PROCEEDINGS OF SCIENCE

Multi-dimensional measurements of parton shower in $p+p$ collisions at RHIC

Monika Robotková (for the STAR Collaboration)[a,b,*]

[a] *Nuclear Physics Institute of the CAS,*
Husinec - Řež, 130, Řež 250 68, Czech Republic

[b] *Department of Physics, Faculty of Nuclear Sciences and Physical Engineering, Czech Technical University in Prague,*
Břehová 7, Praha, 115 19, Czech Republic

E-mail: `robotkova@ujf.cas.cz`

Jets, collimated sprays of hadrons, serve as an experimental tool for studying parton shower evolution. Differential measurements of jet substructure observables enable the exploration of perturbative and non-perturbative QCD processes. The SoftDrop grooming technique is based on removing soft wide-angle radiation and products of this procedure are substructure observables, such as the shared momentum fraction (z_{g}) and groomed jet radius (R_{g}). We present fully corrected correlations between the z_{g} and R_{g} at the first split for jets of varying momenta in $p+p$ collisions at the center of mass energy $\sqrt{s} = 200$ GeV. To study the evolution along the jet shower, we also present the z_{g} and R_{g} observables at the first, second, and third splits for various jet momenta. As these novel measurements are presented in three dimensions, we outline the correction procedure so that it can be used as a template for future multi-differential measurements across all experiments.

41st International Conference on High Energy physics - ICHEP2022
6-13 July, 2022
Bologna, Italy

---

[*] Speaker

1. Introduction

Hard scattered partons in high enegy collisions evolve via parton showering and hadronization. Collimated sprays of hadrons created during this evolution are called jets and can be defined using jet clustering algorithms. Algorithms used in our analysis are anti-k_T [1] and Cambridge/Aachen (C/A) [2]. Jet substructure describes the dynamics of quarks and gluons inside the jet. Study of jet substructure help us understand the perturbative (parton shower) and non-perturbative (hadronization) processes and can be accessed using grooming techniques such as SoftDrop [3]. This technique removes wide-angle radiation based on the following SoftDrop condition:

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

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 $z_\mathrm{cut} = 0.1$, where z_cut is momentum fraction cut that reduces sensitivity to non-perturbative effects.

Products of the SoftDrop procedure are two observables called the shared momentum fraction (z_g) and groomed radius (R_g). We present two ways to study parton shower using these two observables: correlation between z_g and R_g at the first split, and the evolution of the substructure observables at the first, second, and third splits.

2. Correletion between z_g and R_g at the first split

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

We need to correct the data for the finite instrumental resolution in order to obtain the true particle-level distributions. Our observables lie in 3-dimensional ($p_\mathrm{T,jet}$, z_g, R_g) space, requiring usage of multi-dimensional unfolding techniques. First, we unfold z_g vs. R_g spectra using the 2D Iterative Bayesian unfolding [6] for each detector-level bin in jet transverse momentum, $p_\mathrm{T,jet}$. Then we use the $p_\mathrm{T,jet}$ response matrix where on the x-axis is the particle-level $p_\mathrm{T,jet}$ and on the y-axis is the detector-level $p_\mathrm{T,jet}$ to perform the projection of each particle-level $p_\mathrm{T,jet}$ bin onto detector-level $p_\mathrm{T,jet}$ bins. We obtain weights from these projections and use them for weighting the 2D unfolded z_g vs. R_g spectra which are then summed. Additional corrections for trigger and jet finding efficiencies are applied as well.

Figure 1 shows fully unfolded z_g distributions for different $p_\mathrm{T,jet}$ bins and $R = 0.4$. Each color corresponds to different R_g bin and bands around the data points represent systematic uncertainties. We observe a strong dependence of z_g on R_g and only a mild dependence on $p_\mathrm{T,jet}$. The z_g distributions become steeper with larger R_g which means that softer wide-angle splitting is enhanced.

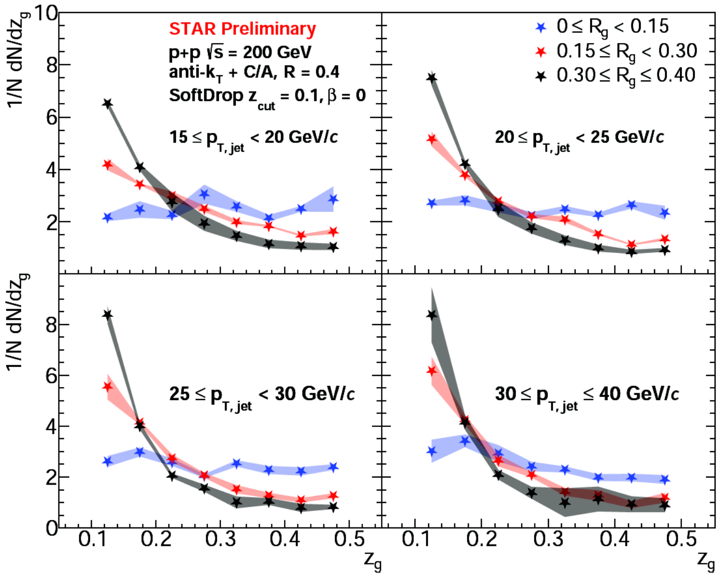

Figure 1: Fully unfolded z_{g} distributions for three R_{g} bins for jets with $R = 0.4$ in p+p collisions at $\sqrt{s} = 200$ GeV. Individual panels correspond to different $p_{\mathrm{T,jet}}$ intervals (see legend).

3. Evolution of the splitting kinematics along the jet shower

In the second part of our analysis, the evolution of the substructure observables at the first, second, and third splits is studied. The data sample is the same as described in Sec. 2. To study more splits than only the first one we need to use a special variant of the SoftDrop technique called iterative SoftDrop [7].

As in previous case, we need to unfold the data in the 3-dimensional space. In this case, the dimensions are z_{g} vs. $p_{\mathrm{T,jet}}$ vs. split number and R_{g} vs. $p_{\mathrm{T,jet}}$ vs. split number. We use the 2D Iterative Bayesian unfolding to unfold z_{g} or R_{g} vs. $p_{\mathrm{T,jet}}$ and then we reconstruct a hierarchy matrix with particle-level splits on the x-axis and detector-level splits on the y-axis. Unfolded distributions are then weighted according to the splitting matching hierarchy and summed.

Fully unfolded z_{g} and R_{g} distributions for $R = 0.4$ jets in two different $p_{\mathrm{T,jet}}$ bins are shown in Fig. 2. Each color corresponds to a different split and bands around the data points represent systematic uncertainties. We observe that the splitting becomes harder and more collinear with increasing split number. As in the previous section, we observe only a mild dependence on $p_{\mathrm{T,jet}}$.

4. Conclusions

We presented fully unfolded z_{g} vs. R_{g} as a function of $p_{\mathrm{T,jet}}$ at the first split, and z_{g} and R_{g} distributions as a function of $p_{\mathrm{T,jet}}$ for the first, second, and third splits. We observe that the z_{g} distribution at the first split with small R_{g} has a similar trend as the z_{g} distribution at the third split. We plan to extend our studies to correlations of other

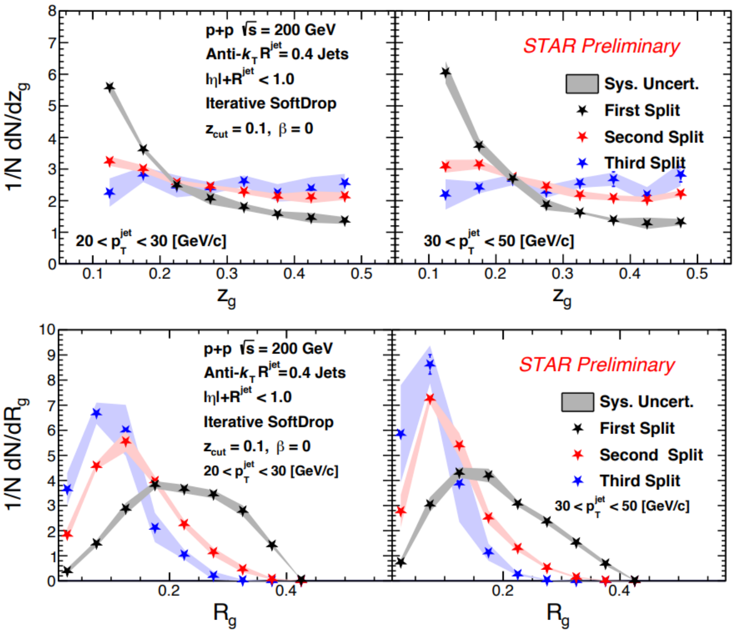

Figure 2: Fully unfolded z_g (top) and R_g (bottom) distributions for different splits of jets with $R = 0.4$ in p+p collisions at $\sqrt{s} = 200$ GeV. The top and bottom panels are differential in jet p_T for two bins $20 < p_T^{jet} < 30$ GeV/c (left) and $30 < p_T^{jet} < 50$ GeV/c (right).

substructure observables at the first split and z_g and R_g observables for various initiator prong transverse momentum at the first, second, and third splits.

Acknowledgments

The work has been supported by the grant LTT18002 of Ministry of Education, Youth and Sports of the Czech Republic.

References

[1] M. Cacciari et al. The anti-kt jet clustering algorithm. *JHEP*, 2008(04):063, apr 2008.

[2] R. Atkin. Review of jet reconstruction algorithms. *Jour. of Phys: Conf Series*, 645(1):012008, sep 2015.

[3] A. J. Larkoski et al. Soft Drop. *JHEP*, 2014(5), 2014.

[4] STAR, K. H. Ackermann et al. STAR detector overview. *Nucl. Instrum. Meth. A*, 499:624–632, 2003.

[5] STAR, J. Adam et al. Measurement of Groomed Jet Substructure Observables in p+p Collisions at $\sqrt{s_{NN}}$= 200 GeV with STAR. *Phys. Lett. B*, 811:135846, 2020.

[6] G. D'Agostini. A multidimensional unfolding method based on bayes' theorem. *Nucl. Instrum. Meth. A*, 362(2-3):487–498, 1995.

[7] F. A. Deyer et al. Review of jet reconstruction algorithms. *JHEP*, 2018(93), 2018.