QUARK MATTER 2015

The XXVth International Conference on Ultrarelativistic Nucleus-Nucleus Collisions

PHENIX results on reconstructed jets in *p+p* and heavy ion collisions

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for the PHENIX Collaboration

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PHENIX

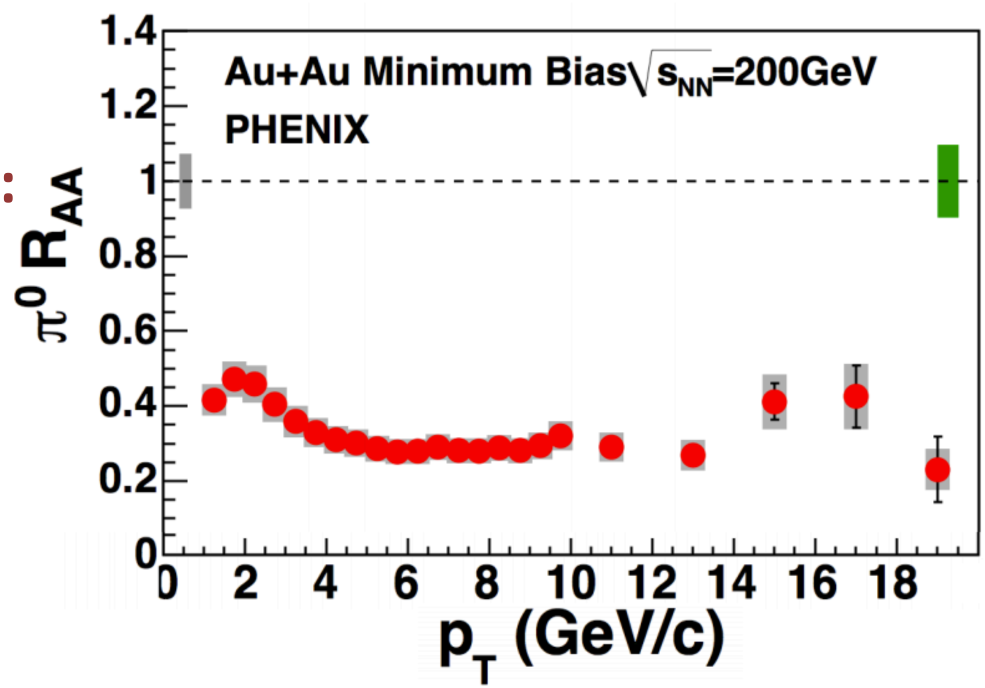
STATE

Jets at RHIC

- Can measure jet modification at lower energies- allows exploration of $\sqrt{s_{NN}}$ dependence of energy loss
- Versatility of RHIC provides ability to study jet modification in different collision geometries, system sizes, and energy densities

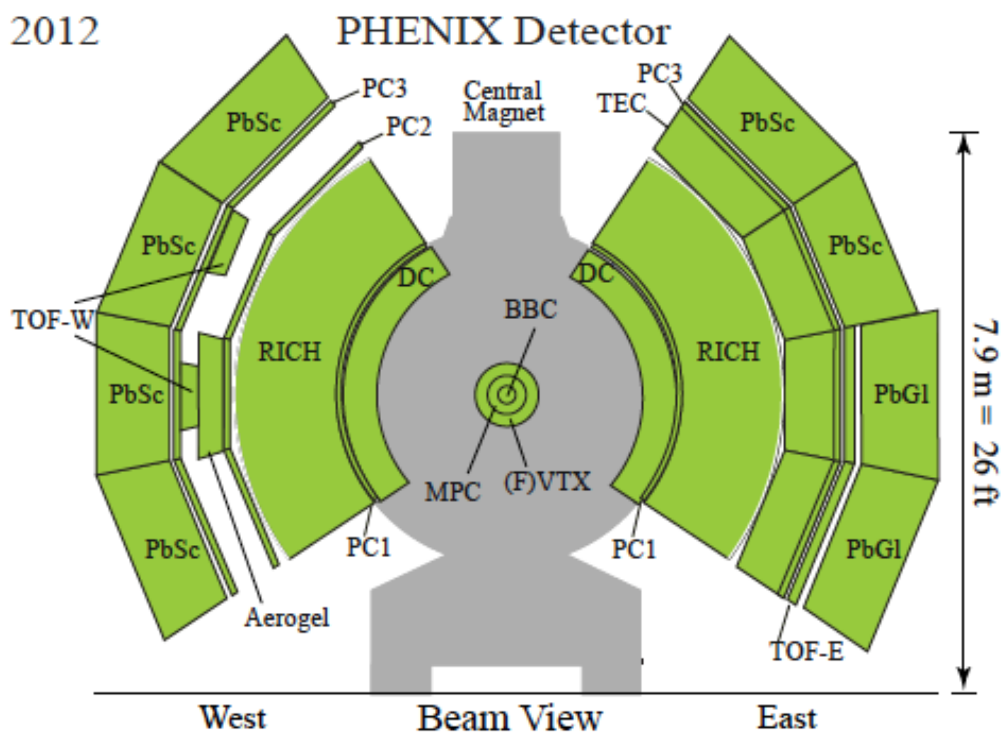
Moving beyond single particles:

Jet measurements in heavy ion collisions -> quantify the energy loss of hard-scattered partons



Phys. Rev. Lett. 101, 232301

The PHENIX Detector



PHENIX central arms: $|\eta| < 0.35$, $\Delta\phi = \pi$

- Charged particle tracks are reconstructed using the Drift Chamber (DC), the Pad Chamber (PC), and the collision point

- Neutral clusters are measured in the Electromagnetic Calorimeter (EMCal). EMCals (PbSc & PbGl) measures π^0, γ, and some hadrons (with lower efficiency).

Jets in PHENIX

- 2012 $\sqrt{s_{NN}}$ = 200 GeV p+p and Cu+Au

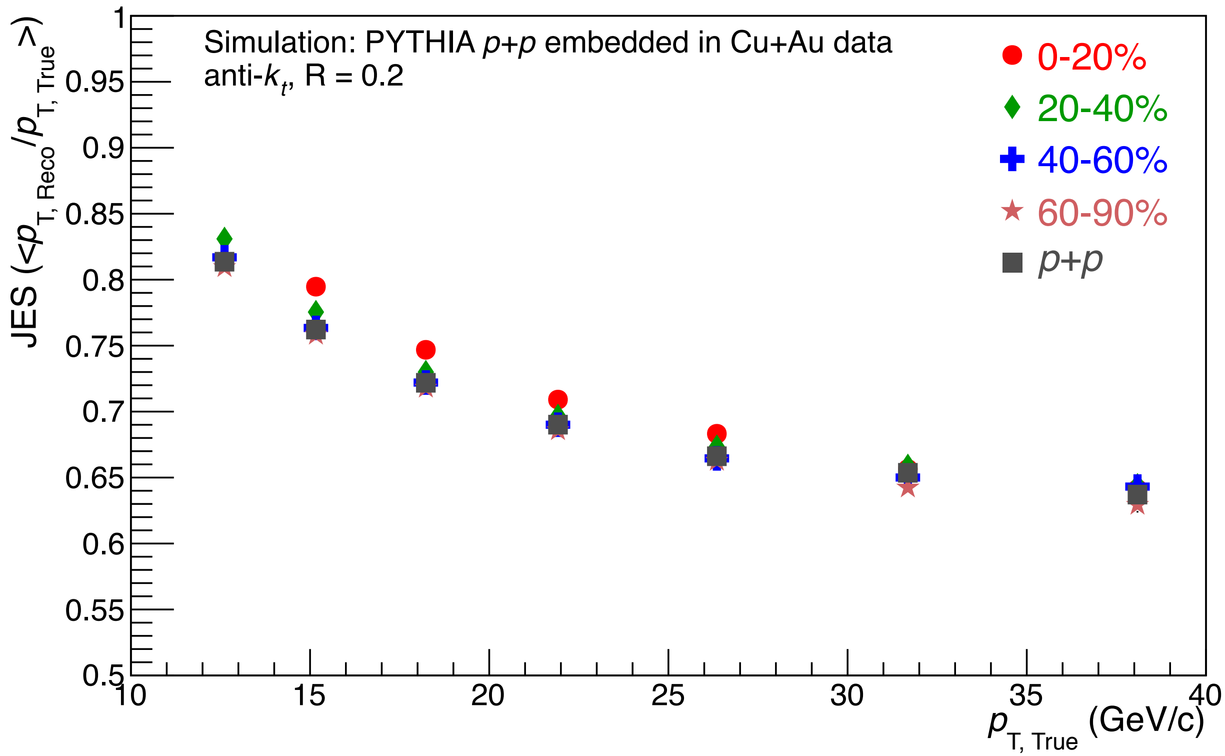
- Jets reconstructed using the anti-k_t algorithm with ***R* = 0.2**
  - track p_T > 500 MeV/c
  - clusters energy > 500 MeV

- Jet-level cuts
  - number of constituents ≥ 3
  - 0.2 < charged fraction < 0.7
  - jet axis from edge: $|\eta|$ > 0.05, $\Delta\phi$ > 0.12

Note: No single hard particle requirement in a jet

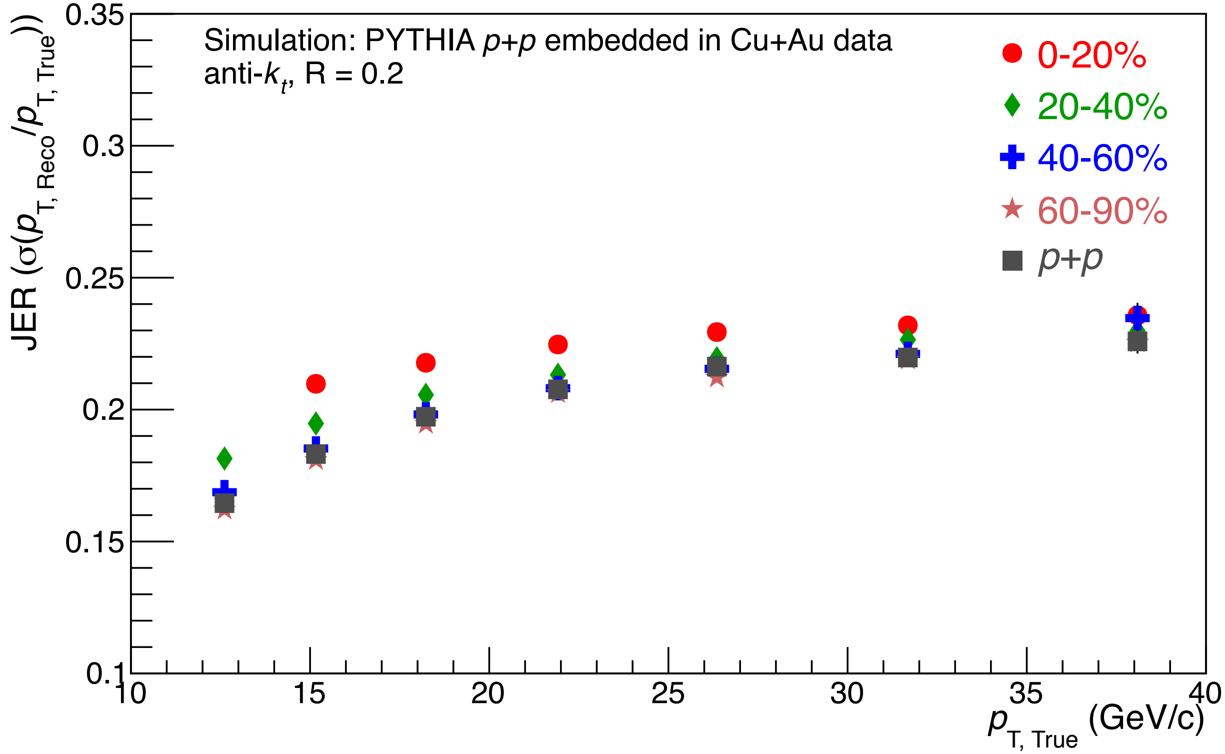
- Centrality-dependent response matrices generated by embedding PYTHIA p+p jets into real Cu+Au events

Jets in PHENIX: Jet Energy Scale



- For each $p_{T,\ True}$ bin, $p_{T,\ Reco}/p_{T,\ True}$ distribution is examined
- Due to missing neutral hadronic energy and tracking inefficiency, on average, PHENIX gets ≈70% of the true jet energy
- For 0-20%, the UE increases the $p_{T,\ Reco}$ up to 3.2% (1.7%) at 15 GeV/c (26 GeV/c) relative to that in *p*+*p* events

Jets in PHENIX: Jet Energy Resolution



- The width of $p_{T, Reco}/p_{T, True}$ distribution is ≈16-24%
- In PHENIX, the resolution is not driven by EMCal & DC resolution but by jet-by-jet fluctuations
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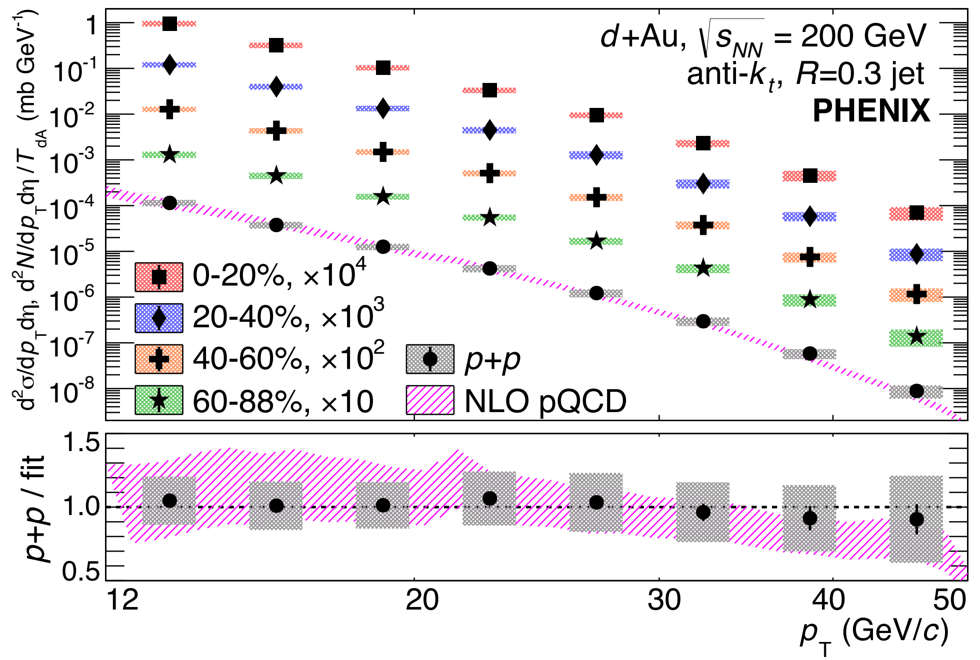
Jets in PHENIX

Similar jet reconstruction method proven to work in *p*+*p* and *d*+Au!!!

arXiv:1509.04657 [nucl-ex]



For *d*+Au jet results, please see

- talk by Ali Hanks (Sept. 29 at 11:50)
- poster #0421 by D. Perepelitsa

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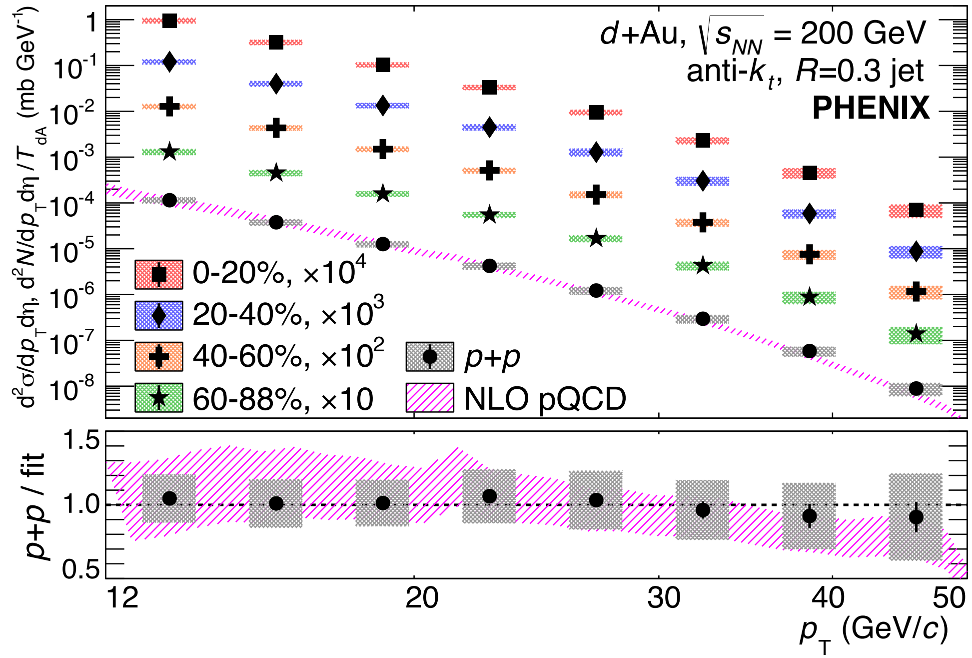

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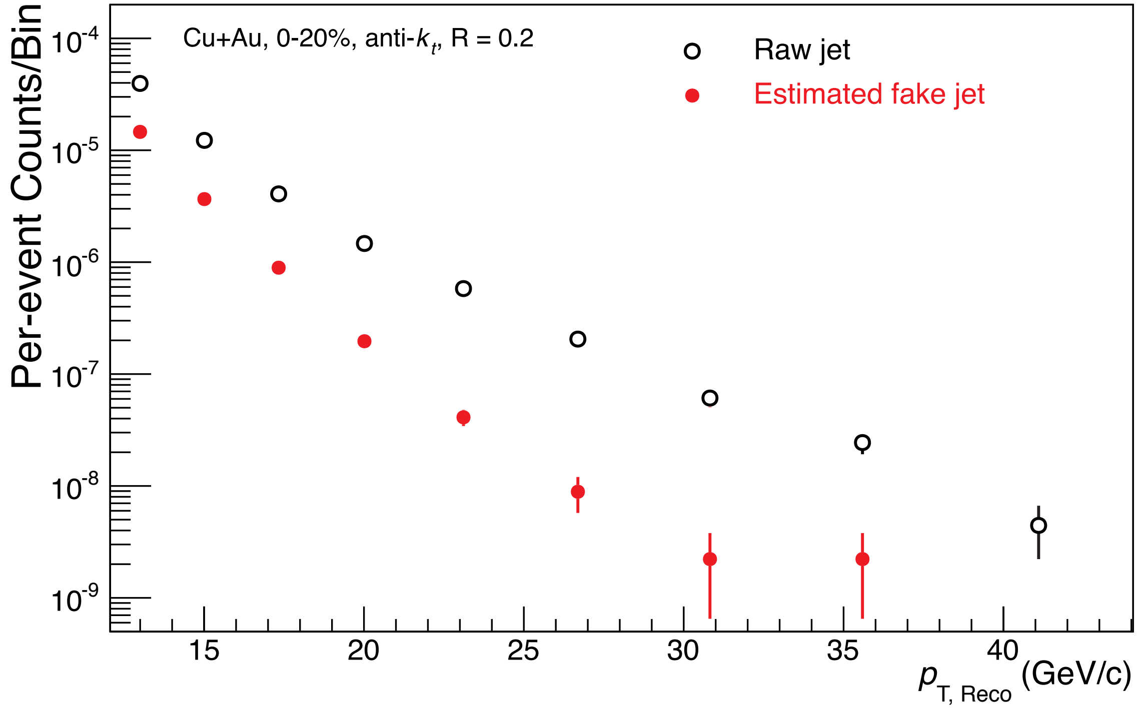
Cu+Au comes with challenges

- Stronger underlying event contribution
  -> choice of smaller cone size
- Fake jet contribution
  -> fake jet subtraction

Fake jet

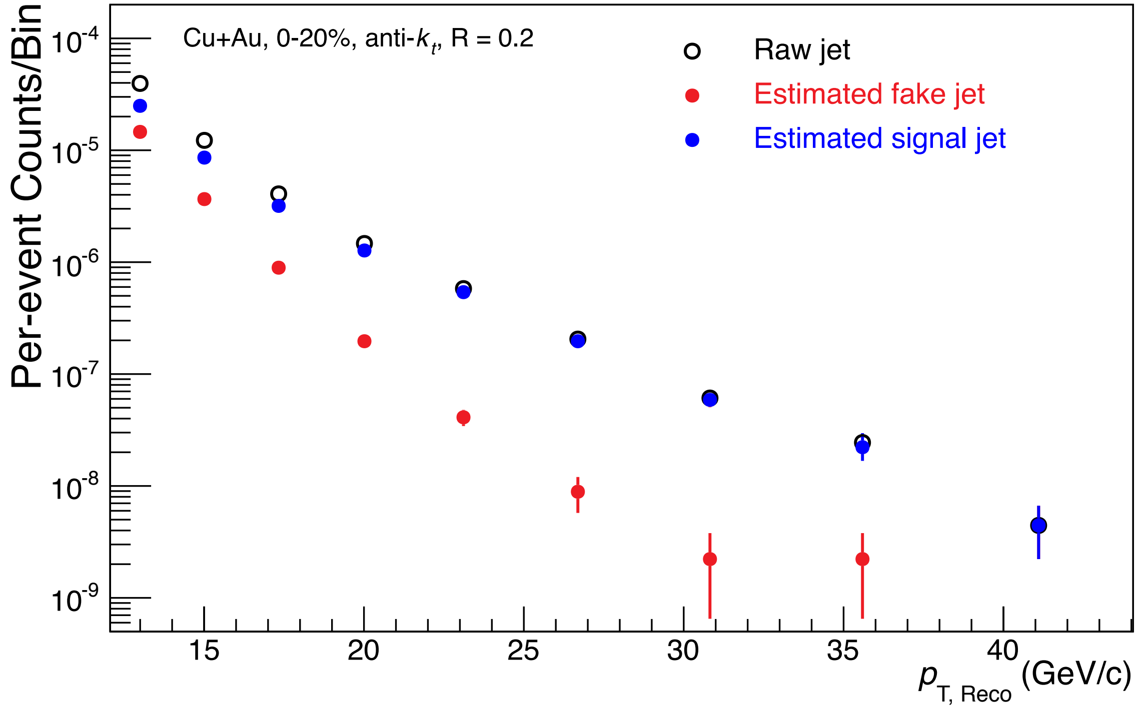


Data driven method of estimating and statistically subtracting fake jet contribution

- For events in which jet is not reconstructed, position (η, ϕ) of tracks and position (η, ϕ) of clusters are randomly shuffled
- Jet reconstruction performed in these shuffled tracks and clusters

  -> returns estimated fake jet

Fake jet

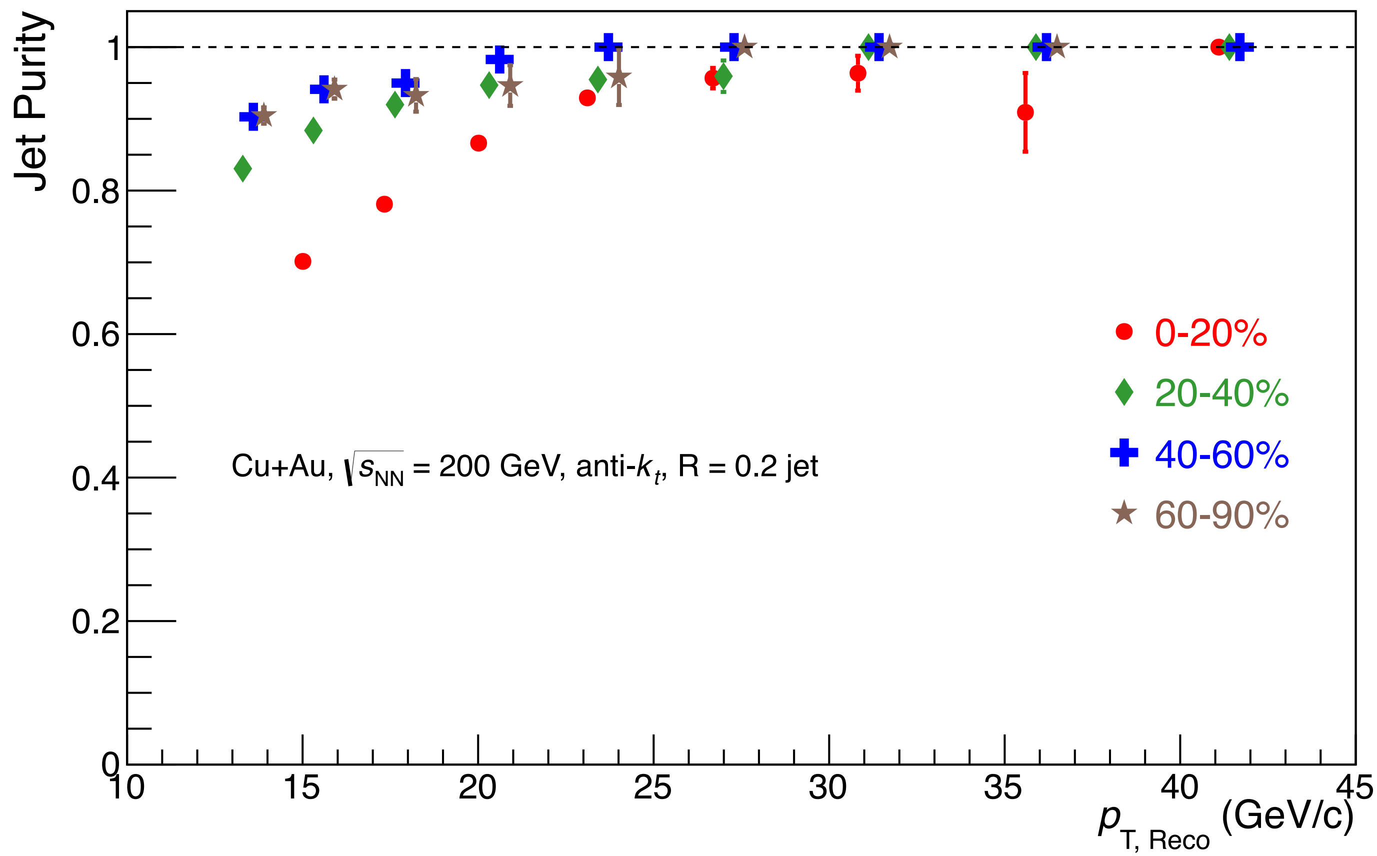


Data driven method of estimating and statistically subtracting fake jet contribution

- For events in which jet is not reconstructed, position (η, ϕ) of tracks and position (η, ϕ) of clusters are randomly shuffled
- Jet reconstruction performed in these shuffled tracks and clusters
  -> returns estimated fake jet
- Estimated fake jet yield is statistically subtracted from the raw jet yield
  -> returns estimated signal jet

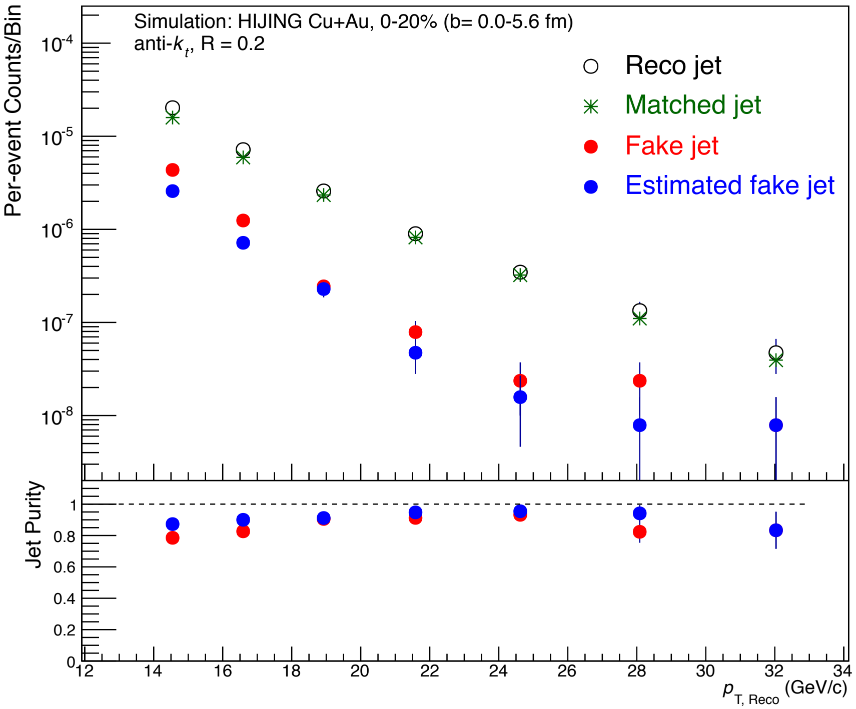
Fake jet

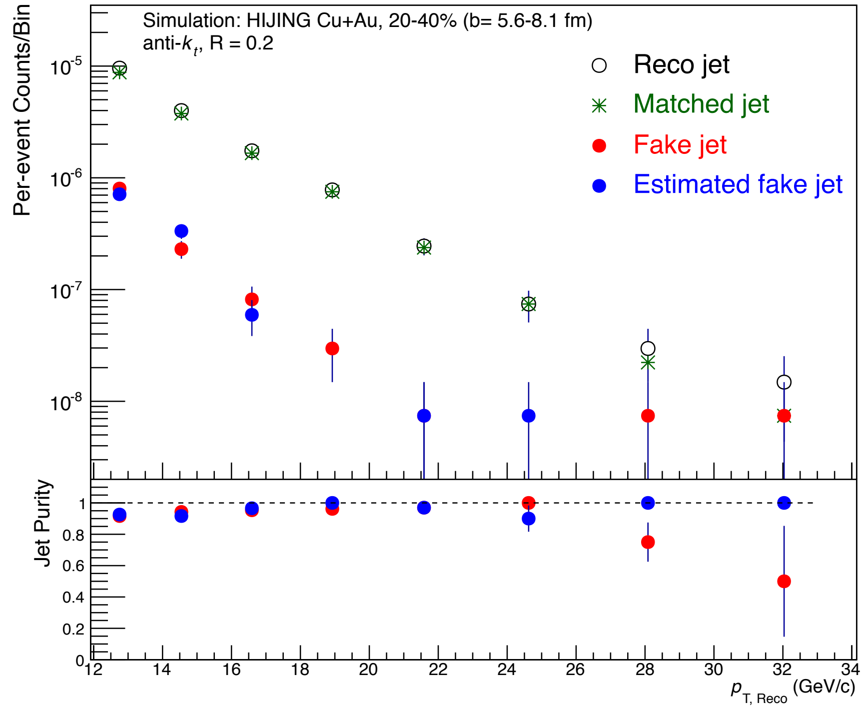
$$\text{Purity} = \frac{\text{Signal jets}}{\text{Raw jets}}$$



- Fake jet contribution is both p_T and centrality dependent; the contribution being largest for central collisions and at low p_T
  - for 0-20%, purity is 70% (93%) at 15 GeV/c (23 GeV/c)

Fake jet HIJING simulation study



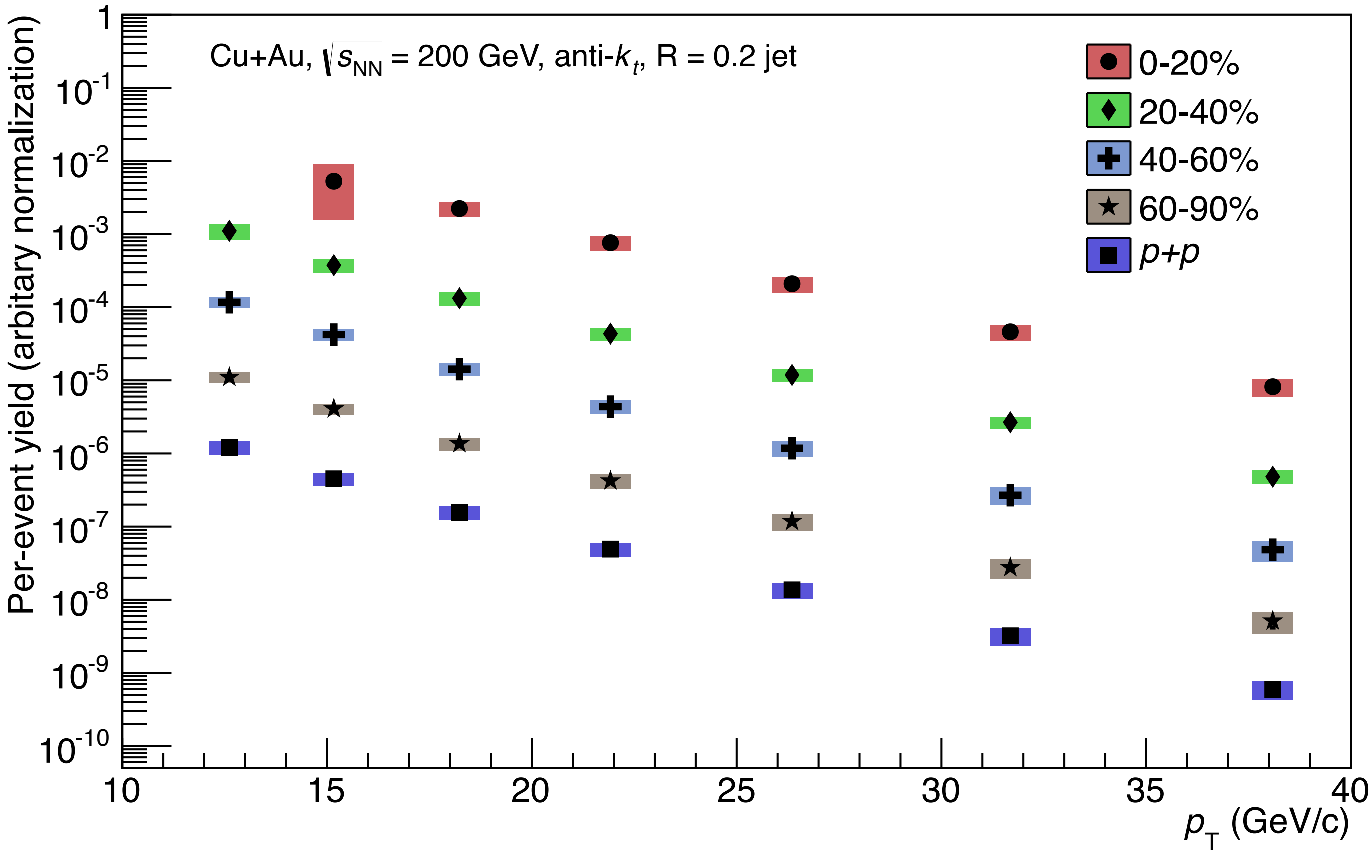


- Matched jet: Reco jet which is within ΔR < 0.2 of true jet
- Fake jet: Reco jet which is not matched

Fake jet estimation procedure gives comparable result!

Fake jet contribution analyzed alternately by re-running the analysis with cluster and track selections of > 2 GeV

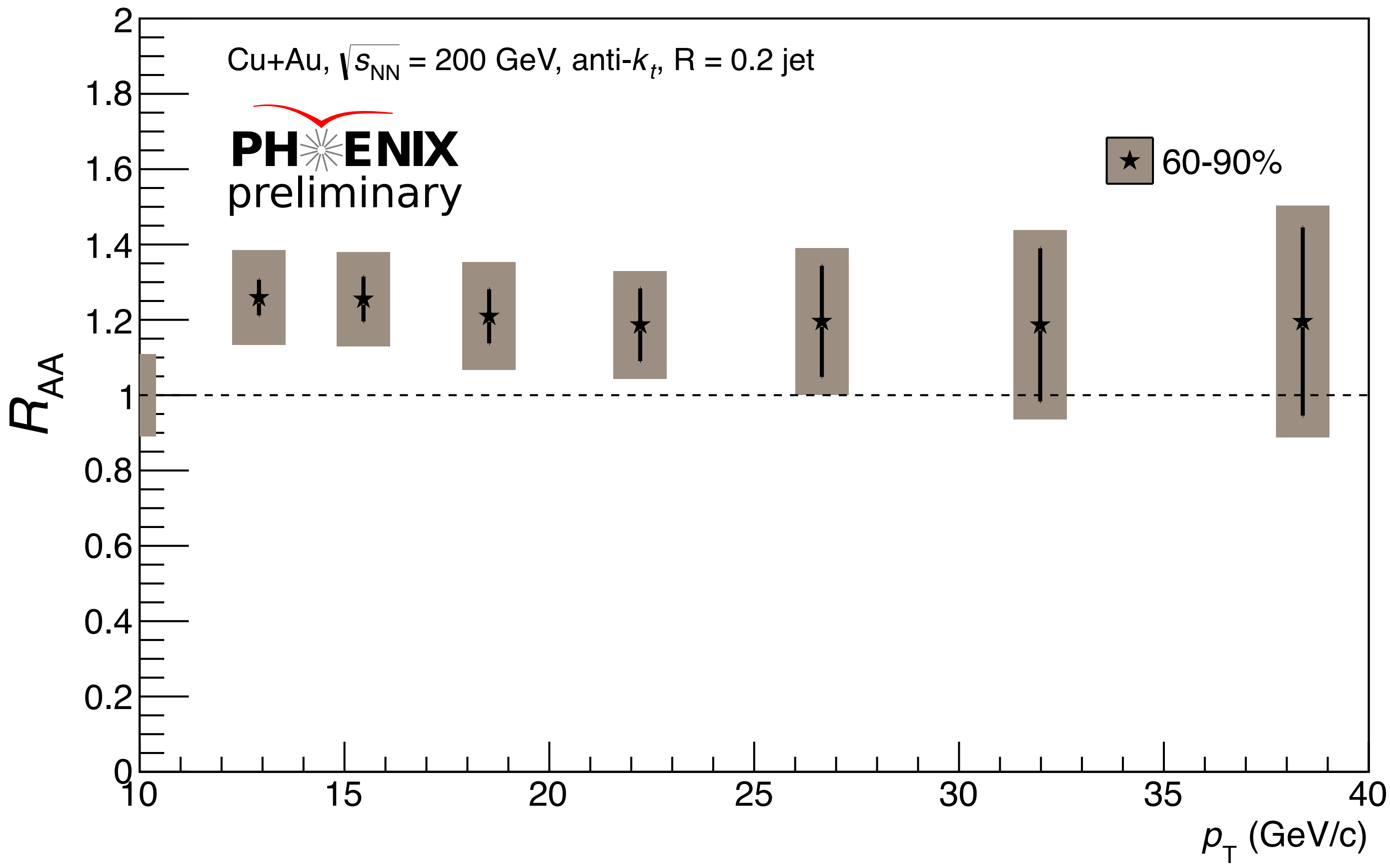
Jet yields



- Spectra unfolded using SVD method (cross-checked using iterative Bayesian method)
  - detector effects
  - centrality dependent underlying event fluctuations

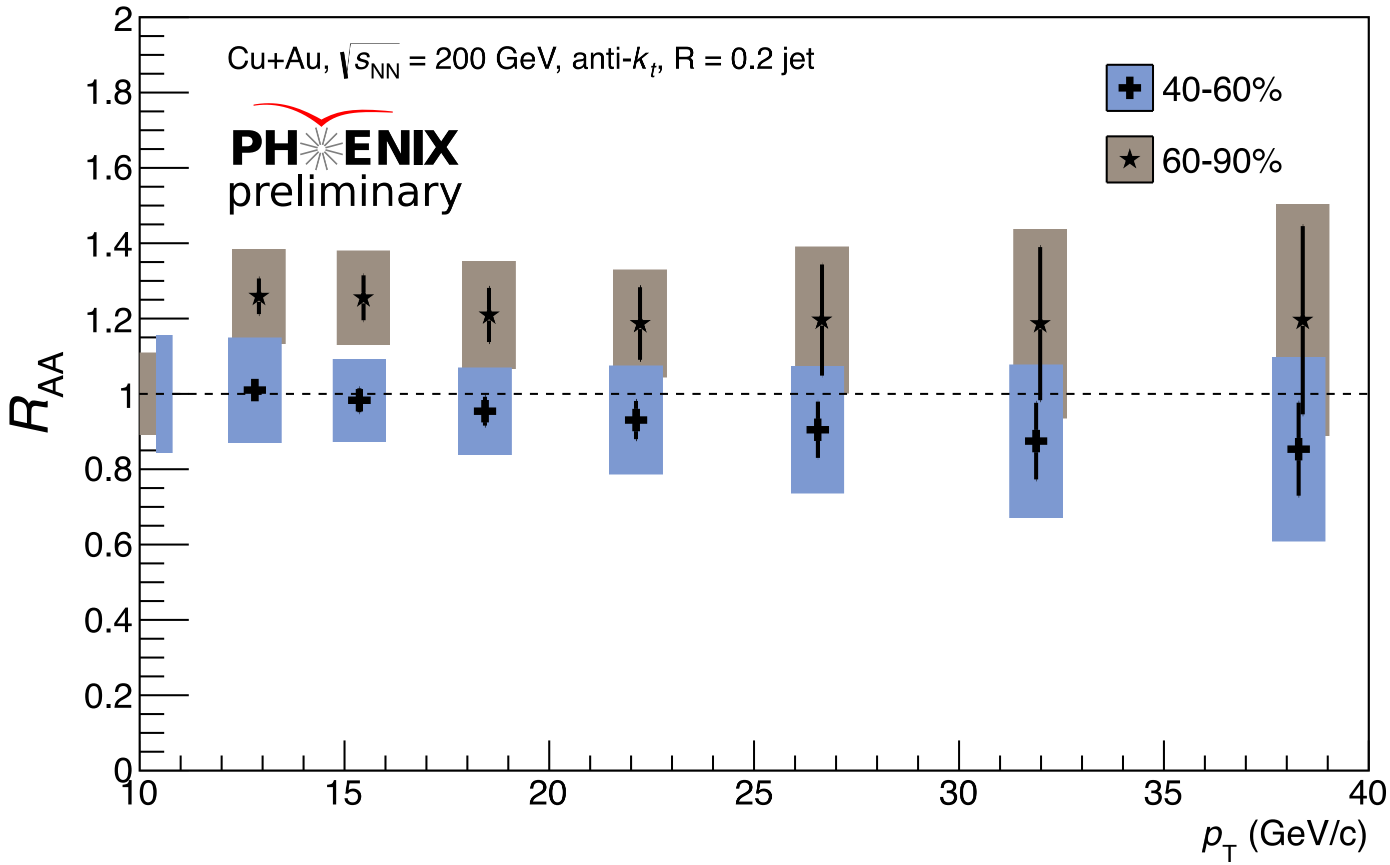
Jet suppression: R_{AA} vs. p_T

$$R_{\mathrm{AA}}^{\mathrm{cent}} = \frac{\left(\frac{1}{N_{\mathrm{evts}}^{\mathrm{cent}}}\frac{\mathrm{d}N}{\mathrm{d}p_{\mathrm{T}}}^{\mathrm{cent}}\right)_{\mathrm{CuAu}}}{T_{\mathrm{AB}}^{\mathrm{cent}} \times \frac{\mathrm{d}\sigma}{\mathrm{d}p_{\mathrm{T}}}}$$



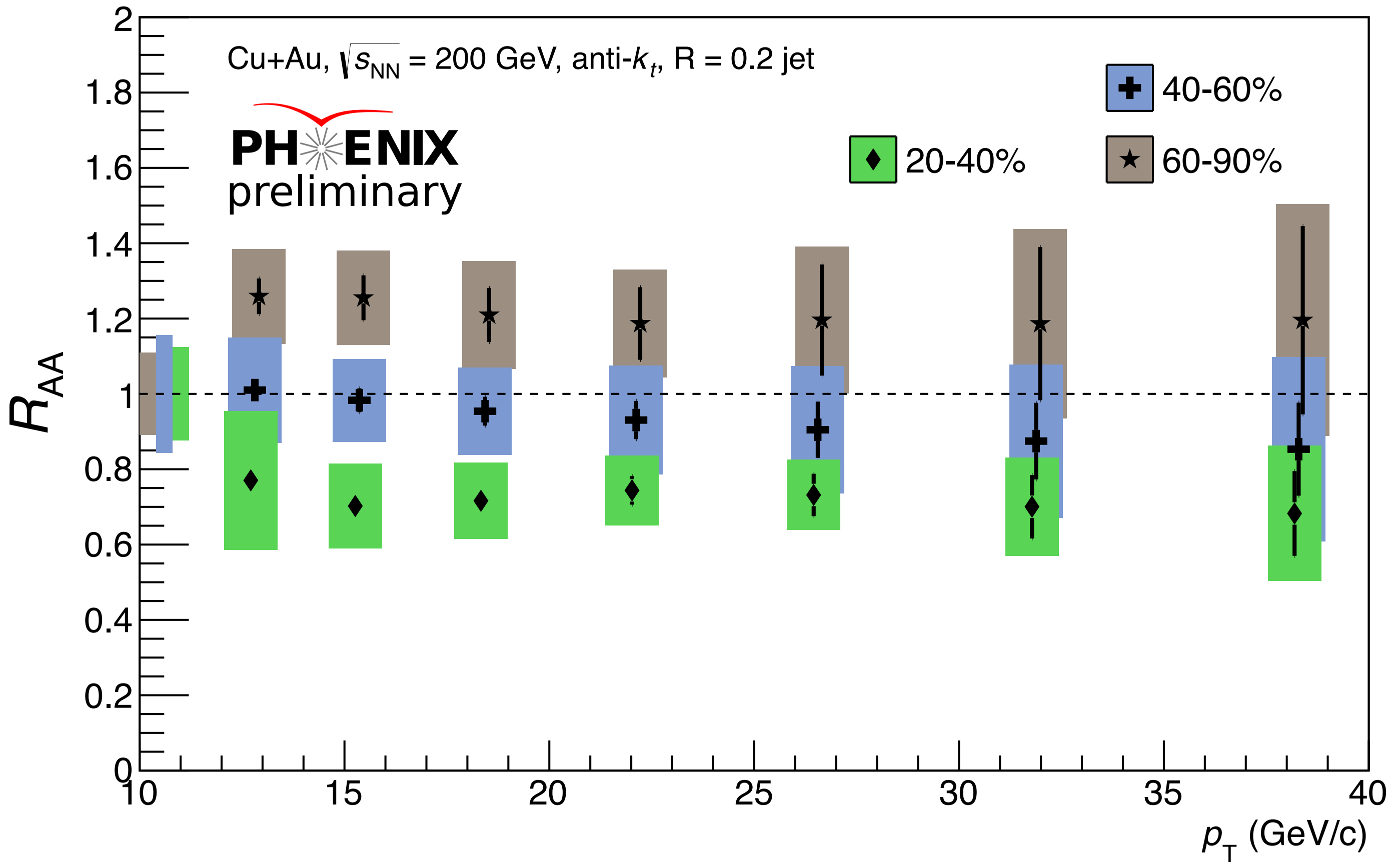
At high p_T, consistent with 1 within the uncertainties

Jet suppression: R_{AA} vs. p_T



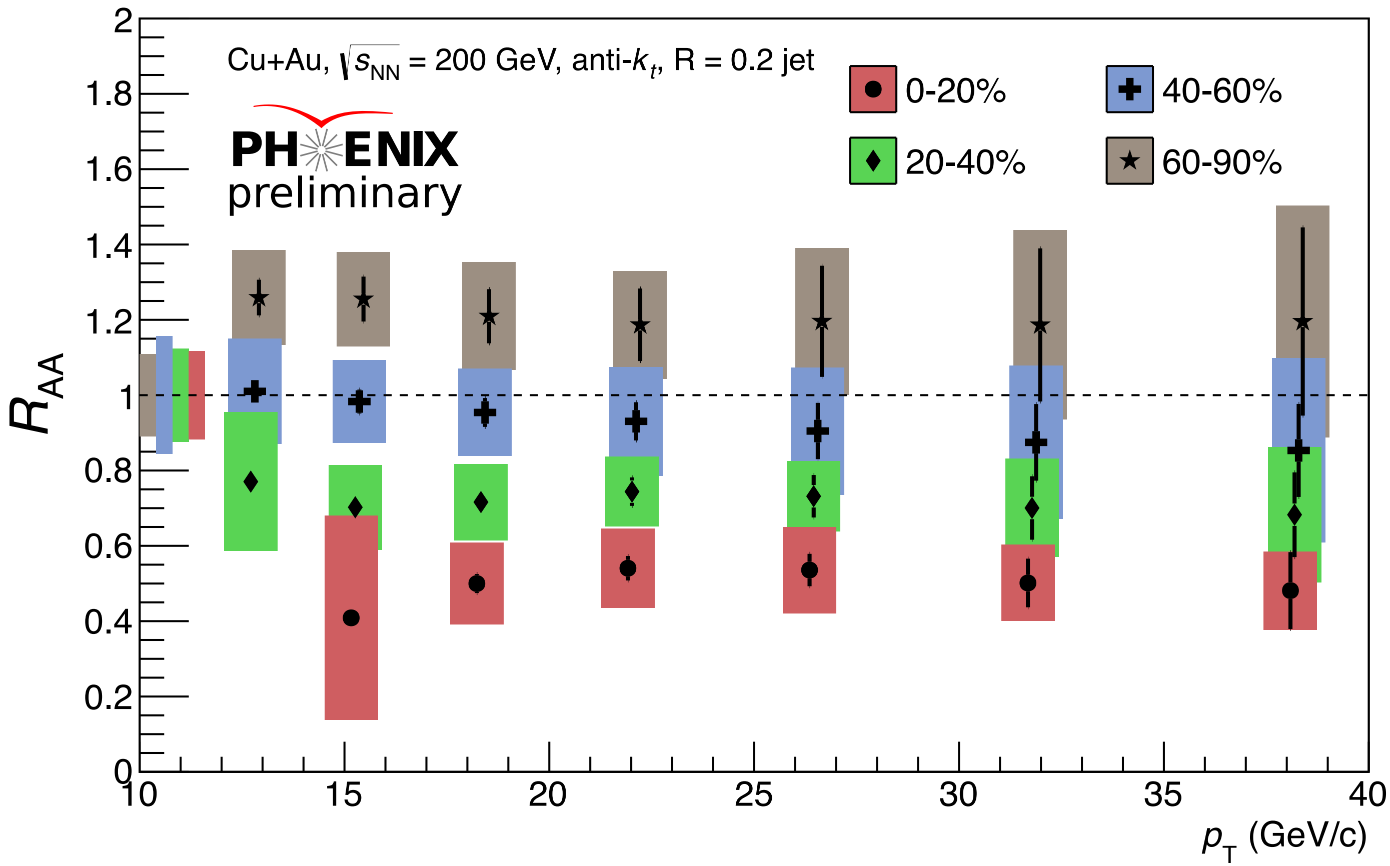
- Suppression shows centrality dependence

Jet suppression: R_{AA} vs. p_T



- Suppression shows centrality dependence
- No p_T dependence

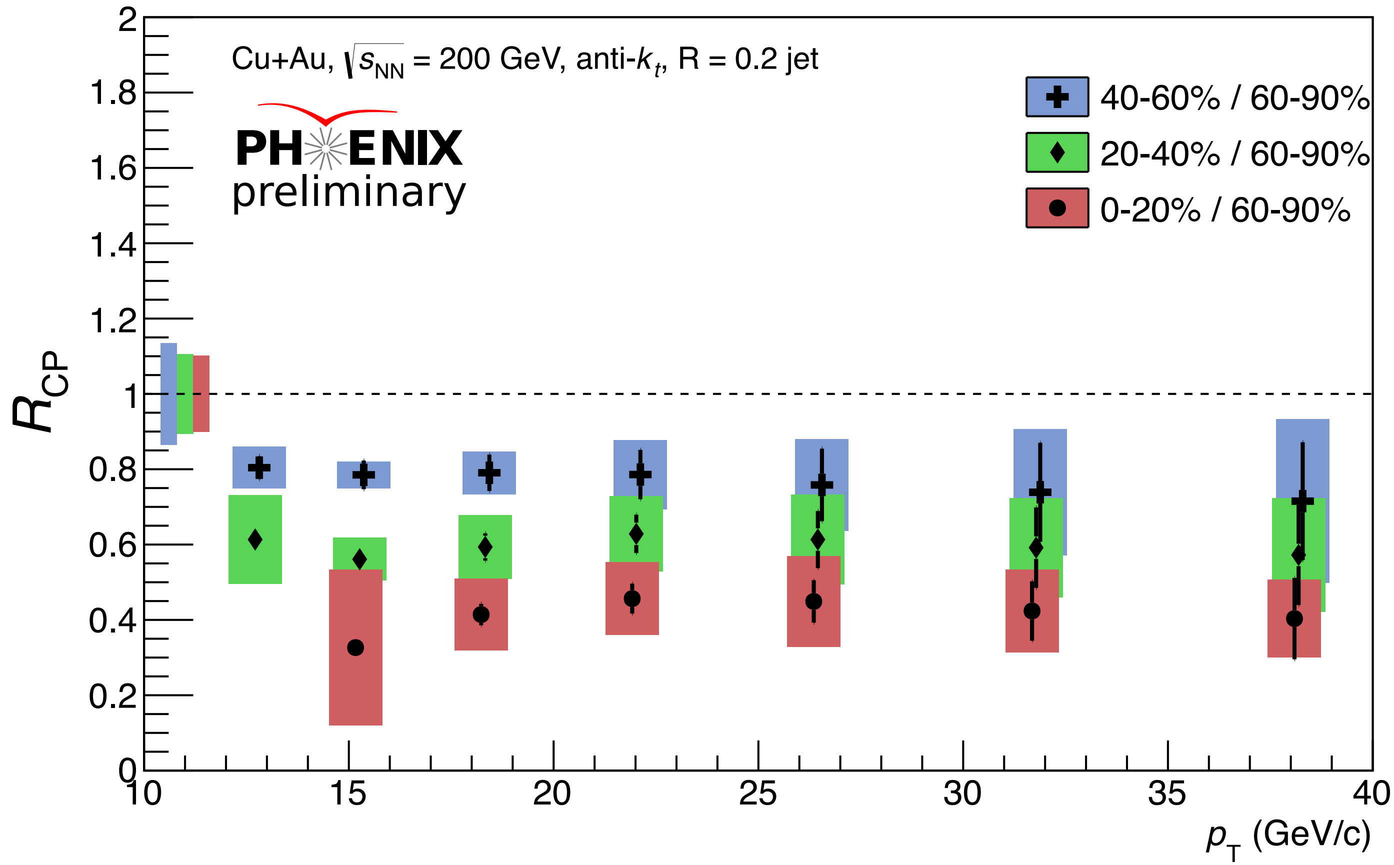
Jet suppression: R_{AA} vs. p_T



- For central collisions, jets are suppressed by approximately a factor of two

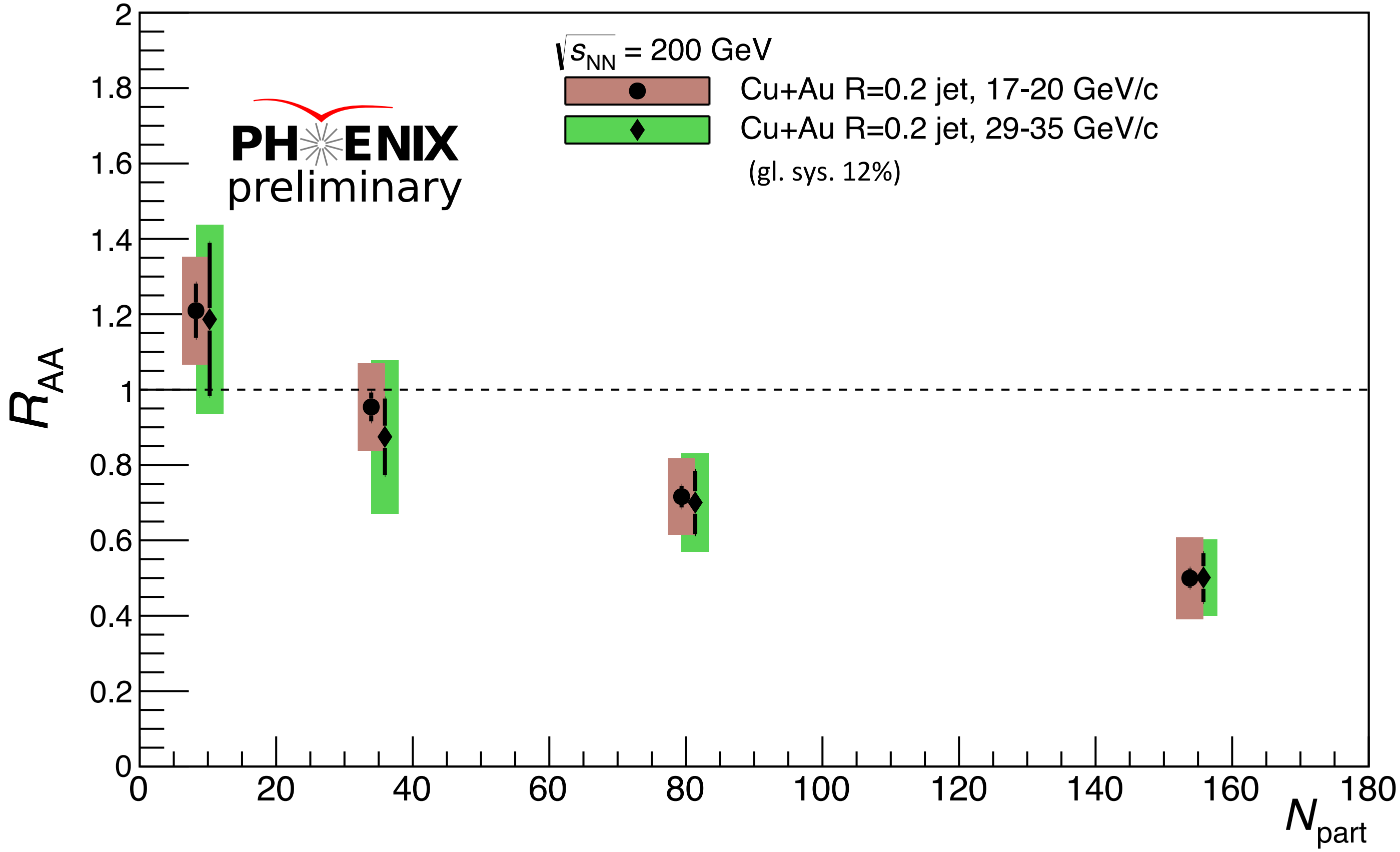
Jet suppression: R_{CP} vs. p_T

$$R_{CP}^{cent} = \frac{\left(\frac{1}{N_{coll}^{cent}}\right)\left(\frac{1}{N_{evts}^{cent}}\frac{dN}{dp_T}^{cent}\right)_{CuAu}}{\left(\frac{1}{N_{coll}^{60\%-90\%}}\right)\left(\frac{1}{N_{evts}^{60\%-90\%}}\frac{dN}{dp_T}^{60\%-90\%}\right)_{CuAu}}$$



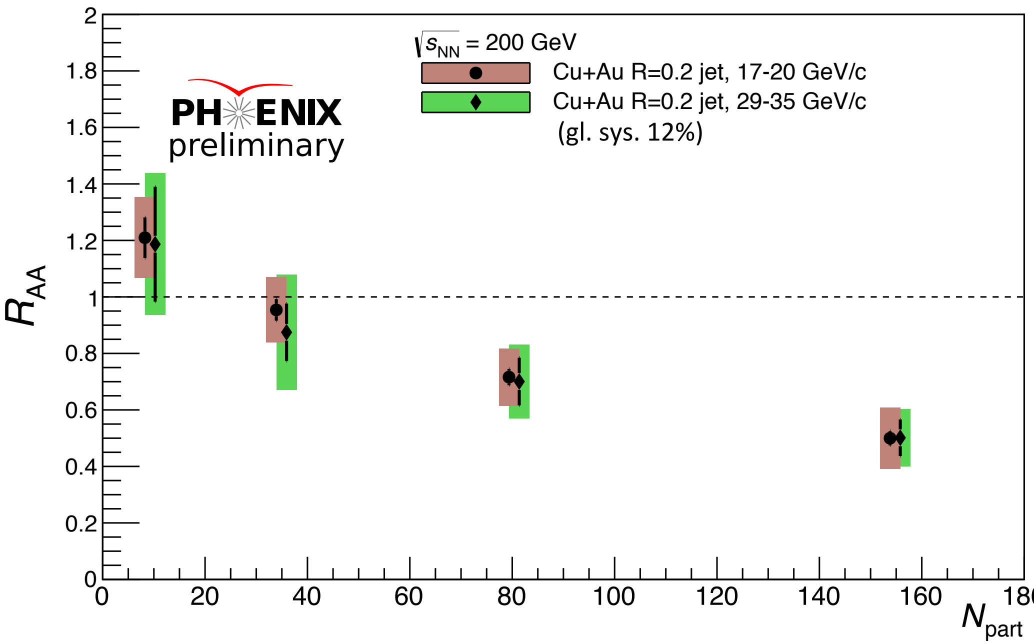
- R_{CP} probes relative central vs. peripheral (60-90%) jet production
- Relatively reduced systematics

Jet suppression: R_{AA} vs. N_{part}

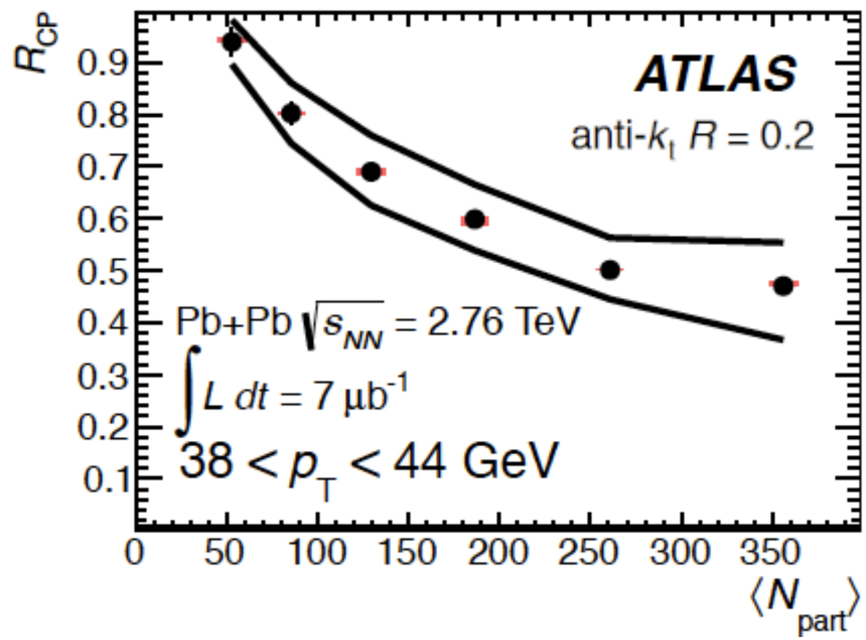


R_{AA} shows strong centrality dependence and no p_T dependence

Jet suppression: comparison

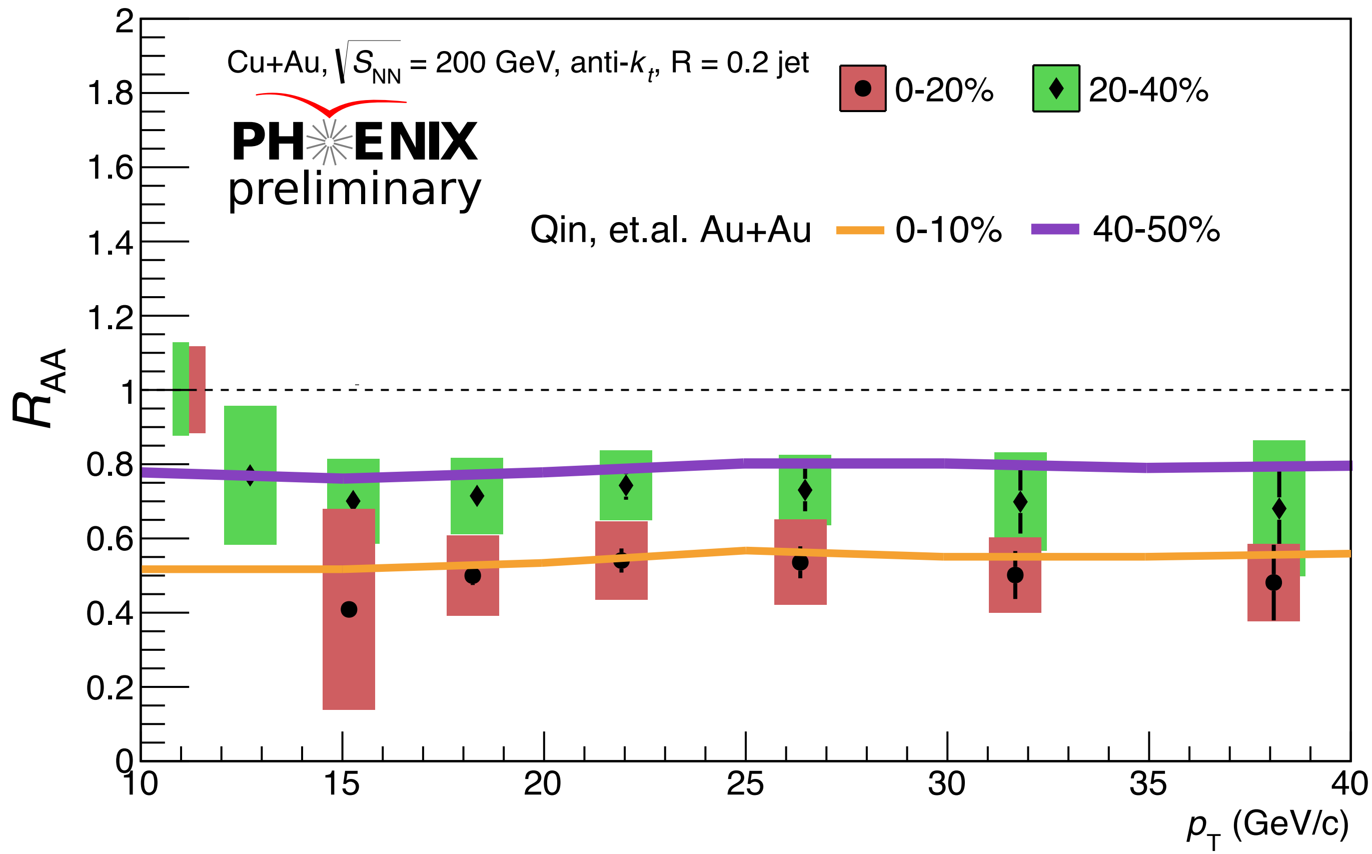


arXiv:1208.1967 [hep-ex]



- ATLAS result is R=0.2 R_{CP} for $38 < p_T < 44$ GeV
- Both results asymptote towards the same value

Jet suppression: theory teaser



Cu+Au 20-40%
<N_{part}> = 80.37
Au+Au 40-50%
<N_{part}> = 74.4

Cu+Au 0-20%
<N_{part}> = 154.8
Au+Au 0-10%
<N_{part}> = 325.2

- Calculation done for R=0.2 but for Au+Au and different centrality classes
- Is suppression stronger than expected within this model?

Conclusion

- The ratios of jet spectra from different centrality selections of Cu+Au collisions show a strong modification of jet production at all p_T
  - Jets are found to be suppressed by approximately a factor of two in central Cu+Au collisions as compared to *p*+*p* collisions
  - Suppression shows no p_T dependence
- Work progressing towards finalizing the results and heading towards publication

Backup

Evaluation of systematic uncertainty

⇒ Variation is made in unfolding procedure. The default data is unfolded with modification in unfolding procedure.

- Shape of input spectrum: The input spectrum is obtained by modifying the power of the truth spectrum by ± 0.5.
- Unfolding is performed with Bayes method (default is SVD method).

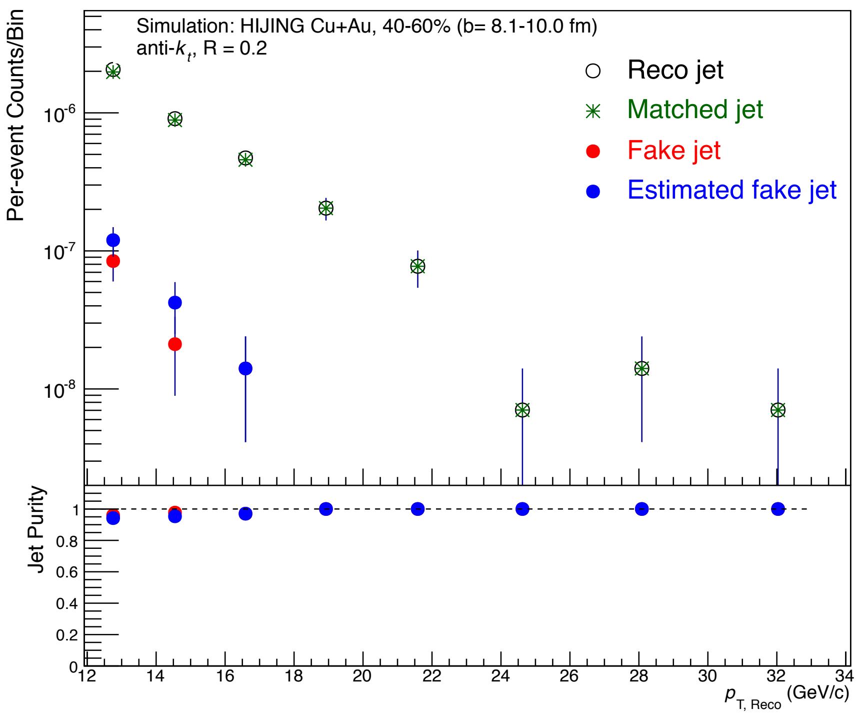
⇒ Variation is made in simulation. The default data is unfolded with modified response matrix.

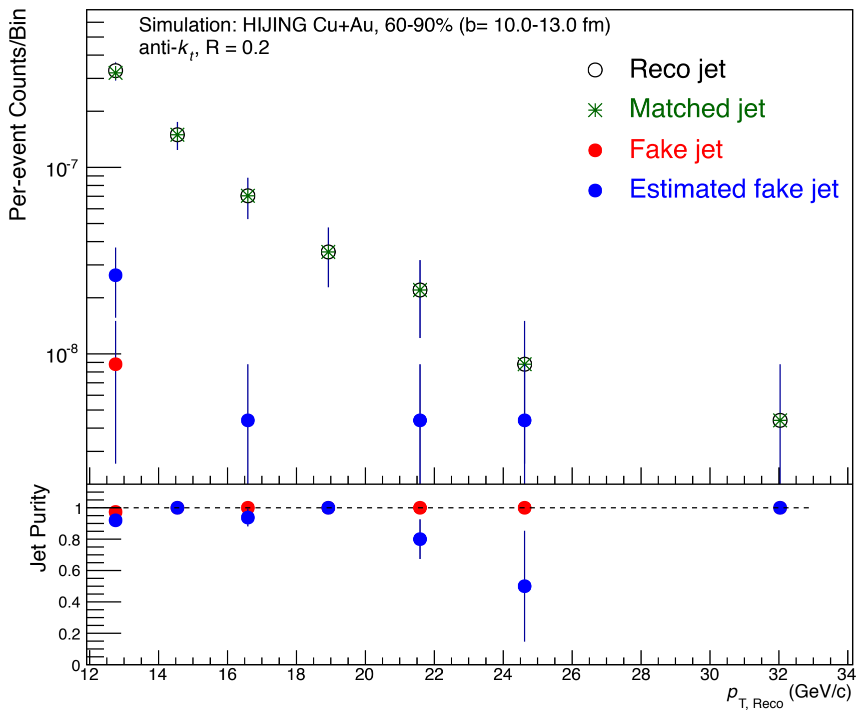
- Energy scale
  - EMCal energy scale: The energy of EMCal clusters is varied by $\pm 3\%$
  - DC p_T scale: The p_T of tracks is varied by p_T dependent way: 2% for $p_T < 10$ GeV/c and increased linearly such that it is 4% at 30 GeV/c.

⇒ Same variation is made in both data and simulation. The modified data is unfolded with modified response matrix.

- Jet-level cuts:
  - Default: $nc >= 3$ && $cf > 0.2$ && $cf < 0.7$. Variation: $nc >= 5$ && $cf > 0.2$ && $cf < 0.6$
- Acceptance
  - Fiducial cut: The reconstructed jets are required to lie within tighter phase space.
  - East/West arm: East arm yield is unfolded with response matrix for east arm and west arm yield is unfolded with response matrix for west arm.
- Fake jet
  - Default: Cluster energy > 0.5 GeV, track $p_T > 0.5$ GeV/c. Variation: Cluster energy > 2.0 GeV, track $p_T > 2.0$ GeV/c.

Fake jet simulation





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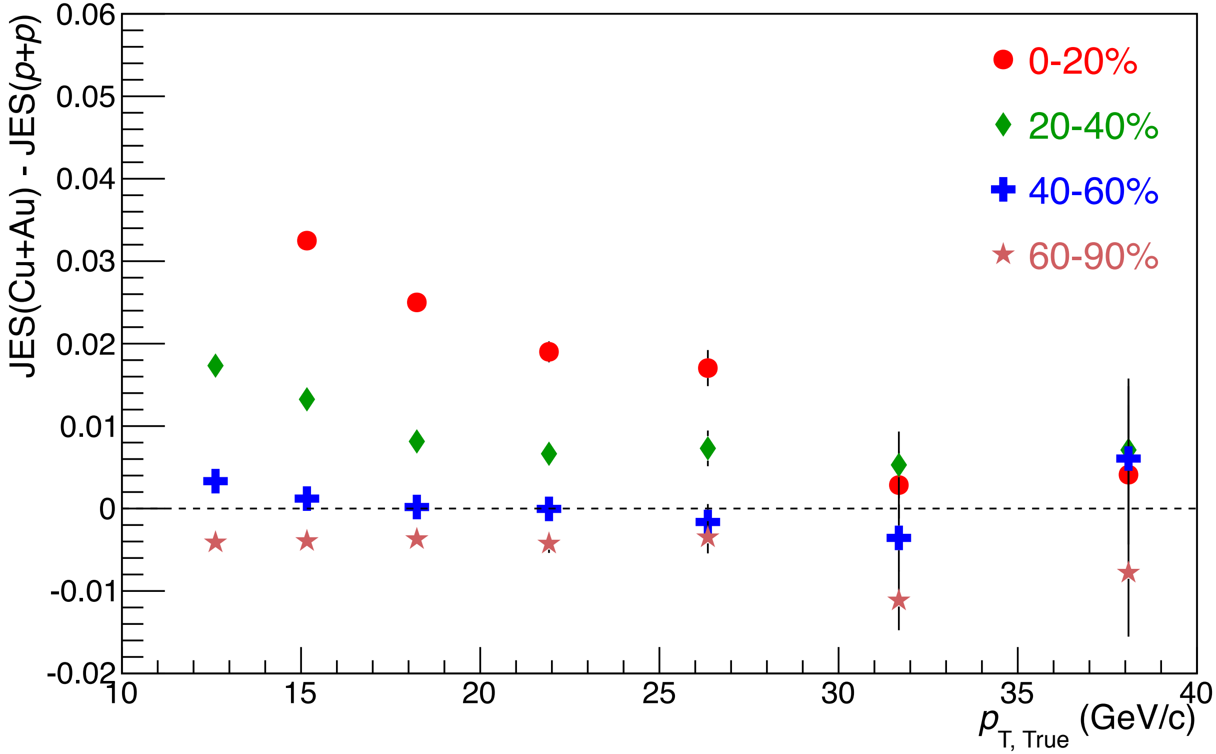

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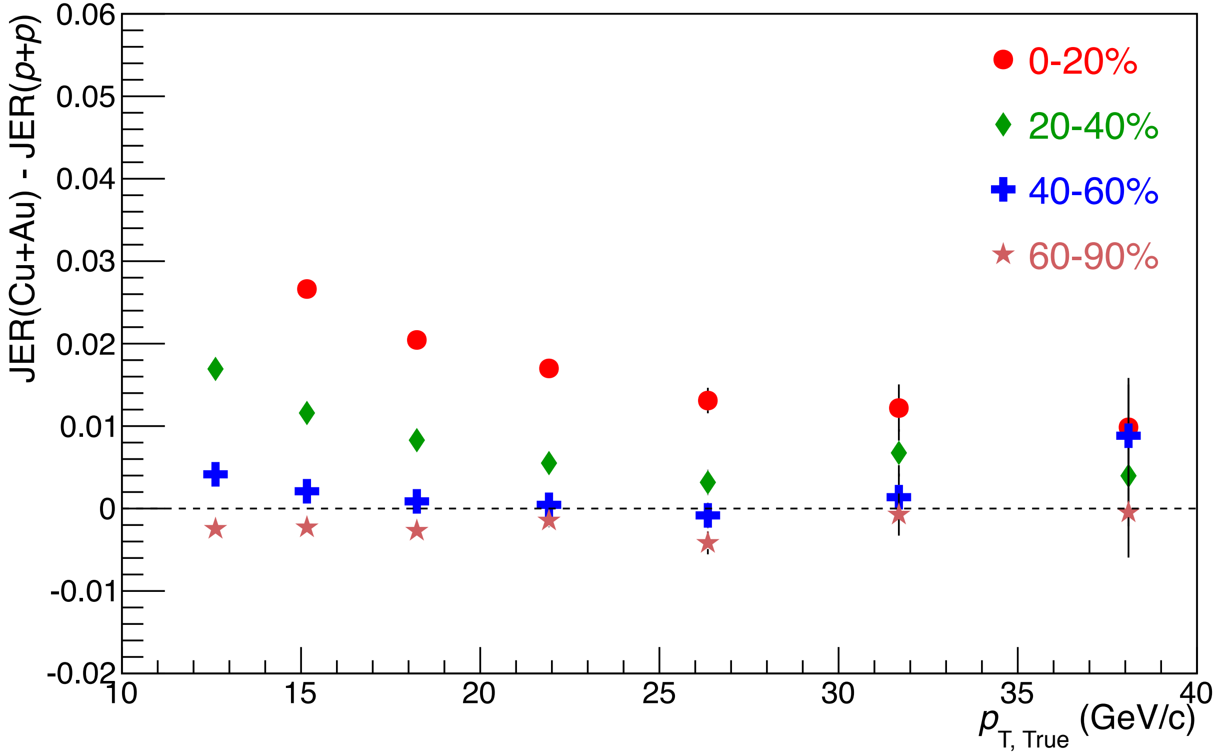

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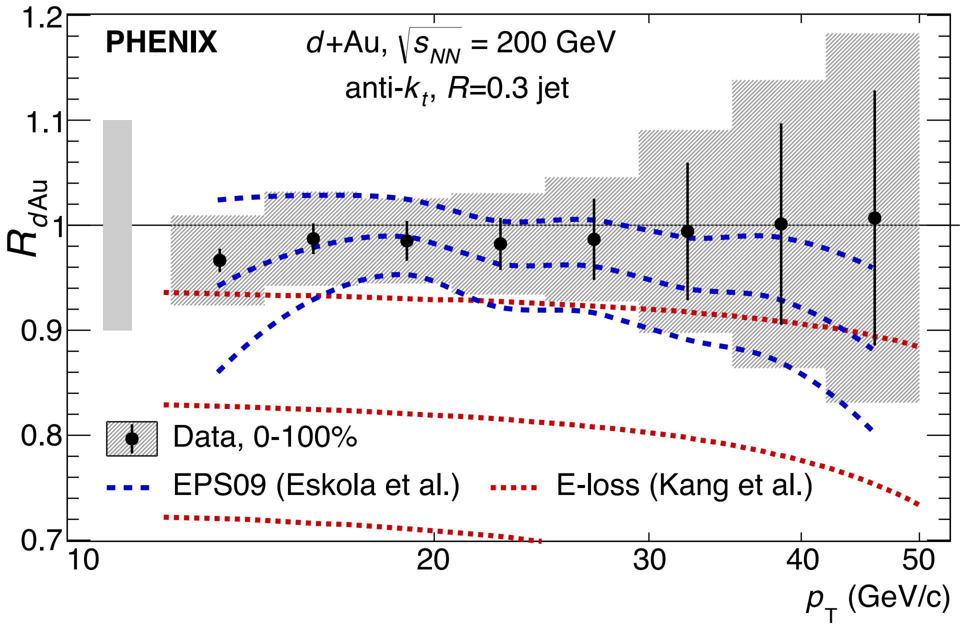
d+Au results



Consistent with nPDF calculations

Central d+Au shows suppression consistent with modest CNM E-loss, but enhancement in peripheral d+Au challenging to understand within these models