PROCEEDINGS OF SCIENCE

Search for central exclusive production of top quark pairs with the CMS and TOTEM experiments

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A search for central exclusive production of top quark pairs ($\mathrm{t\bar{t}}$) is presented using collision data collected by CMS and the CMS-TOTEM Precision Proton Spectrometer in 2017. A data-driven method to estimate the background from coincidences of inclusive events and pileup protons is described, as well as the development of a Boosted Decision Tree classifier to separate the exclusive $\mathrm{t\bar{t}}$ signal from the inclusive $\mathrm{t\bar{t}}$ background. The first-ever upper limits on the cross section of exclusive $\mathrm{t\bar{t}}$ are shown.

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1. Introduction

In central exclusive production (CEP) processes at the LHC, the incoming protons do not dissociate during the interaction but lose energy by exchanging high energy photons or gluons. The energy lost in the interaction is used to create a system of particles X. In the case of this work, X is a top quark and antiquark pair ($\mathrm{t\bar{t}}$). Intact protons can be tagged using dedicated near-beam detectors, such as the CMS-TOTEM Precision Proton Spectrometer (CT-PPS) [3], described in the next section.

The CEP of $\mathrm{t\bar{t}}$ is predicted to occur at LHC with very low cross section (order of 0.3 fb [4]). As the process is sensitive to the electroweak top-quark-photon coupling, it can be used to look for new physics in EFT or anomalous couplings frameworks [5].

This work reports the the first-ever search for this process. We have used data collected by CMS and CT-PPS in 2017 to set an upper limit on the production cross section of CEP of $\mathrm{t\bar{t}}$ [2]. The $\mathrm{t\bar{t}}$ dilepton and lepton+jets decay modes are explored.

2. Tagging protons with CT-PPS

CT-PPS is a set of near-beam detectors which can measure protons that leave intact from the CMS interaction point (IP). The detectors are located at ≈200 m from the IP, on both sides of CMS.

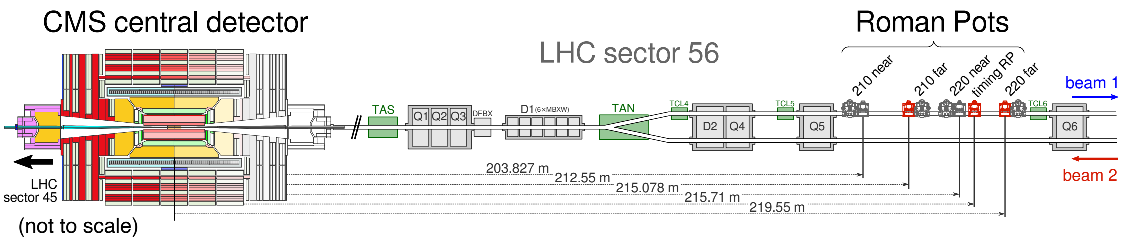

Figure 1: A schematic layout of one arm of CT-PPS along the LHC beam line. The Roman Pots shown in red are those used by CT-PPS; those in grey are part of the TOTEM experiment. From [2].

A scheme of one of the arms of CMS, showing the location of the CT-PPS detector stations - Roman Pots (RP) - is shown in Fig. 1. With the CT-PPS setup in 2017, we can measure protons that lost 2-20% of their momentum, which translates into an acceptance starting at $M_{\mathrm{X}} \approx 300$ GeV. The fractional momentum loss ξ of the protons can be obtained from the proton track positions (details can be found in [6]).

3. Analysis strategy

3.1 Event selection

Physics objects in the CMS detector are reconstructed based on the particle-flow (PF) algorithm. A series of transverse momentum (p_{T}) and absolute pseudorapidity ($|\eta|$) requirements are applied to the charged leptons (electrons and muons) and jets, as well as further offline quality requirements. Jets originating from b hadrons are identified using a machine learning algorithm. Protons in

CT-PPS are reconstructed using the so-called multi RP method [6], which requires matching tracks to be found in two RP stations per arm.

In the dilepton mode, events are further required to contain exactly two charged leptons (electrons or muons) and at least 2 b-tagged jets. In the lepton+jets mode, exactly one lepton is required, as well as at least 2 b-tagged jets and at least 2 light flavour (u,d,c,s or g) jets. For both modes, exactly one proton on each arm of CT-PPS is required.

3.2 Pileup proton background modelling

Background events can emulate the signal signature, when QCD $t\bar{t}$ events get randomly associated with protons from simultaneous interactions (pileup) or from the beam halo. In the simulated signal and background samples ($t\bar{t}$, Z+jets, etc.), there is no information about pileup/halo protons. This contribution is evaluated through a data-driven estimation. A large sample of events with exactly 2 protons is extracted from data, and the proton information from these events is randomly matched with events from the simulated samples, creating "mixed" samples with pileup proton information.

3.3 Discrimination between signal and QCD $t\bar{t}$ background

For each mode, a Boosted Decision Tree (BDT) algorithm is trained to separate the signal from the non-exclusive backgrounds. As input variables, the kinematics of leptons and jets are used, as well as the kinematic variables obtained from proton reconstruction, and the ones obtained by reconstructing of the $t\bar{t}$ system.

The resulting BDT distributions for each of the channels can be found in Fig. 2.

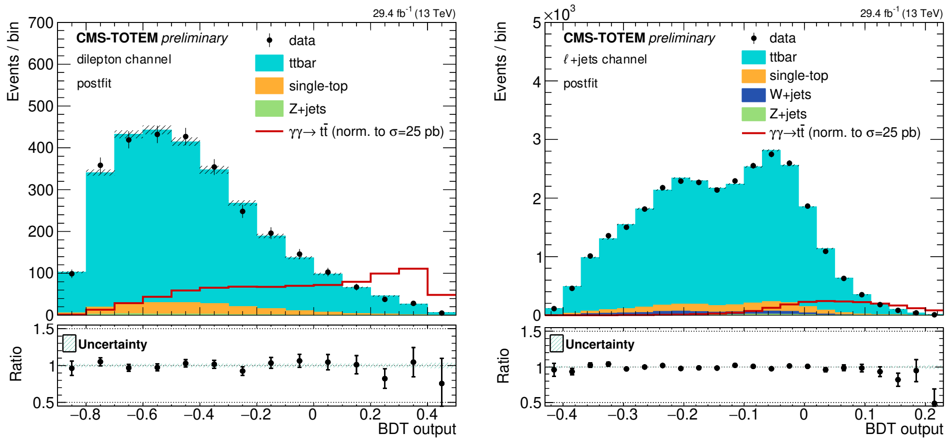

Figure 2: Distribution of the BDT output in the signal region for data and for simulated events after fitting to the data. Left: dilepton mode; right: lepton + jets mode. The red open histogram shows the expected distribution for signal, normalized to a cross section of 25 pb, approximately 10^5 larger than the SM cross section prediction from [4]. From [2].

3.4 Signal extraction

In the extraction of the signal strength, the statistical uncertainty is by far the dominant contribution to the overall uncertainty. Systematic uncertainties from experimental and theoretical sources are also considered and taken from simulation. The uncertainty in the data-driven background estimation is computed from data.

We set an upper limit on the production cross section of $\mathrm{pp} \to \mathrm{p}t\bar{t}\mathrm{p}$. The observed (expected) limit is found to be 0.59 pb (1.14 pb). Figure 3 shows this result.

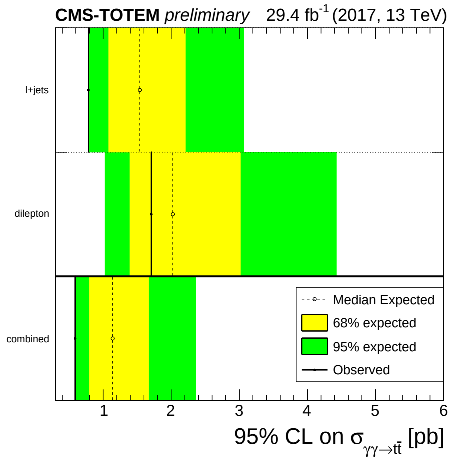

Figure 3: Expected 95% CL upper limit for the signal cross section, for the two reconstruction modes and for the combination. The green and yellow bands show the $\pm1\sigma$ and $\pm2\sigma$ intervals, respectively. From [2].

4. Conclusion

We performed a search for CEP of $\mathrm{t\bar{t}}$ using data collected by CMS and CT-PPS in 2017, resulting in the first-ever upper limit on its production cross section. The observed (expected) limit is 0.59 pb (1.14 pb).

This first study shows the potential of exploring the top quark sector using tagged protons. More data and an improved PPS setup in the Run 3 of the LHC and beyond will allow for setting more stringent limits on this process and possibly for its observation.

References

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