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# 8 GeV WIMP

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# The Question...

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If there is an  $\sim 8$  GeV dark matter WIMP candidate, what follow up experiments would you perform to verify its existence and study its properties?

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To frame our answer, we chose to be agnostic:

- No discovery yet of DM at a particular experiment
  - Unknown cross section with the SM particles
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# What 8 GeV dark matter isn't

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- 8 GeV is "light"
  - If it were heavy, e.g., 1 TeV, there would be a number of handles
    - High-energy cosmic rays
    - Higher-energy recoils in direct-detection experiments
    - SUSY at the LHC/ILC
    - Restricted kinematic phase space at the LHC/ILC
    - Heavy enough to set an energy scale
  - We want to tailor a program to discover DM and pin down its properties
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# DM & SM

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- If a thermal relic, it's very likely that DM couples to at least some of the SM particles
- The scale DM interacts with the SM?
- We want to show that direct detection experiments have a strong potential for the discovery of DM interacting with SM particles

- Must make some general assumptions:

- DM is a fermion
- 4-fermion interactions
- Single species of DM

$$\mathcal{L} \supset \frac{g^2}{\Lambda^2} (\bar{\chi} \Gamma \chi) (\bar{f}' \Gamma f)$$

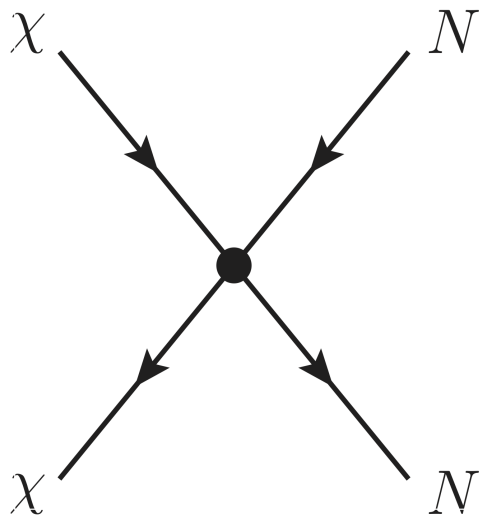
- ~800 operators (~120 if  $f' = f$ )
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# Direct Detection

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## Tree Level

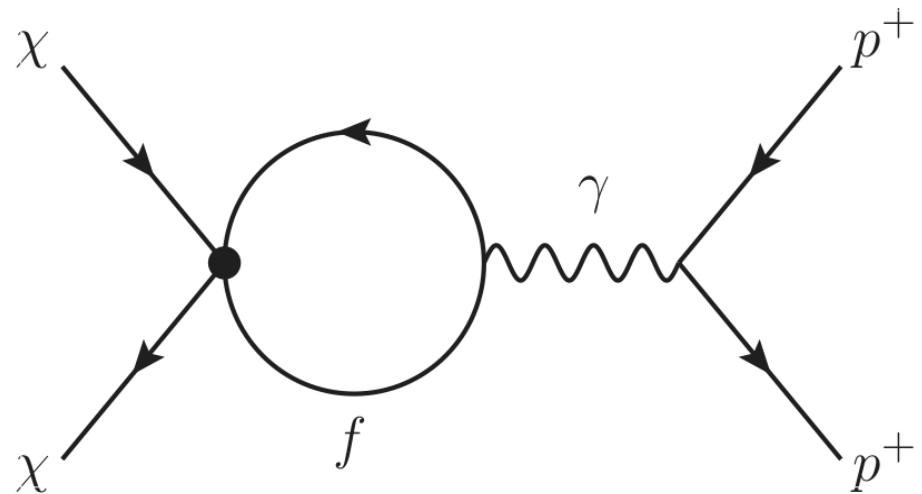
Couples to nucleons



If  $\sim 1$

## 1-loop

Only couples to protons



Then  $\sim 0.0001$

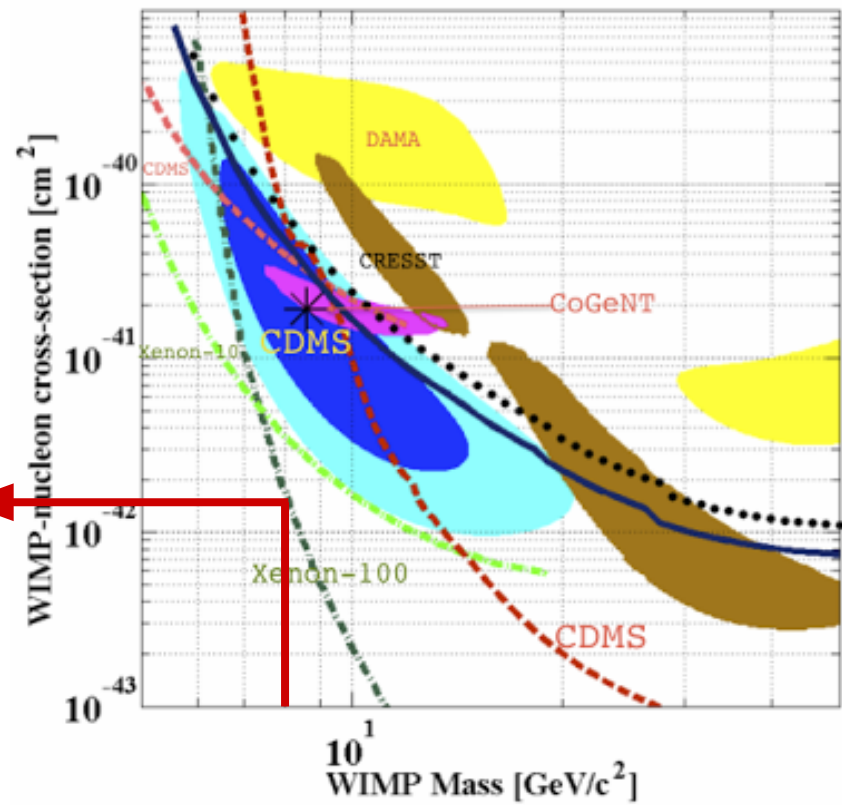
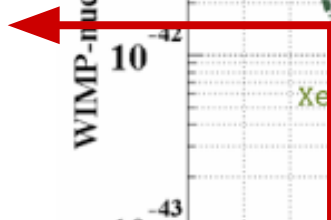
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# Scales from Tree Level

DM coupling to only  
u and d quarks

$$\Lambda \sim \mathcal{O}(0.1-3 \text{ TeV})$$

Cheung et al., (1201.3402)



(1304.4279)

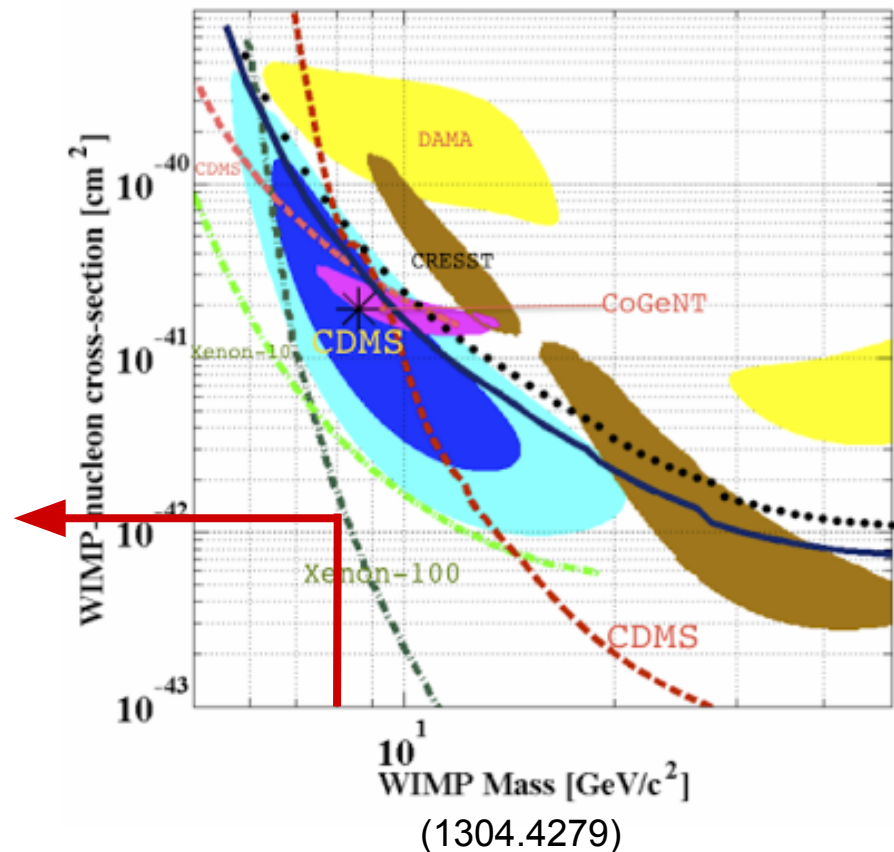
# Scales from 1-Loop Level

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DM coupling to only  
charged leptons

$$\Lambda \sim \mathcal{O}(500 \text{ GeV})$$

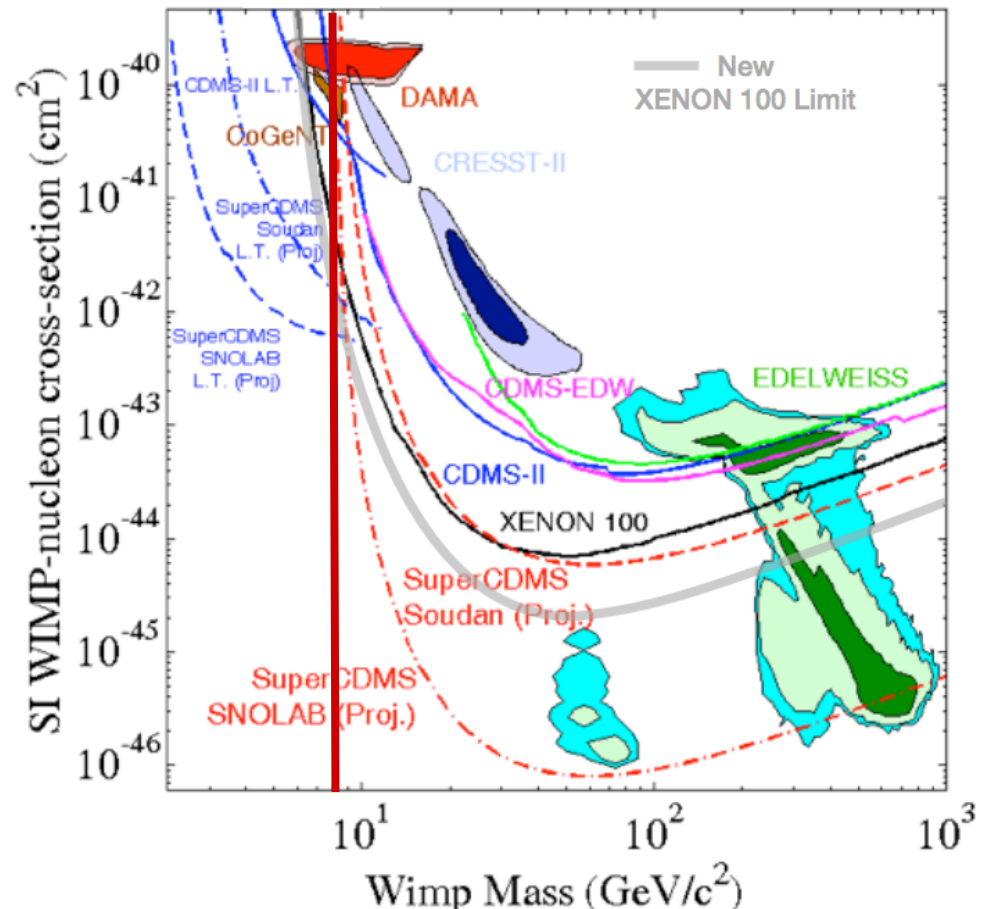
Fox et al., (1103.0240)





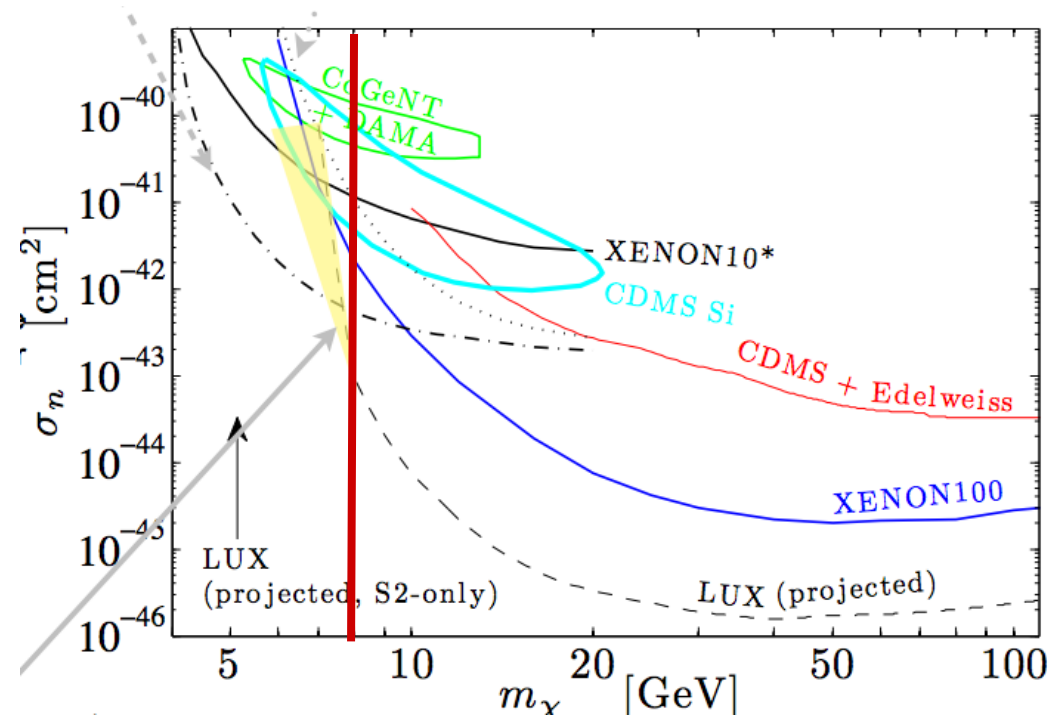
# Future of Direct-Detection

- SuperCDMS
- LUX



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(1210.4569)

# Moral from Direct Detection

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- One can place limits of  $O(0.1 - 10 \text{ TeV})$  on the scale of the interaction between DM and SM.
    - Can probe large range in scales
    - Sensitive to light DM
    - If DM only couples to charged leptons at scale  $\sim 10 \text{ TeV}$ , need  $\sim 4$  orders of magnitude increase in sensitivity
  - The challenge of light DM for direct detection experiments are low-energy recoils
  - Keep going to with direct detection!
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# Other Ways at DM

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- A consistent signal among many direct-detection experiments is a strong indication of dark matter
  - Consistent signals then can be expected by indirect detection and beam-based experiments
  - These other methods, however, come with a higher degree of ambiguity concerning the nature of a signal
  - Flavor physics??
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# Indirect Detection

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- Indirect detection of DM looks for cosmic rays from DM self-annihilation
    - DM is non-relativistic
    - 8 GeV DM annihilations will produce cosmic rays with energy  $O(1 \text{ GeV})$
    - Backgrounds can be large
  - Anomalies in indirect detection experiments can be ambiguous
    - Difficult to know what something is unless you know where to look
  - Could get at DM branching ratios
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# Hadron Colliders

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- Mono-jet and mono-photon signals
    - DM pair produced (coupling to quarks/gluons)
    - Event tagged with high- $p_T$  jet or photon
    - Backgrounds can be very large
    - Pileup can be inhibitive severe
    - Limits on the scale from CMS and ATLAS are currently  $>800$  GeV
    - May not be able to place limits above a few TeV
  - DM produced in decay chains
    - Similar to SUSY scenarios
    - May be impossible to distinguish 8 GeV DM from other states that are associated with missing energy
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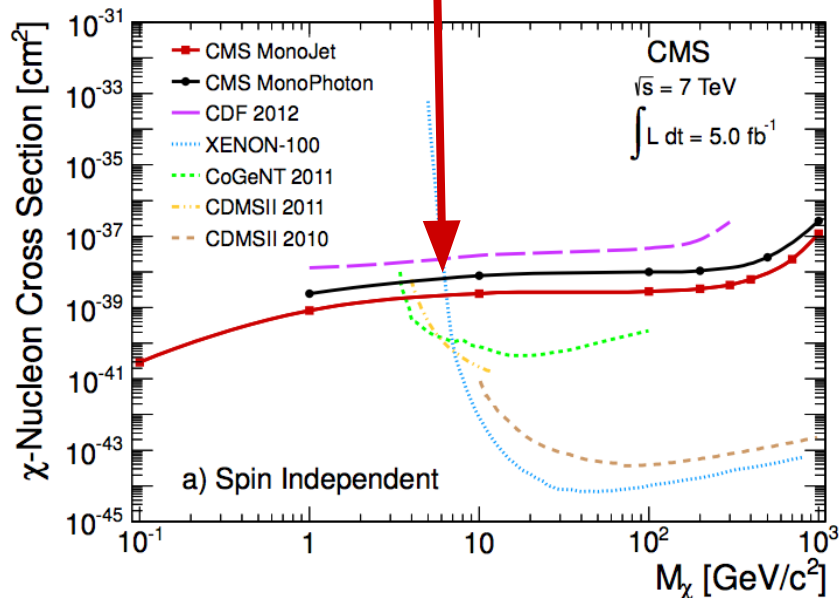
# Lepton Colliders

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- Mono-photon signals (coupling to electrons)
  - Best scenario for finding DM with the ILC with the highest center-of-mass energy and largest data set
    - If  $\sqrt{s} = 1$  TeV and gather  $1000 \text{ fb}^{-1}$  data, best limit on the scale of DM interacting with electrons is a few TeV (1211.4008)
  - May be difficult for beam experiments to study properties of DM other than cross section
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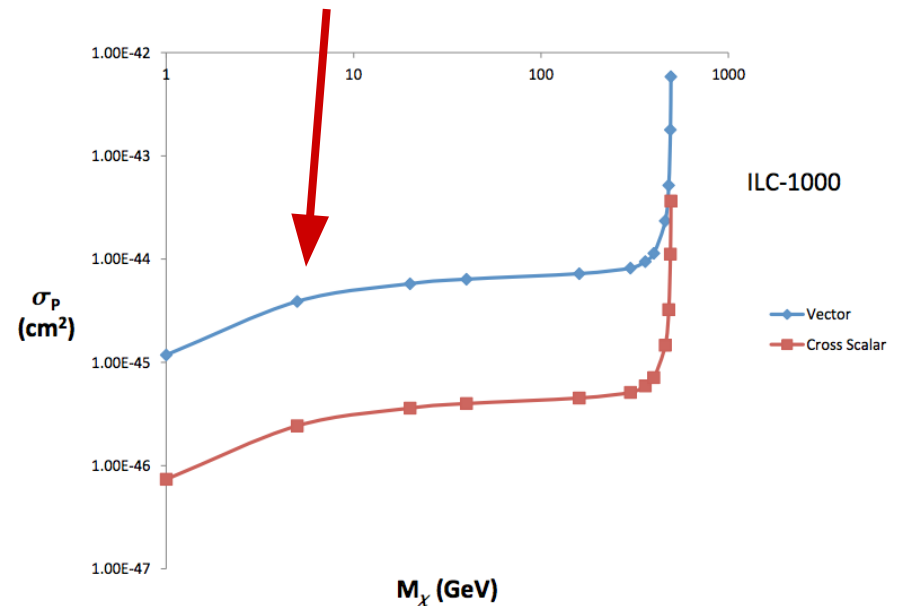
# Limits from Colliders

$$\Lambda \gtrsim 800 \text{ TeV}$$



CMS results  
(1206.5663)

$$\Lambda > \mathcal{O}(2 \text{ TeV})$$



ILC projections  
 $\sqrt{s} = 1 \text{ TeV}, 1000 \text{ fb}^{-1}$   
 DM only couples to electrons  
 (1211.4008)



# Conclusions and outlook

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- Direct detection has a strong potential for discovering 8 GeV DM
    - For many couplings to charged SM particles, at broad range of scales
  - Indirect detection offer complementary signals for DM annihilation
  - Potential for LHC and ILC discovery of large missing-energy signal
    - Couplings to first generation
    - No guarantee that what is made in a collider is the DM
  - There is new physics out there! Find its scale, and decide on the program to study it
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