Long-lived dark mediators from a Higgs portal model

SAPHIR

Author
Manuel López

Advisor
Giovanna Cottin

Affiliations
Pontificia Universidad Católica de Chile (PUC)

PONTIFICIA UNIVERSIDAD CATÓLICA DE CHILE

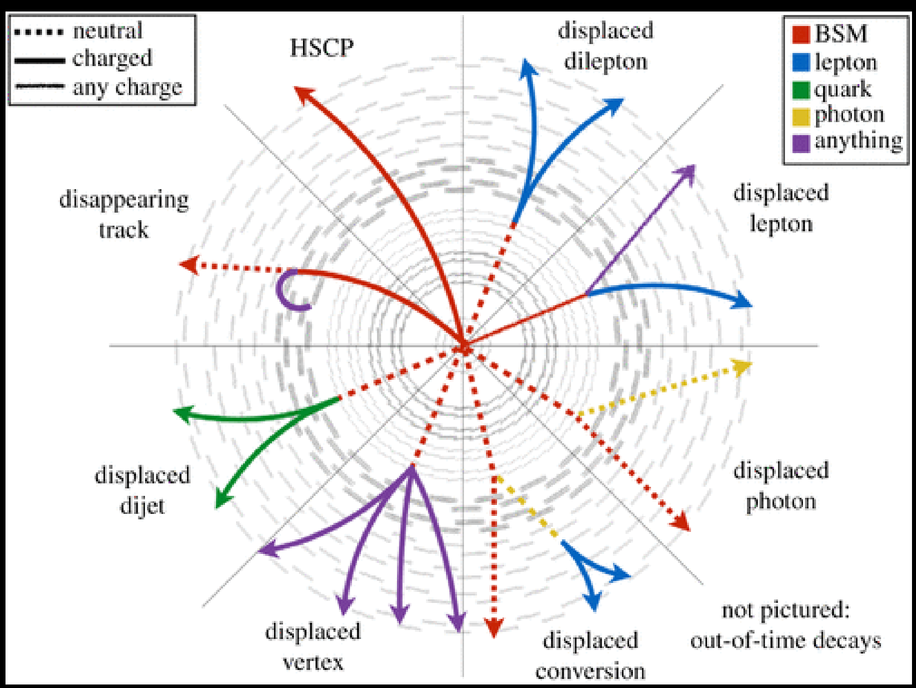
Phenomenological collider study of a Higgs portal that extend the Standard Model (SM) with a long-lived second Higgs and a Dark Matter (DM) candidate. We expect Future Circular Collider (FCC) to realistically be able to search for this model.

Motivation

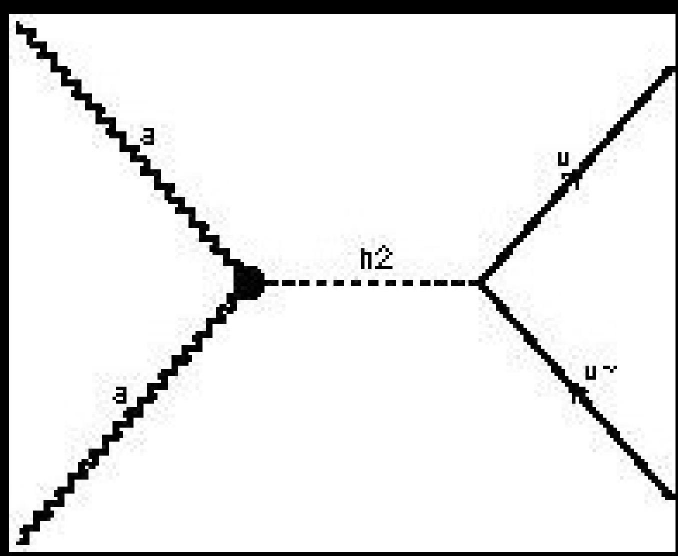
Even though the SM cannot explain some phenomena, such as the discrepancy between visible and actual matter in large-scale structures, no new physics has been observed in colliders since the discovery of the Higgs boson. Then, the possibility of long-lived particles (LLPs) arises, which can be acomplished with feebly interacting particles, thus allowing to propose Dark Matter (DM) and Higgs Portals that satisfy the experimental constraints.

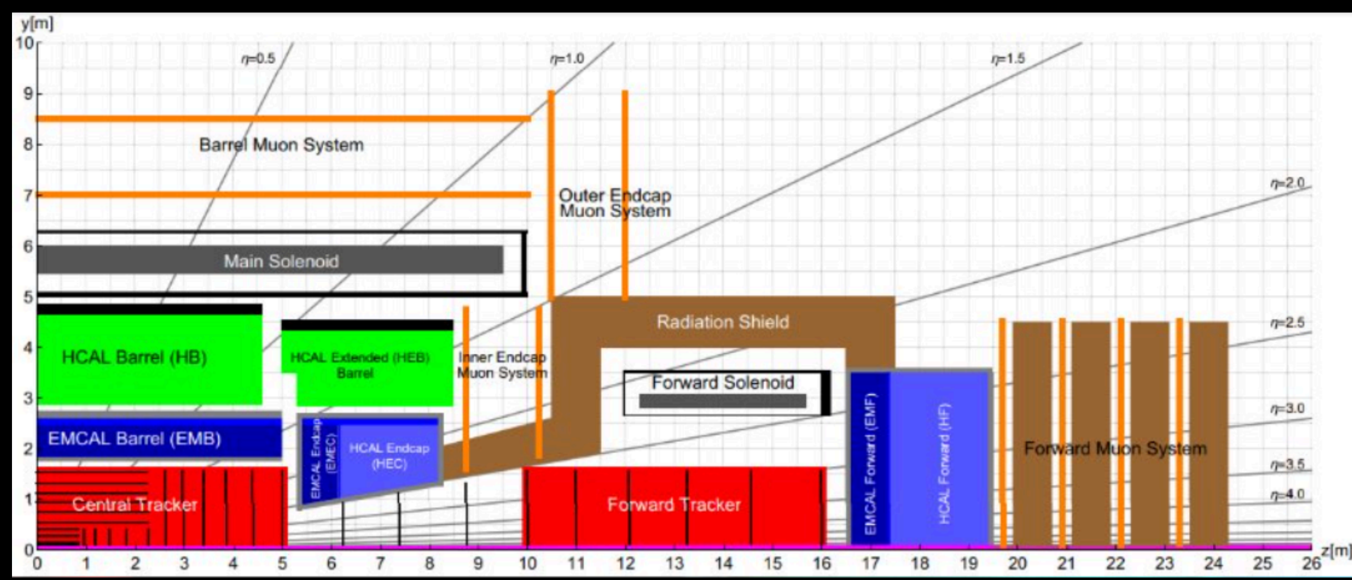
Methodology

Our previous analysis found the parameter space that High-Luminosity Large Hadron Collider (HL-LHC) and Future Circular Collider (FCC) could probe at ideal efficiency. Here we show an estimation for the detector acceptance using Pythia and the constraint it establish.



Roeck Albert. Searching for long-lived particles at the Large Hadron Collider and beyond. 377:20190047.





Benedikt, Michael (CERN), et al. "FCC-hh: The Hadron Collider : Future Circular Collider Conceptual Design Report Volume 3" .. 10.1140/epjst/e2019-900087-0

The Higgs Portal Model

$$V = -\frac{\mu_H^2}{2}|H|^2 - \frac{\mu_S^2}{2}|S|^2 + \frac{\lambda_H}{2}|H|^4 + \lambda_{HS}|H|^2|S|^2 + \frac{\lambda_S}{2}|S|^4 + \left(-\frac{\mu_S'^2}{4}S^2 + H.c.\right)$$

Christian Gross, Oleg Lebedev, and Takashi Toma. "Cancellation Mechanism for Dark-Matter–Nucleon Interaction". arXiv:1708.02253

Expand both fields around their Vacuum Expectation Values (VEVs)

$$H = \frac{1}{\sqrt{2}}\begin{bmatrix} 0 \\ v+h \end{bmatrix} \quad \wedge \quad S = \frac{1}{\sqrt{2}}(v_S + s + i\chi)$$

Build the yukawa sector with the new Higgs isospin doublet due to diagonalization of mass matrix

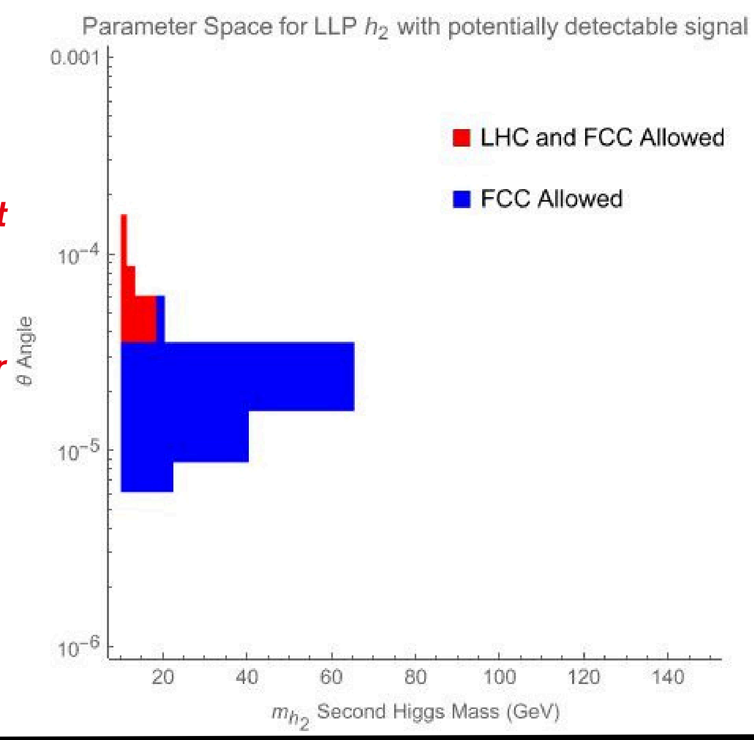
$$\mathcal{L}_Y = \frac{-g_f}{\sqrt{2}}\left[v + h_1 cos(\theta) + h_2 sen(\theta)\right](\bar{f}f)$$

For phenomenological purpose we chose the input parameters of the model to be:

$$m_{h_2}, m_\chi, v_S, \theta$$

While h1 is chose as the 125GeV Higgs with VEV v $h_1 \approx 125GeV \quad \wedge \quad v \approx 246GeV$

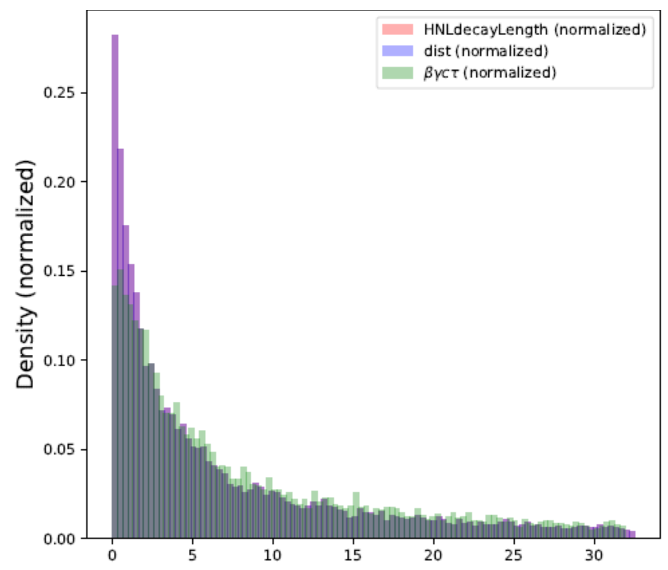
From previous study of producing long-lived h2 at HL-LHC and FCC-hh assuming ideal total efficiency, we have the following initial parameter space:

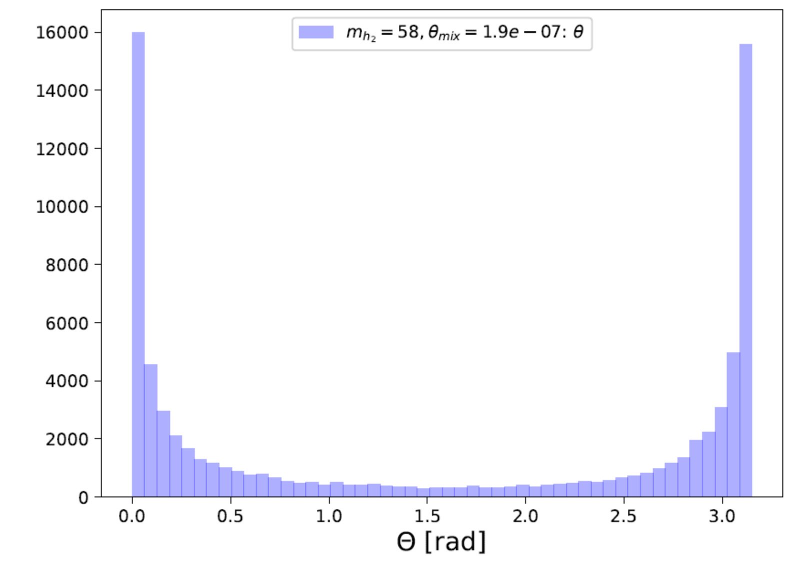


In the shared region, FCC-hh have 2 order of magnitude more expected number of events (N) than HL-LHC. That is due to the increased luminosity and center of mass energy of FCC-hh

Kinematics of the produced h2

This new Higgs would tend to the beam pipe axis (In this plot mayus theta is the scattering angle). Also, the decay length of h2 has an exponential distribution

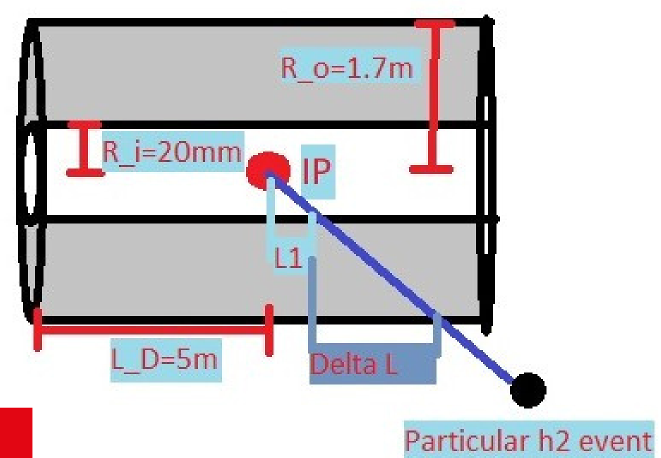




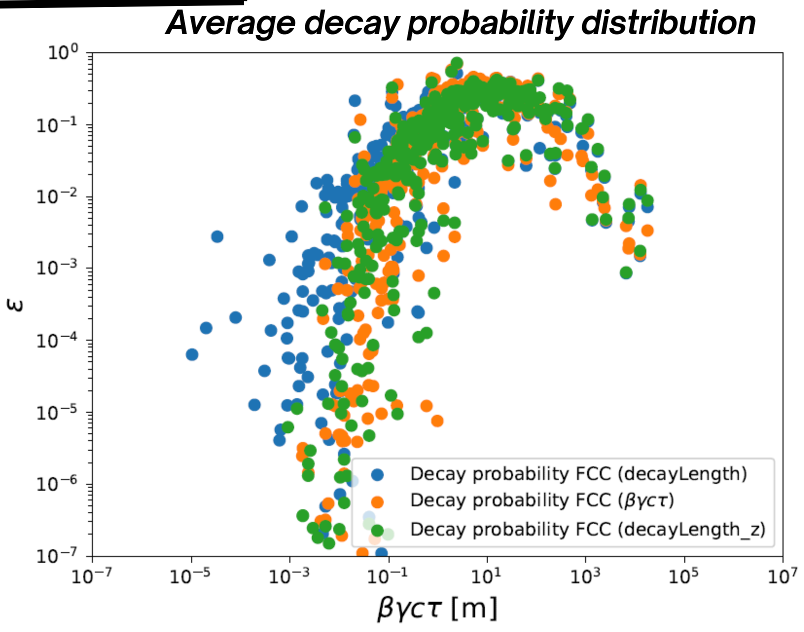
Ignoring HL-LHC due to small rates, we can use the following equation to obtain the probability of finding h2 in a fiducial volume and a more realistic N for FCC-hh

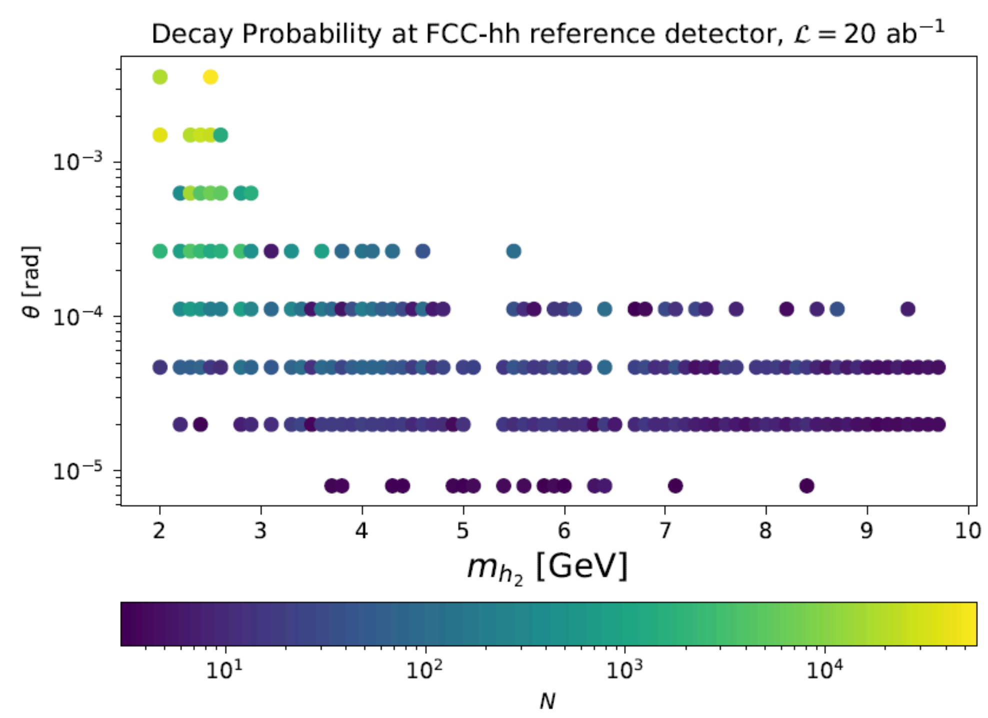
$$N = \sigma \cdot BR \cdot \mathcal{L} \cdot \langle \epsilon \rangle \cdot (eff_{exp})$$

$$\epsilon = e^{-\frac{L_1}{\beta_z \gamma c \tau}} \cdot \left(1 - e^{-\frac{\Delta L}{\beta_z \gamma c \tau}}\right)$$



Average decay probability distribution





Conclusion

The entire initial parameter space gets excluded when using the equation of expected number of events with average probability of finding h2 inside the proposed detector. "This further justifies disregarding the HL-LHC for testing this model. However, for FCC-hh, we expect two orders of magnitude more events (N), allowing us to probe this model for an h2 mass between 2GeV and 10 GeV and mixing angle theta between 1e-3 and 1e-6