PROCEEDINGS OF SCIENCE

Measurement of inclusive and differential cross sections of $t\bar{t}$ and $t\bar{t}$ in association with heavy flavours cross sections in CMS

Javier Cuevas[a,*] **on behalf of the CMS collaboration**

[a] *Department of Physics, University of Oviedo,*
Federico García Lorca 18, Oviedo, Spain

E-mail: Javier.Cuevas@cern.ch

A comprehensive set of measurements of top quark pair production is presented at a centre-of-mass energy of 13 TeV. The measurement of the inclusive cross-section in final states with one e or μ and an hadronically decaying τ lepton is reported. The measurument of the cross section for the production of $t\bar{t}$ in association with a pair of b-jets or two light jets using different final states is presented. A measurement is reported of differential $t\bar{t}$ production cross sections, where top quarks are produced at large transverse momenta.

The Eighth Annual Conference on Large Hadron Collider Physics-LHCP2020
25-30 May, 2020
online

*Speaker

PoS(LHCP2020)068

1. Introduction

Measurements of top quark pair ($t\bar{t}$) production are important for checking the validity of the standard model (SM) and searching for new phenomena.

In this document, I present a review of the most recent results of $t\bar{t}$ production performed by CMS [1] using data from the LHC at a centre-of-mass energies of 13 TeV corresponding to an integrated luminosity of 35.9 fb^{-1}. They include dilepton final states containing one tau lepton, $t\bar{t}$ produced in association with b quarks ($t\bar{t}b\bar{b}$) in different final states, and differential top quark pair ($t\bar{t}$) production cross sections, where top quarks are produced at large transverse momenta.

2. Measurement of the top quark pair production cross section in dilepton final states containing one τ lepton

The $t\to(\tau\nu_\tau)$ b decay exclusively involves third-generation leptons and quarks which, owing to their large masses, may be particularly sensitive to beyond SM contributions.

The cross section of top quark pair production is measured in the $t\bar{t} \to (\ell\nu_\ell)(\tau_h\nu_\tau)b\bar{b}$ final state [2], where τ_h refers to the hadronic decays of the lepton, and ℓ is either an electron or a muon.

The $t\bar{t}$ production cross section is extracted from a profile likelihood ratio (PLR) fit of the binned distribution of the transverse mass (m_T) of the lepton and p_T^{miss} in two kinematic event categories, for each of the $e\tau_h$ and $\mu\tau_h$ final states. The m_T distributions of the selected events are shown in Fig. 1, for $\mu\tau_h$ final states.

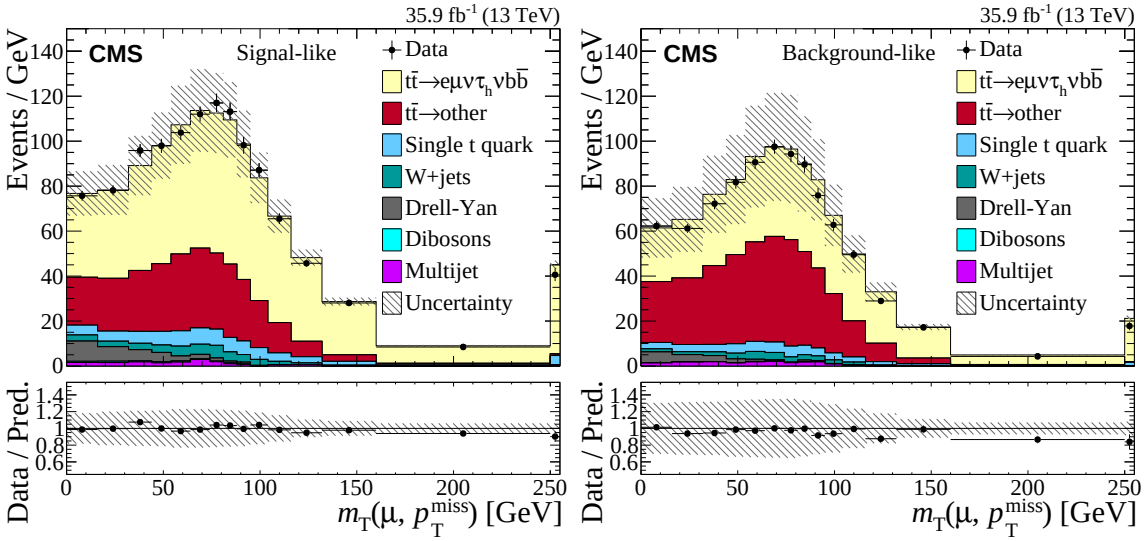

Figure 1: The transverse mass distributions between μ and p_T^{miss}, m_T, in the signal-like (left) and background-like (right) event categories observed prior to fitting. Distributions obtained from data (filled circles) are compared with simulation (shaded histograms). The ratio of the data to the total SM prediction is shown in the lower panel. The vertical bars on the data points indicate the statistical uncertainties, the hatched band indicates the systematic uncertainties and the statistical uncertainties in all simulated samples [2].

A good shape agreement is observed between the data and the expected sum of signal and background distributions. The measured cross section is $\sigma_{t\bar{t}} = 781 \pm 7\,(\text{stat.}) \pm 62\,(\text{syst.}) \pm 20\,\text{pb}$, and

the ratio of the partial width $\Gamma(\rightarrow \tau\nu_\tau \mathrm{b})$ to the total decay width of the top quark is measured to be 0.1050±0.0009 (stat.)±0.0071 (syst.). This is the first measurement of the $\mathrm{t\bar{t}}$ production cross section in proton-proton collisions at $\sqrt{s} = 13$ TeV that explicitly includes τ leptons. The ratio of the cross sections in the $\ell\tau_h$ and $\ell\ell$ final states yields a value $R_{\ell\tau_h/\ell\ell} = 0.973 \pm 0.009\,(\text{stat.}) \pm 0.066\,(\text{syst.})$, consistent with lepton universality.

3. Measurement of the cross section for $\mathrm{t\bar{t}}$ production with additional jets and b jets in pp collisions at $\sqrt{s} = 13$ TeV

The production of top quark-antiquark pairs in association with two inclusive jets, $\mathrm{t\bar{t}jj}$, and the special case of $\mathrm{t\bar{t}}$ production in association with a $\mathrm{b\bar{b}}$ pair ($\mathrm{t\bar{t}b\bar{b}}$) are interesting from theoretical and experimental points of view. The experimental measurements of the production cross sections for $\mathrm{pp} \rightarrow \mathrm{t\bar{t}jj}$ and $\mathrm{pp} \rightarrow \mathrm{t\bar{t}b\bar{b}}$ provide a useful test of next to leading order (NLO) QCD calculations that suffer from large uncertainties in the choice of factorization and renormalization scales because of the presence of two very different scales, the top quark mass (m_t) and the jet transverse momentum (p_T), that both play a role in these processes.

The measurements are performed in a fiducial phase space and extrapolated to the full phase space, separately for the dilepton, lepton+jets [3] and all-hadronic [4] channels, where lepton corresponds to either an electron or a muon. The measurements of the cross sections for the dilepton channel and their ratio in the FPS are shown in Fig. 2 left and for the all-hadronic channel are shown in Fig. 2 right.

For the all-hadronic channel, the cross section is determined for the total phase space to be $5.5 \pm 0.3\,(\text{stat.})^{+1.6}_{-1.3}\,(\text{syst.})$ pb and also measured for two fiducial $\mathrm{t\bar{t}b\bar{b}}$ definitions. The results of the measurements in the fiducial phase space for the dilepton and lepton+jets channels, respectively, are $\sigma_{\mathrm{t\bar{t}jj}} = 2.36 \pm 0.02\,(\text{stat.}) \pm 0.20\,(\text{syst.})$ pb and $31.0 \pm 0.2\,(\text{stat.}) \pm 2.9\,(\text{syst.})$ pb, and for the cross section ratio $0.017 \pm 0.001\,(\text{stat.}) \pm 0.001\,(\text{syst.})$ and $0.020 \pm 0.001\,(\text{stat.}) \pm 0.001\,(\text{syst.})$.

These measurements are the most precise to date and are consistent, within the uncertainties, with the standard model expectations obtained using a matrix element calculation at next-to-leading order in quantum chromodynamics matched to a parton shower.

4. Measurement of differential $\mathrm{t\bar{t}}$ production cross sections using top quarks at large transverse momenta in pp collisions at $\sqrt{s} = 13$ TeV

The measurement uses events where at least one top quark decays as $\mathrm{t} \rightarrow \mathrm{Wb} \rightarrow \mathrm{q\bar{q}'b}$ and is reconstructed as a large-radius jet with transverse momentum in excess of 400 GeV [5]. The second top quark is required to decay either in a similar way, or leptonically, as inferred from a reconstructed electron or muon, a bottom quark jet, and a missing transverse momentum due to the undetected neutrino.

The cross section is extracted as a function of kinematic variables of individual top quarks or of the $\mathrm{t\bar{t}}$ system. The results are presented at the particle level, within a region of phase space close to that of the experimental acceptance, and at the parton level, and are compared with theory using the POWHEG matrix element generator, interfaced to either PYTHIA or HERWIG++ for the underlying event and parton showering, and with the MG5_aMC@NLO matrix element generator, interfaced to

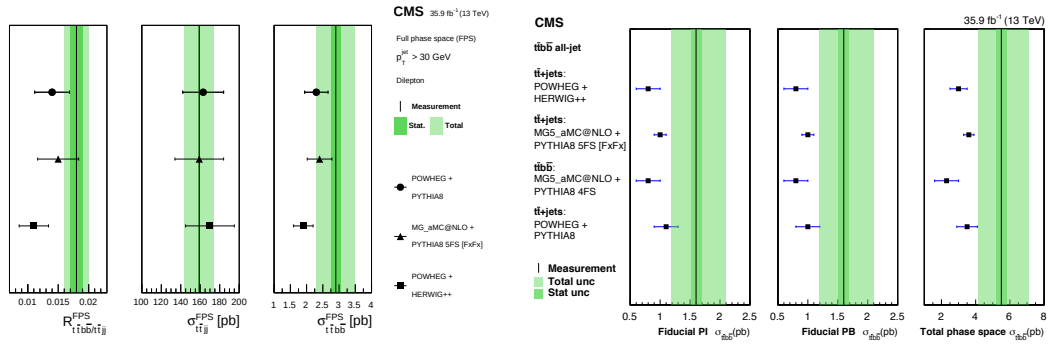

Figure 2: (left) Measured values (vertical lines) of the $\mathrm{t\bar{t}b\bar{b}}$ and $\mathrm{t\bar{t}jj}$ cross sections and their ratio, along with their statistical and total uncertainties (dark and light bands) in the dilepton channel in the FPS. The uncertainties in the MC predictions are a combination of the statistical, μ_F/μ_R scale, and PDF components [3]. (right) Comparison of the measured $\mathrm{t\bar{t}b\bar{b}}$ production cross sections (vertical lines) in the all-jets channel with predictions from several Monte Carlo generators (squares), for three definitions of the $\mathrm{t\bar{t}b\bar{b}}$ regions of phase space: fiducial parton-independent (left), fiducial parton-based (middle), total (right). The dark (light) shaded bands show the statistical (total) uncertainties in the measured value [4].

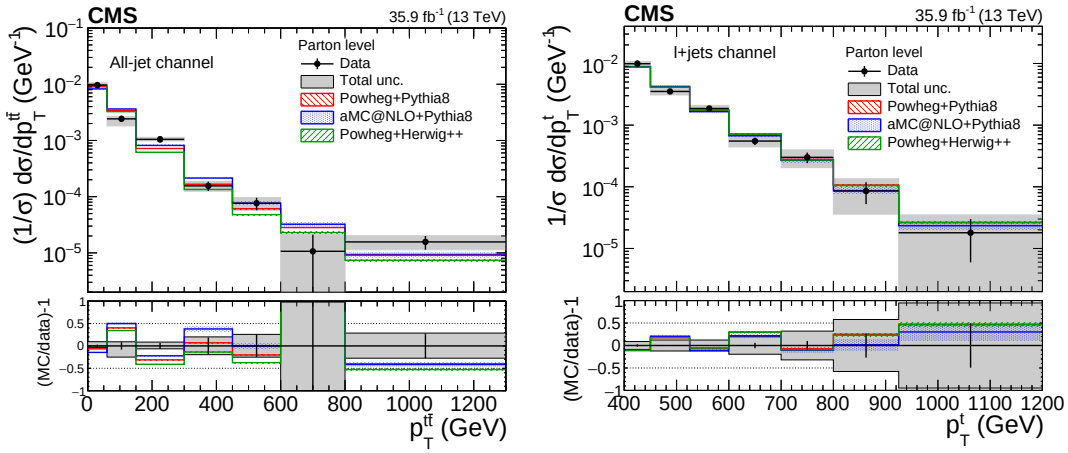

Figure 3: Differential cross section unfolded to the parton level, normalized, as a function of $p_{\mathrm{T}}^{\mathrm{t\bar{t}}}$, (left) in the all-jet channel (right) in the ℓ+jets channel. The vertical bars on the data and in the ratio represent the statistical uncertainty in data, while the shaded band shows the total statistical and systematic uncertainty added in quadrature.The lower panels show the deviation from the ratio (MC/data) from 1 [5].

PYTHIA. The unfolded cross sections at the parton level for the all-jet and l+jets channels are shown in Fig. 3 as a function of $p_{\mathrm{T}}^{\mathrm{t\bar{t}}}$ and the leading top quark p_{T} respectively.

All the models significantly exceed the absolute cross section in the phase spaces of the measurements. However, the normalized differential cross sections are consistently well described. The most notable discrepancies are observed in the invariant mass of the $\mathrm{t\bar{t}}$ system and the subleading top quark p_{T} in the all-jet channel, where theory predicts a higher cross section at high mass and at high p_{T}, respectively. To further investigate the severity of this discrepancy, more data are needed to enhance the statistical significance of the measurement in this region of phase space.

References

[1] CMS Collaboration, *JINST* 3, **S08004** (2008)

[2] CMS Collaboration, *JHEP* **02** (2020) 191.

[3] CMS Collaboration, *JHEP* **07** (2020) 125.

[4] CMS Collaboration, *PLB* **803** (2020) 135285.

[5] CMS Collaboration, arXiv:2008.07860