Dark Matter at Colliders

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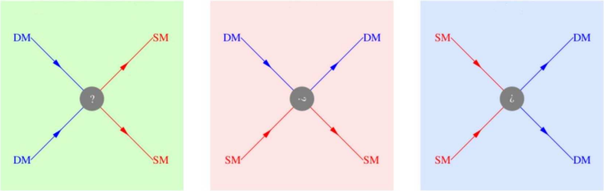
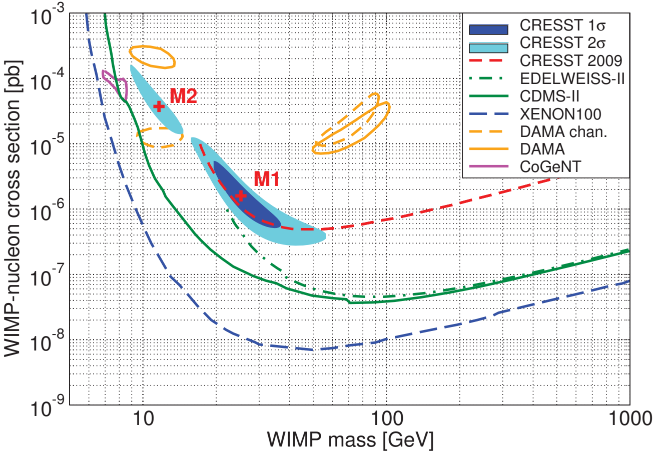
Why WIMPS?

Focusing on **WIMPS**

- Structures $\rightarrow$ "cold" dark matter
- Wimp Miracle: $M_{DM} \sim 100GeV$ and a typical weak scale annihilation cross section give naturally the observed Ω_{DM}
- Various detection channels:
  - Indirect (cosmic rays, ecc...): $E \sim O(10-100)\ GeV$,
  - **Direct Detection** (recoil of target nuclei): $E \sim O(1-10)\ KeV$,
  - **Production at colliders** (e.g. $pp \rightarrow \chi\chi$): $E \sim TeV$,



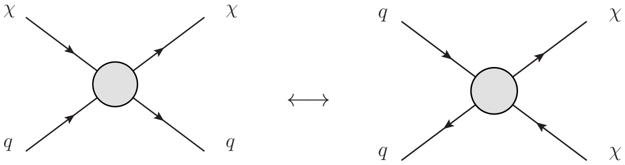
Present Direct Detection situation



CRESST-II coll. [1109.0702]

Main Idea

- If DM interacts with quarks (or leptons) and gluons both direct searches and collider production are valid



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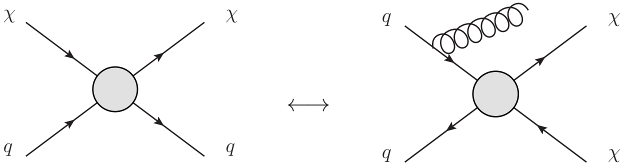
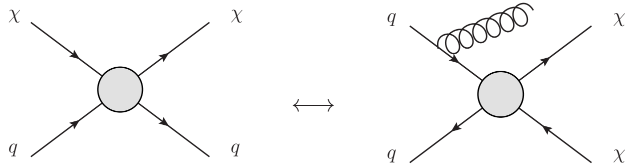
- If DM interacts with quarks (or leptons) and gluons both direct searches and collider production are valid
- How to search for dark matter at colliders? DM(=MET) plus mono-jet or mono-photon



Main Idea

- If DM interacts with quarks (or leptons) and gluons both direct searches and collider production are valid
- How to search for dark matter at colliders? DM(=MET) plus mono-jet or mono-photon
- Minimal amount of assumptions (and knowledge) on the NP sector
- Easy to construct effective operators involving DM+SM



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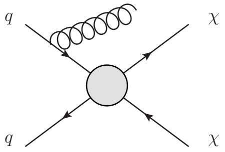

Representative sample of operators:

$$\mathcal{O}_1 = \frac{m_q}{\Lambda_1^2}(\bar{\chi}\chi)\,(\bar{q}q) \quad \mathcal{O}_2 = \frac{1}{\Lambda_2^3}(\bar{\chi}\chi)\,(\frac{\alpha_s}{12\pi}G^{\mu\nu}G_{\mu\nu})$$

$$\mathcal{O}_3 = \frac{1}{\Lambda_3^2}(\bar{\chi}\gamma^\mu\chi)\,(\bar{q}\gamma_\mu q) \quad \mathcal{O}_4 = \frac{1}{\Lambda_4^2}(\bar{\chi}\gamma^\mu\gamma^5\chi)(\bar{q}\gamma_\mu\gamma_5 q)$$

E.g. s-channel exchange $\Lambda \sim M/\sqrt{g_q\, g_\chi}$

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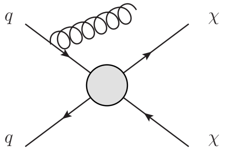

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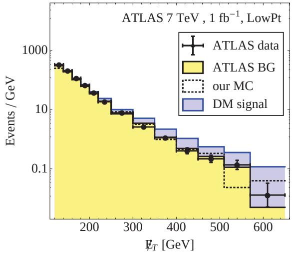
	ATLAS LowPT 1.0 fb^{-1}	ATLAS HighPT 1.0 fb^{-1}	ATLAS veryHighPT 1.0 fb^{-1}
Expected	15100 ± 700	1010 ± 75	193 ± 25
Observed	15740	965	167



ATLAS coll. [ATLAS-CONF-2011-096]

Fox et al. [1109.4398]

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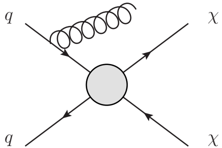

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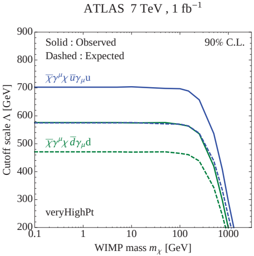
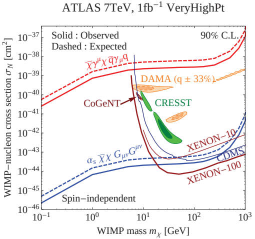
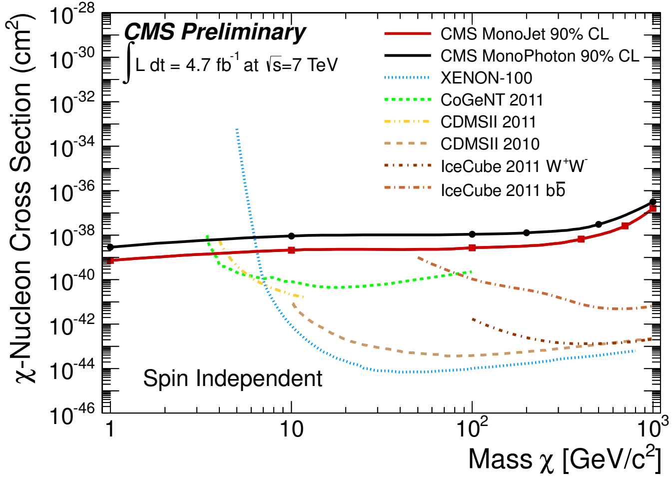


$\longleftrightarrow$



Fox et al. [1109.4398]

Recent results (CMS)



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D4	$\bar{\chi}\gamma^5\chi\bar{q}\gamma^5 q$	m_q/M_*^3
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D8	$\bar{\chi}\gamma^\mu\gamma^5\chi\bar{q}\gamma_\mu\gamma^5 q$	$1/M_*^2$
D9	$\bar{\chi}\sigma^{\mu\nu}\chi\bar{q}\sigma_{\mu\nu} q$	$1/M_*^2$
D10	$\bar{\chi}\sigma_{\mu\nu}\gamma^5\chi\bar{q}\sigma_{\mu\nu} q$	i/M_*^2
D11	$\bar{\chi}\chi G_{\mu\nu}G^{\mu\nu}$	$\alpha_s/4M_*^3$
D12	$\bar{\chi}\gamma^5\chi G_{\mu\nu}G^{\mu\nu}$	$i\alpha_s/4M_*^3$
D13	$\bar{\chi}\chi G_{\mu\nu}\tilde{G}^{\mu\nu}$	$i\alpha_s/4M_*^3$
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M10	$\bar{\chi}\gamma^5\chi G_{\mu\nu}\tilde{G}^{\mu\nu}$	$\alpha_s/8M_*^3$
C1	$\chi^\dagger\chi\bar{q}q$	m_q/M_*^2
C2	$\chi^\dagger\chi\bar{q}\gamma^5 q$	im_q/M_*^2
C3	$\chi^\dagger\partial_\mu\chi\bar{q}\gamma^\mu q$	$1/M_*^2$
C4	$\chi^\dagger\partial_\mu\chi\bar{q}\gamma^\mu\gamma^5 q$	$1/M_*^2$
C5	$\chi^\dagger\chi G_{\mu\nu}G^{\mu\nu}$	$\alpha_s/4M_*^2$
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R1	$\chi^2\bar{q}q$	$m_q/2M_*^2$
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Goodman et Al. [1009.0008]

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- Translation and comparison on the Direct Detection plane (reintroduces atomic and astro uncertainties)

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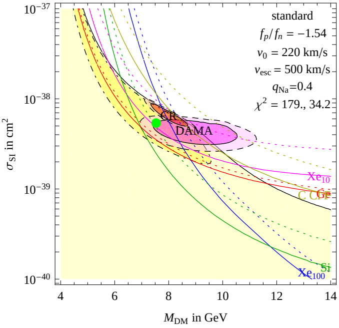
Goodman et Al. [1009.0008]

Three good examples I: isospin violating couplings

- DAMA and CoGeNT can be accomodate by different couplings to u and d quarks
- It is required $f_p/f_n = -1.54$



MF et al. [1107.0715]

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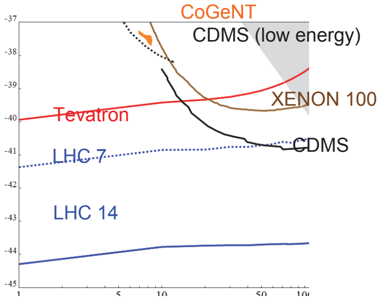
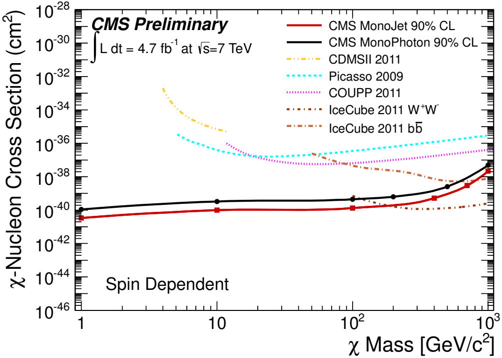


Rajaraman et al. [1108.1196]

Three good examples II: spin dependent scattering

Collider bounds do not suffer from spin-spin suppression

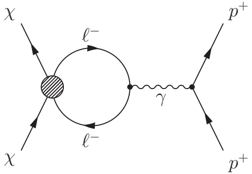


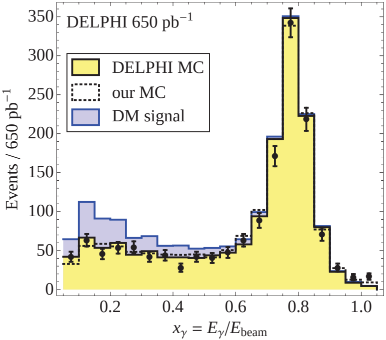
Three good examples III: LEP(tons)

- Yet another way to alleviate the tension between experiments
- Coupling to leptons only e.g.

$$\mathcal{O}_l = \frac{1}{\Lambda^2}(\bar{\chi}\chi)\,(\bar{l}l)$$

- LEP searches for $\gamma + MET$





Fox et al. [1103.0204]

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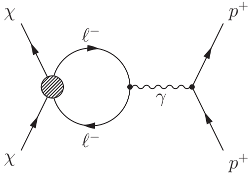
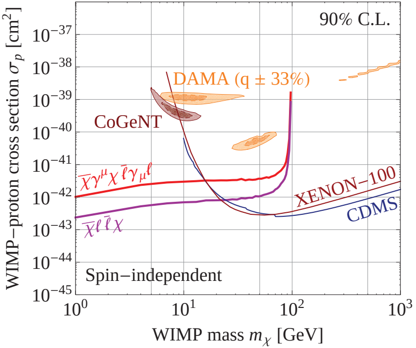
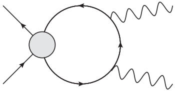


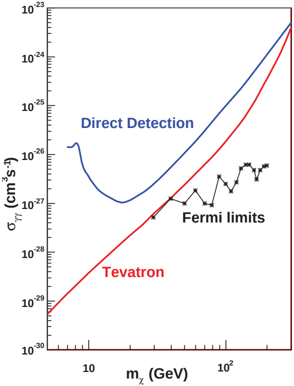


Fox et al. [1103.0204]

FERMI and Colliders?

Comparison is possible also with Indirect Detection experiments.
For example FERMI data ($\chi\chi \to \gamma\gamma$, $\chi\chi \to \gamma Z$)





Goodman et al. [1009.0008]

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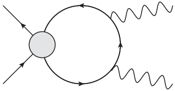
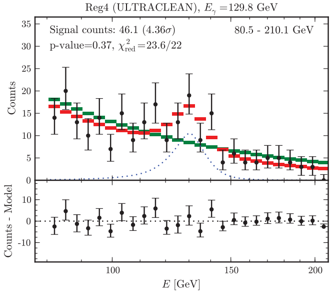
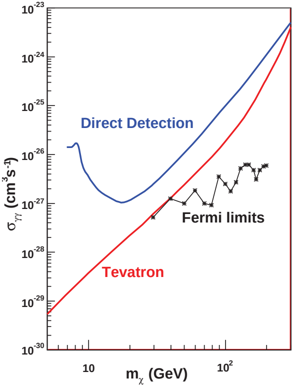




Weniger [1204.2797]



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Conclusions

- Comparison of different types of experiments is possible with a minimal set of assumptions
- Effective Operators are powerful (if handled with care)
- Is it all in the hands of experimental collaborations?
  No! We just have to scratch our heads more (new signals, new channels, old colliders)

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- Questions? Ask Tim on Friday