Fermi-LAT limits on mass degenerate dark matter scenarios

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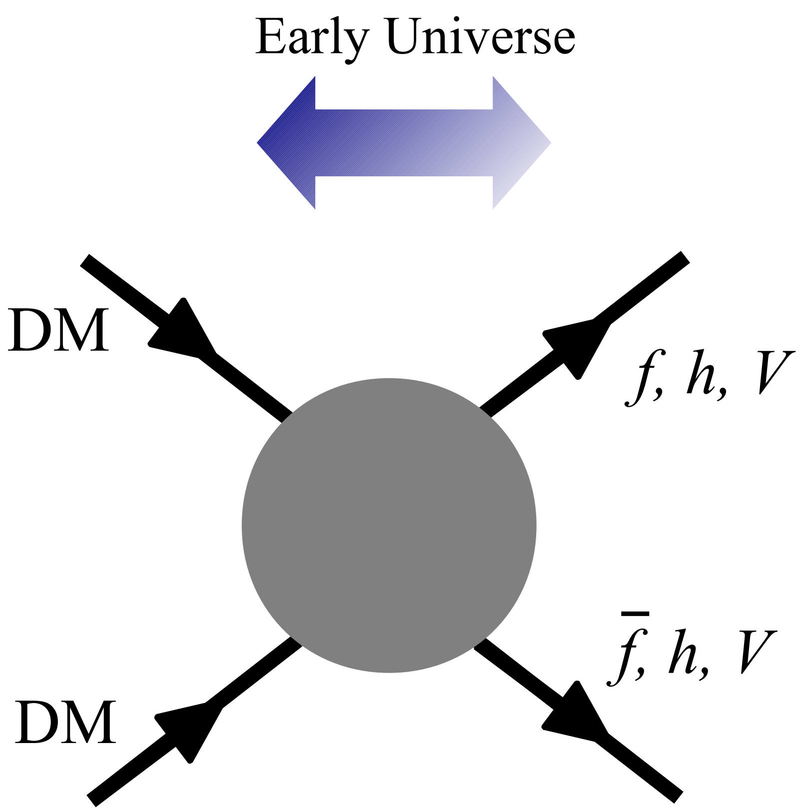
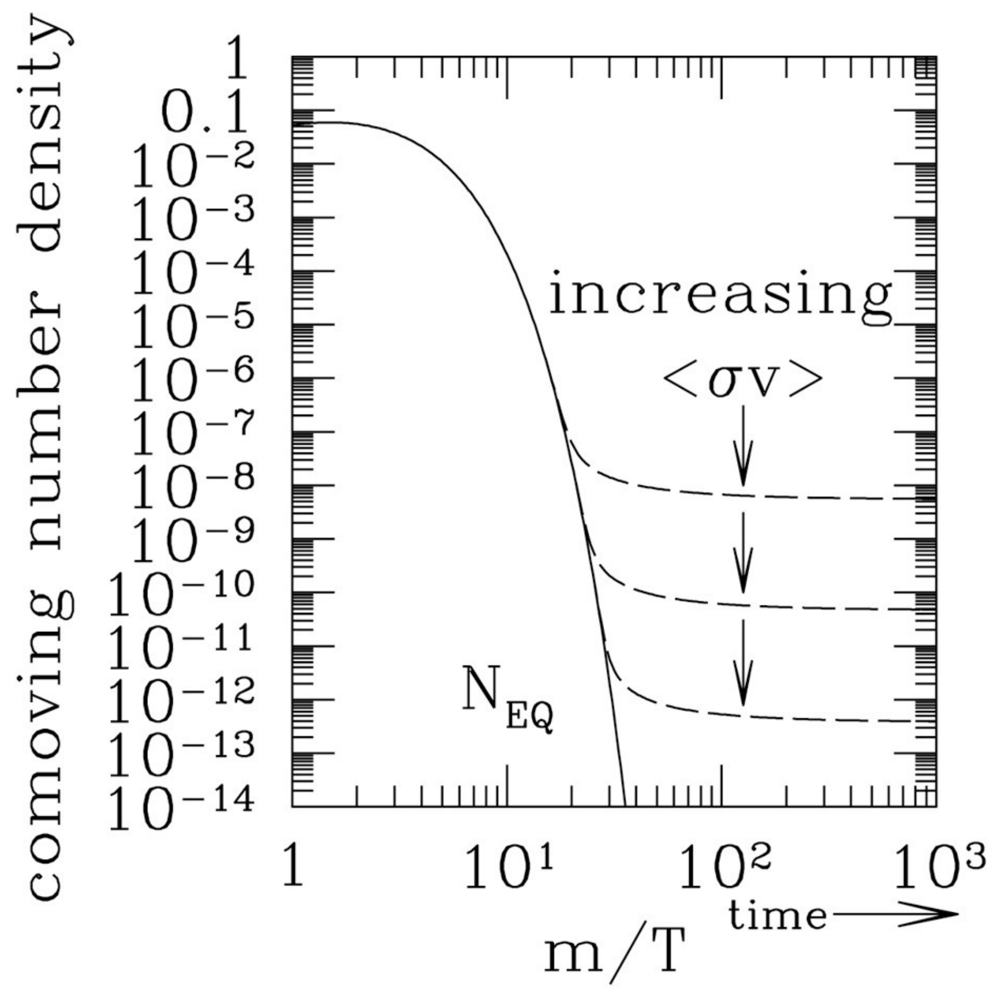
4 March 2013

Dark matter annihilations: standard picture

Thermal production of WIMPs

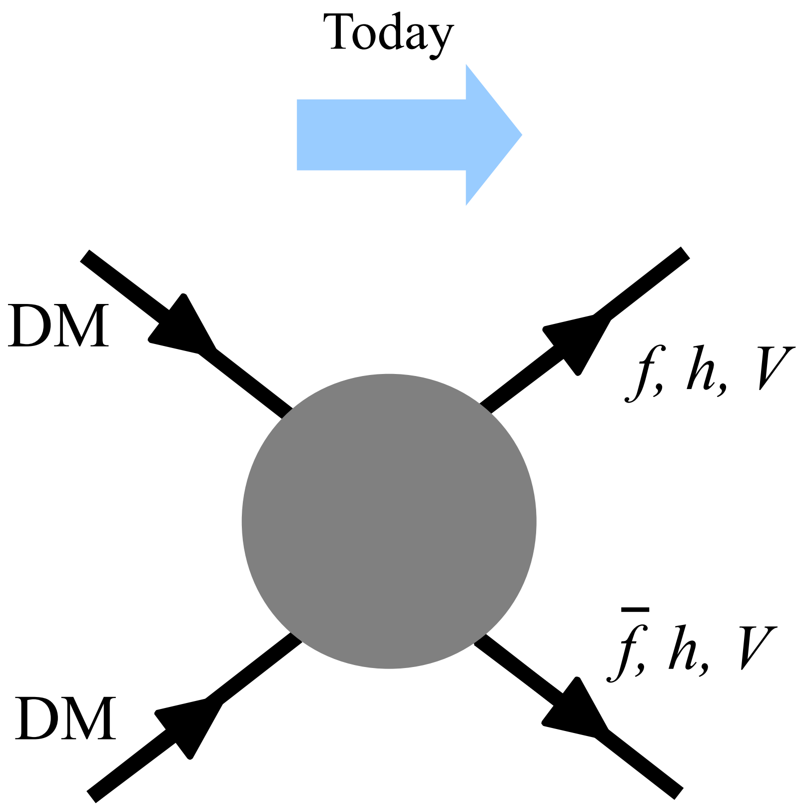




$$\Omega_{\rm DM} h^2 \simeq 0.11 \times \frac{3 \times 10^{-26} {\rm cm}^3 {\rm s}^{-1}}{\langle \sigma_{\rm ann} v \rangle}$$

Dark matter annihilations: standard picture

Annihilations in galactic dark matter haloes



Canonical value of the velocity weighted annihilation cross-section

$$\langle \sigma_{\rm ann} v \rangle \simeq 3 \times 10^{-26} {\rm cm}^3 {\rm s}^{-1}$$

Target value for experiments

However, here it has been implicitly assumed that the velocity weighted annihilation cross section does not depend on the velocity.

Decompose the annihilation cross section as:

$$\langle \sigma v \rangle = a + b v^2$$

$a,b \longrightarrow$ calculable in a given DM model
$v \longrightarrow$ depends on the astrophysical conditions

Freeze-out $\langle v^2 \rangle \sim \frac{6 T_{\text{f.o.}}}{m_{\text{DM}}} \sim 0.3$ ← $T_{\text{f.o.}} \sim \frac{m_{\text{DM}}}{20}$

Galactic center $v \sim 10^{-3}$

$$a \gg b v^2 \quad \Longrightarrow \quad \frac{\langle \sigma v \rangle_{\text{G.C.}}}{\langle \sigma v \rangle_{\text{f.o.}}} \sim 1$$

$$a \ll b v^2 \quad \Longrightarrow \quad \frac{\langle \sigma v \rangle_{\text{G.C.}}}{\langle \sigma v \rangle_{\text{f.o.}}} \sim 3 \times 10^{-6}$$

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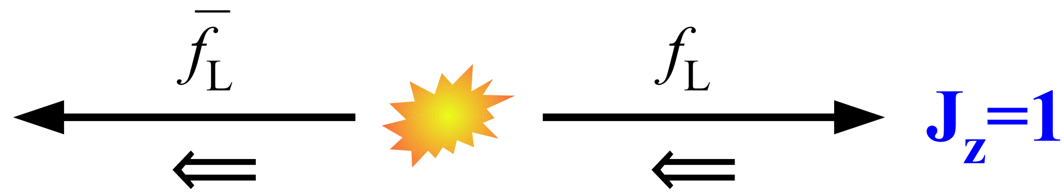
- Consider the annihilation DM DM $\rightarrow f\bar{f}$, with DM a Majorana fermion or a scalar particle



In the limit $v \rightarrow 0$,
no preferred direction

J_z=0

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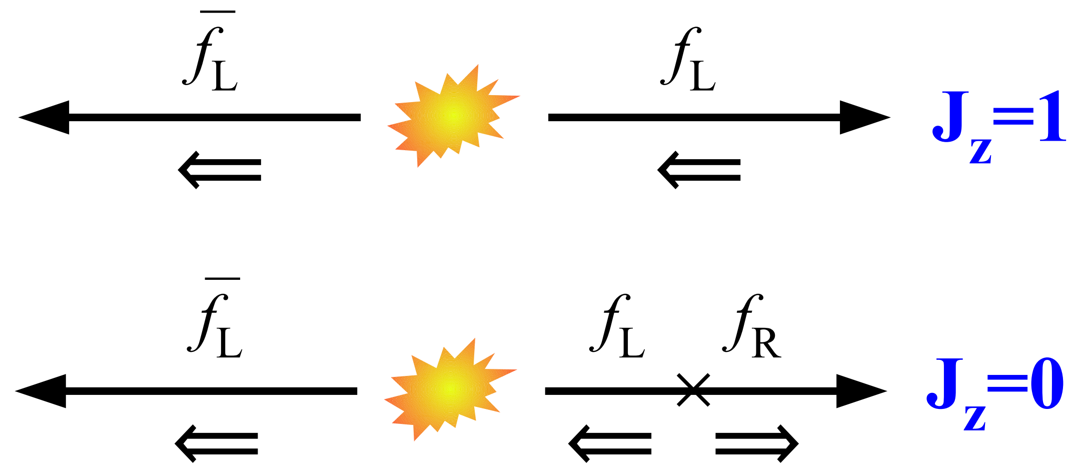

Rate of DM DM $\rightarrow f\bar{f}$ suppressed by $(m_f/m_{DM})^2$ if v=0. Otherwise by v^2.

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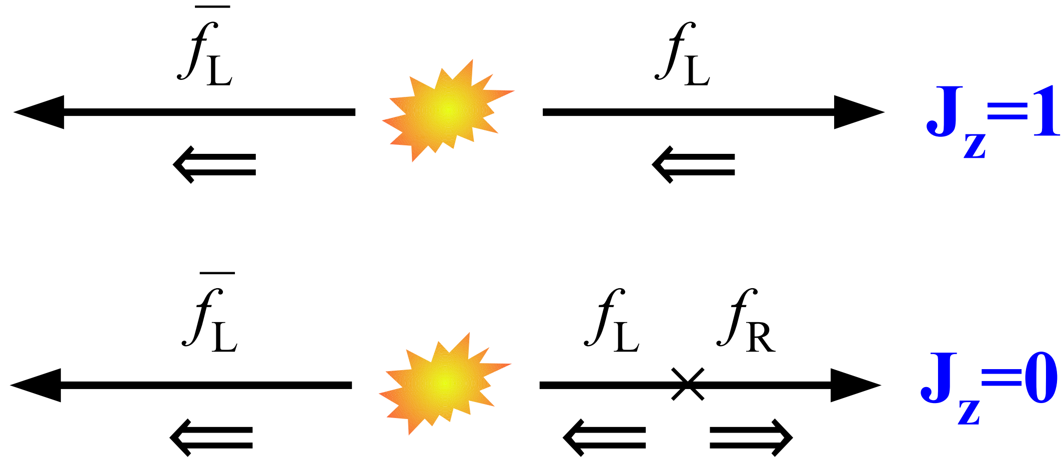


Rate of DM DM $\rightarrow f\bar{f}$ suppressed by $(m_f/m_{DM})^2$ if v=0. Otherwise by v^2.

- Relative contributions to the velocity weighted annihilation cross section $\langle \sigma v \rangle = a + bv^2$ for annihilations into light fermions:

For m=300 GeV, $$\frac{a}{bv^2} \sim \frac{m_f^2}{m_{\mathrm{DM}}^2 v^2} \sim \begin{cases} 10^{-6} & \text{for electrons} \\ 0.1 & \text{for muons} \\ 10^{-5} & \text{for up-type quarks} \end{cases}$$

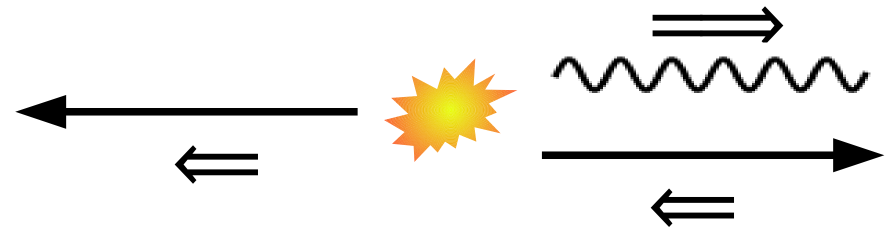
$$\Longrightarrow \langle \sigma v \rangle_{\mathrm{G.C.}} \sim 3 \times 10^{-6} \langle \sigma v \rangle_{\mathrm{f.o.}} \sim 10^{-31}\,\mathrm{cm}^3\mathrm{s}^{-1}$$

Indirect detection hopeless?? Not really... higher order effects become important.

• Consider the annihilation DM DM $\rightarrow f\bar{f}V$, with DM a Majorana fermion or a scalar particle and V a vector

In the limit $v \rightarrow 0$,
no preferred direction

J_z=0



J_z=0

No suppression by mass insertion. Suppressed, however, by the extra coupling constant and by the 3-body phase space.

Bergström
Flores, Olive, Rudaz

For annihilations into light fermions, the dominant annihilation channel *today* can be DM DM $\rightarrow f\bar{f}V$, while at the time of freeze-out, DM DM $\rightarrow f\bar{f}$

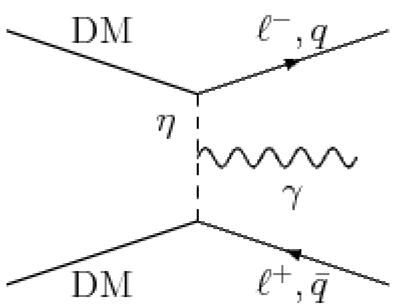
$$\langle\sigma v\rangle^{2\rightarrow 3}_{G.C.} \sim \frac{\alpha}{0.3\pi}\langle\sigma v\rangle^{2\rightarrow 2}_{f.o.} \sim 10^{-28}\mathrm{cm}^3\mathrm{s}^{-1}$$

Target cross section for this class of scenarios, instead of $3\times10^{-26}\,\mathrm{cm}^3\mathrm{s}^{-1}$.

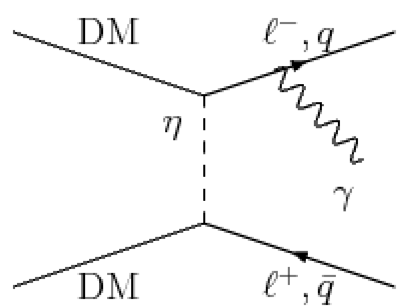
Simplified models with internal Bremsstrahlung

Consider a toy model with a Majorana dark matter particle, χ, an intermediate scalar particle η, and a right-handed SM fermion $\Psi = \mu,\ \tau,\ b$.

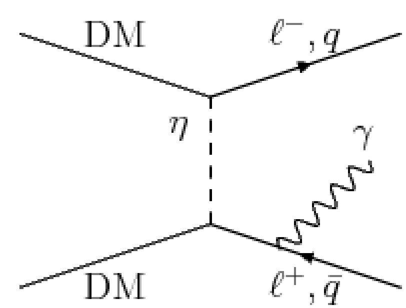
Interaction Lagrangian: $\mathcal{L}_{\rm int} = -y\bar{\chi}\Psi_R\eta + \text{h.c.}$



Virtual internal Bremsstrahlung

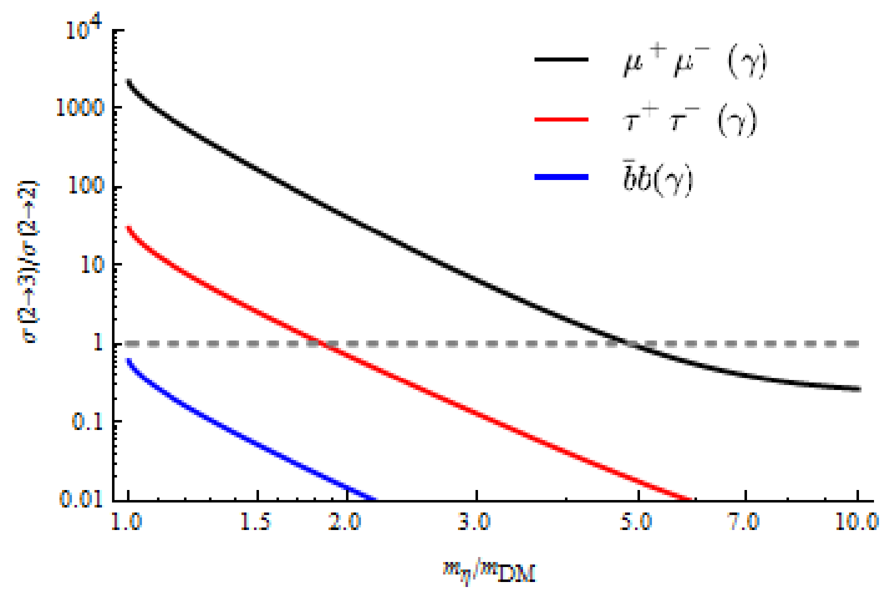


Final state radiation



Final state radiation

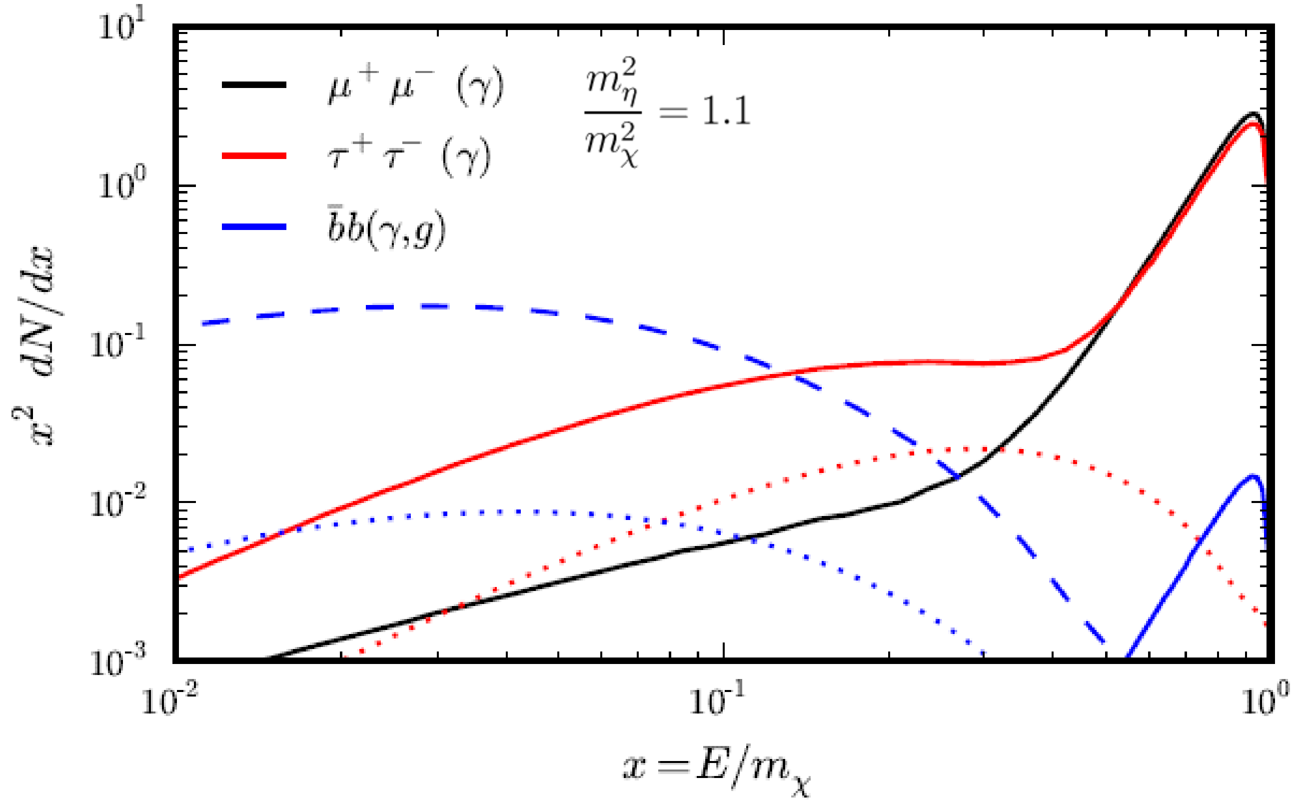
The cross section of the $2 \rightarrow 3$ process is enhanced when $m_\eta/m_{DM} \simeq 1$.



Bergström
Flores, Olive, Rudaz

Simplified models with internal Bremsstrahlung

Bonus: if η is sufficiently degenerate in mass with the dark matter particle, the gamma-ray spectrum displays a characteristic feature

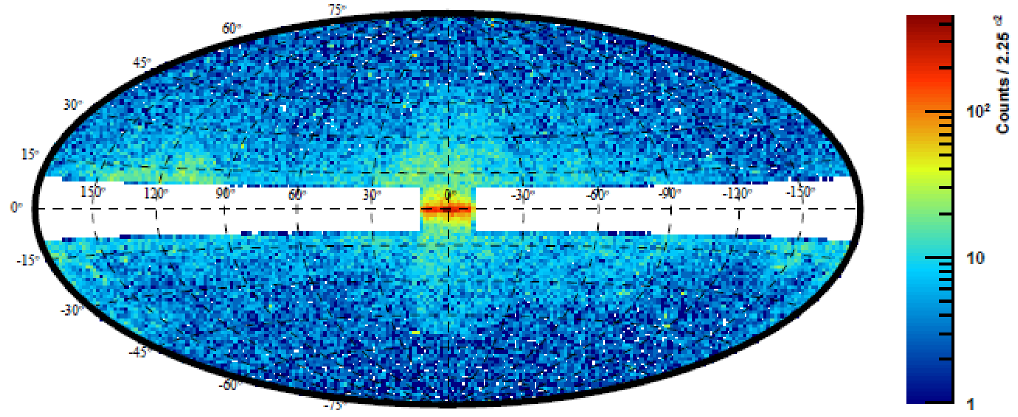


Bringmann, Huang, AI, Vogl, Weniger arXiv:1203.1312

Search for signatures of internal Bremsstrahlung with the Fermi-LAT

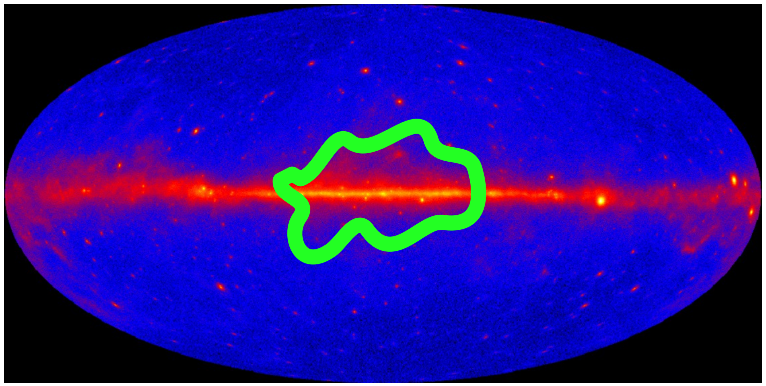
<u>Traditional approach</u>: select a fixed region of the sky and search for features.

e.g region |b|>10° plus a 20°×20° square centered at the Galactic Center (Fermi coll.)



<u>Disadvantage</u>: in the chosen region the background could be too large and bury the signal

<u>Our approach</u>: choose regions where, for a given dark matter profile, the signal-to-background ratio is maximized

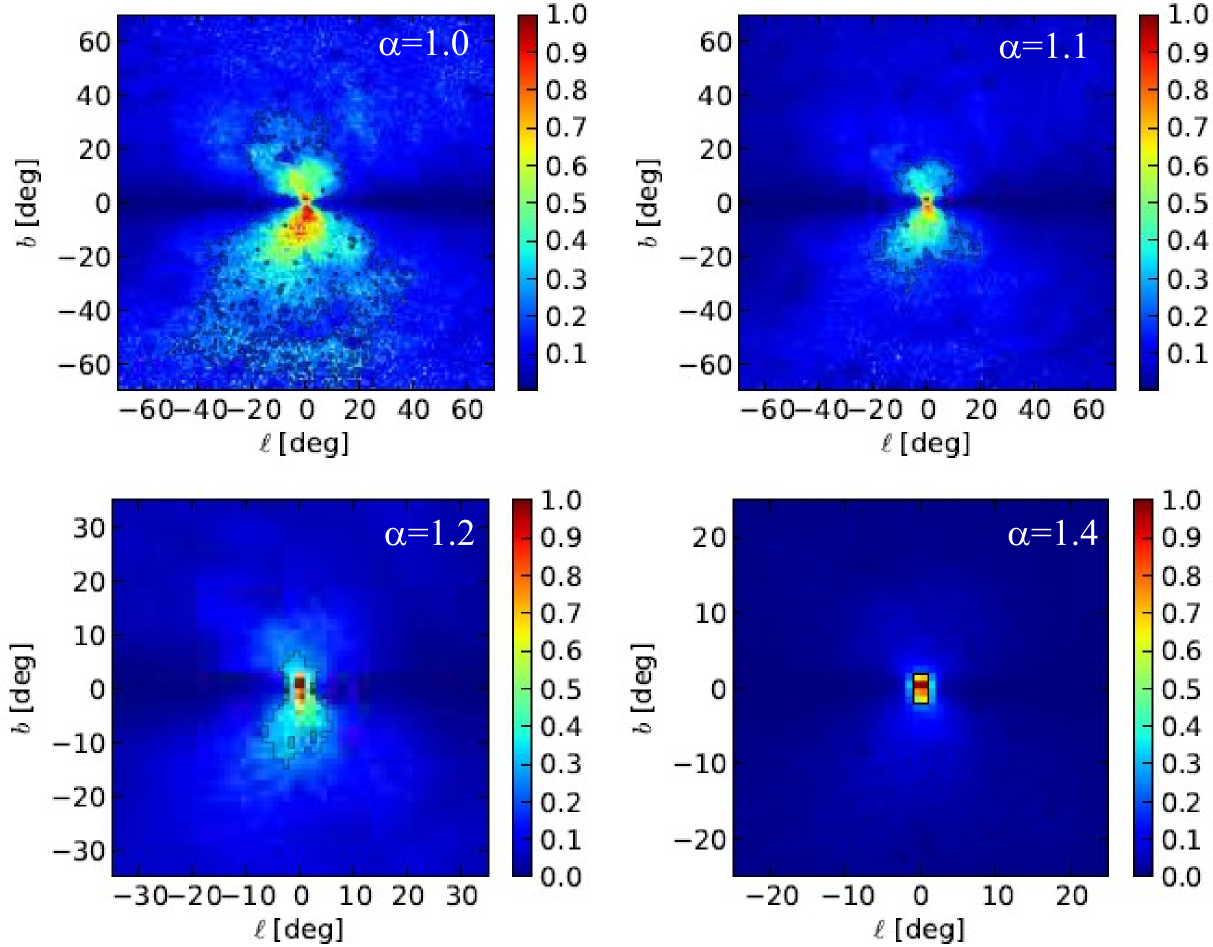


Search for signatures of internal Bremsstrahlung with the Fermi-LAT

Consider a generalized NFW profile

$$\rho_\chi(r) \propto \frac{1}{(r/r_s)^\alpha \, (1 + r/r_s)^{3-\alpha}}$$

Target regions which maximize the signal-to-background ratio:



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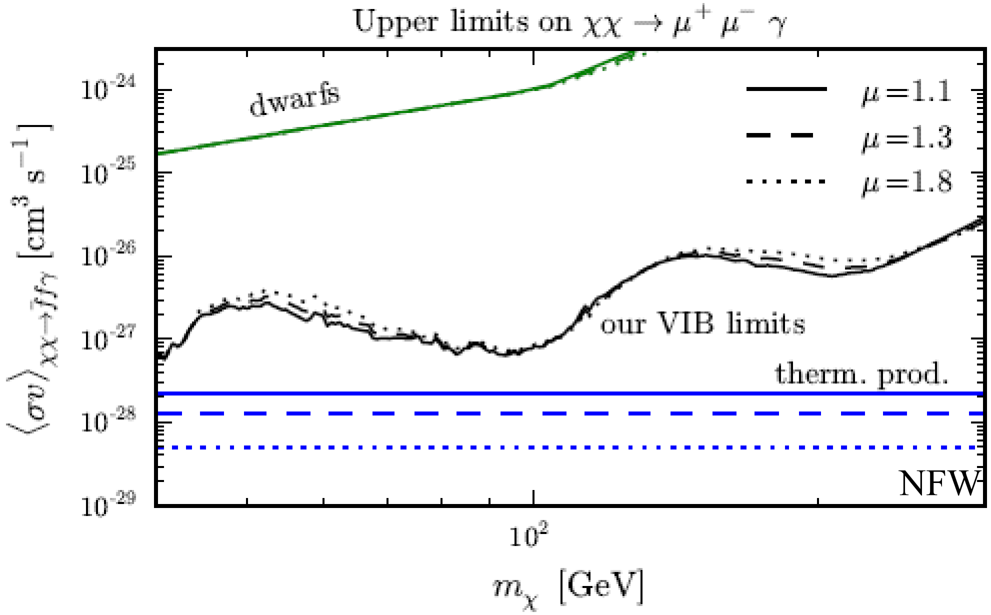

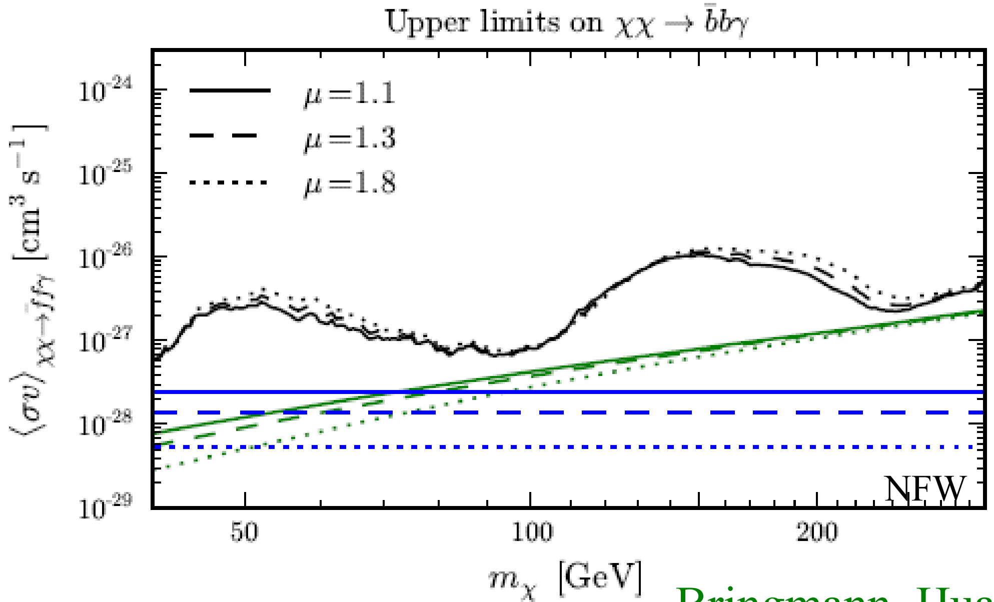

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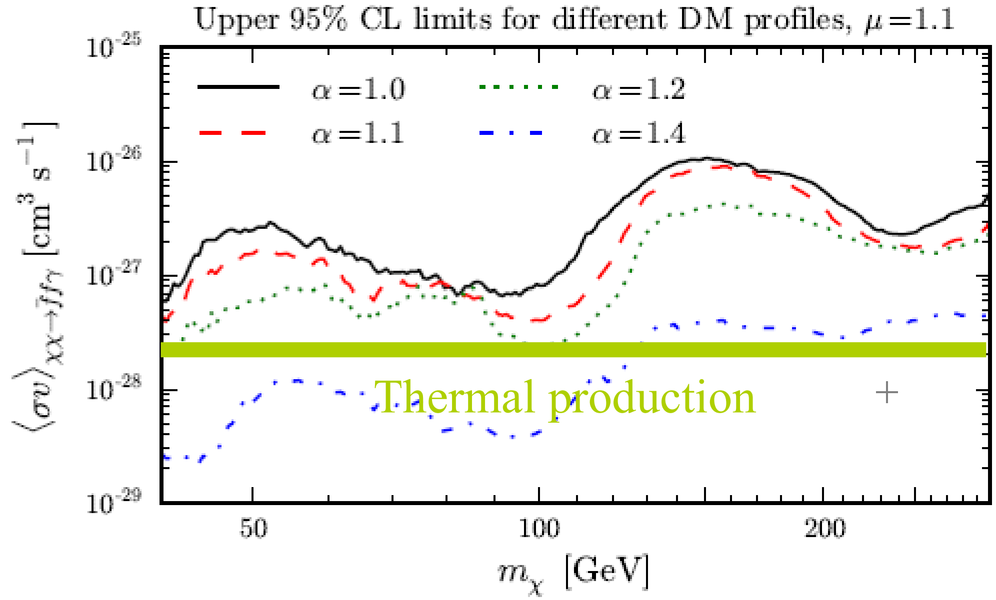
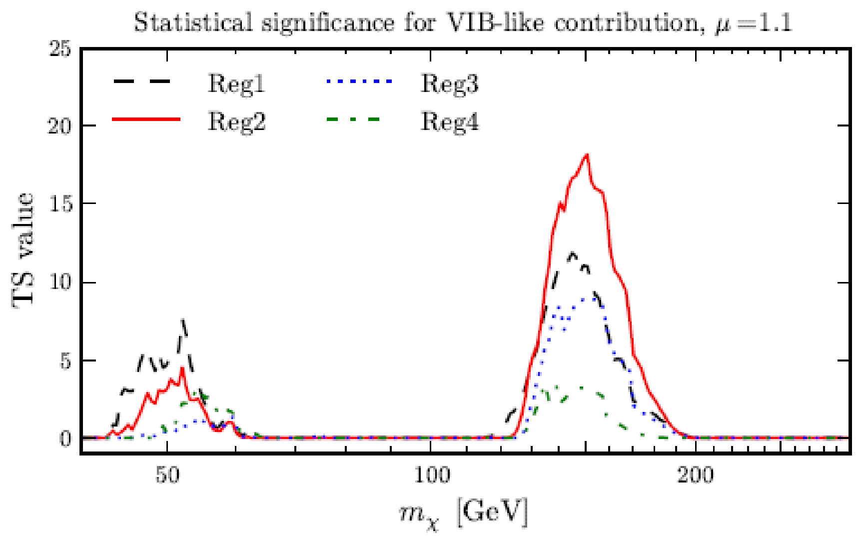
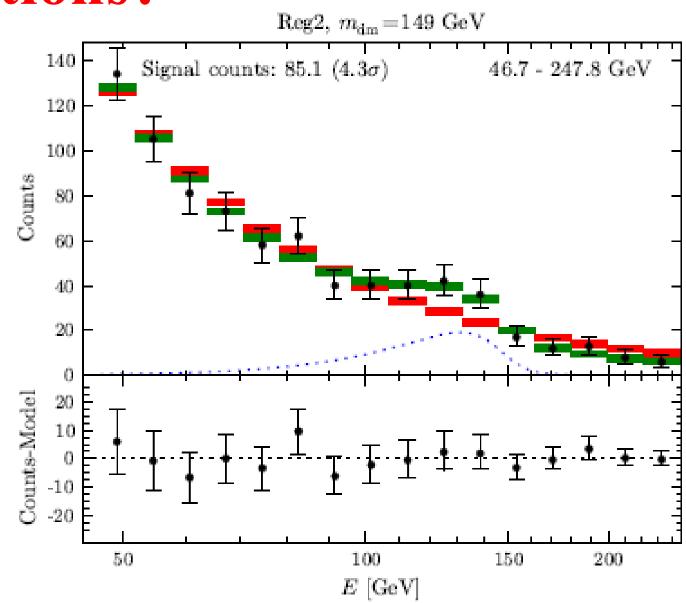


Search for signatures of internal Bremsstrahlung with the Fermi-LAT

A possible hint of dark matter annihilations?





$$m_\chi = (149 \pm 4)\ \text{GeV}$$

$$\langle \sigma v \rangle = (5.7 \pm 1.4) \times 10^{-27}\ \text{cm}^3\ \text{s}^{-1}$$

4.3 σ (3.1 σ with LEE) in Reg2

Bringmann, Huang, AI, Vogl, Weniger arXiv:1203.1312

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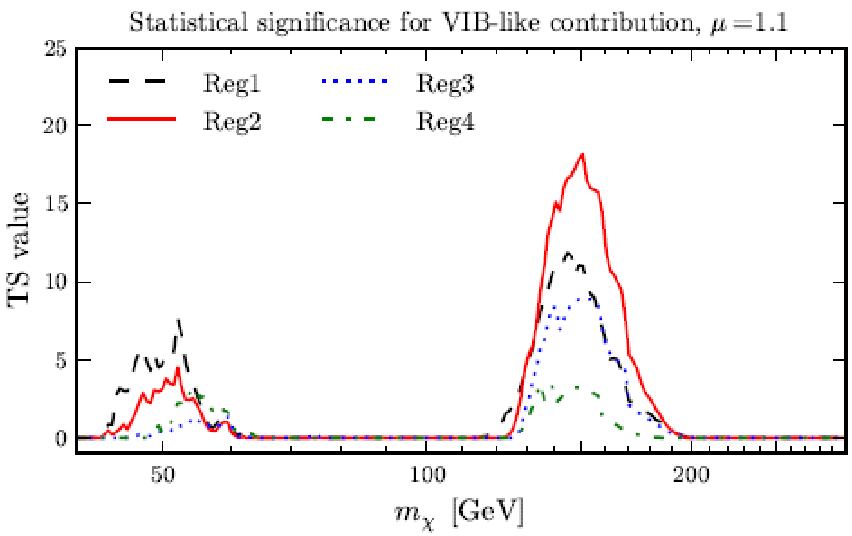

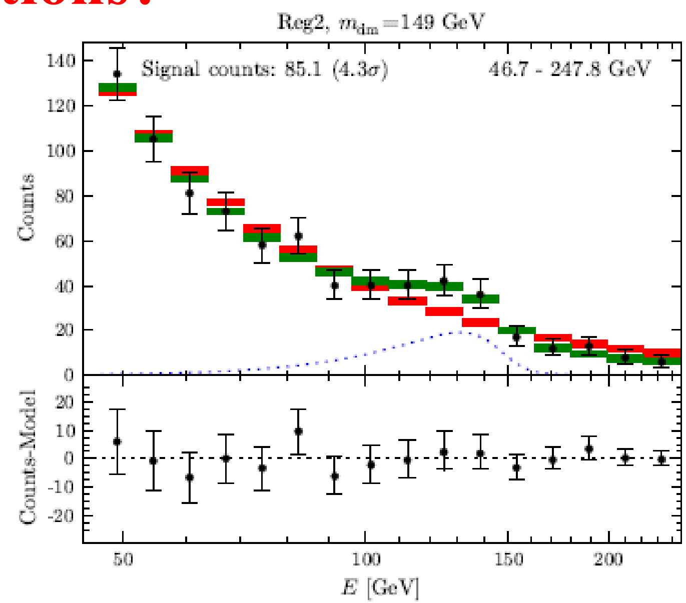

Bringmann, Huang, AI, Vogl, Weniger
arXiv:1203.1312

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The excess can also be fitted by a line $\begin{cases} m_\chi \sim 130\ \mathrm{GeV} \\ \langle \sigma v \rangle_{\chi\chi \to \gamma\gamma} \sim 10^{-27}\ \mathrm{cm^3\ s^{-1}} \end{cases}$

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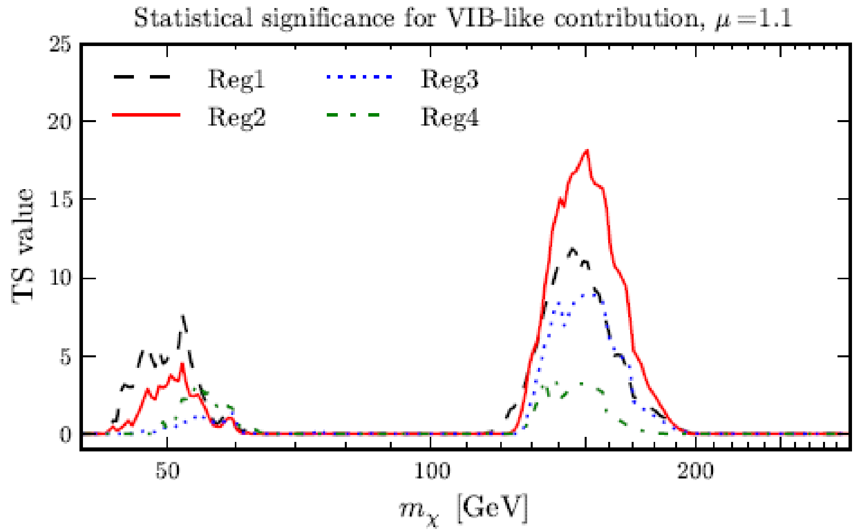

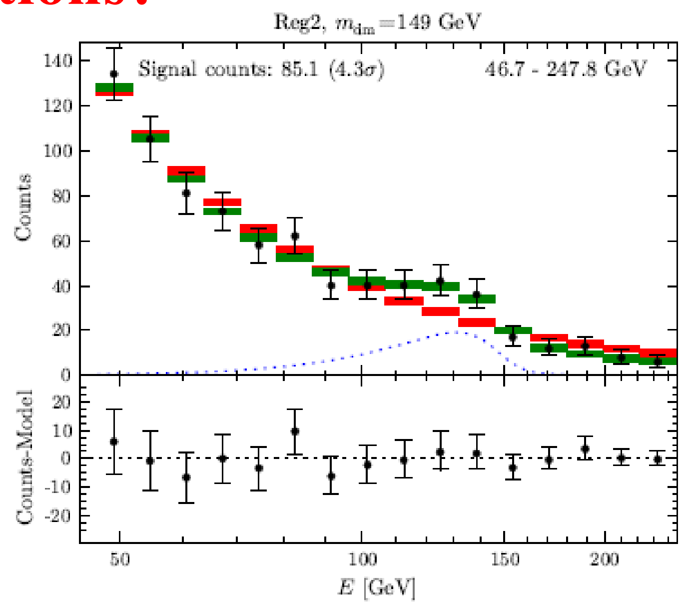

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The excess can also be fitted by a line

$$m_\chi = 129.8 \pm 2.4^{+7}_{-13}\ \text{GeV}$$

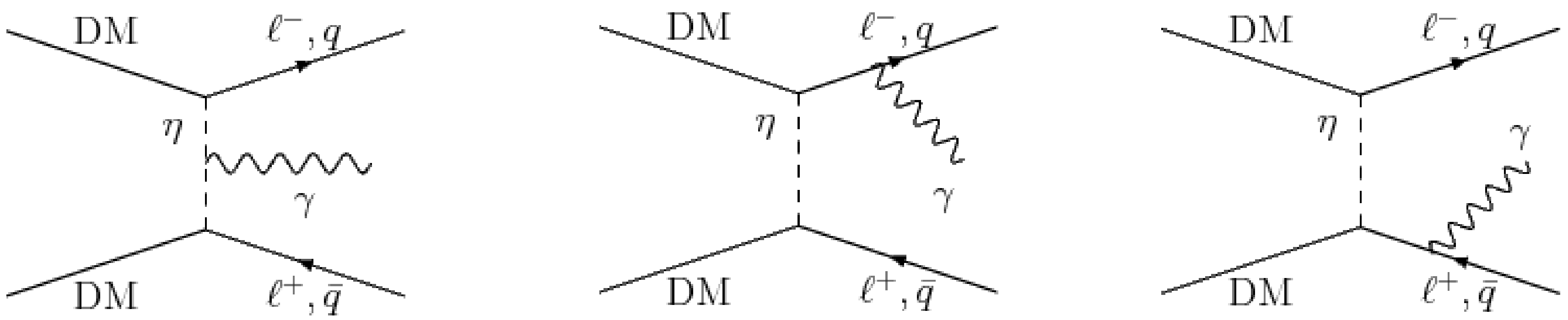
$$\langle \sigma v \rangle = (1.27 \pm 0.32^{+0.18}_{-0.28}) \times 10^{-27}\ \text{cm}^3\ \text{s}^{-1}$$

Weniger, arXiv:1204.2797

4.6 σ (3.3 σ with LEE) for Einasto

Other limits on mass degenerate scenarios

Interplay with antiproton limits



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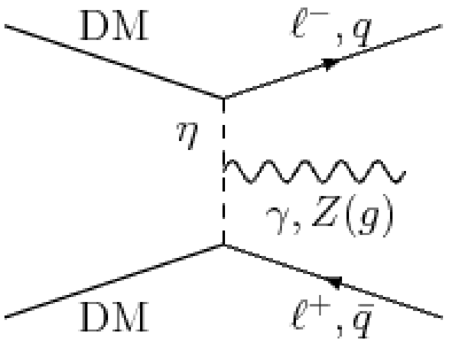

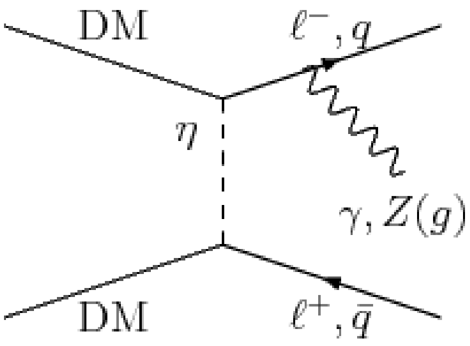

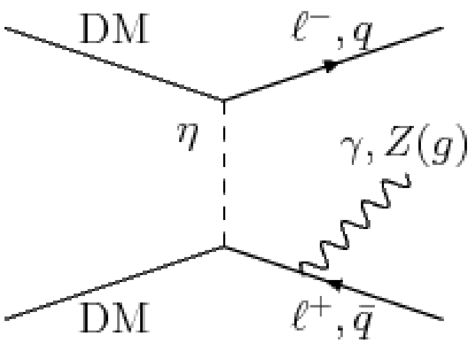

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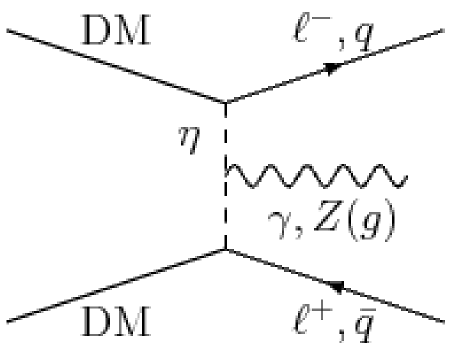
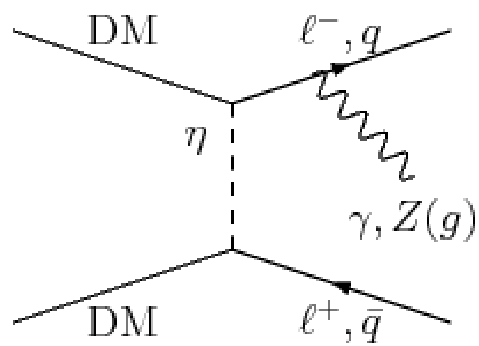
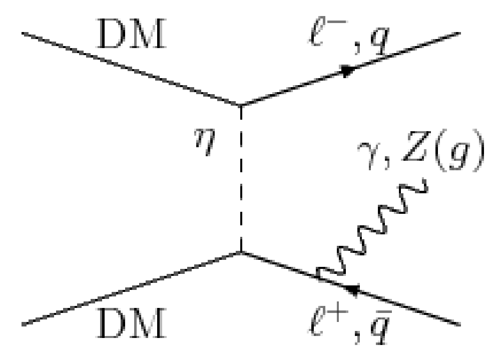
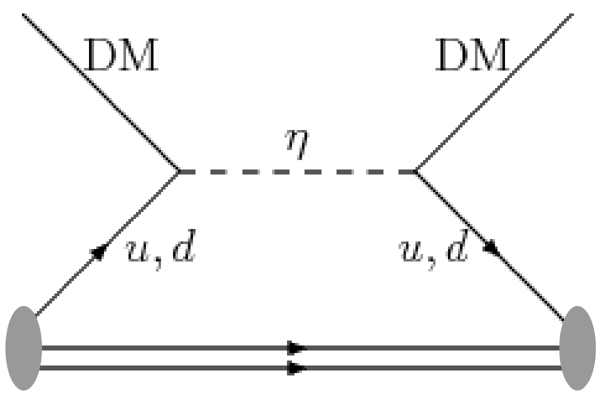
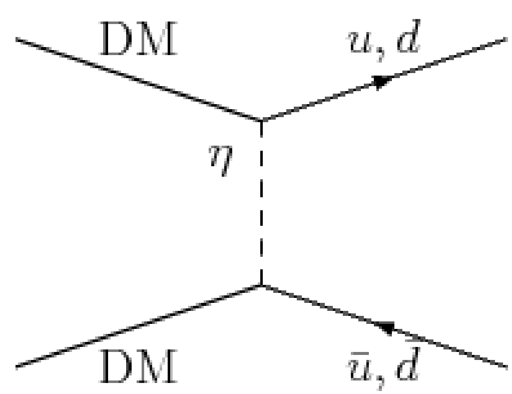






Interplay with direct detection limits





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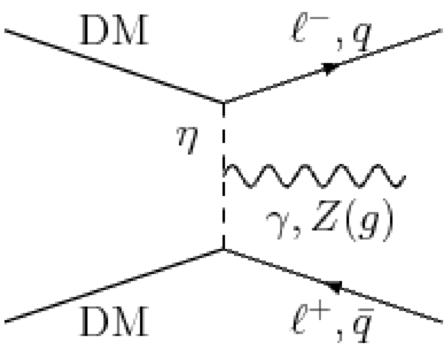
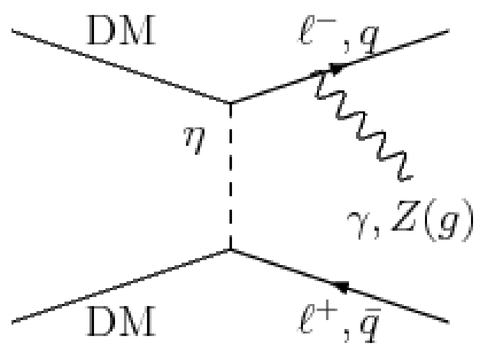
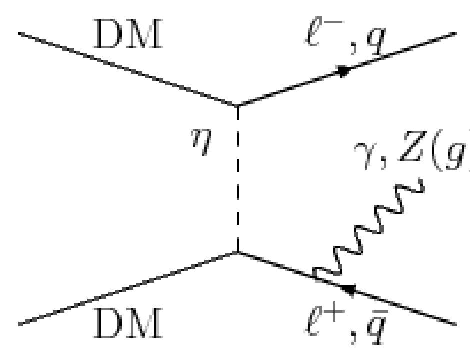
Interplay with antiproton limits







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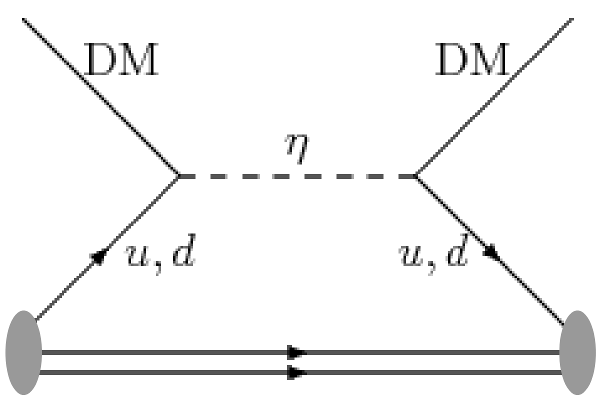
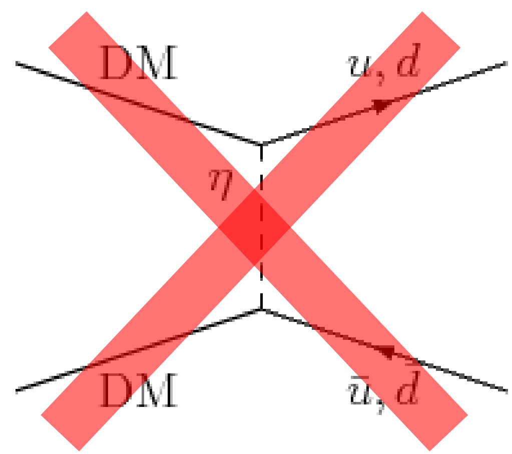
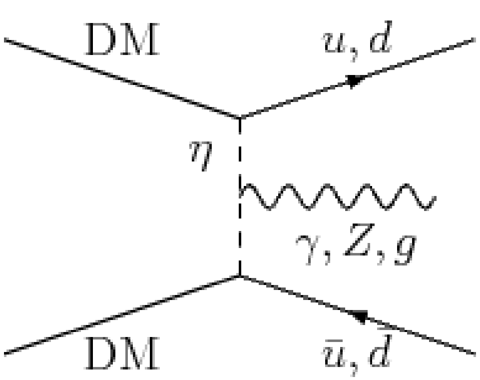
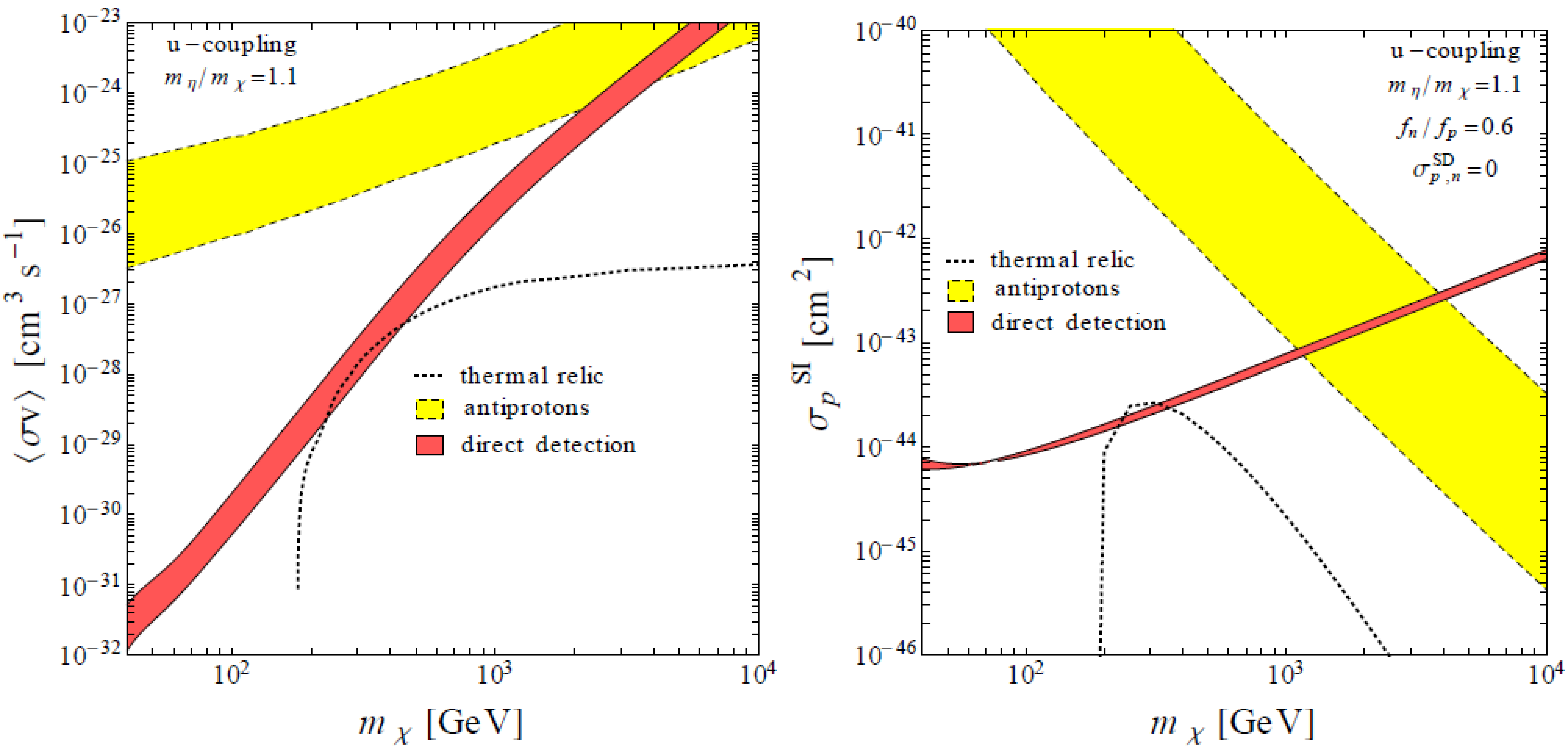




Very suppressed!

$\langle \sigma v \rangle \propto (m_{u,d}/m_{\mathrm{DM}})^2$



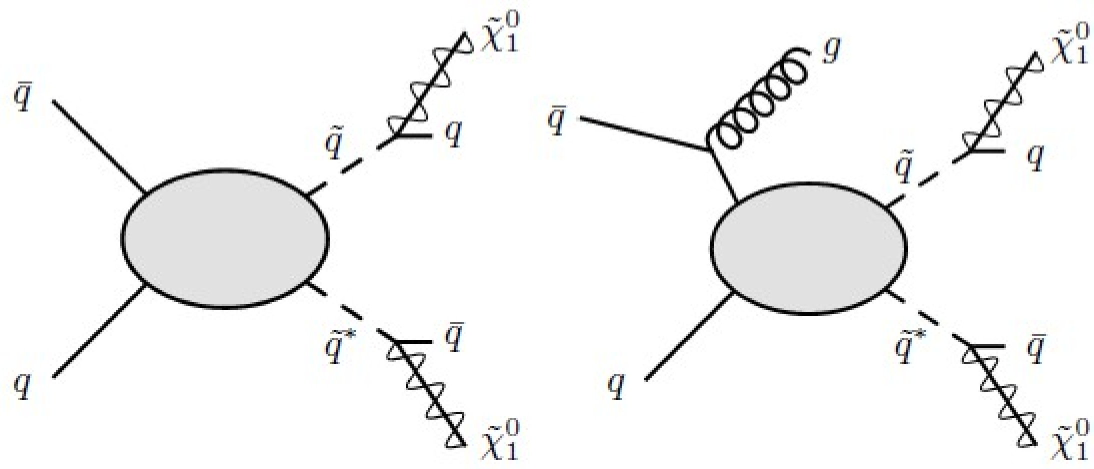


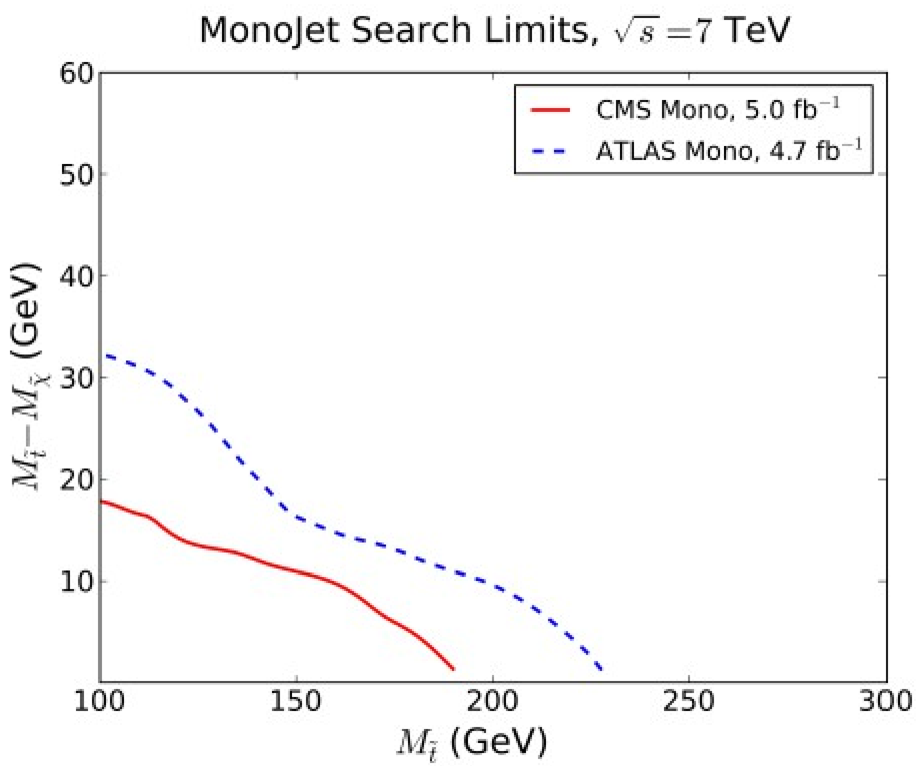
Garny, AI, Pato, Vogl
arXiv:1207.1431

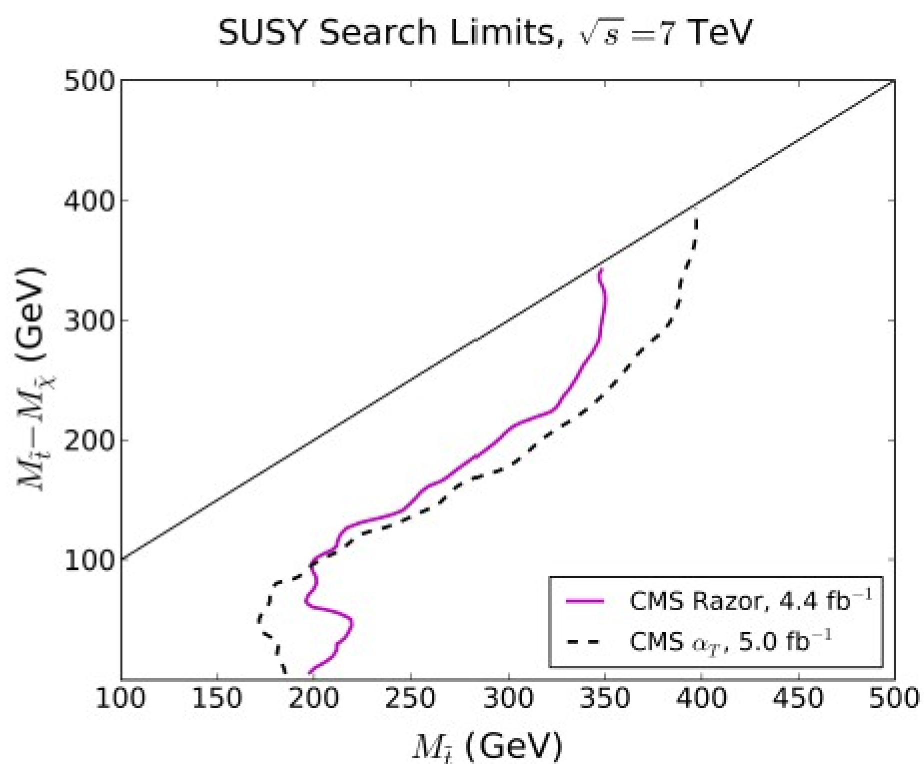
Interplay with collider limits

Hadronic
+
monojet searches

Dreiner, Krämer, Tattersal, arXiv:1211.4981







Conclusions

• In scenarios with Majorana (or scalar) dark matter particles which couple to light fermions, the higher order annihilation process DM DM $\rightarrow f\bar{f}V$ can be important (even dominant).

• We have searched in the Fermi-LAT data for a signal from DM DM $\rightarrow f\bar{f}\gamma$. the limits are fairly stringent and are only one-two orders of magnitude above the cross sections expected from thermal production. In fact, we already find a hint for a signal at $m_\chi \simeq 149$ GeV.

• Interesting interplay between direct detection limits, antiproton limits, gamma-ray limits and collider limits in the case that the dark matter particle couples to light quarks.

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Thank you for your attention!