Chapter 8

Results and Conclusions

In this thesis, the first experimental results on the measurement of subjet multiplicities in proton-proton collisions at $\sqrt{s}=7$ TeV are presented. The subjet multiplicity is a variable which can discriminate between quark and gluon jets. The classification of gluon and quark jets is unambiguous only in leading order QCD, where there are two, and only two, jets in the final state of pp collision. For this reason, a sample of dijet events is selected to perform the studies. The data used to measure the subjet multiplicity have been collected with the CMS detector during the year 2010 of LHC running, which correspond to about 36 pb$^{-1}$ of integrated luminosity. Various collinear and infrared safe jet algorithms exist. The adopted standard algorithm in the LHC experiments is the anti-$k_T$ jet algorithm, but the jets are defined using the $k_T$ jet algorithm in this thesis. Although anti-$k_T$ jet algorithm follows a sequential recombination procedure, the jets leading in $p_T$ resemble in shape the jets reconstructed using algorithms with fixed cone sizes due to the fact that it starts clustering with the hardest (highest $p_T$) objects in an event. Hence it is less sensitive to details of the distribution of softer objects in an event (or within jets) and less well suited for an investigation of jet substructure. The jets and subjets have been resolved with the $k_T$ jet algorithm for a jet size of $R=0.6$ and a subjet resolution cutoff $\Delta R_{sub}=10^{-3}$. We have measured the subjet multiplicity and mean subjet multiplicity ($<M>$) using information from the calorimetric jets and the
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particle flow jets, for a sample of dijet events selected in the rapidity region ($|y| < 2$) and with jet transverse momentum in the range of 97-1032 GeV. The measurements are corrected for the detector effect using bin-by-bin correction factor method, which neglects correlations completely and bayesian unfolding, which is employed to derive the central unfolded results under consideration of correlations and bin-to-bin migrations. The estimation of statistical uncertainty and systematic uncertainties due to pile up, jet energy scale, jet energy resolution and different physics models employed for simulation, have been performed.

The average subjet multiplicity $< M >$ is found to decrease from $3.28 \pm 0.03$ (stat.) $\pm 0.10$ (syst.) down to $1.83 \pm 0.09$ (stat.) $\pm 0.04$ (syst.) at central jet rapidity $|y| < 1$ and from $3.19 \pm 0.03$ (stat.) $\pm 0.12$ (syst.) down to $1.68 \pm 0.13$ (stat.) $\pm 0.08$ (syst.) for $1 \leq |y| < 2$ with increasing jet $p_T$ for PFJets. In case of CaloJets it decreases from $3.35 \pm 0.01$ (stat.) $\pm 0.07$ (syst.) to $1.88 \pm 0.08$ (stat.) $\pm 0.46$ (syst.) with increasing jet $p_T$ for $|y| < 2$. This is a clear indication of a higher degree of collimation and a higher fraction of quark initiated jets with rising jet $p_T$. From inner to outer rapidities the subjet multiplicity tends to decrease as well. The systematic uncertainties from pile-up collisions, the jet energy scale and resolution as well as the detector unfolding amount up to $\pm 2 - 6\%$ uncertainty on the measurement while statistical uncertainties range from about $0.2\%$ to $7.7\%$, when going from low to high jet $p_T$'s. Predictions for the subjet multiplicities have also been made from various MonteCarlo event generators. MC predictions by HERWIG++ tune 2.3 agree well with the data while PYTHIA8 tune 4C predicts larger and PYTHIA6 tunes, D6T and Z2 predict smaller average subjet multiplicities than measured. Since the fraction of gluon to quark initiated jets is even higher in PYTHIA6 compared to HERWIG++ for $p_T > 300$ GeV this is explained by the generally higher subjet multiplicities in HERWIG++ for gluon and quark jets. Although PYTHIA8 assumes gluon fractions like PYTHIA6, it is nevertheless able to even overshoot the data. Due to this large model dependence, a direct conclusion on the gluon to quark

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fraction cannot be drawn.

Previously, the results on the internal jet structure using subjet multiplicity measurements have been given by the Tevatron experiment D0, which employed the $k_T$ algorithm to resolve subjets in jet samples at $\sqrt{s} = 1800$ GeV and 630 GeV and extracted separately the multiplicity of subjets for gluon and quark jets. Because exploiting data at different center-of-mass energies, the model dependence to extract gluon to quark fraction can potentially be eliminated, two center of mass energies were used. The details of this technique can be found in Ref. [98]. Due to non availability of the data at LHC for second center-of-mass energy, only the jet $p_T$ dependent results are studied. The technique used at D0 could also be used at the LHC, once data at higher collision energies become available.

For the inclusive jet crossections, the correction functions for non-perturbative effects on jets with high transverse momentum in the LHC environment have been derived for the $k_T$ 0.6 and SISCone 0.7 algorithms. With these corrections it will be possible to compare fully hadronized events from leading-order Monte Carlo generators and ultimately real measured data with theoretical next-to-leading order predictions at 10 TeV. Because going from partons of NLO calculation to the final state hadrons the additional steps of parton showering, hadronization, decays and multiple parton interactions have to be performed. In particular for hadronization and multiple parton interactions only phenomenological models exist that currently can solely be used together with LO matrix element for the inclusive jet crossection. Therefore correction factors for the non-perturbative contribution, steps have to be applied to the NLO results. By taking into account several event generators, an estimation of the systematical uncertainty also becomes possible.