Fragmentation through Heavy and Light-flavor Measurements with the LHC ALICE Experiment

A few microseconds after the Big Bang, the universe was filled with an extremely hot and dense mixture of particles, called the quark-gluon plasma (QGP). We can recreate this extreme state of matter in the laboratory by colliding heavy-ions. While the QGP is not expected to form in small systems such as proton-proton collisions, collective features have been observed, such as long-range near-side correlations and the asymmetry in the azimuthal distribution of final state particles, which have been traditionally associated with the presence of the QGP. A possible explanation is that quark-gluon plasma can be created in a small volume in a fraction of collisions of small systems. There are, however, alternative explanations of these observed phenomena that do not assume the quark-gluon plasma. Semi-soft vacuum QCD effects such as multiple-parton interactions are shown to produce signatures of collectivity.

The aim of this thesis is to study heavy and light-flavor jet fragmentation and hadronization properties in high-energy proton-proton collisions to shed light on the particle production mechanisms that lead to collective-like behavior in small systems. One of the main research areas for this purpose is the study of jets. I characterized differential and integral jet shapes to look for modifications caused by non-trivial quantum chromodynamics (QCD) effects. I also investigated the multiplicity distributions (number of charged final state particles) as a function of the jet transverse momentum. Motivated by recent results showing that these multiplicity distributions follow a scaling similar to the Koba-Nielsen-Olesen (KNO) scaling, I searched for the KNO-like scaling in simulations for heavy-flavor jets, and I also carried out the first measurement of jet-momentum-dependent jet multiplicity distributions with the ALICE experiment.

In high-energy hadron collisions, heavy quarks (charm and beauty) are mainly produced in hard parton scattering processes. Two-particle angular correlations originating from heavy-flavor particles allow for the characterization of parton shower and fragmentation. The ALICE collaboration measured the heavy-flavor electron-hadron azimuthal correlation distributions between heavy-flavor decay electrons and associated charged particles in p-p and p-Pb collisions at $\sqrt{s}=5.02$ TeV. I contributed to the analysis with detailed simulations to compare the near- and away-side peaks of the azimuthal-correlation distributions to the model predictions. This allowed verifying the model implementation of the processes of charm- and beauty-quark production, fragmentation, and hadronization, which have an impact on the observables studied in this analysis. I also determined the correlation peak shape using FONLL pQCD calculations for the modelling of charm and beauty contributions.

Another major topic in my thesis, connected to jet fragmentation, concerns the understanding of heavy-flavor hadroproduction in proton-proton collisions at LHC energies. The production cross section of hadrons can be calculated using the factorization theorem, which usually assumes that the fragmentation functions are universal across different collision systems. Experimental results such as the enhanced production of charmed baryons question this assumption. I used a model with color reconnection beyond leading color approximation (CR-BLC) to seek explanation for the charm-baryon enhancement, and proposed new observables for future measurements. I characterized the collision events using different event-activity classifiers, that allow for investigating the connections between the leading QCD processes and the underlying event.

The primary motivation driving my research is to explore the boundary between hard and soft processes occurring in proton-proton collisions, which is a significant yet relatively unexplored area.