Rare Exotic Higgs Decays

Physics of HL-LHC, perspectives at HE-LHC CERN, November 1, 2017

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Outline

- One slide motivation
- Classification of channels
- Recent progress
- HL-, HE-LHC speculations
- Outlook

One-Slide Motivation

Low-dimension gauge invariants of the SM:

$$F_{\mu\nu}, \quad HL_\alpha, \quad |H|^2$$

Hypercharge portal, constrained by low-energy probes

Neutrino portal, most info comes from the ν experiments

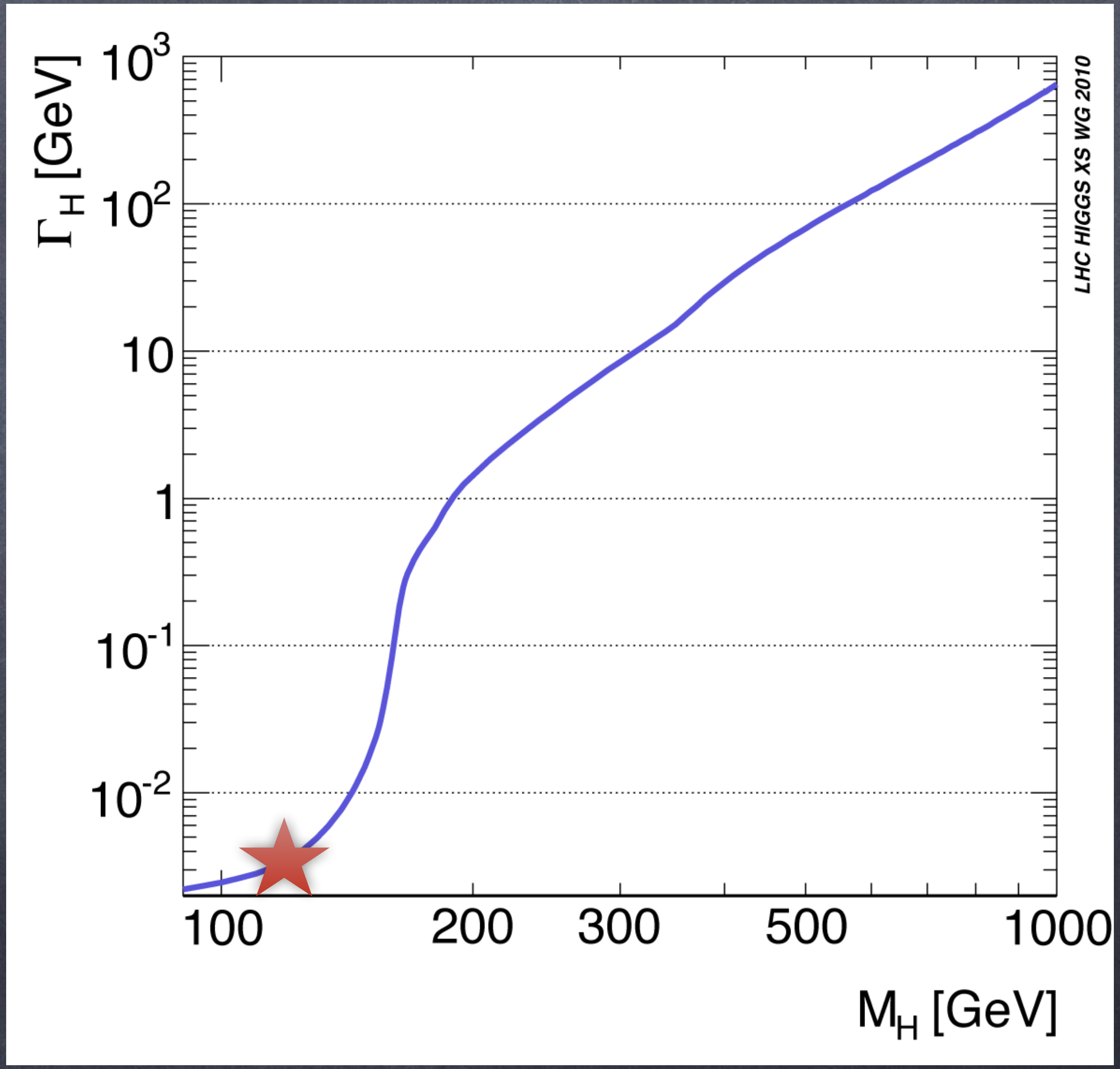
Higgs portal, chance for rare exotic Higgs decays

The Higgs Is Very Sensitive

Higgs width:

$\Gamma(m_h=125\ \text{GeV}) \approx 4\ \text{MeV}$

The sharp raise of the ZZ* and WW* channels just opens up. Enough to measure these channels, not enough to overwhelm the total width.

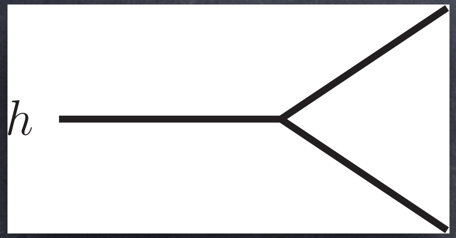


Small BSM couplings can yield considerable BRs

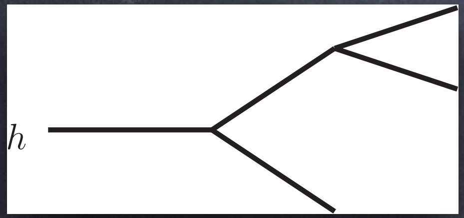
Categorization: Assumptions

- The observed 125 GeV Higgs is principally responsible for the EW symmetry breaking
- The Higgs is mostly SM-like, the exotic decays are rare
- Restrict ourselves to exotic decays into 2 neutral light BSM particles that might or might not decay back to the SM

Classification of Decays



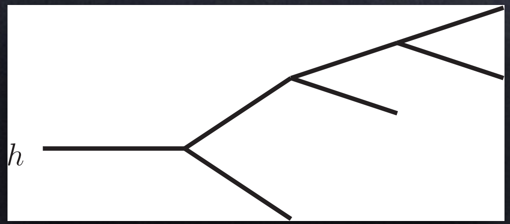
Two long-lived or stable light BSM particle. h → invisible mode



Higgs to two, one of the particle is collider stable, another is not.

Examples:

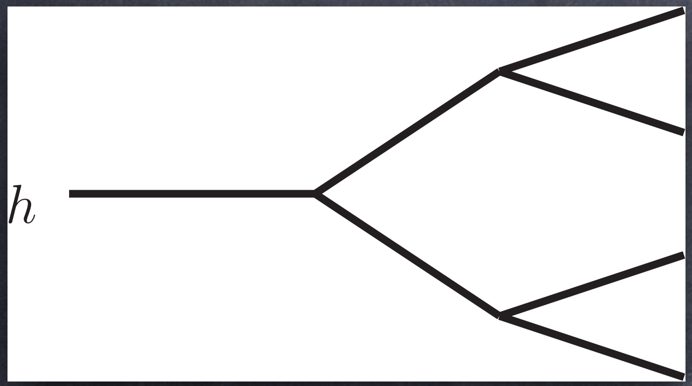
$$h \to (jj) + \not{E}_T, \quad h \to (l^+ l^-) + \not{E}_T, \quad h \to (\tau^+ \tau^-)$$



One of the Higgs decay products undergoes a cascade decay.

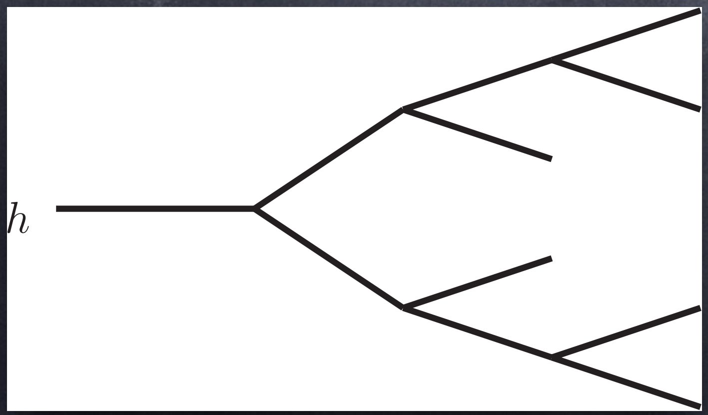
$$h \to \chi_2 \chi_2, \quad \chi_2 \to a \chi_1, \quad a \to f\bar{f}/\gamma\gamma/jj$$

Classification of Decays



Higgs to two, with subsequent decays to the SM

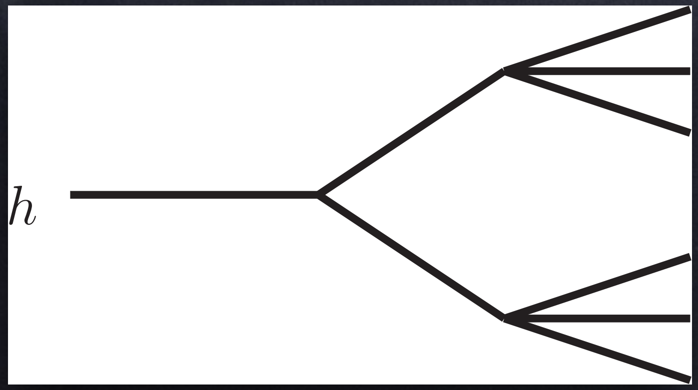
$$(\bar{b}b)(\bar{b}b), \quad (\bar{b}b)(\tau^+\tau^-), \quad (\gamma\gamma)(\gamma\gamma), \quad (jj)(\gamma\gamma)$$



Higgs daughters undergo cascade decays, e.g.

$$h \to \chi_2\chi_2, \quad \chi_2 \to a\chi_1, \quad a \to \bar{f}f$$

example signature $(\bar{b}b)(\bar{b}b) + \not{E}_T$



The daughters undergo 1→3 decays

$$h \to \chi_1\chi_1, \quad \chi_1 \to jjj$$

Easy-to-Probe Modes

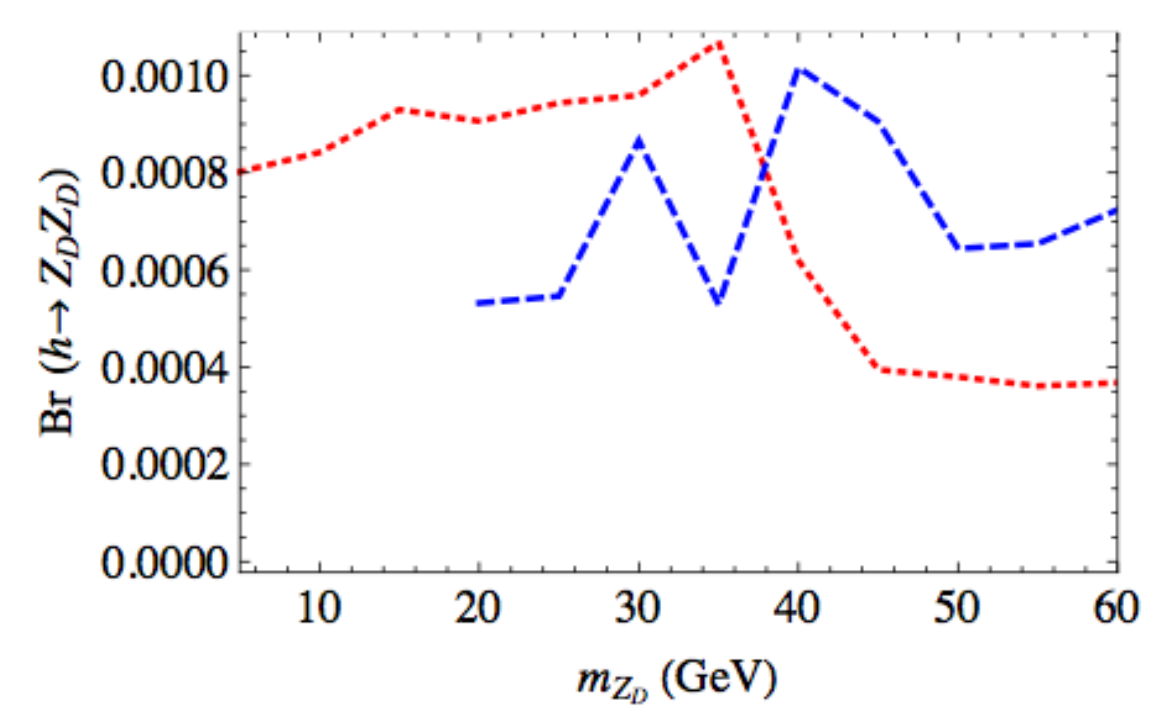
- Leptons at hadron collider are easy to spot
- Higgs mass is fully reconstructable ☛ no MET

with assumption BR($Z_D \to ll$) = 0.3

$h \to ZZ'$ CMS recast

Atlas $\sigma(ZZ)$ measurement recast

Taking into account the BRs this takes us to the ballpark of BR~10^{-5}

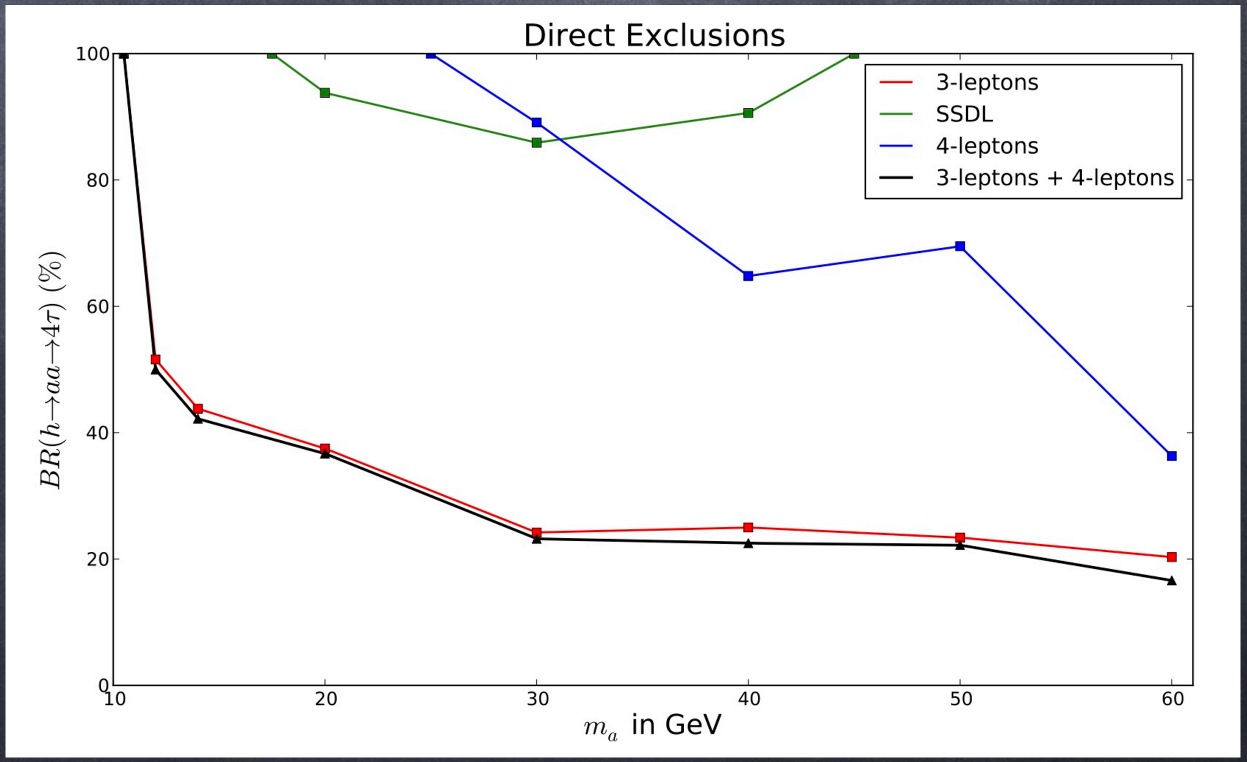


Slightly More Difficult Modes

Possible problems: the leptons are still there, but the Higgs mass is impossible to reconstruct

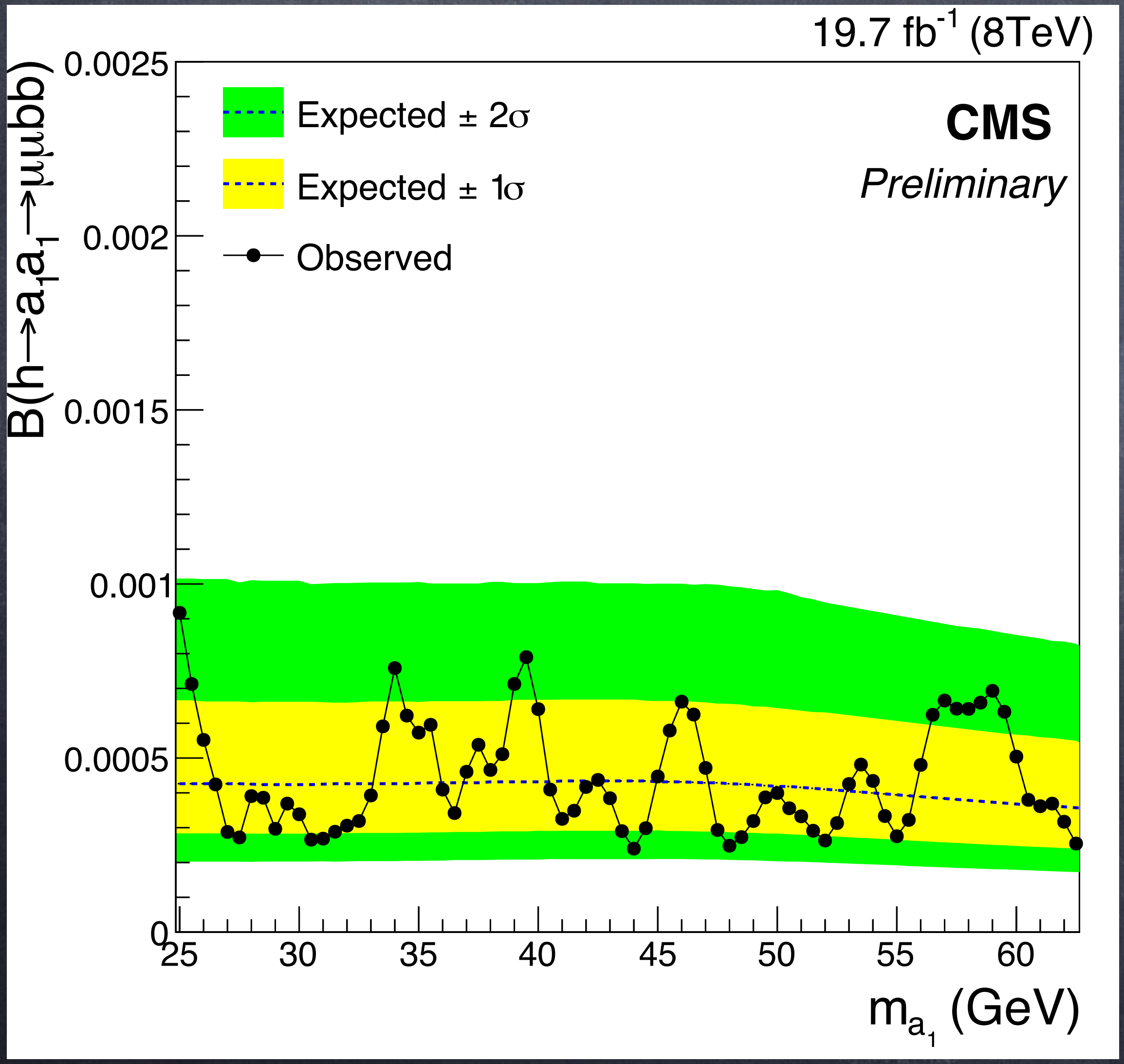
Example: $h \to 4\tau$

Merely 7 TeV bounds, but the improvement with the current data is probably mild. Cut-and-count

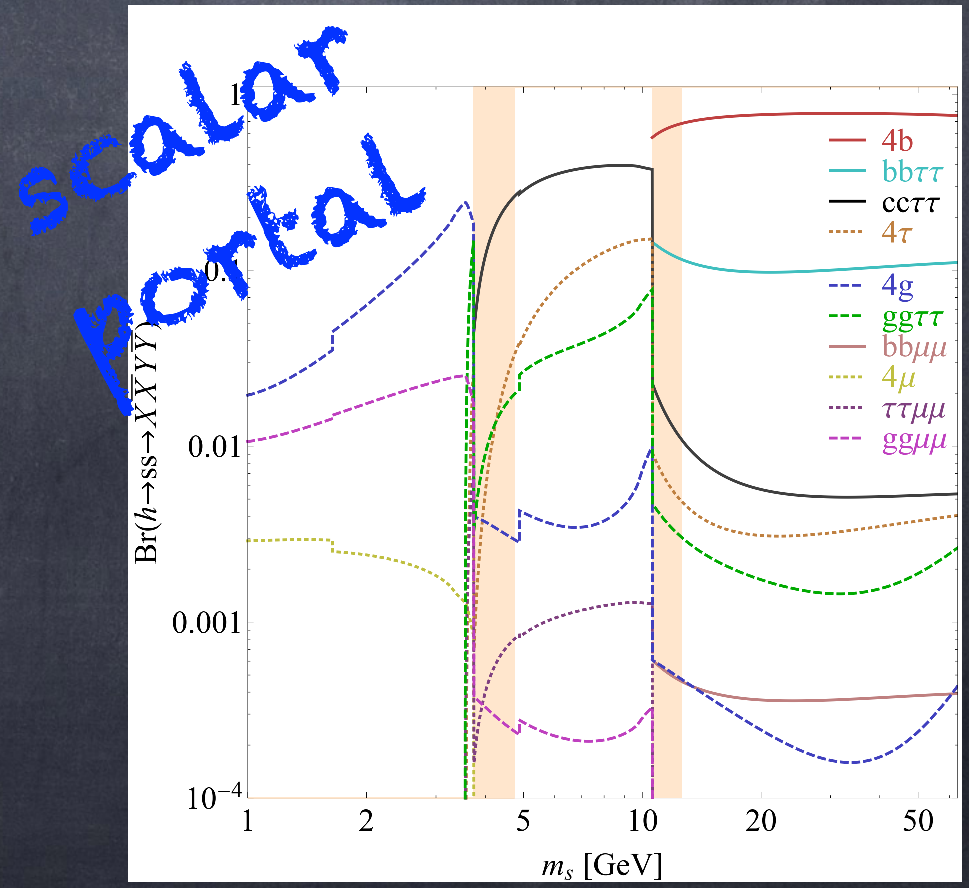


"Recent" Progress: $h \to (bb)(\mu\mu)$

CMS-PAS-HIG-14-041



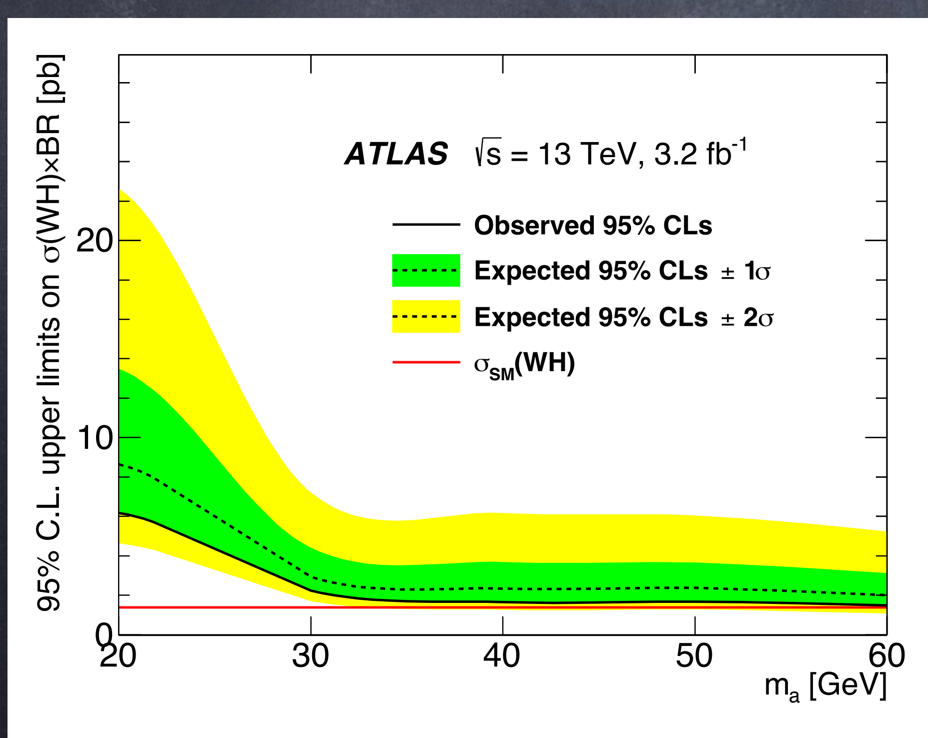
These results go to the range of <0.1% (muons are distinctive). How much do we expect?



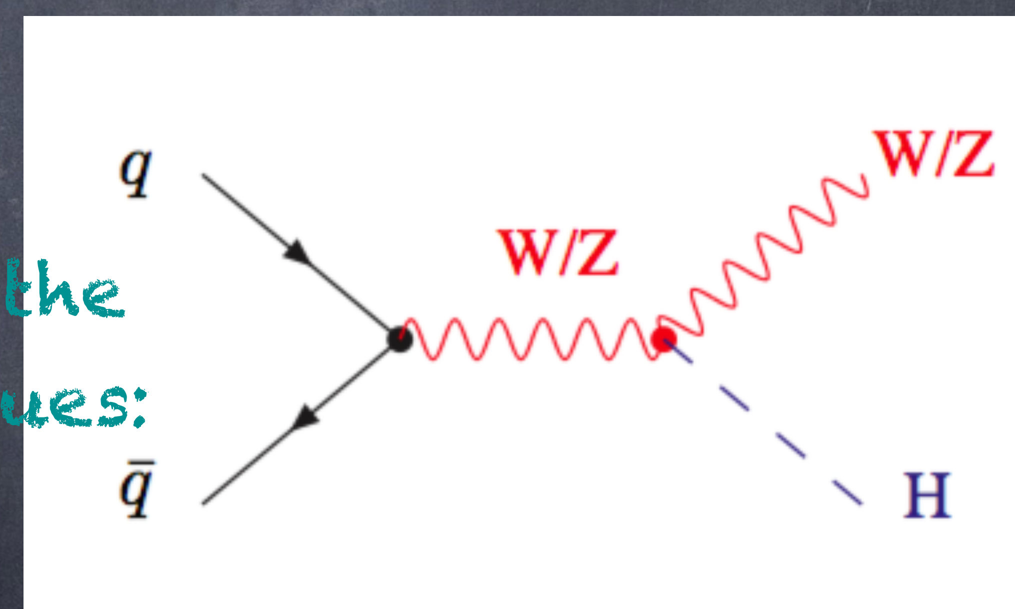
"Recent" Progress: $h \to 4b$

One of the hardest channels, however in lots of models it is expected to be the most abundant ones

Atlas, 1606.08391



To avoid the trigger issues:



Currently cannot even exclude BR = 100%. Wrong way to go?

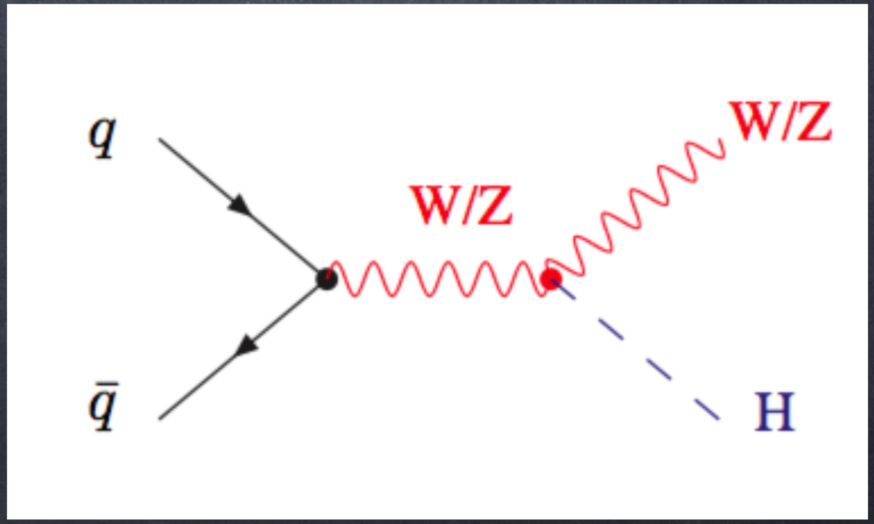
What To Expect from the HL LHC?

Easy channels – statistics limited (leptons).
Difficult channels –backgrounds limited.
Triggers?

More instantaneous luminosity – higher is the pileup.

Back to the 4b:

Can we do better than that? Can we exploit tth? Other channels?



HE LHC: Easy or Difficult?

- The production cross sections will be much higher
- Increase in tth cross section – new opportunities?
- Soft objects will become even more difficult to identify
- The trigger threshold will go up
- Can we exploit the hh channel to find the exotic decays?

Outlook

- Exotic Higgs decays can emerge in many BSM scenarios
- The easy decays (into the leptons with full mass reconstruction) are already nicely constrained
- Hadronic modes and the modes with MET are still mostly indirectly constrained
- The most "recent" progress in some difficult channels motivates looking for new strategies
- Future colliders: can we use new channels? Can we do better than just looking for constraints in associated productions mode?