CMS Draft Analysis Note

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Measurement of the top-anti-top differential production cross section of high transverse momentum top quarks in the all-hadronic final state using the full Run II proton-proton collision data at sqrt(s) = 13 TeV.

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Abstract

A measurement of the production cross section of high transverse momentum (p_T) top quark pairs is reported. The dataset was collected during the full Run II with the CMS detector at the CERN LHC from proton-proton collisions at a center-of-mass energy of 13 TeV. The measurement uses events where either both top quark candidates decay hadronicallya nd are reconstructed as large-R jets with $p_T > 400$GeV.The cross section is extracted differentially as a function of kinematic variables of the top quark or top quark pair system. The results are unfolded to the particle and parton levels, and are compared to various theoretical models.

Contents

1 Introduction

The top quark completes the third generation of quarks in the standard model (SM), and the precise knowledge of its properties is critical for the overall understanding of the theory. Measurements of the top-anti-top quark pair ($\mathrm{t\bar{t}}$) production cross section confront the predictions from quantum chromodynamics (QCD) and have the potential to constrain the QCD parameters, while being sensitive to physics beyond the SM. Also, the $\mathrm{t\bar{t}}$ production process is a dominant SM background to searches for new physics phenomena and therefore its precise knowledge is essential for new discoveries.

The large $\mathrm{t\bar{t}}$ yield expected in proton-proton (pp) collisions at the CERN LHC allows to perform measurements of the $\mathrm{t\bar{t}}$ production rate in a large phase space, and, more importantly, differentially, as a function of the $\mathrm{t\bar{t}}$ kinematic properties. Such measurements have been performed by the ATLAS [1–6] and CMS [7–15] Collaborations at 7, 8, and 13 TeV center-of-mass energies, under the hypothesis of the resolved final state, where the decay products of the $\mathrm{t\bar{t}}$ pair can be reconstructed individually. This hypothesis is valid for top quark transverse momenta, p_{T}, up to approximately 500 GeV. However, at higher p_{T} ($p_{\mathrm{T}}/m \approx 1$), the top quark decay products are highly collimated ("boosted") and they can no longer be reconstructed separately. In order to explore the highly boosted phase space, hadronic top quark decays are reconstructed as large-radius jets. Previous efforts in this domain by the ATLAS [16, 17] and CMS [18–20] Collaborations confirm that it is feasible to perform precise differential measurements of the $\mathrm{t\bar{t}}$ production and have also shown interesting deviations from the theory predictions.

In this note, a measurement of the differential boosted $\mathrm{t\bar{t}}$ production cross section in the hadronic final state is presented, using pp collisions at $\sqrt{s} = 13$ TeV recorded with the CMS detector during the 2016 LHC run and amounting to a total integrated luminosity of $35.9\,\mathrm{fb}^{-1}$. In the hadronic decay channel, each W boson arising from the top quark decays into a pair of light quarks. As a result, the final state consists of at least six partons (more are possible due to initial- and final-state radiation), two of which are b quarks. Due to the high boost considered in this measurement ($p_{\mathrm{T}} > 400$ GeV), the top quarks are reconstructed unambiguously as large-radius jets and the final state consists of at least two such jets.

2 Reconstrunction and Selection

In this section we present the objects used in the analysis, the multivariate method that discriminated $\mathrm{t\bar{t}}$ events from the QCD multijet background, and we describe the event selection.

2.1 Object Reconstruction

The leptons (muons, electrons) used in this analysis come from the default reconstructed collections in CMS samples (`'slimmedMuons'` and `'slimmedElectrons'`) and must have $p_{\mathrm{T}} > 20$ GeV. Muons are required to pass the medium ID working point and electrons must pass the tight working point, while both lepton types must have a relative mini-isolation less that 0.1.

Jets are reconstructed from particle-flow (PF) candidates. These can be further classified based on different pileup reduction techniques. In this analysis we use the PUPPI jets (Pileup Per Particle Identification). The momentum 4-vectors of the PF candidates are clustered using the anti-kt algorithm where the distance parameter R is set to $R = 0.8$. Hence we will refer to these candidates as AK8 PFPUPPI jets. The aforementioned jets are required to pass the tight jet ID. Also, an algorithm runs with purpose to identify subjets of distance parameter $R = 0.4$ within the AK8 jets. The soft-drop technique is used in order to evaluate the mass of the AK8 jet. For all the aforementioned algorithms, our group has used the default definitions in the CMS software and the default collections in the MINIAOD data and Monte Carlo samples.

The selection of the AK8 jets originating from the top (anti-top) decay relies on the identification of at least one b-jet within the respective large-R jet. For this purpose, we use the DeepCSV b-tagging algorithm that is applied on the AK4 subjets of each AK8 jet. More specifically, we use the medium working point, which reuires the value of the tagger to be greater than: 0.6321, 0.4941, 0.4184 for 2016, 2017 and 2018 respectively.

Since leptons are also reconstructed as jets, we perform a cross cleaning by removing each identified lepton from the jet collection with geometrical mathcing in the $\eta - \phi$ space: if a jet has $\Delta R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2} < 0.4$ from any accepted lepton candidate it is removed from the jet collection.

2.2 Selection

The baseline selection, summarized in Table is common for all regions used in the analysis. It requires at least two large-R jets ($R = 0.8$) in the event with $p_{\mathrm{T}} > 400\,\mathrm{GeV}$ and softDrop mass values within the range $(50, 300)\,\mathrm{GeV}$. Furthermore, a veto on the leptons is applied in order to minimze the probability to select leptonic top decays. On top of the baseline selection, we define four specific regions based on the output of our BDT (Boosted Decision Tree) that discriminates ttbar signal from QCD background, the jets' softDrop masses and the number of the b-tagged subjets in each jet, that serve different analysis purposes. The signal region (SR) is where we perform the differential measurements and it required both jets to have a b-tagged subjet, a tighter selection of the jet mass softDrop value $120 - 220\,\mathrm{GeV}$. The pure QCD control region (CR) has the same selection criteria with the aforementioned Signal Region, with the only difference being that the b-tagging requirement is reverted (the jets must not contain a b-tagged subjet). This region is used to get the QCD shape of the QCD background from the data (data driven method) for each variable of interest. Then, we employ the signal region A (SR_A), which is used to determine the normalization of the QCD background, and finally the signal region B (SR_B), which is used to constrain some of the signal modelling uncertainties.

References

[1] ATLAS Collaboration, "Measurements of top-quark pair differential cross-sections in the lepton+jets channel in *pp* collisions at $\sqrt{s} = 13$ TeV using the ATLAS detector", *JHEP* **11** (2017) 191, doi:10.1007/JHEP11(2017)191, arXiv:1708.00727.

[2] ATLAS Collaboration, "Measurements of top-quark pair differential cross-sections in the $e\mu$ channel in *pp* collisions at $\sqrt{s} = 13$ TeV using the ATLAS detector", *Eur. Phys. J.* **C77** (2017), no. 5, 292, doi:10.1140/epjc/s10052-017-4821-x, arXiv:1612.05220.

[3] ATLAS Collaboration, "Measurement of lepton differential distributions and the top quark mass in $t\bar{t}$ production in *pp* collisions at $\sqrt{s} = 8$ TeV with the ATLAS detector", *Eur. Phys. J.* **C77** (2017), no. 11, 804, doi:10.1140/epjc/s10052-017-5349-9, arXiv:1709.09407.

[4] ATLAS Collaboration, "Measurement of top quark pair differential cross-sections in the dilepton channel in *pp* collisions at $\sqrt{s}$ = 7 and 8 TeV with ATLAS", *Phys. Rev.* **D94** (2016), no. 9, 092003, doi:10.1103/PhysRevD.94.092003, arXiv:1607.07281.

[5] ATLAS Collaboration, "Differential top-antitop cross-section measurements as a function of observables constructed from final-state particles using pp collisions at $\sqrt{s} = 7$ TeV in the ATLAS detector", *JHEP* **06** (2015) 100, `doi:10.1007/JHEP06(2015)100`, `arXiv:1502.05923`.

[6] ATLAS Collaboration, "Measurements of top quark pair relative differential cross-sections with ATLAS in pp collisions at $\sqrt{s} = 7$ TeV", *Eur. Phys. J.* **C73** (2013), no. 1, 2261, `doi:10.1140/epjc/s10052-012-2261-1`, `arXiv:1207.5644`.

[7] CMS Collaboration, "Measurement of normalized differential $\mathrm{t\bar{t}}$ cross sections in the dilepton channel from pp collisions at $\sqrt{s} = 13$ TeV", *JHEP* **04** (2018) 060, `doi:10.1007/JHEP04(2018)060`, `arXiv:1708.07638`.

[8] CMS Collaboration Collaboration, "Measurements of normalised multi-differential cross sections for top quark pair production in pp collisions at $\sqrt{s} = 13$ TeV and simultaneous determination of the strong coupling strength, top quark pole mass and parton distribution functions", Technical Report CMS-PAS-TOP-18-004, CERN, Geneva, 2018.

[9] CMS Collaboration, "Measurements of $\mathrm{t\bar{t}}$ differential cross sections in proton-proton collisions at $\sqrt{s} = 13$ TeV using events containing two leptons", *Submitted to: JHEP* (2018) `arXiv:1811.06625`.

[10] CMS Collaboration, "Measurement of differential cross sections for top quark pair production using the lepton+jets final state in proton-proton collisions at 13 TeV", *Phys. Rev.* **D95** (2017), no. 9, 092001, `doi:10.1103/PhysRevD.95.092001`, `arXiv:1610.04191`.

[11] CMS Collaboration, "Measurements of differential cross sections of top quark pair production as a function of kinematic event variables in proton-proton collisions at $\sqrt{s} = 13$ TeV", *JHEP* **06** (2018) 002, `doi:10.1007/JHEP06(2018)002`, `arXiv:1803.03991`.

[12] CMS Collaboration, "Measurement of double-differential cross sections for top quark pair production in pp collisions at $\sqrt{s} = 8$ TeV and impact on parton distribution functions", *Eur. Phys. J.* **C77** (2017), no. 7, 459, `doi:10.1140/epjc/s10052-017-4984-5`, `arXiv:1703.01630`.

[13] CMS Collaboration, "Measurement of the differential cross section for top quark pair production in pp collisions at $\sqrt{s} = 8$ TeV", *Eur. Phys. J.* **C75** (2015), no. 11, 542, `doi:10.1140/epjc/s10052-015-3709-x`, `arXiv:1505.04480`.

[14] CMS Collaboration, "Measurement of the differential cross sections for top quark pair production as a function of kinematic event variables in pp collisions at $\sqrt{s}$=7 and 8 TeV", *Phys. Rev.* **D94** (2016), no. 5, 052006, `doi:10.1103/PhysRevD.94.052006`, `arXiv:1607.00837`.

[15] CMS Collaboration, "Measurement of differential top-quark pair production cross sections in pp colisions at $\sqrt{s} = 7$ TeV", *Eur. Phys. J.* **C73** (2013), no. 3, 2339, `doi:10.1140/epjc/s10052-013-2339-4`, `arXiv:1211.2220`.

[16] ATLAS Collaboration, "Measurements of $t\bar{t}$ differential cross-sections of highly boosted top quarks decaying to all-hadronic final states in pp collisions at $\sqrt{s} = 13$ TeV using the

ATLAS detector”, *Phys. Rev.* **D98** (2018), no. 1, 012003, doi:10.1103/PhysRevD.98.012003, arXiv:1801.02052.

[17] ATLAS Collaboration, “Measurement of the differential cross-section of highly boosted top quarks as a function of their transverse momentum in $\sqrt{s}$ = 8 TeV proton-proton collisions using the ATLAS detector”, *Phys. Rev.* **D93** (2016), no. 3, 032009, doi:10.1103/PhysRevD.93.032009, arXiv:1510.03818.

[18] CMS Collaboration Collaboration, “Measurement of the $\mathrm{t\bar{t}}$ production cross section at 13 TeV in the all-jets final state”, Technical Report CMS-PAS-TOP-16-013, CERN, Geneva, 2016.

[19] CMS Collaboration, “Measurement of the integrated and differential $t\bar{t}$ production cross sections for high-p_t top quarks in pp collisions at $\sqrt{s} = 8$ TeV”, *Phys. Rev.* **D94** (2016), no. 7, 072002, doi:10.1103/PhysRevD.94.072002, arXiv:1605.00116.

[20] CMS Collaboration Collaboration, “Measurement of the differential $\mathrm{t\bar{t}}$ cross section with high-p_{T} top-quark jets in the all-hadronic channel at $\sqrt{s} = 8$ TeV”, Technical Report CMS-PAS-TOP-16-018, CERN, Geneva, 2017.