Multilepton Higgs Decays through the Dark Portal

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KIAS

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Outline

1. Introduction
2. $SU(2)_L \times U(1)_Y \times U(1)_D$ MODEL
3. NON-STANDARD DECAYS OF h_1
4. MULTILEPTON-JETS AT LHC
5. Summary

Introduction

The $U(1)_d$ gauge sector containing one dark Higgs boson h_D and one dark photon γ_D is explored through the decays of the 126 GeV particle discovered at the LHC, assumed here as the heavier mass eigenstate h_1 in the mixing of the standard model h with h_D.

The various decays of h_1 to $\gamma_D\gamma_D$, h_2h_2, $h_2\gamma_D\gamma_D$, etc, would yield multilepton final states. Future detailed studies at the LHC may reveal the existence of this possible dark sector governed simply by the original Abelian Higgs model.

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$SU(2)_L \times U(1)_Y \times U(1)_D$ MODEL

$$\mathcal{L}_{\rm B} = \mathcal{L}_{\rm gauge} + \mathcal{L}_{\rm scalar}$$

with

$$\mathcal{L}_{\rm gauge} = -\frac{1}{4}\vec{W}_{\mu\nu}\cdot\vec{W}^{\mu\nu} - \frac{1}{4}B_{\mu\nu}B^{\mu\nu} - \frac{1}{4}C_{\mu\nu}C^{\mu\nu} - \frac{\epsilon}{2}B_{\mu\nu}C^{\mu\nu}$$

$$\mathcal{L}_{\rm scalar} = |D_\mu\Phi|^2 + |D_\mu\chi|^2 - V_{\rm scalar}(\Phi,\chi)$$

and

$$D_\mu\Phi = \left(\partial_\mu + ig\frac{1}{2}\sigma_a W_{a\mu} + i\frac{1}{2}g' B_\mu\right)\Phi$$

$$D_\mu\chi = (\partial_\mu + ig_D C_\mu)\,\chi$$

potential

$$V_{\rm scalar} = -\mu_\Phi^2\Phi^\dagger\Phi + \lambda_\Phi\left(\Phi^\dagger\Phi\right)^2 - \mu_\chi^2\chi^*\chi + \lambda_\chi\left(\chi^*\chi\right)^2 + \lambda_{\Phi\chi}\left(\Phi^\dagger\Phi\right)\left(\chi^*\chi\right)$$

Detail arXiv:1308.6071

$SU(2)_L \times U(1)_Y \times U(1)_D$ MODEL

Higgs:

$$\Phi(x) = \frac{1}{\sqrt{2}} \begin{pmatrix} 0 \\ v + h(x) \end{pmatrix} \qquad \chi(x) = \frac{1}{\sqrt{2}} (v_D + h_D(x))$$

Mass of Higgs:

$$M_S^2 = \begin{pmatrix} m_{11}^2 & m_{12}^2 \\ m_{21}^2 & m_{22}^2 \end{pmatrix} = \begin{pmatrix} 2\lambda_\Phi v^2 & \lambda_{\Phi\chi} v v_D \\ \lambda_{\Phi\chi} v v_D & 2\lambda_\chi v_D^2 \end{pmatrix}$$

$$m_{1,2}^2 = \frac{1}{2} \left[\mathrm{Tr} M_S^2 \pm \sqrt{(\mathrm{Tr} M_S^2)^2 - 4\, \mathrm{Det} M_S^2} \right]$$

Mixing of Higgs:

$$\begin{pmatrix} h_1 \\ h_2 \end{pmatrix} = \begin{pmatrix} \cos\alpha & \sin\alpha \\ -\sin\alpha & \cos\alpha \end{pmatrix} \begin{pmatrix} h \\ h_D \end{pmatrix}$$

$$\sin 2\alpha = \frac{2 m_{12}^2}{m_1^2 - m_2^2}$$

Detail arXiv:1308.6071

NON-STANDARD DECAYS OF h_1

$$M^2_{Z,\gamma_D} = (q \pm p)/2$$

$$p = \sqrt{q^2 - g_D^2 v_D^2 v^2 (g^2 + g'^2)\beta^2}\ , q = g_D^2 v_D^2 \beta^2 + \frac{1}{4}\left(g^2 + g'^2\beta^2\right) v^2\ .$$

The O matrix diagonalize this $\tilde{M}^2_G$ matrix

$$M^2_{\mathrm{G,diag}} = O^T \tilde{M}^2_G O = \begin{pmatrix} M^2_{\gamma'} & 0 & 0 \\ 0 & M^2_Z & 0 \\ 0 & 0 & M^2_\gamma \end{pmatrix}$$

$$tan\theta = \frac{g'}{g}, \qquad tan\phi = \frac{-\epsilon}{\sqrt{1-\epsilon^2}},$$

$$tan\psi = \pm\frac{tan\phi cos\theta}{tan\theta}\left[\frac{1 - M_z^2/M_w^2}{1 - M_z^2/g_D^2 v_D^2} + tan^2\theta\right]$$

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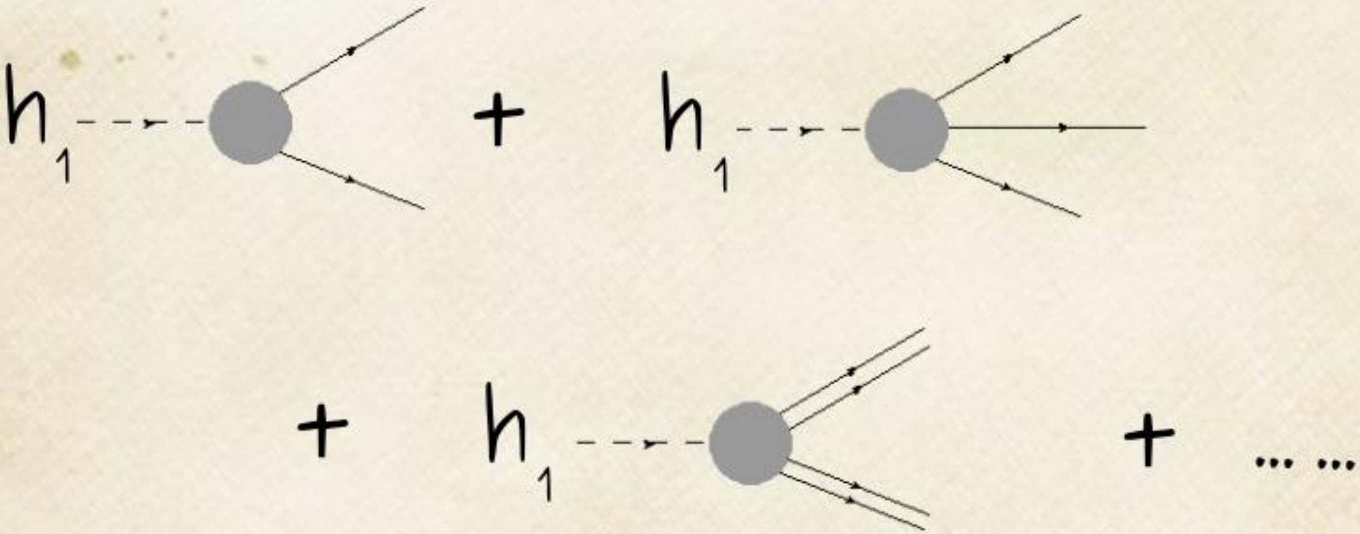
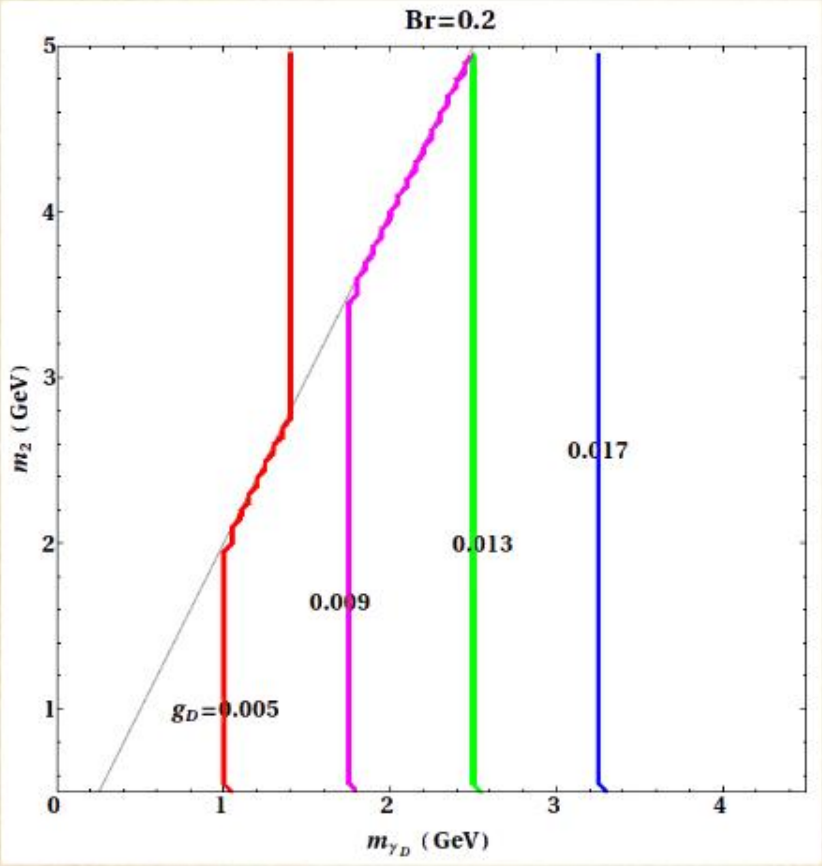
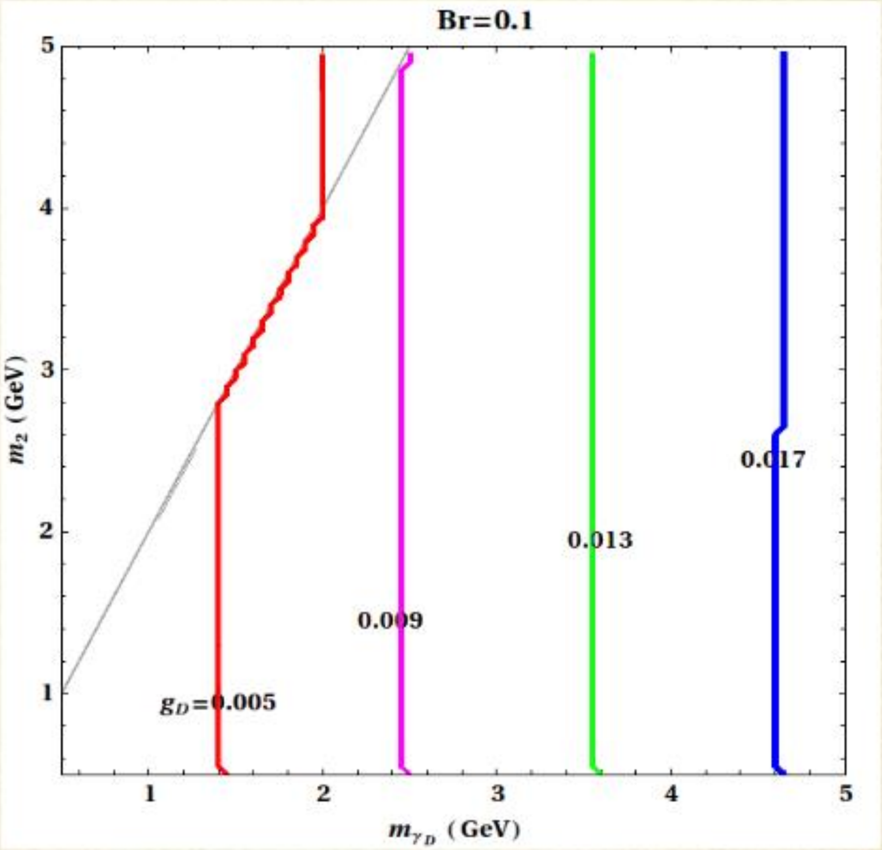


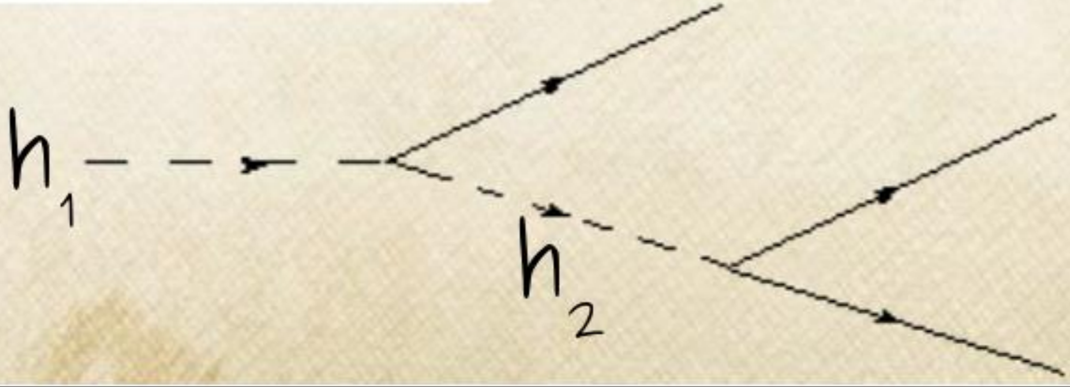
$$\Gamma_{h_1}^{NS} = \sin^2\alpha\,\hat{\Gamma}(h_1 \to \gamma_D\gamma_D) + \Gamma(h_1 \to h_2 h_2) + \Gamma(h_1 \to h_2\gamma_D\gamma_D) + \Gamma(h_1 \to h_2 h_2 h_2) + \cdots$$

$$\Gamma_{h_1} = \cos^2\alpha\,\hat{\Gamma}_h + \Gamma_{h_1}^{NS}$$

NON-STANDARD DECAYS OF h_1







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MULTILEPTON–JETS AT LHC

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(II) $pp \to VV \to l^+ l^- l^+ l^-$

} SM

(III) $pp \to h_1 \to XX \to l^+ l^- l^+ l^-$

(IV) $pp \to h_1 \to h_2 h_2 \to \gamma_D \gamma_D \gamma_D \gamma_D \to l^+ l^- l^+ l^- l^+ l^- l^+ l^-$

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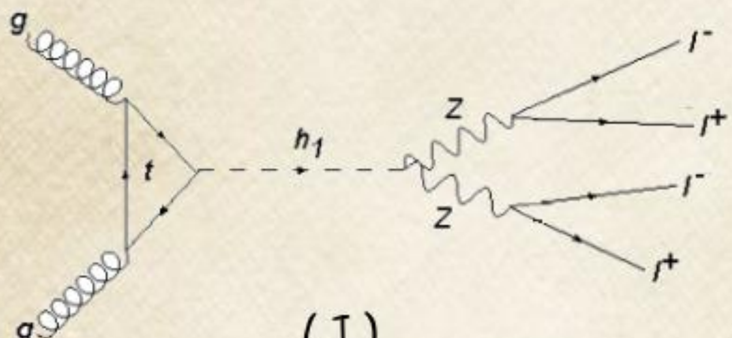

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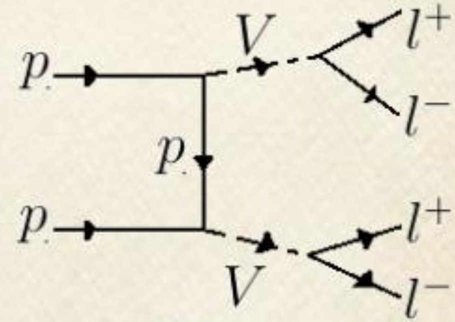

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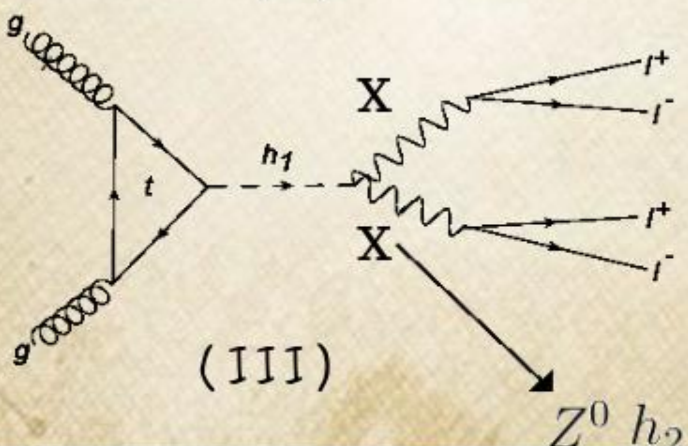

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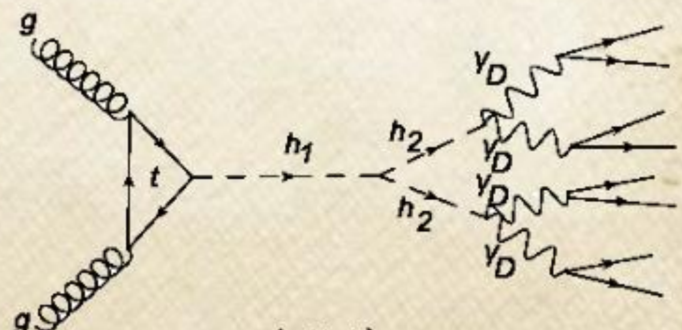

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Point	g_D	$sin^2\alpha$	M_{γ_D}	M_2	$Br_{h1 \to Dark}$	$Br_{h2 \to \gamma_D \gamma_D}$	$Br_{\gamma_D \to l^+ l^-}$
A	0.005	10^{-3}	1.5	4	$\sim 16\%$	99%	50%
B	0.009	10^{-3}	1.8	10	$\sim 20\%$	100%	50%
C	0.005	10^{-3}	1.5	40	$\sim 15\%$	99%	50%
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$\epsilon = 10^{-4}$

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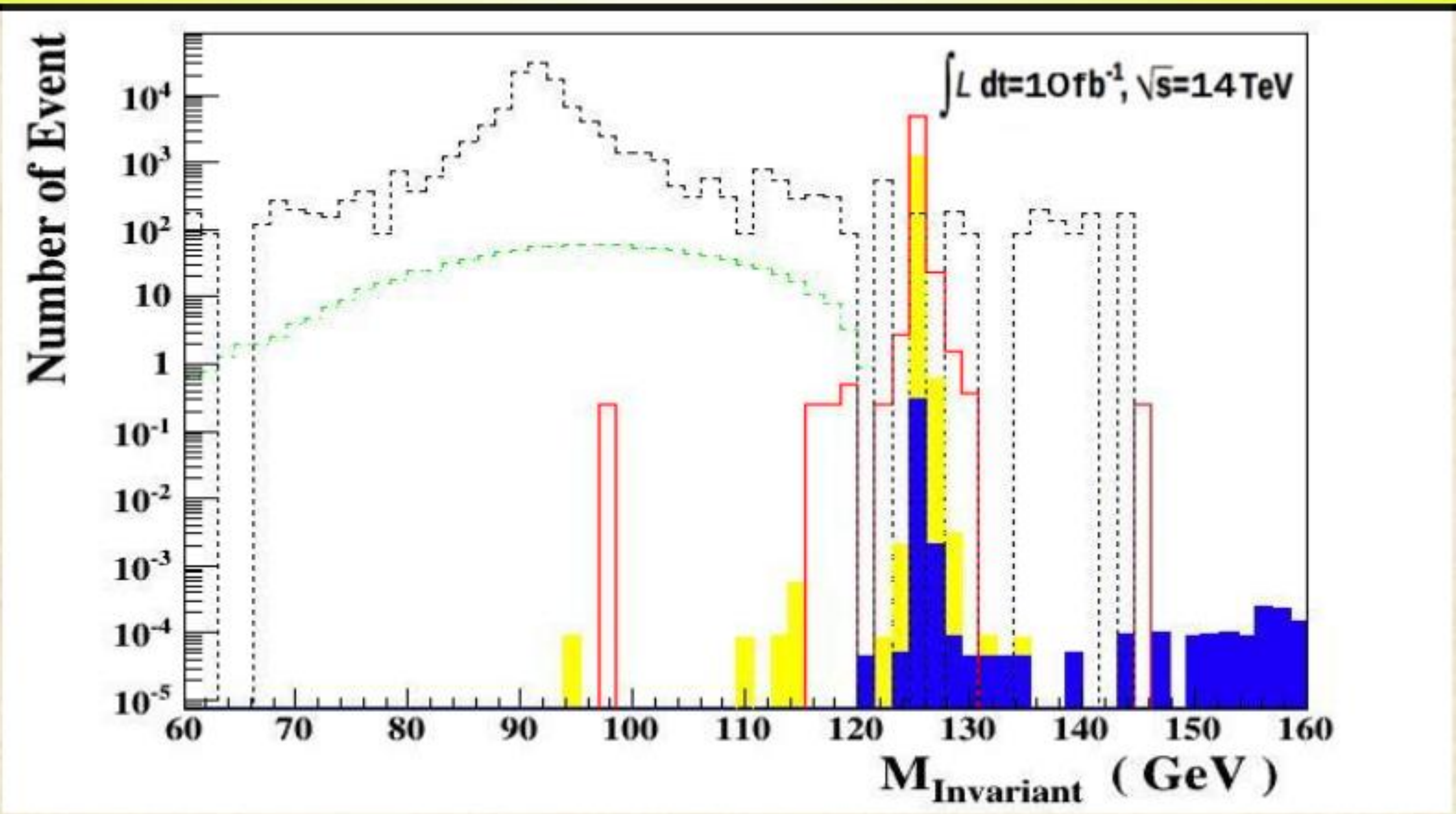

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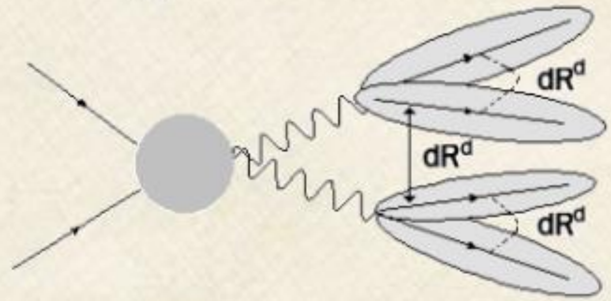
MULTILEPTON-JETS AT LHC

Basic cuts: $p_{Tl} \geq 20, 10, 10, 10$ GeV $\quad |\eta_l| < 2.3,$

4 Lepton-Jets cuts:

$$\Delta R^d_{j_i j_j} > 0.7, \quad \Delta R^s_{l_i l_j} < 0.2, \quad M_{invariant} = M_{h_1} \pm 10 \text{ GeV},$$



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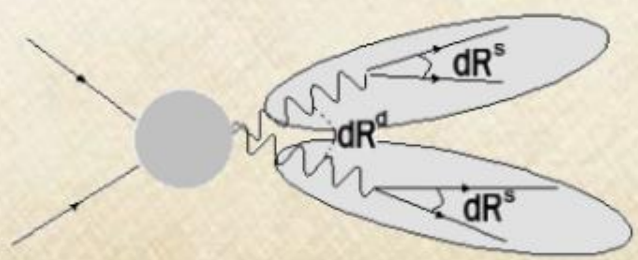

MULTILEPTON-JETS AT LHC

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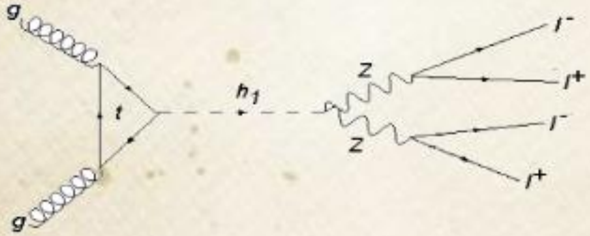

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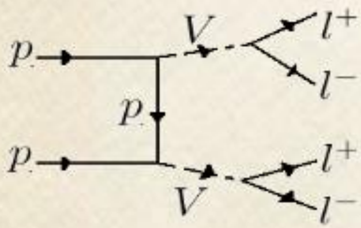

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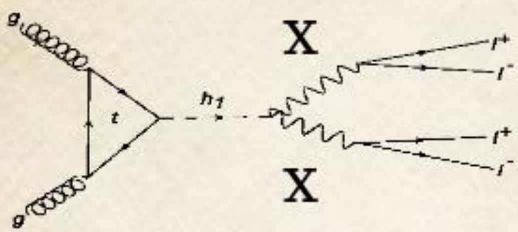

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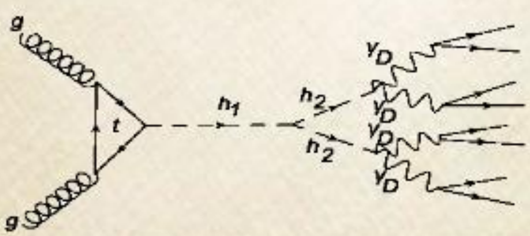

Cuts	Decision	I	II	III	IV
Basic cuts only	A	0.118	70.7	95.3	23.2
	B	0.118	70.7	204	45.8
	C	0.118	70.7	96.7	19.2
	D	0.118	70.7	68.3	13.1
4 Lepton-Jets	A	9.63×10^{-3}	0.337	9.86×10^{-3}	$\leq 10^{-10}$
	B	9.63×10^{-3}	0.337	9.80×10^{-3}	$\leq 10^{-10}$
	C	9.63×10^{-3}	0.337	9.93×10^{-3}	3.05
	D	9.63×10^{-3}	0.337	9.84×10^{-3}	0.92
2 Lepton-Jets	A	$\leq 10^{-10}$	0.08	95.3	1.75
	B	$\leq 10^{-10}$	0.08	201	$\leq 10^{-10}$
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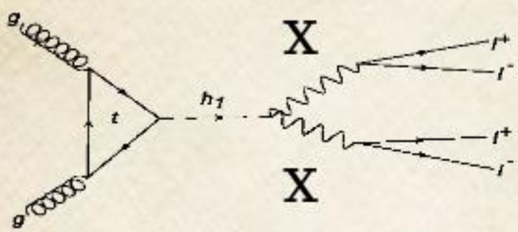

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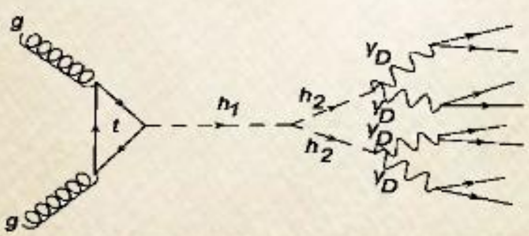

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X= Z^0 h_2 γ_D

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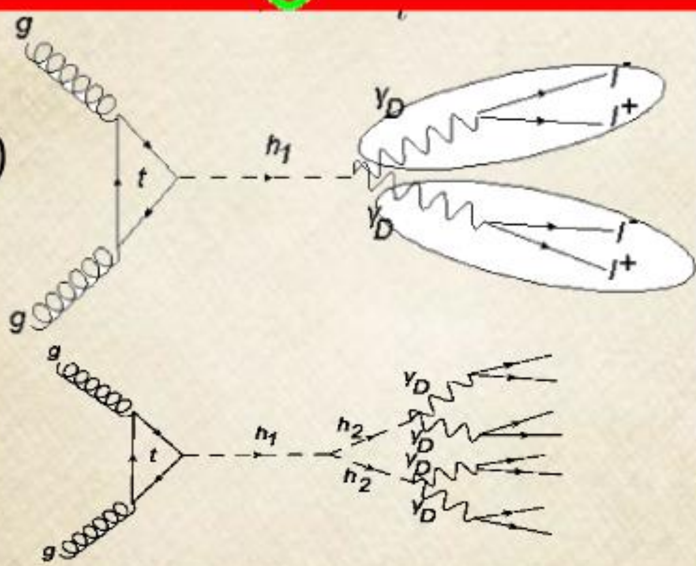

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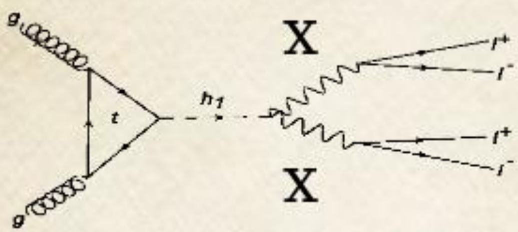

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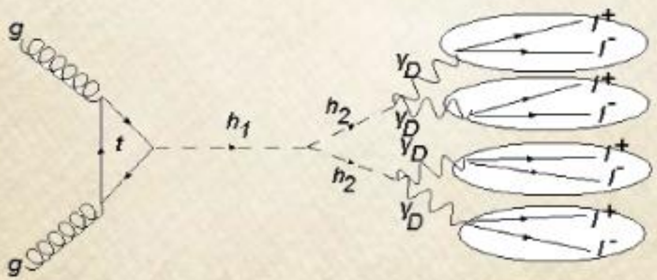

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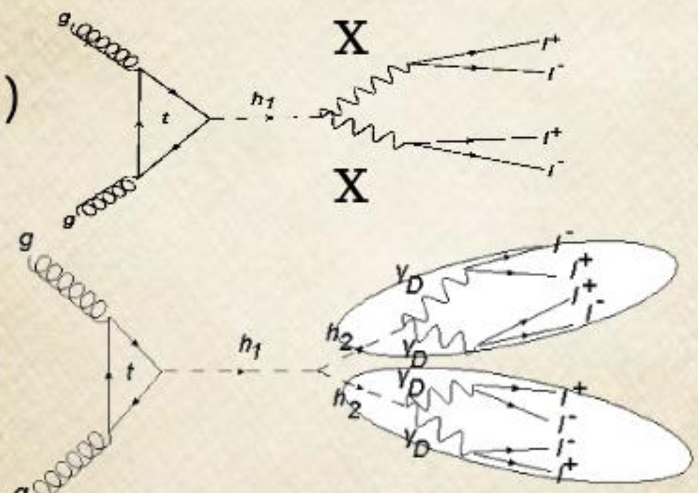

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Summary

Trough additional kinetic mixing and $U(1)_D$ gauge in SM model , we have extra interaction $h_1 \rightarrow h_2 h_2$, $h_1 \rightarrow \gamma_D \gamma_D$, $h_2 \rightarrow \gamma_D \gamma_D$, etc.
In parameter space, that satisfy some condition (for example : dark photons with short lifetimes and $Br(h_1 \rightarrow Dark) < 20\%$,etc). and We have the result:

1. our model have MULTILEPTON final state through h_1 decay.

2. The signal of MULTILEPTON-JETS can be higher than Standard Model background signal (include 2,4,8 Multilepton-Jets).

Thanks for listening

감사합니다~

Thanks for listening

감사합니다

kam ca ha mi da