Status and plans of the MSSM subgroup

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4 December 2024

The 21th 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

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
WG support to the release of experimental likelihoods	In progress	Continuous
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Support the experimental effort, mainteinance of the ROOT files	In progress	Continuous
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Public note on the ROOT files

LHCHWG-2021-001

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
- Last update in September 2023 $\rightarrow$ fixed 14 TeV cross sections for the hMSSM

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 $\rightarrow$ 13.6 TeV work-in-progress

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 by the LHCHWG
- Charged Higgs cross sections are interpolated from LHCHWG grids as well

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

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

Cross sections at 13.6 TeV/PDF4LHC21

- For gluon fusion no problem, since we use the code **SusHi**
- PDF update?

- 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

ttH

- For $v\phi$ we rescale the cross sections provided by *VH* subgroup

VH

- Joined forces with the *Extended Higgs Sector subgroup* → See my talk on Thursday

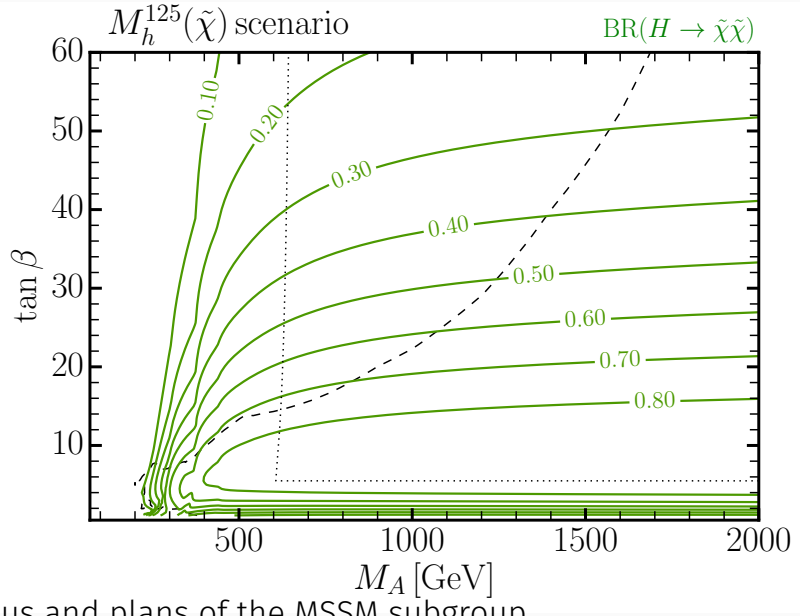
Charged Higgs

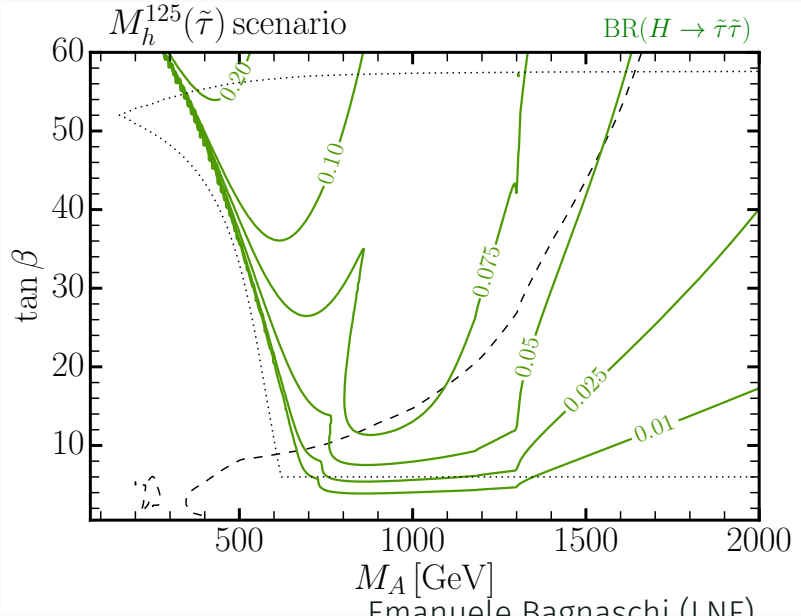
- Official interim results available from WG1 for 125 GeV Higgs (https://arxiv.org/pdf/2402.09955)
- Interpolation for the whole mass range available for everything but *ttH*

A/H to SUSY states

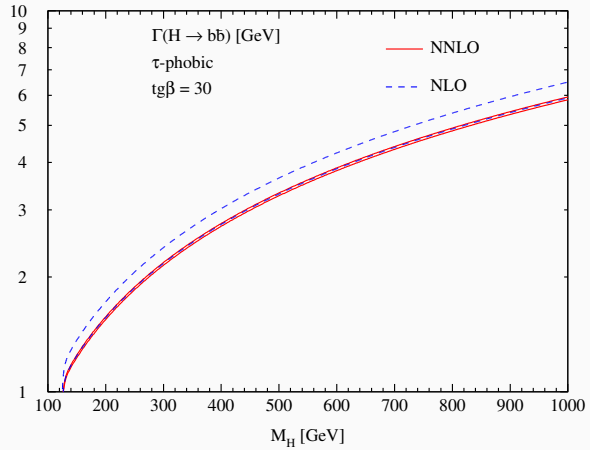
- Some of the scenarios are characterized by large branching ratios to SUSY states.
- A separate set of ROOT files is planned to be released with the different channels saved separately (in the current ROOT files all the BRs to SUSY are summed in a single histogram).
- Discussions in progress to see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

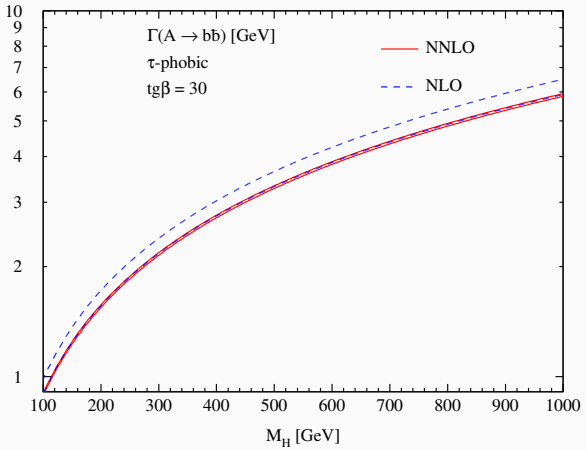
Higgs to BSM

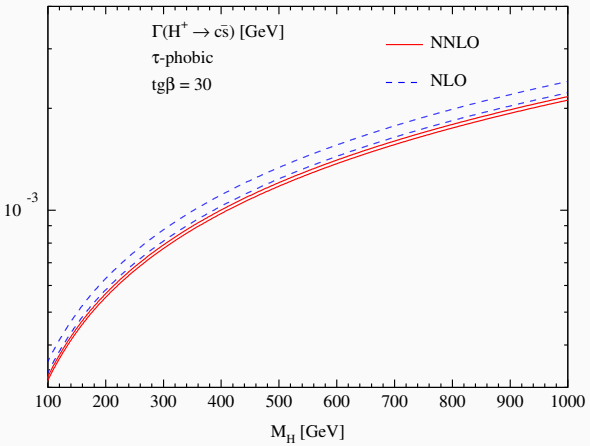




Developments on the theory side: neutral Higgs



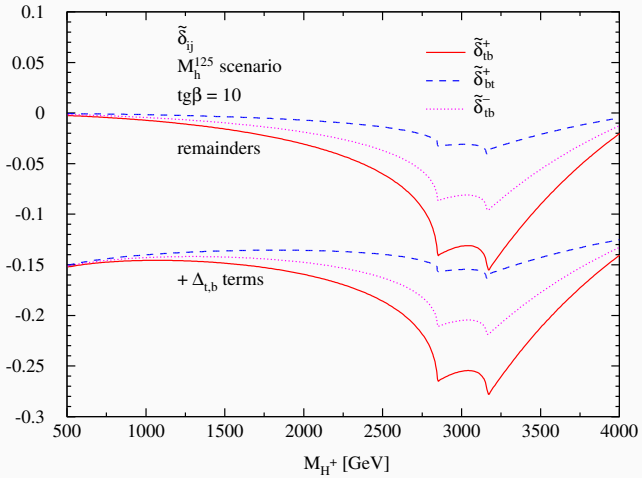


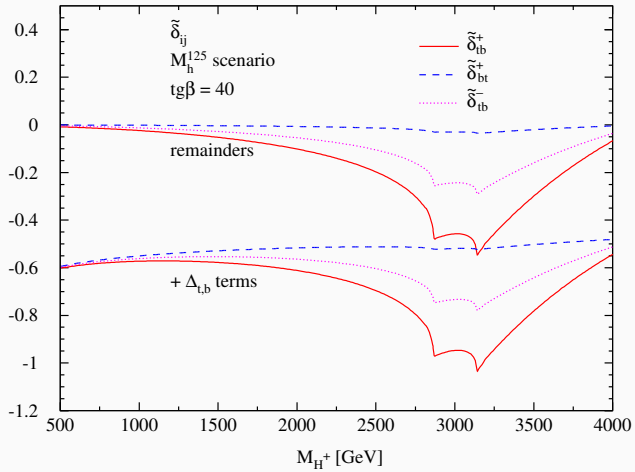


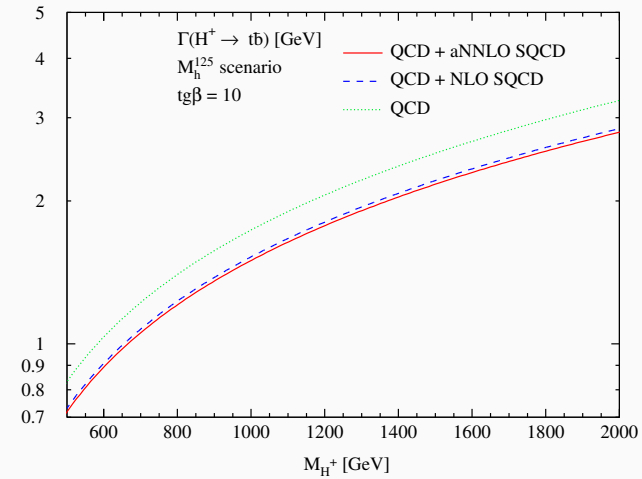
Ghezzi, Glaus, Müller, Schmidt, S.

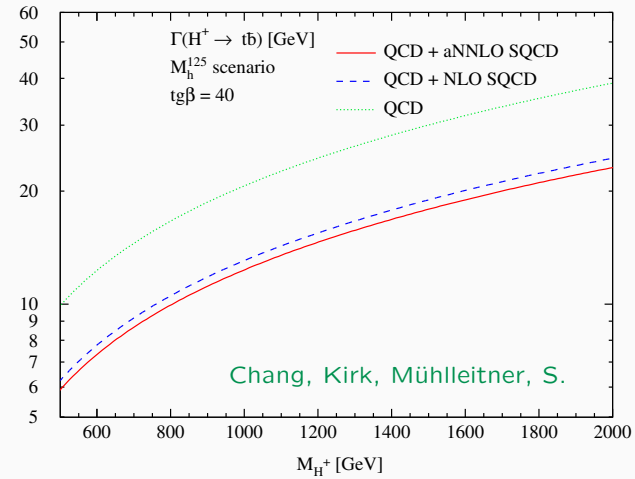
- Extension of Δ_b resummation to A_b terms and electroweak gauge couplings; calculation also extended for strange Yukawa couplings
- See the talk of M. Spira in the WG3 BSM Higgs parallel on Thursday

Developments on the theory side: charged Higgs









- Extension of Δ_t resummation
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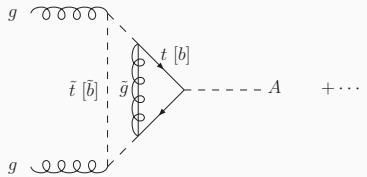
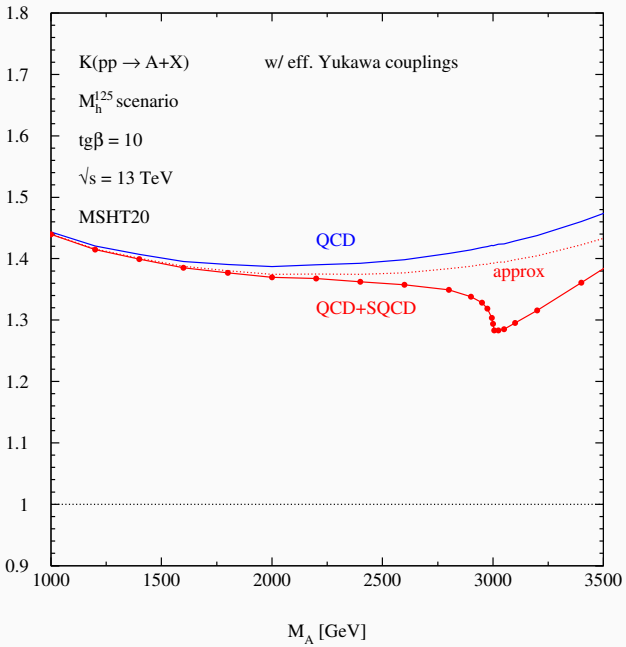
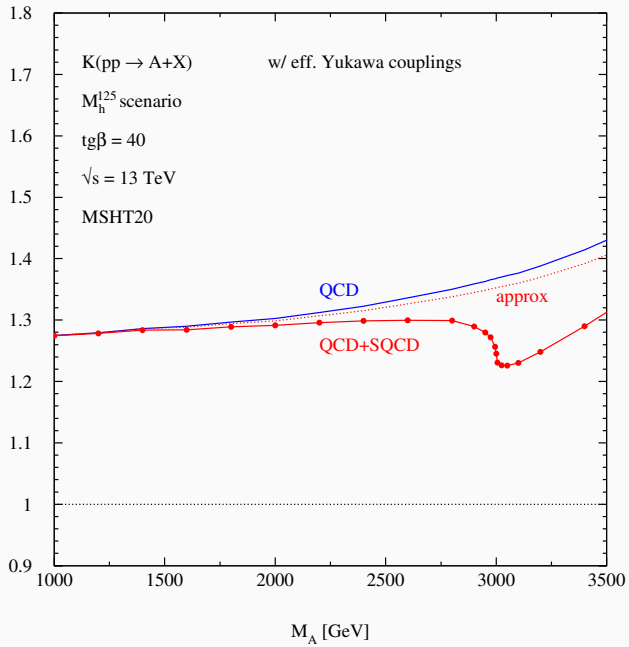
Developments on the theory side: ggH

$$\sigma(gg \to A) = \sigma_{LO}(\tilde{g}_t^A, \tilde{g}_b^A)\left[1 + \delta_{QCD} + \delta_{SQCD}\right]$$







Bagnaschi, Fritz, Liebler, Mühlleitner, Nguyen, S.

- $gg \to H$ complete SUSY-QCD calculation
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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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