Status and plans of the MSSM subgroup

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The 19th workshop of the LHC Higgs working group

✉ lhc-higgs-mssm-group@cern.ch

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

- P. Slavich (LPTHE) stepped down (2012-2022)   [theory]

We would like to thank Pietro for all the outstanding work he performed for the working group during his subgroup convenership!

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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Benchmark Scenarios for MSSM
Higgs-Boson Searches at the LHC

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ROOT file note

- The public note on the ROOT files was accepted in its final version in January 2022 – `https://cds.cern.ch/record/2791954/`

- Release of the ROOT files on Zenodo has started (title of the record "LHCHWG MSSM ROOT files")

- Versioning of the Zenodo record is used – 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 $\tan \beta$ 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 → 13.6 TeV work-in-progress

Branching ratios

Neutral Higgs
$<\phi> = h,H,A$
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
$<\phi> = h,H,A$
$\mathcal{CP}$-violating scenario
$<\phi> = H1,H2,H3$
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_csW
br_Hp_SUSY
br_t_Hpb

Neutral Higgs
$\mathcal{CP}$-violating scenario
$<\phi> = H1,H2,H3$
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_H3_H2H1
br_H3_H1H1H1

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
$<\phi> = h,H,A$
$\mathcal{CP}$-violating scenario
$<\phi> = H1,H2,H3$
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>_scaleup
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
$<\phi> = h,H,A,Hp$
$\mathcal{CP}$-violating scenario
$<\phi> = H1,H2,H3,Hp$
m_<ϕ>

Couplings
$<\phi> = h,H,A$
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
$<\phi> = h,H,A,Hp$
$\mathcal{CP}$-violating scenario
$<\phi> = H1,H2,H3,Hp$
width_<ϕ>
width_HSM
width_t

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

Theory setup

- 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

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

$$+ \Gamma^{HD}_{\phi \to gg} + \Gamma^{HD}_{\phi \to \gamma\gamma} + \Gamma^{HD}_{\phi \to Z\gamma} + \Gamma^{FH}_{\phi \to Higgs} + \Gamma^{FH}_{\phi \to SUSY}$$

$$\Gamma_{H^\pm} = \Gamma^{FH}_{H^\pm \to \tau\nu_\tau} + \Gamma^{FH}_{H^\pm \to \mu\nu_\mu} + \Gamma^{FH}_{H^\pm \to hW} + \Gamma^{FH}_{H^\pm \to HW} + \Gamma^{FH}_{H^\pm \to AW} + \Gamma^{HD}_{H^\pm \to tb} + \Gamma^{HD}_{H^\pm \to ts}$$

$$+ \Gamma^{HD}_{H^\pm \to td} + \Gamma^{HD}_{H^\pm \to cb} + \Gamma^{HD}_{H^\pm \to cs} + \Gamma^{HD}_{H^\pm \to cd} + \Gamma^{HD}_{H^\pm \to ub} + \Gamma^{FH}_{H^\pm \to SUSY}$$

Cross sections at 13.6 TeV/PDF4LHC21 – open issues

- For gluon fusion no problem, since we use the code `SusHi` that we run autonomously
- New cross sections are/should be run with `PDF4LHC21` – consistency would require to rerun also the cross sections at 8 and 13 TeV with the same PDFs

- For $bb\phi$ we rescale the cross sections provided by bbH subgroup by the author of [1508.03288, 1605.01733].
- We are currently in contact with F. Tackmann (DESY) and M. Bonvini (INFN Rome 1) to provide grids at 13.6 TeV

  bbH

- For $tt\phi$ we rescale the cross sections provided by ttH subgroup, as they are included in `FeynHiggs`
- In contact with M. Zaro (ttH convener)

  ttH

- Intermediate mass range charged Higgs (145-200 GeV) computed using the results from [1607.05291]
- In contact with M. Zaro (U. Milano) to discuss how to proceed

  Charged Higgs

- For $v\phi$ we rescale the cross sections provided by VH subgroup, as they are included in `FeynHiggs`
- In contact with G. Ferrera (VH convener)

  VH

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
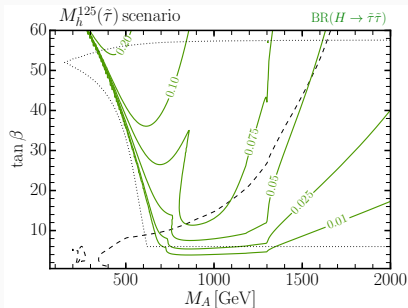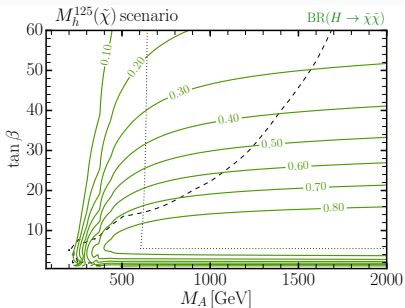
Higgs $p_\perp^\phi$ reiweighting

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`
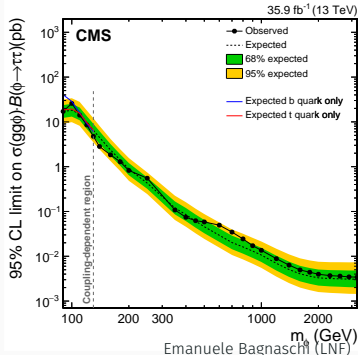- Effect included in the CMS analysis [JHEP 09 (2018) 007]

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
- ROOT files upgrade to support LHC 13.6 TeV analyses
- Possible interactions with other working groups

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