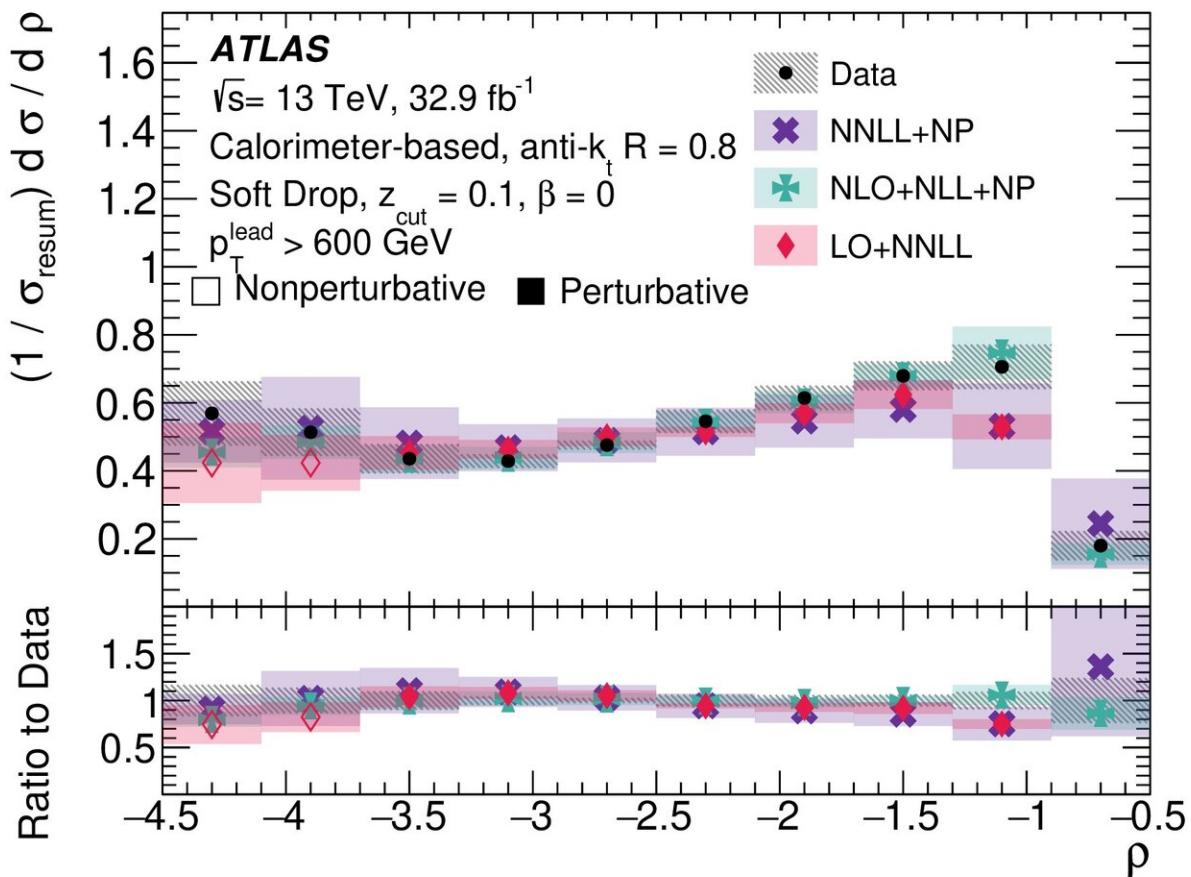


Novel probes of the strong force: Precision jet substructure and the Lund jet plane

June 8 2020



A histogram of the logarithm of the invariant mass normalized by the jet momentum (ρ) at the point in the jet history when a quark or a gluon radiated a significant fraction of its energy. The metric for determining “significant” is the soft-drop criteria. The ATLAS data are in black and various predictions from state-of-the-art QCD theory are shown in coloured markers. Credit: ATLAS Collaboration/CERN

A hallmark of the strong force at the Large Hadron Collider (LHC) is the dramatic production of collimated jets of particles when quarks and gluons scatter at high energies. Particle physicists have studied jets for decades to learn about the structure of quantum chromodynamics—or QCD, the theory of the strong interaction—across a wide range of energy scales.

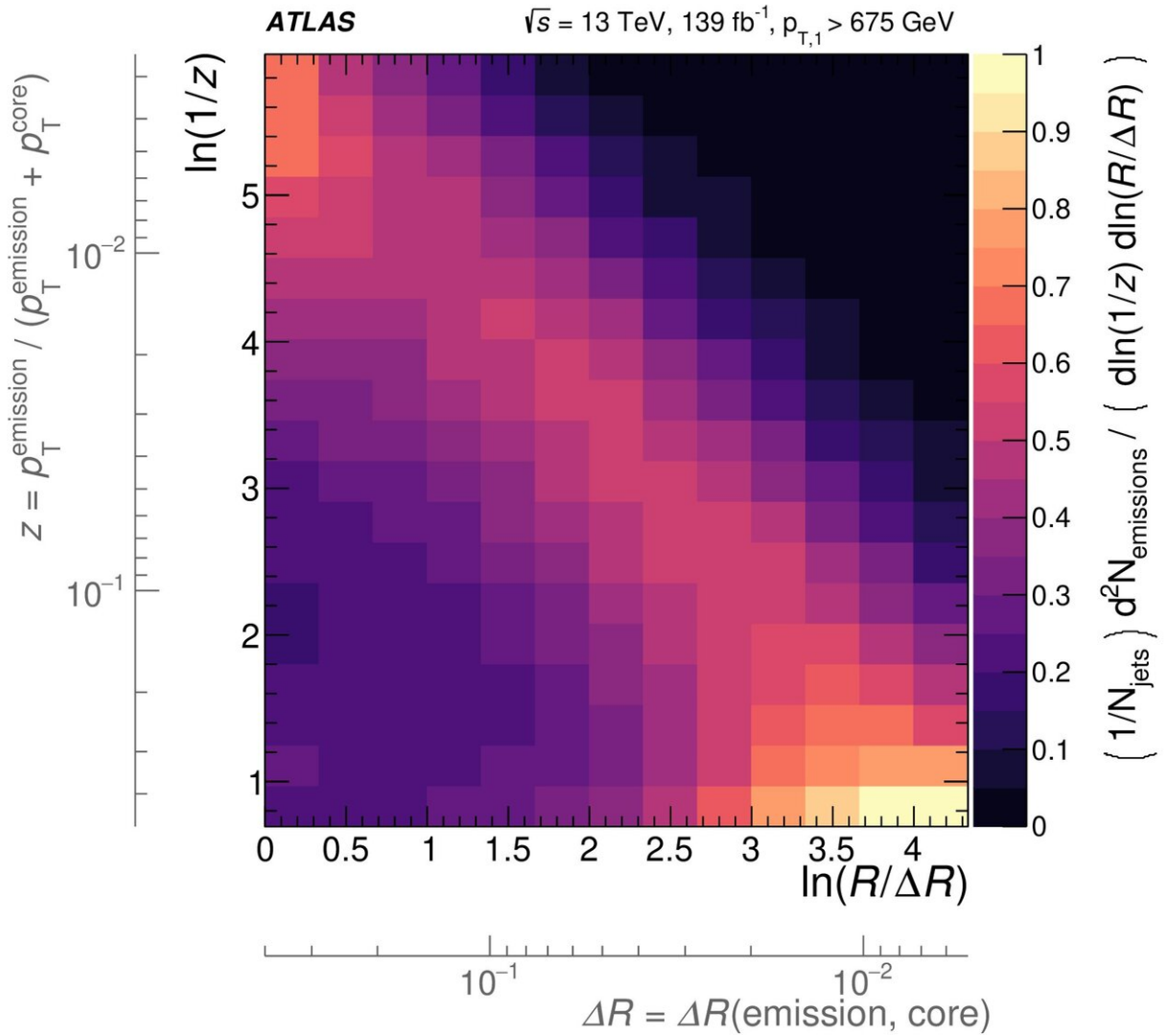
Due to their ubiquity, our understanding of jet formation and QCD is one of the factors which can limit understanding of other facets of the Standard Model at the LHC. By studying the rich substructure of jets, physicists can gather new clues about the behavior of the strong force at high energies. An improved understanding of their formation also benefits a broad range of other studies, including measurements of the top quark and Higgs boson.

Precision jet substructure

Dissecting jet substructure requires both precise experimental measurements and theoretical calculations—two areas that have advanced significantly during Run 2 of the LHC. On the experimental side, the ATLAS experiment has developed an accurate new method for reconstructing charged particle tracks inside jets. This has traditionally been quite challenging, due to the high density of particles inside the core of jets.

On the theory side, there has been an outburst of new techniques for representing jet substructure, including new analytic predictions for what experiments should observe in their data. A key new theoretical idea makes use of clustering algorithms to study a jet's constituents. Jets are constructed by taking a set of particles (experimentally, tracks and calorimeter energy deposits) and sequentially clustering them in pairs

until the area of the jet candidates reaches a fixed size. The steps in a jet's clustering history can also be traversed in reverse, allowing parts of the process to be associated with various steps in a jet's evolution.



The average number of declustering emissions in a given bin of relative energy (y-axis) and relative angle (x-axis), after accounting for detector effects. Credit: ATLAS Collaboration/CERN

The ATLAS Collaboration has released [new measurements](#) using this novel declustering methodology. Physicists were able to examine specific moments in a jet's evolution where a quark or a gluon radiates a significant fraction of its energy. The jet's mass at this stage is amenable to precise theoretical predictions, as shown in Figure 1.

Achieving this result was a significant endeavor, as ATLAS physicists had first to account for distortions in the data due to the measurement process and to estimate the uncertainty on these corrections. The new theoretical predictions provided an excellent model of the data, allowing physicists to perform a stringent test of the strong force in a regime that had not been previously tested with this level of experimental and theoretical precision.

Lund jet plane

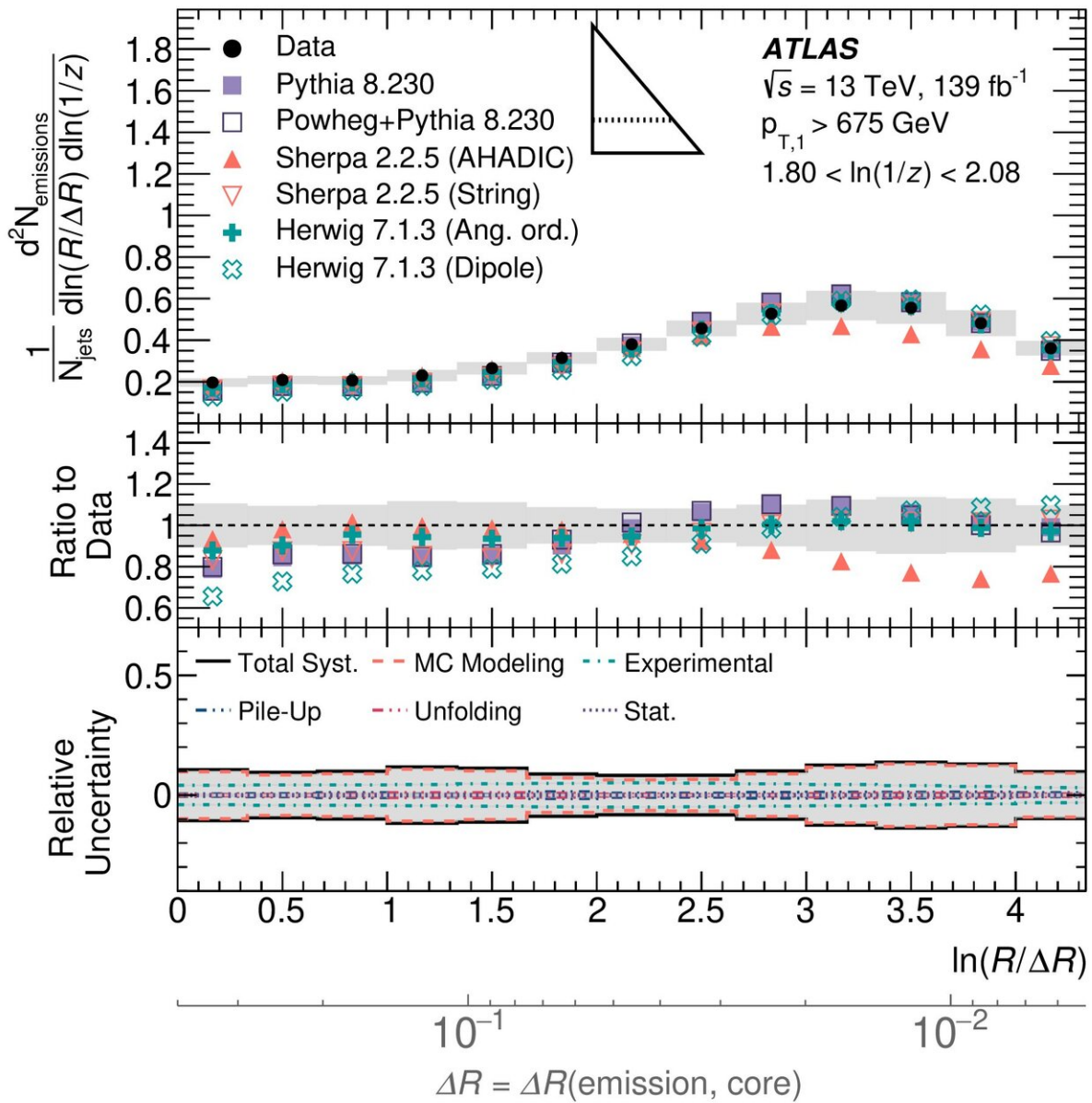
Physicists can also look beyond a single step in the clustering history by studying a new observable: the Lund jet plane. Its name is derived from the Lund plane diagrams that have been used by the QCD community for over 30 years, after their introduction in a paper by authors from Lund University (Sweden). In 2018, theorists applied the approach to jet substructure for the [first time](#), designing a Lund jet plane to characterize the relative energy and angle of each declustering step (or emission) during a jet's evolution. Through its study, physicists can investigate the statistical properties of all instances where the quark or gluon that initiated the jet radiated some fraction of its energy. Different physical effects become localized in specific regions of the plane, so that if predictions do not describe the data, physicists can identify the epoch in a jet's history that needs to be investigated.

ATLAS has performed the [first measurement of the Lund jet plane](#), which is built from the energies and angles of each step in a jet's evolution. ATLAS studied about 30 million jets to form the plane shown

in Figure 2. For this result, physicists used measurements of particle tracks, as they provide excellent angular resolution for reconstructing radiation found in the dense core of jets.

The figure uses color to describe the average number of emissions observed in that region. The angular information of the jet is described in the horizontal axis, and its energy by the vertical axis. The number of emissions is approximately constant in the lower left corner (wide angle, large energy fraction) and there is a large suppression of emissions in the top right corner (where the angle is nearly collinear, low [energy](#) fraction). The first of these observations is related to the near scale-invariance of the strong force, as the masses of most quarks are tiny compared to the relevant energies at the LHC. The suppression in the top right corner is due to hadronization, the process by which quarks form bound states.

To truly test the strong force, physicists dug deeper into this result. Figure 3 shows a horizontal slice through the plane, compared with state-of-the-art predictions based on the parton shower method. Parton showers are numerical simulations which describe the full radiation pattern inside jets, including the number of particles in the shower, their energies, angles and type.



The horizontal slice through Figure 2 including comparisons to QCD predictions. Credit: ATLAS Collaboration/CERN

The different colored predictions in Figure 3 change one aspect of the physics modeling at a time. For example, the orange markers show one

prediction where the only difference between the open and closed markers is the model used to describe hadronization. It is exciting to see that the open and closed orange markers only differ on the right side of the plot, which is exactly where hadronization effects are expected to be localized. The same is true for the other colors, for example the open and closed green markers differ only on the left side of the plot. This demonstrates the utility of the ATLAS data for learning more about the various facets of the strong force and improving parton shower models.

A growing field of exploration

The highly-granular ATLAS detector is well-suited to measure jet substructure in great detail, and there is still much to learn about the strong force at high energies. While extracting insights cleanly from jet substructure measurements has historically been challenging, recent theoretical advancements have resulted in better first-principles understanding than ever before. This has opened new doors to put QCD to the test with ATLAS data, which have been made [publicly available](#), so the QCD community will be able to learn from these additions to the growing field of precision jet substructure measurements for years to come.

More information: Measurement of the Lund jet plane using charged particles in 13 TeV proton-proton collisions with the ATLAS detector (arXiv: 2004.03540): arxiv.org/abs/2004.03540

Measurement of soft-drop jet observables in proton-proton collisions with the ATLAS detector at 13 TeV (Phys. Rev. D 101 (2020) 052007): journals.aps.org/prd/abstract/.../PhysRevD.101.052007

Provided by ATLAS Experiment

Citation: Novel probes of the strong force: Precision jet substructure and the Lund jet plane (2020, June 8) retrieved 8 May 2024 from <https://phys.org/news/2020-06-probes-strong-precision-jet-substructure.html>

This document is subject to copyright. Apart from any fair dealing for the purpose of private study or research, no part may be reproduced without the written permission. The content is provided for information purposes only.