Interplay of dark matter searches

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and work in progress

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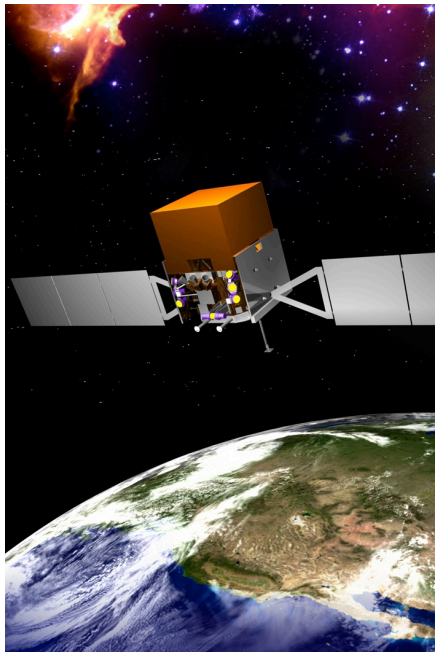
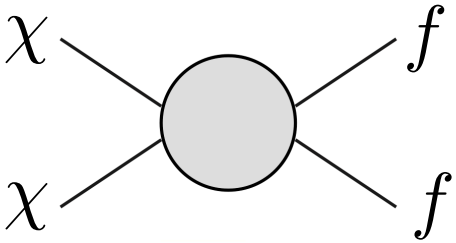
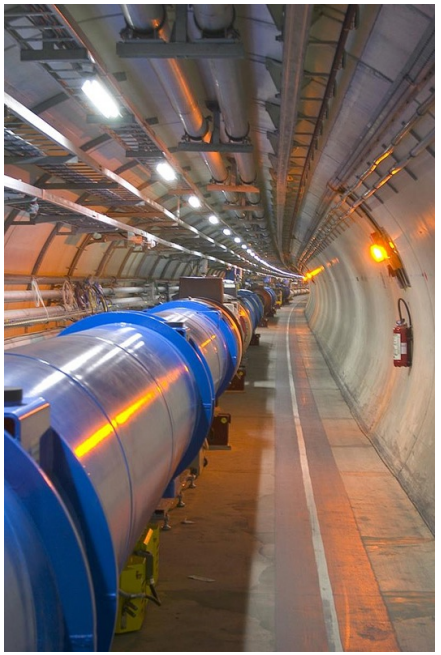
Searches for (WIMP) dark matter

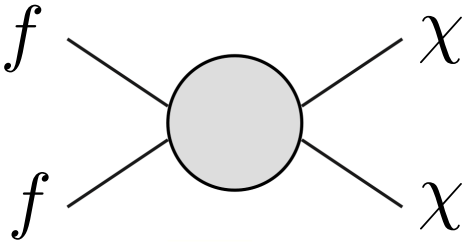
- Indirect detection



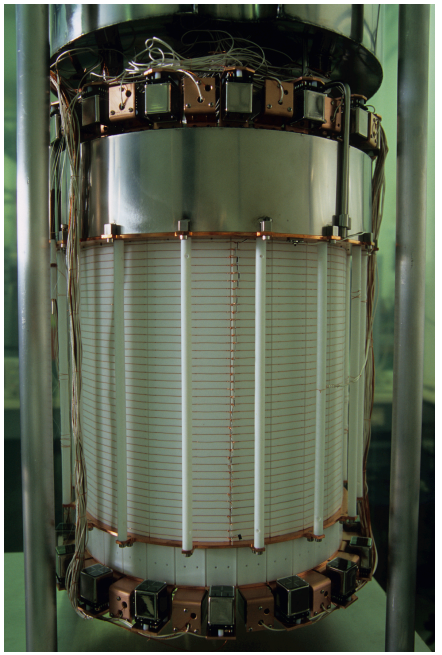


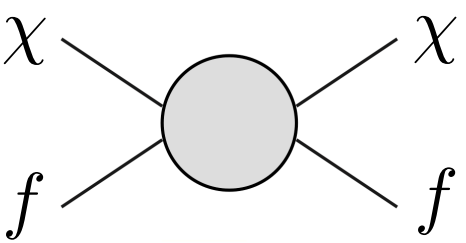
- Collider production





- Direct detection

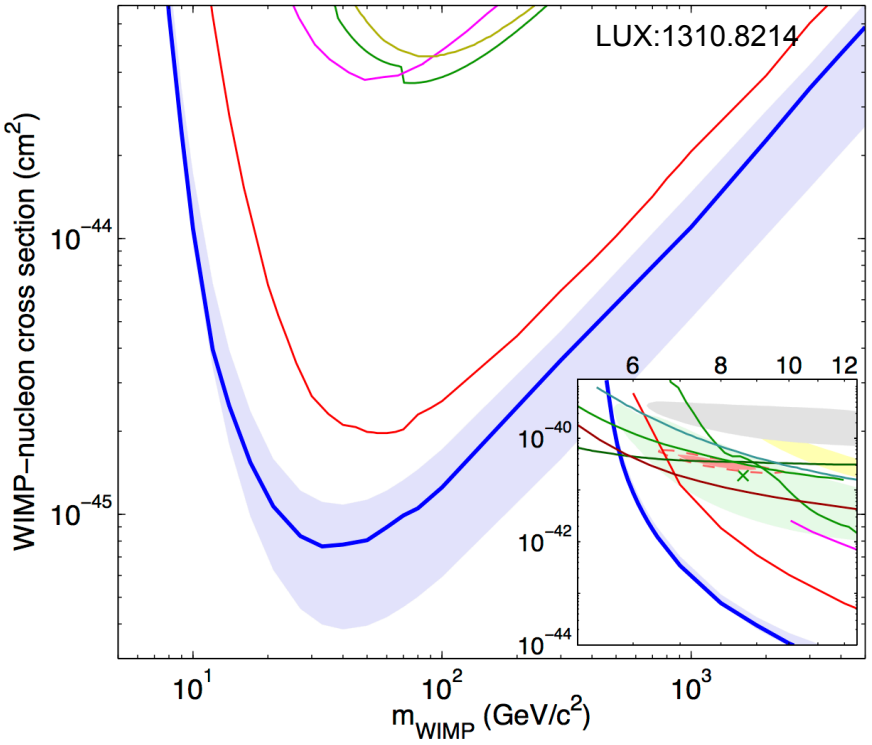




Interpreting searches

- We don't know the correct theory of particle dark matter
- Search results should be presented within a general framework that constrains a large number of theories
- Interpret results from
  1. Direct detection
  2. Colliders: LHC monojet search
  3. (Indirect detection)

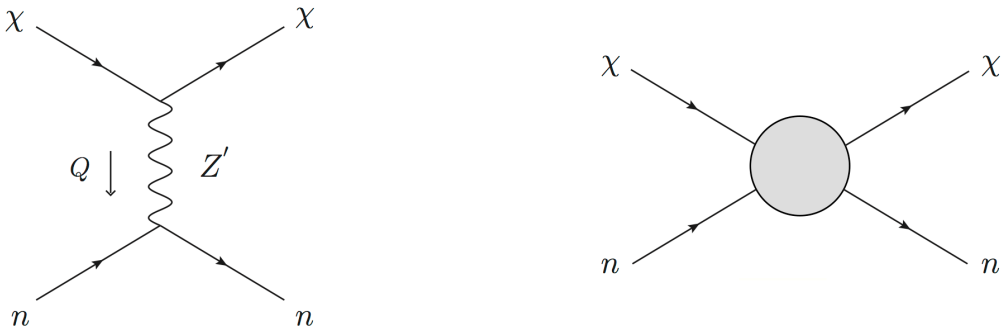
Direct detection searches



- Limits are quoted in terms of σ_n: the 'WIMP-nucleon cross section'
  - Is this limit applicable to all theories...? No...

Direct detection searches: assumptions

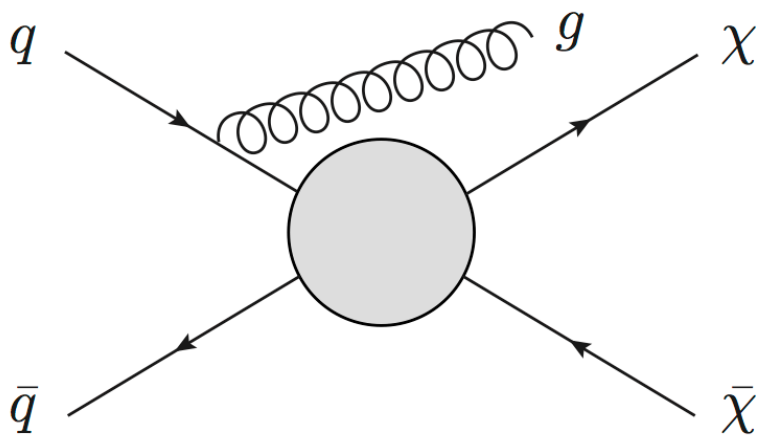
- Many assumptions made: Spin-independent / spin-dependent /...
- Also assumes a 'contact interaction'

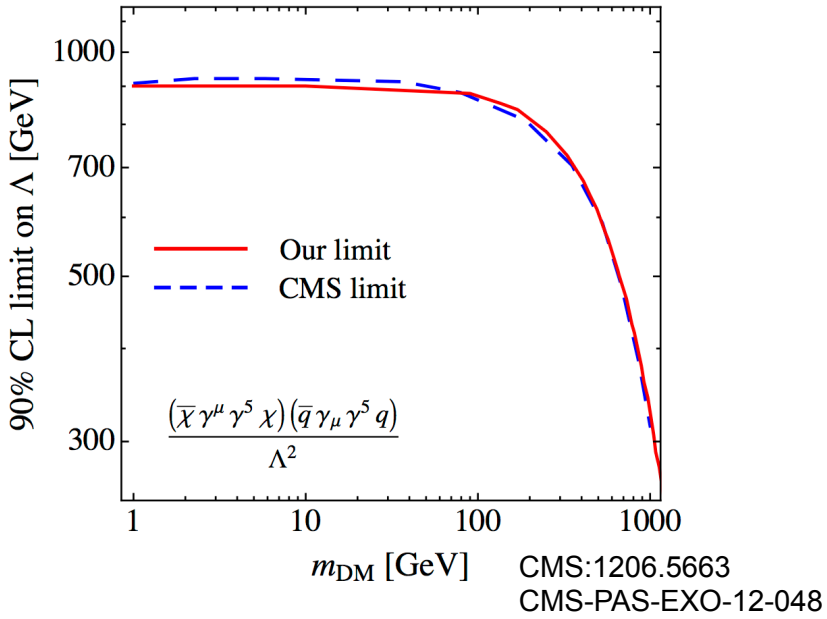


$$\sigma_n \sim \left(\frac{g_n g_\chi}{Q^2 - m_{Z'}^2} \right)^2 \approx \frac{g_n^2 g_\chi^2}{m_{Z'}^4} \left(1 + \frac{Q^2}{m_{Z'}^2} + \cdots \right)^2$$

- Contact interaction if $m_{Z'} \gg Q = \sqrt{2 m_n E_{\mathrm{R}}} \approx 50 \text{ MeV}$
- Lots of theories satisfy this constraint
  - A useful way to parameterize the results

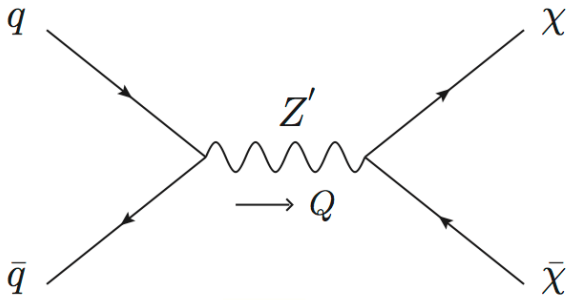
Dark matter searches at LHC



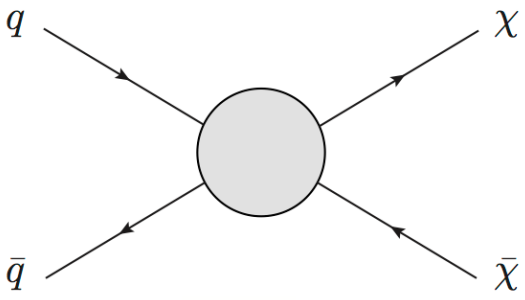


- Monojet search: look for a hard jet and missing energy
- Make use of effective field theory (EFT) to place a limit on the 'contact interaction scale' Λ.

Effective field theory (EFT)



'Integrate out the mediator'



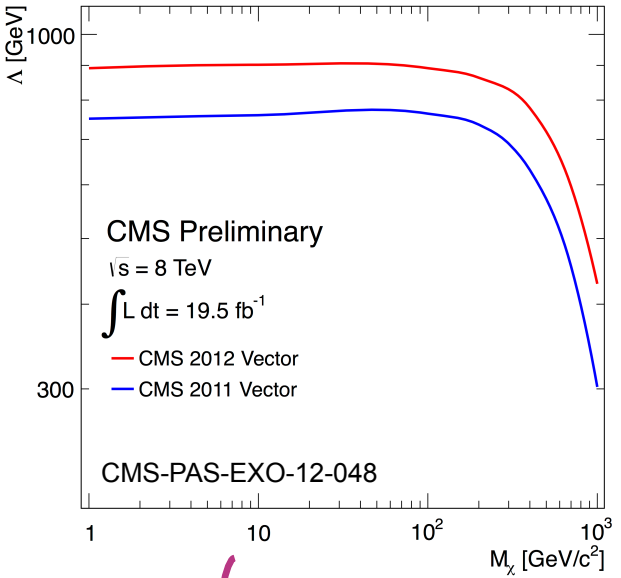
$$\mathcal{L} \sim g_\chi Z'_\mu \bar{\chi}\gamma^\mu\chi + g_q Z'_\mu \bar{q}\gamma^\mu q + \frac{1}{2} m^2_{Z'} Z'_\mu Z'^\mu + \cdots$$

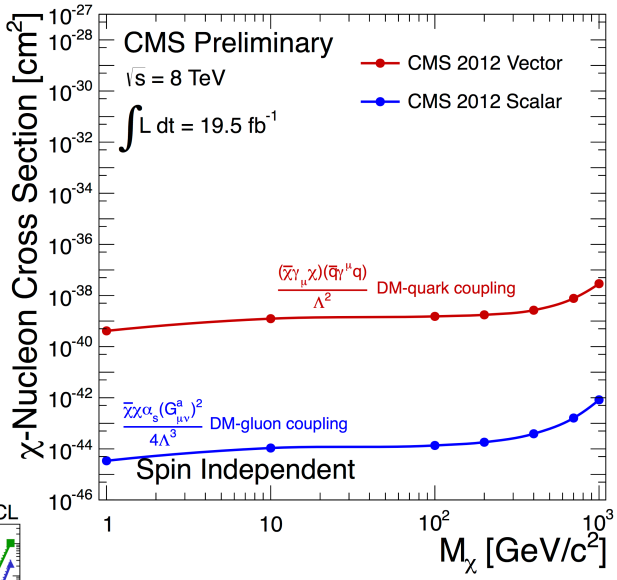
$$\mathcal{L} \sim \frac{1}{\Lambda^2}\bar{q}\gamma_\mu q\,\bar{\chi}\gamma^\mu\chi$$

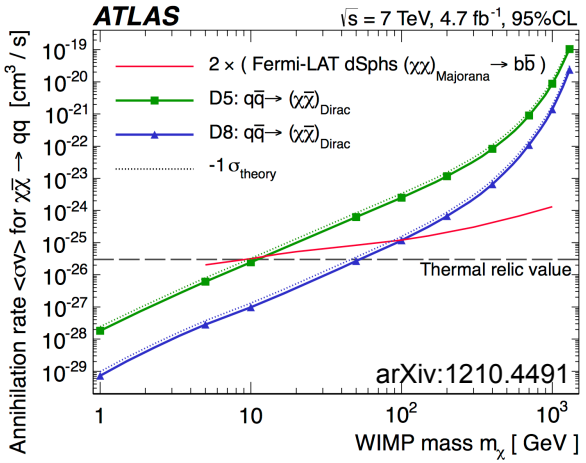
- Parameter of interest is Λ
- Λ related to parameters in the full theory: $\Lambda \equiv \dfrac{m_{Z'}}{\sqrt{g_q g_\chi}}$

Advantage of EFT approach

- Comparison with other dark matter searches is straightforward

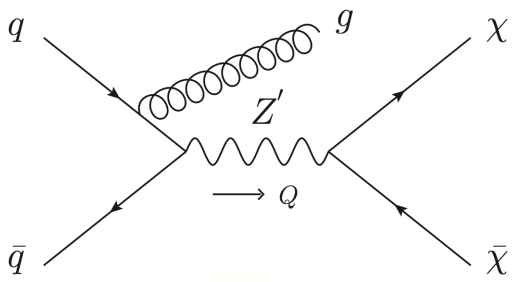






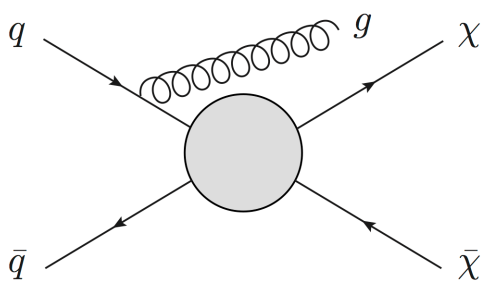
Disadvantage of EFT approach

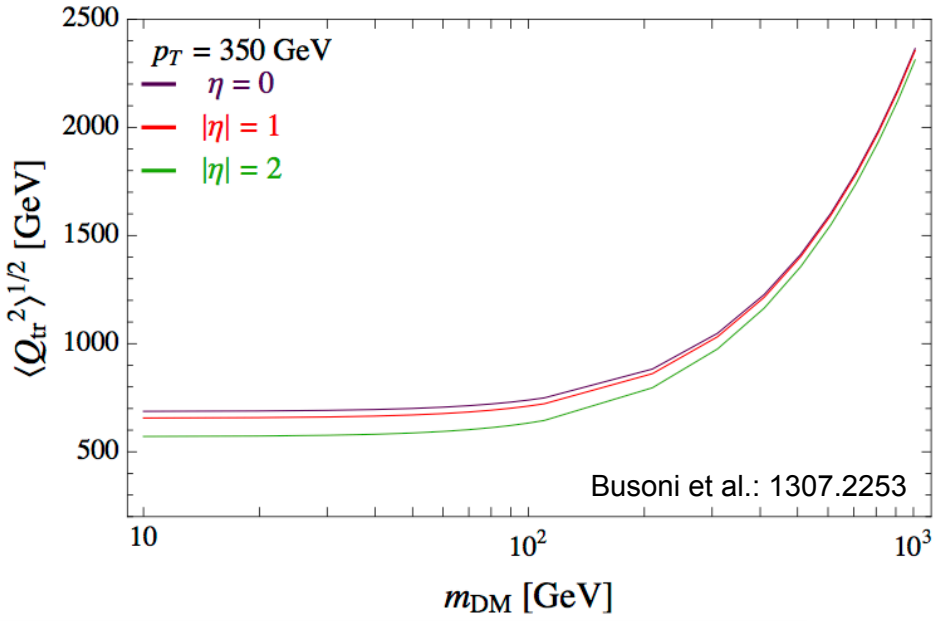
- Is it valid...?



Good approximation if

$$M_{Z'} \gg Q$$

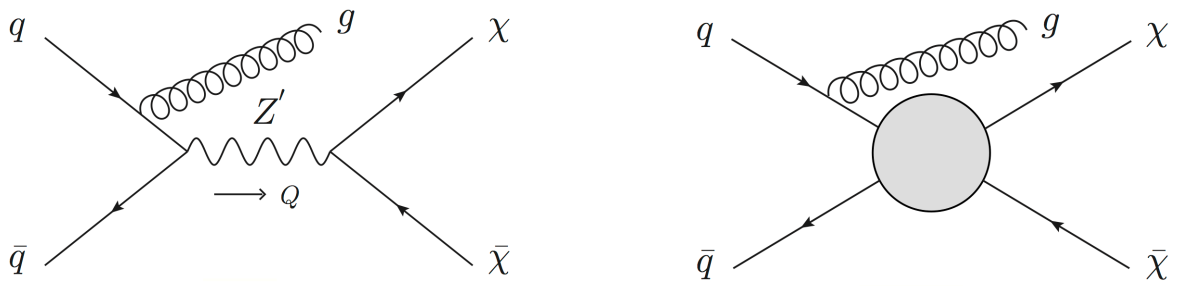




$$\rightarrow M_{Z'} \sim \text{TeV}$$

When is EFT valid?

- Better estimate: Compare a simple model with EFT result



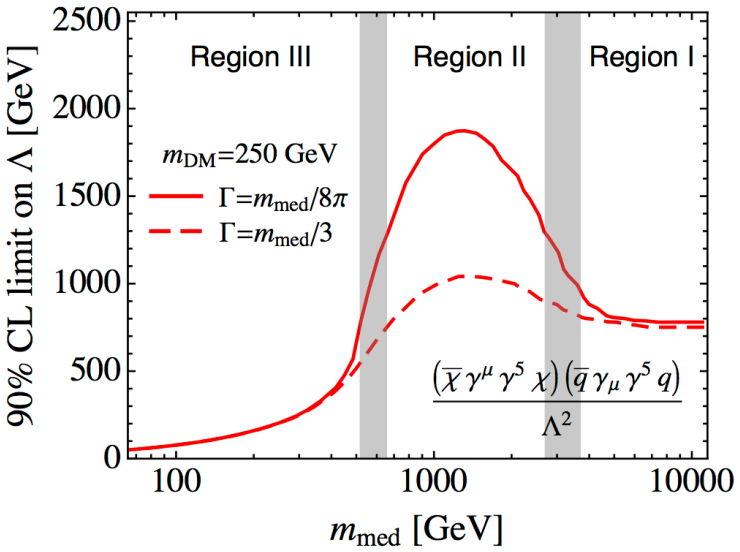
- Assumptions:
  1. s-channel axial-vector mediator
  2. Equal coupling to all quarks
  3. No coupling to leptons or SM gauge bosons

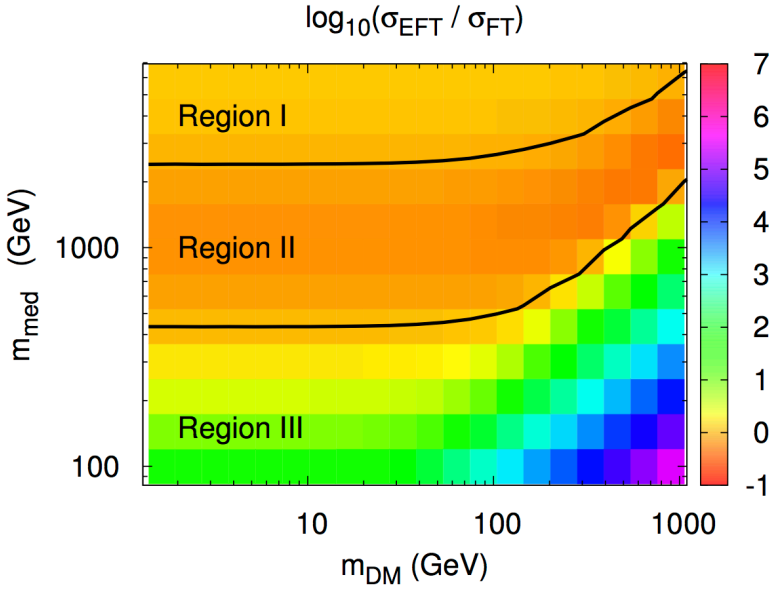
- For those who like Lagrangians:

$$\mathcal{L} \supset g_\chi Z'_\mu \bar{\chi}\gamma^\mu\gamma^5\chi + g_q Z'_\mu \bar{q}\gamma^\mu\gamma^5 q \quad \text{vs} \quad \mathcal{L} \supset \frac{1}{\Lambda^2}\bar{\chi}\gamma^\mu\gamma^5\chi\,\bar{\chi}\gamma_\mu\gamma^5\chi$$

When is EFT valid?

- Look at limit on $\Lambda = \dfrac{m_{\rm med}}{\sqrt{g_q g_\chi}}$





- Region I: EFT limit is good $m_{\rm med} \gtrsim 3$ TeV
- Region II: EFT limit is too weak
- Region III: EFT limit is too strong $m_{\rm med} \lesssim 500$ GeV

When is EFT valid?

EFT limit applies to a small class of theories:

- Large mediator mass:

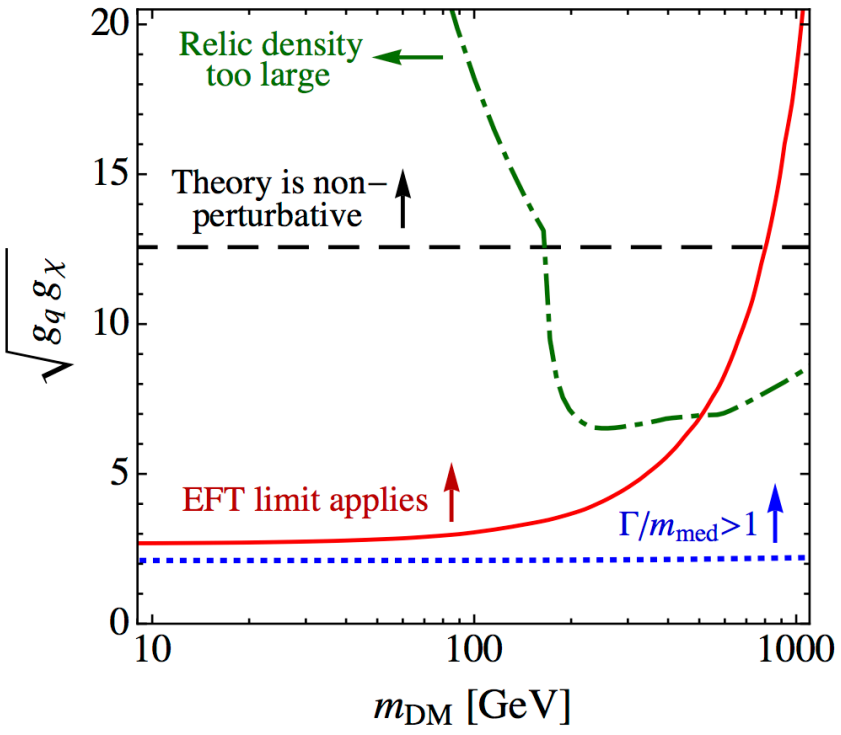
$$m_{\rm med} \gtrsim 3 \text{ TeV}$$

- Large couplings:

$$\sqrt{g_q g_\chi} = \frac{m_{\rm med}}{\Lambda}$$

- Large mediator width:

$$\Gamma > m_{\rm med}$$



A different approach

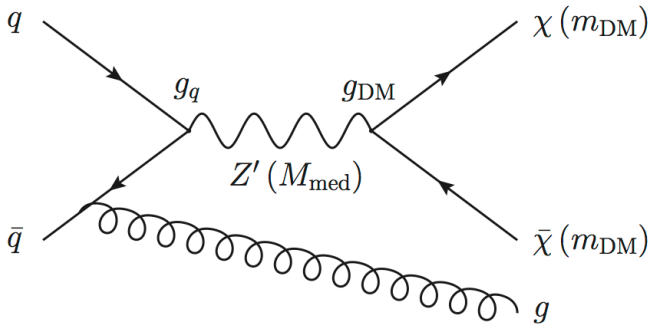
- What are we trying to achieve?

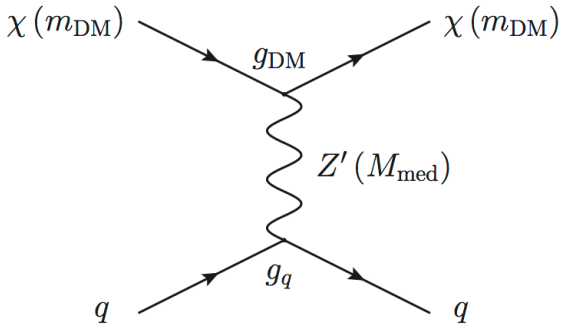
- Want a framework that holds for all dark matter (collider/direct/indirect) constraints
- It looks difficult to give an interpretation of monojet seaches were you just read off the limit
  - At least give intuition for what the constraints will look like

- Minimal/simple
- Extendable:
  - Different mediators (vector/scalar/pseudoscalar...)
  - Different dark matter (Dirac/Majorana/scalar...)
  - Include s-channel, t-channel exchange
  - ...

Minimal simplified DM model

- Consider Dirac DM with axial-vector mediator





Frandsen et al
Mambrini et al
Alves et al
Fairbairn et al

- Can characterise production (including mediator width), scattering and annihilation processes with four parameters:

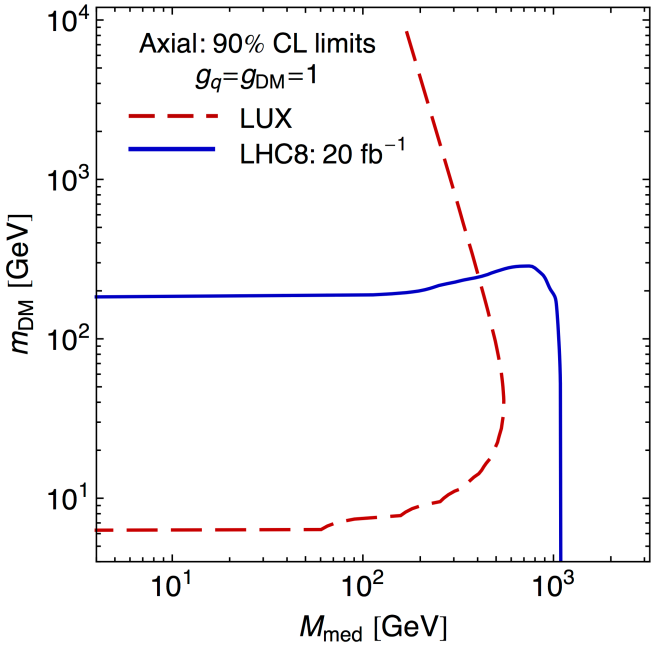
$$\mathcal{L}_{\rm axial} \supset -\sum_q g_q Z'_\mu \bar{q}\gamma^\mu\gamma^5 q - g_{\rm DM} Z'_\mu \bar{\chi}\gamma^\mu\gamma^5\chi$$

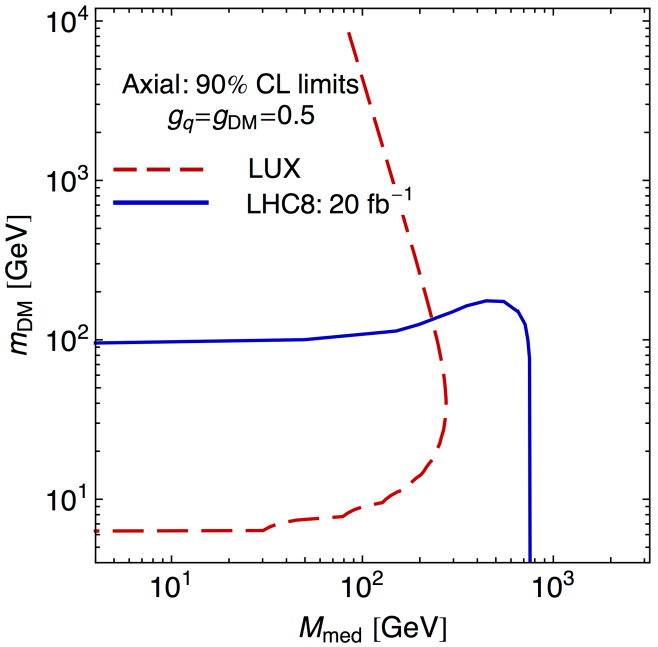
$m_{\rm DM}$	$g_{\rm DM}$
$M_{\rm med}$	g_q

Slicing through parameter space

- We need to fix two parameters to show results

$m_{\rm DM}$	$g_{\rm DM}$
$M_{\rm med}$	g_q



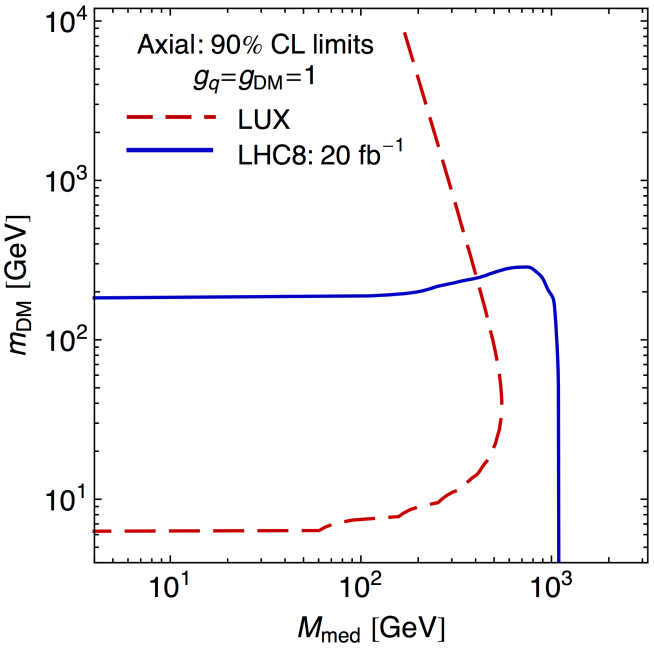


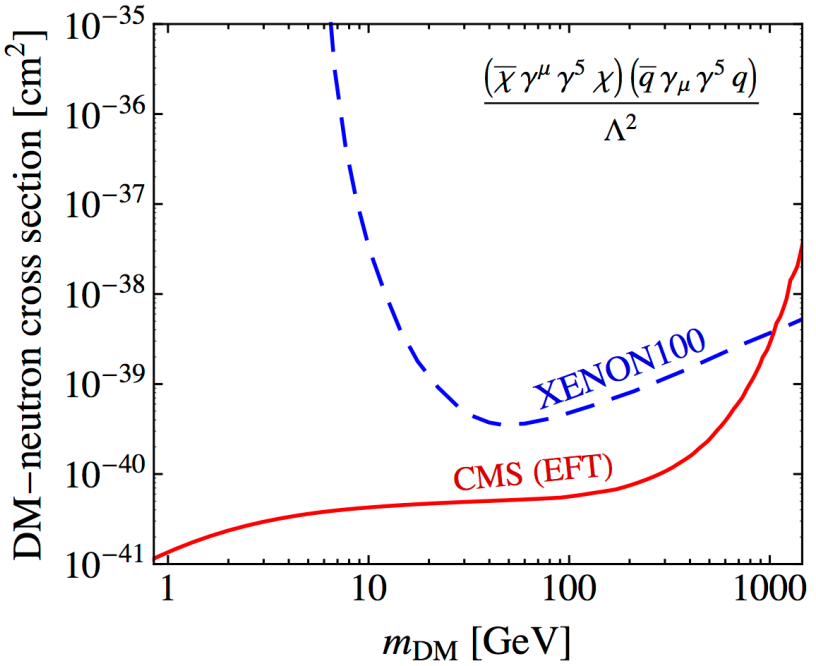
- LHC and LUX constraints are complementary

Slicing through parameter space

- Contains more information than you get from EFT result:

$m_{\rm DM}$	$g_{\rm DM}$
$M_{\rm med}$	g_q

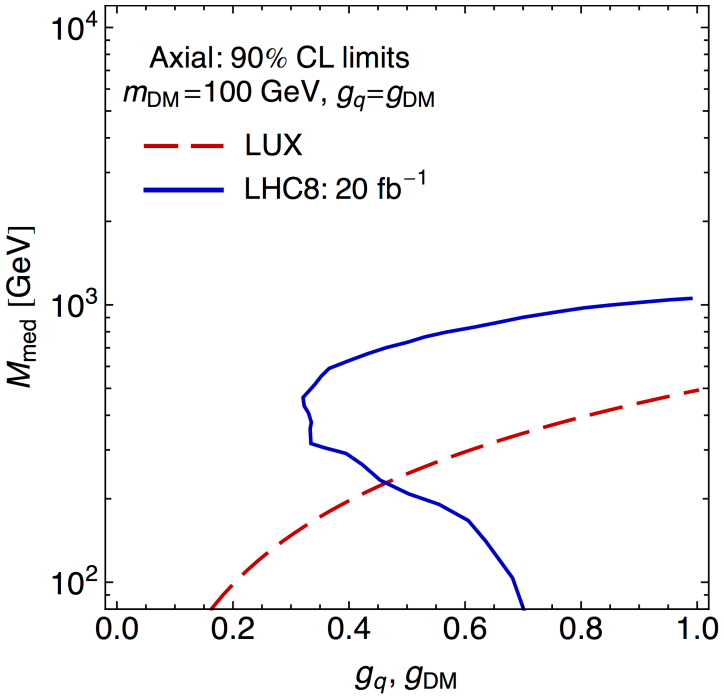




Slicing through parameter space

- Other planes also show complementarity between LHC and LUX

$m_{\rm DM}$	$g_{\rm DM}$
$M_{\rm med}$	g_q



Extensions

m_{DM}	g_{DM}
M_{med}	g_q

- Constraints from other other dark matter searches (indirect detection, relic density constraints...) and collider searches (dijets...) can also be mapped onto the same four parameter models

- Straightforward to generalise to other mediators/dark matter candidates/t-channel

Summary

- Important to interpret dark matter searches in the right framework

- Comparing LHC monojet searches with other dark matter searches is not straightforward
  - EFT approach constrains few theories and comparison and naïve comparison can lead to incorrect conclusions

- Need to go beyond EFT – 'minimal simplified DM models' capture more physics but at the expense of extra parameters
  - Work required to optimise the choice of simple models