# Direct photon-hadron correlation measurement at RHIC

*Recent jet-like correlation measurements*
*and a way towards photon-triggered jets at RHIC*

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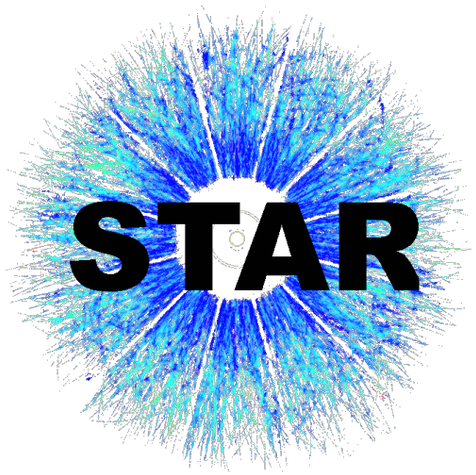
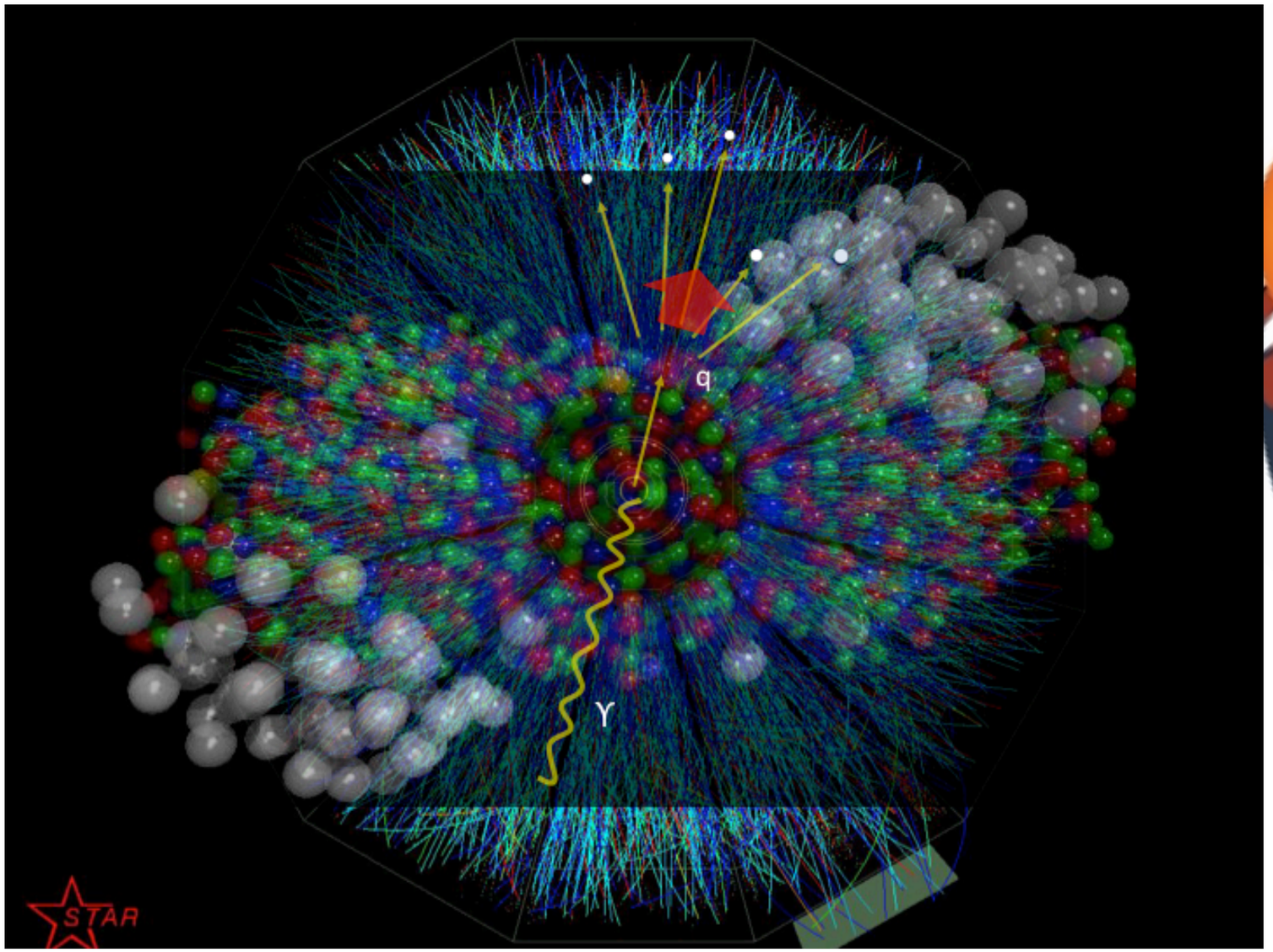
**Hot Quarks 2016**



# Motivation for γ-jet in heavy ion collisions




Direct photon+jet coincidence: a self generated tomographic probe

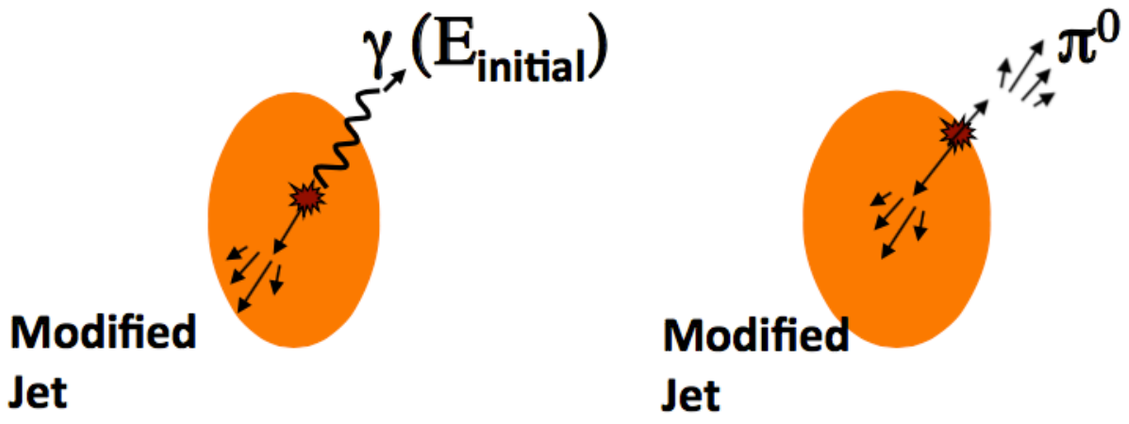
- Doesn't interact with QCD medium
- Transverse energy approximates that of initial parton $p_T$ in γ-jet events
- Volume emission dominates for γ-trigger events

# What physics we are looking for ?

An interesting comparison between γ-jet and $\pi^0$-jet

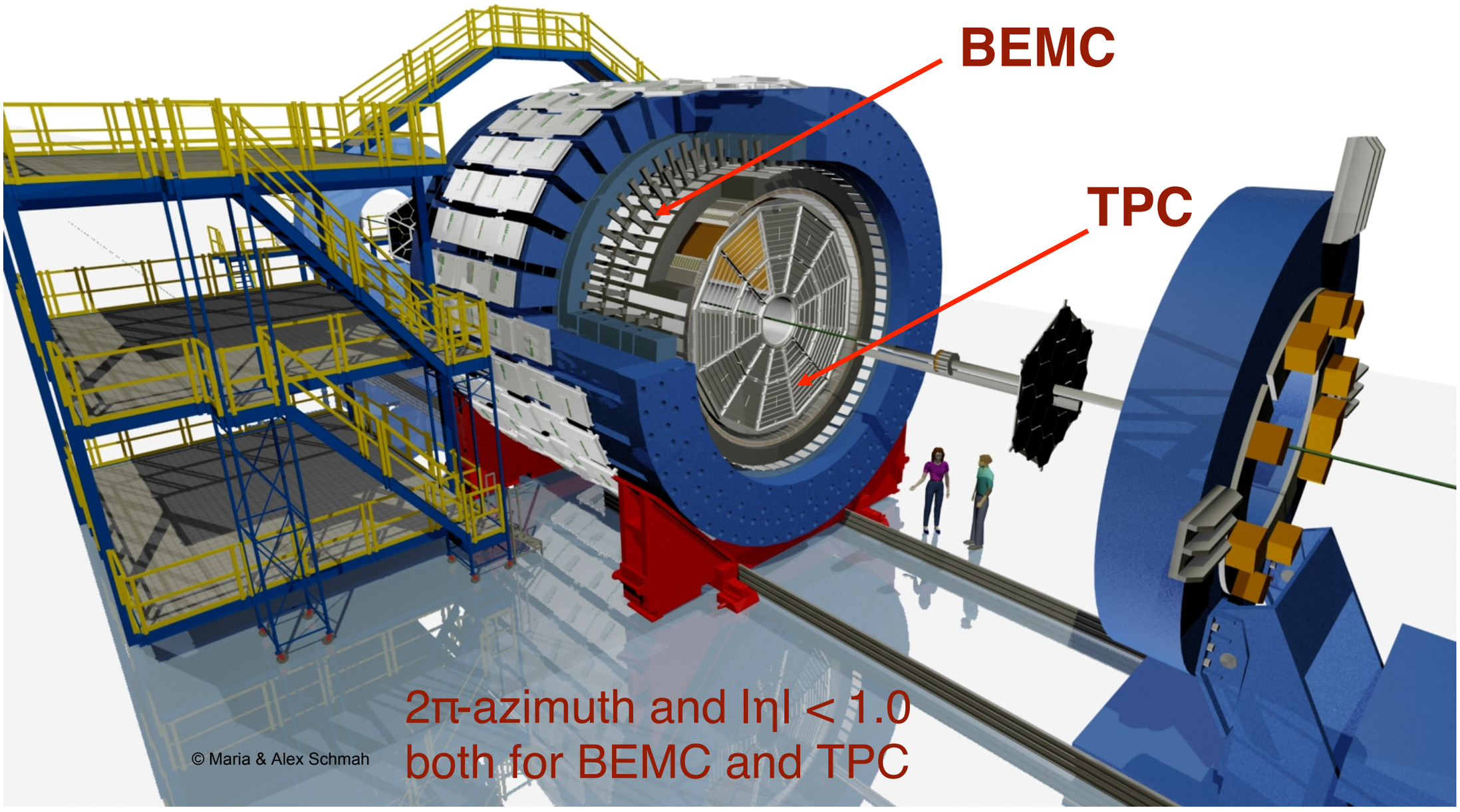
- Recoil parton from direct photon predominantly quarks, whereas that of $\pi^0$ are gluons (D. de Florian et al., PRD 91, 014035 (2015),T. Kaufmann et al., PRD 92, 054015 (2015))
  - γ-triggered parton (jet) expected to lose less energy than that of $\pi^0$-trigger due to color factor ( $C_A/C_F = 9/4$)

- γ-triggers are mainly volume emission, whereas $\pi^0$-triggers are surfaced biased
  - on ave. γ-triggered parton (jet) expected to lose less energy than that of $\pi^0$-trigger due to in medium path length difference



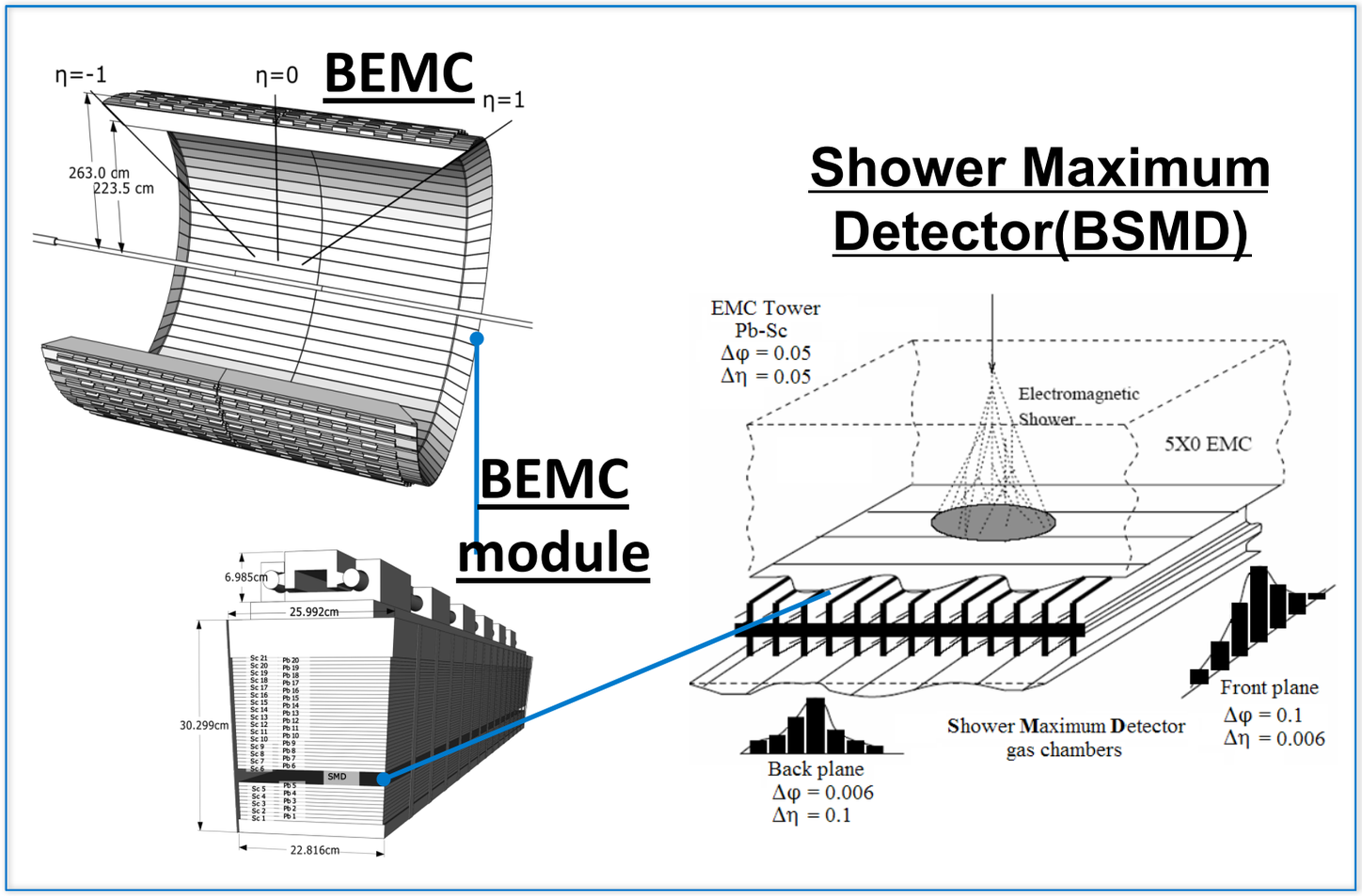

- Energy loss as a function of
  - Trigger $p_T$ of direct photon
  - Associated hadron $p_T$

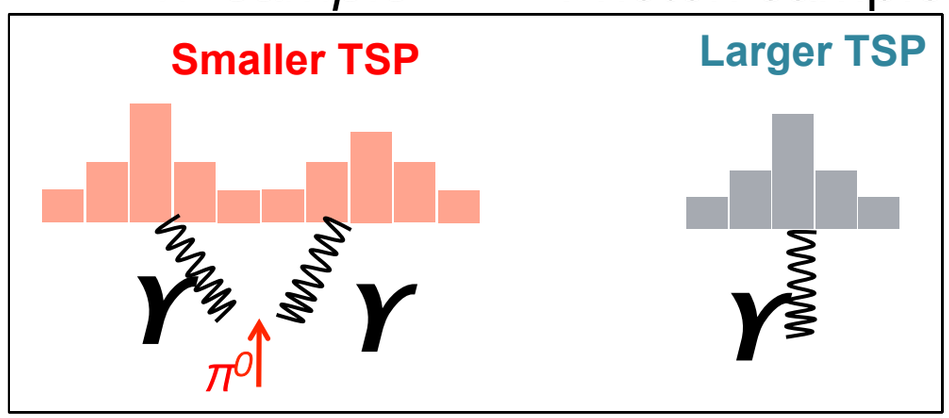
# STAR detector system




- ***Discrimination between $\pi^0 \rightarrow \gamma\gamma$ and $\gamma_{dir}$ is key part of this analysis***
  - **By Transverse Shower Profile (TSP) method**
  - **Using Barrel Shower Maximum Detector (BSMD)**

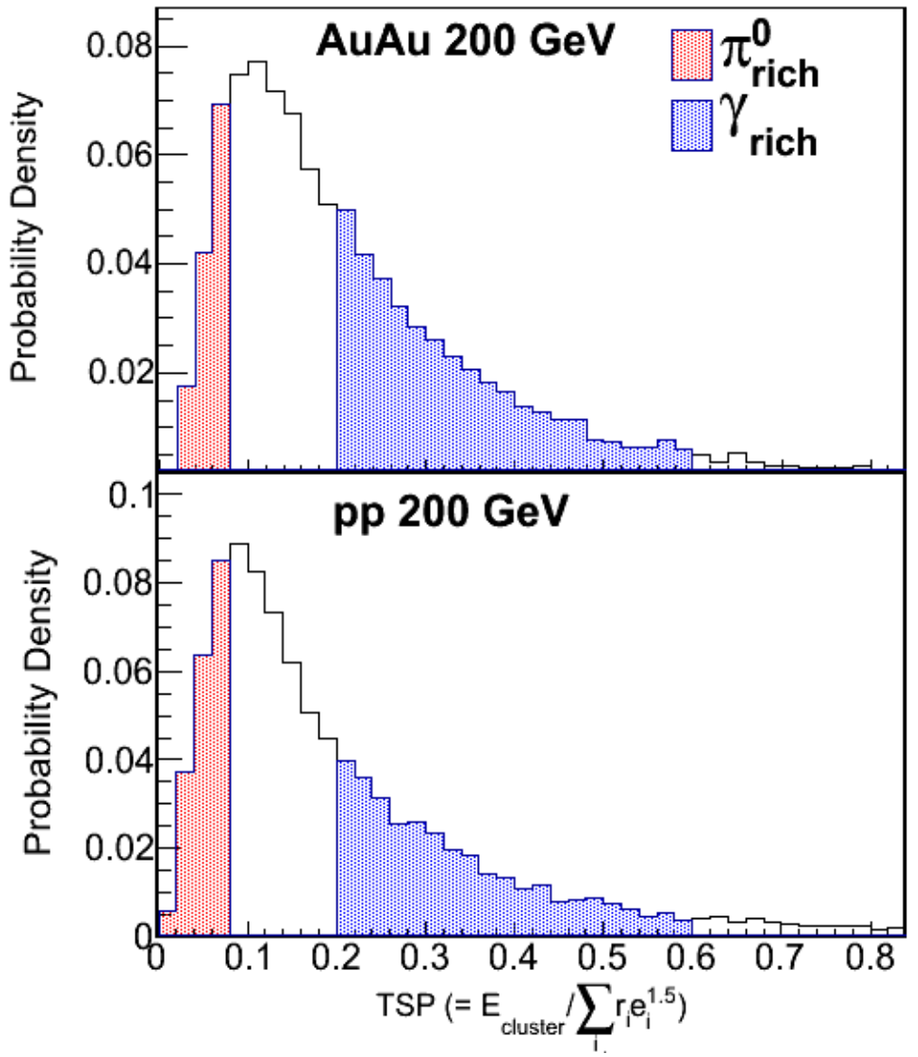
# Transverse shower profile: $\pi^0/\gamma_{dir}$ discrimination



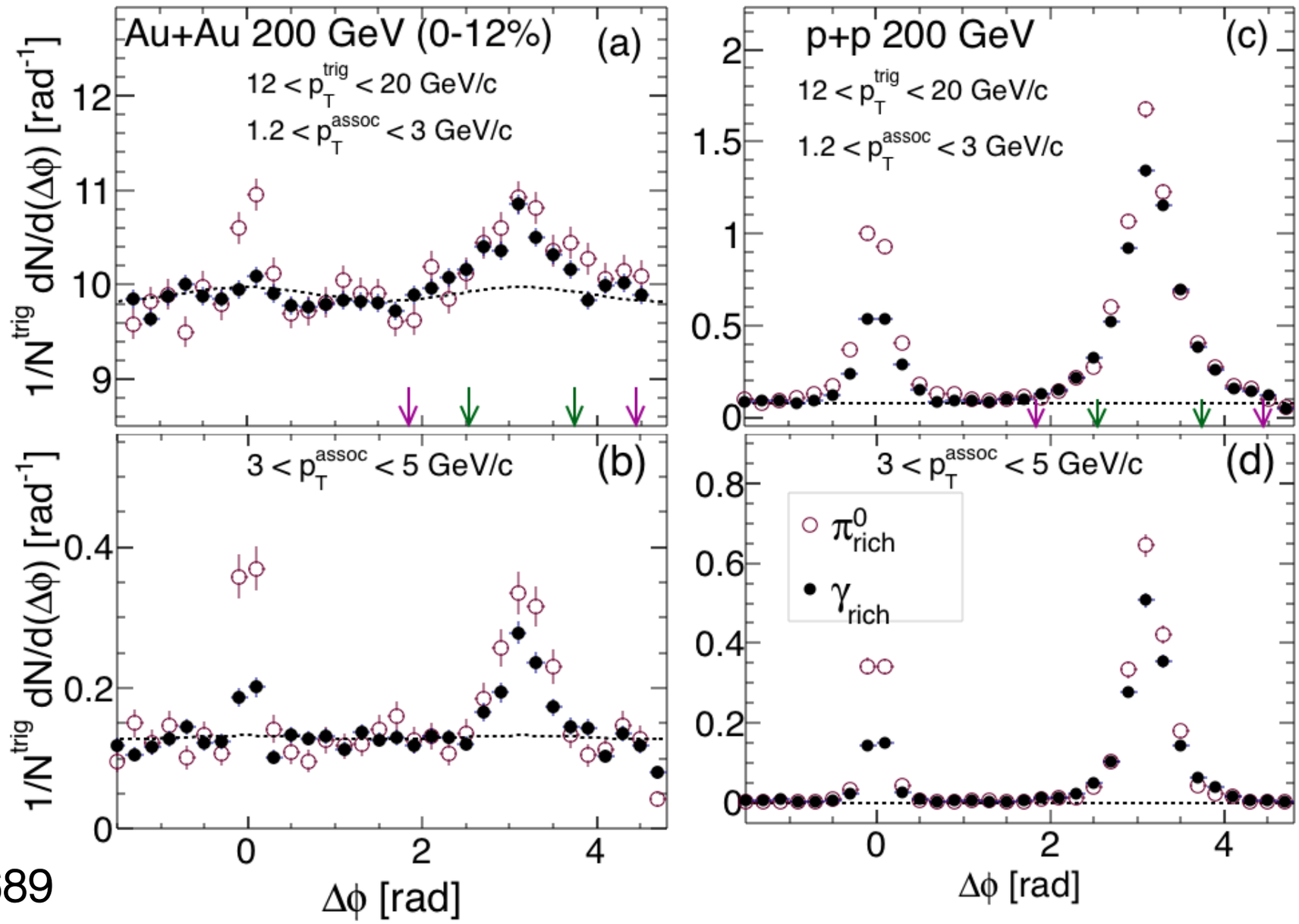

$$\mathbf{TSP} = \frac{\mathbf{E_{cluster}}}{\sum_i \mathbf{e_i r_i^{1.5}}}$$

$E_{cluster}$: Cluster energy, $e_i$: BSMD strip energy,
$r_i$: distance of the strip from the center of the cluster




- **a nearly pure sample of $\pi^0$ (called " $\pi^0_{rich}$ ")**
- **a sample with enhanced fraction of $\gamma_{dir}$ (called `` $\gamma_{rich}$**

# Jet-like azimuthal correlation functions

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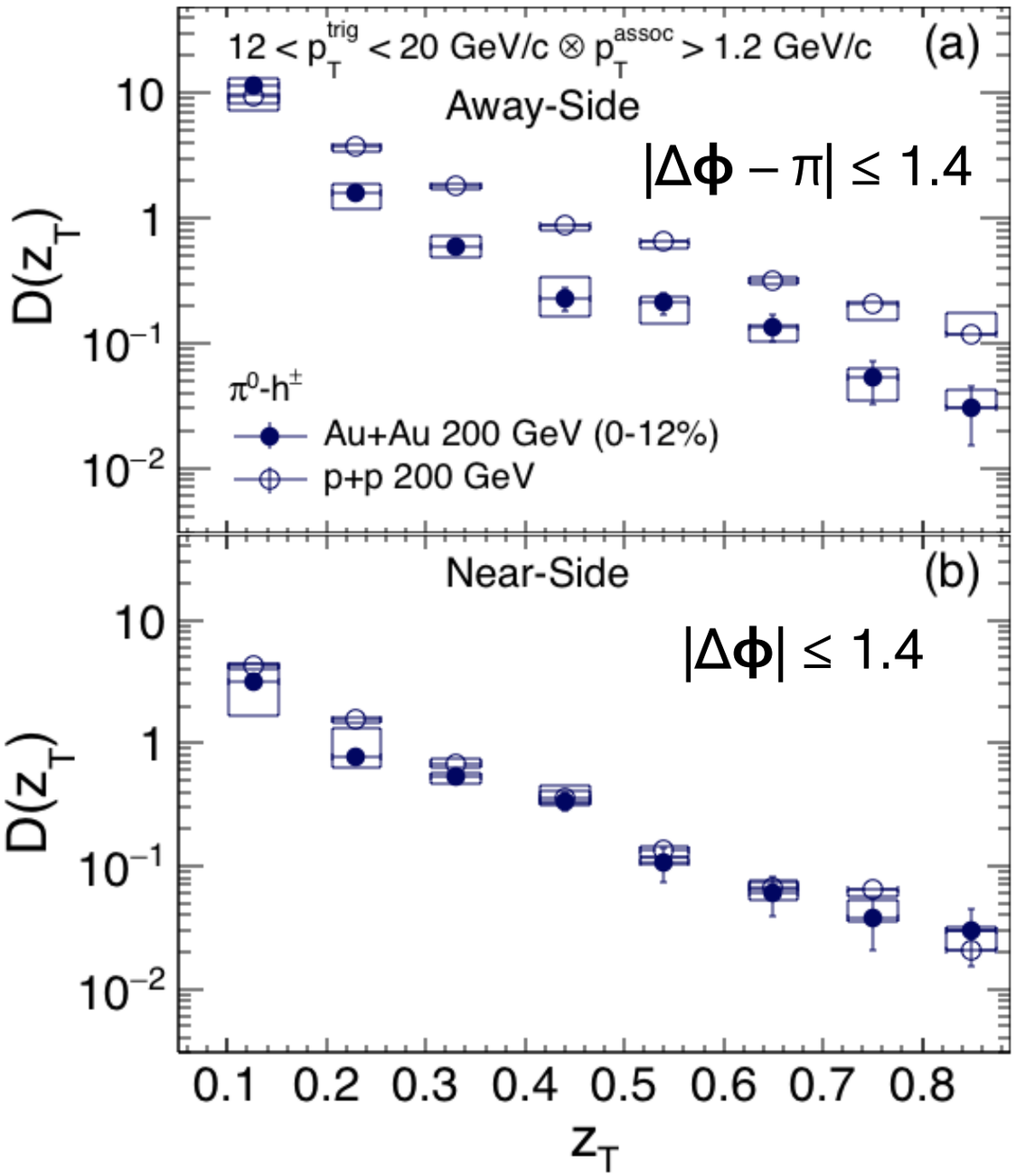
- In $\gamma_{rich}$ small peak due to some contamination of $\pi^0$
- Background subtracted from flow modulated background level determined using Zero Yield At 1 (ZYA1) method
- Near-side yield is by definition zero for true direct-photon trigger

# Associated yields of $\pi^0$-hadron correlations

Some discussion of $\pi^0$ –hadron correlations

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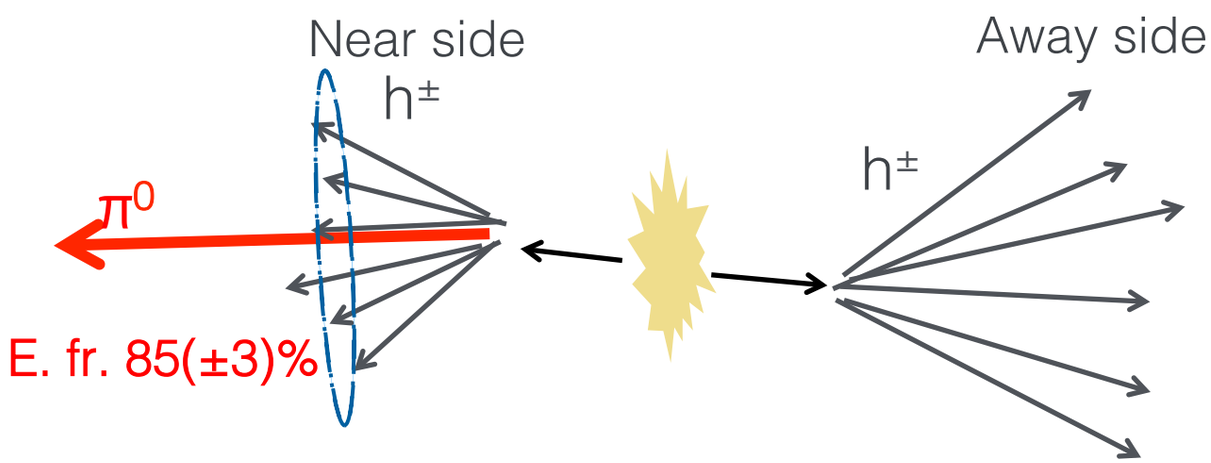
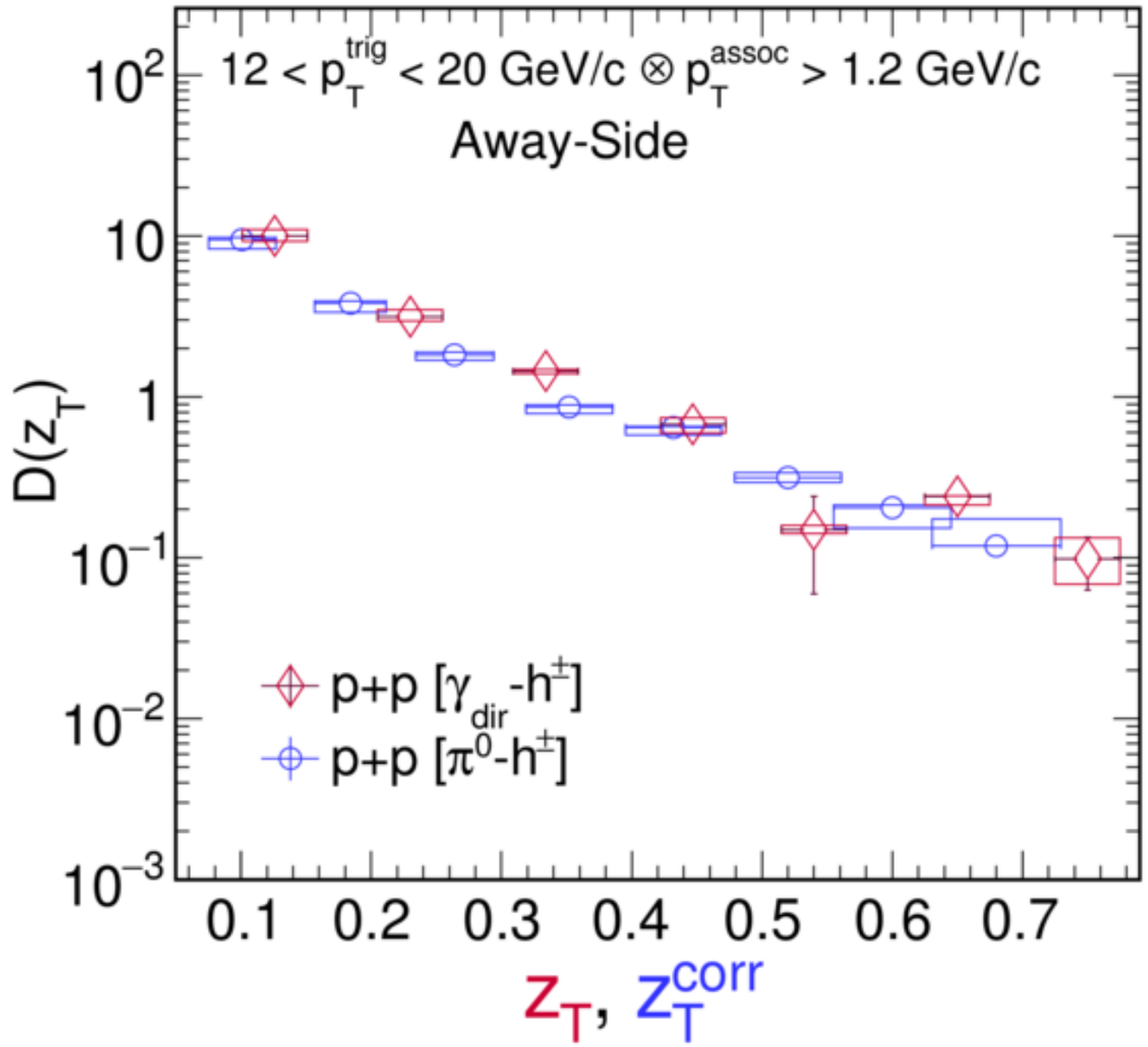
- Away-side yields show suppression
- Near-side shows no suppression

- 85(±3)% fraction of energy carried by $\pi^0$ over "jet energy" ($\pi^0$ + charged hadrons) in pp 200 GeV

- In PYTHIA, it is found to be 80(±5)% which is consistent with data



# $z_T$ correction for $\pi^0$-hadron correlations

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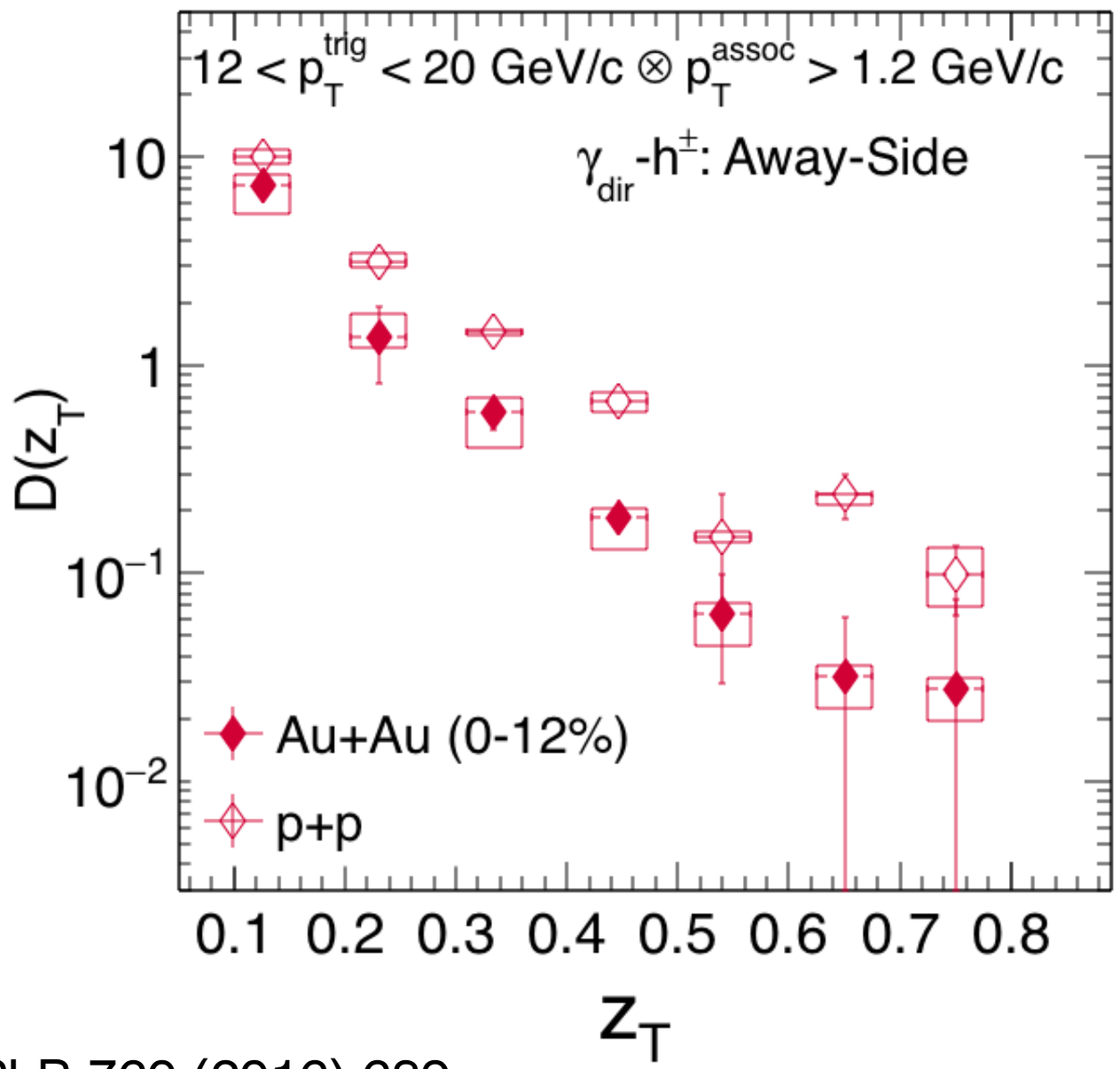
- Applying correction factor to $z_T$ ($z_T^{corr}$) of $\pi^0$ triggers in pp
- $D(z_T^{corr})$ is directly compared to the fragmentation function measured via direct-photon triggers

# Yields associated with $\Upsilon_{dir}$ – trigger: Fragmentation function

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$$Y_{\gamma_{dir}+h} = \frac{Y^{a}_{\gamma_{rich}+h} - RY^{a}_{\pi^0+h}}{1-R}$$

$Y^{a(n)}_{\gamma_{rich}+h}$ and $Y^{a(n)}_{\pi^0+h}$ : away-side (near-side) yields of associated particles per $\gamma_{rich}$ and $\pi^0$ trigger, respectively.

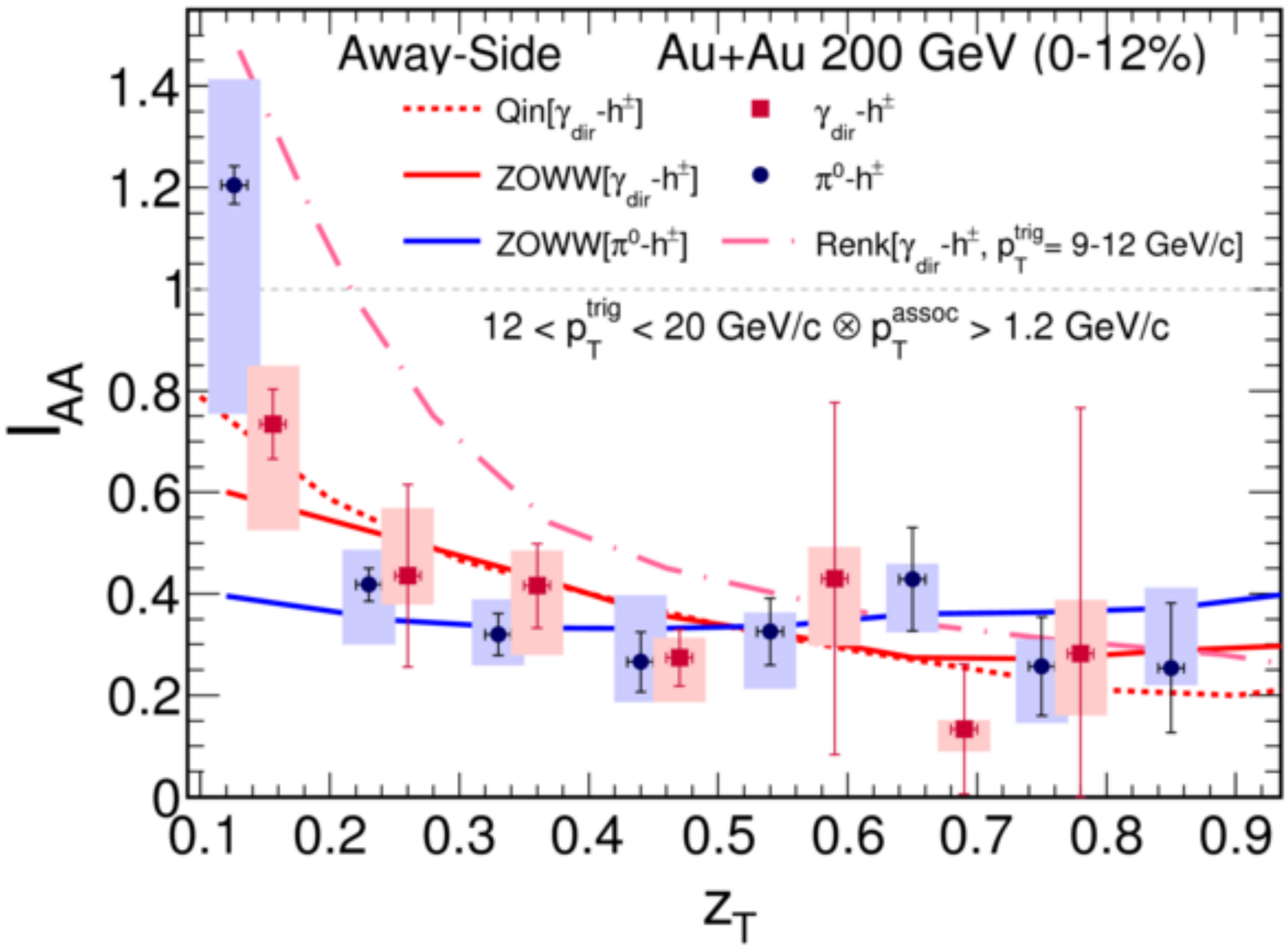
Purity of $\gamma^{rich}$ sample

$$1-R = \frac{N_{\gamma^{dir}}}{N_{\gamma^{rich}}}$$

(1-*R*) are ~40% and ~70% for p+p and Au+Au central (0-12%) collisions, respectively

- Fragmentation function is modified
- Away-side yields show suppression in Au+Au collisions as compared with p+p

# Nuclear modification factor: $I_{AA}$ of $\Upsilon_{dir}$ and $\pi^0$




Qin:
*G.-Y Qin et al.*,PRC 80, 054909 (2009)

ZOWW:
*X. N. Wang et al.,*
*Phys. Rev. C 84, 034902 (2011)*
*Phys. Rev. C 81, 064908 (2010)*
*Phys. Rev. Lett. 103, 032302 (2009)*

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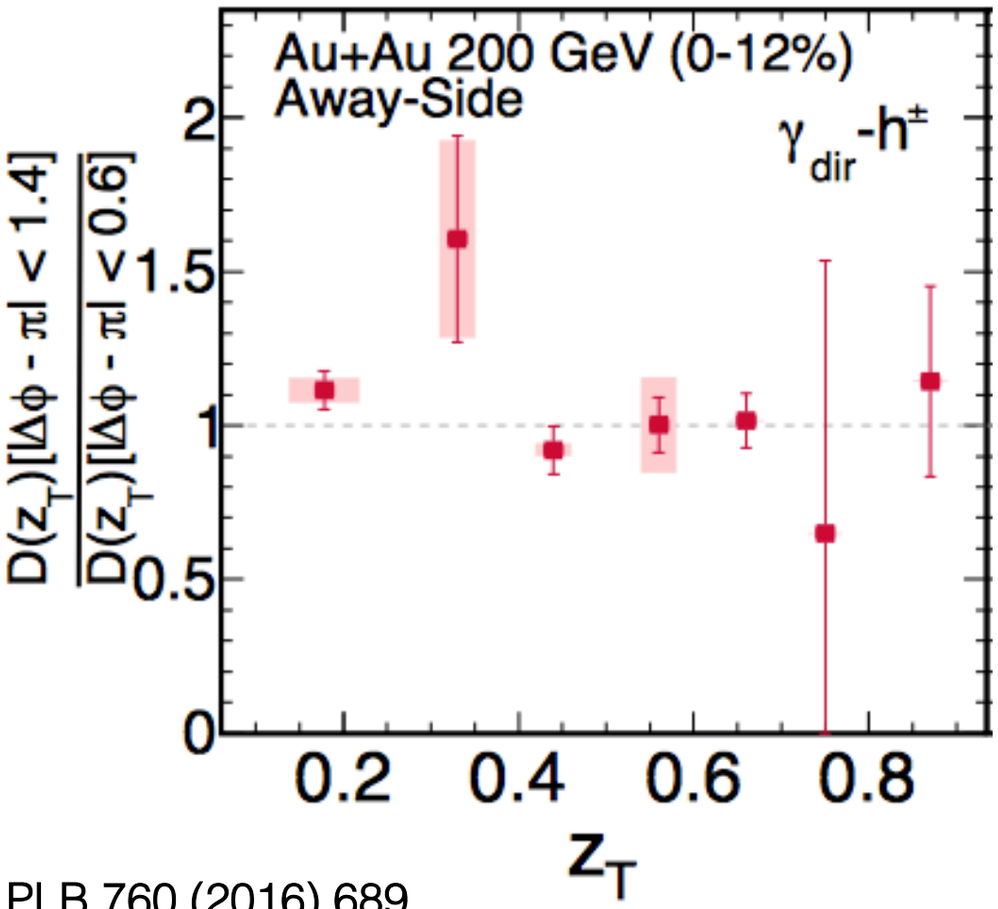
Path length and color factor effect: need greater sensitivity to observe

- *Within large uncertainties*, $I_{AA}^{\pi 0\text{-h}}$ and $I_{AA}^{\Upsilon dir\text{-}h}$ show
  - similar suppression : No clear path length and color factor effect observed
  - strong suppression: particularly for $z_T > 0.2$
- Models show a difference between γ and $\pi^0$ trigger but uncertainties in the data are too large to confirm or reject predicted size of effect

# Energy loss in azimuthal windows

## STAR experiment

$12 < p_T^{trig} < 20$ GeV/c  [$\pm 35^0$ vs $\pm 80^0$]

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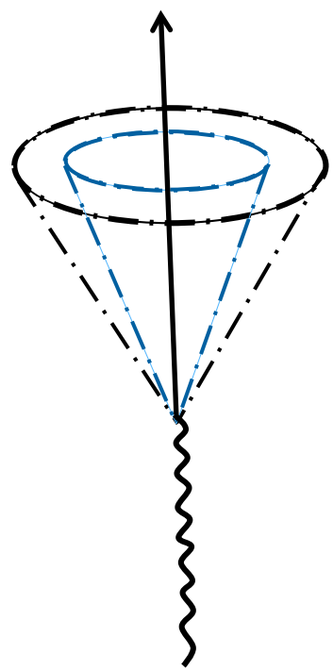
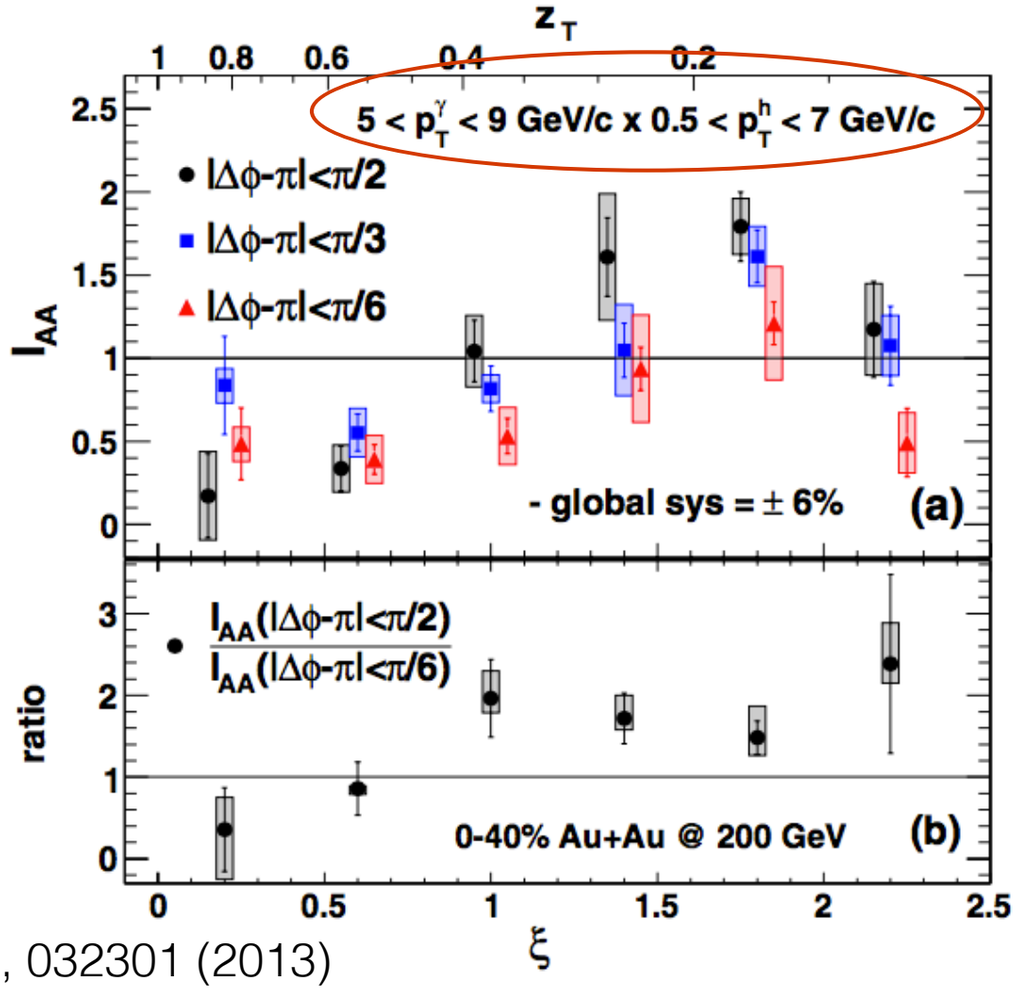


## PHENIX experiment

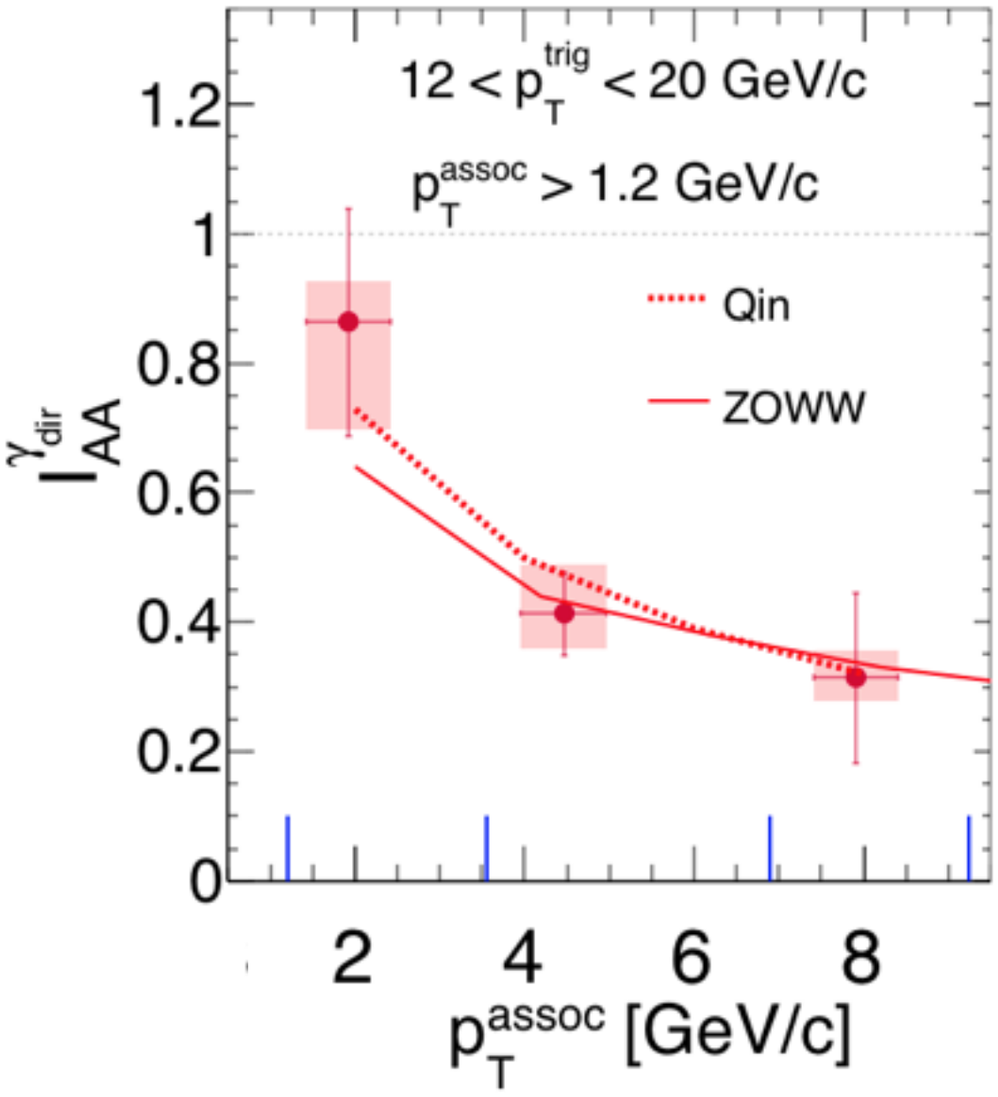


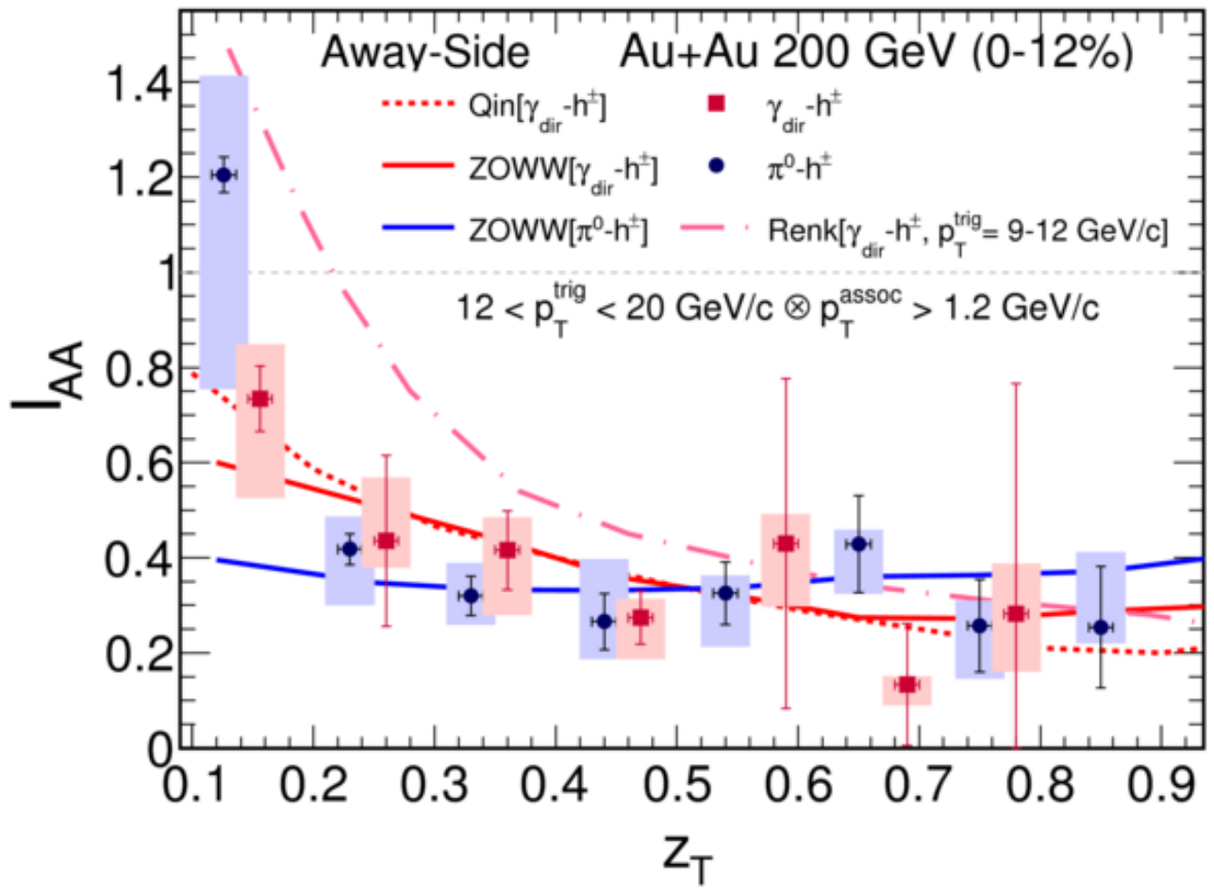

PRL 111, 032301 (2013)

- High trigger $p_T$, no recovery of energy loss even at wider azimuthal angle
  [$12 < p_T^{trig} < 20$ GeV/c ➔ $0.1 < z_T < 0.4$ ➔ $1.2 < p_T^{asso} < 8$ GeV/c]
- Low trigger $p_T$, recovery at smaller $z_T$
  [$5 < p_T^{trig} < 9$ GeV/c ➔ $0.1 < z_T < 0.4$ ➔ $0.5 < p_T^{asso} < 3.6$ GeV/c]

soft particles coming out at wider azimuthal window !!!!

# Energy Loss as a function of associated hadron $p_T$

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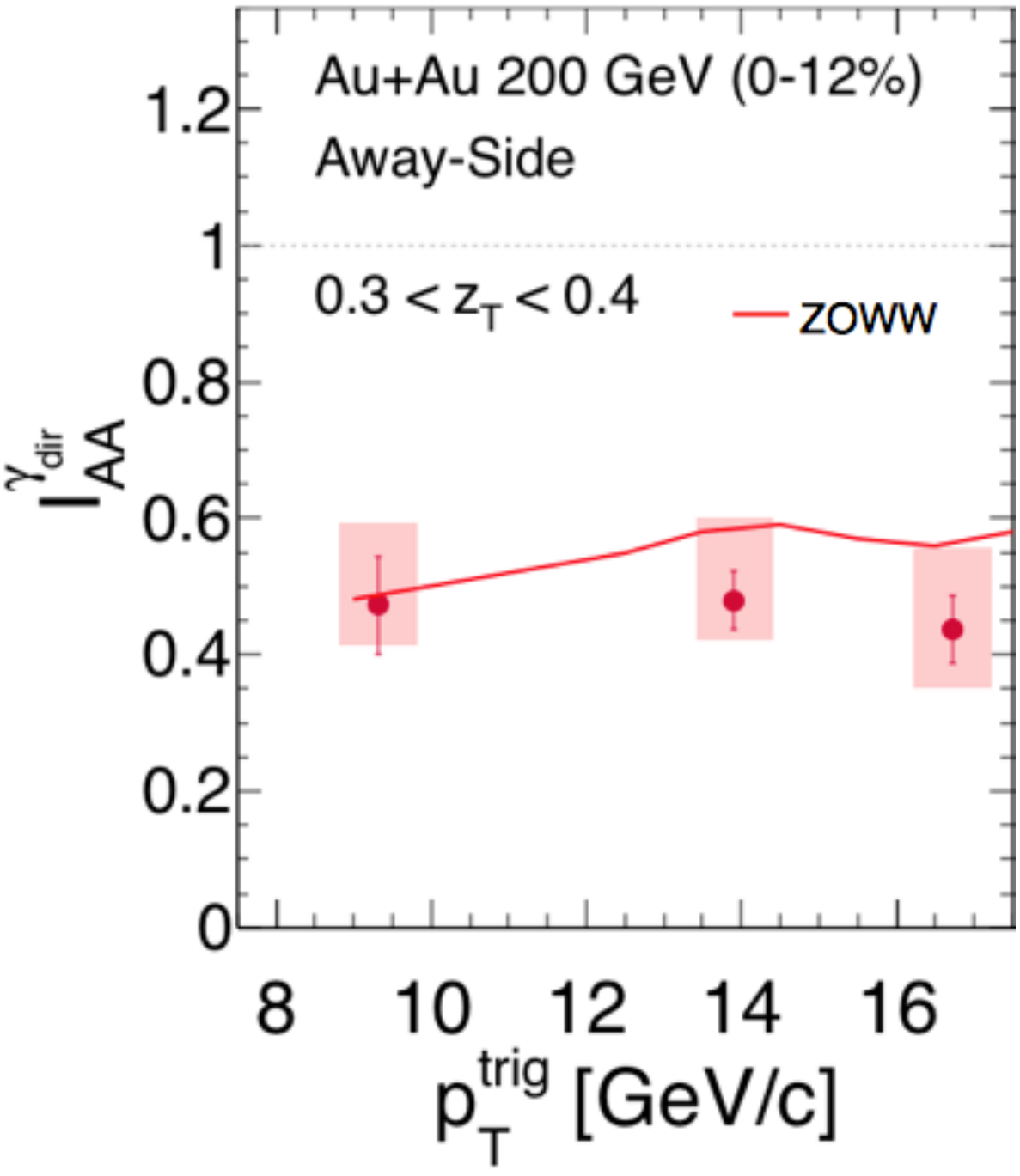
- Soft associated particles are less suppressed compared with high $p_T$
- Energy loss as a function of $z_T$ and associated hadron $p_T$ respond similarly

# Energy Loss as a function of triggered direct photon $p_T$




Energy loss is insensitive to the energy of direct photon trigger at high $p_T$ ( 8-20 GeV/c)

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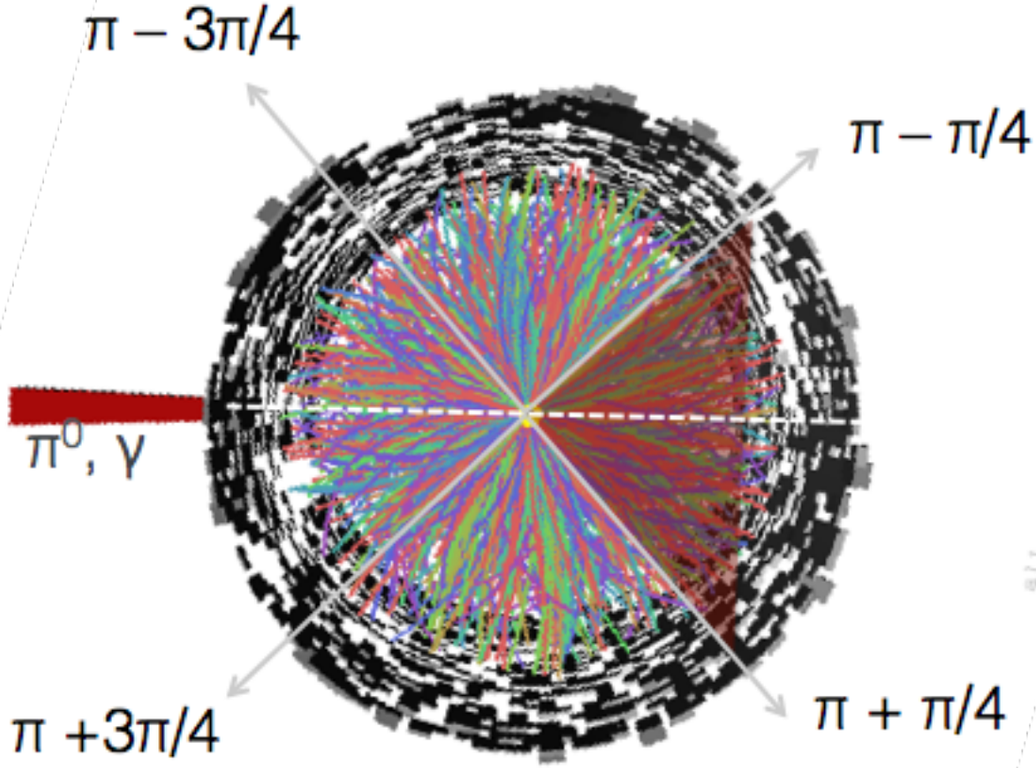
# $\Upsilon_{dir}$ tagged jet measurement in STAR experiment

On-going measurement in STAR



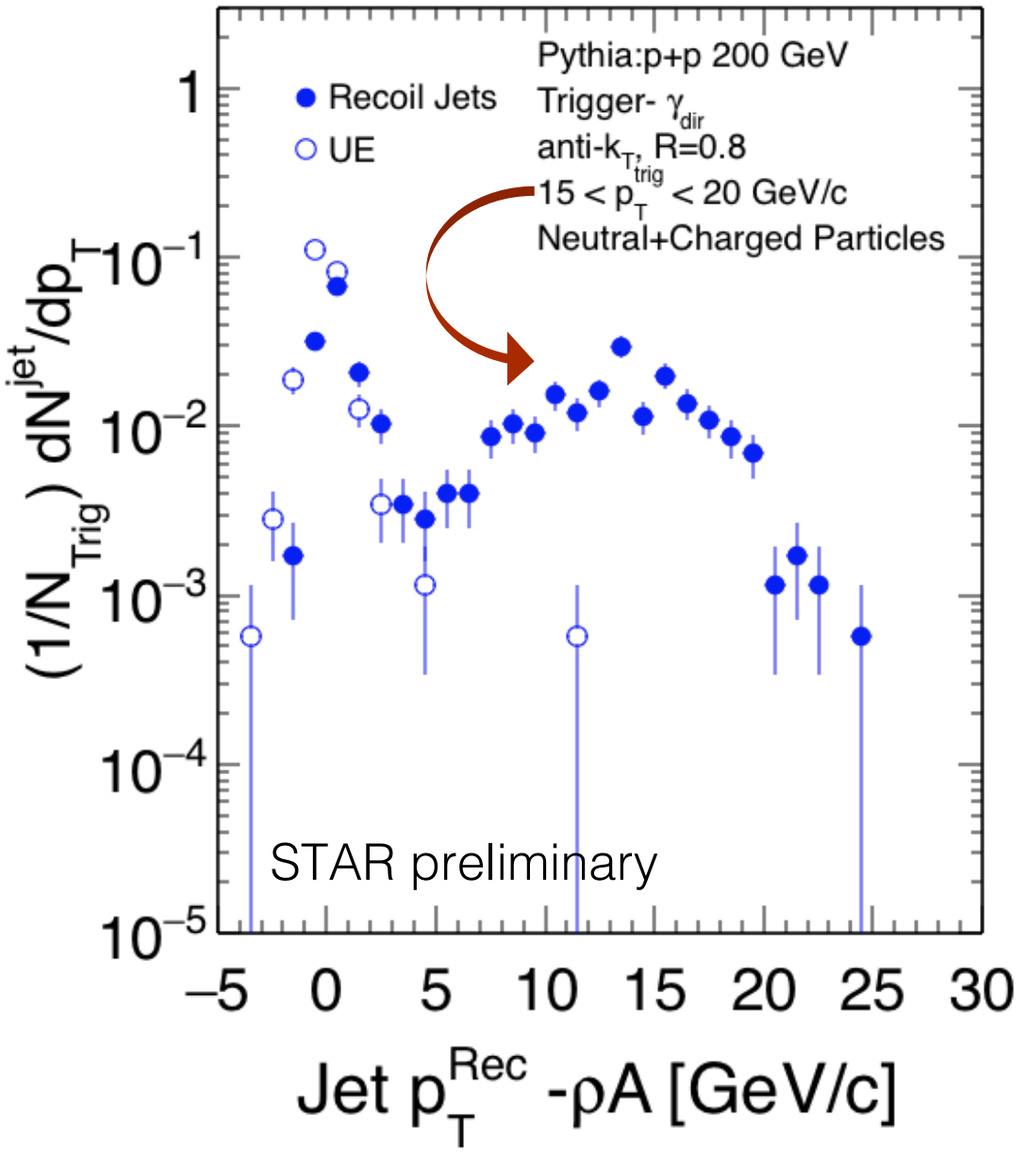

Charged and Full jet reconstruction using STAR TPC and BEMC detector system

Using fastjet jet reconstruction (anti-$k_T$, $k_T$ algo.)

For wide range of jet radii ($0.3 < R < 0.6$) since large acceptance in TPC and BEMC

# $\Upsilon_{dir}$ triggered recoil full jet reconstruction (Pythia)

Preliminary Pythia8 simulation study




- For full Jet reconstruction, nice peak at $15 < p_T^{trig} < 20$ GeV/c
- Work is ongoing using STAR data for Au+Au and p+p collisions…..
- Stay tuned for QM2017

# Summary and Outlook

- Within uncertainties, no clear path length and color factor effect observed in $\pi^0$ vs. γ triggers !
  - These effects are not large enough to be observed within our current precision.
- "Modified" FF dependent on $p_T^{trig}$
- Less suppression or even enhancement at low $p_T^{assoc}$
- Soft particles ($p_T^{assoc}$ < 2 GeV/c) coming out at wider azimuthal angles
- Energy loss is insensitive to the energy of triggered γ at high $p_T$ (8-20 GeV/c) at RHIC

Work is ongoing in STAR experiment to measure both γ- and $\pi^0$-tagged charged/Full jet reconstruction to improve our understanding on parton energy loss at RHIC.


Interesting Direct photon-Jet physics is ongoing at RHIC

Stay tuned…..

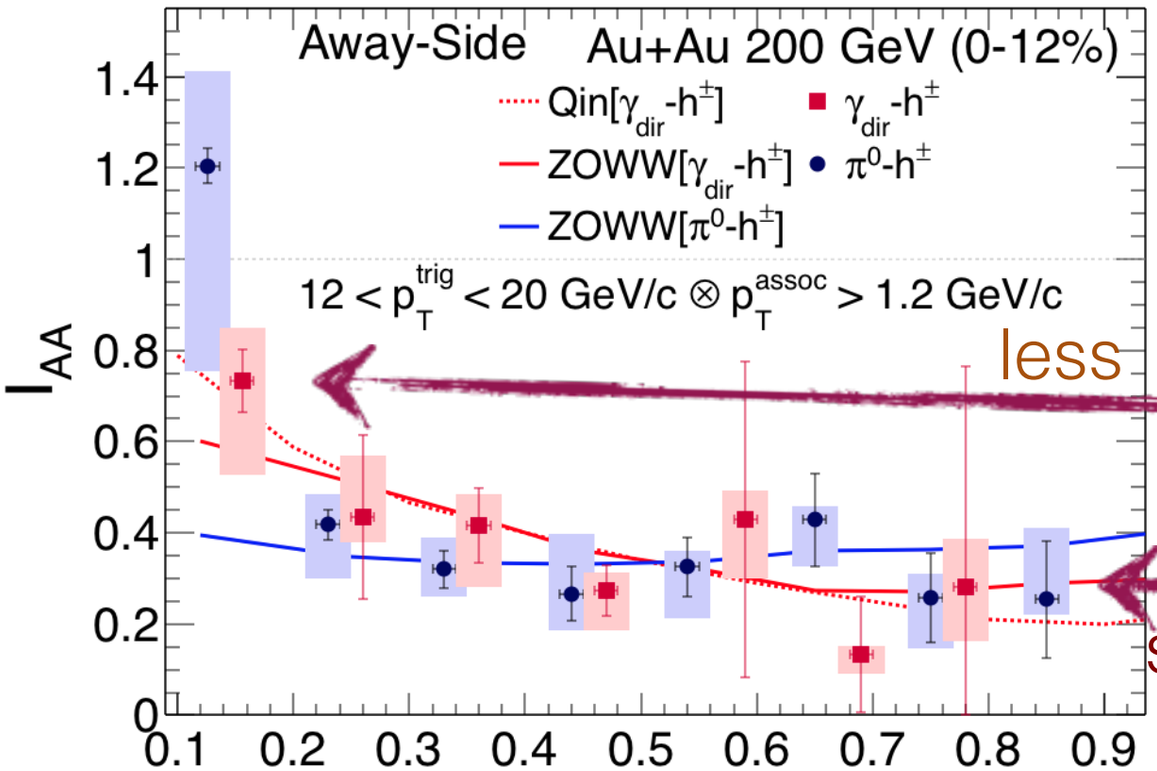
Thank you!

# Back Up

# Nuclear modification factor: $I_{AA}$ of $\Upsilon_{dir}$

## STAR experiment

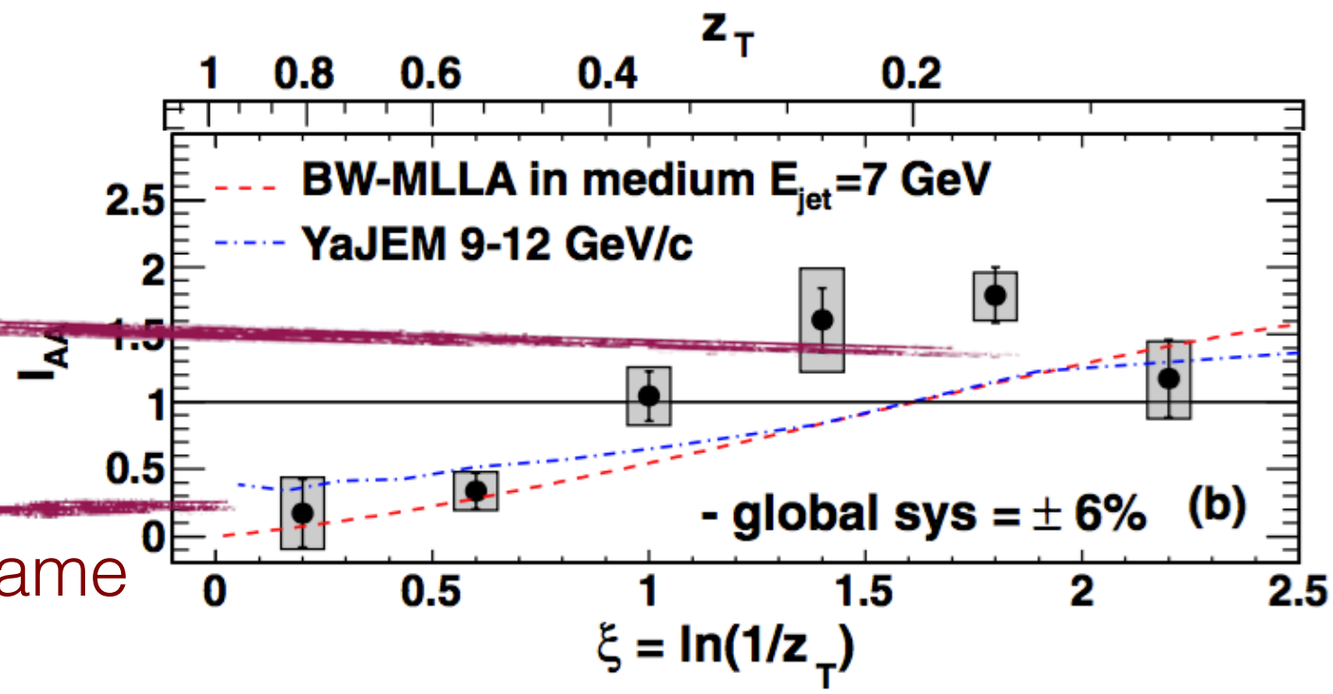
$12 < p_T^{trig} < 20$ GeV/c




arXiv:1604.01117

## PHENIX experiment

$5 < p_T^{trig} < 9$ GeV/c




PRL 111, 032301 (2013)

less

same

- At low $z_T$, $I_{AA}$ is less suppressed at high $p_T^{trig}$ than at low $p_T^{trig}$
- At high $z_T$, similar level suppression in both $p_T^{trig}$ regions

- Redistribution of energy in YaJEM model to differentiate between PHENIX and STAR $I_{AA}$
- Qin, ZOWW models don't show enhancement at low $z_T$ (for 12-20 GeV/c)