Reassessing the T-Channel Mediator Portal Landscape

David Cabo Almeida

Based on a collaboration with: Giorgio Arcadi, Federico Mescia, Javier Virto

Università degli Studi di Messina

INFN

T-channel Portal

We have provided a reappraisal of the DM phenomenology, with strong focus on Direct Detection, of a class of DM models dubbed t-channel portals

From High energy

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

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

where:

$$\mathcal{O}^q_{\mu\nu} \equiv \bar{q}i\left(\frac{D_\mu\gamma_\nu + D_\nu\gamma_\mu}{2} - \frac{1}{4}g_{\mu\nu}\not{D}\right)q,$$

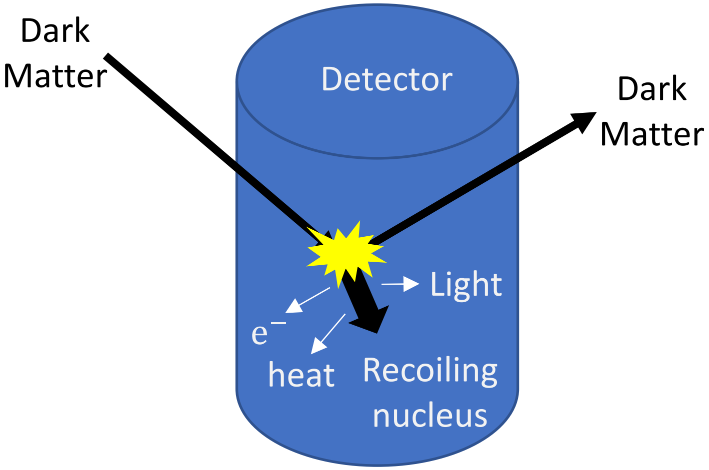
$$\mathcal{O}^g_{\mu\nu} \equiv G^{a\rho}_\mu G^a_{\nu\rho} - \frac{1}{4}g_{\mu\nu}G^a_{\rho\sigma}G^{a\rho\sigma},$$

To Low energy

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

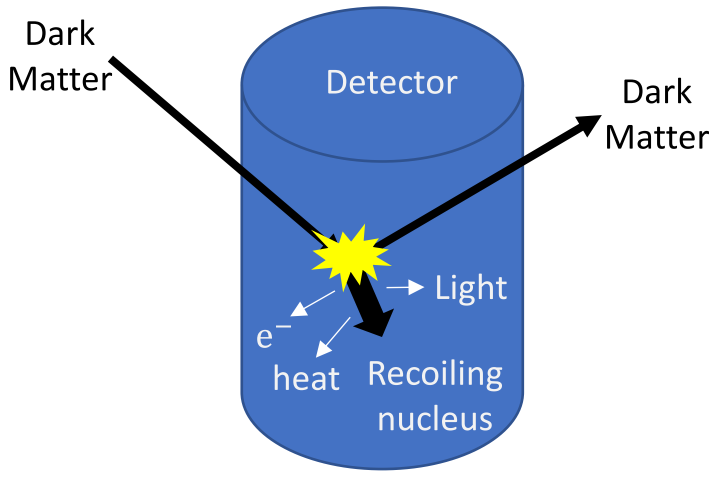
$$\begin{aligned}\mathcal{L}^{{\rm Dirac},q}_{\rm eff} = &\sum_{q=u,d} c^q\bar{\Psi}_{\rm DM}\gamma_\mu\Psi_{\rm DM}\bar{q}\gamma^\mu q + \sum_{q=u,d,s}\tilde{c}^q\bar{\Psi}_{\rm DM}\gamma_\mu\gamma_5\Psi_{\rm DM}\bar{q}\gamma^\mu\gamma_5 q \\ &+ \sum_{q=u,d,s} d^q m_q\bar{\Psi}_{\rm DM}\Psi_{\rm DM}\bar{q}q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

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



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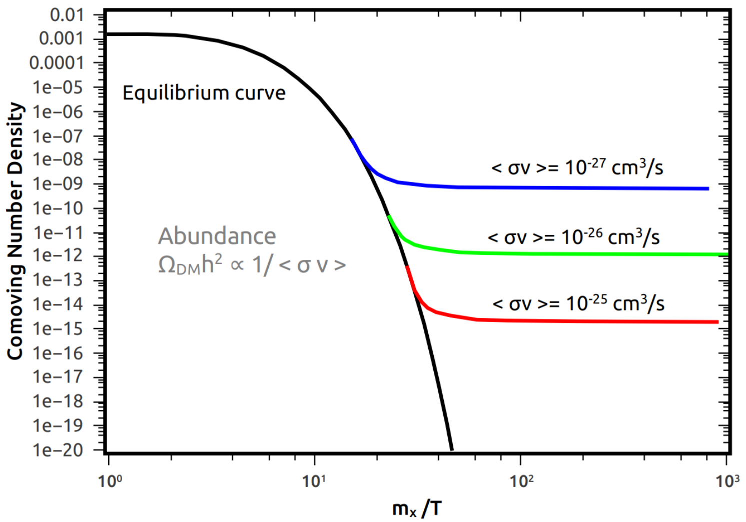
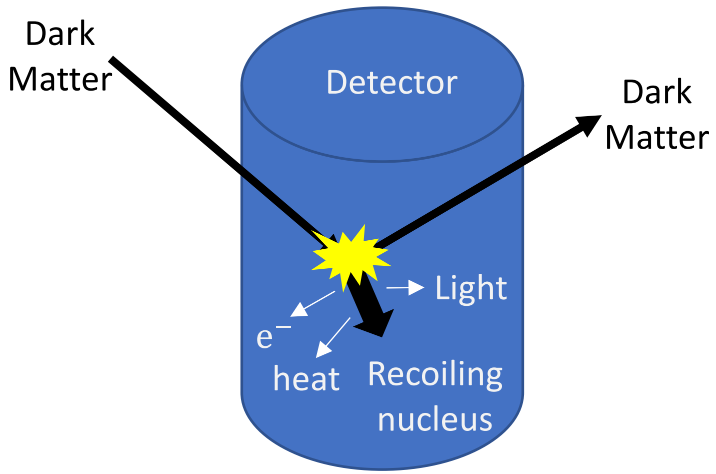
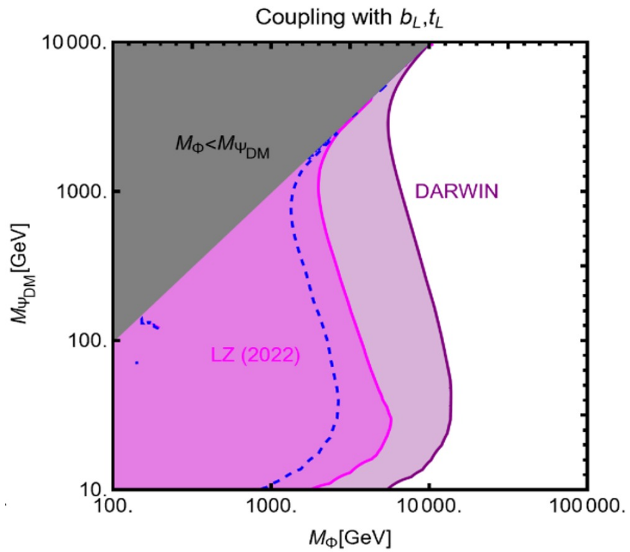


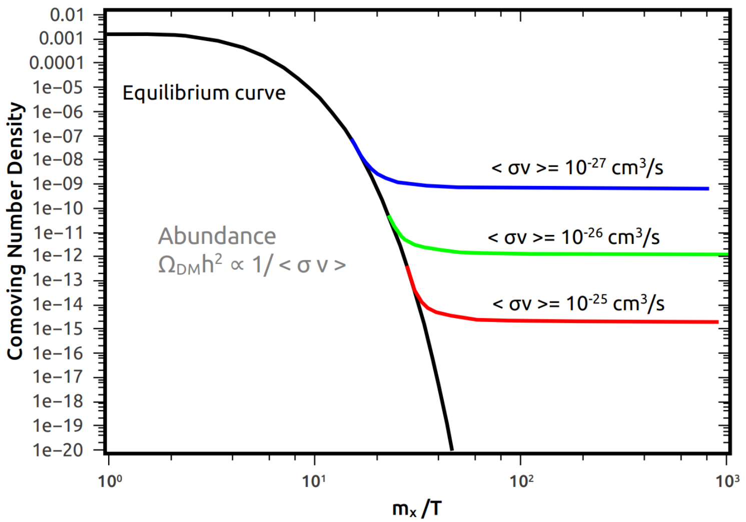
$$\Omega_{\mathrm{DM}}h^2 \approx 8.76\times 10^{-11}\mathrm{GeV}^{-2}\left[\int_{T_{\mathrm{f.o.}}}^{T_0} g_*^{1/2}\langle\sigma v\rangle_{\mathrm{eff}}\frac{dT}{M_{\mathrm{DM}}}\right]^{-1}$$

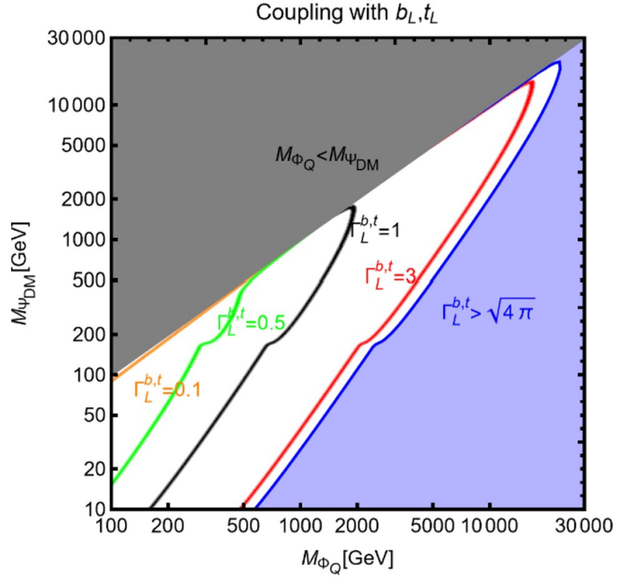
arXiv:hep-ph/9704361

Experimental bounds



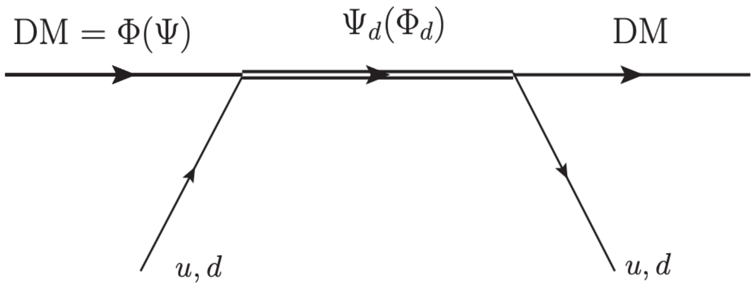


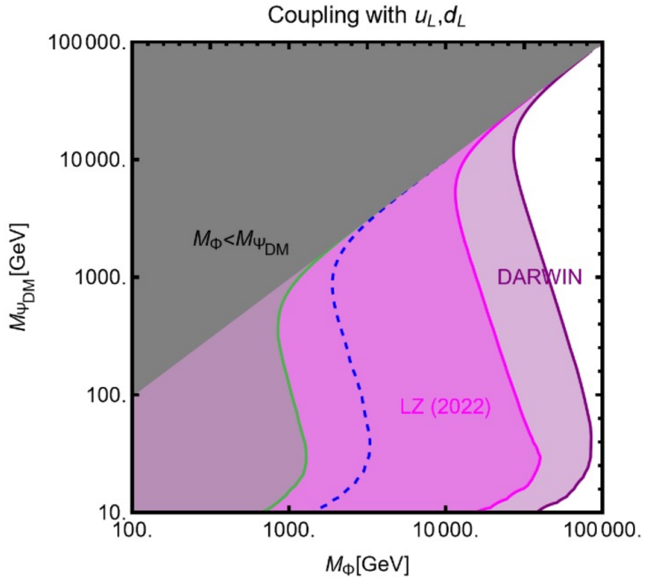




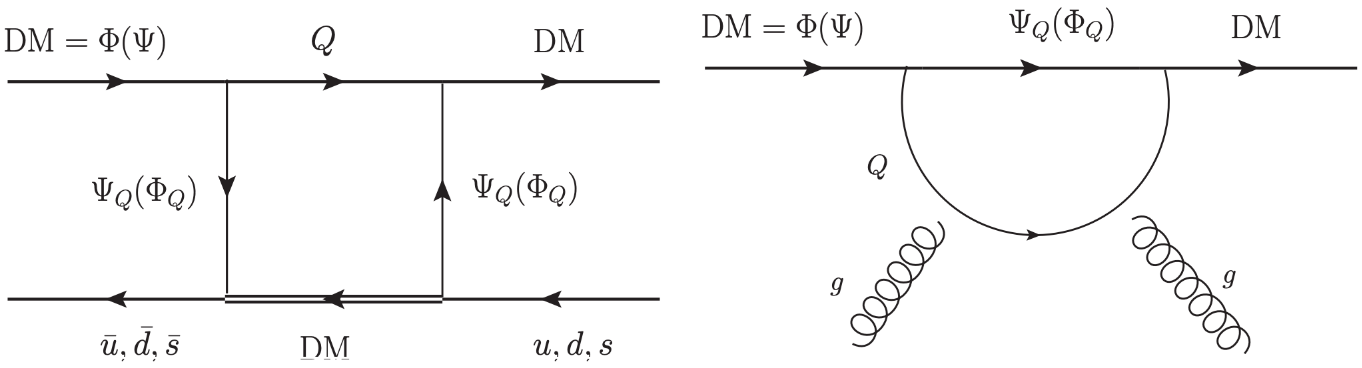
Why do we need radiative corrections?

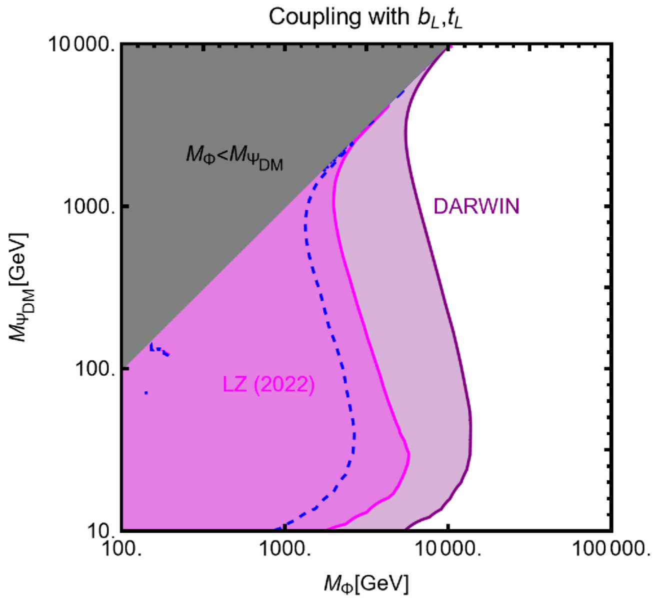
Coupling first generation





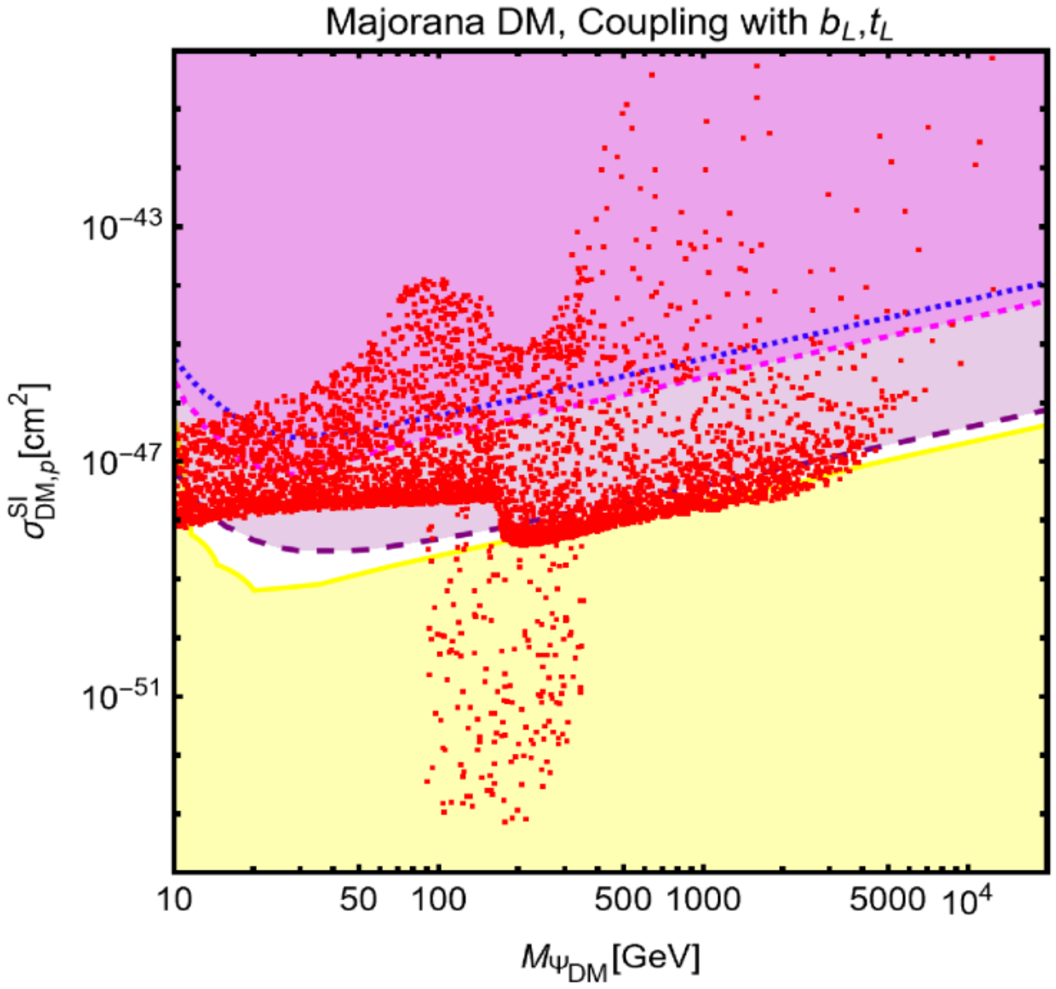
Coupling 2º & 3º generation





Scan with RD & DD bounds

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



Conclusions

- To our best knowledge, we have provided the first complete computations for both scalars and fermionic DM candidates.
- Strong bounds for the complex case and real case, with the exception of the very fine-tuned coannihilation region
- Dirac DM, direct detection sets an analogous lower bound on the DM mass as for complex Scalar DM.
- 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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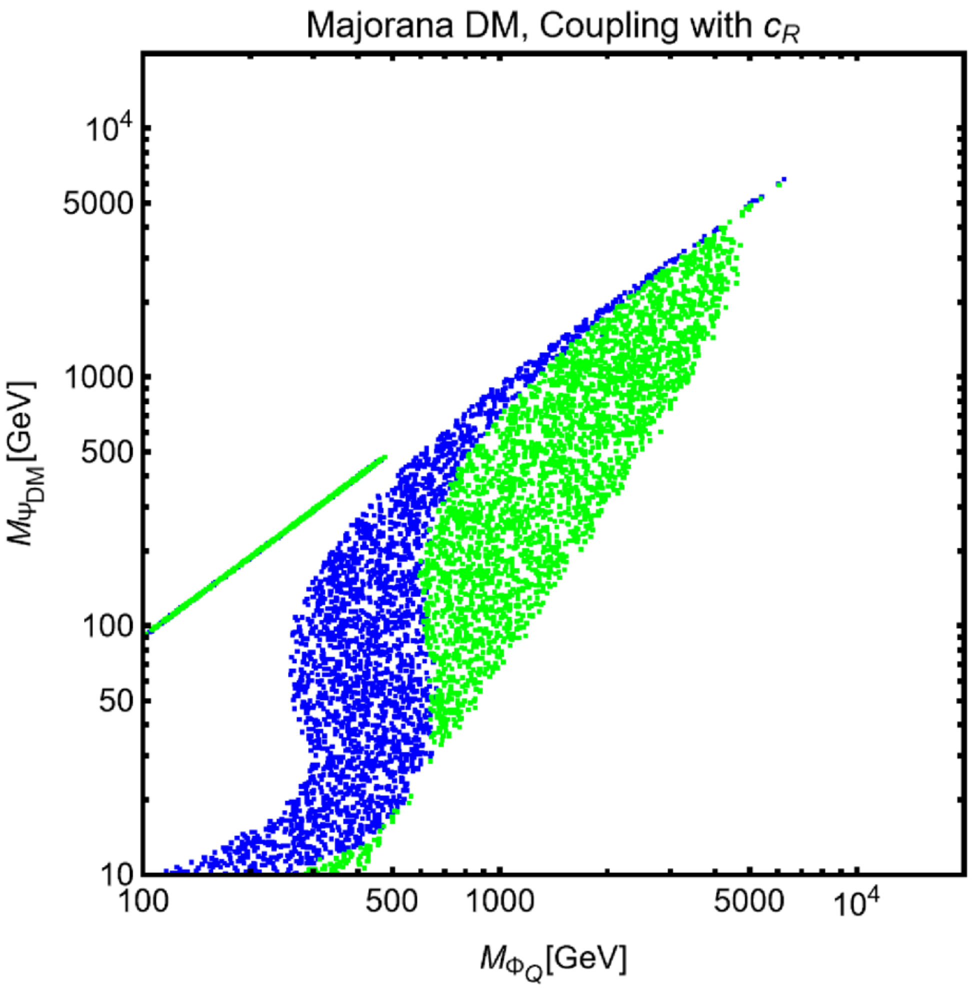
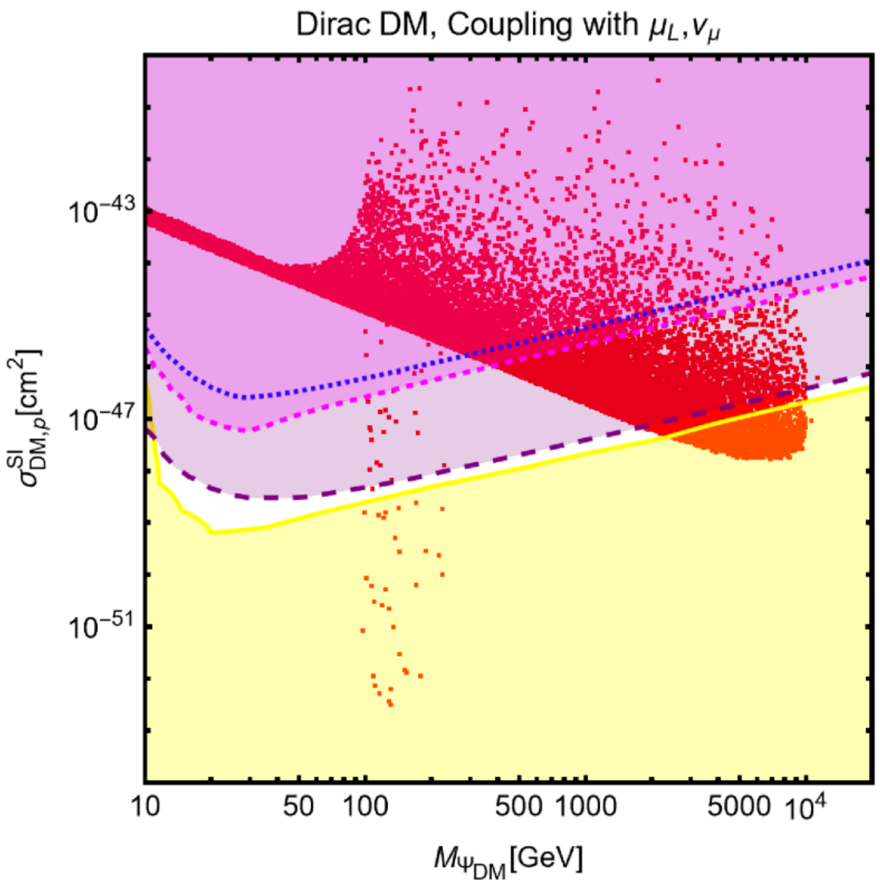
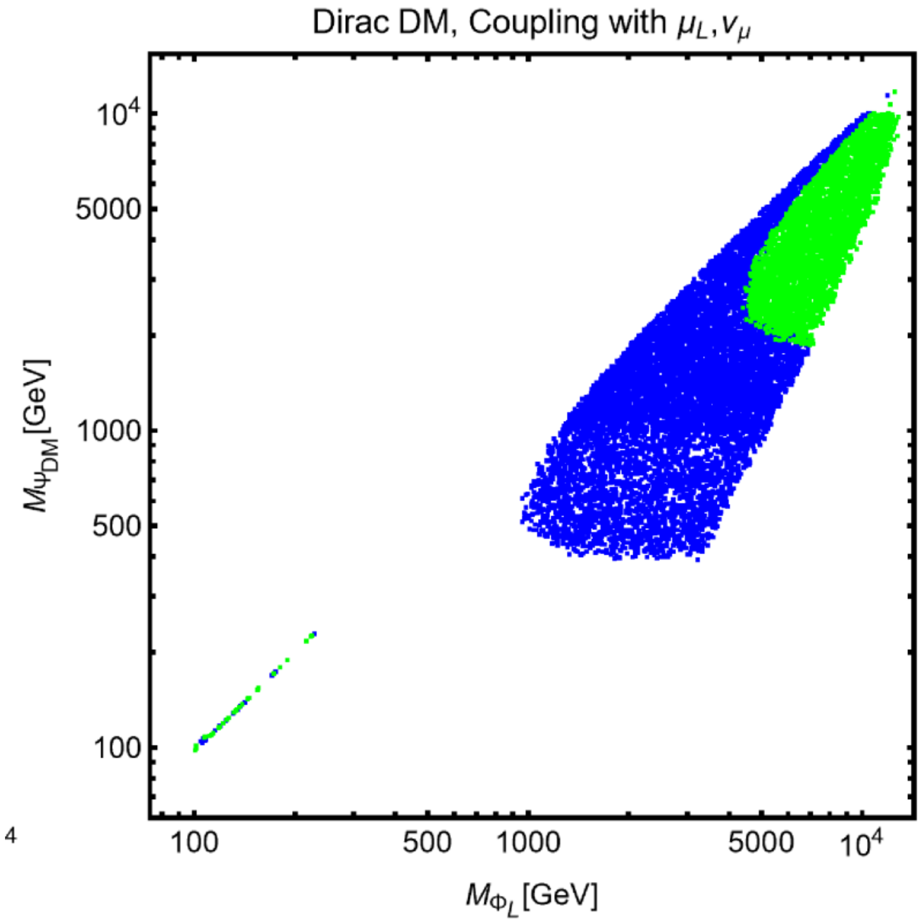
Back up

Majorana Bidimensional

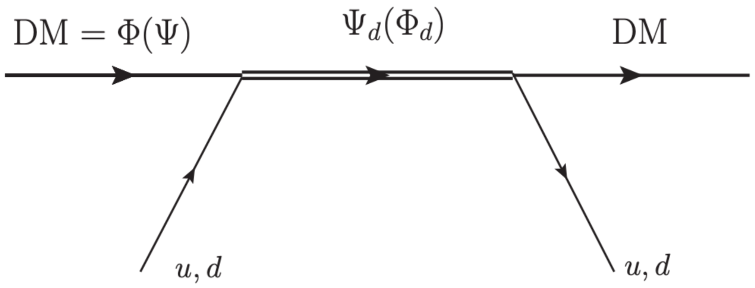


Lepton couplings





Tree level in real DM scenario



$$c^q \left(\Phi_{\mathrm{DM}}^{\dagger} i \overleftrightarrow{\partial}_{\mu} \Phi_{\mathrm{DM}} \right) \bar{q} \gamma^{\mu} q$$

Arise a tree level contribution to the Wilson Coefficient

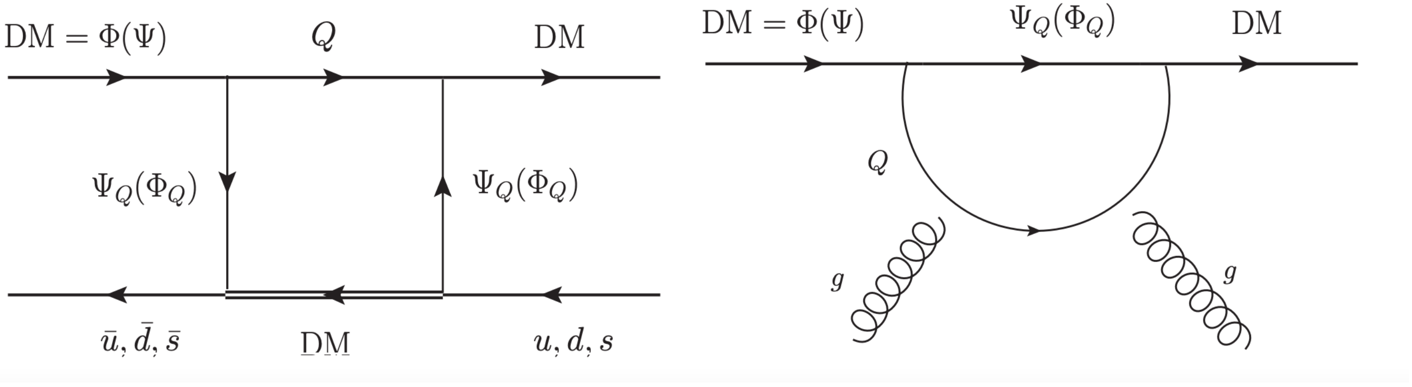
However…

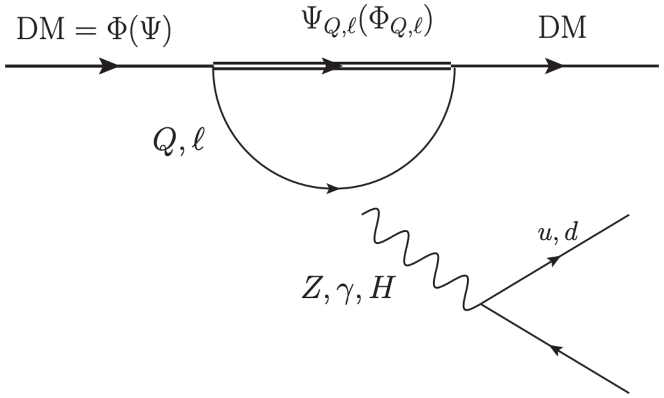
This operator dosen't exist for:

- Complex Real
- Majorana Fermion

$$c^q \left(\Phi_{\mathrm{DM}}^{\dagger} i \overleftrightarrow{\partial}_{\mu} \Phi_{\mathrm{DM}} \right) \bar{q} \gamma^{\mu} q$$

Representative Loops





Spin dependent/Spin Independent

- Because of its large de Broglie wavelength, the **WIMP interacts coherently** with all nucleons in the target nucleus.

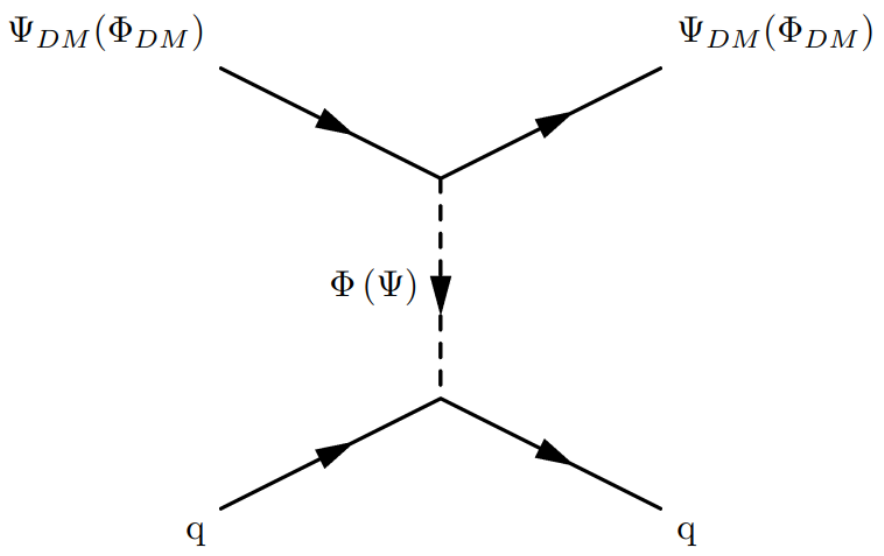
- For higher moment transverse (q) de Broglie wavelength is reduced and only part of the nucleus participates in the interaction. This loss of coherence is accounted for by the **finite form factors.**

$$\frac{d\sigma}{dE_R} = \left(\frac{M_T}{2\pi v^2} \left| f^T \right|^2 + \alpha_{\rm em} \tilde{b}_\Psi^2 Z^2 \left(\frac{1}{E_R} - \frac{M_T}{2\mu_T^2 v^2} \right) \right) \left| F_{\rm SI} \left(E_R \right) \right|^2 + \tilde{b}_\Psi^2 \frac{\mu_T^2 M_T}{\pi v^2} \frac{J_T + 1}{3 J_T} \left| F_{\rm D} \left(E_R \right) \right|^2$$

Model: t-Channel mediator

- Add the term:

$$\mathcal{L}_Y = \lambda_i \overline{f}_i P_R \Psi_{f_i} \Phi_{f_i} + \text{h.c.}$$



- Consider a new vector-like fermion or scalar which mediates between the SM and Dark sector

- Same constraints (SU(3),SU(2),U(1)$_Y$)

Quark Mediator		Lepton Mediator	
$\Phi_Q/\Psi_Q(DM)$	Ψ_Q/Φ_Q	$\Phi_\ell/\Psi_\ell(DM)$	$\Psi_\ell\Phi_\ell$
$(1,1,0)$	$(3,2,1/6)$	$(1,1,0)$	$(1,2,-1/2)$
$(1,3,0)$	$(3,2,1/6)$	$(1,3,0)$	$(1,2,-1/2)$