Search for Dark Matter Particles Produced in Association with a Top Quark Pair at $\sqrt{s} = 13$ TeV

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A search is performed for dark matter particles produced in association with a top quark pair in proton-proton collisions at $\sqrt{s} = 13$ TeV. The data correspond to an integrated luminosity of 35.9 fb^{-1} recorded by the CMS detector at the LHC. No significant excess over the standard model expectation is observed. The results are interpreted using simplified models of dark matter production via spin-0 mediators that couple to dark matter particles and to standard model quarks, providing constraints on the coupling strength between the mediator and the quarks. These are the most stringent collider limits to date for scalar mediators, and the most stringent for pseudoscalar mediators at low masses.

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Astrophysical observations strongly motivate the existence of dark matter [1–4], which may originate from physics beyond the standard model. In a large class of models, dark matter consists of stable, weakly interacting massive particles (χ) [4], which may be pair produced at the CERN LHC via mediators that couple both to dark matter particles and to standard model quarks. The dark matter particles would escape detection, thereby creating a transverse momentum imbalance ($\vec{p}_T^{\,\mathrm{miss}}$) in the event. Searches at collider experiments can offer insights on the nature of the mediator and provide constraints on dark matter masses of $\mathcal{O}(10\ \mathrm{GeV})$ and below, a region that is difficult to explore both in direct and indirect searches for dark matter. A favored class of models proposes a spin-0 mediator with standard model Higgs-like Yukawa coupling to quarks, which therefore couples preferentially to the top quark [5–9]. Consequently, in this class of models dark matter production in association with a top quark pair ($t\bar{t}$) can offer better search sensitivity compared to other modes such as production in association with a jet [10–14]. At the LHC, the $t\bar{t} + \chi\bar{\chi}$ process is probed through the signature of $t\bar{t}$ accompanied by $\vec{p}_T^{\,\mathrm{miss}}$ [15,16].

The top quark almost always decays to a W boson and a b quark. The W boson can decay leptonically (to a charged lepton and a neutrino) or hadronically (to a quark pair). The signal regions (SRs) of the search cover three $t\bar{t}$ decay modes: the all-hadronic, lepton + jets (ℓ + jets where $\ell = e, \mu$), and dileptonic (ee, $e\mu$, $\mu\mu$) final states where neither, either, or both of the W bosons decay to leptons, respectively. This Letter presents a search for $t\bar{t} + \chi\bar{\chi}$ in pp collisions at $\sqrt{s} = 13$ TeV with data recorded by the CMS experiment in 2016, corresponding to an integrated luminosity of 35.9 fb^{-1}. The analysis strategy is similar to Ref. [17], but includes additional SRs for the dileptonic mode.

The central feature of the CMS detector is a superconducting solenoid providing a magnetic field of 3.8 T. Within the solenoid volume are the silicon pixel and strip trackers, a lead tungstate crystal electromagnetic calorimeter, and a brass and scintillator hadron calorimeter. A steel and quartz-fiber Cherenkov forward hadron calorimeter extends the pseudorapidity (η) coverage. The muon system consists of gas-ionization detectors embedded in the steel flux-return yoke outside the solenoid. A two-tiered trigger system [18] selects events at a rate of about 1 kHz for storage. A detailed description of the CMS detector is provided in Ref. [19].

The event reconstruction is based on the CMS particle-flow algorithm [20], which reconstructs and identifies individual particles using an optimized combination of the detector information. The $\vec{p}_T^{\,\mathrm{miss}}$ vector is computed as the negative vector sum of the transverse momenta ($\vec{p}_T$) of all the particles in an event. Jets are formed from particles using the anti-k_T algorithm [21,22] with a distance parameter of 0.4. Corrections are applied to calibrate the jet momentum [23] and to remove energy from additional collisions in the same or adjacent bunch crossings (pileup) [24]. Jets in the analysis are required to have $p_T > 30$ GeV and $|\eta| < 2.4$, and to satisfy identification criteria [25] that minimize spurious detector effects. A combined secondary vertex b tagging algorithm [26] is used to identify jets originating from b quarks (b-tagged jets). A multivariate discriminant, the "resolved top tagger" (RTT) [17], based

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for dark matter masses of $\mathcal{O}$ (10 GeV) and below. Over much of the parameter space, the $t\bar{t}+\chi\bar{\chi}$ signature has better sensitivity for spin-0 mediators than dark matter production in association with a jet [14]—previously considered to be the most sensitive signature. For the pseudoscalar model, the $t\bar{t}+\chi\bar{\chi}$ signature provides the most stringent cross section constraints for mediator masses of around 200 GeV and below. The observed (expected) limits exclude a pseudoscalar mediator with mass below 220 (320) GeV under the $g_q = g_\chi = 1$ benchmark scenario. The $t\bar{t}+\chi\bar{\chi}$ signature provides the best sensitivity for the scalar mediator model and is currently the only collider signature that is sufficiently sensitive to exclude regions of parameter space with these values of the couplings. The observed exclusion of a mediator with mass below 160 GeV (240 GeV expected) provides the most stringent constraint to date on this model.

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