Discussion of theoretical and parametric uncertainties on the Higgs Branching ratios

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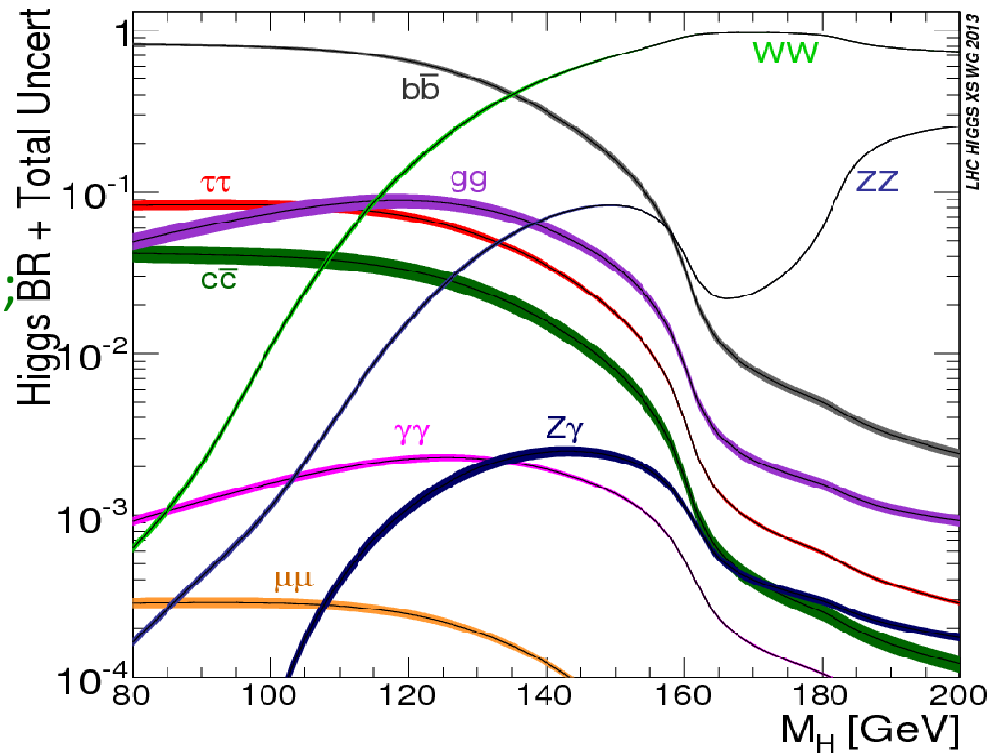
Disclaimer: I was asked to lead the discussion for the theoretical and parametric uncertainties on Higgs Br's.

But, because of the lack of my knowledge and preparation, I could only summarize current status on them from published papers.

After the overview, I would like to call for discussion from you.

References:

Carena,Haber,Logan,Mrenna(02);
Droll,Logan(07); Baglio,Djouadi(11);
Denner,Heinemeyer,Puljak,Rebuzzi,Spira(11);
LHC Higgs XS WG(13);
Almeida,Lee,Pokorski,Wells(14);
Lepage,Mackenzie,Peskin(14), etc.



ILC coupling measurement accuracy

ILC Higgs White Paper(13)

Expected accuracies of coupling determination at the ILC:

- $\sigma \times BR_i \rightarrow BR_i \rightarrow \Gamma_i \rightarrow g_i$ [$\delta g/g = 1/2 \cdot \delta\Gamma/\Gamma$] Plenary talk by K.Fujii
- Expected accuracy for each coupling is estimated in model-dependent and model-independent analysis

model dependent

	ILC(250)	ILC(500)	ILC500(LumUp)
$\sqrt{s}$ (GeV)	250	250+500	250+500
L (fb^{-1})	250	250+500	1150+1600
$\gamma\gamma$	17 %	8.3 %	4.4 %
gg	6.1 %	2.0 %	1.1 %
WW	4.7 %	0.4 %	0.3 %
ZZ	0.7 %	0.5 %	0.3 %
$t\bar{t}$	6.4 %	2.5 %	1.4 %
$b\bar{b}$	4.7 %	1.0 %	0.6 %
$\tau^+\tau^-$	5.2 %	1.9 %	1.0 %
$\Gamma_T(h)$	9.0 %	1.7 %	1.0 %
$\mu^+\mu^-$	91 %	91 %	42 %
hhh	–	83 %	46 %
BR(invis.)	$<$ 0.9 %	$<$ 0.9 %	$<$ 0.4 %
$c\bar{c}$	6.8 %	2.8 %	1.5 %

model independent

	ILC(250)	ILC(500)	ILC500(LumUp)
$\sqrt{s}$ (GeV)	250	250+500	250+500
L (fb^{-1})	250	250+500	1150+1600
$\gamma\gamma$	18 %	8.4 %	4.5 %
gg	6.4 %	2.3 %	1.2 %
WW	4.8 %	1.1 %	0.6 %
ZZ	1.3 %	1.0 %	0.5 %
$t\bar{t}$	–	14 %	7.8 %
$b\bar{b}$	5.3 %	1.6 %	0.8 %
$\tau^+\tau^-$	5.7 %	2.3 %	1.2 %
$c\bar{c}$	6.8 %	2.8 %	1.5 %
$\mu^+\mu^-$	91 %	91 %	42 %
$\Gamma_T(h)$	12 %	4.9 %	2.5 %
hhh	–	83 %	46 %
BR(invis.)	$<$ 0.9 %	$<$ 0.9 %	$<$ 0.4 %

Theoretical Uncertainties

Available H.O. corrections

c.f.: Higgs XS WG report,
HDECAY,,,

- $h \to ff$: QCD N^4LO; EW $O(\alpha^2 m_t^4/m_h^4)$
- $h \to gg$: QCD N^3LO(HQ limit); EW $O(\alpha)$
- $h \to \gamma\gamma$: $O(\alpha^2, \alpha\alpha_s^3)$
- $h \to VV \to 4f$: full NLO QCD & EW ,,,

Remaining uncertainties:

EW corrections more serious than QCD

Denner,Heinemeyer,Puljak,Rebuzzi,Spira(11)

$\delta_{QCD} < \delta_{EW}$

	Partial Width	QCD	Electroweak	Total	
★	$H \to b\bar{b}/c\bar{c}$	$\sim 0.1\%$	~ 1–2% for $M_H \lesssim 135$ GeV	$\sim 2\%$	(1.2%/3%)
★	$H \to \tau^+\tau^-/\mu^+\mu^-$		~ 1–2% for $M_H \lesssim 135$ GeV	$\sim 2\%$	(2%)
	$H \to t\bar{t}$	$\lesssim 5\%$	$\lesssim 2$–5% for $M_H < 500$ GeV	$\sim 5\%$	
			$\sim 0.1(\frac{M_H}{1\,\mathrm{TeV}})^4$ for $M_H > 500$ GeV	~ 5–10%	
	$H \to gg$	$\sim 3\%$	$\sim 1\%$	$\sim 3\%$	(2.2%)
	$H \to \gamma\gamma$	$< 1\%$	$< 1\%$	$\sim 1\%$	
★	$H \to Z\gamma$	$< 1\%$	$\sim 5\%$	$\sim 5\%$	
★	$H \to WW/ZZ \to 4f$	$< 0.5\%$	$\sim 0.5\%$ for $M_H < 500$ GeV	$\sim 0.5\%$	(0.6%)
			$\sim 0.17(\frac{M_H}{1\,\mathrm{TeV}})^4$ for $M_H > 500$ GeV	~ 0.5–15%	

Parametric Uncertainties

PDG2014

$$\begin{cases} \bar{m}_b(\bar{m}_b) = 4.18 \pm 0.03 \text{ [GeV] } (0.7\%) \\ \bar{m}_c(\bar{m}_c) = 1.275 \pm 0.025 \text{ [GeV] } (2\%) \\ \alpha_s(m_Z) = 0.1184 \pm 0.0006 \ (0.5\%) \\ m_h = 125.7 \pm 0.4 \text{ [GeV] } (0.3\%) \end{cases}$$

Parametric uncertainties can be described as $\frac{\delta \Gamma_i}{\Gamma_i} = \sum_k \left| \frac{x_k \partial \Gamma_i}{\Gamma_i \partial x_k} \right| \cdot \frac{\delta x_k}{x_k}$

- Normalized derivative: $\frac{x_j}{\Gamma_k} \frac{\partial \Gamma_k}{\partial x_j}$

	M_b	M_c	$\alpha_s(m_Z)$
Γ_b	2.5	0	-2.5
Γ_c	0	3.6	-9.2
Γ_g	-0.07	0	2.5

Almeida,Lee,Pokorski,Wells(14)

	m_H
Γ_W	13.7
Γ_Z	15.3

Parametric Uncertainties: Current status

ILC goal

$$\frac{\delta\Gamma_b}{\Gamma_b} = \left|2.5\frac{\delta\bar{m}_b}{\bar{m}_b}\right| \oplus \left|-2.5\frac{\delta\alpha_s}{\alpha_s}\right| = |2.5\cdot 0.7\%| \oplus |-2.5\cdot 0.5\%| = \underline{3\%}$$

(1.2%)

$$\frac{\delta\Gamma_c}{\Gamma_c} = \left|3.6\frac{\delta\bar{m}_c}{\bar{m}_c}\right| \oplus \left|-9.2\frac{\delta\alpha_s}{\alpha_s}\right| = |3.6\cdot 2\%| \oplus |-9.2\cdot 0.5\%| = \underline{11.8\%}$$

(3.0%)

$$\frac{\delta\Gamma_g}{\Gamma_g} = \left|2.5\frac{\delta\alpha_s}{\alpha_s}\right| = |2.5\cdot 0.5\%| = 1.3\%$$

(2.2%)

$$\frac{\delta\Gamma_W}{\Gamma_W} = \left|13.7\frac{\delta m_h}{m_h}\right| = |13.7\cdot 0.3\%| = \underline{4.1\%}$$

(0.6%)

$$\frac{\delta\Gamma_Z}{\Gamma_Z} = \left|15.3\frac{\delta m_h}{m_h}\right| = |15.3\cdot 0.3\%| = \underline{4.6\%}$$

(0.6%)

Future precision on Higgs mass

100MeV(0.08%) [LHC14]	30MeV (0.024%) [ILC]
$\rightarrow 1.1\%$	$\rightarrow \underline{0.33\%}$
$\rightarrow 1.2\%$	$\rightarrow \underline{0.37\%}$

Parametric Uncertainties: Future Prospects

Lepage,Mackenzie,Peskin(14): Future development in Lattice calculation improve the uncertainties for quark masses and QCD coupling constant.

McNeile,Davies,Follana, Hornbostel,Lepage(10)

$$\begin{cases} m_b(10\ \text{GeV}) = 3.617 \pm 0.025\ [\text{GeV}] \\ m_c(3\ \text{GeV}) = 0.986 \pm 0.006\ [\text{GeV}] \\ \alpha_s(m_Z) = 0.1184 \pm 0.0006 \end{cases}$$

	$\delta m_b(10)$	$\delta\alpha_s(m_Z)$	$\delta m_c(3)$	Γ_b	Γ_c	Γ_g
current errors [10]	0.70	0.63	0.61	2.6%	7.7%	1.6%
(one order improvement in P.T.) + PT	0.69	0.40	0.34	2.2%	4.9%	1.0%
(lattice spacing reduce to 0.03fm) + LS	0.30	0.53	0.53	2.0%	6.8%	1.3%
(the same but to 0.023fm) + LS^2	0.14	0.35	0.53	1.2%	5.1%	0.88%
+ PT + LS	0.28	0.17	0.21	1.1%	2.3%	0.43%
+ PT + LS^2	0.12	0.14	0.20	0.65%	2.0%	0.35%
+ PT + LS^2 + ST	0.09	0.08	0.20	0.43%	1.5%	0.20%
ILC goal				(1.2%	3%	2.2%)

Summary and discussions:

- To-do list for the higher-order calculations :

  full two-loop EW corrections to $h \to ff$ decays,

  next order in QCD & EW to $h \to gg$,

  NNLO EW corrections to $h \to VV \to 4f$,,,

- Lattice development for QCD parameter determination

  are these errors correctly estimated?

  consistency check by different group?

  is there correlation on the uncertainties of m_b, m_c and α_s?

- Can Higgs mass determination be more accurate at the ILC?

  it can limit the $\Gamma_{W,Z}$ accuracies, and therefore, κ_V.