

Higgs decays into sfermions

K. Kovařík

High-energy Physics Institute
Austrian Academy of Sciences
Vienna

ILC-ECFA Valencia, 2006

Outline

- 1 Overview of the Calculation
 - Diagrammatics
 - Renormalization Scheme
- 2 SPA numerical analysis
 - SPA & Tools
 - Results

Decays of Higgs bosons into sfermions

All decay channels

- Decays of Higgs bosons h^0, H^0, A^0, H^\pm into all possible sfermions including crossed channels

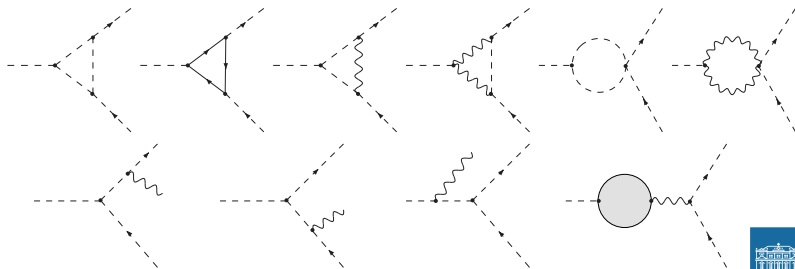
$$\begin{aligned}
 h^0, H^0, A^0 &\rightarrow \tilde{f}_i \tilde{f}_j & H^\pm &\rightarrow \tilde{f}_i \tilde{f}_j' \\
 \tilde{f}_i &\rightarrow (h^0, H^0, A^0) \tilde{f}_j & \tilde{f}_i &\rightarrow H^\pm \tilde{f}_j'
 \end{aligned}$$

Decays of Higgs bosons into sfermions

Diagrams and contributions

- Everything at one-loop incl. full QCD & EW corrections and gluon/photon radiation

Vertex diagrams



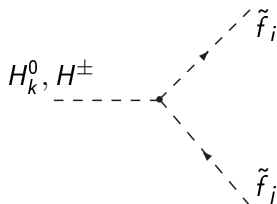
Bremsstrahlung diagrams & Higgs-Vector mixing



Renormalization Scheme

On-shell scheme and its problems

- Tree level



for A^0 the tree-level coupling is

$$G_{12}^{\tilde{f}} = \frac{i}{\sqrt{2}} h_f \left(A_f \begin{Bmatrix} \cos\beta \\ \sin\beta \end{Bmatrix} + \mu \begin{Bmatrix} \sin\beta \\ \cos\beta \end{Bmatrix} \right)$$

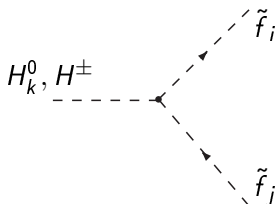
- On-shell renormalization

- Counterterms $\delta h_f, \delta A_f, \delta\mu, \delta \tan\beta$
- For large $\tan\beta \rightarrow \delta m_f, \delta A_f$ numerically large

Renormalization Scheme

On-shell scheme and its problems

- Tree level



for A^0 the tree-level coupling is

$$G_{12}^{\tilde{f}} = \frac{i}{\sqrt{2}} h_f \left(A_f \begin{Bmatrix} \cos\beta \\ \sin\beta \end{Bmatrix} + \mu \begin{Bmatrix} \sin\beta \\ \cos\beta \end{Bmatrix} \right)$$

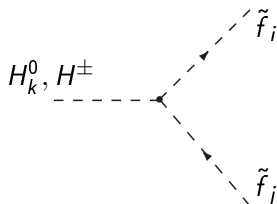
- On-shell renormalization

- Counterterms δh_f , δA_f , $\delta\mu$, $\delta \tan\beta$
- For large $\tan\beta \rightarrow \delta m_f$, δA_f numerically large

Renormalization Scheme

On-shell scheme and its problems

- Tree level



for A^0 the tree-level coupling is

$$G_{12}^{\tilde{f}} = \frac{i}{\sqrt{2}} h_f \left(A_f \begin{Bmatrix} \cos\beta \\ \sin\beta \end{Bmatrix} + \mu \begin{Bmatrix} \sin\beta \\ \cos\beta \end{Bmatrix} \right)$$

- On-shell renormalization

- Counterterms δh_f , δA_f , $\delta\mu$, $\delta \tan\beta$
- For large $\tan\beta \rightarrow \delta m_f$, δA_f numerically large

Renormalization Scheme

Improvements - A_f & m_f running

- The counterterm δA_f fixed via the sfermion mixing matrix
- Large δA_f for large values of $\tan \beta$

$$\delta A_f = \delta \left(m_f \mu \begin{Bmatrix} \cot \beta \\ \tan \beta \end{Bmatrix} \right) - \delta m_f + \frac{1}{2} \left(\delta m_{\tilde{f}_1}^2 - \delta m_{\tilde{f}_2}^2 \right) \sin 2\theta_{\tilde{f}} \\ + \left(m_{\tilde{f}_1}^2 - m_{\tilde{f}_2}^2 \right) \cos 2\theta_{\tilde{f}} \delta \theta_{\tilde{f}}$$

- Use of A_f & m_f running necessary

$$A_f^{\overline{\text{DR}}} + \delta^{\overline{\text{DR}}} A_f = A_f^{\text{OS}} + \delta^{\text{OS}} A_f$$

Renormalization Scheme

Improvements - A_f & m_f running

- The counterterm δA_f fixed via the sfermion mixing matrix
- Large δA_f for large values of $\tan \beta$

$$\delta A_f = \delta \left(m_f \mu \begin{Bmatrix} \cot \beta \\ \tan \beta \end{Bmatrix} \right) - \delta m_f + \frac{1}{2} \left(\delta m_{\tilde{f}_1}^2 - \delta m_{\tilde{f}_2}^2 \right) \sin 2\theta_{\tilde{f}} \\ + \left(m_{\tilde{f}_1}^2 - m_{\tilde{f}_2}^2 \right) \cos 2\theta_{\tilde{f}} \delta \theta_{\tilde{f}}$$

- Use of A_f & m_f running necessary

$$A_f^{\overline{\text{DR}}} + \delta^{\overline{\text{DR}}} A_f = A_f^{\text{OS}} + \delta^{\text{OS}} A_f$$

Renormalization Scheme

Improvements - A_f & m_f running

- The counterterm δA_f fixed via the sfermion mixing matrix
- Large δA_f for large values of $\tan \beta$

$$\begin{aligned} \delta A_f &= \delta \left(m_f \mu \begin{Bmatrix} \cot \beta \\ \tan \beta \end{Bmatrix} \right) - \delta m_f + \frac{1}{2} \left(\delta m_{\tilde{f}_1}^2 - \delta m_{\tilde{f}_2}^2 \right) \sin 2\theta_{\tilde{f}} \\ &\quad + \left(m_{\tilde{f}_1}^2 - m_{\tilde{f}_2}^2 \right) \cos 2\theta_{\tilde{f}} \delta \theta_{\tilde{f}} \end{aligned}$$

- Use of A_f & m_f running necessary

$$A_f^{\overline{\text{DR}}} + \delta^{\overline{\text{DR}}} A_f = A_f^{\text{OS}} + \delta^{\text{OS}} A_f$$

SPA Project

Numerical analysis

SPA CONVENTION

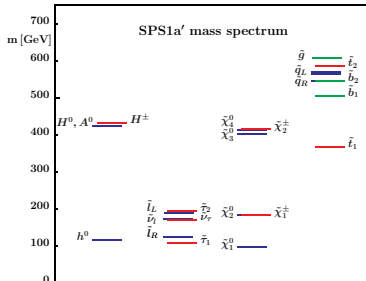
- The masses of the SUSY particles and Higgs bosons are defined as pole masses.
- All SUSY Lagrangian parameters, mass parameters and couplings, including $\tan\beta$, are given in the $\overline{\text{DR}}$ scheme and defined at the scale $\tilde{M} = 1 \text{ TeV}$.
- Gaugino/higgsino and scalar mass matrices, rotation matrices and the corresponding angles are defined in the $\overline{\text{DR}}$ scheme at \tilde{M} , except for the Higgs system in which the mixing matrix is defined in the on-shell scheme, the momentum scale chosen as the light Higgs mass.
- The Standard Model input parameters of the gauge sector are chosen as G_F , α , M_Z and $\alpha_s^{\overline{\text{MS}}}(M_Z)$. All lepton masses are defined on-shell. The t quark mass is defined on-shell; the b , c quark masses are introduced in $\overline{\text{MS}}$ at the scale of the masses themselves while taken at a renormalization scale of 2 GeV for the light u , d , s quarks.

SPA Project

Numerical analysis

SPS1a' benchmark point

g'	0.36354	M_1	103.01
g	0.64804	M_2	192.84
g_s	1.08412	M_3	571.44
Y_τ	0.09958	A_τ	-249.8
Y_t	0.88176	A_t	-487.7
Y_b	0.13143	A_b	-766.9
μ	362.35	$\tan \beta$	10.0
M_{L1}^2	$3.7821 \cdot 10^4$	M_{L3}^2	$3.7513 \cdot 10^4$
M_{E1}^2	$1.8399 \cdot 10^4$	M_{E3}^2	$1.7773 \cdot 10^4$
M_{Q1}^2	$28.177 \cdot 10^4$	M_{Q3}^2	$23.416 \cdot 10^4$
M_{U1}^2	$26.198 \cdot 10^4$	M_{U3}^2	$16.734 \cdot 10^4$
M_{D1}^2	$25.972 \cdot 10^4$	M_{D3}^2	$25.682 \cdot 10^4$
M_{H1}^2	$3.2864 \cdot 10^4$	M_{H2}^2	$-11.804 \cdot 10^4$



SPA numerical analysis

DRbar20S & SPheno



Tools used in numerical evaluation - SPheno & DRbar20S

- In MSSM beyond tree-level - parameters interdependent
- Parameter plot implies varying a parameter \rightarrow more parameters are actually varied
- Calculation in on-shell scheme (with A_f and m_f running) - transformation from SPA necessary
- SPA parameters varied and transformed for each single parameter point
- SPheno - transforms SPA to pure $\overline{\text{DR}}$ parameter set
- DRbar20S - transforms $\overline{\text{DR}}$ parameter set to on-shell input parameters

SPA numerical analysis

DRbar20S & SPheno



Tools used in numerical evaluation - SPheno & DRbar20S

- In MSSM beyond tree-level - parameters interdependent
- Parameter plot implies varying a parameter \rightarrow more parameters are actually varied
- Calculation in on-shell scheme (with A_f and m_f running) - transformation from SPA necessary
- SPA parameters varied and transformed for each single parameter point
- SPheno - transforms SPA to pure $\overline{\text{DR}}$ parameter set
- DRbar20S - transforms $\overline{\text{DR}}$ parameter set to on-shell input parameters

SPA numerical analysis

DRbar20S & SPheno



Tools used in numerical evaluation - SPheno & DRbar20S

- In MSSM beyond tree-level - parameters interdependent
- Parameter plot implies varying a parameter \rightarrow more parameters are actually varied
- Calculation in on-shell scheme (with A_f and m_f running) - transformation from SPA necessary
- SPA parameters varied and transformed for each single parameter point
- SPheno - transforms SPA to pure $\overline{\text{DR}}$ parameter set
- DRbar20S - transforms $\overline{\text{DR}}$ parameter set to on-shell input parameters

SPA numerical analysis

DRbar20S & SPheno



Tools used in numerical evaluation - SPheno & DRbar20S

- In MSSM beyond tree-level - parameters interdependent
- Parameter plot implies varying a parameter \rightarrow more parameters are actually varied
- Calculation in on-shell scheme (with A_f and m_f running) - transformation from SPA necessary
- SPA parameters varied and transformed for each single parameter point
- SPheno - transforms SPA to pure $\overline{\text{DR}}$ parameter set
- DRbar20S - transforms $\overline{\text{DR}}$ parameter set to on-shell input parameters

SPA numerical analysis

DRbar20S & SPheno



Tools used in numerical evaluation - SPheno & DRbar20S

- In MSSM beyond tree-level - parameters interdependent
- Parameter plot implies varying a parameter \rightarrow more parameters are actually varied
- Calculation in on-shell scheme (with A_f and m_f running) - transformation from SPA necessary
- SPA parameters varied and transformed for each single parameter point
- SPheno - transforms SPA to pure $\overline{\text{DR}}$ parameter set
- DRbar20S - transforms $\overline{\text{DR}}$ parameter set to on-shell input parameters

SPA numerical analysis

DRbar20S & SPheno



Tools used in numerical evaluation - SPheno & DRbar20S

- In MSSM beyond tree-level - parameters interdependent
- Parameter plot implies varying a parameter \rightarrow more parameters are actually varied
- Calculation in on-shell scheme (with A_f and m_f running) - transformation from SPA necessary
- SPA parameters varied and transformed for each single parameter point
- SPheno - transforms SPA to pure $\overline{\text{DR}}$ parameter set
- DRbar20S - transforms $\overline{\text{DR}}$ parameter set to on-shell input parameters

SPA numerical analysis

DRbar20S & SPheno

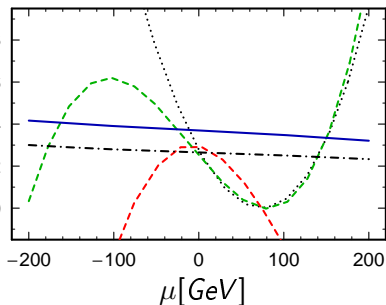
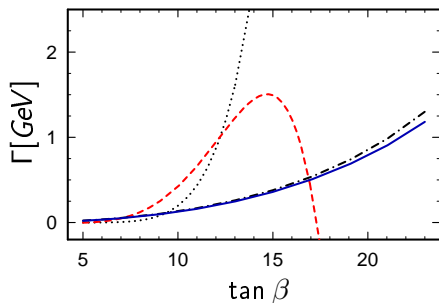


Tools used in numerical evaluation - SPheno & DRbar20S

- In MSSM beyond tree-level - parameters interdependent
- Parameter plot implies varying a parameter \rightarrow more parameters are actually varied
- Calculation in on-shell scheme (with A_f and m_f running) - transformation from SPA necessary
- SPA parameters varied and transformed for each single parameter point
- SPheno - transforms SPA to pure $\overline{\text{DR}}$ parameter set
- DRbar20S - transforms $\overline{\text{DR}}$ parameter set to on-shell input parameters

$$A^0 \rightarrow \tilde{b}_1 \tilde{b}_2$$

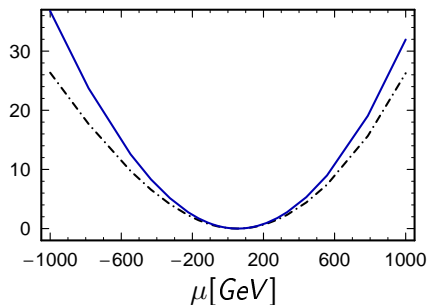
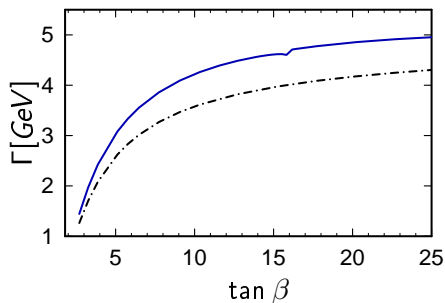
SPS1a' parameter shift - $m_{D_3} \rightarrow 150 \text{ GeV}$ $m_{A^0} \rightarrow 1000 \text{ GeV}$



- $\overline{\text{DR}}$ full
- · - $\overline{\text{DR}}$ tree
- - - OS full
- OS tree

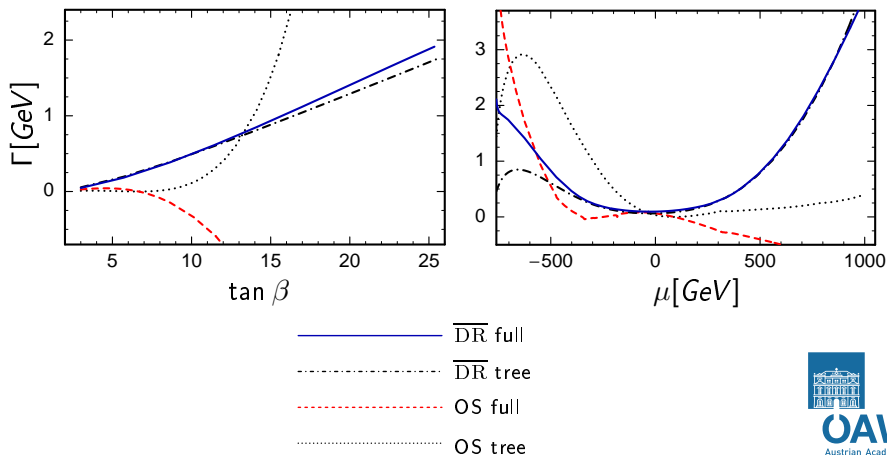
$$A^0 \rightarrow \tilde{t}_1 \tilde{t}_2$$

SPS1a' parameter shift - $m_{U_3} \rightarrow 150 \text{ GeV}$ $m_{A^0} \rightarrow 1000 \text{ GeV}$



- $\overline{\text{DR}}$ full
- · - $\overline{\text{DR}}$ tree
- · - OS full
- OS tree

$$H^+ \rightarrow \tilde{t}_1 \tilde{b}_2$$

 SPS1a' parameter shift - $m_{A^0} \rightarrow 1000$ GeV


Summary

- All Higgs decays into sfermions (or crossed-channels) calculated to one-loop
- Pure on-shell scheme not appropriate - A_f , m_f taken running
- SPA analysis for decays possible for on-shell renormalization scheme using SPheno & DRbar20S

- Outlook
 - Inclusion of the result in a package calculating all Higgs decay-channels to one-loop