

Higgs Cross Sections for the LHC

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LHC Higgs Cross Section WG SM Higgs Branching Ratio Uncertainties



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on behalf of the BR subgroup



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

Tools

- **HDECAY** version 3.60 [A. Djouadi, J. Kalinowski, M.M. Mühlleitner, M. Spira]
- **Prophecy4f** [A. Bredenstein, A. Denner, S. Dittmaier, A. Mück, M.M. Weber]
- **EW-NLO Corrections** to $H \rightarrow \gamma\gamma$ and $H \rightarrow gg$ [S. Actis, G. Passarino, C. Sturm, S. Uccirati] - available as a grid, included in HDECAY

Strategy (reminder, adopted for the YR)

- Calculate decay partial width as accurate as possible for each decay mode
- Calculate branching ratios from full set of partial widths
- Definition of *Higgs total width*

$$\Gamma_H = \Gamma_{HDECAY}^{HDECAY} - \Gamma_{ZZ}^{HDECAY} - \Gamma_{WW}^{HDECAY} + \Gamma_{4f}^{Prophecy4f}$$

- *Prophecy4f width*

$$\Gamma_{4f}^{Prophecy4f} = \Gamma_{H \rightarrow W^*W^* \rightarrow 4f} + \Gamma_{H \rightarrow Z^*Z^* \rightarrow 4f} + \Gamma_{WW/ZZ-int}$$

BR Benchmark Calculation

- Input parameters identical to the YR ones (PDG 2009), with small changes on Z, W and c-quark masses, *almost not affecting the YR results* (changes at 0.1% level)

Parameter	YR Value		Current Value	
	Input	Derived (*)	Input	Derived (*)
M_Z [GeV]	91.1886	91.15449	91.1876	91.15349
Γ_Z [GeV]	2.495	2.49595	2.495	2.49581
M_W [GeV]	80.40	80.37151	80.398	80.36951
Γ_W [GeV]	2.141	2.08872	2.141	2.08856

Parameter	YR Value	Current Value
m_c [GeV]	1.55 (**)	1.41 (***)

(*) Derived values are the 'pole masses' calculated at NLO from the Input masses (based on running widths) - they ensure that W and Z BRs add up to 1

(**) two-loop pole mass (***) one-loop pole mass

- Current binning: [90, 200] GeV → 5 GeV step - [200, 1000] GeV → 10 GeV step

Parametric Uncertainty Estimation Baselines

- Parametric uncertainties estimated by changing *separately*, while leaving all others at their central values, each of the following relevant parameters: α_s , m_b , m_c , m_t

Parameter	Central Value	Uncertainty
α_s	0.119	± 0.002 (90% CL)
m_b [GeV]	4.49 (*)	± 0.03 (2σ) (**)
m_c [GeV]	1.41 (*)	± 0.03 (2σ) (**)
m_t [GeV]	172.5	± 2.5

(*) one-loop pole mass,
from our TWiki

(**) errors from Ref.
[arXiv:0907.2110](https://arxiv.org/abs/0907.2110)

Comments:

- One-loop pole masses (differently from MSbar masses) accidentally show negligible dependence on α_s , so that their variation can be independent from α_s (***)
- Uncertainty on b - and c -masses taken from the indicated reference (PDG uncertainties are way *larger*: $m_b^{\text{MSbar}} = 4.19 + 0.18 - 0.06$ GeV, $m_c^{\text{MSbar}} = 1.27 + 0.07 - 0.09$ GeV)
- Dependency of the EW NLO corrections to $H \rightarrow \gamma\gamma$ and $H \rightarrow gg$ on m_t accounted for automatically in HDECAY - all the other parametric uncertainties of the EW corrections are negligible

(***) Similar procedure followed in A. Djouadi, M. Spira, P.M. Zerwas [hep-ph/9511344](https://arxiv.org/abs/hep-ph/9511344)

BR Uncertainty Estimation Baseline

1. Parametric uncertainties:

- Evaluate *partial widths* and *BRs* with p , $p + \Delta p$, $p - \Delta p$ (where p is a generic parameter) and take the differences w.r.t. central values
- Upper ($p + \Delta p$) and lower ($p - \Delta p$) errors summed *in quadrature* to obtain a *Combined Parametric Errors*

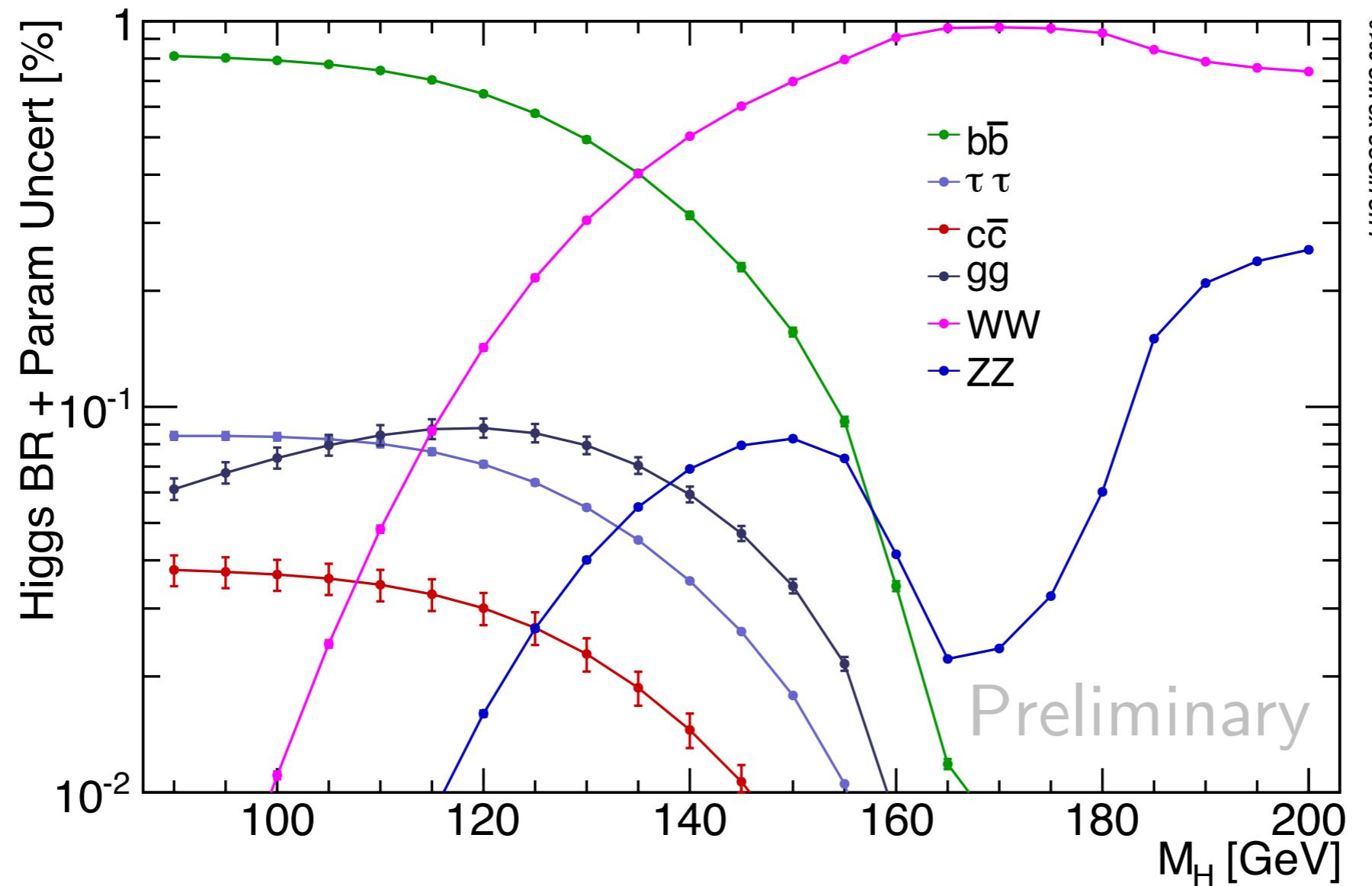
2. Theoretical uncertainties:

- Calculate errors for partial widths and corresponding BRs for each theoretical uncertainty listed in our TWiki (<https://twiki.cern.ch/twiki/bin/view/LHCPhysics/BRs>)
- Combine the individual theoretical uncertainties *linearly* to obtain *Total Theoretical Uncertainty*

3. Total uncertainties: *linear* sum of the Combined Parametric Error with the Total Theoretical Uncertainties

- **Results** (tables and plots) provided: for each parameter variation, for combined parametric error, for total parametric + theoretical errors ★ *see next slides*

Combined Parametric Errors: BR low masses

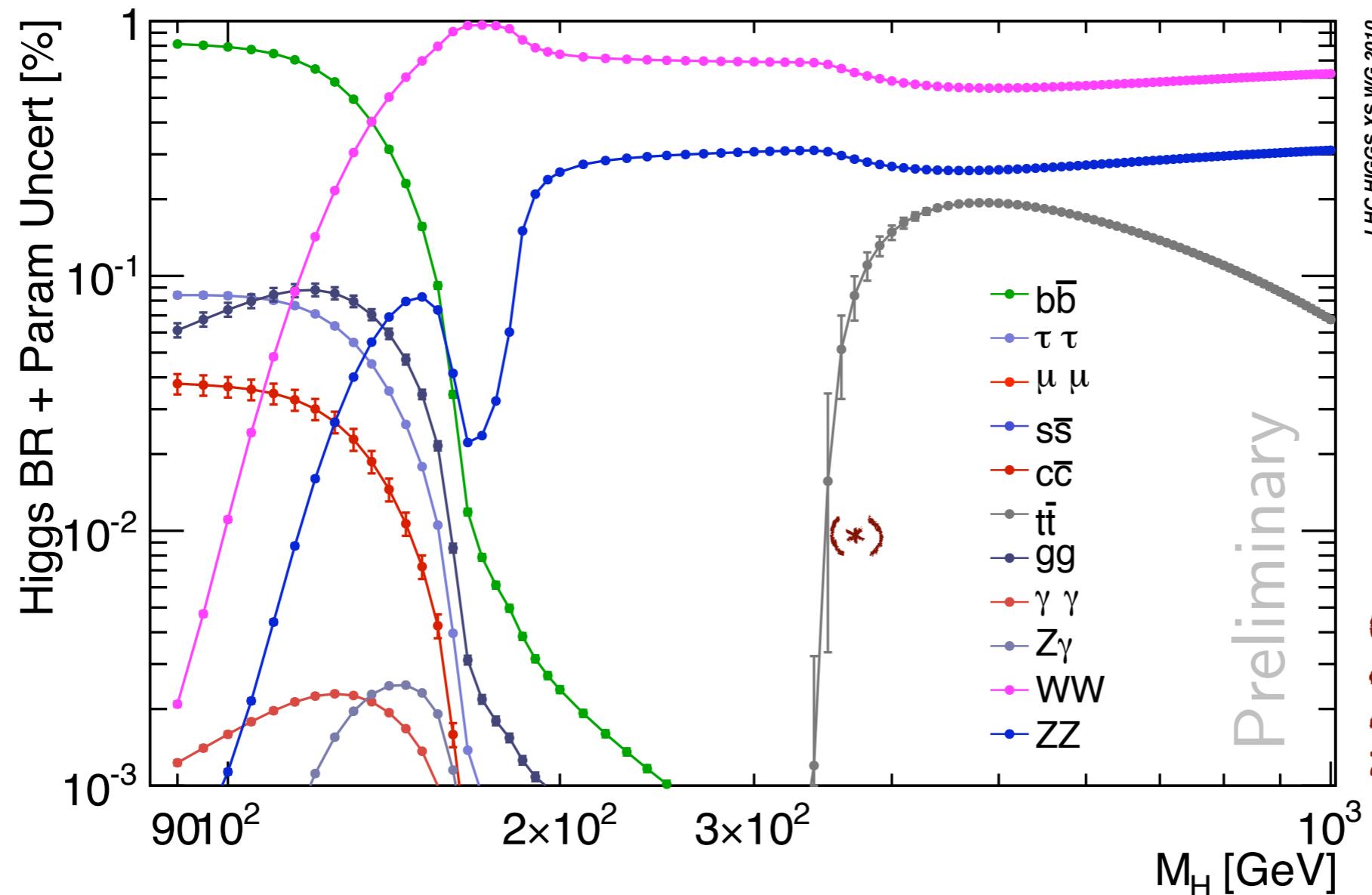


Combined Parametric Errors on BRs

$H \rightarrow b\bar{b}$	$O(3\text{-}4\%)$ for $M_H > 165$ GeV	$H \rightarrow \tau\tau$	$O(1\%)$ for $M_H > 140$ GeV
$H \rightarrow c\bar{c}$	$O(10\%)$	$H \rightarrow gg$	$O(5\text{-}6\%)$
$H \rightarrow WW$	$O(1\%)$ for $M_H > 120$ GeV	$H \rightarrow ZZ$	$O(1\%)$ for $M_H > 120$ GeV

Parametric errors relevant only for $H \rightarrow cc$ and $H \rightarrow gg$ BRs

Combined Parametric Errors: all masses



Combined Parametric Errors on BRs

$H \rightarrow WW$ O(1%) for $M_H > 120$ GeV | $H \rightarrow ZZ$ O(1%) for $M_H > 120$ GeV

$H \rightarrow t\bar{t}$ O(30-40%) for $260 < M_H < 380$ GeV, O(200%) for $M_H \approx 2m_t$

(*)

Parametric errors relevant only for $H \rightarrow tt$ below 450 GeV

Comparison with arXiv:1012.0530v3

- Parameter choice:

Parameter	LHC BR Group	arXiv:1012.0530v3
$\alpha_s(M_Z)$	0.119 ± 0.002 (90% CL)	0.1171 ± 0.0014 (68% CL)
m_b [GeV]	4.49 ± 0.03 (2σ) (*)	$4.419^{+0.18}_{-0.06}$ (**)
m_c [GeV]	1.41 ± 0.03 (2σ) (*)	$1.27^{+0.07}_{-0.09}$ (**)
m_t [GeV]	172.5 ± 2.5	-

(*) one-loop pole mass
 (**) MSbar PDG mass and relative uncertainty
 ($\alpha_s = 0.1171$ at NNLO in these uncertainties calculations)

- Results in percentage (selection):

		LHC BR Group					arXiv:1012.0530v3					
Channel	M_H	BR	Δm_c	Δm_b	$\Delta \alpha_s$	Δm_t	ΔBR	BR	Δm_c	Δm_b	$\Delta \alpha_s$	ΔBR
$H \rightarrow b\bar{b}$	120	64.8	+0.2 -0.2	+0.6 -0.6	+0.9 -1.0	+0.02 -0.02	+1.1 -1.2	65.1	+0.7 -0.6	+3.4 -1.2	+0.7 -0.8	+3.6 -1.6
	135	40.3	+0.1 -0.1	+1.0 -1.0	+1.6 -1.7	+0.04 -0.04	+1.9 -1.9	40.2	+0.4 -0.4	+6.0 -2.1	+1.3 -1.3	+6.2 -2.5
	150	15.6	+0.0 -0.1	+1.3 -1.4	+2.2 -2.3	-0.01 -0.05	+2.6 -2.7	15.5	+0.2 -0.1	+8.7 -3.0	+1.9 -1.9	+8.9 -3.6
$H \rightarrow WW$ (***)	120	14.2	+0.2 -0.2	+1.0 -1.0	+1.6 -1.5	-0.04 -0.02	+1.9 -1.8	14.7	+0.7 -0.6	+2.3 -6.3	+1.4 -1.4	+2.8 -6.5
	135	40.2	+0.1 -0.1	+0.6 -0.6	+0.9 -0.9	-0.02 -0.01	+1.1 -1.1	41.1	+0.4 -0.4	+1.4 -4.0	+0.9 -0.9	+1.7 -4.1
	150	69.8	+0.1 -0.1	+0.2 -0.3	+0.3 -0.3	-0.01 -0.00	+0.4 -0.4	70.3	+0.2 -0.1	+0.5 -1.6	+0.3 -0.3	+0.7 -1.6

(***) Uncertainties (in percentage) on $H \rightarrow \tau\tau$ and $H \rightarrow ZZ, YY$ SAME AS $H \rightarrow WW$

ΔBR discrepancy (mostly) due to different quark masses and uncertainties

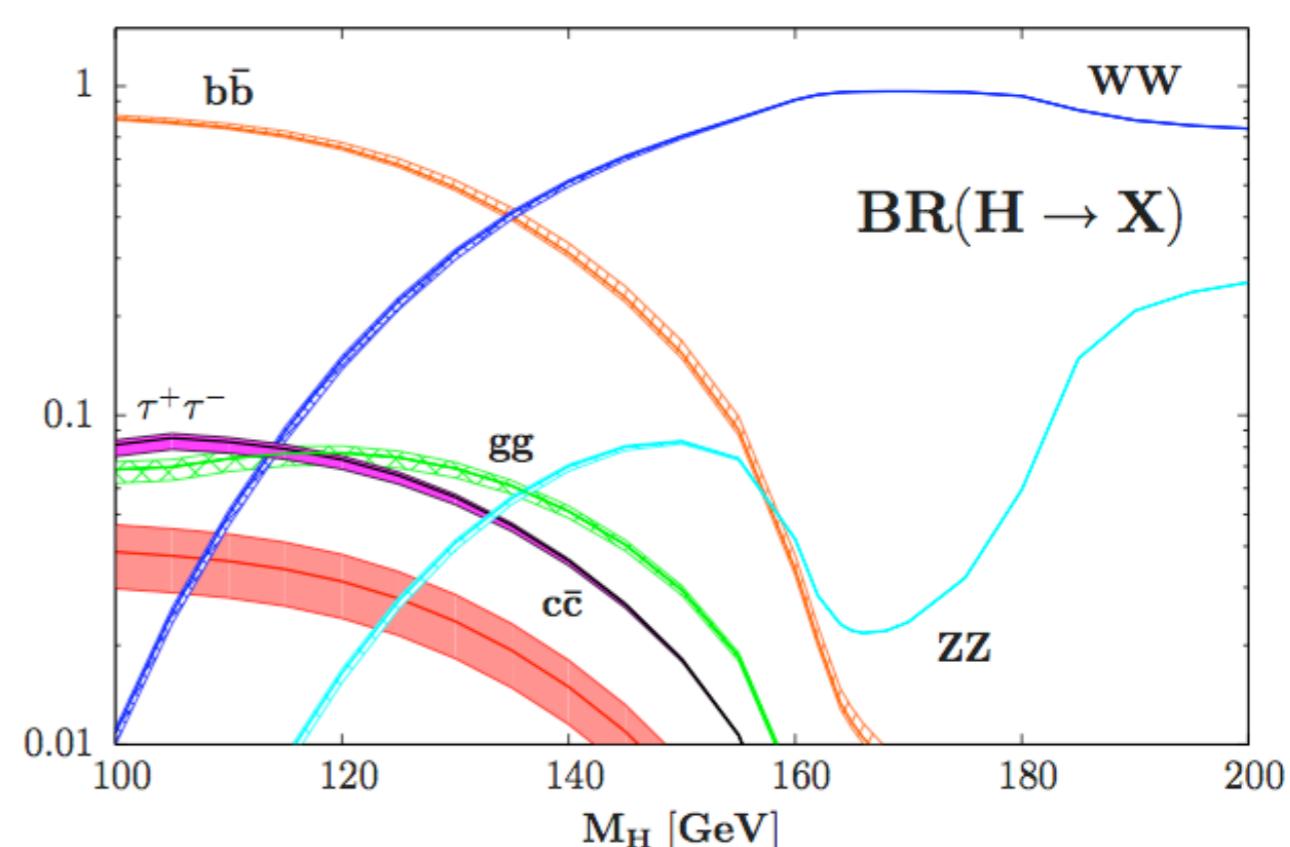
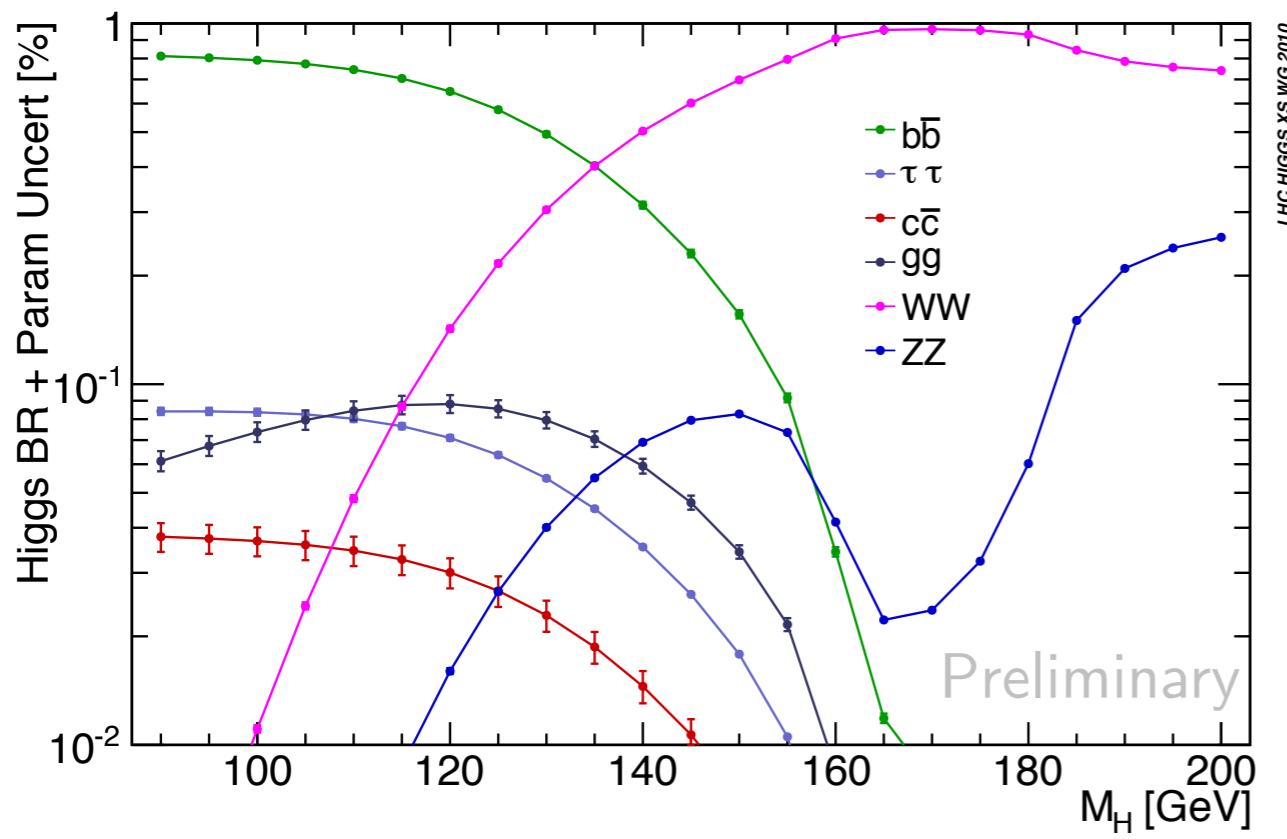
Comparison with arXiv:1012.0530v3 (cont'd)

- Other channel comparisons:

**ΔBR($H \rightarrow cc$) discrepancy
(mostly) due to m_c**

$BR(H \rightarrow gg)$: similar uncertainties but $O(12\text{--}13\%)$ discrepancy for central values, to be understood

Channel	M_H [GeV]	LHC BR Group		arXiv:1012.0530v3	
		BR [%]	ΔBR [%]	BR [%]	ΔBR [%]
$H \rightarrow c\bar{c}$	120	3.00	+9.5 -9.6	3.13	+20.7 -22.8
	135	1.87	+10.0 -10.1	1.93	+20.5 -23.0
	150	0.72	+10.6 -10.6	0.74	+20.6 -23.2
$H \rightarrow gg$	120	8.81	+5.9 -5.6	7.69	+4.9 -7.8
	135	7.04	+5.1 -4.9	6.10	+3.9 -5.5
	150	3.43	+4.3 -4.2	2.94	+3.0 -3.4



Theoretical Uncertainty Baselines

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

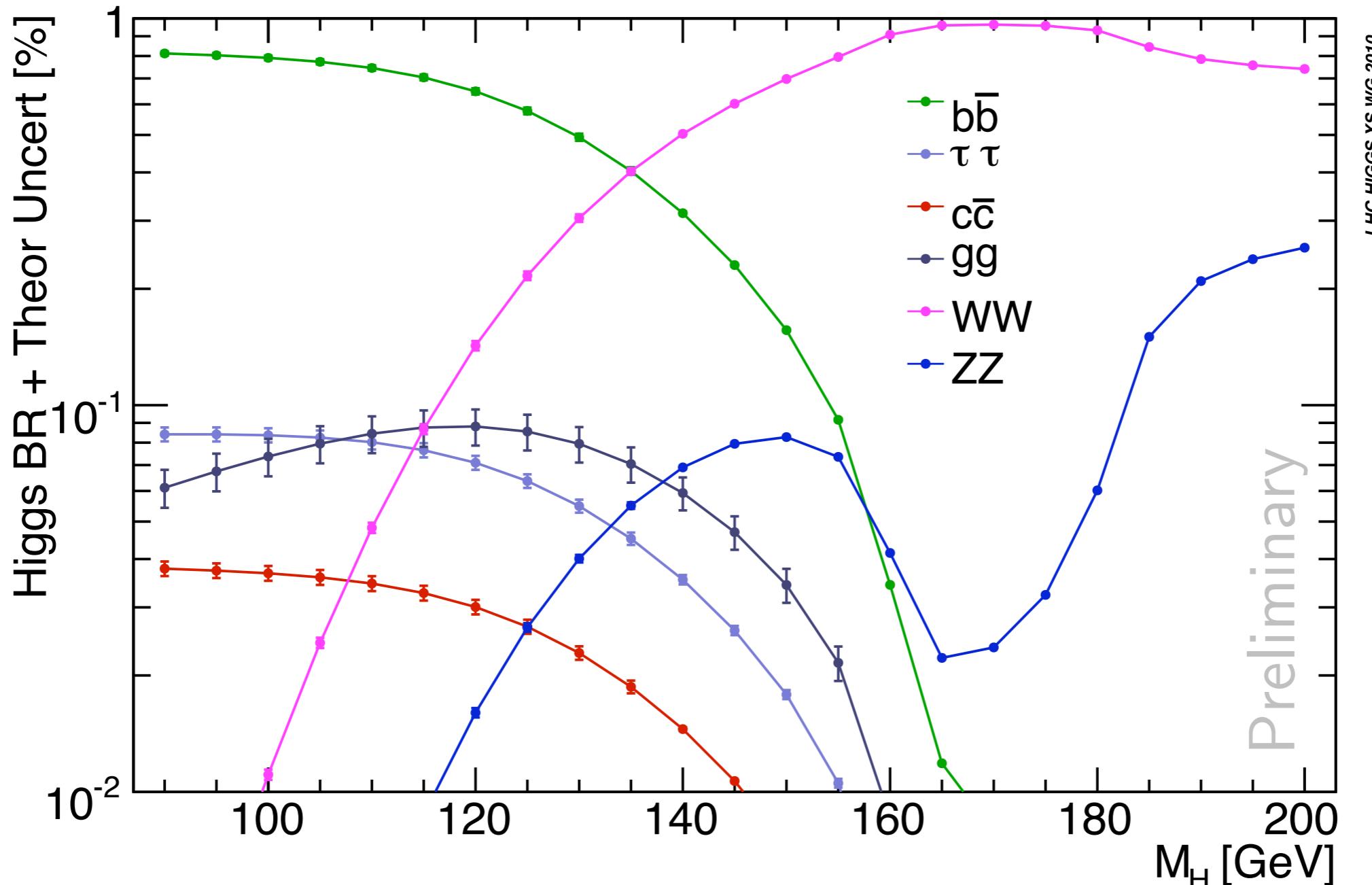
Process	Uncertainty (*)	Total
$H \rightarrow bb/cc$	QCD 0.1-0.2% EW 1-2% for $M_H \leq 135$ GeV	1-2%
$H \rightarrow \tau\tau$	EW 1-2%	1-2%
$H \rightarrow WW/ZZ \rightarrow 4f$	EW 0.5% for $M_H < 500$ GeV $\sim 0.17 \cdot (M_H/1 \text{ TeV})^4$ for $M_H > 500$ GeV	0.5-15%
$H \rightarrow t\bar{t}$	QCD $\leq 5\%$ (only NLO mass effects) EW $\sim 2\%$ for $M_H < 500$ GeV $\sim 0.1 \cdot (M_H/1 \text{ TeV})^4$ for $M_H > 500$ GeV	5-10%
$H \rightarrow gg$	QCD $\sim 10\%$ (only NNLO included in HDECAY) EW $\sim 1\%$	$\sim 10\%$
$H \rightarrow \gamma\gamma$	QCD+EW $\sim 1\%$	$\sim 1\%$

(*) HDECAY + Prophecy4f uncertainties
on the Higgs partial widths

Comments:

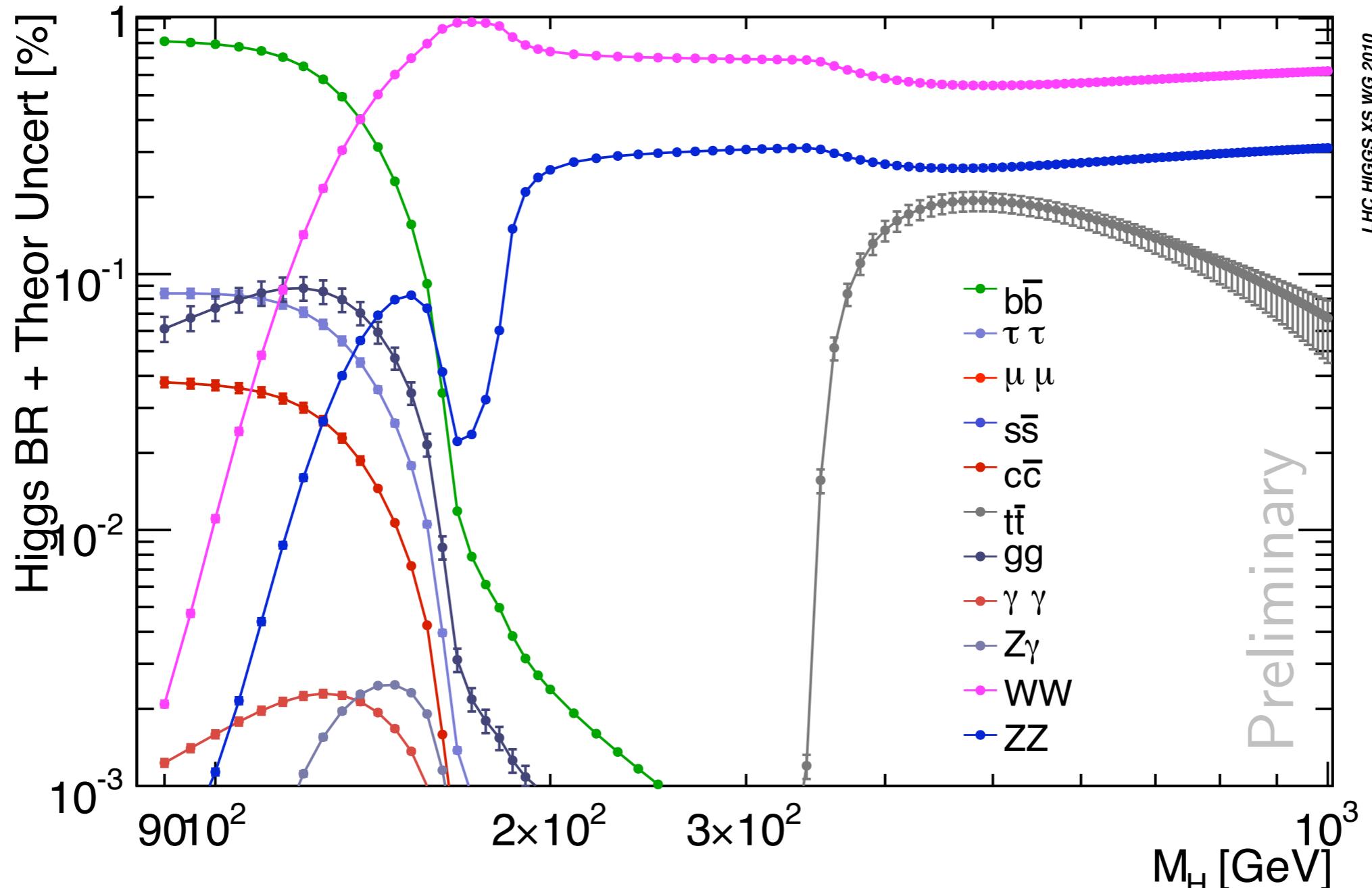
- QCD corrections: variation of the Higgs widths from a scale change by factor 2 and 1/2
- EW corrections: missing HO estimation based on the known structure and size of the NLO corrections
- For $M_H > 500$ GeV: higher-order heavy-Higgs corrections dominate error
- Different uncertainties on a given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

Theoretical Uncertainties: BR low masses



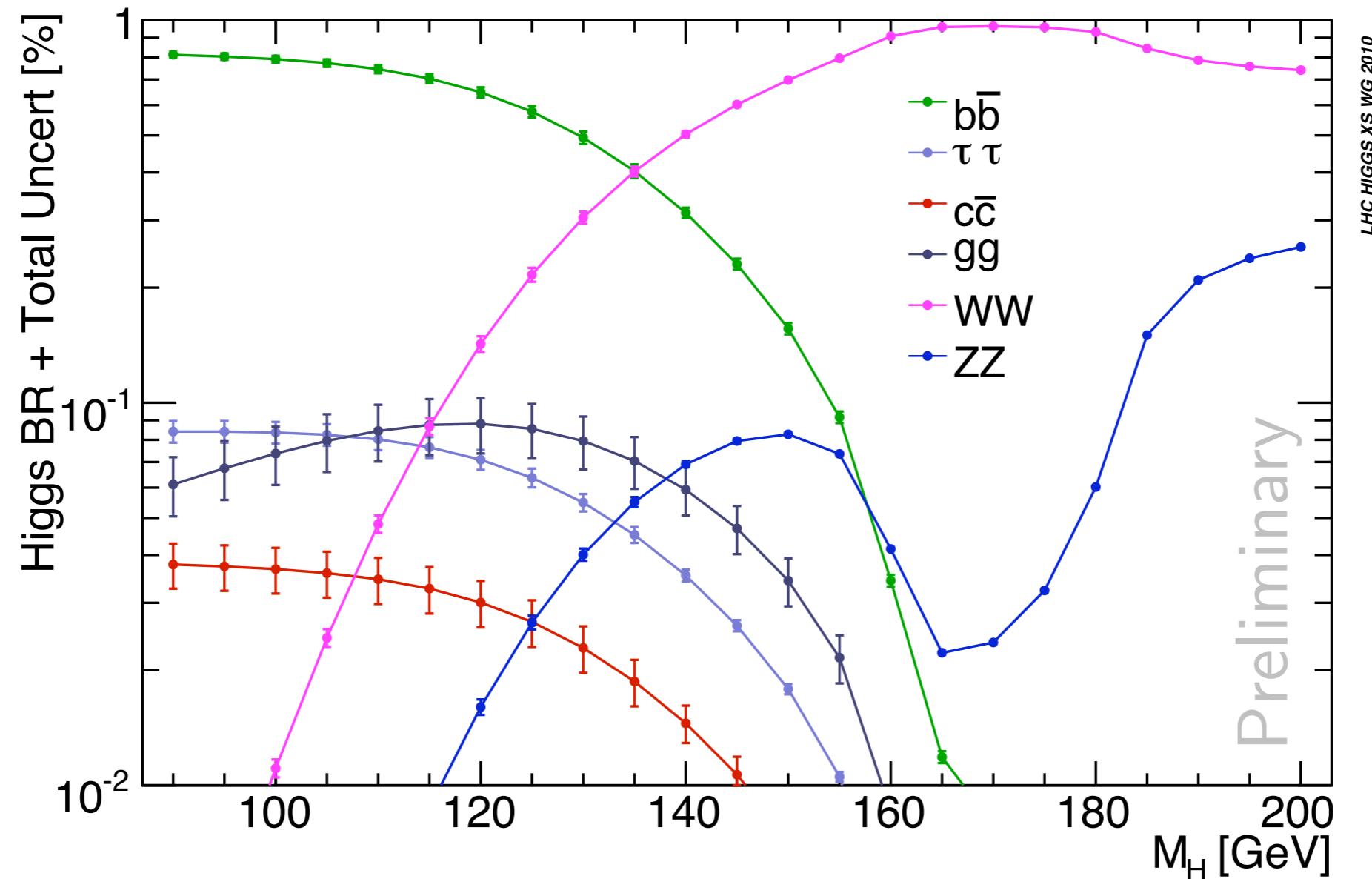
Theoretical errors relevant only for $BR(H \rightarrow gg)$ $O(10\%)$
(for $BR(H \rightarrow bb/cc)$ and $BR(H \rightarrow \tau\tau)$ $O(1\%)$)

Theoretical Uncertainties: BR all masses



**Theoretical errors relevant only for $H \rightarrow t\bar{t}$ O(5-10%)
(for $H \rightarrow WW/ZZ$ O(2%) for $M_H > 400$ GeV)**

Total Higgs BR Uncertainties: low masses



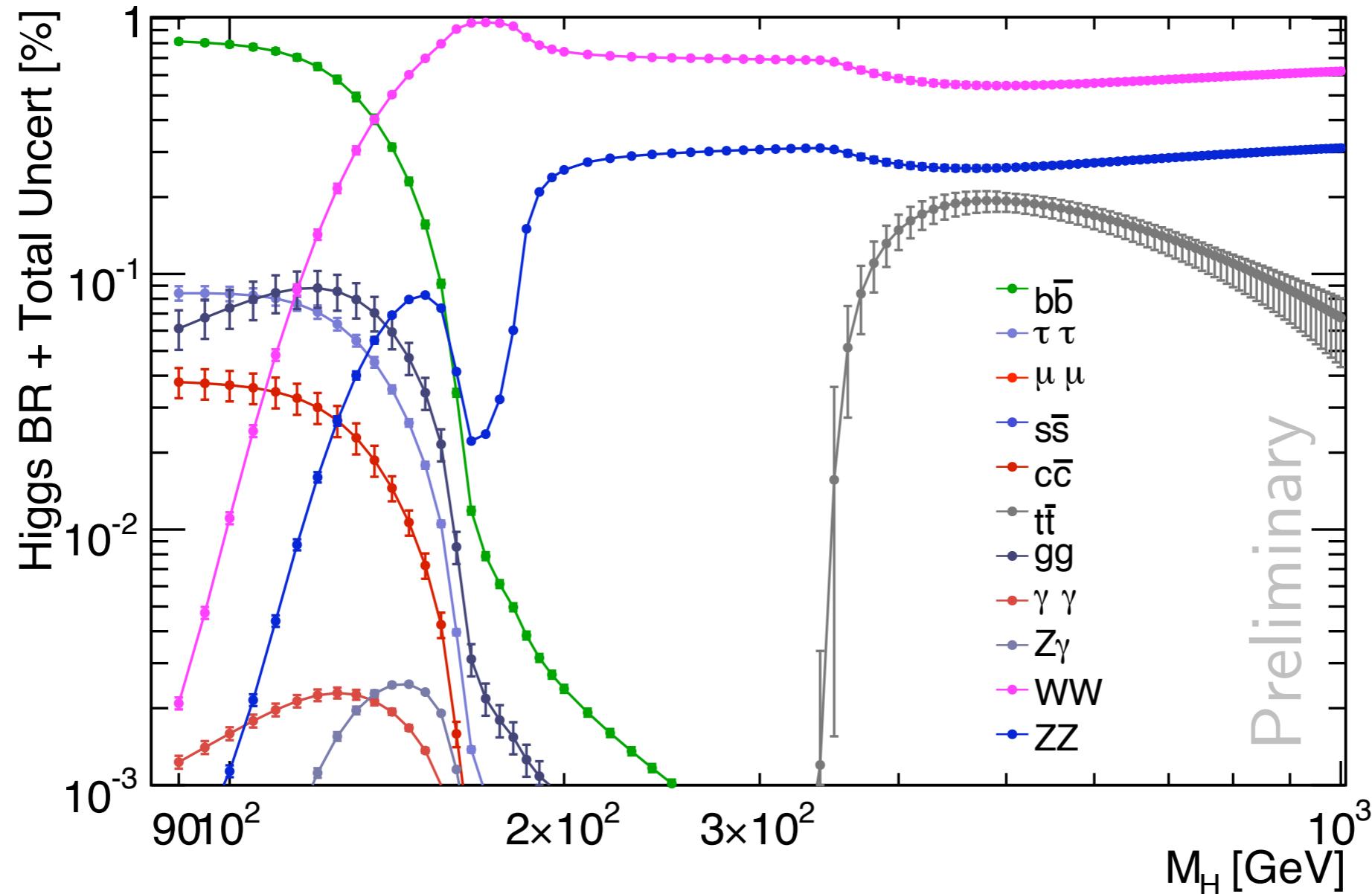
Total Uncertainties on BRs for $M_H < 200$ GeV

$H \rightarrow b\bar{b}$	$O(3-4\%)$	$H \rightarrow \tau\tau$	$O(3-6\%)$
$H \rightarrow c\bar{c}$	$O(10-13\%)$ (*)	$H \rightarrow gg$	$O(15-17\%)$ (**)
$H \rightarrow WW$	below 1% for $M_H > 150$ GeV	$H \rightarrow ZZ$	below 1% for $M_H > 150$ GeV

(*) parametric errors dominant

(**) theoretical errors dominant

Total Higgs BR Uncertainty: all masses



Total Uncertainties on BRs for $M_H > 200$ GeV

$H \rightarrow WW$	O(2%) for $M_H > 360$ GeV	$H \rightarrow ZZ$	O(2%) for $M_H > 350$ GeV
$H \rightarrow t\bar{t}$	O(40-50%) for $260 < M_H < 380$ GeV, O(200%) for $M_H \approx 2m_t$ (*) below 10% for $M_H < 450$ GeV (**)		

(*) parametric errors dominant (**) theoretical errors dominant

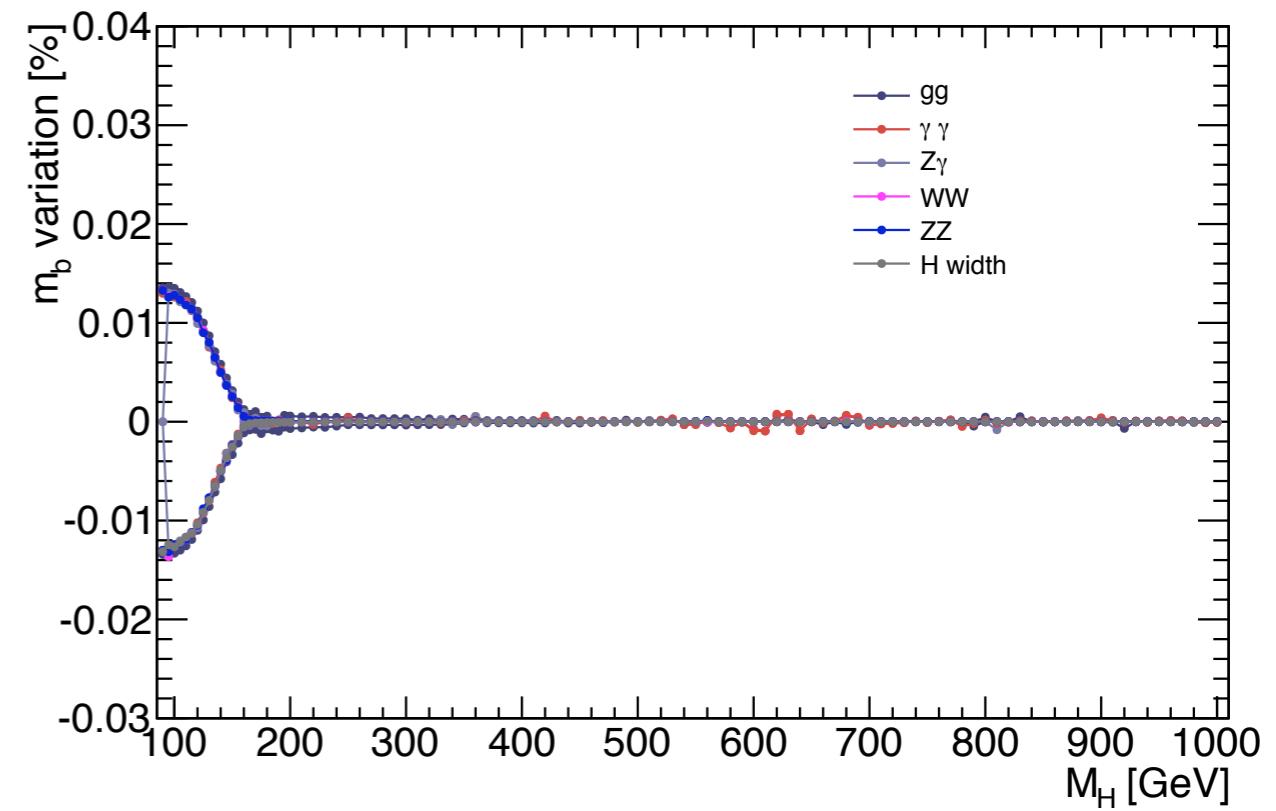
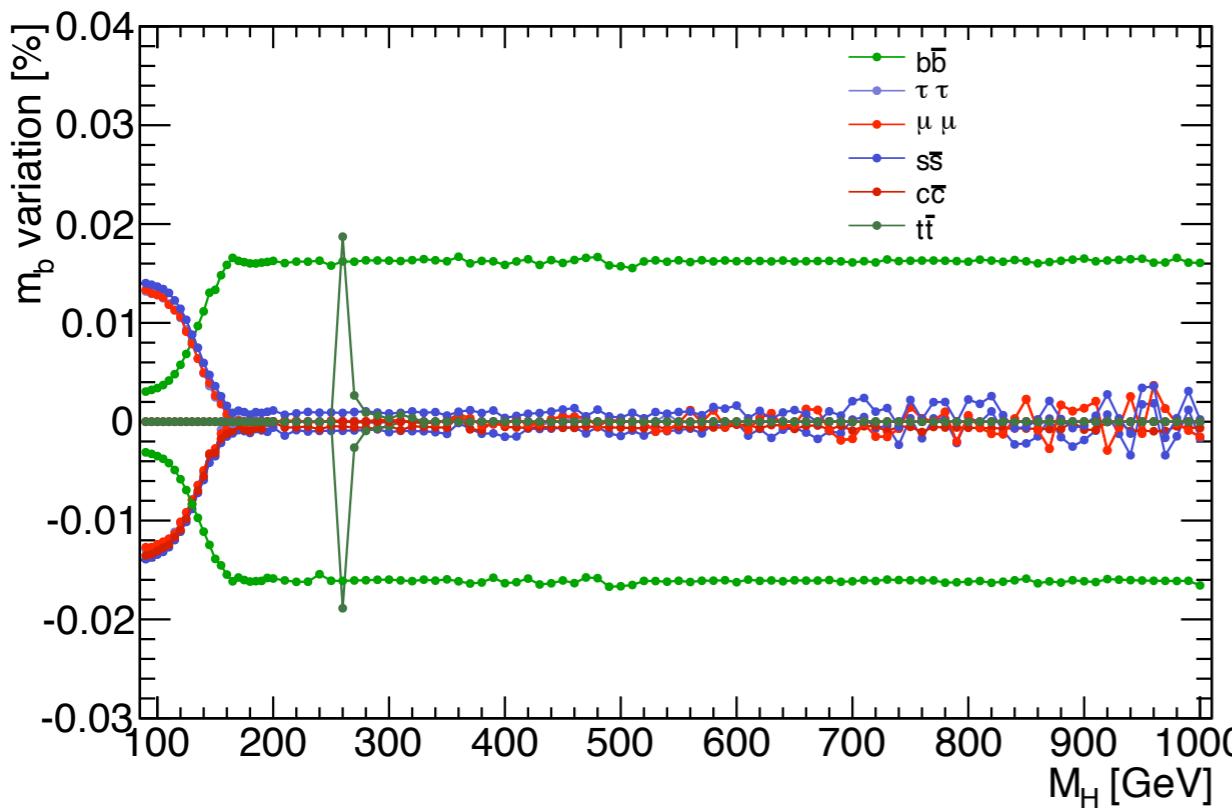
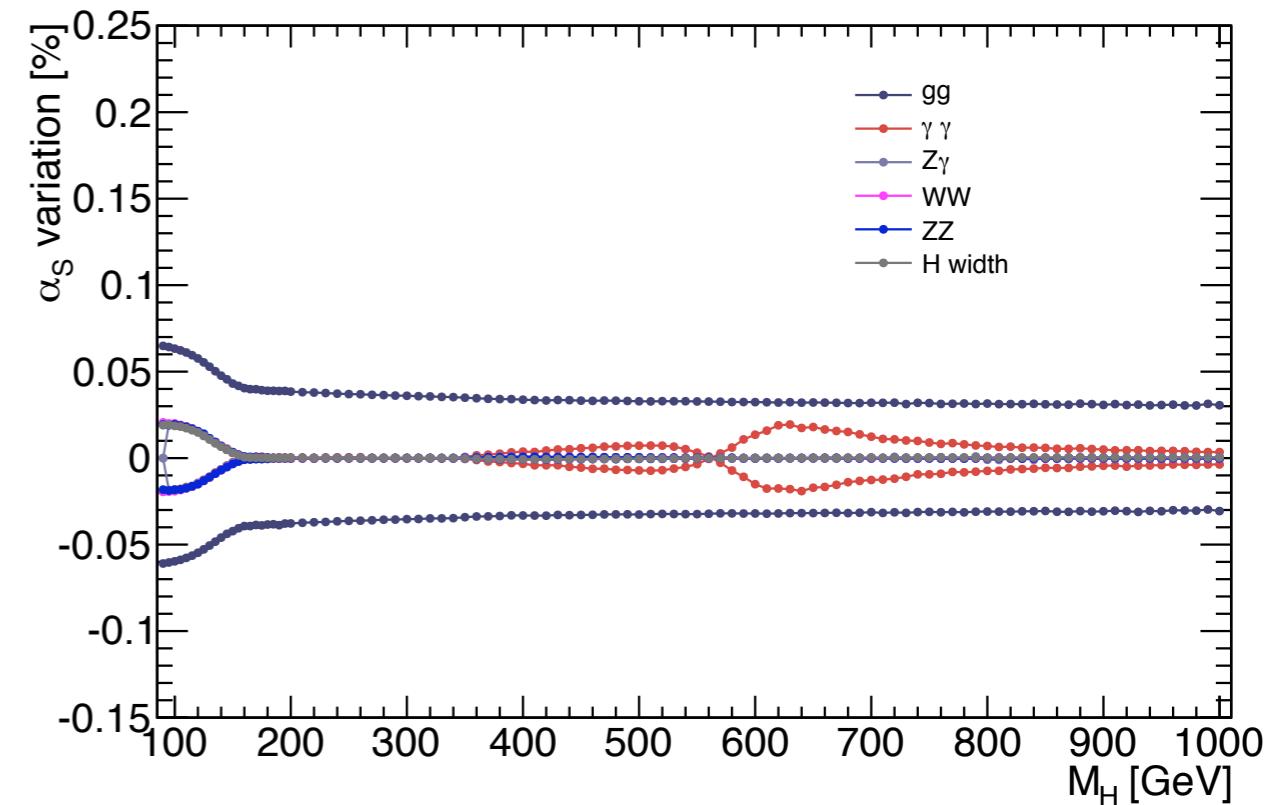
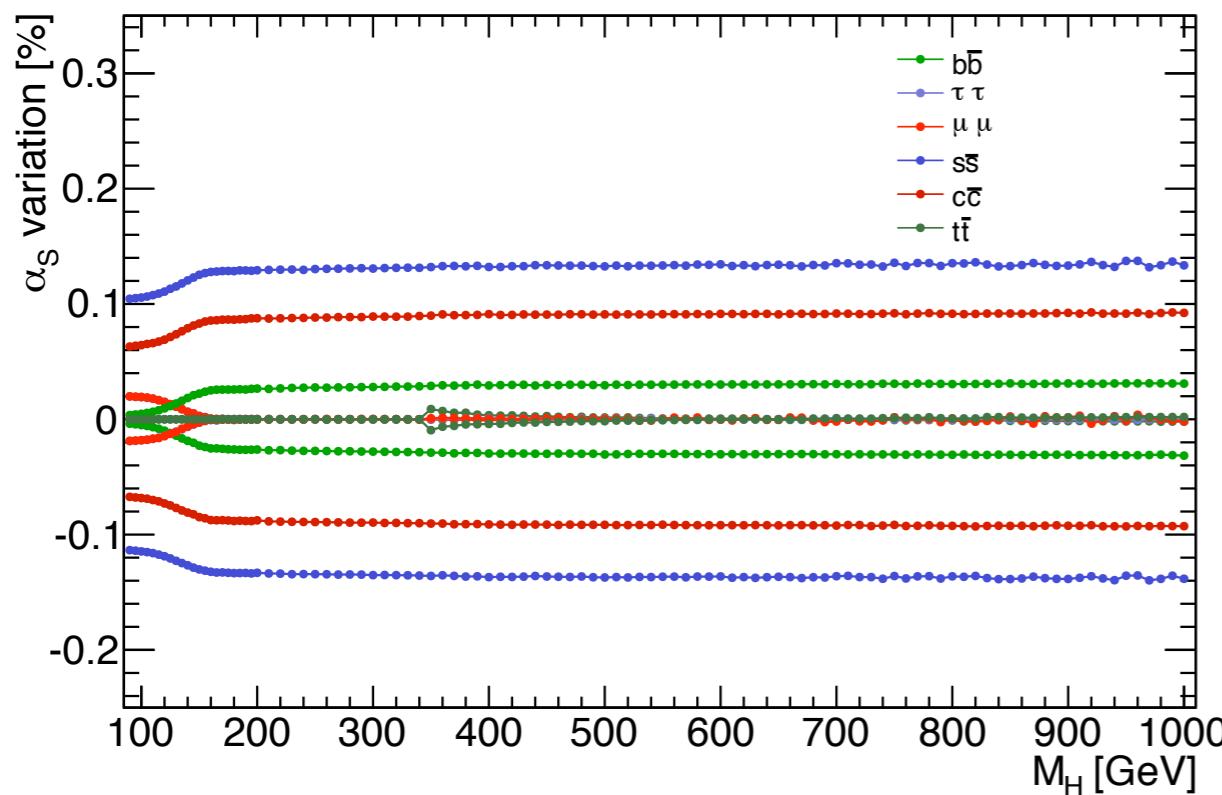
- Higgs BR parametric uncertainties have been estimated
- With the chosen parameter choice:
 - Parametric uncertainties affect significantly only $\text{BR}(\text{H} \rightarrow \text{cc})$, $\text{BR}(\text{H} \rightarrow \text{gg})$ and $\text{BR}(\text{H} \rightarrow \text{tt})$ (below 450 GeV)
 - Parametric uncertainties on the important Higgs BR ($\text{H} \rightarrow \text{WW}/\text{ZZ}/\gamma\gamma$) below 1% for $M_H > 120$ GeV
- Parametric uncertainties combined to the theoretical errors and *total BR uncertainty estimated* (theoretical uncertainties not included in arXiv:1012.0530v3)
 - Total uncertainties affect significantly only $\text{H} \rightarrow \text{cc}$, $\text{H} \rightarrow \text{gg}$ and $\text{H} \rightarrow \text{tt}$

Plans

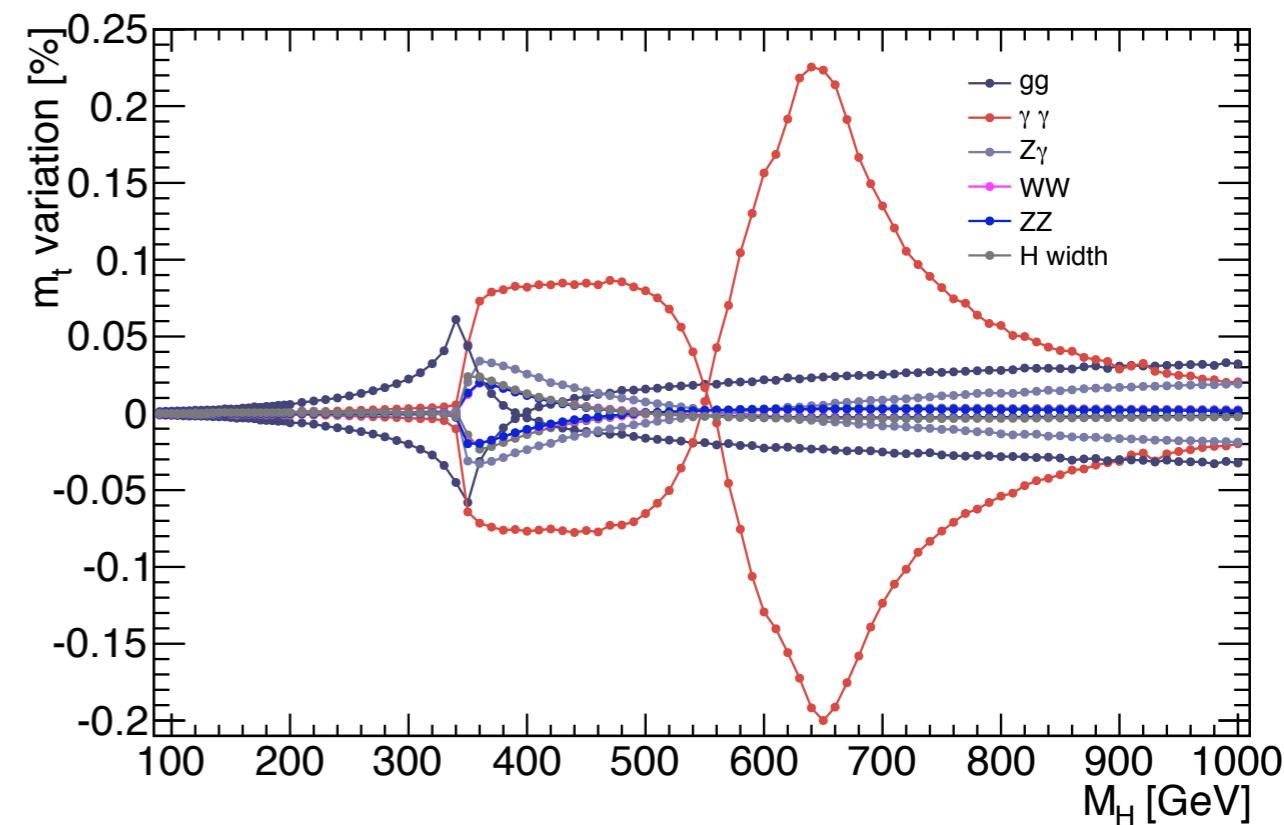
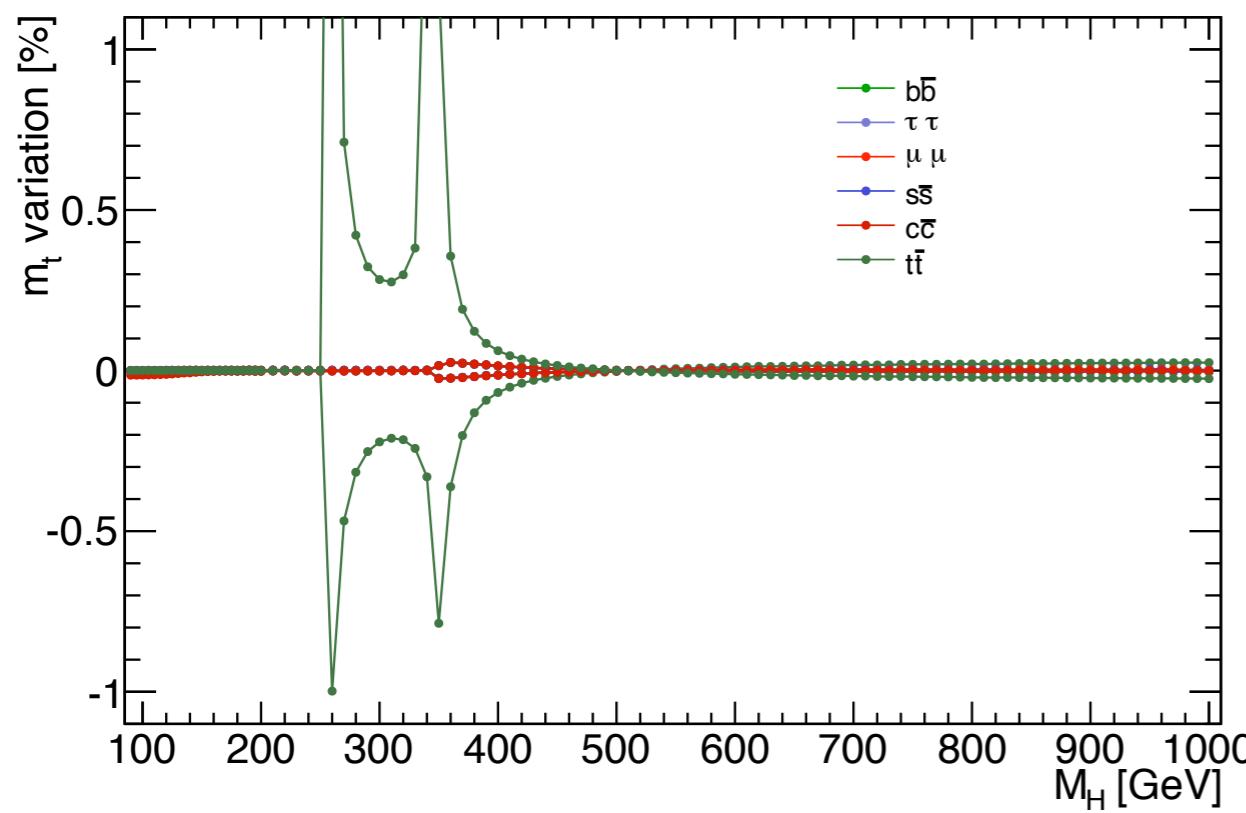
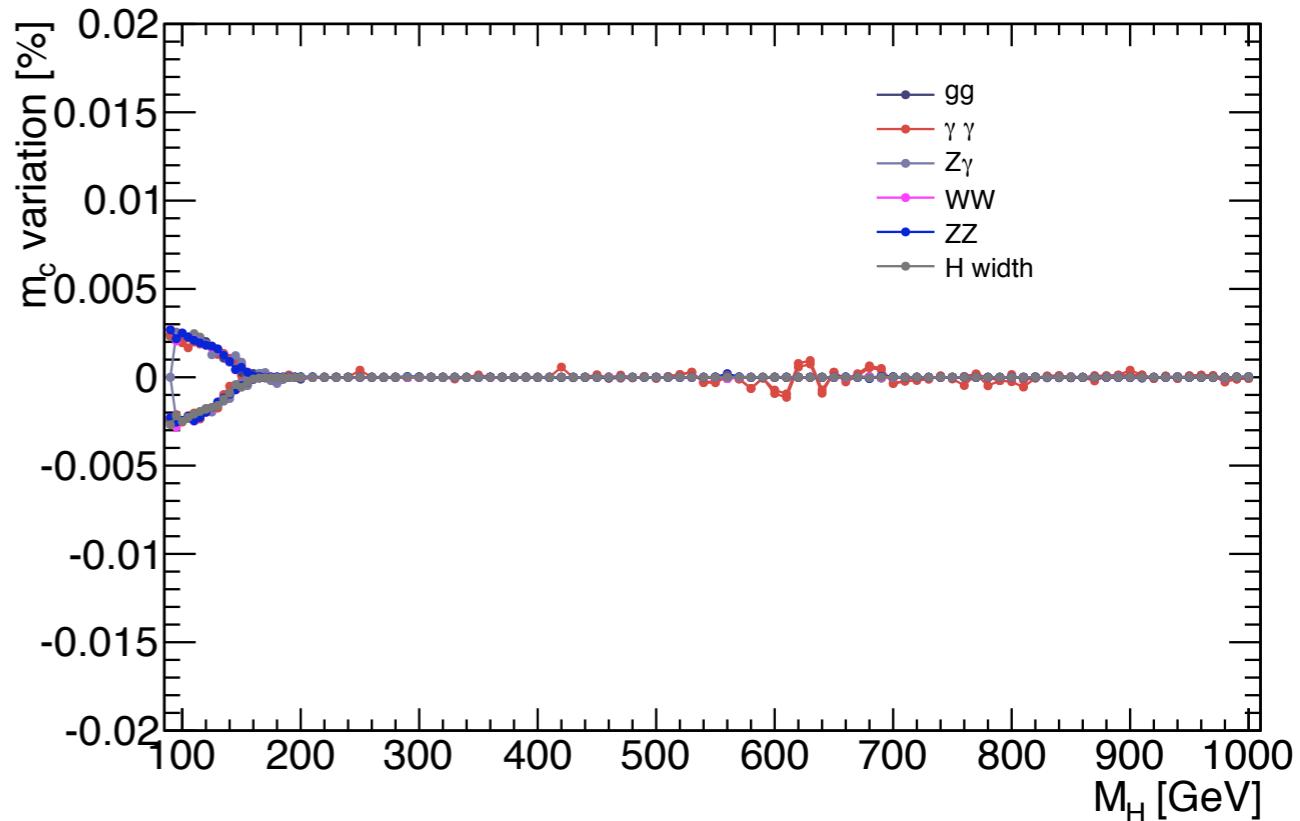
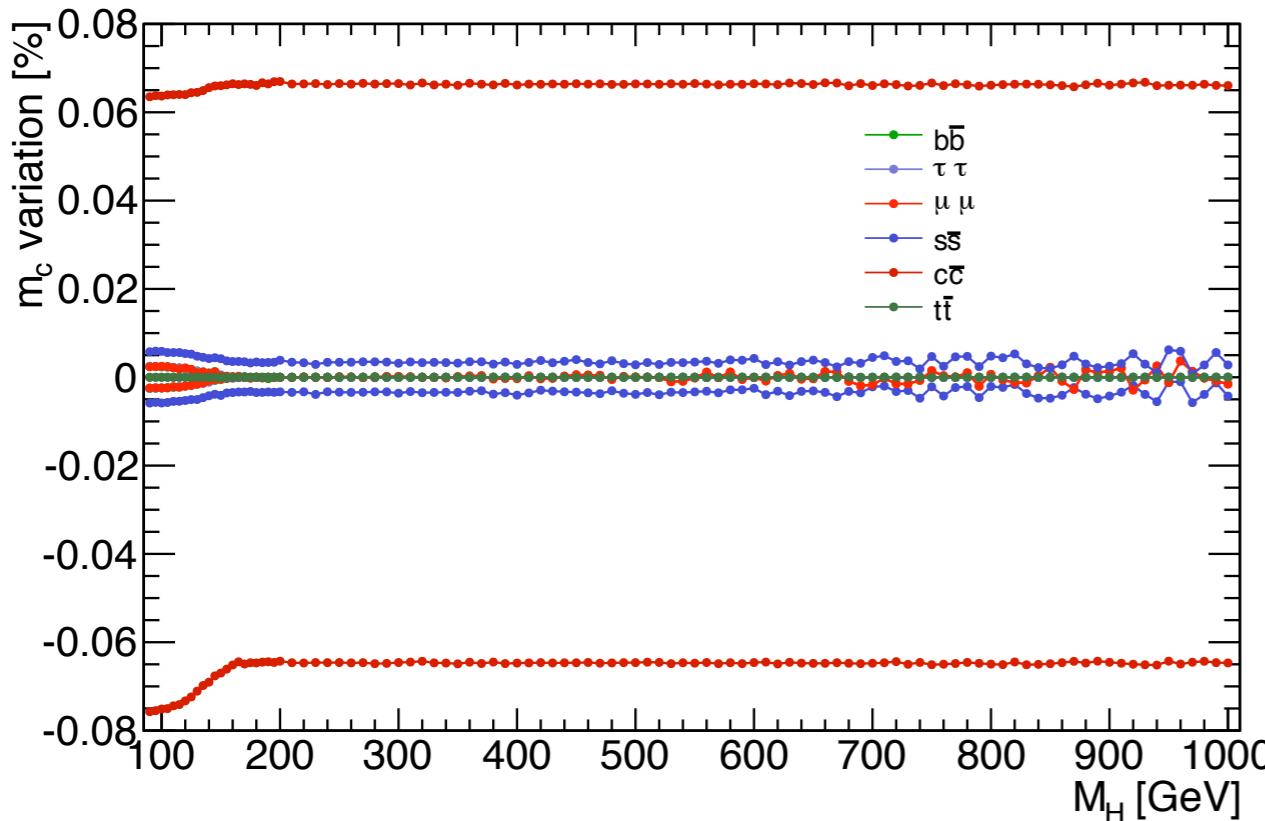
- Provide on the Sharepoint/TWiki tables and plots for (single and total) parametric and theoretical uncertainties, as well as for the overall combination
- Calculate BR with a finer mass granularity (request for summer conferences)

Backup Slides

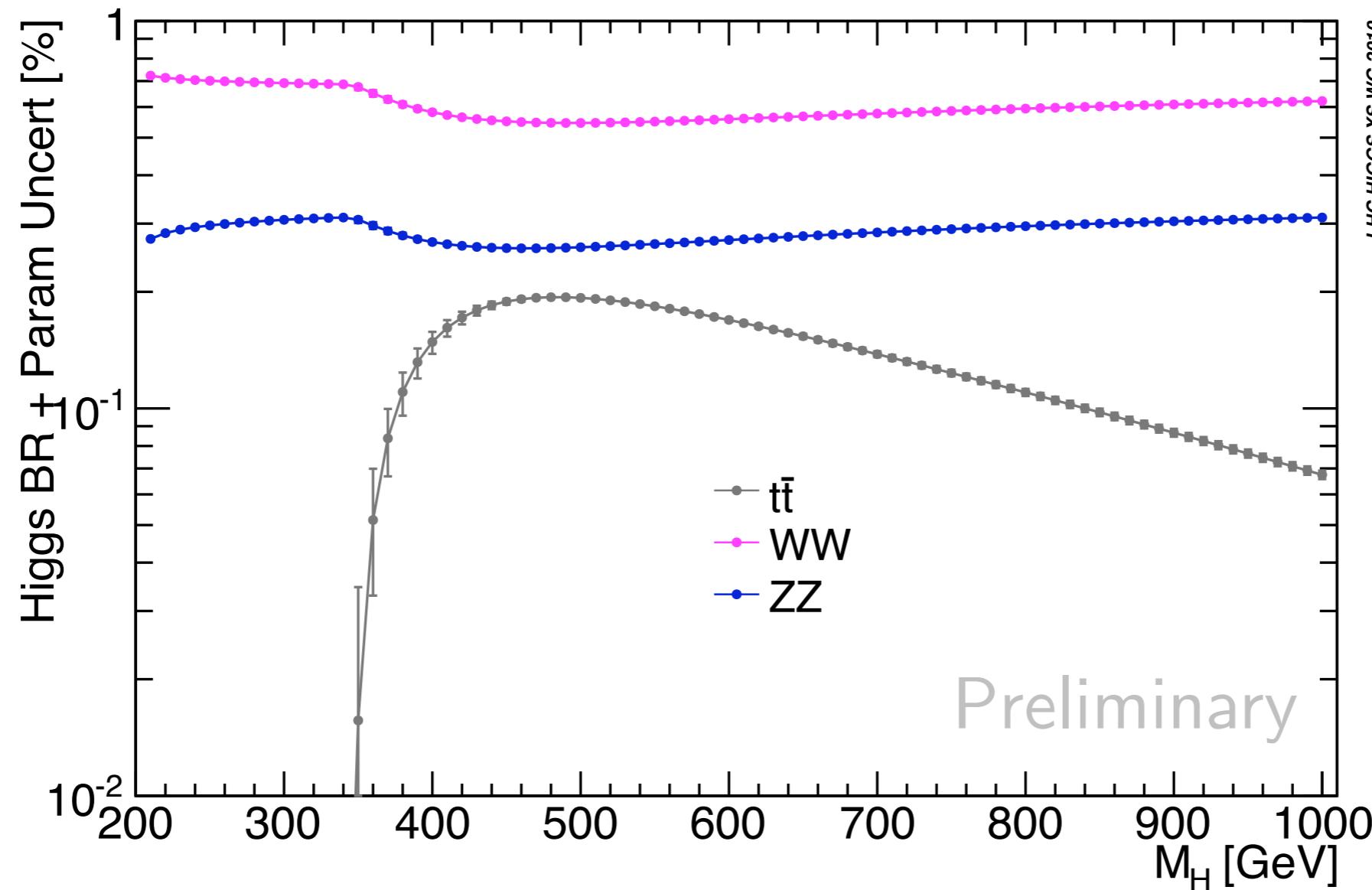
α_s and m_b Variations



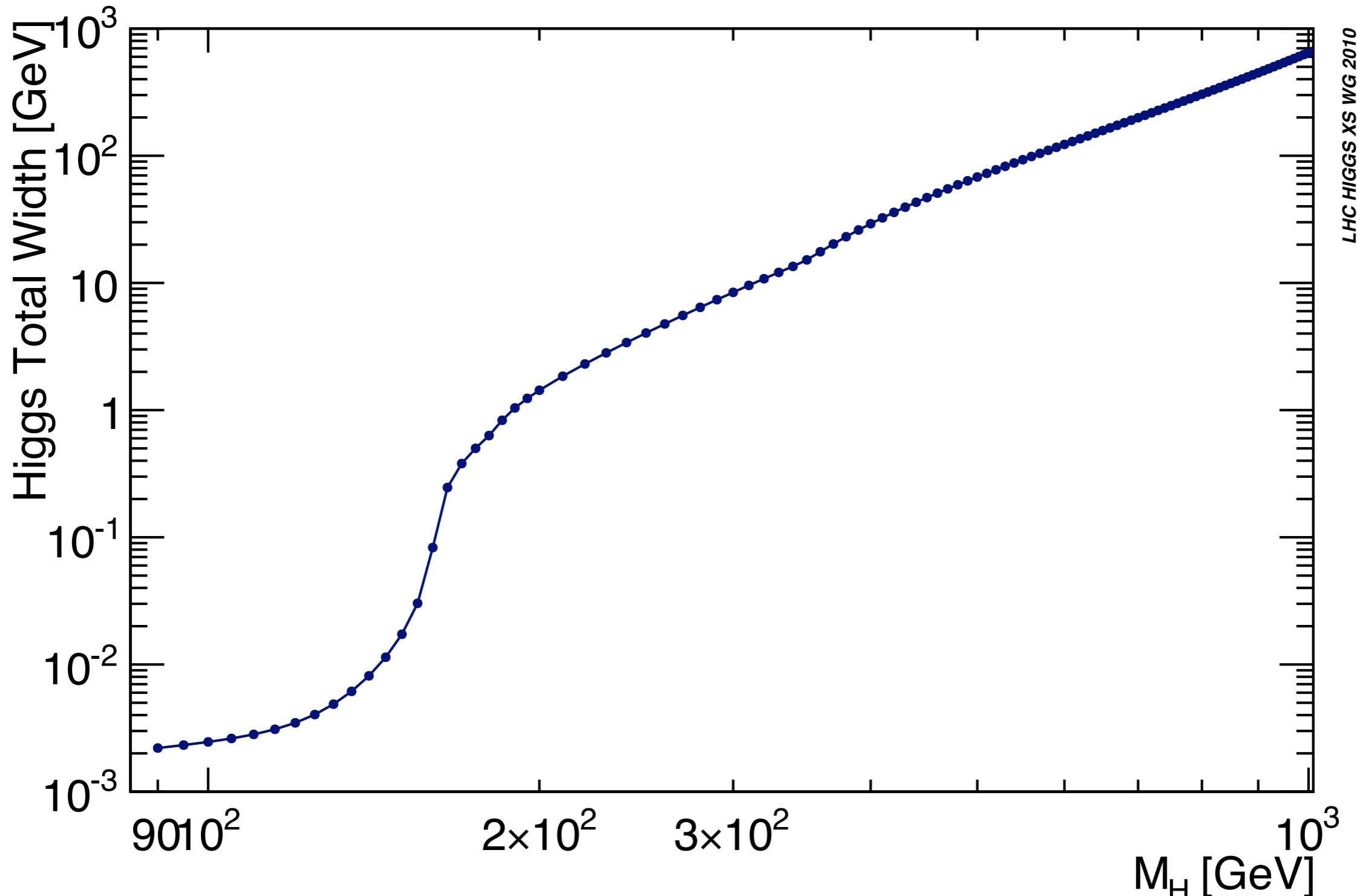
m_c and m_t Variations



Combined Parametric Errors: BR high masses



Combined Parametric Errors: Total Width



Parametric errors below 2% over all the mass range

PROPHECY4F calculates partial widths for specific 4f final states
 need to sum to get Γ_{4f}

$$\Gamma_{4f}^{\text{Prop.}} = \Gamma_{H \rightarrow W^*W^* \rightarrow 4f} + \Gamma_{H \rightarrow Z^*Z^* \rightarrow 4f} + \Gamma_{WW/ZZ-\text{int.}}$$

$$\Gamma_{H \rightarrow W^*W^* \rightarrow 4f} = 9 \cdot \Gamma_{H \rightarrow \nu_e e^+ \mu^- \bar{\nu}_\mu} + 12 \cdot \Gamma_{H \rightarrow \nu_e e^+ d \bar{u}} + 4 \cdot \Gamma_{H \rightarrow u \bar{d} s \bar{c}}$$

$$\begin{aligned} \Gamma_{H \rightarrow Z^*Z^* \rightarrow 4f} = & 3 \cdot \Gamma_{H \rightarrow \nu_e \bar{\nu}_e \nu_\mu \bar{\nu}_\mu} + 3 \cdot \Gamma_{H \rightarrow e^- e^+ \mu^- \mu^+} + 9 \cdot \Gamma_{H \rightarrow \nu_e \bar{\nu}_e \mu^- \mu^+} \\ & + 3 \cdot \Gamma_{H \rightarrow \nu_e \bar{\nu}_e \nu_e \bar{\nu}_e} + 3 \cdot \Gamma_{H \rightarrow e^- e^+ e^- e^+} \\ & + 6 \cdot \Gamma_{H \rightarrow \nu_e \bar{\nu}_e u \bar{u}} + 9 \cdot \Gamma_{H \rightarrow \nu_e \bar{\nu}_e d \bar{d}} + 6 \cdot \Gamma_{H \rightarrow u \bar{u} e^- e^+} + 9 \cdot \Gamma_{H \rightarrow d \bar{d} e^- e^+} \\ & + 1 \cdot \Gamma_{H \rightarrow u \bar{u} c \bar{c}} + 3 \cdot \Gamma_{H \rightarrow d \bar{d} s \bar{s}} + 6 \cdot \Gamma_{H \rightarrow u \bar{u} s \bar{s}} + 2 \cdot \Gamma_{H \rightarrow u \bar{u} u \bar{u}} \\ & + 3 \cdot \Gamma_{H \rightarrow d \bar{d} d \bar{d}} \end{aligned}$$

$$\begin{aligned} \Gamma_{WW/ZZ-\text{int.}} = & 3 \cdot \Gamma_{H \rightarrow \nu_e e^+ e^- \bar{\nu}_e} - 3 \cdot \Gamma_{H \rightarrow \nu_e \bar{\nu}_e \mu^- \mu^+} - 3 \cdot \Gamma_{H \rightarrow \nu_e e^+ \mu^- \bar{\nu}_\mu} \\ & + 2 \cdot \Gamma_{H \rightarrow u \bar{d} d \bar{u}} - 2 \cdot \Gamma_{H \rightarrow u \bar{u} s \bar{s}} - 2 \cdot \Gamma_{H \rightarrow u \bar{d} s \bar{c}} \end{aligned}$$

$\Gamma_{H \rightarrow \nu_e e^+ e^- \bar{\nu}_e}$ and $\Gamma_{H \rightarrow u \bar{d} d \bar{u}}$ contribute to $\Gamma_{H \rightarrow W^*W^* \rightarrow 4f}$, $\Gamma_{H \rightarrow Z^*Z^* \rightarrow 4f}$ and $\Gamma_{WW/ZZ-\text{int.}}$