Status and plans of the MSSM subgroup (theory)

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The 18th workshop of the LHC Higgs working group

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Outline

Subgroup mission

- To be a common ground for discussion between experimentalists and theorists
- To clarify theoretical aspects important for experimental studies
- To provide benchmark scenarios to be used by experimental collaboration
- To discuss possible future developments on probing the MSSM Higgs sector at the LHC

Subgroup changes

- A. Gottman (KIT) $\rightarrow$ A. Anuar (DESY) [experiment]

- T. Barklow will provide the experimental update in the following talk

Task list

- Scenarios/ROOT files
- Experimental/phenomenological aspects
- A/H Higgs transverse momentum distribution
- Working group notes

Lines of activity

Task	Status	Timescale ↑
Keep an eye on potentially missing signatures	In progress	Continuous
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Public note on the ROOT files

LHCWG-XX-YYYY

Benchmark Scenarios for MSSM
Higgs Boson Searches at the LHC

Emanuele Bagnaschi[a], Sven Heinemeyer[b], Stefan Liebler[c], Pietro Slavich[d], Michael Spira[e]

ROOT file note

- We prepared a public note that describes the setup used to generate the ROOT files and their use – `https://cds.cern.ch/record/2791954/`
- The idea is to keep the note in sync with each ROOT file release, in such a way that it works as a reference
- The WG note has been submitted to the working group conveners and it will start the review process soon – **observations and comments are welcome**
- The ROOT files from now on will be released on Zenodo (title of the record "LHCHWG MSSM ROOT files")
- Versioning will be used on Zenodo – please cite the exact version that you use in your study

Structure of the ROOT files

File Content

- Six scenarios from [EB et al. EPJC 79 (2019) 7, 617] which covers different phenomenologies
- Three $\mu < 0$ scenarios from [Bahl et al. EPJC 80 (2020) 10, 916]
- Two low tan β scenarios from [Bahl et al. EPJC 79 (2019) 3, 279]
- hMSSM scenario from [Djouadi & Quevillon JHEP 10 (2013) 028, Maiani et al. PLB 724 (2013) 274-277, Djouadi et al. EPJC 73 (2013) 2650, Djouadi et al. JHEP 06 (2015) 168]
- Cross sections evaluated at three different energies: 8, 13, 14 TeV

Branching ratios

Neutral Higgs
<ϕ> = h,H,A

br_<ϕ>_bb
br_<ϕ>_cc
br_<ϕ>_gamgam
br_<ϕ>_gluglu
br_<ϕ>_mumu
br_<ϕ>_SUSY
br_<ϕ>_tautau
br_<ϕ>_tt
br_<ϕ>_WW
br_<ϕ>_Zgam
br_<ϕ>_ZZ
br_H_AA
br_H_hh
br_H_WHp
br_A_Zh

Charged Higgs
<ϕ> = h,H,A

$\mathcal{CP}$-violating scenario
<ϕ> = H1,H2,H3

br_Hp_cb
br_Hp_cd
br_Hp_cs
br_Hp_munu
br_Hp_taunu
br_Hp_tb
br_Hp_ts
br_Hp_td
br_Hp_ub
br_Hp_<ϕ>W
br_Hp_SUSY
br_t_Hpb

Neutral Higgs
$\mathcal{CP}$-violating scenario
<ϕ> = H1,H2,H3

br_<ϕ>_bb
br_<ϕ>_cc
br_<ϕ>_gamgam
br_<ϕ>_gluglu
br_<ϕ>_mumu
br_<ϕ>_SUSY
br_<ϕ>_tautau
br_<ϕ>_tt
br_<ϕ>_WW
br_<ϕ>_Zgam
br_<ϕ>_ZZ
br_H2_H1H1
br_H3_H1H1
br_H2_WHp
br_H3_WHp
br_H2_ZH1
br_H3_ZH1

SM Higgs

br_HSM_bb
br_HSM_cc
br_HSM_gamgam
br_HSM_gluglu
br_HSM_mumu
br_HSM_tautau
br_HSM_tt
br_HSM_WW
br_HSM_Zgam
br_HSM_ZZ

Cross sections

Neutral Higgs
<ϕ> = h,H,A

$\mathcal{CP}$ violating scenario
<ϕ>= H1,H2,H3

xs_bb_<ϕ>
xs_bb_<ϕ>_down
xs_bb_<ϕ>_up
xs_gg_<ϕ>
xs_gg_<ϕ>_pdfasdown
xs_gg_<ϕ>_pdfasup
xs_gg_<ϕ>_scaledown
xs_gg_<ϕ>_scalesup
xs_vbf_<ϕ>
xs_hs_Z<ϕ>
xs_hs_W<ϕ>
xs_tth_<ϕ>

SM Higgs

xs_bb_HSM
xs_gg_HSM
xs_vbf_HSM
xs_hs_ZHSM
xs_hs_WHSM
xs_tth_HSM

Charged Higgs

xs_pp_Hp
xs_pp_down
xs_pp_up

Other quantities

Masses
<ϕ> = h,H,A,Hp

$\mathcal{CP}$-violating scenario
<ϕ> = H1,H2,H3,Hp

m_<ϕ>

Couplings
<ϕ> = h,H,A
lam3_HHH only for M_H^{125}

rescale_gt_<ϕ>
rescale_gb_<ϕ>
rescale_deltab
rescale_im_deltab
lam3_hhh (lam3_HHH)
lam3_HSM
lam3_HSM_tree
alpha

Couplings
$\mathcal{CP}$-violating scenario
<i>,<j>=1,2,3

rescale_deltab
rescale_im_deltab
lam3_H1H1H1
lam3_HSM
lam3_HSM_tree
Hmix_<i><j>
alpha_tree

Total widths
<ϕ> = h,H,A,Hp

$\mathcal{CP}$-violating scenario
<ϕ> = H1,H2,H3,Hp

width_<ϕ>
width_HSM
width_t

Interference factors
$\mathcal{CP}$-violating scenario
<ϕ> = H1,H2,H3

int_bb_tautau_<ϕ>
int_gg_tautau_<ϕ>

Theory setup

Overview

- Branching ratios are obtained by combining state-of-the-art predictions from `FeynHiggs` and `HDECAY`, aside from the EFT and CPV scenarios, for which only `FeynHiggs` is used, and the `hMSSM` for which only `HDECAY` is used
- Gluon fusion production cross-sections are computed using the code `SusHi`
- Bottom-associated production cross-sections are computed by rescaling the matched predictions provided by the bbH working group
- Cross sections for the other production processes (VBF, WH, ZH and ttH) are computed by rescaling the grids provided the LHCHWG
- Charged Higgs cross sections are interpolated from LHCHWG grids as well

$$\Gamma_{\phi} = \Gamma^{\mathrm{FH}}_{\phi\to\tau^+\tau^-} + \Gamma^{\mathrm{FH}}_{\phi\to\mu^+\mu^-} + \Gamma^{\mathrm{FH/P4f}}_{\phi\to \mathrm{W}^{(*)}\mathrm{W}^{(*)}} + \Gamma^{\mathrm{FH/P4f}}_{\phi\to \mathrm{Z}^{(*)}\mathrm{Z}^{(*)}} + \Gamma^{\mathrm{HD}}_{\phi\to \mathrm{b\bar{b}}} + \Gamma^{\mathrm{HD}}_{\phi\to \mathrm{t\bar{t}}} + \Gamma^{\mathrm{HD}}_{\phi\to \mathrm{c\bar{c}}}$$
$$+ \Gamma^{\mathrm{HD}}_{\phi\to \mathrm{gg}} + \Gamma^{\mathrm{HD}}_{\phi\to \gamma\gamma} + \Gamma^{\mathrm{HD}}_{\phi\to \mathrm{Z}\gamma} + \Gamma^{\mathrm{FH}}_{\phi\to \mathrm{Higgs}} + \Gamma^{\mathrm{FH}}_{\phi\to \mathrm{SUSY}}$$

$$\Gamma_{\mathrm{H}^\pm} = \Gamma^{\mathrm{FH}}_{\mathrm{H}^\pm\to\tau\nu_\tau} + \Gamma^{\mathrm{FH}}_{\mathrm{H}^\pm\to\mu\nu_\mu} + \Gamma^{\mathrm{FH}}_{\mathrm{H}^\pm\to \mathrm{hW}} + \Gamma^{\mathrm{FH}}_{\mathrm{H}^\pm\to \mathrm{HW}} + \Gamma^{\mathrm{FH}}_{\mathrm{H}^\pm\to \mathrm{AW}} + \Gamma^{\mathrm{HD}}_{\mathrm{H}^\pm\to \mathrm{tb}} + \Gamma^{\mathrm{HD}}_{\mathrm{H}^\pm\to \mathrm{ts}}$$
$$+ \Gamma^{\mathrm{HD}}_{\mathrm{H}^\pm\to \mathrm{td}} + \Gamma^{\mathrm{HD}}_{\mathrm{H}^\pm\to \mathrm{cb}} + \Gamma^{\mathrm{HD}}_{\mathrm{H}^\pm\to \mathrm{cs}} + \Gamma^{\mathrm{HD}}_{\mathrm{H}^\pm\to \mathrm{cd}} + \Gamma^{\mathrm{HD}}_{\mathrm{H}^\pm\to \mathrm{ub}} + \Gamma^{\mathrm{FH}}_{\mathrm{H}^\pm\to \mathrm{SUSY}}$$

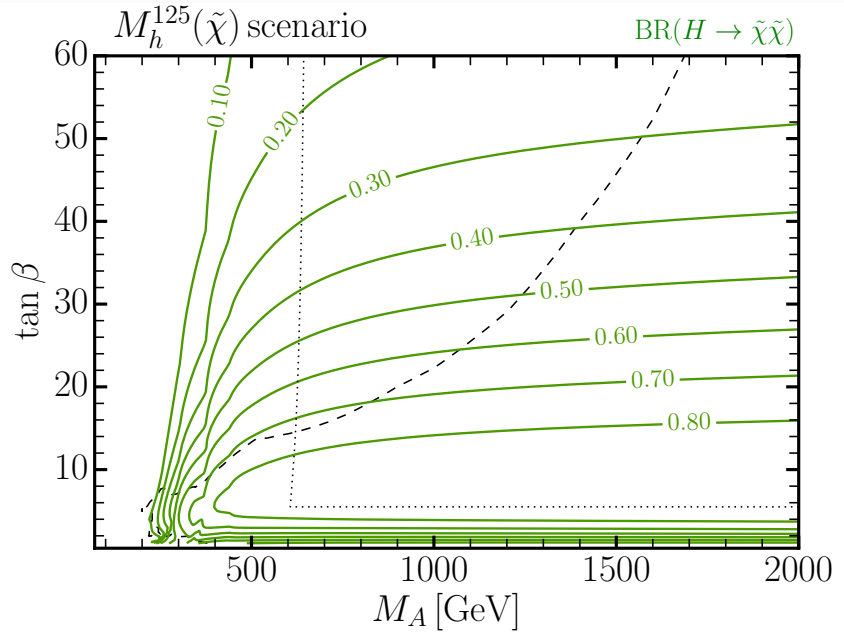
Recent updates

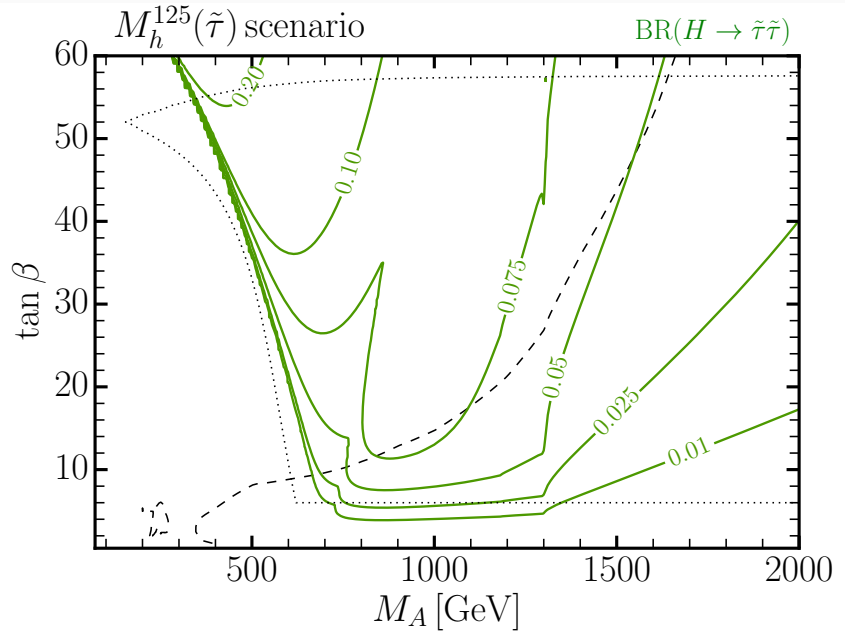
- Added the SM BRs to the low tan β scenarios
- Disabled EW corrections from the SM predictions we obtain from `HDECAY` in order to be consistent with the accuracy of the MSSM predictions
- Updated the hMSSM ROOT file to the same setup used for the other scenarios (latest version of `SusHi`; PDF4LHC15 recommendations; *bb* cross-sections from the matched results provided by the bbH WG; inclusion of reference SM histograms)
- Added the cross sections for the VBF, Higgsstrahlung and ttH production processes for the three neutral Higgses and for the SM reference case
- Added mixing information of the neutral Higgs sector
- Added the trilinear self-coupling of the SM-like Higgs, and of a SM Higgs with the same (the latter at tree level and including the m_t^4 term)
- Cleaned-up and reorganized the histograms with a more consistent naming
- Removed the decay $H^\pm \to us$ due to theoretical issues
- Update to the latest `HDECAY` version (Δ_b with electroweak 2-loop corrections proportional to α_1 and α_2; m_t^4 term in the hMSSM trilinear self-coupling)

Future plans: A/H to SUSY states

- Some of the scenarios are characterized by large branching ratios to SUSY states.
- A separate set of ROOT files is planned to be released with the different channels saved separately (in the current ROOT files all the BRs to SUSY are summed in a single histogram).
- Discussions in progress to see whether there is interest from the experimental community in probing these decay channels. Feedback welcome.

New ROOT files





Higgs $p_\perp^\phi$ reiweighting

Goal: account for the impact on the acceptance of the different shape of the Higgs $p_\perp^\phi$ distribution in the MSSM

- Several theoretical studies in the literature [JHEP 02 (2012) 088, JHEP 11 (2014) 116, JHEP 01 (2016) 056, JHEP 01 (2016) 090, ...]
- State of the art predictions available in the `POWHEG-BOX`, `aMCSusHi`, `MoRe-SusHi`
- Effect included in the CMS analysis [JHEP 09 (2018) 007]

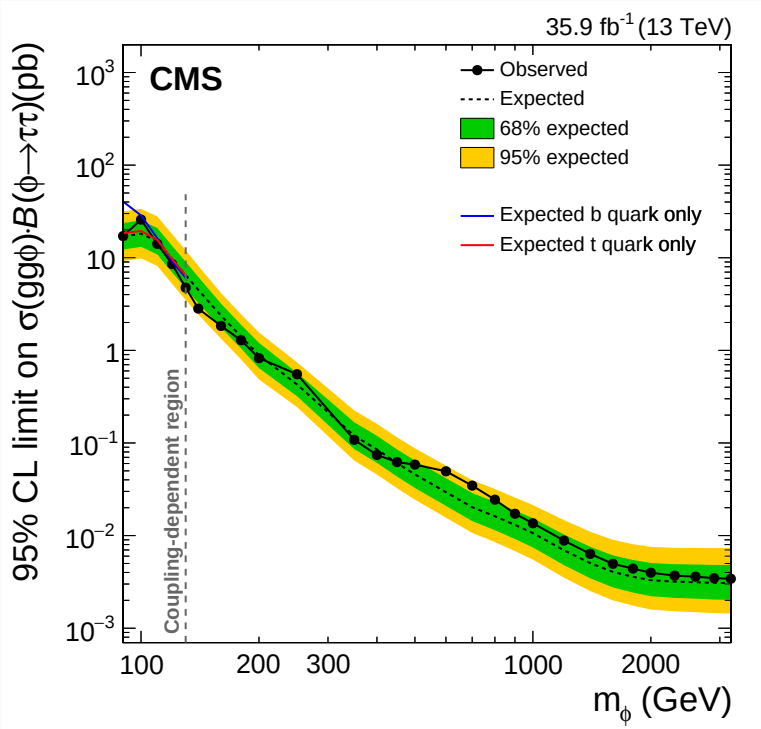
Current prescription

Current prescription is to treat each term differently

$$\frac{d\sigma}{dp_\perp^\phi} = \frac{d\sigma}{dp_\perp^\phi}\bigg|_{\text{top}} + \frac{d\sigma}{dp_\perp^\phi}\bigg|_{\text{bot}} + \frac{d\sigma}{dp_\perp^\phi}\bigg|_{\text{int}}$$

- Grid based on a 2HDM calculation
- Release a public access tool and a public note

Overview



Summary and outlook

- Ongoing work on the scenarios
- New ROOT file releases
- Ongoing activity on the Higgs $p_\perp^\phi$ framework, with the idea of publishing another WG note
- Possible interactions with other working groups

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