Search for Dark Matter at CMS

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The latest results from CMS searches for dark matter are presented based on 20/fb of pp collision data collected at $\sqrt{s}$= 8 TeV at the LHC. Analyses are performed in several final states, including a single jet/photon/W-boson or a single top quark as well as production in association with $t\bar{t}$-pairs. No indication of dark matter was found so far and exclusion limits on the DM-nucleon scattering cross section are set using an effective field approach.

1 The dark matter model

Indications for the existence of dark matter (DM) are one of the strongest hints for physics beyond the SM. Many experiments seek their detection and understanding of their nature. Candidates particles for dark matter occur in many theoretical models. They may also be pair produced in pp collisions at the LHC and directly be searched for without specific theoretical assumptions. Up to now, such production has been described by an effective field theory (EFT) without modeling a specific messenger, assuming a contact interaction between Standard Model (SM) particles and DM. This approach allows to probe different models, while being specific enough to make predictions. The EFT description is valid as long as the messenger mass M is larger than the energy and momentum transfer in the partonic collision. Then two characterizing parameters fully determine the interaction, the scale of the effective interaction $\Lambda = M/\sqrt{(g_{DM} g_{SM})}$ and the mass of the dark matter candidate M_χ. Different assumptions for the coupling with DM are possible, such as vector, scalar and axial-vector coupling.

Weakly interaction DM particles would not yield a detectable signal in the detector and rather contribute to missing transverse energy (MET) which can also be created by neutrinos or other weakly interacting particles. Therefore, their detection has to be based on additional particles - the emission of a single photon or a single jet as initial-state or final-state radiation or through a recoiling particle, such as a W- or a Z-boson. The CMS experiment [1] has performed such searches using the full 2012 pp dataset at $\sqrt{s}$=8 TeV.

2 The mono-X search channels

The pioneering search for pair-produced DM at hadronic colliders exploits the single jet + MET final state [2]. It is challenged by the trigger and high QCD background. Single-jet trigger thresholds would be far too high, therefore the trigger either uses MET above 120 GeV or a jet+MET combination with jet transverse momentum p_T >80 GeV and MET>105 GeV. To suppress instrumental and beam-related backgrounds, events are rejected if less than 20% of

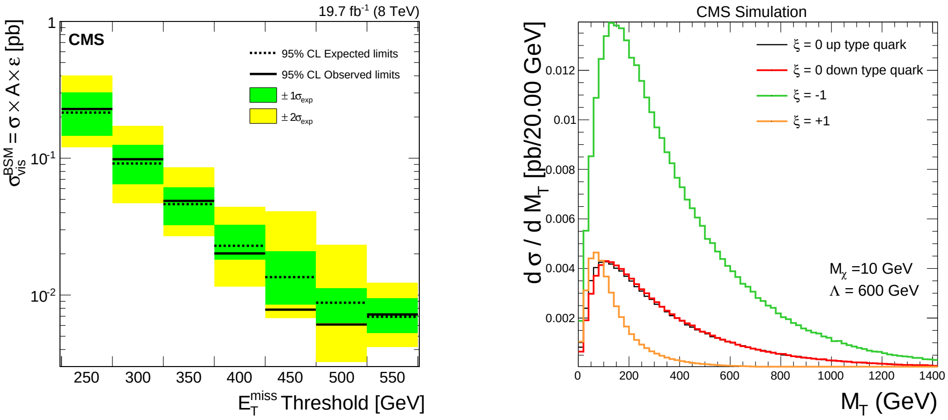

Figure 1: Left: The monojet analysis searches the MET distribution after all selections in seven bins. Shown are the model-independent observed and expected 95% C.L. upper limits on the visible cross section times acceptance times efficiency ($\sigma \times A \times \epsilon$) for non-SM production of events. Right: The mono-W channel could disentangle potentially different couplings to up- and down-type quarks, described by the parameter ξ. The resulting cross section and M_T shape would differ strongly.

the energy of the highest p_T jet is carried by charged hadrons or more than 70% of this energy is carried by either neutral hadrons or photons. The most energetic jet is required to have $p_T >$ 110 GeV within $|\eta| < 2.4$. A second jet is only allowed if nearby, in order to suppress QCD dijet events. The dominant backgrounds after all selection steps are due to Z($\nu\nu$) and W+jet events, estimated from data samples of Z($\mu\mu$) andW($\mu\nu$) events. The analysis is performed in seven regions of MET (see Fig. 1-left). Upper limits on the cross section $\times$ acceptance $\times$ efficiency ($\sigma \times A \times \epsilon$) are placed ranging from 2 pb for MET>250 GeV to 10^{-2}pb for MET>500 GeV.

The same $\sqrt{s}$=8 TeV dataset was used for searches with a single photon [3] instead. Events are triggered with either a single photon or a photon+MET cross trigger with offline thresholds of MET>140 GeV and p_T^γ >145 GeV. A tight photon ID rejects fakes. Events with either a single lepton or hadronic activity are being vetoed. The dominant irreducible backgrounds after selection are due to $Z(\rightarrow \nu\nu) + \gamma$ and $W(\rightarrow \ell\nu) + \gamma$ along with fake photon backgrounds. Searching in six bins of p_T^γ shows that data are compatible with the SM expectation and 90% C.L. limits are set on Λ using effective operators in the EFT approach. The resulting DM-nucleon cross section limits are depicted in Fig. 2-left.

The monolepton channel [4] – where DM recoils against a W-boson which subsequently decays to an electron(muon) and corresponding neutrino – is special as it allows to disentangle possibly different couplings to the up- or the down-type quark. Their relative coupling strength is parametrized by the factor ξ with the considered values of 0, +1, -1, following ref.[5]. The factor ξ could modify either the up or down-type quark couplings with the resulting M_T distributions shown in Fig. 1-right. The coupling changes the total cross section and the shape of the spectrum which in turn impacts the sensitivity. While the very high end of the transverse mass spectrum is nearly background free, at lower masses the small signal has to be separated from background.

In the monolepton search, candidate events with at least one high transverse momentum lepton are selected using single electron(muon) triggers with offline p_T >100(45) GeV. The lepton reconstruction is optimized for high momenta. The main observable is the transverse mass (M_T) of the lepton-MET spectrum. The main background $W \to \ell\nu$ is described with an M_T-binned k-factor for higher order QCD and electroweak corrections. Other backgrounds are Z/DY, ttbar, multi-jet QCD and di-boson processes, all are derived from simulation using NLO cross sections (except QCD). In order to suppress backgrounds, events exhibiting a back-to-back kinematics are selected. The three cases of ξ with related cross sections yield three limits on λ which subsequently are translated to limits of the DM-nucleon cross section (see Fig. 2-right).

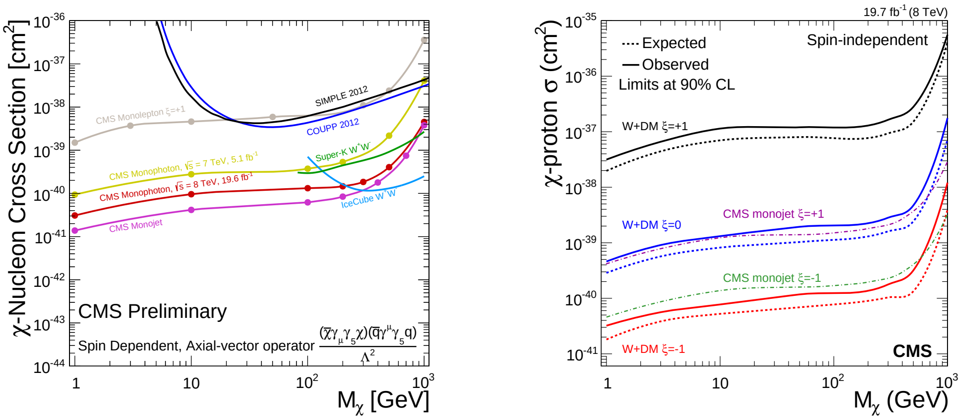

Figure 2: Dark matter nucleon exclusion limits with EFT assumption for different channels addressing the spin dependent (axial-vector) coupling (left) and spin independent (vector) coupling (right).

3 Using top quarks

Unlike the previously discussed vector and axial-vector couplings which are simply proportional to Λ^{-2}, scalar couplings do contain a mass term (m_q/Λ^3 for D1 and m_q/Λ^2 for C1). Such searches are therefore performed best with top quarks. A single DM particle could be produced along with a top-quark in the s- or t-channel [6] or DM pairs in association with top-quark pairs [7, 8]. All channels require large MET due to DM, with thresholds of 320 GeV and 350 GeV for the monotop and top-pair channel, respectively. Depending on the W decay originating from $t \to Wb$, the final state contains several jets or jets plus leptons.

The fully hadronic channel is used in the monotop search [6], thus yielding three final state jets of which one has to be b-tagged and the two leading ones exhibit p_T >60 GeV. No isolated electron or muon should be present. Along with the MET requirement this selection removes about 4/5 of the background. The main remaining backgrounds are $t\bar{t}$ (with the leptonic decay of the W and undetected lepton) and V+jets while QCD multi-jet and diboson events are largely suppressed by the b-tag. The invariant mass of the three leading jets in selected events with one b-tag is depicted in Fig. 3-left. Data are compared to the simulated backgrounds and a

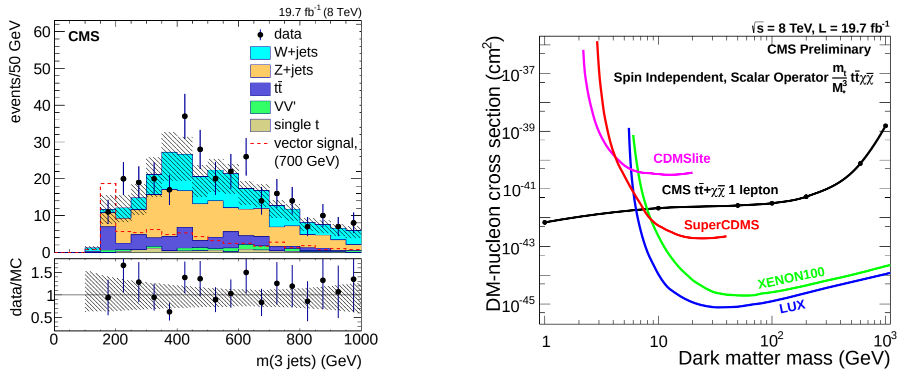

Figure 3: Left: The invariant mass of the three leading jets in selected events with one b-tag in the monotop DM search. Measured data points are compared to the simulated backgrounds (stacked histograms) and one of the signal models (solid line) scaled to 19.7/fb. The shaded area represents systematic uncertainties. Right: The 90% C.L. upper limits on the dark matter-nucleon spin-independent scattering cross sections for the scalar operator considered in the ttbar analysis, compared to results from selected direct detection experiments.

signal model. In the full 8 TeV data sample, no deviation from the SM expectation is observed and DM masses below 655(327) GeV are excluded at 95% C.L. for vector(scalar) couplings.

Assuming DM may be pair-produced in association with top-quarks, searches are performed in the dilepton $\ell\ell bb + MET$ [7] and the semi-leptonic $\ell jjjb + MET$ final state [8]. Events are selected with one lepton + $\geq$3 jets + $\geq$1 b-jet along with the MET requirement. Both W-bosons are reconstructed via M_T. According to its final state, the dilepton search rather selects events with 2 leptons + $\geq$2 jets and applies cuts on the scalar sum of leptons and jets, and lepton opening angle. The main background for both analyses is $t\bar{t}$. Signal efficiencies are about 1-2% but the background is also very low. Using the EFT description from above with the characteristic parameters Λ and M_χ, values of Λ <120(90) GeV are excluded in the semi-leptonic(dileptonic) channel for M_χ <100 GeV. Combining both results, the excluded DM-nucleon cross sections are shown in Fig. 3-right for a scalar operator where other channels rarely set limits due to their low sensitivity.

4 Summary

Several analyses based on the full 2012 data sample search for pair-produced DM in pp collisions at the LHC but found no significant indication of such signals. Based on an effective field approach for the SM-DM interaction, limits on the DM-nucleon scattering cross section are being set for different types of interaction (vector, axial-vector and scalar).

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