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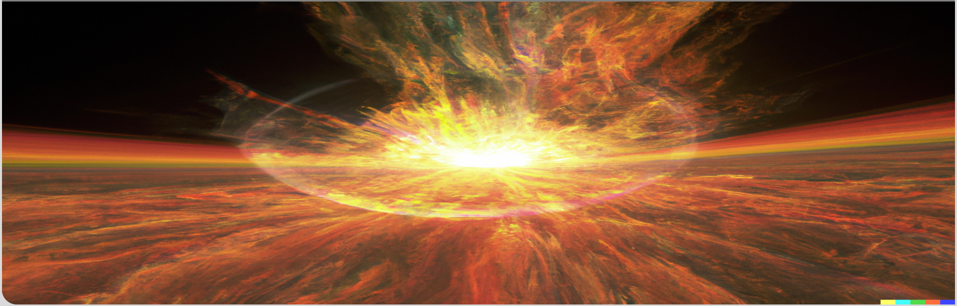
Dark Matter Generation Mechanisms of the Model CP In The Dark

Invisibles23

Johann Plotnikov

Department of Physics, Institute of Theoretical Physics



The Potential of CP in the Dark

[D. Azevedo et al. 2018]

- Extension of the scalar sector by a complex scalar doublet Φ_2 and a real scalar singlet Φ_S
- Impose a $\mathbb{Z}_2$ symmetry of the form

$$\Phi_1 \to \Phi_1 \quad , \quad \Phi_2 \to -\Phi_2 \quad , \quad \Phi_S \to -\Phi_S$$

- Most general scalar potential

$$\begin{aligned} V =& m_{11}^2|\Phi_1|^2 + m_{22}^2|\Phi_2|^2 + \frac{1}{2}m_S^2\Phi_S^2 + (A\Phi_1^\dagger\Phi_2\Phi_S + h.c.) \\ &+ \frac{1}{2}\lambda_1|\Phi_1|^4 + \frac{1}{2}\lambda_2|\Phi_2|^4 + \lambda_3|\Phi_1|^2|\Phi_2|^2 + \lambda_4|\Phi_1^\dagger\Phi_2|^2 \\ &+ \frac{1}{2}\lambda_5\left[\left(\Phi_1^\dagger\Phi_2\right)^2 + h.c.\right] + \frac{1}{4}\lambda_6\Phi_S^4 + \frac{1}{2}\lambda_7|\Phi_1|^2\Phi_S^2 \\ &+ \frac{1}{2}\lambda_8|\Phi_2|^2\Phi_S^2 \end{aligned}$$

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Features of CP in the Dark

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Features of CP in the Dark

- 5 Dark Sector (DS) particles $H^{\pm}, h_1, h_2, h_3$
- Yukawa sector identical to the SM
- No tree-level flavour changing neutral currents
- Additional CP violation only through the DS

The problem with freeze-in and gauge couplings

Typical couplings between DM and the bath for freeze-in are $\lambda_{\text{FI}} \leq 10^{-10}$! [Hall et al., 2010]

Making Freeze-in Possible

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Reduce the gauge couplings:

$$\mathrm{V}\left(h_1, h_2, Z\right) = \frac{g}{cos\Theta_W} c_{\alpha_2} c_{\alpha_3}$$
$$\mathrm{V}\left(h_1, h_3, Z\right) = \frac{g}{cos\Theta_W} c_{\alpha_2} s_{\alpha_3}$$

$\Rightarrow \alpha_2 = \pi/2$
Mass eigenstates become:

$$h_1 = s$$
$$h_2 = - s_{\alpha_1+\alpha_3}\rho + c_{\alpha_1+\alpha_3}\eta$$
$$h_3 = - c_{\alpha_1+\alpha_3}\rho - s_{\alpha_1+\alpha_3}\eta$$

h_1 has been decoupled from the $SU(2)$ doublet

Implications of the Decoupling

$$
\begin{aligned}
V = & m_{11}^2|\Phi_1|^2 + m_{22}^2|\Phi_2|^2 + \frac{1}{2}m_S^2\Phi_S^2 \\
& + \frac{1}{2}\lambda_1|\Phi_1|^4 + \frac{1}{2}\lambda_2|\Phi_2|^4 + \lambda_3|\Phi_1|^2|\Phi_2|^2 + \lambda_4|\Phi_1^\dagger\Phi_2|^2 \\
& + \frac{1}{4}\lambda_6\Phi_S^4 + \frac{1}{2}\lambda_7|\Phi_1|^2\Phi_S^2 + \frac{1}{2}\lambda_8|\Phi_2|^2\Phi_S^2
\end{aligned}
$$

Red terms are responsible for freeze-out of $h_{2/3}$ and $H^\pm$
Blue terms are responsible for freeze-in of h_1

Results

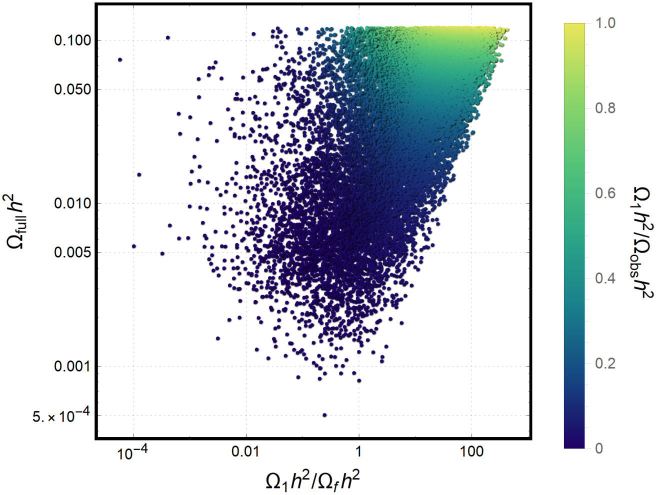
Constraints on Parameter Scan

The scan is performed using ScannerS to check following constraints

[Coimbra, Sampaio, and Santos, 2013; Mühlleitner et al., 2020]

- Tree-level pertubative unitarity
- Boundedness from below
- Peskin-Takeuchi electroweak precision parameters S, T and U [M. Peskin and T. Takeuchi., 1992]
- We choose $m_{h_1} > 70$ GeV
- HiggsSignals [Heinemeyer, et al., 2014] and HiggsBounds [P. Bechtle et al., 2010] is used to check with collider Higgs data
- Freeze-out contribution to relic density via MicrOMEGAs [G. Belanger et al., 2013]
- Freeze-in contribution to relic density ourselves
- Direct detection constraints by LZ [J. Aalbers et al., 2022]

Relic Denstiy Contributions

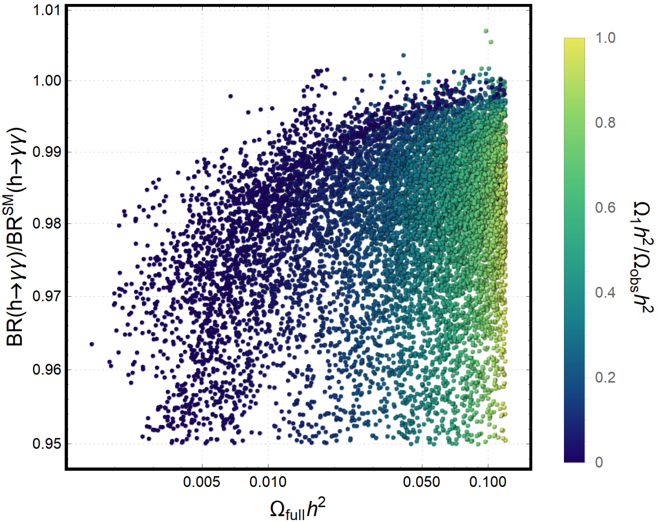


Di-Photon Branching Ratio

The additional charged Higgs $H^{\pm}$ adds an additional loop contribution to the leading order di-photon decay of the Higgs boson measured by ATLAS at [ATLAS Collaboration, 2022]

$$\frac{\mathrm{BR}(h \to \gamma\gamma)}{\mathrm{BR}^{SM}(h \to \gamma\gamma)} = 1.04^{+0.10}_{-0.09}$$

Di-Photon Branching Ratio



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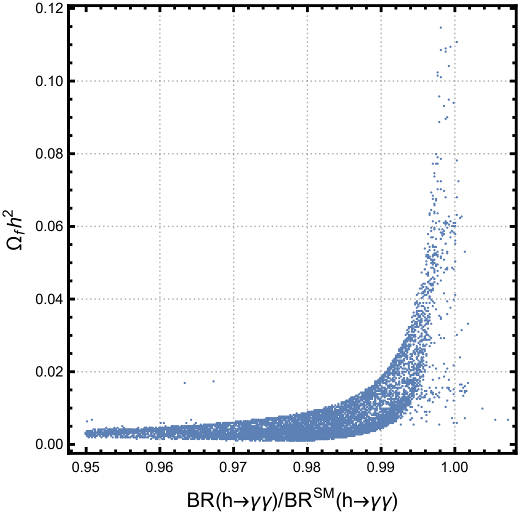
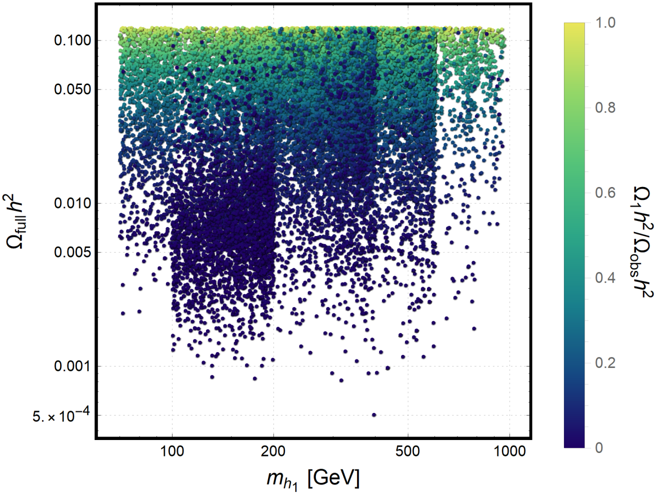


Conclusions

- Freeze-in and freeze-out are simultaneously possible in CP in the Dark
- However, the additional CP violating properties are lost
- If we assume that the model accounts for the full observed relic density then it is possible to differentiate between a freeze-out dominated and a freeze-in dominated relic density
- The freeze-in contribution is able to fill the relic density to the observed one independently of experimental constraints

Mass Spectrum



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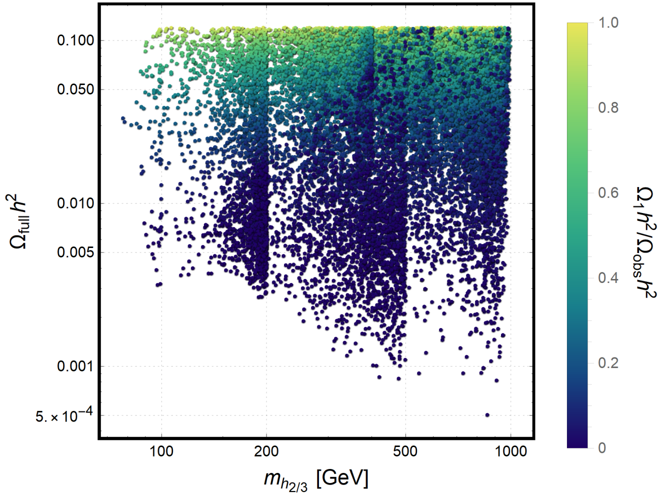
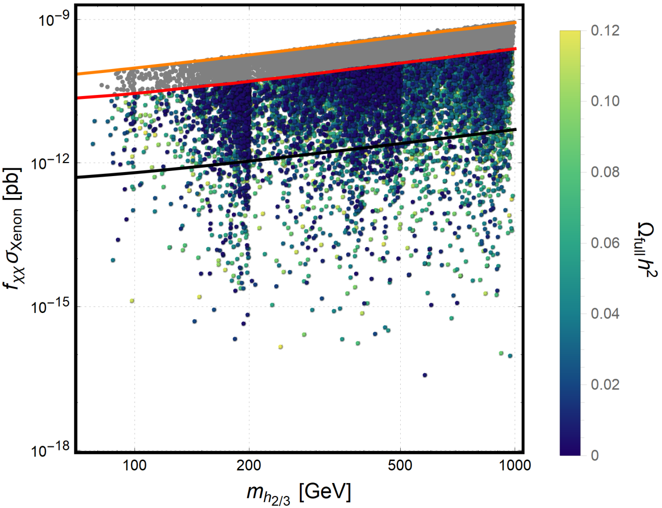


Direct Detection



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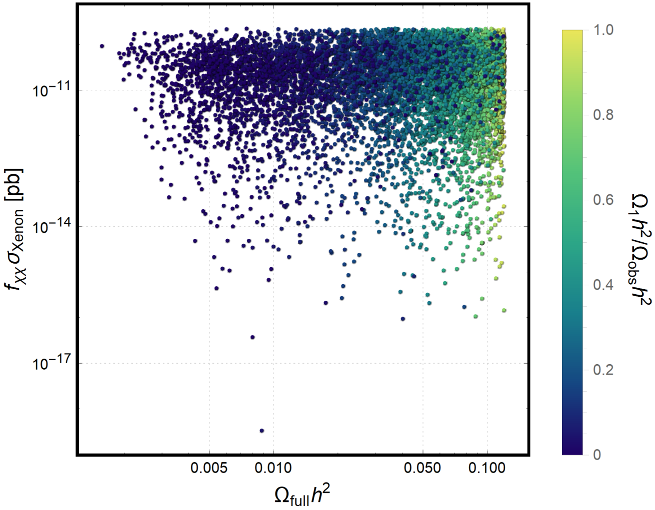

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