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Searches for dark matter at the LHC with the CMS experiment

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Abstract

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Searches for dark matter at the LHC with the CMS experiment

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Keywords: CMS, physics, dark matter, monolepton, monojet

1. Introduction

This Summary describes the dark matter interpretation of the final state with one electron or muon and missing transverse energy (E_T^{miss}), called monolepton and with one jet and E_T^{miss} , called monojet. The analysis uses 20fb^{-1} of proton-proton collision data recorded with the Compact Muon Solenoid (CMS) detector¹ at the Large Hadron Collider (LHC) in 2012 at a center-of-mass energy of 8 TeV. The analysis is documented in detail in PAS-EXO-13-004² (monolepton) and in PAS-EXO-12-048³ (monojet).

2. Dark matter model

The production of dark matter (DM) at the LHC can be described by an effective field theory (EFT). A summary of the models can be found in.⁴⁻⁶

In this model, DM is produced in pairs along with a W which subsequently decays into a charged lepton (electron or muon) and a neutrino. Both, the neutrino and the DM pair contribute to the experimental signature of missing transverse energy in the monolepton channel. For the monojet channel, DM is produced in pairs along with a jet.

Based on experimental observations, several assumptions on the nature of dark matter can be made to constrain the search. Cosmological observables suggest that the DM candidate is very likely a fermionic weakly interacting massive particle (WIMP).⁷ Different assumptions for the coupling with the dark matter particle are possible, and are summarized in Ref.⁵ The most prominent are:

$$\text{Spin-independent vector coupling: } (V) \quad \frac{1}{\Lambda^2} \bar{\chi} \gamma^\mu \chi \quad \xi_i \bar{q}_i \gamma_\mu q_i \quad (1)$$

$$\text{Spin-dependent axial-vector coupling: } (AV) \quad \frac{1}{\Lambda^2} \bar{\chi} \gamma^\mu \gamma^5 \chi \quad \xi_i \bar{q}_i \gamma_\mu \gamma^5 q_i \quad (2)$$

The characterizing parameters of the model are the scale of the effective interaction $\Lambda = \frac{M_{\text{messenger}}}{\sqrt{g_\chi g_q}}$, and the mass of the dark matter particle M_χ which is included in the spinors χ and $\bar{\chi}$. In addition, the relative coupling to different quark flavors i is parametrized by ξ_i .

The nature of the DM coupling results in interference for the mono-lepton channel. The DM particles either couple to the up- or the down-type quark with their relative coupling strength parametrized by the factor ξ .

The considered values of ξ are $0, \pm 1$, following Ref.⁸ The factor ξ could modify either the up or down-type quark couplings, resulting in the same interference behavior. A value of $\xi = 0$ results in a coupling only to one quark type, where as $\xi = +1$ corresponds to destructive interference and $\xi = -1$ to constructive interference. The interference changes the total cross section and steepens the M_T spectrum. In the monojet channel only the $\xi = +1$ case is considered.

3. Event selection

Candidate events with at least one high-transverse-momentum (p_T) lepton are selected using single-muon (with offline $p_T > 45\text{GeV}$) and single-electron (with offline $p_T > 100\text{GeV}$) triggers. The main observable in the mono-lepton channel is the transverse mass M_T of the lepton- E_T^{miss} system, calculated as $M_T = \sqrt{2 \cdot p_T^\ell \cdot E_T^{\text{miss}} \cdot (1 - \cos \Delta\phi_{\ell,\nu})}$ where $\Delta\phi_{\ell,\nu}$ is the azimuthal opening angle between the charged lepton's transverse momentum (p_T^ℓ) and E_T^{miss} . To select the signature-like events the back to back kinematics is used, requiring the ratio between lepton p_T and the E_T^{miss} to be $0.4 < p_T/E_T^{\text{miss}} < 1.5$. Secondly, the angle $\Delta\phi$ between the charged lepton and E_T^{miss} is required to be $> 0.8\pi$.

The transverse mass distributions for events passing all selection criteria are shown for the electron and muon channels in Fig. 1, along with examples

of a possible DM signal. The final distribution for the monojet channel, the E_T^{miss} distribution is shown in Fig. 2.

Fig. 1. Observed transverse mass distribution for the electron (left) and muon (right) channel. Both channels use a M_T binning derived from the corresponding lepton momentum(energy) resolution. The shaded area represents the total systematic uncertainty on the SM background. Simulated signal distributions for a $M_\chi = 300\text{ GeV}$, $\Lambda = 200\text{ GeV}$ and $\xi = \pm 1, 0$ are also shown, including detector resolution effects.

Fig. 2. Observed transverse mass distribution for the monojet channel. Simulated signal distributions for a $M_\chi = 1\text{ GeV}$, $\Lambda = 900\text{ GeV}$ and $\xi = +1$ is also shown.

4. Results and Summary

No significant excess has been observed in data. Therefore limits are set. The two couplings from Eq. 1 were tested, which are the vector and axial-vector couplings. Three other parameters specify the dark matter model, the mass of the dark matter particle M_χ , the effective scale Λ and the interference parameter ξ . The limits are set on the production cross section and the DM-proton cross section. The limits on the collider cross sections for both considered couplings and the three interference cases are shown in Fig. 3. Those are converted to direct dark matter-proton cross section limits. The last representation is chosen to compare to other direct DM-nucleon experiments, shown in Fig. 4. To increase sensitivity we combine the electron and muon channels for all exclusion limits.

Fig. 3. Excluded collider cross sections for axial-vector-like (spin dependent, upper row) and vector-like couplings (spin independent, lower row) combining electron and muon channels. The limits are calculated for the cases (from left to right) $\xi=+1$, $\xi=0$ and $\xi=-1$. Note the different cross section scales.

The conversion formula for the spin-dependent (σ_{SD}) and spin-independent (σ_{SI}) dark matter-proton interaction can be found in Ref.¹⁶

An interpretation of the lepton + E_T^{miss} and jet + E_T^{miss} final state in terms of an effective DM theory is performed. The theoretical model assumes the pair production of DM particles of a certain mass M_χ and a parameter

Fig. 4. Excluded proton-dark matter cross section for axial-vector-like (spin dependent, upper row) vector-like (spin independent, lower row) at 90% C.L.. In the left column the limits for the monolepton channel and $\xi = +1$ are shown. In the middle column the proton-dark matter cross section is shown for different values of ξ . In the right column the excluded proton-dark matter cross section for the monojet channel is shown. As a comparison some direct detection results are shown.^{9–15}

Λ with either vector-like or axial-vector-like couplings.

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