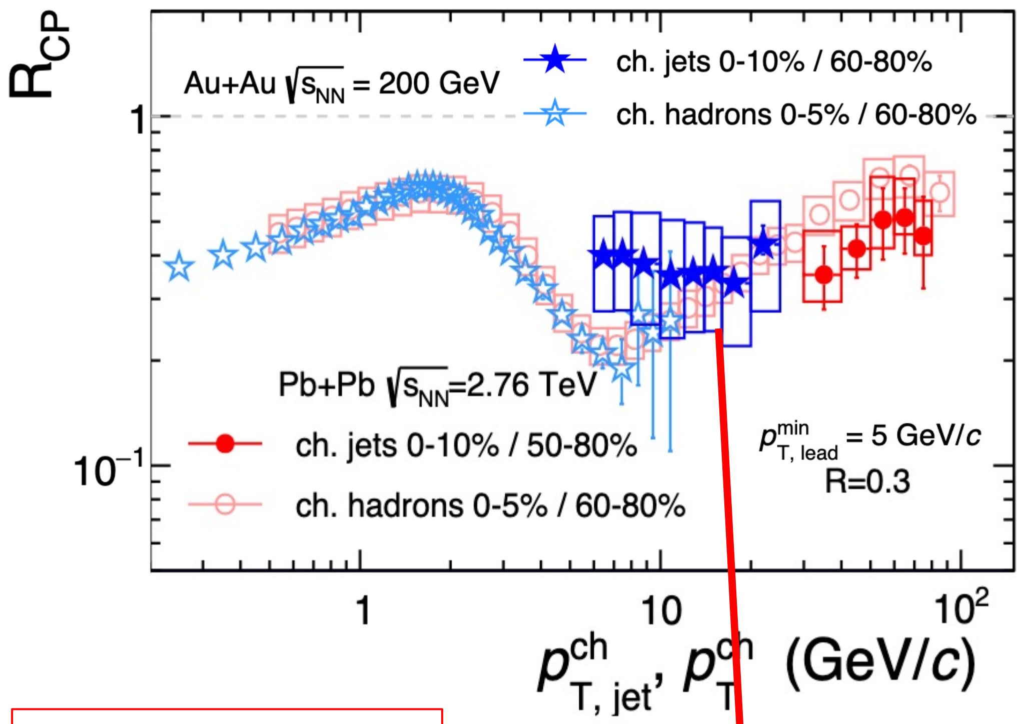
Flavor Dependence of Jet Spectrum and Shape Modifications in Au+Au Collisions at $\sqrt{s_{\mathrm{NN}}}$ = 200 GeV

Diptanil Roy
Rutgers University
For the *STAR Collaboration*
roydiptanil@gmail.com

Supported in part by

Jets in Heavy Ion Collisions

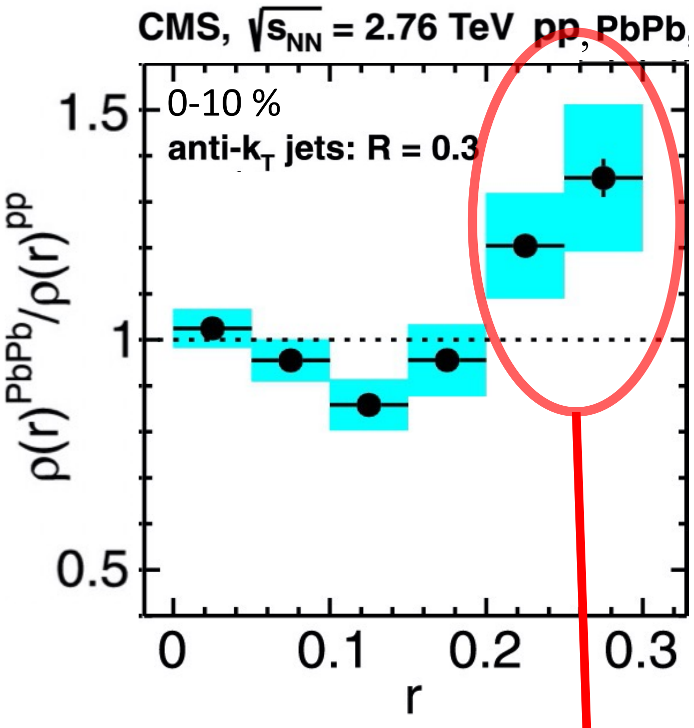
Jet Quenching



ALICE, JHEP03 (2014) 013

STAR, Phys.Rev.C 102 (2020) 5, 054913

Jet Broadening



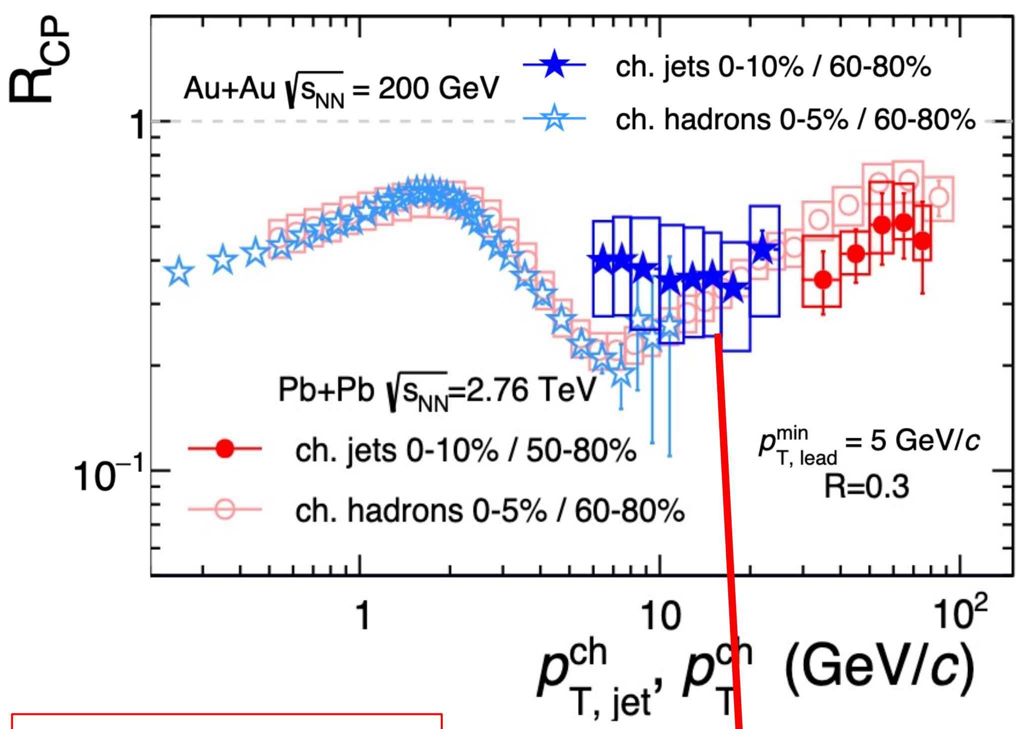
CMS, Phys. Lett. B 730 (2014) 243

Inclusive jets are heavily quenched in the presence of QGP

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

Jets in Heavy Ion Collisions

Jet Quenching



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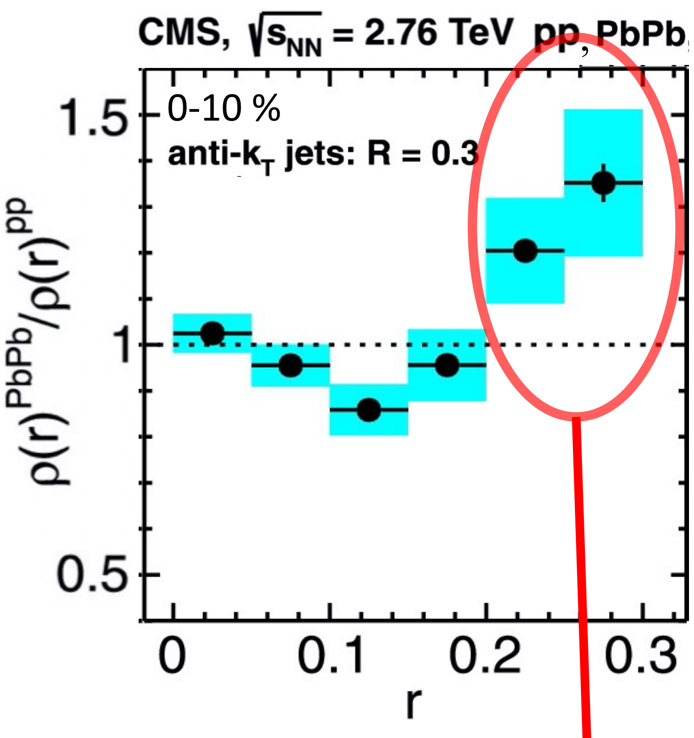


CMS, Phys. Lett. B 730 (2014) 243

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

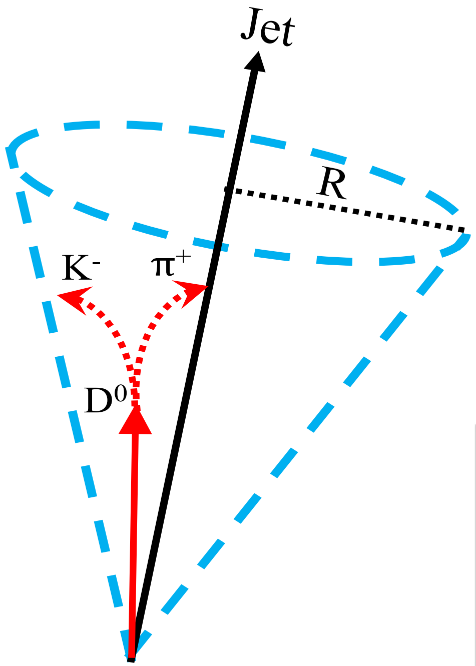
Possible mechanisms:

- Multiple scattering
- Medium-induced bremsstrahlung
- Medium response

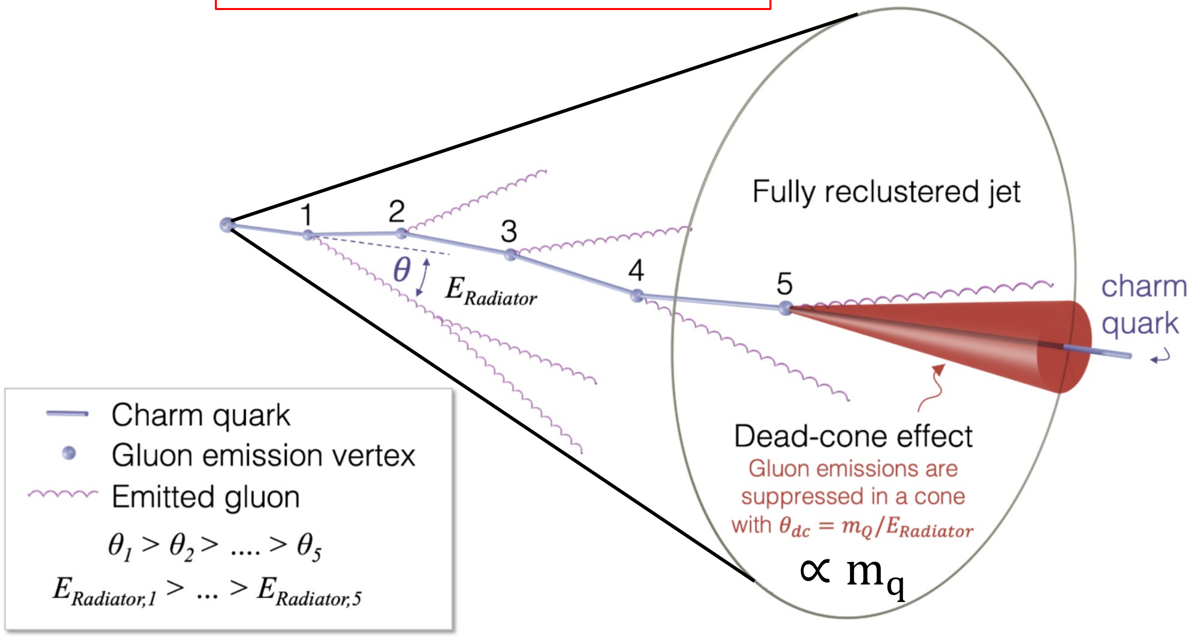
Dependent on the mass of the initiating parton

Motivation to study heavy-flavor jets

Heavy Flavor Tagged Jets



ALICE, Nature 605 (2022) 440-446



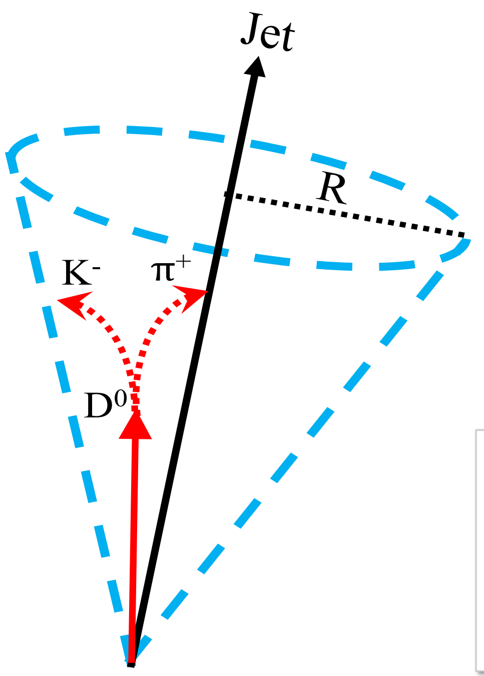
Heavy-flavor emission spectra at small angles suppressed due to dead-cone effect [1]

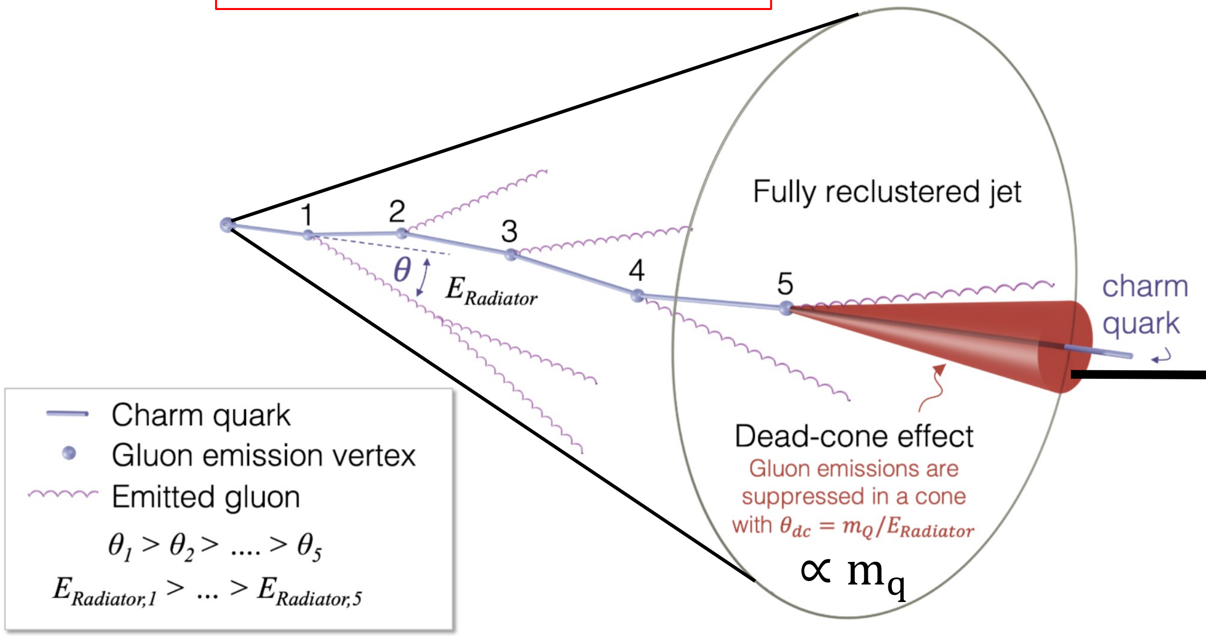
[1] J. Phys. G: Nucl. Part. Phys. **17** 1602 (1991)

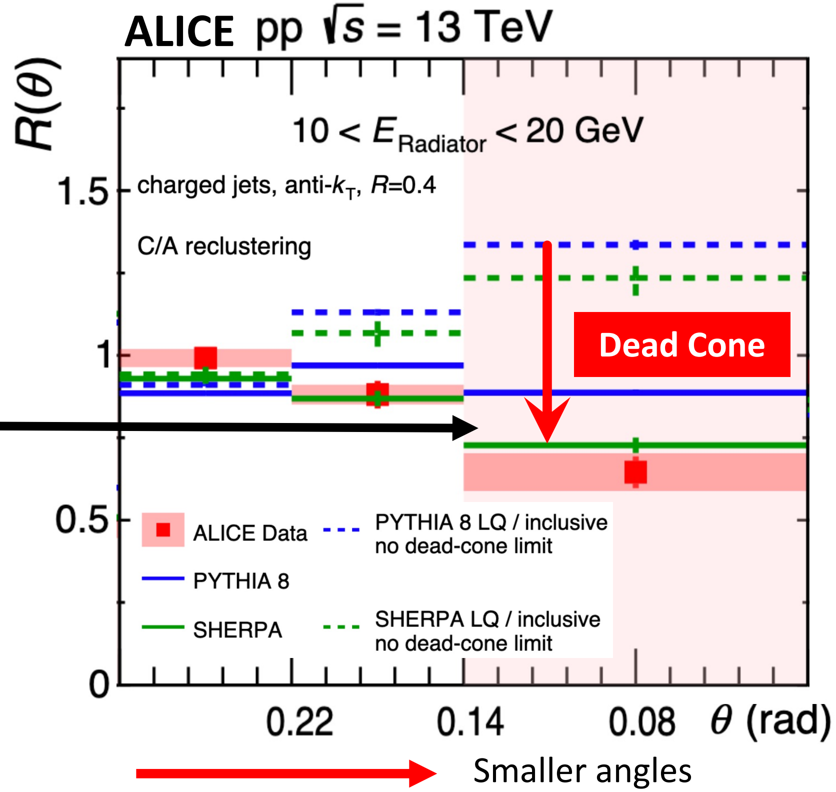
Heavy Flavor Tagged Jets

$$R(\theta) = \frac{1}{N_{D^0\text{jet}}}\frac{\mathrm{d}n_{D^0\text{jet}}}{\mathrm{d}\ln(1/\theta)} \Big/ \frac{1}{N_{\text{inclusive jet}}}\frac{\mathrm{d}n_{\text{inclusive jet}}}{\mathrm{d}\ln(1/\theta)}$$

ALICE, Nature 605 (2022) 440-446







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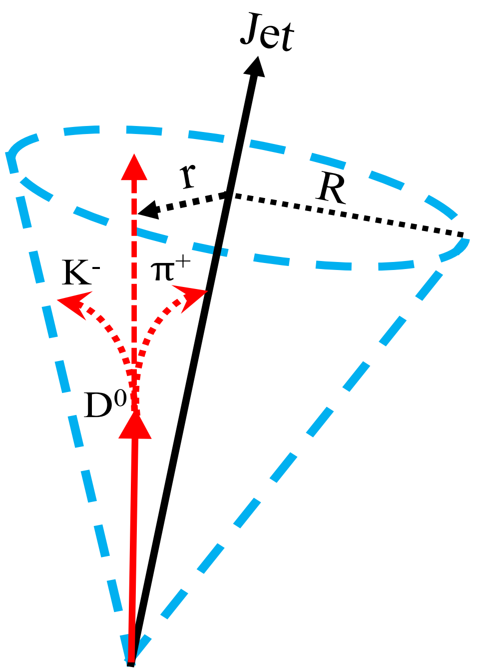
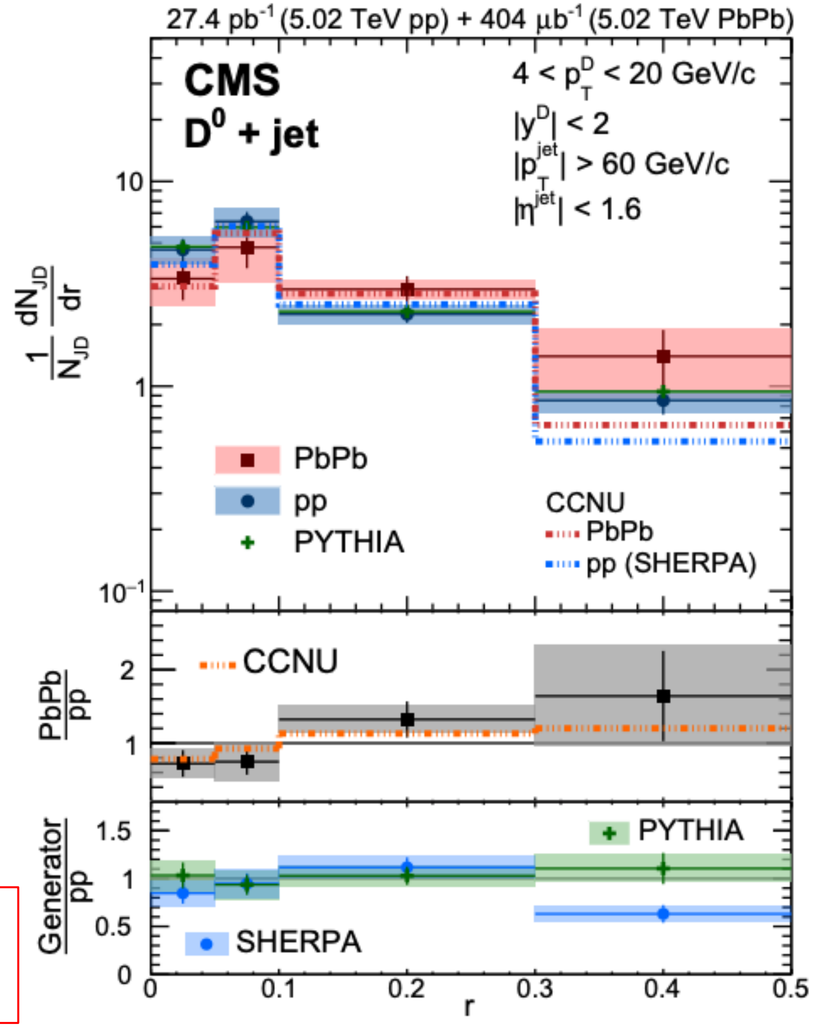
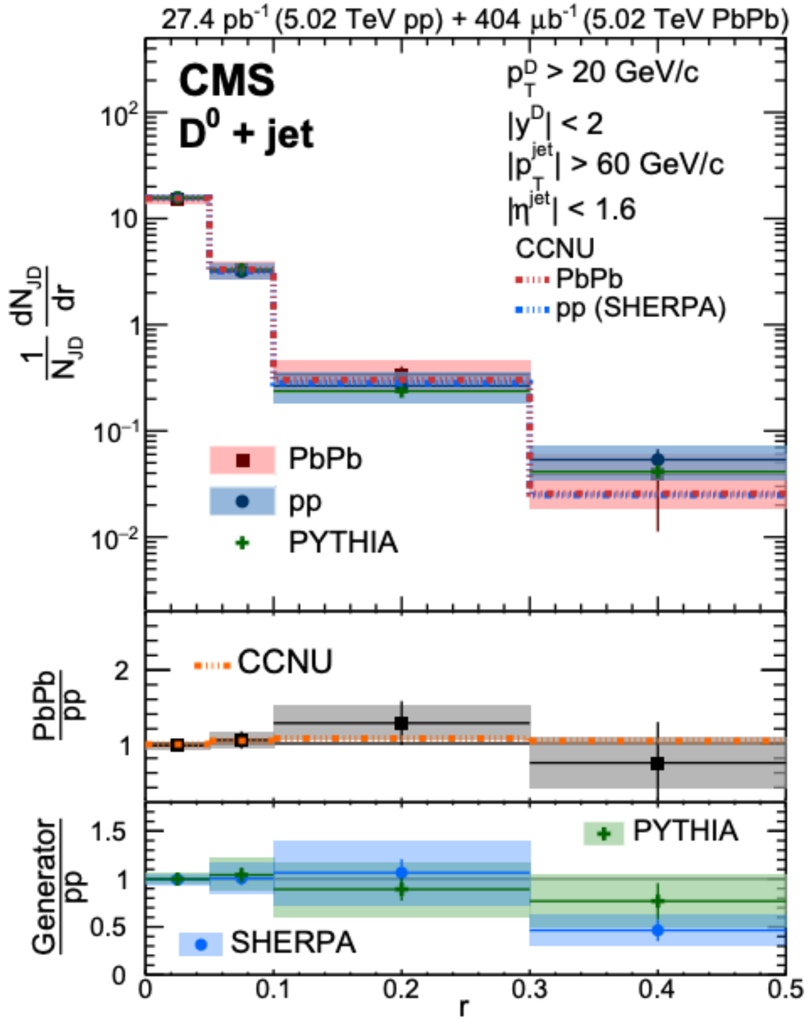
Heavy Flavor Tagged Jets

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



Low p_T D^0 mesons slightly diffused in the presence of QGP at LHC



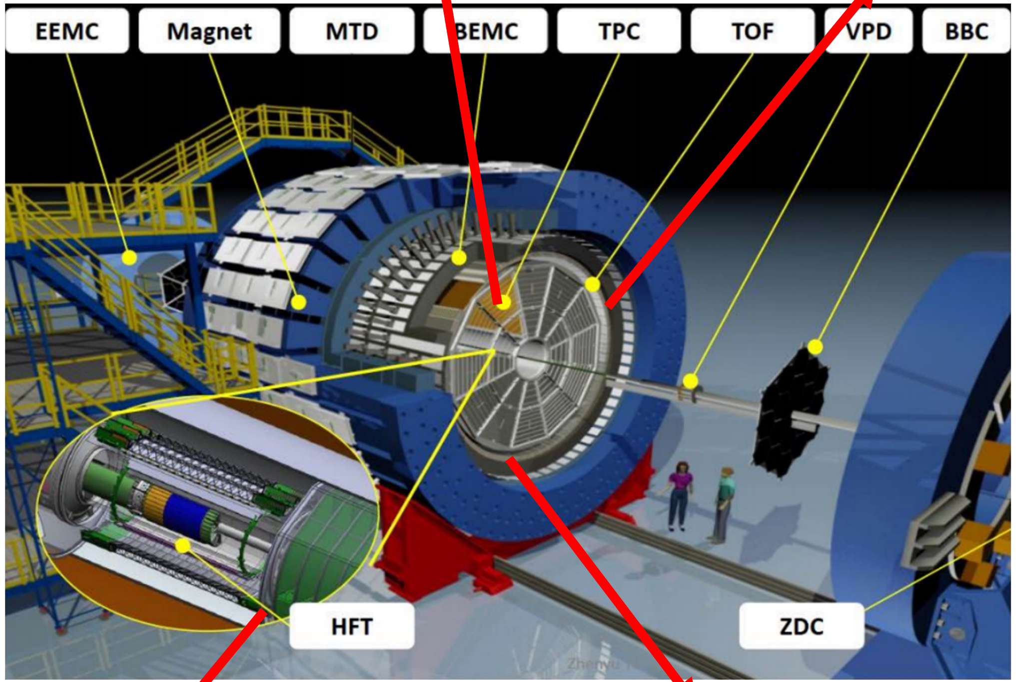


- **Lower p_T D^0 mesons accessible at RHIC energies**
- **Contribution from the underlying background is smaller at RHIC for a given jet p_T**

STAR Detector & Selection Criteria

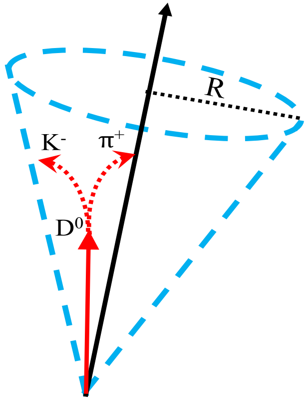
Time Projection Chamber (TPC)
- Measures momentum, track trajectory, and identifies charged particles

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



Barrel Electromagnetic Calorimeter (BEMC)
- Measures neutral component of energy in jets

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



Event Selection:

- Au+Au $\sqrt{s_{NN}}$ = 200 GeV, Year 2014
- Minimum bias (MB)
- Centrality ∈ [0, 80]% (3 bins: [0-10], [10-40], [40-80])

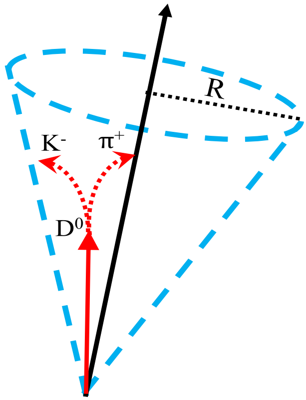
Constituent Selection:

- $0.2 < p_{T,track}$ [GeV/c] < 30 ; $0.2 < E_{T,tower}$ [GeV] < 30
- $|\eta_{track}| < 1$; $|\eta_{tower}| < 1$
- $D^0 \rightarrow K^{\mp} + \pi^{\pm}$ [B.R. = 3.82 %]
- For D^0 reconstruction: Tracks contain at least three hits on HFT
- $5 < p_{T,D^0}$ [GeV/c] < 10

D^0 Jet Selection:

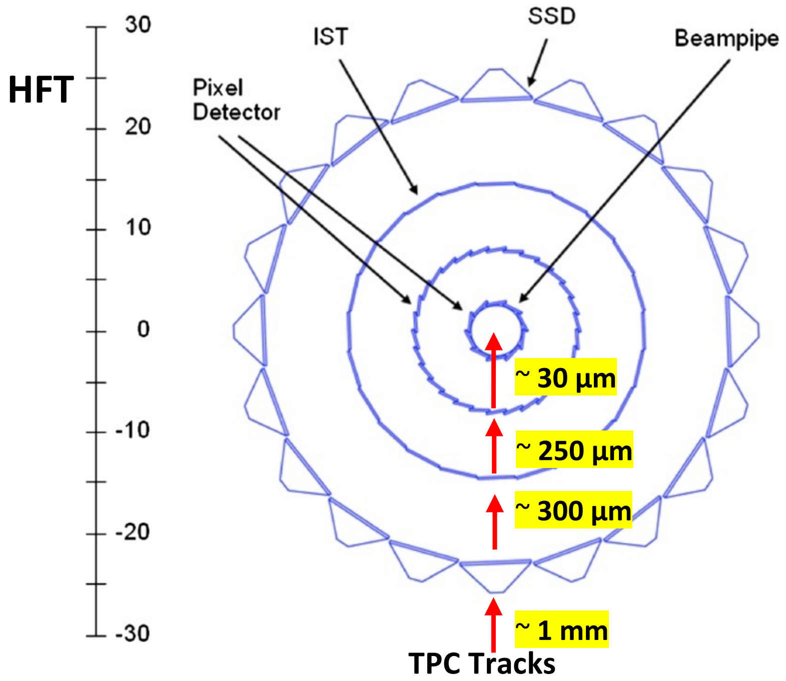
- Anti-k_T full jets of radius $R = 0.4$, area-based background subtraction
- $|\eta_{jet}| < 0.6$

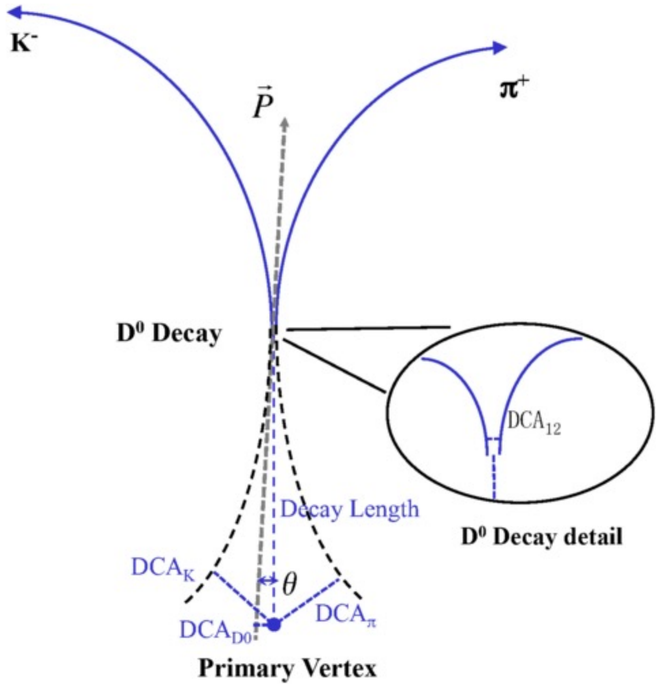
D^0 Reconstruction

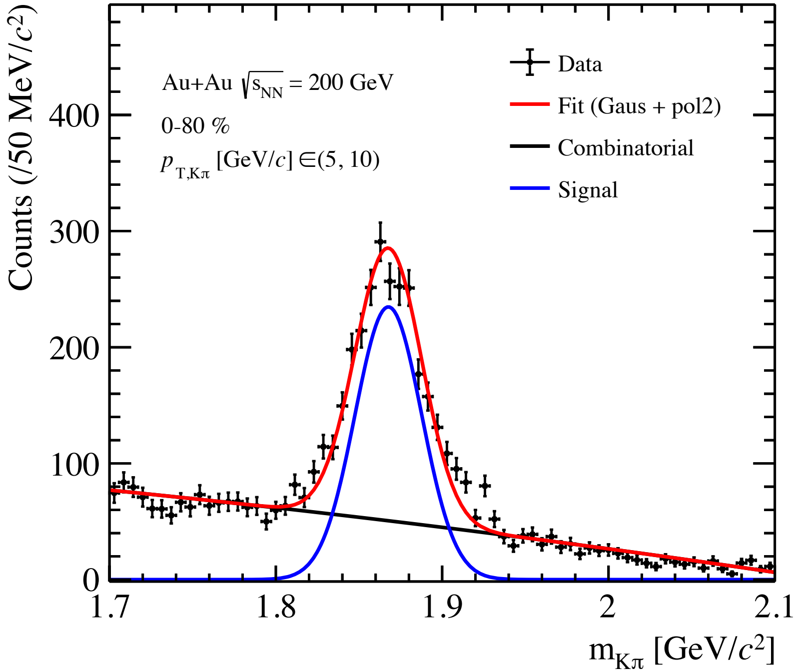


- Kaons and Pions identified using TPC and TOF

STAR, Phys. Rev. C 99 (2021) 034908





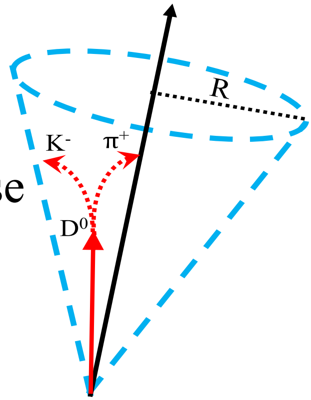


Topological cuts on the D^0 candidates improve signal significance

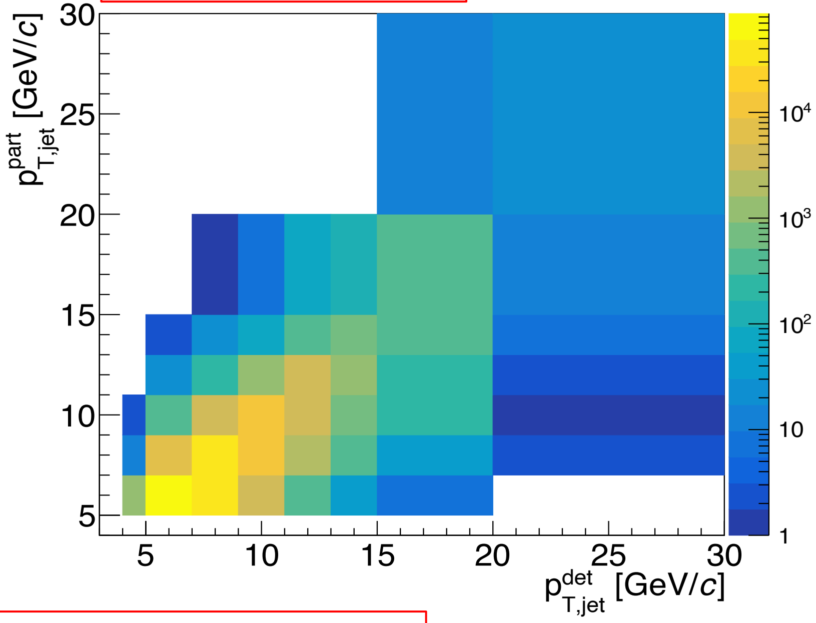
Yield is calculated using sPlot method [1]

[1] Nucl. Instrum. Methods Phys. Res., A (2005) 555

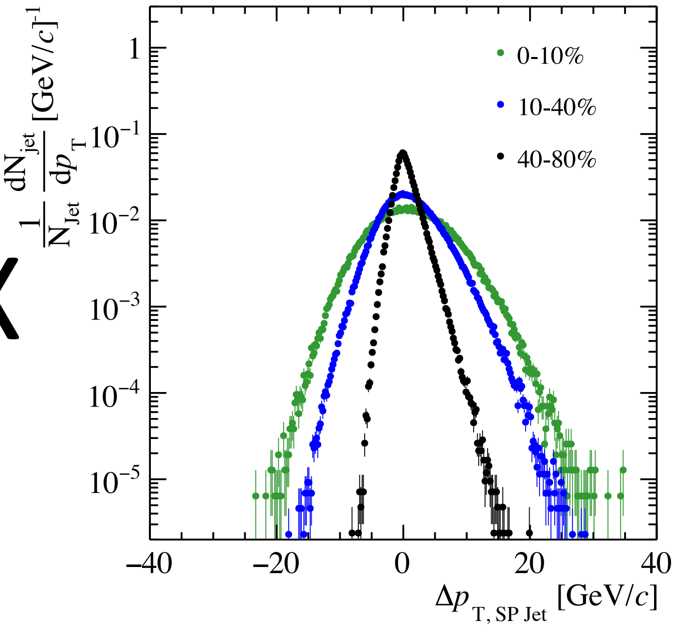
Correction to the Jet Yield



1. Response matrix for p+p collisions at $\sqrt{s}$ = 200 GeV from PYTHIA and GEANT3 to mimic the detector response
2. Single Particle (SP) embedding in heavy ion events to model fluctuations in area-based background subtraction
3. Reweight PYTHIA with c-quark distribution from FONLL [1] to modify the shape of the jet p_T spectra
4. Heavy-flavor jet fragmentation modeled using PYTHIA
5. Systematics from variation in fragmentation model will be studied later



X



[1]. **FONLL**, JHEP03 (2001) 006

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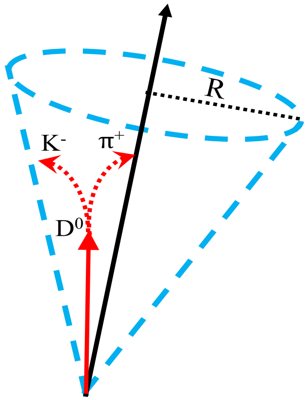

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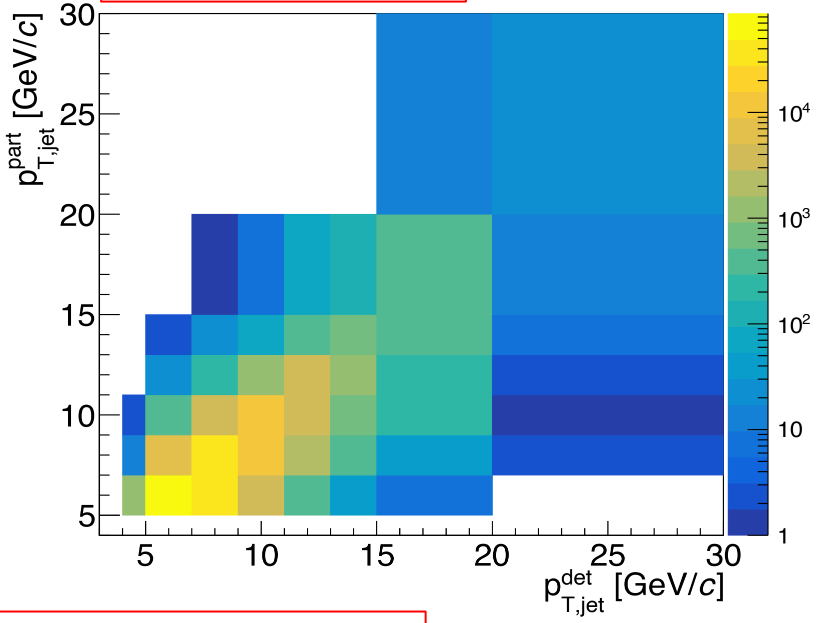
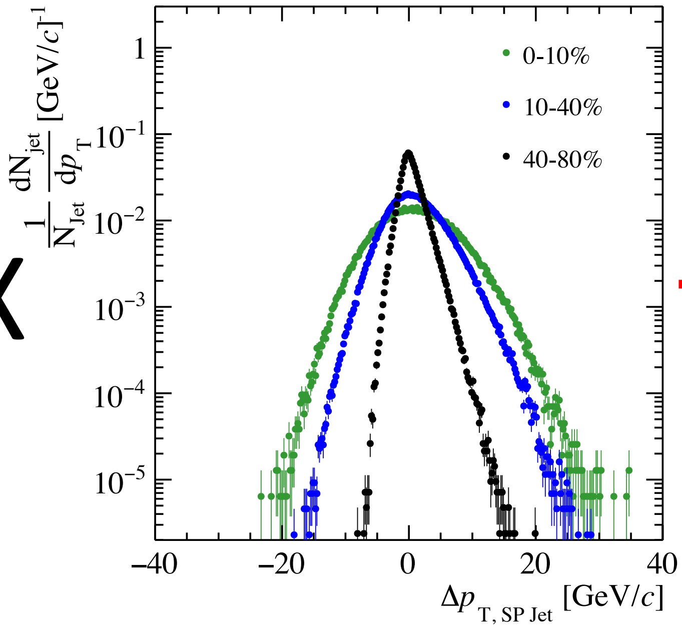
anti-k_T jets with D^0, $R = 0.4$
$5 < p_{T,K\pi} < 10$ [GeV/c]

$\sqrt{s}$ = 200 GeV p+p
PYTHIA 8 + GEANT 3



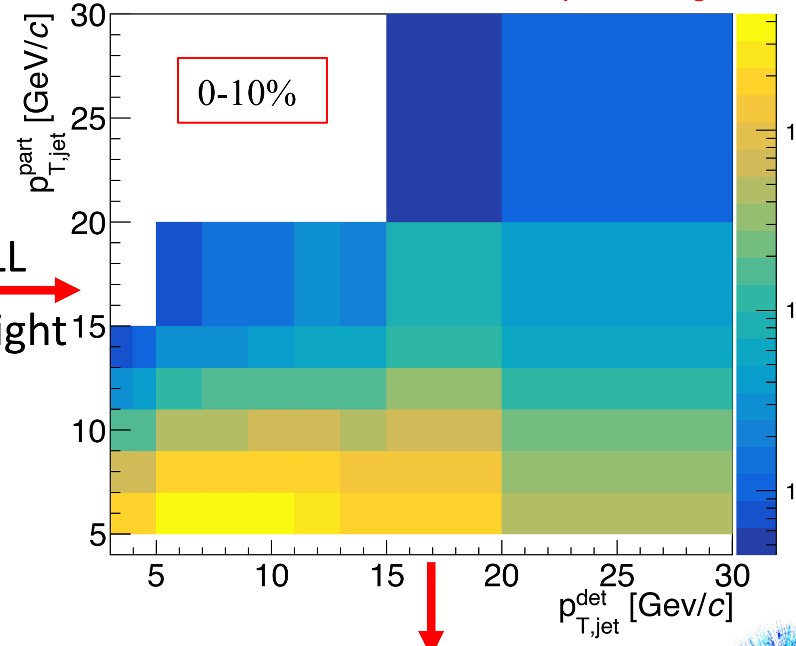
X

Au+Au Heavy Ion Background



FONLL
Reweight

PYTHIA 8 + GEANT 3 + Au+Au Heavy Ion Background



Complete response matrix to unfold $p_{T,Jet}$

[1]. **FONLL,** JHEP03 (2001) 006

Correction to the Jet Radial Profile

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3. Reweight PYTHIA with a prior (FONLL [1
4. Heavy-flavor jet fragmentation modeled fro
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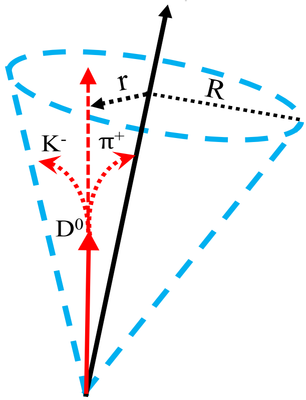
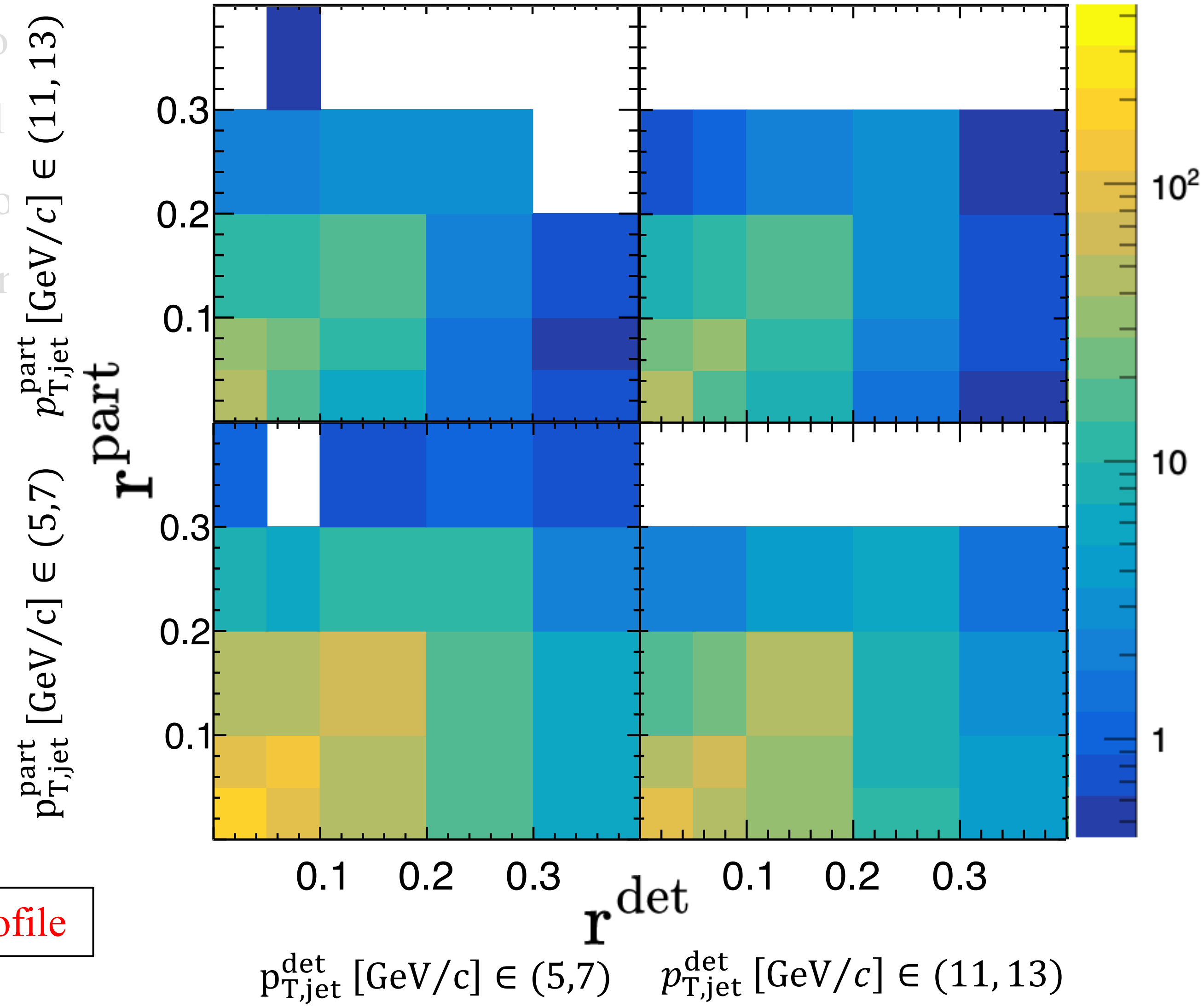


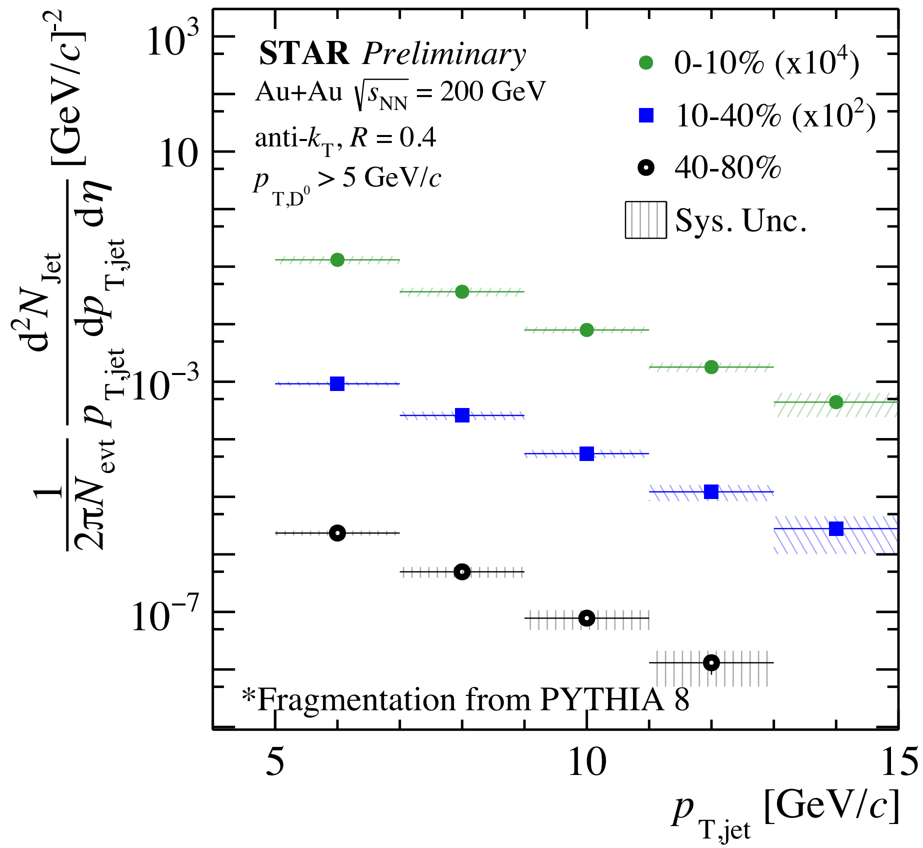


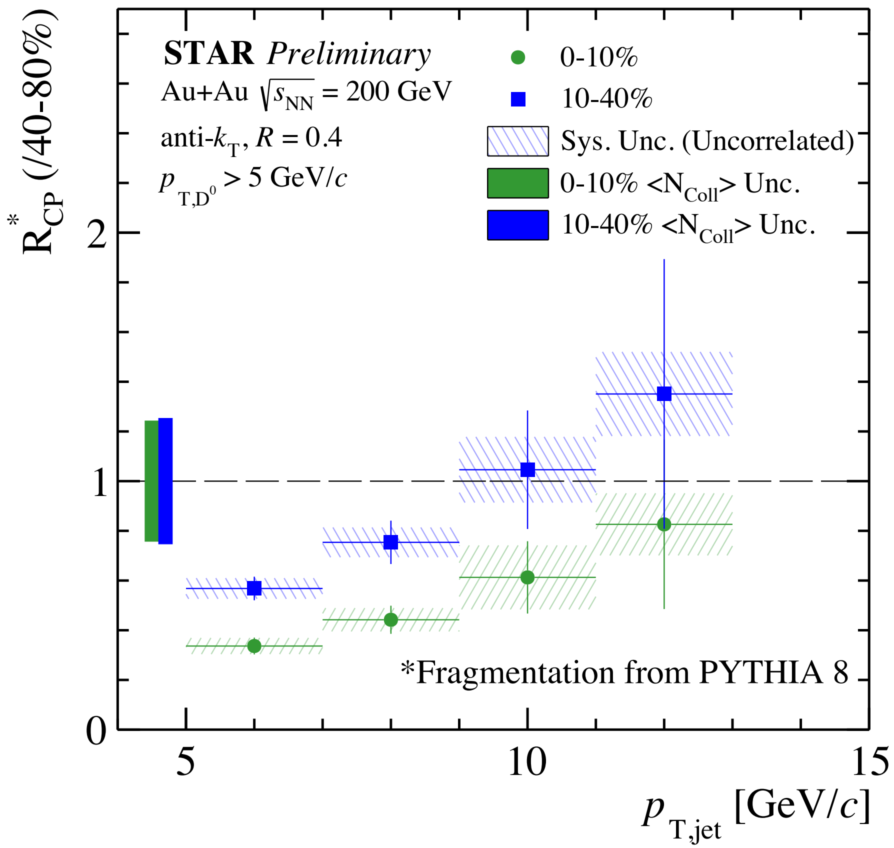
anti-k_T jets with D^0, $R = 0.4$
$|\eta_{jet}| < 0.6$
$p_{T,const} > 0.2$ GeV/c
$5 < p_{T,K\pi} < 10$ (GeV/c)

$\sqrt{s}$ = 200 GeV p+p
PYTHIA 8 + GEANT 3
Au+Au Heavy Ion Background

Complete 4D response matrix to unfold radial profile

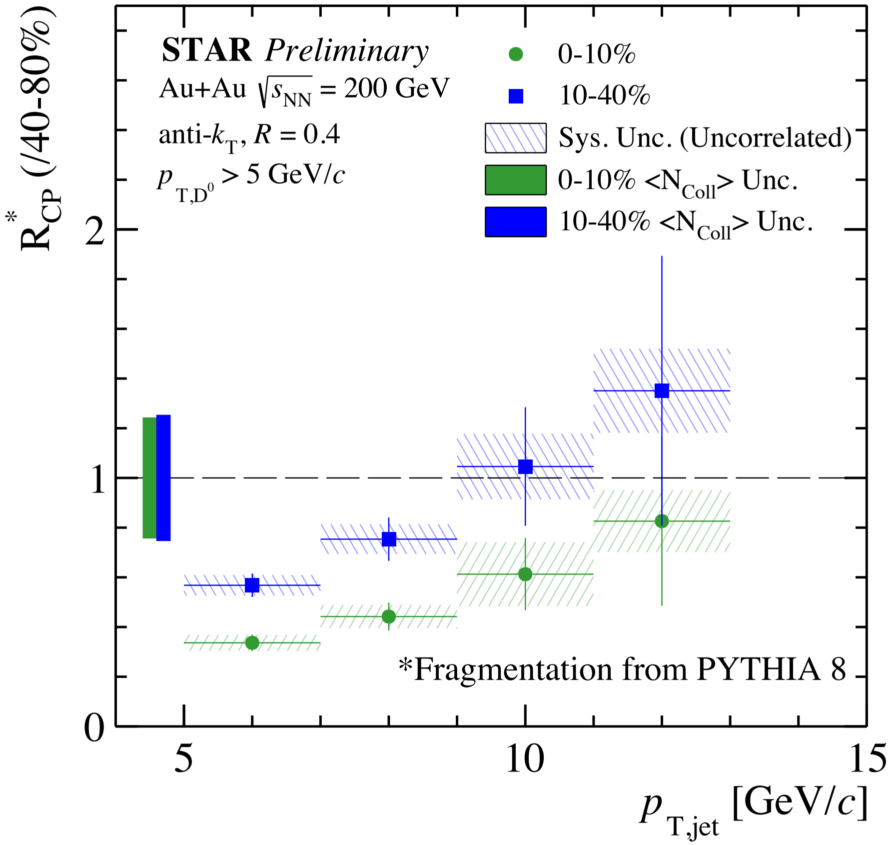
Jet Spectra

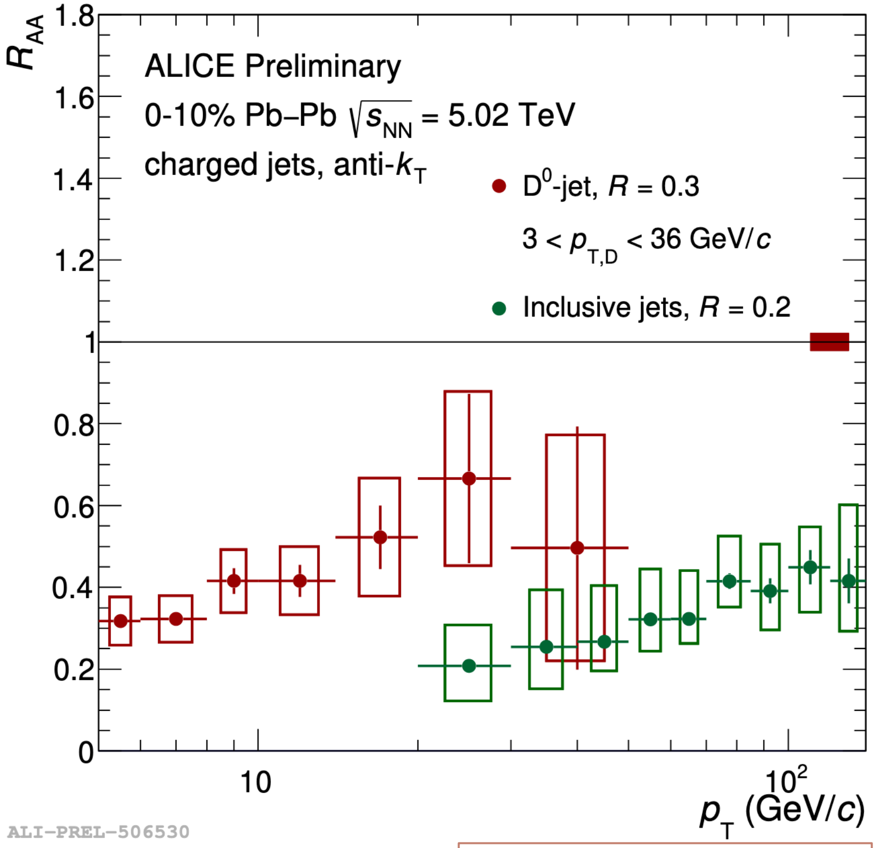




- Peripheral events have limited D^0 p_T reach
- Yields in most central collisions are more suppressed than mid-central
- R^*_{CP} shows strong suppression at low $p_{T,jet}$, hint of an increasing trend with $p_{T,jet}$
- D^0-tagged jet measurement for R_{AA} will be explored using high-statistics p+p data in 2024

Energy Dependence

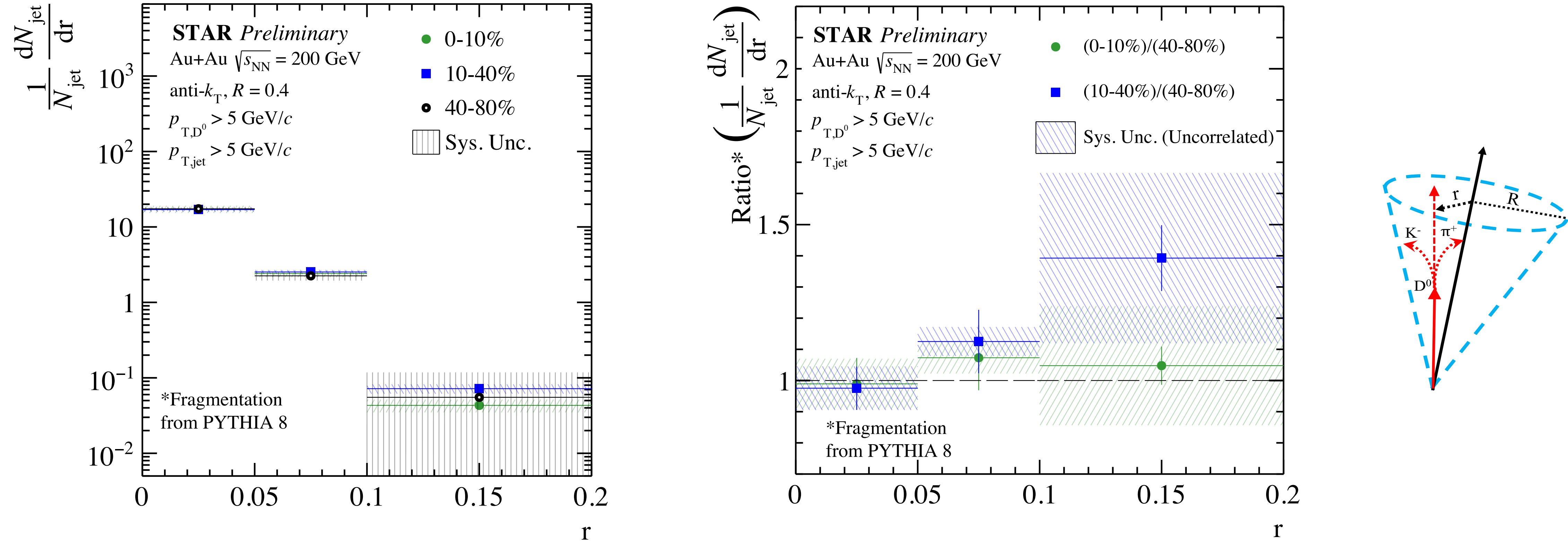




ALICE, arXiv:2208.10908

- Strong in-medium suppression for D^0-tagged jets at 200 GeV from STAR and 5.02 TeV from ALICE

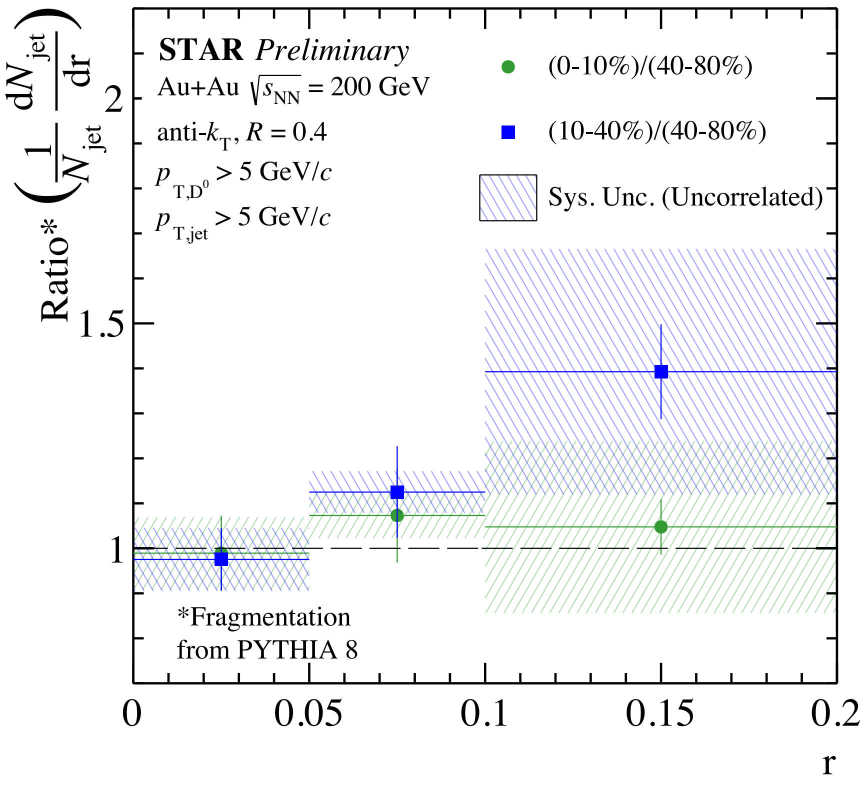
Radial Profile of D^0 Mesons in Jets

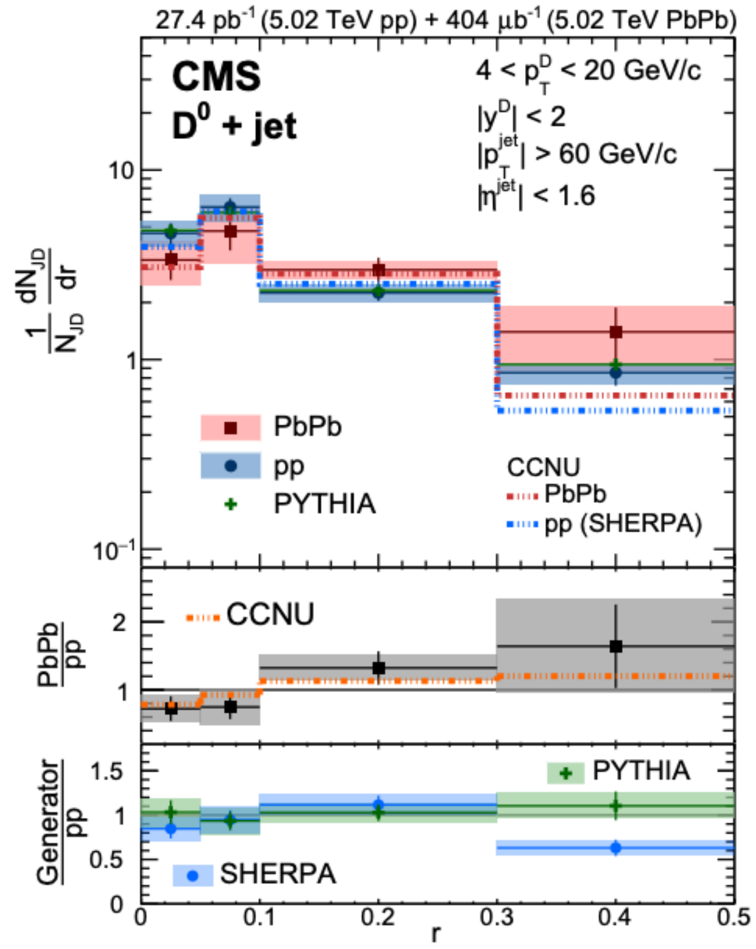


- For D^0 $p_T > 5$ GeV/c, the ratio of radial distributions is consistent with unity within uncertainties
- Extending the analysis to lower D^0 kinematics to further study D^0 diffusion

Energy Dependence

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

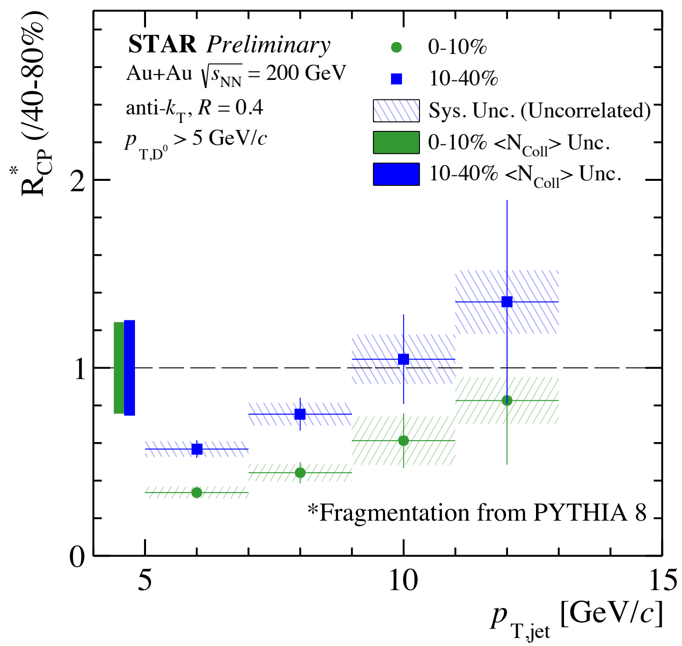


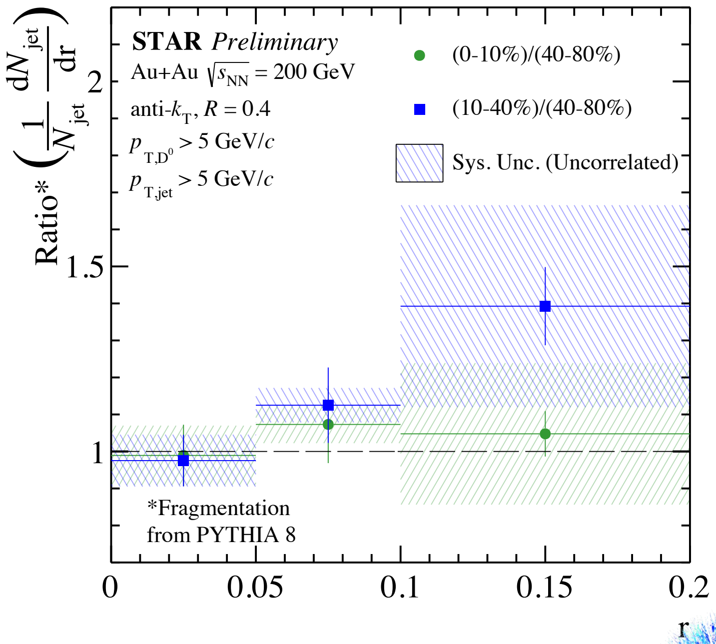


- No strong diffusion, within uncertainty, seen at 200 GeV from STAR for D^0 p_T > 5 GeV/c and $p_{T,Jet}$ > 5 GeV/c
- Hint of diffusion observed at 5.02 TeV from CMS for 4 < D^0 p_T < 20 GeV/c and $p_{T,Jet}$ > 60 GeV/c

Summary

- First D^0-tagged jet measurement at RHIC energies
- Fragmentation from PYTHIA 8 used for correcting jet momenta and substructure
  - ✓ Spectra for D^0-tagged jets in central and mid-central events are suppressed with respect to peripheral events
  - ✓ Ratio of radial profiles of D^0 mesons in jets consistent with unity within uncertainties.





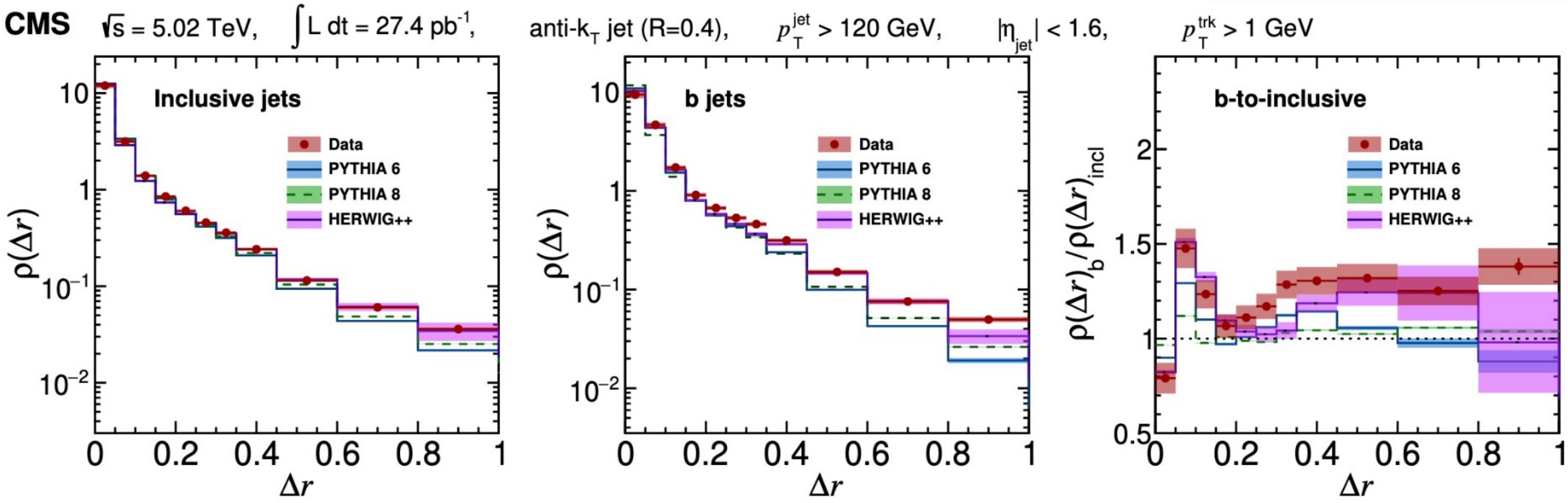
Outlook

- Measure fragmentation function for D^0-tagged jets in Au+Au collisions
- Extend kinematic reach to low D^0 p_T to get closer to charm quark mass

Backup

Differential jet shape for heavy quark in vacuum

CMS, JHEP05 (2021) 054

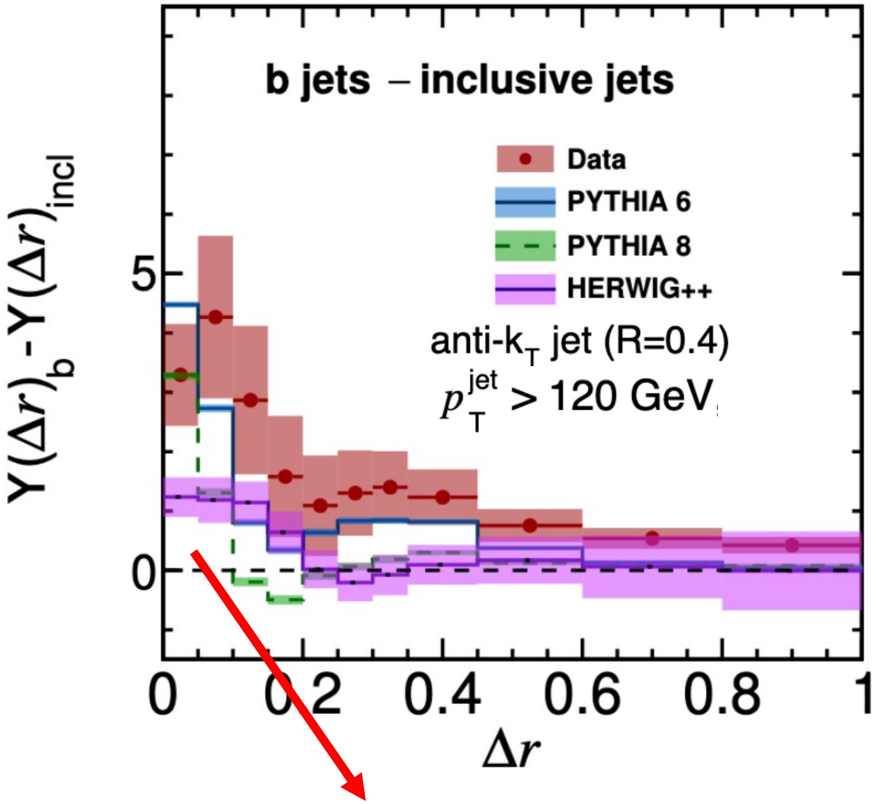


Bottom quark jet (b-jets) shapes modified in vacuum, possibly due to dead cone

Fragmentation pattern for heavy quark

CMS, JHEP05 (2021) 054

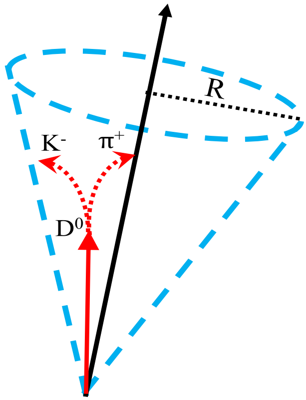
$$Y(\Delta r) = \frac{1}{N_{\mathrm{jet}}} \frac{\mathrm{d}^2 N_{\mathrm{track}}}{\mathrm{d}\Delta r \mathrm{d}p_{\mathrm{T,track}}}$$



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

~ Different fragmentation pattern for heavy quarks

D^0-Jet Yield Extraction



$_s\mathcal{P}lot$

Nucl. Instrum. Methods Phys. Res., A (2005) 555

- Native class in RooStats, and widely used in HEP
- Unbinned maximum likelihood fit to invariant mass integrated over all kinematics
- $p_{\mathrm{T,jet}}$ and radial distributions with all D^0-tagged jet candidates using sWeights
- Easy to include reconstruction efficiencies versus D^0 kinematics

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

<u>Unbinned max. likelihood fit</u>

n = n-th fit component(sig/bkg)

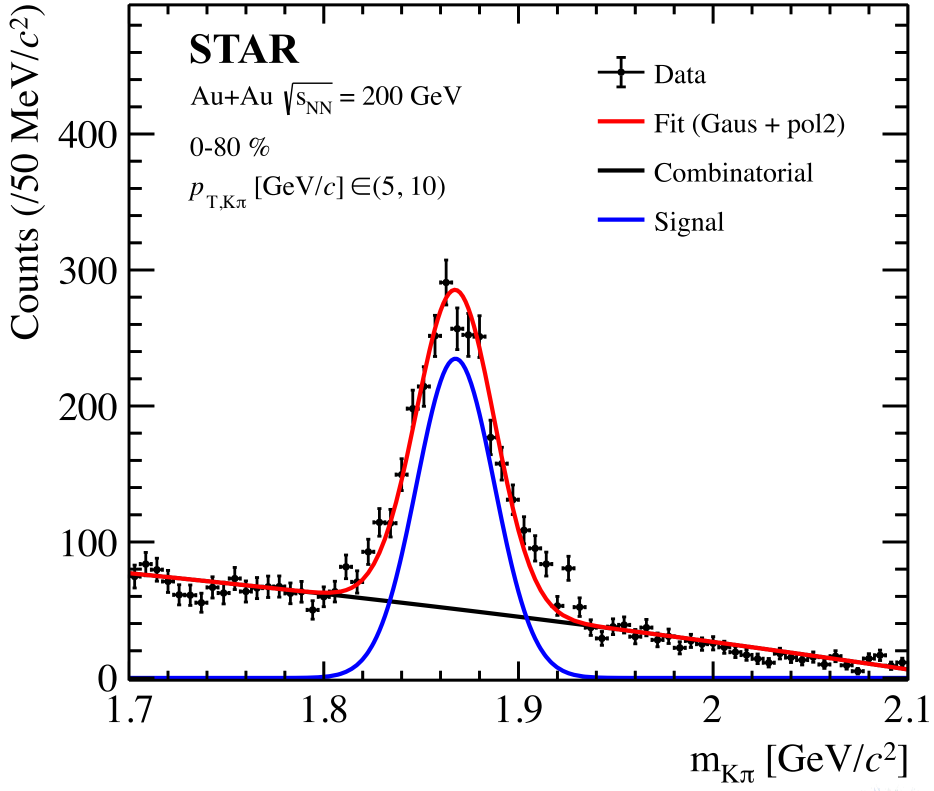
N_k = k-th yield (T=2)

$f_k(m_{K\pi,i})$ = per-event PDF value with k^{th} hypothesis

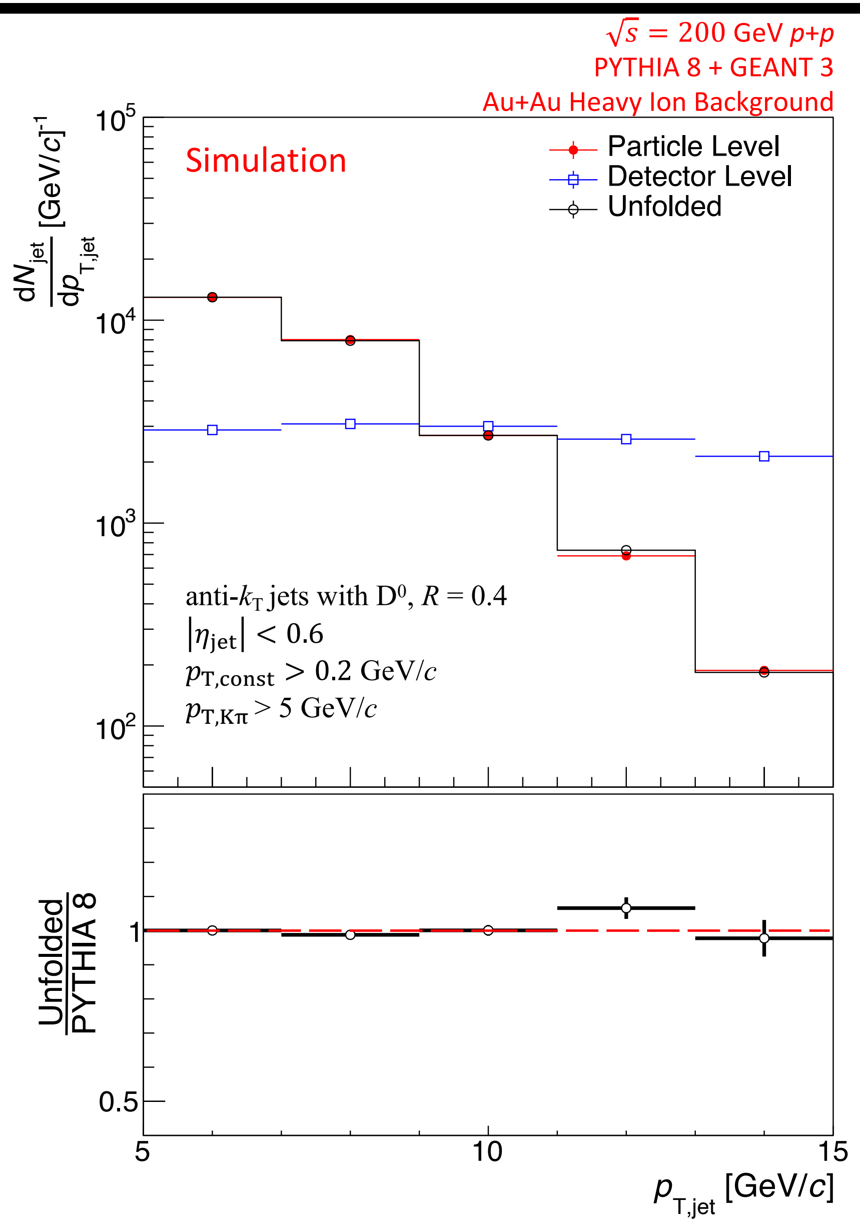
V = cov. matrix

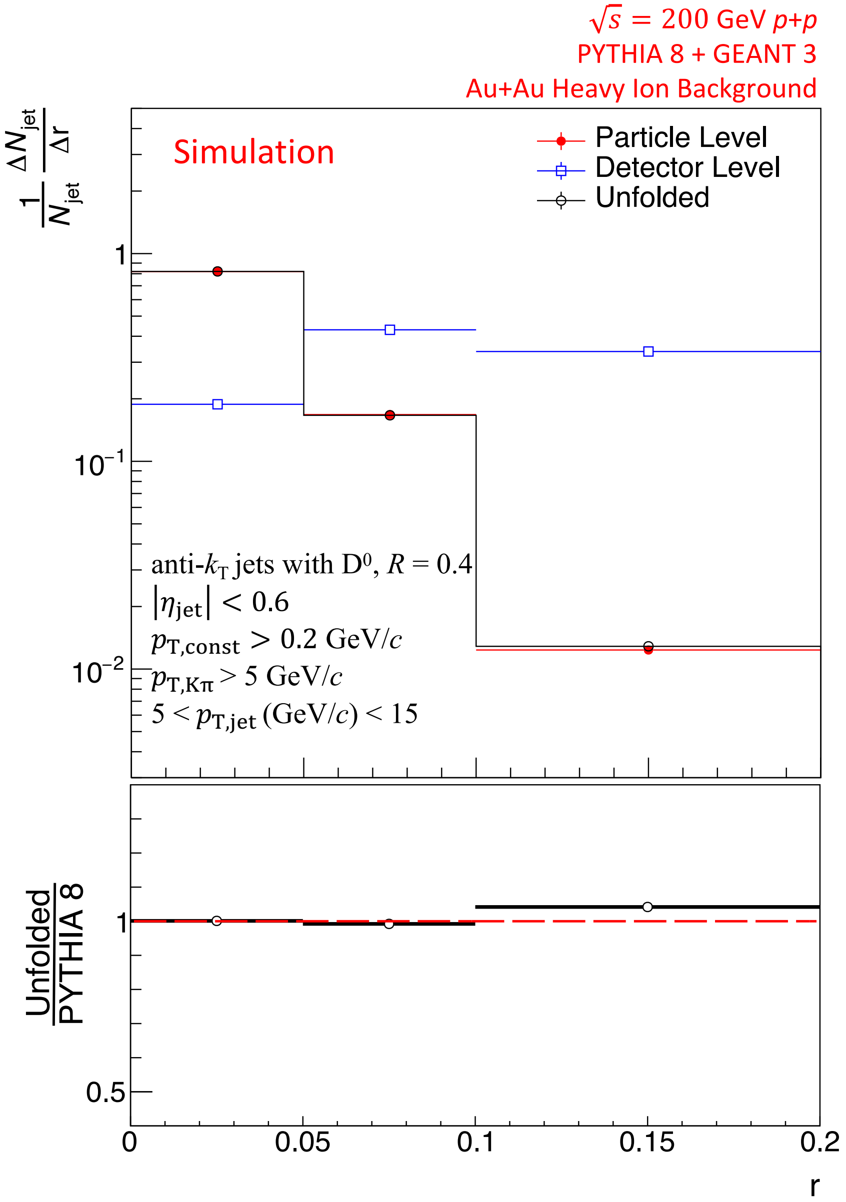
Efficiency Correction →

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



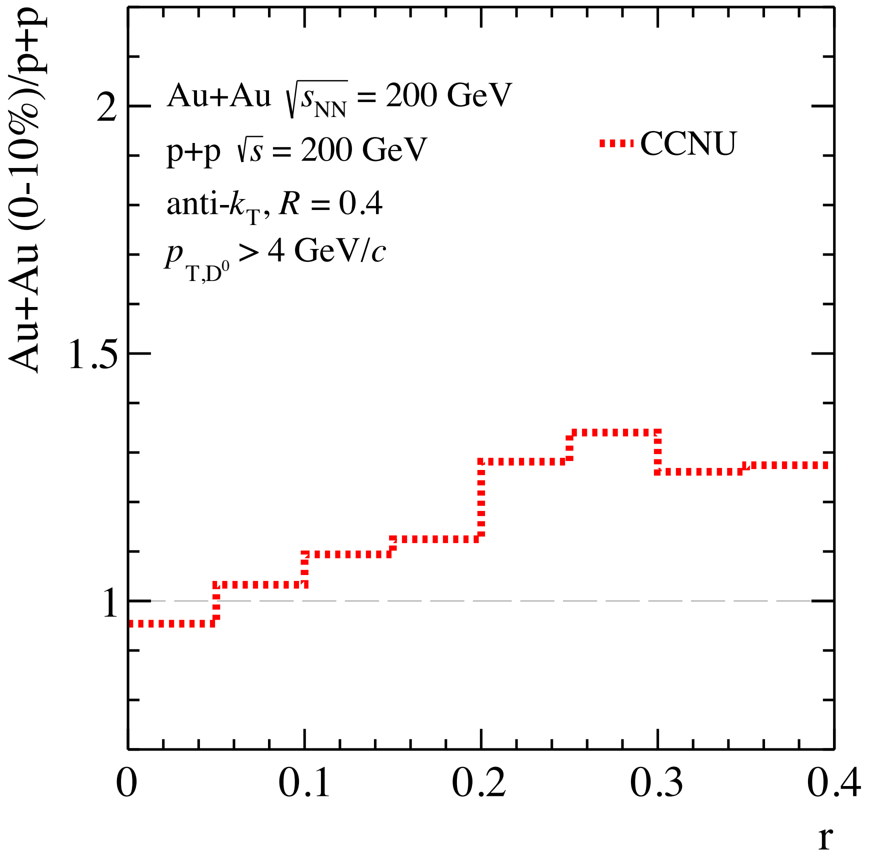
Closures For Unfolding



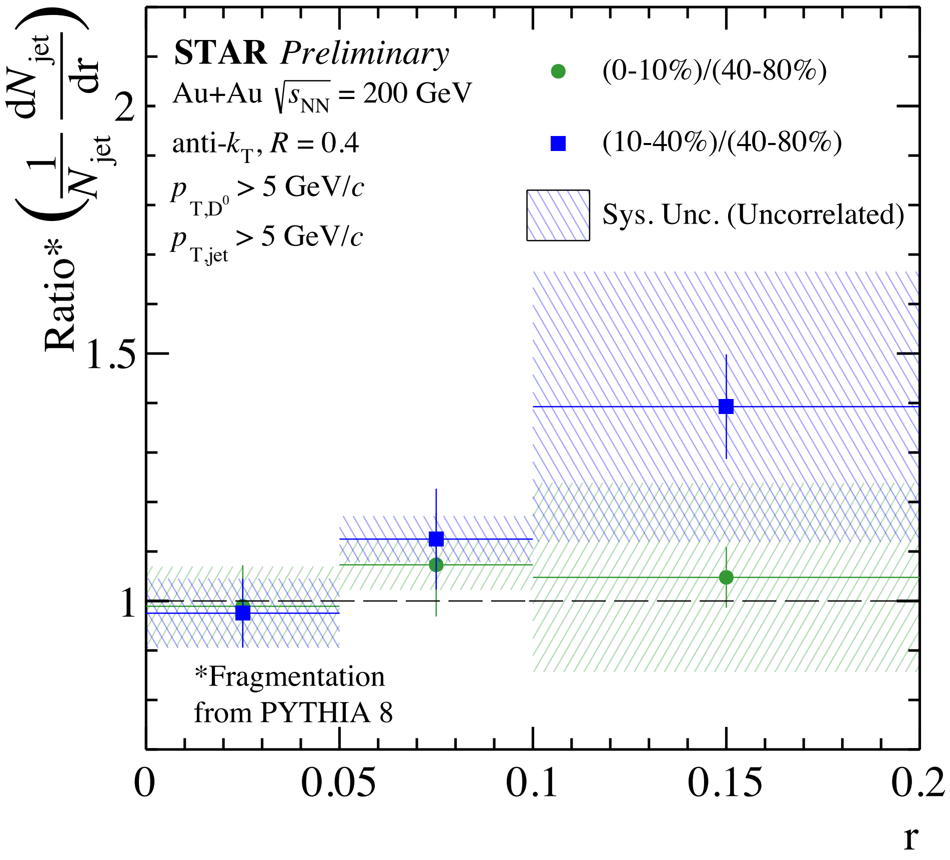


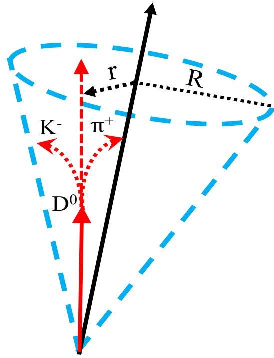
Radial Profile: Data vs Model

CCNU, Eur. Phys. J. C79 (2019) 789



Note: calculation uses p+p as reference





Theory calculation shows small amount of diffusion - consistent with data within uncertainties

Sources of Systematics

Dominant systematic uncertainties are:

- Difference in yield extraction from the two methods, ${}_s\mathcal{P}lot$ and like sign subtraction
- Systematics from D^0 reconstruction (Details here: Phys. Rev. C 99 (2021) 034908)

Sub-dominant systematic uncertainties are:

- FONLL as a prior vs PYTHIA 8 as a prior for the jet spectrum for unfolding
- Iteration parameter in unfolding