Standard Model Higgs Phenomenology

Majid Hashemi

Shiraz University

&

SPA, IPM,

IPM, Tehran, 16 Shahrivar 1390

- The theory of electroweak interactions started by proposing massless weak bosons with the following Lagrangian:

$$L = -\frac{1}{4}\overrightarrow{W_{\mu\nu}}.\overrightarrow{W^{\mu\nu}} - \frac{1}{4}B_{\mu\nu}B^{\mu\nu} + \overline{\psi} i\gamma^{\mu}D_{\mu}\psi$$

$$\overrightarrow{W_{\mu\nu}} = \partial_{\mu}\overrightarrow{W_{\nu}} - \partial_{\nu}\overrightarrow{W_{\mu}} - g\overrightarrow{W_{\mu}} \times \overrightarrow{W_{\nu}}$$

$$B_{\mu\nu} = \partial_{\mu}B_{\nu} - \partial_{\nu}B_{\mu}$$

- A combination of W^1 and W^2 makes W^+ and W^-
- A combination of W^3 and B makes Z and γ

  but they are massless at this moment.

- To give masses to weak boson while keeping the renormalizability of the theory a Higgs boson field was introduced with the following Lagrangian:

$$L = (D_\mu\phi)^\dagger(D_\mu\phi) + \mu^2 \phi^\dagger\phi + \lambda (\phi^\dagger\phi)^2, \quad \varphi = \begin{pmatrix} \varphi^+ \\ \varphi^0 \end{pmatrix}$$

- If a spontaneous symmetry breaking happens and Higgs potential chooses $\phi^+=0$ and $\phi^0=(v+H)/\sqrt{2}$, a mass spectrum is obtained:

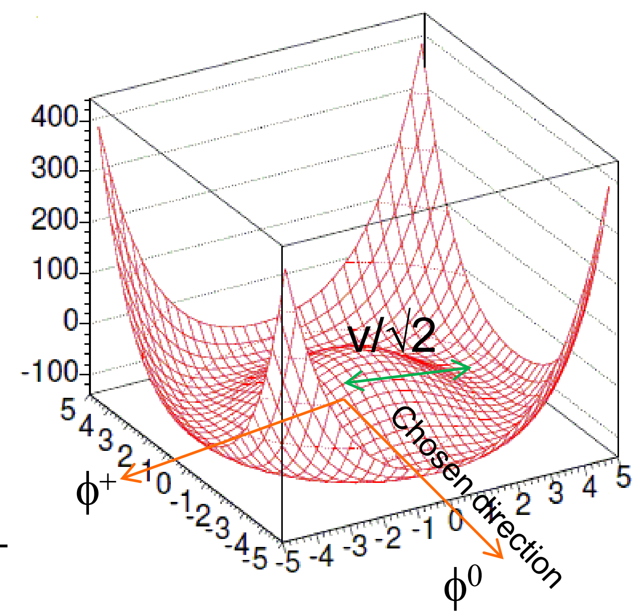
$$\varphi = \frac{1}{\sqrt{2}}\begin{pmatrix} 0 \\ v+H \end{pmatrix}$$

$$M_W = \frac{gv}{2}$$

$$M_Z = \frac{g_Z v}{2}$$

$$M_\gamma = 0$$

$$M_H = \sqrt{-2\mu^2}$$



- The Higgs potential vev (v) is obtained in terms of G_F measured from low energy muon decay :

$$v = \frac{2M_W}{g} = (\sqrt{2}G_F)^{-1/2} \cong 246\ GeV$$

- M_W and M_Z are predicted to be

$$M_W = A/\sin\theta_W$$
$$M_Z = A/\sin\theta_W \cos\theta_W$$
$$A(\alpha_{em}, G_F) \cong 37 GeV$$

- $\sin^2\theta_W \sim 0.23$ from Z-exchange involved scattering e.g. $e^+e \rightarrow ee$,…

- Therefore the Higgs mechanism predicts

$$M_W \cong 80 GeV$$
$$M_Z \cong 90 GeV$$
$$M_\gamma = 0$$

- The same values for M_W and M_Z were measured at LEP experiment at CERN.

- But the Higgs boson mass remains as the open parameter of the model.

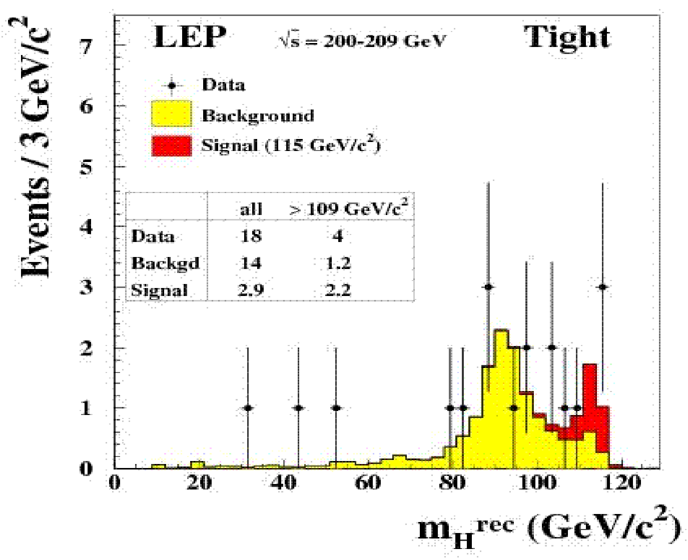
W and Z boson discovery

- The W and Z bosons were discovered at LEP (Large electron positron collider) at CERN,

- The Higgs boson process was $e^- e^+ \to Z\,H$
- The center of mass energy was ~210 GeV
- The Higgs boson upper mass to search for was 210-90=120 GeV

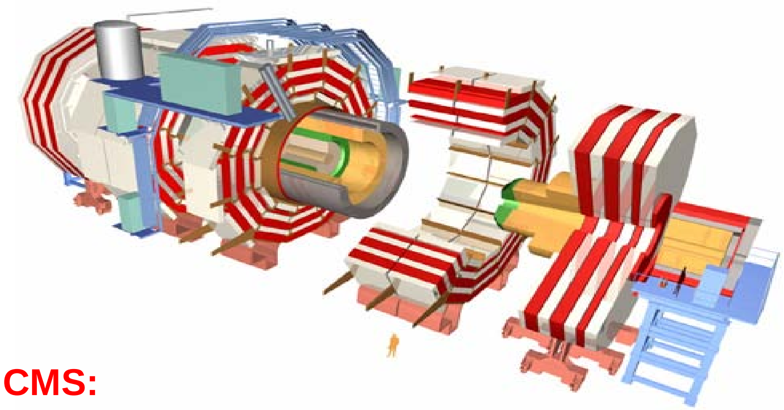
- But no Higgs boson was not found in the mass range below 120 GeV
- Although a 3sigma evidence was observed around m(H)~114 GeV

- To complete the mission, LEP was upgraded to LHC
- The same tunnel was used with upgraded magnets, detectors, …

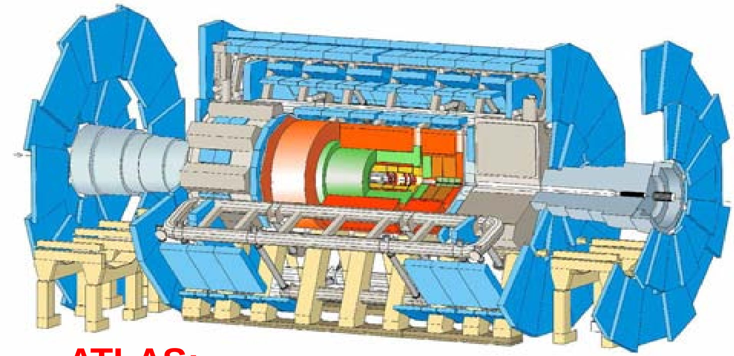


INSTITUTE FOR RESEARCH IN FUNDAMENTAL SCIENCES

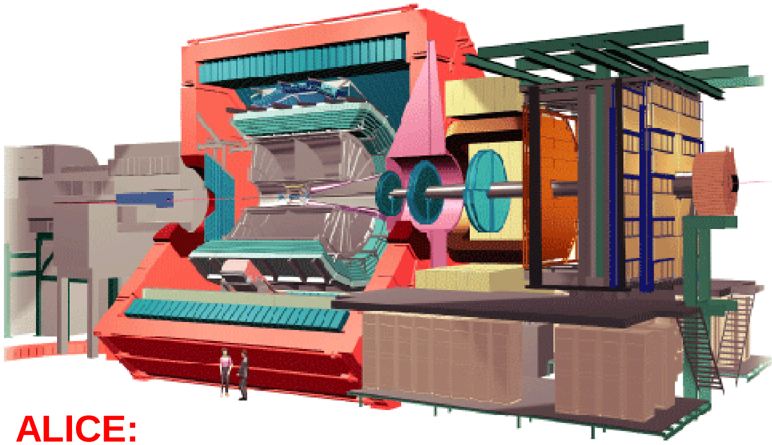
LHC has 4 main detectors:



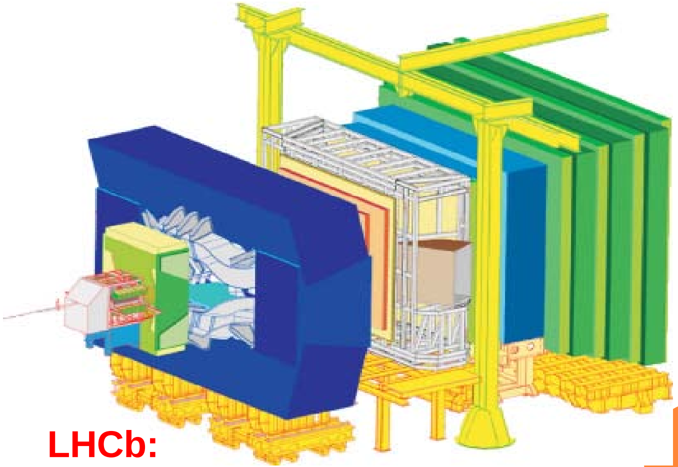
CMS:
Size: 21 m long, 15 m wide and 15 m high.
Weight: 12 500 tonnes
Location: Cessy, France.



ATLAS:
Size: 46 m long, 25 m high and 25 m wide.
Weight: 7000 tonnes
Location: Meyrin, Switzerland.



ALICE:
Size: 26 m long, 16 m high, 16 m wide
Weight: 10 000 tonnes
Location: St Genis-Pouilly, France



LHCb:
Size: 21m long, 10m high and 13m wide
Weight: 5600 tonnes
Location: Ferney-Voltaire, France.

Current results from Higgs boson searches

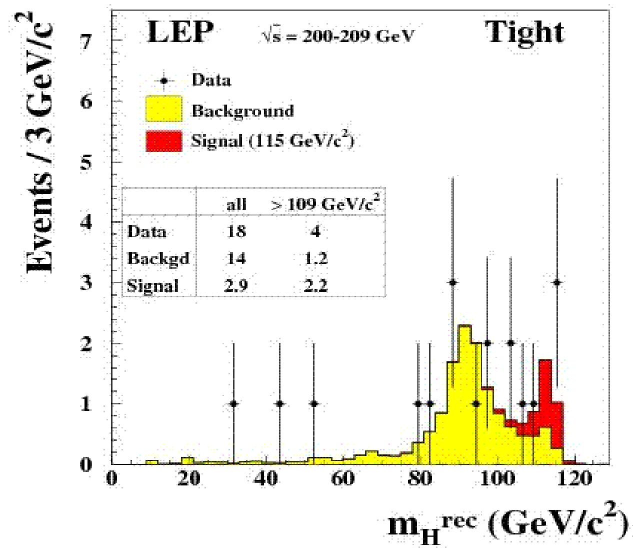
- Results already obtained from LEP (in the same tunnel before upgrading to LHC) shows a Higgs boson mass lower limit of 114.4GeV at 95% C.L. (CERN-EP 2003-011)

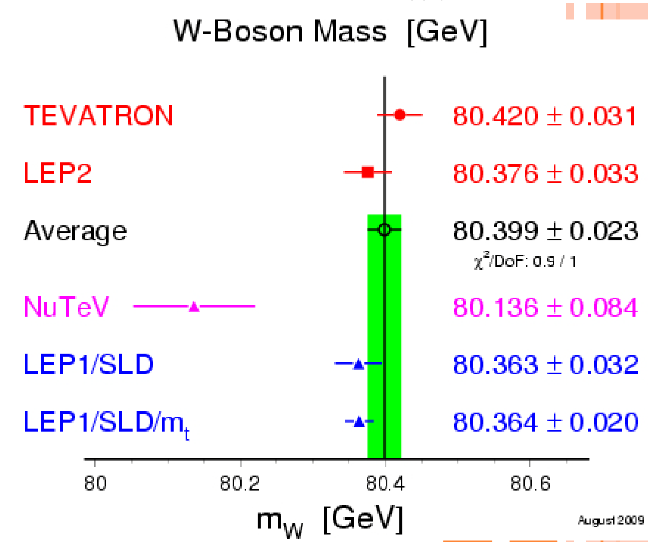
- Indirect searches including fits to precision electroweak measurements set an upper limit of 182GeV (hep-ex 0710.4983)

- Recently including results on W mass measurements in Tevatron the upper limit was set to m(H)<158 GeV from EW fits.

- The current indirect search result:

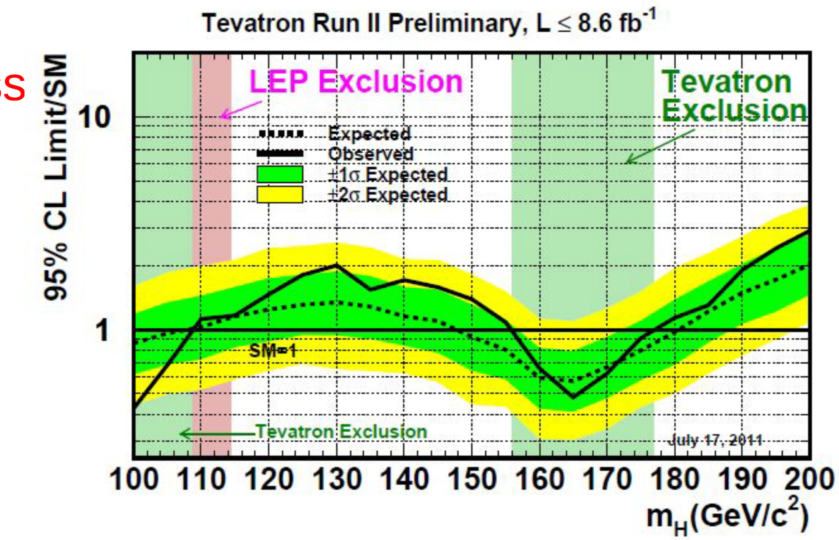
m(H)<158 GeV





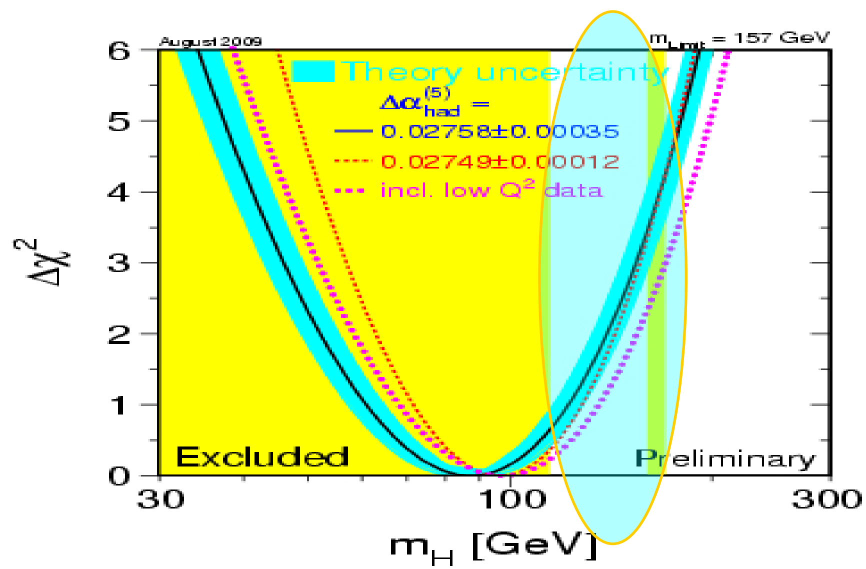
Current results from Higgs boson searches (2)

- Tevatron has recently excluded the mass range between 156 and 177 GeV, arXiv: 1107.5518[hep-ex]



- The most probable region would be

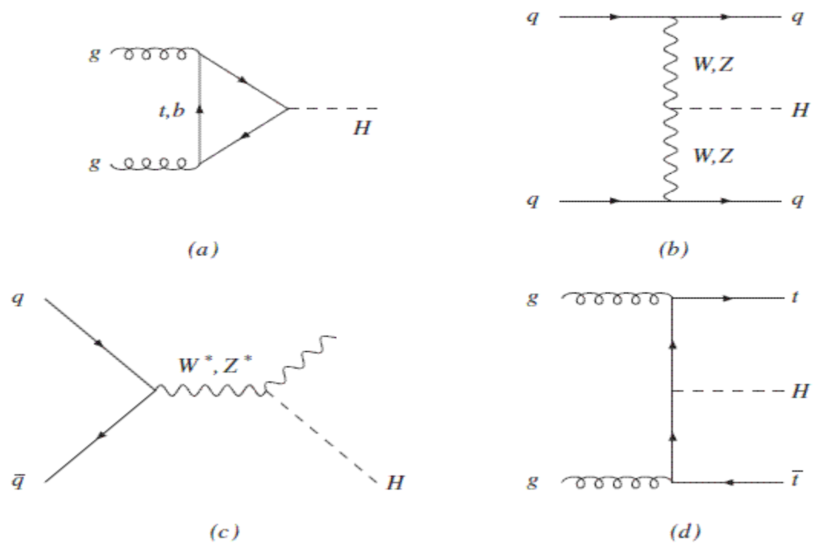
114.4<m(H)<156 GeV



Search strategy in CMS

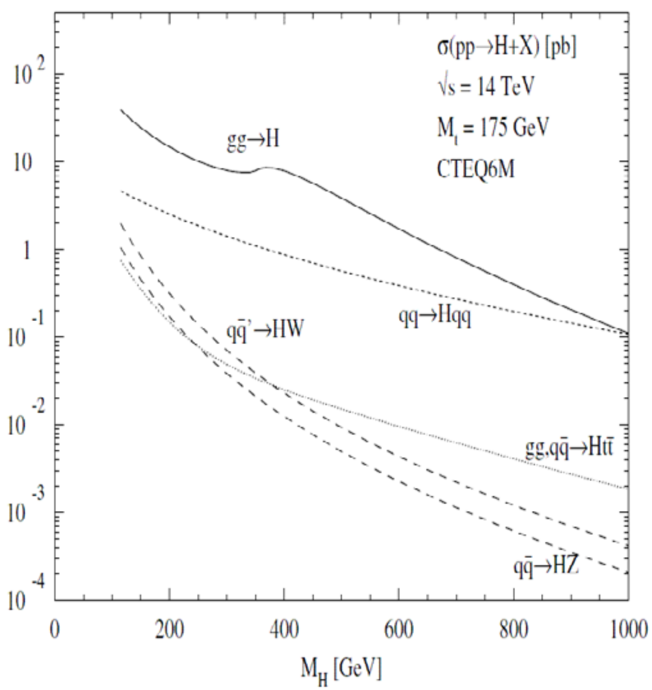
❑CMS search channels:

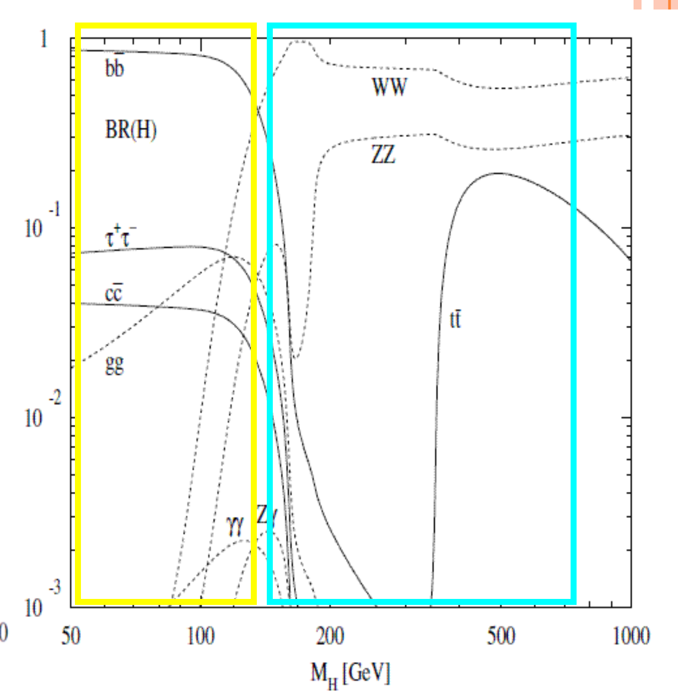
- $pp \rightarrow H \rightarrow \gamma\gamma$
- $pp \rightarrow H \rightarrow ZZ^{(*)} \rightarrow 4l\,(l = e, \mu)$
- $pp \rightarrow qqH \rightarrow qq\tau^{+}\tau^{-}$
- $pp \rightarrow H \rightarrow W^{+}W^{-} \rightarrow l\nu l\nu, l\nu qq$



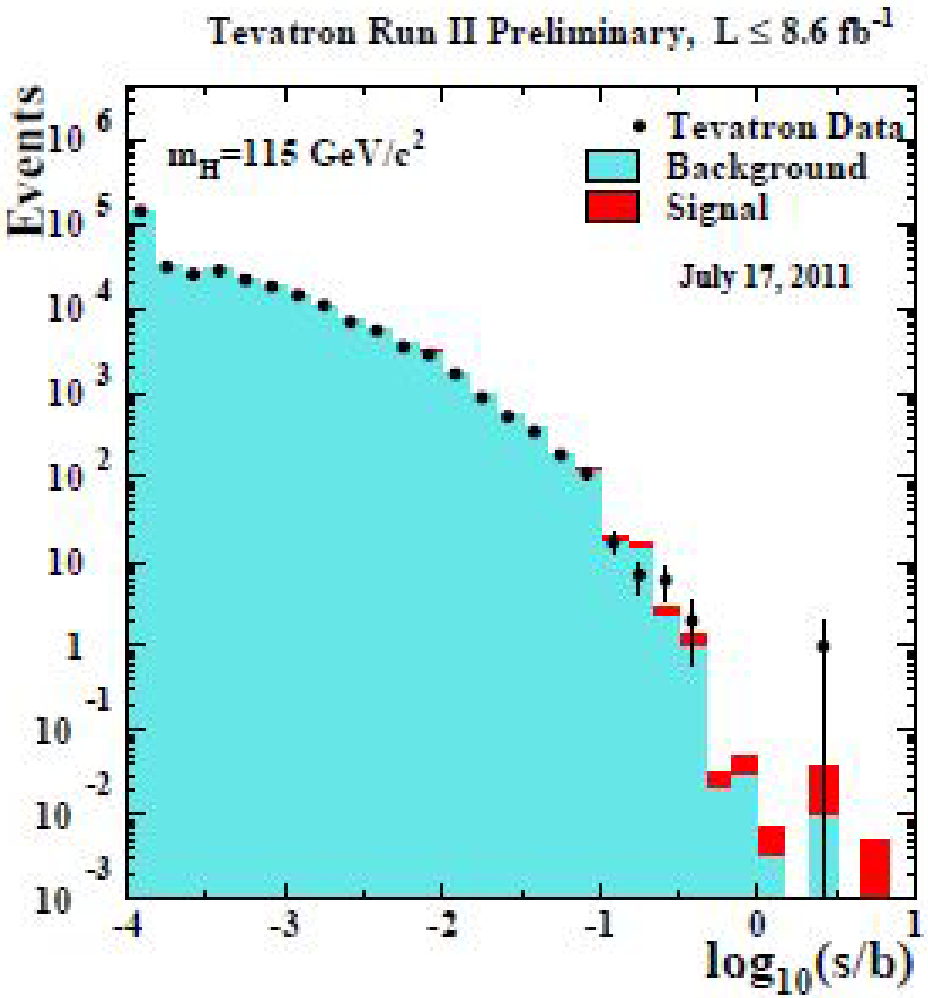
❑$H\rightarrow\gamma\gamma$ and $H\rightarrow\tau\tau$ are used for low mass Higgs boson search m(H)<135 GeV

❑$H\rightarrow WW$ and $H\rightarrow ZZ$ are used for intermediate and high mass searches 130<m(H)<700 GeV.



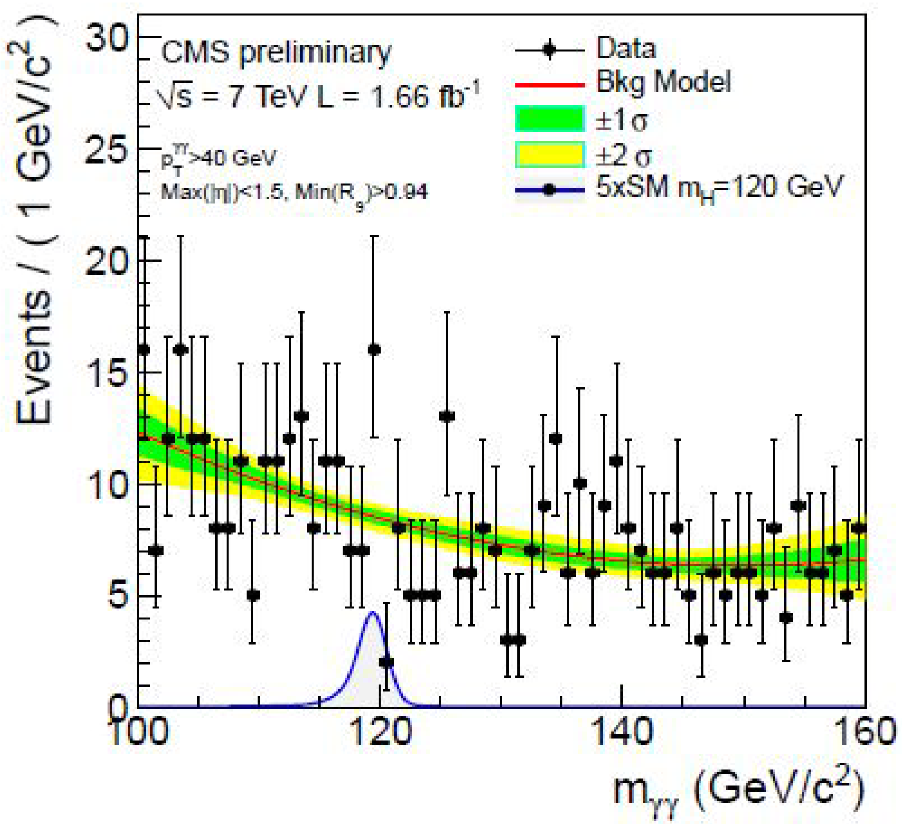


A reminder

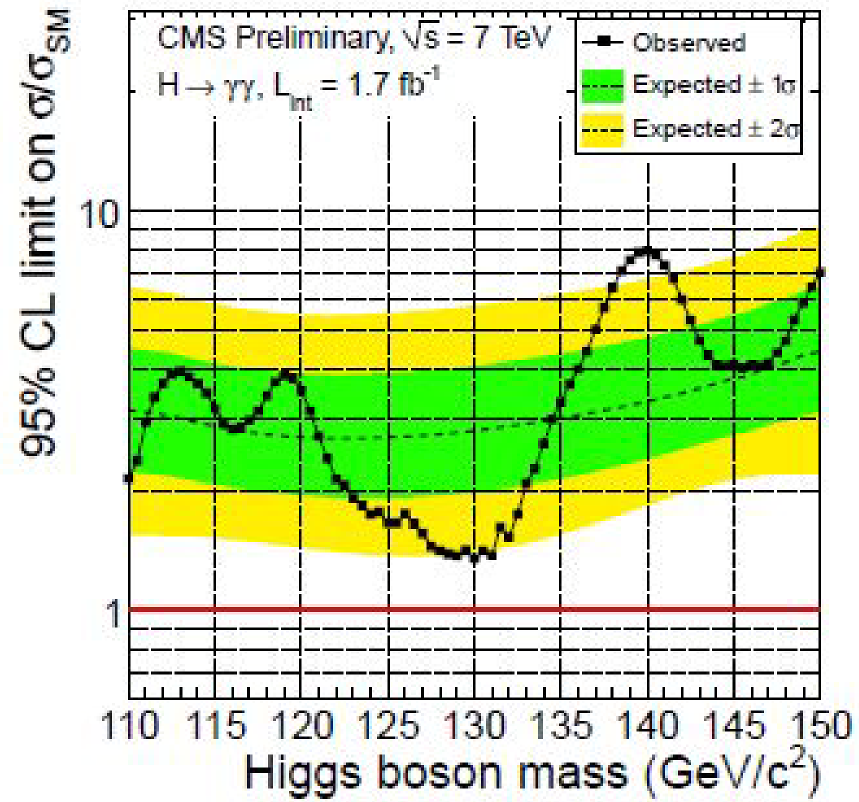


Before going to LHC results I should mention that all Tevatron and LHC results are based on searches for tiny effects and very small deviations from SM.

H -> γγ in CMS

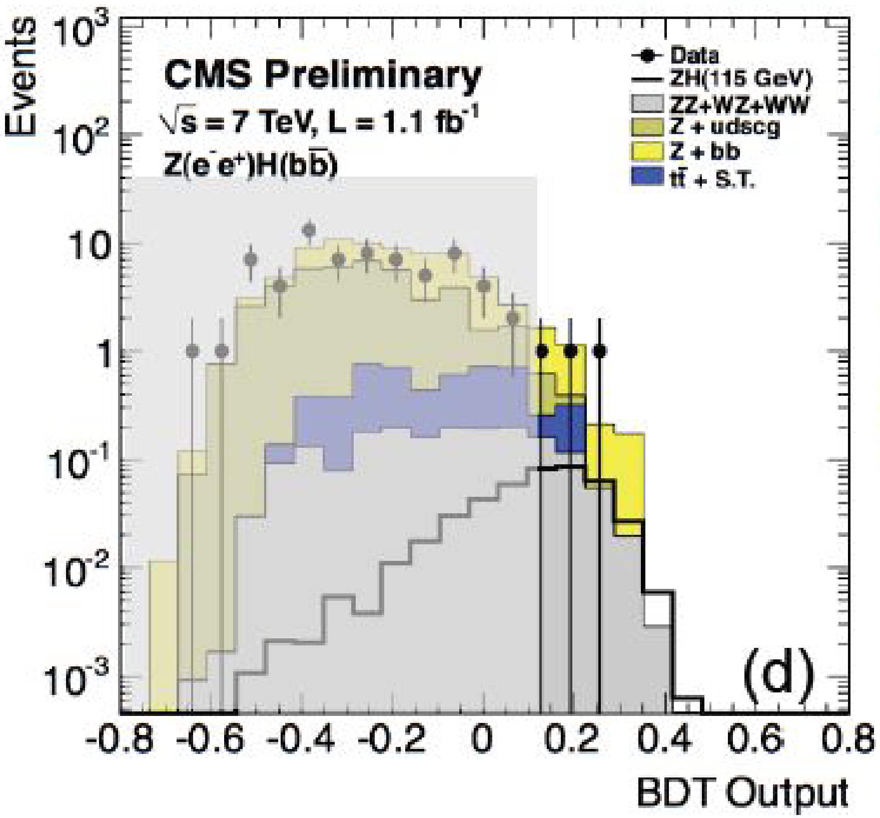


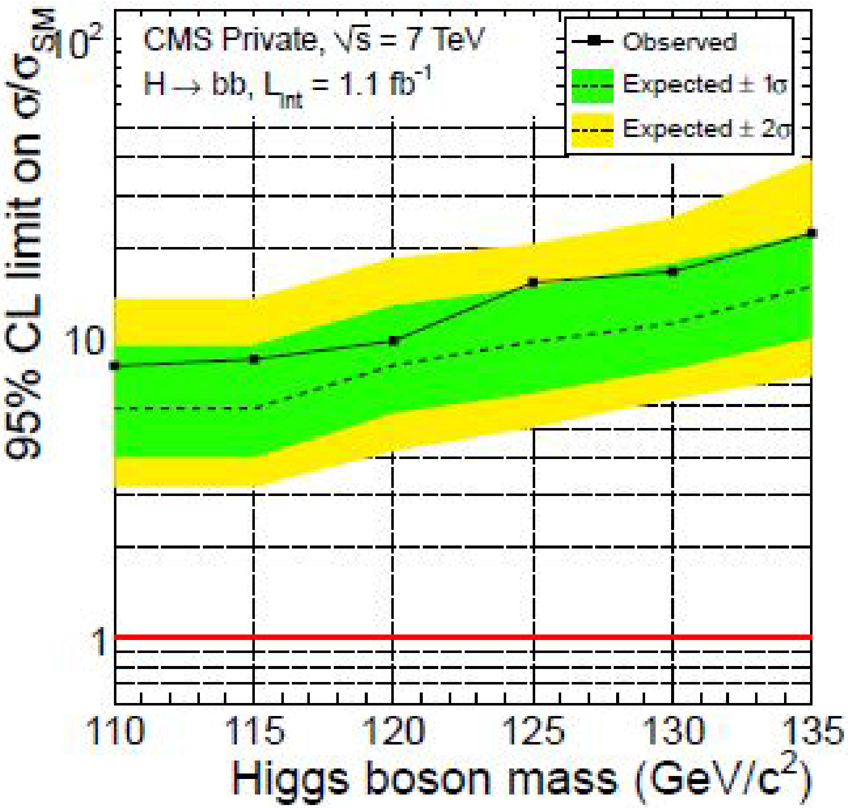
CMS preliminary
√s = 7 TeV L = 1.66 fb-1
Data
Bkg Model
±1σ
±2σ
5xSM mH=120 GeV
Events / (1 GeV/c2)
mγγ (GeV/c2)



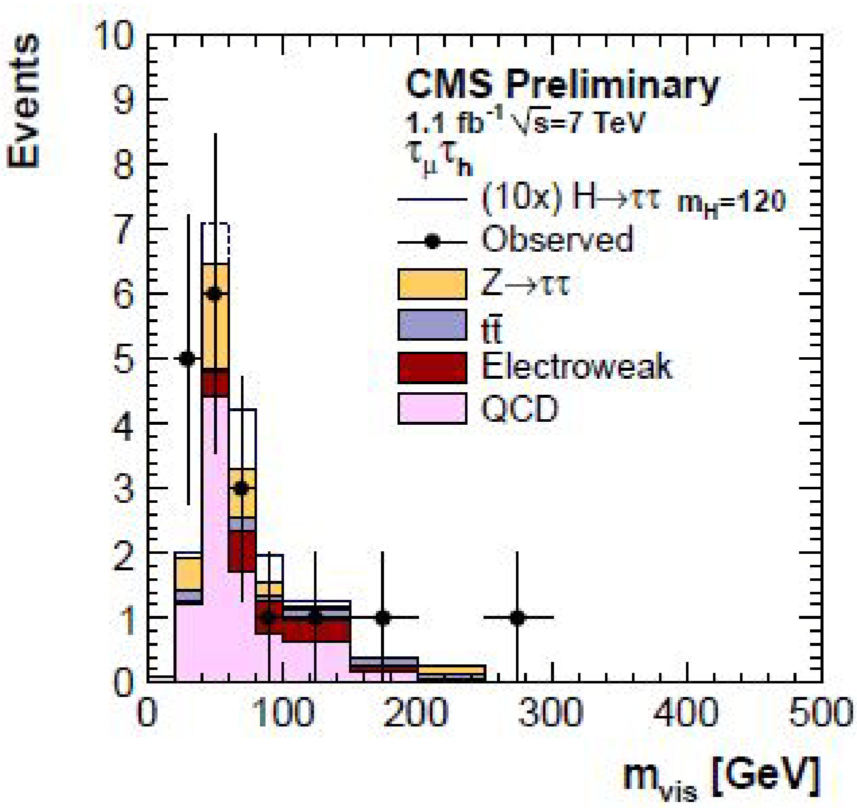
CMS Preliminary, √s = 7 TeV
H→γγ, Lint = 1.7 fb-1
Observed
Expected ± 1σ
Expected ± 2σ
95% CL limit on σ/σSM
Higgs boson mass (GeV/c2)

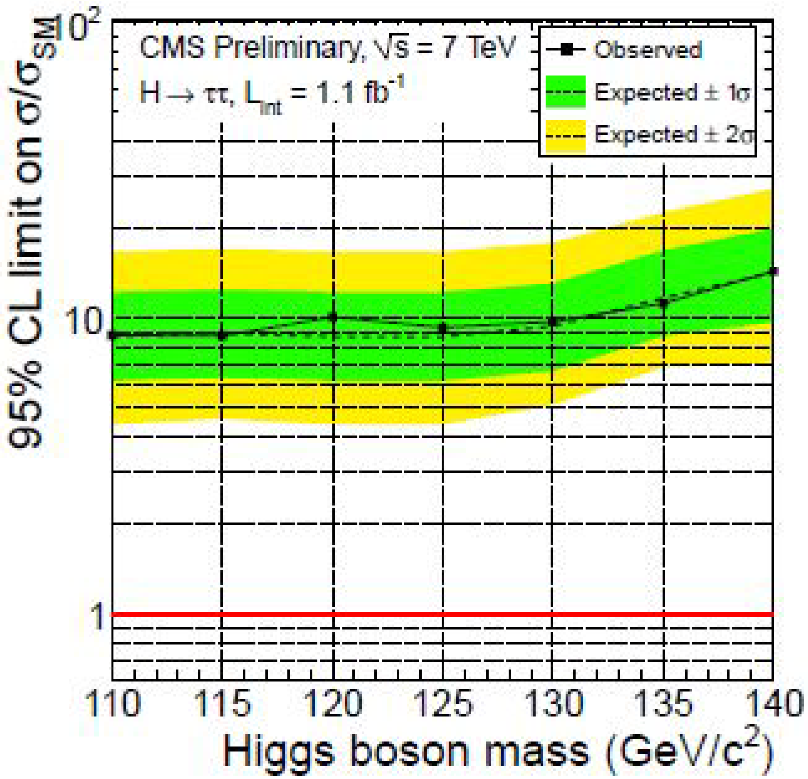
H -> bb in CMS


CMS Preliminary
$\sqrt{s}$ = 7 TeV, L = 1.1 fb^{-1}
Z(e$^-$e$^+$)H(b$\bar{b}$)
Data
ZH(115 GeV)
ZZ+WZ+WW
Z + udscg
Z + bb
t$\bar{t}$ + S.T.
(d)
Events
BDT Output

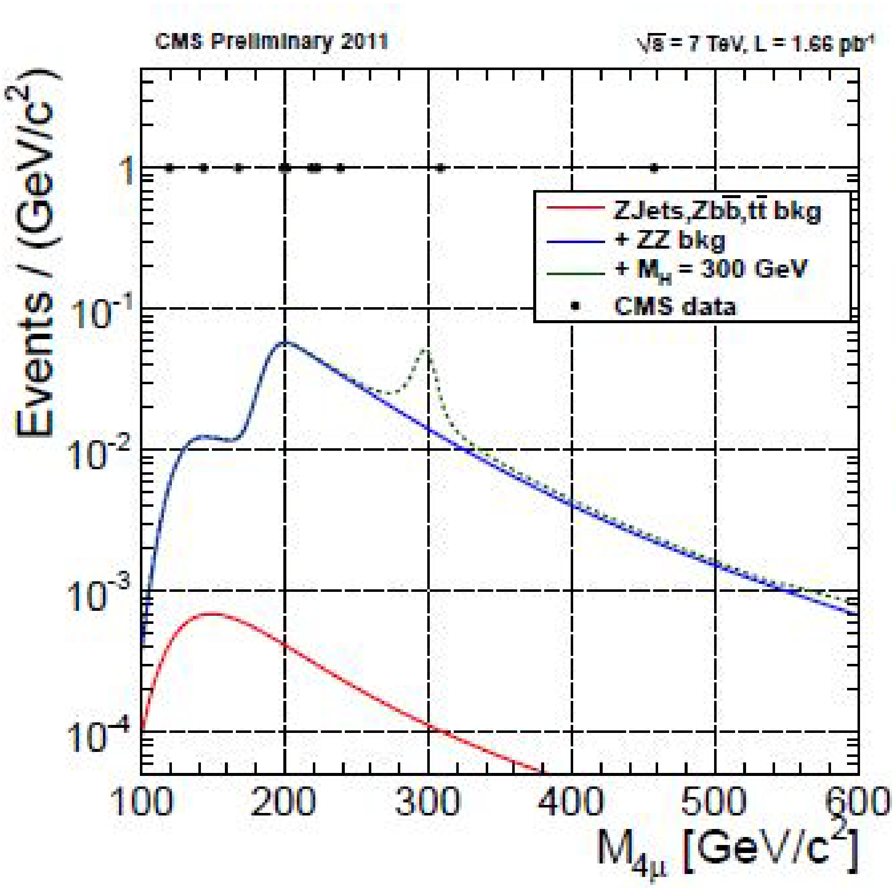

CMS Private, $\sqrt{s}$ = 7 TeV
H → bb, L$_{int}$ = 1.1 fb^{-1}
Observed
Expected ± 1σ
Expected ± 2σ
95% CL limit on σ/σ$_{SM}$
Higgs boson mass (GeV/c^2)

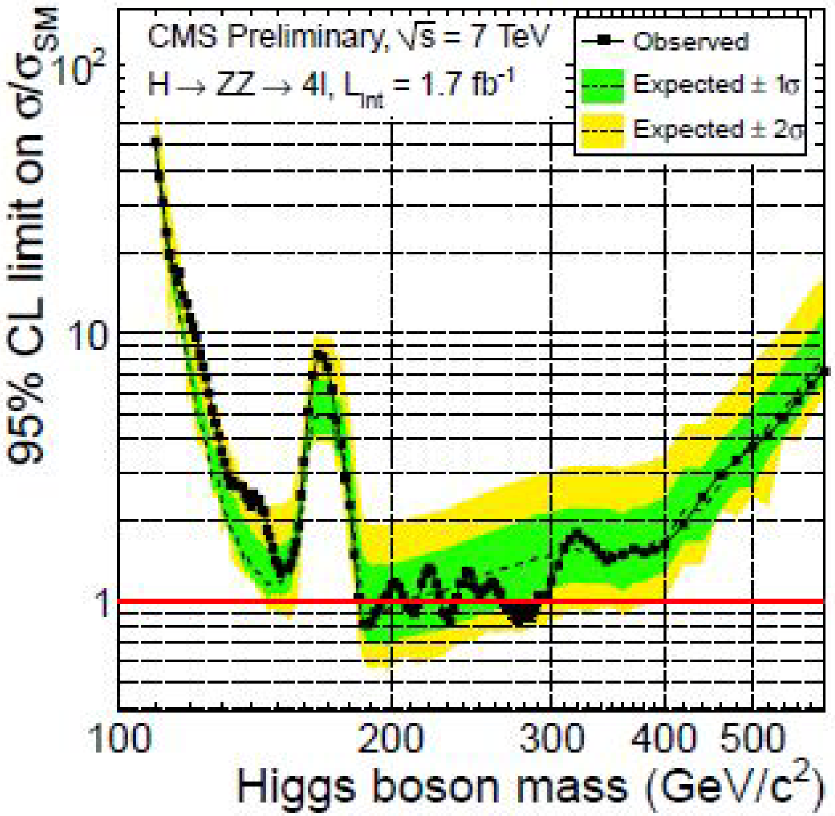
H -> ττ in CMS

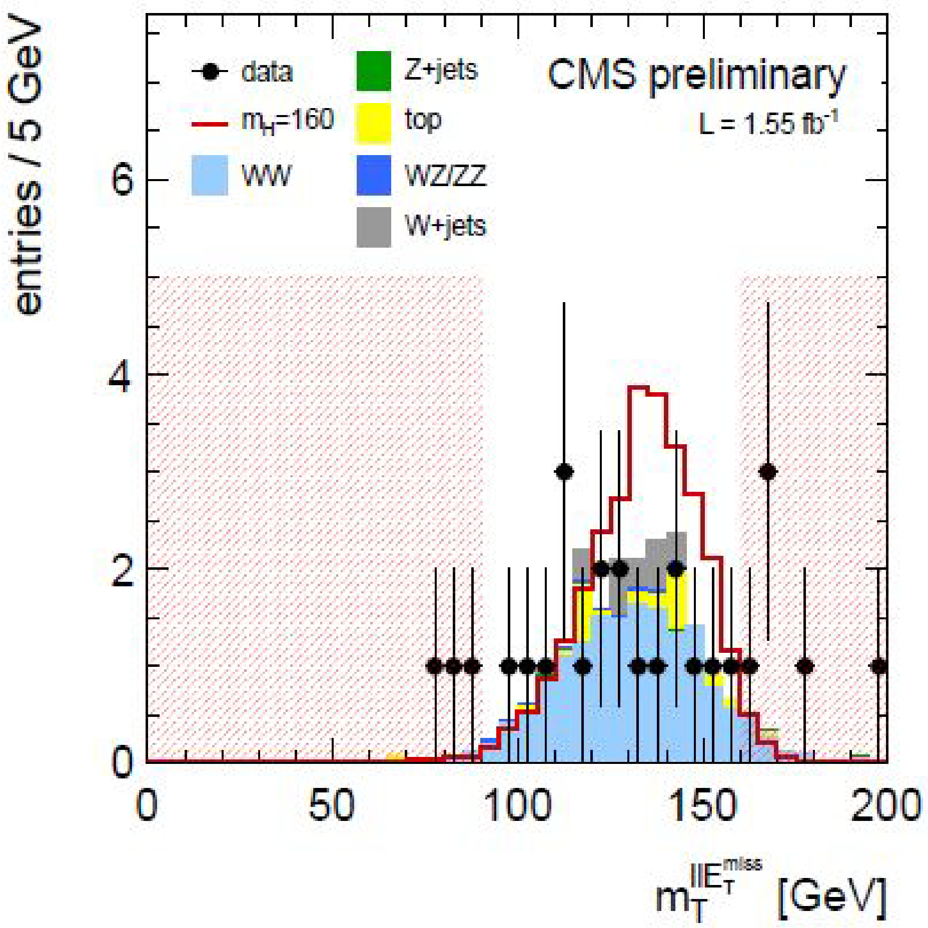

CMS Preliminary
1.1 fb-1 √s=7 TeV
τμτh
(10x) H→ττ mH=120
Observed
Z→ττ
tt̄
Electroweak
QCD
Events
mvis [GeV]

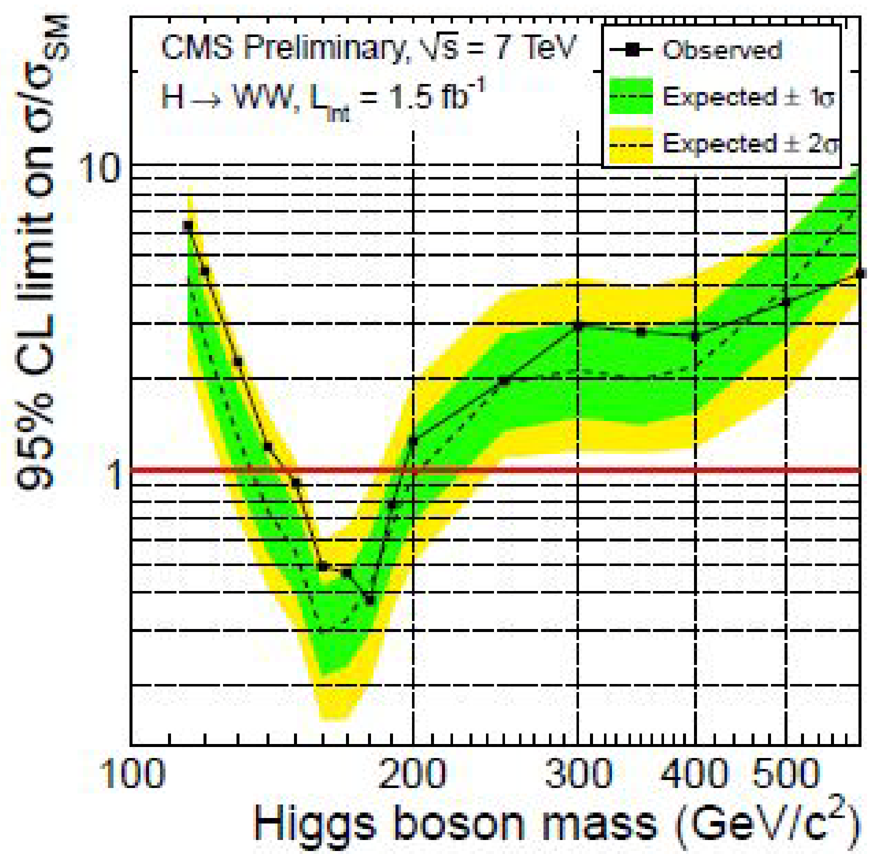

CMS Preliminary, √s = 7 TeV
H→ ττ, Lint = 1.1 fb-1
Observed
Expected ± 1σ
Expected ± 2σ
95% CL limit on σ/σSM
Higgs boson mass (GeV/c2)

H -> ZZ in CMS

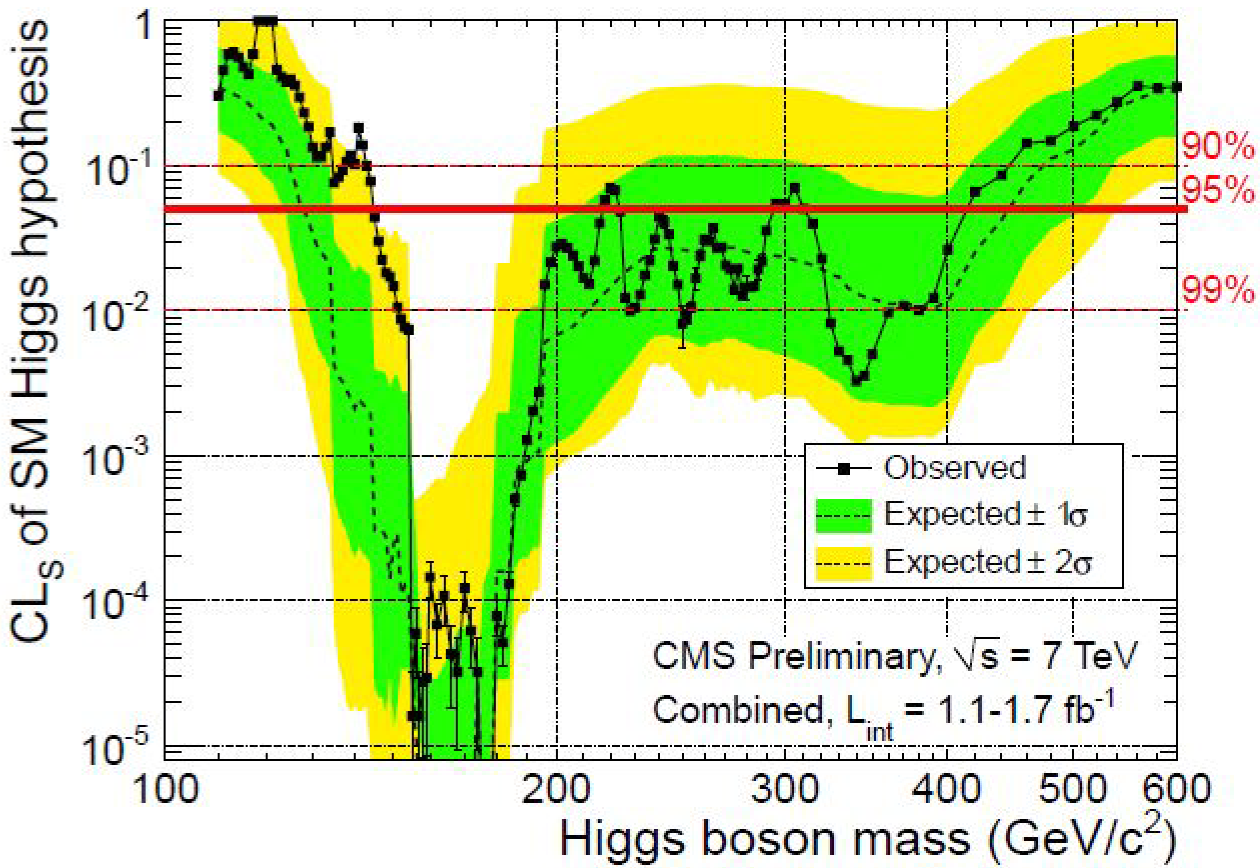

CMS Preliminary 2011
√s = 7 TeV, L = 1.66 pb⁻¹
ZJets,Zbb̄,tt̄ bkg
+ ZZ bkg
+ M_H = 300 GeV
CMS data
Events / (GeV/c²)
M_4μ [GeV/c²]


CMS Preliminary, √s = 7 TeV
H → ZZ → 4l, L_int = 1.7 fb⁻¹
Observed
Expected ± 1σ
Expected ± 2σ
95% CL limit on σ/σ_SM
Higgs boson mass (GeV/c²)

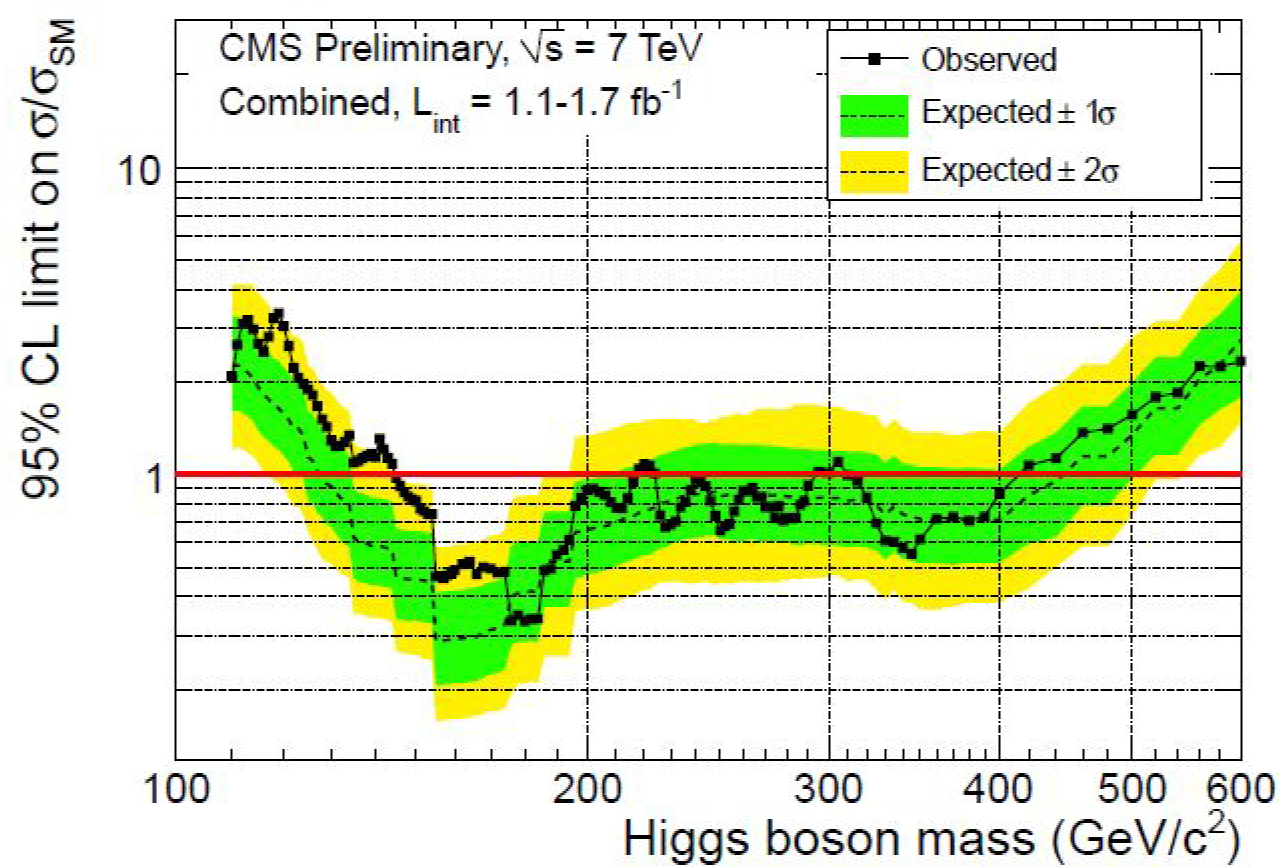

data
m_H=160
WW
Z+jets
top
WZ/ZZ
W+jets
CMS preliminary
L = 1.55 fb^{-1}
entries / 5 GeV
0
2
4
6
0
50
100
150
200
$m_T^{llE_T^{miss}}$ [GeV]


CMS Preliminary, $\sqrt{s}$ = 7 TeV
H → WW, L_{int} = 1.5 fb^{-1}
Observed
Expected ± 1σ
Expected ± 2σ
95% CL limit on σ/σ_{SM}
1
10
100
200
300
400
500
Higgs boson mass (GeV/c^2)

Full results based on CLs in CMS



95% C.L. upper limits on SM Higgs from CMS



Conclusions:

One of the main goals of the LHC has been to search for the Higgs boson,

Discovery of such a particle could answer a fundamental question about the mass spectrum,

Tevatron has set limits on the Higgs boson mass as $156 < m(H) < 177$ GeV

The LHC results have now taken over those of Tevatron,

The current CMS result is $145 < m(H) < 216$ GeV

The most probable region to find the Higgs boson is currently $115 < m(H) < 145$ GeV