Exploring t-channel models for Dark Matter

David Cabo-Almeida

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In collaboration with: Giorgio Arcadi, Federico Mescia, Javier Virto

Università degli Studi di Messina

Universitat de Barcelona

T-channel Portal

We have provided a complete matching of the t-channel portal, with a complete analysis focused on Direct Detection and Relic Density

From High energy

$$\mathcal{L}_{scalar} = \Gamma_L^{f_i} \bar{f}_i P_R \Psi_{f_i} \Phi_{\rm DM} + \Gamma_R^{f_i} \bar{f}_i P_L \Psi_{f_i} \Phi_{DM} + \text{h.c.}$$
$$+ \lambda_{1H\Phi} (\Phi_{DM}^\dagger \Phi_{DM})(H^\dagger H) + \lambda_{2H\Phi} (\Phi_{DM}^\dagger T_\Phi^a \Phi_{DM})(H^\dagger \frac{\sigma^a}{2} H)$$

$$\mathcal{L}_{fermion} = \Gamma_L^{f_i} \bar{f}_i P_R \Phi_{f_i} \Psi_{\rm DM} + \Gamma_R^{f_i} \bar{f}_i P_L \Phi_{f_i} \Psi_{DM} + \text{h.c.}$$
$$+ \lambda_{1H\Phi} (\Phi_{f_i}^\dagger \Phi_{f_i})(H^\dagger H) + \lambda_{2H\Phi} (\Phi_{f_i}^\dagger T_\Phi^a \Phi_{f_i})(H^\dagger \frac{\sigma^a}{2} H)$$

where:

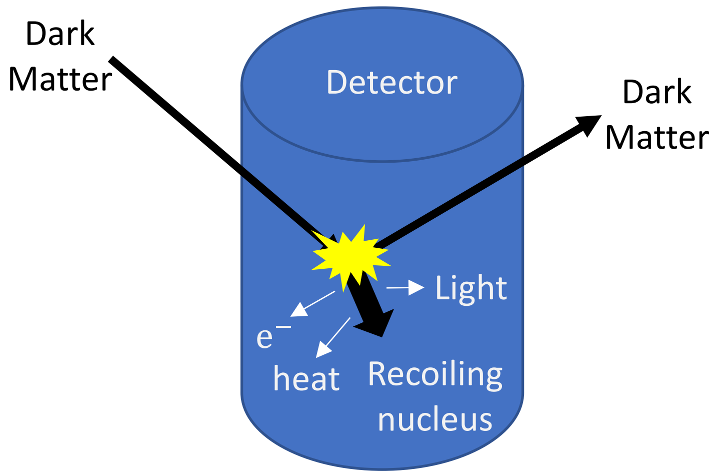
$$\mathcal{O}_{\mu\nu}^q \equiv \bar{q} i \left(\frac{D_\mu \gamma_\nu + D_\nu \gamma_\mu}{2} - \frac{1}{4} g_{\mu\nu} \not{D} \right) q,$$
$$\mathcal{O}_{\mu\nu}^g \equiv G_\mu^{a\rho} G_{\nu\rho}^a - \frac{1}{4} g_{\mu\nu} G_{\rho\sigma}^a G^{a\rho\sigma},$$

To Low energy

$$\mathcal{L}_{\rm eff}^{\rm Scalar,q} = \sum_{q=u,d} c^q \left(\Phi_{\rm DM}^\dagger i \overleftrightarrow{\partial}_\mu \Phi_{\rm DM} \right) \bar{q} \gamma^\mu q + \sum_{q=u,d,s} d^q M_q \Phi_{\rm DM}^\dagger \Phi_{\rm DM} \, \bar{q} q + d^g \frac{\alpha_s}{\pi} \Phi_{\rm DM}^\dagger \Phi_{\rm DM} \, G^{a\mu\nu} G_{\mu\nu}^a$$
$$+ \sum_{q=u,d,s} g_1^q \frac{\Phi_{\rm DM} (i\partial^\mu)(i\partial^\nu) \Phi_{\rm DM} \, \mathcal{O}_{\mu\nu}^q}{M_{\Phi_{\rm DM}}^2} + g_1^g \frac{\Phi_{\rm DM} (i\partial^\mu)(i\partial^\nu) \Phi_{\rm DM} \, \mathcal{O}_{\mu\nu}^g}{M_{\Phi_{\rm DM}}^2},$$

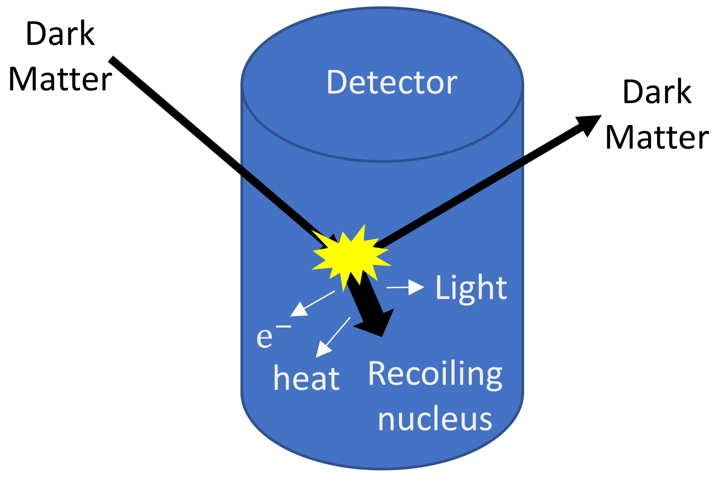
$$\mathcal{L}_{\rm eff}^{\rm Dirac,q} = \sum_{q=u,d} c^q \bar{\Psi}_{\rm DM} \gamma_\mu \Psi_{\rm DM} \bar{q} \gamma^\mu q + \sum_{q=u,d,s} \tilde{c}^q \bar{\Psi}_{\rm DM} \gamma_\mu \gamma_5 \Psi_{\rm DM} \bar{q} \gamma^\mu \gamma_5 q$$
$$+ \sum_{q=u,d,s} d^q m_q \bar{\Psi}_{\rm DM} \Psi_{\rm DM} \bar{q} q + \sum_{q=c,b,t} d_q^g \bar{\Psi}_{\rm DM} \Psi_{\rm DM} G^{a\mu\nu} G_{\mu\nu}^a$$
$$+ \sum_{q=u,d,s} \left(g_1^q \frac{\bar{\Psi}_{\rm DM} i\partial^\mu \gamma^\nu \Psi_{\rm DM} \mathcal{O}_{\mu\nu}^q}{M_{\Psi_{\rm DM}}} + g_2^q \frac{\bar{\Psi}_{\rm DM} (i\partial^\mu)(i\partial^\nu) \Psi_{\rm DM} \mathcal{O}_{\mu\nu}^q}{M_{\Psi_{\rm DM}}^2} \right)$$
$$+ \sum_{q=c,b,t} \left(g_1^{g,q} \frac{\bar{\Psi}_{\rm DM} i\partial^\mu \gamma^\nu \Psi_{\rm DM} \mathcal{O}_{\mu\nu}^g}{M_{\Psi_{\rm DM}}} + g_2^{g,q} \frac{\bar{\Psi}_{\rm DM} (i\partial^\mu)(i\partial^\nu) \Psi_{\rm DM} \mathcal{O}_{\mu\nu}^g}{M_{\Psi_{\rm DM}}^2} \right).$$

Experimental bounds

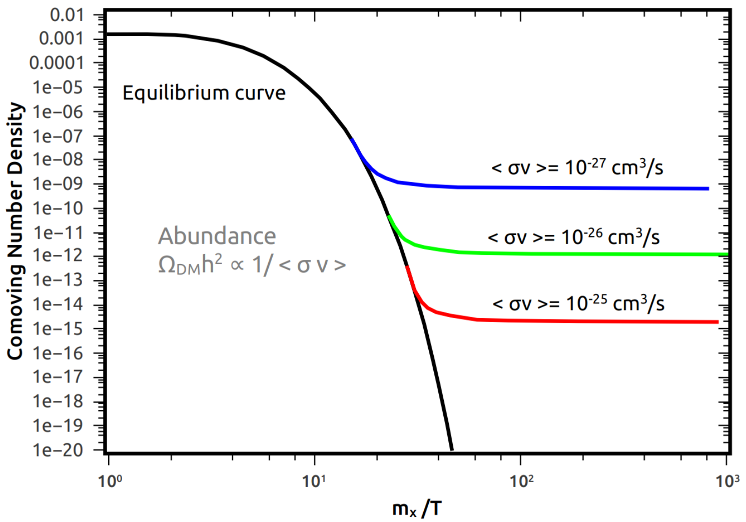


$$\sigma^{\mathrm{SI},p}_{\Phi_{\mathrm{DM}}} = \frac{\mu^2_{\Phi_{DM}p}}{\pi} \frac{\left[Z f_p + (A - Z) f_n\right]^2}{A^2}$$

Experimental bounds



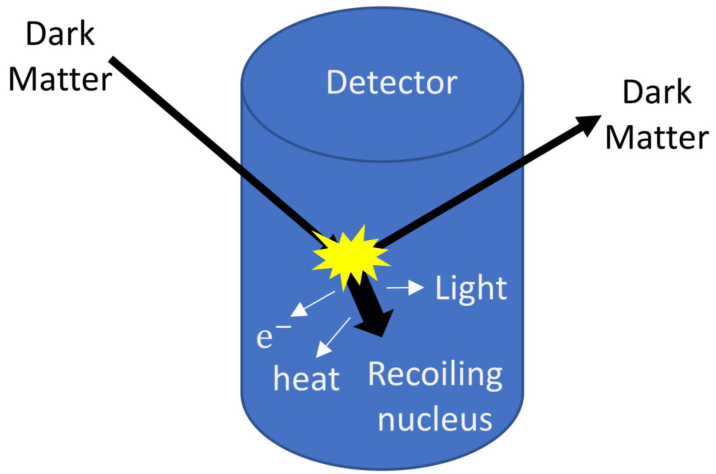
$$\sigma^{\mathrm{SI},p}_{\Phi_{\mathrm{DM}}} = \frac{\mu^2_{\Phi_{DM}p}}{\pi}\frac{[Zf_p + (A-Z)f_n]^2}{A^2}$$

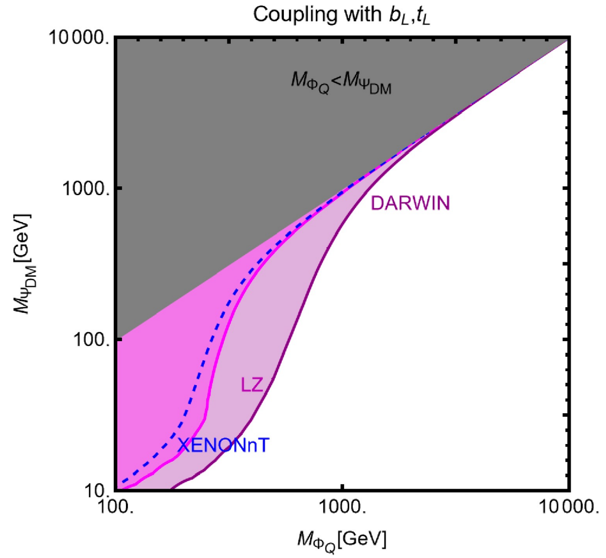


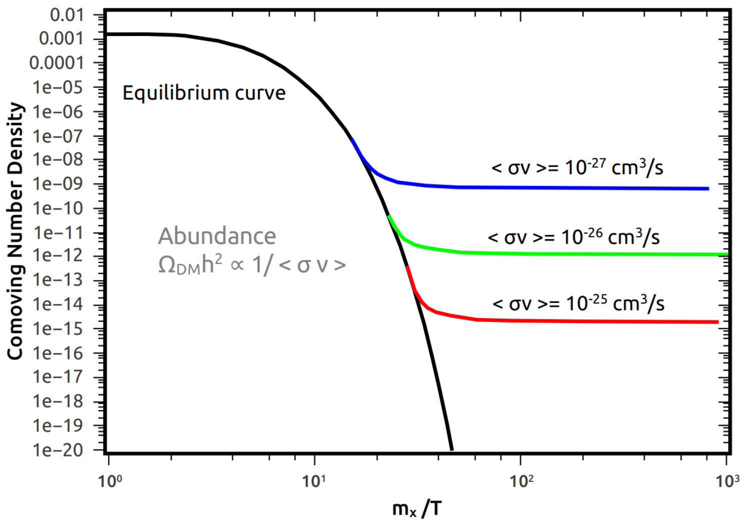
$$\Omega_{\mathrm{DM}}h^2 \approx 8.76\times 10^{-11}\mathrm{GeV}^{-2}\left[\int_{T_{\mathrm{f.o.}}}^{T_0} g_*^{1/2}\langle\sigma v\rangle_{\mathrm{eff}}\frac{dT}{M_{\mathrm{DM}}}\right]^{-1}$$

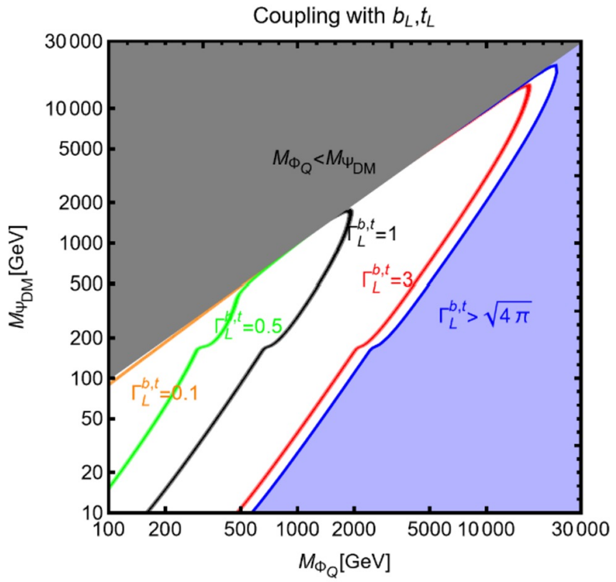
arXiv:hep-ph/9704361

Experimental bounds



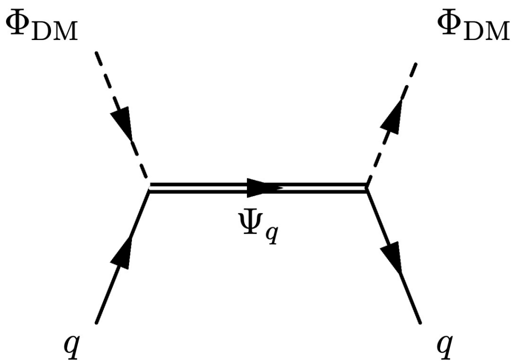


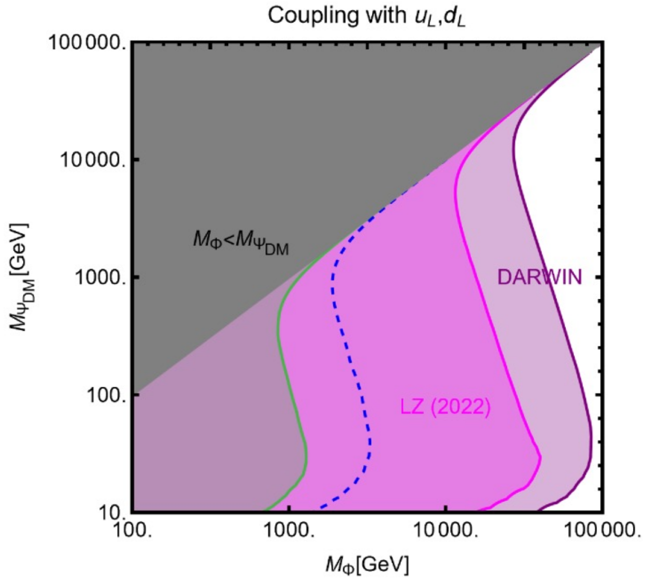




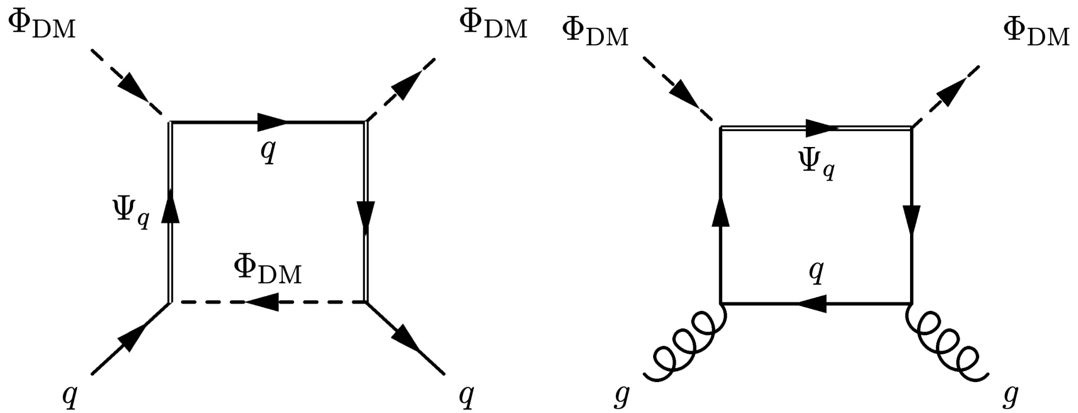
Why do we need radiative corrections?

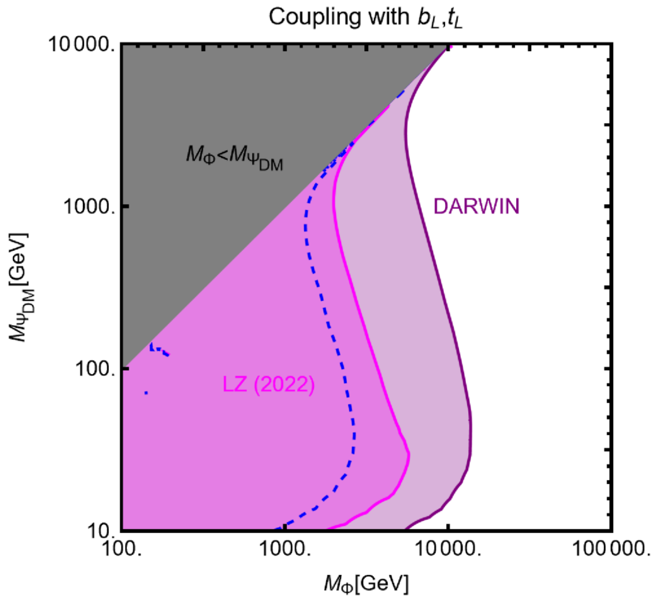
Coupling 1º generation





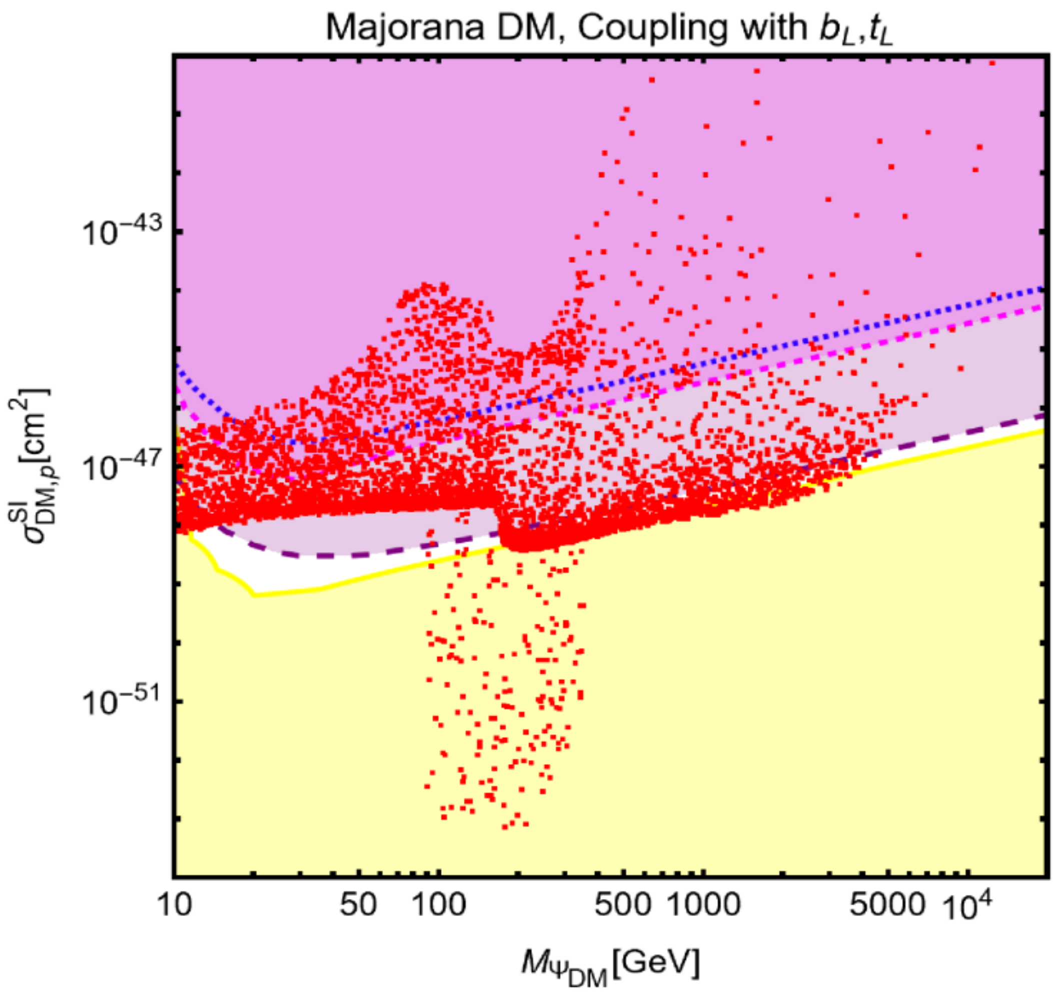
Coupling 2º & 3º generation





Scan with RD & DD bounds

$$M_{\Phi_{\rm DM},\Psi_{\rm DM}} \in \left[10, 10^5\right]\ \text{GeV} \qquad M_{\Phi_f,\Psi_f} \in \left[100, 10^5\right]\ \text{GeV} \qquad \Gamma^f_{L,R} \in \left[10^{-3}, \sqrt{4\pi}\right]$$



More scenarios in:
JCAP 02(2024)005

Conclusions

- Complete matching for both scalars and fermionic DM candidates to DD EFT Lagrangian.
- Strong bounds for the Complex case and Dirac case, with the exception of the very fine-tuned coannihilation region.
- Real DM weaker DD constrains but very suppressed annihilation cross-section which also strongly constrain the candidate.
- Majorana DM results the most favored among the ones considered in this work and the only allowing for viable masses of order or below 100 GeV.

Thank You!

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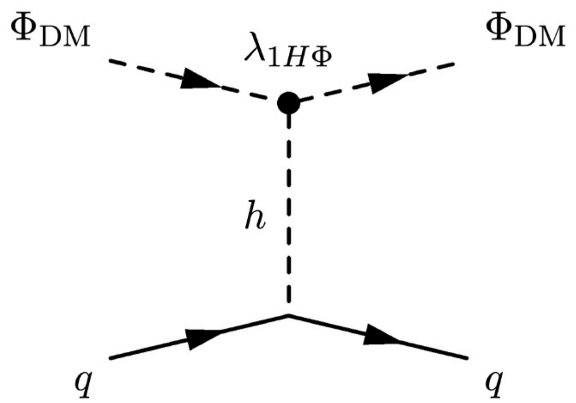
Back up

Hidden Higgs portal

$$\lambda_{1H\Phi}^{(0)} = \lambda_{1H\Phi}(\mu) + \sum_f \frac{g^2 m_f^2 \left|\Gamma_{L,R}^f\right|^2}{16\pi^2 m_W^2} \left(\frac{1}{\varepsilon} + \log\frac{\mu^2}{m_f^2}\right)$$



Without resummation:

$$\lambda_{1H\Phi}(\mu) = \lambda_{1H\Phi}(M) - \log\frac{\mu^2}{M^2} \sum_f \frac{g^2 m_f^2 \left|\Gamma_{L,R}^f\right|}{16 m_W^2 \pi^2}$$

Velocity expansion

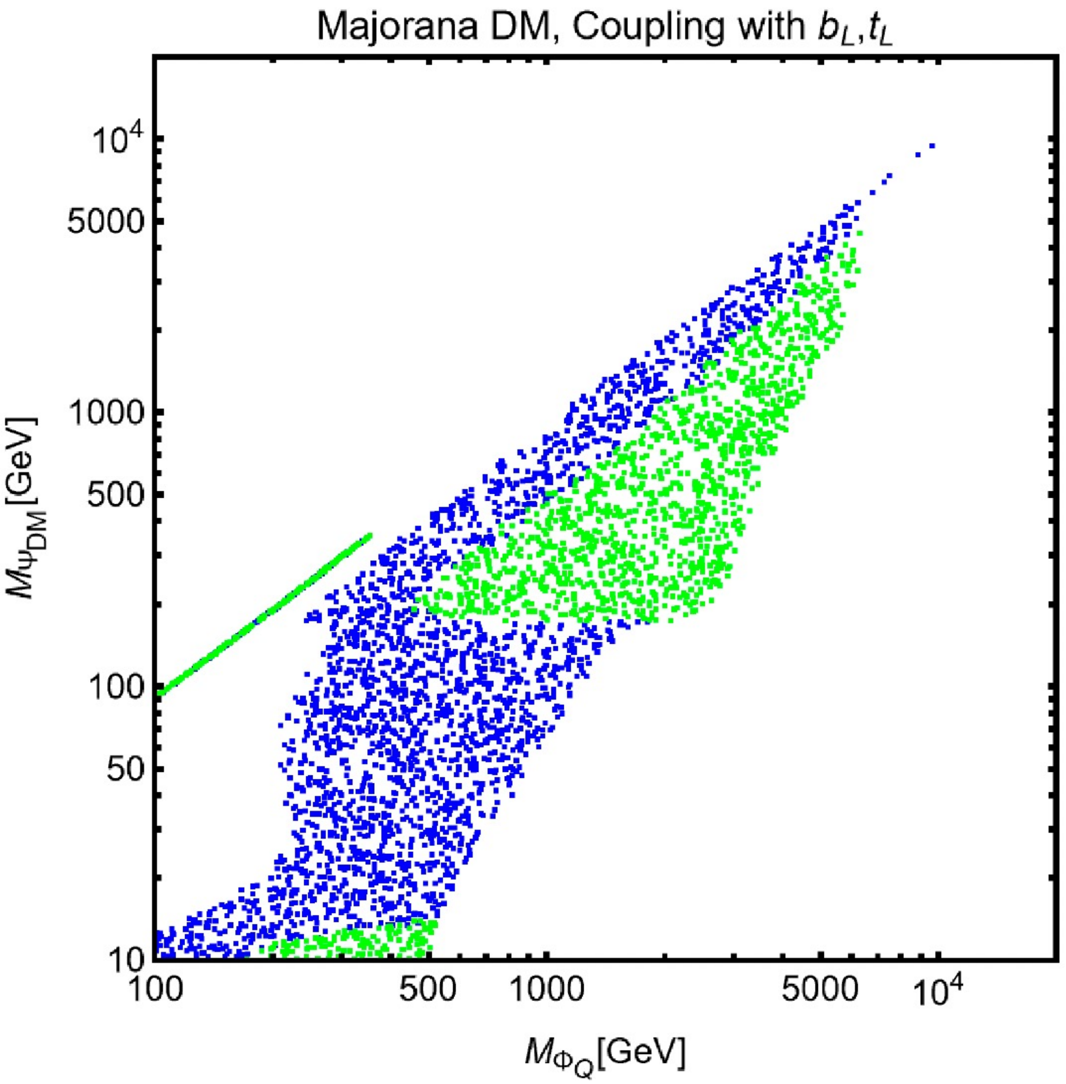
$$\langle\sigma v\rangle^{\text{Majorana}}_{\text{DMDM}} = \sum_f N_c^f \frac{\left|\Gamma^f_{L,R}\right|^4 M^2_{\Psi_{\text{DM}}}\left(M^4_{\Psi_{\text{DM}}} + M^4_{\Phi_f}\right) v^2}{48\pi\left(M^2_{\Psi_{\text{DM}}} + M^2_{\Phi_f}\right)^4}$$

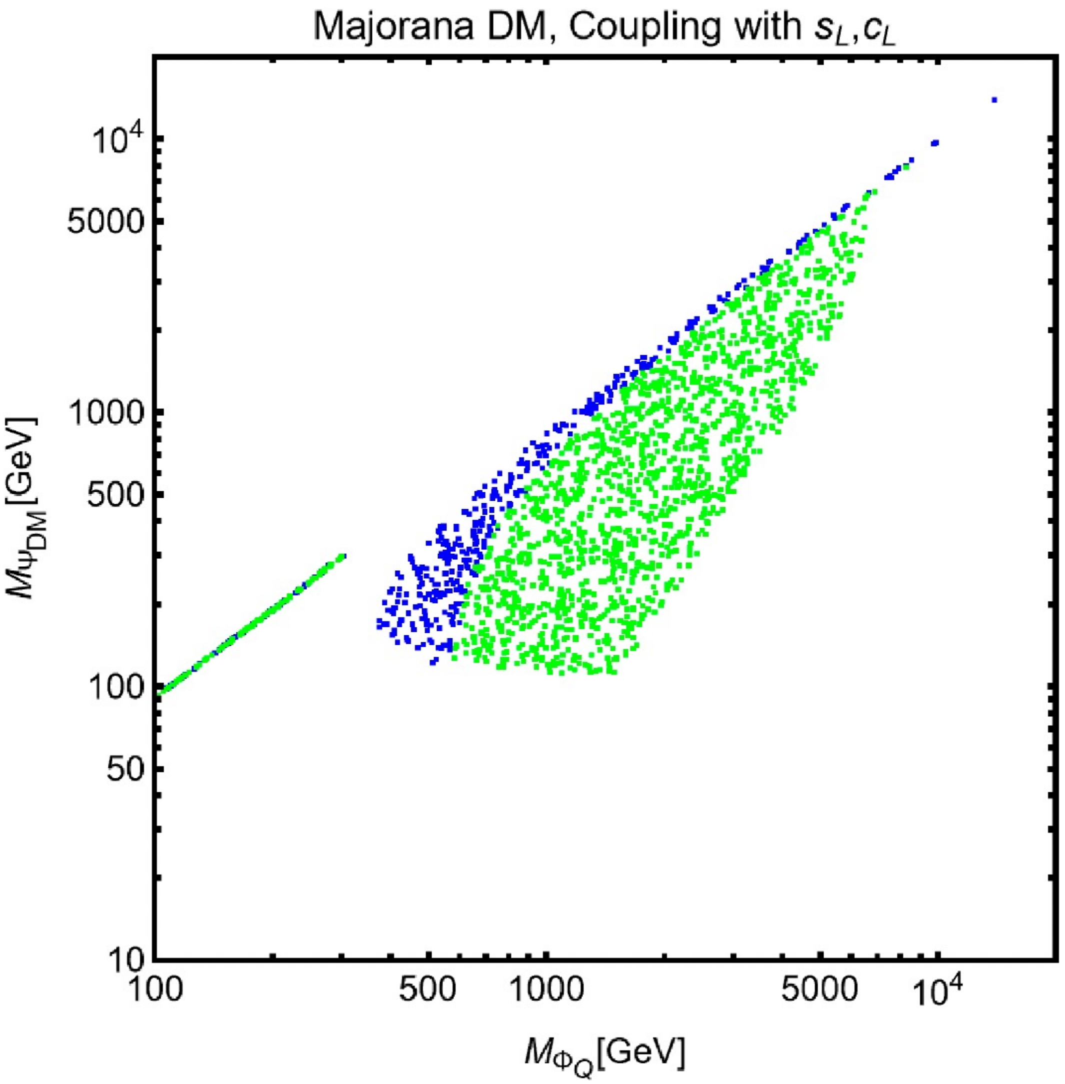
$$\langle\sigma v\rangle^{\text{Dirac}}_{\text{DMDM}} = \sum_f N_c^f \frac{\left|\Gamma^f_{L,R}\right|^4 M^2_{\Psi_{\text{DM}}}}{32\pi\left(M^2_{\Psi_{\text{DM}}} + M^2_{\Phi_f}\right)^2}$$

$$\langle\sigma v\rangle^{\text{Real}}_{\text{DMDM}} = \sum_f N_c^f \frac{\left|\Gamma^f_{L,R}\right|^4 M^6_{\Phi_{\text{DM}}} v^4}{60\pi\left(M^2_{\Phi_{\text{DM}}} + M^2_{\Psi_f}\right)^4}$$

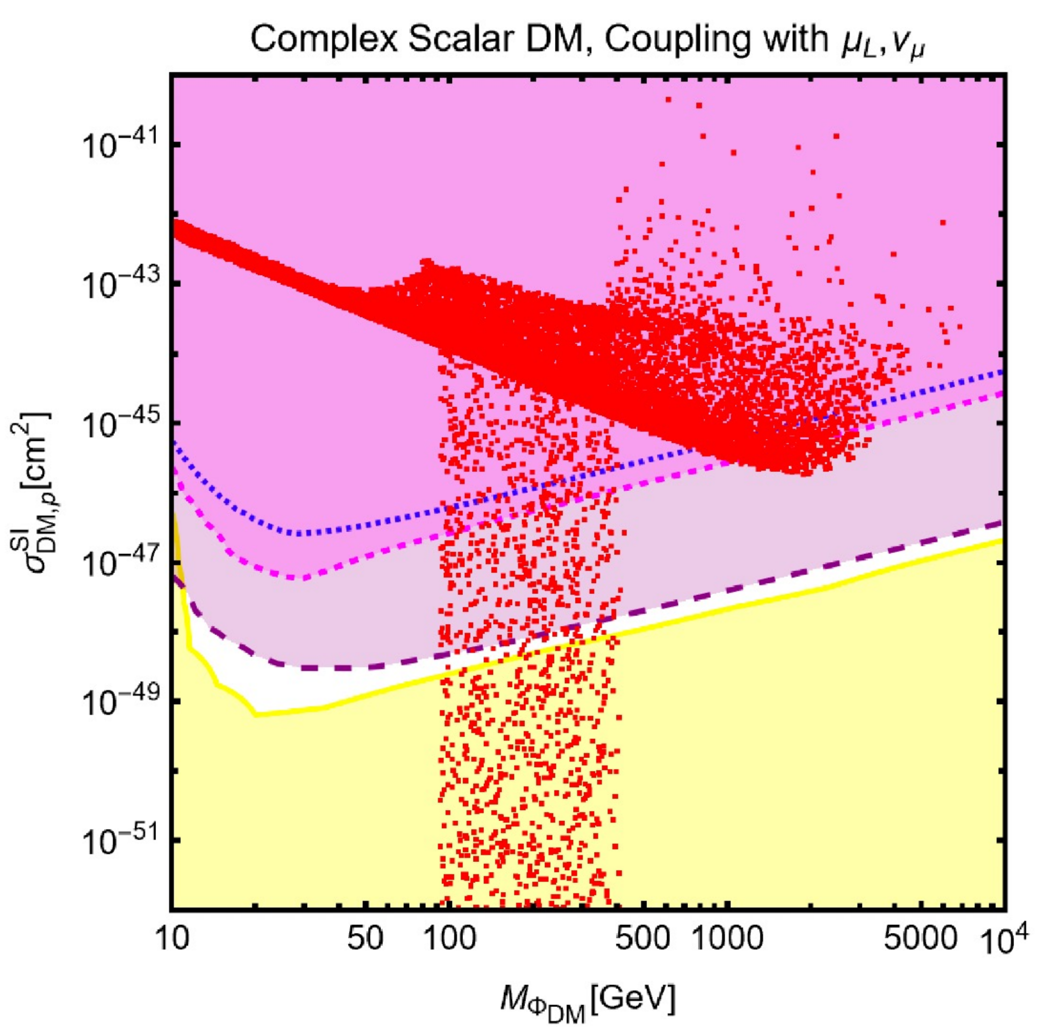
$$\langle\sigma v\rangle^{\text{Complex}}_{\text{DMDM}} = \sum_f N_c^f \frac{\left|\Gamma^f_{L,R}\right|^4 M^2_{\Phi_{\text{DM}}} v^2}{48\pi\left(M^2_{\Phi_{\text{DM}}} + M^2_{\Psi_f}\right)^2},$$

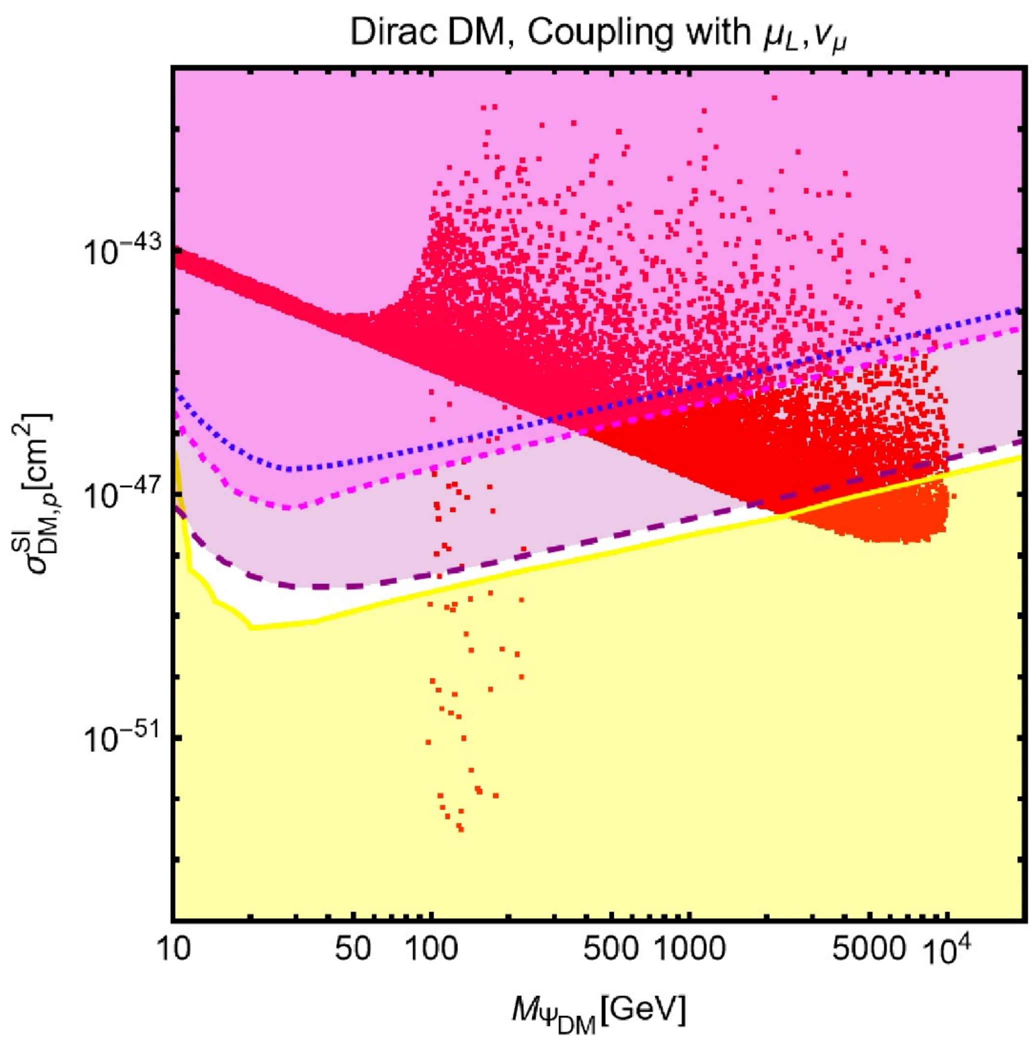
Majorana Bidimensional



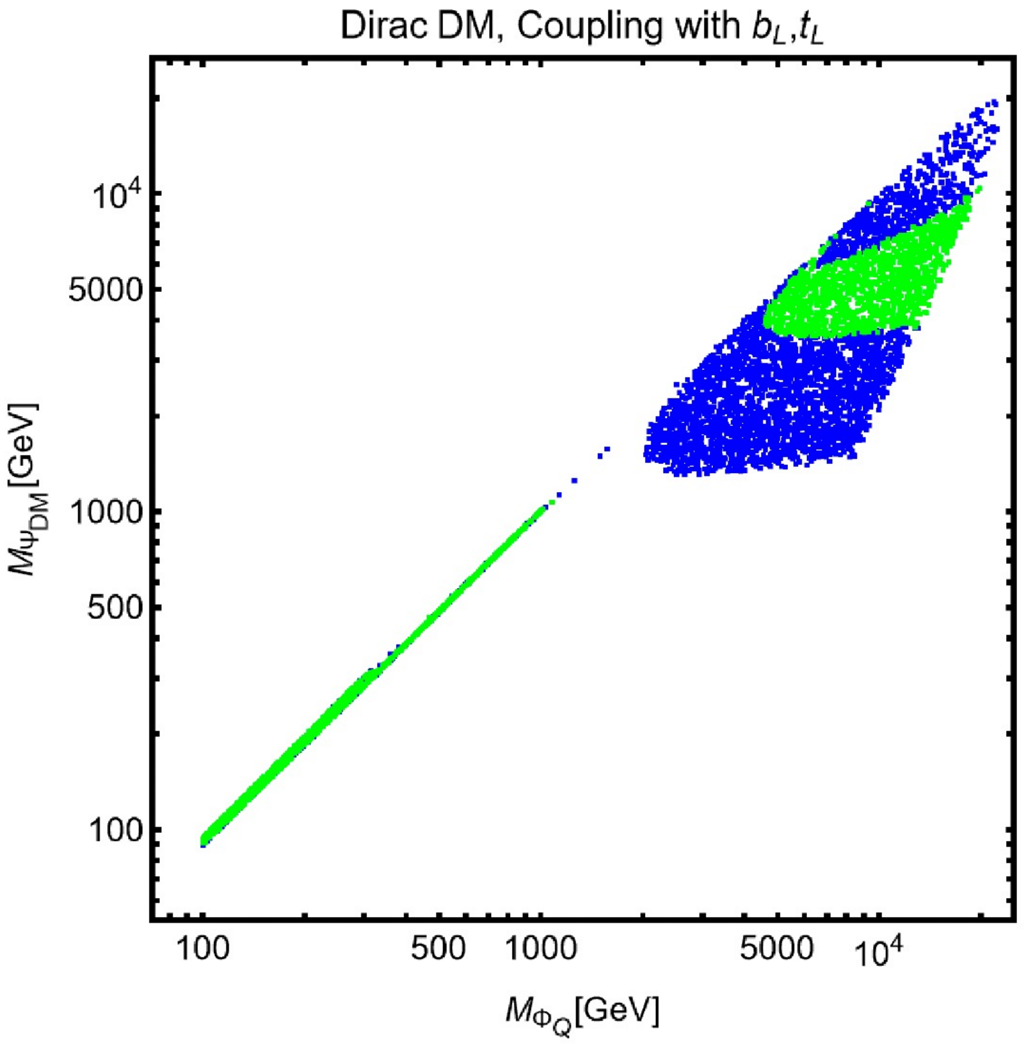


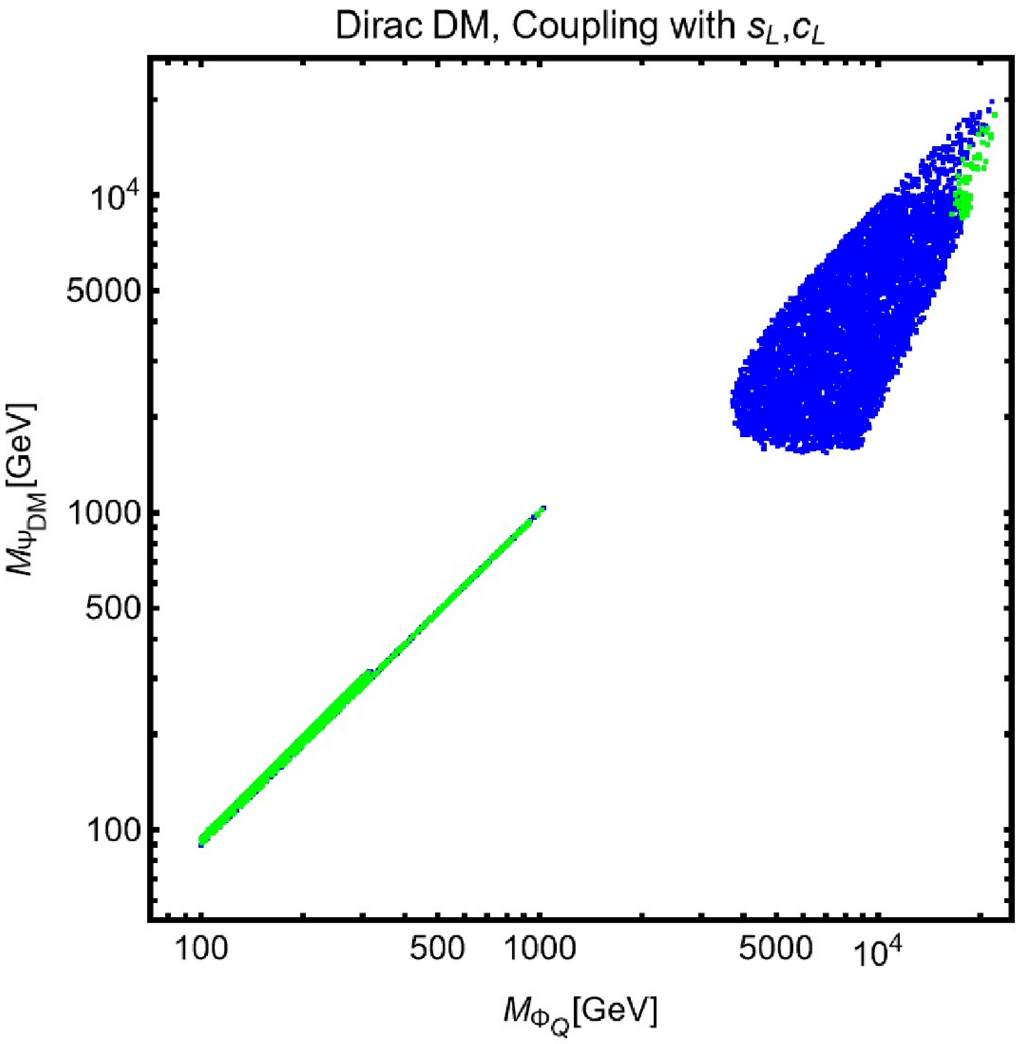
Lepton couplings



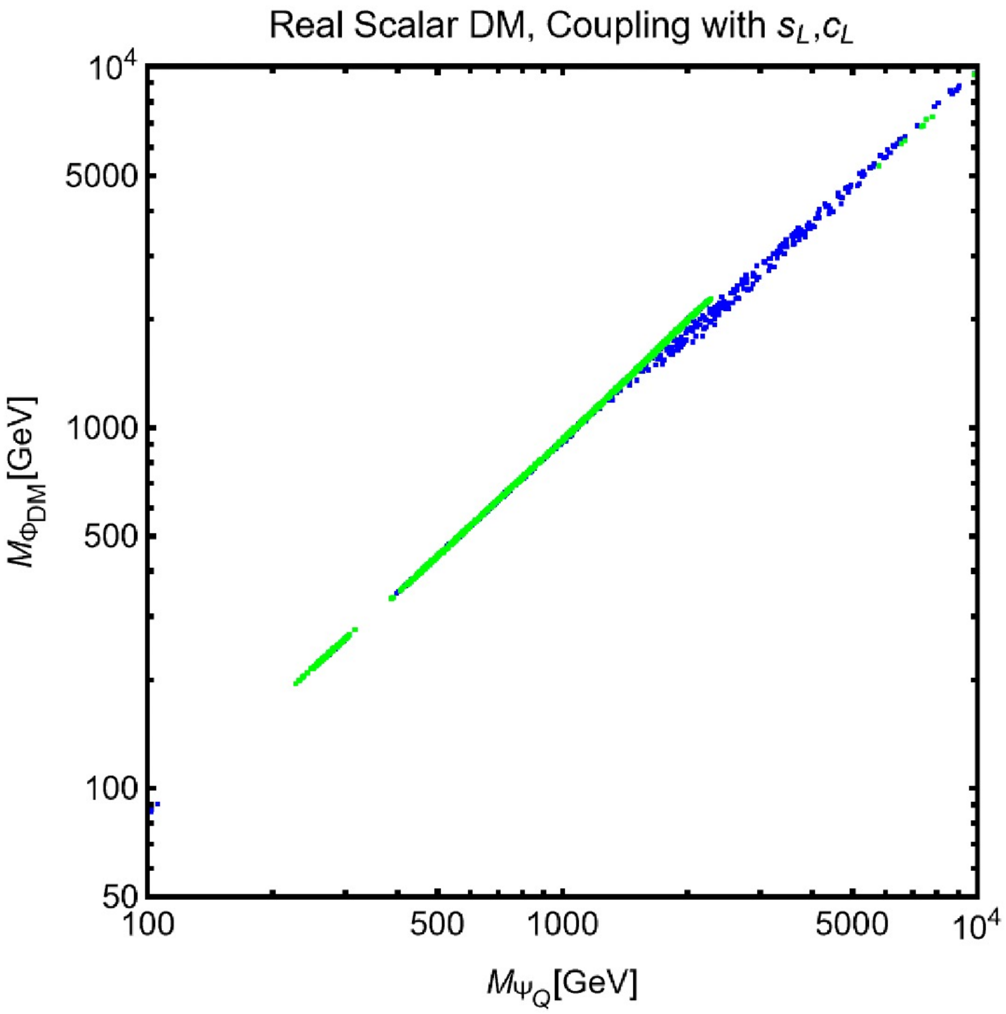


Diarc Fermion

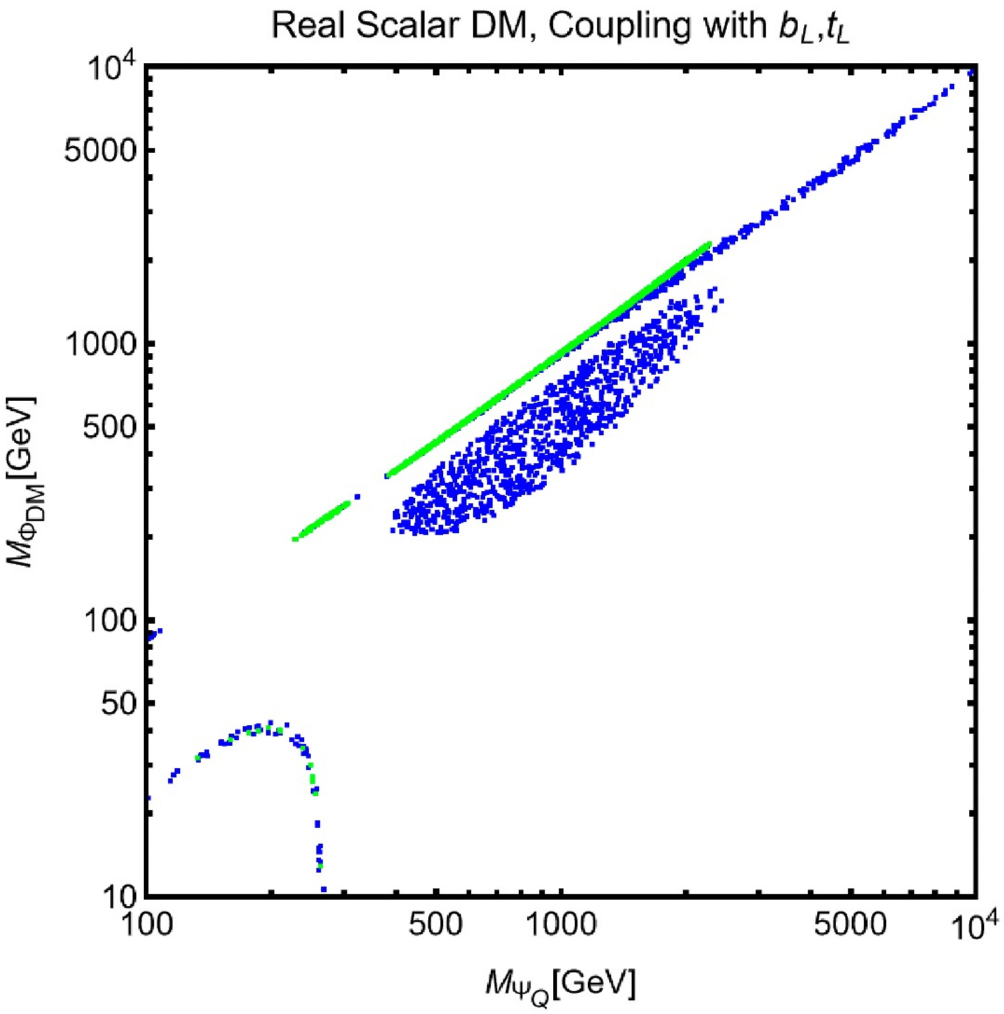




Real Scalar

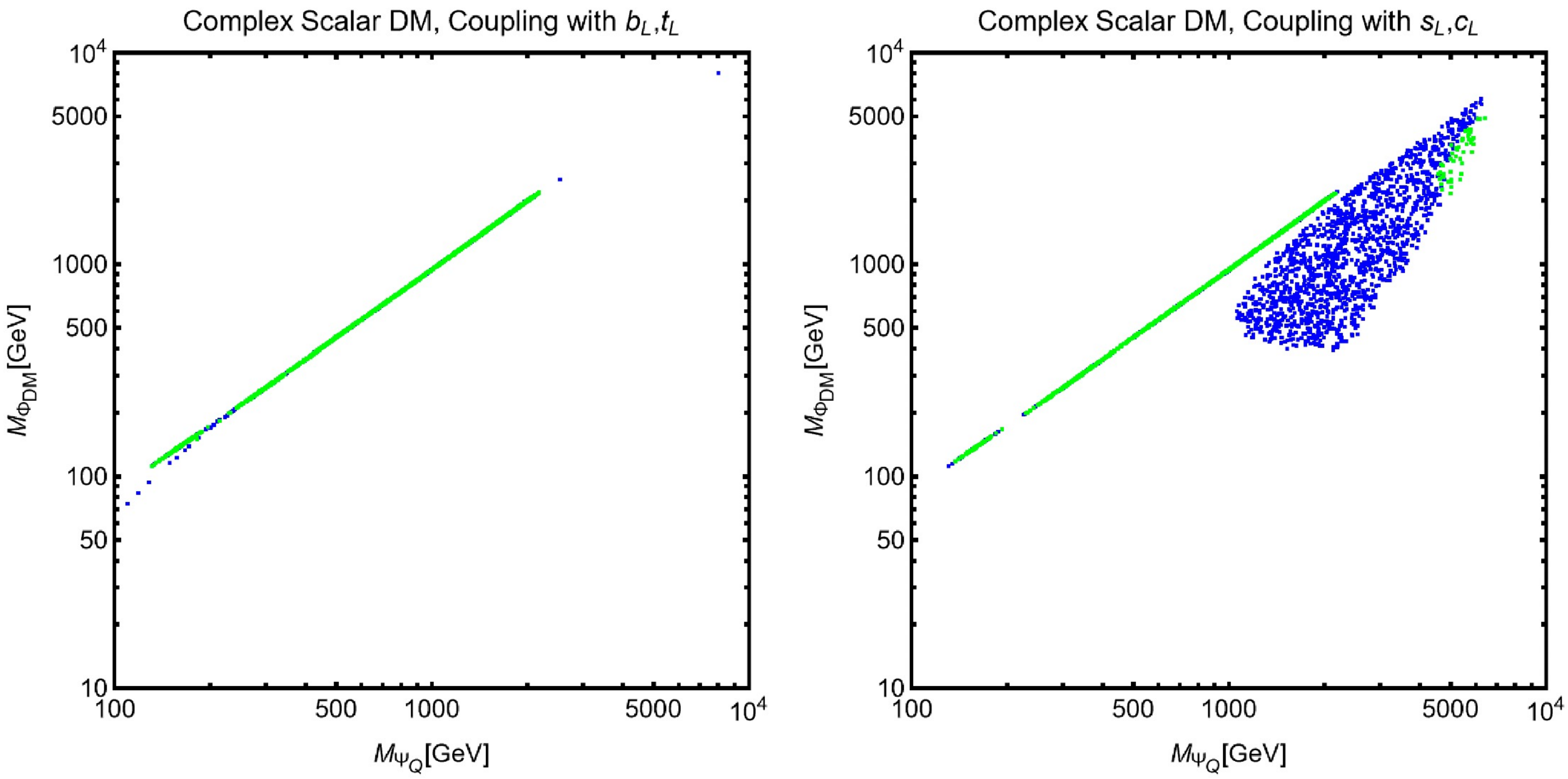


Real Scalar DM, Coupling with s_L,c_L
10^4
5000
1000
500
100
50
100
500
1000
5000
10^4
$M_{\Phi_{DM}}$[GeV]
M_{Ψ_Q}[GeV]

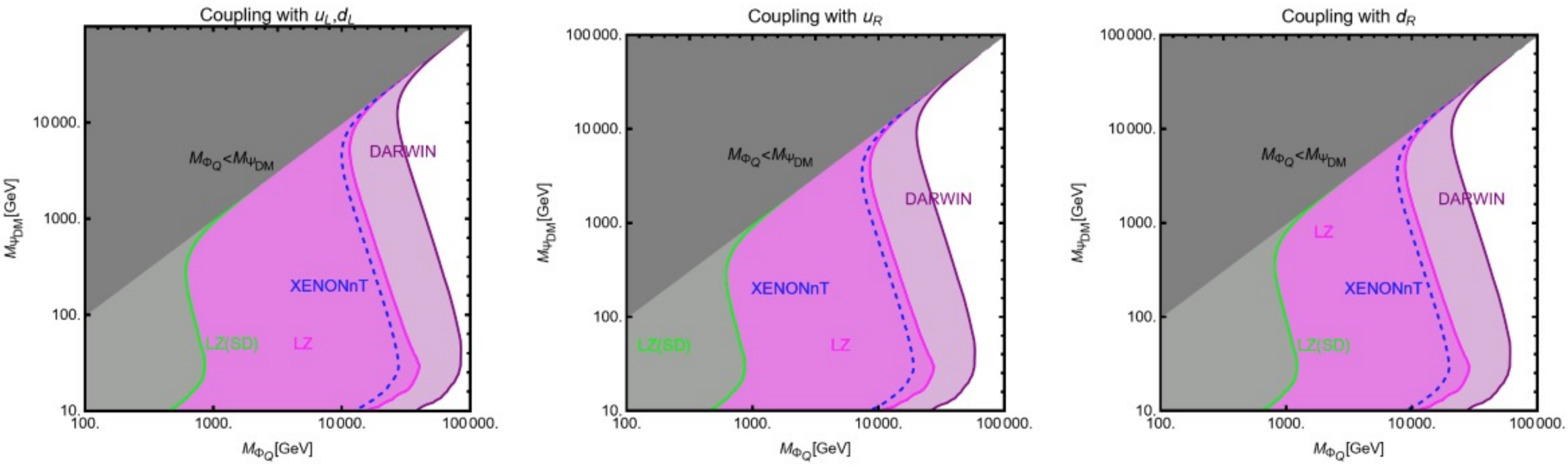


Real Scalar DM, Coupling with b_L,t_L
10^4
5000
1000
500
100
50
10
100
500
1000
5000
10^4
$M_{\Phi_{DM}}$[GeV]
M_{Ψ_Q}[GeV]

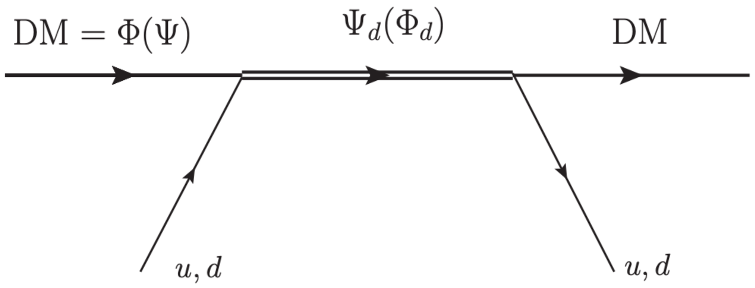
Complex Scalar



Tree-level couplings



Tree level in real DM scenario



$$c^q \left(\Phi^\dagger_{\mathrm{DM}} i \overset{\leftrightarrow}{\partial}_\mu \Phi_{\mathrm{DM}} \right) \bar{q} \gamma^\mu q$$

Tree level contribution to the Wilson Coefficient

However,…

This operator dosen't exist for:

- Complex Real
- Majorana Fermion

$$c^q \left(\Phi^\dagger_{\mathrm{DM}} i \overset{\leftrightarrow}{\partial}_\mu \Phi_{\mathrm{DM}} \right) \bar{q} \gamma^\mu q$$