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

Higgs BR Tools and Strategy

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 $\to\gamma\gamma$ and H $\to$ 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*

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

- *Prophecy4f width*

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

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 $\rightarrow$ 5 GeV step - [200, 1000] GeV $\rightarrow$ 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	$\pm$ 0.002 (90% CL)
m_b [GeV]	4.49 (*)	$\pm$ 0.03 (2σ) (**)
m_c [GeV]	1.41 (*)	$\pm$ 0.03 (2σ) (**)
m_t [GeV]	172.5	$\pm$ 2.5

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

(**) errors from Ref. arXiv: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 $H \to \gamma\gamma$ and $H \to gg$ 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

BR Uncertainty Estimation Baseline

1. Parametric uncertainties:

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

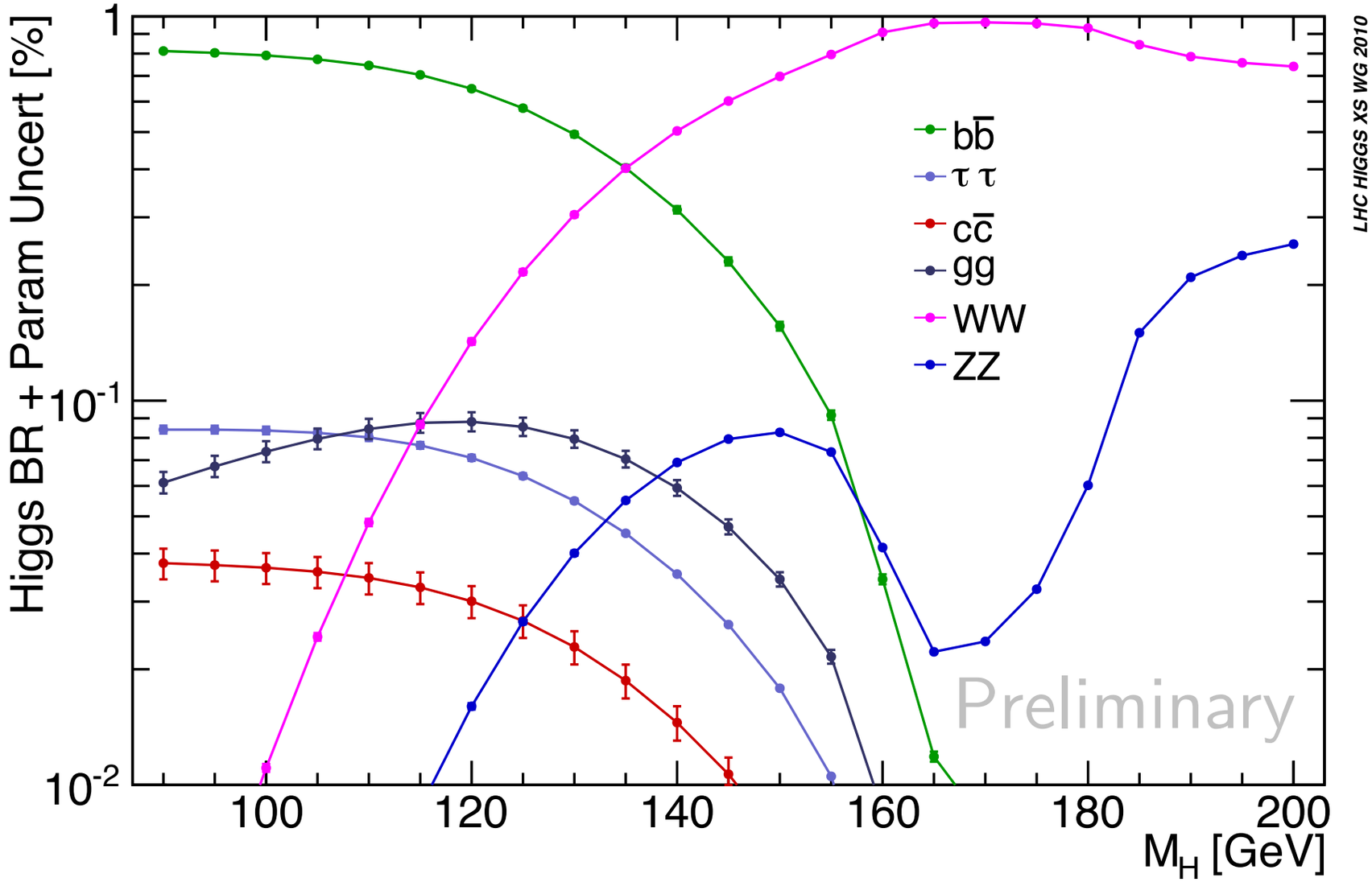
2. Theoretical uncertainties:

- 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

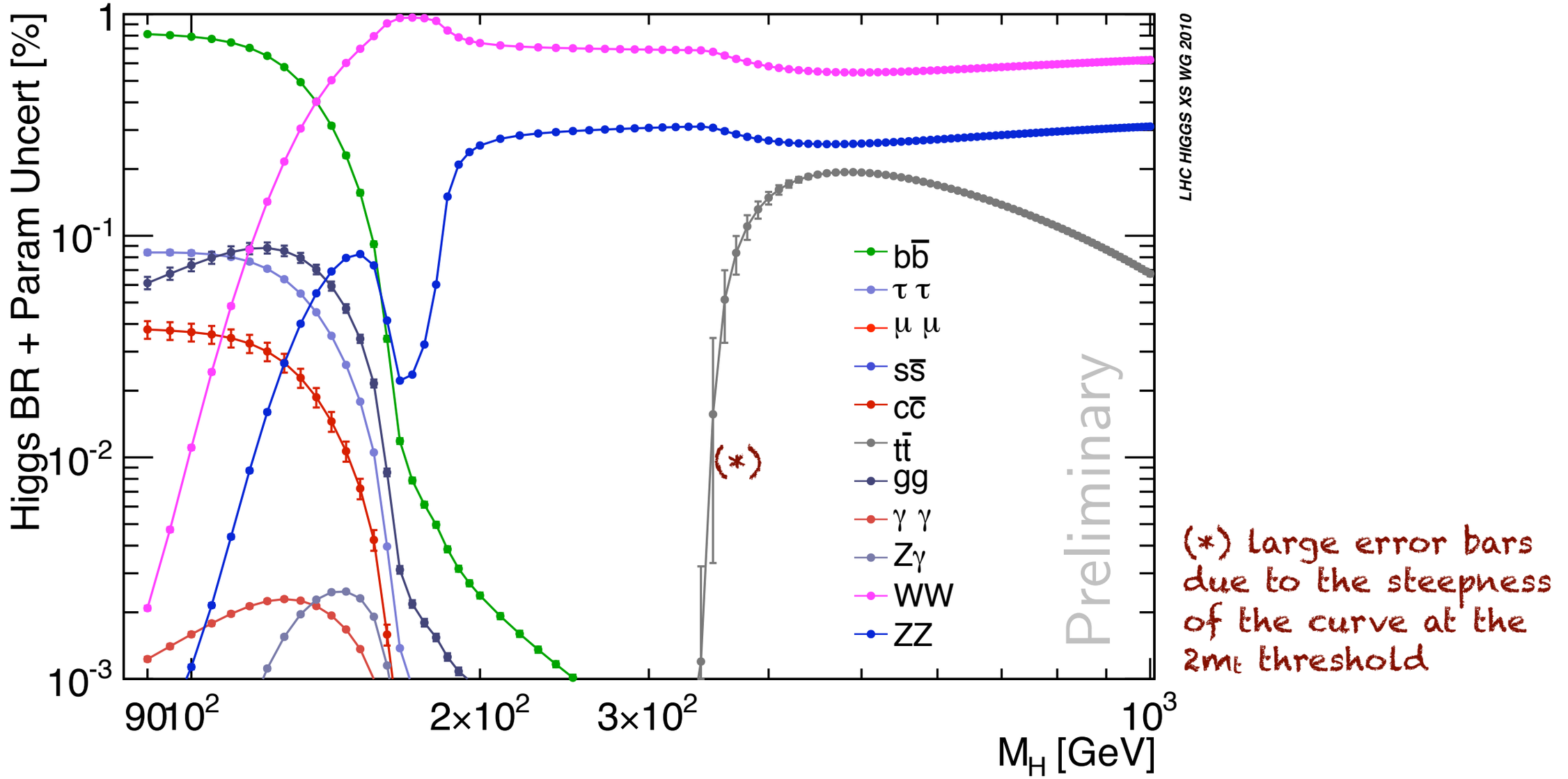
Combined Parametric Errors: BR low masses



Combined Parametric Errors on BRs			
$H \to b\bar{b}$	O(3-4%) for $M_H > 165$ GeV	$H \to \tau\tau$	O(1%) for $M_H > 140$ GeV
$H \to c\bar{c}$	O(10%)	$H \to gg$	O(5-6%)
$H \to WW$	O(1%) for $M_H > 120$ GeV	$H \to ZZ$	O(1%) for $M_H > 120$ GeV

Parametric errors relevant only for H → cc and H → gg BRs

Combined Parametric Errors: all masses



(*) large error bars due to the steepness of the curve at the $2m_t$ threshold

Combined Parametric Errors on BRs			
$H \to WW$	O(1%) for $M_H > 120$ GeV	$H \to ZZ$	O(1%) for $M_H > 120$ GeV
$H \to t\bar{t}$	O(30-40%) for $260 < M_H < 380$ GeV, O(200%) for $M_H \approx 2m_t$ (*)		

Parametric errors relevant only for H → 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 (α_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
$H \to b\bar{b}$	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	$^{+0.2}_{-0.1}$	$^{+8.7}_{-3.0}$	$^{+1.9}_{-1.9}$	$^{+8.9}_{-3.6}$
$H \to WW$ (***)	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→ττ and H→ZZ,γγ SAME AS H→WW

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

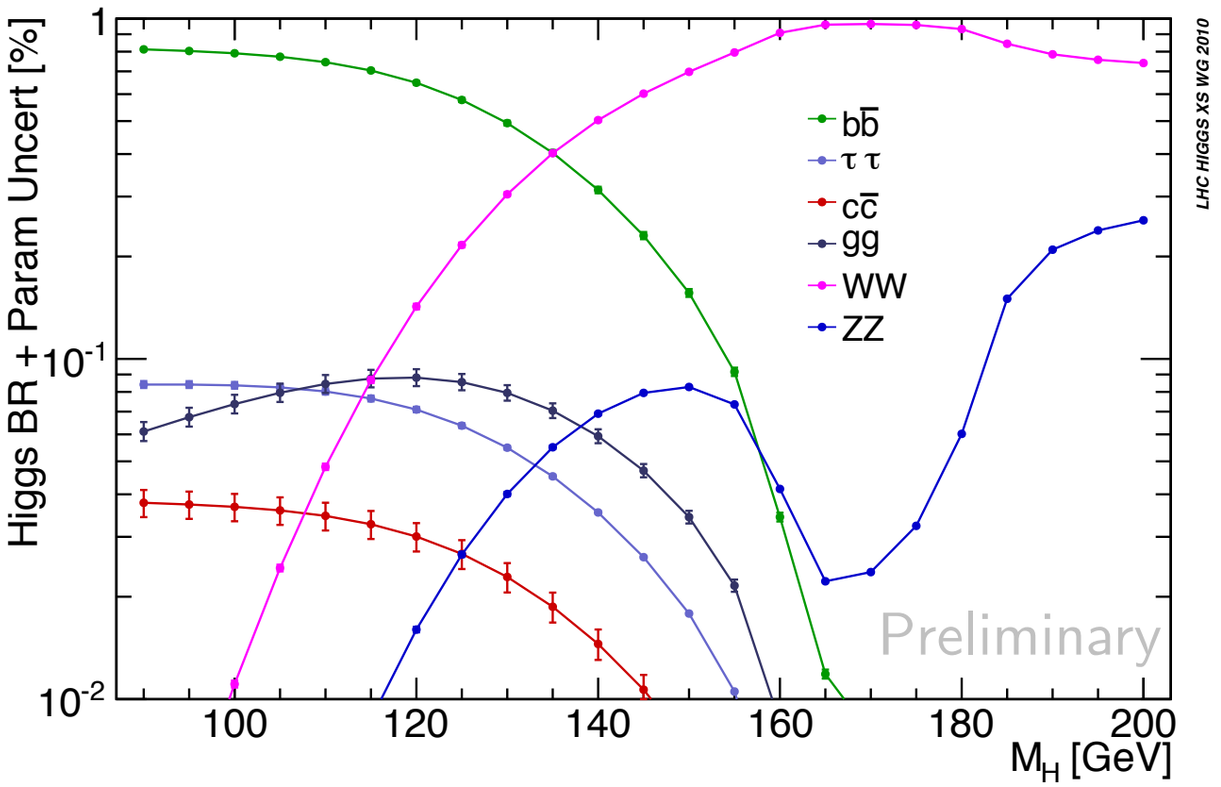
Comparison with arXiv:1012.0530v3 (cont'd)

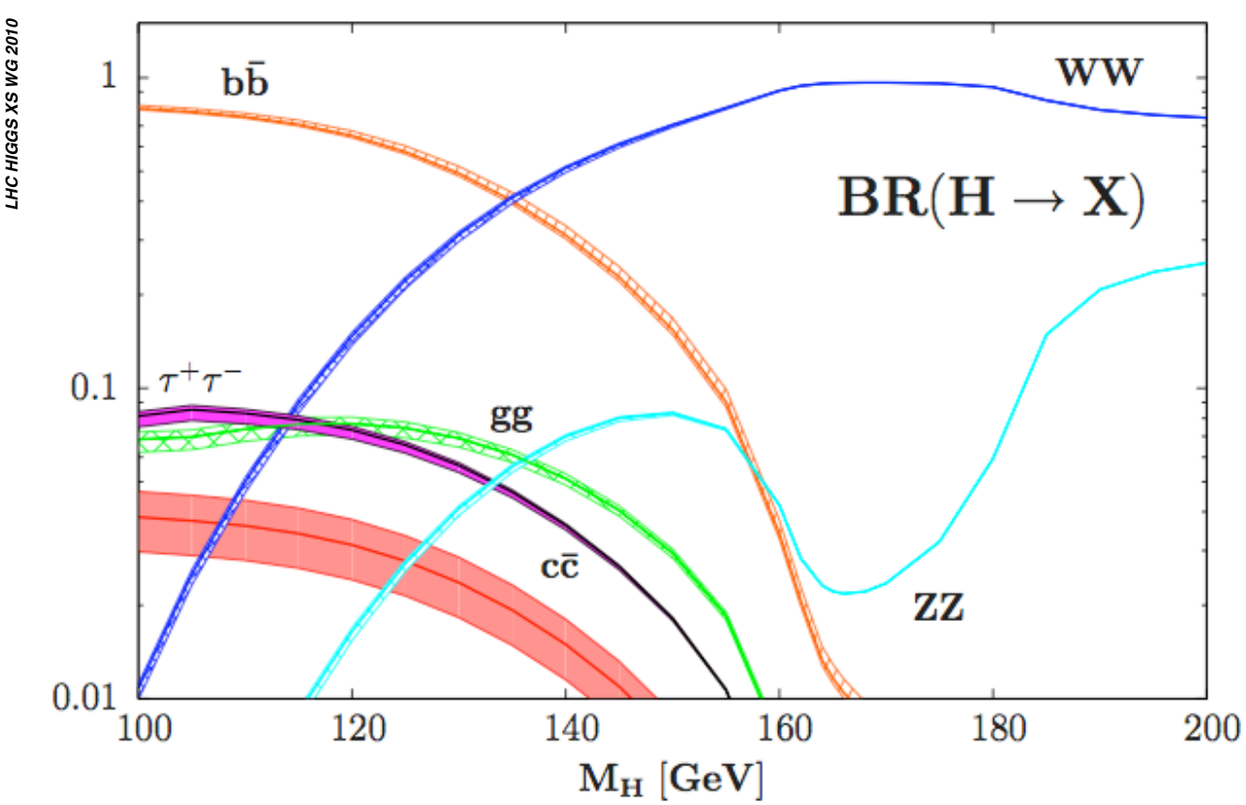
- Other channel comparisons:

ΔBR(H→cc) discrepancy (mostly) due to m_c

BR(H→gg): similar uncertainties but O(12-13%) discrepancy for central values, to be understood

		LHC BR Group		arXiv:1012.0530v3	
Channel	M_H [GeV]	BR [%]	ΔBR [%]	BR [%]	ΔBR [%]
$H \to c\bar{c}$	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	$^{+20.6}_{-23.2}$
$H \to gg$	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

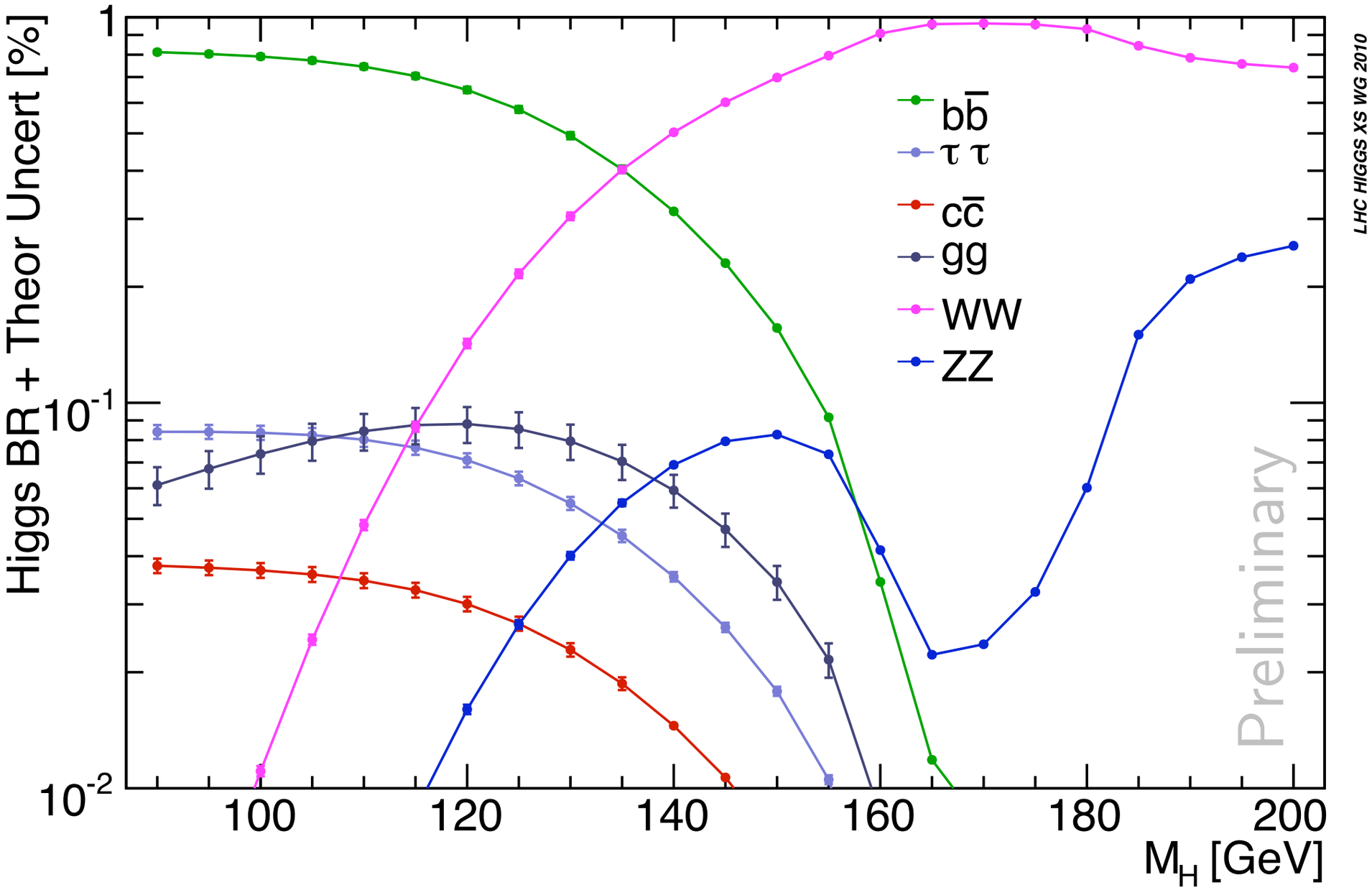
https://twiki.cern.ch/twiki/bin/view/LHCPhysics/BRs

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

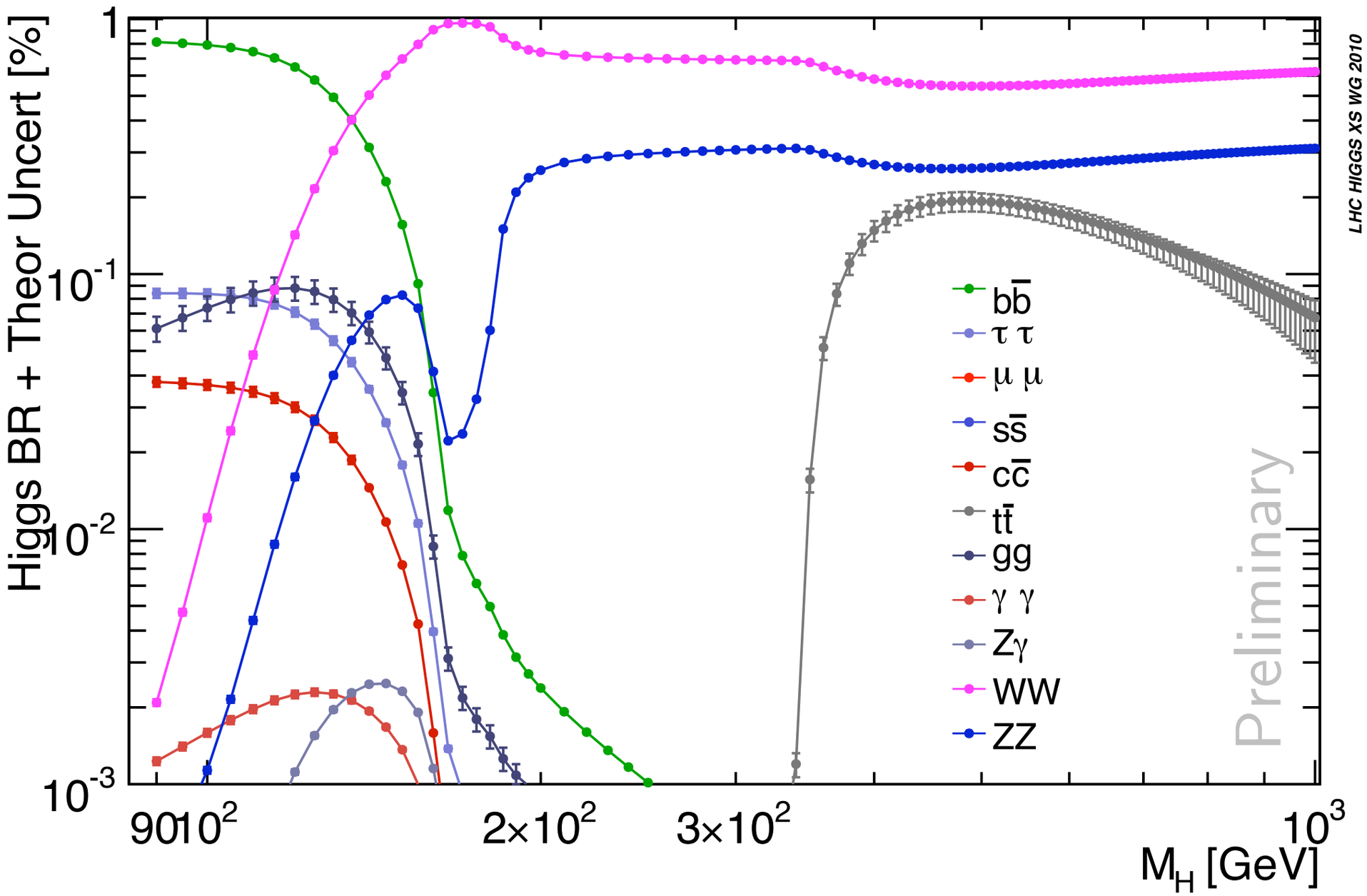
Theoretical Uncertainties: BR low masses



Theoretical errors relevant only for BR(H → gg) O(10%)

(for BR(H → bb/cc) and BR(H → ττ) O(1%))

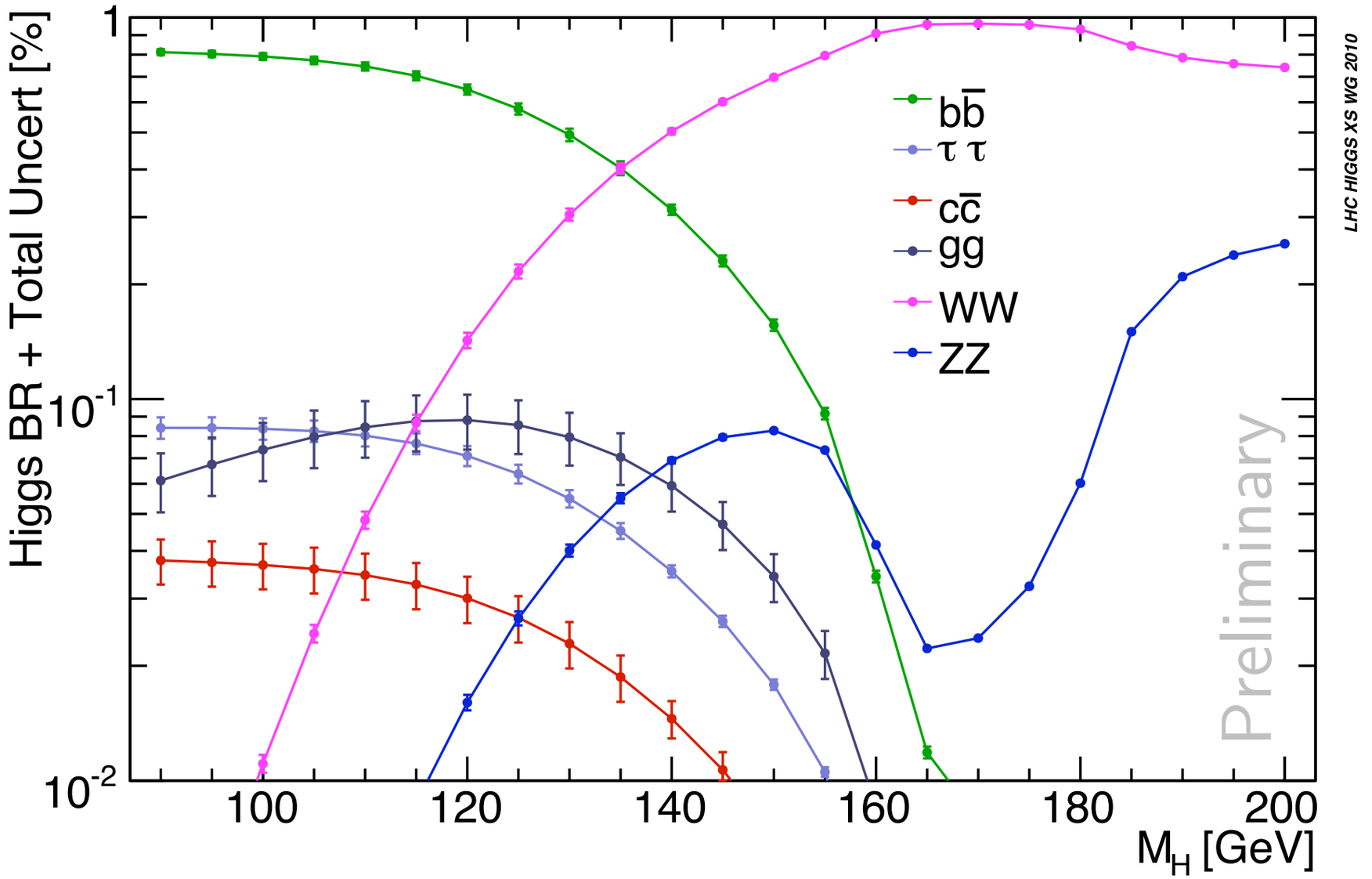
Theoretical Uncertainties: BR all masses



Theoretical errors relevant only for H → tt O(5-10%)

(for H → WW/ZZ O(2%) for $M_H > 400$ GeV)

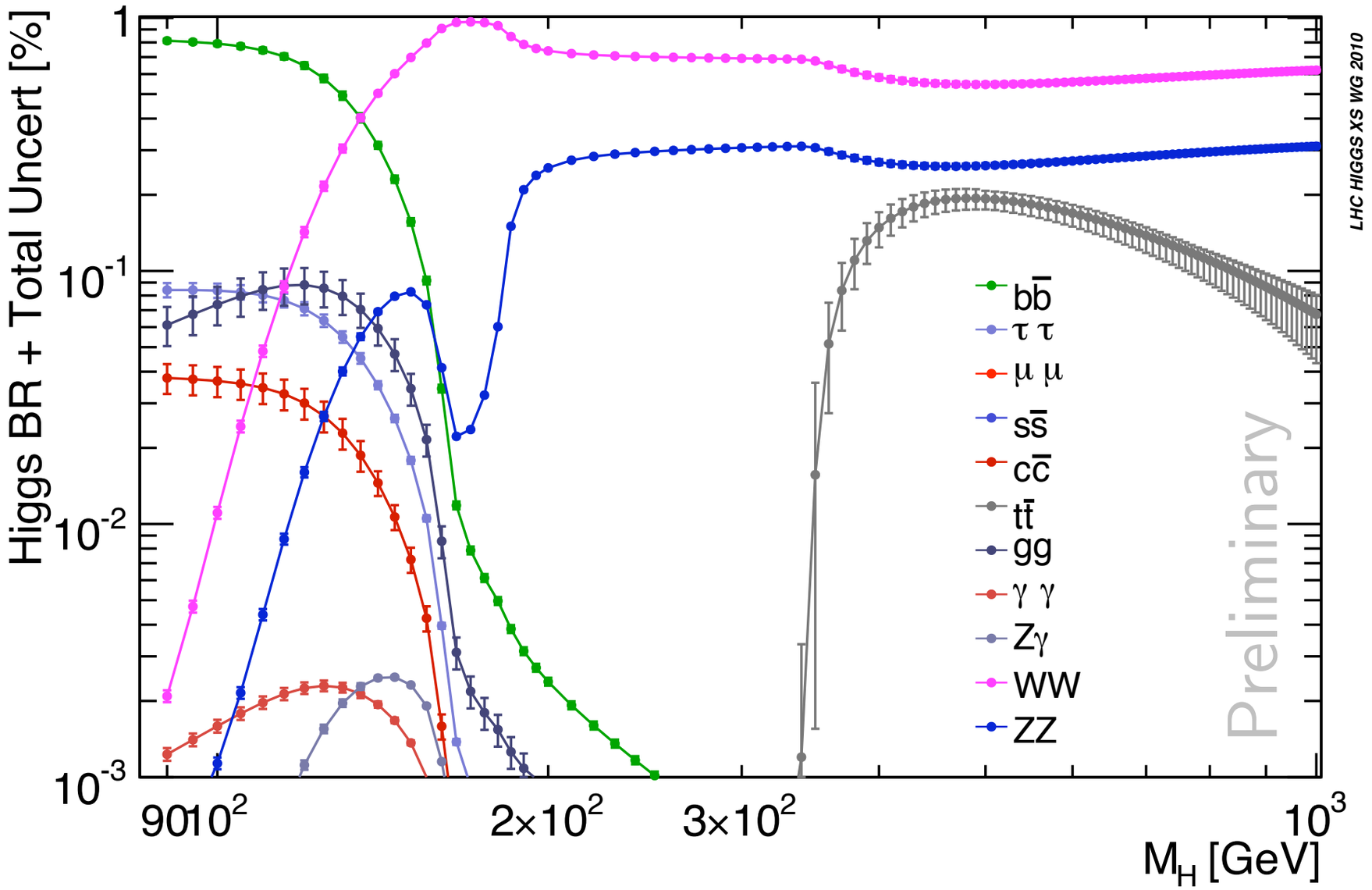
Total Higgs BR Uncertainties: low masses



Total Uncertainties on BRs for $M_H < 200$ GeV			
$H \to b\bar{b}$	O(3-4%)	$H \to \tau\tau$	O(3-6%)
$H \to c\bar{c}$	O(10-13%) (*)	$H \to gg$	O(15-17%) (**)
$H \to WW$	below 1% for $M_H > 150$ GeV	$H \to ZZ$	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			
$H \to WW$	O(2%) for $M_H > 360$ GeV	$H \to ZZ$	O(2%) for $M_H > 350$ GeV
$H \to t\bar{t}$	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

Conclusions and Plans

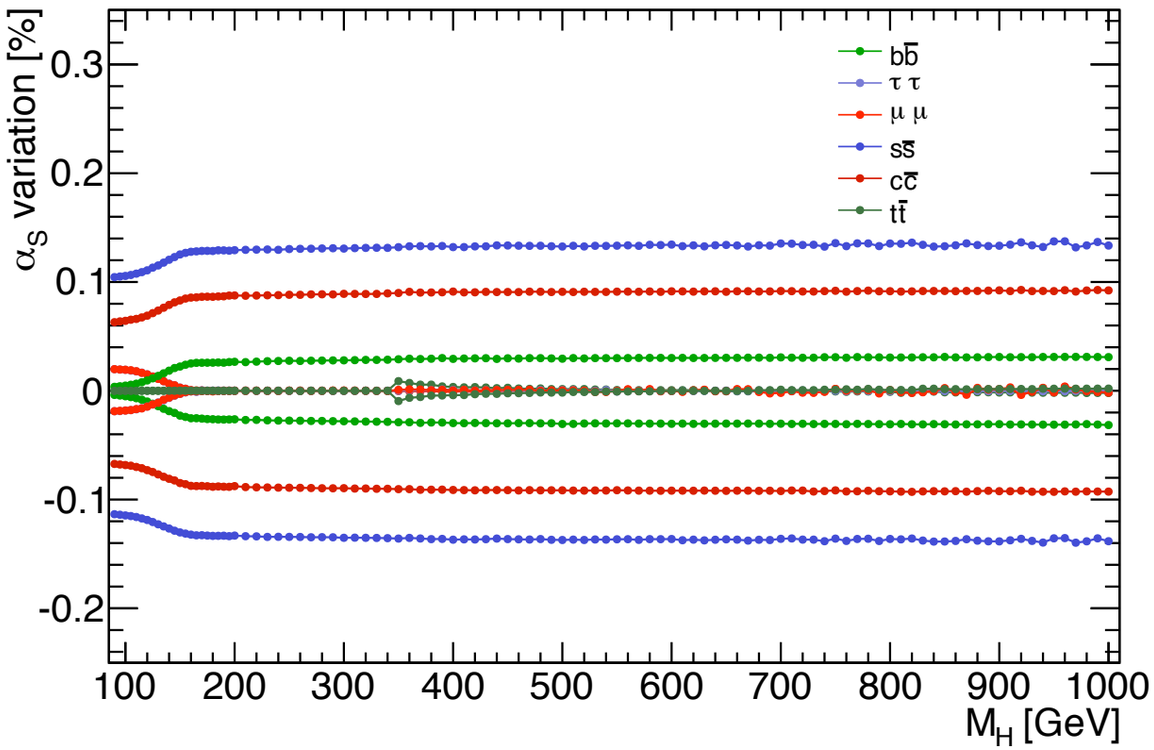
- Higgs BR parametric uncertainties have been estimated
- With the chosen parameter choice:
  - Parametric uncertainties affect significantly only BR(H $\rightarrow$ cc), BR(H $\rightarrow$ gg) and BR(H $\rightarrow$ tt) (below 450 GeV)
  - Parametric uncertainties on the important Higgs BR (H $\rightarrow$WW/ZZ/$\gamma\gamma$) 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 H $\rightarrow$ cc, H $\rightarrow$ gg and H $\rightarrow$ tt

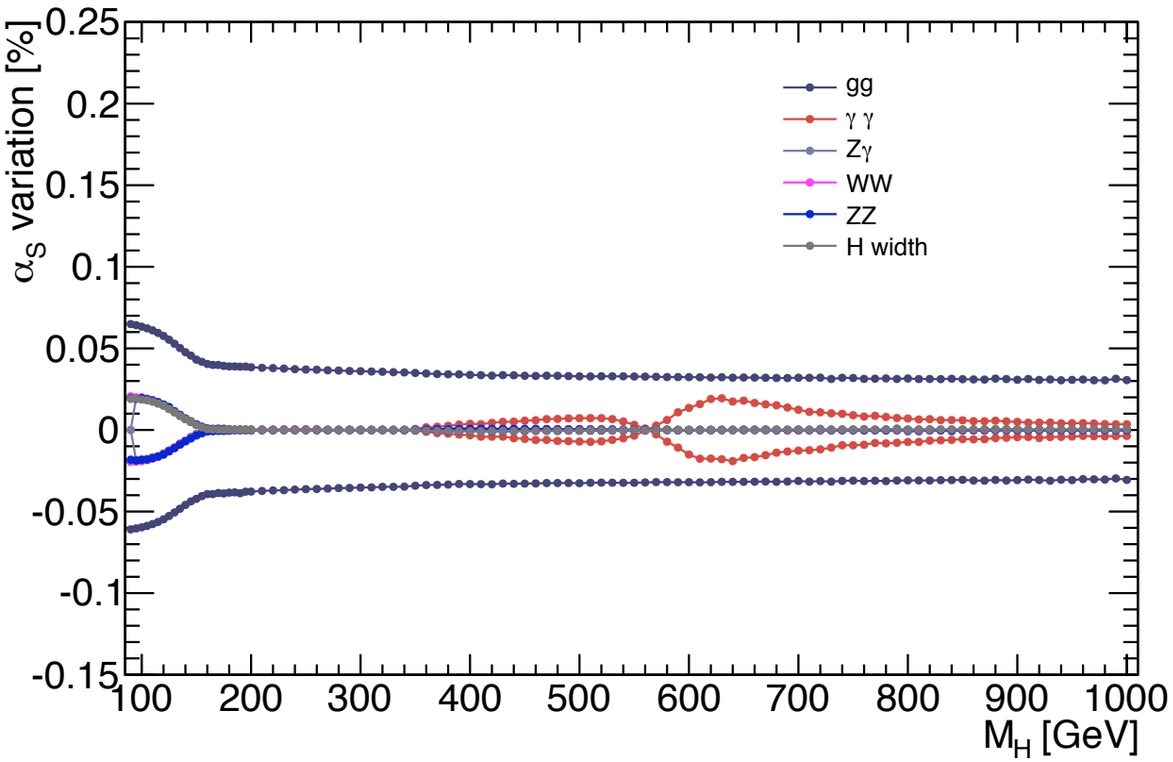
Plans

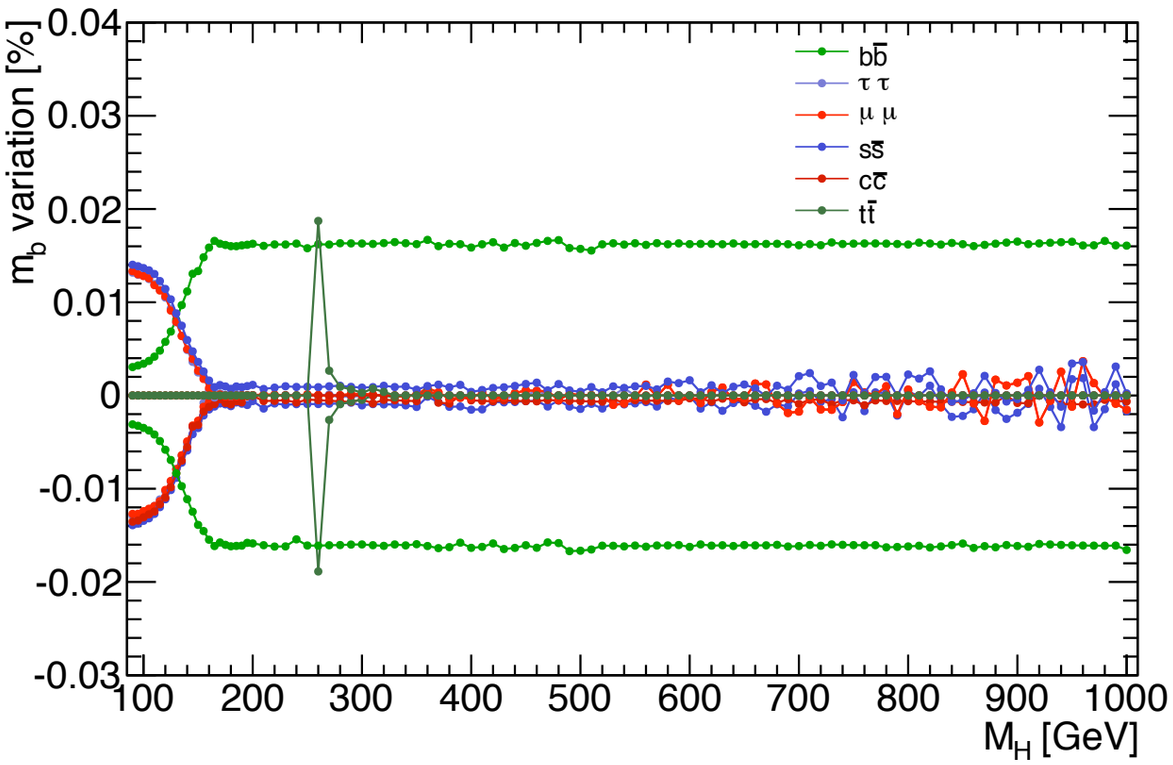
- Provide on the Sharepoint/TWiki tables and plots for (single and total) parametric and theoretical uncertainties, as well as for the overall combination
- Calculate BR with a finer mass granularity (request for summer conferences)

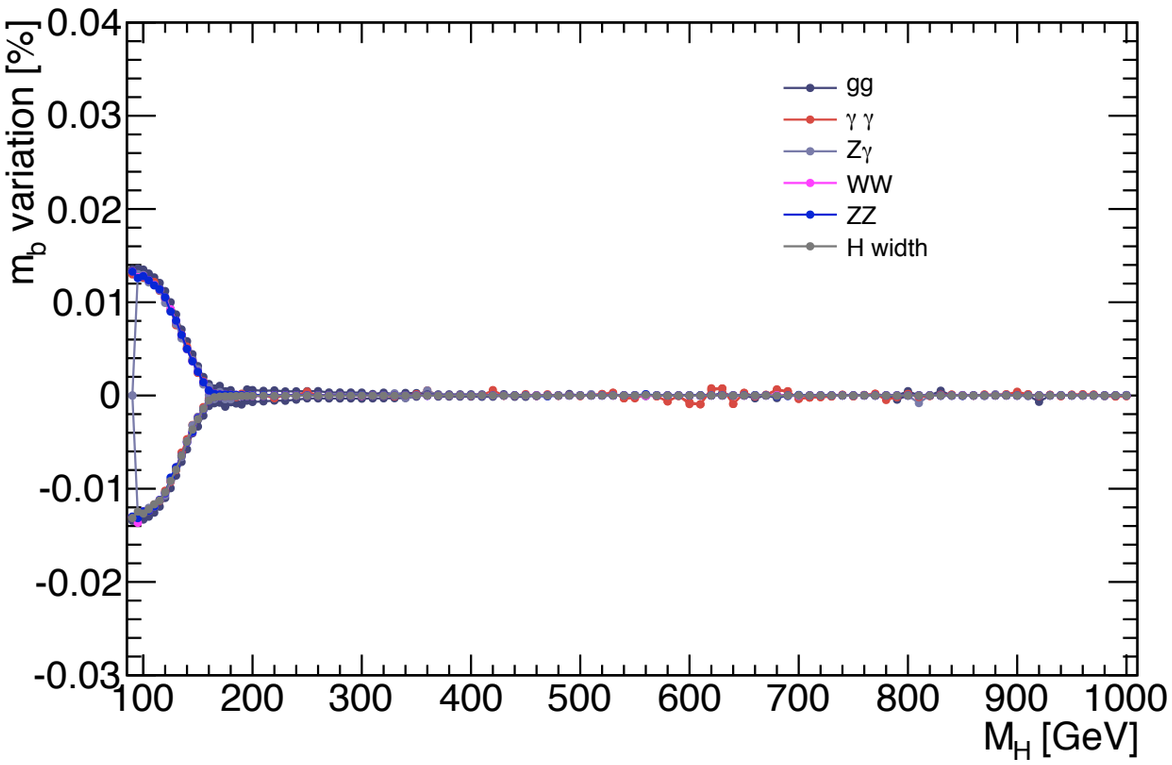
Backup Slides

α_S and m_b Variations

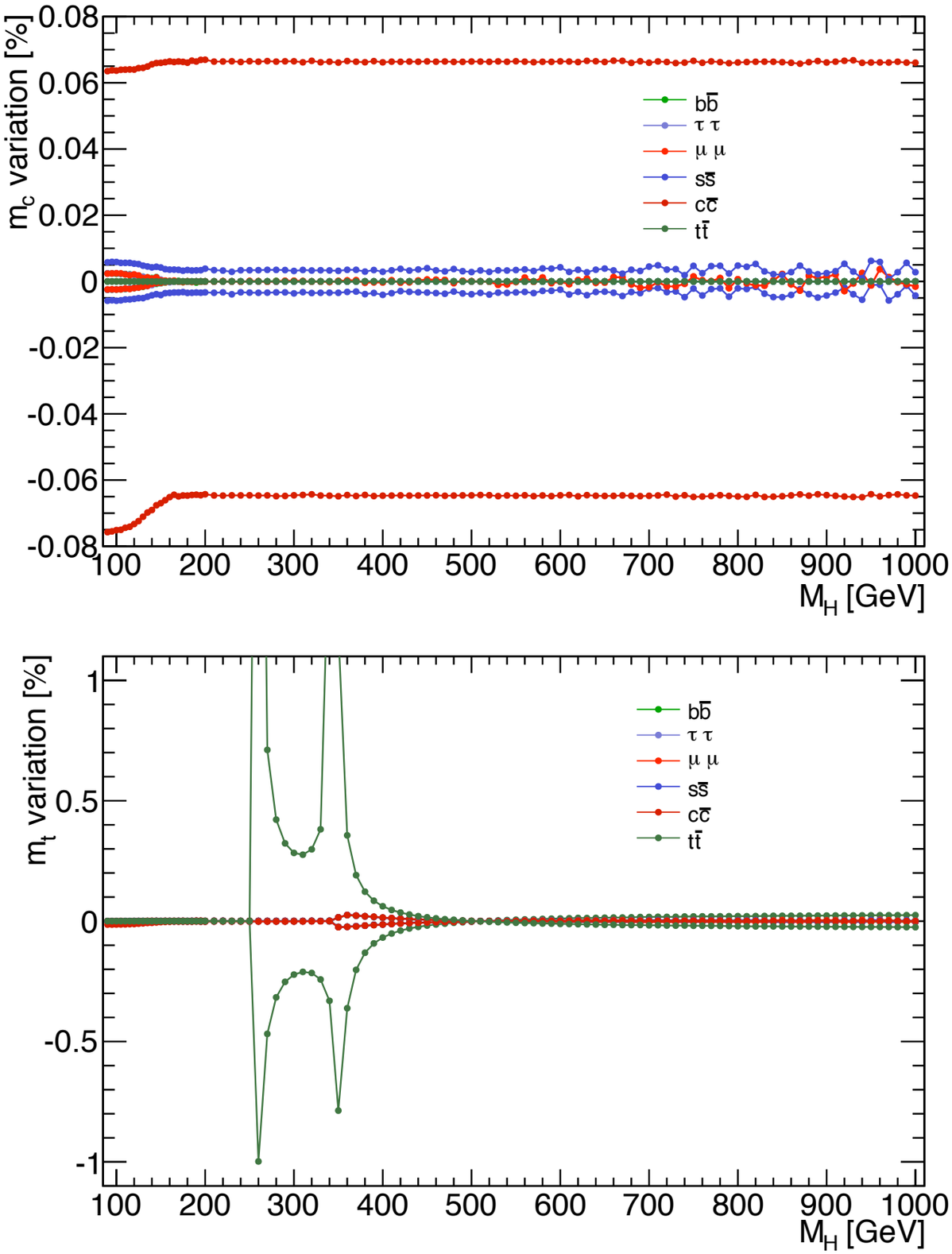


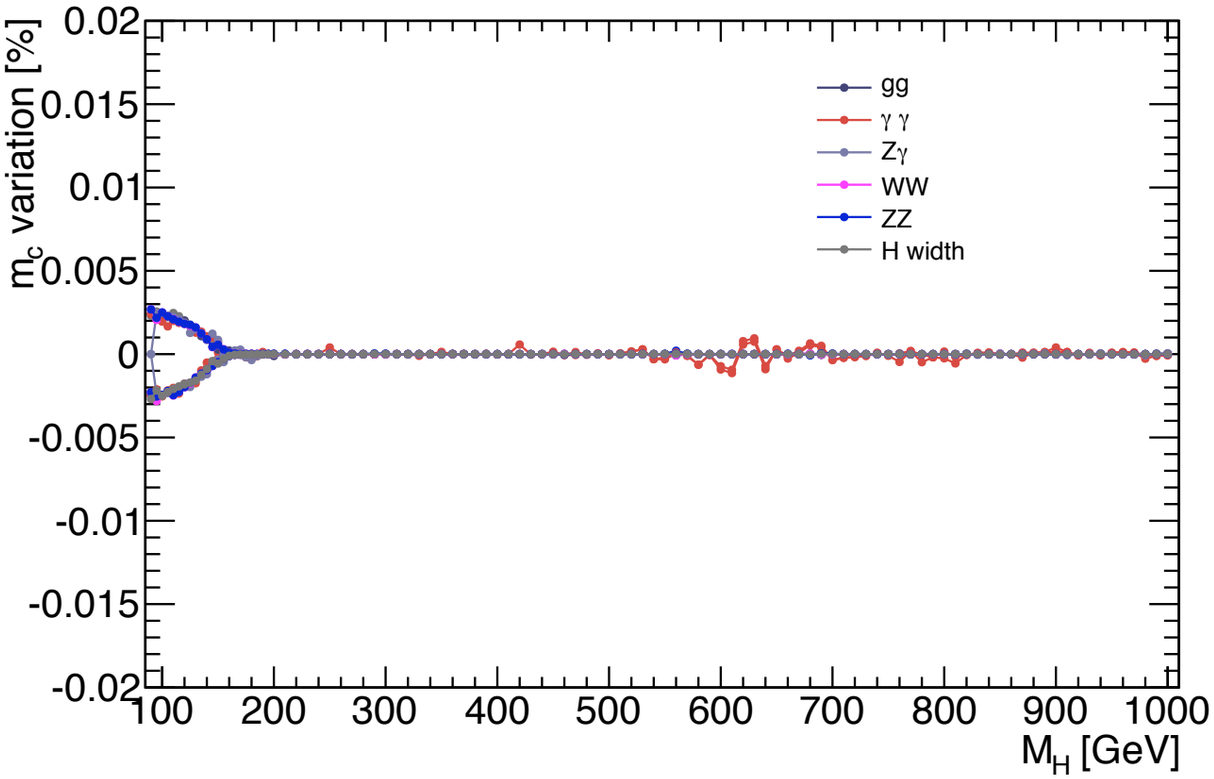


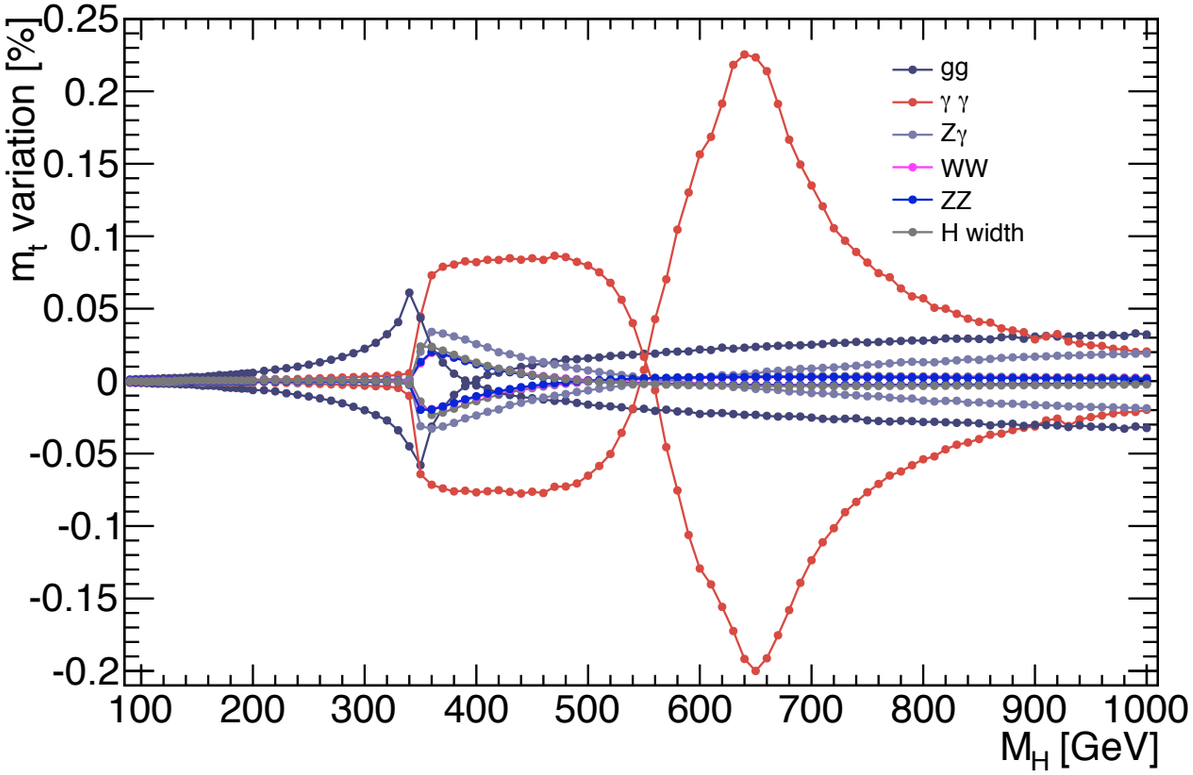




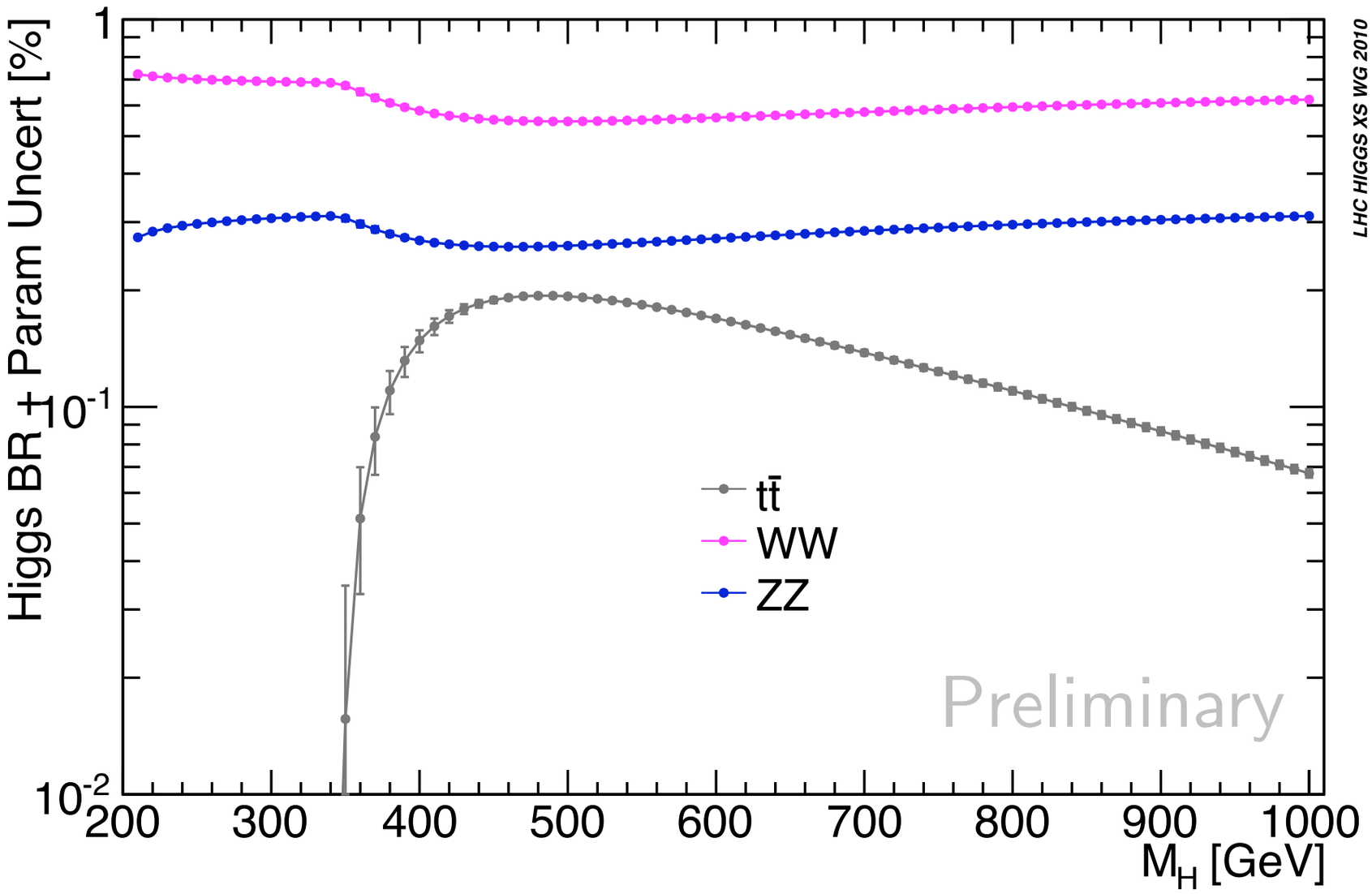
m_c and m_t Variations



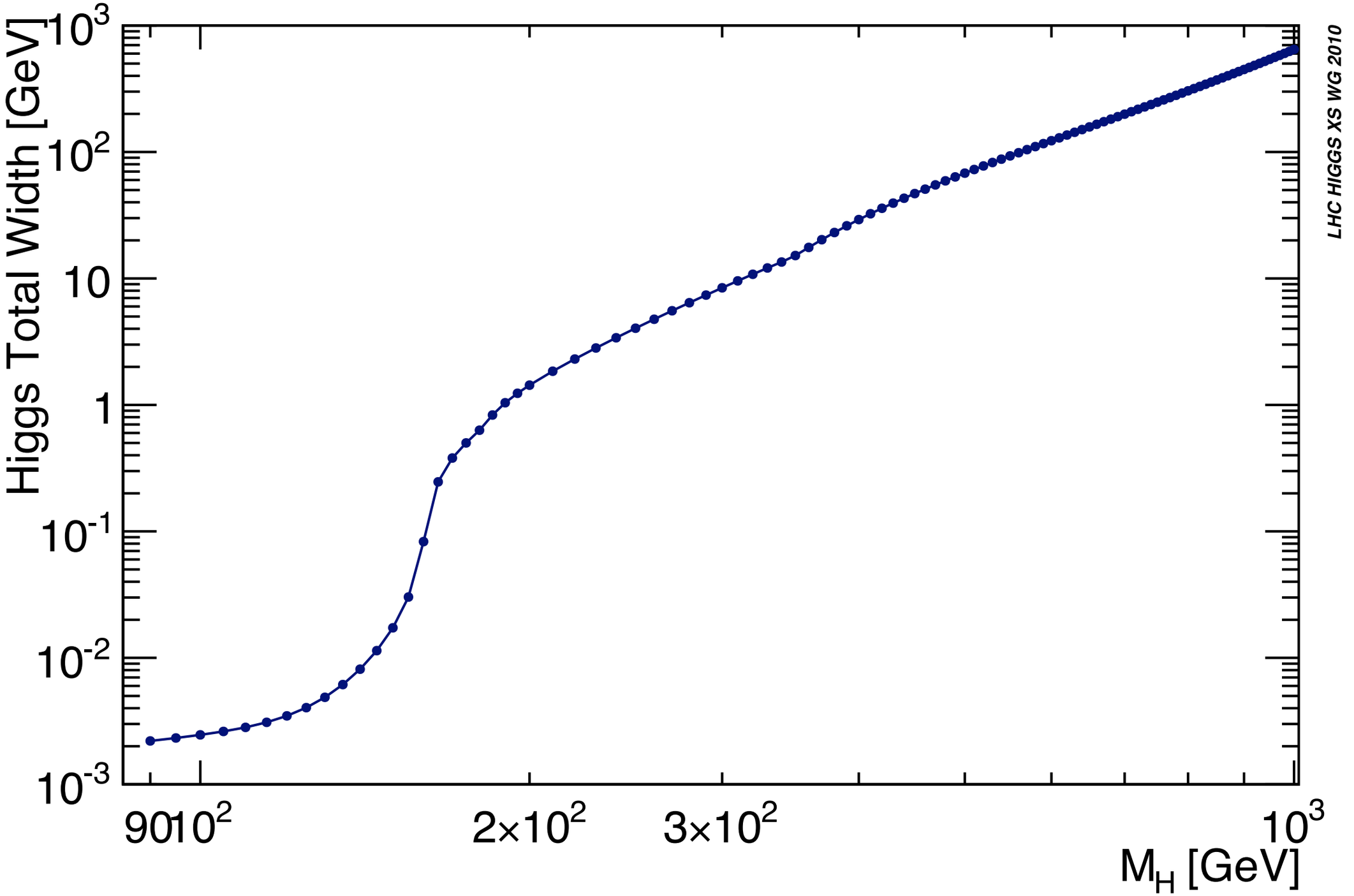




Combined Parametric Errors: BR high masses



Combined Parametric Errors: Total Width



Parametric errors below 2% over all the mass range

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Γ_{4f} in PROPHECY4F

PROPHECY4F calculates partial widths for specific 4f final states

need to sum to get Γ_{4f}

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

$$\begin{aligned}
\Gamma_{\text{H}\to\text{W}^*\text{W}^*\to 4f} &= 9\cdot\Gamma_{\text{H}\to\nu_\text{e}\text{e}^+\mu^-\bar{\nu}_\mu} + 12\cdot\Gamma_{\text{H}\to\nu_\text{e}\text{e}^+\text{d}\bar{\text{u}}} + 4\cdot\Gamma_{\text{H}\to\text{u}\bar{\text{d}}\text{s}\bar{\text{c}}} \\
\Gamma_{\text{H}\to\text{Z}^*\text{Z}^*\to 4f} &= 3\cdot\Gamma_{\text{H}\to\nu_\text{e}\bar{\nu}_\text{e}\nu_\mu\bar{\nu}_\mu} + 3\cdot\Gamma_{\text{H}\to\text{e}^-\text{e}^+\mu^-\mu^+} + 9\cdot\Gamma_{\text{H}\to\nu_\text{e}\bar{\nu}_\text{e}\mu^-\mu^+} \\
&\quad + 3\cdot\Gamma_{\text{H}\to\nu_\text{e}\bar{\nu}_\text{e}\nu_\text{e}\bar{\nu}_\text{e}} + 3\cdot\Gamma_{\text{H}\to\text{e}^-\text{e}^+\text{e}^-\text{e}^+} \\
&\quad + 6\cdot\Gamma_{\text{H}\to\nu_\text{e}\bar{\nu}_\text{e}\text{u}\bar{\text{u}}} + 9\cdot\Gamma_{\text{H}\to\nu_\text{e}\bar{\nu}_\text{e}\text{d}\bar{\text{d}}} + 6\cdot\Gamma_{\text{H}\to\text{u}\bar{\text{u}}\text{e}^-\text{e}^+} + 9\cdot\Gamma_{\text{H}\to\text{d}\bar{\text{d}}\text{e}^-\text{e}^+} \\
&\quad + 1\cdot\Gamma_{\text{H}\to\text{u}\bar{\text{u}}\text{c}\bar{\text{c}}} + 3\cdot\Gamma_{\text{H}\to\text{d}\bar{\text{d}}\text{s}\bar{\text{s}}} + 6\cdot\Gamma_{\text{H}\to\text{u}\bar{\text{u}}\text{s}\bar{\text{s}}} + 2\cdot\Gamma_{\text{H}\to\text{u}\bar{\text{u}}\text{u}\bar{\text{u}}} \\
&\quad + 3\cdot\Gamma_{\text{H}\to\text{d}\bar{\text{d}}\text{d}\bar{\text{d}}} \\
\Gamma_{\text{WW/ZZ}-\text{int.}} &= 3\cdot\Gamma_{\text{H}\to\nu_\text{e}\text{e}^+\text{e}^-\bar{\nu}_\text{e}} - 3\cdot\Gamma_{\text{H}\to\nu_\text{e}\bar{\nu}_\text{e}\mu^-\mu^+} - 3\cdot\Gamma_{\text{H}\to\nu_\text{e}\text{e}^+\mu^-\bar{\nu}_\mu} \\
&\quad + 2\cdot\Gamma_{\text{H}\to\text{u}\bar{\text{d}}\text{d}\bar{\text{u}}} - 2\cdot\Gamma_{\text{H}\to\text{u}\bar{\text{u}}\text{s}\bar{\text{s}}} - 2\cdot\Gamma_{\text{H}\to\text{u}\bar{\text{d}}\text{s}\bar{\text{c}}}
\end{aligned}$$

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