PROCEEDINGS OF SCIENCE

Jet substructure measurements and precision measurements of multijet production with the ATLAS experiment

Zdenek Hubacek[a,*] **on behalf of the ATLAS Collaboration**

[a] *Czech Technical University in Prague,*
CTU FNSPE, Brehova 7, 115 19 Praha 1, Czech Republic

E-mail: zdenek.hubacek@cern.ch

Jets, the collimated streams of hadrons resulting from the fragmentation of highly energetic quarks and gluons, are some of the most commonly observed radiation patterns in hadron collider experiments. The distribution of Quantum Chromodynamics radiation within jets is determined by complex processes, the production of showers of quarks and gluons and their subsequent recombination into hadrons. In these proceedings, two recent measurements of the jet substructure from the ATLAS experiment at the Large Hadron Collider are presented. The first concerns the measurements of the differential cross-section of Lund subjet multiplicities. The second measurement introduces new event-shape jet observables defined in terms of reference geometries with cylindrical and circular symmetries using the energy mover's distance.

31st International Workshop on Deep Inelastic Scattering (DIS2024)
8–12 April 2024
Grenoble, France

*Speaker

https://pos.sissa.it/

PoS(DIS2024)180

1. Introduction

Precise studies of jet production in proton–proton collisions are important in understanding the strong interaction in the framework of Quantum Chromodynamics (QCD). In QCD, jets are interpreted as results of the quark and gluon interaction and fragmentation. Jet cross-sections measurements provide information about the structure of the proton (parton distribution functions, PDFs) and fundamental parameters of QCD, like the strong coupling constant α_S.

This short summary presents two recent results of the ATLAS Experiment [1] at the Large Hadron Collider [2].

2. Lund Jet Plane

Lund diagrams are a theoretical representation of the phase space within jets. It is possible to construct them experimentally, and one option is to re-cluster a jet with a Cambridge/Aachen jet algorithm and then de-cluster the jet constituents following the hardest branch [3]. In this context, this definition brings many soft-drop related observables into a single framework to study the soft QCD emissions inside hard QCD particle jets.

In Ref. [4], the ATLAS Collaboration measures the Lund subjet multiplicities (number of subjets above certain transverse momentum threshold inside a jet) in dijet events collected in proton–proton collisions at the center of mass energy $\sqrt{s} = 13$ TeV. The measurement is performed differentially in the jet transverse momentum and relative-rapidity bins (separating more-central and more-forward dijet production) and in the transverse momentum of the emission with respect to the jet core, k_t. Representative examples are shown in Fig. 1.

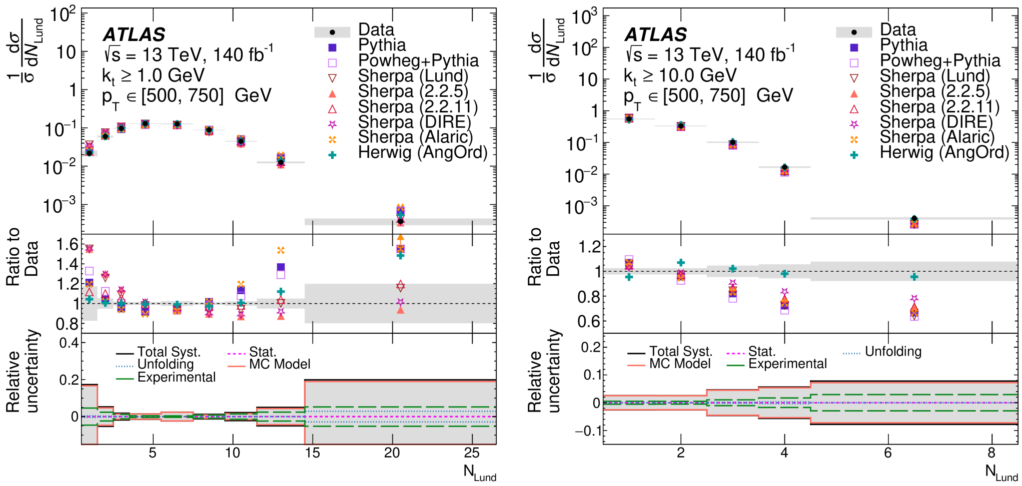

Figure 1: A representative measured normalized differential cross-section of N_{Lund} subjet multiplicities for an emission k_t requirement of 1 GeV (nonperturbative regime, left) and 10 GeV (perturbative regime, right). The data are shown in an inclusive bin of jet rapidity and a bin of jet p_T between 500–750 GeV. The unfolded data are compared with several MC predictions, and the total uncertainty on the data is indicated by a shaded grey region. Taken from Ref. [4].

Additionally, the measurements are also compared with the state-of-the-art parton showers (PS) and with analytical next-to-leading-order and next-to-next-to-double-logarithmic accuracy (NLO+NNDL) calculations in Fig. 2.

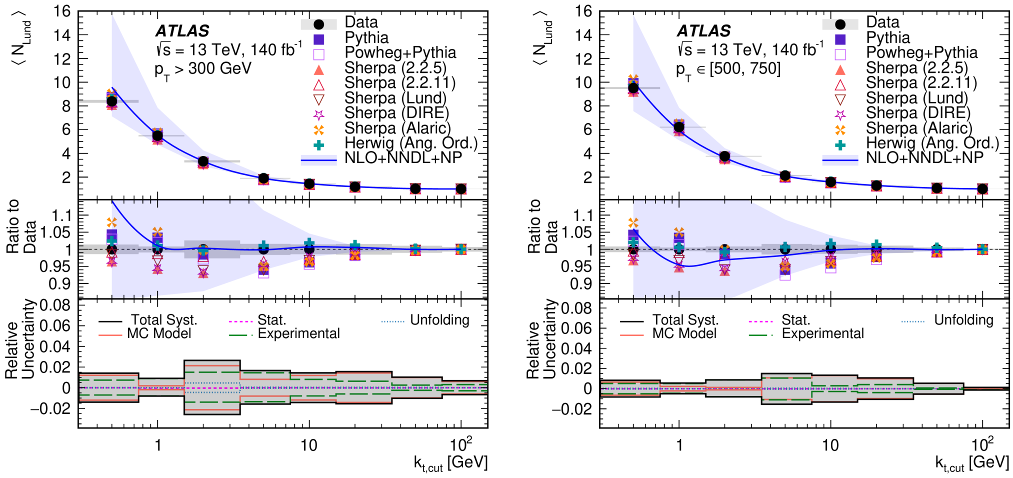

Figure 2: $\langle N_{\text{Lund}} \rangle$ is shown as a function of the emission k_{t} requirement, $k_{\text{t,cut}}$. The unfolded data are compared with several MC predictions in an inclusive p_{T} bin above 300 GeV (left) and a p_{T} bin between 500–750 GeV (right). The distributions are also compared with an analytic NLO+NNDL+NP prediction (with additional non-perturbative corrections (NP)), depicted as a solid line. Taken from Ref. [4].

3. Event Isotropies

Multijet event isotropies provide a generalization of the event-shape variables [5]. The event isotropies remain infrared- and collinear-safe observables which transfer the event shape variables into a geometrical problem which could be solved using standard tools like Optimal Transport methods. The event isotropies selected in the recent measurement [6] characterize how a given event is similar to three classes of symmetric radiation patterns. Three different event isotropies I^2_{Ring}, $1 - I^{128}_{\text{Ring}}$ and $1 - I^{16}_{\text{Cyl}}$ compare the events to three isotropic radiation patterns: dipole isotropy in azimuthal angle, isotropy in the full azimuthal angle, and cylindrical isotropy in the azimuthal angle and rapidity, respectively. An event display of a selected isotropically produced multijet event is shown in Fig. 3.

The analysis is performed using jets with transverse momenta $p_{\text{T}} > 60\,\text{GeV}$ and rapidities $|y| < 4.5$. The events are required to have at least two jets and $H_{\text{T2}} = p_{\text{T},1} + p_{\text{T},2} > 400\,\text{GeV}$ in four inclusive jet multiplicity bins ($N_{\text{jets}} > 2, 3, 4, 5$) and three inclusive $H_{\text{T},2}$ bins ($H_{\text{T},2} > 500, 1000, 1500\,\text{GeV}$). Demonstrative results of the unfolded data and several state-of-the-art MC predictions considering different hadronization and parton shower models can be found in Fig. 4.

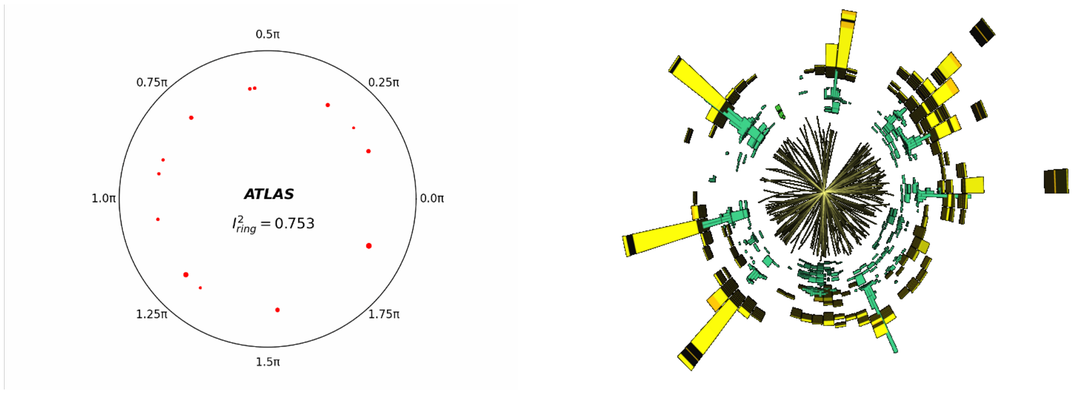

Figure 3: The visualization of the Run 300687, Event 1358542809 – the most isotropic ($1 - I^{128}_{\text{Ring}} = 0.922$) which has 12 jets with transverse momentum above 60 GeV. The conference presentation included an animated version explaining the calculation of the I isotropy variable. Taken from Ref. [6].

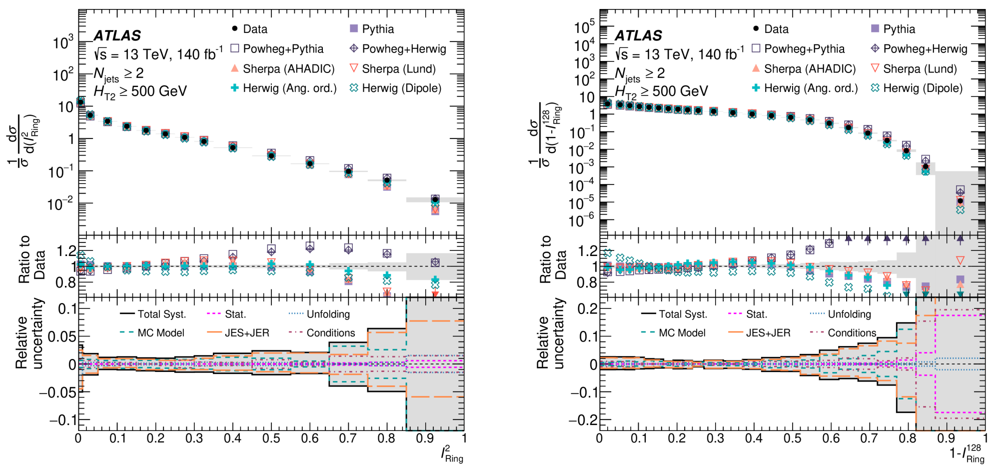

Figure 4: The shape-normalized I^2_{Ring} (left) and $1 - I^{128}_{\text{Ring}}$ (right) cross-sections in data (closed circles), compared with predictions from several Monte Carlo generators. Events with $H_{T2} \geq 500$ GeV and more than 2 jets are included. Values of $I^2_{\text{Ring}} \sim 0$ correspond to well balanced dijet events while $I^2_{\text{Ring}} \sim 1$ represent symmetric 3-jet events (left). The $1 - I^{128}_{\text{Ring}}$ range represents configurations from balanced dijets to isotropically distributed multijet events (right). Taken from Ref. [6].

4. Summary

The Lund subjet multiplicities cross-sections and the novel event-shape observables (event isotropies) are measured by the ATLAS Collaboration in proton–proton collisions at the Large Hadron Collider at a centre-of-mass energy of 13 TeV. Both measurements were compared with the state-of-the-art PS MC models.

The measurement of Lund subjet multiplicities is made for increasing requirements on the subjet transverse momentum relative to the jet core. Out of the studied PS MC setups, a Herwig sample generated with the default angular-ordered PS is found to agree best overall with the measured data for both the multiplicity distributions and their extracted average values. Several recent Sherpa setups also correspond most accurately when low transverse momentum emissions are allowed. Other models often fail to accurately describe the measured data, so this measurement could be used as an input to future parton shower tuning and development.

The event isotropies are shown to have increased sensitivity to isotropic multijet events when compared with the standard event shapes. For the measurement of I^2_{Ring} observable, the predictions of NLO MC generators are shown to generally outperform those of LO simulation.

Acknowledgments

The author gratefully acknowledges the financial support from Fundamental constituents of matter through frontier technologies (FORTE) project No. CZ.02.01.01/00/22_008/0004632.

References

[1] ATLAS Collaboration, *The ATLAS Experiment at the CERN Large Hadron Collider*, *JINST* **3** (2008) S08003.

[2] L. Evans and P. Bryant, *LHC Machine*, *JINST* **3** (2008) S08001.

[3] F.A. Dreyer, G.P. Salam and G. Soyez, *The Lund Jet Plane*, *JHEP* **12** (2018) 064 [1807.04758].

[4] ATLAS Collaboration, *Measurements of Lund subjet multiplicities in* 13 *TeV proton–proton collisions with the ATLAS detector*, 2402.13052.

[5] C. Cesarotti and J. Thaler, *A Robust Measure of Event Isotropy at Colliders*, *JHEP* **08** (2020) 084 [2004.06125].

[6] ATLAS Collaboration, *Measurements of multijet event isotropies using optimal transport with the ATLAS detector*, *JHEP* **10** (2023) 060 [2305.16930].