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Dark matter in the two-doublet Higgs model with b-quarks in the final state

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Introduction

Dark matter (DM) is one of the greatest mysteries in modern science, acting as an invisible framework that shapes our entire universe. DM is the most concrete evidence we have that the Standard Model of particle physics is incomplete. Because no known Standard Model particle meets the criteria for dark matter (stable, neutral, and abundant), physicists must look to Physics Beyond the Standard Model (BSM) to explain it.

Astrophysical evidence indicates that dark matter (DM) comprises about 26% of universe's total mass-energy budget (about 85% of the matter in the universe) (fig.1), strongly motivating physics beyond the Standard Model (SM).

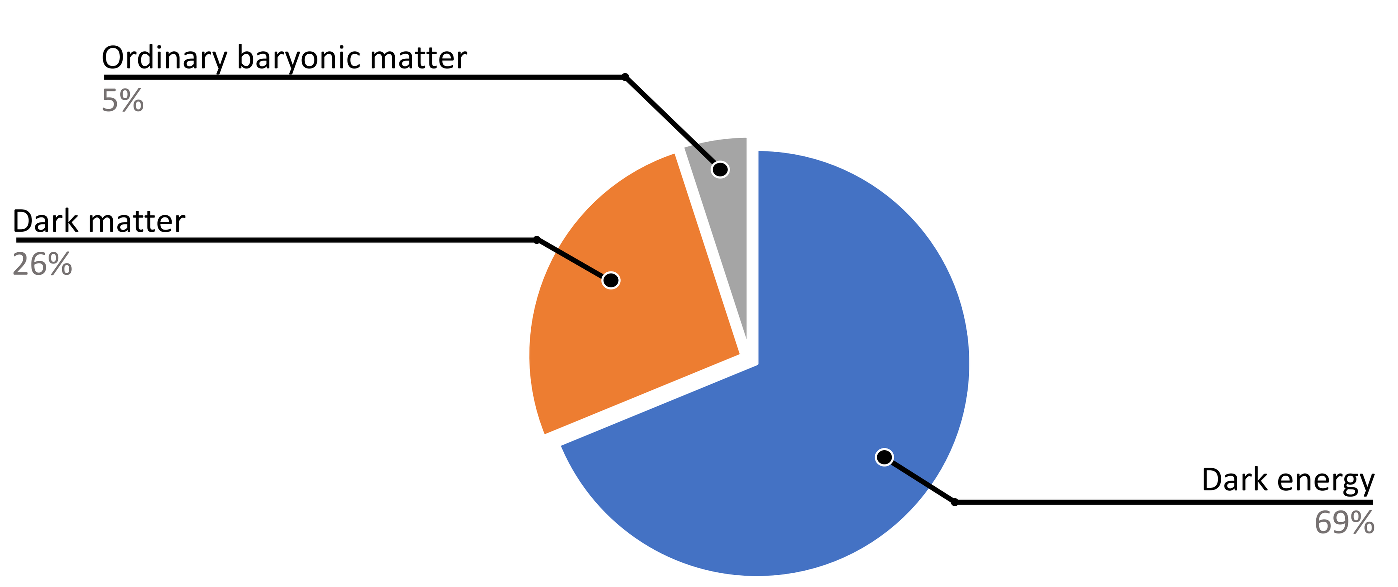

Figure 1. The contents of the universe

Portal models assume that DM matter belongs to a completely separate "Dark Sector" (or Hidden Sector) of particles that do not feel the forces of our Standard Model. To communicate, the two worlds interact through a "portal"— a unique particle that acts as a bridge, possessing properties that allow it to couple with both normal and dark matter.

The 2HDM+a model is one of the most prominent framework extensions used by physicists at CERN and the LHC to describe dark matter via an advanced portal mechanism. It stands for the Two-Higgs-Doublet Model (2HDM) plus an additional pseudoscalar singlet (a).

If DM particles have non-gravitational interactions with SM particles, they could be produced in high-energy hadron collisions. Assuming production through a spin-0 or spin-1 mediator, DM particles would escape the detector unseen, but their presence can be inferred from a large transverse momentum imbalance when they are produced in association with a detectable SM particle. A search for DM produced in association with a Higgs boson decaying to a bottom quark-antiquark pair ($b\bar{b}$) is presented (fig.2). This $b\bar{b}$ decay mode has the largest branching fraction and provides the highest signal yield among possible decay channels.

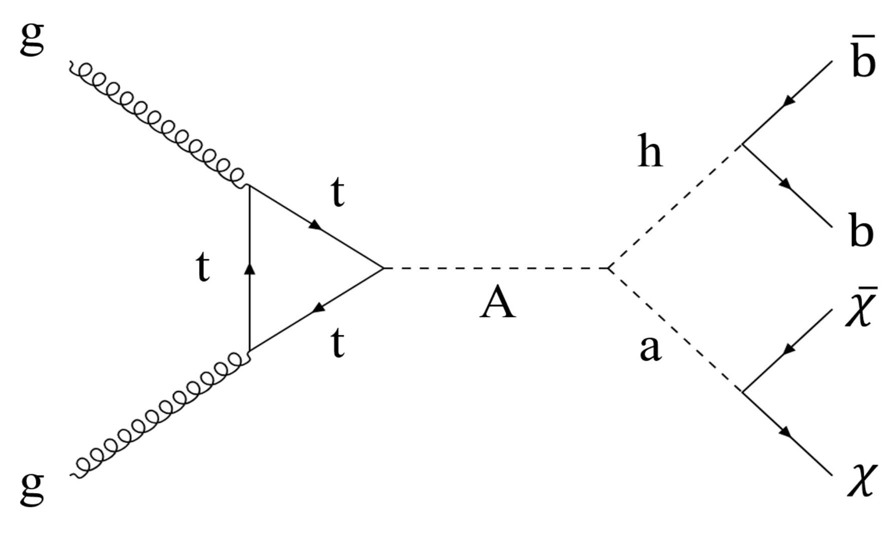

Figure 2. Feynman diagram for 2HDM+a model

Analyzed data

The data analyzed in this search are from pp collisions at $\sqrt{s}$ = 13 TeV collected by the CMS experiment (fig.3) in 2017 and 2018, corresponding to an integrated luminosity of 101 fb^{-1}. Signal and background contributions are modeled using Monte Carlo (MC) simulations. The parton shower, hadronization, and the underlying event simulation are provided by PYTHIA version 8.202 or later with the underlying event tune CP5. The response of the CMS detector is simulated with the GEANT4 package.

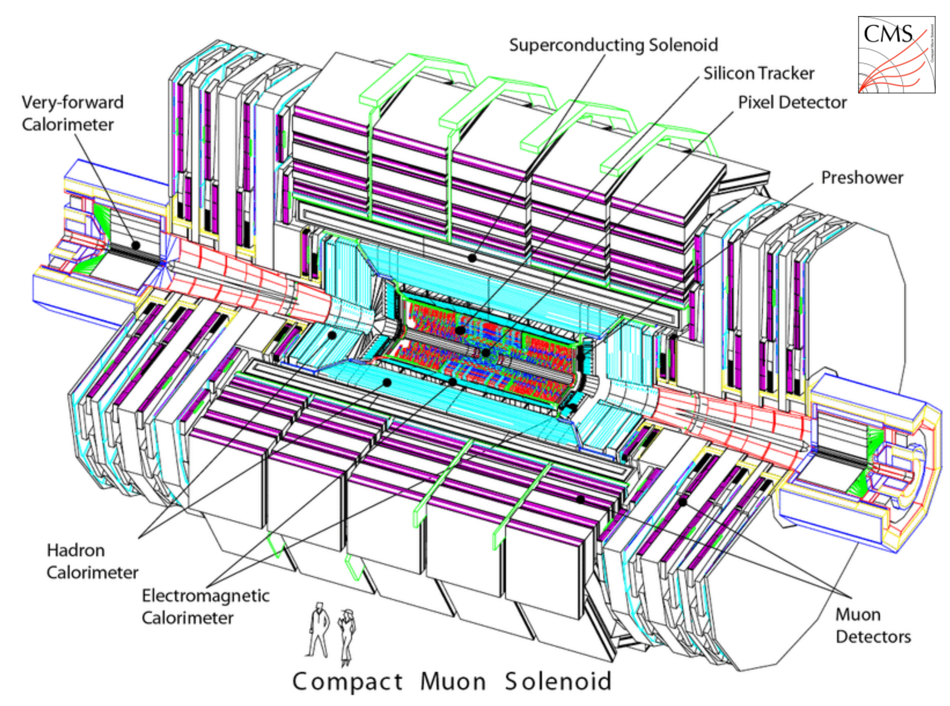

Figure 3. CMS schematic overview

The signal samples are generated at leading order (LO) using MADGRAPH5 aMC@NLO version 2.6.5. The dominant background arises from the production of $Z(\nu\nu)$+jets and $t\bar{t}$ pairs.

Event reconstruction and event selection

The CMS particle-flow (PF) algorithm was used for reconstructing events. It aims to reconstruct and identify each individual particle in an event, with an optimized combination of information from the various elements of the CMS detector.

Events are first considered for the merged category, and those failing this selection are passed on to the selection criteria for the resolved category. This helps improve the overall sensitivity of the analysis to different regions of parameter space.

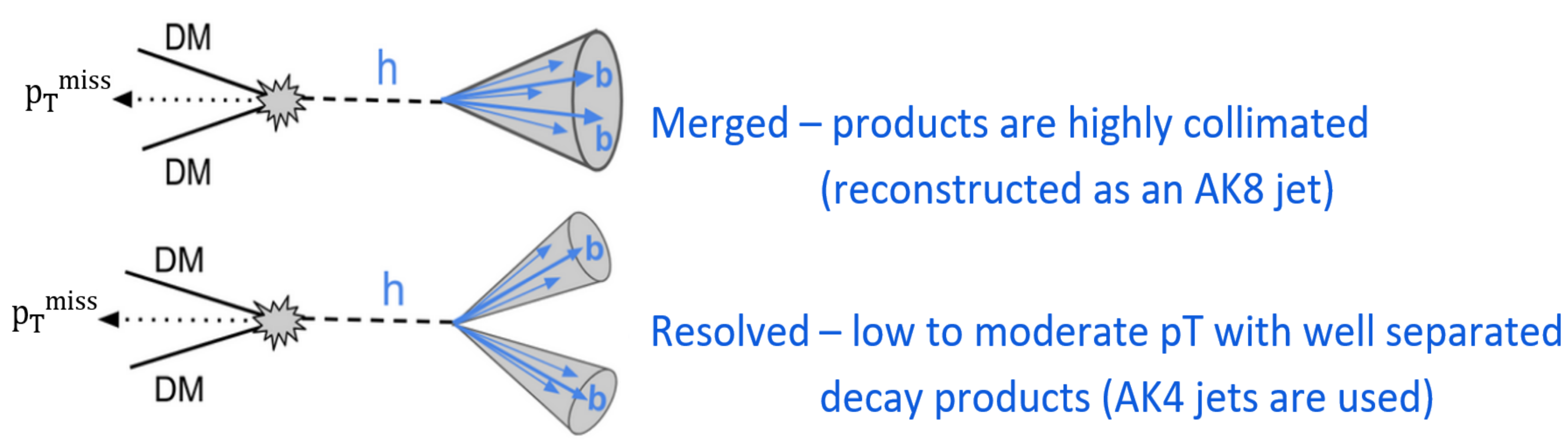

Figure 4. Schemes for resolved and merged categories .

Signal extraction

The analysis is performed in the merged and resolved categories using a two-dimensional maximum likelihood fit. The observables are pT_{miss} and the Higgs boson candidate mass, m_{SD} in the merged category and $m_{b\bar{b}}$ in the resolved category. The Higgs boson candidate mass provides strong discrimination, as only the signal and well-understood, subdominant SM backgrounds exhibit a resonant peak in this distribution.

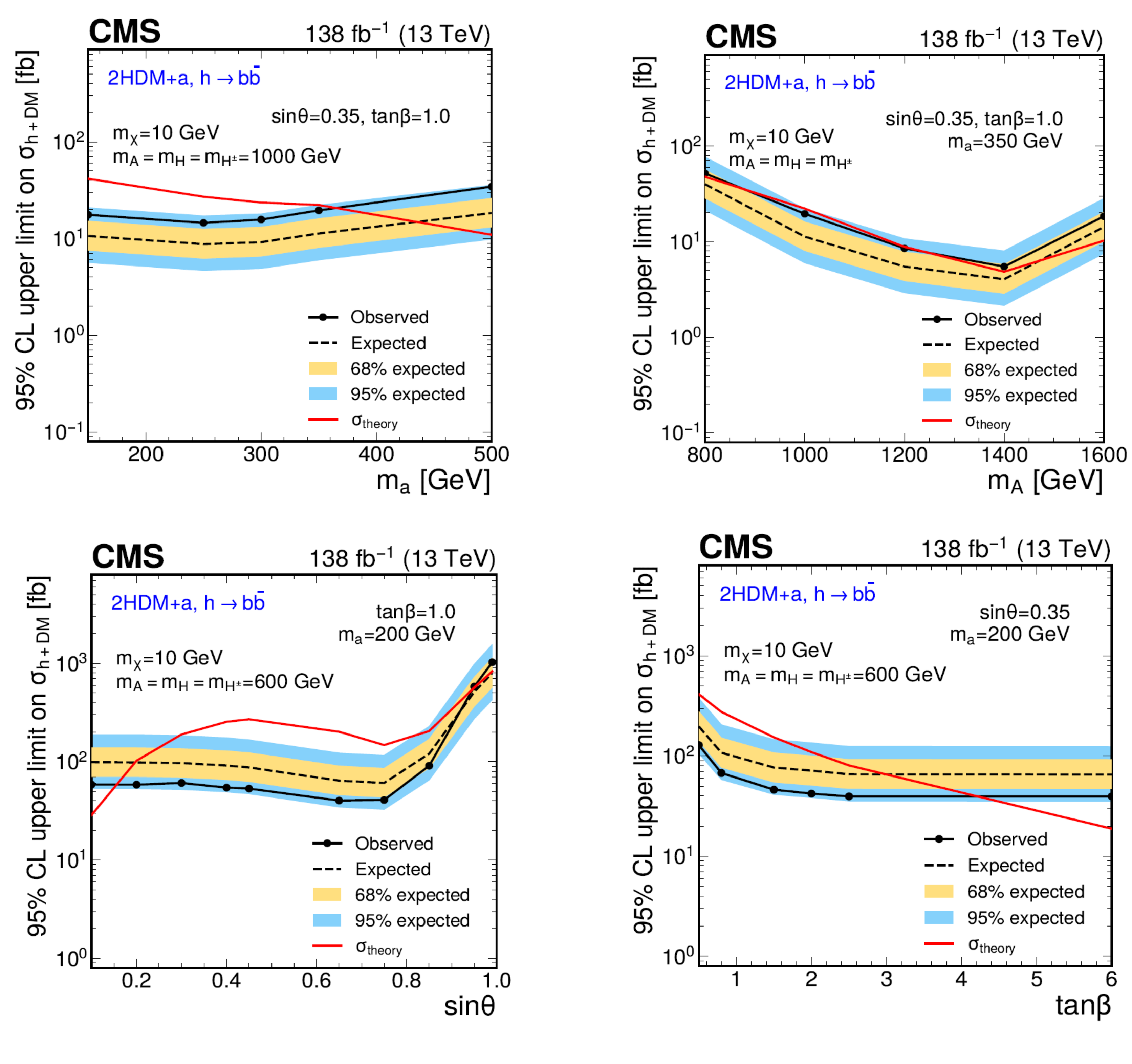

Figure 5. Observed and expected exclusion limits at 95% CL on the signal cross section σ_{h+DM} for the 2HDM+a model as a function of the model parameters: m_a (upper left), m_A (upper right), sin θ (lower left), and tan β (lower right) while fixing the values of the other parameters, as indicated in the legends. Mass points below the solid red line are excluded.

Summary

Observed data is in excellent agreement with Standard Model background predictions and no signal of dark matter production in the 2HDM+a model was detected so far in the data. Exclusion limits are set on the model parameters at 95% confidence level. In the 2HDM+a framework, light pseudoscalar masses m_a below 360 GeV are excluded. For a heavy pseudoscalar mass m_A of 1000 GeV, and m_A masses between 850 and 1300 GeV are excluded for m_a of 350 GeV. For the other model parameters, $\sin\theta$ values between 0.15 and 0.95 are excluded, while $\tan\beta$ values less than 4.2 are excluded.

References

Sirunyan, A.M., Tumasyan, A., Adam, W. et al. Eur. Phys. J. C 79, 280 (2019).

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