

SM PRECISION PREDICTIONS FOR HIGGS PARTIAL WIDTHS

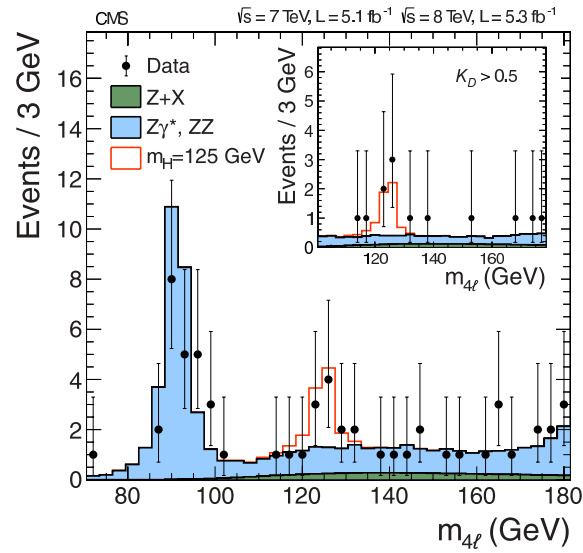
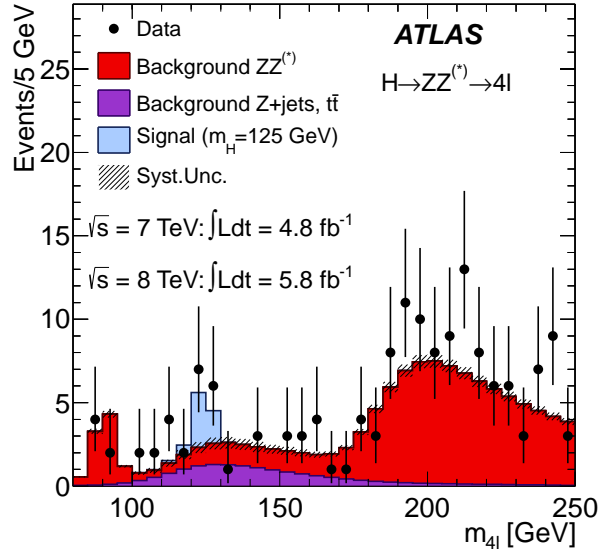
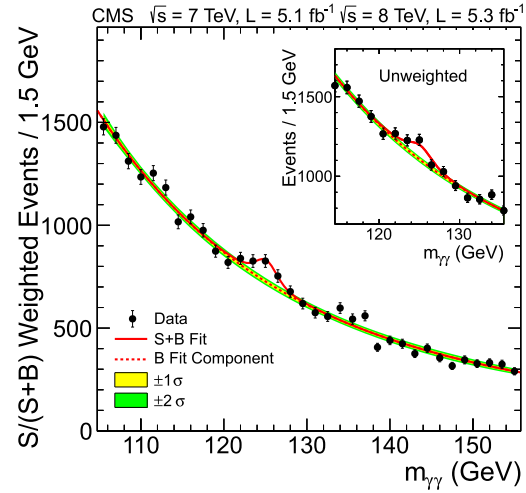
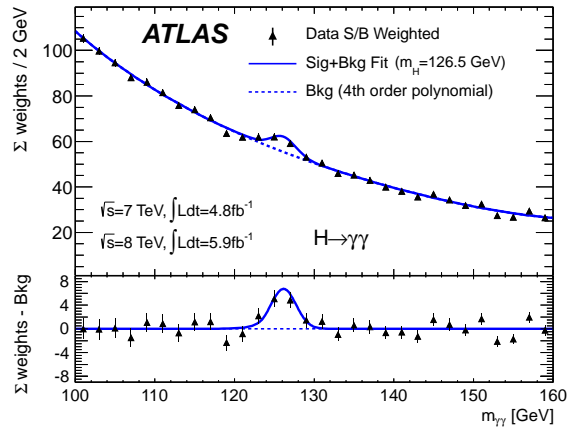
Michael Spira (PSI)

- I Introduction
- II Higgs Boson Decays
- III Summary

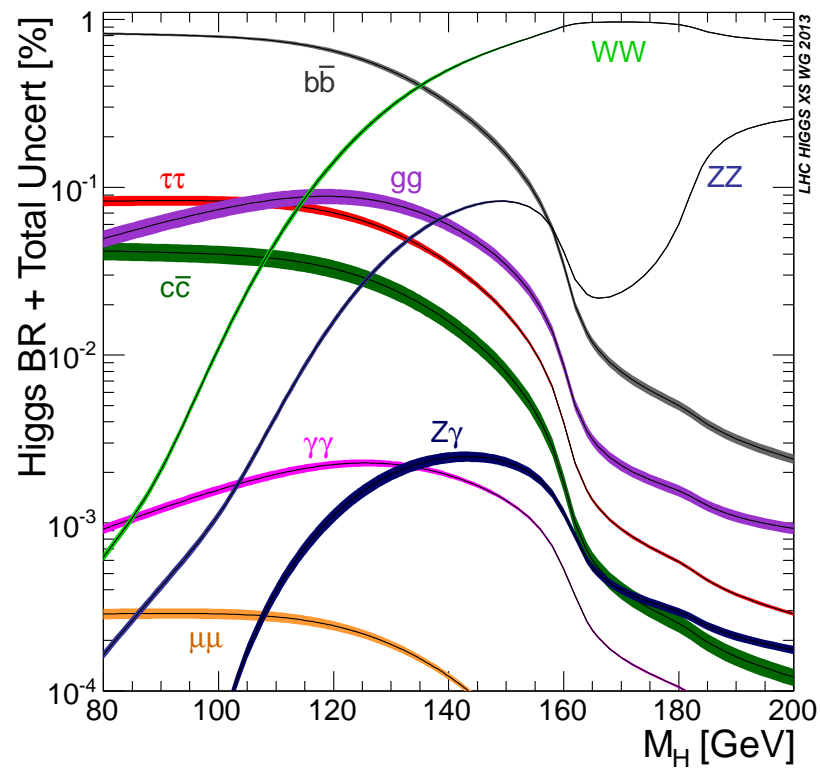
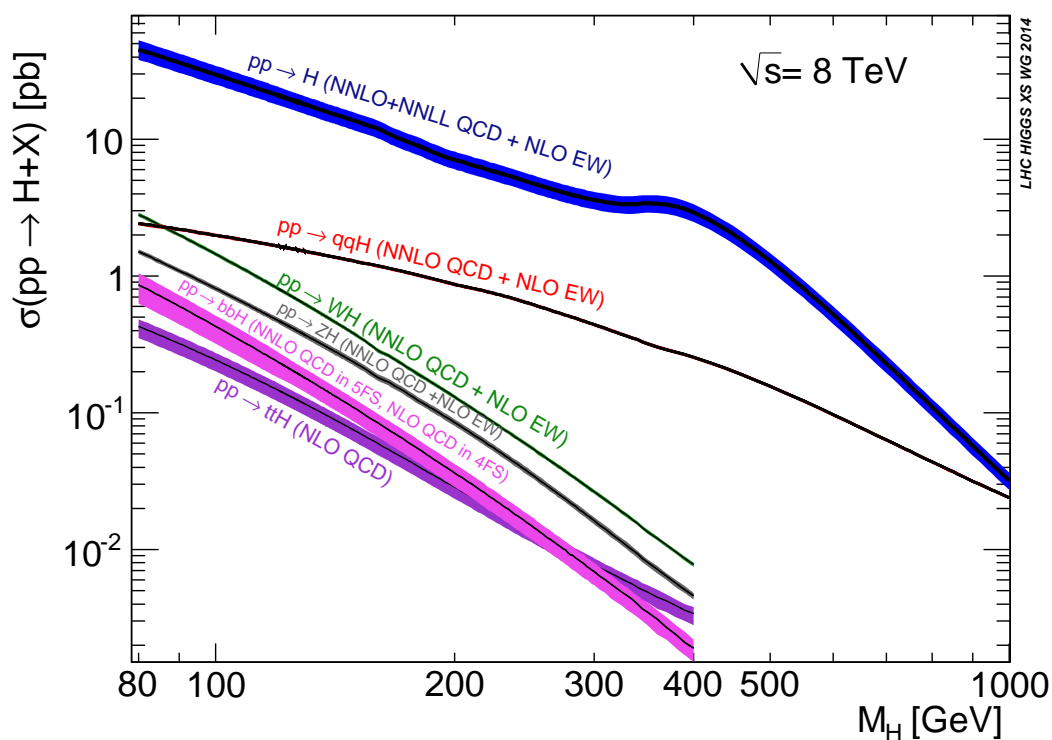
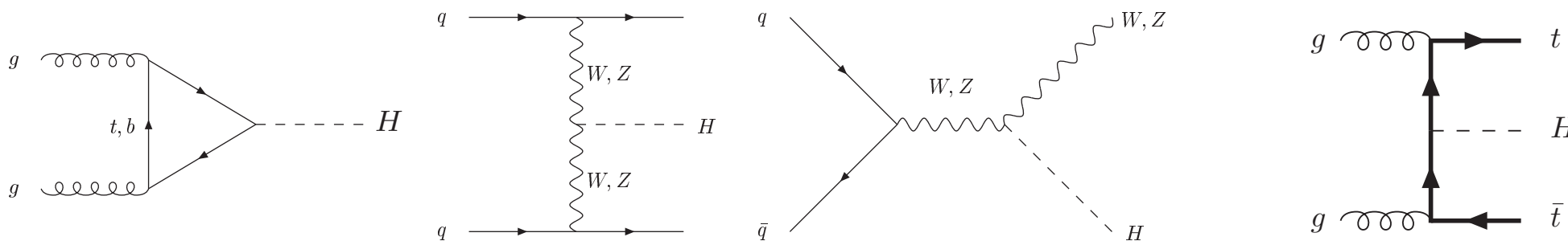
I INTRODUCTION

- SM very successful ← 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, . . .]

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



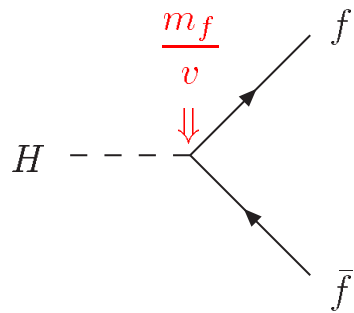
• Higgs Boson Production & Decay



LHC Higgs XS WG

II HIGGS BOSON DECAYS

Standard Model



$$BR(H \rightarrow b\bar{b}) \sim 58\%$$

$$BR(H \rightarrow \tau^+\tau^-) \sim 6\%$$

$$BR(H \rightarrow c\bar{c}) \sim 3\%$$

$$BR(H \rightarrow \mu^+\mu^-) \sim 0.02\%$$

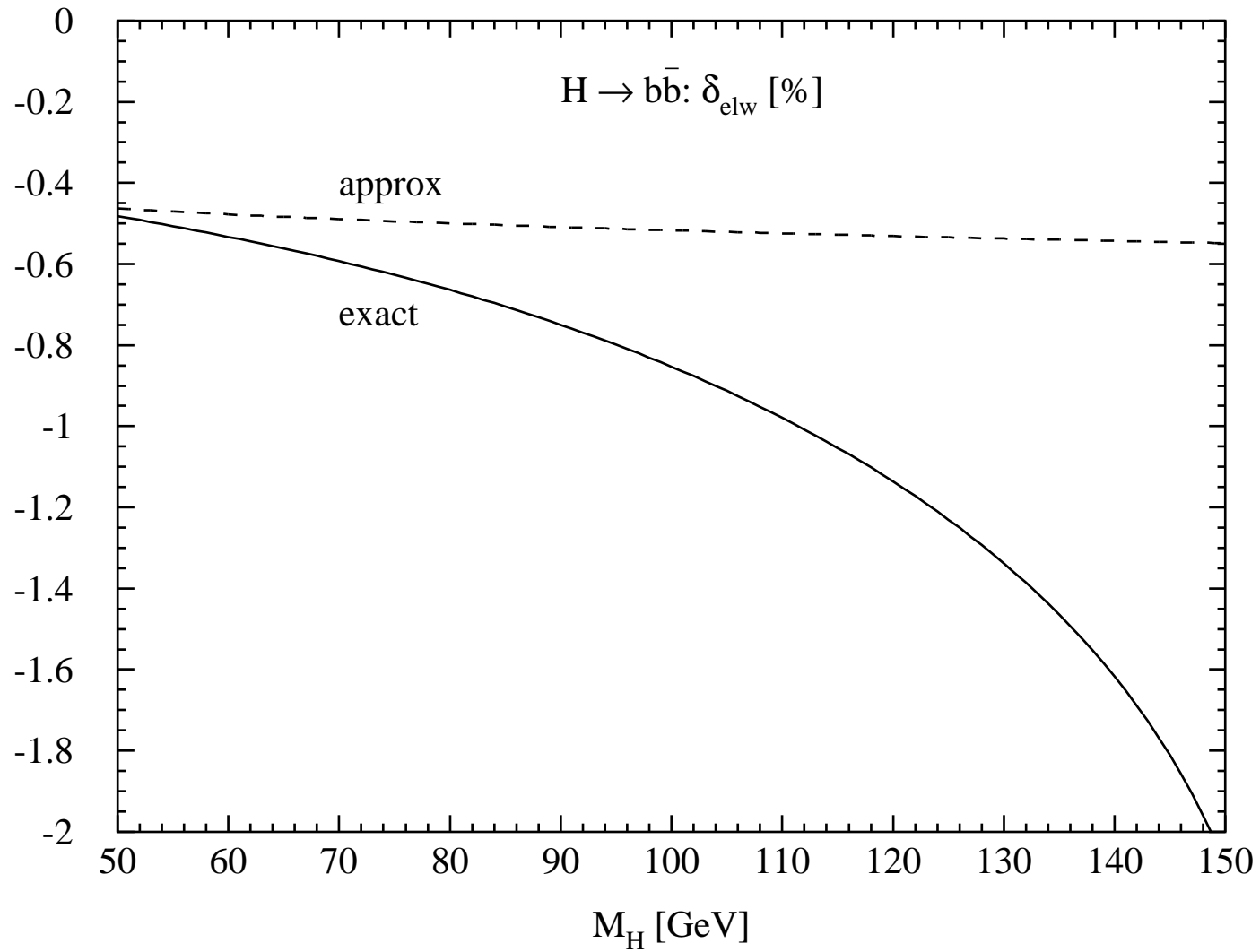
- $H \rightarrow b\bar{b}$ dominant

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

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

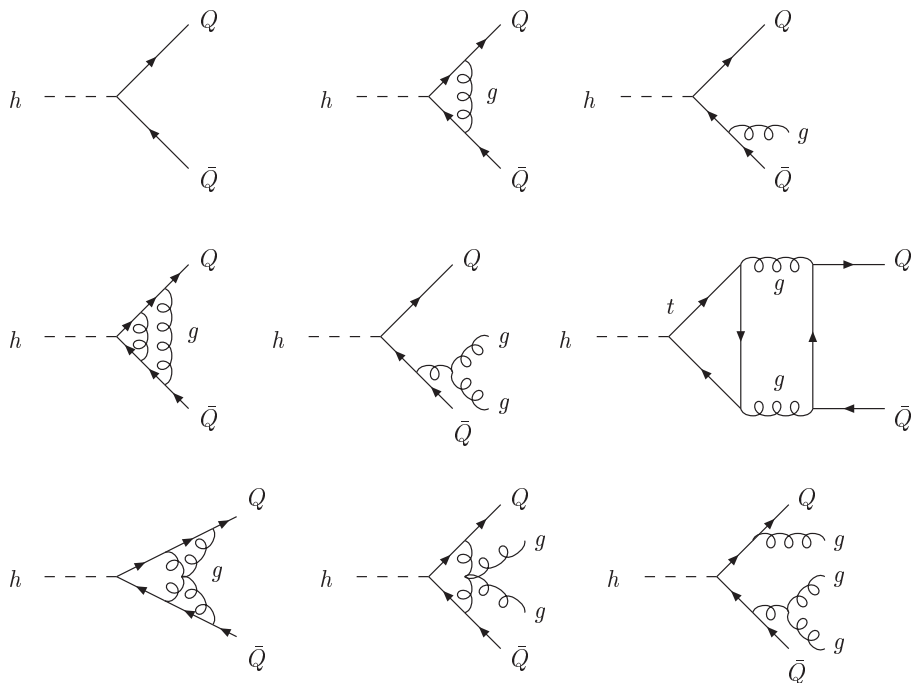
Fleischer, Jegerlehner
Bardin, ...
Dabelstein, Hollik
Kniehl

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



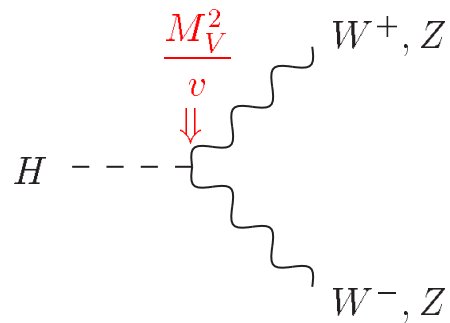
- -0.5% shift from approx \rightarrow exact

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



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

- dominant effect: $m_b \rightarrow \bar{m}_b(M_h) \Rightarrow \sim 25\%$ 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



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

$$BR(H \rightarrow Z^{(*)}Z^{(*)}) \sim 3\%$$

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

Rizzo
Keung, Marciano
Cahn

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

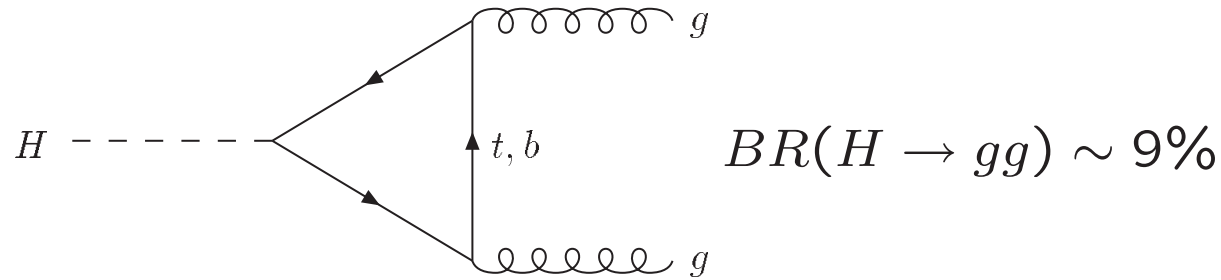
Fleischer, Jegerlehner
Bardin, ...
Kniehl
Bredenstein, Denner, Dittmaier, Weber

- HDECAY: approx. NLO elw. corrections
→ Prophecy4f

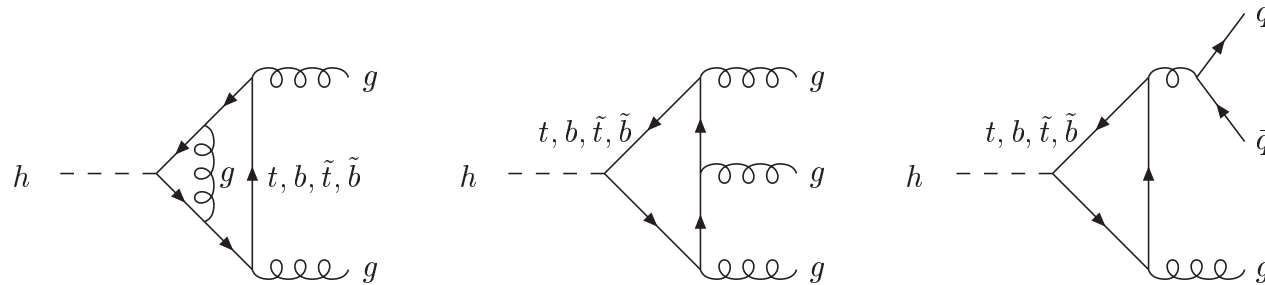
Bredenstein, Denner, Dittmaier, Weber

- Hto4l: NLO elw. matched to parton showers

Boselli, Carloni Calame, Montagna, Nicosini, Piccinini



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



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

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

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

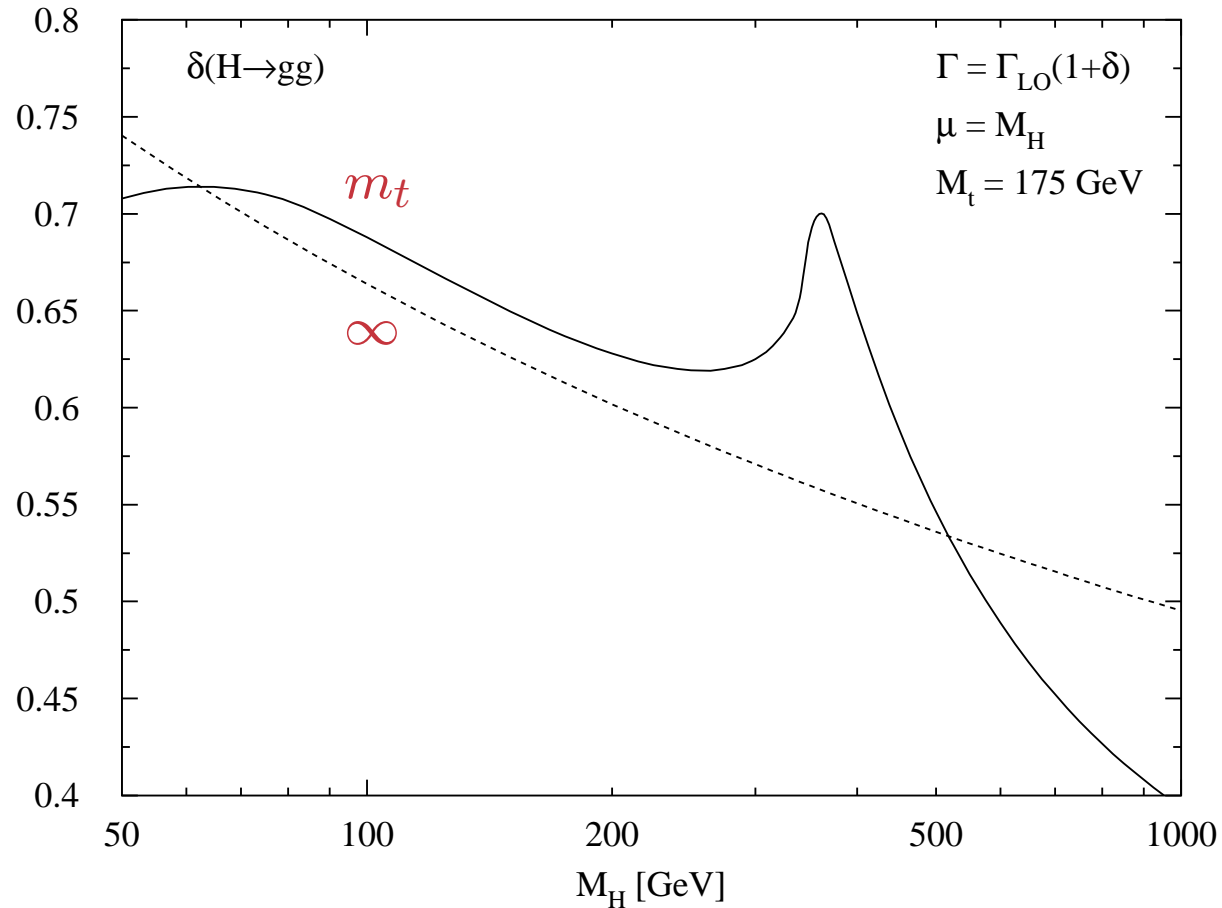
Chetyrkin, Kniehl, Steinhauser
Baikov, Chetyrkin

- can be obtained from

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

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

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

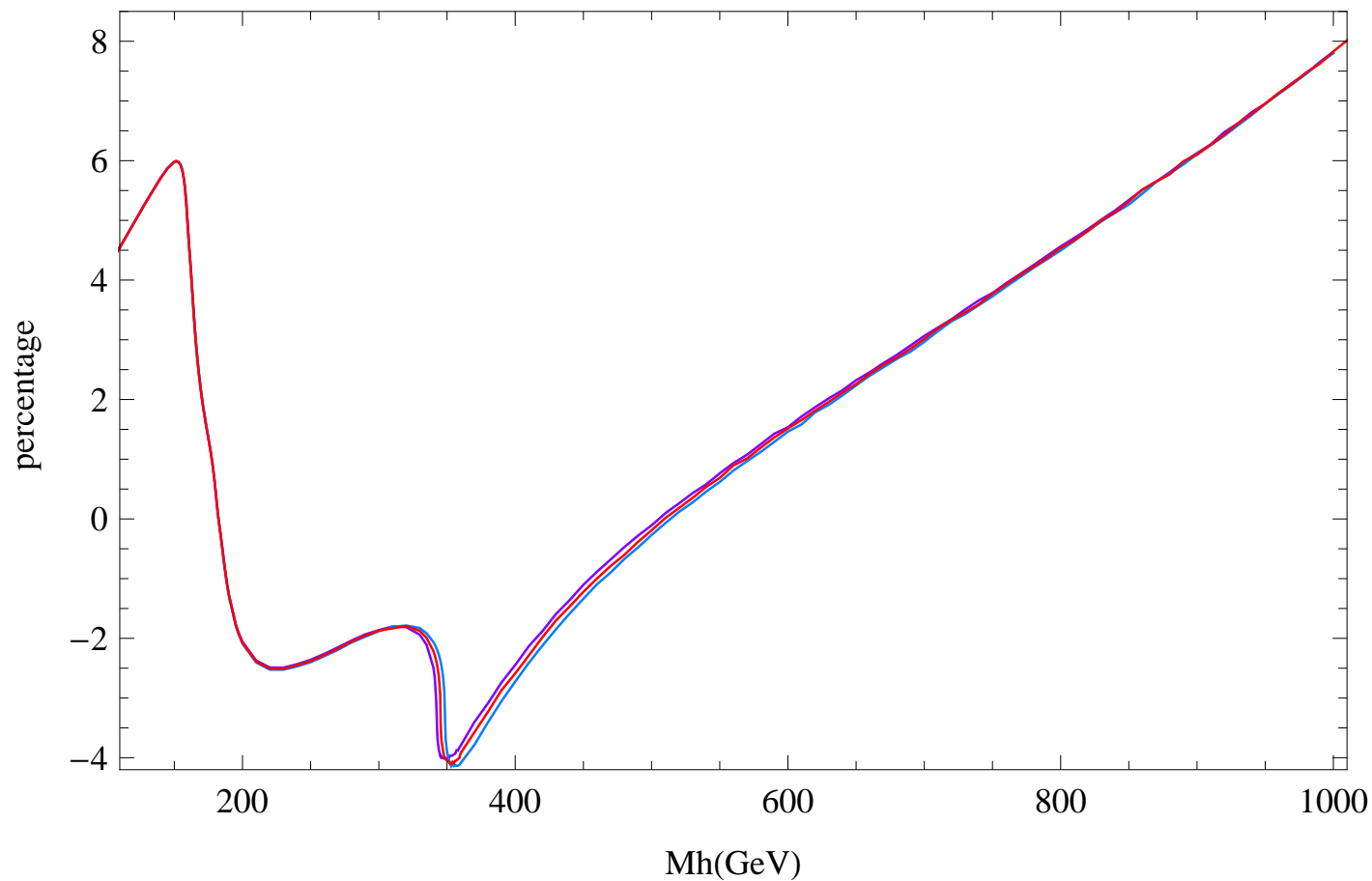


S., Djouadi, Graudenz, Zerwas

NLO QCD: full mass dependence \rightarrow HDECAY

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

$H \rightarrow gg$



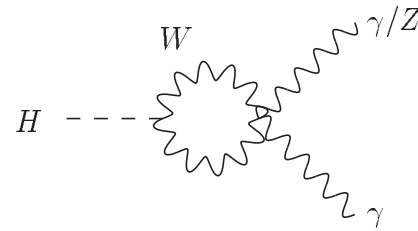
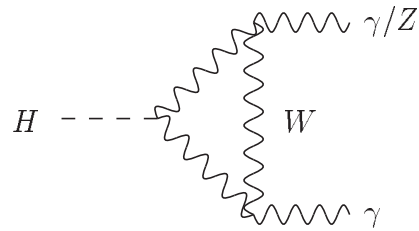
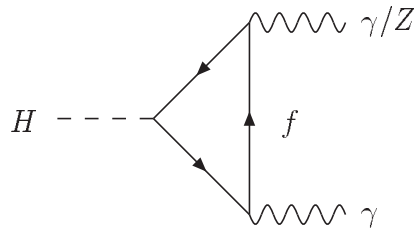
Actis, Passarino, Sturm, Uccirati

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

Aglietti, Bonciani, Degrassi, Vicini
Degrassi, Maltoni

Actis, Passarino, Sturm, Uccirati

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



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

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

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

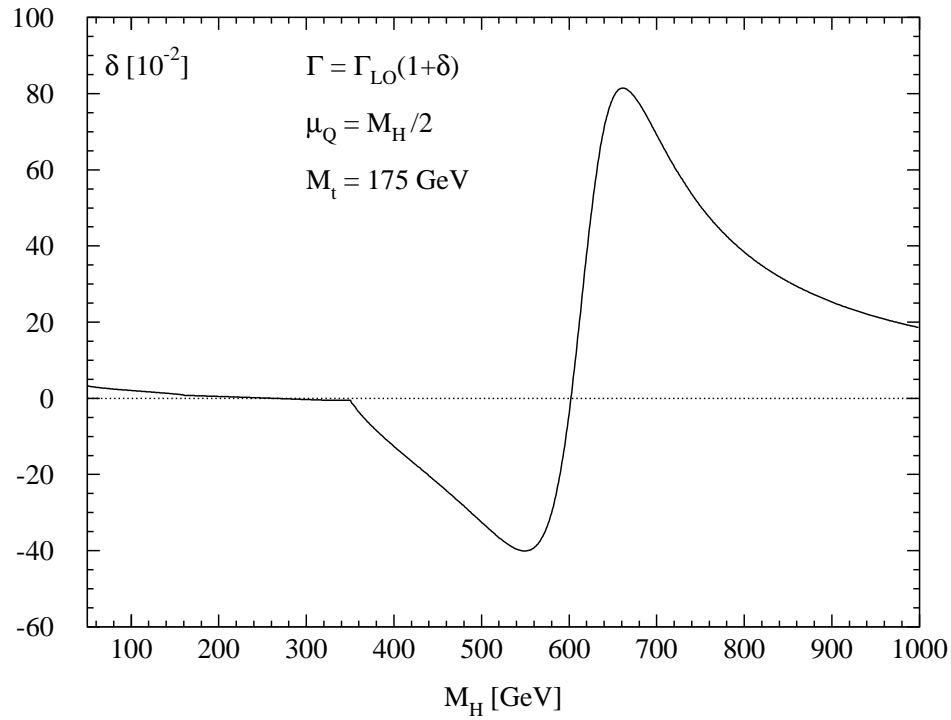
NNLO: per-mille range

Steinhauser
Maierhöfer, Marquard
Sturm

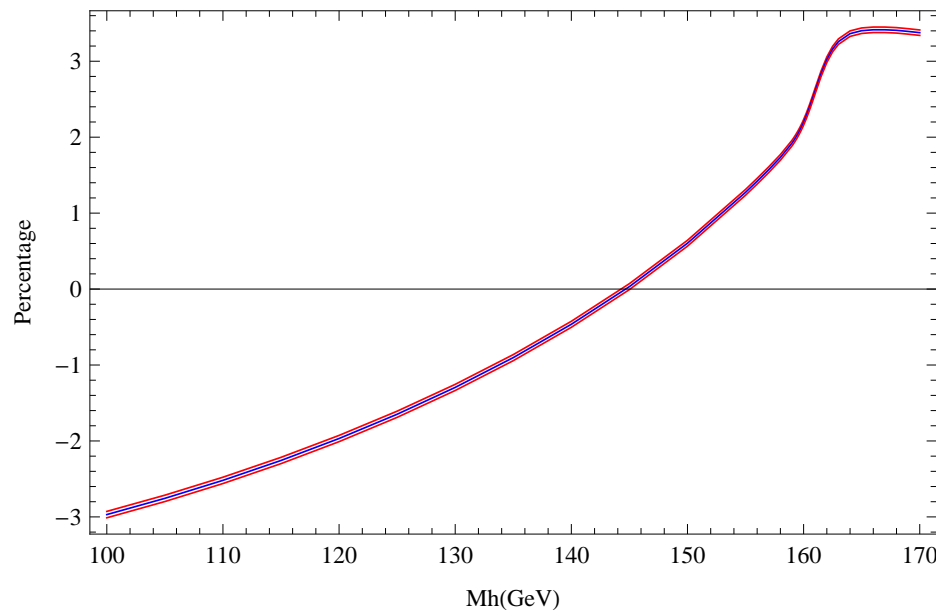
- elw. corr.: $\sim -2\%$

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

$H \rightarrow \gamma\gamma$



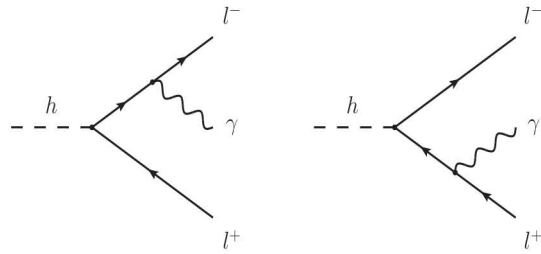
S., Djoaudi, Zerwas



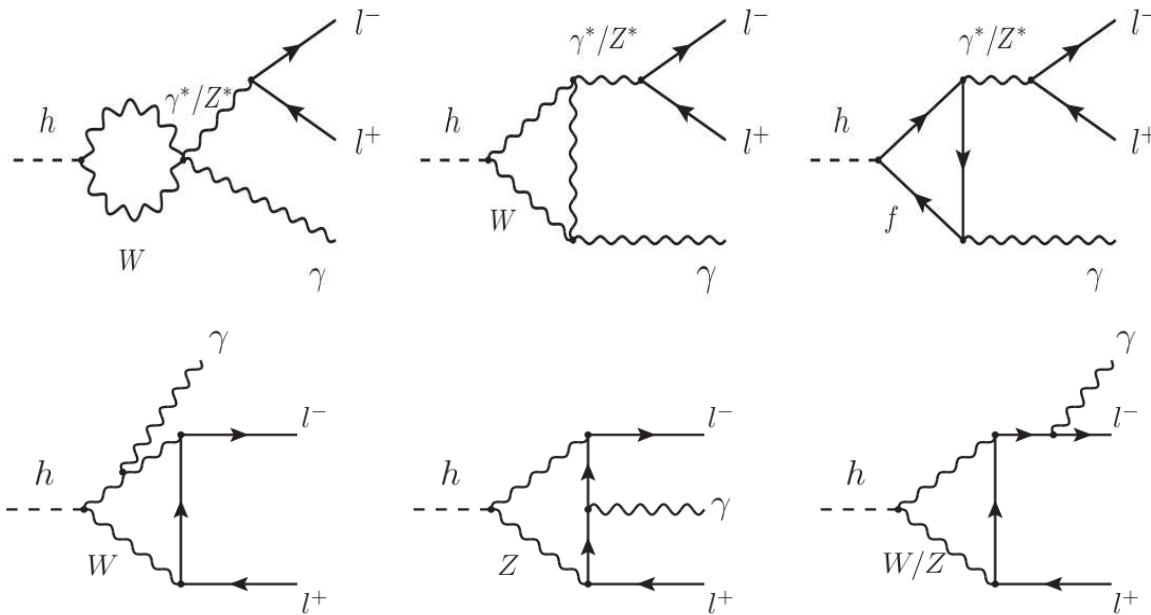
Actis, Passarino, Sturm, Uccirati

NLO QCD + elw.: full mass dependence \rightarrow HDECAY

HIGGS DALITZ DECAYS



tree



off-shell

boxes

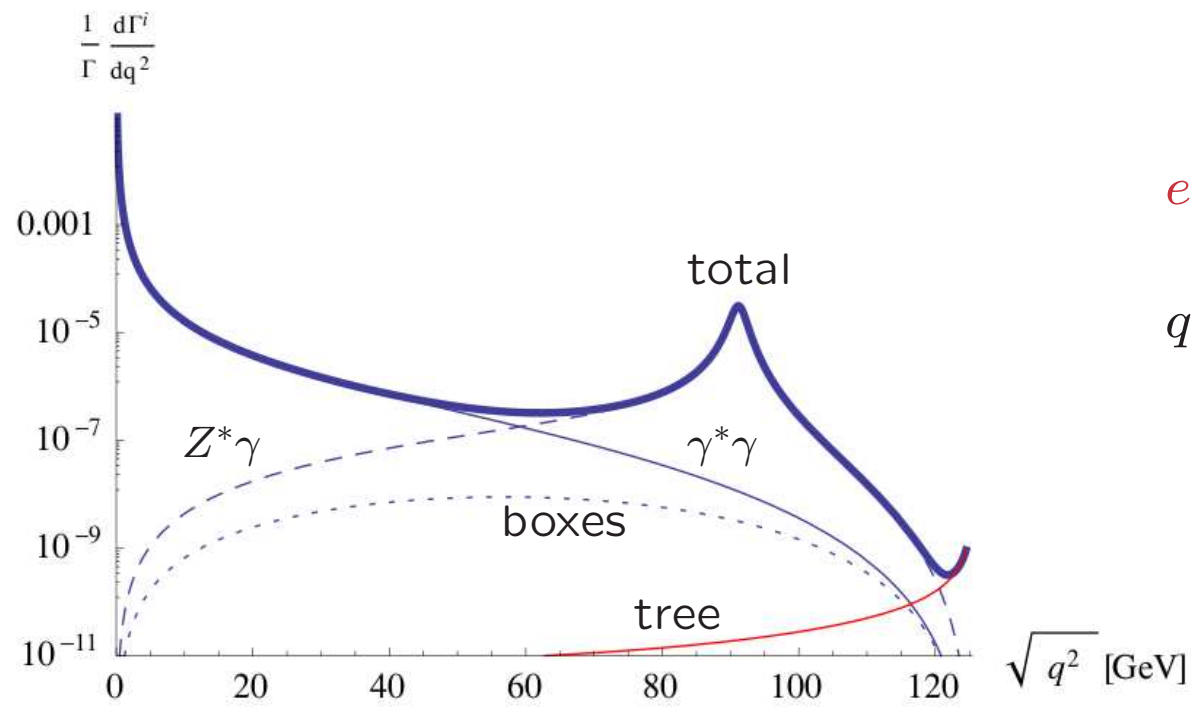
Abbasabadi, Bowser-Chao, Dicus, Repko
Sun, Chang, Gao
Passarino

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

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

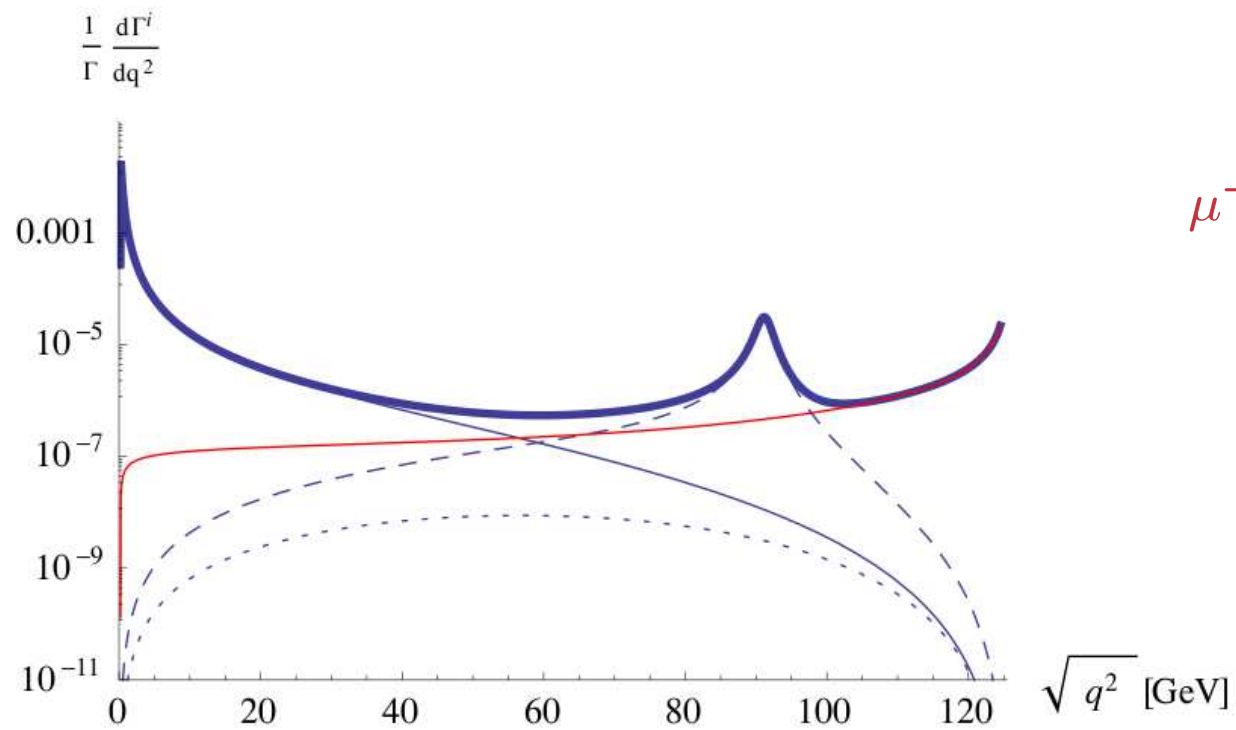
$(E_\gamma > 1 \text{ GeV})$

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



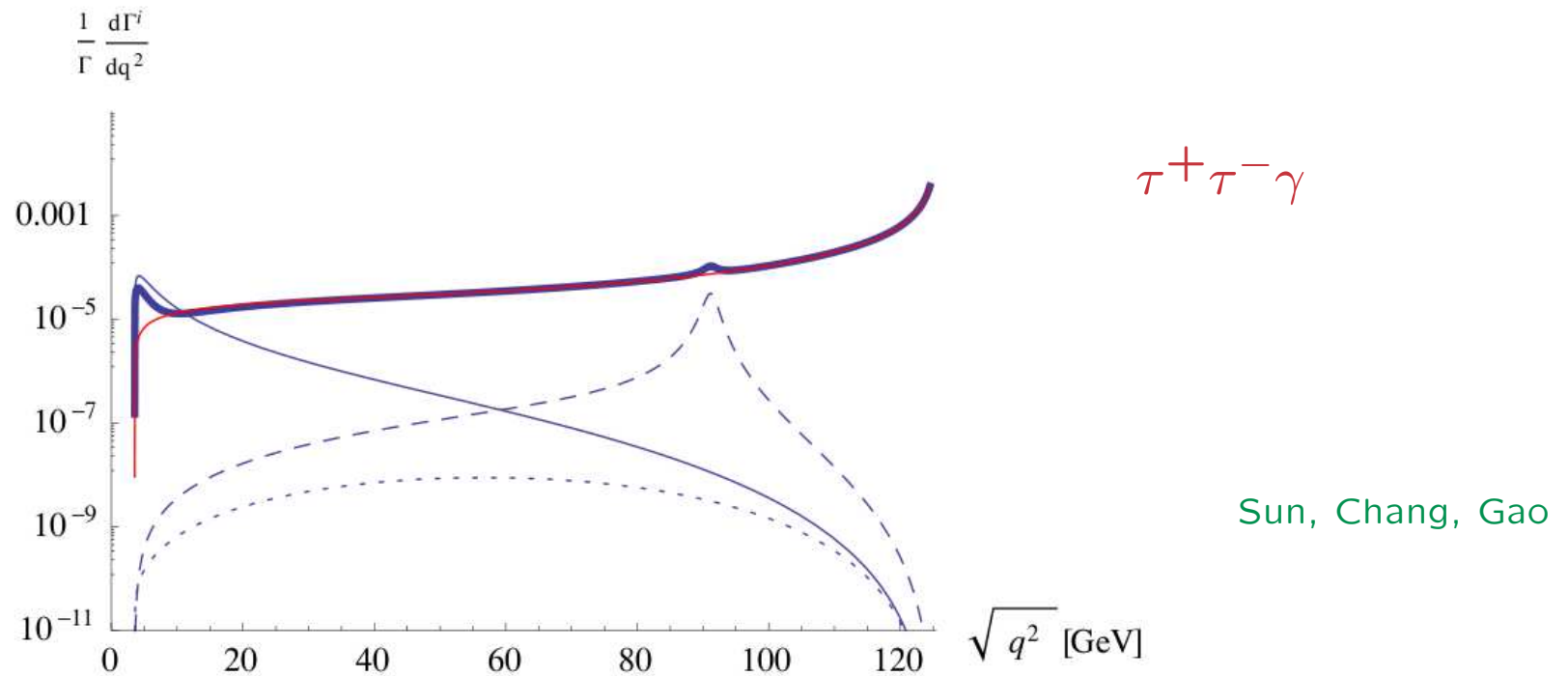
$e^+e^-\gamma$

$$q^2 = M_{\ell^+\ell^-}^2$$



Sun, Chang, Gao

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



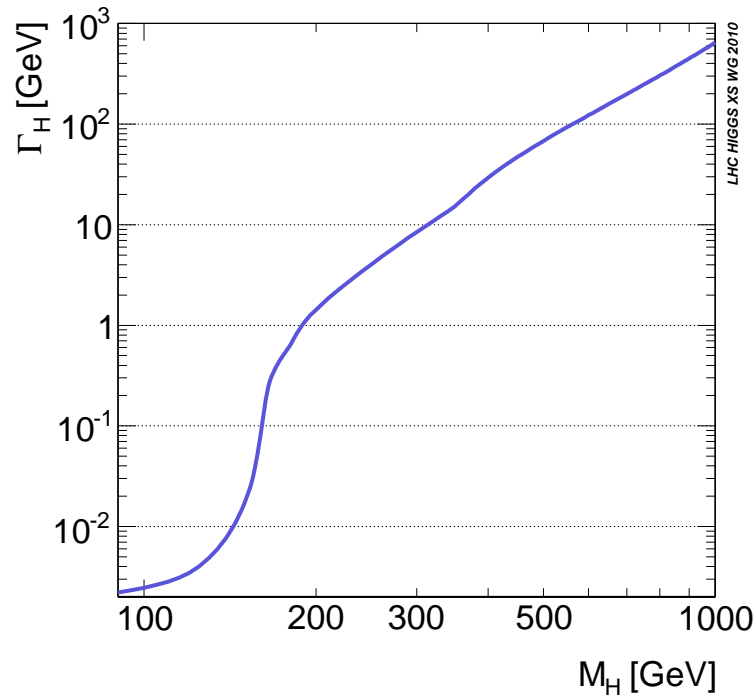
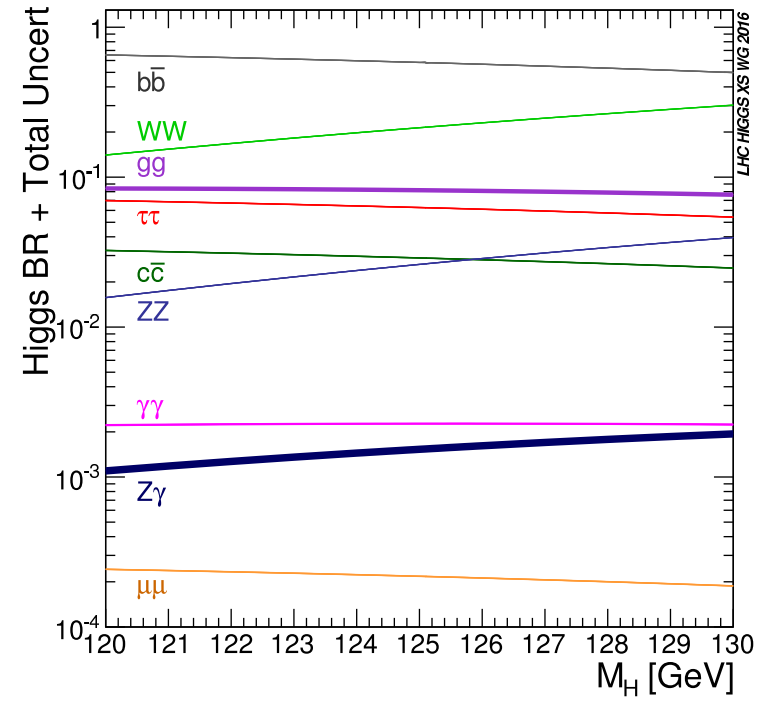
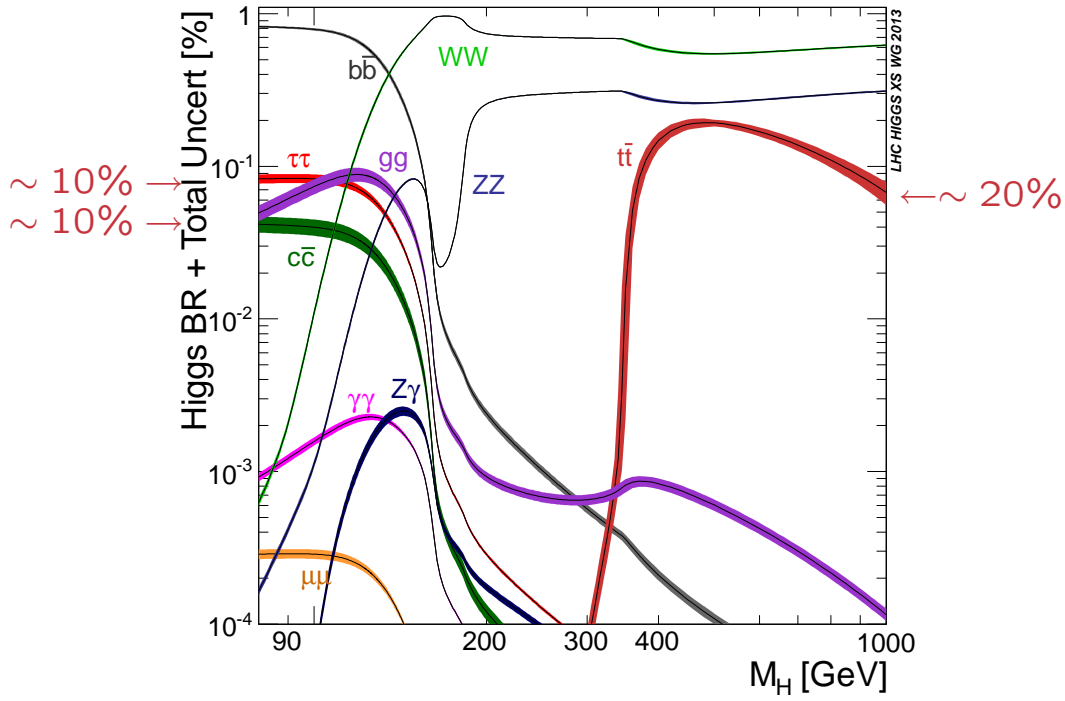
- Dalitz decays ($H \rightarrow Z\gamma \Leftrightarrow H \rightarrow l^+ l^- \gamma$)
[waiting for agreement ATLAS/CMS]

Partial Width	QCD	Electroweak	Total	
$H \rightarrow b\bar{b}/c\bar{c}$	$\sim 0.2\%$	$\sim 0.5\%$	$\sim 0.5\%$	NNNNLO / NLO
$H \rightarrow \tau^+\tau^-/\mu^+\mu^-$		$\sim 0.5\%$	$\sim 0.5\%$	NLO
$H \rightarrow t\bar{t}$	$\lesssim 5\%$	$\sim 0.5\%$	$\sim 5\%$	(NNN)NLO / LO
		$\sim 0.1(\frac{M_H}{1\text{TeV}})^4$ for $M_H > 500\text{GeV}$	$\sim 5\text{--}10\%$	
$H \rightarrow gg$	$\sim 3\%$	$\sim 1\%$	$\sim 3\%$	NNNLO approx. / NLO
$H \rightarrow \gamma\gamma$	$< 1\%$	$< 1\%$	$\sim 1\%$	NLO / NLO
$H \rightarrow Z\gamma$	$< 1\%$	$\sim 5\%$	$\sim 5\%$	(N)LO / LO
$H \rightarrow WW/ZZ \rightarrow 4f$	$< 0.5\%$	$\sim 0.5\%$ for $M_H < 500\text{GeV}$	$\sim 0.5\%$	(N)NLO
		$\sim 0.17(\frac{M_H}{1\text{TeV}})^4$ for $M_H > 500\text{GeV}$	$\sim 0.5\text{--}15\%$	

- QCD: variation of Higgs widths for scale by factor 2 and 1/2
 elw: missing HO estimated from known structure at NLO
 $M_H \gtrsim 500$ GeV: Higgs self-interactions dominate error
 different uncertainties added linearly for each channel
- parametric uncertainties:

$$m_t = 172.5 \pm 1 \text{ GeV} \quad \alpha_s(M_Z) = 0.118 \pm 0.0015$$

$$m_b(m_b) = 4.18 \pm 0.03 \text{ GeV} \quad m_c(3 \text{ GeV}) = 0.986 \pm 0.026 \text{ GeV}$$
 different uncertainties added quadratically for each channel
- total uncertainties: parametric & theor. uncertainties added linearly



Denner, Heinemeyer,
Puljak, Reuzzi, S.

III SUMMARY

Standard Model

- decay widths and BRs known with sufficient accuracy for the LHC
[→ ILC: more to be done]
- sizeable corrections from QCD
- elw. corrections required for high precision

BACKUP SLIDES