Implementing Simplified Models in the Search for Dark Matter

Presented by
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Based on work with*
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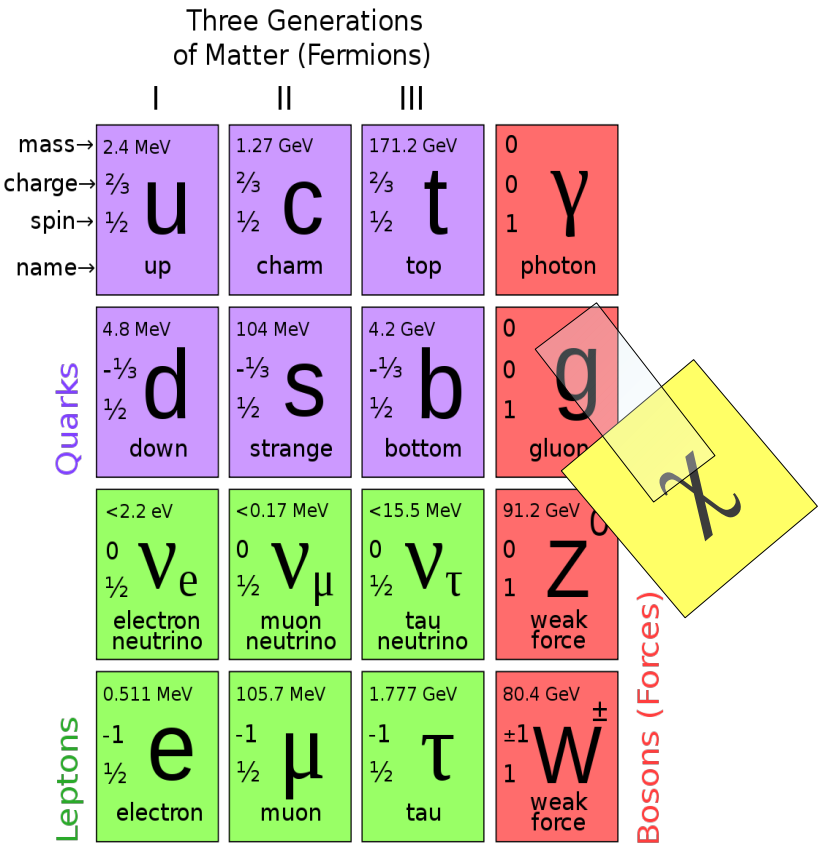
* AD, Nagao, Rajaraman, Tait arxiv:1308.2679

A Fundamental Understanding of DM

Being able to write a Lagrangian which fits DM into an extension of the Standard Model

Writing down interactions aid in the search and tell us what DM is not!

Where do we get a Lagrangian?

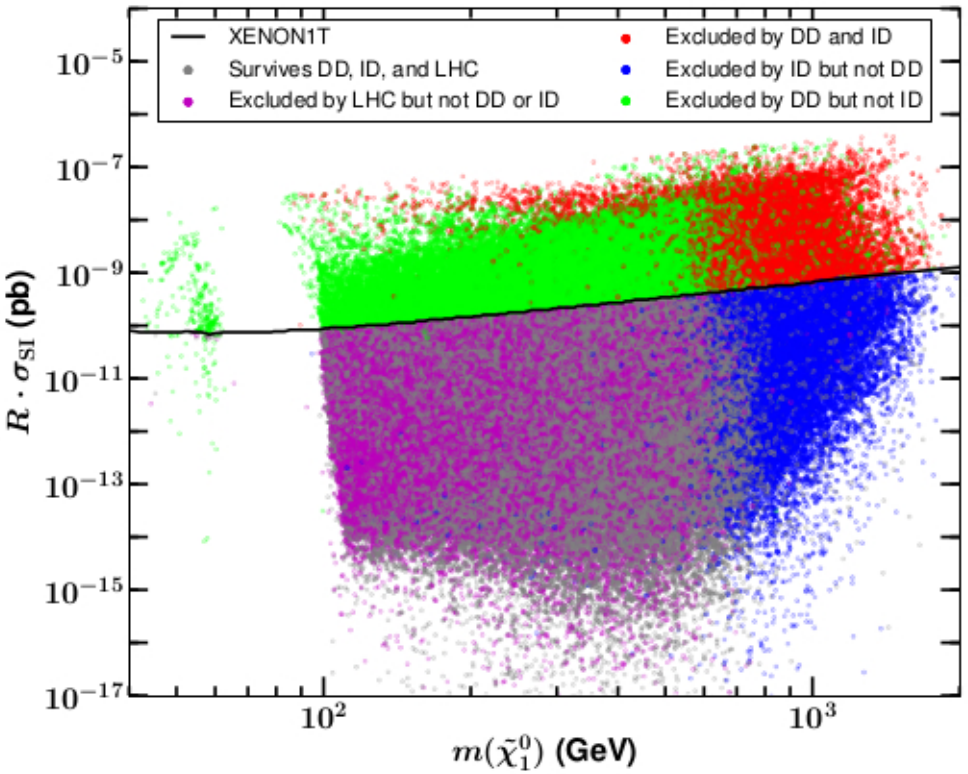


Complete Theories

Created with a symmetry or a physics problem in mind...but must contain a DM candidate

There are many complete theories, each very detailed, and often with high degrees of freedom

Bounds are bounds on the specific configuration of that theory



Cahill-Rowley et al, 1305.6921

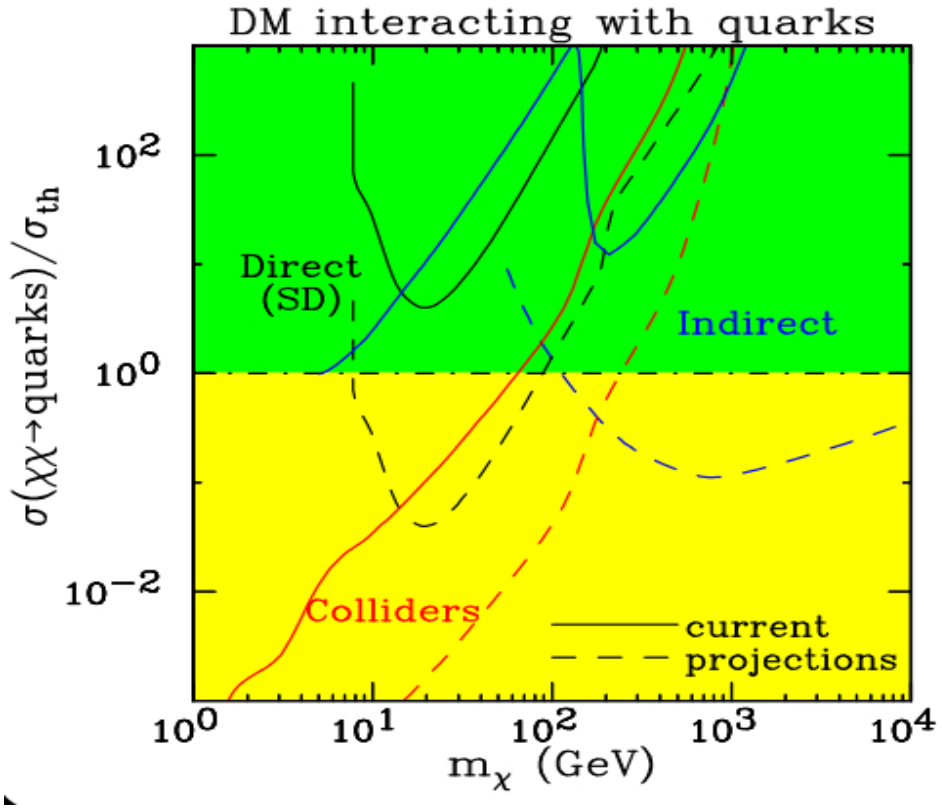
Effective Theories

Ignore underlying theory, focus on what DM interacts with

Enumerate operators involving DM and SM particles, place bounds on each

Relation between different operators and experiments is lost

Not always applicable, especially at energies near the unknown mass of the underlying mediator



Bauer et al, arxiv: 1305.1605

Simplified Models

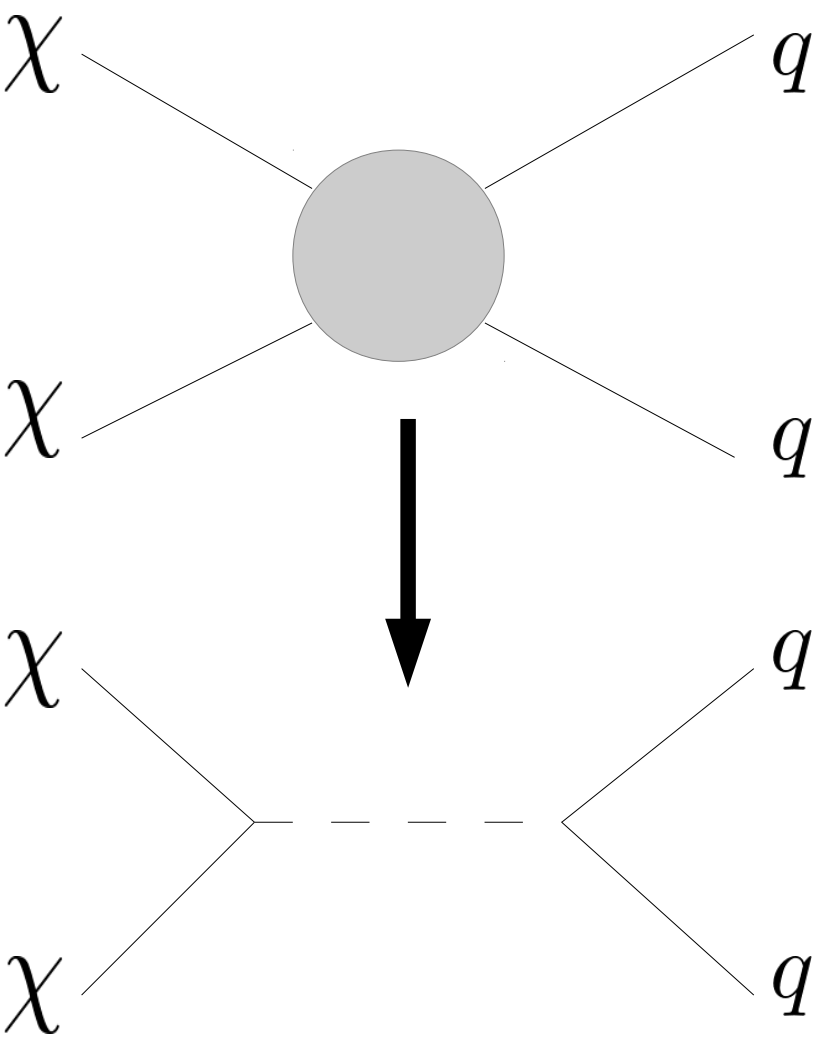
Usually to simplify the parameter space of a Complete Theory

Instead let's build a model which shares commonalities between many theories

Valid at Collider and Direct Detection energies

Operators are all clearly related

Gain a clearer picture of which experiments are most beneficial to a class of theories



Our Simplified Models

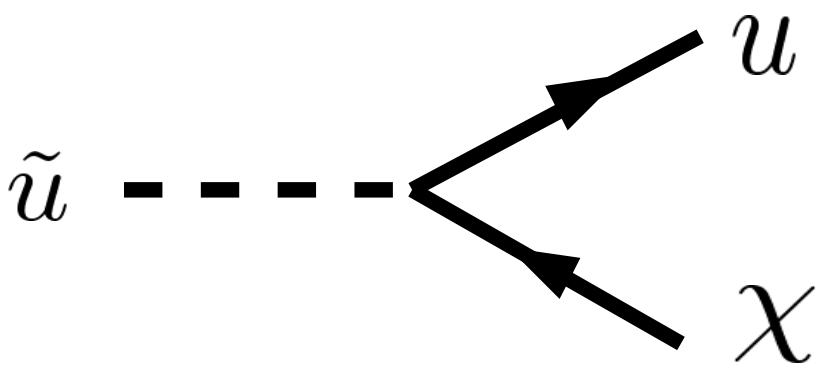
Fermionic DM and scalar mediator

Scalar in terms of (SU(3), SU(2))$_Y$

$$\tilde{u} : (3,1)_{2/3} \quad \tilde{d} : (3,1)_{-1/3} \quad \tilde{q} : (3,2)_{1/6}$$

Interactions

$$g_{DM}\tilde{u}^*\bar{\chi}P_R u \qquad g_{DM}\tilde{d}^*\bar{\chi}P_R d \qquad g_{DM}\tilde{q}^*\bar{\chi}P_L q \qquad (+h.c)$$



Dirac DM, u_R model

LHC !
(CMS study)

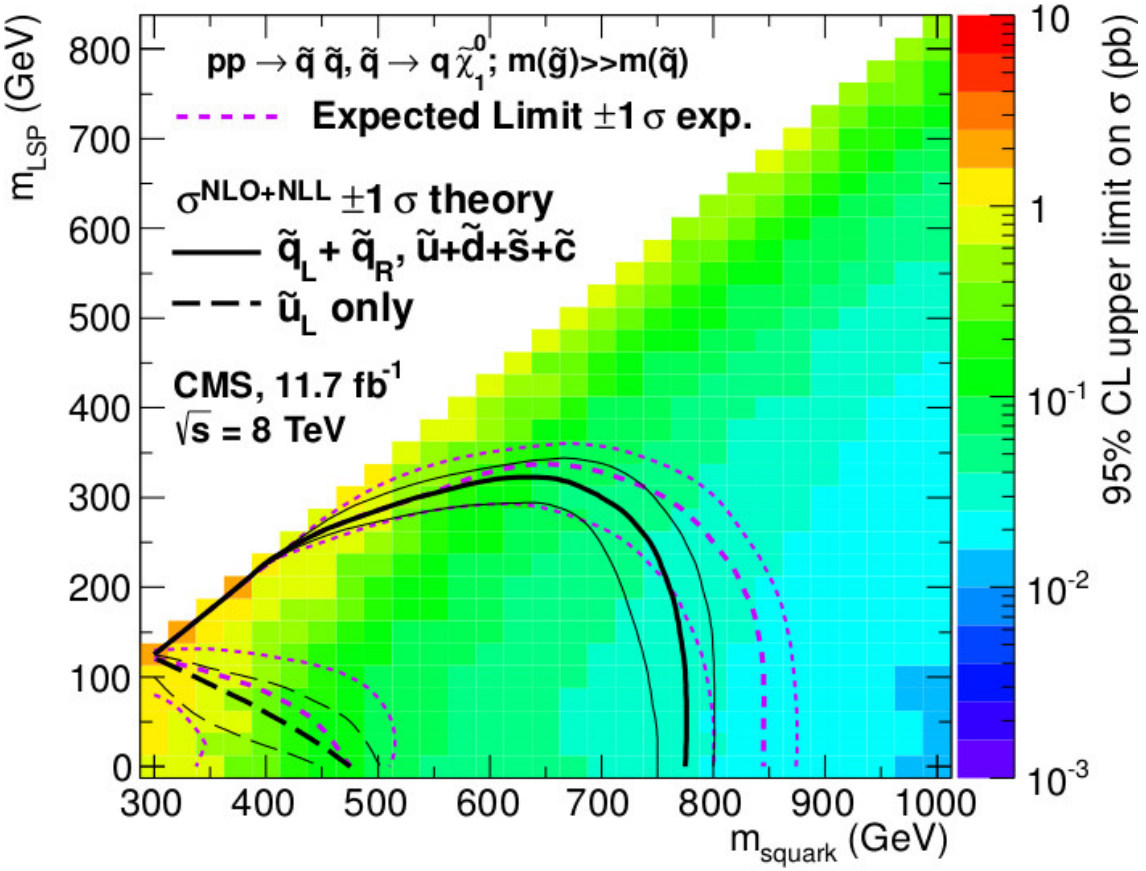
$$\frac{ig_{DM}^2}{8M_{\tilde{u}}^2}[(\bar{\chi}\gamma^\mu\chi)(\bar{u}\gamma_\mu u) - (\bar{\chi}\gamma^\mu\gamma^5\chi)(\bar{u}\gamma_\mu\gamma_5 u)]$$

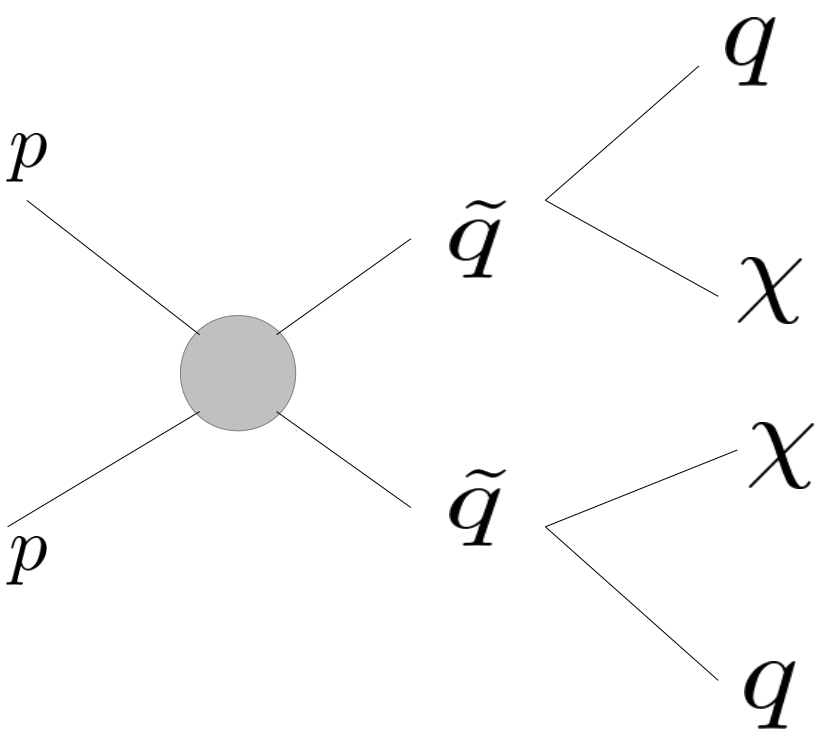
$$\sigma_{SI} = \frac{1}{64\pi}\frac{M_N^2 M_\chi^2}{(M_N + M_\chi)^2}\left(\frac{g_{DM}}{M_{\tilde{u}}}\right)^4\left(1 + \frac{Z}{A}\right)^2$$

$$\sigma_{SD} = \frac{3}{64\pi}\frac{M_N^2 M_\chi^2}{(M_N + M_\chi)^2}\left(\frac{g_{DM}}{M_{\tilde{u}}}\right)^4 (\Delta u^N)^2$$

Direct Detection!

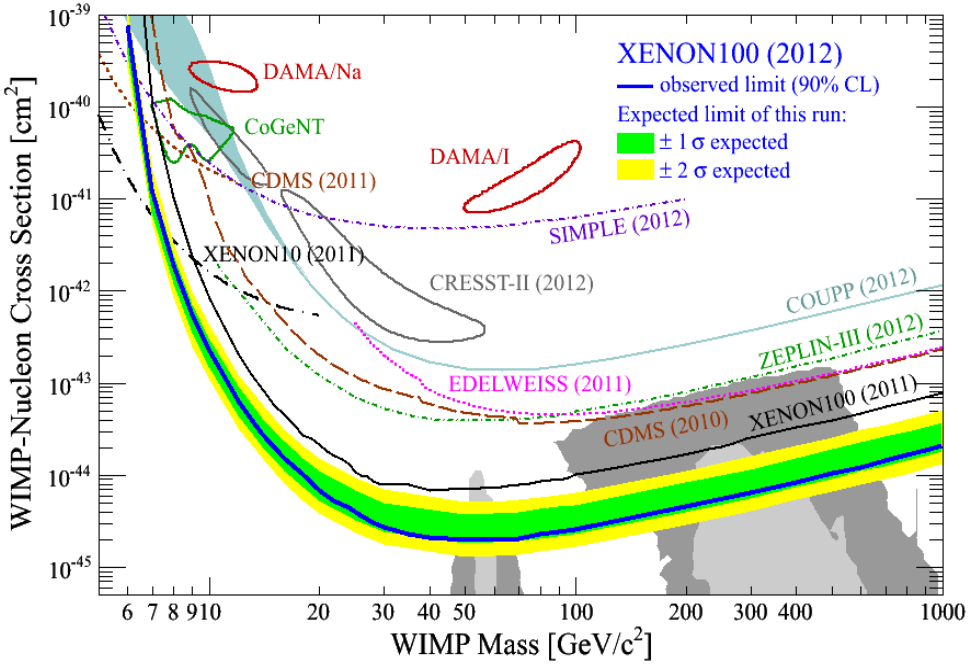
CMS bounds

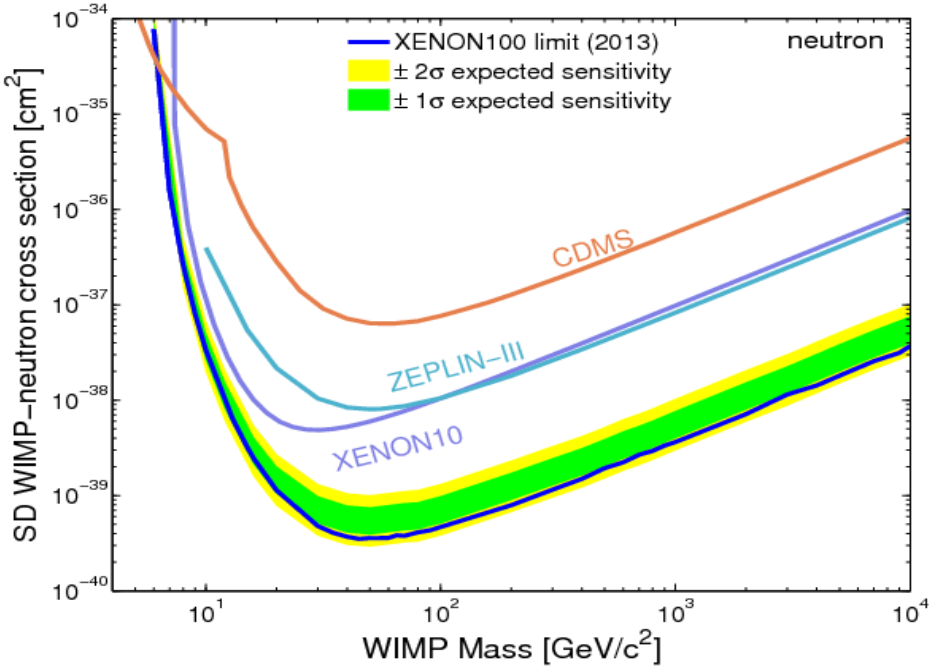




[CMS Collaboration], CMS-PAS-SUS-12-028.

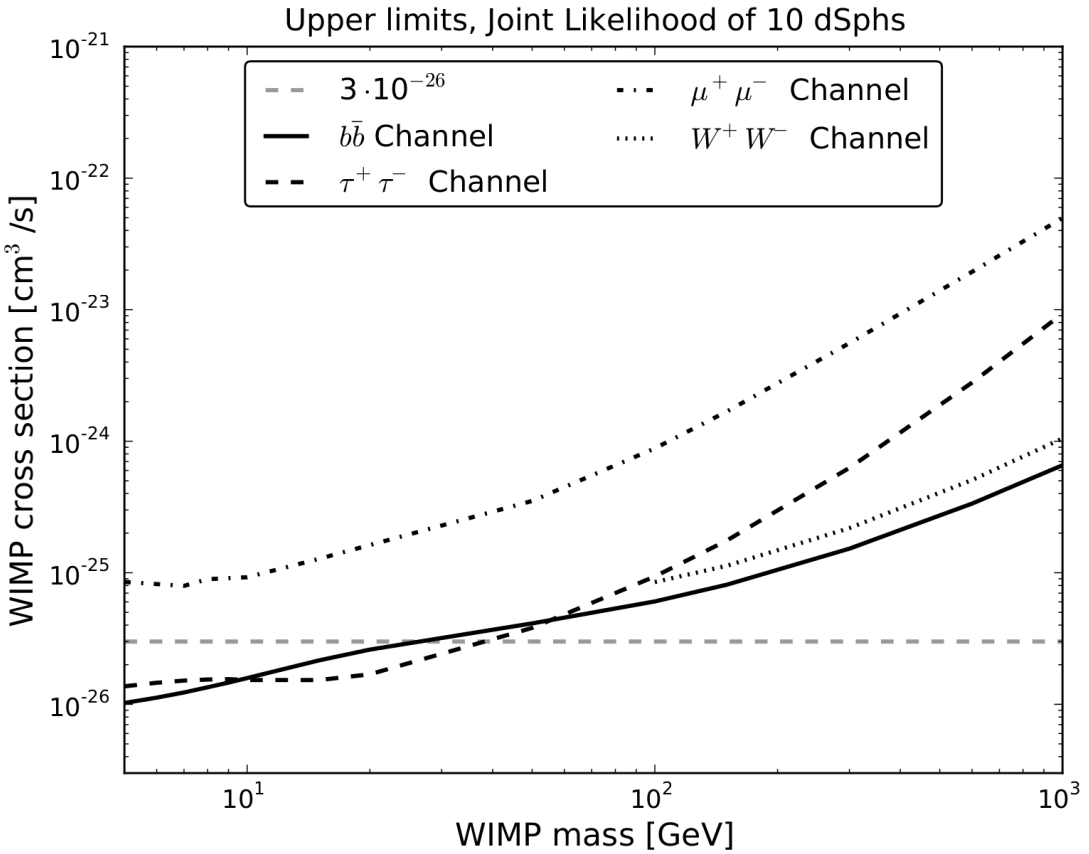
Direct Detection Bounds



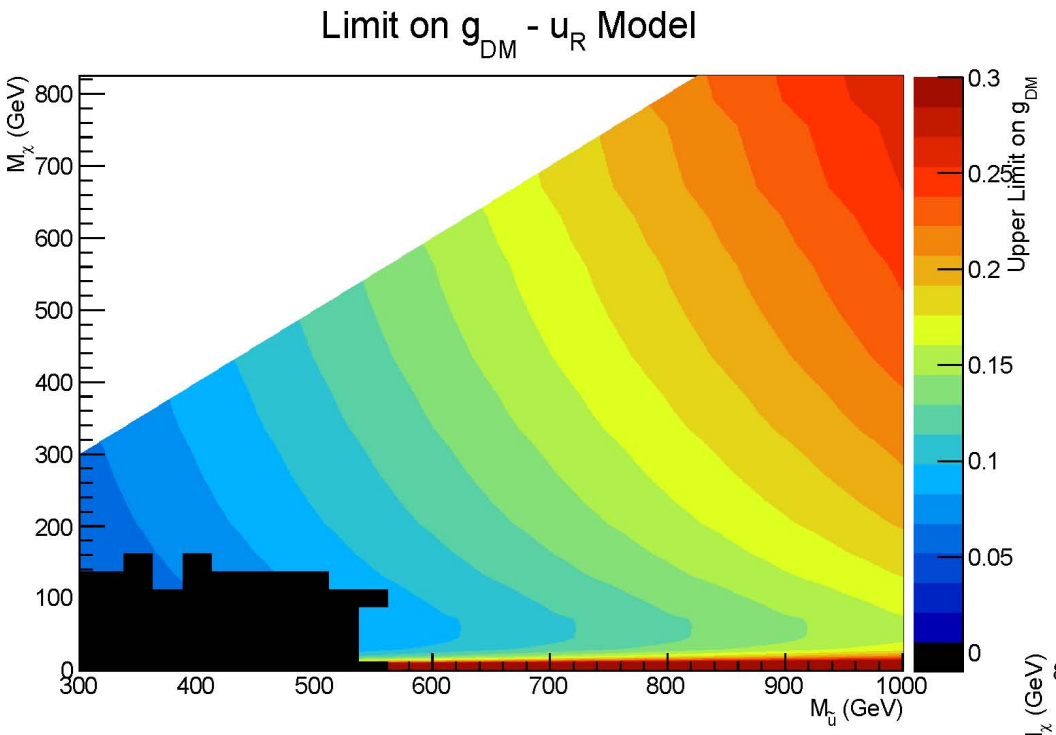


-SI: XENON100, Phys. Rev. Lett. 109, 181301 (2012)
-SD: XENON100, arXiv:1301.6620

Annihilation Bounds



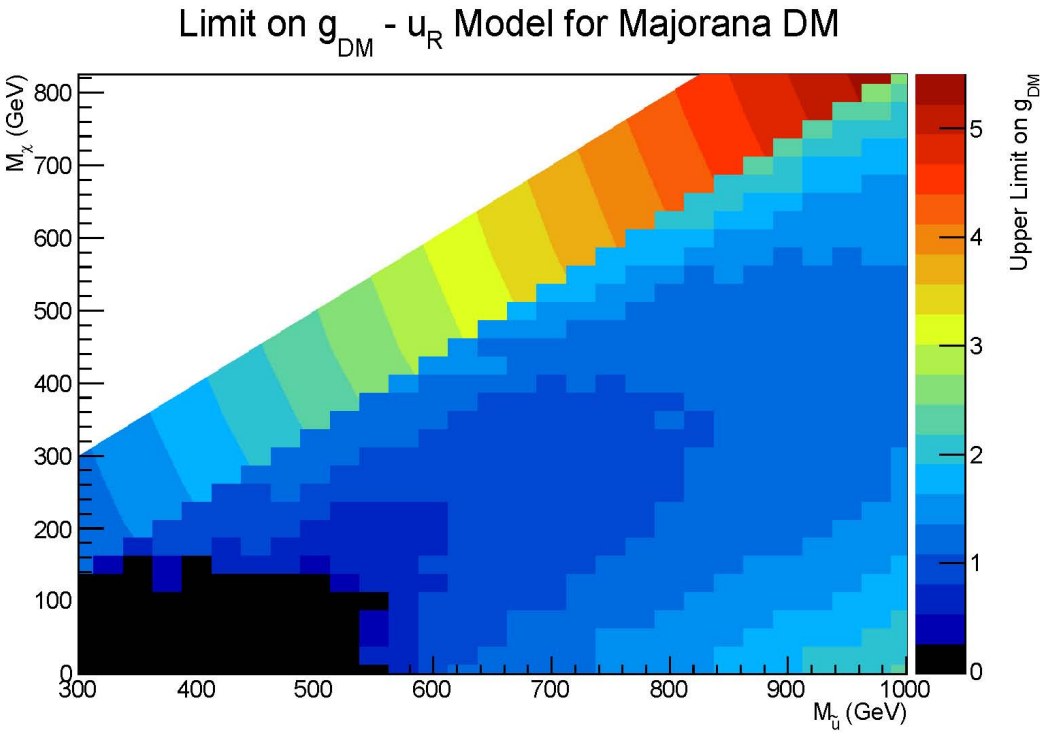
Fermi-LAT Collaboration Phys.Rev.Lett. 107 (2011) 241302, arXiv:1108.3546

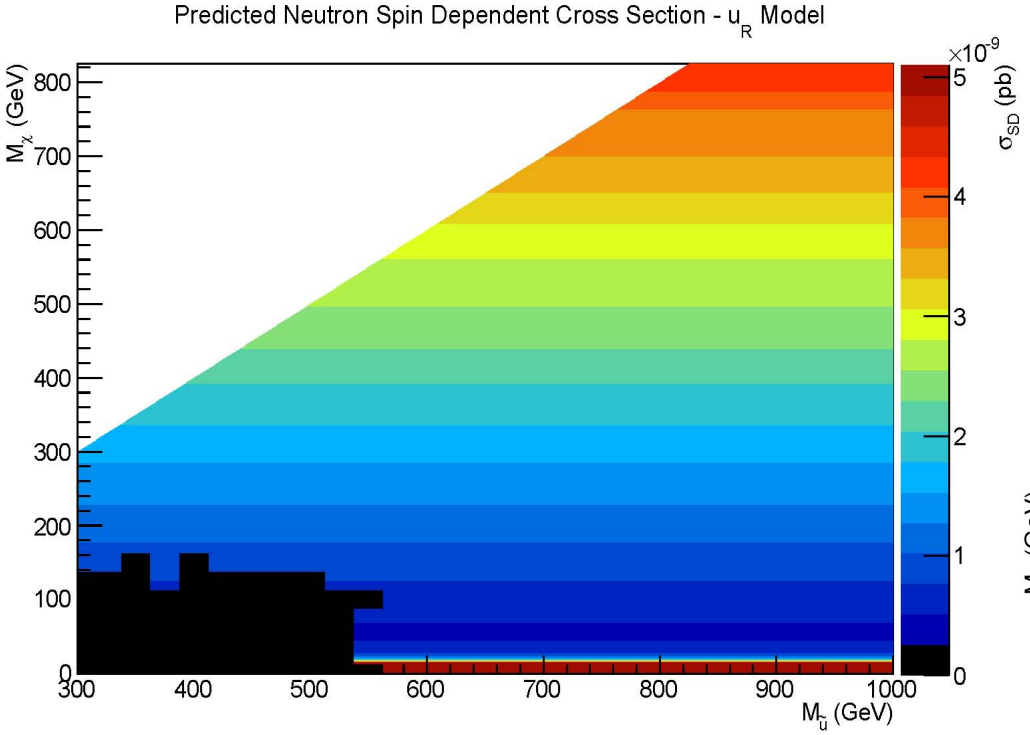


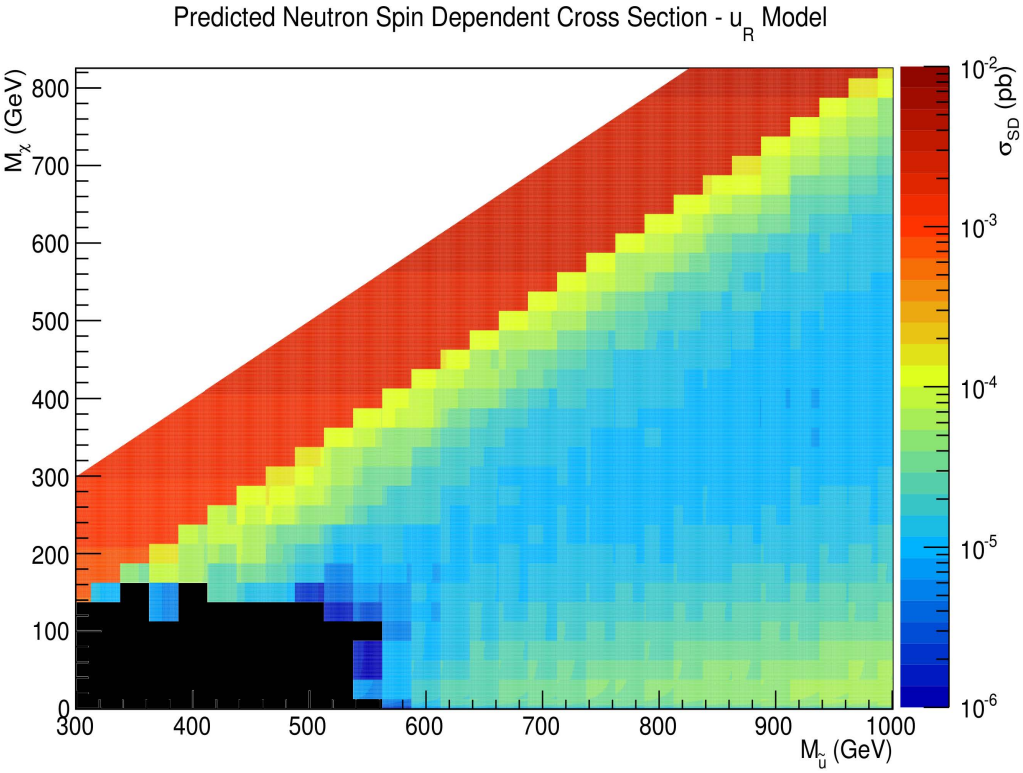
Dirac: dominated by Xenon100 SI bounds

But LHC can exclude some parameter space

Majorana: dominated by LHC bounds!




Predicted Neutron Spin Dependent Cross Section - u_R Model
M_χ (GeV)
M_ũ (GeV)
σ_SD (pb)
×10^-9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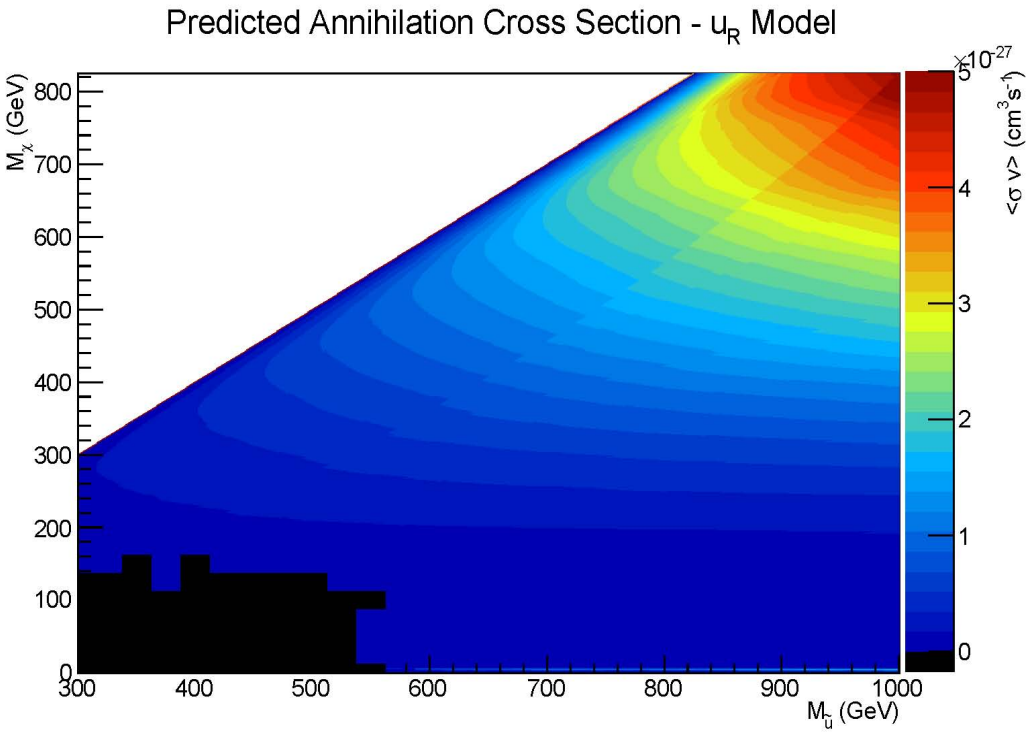
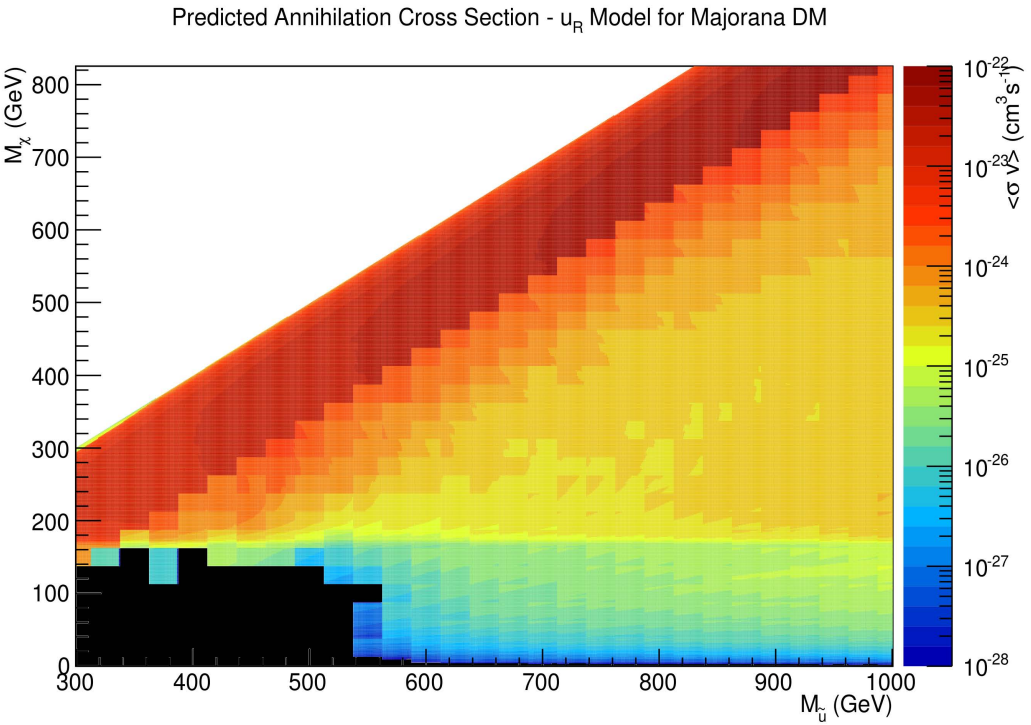


Too small to get right relic density

Still viable as is!



Similar work!

- J. Goodman and W. Shepherd, arXiv:1111.2359
- M. T. Frandsen, F. Kahlhoefer, S. Sarkar and K. Schmidt-Hoberg, JHEP 1109, 128 (2011) arXiv:1107.2118
- I. M. Shoemaker and L. Vecchi, Phys. Rev. D 86, 015023 (2012) arXiv:1112.5457
- H. An, X. Ji and L. -T. Wang, JHEP 1207,182 (2012) arXiv:1202.2894
- M. T. Frandsen, F. Kahlhoefer, A. Preston, S. Sarkar and K. Schmidt-Hoberg, JHEP 1207, 123 (2012) arXiv:1204.3839
- G. Busoni, A. De Simone, E. Morgante and A. Riotto, arXiv:1307.2253
- R. C. Cotta, A. Rajaraman, T. M. P. Tait and A. M. Wijangco, arXiv:1305.6609
- S. Profumo, W. Shepherd and T. Tait, arXiv:1307.6277
- Y. Gershtein, F. Petriello, S. Quackenbush and K. M. Zurek, Phys. Rev. D 78, 095002 (2008) arXiv:0809.2849
- F. J. Petriello, S. Quackenbush and K. M. Zurek, Phys. Rev. D 77, 115020 (2008) arXiv:0803.4005
- P. Agrawal, Z. Chacko, C. Kilic and R. K. Mishra, arXiv:1003.1912
- M. Garny, A. Ibarra, M. Pato and S. Vogl, JCAP 1211, 017 (2012) arXiv:1207.1431

What can we learn from this?

- About this Simplified Model:

  With current limits, Dirac DM bound is dominated by SI Direct Detection, though would need modification due to relic density constraint

  LHC dominates Majorana DM bound

- About Simplified Models in general:

  Good compromise between model independence and having a detailed, valid theory

  Useful for guiding where to search and what to search with