One-loop corrections to Higgs decay to dark matter

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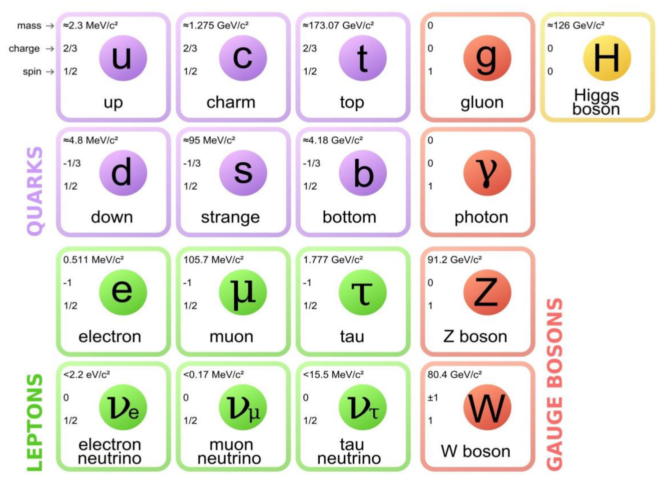
The problem

The **Standard Model of Particle Physics (SM)** is one of the most successful models in Physics and it has shown exceptional agreement with experimental measurements.



However, the Standard Model still can't explain many experimental observations such as:

- Dark matter
- Matter/antimatter asymmetry

The model

The **Next-to-minimal 2-Higgs Doublet Model (N2HDM)** is a simple SM extension that provides phenomenology compatible with the existence of dark matter candidates. To the usual SM $SU(2)_L \times U(1)_Y$ scalar doublet, a second doublet and a real singlet are added.

$$V_{scalar} = m_{11}^2\Phi_1^\dagger\Phi_1 + \frac{\lambda_1}{2}(\Phi_1^\dagger\Phi_1)^2 + m_{22}^2\Phi_2^\dagger\Phi_2 + \frac{\lambda_2}{2}(\Phi_2^\dagger\Phi_2)^2 - m_{12}^2(\Phi_1^\dagger\Phi_2 + h.c.) + \lambda_3\Phi_1^\dagger\Phi_1\Phi_2^\dagger\Phi_2$$
$$+\lambda_4\Phi_1^\dagger\Phi_2\Phi_2^\dagger\Phi_1 + \frac{\lambda_5}{2}\left((\Phi_1^\dagger\Phi_2)^2 + h.c.\right) + \frac{1}{2}m_S^2\Phi_S^2 + \frac{\lambda_6}{8}\Phi_S^4 + \frac{\lambda_7}{2}\Phi_1^\dagger\Phi_1\Phi_S^2 + \frac{\lambda_8}{2}\Phi_2^\dagger\Phi_2\Phi_S^2$$

$$\Phi_1 = \begin{pmatrix} \Phi_1^+ \\ \frac{1}{\sqrt{2}}(v_1 + \rho_1 + i\eta_1) \end{pmatrix} \qquad \Phi_2 = \begin{pmatrix} \Phi_2^+ \\ \frac{1}{\sqrt{2}}(v_2 + \rho_2 + i\eta_2) \end{pmatrix} \qquad \Phi_S = v_S + \rho_S$$

The dark phases

The N2HDM allows for several vacua, to spontaneously break the electroweak symmetry. Some of these vacua, to which we call **dark phases**, allow for the existence of dark matter candidates.

We are interested in two of these phases:

- In the **Inert Doublet Phase**, only one of the doublets and the singlet acquire a non-vanishing vaccum expectation value (VEV). The dark matter candidate originates from the doublet with the vanishing VEV.

$$v_1 = 0 \qquad v_2 = v_{SM} \qquad v_S \neq 0$$

- In the **Dark Singlet Phase**, both doublets acquire a non-zero VEV while the singlet's VEV vanishes. In this case the dark matter candidate originates from the singlet.

$$v_1 \neq 0 \qquad v_2 \neq 0 \qquad v_S = 0 \qquad v_{SM}^2 = v_1^2 + v_2^2$$

The new particles

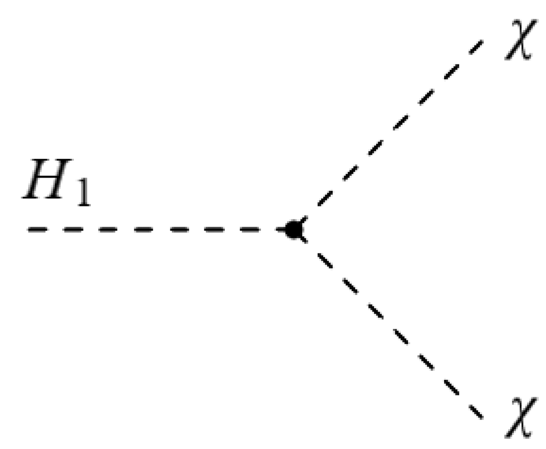
The N2HDM produces several **new scalar particles**, including a dark matter candidate, χ.

Higgs-like	$H_1 \quad H_2$
Charged Higgs	$H_+ \quad H_-$
Neutral, CP-odd	A_0
Dark particle	χ

Depending on the phase, these particles can have different phenomenology.

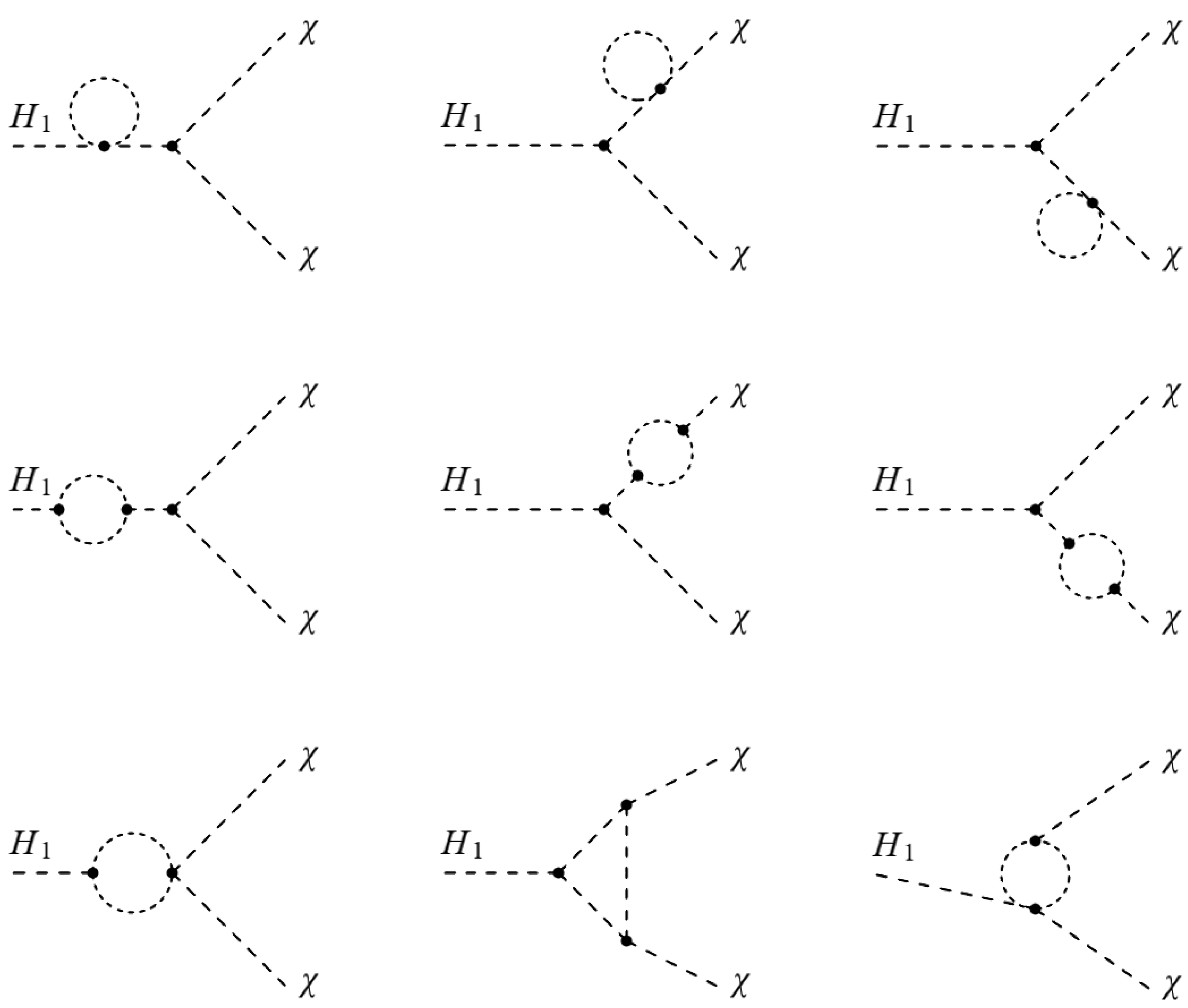
The decay

One way the N2HDM allows for the creation of dark matter, is through the decay of the Higgs boson to two dark particles. This Higgs decay could be a good way to detect dark matter in a particle accelerator.



The 1-loop corrections

To constrain our parameter space with increased precision, we need to calculate our observables to next-to-leading order (NLO) of perturbation theory. This means that we need to consider **every 1-loop Feynman diagram** allowed by the model for the process we want to study:



These additional diagrams introduce new constraints to the parameters of the model, thus correcting the amplitudes of the decay.

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The authors acknowledge all the financial support from the Portuguese Foundation for Science and Technology (FCT), Contracts UIDB/00618/2020, UIDP/00618/2020, PTDC/FIS-PAR/31000/2017 and CERN/FIS-PAR/0002/2017, and by the HARMONIA project, contract UMO-2015/18/M/ST2/00518.