Theory Uncertainties in SM Higgs Decays

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LHC Higgs Cross Section Working Group (BR)
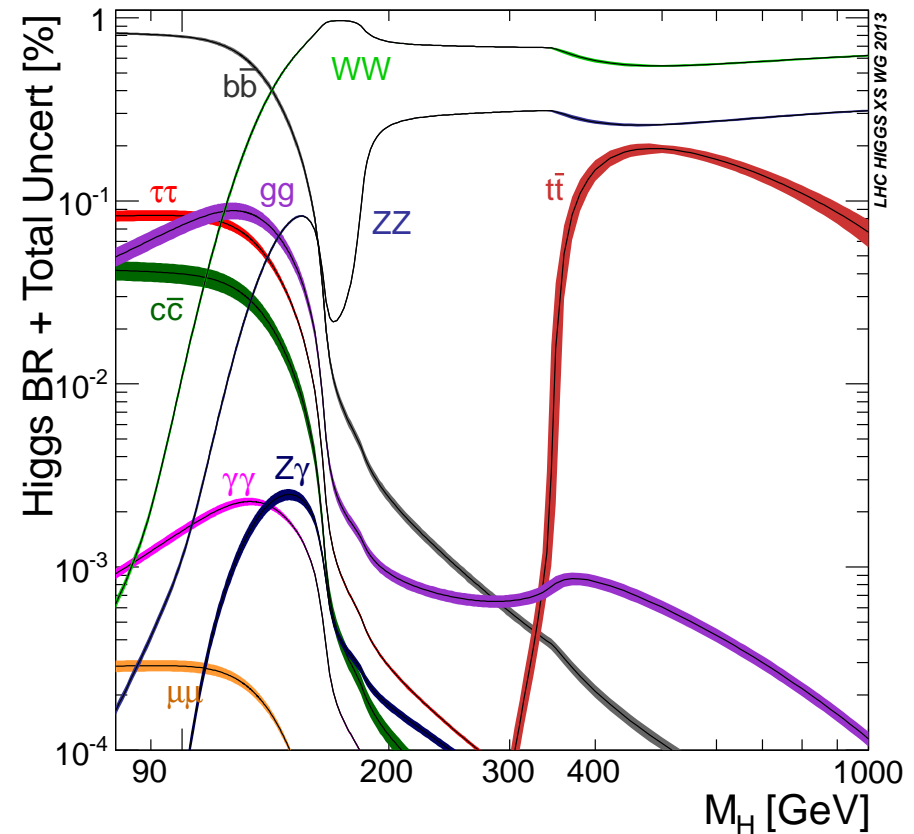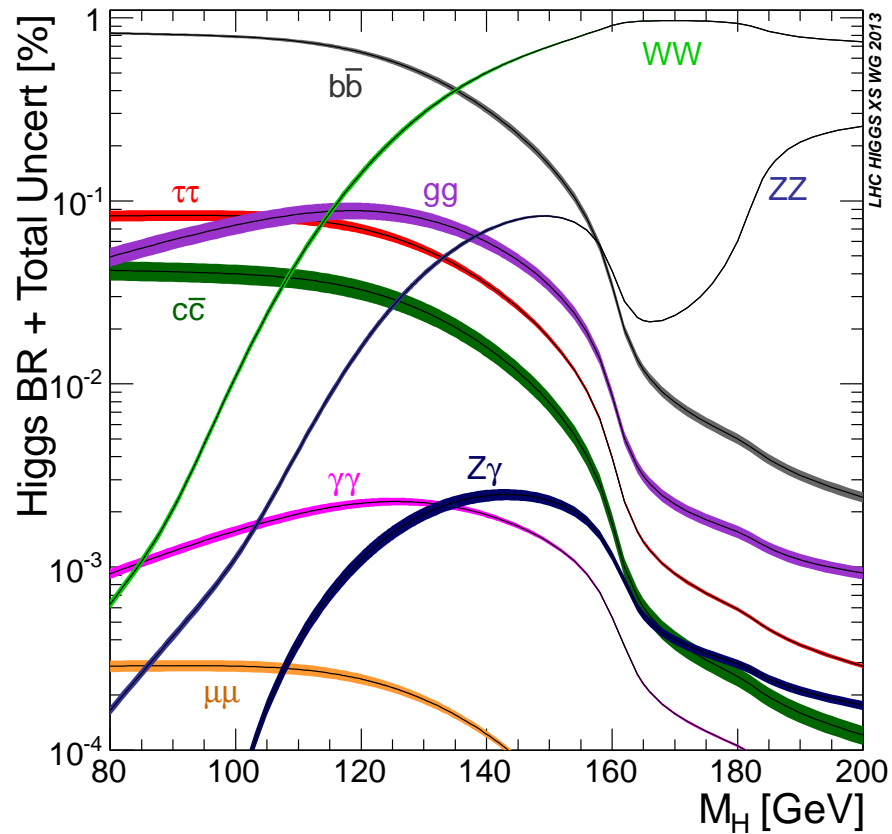
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All the details:

https://twiki.cern.ch/twiki/bin/view/LHCPhysics/BRs

Eur. Phys. J. C 71 (2011) 1753 (2011) [arXiv:1107.5909 [hep-ph]]

Latest SM Higgs BR predictions:

Based on HDECAY and Prophecy4f:

$$\Gamma_H = \Gamma^{HD} - \Gamma_{ZZ}^{HD} - \Gamma_{WW}^{HD} + \Gamma_{4f}^{P4f}$$

Theoretical uncertainties: General recipe:

1. **Parametric Uncertainties:** $p \pm \Delta p$

   – Evaluate partial widths and BRs with p, $p + \Delta p$, $p - \Delta p$
   and take the differences w.r.t. central values

   – Upper $(p + \Delta p)$ and lower $(p - \Delta p)$ uncertainties summed in
   quadrature to obtain the Combined Parametric Uncertainty

2. **Theoretical Uncertainties:**

   – Calculate uncertainty for partial widths and corresponding BRs for
   each theoretical uncertainty

   – Combine the individual theoretical uncertainties linearly to obtain the
   Total Theoretical Uncertainty

3. **Total Uncertainty:**

   Linear sum of the Combined Parametric Uncertainty and the
   Total Theoretical Uncertainties

Parametric uncertainties:

Parameter	Central Value	Uncertainty	$m_q(m_q)$
$\alpha_s(M_Z)$	0.119	$\pm 0.002(90\% \text{ CL})$	
m_c	1.42 GeV	$\pm 0.03 \text{ GeV}(2\,\sigma)$	1.28 GeV
m_b	4.49 GeV	$\pm 0.06 \text{ GeV}(2\,\sigma)$	4.16 GeV
m_t	172.5 GeV	$\pm 2.5 \text{ GeV}$	165.4 GeV

Comments:

— m_b, m_c: one-loop pole masses
those masses accidentally show negligible dependence on α_s, so that their variation can be done independently from α_s

— m_b, m_c uncertainties:

[K. Chetyrkin, J. Kühn, A. Maier, P. Maierhöfer, P. Marquard, M. Steinhauser, C. Sturm [arXiv:0907.2110]]
(PDG uncertainties much larger . . .)

Theoretical uncertainties:

Partial Width	QCD	Electroweak	Total
$H \to b\bar{b}/c\bar{c}$	$\sim 0.1\%$	$\sim 1\text{–}2\%$ for $M_H \lesssim 135$ GeV	$\sim 2\%$
$H \to \tau^+\tau^-/\mu^+\mu^-$		$\sim 1\text{–}2\%$ for $M_H \lesssim 135$ GeV	$\sim 2\%$
$H \to t\bar{t}$	$\lesssim 5\%$	$\lesssim 2\text{–}5\%$ for $M_H < 500$ GeV	$\sim 5\%$
		$\sim 0.1(\frac{M_H}{1\ \text{TeV}})^4$ for $M_H > 500$ GeV	$\sim 5\text{–}10\%$
$H \to gg$	$\sim 3\%$	$\sim 1\%$	$\sim 3\%$
$H \to \gamma\gamma$	$< 1\%$	$< 1\%$	$\sim 1\%$
$H \to Z\gamma$	$< 1\%$	$\sim 5\%$	$\sim 5\%$
$H \to WW/ZZ \to 4f$	$< 0.5\%$	$\sim 0.5\%$ for $M_H < 500$ GeV	$\sim 0.5\%$
		$\sim 0.17(\frac{M_H}{1\ \text{TeV}})^4$ for $M_H > 500$ GeV	$\sim 0.5\text{–}15\%$

Comments:
− QCD corrections: scale change by factor 2 and 1/2
− EW corrections: missing HO estimation based on the known structure
  and size of the NLO corrections
− For $M_H > 500$ GeV: higher-order heavy-Higgs corrections dominate error
− Different uncertainties on a given channel added linearly

Full BR uncertainty overview:

M_H = 126 GeV			
Decay	TU [%]	PU [%]	Total [%]
$H \to \gamma\gamma$	±2.7	±2.2	±4.9
$H \to b\bar{b}$	±1.5	± 1.9	±3.3
$H \to \tau\tau$	±3.5	±2.1	±5.6
$H \to WW$	±2.0	±2.2	±4.1
$H \to ZZ$	±2.0	±2.2	±4.2

But:

To take into accout correlations it is better/easier to work with uncertainties for the individual decay widths

Uncertainties on decay widths: [YR3, to appear]

Channel	Γ [MeV]	$\Delta\alpha_s$	Δm_b	Δm_c	Δm_t	THU
$H \to b\bar{b}$	2.36	-2.3% $+2.3\%$	$+3.3\%$ -3.2%	$+0.0\%$ -0.0%	$+0.0\%$ -0.0%	$+2.0\%$ -2.0%
$H \to \tau^+\tau^-$	$2.59\cdot10^{-1}$	$+0.0\%$ $+0.0\%$	$+0.0\%$ -0.0%	$+0.0\%$ -0.0%	$+0.1\%$ -0.1%	$+2.0\%$ -2.0%
$H \to \mu^+\mu^-$	$8.99\cdot10^{-4}$	$+0.0\%$ $+0.0\%$	$+0.0\%$ -0.0%	-0.1% -0.0%	$+0.0\%$ -0.1%	$+2.0\%$ -2.0%
$H \to c\bar{c}$	$1.19\cdot10^{-1}$	-7.1% $+7.0\%$	-0.1% -0.1%	$+6.2\%$ -6.1%	$+0.0\%$ -0.1%	$+2.0\%$ -2.0%
$H \to gg$	$3.57\cdot10^{-1}$	$+4.2\%$ -4.1%	-0.1% -0.1%	$+0.0\%$ -0.0%	-0.2% $+0.2\%$	$+3.0\%$ -3.0%
$H \to \gamma\gamma$	$9.59\cdot10^{-3}$	$+0.0\%$ -0.0%	$+0.0\%$ -0.0%	$+0.0\%$ -0.0%	$+0.0\%$ -0.0%	$+1.0\%$ -1.0%
$H \to Z\gamma$	$6.84\cdot10^{-3}$	$+0.0\%$ -0.0%	$+0.0\%$ -0.0%	$+0.0\%$ -0.1%	$+0.0\%$ -0.1%	$+5.0\%$ -5.0%
$H \to WW^*$	$9.73\cdot10^{-1}$	$+0.0\%$ -0.0%	$+0.0\%$ -0.0%	$+0.0\%$ -0.0%	$+0.0\%$ -0.0%	$+0.5\%$ -0.5%
$H \to ZZ^*$	$1.22\cdot10^{-1}$	$+0.0\%$ -0.0%	$+0.0\%$ -0.0%	$+0.0\%$ -0.0%	$+0.0\%$ -0.0%	$+0.5\%$ -0.5%

Data available for $M_H = 122$ GeV, 126 GeV, 130 GeV

$\Rightarrow$ used for ATLAS and CMS evaluations $\Rightarrow$ provided to Snowmass/Higgs

Summary:

- SM Higgs BRs evaluated by combining HDECAY and Prophecy4f

- Parametric uncertainties: α_s, m_b, m_c, m_t

- Theoretical uncertainties: estimate of missing QCD and EW corrections

- Total uncertainties: linear sum

- Available from LHCHXSWG: uncertainties for BRs and decay widhts
  (the latter preferred for correlations)

- Results used for ATLAS and CMS evaluations
  Results provided to Snowmass/Higgs

  Thanks to A. Denner, A. Mück, I. Puljak, D. Rebuzzi, M. Spira