PROCEEDINGS OF SCIENCE

Search for Dark Matter with mono-X Signatures in CMS

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Searches in CMS for dark matter in final states with invisible particles recoiling against visible states are presented. Various topologies and kinematic variables are explored, including jet substructure as a means of tagging heavy bosons. In this talk, we focus on the recent results obtained using the full Run-II dataset collected at the LHC.

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1. Introduction

The existence of Dark Matter (DM) is known from a variety of astrophysical and cosmological experiments. Although it is measured to be about 26.4% [1] of the total energy density of the Universe via indirect observations, the exact nature of DM particles is still unknown. All we know is that it is electrically neutral, participates only in gravitational interactions, and does not interact with ordinary baryonic matter. The CMS collaboration [2] searches for the production of such particles at the CERN LHC, and interprets results in the context of simplified models, which contain new beyond-the-standard-model (BSM) particle interactions. The BSM boson mediates the interaction between the standard model (SM) and dark sector. The BSM models with a BSM boson and a fermion DM particle are described by four parameters: the mediator mass m_{med} and the dark matter mass m_{DM}, as well as the couplings of the mediator to quarks g_q and DM g_{DM} [3].

Since DM particles themselves do not produce signals in the LHC detectors, searches rely on missing transverse momentum p_T^{miss} in association with a visible SM particle. All results presented here use full Run-II dataset corresponding to 137 fb^{-1} of proton-proton collisions at $\sqrt{s} = 13$ TeV recorded with the CMS detector.

2. Mono-jet/V

A mono-jet topology is obtained using events containing an imbalance in transverse momentum and one or more energetic jets arising from initial state radiation or the hadronic decay of vector bosons ($W^{\pm}$ or Z)[4]. Two signal categories are defined for events with and without an identified V candidate. The dominant backgrounds W+jets and Z+jets are estimated using dedicated control regions. A simultaneous shape fit exploiting the distribution of the total transverse momentum recoiling against hadronic activity in the events is performed to extract the signal. No significant deviation from the background prediction is observed. Thus limits on the signal strengths of the BSM scenarios under study are set, providing new excluded areas in the parameters space of these models. Exclusion limits at 95% CL on the signal strength in the $m_{\text{med}} - m_{\text{DM}}$ plan are shown in Fig. 1. Figure 2 shows exclusion limits on the couplings g_{DM} (left) and g_q (right) for an axial-vector mediator.

3. Mono-Z

The final state considered in this analysis is the production of a pair of leptons (e^+e^- or $\mu^+\mu^-$) consistent with originating from a Z boson, together with a large magnitude of missing transverse momentum. At least one lepton of the pair is required to have $p_T > 25$ GeV, while the second lepton is required to have $p_T > 20$ GeV. The dilepton invariant mass within 15 GeV of the average Z boson mass m_Z [5] is applied to reduce the nonresonant background. The main powerful discriminating variables; the azimuthal angle between the dilepton p_T and p_T^{miss}, $\Delta\Phi(p_T^{ll}, p_T^{miss})$, and the balance ratio $|p_T^{miss} - p_T^{ll}|/p_T^{ll}$, rejects Drell–Yan and Top background with cut > 2.6 and

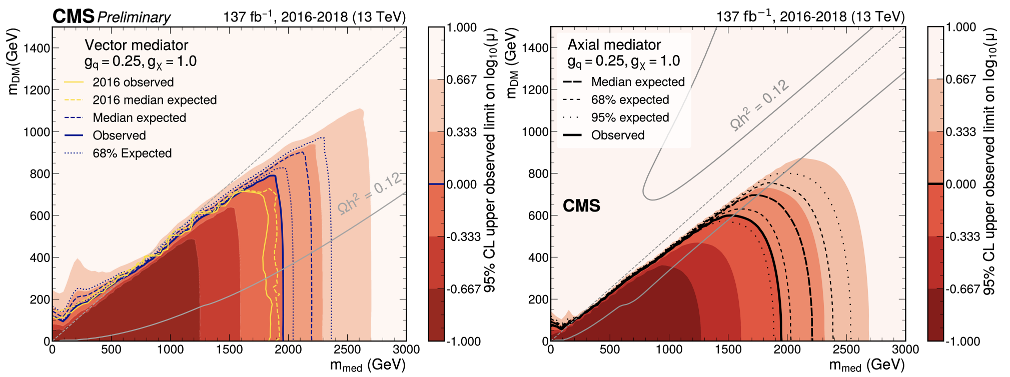

Figure 1: Exclusion limits at 95% CL on the signal strength $\mu = \sigma \ / \ \sigma_{theory}$ in the $m_{\text{med}} - m_{\text{DM}}$ plane for coupling values of g_q= 0.25 and g_{DM}= 1.0 for a vector mediator(left) and an axial-vector mediator(right) [4].

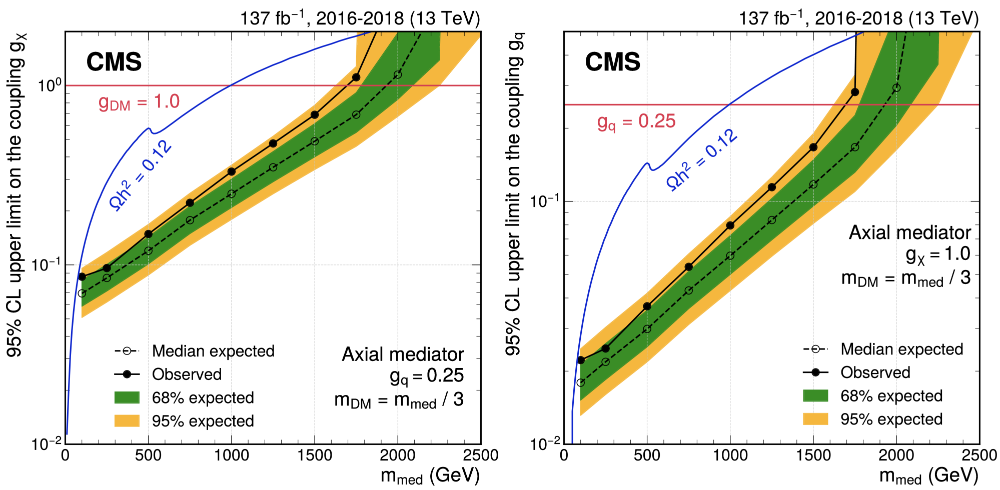

Figure 2: Exclusion limits at 95% CL on the couplings g_{DM}(left) and g_q(right) for an axial-vector mediator. In each panel, the result is shown as a function of the mediator mass m_{med}, with the mass of the DM candidate fixed to m_{DM}=m_{med}/3. In either case, only one coupling is varied, while the other coupling is fixed at its default value (g_q=0.25 or g_{DM}=1.0)[4].

< 0.4 respectively. A simultaneous fit is performed on p_T^{miss} and m_T distributions to extract the signal in two different BSM models. The observed numbers of events are found compatible with the background predictions, upper limits set on Dark Matter production in context of simplified model and 2HDM+a.

Limits for the axial-vector mediators are shown in Fig. 3 (left) as a function of the mediator mass m_{med} and DM particle mass m_{DM}. The highest limit reached in the allowed region is about $m_{\text{med}} >$ 870 GeV. Figure 3 (right) shows the limits on both the heavy pseudoscalar and lighter pseudoscalar mediator with the mixing angles $\sin\theta = 0.35$, $\tan\beta$=1. The mediator mass with the most sensitivity is m_A =1000 GeV, where the observed (expected) limit on m_a is 440 (340) GeV. For small values of m_a, the limit on m_A is about 1200 GeV.

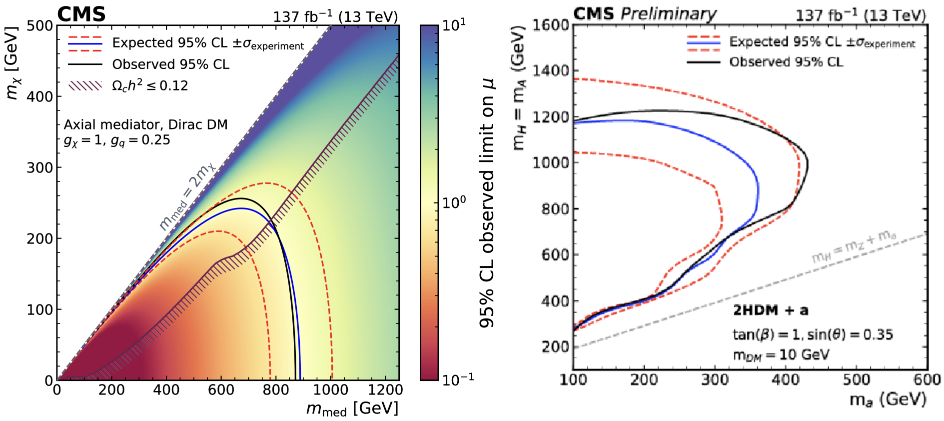

Figure 3: The 95% CL exclusion limits for the axial-vector(left) simplified models. The limits are shown as a function of the mediator and DM particle masses. The coupling to quarks is fixed to $g_q = 0.25$ and the coupling to DM is set to $_{\mathrm{DM}}$ =1. The 95% CL exclusion limits on the 2HDM+a model(right) with the mixing angles set to tanβ=1 and sinθ=0.35 and with a DM particle mass of $m_{\mathrm{DM}} = 10$ GeV. The limits are shown as a function of the heavy Higgs boson and the pseudoscalar masses[6].

4. Dijet Searches

In order to probe the parameter space with $m_{\mathrm{DM}} > m_{\mathrm{med}}/2$, searches for mediator decays to SM particles, such as jets are used. Events are selected with dijet mass m_{jj} greater than 1.5 TeV. Quantum chromodynamics (QCD) is the main background, which is predicted using two methods; fit method and ratio method. The fit method uses an empirical functional form to fit the dijet mass distribution of the background in the signal region, defined by requiring the pseudorapidity separation of two jets in dijet system $|\Delta\eta_{jj}| < 1.1$ while the ratio method uses two control regions at higher values of $\Delta\eta$ to predict the background in the signal region. The ratio method enhance the sensitivity due to small uncertainty compare to fit method for same mass range, resulting in the exclusion at 95% confidence level of a DM mediator with mass less than 4.8 TeV for a width equal to 45% of the mass, which corresponds to a coupling to quarks $g_q = 0.9$ as shown in Fig. 4.

5. Dilepton Searches

Following a similar strategy as the the Dijet searches, Dilepton analysis searches for an excess over the SM continuum in the dilepton mass spectrum. For small m_{DM}, the mediator will dominantly decay to DM particles. This decay becomes suppressed for $m_{\mathrm{DM}} > m_{\mathrm{med}}/2$, enhancing the decays into leptons and increasing the sensitivity of the dilepton channel. Observed data matches with background, no significant resonant peaks are observed, and limits are placed on dark matter mediator mass and dark matter mass. The results are interpreted in the context of the simplified DM models as shown in Fig. 5 for both the vector and axial-vector coupling models. The limits are strongest for large values of m_{DM} where the decay width of the mediator is small. Here, mediators with masses below 1.92 (4.64) TeV are excluded in the vector (axial-vector) model. For $m_{\mathrm{DM}} = 0$, the limit is 3.41 TeV in the axial-vector model. In the vector model, the largest excluded mediator mass for $m_{\mathrm{DM}} = 0$ is 1.04 TeV.

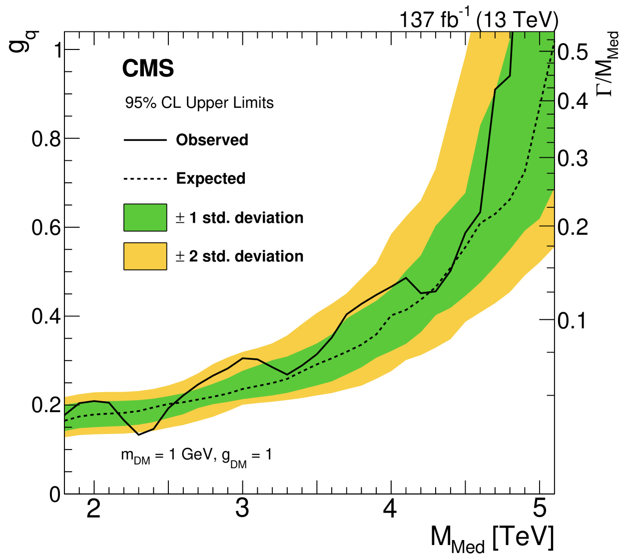

Figure 4: The 95% CL upper limits on the universal quark coupling g_q as a function of resonance mass for a vector mediator of interactions between quarks and DM particles[7].

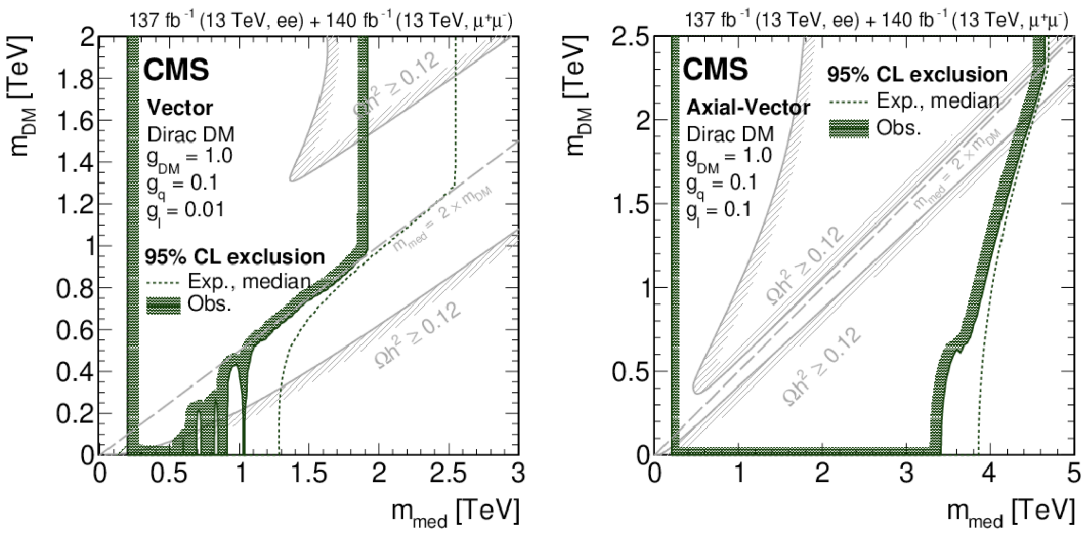

Figure 5: Upper limits at 95% CL on the masses of the DM particle, which is assumed to be a Dirac fermion, and its associated mediator, in a simplified model of DM production via a (left) vector or (right) axial-vector mediator [8].

6. Summary

The CMS collaboration has presented a number of new search results for dark matter with a wide range of masses. The most stringent limits are set on a variety of signal hypotheses. More searches for dark sector mediators exploiting the full Run-II dataset are expected soon.

References

[1] N. Aghanim, Y. Akrami, F. Arroja, M. Ashdown, J. Aumont, C. Baccigalupi, M. Ballardini, A. J. Banday, and R. Planck 2018 results. *Astronomy Astrophysics*, 641:A1, Sep 2020. doi: 10.1051/0004-6361/201833880. URL https://doi.org/10.1051%2F0004-6361%2F201833880.

[2] The CMS Collaboration. The CMS experiment at the CERN LHC. *Journal of Instrumentation*, 3(08):S08004, Aug 2008. doi: 10.1088/1748-0221/3/08/S08004. URL https://dx.doi.org/10.1088/1748-0221/3/08/S08004.

[3] Daniel Abercrombie et al. Dark Matter benchmark models for early LHC Run-2 Searches: Report of the ATLAS/CMS Dark Matter Forum. *Phys. Dark Univ.*, 27:100371, 2020. doi: 10.1016/j.dark.2019.100371.

[4] Armen Tumasyan et al. Search for new particles in events with energetic jets and large missing transverse momentum in proton-proton collisions at $\sqrt{s}$ = 13 TeV. *JHEP*, 11:153, 2021. doi: 10.1007/JHEP11(2021)153.

[5] M. Tanabashi, K. Hagiwara, and K. Hikasa. Review of Particle Physics. *Phys. Rev. D*, 98: 030001, Aug 2018. doi: 10.1103/PhysRevD.98.030001. URL https://link.aps.org/doi/10.1103/PhysRevD.98.030001.

[6] Albert M Sirunyan et al. Search for dark matter produced in association with a leptonically decaying Z boson in proton-proton collisions at $\sqrt{s}$ = 13 TeV. *Eur. Phys. J. C*, 81(1):13, 2021. doi: 10.1140/epjc/s10052-020-08739-5. [Erratum: Eur.Phys.J.C 81, 333 (2021)].

[7] Albert M Sirunyan et al. Search for high mass dijet resonances with a new background prediction method in proton-proton collisions at $\sqrt{s}$ = 13 TeV. *JHEP*, 05:033, 2020. doi: 10.1007/JHEP05(2020)033.

[8] Albert M Sirunyan et al. Search for resonant and nonresonant new phenomena in high-mass dilepton final states at $\sqrt{s}$ = 13 TeV. *JHEP*, 07:208, 2021. doi: 10.1007/JHEP07(2021)208.

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