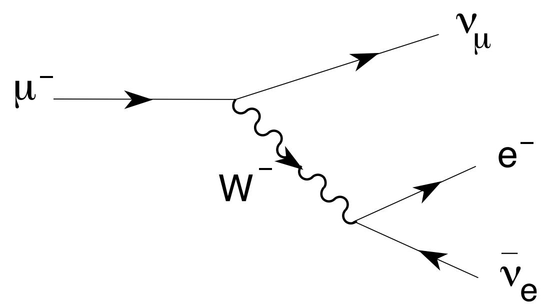
$M_W - M_Z$ correlation



$$\frac{G_F}{\sqrt{2}} = \frac{\pi\alpha}{2M_W^2\left(1 - M_W^2/M_Z^2\right)}$$

with loop contributions

$$\frac{G_F}{\sqrt{2}} = \frac{\pi\alpha}{2M_W^2\left(1 - M_W^2/M_Z^2\right)} \cdot (1 + \Delta r)$$

Δr : quantum correction

$\Delta r = \Delta r(m_t, M_H)$

$$\Delta r = \Delta\alpha - \frac{c_W^2}{s_W^2}\Delta\rho + \cdots$$

$$\Delta\rho \sim \frac{m_t^2}{M_W^2}$$

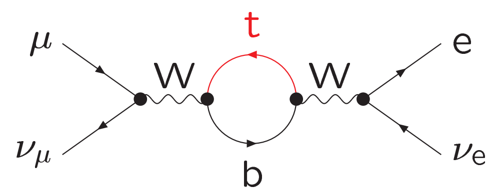
determines W mass

$$M_W = M_W(\alpha, G_F, M_Z, m_t, M_H)$$

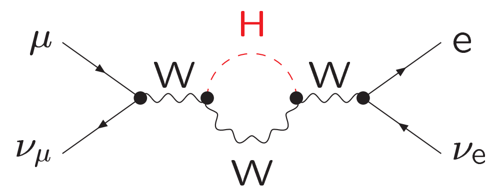
complete at 2-loop order

1-loop examples

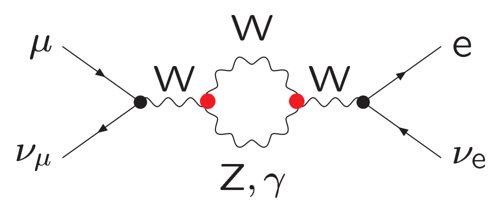
- top quark



- Higgs boson

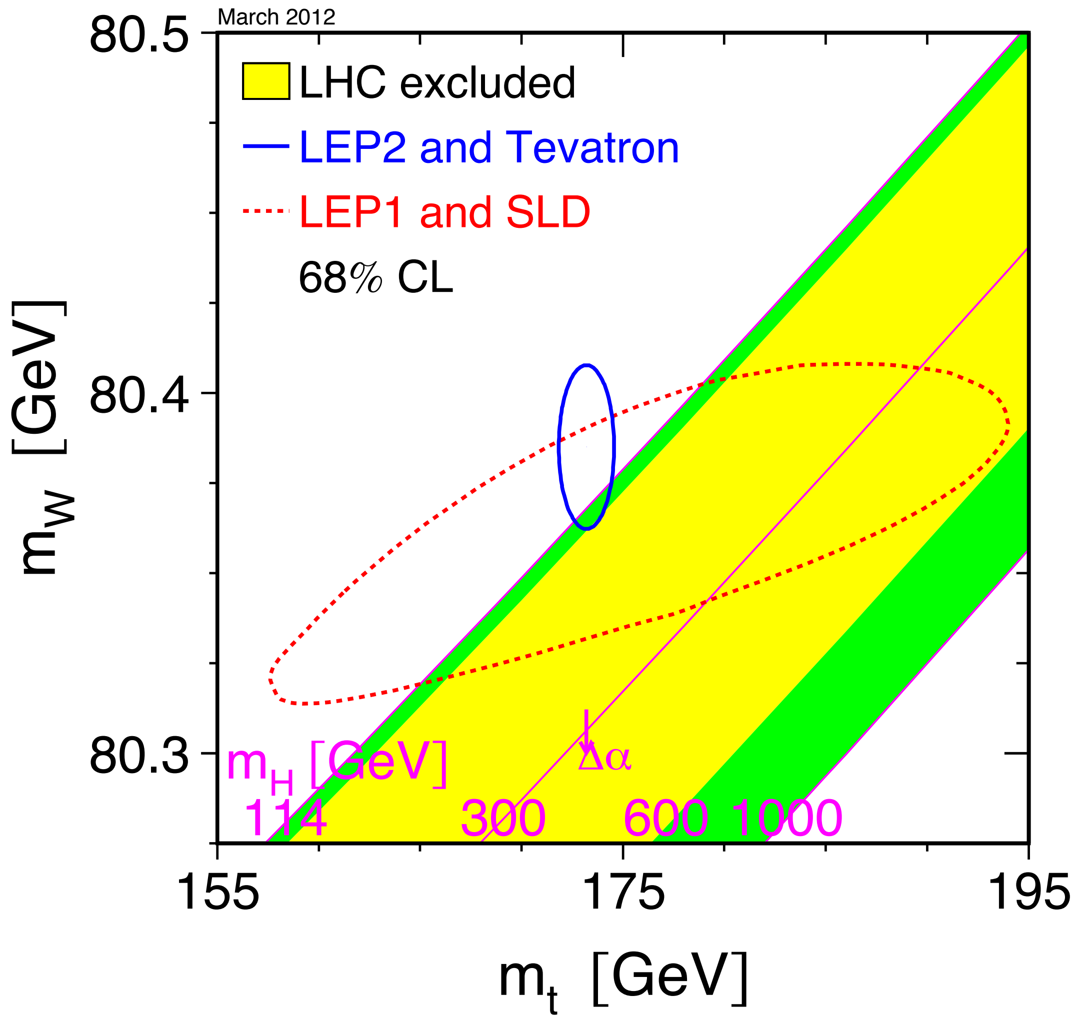


- gauge-boson self-couplings

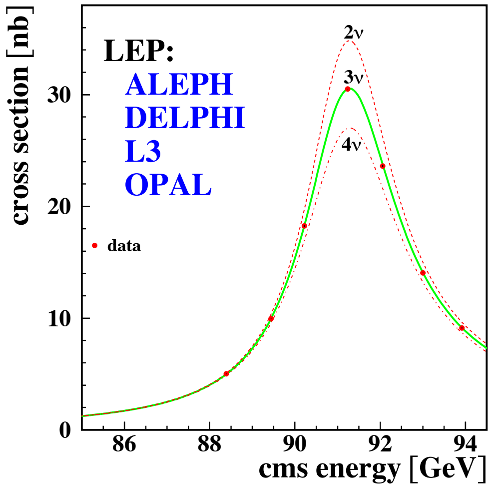


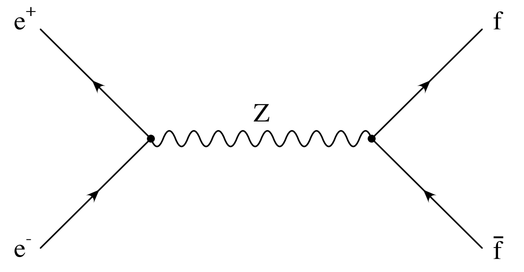
full structure of SM

http://lepewwg.web.cern.ch/LEPEWWG/



Z resonance





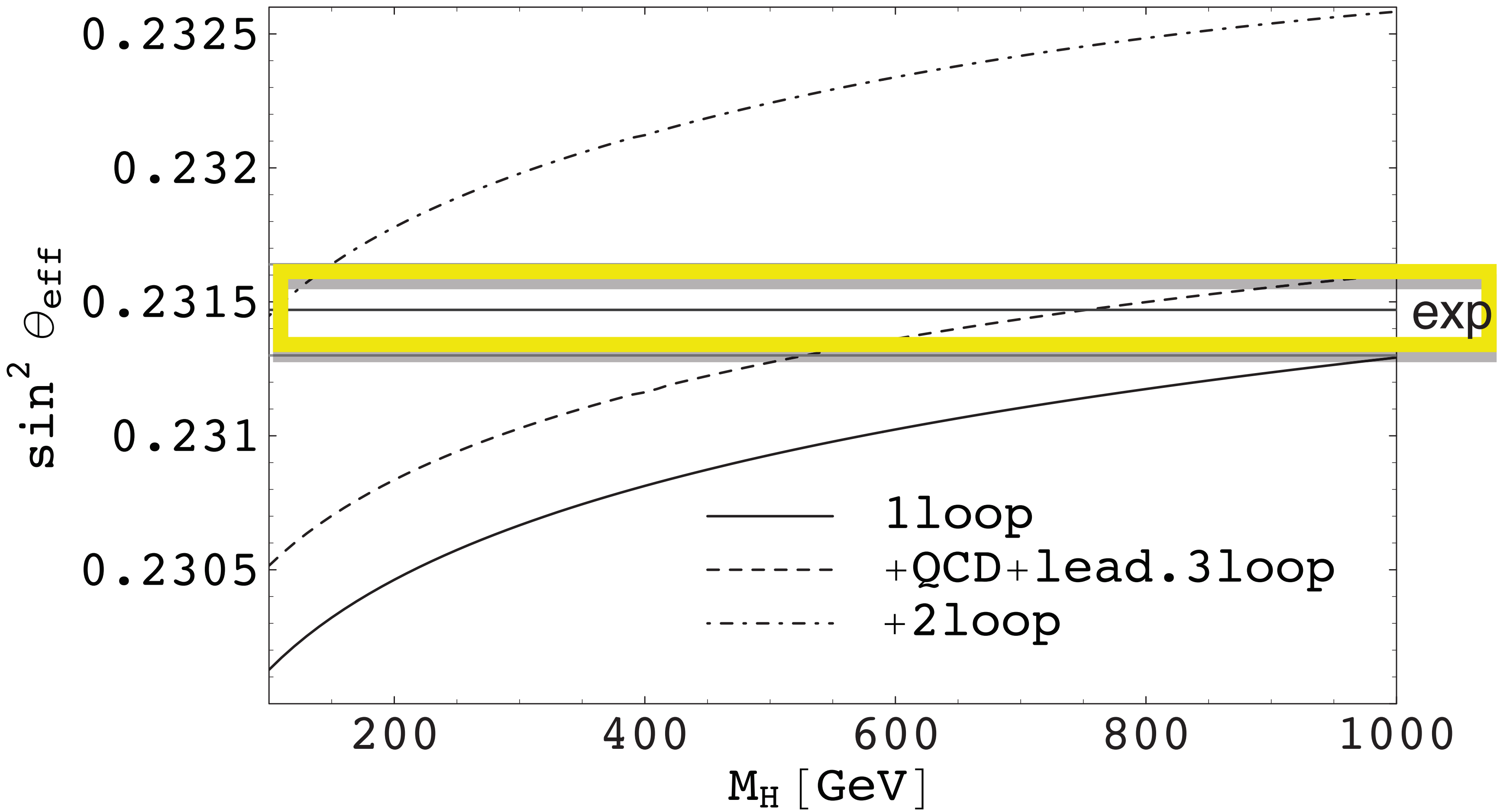
- effective Z boson couplings with higher-order $\Delta g_{V,A}$

$$v_f \to g_V^f = v_f + \Delta g_V^f, \qquad a_f \to g_A^f = a_f + \Delta g_A^f$$

- effective ew mixing angle (for $f = e$):

$$\sin^2\theta_{\text{eff}} = \frac{1}{4}\left(1 - \text{Re}\,\frac{g_V^e}{g_A^e}\right) = \kappa \cdot \left(1 - \frac{M_W^2}{M_Z^2}\right)$$

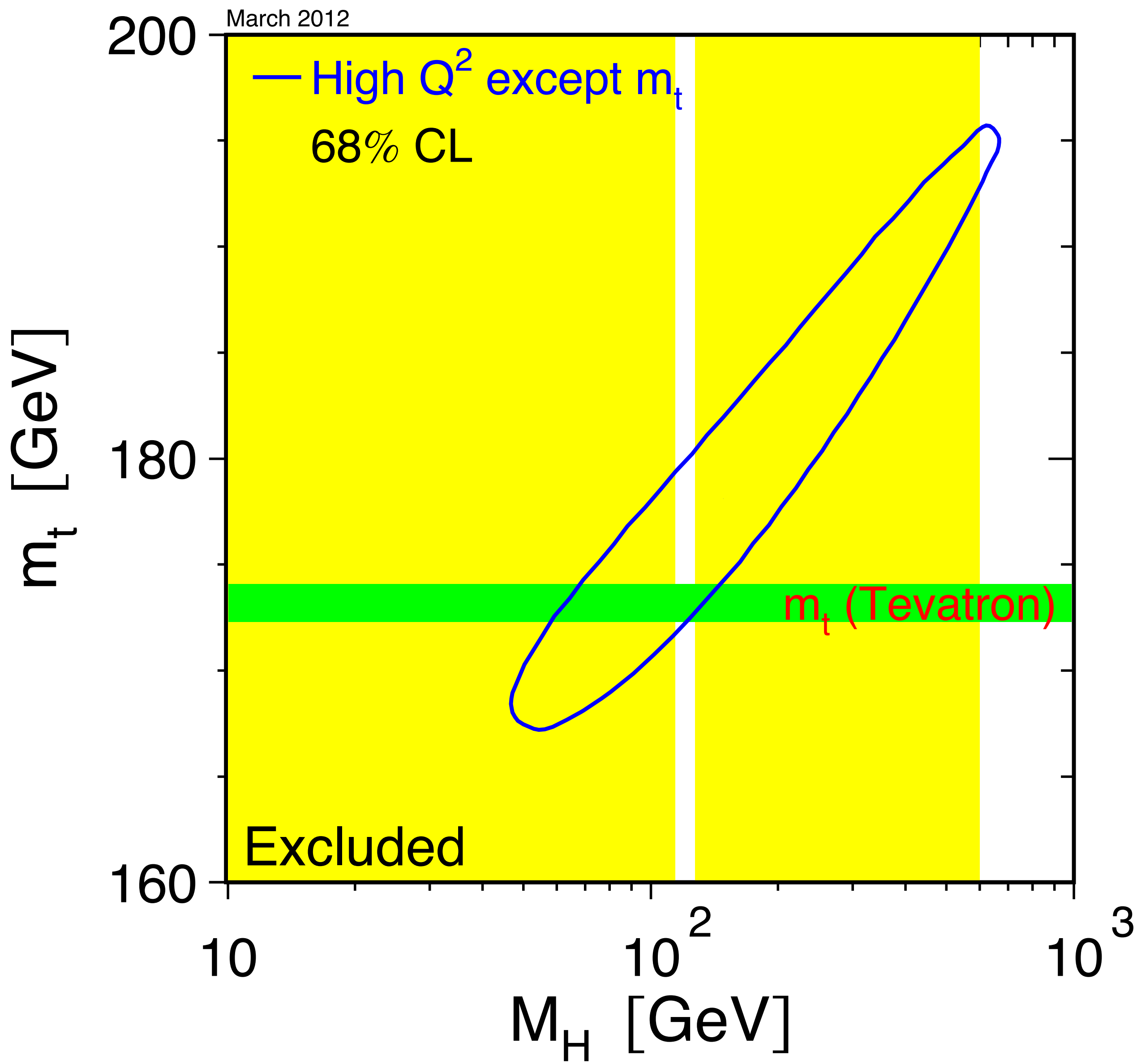
importance of two-loop calculations



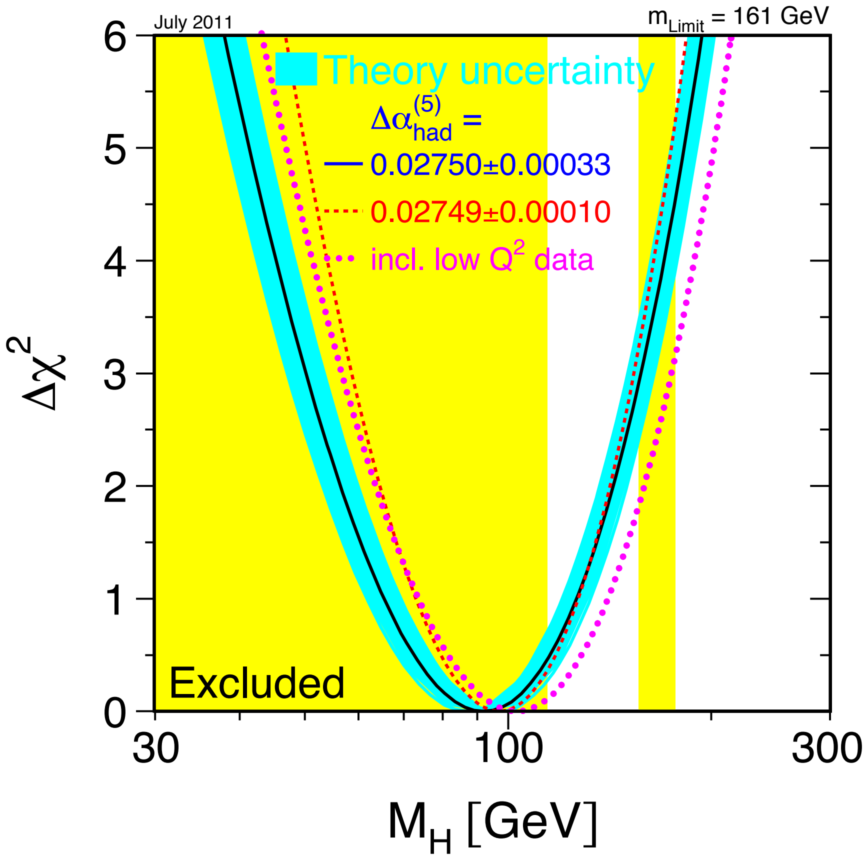
lowest order: $\sin^2\theta_W = 1 - \frac{M_W^2}{M_Z^2} = 0.22290 \pm 0.00029$

exp. value: $\sin^2\theta_{\rm eff} = \qquad 0.23153 \pm 0.00016$

Global analysis within the SM



Global fit to the Higgs boson mass

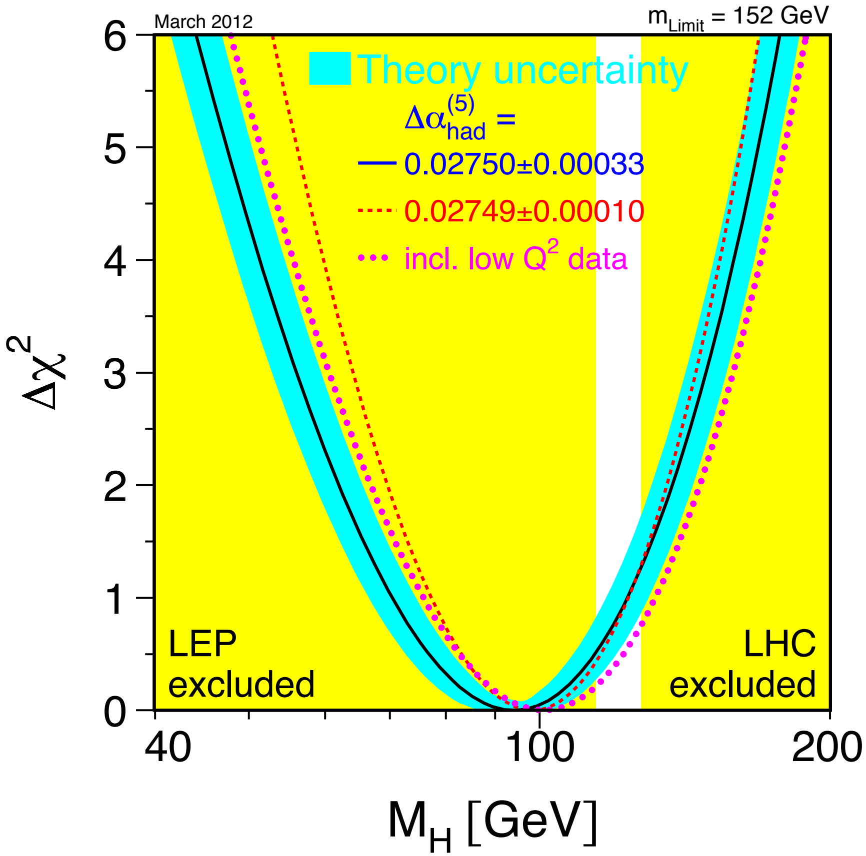


blueband: Theory uncertainty

"Precision Calculations
at the Z Resonance"
CERN 95-03

[Bardin, WH, Passarino (eds.)]

$$M_{\rm H} < 161 \text{ GeV} \quad (\text{at } 95\% \text{ C.L.})$$



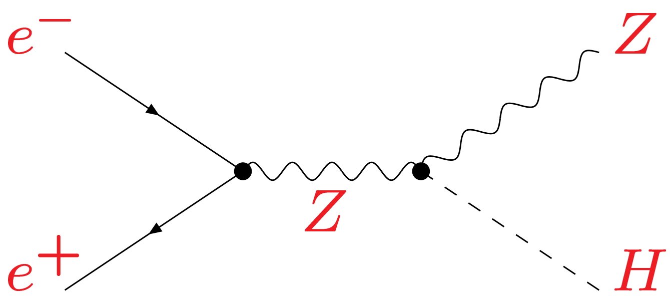
after the 2011 results
from the LHC
on the Higgs boson mass

$$M_{\mathrm{H}} < 152\ \mathrm{GeV} \quad (95\%\mathrm{C.L.})$$

$$M_{\mathrm{H}} = 94^{+29}_{-24}\,\mathrm{GeV}$$

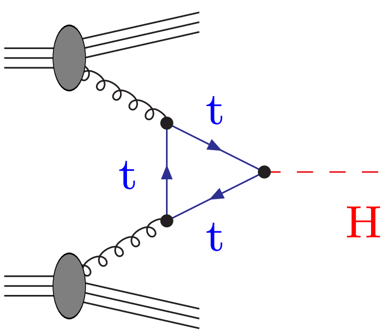
The direct search for the Higgs boson

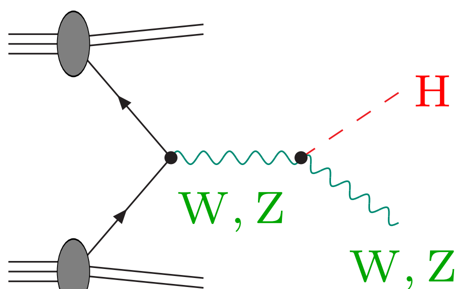
Higgs production at LEP:



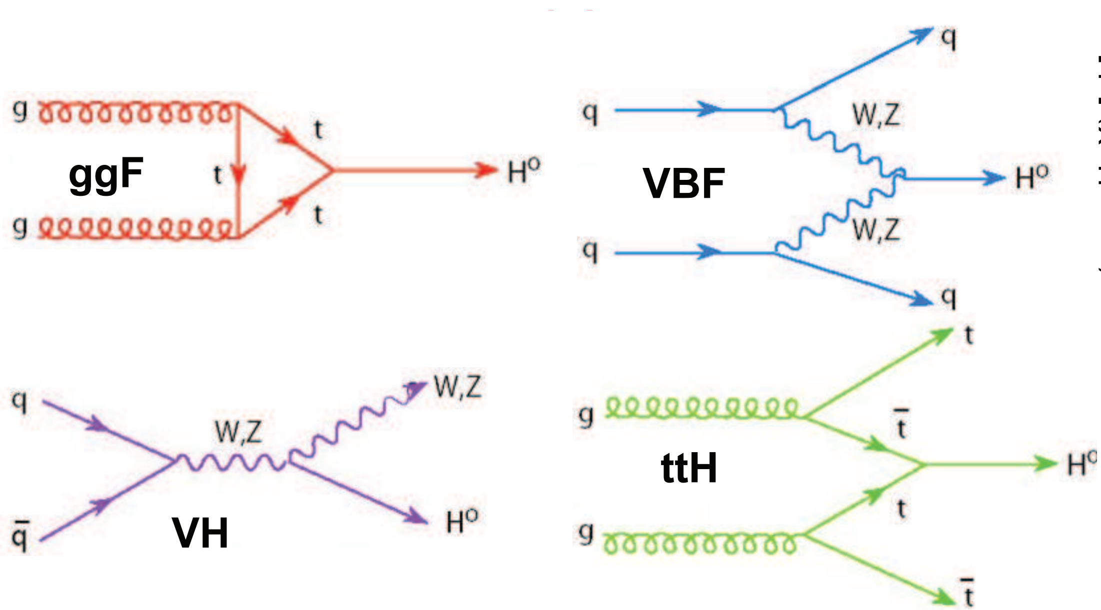
excluded $M_H < 114\,\mathrm{GeV}$

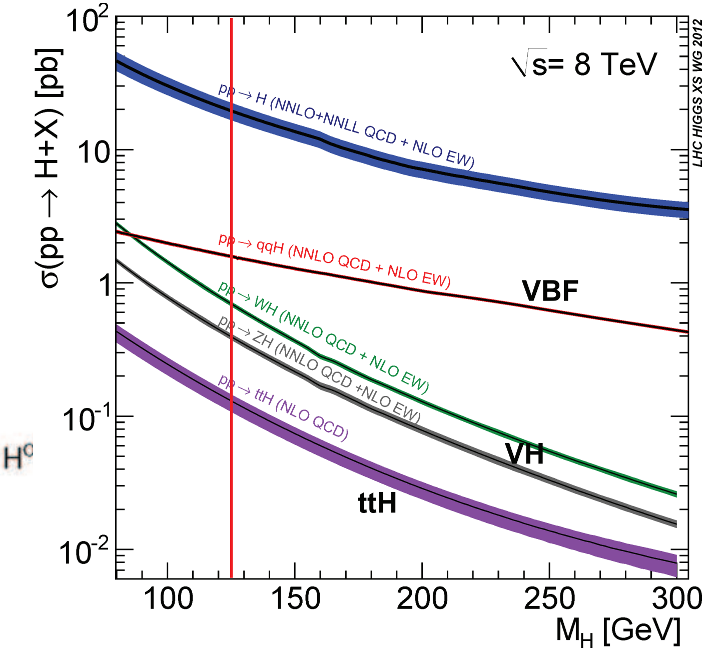
Higgs production at the Tevatron:





Higgs production at the LHC

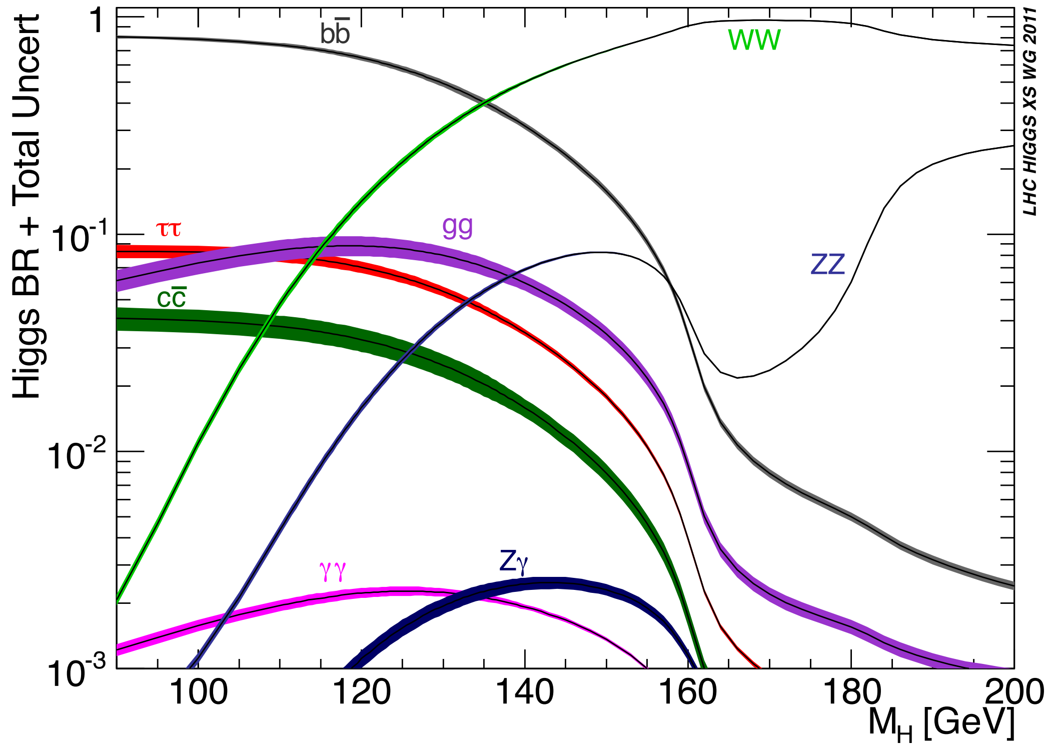


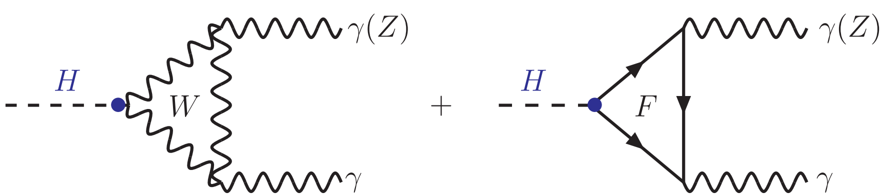


Handbook of Higgs Cross sections, arXiv:1101.0593, arXiv:1201.3084

Higgs boson decay channels

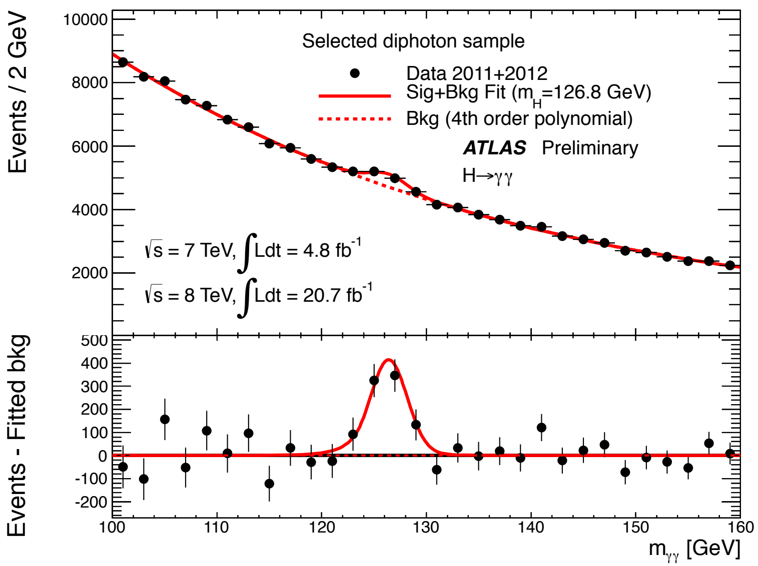
branching ratios $BR(H \to X) = \frac{\Gamma(H \to X)}{\Gamma(H \to \mathrm{all})}$

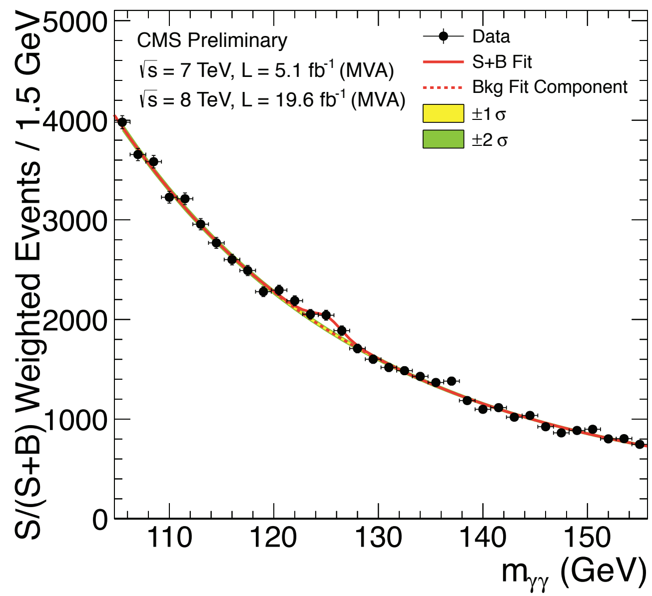




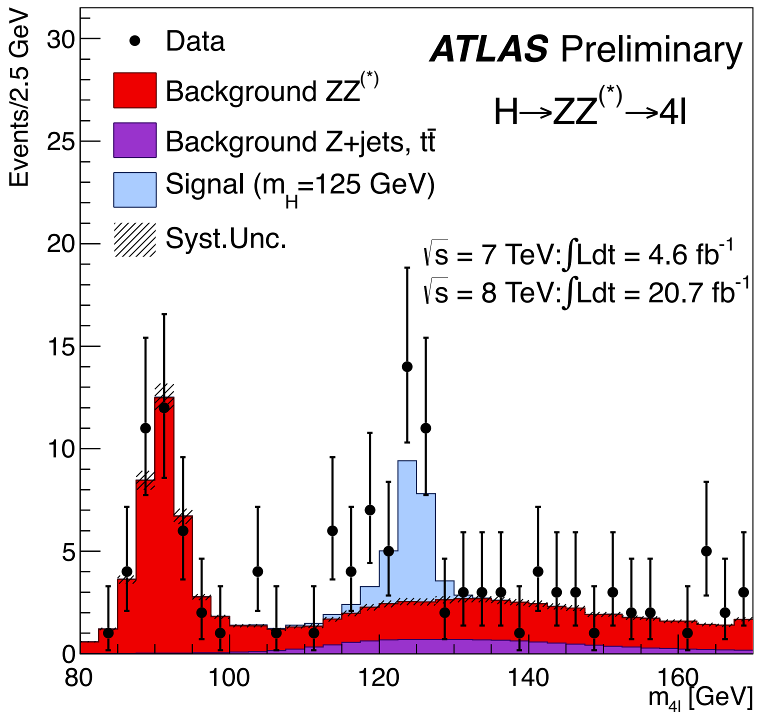
loop-induced (rare) decays

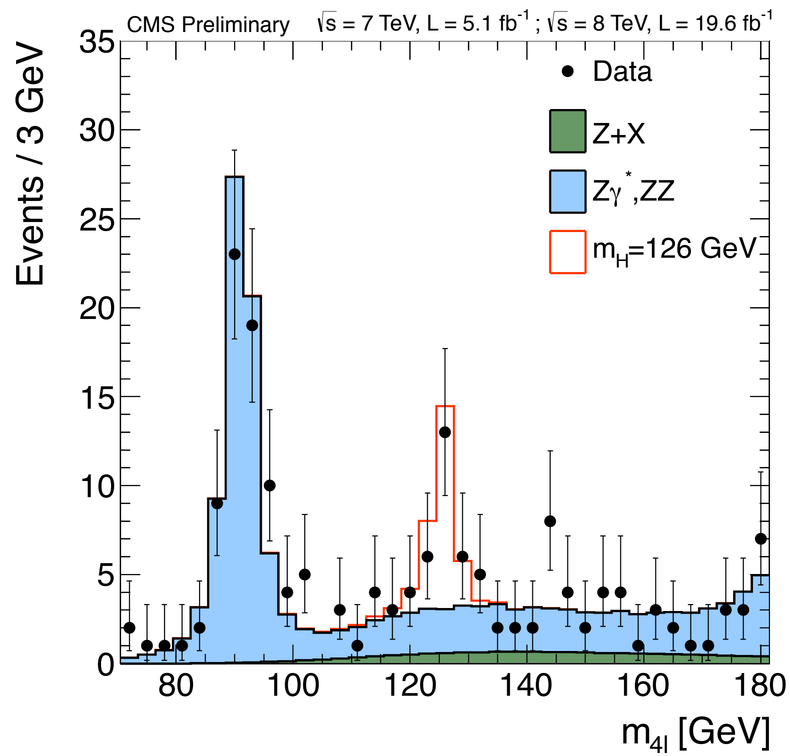
$H \rightarrow \gamma\gamma$

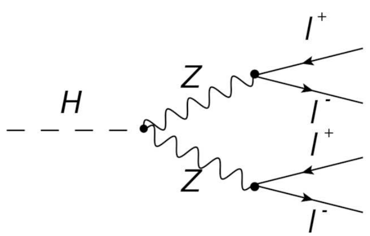




$$H \to ZZ \to l^+l^- \, l^+l^-$$

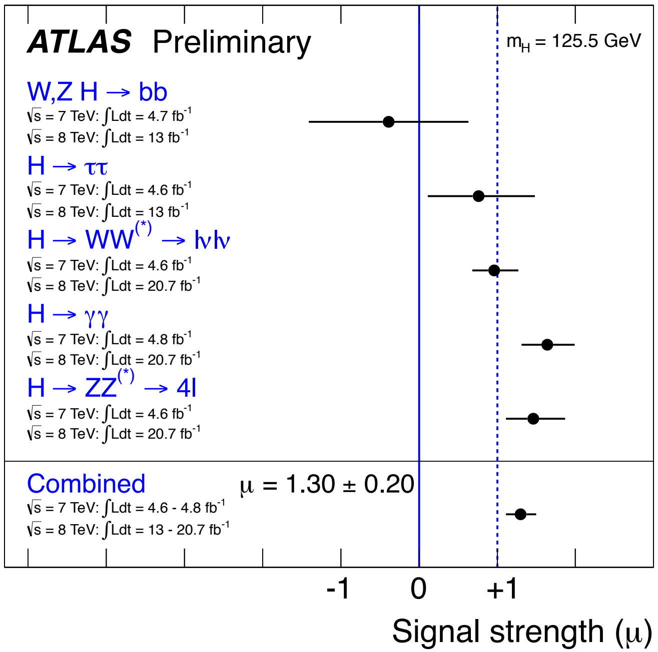


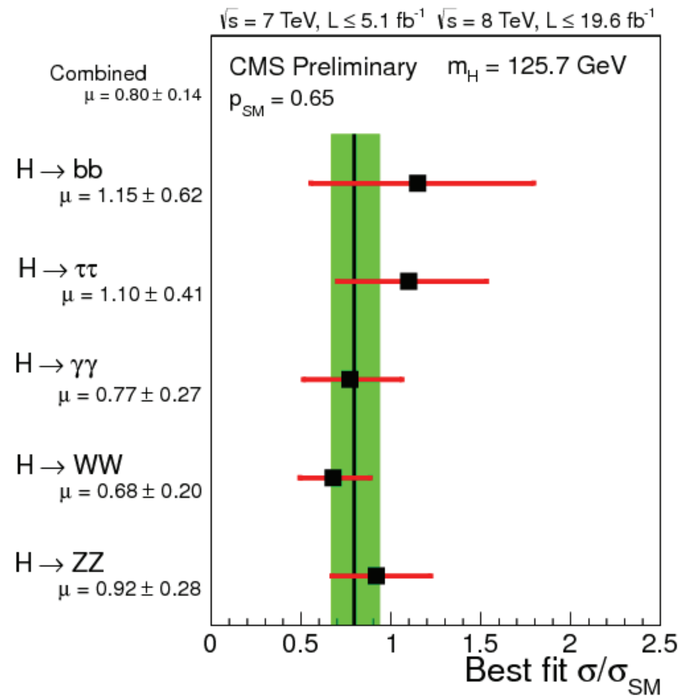




signal + background

A Standard Model Higgs boson at the LHC?





H mass ATLAS (GeV)

$$125.5 \pm 0.2 \pm 0.6$$

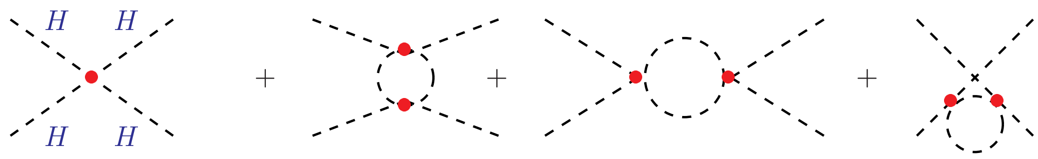
H mass CMS (GeV)

$$125.7 \pm 0.3 \pm 0.3$$

Theory: $\sigma(pp \to H) \cdot BR(H \to X)$

Landau pole

Higgs self coupling is scale dependent, $\lambda(Q)$



variation with scale Q described by RGE

$$Q^2 \frac{d\lambda}{dQ^2} = \beta(\lambda) = \frac{3}{4\pi^2}\,\lambda^2$$

solution:

$$\lambda(Q) = \frac{\lambda(v)}{1 - \frac{3}{4\pi^2}\lambda(v)\log\frac{Q^2}{v^2}} \quad \text{with} \quad \lambda(v) = \frac{M_H^2}{2v^2}$$

diverges at scale $Q = \Lambda_C$ (Landau pole)

$$\Lambda_C = v\,\exp\left(\frac{4\pi^2 v^2}{3M_H^2}\right)$$

self-coupling diverges at

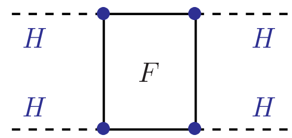
$$\Lambda_C = v \, \exp\left(\frac{4\pi^2 v^2}{3M_H^2}\right)$$

maximum Higgs mass by condition $\Lambda_C > M_H$

$$\Rightarrow \quad M_H < 800\,\mathrm{GeV}$$

vacuum stability

top-quark Yukawa coupling $g_t \sim m_t$ contributes to the running Higgs self coupling $\lambda(Q)$ through top loop $\sim g_t^4$



variation with scale Q described by RGE

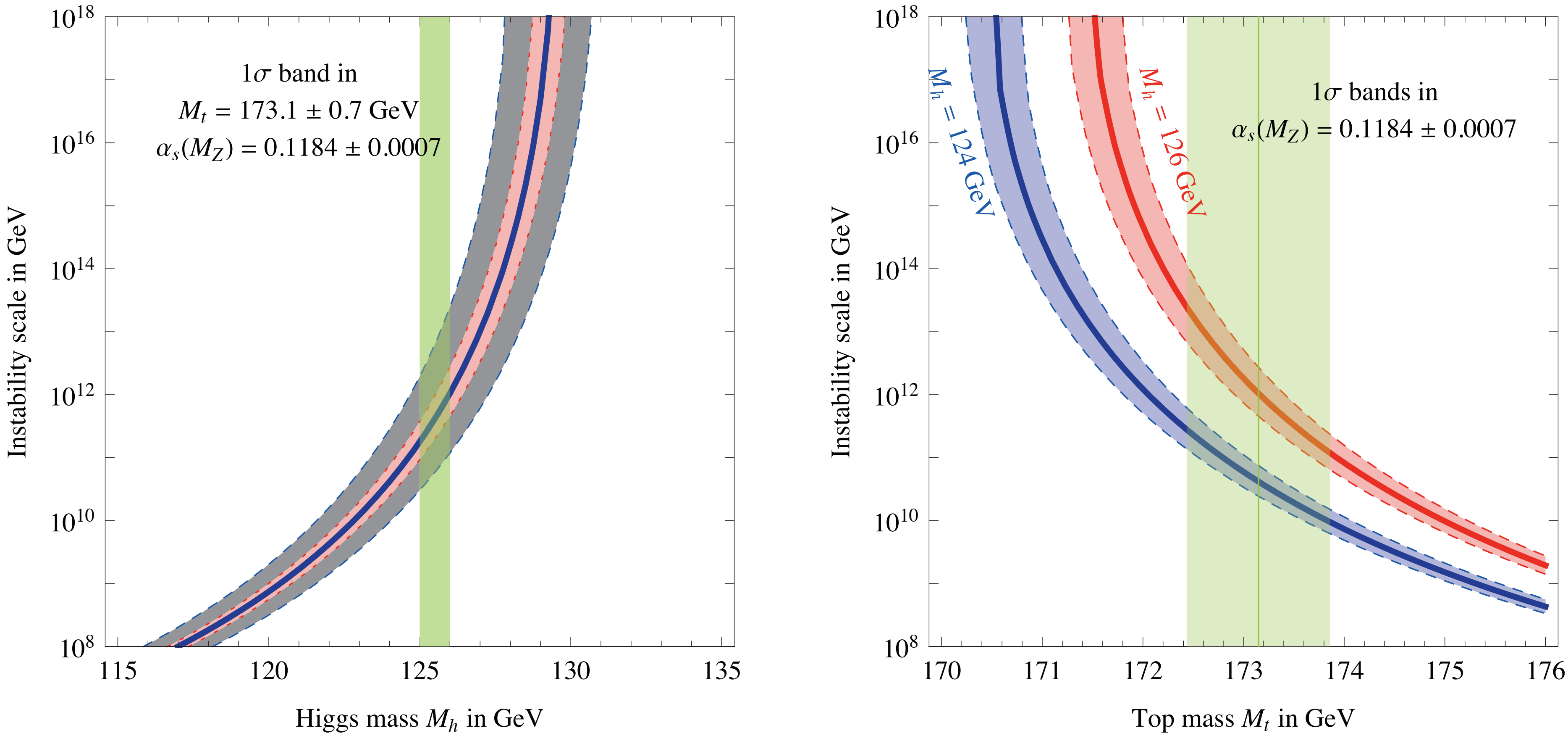
$$Q^2 \frac{d\lambda}{dQ^2} = \frac{3}{4\pi^2} \left(\lambda^2 - \frac{m_t^4}{v^4} \right)$$

approximate solution:

$$\lambda(Q) = \lambda(v) - \frac{3m_t^4}{2\pi^2 v^4} \log \frac{Q}{v}$$

$\lambda(Q) < 0$ for $Q > \Lambda_C$ $\rightarrow$ vacuum not stable

high value of Λ_C needs M_H large enough



[Degrassi et al. 2012]