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Direct-photon+hadron correlations for the study of parton energy loss at the top RHIC energy

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Outline

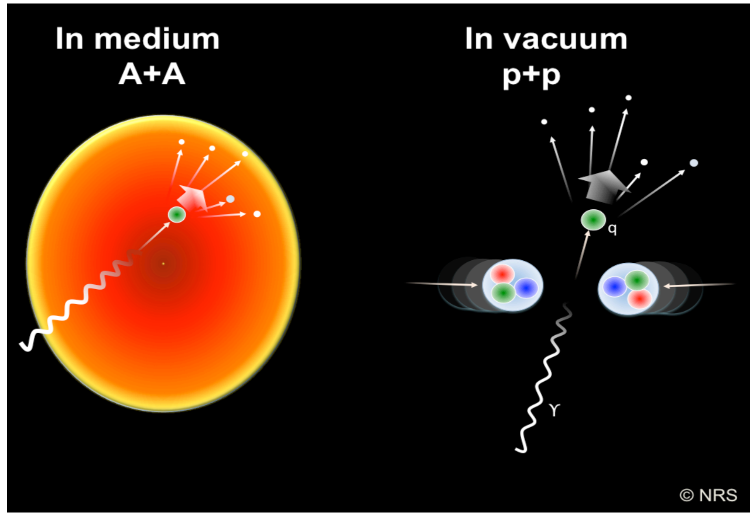
- **Motivation:** ***Direct Photon-hadron correlation***
- **STAR detector system:** ***Advantage and data***
- **Direct-photons/π^0 discrimination:** ***Transverse shower profile***
- **Results:** ***Fragmentation functions and Nuclear modification factor***
- **Summary**

Motivation: *Direct Photon-hadrons correlation*

Direct Photon (γ_{dir}) production ➡

qg- Compton scattering qqbar- annihilation

- γ_{dir} **doesn't interact in QCD medium**
- **Transverse energy of γ_{dir} approximates that of initial parton p_T in γ_{dir}-jet events**
- **High-p_T suppression at away-side γ_{dir}-jet events can give information about dense medium created in high energy heavy-ion collisions**



PRL 103, 032302 (2009),PRL 77, 231 (1996), PRL 98, 212301 (2007), PRC 80, 054909 (2009), etc.

- **Initial energy loss of away side parton (Frag. into Jet) in medium depends on**
  - **Initial energy, Path length and/or Color factor, coupling strength, etc.**
- **γ_{dir}-hadron correlation for the estimation of medium effect by,**

Nuclear modification factor:

$$I_{AA} = \frac{D(z_T)_{AA}}{D(z_T)_{pp}}$$

(Away-side FF of Au+Au collisions)
(Away-side FF of p+p collisions)

Nuclear modification factor: I_{AA} of $Υ_{dir}$-jet

- **Tangential and surface emission affect single and di-hadron spectra for the study of nuclear modification factor** Zhang et al., PRL 98, 212301 (2007)

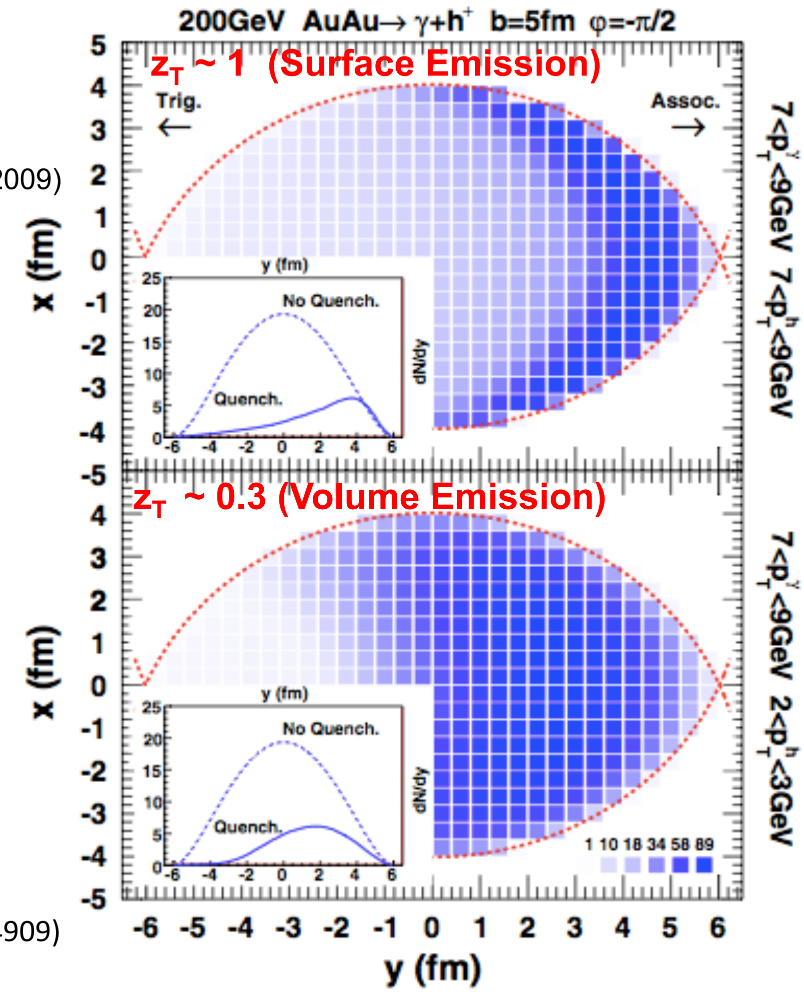
- **NLO pQCD calculation:** PRL 103, 032302 (2009)
  - **The Υ-triggered hadron spectra at**
    - **Small z_T dominated by volume emission**
    - **Large z_T dominated by surface emission**

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

- **$Υ_{dir}$ trigger of away-side jet can give approximate initial p_T of parton**
  - **Initial energy**:
    - **$Υ_{dir}$-$h^{\pm}$ correlation at different p_T^{trig}**
  - **Path length** or **Color factor :**
    - **$Υ_{dir}$-$h^{\pm}$ and π^0-$h^{\pm}$ correlation**

(STAR Collab., PRC 82, 034909)

Transverse spatial distributions of the initial Υ-jet production vertices

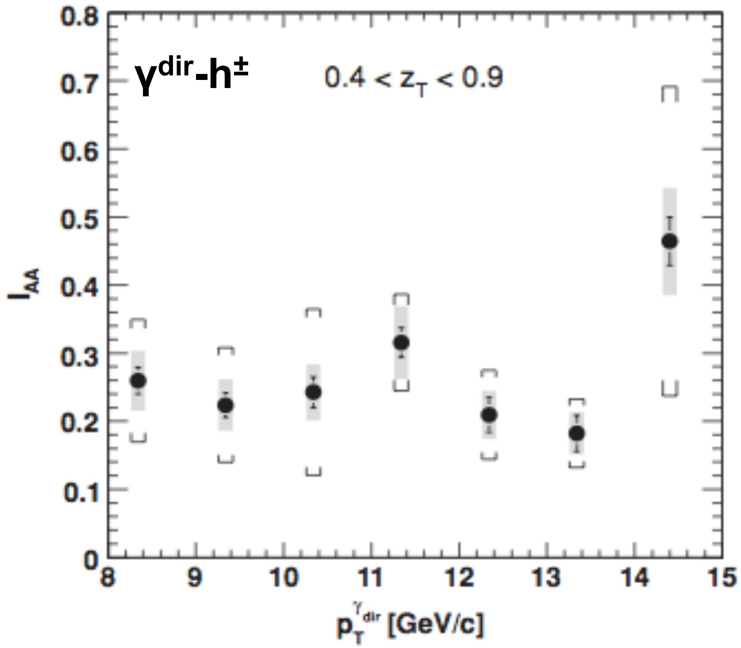


Zhang et al., PRL 103, 032302 (2009)

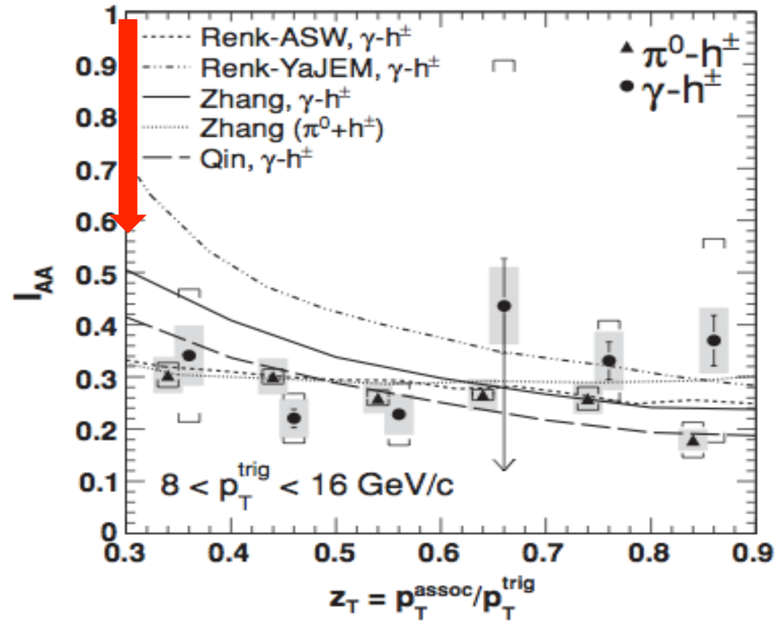
Published STAR experiment results: I_{AA} of γ_{dir}-jet

(STAR Collab., PRC 82, 034909)

AuAu at 200 GeV



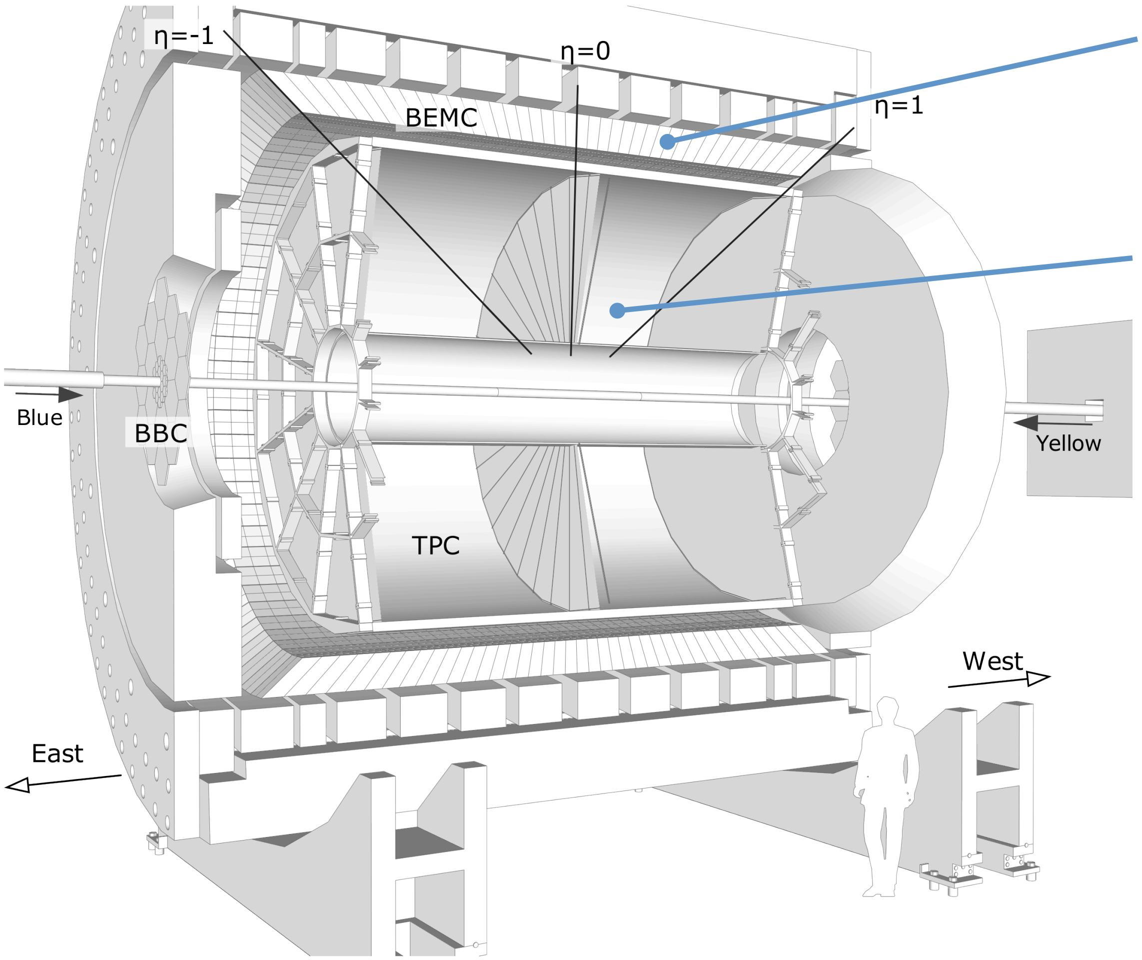
Where is this lost energy ?



- The dependence of I_{AA} (γ^{dir}-$h^{\pm}$) on p^{trig} shows no significant dependence on the initial parton energy within kinematic region $0.4 < z_T < 0.9$
- I_{AA} of γ^{dir}-$h^{\pm}$ shows no z_T dependence within $0.3 < z_T < 0.9$

- Hence, investigation on the behavior of nuclear modification factor at low z_T
- To achieve this region we use,
  - triggered by high p_T γ^{dir} and π^0 : $12 < p_T^{trig} < 20$ GeV/c
  - low p_T associated hadron: $1.2 < p_T^{assoc}$ (GeV/c)

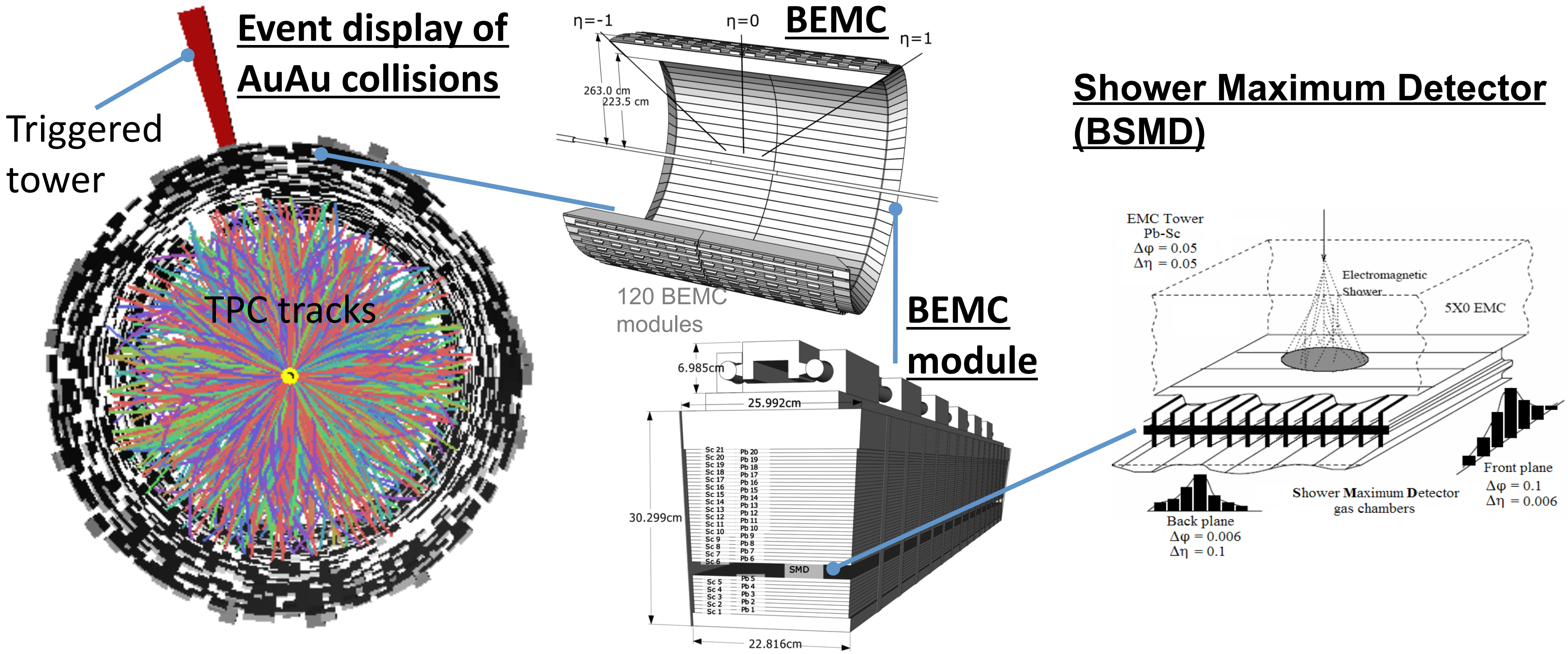
STAR detector system: *Advantage and data sets*



- **Barrel ElectroMagnetic Calorimeter (BEMC) is used to identify EM clusters**
- **Time Projection Chamber (TPC) is used for identifying charged hadron tracks**
- **AuAu 200 GeV (Year 2011)**
- **pp 200 GeV (Year 2009)**
- **STAR detector system gives unique opportunity, full 2π-azimuth and wide |η| < 1.0, both for BEMC and TPC**
- **Triggered on high energy tower in the BEMC**

- **Important part of this analysis :- *Discrimination between π^0 and Υ_{dir}***
  - **By Transverse Shower Profile (TSP) method**
  - **Using Barrel shower Maximum detector (BSMD)**

STAR detector system: *BEMC and BSMD*



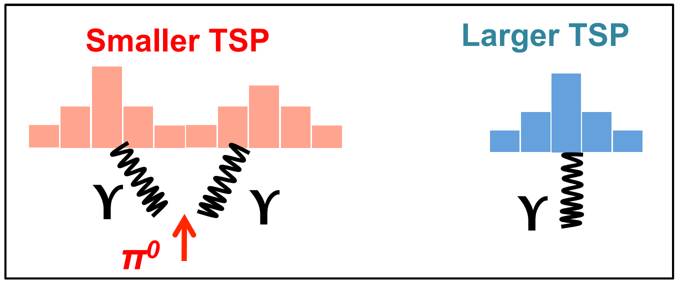
- **BEMC:- The energy deposition of EM cluster**
- **BSMD:- The η and ϕ positions of EM cluster**

- **Correlation between triggered EM neutral clusters and Charged hadron tracks from TPC**
- **Trigger tower with tracks, having p > 3 GeV/c, pointing to it is rejected**

- **Crucial part of this analysis**
  - **Υ/π^0 discrimination and**
  - **Υ_{dir} yield extraction**

Transverse shower profile: π^0/Υ_{dir} discrimination

- BSMD η-trips and ϕ-strips along with BEMC tower give information about Transverse Shower Profile (TSP)

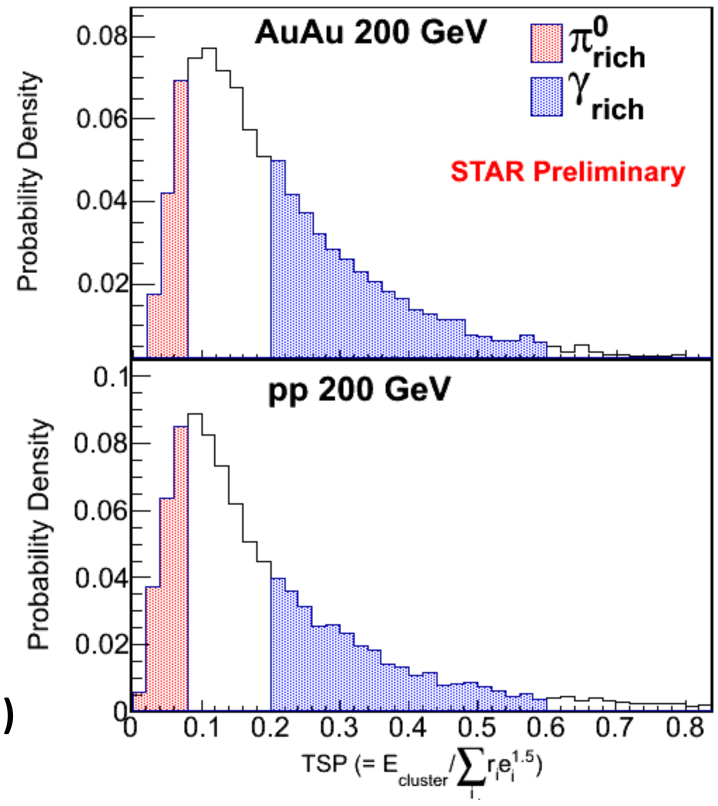


$$\mathrm{TSP} = \frac{\mathrm{E_{cluster}}}{\sum_i \mathrm{e_i r_i^{1.5}}}$$

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

(Exponent in r_i is decided based on the best discrimination results obtained between π^0/Υ sample from simulation study)

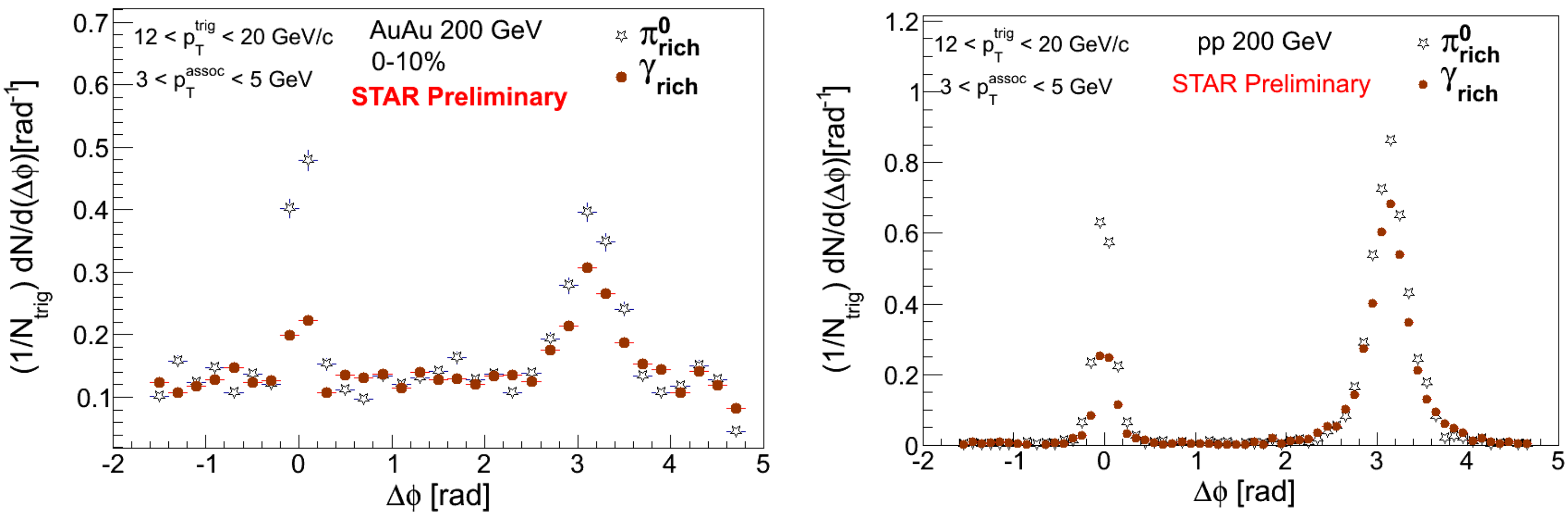
Probability density of TSP



- **TSP cuts are tuned to get**
  - **a nearly pure sample of π^0 (called " π^0_{rich}")**
  - **a sample with enhanced fraction of Υ_{dir} (called `Υ_{rich}')**

Correlation function: π^0_{rich} and Υ_{rich}

Raw correlation functions



- **Raw correlation functions for π^0_{rich} and Υ_{rich} triggered associated hadrons in $|\eta| < 1.0$**
- **Uncorrelated background is then subtracted and $\Delta\phi$ acceptance is corrected using the mixed events (modulated with elliptic flow for AuAu collisions)**

Extraction of *associated Yields:* *Of Υ_{dir} and π^0 trigger*

- **Near-side and away-side yields are extracted within $|\Delta\phi| \leq 1.3$ and $|\Delta\phi - \pi| \leq 1.3$**
- **Extracted raw yields are corrected for charge particle reconstruction efficiency**

- **Extraction of Υ_{dir} associated yields:**
  Assuming near side Υ_{dir} associated hadron yield is zero,

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

$$R = \frac{Y^{n}_{\gamma_{rich}+h}}{Y^{n}_{\pi^0+h}} \quad \textbf{and} \quad 1 - R = \frac{N^{\gamma_{dir}}}{N^{\gamma_{rich}}}$$

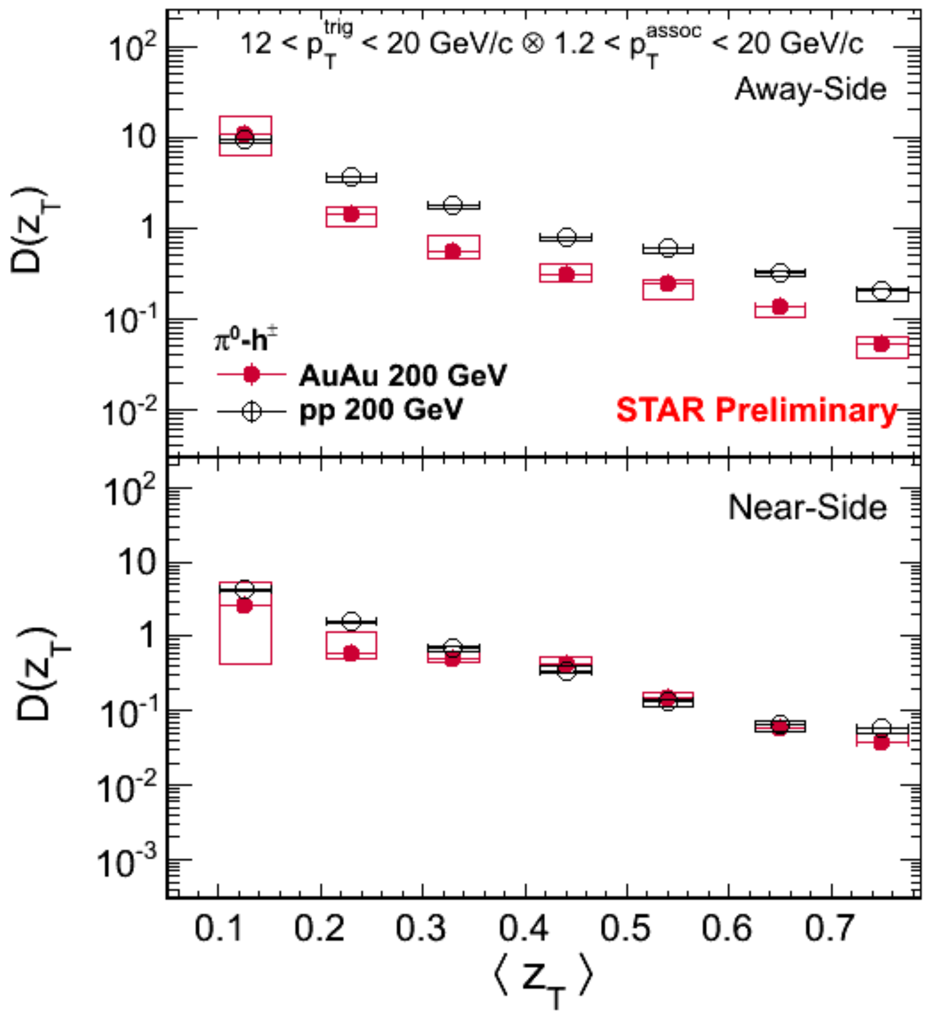
$Y^{a(n)}_{\gamma_{rich}+h}$ **: away-side (near-side) yields of associated particles per Y_{rich} trigger**

$Y^{a(n)}_{\pi^0+h}$ **: away-side (near-side) yields of associated particles per π^0 trigger**

- **The values of (1-$\mathcal{R}$) are found to be ~40% and ~70% for pp and AuAu central (0-10%) collisions, respectively**

Yields associated with π^0 - trigger

- Associated hadron yields with π^0 per number of trigger as a function of z_T within $|\eta| < 1.0$



▪ AuAu central (0-10%) collisions compare with pp collisions at 200 GeV colliding energy

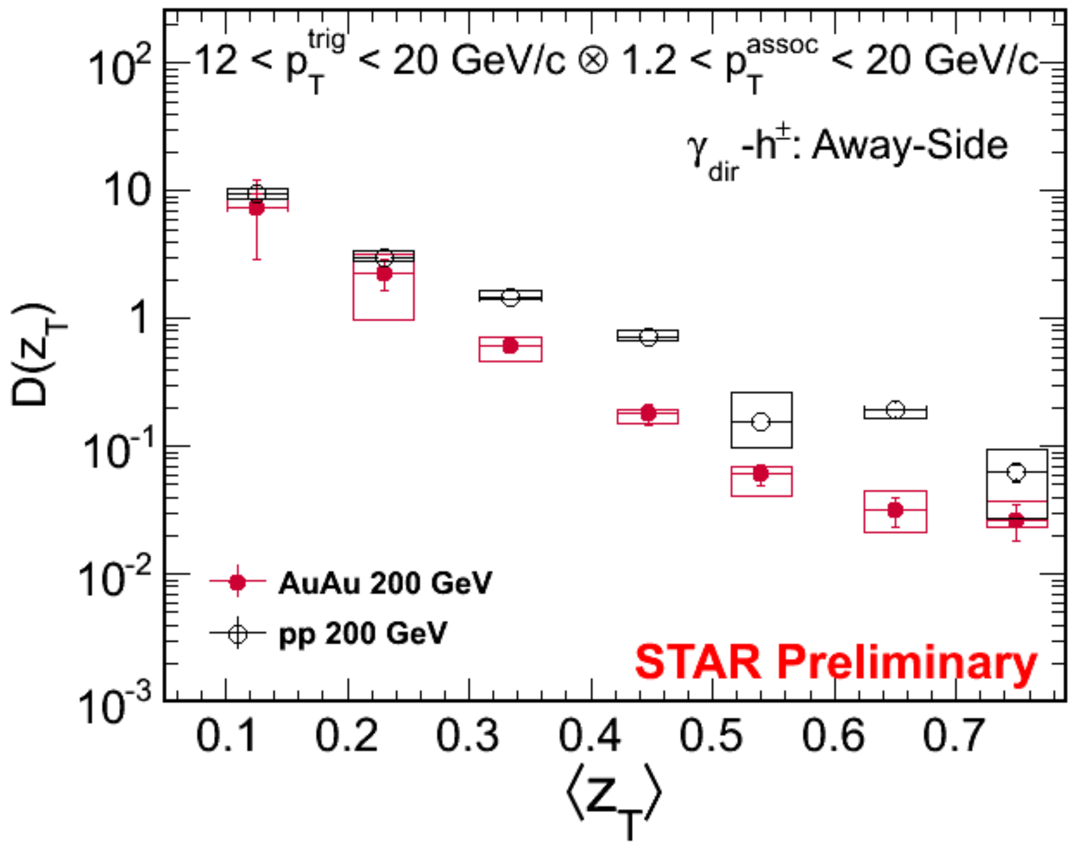
▪ Away-side yields show suppression in AuAu collisions as compared with pp collisions

▪ Near-side shows no significant suppression

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

Fragmentation function: *triggered Υ_{dir} - hadrons*

- **Associated hadron yields with Υ_{dir} per number of trigger as a function of z_T within $|\eta| < 1.0$**



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

- **AuAu central (0-10%) collisions compare with pp at 200 GeV colliding energy**
- **Away-side yields shows suppression in AuAu collisions as compared with pp**

Nuclear modification factor: *|Δϕ – π| integration window*

12 < p_T^{trig} < 24 GeV/c, and 3 < p_T^{assoc} (GeV/c)

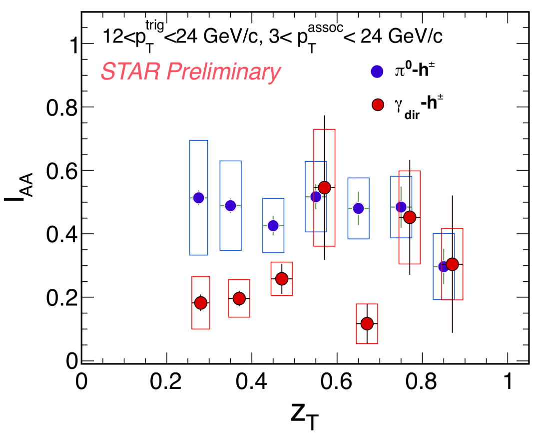
12 < p_T^{trig} < 20 GeV/c, and 1.2 < p_T^{assoc} (GeV/c)

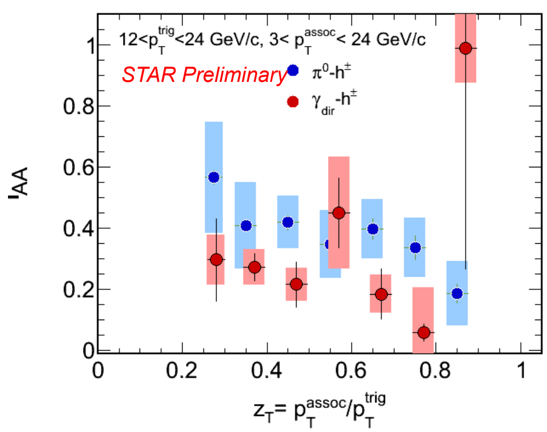
Yields extracted within $|\Delta\phi - \pi| \leq 0.63$

$|\Delta\phi - \pi| \leq 1.3$

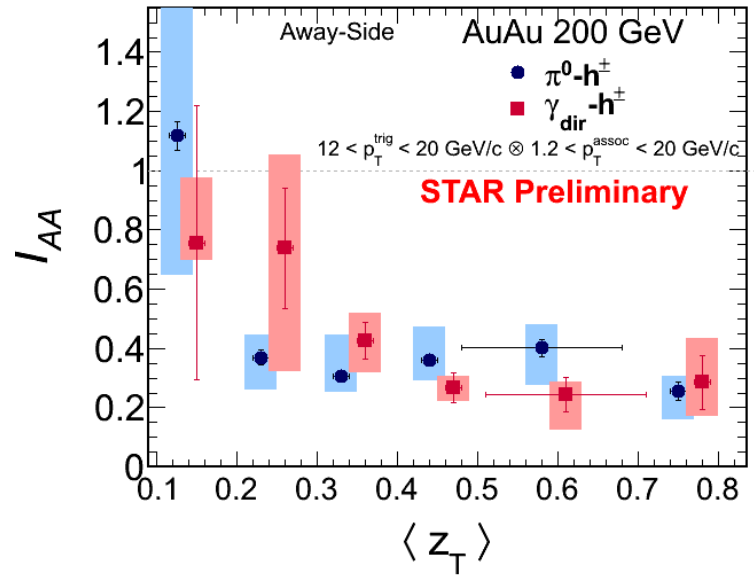
$|\Delta\phi - \pi| \leq 1.3$

[QM2014] AuAu 0-10% central collisions





AuAu 0-10% central collisions

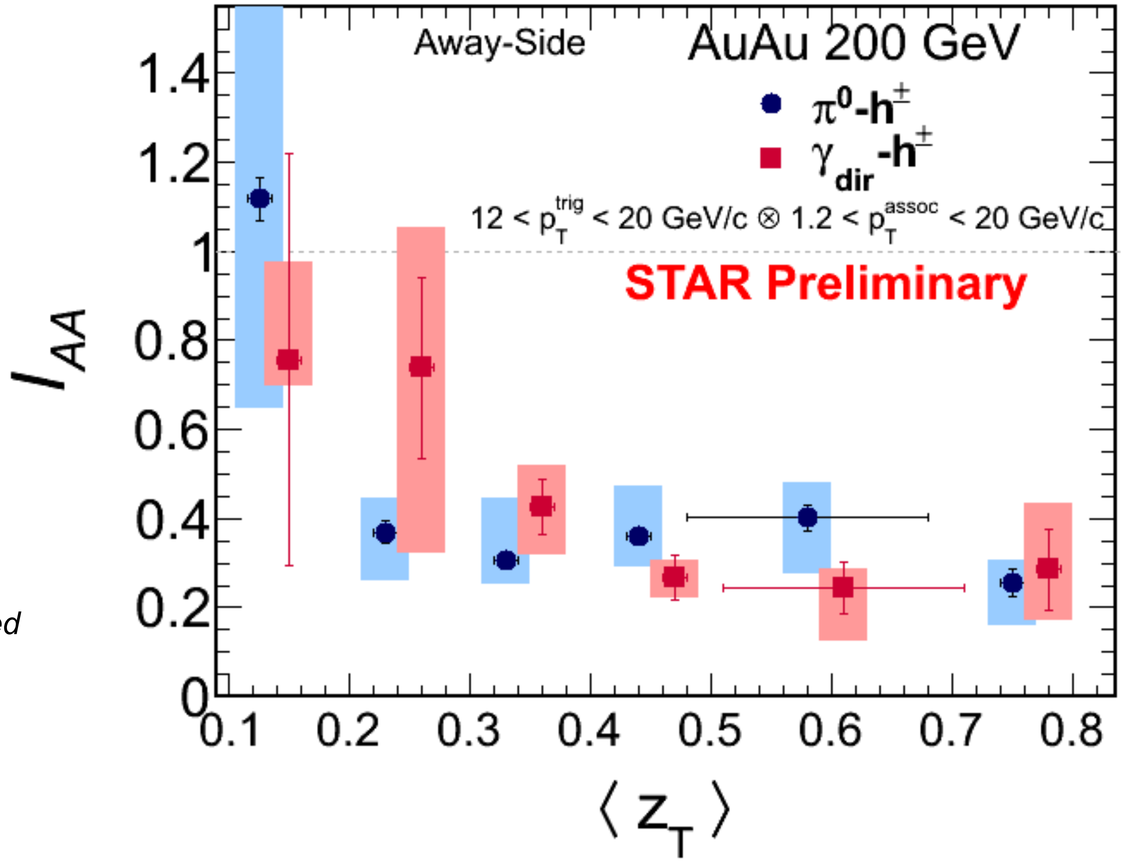


- **Changing Δϕ integration window doesn't change I_{AA} results significantly, mainly at high z_T**
- **Lower associated p_T range (1.2 < p_T GeV/c) provides lower-z_T reach**

Nuclear modification factor: I_{AA} of γ_{dir} and π^0

- **Yields extracted within $|\Delta\phi - \pi| \leq 1.3$**
- **$12 < p_T^{trig} < 20$ GeV/c, and $1.2 < p_T^{assoc}$ (GeV/c)**

AuAu 0-10% central collisions



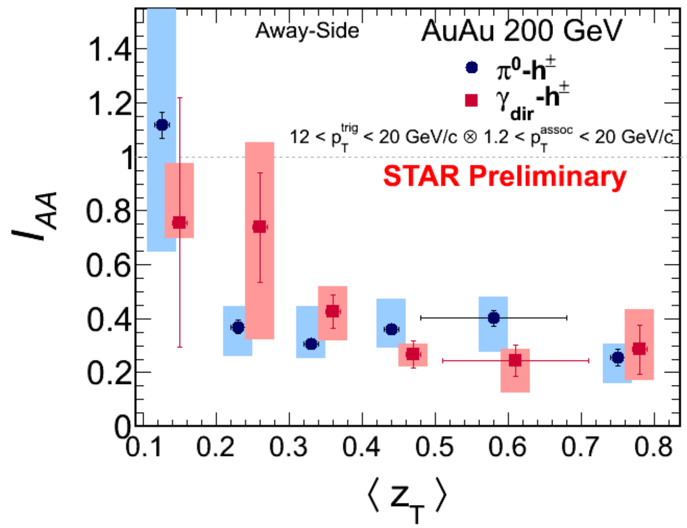
(z_T bins of $I_{AA}^{\gamma dir\text{-}h}$ *are shifted by 0.03 unit for visibility)*

- **$I_{AA}^{\pi 0\text{-}h}$ and $I_{AA}^{\gamma dir\text{-}h}$ show similar and strong suppression**
- **At low z_T, data suggests lost energy may start to be recovered (with large uncertainty)**

Summary

- Parton energy loss, due to hot and dense medium creation, can be studied by using Υ_{dir}-hadron correlation
- Υ_{dir}-triggers give access to initial parton energy for the study of parton energy loss
- A transverse shower profile technique is used for the Υ/π^0 discrimination

- $I_{AA}^{\pi 0\text{-}h}$ and $I_{AA}^{\Upsilon dir\text{-}h}$ show similar and strong suppression
- At low z_T, data suggests lost energy may start to be recovered (with large uncertainty)

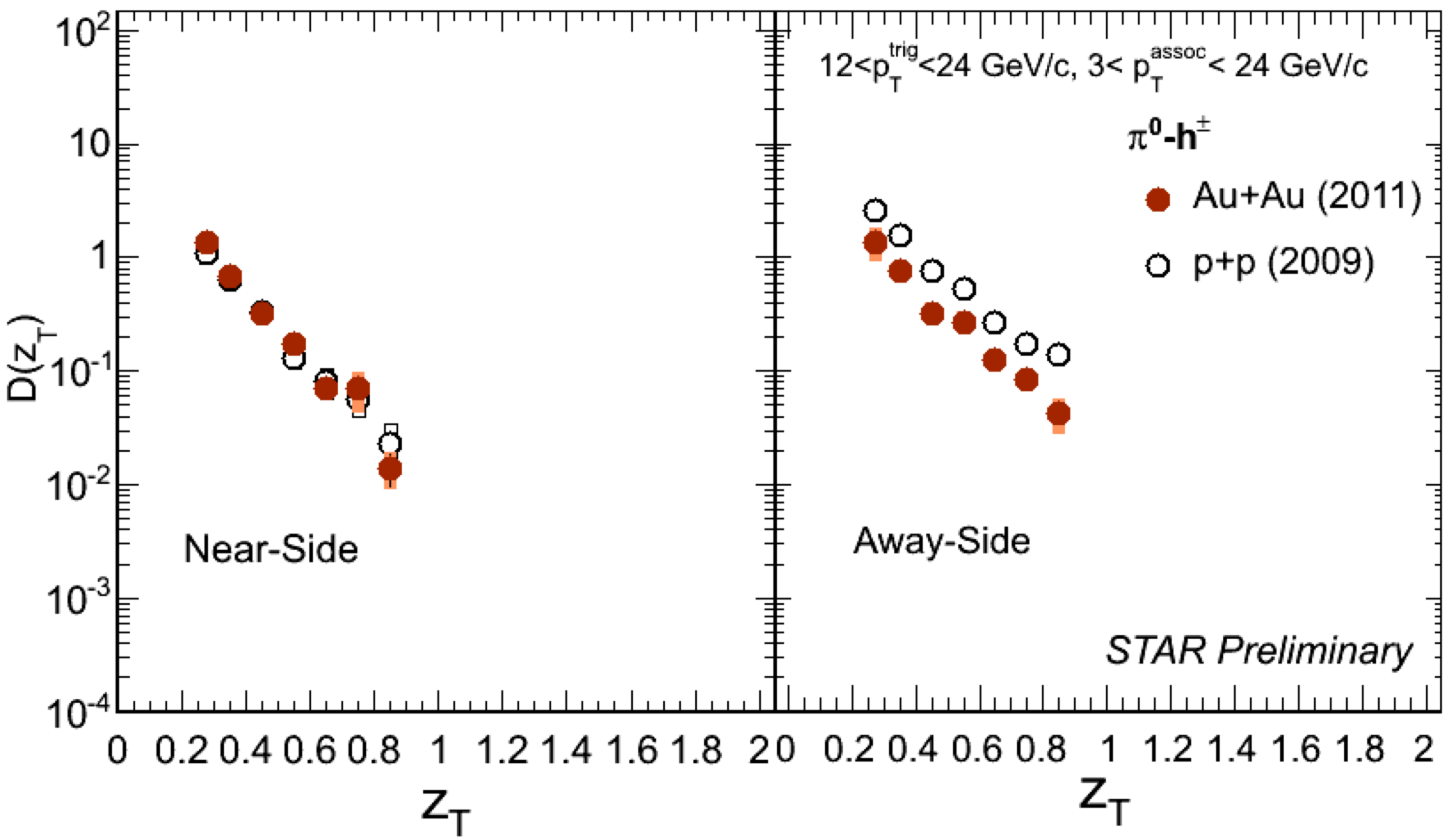


Back Up

Fragmentation function: *triggered π^0 - hadrons*

QM2014

$12 < p_T^{trig} < 24$ GeV/c, and $3 < p_T^{assoc} < 24$ GeV/c
Yields extracted within $|\Delta\phi - \pi| \leq 0.63$

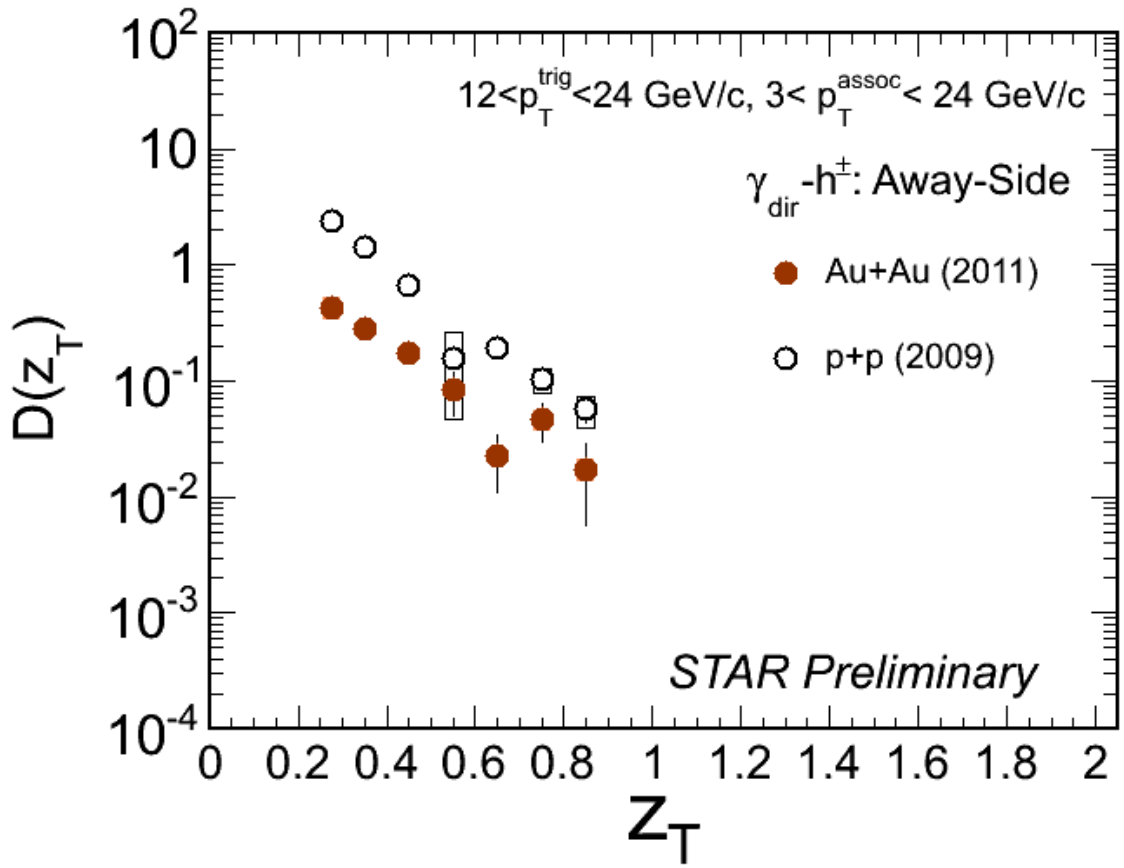


Fragmentation function: *triggered γ_{dir} - hadrons*

QM2014

$12 < p_T^{trig} < 24$ GeV/c, and $3 < p_T^{assoc} < 24$ GeV/c

Yields extracted within $|\Delta\phi - \pi| \leq 0.63$



Dependence of yields on integration window

Fragmentation function as a function of $\Delta\phi$ width at $0.1 < z_T < 0.2$