QUARK MATTER
KRAKÓW
2022

STAR

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

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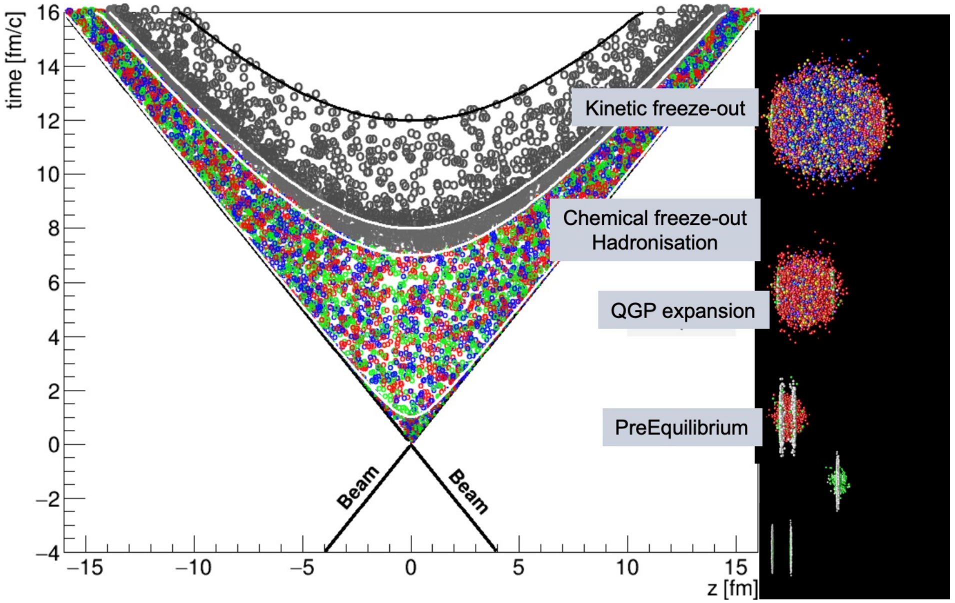
Introduction

Lorentz Contracted Nuclei collide, form **Quark-Gluon Plasma**

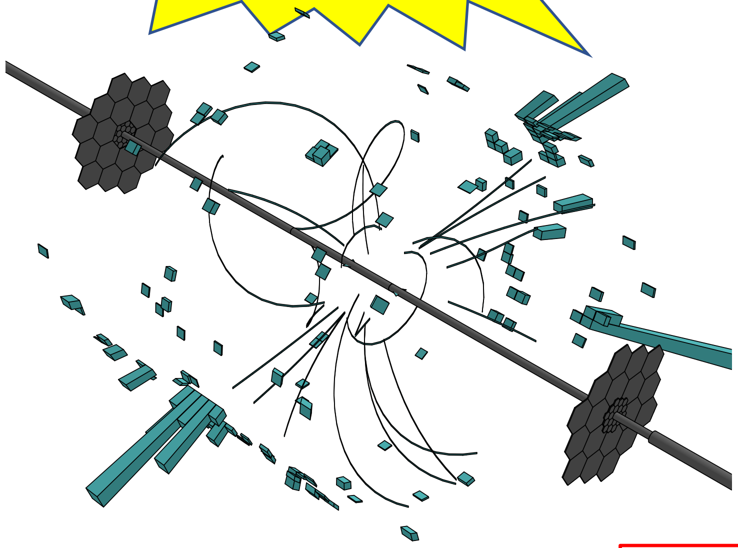


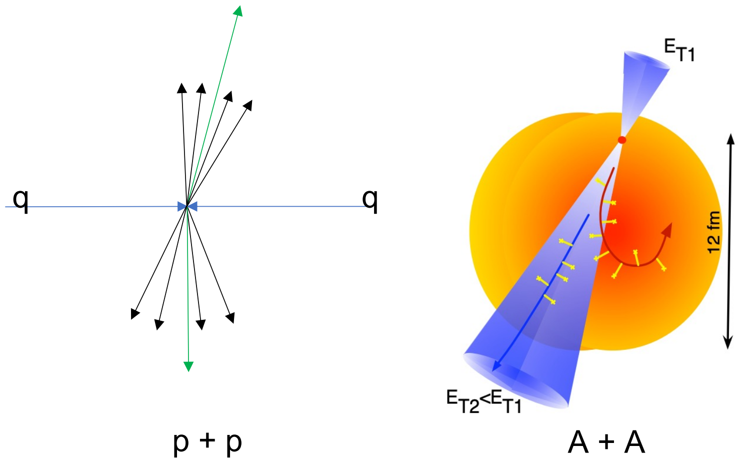
- Loss of energy and momentum in the QGP medium
- Broaden due to medium-induced radiation and scattering
- Reconstructed in experiment by a clustering algorithm, commonly anti-k_T [1]

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

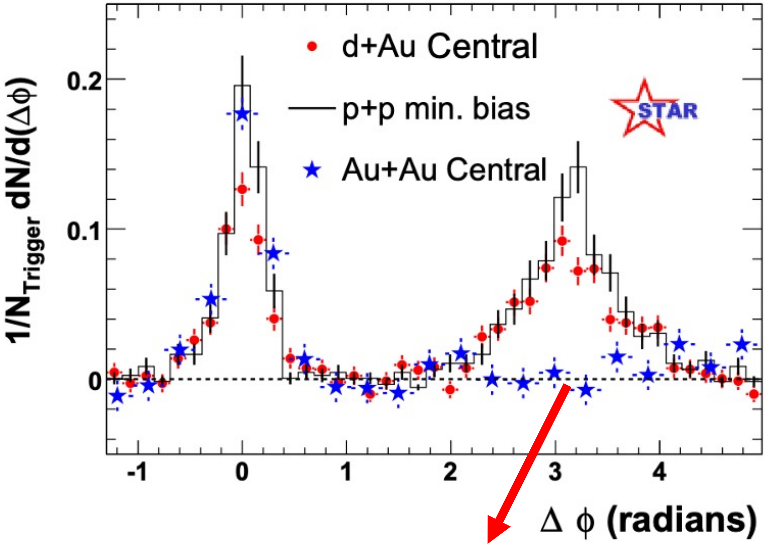
Hard probe → Strong interaction between high p_T partons and medium

One such probe is jets



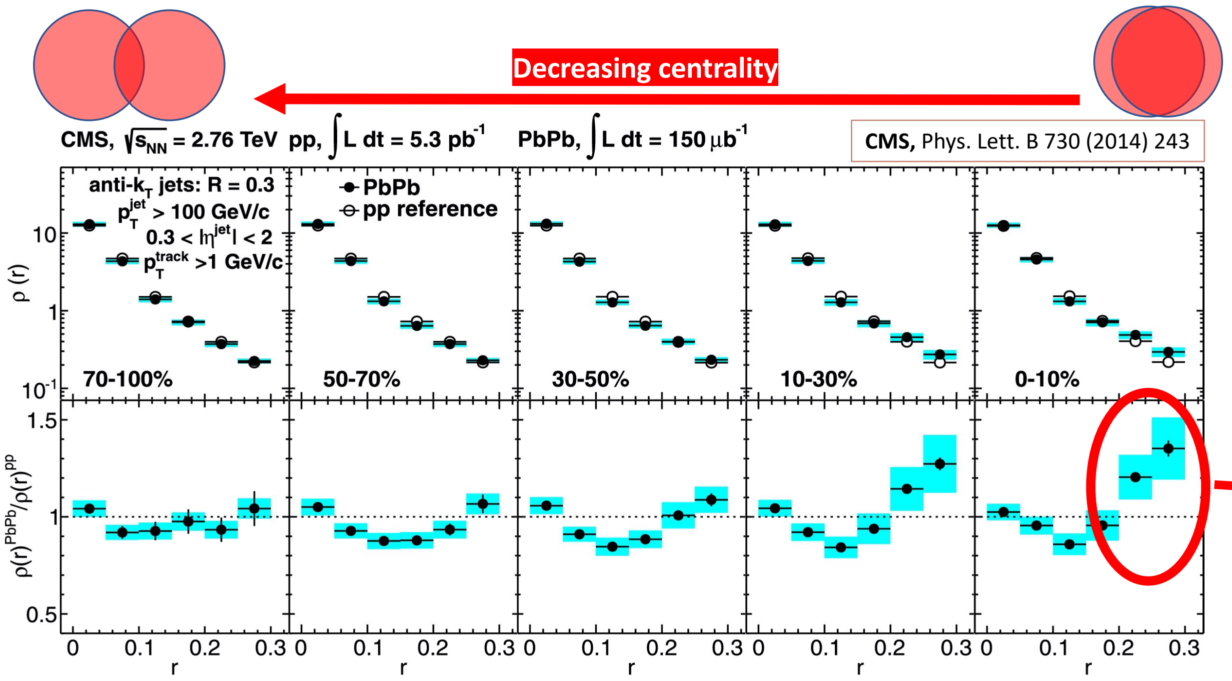


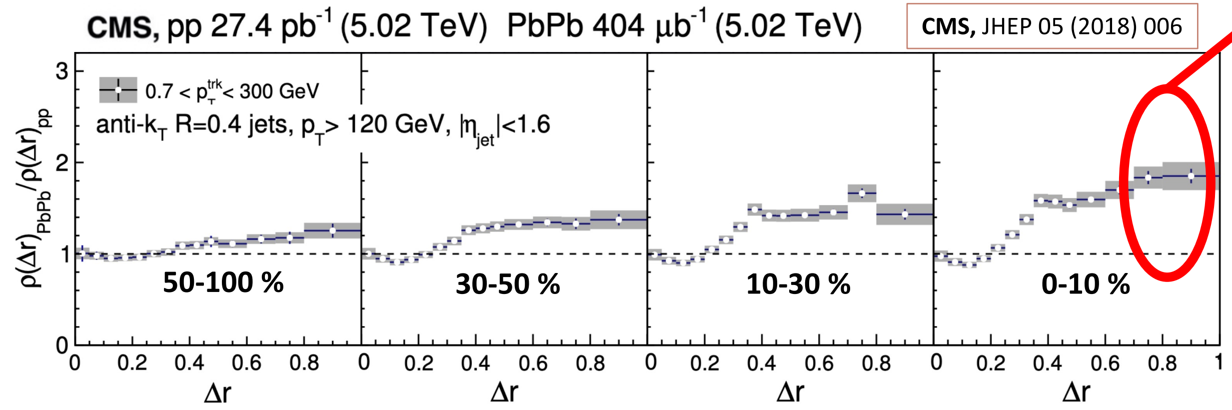
STAR, Phys. Rev. Lett. 91 (2003) 072304

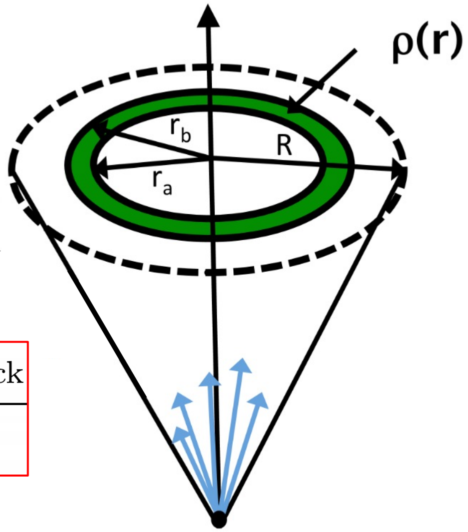


Far side jets are heavily quenched in the presence of QGP.

Previous Jet Results







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

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

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

Possible mechanisms:

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

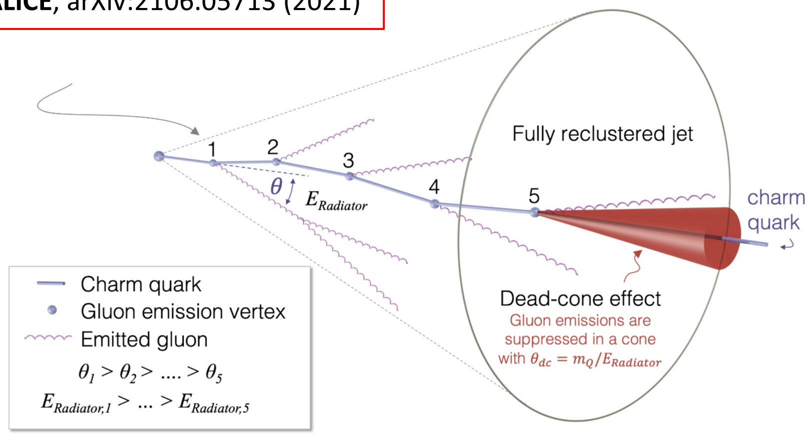
Dependent on the mass of the underlying parton

Motivation to look at heavy flavor jets

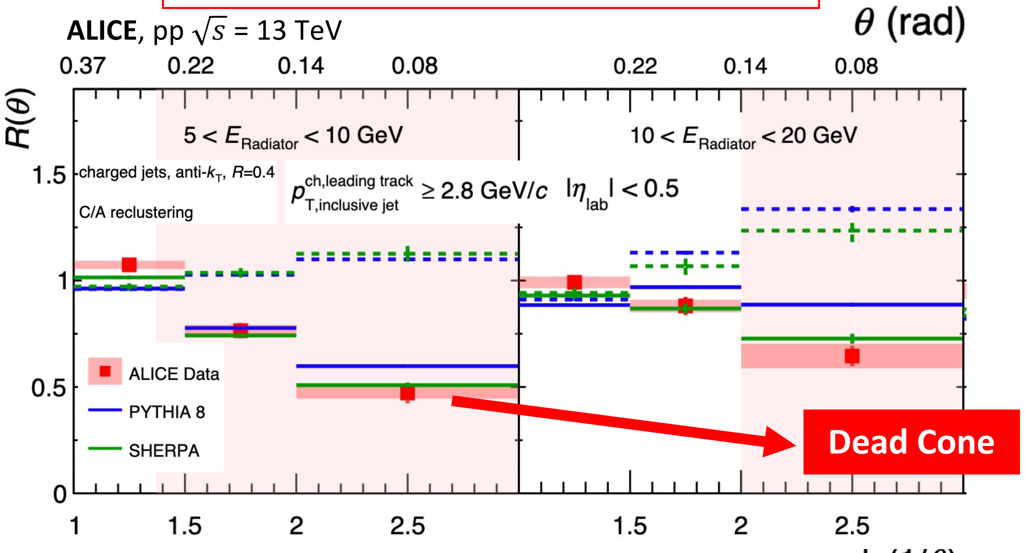
Previous Jet Results

Jets from Heavy Flavor

ALICE, arXiv:2106.05713 (2021)

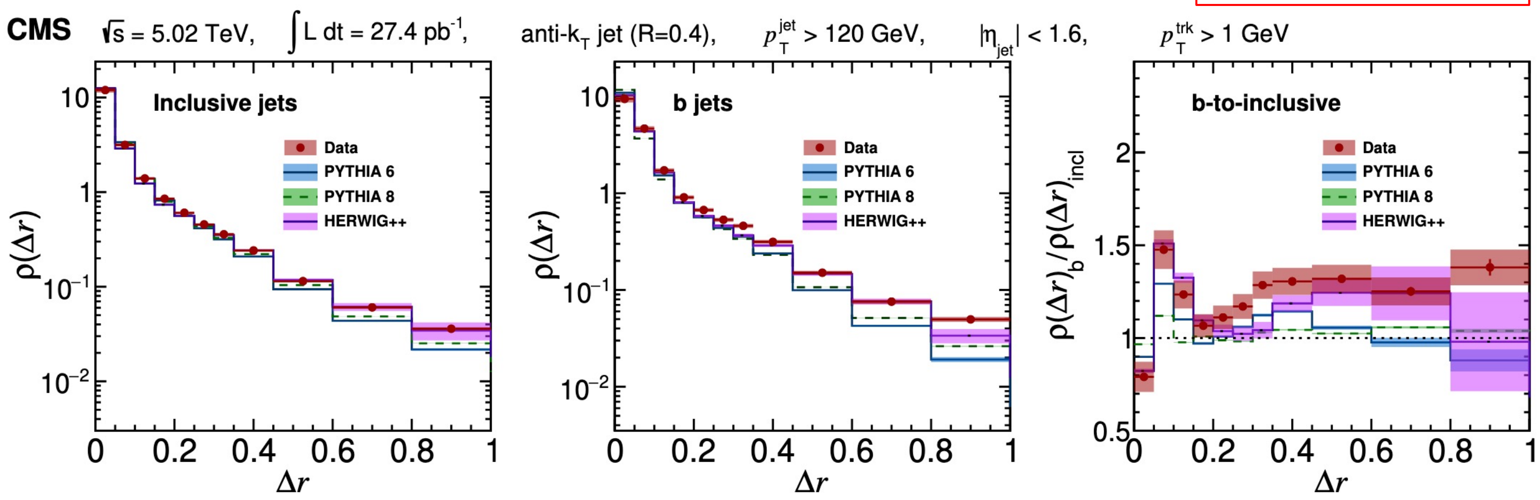


$$R(\theta) = \frac{1}{N^{\mathrm{D^0\,jets}}} \frac{\mathrm{d}n^{\mathrm{D^0\,jets}}}{\mathrm{d}\ln(1/\theta)} \Bigg/ \frac{1}{N^{\mathrm{inclusive\,jets}}} \frac{\mathrm{d}n^{\mathrm{inclusive\,jets}}}{\mathrm{d}\ln(1/\theta)}$$



- 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 '*dead cone*' effect
  - ✓ Results in different emission spectra compared to light quarks in vacuum.

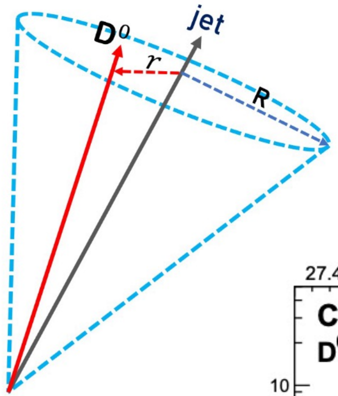
CMS, JHEP05 (2021) 054



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

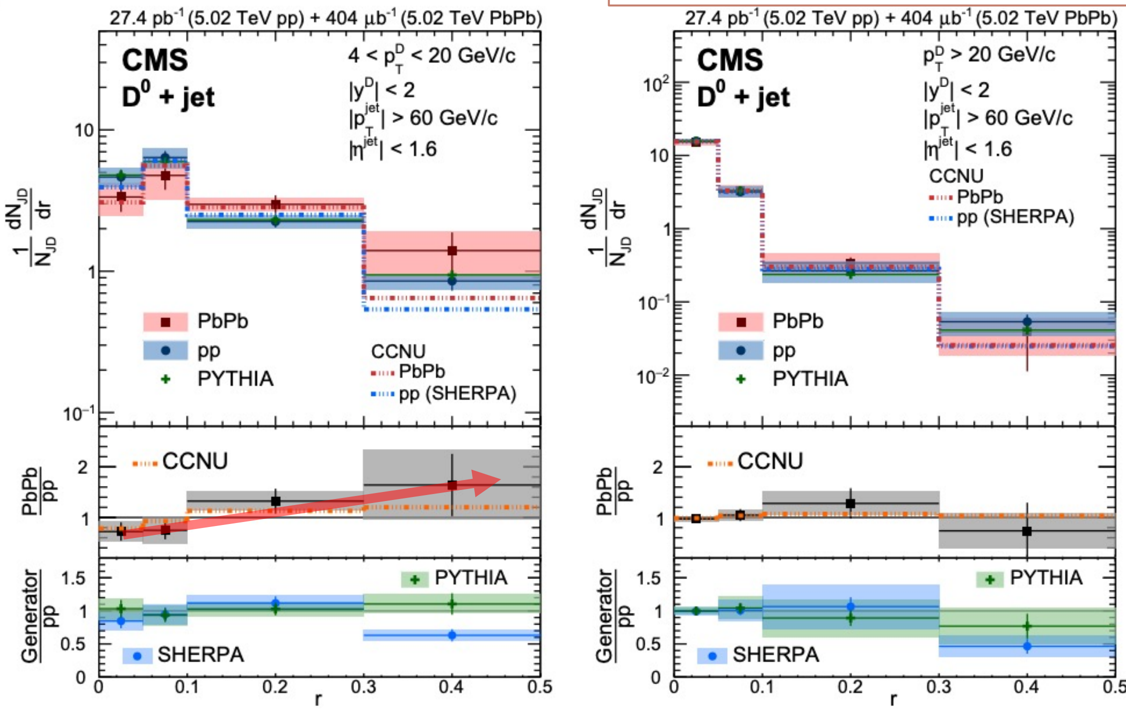
Previous Jet Results

Jets from Heavy Flavor



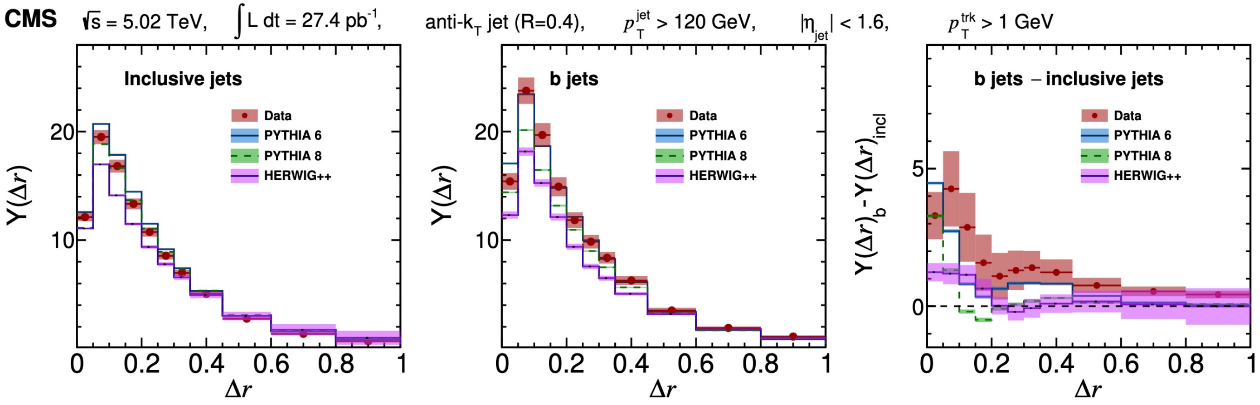
$$\text{Radial Distribution} = \frac{1}{N_{\text{Jet},D^0}} \frac{dN_{\text{Jet},D^0}}{dr}$$

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



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

CMS, JHEP05 (2021) 054



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]

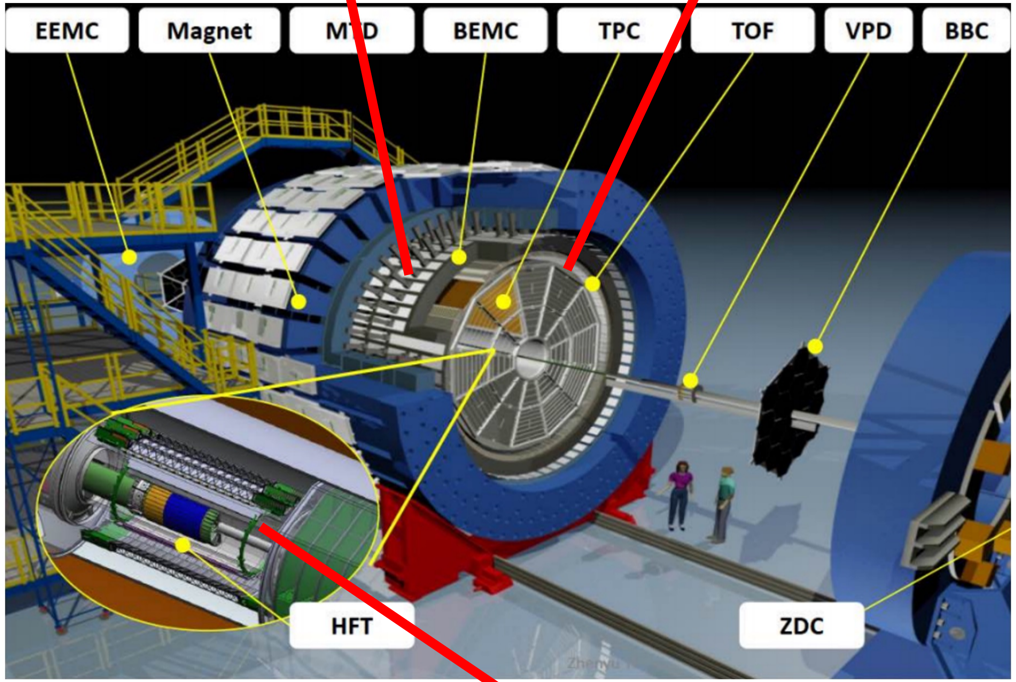
Better access to low p_T D^0 region at RHIC energies

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



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 :

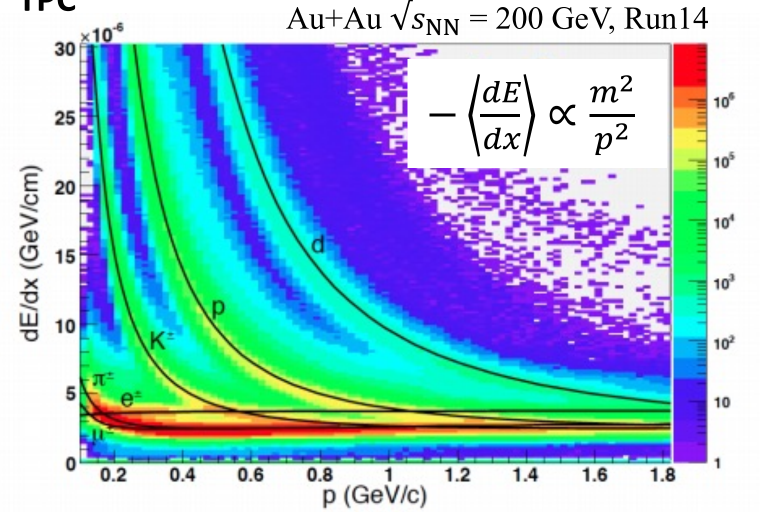
- $0.2 < p_{T,track}$ [GeV/c] < 30 ; $0.2 < p_{T,tower}$ [GeV/c] < 30
- $|\eta_{track}| < 1$; $|\eta_{tower}| < 1$
- $D^0 \rightarrow K^- + \pi^+$ (and the conjugate) [B.R. = 3.82 %]
- For D^0 reconstruction: Tracks need at least two hits in HFT
- $1 < p_{T,D^0}$ [GeV/c] < 10

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

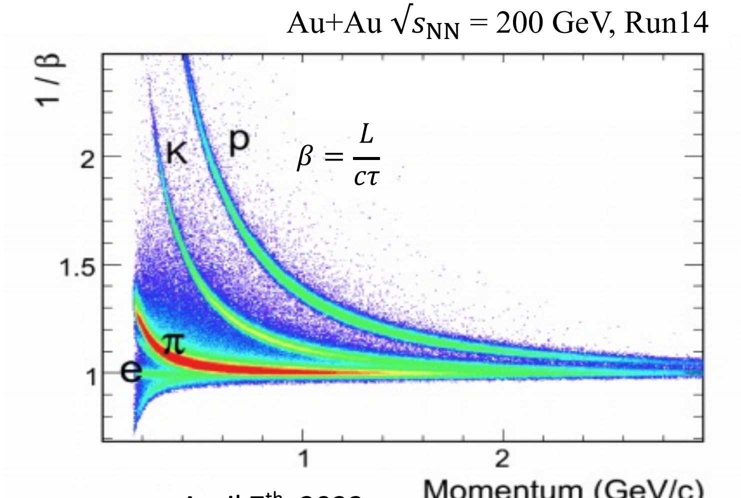
TPC



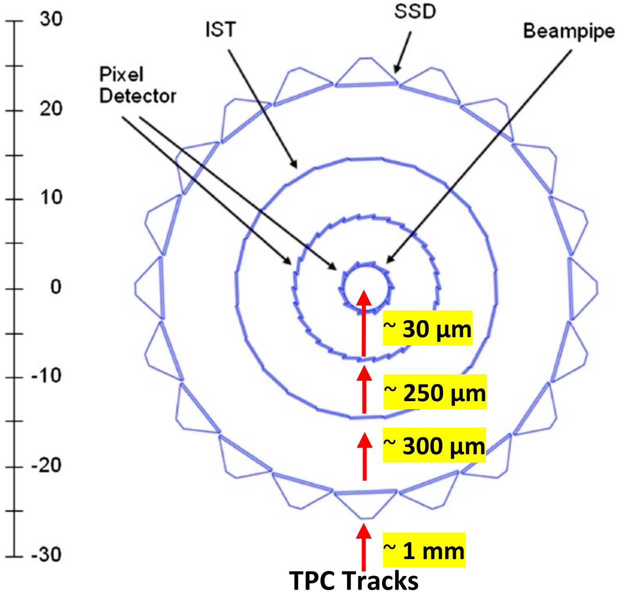
$|n\sigma_\pi| < 3.0$; $|n\sigma_K| < 2.0$

$\left| \frac{1}{\beta} - \frac{1}{\beta_{exp}} \right| < 0.03$

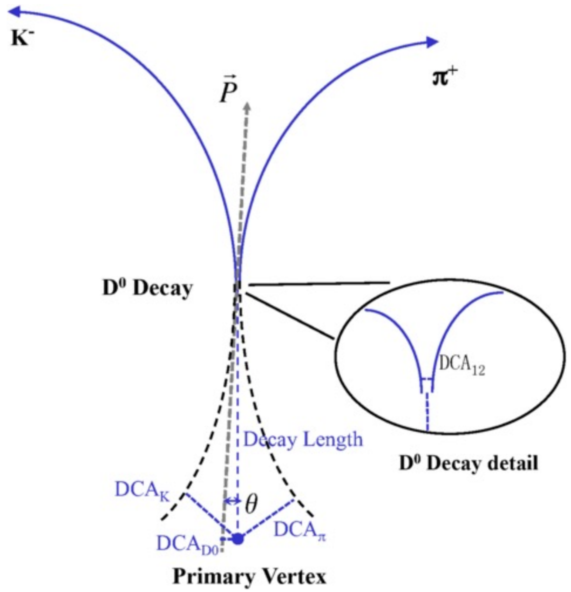
TOF



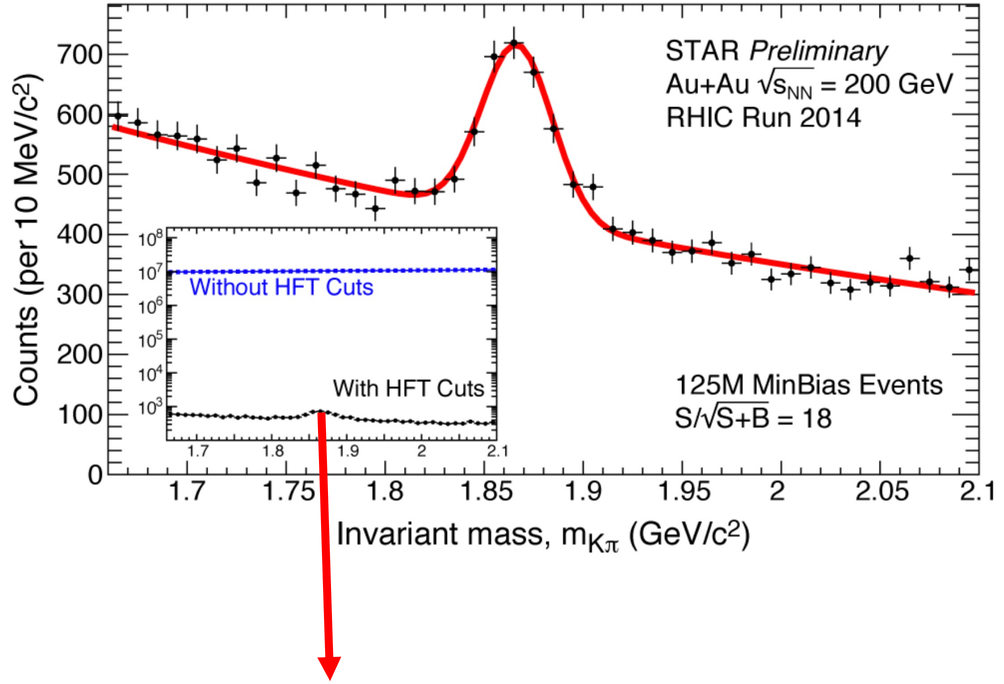
HFT



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 Reconstruction

sPlot Method (Short Method and yield comparison plot for one bin)

${}_s\mathcal{P}$lot Method (doi.org/10.1016/j.nima.2005.08.106)

Native class in RooStats + widely used in HEP (particularly HF measurements)

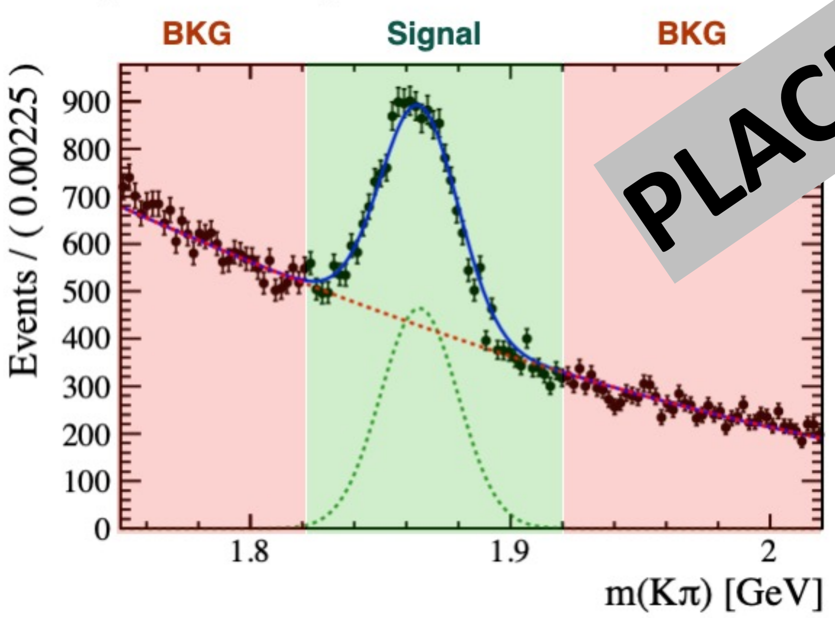
Method to re-weight (using "sWeights") data populated with signal+background to reconstruct distributions of interest for signal *only*

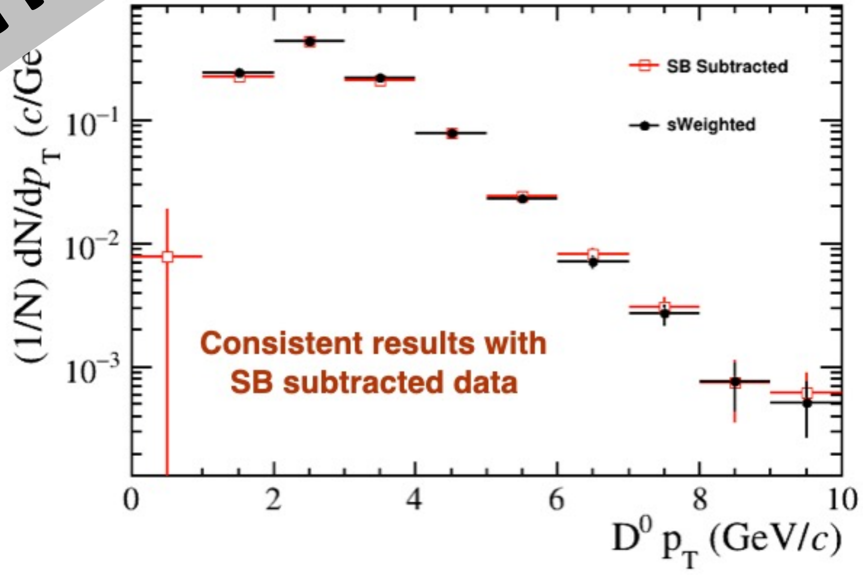
- Relies on some (uncorrelated) *known* discriminating variable
- Full formalism in poster (M. Kelsey)

$$ {}_s\mathcal{P}_n(\ldots \; \frac{\ldots V_{nj} f_j(y_e)}{\sum_{k=1} N_k f_k(y_e)} \qquad N_n^{\epsilon} = \sum_{e=1}^{N} \frac{{}_s\mathcal{P}_n(y_e)}{\epsilon(x_e)} $$

Essentially a more sophisticated side-band subtra… …me additional beneficial features (more later)

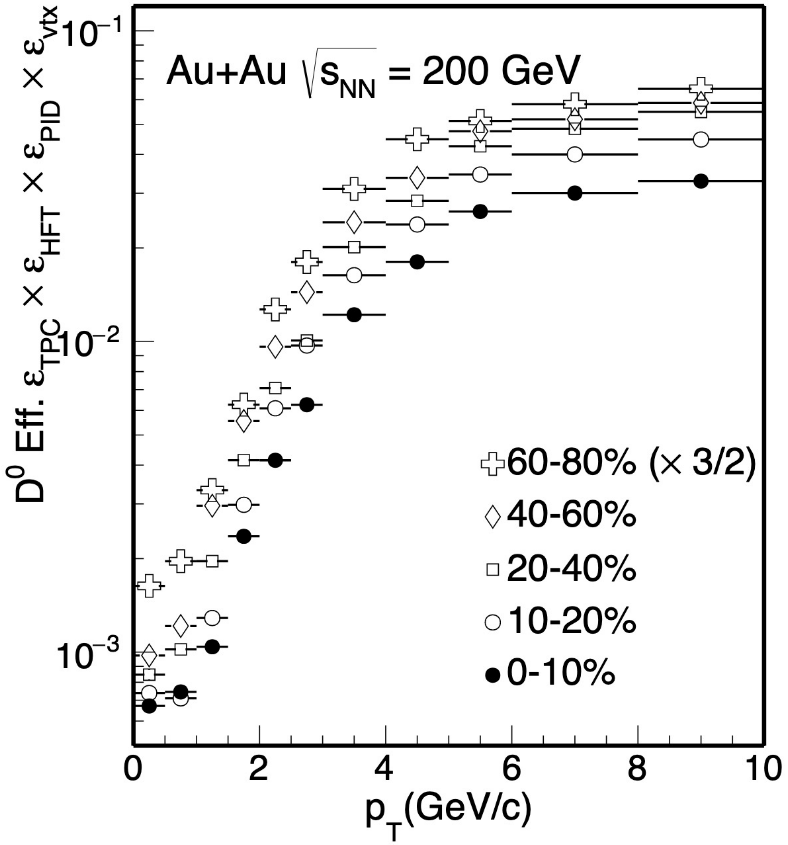
PLACEHOLDER





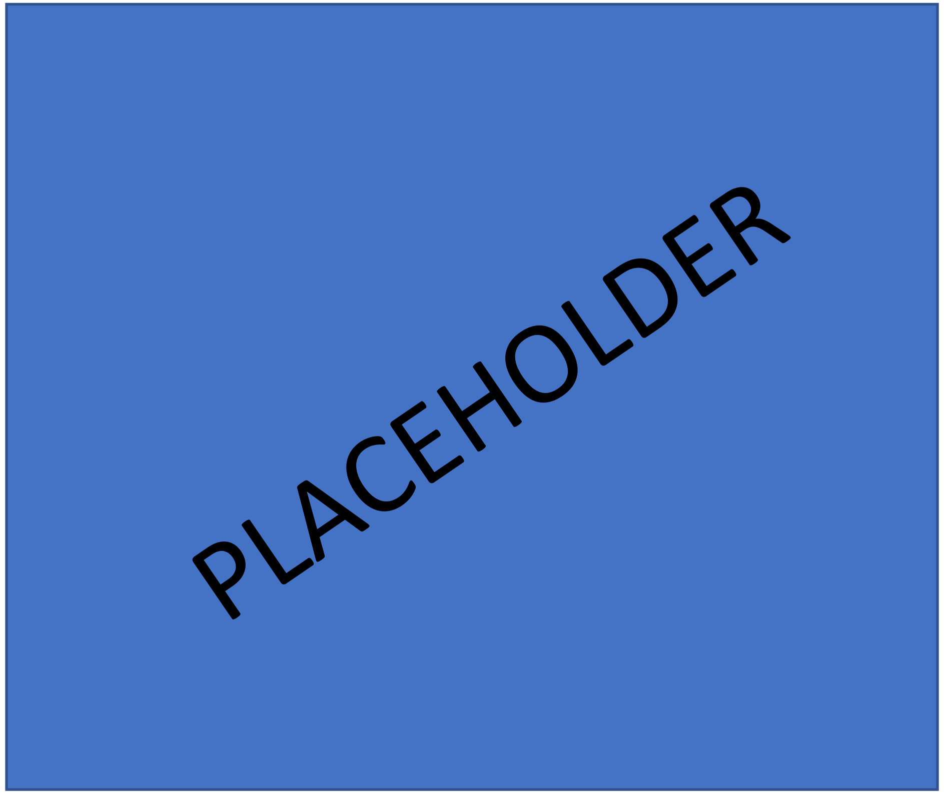
Efficiency Corrected D^0 Jet Yield

STAR, Phys. Rev. C 99 (2019) 034908



D^0 yield corrected for reconstruction efficiency

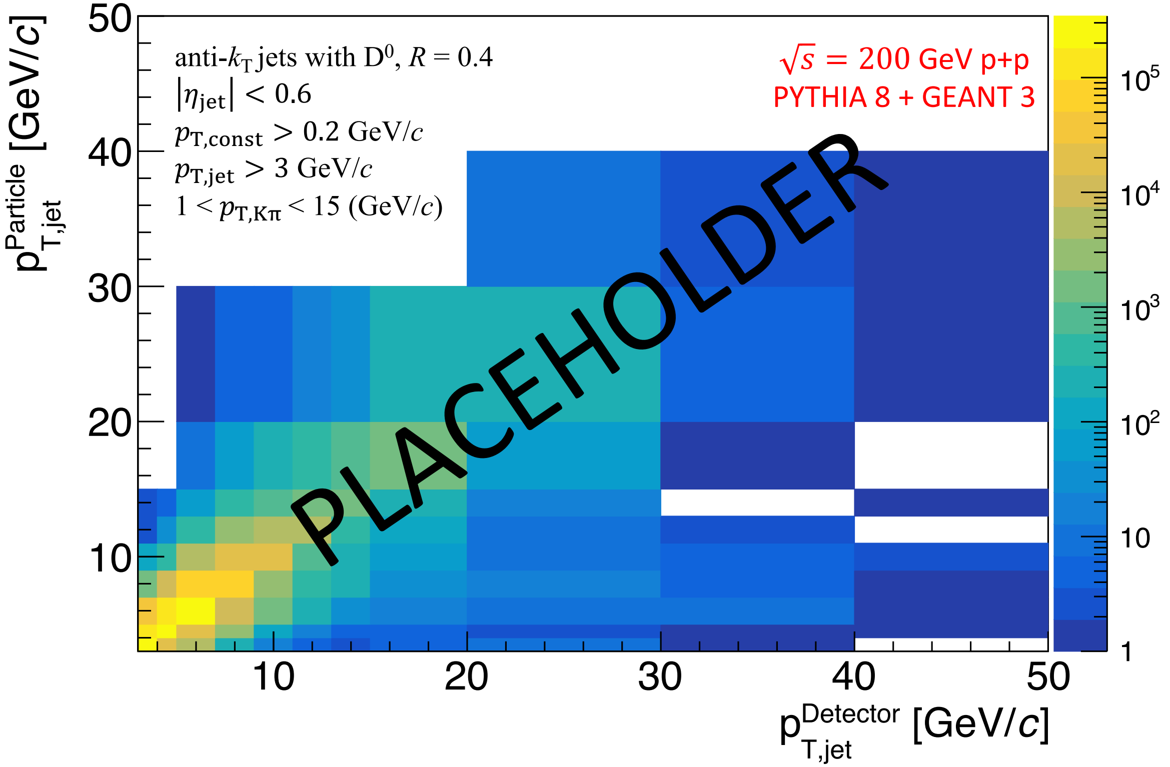
The efficiency weights were derived using a data-driven fast simulation method



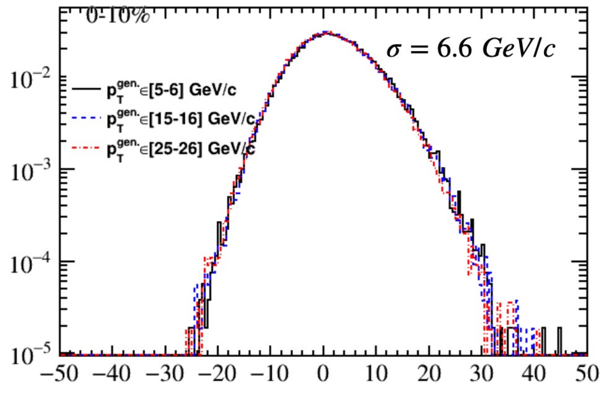
Raw Au + Au D^0 Jet Spectrum and Radial Distribution of D^0 in Jet

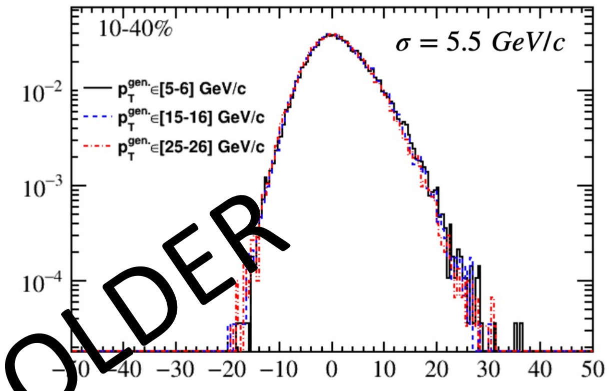
Efficiency Correction Using Unfolding

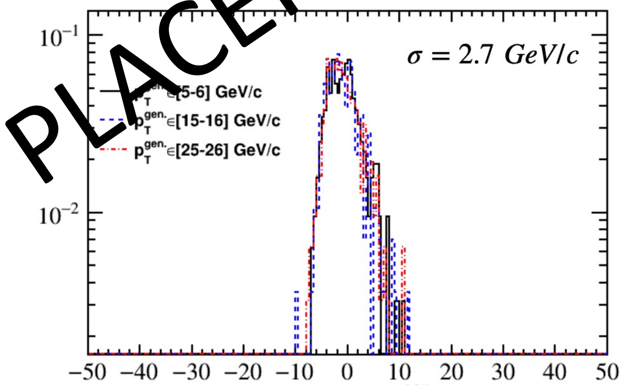
Instead of a full embedding sample, existing fast simulation method along with a *PYTHIA 8* simulation to estimate detector effects.



HI background fluctuation estimated by embedding a hard track in min-bias events

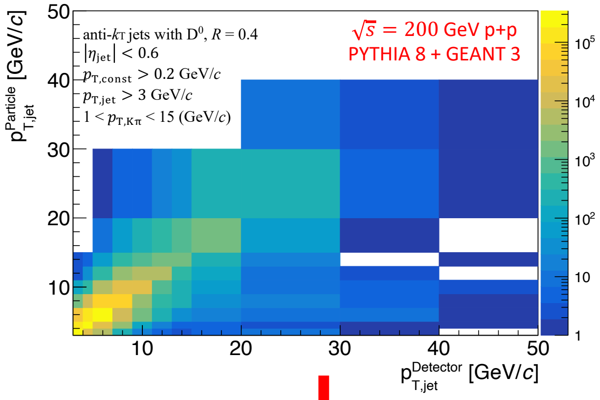




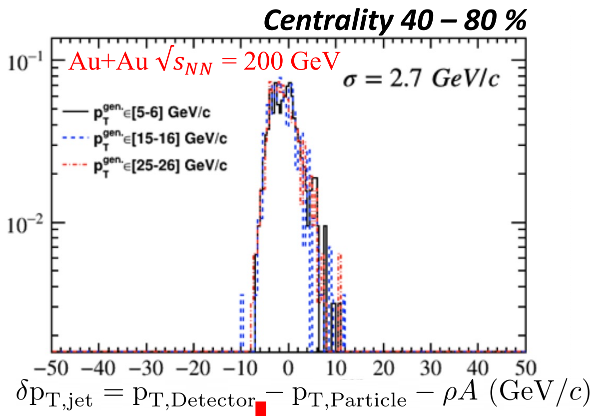


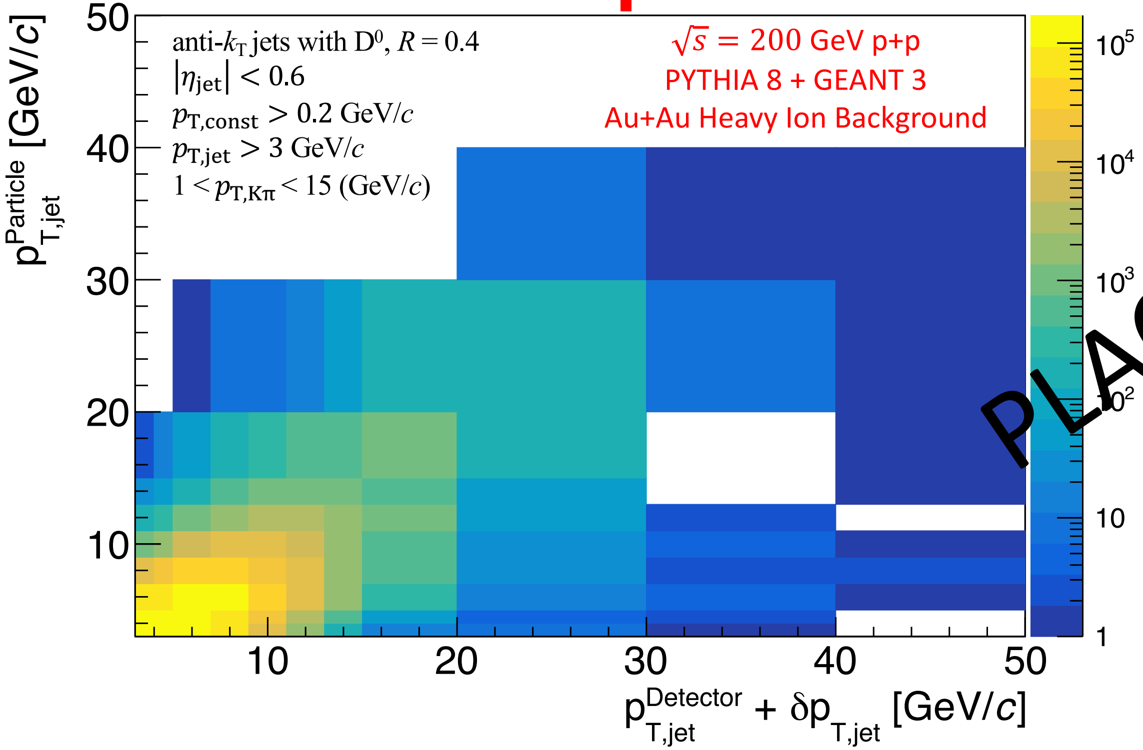
Background fluctuation is independent of p_T of hard track

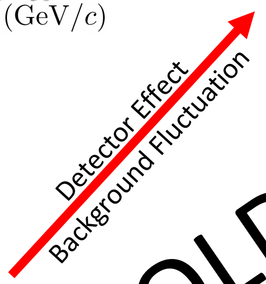
Closure for Unfolding Jet Spectrum

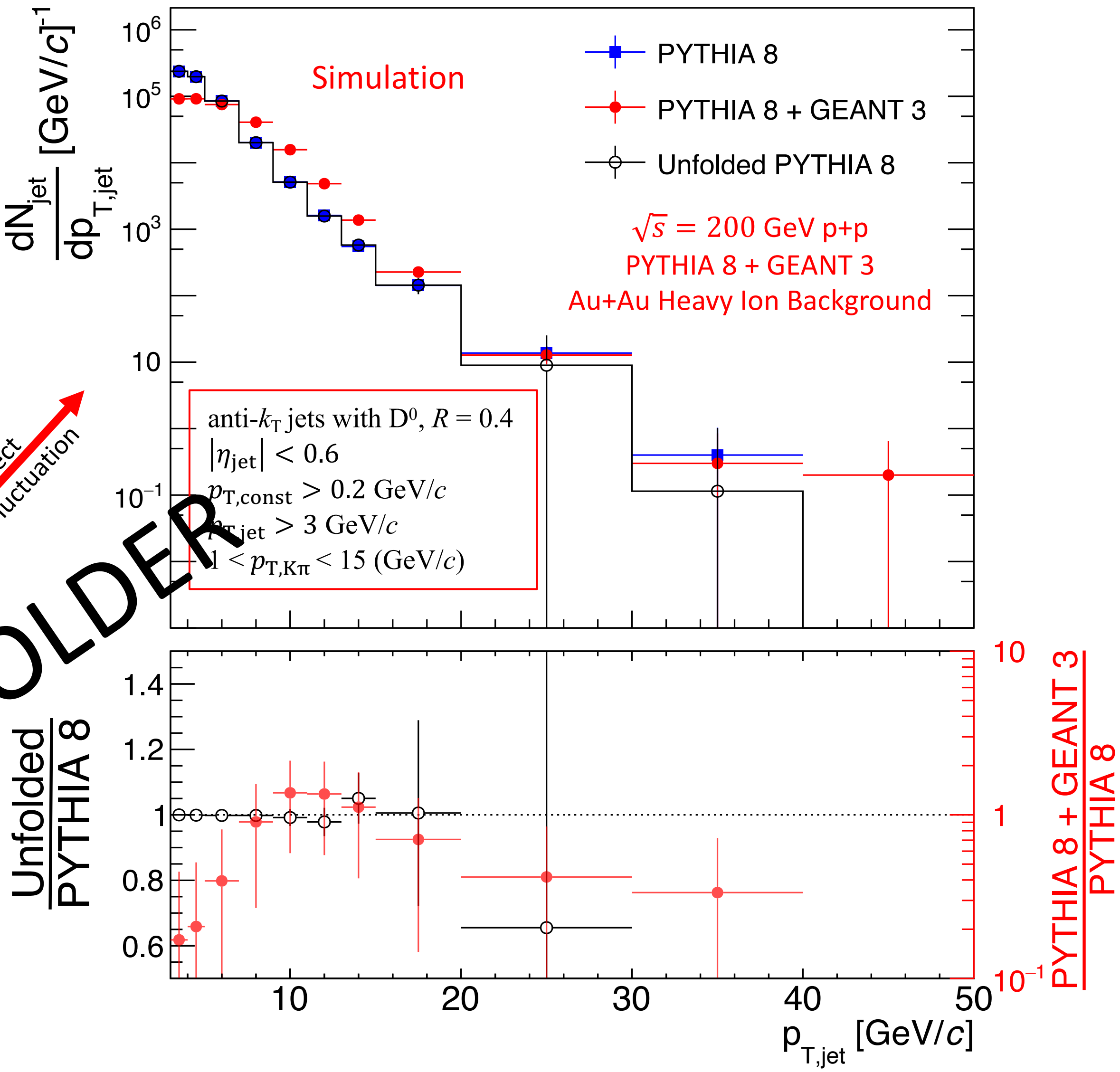


X









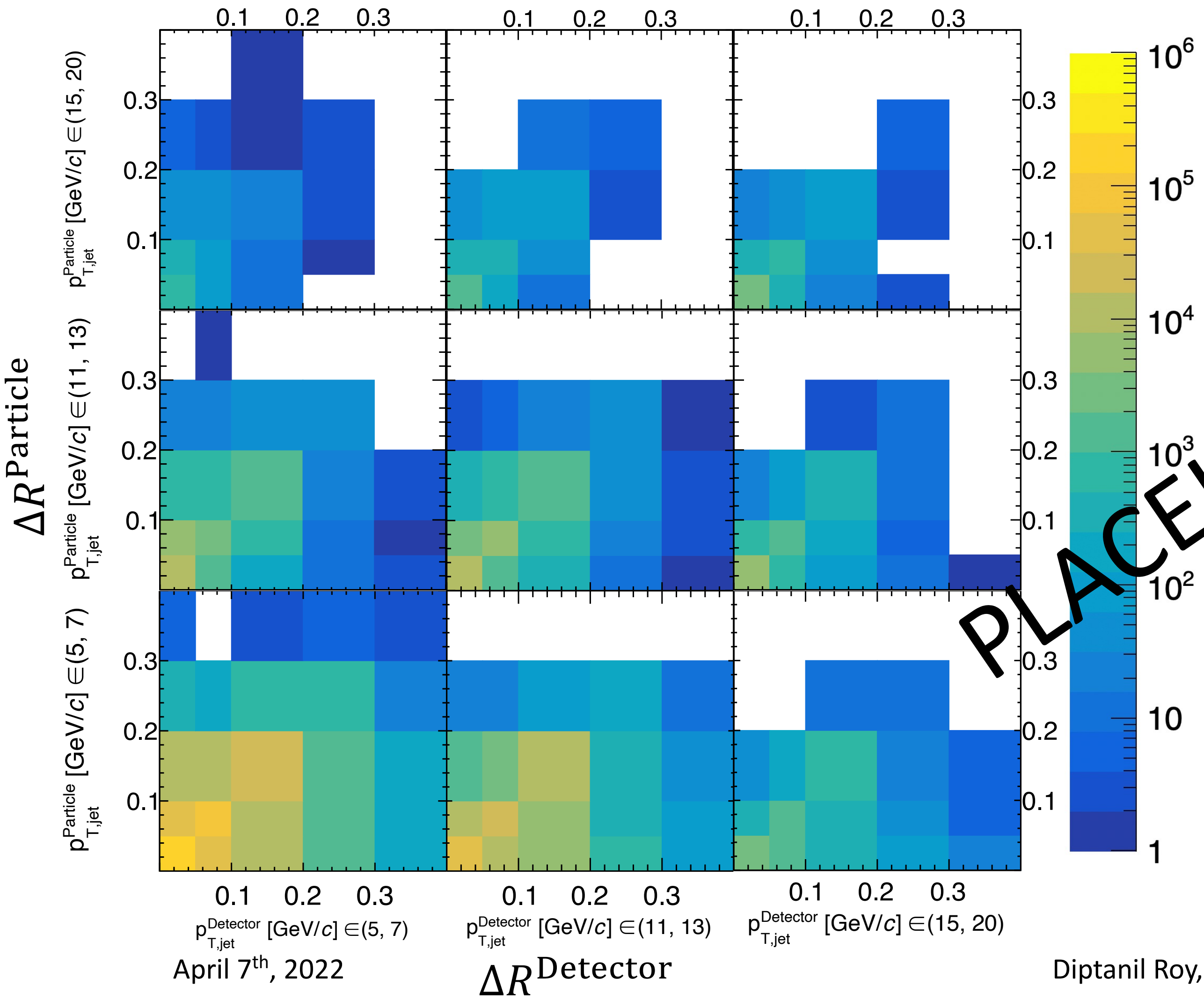
Closure test shows that we can reproduce the particle level $p_{T,jet}$ spectrum using unfolding

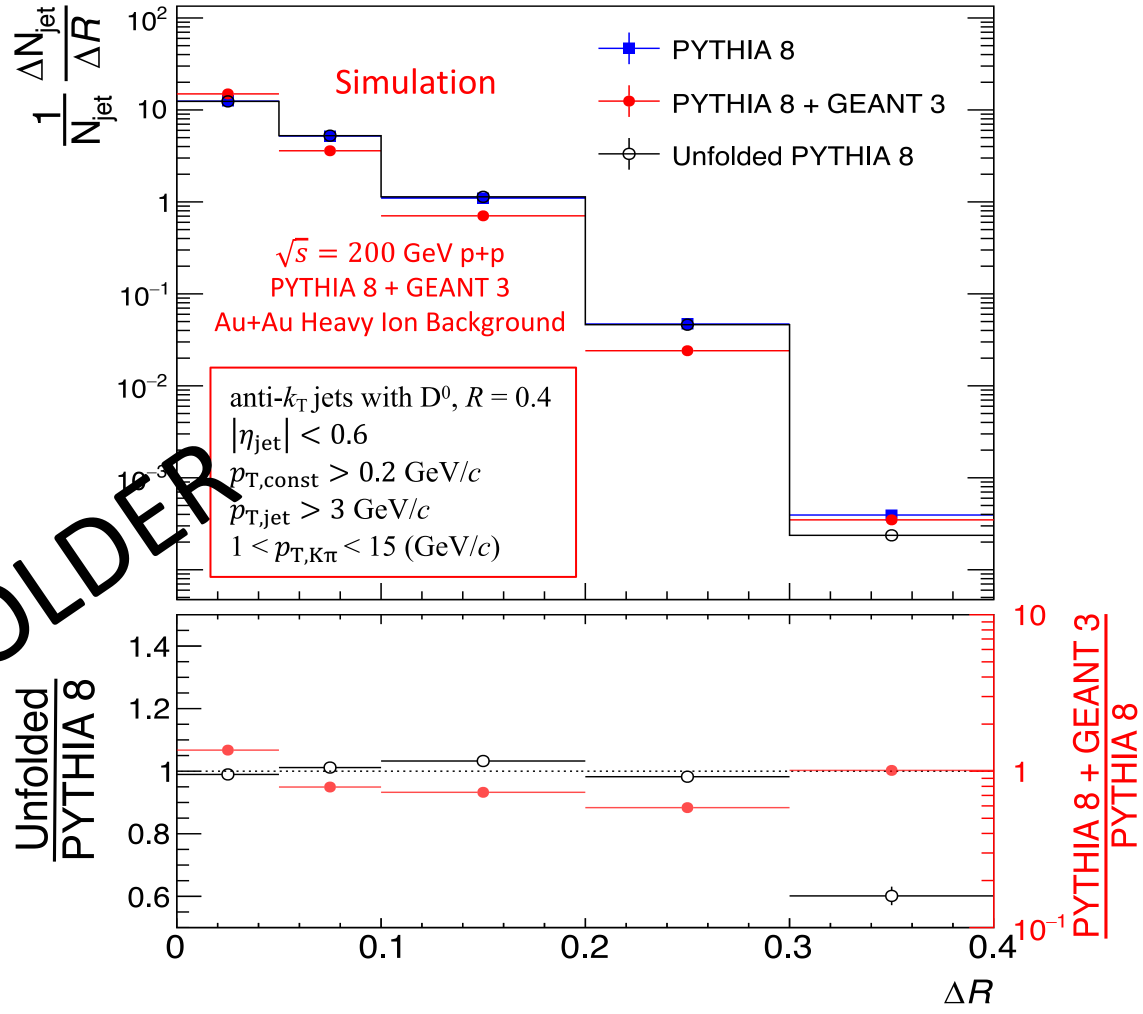
Closure for Unfolding Radial Distribution of D^0 Mesons in Jets

anti-k_T jets with D^0, $R = 0.4$
$|\eta_{jet}| < 0.6$
$p_{T,const} > 0.2$ GeV/c
$p_{T,jet} > 3$ GeV/c
$1 < p_{T,K\pi} < 15$ (GeV/c)

Radial distribution is unfolded along with the $p_{T,jet}$

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





- **Closure test shows that we can reproduce the radial distribution of D^0 mesons for low and mid ΔR using 2D unfolding**

Jet Spectrum and R_{CP}

Probable comparison to inclusive charged jets RCP, D0 RCP here

Radial Distribution of D^0 Mesons in Jets and R_{CP}

RCP in two D0 pT bins (1-4, 4-10). Comparison with CCNU (???)

Summary