Charged Higgs cross section plans

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Outline

Task force mission

- Joint effort between the **MSSM** and the **Extended Higgs sectors subgroup**
- To provide charged Higgs cross sections at 13.6 TeV
- To provide cross sections obtained with newer PDF sets, i.e. `PDF4LHC21`

MSSM 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>

Charged Higgs cross section in the MSSM ROOT files

- The cross section stored in the **ROOT** files comes from three different prediction sets, originally provided by the `Charged Higgs group`
- This subgroup was merged in 2018 into the `Extended Higgs sectors subgroup`
- The predictions are available at LHCHWGMSSMCharged-twiki

Cross section sets

- **low-mass range** ($m_{H^\pm} < 145$ GeV) -- actually we provide only the $\mathrm{BR}\,(t \to H^\pm b)$, the user is assumed to compute his own top production cross section
- **intermediate mass range** (145 GeV < $m_{H^\pm}$ < 200 GeV) -- cross sections provided by M. Zaro and collaborators [Degrande et al. 1607.05291]
- **high mass range** ($m_{H^\pm}$ > 200 GeV) -- 4FS and 5FS Santander matched cross sections

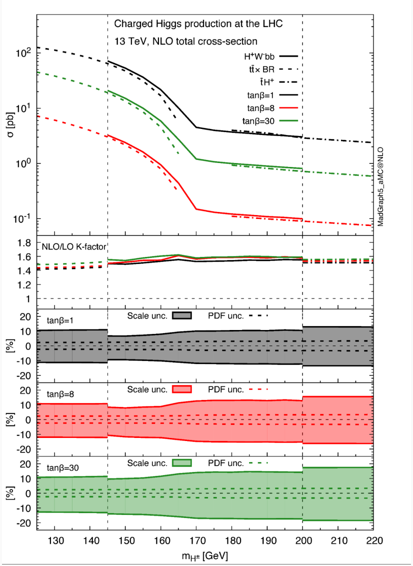
Caveats

Caveats

- No attempt has been made to smooth out the thresholds between the different predictions; more theory work needed to do this properly
- Original predictions were made available in a type-II 2HDM $\rightarrow$ MSSM effects included only via an effective bottom Yukawa coupling (Δ_b corrections).

  Recipe, for a given value of $\tan\beta$ (Sven Heinemeyer)
  - Obtain Δ_b from `FeynHiggs` (note that Δ_b can be complex)
  - Compute $\tan\beta_{\rm eff} = \frac{\tan\beta}{\sqrt{|1+\Delta_b|}}$
  - Look up the cross section for $\tan\beta_{\rm eff}$
  - Multiply the cross section by $\frac{1}{|1+\Delta_b|}$
- This is **not** appropriate for the low $\tan\beta$ regime $\rightarrow$ add a 10% uncertainty to the uncertainty estimation available by the grids

Matching between the different predictions



Further details on the behaviour of the scale uncertainties can be inferred from Fig. 3, where we compare our intermediate-mass range results to dedicated predictions for light and heavy charged Higgs production. The input parameters have been chosen consistently across all the mass range, in particular all cross sections are computed in the 4FS, the central scale for low-mass range is also set to $\mu = 125$ GeV, while the scale $\mu = (m_t + m_{H^\pm} + m_b)/3$ is used for the heavy charged Higgs case. The central predictions in the main frame develop a prominent structure with a kink at the threshold $m_{H^\pm} \simeq m_t - m_b$. The effect of the single-resonant contributions ($pp \to tW^-$ and $pp \to \bar{t}H^+$) is visible when comparing our results in the intermediate-mass range with the low-mass prediction. Indeed, the single-resonant contributions are missing in the low-mass prediction and amount to $10\% - 15\%$ of the $pp \to t\bar{t}$ cross section depending on the specific value of $\tan\beta$. In contrast, looking at the matching of the intermediate-mass predictions to the heavy charged Higgs cross section, we observe a $5\% - 10\%$ gap for $\tan\beta = 8$ and $\tan\beta = 30$, while there is essentially no gap for $\tan\beta = 1$. Such a gap originates from the non-resonant part of the $pp \to H^\pm W^\mp b\bar{b}$ amplitude, which, because of the chiral structure of the H^+tb and Wtb vertices, is enhanced (suppressed) for large (small) values of $\tan\beta$. At 145 and 200 GeV, the size of the scale uncertainty in the intermediate region and the side-bands is slightly different. These discontinuities are related to missing subleading terms in the predictions used in the low and high-mass regions, i.e. mostly single-resonant and non-resonant, respectively, although it is difficult to pin down exactly the origin of the discontinuities because of the non-trivial separation of these contributions beyond leading order. Finally, we note that the K-factor in the intermediate region interpolates very well the ones in the low and high-mass range.

[Degrande et al. 1607.05291]

- Pratical approach: mismatch not too large; made peple aware of the mismatch, but in first approximation provide no interpolation

Current status *Extended Higgs sector side*

Extended Higgs sector subgroup

- **low-mass range** ($m_{H\pm} < 145$ GeV) -- Updated in 2023 by Nikos, provided in the old mhmax scenario; top cross sections from ATLAS+CMS recommendations
- **intermediate mass range** (145 GeV < $m_{H\pm}$ < 200 GeV) -- cross sections provided by M. Zaro and collaborators [Degrande et al. 1607.05291], type I and type II 2HDM
- **high mass range** ($m_{H\pm}$ > 200 GeV) -- 4FS and 5FS Santander matched cross sections in a type II 2HDM. 8 and 14 TeV obtained with the use of `Prospino` (5FS) and a private code from M. Spira (4FS), while the 13 TeV (YR4) numbers are from M. Zaro

Plans and Work in progress

Joint work from the two subgroups

- **low-mass range** ($m_{H^\pm} < 145$ GeV) -- provide the cross sections in a generic type I 2HDM (N. Rompotis)
- **intermediate mass range** (145 GeV < $m_{H^\pm}$ < 200 GeV) -- cross sections provided by M. Zaro in a type II 2HDM (private code), will be managed by E. Bagnaschi and made available also a type I 2HDM grid
- **high mass range** ($m_{H^\pm}$ > 200 GeV) -- 4FS and 5FS Santander matched cross sections in a type II 2HDM
  - Cross check between `Prospino`/private code from M. Spira and `MG5_aMC@NLO`
  - For existing mass points, 13.6 TeV will be obtained via interpolation (but same PDF then (?))
  - Extension of the grids up to 2 TeV

Backup slides

2HDM Reweighting

miss effects due to the $\tan\beta$ dependence of the top width. We verified that, if the top-width dependence is included as an overall factor, we are able to reproduce our $\tan\beta = 1$ and $\tan\beta = 30$ NLO cross sections and uncertainties starting from the numbers at $\tan\beta = 8$ with an accuracy of 1% or better, using the relation (the dependence on $m_{H^\pm}$ is understood)

$$\sigma^{\mathrm{t-II}}(\tan\beta') = \left[\left(\frac{\tan\beta'}{\tan\beta}\right)^2 \sigma^{\mathrm{t-II}}_{y_b^2}(\tan\beta) + \sigma^{\mathrm{t-II}}_{y_b y_t}(\tan\beta) + \left(\frac{\tan\beta}{\tan\beta'}\right)^2 \sigma^{\mathrm{t-II}}_{y_t^2}(\tan\beta)\right] \times \left(\frac{\Gamma_t(\tan\beta)}{\Gamma_t(\tan\beta')}\right)^2 . \quad (1)$$

This also shows that effects due to the width-dependent complex phase of y_t are very small. Concerning how to extend our results in a type-I 2HDM, we first point out that for $\tan\beta = 1$, the cross-section is identical to the type-II case. Then, the cross-section for any other value of $\tan\beta$ can be simply obtained as

$$\sigma^{\mathrm{t-I}}(\tan\beta') = \frac{\sigma^{\mathrm{t-I}}(\tan\beta = 1)}{(\tan\beta')^2} \times \left(\frac{\Gamma_t(\tan\beta)}{\Gamma_t(\tan\beta')}\right)^2 . \quad (2)$$

[Degrande et al. 1607.05291]