Jet and Event Shape Observables at LHC

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During the first, very successful year 2010 of LHC operation, which saw an increase in instantaneous luminosity by a factor of ≈ 10000, an excellent performance of the LHC experiments ATLAS and CMS has been observed. The achieved understanding in detector operation and behaviour has lead to uncertainties of the order of 11% on the luminosity, 3–5% on the jet energy scale and about 5–20% on the jet energy resolution depending on experiment and phase space. With respect to their impact on QCD measurements three general analysis strategies can be differentiated: Absolute measurements like the inclusive jet p_T, shape measurements like jet angular variables and event shapes, or ratios of cross sections. The latter two exhibit much smaller experimental uncertainties due to cancellation effects and are, at least in the beginning, better suited for precise QCD studies in order to constrain parton distribution functions (PDFs) and/or determine the strong coupling constant α_s. The total experimental uncertainties on the jet cross sections currently are of the order of 20 to 40% for transverse momenta larger than $\approx 50\,\mathrm{GeV}$ while theoretical uncertainties from the PDFs, the renormalization and factorization scales, and non-perturbative corrections amount to 8 to 15%. With further improvements and much more data to come the jet cross sections are very promising for the future. In the following, some aspects of a shape measurement, the azimuthal decorrelation $\Delta\Phi_{jj}$, and the 3-jet ratio R_{32} will be discussed.

Azimuthal decorrelations $\Delta\Phi_{jj}$, recently published for LHC data by CMS and ATLAS [1], are normalized to the total dijet cross section eliminating luminosity uncertainties. They are a direct measure of additional activity like a radiated third jet in comparison to a normal dijet event perfectly balanced in transverse momentum. Restricting the observation to differences in azimuthal angle between the leading two jets reduces significantly uncertainties due to the jet energy scale and resolutions. In case of balanced dijet events the azimuthal angles between the leading jets are completely correlated to give distances of $\Delta\Phi_{jj} = \pi$. Additional radiation of any of the two jets decrease this distance where the extent to which this is possible depends on the jet multiplicity as demonstrated e.g. in Fig. 1 of the ATLAS analysis in [1]. Comparisons to pQCD at NLO are possible in the range $2\pi/3 < \Delta\Phi_{jj} < \pi$ with NLOJet++ [4] providing the required 3-parton and 4-parton final states. Below $2\pi/3$ mostly final states with four or more partons contribute such that the result of NLOJet++ effectively becomes LO only. This can also be seen by an associated increase of the scale uncertainties. At $\Delta\Phi_{jj} = \pi$ the 3- and 4-parton final states need to be complemented by the 2-parton ones requiring 2-loop corrections for a complete NNLO result which is not available as of today. This demonstrates that azimuthal decorrelations are a precisely measurable QCD observable providing a lot of information on multijet production. Redefining the azimuthal distance to $\Delta\Phi'_{jj} = \Delta\Phi_{jj} - \pi$ such that balanced dijets have $\Delta\Phi'_{jj} = 0$ this quantity can also be considered an event shape for which resummed predictions are conceivable [2]. Azimuthal decorrelations can also be investigated for leading particles.

Following a publication of D0, preliminary results by ATLAS and CMS [3] are reported for the inclusive 3- to 2-jet ratio R_{32} versus the scalar sum of all transverse jet momenta H_T. The suggested study, however, is far from optimal with respect to comparisons to pQCD. First

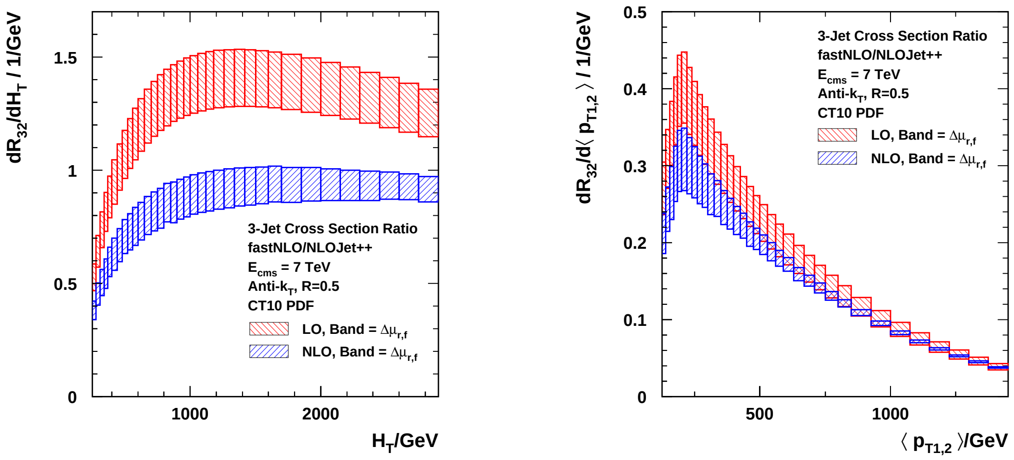

Figure 1: LO (red) and NLO (blue) predictions including scale uncertainties for an analysis similar as in [3] (left) in comparison to the one suggested here (right) requiring a minimal p_T of 25% of the leading dijet average $< p_{T1,2} >$.

of all, the LO prediction including the scale uncertainty as shown in Fig. 1 left as upper red hatched band is unreliable and gives unphysical values larger than one. The NLO presented in blue looks more reasonable and is not far off the CMS data, but the associated scale uncertainties are not much smaller with respect to LO. This points to a bad convergence of the perturbative series. In fact, ratios R_{32} of ≈ 0.8 where jets with $p_T > 50\,\mathrm{GeV}$ are counted even for leading jet momenta of $p_{T,max} \approx 1\,\mathrm{TeV}$ are not representative for hard processes with probabilities related to α_s at high scales. For that purpose it would be better to require a minimal hardness of third jets of e.g. a certain percentage like 25% of the average transverse momentum of the two leading jets. An example calculation performed with NLOJet++ in the fastNLO framework [5] for such an event selection is presented in Fig. 1 right leading to reasonable predictions already at LO and larger reductions of the scale uncertainties at NLO at least at high p_T. The abundant production of jets at highest transverse momenta at the LHC will enable many new precision tests of perturbative QCD in the near future.

References

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