The Compact Muon Solenoid Experiment

Conference Report

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28 February 2017 (v2, 06 March 2017)

Search for Dark Matter and Large Extra Dimensions in the photon + MET final state in pp Collisions at $\sqrt{s} = 13$ TeV

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Abstract

A search is conducted for dark matter pair-production and for graviton production predicted by the ADD large extra dimensions model in a final state with a photon and missing transverse energy in pp collisions at $\sqrt{s} = 13$ TeV. Data taken by the CMS experiment at the CERN LHC in 2016 corresponding to an integrated luminosity of 12.9 fb⁻¹ is analyzed. We find no deviation from the Standard Model prediction for this final state, and achieve an extension of the current limits on parameter space.

Presented at *DAE-HEP Symposium XXII DAE-BRNS High Energy Physics Symposium*

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Keywords: Dark Matter, Extra Dimension, ADD Model, CMS Experiment, Beyond Standard Model, Searches at LHC

1 Introduction

A search in pp collisions at the Large Hadron Collider (LHC) for a final state consisting of a photon (γ) of large transverse momentum (p_T) and missing transverse momentum (E_T^{miss}) is used to investigate two extensions to the standard model (SM). We search for dark matter (DM), which is considered to be the dominant non-baryonic contribution to the matter density of the universe [1], its detection and identification in ground-based and spaceborne experiments remain elusive. At LHC, production of DM particles may be inferred from pp collisions with large E_T^{miss} , if the DM particles indirectly interact with the standard model (SM) quarks and gluons via forces of the electroweak scale.

The second SM extension is the large extra dimension model [2], which is motivated by the hierarchy problem, namely the large gap between the electroweak (M_{EW}) and Planck (M_{Pl}) scales. This model postulates that there exist n compactified extra dimensions, in which gravitons can propagate freely, and that the true scale of the gravitational interaction in this $4 + n$ dimension space-time (M_D) is of the same order as M_{EW} . The compactification length scale R of the additional dimensions can be large from a particle physics perspective, admitting a near-continuous mass spectrum of the Kaluza-Klein graviton states. Production of such gravitons at the LHC will therefore also manifest itself as events with broadly distributed in E_T^{miss} .

Events with large missing transverse momentum exist only if there are visible objects recoiling against the invisible particles. Among the many possibilities, a recoiling photon (γ) has the advantage of being identifiable with high efficiency and purity. The results of the search are interpreted in terms of the DM simplified models as proposed by the CMS-ATLAS Dark matter forum group [3] and the ADD graviton production.

2 Event Selection and Background Estimation

The analyzed data sample corresponds to an integrated luminosity of 12.9 fb^{-1} is collected by CMS detector [4]. Events are required to have $E_T^{miss} > 170 \text{ GeV}$ and at least one photon with $p_T^\gamma > 175 \text{ GeV}$ in the central region ($|\eta| < 1.44$) of the detector and vetoed with well-identified electrons and muons. Events are rejected if the minimum azimuthal opening angle ($\Delta\phi$) between E_T^{miss} and up to four leading jets is less than 0.5 radian. This requirement significantly suppresses the background where jet energy mismeasurement gives rise to large E_T^{miss} . Only jets with $p_T > 30 \text{ GeV}$ and $|\eta| < 5$ are considered. The candidate photon and E_T^{miss} must also be separated by more than 2 radians.

The major background from the $Z(\rightarrow \nu\bar{\nu}) + \gamma$ and $W(\rightarrow l\nu) + \gamma$ processes is estimated using simulated events with NNLO QCD and NLO EWK corrections and cross-checked with control data dominated by well-reconstructed $Z(\rightarrow l^+l^-) + \gamma$ and $W(\rightarrow l\nu) + \gamma$ events. Background from jets or electrons mis-identified as photons is estimated by measuring the mis-identification rates in control samples in data. Finally, non-collision backgrounds due to beam halo and ECAL spikes are estimated by fits to distributions of the azimuthal angle (ϕ) and the electromagnetic cluster seed time.

3 Results and Interpretation

A total of 400 events are observed in data, which is in agreement with the total expected background of 414.6 ± 38 events. Because no excess with respect to the SM prediction is observed, limits are set on the considered DM production models and ADD extra dimension scenarios. For each signal model, a 95% confidence level (CL) cross section upper bound is obtained utilizing the asymptotic CL_s prescription [5–7]

3.1 Limits on simplified dark matter models

The DM simplified models are designed to facilitate the comparison and translation of various DM search results by limiting the degrees of freedom of the DM production interaction. In the models considered in this analysis, Dirac DM particles couple to a vector or axial-vector mediator, which in turn has couplings to the SM quarks. Model points are identified by a set of four parameters: the DM mass m_{DM} , the mediator mass M_{med} , the universal mediator coupling to

quarks g_q and the mediator coupling to DM g_{DM} . In this analysis, we fix the values of g_q and g_{DM} to 0.25 and 1, respectively, and scan the M_{med} - m_{DM} plane. Figure 1 shows the cross section upper limits with respect to the corresponding

Fig. 1: 95% CL upper limits on $\mu = \sigma/\sigma_{Theory}$ in the M_{med} - m_{DM} plane for vector and axial-vector mediator, assuming $g_q = 0.25$ and $g_{DM} = 1$. Expected and observed exclusion contours are overlaid, where mass points to the lower left of the curves are excluded [8].

theoretical cross section ($\mu = \sigma^{95\%}/\sigma_{Theory}$) for the vector and axial-vector mediator scenarios on the M_{med} - m_{DM} plane. The solid red and black curves are the expected and observed exclusion contours. The uncertainty on the expected upper limit includes the experimental uncertainties. The uncertainty in the theoretical cross section is translated to the uncertainty in the observed exclusion contour. For the simplified DM models considered, mediator masses of up to 760 GeV are excluded for small m_{DM} [8].

3.2 Limits on ADD Model

Figure 2 shows the upper limit and the theoretical calculation of ADD graviton production cross section for $n = 3$ as a function of M_D . Lower limits on M_D in different number of extra dimensions are compared to CMS Run1 [9] results in Fig. 3. The trends of the two results differ because the graviton production cross section can be increasing or decreasing in n depending on the values of $\sqrt{s}$ and M_D [10]. Values of M_D up to 2.60 TeV for $n = 6$ are excluded [8].

Fig. 2: The 95% CL upper limits on the ADD graviton production cross sections as a function of M_D for $n = 3$ [8].

Fig. 3: Lower limit on M_D as a function of n [8].

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