DM @ LEP

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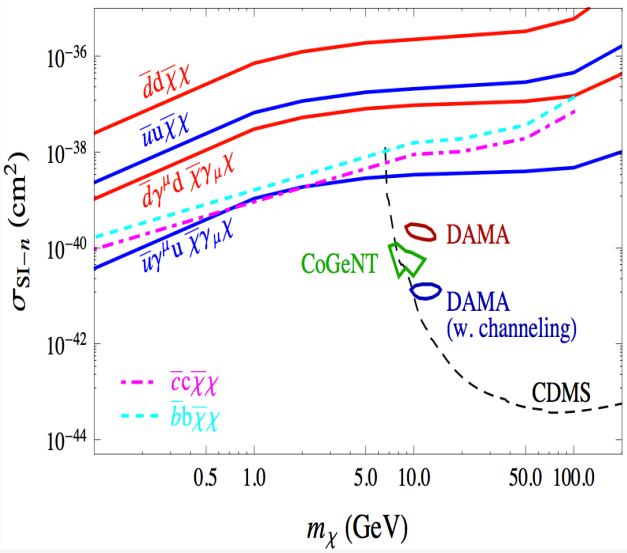
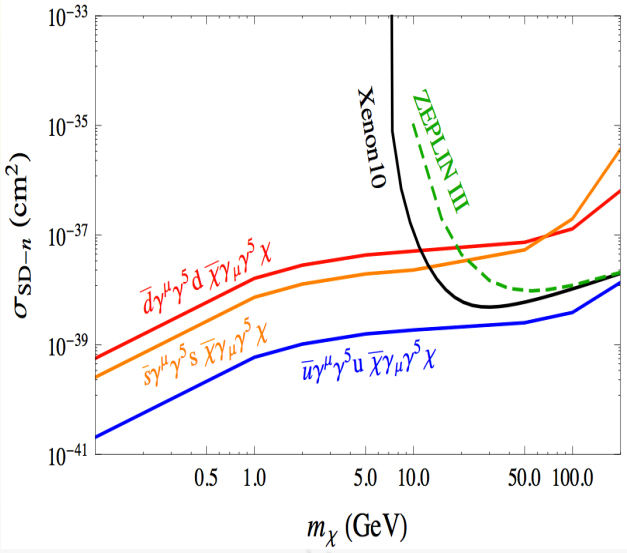
Cornell University

Fermilab

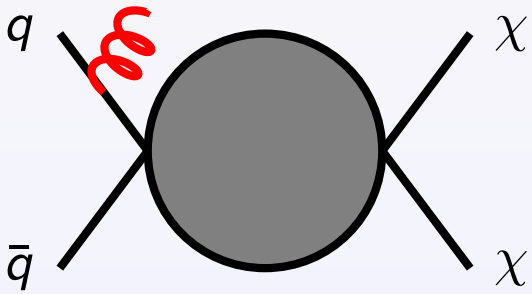
Earlier result: Bounds from Tevatron

Y. Bai et al. (10), J. Goodman et al. (10), J. Goodman et al. (11)

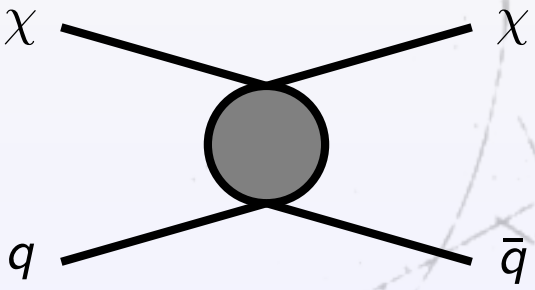




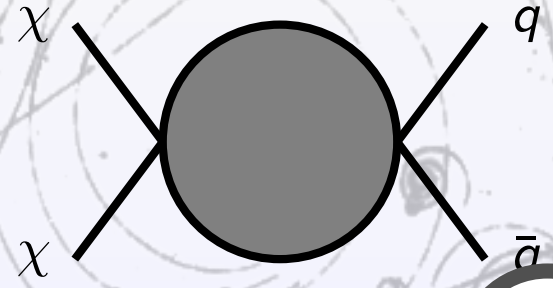
Collider



Direct

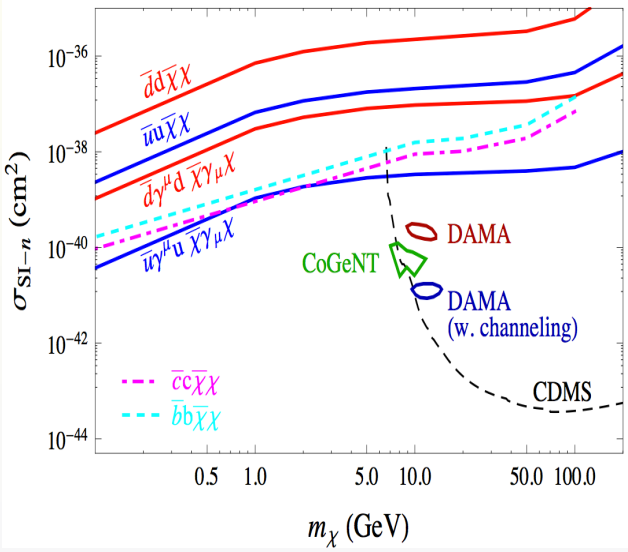


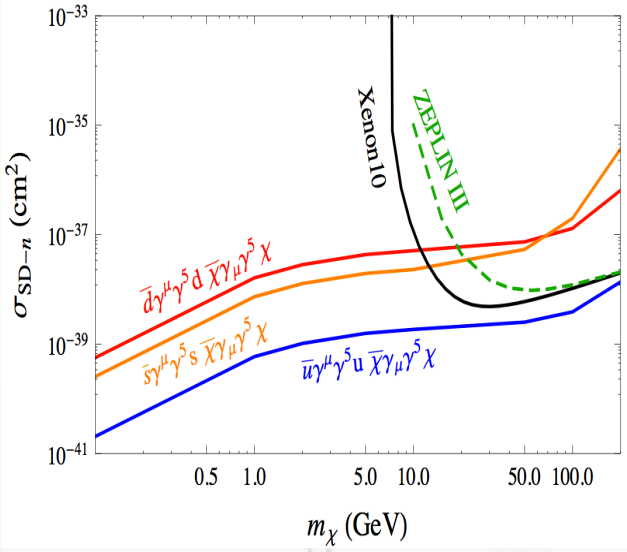
Indirect



Direct Detection Bound from Tevatron

Y. Bai et al. (10), J. Goodman et al. (10), J. Goodman et al. (11)

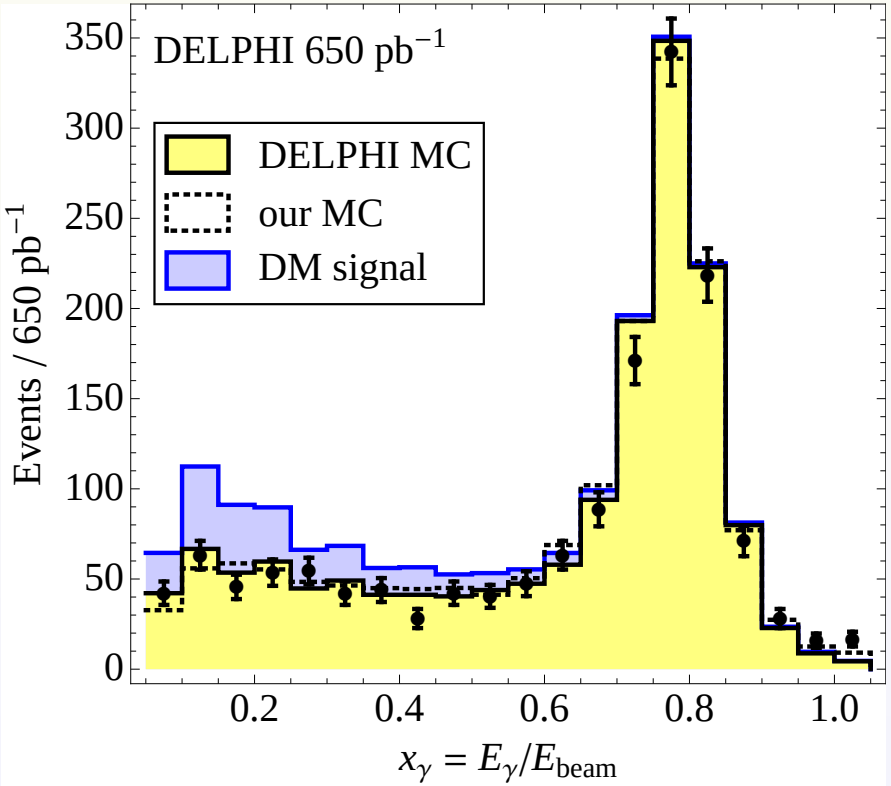




- independent of astrophysical and experimental assumptions.
- good bounds on light DM.
- good bounds on spin dependent case.

Jet $\rightarrow$ Photon, Tevatron $\rightarrow$ LEP

- In search of Large Extra Dimension (ADD)
- New physics channels: $e\,\bar{e} \rightarrow \gamma\, G$

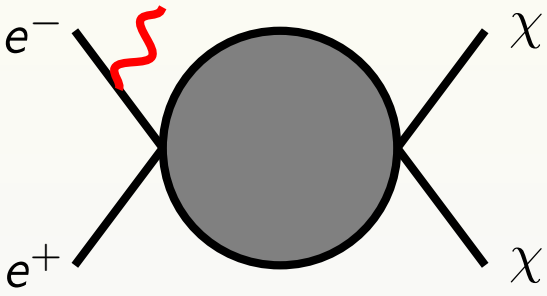


- Experiment: DELPHI
- $E_{\rm beam}$: $90 - 105$ GeV
- Use the cuts in [1], ($E_\gamma \gtrsim 10\mathrm{GeV}$).
- Background: $e^+e^- \rightarrow \gamma\nu\bar{\nu}$
- We use CompHEP.

[1] DELPHI Collaboration, hep-ex/0406019.

Direct Detection Bound

- Assume DM particle is a Dirac fermion.
- Use shape analysis (χ^2) to contraint the size the coupling



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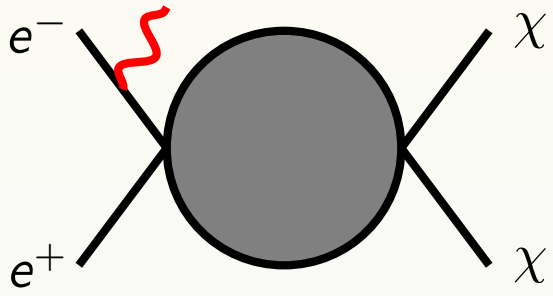

Need the coupling to quarks!

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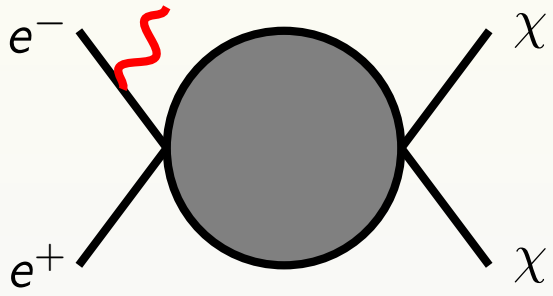
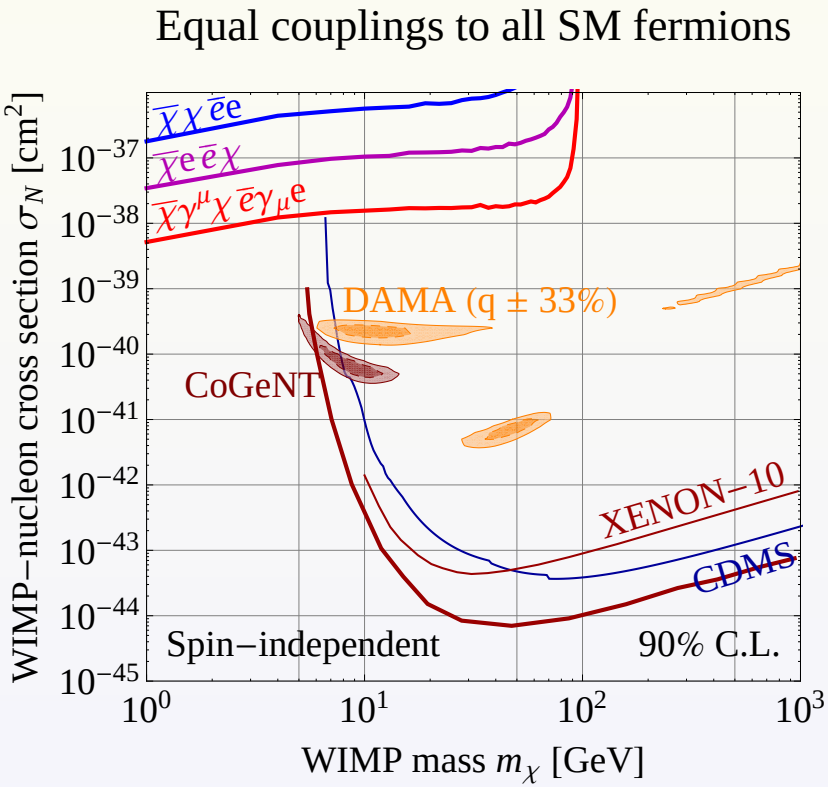


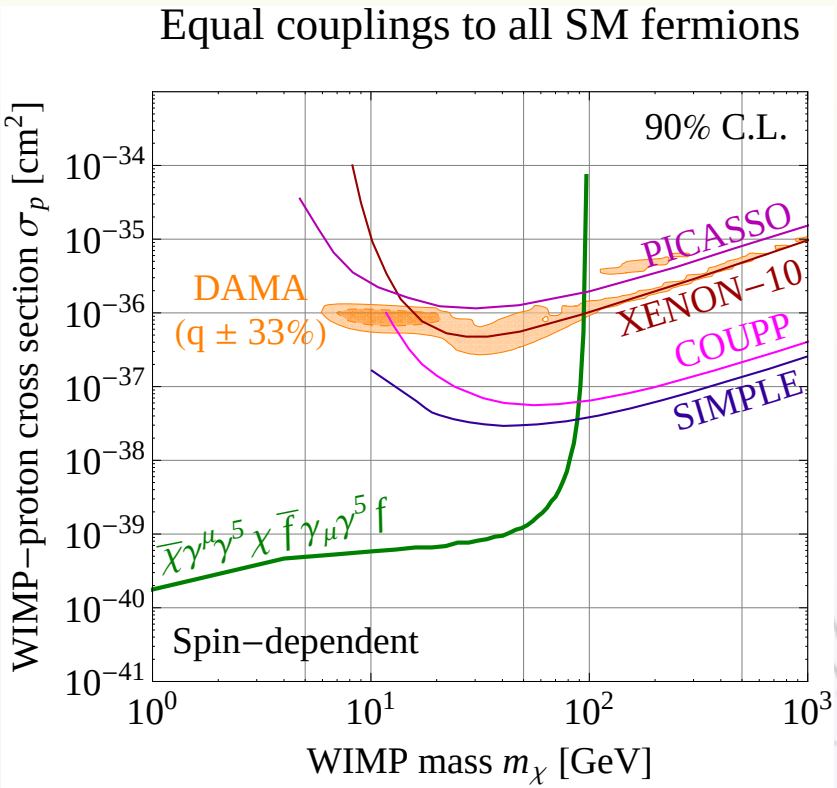
Need the coupling to quarks!

Consider Two Possibilities:

- Equal Coupling: to quarks and leptons.
- Leptophilic: coupling to leptons only.

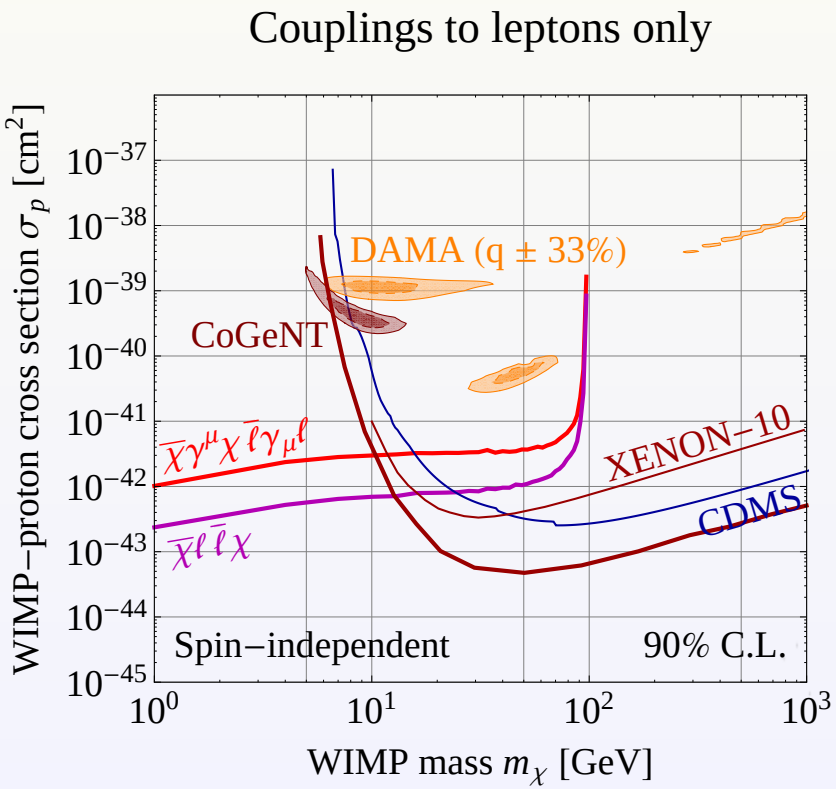
Equal couplings

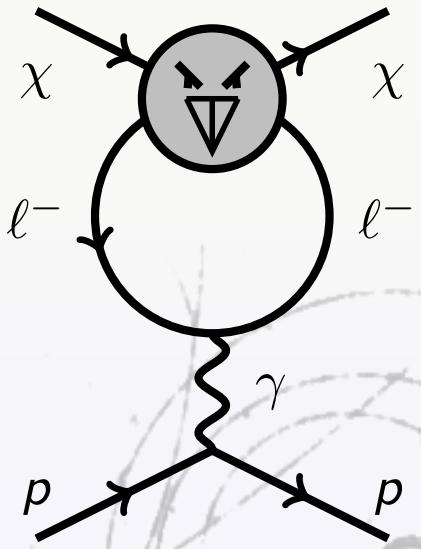




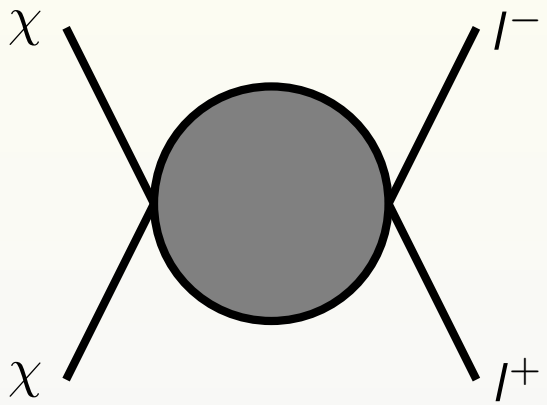
Leptophilic: no tree-level coupling to q's

- Get loop suppression. $\mathcal{O}_A$, $\mathcal{O}_S$ vanish at one loop.
- Leptophilic model proposed to explain DAMA or CoGeNt is ruled out.



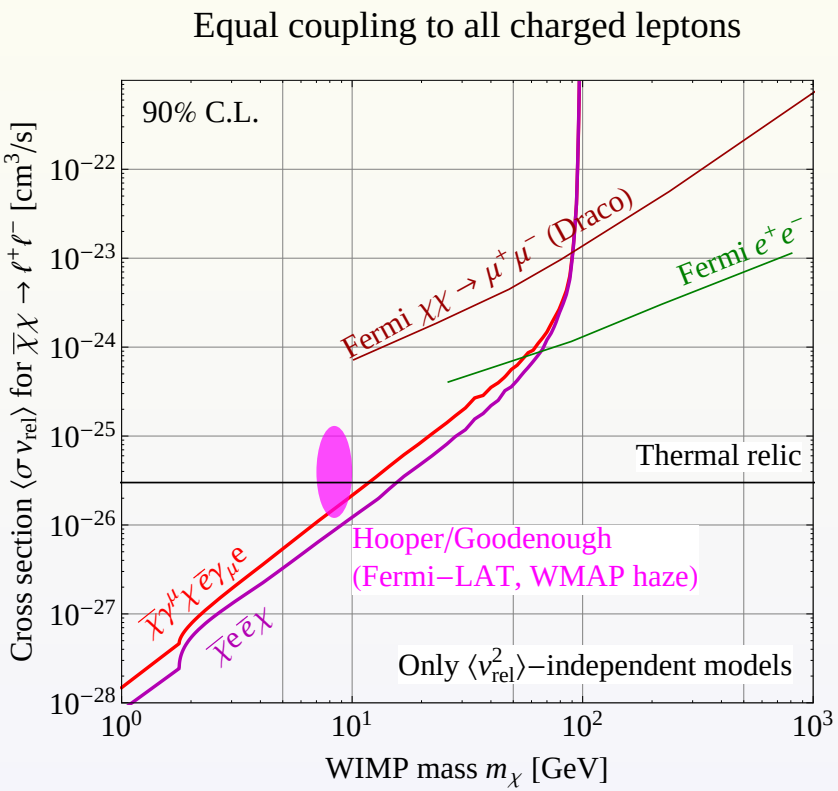


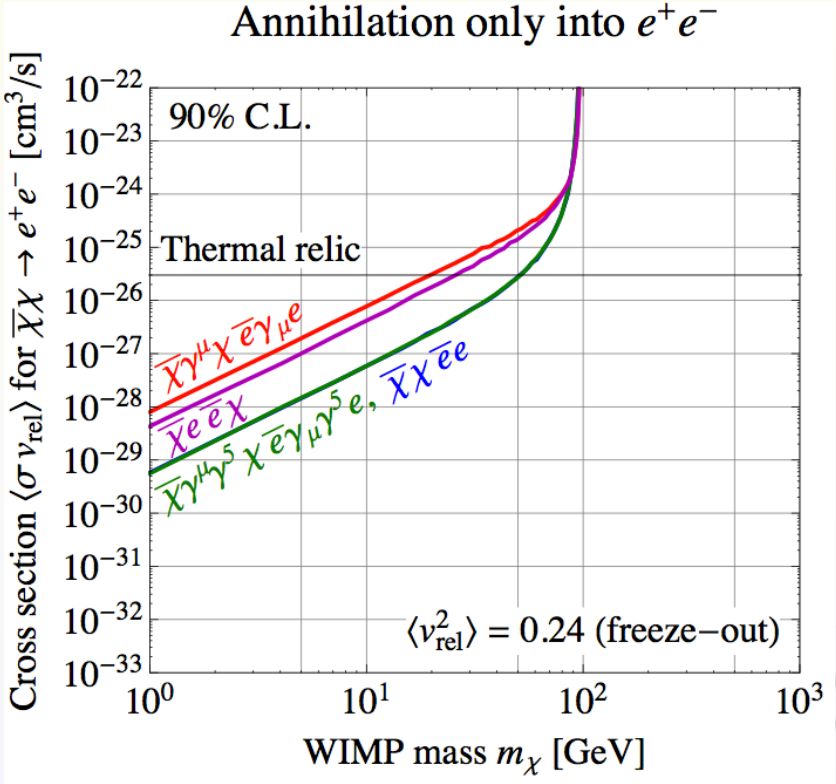
Bounds for Indirect Detections



- Velocity suppression for scalar and axial-vector operators.
- Compare the cross section to the thermal-relic or the Fermi observation bounds.

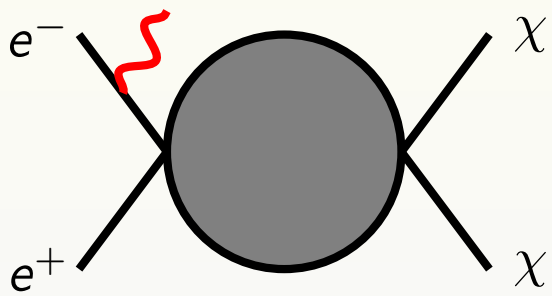
Bounds for Indirect Detections

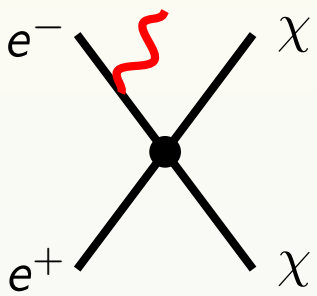




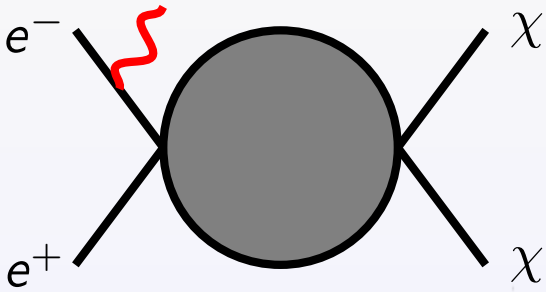
What happens if the mediator is light?

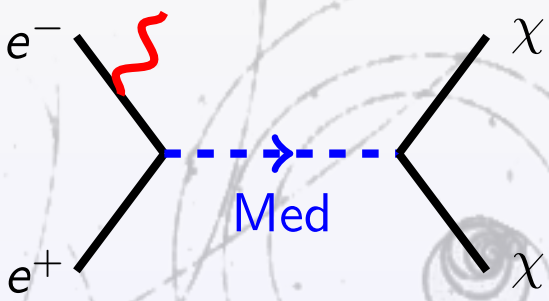
- When it is heavy, we consider contact operators only:
  $m_{\rm Med} \gg 2\,E_{\rm beam}$



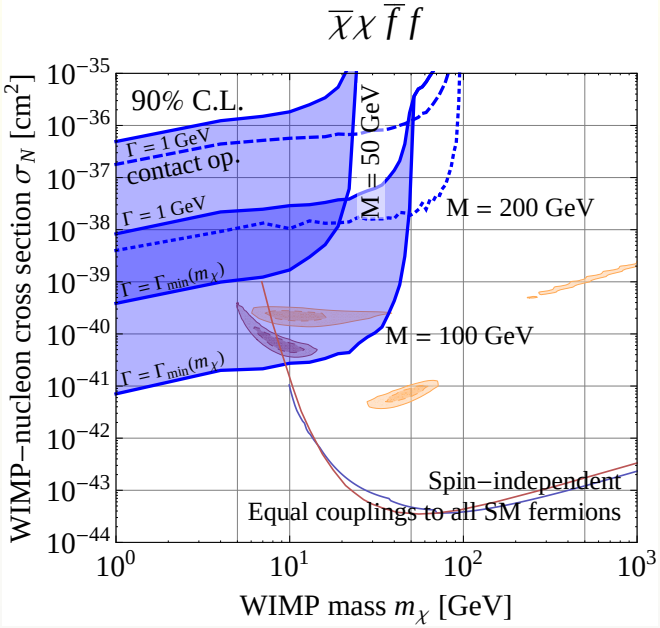


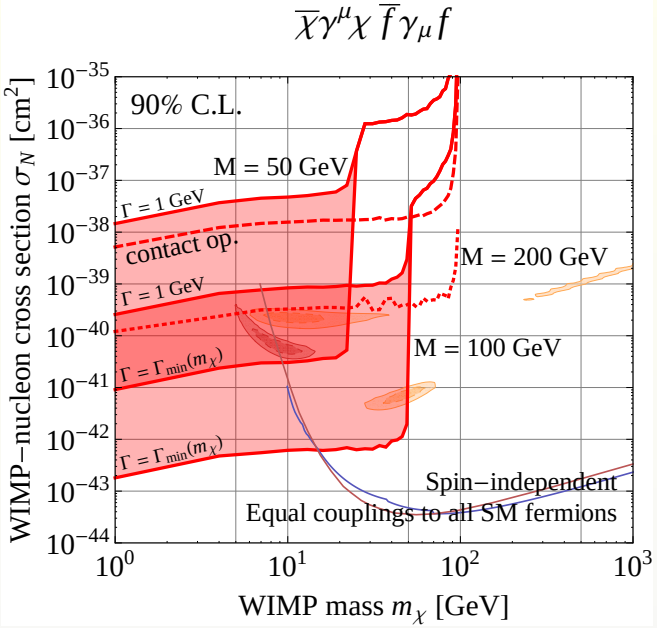
- When it can be on-shell, the kinematics is important:
  $m_{\rm Med} \ll 2\,E_{\rm beam}$

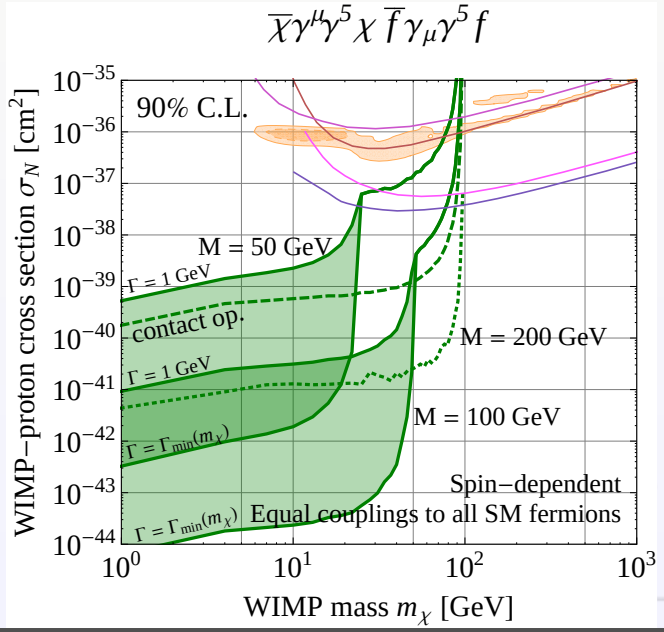


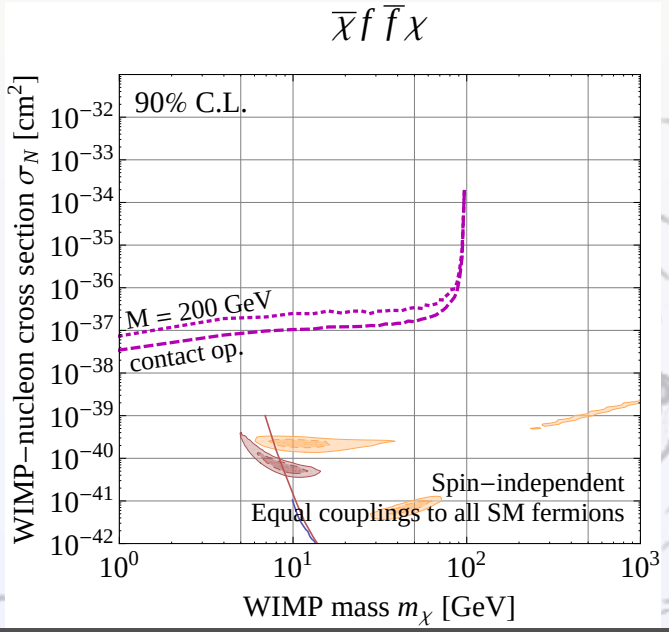


Direct Detection w/ light mediator

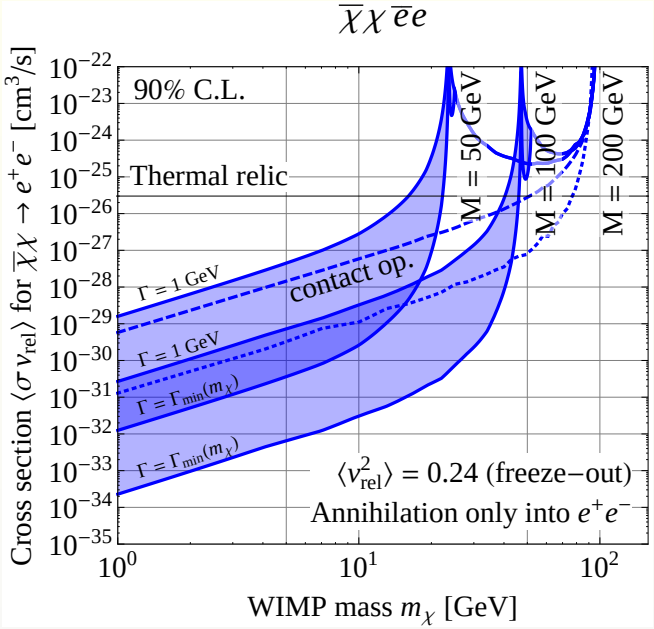


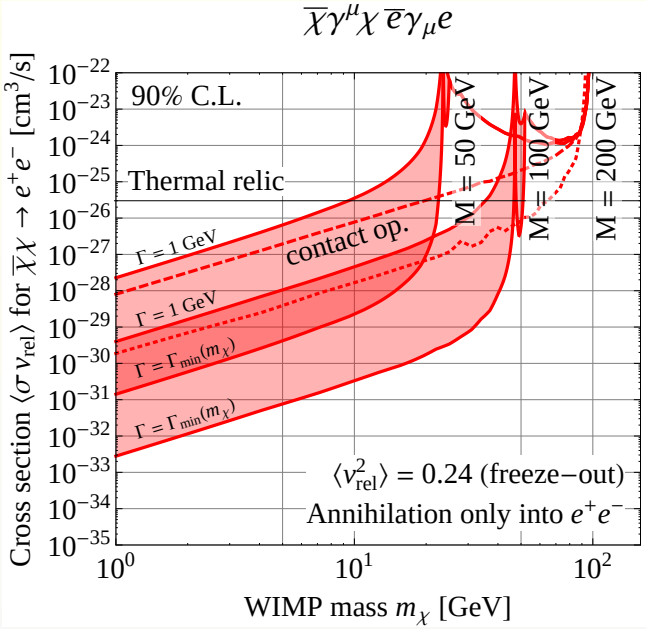


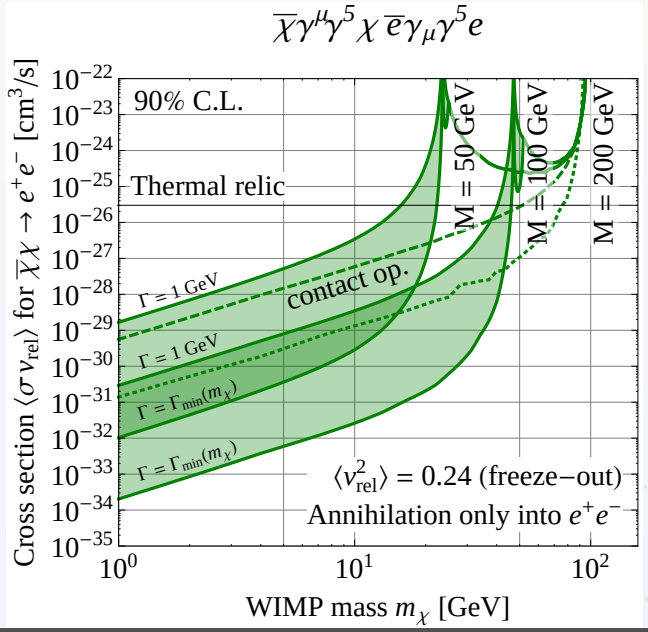


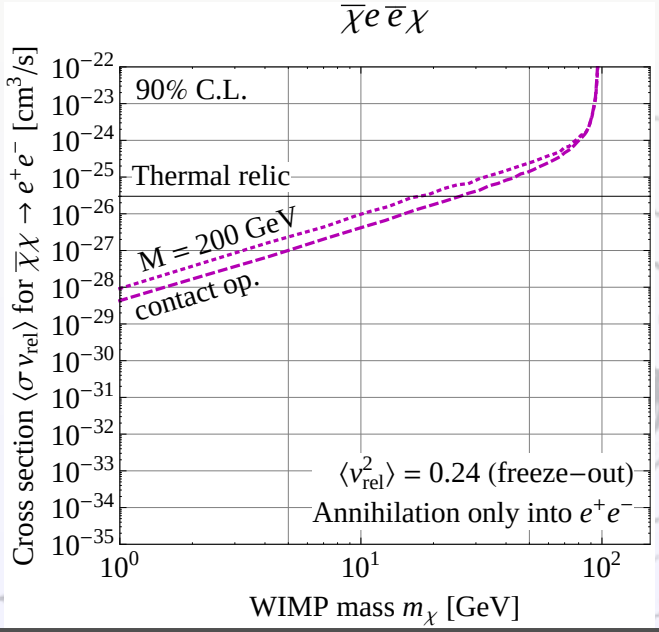


Indirect Detection w/ Light Mediators



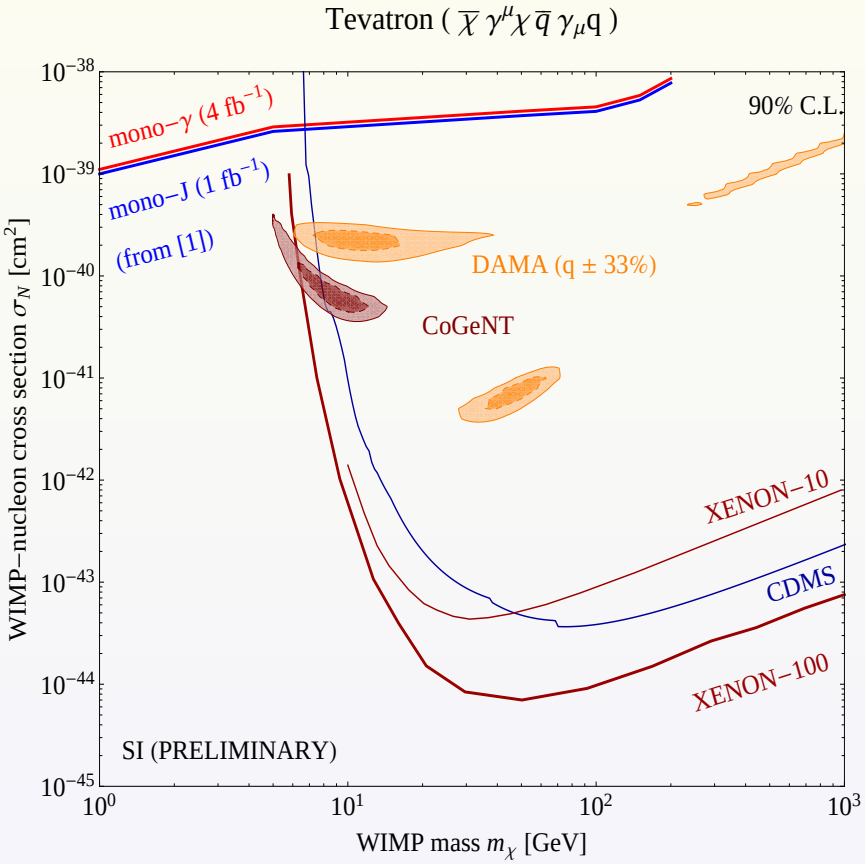


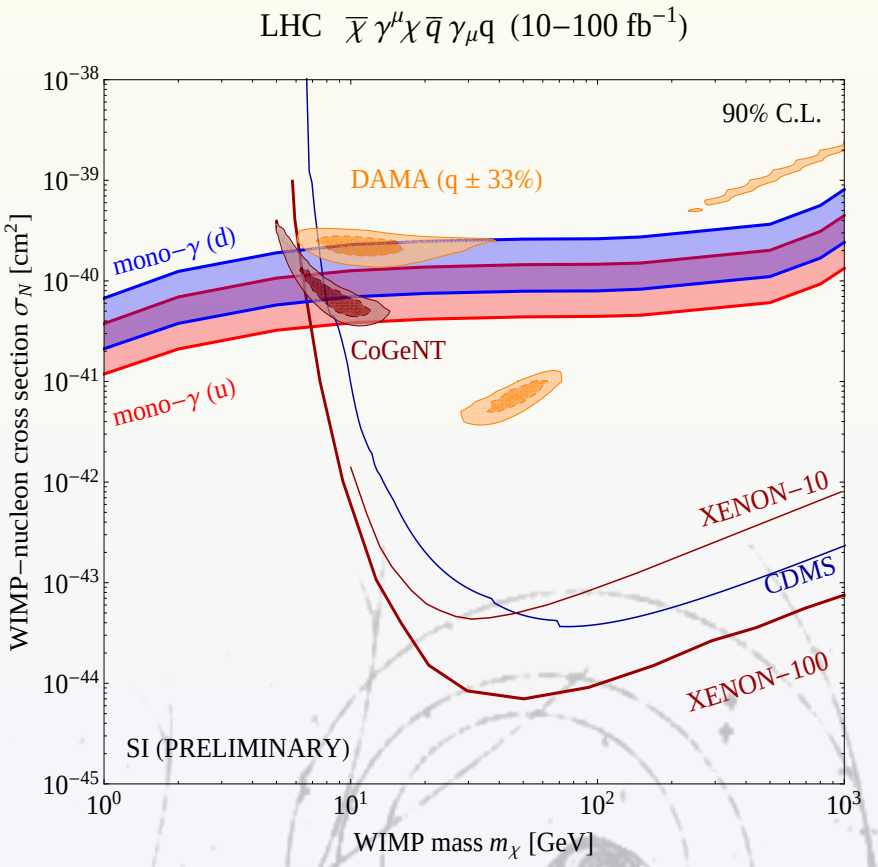




Some Non-LEP Results

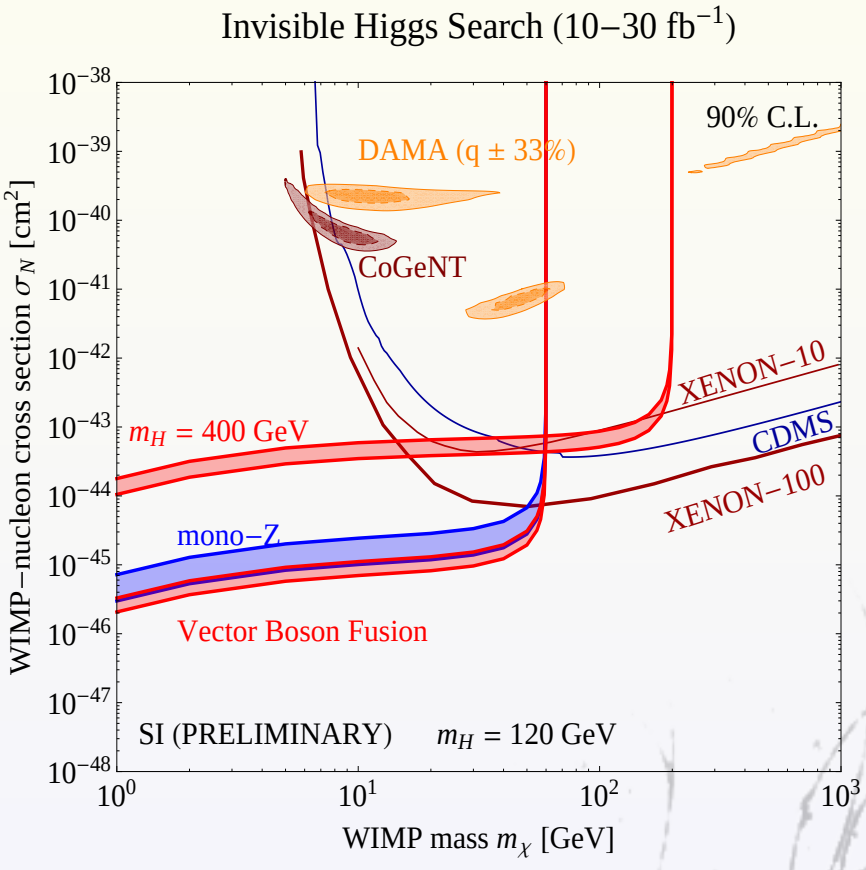
MonoPhoton @ Tevatron and LHC





[1] Y. Bai, P. J. Fox, and R. Harnik, **JHEP 12**, 048 (2010)

MonoPhoton @ Tevatron and LHC



Conclusion

- Mono-photon at LEP is important for direct detection bound.
- LEP bound gives good constrains on indirect detections.
- The bounds can be even more important for light mediators.

From raw data to direct detection bounds

$$\frac{d\,R}{d\,E_R} = N_T\,\frac{\rho_0}{m_\chi}\int_{v_{\rm min}}^{v_{esc}} d^3v\,\frac{d\,\sigma}{d\,E_R}\,v\,f(v)$$

- DM density $\rho_0 \sim 0.3\,\mathrm{GeV\,cm^{-3}}$
- Recoil energy $E_{\rm R} = E_{\rm obv}$ / quenching $q_{\rm Na} = 0.3 \pm 0.1$, $q_{\rm I} = 0.09 \pm 0.03$
- Velocity distribution $f(v)$ Maxwell-Boltzman
- Escape velocity $v_{\rm esc} \sim 650\,\mathrm{km\,s^{-1}}$
- $v_{\rm min}$, (in-)elastic scattering?
- Spin Independent σ, Spin Dependent $\sigma(v)$.
- XXXX

Annihilation cross sections

σ_S and σ_A are velocity suppressed:

$$
\begin{aligned}
\sigma_S v_{rel} &= \beta\,(m_\chi^2 - m_\ell^2)\, v_{rel}^2 \,, \\
\sigma_V v_{rel} &= \frac{1}{6}\beta\left(24(2m_\chi^2 + m_\ell^2) + \frac{8m_\chi^4 - 4m_\chi^2 m_\ell^2 + 5m_\ell^4}{m_\chi^2 - m_\ell^2}\, v_{rel}^2\right) \,, \\
\sigma_A v_{rel} &= \frac{1}{6}\beta\left(24 m_\ell^2 + \frac{8m_\chi^4 - 22m_\chi^2 m_\ell^2 + 17m_\ell^4}{m_\chi^2 - m_\ell^2}\, v_{rel}^2\right) \,, \\
\sigma_t v_{rel} &= \frac{1}{24}\beta\left(24(m_\chi + m_\ell)^2 + \frac{(m_\chi + m_\ell)^2(8m_\chi^2 - 16 m_\chi m_\ell + 11 m_\ell^2)}{m_\chi^2 - m_\ell^2}\, v_{rel}^2\right) \,, \\
\beta &= \frac{1}{8\pi\Lambda^4}\sqrt{1 - \frac{m_\ell^2}{m_\chi^2}} \,.
\end{aligned}
$$

Few remarks about the loop calculation

(show this if people stay awake)

The loop-suppressed cross section is

$$\sigma_{1-\mathrm{loop}} \simeq \frac{4\alpha^2\mu_p^2}{18^2\pi^3\Lambda^4} \cdot \left[\sum_{\ell=e,\mu,\tau} f(q^2, m_\ell)\right]^2$$

where $f(q^2, m_\ell) =$

$$\frac{1}{q^2}\left[5q^2+12m_\ell^2+6(q^2+2m_\ell^2)\sqrt{1-\frac{4m_\ell^2}{q^2}}\coth^{-1}\left(\sqrt{1-\frac{4m_\ell^2}{q^2}}\right)-3q^2\ln\left(\frac{m_\ell^2}{\Lambda_{\mathrm{ren}}{}^2}\right)\right]$$

- Take the most conservative case (the largest σ): $v_\chi = v_{\mathrm{esc}} = 500$ km/sec, scattering angle 180°.
- This gives $q^2 = -4\mu_p^2 v_\chi^2$.
- Take the cutoff Λ_{ren} from the loop integral the same as the operator cutoff Λ.

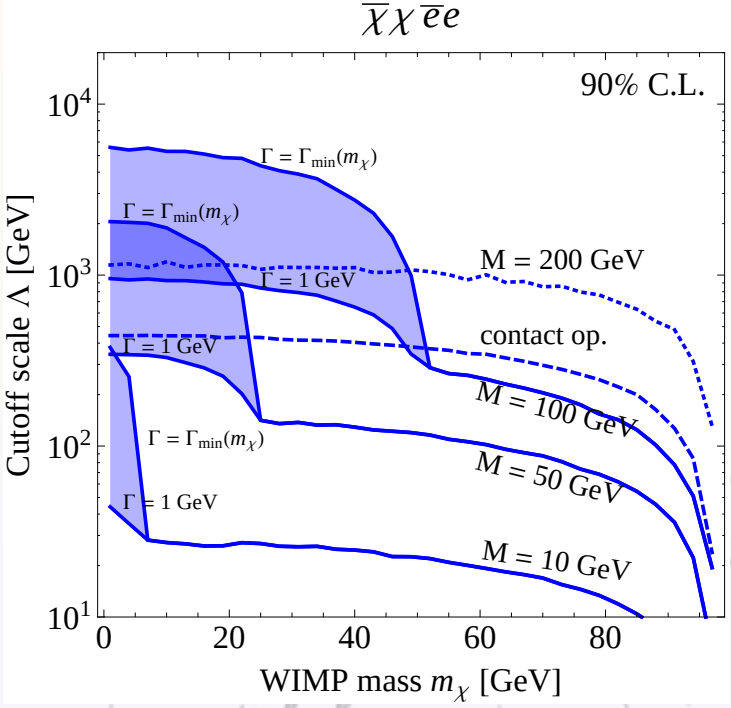
Direct Detection bounds w/ light mediator

$$\mathcal{A} \propto \frac{g_e\, g_\chi}{q^2 - M^2 + iM\Gamma} = \frac{M^2}{q^2 - M^2 + iM\Gamma}\frac{g_e\, g_\chi}{M^2} \equiv (R \times \Lambda)^{-2} = \Lambda_{\rm exp}{}^{-2}.$$

Λ: the cutoff in the plot. $\Lambda_{\rm exp}$: the collider constrained cutoff.

S-channel

- $M \gg 2E_{\rm beam}$: $\Lambda = \Lambda_{\rm exp}$.
- $M > 2E_{\rm beam}$: $\Lambda \sim \frac{M}{\sqrt{M^2 - q^2}}\Lambda_{\rm exp}$.
- $2m_\chi < M < 2E_{\rm beam}$: $\Lambda \sim \left(\frac{M}{\Gamma}\right)^{\frac{1}{4}}\Lambda_{\rm exp}$.
- $M < 2m_\chi$: $\Lambda \sim \frac{M}{\sqrt{q^2 - M^2}}\Lambda_{\rm exp}$.



T-channel

- For any M: $\Lambda = \frac{M}{\sqrt{|q|^2 + M^2}}\Lambda_{\rm exp}$.

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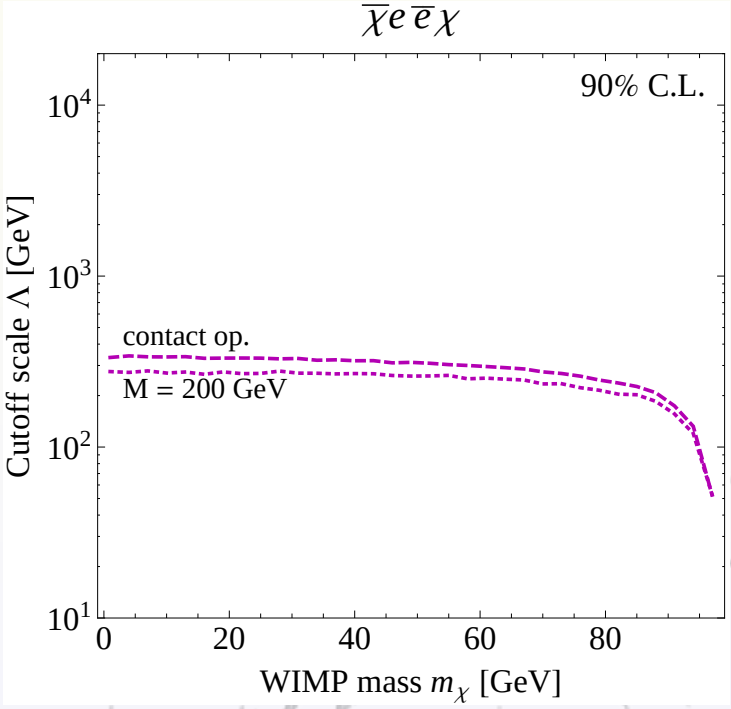

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