Beyond EFT for dark matter searches at the LHC

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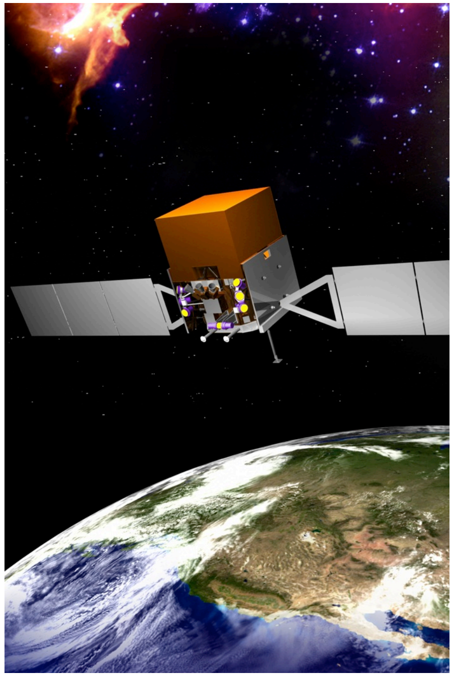
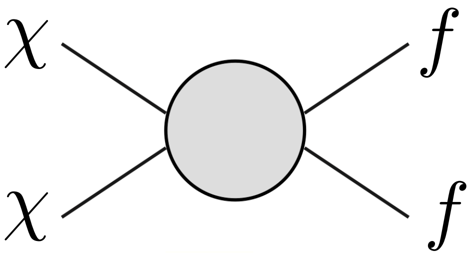
arXiv:1308.6799

The Violent Universe, Institute of Physics, London – 1st November 2013

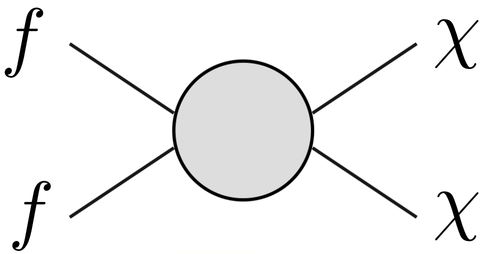
Searches for (WIMP) dark matter

- Indirect detection

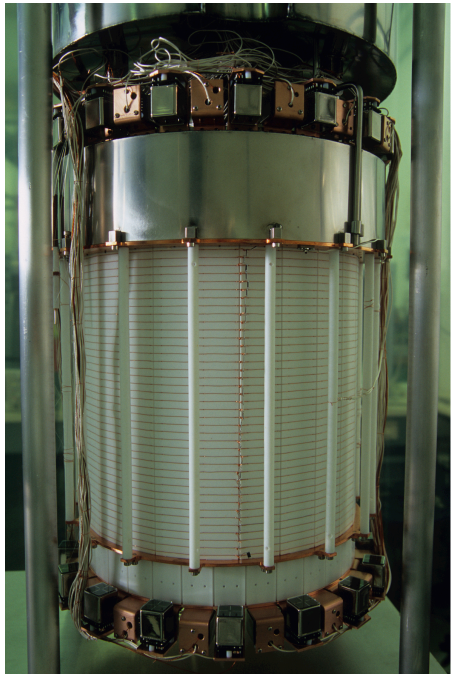


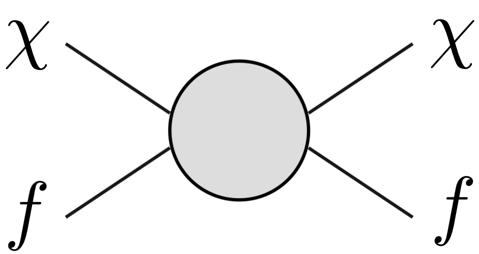


- Collider production



- Direct detection

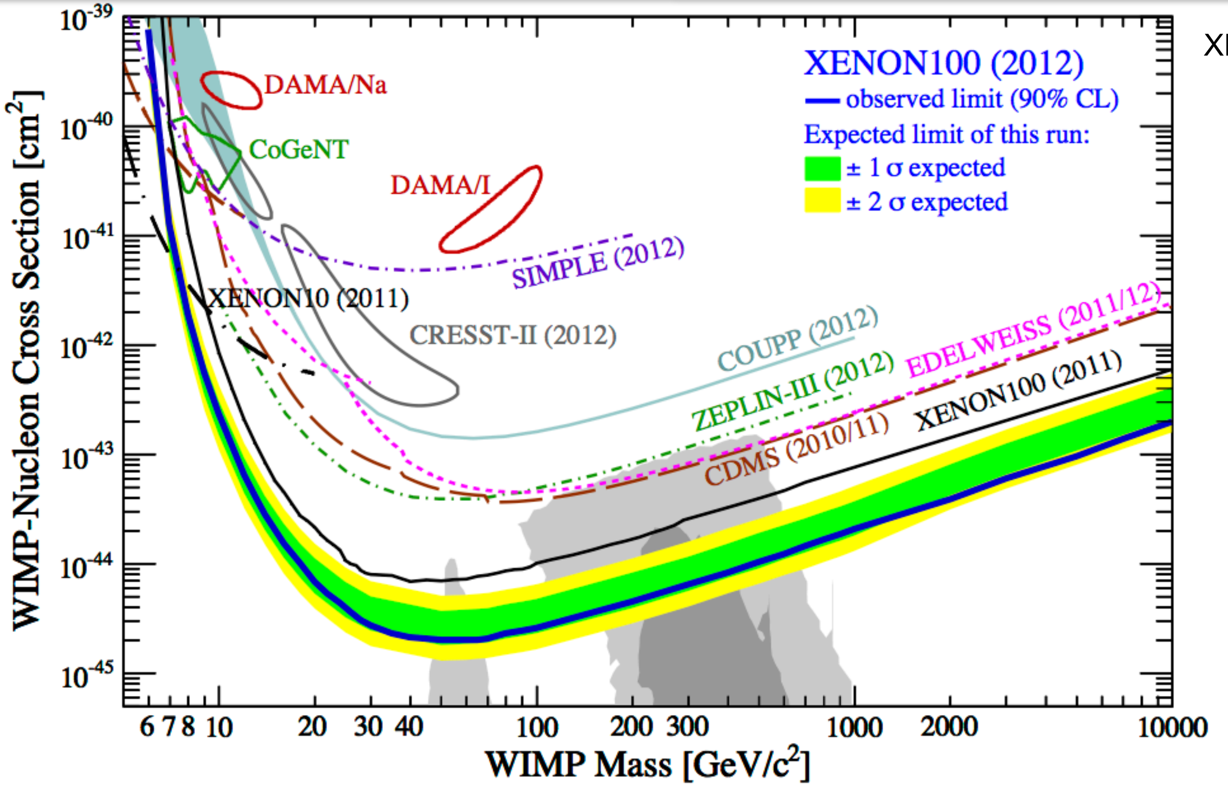




Interpreting searches

- We don't know the correct theory of particle dark matter
- Search results should be presented within a general framework that allows a large number of theories to be constrained
- Examples from
  1. Direct detection searches
  2. LHC monojet searches

Direct detection searches

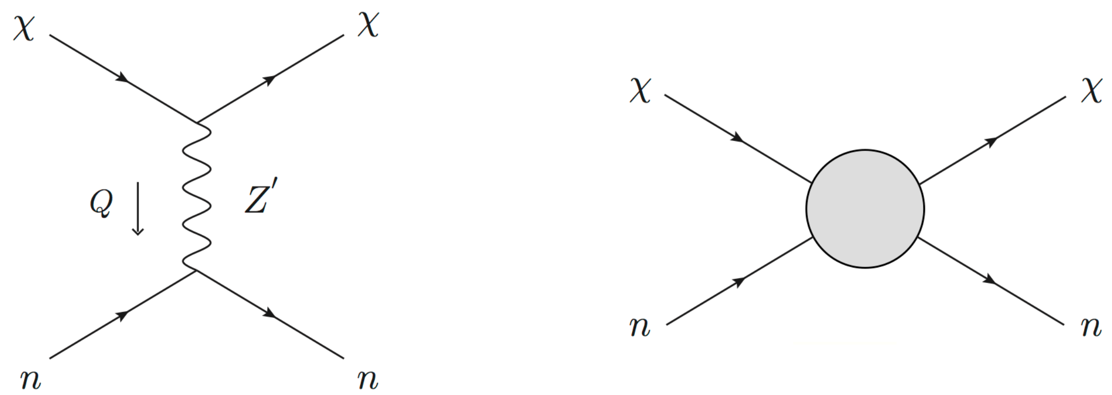


XENON100: 1207.5988

- 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

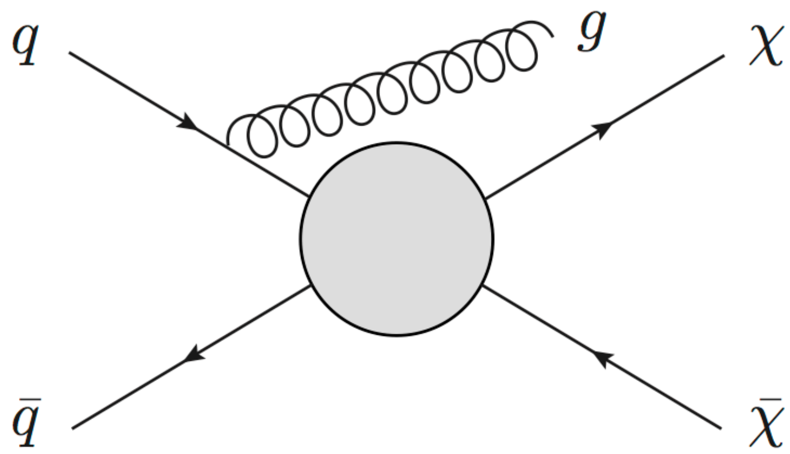
- Assumes a 'contact interaction'

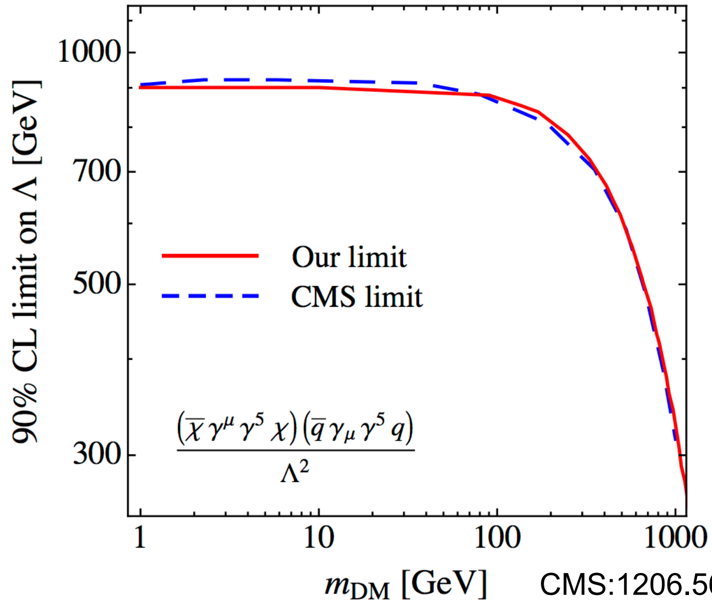


$$\sigma_n \sim \left(\frac{g_n g_\chi}{Q^2 - m_{Z'}^2} \right)^2 \approx \frac{g_n^2 g_\chi^2}{m_{Z'}^4} \left(1 + \frac{Q^2}{m_{Z'}^2} + \cdots \right)^2$$

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

Dark matter searches at LHC



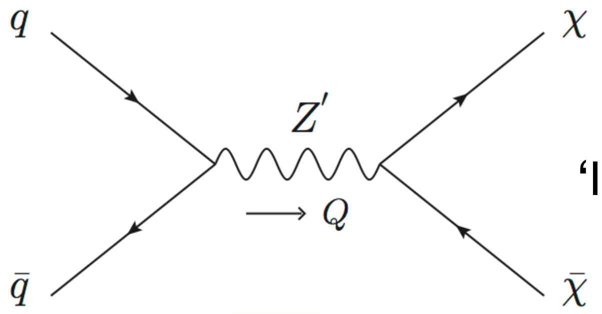


CMS:1206.5663
CMS-PAS-EXO-12-048

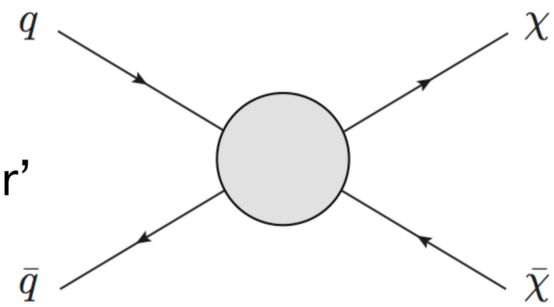
- Monojet search: look for a hard jet and missing energy

- 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’

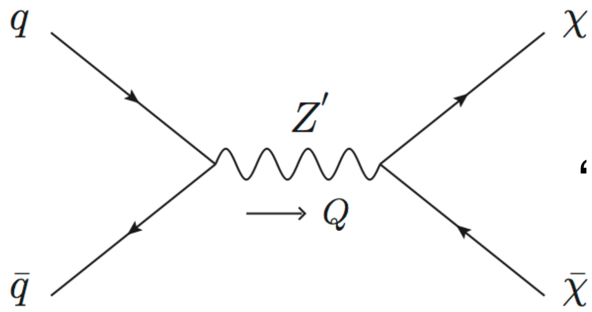


$$\mathcal{L} \sim g_\chi Z'_\mu \bar{\chi}\gamma^\mu\chi + g_q Z'_\mu \bar{q}\gamma^\mu q + \cdots$$

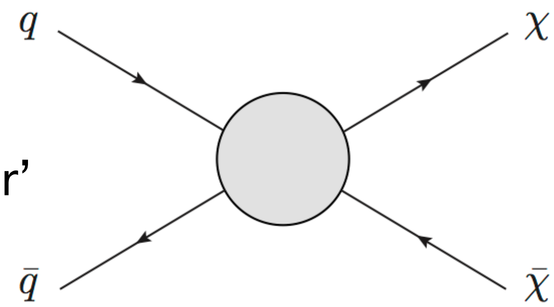
$$\mathcal{L} \sim \frac{1}{\Lambda^2}\bar{q}\gamma_\mu q\,\bar{\chi}\gamma^\mu\chi$$

- Λ related to parameters in the full theory: $\Lambda \equiv \dfrac{m_{Z'}}{\sqrt{g_q g_\chi}}$
- Useful - we don’t need to know all details of the full theory
  - eg. Fermi could describe β-decay without knowing the $W^\pm$ mass or the gauge couplings

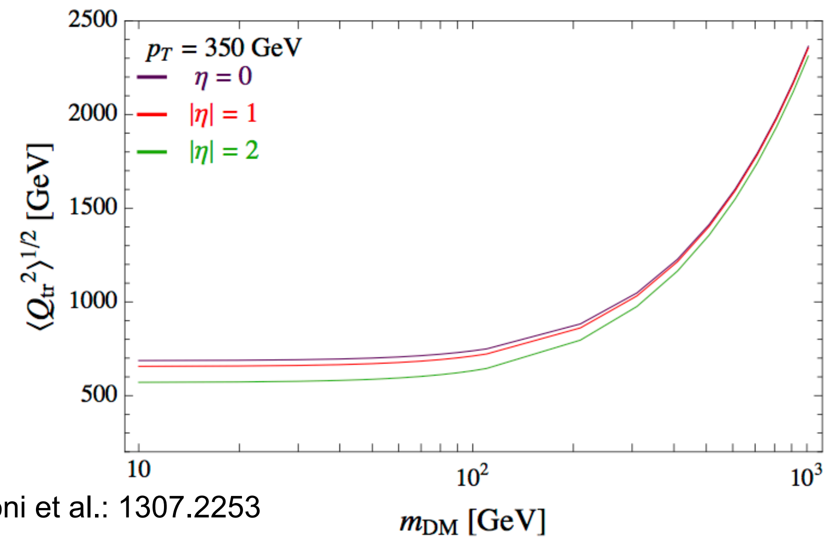
When is EFT valid?



'Integrate out the mediator'



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

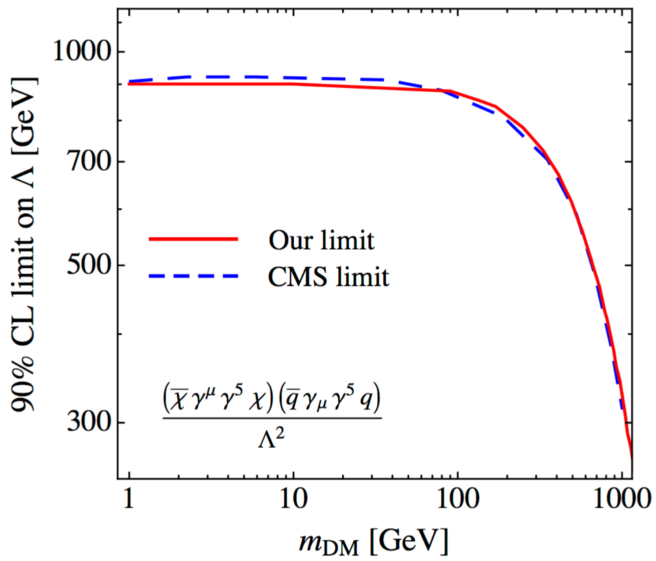


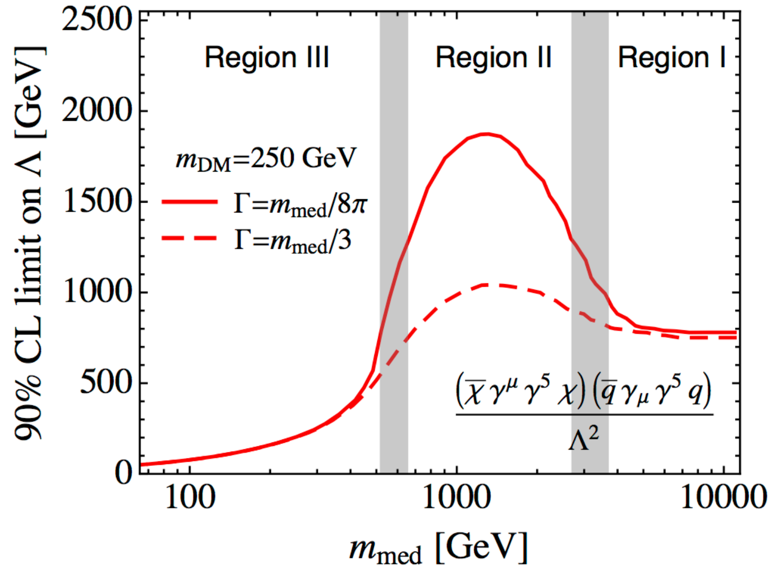
Busoni et al.: 1307.2253

- Requires $m_{Z'} \gg Q \sim \ \mathrm{TeV}$

When is EFT valid?

- Compare 'simplified model' with EFT result. When do they agree?





- Region I: EFT limit is good
- Region II: EFT limit is too weak
- Region III: EFT limit is too strong

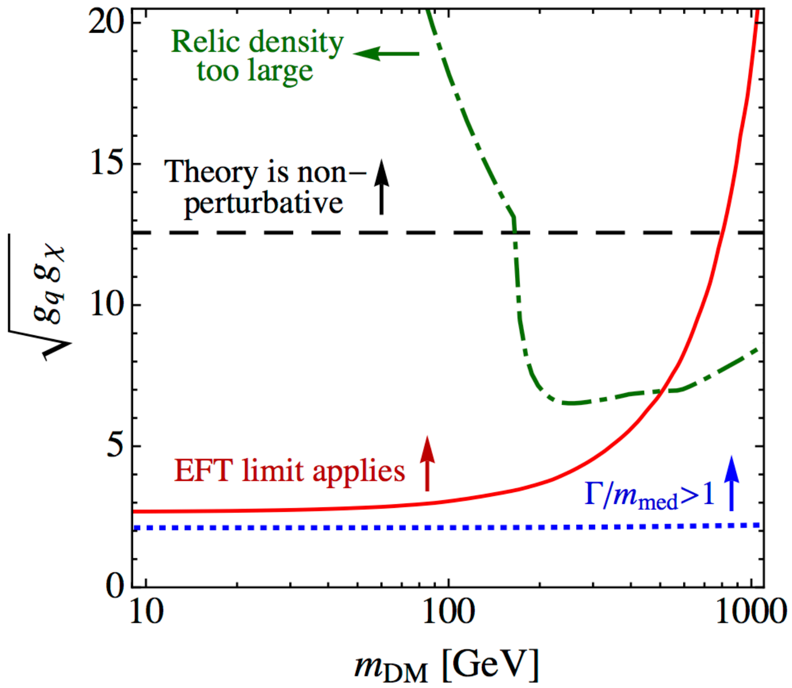
Theories constrained by EFT limit

- Mediator mass is large: $m_{\rm med} \gtrsim 3\ \mathrm{TeV}$

- What about the couplings?
  ...they must be large

- Compare with known couplings:

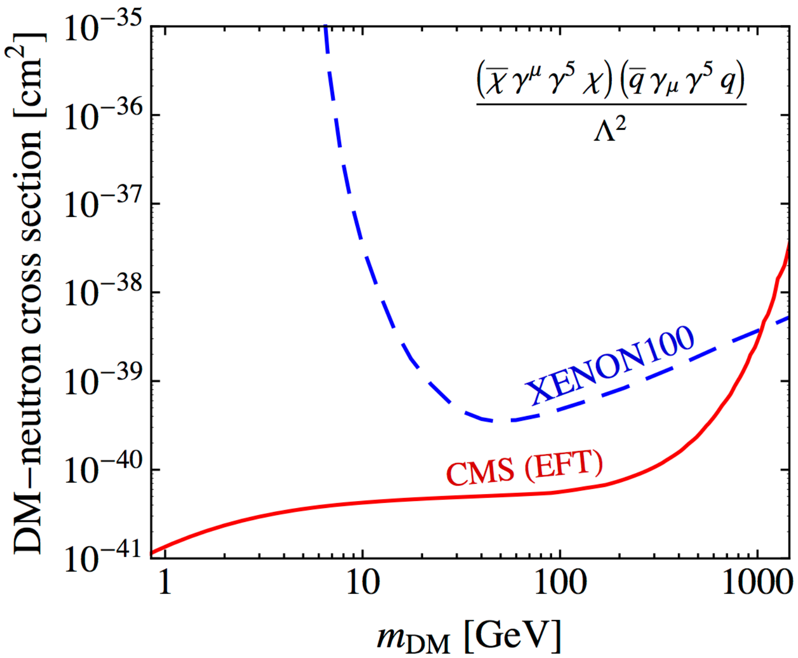
$$g_{\rm strong} \approx 1.2$$
$$g_{\rm weak} \approx 0.6$$
$$g_{\rm hypercharge} \approx 0.4$$

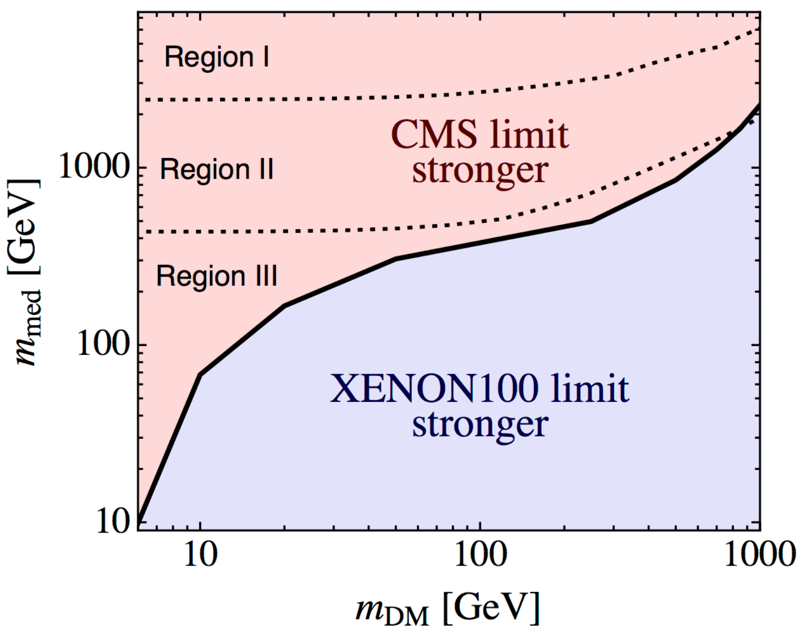


- Couplings of this size typical in strongly interacting theories
  - EFT limit applies to a small class of theories

Other problems

- Comparison with direct detection
  - Naïve EFT limit gives the wrong impression



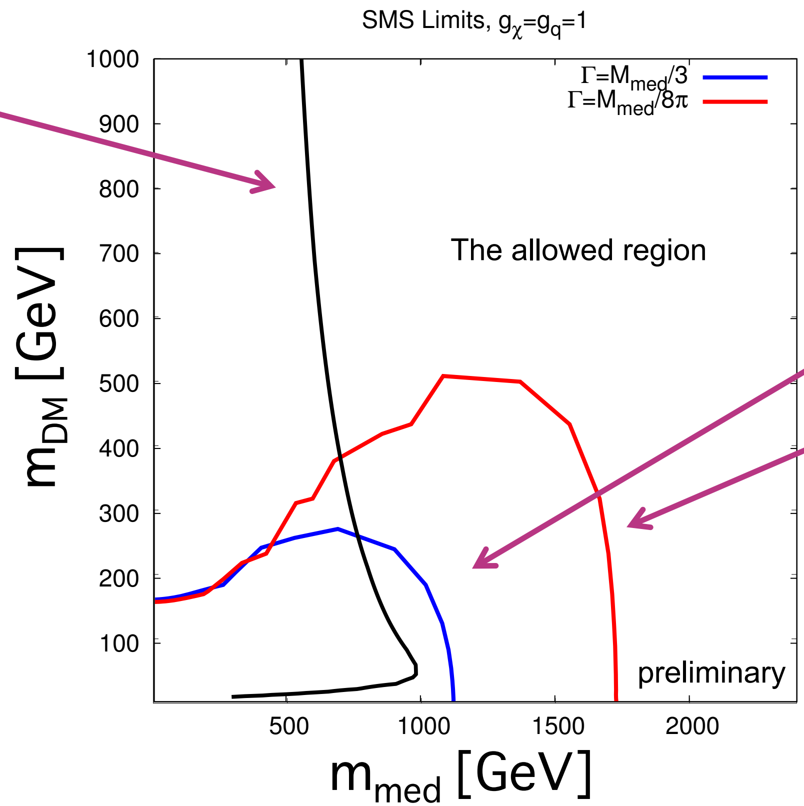


- As m_{med} decreases, direct detection limit is stronger

Beyond EFT: simplified models

- Another way to present the results:

XENON100 limit
- Extends to large m_{DM}

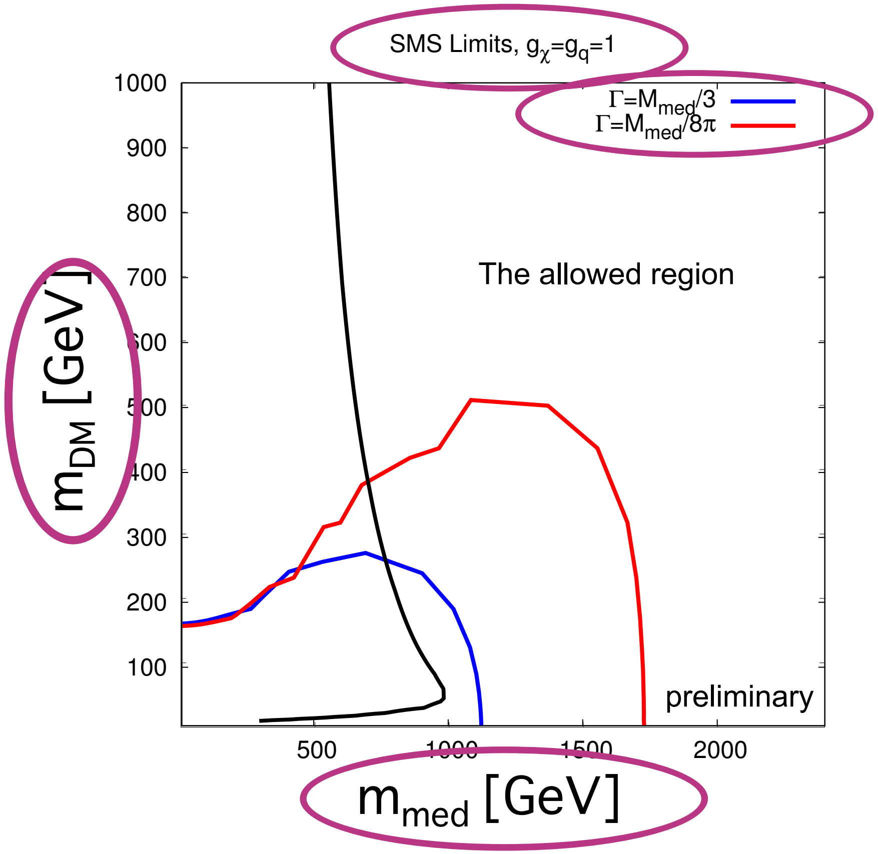


LHC limits
- Extends to large m_{med}

- Can see that searches are complementary

Beyond EFT: simplified models

- Difficulty: representing results in 4D parameter space



1. m_{DM}
2. m_{med}
3. Γ
4. g

- Best way to present the results not optimized - in progress!

Summary

- Important to interpret dark matter searches in the right framework
- Direct detection experiments constrain the 'WIMP-nucleon cross section'
  - Very useful: constrains a large number of theories
- LHC monojet searches have been interpreted in an EFT framework
  - Limited use: constrains few theories and comparison with direct detection limits is too naïve
- Need to go beyond EFT – 'simplified models' capture more physics but at the expense of extra parameters