Constraining Multi-scalars models with colliders and Dark Matter

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Motivation and Research plan of PhD

Motivation for NHDM:

- Simple extension of the SM that allows for scalar CP violation.
- Possibility for Dark Matter.
- Large portions of parameter space testable at LHC.

Objectives:

- Develop tools for the analysis of models with new scalars and the symmetries. Focus on theoretical conditions on the parameter space of Three Higgs Doublet Models (3HDMs).
- Extend numerical code previously developed for 2HDMs to more general models. Confront parameter space of the model with space and ground experiments data.
- Study models and signals of complex DM components.

Timeline of work

- Current bounds on the type-Z Z3 three-Higgs-doublet model,
  R. Boto, J. C. Romão, and J. P. Silva, Phys. Rev. D 104 (2021), no. 9 095006, [2106.11977];
- Bounded from below conditions on a class of symmetry constrained 3HDM,
  R. Boto, J. C. Romão, and J. P. Silva, Phys. Rev. D 106 (2022), no. 11 115010, [2208.01068];
- Fingerprinting the type-Z three-Higgs-doublet models,
  R. Boto, D. Das, L. Lourenço, J. C. Romão, and J. P. Silva, Phys.Rev.D 108 (2023) 1, 015020 [2304.13494];
- New physics interpretations for nonstandard values of decays,
  R. Boto, D. Das, I. Saha, J. C. Romão, and J. P. Silva, Phys.Rev.D 109 (2024) 9, 095002 [2312.13050];
- Large pseudoscalar Yukawa couplings in the complex 3HDM,
  R. Boto, L. Lourenço, J. C. Romão, and J. P. Silva, in final stages of review [2407.19856];
- Novel two component dark matter features in the $\mathbb{Z}_2 \times \mathbb{Z}_2$ 3HDM,
  R. Boto, P. Figueiredo, J. C. Romão, and J. P. Silva, in final stages of review [2407.15933];
- Other projects in progress,
- Thesis writing and conclusion in summer 2025.

Constraints on a Model

The restrictions to consider when performing parameter scans for a given model include,

- the S matrix must satisfy perturbative unitarity, [Bento et al., 2022] for all 3HDMs;
- the Higgs potential must be bounded from below (BFB),
  $\Rightarrow$ Derived method of obtaining sufficient conditions for 3HDMs [Boto et al., 2022];
- Agreement with the S, T and U electroweak parameters [Grimus et al., 2008];
- Coupling modifiers and cross section ratios μ_{if}^{h} from [ATLAS Collaboration, 2022],

$$\mu_{if}^{h} = \left(\frac{\sigma_i^{\mathrm{3HDM}}(pp \to h)}{\sigma_i^{\mathrm{SM}}(pp \to h)} \right) \left(\frac{\mathrm{BR}^{\mathrm{3HDM}}(h \to f)}{\mathrm{BR}^{\mathrm{SM}}(h \to f)} \right); \qquad (1)$$

- HiggsTools [Bahl. et al., 2022] that uses the experimental cross section limits from the LEP, the Tevatron and the LHC (at 95% C.L). Can also do combined fits to Higgs precision data.

We built a FORTRAN program for each model that numerically calculates all the necessary quantities for a randomly generated set of parameters and then tests the restrictions implemented.

Constraints on a Model

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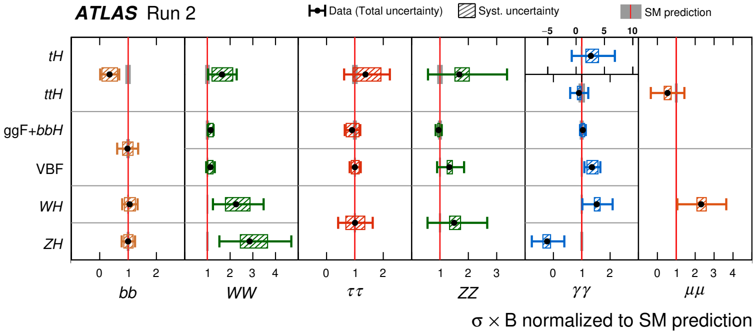


Multi-component Dark Matter

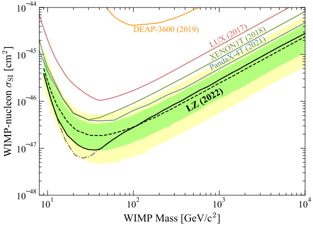
With some 3HDM, there is the possibility of two of the Higgs being DM candidates. The total relic density is given by the sum of the contributions from both DM candidates H_1 and H_2,

$$\Omega_T h^2 = \Omega_{H_1} h^2 + \Omega_{H_2} h^2, \tag{3}$$

and is constrained by [Planck, 2018] data to be:

$$\Omega_T h^2 = 0.1200 \pm 0.0012. \tag{4}$$

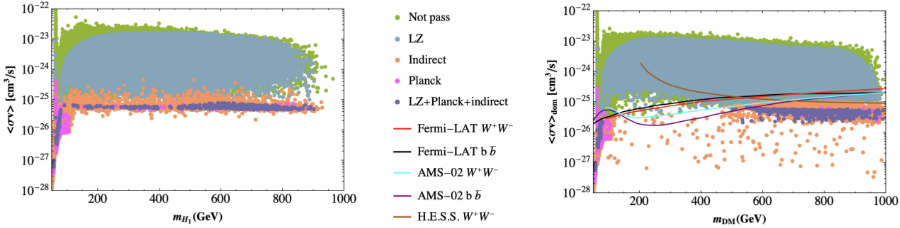
The current published upper limit on the scattering cross-section of DM (direct detection) is given by the LUX-ZEPLIN experiment [LZ, 2022],



In the GeV mass scale, the indirect detection limit is of order $< \sigma v > \approx 10^{-25}\, cm^3/s$, from Fermi-LAT, AMS-02 and HESS experiments .

Multi-component Dark Matter

For the $\mathbb{Z}_2 \times \mathbb{Z}_2$ model, take points that pass through all the collider constraints then test the DM observables,



Total indirect detection observable $\langle \sigma v \rangle$ as function of mass of DM1 (left) and dominant candidate (right).
The whole mass range for a given component can be populated. Possible to find regions with similar contributions of each candidate.

Summary of PhD until now

Published and upcoming works

- 6 PhD papers published, [2106.11977] [2208.01068] [2304.13494] [2312.13050] [2407.15933] [2407.19856];
- 1 paper in writing stage;
- Projects in development related to PhD objectives.

Teaching

- Analytical Mechanics - Physics IST - 22/23 and 23/24;
- Physics II - Electrical Engineering IST - 22/23 - Docente excelente;

The End