

New Dark Matter Models for the Muon / Electron $g-2$ Anomalies

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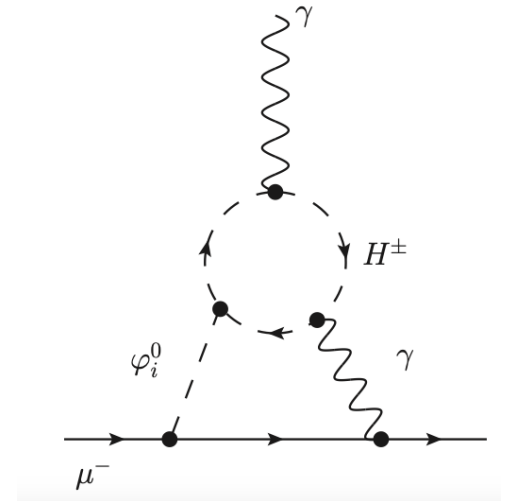
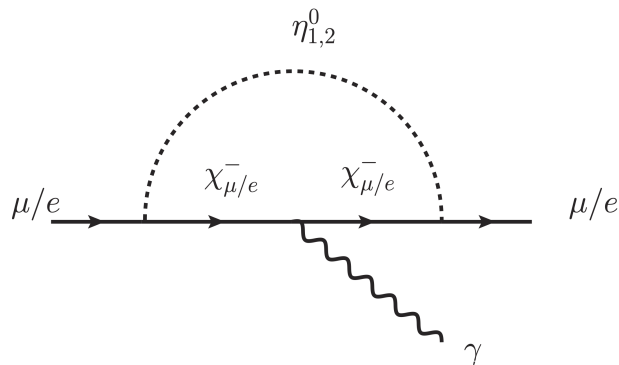
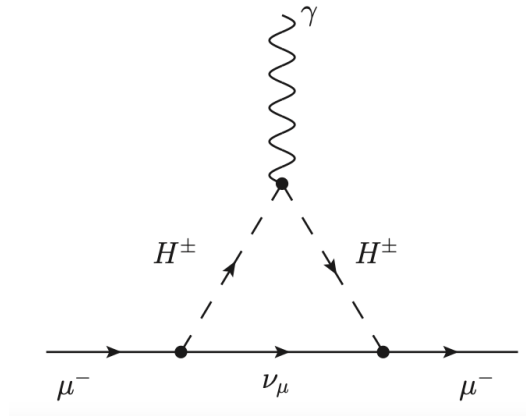
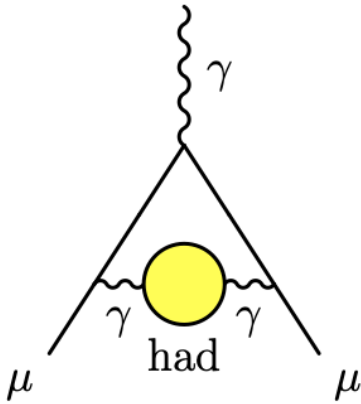
An explanation for the muon and electron $g - 2$ anomalies and dark matter

Kai-Feng Chen,^{a,b} Cheng-Wei Chiang^a and Kei Yagyu^c

arXiv:2006.07929

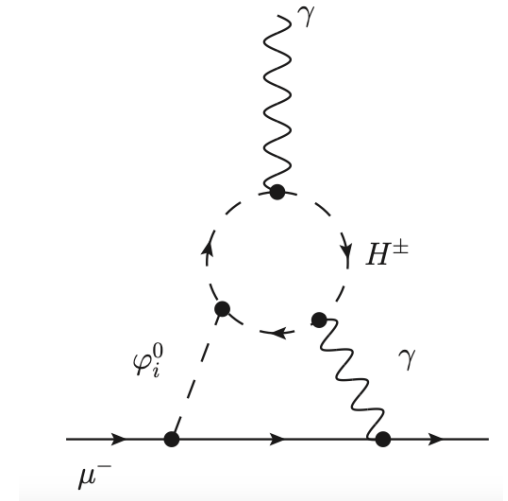
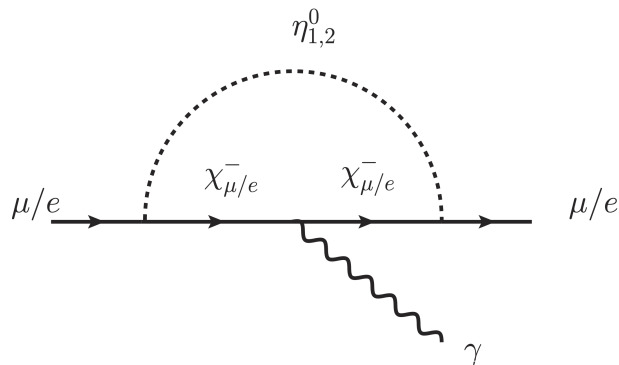
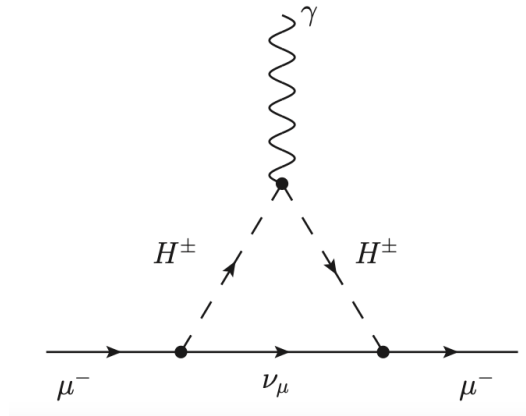
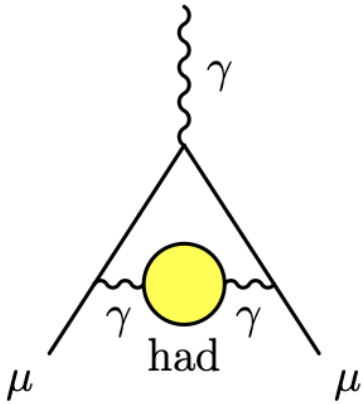
Muon $g - 2$

$$\Delta a_\mu \equiv a_\mu^{\text{exp}} - a_\mu^{\text{SM}} = 261(79) \times 10^{-11}$$



Electron $g - 2$

$$\Delta a_e \equiv a_e^{\text{exp}} - a_e^{\text{SM}} = -88(36) \times 10^{-14}$$



Summary of Our Model

	Fermion			Scalar		
Fields	$(L_L^e, L_L^\mu, L_L^\tau)$	(e_R, μ_R, τ_R)	(χ_e, χ_μ)	Φ	η_D	η_S
$SU(2)_L$	2	1	1	2	2	1
$U(1)_Y$	$-1/2$	-1	$-Y_D$	$1/2$	$Y_D - 1/2$	$Y_D - 1$
$U(1)_\ell$	$(q_e, q_\mu, 1)$	$(q_e, q_\mu, 1)$	(q_e, q_μ)	0	0	0
$\mathbb{Z}_2$	+	+	−	+	−	−

$$\mathcal{L}_Y \supset \sum_{a=e,\mu} \left[f_L^a (\bar{L}_L^a \chi_{R,a}) \eta_D + f_R^a (\bar{\ell}_R^a \chi_{L,a}) \eta_S + M_{\chi_a} (\bar{\chi}_{L,a} \chi_{R,a}) \right] + \text{h.c.}$$

$$\begin{aligned} V = & -\mu_\Phi^2 |\Phi|^2 + \mu_D^2 |\eta_D|^2 + \mu_S^2 |\eta_S|^2 \\ & + \frac{\lambda_1}{2} |\Phi|^4 + \frac{\lambda_2}{2} |\eta_D|^4 + \lambda_3 |\Phi|^2 |\eta_D|^2 + \lambda_4 |\Phi^\dagger \eta_D|^2 + \left[\frac{\lambda_5}{2} (\Phi \cdot \eta_D)^2 + \text{h.c.} \right] \\ & + \frac{\lambda_6}{2} |\eta_S|^4 + \lambda_7 |\Phi|^2 |\eta_S|^2 + \lambda_8 |\eta_D|^2 |\eta_S|^2 + [\kappa (\eta_D^\dagger \Phi \eta_S) + \text{h.c.}] \end{aligned}$$

Summary of Our Model

$$(g - 2)_\ell$$

Relic Density

DM Direct Searches

Pair Production in Colliders

$$h \rightarrow \gamma\gamma, h \rightarrow Z\gamma$$

Perturbative Unitarity

Vacuum Stability

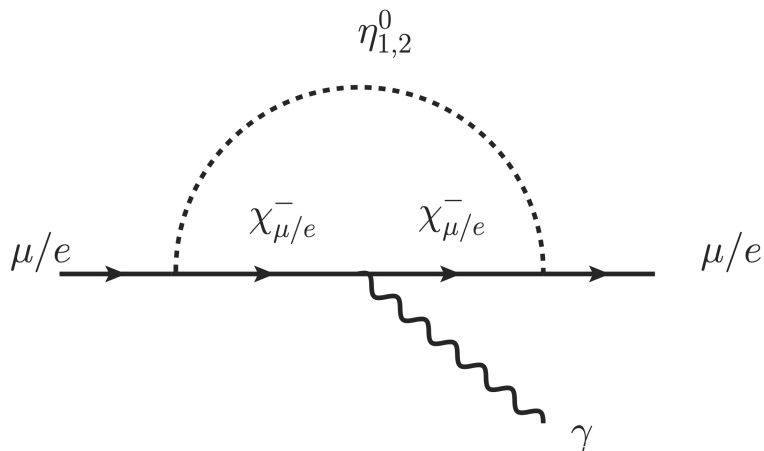
$$m_{\eta_1}, m_{\eta_2}, m_{\eta^\pm}, m_{\eta_A}, \theta$$

$$\lambda_3, \lambda_7, \lambda_2, \lambda_6, \lambda_8$$

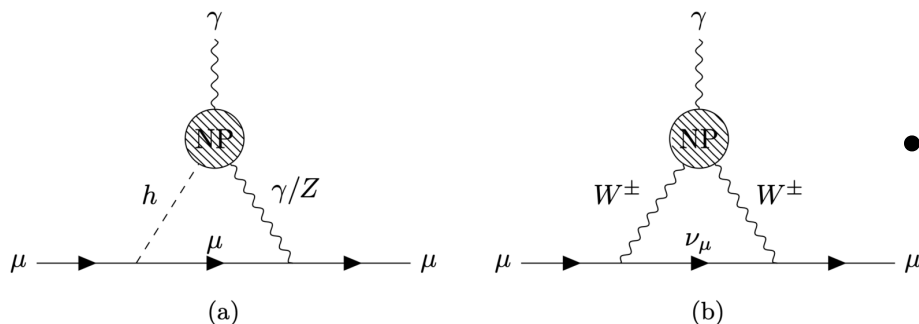
$$M_{\chi_\ell}, f_L^\ell, f_R^\ell$$

Constraints from $(g - 2)_\ell$

$$\Delta a_\ell^{\text{NP}} = -\frac{1}{16\pi^2} \sum_{k=1,2} \left[\frac{m_\ell^2}{M_{\chi_\ell}^2} (|g_L^{\ell,k}|^2 + |g_R^{\ell,k}|^2) F_2 \left(\frac{m_{\eta_k}^2}{M_{\chi_\ell}^2} \right) + \frac{2m_\ell}{M_{\chi_\ell}} \text{Re}(g_L^{\ell,k} g_R^{\ell,k*}) F_1 \left(\frac{m_{\eta_k}^2}{M_{\chi_\ell}^2} \right) \right]$$



- Cancellation between two scalars
-> Need Mass Splitting
- Lighter scalar dominants
-> $\text{sgn}(\Delta a_\ell^{\text{NP}}) = \text{sgn}(g_L^{\ell,1} g_R^{\ell,1})$



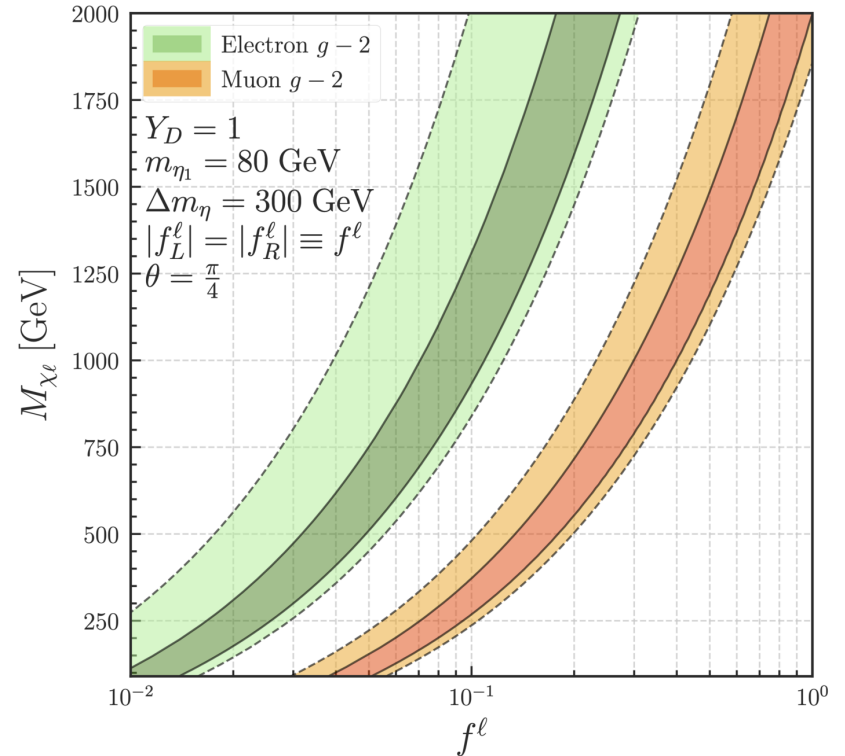
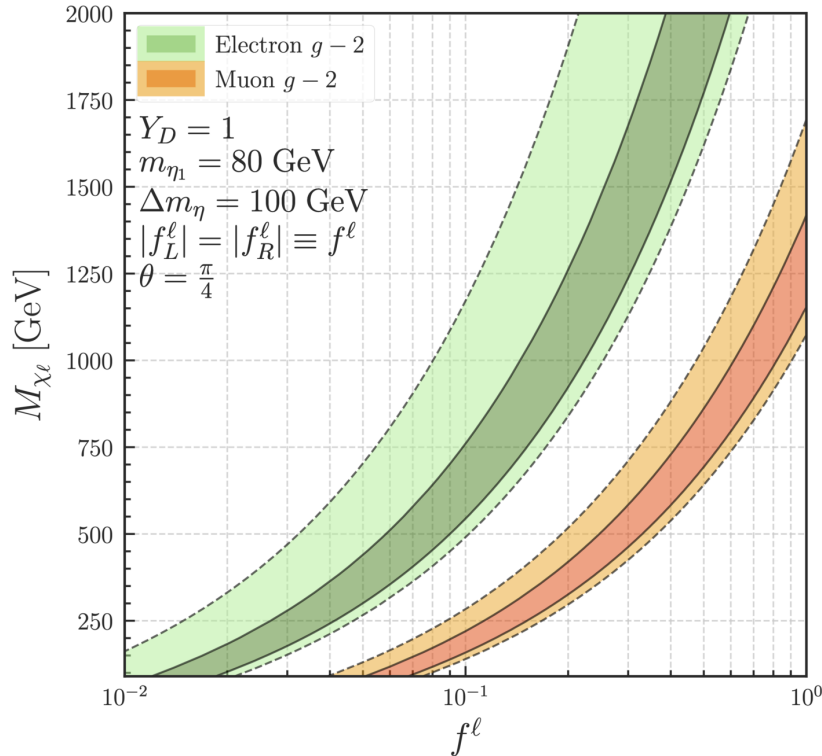
- > two orders of magnitude smaller

Constraints from $(g - 2)_\ell$

$$\Delta a_\ell^{\text{NP}} = -\frac{1}{16\pi^2} \sum_{k=1,2} \left[\frac{m_\ell^2}{M_{\chi_\ell}^2} (|g_L^{\ell,k}|^2 + |g_R^{\ell,k}|^2) F_2 \left(\frac{m_{\eta_k}^2}{M_{\chi_\ell}^2} \right) + \frac{2m_\ell}{M_{\chi_\ell}} \text{Re}(g_L^{\ell,k} g_R^{\ell,k*}) F_1 \left(\frac{m_{\eta_k}^2}{M_{\chi_\ell}^2} \right) \right]$$

$$g_L^{\ell,1} = \frac{f_L^\ell}{\sqrt{2}} c\theta, \quad g_L^{\ell,2} = -\frac{f_L^\ell}{\sqrt{2}} s\theta, \quad g_R^{\ell,1} = f_R^\ell s\theta, \quad g_R^{\ell,2} = f_R^\ell c\theta$$

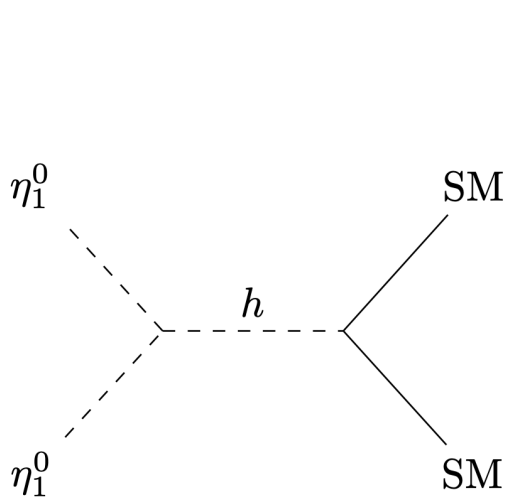
$$f_L^\mu > 0, \quad f_R^\mu < 0, \quad f_{L,R}^e > 0$$



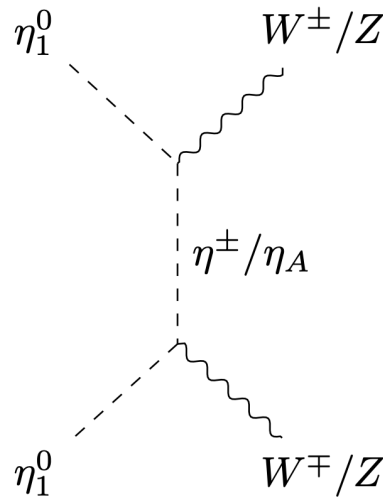
Constraints from Dark Matter

	Scalar		
Fields	Φ	η_D	η_S
$SU(2)_L$	2	2	1
$U(1)_Y$	$1/2$	$Y_D - 1/2$	$Y_D - 1$
$U(1)_\ell$	0	0	0
$\mathbb{Z}_2$	+	−	−

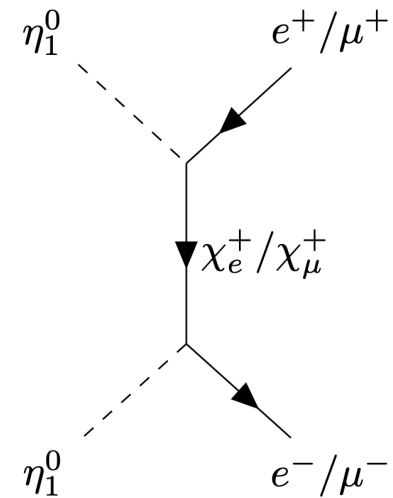
$$\begin{array}{l}
 \text{---} Y_D = 1 : \eta_1 \\
 \text{---} Y_D = 0 : \eta_S, \chi^0
 \end{array}$$



(a)

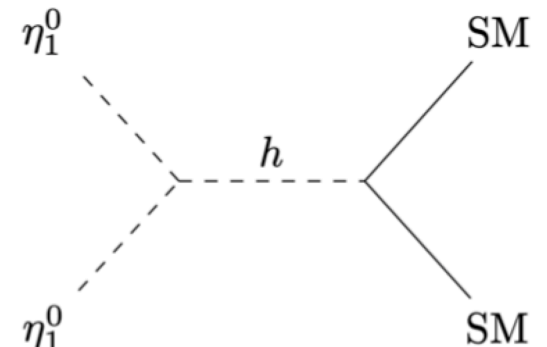
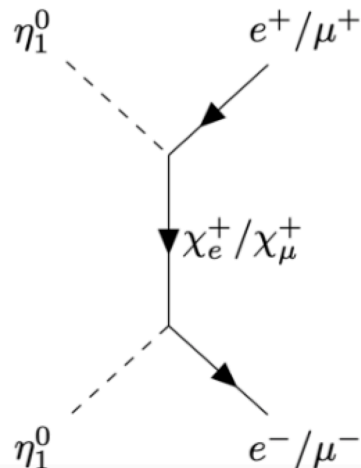
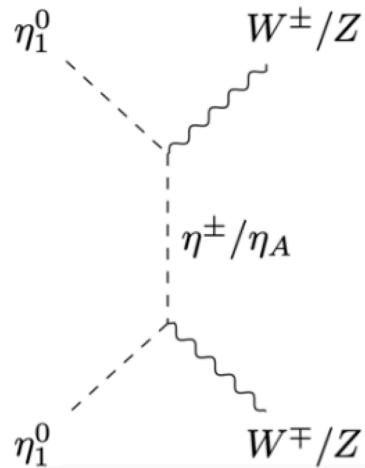
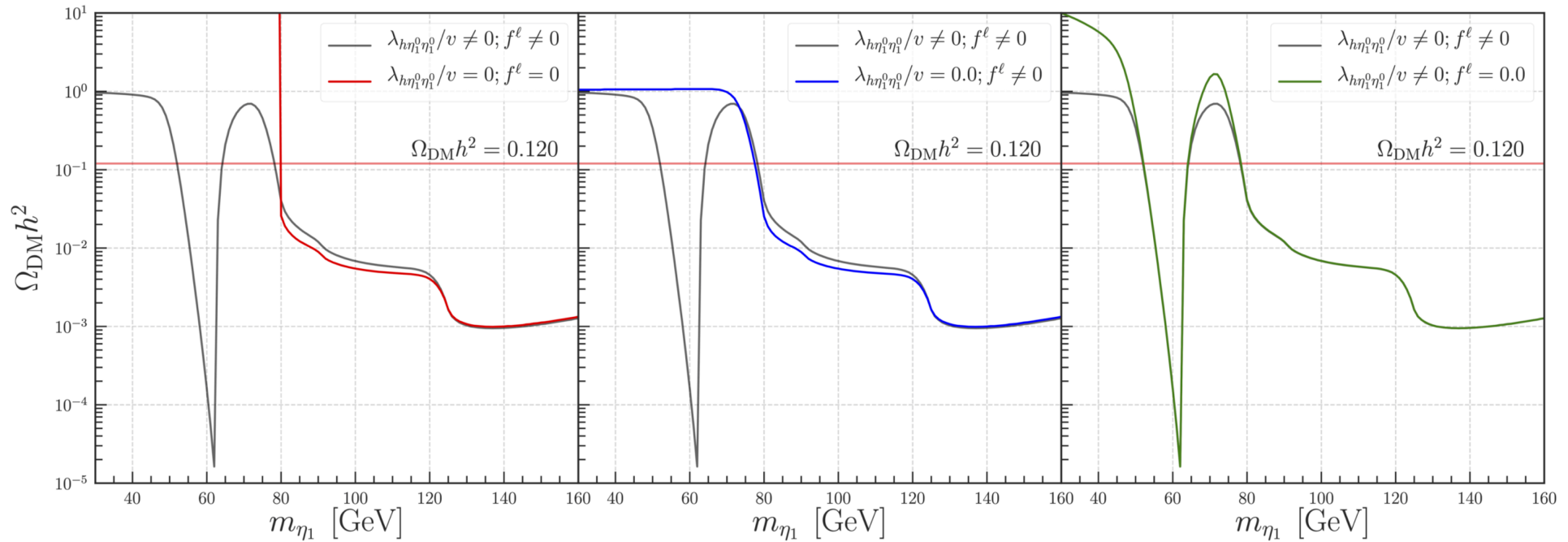


(b)

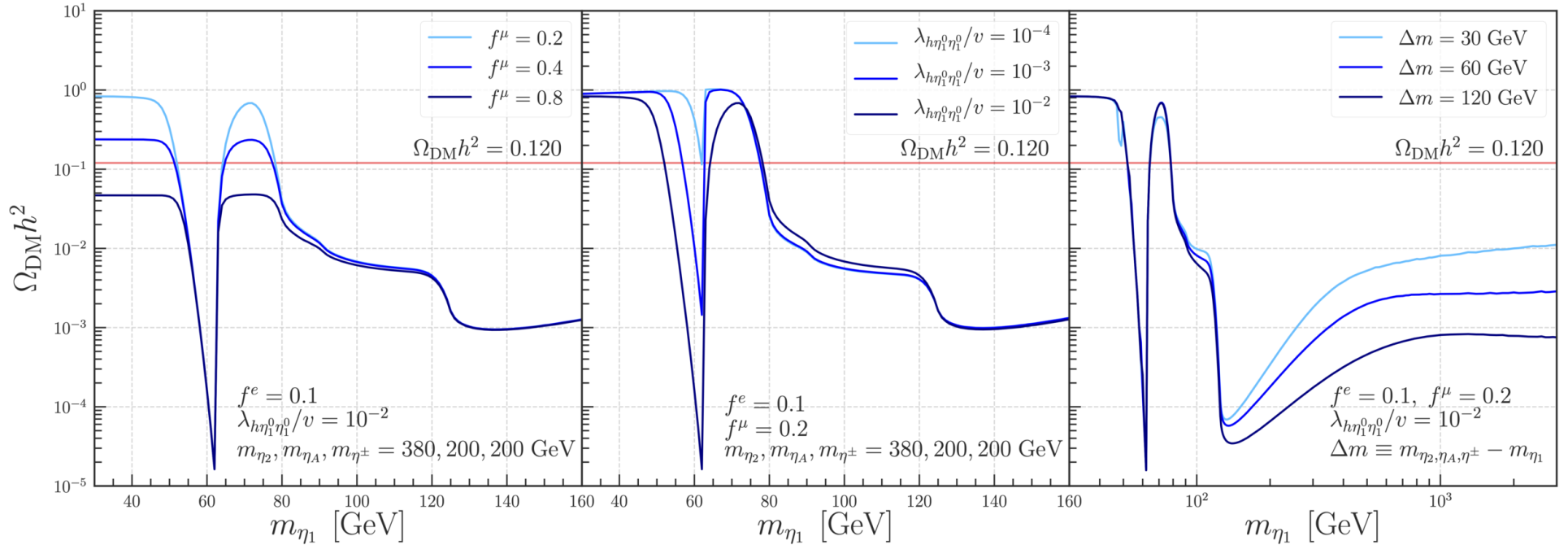


(c)

Constraints from Dark Matter

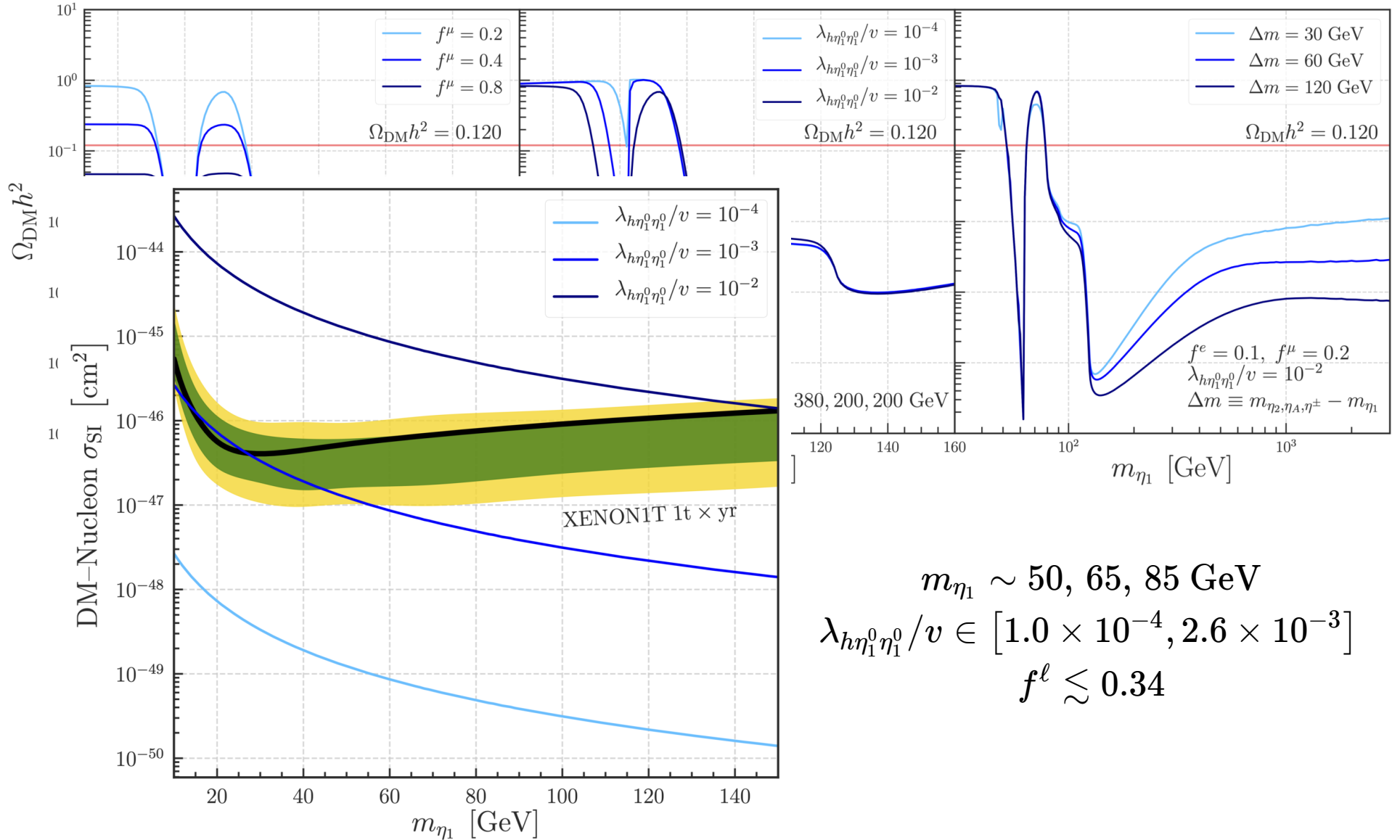


Constraints from Dark Matter



Allowed parameters : $m_{\eta_1} \sim 50, 65, 85$ GeV
 $\lambda_{h\eta_1^0\eta_1^0}/v \in [1.0 \times 10^{-4}, 1.0 \times 10^{-1}]$
 $f^\ell \lesssim 0.34$

Constraints from Dark Matter

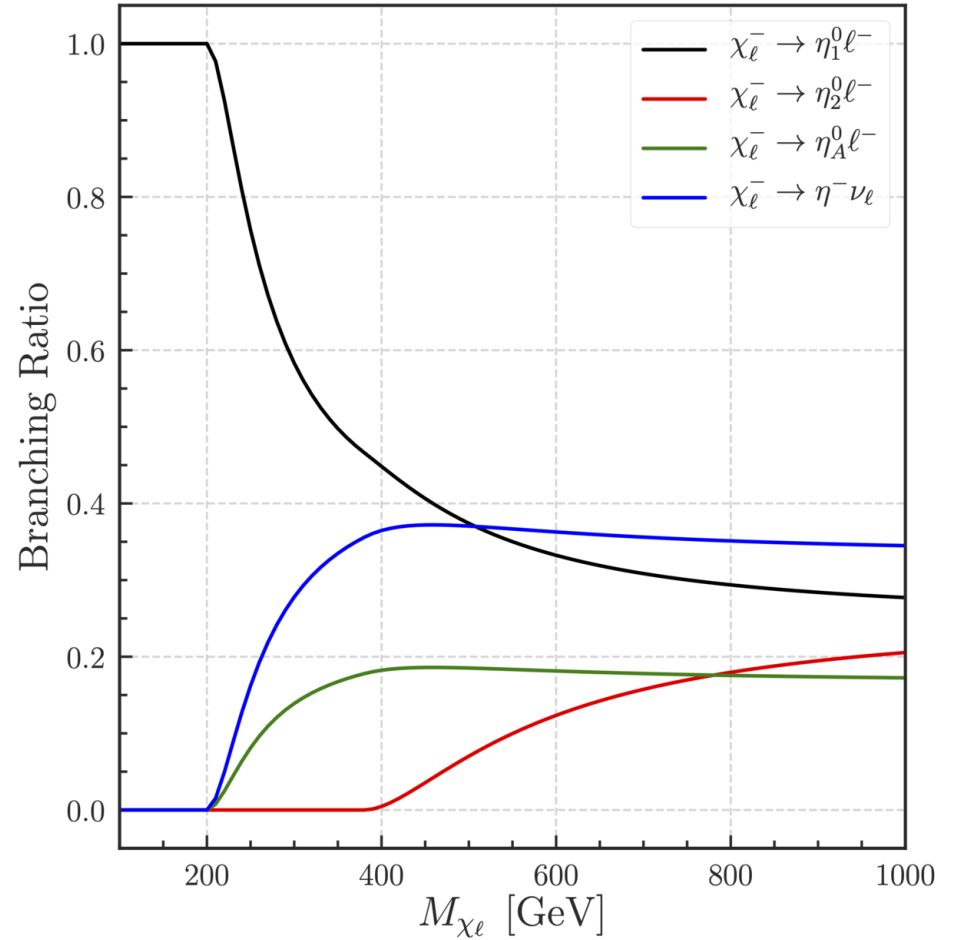
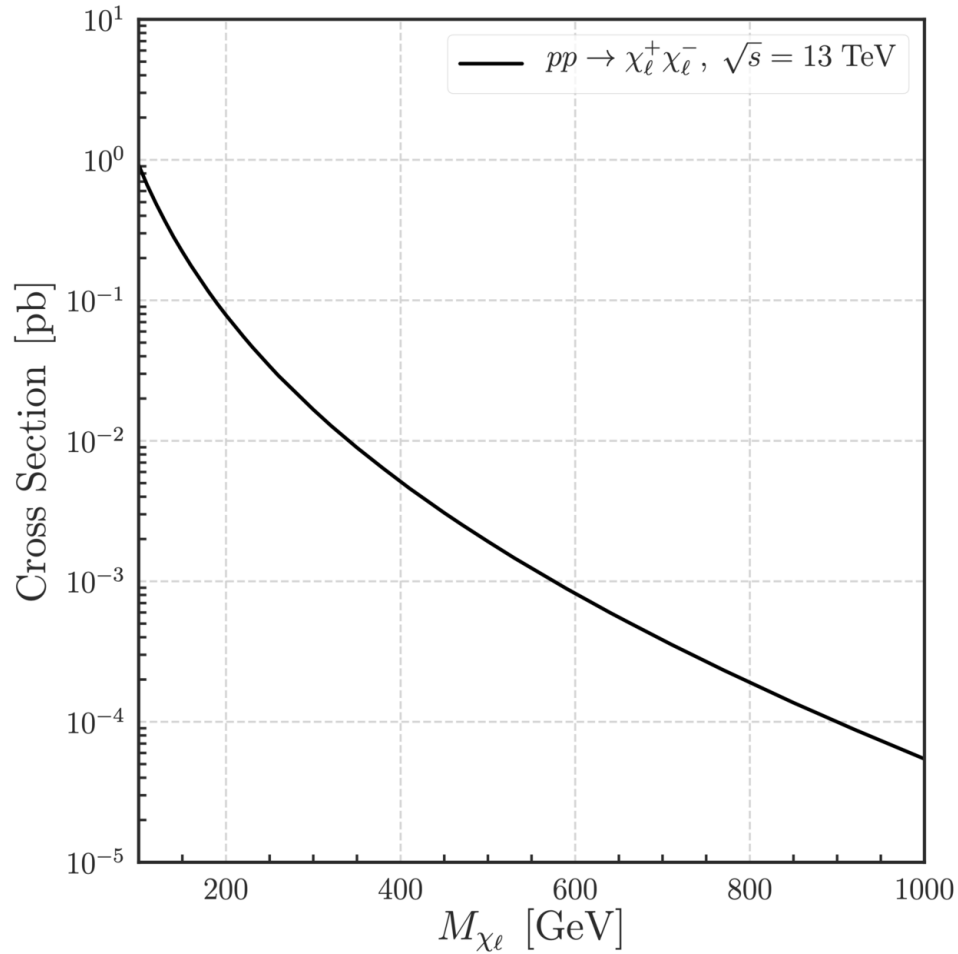


$$m_{\eta_1} \sim 50, 65, 85 \text{ GeV}$$

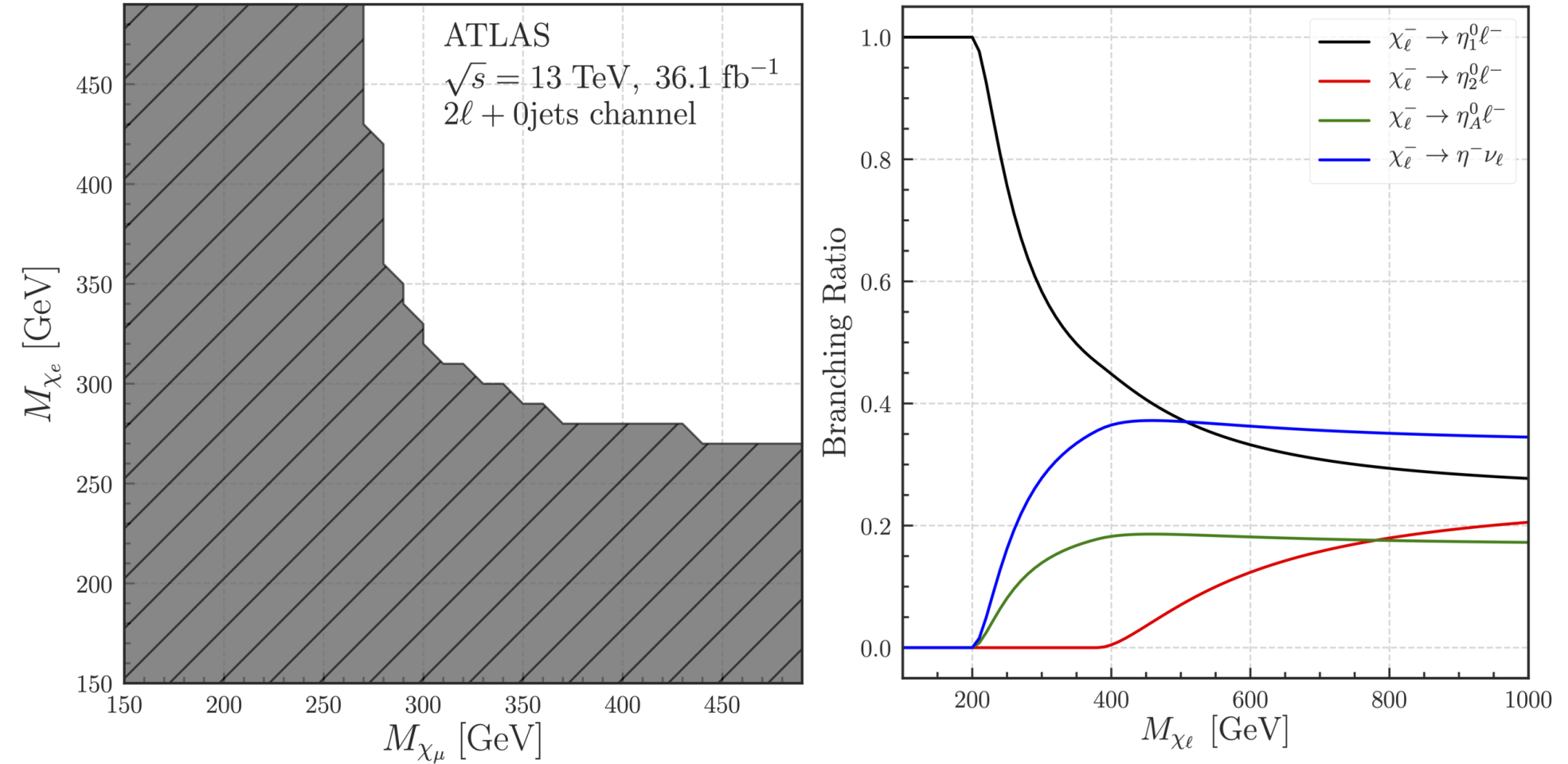
$$\lambda_{h\eta_1^0\eta_1^0}/v \in [1.0 \times 10^{-4}, 2.6 \times 10^{-3}]$$

$$f^\ell \lesssim 0.34$$

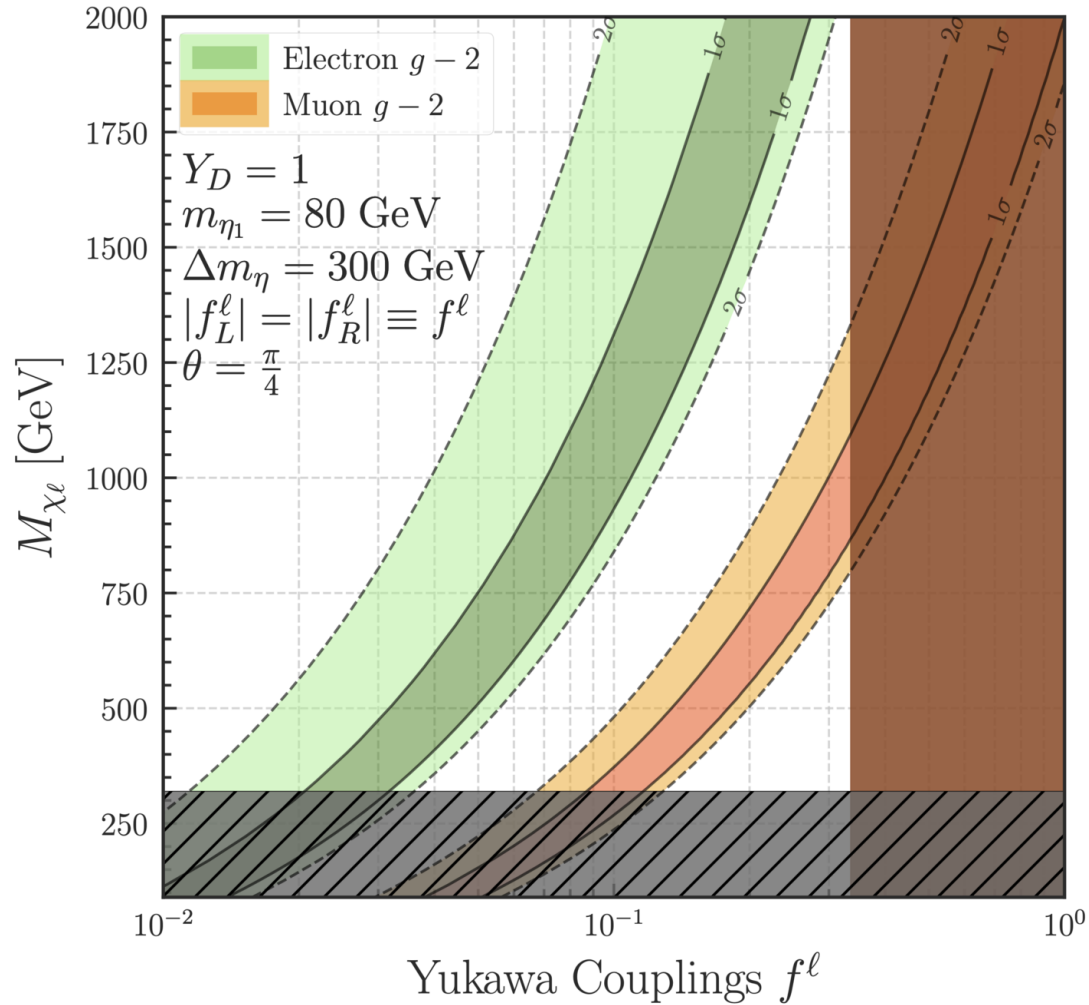
Constraints from Colliders



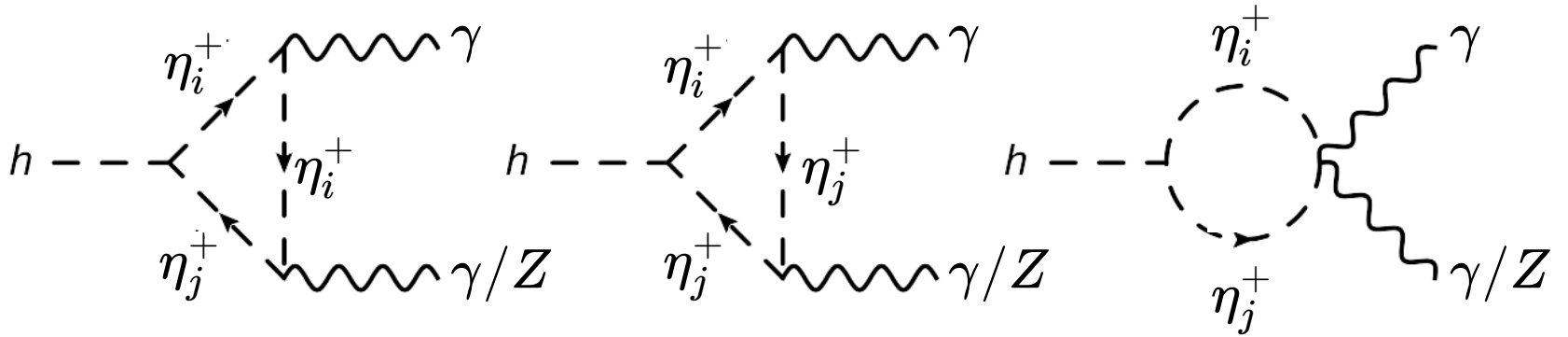
Constraints from Colliders



Constraints from Colliders



Constraints from Higgs



$$\lambda_{h\eta^+\eta^-} = -v\lambda_3$$

for $Y_D = 1$

$$\lambda_{h\eta_1^+\eta_1^-} = v \left[\left(\frac{m_{\eta_A}^2}{v^2} + \frac{m_{\eta_H}^2}{v^2} - \frac{2m_{\eta_1^\pm}^2}{v^2} - \lambda_3 \right) c_\theta^2 - \lambda_7 s_\theta^2 \right]$$

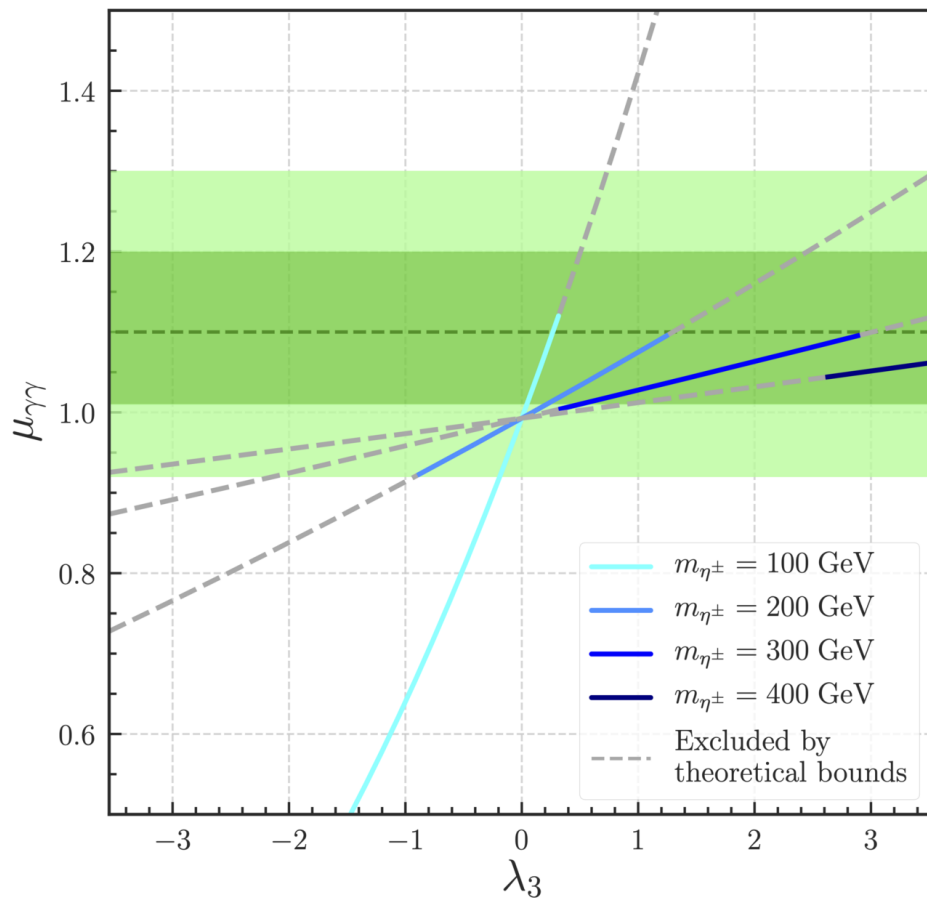
for $Y_D = 0$

$$\lambda_{h\eta_2^+\eta_2^-} = v \left[\left(\frac{m_{\eta_A}^2}{v^2} + \frac{m_{\eta_H}^2}{v^2} - \frac{2m_{\eta_2^\pm}^2}{v^2} - \lambda_3 \right) s_\theta^2 - \lambda_7 c_\theta^2 \right]$$

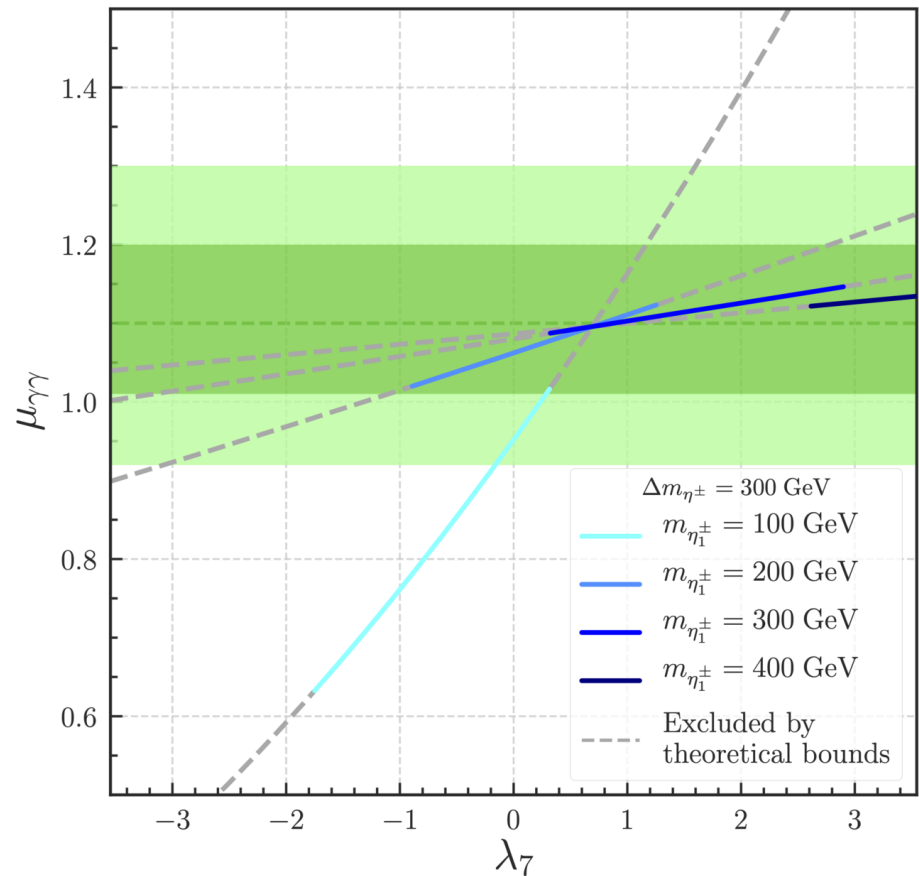
Constraints from Higgs

$$\mu_{\gamma\gamma/Z\gamma} \equiv \frac{\sigma_h \times \text{BR}(h \rightarrow \gamma\gamma/Z\gamma)}{[\sigma_h \times \text{BR}(h \rightarrow \gamma\gamma/Z\gamma)]_{\text{SM}}}$$

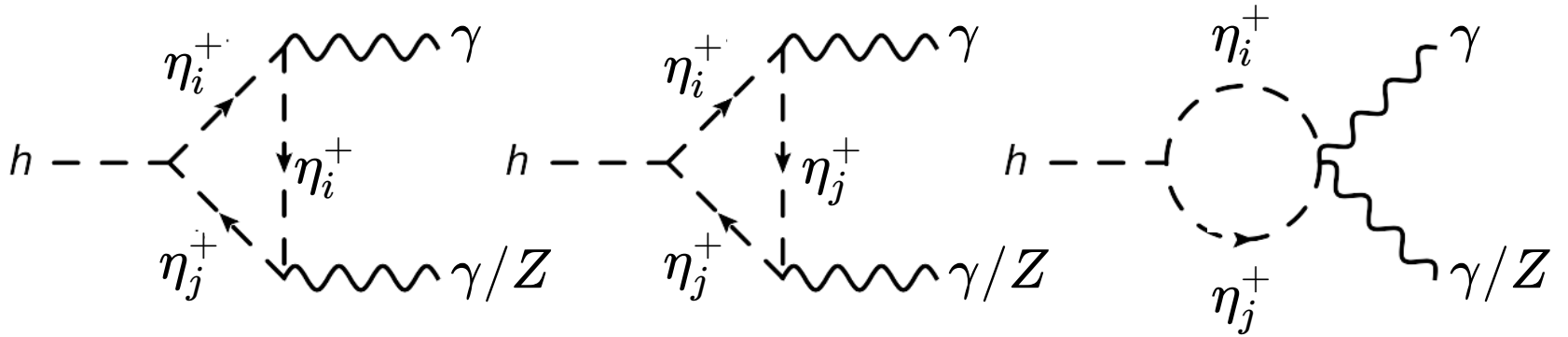
$Y_D = 1$



$Y_D = 0$



Constraints from Higgs



$$\lambda_{h\eta^+\eta^-} = -v\lambda_3$$

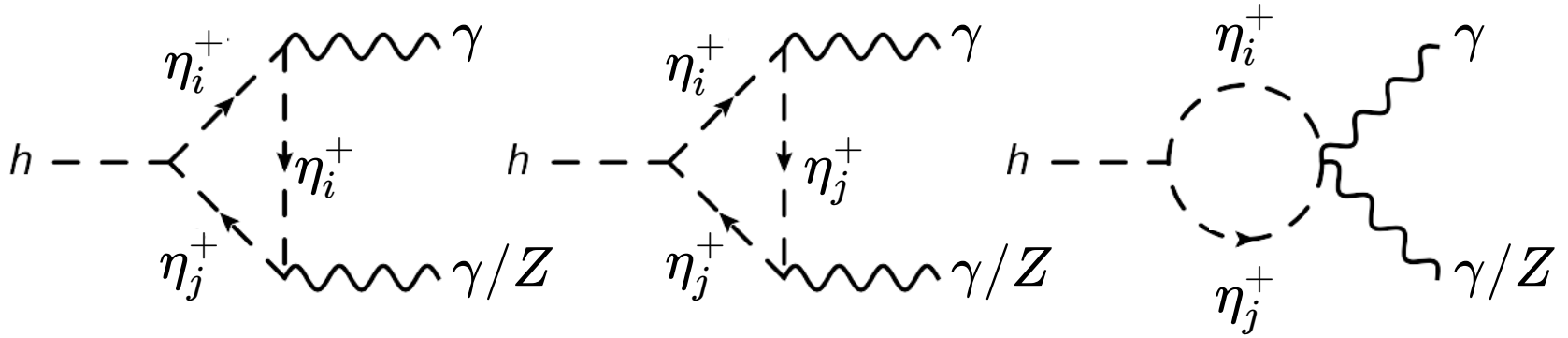
for $Y_D = 1$

$$\lambda_{h\eta_1^+\eta_1^-} = v \left[\left(\frac{m_{\eta_A}^2}{v^2} + \frac{m_{\eta_H}^2}{v^2} - \frac{2m_{\eta_1^\pm}^2}{v^2} - \lambda_3 \right) c_\theta^2 - \lambda_7 s_\theta^2 \right]$$

for $Y_D = 0$

$$\lambda_{h\eta_2^+\eta_2^-} = v \left[\left(\frac{m_{\eta_A}^2}{v^2} + \frac{m_{\eta_H}^2}{v^2} - \frac{2m_{\eta_2^\pm}^2}{v^2} - \lambda_3 \right) s_\theta^2 - \lambda_7 c_\theta^2 \right]$$

Constraints from Higgs

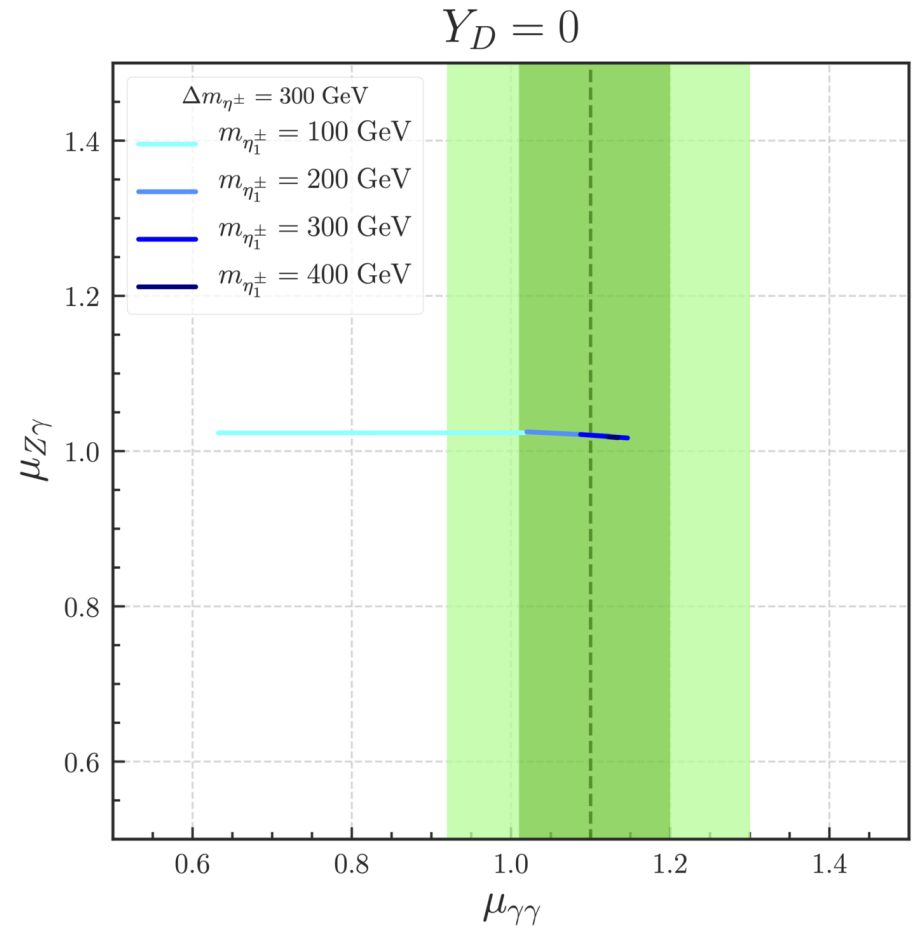
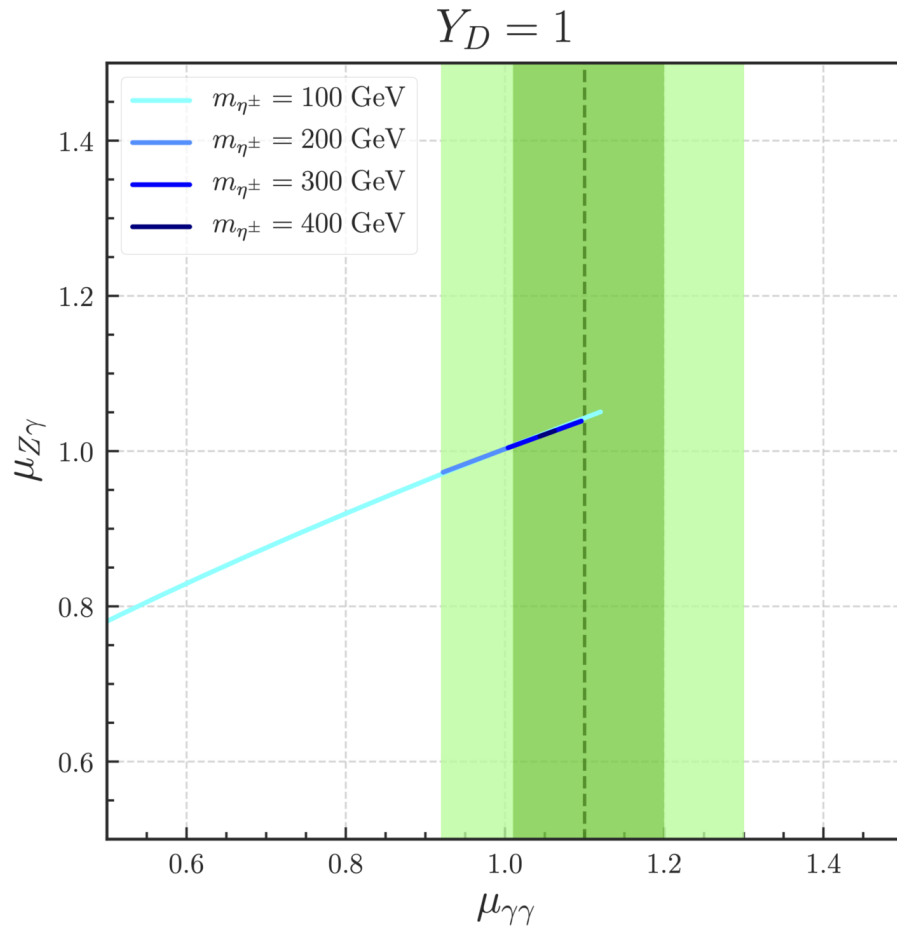


$$\lambda_{h\eta_1^+\eta_2^-} = v s_\theta c_\theta \left[\lambda_3 + \frac{1}{v^2} \left(m_{\eta_1^\pm}^2 + m_{\eta_2^\pm}^2 - m_{\eta_A}^2 - m_{\eta_H}^2 \right) - \lambda_7 \right]$$

$$\lambda_{h\eta_1^+\eta_1^-} = v \left[\left(\frac{m_{\eta_A}^2}{v^2} + \frac{m_{\eta_H}^2}{v^2} - \frac{2m_{\eta_1^\pm}^2}{v^2} - \lambda_3 \right) c_\theta^2 - \lambda_7 s_\theta^2 \right] \quad \text{for } Y_D = 0$$

$$\lambda_{h\eta_2^+\eta_2^-} = v \left[\left(\frac{m_{\eta_A}^2}{v^2} + \frac{m_{\eta_H}^2}{v^2} - \frac{2m_{\eta_2^\pm}^2}{v^2} - \lambda_3 \right) s_\theta^2 - \lambda_7 c_\theta^2 \right]$$

Constraints from Higgs



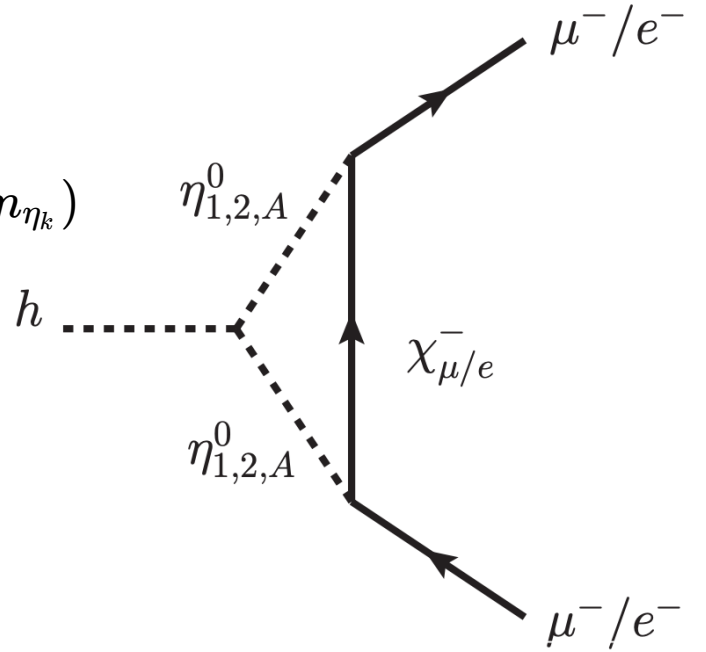
Constraints from Higgs

$$\Delta y_\ell = \frac{M_{\chi_\ell}}{8\pi^2} \left[\sum_{k=1,2} \lambda_{h\eta_k^0\eta_k^0} g_L^{k,\ell} g_R^{k,\ell} C_0(0, 0, m_h^2; m_{\eta_k}, M_{\chi_\ell}, m_{\eta_k}) \right]$$

$$\simeq \frac{(f^\ell)^2}{16\sqrt{2}\pi^2} \frac{\lambda_{h\eta_1^0\eta_1^0} + \sigma_\ell \lambda_{h\eta_2^0\eta_2^0}}{M_{\chi_\ell}} \left(1 - \ln \frac{M_{\chi_\ell}^2}{m_{\eta^0}^2} \right)$$



$$\Delta y_\mu \simeq 1.63 \times 10^{-4}$$



Summary of Our Model

$$(g - 2)_\ell$$

Relic Density

DM Direct Searches

Pair Production in Colliders

$$h \rightarrow \gamma\gamma, h \rightarrow Z\gamma$$

Perturbative Unitarity

Vacuum Stability

$$m_{\eta_1}, m_{\eta_2}, m_{\eta^\pm}, m_{\eta_A}, \theta$$

$$\lambda_3, \lambda_7, \lambda_2, \lambda_6, \lambda_8$$

$$M_{\chi_\ell}, f_L^\ell, f_R^\ell$$