Di-photon resonance and Dark Matter

Giorgio Arcadi

LPT Orsay

Based on:

G.A, P. Ghosh, Y. Mambrini, M. Pierre

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Outline and motivation

Diphoton resonances are one of the most clean collider signatures of BSM physics.
They attracted recent interest because of the hint (not confirmed by the last data) of the detection of a 750 GeV resonance.

Experimentally accessible cross-section can be investigated through the requirement of a viable UV completion.

New spin-0 states can also act as portals for Dark Matter Interactions.

The model

$$\mathcal{L}_\Phi = \partial_\mu \Phi \partial^\mu \Phi^* + \mu_\Phi^2 |\Phi|^2 - \lambda |\Phi|^4 + \frac{\epsilon_\Phi^2}{2}(\Phi^2 + \text{ h.c.})$$

$$\Phi = \frac{1}{\sqrt{2}}(v_\Phi + s + ia)$$ → Scalar resonance part of a complex field

↓

$$m_a = \sqrt{2}\epsilon_\Phi$$ Light pseudo-goldstone boson

New fermions.

$$\mathcal{L}_F = i\bar{F}_L \gamma^\mu D_\mu F_L + i\bar{F}_R \gamma^\mu D_\mu F_R - (y_F \Phi \bar{F}_L F_R + \text{h.c.}) = i\bar{F}\gamma^\mu D_\mu F - \frac{y_F}{\sqrt{2}} s\bar{F}F - i\frac{y_F}{\sqrt{2}} a\bar{F}\gamma^5 F$$

The masses of the new fermions are dynamically generated by the spontaneous breaking of the new U(1).

$$y_F = \sqrt{2} m_F / v_\Phi = 2\sqrt{\lambda}(m_F/m_s)$$ Only one relevant coupling (the quartic coupling)

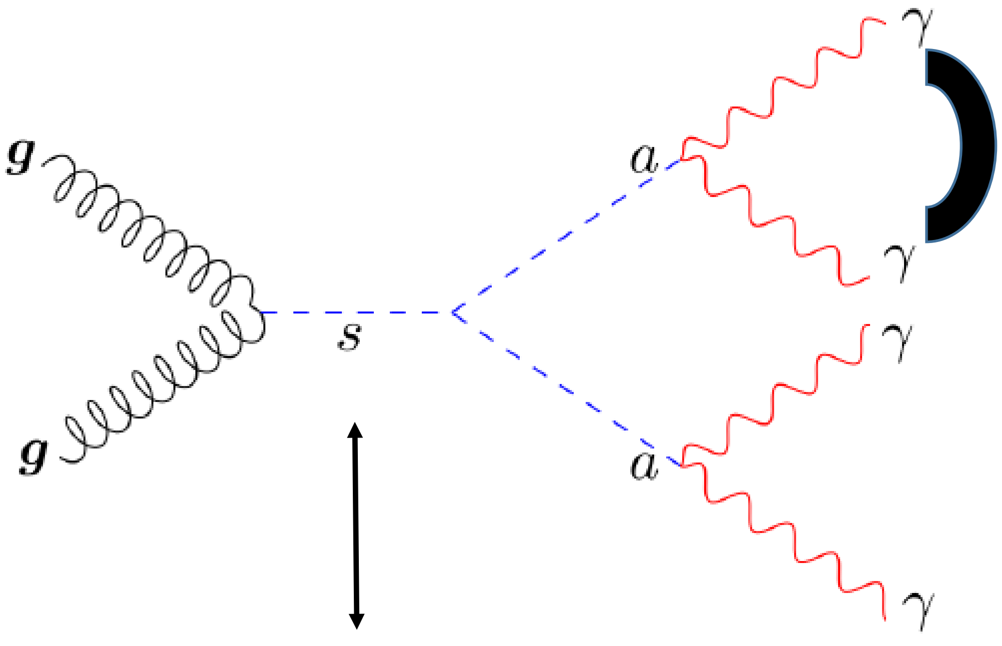
New fermionic sector

N_f pairs of fermions in the fundamental representation of color and with electric charge Q_F but singlet under SU(2).

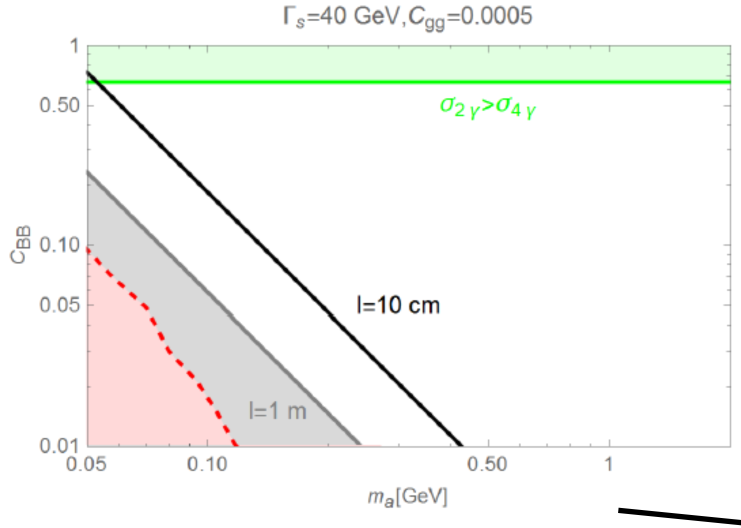
Adding the DM:

$$\mathcal{L}_\chi = \frac{1}{2} i \bar{\chi} \gamma^\mu \partial_\mu \chi - y_\chi \Phi \bar{\chi}^c \chi + \text{h.c.} \quad = \frac{1}{2} i \bar{\chi} \gamma^\mu \partial_\mu \chi - \frac{y_\chi}{\sqrt{2}} s \bar{\chi}^c \chi - i \frac{y_\chi}{\sqrt{2}} a \bar{\chi}^c \gamma^5 \chi$$

The DM belongs to the new fermion sector but it is a SM singlet (it can be also a Majorana fermion)



$\Delta\phi \sim \frac{2}{\gamma}$ < Calorimeter Resolution

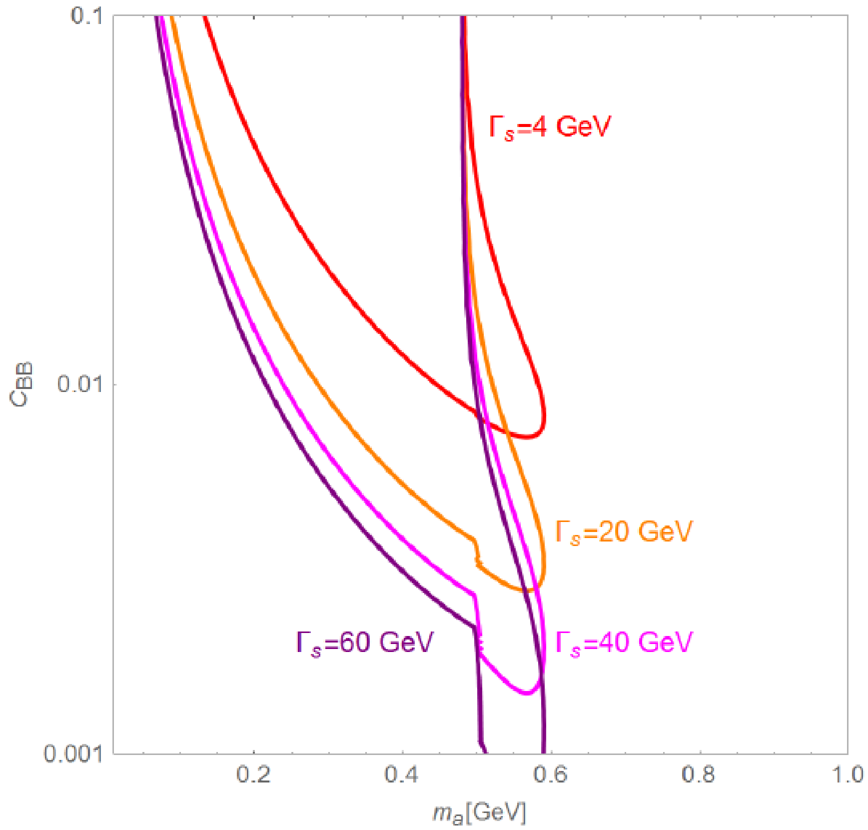


For

$m_s \sim 750$ GeV

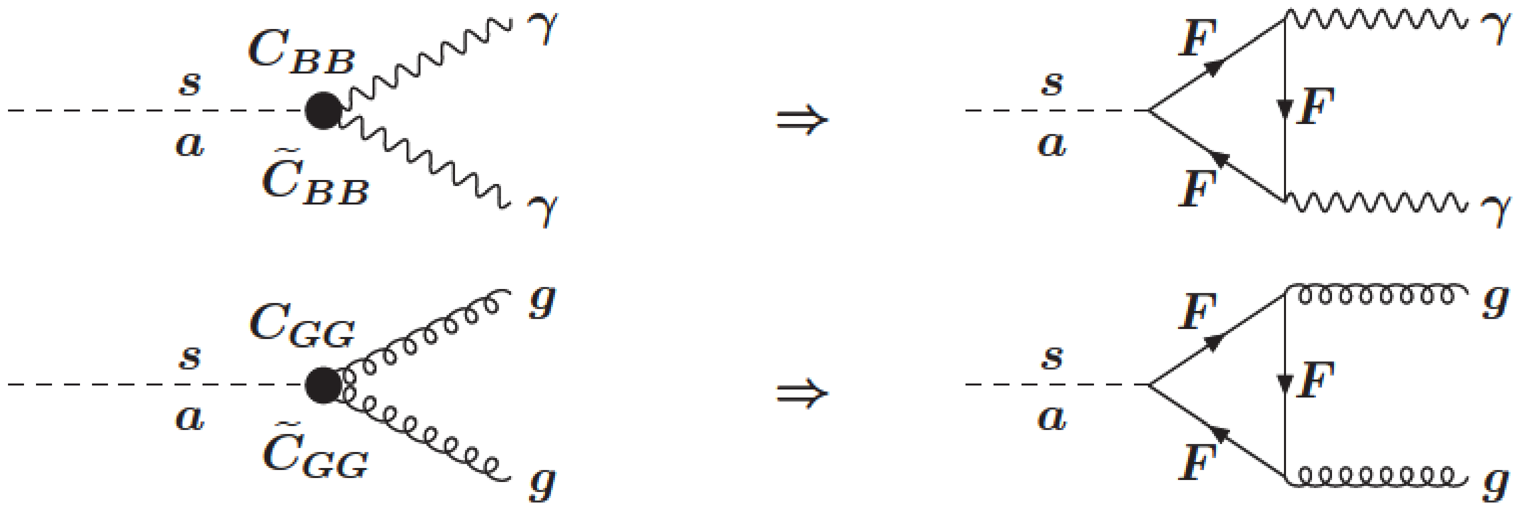
$m_a \sim 0.2-2\,\mathrm{GeV}$

$l = \beta\gamma/\Gamma_a \ll 1\ \mathrm{m}$



Upper limit can be made more stringent by considering suitable calorimeter discrimination variables.

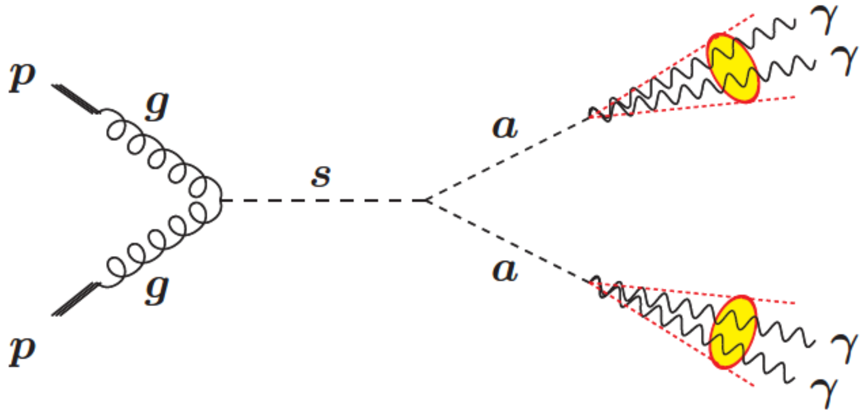
Generating the diphoton signal



$$-\mathcal{L} \supset \frac{\sqrt{\lambda} C_{GG}}{m_s} s G^{\alpha}_{\mu\nu} G^{\mu\nu}_{\alpha} + \frac{\sqrt{\lambda} \widetilde{C}_{GG}}{m_s} a G^{\alpha}_{\mu\nu} \widetilde{G}^{\mu\nu}_{\alpha} + \frac{\sqrt{\lambda} C_{BB} c_W^2}{m_s} s F_{\mu\nu} F^{\mu\nu} + \frac{\sqrt{\lambda} \widetilde{C}_{BB} c_W^2}{m_s} a F_{\mu\nu} \widetilde{F}^{\mu\nu}$$

$$C_{GG} = N_f \frac{\alpha_s}{4\sqrt{2}\pi} f_{1/2}(m_s^2/4m_F^2), \;\; C_{BB} = N_f \frac{3\alpha_{em}}{2\sqrt{2}\pi c_W^2} Q_F^2 f_{1/2}(m_s^2/4m_F^2)$$

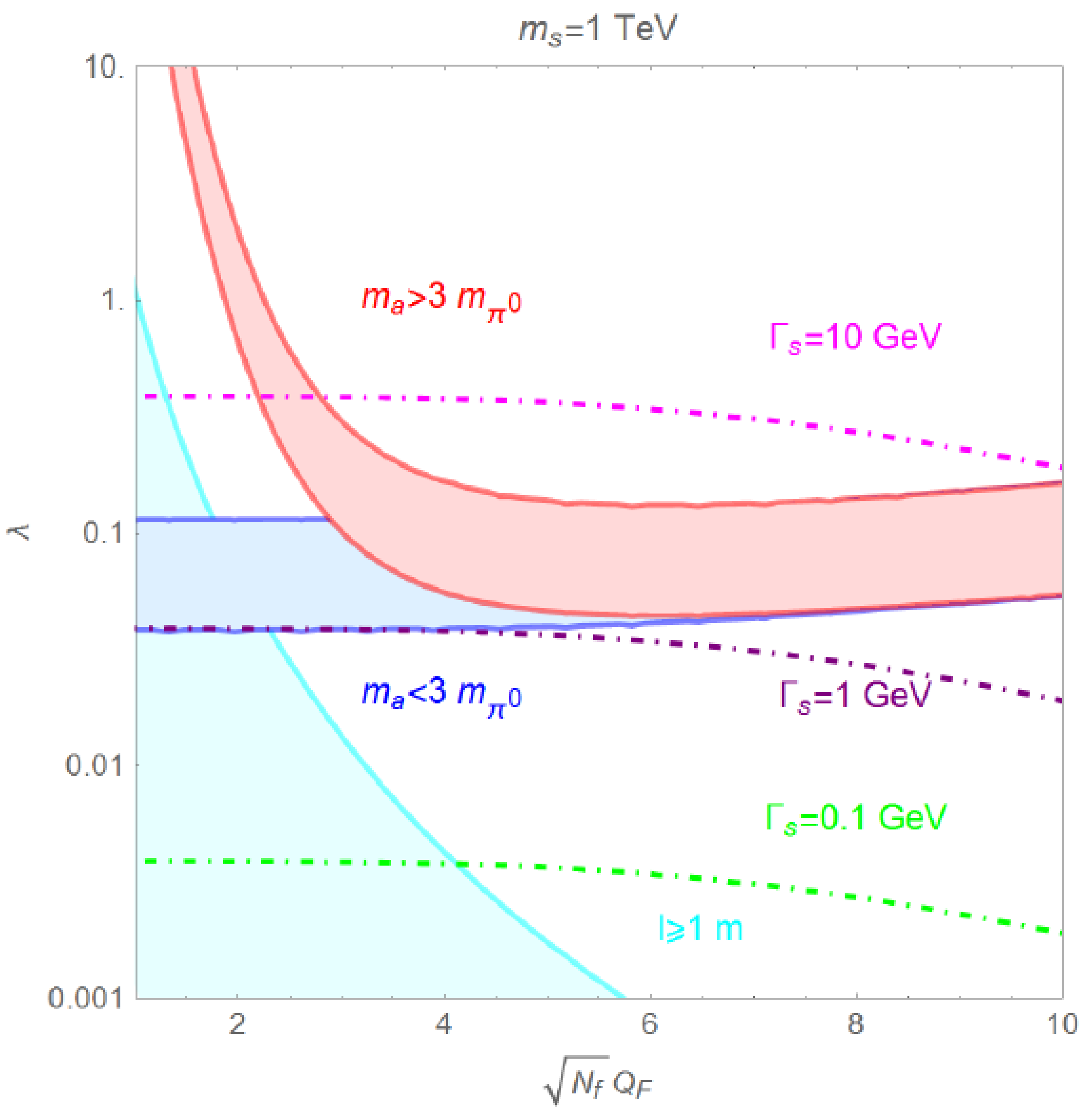
$$\widetilde{C}_{GG} = N_f \frac{\alpha_s}{4\sqrt{2}\pi} \tilde{f}_{1/2}(m_a^2/4m_F^2), \;\; \widetilde{C}_{BB} = N_f \frac{3\alpha_{em}}{2\sqrt{2}\pi c_W^2} Q_F^2 \tilde{f}_{1/2}(m_a^2/4m_F^2)$$



$$\sigma_{4\gamma} = \frac{\pi^2}{8 m_s \mathrm{s}} \Gamma(s \to gg) \mathrm{Br}(s \to aa) [\mathrm{Br}(a \to \gamma\gamma)]^2 I_{GG}(m_s/\sqrt{\mathrm{s}})$$

$$\sigma_{4\gamma} \simeq 1.64 \text{ fb} \frac{(\Gamma_s/m_s)}{10^{-4}} \left(\frac{I_{GG}(m_s/\sqrt{\mathrm{s}})}{2000}\right) N_f^2 \simeq 0.33 \text{ pb} \left(\frac{I_{GG}(m_s/\sqrt{\mathrm{s}})}{2000}\right) N_f^2 \lambda \qquad [\text{for } \mathrm{m_a} \lesssim 3\mathrm{m}_{\pi^0}]$$

$$\sigma_{4\gamma} \simeq 0.63 \text{ fb} \frac{(\Gamma_s/m_s)}{0.1} \left(\frac{I_{GG}(m_s/\sqrt{\mathrm{s}})}{2000}\right) N_f^2 Q_F^8 \simeq 0.12 \text{ fb} \left(\frac{I_{GG}(m_s/\sqrt{\mathrm{s}})}{2000}\right) N_f^2 Q_F^8 \lambda \qquad [\text{for } \mathrm{m_a} \gtrsim 3\mathrm{m}_{\pi^0}]$$



m_s=1 TeV
m_a>3 m_{π^0}
Γ_s=10 GeV
m_a<3 m_{π^0}
Γ_s=1 GeV
Γ_s=0.1 GeV
l⩾1 m
λ
$\sqrt{N_f}\,Q_F$
10.
1.
0.1
0.01
0.001
2
4
6
8
10

UV regime

We have to focus on the RGE for the yukawas and for the quartic couplings

$$\alpha_1(\mu) = \left[\frac{1}{\alpha_{1,\mathrm{SM}}(m_F)} - \frac{b_1^{\mathrm{SM}} + \Delta b_1}{2\pi} \ln\left(\frac{\mu}{m_F}\right)\right]^{-1}$$

$$\alpha_s(\mu) = \left[\frac{1}{\alpha_{s,\mathrm{SM}}(m_F)} - \frac{b_3^{\mathrm{SM}} + \Delta b_3}{2\pi} \ln\left(\frac{\mu}{m_F}\right)\right]^{-1}$$

$$\frac{dy_F}{d\ln\mu} = \beta_y = \frac{1}{16\pi^2}\left((1+6N_f)y_F^3 - 24\pi y_F \alpha_1 Q_F^2 - 32\pi y_F \alpha_s\right)$$

$$\frac{d\lambda}{d\ln\mu} = \beta_\lambda = \frac{1}{16\pi^2}(20\lambda^2 - 12N_f y_F^4 + 24\lambda N_f y_F^2)$$

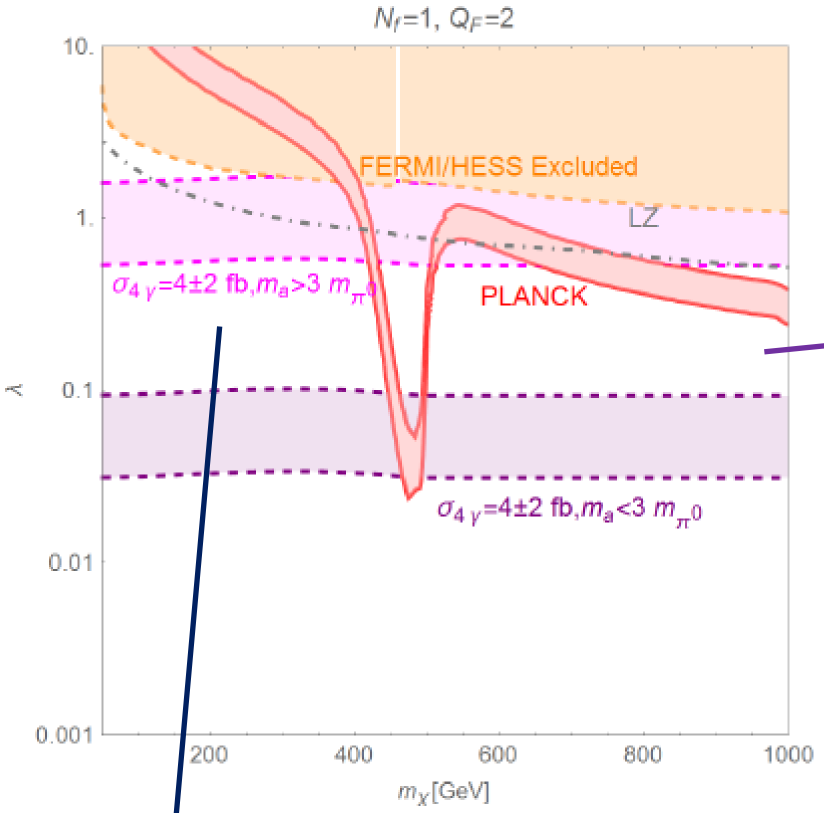
Sizable cross-sections need moderate fermion content; the Landau pole lies at rather high scales.

Radiative corrections typically mostly affect the quartic coupling

$$\left|\frac{\beta_\lambda}{\lambda}\right| \simeq \frac{12N_f}{\pi^2}\lambda\left(\frac{m_F}{m_s}\right)^4 \quad \leq 1 \quad \longrightarrow \quad \sigma_{4\gamma} \lesssim 0.83\,\mathrm{fb}\; Q_F^8 \left(\frac{m_s}{m_F}\right)^4 \left(\frac{I_{GG}(m_s/\sqrt{s})}{2000}\right)$$

Goertz et al. 1512.08500

Requiring that the quartic coupling does not become negative at too low scales limit the value of the diphoton cross-section.



$$\sigma_{4\gamma} \approx 163\,\text{fb}\, N_f^2 \left(\frac{I_{GG}(m_s/\sqrt{s})}{2000}\right)\left(\frac{\langle\sigma v\rangle_{sa}}{3\times 10^{-26}\,\text{cm}^3\text{s}^{-1}}\right)^{1/2}\left(\frac{500\,\text{GeV}}{m_\chi}\right)\left(\frac{m_s}{1\,\text{TeV}}\right)^2$$

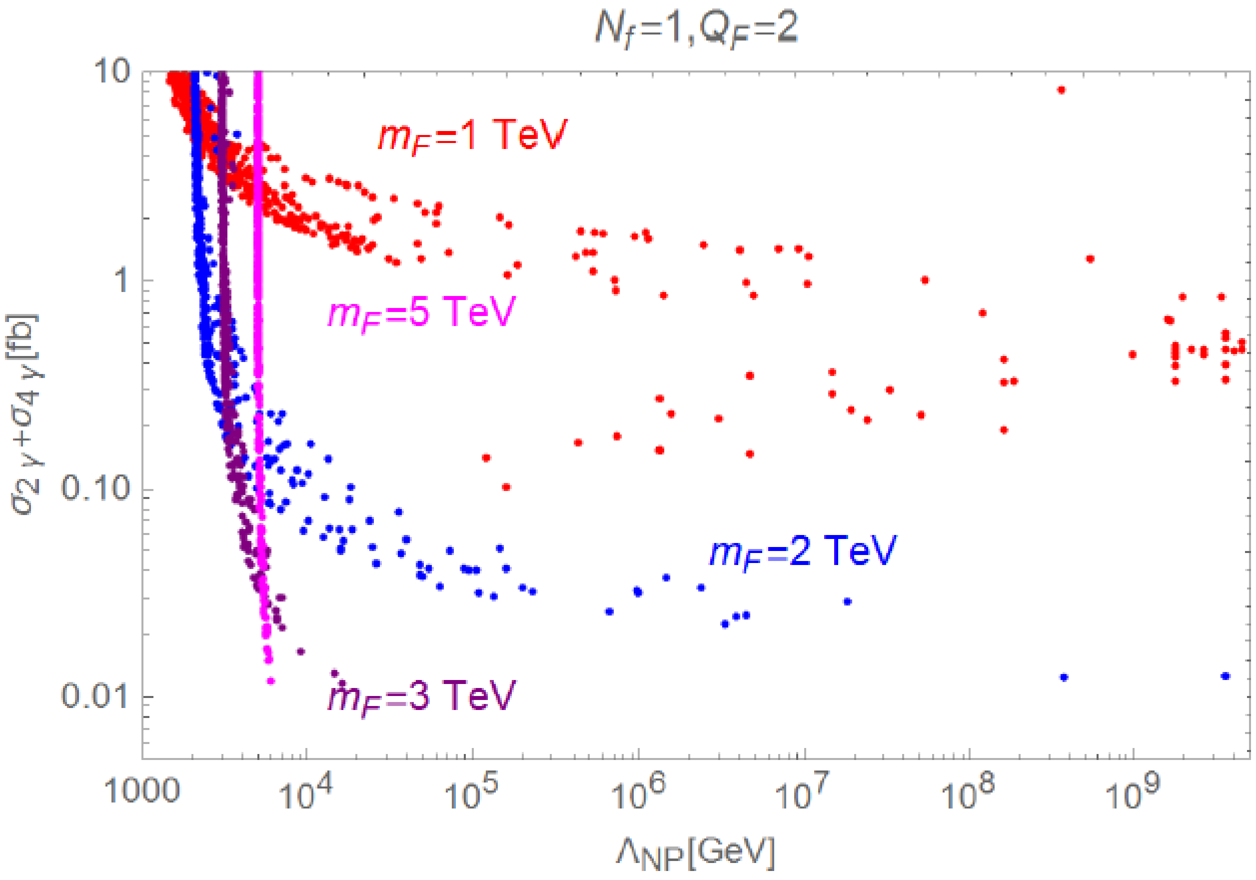
$$\sigma_{4\gamma} \approx 0.06\,\text{fb}\;\; N_f^2 Q_F^8 \left(\frac{I_{GG}(m_s/\sqrt{s})}{2000}\right)\left(\frac{\langle\sigma v\rangle_{sa}}{3\times 10^{-26}\,\text{cm}^3\text{s}^{-1}}\right)^{1/2}\left(\frac{500\,\text{GeV}}{m_\chi}\right)\left(\frac{m_s}{1\,\text{TeV}}\right)^2$$

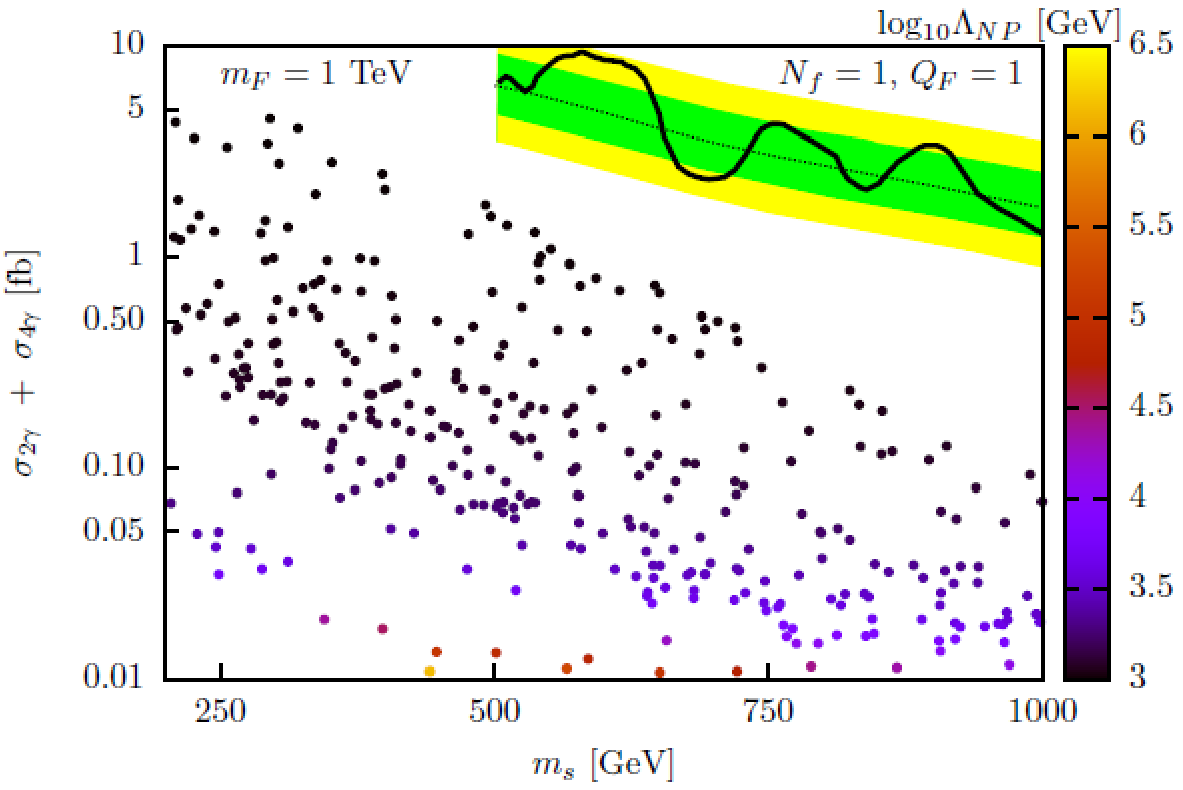
To achieve LHC limits and correct relic density $Q_F \leq 2$

$$\sigma_{4\gamma} \approx 3.4\,\text{pb}\, N_f^2 \left(\frac{I_{GG}(m_s/\sqrt{s})}{2000}\right)\left(\frac{\langle\sigma v\rangle_{aa}}{3\times 10^{-26}\,\text{cm}^3\text{s}^{-1}}\right)^{1/2}\left(\frac{100\,\text{GeV}}{m_\chi}\right)\left(\frac{m_s}{1\,\text{TeV}}\right)^2$$

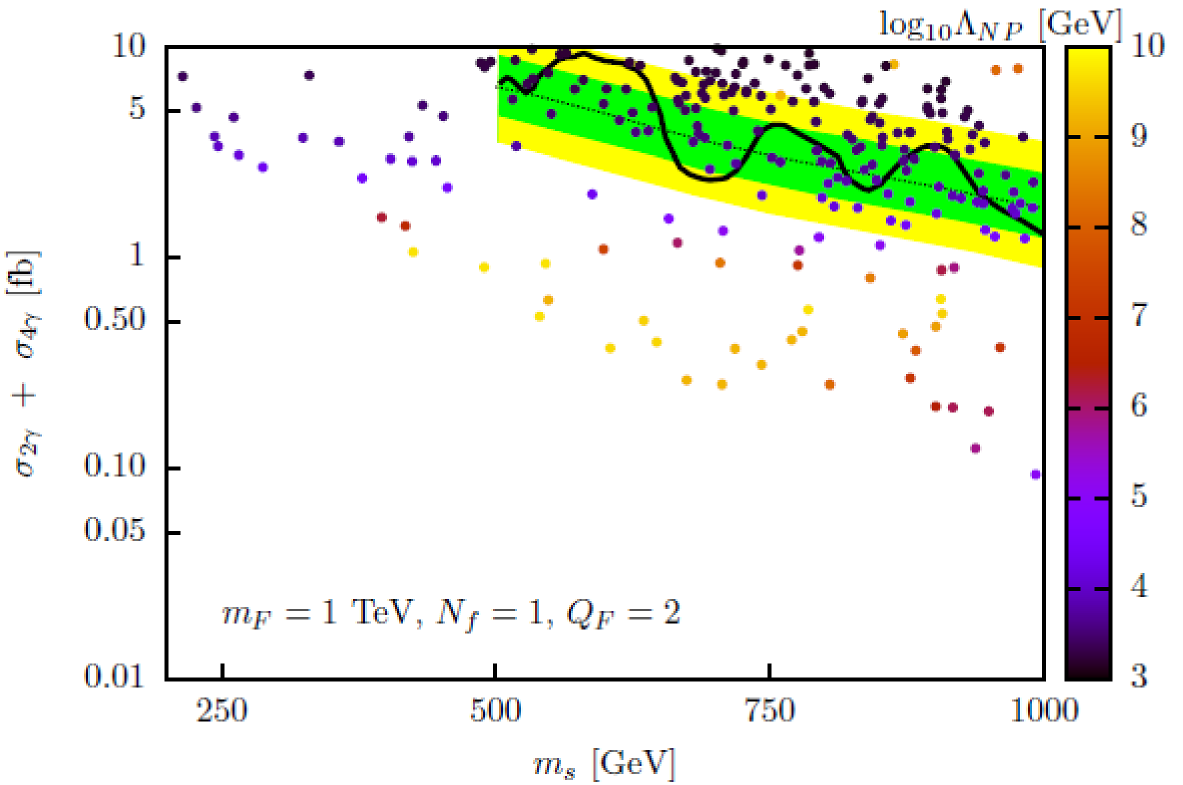
$$\sigma_{4\gamma} \approx 1.3\,\text{fb}\;\; N_f^2 Q_F^8 \left(\frac{I_{GG}(m_s/\sqrt{s})}{2000}\right)\left(\frac{\langle\sigma v\rangle_{aa}}{3\times 10^{-26}\,\text{cm}^3\text{s}^{-1}}\right)^{1/2}\left(\frac{100\,\text{GeV}}{m_\chi}\right)\left(\frac{m_s}{1\,\text{TeV}}\right)^2$$

Numerical scan



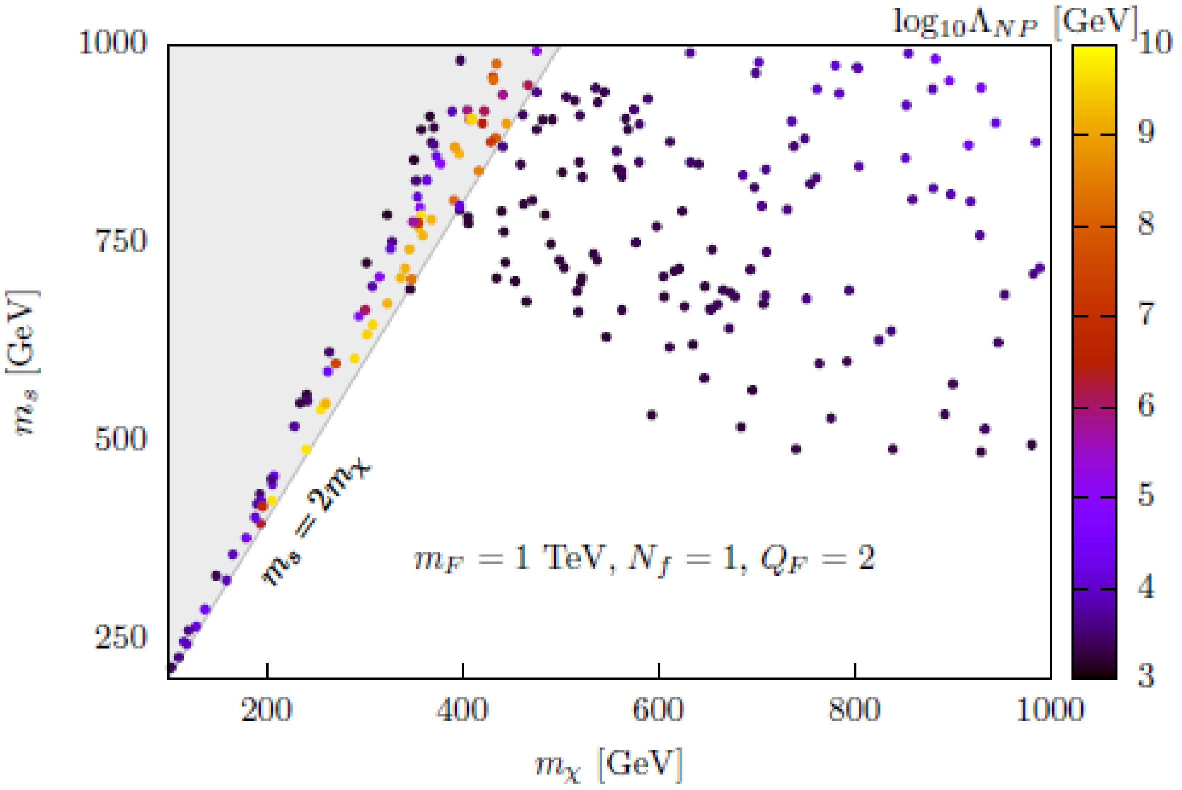


$m_F = 1$ TeV
$N_f = 1,\ Q_F = 1$
$\log_{10}\Lambda_{NP}$ [GeV]
$\sigma_{2\gamma} + \sigma_{4\gamma}$ [fb]
m_s [GeV]



$\log_{10}\Lambda_{NP}$ [GeV]
$m_F = 1$ TeV, $N_f = 1,\ Q_F = 2$
$\sigma_{2\gamma} + \sigma_{4\gamma}$ [fb]
m_s [GeV]

DM and RGE



$\log_{10}\Lambda_{NP}$ [GeV]
10
9
8
7
6
5
4
3
1000
750
500
250
m_s [GeV]
200
400
600
800
1000
m_χ [GeV]
$m_s = 2m_\chi$
$m_F = 1$ TeV, $N_f = 1$, $Q_F = 2$

Conclusions

We have considered a model with a new fermionic sector with masses dynamically generated by the spontaneous breaking of a new U(1) symmetry.

The typical signature is constituted by highly collimated photons from the decay of a light pseudo-goldstone boson.

All the observables are determined by a single coupling.
Strong requirments on the viable diphoton cross-section imposed by theoretical consitency.

Viable DM can be straightforwardly accommodated in this framework.