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Prospects for Dark Boson Searches via Exotic Higgs Decays in Run 3 and High Luminosity Era of the LHC

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Introduction

Higgs is a key to new physics and can be the portal to BSM including dark matter (DM) particles such as the dark vector and dark Higgs bosons. The sensitivity of the Large Hadron Collider (LHC) to the dominant exotic Higgs decays with a final state of multiple displaced (by 1–7500 mm) dimuons is investigated in this presentation.

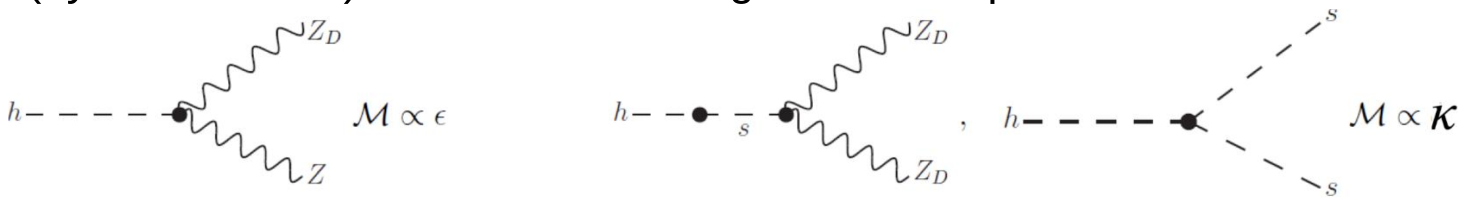

Figure 1: Feynman diagrams for the dominant exotic Higgs decays via the kinetic mixing (left) and Higgs mixing (middle and right) [1].

The current samples are generated by applying Monte Carlo (MC) simulation using the framework of MadGraph5_aMC@NLO v2.7.2 with Hidden Abelian Higgs Model (HAHM) [1].

Keys of acronyms used in this presentation:

SM Higgs boson = h
Dark Higgs boson = s = h_D
Dark vector boson = Z_D
Kinetic mixing parameter = ϵ
Higgs mixing parameter = κ

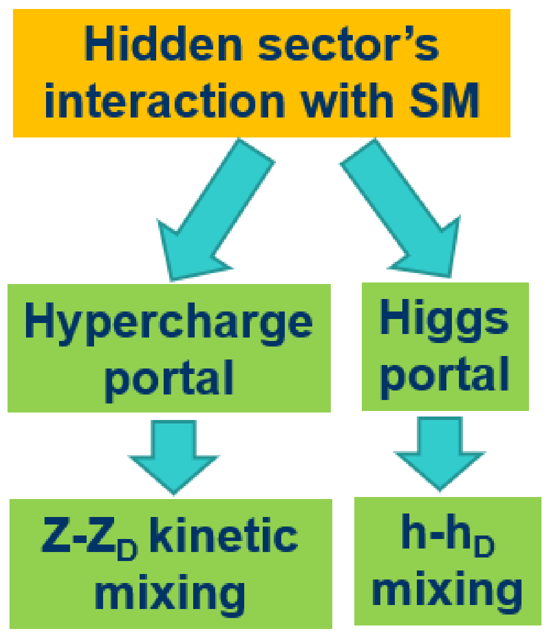

Figure 2: Portals and mixings through which the dark sector can interact with the Standard Model (SM).

Exotic Higgs Decay Widths

The dominant exotic Higgs partial decay widths to LO in m_{ZD}^2/m_Z^2 (Eq. 1) and in κ (Eqs. 2 and 3) are given in Ref. [1].

$$\Gamma(h \to ZZ_D) = \frac{\epsilon^2 tan^2\theta_w}{16\pi} \frac{m_{ZD}^2 (m_h^2 - m_Z^2)^3}{m_h^3 m_Z^2 v^2} \quad (1)$$

$$\Gamma(h \to Z_D Z_D) = \frac{\kappa^2}{32\pi} \frac{v^2}{m_h} \sqrt{1 - \frac{4m_{ZD}^2}{m_h^2}} \frac{(m_h^2 + 2m_{ZD}^2)^2 - 8(m_h^2 - m_{ZD}^2)m_{ZD}^2}{(m_h^2 - m_{hD}^2)^2} \quad (2)$$

$$\Gamma(h \to h_D h_D) = \frac{\kappa^2}{32\pi} \frac{v^2}{m_h} \sqrt{1 - \frac{4m_{hD}^2}{m_h^2}} \frac{(m_h^2 + 2m_{hD}^2)^2}{(m_h^2 - m_{hD}^2)^2} \quad (3)$$

where θ_ω is the Weinberg mixing angle that is measured as 28.75° by LHCb Ref. [4] and υ = 246 GeV is the SM Higgs vacuum expectation value (vev).

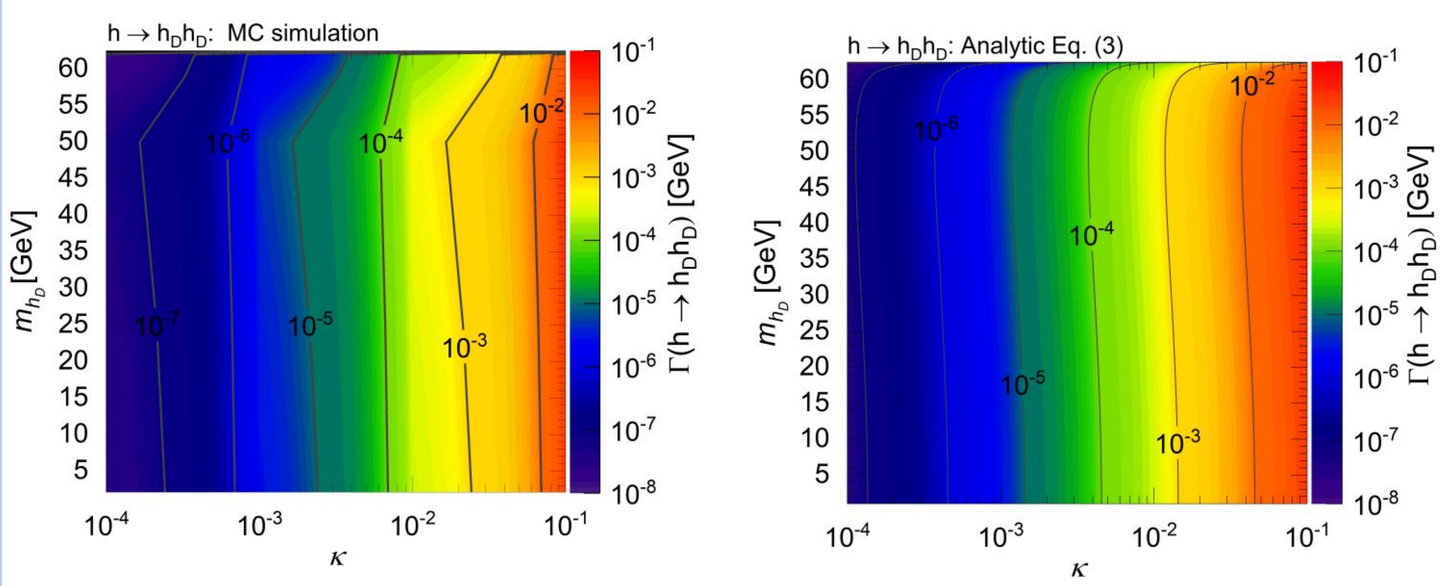

Figure 3: MC simulation (upper panel) against an analytical calculation (lower panel) from Eq. (3) of the partial decay width h→$h_D h_D$ in a scan over the κ-m_{hD} plane, which shows an excellent agreement between the two. The corresponding figures to Fig. 3 for the partial decay widths h→ZZ_D in the scan over the ϵ-m_{ZD} plane and h→$Z_D Z_D$ in the scan over the κ-m_{ZD} plane are given in Ref. [2], which is the updated version of Ref. [3].

Branching Fractions of Exotic Higgs Decays

The corresponding figures to Fig. 4 for the exotic Higgs decays h→ZZ_D→$2\mu^+2\mu^-$ and h→$Z_D Z_D$→$2\mu^+2\mu^-$ are given in Ref. [2], which is the updated version of Ref. [3].

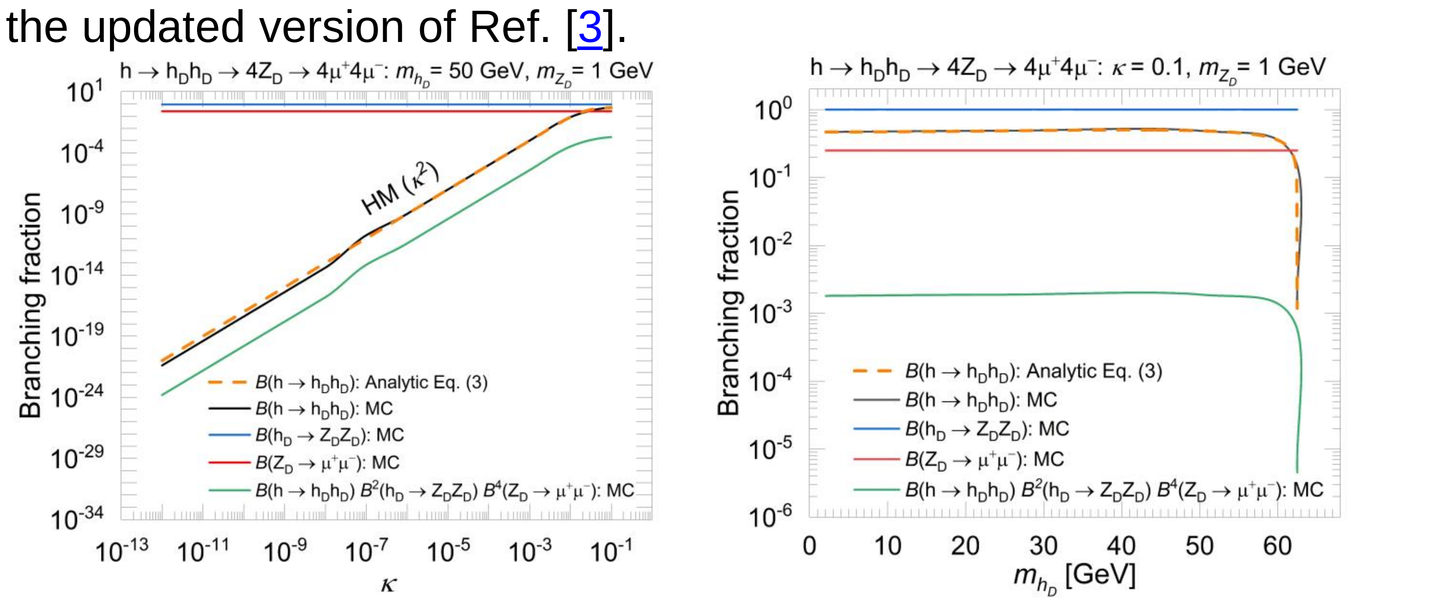

Figure 4: MC simulation of B(h→$h_D h_D$) (black), B(h_D→$Z_D Z_D$), B(Z_D→$\mu^+\mu^-$), and the product of B(h→$h_D h_D$), B^2(h_D→$Z_D Z_D$), and B^4(Z_D→$\mu^+\mu^-$) as well as an analytical calculation of B(h→$h_D h_D$) (orange) from Eq. (3) in a scan over κ (left panel) and over m_{hD} (right panel), which shows an excellent agreement between the two approaches.

Sensitivity of the LHC in Run 3 and HL Era to Various Exotic Higgs Decays

The SM Higgs is assumed to be produced through the production channel of gluon-gluon fusion (ggF) for which the production cross section of 49.85 pb, calculated to a combination of next-to-next-to-next-to-leading order with QCD corrections (N³LO QCD) and next-to-leading order with electroweak corrections (NLO EW) from Ref [5], is used.

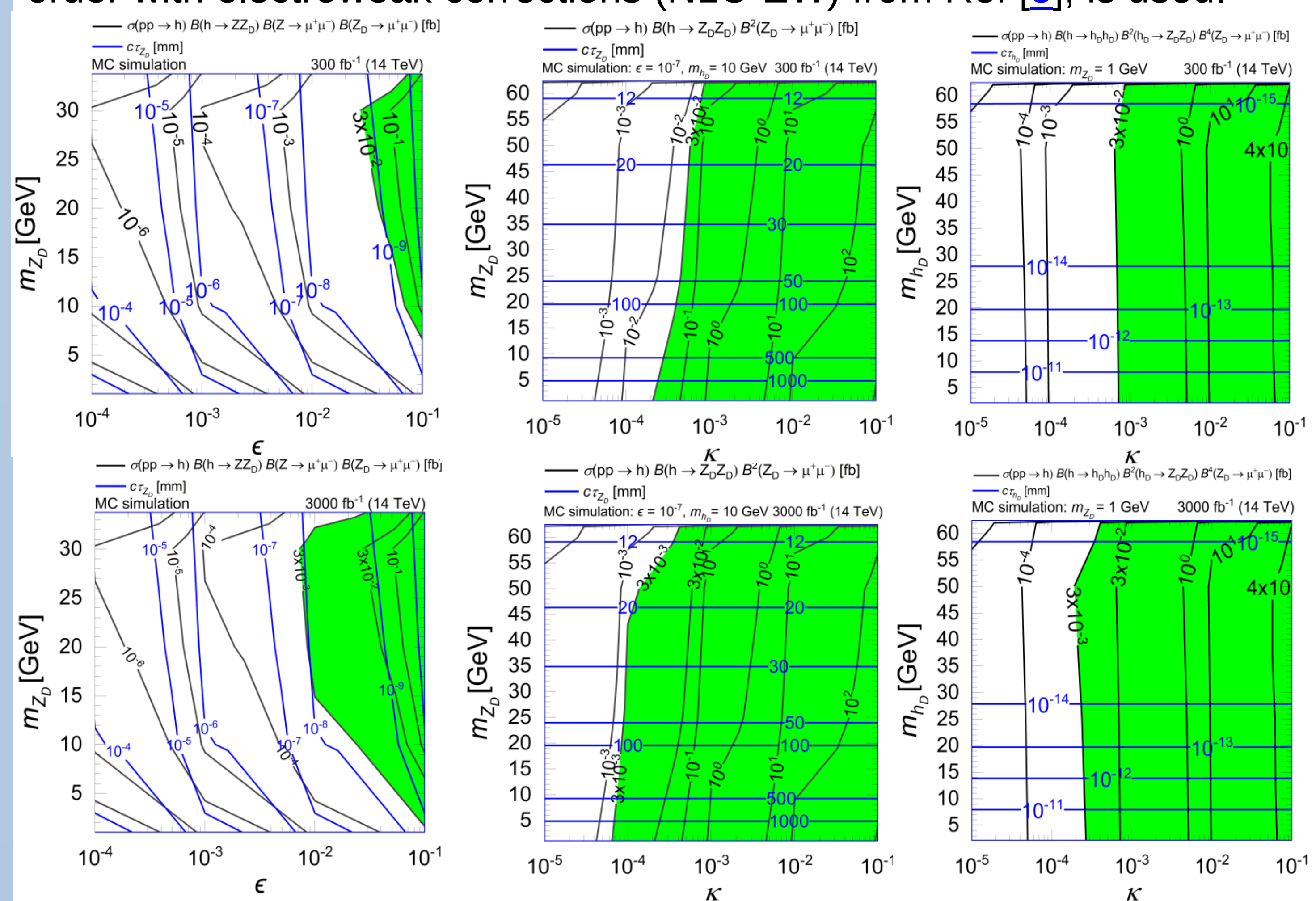

Figure 5: MC simulation showing the contour lines of total cross section (black) and decay length (blue) for the exotic Higgs decays h→ZZ_D→$2\mu^+2\mu^-$ (left panels), h→$Z_D Z_D$→$2\mu^+2\mu^-$ (middle panels), and h→$h_D h_D$→$4Z_D$→$4\mu^+4\mu^-$ (right panels) in a scan over the ϵ-m_{ZD}, the κ-m_{ZD}, and the κ-m_{hD} planes, respectively, for Run 3 (upper panels) and high luminosity (HL) era (lower panels) of the LHC for which sensitivity regions are shaded in green.

Conclusion

1. The LHC is found to be more sensitive to h→$Z_D Z_D$→$2\mu^+2\mu^-$ (down to κ = 2.0 × 10^{-4} and κ = 6.5 × 10^{-5}) and h→$h_D h_D$→$4Z_D$→$4\mu^+4\mu^-$ (down to κ = 7.0 × 10^{-4} and κ = 2.5 × 10^{-4}) irrespective of the mass value acquired by Z_D or h_D compared to h→ZZ_D→$2\mu^+2\mu^-$ (down to ϵ = 2.5 × 10^{-2} for m_{ZD} range of 6.5–33.8 GeV and ϵ = 7.0 × 10^{-3} for m_{ZD} range of 1.5–33.8 GeV) in Run 3 and HL era, respectively.

2. While the decay mode h→$Z_D Z_D$→$2\mu^+2\mu^-$ can produce prompt or long-lived Z_D based on the kinetic mixing strength ($c\tau_{ZD}$ = 10–2000 mm for ϵ = 10^{-7} with $c\tau_{ZD}$ and m_{ZD} being inversely proportional to each other), h→ZZ_D→$2\mu^+2\mu^-$ and h→$h_D h_D$→$4Z_D$→$4\mu^+4\mu^-$ are limited to produce prompt Z_D.

References

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Acknowledgements

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