Measurement of Higgs-Boson couplings

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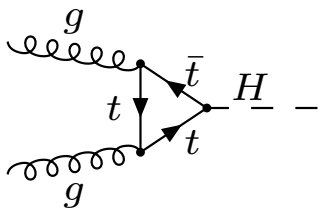
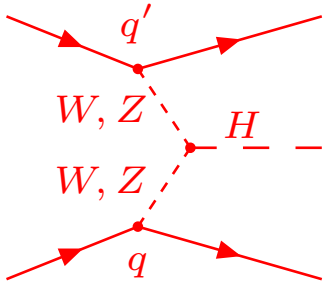
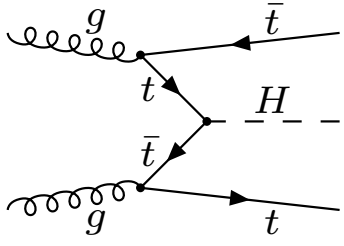
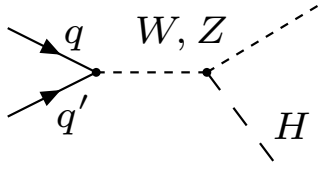
- Overview
- Method
- Measurement of relative branching ratios
- Measurement of relative couplings
- Measurement of absolute couplings
- Limit on Γ_H
- Summary

Overview of all available studies

(ATLAS, 110 GeV $\leq m_H \leq$ 200 GeV)

Production		Decay	Range of masses
	Gluon-Fusion ($gg \to H$)	$H \to ZZ \to 4l$	110 GeV - 200 GeV
		$H \to WW \to l\nu\, l\nu$	110 GeV - 200 GeV
		$H \to \gamma\gamma$	110 GeV - 150 GeV
	VBF ($qq\,H$)	$H \to ZZ \to 4l$	110 GeV - 200 GeV
		$H \to WW \to l\nu\, l\nu$	110 GeV - 190 GeV
		$H \to \tau\tau \to l\nu\nu\, l\nu\nu$	110 GeV - 150 GeV
		$H \to \tau\tau \to l\nu\nu\, \mathrm{had}\nu$	110 GeV - 150 GeV
		$H \to \gamma\gamma$	110 GeV - 150 GeV
	$t\bar{t}H$	$H \to WW \to l\nu\, l\nu\, (l\nu)$	120 GeV - 200 GeV
		$H \to b\bar{b}$	110 GeV - 140 GeV
		$H \to \tau\tau$ (not included)	110 GeV - 150 GeV
		$H \to \gamma\gamma$	110 GeV - 120 GeV
	WH	$H \to WW \to l\nu\, l\nu\, (l\nu)$	150 GeV - 190 GeV
		$H \to \gamma\gamma$	110 GeV - 120 GeV
	ZH	$H \to \gamma\gamma$	110 GeV - 120 GeV

Method of Fit (1)

Aim : simultaneous global Maximum-Likelihood-Fit of coupling-parameters to all studies

Maximum Likelihood-Fit (only # of events, no shape):

- Fit-probability $P = \prod_{i}^{n_{\text{studies}}} P_i(\vec{x}) \cdot \prod_{k}^{n_{\text{syst.}}} P_{\epsilon_k}(\vec{x})$
- $P_i(\vec{x})$: probability density function for one of the studies i listed on the previous slide
- $P_{\epsilon_k}(\vec{x}) = P_G(\epsilon_k - x_{\epsilon_k}, \Delta\epsilon_k)$: probability density function for Gaussian distributed systematic uncertainty x_{ϵ_k} (mean ϵ_k, uncertainty $\Delta\epsilon_k$)
- $\vec{x} = (x_1, \ldots, x_n)$: free parameters of fit

Method of Fit (2)

Probability density function for study i (consisting of channels j):

- $P_i(\vec{x}) = P_{i,\mathrm{stat}}(\vec{x}) \cdot P_{i,\mathrm{syst}}(\vec{x})$
- statistical probability function (Poisson):
  $P_{i,\mathrm{stat}}(\vec{x}) = P_P\left(N_i, \lambda_i(\vec{x})\right)$
- systematic probability function for background normalization (Gauss):
  $P_{i,\mathrm{syst}}(\vec{x}) =$
  $P_G\left(N_{i,B} - \lambda_{i,B}(\vec{x}), \Delta N_{i,B}\right)$
- expectation for signal and background:
  $\lambda_{i,S}(\vec{x}) = \sum_{j \in S} \lambda_{i,j}(\vec{x})$
  $\lambda_{i,B}(\vec{x}) = \sum_{j \in B} \lambda_{i,j}(\vec{x})$

Definitions:

i	some study
$N_{i,S}$	# of signal events
$N_{i,B}$	# of backgr. events
N_i	$= N_{i,S} + N_{i,B}$
$\vec{x}$	$= (x_1, \ldots, x_n)$ Parameters of fit
$\lambda_{i,S}(\vec{x})$	signal expectation
$\lambda_{i,B}(\vec{x})$	backgr. expectation
$\lambda_{i,j}(\vec{x})$	expectation for one contributing channel j
$\lambda_i(\vec{x})$	$= \lambda_{i,S}(\vec{x}) + \lambda_{i,B}(\vec{x}) = \sum_j \lambda_{i,j}(\vec{x})$
$\Delta N_{i,B}$	syst. error on backgr.

Method of Fit (3)

For each contributing channel j:

- expectation for one channel j:
  $\lambda_{i,j}(\vec{x}) = (\sigma \cdot \mathrm{BR})_j (\vec{x}) \cdot L \cdot \eta_{i,j} \cdot \epsilon_1 \cdots \cdots \epsilon_k$
- for signal channels:
  $(\sigma \cdot \mathrm{BR})_j (\vec{x})$ function of fit parameters
- for background channels:
  $(\sigma \cdot \mathrm{BR})_j$: systematic uncertainty x_{ϵ_k},
  $\epsilon_k = (\sigma \cdot \mathrm{BR})_j$
  $\Delta\epsilon_k = \Delta (\sigma \cdot \mathrm{BR})_j$
  (from theory or exp. measurement)

Definitions:

i	some study
j	some channel contributing to study i
$\vec{x}$	$= (x_1, \ldots, x_n)$ Parameters of fit
$\lambda_{i,j}(\vec{x})$	expectation for one channel j
L	integ. Luminosity
$\eta_{i,j}$	acceptance of study i for channel j
ϵ_k	systematic uncertainties

Systematic Uncertainties

- only estimated uncertainties ! -

Reconstruction, Detector		
L	5 %	Luminosity
ϵ_D	2 %	Detector eff.
ϵ_L	2 %	Lepton reconstr.
ϵ_γ	2 %	Photon reconstr.
ϵ_b	3 %	b-tag
ϵ_τ	3 %	τ-tag
ϵ_{Tag}	5 %	tag-jets
ϵ_{Iso}	3 %	Lepton isolation

Backgr. normalization $\Delta N_{i,B}$	
sharp Mass-peak ($\gamma\gamma$, ZZ):	1 %
all other:	10 %

Background cross sections $\Delta\left(\sigma \cdot \mathrm{BR}\right)_j$
between 10 % and 40 %

Measurement of coupling-parameters

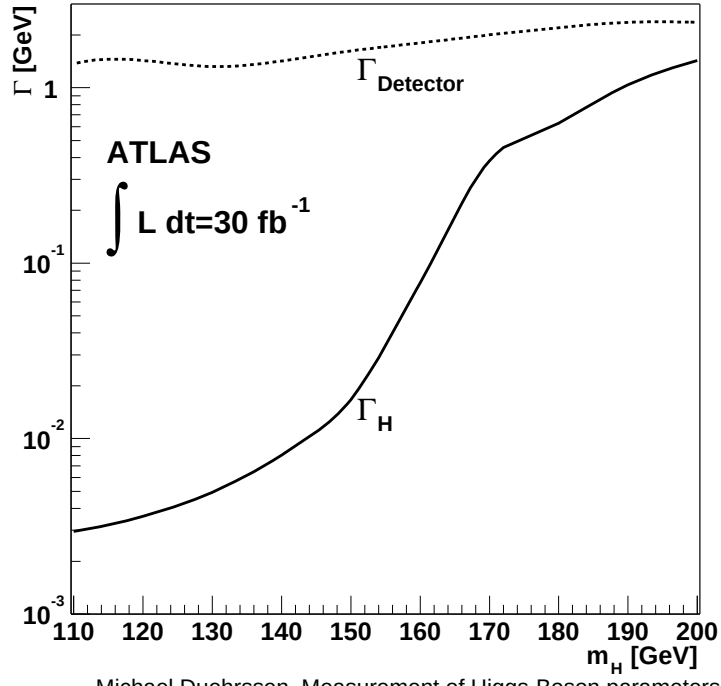
- relative branching ratios -

- Theoretical assumption : only one Higgs-Boson (Spin 0, CP-even)!
- Experimentell limitation : only relative measurement since the total width Γ_H of the Higgs-Boson cannot be measured directly ($m_H < 200$ GeV) !

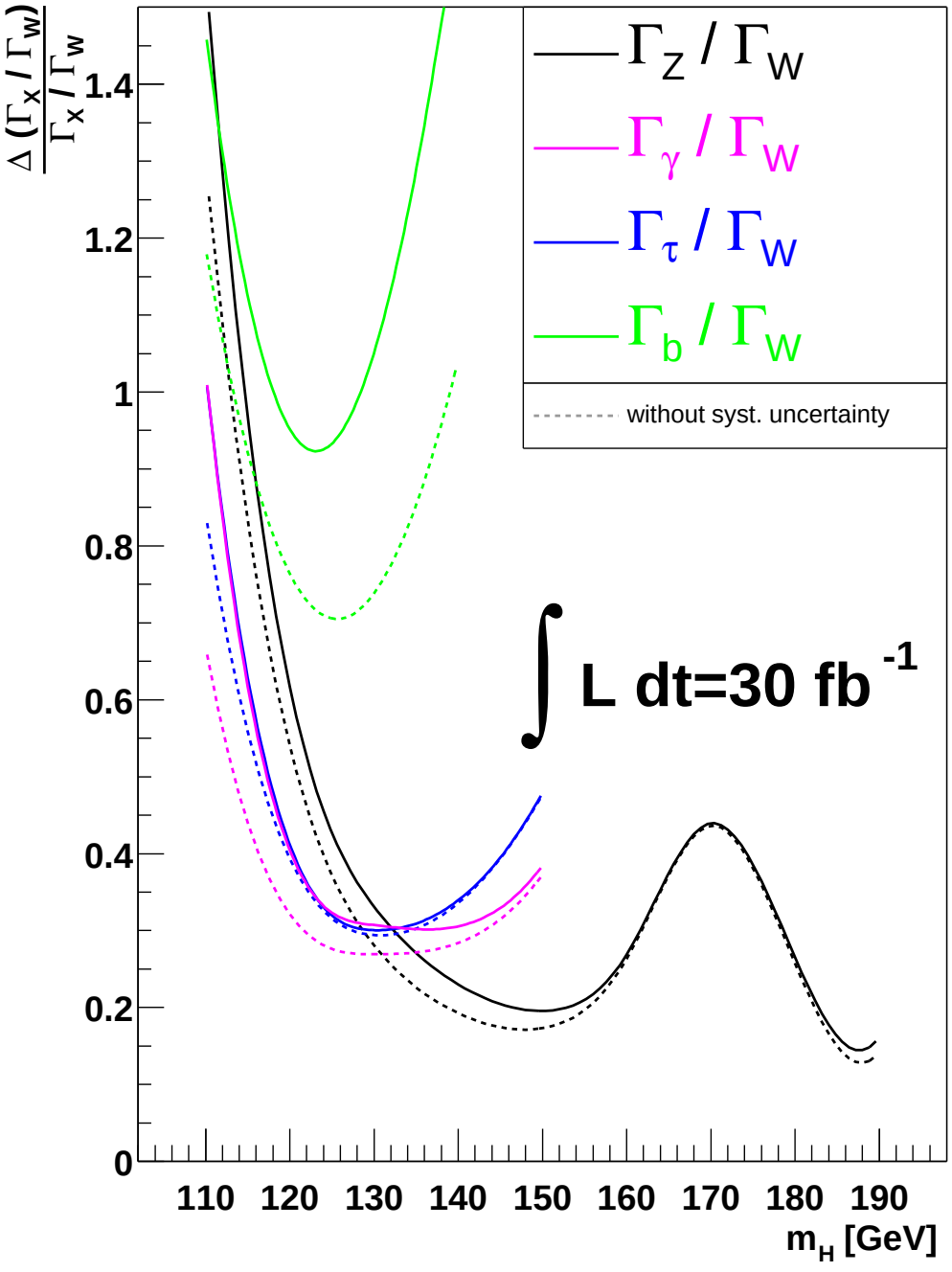
Production:	Decay:
$\sigma_{ggH(H\to WW)}$	$\frac{\mathrm{BR(H\to ZZ)}}{\mathrm{BR(H\to WW)}} = \frac{\Gamma_Z}{\Gamma_W}$
$\sigma_{VBF(H\to WW)}$	$\frac{\mathrm{BR(H\to \gamma\gamma)}}{\mathrm{BR(H\to WW)}} = \frac{\Gamma_\gamma}{\Gamma_W}$
$\sigma_{t\bar{t}H(H\to WW)}$	$\frac{\mathrm{BR(H\to \tau\tau)}}{\mathrm{BR(H\to WW)}} = \frac{\Gamma_\tau}{\Gamma_W}$
$\sigma_{WH(H\to WW)}$	$\frac{\mathrm{BR(H\to b\bar{b})}}{\mathrm{BR(H\to WW)}} = \frac{\Gamma_b}{\Gamma_W}$
$\sigma_{ZH(H\to WW)}$	

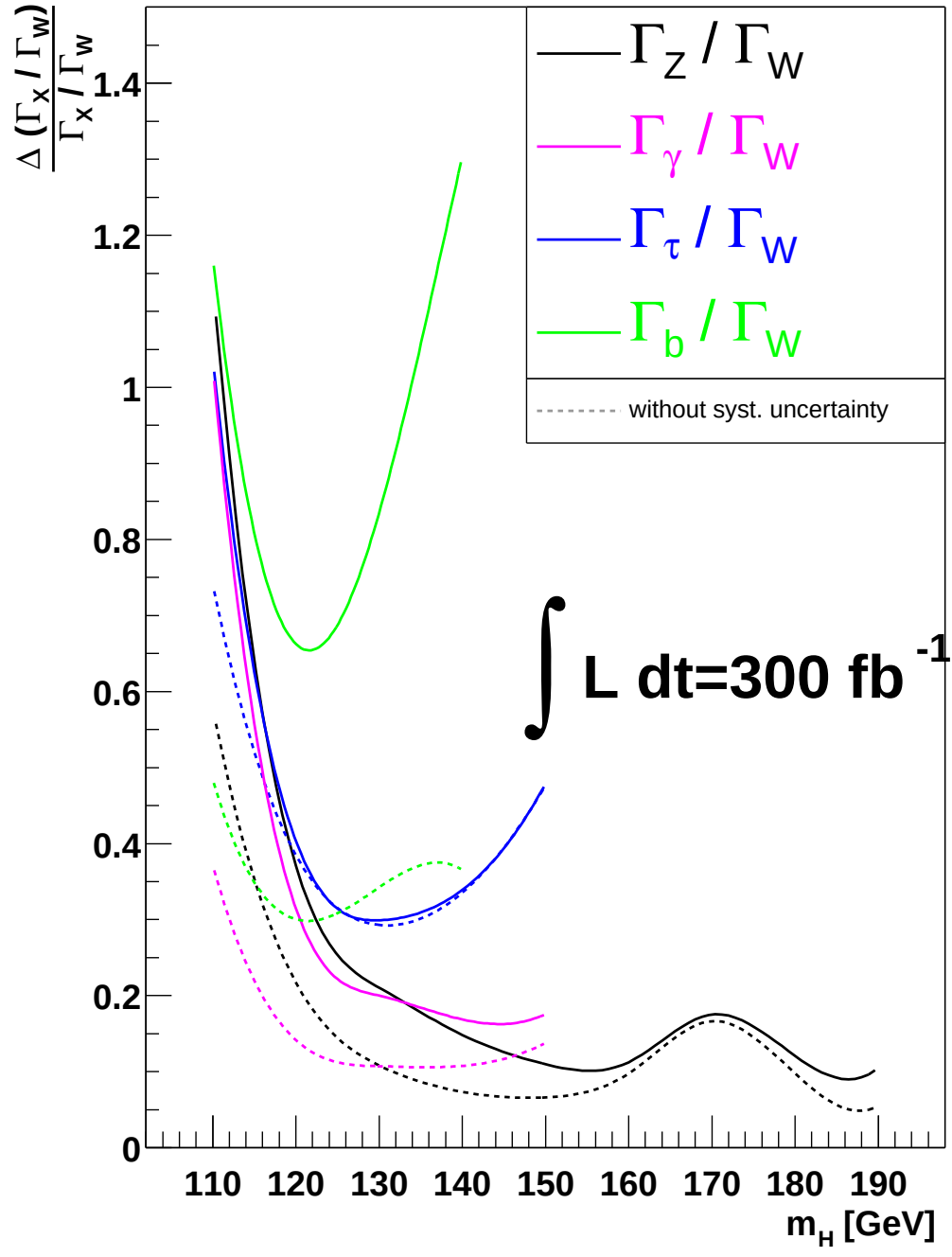
No knowledge of theory needed to get these quantities!

total-width Γ_H and detector resolution $\Gamma_{\mathrm{Detector}}$



Measurement of relative branching ratios



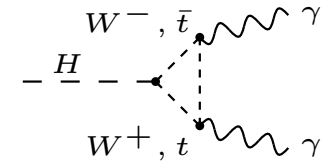


Measurement of coupling-parameters

- relative Higgs-Boson couplings -

- Additional theoretical assumption : only particles of Standard-Model !

Production		Decay	
σ_{ggH}	$\propto g_t^2$	$\mathrm{BR(H \to WW)}$	$\propto \frac{g_W^2}{\Gamma_H}$
σ_{VBF}	$\propto a\, g_W^2 + b\, g_Z^2$	$\mathrm{BR(H \to ZZ)}$	$\propto \frac{g_Z^2}{\Gamma_H}$
$\sigma_{t\bar{t}H}$	$\propto g_t^2$	$\mathrm{BR(H \to \tau\tau)}$	$\propto \frac{g_\tau^2}{\Gamma_H}$
σ_{WH}	$\propto g_W^2$	$\mathrm{BR(H \to b\bar{b})}$	$\propto \frac{g_b^2}{\Gamma_H}$
σ_{ZH}	$\propto g_Z^2$	$\mathrm{BR(H \to \gamma\gamma)}$	$\propto \frac{(a\, g_W - b\, g_t)^2}{\Gamma_H}$



Uncertainties on '$\propto$'

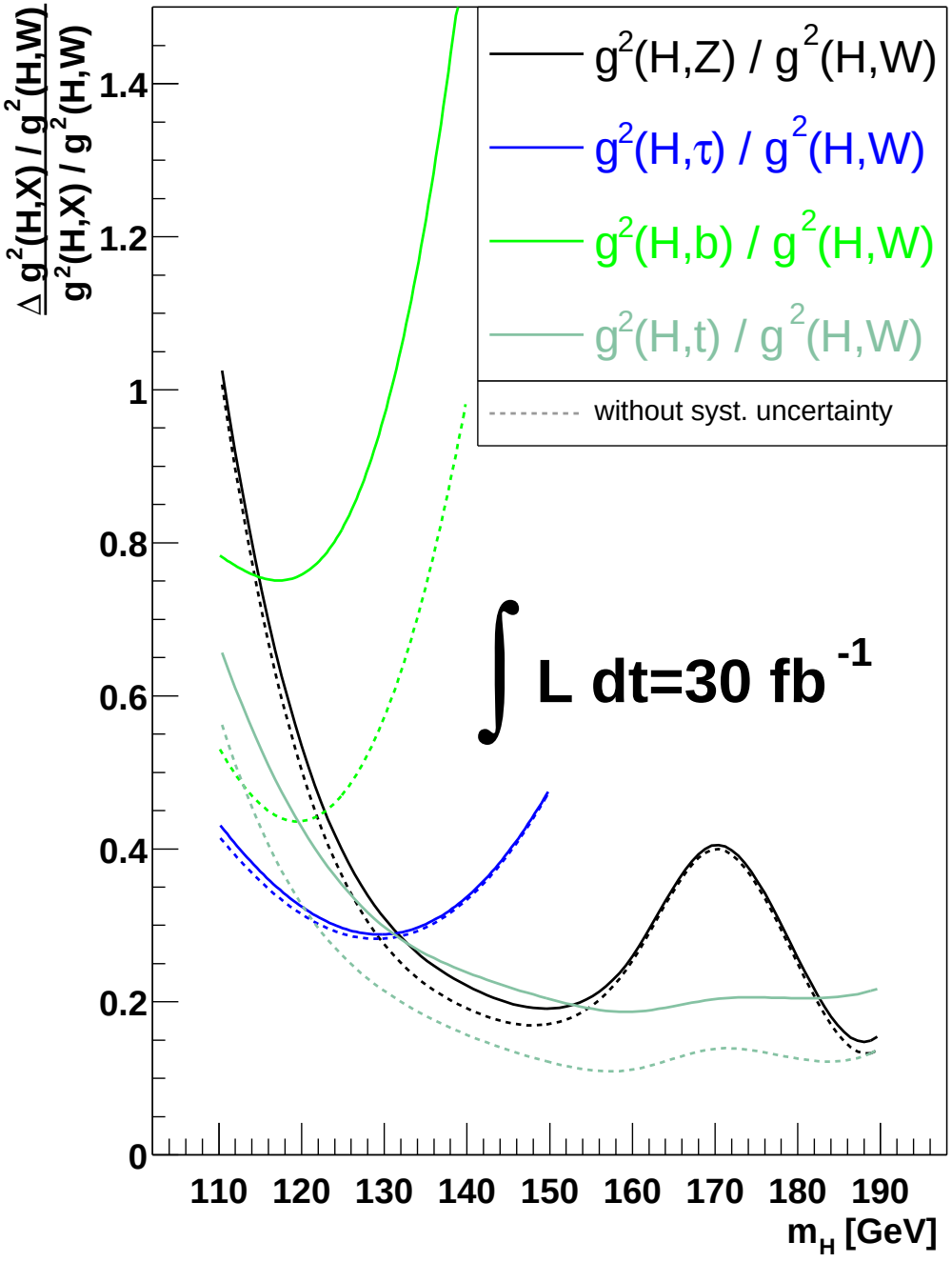
$\sigma_{ggH}, \sigma_{t\bar{t}H}$:	15%
$\sigma_{VBF}, \sigma_{WH/ZH}$:	5%
$\mathrm{BR(H \to XX)}$:	1%

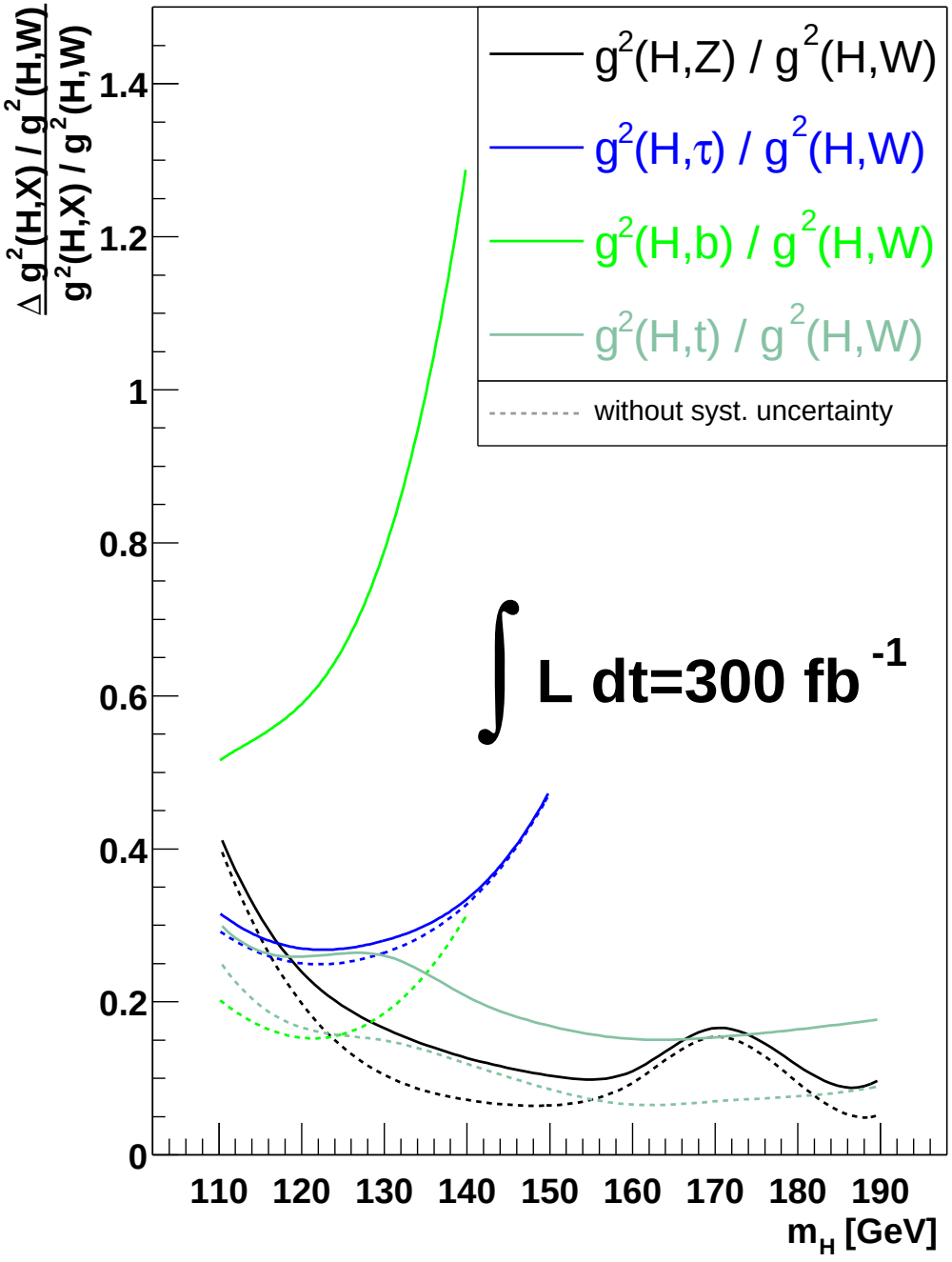
$\to$ M. Spira

Higgs-Boson parameters in this fit:

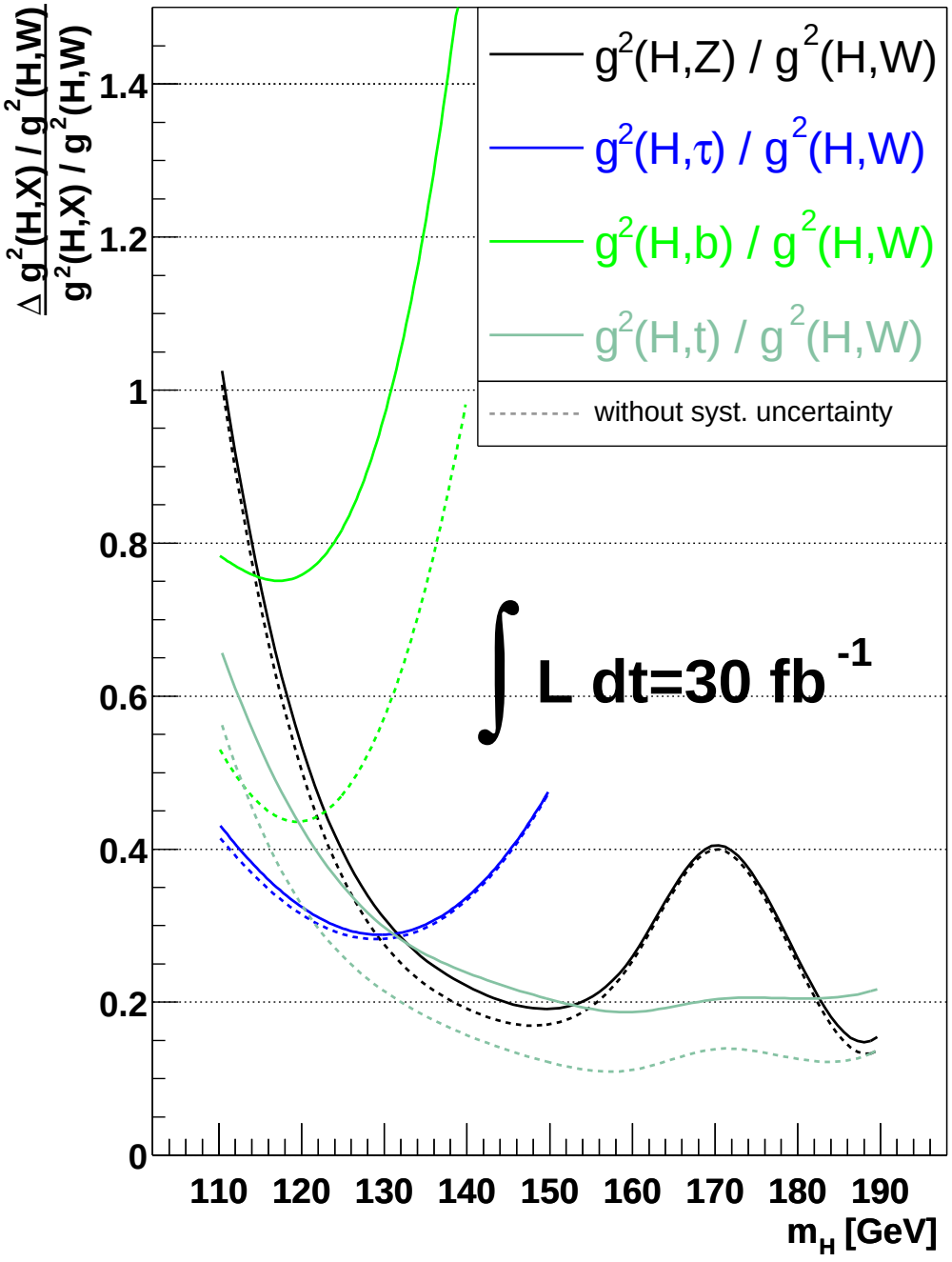
$$\frac{g_Z^2}{g_W^2}\ ,\ \frac{g_\tau^2}{g_W^2}\ ,\ \frac{g_b^2}{g_W^2}\ ,\ \frac{g_t^2}{g_W^2} \text{ and scale } \frac{g_W^2}{\sqrt{\Gamma_H}}$$

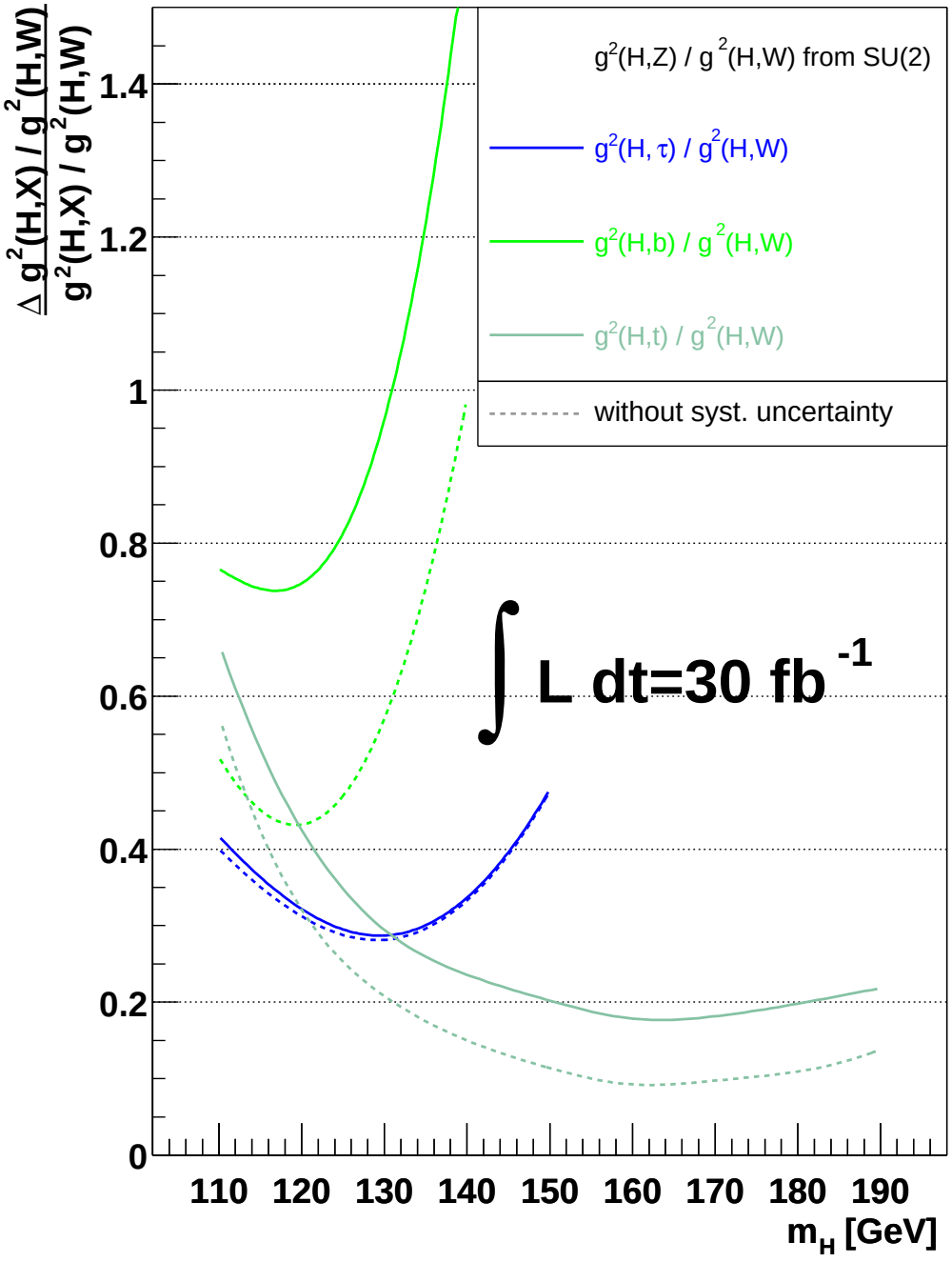
Measurement of relative couplings





Measurement of relative couplings - SU(2)-Symmetry

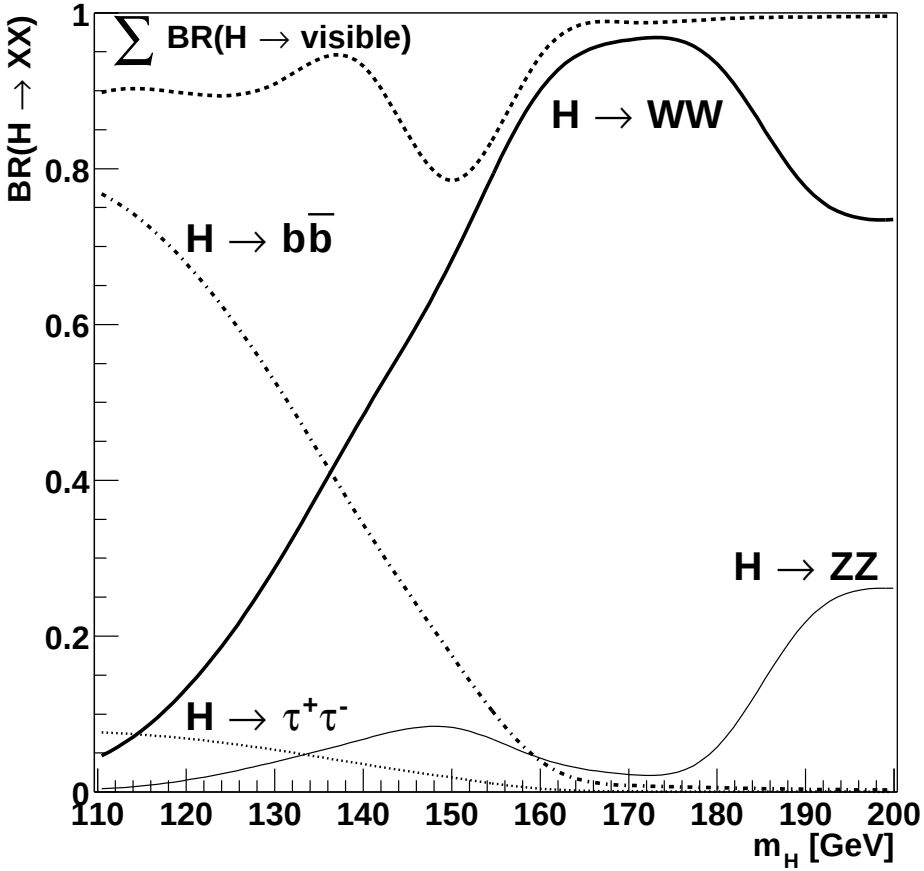




Measurement of coupling-parameters

- absolute Higgs-Boson couplings and total width-

- Additional theoretical assumption : Sum of all visible Higgs-Boson BR:
  $\sum \mathrm{BR} = 1 - \epsilon \pm \epsilon$, where ϵ is taken from the Standard Model.

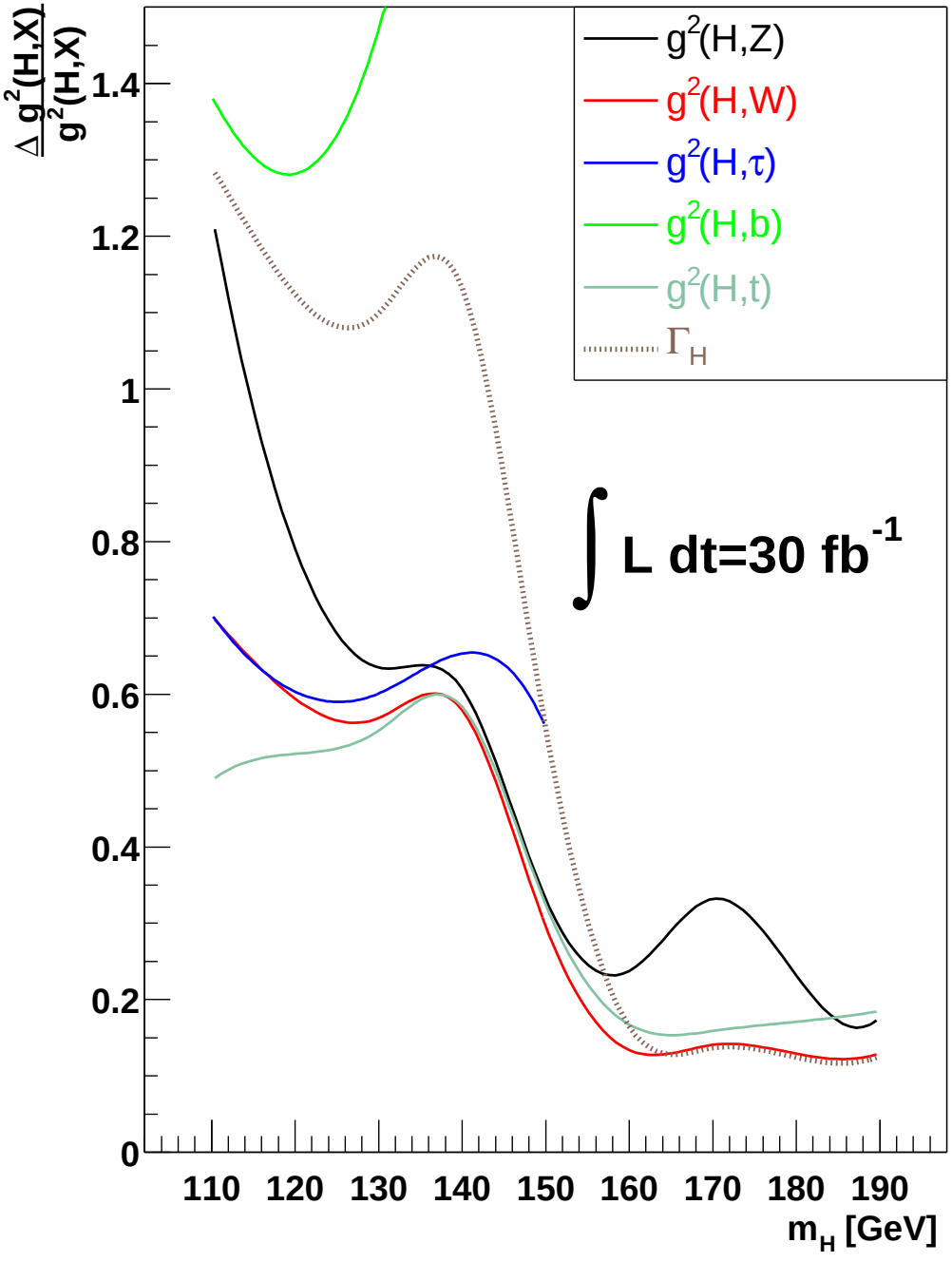


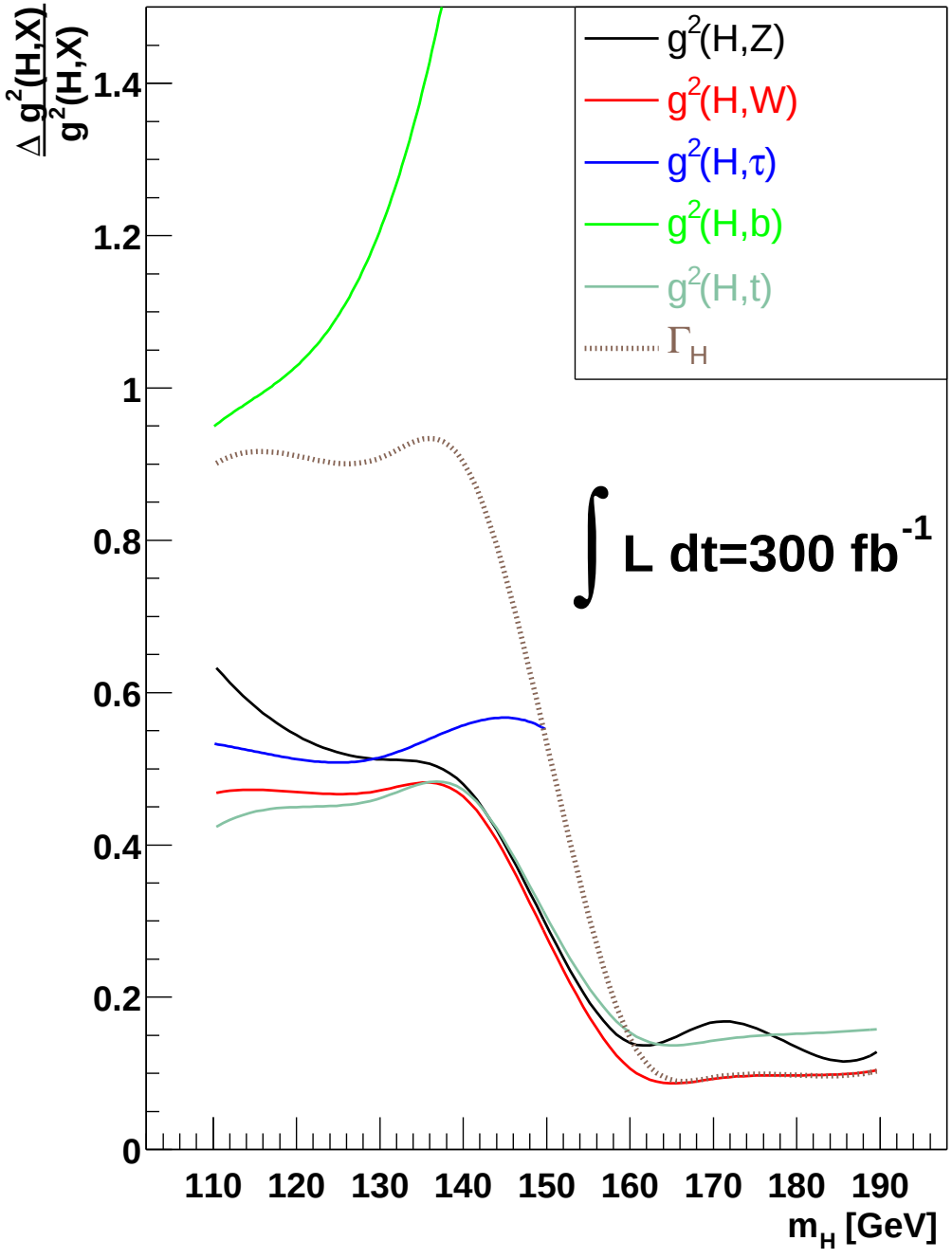
Higgs-Boson parameters in this fit:

$$g_W^2 \, , \, g_Z^2 \, , \, g_\tau^2 \, , \, g_b^2 \, , \, g_t^2$$

and total width Γ_H

Measurement of absolute couplings

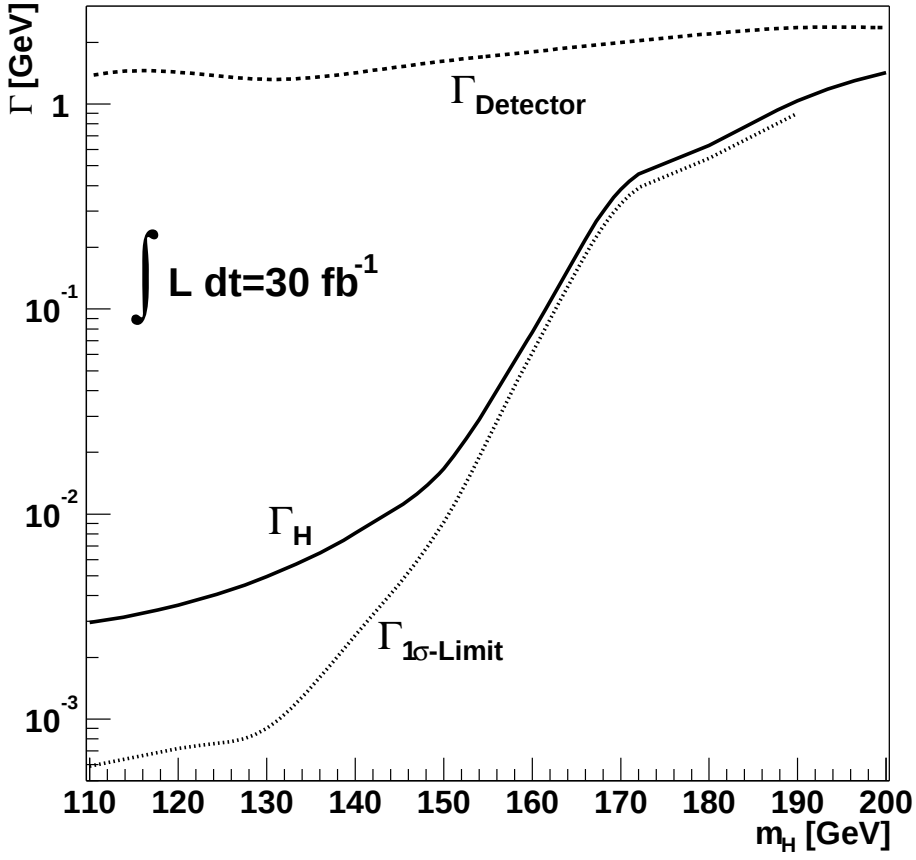




Measurement of coupling-parameters

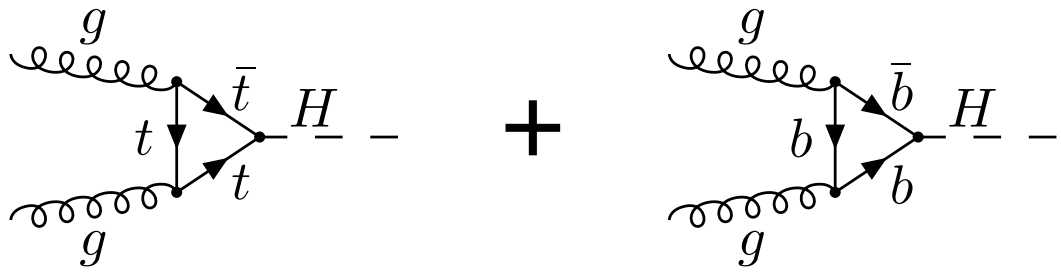
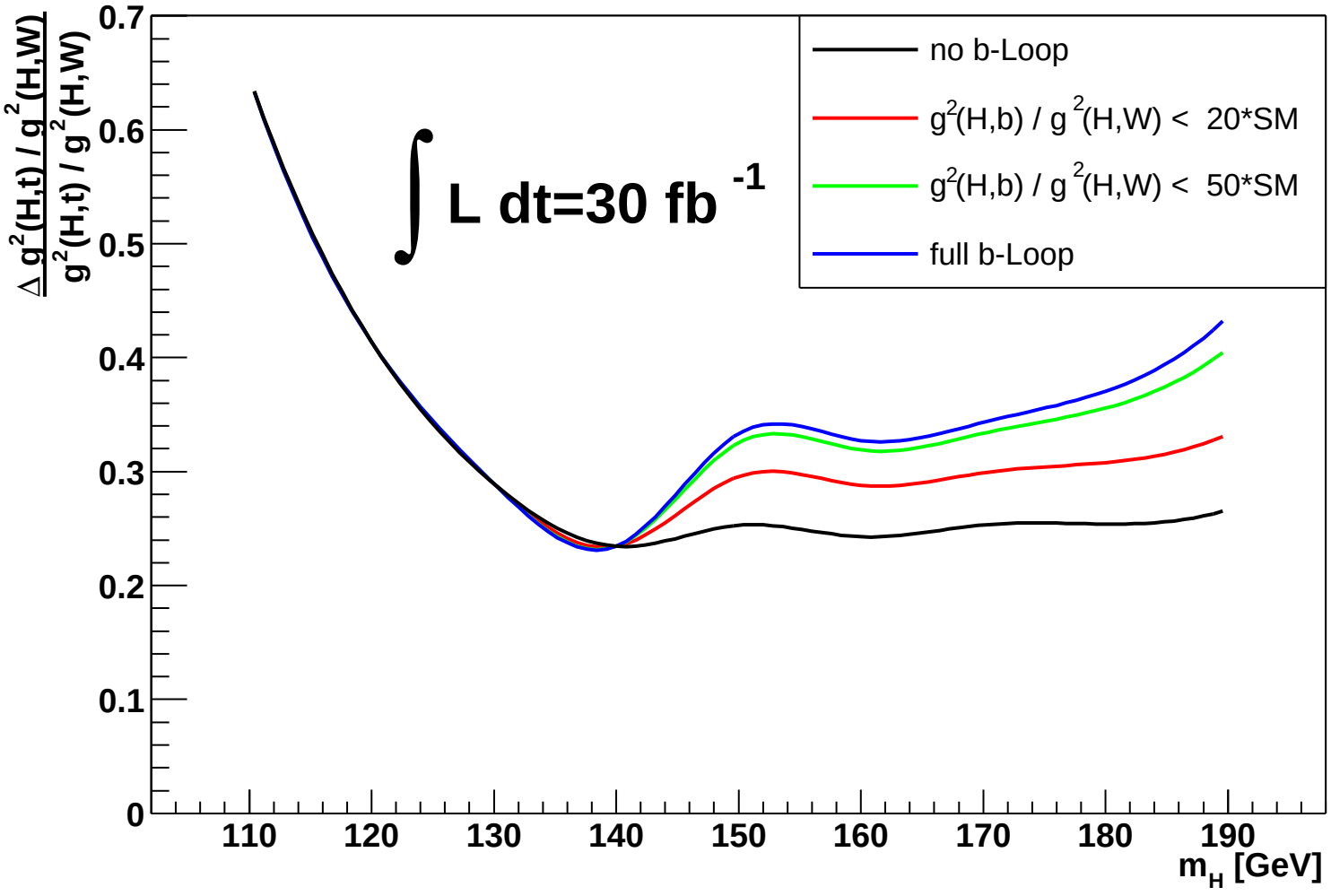
- lower Limit on total width Γ_H -

- theoretical assumption : the same as for measurement of relative couplings



Without further assumptions a lower limit on Γ_H is defined by the sum of all visible decays.

Summary

- All relative branching ratios (except $H \longrightarrow b\bar{b}$) can be measured with a precision of 20% to 50%
  (125 GeV $\leq m_H \leq$ 190 GeV, $L = 30\,\mathrm{fb}^{-1}$).
- All relative couplings (except g_b^2/g_W^2) can be measured with a precision of 15% to 45%. The top-coupling ratio can be measured at 20% to 30%.
  (125 GeV $\leq m_H \leq$ 190 GeV, $L = 30\,\mathrm{fb}^{-1}$)
- A lower Limit on Γ_H can be measured

Open problem : Gluon-Fusion