An overview of cross section measurements as a function of jet multiplicities and jet kinematics in association with $t\bar{t}$ production is presented. Both the ATLAS and the CMS collaborations performed a large number of measurements at different center-of-mass energies of the LHC using various $t\bar{t}$ decay channels. Theoretical predictions of these quantities usually rely on parton shower simulations that strongly depend on tunable parameters and come with large uncertainties. The measurements are compared to various theoretical descriptions based on different combinations of matrix-element calculations and parton-shower models.
1 Introduction

At the LHC a large number of top quark-antiquark pairs ($t\bar{t}$) are produced together with additional jets. A measurement of jet multiplicities and jet kinematics provides insights in standard model QCD. However, while on the one hand such measurements have been performed with high precision by the ATLAS\cite{3} and CMS\cite{3} collaborations, one the other hand the theoretical prediction is difficult. Full fixed order calculations are challenging for high jet multiplicities and have to be matched to parton-shower simulations. We will show that the tuning of the parton shower and the matching between matrix-element calculation and parton shower has large impact on the theoretical description.

The measured results are usually shown for a limited range of the phase space, which is similar to the experimental acceptance, and are presented at particle level. The particle level is described by long-living particles, which directly affect the measurements within the detectors. Such a definition of the measured observables minimizes the dependency on theoretical extrapolations.

2 Measurements

Based on an integrated luminosity of 20.3 fb$^{-1}$ recorded at 8 TeV ATLAS\cite{3} measured the jet multiplicity and the transverse momentum $p_T$ of the additional jets ordered by their rank where the additional jet with the highest $p_T$ has rank one, with the second highest $p_T$ rank two, and so on. In this measurement $t\bar{t}$ events in the dilepton channel are selected with one electron and one muon in the final state. In addition, at least two jets identified as b jets are required. The two b jets most compatible with the b jet assumption are assigned to the $t\bar{t}$ system. All other jets with $p_T > 25$ GeV and a pseudorapidity $|\eta| < 4.5$ are considered as additional jets. The measured distributions are unfolded simultaneously in the $p_T$ and the rank of the jets. The results of the differential cross section as a function of $p_T$ for the three highest ranked jets are shown in Fig.\[1\]. Powheg and MC@NLO perform a NLO calculation of $t\bar{t}$ production. The results are further combined with the parton shower simulations of Pythia and HERWIG, respectively, i.e., the radiation of one additional jet is described with LO precision while all other additional jets are based on the parton-shower simulations. A comparison to the measurement shows that the leading jet is well described and only marginally affected by the variation of $h_{\text{damp}}$ in the Powheg simulations.

A similar analysis is performed by CMS\cite{4}. Based on an integrated luminosity of 19.7 fb$^{-1}$ recorded at 8 TeV. In this measurement the ee, $\mu\mu$, and $e\mu$ channels are used. At least two jets including at least one b-tagged jet with $p_T > 20$ and $|\eta| < 2.4$ are required. Afterwards a kinematic reconstruction of the $t\bar{t}$ system is performed to identify the b jets from top quark decays. The unfolded number of jets above various $p_T$ thresholds are shown in Fig.\[2\]. The measurement is well described by the Powheg and the Madgraph simulations where Madgraph is used to calculate the processes of $t\bar{t}$ plus up to three additional partons with LO accuracy. These are merged and combined with the parton-shower simulation. The combination of MC@NLO and HERWIG underestimates the jet multiplicities; an observation consistent with the ATLAS result.
At least two of the jets have to be identified as b jets. The jet multiplicity measured in the dilepton channel is compared to various theoretical predictions. The lower panels show ratios of various theoretical predictions to the measured result [4].

Figure 1: The top panels show the normalized differential cross section as a function of the $p_T$ of additional jets ranked by their $p_T$. The measured results are compared to various theoretical predictions. The lower panels show ratios of various theoretical predictions to the measured result [3].

The jet multiplicities are also measured in the $e/\mu +$ jets channel by CMS [5]. Events with a single isolated lepton together with at least four jets with $p_T > 30$ GeV are selected. At least two of the jets have to be identified as b jets. The jet multiplicity measured in this channel is shown in Fig. 3. The agreements between measurement and simulations are consistent with those in the dilepton channel.

Meanwhile first results measured at 13 TeV center-of-mass energy are available. Based on 3.7 fb$^{-1}$ ATLAS [6] performed a measurement of jet multiplicities in the dilepton channel.
selecting eμ events with two b-tagged jets. The result is shown in Fig. 4. The measurement is well described by a Powheg, a AM@NLO, and a Sherpa simulation. The effect of the parton shower tuning and matching is demonstrated by varying the parameters within their uncertainties to enhance (RadHi) or reduce (RadLo) the radiation of additional jets. This demonstrates the sensitivity of the calculations to the tuning parameters such as the choices of scales for the parton-shower calculation and the matching.

Figure 3: Multiplicities for jets with $p_T > 30$ GeV measured in the $e/\mu +$ jets channel compared to various theoretical predictions. The lower panel shows the corresponding ratios of the measured result to the predictions [5].

Figure 4: Normalized distributions of multiplicities for jets with $p_T$ above 25 GeV(left), 40 GeV(middle), and 80 GeV(right) compared to various theoretical predictions are shown in the top panels. The middle and bottom panels show the ratios of different predictions to the measured result [6].
Figure 5: Measured differential cross section as a function of the $p_T$ of the $t\bar{t}$ system for different numbers of additional jets compared to various theoretical predictions. The lower panels show the corresponding ratios of the predictions to the measured results [7].

Finally, CMS [7] performed a measurement of differential cross sections as a function of kinematic variables of the $t\bar{t}$ system for various jet multiplicities. This analysis is based on 2.3 fb$^{-1}$ at 13 TeV in the $e/\mu + \text{jets}$ channel. In addition to the lepton at least four jets are required out of which at least two are identified as b jets. Based on the constraints of top quark and W boson masses particle-level top quarks are defined. These are reconstructed in the data and unfolded simultaneously in $p_T$ of the $t\bar{t}$ system and jet multiplicity. The result is shown in Fig. 5. Naively none of the simulations seems to describe the data well, but taking into account the large uncertainties in the predictions, as discussed in the last paragraph, one would not expect a better agreement.

For certain precision measurements and searches beyond the standard model it is helpful to select a simulation that describes the data as well as possible keeping in mind the uncertainties and the risk of over-tuning, which could compromise the simulation towards nonstandard model physics.
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