SM PRECISION PREDICTIONS FOR HIGGS PARTIAL WIDTHS

Michael Spira (PSI)

I *INTRODUCTION*

- SM very successful $\leftarrow$ precision data [LEP, Tevatron, LHC]

- open problems: – mechanism of electroweak symmetry breaking
  – unification of forces
  – space-time structure @ short distances

- LHC: fundamental discoveries: Higgs boson(s?)
  Supersymmetry ?
  Extra space dimensions ?

- electroweak symmetry breaking: two classes of realization:
  – standard Higgs mechanism [SM, SUSY,. . .]
  – strong elw. symmetry breaking [TC, LH, Higgsless, ED,. . .]

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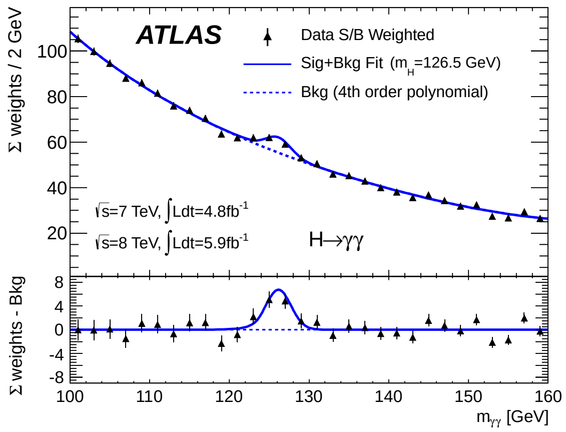
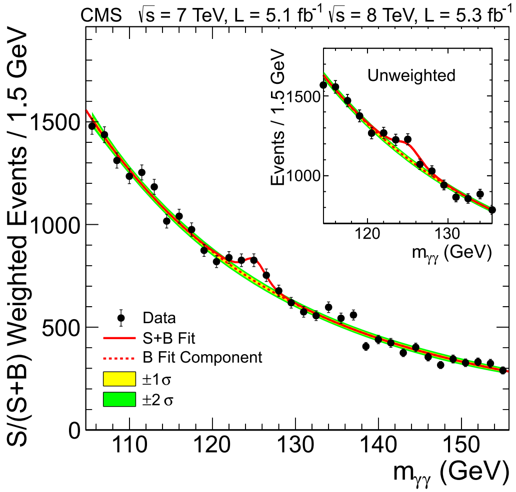
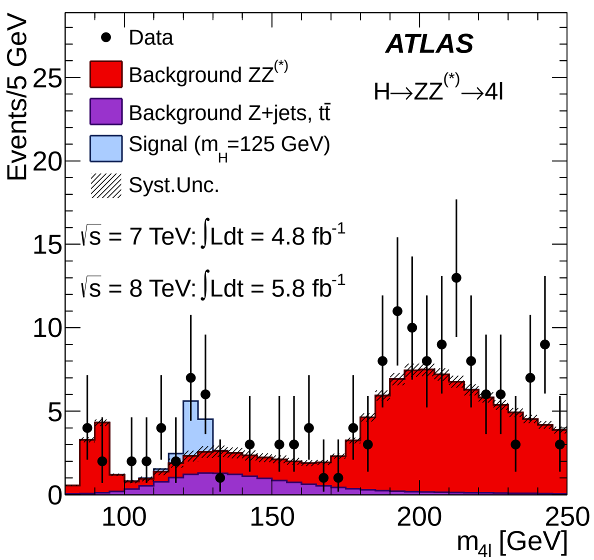
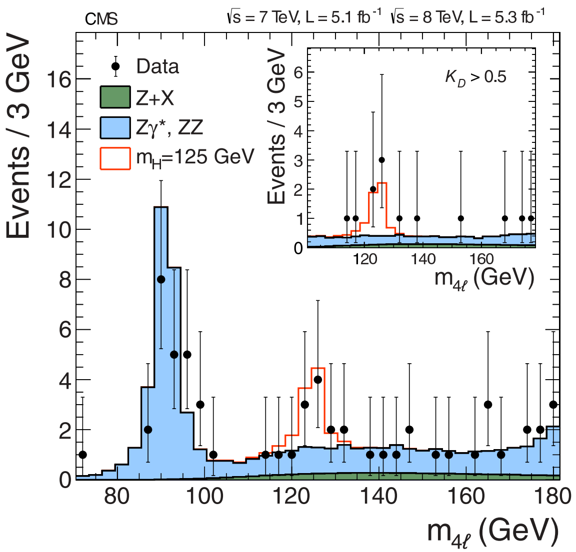
- electroweak symmetry breaking: two classes of realization:
  – standard Higgs mechanism [SM, SUSY,. . .]
  – strong elw. symmetry breaking [TC, LH, ~~Higgsless~~, ED,. . .]

- we have found the Higgs: $M_H \sim 125$ GeV
- $gg \to H$ dominant

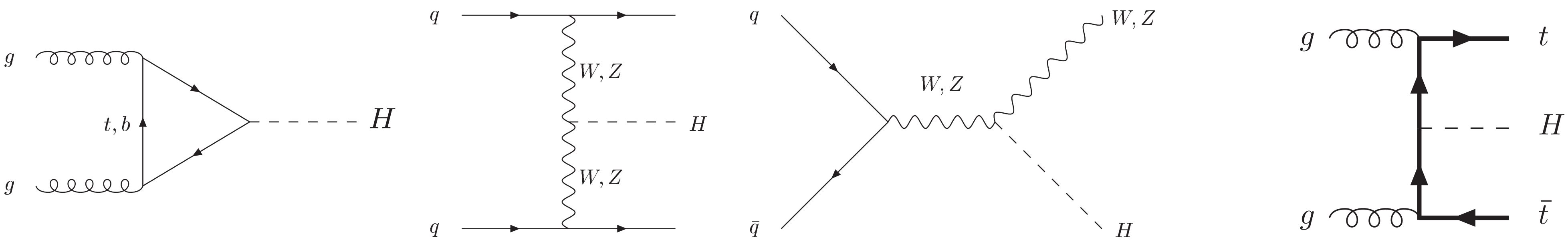


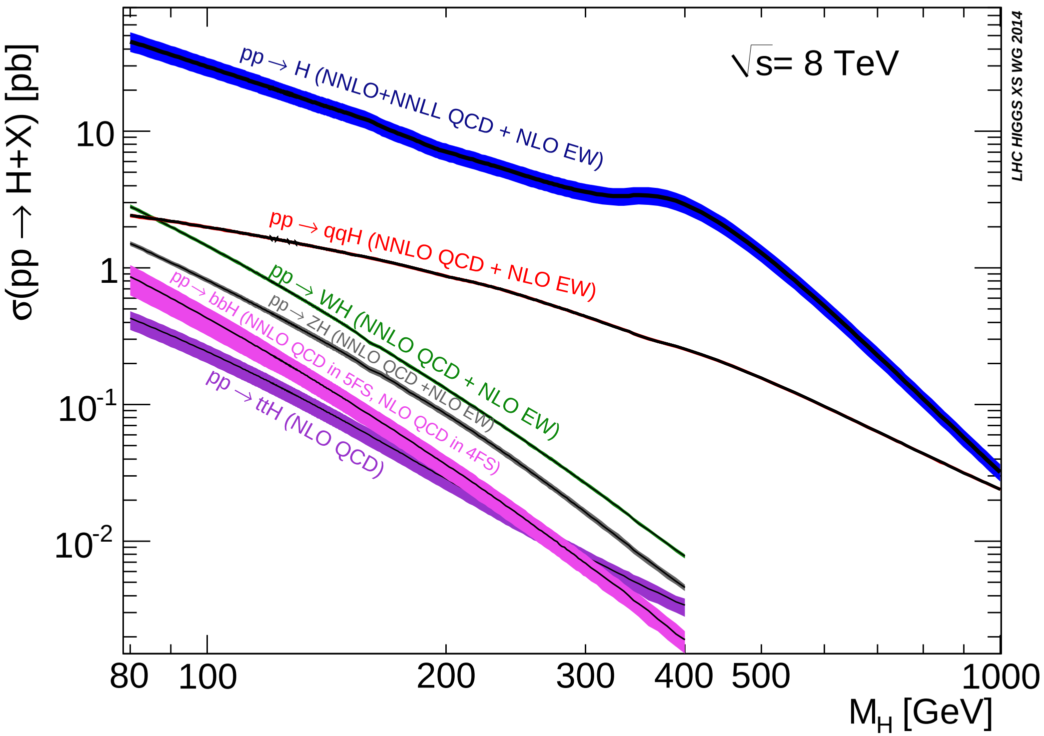


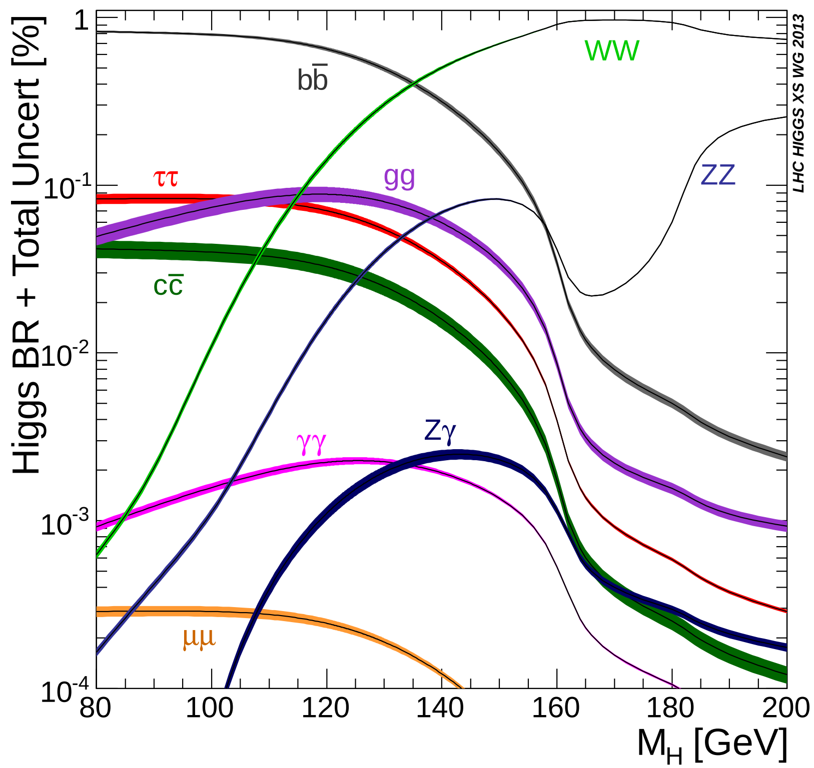




- Higgs Boson Production & Decay







LHC Higgs XS WG

- Discovery: LHC [Tevatron]

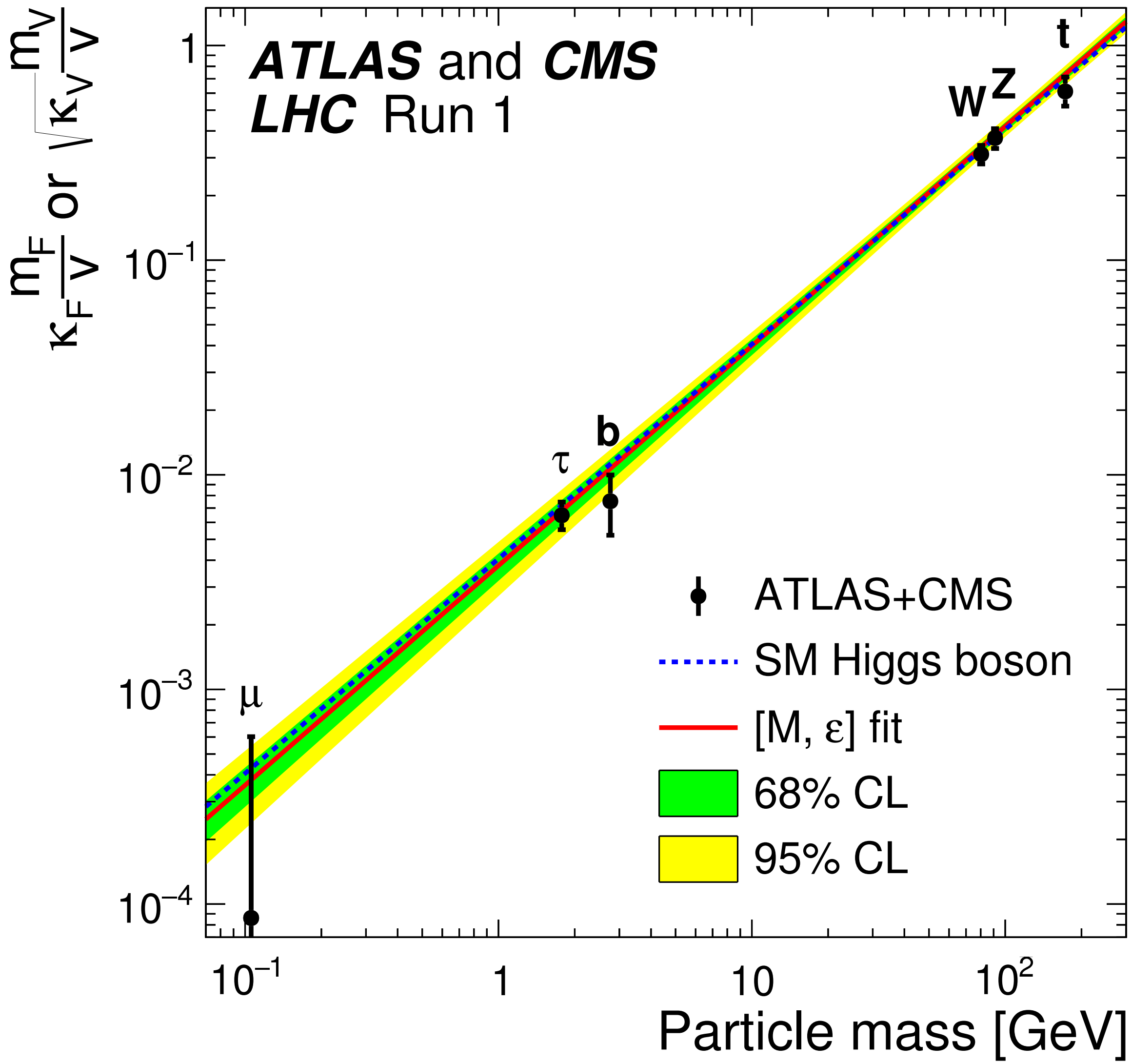
  → Higgs mass

  couplings

  spin

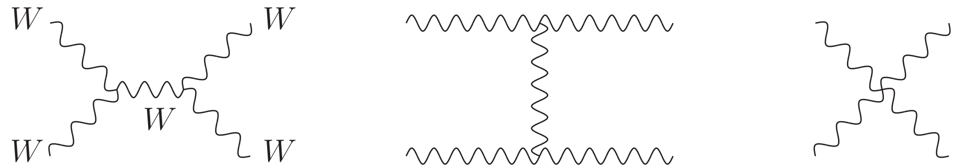
  $\mathcal{CP}$

  λ ?

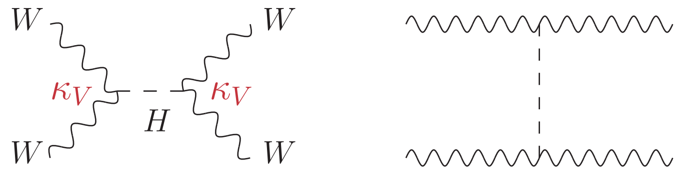


- $WW \to WW$ @ high energies

(a)



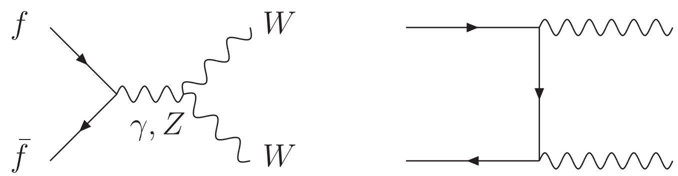
(b)



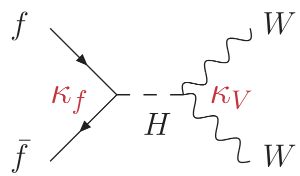
$$\mathcal{A} = \frac{s}{v^2}\left\{1 - \frac{\kappa_V^2 s}{s - M_H^2}\right\} \quad \Rightarrow \quad \kappa_V = 1$$

- $f\bar{f} \to WW$ @ high energies

(a)



(b)



$$\mathcal{A} = \frac{m_f\sqrt{s}}{v^2}\left\{1 - \frac{\kappa_f \kappa_V s}{s - M_H^2}\right\} \quad \Rightarrow \quad \kappa_f = \kappa_V = 1$$

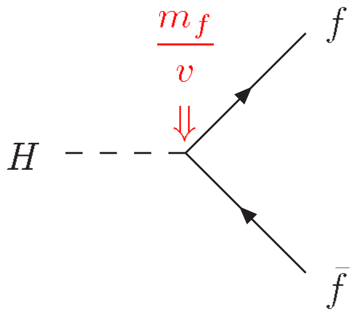
[analogously for κ_H]

- modifications: (i) higher-dim. operators $\to$ eff. Lagrangians
  (ii) extended Higgs sectors (mixing, loop effects)

- $\Gamma = \Gamma_{SM} + \Delta\Gamma_{BSM}$

II *HIGGS BOSON DECAYS*

Standard Model



$BR(H \to b\bar{b}) \sim 58\%$
$BR(H \to \tau^+\tau^-) \sim 6\%$
$BR(H \to c\bar{c}) \sim 3\%$
$BR(H \to \mu^+\mu^-) \sim 0.02\%$

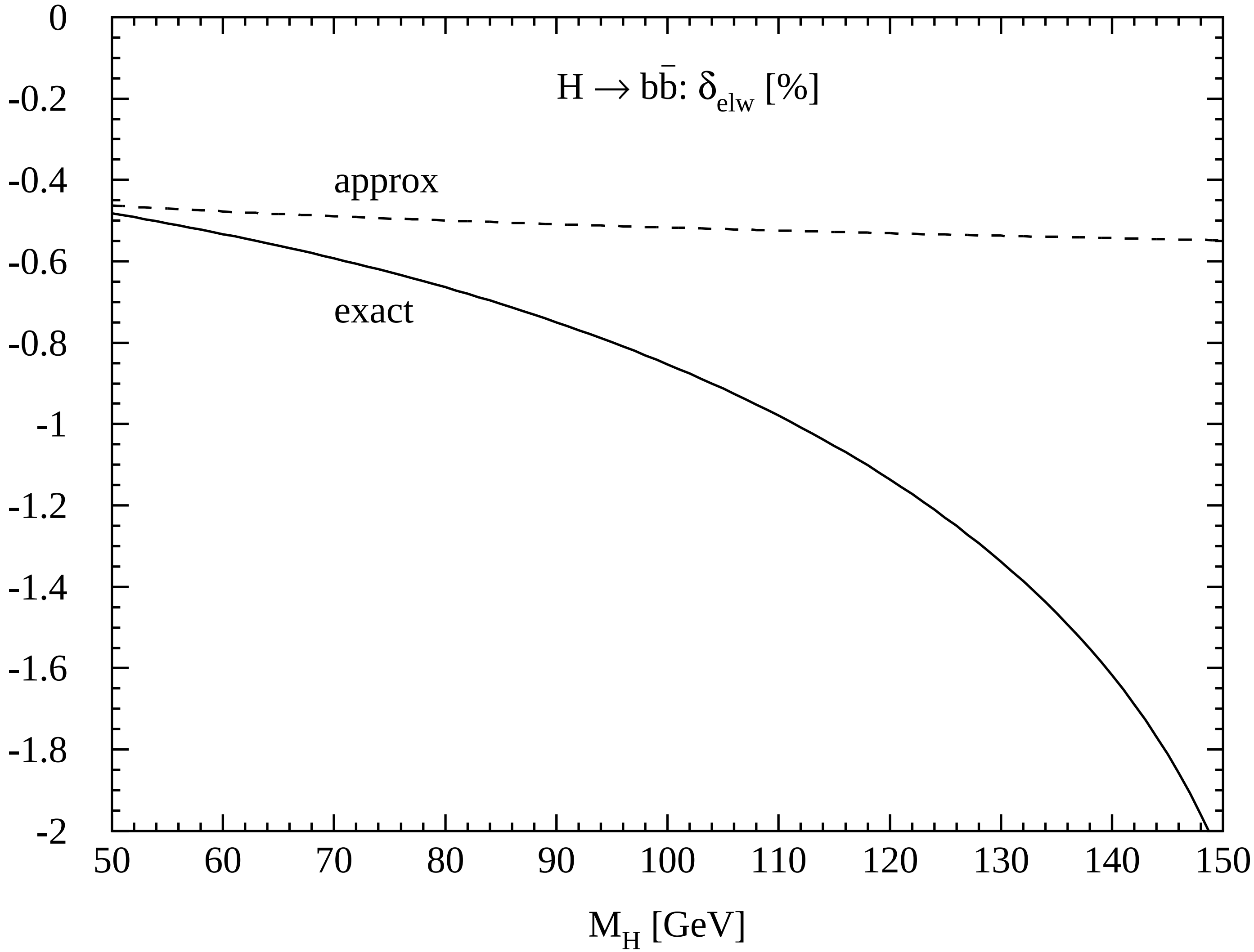
- $H \to b\bar{b}$ dominant

$$\Gamma(H \to f\bar{f}) = \frac{N_c G_F M_H}{4\sqrt{2}\pi}\, m_f^2 \,(1 + \delta_{\mathrm{QCD}} + \delta_t + \delta_{mixed})\,(1 + \delta_{elw})$$

- elw. corr. δ_{elw}: moderate in interm. mass range

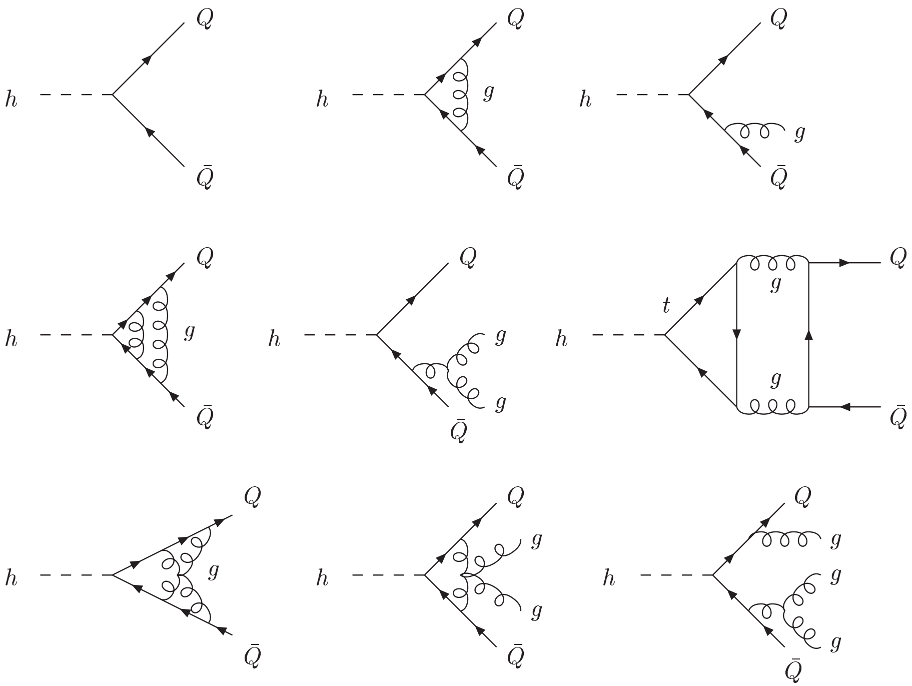
Fleischer, Jegerlehner
Bardin,. . .
Dabelstein, Hollik
Kniehl

$$\delta_{\mathrm{elw}} \approx \frac{3}{2}\frac{\alpha}{\pi} e_f^2 \left(\frac{3}{2} - \log\frac{M_H^2}{M_f^2}\right) + \frac{G_F}{8\pi^2\sqrt{2}}\left\{k_f M_t^2 + M_W^2\left[-5 + \frac{3}{s_W^2}\log c_W^2\right] - M_Z^2\frac{6v_f^2 - a_f^2}{2}\right\}$$



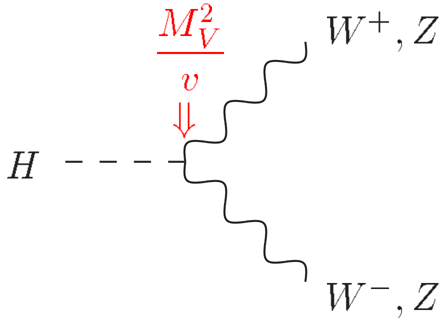
- -0.5% shift from approx $\rightarrow$ exact

- δ_{QCD}: large QCD corrections to $H \to b\bar{b}, c\bar{c}$: $\sim -50 \ldots -80\%$ (known to 4 loops)



Braaten, Leveille
Drees, Hikasa
Gorishnii, Kataev, Larin, Surguladze
Chetyrkin, Kwiatkowski, Steinhauser, Baikov

- dominant effect: $m_b \to \overline{m}_b(M_h) \Rightarrow \sim 25\%$ remaining
- δ_t: top-Yukawa induced QCD corrections: $\sim 1\%$
- δ_{mixed}: mixed QCD-elw. corrections: $\sim 0.1\%$ — Mihaila, Schmidt, Steinhauser
- HDECAY: $(1 + \delta_{QCD} + \delta_t)(1 + \delta_{elw})$ (full elw.)
- differential @ NNLO — Anastasiou, Herzog, Lazopoulos; Del Duca, Duhr, Somogyi, Tramontano, Trocsanyi



$$BR(H \to W^{+(*)}W^{-(*)}) \sim 21\%$$
$$BR(H \to Z^{(*)}Z^{(*)}) \sim 3\%$$

below threshold: $H \to V^{(*)}V^*$ important for $M_H \gtrsim M_V$

Rizzo
Keung, Marciano
Cahn

- elw. corr.: $\sim 5\%$

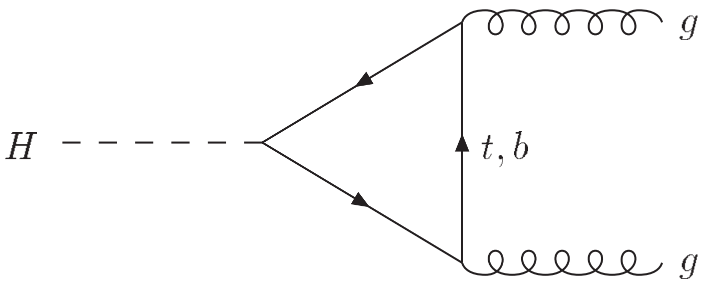
Fleischer, Jegerlehner
Bardin,. . .
Kniehl
Bredenstein, Denner, Dittmaier, Weber

- HDECAY: approx. NLO elw. corrections
  $\to$ Prophecy4f

Bredenstein, Denner, Dittmaier, Weber

- Hto4l: NLO elw. matched to parton showers

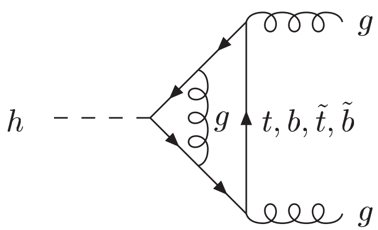
Boselli, Carloni Calame, Montagna, Nicrosini, Piccinini

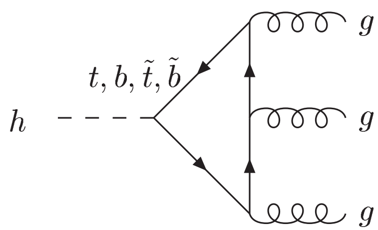


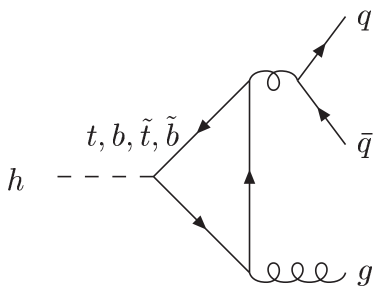
$BR(H \to gg) \sim 8\%$

- large QCD corrections: $\sim +90\%$

Inami, Kubota, Okada
S., Djouadi, Graudenz, Zerwas







$$\Gamma\,(H \to gg) \approx \Gamma_{LO}\,\{1 + 0.67 + 0.20 + 0.02\}$$

- 3/4/5-loop corrections ($M_H \ll 4m_t$): $\mathcal{O}(20\%) \Rightarrow$ perturbatively stable

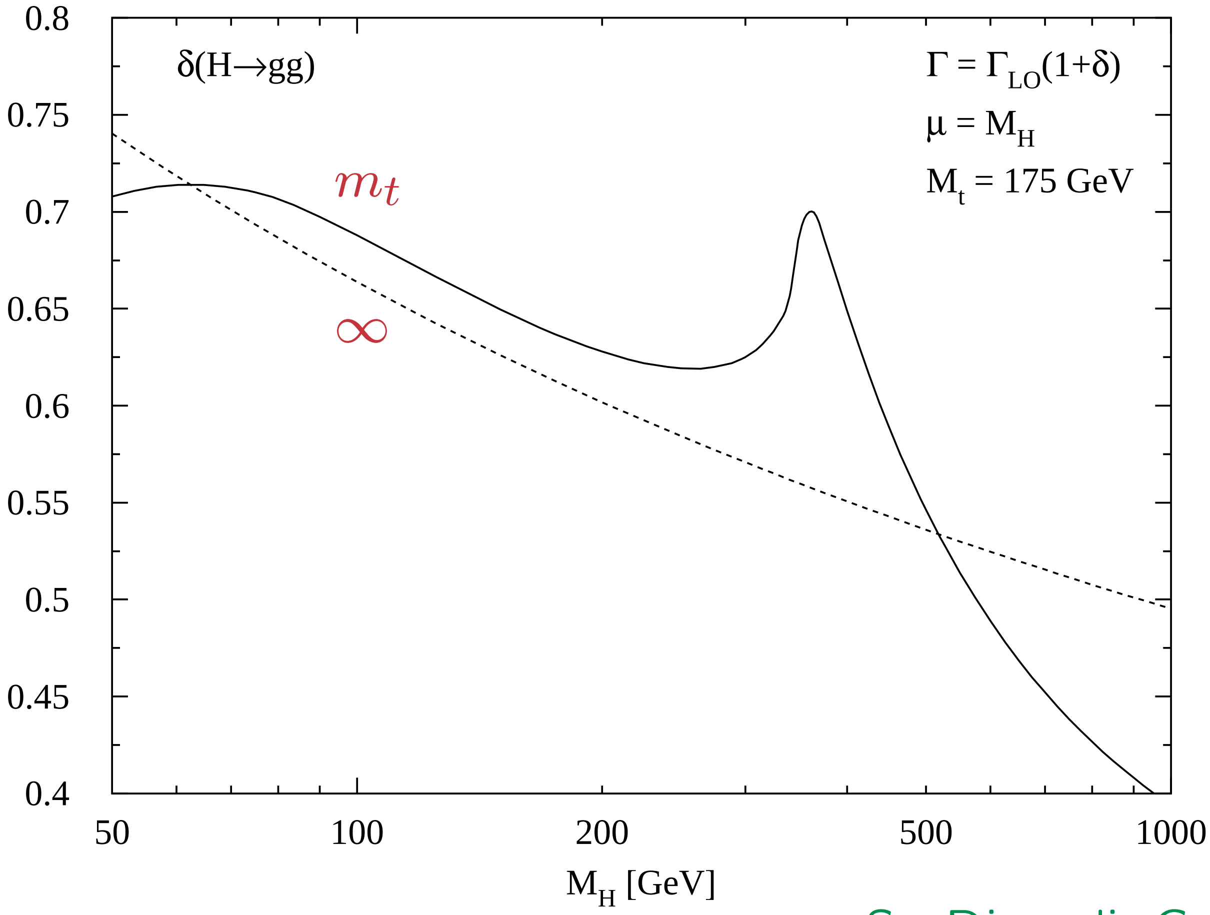
Chetyrkin, Kniehl, Steinhauser
Baikov, Chetyrkin
Herzog, Ruijl, Ueda, Vermaseren, Vogt

- can be obtained from

$$\mathcal{L}_{eff} = \frac{\alpha_s}{12\pi}\left\{1 + \frac{11}{4}\frac{\alpha_s}{\pi} + \cdots\right\} G^{a\mu\nu} G^a_{\mu\nu} \frac{H}{v}$$

Inami, Kubota, Okada
S., Djouadi, Graudenz, Zerwas
Chetyrkin, Kniehl, Steinhauser
Baikov, Chetyrkin

$$\Gamma(H \to gg) = \kappa_t^2 \Gamma_{tt} + \kappa_t \kappa_b \Gamma_{tb} + \kappa_b^2 \Gamma_{bb} \ [+\Gamma_{rem}]$$

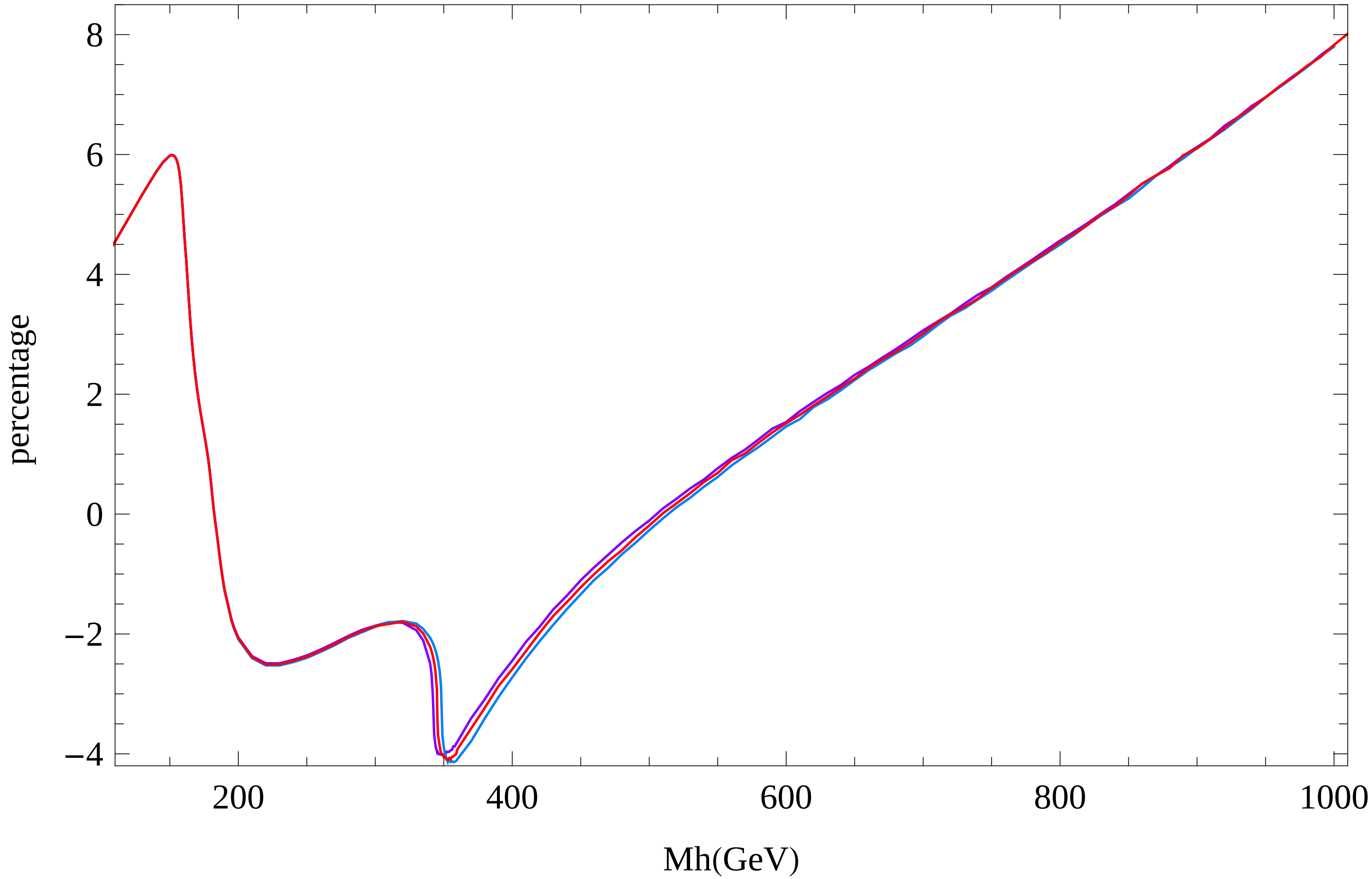


S., Djouadi, Graudenz, Zerwas

NLO QCD: full mass dependence $\to$ HDECAY

charm loops: $\sim 2\%$ $\to$ HDECAY

$H \to gg$

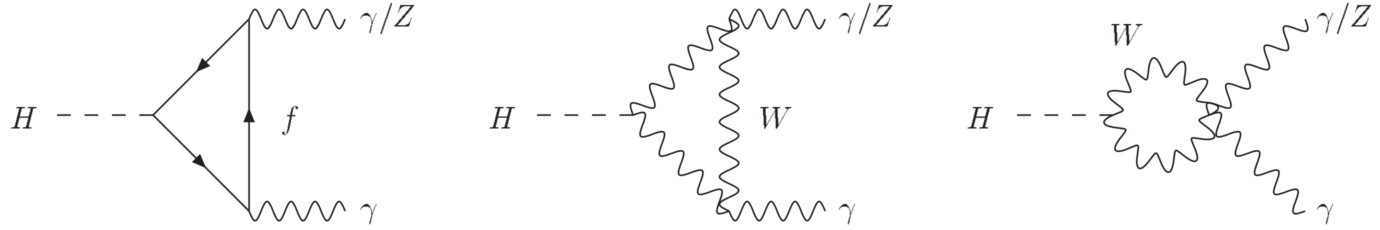


Actis, Passarino, Sturm, Uccirati

moderate elw. corrections: $\mathcal{O}(5\%)$

Aglietti, Bonciani, Degrassi, Vicini
Degrassi, Maltoni
Actis, Passarino, Sturm, Uccirati

HDECAY: 4-loop QCD corrections + NLO elw. corrections



$BR(H \to \gamma\gamma, Z\gamma) \lesssim 2 \times 10^{-3}$

- $H \to \gamma\gamma$ extremely important decay channel @ LHC
- $W-$loop dominant
- QCD corrections: $\sim 2\%$ in intermediate mass range

Zheng, Wu
Djouadi, S., Zerwas
Melnikov, Yakovlev
Inoue,. . .

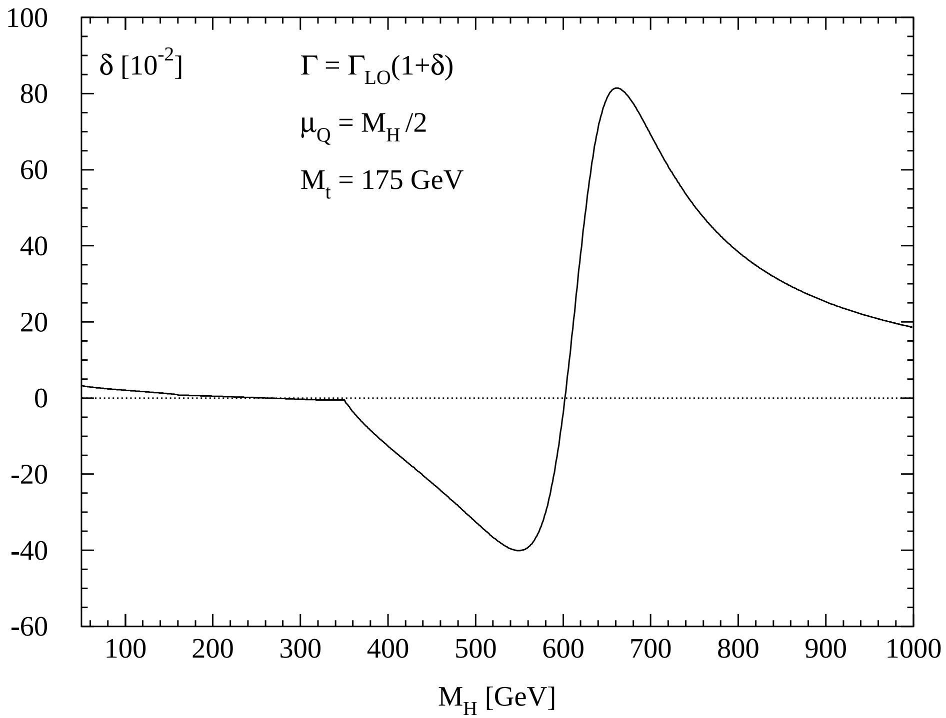
NNLO: per-mille range

Steinhauser
Maierhöfer, Marquard
Sturm

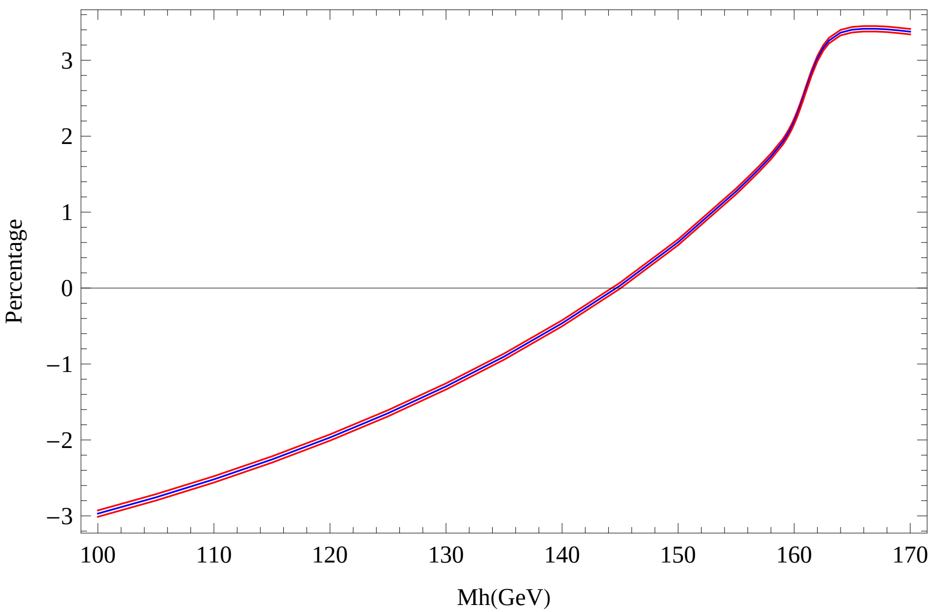
- elw. corr.: $\sim -2\%$

Aglietti, Bonciani, Degrassi, Vicini
Degrassi, Maltoni
Actis, Passarino, Sturm, Uccirati

$\underline{H \to \gamma\gamma}$



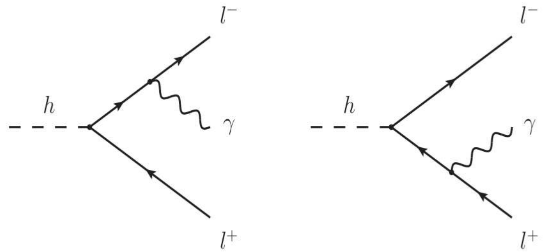
S., Djoaudi, Zerwas



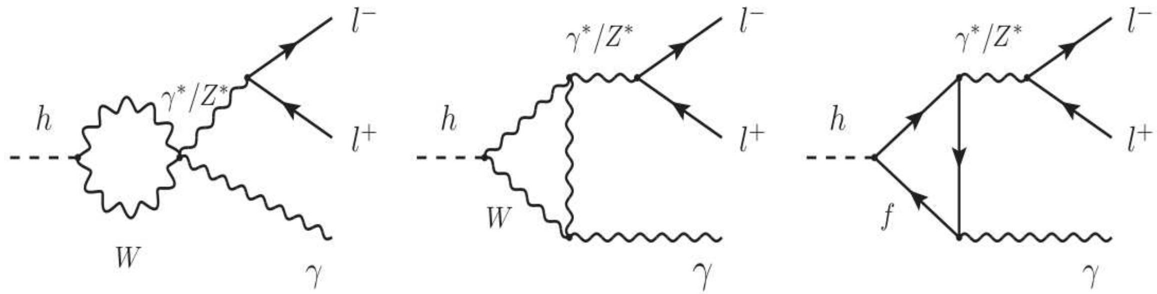
Actis, Passarino, Sturm, Uccirati

NLO QCD + elw.: full mass dependence → HDECAY

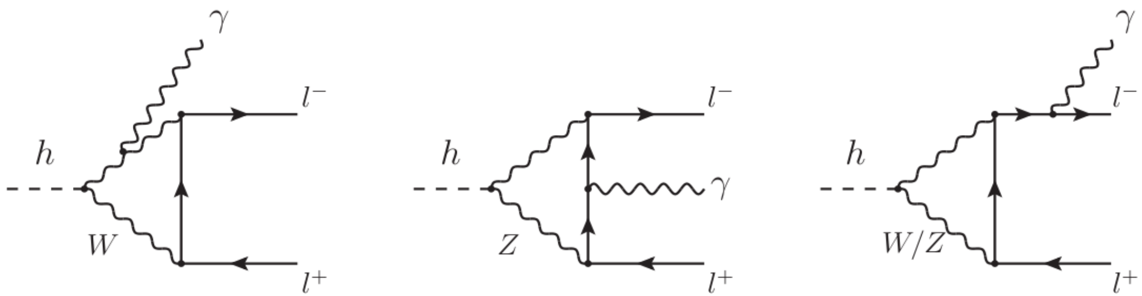
HIGGS DALITZ DECAYS



tree



off-shell



boxes

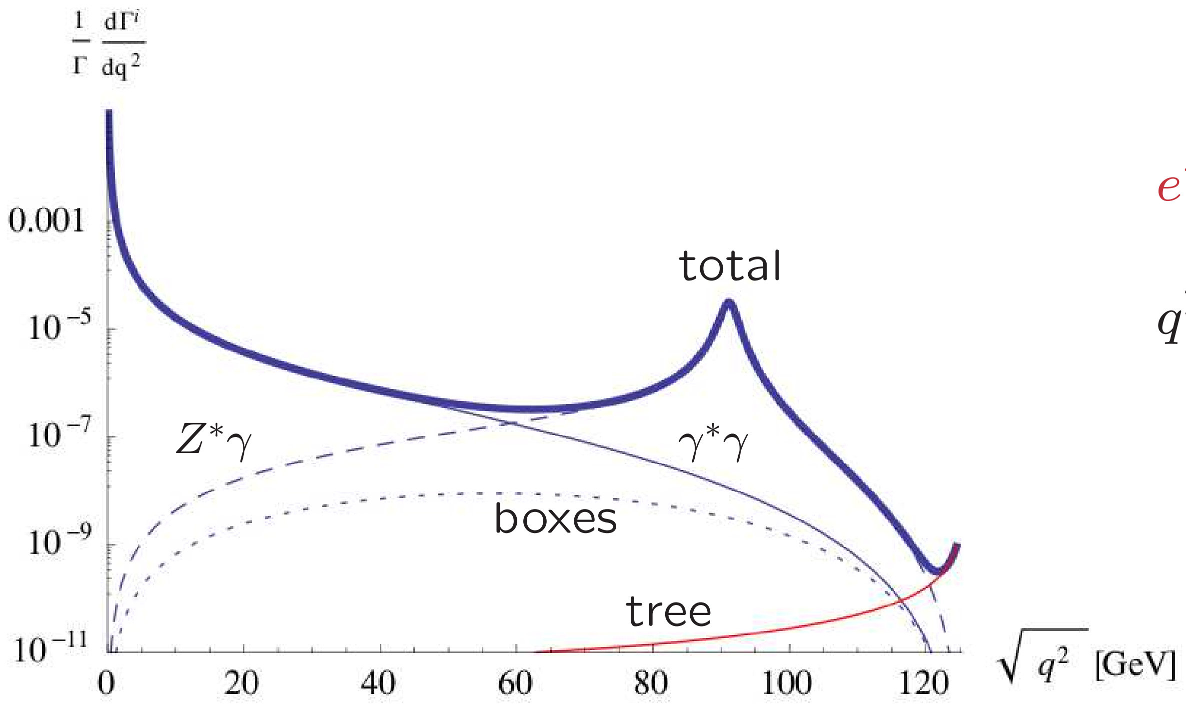
Abbasabadi, Bowser–Chao, Dicus, Repko
Sun, Chang, Gao
Passarino

$$\frac{\Gamma(h \to \gamma e^+ e^-)}{\Gamma(h \to \gamma\gamma)} = 5.7\%$$

$$\frac{\Gamma(h \to \gamma \mu^+ \mu^-)}{\Gamma(h \to \gamma\gamma)} = 5.8\%$$

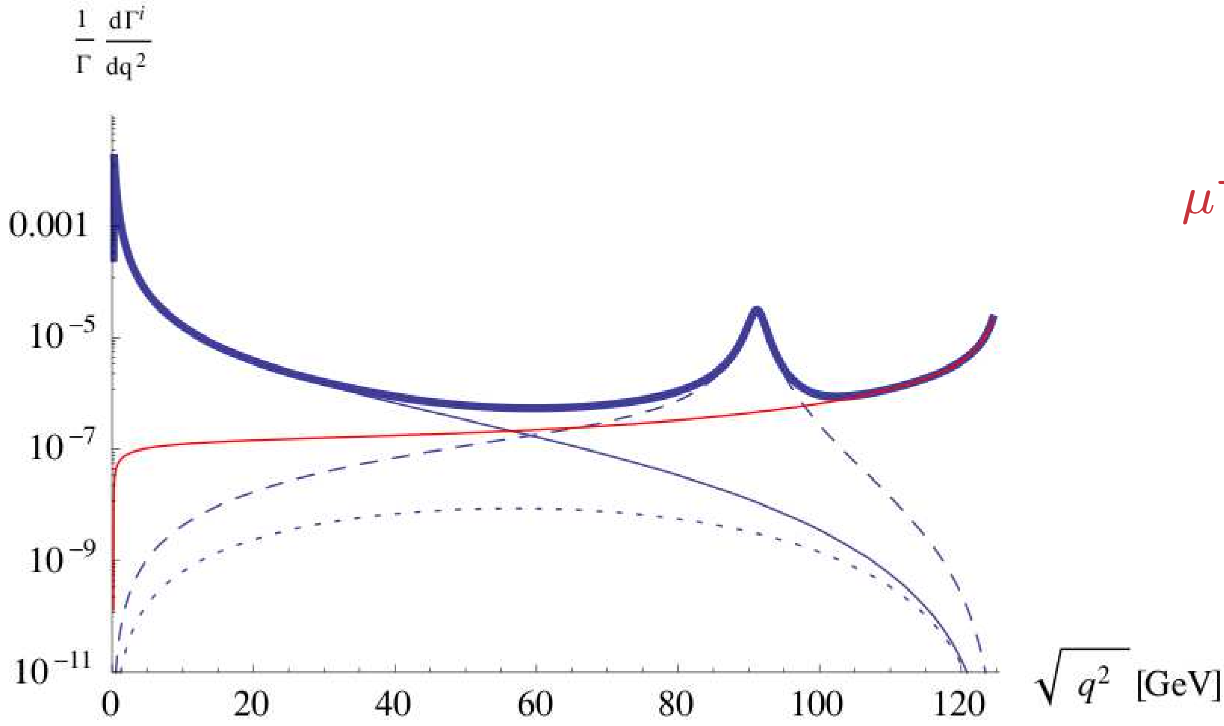
($E_\gamma > 1$ GeV)

$$\frac{\Gamma(h \to \gamma \tau^+ \tau^-)}{\Gamma(h \to \gamma\gamma)} = 3.04$$



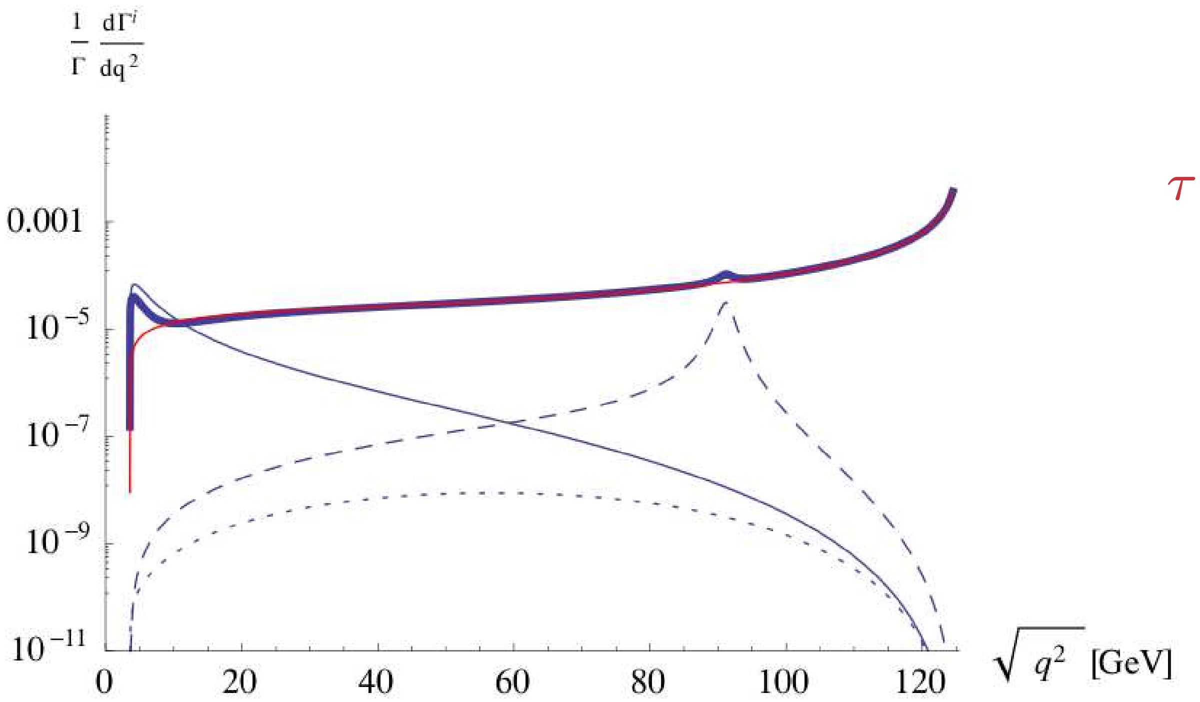
$e^+e^-\gamma$

$q^2 = M^2_{\ell^+\ell^-}$



Sun, Chang, Gao

$\mu^+\mu^-\gamma$



$\tau^+\tau^-\gamma$

Sun, Chang, Gao

- Dalitz decays ($H \to Z\gamma \Leftrightarrow H \to \ell^+\ell^-\gamma$)

Partial Width	QCD	Electroweak	Total	on-shell Higgs
$H \to b\bar{b}/c\bar{c}$	$\sim 0.2\%$	$\sim 0.5\%$	$\sim 0.5\%$	NNNNLO / NLO
$H \to \tau^+\tau^-/\mu^+\mu^-$		$\sim 0.5\%$	$\sim 0.5\%$	NLO
$H \to gg$	$\sim 3\%$	$\sim 1\%$	$\sim 3\%$	NNNLO approx. / NLO
$H \to \gamma\gamma$	$< 1\%$	$< 1\%$	$\sim 1\%$	NLO / NLO
$H \to Z\gamma$	$< 1\%$	$\sim 5\%$	$\sim 5\%$	(N)LO / LO
$H \to WW/ZZ \to 4f$	$< 0.5\%$	$\sim 0.5\%$	$\sim 0.5\%$	(N)NLO

- QCD: variation $\mu_R = [1/2, 2]\mu_0$
  elw: missing HO estimated from known structure at NLO
  different uncertainties added linearly for each channel

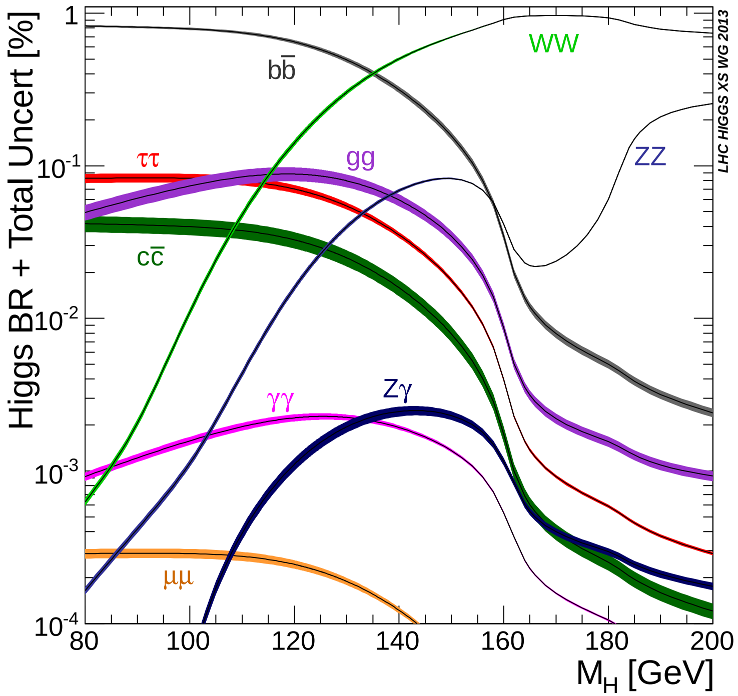
- parametric uncertainties:
  $m_t = 172.5 \pm 1$ GeV $\qquad \alpha_s(M_Z) = 0.118 \pm 0.0015$
  $m_b(m_b) = 4.18 \pm 0.03$ GeV $\qquad m_c(3\text{GeV}) = 0.986 \pm 0.025$ GeV
  different uncertainties added quadratically for each channel

- total uncertainties: parametric & theor. uncertainties added linearly

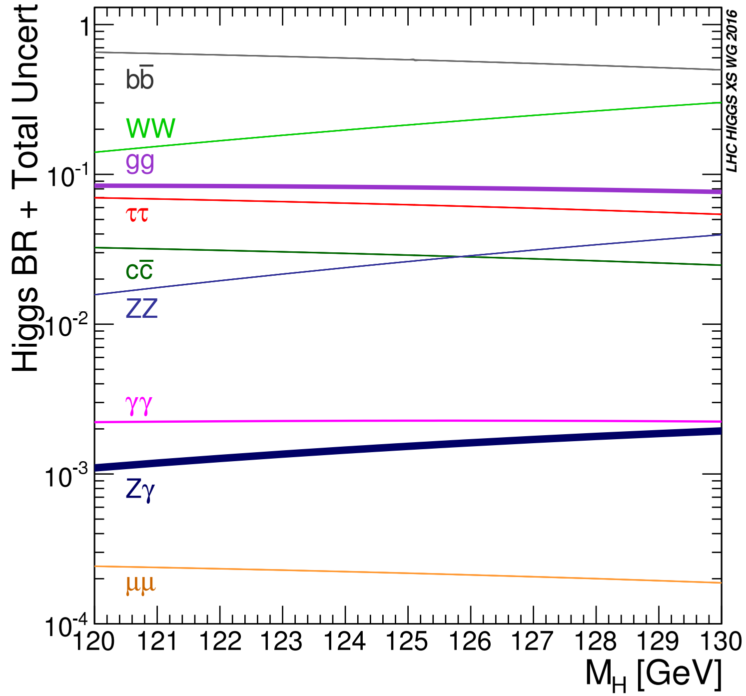
YR3 HDECAY & Prophecy4f YR4

$\sim 10\% \rightarrow$

$\sim 10\% \rightarrow$



$\longrightarrow$



Denner, Heinemeyer, Puljak, Rebuzzi, S.

- refinements input parameters
- full NLO elw. corrections to $H \rightarrow f\bar{f}$
- NLO quark-mass effects in $H \rightarrow gg$

III *SUMMARY*

Standard Model

- decay widths and BRs known with sufficient accuracy for the LHC
[$\to$ e^+e^-: more to be done]

- sizeable corrections from QCD

- elw. corrections required for high precision

BACKUP SLIDES