Higgs portal dark matter

and invisible width

Higgs Portal

- Second simplest model of WIMP dark matter
- Rich phenomenology: direct and indirect detection as well as collider signals possible
- Motivated: |H|^2 is lowest dimension SM singlet, so SM singlet dark matter may naturally couple to SM via this operator
- Dark matter could be scalar, fermion, or vector
- Simplest scalar case:

$$\Delta\mathcal{L}_{\mathrm{Scalar}} = -\frac{\lambda}{4} S^2 H^\dagger H$$

Burgess, Pospelov, ter Veldhuis, hep-ph/0011335

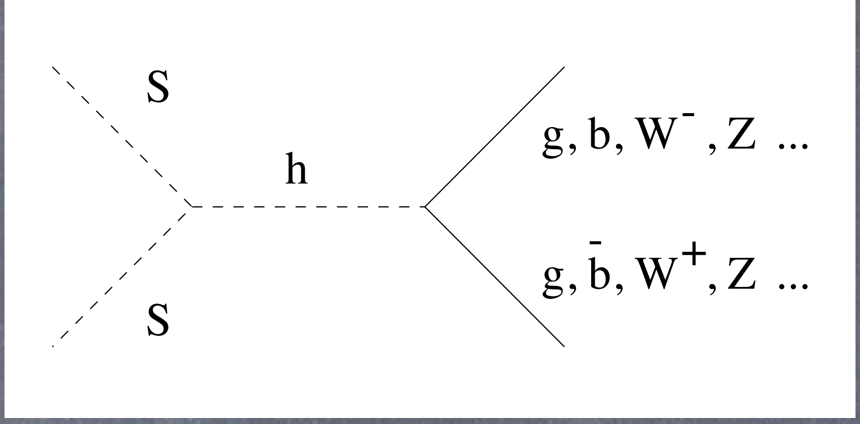
2 parameter model:

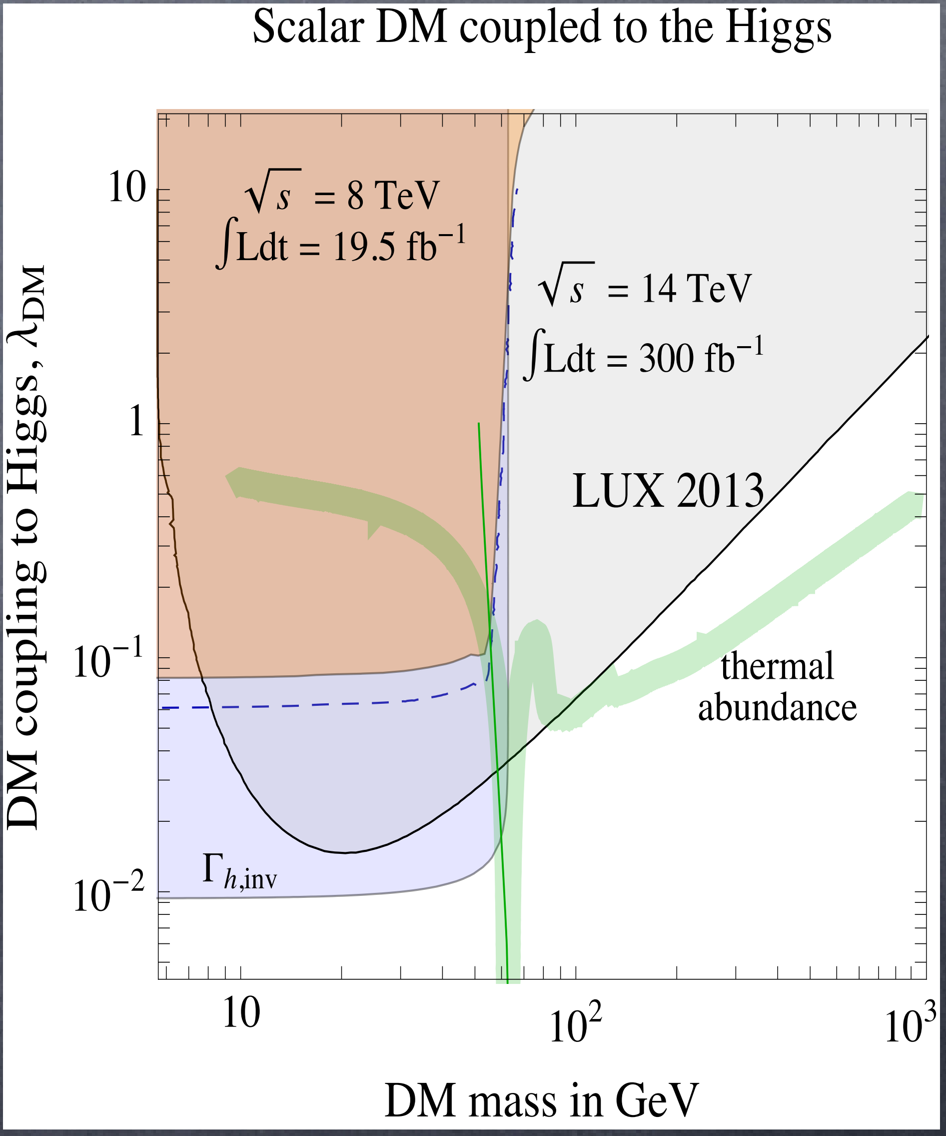
phenomenology fully determined by mass m_s and coupling λ

Higgs Portal: scalar case

- Dark matter annihilation proceeds via s-channel Higgs
- For given (m_s, λ) annihilation cross section is fixed
- Insisting on thermal abundance of dark matter fixes $\lambda(m_s)$
- For weak scale dark matter and order 0.1-1 coupling dark matter relic abundance in right ballpark

$$\Delta\mathcal{L}_{\text{Scalar}} = -\frac{\lambda}{4} S^2 H^\dagger H$$





de Simone, Giudice, Strumia
1402.6287

Higgs Portal: scalar case

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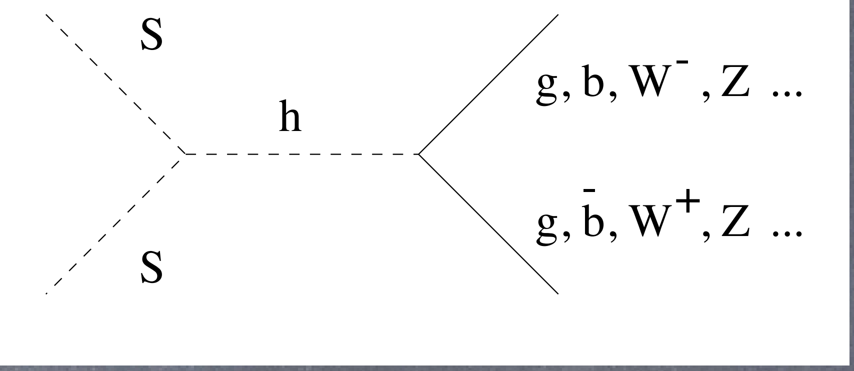
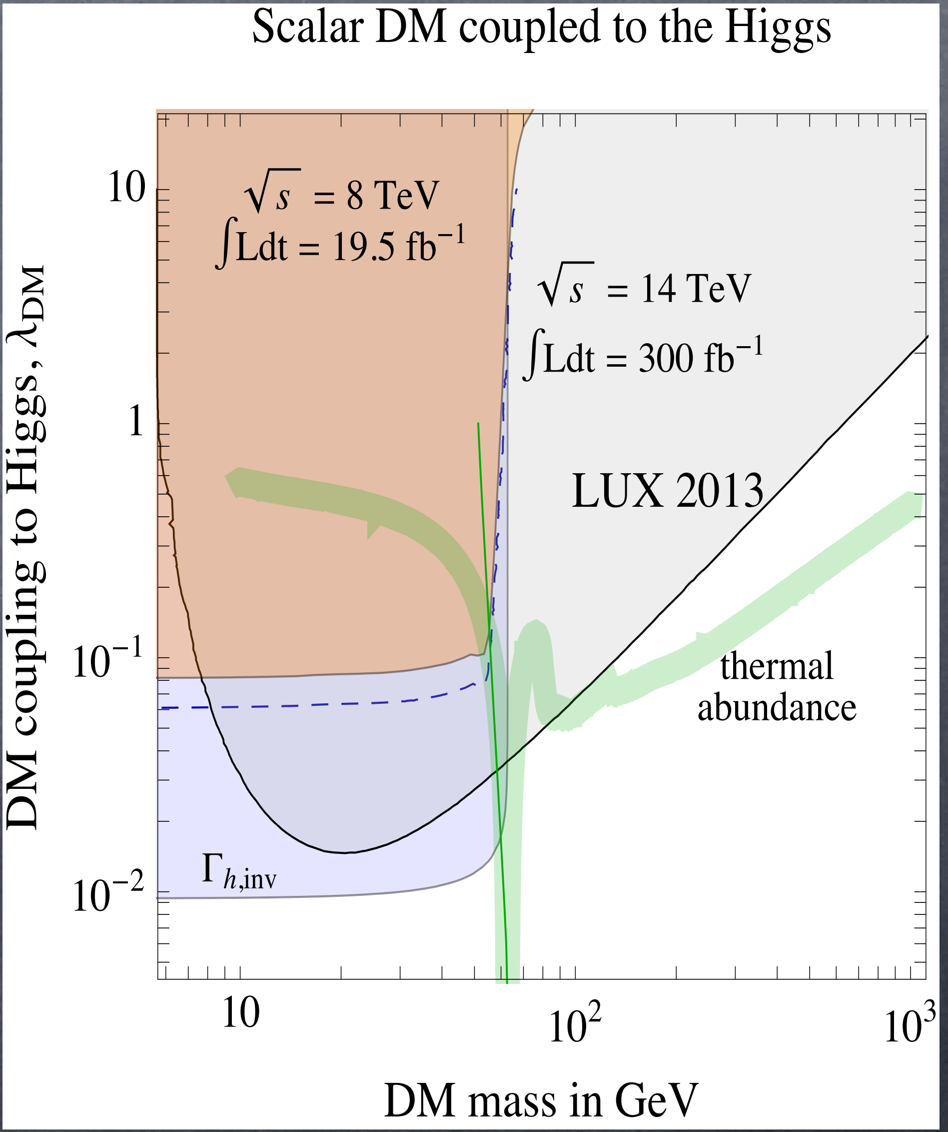


- For thermal abundance low mass dark matter region, $m_s < m_h/2$ excluded
- Actually, doubly excluded: by direct detection constraints and by Higgs invisible width



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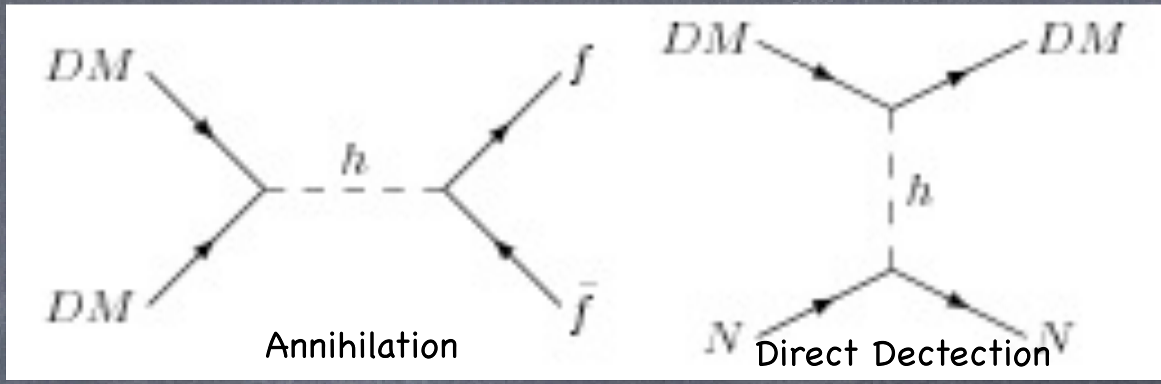
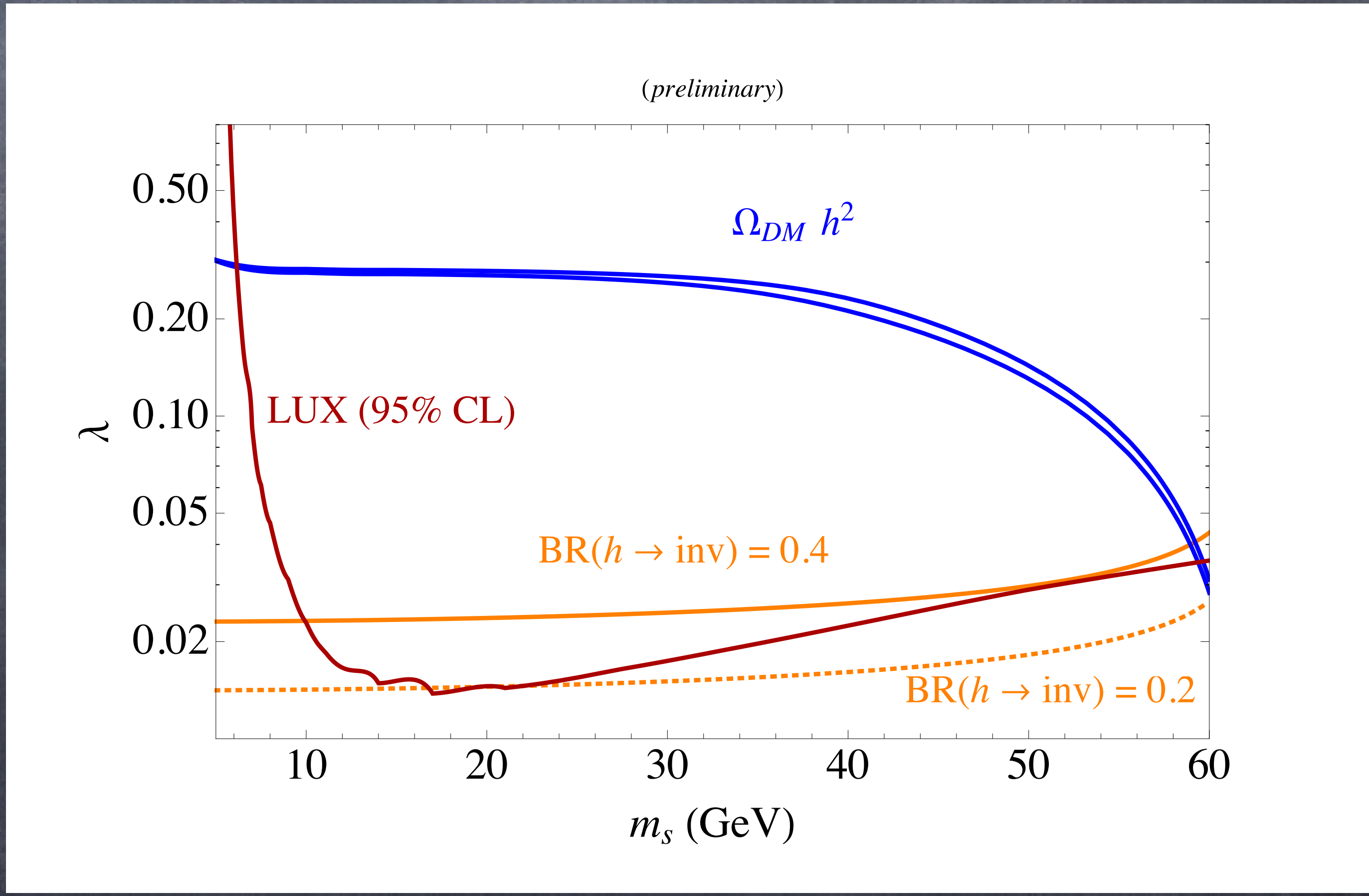
Higgs Portal: constraints from direct detection

$$c_1^N S^2 \bar{N} N$$

$$c_1^n \approx c_1^p = -0.45 \lambda_{\rm DM} \frac{m_N v}{M_h^2}.$$



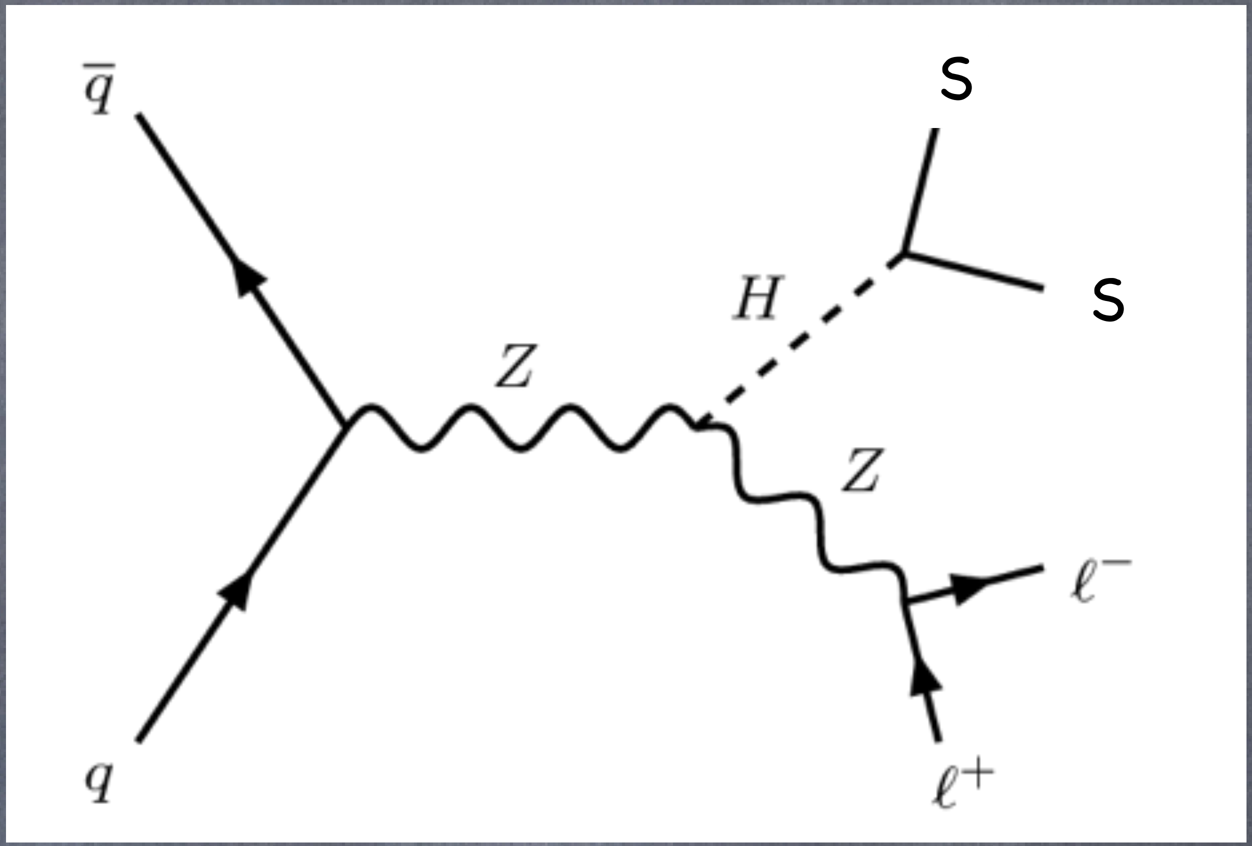
- Higgs exchange induces effective coupling of dark matter to nucleons
- For given (m_s, λ) scattering cross section on nucleons fixed
- For λ(m_s) fixed by thermal relic abundance, direct detection safely excluded for m_s >7 GeV



Jessie Shelton, private com

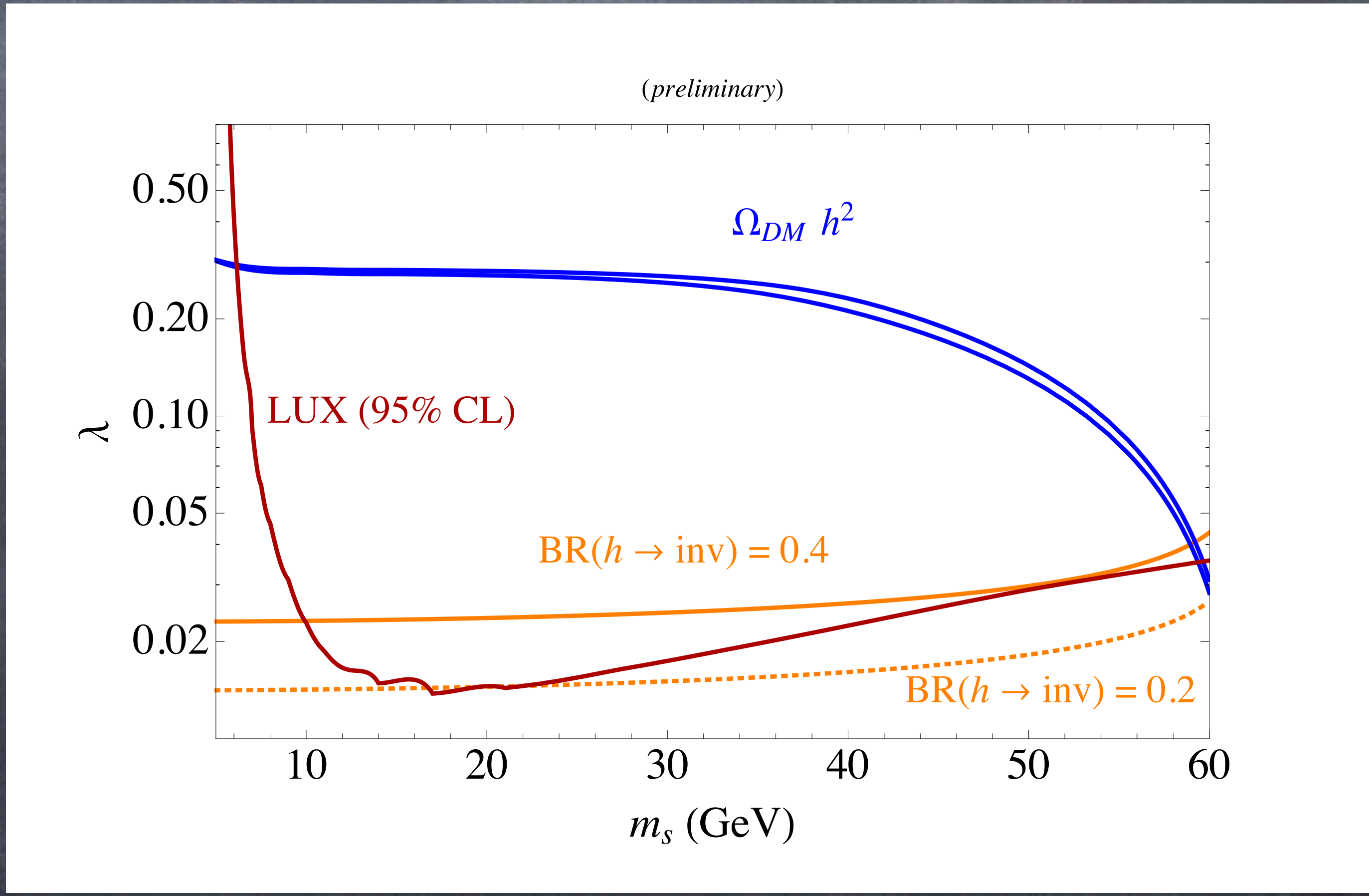
Higgs Portal: constraints from direct detection

- For $m_s < m_h/2$ Higgs can decay directly to dark matter, leading to invisible width
- Branching fraction is huge for thermal region of parameter space



$$\Gamma(h \to \text{invisible}) = \frac{\lambda^2 v^2}{64\pi m_h}\sqrt{1 - 4m_S^2/m_h^2}$$

$$\frac{\Gamma(h \to \text{invisible})}{\Gamma_h^{\text{SM}}} \approx \left(\frac{\lambda}{0.04}\right)^2$$



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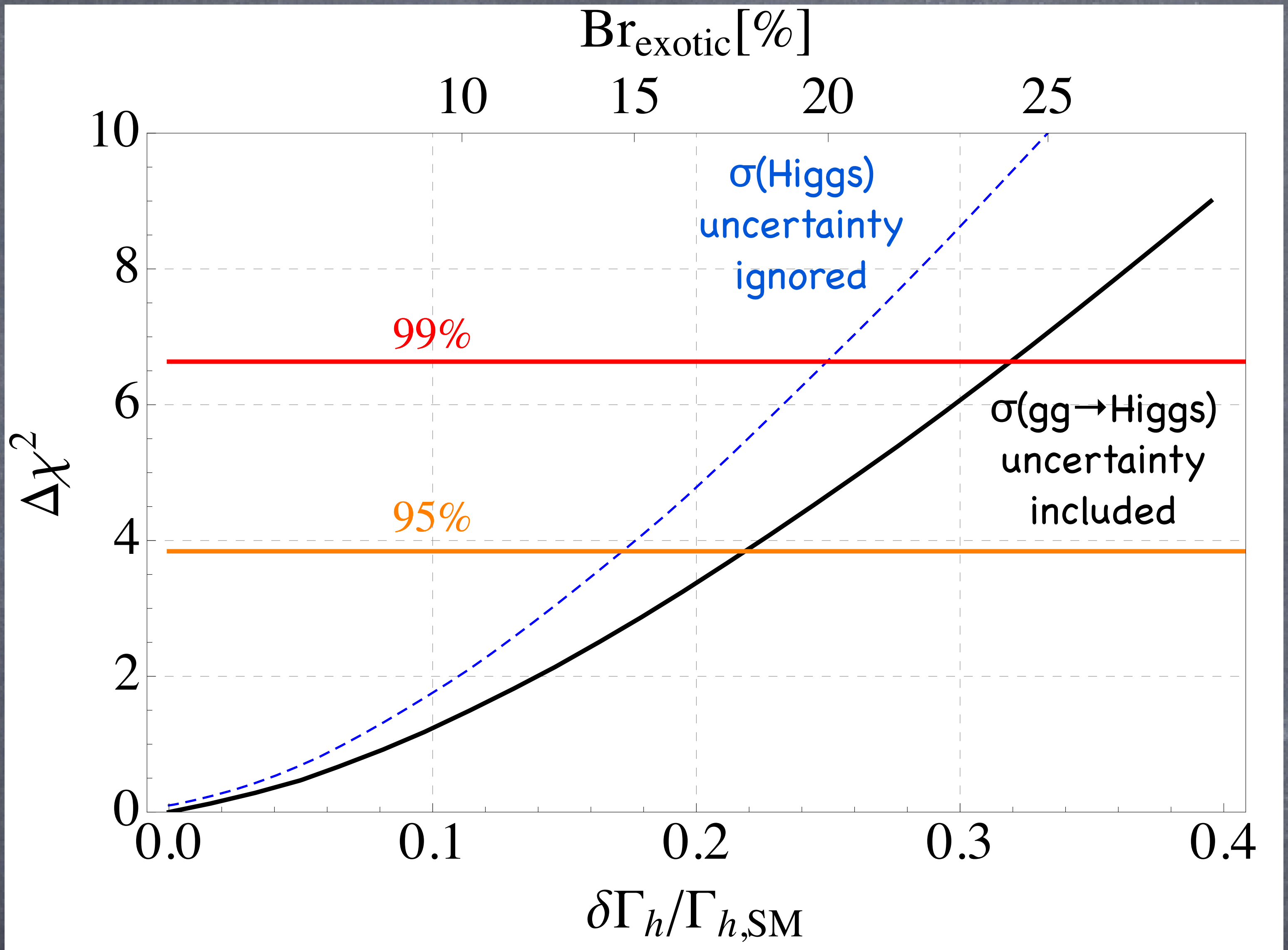
Limits on exotic Higgs branching fraction

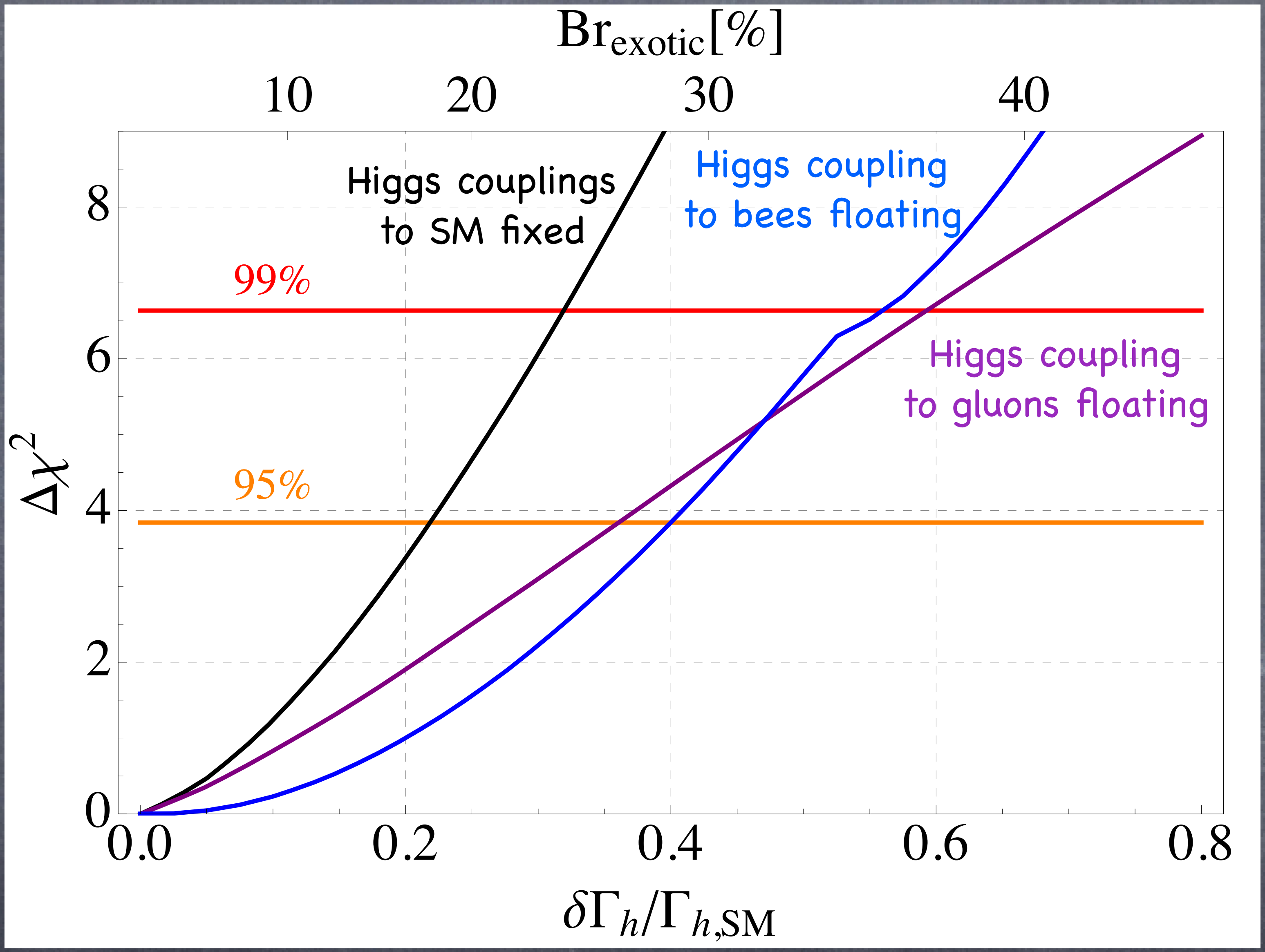
Assuming Higgs couplings to SM fixed



Br(h→exotic) ≲ 18% at 95% CL

Limits on exotic Higgs branching fraction

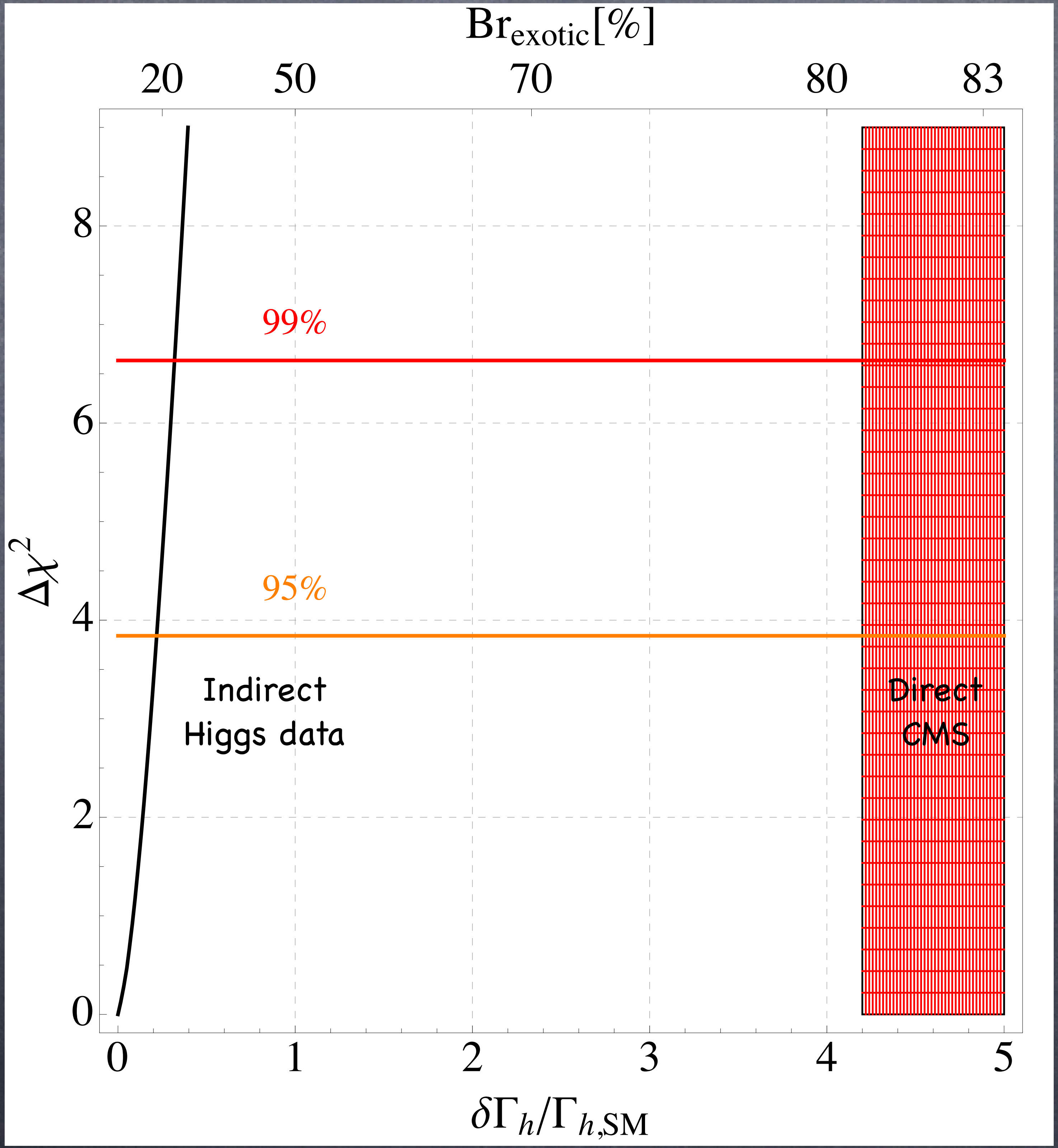
Allowing some Higgs couplings to SM to float



Br(h→exotic) ≲ 30% at 95% CL

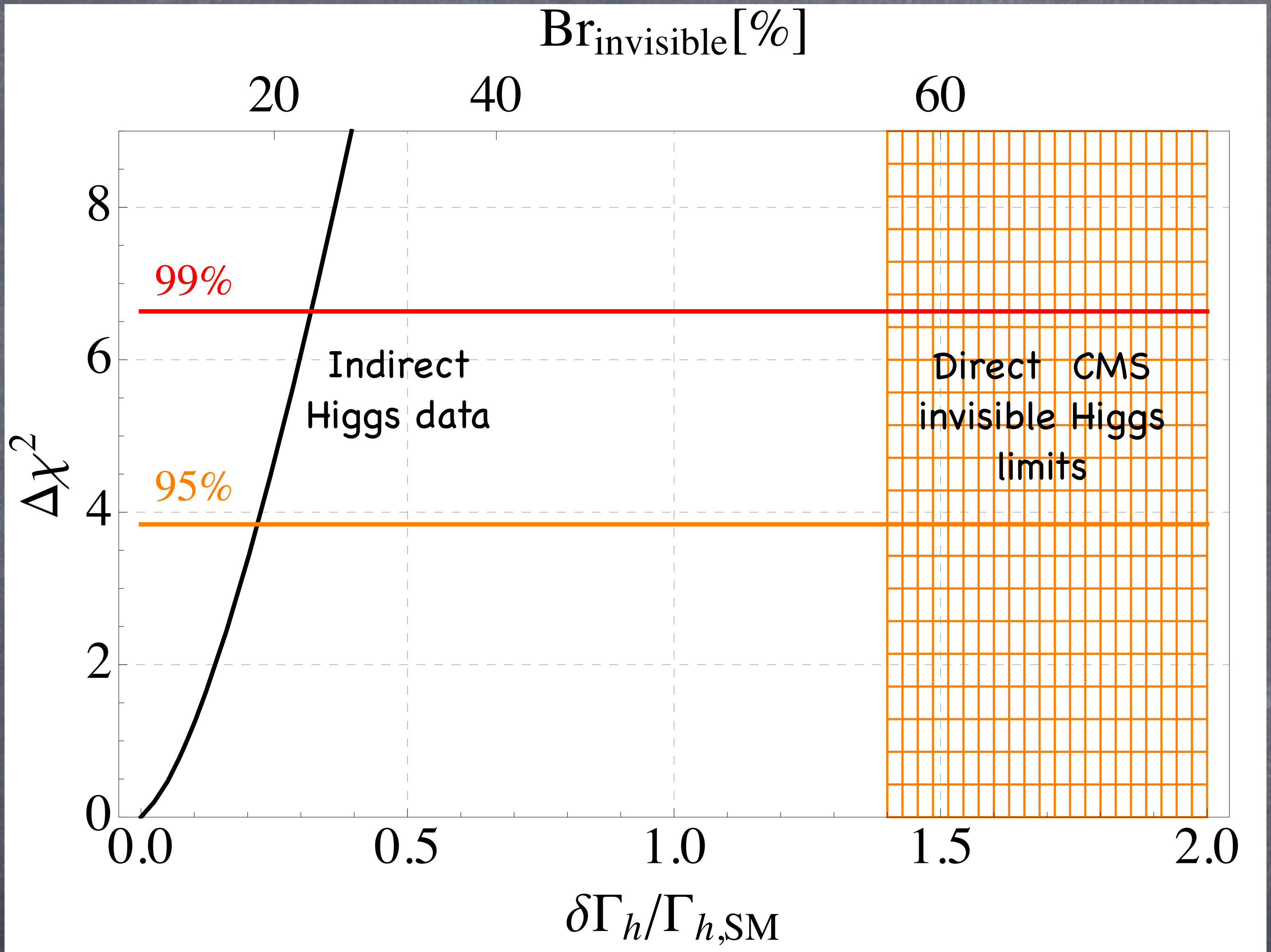
Limits on exotic Higgs branching fraction

Compare direct and indirect width constraints



Limits on invisible Higgs branching fraction

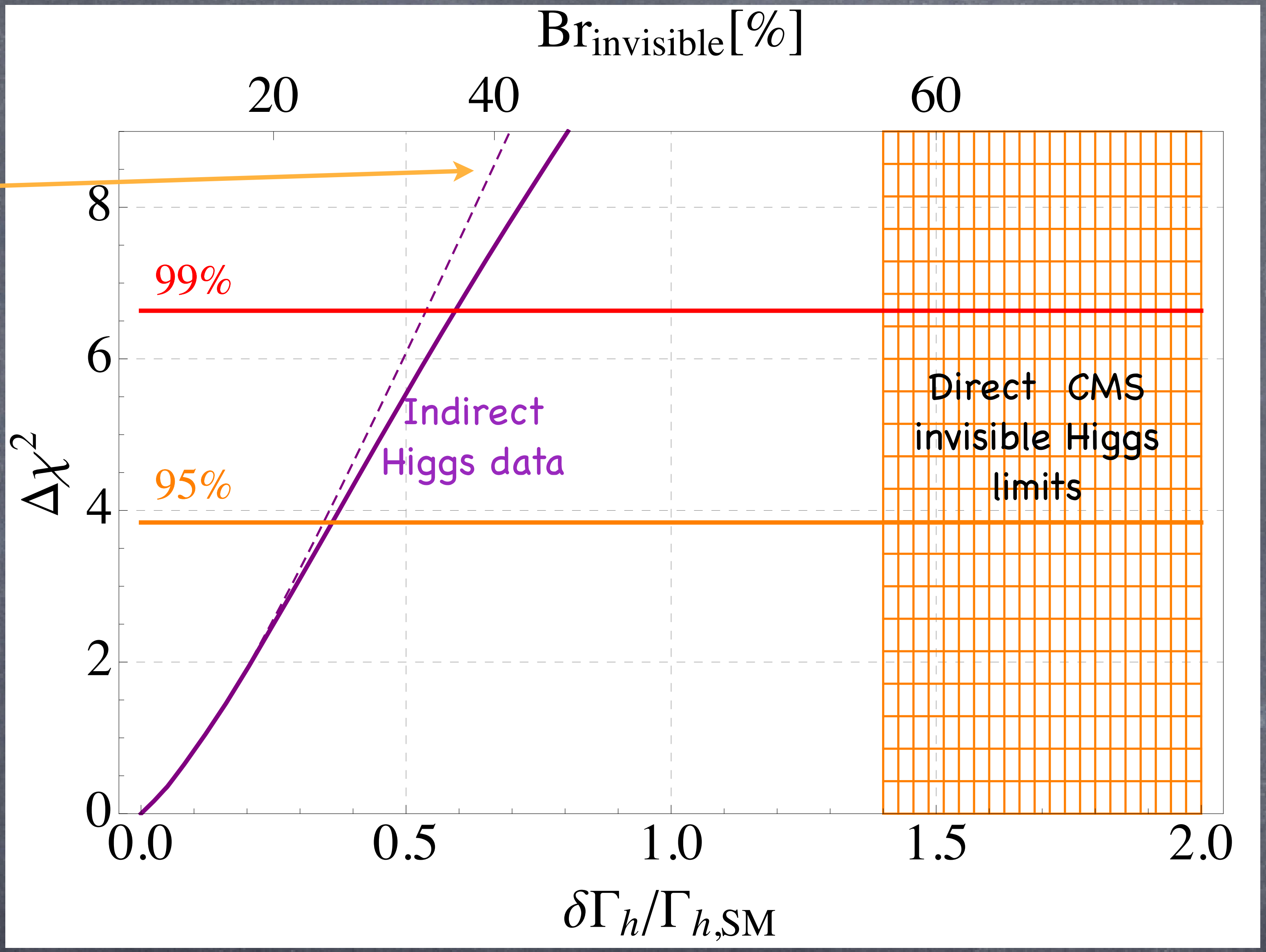
Assuming Higgs couplings to SM fixed



Limits on invisible Higgs branching fraction

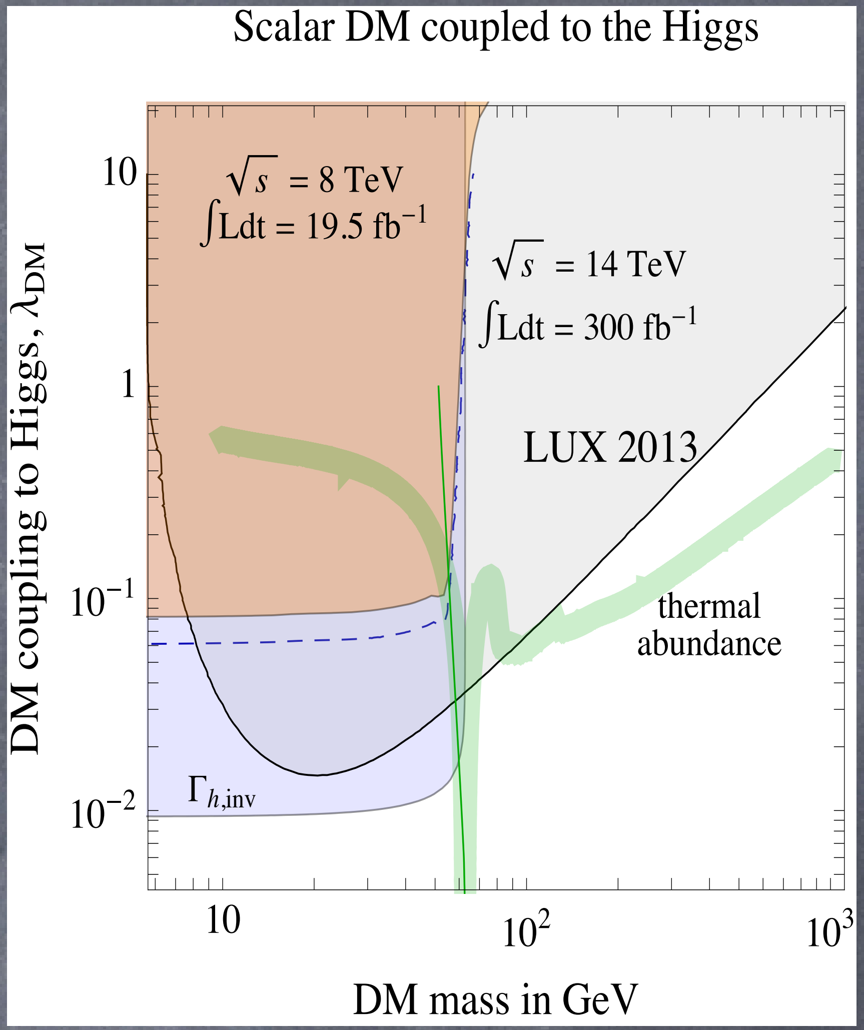
Assuming Higgs coupling to gluons floating

Effect of monojet constraints recast from CMS and ATLAS monojets searches by Djouadi et al. 1205.3169



Scalar Higgs portal summary

- Barring biggest conspiracy since Roswell Br(h→invisible) ≲ 30% (and most likely ≲ 20%)
- Direct limits from CMS and ATLAS yield Br(h→invisible) ≲ 58% for SM Higgs coupling to V
- For ms < mh/2 this translates to λ ≳ 0.03 (0.02) and excludes couplings corresponding to thermal WIMP
- For 10 GeV < ms comparable constraints on λ from direct detection



Light Higgs portal DM should be non-thermal. Then probed via (small) invisible Higgs width at LHC or in direct detection experiments

Higgs portal DM exactly at resonance (ms=mh/2) or heavier than 100 GeV can be thermal. Then probed in direct detection experiments. What about LHC?

Fermion and vector Higgs portal

- Fermionic or vector dark matter can also couple via Higgs portal, though in this case portal interaction is non-renormalizable

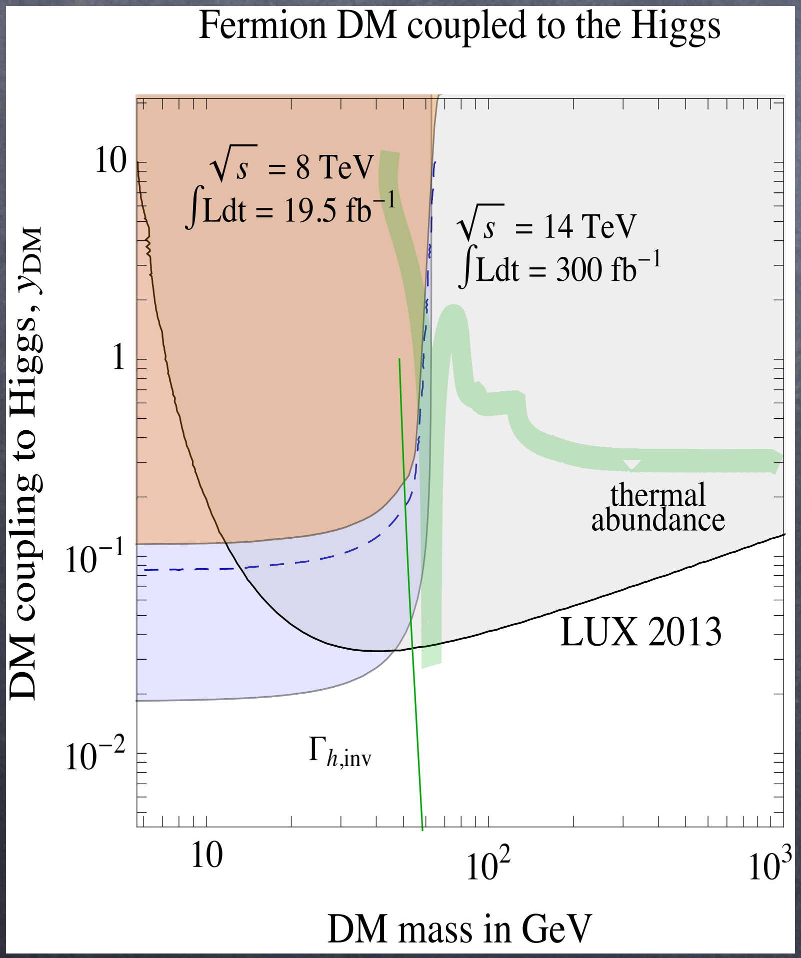
Lopez-Honorez, Schwetz, Zupan, arXiv:1203.2064.
Djouadi, Lebedev, Mambrini, Quevillon, arXiv:1112.3299.

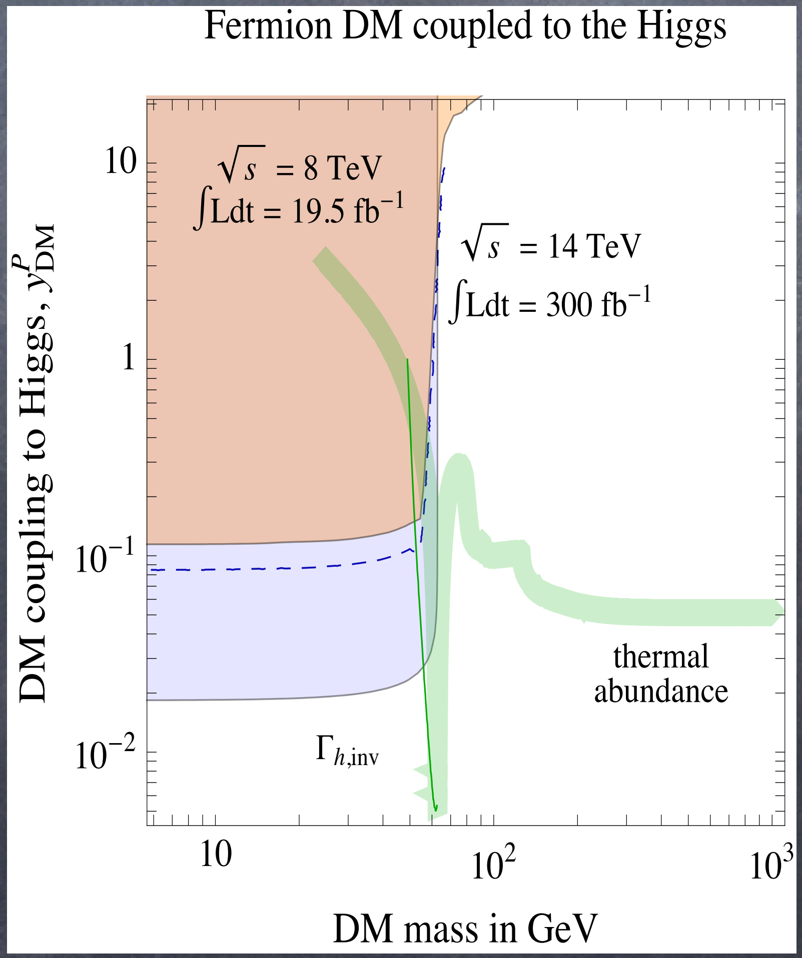
- For light dark matter conclusions similar as in scalar case...

- For heavy dark matter thermal cross section excluded by direct detection except for purely imaginary y where direct detection cross section is spin dependent and velocity suppressed

$$\Delta\mathcal{L}_{\rm Fermion} = -\frac{y}{2v}\psi\psi H^\dagger H + \text{h.c.}$$

$$\Delta\mathcal{L}_{\rm Vector} = -\lambda_V V_\mu V_\mu H^\dagger H$$





de Simone, Giudice, Strumia 1402.6287

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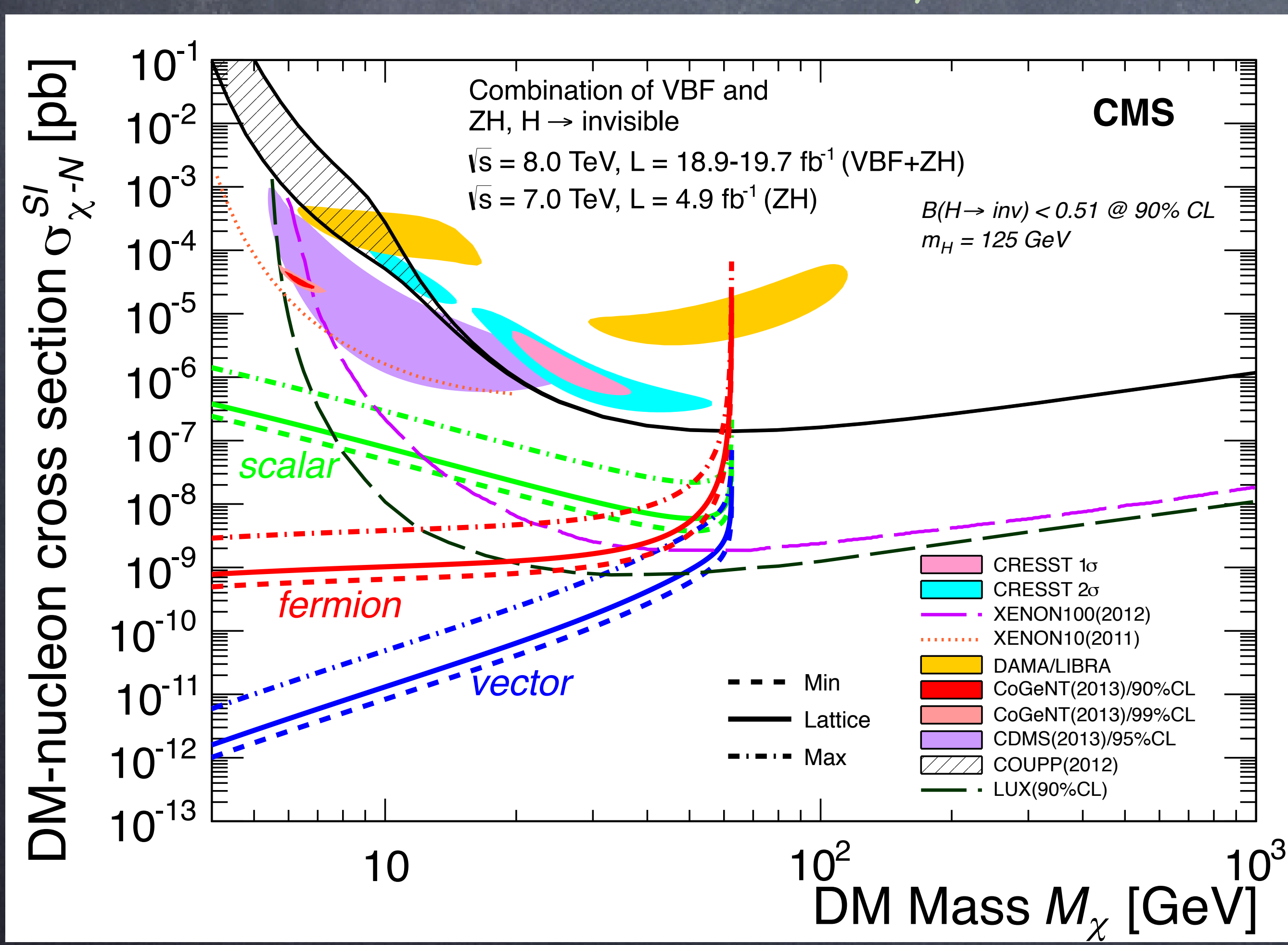
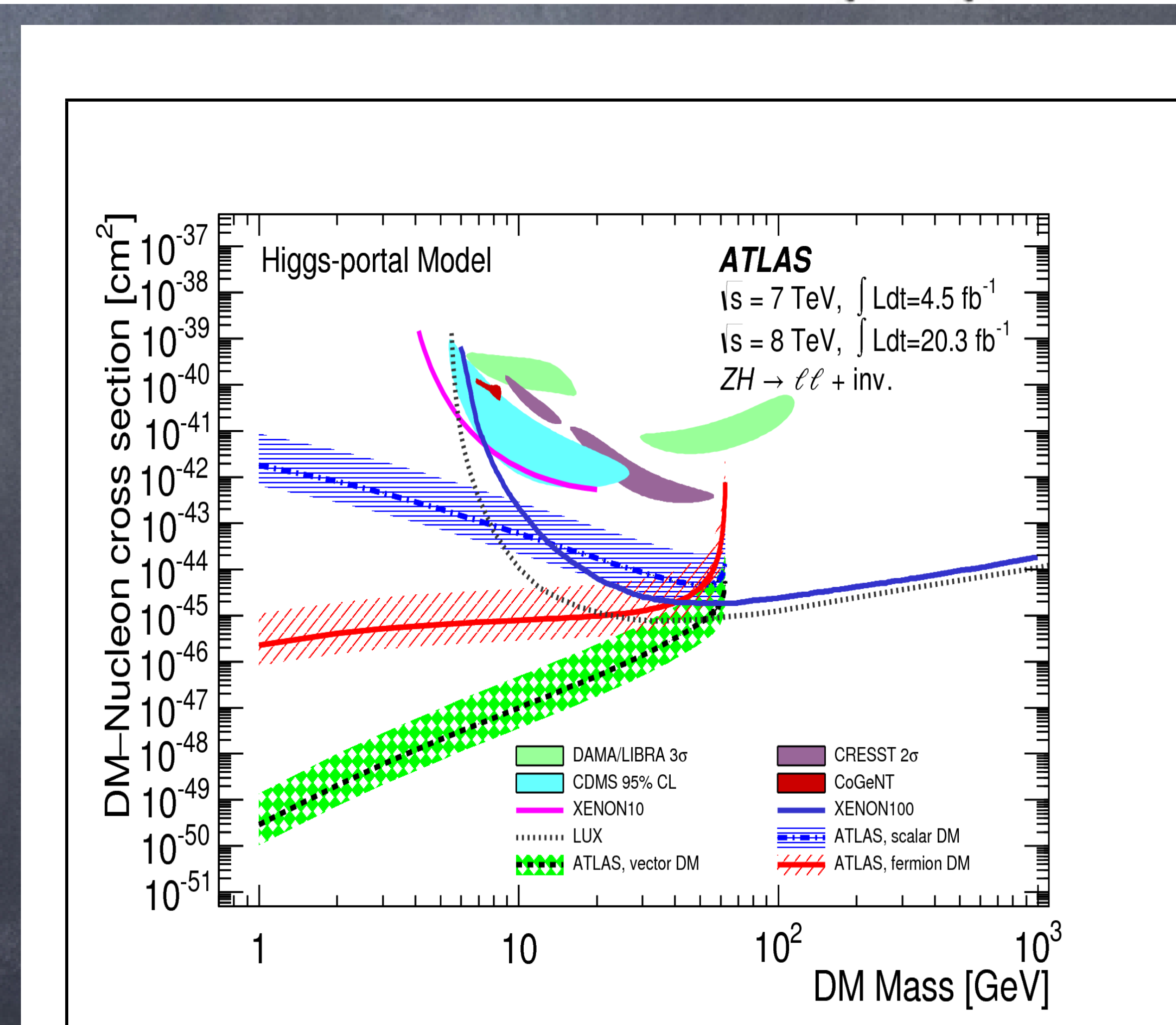
CMS, 1404.1344
ATLAS, 1402.3244





Take-away

- Higgs portal DM is a very motivated and very predictive scenario for dark matter.
- Predicts direct and indirect detection signals as well as collider signals
- For $m_S < 60$ GeV region of parameter space corresponding to thermal relic abundance is safely excluded by both LHC and direct detection experiments
- Heavier region will be probed by direct detection in near future
- Can we probe heavier Higgs portal DM at LHC? Or at ILC/TLEP? Or at 100 TeV