Abstract

This masters project used the recent ATLAS jet substructure measurements to see if any improvements can be made to the commonly used Pythia8 Monash and A14 tunes.

Keywords:
Pythia8, jet substructure, FSR, tune

1. Introduction

The commonly used Pythia8 [1, 2] tunes, Monash [3] and A14 [4] are rather dated, and the latter was observed to have some tension with LEP measurements, primarily due to its lower Final State Radiation (FSR) $\alpha_s$ value. In last couple of years, a plethora of jet substructure [5, 6, 7, 8] measurements have been published by both ATLAS and CMS collaborations, utilising LHC Run 2 data. Here, we investigate the effect of four such ATLAS measurements on parameters sensitive to jet substructure observables.

2. Tuning setup

The following ATLAS measurements were considered in this study (along with their Rivet identifiers):

- Soft-Drop Jet Mass [9] (ATLAS_2017_I1637587)
- Jet substructure measurements in multijet events [10] (ATLAS_2019_I1724098)
- Soft-drop observables [11] (ATLAS_2019_I1772062)
- Lund jet plane with charged particles [12] (ATLAS_2020_I1790256)

The following parameters were considered in this tuning exercise, with the ranges stated in Table 1.

| Parameter                        | Lower value | Upper value |
|----------------------------------|-------------|-------------|
| BeamRemnants:primordialKThard   | 1.25        | 3           |
| ColorReconnection:range          | 1.25        | 3           |
| TimeShower:pTmin                 | 0.5         | 1.5         |
| MultipartonInteractions:pT0Ref   | 1.5         | 3           |
| TimeShower:alphaSvalue           | 0.118       | 0.145       |

Table 1: Sampling range of the parameters considered

Weighted hardQCD events were generated with a $PThatMin$ of 300 GeV. 100 Sampling runs were performed, each with 100000 events. Rivet3 [13] and Professor tuning system [14] were used. The goodness of sampling and the weight files used can be found in Appendix 5.2 and in Appendix 5.3.
3. Results

The first step was to ascertain where we have a scope of improvement. While a detailed observable-by-observable determination was performed (see Appendix 5.1), here we highlight the most salient features:

- For Lund Jet Plane (LJP) distributions, we observed that the hard-wide angle emissions part is better modelled by the Monash tune whereas the region ranging from UE/MPI to Soft-collinear and Collinear limits are in general better modelled by the A14 tune. However, this distributions also offer the biggest scope of improved modelling.

- For the soft drop $\rho$ and $r_\perp$ observables, in general Monash tune performs somewhat better than A14. One deviation from this trend is when the jet construction is Cluster based, in which case the A14 tune performs better over a large range.

- Both the Jet Substructure and Soft drop jet mass distributions are somewhat better modelled by the A14 tune.

Table 2 lists the parameter values of A14 and Monash along with our tuned values. A separate tune for LJP was performed as this analysis had the largest discrepancy. The LJP tune column shows the parameter values corresponding to the best tune for LJP and the Common Tune column shows the values of the best tune for all the analyses considered. Figures 1 and 2 show the tuned distributions for the one dimensional vertical slices of the LJP. Figure 3 shows the tuned distributions for the soft drop observables. Figure 4 shows the tuned distributions for soft drop mass. And lastly, Figure 5 shows the tuned distributions for the jet substructure observables.

| Parameters                              | A14   | Monash | LJP Tune | Common Tune |
|-----------------------------------------|-------|--------|----------|-------------|
| BeamRemnants:primordialKThard          | 1.88  | 1.8    | 2.28     | 2.065       |
| ColorReconnection:range                 | 1.71  | 1.8    | 2.73     | 1.69        |
| TimeShower:pTmin                       | 0.40  | 0.50   | 1.28     | 0.775       |
| MultipartonInteractions:pT0Ref         | 2.09  | 2.28   | 2.76     | 2.91        |
| TimeShower:alphaSvalue                 | 0.127 | 0.1365 | 0.1308   | 0.1309      |

Table 2: Comparison of tuned values with Monash and A14
Figure 1: Comparison of our tunes with A14 and Monash tunes for Lund Jet Plane distributions (vertical slices)
Figure 2: Comparison of our tunes with A14 and Monash tunes for Lund Jet Plane distributions (horizontal slices)
Figure 3: Comparison of our tunes with A14 and Monash tunes for soft drop jet mass distributions.
Figure 4: Comparison of our tunes with A14 and Monash tunes for soft drop jet mass distributions
Figure 5: Comparison of our tunes with A14 and Monash tunes for jet substructure observable distribution for dijet selection.
4. Summary

The results obtained show small improvements of roughly 5-10% in the distributions of the Lund Jet Plane and Soft Drop Mass distributions from the previous A14 and Monash Tunes. As in Table 2, it can be seen that the parameter values of the tunes obtained are pulled up from the A14 and Monash Tunes. In the case of the LJP, we see that the A14 and Monash Tunes deviate most from the data near the peaks of the distributions. This is the region where soft collinear effects transitions to UE/MPI effects in the LJP. Since the tunes we obtained improve this region of the distributions, it can be inferred that higher values of these parameters facilitate more soft radiations in the final state.

In the case of the soft drop observable distributions, there are regions that require generation of more mass to model the data better. These compete with the LJP values and decreases values of parameters: BeamRemnants:primordialKThard from 2.288 to 2.065, ColorReconnection:range from 2.73 to 1.69, TimeShower:pTmin from 1.288 to 0.775. For the other two parameters, MPI:pT0Ref and TimeShower:alphaSvalue, the values increased slightly.

Acknowledgements

DK is funded by National Research Foundation (NRF), South Africa through Competitive Programme for Rated Researchers (CPRR), Grant No: 118515. We thank Andy Buckley and Holger Schulz for technical assistance with Professor program, as well as for physics discussions.

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## 5. Appendix

### 5.1. Tune performance

| Plots | Observable | Int(R/∆R) or ln(1/z) Slice | Better Tune Performance regions | Better Tune (overall) |
|-------|------------|-----------------------------|---------------------------------|----------------------|
| d03-x01-y01 | ln(1/z) | 0.00-0.33 | 4.3-6 | 0.7-4.3 | Monash |
| d04-x01-y01 | ln(1/z) | 0.33-0.67 | 3.4-4.2 | 0.7-3.4, 4.4-6 | Monash |
| d05-x01-y01 | ln(1/z) | 0.67-1.00 | 3-5 | 0.7-3, 5.6 | Monash |
| d06-x01-y01 | ln(1/z) | 1.00-1.33 | 3-4.2 | 0.7-3, 4.2-6 | Monash |
| d07-x01-y01 | ln(1/z) | 1.33-1.67 | 2.4-4.2 | 0.7-2.4, 4.3-6 | Monash |
| d08-x01-y01 | ln(1/z) | 1.67-2.00 | 2-4, 3.2, 5.8 | 0.7-2, 4.5, 5.5 | - |
| d09-x01-y01 | ln(1/z) | 2.00-2.33 | 1.8-4, 4.7, 5.2-6 | 0.7-1.8, 4.4-4.4 | A14 |
| d10-x01-y01 | ln(1/z) | 2.33-2.67 | 1.6-3, 4.4-5.8 | 0.7-1.4, 3.2-4.2 | A14 |
| d11-x01-y01 | ln(1/z) | 2.67-3.00 | 1.4-5 | 0.7-1.2, 5.2-5.8 | A14 |
| d12-x01-y01 | ln(1/z) | 3.00-3.33 | 0.8-1.4, 3.4-4.7, 5.8 | 1.6-3.3, 4.4-5, 5-5.6 | - |
| d13-x01-y01 | ln(1/z) | 3.33-3.67 | 0.7-3.4, 4.6-5 | 3.6-4.4, 5.1-6 | A14 |
| d14-x01-y01 | ln(1/z) | 3.67-4.00 | 0.3-4 | 3.6-4.6 | A14 |
| d15-x01-y01 | ln(1/z) | 4.00-4.33 | 0.7-2.6, 3.6, 4-4.6, 5, 5.57 | 2.7-3.4, 3.9, 4.7, 5.23 | A14 |
| d16-x01-y01 | ln(R/∆R) | 0.69-0.97 | 3-4.5 | 0-3 | Monash |
| d17-x01-y01 | ln(R/∆R) | 0.97-1.25 | 3-4 | 0-3 | Monash |
| d18-x01-y01 | ln(R/∆R) | 1.25-1.52 | 2.7-3.2, 3.5-4 | 0-2.6 | Monash |
| d19-x01-y01 | ln(R/∆R) | 1.52-1.80 | 2.3-4.5 | 0.8-2.3 | - |
| d20-x01-y01 | ln(R/∆R) | 1.80-2.08 | 2, 3, 3.3-4.5 | 0-2 | - |
| d21-x01-y01 | ln(R/∆R) | 2.08-2.36 | 1.6-4.5 | 0.1-2.2, 3.4-4 | - |
| d22-x01-y01 | ln(R/∆R) | 2.36-2.63 | 1.4-3, 3.6-4.5 | 0.1-3, 3.6 | A14 |
| d23-x01-y01 | ln(R/∆R) | 2.63-2.91 | 1.3-3.5 | 0-3.5 | A14 |
| d24-x01-y01 | ln(R/∆R) | 2.91-3.19 | 0.6-4.5 | 0.5 | A14 |
| d25-x01-y01 | ln(R/∆R) | 3.19-3.47 | 0.6-2.4, 3.4-4.5 | 0-0.5, 2.4-3.3 | A14 |
| d26-x01-y01 | ln(R/∆R) | 3.47-3.74 | 0.5-4.5 | 0.2, 1, 2, 2.5, 3.5 | A14 |
| d27-x01-y01 | ln(R/∆R) | 3.74-4.02 | 0.3-4.5 | 0.2 | A14 |
| d28-x01-y01 | ln(R/∆R) | 4.02-4.30 | 0-3.4, 3.7-4.5 | 1.7-3.6 | - |
| d29-x01-y01 | ln(R/∆R) | 4.30-4.57 | 0.2, 0.5-1.2, 2.3-4.5, 0.8-4.2, 3.2, 3.8 | - |
| d30-x01-y01 | ln(R/∆R) | 4.57-4.85 | 0.2, 1-3.3, 3.5 | 0.3-1.5, 3.7-4.5 | - |
| d31-x01-y01 | ln(R/∆R) | 4.85-5.13 | 0-3.4, 4.4-5 | 3.2 | A14 |
| d32-x01-y01 | ln(R/∆R) | 5.13-5.41 | 0.2, 1.7-4 | 0.4-1.7, 2.75 | A14 |
| d33-x01-y01 | ln(R/∆R) | 5.41-5.69 | 0.2, 2-3 | 0.5-2, 3.2-4 | Monash |
| d34-x01-y01 | ln(R/∆R) | 5.68-5.96 | 1.7-2.3 | 0-1.7, 2.5-3 | Monash |

Table 3: ATLAS_2020_J1790256(LJP)
### Table 4: ATLAS 2019 I1772062(Soft Drop Jet Observables)

| Plots          | Observable                  | Better Tune Performance regions | Better Tune |
|----------------|-----------------------------|---------------------------------|-------------|
| d01-x01-y01    | Calorimeter based           | 0                               | A14 Monash  |
| d02-x01-y01    | Track based                 | 0                               | A14 Monash  |
| d03-x01-y01    | Cluster based               | 1                               | A14 Monash  |
| d04-x01-y01    | Track based                 | 1                               | A14 Monash  |
| d05-x01-y01    | Cluster based               | 2                               | A14 Monash  |
| d06-x01-y01    | Track based                 | 3                               | A14 Monash  |
| d07-x01-y01    | Track based                 | 1                               | A14 Monash  |
| d16-x01-y01    | Track based                 | 1                               | Monash      |
| d17-x01-y01    | Cluster based               | 2                               | A14 Monash  |
| d18-x01-y01    | Track based                 | 2                               | Monash      |
| d19-x01-y01    | Central jet/Calorimeter     | 0                               | A14 Monash  |
| d20-x01-y01    | Central jet/Track           | 0                               | A14 Monash  |
| d21-x01-y01    | Central jet/Cluster         | 1                               | A14 Monash  |
| d22-x01-y01    | Central jet/Track           | 1                               | A14 Monash  |
| d23-x01-y01    | Central jet/Cluster         | 2                               | A14 Monash  |
| d24-x01-y01    | Central jet/Track           | 2                               | A14 Monash  |
| d25-x01-y01    | Central jet/Track           | 2                               | A14 Monash  |
| d26-x01-y01    | Central jet/Cluster         | 2                               | A14 Monash  |
| d27-x01-y01    | Central jet/Track           | 2                               | A14 Monash  |
| d28-x01-y01    | Central jet/Track           | 2                               | A14 Monash  |
| d29-x01-y01    | Forward jet/Calorimeter     | 0                               | A14 Monash  |
| d30-x01-y01    | Forward jet/Cluster         | 1                               | A14 Monash  |
| d31-x01-y01    | Forward jet/Track           | 1                               | A14 Monash  |
| d32-x01-y01    | Forward jet/Cluster         | 2                               | A14 Monash  |
| d33-x01-y01    | Forward jet/Track           | 2                               | A14 Monash  |
| d34-x01-y01    | Forward jet/Track           | 2                               | A14 Monash  |
| d35-x01-y01    | Forward jet/Cluster         | 2                               | A14 Monash  |
| d36-x01-y01    | Forward jet/Track           | 2                               | A14 Monash  |
| d37-x01-y01    | Forward jet/Cluster         | 2                               | A14 Monash  |
| d38-x01-y01    | Forward jet/Track           | 2                               | A14 Monash  |
| d41-x01-y01    | Forward jet/Cluster         | 2                               | A14 Monash  |
| d42-x01-y01    | Forward jet/Track           | 2                               | A14 Monash  |
| d43-x01-y01    | Forward jet/Cluster         | 2                               | A14 Monash  |
| d44-x01-y01    | Forward jet/Track           | 2                               | A14 Monash  |
| d45-x01-y01    | Forward jet/Cluster         | 2                               | A14 Monash  |
| d46-x01-y01    | Forward jet/Track           | 2                               | A14 Monash  |

### Table 5: ATLAS 2019 I1724098(JSS, Dijet Selection)

| Plots          | Observable                  | Better Tune Performance regions | Better Tune |
|----------------|-----------------------------|---------------------------------|-------------|
| d01-x01-y01    | Nsubjets                    | 0                               | A14 Monash  |
| d02-x01-y01    | C2                          | 0.086                           | A14 Monash  |
| d03-x01-y01    | D2                          | 0.05                            | A14 Monash  |
| d04-x01-y01    | LHA                         | 0.45                            | A14 Monash  |
| d05-x01-y01    | ECF^{soft}\rho_{ungroomed}  | 0.0252                          | A14 Monash  |
| d06-x01-y01    | ECF^{hard}\rho_{ungroomed}  | 0.04                            | A14 Monash  |
| d23-x01-y01    | Nsubjets                    | 1.2                             | 2.5         |
| d24-x01-y01    | C2                          | 0.038                           | 0.4.04-0.5, 0.54.62 | A14 Monash  |
| d25-x01-y01    | D2                          | 0.48                            | A14 Monash  |
| d26-x01-y01    | LHA                         | 0.14                            | 1.4.9       |
| d27-x01-y01    | ECF^{hard}\rho_{ungroomed}  | 0.23                            | ECF^{hard}\rho_{ungroomed} | A14 Monash  |
| d28-x01-y01    | ECF^{hard}\rho_{ungroomed}  | 0.02                            | 0.02-0.32   | A14 Monash  |

### Table 6: ATLAS 2017 I1637587(Soft Drop Mass)

| Plots          | Observable                  | Better Tune Performance regions | Better Tune |
|----------------|-----------------------------|---------------------------------|-------------|
| d01-x01-y01    | log_{10}(m_{soft drop}/p_T^{ungroomed})^2 | 0                               | [-2.5,-0.5] |
| d02-x01-y01    | log_{10}(m_{soft drop}/p_T^{ungroomed})^2 | 1                               | [-4.5,-0.5] |
| d03-x01-y01    | log_{10}(m_{soft drop}/p_T^{ungroomed})^2 | 2                               | [-4.5,-0.5] |
5.2. Envelope plots

Having decided the range of values for each parameter, we visualise the region of the distributions to check its utility and hence it is important before proceeding further. This can be done using the PROFESSOR tool by generating envelopes plots with the command `prof2-envelopes`. The envelope plots show an area covering the distributions which indicates the bin values that the observables can take within the selected parameter ranges. These are shown in the following subsections.

5.2.1. Soft Drop Mass Distributions

As can be seen in Figure 6, the envelopes cover the reference data in almost every bin and hence we can say that the range selected for the parameters are appropriate.

5.2.2. Lund Jet Plane Distributions

As can be seen in Figure 7, the envelopes do not entirely cover the reference data. This is because we have reached a limit as to how much the distribution can be further fitted to the data with Pythia. Thus we consider this suitable for the purpose of this report and proceed with our set of parameter ranges.
5.2.3. Soft Drop Observables Distributions

In the Figure 8 we see that the envelopes cover the data points in almost all the bins of our distributions of interest i.e. soft drop jet mass from the soft drop jet observables analysis. Thus the parameter ranges are suitable for proceeding to tune the distributions.
Figure 8: Envelope plots for Soft Drop Mass observable
5.3. Weight file

The weight file assigns weights to the distributions to be tuned and hence is manually changed depending on our interests. For this project, a total of 16 distributions were assigned weights greater than 1 and 6 distributions were given no weight i.e 0 for obtaining the Common Tune. These are:

| Analysis | Distribution code | Weight |
|----------|-------------------|--------|
| ATLAS_2020_I1790256 | d03-x01-y01 | 106 |
| ATLAS_2020_I1790256 | d04-x01-y01 | 112 |
| ATLAS_2020_I1790256 | d05-x01-y01 | 108 |
| ATLAS_2020_I1790256 | d06-x01-y01 | 20 |
| ATLAS_2020_I1790256 | d07-x01-y01 | 16.6 |
| ATLAS_2020_I1790256 | d08-x01-y01 | 16 |
| ATLAS_2020_I1790256 | d09-x01-y01 | 16 |
| ATLAS_2019_I1772062 | d19-x01-y01 | 75 |
| ATLAS_2019_I1772062 | d20-x01-y01 | 75 |
| ATLAS_2019_I1772062 | d21-x01-y01 | 200 |
| ATLAS_2019_I1772062 | d22-x01-y01 | 80 |
| ATLAS_2019_I1772062 | d23-x01-y01 | 200 |
| ATLAS_2019_I1772062 | d24-x01-y01 | 80 |
| ATLAS_2017_I1637587 | d01-x01-y01 | 500 |
| ATLAS_2017_I1637587 | d02-x01-y01 | 500 |
| ATLAS_2017_I1637587 | d03-x01-y01 | 500 |
| ATLAS_2019_I1772062 | d61-x01-y01 | 0 |
| ATLAS_2019_I1772062 | d62-x01-y01 | 0 |
| ATLAS_2019_I1772062 | d79-x01-y01 | 0 |
| ATLAS_2019_I1772062 | d80-x01-y01 | 0 |
| ATLAS_2019_I1772062 | d97-x01-y01 | 0 |
| ATLAS_2019_I1772062 | d98-x01-y01 | 0 |

Table 7: Weights assigned to obtain the Common tune