Dark Matter Models for the Galactic Center Gamma-Ray Excess

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With **Dan Hooper** & **Sam Witte**

TeVPA, 7th of August 2017

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The Galactic Center Gamma-Ray Excess

Observational status:

see yesterday's Mini-workshop!

The Galactic Centre Gamma-Ray Excess is very well established (Fermi-LAT 1704.03910).

However, at this point in time, there is no clear resolution to the question of the origin of the Galactic Center excess.

Precise answers may come in the following years after more Dwarf analysis, or from future experiments targeting millisecond pulsars.

Dark Matter interpretation:

This work

$$\chi\chi \to b\bar{b}, f\bar{f}$$

1411.2592 Agrawal, Batell, Fox, Harnik

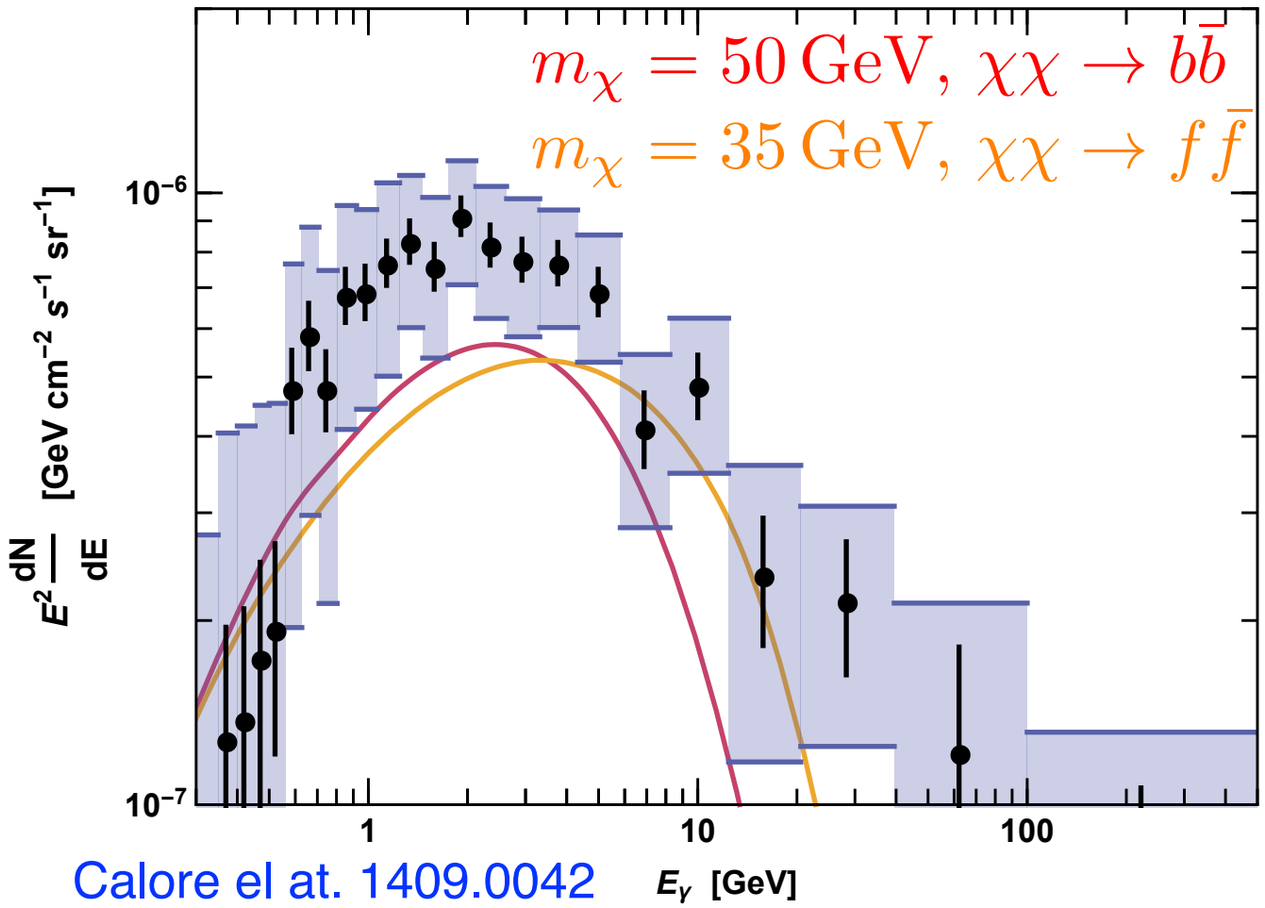
$$\chi\chi \to ZZ, W^+W^-, hh$$

1706.02336 Arcadi, Queiroz, Siqueira

$$\chi\chi \to \chi + h/Z$$

1405.0272 Martin, Shelton, Unwin

$$\chi\chi \to V + V \to 4f$$



Calore el at. 1409.0042

Simplified model approach

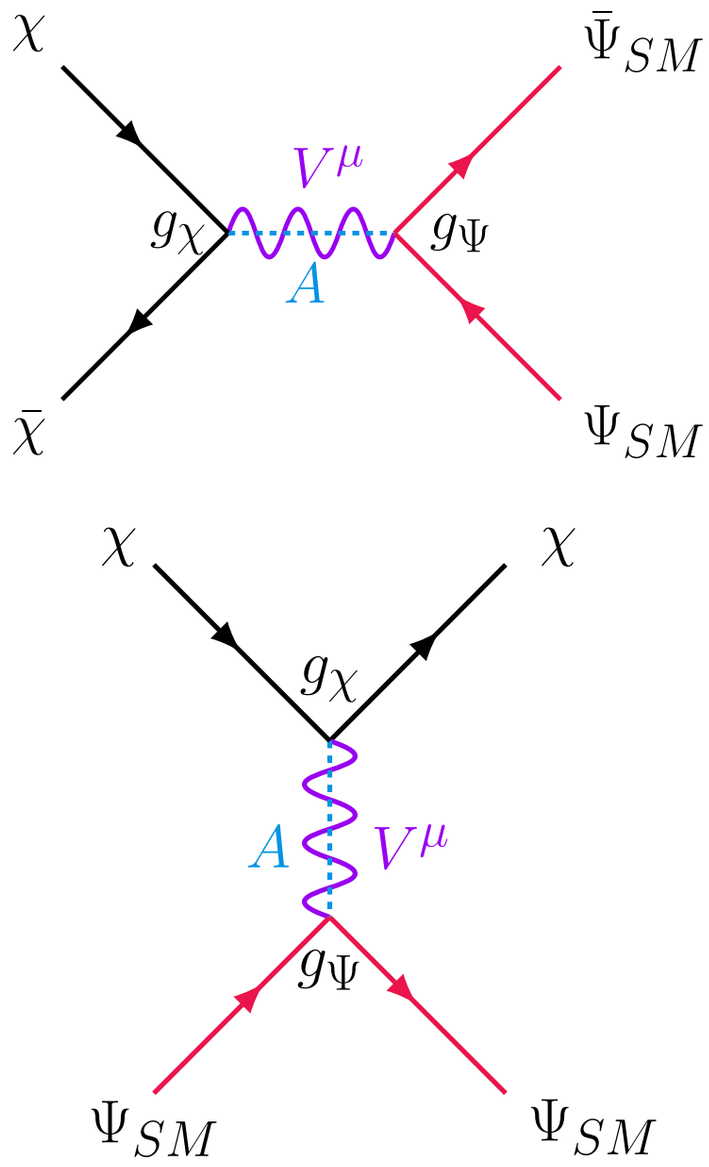
Simplified models generically assess the viability of a dark matter model interpretation of the GC excess and identify the parameter space that needs to be probed by future searches.

Viable models after Berlin, Hooper, McDermott 1404.0022

Dark Matter	***Mediator***	***Interactions***	**Direct Detection**	
Dirac Fermion, χ	Spin-0	$\bar{\chi}\gamma^5\chi,\ \bar{f}f$	$\sigma_{\rm SI} \propto (q/2m_\chi)^2$	**s-wave!**
Majorana Fermion, χ	Spin-0	$\bar{\chi}\gamma^5\chi,\ \bar{f}f$	$\sigma_{\rm SI} \propto (q/2m_\chi)^2$	
Dirac Fermion, χ	Spin-0	$\bar{\chi}\gamma^5\chi,\ \bar{f}\gamma^5 f$	$\sigma_{\rm SD} \propto (q^2/4m_n m_\chi)^2$	**s-channel scalar mediator A**
Majorana Fermion, χ	Spin-0	$\bar{\chi}\gamma^5\chi,\ \bar{f}\gamma^5 f$	$\sigma_{\rm SD} \propto (q^2/4m_n m_\chi)^2$	
Complex Scalar, ϕ	Spin-0	$\phi^\dagger\phi,\ \bar{f}\gamma^5 f$	$\sigma_{\rm SD} \propto (q/2m_n)^2$	
Real Scalar, ϕ	Spin-0	$\phi^2,\ \bar{f}\gamma^5 f$	$\sigma_{\rm SD} \propto (q/2m_n)^2$	
Complex Vector, X	Spin-0	$X^\dagger_\mu X^\mu,\ \bar{f}\gamma^5 f$	$\sigma_{\rm SD} \propto (q/2m_n)^2$	
Real Vector, X	Spin-0	$X_\mu X^\mu,\ \bar{f}\gamma^5 f$	$\sigma_{\rm SD} \propto (q/2m_n)^2$	
Dirac Fermion, χ	Spin-1	$\bar{\chi}\gamma^\mu\chi,\ \bar{b}\gamma_\mu b$	$\sigma_{\rm SI} \sim$ loop (vector)	**s-channel vector mediator V^μ**
Dirac Fermion, χ	Spin-1	$\bar{\chi}\gamma^\mu\chi,\ \bar{f}\gamma_\mu\gamma^5 f$	$\sigma_{\rm SD} \propto (q/2m_n)^2$ or $(q/2m_\chi)^2$	
Dirac Fermion, χ	Spin-1	$\bar{\chi}\gamma^\mu\gamma^5\chi,\ \bar{f}\gamma_\mu\gamma^5 f$	$\sigma_{\rm SD} \sim 1$	
Majorana Fermion, χ	Spin-1	$\bar{\chi}\gamma^\mu\gamma^5\chi,\ \bar{f}\gamma_\mu\gamma^5 f$	$\sigma_{\rm SD} \sim 1$	
Dirac Fermion, χ	Spin-0 (t-ch.)	$\bar{\chi}(1\pm\gamma^5)b$	$\sigma_{\rm SI} \propto$ loop (vector)	**t-channel to the b**
Dirac Fermion, χ	Spin-1 (t-ch.)	$\bar{\chi}\gamma^\mu(1\pm\gamma^5)b$	$\sigma_{\rm SI} \propto$ loop (vector)	
Complex Vector, X	Spin-1/2 (t-ch.)	$X^\dagger_\mu\gamma^\mu(1\pm\gamma^5)b$	$\sigma_{\rm SI} \propto$ loop (vector)	
Real Vector, X	Spin-1/2 (t-ch.)	$X_\mu\gamma^\mu(1\pm\gamma^5)b$	$\sigma_{\rm SI} \propto$ loop (vector)	

Constraints

Annihilation



Require the right cross section for the GC

$$\langle \sigma v \rangle \leq 2.2 \times 10^{-26}\,\mathrm{cm}^3/\mathrm{s}$$

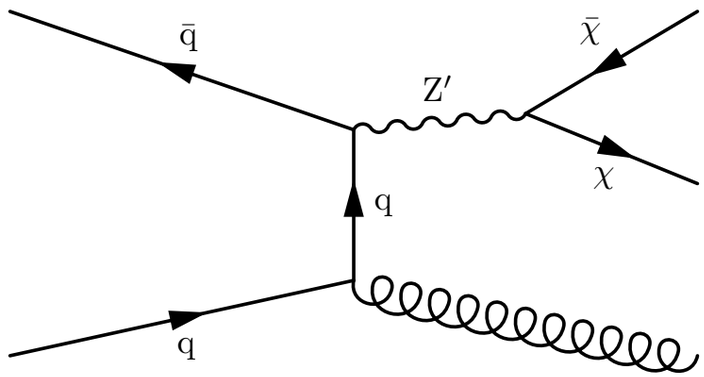
$$\langle \sigma v \rangle \geq 6 \times 10^{-27}\,\mathrm{cm}^3/\mathrm{s}$$

$$g_\chi \times g_{\mathrm{SM}} = \mathrm{constant}$$

Direct Detection

$$g_\chi \times g_{\mathrm{SM}} < \mathrm{constant}_{DD}$$

Collider Searches



$$g_{\mathrm{SM}} < \mathrm{constant}_{\mathrm{Collider}}$$

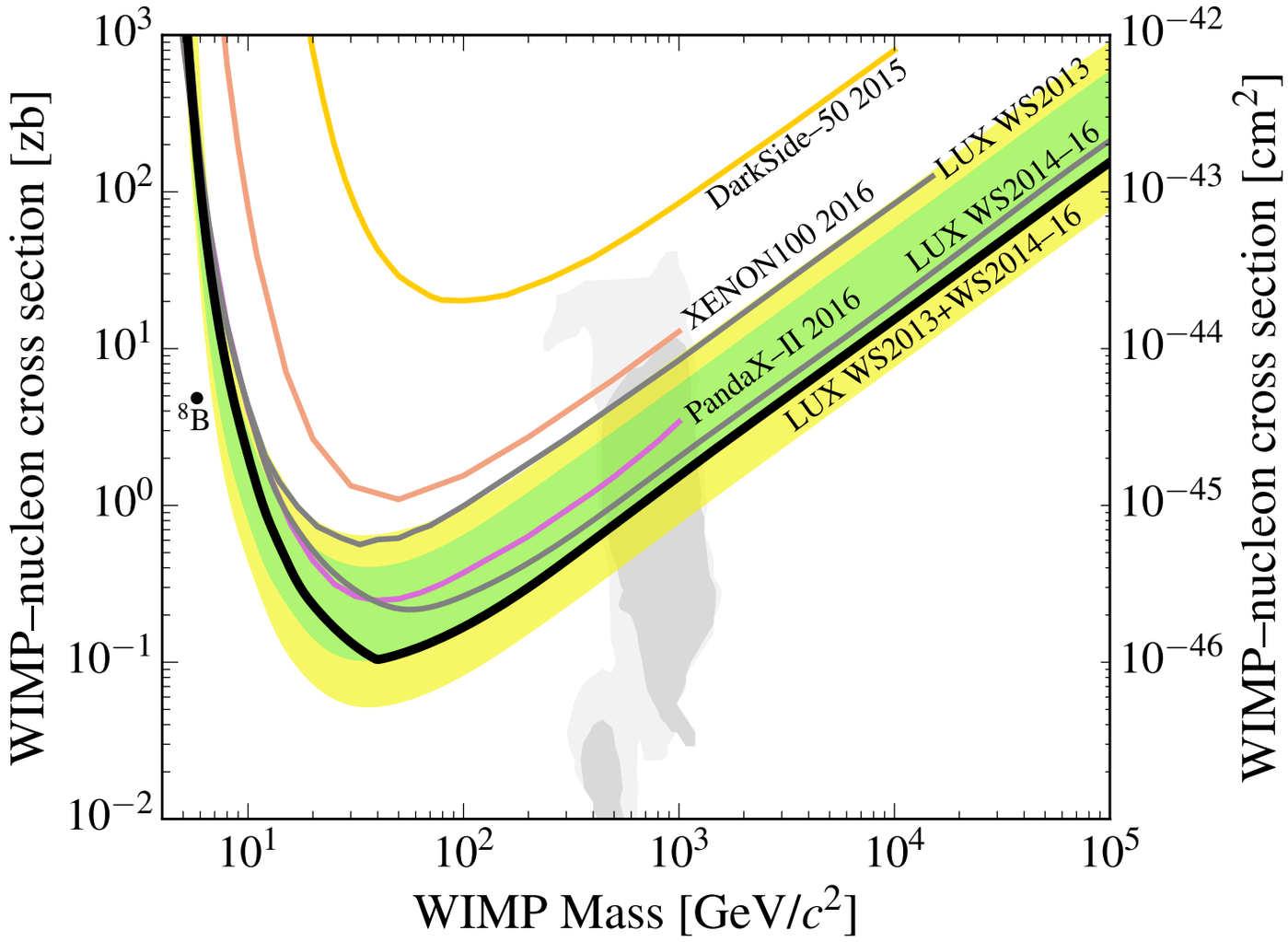
Direct Detection

Data LUX/PandaX-2016

1608.07648

1607.07400

$$\sigma^{SI} < 1.1 \times 10^{-46}\mathrm{cm}^2$$
$$m_\chi \sim 50\,\mathrm{GeV}$$



Although see Xenon1T

1705.06655

$$\sigma^{SI} < 7.7 \times 10^{-47}\mathrm{cm}^2$$
$$m_\chi \sim 35\,\mathrm{GeV}$$

Although see talk by Ji!

PANDAX

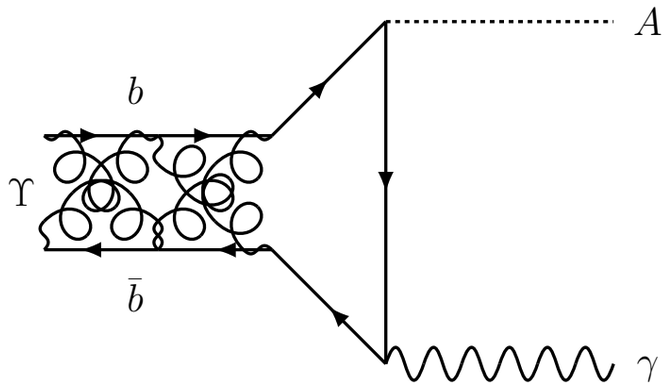
$$\sigma^{SI} < 6 \times 10^{-47}\mathrm{cm}^2$$
$$m_\chi \sim 45\,\mathrm{GeV}$$

Dark Matter Non-Relativistic EFT

Fitzpatrick, Haxton, Katz, Lubbers, Xu, 1203.3542

Collider Constraints

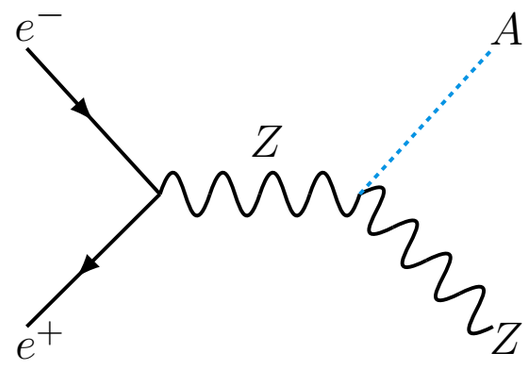
BaBar, pseudo-scalars



Range $m_A \in [1, 10]\,\mathrm{GeV}$

Probe directly bbA couplings!

LEP, Higgs-like searches



Range $m_A \in [10, 100]\,\mathrm{GeV}$

Assuming the same ZZA coupling as the Higgs, very model dependent.

LHC:

Mono-jet + MET

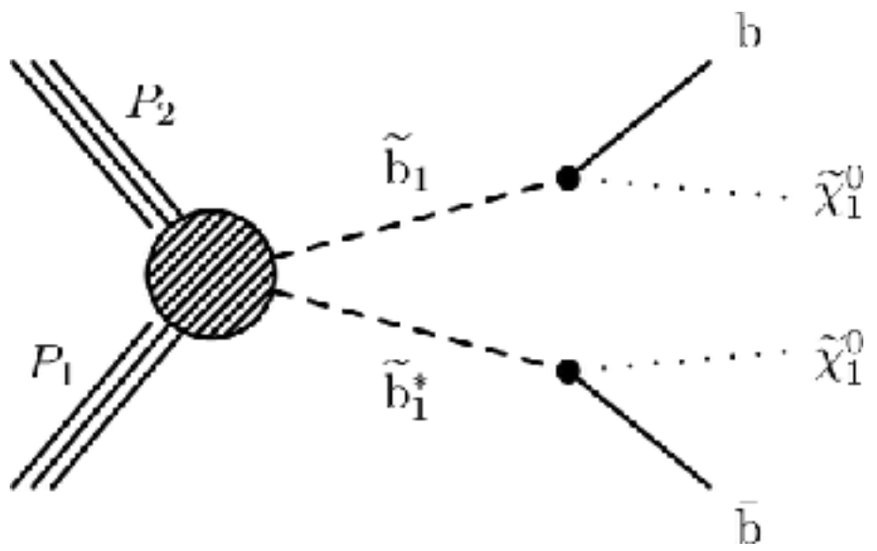
Mono-Z/gamma + MET

Di-lepton

Di-tau

Di-jet

Sbottom Searches



Spin-1 mediator, spin 1/2 DM

Spectrum requires ~35 GeV DM, same couplings to all SM fermions

$$\mathcal{L} \supset \left[a\bar{\chi}\gamma^\mu(g_{\chi v} + g_{\chi a}\gamma^5)\chi + \sum_f \bar{f}\gamma^\mu(g_{fv} + g_{fa}\gamma^5)f \right] V_\mu$$

LHC: Di-lepton
Monojet + MET

Breakdown of the model

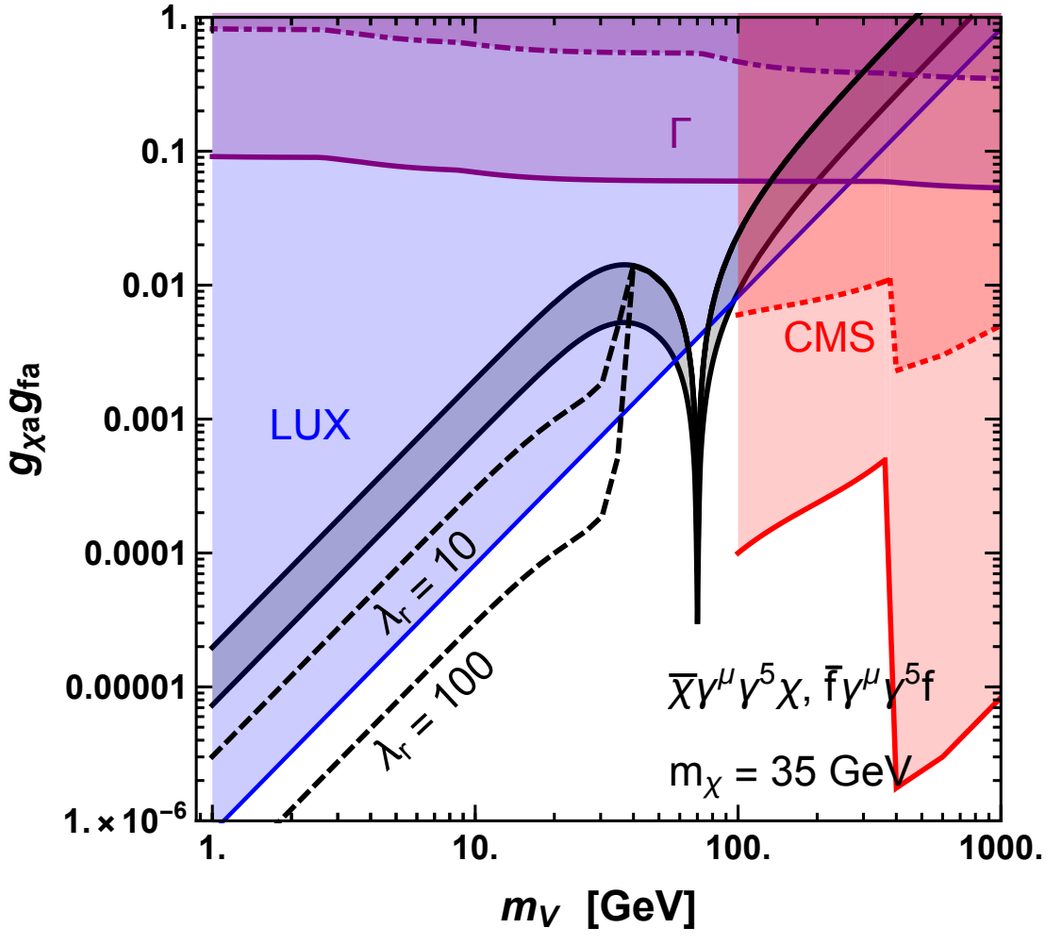
$$\Gamma \Leftrightarrow \Gamma_V/m_V > 0.1$$

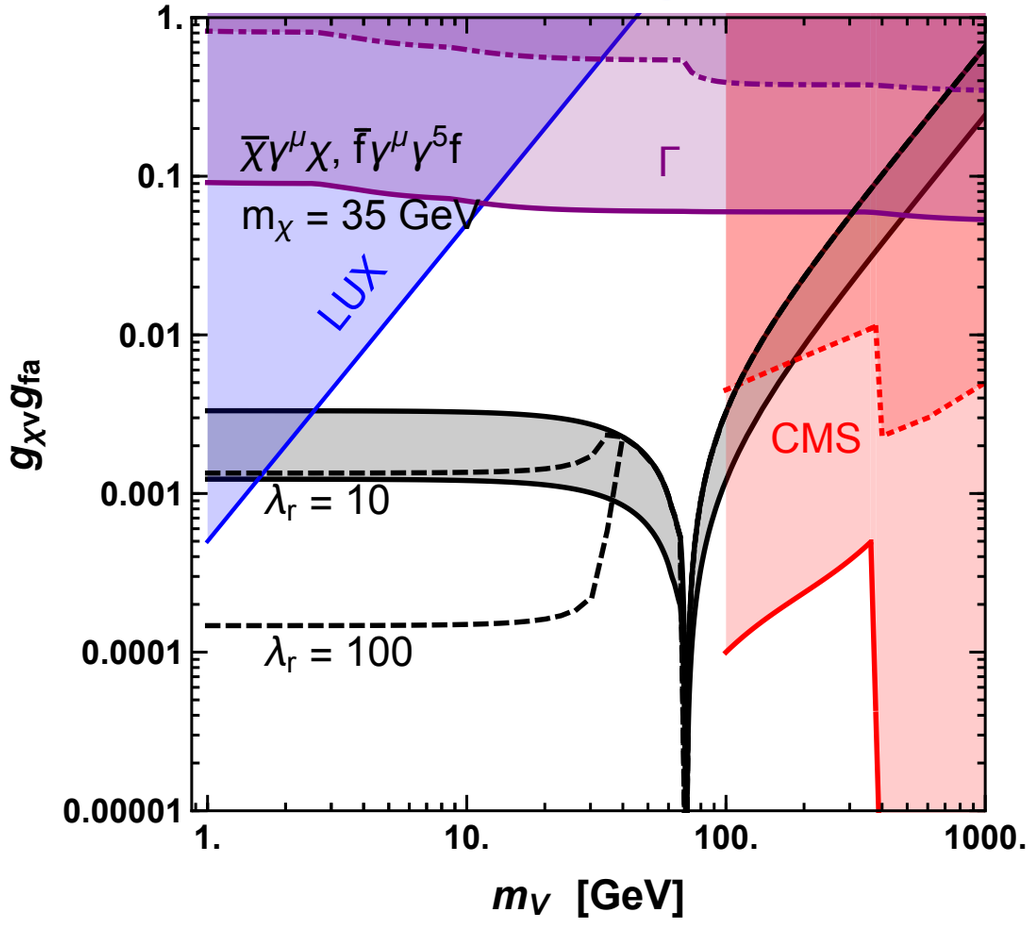
$$\lambda_r = \lambda_{\rm DM}/\lambda_{\rm SM}$$

$$\lambda_r = 1/3\,({\rm Solid})$$
$$g_\chi = 1,\ (i.e.\ \lambda_r \gg 1\,{\rm dashed})$$

Loop suppressed SI interactions may enhance DD bounds, although model dependent

see D'Eramo, Kavanagh & Panci 1605.04917





Spin-0 mediator, spin 1/2 DM

Spectrum requires ~50 GeV DM, Couplings to SM fermions proportional to SM Yukawa (MFV)

$$\mathcal{L} \supset \left[a\bar{\chi}\lambda_{\chi p} i\gamma^5 \chi + \sum_f y_f \bar{f}(\lambda_{fs} + \lambda_{fp} i\gamma^5) f \right] A$$

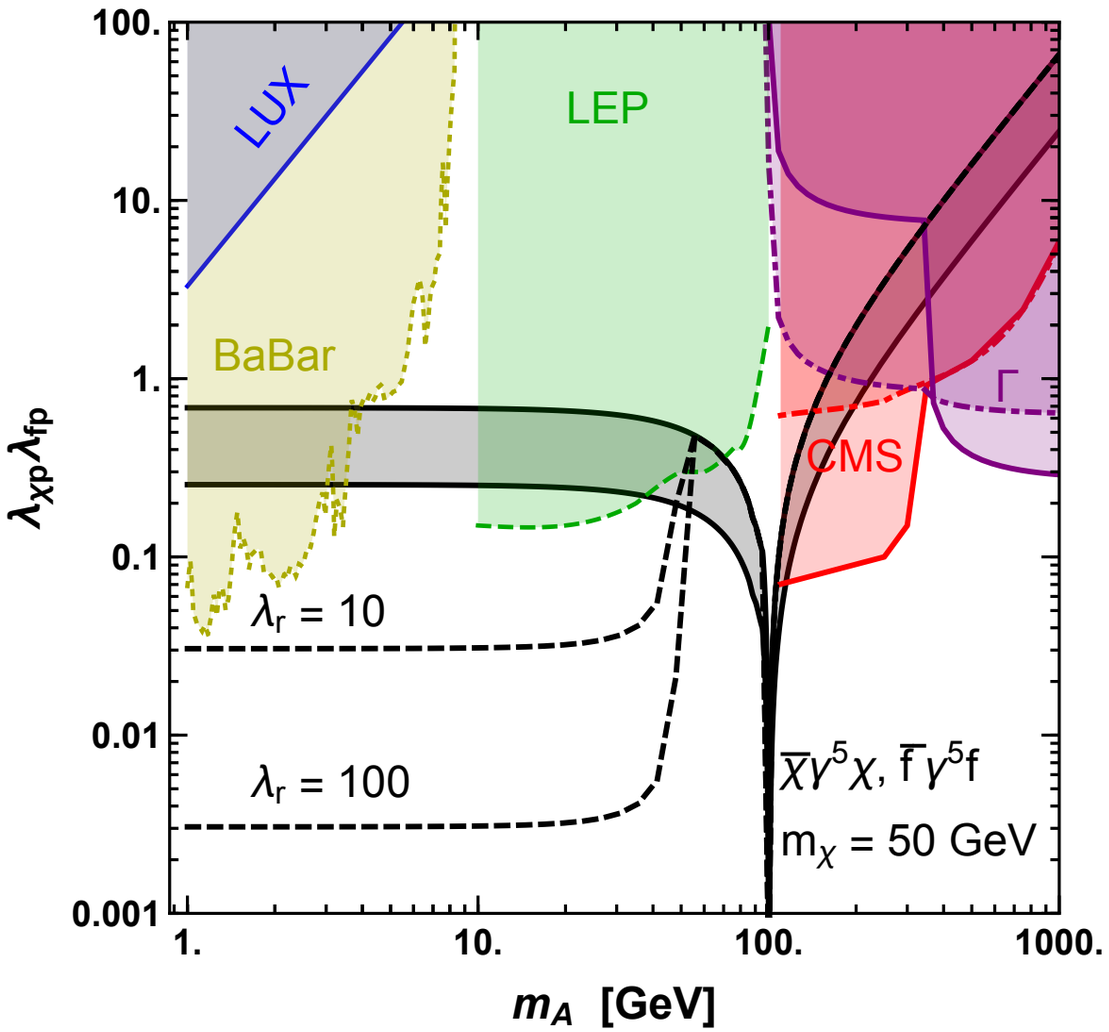
$\lambda_r = 3$, (dashed) $\quad \lambda_r = \lambda_{\rm DM}/\lambda_{\rm SM}$

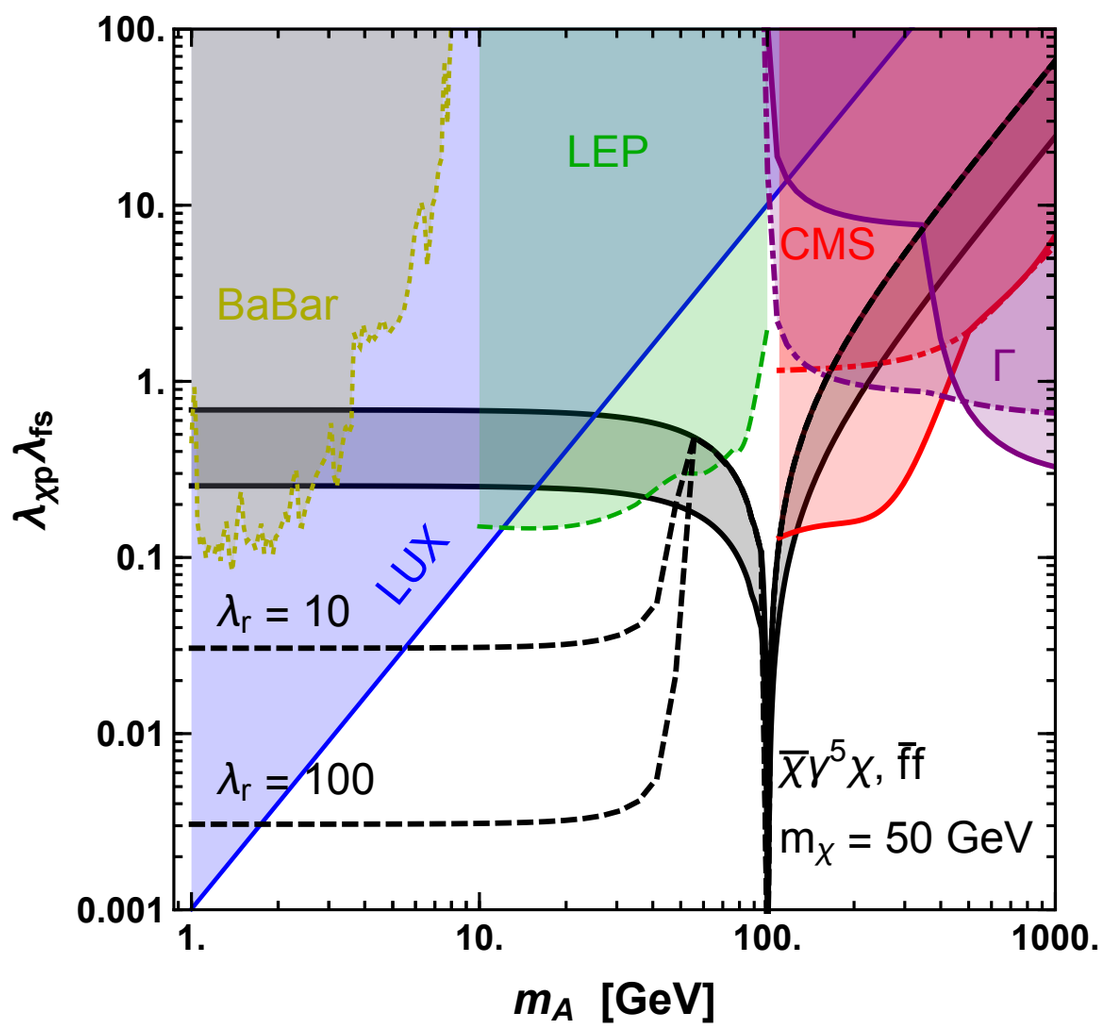
$\lambda_r = 1/3$, (solid) $\quad \lambda_r = 1$

$\lambda_r = 10$

LHC: Monojet+MET

CP violating



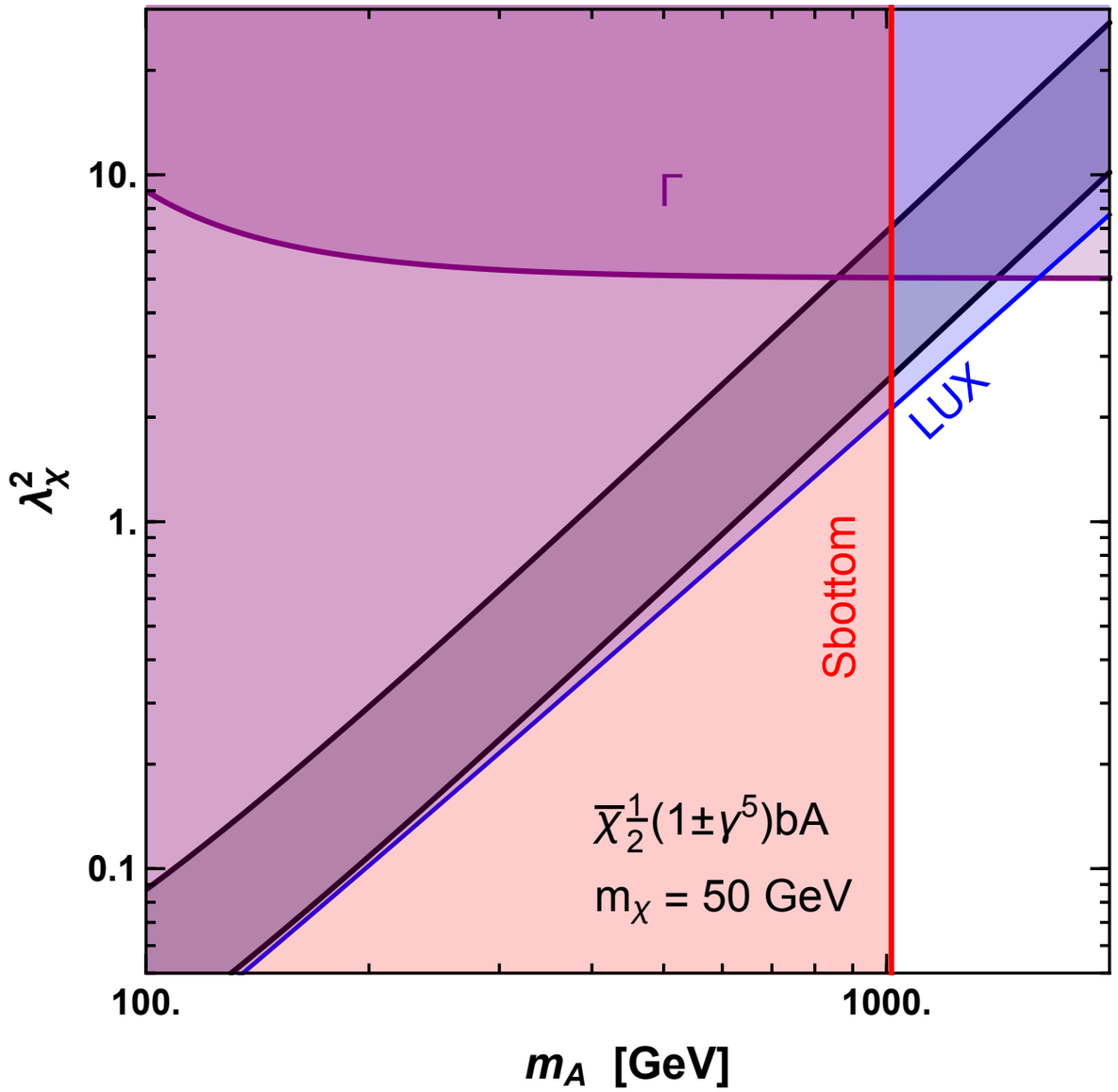


LHC constraints can be alleviated for asymmetric couplings to up-like to down-like quarks

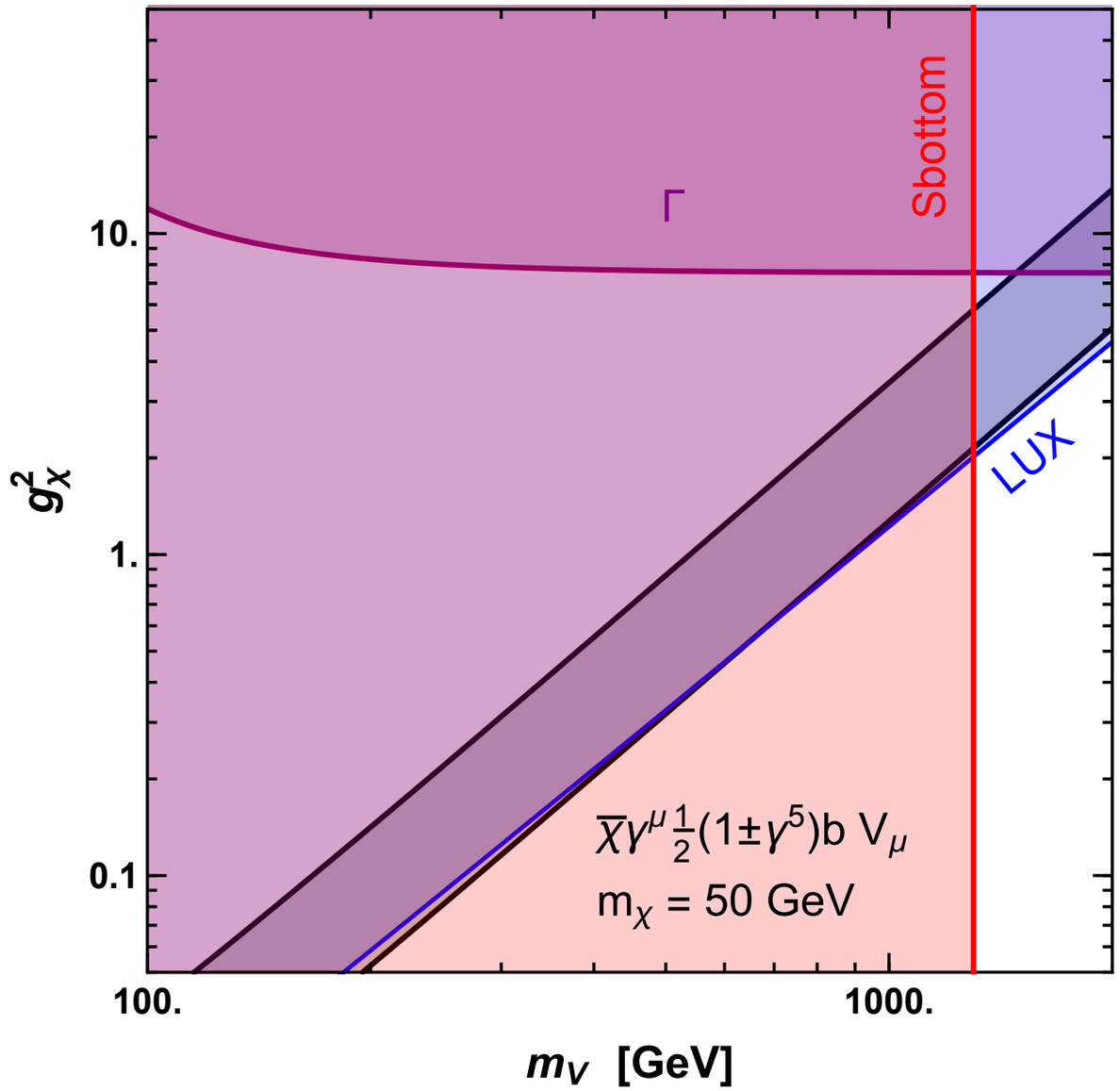
t-channel

Need for charged and coloured mediators, now ruled out by LHC and DD

$$\mathcal{L} \supset \lambda_\chi \bar{\chi}(1+\gamma^5) f A + \text{h.c.}$$



$$\mathcal{L} \supset g_\chi \bar{\chi}\gamma^\mu(1+\gamma^5) f V_\mu + \text{h.c.}$$



Conclusions

Vector mediated models ruled out except on resonance

Pseudoscalar mediated models survive, in particular those with CP conserving couplings

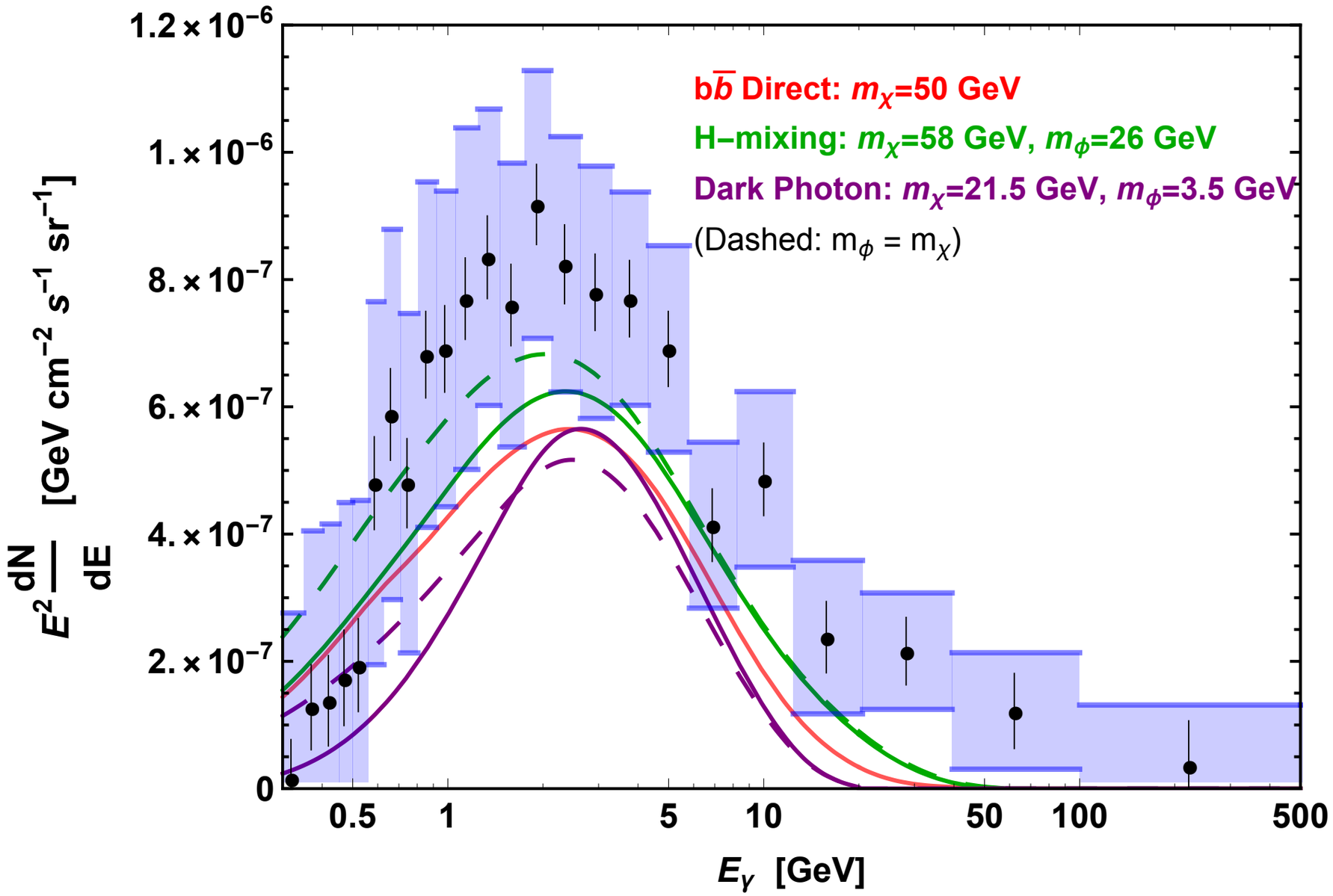
t-channel mediated models are entirely ruled out by a combination of Direct Detection and LHC data

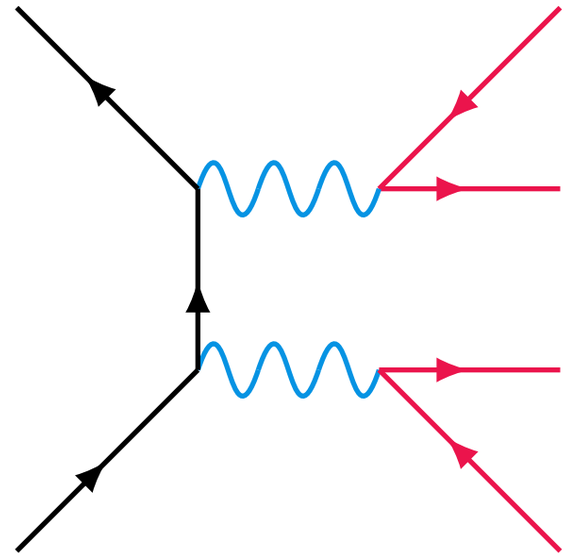
Very weakly coupled Hidden sectors?

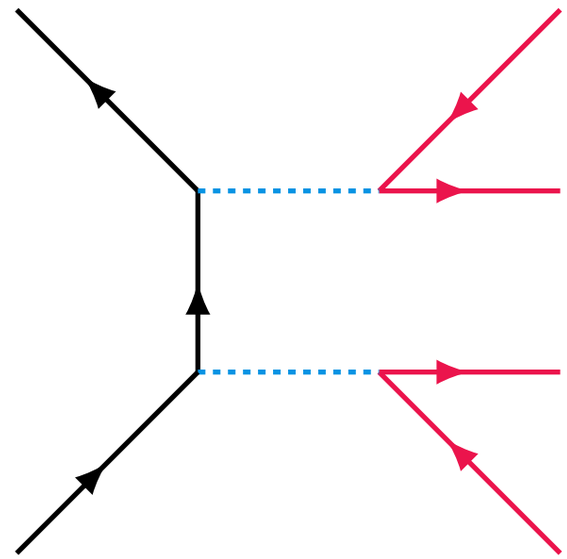
Hidden sector models are extremely difficult to probe, and if excesses are observed in dwarf galaxies in the near future, these models may gain significant interest

Outlook: Hidden Sector Models

In preparation: Escudero, Hooper and Witte







Thank You!

arXiv:1612.06462 Escudero, Hooper, Witte

Back up: Collider Constraints

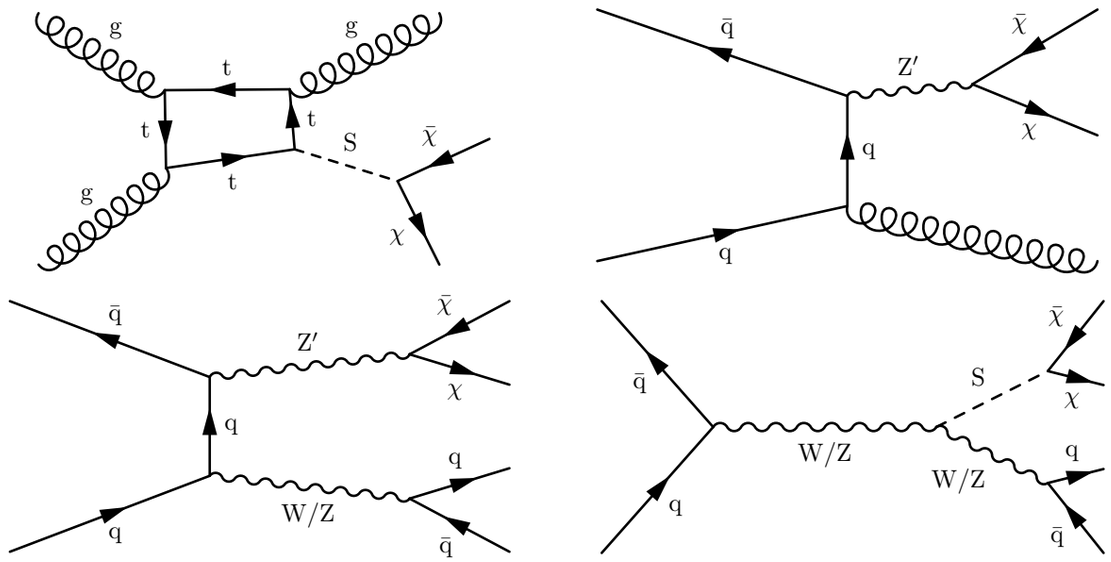
LHC:

Di-lepton

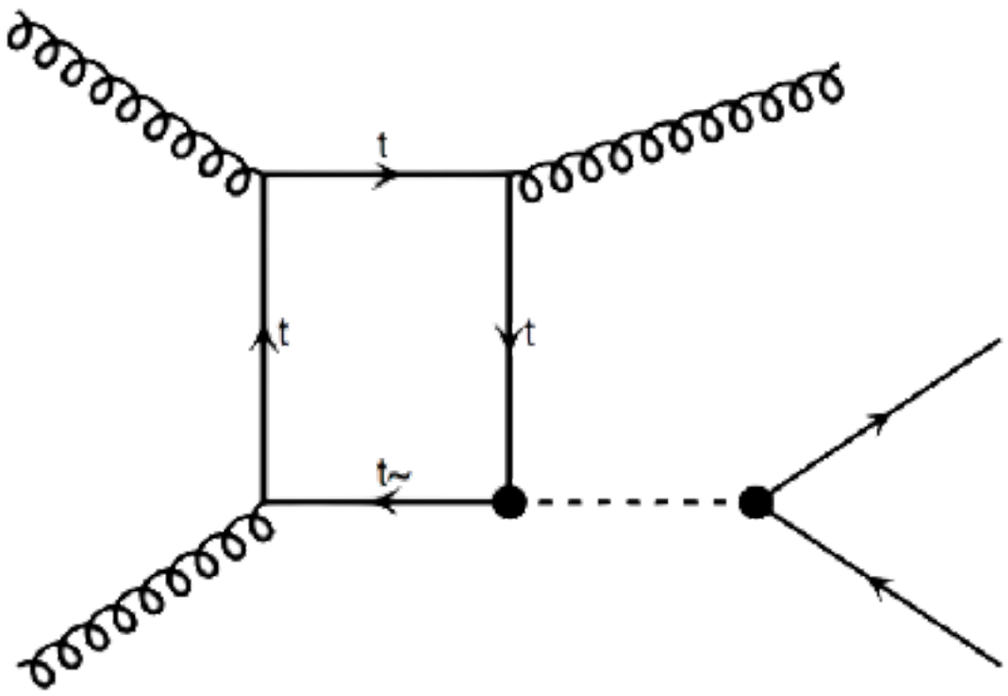
Di-tau Mostly for V-mediated cases

Di-jet

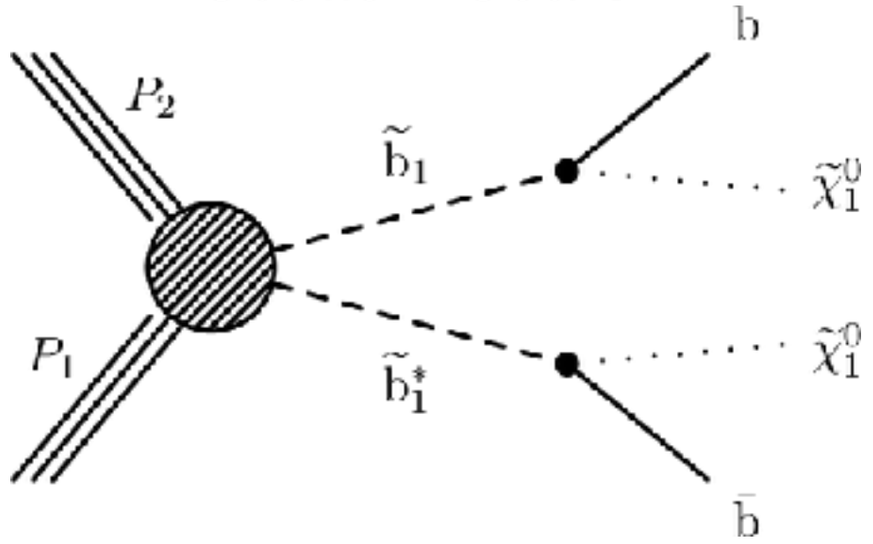
Mono-jet-Z-W + MET



Mono-jet + MET

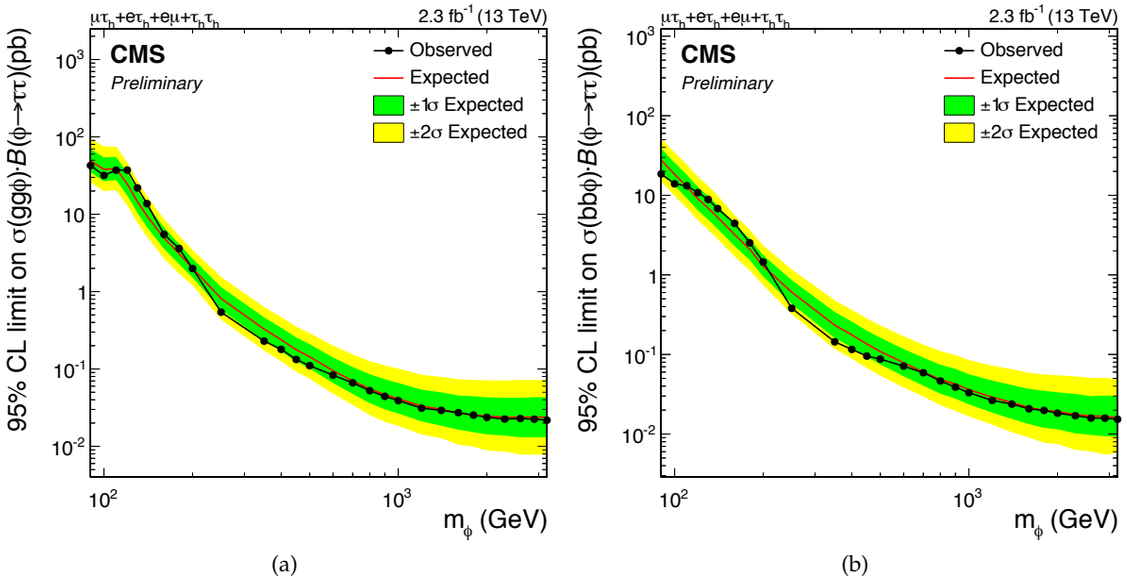


Sbottom Search

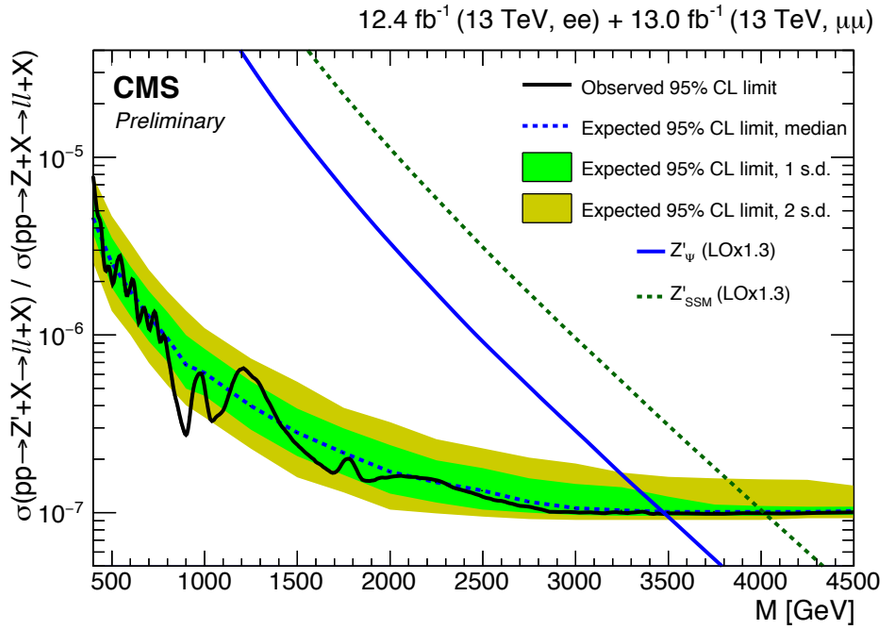


Back up: Collider Constraints

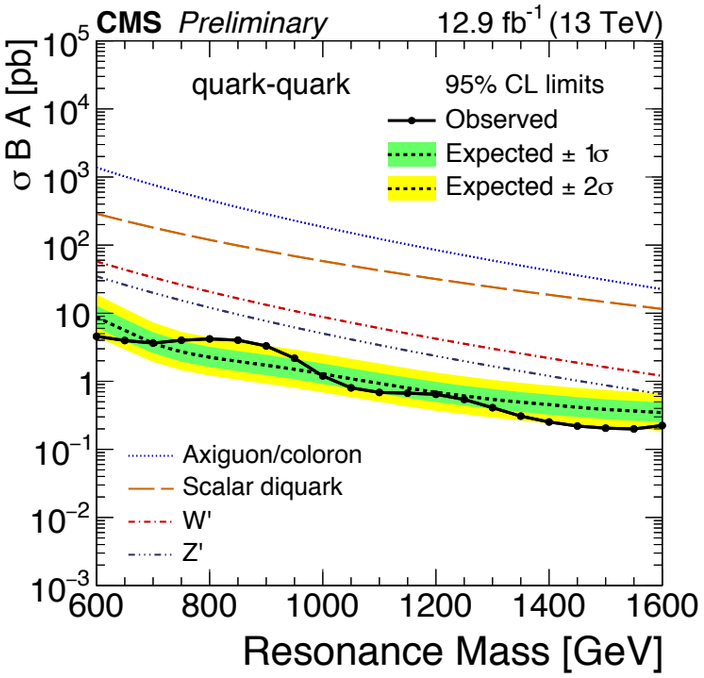
Di-tau



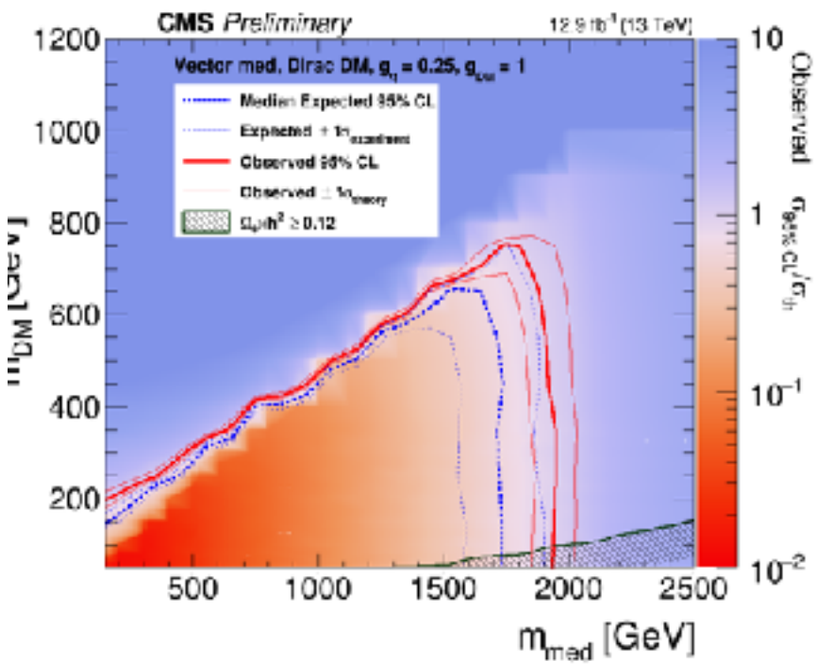
Di-lepton



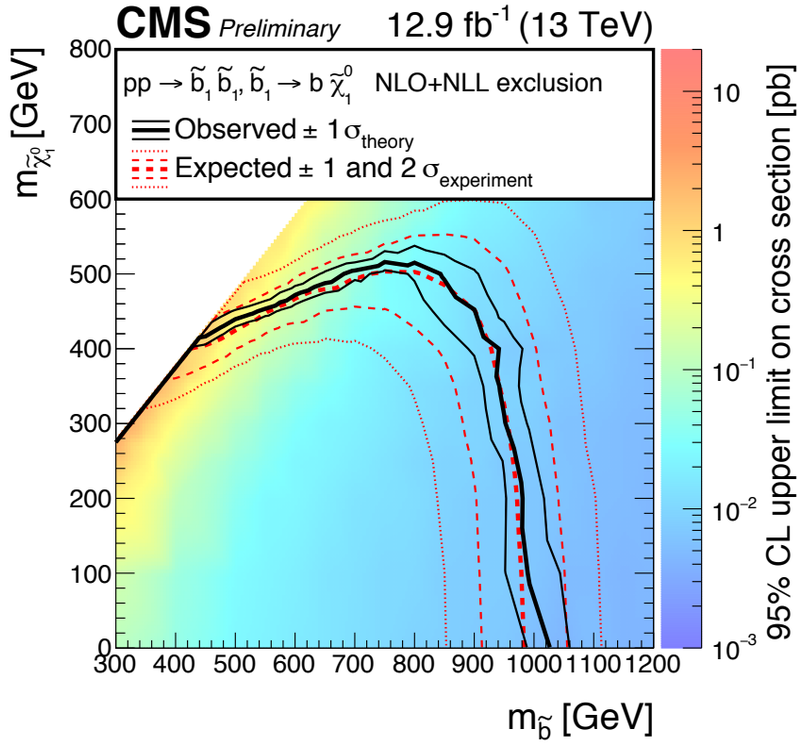
Di-jet



Mono-jet + MET



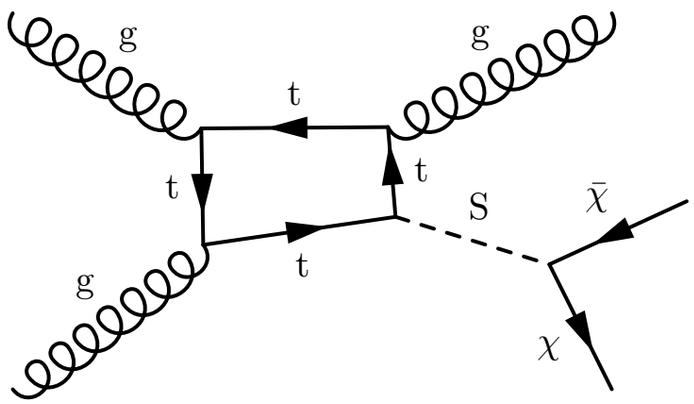
Sbottom Search



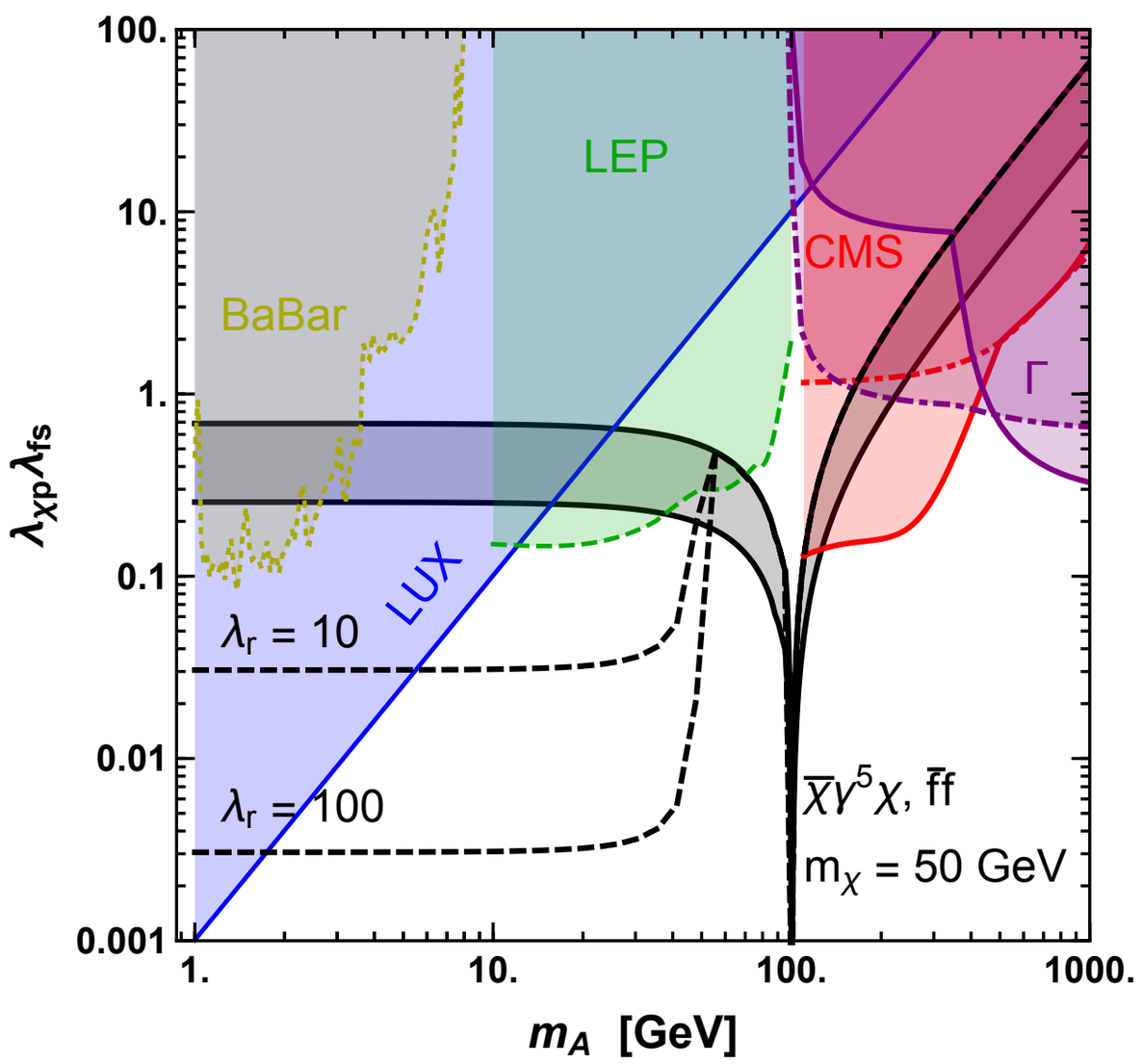
Back up: Spin-0 mediator, spin 1/2 DM

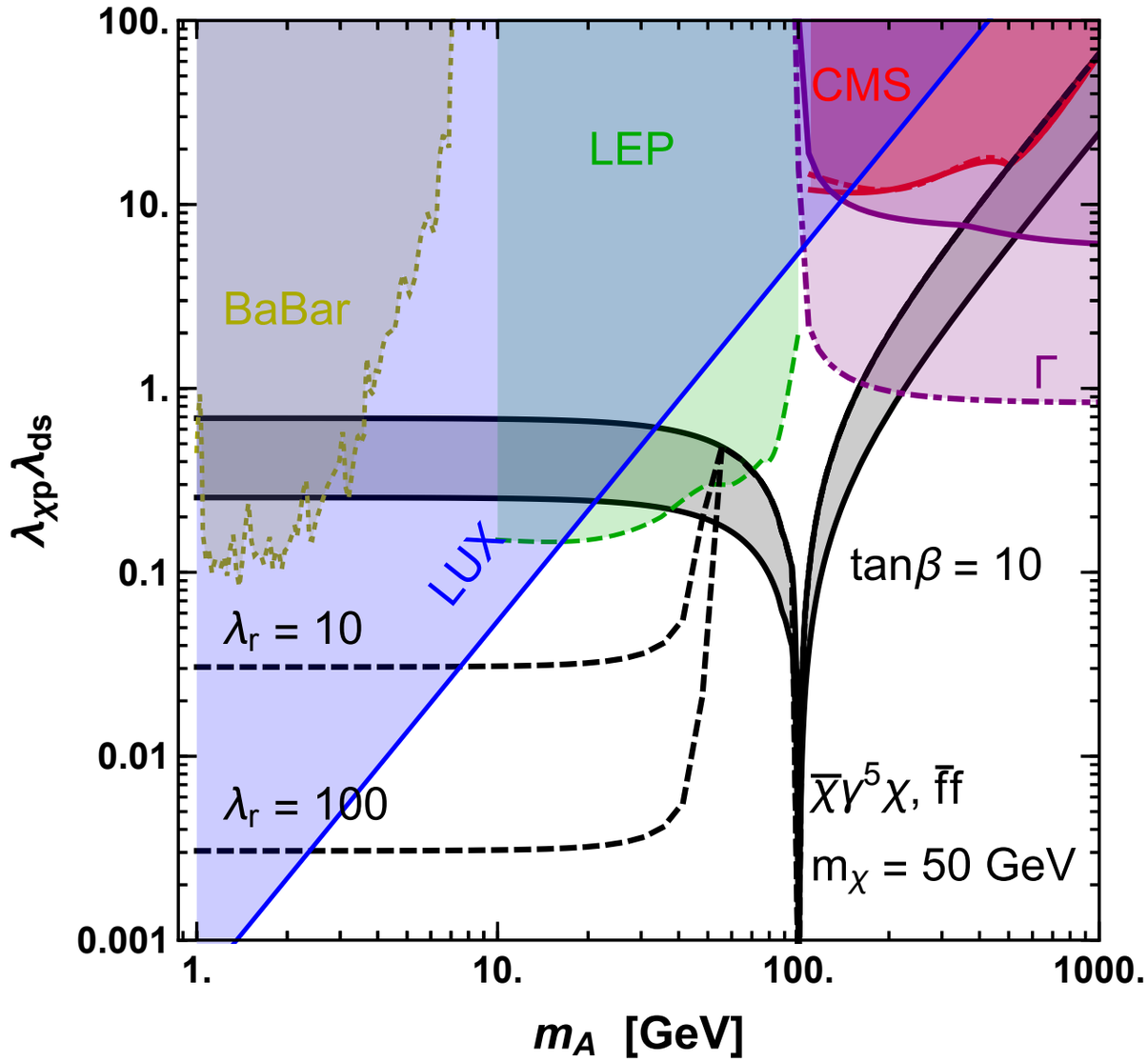
Pseudo-scalar mediator large tan-beta

$$\mathcal{L} \supset \left[a\bar{\chi}\lambda_{\chi p} i\gamma^5 \chi + \sum_f y_f \bar{f}(\lambda_{fs} + \lambda_{fp} i\gamma^5) f \right] A$$



Mono Jet+MET





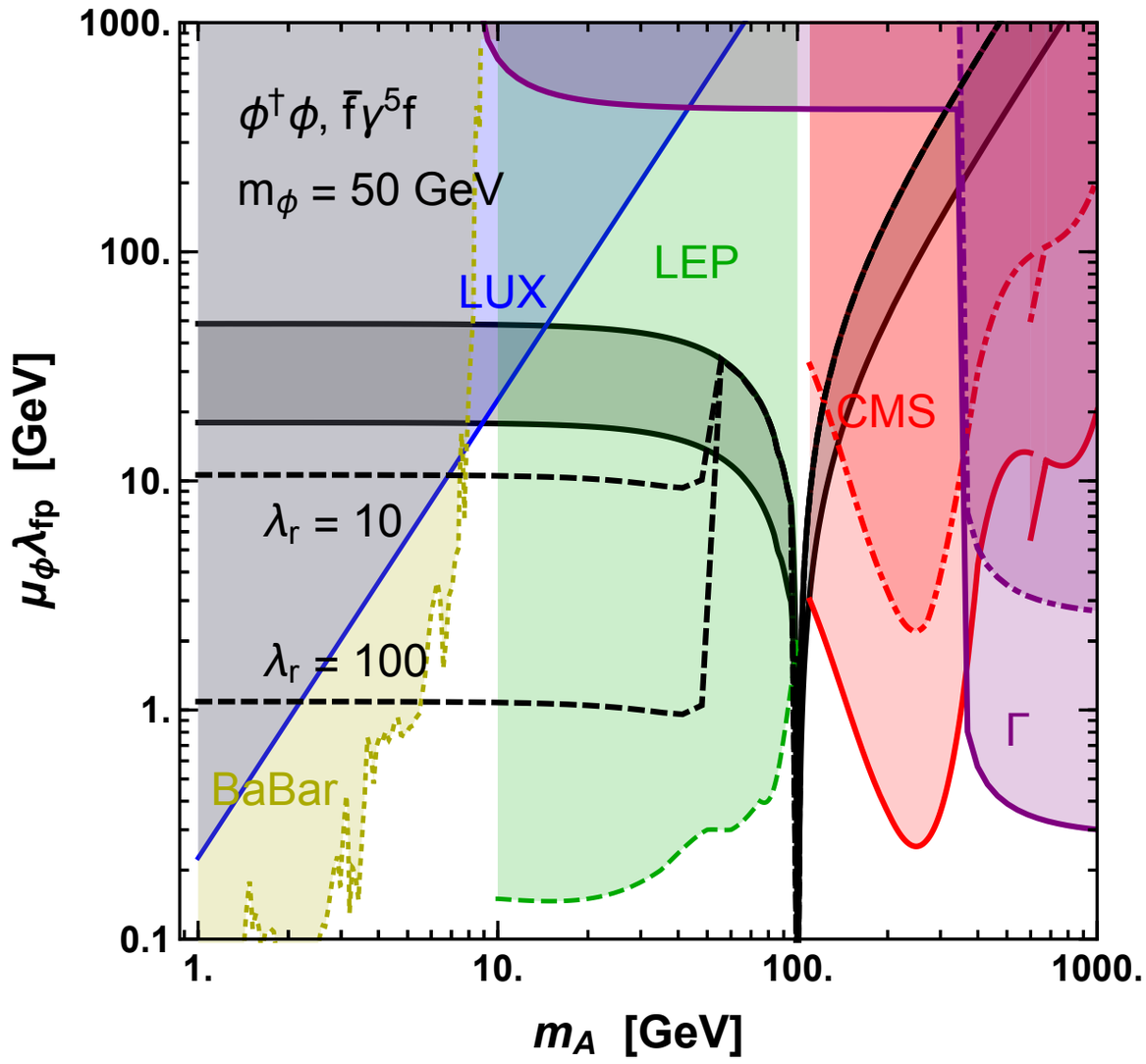
Back up: Spin-0 mediator, spin 0 DM

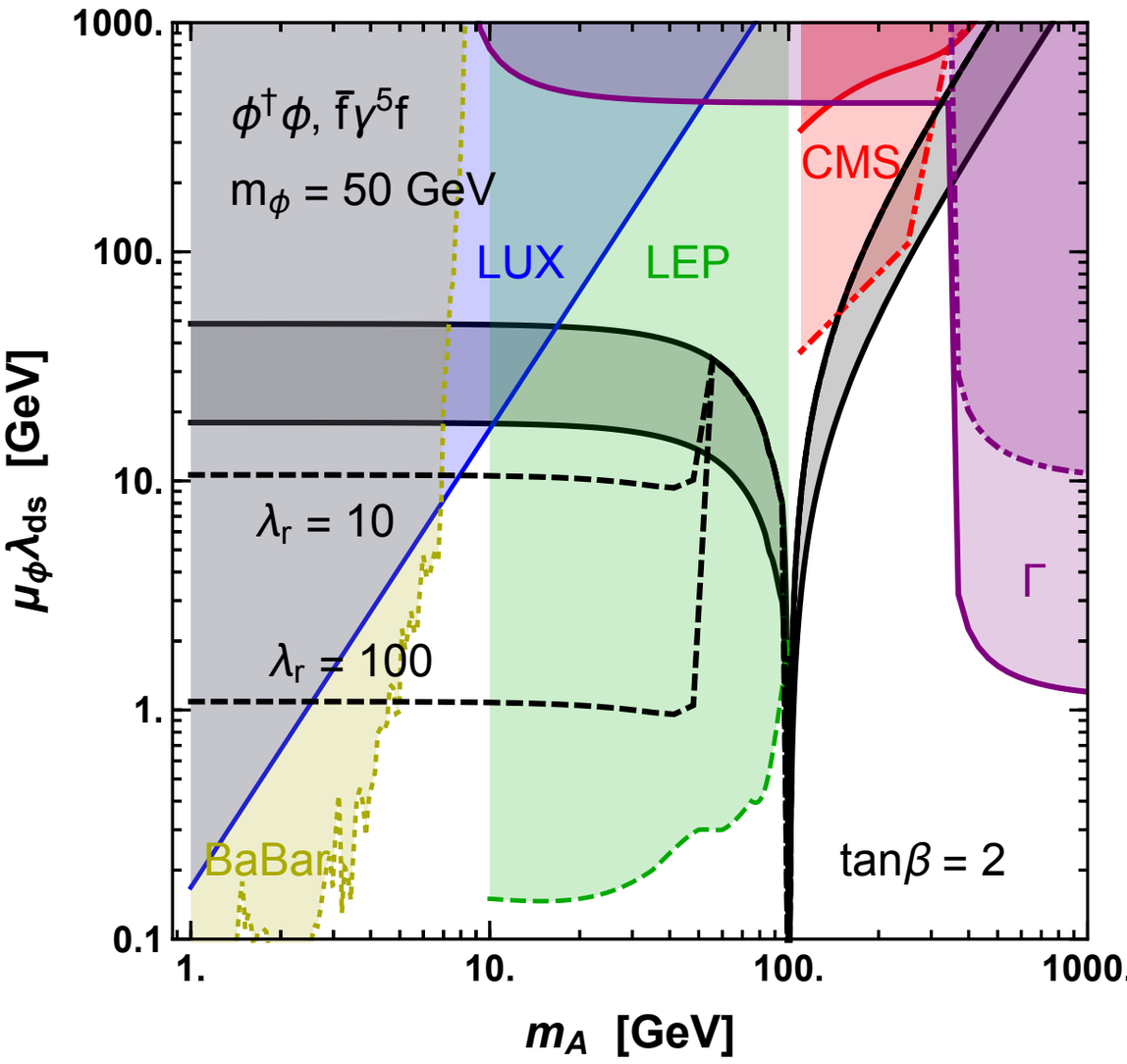
$$\mathcal{L} \supset \left[a\mu_\phi |\phi|^2 + \sum_f y_f \bar{f} \lambda_{fp} i\gamma^5 f \right] A$$

Due to a change on branching ratios

DI Tau

DI Jet $\quad m_A > 600\,\mathrm{GeV}$

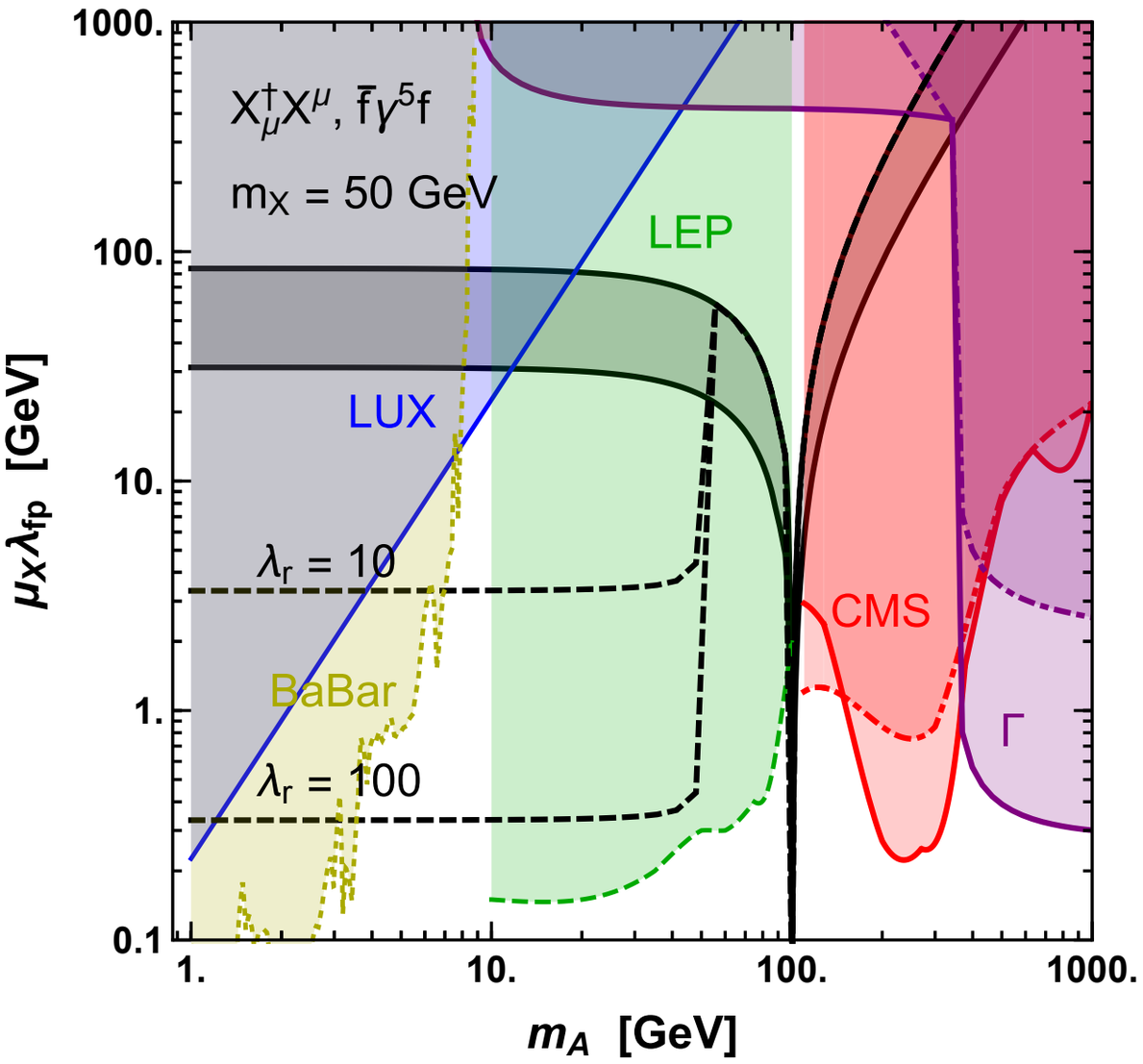


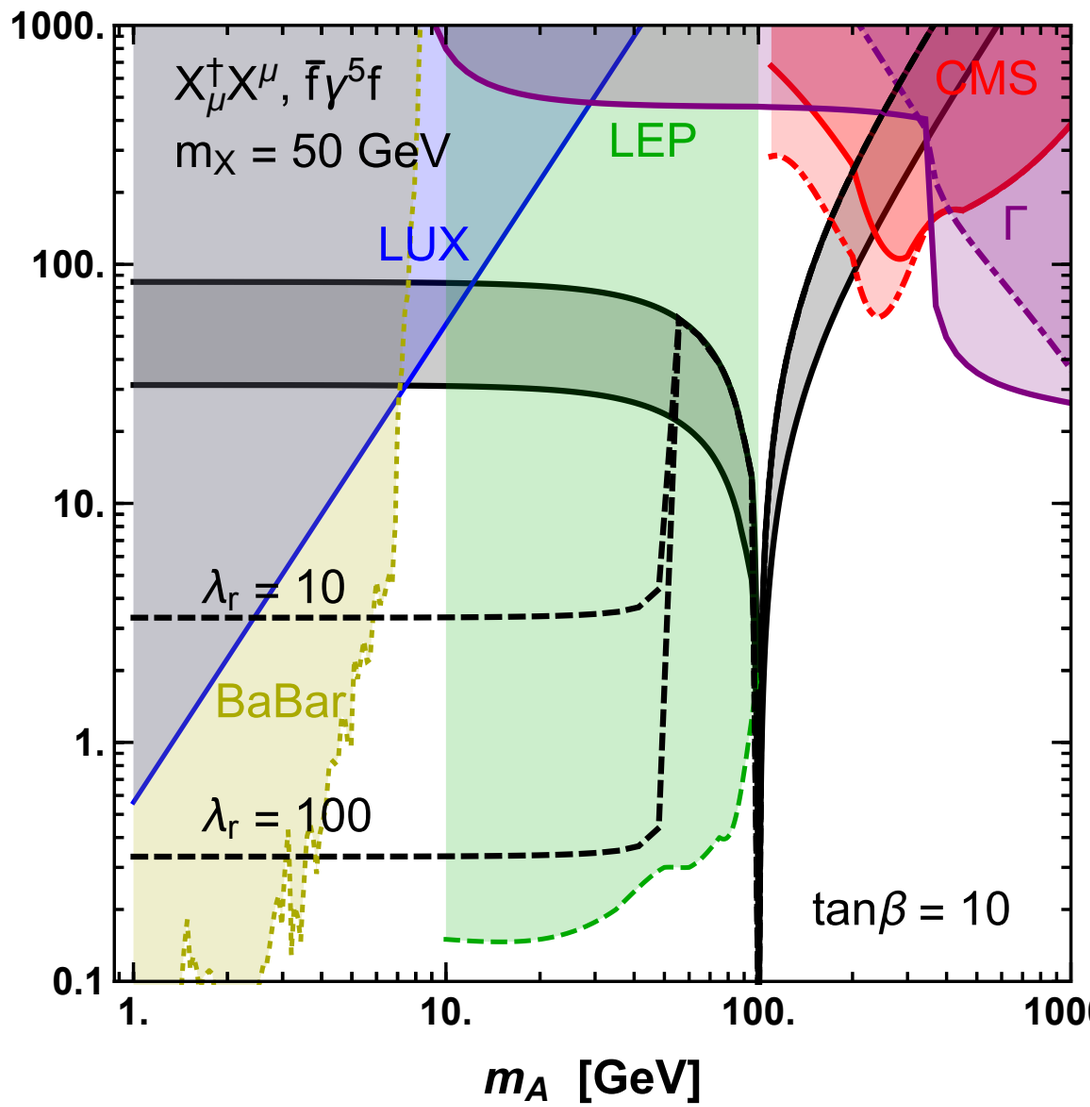


Back up: Spin-1 mediator, spin 0 DM

$$\mathcal{L} \supset \left[a\mu_X X^\mu X_\mu^\dagger + \sum_f y_f \bar{f} \lambda_{fp} i\gamma^5 f \right] A$$

MonoJet + MET
DI Tau
DI Jet

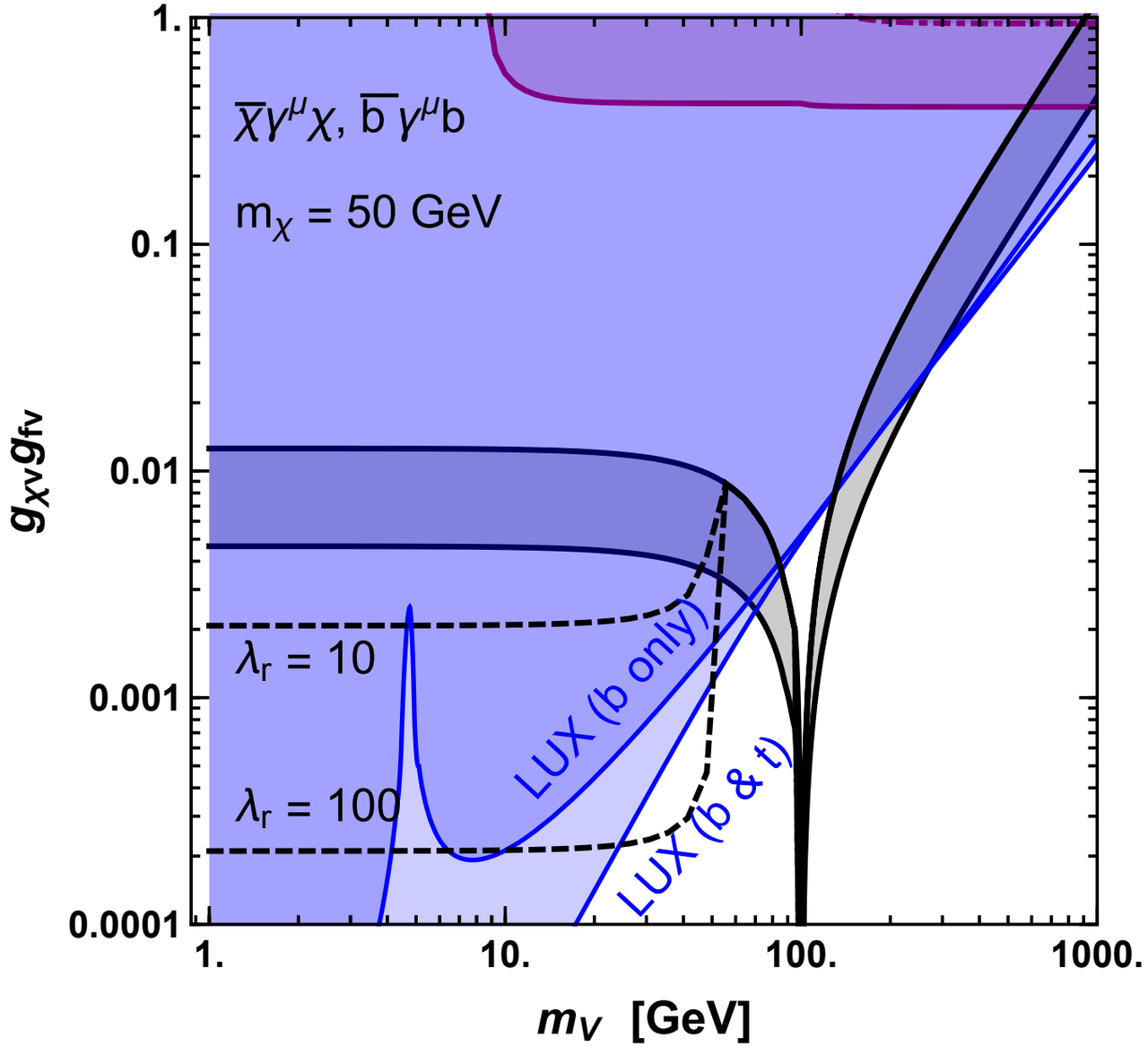




Back up: Spin-1 mediator, spin 1/2 DM

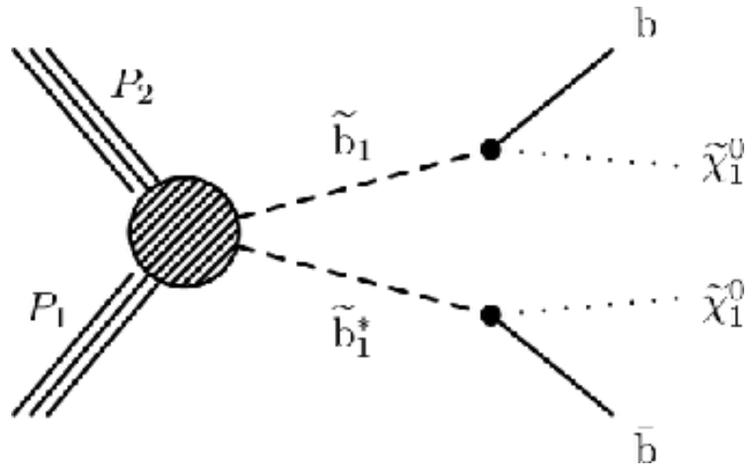
MonoJet + MET

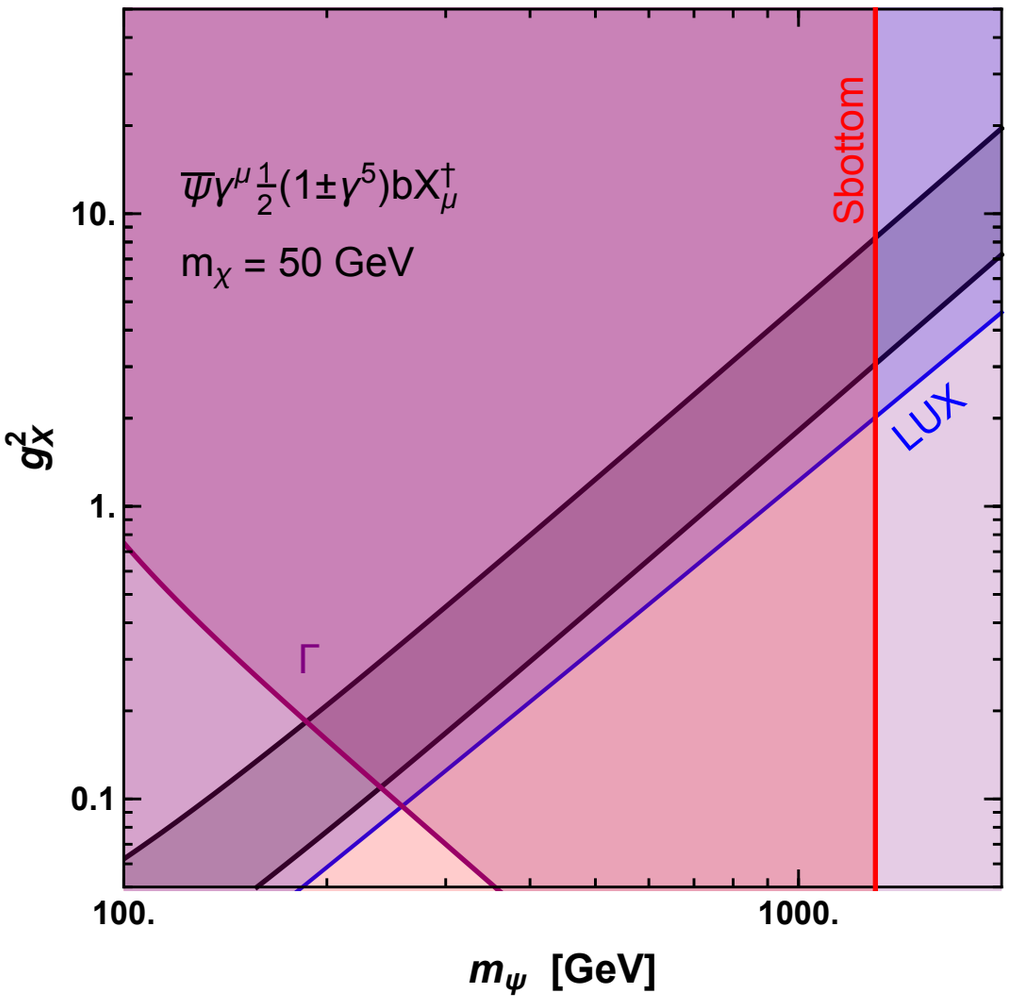
DI Lepton

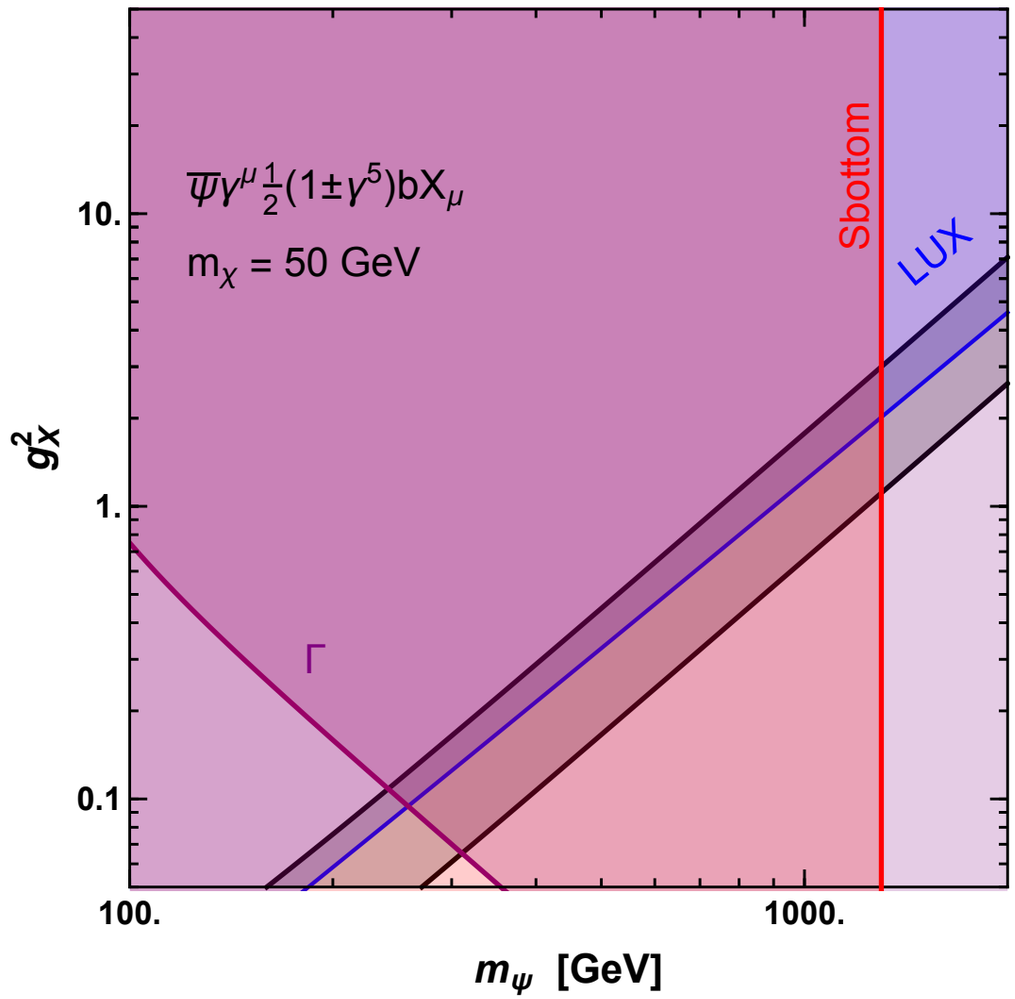


Back up: t-channel models

Sbottom-searches







Back up: Models with Pseudoscalars

1502.06000 Berlin, Gori, Lin, Wang Model: MSSM

1404.3716 Ipek, McKeen, Nelson Model: 2HDM

1612.07115 Butter, Murgia, Plehn, Tait Model: MSSM