Pushing the Precision Limit for QCD Measurements with Proton–Proton Collisions at the Large Hadron Collider – Looking Inside Particle Jets with the ATLAS Detector with New Approaches to Signal Definition and Calibration

Peter Loch
Department of Physics
University of Arizona
Tucson, Arizona, USA

The Large Hadron Collider (LHC) at CERN, Geneva, Switzerland, produces the highest energy proton collisions at the highest intensity of any colliding beam experiment so far. The reconstruction of the final state of these collisions faces significant challenges in achieving the required precision in, for example, the measurements of the strong force. In particular, the measurement of the strong coupling constant α_s introduced in Quantum Chromo Dynamics (QCD), the principal theoretical model describing this force in the Standard Model of Particle Physics, is of paramount interest. In addition, recent progress in QCD does not only extend the regime of *perturbative* QCD calculations to higher orders in terms of α_s for many processes but also includes new approaches to calculate the particle emission in the regime of lower scales characterized by small angle (near collinear) and softer (lower energy) emissions. This imposes new precision requirements on experiments to confirm the theoretical findings and thus enhance our understanding of the strong force.

The formation of *particle jets* emerging from the fragmentation of partons or the decay of short-lived particles generated in the final state of the proton–proton collisions at the LHC is governed by QCD. The internal particle flow pattern of these jets, if reconstructed with sufficient precision in the experiment, can provide access to a large spectrum of emission characteristics within one coherently generated composite final state object, up to the limit of the experimental sensitivity. This makes the *running of* α_s, a long-standing observation in other measurements, accessible in these flow patterns. A modern tool useful for the extraction of α_s is the so-called *Lund Jet Plane* (LJP) that represents a simultaneous measurement of both the emission angles and the emitted energies. The LJP is not only employed in comparisons of perturbative QCD calculations with experimental data in the kinematic domain of the jet fragmentation that is covered by such calculations but also for the corresponding comparisons to the phenomenological modeling in non-perturbative domains. Its measurement requires highly precise signal reconstruction in the typically dense particle flow environment inside jets to (1) compete with recent other α_s measurements at the LHC involving gauge boson production and hadronic event shapes, and to (2) serve as a reference for new or re-tuned non-perturbative emission models and as a target of such tuning.

In this talk we first discuss the major challenges of such measurements introduced by the LHC collision environment and the experimental limitations of the detectors in the ATLAS experiment, which is one of the two general purpose experiments operating at the LHC. This is followed by the presentation of present-day strategies to overcome some of these limitations by optimizing the composition and selection of the input signals to the jet reconstruction and some of the results at hand for QCD measurements so far. Lastly, expectations for further improvements of the precision that potentially involve machine-learned approaches to signal calibration and classifications are discussed.