DM at the LHC via s-channel Simplified Models

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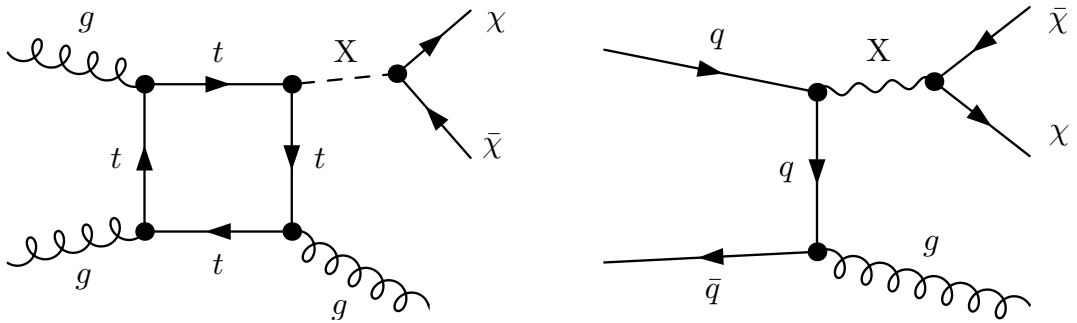
Simplified Models: Constraining Dark Particles at the LHC

- Dark Sector should contain Dark Matter (which is cosmologically stable) plus other Dark Particles.
- At colliders Dark Particles manifest themselves as missing transverse momentum (aka missing transverse energy MET).
- These are stable on collider scales – this is much less restrictive than the cosmological DM – i.e. can look for more than cosmologically stable DM.
- Use a mono-jet to recoil, i.e. concentrate here on a mono-object + MET.
- Dark Particles interact with the Standard Model by exchanging a *mediator* field X.
- Four basic types of mediators: vectors, axial-vectors, scalars, pseudo-scalars.



Representative Feynman diagrams.

Simplified Models: Constraining Dark Particles at the LHC

- Difference with EFT characterisation: at LHC energies mediators are dynamical and can be resolved.
- Four basic types of mediators to the dark sector associated with scalar S, pseudo-scalar P, vector Z' and axial-vector Z'' fields with interactions,

$$\mathcal{L}_{\rm scalar} \supset -\frac{1}{2} m^2_{\rm MED} S^2 - g_{\rm DM} S\, \bar{\chi}\chi - g^t_{SM} S\, \bar{t}t - g^b_{SM} S\, \bar{b}b$$

$$\mathcal{L}_{\rm pseudo-scalar} \supset -\frac{1}{2} m^2_{\rm MED} P^2 - g_{\rm DM} P\, \bar{\chi}\gamma^5\chi - g^t_{SM} P\, \bar{t}\gamma^5 t - g^b_{SM} P\, \bar{b}\gamma^5 b$$

$$\mathcal{L}_{\rm vector} \supset \frac{1}{2} m^2_{\rm MED} Z'_\mu Z'^\mu - g_{\rm DM} Z'_\mu \bar{\chi}\gamma^\mu\chi - \sum_q g^q_{SM} Z'_\mu \bar{q}\gamma^\mu q$$

$$\mathcal{L}_{\rm axial} \supset \frac{1}{2} m^2_{\rm MED} Z''_\mu Z''^\mu - g_{\rm DM} Z''_\mu \bar{\chi}\gamma^\mu\gamma^5\chi - \sum_q g^q_{SM} Z''_\mu \bar{q}\gamma^\mu\gamma^5 q$$


J. Abdallah, A. Ashkenazi, A. Boveia, *et al.*, arXiv:1409.2893


S. Malik, C. McCabe, H. Araujo, *et al.*, arXiv:1409.4075


M. R. Buckley, D. Feld and D. Goncalves, arXiv:1410.6497


P. Harris, VVK, M. Spannowsky and C. Williams, arXiv:1411.0535

Simplified Models: Constraining Dark Particles at the LHC

The couplings of Scalar and Pseudo-Scalar messengers to all six flavours of SM quarks are taken to be proportional to the corresponding Higgs Yukawa couplings, y_q, and to make our definitions look symmetric we choose to parametrise the DM couplings in a similar fashion.

Such parameterisation of $g_{\rm DM}$ is historical and is not necessary in future.

$$\text{for scalar \& pseudo} - \text{scalar messengers}: \quad g^q_{\rm SM} \equiv g_q y_q\,, \quad g_{\rm DM} \equiv g_\chi y_\chi$$

$$\text{where} \quad y_\chi \equiv \frac{m_\chi}{v} = \frac{m_{\rm DM}}{v}\,.$$

The product of the top and χ couplings to messengers,

$$g^q_{\rm SM}\, g_{\rm DM} \;=\; g_t g_\chi\, y_t y_\chi \;=\; g_q g_\chi\, \frac{m_t m_{\rm DM}}{v^2}\,,$$

and we keep the scaling g_q flavour-universal for all quarks, so $g_t = g_q$.

Simplified Models: Constraining Dark Particles at the LHC

Our Simplified Models for Dark Particles searches at colliders are characterised by the type of the mediator plus by the following free parameters:

1. mediator mass $m_{\rm MED}$
2. mediator width $\Gamma_{\rm MED}$
3. dark matter mass $m_{\rm DM}$
4. effective coupling parameter $g_q \cdot g_\chi$ for scalar and pseudo-scalars; and $g_{\rm SM} \cdot g_{\rm DM}$ for axial-vector and vector mediators.

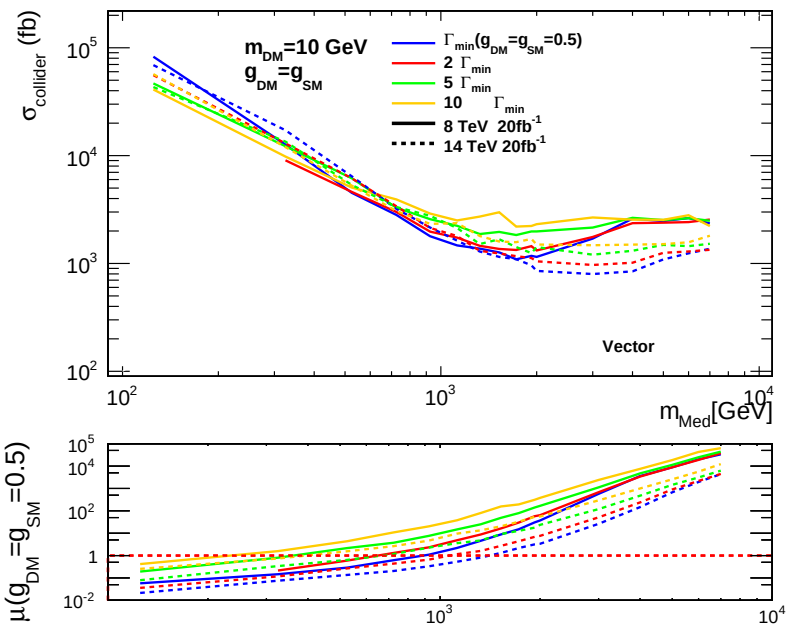
We have implemented simplified models based on these parameters into a fully flexible (and public) Monte Carlo code, MCFM. We used MCFM to generate signal events, which were processed through event and detector simulation for the 8 and 14 TeV LHC.

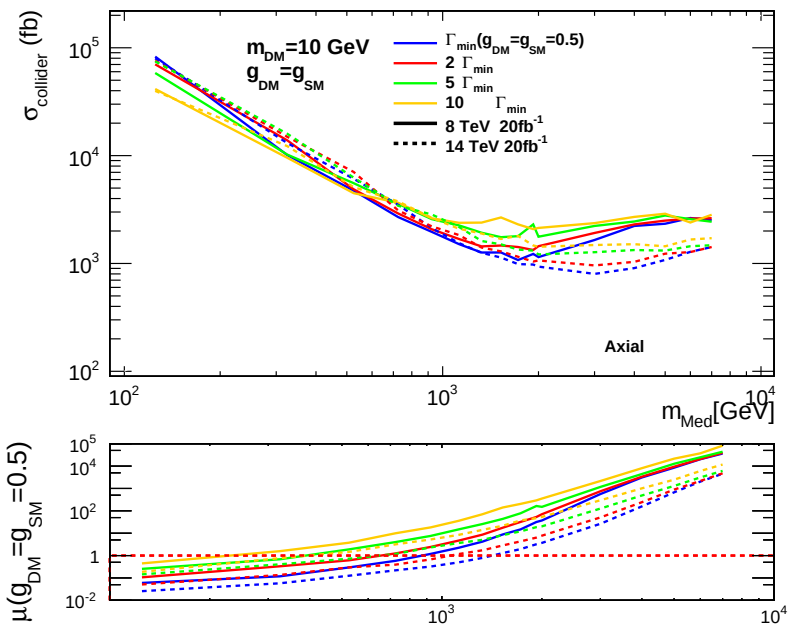
P. Harris, VVK, M. Spannowsky and C. Williams, arXiv:1411.0535

Simplified Models: Constraining Dark Particles at the LHC

Limit bounds and projections for LHC cross sections at 8 and 14 TeV.

- Vector and Axial-vector mediators:





μ is the ratio of the exclusion cross section to the predicted cross section

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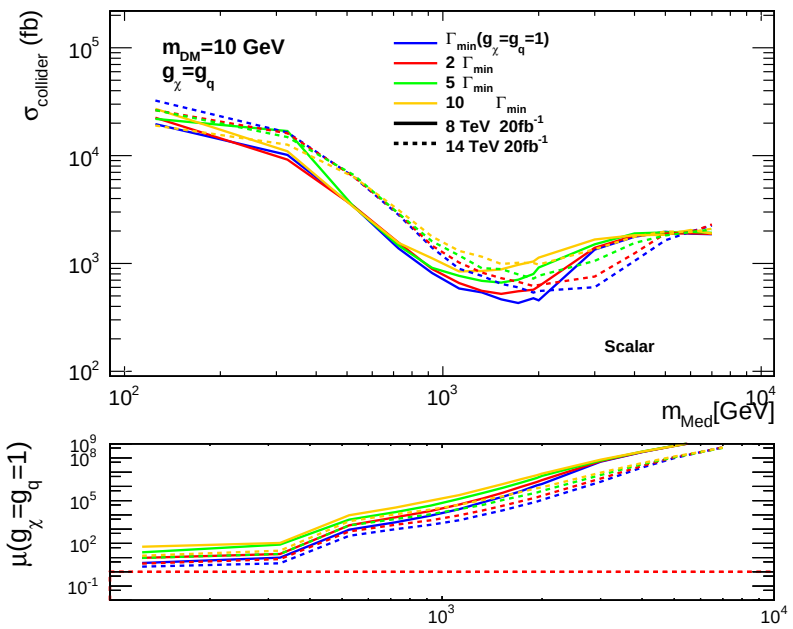

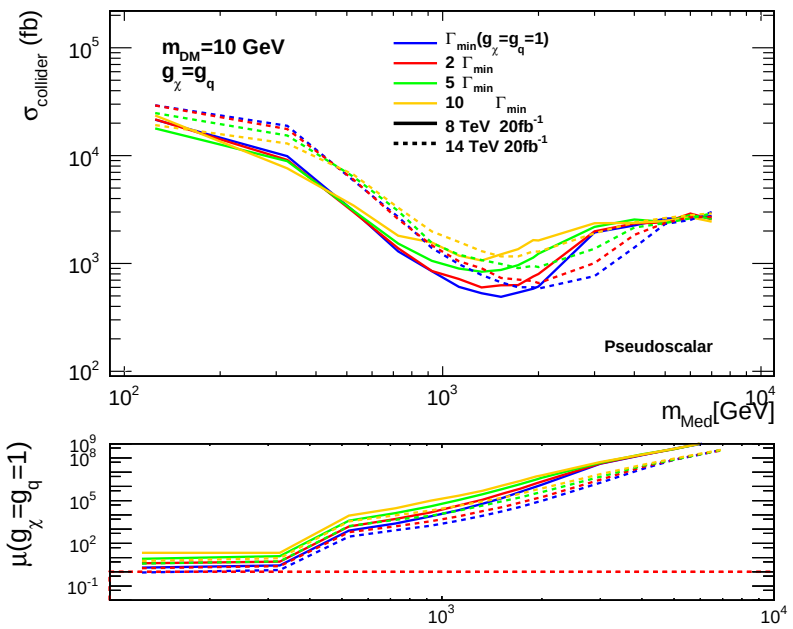

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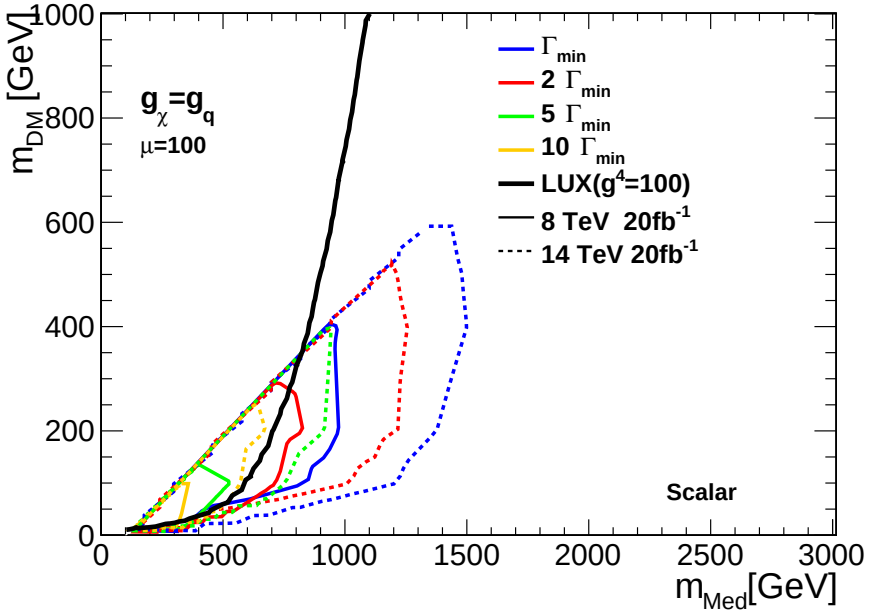
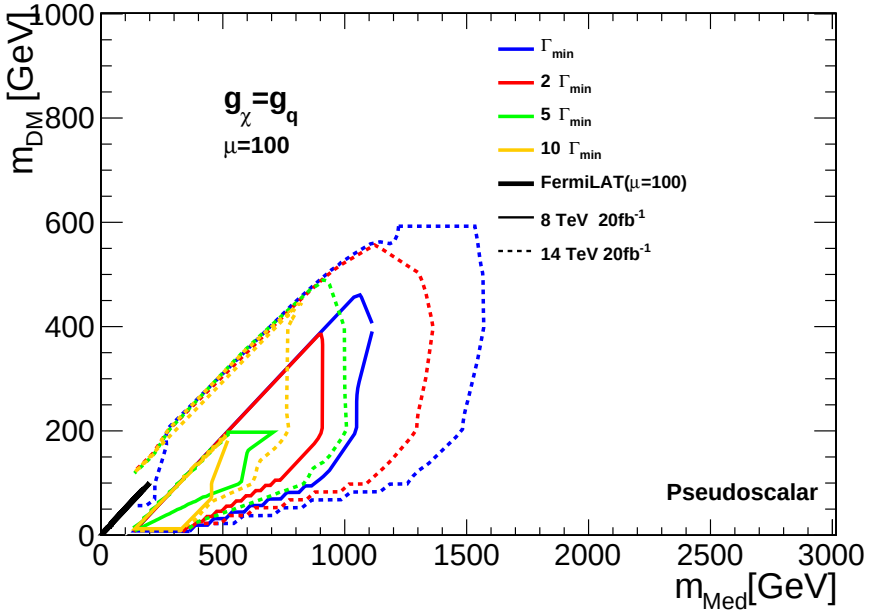
Simplified Models: Constraining Dark Particles at the LHC

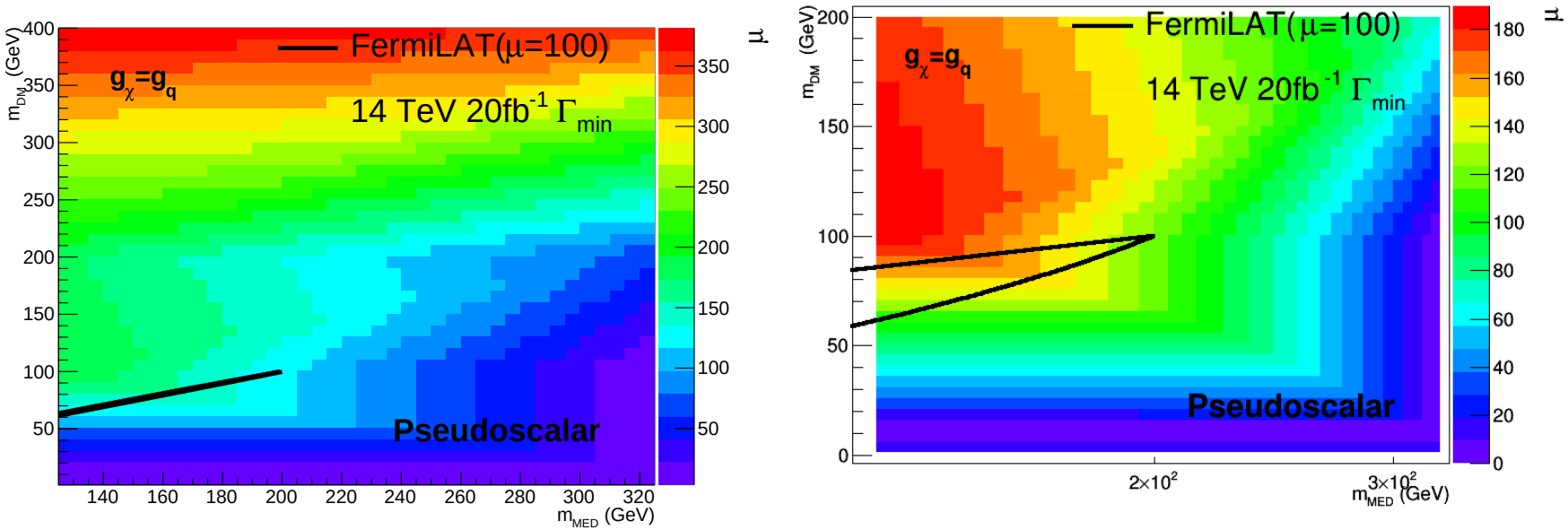
• Scalar and Pseudo-scalar mediators:
Compare the predicted value of the cross section for a given parameter set against the limit set by the LHC. We present the constrained region as a function of the dark matter and mediator mass:





Signal (cross section) for scalars and pseudo-scalars was enhanced by $\mu = 100$ to have non-trivial collider limits.

1. Absorbing $\mu = 100$ is equivalent to changing $g_\chi \to 10 g_\chi$. Since we defined $g_{DM} = g_\chi m_{DM}/v$ increasing the coupling by a factor of 10 for light DM is fine, e.g. $m_{DM} \lesssim 25$ GeV , such that we remain in the perturbative regime $g_{DM} < 1$.



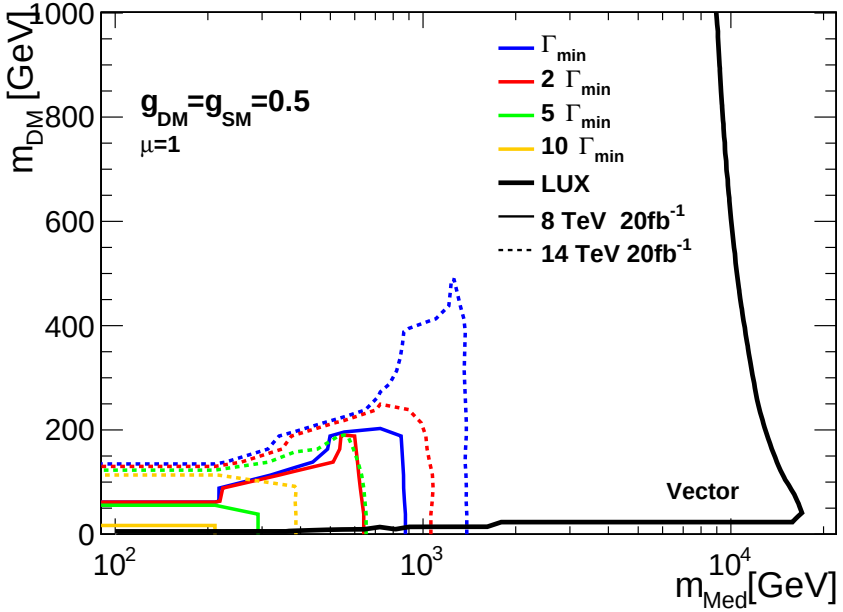
Plots illustrate the contours of the required μ-factor necessary to enhance the signal for pseudo-scalar messenger models to set a 90% CL at 14 TeV LHC assuming the minimal width.

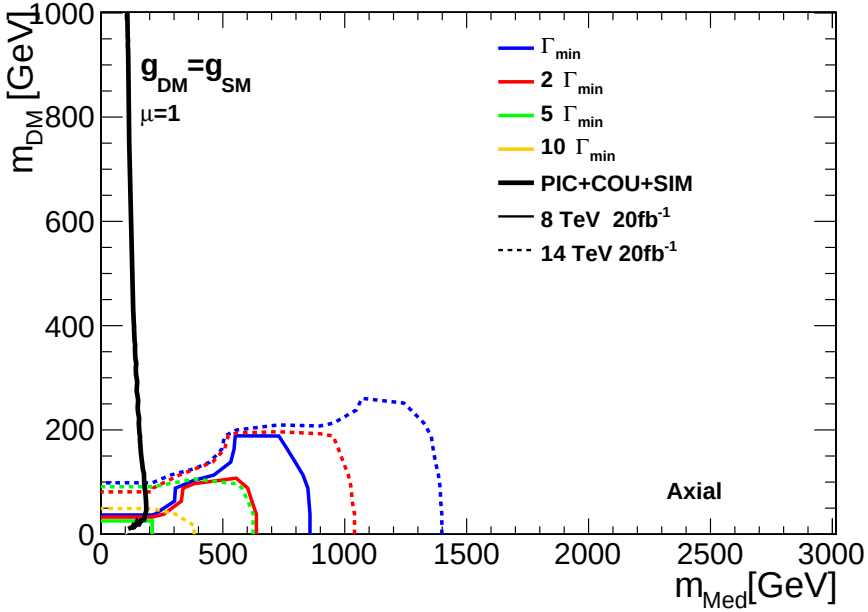
2. The question of whether a parameter point is visible at the LHC depends on the ability to separate signal processes from the background. A better background rejection will boost sensitivity independently of the signal parameterisation and the real analysis sensitivity is likely to improve by a substantial amount. Hence this figure only serves as baseline for our current sensitivity.

Simplified Models: Constraining Dark Particles at the LHC

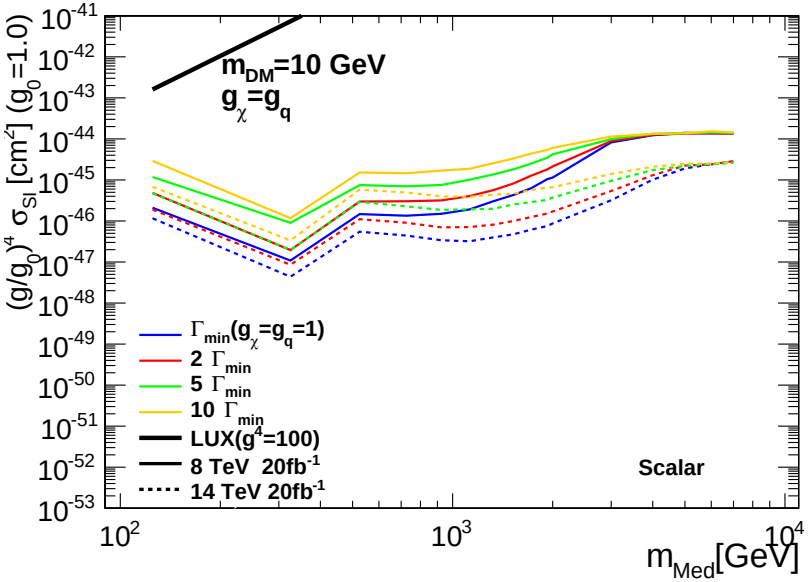
- Vector and Axial-vector mediators:

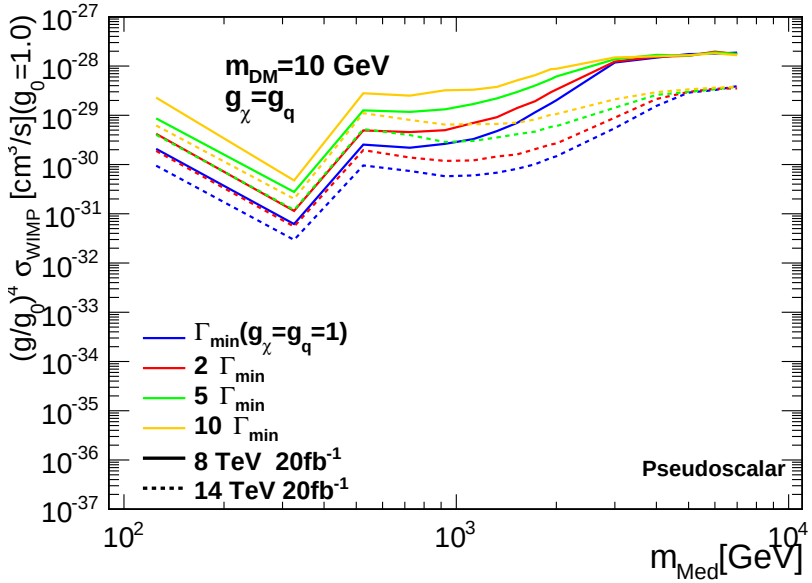
Compare the predicted value of the cross section for a given parameter set against the limit set by the LHC. We present the constrained region as a function of the dark matter and mediator mass:

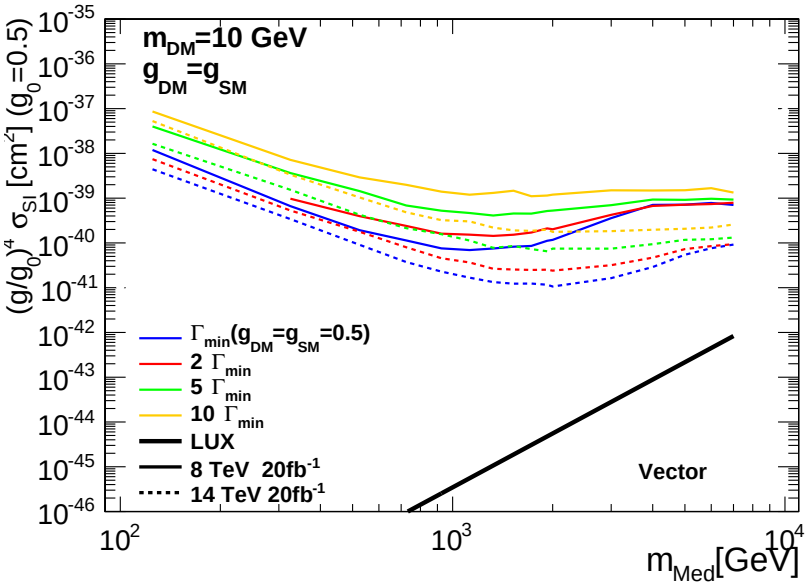


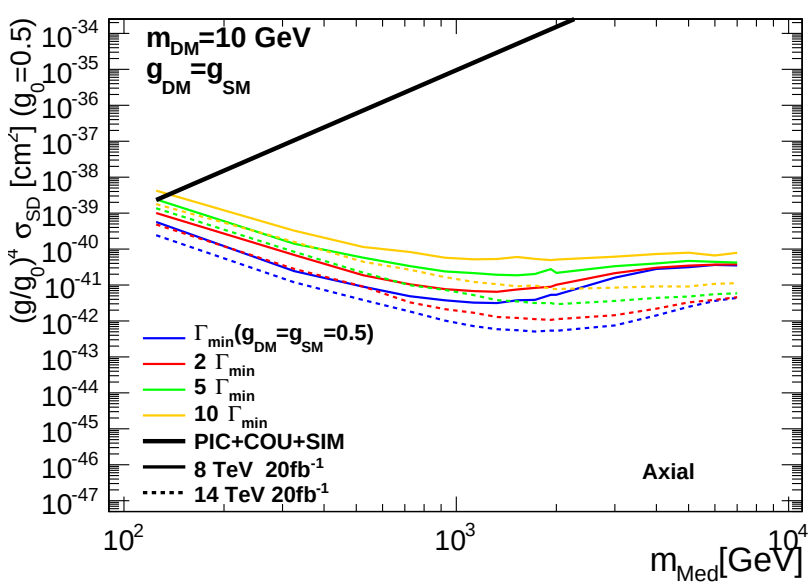


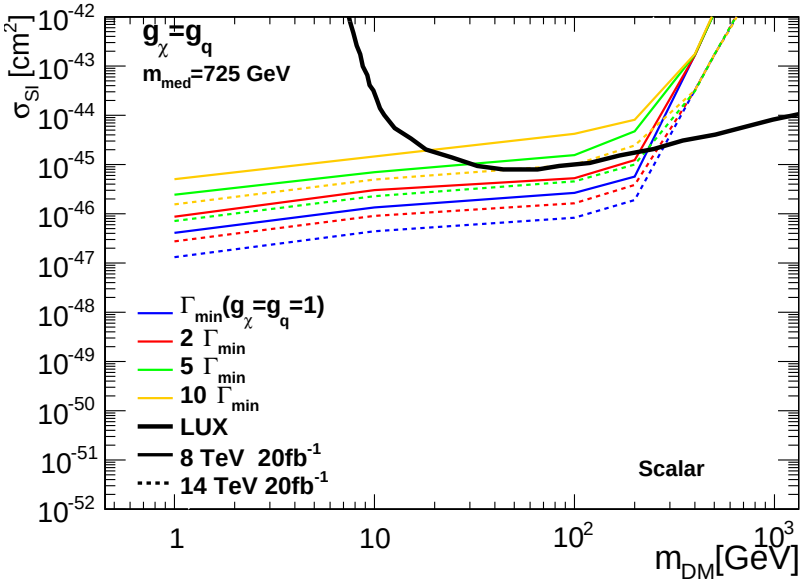
$\mu = 1$ for vectors and axial-vectors here

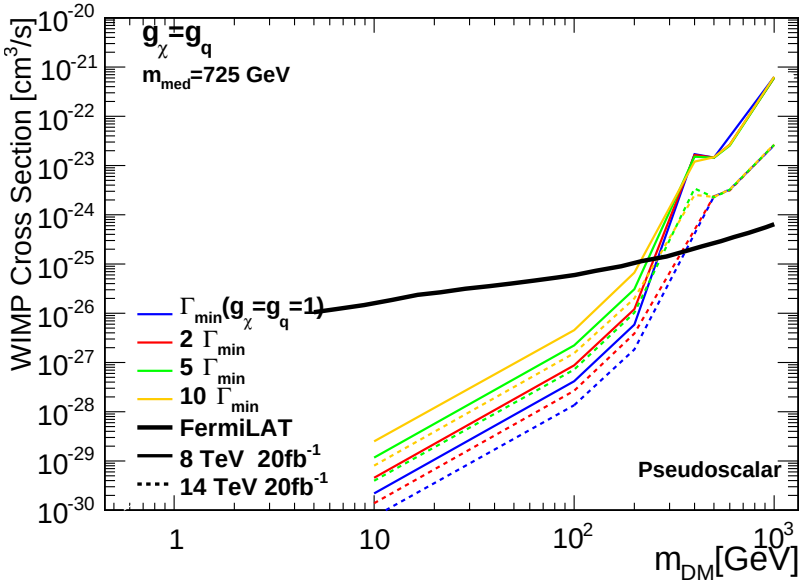

m_{DM}=10 GeV
g_χ=g_q
$(g/g_0)^4$ σ_{SI} [cm^2] (g_0=1.0)
Γ_{min}(g_χ=g_q=1)
2 Γ_{min}
5 Γ_{min}
10 Γ_{min}
LUX(g^4=100)
8 TeV 20fb^{-1}
14 TeV 20fb^{-1}
Scalar
m_{Med}[GeV]

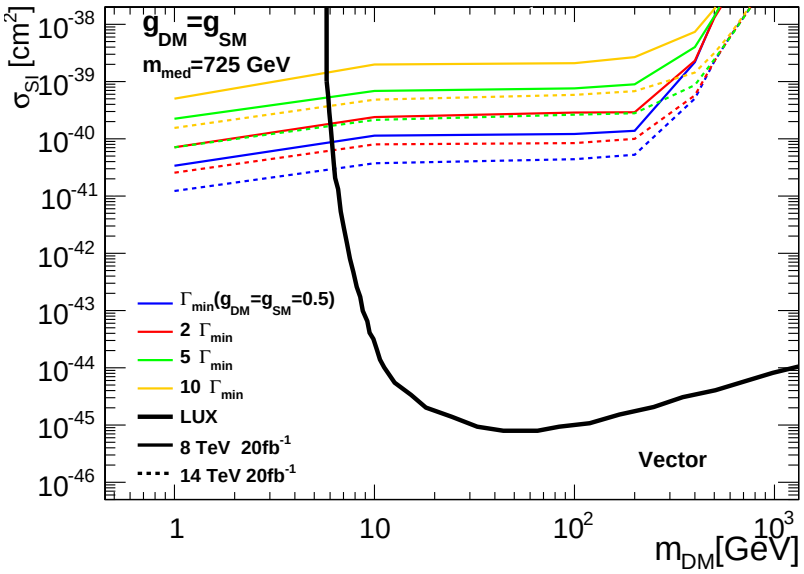

m_{DM}=10 GeV
g_χ=g_q
$(g/g_0)^4$ σ_{WIMP} [cm^3/s] (g_0=1.0)
Γ_{min}(g_χ=g_q=1)
2 Γ_{min}
5 Γ_{min}
10 Γ_{min}
8 TeV 20fb^{-1}
14 TeV 20fb^{-1}
Pseudoscalar
m_{Med}[GeV]

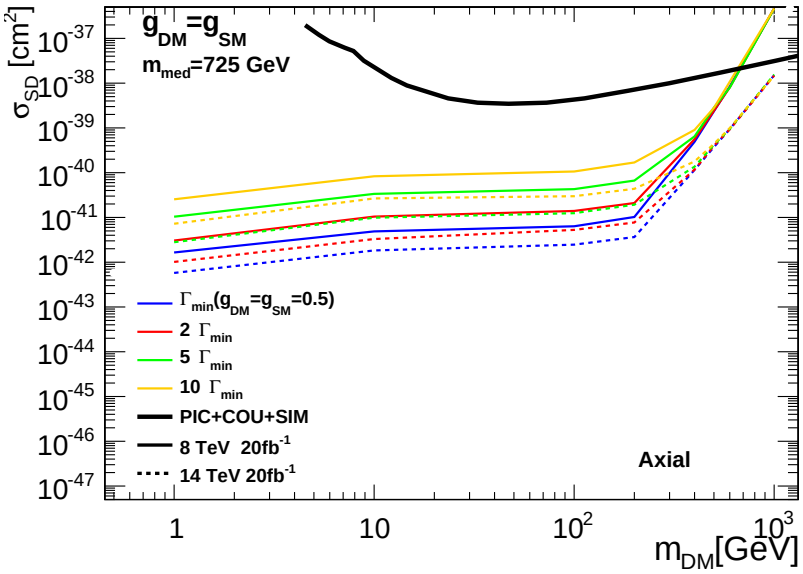

m_{DM}=10 GeV
g_{DM}=g_{SM}
$(g/g_0)^4$ σ_{SI} [cm^2] (g_0=0.5)
Γ_{min}(g_{DM}=g_{SM}=0.5)
2 Γ_{min}
5 Γ_{min}
10 Γ_{min}
LUX
8 TeV 20fb^{-1}
14 TeV 20fb^{-1}
Vector
m_{Med}[GeV]


m_{DM}=10 GeV
g_{DM}=g_{SM}
$(g/g_0)^4$ σ_{SD} [cm^2] (g_0=0.5)
Γ_{min}(g_{DM}=g_{SM}=0.5)
2 Γ_{min}
5 Γ_{min}
10 Γ_{min}
PIC+COU+SIM
8 TeV 20fb^{-1}
14 TeV 20fb^{-1}
Axial
m_{Med}[GeV]


$g_\chi = g_q$
m_{med}=725 GeV
σ_{SI} [cm^2]
$\Gamma_{min}(g_\chi = g_q = 1)$
2 Γ_{min}
5 Γ_{min}
10 Γ_{min}
LUX
8 TeV 20fb^{-1}
14 TeV 20fb^{-1}
Scalar
m_{DM}[GeV]


$g_\chi = g_q$
m_{med}=725 GeV
WIMP Cross Section [cm^3/s]
$\Gamma_{min}(g_\chi = g_q = 1)$
2 Γ_{min}
5 Γ_{min}
10 Γ_{min}
FermiLAT
8 TeV 20fb^{-1}
14 TeV 20fb^{-1}
Pseudoscalar
m_{DM}[GeV]


$g_{DM} = g_{SM}$
m_{med}=725 GeV
σ_{SI} [cm^2]
$\Gamma_{min}(g_{DM} = g_{SM} = 0.5)$
2 Γ_{min}
5 Γ_{min}
10 Γ_{min}
LUX
8 TeV 20fb^{-1}
14 TeV 20fb^{-1}
Vector
m_{DM}[GeV]


$g_{DM} = g_{SM}$
m_{med}=725 GeV
σ_{SD} [cm^2]
$\Gamma_{min}(g_{DM} = g_{SM} = 0.5)$
2 Γ_{min}
5 Γ_{min}
10 Γ_{min}
PIC+COU+SIM
8 TeV 20fb^{-1}
14 TeV 20fb^{-1}
Axial
m_{DM}[GeV]