2HDM studies: H signal kinematics

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Introduction

- In the 2HDM one introduces two identical, complex scalar $SU(2)$ doublet fields $\Phi_i = (\Phi_i^{\pm}, \Phi_i^0)^T$
- The most general, gauge invariant and renormalizable potential of the 2HDM has the following form:

$$
\begin{aligned}
V_{\text{gen}} &= m_{11}^2 \Phi_1^\dagger \Phi_1 + m_{22}^2 \Phi_2^\dagger \Phi_2 - (m_{12}^2 \Phi_1^\dagger \Phi_2 + \text{h.c}) \\
&+ \frac{1}{2}\lambda_1 (\Phi_1^\dagger \Phi_1)^2 + \frac{1}{2}\lambda_2 (\Phi_2^\dagger \Phi_2)^2 + \lambda_3 (\Phi_1^\dagger \Phi_1)(\Phi_2^\dagger \Phi_2) + \lambda_4 (\Phi_1^\dagger \Phi_2)(\Phi_2^\dagger \Phi_1) \\
&+ \left[\frac{1}{2}\lambda_5 (\Phi_1^\dagger \Phi_2)^2 + \Big(\lambda_6 (\Phi_1^\dagger \Phi_1) + \lambda_7 (\Phi_2^\dagger \Phi_2)\Big)(\Phi_1^\dagger \Phi_2) + \text{h.c.}\right]
\end{aligned}
$$

with $m_{11}^2, m_{22}^2, \lambda_1, \ldots, \lambda_4 \in \mathbb{R}$ and $m_{12}^2, \lambda_5, \ldots, \lambda_7 \in \mathbb{C}$.

2HDM Parameters

- The possible bases can be parametrized in terms of the vacuum expectation values (vev) of the doublets:

$$\langle\Phi_1\rangle = \frac{v}{\sqrt{2}}\begin{pmatrix}0\\ \cos\beta\end{pmatrix}\ \langle\Phi_2\rangle = \frac{v}{\sqrt{2}}\begin{pmatrix}0\\ e^{i\xi}\sin\beta\end{pmatrix}\ \tan\beta = \frac{|\langle\Phi_2\rangle|}{|\langle\Phi_1\rangle|}$$

- Non-zero imaginary parts of the λ's in the potential as well as in the vev lead to $\mathcal{CP}$ violation.
- When the $SU(2)$ symmetry is broken, one usually expresses the doublets in states with definite physical properties.
- With a mixing angle α, which diagonalizes the mass matrix of the $\mathcal{CP}$-even states, the original doublets are:

$$\Phi_1 = \frac{1}{\sqrt{2}}\begin{pmatrix}\sqrt{2}(G^+\cos\beta - H^+\sin\beta)\\ v\cos\beta - h\sin\alpha + H\cos\alpha + i(G^0\cos\beta - A\sin\beta)\end{pmatrix}$$

$$\Phi_2 = \frac{1}{\sqrt{2}}\begin{pmatrix}\sqrt{2}(G^+\sin\beta + H^+\cos\beta)\\ v\sin\beta - h\cos\alpha + H\sin\alpha + i(G^0\sin\beta - A\cos\beta)\end{pmatrix}$$

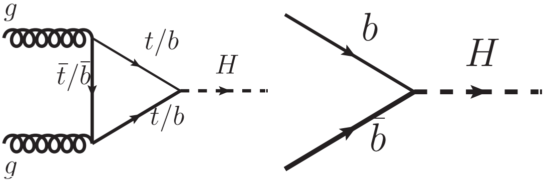
Modification of the couplings

- We consider 2 models with natural flavor conservation known as "type I" and "type II" models.
- Type I: All quarks couple to one of the Higgs doublets
- Type II: The right-handed up-type quarks couple to one doublet, the down-type quarks to the other
- Coupling modifications in the 2HDM:

	Type I	Type II
$\xi_{\mathbf{h}}^{V}$	$\sin(\beta-\alpha)$	$\sin(\beta-\alpha)$
$\xi_{\mathbf{h}}^{u}$	$\cos\alpha/\sin\beta$	$\cos\alpha/\sin\beta$
$\xi_{\mathbf{h}}^{d}$	$\cos\alpha/\sin\beta$	$-\sin\alpha/\cos\beta$
$\xi_{\mathbf{h}}^{l}$	$\cos\alpha/\sin\beta$	$-\sin\alpha/\cos\beta$
$\xi_{\mathbf{H}}^{V}$	$\cos(\beta-\alpha)$	$\cos(\beta-\alpha)$
$\xi_{\mathbf{H}}^{u}$	$\sin\alpha/\sin\beta$	$\sin\alpha/\sin\beta$
$\xi_{\mathbf{H}}^{d}$	$\sin\alpha/\sin\beta$	$\cos\alpha/\cos\beta$
$\xi_{\mathbf{H}}^{l}$	$\sin\alpha/\sin\beta$	$\cos\alpha/\cos\beta$

Kinematic distributions

- The p_T-distribution of the (SM) Higgs boson is known up to NNLL+NLO accuracy arXiv:1109.2109 [hep-ph].
- The top and bottom mass effects in (SM) Higgs production have been examined arXiv:1210.8263 [hep-ph]
- Due to the coupling modification, the following production modes can become important:



- At high values of $\tan\beta$ the bottom contributions become dominant and cannot be neglected.

2HDM cross sections with SusHi

- SusHi calculates both the ggF and the $b\bar{b} \to H$ cross section.
- ggF:
  - NNLO effects are taken into account for the t-induced gluon-Higgs coupling using `ggh@nnlo`.
  - SusHi incorporates all NLO QCD contributions up to the third generation of quarks and squarks.
  - Electroweak corrections are implemented as tabulated correction factors.
- $b\bar{b} \to H$:
  - SusHi uses `bbh@nnlo` for the calculation of the $b\bar{b} \to H$ cross section, where the
  - The program is linked to the LHAPDF library, so that PDF sets can be exchanged easily.
  - For the 2 loop calculation in the MSSM SusHi uses `FeynHiggs`.

SusHi-Workflow

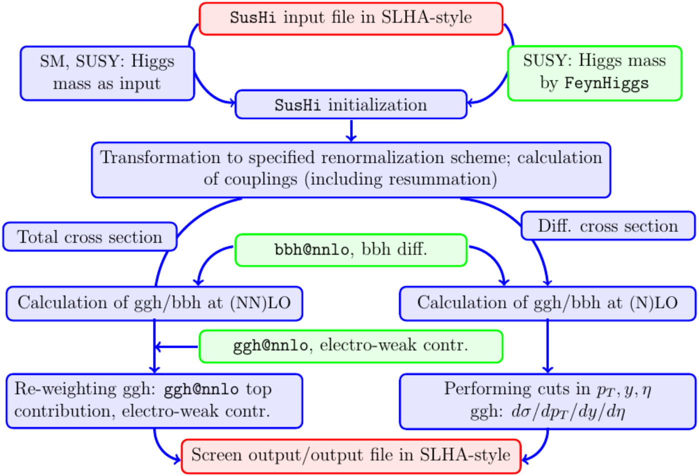
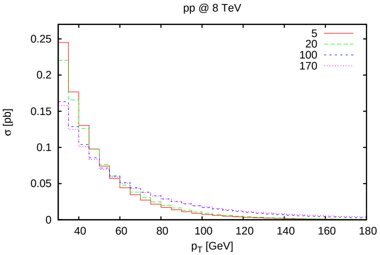


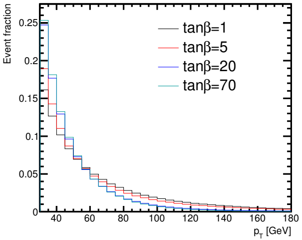
Figure 4: Internal workflow of SusHi. Red boxes indicate interaction with the user, who has to provide an input and gets an output file, if no error messages are shown. Green boxes refer to external code (see text), which is linked to/included in SusHi.

Influence of the b to the distribution

- The p_T-distribution of the Higgs, which is produced via a b-loop, is expected to be softer compared to the production via a t-loop.
- This can be obtained by varying m_t or by choosing large values for $\tan\beta$



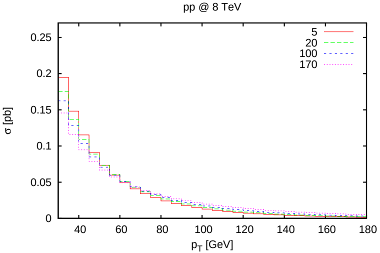
p_T-distribution of the SM Higgs with $m_\mathbf{h} = 125$ GeV



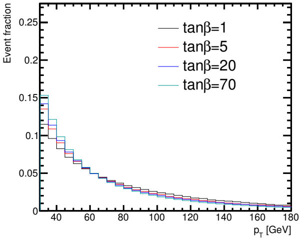
p_T-distribution of the light type II 2HDM Higgs with $m_\mathbf{h} = 125$ GeV

Influence of the Higgs mass to the distribution

- The influence of $\tan\beta$ should become smaller, since the impact from t and b are similar at higher masses.



p_T-distribution of the SM Higgs with $m_\mathbf{h} = 250$ GeV



p_T-distribution of the heavy type II 2HDM Higgs with $m_\mathbf{h} = 250$ GeV

Summary

- The influence of the the b to the p_T-distribution is visible and looks as expected.
- The difference of the distributions is larger at small values of p_T and the distributions become more similar (especially at higher masses) at large values of p_T.
- As a consequence, we consider a reweighting of the events in dependence of $\tan\beta$.