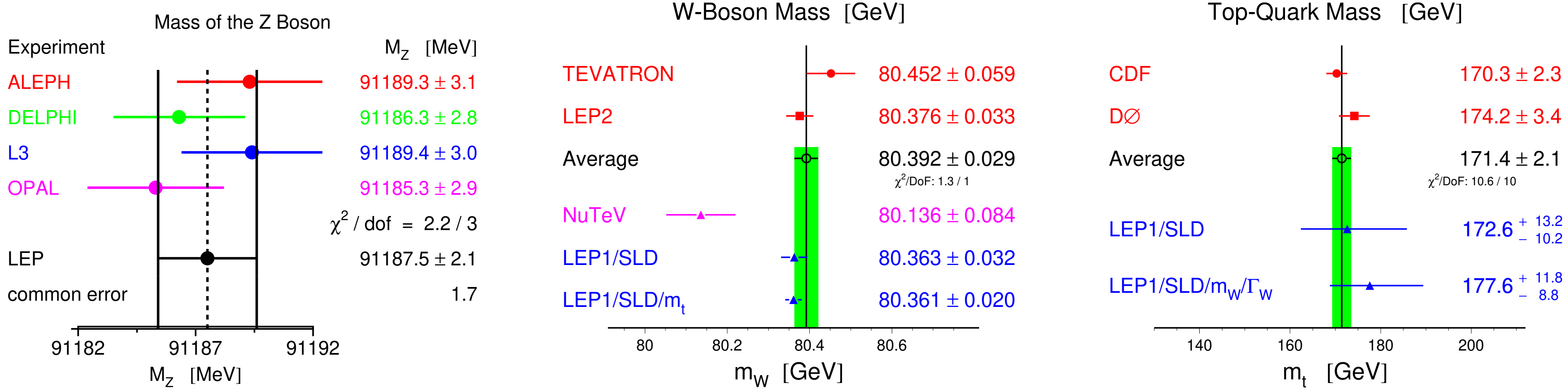
Indirect bound on m_h from M_W versus m_{top}

At one or more loop level

$$M_W^2\left(1-\frac{M_W^2}{M_Z^2}\right)=\frac{\pi\alpha}{\sqrt{2}G_F}\frac{1}{1-\Delta r(m_{top},m_h)}$$



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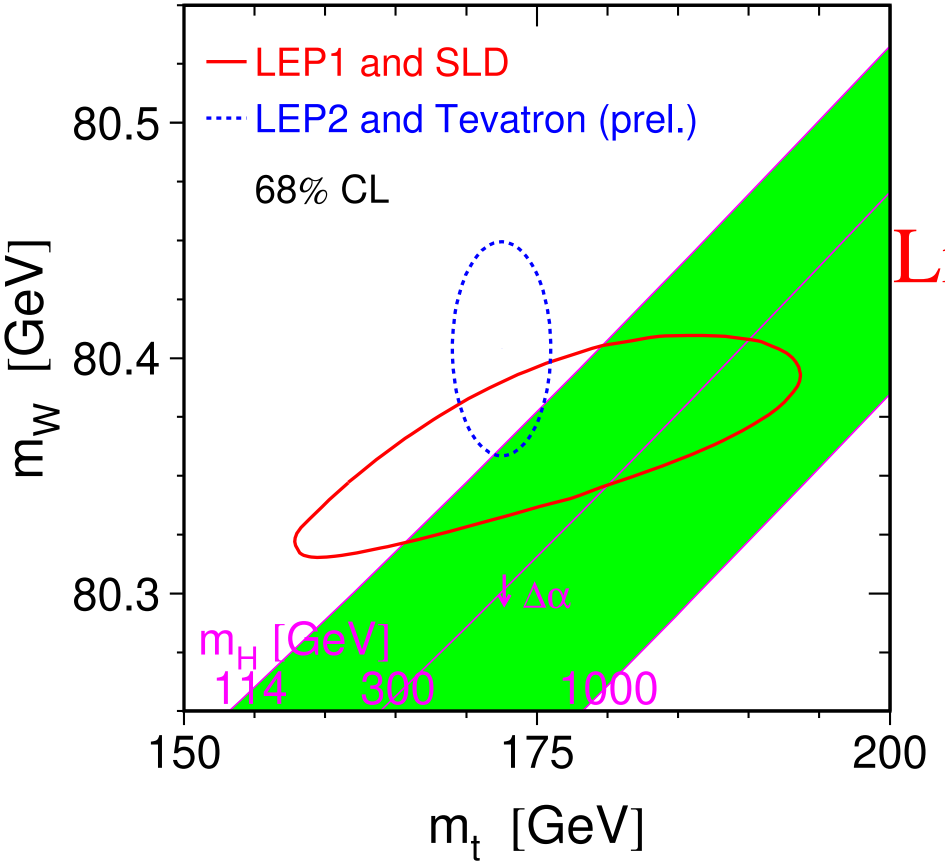
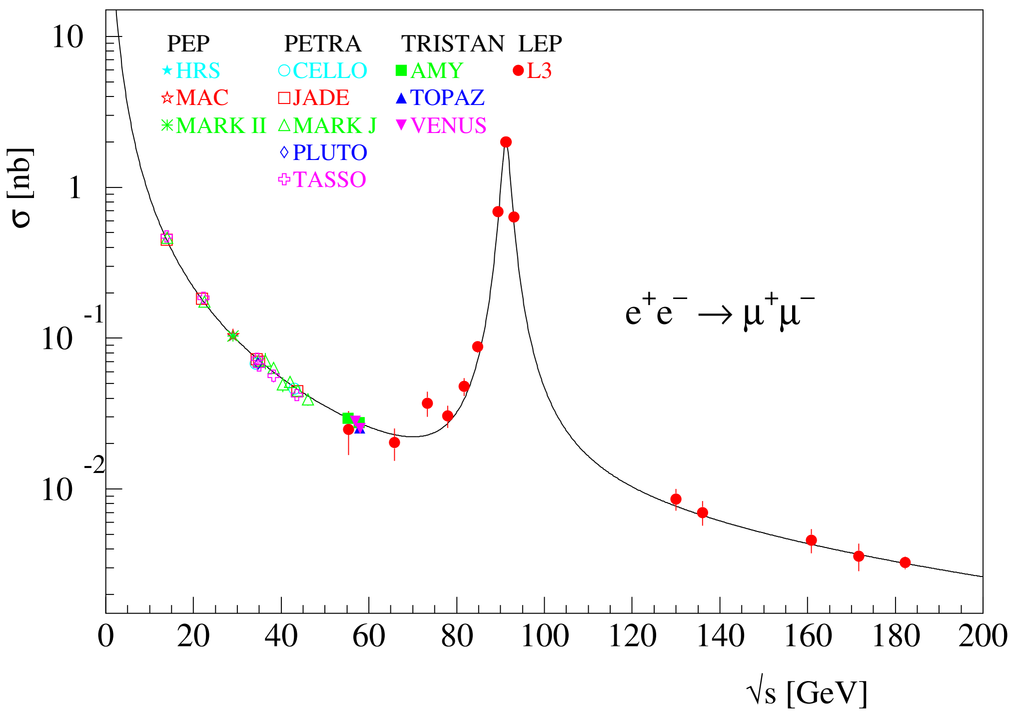


Light higgs favoured

$e^+e^- \to f\bar{f}$: Total cross section

$$\mathcal{L} = -e\,Q_f\,\bar{f}\gamma^\mu A_\mu f - \frac{g}{2\cos\theta_W}\,\bar{f}\,\gamma_\mu(g_V^d + g_A^f\gamma^5)f\,Z^\mu$$

$$\sigma = \frac{4\pi\alpha^2 N_c}{3s}Q_f^2 + \frac{N_c G_F^2 M_Z^4 s}{6\pi[(s-M_Z^2)^2+\Gamma_Z^2 M_Z^2]}({g_V^e}^2+{g_A^e}^2)({g_V^f}^2+{g_A^f}^2)$$
$$+\frac{4N_c\alpha G_F M_Z^2(s-M_Z^2)}{3\sqrt{2}[(s-M_Z^2)^2+\Gamma_Z^2 M_Z^2]}Q_f g_V^e g_V^f$$

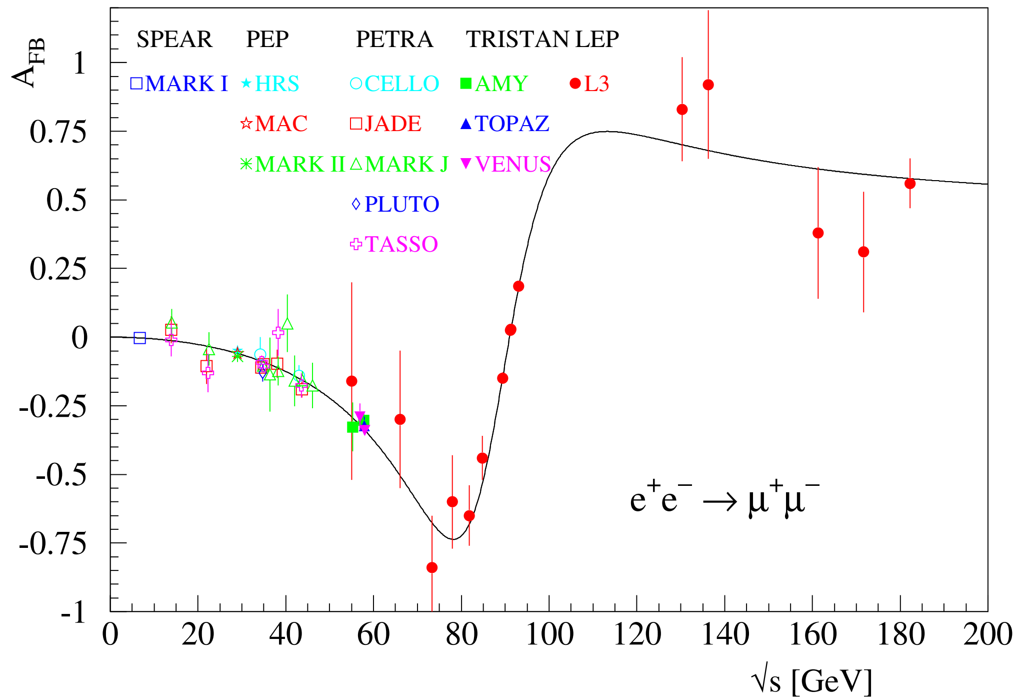


$e^+e^- \to f\bar{f}$: Forward-Backward asymmetry

$$\frac{d\sigma}{d\cos\theta} = \frac{N_c \pi\alpha^2}{2s} Q_f^2 (1+\cos^2\theta) - \frac{N_c \alpha G_F M_Z^2 (s - M_Z^2) Q_f}{2\sqrt{2}[(s-M_Z^2)^2 + \Gamma_Z^2 M_Z^2]} \left[g_V^e g_V^f (1+\cos^2\theta) + 2 g_A^e g_A^f \cos\theta \right]$$

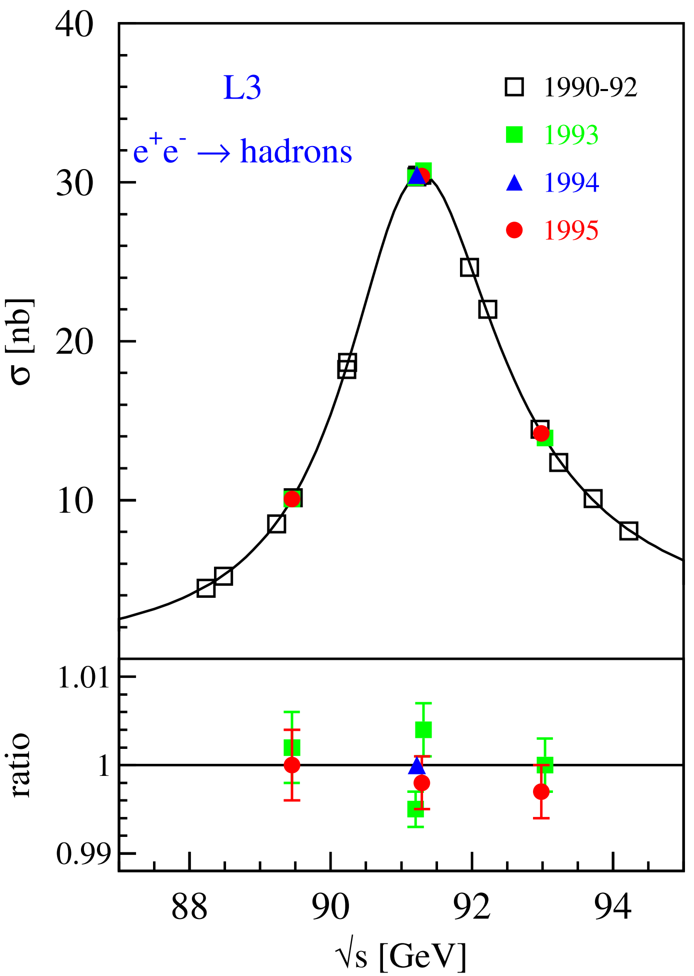
$$+ \frac{G_F^2 M_Z^4 s}{16\pi[(s-M_Z^2)^2 + \Gamma_Z^2 M_Z^2]} ({g_V^e}^2 + {g_A^e}^2)({g_V^f}^2 + {g_A^f}^2)(1+\cos^2\theta) + 2 g_V^e g_A^e g_V^f g_A^f \cos\theta \Big\}$$

$$A_{FB} = \frac{\int_0^1 \frac{d\sigma}{d\cos\theta} - \int_{-1}^0 \frac{d\sigma}{d\cos\theta}}{\int_{-1}^1 \frac{d\sigma}{d\cos\theta}}$$



$e^+e^- \to f\bar{f}$ at $\sqrt{s} \sim M_Z$

- LEP (CERN) produced 2×10^7 unpolarized Z's
- SLD (SLAC) produced 2×10^5 Z's with $P_e \sim 75\%$



$\Rightarrow$ M_Z and Γ_Z

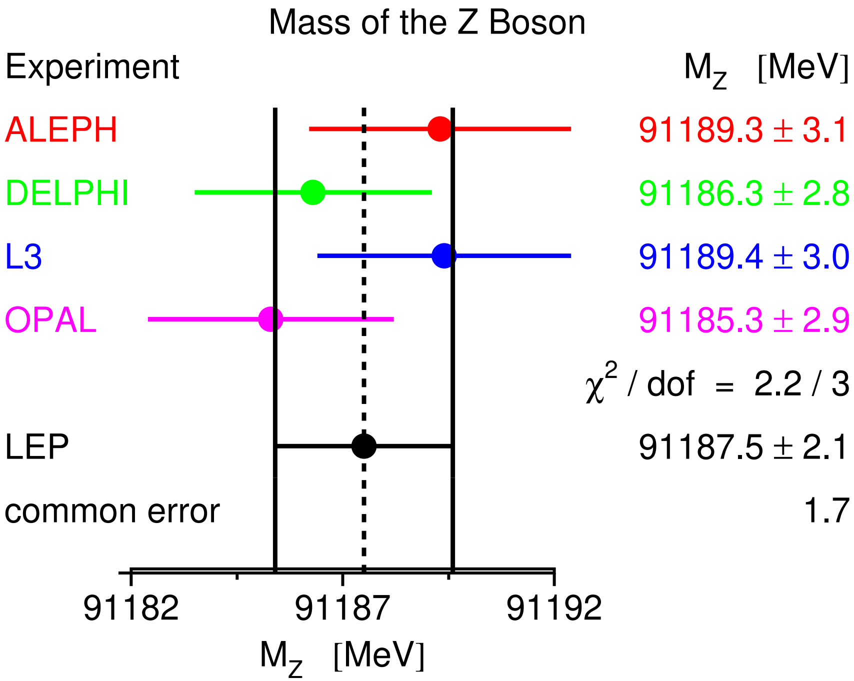
Knowing M_Z and G_F

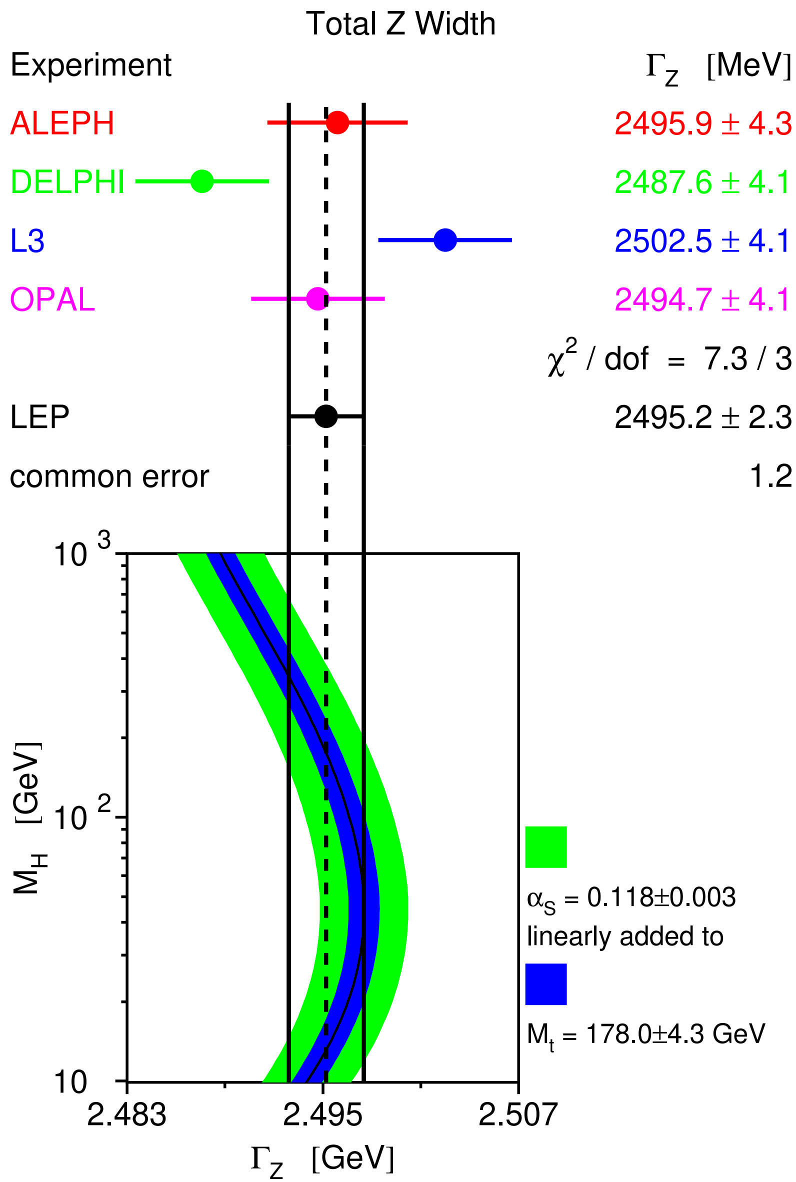
$\Rightarrow$ prediction of Γ_Z in terms of $\overline{\sin^2\theta_W}$

Incluing loop corrections

$$\overline{\sin^2\theta_W} = \left(1 - \frac{M_W^2}{M_Z^2}\right)\Delta(m_{\rm top}, M_H)$$

$e^+e^- \to f\bar{f}$ at $\sqrt{s} \sim M_Z$

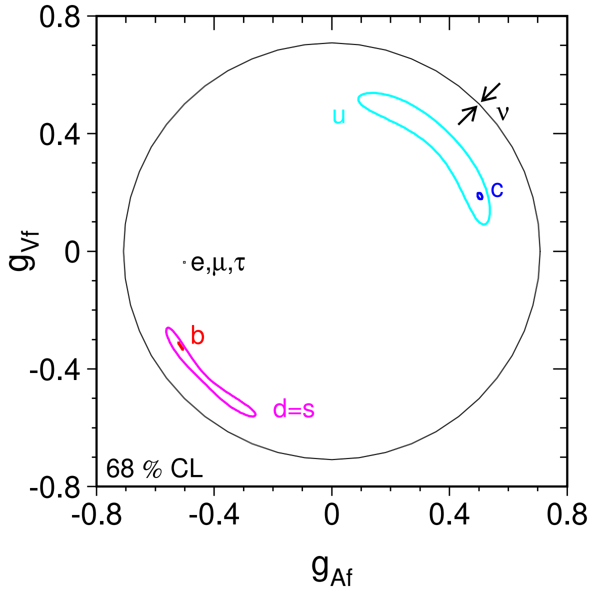




$e^+e^- \to f\bar{f}$ at $\sqrt{s} \sim M_Z$

- The decay width into the different fermions:

$$\Gamma(Z \to \bar{f}f) = \frac{G_F M_Z^3}{6\sqrt{2}\pi} N_C^f ({g_V^f}^2 + {g_A^f}^2)$$

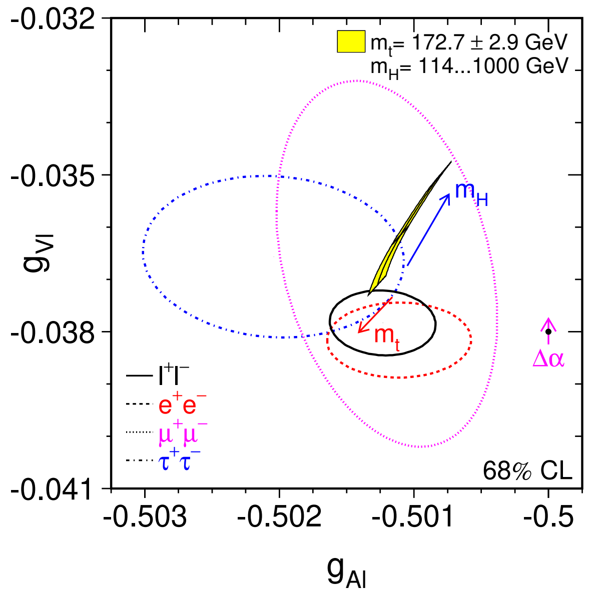


- The forward-backward asymmetry

$$A_{FB}(M_Z) = 3 \frac{g_V^f g_A^f}{({g_V^f}^2 + {g_A^f}^2)} \frac{g_V^e g_A^e}{({g_V^e}^2 + {g_A^e}^2)}$$

$\Rightarrow$ Good determination of couplings

$$g_V^f = T_3^f - 2Q_f \overline{\sin^2\theta_W}$$
$$g_A^f = T_3^f$$

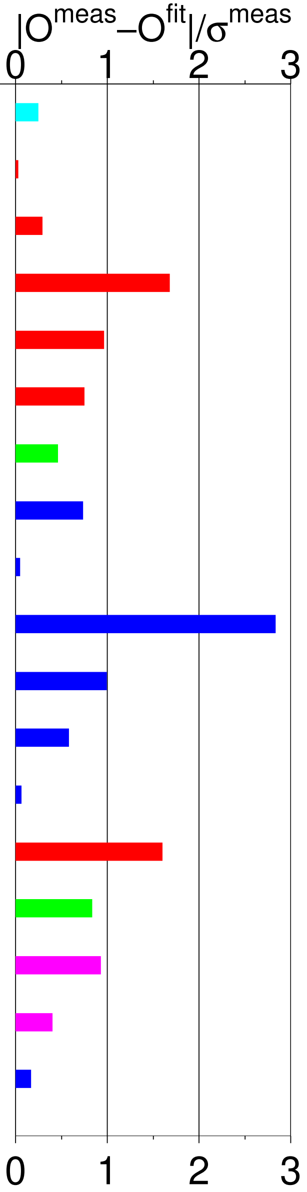


Where incluing loop corrections

$$\overline{\sin^2\theta_W} = \left(1 - \frac{M_W^2}{M_Z^2}\right) \Delta(m_{\rm top}, M_H)$$

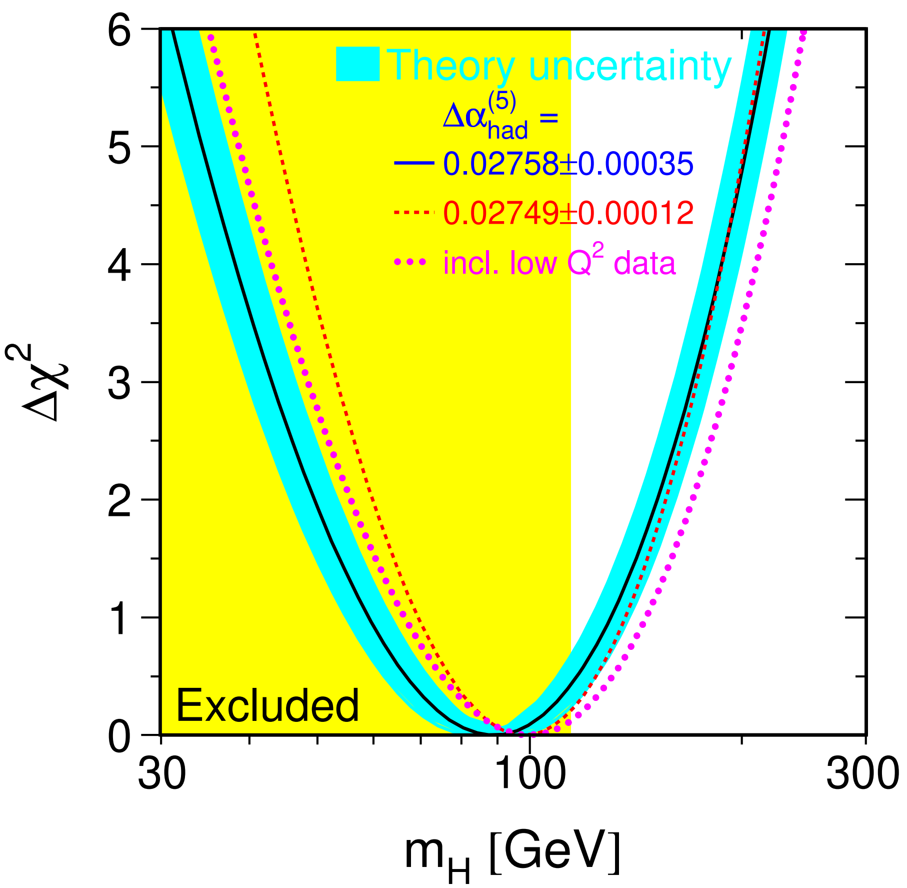
Precision Electroweak Observations

	Measurement	Fit
$\Delta\alpha_{had}^{(5)}(m_Z)$	0.02758 ± 0.00035	0.02767
m_Z [GeV]	91.1875 ± 0.0021	91.1874
Γ_Z [GeV]	2.4952 ± 0.0023	2.4959
σ_{had}^{0} [nb]	41.540 ± 0.037	41.478
R_l	20.767 ± 0.025	20.743
$A_{fb}^{0,l}$	0.01714 ± 0.00095	0.01643
$A_l(P_\tau)$	0.1465 ± 0.0032	0.1480
R_b	0.21629 ± 0.00066	0.21581
R_c	0.1721 ± 0.0030	0.1722
$A_{fb}^{0,b}$	0.0992 ± 0.0016	0.1037
$A_{fb}^{0,c}$	0.0707 ± 0.0035	0.0742
A_b	0.923 ± 0.020	0.935
A_c	0.670 ± 0.027	0.668
$A_l(SLD)$	0.1513 ± 0.0021	0.1480
$\sin^2\theta_{eff}^{lept}(Q_{fb})$	0.2324 ± 0.0012	0.2314
m_W [GeV]	80.404 ± 0.030	80.376
Γ_W [GeV]	2.115 ± 0.058	2.092
m_t [GeV]	172.5 ± 2.3	172.9



Tested with 1% precision, but…

Light Higgs Required



The Higgs Decay Modes

$$\Gamma(h \to f\bar{f}) = \frac{G_F m_f^2 (N_c)}{4\sqrt{2}\pi} M_h \left(1 - r_f\right)^{\frac{3}{2}} \qquad r_i \equiv \frac{4M_i^2}{M_h^2}$$

$$\Gamma(h \to W^+W^-) = \frac{G_F M_h^3}{8\pi\sqrt{2}} \sqrt{1 - r_W}\left(1 - r_W + \tfrac{3}{4} r_W^2\right)$$

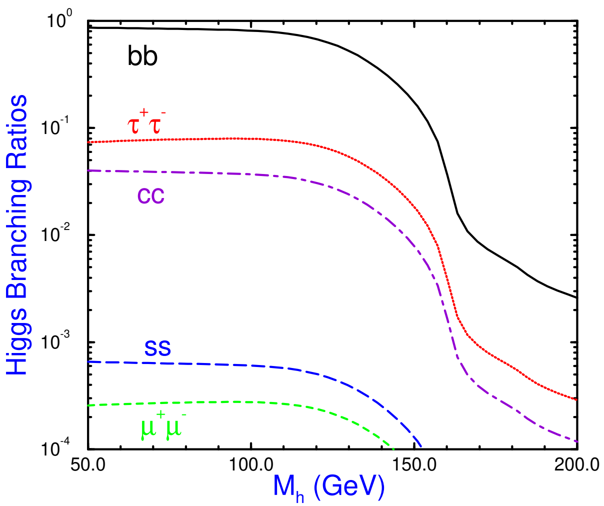
$$\Gamma(h \to ZZ) = \frac{G_F M_h^3}{8\pi\sqrt{2}} \sqrt{1 - r_Z}\left(1 - r_Z + \tfrac{3}{4} r_Z^2\right)$$

$$\Gamma_0(h \to gg) = \frac{G_F \alpha_s^2 M_h^3}{64\sqrt{2}\pi^3} \mid \sum_q F_{1/2}(r_q) \mid^2 \qquad \Gamma(h \to \gamma\gamma) = \frac{\alpha^2 G_F}{128\sqrt{2}\pi^3} g_V M_h^3 \mid \sum_{q,W} N_{ci} Q_i^2 F_i(r_i) \mid^2$$

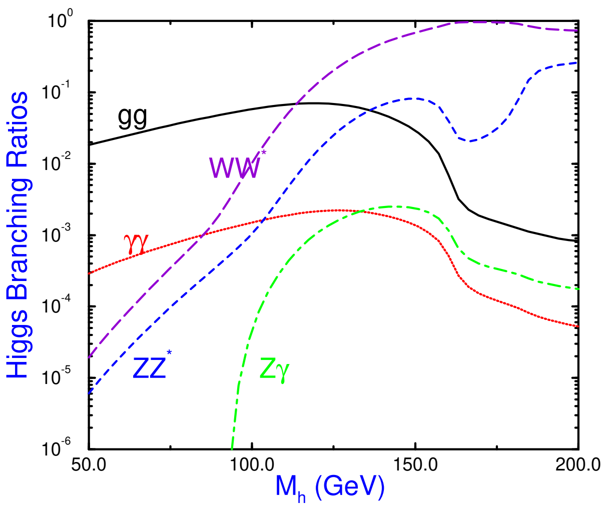
$$F_{1/2}(r_q) \equiv -2r_q[1 + (1 - r_q) f(r_q)] \qquad f(x) = \begin{cases} \sin^{-2}(\sqrt{1/x}), & \text{if } x \geq 1 \\ -\frac{1}{4}\left[\log\left(\frac{1+\sqrt{1-x}}{1-\sqrt{1-x}}\right) - i\pi\right]^2, & \text{if } x < 1, \end{cases}$$

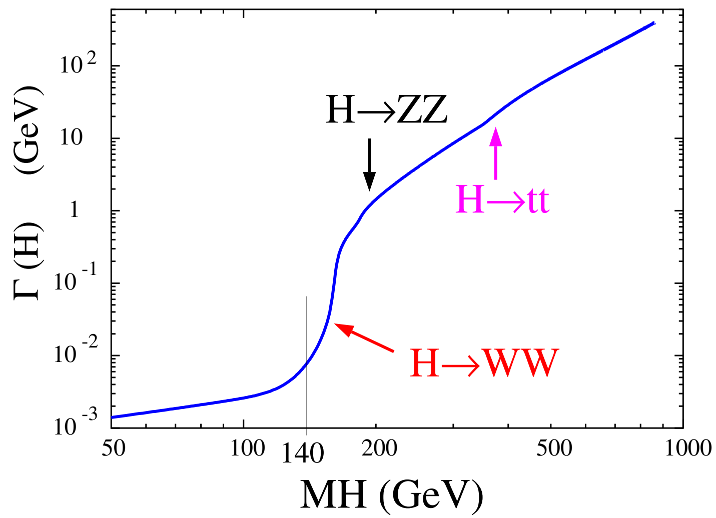
$$F_W(r_W) = 2 + 3r_W[1 + (2 - r_W) f(r_W)]$$

Higgs Branching Ratios to Fermion Pairs



Higgs Branching Ratios to Gauge Boson Pairs

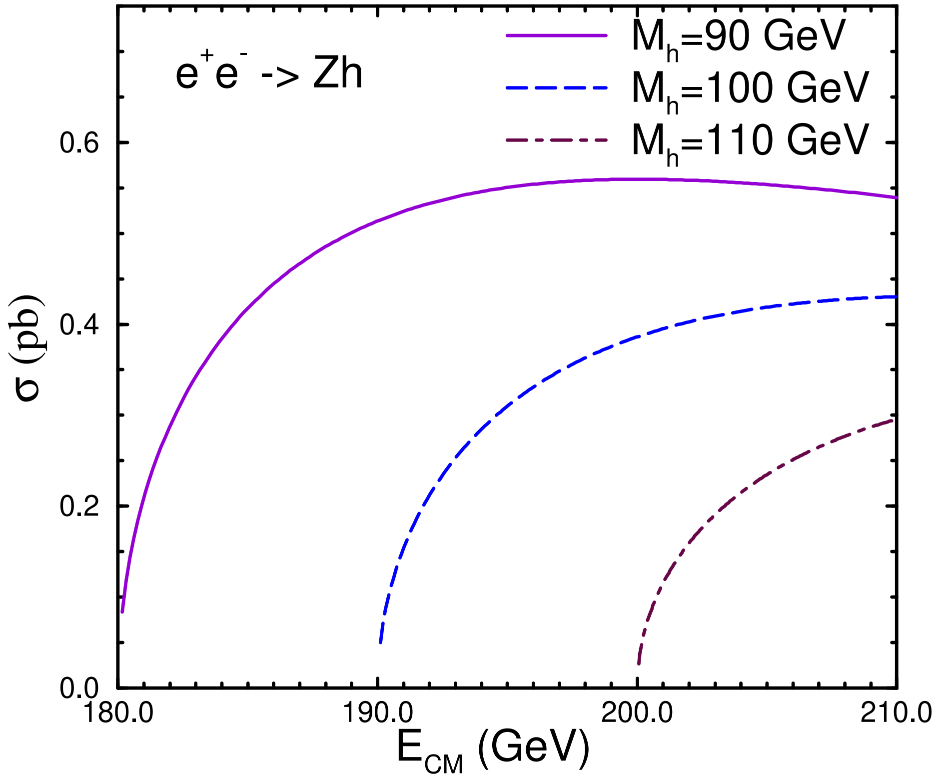




Higgs Production at e^+e^-

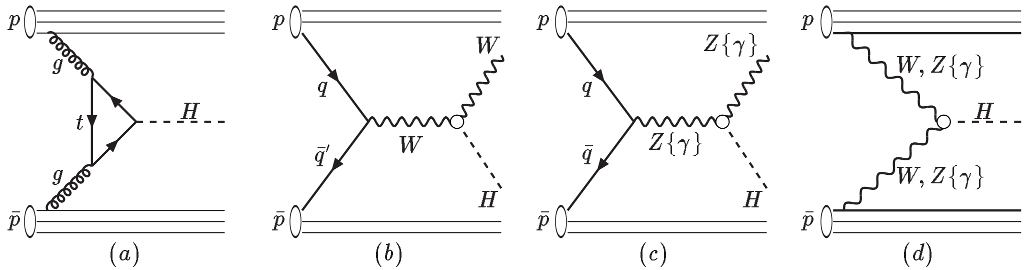
$$\sigma(e^+e^- \to Zh) = \frac{\pi\alpha^2\lambda_{Zh}^{1/2}[\lambda_{Zh} + 12\frac{M_Z^2}{s}][1 + (1 - 4\sin^2\theta_W)^2]}{192 s \sin^4\theta_W \cos^4\theta_W (1 - M_Z^2/s)^2}$$

$$\lambda_{Zh} \equiv (1 - \frac{M_h^2 + M_Z^2}{s})^2 - \frac{4 M_h^2 M_Z^2}{s^2} \qquad s = (p_{e^+} + p_{e^-})^2$$

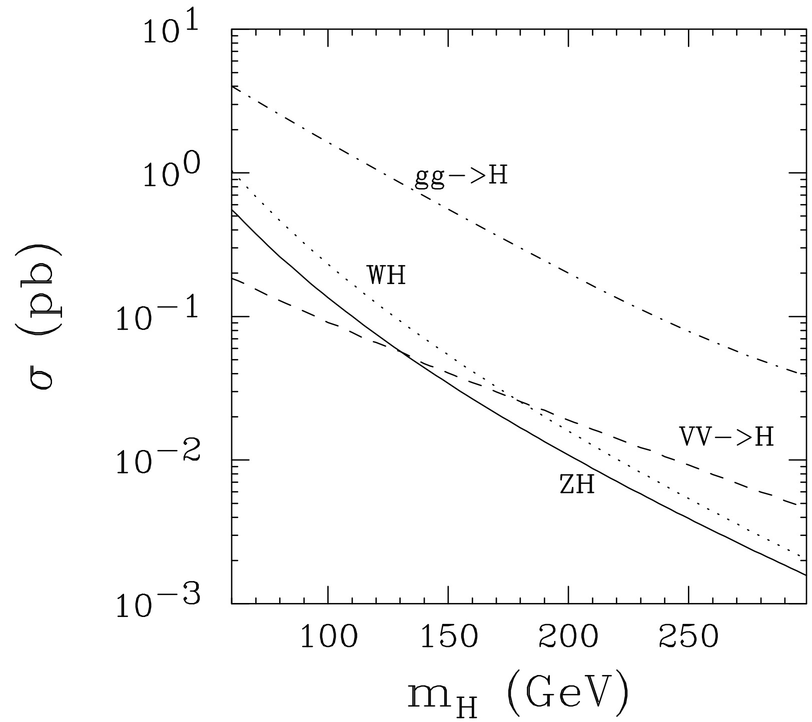


Searches at LEP (e^+e^- $\sqrt{s} = 90 - 210$ GeV) $\Rightarrow$ $M_H \geq 114.4$ GeV

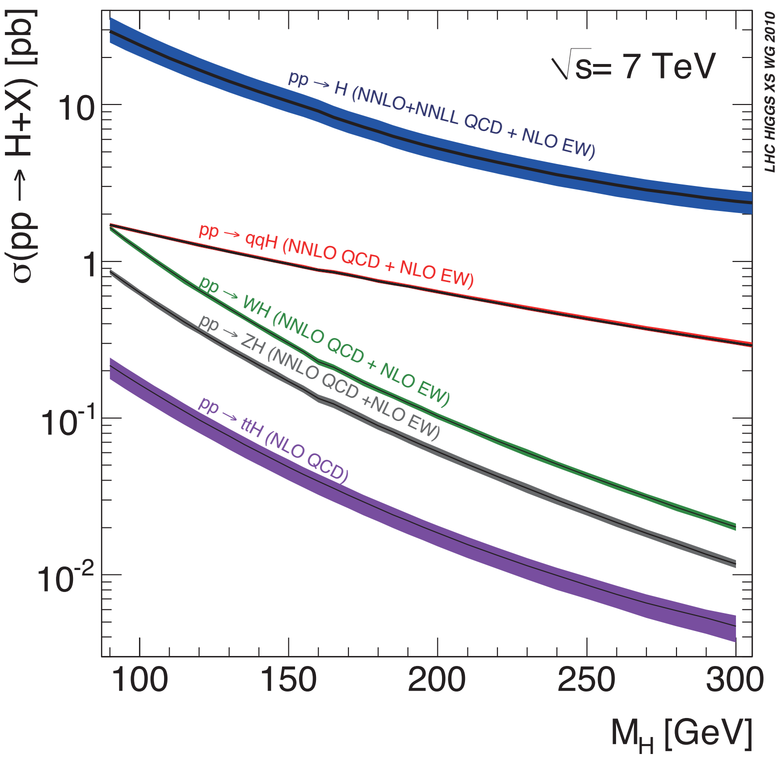
Higgs Production at Hadron Colliders



Tevatron ($p\bar{p}$ $\sqrt{s} = 2$ TeV)



LHC (pp $\sqrt{s} = 7$–14 TeV)



Higgs Production at LHC 7-8 TeV

SM main discovery modes for $\simeq$125 GeV:

.

$pp \to \gamma\gamma$

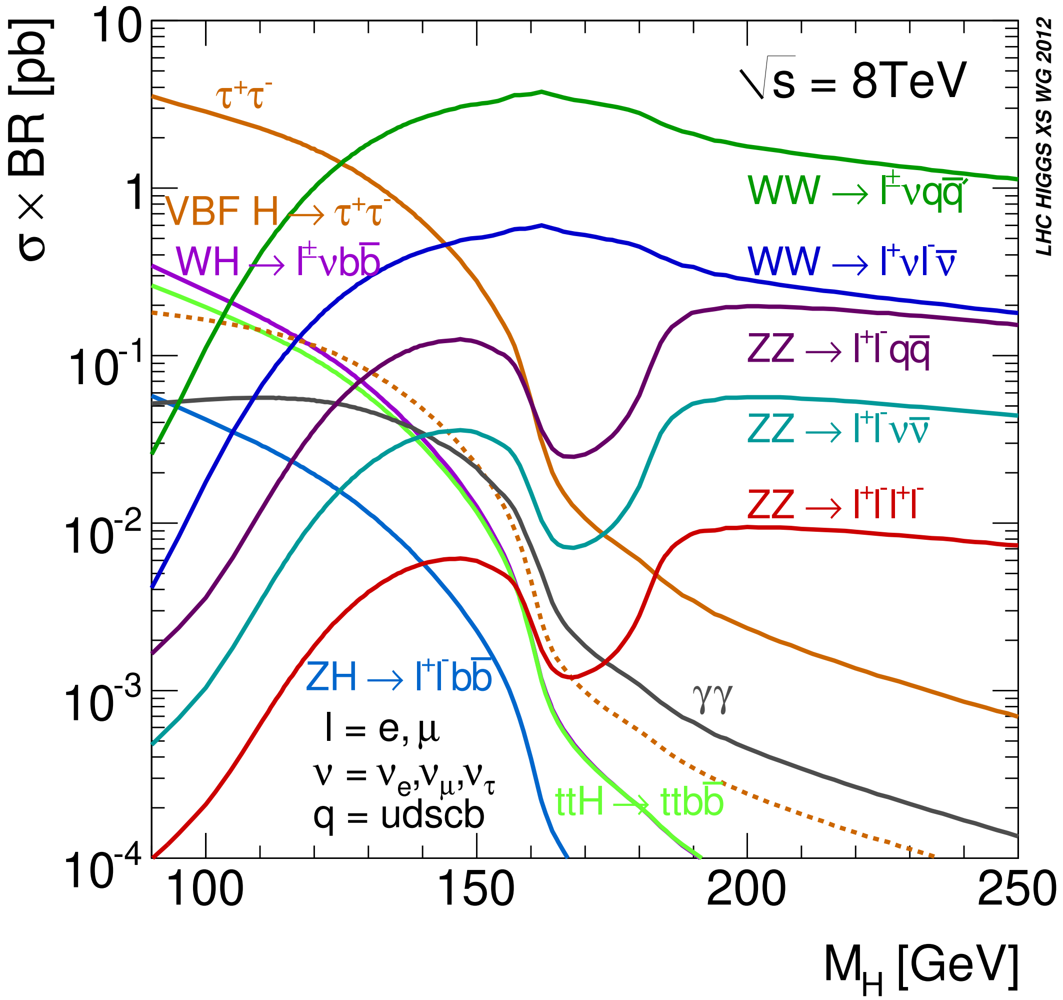
$pp \to ZZ \to \ell\ell\ell\ell$

$pp \to WW \to \ell\nu\ell\nu$

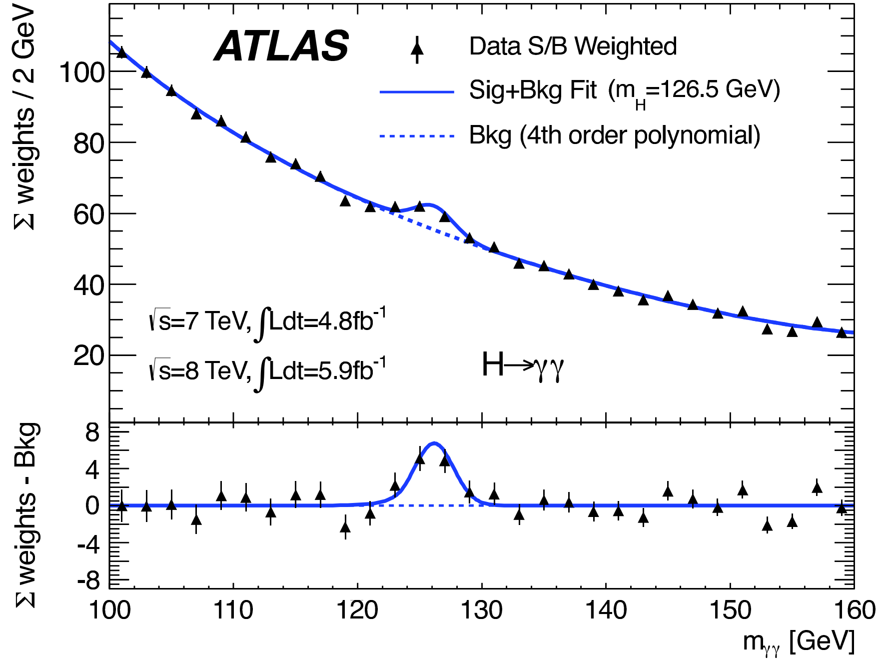
Also may be possible in:

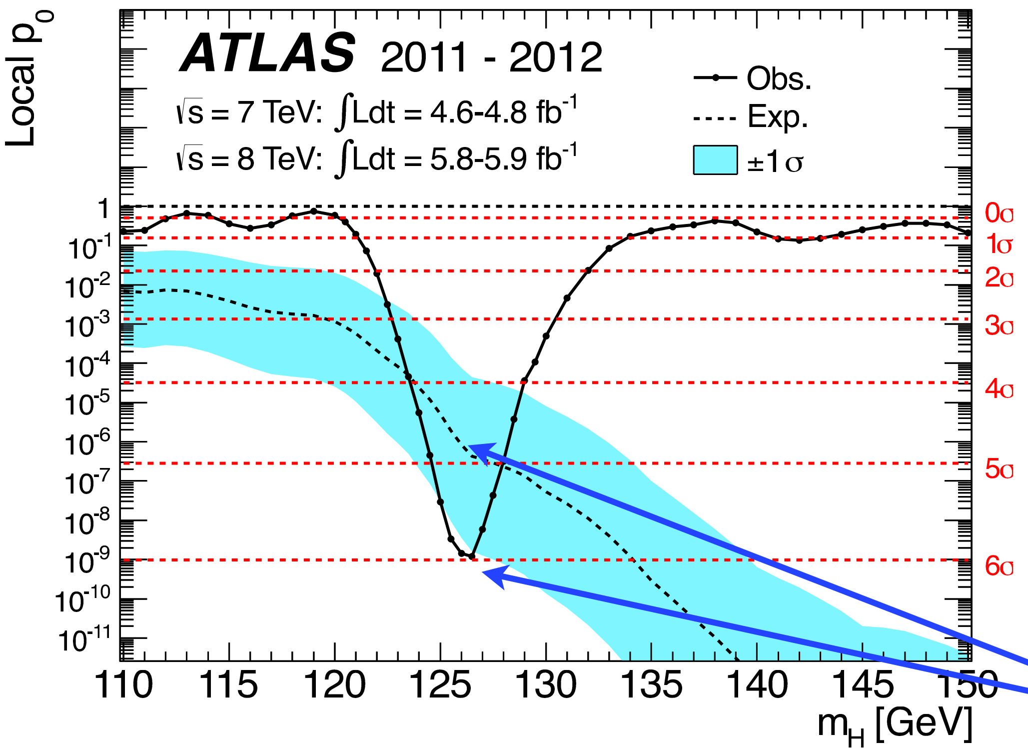
$pp \to b\bar{b}$ (only VH)

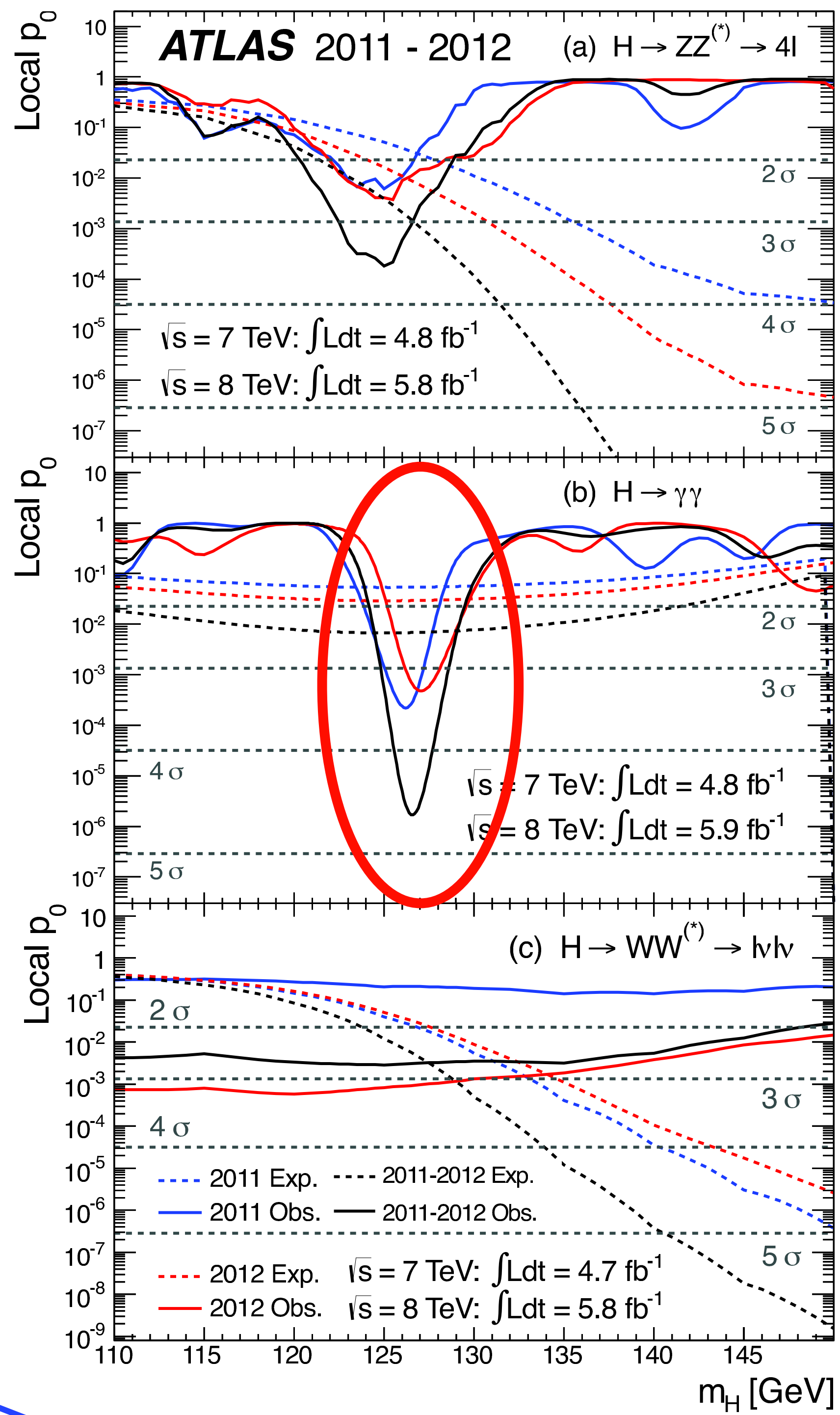
$pp \to \tau\bar{\tau}$



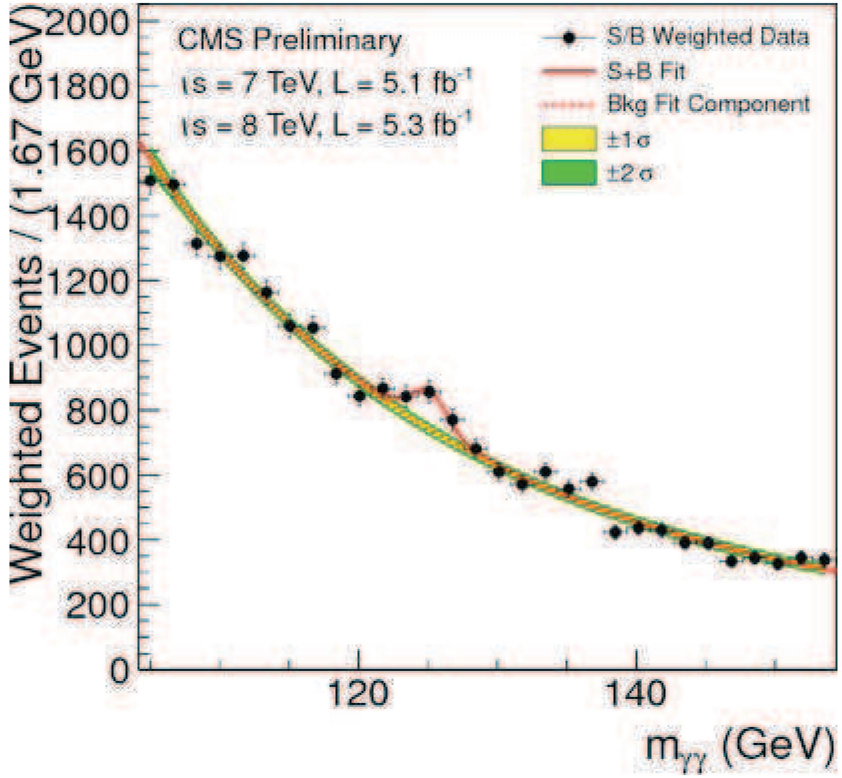
ATLAS:

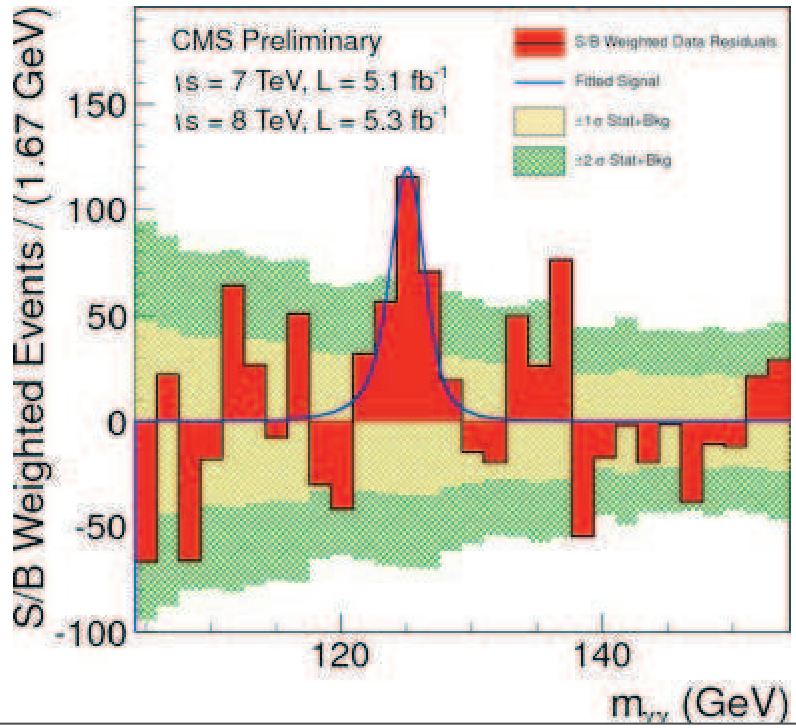






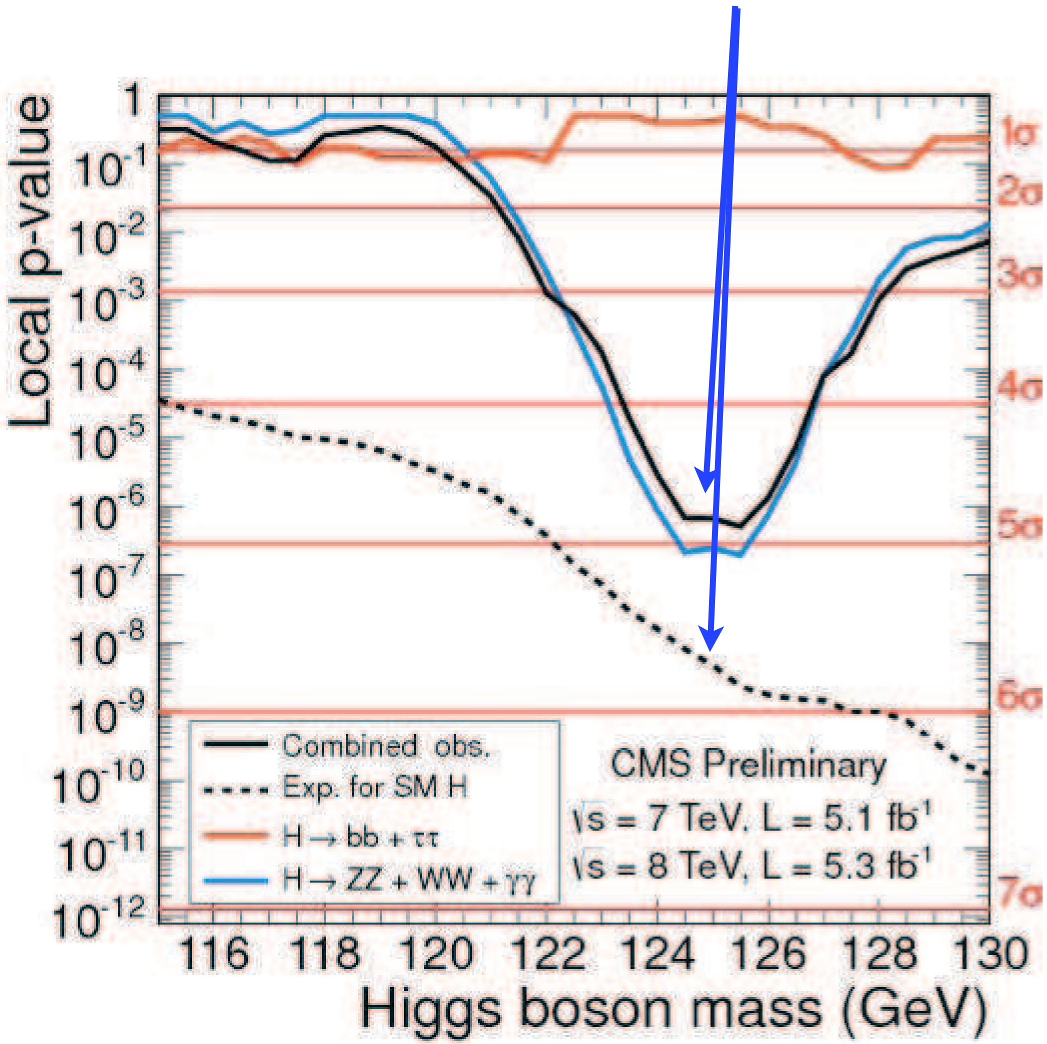
better than expected



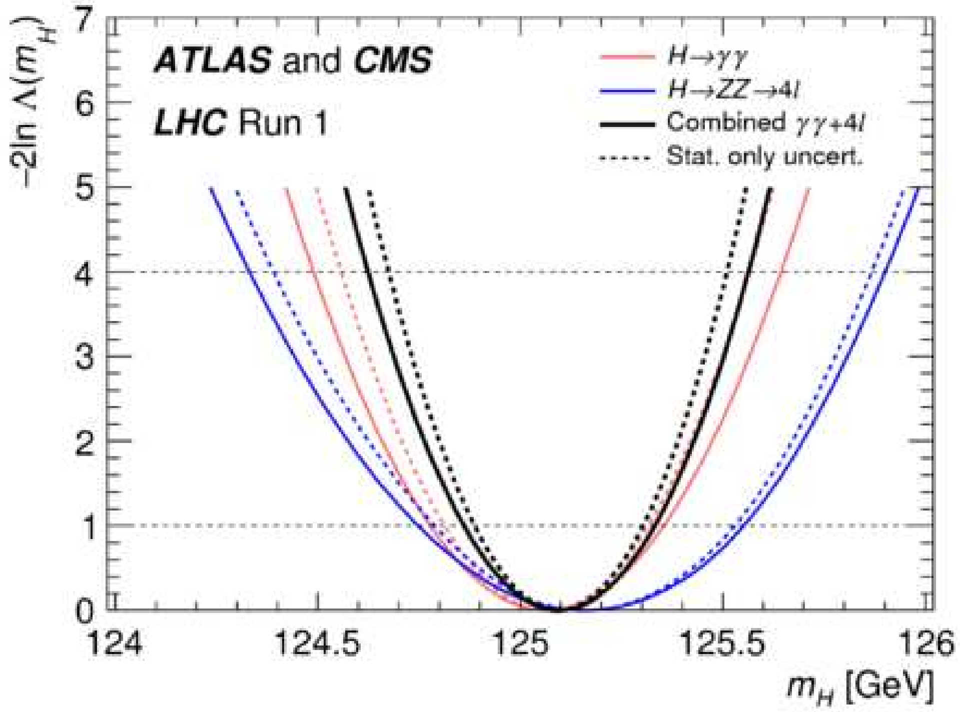


CMS:

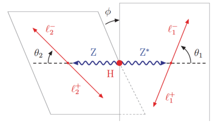
less than expected



Meassured Higgs Mass

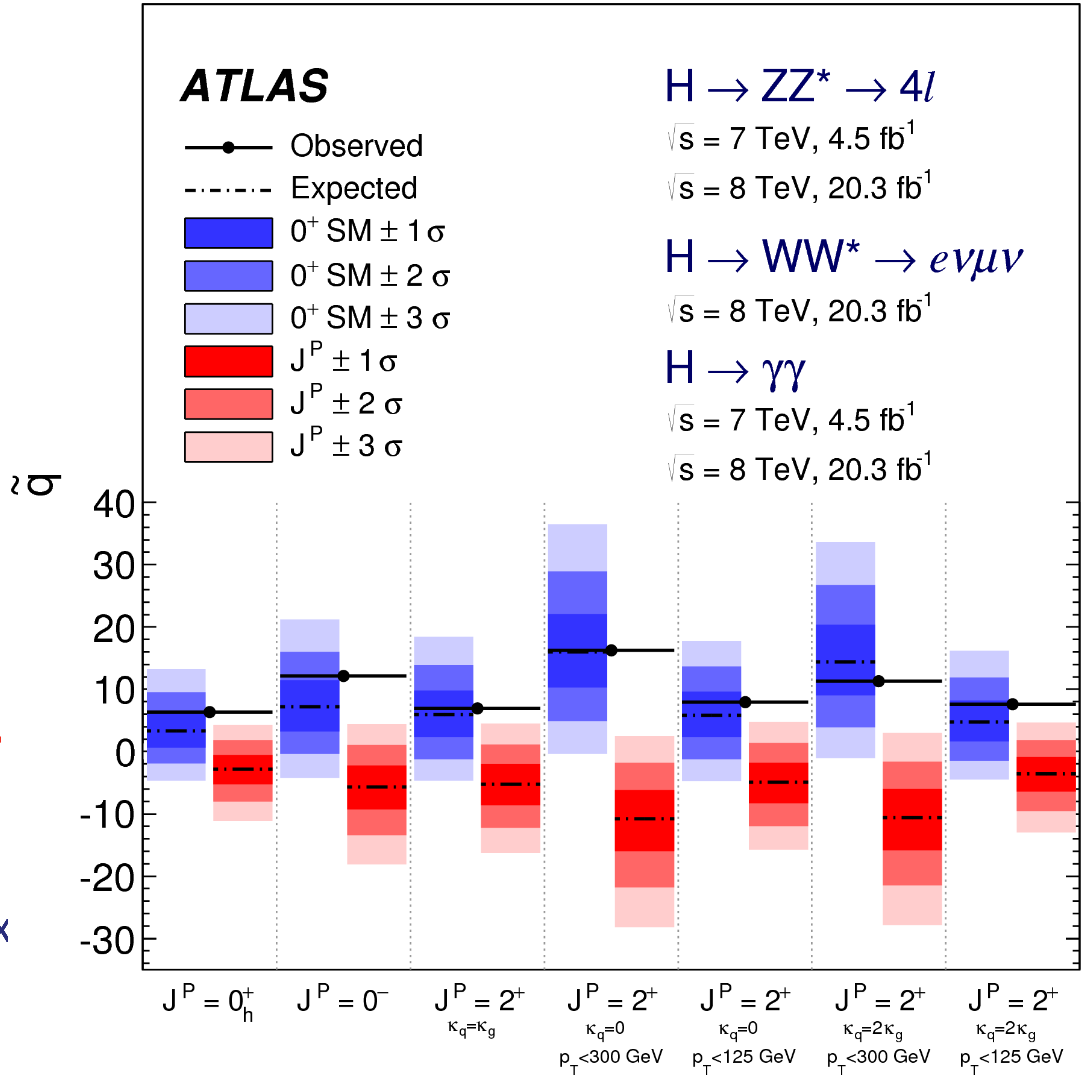


Spin-Parity Determination



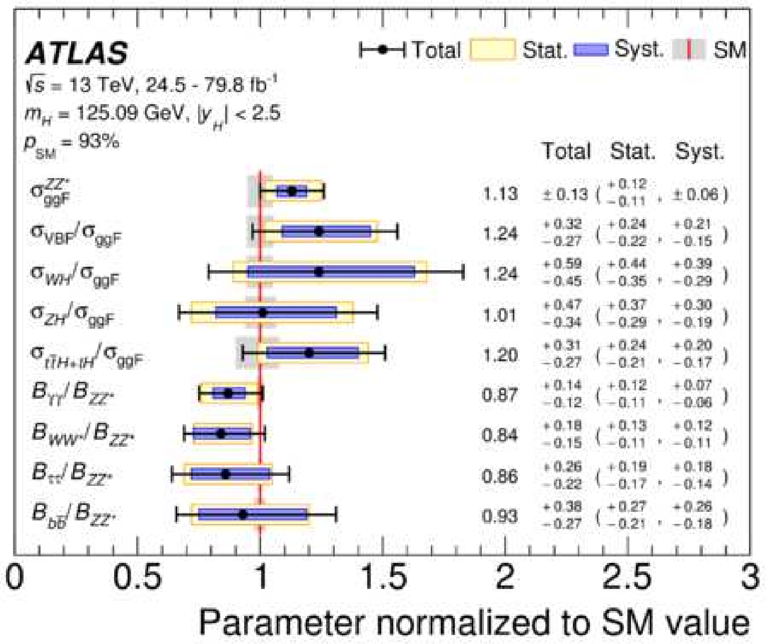
Analyzed channels:

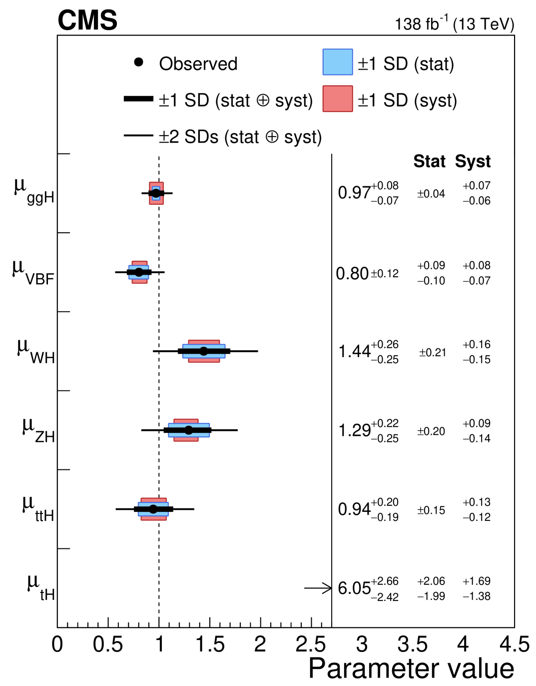
- H→ γγ decay angle cos(θ*) in Collins-Sopper frame sensitive to J
- H → WW* → ℓνℓν Several variables sensitive to J^P
  - $\Delta\phi_{\ell\ell}$, $M_{\ell\ell}$, ..
  - Combined with Boosted-Decision-Tree (BDT)
- H → ZZ* →4ℓ: Full final state reconstruction sensitive to J^P
  - 2 masses (M_{Z1},M_{Z2}) and 5 angles
  - Combined with BDT or Matrix Element-based discriminant D_{JP}

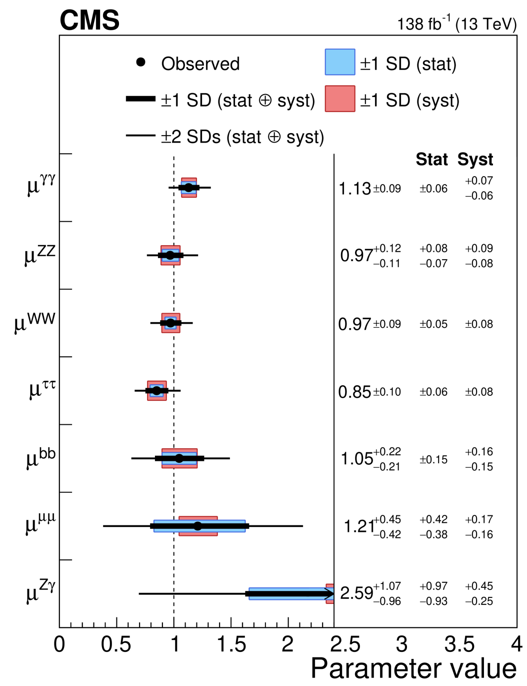


Observed Production+Decay Channels in Brief

$$\mu = \frac{(\sigma)_{obs}}{(\sigma)_{SM}} \times \frac{(BR)_{obs}}{(BR)_{SM}}$$







Higgs Couplings to SM Particles