Higgs-boson decay to four fermions in the Two-Higgs-Doublet Model and PROPHECY4F

Heidi Rzehak

in collaboration with Lukas Altenkamp and Stefan Dittmaier

based on arXiv:1704.02645 and arXiv:1710.07598

CP3 Origins, SDU, Odense

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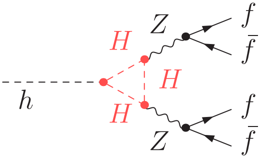
Higgs-boson decay to four fermions

- One of the best measured Higgs-decay channels
- Higgs decay to four charged leptons: very clean channel
- Beyond-Standard-Model effects?



Two-Higgs-Doublet Model

Simple extension of the Standard Model:

- Only one Higgs doublet added to the Standard Model
- Simplest extension containing a charged Higgs boson (3 neutral, 2 charged)
- Embedded in other, more “complete” theories, e.g. supersymmetric extensions such as the MSSM

Two-Higgs-Doublet Model

Higgs potential:

$$\begin{aligned}V = {} & m_{11}^2 \Phi_1^\dagger \Phi_1 + m_{22}^2 \Phi_2^\dagger \Phi_2 + m_{12}^2 (\Phi_1^\dagger \Phi_2 + \text{h.c.}) \\ & + \lambda_1 (\Phi_1^\dagger \Phi_1)^2 + \lambda_2 (\Phi_2^\dagger \Phi_2)^2 + \lambda_3 (\Phi_1^\dagger \Phi_1)(\Phi_2^\dagger \Phi_2) \\ & + \lambda_4 (\Phi_1^\dagger \Phi_2)(\Phi_2^\dagger \Phi_1) + \lambda_5 \left[(\Phi_1^\dagger \Phi_2)^2 + (\Phi_2^\dagger \Phi_1)^2 \right]\end{aligned}$$

- CP conserving
- invariant under $\Phi_1 \to -\Phi_1$ for $m_{12}^2 = 0$

with the complex scalar $SU(2)$ doublets:

$$\Phi_1 = \frac{1}{\sqrt{2}} \begin{pmatrix} \phi_1^+ \\ v_1 + \eta_1 + \mathrm{i}\chi_1 \end{pmatrix} \qquad \Phi_2 = \frac{1}{\sqrt{2}} \begin{pmatrix} \phi_2^+ \\ v_2 + \eta_2 + \mathrm{i}\chi_2 \end{pmatrix}$$

Two-Higgs-Doublet Model

Higgs potential:

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- CP conserving
- invariant under $\Phi_1 \to -\Phi_1$ for $m_{12}^2 = 0$
- m_{11}^2, m_{22}^2 fixed by minimum condition
  m_{12}^2, λ_1, ..., λ_5 free parameters

⇒ enough free parameters to define all Higgs masses independently

⇒ all Higgs masses can be chosen as pole masses (on-shell)

Higgs-mass eigenstates

CP-even Higgs bosons:

$$\begin{pmatrix} H \\ h \end{pmatrix} = \begin{pmatrix} \cos\alpha & \sin\alpha \\ -\sin\alpha & \cos\alpha \end{pmatrix} \begin{pmatrix} \eta_1 \\ \eta_2 \end{pmatrix}$$

CP-odd Higgs bosons:

$$\begin{pmatrix} G^0 \\ A^0 \end{pmatrix} = \begin{pmatrix} \cos\beta_{\mathsf{n}} & \sin\beta_{\mathsf{n}} \\ -\sin\beta_{\mathsf{n}} & \cos\beta_{\mathsf{n}} \end{pmatrix} \begin{pmatrix} \chi_1 \\ \chi_2 \end{pmatrix} \quad \text{with} \quad \tan\beta_{\mathsf{n}} = \tan\beta = \frac{v_2}{v_1} \text{ at LO}$$

Charged Higgs bosons:

$$\begin{pmatrix} G^\pm \\ A^\pm \end{pmatrix} = \begin{pmatrix} \cos\beta_{\mathsf{c}} & \sin\beta_{\mathsf{c}} \\ -\sin\beta_{\mathsf{c}} & \cos\beta_{\mathsf{c}} \end{pmatrix} \begin{pmatrix} \phi_1^\pm \\ \phi_2^\pm \end{pmatrix} \quad \text{with} \quad \tan\beta_{\mathsf{c}} = \tan\beta \text{ at LO}$$

Input parameters

Originally:

$$\overbrace{m_{11}^2 \quad m_{22}^2 \quad m_{12}^2 \quad \lambda_1 \quad \lambda_2 \quad \lambda_4}^{\text{parameters of Higgs potential}} \qquad \overbrace{v_1 \quad v_2}^{\text{vacuum expectation values}} \qquad \overbrace{g \quad g'}^{\text{gauge couplings}} \qquad \overbrace{\lambda_3 \quad \lambda_5}^{\text{parameters of Higgs potential}}$$

Chosen:

$$\underbrace{\overbrace{t_h \quad t_H}^{\text{tadpole parameters}}}_{\text{Minimum condition}} \quad \underbrace{\overbrace{M_h \quad M_H \quad M_A \quad M_{H^+}}^{\text{Higgs masses}} \quad \overbrace{M_W \quad M_Z}^{\text{gauge-boson masses}} \quad \overbrace{e}^{\text{electric charge}}}_{\text{on-shell}} \quad \underbrace{\overbrace{\tan\beta}^{=\frac{v_2}{v_1}} \quad \overset{\substack{\text{mixing angle}\\ \downarrow}}{\lambda_3/\alpha} \quad \lambda_5}_{\overline{\text{MS}}}$$

Renormalization

see also [Santos, Barroso 97, Kanemura, Okada, Senaha, Yuan hep-ph/0408364; Lopez-Val, Sola 0908.2898; Degrande 1406.3030; Krause, Mühlleitner, Lorenz, Santos, Ziesche 1605.04853; Denner, Jenniches, Lang, Sturm 1607.07352; Krause, Mühlleitner, Santos, Ziesche 1609.04185]

On-shell renormalization:

- Masses M_h, M_H, M_A, M_{H^+}, M_W, M_Z: Pole masses
- Fields exploiting matrix-valued renormalization:

$$\begin{pmatrix} H_0 \\ h_0 \end{pmatrix} = \begin{pmatrix} 1+\frac{1}{2}\delta Z_H & \frac{1}{2}\delta Z_{Hh} \\ \frac{1}{2}\delta Z_{hH} & 1+\frac{1}{2}\delta Z_h \end{pmatrix} \begin{pmatrix} H \\ h \end{pmatrix} \text{ etc.}$$

  → no mixing of external on-shell fields

- Electric charge: via $ee\gamma$ vertex in the Thomson limit

$\overline{\text{MS}}$ renormalization:

- $\tan\beta$
- λ_3 or α
- λ_5

$\left.\begin{matrix} \tan\beta \\ \lambda_3 \text{ or } \alpha \\ \lambda_5 \end{matrix}\right\} \rightarrow$ renormalization-scale dependent parameter

Remark about mixing angles

A priori: at NLO not well-defined:

can be absorbed by field-renormalization constants

→ no need to renormalize mixing angles

But: If original parameters replaced by mixing angles

→ mixing angle fixed via the relation between original parameter and α

Tadpole renormalization

Two variants:

a) Vanishing renormalized tadpoles: $t_{S,0} = \overbrace{t_S}^{=0} + \delta t_S$

Condition: $\delta t_S + (\text{explicit tadpole loops}) = 0$

$\Rightarrow$ no explicit tadpole diagrams need to be included

Disadvantage: $t_{S,0} = \delta t_S$ enters in relations between bare input parameters
→ potentially gauge-dependent terms enter relations between renormalized parameters and observables

b) Vanishing bare tadpoles: $t_{S,0} = 0$ [Fleischer, Jegerlehner 80; Actis, Ferroglia, Passera, Passarino hep-ph/0612122]

Explicit tadpole diagrams have to be taken into account
Advantage: no gauge-dependent δt_S enters in relations between bare input parameters
→ relation between renormalized parameters and observables are gauge independent

Four possibilities for λ_3/α and β

- Scheme $\lambda_{3_{\overline{\text{MS}}}}$: see [Altenkamp, Dittmaier, HR 1704.02645]

  λ_3 $\overline{\text{MS}}$, $\tan\beta$ $\overline{\text{MS}}$
  tadpole scheme: $t_S = 0$

- Scheme $\alpha_{\overline{\text{MS}}}$:

  α instead of λ_3: α $\overline{\text{MS}}$, $\tan\beta$ $\overline{\text{MS}}$
  tadpole scheme: $t_S = 0$

- Scheme FJ:

  α $\overline{\text{MS}}$, $\tan\beta$ $\overline{\text{MS}}$
  tadpole scheme: $t_{S,0} = 0$

- Scheme FJ λ_3:

  λ_3 $\overline{\text{MS}}$, $\tan\beta$ $\overline{\text{MS}}$
  tadpole scheme: $t_{S,0} = 0$

see also [Krause, Mühlleitner, Lorenz,
Santos, Ziesche 1605.04853;
Denner, Jenniches, Lang,
Sturm 1607.07352]

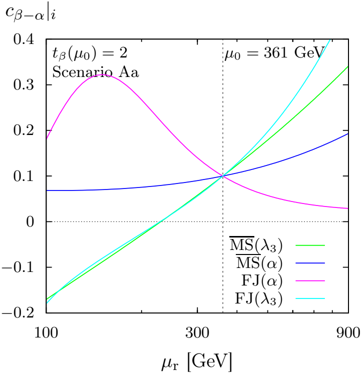
Running of $\cos(\beta - \alpha)$ in different schemes

[Altenkamp, Dittmaier, HR 1704.02645, 1710.07598]

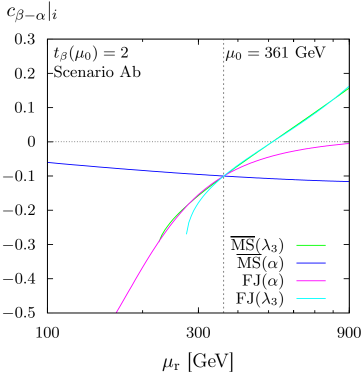
Scenario A: $M_h = 125$ GeV, $M_H = 300$ GeV, $M_{A_0} = M_{H^+} = 460$ GeV, $\lambda_5 = -1.9$, $\tan\beta = 2$

$\mu_0 = M_h + M_H + M_A + 2M_{H^+}$ for 2HDM type 1

Aa: $\cos(\beta - \alpha)|_{\text{input scheme}}(\mu_0) = 0.1$:



Ab: $\cos(\beta - \alpha)|_{\text{input scheme}}(\mu_0) = -0.1$:

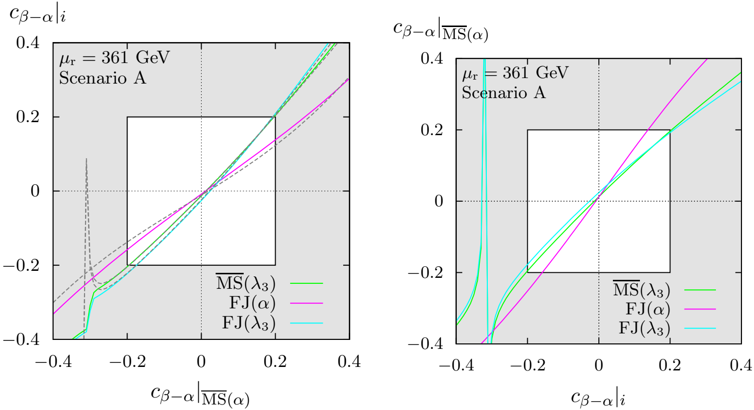


⇒ sizeable running effects

Conversion of parameters

[Altenkamp, Dittmaier, HR 1704.02645, 1710.07598]

Conversion: $p_{\mathrm{RS2}} = p_{\mathrm{RS1}} + \delta p_{\mathrm{RS1}}(p_{\mathrm{RS1}}) - \delta p_{\mathrm{RS2}}(p_{\mathrm{RS2}})$



- Scenarios depend on the chosen renormalization scheme.

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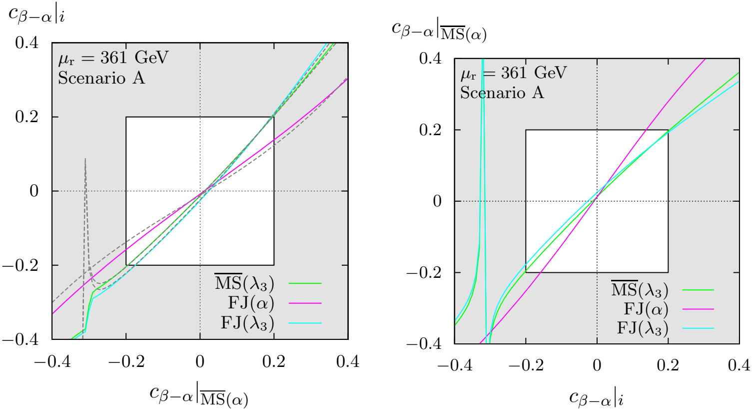

- Peak region: λ_3 is a bad input parameter if $\cos(2\alpha) \approx 0$,
  (to avoid the issue: choose different λ_i).

Implementation in `PROPHECY4F`

`PROPHECY4F`: A Monte Carlo generator for a
Proper description of the Higgs decay into 4 fermions

[Bredenstein, Denner, Dittmaier, Weber hep-ph/0604011; hep-ph/0607060; hep-ph/0611234]

→ use the functionality of `PROPHECY4F` for 2HDM

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Implementation:

- model file generation with and without `FeynRules` [Christensen, Duhr 0806.4194]

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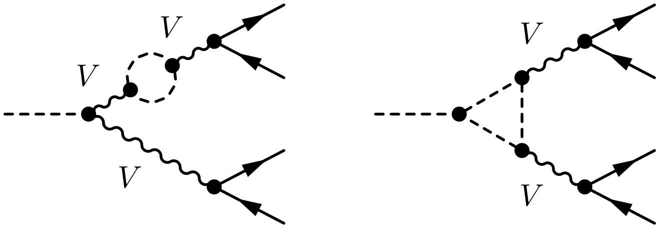

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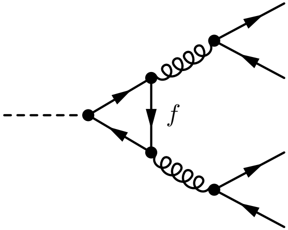
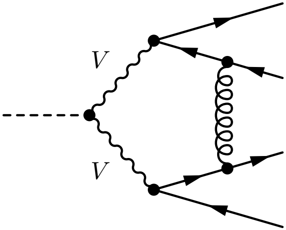
  virtual QCD diagrams: obtained by proper rescaling of Higgs couplings





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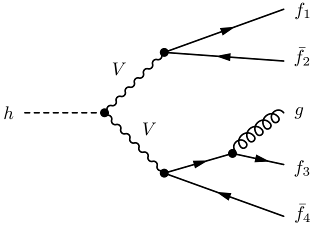
  real diagrams: obtained by rescaling of Higgs coupling $g_{hVV} = \sin(\beta - \alpha) g_{hVV}^{\mathrm{SM}}$



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- W/Z resonances treated in complex-mass scheme

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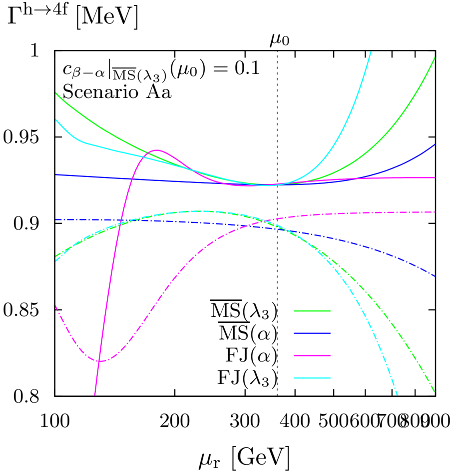
- infrared divergences treated with dipole subtraction [Catani, Seymour hep-ph/9605323; Dittmaier hep-ph/9904440]

μ dependence of $\Gamma(h \to 4f)$

[Altenkamp, Dittmaier, HR 1704.02645]



$\mu_0 = (M_h + M_H + M_{A_0} + 2M_{H^+})/5$

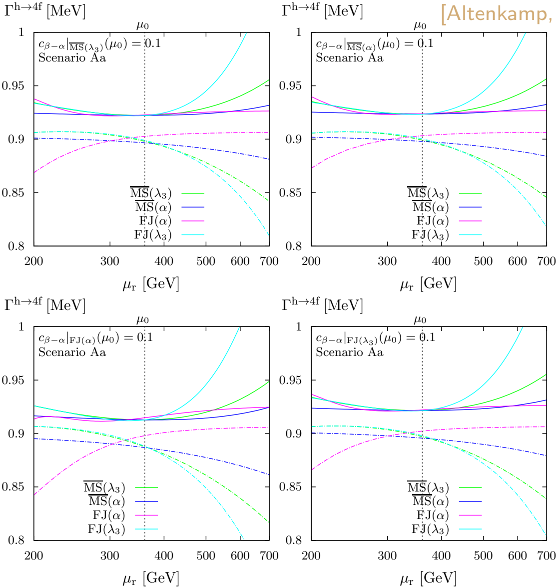
LO: dashed

NLO EW: solid

- Scheme λ_3 $\overline{\mathrm{MS}}$ used
- Clear plateau around $\mu_r = \mu_0$ at NLO
- Scale dependence reduced from LO to NLO

μ dependence of $\Gamma(h \to 4f)$

[Altenkamp, Dittmaier, HR 1710.07598]

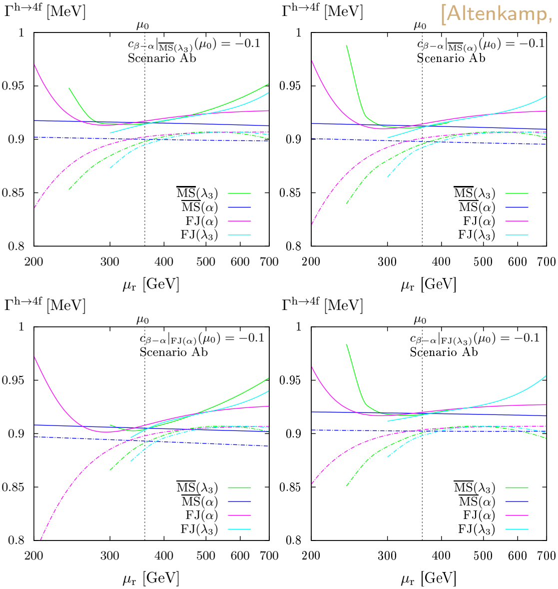


For all input schemes:

- Clear plateau
- Reduction of scale dependence from LO to NLO

μ dependence of $\Gamma(h \to 4f)$

[Altenkamp, Dittmaier, HR 1710.07598]



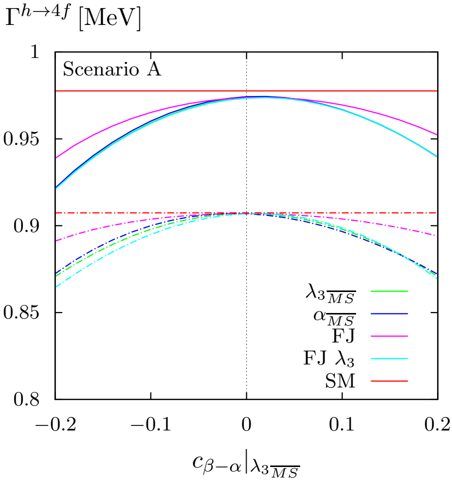
Now scenario Ab:

For all input schemes:

- Plateau
- Reduction of scale dependence from LO to NLO

$\cos(\beta-\alpha)$ dependence of $\Gamma(h \to 4f)$

[Altenkamp, Dittmaier, HR 1704.02645, 1710.07598]



$\mu_0 = (M_h + M_H + M_{A_0} + 2M_{H^+})/5$

LO: dashed

NLO: solid

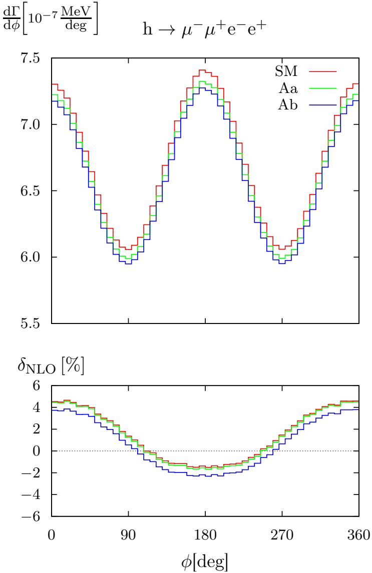
- Scheme λ_3 $\overline{\text{MS}}$ used:

$$\Gamma^{h\to 4f}_{\text{2HDM, LO}}\Big|_{\lambda_3,\overline{\text{MS}}} = s^2_{\beta-\alpha}\Gamma^{h\to 4f}_{\text{SM, LO}}$$

Partial decay widths for scenario Ab (scheme λ_3 $\overline{\mathrm{MS}}$)

Final state	$\Gamma^{\mathrm{h}\to 4f}_{\mathrm{NLO}}$ [MeV]	δ_{EW} [%]	δ_{QCD} [%]	$\Delta^{\mathrm{NLO}}_{\mathrm{SM}}$ [%]	$\Delta^{\mathrm{LO}}_{\mathrm{SM}}$ [%]
inclusive $\mathrm{h}\to 4f$	0.95980(7)	1.87(0)	4.97(1)	−1.82(1)	−1.00(1)
ZZ	0.105464(5)	−0.34(0)	4.90(0)	−1.75(1)	−1.00(0)
WW	0.85938(8)	2.14(0)	5.01(1)	−1.83(1)	−1.00(1)
WW/ZZ int.	−0.00504(5)	0.5(1)	10.7(8)	−2(1)	−1(1)
$\nu_{\mathrm{e}}\mathrm{e}^+\mu^-\bar{\nu}_\mu$	0.010116(1)	2.17(1)	0.00	−1.87(1)	−1.00(1)
$\nu_{\mathrm{e}}\mathrm{e}^+\mathrm{u}\bar{\mathrm{d}}$	0.031463(4)	2.16(0)	3.76(1)	−1.84(2)	−1.00(1)
$\mathrm{u}\bar{\mathrm{d}}\mathrm{s}\bar{\mathrm{c}}$	0.09770(2)	2.11(0)	7.52(1)	−1.81(2)	−1.00(1)
$\nu_{\mathrm{e}}\mathrm{e}^+\mathrm{e}^-\bar{\nu}_{\mathrm{e}}$	0.010112(1)	2.27(1)	0.00	−1.87(1)	−1.00(1)
$\mathrm{u}\bar{\mathrm{d}}\mathrm{d}\bar{\mathrm{u}}$	0.09972(2)	1.99(0)	7.38(2)	−1.80(2)	−1.00(1)
$\nu_{\mathrm{e}}\bar{\nu}_{\mathrm{e}}\nu_\mu\bar{\nu}_\mu$	0.000943(0)	2.34(0)	0.00	−1.78(1)	−1.00(1)
$\mathrm{e}^-\mathrm{e}^+\mu^-\mu^+$	0.000237(0)	0.62(1)	0.00	−1.79(2)	−1.00(1)
$\nu_{\mathrm{e}}\bar{\nu}_{\mathrm{e}}\mu^-\mu^+$	0.000474(0)	1.78(1)	0.00	−1.78(2)	−1.00(1)
$\nu_{\mathrm{e}}\bar{\nu}_{\mathrm{e}}\nu_{\mathrm{e}}\bar{\nu}_{\mathrm{e}}$	0.000565(0)	2.23(0)	0.00	−1.79(2)	−1.00(1)
$\mathrm{e}^-\mathrm{e}^+\mathrm{e}^-\mathrm{e}^+$	0.000131(0)	0.45(1)	0.00	−1.78(2)	−1.00(1)
$\nu_{\mathrm{e}}\bar{\nu}_{\mathrm{e}}\mathrm{u}\bar{\mathrm{u}}$	0.001668(0)	−0.08(1)	3.76(1)	−1.76(2)	−1.00(1)
$\nu_{\mathrm{e}}\bar{\nu}_{\mathrm{e}}\mathrm{d}\bar{\mathrm{d}}$	0.002163(0)	1.02(0)	3.76(1)	−1.76(2)	−1.00(1)
$\mathrm{e}^-\mathrm{e}^+\mathrm{u}\bar{\mathrm{u}}$	0.000840(0)	−0.57(1)	3.76(1)	−1.77(2)	−1.00(1)
$\mathrm{e}^-\mathrm{e}^+\mathrm{d}\bar{\mathrm{d}}$	0.001081(0)	−0.21(1)	3.76(1)	−1.76(2)	−1.00(1)
$\mathrm{u}\bar{\mathrm{u}}\mathrm{c}\bar{\mathrm{c}}$	0.002952(0)	−2.48(1)	7.51(1)	−1.75(2)	−1.00(1)
$\mathrm{d}\bar{\mathrm{d}}\mathrm{d}\bar{\mathrm{d}}$	0.002545(1)	−1.06(0)	4.57(2)	−1.67(3)	−1.00(1)
$\mathrm{d}\bar{\mathrm{d}}\mathrm{s}\bar{\mathrm{s}}$	0.004925(1)	−1.04(0)	7.51(1)	−1.74(2)	−1.00(1)
$\mathrm{u}\bar{\mathrm{u}}\mathrm{s}\bar{\mathrm{s}}$	0.003828(1)	−1.35(1)	7.51(1)	−1.74(2)	−1.00(1)
$\mathrm{u}\bar{\mathrm{u}}\mathrm{u}\bar{\mathrm{u}}$	0.001500(0)	−2.60(1)	4.31(2)	−1.65(3)	−1.00(1)

Example distribution



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$$\mu_0 = (M_h + M_H + M_{A_0} + 2M_{H^+})/5$$

- Scheme λ_3 $\overline{\text{MS}}$ used
- negligible shape differences between SM and 2HDM

Summary

- PROPHECY4F: Extended to the 2HDM (available on request):

  Features:

  - 4 different renormalization schemes:
    - ⋆ Different options for α/λ_3 and $\tan\beta$
    - ⋆ Masses and field-strength-renormalization constants on-shell, λ_5 $\overline{\text{MS}}$
      Note: m_{12}^2 is not an input parameter
  - Consistent conversion of parameters between the different ren. schemes
  - Running of $\overline{\text{MS}}$ parameters

- Effects of running and conversion of parameters can be sizeable
- Deviation from the SM about 0 to -6%
  NLO corrections contribute 1–2%.

Mixing angles and field renormalization

$$\begin{pmatrix}\varphi_{1,0}\\ \varphi_{2,0}\end{pmatrix} = \mathbf{R}_{\varphi}(\theta_0)\begin{pmatrix}h_{1,0}\\ h_{2,0}\end{pmatrix} = \begin{pmatrix}c_{\theta,0} & -s_{\theta,0}\\ s_{\theta,0} & c_{\theta,0}\end{pmatrix}\begin{pmatrix}h_{1,0}\\ h_{2,0}\end{pmatrix},$$

$$\begin{pmatrix}h_{1,0}\\ h_{2,0}\end{pmatrix} = \begin{pmatrix}1+\frac{1}{2}\delta Z_{\mathrm{h_1h_1}} & \frac{1}{2}\delta Z_{\mathrm{h_1h_2}}\\ \frac{1}{2}\delta Z_{\mathrm{h_2h_1}} & 1+\frac{1}{2}\delta Z_{\mathrm{h_2h_2}}\end{pmatrix}\begin{pmatrix}h_1\\ h_2\end{pmatrix}, \qquad \theta_0 = \theta + \delta\theta.$$

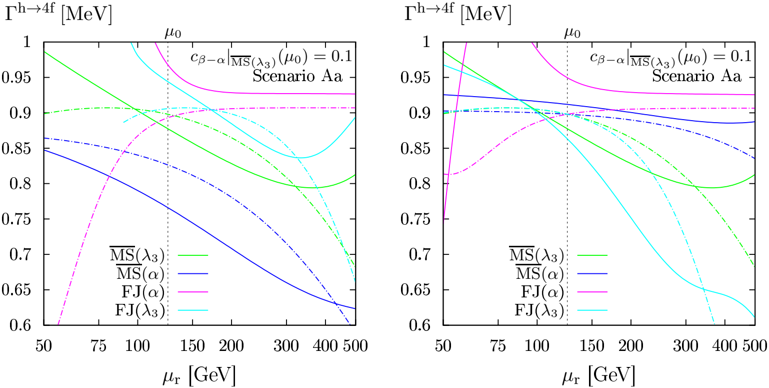
$$\begin{pmatrix}\varphi_{1,0}\\ \varphi_{2,0}\end{pmatrix} = \left[\begin{pmatrix}c_\theta & -s_\theta\\ s_\theta & c_\theta\end{pmatrix}\begin{pmatrix}1+\frac{1}{2}\delta Z_{\mathrm{h_1h_1}} & \frac{1}{2}\delta Z_{\mathrm{h_1h_2}}\\ \frac{1}{2}\delta Z_{\mathrm{h_2h_1}} & 1+\frac{1}{2}\delta Z_{\mathrm{h_2h_2}}\end{pmatrix} + \begin{pmatrix}-s_\theta & -c_\theta\\ c_\theta & -s_\theta\end{pmatrix}\delta\theta\right]\begin{pmatrix}h_1\\ h_2\end{pmatrix}$$

$$= \begin{pmatrix}c_\theta & -s_\theta\\ s_\theta & c_\theta\end{pmatrix}\begin{pmatrix}1+\frac{1}{2}\delta Z_{\mathrm{h_1h_1}} & \frac{1}{2}(\delta Z_{\mathrm{h_1h_2}} - 2\delta\theta)\\ \frac{1}{2}(\delta Z_{\mathrm{h_2h_1}} + 2\delta\theta) & 1+\frac{1}{2}\delta Z_{\mathrm{h_2h_2}}\end{pmatrix}\begin{pmatrix}h_1\\ h_2\end{pmatrix}.$$

μ dependence of $\Gamma(h \to 4f)$

[Altenkamp, Dittmaier, HR 1704.02645]

with conversion: without conversion:



$\mu_0 = M_h$

LO: dashed
NLO EW: solid

Scheme λ_3 $\overline{\text{MS}}$ used

Partial decay widths for scenario Aa (scheme λ_3 $\overline{\mathrm{MS}}$)

Final state	$\Gamma^{\mathrm{h}\to 4f}_{\mathrm{NLO}}$ [MeV]	δ_{EW} [%]	δ_{QCD} [%]	$\Delta^{\mathrm{NLO}}_{\mathrm{SM}}$ [%]	$\Delta^{\mathrm{LO}}_{\mathrm{SM}}$ [%]
inclusive $\mathrm{h}\to 4f$	0.96730(7)	2.71(0)	4.96(1)	−1.05(1)	−1.00(1)
ZZ	0.106126(6)	0.34(0)	4.88(0)	−1.13(1)	−1.00(0)
WW	0.86630(8)	3.00(0)	5.01(1)	−1.04(1)	−1.00(1)
WW/ZZ int.	−0.00513(5)	1.3(2)	12.0(8)	−1(1)	−1(1)
$\nu_{\mathrm{e}}\mathrm{e}^+\mu^-\bar{\nu}_\mu$	0.010201(1)	3.03(0)	0.00	−1.04(1)	−1.00(1)
$\nu_{\mathrm{e}}\mathrm{e}^+\mathrm{u}\bar{\mathrm{d}}$	0.031719(4)	3.02(0)	3.76(1)	−1.04(2)	−1.00(1)
$\mathrm{u}\bar{\mathrm{d}}\mathrm{s}\bar{\mathrm{c}}$	0.09847(2)	2.97(0)	7.52(1)	−1.04(2)	−1.00(1)
$\nu_{\mathrm{e}}\mathrm{e}^+\mathrm{e}^-\bar{\nu}_{\mathrm{e}}$	0.010197(1)	3.12(0)	0.00	−1.04(1)	−1.00(1)
$\mathrm{u}\bar{\mathrm{d}}\mathrm{d}\bar{\mathrm{u}}$	0.10048(2)	2.85(0)	7.35(2)	−1.06(3)	−1.00(1)
$\nu_{\mathrm{e}}\bar{\nu}_{\mathrm{e}}\nu_\mu\bar{\nu}_\mu$	0.000949(0)	3.01(0)	0.00	−1.14(1)	−1.00(1)
$\mathrm{e}^-\mathrm{e}^+\mu^-\mu^+$	0.000239(0)	1.30(1)	0.00	−1.13(2)	−1.00(1)
$\nu_{\mathrm{e}}\bar{\nu}_{\mathrm{e}}\mu^-\mu^+$	0.000477(0)	2.45(1)	0.00	−1.13(2)	−1.00(1)
$\nu_{\mathrm{e}}\bar{\nu}_{\mathrm{e}}\nu_{\mathrm{e}}\bar{\nu}_{\mathrm{e}}$	0.000569(0)	2.90(0)	0.00	−1.14(2)	−1.00(1)
$\mathrm{e}^-\mathrm{e}^+\mathrm{e}^-\mathrm{e}^+$	0.000132(0)	1.12(1)	0.00	−1.12(2)	−1.00(1)
$\nu_{\mathrm{e}}\bar{\nu}_{\mathrm{e}}\mathrm{u}\bar{\mathrm{u}}$	0.001679(0)	0.60(1)	3.76(1)	−1.12(2)	−1.00(1)
$\nu_{\mathrm{e}}\bar{\nu}_{\mathrm{e}}\mathrm{d}\bar{\mathrm{d}}$	0.002177(1)	1.69(0)	3.76(1)	−1.12(2)	−1.00(1)
$\mathrm{e}^-\mathrm{e}^+\mathrm{u}\bar{\mathrm{u}}$	0.000845(0)	0.11(1)	3.76(1)	−1.12(2)	−1.00(1)
$\mathrm{e}^-\mathrm{e}^+\mathrm{d}\bar{\mathrm{d}}$	0.001088(0)	0.47(1)	3.76(1)	−1.12(2)	−1.00(1)
$\mathrm{u}\bar{\mathrm{u}}\mathrm{c}\bar{\mathrm{c}}$	0.002971(0)	−1.80(1)	7.51(1)	−1.11(2)	−1.00(1)
$\mathrm{d}\bar{\mathrm{d}}\mathrm{d}\bar{\mathrm{d}}$	0.002556(1)	−0.38(0)	4.38(2)	−1.21(3)	−1.00(1)
$\mathrm{d}\bar{\mathrm{d}}\mathrm{s}\bar{\mathrm{s}}$	0.004956(1)	−0.36(0)	7.51(1)	−1.12(2)	−1.00(1)
$\mathrm{u}\bar{\mathrm{u}}\mathrm{s}\bar{\mathrm{s}}$	0.003852(1)	−0.66(1)	7.51(1)	−1.11(2)	−1.00(1)
$\mathrm{u}\bar{\mathrm{u}}\mathrm{u}\bar{\mathrm{u}}$	0.001506(0)	−1.92(1)	4.06(3)	−1.24(4)	−1.00(1)