Multi-dimensional measurements of the parton shower in pp collisions at $\sqrt{s} = 200$ GeV*

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Jets are collimated sprays of hadrons and can serve as an experimental tool for studying the dynamics of quarks and gluons. The SoftDrop grooming technique utilizes the angular ordered Cambridge/Aachen reclustering tree and provides a correspondence between the experimental observables such as the shared momentum fraction (z_{g}), groomed jet radius, or split opening angle (R_{g}), and the QCD splitting functions in vacuum. We present fully corrected correlations between z_{g} and R_{g} at the first split of jets at varying momenta and radii in pp collisions at $\sqrt{s} = 200$ GeV. To study the evolution along the jet shower, we also present the splitting observables at the first, second and third splits along the jet shower for various jet momenta.

1. Introduction

Jets are created by the fragmentation of high energy partons, liberated during hard scatterings. They are reconstructed using clustering algorithms and can serve as an experimental tool for studying Quantum Chromodynamics (QCD). We can access the parton shower via jet substructure observables to probe perturbative and non-perturbative QCD processes. We use the grooming technique called SoftDrop [1] to explore jet substructure in this measurement. Jets are first reconstructed with the anti-k_{T} algorithm [2] and then reclustered with the Cambridge/Aachen (C/A) algorithm [3] in order to get the angular ordered tree. We obtain two subjets, labeled 1

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and 2, from the original jet by undoing the last step of C/A reclustering iteratively until the splitting satisfies the condition:

$$z_{\mathrm{g}} = \frac{\min(p_{\mathrm{T},1}, p_{\mathrm{T},2})}{p_{\mathrm{T},1} + p_{\mathrm{T},2}} > z_{\mathrm{cut}} \left(\frac{R_{\mathrm{g}}}{R}\right)^{\beta}, \quad (1)$$

where $p_{\mathrm{T,i}}$ is the transverse momentum of the corresponding subjet, R is the resolution parameter of the jet, and R_{g} is the distance between the two subjets. There are two free parameters in Eq. 1, which we set in our analysis to $\beta = 0$ and $z_{\mathrm{cut}} = 0.1$.

Products of the SoftDrop procedure are two substructure observables, shared momentum fraction (z_{g}) and groomed radius (R_{g}). We perform two sets of 3-D differential measurements of the jet substructure evolution: look at the first split and explore the correlation between z_{g} and R_{g}, or study the evolution of z_{g} and R_{g} along the jet shower.

2. Correlation between observables at the first split

Data were collected by the STAR experiment [4] in 2012 for p+p collisions at $\sqrt{s} = 200$ GeV. A detailed description of the collected data and analysis cuts can be found in Ref. [5].

Since the measurements are affected by the detector effects such as detector efficiency and p_{T}-resoluton, we need to unfold data to obtain the true particle-level spectra. In our case, multi-dimensional unfolding is needed, because our observables lie in 3-dimensional ($p_{\mathrm{T,jet}}$, z_{g}, R_{g}) space. We unfold z_{g} vs. R_{g} using 2D Iterative Bayesian unfolding separately for different $p_{\mathrm{T,jet}}$ bins and then correct for the jet energy scale and resolution on an ensemble basis. Additional corrections for trigger and jet finding efficiencies are applied to yield a fully corrected measurement.

Fully unfolded z_{g} distributions for different $p_{\mathrm{T,jet}}$ and R_{g} bins are shown in Fig. 1. Different colors represent different R_{g} intervals and bands around the data points are the systematic uncertainties, where the largest contribution comes from the unfolding.

We observe that the z_{g} distribution becomes steeper for larger R_{g} which indicates that we move from harder symmetric splitting to the softer wide angle splitting. The distributions change only mildly with $p_{\mathrm{T,jet}}$ and R_{g} is the driving factor.

3. Evolution of the splitting kinematics along the jet shower

To study the evolution of the parton shower, we focus on the substructure observables at the first, second, and third splits. Data used for the

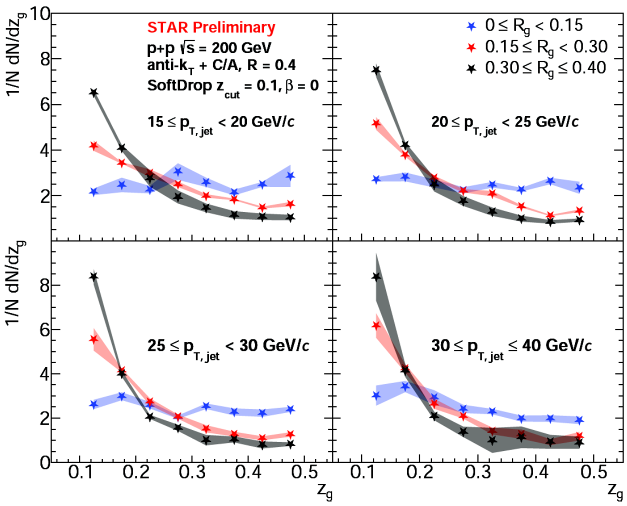

Fig. 1. Fully unfolded $z_{\rm g}$ distributions for three $R_{\rm g}$ bins for jets with $R = 0.4$ in p+p collisions at $\sqrt{s} = 200$ GeV. Individual panels correspond to different $p_{\rm T,jet}$ intervals (see legend).

analysis are the same as in Sec. 2. To study the further splits, we need to use a variant of the SoftDrop technique called iterative SoftDrop [6].

Similarly as in the previous section, we also need to apply multi-dimensional unfolding. We unfold $z_{\rm g}$ or $R_{\rm g}$ vs. $p_{\rm T,jet}$ at a given split via 2D Iterative Bayesian unfolding and then apply the correction on the splitting hierarchy, since detector effects can result in a reshuffling of the splitting hierarchy where the first split at the particle level can be the second split at the detector level and vice-versa. Particle-level and detector-level splits are matched via a $\Delta R < 0.1$ cut between the prongs in the split. Unfolded distributions are then summed according to the split matching hierarchy, and the final results are shown in Fig. 2.

We observe very similar trend as in the $z_{\rm g}$ distributions at the first split. With higher split, splittings become harder and distributions become flatter. We also see that splitting is narrower in $R_{\rm g}$ when we go from the first to the third split. Similarly as in the previous section we observe only a weak dependence on $p_{\rm T,jet}$.

4. Conclusions

In these proceedings, we present the first fully unfolded $z_{\rm g}$ vs. $R_{\rm g}$ distribution as a function of $p_{\rm T,jet}$ at the first split, and fully unfolded $z_{\rm g}$ and $R_{\rm g}$ distributions as a function of $p_{\rm T,jet}$ for the first, second, and third split. We

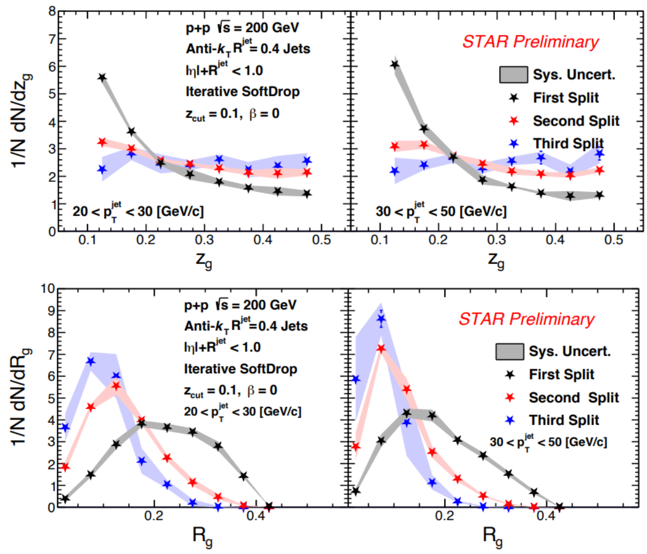

Fig. 2. Fully unfolded z_{g} (top) and R_{g} (bottom) distributions for different splits in p+p collisions at $\sqrt{s} = 200$ GeV. The top (bottom) panels are differential in jet p_{T} for two bins $20 < p_{\mathrm{T}}^{\mathrm{jet}} < 30$ GeV/c (left) and $30 < p_{\mathrm{T}}^{\mathrm{jet}} < 50$ GeV/c (right).

can observe that selecting on R_{g} at the first split results in similar changes in z_{g} distributions as selecting on the split number along the jet clustering tree. This allows us to disentangle perturbative (parton showers) wide angle emissions from mostly non-perturbative (hadronization) dynamics within the jet shower. In the upcoming publication, we would like to compare our data with different implementations of perturbative and non-perturbative models to study their impacts on the jet shower.

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REFERENCES

[1] A. J. Larkoski *et al.*, JHEP **2014**, 146 (2014).
[2] M. Cacciari *et al.*, JHEP **2008**, 063 (2008).
[3] R. Atkin, Jour. of Phys: Conf Series **645**, 012008, (2015).
[4] STAR, K. H. Ackermann *et al.*, Nuc. Inst. and Meth. in Phys. Res. Sec. A: **499**, 624 (2003).
[5] STAR, J. Adam *et al.*, Phys. Lett. B **811**, 135846 (2020).
[6] F. A. Dreyer *et al.*, JHEP **06**, 093 (2018).