Search for a pair production of dark photons via the Higgs portal at CMS

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Motivation

The Standard Model (SM) is known to be an incomplete framework. It fails explaining a number of experimental observations, for instance, the nature of dark matter. Recent astronomical observations [1] suggest that dark matter could be composed of elementary particles. Three astrophysics experiments observed an excess on the positron flux (Figure 1) that could be explained as the product of the annihilation of dark matter particles. Such observations have motivated scientists to search for possible hints of dark matter particles produced at modern accelerators and detected with complex apparatus such as the Compact Muon Solenoid (CMS) experiment (Figure 2).

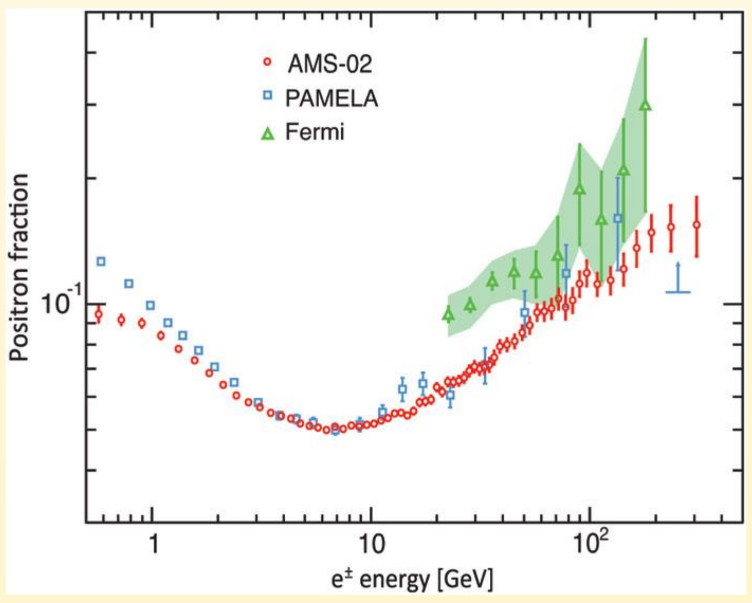

Figure 1. The fraction of positrons measured by AMS-02, PAMELA and Fermi-LAT. The positron excess at high energies indicates a possible contribution from the annihilation of dark matter particles

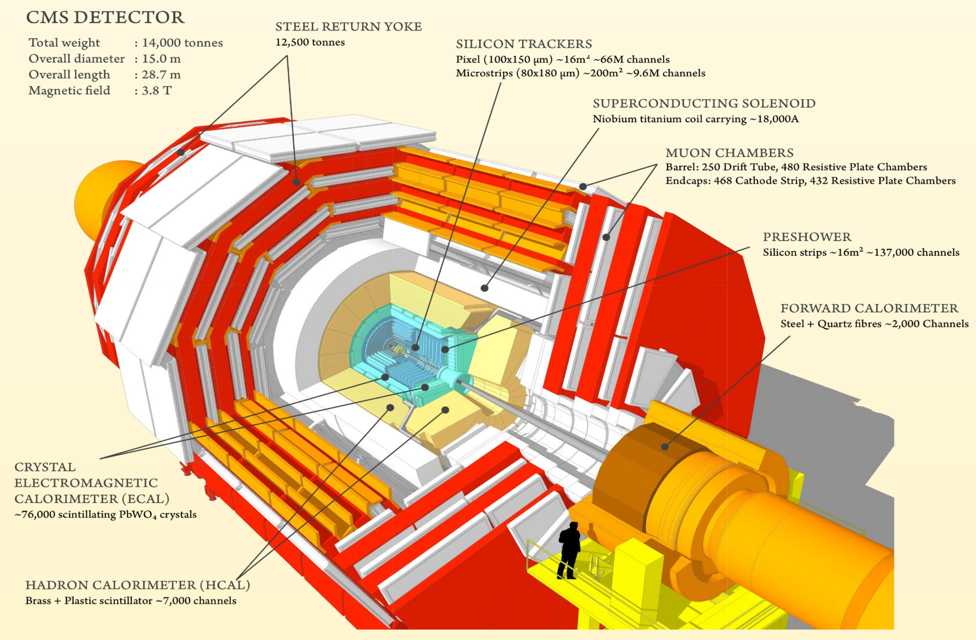

Figure 2. Schematic view of the Compact Muon Solenoid (CMS) experiment, one of the multipurpose detectors at the CERN Large Hadron Collider.

Signal models

Several beyond SM theories predict the existence of new particles (light bosons) that could be connected with new physics, including a candidate to explain the nature of the dark matter. In this analysis we explore a non-SM decay of the Higgs boson to a pair of new light bosons that subsequentially decay to four muons (Figure 3). Two models fit into this category, the first one in the context of the next-to-minimal-supersymmetric-standard-model (NMMS) in which one of the extra Higgs bosons could be associated to the new light boson, the second one in the context of supersymmetry (SUSY) with "dark" sectors (dark SUSY) in which the new light boson is identified as the dark photon [2].

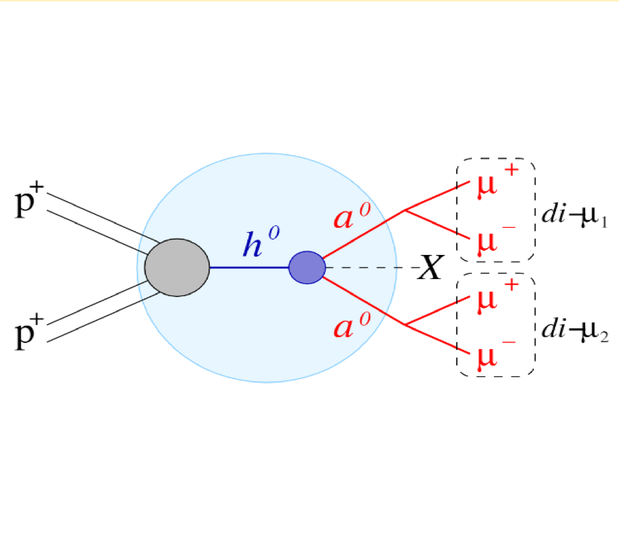

Figure 3. Schematic representation of the decay of a Higgs boson to a pair of new light bosons

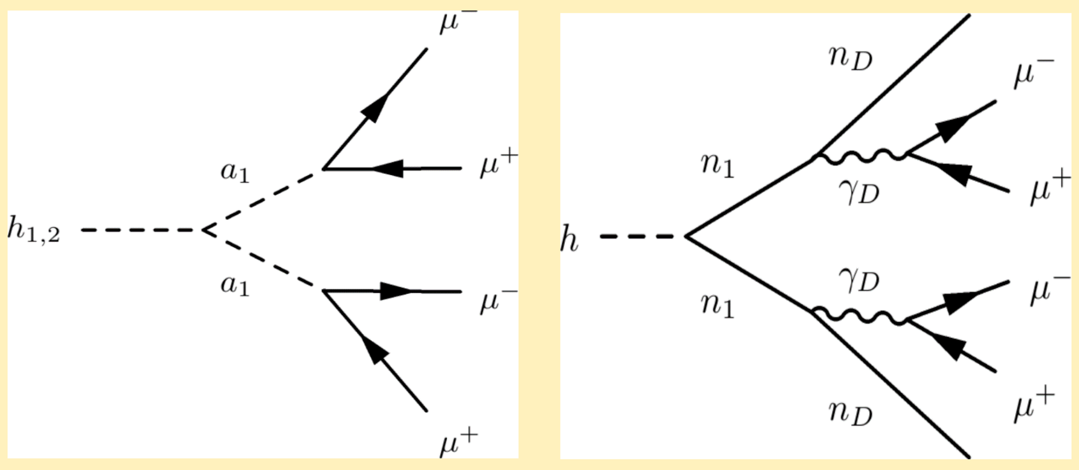

Figure 4. Feynman diagram of the decay of a Higgs boson to new light bosons in the contact of NMSSM model (left). Feynman diagram of the decay of a Higgs boson to supersymmetric particles and dark photons in the context of dark SUSY model.

Event selection

The event selection follows closely a previously published study [3] with some major improvements: A preliminary selection using a dedicated trigger sensitive to particles with long lifetime which is particularly important for dark photons. Also the mass range was extended up to 8.5 GeV allowing to cover a larger parameter space,

After the preliminary selection, the resulting events should satisfy the following criteria:

- At least four muons in the event
- Oppositely charged muons are paired according to a common vertex (dimuons). It is required to have exactly two dimuons per event
- The mass of the dimuons must be consistent (as if they were originated from same mother particle)

The previous selections define the signal region. In Figure 5. we can observe a visualization of a characteristic signal event candidate collected by CMS during Run-1 campaign.

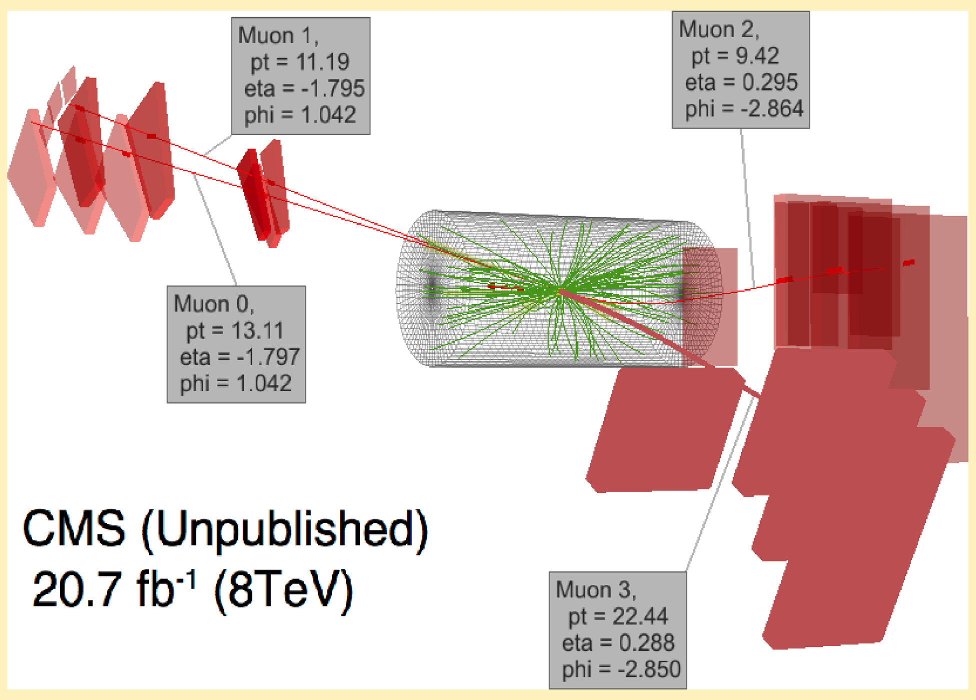

Figure 5. Visualization of a signal candidate in pp collision data

Table 1: The full reconstruction efficiency over signal acceptance $\epsilon_{full}/\alpha_{gen}$ in % for several representative signal NMSSM (upper) and dark SUSY benchmark models (lower). All uncertainties are statistical.

m_{h_1} [GeV]	90	100	110	125	150
m_{a_1} [GeV]	2	0.5	3	1	0.75
ϵ_{full} [%]	8.85 ± 0.06	13.23 ± 0.08	11.96 ± 0.07	14.68 ± 0.08	18.48 ± 0.09
α_{gen} [%]	13.93 ± 0.08	20.47 ± 0.09	19.24 ± 0.09	23.59 ± 0.10	29.93 ± 0.10
$\epsilon_{full}/\alpha_{gen}$ [%]	63.52 ± 0.29	64.62 ± 0.24	62.19 ± 0.25	62.23 ± 0.22	61.73 ± 0.20

m_{γ_D} [GeV]	0.25			8.5		
$c\tau_{\gamma_D}$ [mm]	0	1	5	0	2	20
ϵ_{full} [%]	9.12 ± 0.21	1.72 ± 0.06	0.12 ± 0.01	12.78 ± 0.12	12.25 ± 0.06	3.61 ± 0.02
α_{gen} [%]	13.52 ± 0.25	2.85 ± 0.07	0.20 ± 0.01	20.49 ± 0.14	20.05 ± 0.08	6.16 ± 0.03
$\epsilon_{full}/\alpha_{gen}$ [%]	67.47 ± 0.91	60.2 ± 1.3	58.39 ± 2.0	62.36 ± 0.38	61.10 ± 0.21	58.70 ± 0.24

The full event selection was applied to Monte Carlo simulated samples (NMSSM and dark SUSY models) and the results are presented in Table 1. It is important to notice that the ratio of reconstructed vs generated efficiency is constant for the different variations in the model parameters, this is an indication that this search is model independent and can be used to interpret various signal models with similar topology.

Background Estimation

Three are the dominant backgrounds from standard model that can mimic our signal:

- **Semi-leptonic decay of two b-quarks (bbbar):** This is the largest background due to the huge cross section of the process, with additional contribution from the decay of low-mass meson resonances such as ω,ρ,ϕ,J/ψ and ψ (2S) , The contribution to the signal region is obtained with a purely data-driven method in which the background shape is extrapolated from a control region into the signal region.
- **Prompt Double J/ψ:** This is the second dominant background, the background contribution is located around the mass of the resonance (around 3.1 GeV) . This contribution is estimated with a semi-data-driven method in which a control region in data is used to extrapolate a correction factor data/MC to the signal region.
- **Electro weak production of 4 muons**: This is the weakest contribution and is dominated for the decay of a pair of Z bosons to four muons, the contribution to the signal region is obtained purely from Monte Carlo simulation.

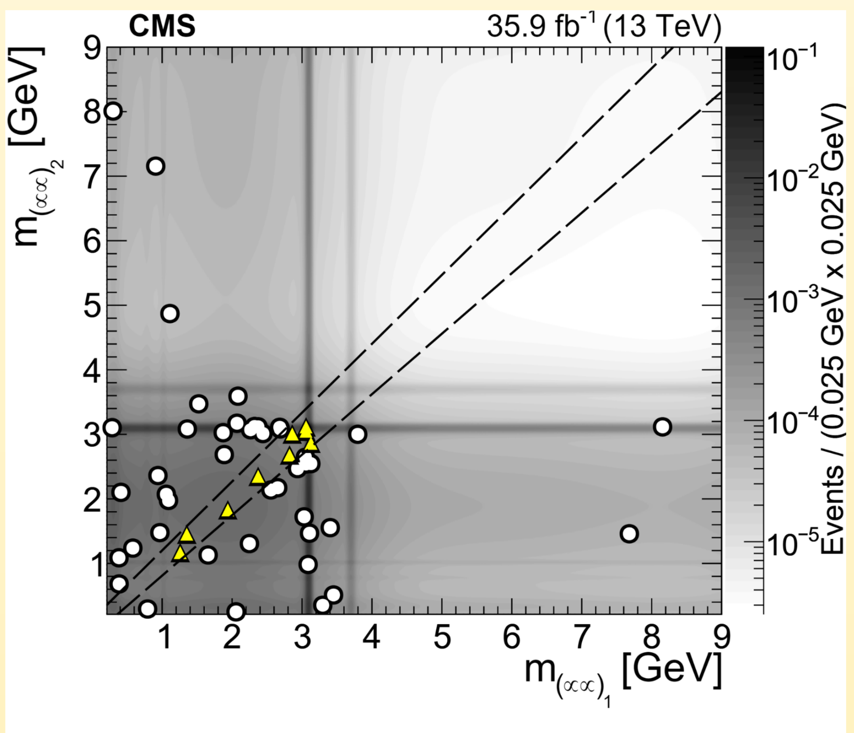

Figure 6. Number of events in the 2D plane defined by the reconstructed mass of the two dimuons, this after the whole event selection, the points and triangles show the events in data while the color area represent the estimated SM background

The data analyzed correspond to an integrated luminosity of 35.9fb^{-1} that was collected during 2016 with the CMS detector, the signal region is defined by the corridor in the 2D plane of Figure 6. The number of observed events (9) is consistent with the SM expectations of 7.95±1.12(stat) ±1.45(syst). This agreement indicates the null presence of new physics in the data analyzed.

Results

In the absence of signal, exclusion plots were obtained for both dark-SUSY and NMSSM scenarios as shown in Figures 7 and 8 respectively. Limits were set using the CLs method. For the dark-SUSY scenario, a 90% CL upper limit is set on the product of the Higgs boson production cross section and the branching fractions of the Higgs boson (cascade) decay to a pair of dark photons. The limit is presented as areas excluded in a two-dimensional plane of ε (kinetic mixing parameter) and the mass of the dark photon. For NMSSM the limit is expressed as a function of the cross section of the Higgs decaying to two light bosons times the Branching fraction of the light boson to two muons.

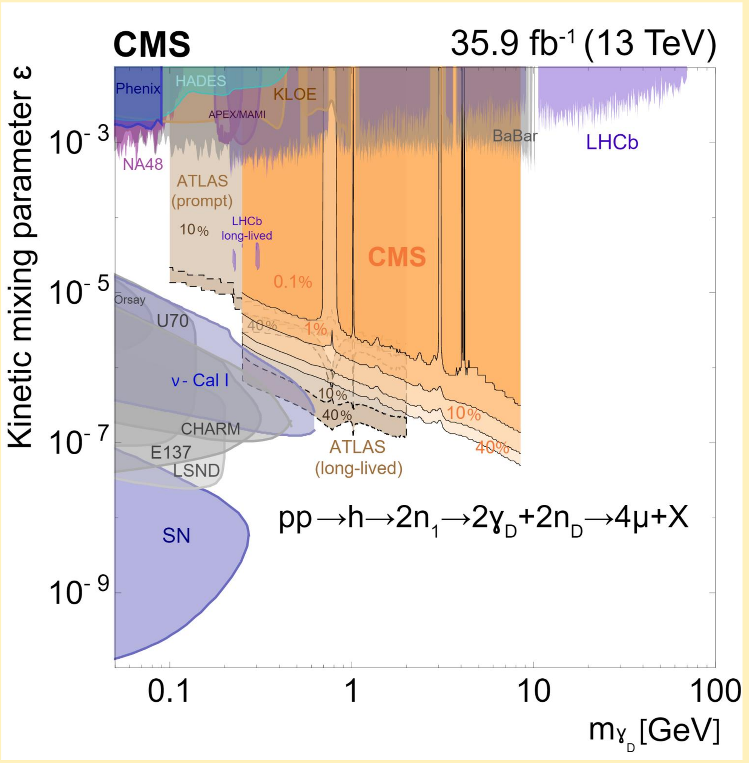

Figure 7. Exclusion limit for the dark-SUSY model, expressed as excluded areas in the two dimensional plane defined by ε and the mass of the dark photon.

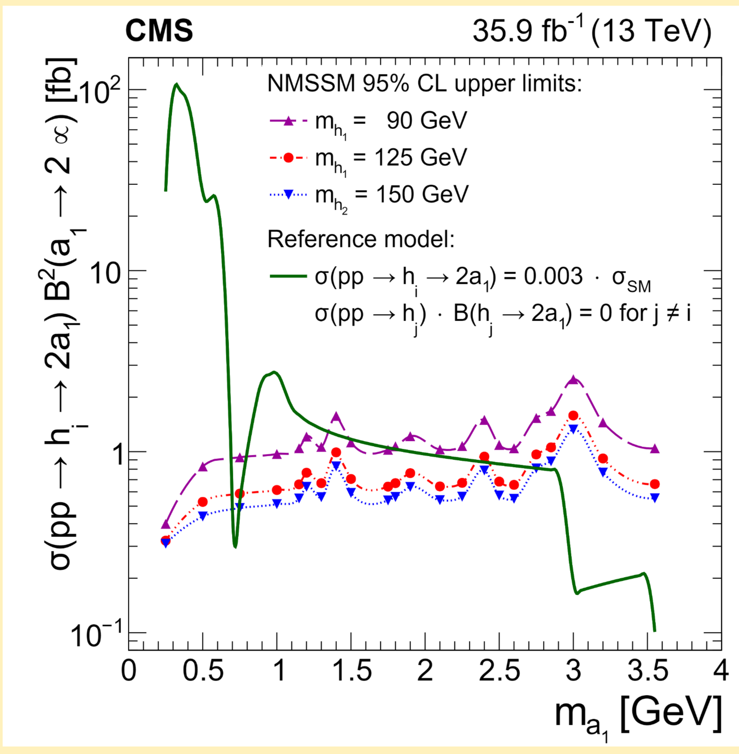

Figure 8. Exclusion limit for the NMSSM model, expressed as the limit on the Higgs boson production cross section and the Branching fraction of the Higgs boson decay to a pair of light bosons as a function of the mass of the new boson

Conclusions and future plans

A search for the production of new light bosons was performed with pp collision data collected during part of the Run-2 data taking campaign corresponding to a total integrated luminosity of 35.9 fb^{-1}. This search was performed as model independent in which several signal models could be interpreted. The models used as benchmark scenarios and to optimize the event selection were the NMSSM and dark-SUSY scenarios, After a detailed analysis on signal models and background estimation no excess was observed in the data and limits were set on the two models obtaining with this the most stringent limits up to date.

This search will be continued during the High luminosity LHC era, in which the vast amount collected of data will be used to develop new background estimation techniques, new selection criteria (i.e. machine learning) and explore a larger available kinematical space.

Acknowledgements

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References

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[4] A search for the production of new light bosons decaying into muons in proton proton collisions at 13 TeV, arXiv:1812.00380