γ-jet coincidence measurements and parton energy loss in the QCD medium

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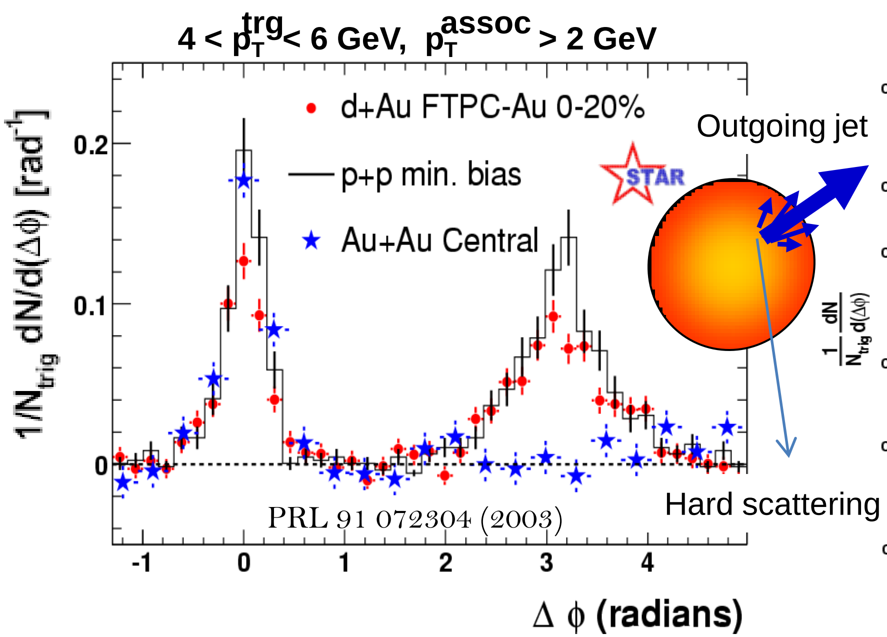
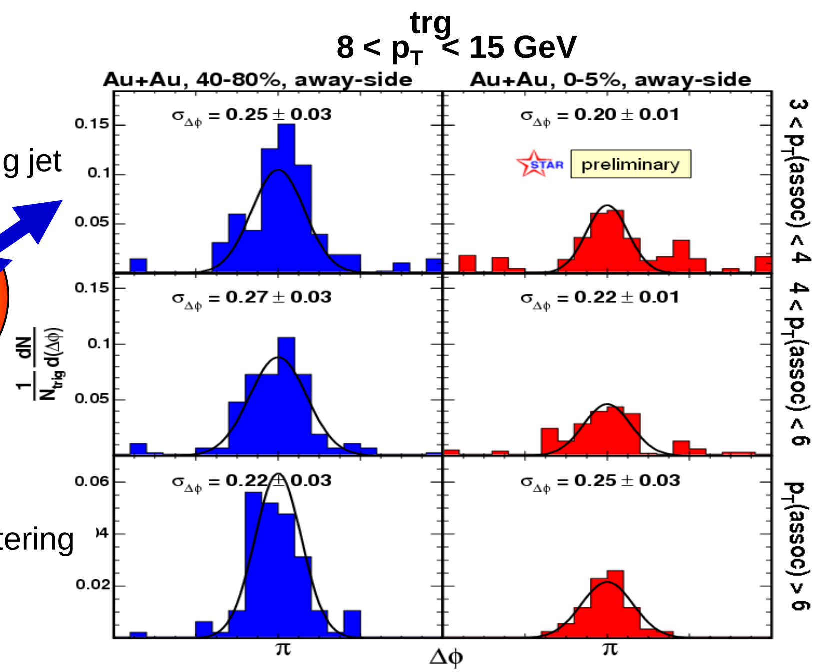
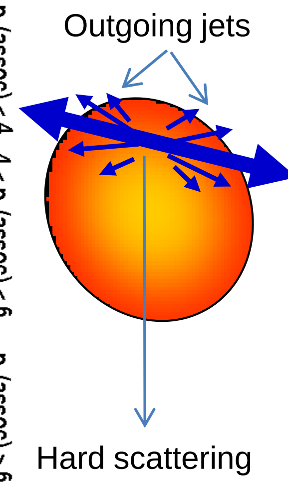
Parton energy loss in the QCD medium

Energy Loss of Energetic Partons in Quark-Gluon Plasma: Hadron-Hadron Collisions.

"An interesting signature may be events in which the hard collisions occurs near the edge of the overlap region, with one jet escaping without absorption and the other fully absorbed." **J. D. BJORKEN, 1982**





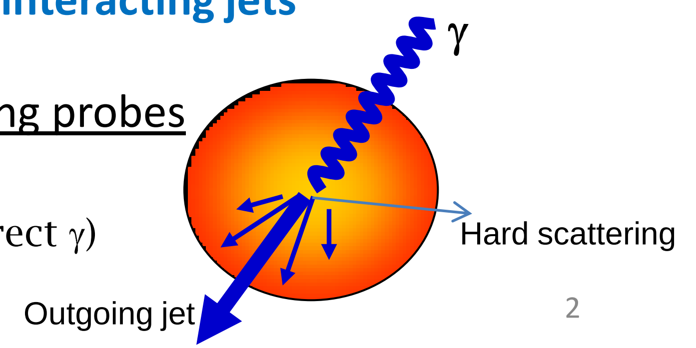


○ **Final-state effect**
○ **Surface-biased emission**

○ **Tangential-biased and/or punch-through "non interacting jets"**

Medium tomography requires more penetrating probes

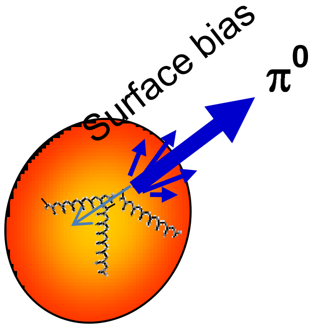
❑ Probe samples uniform spatial distribution of the hard scattering vertex inside the medium (direct γ)

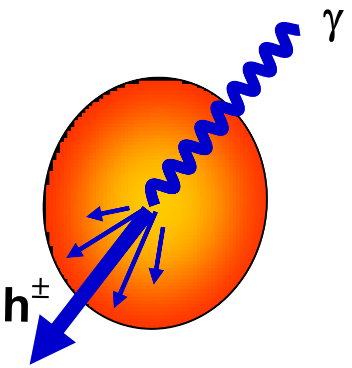


Medium tomography via the recoiling jets of γ^{dir}-jet and π^0-jet

Conjecture of energy loss functional form for particular QCD medium:

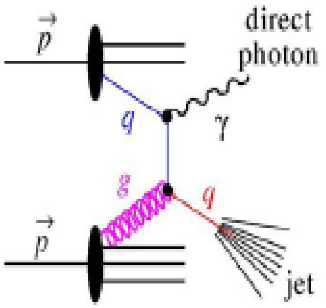
$$p(\Delta E)\ \alpha\ f\ (E, L, C_R, f)$$





1. $p(\Delta E)\ \alpha\ f\ (L)$:

The recoiling jet from π^0 travel on average longer distance within the medium than that of γ^{dir}



2. $p(\Delta E)\ \alpha\ f\ (C_R)$:

The recoiling jet of π^0 is a mix of q/g while for γ^{dir} the dominant is q at mid-rapidity at RHIC

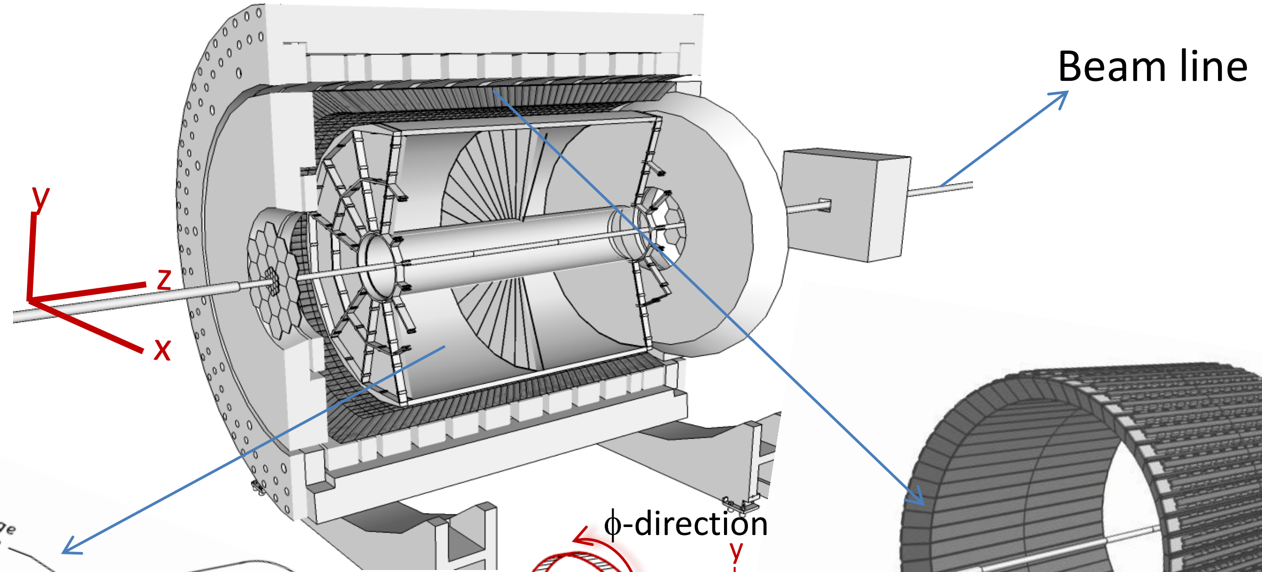
► These two factors cause the recoil jet from π^0 to lose more energy than that of γ^{dir}

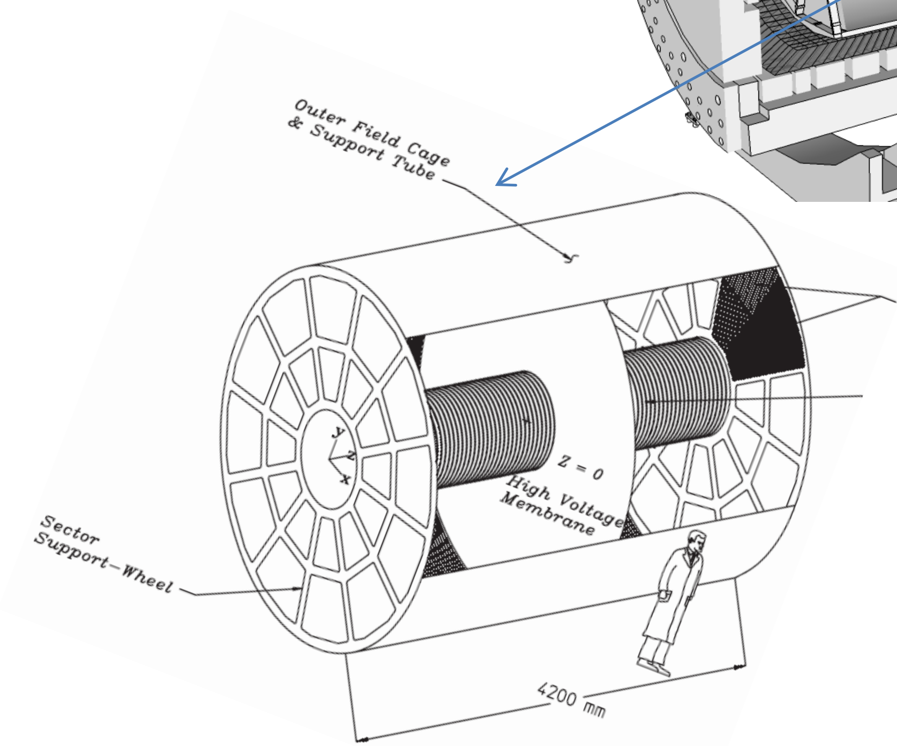
3. **$p(\Delta E)\ \alpha\ f\ (E)$:**

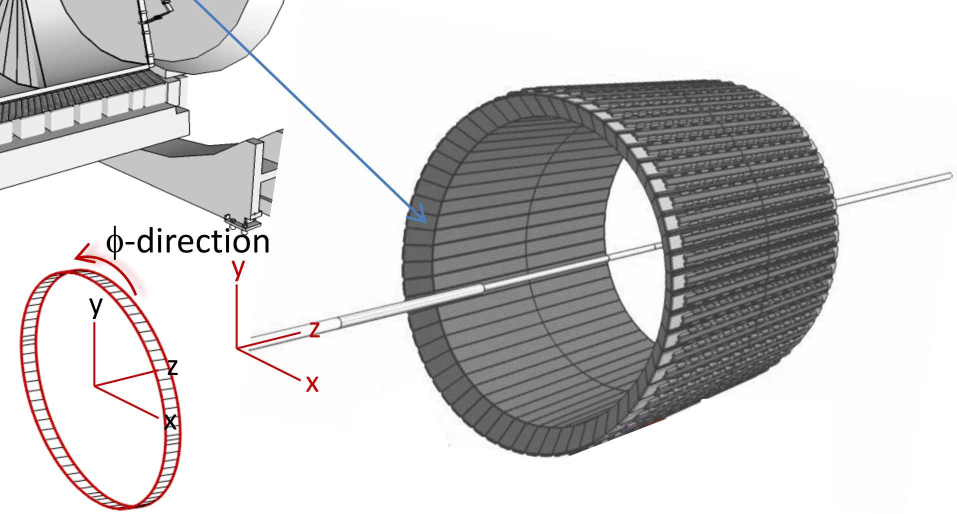
The energy of the recoiling jet from π^0 is greater than that of γ^{dir}.

✓ needs to be measured

STAR detector and on-line γ-rich event selections







Barrel ElectroMagnetic Calorimeter

BEMC: $|\eta| < 1$, $0 < \phi < 2\pi$

Time Projection Chamber

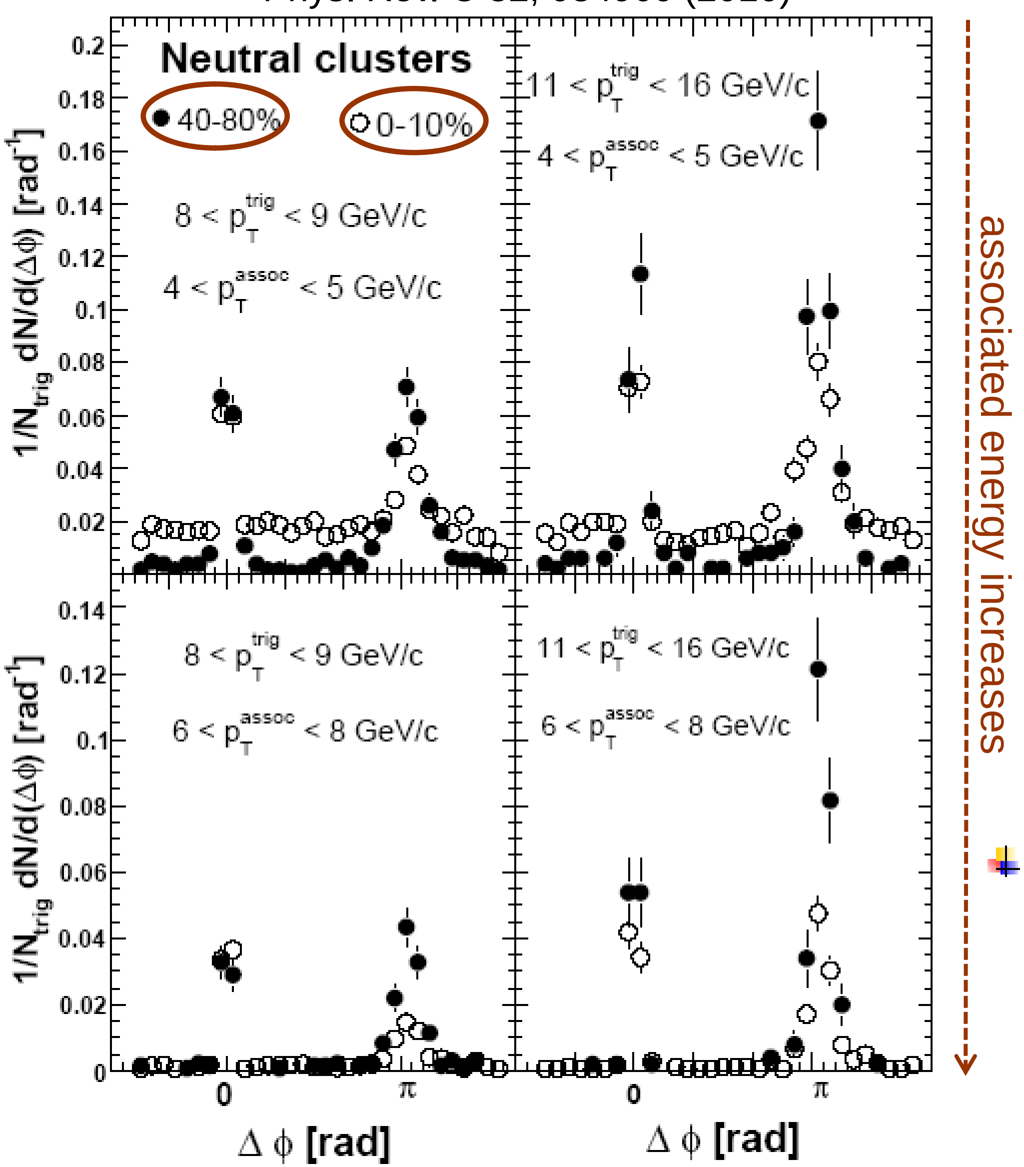
TPC: $|\eta| < 1$, $0 < \phi < 2\pi$

- **STAR is well-suited detector for correlation measurements**

Azimuthal correlation functions of neutral clusters

trigger energy increases

Phys. Rev. C 82, 034909 (2010)



di-jet characteristics

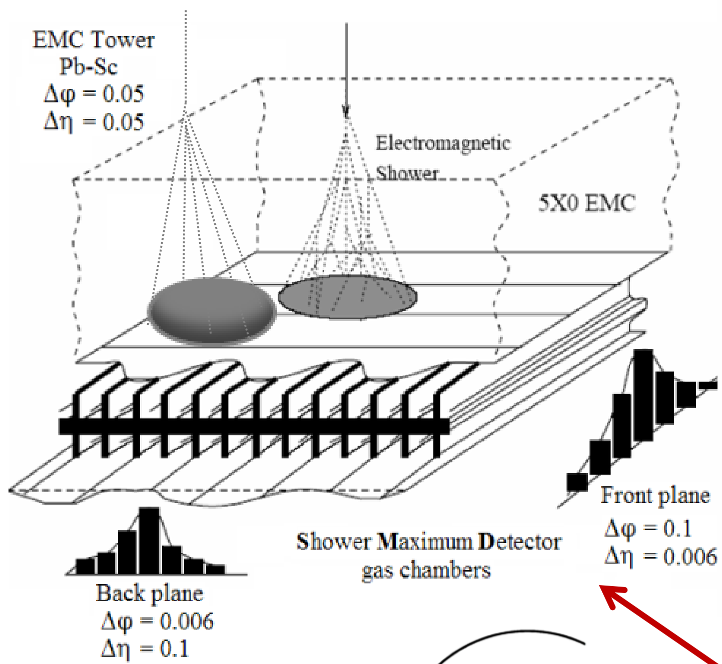
- Both near and away-side yields increase with trigger energy
- The level of uncorrelated bg is suppressed relative to the signal with associated energy.
- The increase on the away side is larger due to the trigger bias.

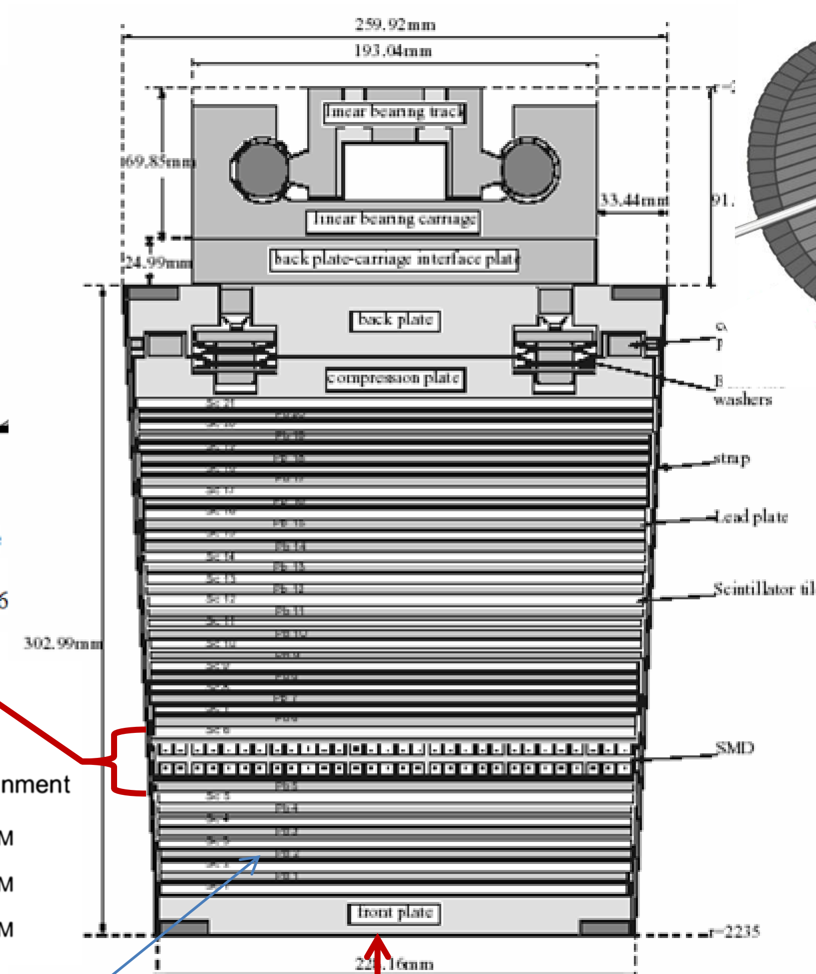
medium effect

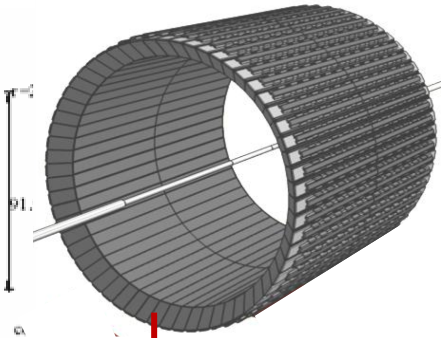
- Causes the away-side to be increasingly suppressed with centrality.

Em Transverse Shower Profile in STAR

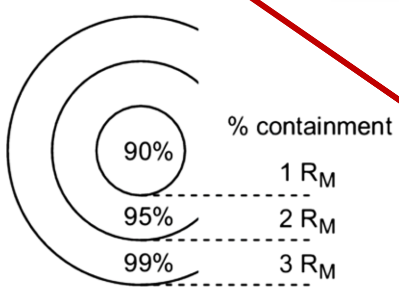
BSMD





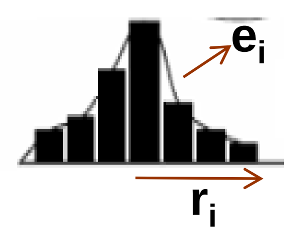


Cross section
in ϕ

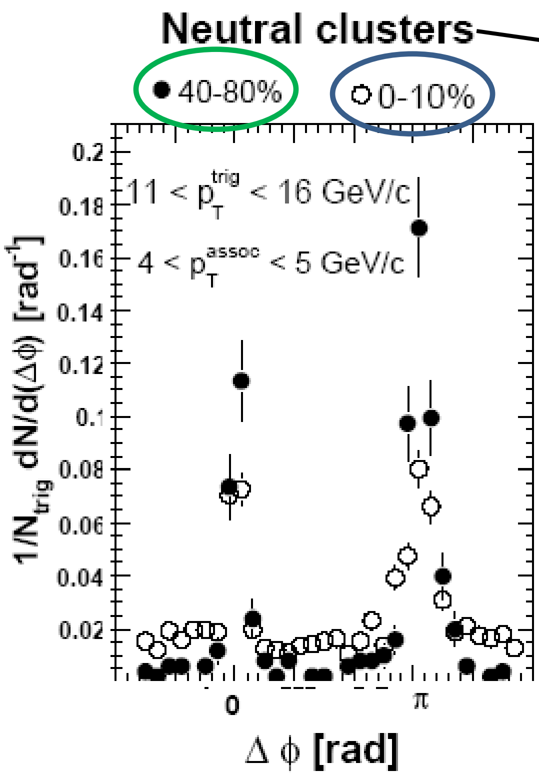


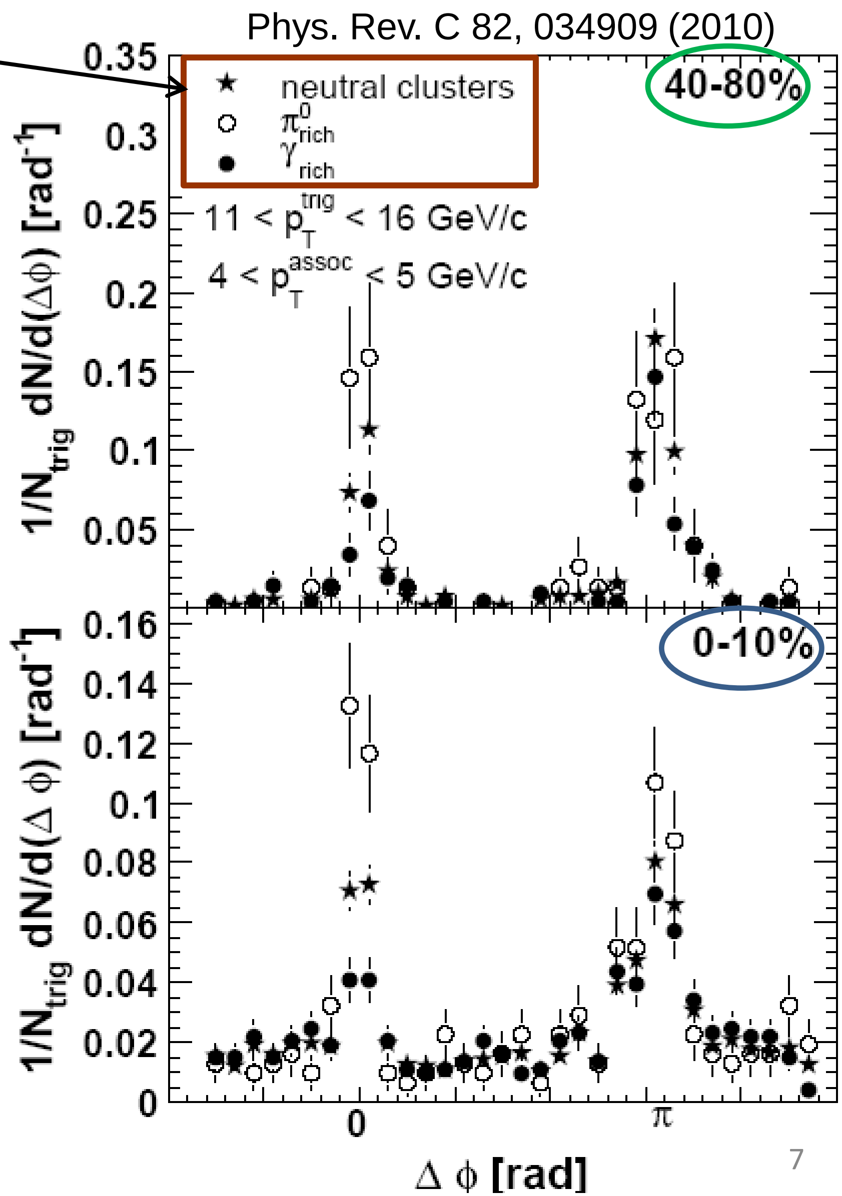
The two photons originated from π^0 hit the same tower at p_T>8GeV/c

The shower shape quantity $E_{cluster} / \sum_i e_i r_i^{1.5}$



Azimuthal Correlation functions of neutral clusters, $\pi^0(\gamma^{dir}$ free), and γ^{rich} samples with charged hadrons





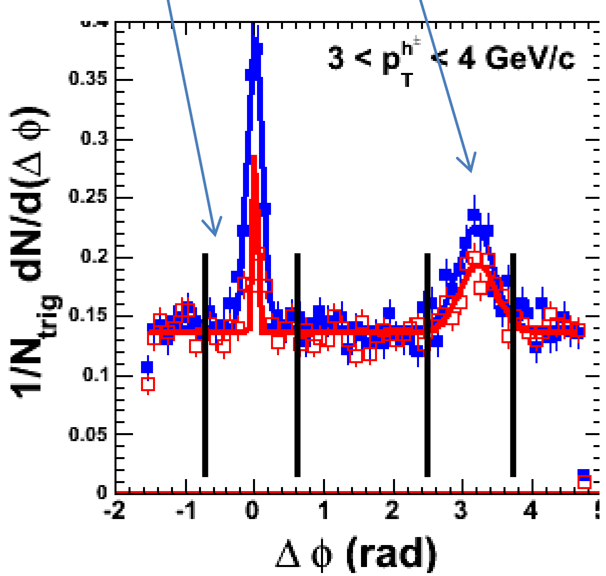
- γ^{rich} sample has lower near-side yields, but not zero!
- background from asymmetric decays of π^0, η, γ^{frag}.

Yield associated with π^0-jet coincidence measurements

Fitting the correlation function with 2 Gaussians and a constant

$D = (1/N_{trig})dN/d(\Delta\phi)$ "bin contents"

$|\,\Delta\phi\,| \leq 0.63$ and $|\,\Delta\phi - \pi\,| \leq 0.63$



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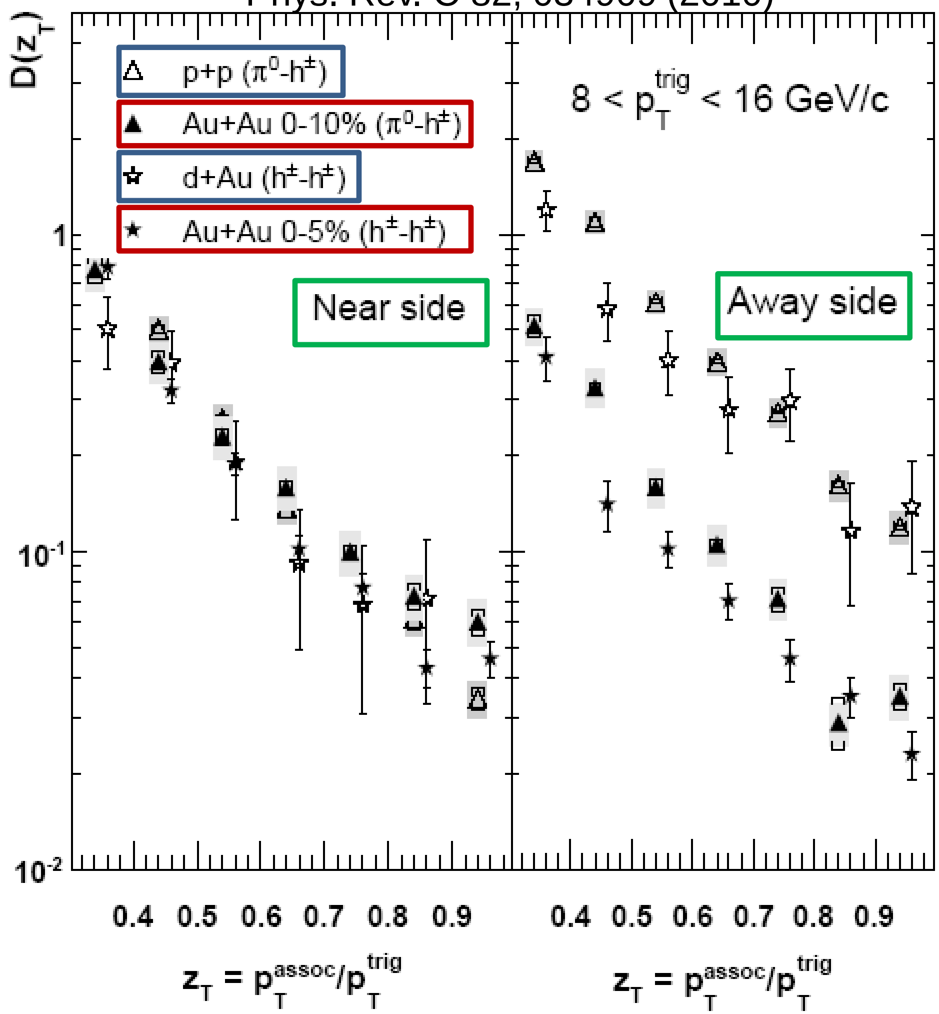

- A general agreement of π^0-$h^{\pm}$ and $h^{\pm}$-$h^{\pm}$ $\rightarrow$ the π^0-rich sample is free of γ^{dir}.

Extraction of the associated yields with γ^{dir}-jet coincidence measurements

$$Y^{\gamma_{dir}+h} = \frac{\left(Y^{\gamma_{rich}+h} - \mathcal{R} Y^{\pi^0+h}\right)}{1-\mathcal{R}} \qquad \mathcal{R} \simeq \frac{N^{\pi^0}}{N^{\gamma_{rich}}} = \frac{Y_{NS}^{\gamma_{rich}+h}}{Y_{NS}^{\pi^0+h}}$$

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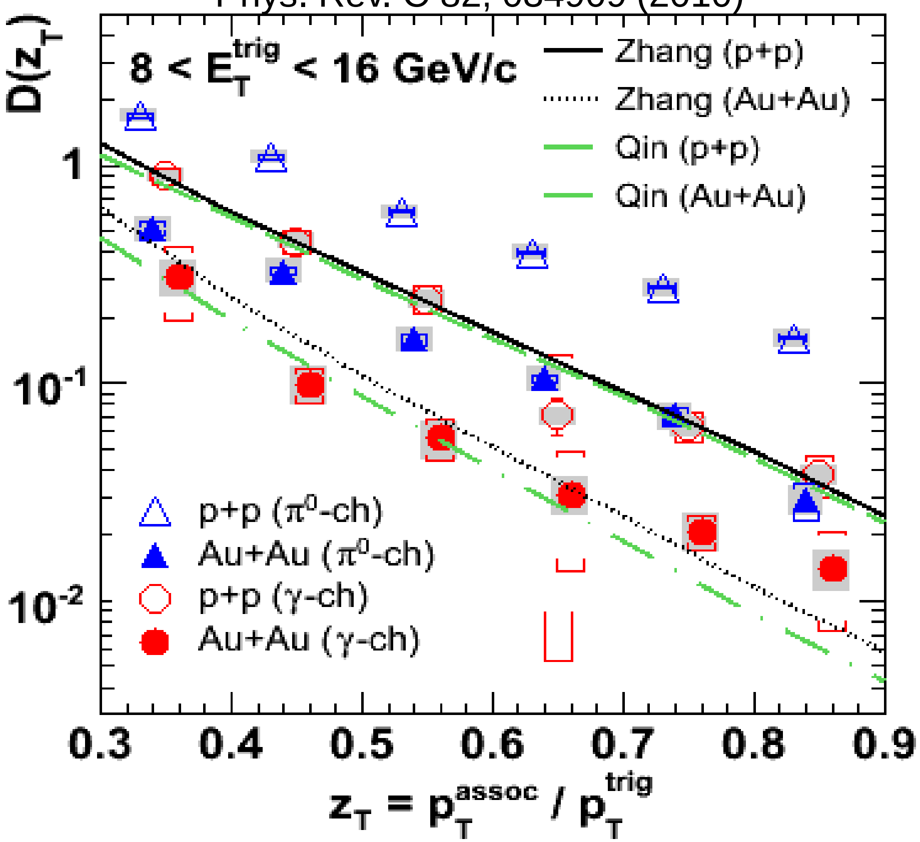

- The away-side yield per π^0 trigger is significantly larger than that per γ^{dir} trigger.

p+p

→ γ^{dir} carries the total scattered constituent momentum while π^0 carries only a fraction of it.

→ different proportions of q and g recoiling from γ^{dir} and π^0 triggers.

Au+Au

→ different path length for the recoiling jet from π^0 trigger and γ^{dir} trigger.

→ color factor effect on energy loss.

→ different parton initial energy.

- The yields in p+p and Au+Au are well described by theoretical models.

Quantifying medium effect

I_{AA}= ratio of associated yield per trigger in Au+Au to that in p+p

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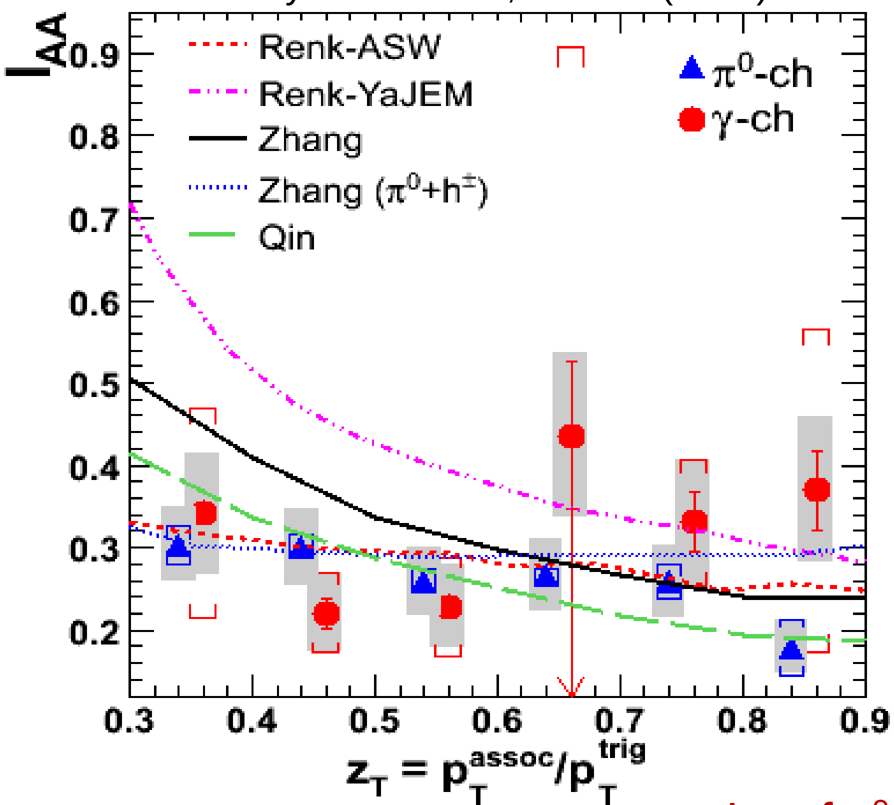

I_{AA} of π^0 vs. theory

→ agrees with Zhang et al. within the current uncertainties.

I_{AA} of γ^{dir} vs. theory

→ disfavors Renk-YaJEM→ lost energy is distributed to very low pt and large angle.

→ agrees with Renk-ASW, Qin et al., and Zhang et al. within current uncertainties.

→ shows no strong rise at low z_T.

I_{AA} of π^0 vs. I_{AA} of γ^{dir}

similar level and pattern of suppression

→Effect of fluctuations in energy loss dominates over the effect of geometry (f **(L))**

(Phys. Rev. C80, 014901 (2009)).

→ Energy loss dependence of parton initial energy smeared out the expected differences.

Energy loss dependence of parton initial energy

- High-p_T γ^{dir} balances the p_T of the other outgoing parton
k_T effect (several hundred MeV "theoretically" and ~3GeV reported by PHENIX).

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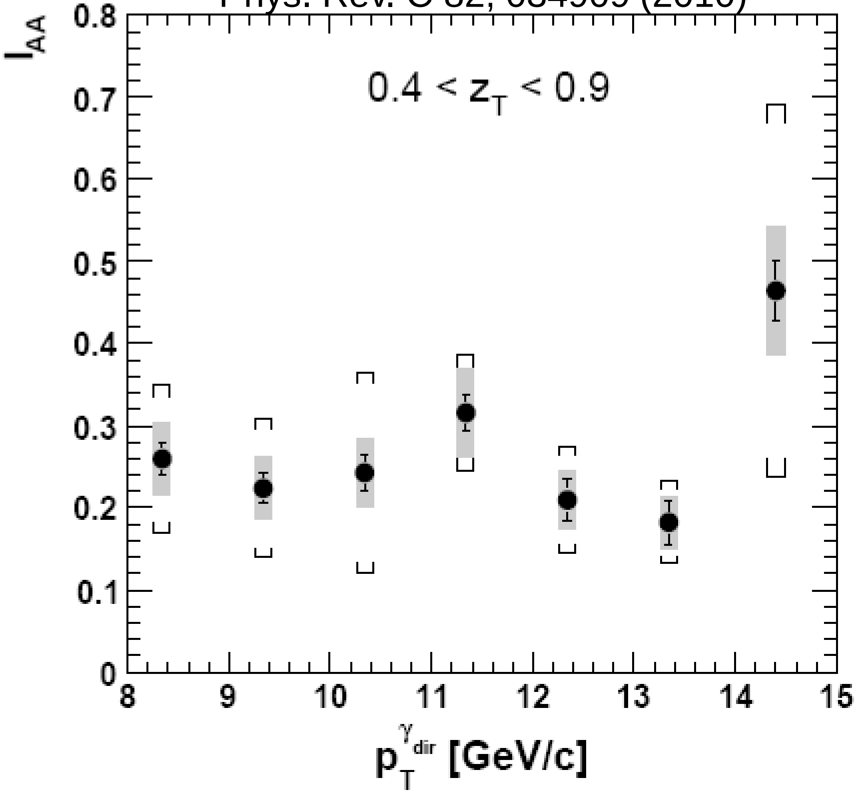


Recall, we expect the recoil parton of π^0 to lose more energy than that of γ^{dir} due to the longer path length and color factor.

Is it compensated with $P(\Delta E) \propto F(E)$?

- No, I_{AA} of γ^{dir} shows no strong dependence on E.

- The energy loss dependence on:
1. Path length 2. Color factor
is not observed
within the covered kinematic range

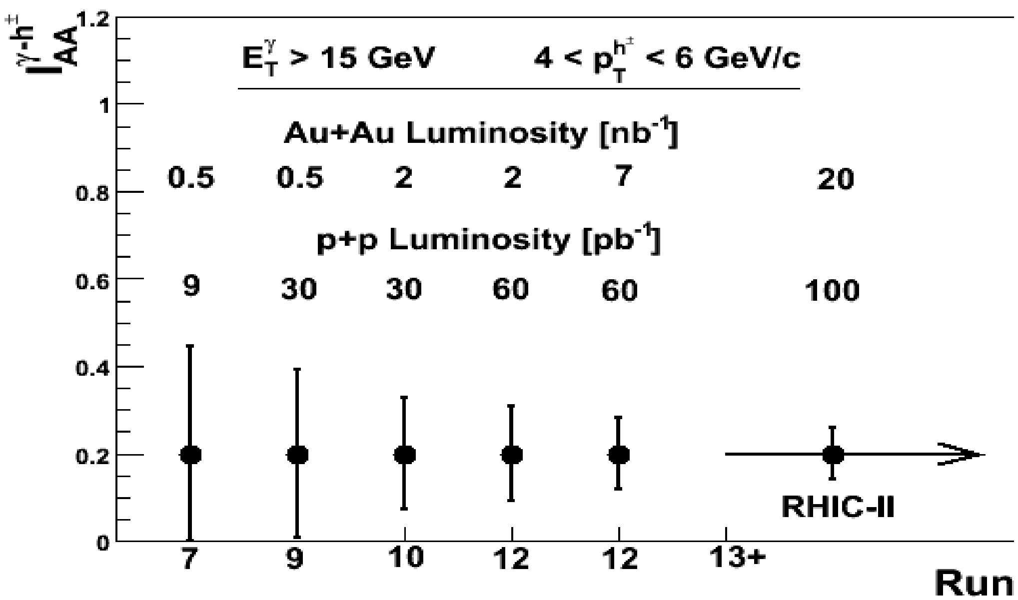
Summary && Outlook

1. STAR, due to its acceptance, is capable of multi-analysis for more penetrating probes.

2. Direct photon-charged hadron coincidence measurement is clean probe for the energy loss dependence of parton initial energy.

3. Comparison of direct photon-charged hadron coincidence measurement with the neutral pion-charged hadron coincidence measurement provides tool for the energy loss dependence of path length and color factor, and therefore "medium tomography".

4. Within the covered kinematic range, the parton energy loss in the QCD medium shows no dependence on parton initial energy, path length through the medium, and color factor.



- ➢ Coming runs help to reduce uncertainties and provide statistically significant measurements at the low z_T region.

Backup slide

Novel Method

Statistical measurement of γ-jet yields

- Use the transverse shower shape to select γ^{dir} free (π^0-rich) sample and γ^{rich} sample from the neutral clusters.

- Impose the condition of zero-near side yield associated with γ^{dir}

$$Y^{\gamma_{dir}+h} = \frac{\left(Y^{\gamma_{rich}+h} - \mathcal{R}Y^{bgd+h}\right)}{1-\mathcal{R}} \qquad \mathcal{R} = \frac{N^{bgd}}{N^{\gamma_{rich}}}$$

(a measure of bg in the γ_{rich} sample)

- Shower shape analysis doesn't measure all bg, it measures only the π^0 in its symmetric decay mode.

All sources of bg are approximated to the measured π^0

$$Y^{\gamma_{dir}+h} = \frac{\left(Y^{\gamma_{rich}+h} - \mathcal{R}Y^{\pi^0+h}\right)}{1-\mathcal{R}} \qquad \mathcal{R} \simeq \frac{N^{\pi^0}}{N^{\gamma_{rich}}} = \frac{Y_{NS}^{\gamma_{rich}+h}}{Y_{NS}^{\pi^0+h}}$$

Do the other sources of bg have similar correlations with charged hadrons as that of the measured π^0?

Note : ~10% of all π^0 (8-16GeV/c) decay asymmetrically with one gamma has p_T > 8 GeV/c within STAR-BEMC acceptance. η causes similar level of background as asymmetric π^0.