Pseudoscalar Higgs Decays into Electroweak Gauge Bosons

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Introduction

- Higgs decays into electroweak gauge bosons yield very clean signals.
- For a sufficiently heavy (SM) Higgs the decay into WW and ZZ are the dominant decay modes.
- The CP eigenvalue of the Higgs can (in principle) be determined in these decay modes by measuring the angle between the decay planes of the Ws or Zs.

Pseudoscalar Higgses

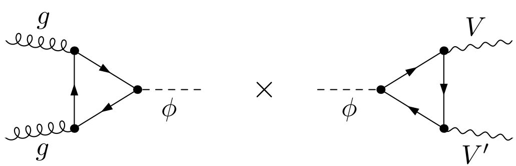
- Most non-standard Higgs sectors also contain pseudoscalar particles.
- In models without Higgs sector CP violation, there are no tree-level couplings between pseudoscalar Higgses and gauge bosons.
- The bosonic sectors of most SM extensions conserve parity and cannot induce AVV' couplings at any order.

  $\Rightarrow$ AVV' couplings must be induced trough fermion loops.

  $\Rightarrow$ The branching ratios are usually expected to be small.
- But: If the Higgs-fermion couplings are large the loop-induced decays might be visible.

Higgs Production

- At the LHC the dominant production mode is gluon fusion.
- We compute $\sigma(pp \to \phi \to VV')$ (with $\phi = H, A$ and $VV' = WW,\ ZZ,\ Z\gamma,\ \gamma\gamma$) in the narrow width approximation



$$\sigma(pp \to \phi) \quad \times \quad B(\phi \to VV')$$

$\Rightarrow$ Strong couplings of ϕ to coloured particles enhances production cross section and branching ratio.

How large can the cross sections $\sigma(pp \to \phi \to VV')$ get in different SM extensions?

Effective Coupling Approximation

- In the SM, two loop QCD corrections to $\sigma(gg \to H)$ can be as large as 100%. [Djouadi, Graudenz, Spira, Zerwas (1993)]
- In an SM extension we can approximate $\sigma(gg \to \phi)_{\mathsf{BSM}}$ by

$$\sigma(gg \to \phi)_{\mathsf{BSM}} \approx \sigma(gg \to H_{\mathsf{ref}})_{\mathsf{SM}} \frac{\Gamma(\phi \to gg)_{\mathsf{BSM}}}{\Gamma(H_{\mathsf{ref}} \to gg)_{\mathsf{SM}}} ,$$

  with $\phi = H, A$ and $m_{H_{\mathsf{ref}}} = m_\phi$.
- $\sigma(gg \to H_{\mathsf{ref}})_{\mathsf{SM}}$ and $\Gamma(H_{\mathsf{ref}} \to gg)_{\mathsf{SM}}$ were extracted from `FeynHiggs`. [Heinemeyer, Hollik, Rzehak, Weiglein]

The Two Higgs Doublet Model

Consider a type-II two-Higgs doublet model with a CP invariant Higgs potential.

Spin zero particle content:

- two neutral scalar Higgses h, H.
- one neutral pseudoscalar Higgs A.
- one charged Higgs $H^{\pm}$.

Parameters:

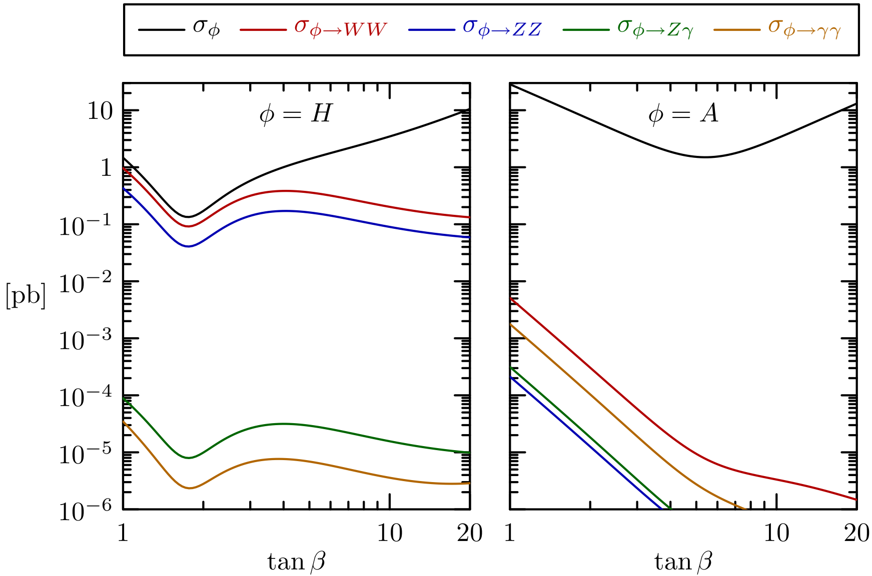
- $\tan\beta$ (ratio of the two VEVs).
- Scalar Higgs mixing angle α.
- m_{12}^2 (off-diagonal mass term).

Experimental Bounds

The 2HDM parameter space is constrained by

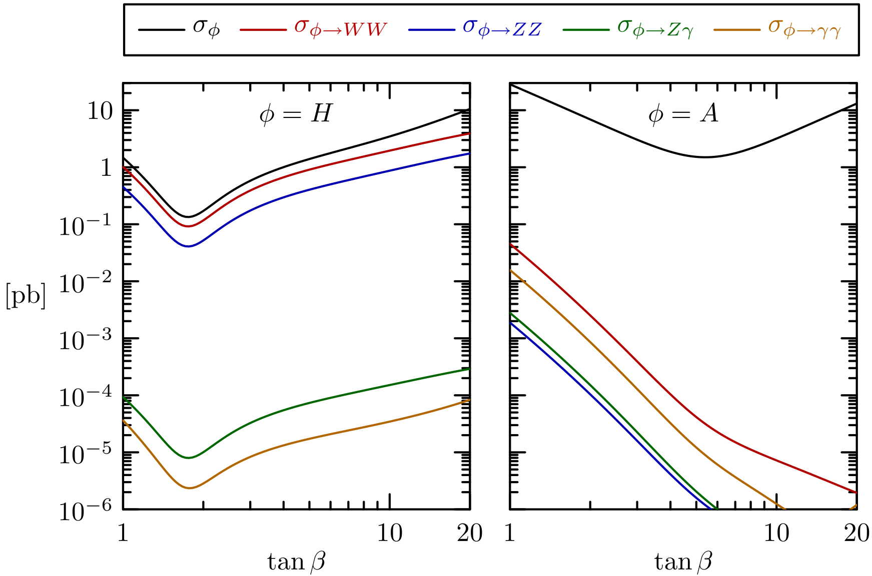
- Direct searches at LEP and TEVATRON (`HiggsBounds`) [Bechtle, Brein, Heinemeyer, Weiglein, Williams]
- Electroweak precision data (`2HDMC`) [Eriksson, Rathsman, Stål]
- R_b $(\tan\beta > 1)$
- $b \to s\gamma$ $(m_{H^\pm} > 300\,\mathrm{GeV})$

2HDM Cross Sections



$m_h = 115\,\mathrm{GeV}$, $m_H = m_A = 300\,\mathrm{GeV}$, $m_{H^\pm} = 350\,\mathrm{GeV}$, $\beta - \alpha = \pi/3$.

2HDM Cross Sections



$m_h = 190\,\text{GeV}$, $m_H = m_A = 300\,\text{GeV}$, $m_{H^\pm} = 350\,\text{GeV}$,
$\beta - \alpha = \pi/3$.

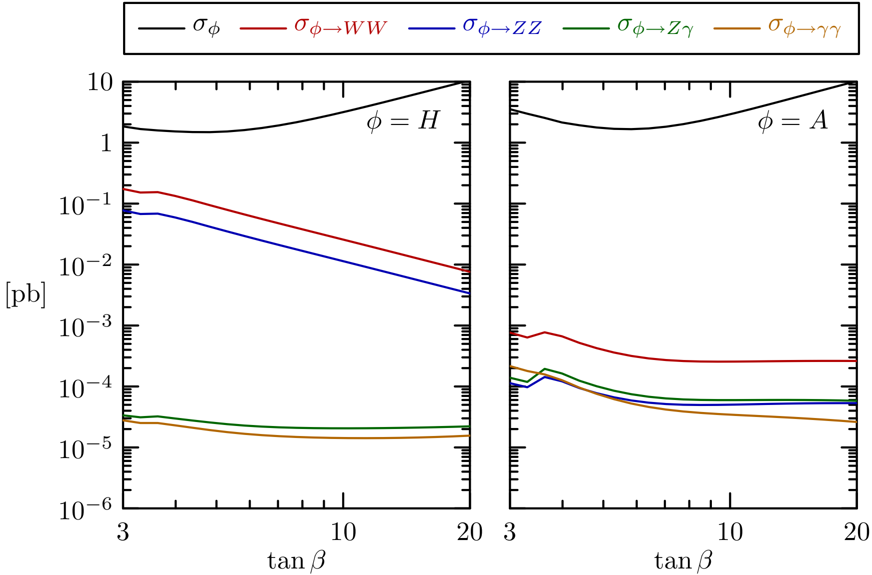
MSSM

- In the MSSM decays of the pseudoscalar Higgs can also be mediated by chargino and neutralino loops.
- The chargino/neutralino-Higgs couplings are not proportional to the chargino/neutralino mass.
- Charginos and neutralinos can still have masses of $\mathcal{O}(100\,\mathrm{GeV})$.

Parameters:

$$\mu = 200\,\mathrm{GeV} \quad , \quad M_1 = \frac{5s_W^2}{3c_W^2} M_2 \quad , \quad m_{\tilde{g}} = 500\,\mathrm{GeV} \quad ,$$
$$M_{L_i} = M_{E_i} = M_{Q_i} = M_{D_i} = M_{U_{1,2}} = 500\,\mathrm{GeV} \quad ,$$
$$A_{L_i} = A_{U_{1,2}} = A_{D_i} = 0 \quad ,$$
$$m_h = 115\,\mathrm{GeV} \quad , \quad m_A = 300\,\mathrm{GeV} \quad ,$$
$$m_{\tilde{\chi}_1^0} = 100\,\mathrm{GeV} \quad , \quad m_{\tilde{t}_1} = 400\,\mathrm{GeV} \quad .$$

MSSM Cross Sections



A 4th Generation of Fermions

- We consider a 4th generation of heavy chiral fermions $(u_4, d_4, \nu_4, \ell_4)$ with Dirac neutrinos.

- Mass bounds from direct searches at LEP and TEVATRON:

$$m_{u_4} > 310\,\mathrm{GeV}\ ,\ m_{d_4} > 190\,\mathrm{GeV}\ ,$$
$$m_{\nu_4} > 90\,\mathrm{GeV}\ ,\ m_{\ell_4} > 100\,\mathrm{GeV}\ .$$

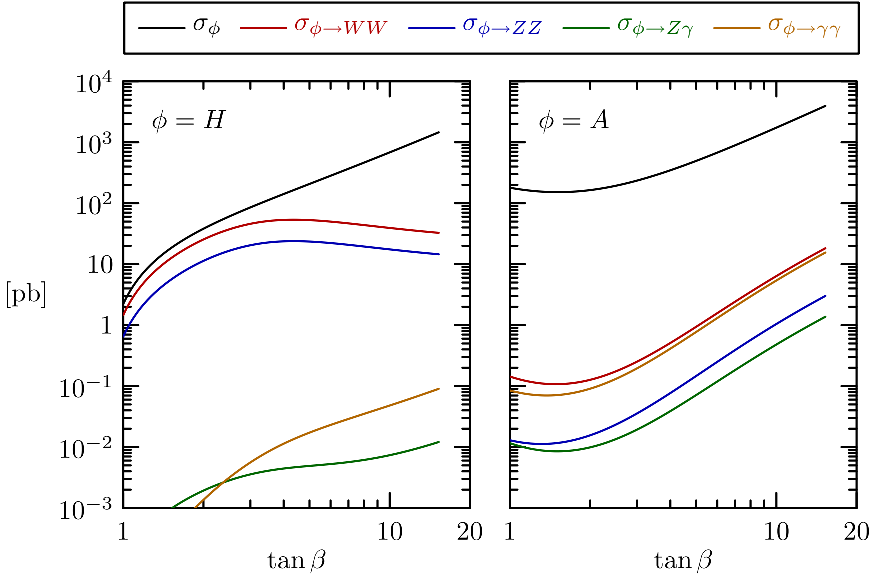
- The strongest constraints come from the oblique electroweak parameters S and T. [Kribs, Plehn et al. arXiv:0706.3718]

$$m_{u_4} = 310\,\mathrm{GeV}\ ,\ m_{d_4} = 260\,\mathrm{GeV}\ ,$$
$$m_{\nu_4} = 100\,\mathrm{GeV}\ ,\ m_{\ell_4} = 155\,\mathrm{GeV}$$
$$\Rightarrow \quad \Delta S_{\text{4th gen}} = 0.15 \quad , \quad \Delta T_{\text{4th gen}} = 0.19$$

- For our choice of 2HDM parameters:

$$\Delta S_{\text{2HDM}} = 0.02 \quad , \quad \Delta T_{\text{2HDM}} = 0.06$$

2HDM+4 Cross Sections



$m_h = 115\,\text{GeV}$, $m_H = m_A = 300\,\text{GeV}$, $m_{H^\pm} = 350\,\text{GeV}$, $\beta - \alpha = \pi/3$.

Conclusions

2HDM:

- $B(A \to VV')$ decrease rapidly with increasing $\tan\beta$.
- Largest $pp \to A \to VV'$ cross sections of $\mathcal{O}(0.01\,\text{pb})$ for small $\tan\beta$ and large m_h.

MSSM:

- Chargino/neutralino loops assure $pp \to A \to VV'$ cross sections of $\mathcal{O}(10^{-4}\,\text{pb})$ also for large $\tan\beta$.

2HDM + 4th generation:

- In the 2HDM a 4th generation of fermions can greatly enhance both $\sigma(pp \to \phi)$ and $B(\phi \to VV')$.
- For large $\tan\beta$ the $pp \to A \to VV'$ cross sections can exceed $1\,\text{pb}$.