Dark Matter Direct Detection in t-channel mediator models

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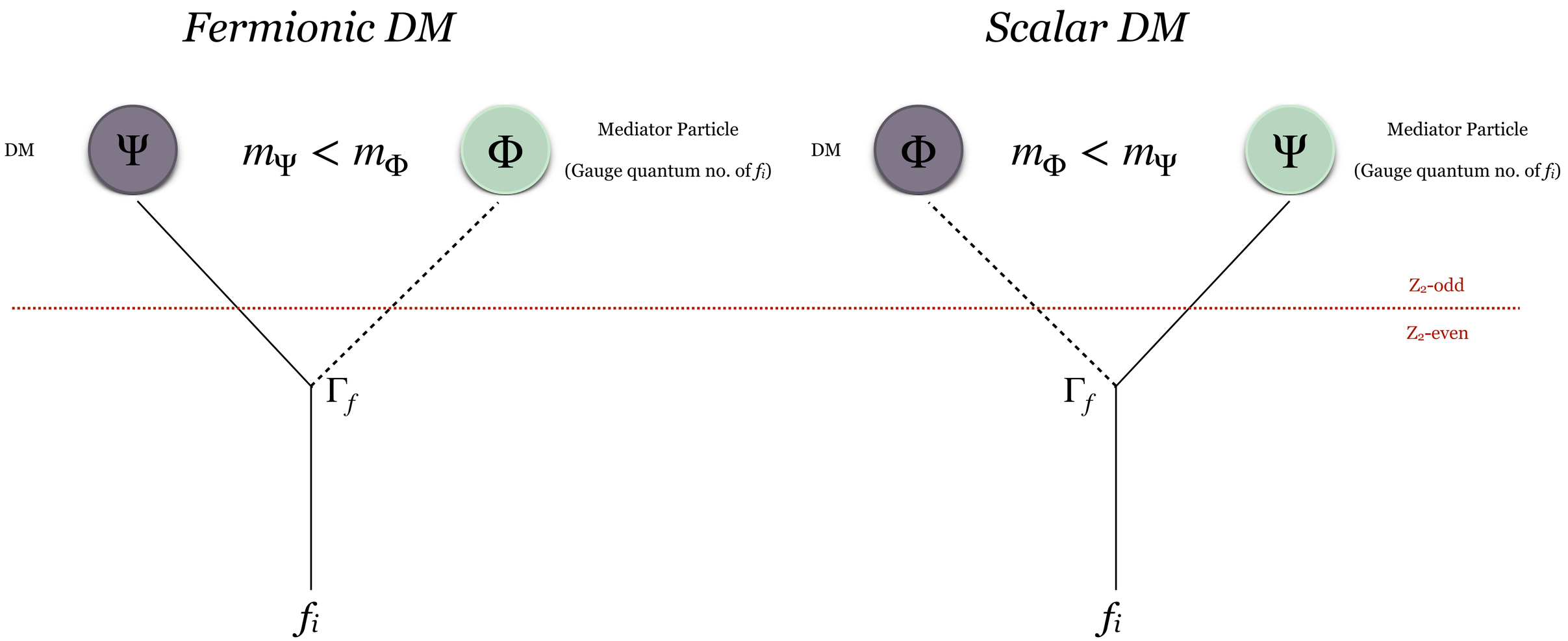
T-channel mediator Dark Matter



Model

$$\mathscr{L}_{\text{scalar}} = \Gamma_L^{f_i} \bar{f}_i P_R \Psi_{f_i} \Phi_{\text{DM}} + \Gamma_R^{f_i} \bar{f}_i P_L \Psi_{f_i} \Phi_{DM} + \text{ h.c.}$$

$$+\lambda_{1H\Phi} \left(\Phi_{DM}^\dagger \Phi_{DM} \right) \left(H^\dagger H \right) + \lambda_2 H\Phi \left(\Phi_{DM}^\dagger T_\Phi^a \Phi_{DM} \right) \left(H^\dagger \frac{\sigma^a}{2} H \right)$$

$$\mathscr{L}_{\text{fermion}} = \Gamma_L^{f_i} \bar{f}_i P_R \Phi_{f_i} \Psi_{\text{DM}} + \Gamma_R^{f_i} \bar{f}_i P_L \Phi_{f_i} \Psi_{DM} + \text{ h.c.}$$

$$+\lambda_{1H\Phi} \left(\Phi_{f_i}^\dagger \Phi_{f_i} \right) \left(H^\dagger H \right) + \lambda_{2H\Phi} \left(\Phi_{f_i}^\dagger T_\Phi^a \Phi_{f_i} \right) \left(H^\dagger \frac{\sigma^a}{2} H \right)$$

Model

$$\mathscr{L}_{\text{scalar}} = \Gamma_L^{f_i} \bar{f}_i P_R \Psi_{f_i} \Phi_{\text{DM}} + \Gamma_R^{f_i} \bar{f}_i P_L \Psi_{f_i} \Phi_{DM} + \text{ h.c.}$$

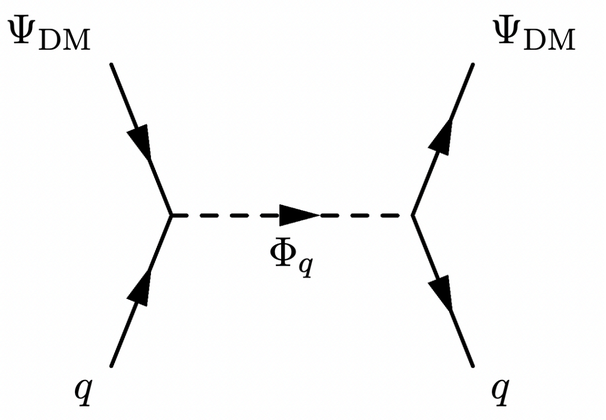
$$+\lambda_{1H\Phi} \left(\Phi_{DM}^\dagger \Phi_{DM} \right) \left(H^\dagger H \right) + \lambda_2 H\Phi \left(\Phi_{DM}^\dagger T_\Phi^a \Phi_{DM} \right) \left(H^\dagger \frac{\sigma^a}{2} H \right)$$

Theoretical reason

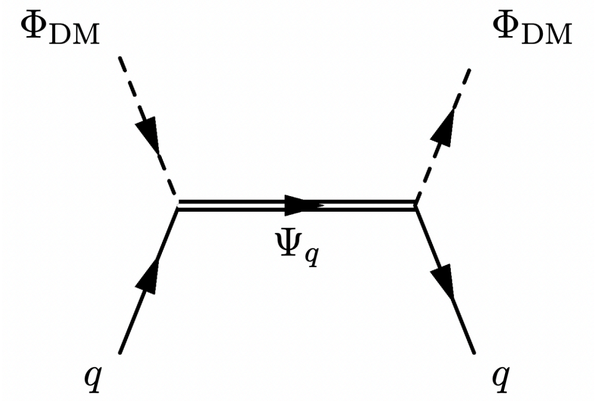
$$\mathscr{L}_{\text{fermion}} = \Gamma_L^{f_i} \bar{f}_i P_R \Phi_{f_i} \Psi_{\text{DM}} + \Gamma_R^{f_i} \bar{f}_i P_L \Phi_{f_i} \Psi_{DM} + \text{ h.c.}$$

$$+\lambda_{1H\Phi} \left(\Phi_{f_i}^\dagger \Phi_{f_i} \right) \left(H^\dagger H \right) + \lambda_{2H\Phi} \left(\Phi_{f_i}^\dagger T_\Phi^a \Phi_{f_i} \right) \left(H^\dagger \frac{\sigma^a}{2} H \right)$$

Tree-level results

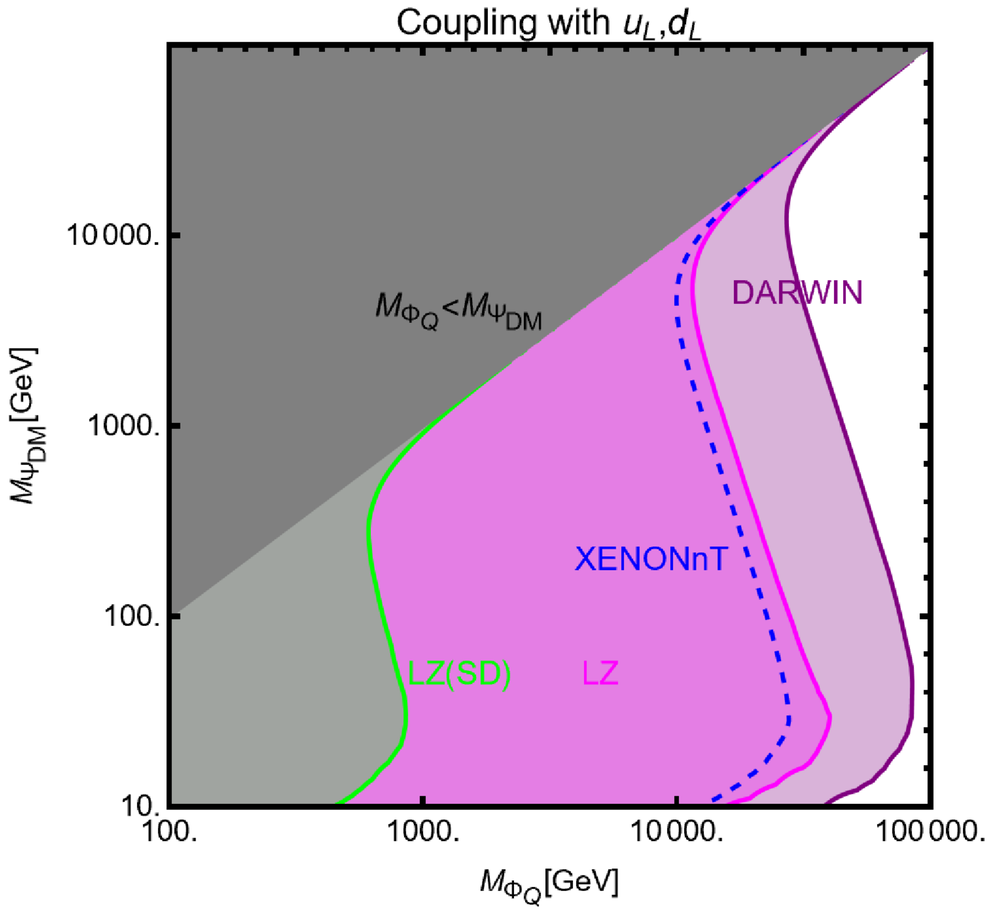


$$c^q \left(\Psi^\dagger_{\rm DM} i \overleftrightarrow{\partial_\mu} \Psi_{\rm DM} \right) \bar{q} \gamma^\mu q$$

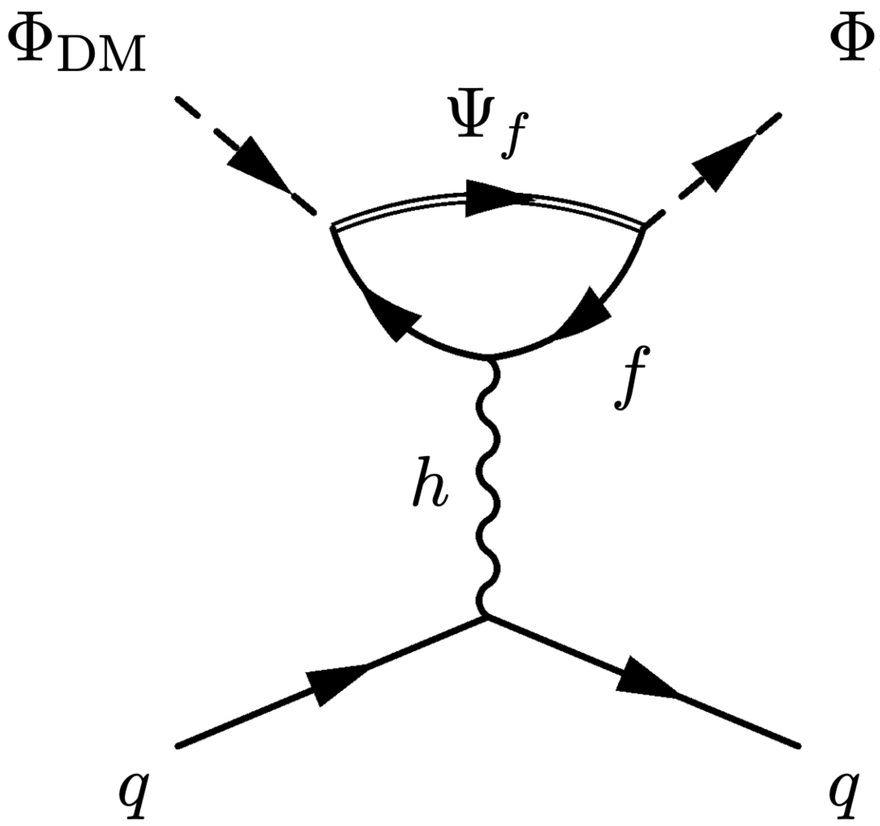


$$c^q \left(\Phi^\dagger_{\rm DM} i \overleftrightarrow{\partial_\mu} \Phi_{\rm DM} \right) \bar{q} \gamma^\mu q$$

Dirac DM

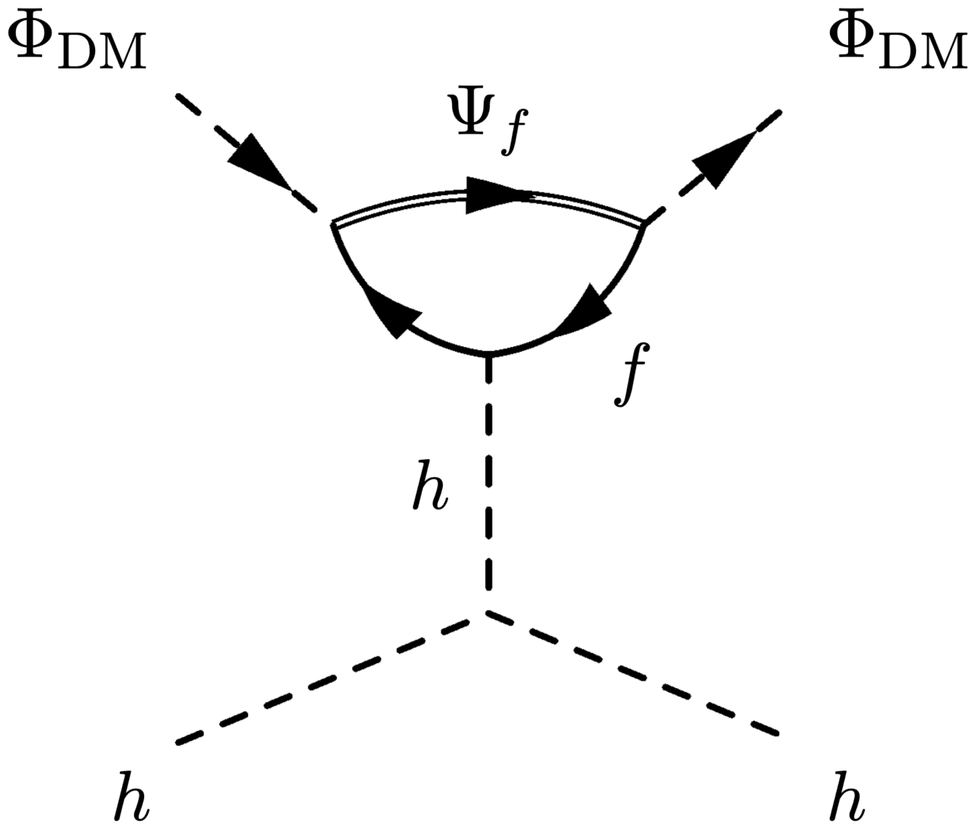


Higgs Scalar coupling



$$d_H^q = \sum_f \frac{g^2 \left|\Gamma_{L,R}^f\right|^2 m_f^2}{16\pi^2 m_H^2 m_W^2} \left(\left(\frac{1}{\varepsilon} + \log \frac{\mu^2}{m_f^2} \right) + \text{finite terms} \right)$$

Higgs Scalar coupling



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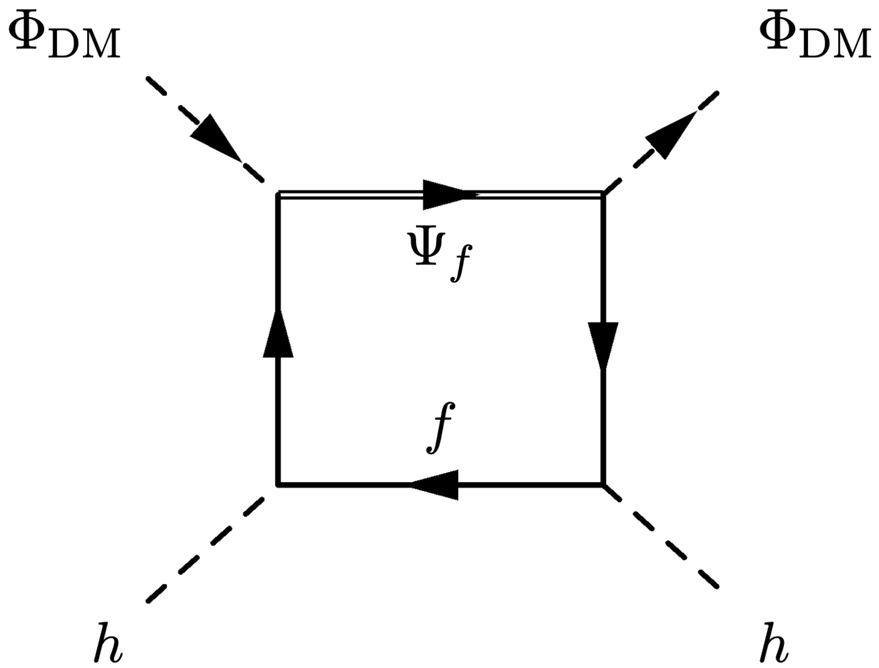
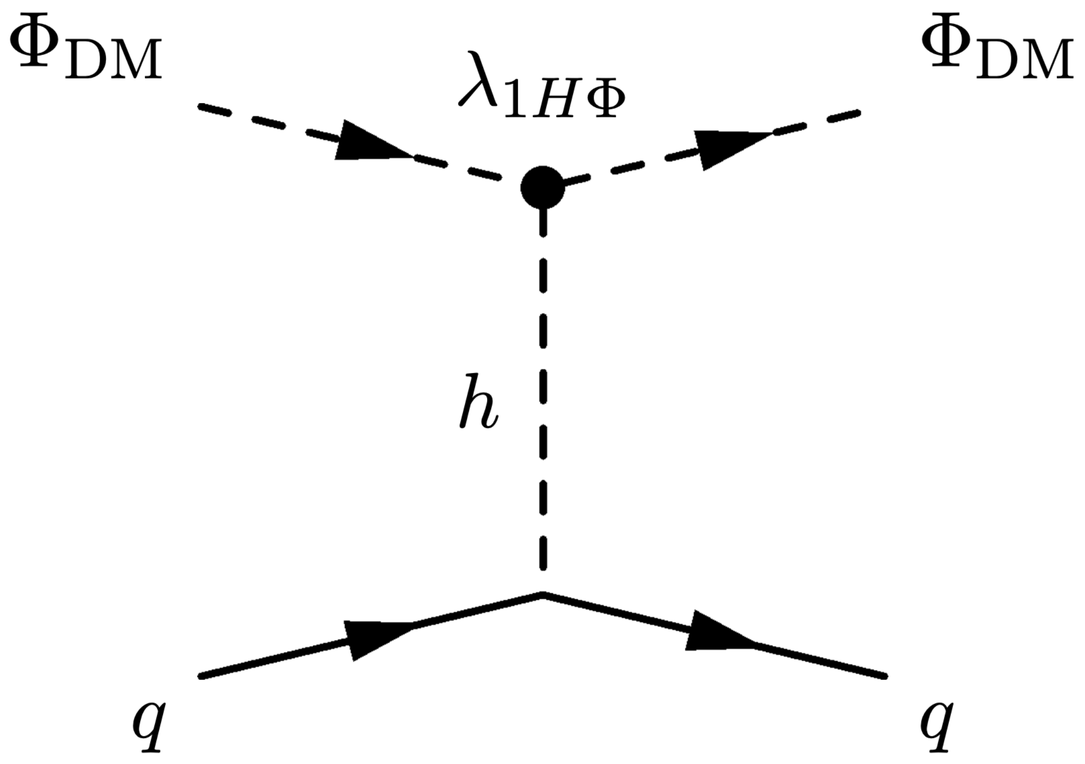


$$\mathscr{A}\left(\Phi_{\rm DM}H \to \Phi_{\rm DM}H\right) = -\sum_f \frac{g^2 m_f^2 \left|\Gamma^f_{L,R}\right|^2}{16\pi^2 m_W^2}(1-3)\left(\frac{1}{\varepsilon} + \log\frac{\mu^2}{m_f^2}\right) + \text{ counterterms } + \text{ finite },$$

Higgs Scalar coupling

$$\lambda_{1H\Phi}\left(\Phi^{\dagger}_{DM}\Phi_{DM}\right)\left(H^{\dagger}H\right)$$



Matching Scale

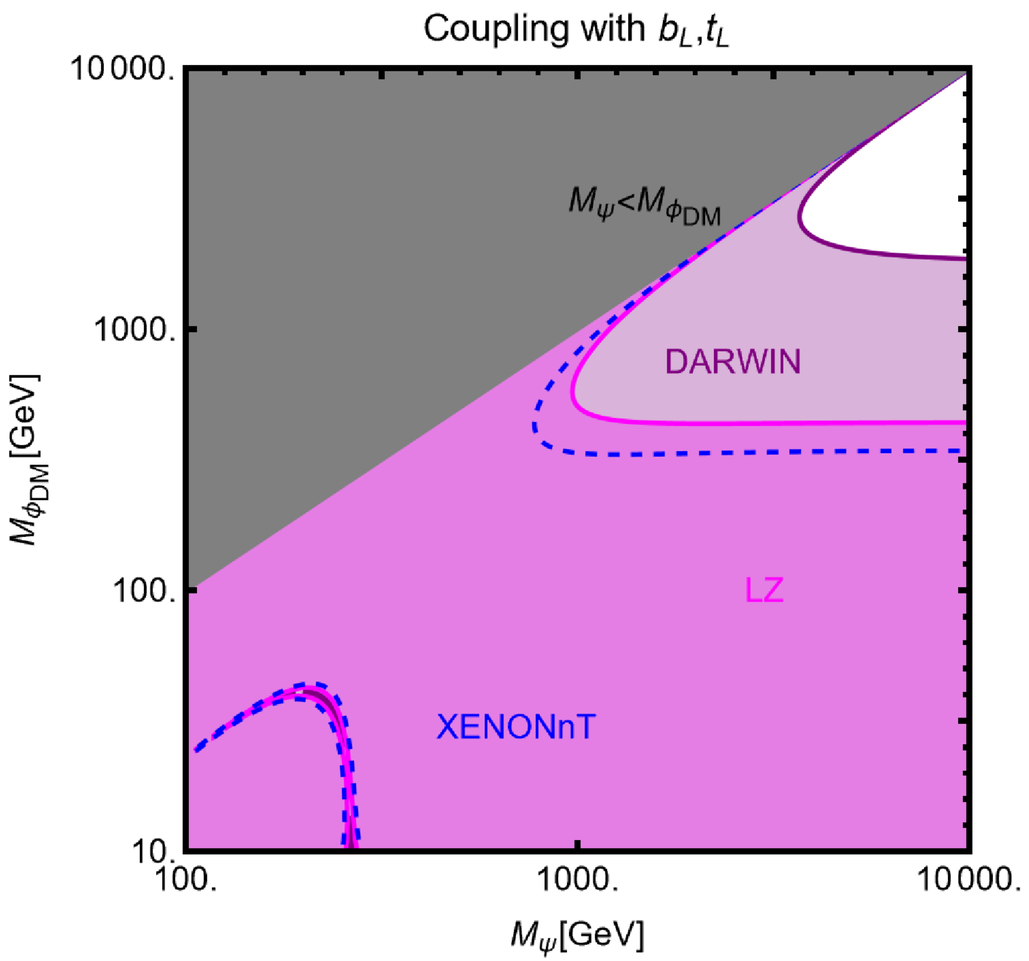
$$\lambda_{1H\Phi}(\mu) = \lambda_{1H\Phi}(M) - \log\frac{\mu^2}{M^2}\sum_f \frac{g^2 m_f^2 \left|\Gamma^f_{L,R}\right|^2}{16 m_W^2 \pi^2}$$

$$\lambda_{1H\Phi}(M_{\Psi_f}) = 0 \quad \text{But} \quad \lambda_{1H\Phi}(1GeV) \neq 0$$

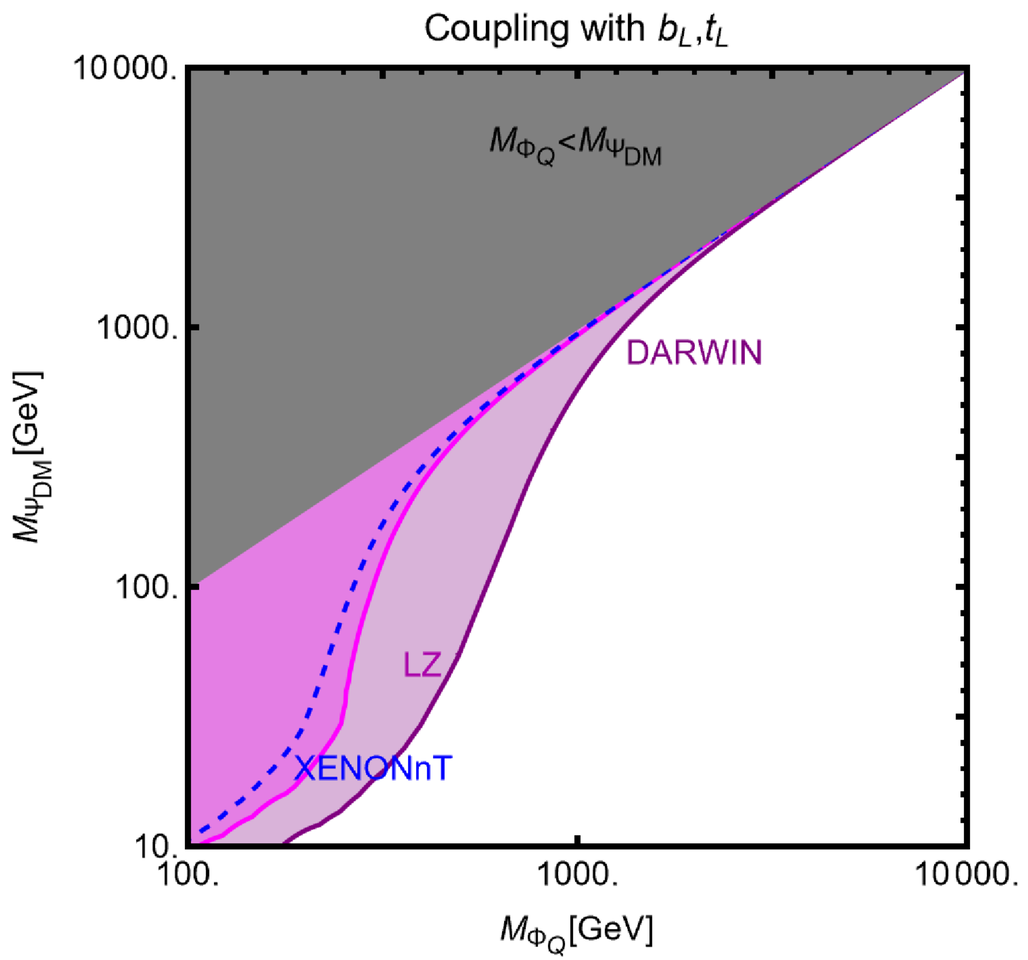
Mimic Higgs Portal

Direct Detection

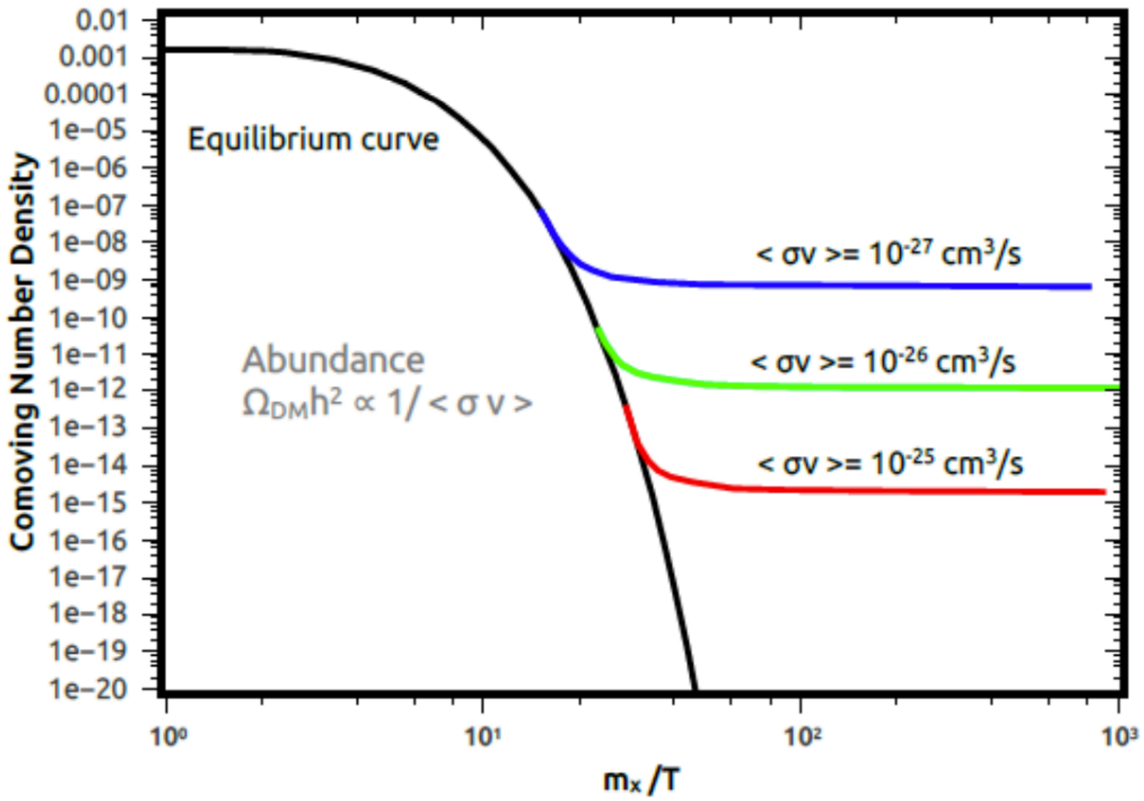
Real DM



Majorana DM



WIMP Freeze out



$$m_f \to 0$$

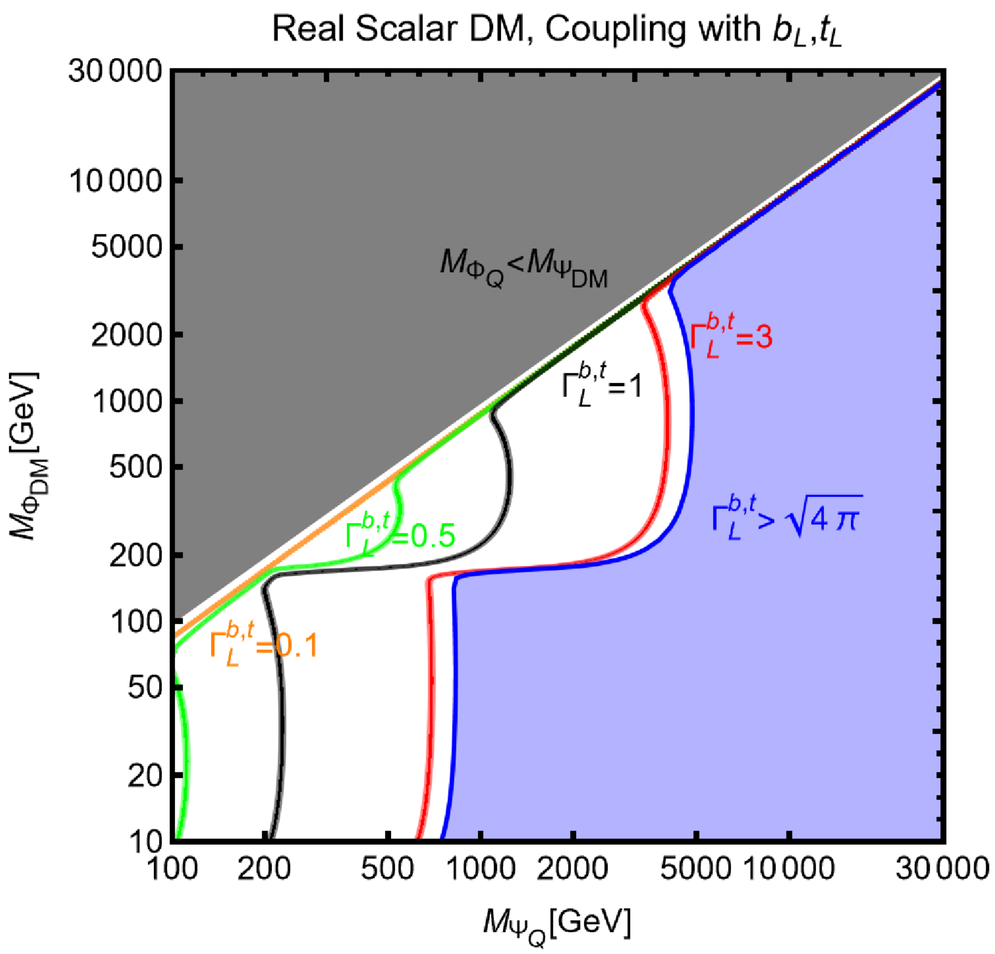
$$\langle\sigma v\rangle^{\text{Majorana}}_{\text{DMDM}} = \sum_f N_c^f \frac{\left|\Gamma^f_{L;R}\right|^4 M^2_{\Psi_{\text{DM}}}\left(M^4_{\Psi_{\text{DM}}} + M^4_{\Phi_f}\right) v^2}{48\pi\left(M^2_{\Psi_{\text{DM}}} + M^2_{\Phi_f}\right)^4}$$

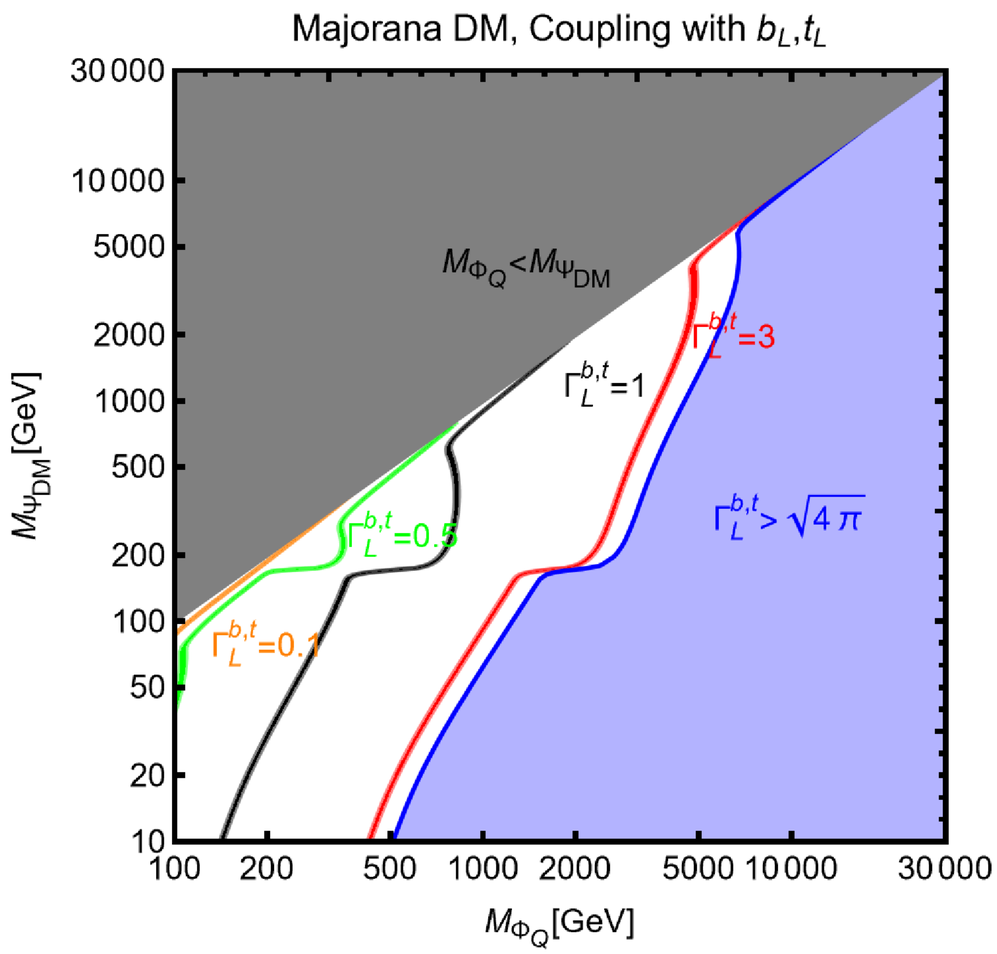
$$\langle\sigma v\rangle^{\text{Dirac}}_{\text{DMDM}} = \sum_f N_c^f \frac{\left|\Gamma^f_{L,R}\right|^4 M^2_{\Psi_{\text{DM}}}}{32\pi\left(M^2_{\Psi^2_{\text{DM}}} + M^2_{\Phi_f}\right)^2}$$

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

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

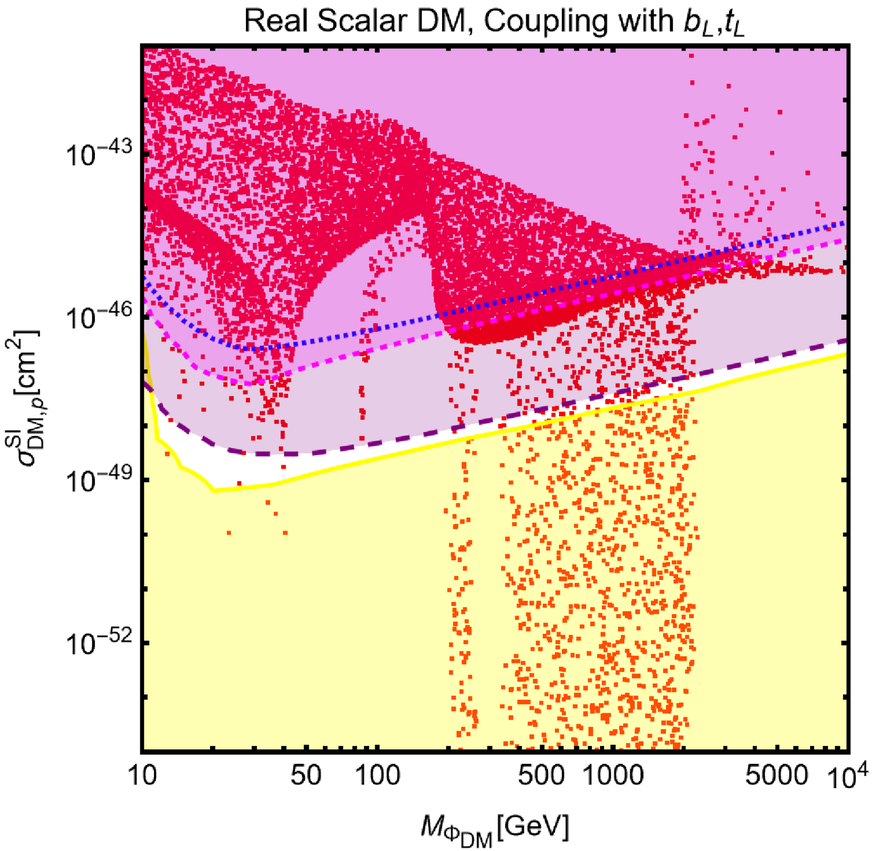
Relic Density

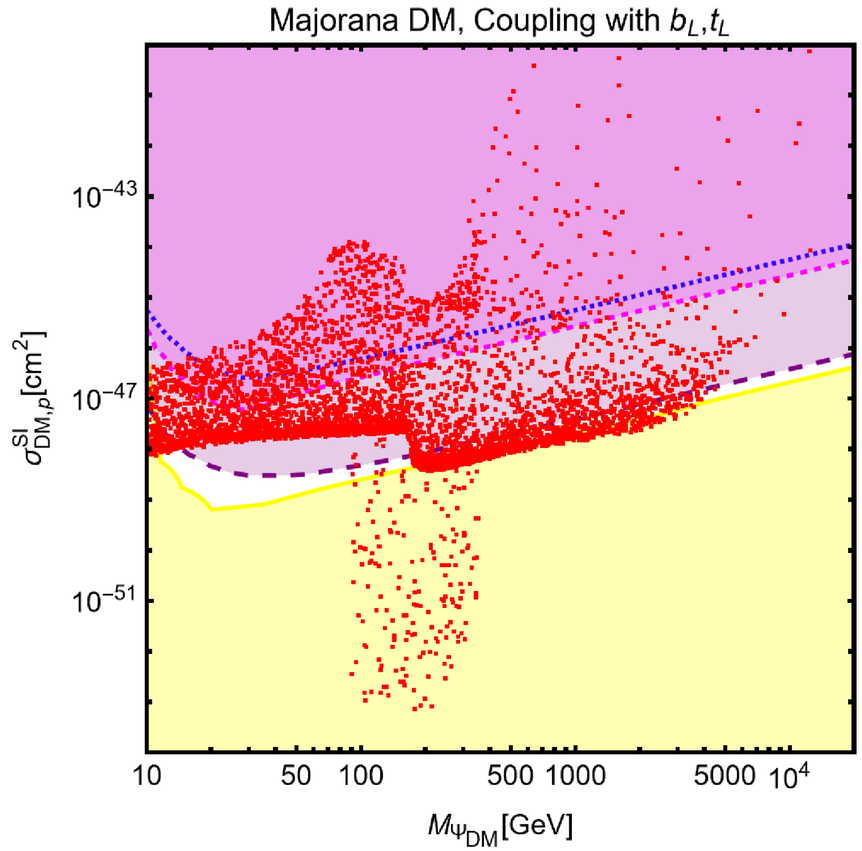




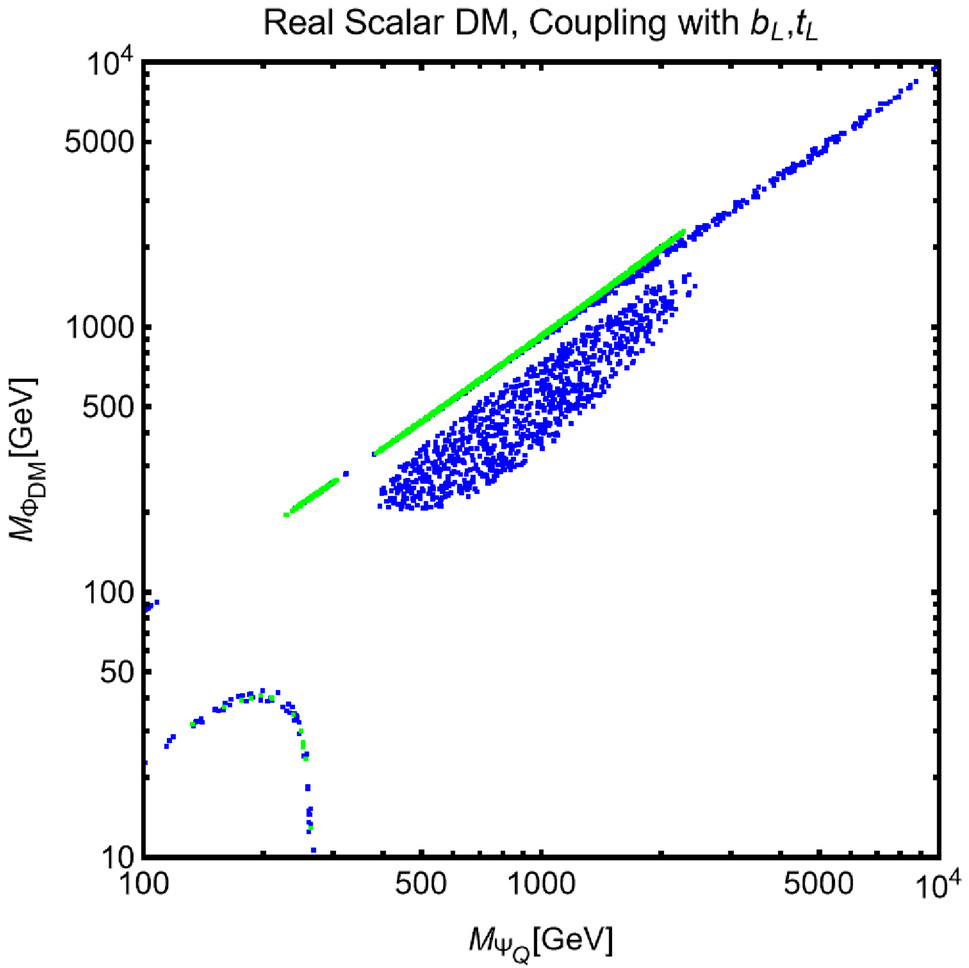
Results

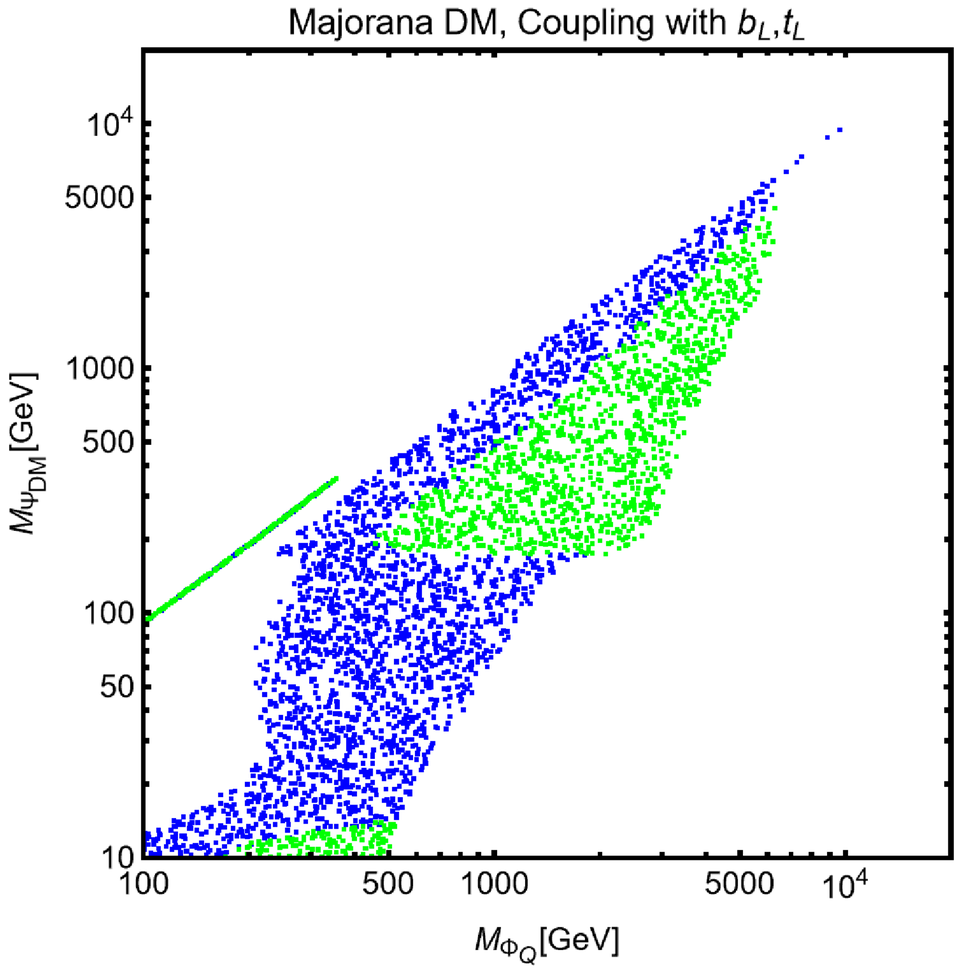
$$M_{\Phi_{\rm DM},\Psi_{\rm DM}} \in \left[10, 10^5\right] \text{GeV} \qquad M_{\Phi_f,\Psi_f} \in \left[100, 10^5\right] \text{GeV} \qquad \Gamma^f_{L,R} \in \left[10^{-3}, \sqrt{4\pi}\right]$$





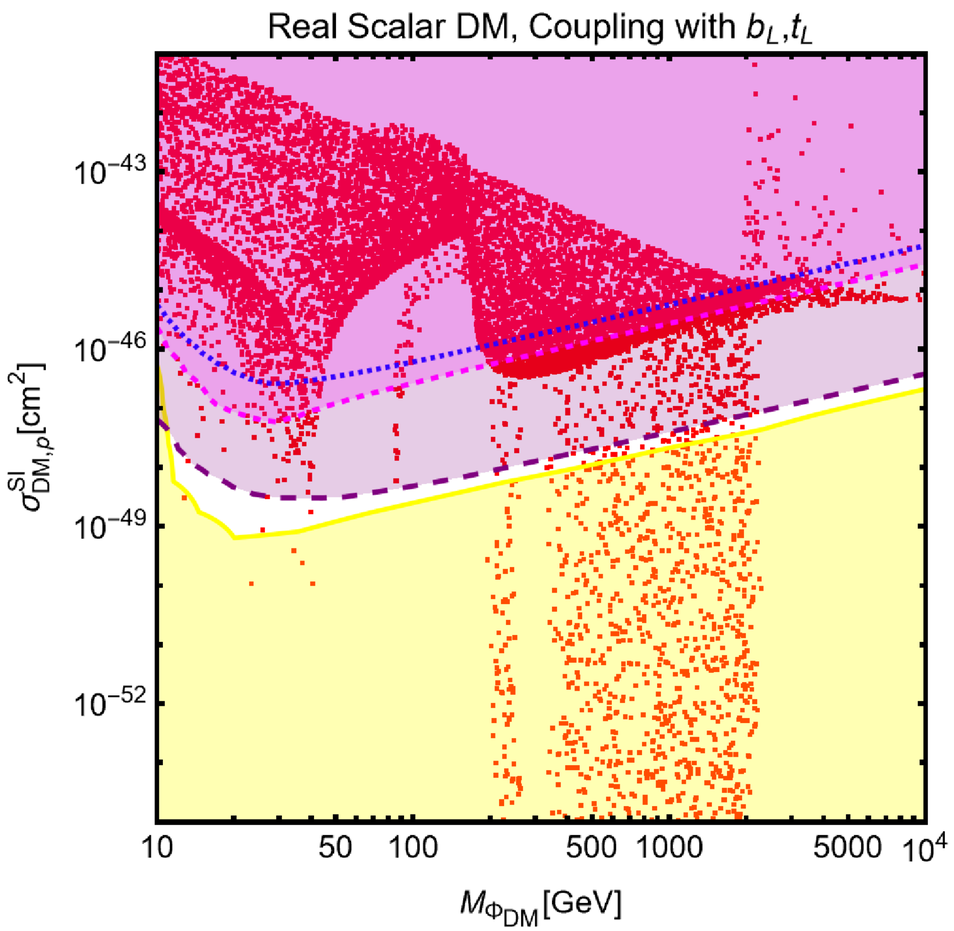
Results


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

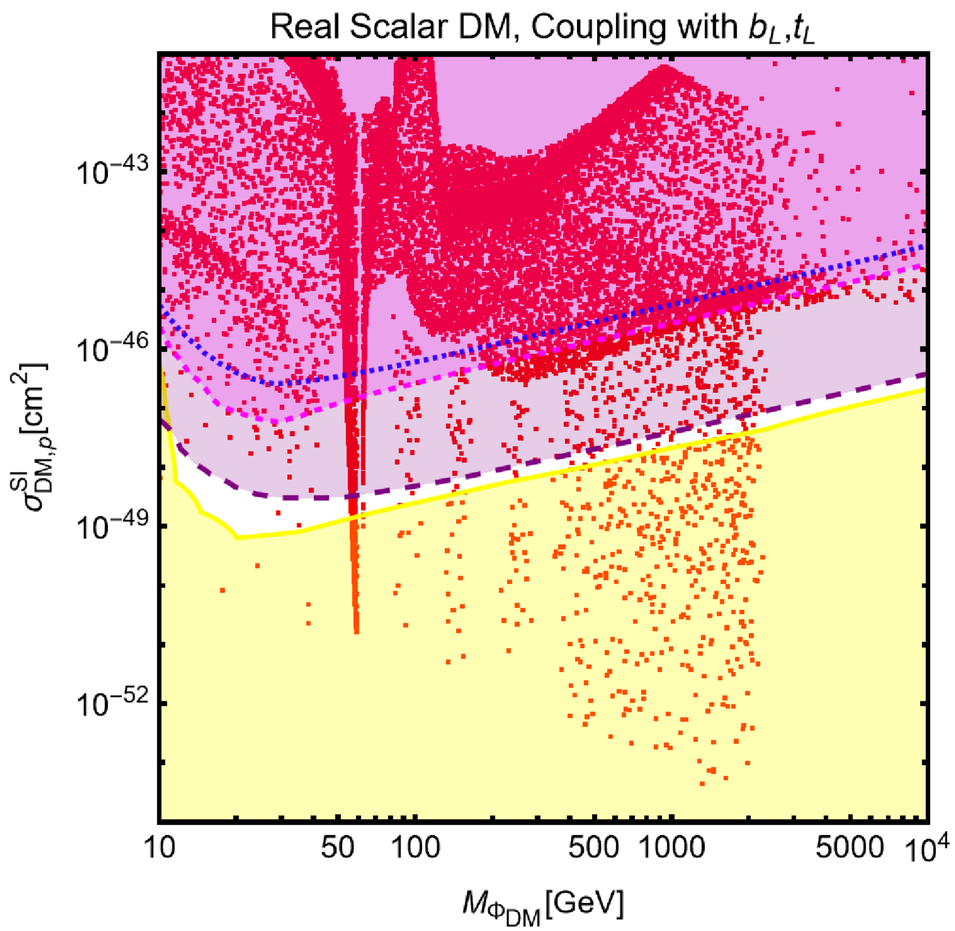

Majorana DM, Coupling with b_L,t_L
$M_{\Psi_{DM}}$[GeV]
M_{Φ_Q}[GeV]
10^4
5000
1000
500
100
50
10
100
500
1000
5000
10^4

Portal Higgs

Zero portal Higgs



Non-zero portal Higgs

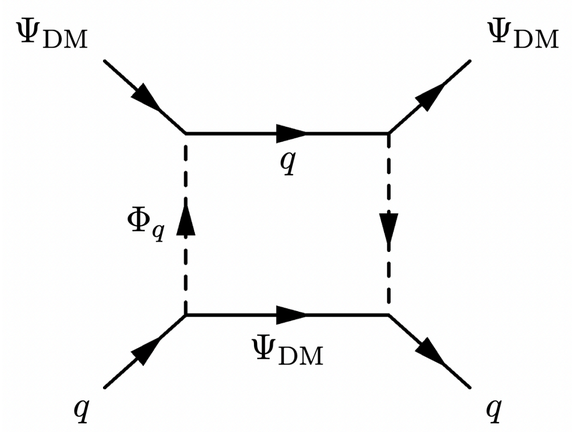


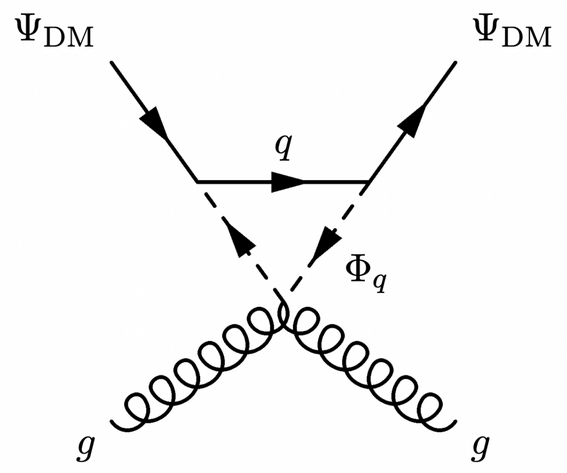
Summary

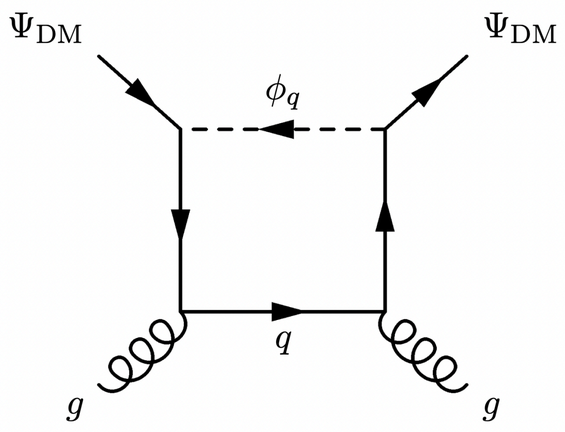
- Complete matching for both scalars and fermion DM candidates to DD EFT Lagrangian
- Strong bounds for the Complex case and Dirac case, with the exception of the very fine tuned coannihilation region.
- Real DM weaker DD constrains but very suppressed annihilation cross-section which also strongly constrain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

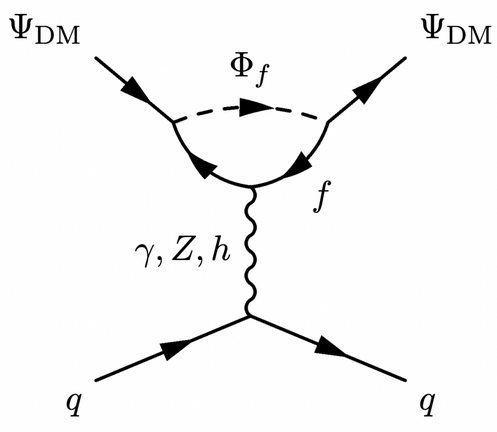
Back up

Loop Diagrams









Coannihilation

$$\langle\sigma v\rangle_{\rm eff} = \frac{1}{2}\langle\sigma v\rangle_{\rm DMDM}\frac{g_{\rm DM}^2}{g_{\rm eff}^2} + \langle\sigma v\rangle_{\rm DMM}\frac{g_{\rm DM}g_{\rm M}}{g_{\rm eff}^2}(1+\tilde{\Delta})^{3/2}\exp[-x\tilde{\Delta}]$$

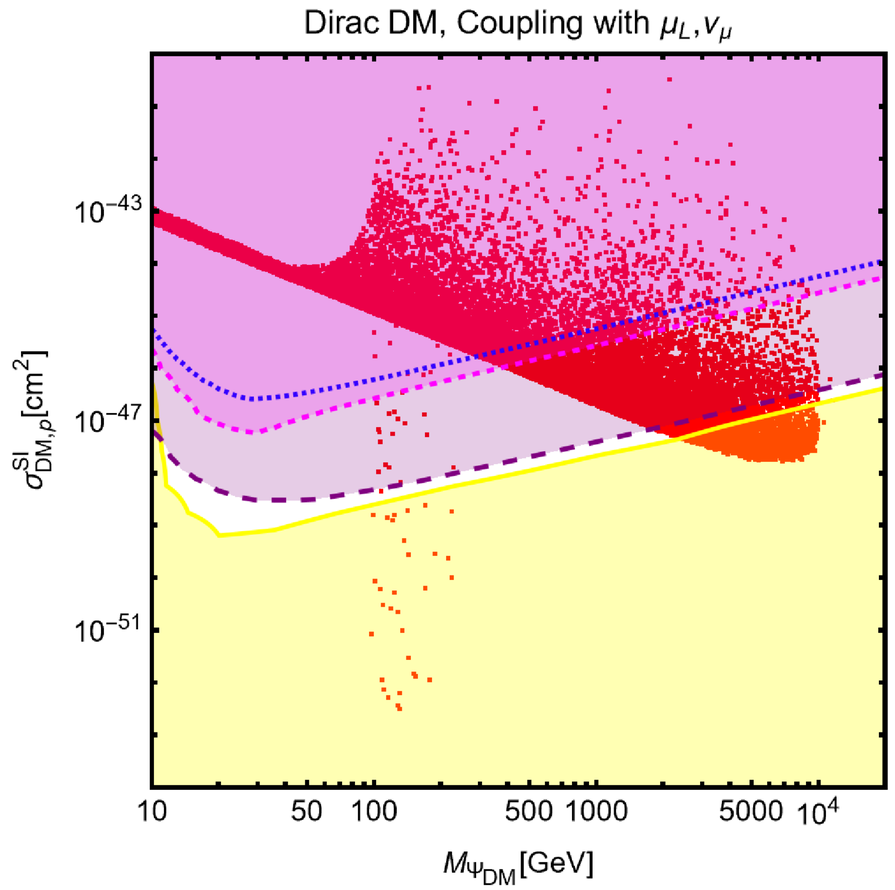
$$+\frac{1}{2}\langle\sigma v\rangle_{\rm M^\dagger M}\frac{g_{\rm M}^2}{g_{\rm eff}^2}(1+\tilde{\Delta})^{3}\exp[-2x\tilde{\Delta}]$$

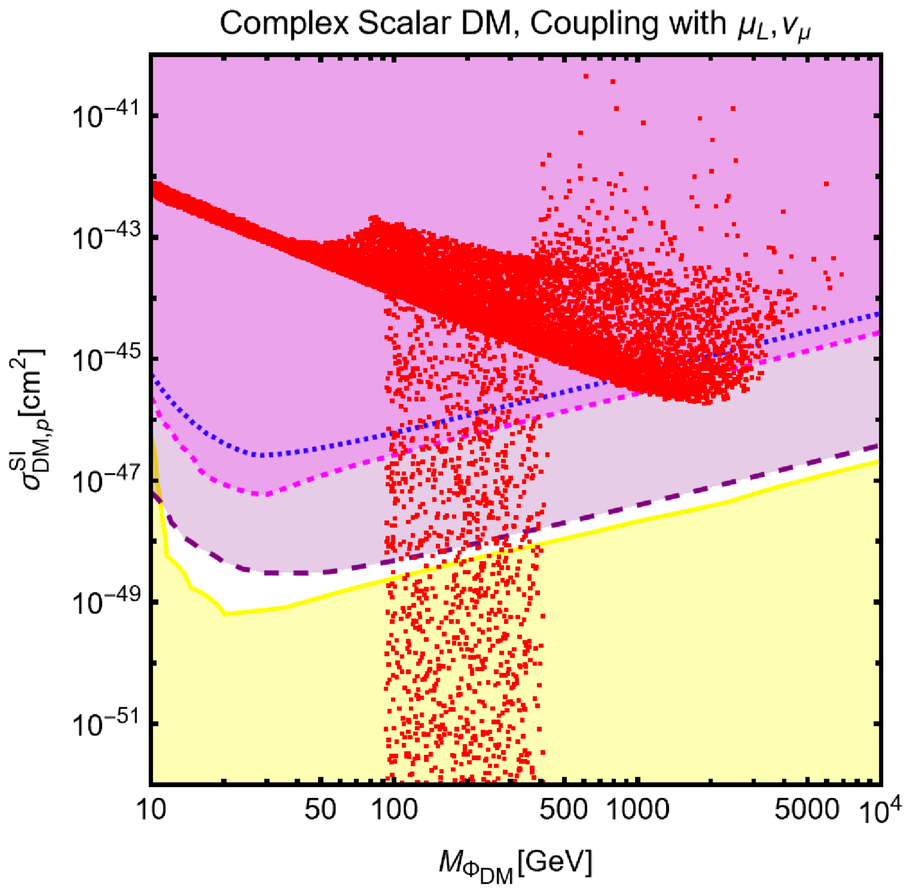
$$\langle\sigma v\rangle_{\rm eff} = \langle\sigma v\rangle_{\rm DMDM}\frac{g_{\rm DM}^2}{g_{\rm eff}^2} + \langle\sigma v\rangle_{\rm DMM}\frac{g_{\rm DM}g_{\rm M}}{g_{\rm eff}^2}(1+\tilde{\Delta})^{3/2}\exp[-x\tilde{\Delta}]$$

$$+\left(\langle\sigma v\rangle_{\rm M^\dagger M} + \langle\sigma v\rangle_{\rm MM}\right)\frac{g_{\rm M}^2}{g_{\rm eff}^2}(1+\tilde{\Delta})^{3}\exp[-2x\tilde{\Delta}]\,.$$

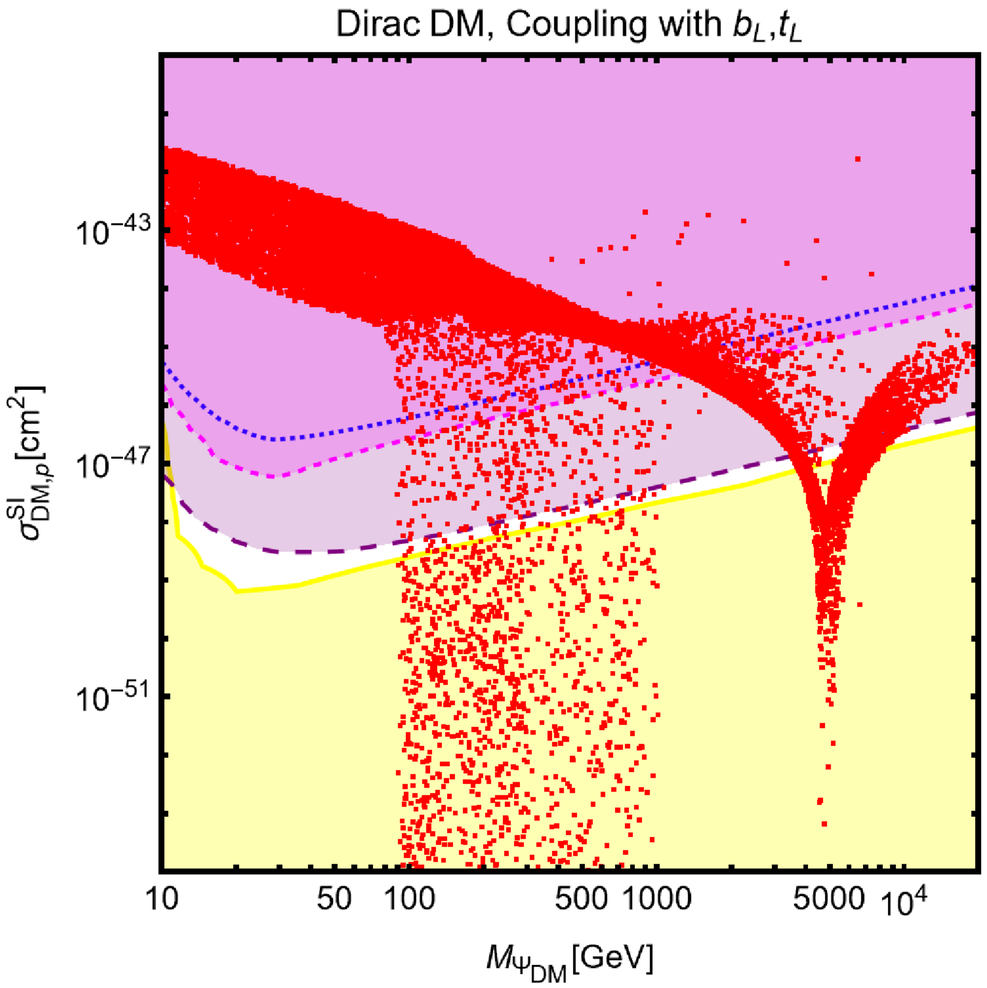
With $g_{\rm eff} = g_{\rm DM} + g_{\rm M}(1+\tilde{\Delta})^{3/2}\exp[-x\tilde{\Delta}]$ and $\tilde{\Delta} = \left(M_{\rm M} - M_{\rm DM}\right)/M_{\rm DM}$

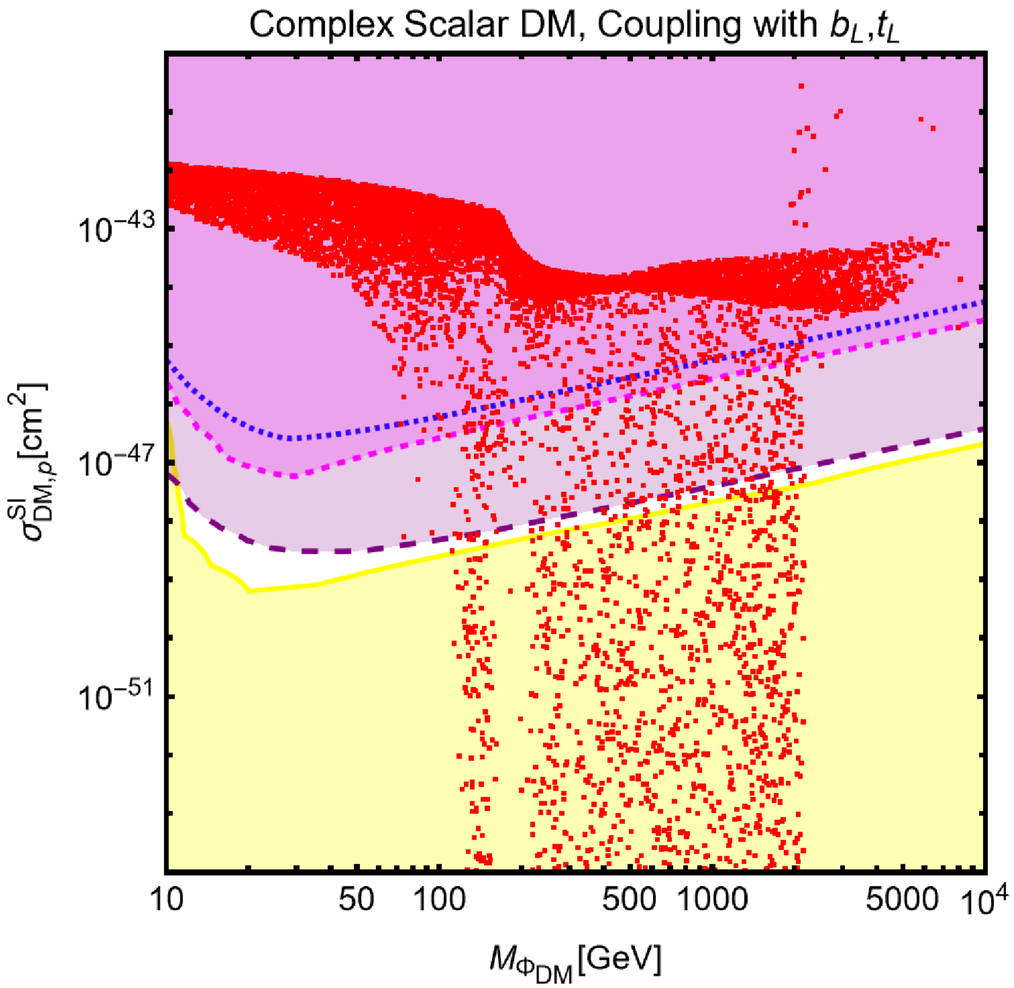
Leptons


Dirac DM, Coupling with μ_L, ν_μ
$\sigma^{SI}_{DM,p}[cm^2]$
10^{-43}
10^{-47}
10^{-51}
10
50
100
500
1000
5000
10^4
$M_{\Psi_{DM}}$[GeV]


Complex Scalar DM, Coupling with μ_L, ν_μ
$\sigma^{SI}_{DM,p}[cm^2]$
10^{-41}
10^{-43}
10^{-45}
10^{-47}
10^{-49}
10^{-51}
10
50
100
500
1000
5000
10^4
$M_{\Phi_{DM}}$[GeV]

Dirac and Complex





Light quarks at Loop Level