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SEARCH FOR DARK MATTER CANDIDATE PRODUCED IN ASSOCIATION WITH A HIGGS BOSON AND TAU LEPTONS AT √s=14 TeV

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A search for dark matter produced in association with a Higgs boson in final states with two τ-leptons and missing transverse momentum, $pp \to A \to ah\tau^+\tau^-$ is presented. The corresponding experimental analysis between 2015–2018 years used 139 fb^{-1} of proton–proton collision data at $\sqrt{s}$ = 13 TeV collected by the ATLAS experiment at the LHC. The results are interpreted in terms of a 2HDM+a model with physics beyond the Standard Model featuring two scalar Higgs doublets and a pseudoscalar singlet field. Two sets of parameters, derived from experimental exclusion limits, for calculating the axions and bosons production cross sections were selected using the MADGRAPH5@NLO computer program. The obtained information, together with kinematic constraints on the transverse momentum and angular distribution of axions and bosons, allows us to conclude about the existence of CP-odd Higgs bosons with a mass in the region of 400 GeV and a dark matter candidate, the axion, with a mass of up to 200 GeV.

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INTRODUCTION

One of the most popular and long-studied dark matter candidates [1–3] are the axion-like particles (ALP). The only way to identify this particle by its interaction constant has long been studied by many collaborations such as Belle II, LEP, CDF, ATLAS, CMS and so on [4]. The lack of information regarding the mass, type of particle (scalar or pseudoscalar) and only the gravitational type of interaction leads to complications in both experimental identification and theoretical interpretation of ALPs. Thanks to modern Monte Carlo programs, it is possible to model the properties of such particles to indicate optimal mass regions, kinematic restrictions on momentum and pseudorapidity to facilitate a targeted search for BSM physics. To search for ALP, simplified models are usually used with a minimal set of new candidate dark matter particles with one mediator, which, depending on the model, can be a vector, axial-vector, scalar or pseudoscalar particle [5]. We used the reference model of two Higgs doublets (2HDM) plus a pseudoscalar mediator denoted as 2HDM+a [6]. The model is described by 12 additional parameters:

- Masses of the CP-odd, CP-even and charged Higgs bosons ($A,H,H^{\pm}$) are set to be equal to each other;
- Mixing angles α and β are constrained to be $\cos(\beta-\alpha) = 0$, where α is the mixing angle between CP-even Higgs bosons h and H, and $\tan\beta$ is the ratio of the vacuum expectation values (VEV) of the two Higgs doublets;
- The mass of the lightest Higgs boson h is fixed to be $m \approx 125$ GeV;
- The mixing angle between the two pseudoscalars, θ, is required to satisfy $\sin\theta = 0.35$ or $\sin\theta = 0.7$.

The goal of our work is to use the MadGraph5 a MC@NLO program [7] to model the production processes of the CP-odd Higgs boson, A, with subsequent decay into ALP and the lightest Higgs boson, h. So, the process of ALP formation together with the Higgs boson and two tau-leptons in the final state, $pp \to A \to ah\tau^+\tau^-$, is studied. Representative Feynman diagrams for the dominant gluon-induced and quark-induced production and decay modes in the 2HDM+ a are presented in Fig. 1.

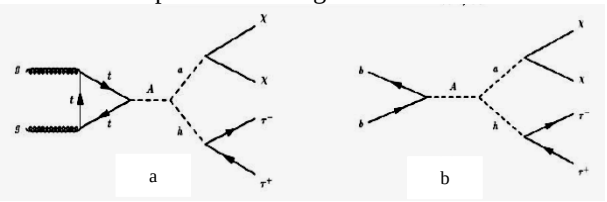

Fig. 1. Feynman diagrams describing the 2HDM+a model scenarios for the creation of mono-Higgs signatures: a – gluon-gluon merger and b – bb annihilation

COMPUTER MODELING OF ALP PROPERTIES

The corresponding experimental search for ALP was performed by the ATLAS collaboration at the LHC during 2015–2018 at an integral luminosity of 139 fb^{-1} in proton-proton collisions at $\sqrt{s}$ = 13 TeV, [8]. Using the restrictions on 2HDM+a model parameters obtained from experimental data, we selected two sets of parameters, which are listed in Table.

Parameter scenarios for the 2HDM+a model

Scenarios	m_a	m_A	tan β	sin θ
BP1	500 GeV	1400 GeV	1	0.35
BP2	150 GeV	500 GeV	2	0.7

The use of the scenarios listed in Table made it possible to calculate the cross-sections of the formation of bosons (Fig. 2) and axions (Fig. 3) using the MadGraph5 a MC@NLO computer program.

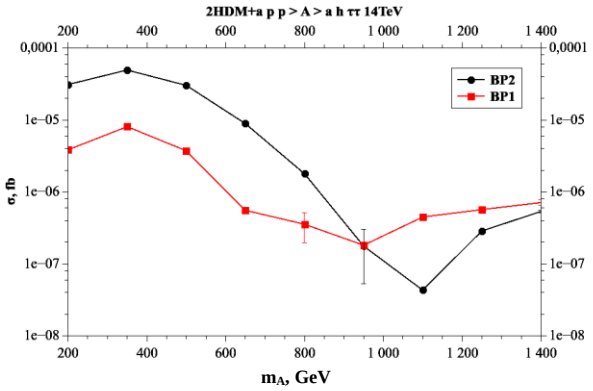

Fig. 2. Cross-sections for Higgs boson formation as a function of Higgs boson mass, m_A

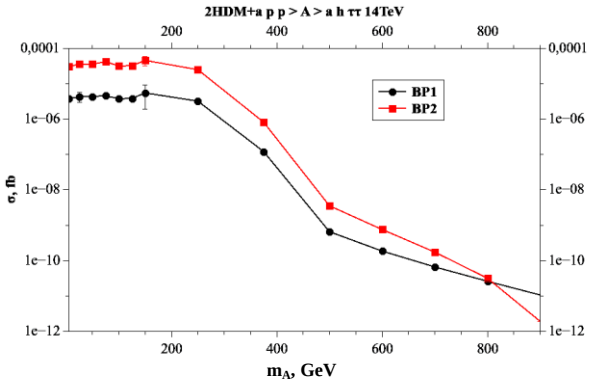

Fig. 3. Cross-sections for axion formation as a function of the axion mass, m_a

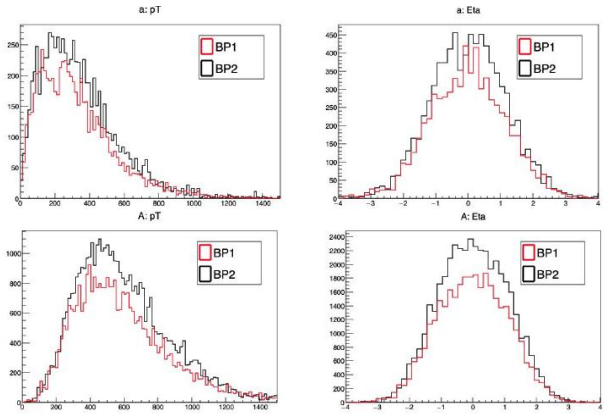

Fig. 4. Kinematical data for CP-odd bosons, A (up) and ALP (down)

The corresponding kinematic restrictions for momentum (left) and pseudorapidity (right) for CP-odd bosons, A, and ALP are shown in Fig. 4. From the data presented in Fig. 4, it is necessary to conclude about the predominance of momentum values in the region of 400…600 GeV for CP-odd Higgs boson, A, and from 100 to 400 GeV for ALP. Regarding pseudorapidity, for the CP-odd Higgs bosons, a larger number of events are located in the region from -3 to 3. For ALP, the behavior of pseudorapidity is more symmetrical for the BP2 scenario in the region from -1.5 to 1.5.

CONCLUSIONS

The 2HDM+a model for searching and modeling ALP particles is considered. Experimental constraints on the search for ALP particles became the basis for the selection of simulation scenarios. The obtained kinematic constraints on the transverse momentum and angular distribution allow the realization of possible searches for the CP-odd Higgs boson with a mass in the region of 400 GeV and a dark matter candidate, ALP, with a mass up to 200 GeV. The obtained data demonstrate the priority of the second BP2 scenario, which correlates with the latest experimental constraints of the ATLAS collaboration.

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ПОШУКИ КАНДИДАТІВ ТЕМНОЇ МАТЕРІЇ, УТВОРЕНИХ РАЗОМ З БОЗОНОМ ХІГГСА І ТАУ-ЛЕПТОНАМИ ПРИ $\sqrt{s}$=14 ТеВ

Тетяна Обіход, Євгеній Петренко

У рамках вивчення властивостей кандидатів темної матерії наведено процес утворення аксіонів разом із бозоном Хіггса і двома тау-лептонами у кінцевому стані, $pp \to A \to ah\tau^+\tau^-$. Відповідний експериментальний пошук аксіонів було виконано ATLAS колаборацією на ВАК протягом 2015–2018 років при інтегральній світності 139 fb^{-1} у протон-протонних зіткненнях при $\sqrt{s}$=13 ТеВ. Результати інтерпретовані у межах 2HDM+a-моделі, яка описує фізику за межами Стандартної моделі. Використовуючи отримані з експериментальних даних обмеження на параметри моделі, нами були обрані два набори параметрів для проведення розрахунків поперечних перерізів утворення аксіонів і бозонів за допомогою комп'ютерної програми MADGRAPH5@NLO. Отримана інформація разом із кінематичними обмеженнями на поперечний імпульс та кутовий розподіл аксіонів і бозонів дає змогу зробити висновок про існування CP-непарних бозонів Хіггса із масою в області 400 ГеВ та кандидата на темну матерію, аксіону, із масою до 200 ГеВ.