An Effective Understanding of Dark Matter Constraints

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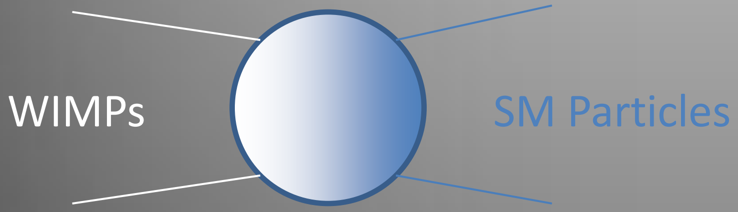
PHENO Conference
Madison, WI
May 9, 2011

Related work: Bai, Fox, Harnik [1005.3797]

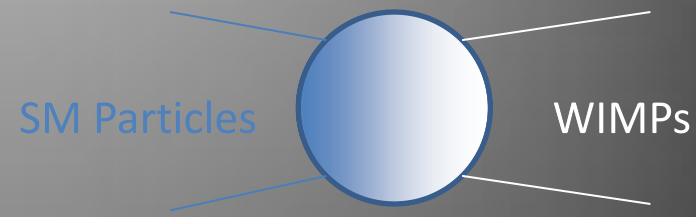
Goodman, Ibe, Rajaraman, WS, Tait, and Yu
[1005.1286], PLB
[1008.1783], PRD
[1009.0008], NPB

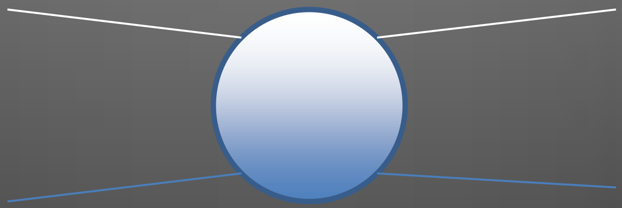
Dark Matter Searches



Indirect Detection

Collider Searches





Direct Detection

The Question of the day:

How can we relate the many different strategies for finding dark matter to one another?

Effective Theory

- What I'd like to tell you about today are effective quantum field theory (EFT) descriptions of dark matter.
- The goal is to capture the physics of WIMP models in a way that is fairly insensitive to the details of the models themselves.
- As effective theories, they can only describe physics correctly within some energy range, and they have very specific assumptions built in to them. Whether they work or not will depend on what kind of WIMP nature has given us for study.
- They provide a dictionary for studying the interactions of WIMPs with Standard Model fields. Using this dictionary we can translate results from one type of experiment onto the signal space of another.

EFT Assumptions

- WIMP has spin ½ or 0.
- WIMP is completely stable.
- WIMP is a SM singlet.
- WIMP couplings are MFV.
- WIMP is only new light state.
  – I'll even take the SM higgs to be heavy.

Example EFT: Majorana WIMP

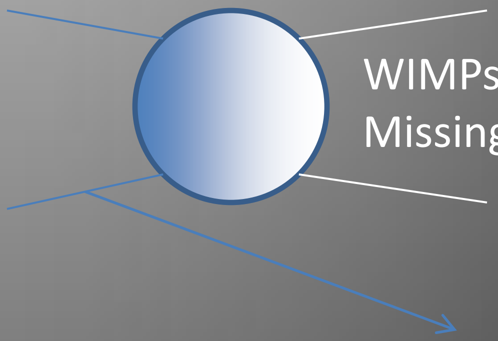
- For example, we can write down the interesting operators for a Majorana WIMP.
- There are 10 leading operators consistent with Lorentz and good gauge symmetries of the SM which couple WIMPs to quarks and gluons.
- Gluon operators are normalized by α_s, consistent with their being induced by loops.
- Each operator has a distinct coefficient M* which parametrizes it's strength.

Name	Type	G_χ	Γ^χ	Γ^q
M1	qq	$m_q/2M_*^3$	1	1
M2	qq	$im_q/2M_*^3$	γ_5	1
M3	qq	$im_q/2M_*^3$	1	γ_5
M4	qq	$m_q/2M_*^3$	γ_5	γ_5
M5	qq	$1/2M_*^2$	$\gamma_5\gamma_\mu$	γ^μ
M6	qq	$1/2M_*^2$	$\gamma_5\gamma_\mu$	$\gamma_5\gamma^\mu$
M7	GG	$\alpha_s/8M_*^3$	1	-
M8	GG	$i\alpha_s/8M_*^3$	γ_5	-
M9	$G\tilde{G}$	$\alpha_s/8M_*^3$	1	-
M10	$G\tilde{G}$	$i\alpha_s/8M_*^3$	γ_5	-

$$\sum_q G_\chi[\bar{\chi}\Gamma^\chi\chi][\bar{q}\Gamma^q q]$$

Collider Studies: Jets and Missing Energy

- We look at a more generic signature, where the WIMPs are produced from incoming particles and recoil against a jet.
- We compare with a CDF monojet search for ADD KK graviton production, which required:
  - Leading jet PT > 80 GeV
  - Missing ET > 80 GeV
  - 2^{nd} jet allowed with PT < 30 GeV
  - Veto more jets with PT > 20 GeV
  - Veto isolated leptons with PT >10 GeV

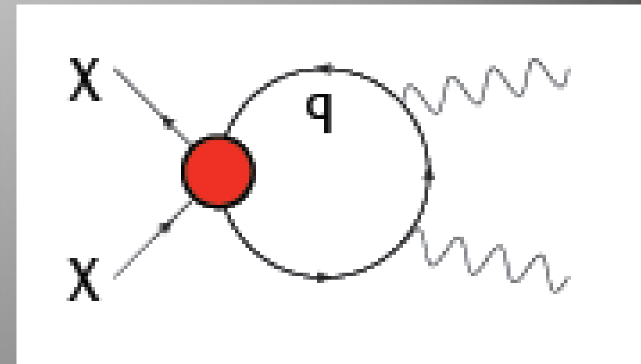


Based on 1 fb-1, CDF constrains new physics (after cuts) σ < 0.66 pb.
CDF, 0807.3132 http://www-cdf.fnal.gov/physics/exotica/r2a/20070322.mono_jet/public/ykk.html
LHC reach from similar study by Vacavant and Hnchliffe, J Phys G 27, 1839 (2001)

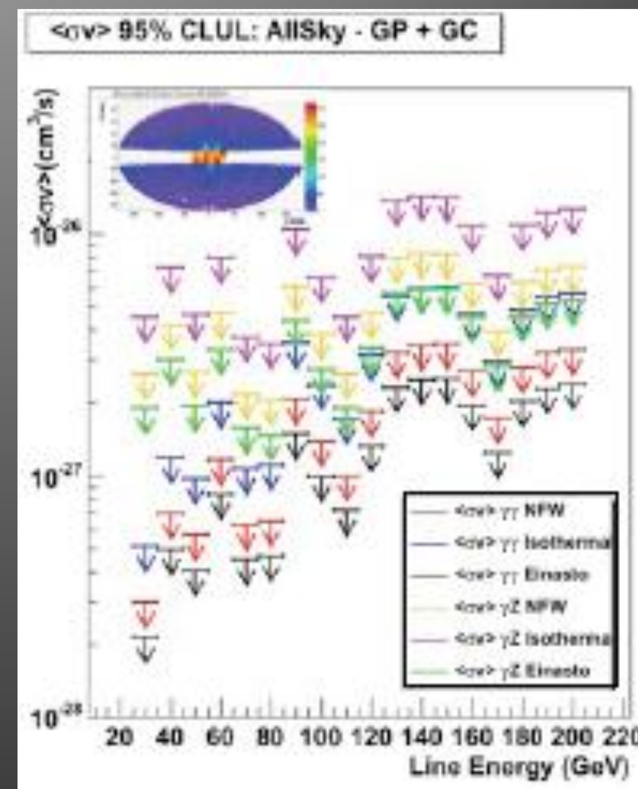
Indirect Detection

- Like direct searches, indirect searches for dark matter have the advantage that they are looking for the actual dark matter present in the galactic halo.
  - Collider missing energy could be due to other new physics than just dark matter.
- Unlike collider searches, they suffer from complicated and irreducible astrophysical backgrounds.
  - As a particle theorist, understanding these backgrounds is above my pay grade.
- I'll focus on one signal that doesn't have any known background mechanism.

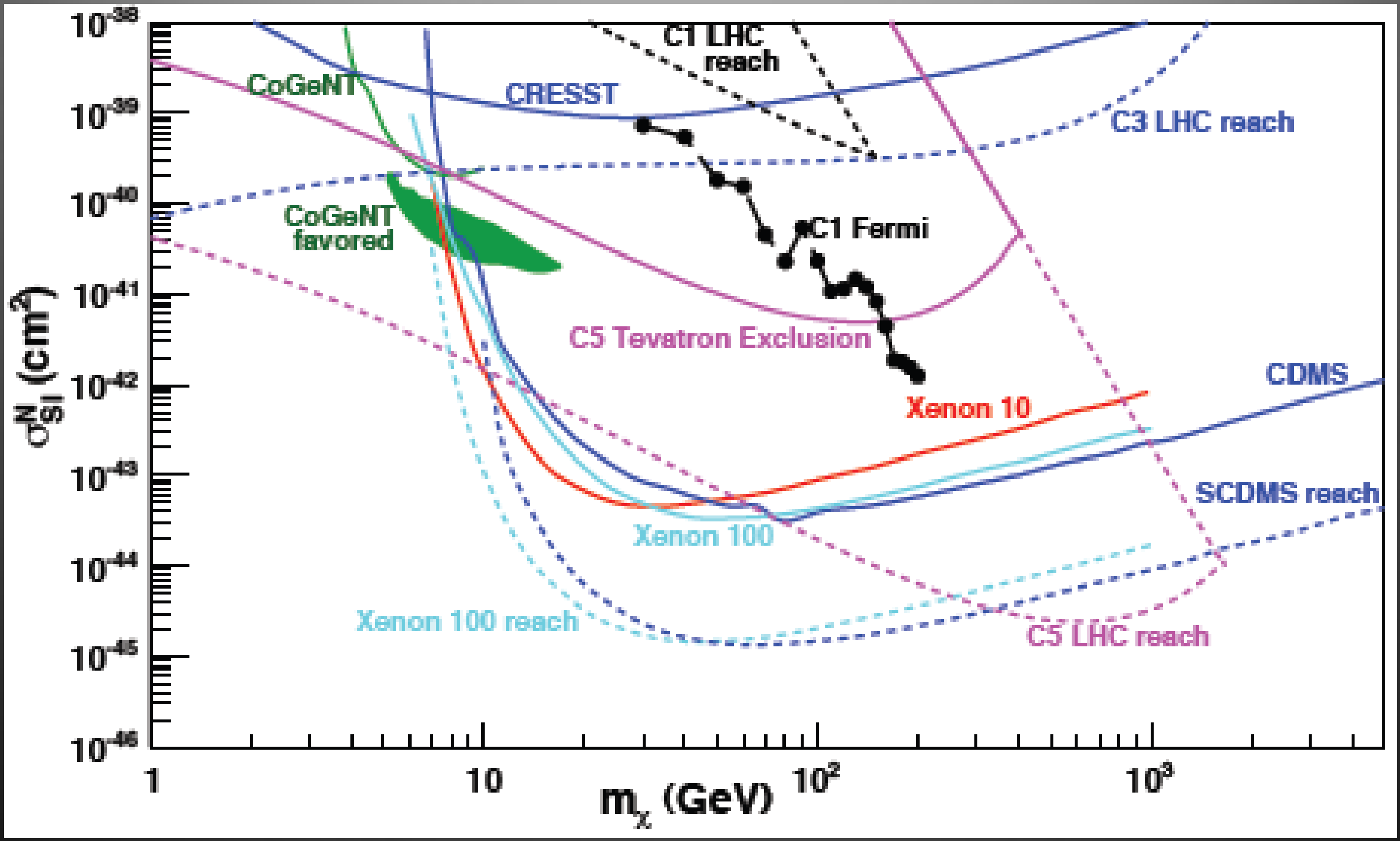
Gamma Ray Lines



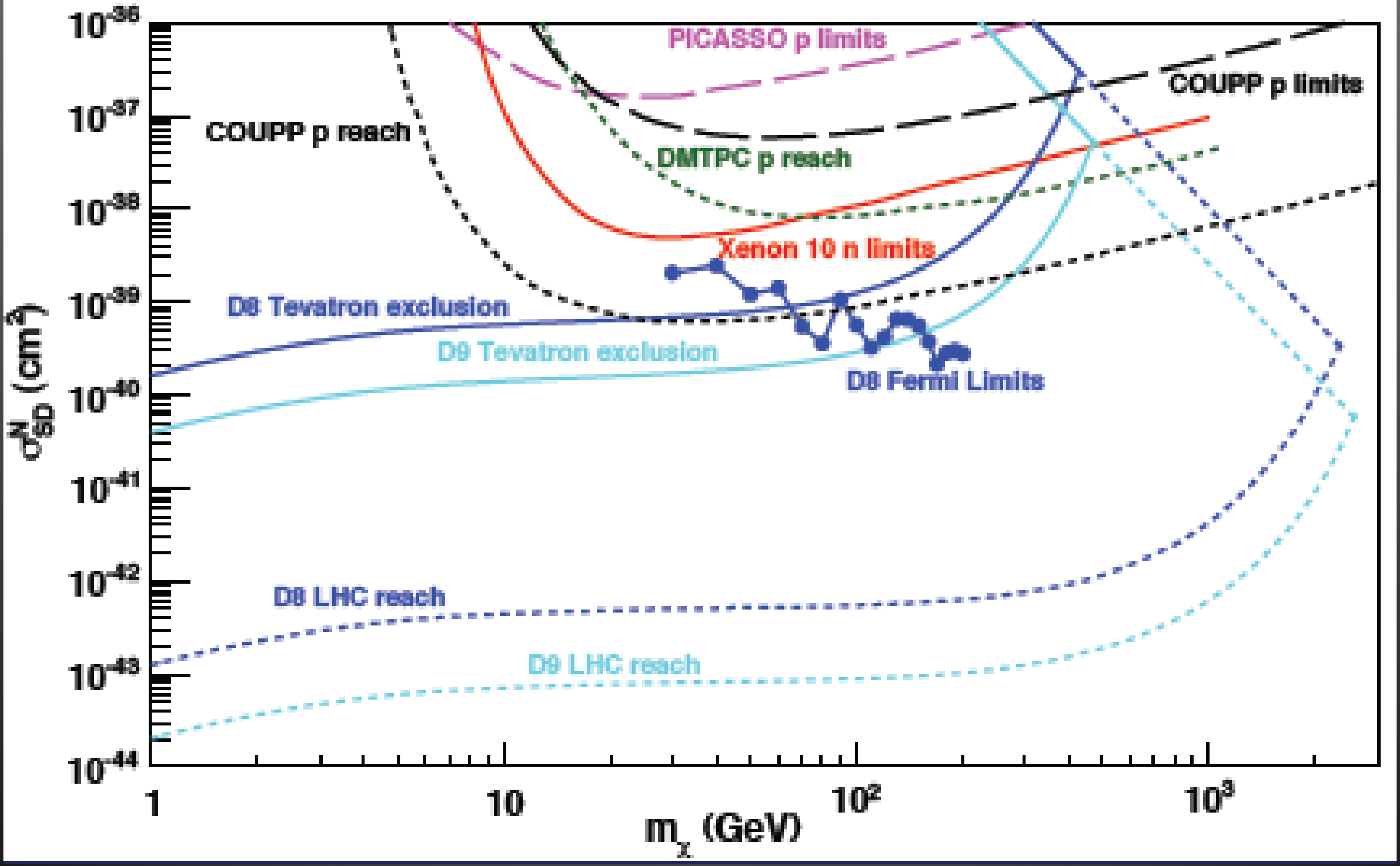
- A new spectral line would be a smoking gun signature of dark matter annihilation.
- Our effective operators can lead to such a signal at one loop.
- We use the most conservative bounds quoted by Fermi/GLAST:
  - Dark matter halo in an isothermal profile.
  - These bounds are about 3x those for an NFW profile.



Complex Scalar WIMP, SI

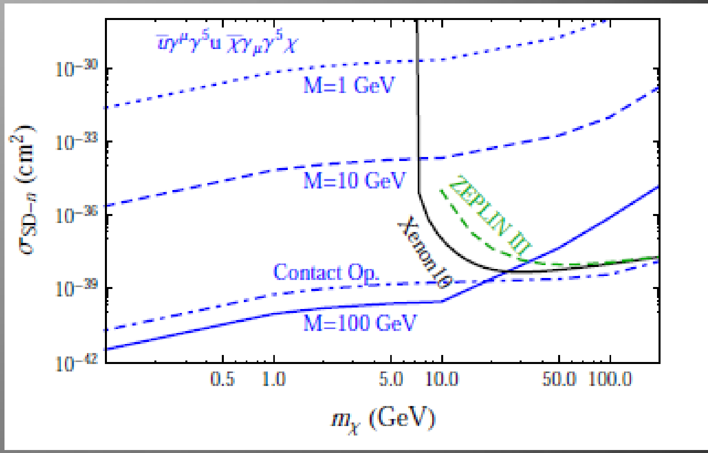


Dirac WIMP, SD

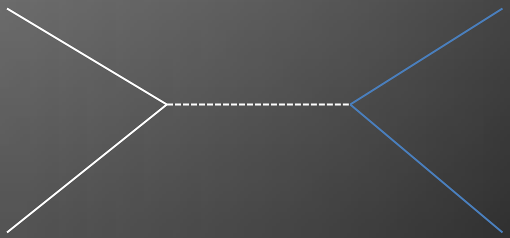


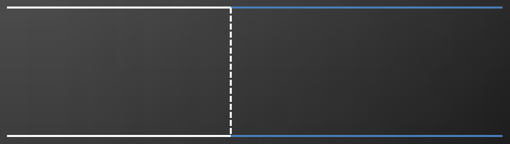
UV Concerns

- The effective theory breaks down when the mediating particle is light compared to the kinematic scales of the interaction.
  - Direct detection is largely safe from these effects.
  - Colliders can easily probe other massive new physics.
- Light mediators can significantly alter the conclusions, while SUSY-like UV completions are often subject to more stringent constraints.



Bai, Fox, Harnik [1005.3797]

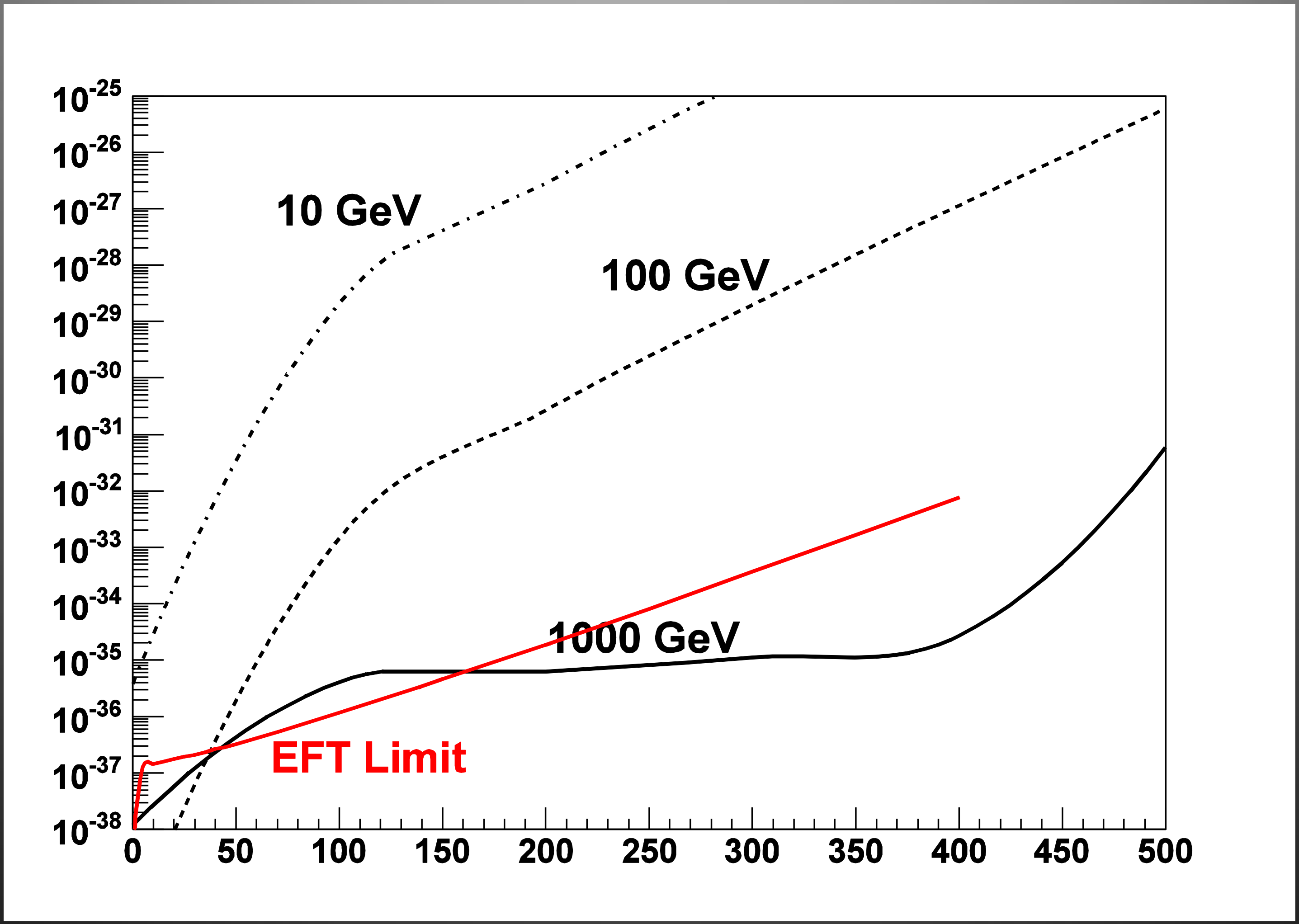




Light Mediators

- In an effort to fully understand the effects of introducing a light mediator into the theory, we write down all of the possible tree level UV completions of a contact operator like those we have discussed.
- Searching in the parameter space of coupling, dark matter mass, and mediator mass using the same CDF search, we are able to place limits on the new models.

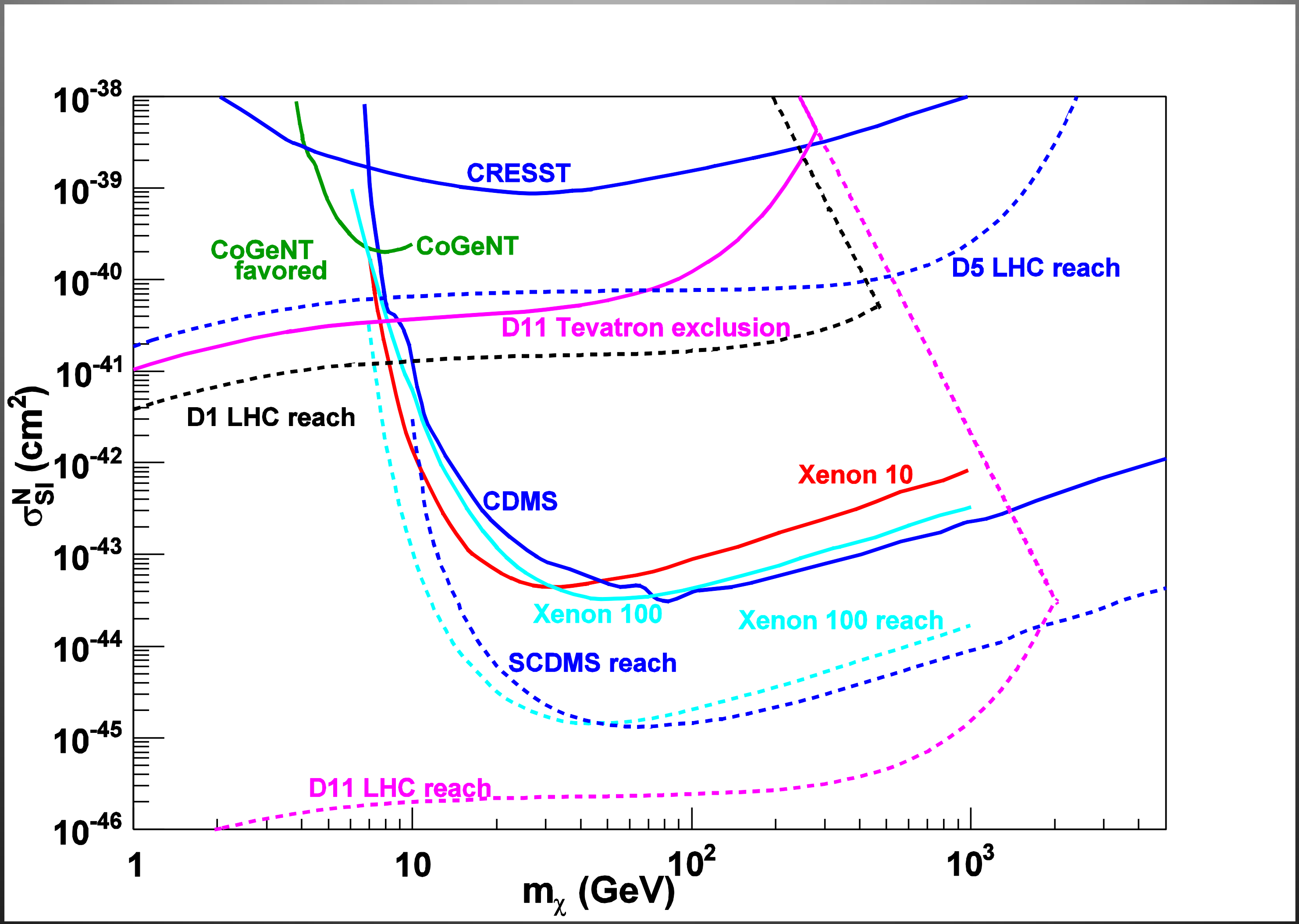
UV Complete Direct Detection: Dark Higgs



Outlook

- These types of analyses are ripe for extension:
  - One could include the possibilities of SU(2) charged WIMPs, higgs interactions, leptonic couplings (Explored by Fox, Harnik, Kopp, and Tsai) or anything else one can think of.
- We can learn which generic types of interactions to expect in our complete theory by comparing a future detection of dark matter with the predictions of the EFT.

Bonus Material: Dirac SI



Dirac WIMPs

- We can repeat the exercise for other WIMP properties
- For a Dirac WIMP, we have a few more allowed Lorentz structures
  - Vector and Tensor operators are allowed.
  - This also allows the magnetic and electric dipole operators.
- We assume, when it matters, that the galactic halo is half particle and half anti-particle.

Name	Operator	Coefficient
D1	$\bar{\chi}\chi\bar{q}q$	m_q/M_*^3
D2	$\bar{\chi}\gamma^5\chi\bar{q}q$	im_q/M_*^3
D3	$\bar{\chi}\chi\bar{q}\gamma^5 q$	im_q/M_*^3
D4	$\bar{\chi}\gamma^5\chi\bar{q}\gamma^5 q$	m_q/M_*^3
D5	$\bar{\chi}\gamma^\mu\chi\bar{q}\gamma_\mu q$	$1/M_*^2$
D6	$\bar{\chi}\gamma^\mu\gamma^5\chi\bar{q}\gamma_\mu q$	$1/M_*^2$
D7	$\bar{\chi}\gamma^\mu\chi\bar{q}\gamma_\mu\gamma^5 q$	$1/M_*^2$
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	$\bar{\chi}\sigma_{\mu\nu}\gamma^5\chi\bar{q}\sigma_{\alpha\beta}q$	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	$\bar{\chi}\chi G_{\mu\nu}\tilde{G}^{\mu\nu}$	$i\alpha_s/4M_*^3$
D14	$\bar{\chi}\gamma^5\chi G_{\mu\nu}\tilde{G}^{\mu\nu}$	$\alpha_s/4M_*^3$

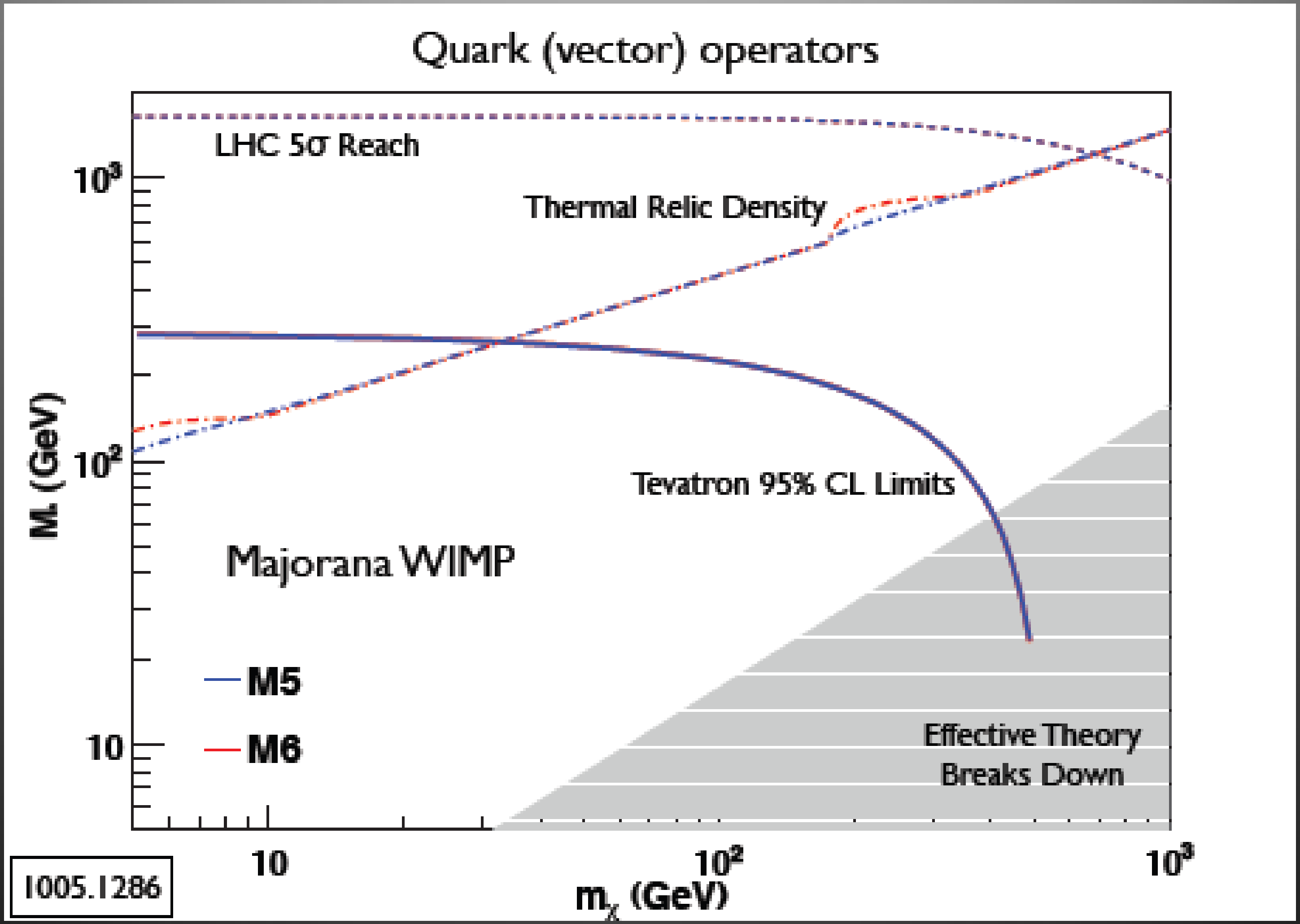
Scalar WIMPs

- Scalar WIMPs admit far fewer distinct interactions than fermionic WIMPS.
- Vector interactions of real WIMPs can be reexpressed in terms of scalar operators through the equation of motion.
- For complex WIMPs we again assume that the local dark matter is not asymmetric.

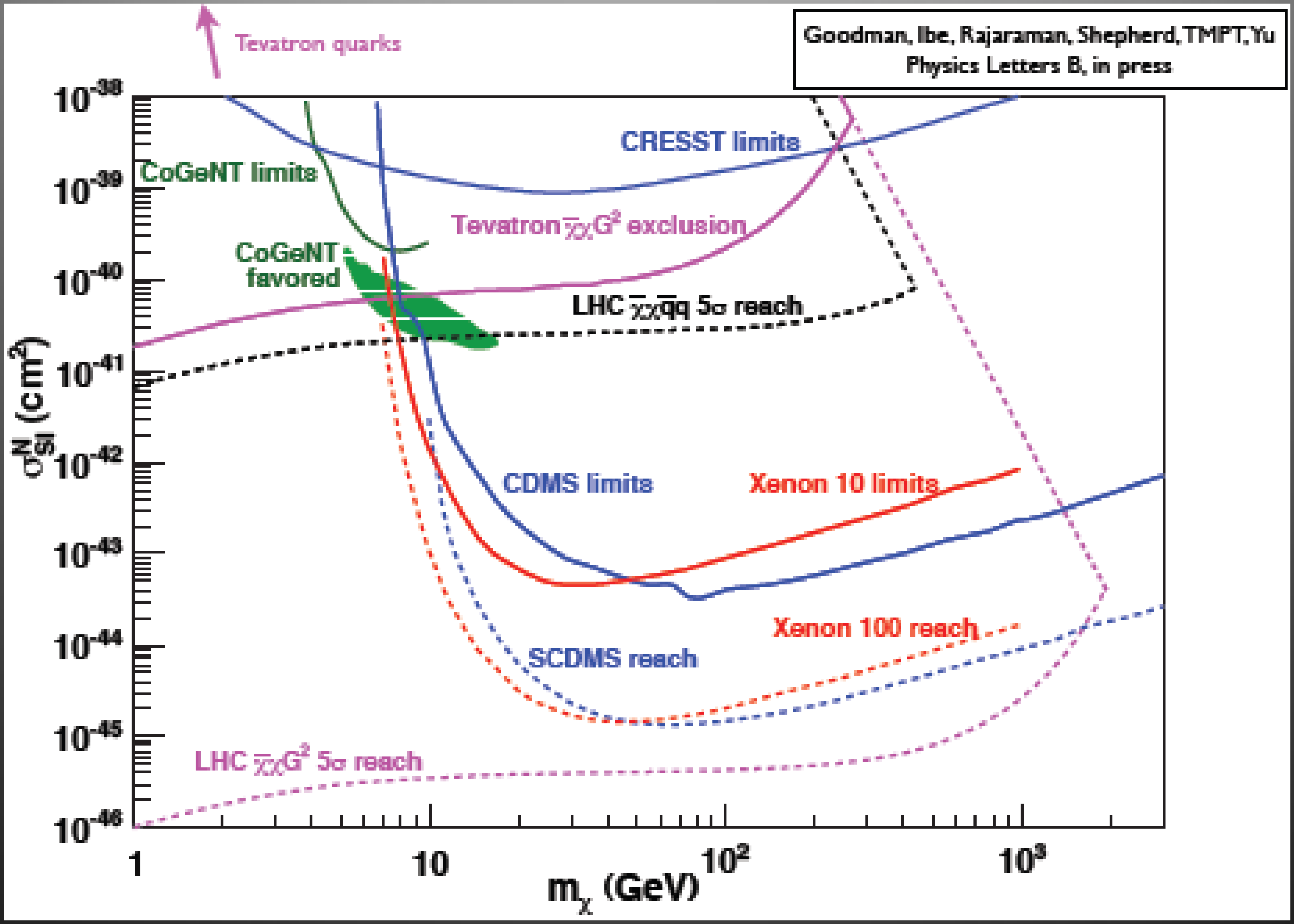
R1	$\chi^2\bar{q}q$	$m_q/2M_*^2$
R2	$\chi^2\bar{q}\gamma^5 q$	$im_q/2M_*^2$
R3	$\chi^2 G_{\mu\nu}G^{\mu\nu}$	$\alpha_s/8M_*^2$
R4	$\chi^2 G_{\mu\nu}\tilde{G}^{\mu\nu}$	$i\alpha_s/8M_*^2$

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	$\chi^\dagger\chi G_{\mu\nu}G^{\mu\nu}$	$\alpha_s/4M_*^2$
C6	$\chi^\dagger\chi G_{\mu\nu}\tilde{G}^{\mu\nu}$	$i\alpha_s/4M_*^2$

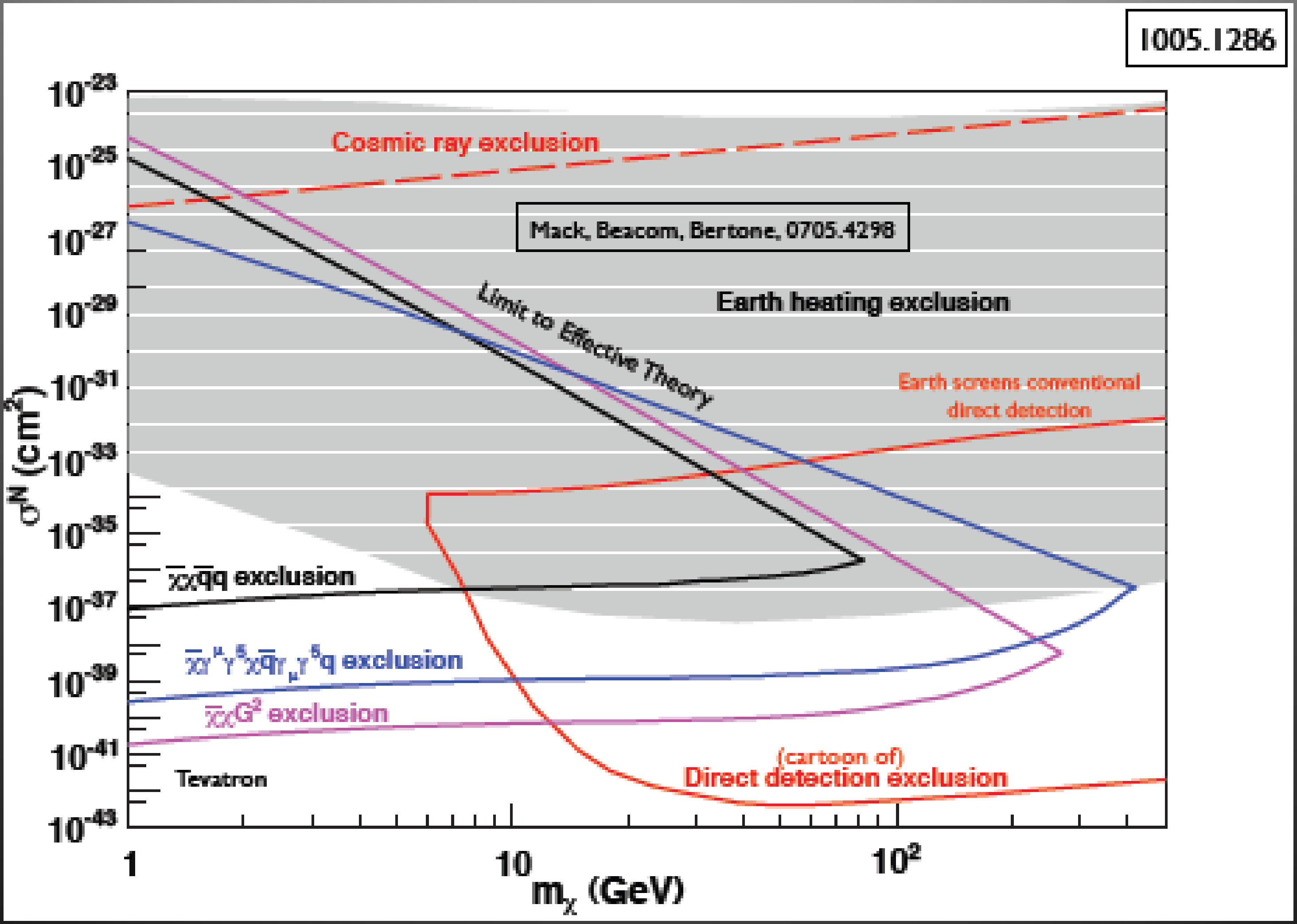
Example of Limits and Sensitivity



Spin-Independent



Leading Bounds on Strong Interactions



Spin-Dependent