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Top quark cross sections in CMS

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Abstract

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TOP QUARK CROSS SECTIONS IN CMS

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Recent measurements of top quark pair production and single top quark production in pp collisions at the CMS experiment are presented. These proceedings focus on the measurement of top quark pair production at 5 TeV center-of-mass energy, mesurements of top quark pair production in the full kinematic range at 13 TeV, and the measurement of single top quark production associated with a W in the lepton+jets channel at 13 TeV. The status of related measurements is briefly outlined.

1 Introduction

The top quark, with a mass $m_t \approx 173$ GeV, is the heaviest of the discovered elementary particles. Since its coupling to the Higgs boson is of order 1, the top quark plays a major role in many extensions beyond the Standard Model (SM). The LHC produces top quarks in abundance in pp collisions, owing to very large value of the gluon parton distribution function (pdf) in the proton at high momentum transfer. From Tevatron ($\sqrt{s} = 1.96$ TeV) to the LHC Run 2 ($\sqrt{s} = 13$ TeV), top quark pair ($\mathrm{t\bar{t}}$) and single top production profit from an increase of a factor above 100 in cross section. In addition, the large increase in delivered integrated luminosity makes it possible to perform exquisite measurements of $\mathrm{t\bar{t}}$ and single top production.

2 Measurement of top quark pair cross sections at CMS

2.1 Status of top quark pair production measurements

The top quark decays to bW before it can hadronize, and the W boson can decay leptonically or hadronically. Measurements of inclusive $\mathrm{t\bar{t}}$ cross sections ranging from $\sqrt{s} = 5.02$ TeV to $\sqrt{s} = 13$ TeV were performed at CMS [1] in the dilepton, lepton+jets and all-hadronic final states. Best relative precisions achieved are below 4%.

Nowadays, multi-differential cross sections are measured at the CMS experiment at 13 TeV, for instance in the dilepton channel[2]. Measurements of $\mathrm{t\bar{t}}$ cross sections are a test of perturbative Quantum Chromodynamics (pQCD). They can be used to constrain the strong coupling constant α_S, measure the top quark mass, or constrain pdfs.

In the all-hadronic final state, where the QCD background is difficult to control, measurements were performed in the boosted regime, at high top quark p_{T} [3].

2.2 *Top quark pair production at 5 TeV*

The inclusive cross section for $\mathrm{t\bar{t}}$ process has been recently measured in the eμ channel at 5.02 TeV pp collisions, using a luminosity of 304 pb^{-1} of 2017 data [4]. Isolated leptons are required to satisfy $p_{\mathrm{T}} > 20$ (leading lepton) and $p_{\mathrm{T}} > 10$ GeV (subleading lepton) with a pseudorapidity $|\eta| < 2.4$ (2.5) for electrons (muons), and the dilepton mass must be $m_{\mathrm{e}\mu} > 20$ GeV to suppress conversions and low-mass resonances. At least two jets with $p_{\mathrm{T}} > 25$ GeV within $|\eta| < 2.4$ are required.

The Drell-Yan background is estimated from data, using control regions with same flavour leptons. Single top tW and diboson processes are estimated from simulation. The $\mathrm{t\bar{t}}$ yield is corrected for detector efficiencies, geometrical acceptance, and branching ratios. Largest systematic uncertainties arise from jet energy scale, Drell-Yan background estimation, and the estimate of the integrated luminosity. The measured cross section is $\sigma_{t\bar{t}} = 60.3 \pm 5.0$ (stat) ± 2.8 (syst) ± 0.9 (lumi) pb. This measurement is combined with a previous measurement of $\mathrm{t\bar{t}}$ process in the lepton+jets channel at 5.02 TeV using 28 pb^{-1} of 2015 data, resulting in $\sigma_{t\bar{t}} = 62.6 \pm 4.1$ (stat) ± 3.0 (syst+lumi) pb. The results are shown, together with other CMS $\mathrm{t\bar{t}}$ measurements, in Fig. 1.

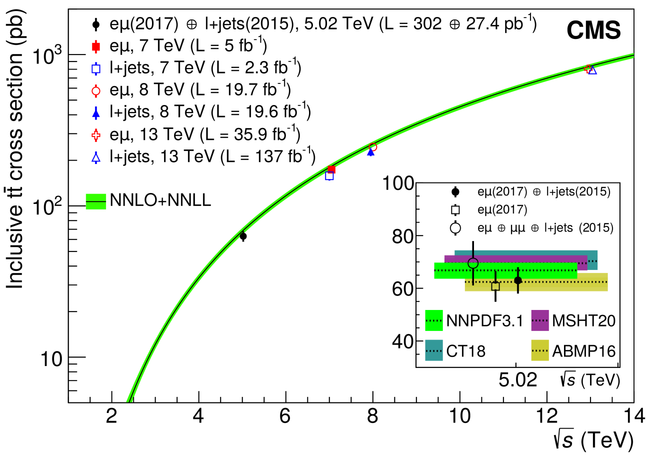

Figure 1 – Inclusive $\mathrm{t\bar{t}}$ cross sections measured at CMS. The black dot represents the measurement described in this section [4].

2.3 *Measurement of top quark pair production in the full kinematic range at 13 TeV*

Differential cross sections for top quark pair production are measured in the full kinematic range at 13 TeV with an integrated luminosity of 137 fb^{-1}, in the lepton+jets channel [5]. This measurement combines low-p_{T} analysis (resolved top quark decay products) with high-p_{T} analysis, where top quark decay products overlap.

At least one isolated electron or muon must be reconstructed, with $p_{\mathrm{T}} > 30$ GeV and $|\eta| < 2.4$. Resolved jets, reconstructed with the anti-k_t algorithm with a parameter of 0.4, are also required to satisfy $p_{\mathrm{T}} > 30$ GeV within $|\eta| < 2.4$.

Four event categories are defined:
- "2t": Among the jets, there must be at least two jets identified as b jets with a tight criterion.
- "1t1l": Among the jets, there must be one jet identified as b jets with a tight criterion, and a second jet identified with a looser criterion.

In the "2t" and "1t1l" categories, the top quark system is reconstructed assuming "resolved" reconstruction, where each of the decay products are identified with a reconstructed particle in

the event. A quadratic equation is solved to find missing information on the neutrino. Jets are assigned using a likelihood method.
- "BHRL" (boosted hadronic resolved leptonic): there must be one jet reconstructed with the anti-k_t algorithm with a parameter of 0.8, with $p_{\mathrm{T}} > 400$ GeV and $|\eta| < 2.4$, and a jet mass $m_j > 120$ GeV (boosted hadronic top candidate). The PUPPI algorithm is used for pileup mitigation. A neural network is used to identify the subjets arising from the top quark.
- "BHBL"(boosted hadronic boosted leptonic): a boosted hadronic top candidate must be reconstructed, accompanied with a boosted leptonic top candidate, which is reconstructed by requiring a non-isolated lepton with $p_{\mathrm{T}} > 50$ GeV close to a jet, identified with a neural network trained to identify leptons arising from a W boson against multi jet background.

The categories are exclusive. The resulting spectra are presenting a smooth transition between resolved and boosted regimes. The distributions are unfolded for detector effects within a fiducial volume as close as possible to the recontructed criteria. The systematic uncertainties are estimated by repeating the fit with varied response matrix. Figure 2 shows the differential distributions for hadronic and leptonic top p_{T}, as an example.

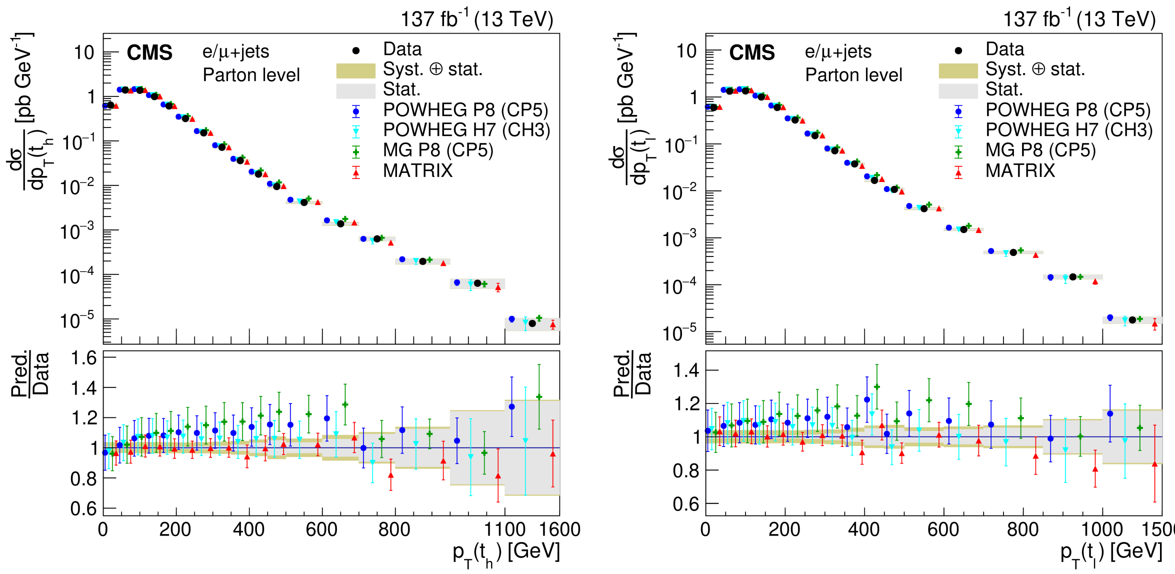

Figure 2 – Differential distributions for hadronic and leptonic top p_{T} [5]

3 Measurements of single top cross sections at CMS

3.1 Status of single top production measurements

Single top quark production can be produced in t channel (largest cross section at the LHC), in association with a W boson or in the s channel. Measurements in the t channel at CMS are able to provide differential cross sections as well as ratios of differential cross sections between top and antitop production [6]. The tW channel is measured differentially in the dilepton channel [7]. The s channel is yet to be observed at the LHC. In addition, measurements of single top in association with a photon or a Z boson have been performed.

3.2 Measurement of single top tW production in lepton+jets channel

The inclusive cross section for single top tW production is measured in the lepton+jets channel at 13 TeV for the first time, using 36 fb^{-1} of pp 2016 data [8]. Events with a single muon (electron) having $p_{\mathrm{T}} > 26(30)$ GeV are selected. Jets with $p_{\mathrm{T}} > 30$ GeV are required to be away from leptons. Exactly one jet identified as b jet is required.

Three regions are defined: 2 jets (W boson control region), 3 jets (signal region) and 4 jets ($t\bar{t}$ control region). A boosted decision tree (BDT) is trained against $t\bar{t}$ background, exploiting the difference in jet kinematics relative to the signal. The signal is extracted by a simultaneous fit in the three regions. An illustration of the BDT output is shown in Fig. 3.

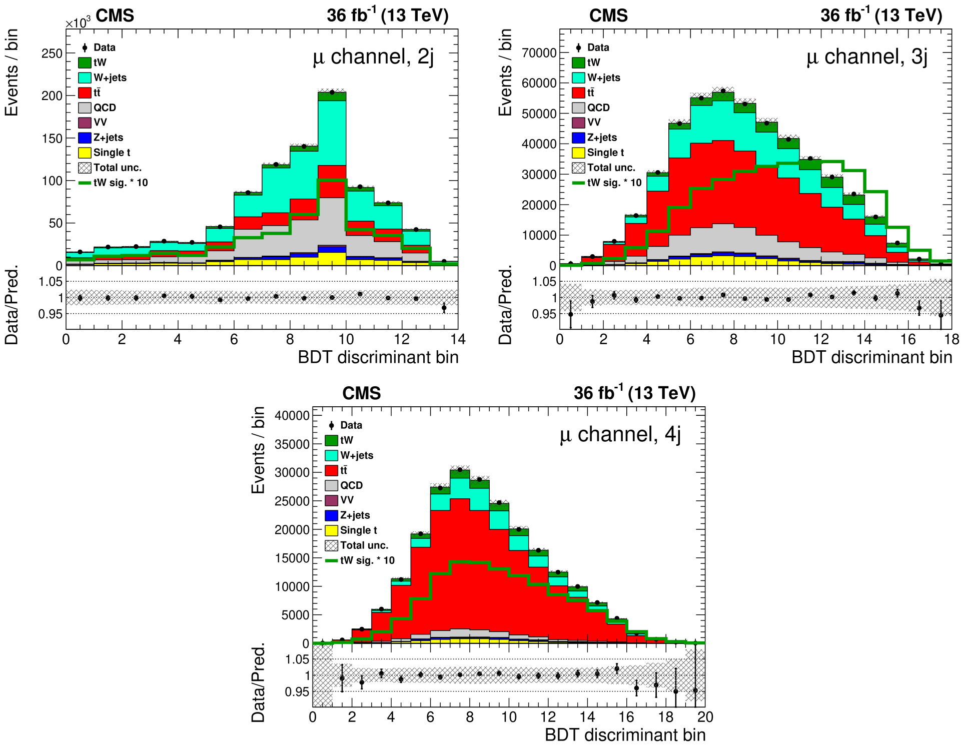

Figure 3 – Boosted decision tree in the three event categories, for the muon channel [8].

The result is the first observation (with more than 5σ) of tW process in the lepton+jet channel, with a cross section $\sigma_{\mathrm{tW}} = 89 \pm 4$ (stat) ± 12 (syst) pb. The largest systematic uncertainties arise from the QCD jets and W+jets background normalization, the jet enenegy scale, the b-tagging efficiency.

4 Summary

Recent measurements of $t\bar{t}$ and single top cross sections have been discussed. Thanks to the large number of top quark pair produced, measurements of $t\bar{t}$ cross sections are now multi-differential and extend into the boosted regime. Observations of more difficult decay channels for single top processes are now performed.

References

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