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Higgs Boson Decays to Dark Photons through the Vectorized Lepton Portal

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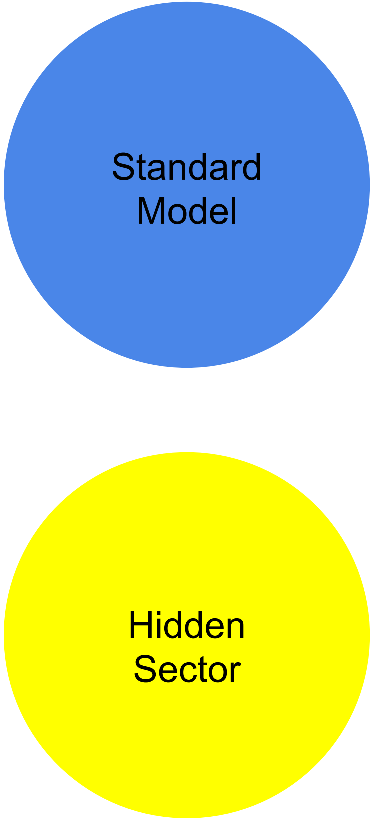
There are three common portals to new physics:

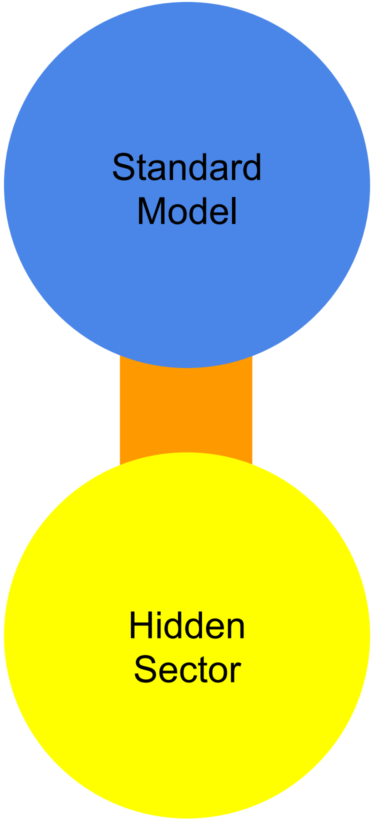
$$\text{Vector Portal}: \quad \frac{\epsilon}{2} B_{\mu\nu} X^{\mu\nu}$$

$$\text{Higgs Portal}: \quad (A\phi + \kappa\phi^2)|H|^2$$

$$\text{Neutrino Portal}: \quad y_N \bar{L} \widetilde{H} N$$



These portals are unique in the sense that the standard model factors in these terms combine to be standard model singlets. The hidden sector are also standard model singlets (by definition), leading to a separation of charges.



- However, all the new physics need not follow this separation of charges between the hidden sector and the standard model.
- There could be messenger fields that carry both standard model and hidden sector charges.

As a simple example, we introduce the vectorized lepton portal.

First, we assume that there is a dark force, $U(1)_X$, with a with a dark photon, X, and mass m_X.

This state can kinetically mix with the photon through the aforementioned vector portal.

We also introduce two fermions charged under this dark force.

A singlet:

$$N = (1, 1, 0;\ q_x)$$

A doublet:

$$P = (1, 2, -1/2;\ q_x)$$

Which allows a Lagrangian:

$$-\mathscr{L} \supset \left(\lambda \overline{P}\widetilde{H}N + h.c.\right) + m_P\overline{P}P + m_N\overline{N}N$$

This Higgs term allows for a portal type interaction, but this is complicated as the Higgs vev also allows for a mixing between the neutral P state and the singlet N.

After symmetry breaking we have:

$$-\mathscr{L} \supset -m_P \overline{P^-} P^- + \left(\overline{N}, \overline{P^0}\right) \begin{pmatrix} m_N & \lambda v \\ \lambda v & m_P \end{pmatrix} \begin{pmatrix} N \\ P^0 \end{pmatrix} + \frac{\lambda}{\sqrt{2}} h \left(\overline{N} P^0 + \overline{P^0} N\right)$$

We can define mass states:

$$\begin{pmatrix} N \\ P^0 \end{pmatrix} = \begin{pmatrix} c_\alpha & s_\alpha \\ -s_\alpha & c_\alpha \end{pmatrix} \begin{pmatrix} \psi_1 \\ \psi_2 \end{pmatrix}$$

where:

$$\tan(2\alpha) = \frac{2\lambda v}{m_P - m_N}$$

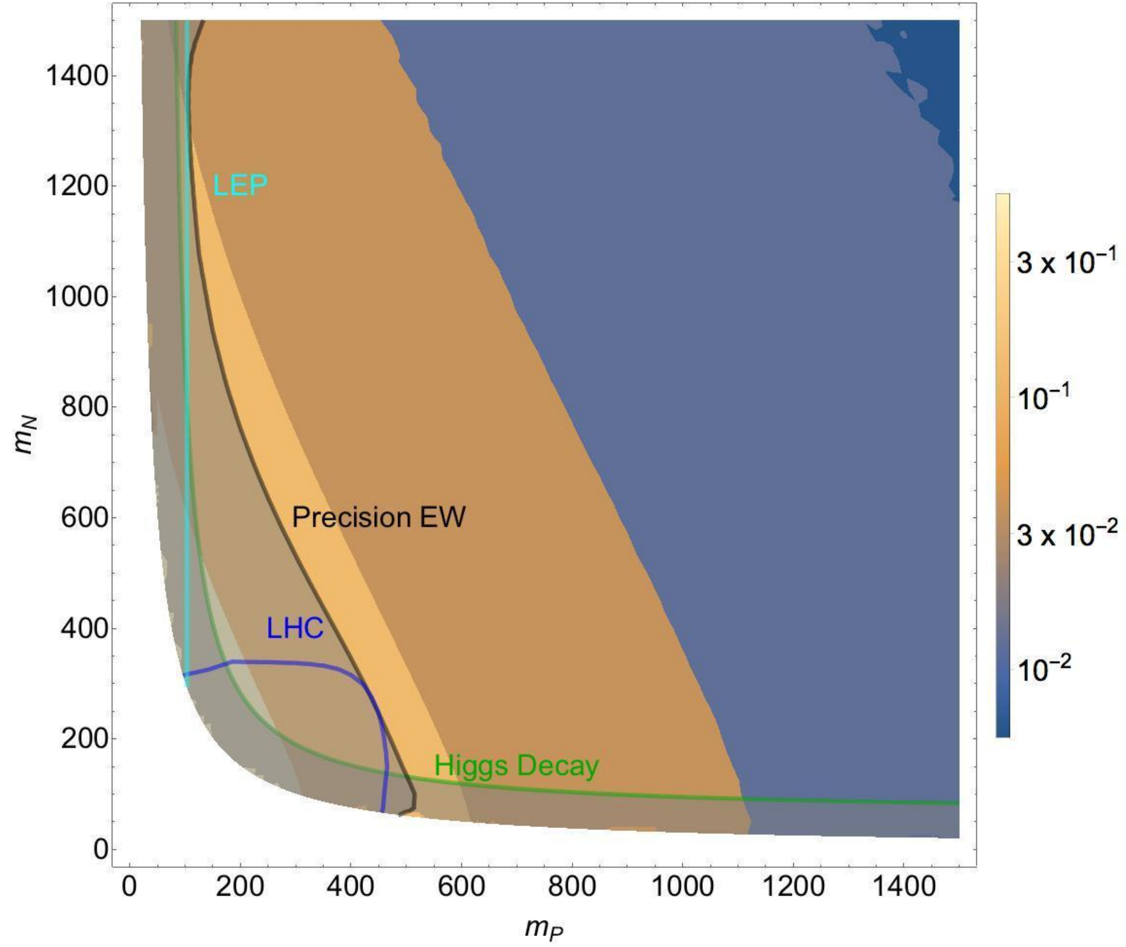
There are bound on this portal from:

-Higgs decays to the lighter state

-Production of the charged state at LEP

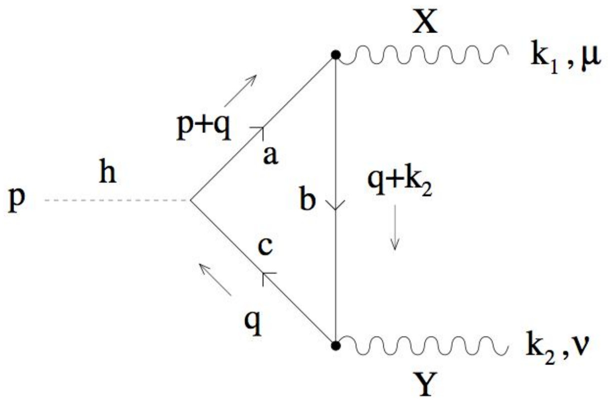
-Production of the neutral states at the LHC

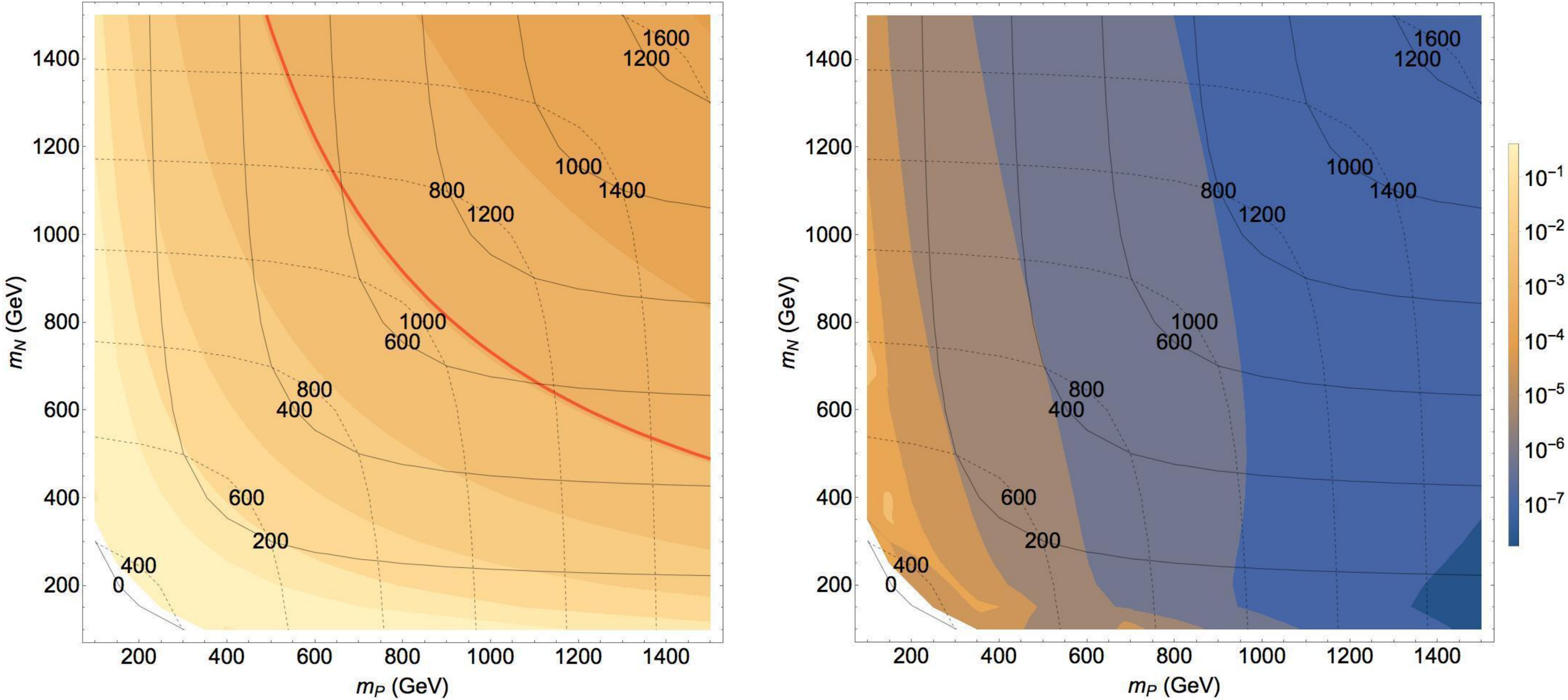
-Precision electroweak constraints



LEP
Precision EW
LHC
Higgs Decay
m_N
m_P
0
200
400
600
800
1000
1200
1400
3×10^{-1}
10^{-1}
3×10^{-2}
10^{-2}

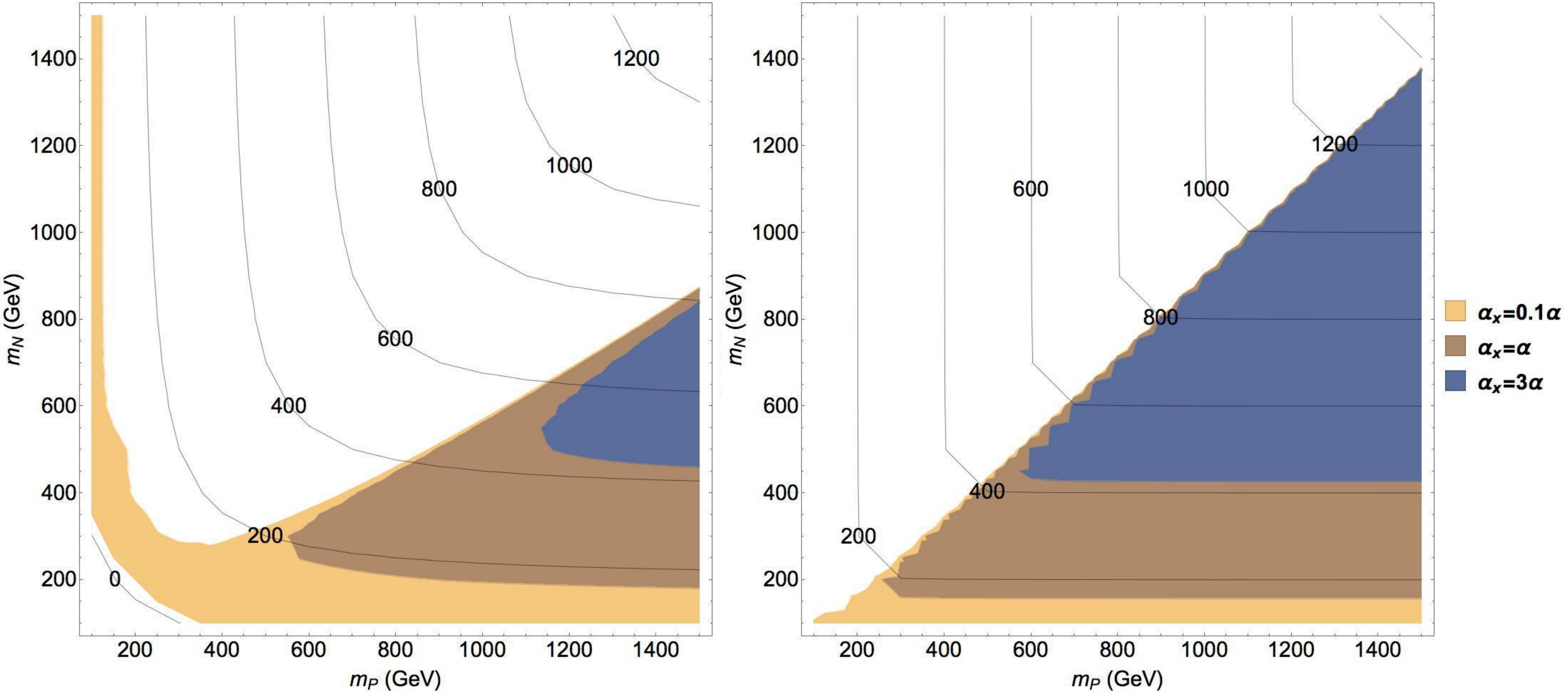
However, charging the new fermions under the dark force can lead to stronger constraints than considering either sector separately. In particular, this allows exotic higgs decays to vector bosons.




1600
1200
1000
1400
800
1200
1000
600
800
400
600
200
400
0
1400
1200
1000
800
600
400
200
m_N (GeV)
200
400
600
800
1000
1200
1400
m_P (GeV)
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}

If ψ_1 is the lightest charged state, then it is stabilized by dark charge conservation. This also implies that ψ_1 is also at least some portions of the dark matter the universe.

This constrains the abundance to be upper bounded by the observed relic density.

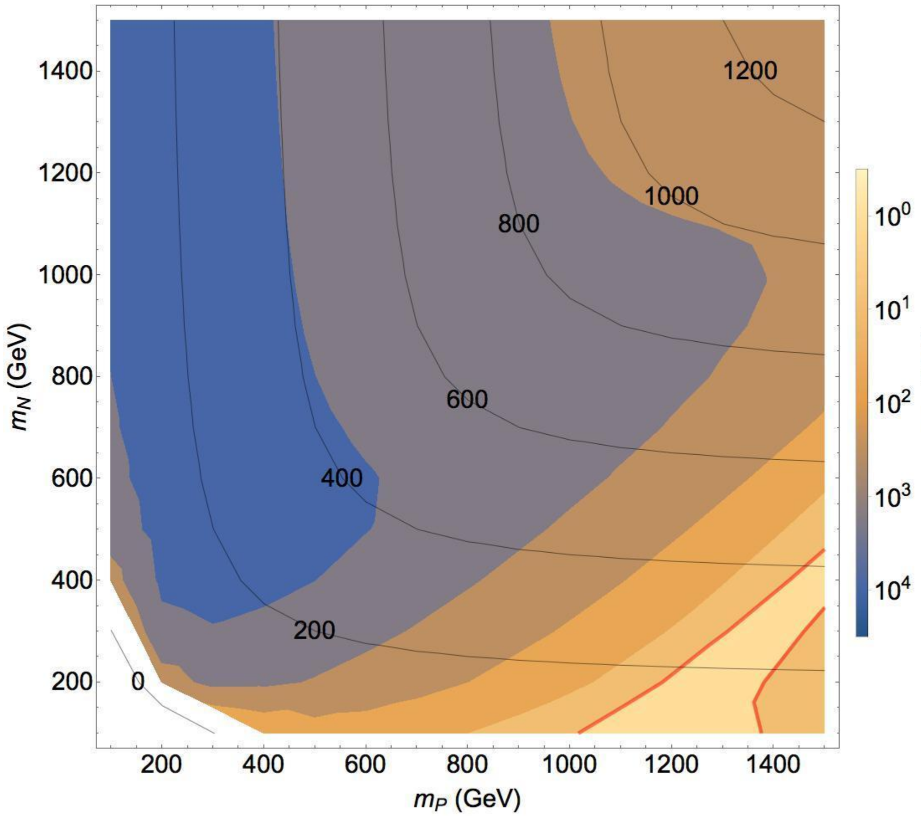


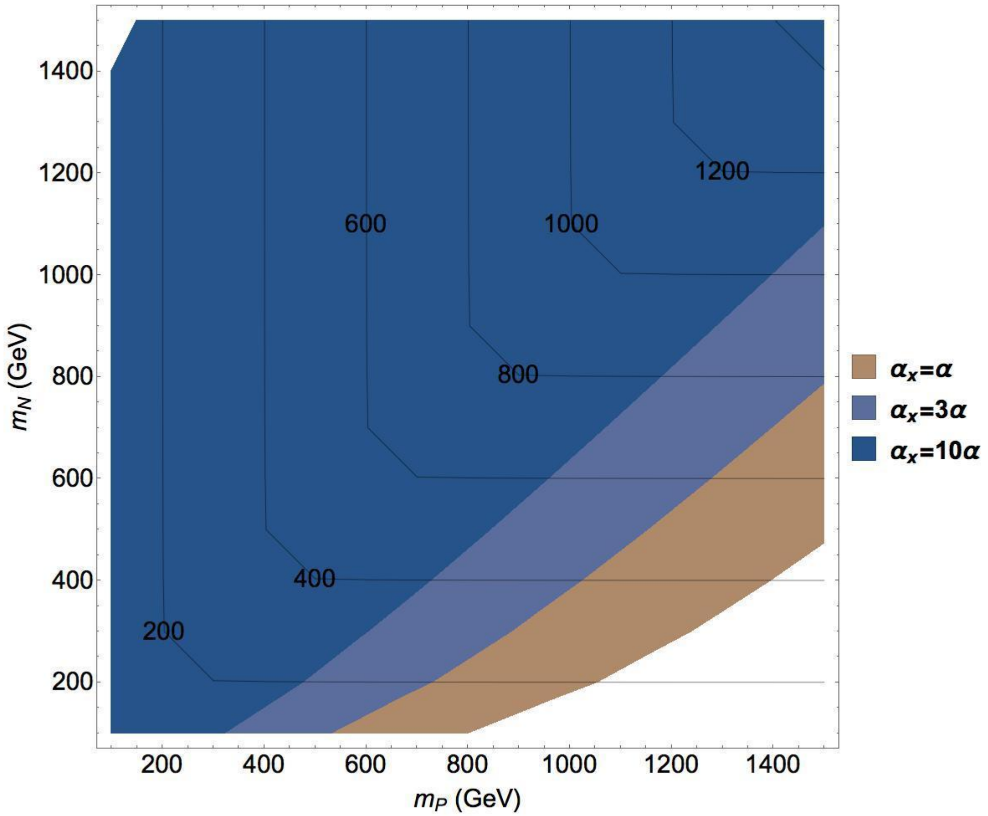
1400
1200
1000
800
600
400
200
m_N (GeV)
200
400
600
800
1000
1200
1400
m_P (GeV)
0
200
400
600
800
1000
1200
α_x=0.1α
α_x=α
α_x=3α

A local abundance of ψ_1 also means that these fields can be probed by direct detection experiments.

This can be mediated by higgs exchange, Z exchange, or a kinetically mixed dark photon.

There is a complementarity between scattering and annihilation, since large weak coupling to dilute the density also leads to large scattering cross sections.


1400
1200
1000
800
600
400
200
200
400
600
800
1000
1200
1400
m_N (GeV)
m_P (GeV)
0
200
400
600
800
1000
1200
10^0
10^1
10^2
10^3
10^4


1400
1200
1000
800
600
400
200
200
400
600
800
1000
1200
1400
m_N (GeV)
m_P (GeV)
200
400
600
800
1000
1200
$\alpha_x=\alpha$
$\alpha_x=3\alpha$
$\alpha_x=10\alpha$

Conclusions

-We introduce the vectorized lepton portal as hidden sector messengers

-We show that exotic higgs decays can provide strong constraints into the coupling of this portal

-If the lighter state is stable, there are additional constraints from dark matter considerations.

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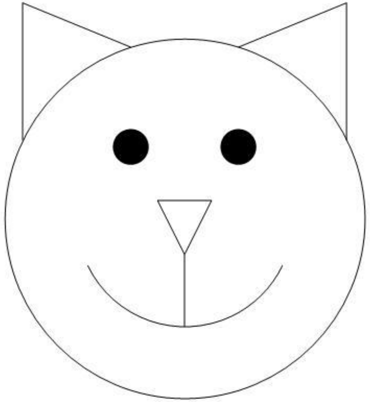

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Interaction terms:

$$-\mathscr{L} \supset \frac{\lambda}{\sqrt{2}} h \left[2 s_\alpha c_\alpha \left(-\overline{\psi}_1 \psi_1 + \overline{\psi}_2 \psi_2\right) + \left(c_\alpha^2 - s_\alpha^2\right)\left(\overline{\psi}_1 \psi_2 + \overline{\psi}_2 \psi_1\right)\right]$$

$$\begin{aligned} -\mathscr{L} \supset\ & \bar{g}(-\frac{1}{2} + s_W^2) Z_\mu \overline{P^-} \gamma^\mu P^- - e A_\mu \overline{P^-} \gamma^\mu P^- \\ & + \frac{g}{\sqrt{2}} \left[W_\mu^+ \overline{P^-} \gamma^\mu (-s_\alpha \psi_1 + c_\alpha \psi_2) + (h.c.)\right] \\ & + \frac{1}{2} \bar{g} Z_\mu \left[s_\alpha^2 \overline{\psi}_1 \gamma^\mu \psi_1 + c_\alpha^2 \overline{\psi}_2 \gamma^\mu \psi_2 - s_\alpha c_\alpha (\overline{\psi}_1 \gamma^\mu \psi_2 + \overline{\psi}_2 \gamma^\mu \psi_1)\right] \\ & + g_x X_\mu \left[\overline{\psi}_1 \gamma_\mu \psi_1 + \overline{\psi}_2 \gamma_\mu \psi_2 + \overline{P^-} \gamma_\mu P^-\right] , \end{aligned}$$

Non Abelian dark force:

-Higgs decays go from h->XX->dark glueballs if glueballs are light enough (no h->XZ)

-Most direct production cross sections are modified to by a sum over colors

-May be additional dark matter relic constraints depending on nature of glueball decay