Jets and high-p_T probes measured in the STAR experiment

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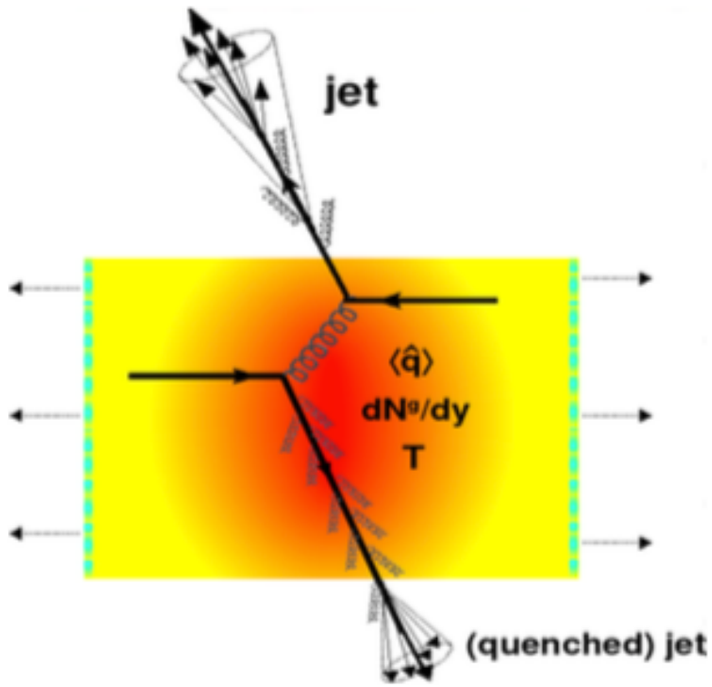
Jets and high-p_T measurements in Heavy-Ion Collisions

Jets and high-p_T particles:

- Tomography to probe the hot and dense QCD medium ($p_T > Q_0 >> \Lambda_{QCD}$)
- Directly coupled to QCD degrees of freedom
- Produced on very short time scales ($\tau \sim 0.1$ fm/c)



To understand the medium properties:

Parton energy loss in QCD medium depends on
- Initial energy of parton, color factor, path length, gluon density, transport coefficient, etc.

Jets and high-p_T physics help to understand the properties of hot and dense QCD medium (QGP)

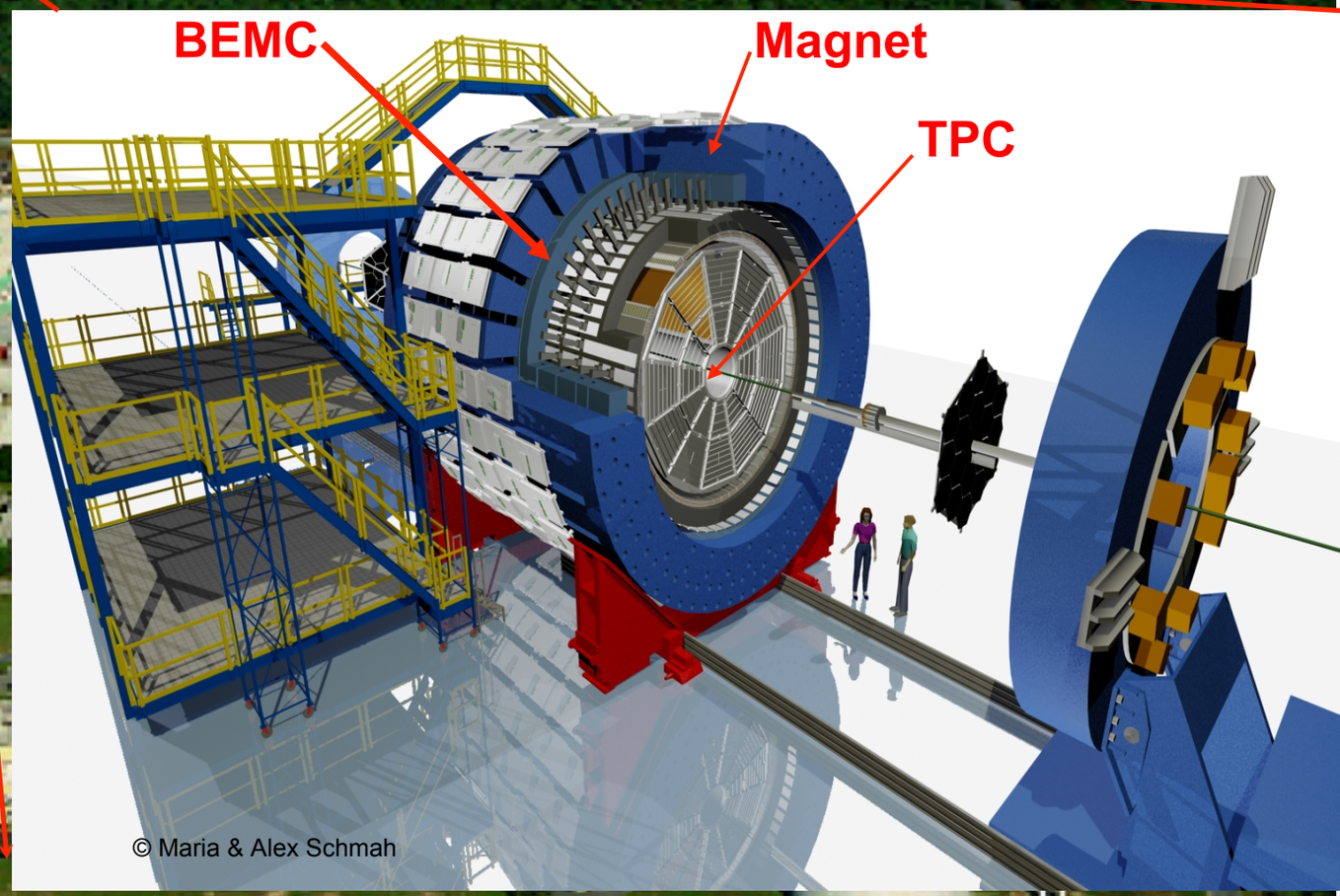
PHENIX

STAR

AGS

TANDEM

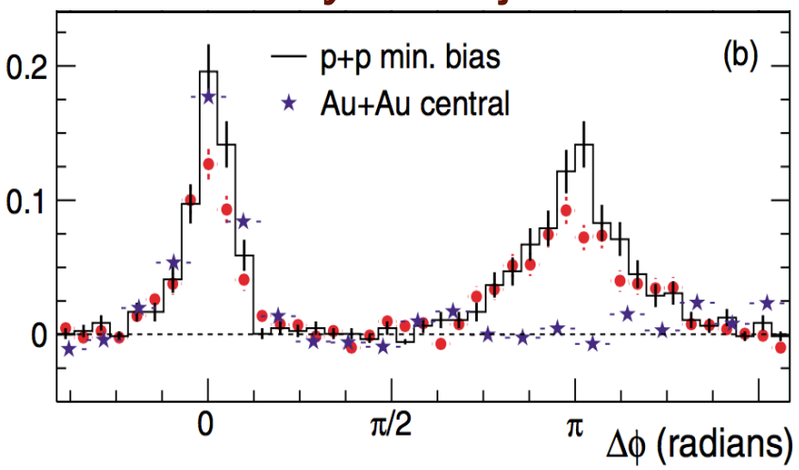
- 2π azimuthal acceptance
- Extended mid rapidity |η| < 1
- Excellent PID capability (using TPC and ToF)
- BEMC and TPC: Neutral and charged particles



Some of the interesting observations in STAR exp.

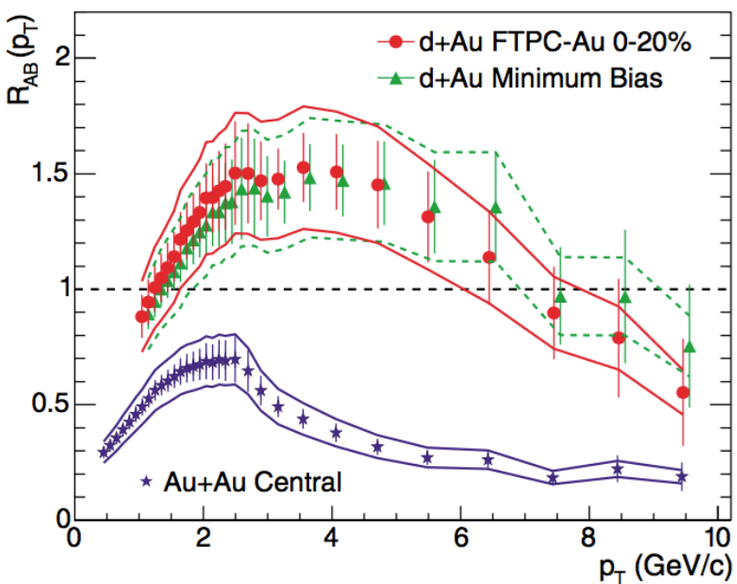
Central AuAu collisions

Disappearance of away side jet



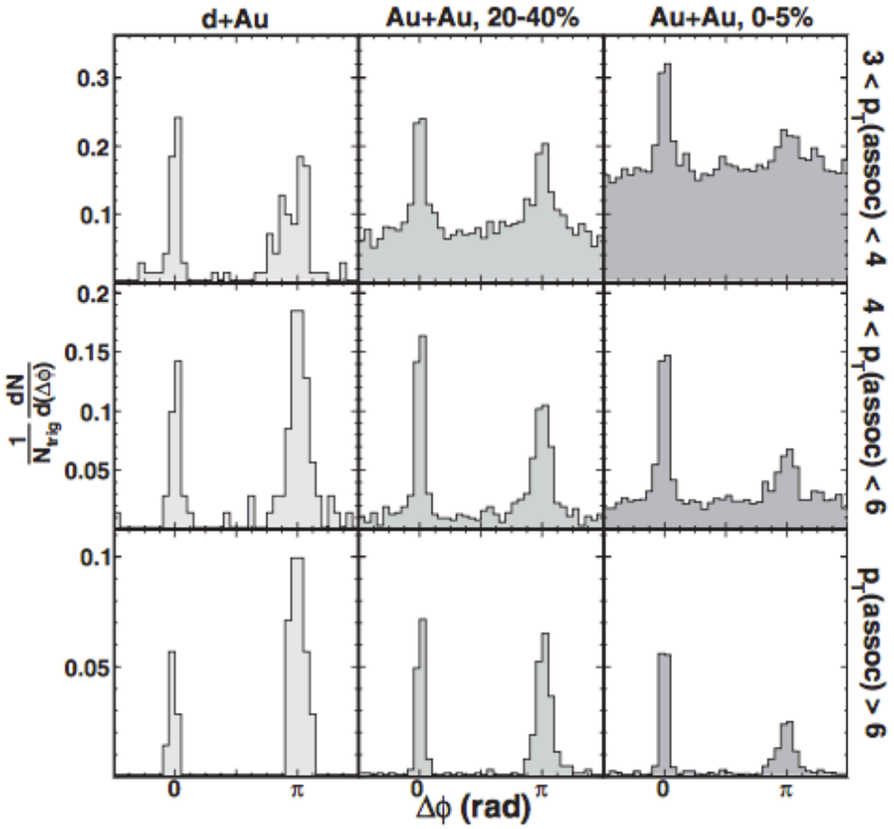
PRL 91, 072304 (2003)

High-p_T suppression



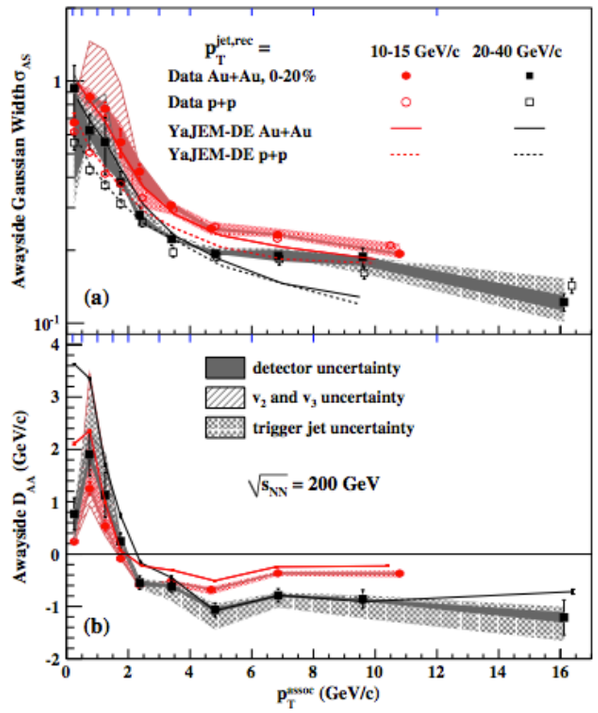
PRL 91, 072304 (2003)

Di-Jet: Disappearance at low p_T and survival at high-pT



PRL **97**, 162301 (2006)

Jet-h correlations: High-p_T balanced by Low p_T enhancement



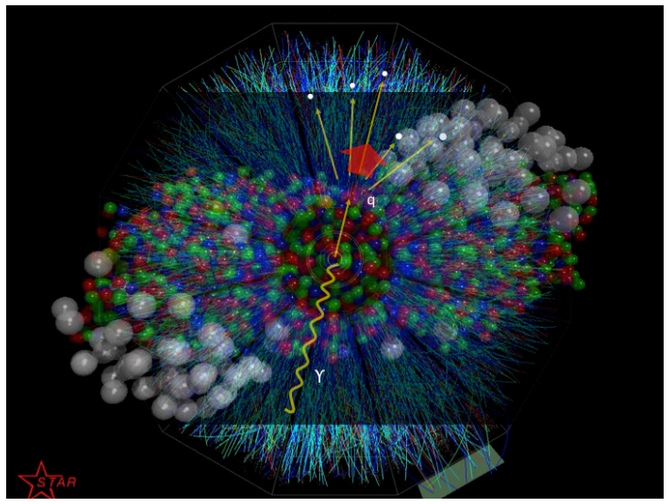
PRL112, 122301 (2014)

Jet quenching effect: signatures of hot and dense medium (QGP)

Recent measurements in STAR experiment

- γ-hadrons and π^0-hadrons correlations

  (jet-like correlations)

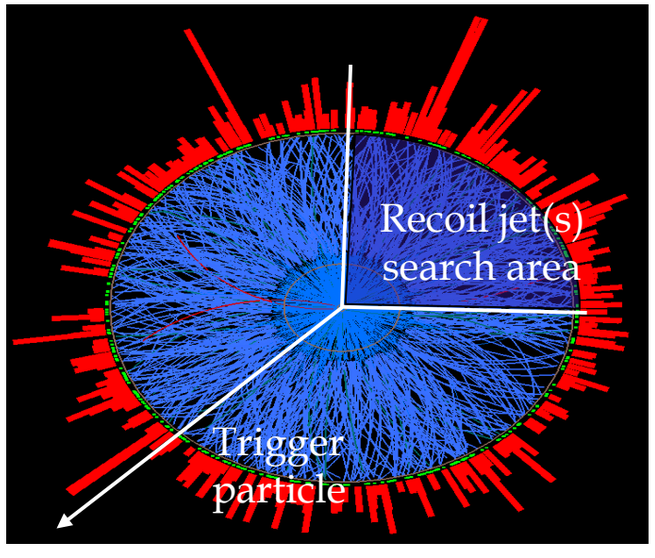


- Di-jets p_T imbalance

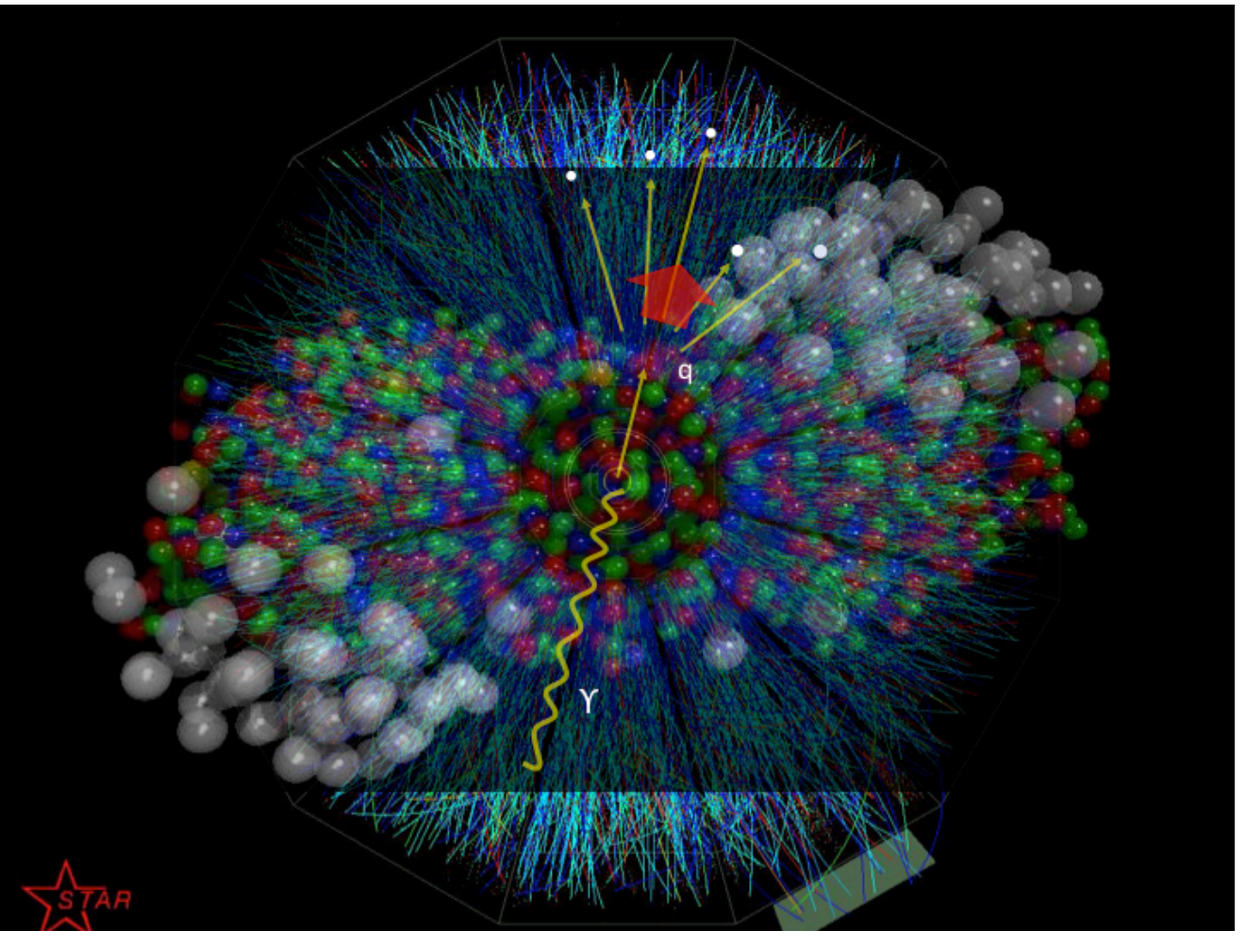
  (Full jet reconstruction using anti-k_T algo.)

- Semi-inclusive recoil charged jets

  (charged jet reconstruction using anti-k_T algo.)



Direct photon-hadrons and π^0-hadrons correlations



Direct photon+jet coincidence is a good tomographic probe to study the QGP in HIC

- 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

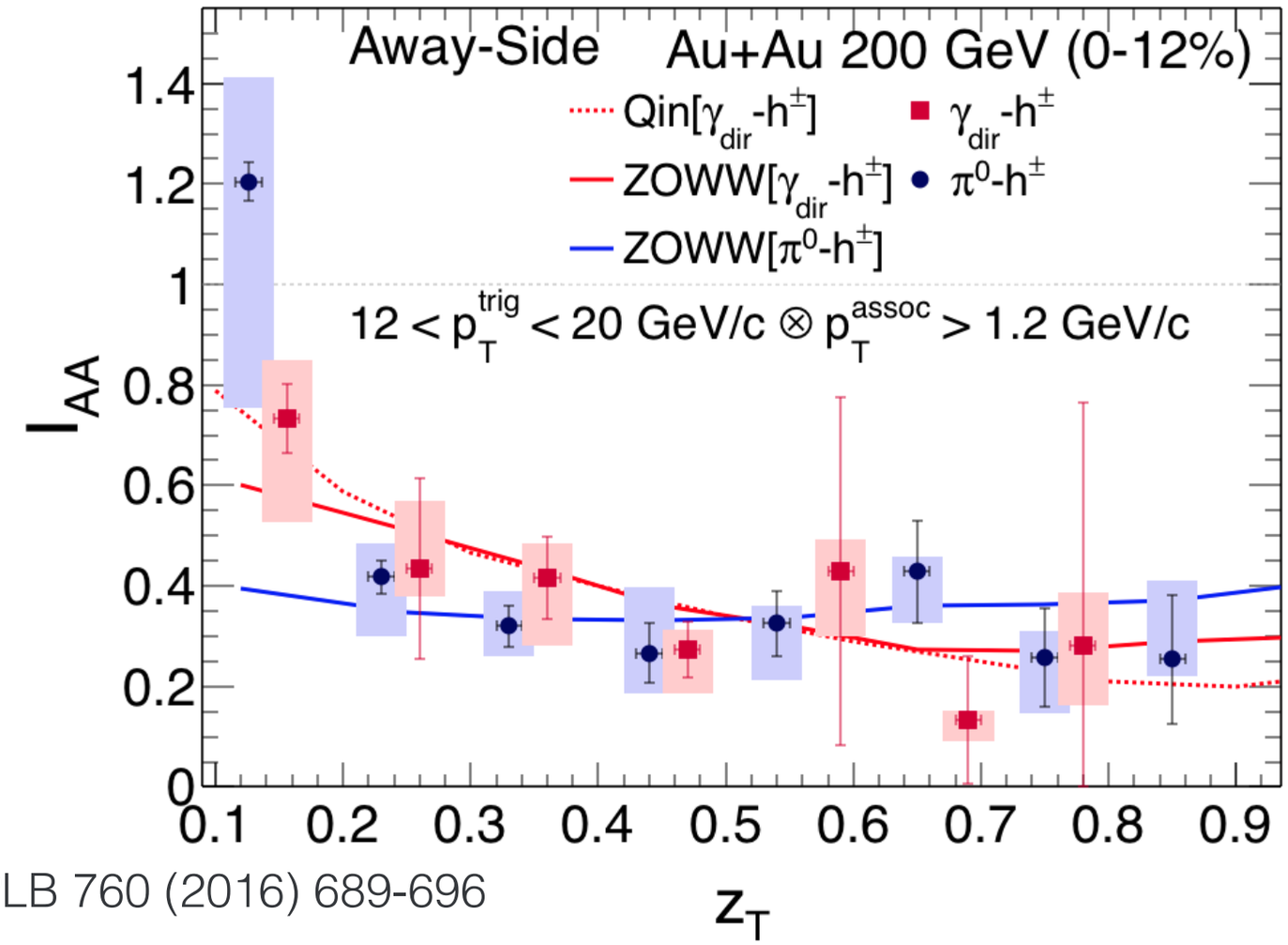
H. Zhang et al. , PRL 103, 032302 (2009).

An interesting comparison with π^0-hadron (jet)

- γ-triggered parton (jet) loses less energy than that of π^0-trigger
  - dominant γ production: qg ->qγ
  - due to color factor ($C_A/C_F = 9/4$)
- on ave. γ-triggered parton (jet) loses less energy than that of π^0-trigger
  - due to path length (surface biased of π^0-trigger)

Direct photon-hadrons and π^0-hadrons correlations

Nuclear modification factor of Υ_{dir} and π^0



PLB 760 (2016) 689-696

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

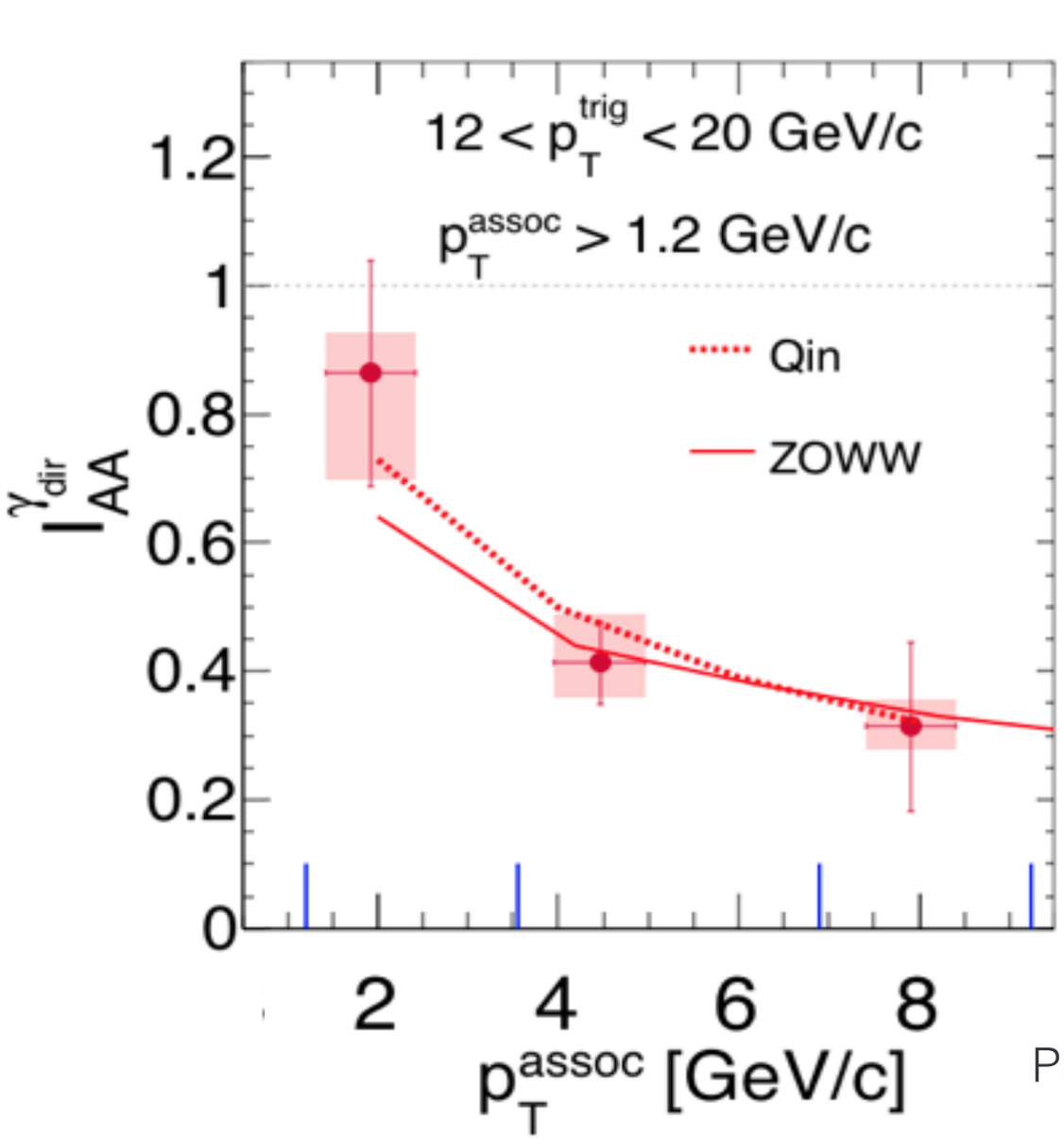
ZOWW:
X. N. Wang et al.,
Phys. Rev. C 84, 034902 (2011)
Phys. Rev. C 81, 064908 (2010)
Phys. Rev. Lett. 103, 032302 (2009)

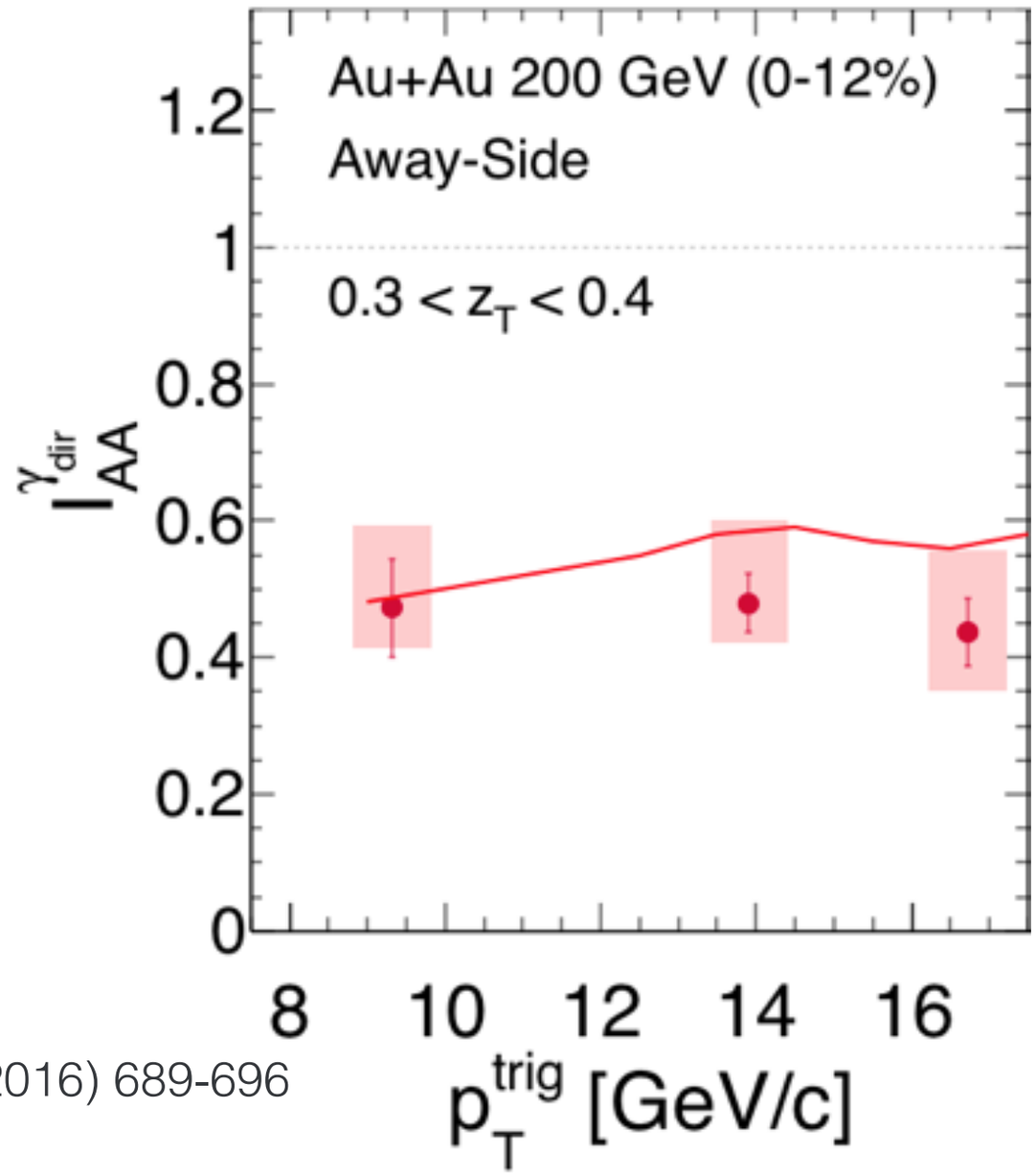
$$I_{AA}(x) = \frac{Y^{Au+Au}(x)}{Y^{p+p}(x)}$$

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

- *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 $z_T > 0.2$
- Indication of less suppression at low z_T, but not significant
- Models show a difference between γ and π^0 trigger but uncertainties in data are too large to prove it

Nuclear modification factor: I_{AA}^{Ydir} (p_T^{assoc}, p_T^{trig})





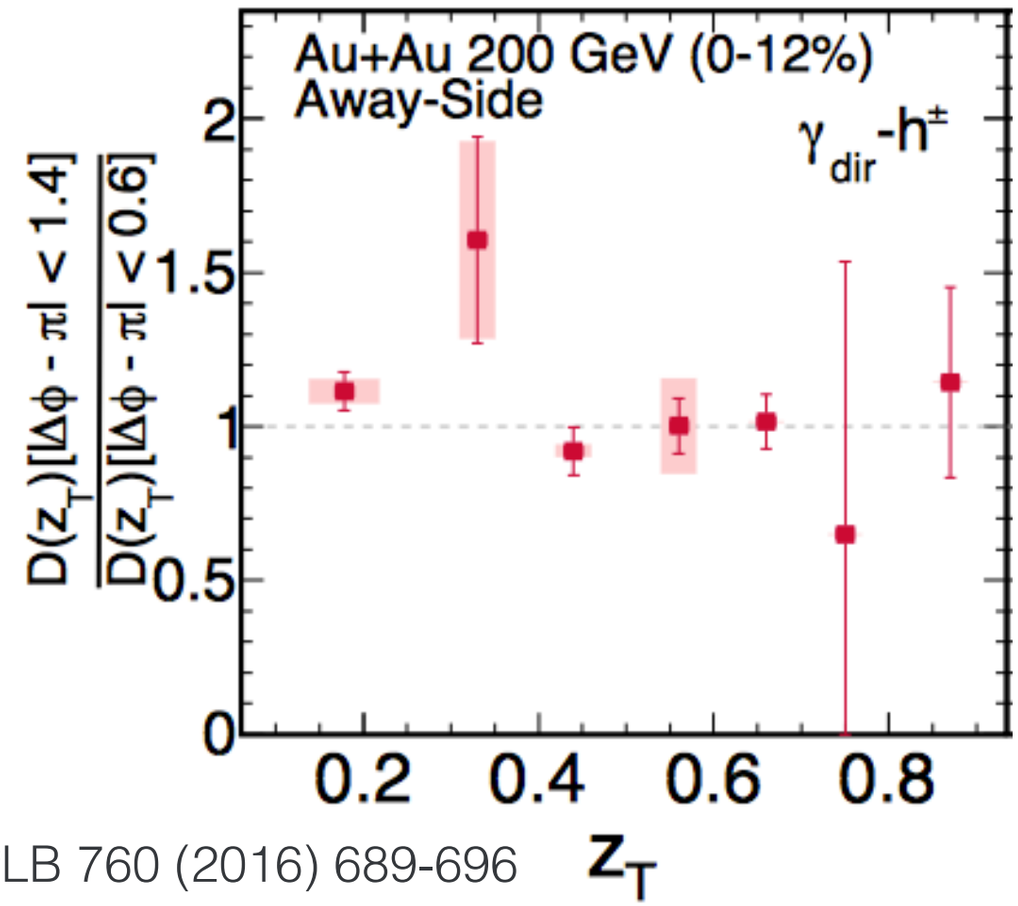
PLB 760 (2016) 689-696

- Soft associated particles are less suppressed compared with high p_T

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

Energy loss in azimuthal windows

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



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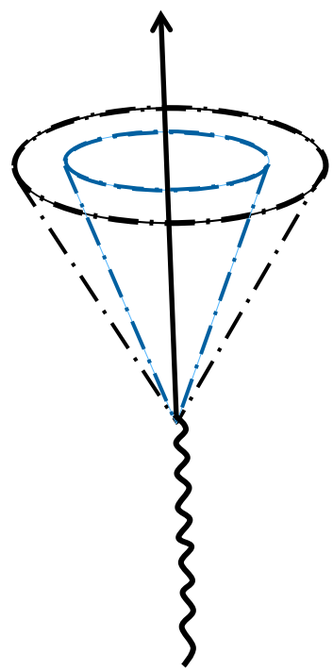
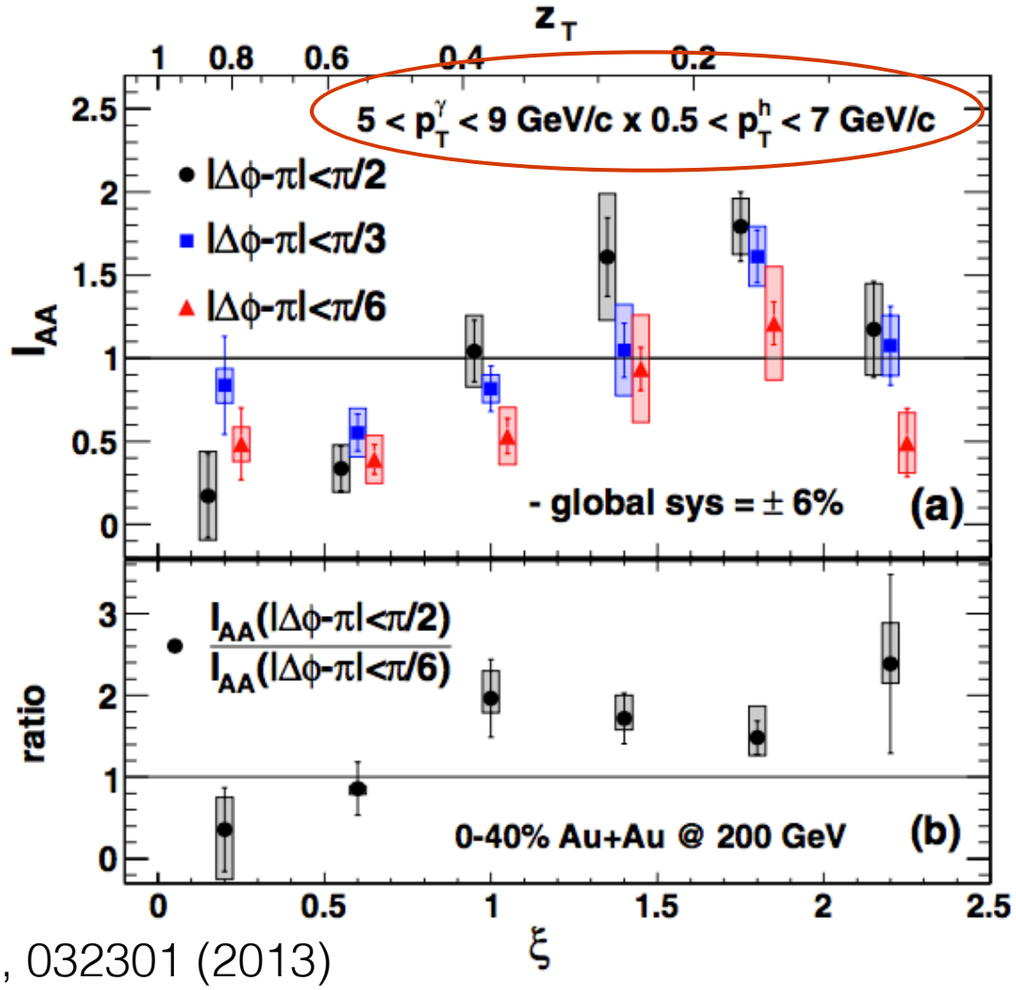


PHENIX experiment

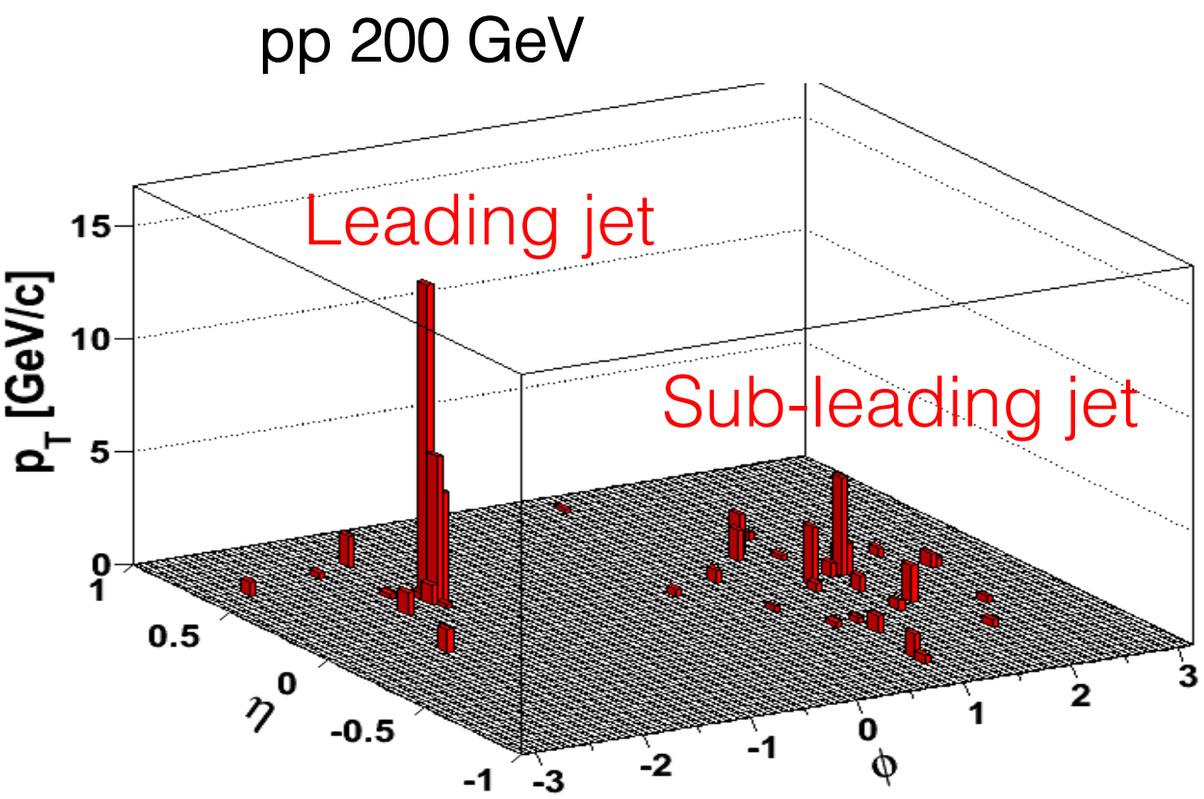


PRL 111, 032301 (2013)

- 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 !

Di-Jet imbalance



Di-jet Selection:

Jet $p_T^{\text{Lead}} > 20$ GeV/c

Jet $p_T^{\text{SubLead}} > 10$ GeV/c

$|\Delta\phi - \pi| < 0.4$

Constituent $p_T^{\text{Cut}} > 2$ GeV/c

Reduce BG and combinatorial jets compared with including constituent $p_T^{\text{Cut}} > 0.2$ GeV/c

Transverse momentum imbalance for back-to-back di-jet pairs

$$A_J = \frac{p_T^{\text{Lead}} - p_T^{\text{SubLead}}}{p_T^{\text{Lead}} + p_T^{\text{SubLead}}}$$

How to understand the background effect and compare that with AuAu ?

Background fluctuations and underlying event study

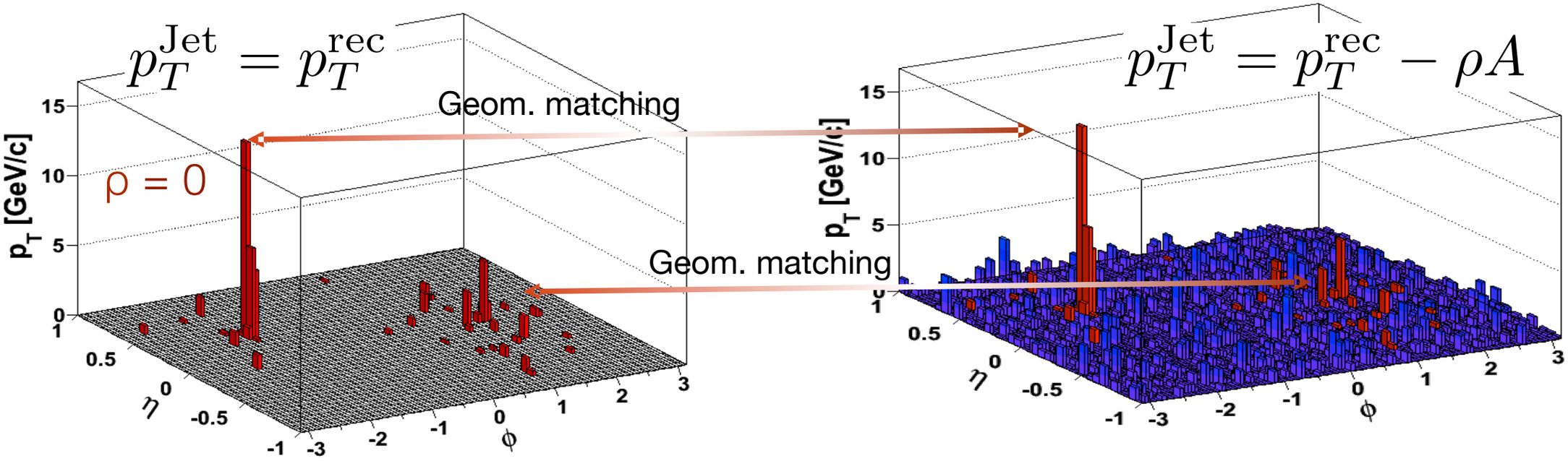
p_T^{Cut}=2 GeV/*c*
p_T^{Lead}>20 GeV/c
$p_T^{SubLead}$>10 GeV/*c*
$|\Delta\phi - \pi| < 0.4$

Rerun jet-finding algorithm anti-k_T on these events

p_T^{Cut}=0.2 GeV/*c*
p_T^{Lead}>20 GeV/*c* (p_T^{Cut}=2 GeV/*c*)
$p_T^{SubLead}$>10 GeV/*c* (p_T^{Cut}=2 GeV/*c*)

pp HT

pp HT ⊗ AuAu MB

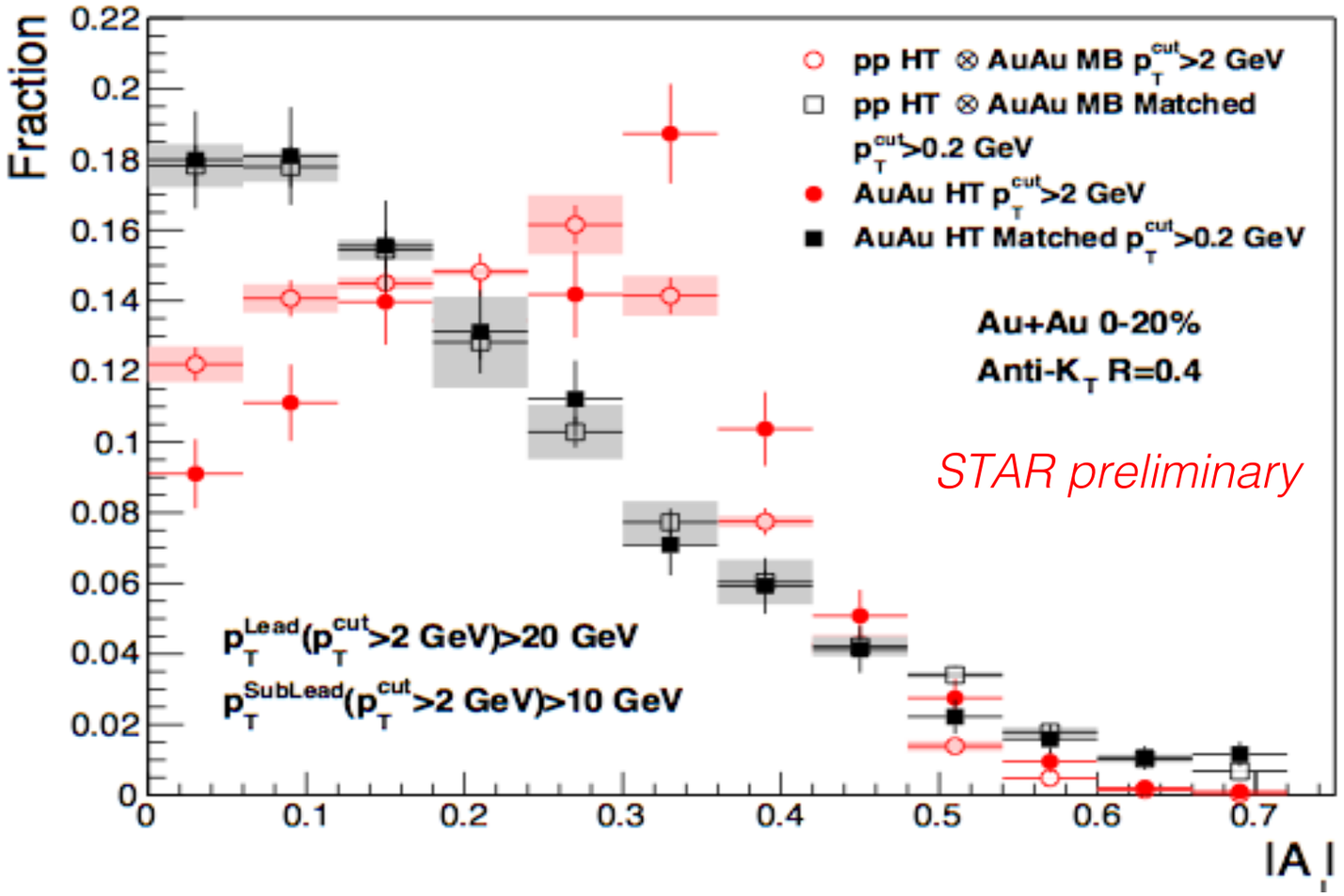


HT: E_T > 5.4 GeV at least one BEMC tower energy per event

Calculate "matched" $|A_J|$ with constituent $p_{T,cut}$>0.2 GeV/c and with geometrical matching condition $\Delta R < 0.4$

Competition between soft ($p_{T,cut}$>0.2 GeV/c) and hard ($p_{T,cut}$> 2.0 GeV/c) contributions ?

Di-Jet imbalance in transverse momentum



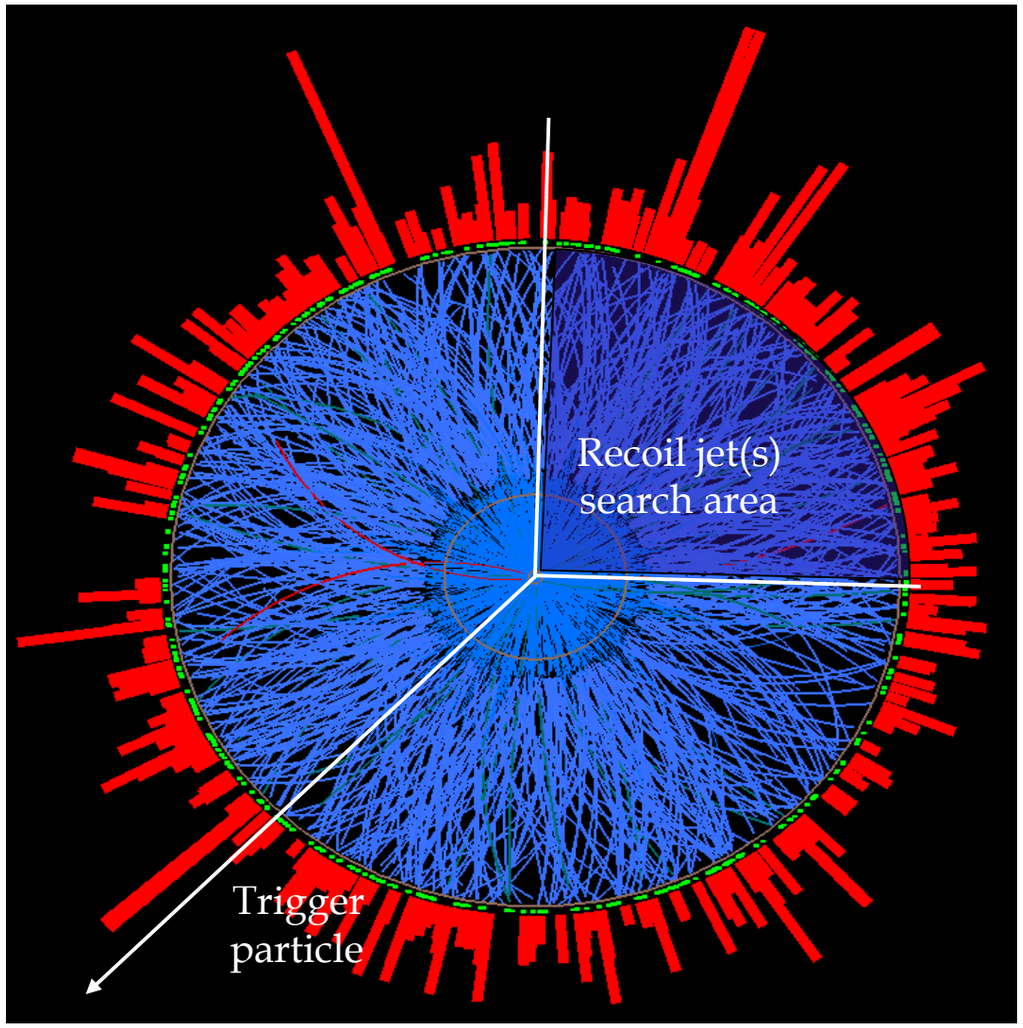
p-value < 10^{-4}

(pp HT ⊗ AuAu MB and AuAu HT not drawn from same A_j distribution

- Central AuAu collisions are significantly more imbalanced than the corresponding pp for constituent p_T > 2 GeV/c
- Balance is restored for R=0.4 when including jet constituents p_T < 0.2 GeV/c

Indication of energy loss of di-jet interacting with the medium and lost energy reappears as soft particles

Semi-inclusive recoil charged jets



Semi-inclusive yield of (charged) jets recoiling from a high-p_T hadron trigger

$$\frac{1}{N^h_{trig}}\frac{dN_{jet}}{dp_{T,jet}} = \frac{1}{\sigma^{pp\to h+X}}\frac{d\sigma^{pp\to h+jet+X}}{dp_{T,jet}}$$

Experimental observable

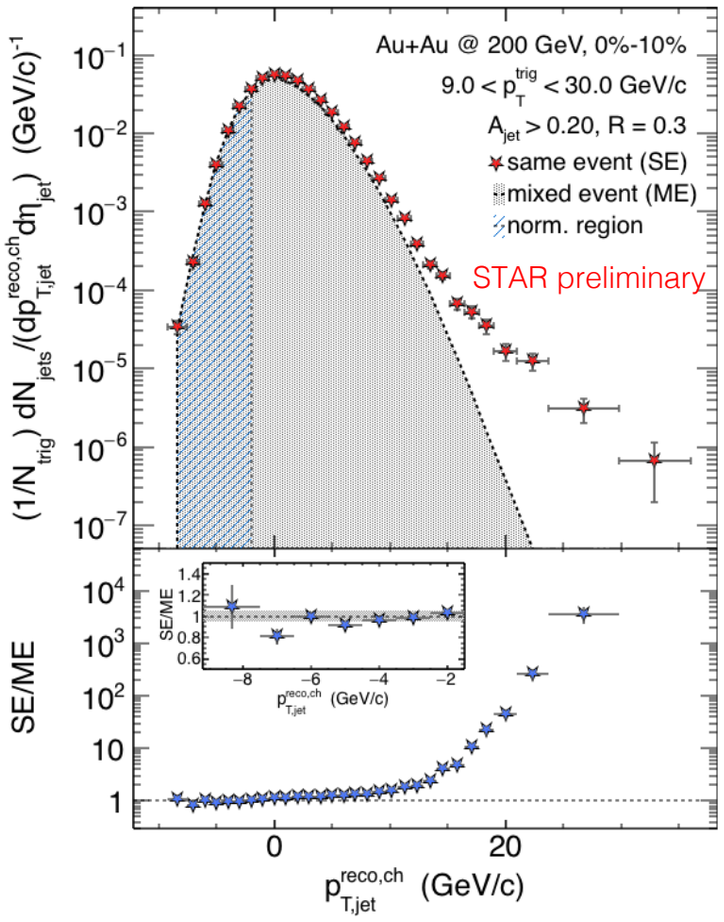
pQCD calculation

(Semi-inclusive charged recoil jet dist., since selection of triggered hadrons not inclusive)

- Trigger on high p_T hadron → Selection of a high p_T process
- Use all jet candidates on the other azimuthal hemisphere within +/- 45 degrees → no fragmentation bias on recoil side!
- Combinatorial background determined via mixed events

Semi-inclusive recoil charged jets: *high p_T suppression*

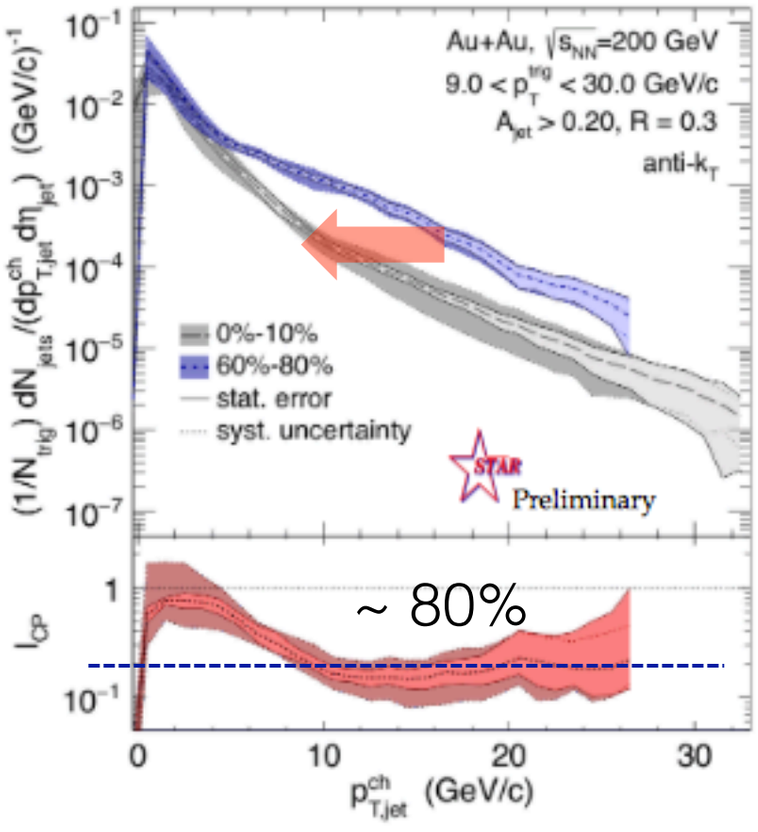
Uncorrected recoil jet dist.



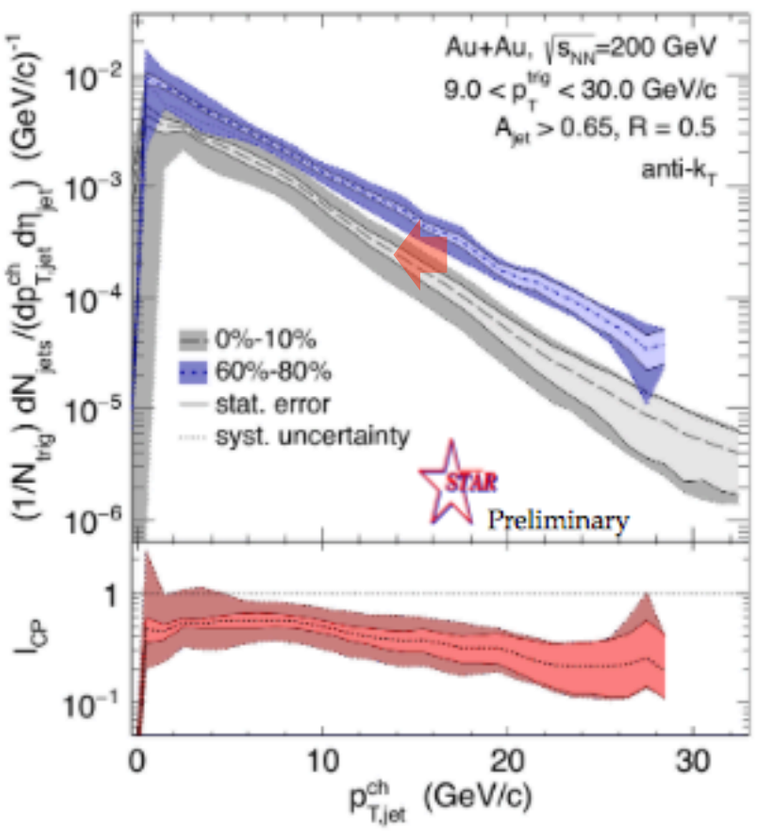
QM2015
arXiv:1512.08784

corrected semi-inclusive recoil jet

After Efficiency and background correction



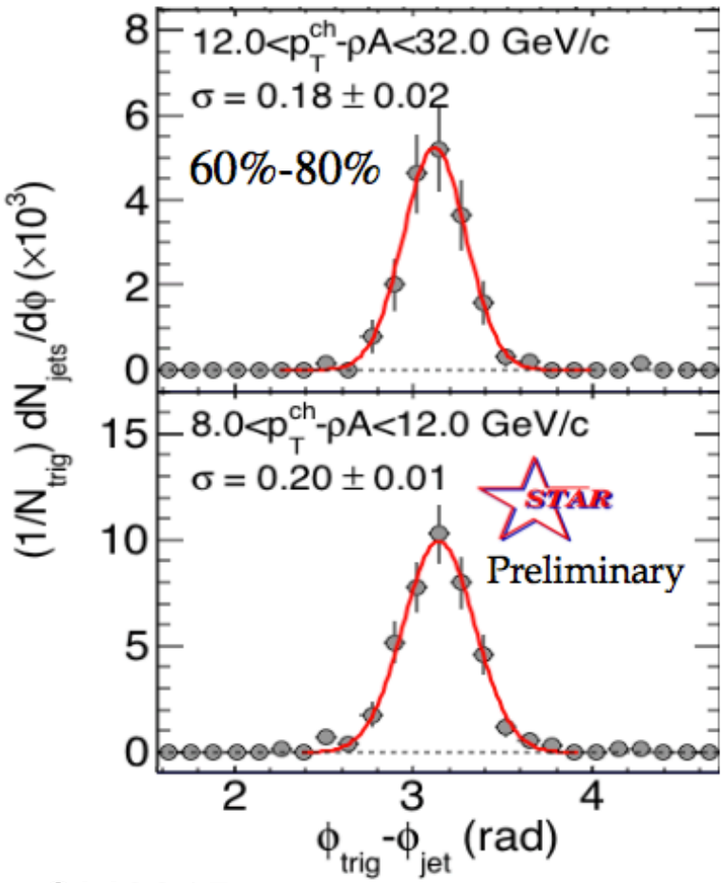
Horizontal shift



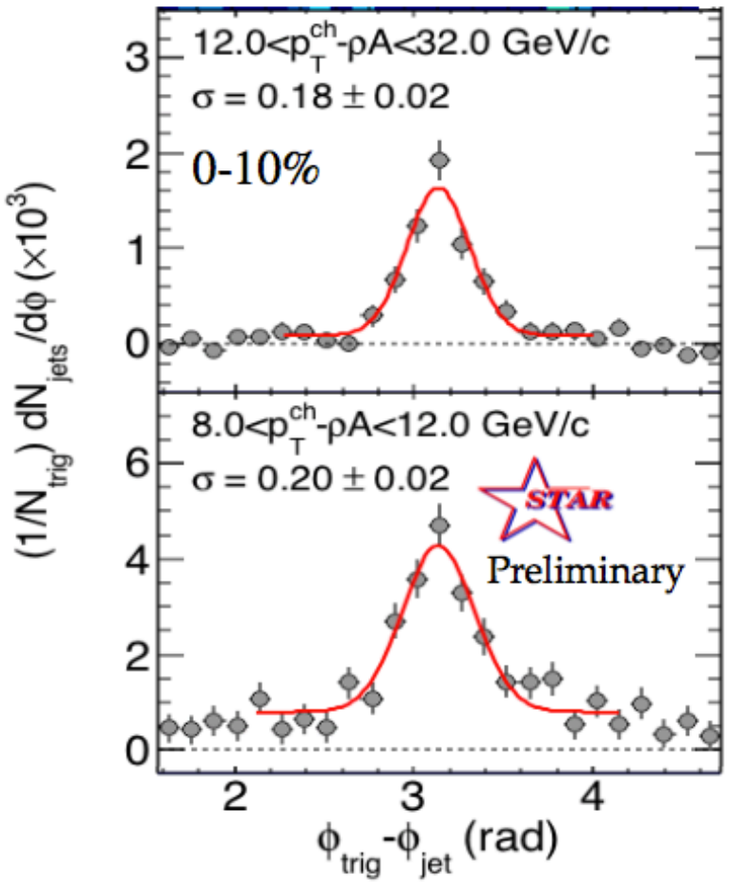
- Significant suppression (~80%) of I_{CP} for R=0.3 compared with R=0.5 ($p_{T,Jet}$ >10 GeV/c)
- Horizontal shift for R =0.3:
  - -- Indication of Energy transported out of the cone: *Jet-quenching effect*
    (Partonic energy loss)

Semi-inclusive recoil charged jets: *Large scattering angle*

Peripheral

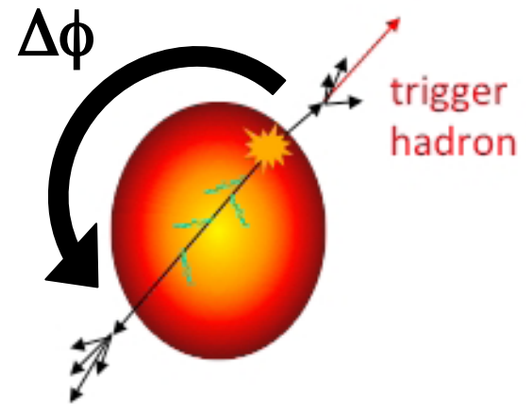


Central



QM2015
arXiv:1512.08784

$$\Delta\phi = \phi_{trig} - \phi_{jet}$$



Scattering probability can give us important information about coupling

- strongly/weakly coupled QGP
- quasiparticles?

(jet energy not corrected for instrumental effects and background fluctuations)

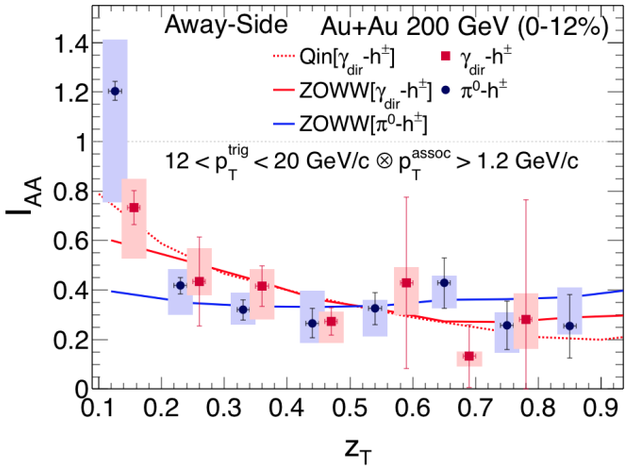
-> medium induced acoplanarity ?
-> No significant large angle scattering

Summary

Recent measurements in STAR experiment

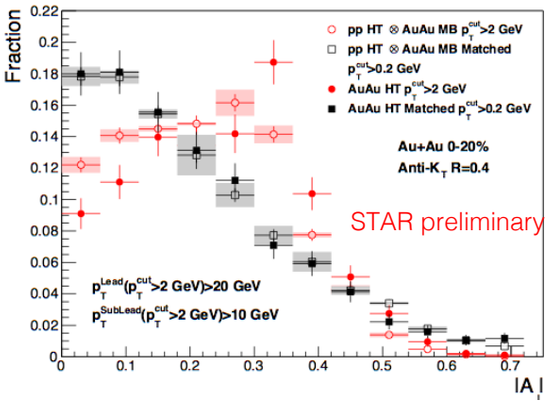
γ-hadrons and π^0-hadrons correlations

- no clear path length and color factor effect observed in π^0 vs. γ triggers I_{AA} ! (Within uncertainties)
- Less suppression at low p_T^{assoc}
- Energy loss is insensitive to the energy of triggered γ at high p_T (8-20 GeV/c) at RHIC



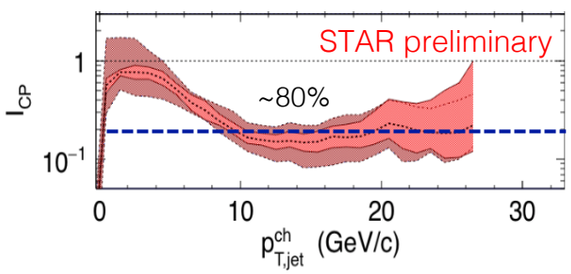
Di-jets p_T imbalance

- Central AuAu collisions are significantly more imbalanced than the corresponding pp for constituent p_T > 2 GeV/c
- Balance restored when including soft particles



Semi-inclusive recoil charged jets

- New mixed event technique can reproduce combinatorial jet background
- Suppression (~80%)
- No large angle scattering is observed so far



Thank you!