Search for dark matter with a mono-top signature at CMS

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Although evidence for dark matter has been established through cosmological observations, questions about its structure and its interactions to other particles are still unanswered. If dark matter particles interacted with ordinary matter, it could be produced in collisions of high-energetic standard model particles, e.g., in proton-proton collisions at the CERN LHC.

This talk presents results of a search for dark matter production in association with a single top quark in proton-proton collisions at the LHC using data recorded with the CMS experiment between 2016 and 2018. The search exploits the "mono-X" strategy which assumes that weakly interacting dark matter is produced in association with another standard model particle that can be observed. Due to its small couplings to SM particles, the DM would not interact with the detector and therefore leave a momentum imbalance in the event.

The search targets a phase space, in which the top quark has a high transverse momentum, and in which the top quark decays hadronically. Then, the decay products of the top quark are collimated and they can be clustered into a single large-radius jet. As the weakly interacting dark matter particles are not detectable, they cause a momentum imbalance in the event. The imbalance can only be measured in the transverse plane, as the initial momenta of the incoming partons are unknown. It is referred to as the hadronic recoil.

The major background processes in this search are $\mathrm{Z} \to \nu\nu$ and $\mathrm{W} \to \ell\nu$ production, which do not contain top quarks in their final state. To reduce these backgrounds, a graph neural network (ParticleNet) is used to distinguish between jets from genuine top quark decays and jets purely produced in quantum chromodynamics processes. By this, a signal region can be built which predominantly contains events, in which the large-radius jets likely arise from top quark decays.

The $\mathrm{Z} \to \nu\nu$ production remains the largest background in the signal region with top quark tagging applied to the large-radius jet. This background is hard to estimate from data in a dedicated control region, as it shares the same final state with the signal process. Therefore, similar processes like $\mathrm{Z} \to \ell\ell$, $\mathrm{W} \to \ell\nu$, and photon production are used to estimate the contribution of this background using data. For these processes, it is possible to accumulate events in control regions by slightly alternating the requirements of the signal region selection, e. g., by requiring additional reconstructed objects in the final state. These processes and control regions are used during the binned maximum likelihood fit to constrain the $\mathrm{Z} \to \nu\nu$ background in the signal region using data from the control regions. In addition, a dedicated control region for $t\bar{t}$ production is used to estimate this background in a similar way.

The signal is extracted with a binned maximum likelihood fit to the hadronic recoil distributions in the signal and control regions. Two versions of each region are included in the fit, one with top quark tagging applied to the large-radius jet and one where the large-radius jet fails the top quark tagging.

No significant deviation from the standard model expectation is observed. Therefore, upper limits on $\sigma\mathcal{B}$ at 95% confidence level are set as function of the mediator and dark matter candidate masses. Here, σ is the production of a top quark in association with a mediator, and $\mathcal{B}$ is the branching fraction of the mediator decay into dark matter candidates. The results are shown in Figure 1. For the considered values of couplings of the mediator to quarks, $(g_{\mathrm{V}}^{U})_{13} = 0.25$, and to dark matter candidates, $g_{\mathrm{V}}^{\chi} = 1$, an exclusion of mediator masses of up to 1.85 (2.0) TeV is observed (expected) for a dark matter candidate mass of 1 GeV. For the mass of the dark matter candidates, an exclusion of 750 (850) GeV is observed (expected).

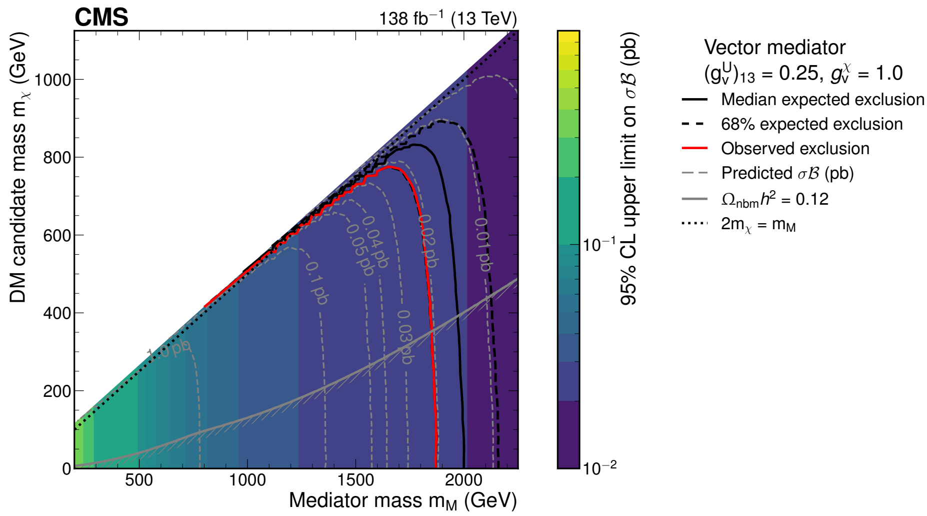

Figure 1: Upper limits on the signal production strength $\sigma\mathcal{B}$ at 95% confidence level as a function of the mediator and the dark matter candidate mass. The black solid line shows the median expected exclusion contour, calculated in a fit to the background-only model. Masses left of and below this contours are excluded by this search. The black dashed lines show the $\pm 1\sigma$ interval of the expected exclusion contour. The red line shows the observed exclusion contour, calculated in a fit to the actual data. The gray line shows the masses, for which the measured dark matter relic density is retained. Values below this line produce a higher relic density than observed and are therefore excluded.