# Towards precise predictions for Higgs-boson production in the MSSM

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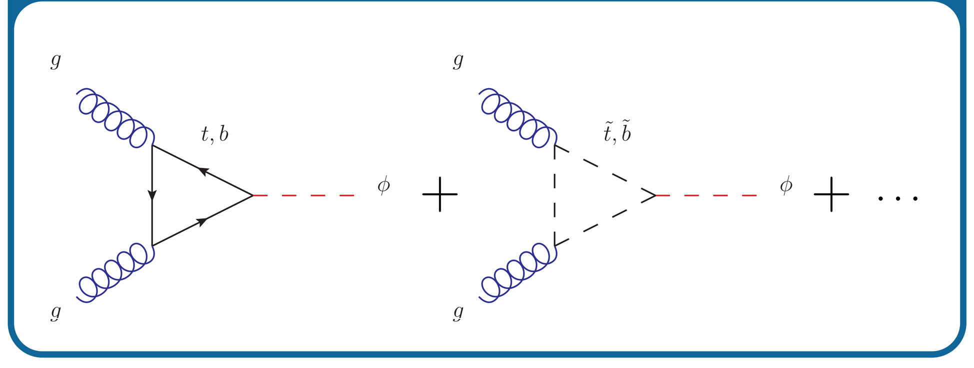
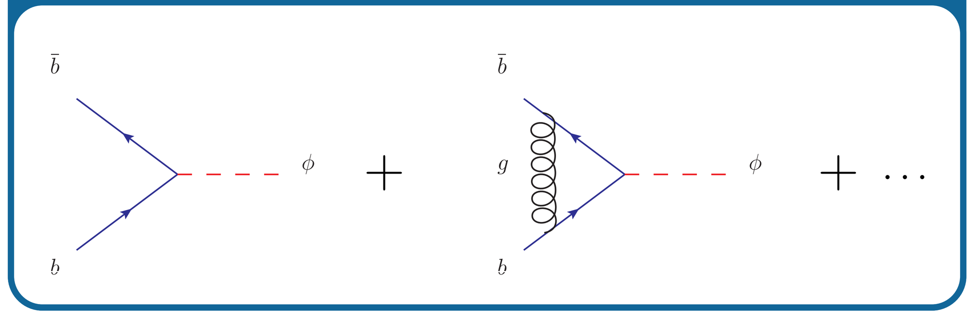
## Aim of the study

Now that we are entering the era of **precision physics at the LHC**, it is important to have a **thorough understanding of the theoretical uncertainties that affect our predictions**. Our work follows this line of research and focuses on the case of **the production of the neutral Higgs bosons of the MSSM in gluon fusion and bottom annihilation**[1].

### Gluon fusion



### Bottom annihilation (5FS)

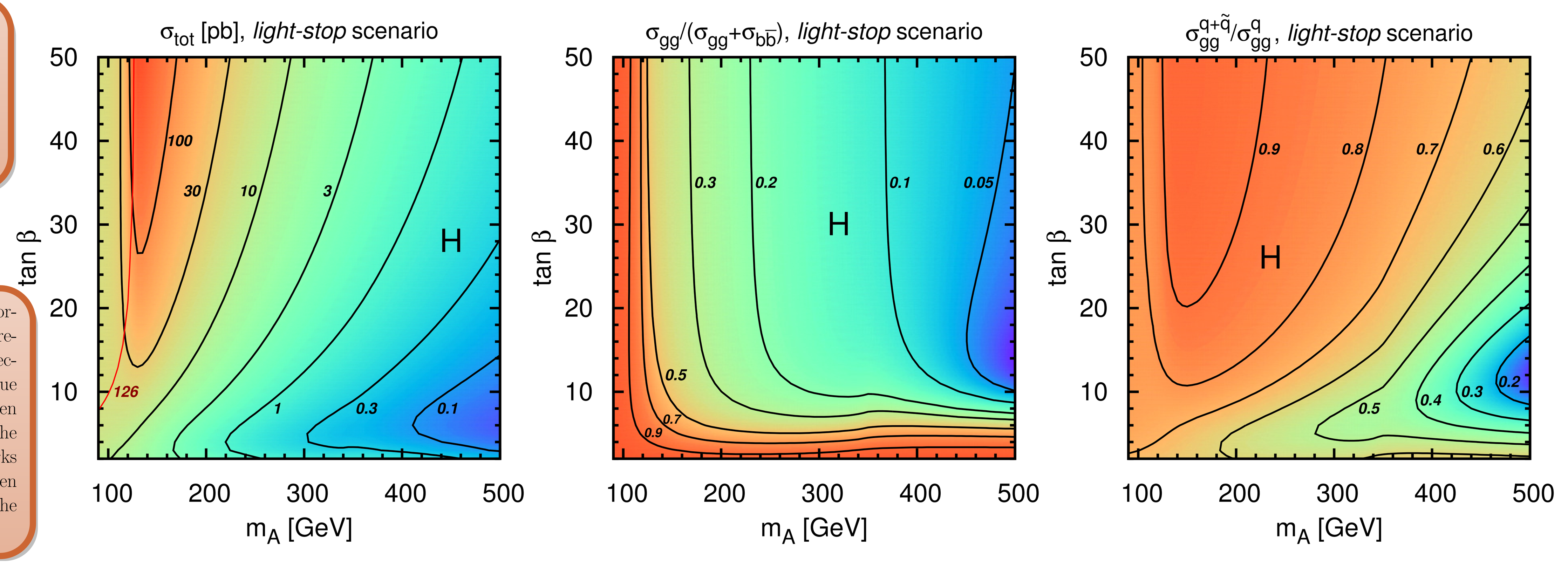


## Outline of the analysis

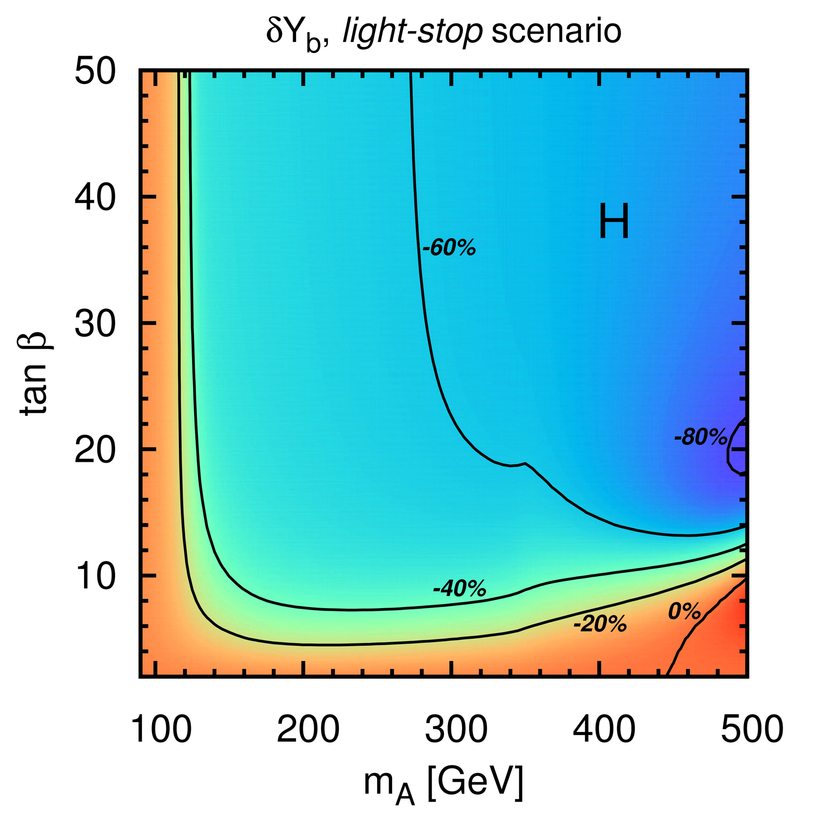
We have studied the production of $\phi = h, H, A$ using the code **SusHi** in the MSSM benchmark scenarios proposed by Carena et al (2013). Gluon fusion in **SusHi** includes: the exact top and bottom contribution up to NLO, the top results in the Heavy Quark Effective Field Theory (HQEFT) at NNLO, SUSY-QCD corrections from the stops and sbottom sectors at NLO and the available stops contribution at NNLO. EW contributions are included in a factorized form at NLO. The bottom Yukawa is rescaled to include tan $\beta$-enhanced corrections ($\Delta_b$). Bottom annihilation is included at NNLO in the 5FS (SUSY-QCD corrections are included in a rescaled bottom Yukawa coupling). The results shown in the poster are for **H production** in the so called **light stop scenario** ($m_{\tilde{t}_1} = 324$ GeV, $m_{\tilde{t}_2} = 672$ GeV). In this box, **from left to right, we show the total cross section, the relative importance of the gluon fusion process and the impact of the SUSY-QCD corrections in the** $\tan\beta - m_A$ **plane**. In the rest of the poster we present the main uncertainties that affect this prediction for the total rate of H production.

The light stop scenario was slightly modified from its original form to evade more recent results from ATLAS and CMS.

In the bottom-right corner lies a *gluophobic* region where the cross section is very small due to a cancellation between the contributions of the quarks and the squarks (as it can be also seen from the last plot on the right).

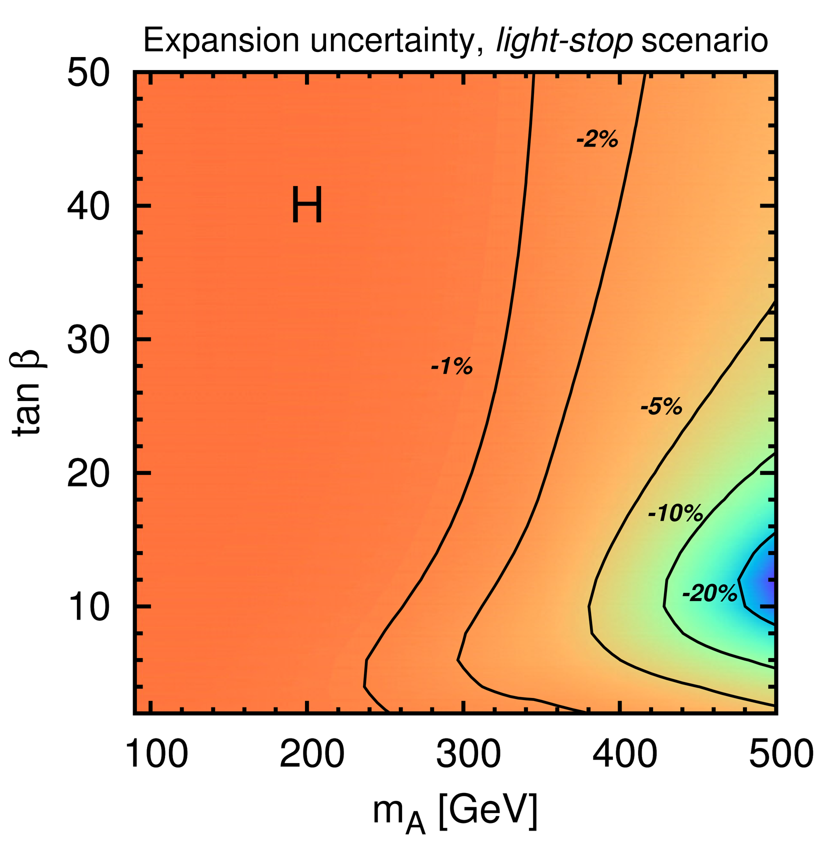



## Bottom Yukawa renormalization scheme in gluon fusion

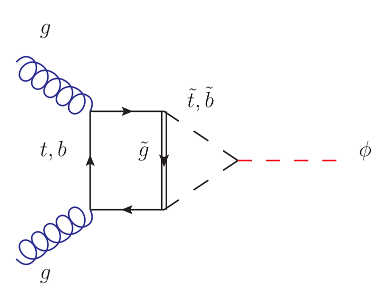



**The bottom quark contribution to the gluon fusion process** is subleading in the SM. **In the MSSM**, on the other hand, it **can be the dominant one**. Traditionally the bottom Yukawa has been extracted from the pole mass $M_b$. However **there are no theoretically justifications to prefer this choice over the one of extracting the Yukawa from the $\overline{\text{MS}}$ mass**, $m_b(\mu_r)$. On the left we show the relative difference of the cross section for H when $Y_b \sim m_b(m_H/2)$ with respect to the canonical one obtained with $Y_b \sim M_b$. We see that that when the bottom contribution is the dominant one we have deviations up to 60%−80%. While such a large uncertainty could appear as worrisome, **we should remember that in these regions the dominant production process is bottom annihilation**, as it can be seen from the middle plot of the top-right box. Analogous considerations are valid for the other Higgses.

## SUSY-QCD expansion uncertainty

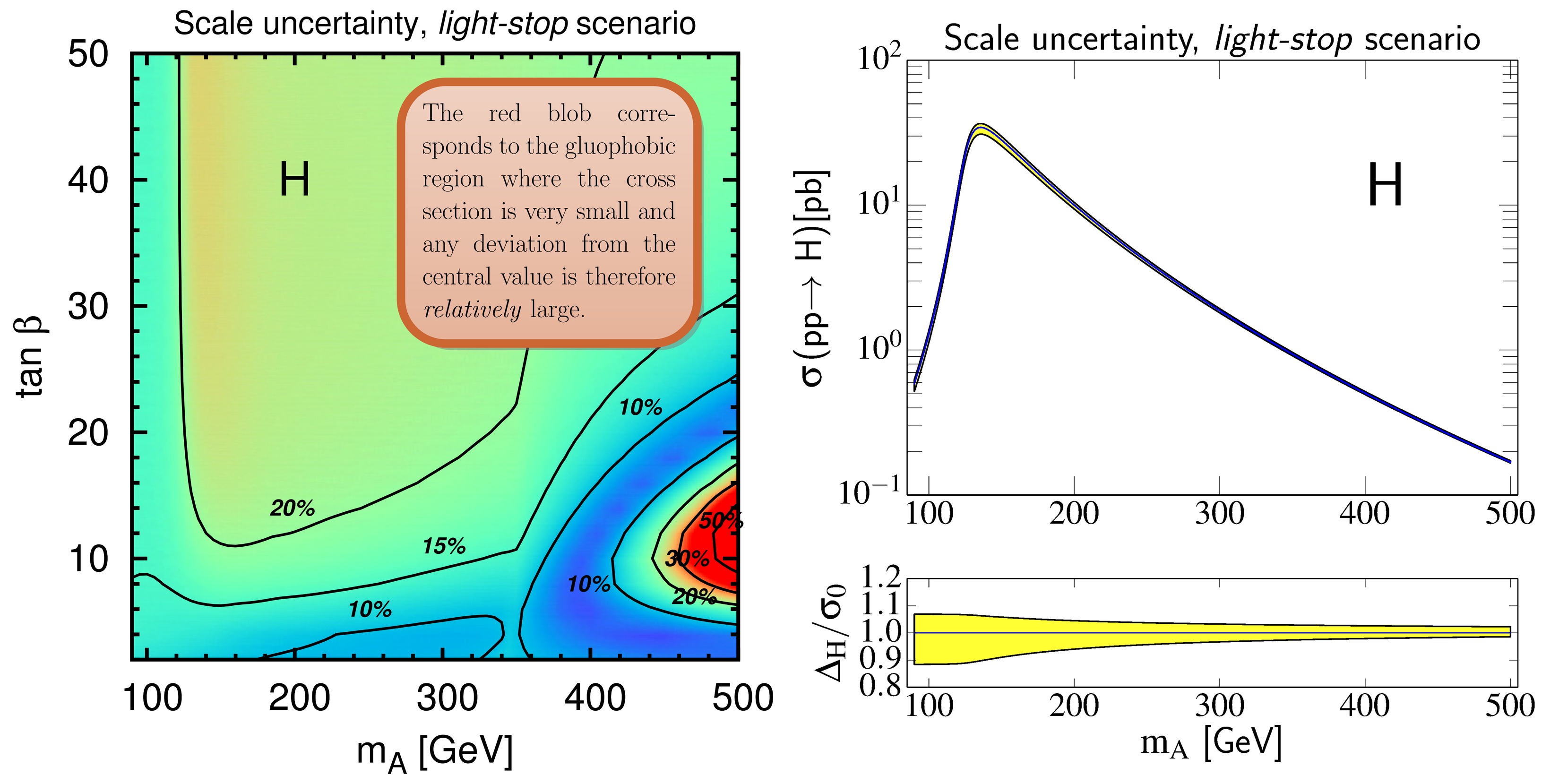



**Not all SUSY-QCD corrections are available at NLO in an exact form**. For example, NLO 2-loop diagrams with quarks, squarks and a gluino are included in **SusHi** in the form of an expansion in the inverse powers of the SUSY-particle masses. We **estimate the error** due to this approximation by **rescaling the NLO result for stops and sbottoms by the test factor** $t \equiv \mathcal{A}^{1l}_{\tilde{q}}/\mathcal{A}^{1l,exp}_{\tilde{q}}$. In the plot we show the relative difference of the cross section for $H$ when computed with the test factor with respect to its canonical value. **We see that, aside from the gluophobic region, the impact in the** $\tan\beta$-$m_A$ **plane is rather modest**. For the pseudoscalar uncertainties have a similar pattern but they are smaller in magnitude due to the fact that the squarks appear at NLO and not at LO.



## Scale uncertainty

The **scale variation uncertainty** is evaluated with the **standard prescription** (a rescaling factor $r = 2$ is used and we opt not to include $\mu_r$ and $\mu_f$ combinations that could introduce potentially large logarithmic deviation from the central value). Here we show the **relative scale-uncertainty band width for** $H$ **production in gluon fusion (left) and bottom annihilation (right)**. In the case of **gluon fusion, we observe that the uncertainty follows the pattern determined by the available accuracy of the dominant contribution** (e.g. where the bottom, known only at NLO, is dominant, the uncertainty is larger with respect to where the top contribution is dominant). In the case of **bottom annihilation**, being the SUSY-QCD corrections only in the rescaled bottom Yukawa, we see a **dependence only on the Higgs mass**. Analogous considerations are valid for $h$ and $A$ production.




## Other sources of uncertainty

There are also other sources of uncertainty that we have considered in our study:

- **The bottom mass dependence in the PDF.**
- **PDF+$\alpha_s$ uncertainty.**
- **Uncertainty due to our incomplete knowledge of NNLO SUSY-QCD corrections.**
- **Estimation of the theoretical uncertainties coming from the $\Delta_b$ corrections.**

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## References

[1] E. Bagnaschi, et al. "Towards precise predictions for Higgs-boson production in the MSSM." *JHEP*, 06:167, 2014. doi:10.1007/JHEP06(2014)167.

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