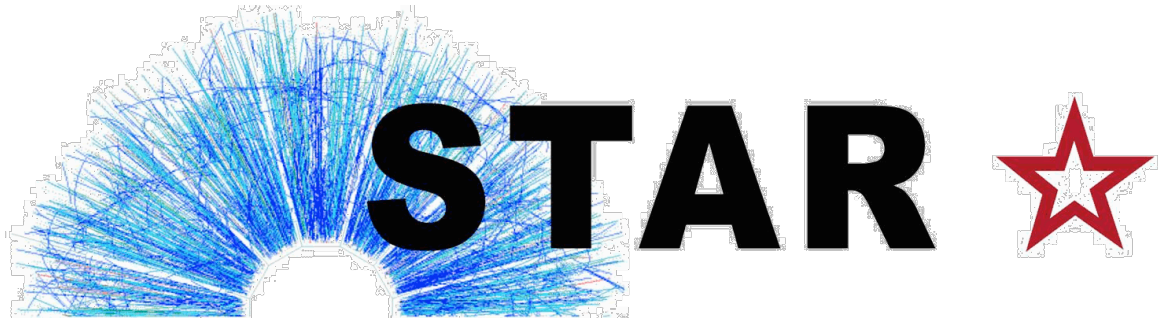

An Investigation of Charm Quark Jet Spectrum and Shape Modifications in Au + Au Collisions at $\sqrt{s_{NN}}$ = 200 GeV

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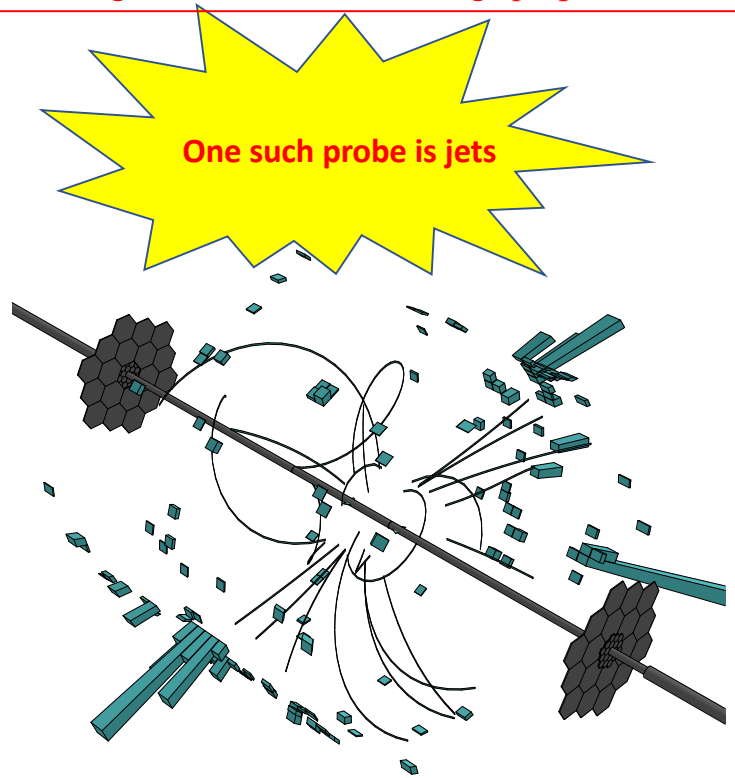
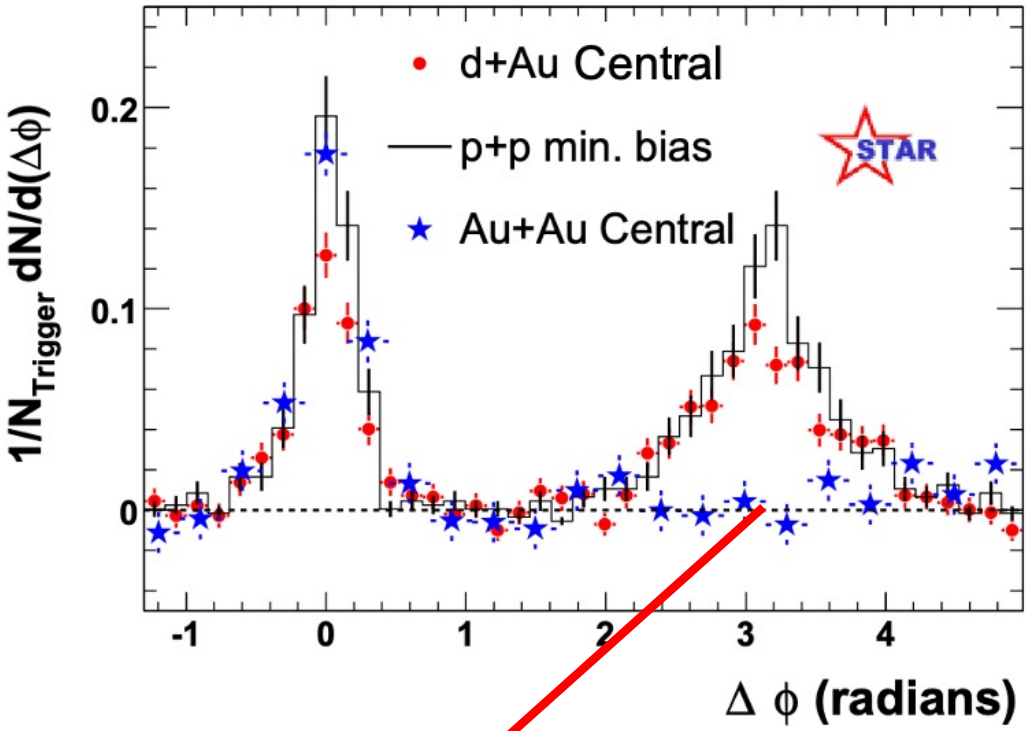
Jets in heavy ion collisions

Hard probe → Strong interaction between high p_T partons and medium



STAR, Phys. Rev. Lett. 91 (2003) 072304



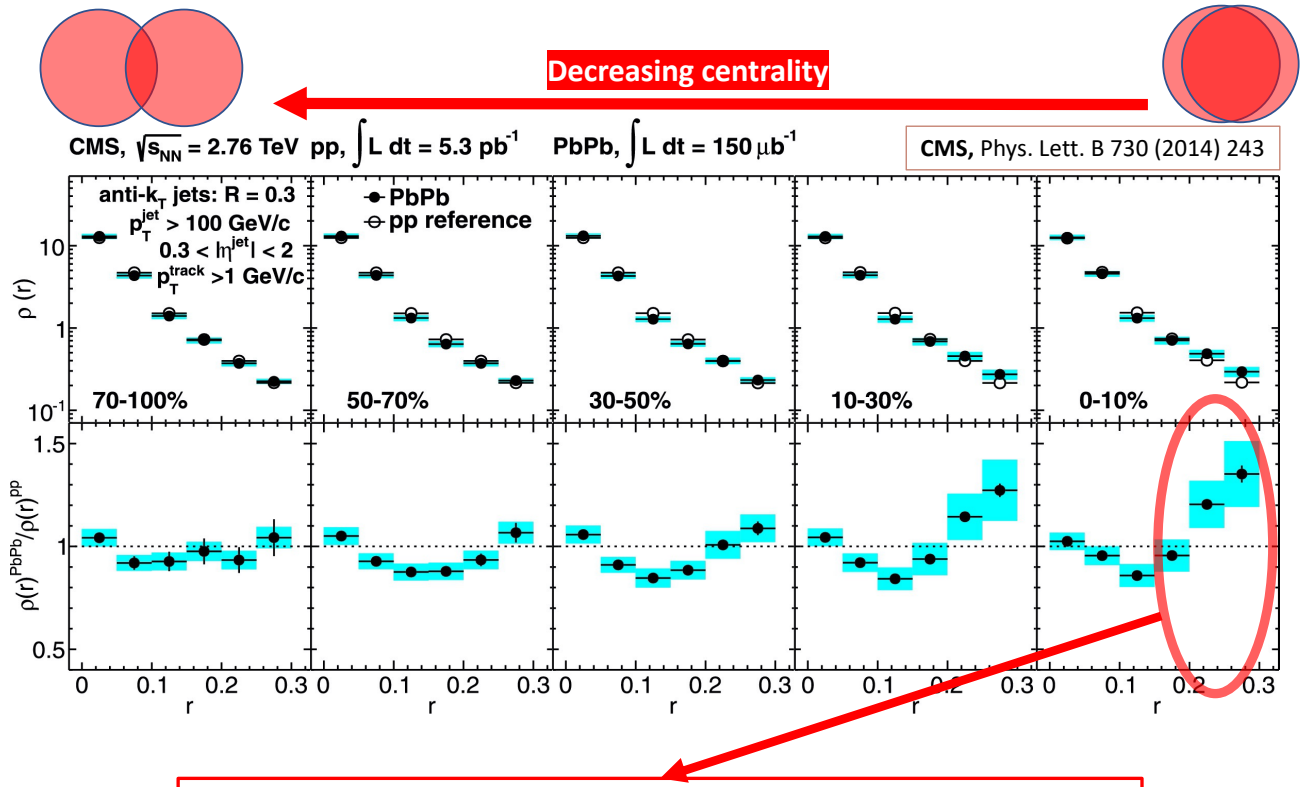
- **Loss of parton energy** in the QGP medium
- **Parton shower broadened** due to medium-induced radiation and scattering
- Jets reconstructed in experiment by a clustering algorithm, commonly anti-k_T [1]

Recoil-side jets are heavily quenched in the presence of QGP

1. Phys. Lett. B 641 (2006) 57-61

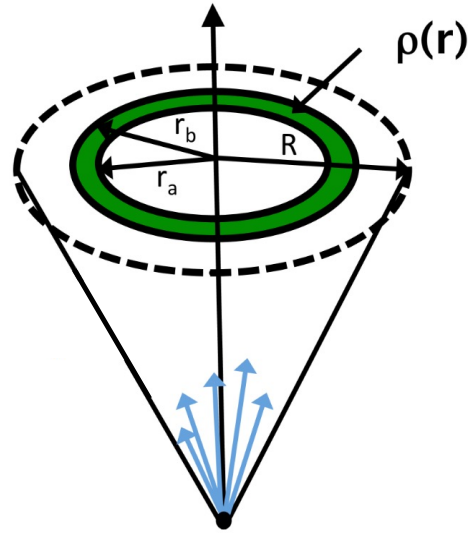
Previous Jet Results

$$\rho(r) = \frac{1}{\Delta r}\frac{1}{N_{\mathrm{jet}}}\sum_{\mathrm{jet}}\frac{\sum_{\mathrm{track}\in(r_a,r_b)} p_{\mathrm{T,track}}}{p_{\mathrm{T,jet}}}$$



Jet energy is redistributed to large distances from the jet axis in the presence of QGP.

$$r = \sqrt{(\eta_{\mathrm{track}} - \eta_{\mathrm{jet}})^2 + (\phi_{\mathrm{track}} - \phi_{\mathrm{jet}})^2}$$



Possible mechanisms:

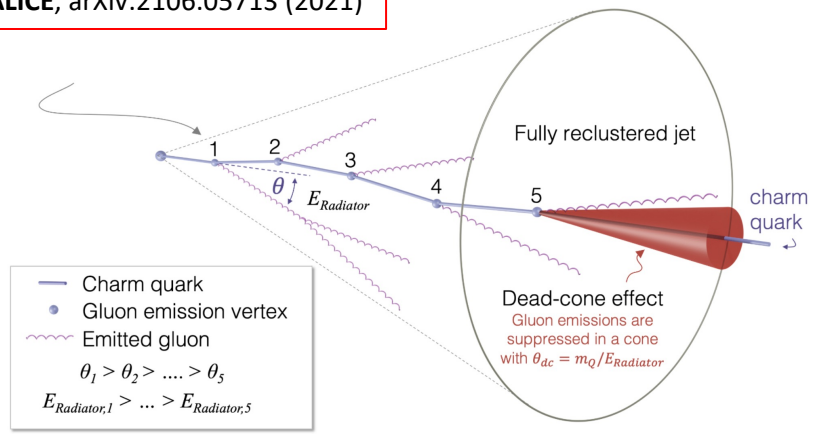
- Spallation of the soft underlying event due to jet
- Multiple-scattering
- Medium-induced Bremsstrahlung
- Medium response

Dependent on the mass of the underlying parton → **Motivation to look at heavy-flavor jets**

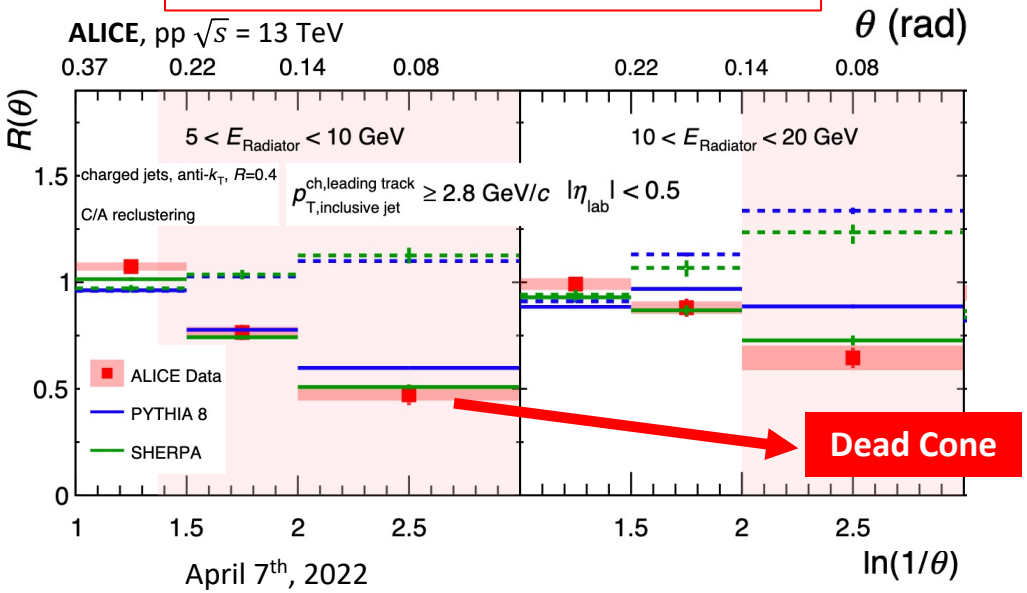
Previous Jet Results

Jets from Heavy Flavor

ALICE, arXiv:2106.05713 (2021)

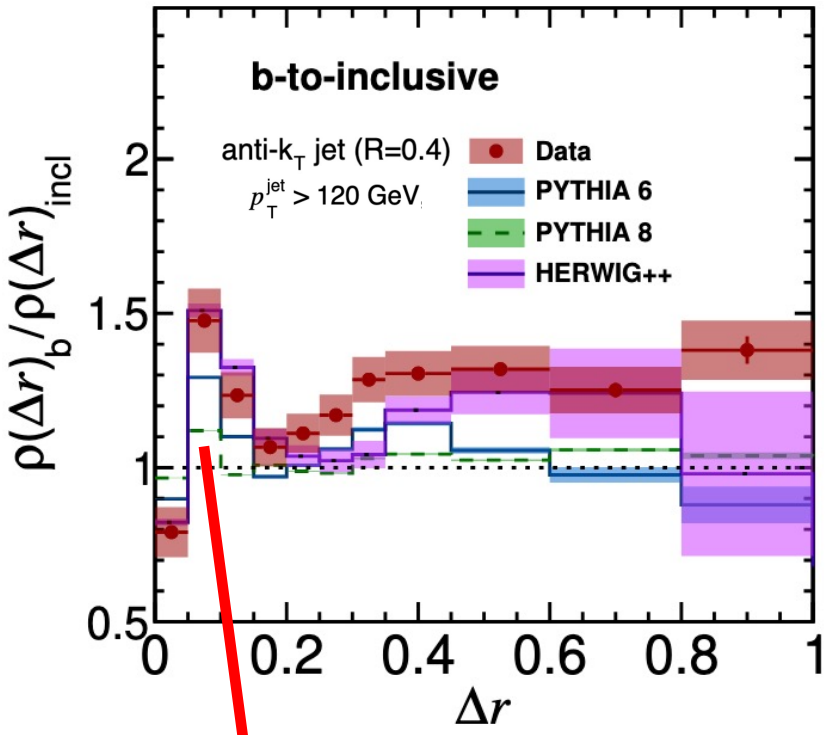


$$R(\theta) = \frac{1}{N^{\mathrm{D^0\,jets}}} \frac{\mathrm{d}n^{\mathrm{D^0\,jets}}}{\mathrm{d}\ln(1/\theta)} \Big/ \frac{1}{N^{\mathrm{inclusive\ jets}}} \frac{\mathrm{d}n^{\mathrm{inclusive\ jets}}}{\mathrm{d}\ln(1/\theta)}$$



- Heavier quarks (Charm (c) ~ 1.3 GeV/c^2 and Bottom (b) ~ 4.2 GeV/c^2)
  - ✓ Usually produced early in the collision, so have access to full QGP evolution
- Radiation for heavy quarks suppressed due to the '*dead cone*' effect
  - ✓ Results in different emission spectra compared to light quarks in vacuum.

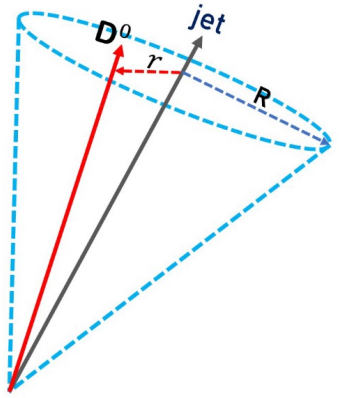
CMS, JHEP05 (2021) 054



Bottom quark jet (b-jets) shapes modified in vacuum, possibly due to dead cone

Previous Jet Results

Jets from Heavy Flavor

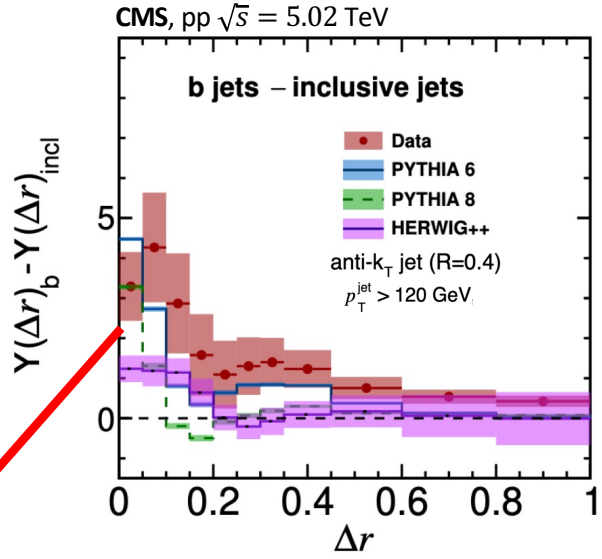


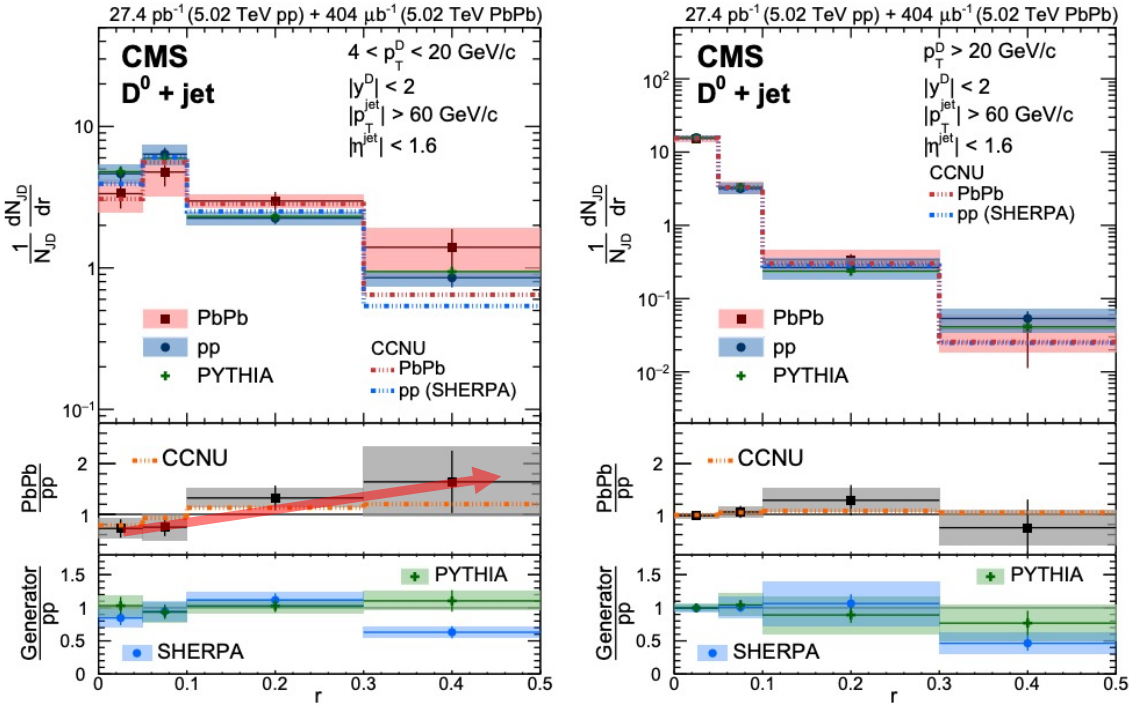
$$\text{Radial Distribution} = \frac{1}{N_{\text{Jet},D^0}} \frac{dN_{\text{Jet},D^0}}{dr}$$

CMS, JHEP05 (2021) 054

CMS, Phys. Rev. Lett. 125 (2020) 102001

$$Y(\Delta r) = \frac{1}{N_{\text{jets}}} \frac{\mathrm{d}^2 N_{\text{trk}}}{\mathrm{d}\Delta r \mathrm{d}p_{\mathrm{T}}^{\text{trk}}}$$





Higher yields of low p_T charged-particle close to jet axis in b-Jets vs inclusive jets in vacuum

Low p_T D^0s diffused in the presence of QGP. High p_T D^0s in jets do not show such modification.

~ Different fragmentation pattern for heavy quarks

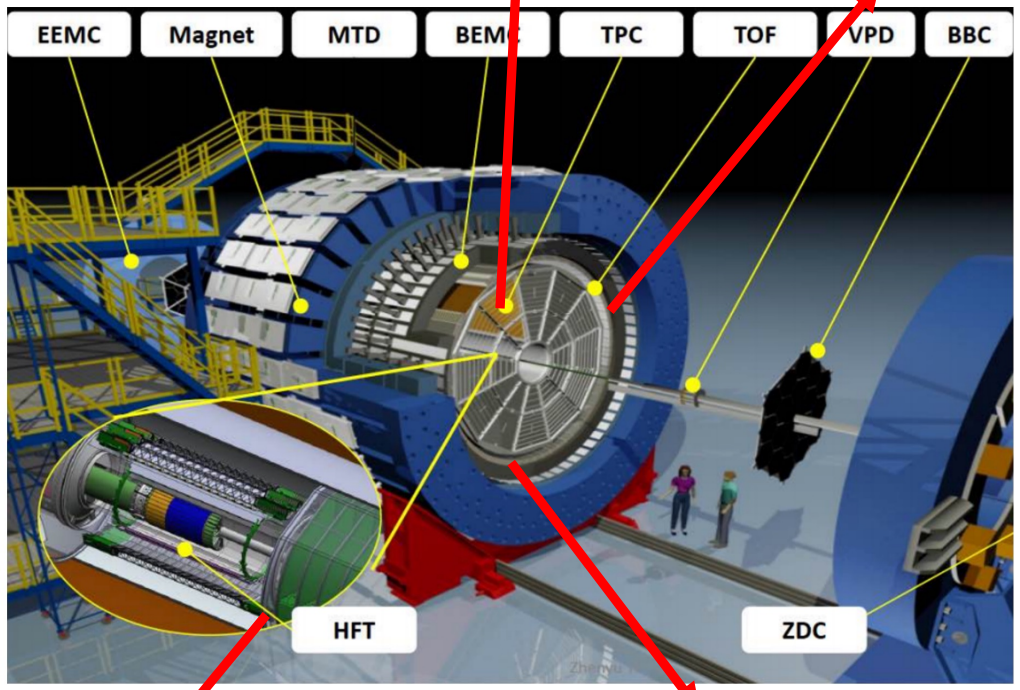
~ Trend explained well by models with collisional and radiative corrections [1]

1. Eur.Phys.J. C79 (2019) 789

STAR Detector and Dataset used

Time Projection Chamber (TPC)
- Measures momentum, track trajectory, and identifies charged particles

Time-of-Flight Detector (TOF)
- Identifies charged particles



Barrel Electromagnetic Calorimeter
- Measures energy for neutral and charged particles

Heavy Flavor Tracker (HFT)
- Improves position resolution for tracks

Event Selection :

- Au+Au $\sqrt{s_{NN}}$ = 200 GeV, Run14
- Minimum bias (MB)
- Centrality ∈ [0, 80]% (3 bins: [0-10], [10-40], [40-80])

Track Selection :

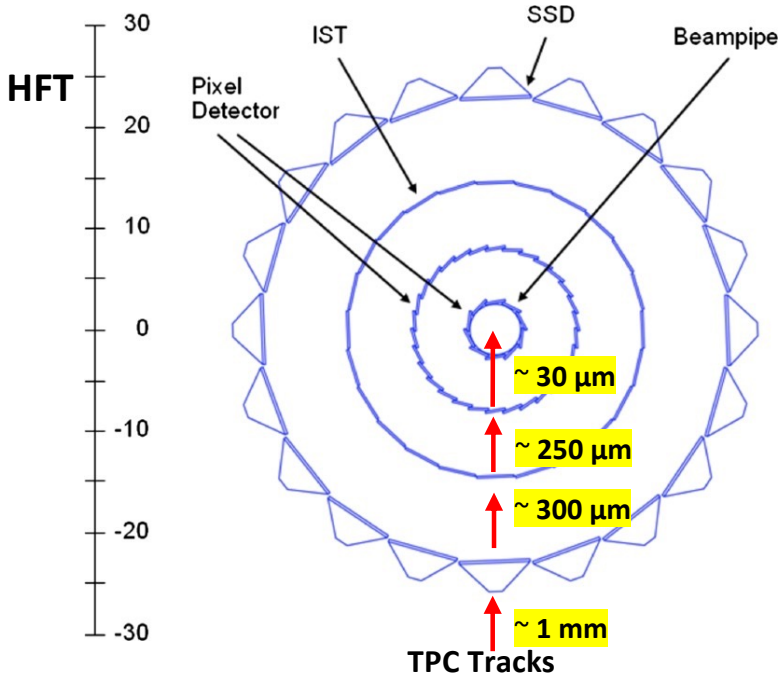
- $0.2 < p_{T,track}$ [GeV/c] < 30 ; $0.2 < p_{T,tower}$ [GeV/c] < 30
- $|\eta_{track}| < 1$; $|\eta_{tower}| < 1$
- $D^0 \rightarrow K^{\mp} + \pi^{\pm}$ [B.R. = 3.82 %]
- For D^0 reconstruction: Tracks need at least two hits in HFT
- $1 < p_{T,D^0}$ [GeV/c] < 10

D^0 Jet Selection :

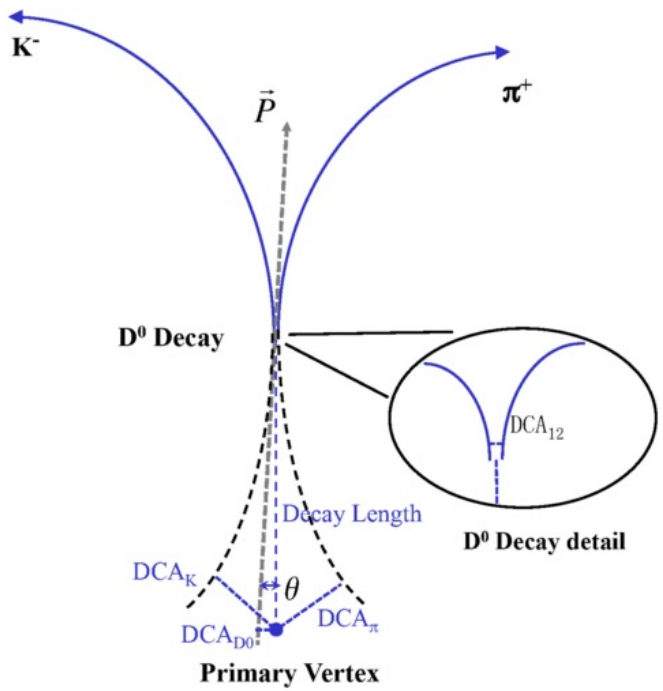
- Anti-k_T jets of radius R = 0.4, area-based background subtraction
- $3 < p_{T,Jet}$ [GeV/c] < 30
- $|\eta_{Jet}| < 0.6$

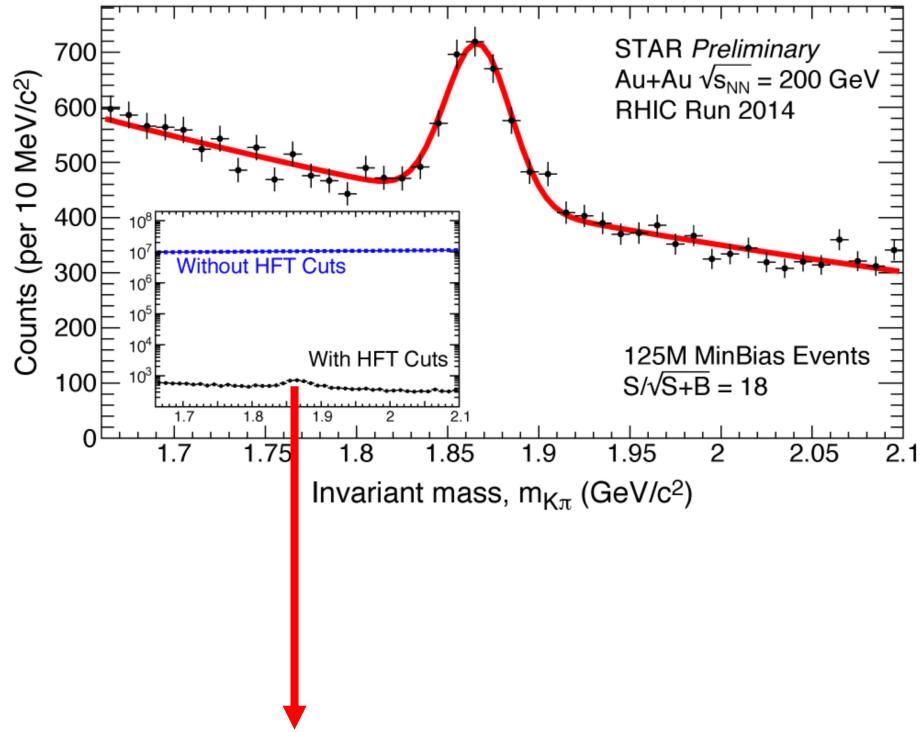
D^0 Reconstruction

- Kaon and Pions identified with hybrid PID from TPC and TOF



STAR, Phys. Rev. C 102 (2020) 014905





- Decay Length of D^0 ~ 123 µm.
- HFT has a resolution of 30 µm for kaons at ~ 1.2 GeV/c
- HFT can reconstruct D^0 candidates based on the decay kinematics

Topological cuts on the D^0 candidates improve signal significance

D^0 - Jet Yield Extraction

sPlot Method

- Native class in RooStats + widely used in HEP
- Unbinned maximum likelihood fit to invariant mass integrated over all kinematics
- $p_{T,Jet}$ and ΔR histograms with all D^0-jet candidates using sWeights
- Trivial to include reconstruction efficiencies versus D^0 kinematics

sWeights →

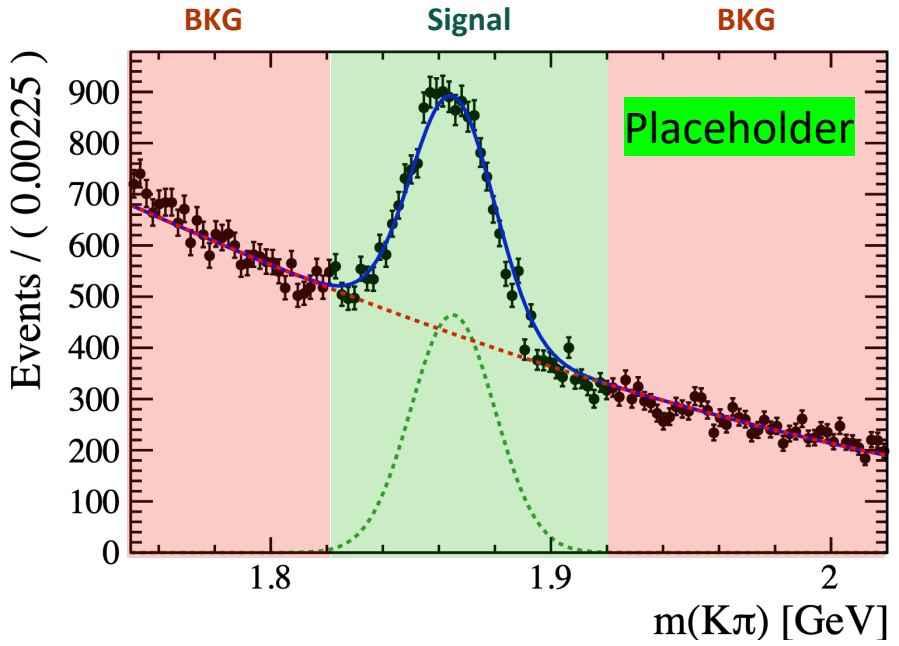
$$ {}_s\mathcal{P}_n(m_{K\pi,i}) = \frac{\sum_{j=1}^{N_T} V_{nj} f_j(m_{K\pi,i})}{\sum_{k=1}^{N_T} N_k f_k(m_{K\pi,i})} $$

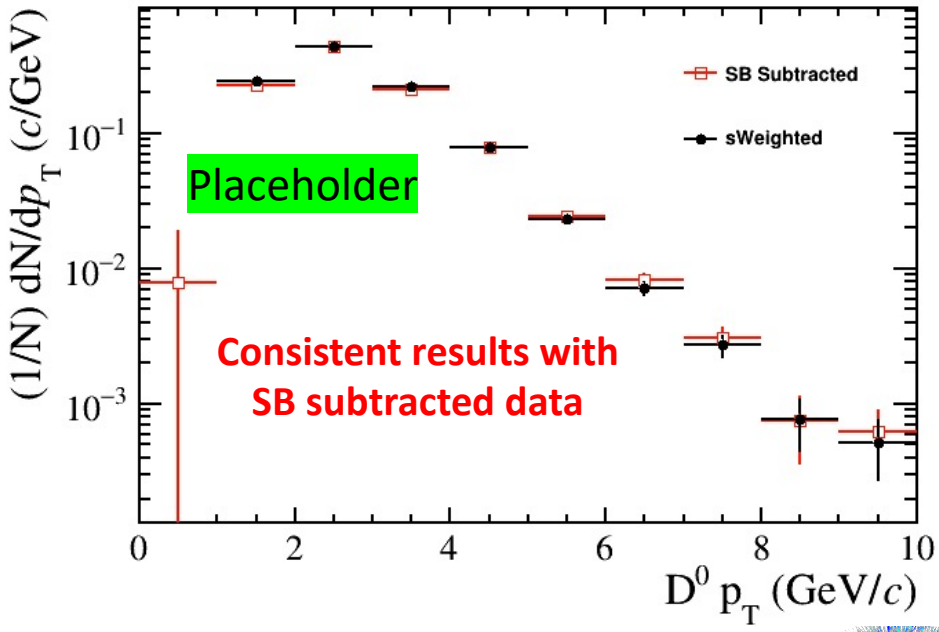
Unbinned max. likelihood fit
n = n-th fit component(sig/bkg)
N_k = k-th yield (T=2)
$f_k(m_{K\pi,i})$ = per-event PDF value with k^{th} hypothesis
V = cov. matrix

Efficiency Correction in sWeights →

$$ {}_s\mathcal{P}_n(m_{K\pi,i}) \rightarrow \frac{{}_s\mathcal{P}_n(m_{K\pi,i})}{\varepsilon(m_{K\pi,i})} $$

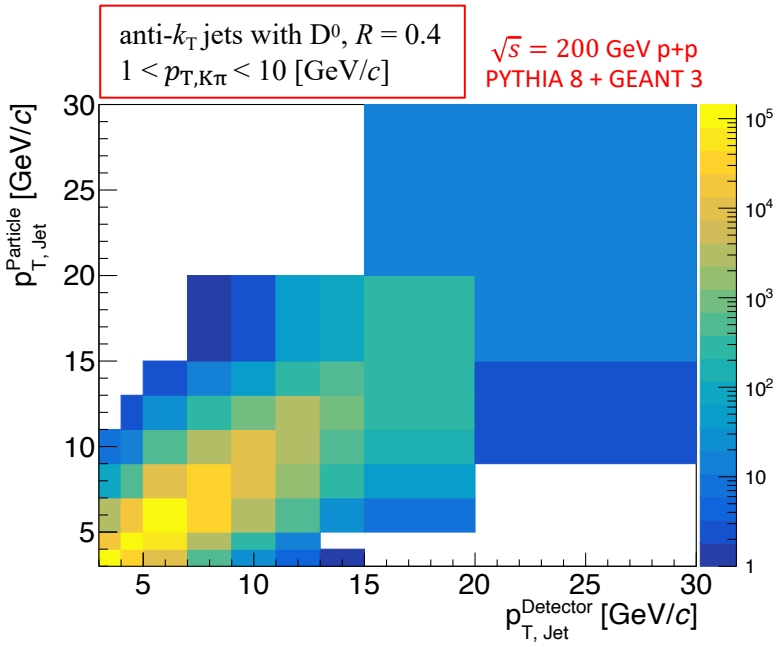
For more information about sPlot, visit poster by Matthew Kelsey.



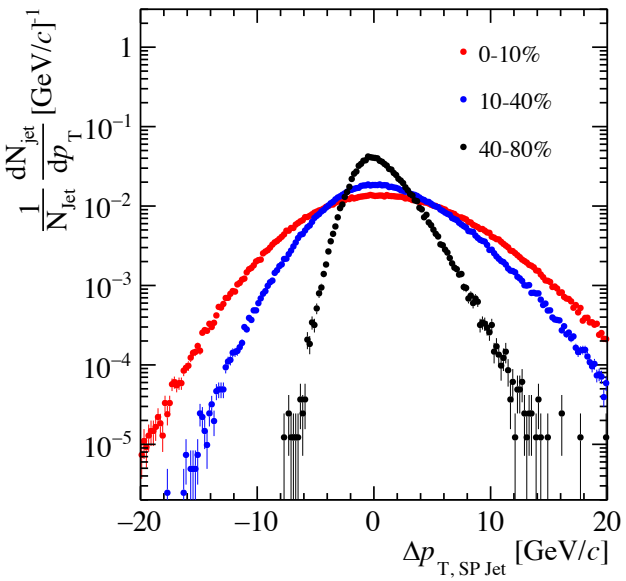


Unfolding for jet reconstruction inefficiencies

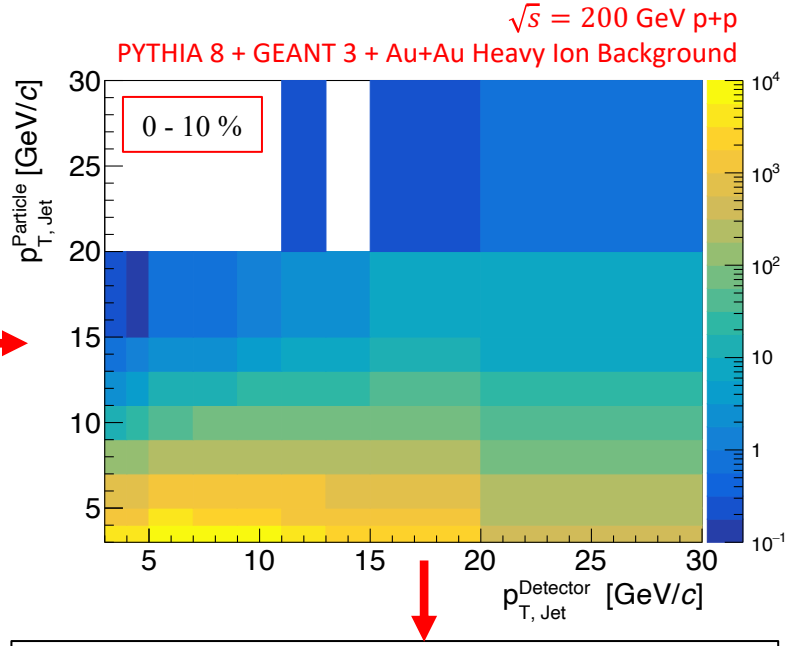
1. Response Matrix for p+p $\sqrt{s}$ = 200 GeV from PYTHIA and GEANT3 to get the detector response
2. Single Particle Embedding in minimum bias events for background fluctuation in the heavy ion event
3. Reweight PYTHIA with a prior (FONLL) to match the shape of the jet p_T spectra



X

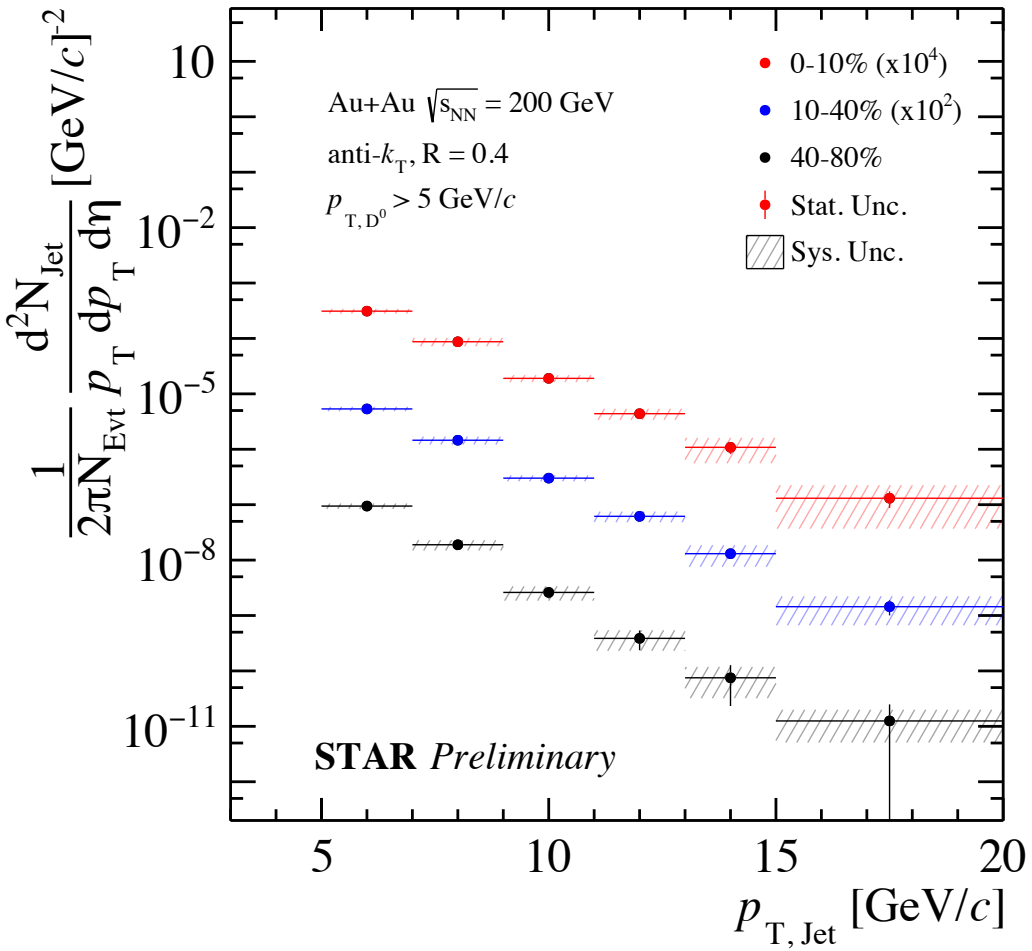


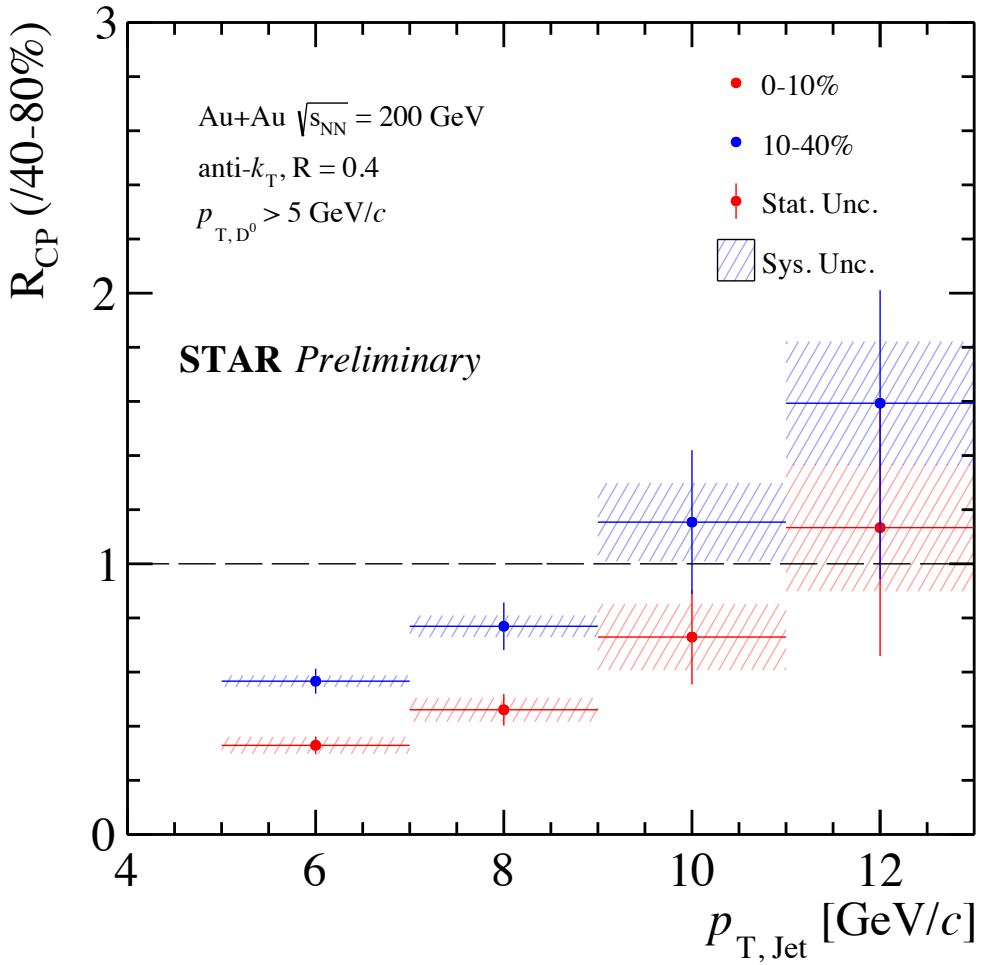
FONLL Reweight



Final Response Matrix to unfold $p_{T,Jet}$

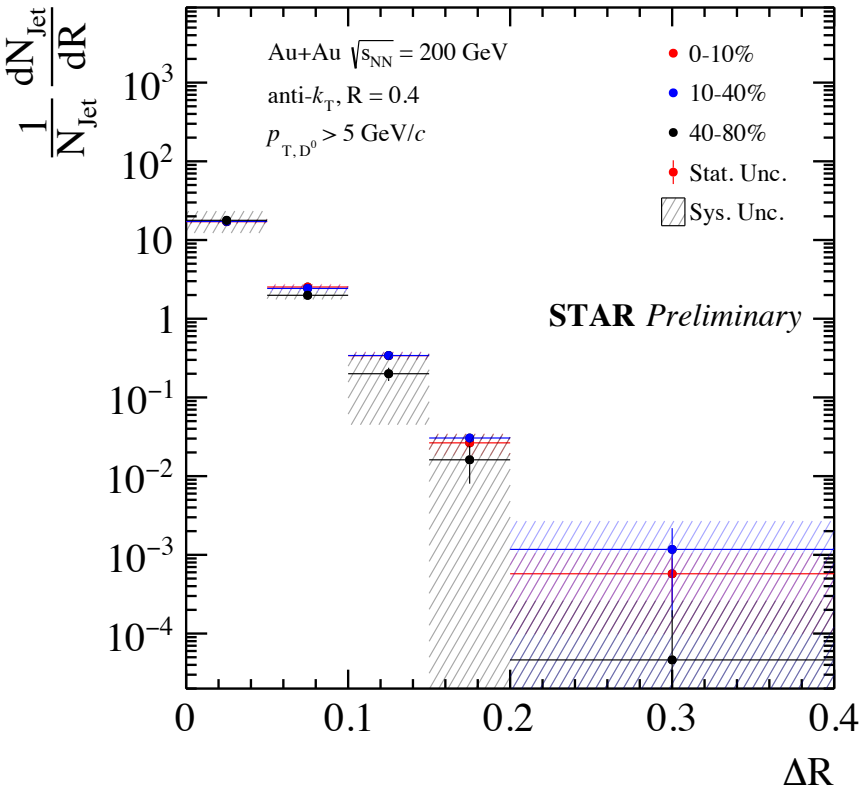
Jet Spectra

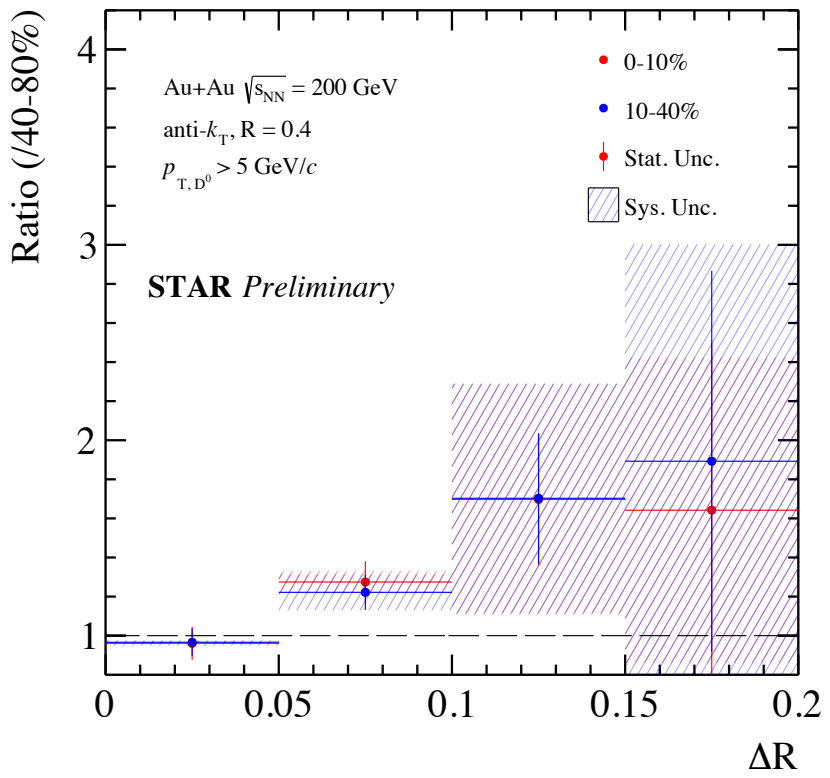


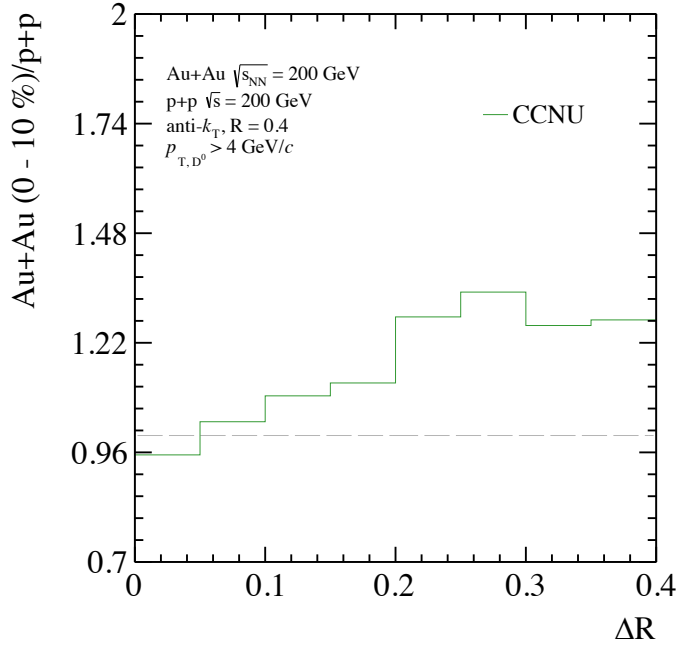


- Peripheral has limited statistics with the D^0 p_T cut
- For central, we can measure out to about 20 GeV/c with 1B minimum bias events

Radial Distribution of D^0 Mesons in Jets







- The furthermost radial bins have limited statistics with the D^0 p_T cut
- Small hint of diffusion in the presence of QGP at STAR energies
- Qualitatively, similar to the predictions from CCNU for R_{AA}

Summary

Backup