Karlsruher Institut für Technologie

NMSSM Higgs boson self-interactions at NLO

ITP research-seminar

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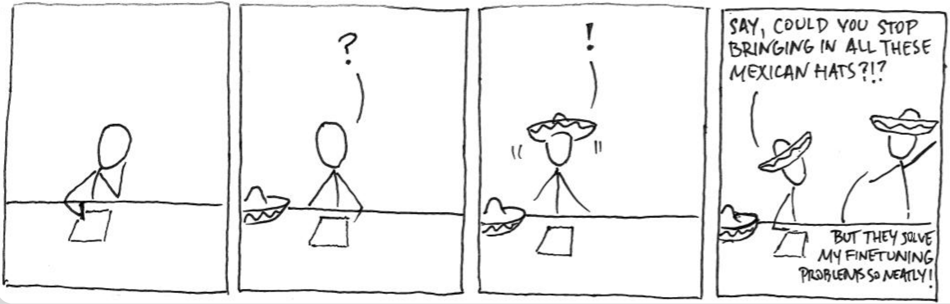
INSTITUT FÜR THEORETISCHE PHYSIK



Outline:

1. Basics and motivation
2. Done so far
3. Outlook:

NMSSM - a short recap:

- MSSM scalar Higgs potential:

$$|\mu|^2(|H_u|^2+|H_d|^2)+\frac{g_1^2+g_2^2}{8}(|H_u|^2-|H_d|^2)^2$$
$$+m_{H_u}^2|H_u|^2+m_{H_d}^2|H_d|^2-\mu B(H_u^T\epsilon H_d+c.c.)$$

- Extended by adding S:

$$\lambda^2|S|^2(|H_u|^2+|H_d|^2)+|\lambda(H_u^T\epsilon H_d)+\kappa S^2|^2$$
$$+\frac{g_2^2}{2}|H_u^\dagger H_d|^2+\frac{g_1^2+g_2^2}{8}(|H_u|^2-|H_d|^2)^2$$
$$+m_{H_u}^2|H_u|^2+m_{H_d}^2|H_d|^2+m_s^2|S|^2+(\lambda A_\lambda(H_u^T\epsilon H_d)S+\frac{\kappa}{3}A_\kappa S^3+c.c.)$$

Advantages:

- Solves the MSSM μ-Problem
- Less fine-tuning is required to satisfy exp. exclusion bounds
- Loosens theoretical Higgs mass constraints

$$\left(m_{h_1}^{\text{MSSM}}\right)^2 < m_Z^2 \cos^2 2\beta \quad \text{vs.} \quad \left(m_{h_1}^{\text{NMSSM}}\right)^2 < m_Z^2 \cos^2 2\beta + \frac{2\lambda^2 \sin^2 2\beta}{g_1^2 + g_2^2}$$

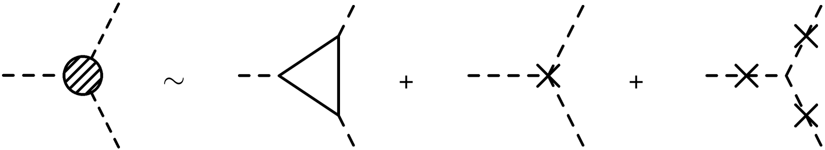
- Loosens LEP Higgs mass constraints due to possible $h_1 \to A_1 A_1$ decays (scenarios with $m_{A_1} < 2m_b, m_{h_1}/2$ are realizable in the NMSSM)

$$m_{h_1}^{\text{MSSM,exp}} > 92\text{GeV} \qquad \text{vs.} \quad m_{h_1}^{\text{NMSSM,exp}} > 82\text{GeV}$$

My thesis:

- Scenarios allowing $h_1 \to A_1 A_1$ decays are of phenomenological interest
- Analysis of NLO corrections to similar Higgs selfcouplings in the MSSM yield large contributions
- Still, NLO corrections to the $h_1 A_1 A_1$ vertex have not yet been computed
- Good starting point for implementation of NLO contributions to the planned NMSSM-decay program (still looking for a catchy name!)

Vertex renormalization:



NLO $\sim$ Loop + Counterterm + Wave function

- Higgs bosons couple only to massive particles $\rightarrow$ no IR-divergences
- UV-divergent part of the truncated 1 loop amplitude canceled by counterterms and wave function contribution

Loop amplitude:

- Computation with FeynArts and FormCalc
- FeynArts NMSSM-Modelfile set up by Kathrin and crosschecked with Thorbens Feynman rules
- Best-case: given a Modelfile, FA&FC compute (the divergent part of) the loop amplitude in terms of scalar functions
- My case: expressions too long to process (2108 diagrams at particle level, products of up to 3 vertex functions)
- Solution: modified modelfile, numerical evaluation

Loop amplitude:

- Substitute Feynman rules in modelfile by generic functions with appropriate index structure
- Result: divergent part in terms of gen. functions with index sums
- As a cross check, this result is piped through 2 independent procedures for numerical evaluation
- Procedure 1: re-substitution$\rightarrow$execute index sums$\rightarrow$num. evaluation
- Procedure 2: execute index sums$\rightarrow$num. evaluation with separately computed gen. function values

Counterterm:

- To exploit as many on-shell conditions as possible, potential parameters x_i replaced by:

$$x: \quad m_{H_u}^2, m_{H_d}^2, m_s^2, g_1, g_2, v_u, v_d, A_\lambda, A_\kappa, \lambda, \kappa, v_s$$
$$\tilde{x}: \quad t_{h_u}, t_{h_d}, t_{h_s}, e, M_W, M_Z, \tan\beta, M_{H^\pm}, A_\kappa, \lambda, \kappa, v_s$$

- $\Gamma(x_i) \to \Gamma(\tilde{x}_i)$
- $\delta\Gamma = \sum_i \frac{\partial\Gamma}{\partial\tilde{x}_i}\delta\tilde{x}_i$
- num. values of $\delta\tilde{x}_i$ already computed

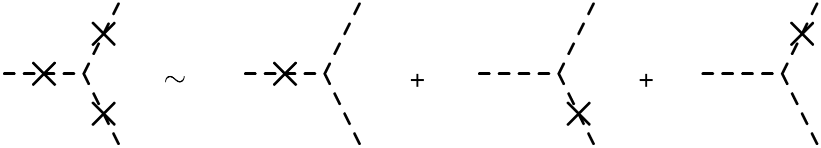
Wave function renormalization:

- Due to mixing in the Higgs sector, the wavefunction counterterms are no longer diagonal:

$$\delta\mathcal{Z}_{h_i h_j} = R^h_{i,k} R^h_{l,j} \delta Z_{k,l} \quad \delta\mathcal{Z}_{A_i A_j} = R^A_{i,k} R^A_{l,j} \delta Z_{k,l}$$

$$\text{with} \qquad \delta Z = \text{diag}(\delta Z_{h_d}, \delta Z_{h_u}, \delta Z_s)$$

- This leads to WFR contribution for the truncated vertex:



$$\text{WFR} \quad = \quad \tfrac{1}{2}(\delta\mathcal{Z}_{h_1 h_i} \Gamma_{i,1,1} \quad + \quad \delta\mathcal{Z}_{A_i A_1} \Gamma_{1,i,1} \quad + \quad \delta\mathcal{Z}_{A_i A_1} \Gamma_{1,1,i})$$

Current state and debugging:

- I have calculated all the above contributions
- Divergence cancellation not achieved so far
- Loop: -20.68867Δ vs. CT: 2.87465Δ for special fixed paramateres
- Parameter scans for both loop evaluation procedures solved 2 minor bugs, results of these are now widely consistent
- Analysis of individual CT-contributions didn't reveal any potential bugs yet

What's next?

- Modify code for $h_1 A_2 A_2$-Vertex in MSSM-like scenario and compare with known results
- Scan parameterspace
- When renormalization is achieved: discuss phenomenological impact
- Check results in different ren. schemes
- Generalize procedure for further vertices