LEP Constraints & The Bounds on DM/Higgs Coupling

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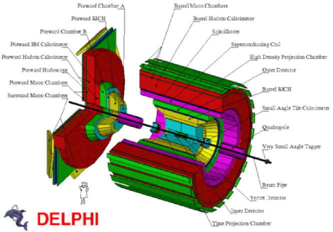
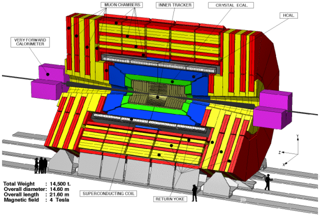
Cornell University

In collaboration with Patrick Fox, Roni Harnik, and Joachim Kopp

DM in Collision, UC Davis, 12 April 2012

MonoPhoton @ LEP

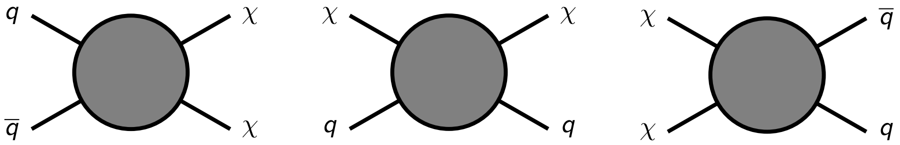




P. J. Fox, R. Harnik, J. Kopp, and YT, 1103.0240

Effective coupling description

Collider Direct Indirect



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

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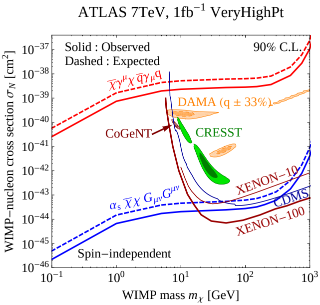

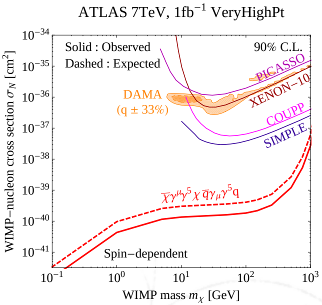

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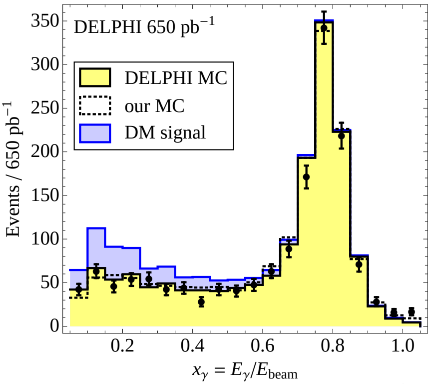
Mono-photon search at LEP

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

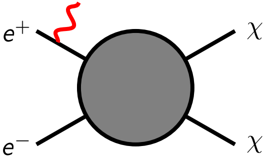


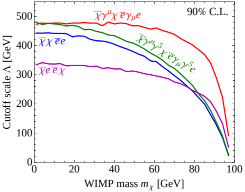
- Experiment: DELPHI
- E_{beam}: 90 – 105 GeV
- Use the cuts in [1], ($E_\gamma \gtrsim 10\text{GeV}$).
- Background: $e^+e^- \to \gamma\nu\bar{\nu}$
- We use CompHEP.

[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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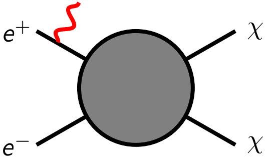

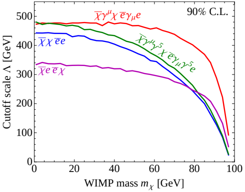

Need the coupling to quarks!

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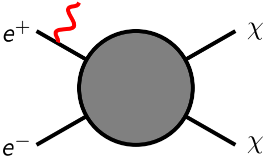
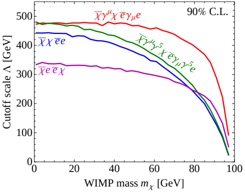


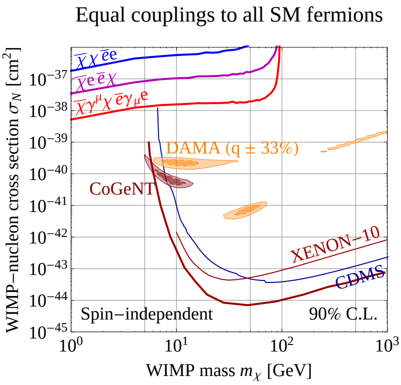


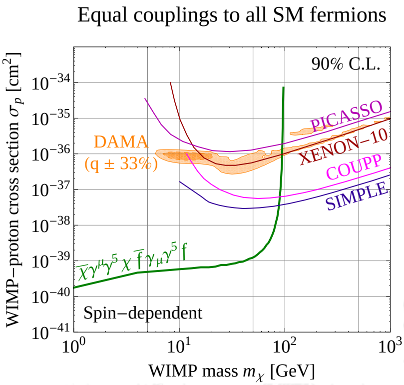
Need the coupling to quarks!

consider two possibilities:

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

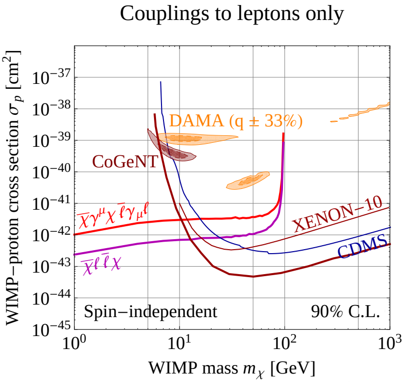
Equal couplings

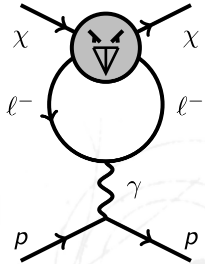




Leptophilic: no tree-level coupling to q's

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

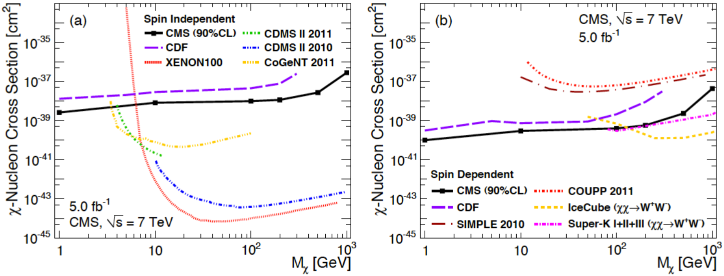




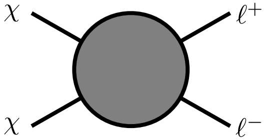
MonoPhoton at LHC

The CMS MonoPhoton search: arXiv:1204.0821

CMS Result: 73 (75.1 ± 9.4)



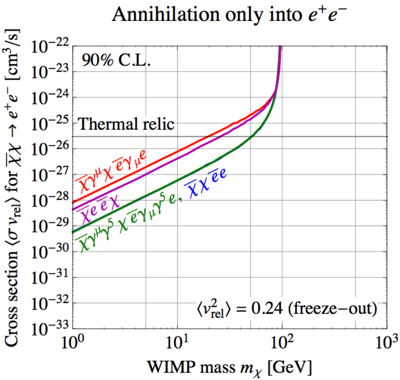
Bounds for Indirect Detections

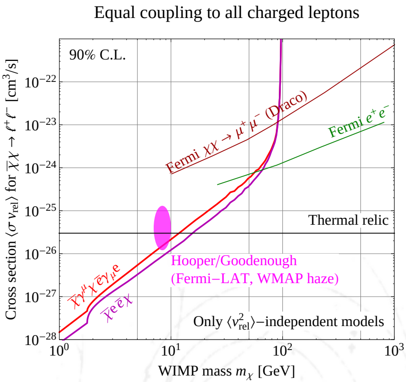


Two things we can compare to:

- Thermal-relic bound
- Fermi observation bounds.

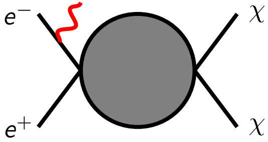
Bounds for Indirect Detections



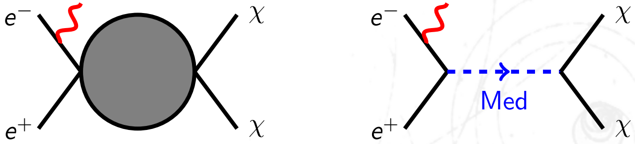


What happens if the mediator is light?

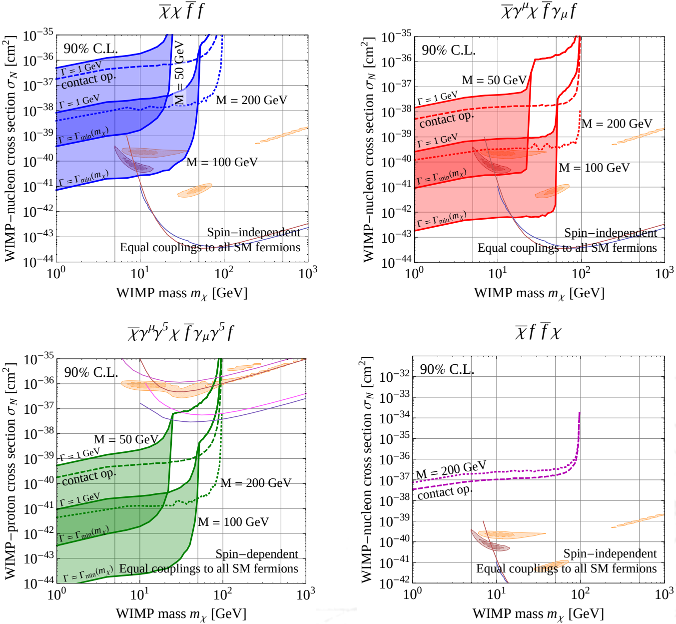
- When it is heavy, we consider contact operators only:
  $m_{\mathrm{Med}} \gg 2\,E_{\mathrm{beam}}$



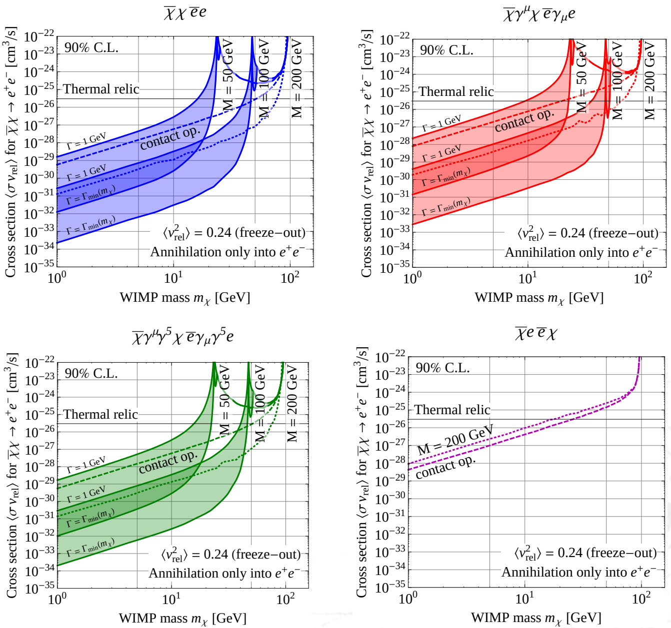
- When it can be on-shell, the kinematics is important:
  $m_{\mathrm{Med}} \ll 2\,E_{\mathrm{beam}}$



Direct Detection with light mediator



Indirect Detection with Light Mediators



DM coupling to Higgs

Based on: P. Fox et al. 1109.4398

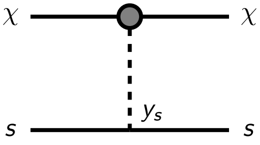
See also:

M. Pospelov et al. 1109.4872; I. Low et al. 1110.4405; C. Englert et all. 1111.1719; O. Lebedev et al. 1111.4482; A. Djouadi et al. 1112.3299.

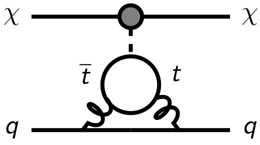
Direct detection through the Higgs portal

Benefits from the additional suppressions

yukawa suppression



loop suppression



Get the $\chi - h - \chi$ bound from:

Direct detection through the Higgs portal

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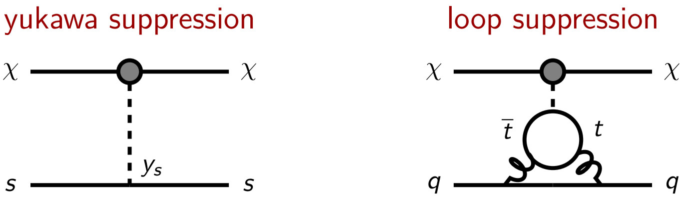

Get the $\chi - h - \chi$ bound from:

- mono-jet search? $\Rightarrow$ light mediator, not good.

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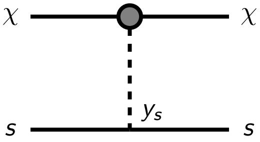

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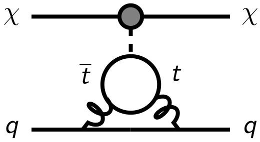
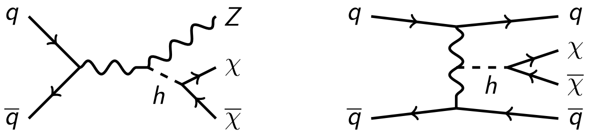
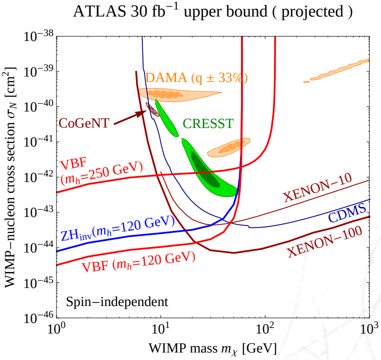


Get the $\chi - h - \chi$ bound from:

- mono-jet search? $\Rightarrow$ light mediator, not good.
- other higgs searches? e.g. invisible Higgs search.

Invisible-higgs search at LHC : Future bounds

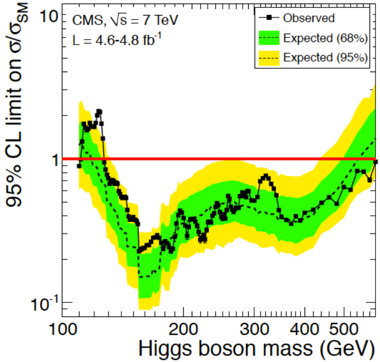


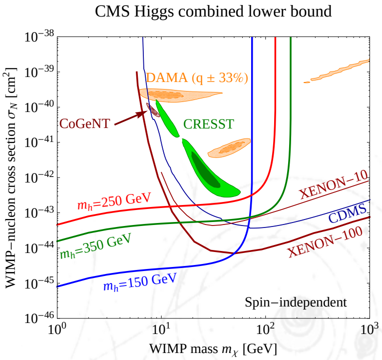


Invisible-higgs search at LHC : Current bounds

Current LOWER bounds under the assumption:

- Higgs was missed at LHC due to its large invisible width.





Conclusion

Mono-photon search at LEP gives:

- important direct detection bounds
- good constrains on indirect detections
- interesting bounds for light mediators

Direct detection bounds for DM coupling through the Higgs:

- get upper bounds from the invisible Higgs search
- get lower bounds from the current Higgs search

From raw data to direct detection bounds

$$\frac{dR}{dE_R} = N_T \frac{\rho_0}{m_\chi} \int_{v_{\min}}^{v_{esc}} d^3v \frac{d\sigma}{dE_R} v f(v)$$

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

Annihilation cross sections

σ_S and σ_A are velocity suppressed:

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

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.

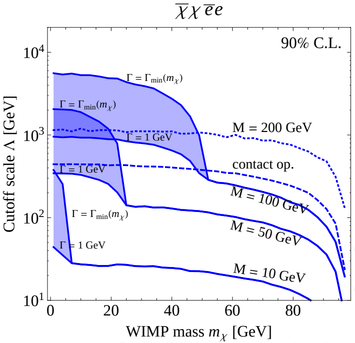
Direct Detection bounds w/ light mediator

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

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

Direct Detection bounds w/ light mediator

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