750 Resonance as Portal for DM Interactions

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Based on:

Y. Mambrini, G. A., A. Djouadi
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and
G.A., P. Ghosh, Y. Mambrini, M. Pierre
1603.05601

Introduction

Since December 2015 Atlas and CMS have reported and excess in diphotons.

The simplest interpretation consists into a 750 GeV, spin 0 or 2 (Landau Theorem), resonance produced through gluon fusion with a cross-section of the order of few fb.

Determination of the total decay width still uncertain, low (~ 0,1 GeV) to rather high (~45 GeV) values allowed.

Case of study: spin 0 resonance coupled with a fermionic DM.

Scenario I: Resonance going into diphotons

Case I: Interactions with only SM fermions

$$\mathcal{L}_{0+} = \frac{c_1}{\Lambda}\phi F_{\mu\nu}F^{\mu\nu} + \frac{c_2}{\Lambda}\phi W^{\mu\nu}W_{\mu\nu} + \frac{c_3}{\Lambda}\phi G^a_{\mu\nu}G^{\mu\nu}_a + g_\phi \phi\bar{\chi}\chi + m_\chi \bar{\chi}\chi$$

$$\mathcal{L}_{0-} = \frac{c_1}{\Lambda}\phi F_{\mu\nu}\tilde{F}^{\mu\nu} + \frac{c_2}{\Lambda}\phi W^{\mu\nu}\tilde{W}_{\mu\nu} + \frac{c_3}{\Lambda}\phi G^a_{\mu\nu}\tilde{G}^{\mu\nu}_a + i g_\phi \phi\bar{\chi}\gamma^5\chi + m_\chi \bar{\chi}\chi$$

$$c_{\gamma\gamma} = c_1 \cos^2\theta_W + c_2 \sin^2\theta_W\,,\ \ c_{ZZ} = c_1 \sin^2\theta_W + c_2\cos^2\theta_W\,, c_{WW} = 2c_2,\ c_{gg} = c_3$$

Large width potentially achieved through invisible channel

Case II: Add Interactions with SM fermions

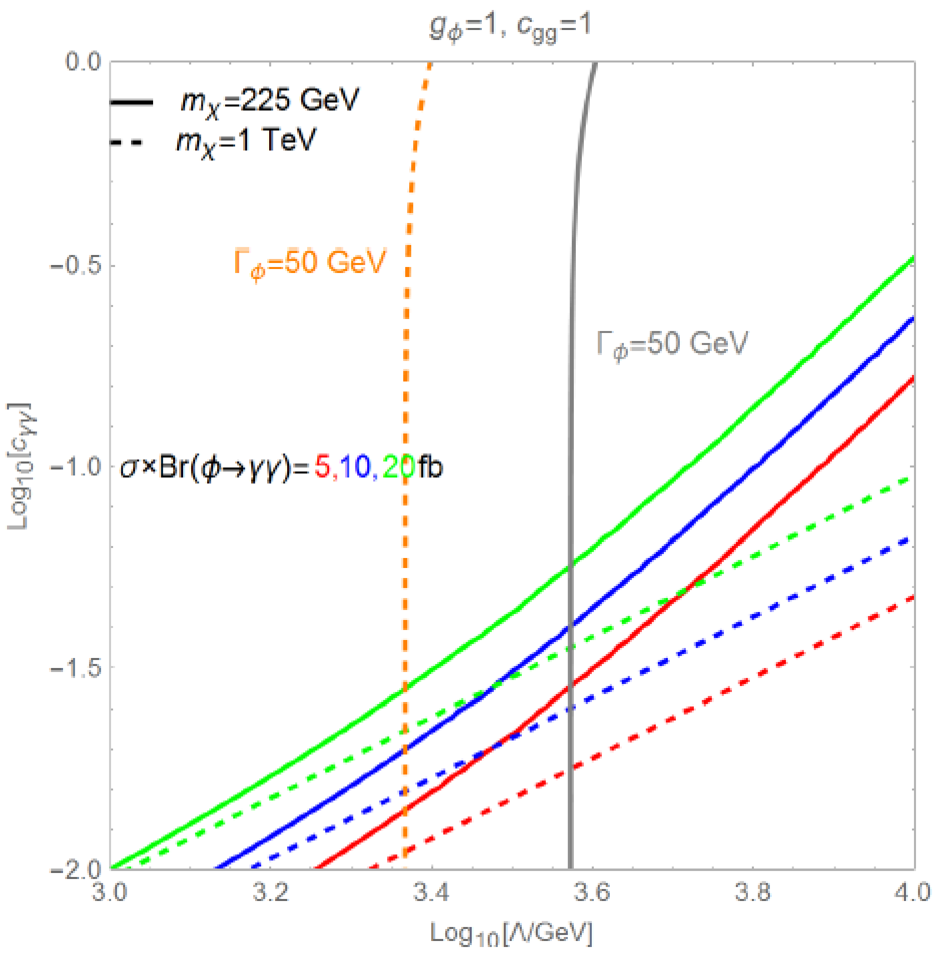
$$\mathcal{L}_1 = \mathcal{L}_{0+} + c_f \frac{m_f}{\Lambda}\phi\bar{f}f$$

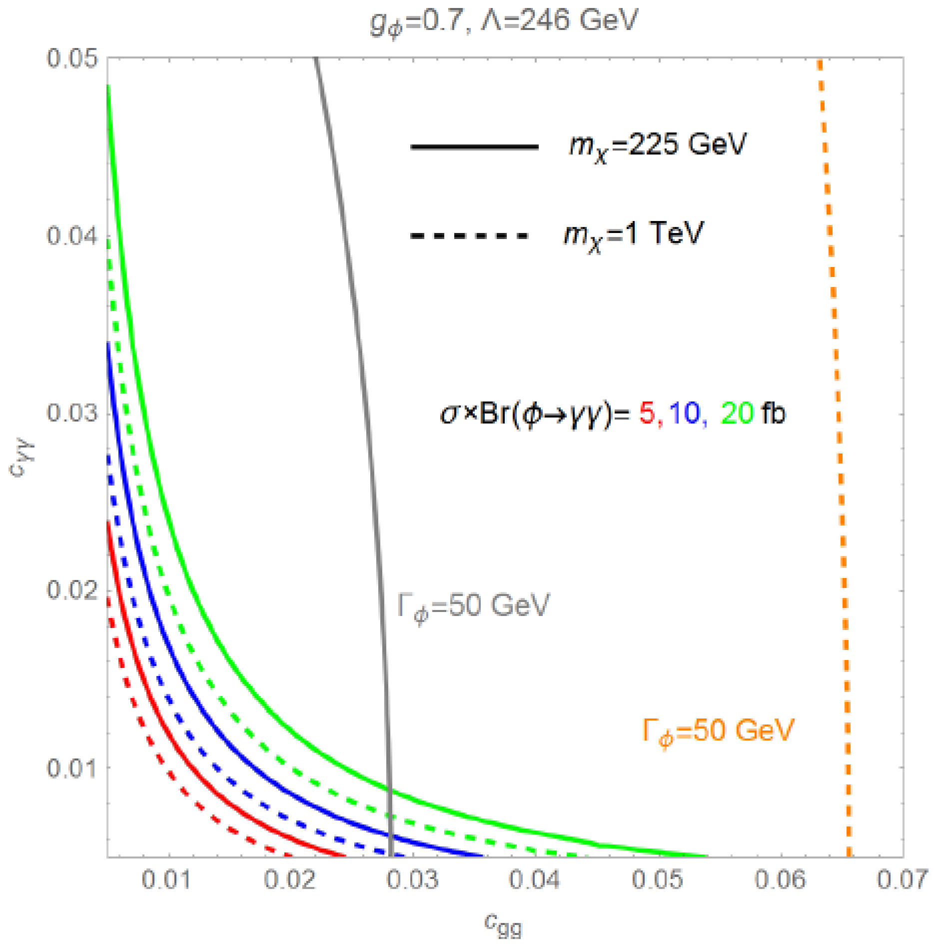
Sizable contribution to the width also from tt channel.

$$\mathcal{L}_1 = \mathcal{L}_{0-} + i c_f \frac{m_f}{\Lambda}\phi\bar{f}\gamma_5 f$$

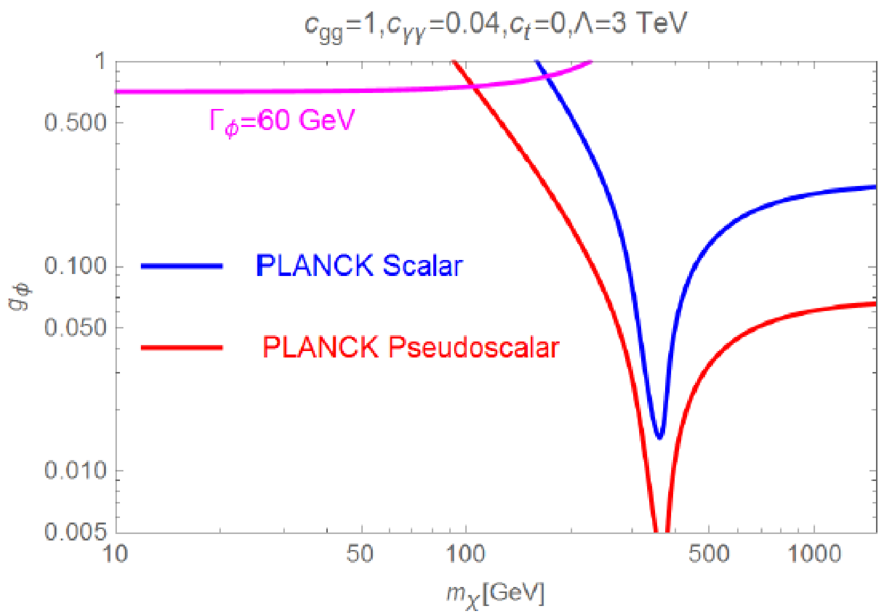
Benchmark 1 $\Lambda = 3\ \text{TeV}, \quad c_t = 0,\ c_{\gamma\gamma} \approx 0.04,\ \ c_{gg} \approx 1$

Benchmark 2 $\Lambda = 246\ \text{GeV},\ c_t = 1,\ c_{\gamma\gamma} \approx 0.01,\ c_{gg} \approx 0.01$





DM Relic Density



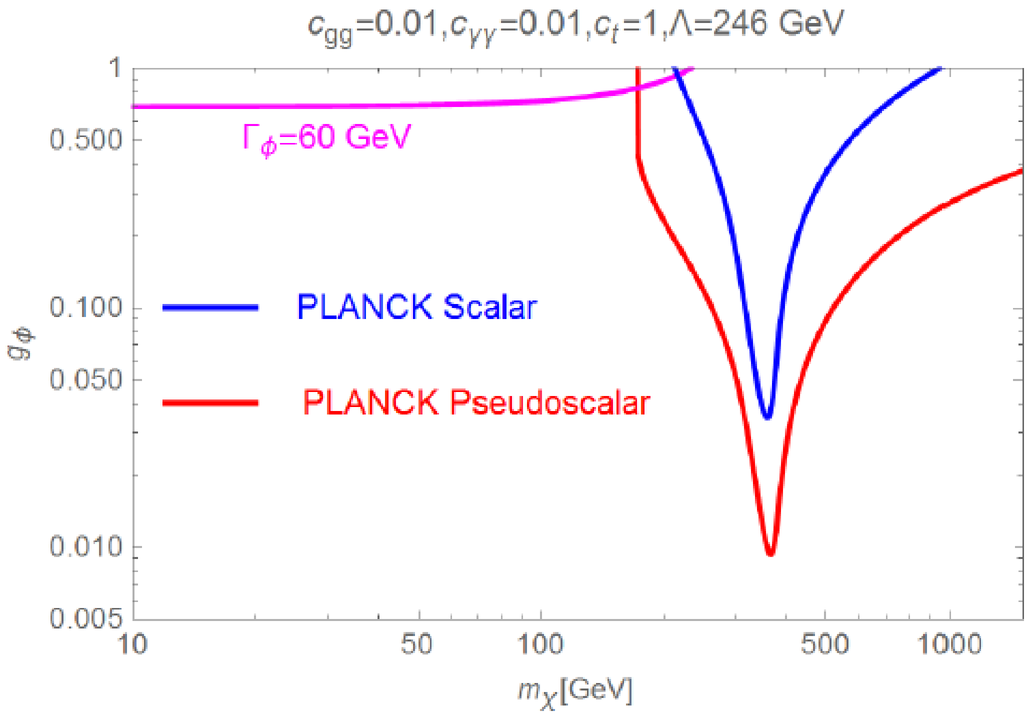
$$\langle\sigma v\rangle_{gg}^{0+} \simeq \frac{128 c_{gg}^2 g_\phi^2 v^2}{\pi\Lambda^2}\left(\frac{m_\chi}{M_\phi}\right)^4 \qquad \langle\sigma v\rangle_{gg}^{0-} \simeq \frac{256 c_{gg}^2 g_\phi^2}{\pi\Lambda^2}\left(\frac{m_\chi}{M_\phi}\right)^4 \qquad m_\chi \ll M_\phi$$

$$\langle\sigma v\rangle_{gg}^{0+} \simeq 8 g_\phi^2 c_{gg}^2 v^2/(\pi\Lambda^2) \qquad \langle\sigma v\rangle_{gg}^{0-} \simeq \frac{16 g_\phi^2 c_{gg}^2}{\pi\Lambda^2} \qquad m_\chi \gg M_\phi$$

$$\langle\sigma v\rangle_{\bar{t}t}^{0+} \approx \frac{g_\phi^2 m_t^2 m_\chi^2 v^2}{4\pi v_h^2 M_\phi^4}\beta_t^3 \qquad \langle\sigma v\rangle_{\bar{t}t}^{0-} \approx \frac{g_\phi^2 m_t^2 m_\chi^2}{\pi v_h^2 M_\phi^4}\beta_t$$

$$\langle\sigma v\rangle_{\bar{t}t}^{+} \approx \frac{g_\phi^2 m_t^2 v^2}{64\pi v_h^2 m_\chi^2} \qquad \langle\sigma v\rangle_{\bar{t}t}^{-} \approx \frac{g_\phi^2 m_t^2}{16\pi v_h^2 m_\chi^2}$$

$$\beta_t = \sqrt{1 - m_t^2/m_\chi^2}$$



DM Constraints

Direct Detection (scalar resonance only)

$$\sigma_{\chi p}^{\rm SI} = \frac{4}{\pi}\left(\frac{m_P m_\chi}{m_P + m_\chi}\right)^2 \frac{g_\phi^2}{M_\phi^2} g_{\phi NN}^2$$

$$g_{\phi NN} = \sum_{f=u,d,s} c_f \frac{m_N}{\Lambda} f_{Tf}^N + \frac{2}{27} f_{TG}^N \left(\sum_{f=c,b,t} c_f \frac{m_N}{\Lambda} - \frac{12\pi c_{gg}}{\alpha_s}\frac{m_N}{\Lambda}\right)$$

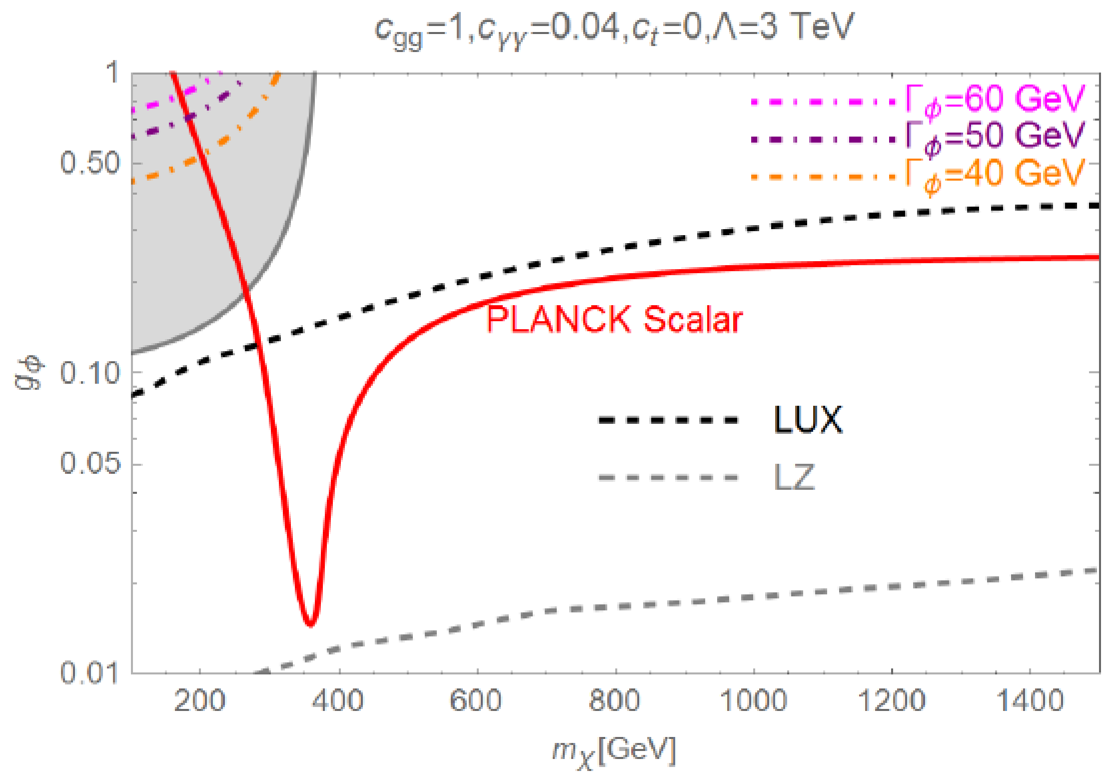
Indirect Detection (pseudo-scalar resonance only)

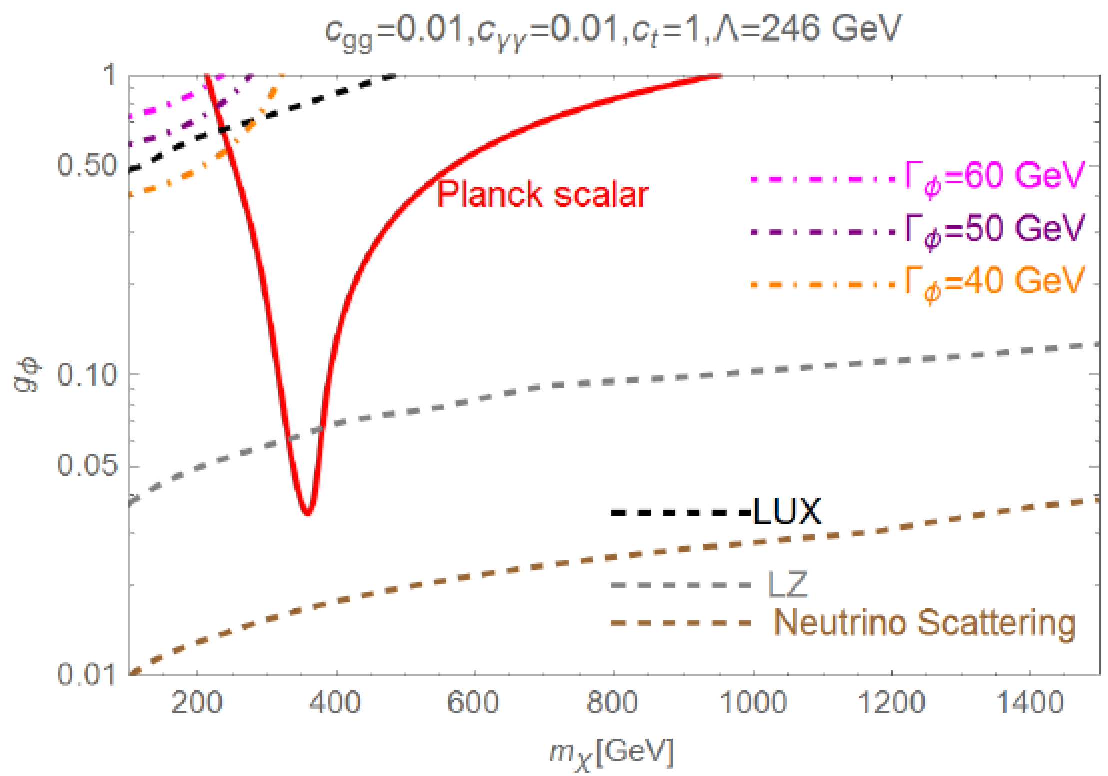
Limit on $\langle \sigma v \rangle_{\gamma\gamma}$ from gamma-ray lines

Limit on $\langle \sigma v \rangle_{ZZ,gg,..}$ from gamma-ray continuum

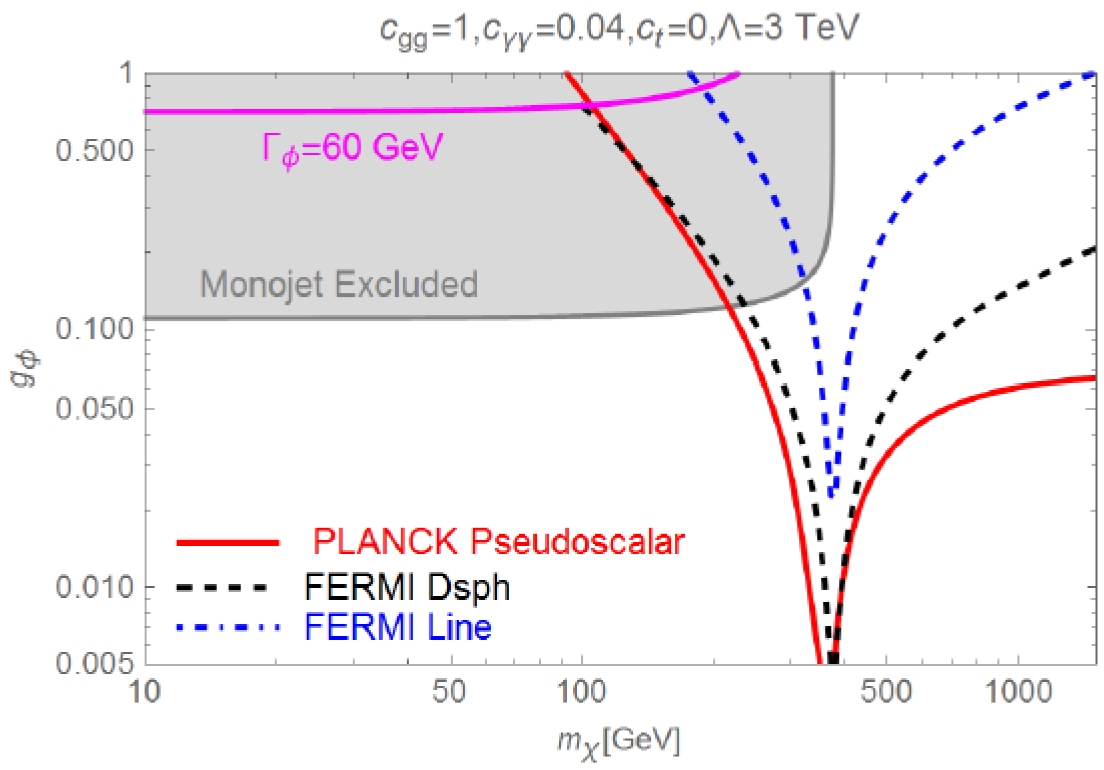
Limits from monojets

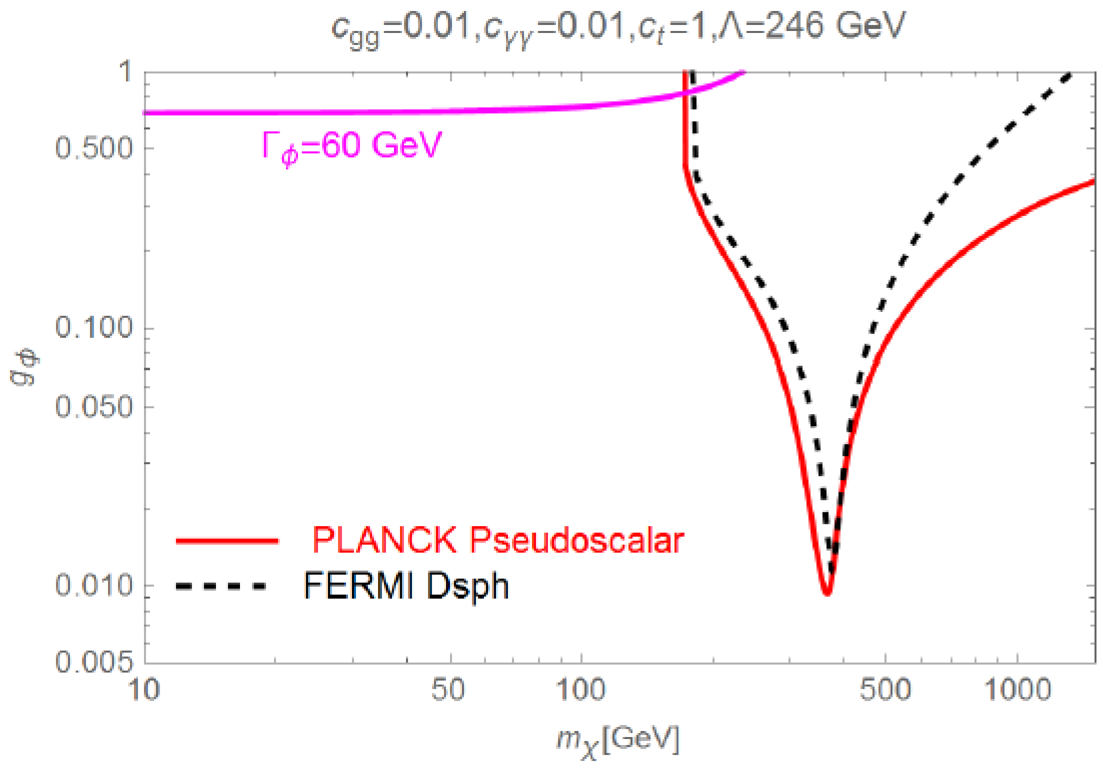
DM: Scalar Resonance



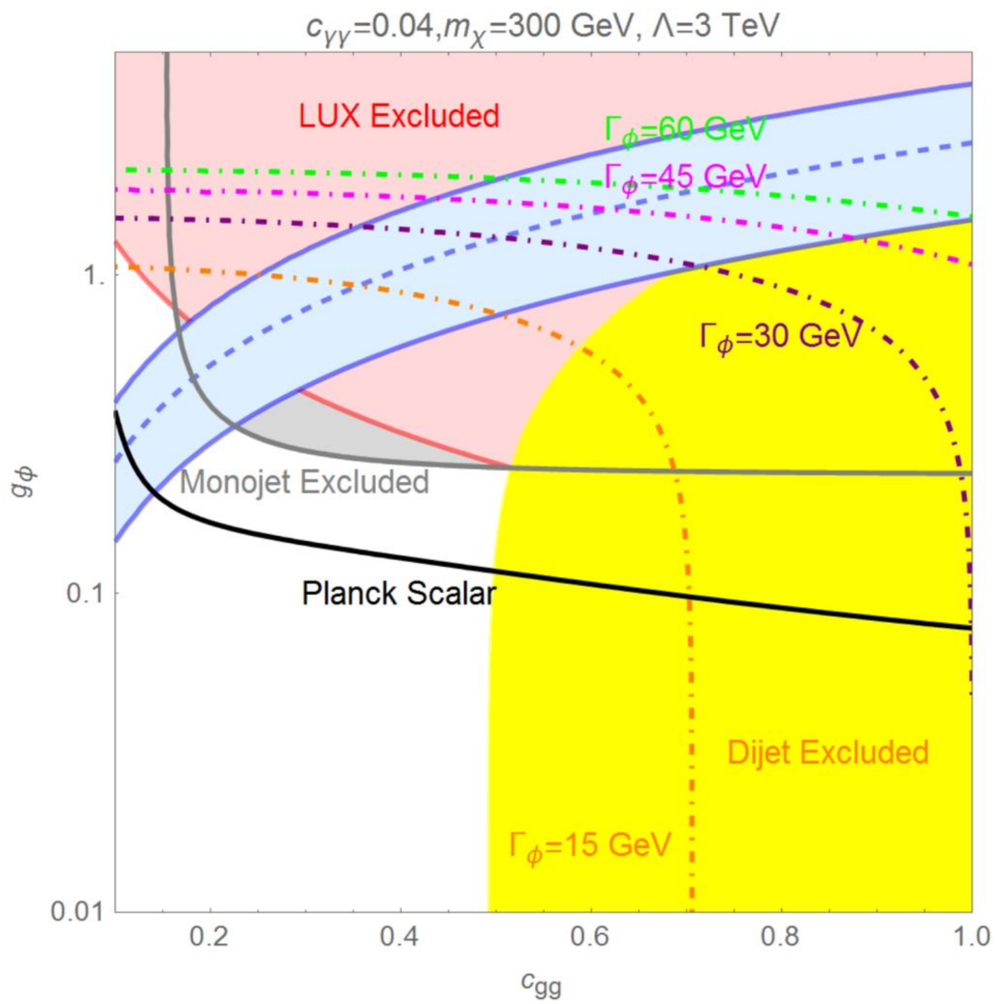


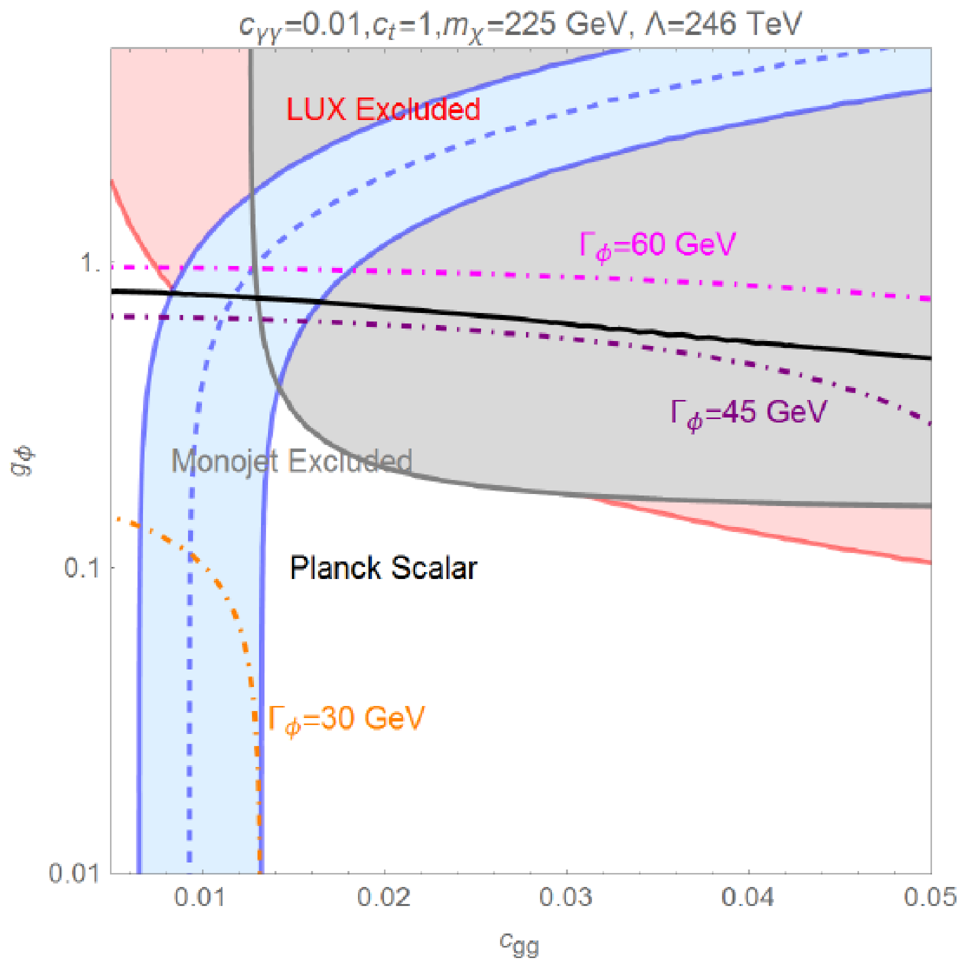
DM: Pseudo-scalar Resonance





Summary Scenario I

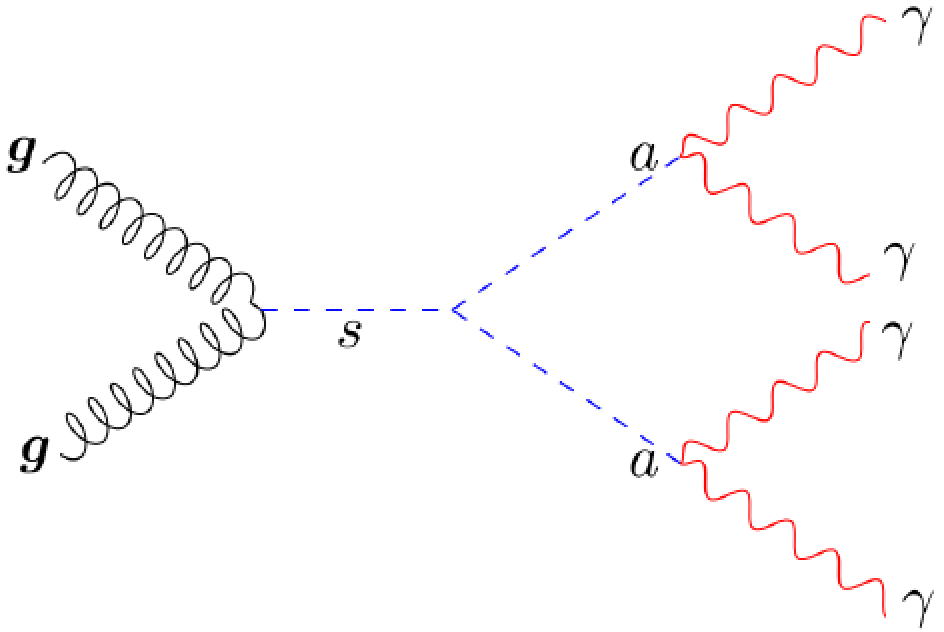




A viable DM can be compatible with a diphoton signal but only for a small (invisible) width. A large width is obtained by considering further decay channels, e.g. tt.

Scenario II: Collimated photons

$$\Phi = \frac{1}{\sqrt{2}}(v_\Phi + s + ia)$$



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

Possible to have large width from s->aa without suppressing the production cross-section.

Order unity

$$-\mathcal{L}_0 = \frac{c_{BB}}{\Lambda}\Phi B^{\mu\nu}B_{\mu\nu} + \frac{c_{WW}}{\Lambda}\Phi W_i^{\mu\nu}W^i_{\mu\nu} + \frac{c_{GG}}{\Lambda}\Phi G_\alpha^{\mu\nu}G^\alpha_{\mu\nu} + \frac{ic_{BB}}{\Lambda}\Phi B^{\mu\nu}\tilde{B}_{\mu\nu} + \frac{ic_{WW}}{\Lambda}\Phi W_i^{\mu\nu}\tilde{W}^i_{\mu\nu} + \frac{ic_{GG}}{\Lambda}\Phi G_\alpha^{\mu\nu}\tilde{G}^\alpha_{\mu\nu} + \text{h.c.}$$

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

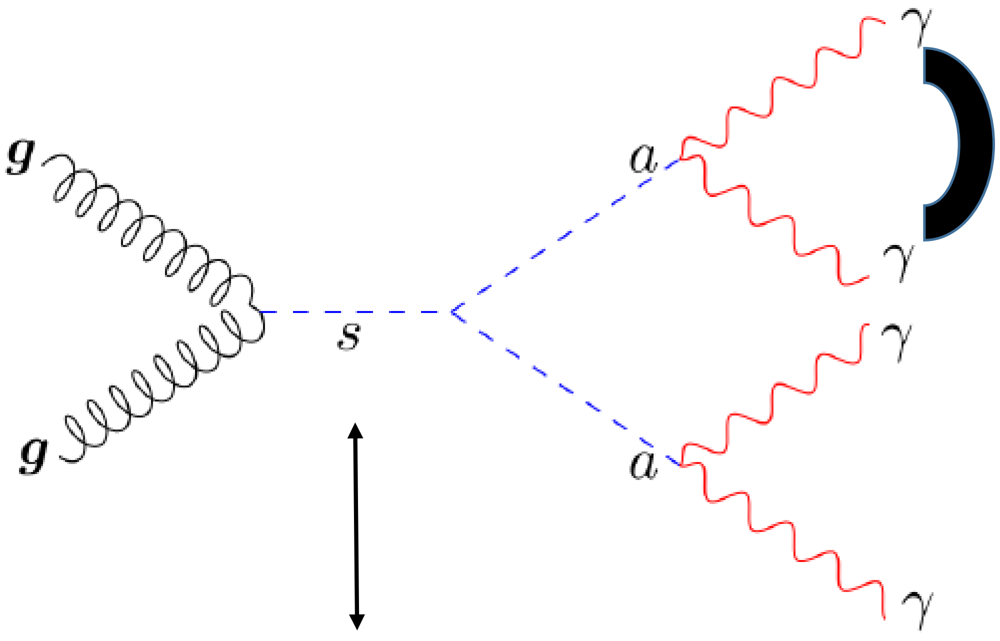
$$\Phi = \frac{1}{\sqrt{2}}(v_\Phi + s + ia)$$ → Scalar resonance part of a complex field

$$\Lambda = v_\Phi$$

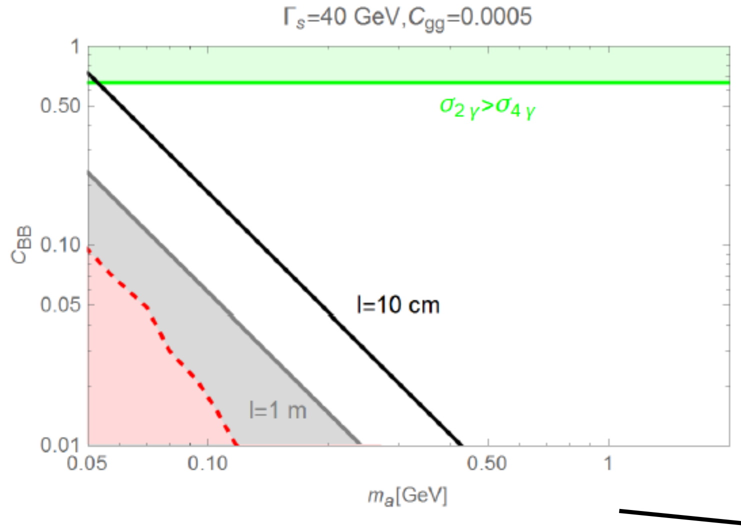
$$m_\chi = \sqrt{2}g_\chi v_\Phi$$

→

$$-\mathcal{L} \supset \frac{\sqrt{\lambda_\Phi}C_{GG}}{m_s}sG^\alpha_{\mu\nu}G^{\mu\nu}_\alpha + \frac{\sqrt{\lambda_\Phi}C_{GG}}{m_s}aG^\alpha_{\mu\nu}\tilde{G}^{\mu\nu}_\alpha$$
$$+\frac{\sqrt{\lambda_\Phi}C_{BB}c_W^2}{m_s}sF^\alpha_{\mu\nu}F^{\mu\nu}_\alpha + \frac{\sqrt{\lambda_\Phi}C_{BB}c_W^2}{m_s}aF^\alpha_{\mu\nu}\tilde{F}^{\mu\nu}_\alpha$$
$$+\sqrt{\frac{\lambda_\Phi}{2}}m_s s a^2 + \frac{m_s^2}{2}s^2 + \frac{m_a^2}{2}a^2 + \sqrt{\frac{\lambda_\Phi}{2}}m_s s^3 + \frac{\lambda_\Phi}{4}(s^2+a^2)^2$$

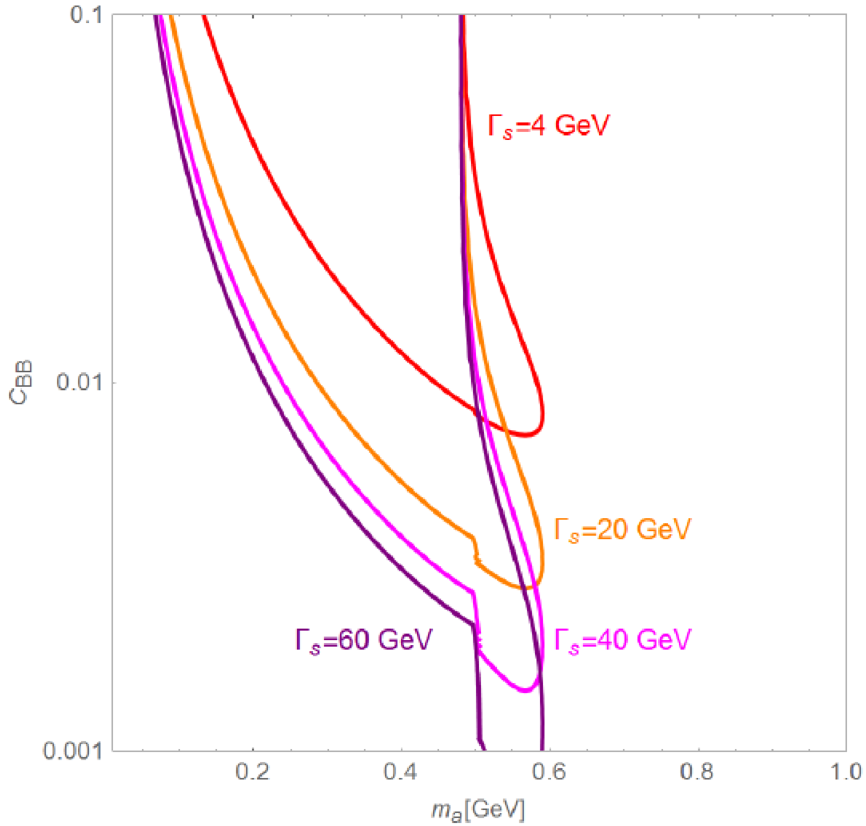


$\Delta\phi \sim \frac{2}{\gamma}$ < Calorimeter Resolution



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

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



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

$$\sigma_{gg\to 4\gamma} \approx 5\,\text{fb} \frac{(\Gamma_s/m_s)}{0.05} \frac{1}{(1+32C_{GG}^2)^2} \left(\frac{C_{BB}}{0.005}\right)^4 \left(\frac{0.005}{C_{GG}}\right)^2$$

$m_{3\pi^0} \leq m_a \leq 2\,\text{GeV}$

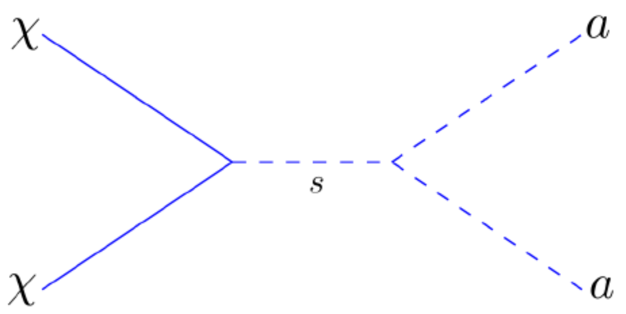
$$\sigma_{gg\to 4\gamma} \approx \frac{4\pi^2}{s} I_{GG} \frac{C_{GG}^2}{(1+32C_{GG}^2)^2} \frac{\Gamma_s}{m_s} \simeq 16\,\text{fb} \frac{(\Gamma_s/m_s)}{0.05} \frac{\left(\frac{C_{GG}}{10^{-3}}\right)^2}{(1+32C_{GG}^2)^2}$$

$m_a \lesssim m_{3\pi^0}$

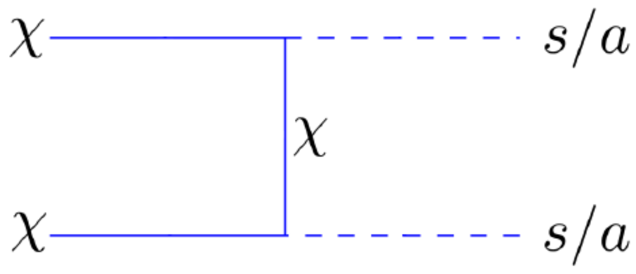
$$\sigma_{\chi p}^{\text{SI}} \approx 6.7 \times 10^{-48}\,\text{cm}^2 \left(\frac{\Gamma_s/m_s}{0.05}\right)^2 \frac{1}{(1+32C_{GG}^2)^2} \left(\frac{750\,\text{GeV}}{m_s}\right)^8 \left(\frac{m_\chi}{100\,\text{GeV}}\right)^2 \left(\frac{C_{GG}}{10^{-3}}\right)^2$$

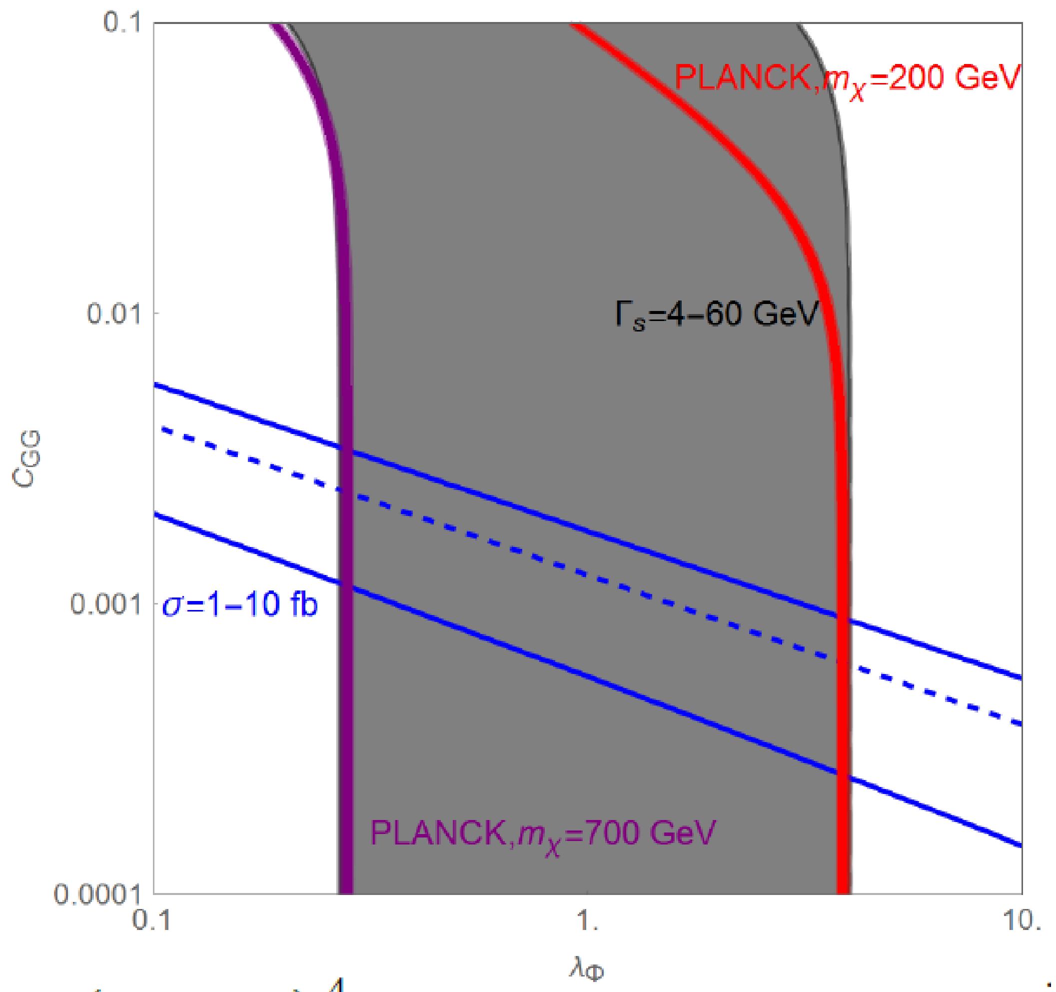
Scattering cross-section suppressed

$g_\chi \propto \frac{m_\chi}{m_s}$ Suppressed by monojet cross-section



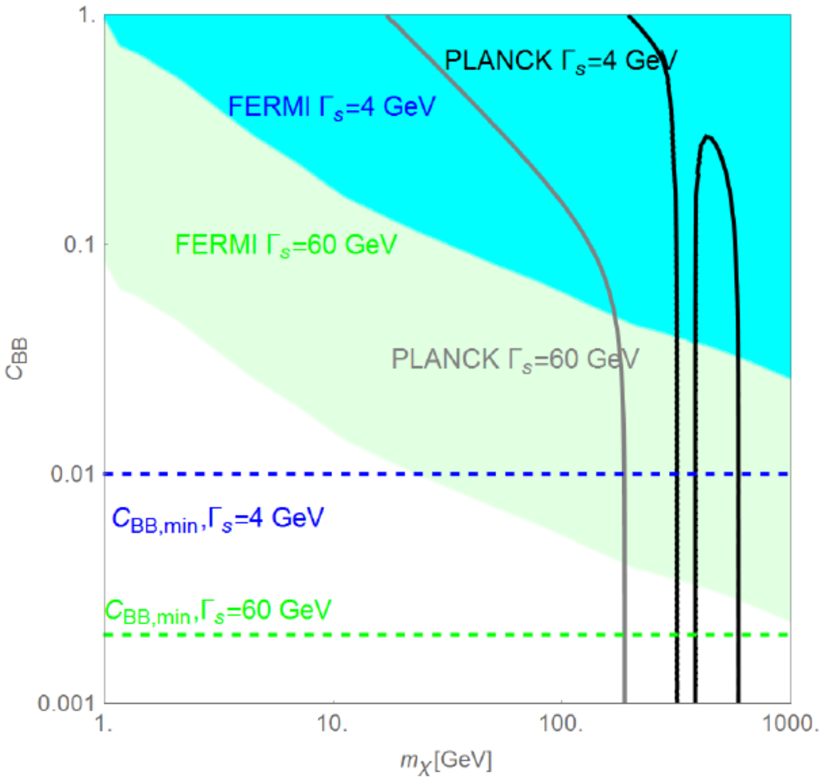
New annhilation channels



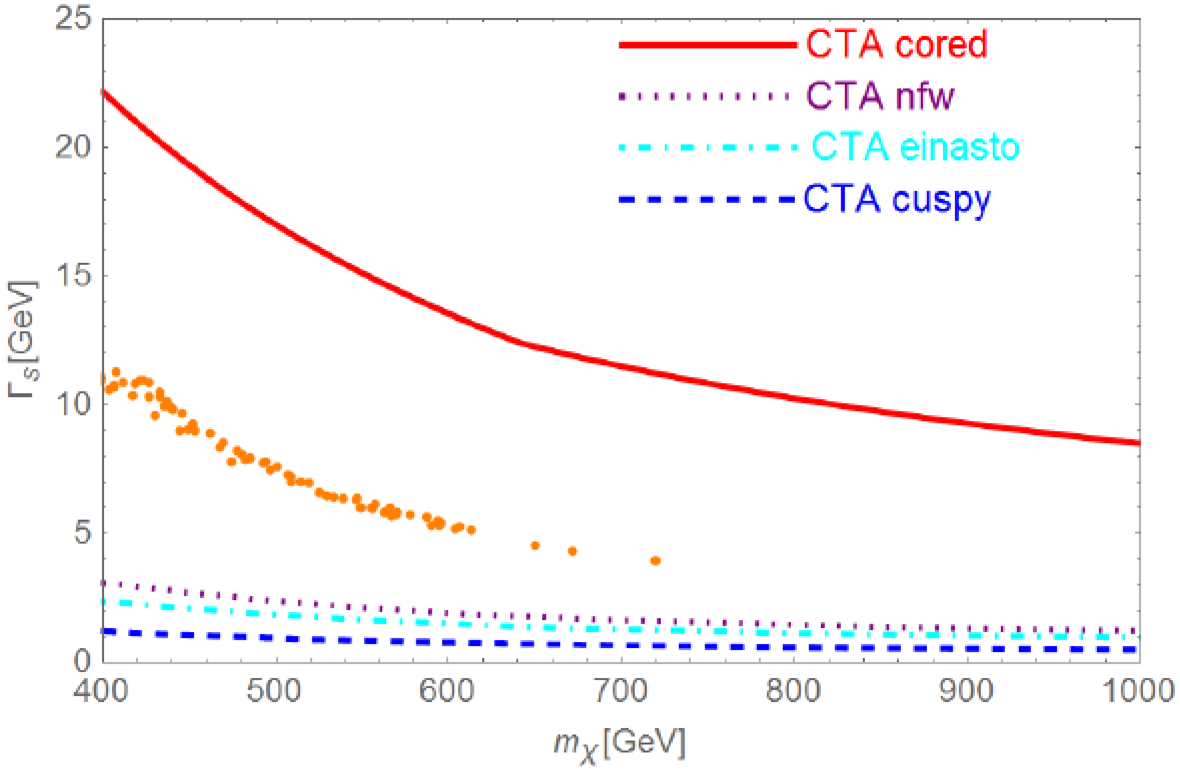


$$\langle \sigma v \rangle_{sa} \simeq \frac{\lambda_\Phi^2}{8\pi} \frac{m_\chi^2}{m_s^4} \simeq \frac{3 \times 10^{-25}\ \text{cm}^3\text{s}^{-1}}{(1+32C_{GG}^2)^2} \left(\frac{\Gamma_s/m_s}{0.05}\right)^2 \left(\frac{m_\chi}{400\ \text{GeV}}\right)^2 \left(\frac{750\ \text{GeV}}{m_s}\right)^4$$

Dark Matter Indirect Detection

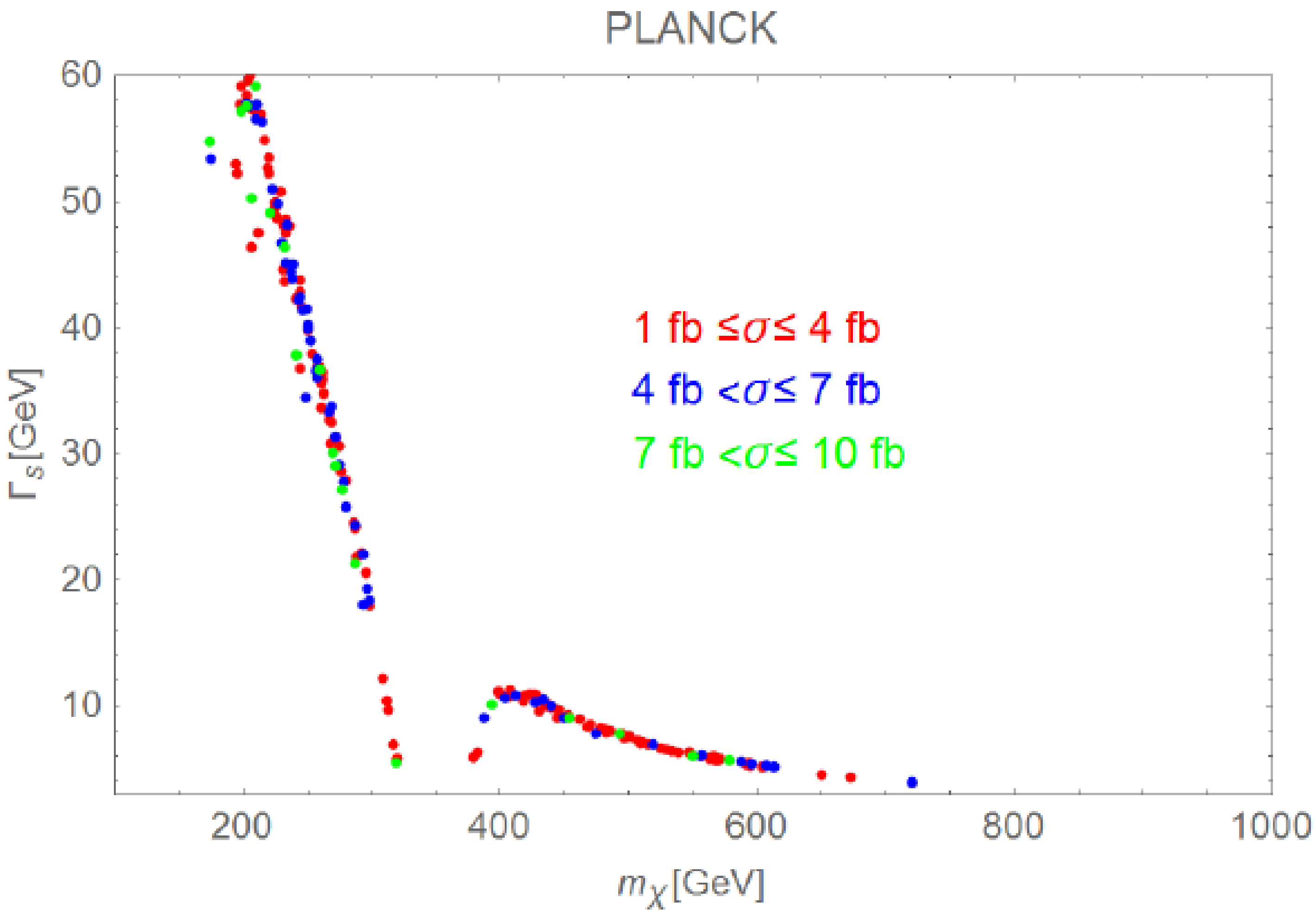


Limits from gamma-lines



At high DM masses annihilation produces wide gamma-ray boxes.
Viable parameter space will be completely probed by CTA.

Summary Scenario II

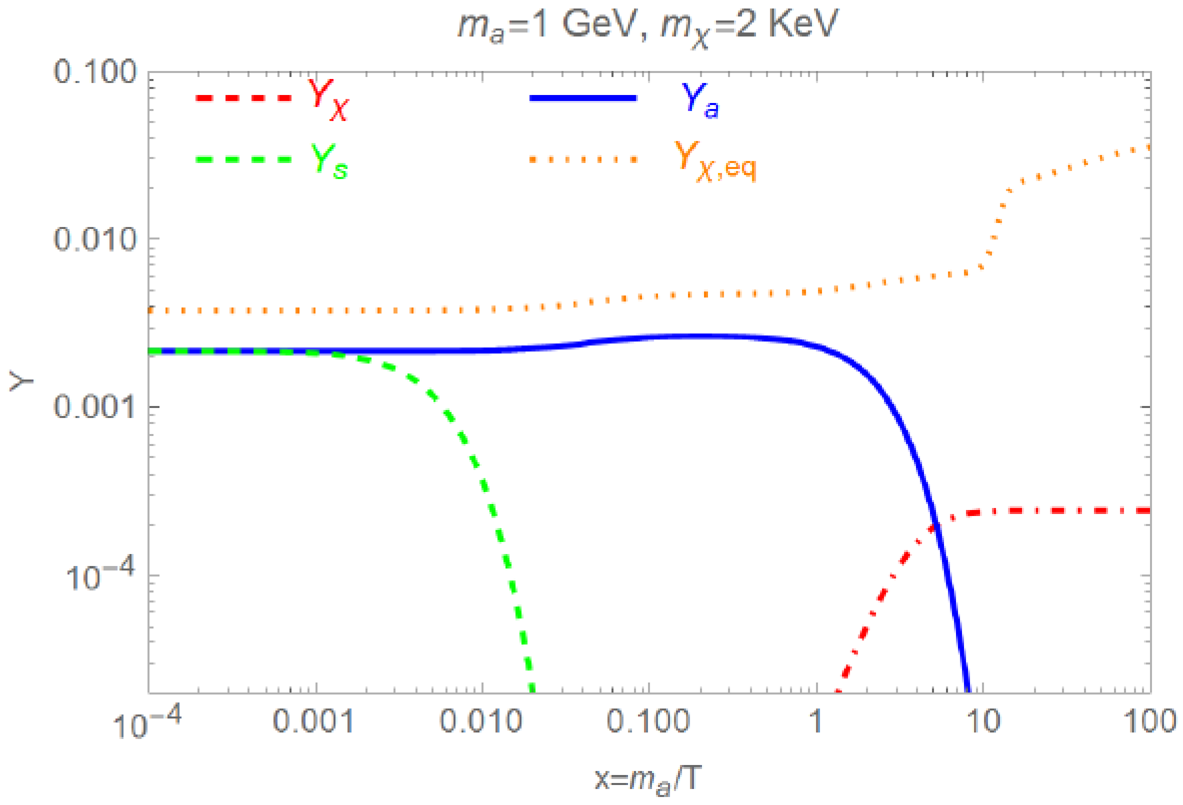


The DM relic density is compatible with a viable diphoton cross-section and a possibly large decay width of the scalar resonance.

Very Light Dark Matter

A very light DM is not capable of be in thermal equilibrium in the Early Universe.

$$\Omega_{FI}h^2 = \frac{1.09\times 10^{27} g_a}{g_{*,S}(T=m_a)^{3/2}}\frac{m_\chi \Gamma(a\to\chi\chi)}{m_a^2},$$
$$\approx 0.3\frac{1}{(1+32C_{GG}^2)}\left(\frac{\Gamma_s/m_s}{0.01}\right)\left(\frac{m_\chi}{1\,\mathrm{keV}}\right)^3 \left(\frac{750\,\mathrm{GeV}}{m_s}\right)^2\left(\frac{1\,\mathrm{GeV}}{m_a}\right)$$



Conclusions

We have considered the possibility that the 750 GeV resonance is a portal for Dark Matter interactions.

The minimal realization, i.e (pseudo)scalar resonance + fermionic DM is strongly constrained, in particular large decay widths are disfavored.

The viable parameter space is enlarged by adding to the spectrum of new particles a light pseudoscalar, such that the LHC signal consists on collimated photons from its decay.