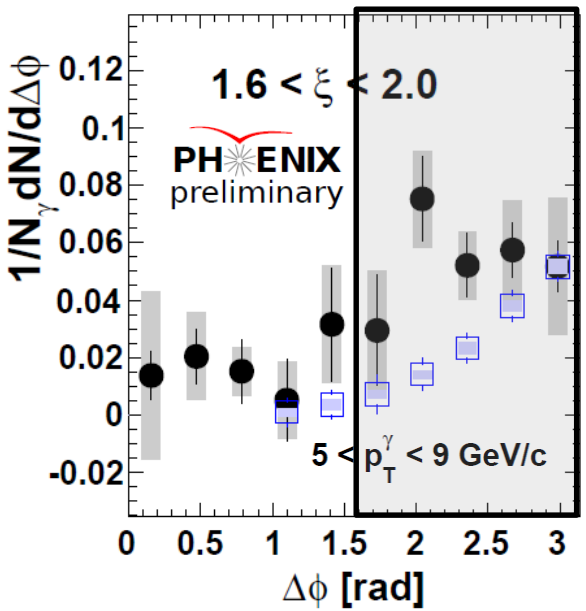


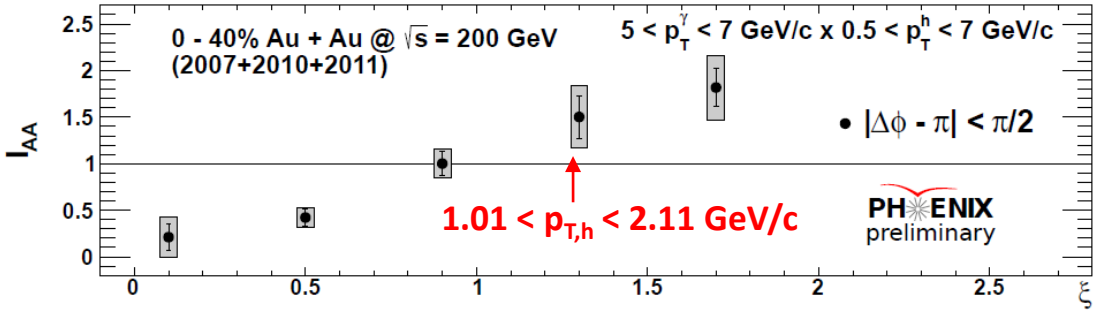


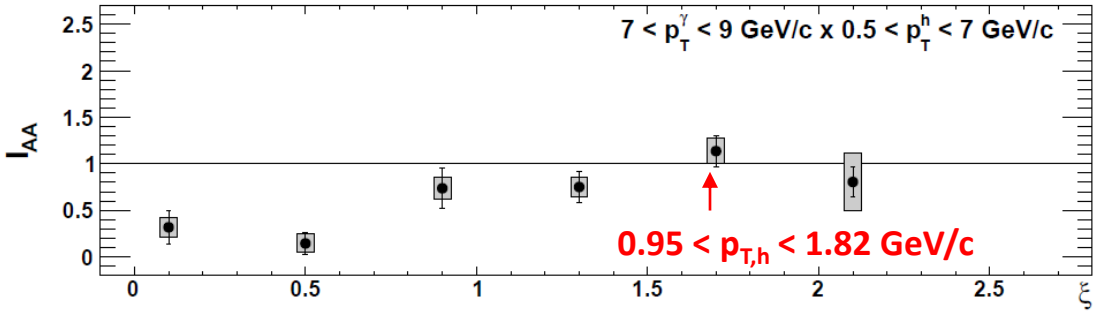
Fixed ξ or fixed $p_{T,assoc}$?

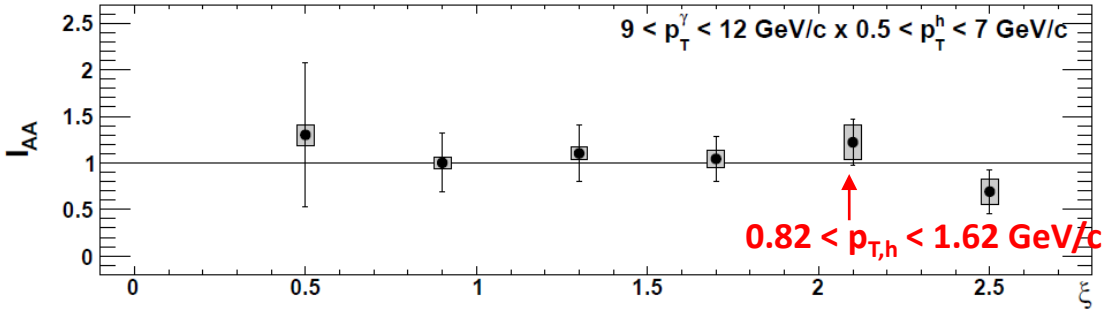
Does not look like fixed ξ

For enhancement vs p+p:
$p_{T,assoc}$ ~ 1-2 GeV/c (?)

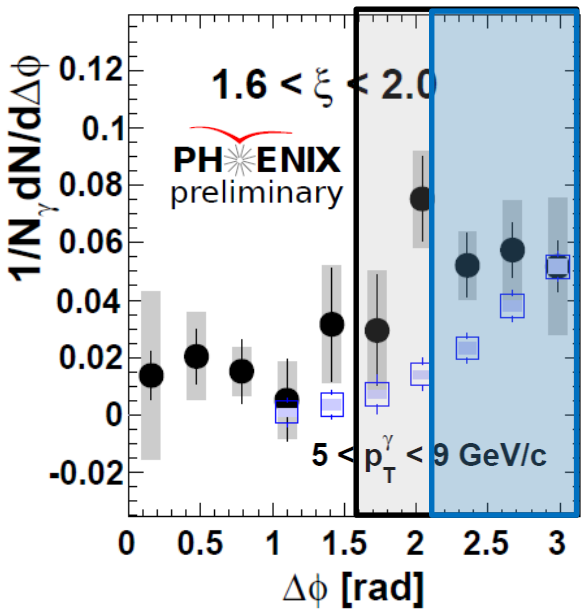


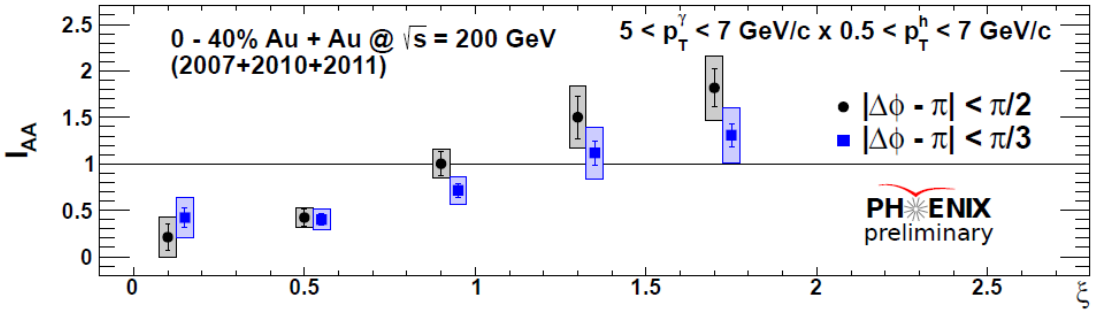


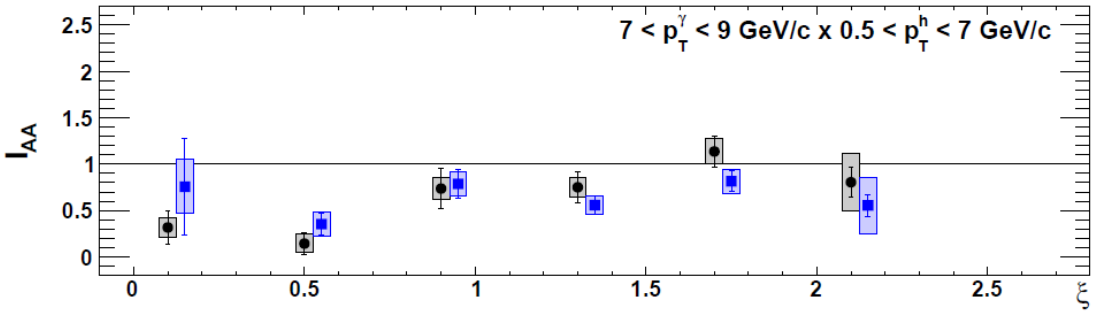


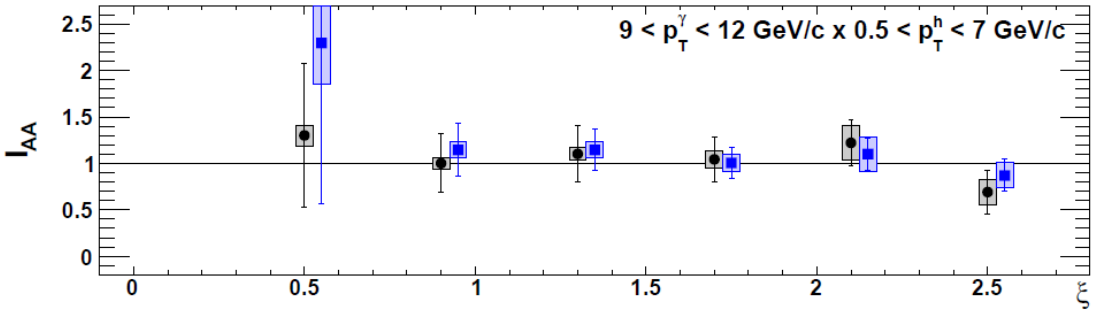


Where does the lost energy go?









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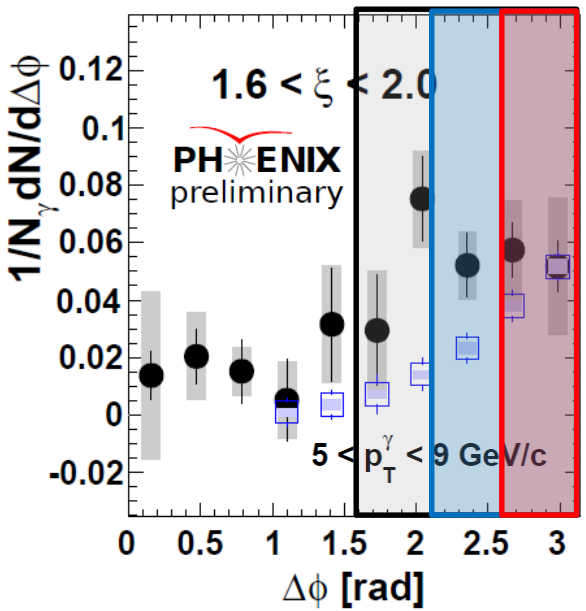
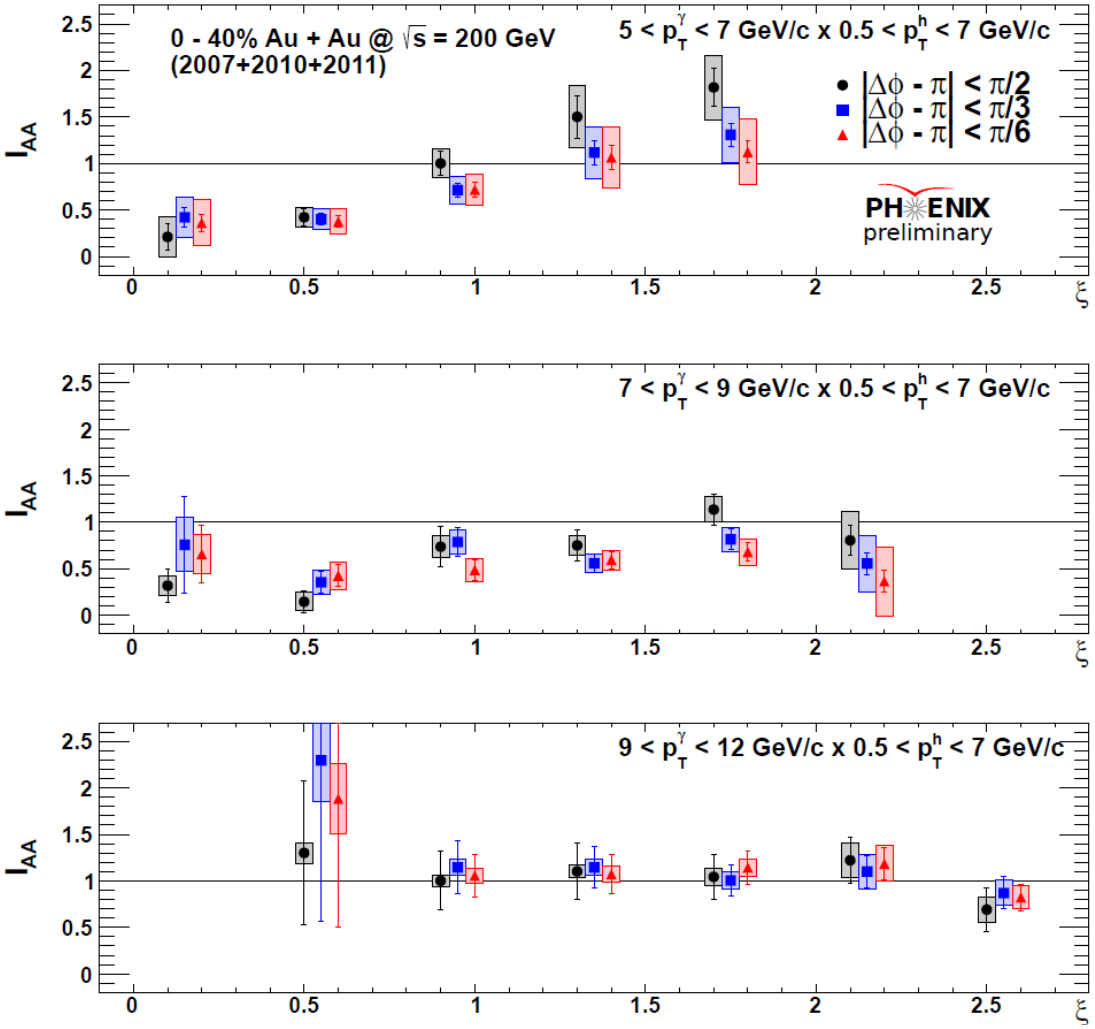


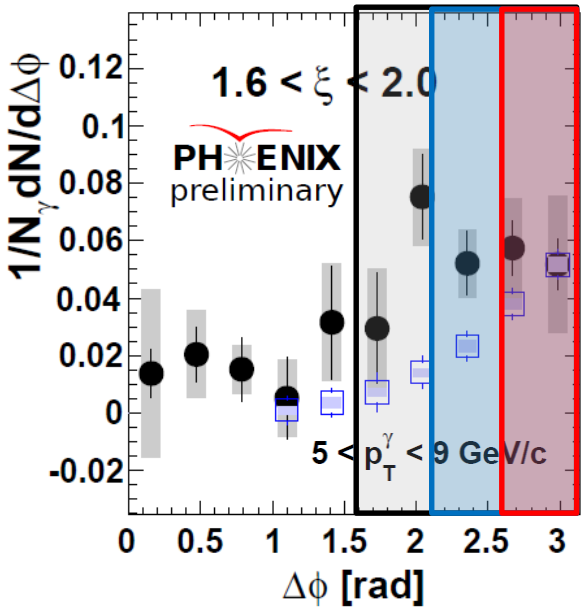


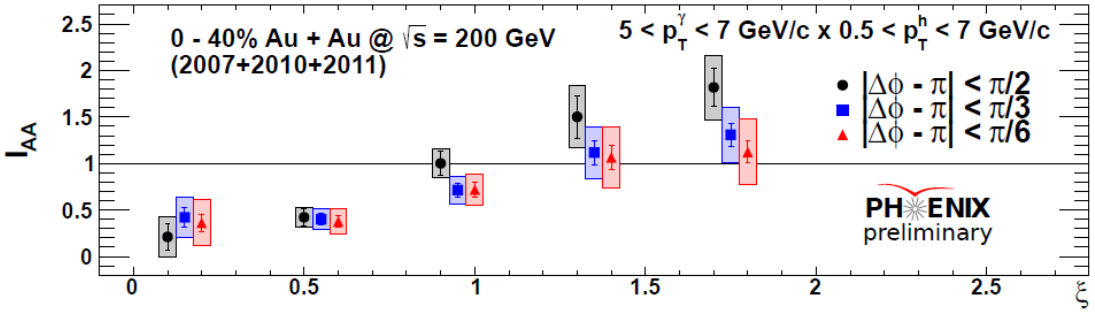
Where does the lost energy go?

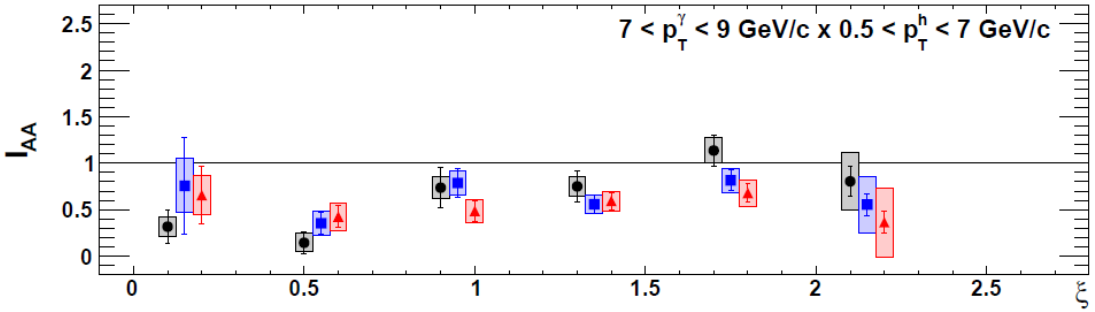
Soft particles enhanced at high ξ compare to low ξ

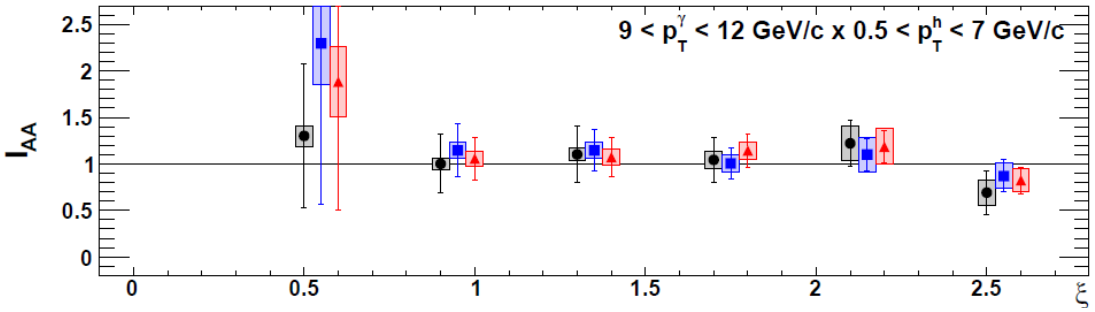
Effect most visible for softest jets and full away-side integration range

Are we seeing the medium response to the jet?









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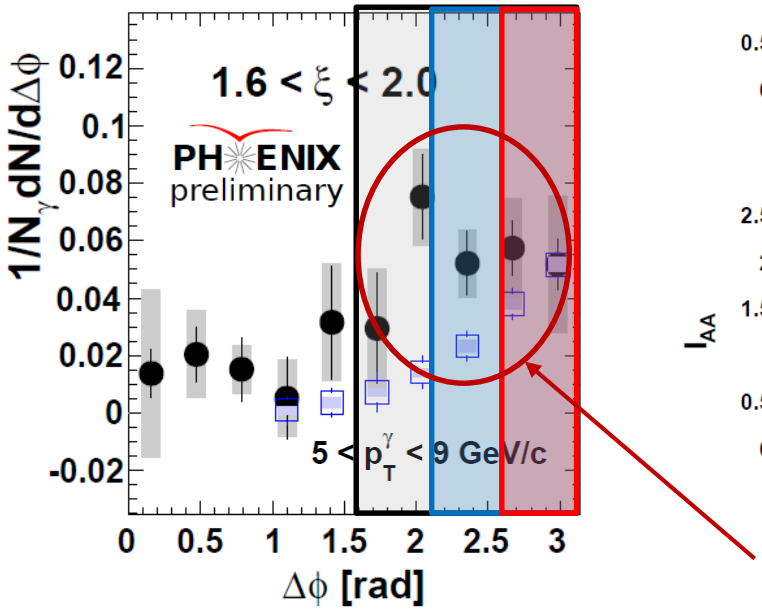
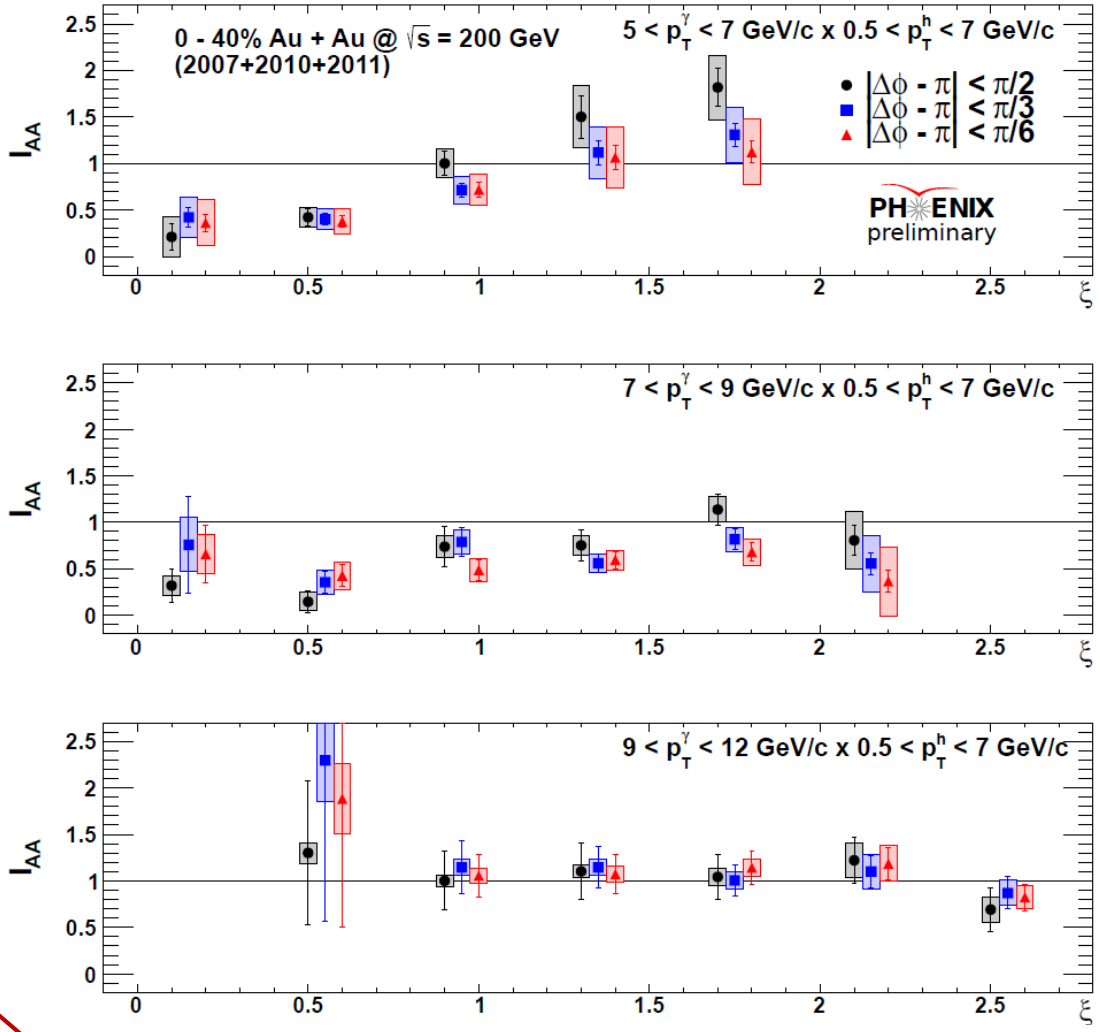
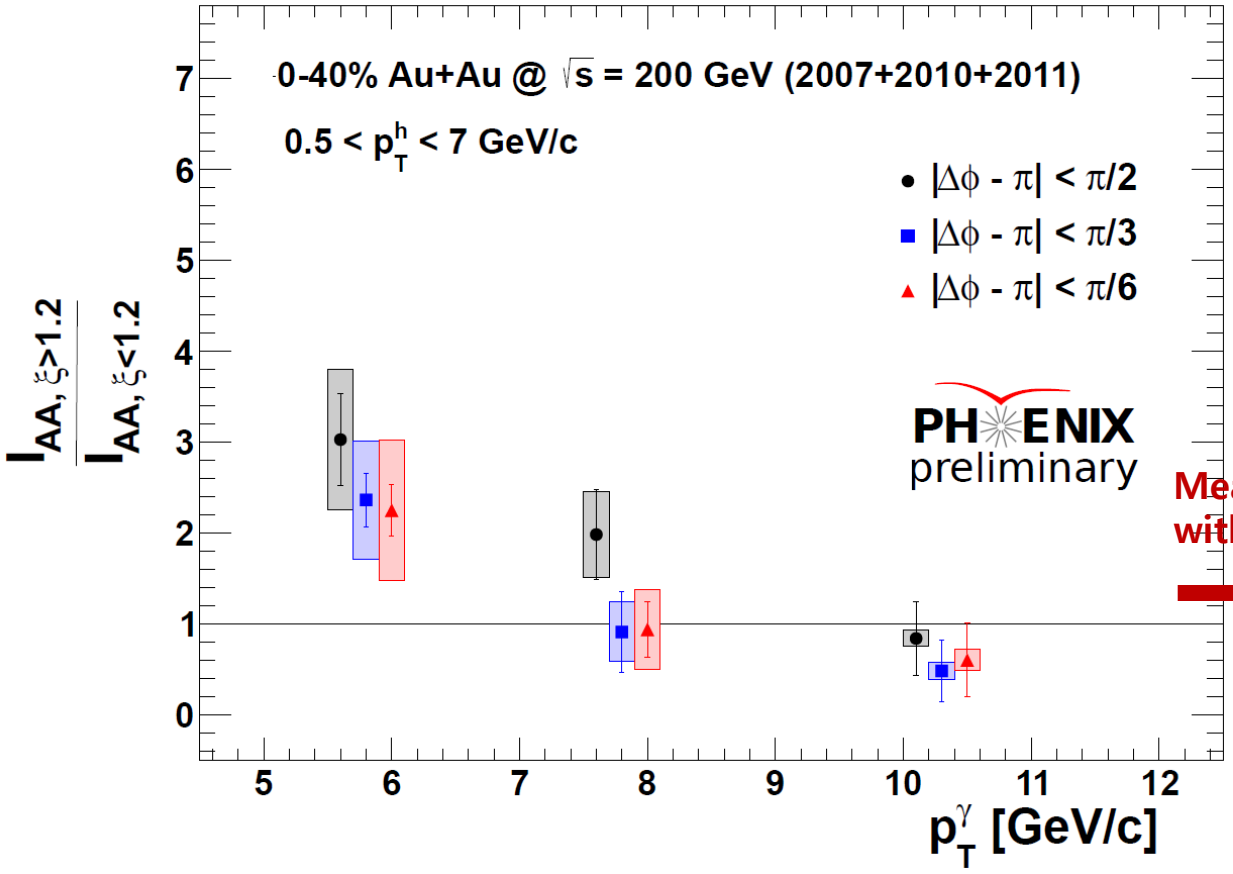




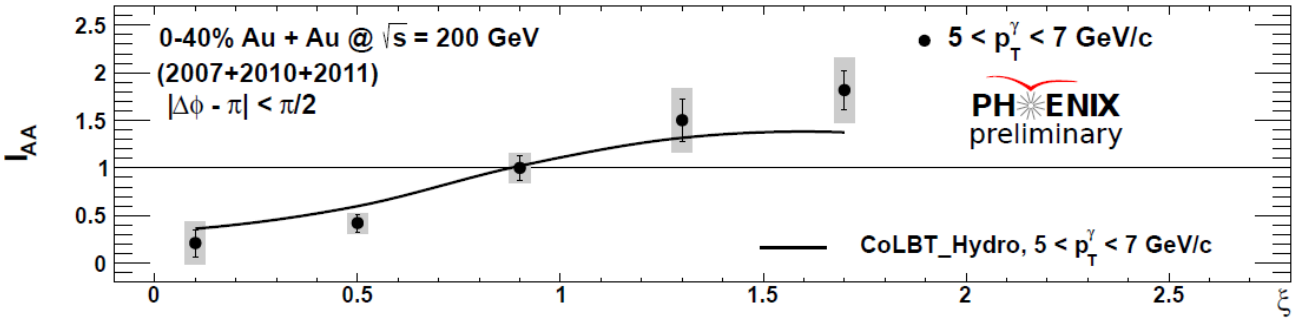
Particle yields enhanced at larger angle with respect to the away-side jet axis.

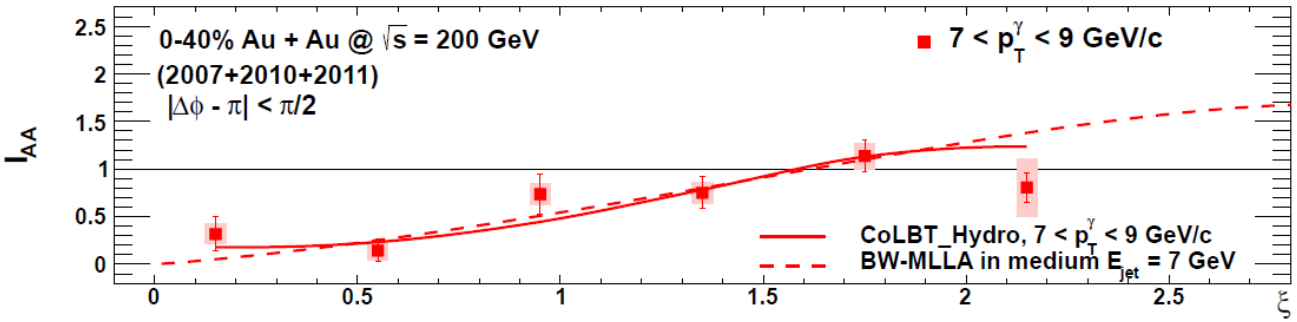
Kinematic dependence of enhancement

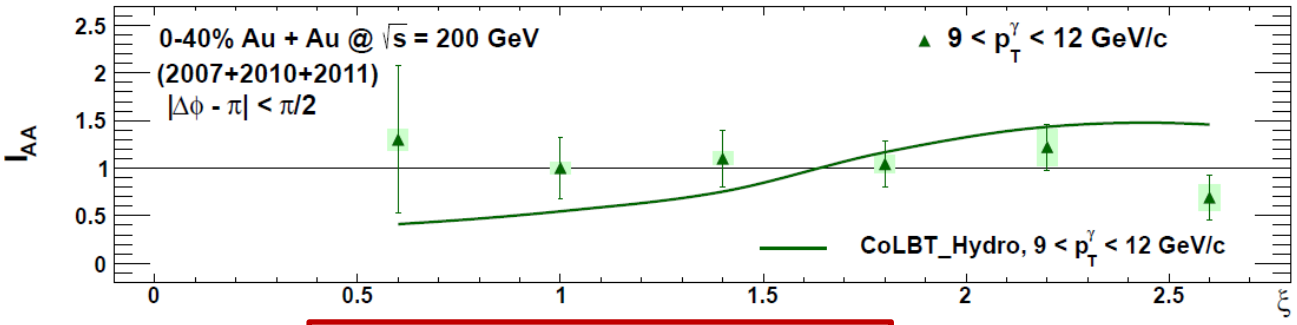


- Relative enhancement show p_T dependence
- Softer jets: more broadened ->particles produced from jet-induced medium excitations?
- Harder jets: more collimated ->particles more correlated with the jet?
  - Consistent with observation of minimal jet shape modification at LHC

Comparisons to theory







Transition not at fixed ξ

Linear Boltzmann Transport

- kinetic description of parton propagation
- hydro description of medium evolution
- track thermal recoil partons & their further interactions in medium

Jet transport in medium + jet induced medium excitations

- He, Luo, Wang and Zhu, arXiv: 1503.03313v2 (2015)
- He, Luo, Wang and Zhu, arXiv:1503.0331;

Modified Leading Log Approximation

Modeling the energy loss in the medium as an increased parton splitting probability

- Borghini and Wiedemann, arXiv: hep-ph/0506218 (2005)

Conclusions

- Modification to effective fragmentation function is observed in Au+Au collisions using γ_{direct}-h correlation measurement.
- Variation of away-side integration range suggests low p_T jet broadening in addition to enhancement at low $p_{T,h}$.
- Results from higher statistics in Au+Au hint that the away-side jet modification is due to medium response.
- In d+Au collisions, no significant modification to yield is observed, suggesting minimal CNM effect.

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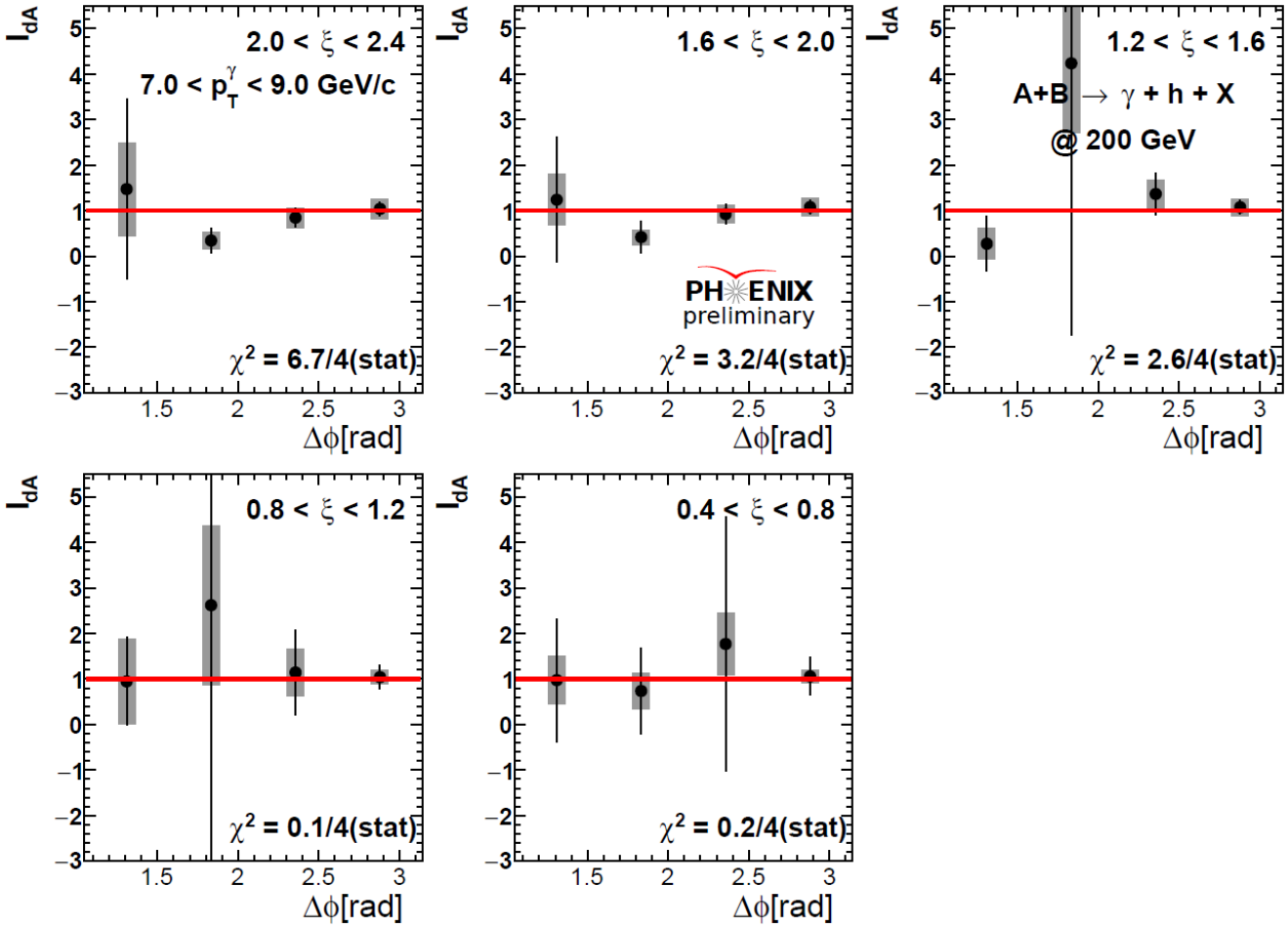
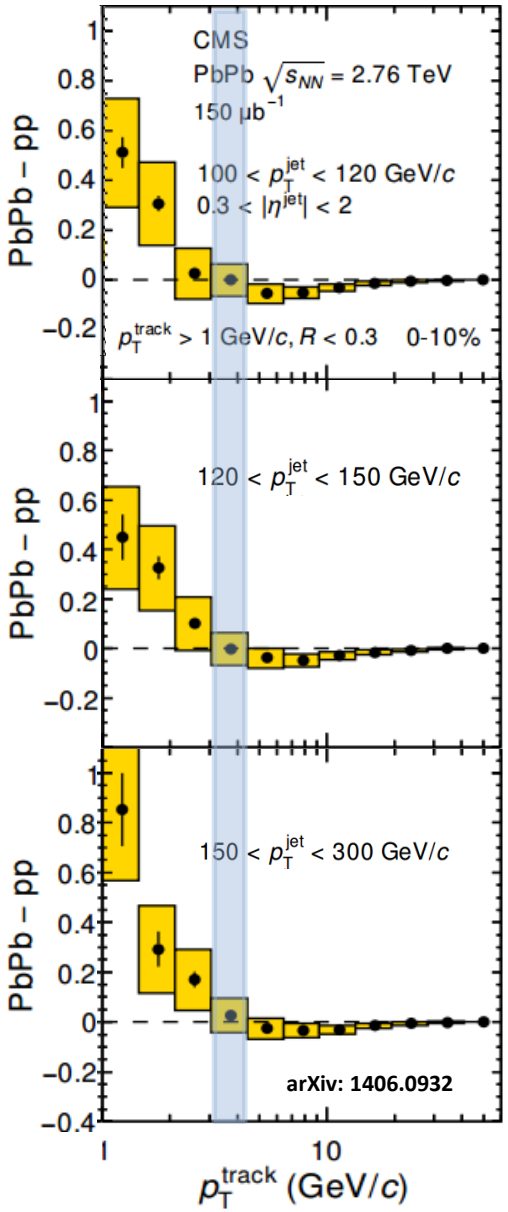
Thank you!

Back up


I_{dA}
2.0 < ξ < 2.4
7.0 < p_T^γ < 9.0 GeV/c
χ^2 = 6.7/4(stat)
Δφ[rad]
1.6 < ξ < 2.0
PHENIX
preliminary
χ^2 = 3.2/4(stat)
1.2 < ξ < 1.6
A+B → γ + h + X
@ 200 GeV
χ^2 = 2.6/4(stat)
0.8 < ξ < 1.2
χ^2 = 0.1/4(stat)
0.4 < ξ < 0.8
χ^2 = 0.2/4(stat)



Soft particle excess at LHC, too

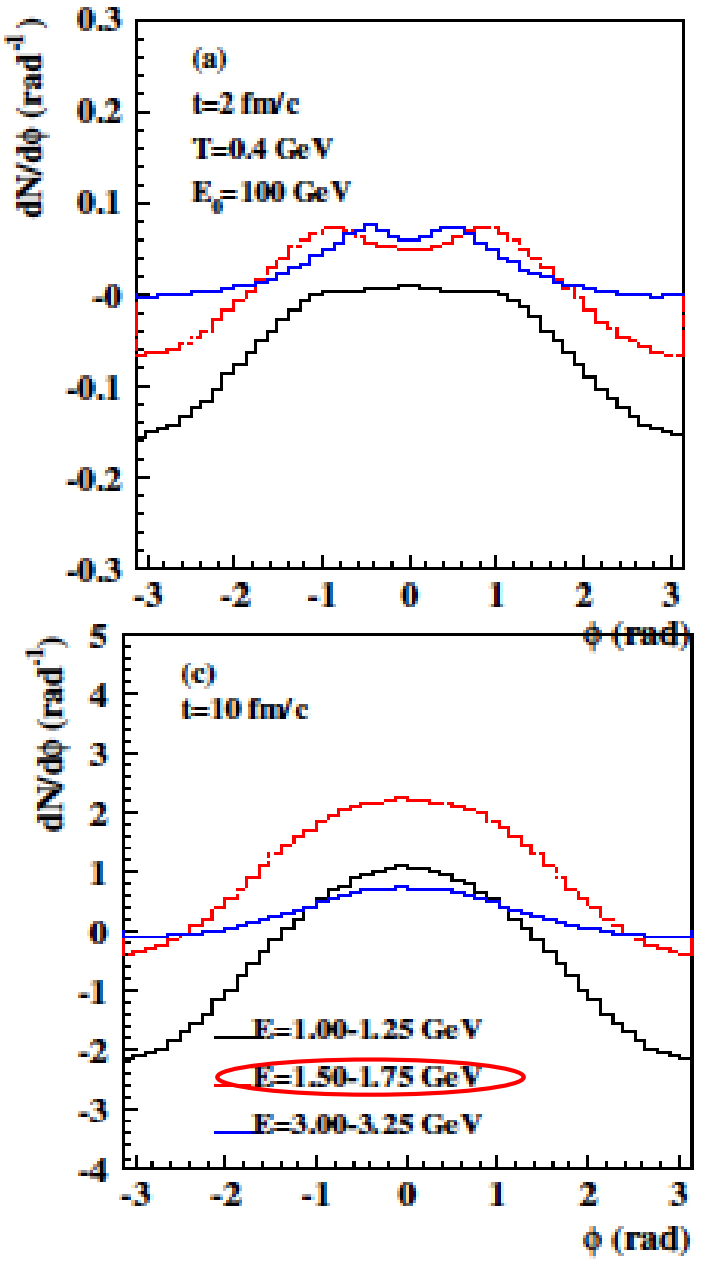
- Look inside jets (p_T > 100 GeV)
  - R = 0.3 *(not wide!)*
- Fragmentation function is modified
  - *But only for soft particles*
  - *Otherwise looks like pp jets*
- Excess soft fragments in PbPb vs. pp for p_T < 3 GeV/c
  - *Is the p_T lower at RHIC?*

Thermal recoil partons?

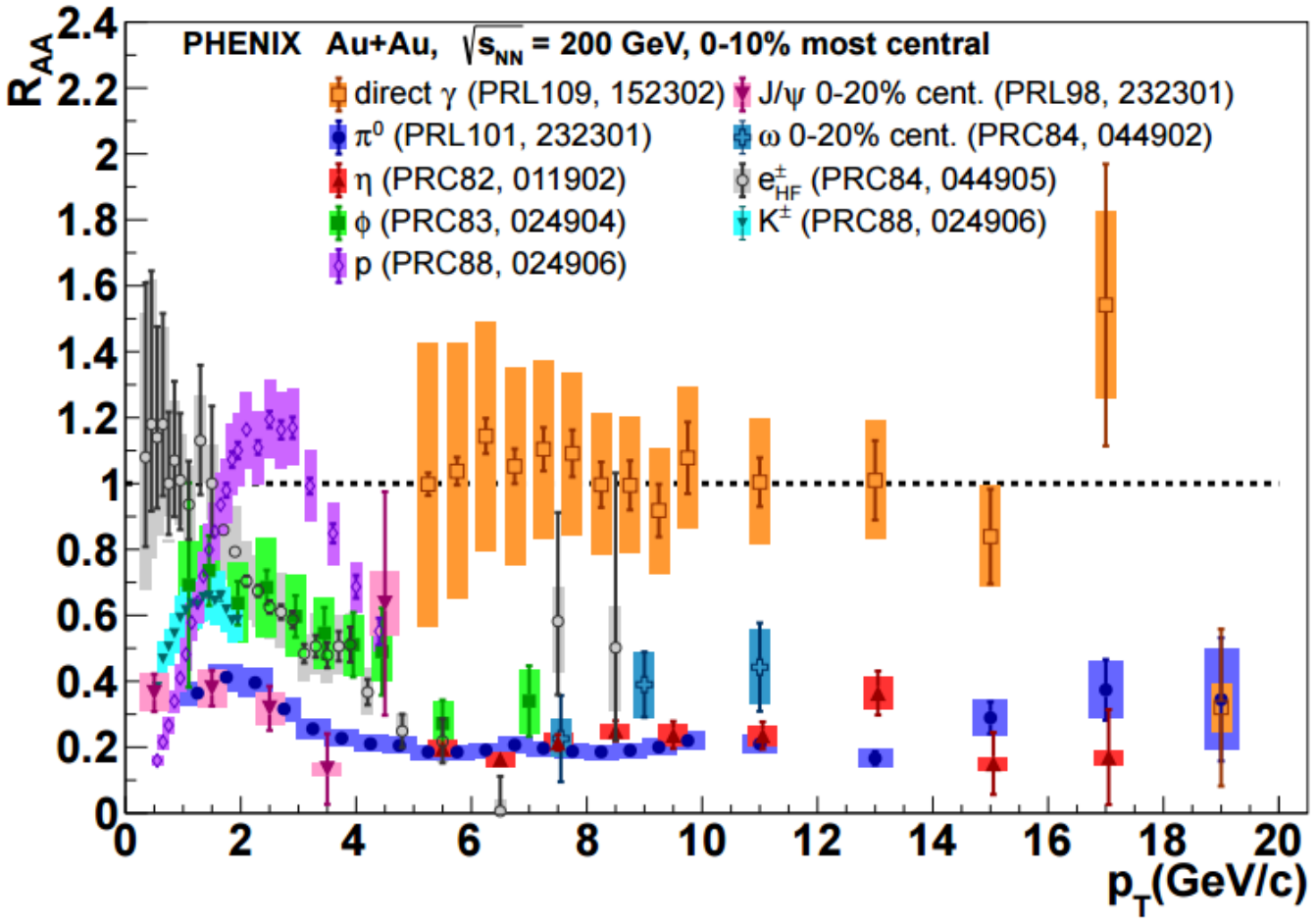
Linear Boltzmann Transport

- kinetic description of parton propagation
- hydro description of medium evolution
- track thermal recoil partons & their further interactions in medium

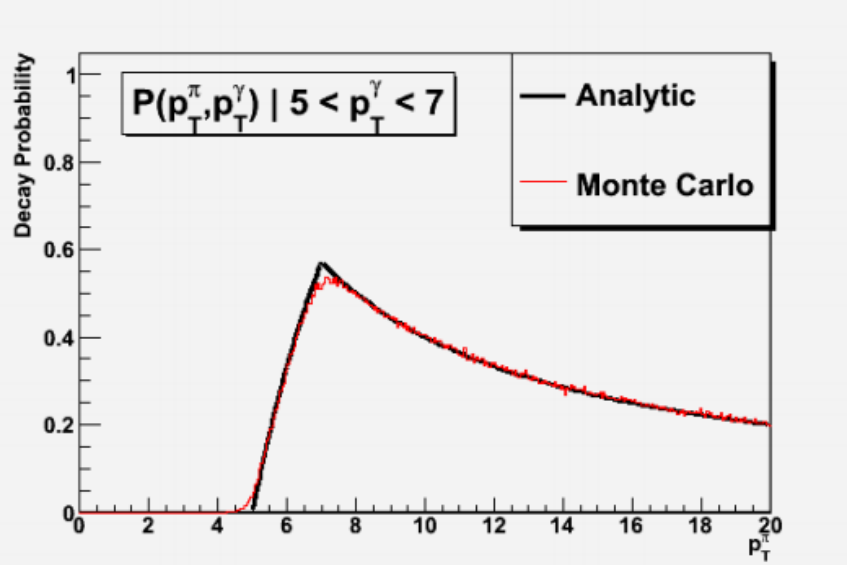
Jet transport in medium + jet induced medium excitations



He, Luo, Wang & Zhu
arXiv:1503.0331


PHENIX Au+Au, $\sqrt{s_{NN}}$ = 200 GeV, 0-10% most central
direct γ (PRL109, 152302)
π⁰ (PRL101, 232301)
η (PRC82, 011902)
φ (PRC83, 024904)
p (PRC88, 024906)
J/ψ 0-20% cent. (PRL98, 232301)
ω 0-20% cent. (PRC84, 044902)
$e^{\pm}_{HF}$ (PRC84, 044905)
$K^{\pm}$ (PRC88, 024906)
R_{AA}
p_T(GeV/c)

- π^0-h pairs $\xrightarrow{p_T \text{ weighting}}$ decay γ-h pairs



Direct photon –
any photon that is not from a decay process