Higgs and Physics beyond the Standard Model (1)

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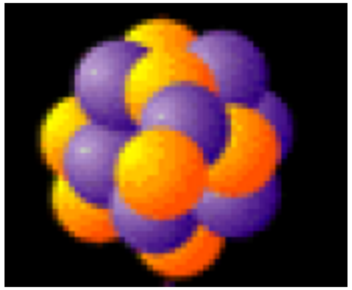
Higgs is the exit from the old world
and the entrance to the new world.

Entering TeV scale physics

MeV



~1930: Discovery of neutrons
Two new forces (strong, weak) are introduced

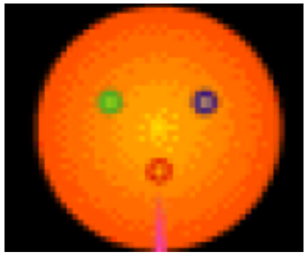
The Fermi constant

The Higgs VEV

$$G_F = \frac{1}{\sqrt{2}v^2}$$

Nambu's Symmetry Breaking

GeV



~1970: Theory of three interactions based on one additional unknown force (electroweak symmetry breaking)

TeV

?

~2010: What is the unknown force?

A Higgs boson

No lose theorem

There must be a Higgs boson(s) or some alternative signals below
a TeV energy scale related to the dynamics of electroweak symmetry breaking.

A Higgs boson is a tool to probe the TeV physics

It is likely to find a Standard Model (SM) -like Higgs boson near future.
May new physics models predict a SM-like Higgs boson as the first signal
to physics behind the electroweak symmetry breaking.

A Higgs boson may play a similar role of the pion for strong interaction
in understanding the weak interaction.

The pion is the Yukawa meson and the Nambu-Goldstone boson associated
with chiral symmetry breaking in strong interaction.

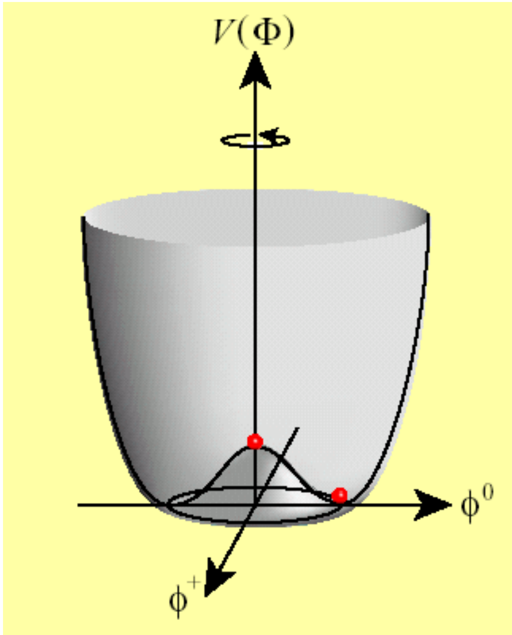
The SM Higgs Lagrangian

$$L = |D_\mu \Phi|^2 - (-\mu^2 |\Phi|^2 + \lambda |\Phi|^4)$$

$$\Phi = \left(\begin{array}{c} \phi^+(x) \\ \frac{v+h(x)}{\sqrt{2}} + i\frac{\eta(x)}{\sqrt{2}} \end{array} \right)$$

v~246 GeV

h(x): physical Higgs boson



Very simple!

Only one free parameter determined by the Higgs boson mass

$$m_h = \sqrt{2\lambda} v$$

But this is supposed to be an effective theory below some cutoff scale.

Fundamental questions are:

Where is the cutoff ?

How does the Higgs field arise?

What determines the Higgs potential?

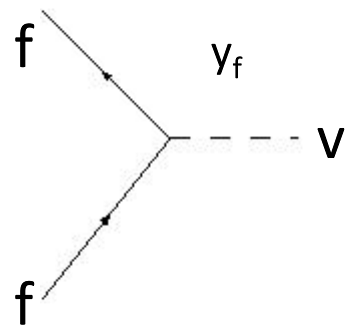
Mass formulas of elementary particles

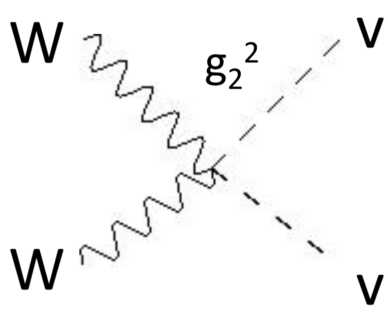
Higgs boson $$m_h = \sqrt{2\lambda} v$$

Quarks, leptons $$m_f = \frac{y_f}{\sqrt{2}} v$$

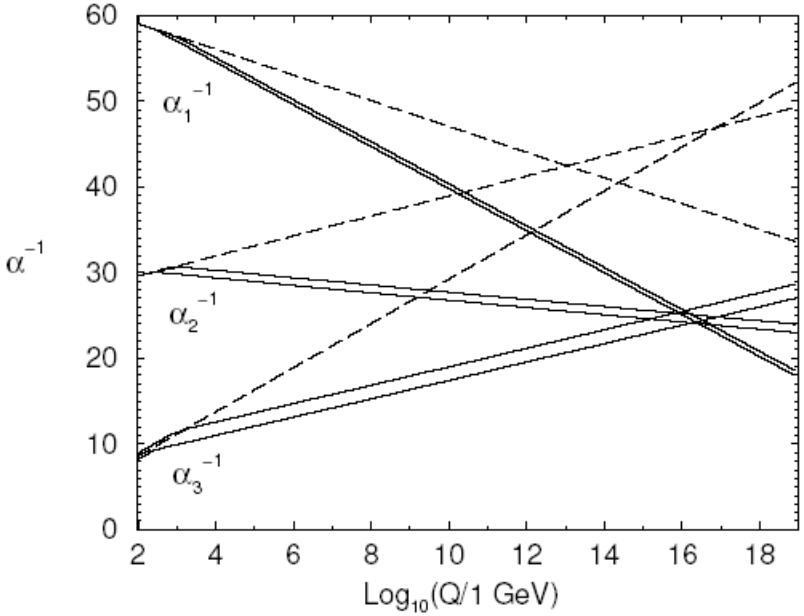
W boson $$m_W = \frac{g_2}{2} v$$

Z boson $$m_Z = \frac{\sqrt{g_1^2 + g_2^2}}{2} v$$

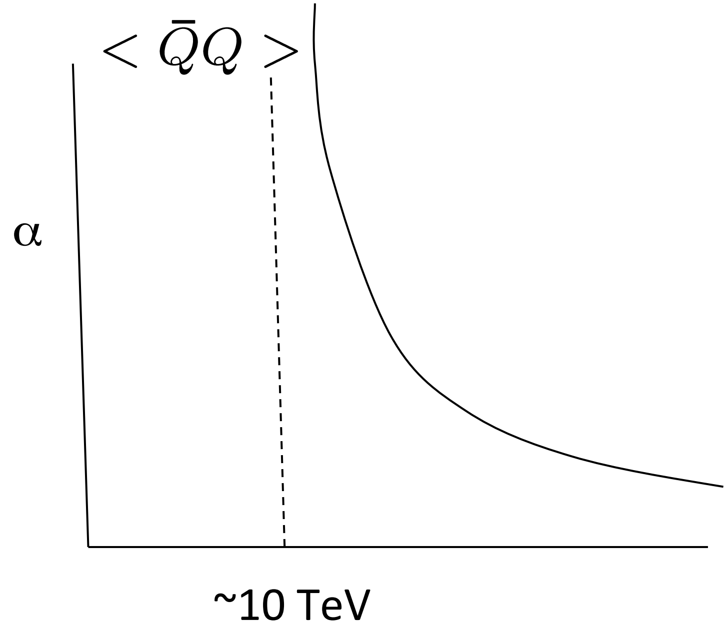




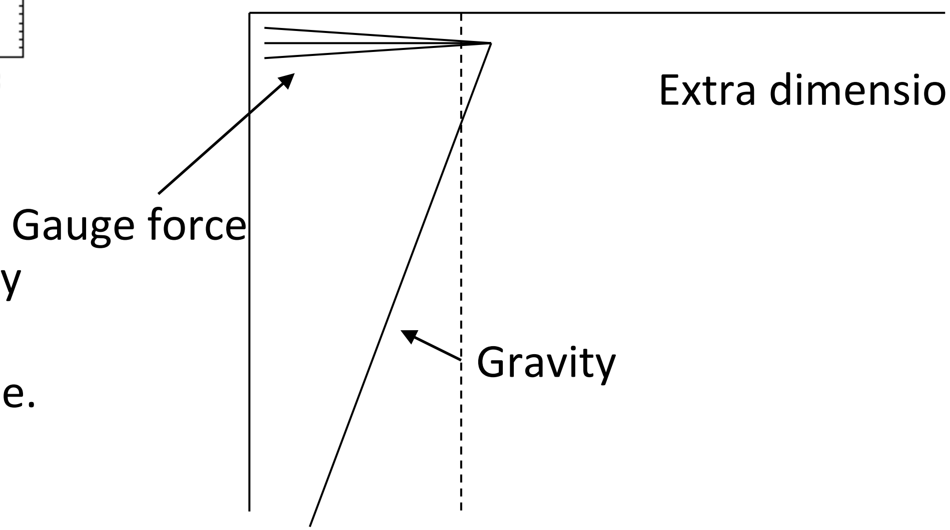
SUSY GUT



Composite model



Extra dimension



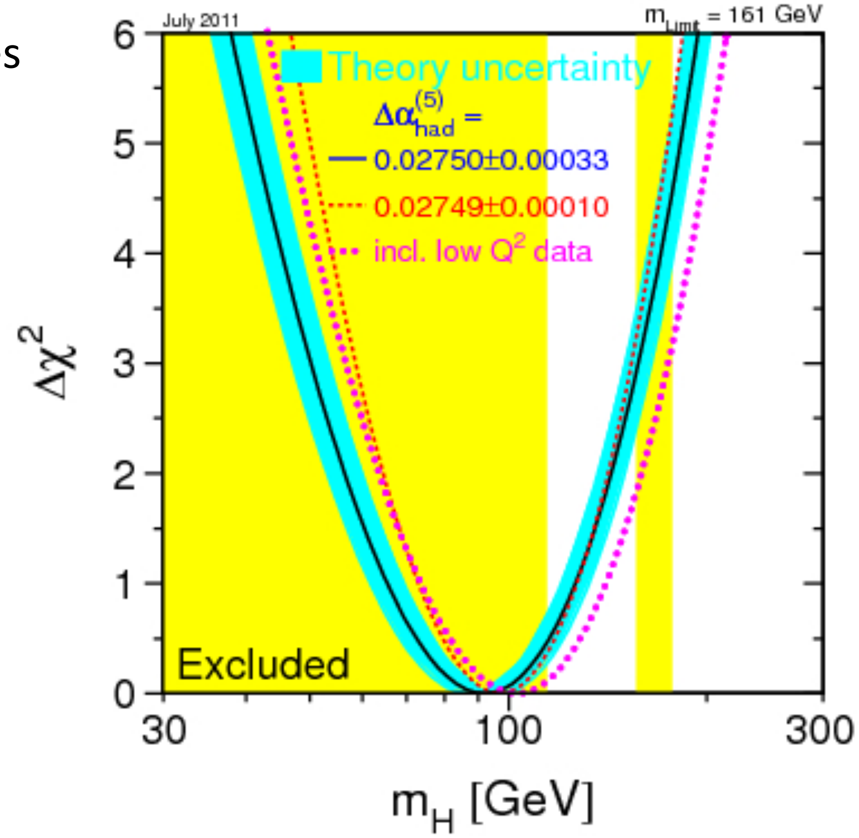
Even if theories looks similar
at 100GeV, they may be completely
different at the energy scale
larger by a few orders of magnitude.

Indirect constraint on the Higgs boson mass before the LHC discovery

Electroweak precision measurements combined with the top and W boson masses indicate a light Higgs boson in the SM.

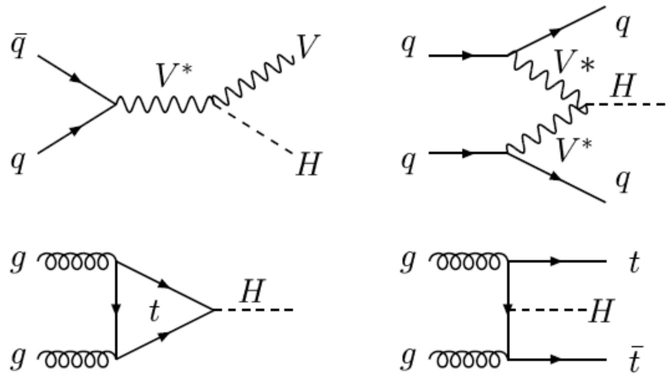
$$m_h < 161 \text{ GeV (95\%CL)}$$

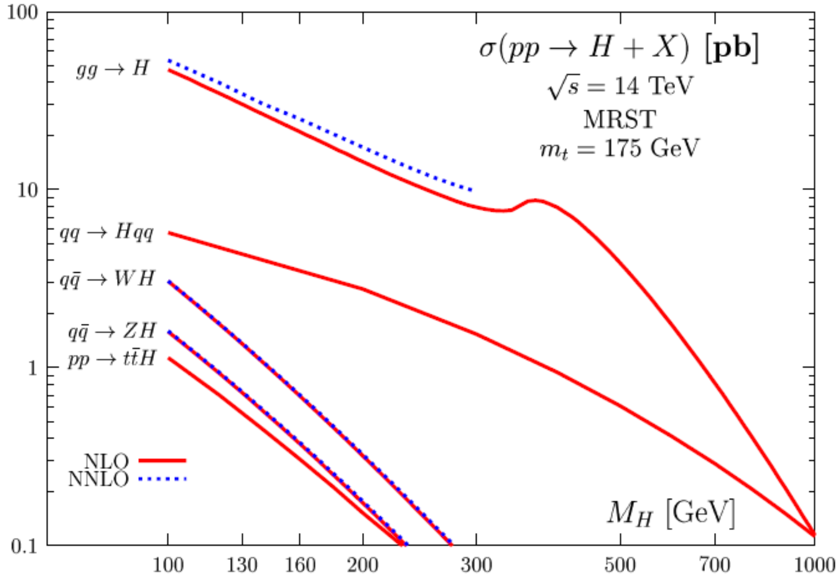
~~If a heaver Higgs boson is found, there should be something more than one Higgs boson.~~



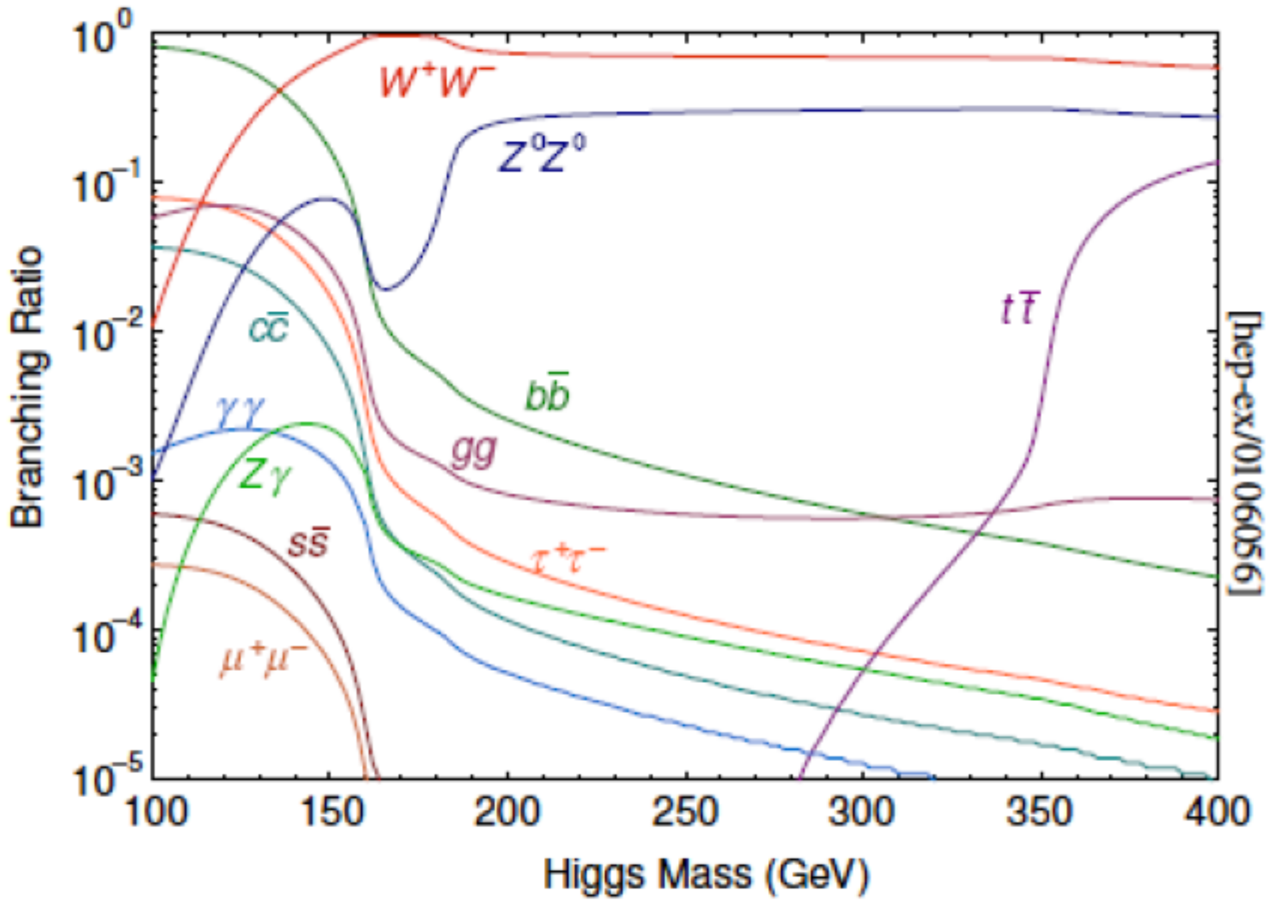
SM Higgs search at the LHC

Production processes and cross sections at the LHC in the SM:





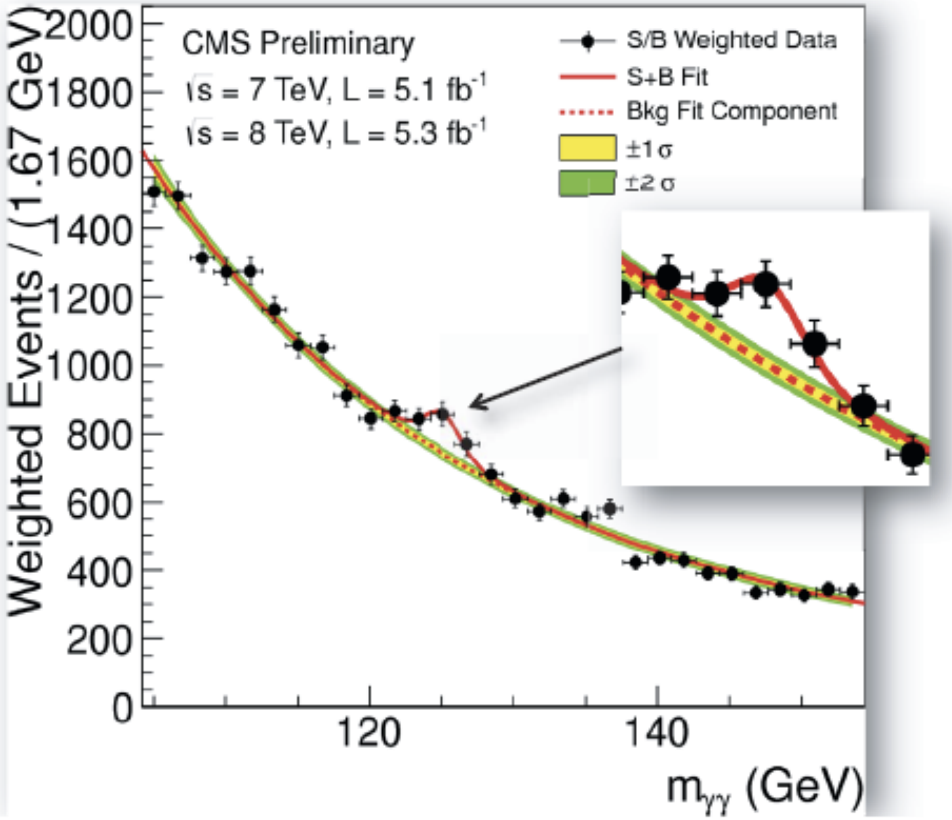
Higgs boson branching ratio



Higgs bosons tend to decay heaviest possible particles.

S/B Weighted Mass Distribution

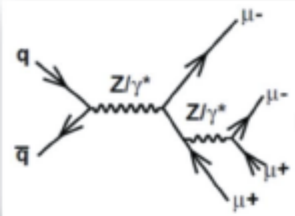
- Sum of mass distributions for each event class, weighted by S/B
  - B is integral of background model over a constant signal fraction interval

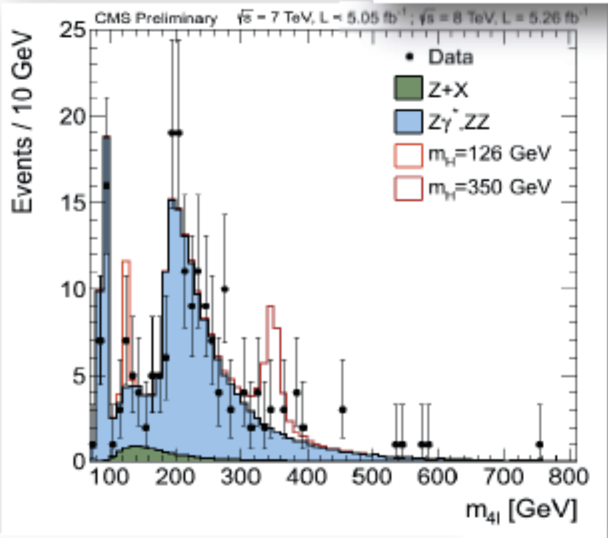


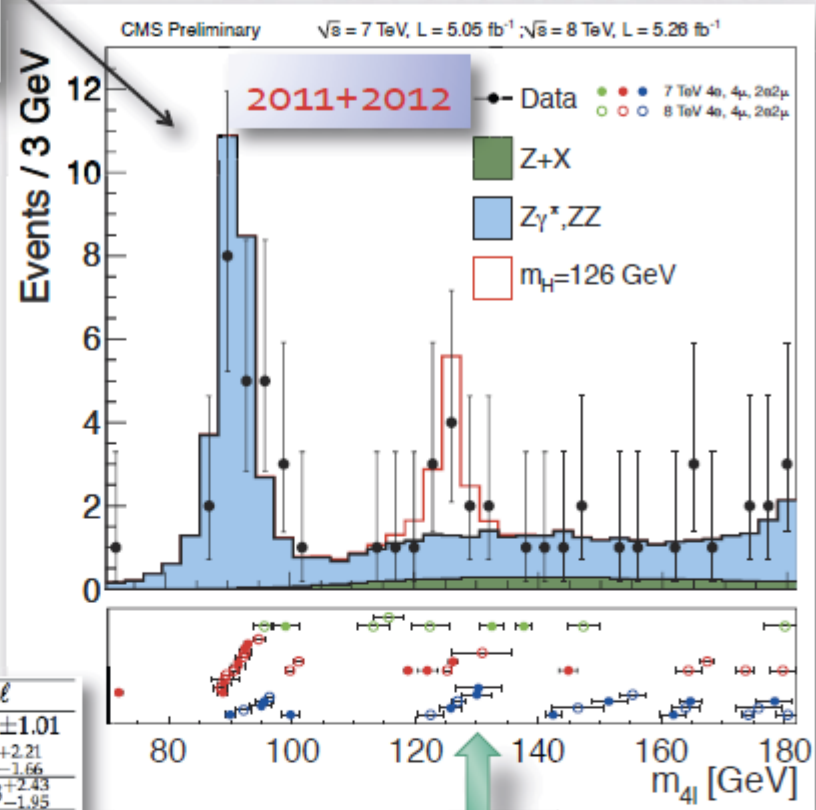
July 9th 2012 ICHEP CMS Higgs J. Incandela for the CMS COLLABORATION

- Not used for calculation
  - But provides a nice viewpoint:
    - Very similar to that seen by the significance calculation!
    - Very resilient

Results: m(4l) spectrum







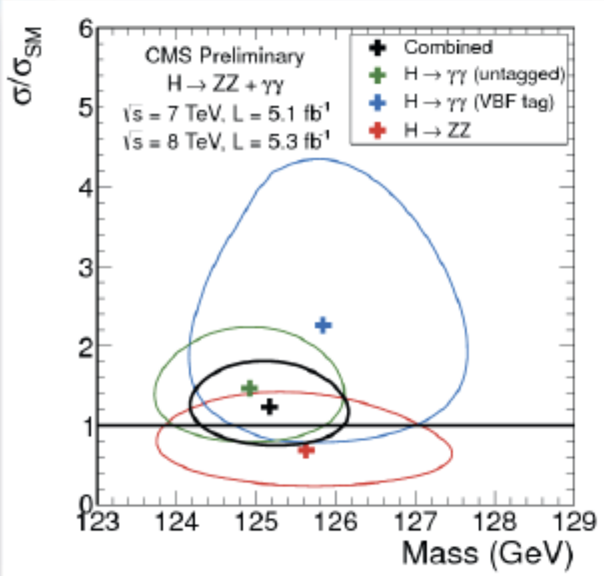
Event-by-event errors

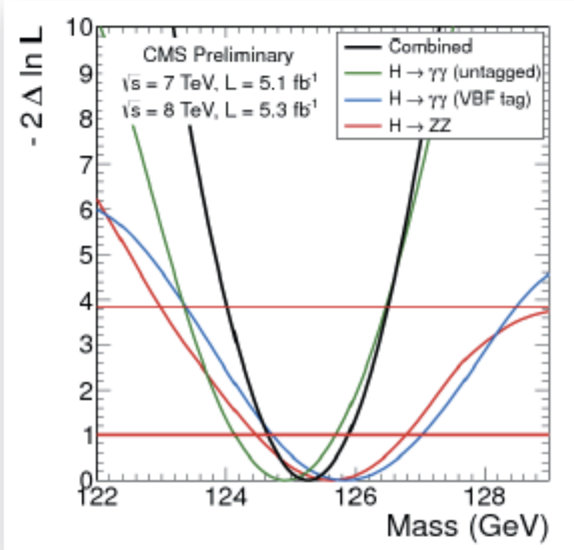
Yields for m(4l)=110..160 GeV

Channel	4e	4μ	2e2μ	4ℓ
ZZ background	2.65 ±0.31	5.65 ±0.59	7.17 ±0.76	15.48 ±1.01
Z+X	$1.20^{+1.08}_{-0.78}$	$0.92^{+0.65}_{-0.55}$	$2.29^{+1.81}_{-1.36}$	$4.41^{+2.21}_{-1.66}$
All backgrounds	$3.85^{+1.12}_{-0.84}$	$6.58^{+0.88}_{-0.81}$	$9.46^{+1.96}_{-1.56}$	$19.88^{+2.43}_{-1.95}$
$m_H = 126$ GeV	1.51 ±0.48	2.99 ±0.60	3.81 ±0.89	8.31 ±1.18

164 events expected in [100, 800 GeV]
172 events observed in [100, 800 GeV]

Characterization of the excess: mass





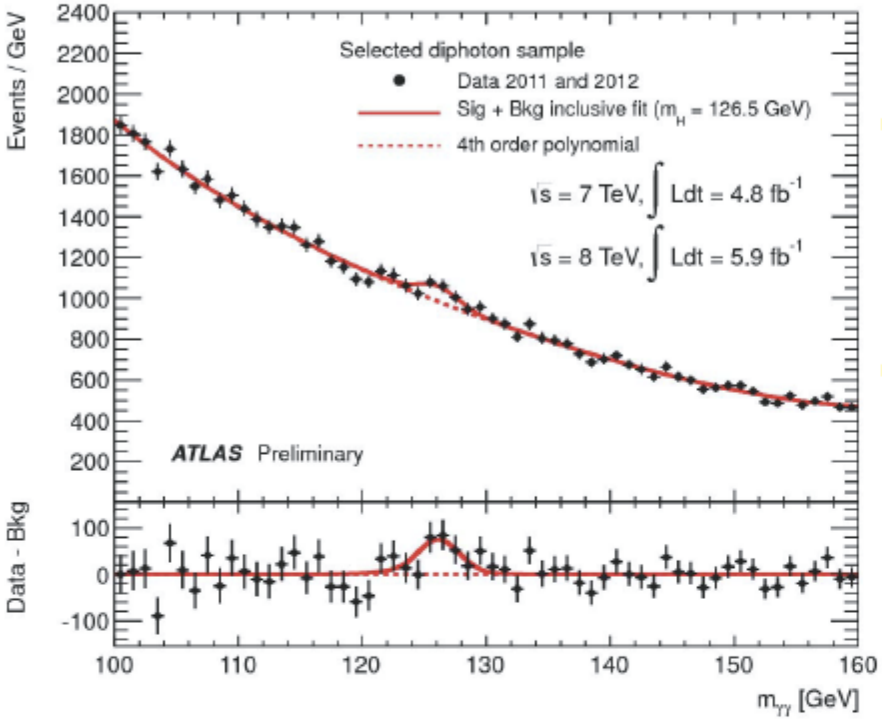
- Likelihood scan for mass and signal strength in three high mass resolution channels
  - results are self-consistent and can be combined

- To reduce model dependence, allow for free cross sections in three channels and fit for the common mass:

m = 125.3 ± 0.4 (stat) ± 0.5 (syst)

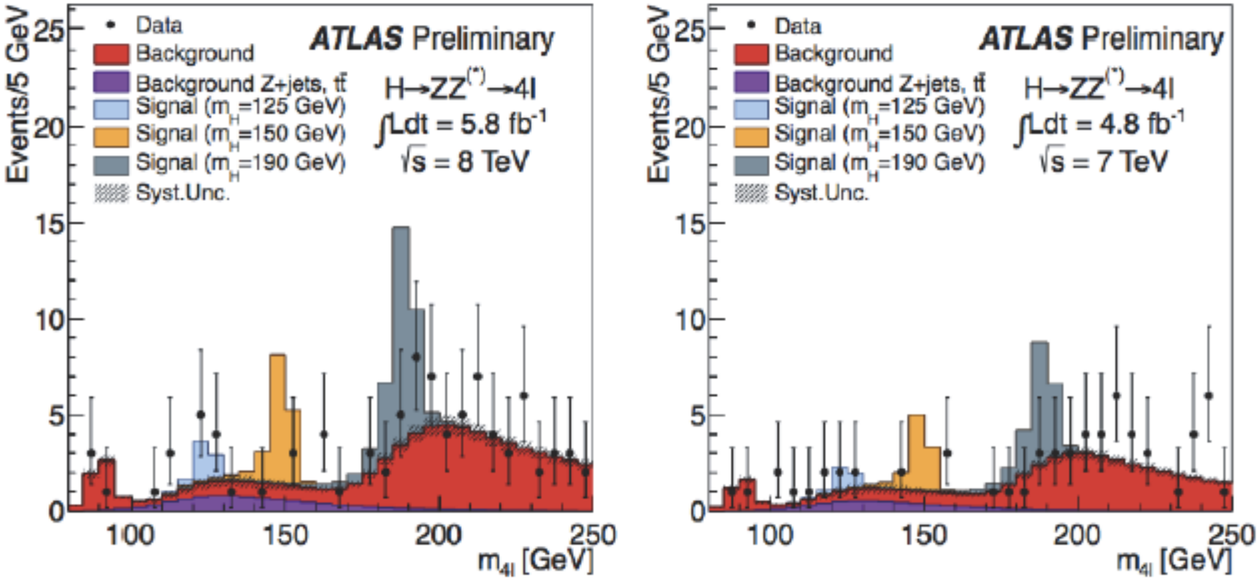
H→γγ analysis: invariant mass distributions

- Invariant mass distribution combining 2012 (35271 events) and 2011 (23788)



- Simple unweighted sum of events passing γγ selection and kinematic cuts, before categorization
  - Fit to signal model at 126.5 GeV+4th order Bernstein b/g mode
- Full results obtained by splitting data into 10 categories and fitting mass distributions separately …

H→4 leptons: Low mass candidates

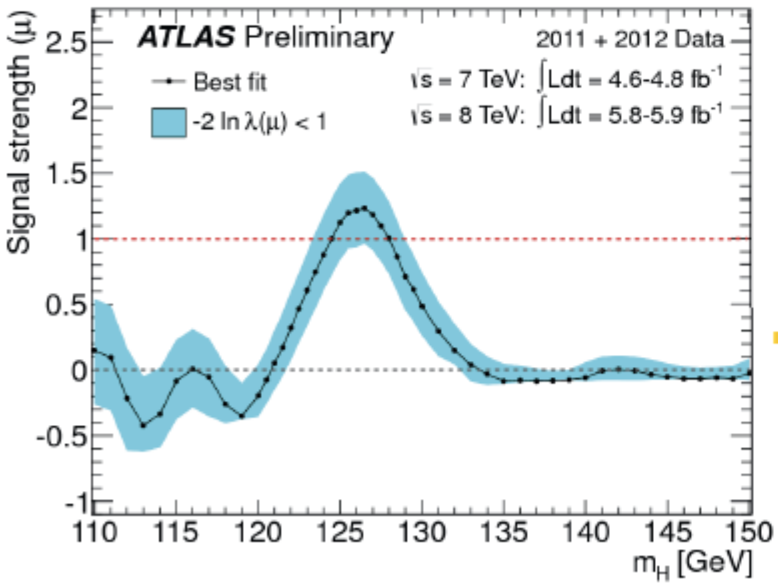


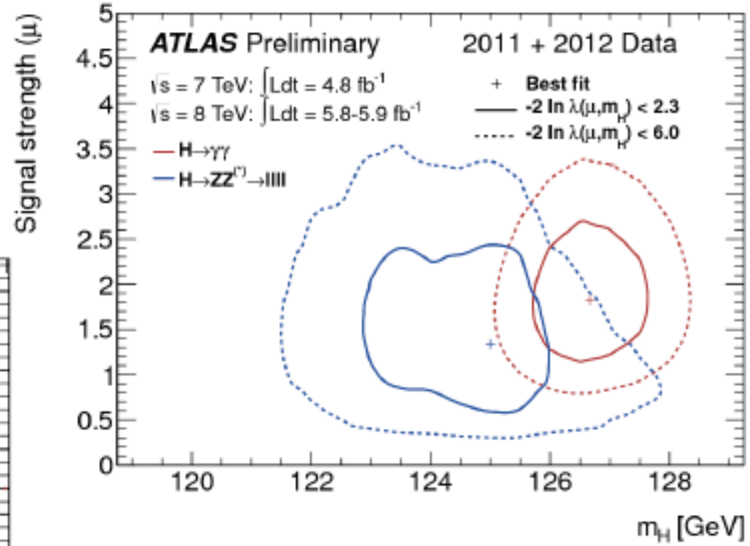
$120<m_{4l}<130$ GeV
Event counts

7+8 TeV	4μ	2e2μ	4e
Background	1.3±0.1	2.2±0.2	1.6±0.2
Data	6	5	2
m_H=125 GeV	2.1±0.3	2.3±0.3	0.9±0.1
S/B	1.6	1.0	0.6

Investigating the excess

- Comb[n] best fit signal strength μ vs m_H
  - Made by scanning m_H and finding the best-fit value of μ at each m_H
  - At 126.5 GeV, μ=1.2±0.3
    - Compatible with SM expectation (μ=1)





- Let m_H and μ float, 2D contour plot around best fit values
  - Done separately for H→γγ and H→4-leptons
  - Best fit masses are compatible
    - ESS has only a small effect