Observing jet quenching using generalized jet angularities in Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV from STAR

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Abstract

Jets originating from hard-scattered partons in the early stages of heavy-ion collisions travel through the Quark Gluon Plasma (QGP) and are modified or quenched relative to a p+p collision baseline. Moments of the jet's transverse momentum (p_T) profile in the $\eta - \phi$ plane relative to the jet-axis, called generalized jet angularities are an important class of jet substructure observables to study in medium modifications of the jet's radiation and fragmentation patterns. Previous measurements of these angularities have been performed using quenched jets from Pb+Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV in the LHC, and similar measurements using heavy-ion collisions at RHIC energies will probe jet quenching in a region of phase space that is complementary to the region probed in the LHC. In this study, we present relative central-preipheral nuclear modification factors (R_{CP}) using fully corrected measurements of various generalized jet angularities using jets from Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV collected by the STAR experiment. We present proof of concept studies done with jets from JEWEL simulation, of a novel machine-learning based method that measures the degree to which quenched and unquenched jets are distinguishable. Measurements are differential in centralities of the Au+Au collisions.

Generalized angularities

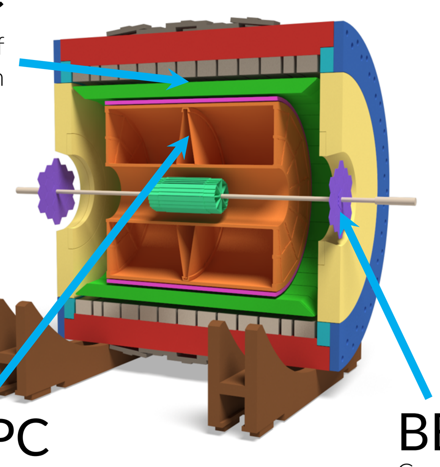
$$\lambda^{\kappa}_{\beta} = \sum_{\text{const}\in\text{jet}} \underbrace{\left(\frac{p_{T,\text{const}}}{p_{T,\text{jet}}}\right)^{\kappa}}_{\text{soft/hard radiation}} \times \underbrace{r(\text{const},\text{jet})^{\beta}}_{\text{collinearity sensitive}}$$

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

- **Jet girth:** $\mathbf{g} = \lambda^1_1$, measure of jet broadening
- **Momentum dispersion:** $\mathbf{p_T^D} = \sqrt{\lambda^0_2}$, soft/hard fragmentation $\implies$ low/high p_T^D
- **Les Houches Angularity:** $\lambda^1_{0.5}$
- **Thrust:** $\lambda^1_2 (\simeq m^2_{\text{jet}}/E^2_{\text{jet}})$

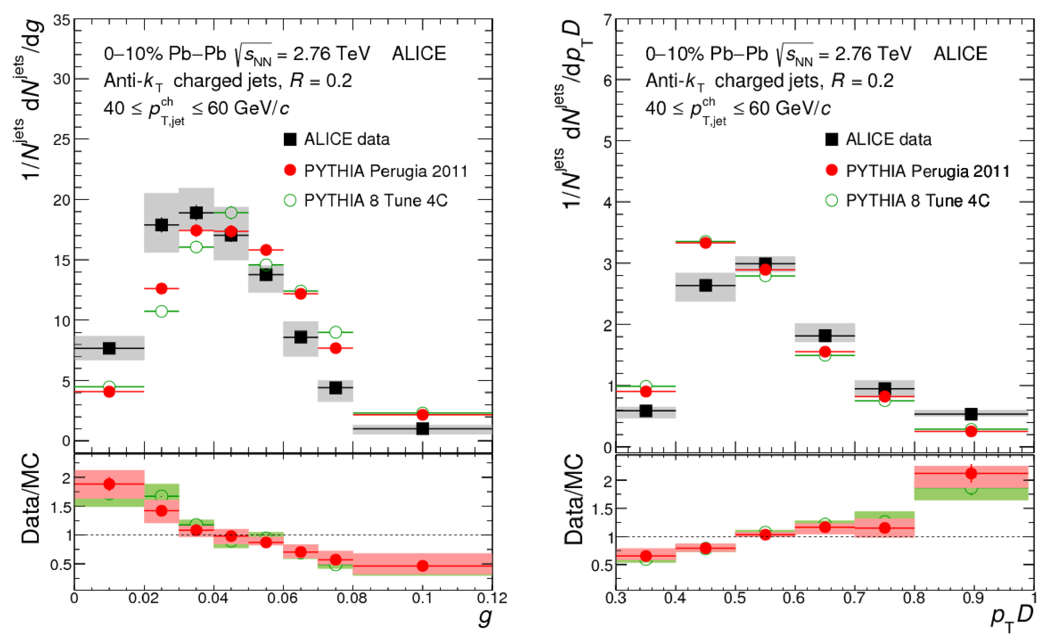
Also added, **LeSub** $= p^{\text{Leading}}_{T,\text{const}} - p^{\text{Subleading}}_{T,\text{const}}$, proxy for hardest splitting in jet

STAR detector



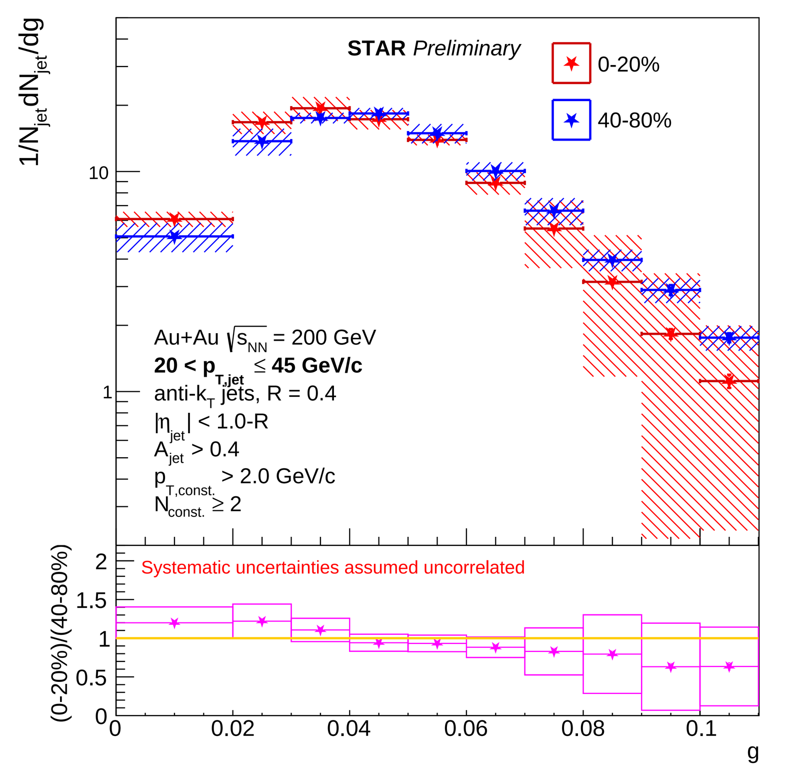
Previous results

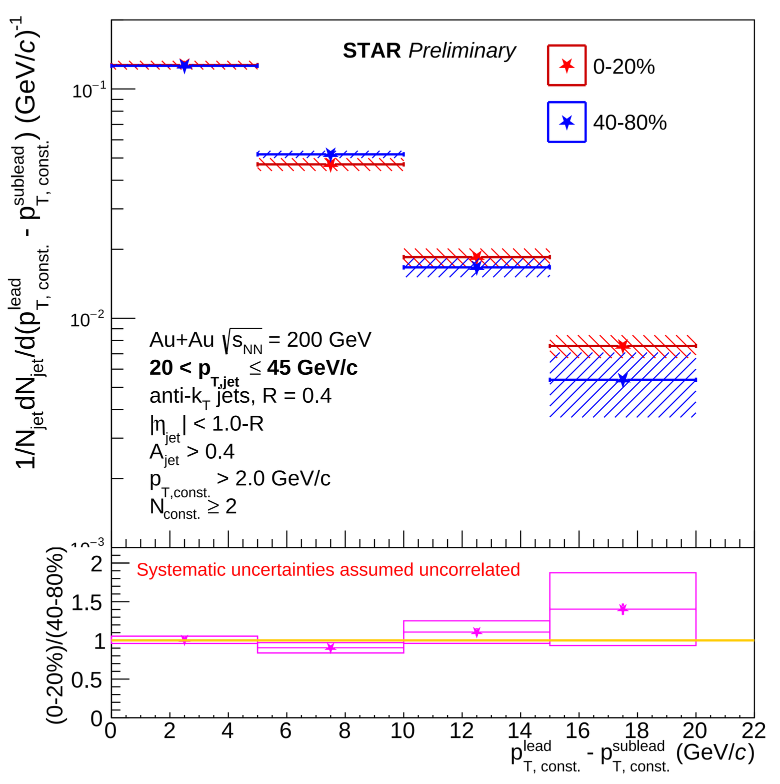
Previous measurements of Girth, p_T^D in Pb+Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV at the LHC [1] qualitative agreement with a more quark-like jet fragmentation (higher p_T^D, lower Girth compared to PYTHIA-6/8)

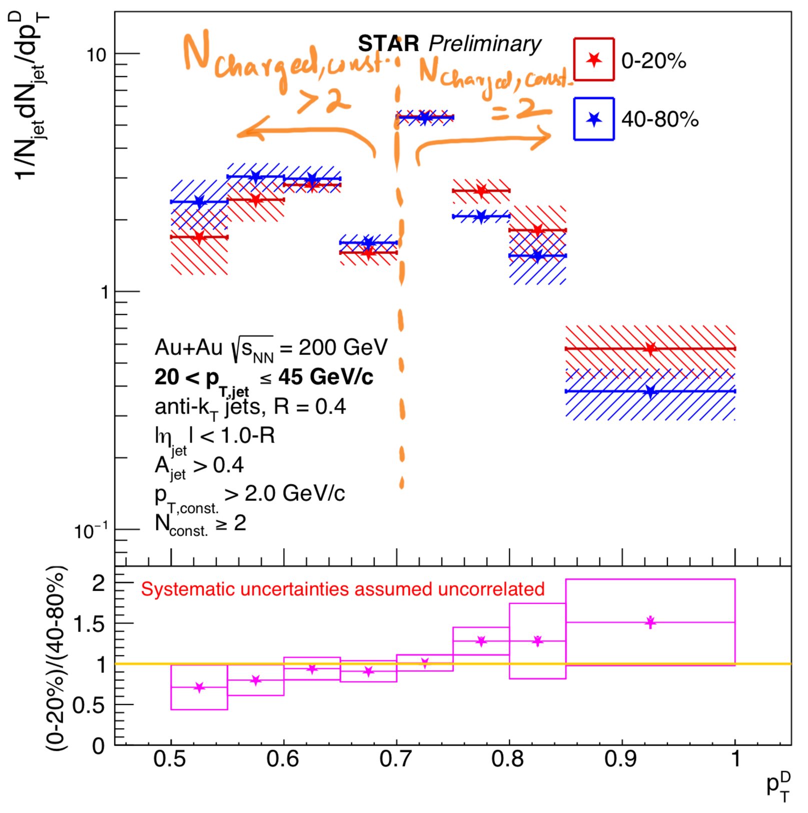


Fragmentation pattern modified?
Selection on quark-like jet properties in medium?
Need further measurements with different medium/jet properties at RHIC energies

R_{CP}







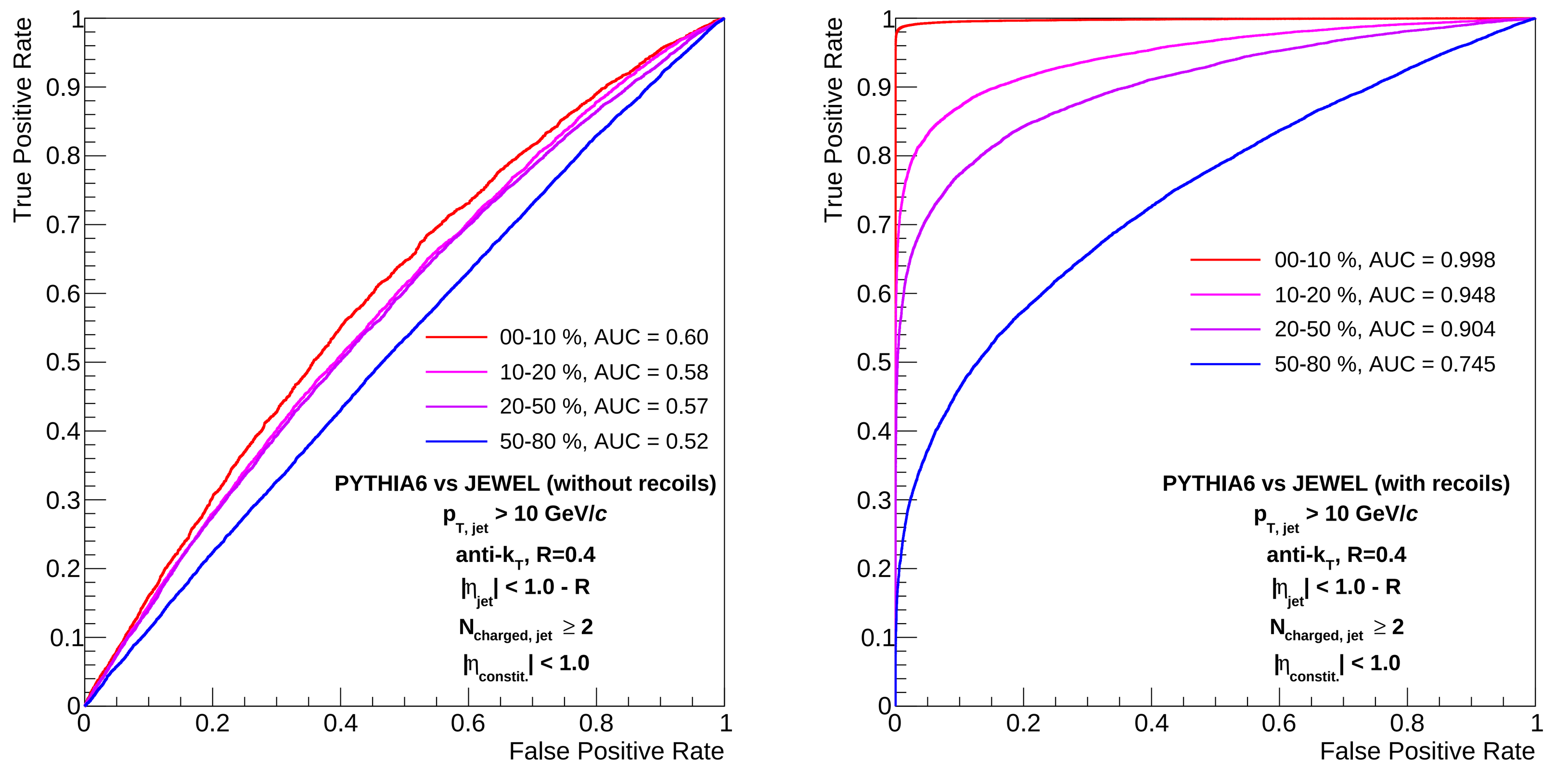
- **System:** Au+Au (2014) @ $\sqrt{s_{NN}} = 200$GeV
- **Jets:** Anti-k_T, $R = 0.4$ jets, $p_{T,\text{constit.}} > 2$ GeV/c, $|\eta_{\text{constit.}}| < 1.0$, $|\eta_{\text{jet}}| < 0.6$
- **High Tower (HT) triggered** events (at least one tower with $E_{\text{tower}} \geq 4$ GeV) to enhance jet signal
- p_T^D, LeSub, Girth consistent within systematic uncertainties between central, peripheral collisions
- p_T^D shows discontinuity at 0.7 due to strong dependence on number of constituents in jet

Further analysis ongoing to improve systematic uncertainties

Classifying medium vs vacuum jets

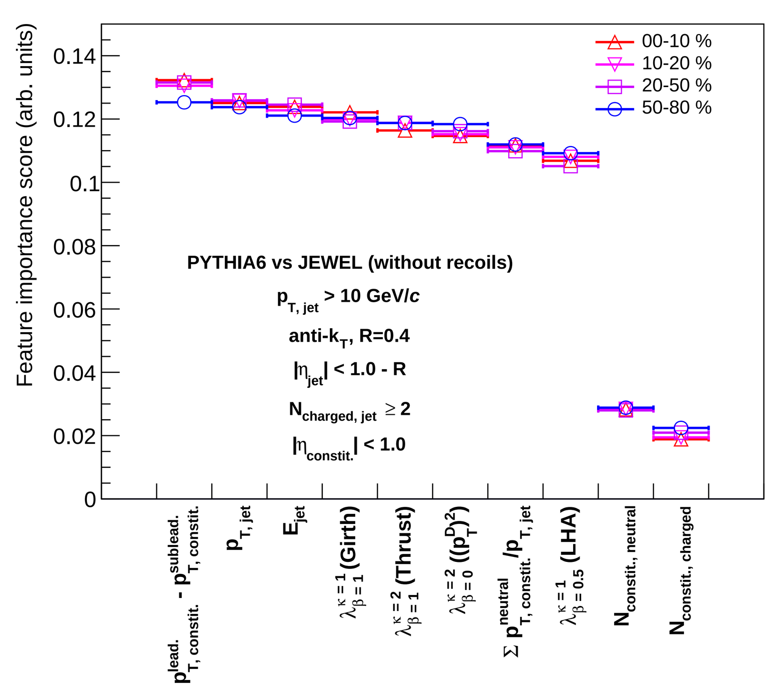
proof of concept study:

Can we tell apart unquenched and quenched jets using classification algorithms?



- PYTHIA6 [4] $\rightarrow$ unquenched jets, JEWEL [5] (with/without recoils) $\rightarrow$ quenched jets
- Dense neural networks (DNNs) classify jets as quenched or unquenched, trained on 80% of generated jets, **Area under ROC curve (AUC) score from remaining 20%**, similar to [3]
- Jets $\rightarrow$ 9-D vectors of features: $p_{T,\text{jet}}$, $N^{\text{charged}}_{\text{constit.,jet}}$, $N^{\text{neutral}}_{\text{constit.,jet}}$, LeSub, λ^2_0, $\lambda^{0.5}_1$, λ^1_1, λ^2_1
- Exagerrated ROC curves from JEWEL with recoils due to "background" of recoil centers
- Quenched jets from JEWEL (w.o. recoils) distinguishable from unquenched jets ($\text{AUC} > 0.5$)
- AUC score decreases from central (0-10%) to peripheral (50-80%) JEWEL (w.o. recoils) events $\implies$ more modification in central compared to peripheral

Which features contribute most to classification?



- Random forest (RF) of boosted decision trees [2] $\rightarrow$ access feature importance scores
- Quenched jets from JEWEL without recoils
- Feature importances similar across all centrality ranges
- Further analysis to understand relation of importance scores to quenching

DNN vs RF

Slightly better AUC scores of DNN over RF

Centrality	RF	DNN
0-10%	0.59	0.6
10-20%	0.54	0.58
20-50%	0.53	0.57
50-80%	0.51	0.52

Outlook

- Further analysis of R_{CP} to reduce systematic uncertainties
- R_{AA} measurements of generalized angularities using jets from STAR p+p collisions at $\sqrt{s_{NN}} = 200$ GeV
- Improve classification algorithms to distinguish between quenched and unquenched jets
- Apply classifiers to distinguish between jets from STAR p+p and Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV

References

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