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Top modelling and tuning in CMS

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Abstract

State-of-the-art theoretical predictions accurate to next-to-leading order QCD interfaced with Pythia8, Herwig, and Sherpa event generators are tested by comparing the unfolded $t\bar{t}$ differential data collected with the CMS detector at 8 and 13 TeV. These predictions are also compared with the underlying event activity distributions in $t\bar{t}$ events using CMS proton-proton data collected at a center of mass energy of 13 TeV. In addition, studies of jet shapes in $t\bar{t}$ events at 13 TeV are presented. Studies to derive and test the new CMS event tune obtained through jet kinematics in $t\bar{t}$ events and global event variables are also described.

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Top modelling and tuning in CMS

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State-of-the-art theoretical predictions accurate to next-to-leading order QCD interfaced with Pythia8, Herwig, and Sherpa event generators are tested by comparing the unfolded $t\bar{t}$ differential data collected with the CMS detector at 8 and 13 TeV. These predictions are also compared with the underlying event activity distributions in $t\bar{t}$ events using CMS proton-proton data collected at a center of mass energy of 13 TeV. In addition, studies of jet shapes in $t\bar{t}$ events at 13 TeV are presented. Studies to derive and test the new CMS event tune obtained through jet kinematics in $t\bar{t}$ events and global event variables are also described.

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*Speaker.

Extracting a maximum of information from top-quark measurements at hadron colliders requires a dedicated effort in theoretical modelling. A new generation of next-to-leading order matrix element (ME) event generators interfaced with new parton-shower (PS) codes are expected to provide improved modelling of the signal and backgrounds for new measurements. However, these codes contain a number of tunable parameters which have to be determined using data.

Several generators are assessed using LHC Run 1 data collected with the CMS detector [1] and with a new set of differential distributions at $\sqrt{s} = 13$ TeV using different top quark pair ($t\bar{t}$) final states [2]. To improve the high jet multiplicities in $t\bar{t}$ events, a number of parameters have been tested and the most sensitive ones to jet kinematics in $t\bar{t}$ events are determined and optimized. For tuning, the PROFESSOR tool was used [3]. As an example, Fig. 1 (left) shows the impact of the h_{damp} parameter, which controls ME/PS matching, and the strong coupling at M_Z used for the initial-state shower, α_s^{ISR}, on the jet multiplicity, N_{jets}, through the bin-wise sensitivity $S = \frac{\text{d}MC(p)}{\text{d}p} \times \frac{p_c}{MC(p_c)}$, where MC denotes the bin value for a parameter value p, and p_c is a reference parameter point. The tuning yields a result of $h_{\text{damp}} = 1.581^{+0.658}_{-0.585} \times m_t$ with $m_t = 172.5$ GeV, and $\alpha_s^{\text{ISR}} = 0.1108^{+0.0145}_{-0.0142}$ for the new tune, CUETP8M1T4. The predictions obtained with these optimized settings are shown in Fig. 1 (right). Also, independent ME scale variations were studied along with ISR and FSR variations with several differential cross section measurements, revealing that ME scale variations affect the normalization scale factor more than the shape and they are larger than PS variations [2].

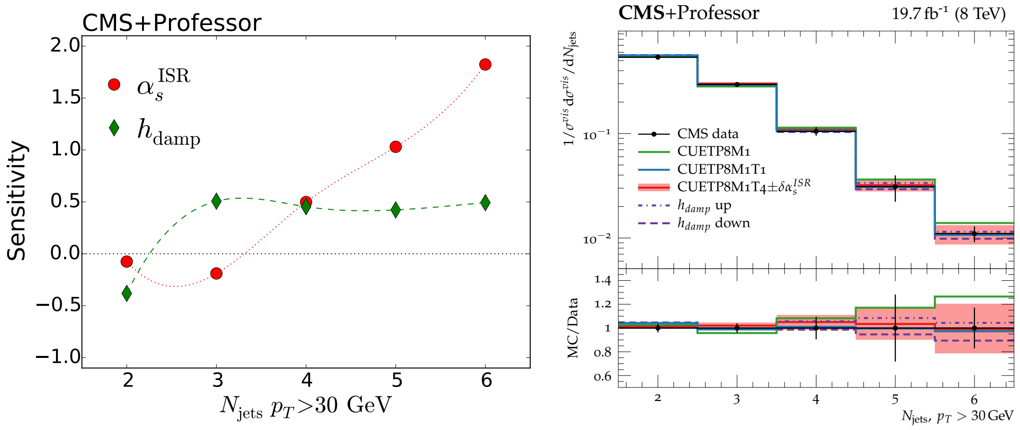

Figure 1: Sensitivity of the multiplicity of jets with $p_T > 30$ GeV to the tuning parameters (left), and the jet multiplicity distribution compared to several theoretical predictions (right) [2].

The state-of-the-art Monte-Carlo (MC) simulations for $t\bar{t}$ and single top quark production take into account the effects due to the finite width of the top quark, which are needed to predict more accurately their off-shell production and the interference with the backgrounds. However, in these calculations the identification of the top quark as an intermediate on-shell particle becomes ill-defined and the relevant observables are the final-state particles produced after the top quark decay and the evolution of the rest of the event. Therefore, future measurements will only fully benefit from these accurate predictions if they adopt a particle-level definition of the top quark. Moreover, from the experimental point of view this particle-level definition is expected to result in decreased uncertainties with respect to a definition at parton level because of the similarities between the particle level phase space definition and those imposed by the detector geometry and reconstruction requirements. Such a concept of particle-level top quarks is reviewed in Ref. [4], where also the adoption of the RIVET framework is described in the official CMS reconstruction code for the definition of particle-level objects. Using these definitions, the synchronization with standalone RIVET routines is expected to be ensured for future CMS top-quark analyses. The new particle-level definitions are used in recent measurements of differential $t\bar{t}$ production cross sections using Run 2 data [5, 6].

When performing precision measurements of top quark properties in hadron colliders, an accurate description of the fragmentation and hadronization of the quarks and of the "underlying event" (UE) is crucial. In $\mathrm{t\bar{t}}$ events, the first measurement of the UE is presented in [7].[1] This measurement provides a direct test of UE universality at smaller distance scales than those probed in minimum bias or Drell-Yan events and is furthermore relevant as a direct probe of color reconnection. Various kinematic distributions of UE are sensitive to different MC parameters. As an example, in Fig. 2 (left) the normalized differential cross section as function of charged particle multiplicity, N_{ch}, is compared to several predictions obtained by varying, according to their uncertainties, the main parameters of the MC simulation. Furthermore, sensitivity of the present results to the choice of α_s in the PS is tested by performing a scan of the χ^2 between data and theory. The most sensitive distribution is the average p_T per charged particle, $\bar{p}_T$. The variation of χ^2 as a function of α_s for the $\bar{p}_T$ distribution is reported in Fig. 2 (right), and an optimal value of α_s^{FSR} is determined.

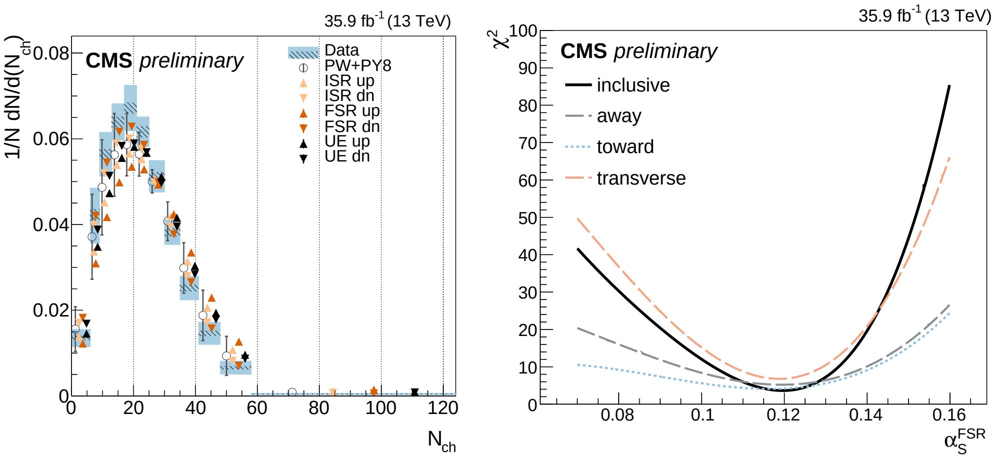

Figure 2: The normalized differential cross section as function of N_{ch} compared to theoretical predictions with varied tunable parameters (left), and scan of the χ^2 as function of the value of α_s^{FSR} when the $\bar{p}_T$ distribution measured in different regions is used (right) [7].

At the LHC energies, the fraction of $t\bar{t}$ events produced with additional hard jets in the final state is large. A measurement of jet substructure observables in $t\bar{t}$ events from proton-proton (pp) collisions at 13 TeV is presented in Ref. [9].[2]. A number of jet substructure observables have been studied. As an example, Fig. 3 presents the distribution of the jet width, λ_1^1, unfolded to the particle level for inclusive jets, compared to different MC predictions. These data have been used

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[1] Updated results are available in Ref. [8]

[2] Updated results are available in Ref. [10]

to determine an optimal value of $\alpha_s^{\rm FSR}$.

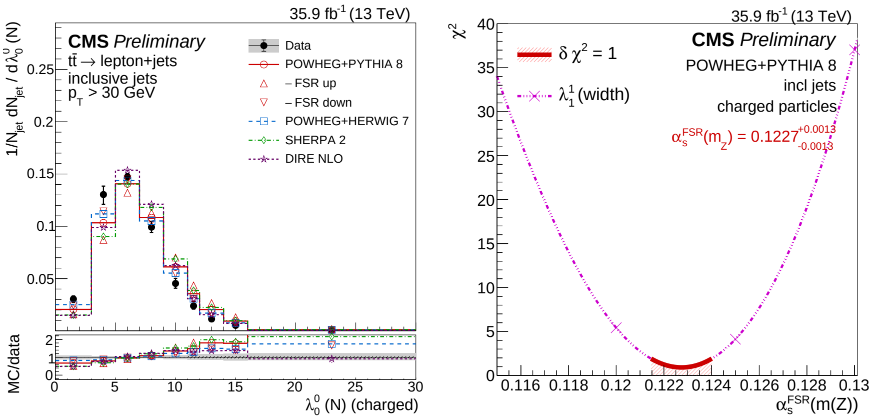

Figure 3: The jet width distribution at particle level for inclusive jets, compared to different MC predictions (left), and scan of the χ^2 as function of the value of $\alpha_s^{\rm FSR}$ using the measured jet width distribution (right) [9].

In summary, several studies of modelling and tuning of MC generators using $t\bar{t}$ events have been done in CMS using Run 1 and Run 2 data. These studies help to reduce modelling uncertainties in forthcoming LHC measurements. All analyses will be available in RIVET to facilitate their future re-interpretation.

References

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