

Updates of Higgs Branching Ratios

Alexander Mück
RWTH Aachen University

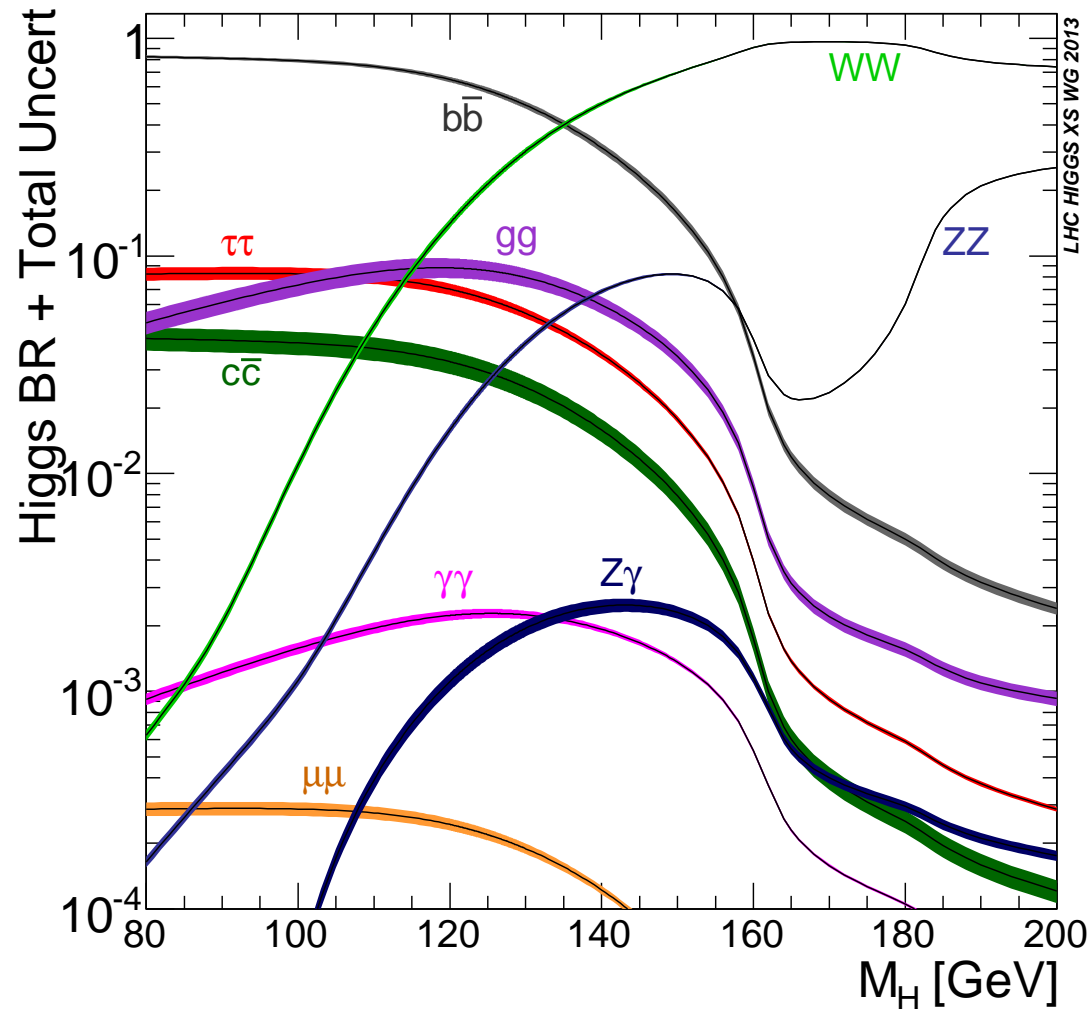
for the BR subgroup

A. Denner, S. Heinemeyer, I. Puljak, D. Rebuszi, M. Spira, ...

Meeting of the LHC Higgs Cross Section Working Group
CERN, June 12, 2014

- Standard Model Branching Ratios
 - within the HXSWG (no changes since YR3)
 - additional activities on BR predictions
 - Dalitz decays: $H \rightarrow e^+ e^- \gamma$
- BSM Branching Ratios
 - MSSM (new benchmarks)
 - 2HDM (tool comparison)
 - eHDECAY (\rightarrow talk by M. Ghezzi)

Branching ratios including error estimates:



SM partial widths

- errors on partial widths induced by **parametric** and **theory uncertainties** (YR3):

| Channel | M_H [GeV] | Γ [MeV] | $\Delta\alpha_s$ | Δm_b | Δm_c | Δm_t | THU |
|--------------------------------|-------------|----------------------|------------------|--------------|--------------|--------------|-------|
| H \rightarrow bb | 122 | 2.30 | -2.3% | +3.2% | +0.0% | +0.0% | +2.0% |
| | | | +2.3% | -3.2% | -0.0% | -0.0% | -2.0% |
| | 126 | 2.36 | -2.3% | +3.3% | +0.0% | +0.0% | +2.0% |
| | | | +2.3% | -3.2% | -0.0% | -0.0% | -2.0% |
| | 130 | 2.42 | -2.4% | +3.2% | +0.0% | +0.0% | +2.0% |
| | | | +2.3% | -3.2% | -0.0% | -0.0% | -2.0% |
| H \rightarrow $\tau^+\tau^-$ | 122 | $2.51 \cdot 10^{-1}$ | +0.0% | +0.0% | +0.0% | +0.0% | +2.0% |
| | | | +0.0% | -0.0% | -0.0% | -0.1% | -2.0% |
| | 126 | $2.59 \cdot 10^{-1}$ | +0.0% | +0.0% | +0.0% | +0.1% | +2.0% |
| | | | +0.0% | -0.0% | -0.0% | -0.1% | -2.0% |
| | 130 | $2.67 \cdot 10^{-1}$ | +0.0% | +0.0% | +0.0% | +0.1% | +2.0% |
| | | | +0.0% | -0.0% | -0.0% | -0.1% | -2.0% |

⋮

- starting point to include **error correlations** for BRs
- **theory uncertainties** based on **existing tools**
(HDECAY, PROPHECY4F)
- next release of HDECAY \rightarrow reduced THU errors
- **conservative** assumptions for **parametric uncertainties**

BR calculations

Almeida, Lee, Pokorski, Wells [arXiv:1311.6721]

- **recalculation** of partial width for $m_H = 125.7 \text{ GeV}$
- using predictions from the literature
- **parametric dependence** in terms of **Taylor coefficients**

$$\Gamma_{H \rightarrow X} = \Gamma_X^{(\text{ref})} \left(1 + \sum_i a_{\tau_i, X} \overline{\delta\tau_i} \right) \quad \text{with} \quad \overline{\delta\tau_i} = \frac{\tau_i - \tau_{i, \text{ref}}}{\tau_{i, \text{ref}}}$$

| | $\Gamma_X^{(\text{Ref})}/\text{GeV}$ | $a_{m_t, X}$ | $a_{m_H, X}$ | $a_{\alpha(M_Z), X}$ | $a_{\alpha_S(M_Z), X}$ | $a_{m_b, X}$ | $a_{M_Z, X}$ | $a_{m_c, X}$ | $a_{m_\tau, X}$ | $a_{G_F, X}$ |
|----------------|--------------------------------------|------------------------|-----------------------|------------------------|------------------------|------------------------|------------------------|-----------------------|----------------------|-----------------------|
| total | 3.96×10^{-3} | -3.48×10^{-2} | 4.53 | 8.77×10^{-1} | -1.35 | 1.4 | -3.49 | 9.05×10^{-2} | 1.3×10^{-1} | 8.43×10^{-1} |
| gg | 3.57×10^{-4} | -1.62×10^{-1} | 2.89 | 0. | 2.49 | -7.1×10^{-2} | 3.77×10^{-1} | 0. | 0. | 1. |
| $\gamma\gamma$ | 1.08×10^{-5} | -2.73×10^{-2} | 4.32 | 2.56 | 1.8×10^{-2} | 9.01×10^{-3} | -1.85 | 0. | 0. | 7.24×10^{-1} |
| $b\bar{b}$ | 2.17×10^{-3} | 8.11×10^{-3} | 8.09×10^{-1} | 3.76×10^{-2} | -2.46 | 2.57 | -4.75×10^{-1} | 0. | 0. | 9.53×10^{-1} |
| $c\bar{c}$ | 9.99×10^{-5} | -4.55×10^{-2} | 7.99×10^{-1} | 1.02×10^{-2} | -9.17 | 0. | -1.41 | 3.59 | 0. | 9.7×10^{-1} |
| $\tau^+\tau^-$ | 2.58×10^{-4} | 4.74×10^{-2} | 9.95×10^{-1} | -2.09×10^{-2} | -2.15×10^{-3} | 0. | -1.61×10^{-2} | 0. | 2.01 | 1.02 |
| WW^* | 9.43×10^{-4} | -1.13×10^{-1} | 1.37×10^1 | 3.66 | 9.04×10^{-3} | 0. | -1.21×10^1 | 0. | 0. | 2.49×10^{-1} |
| ZZ^* | 1.17×10^{-4} | 2.28×10^{-2} | 1.53×10^1 | -7.37×10^{-1} | -1.82×10^{-3} | 0. | -1.12×10^1 | 0. | 0. | 2.53 |
| $Z\gamma$ | 6.88×10^{-6} | -1.54×10^{-2} | 1.11×10^1 | 8.46×10^{-1} | 0. | -9.76×10^{-3} | -4.82 | 0. | 0. | 2.62 |
| $\mu^+\mu^-$ | 8.93×10^{-7} | 4.84×10^{-2} | 9.92×10^{-1} | -4.31×10^{-2} | -2.2×10^{-3} | 0. | -1.62×10^{-2} | 0. | 0. | 1.02 |

different way to give complete information

m_H treated as **input parameter**

BR calculations

Almeida, Lee, Pokorski, Wells [arXiv:1311.6721]

- BRs and their ratios derived **from partial width**
(as in HXSWG)
- **assumptions on parametric errors differ**
(0.7% for α_s ; 0.7% for m_b (\overline{MS} mass))
(more optimistic estimates than HXSWG → also next slide)
- theory uncertainty from **scale variation only**
- **pole** or \overline{MS} masses can be used as input for m_b and m_c
(HXSWG uses \overline{MS} masses internally, pole mass input only as bookkeeping device to minimize correlation with α_s)
- complete **comparison** with HXSWG results **not done yet**

Input Parameters

Lepage, Mackenzie, Peskin [arXiv:1404.0319]

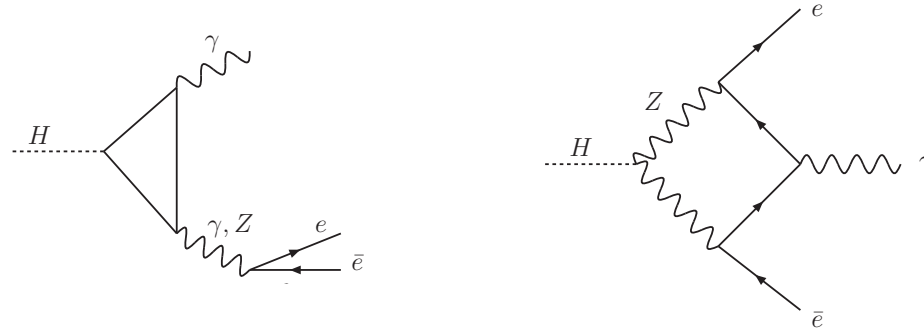
- How well can the **Higgs BRs** be predicted **in the future?**
- **Limitation** due to **parametric errors?**
- use **lattice** gauge theory **to improve** α_s , m_b , and m_c
(e.g. using current-current correlators)
(stated errors already now quite small)
- **optimistic projection** for lattice improvements:

| | $\delta m_b(10)$ | $\delta \alpha_s(m_Z)$ | $\delta m_c(3)$ | δ_b | δ_c | δ_g | |
|-----------------------------|------------------|------------------------|-----------------|------------|------------|------------|---------------|
| current errors [10] | 0.70 | 0.63 | 0.61 | 0.77 | 0.89 | 0.78 | |
| + PT | 0.69 | 0.40 | 0.34 | 0.74 | 0.57 | 0.49 | |
| + LS | 0.30 | 0.53 | 0.53 | 0.38 | 0.74 | 0.65 | |
| + LS ² | 0.14 | 0.35 | 0.53 | 0.20 | 0.65 | 0.43 | |
| + PT + LS | 0.28 | 0.17 | 0.21 | 0.30 | 0.27 | 0.21 | |
| + PT + LS ² | 0.12 | 0.14 | 0.20 | 0.13 | 0.24 | 0.17 | |
| + PT + LS ² + ST | 0.09 | 0.08 | 0.20 | 0.10 | 0.22 | 0.09 | |
| ILC goal | | | | 0.30 | 0.70 | 0.60 | (errors in %) |

time-scale: 10-15 years

Dalitz Decay

- $H \rightarrow e^+e^-\gamma$ not Yukawa suppressed at 1-loop



- $H \rightarrow e^+e^-\gamma$ to be defined by **suitable cuts**

Abbasabadi, Bowser-Chao, Dicus, Repko [hep-ph/9611209]

Chen, Qiao, Zhu [arXiv:1211.6058]

Dicus, Repko [arXiv:1302.2159]

Passarino [arXiv:1308.0422]

- use invariant masses $m_{e^+e^-}$, $m_{e^\pm\gamma}$ as identification cuts

Dicus, Repko [arXiv:1302.2159]

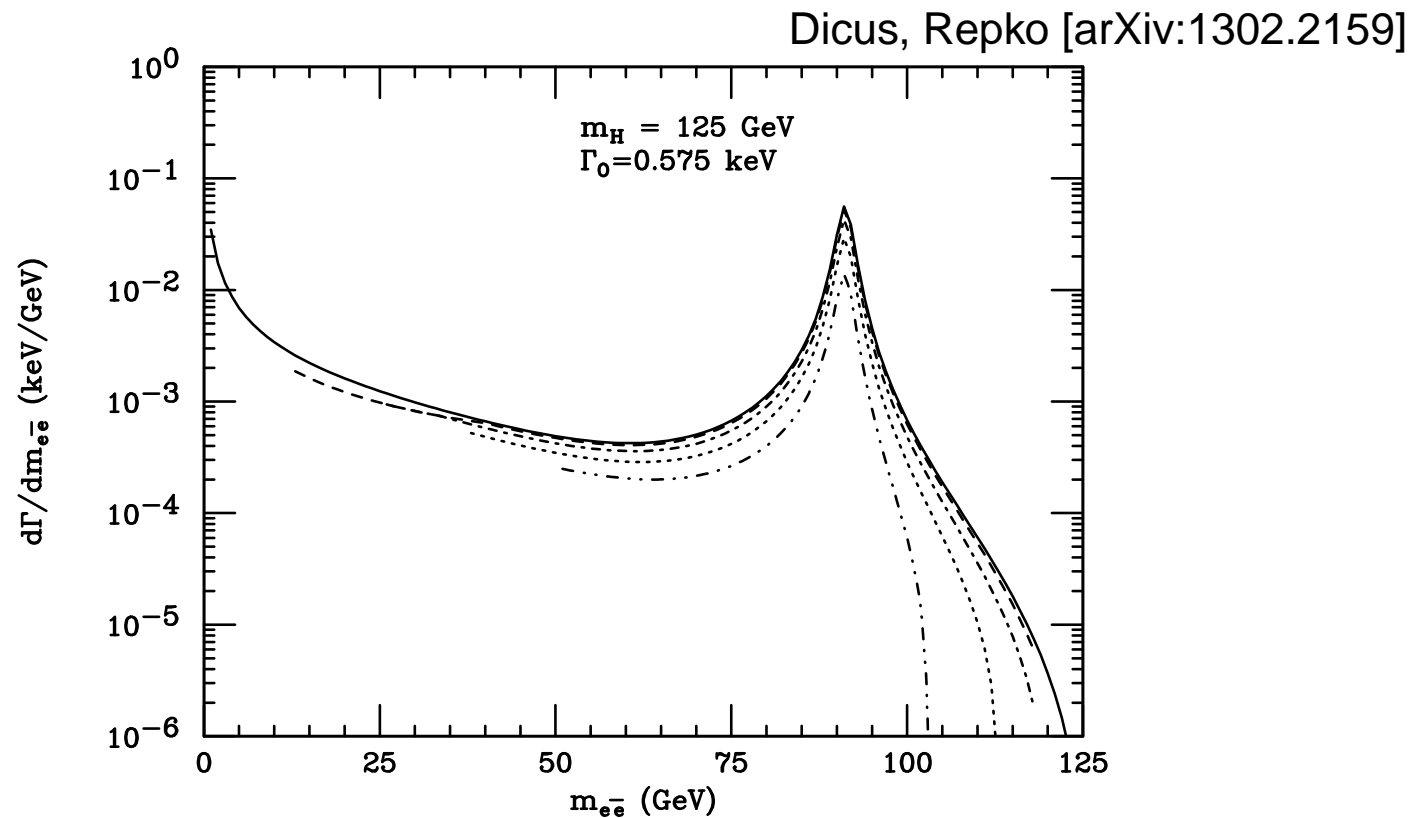
Passarino [arXiv:1308.0422]

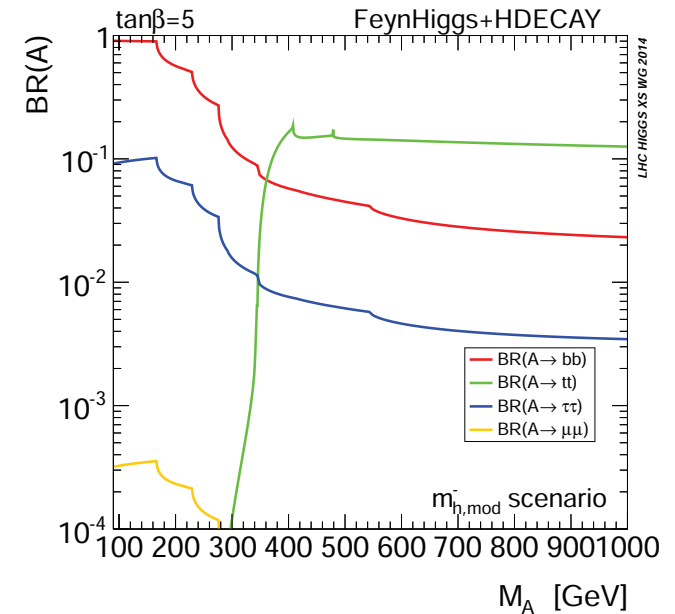
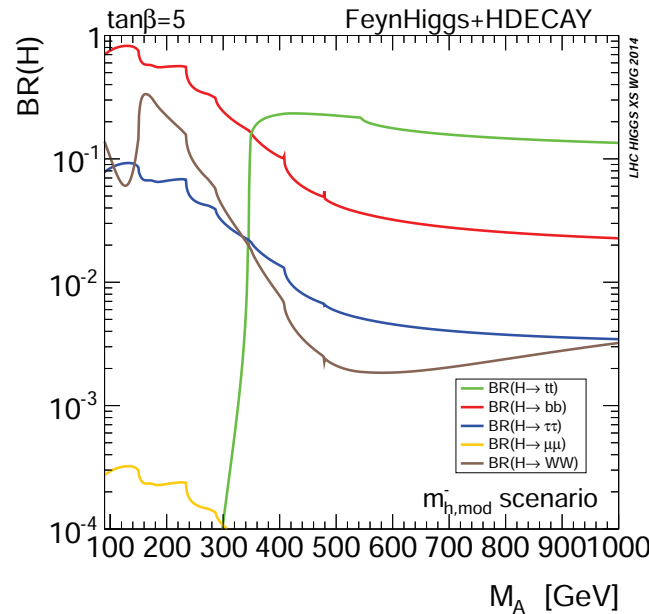
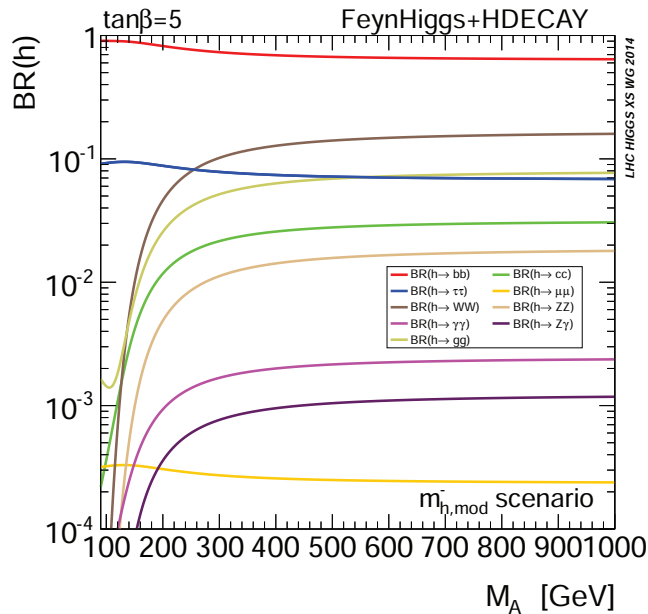
- use proper definition of **pseudo-observable** $H \rightarrow Z\gamma$

Passarino [arXiv:1308.0422]

Dality Decay

- exemplary m_{ee} distributions for different sets of cuts





- results for **new benchmark scenarios** are available
https://twiki.cern.ch/twiki/bin/view/LHCPhysics/CrossSectionsFigures#MSSM_BR_plots
- also for **charged Higgs**
- using predictions by **FeynHiggs** and **HDECAY**

MSSM benchmarks

- Total **work flow**:
 1. Input parameters to **FeynHiggs** (native format or SLHA)
 2. **FeynHiggs** \Rightarrow Higgs masses, couplings, decay widths/BRs
Output via SLHA file (total width and BRs)
 3. SLHA file is stored and fed to **HDECAY**
 4. **HDECAY** \Rightarrow decay widths
Output via SLHA file (total width and BRs)
 5. “**Script**” reads both SLHA files, extracts total width and branching ratios \Rightarrow calculation of partial widths
 6. “**Script**” calculates total width (using best predictions)
 7. “**Script**” calculates BRs
- for neutral and charged Higgs bosons
- not fully automated, but **works** reasonably well

Harlander, Mühlleitner, Rathsman, Spira, Stål [arXiv:1312.5571]

- **tools** for production and decay in the **2HDM**
- available codes for BRs: **2HDMC** and **HDECAY**
 - 2HDMC: Eriksson, Rathsman, Stål [arXiv:0902.0851]
 - HDECAY: Djouadi, Kalinowski, Spira [hep-ph/9704448]
 - Djouadi, Mühlleitner, Spira [hep-ph/0609292]
- **good agreement** for investigated reference scenarios
(generically at the 1% level)
- general strategy:
 - **use** (generic) **SM QCD** corrections
 - **do not use SM EW** corrections (not generic)

Conclusions

- **no big news** from BRs
- recent **activities** in the **SM**
 - recalculation of SM BRs [arXiv:1311.6721]
 - quest for precise input [arXiv:1404.0319]
 - Dalitz decay calculations
[arXiv:1211.6058, 1302.2159, 1308.0422]
- recent **BSM activities**
 - MSSM benchmarks [HXS WG page]
 - 2HDM tool comparison [arXiv:1312.5571]
 - eHDECAY [arXiv:1312.5571]