PROCEEDINGS OF SCIENCE

Measurements of $t\bar{t}$ production and fermion associated $t\bar{t}$ production in CMS

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A set of measurements involving the $t\bar{t}$ production and the fermion associated $t\bar{t}$ production is presented. Data were recorded from proton-proton collisions at the CERN's LHC with the CMS detector, at a center-of-mass energy of 13 and 13.6 TeV. Results include the first measurement produced from the LHC Run-3 at the highest ever energy collision and the observation of four-top production, one of the rarest processes in the standard model of particle physics.

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1. Introduction

After almost thirty years after its discovery, the top quark is still offering unique opportunities in the field of high energy particle physics. Many processes involving top quark production allow to test different aspects of the standard model (SM) with very precise measurements and at the same time, new physics scenarios can be investigated via searches or effective field theory interpretations. This contribution presents the most recent results from the CMS Collaboration [1] involving the $t\bar{t}$ production and the fermion associated $t\bar{t}$ production.

2. Inclusive $t\bar{t}$ cross section

The Run-3 at the LHC started in July 2022 with a center-of-mass energy of 13.6 TeV, the highest ever collision energy produced in a particle collider. The CMS Collaboration performed the first measurement with data collected in 2022 [2]: the $t\bar{t}$ cross section has been measured inclusively with high precision using only 1.21 fb^{-1} of integrated luminosity. A profile likelihood fit is performed on the jet multiplicity in lepton and b-jet categories, as shown in of Figure 1. Novel techniques have been developed to extract b-jet efficiencies directly from the fit and the lepton channels of the $t\bar{t}$ decay (single and double) are measured simultaneously for the first time. The measured inclusive cross section is equal to $882 \pm 23(\text{stat.} + \text{syst.}) \pm (\text{lumi})$ pb, in agreement with the SM prediction of 921^{+29}_{-37} pb.

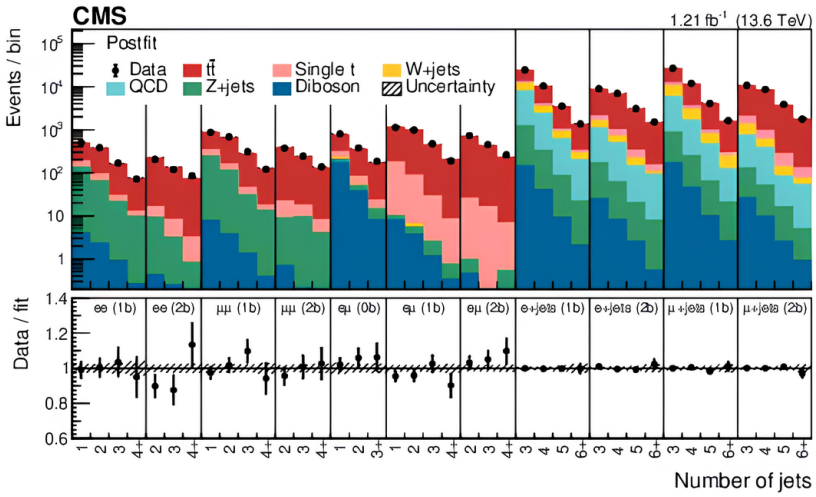

Figure 1: Post-fit distributions of the jet multiplicity, used to extract the $t\bar{t}$ cross section. All the different lepton and b-jet categories are shown in the plot [2].

3. Exclusive $t\bar{t}$ production

In the exclusive $t\bar{t}$ production mode, the two protons remain intact and are detected in the forward region of the detector, while the two top quarks are produced from photons emitted through Bremsstrahlung radiation or pomeron exchange. It is a really rare process with an expected cross

section of the order of 0.1 fb in the SM and its observation is only expected with HL-LHC. However, these events have been already investigated with data recorded with the CMS detector in 2017 [3], as new physics scenarios could enhance the production cross section. Intact protons in the final state are reconstructed with the CMS-TOTEM Precision Proton Spectrometer [4], an array of movable devices installed along the LHC ring. A boosted decision tree (BDT) has been trained to separate signal and background, which is mainly composed by inclusive $t\bar{t}$ and single top events; channels with one and two leptons are considered. The observed limit on the signal cross section is found to be equal to 0.59 pb and it is extracted with a binned fit to the BDT output. Even though the observed limit is orders of magnitude away from the cross section predicted in the SM, the techniques developed in this analysis to reconstruct the exclusive $t\bar{t}$ system will be useful for future studies involving this rare process.

4. Inclusive and differential $t\bar{t}b\bar{b}$

The associated production of top and bottom quark pairs provides an important test for perturbative QCD and parton shower calculations. The most precise measurement of the inclusive $t\bar{t}b\bar{b}$ cross section has been performed with Run-2 data exploiting events with one lepton and at least five jets, three of which are required to be b-tagged [5]. The inclusive cross section is extracted in different phase space regions, each one targeting a different aspect in the modeling of $t\bar{t}b\bar{b}$ (Figure 2). Differential cross section distributions are also tested for different generators as function of two

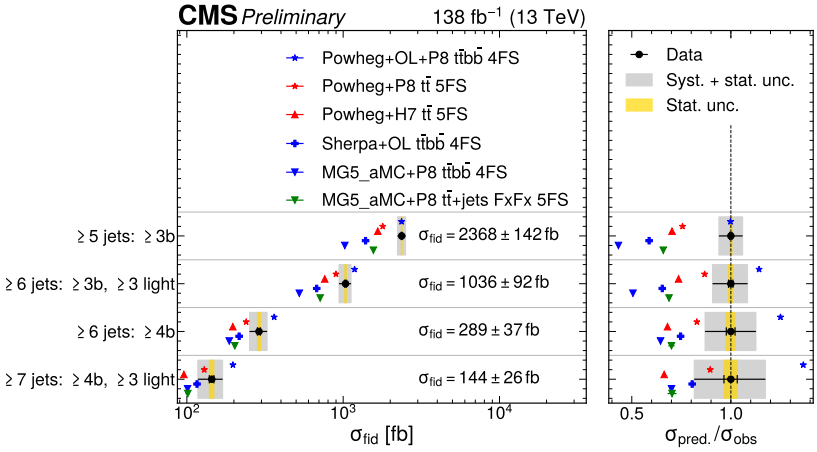

Figure 2: Observed and expected inclusive $t\bar{t}b\bar{b}$ cross sections for different simulation approaches and phase spaces. The blue color refers to models using massive b quarks and NLO QCD $t\bar{t}b\bar{b}$ matrix elements, while red is used for inclusive $t\bar{t}$ generators with massless b quarks [5].

different classes of observables: in the first case, no method is used to identify the additional b-jets (not coming from the decays of the top quarks); in the second case, a multivariate algorithm is used, which leads to more accurate results but depends on the event generator. As an example, the normalized differential cross section is shown in Figure 3 as function of two observables belonging to the different classes.

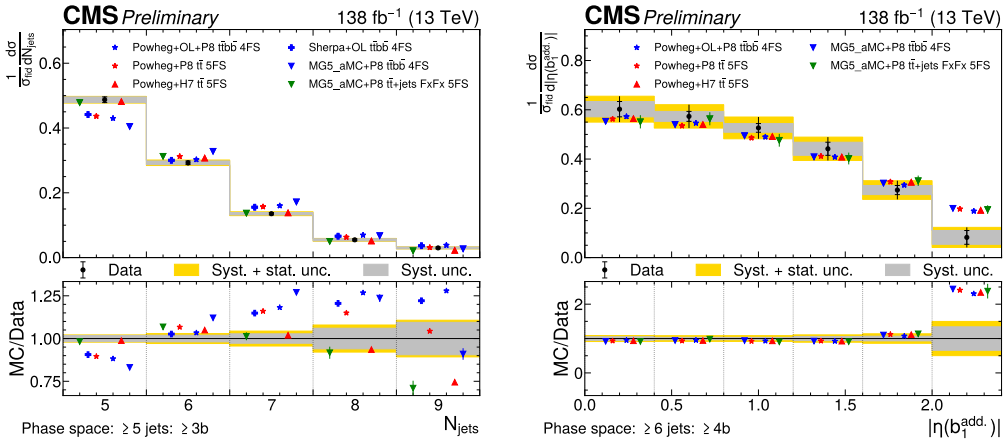

Figure 3: Normalized differential cross sections of $t\bar{t}b\bar{b}$ as function of the jet multiplicity (left) and the pseudorapidity of the leading additional b-jet (right). In the second case, a multivariate algorithm is used to identify the additional b quark pair [5].

5. Four-top quark production

The four-top quark production is one of the rarest process in the SM due to its heavy final state. While previous analyses on this process were focusing on dilepton and multilepton decay channels, the all-hadronic final state has been recently included as well [6]. Combined with earlier results in other final states, the analysis led to the evidence of the four-top quark production by the CMS experiment, with an observed significance equal to 4.0 standard deviations (3.2 expected).

The most recent CMS result on four-top quark production [7] focuses again on the dilepton and multilepton channels in Run-2 data, exploiting multivariate algorithms for lepton and b-jet identification and therefore improving the signal to background discrimination. A BDT is trained and used to extract the significance of the process, which is found to be equal to 5.5 standard deviations (4.9 expected), resulting in the observation of the four-top production by the CMS experiment. The measured cross section is $17.9^{+3.7}_{-3.5}\,(\text{stat.})^{+2.4}_{-2.1}\,(\text{syst.})$ fb, in agreement with the SM prediction of $13.4^{+1.0}_{-1.8}$ fb.

6. Conclusions

A comprehensive overview of the latest CMS results involving the $t\bar{t}$ production and the fermion associated $t\bar{t}$ production has been given. All the analyses used data recorded from proton-proton collisions at the CERN's LHC, with a center-of-mass energy of 13 and 13.6 TeV. Results include both measurements at the precision frontier (inclusive $t\bar{t}$ and $t\bar{t}b\bar{b}$) and rare processes (exclusive $t\bar{t}$ and four-top), consisting in powerful tests for theory predictions as well as bases for new physics interpretations.

References

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