Simplified model for Dark Matter

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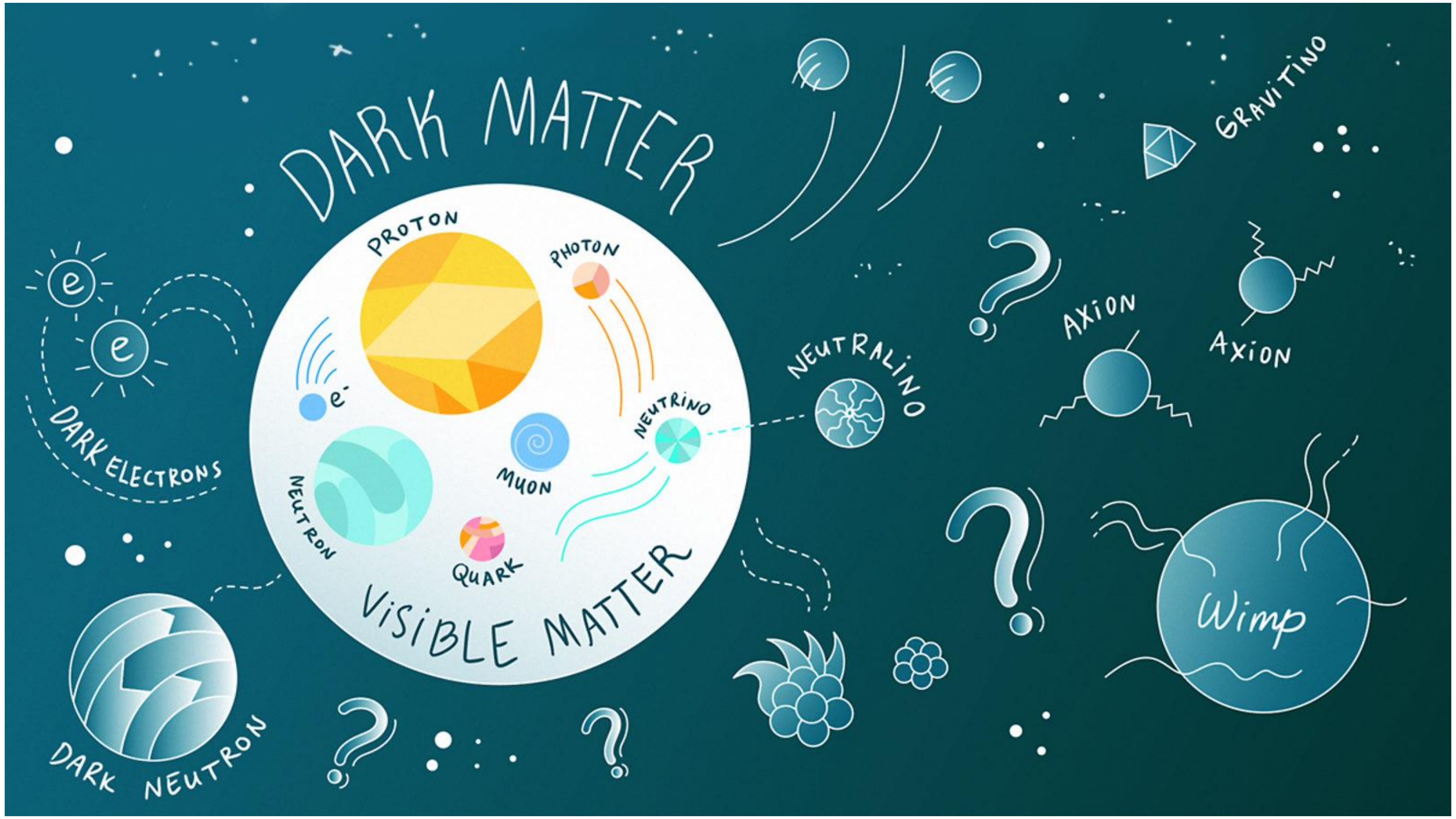
Customary Dark Matter slide



Motivation

- Too many dark matter models
- UV Complete theories have many free parameters
- Easier to constrain and make predictions

Outline

1. The Model
2. Wilson Coefficients
3. Renormalisation Group Evolution
4. Preliminary results from Direct detection constraints

The Simplified Model

- $\mathcal{L} = i\bar{\chi}\partial\!\!\!/\chi + \left(D_\mu\tilde{\phi}_i\right)^*\left(D^\mu\tilde{\phi}_i\right) - M_\phi^2\tilde{\phi}_i{}^*\tilde{\phi}_i + \mathcal{L}_{int}$

Majorana Dark Matter

Coloured scalar(s)

uR model : $\mathcal{L}_{int} = g_{DM}(\tilde{\phi}_i^*\,\bar{\chi}P_R q_i + h.c.)$ $\quad q_i = \{u, c, t\}$

dR model : $\mathcal{L}_{int} = g_{DM}(\tilde{\phi}_i^*\,\bar{\chi}P_R q_i + h.c.)$ $\quad q_i = \{d, s, b\}$

qL model : $\mathcal{L}_{int} = g_{DM}(\tilde{\phi}_i^*\,\bar{\chi}P_L q_i + h.c.)$ $\quad q_i = \{u, d, s, c, b, t\}$

$$D_\mu = \partial_\mu - ig_sT^aG_\mu^a$$

Simplified models for Dark Matter interacting with quarks : https://arxiv.org/pdf/1308.2679.pdf

The Simplified Model

- $\mathcal{L} = i\bar{\chi}\not{\partial}\chi + \left(D_\mu\tilde{\phi}_i\right)^*\left(D^\mu\tilde{\phi}_i\right) - M_\phi^2\tilde{\phi}_i{}^*\tilde{\phi}_i + \mathcal{L}_{int}$
- Effective lagrangian for interaction with quarks and gluons :

$$\mathcal{L}_q^{eff} = f_q(\bar{\chi}\chi)(m_q\bar{q}q) + \frac{g1_Q}{m_\chi}(\bar{\chi}i\partial^\mu\gamma^\nu\chi)(O_{\mu\nu}^q) + \frac{g2_Q}{m_\chi}(\bar{\chi}\, i\partial^\mu\, i\partial^\nu\chi)(O_{\mu\nu}^q)$$

$$\mathcal{L}_g^{eff} = f_g(\bar{\chi}\chi)(G^{a,\mu\nu}G^a{}_{\mu\nu}) + \frac{g1_G}{m_\chi}(\bar{\chi}i\partial^\mu\gamma^\nu\chi)(O_{\mu\nu}^g) + \frac{g2_G}{m_\chi}(\bar{\chi}\, i\partial^\mu\, i\partial^\nu\chi)(O_{\mu\nu}^g)$$

Scalar operators

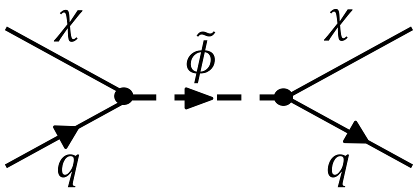
Twist-2 operators

$$O_{\mu\nu}^q = \frac{1}{2}\bar{q}i\left(D_\mu\gamma_\nu + D_\nu\gamma_\mu - \frac{1}{2}g_{\mu\nu}\not{D}\right)q$$

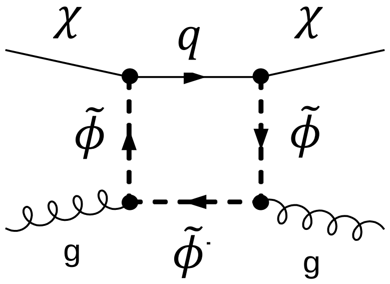
$$O_{\mu\nu}^g = G^{a,\rho}{}_\mu G^a{}_{\rho\nu} + \frac{1}{4}g_{\mu\nu}G^{a,\alpha\beta}G^a{}_{\alpha\beta}$$

The Simplified Model

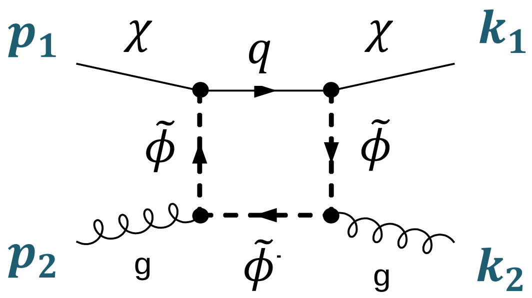
$\chi\, q \rightarrow \chi\, q$:

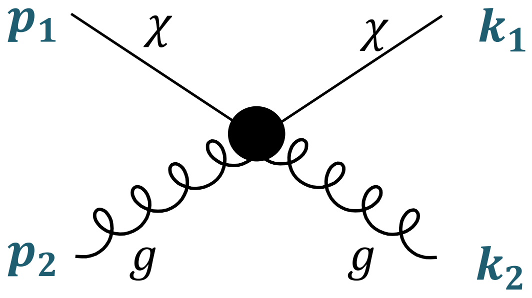


$\chi\, g \rightarrow \chi\, g$:



Wilson Coefficients





In Momentum Space :

$$f_g(\bar{\chi}\chi)(G^{a,\mu\nu}G^a_{\mu\nu}) \longrightarrow 8if_g(p_2^\mu k_2^\nu - g^{\mu\nu}p_2.k_2)\,\epsilon_\mu(p_2)\epsilon_\nu(k_2)\,(\bar{\chi}\chi)$$

$$\frac{g2_G}{m_\chi^2}(\bar{\chi}i\partial^\mu\partial^\nu\chi)(O^g_{\mu\nu}) \longrightarrow g2_G(\ldots)^{\mu\nu}\,\epsilon_\mu(p_2)\epsilon_\nu(k_2)\,(\bar{\chi}\chi)$$

Orthogonal

Neutralino nucleon scattering reexamined : https://journals.aps.org/prd/pdf/10.1103/PhysRevD.48.3483

RG Evolution

- Need effective coupling to nucleons for direct detection constraints

$$\mathcal{L}_N = f_N(\bar{N}N)(\bar{\chi}\chi)$$

- Nuclear matrix elements of $\boldsymbol{m_q \bar{q} q}$, $\boldsymbol{G^{a,\mu\nu} G^a{}_{\mu\nu}}$, etc. are known
- Evolve the parton level Wilson coefficients to nuclear scale

- RG evolution through QCD running and matching at heavy quark thresholds

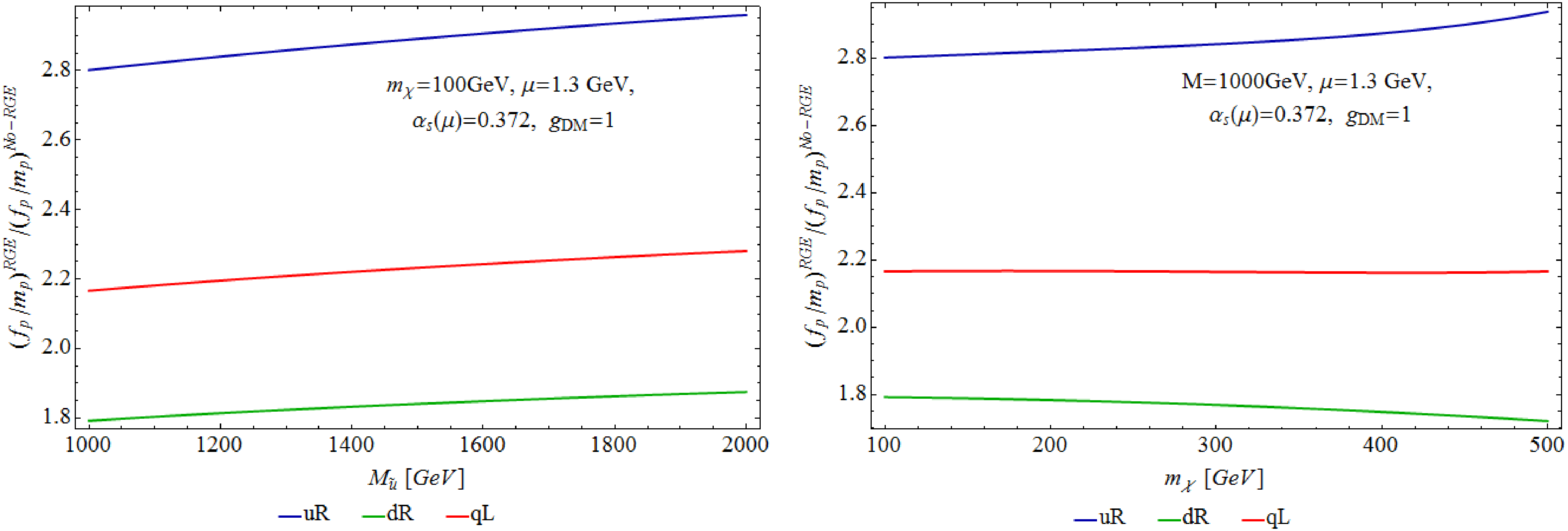
$$c_i(\mu_{low}) = R_{ij}(\mu_{low}, \mu_{high})\, c_j(\mu_{high})$$

$$c_i'(\mu_Q) = M_{ij}(\mu_Q) c_j(\mu_Q)$$

- Corresponds to mixing of operators of same spin and integrating out heavy quarks
- Evaluate the Wilson coefficients at the high scale and evolve them to the nuclear scale

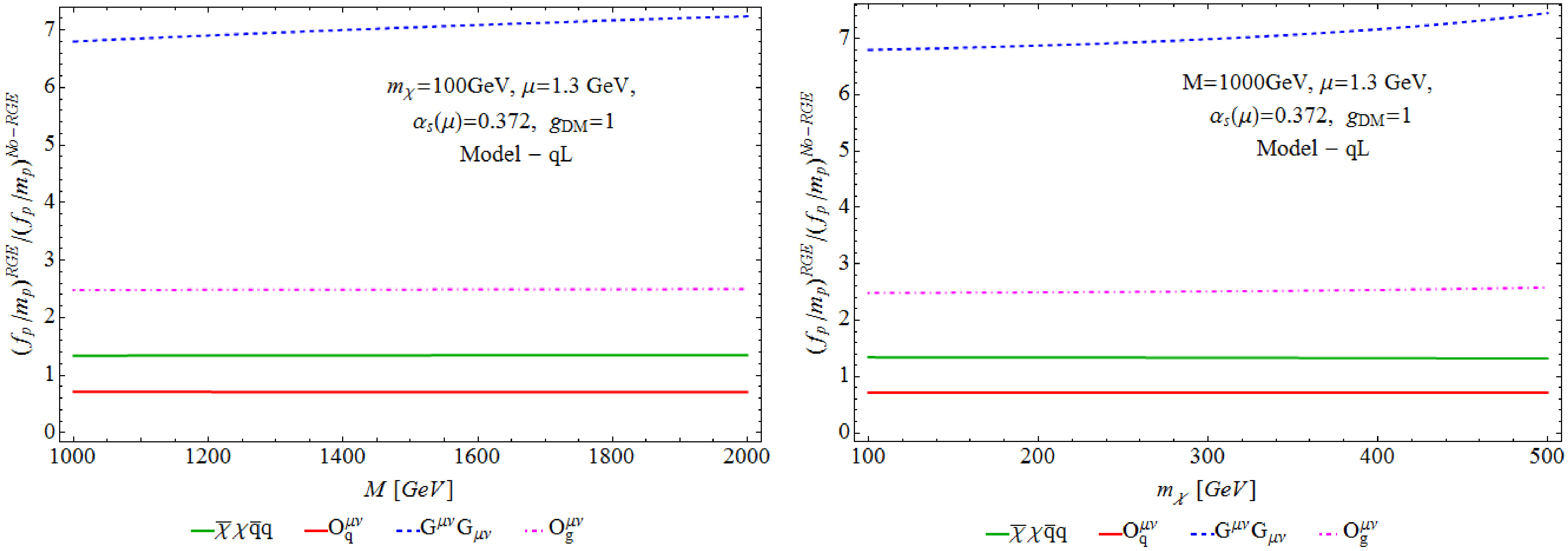
Standard Model anatomy of WIMP dark matter direct detection II: QCD analysis and hadronic matrix elements :- https://arxiv.org/pdf/1409.8290.pdf

RG Evolution



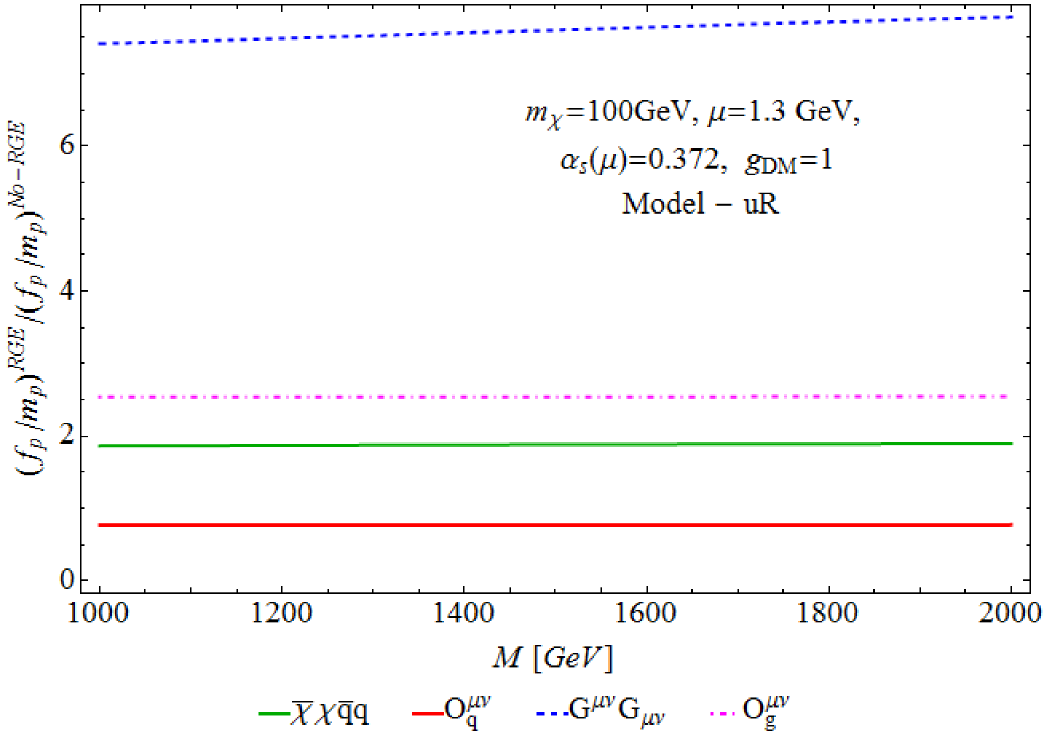
Effect of RGE on nuclear effective coupling for different models

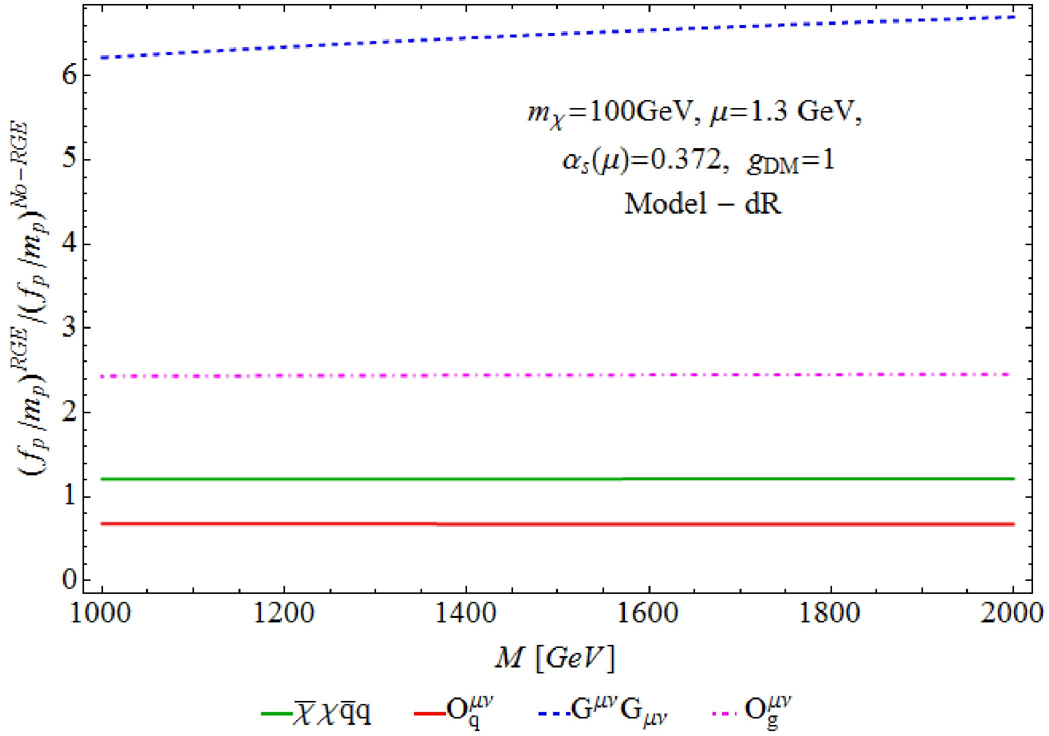
RG Evolution



Effect of RGE on individual operators for varying masses

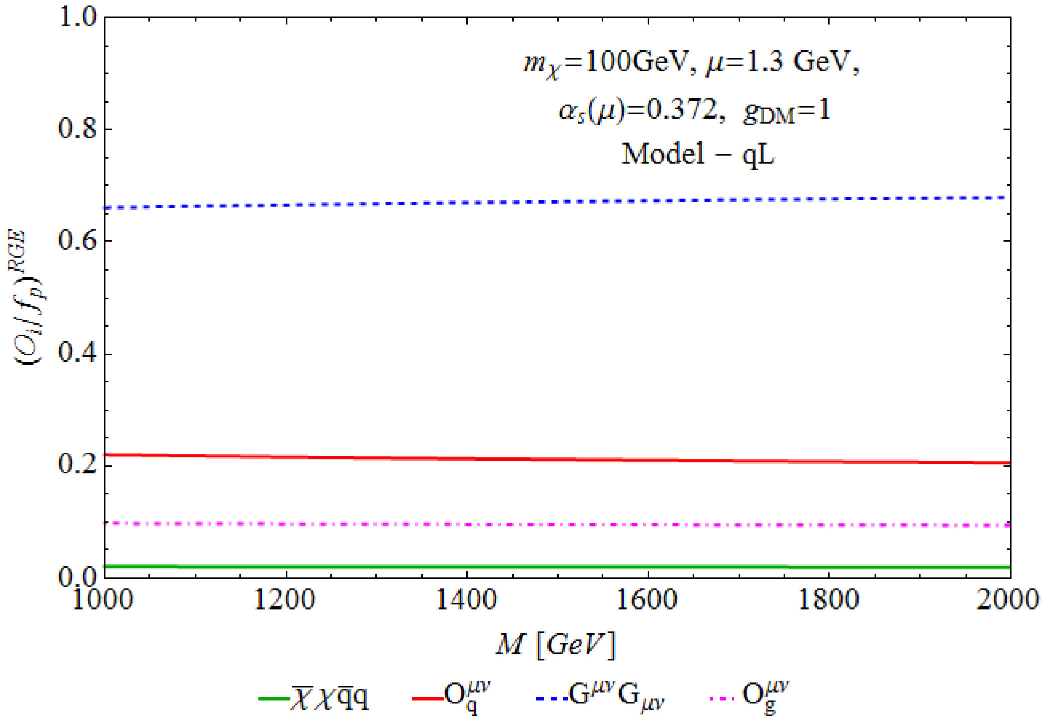
RG Evolution

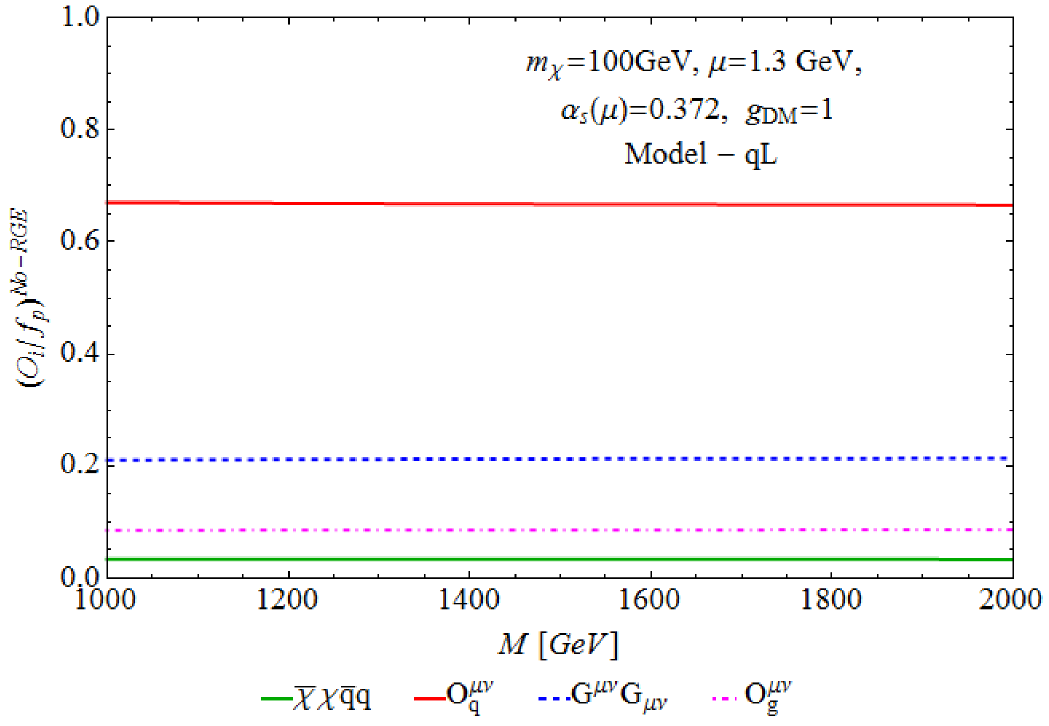




Effect of RGE on individual operators for varying masses

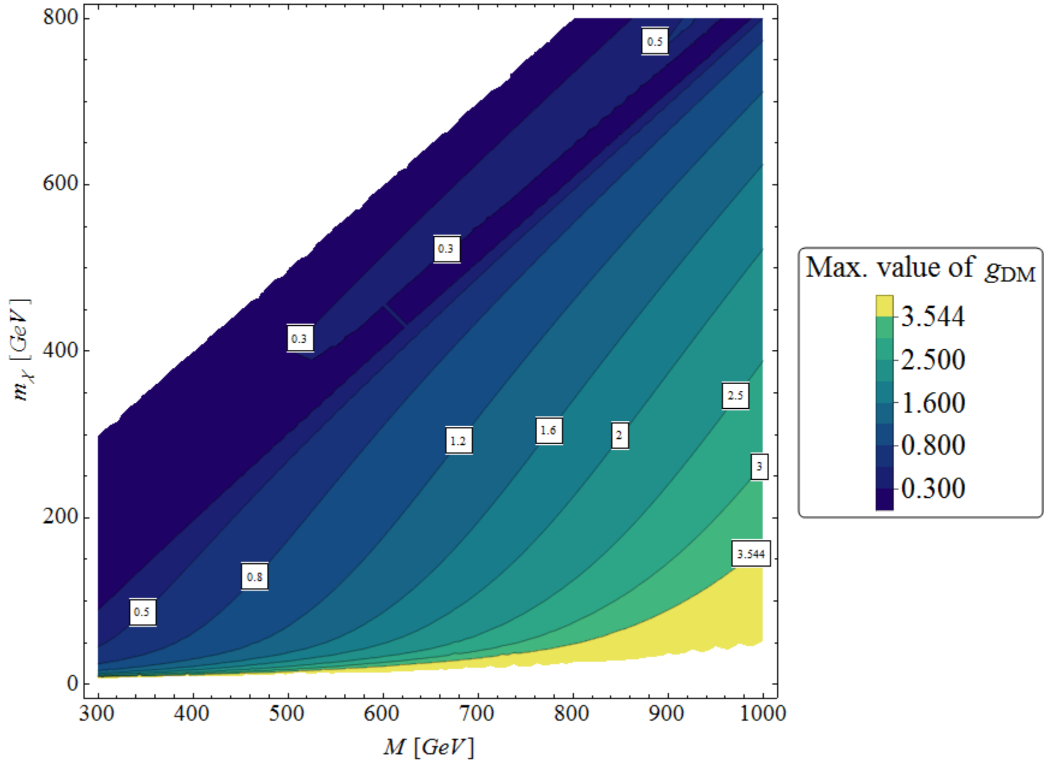
RG Evolution

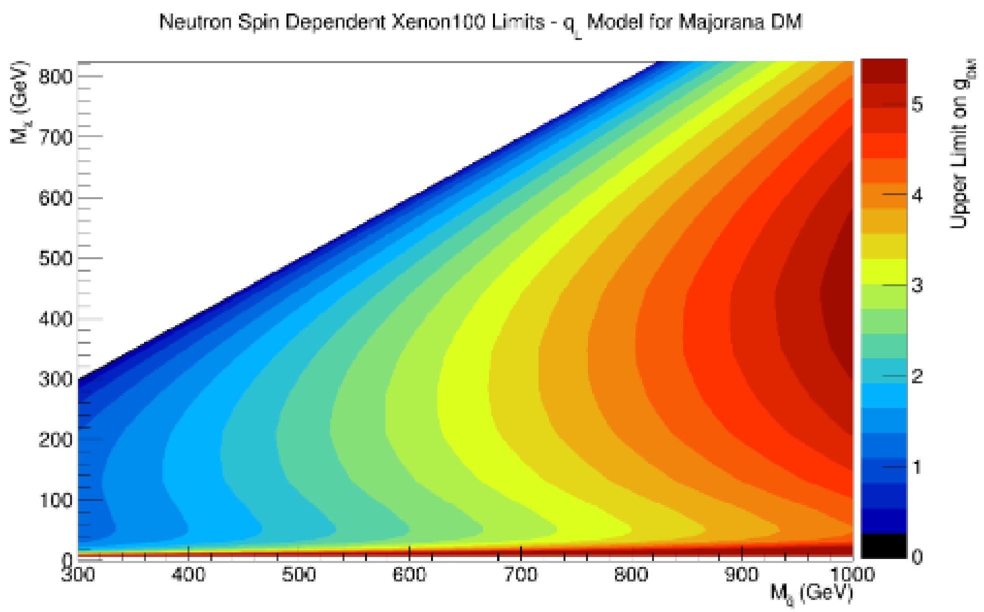




Contribution of each operator with and without RGE

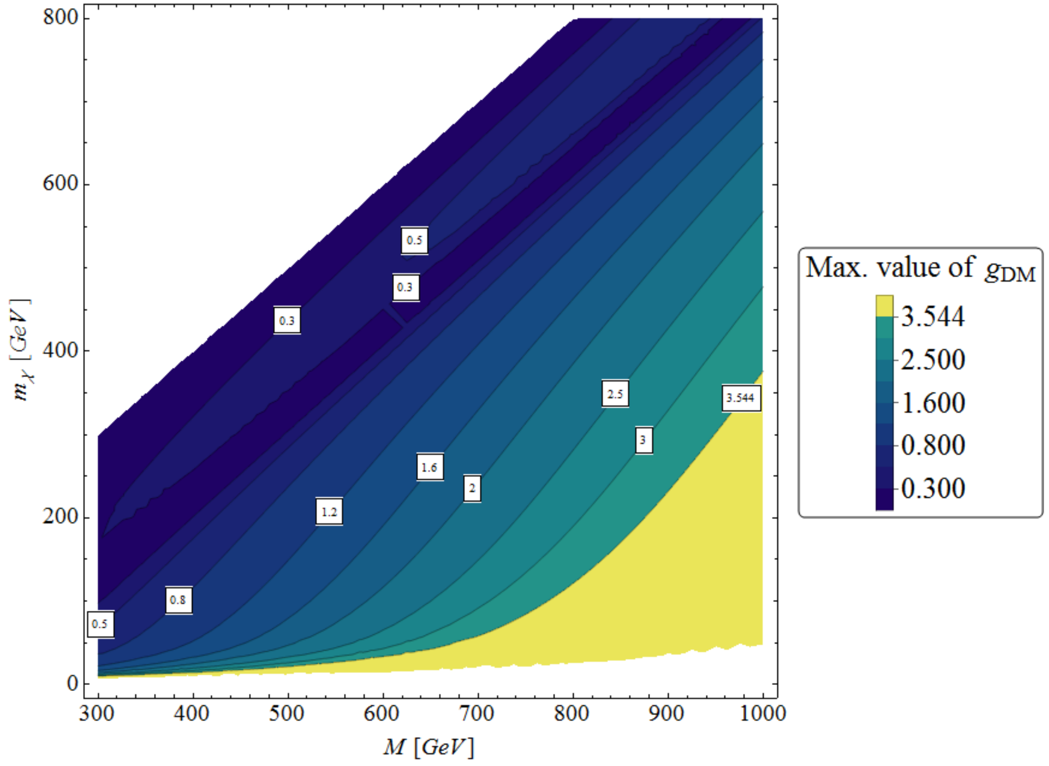
Constraints from direct detection

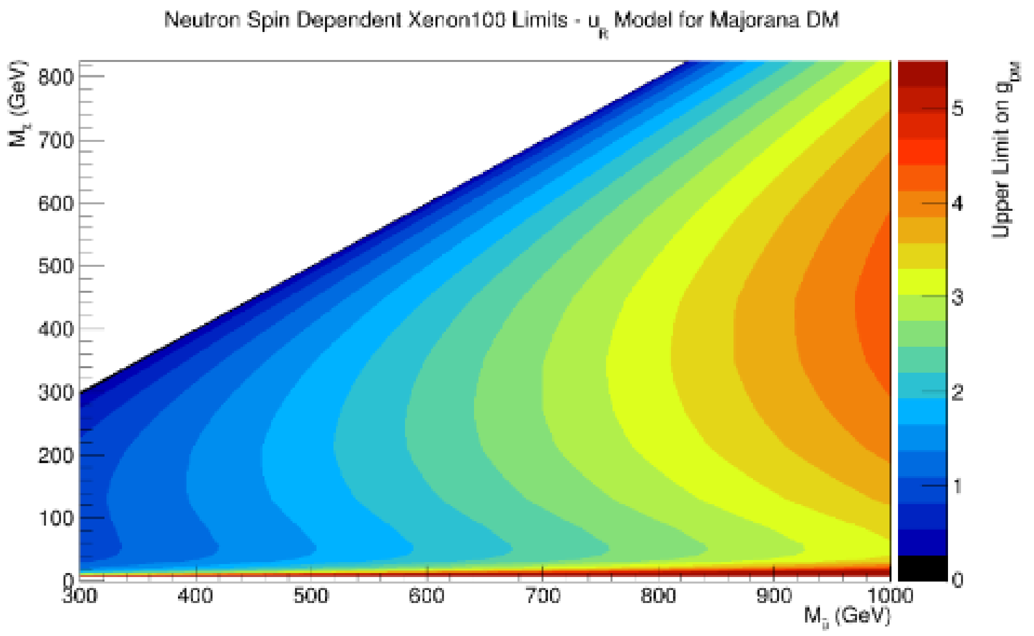




SI constraints on qL model from LUX - https://journals.aps.org/prl/pdf/10.1103/PhysRevLett.118.021303

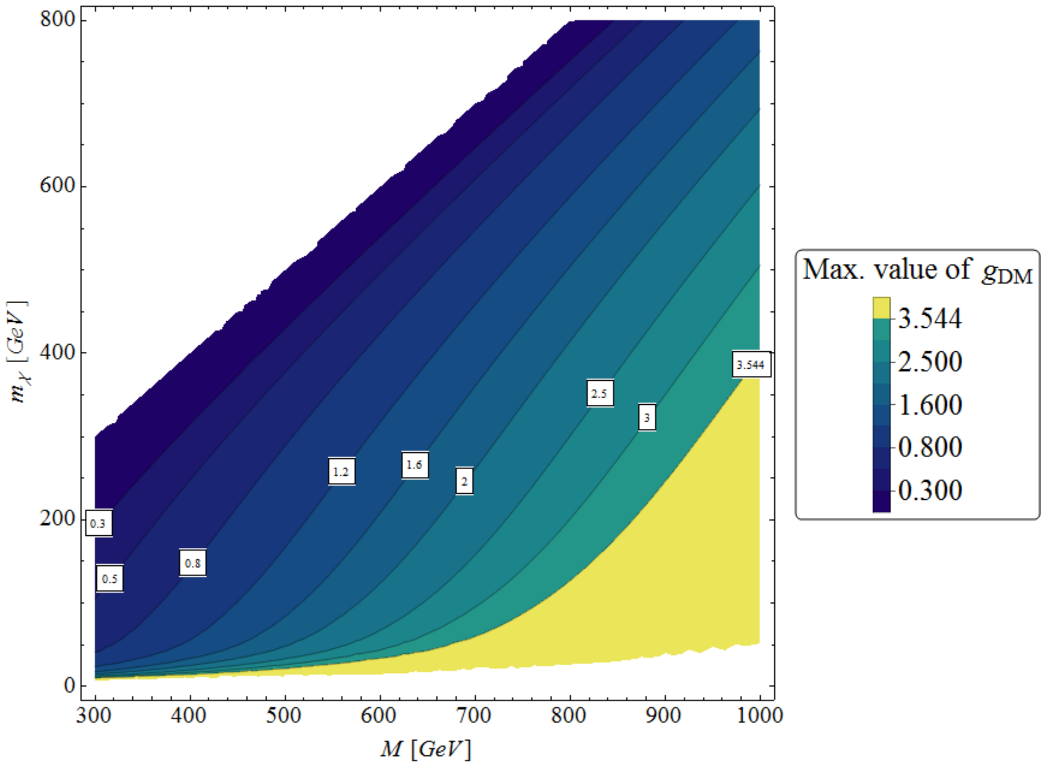
Constraints from direct detection

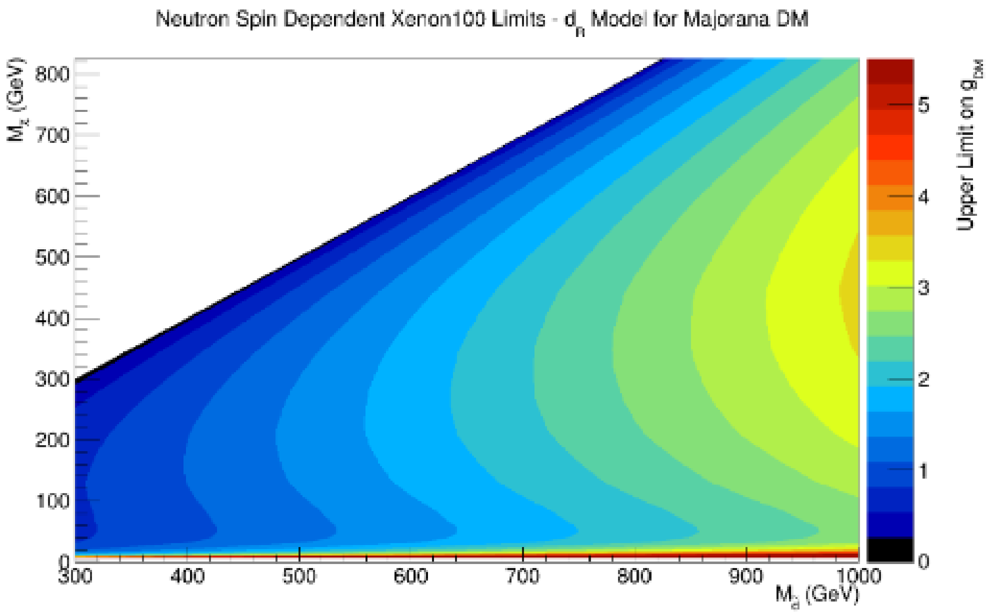




SI constraints on uR model from LUX - https://journals.aps.org/prl/pdf/10.1103/PhysRevLett.118.021303

Constraints from direct detection





SI constraints on dR model from LUX - https://journals.aps.org/prl/pdf/10.1103/PhysRevLett.118.021303

Conclusions

- Study of simplified models useful for constraining BSM physics
- RGE extremely important for direct detection constraints
- Higher-dimensional operators can be relevant, even dominant

- Next: Collider constraints