γ_{dir}+jet and π^0+jet measurement in STAR

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Outline

- Semi-inclusive jet measurement in STAR

  γ_{dir} +jet and π^0 +jet

  In Au+Au and p+p data (π^0+jet) at $\sqrt{s_{NN}}$ = 200 GeV

- Another facet of this measurement

(in the STAR experiment)

  π^0 +jet (γ_{dir} +jet) $\Delta\varphi$ angular correlations

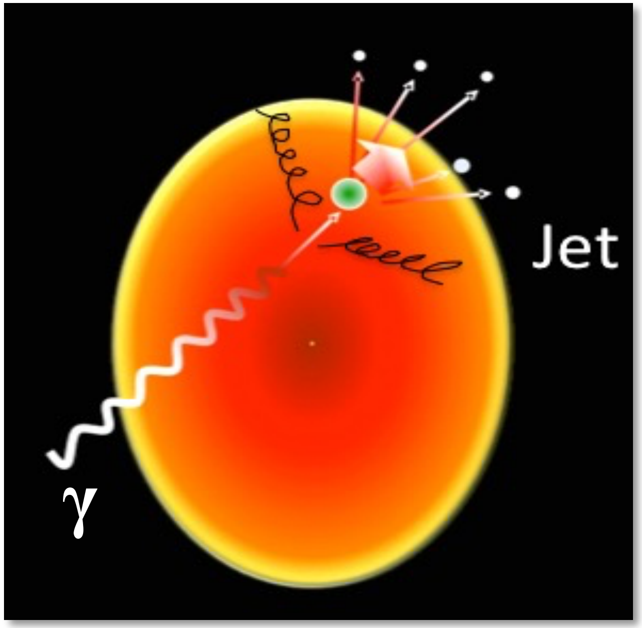
Introduction

- Quantitative understanding of parton energy loss in QCD medium
  - Parton energy loss as a function of path length, color factor, parton energy
  - Redistribution of lost energy inside the medium [Jet radius]
  - RHIC vs. LHC [dependence on temp. and initial gluon density]

- This can be addressed using vector-boson-tagged jet
  - Trigger energy approximates the initial recoil parton energy
  - At RHIC, γ_{dir}+jet is accessible

This is the first fully corrected γ_{dir}+jet measurement at RHIC energy.

And a comparison between γ_{dir}+jet and $h(\pi^0)$+jet.

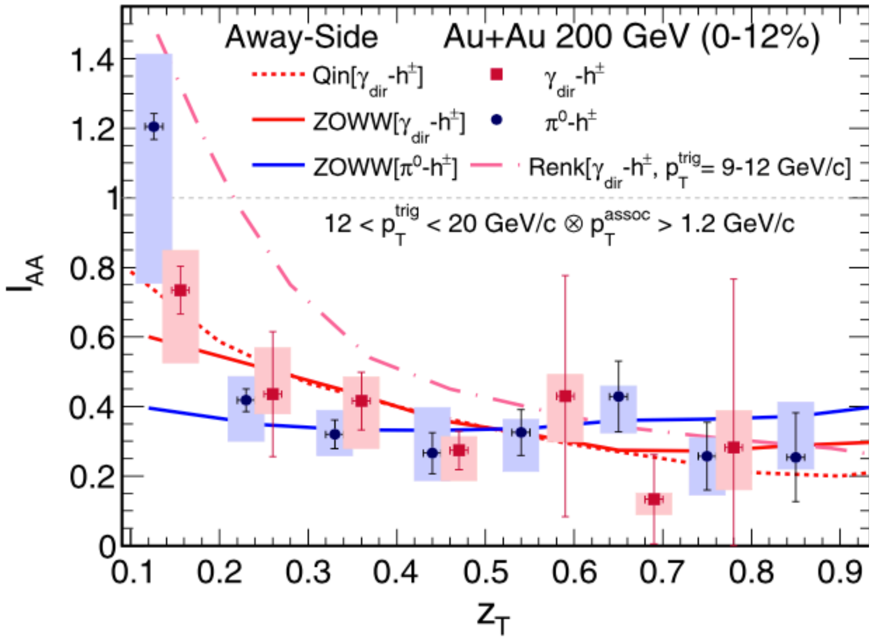


Two important tools developed in STAR

γ_{dir}+hadron and π^0+hadron correlation

STAR: PLB 760 (2016) 689

- γ_{dir}/π^0: trigger and discrimination



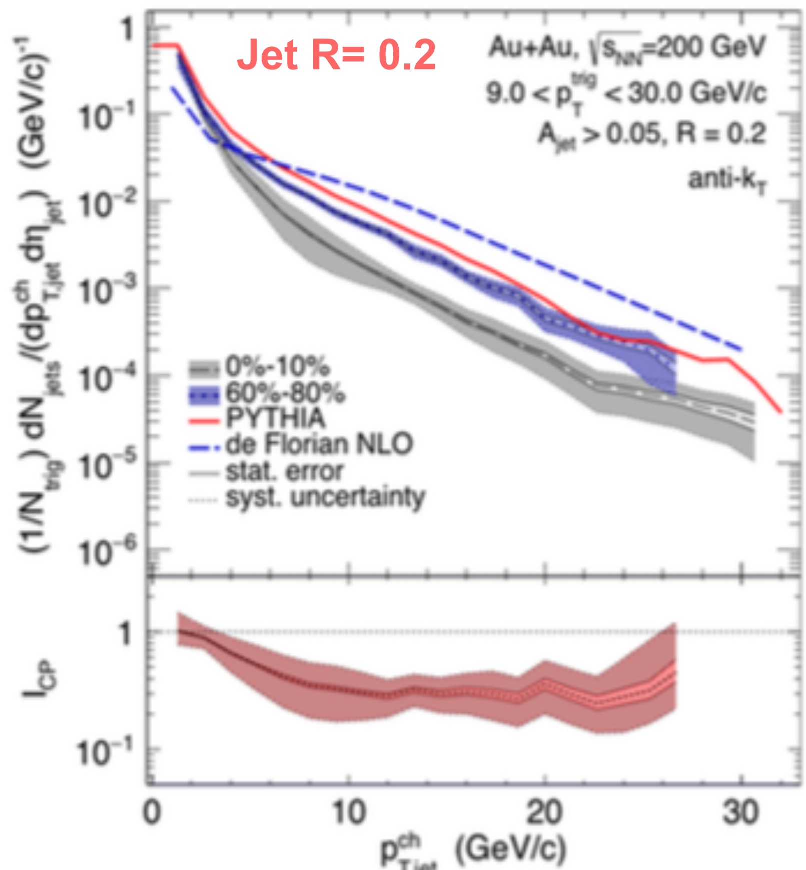
$$I_{AA}(p_T, z_T) = \frac{Y^{\text{Au+Au}}(p_T, z_T)}{Y^{\text{p+p}}(p_T, z_T)}$$

- STAR BEMC and TPC detectors

$h^{\pm}$ +jet

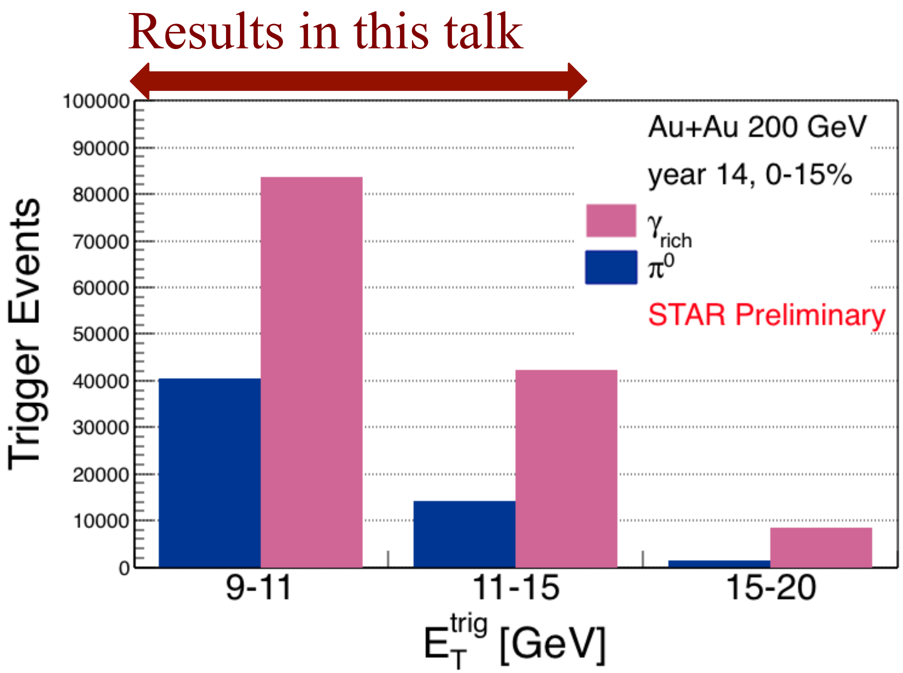
STAR:PRC 96, 024905 (2017)

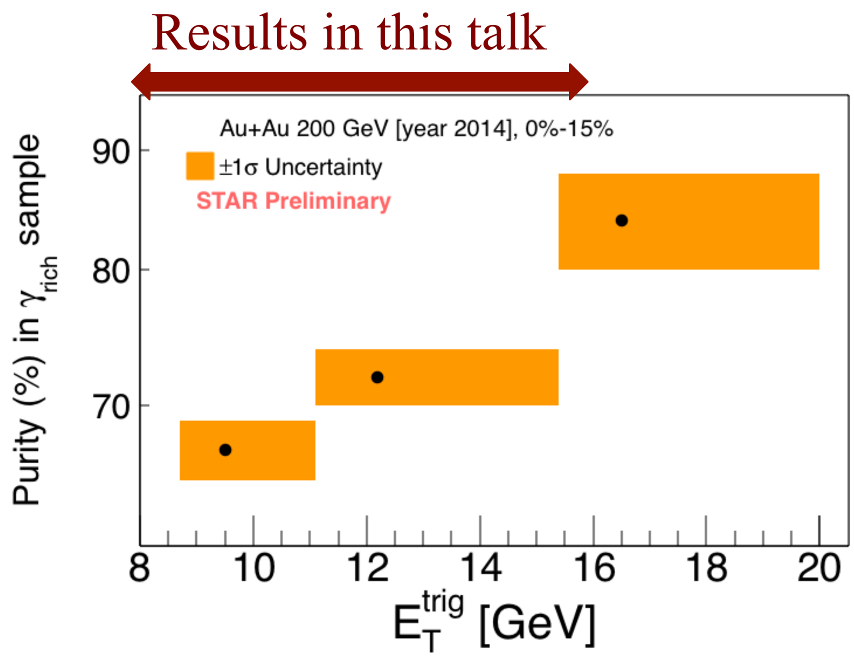
- Handel over uncorrelated background jet
- Final recoil jet correction (Unfolding)



Event statistics and γ_{dir} purity

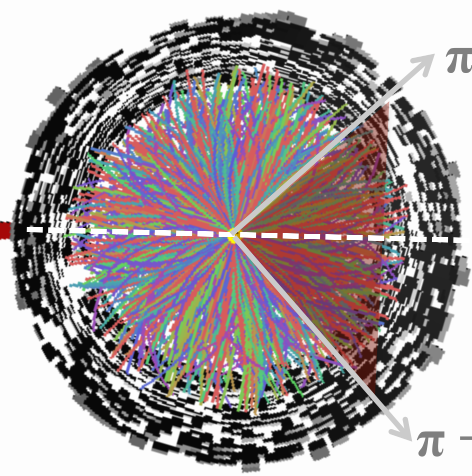
- Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV
- Integrated luminosity of 13 nb^{-1} in the year 2014





- γ_{rich}: Mixture of decay and direct photons
- Purity of direct photons varies between 65% and 89% for $9 < E_T^{trig} < 20$ GeV
- High-purity criteria for π^0 selection limits the statistics
  - Similar procedure as in the previous STAR γ_{dir}+hadron correlation analysis [PLB 760 (2016) 689-696]

Semi-inclusive π^0/γ+jet



- Recoil jets from triggered events
  - With high-E_T trigger: $E_T^{trig} > 9$ GeV
    - High-Q^2 process
  - (Charged) Jet reconstruction:
    - Charged hadron constituents: $p_T^{const} < 15$ GeV/c
    - Same constituent p_T cut also applied at the truth level
    - Algorithm: anti-k_T [Fastjet]
    - Recoil jet region:[π-π/4, π+π/4]
    - Jet radius = 0.2, $|\eta_{jet}| < 1$-R

- Event-mixing technique
  - Uncorrelated jet background
  - Based on h+jet analysis [STAR: PRC **96**, 024905 (2017)]
  - Using same analysis conditions as applied in Same Event (SE)

Full analysis chain

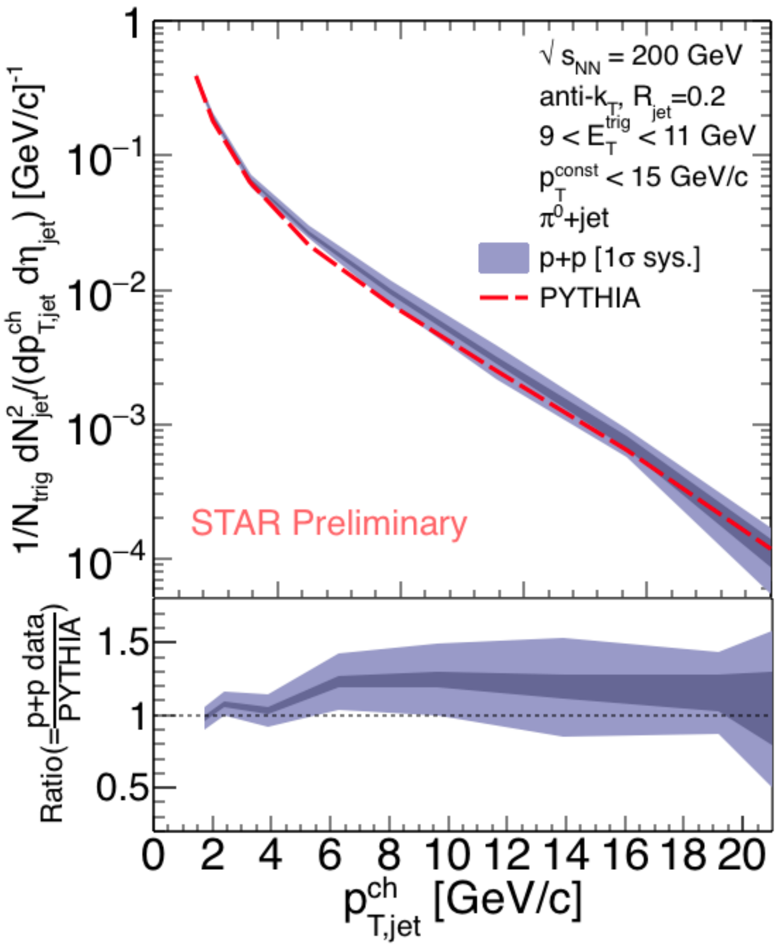
- Discrimination between π^0/γ_{rich}-triggered events
  - Using Transverse Shower Profile method
- Recoil jets from high-tower-triggered events (SE)
  - Estimation of reconstructed jet p_T and background energy density (ρ)

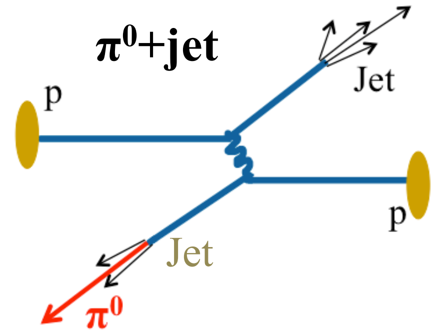
$$p_{\mathrm{T,jet}}^{\mathrm{reco,ch}} = p_{\mathrm{T,jet}}^{\mathrm{raw,ch}} - \rho \cdot A$$

$$\rho = \mathrm{median}\left\{ \frac{p_{\mathrm{T,jet}}^{\mathrm{raw,i}}}{A_{\mathrm{jet}}^{\mathrm{i}}} \right\}$$

- Subtraction of uncorrelated jet background in recoil region
  - Using mixed-event subtraction method
- Correction for detector and heavy-ion background fluctuation effects
  - Using unfolding technique [RooUnfold]
- Conversion from γ_{rich}+jet to γ_{dir}+jet
  - Statistical subtraction based on previously determined purity
- Major sources of systematic uncertainty
  - Unfolding [Prior, methods e.g, SVD and Bayesian, iterations], Mixed-event normalization region, Track-reconstruction effects, γ_{dir} background subtraction [contributes only to γ_{dir}]

π^0-triggered charged recoil jets in p+p collisions



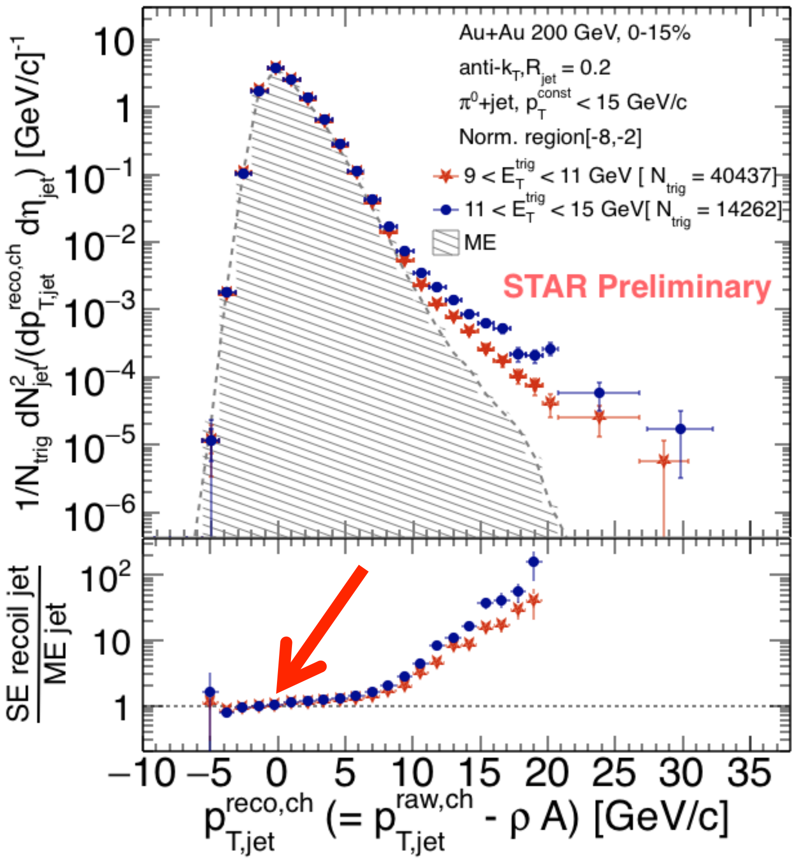


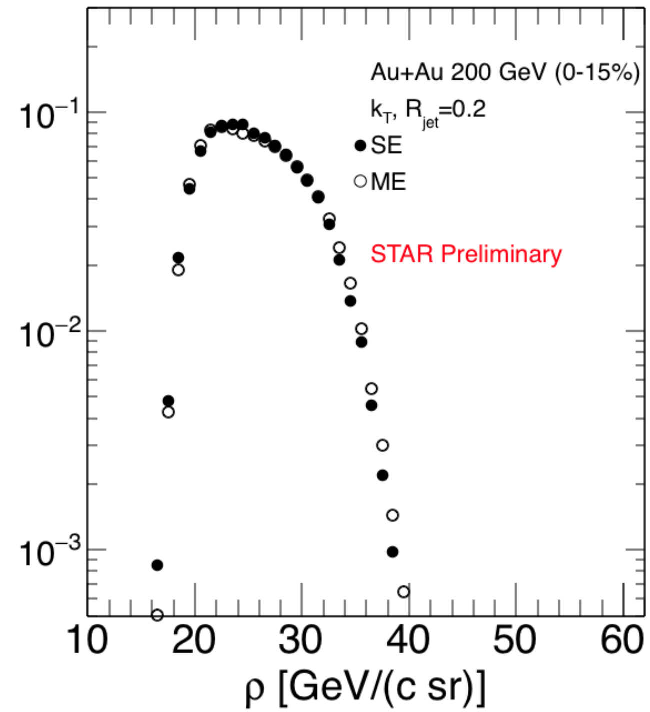
- p+p $\sqrt{s_{NN}}$ = 200 GeV/c
- π^0 triggers with $9 < E_T^{trig} < 11$ GeV, fully unfolded charged jets
  - zero background energy density(ρ)
- π^0-triggered charged-jet spectrum consistent with PYTHIA8.

γ_{dir}+jet and π^0+jet : Higher E_T^{trig} analysis is underway
(Derek Anderson, Ph.D student, TAMU)

Uncorrelated jet background: π^0+jet

SE: Same Events from triggered events, **ME**: Mixed Events from MB dataset



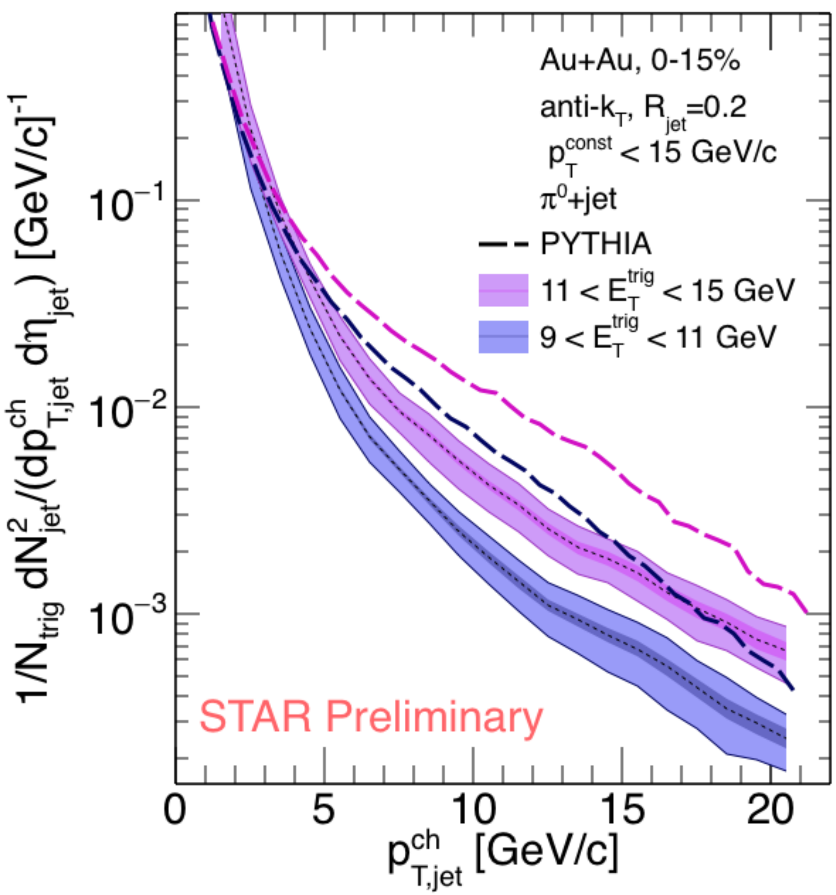


$$\rho = \text{median}\left\{ \frac{p^{\text{raw,i}}_{\text{T,jet}}}{A^{\text{i}}_{\text{jet}}} \right\}$$

- Similar background density distribution for SE and ME

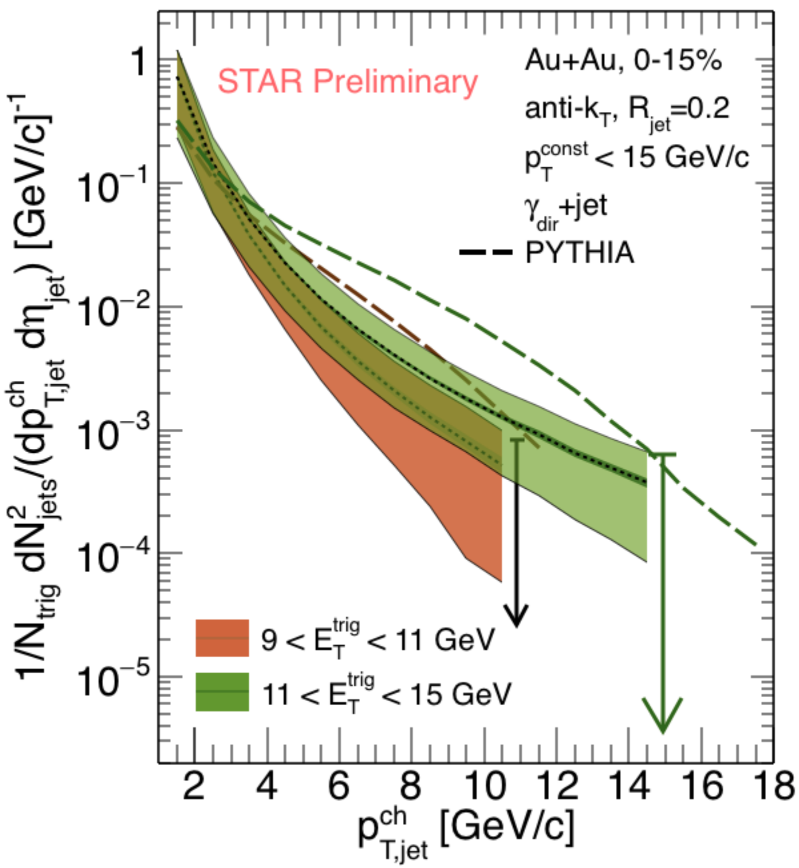
- Recoil charged jet p_T shows π^0-trigger E_T^{trig} dependence for 9-11 and 11-15 GeV
- Recoil charged jets dominate (above ~10 GeV/c) over uncorrelated jet background from mixed events

π^0-triggered charged jets in Au+Au collisions



- π^0-triggered charged recoil jets
  - Fully unfolded spectrum
- A clear difference between recoil-jet spectra for different trigger-E_T: $9 < E_T^{trig} < 11$ GeV vs. $11 < E_T^{trig} < 15$ GeV
- Clear suppression with respect to PYTHIA8
- Higher E_T^{trig} (>15 GeV) and $p_{T,jet}^{ch}$ (> 20 GeV/c) in progress

γ_{dir}-triggered charged jets in Au+Au collisions

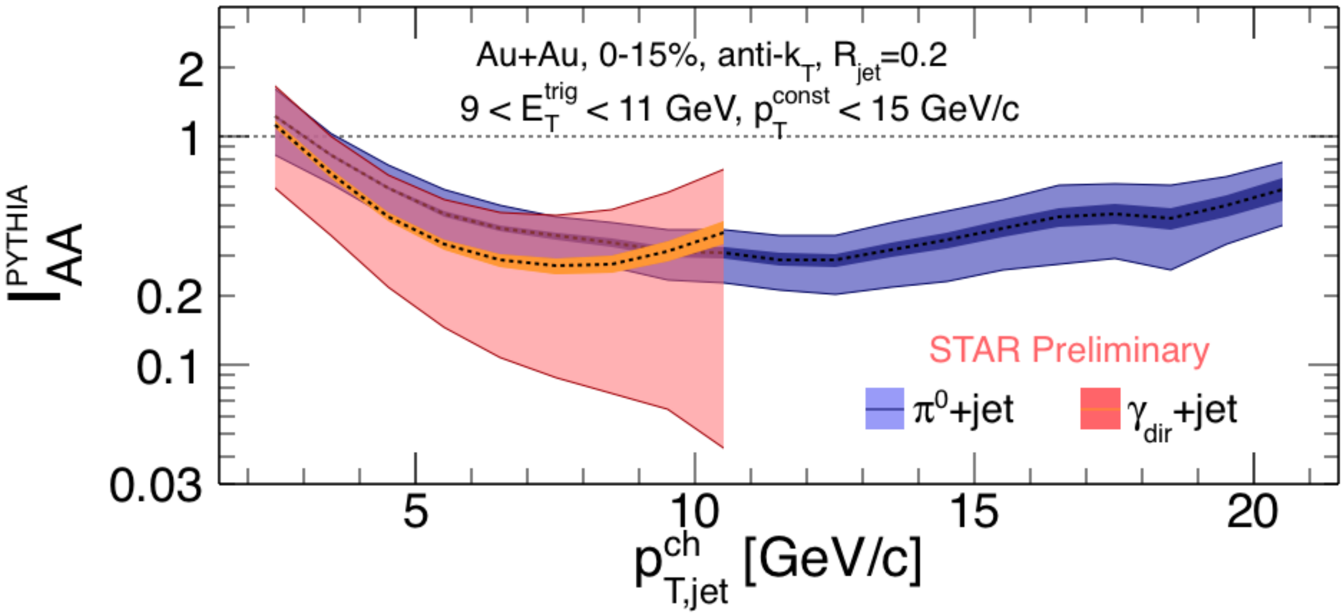


Fully unfolded recoil charged jet p_T

- Indication of systematic difference between recoil-jet spectra for different trigger-E_T: $9 < E_T^{trig} < 11$ GeV vs. $11 < E_T^{trig} < 15$ GeV
  - Downward arrow represents upper limit in yield at:
    $p_{T,jet}^{ch}$ = 11 GeV/c for $9 < E_T^{trig} < 11$ GeV,
    $p_{T,jet}^{ch}$ = 15 GeV/c for $11 < E_T^{trig} < 15$ GeV.
- Clear suppression with respect to PYTHIA8

Recoil jet yield suppression: γ_{dir}+jet vs. π^0+jet

$9 < E_T^{trig} < 11$ GeV



Systematic (lighter band) and statistical (darker band) uncertainties

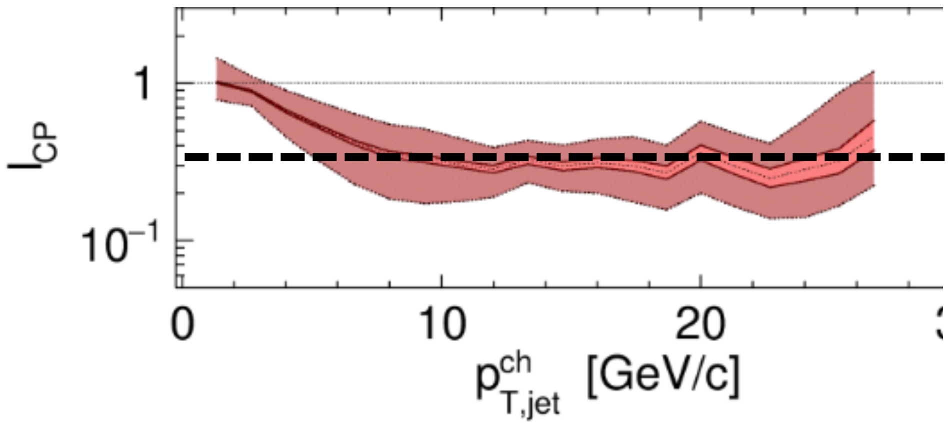
- I_{AA}^{PYTHIA} is the ratio of per triggered recoil jet yield in central Au+Au collisions to PYTHIA
- Semi-inclusive γ_{dir}- and π^0-triggered charged-jet measurements
- Clear suppression for both trigger types with respect to PYTHIA8
- Similar level of suppression in γ_{dir}+jet and π^0+jet, within uncertainties
  - γ_{dir}+jet runs out of kinematic reach

Comparison of $h^{\pm}$+jet to π^0+jet

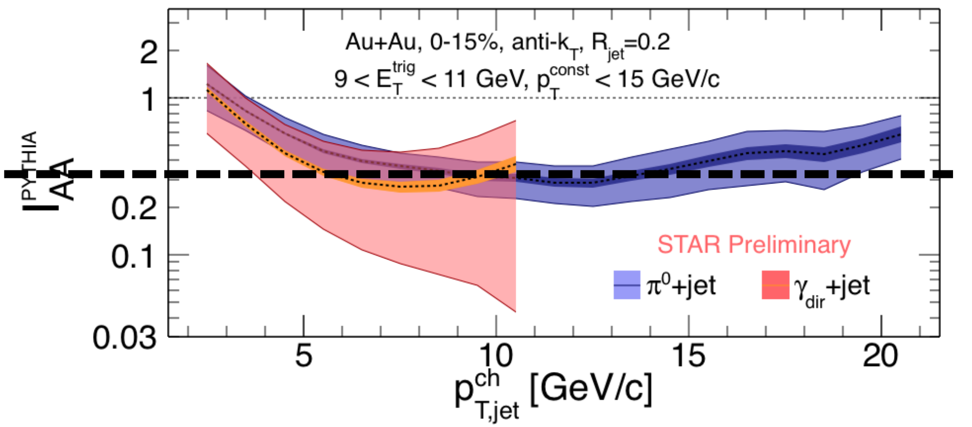
Au+Au 200 GeV

STAR: PRC **96**, 024905 (2017)

$h^{\pm}$+jet: $9 < p_T^{trig} < 30$ GeV/c



This analysis: $9 < E_T^{trig} < 11$ GeV

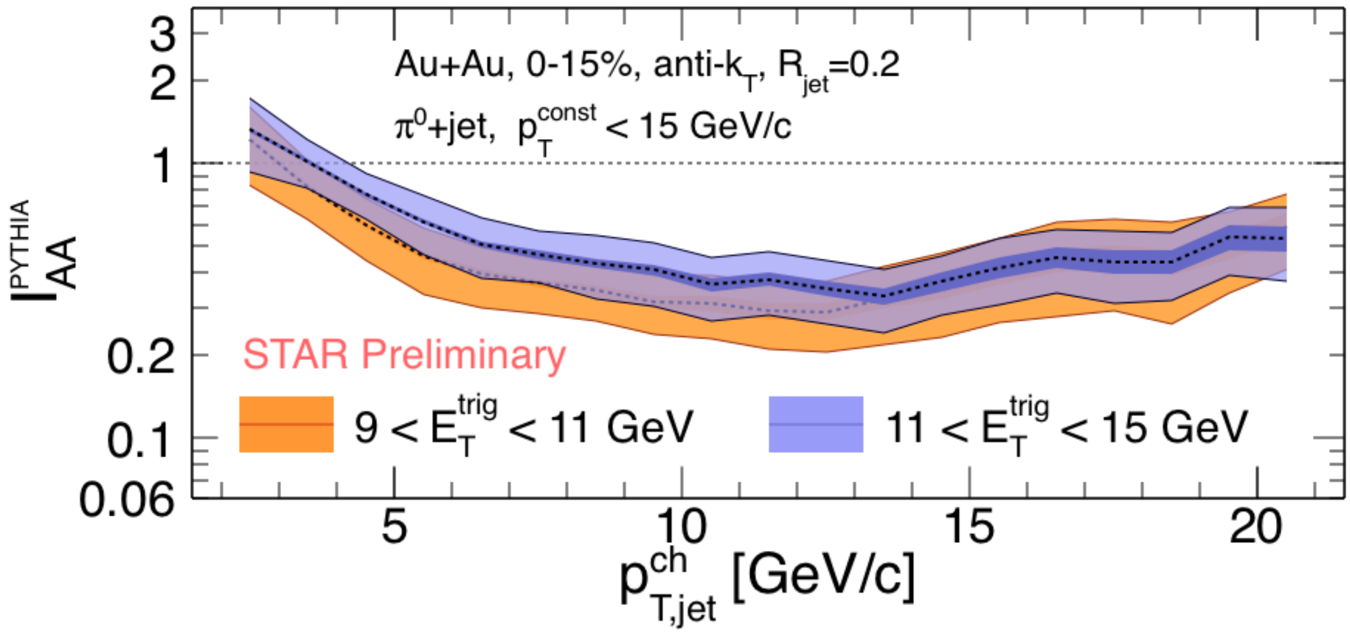


Systematic (lighter band) and statistical (darker band) uncertainties

- Same level of suppression above $p_{T,jet}^{ch} > 9$ GeV/c
  - $h^{\pm}$+jet is I_{CP}, whereas π^0+jet is I_{AA}^{PYTHIA}

Recoil-jet yield suppression at different trigger E_T

π^0 +jet



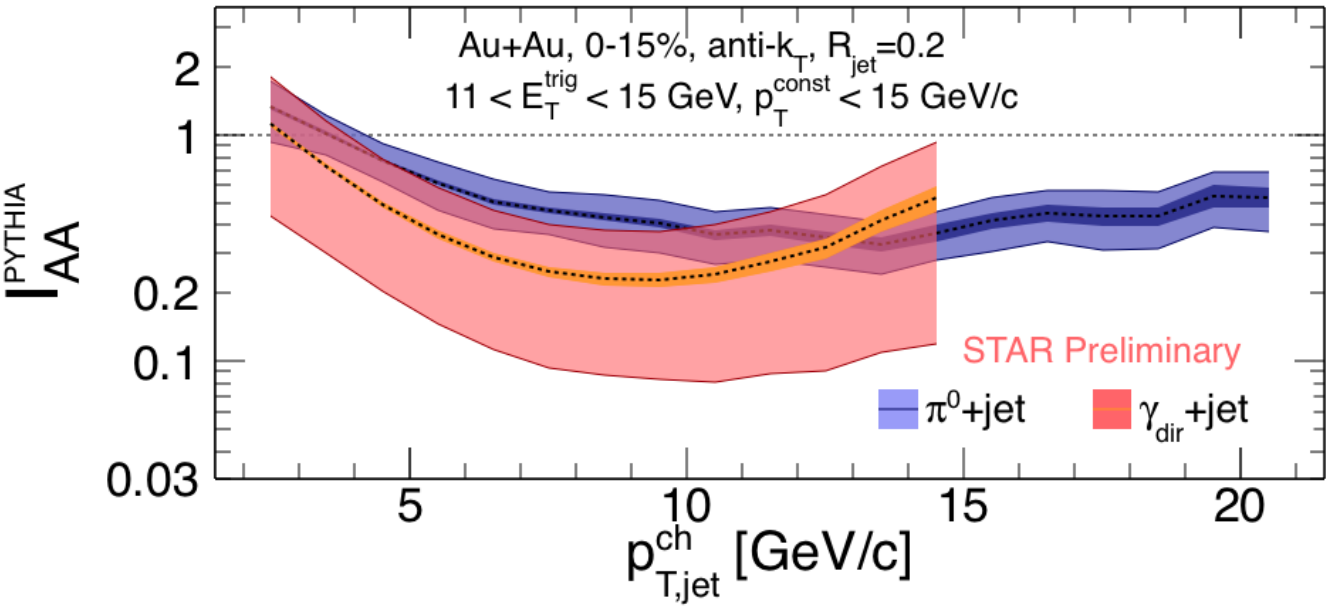
Systematic (lighter band) and statistical (darker band) uncertainties

- No clear π^0-trigger E_T dependence between $9 < E_T^{trig} < 11$ GeV vs. $11 < E_T^{trig} < 15$ GeV, within uncertainties, for jet radius 0.2

Recoil jet yield suppression: γ_{dir}+jet vs. π^0+jet

What about at higher trigger E_T?

$11 < E_T^{trig} < 15$ GeV



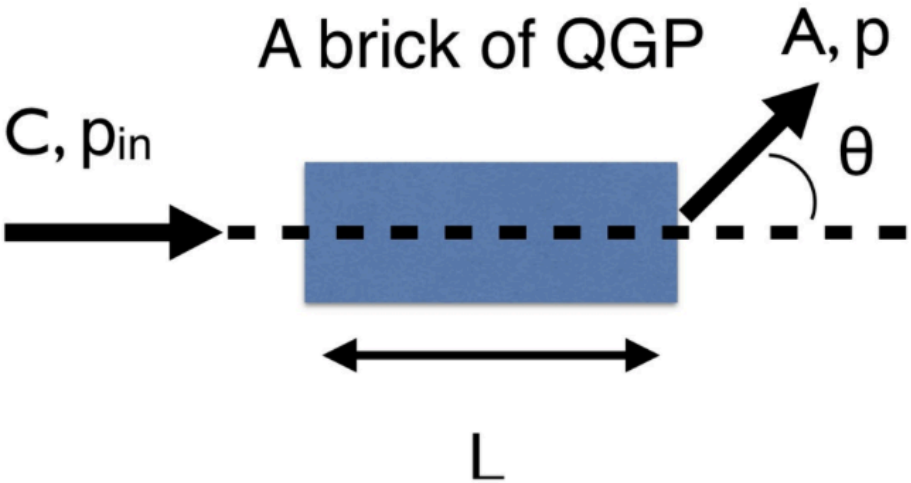
Systematic (lighter band) and statistical (darker band) uncertainties

- Almost same level of suppression in both cases, within uncertainties

Ongoing work related to this analysis in STAR…

π^0+jet (γ_{dir}+jet) $\Delta\varphi$ angular correlation

Single scattering in a brick of QGP



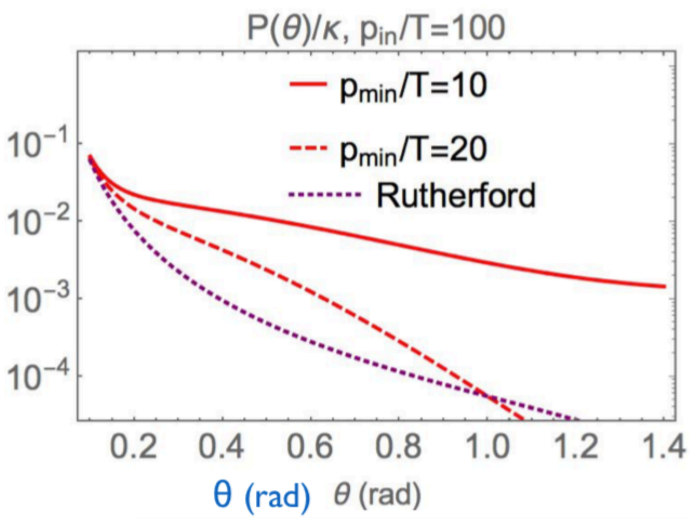
QCD Molière Scattering: A rare large angle scattering

F. D'Eramo, K. Rajagopal, Y. Yin
arXiv:1808.03250
Y. Yin: HP2018 talk
, JETSCAPE talk

In hot-dense QCD

- Firstly do we see this effect?
- Single vs. Multiple scattering domain?
- Parton momentum range?
- QCD medium response?

Angle distribution $P(\theta) \equiv \int_{p_{min}} dp F(p, \theta)$

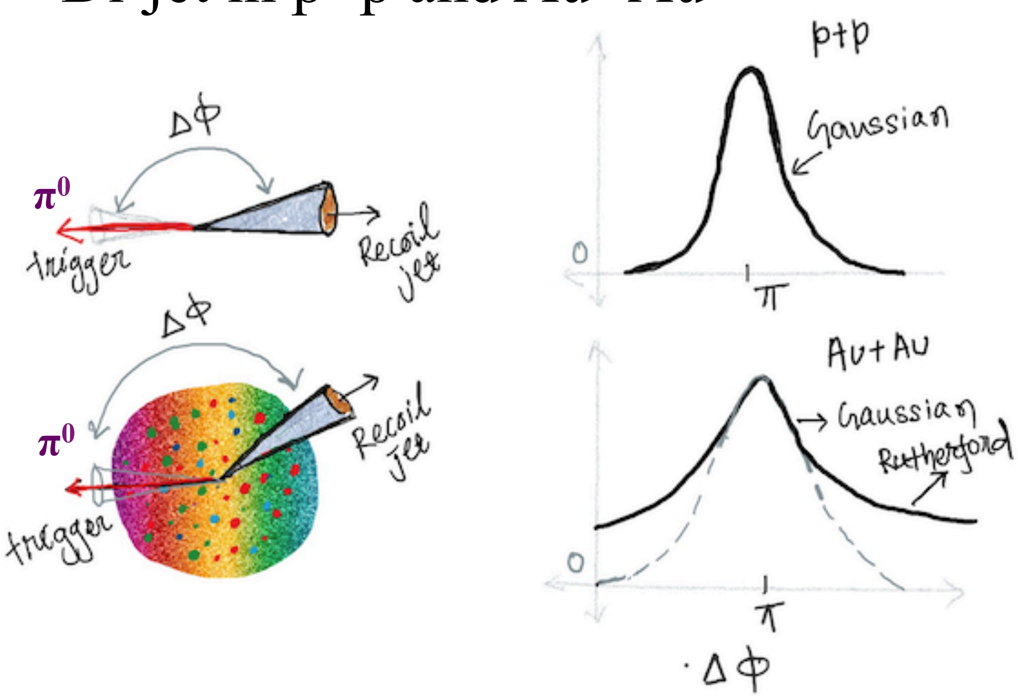


(An incident gluon with initial energy p_i =100T.)

Rutherford Scattering like, gg->gg

In heavy-ion collisions

Di-jet in p+p and Au+Au

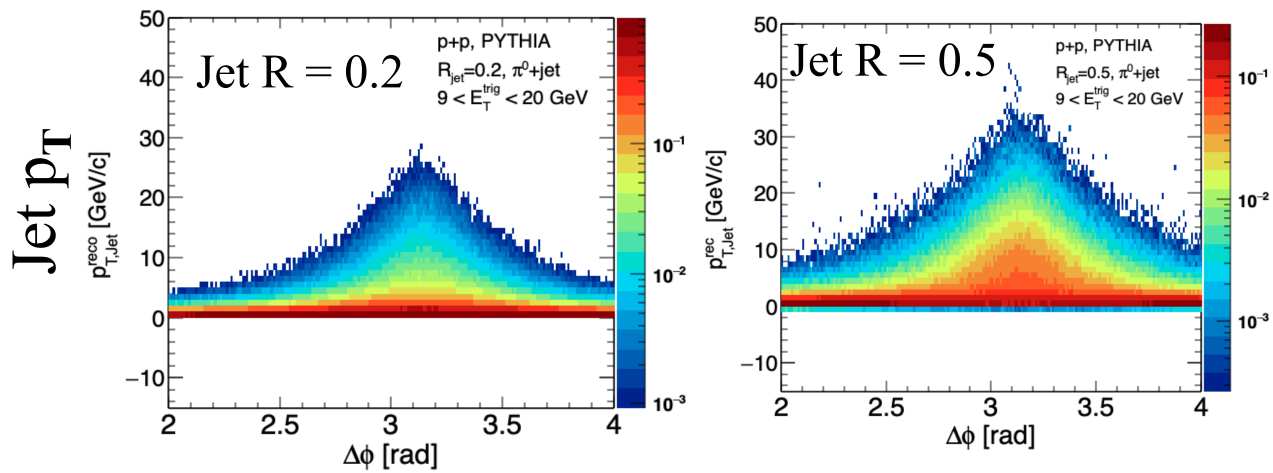


At small angle ⟶ Gaussian Shape
At large angle ⟶ Rutherford Scattering

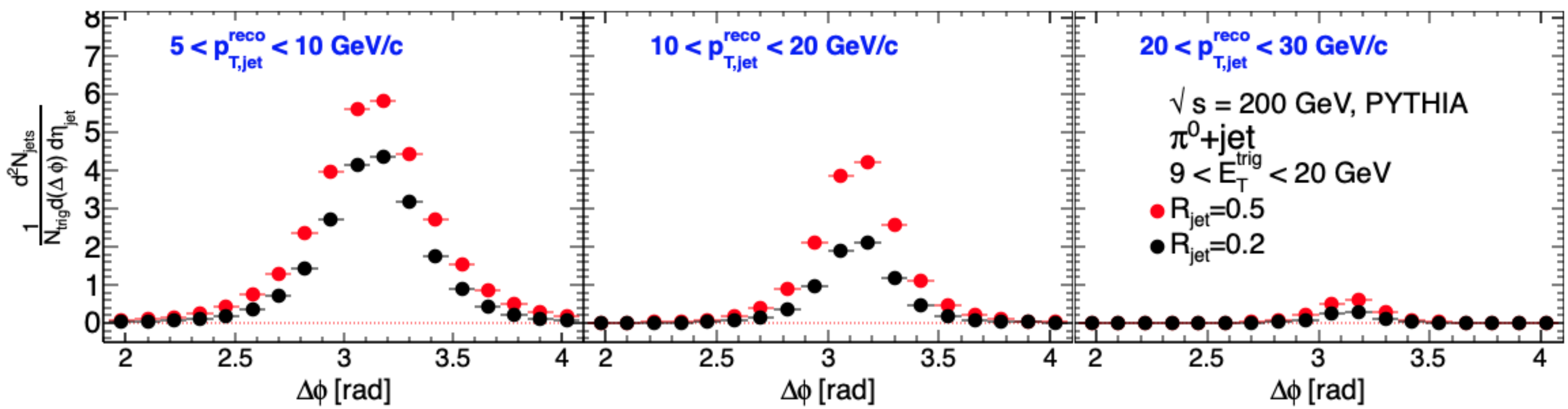
- Scattering of a recoil-jet off quasi-particles in the QGP
  - Intra-jet broadening (Δφ)
- Intriguing to study Δφ correlations for different recoil jet radii and jet p_T in heavy-ion collisions

p+p PYTHIA expectation: π^0+jet

Jet p_T vs. $\Delta\varphi$ correlation function



$\Delta\varphi$ distributions at different jet p_T bins

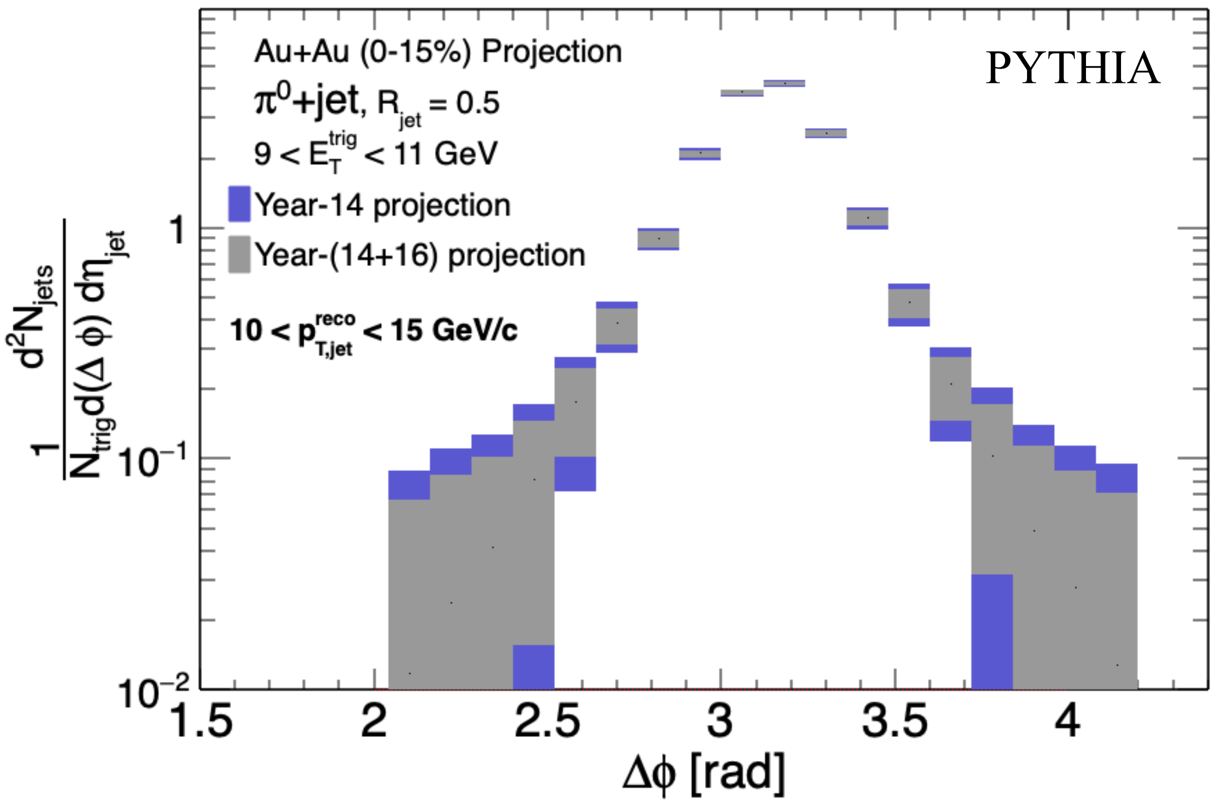


No significant yield at large angular deviation.

Analysis is underway in Au+Au collision for different jet radii and jet p_T.

Heavy-Ion projection

STAR heavy-ion projection for this measurement
Au+Au 200 GeV year 2014 + year 2016:
~25 nb^{-1} Integrated Lumininosity



Summary

- First γ_{dir}+jet and π^0+jet measurements in Au+Au collisions at $\sqrt{s_{NN}}$= 200 GeV at RHIC
- p+p collisions at 200 GeV: π^0-triggered recoil-jet yield consistent in data and PYTHIA8
- Central Au+Au at 200 GeV:
    - A strong suppression of γ_{dir}+jet and π^0+jet
    - Suppression of recoil-jet yield consistent in both cases, for $9 < E_T^{trig} < 15$ GeV

Outlook

Ongoing work in the direction of γ_{dir}+jet and π^0+jet analysis in STAR :

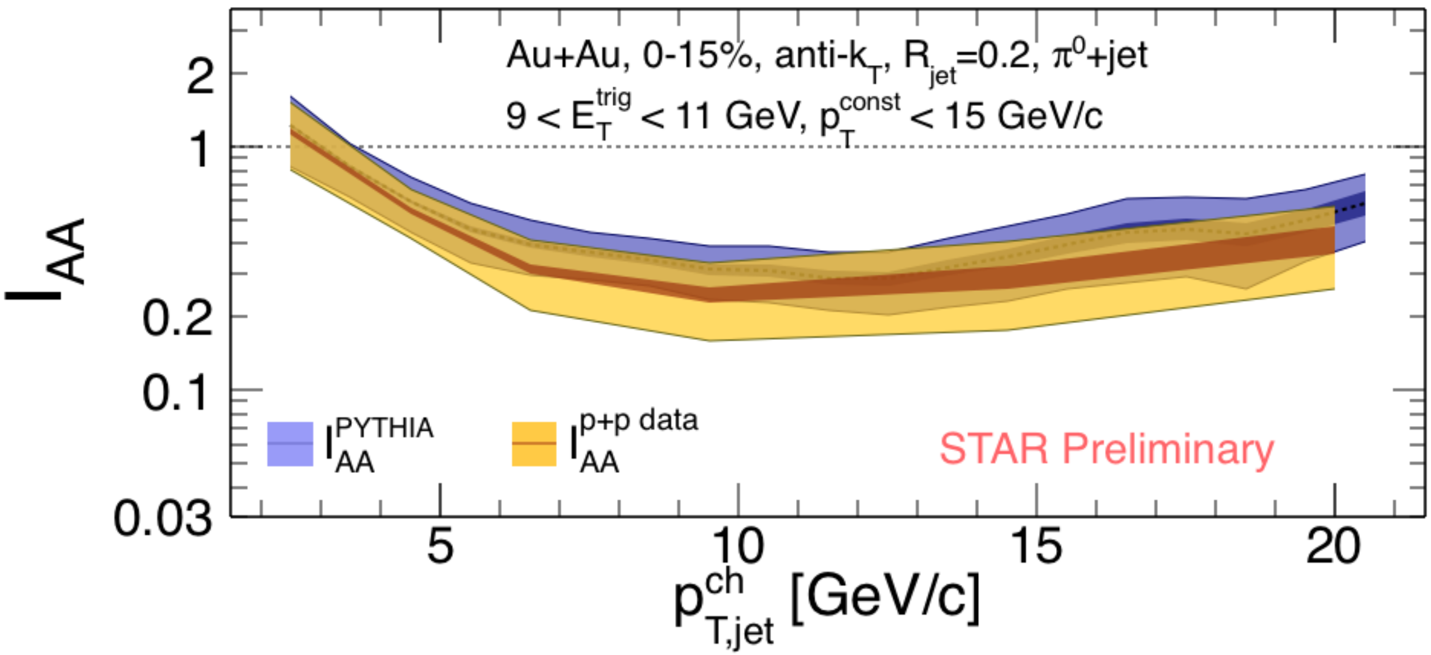
- $E_T^{trig} > 15$ GeV ; larger $p_{T,jet} > 20$ GeV/c; $R_{jet} = 0.5$
- π^0+jet (γ_{dir}+jet) $\Delta\varphi$ angular correlation

JETSCAPE Theory calculations…

Backup

Recoil jet yield suppression: pp vs. PYTHIA

π^0+jet: $9 < E_T^{trig} < 11$ GeV



Systematic (lighter band) and statistical (darker band) uncertainties

- I_{AA} is the ratio of per triggered recoil jet yield in central Au+Au to p+p collisions
- Comparison between π^0-triggered charged jet I_{AA}^{PYTHIA} and $I_{AA}^{p+p\ data}$
- Consistent within uncertainties
- PYTHIA8 provides good representation of p+p data