BSM interpretations of current status of Higgs searches

Ian Low @ LHC2TSP

August 31st, 2011

Argonne NATIONAL LABORATORY

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My Personal
BSM interpretations of current status
of Higgs searches

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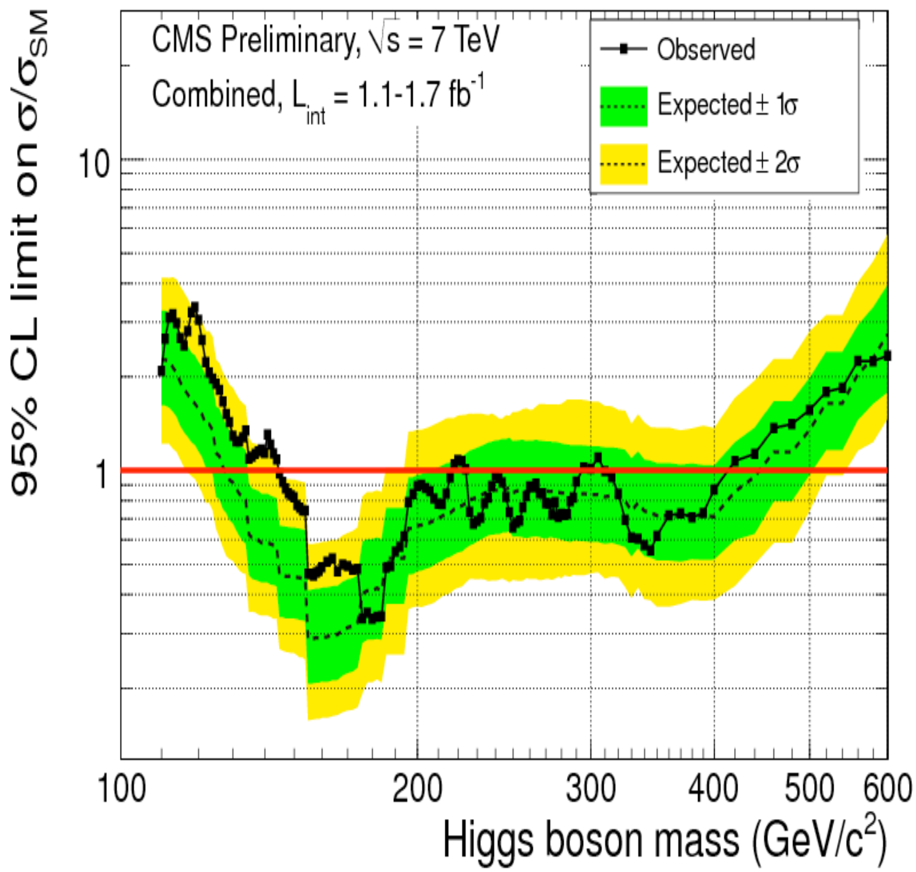
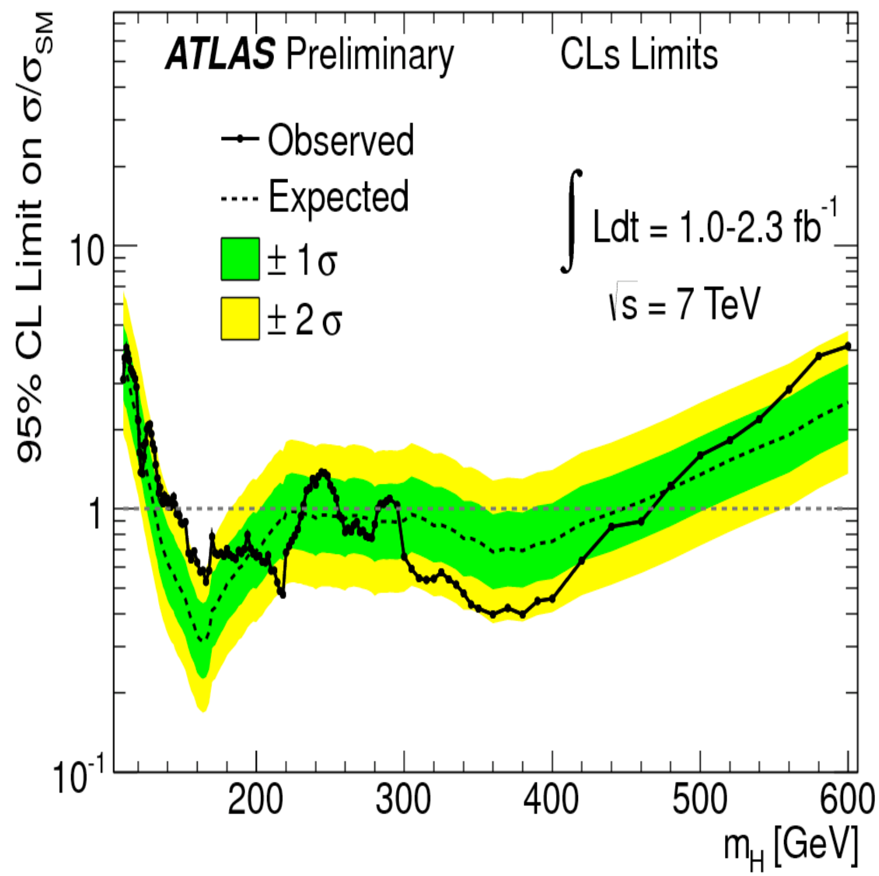
- Both ATLAS and CMS have done amazing jobs!
- A ``Standard Model Higgs'' above 140 GeV is pretty much ruled out!!

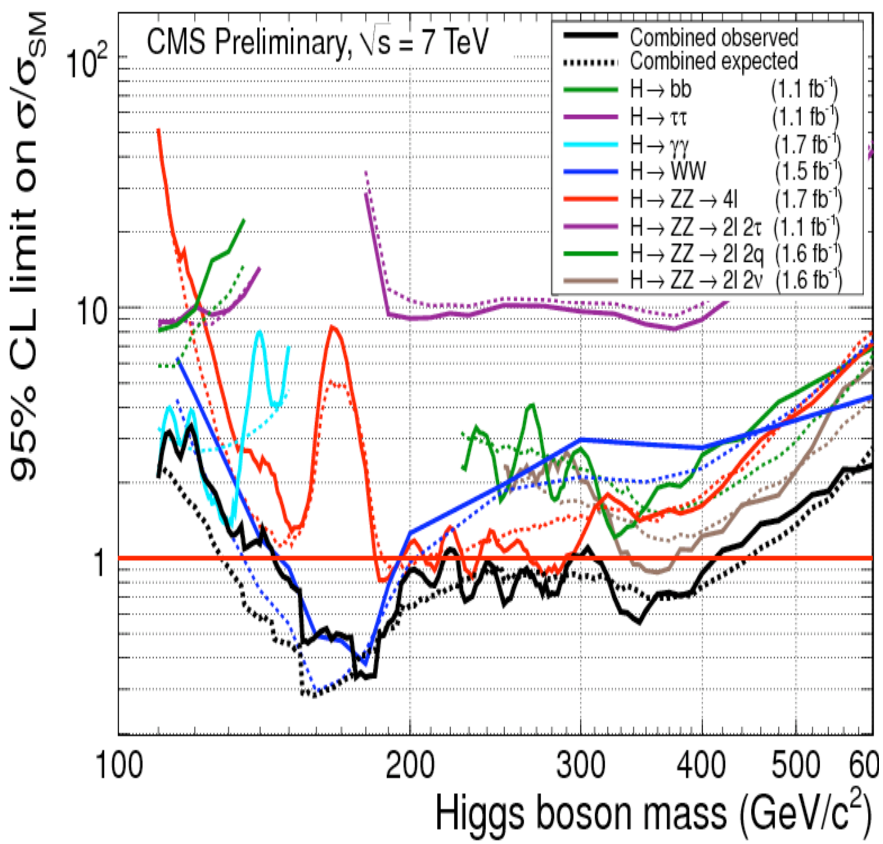


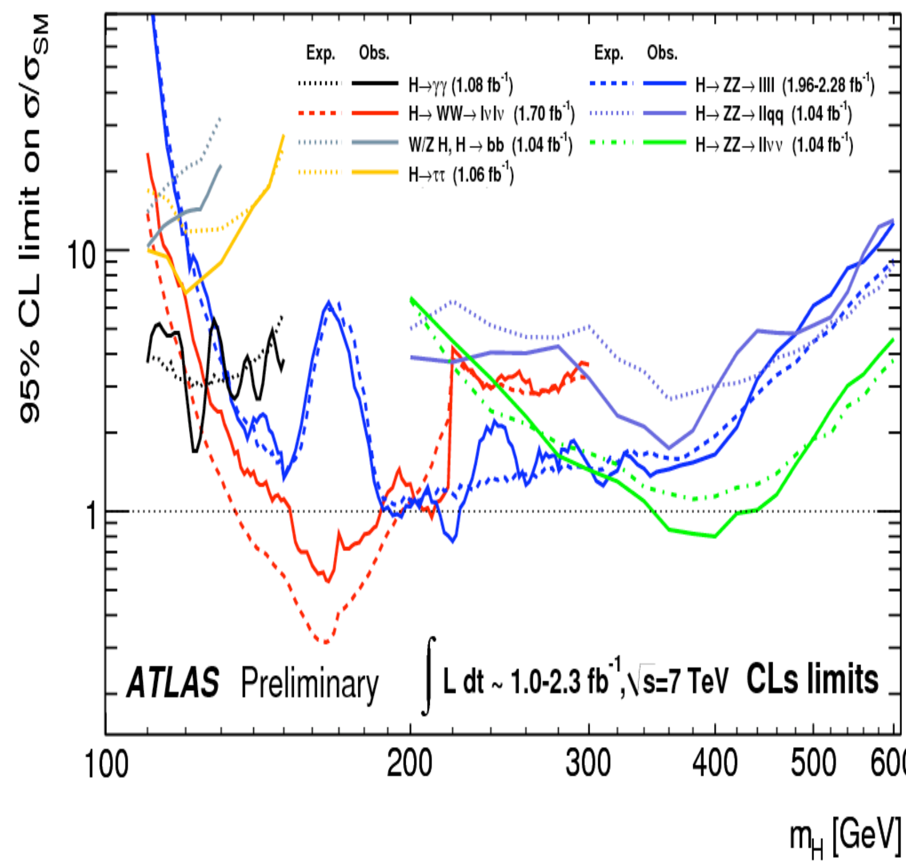


- Personally, knowing the SM Higgs is lighter than 140 GeV is very exciting news!
- But we all want something more than the Higgs.
- Once we assume physics beyond the SM, many Higgs properties get modified.

So what can we learn from the present Higgs search limits about physics at the TeV scale??

- First let's recall how the limits are derived:
  they are derived from a combination of 7 different channels for ATLAS and 8 channels for CMS.





In each channel we measure one number -- the event rate

$$B\sigma(p\bar{p} \to h \to X_{\rm SM}) \equiv \sigma(p\bar{p} \to h) \times br(h \to X_{\rm SM})$$

The branching fraction in a particular $h \to X_{SM}$ channel is given by

$$br(h \to X_{\rm SM}) = \frac{\Gamma(h \to X_{\rm SM})}{\Gamma_{\rm total}}$$

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- Event rate in each of these 7/8 channels is different from others
- Need to define a universal strength modifier to extract a limit.
- The most obvious choice is the production cross section!

$$\frac{\sigma}{\sigma_{\rm SM}}$$

So the first thing we learned:
if the (BSM) Higgs is heavier than 140 GeV, it should have a reduced production rate (from SM expectation) !

$$\sigma(p\bar{p} \to h) \ < \ \sigma_{\rm SM}(p\bar{p} \to h)$$

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if the (BSM) Higgs is heavier than 140 GeV, it should have a reduced production rate (from SM expectation)!

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- However, there exists another universal strength modifier in the event rate:

$$B\sigma(p\bar{p} \to h \to X_{\rm SM}) \equiv \sigma(p\bar{p} \to h) \times \frac{\Gamma(h \to X_{\rm SM})}{\boxed{\Gamma_{\rm total}}}$$

So alternatively the limit can be interpreted as a *lower bound* on the total width of the Higgs:

$$\Gamma(h \to {\rm anything}) \ > \ \Gamma_{\rm SM}(h \to {\rm anything})$$

So if a (BSM) Higgs is heavier than 140 GeV, it should have a larger total decay width!

$$\Gamma \;>\; \Gamma_{\rm SM}$$

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$$\Gamma \ > \ \Gamma_{\rm SM}$$

- It is also important to recall that the present limits are driven by searches in Higgs decays to *WW* and *ZZ*.

  So a non-universal strength modifier is

$$br(h \to WW/ZZ) \ < \ br_{\rm SM}(h \to WW/ZZ)$$

  In this possibility the branching fractions to *WW* and *ZZ* are suppressed!

These considerations motivate the following three scenarios that I will discuss today:

- The natural scenario: $\sigma < \sigma_{\rm SM}$
  Higgs mass is not fine-tuned!

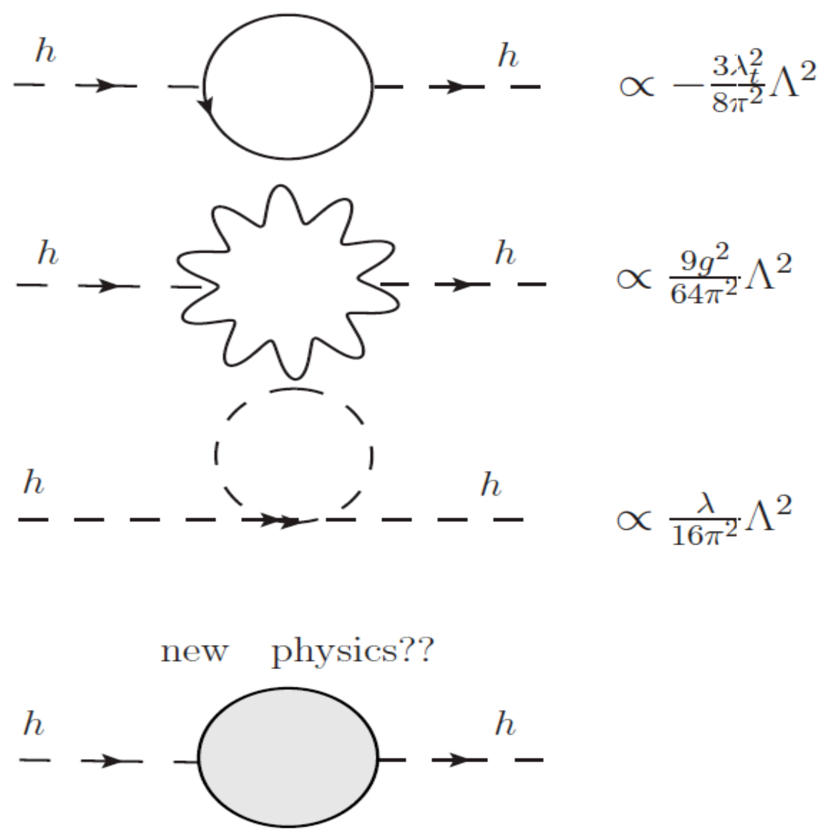
- The dark scenario: $\Gamma > \Gamma_{\rm SM}$
  Higgs has a large invisible decay width!

- The imposter scenario: $br(h \to VV) < br_{\rm SM}(h \to VV)$
  there's no doublet scalar, but only the Higgs imposter!

The natural scenario

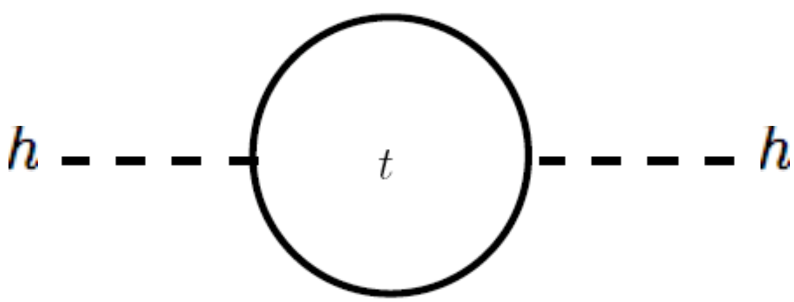
- The expectation for TeV scale physics is built upon the notion of naturalness ----

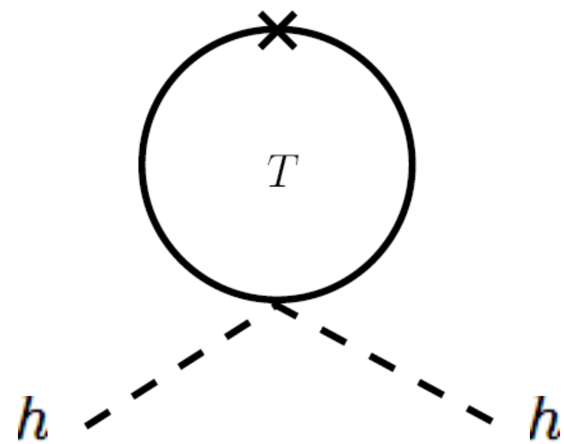
  one-loop quadratic divergences in the Higgs mass must be cancelled by “something” at the TeV scale:



- if there's a fermion that cancels the SM top divergence in the Higgs mass, that fermion will interfere destructively with the SM top in the gluon fusion production.

If the following two diagrams have a relative minus sign, then Higgs quadratic divergence is cancelled. Otherwise, the divergences add up.

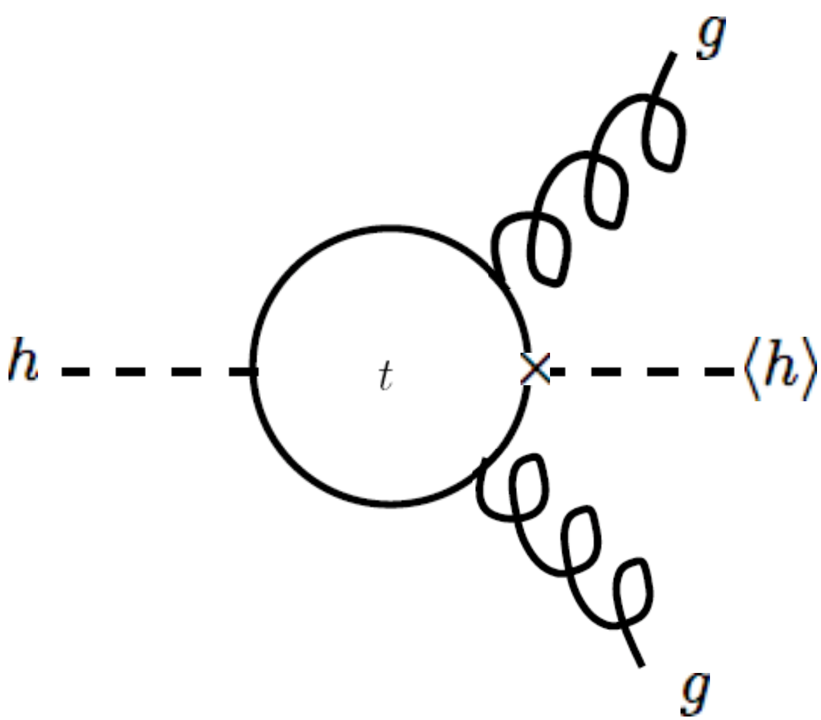


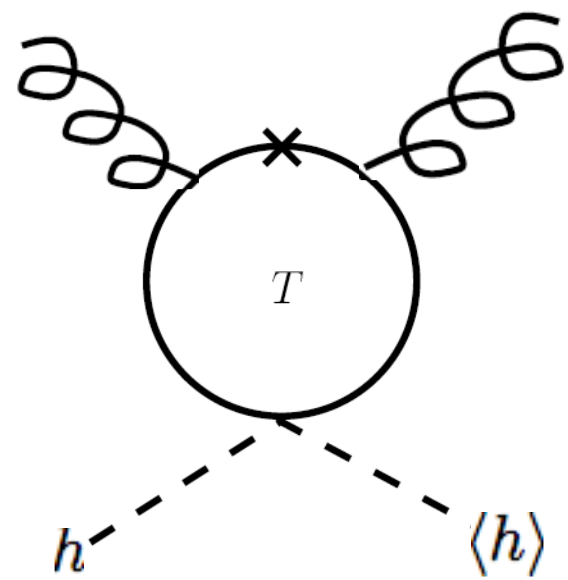


Now let's massage the diagrams a little bit:

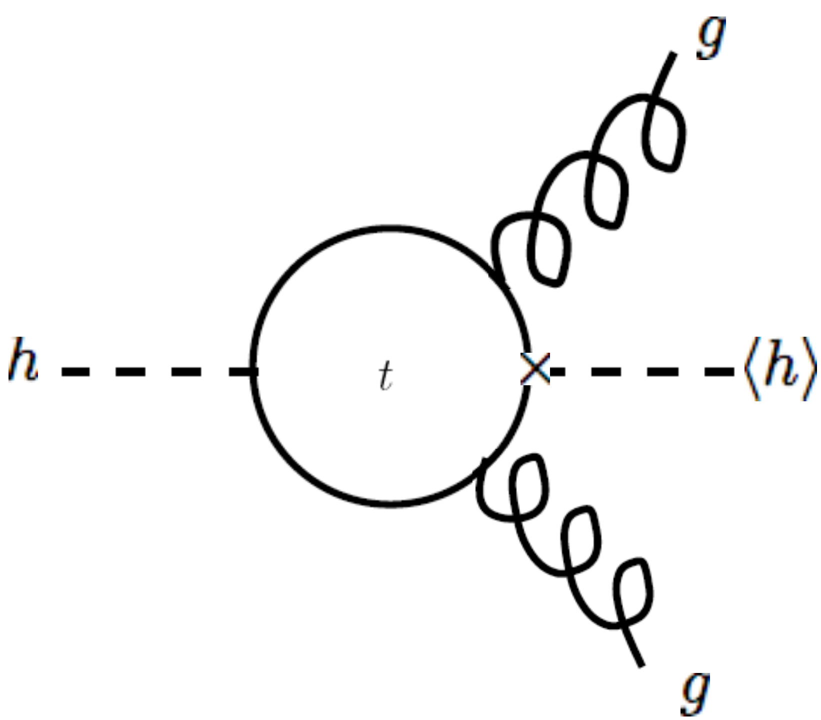
-- First putting one of the Higgs field in its VEV.

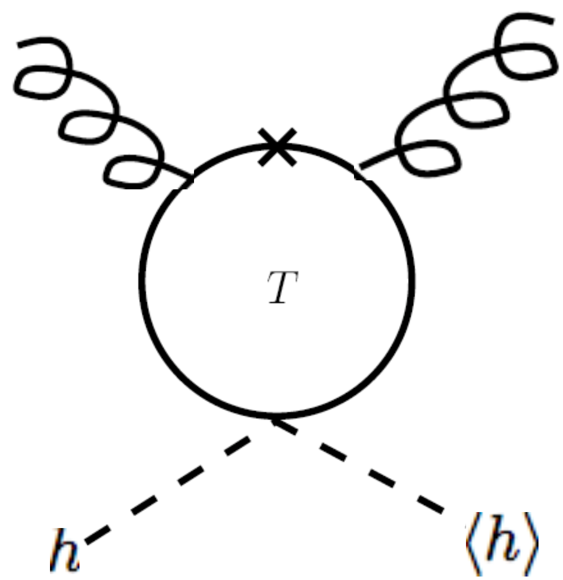
-- Next let's insert two gluons into the fermion line.



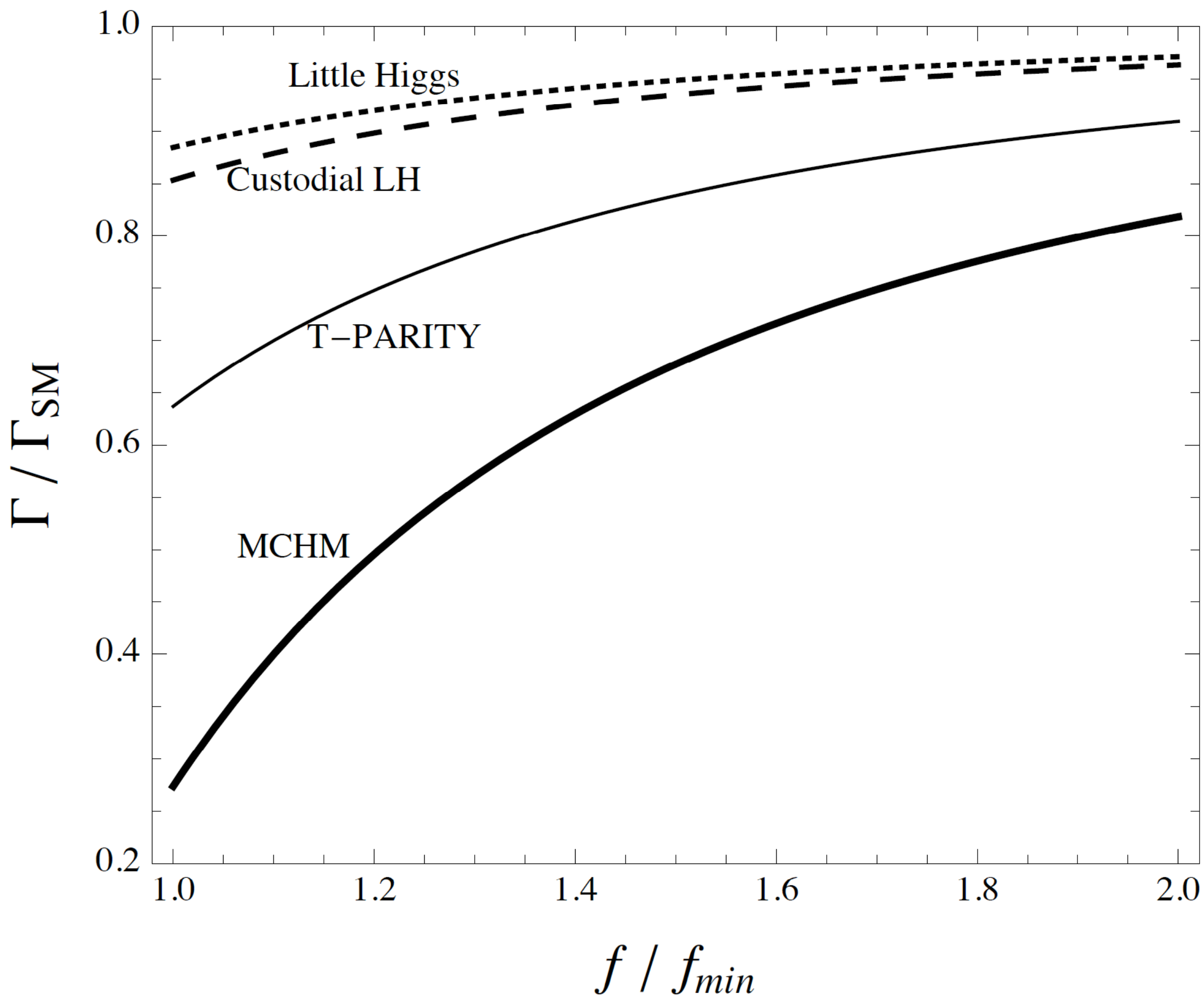


- These are exactly the two diagrams contributing to gluon fusion from the top quark and the new state!
- Because we have the same number of insertions along the fermion line, the relative sign between the diagrams is preserved!



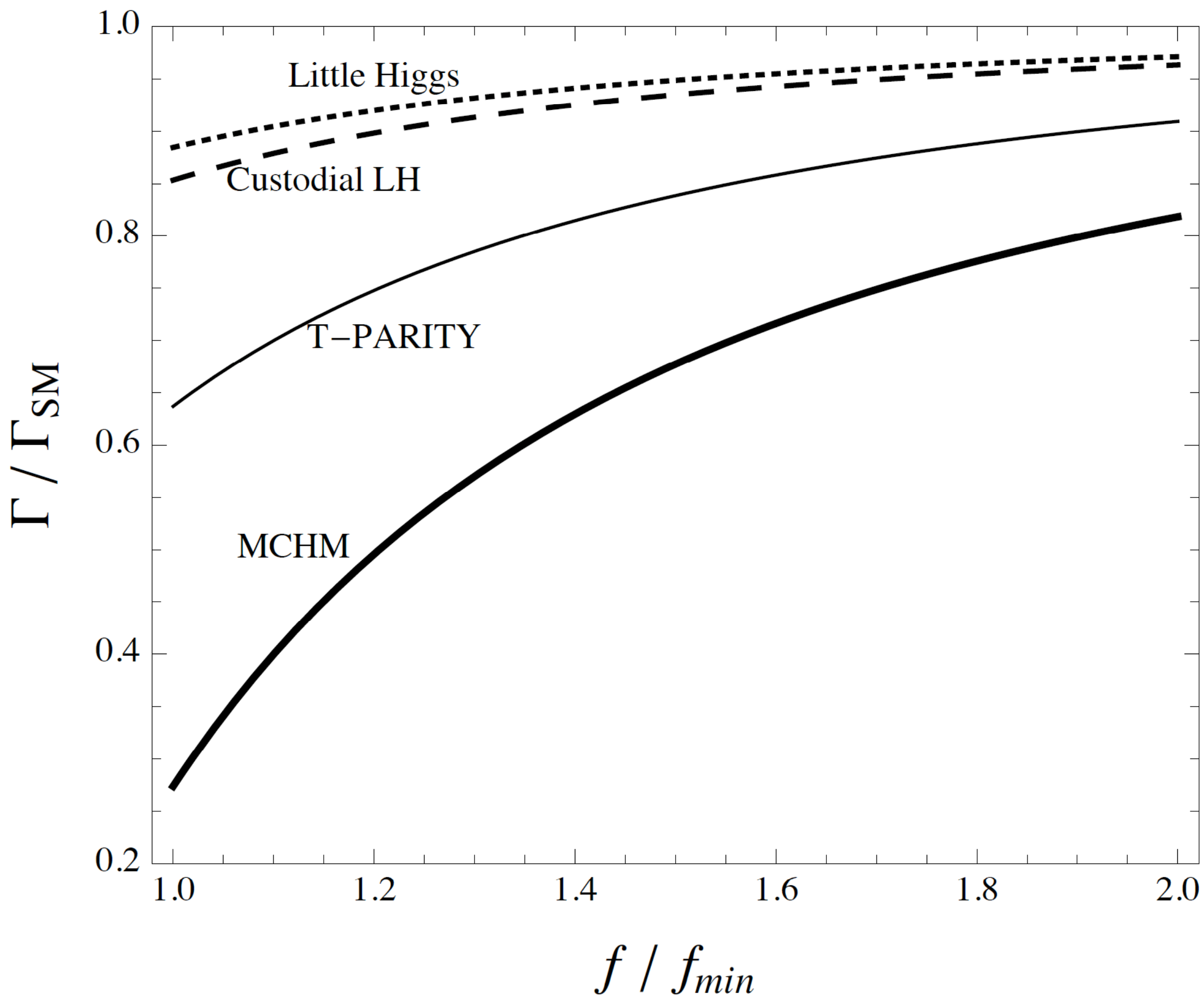


- If the Higgs is a pseudo-Goldstone boson, other effects go in the same direction of reducing the production rate. (Low, Rattazzi, Vichi, 0907.5413)



Low and Vichi, 1010.2753.

- Significant reduction is quite possible!



Low and Vichi, 1010.2753.

- To the contrary, in theories where the Higgs mass is fine-tuned, the production rate is enhanced!

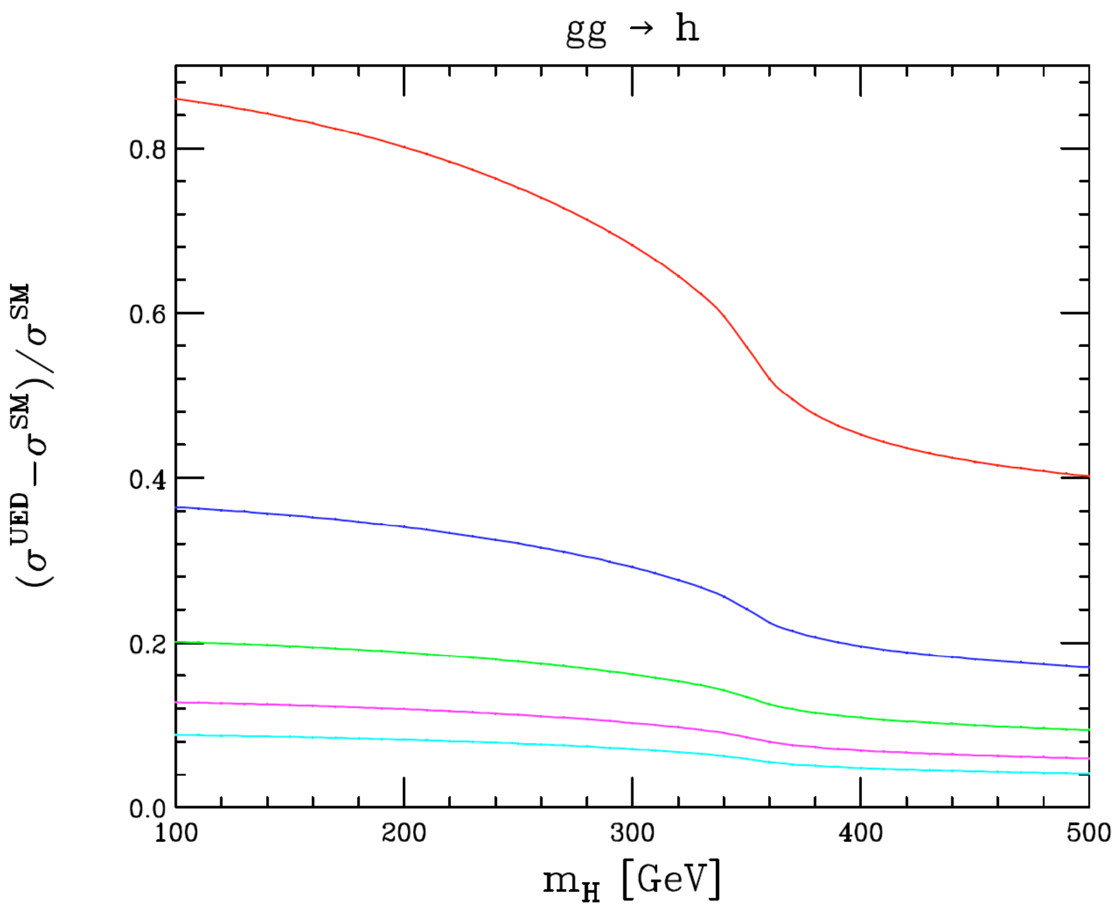


Figure 1: The fractional deviation of the $gg \to h$ production rate in the UED model as a function of m_H; from top to bottom, the results are for $m_1 = 500, 750, 1000, 1250, 1500$ GeV.

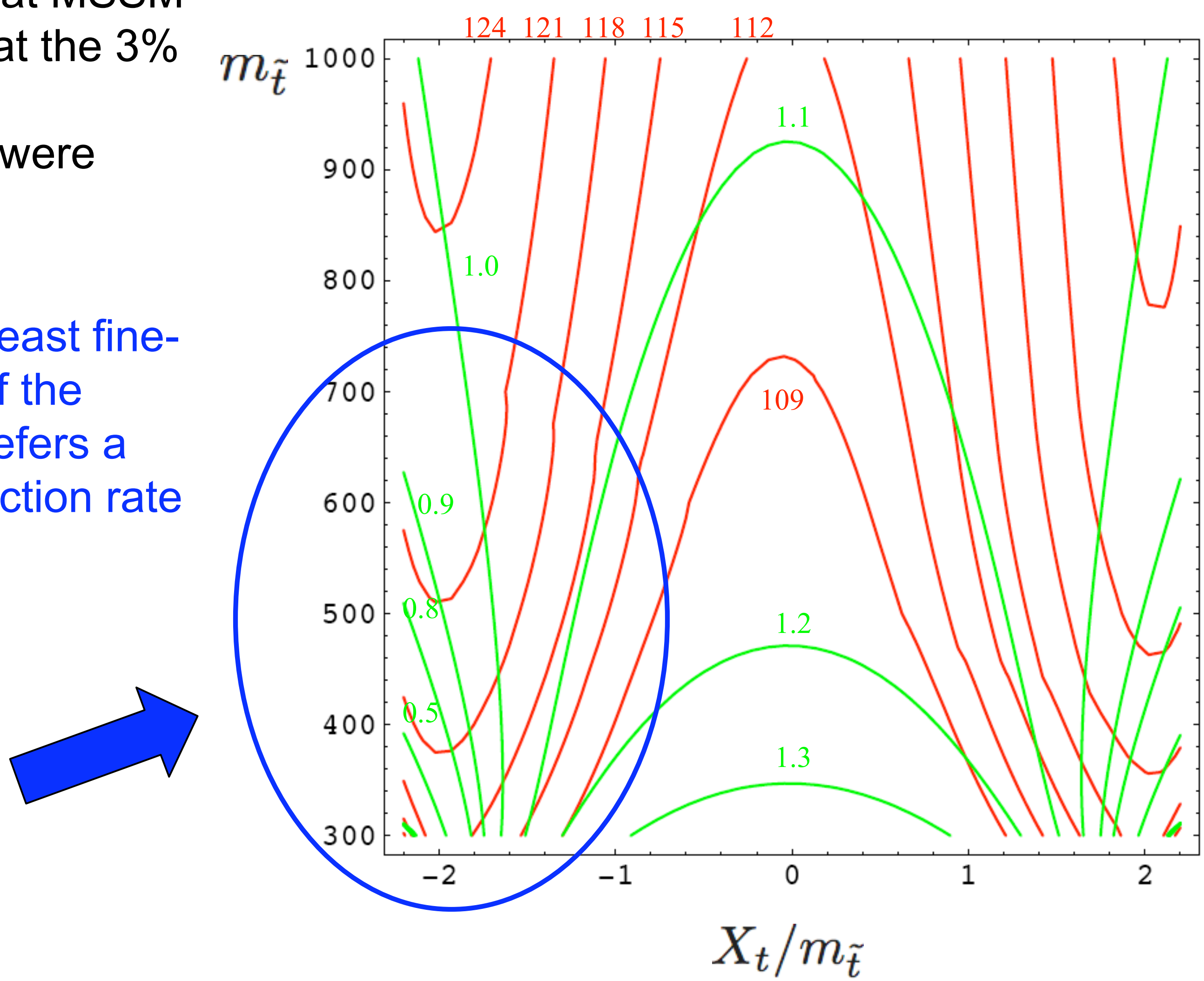
F. Petriello, hep-ph/0204067

What about supersymmetry?

- We all know that MSSM is fined-tuned at the 3% level since no superpartners were found to date.

- Turns out the least fine-tuned region of the MSSM also prefers a reduced production rate of the Higgs:

Least fine-tuned region of MSSM!



Dermisek and Low, hep-ph/0701235

If this is indeed the case, some light colored states responsible for canceling the Higgs divergence might be just around the corner!

One woud need to verify the coupling to the Higgs.

The dark scenario

- So far the strongest empirical evidence for BSM physics is that for dark matter ---

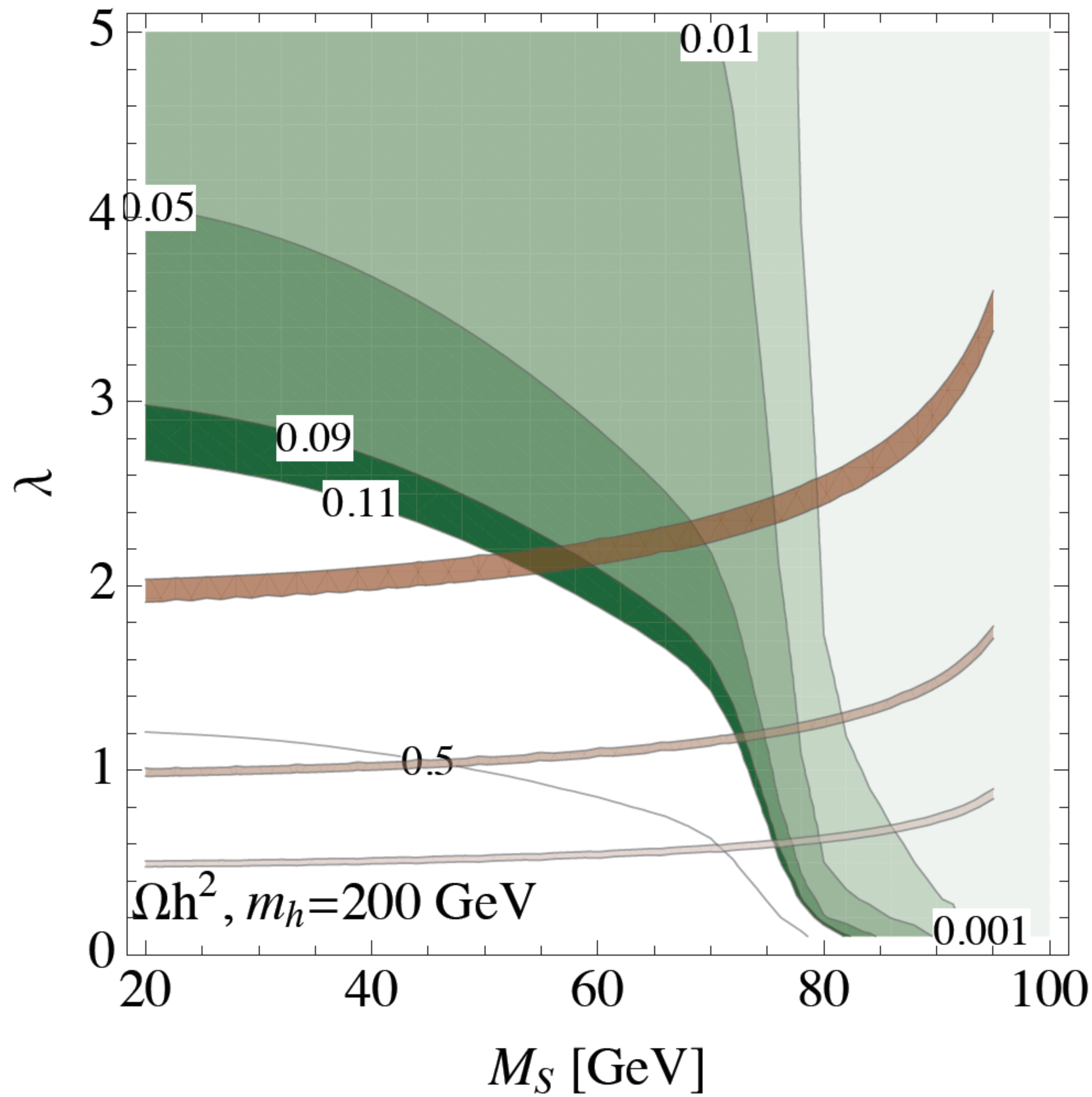
  Higgs could couple to the dark matter, which has a mass below half of the Higgs mass. If

$$\Gamma(h \to X_{invisible}) \sim \Gamma(h \to X_{SM})$$

  then event rate in any channel is suppressed and present limits would not apply.(Low, Schwaller, Shaughnessy, Wager, to appear)

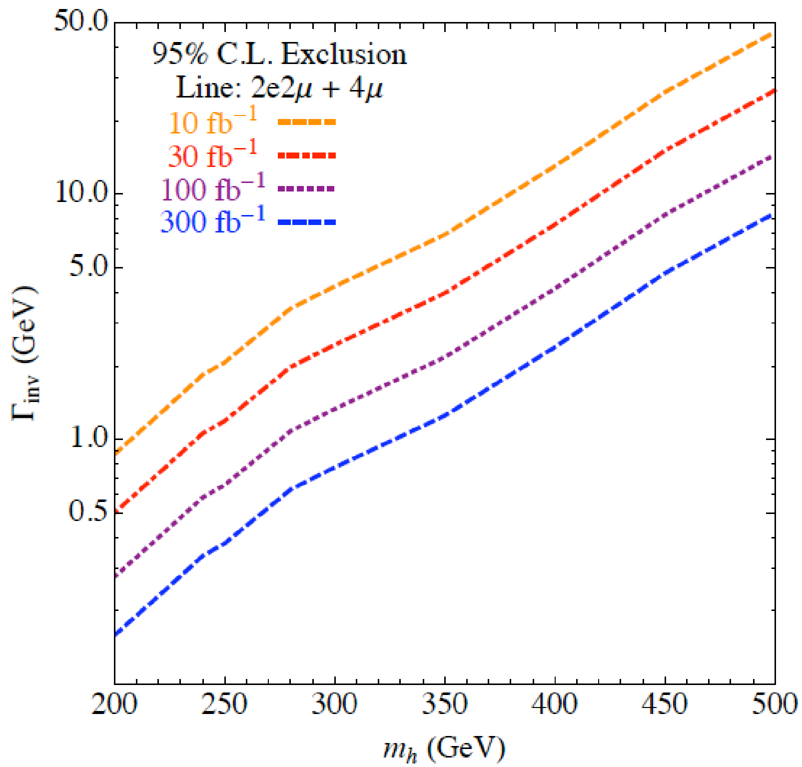
- Higgs coupling strength to dark matter can be inferred. The relic density could work out:

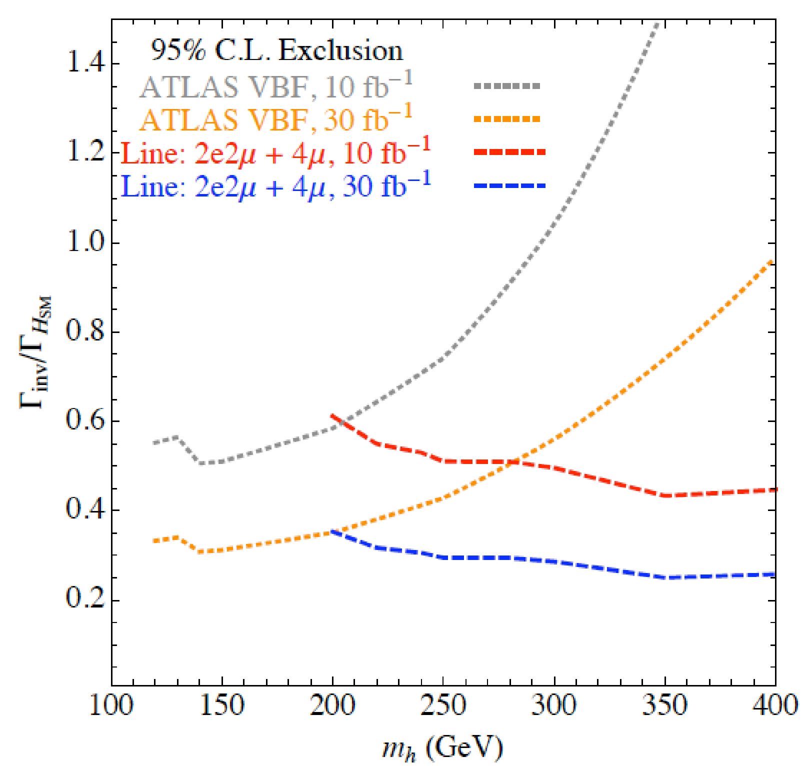
Assuming the dark matter is a singlet scalar:



- In this scenario it’s important to measure the invisible width and the total width if a Higgs is found.
- In the low mass region, look at VBF + MET. (Eboli and Zeppenfeld, 0009158.)
- In the high mass region, one could measure the total width from the line shape in the ZZ -> 4 leptons channel.

- Existing studies on total width measurement didn't include the dilution from a large total width.

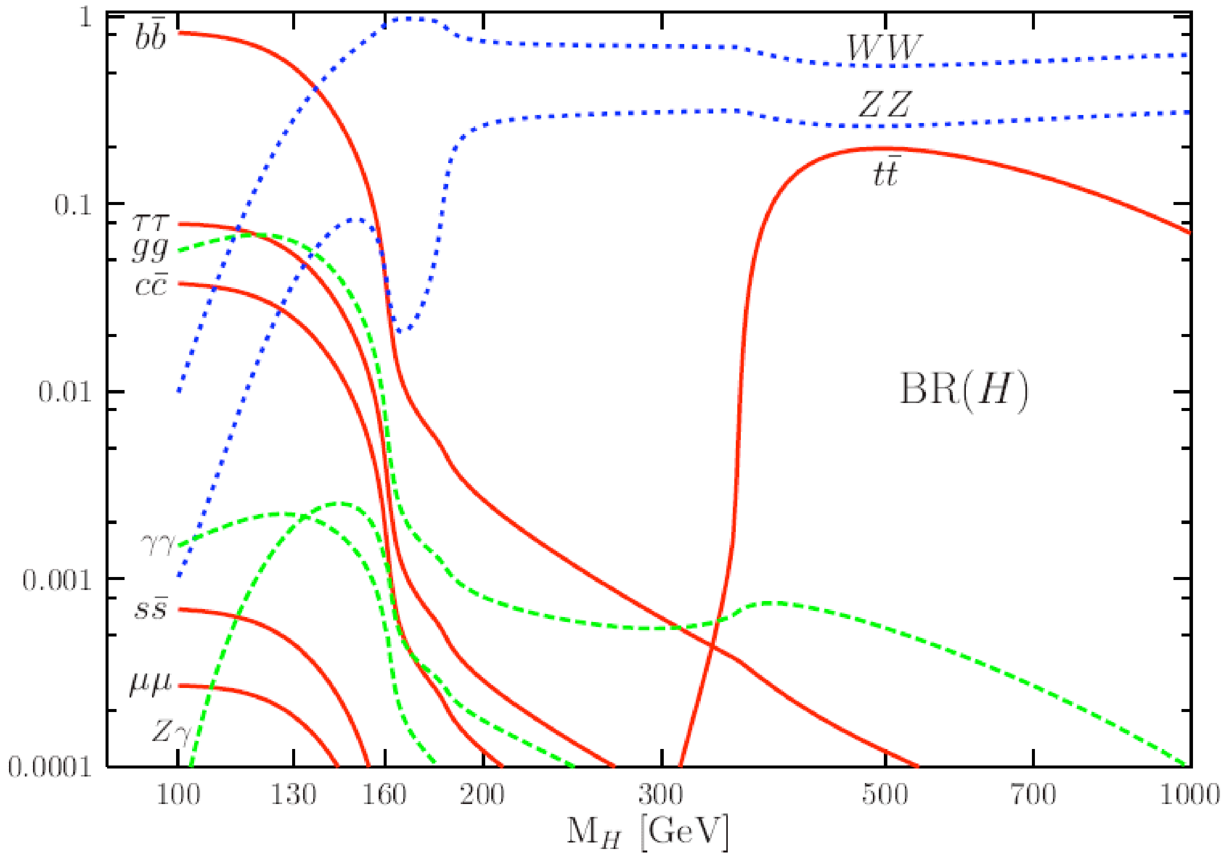




4l line shape is complimentary to VBF extractions!

The imposter scenario

- Over a significant range of masses, Higgs searches are driven by *WW* and *ZZ* channels:



Djouadi, 0503172

- Let’s not forget the the Higgs sector of the SM has never been verified.

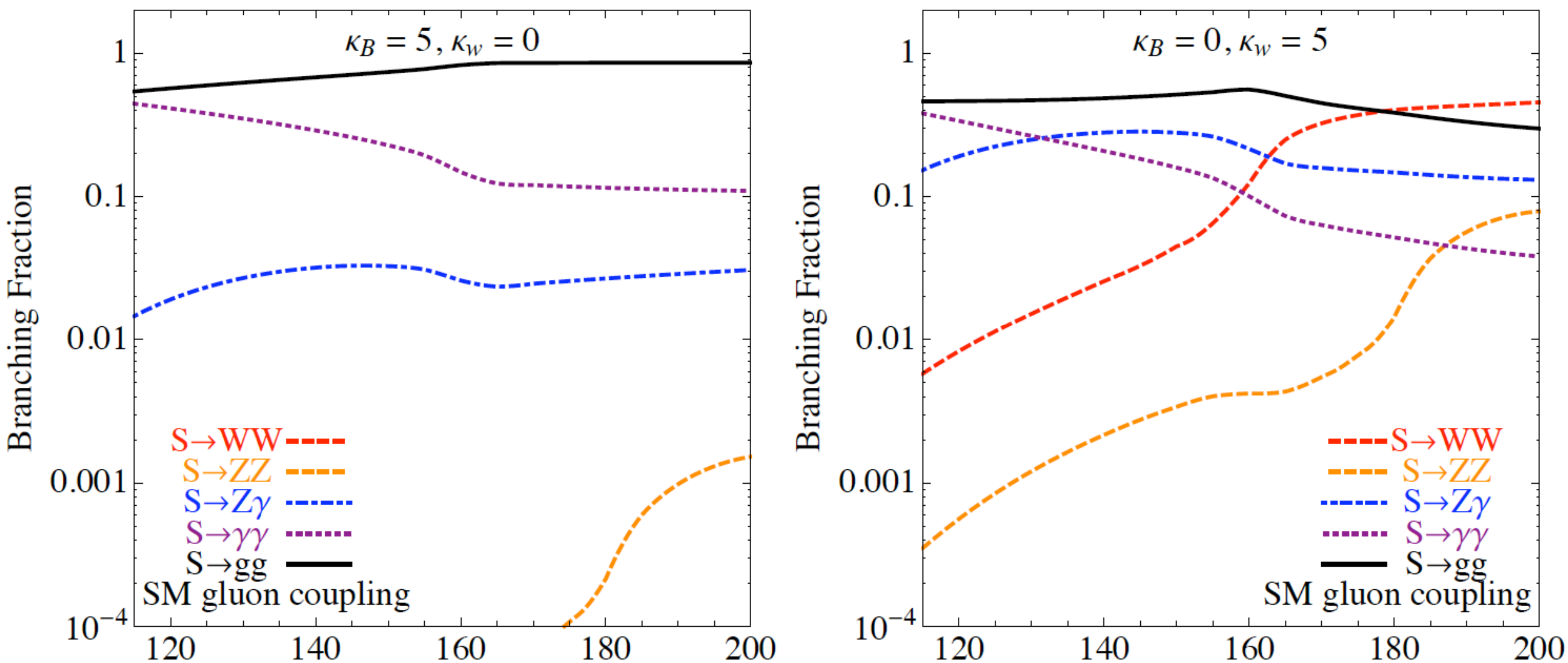
  (there are ways to unitarize WW scattering without a scalar.)

- An electroweak singlet scalar is ubiquitous in BSM theories, whose couplings to pairs of electroweak gauge bosons are controlled by only two parameters at leading order:

$$\kappa_W \frac{\alpha_{em}}{4\pi s_w^2} \frac{S}{4m_S} W^a_{\mu\nu} W^{a\,\mu\nu} + \kappa_B \frac{\alpha_{em}}{4\pi c_w^2} \frac{S}{4m_S} B_{\mu\nu} B^{\mu\nu}$$

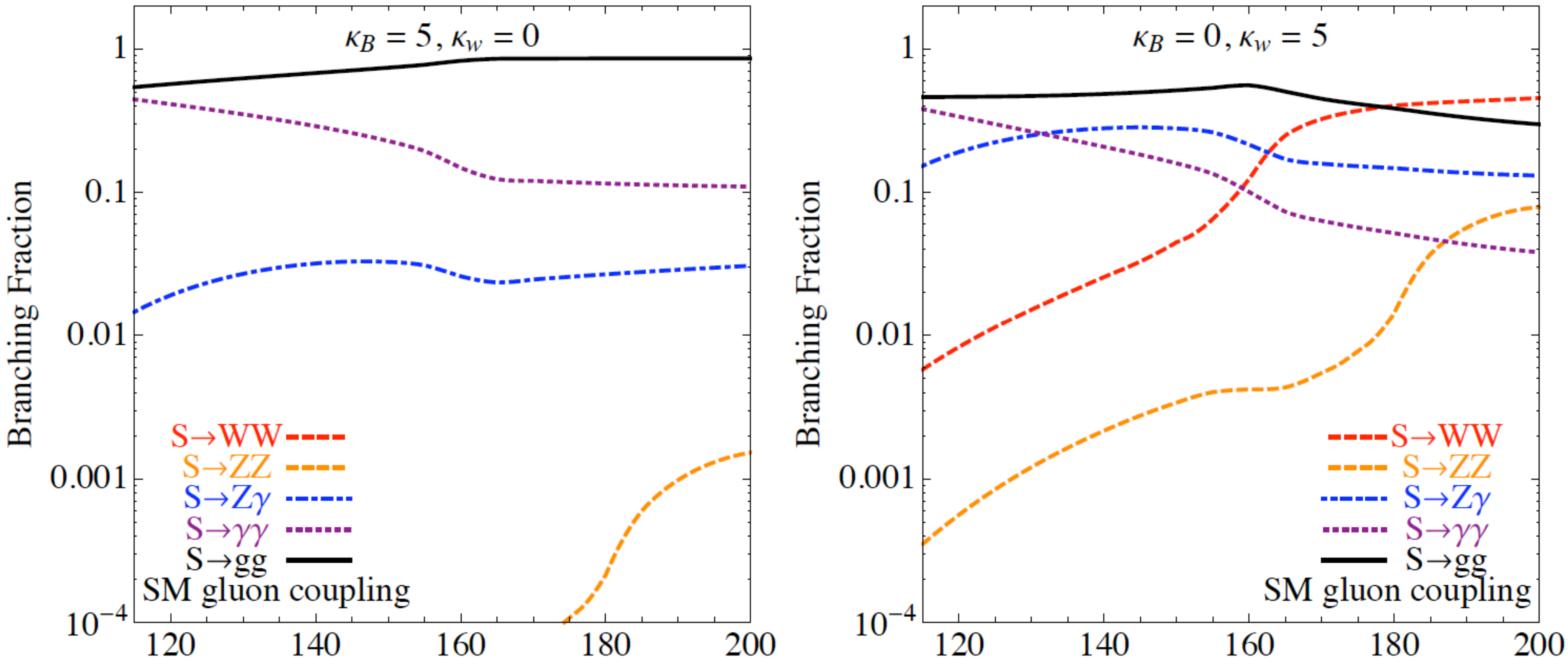
Unlike a doublet scalar, the singlet couplings to VV are democratic, without any hierarchy!

- Decays to VV are entirely determined by kinematics, and branching fractions into *WW* and *ZZ* are much smaller than those in the SM. (Lykken and Low, 1005.0872)



Lykken, Low, Shaughnessy, 1105.4587

- In the left panel, WW channel completely disappeared!
- In the right panel, ZZ channel is highly suppressed!



Lykken, Low, Shaughnessy, 1105.4587

- In all cases, singlet decays to diphoton and Z+photon are much enhanced from the SM expectations.

- There’s no published analysis notes, but I suspect existing data can already say something meaningful about this imposter scenario.

Concluding remarks:

- Let's NOT stop looking in regions where a SM Higgs is ruled out!!

  We all want something *beyond* the standard model!

- In many BSM theories, Higgs properties are modified and its mass doesn't have to be light.

  Strengthening the exclusion limit will have important implications for scale of new physics!

- If Higgs mass is not fine-tuned, its production is expected to be smaller than expected.

- A large invisible width would dilute the signal strength at the LHC.

- A Higgs imposter would not show up in WW and ZZ channels. It's important to keep an eye on diphoton and Z+photon modes.