LHC constraints on vector mediators

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Resonant production

- It is an interesting possibility that the dark mediator mass is comparable to LHC energies ($m_R \sim$ TeV).
- The LHC can produce such a mediator *on-shell*:

$$\sigma\,(j + \mathrm{MET}) \sim \sigma\,(pp \to R + j) \times \mathrm{BR}\,(R \to \text{invisible})$$

- As a consequence, the monojet cross section is not directly proportional to the direct detection cross-section.
- For any meaningful comparison, we need to specify the properties of the mediator (couplings, mass, width).

  One possible approach is to consider specific models where all couplings can be calculated in terms of a few fundamental parameters.

A specific model

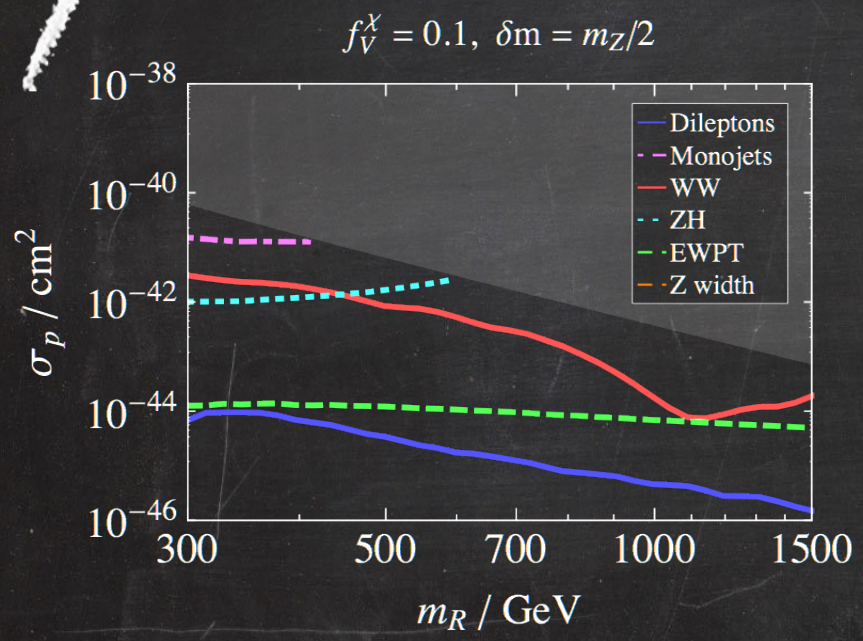
- A popular example for such a specific model is the case where the mediator is the gauge boson of a new $U(1)$ under which only the dark matter particle is charged (often called dark Z' or invisible Z').

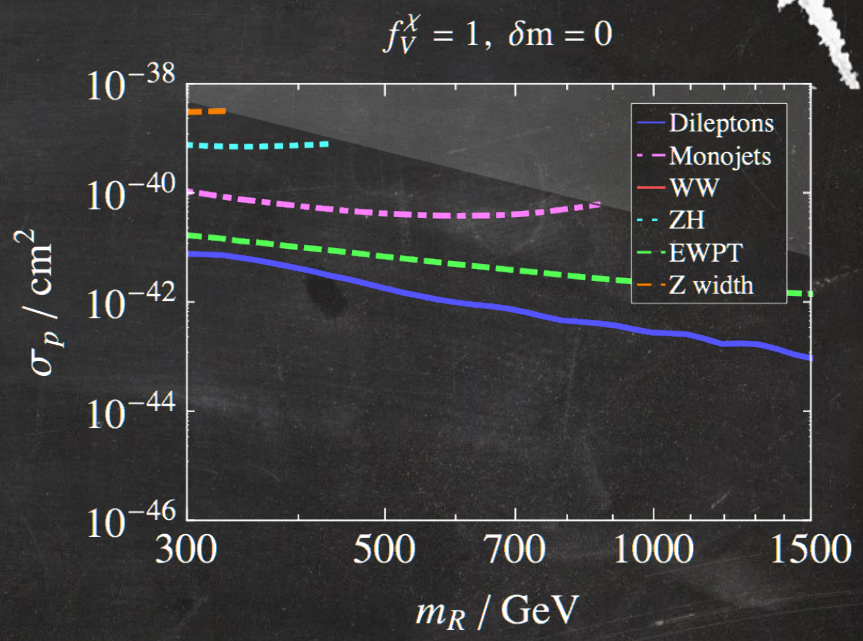
$$\mathcal{L} = \mathcal{L}_{SM} - \frac{1}{4} Z'^{\mu\nu} Z'_{\mu\nu} + \frac{1}{2} m_{Z'}^2 Z'_\mu Z'^\mu$$
$$- \frac{1}{2} \sin\epsilon \, B_{\mu\nu} Z'^{\mu\nu} + \delta m^2 Z_\mu Z'^\mu$$

- There are 4 (or 5) free parameters in this model:
  - The direct coupling f_χ between the Z' and DM.
  - The Z' mass $m_{Z'}$ and the DM mass m_χ.
  - The mixing parameter(s) sin ε (and δm^2).

The dark Z′: Bounds

Frandsen, FK, Preston, Sarkar, Schmidt-Hoberg, JHEP 1207 (2012) 123





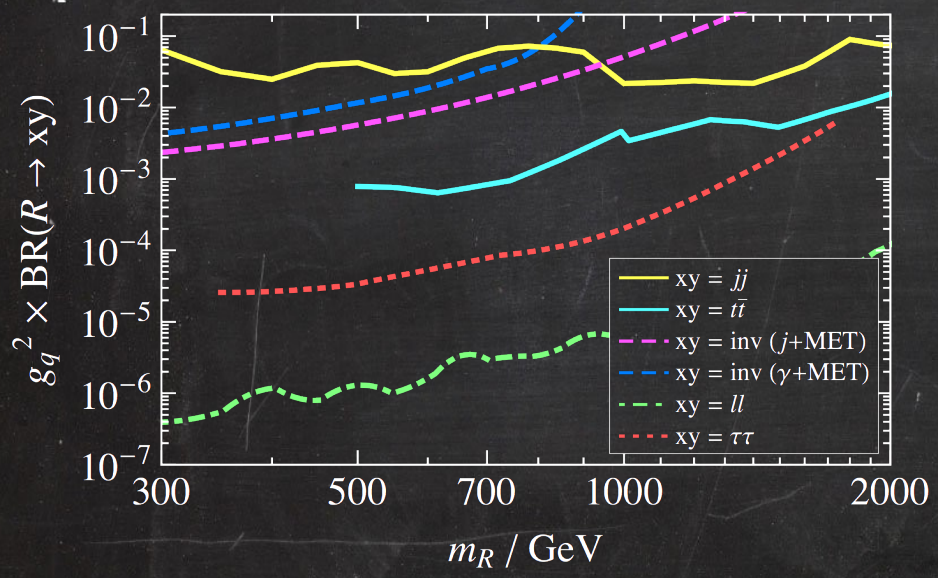
Since the dark *Z′* has comparable couplings to quarks and leptons, dilepton searches are much more constraining than monojet searches, even if we allow for large direct couplings of the *Z′* to DM.

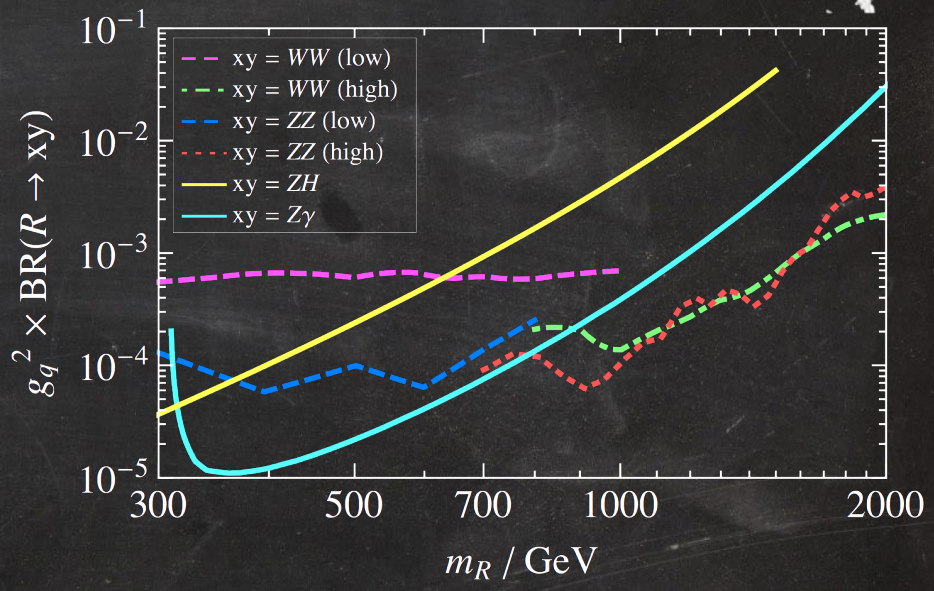
A general approach

- The strongest constraints for a dark *Z'* arise from couplings that are not necessary in order to obtain a large DM scattering cross section.
- To avoid these constraints, one should consider models where the mediator couples much more strongly to quarks than to leptons.
- This is difficult to achieve for a gauge boson (since baryon number is anomalous), so these models are usually not UV-complete but rather effective theories.
- Even very general models are highly constrained by LHC searches, because there are now bounds for every conceivable two-body decay into SM states.

Constraints: Fermions

We can constrain $g_q^2 \cdot \mathrm{BR}(R \to xy) < s_{xy}$
for all possible decay channels.

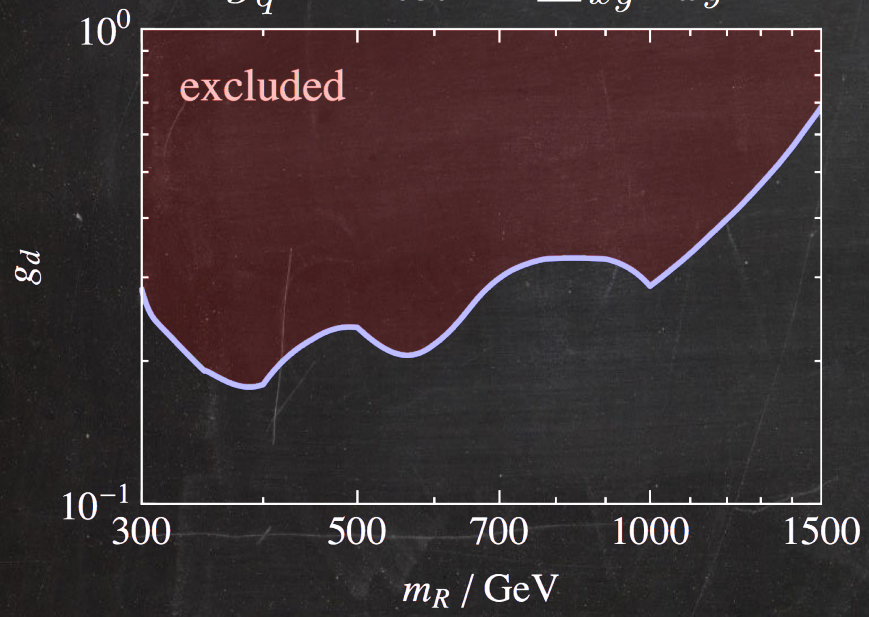


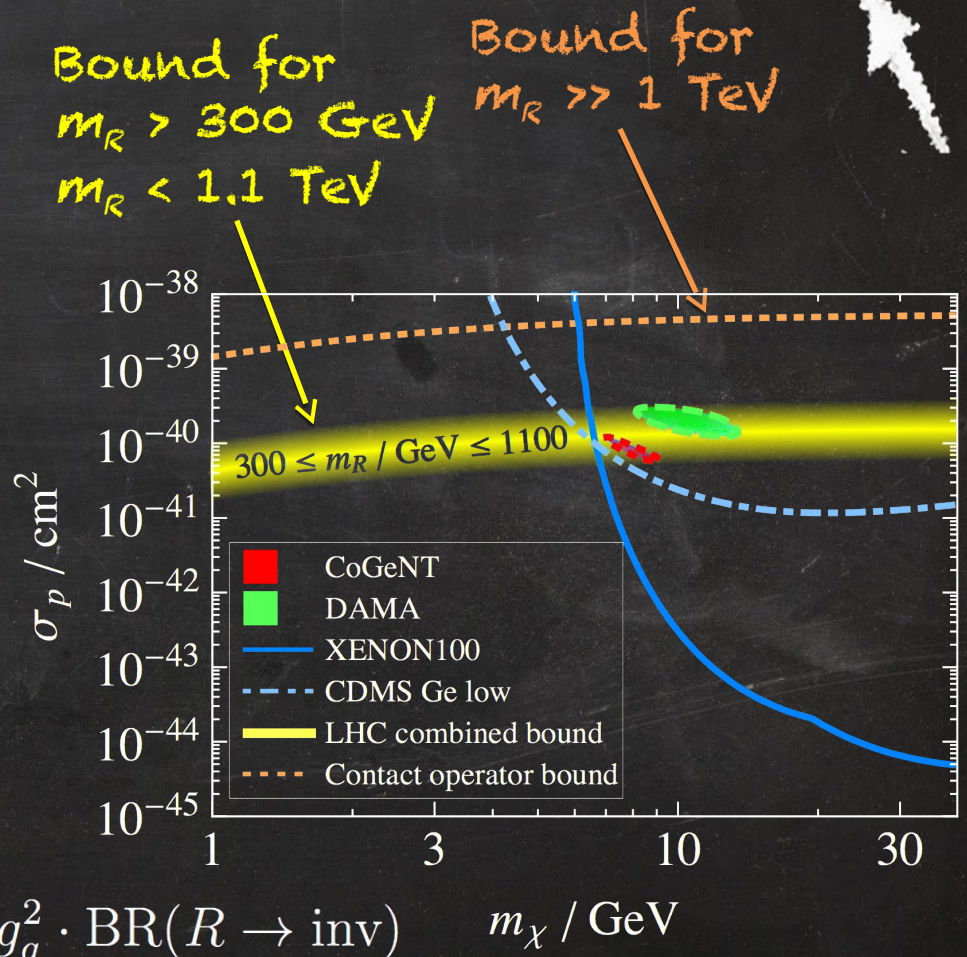


If g_q^2 exceeds the bound $g_q^2 \leq s_{\mathrm{tot}} = \sum_{xy} s_{xy}$ the total number of R particles produced at the LHC is so large that their decays would leave an observable signal in at least one search channel.

Combined Constraints

$$g_q^2 \leq s_{\rm tot} = \sum_{xy} s_{xy}$$





$$\sigma_p \lesssim 12 \frac{\mu_{\chi n}^2 \Gamma_R}{m_R^5} g_q^2 \cdot \mathrm{BR}(R \to \mathrm{inv})$$

Conclusions

i) How strong is the motivation to postulate a dark mediator beyond the Standard Model?

A new mediator is almost inevitable in models with DM masses below 40 GeV.

ii) Which shortcomings should a new mediator address? Which benefits should it provide?

It should provide a flexible framework for mapping out the phenomenology of DM searches at the LHC.

iii) What is the most important experimental/observational strategy to gain more information?

Rather than pushing the sensitivity in a few different search channel, the LHC should aim for a broad coverage of different observables.

Backup

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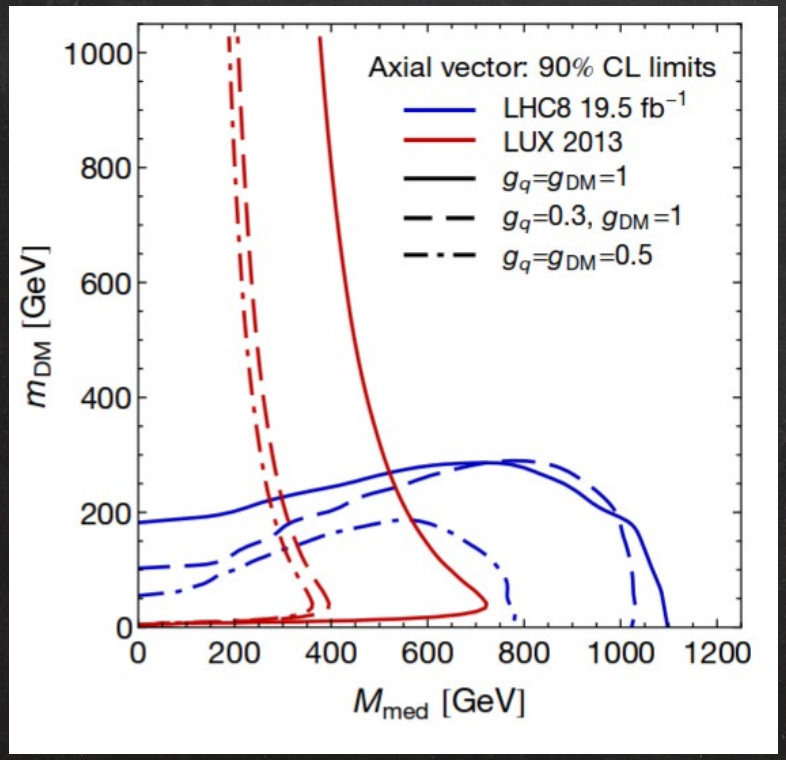
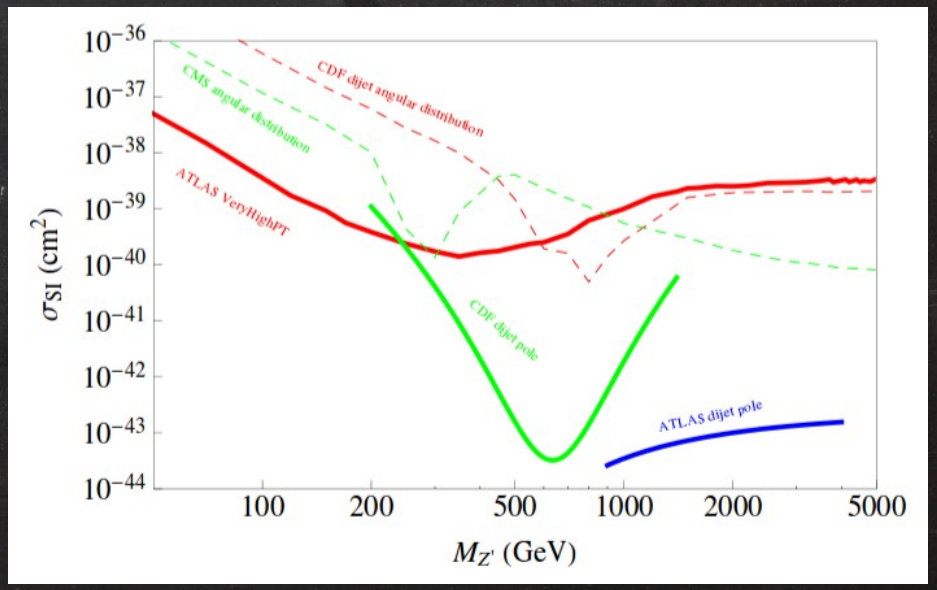
Complementarity of monojet searches and direct detection (left) and of monojet searches and dijet searches (right)

Buchmueler et al., arXiv:1407.8257



An et al., arXiv:1202.2894



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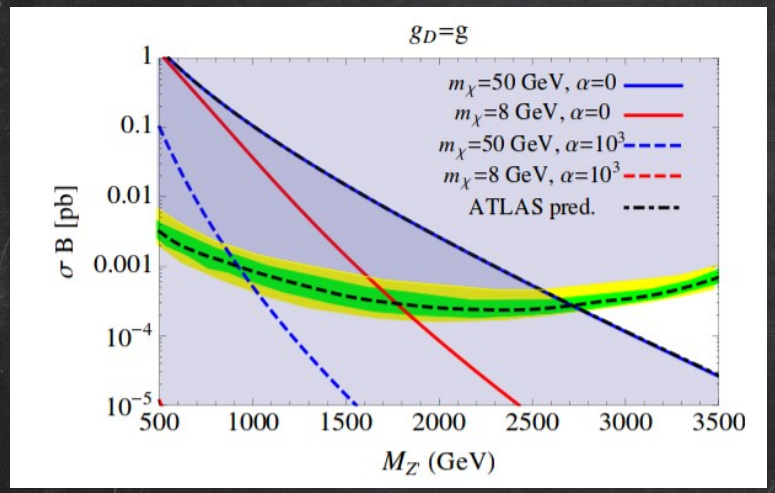
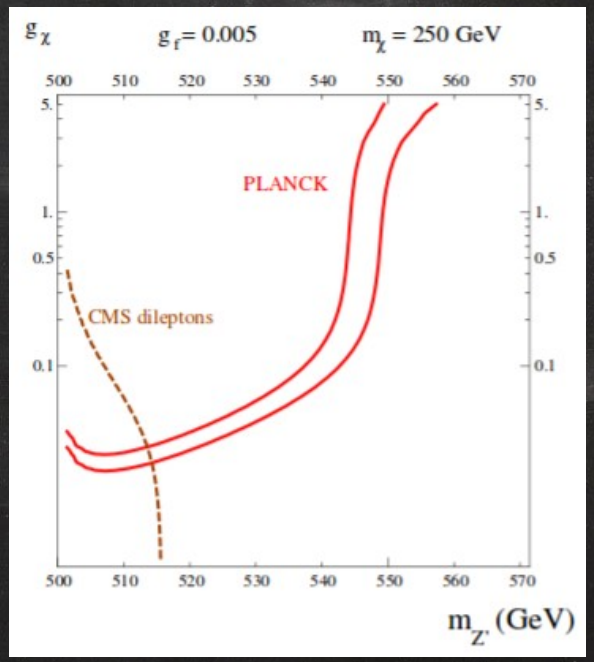
Arcadi et al., arXiv:1401.0221



Very strong constraints from couplings to leptons

Lebedev, Mambrini, arXiv:1403.4837



Alves et al., arXiv:1501.03490