The Light CP-Even Higgs Boson Mass of the MSSM at Three-Loop Accuracy

Edilson A. Reyes R., A. Raffaele Fazio, Sophia C. Borowka
eareyesro@unal.edu.co, arfazio@unal.edu.co, sophia.borowka@cern.ch

QCD@Work 9thEdition

UNIVERSIDAD NACIONAL DE COLOMBIA SEDE BOGOTÁ

Introduction

We have determined the three-loop QCD corrections to the light CP-even Higgs boson mass of the MSSM with real parameters using DRED with Minimal Subtraction ($\overline{DR}$ scheme) to renormalize UV divergences.

We are going to extend our renormalization procedure to include an on-shell renormalization of the squark sector and we will make it consistent with the other higher order corrections currently included in the public code FeynHiggs.

We have performed our calculations without any approximations concerning the masses of the superpartners.

Renormalization

Tree-level mass matrix of CP-even Higgs bosons:

$$\begin{pmatrix} M_Z^2 c_\beta^2 + M_A^2 s_\beta^2 + \frac{T_1}{\sqrt{2}v_1} & -\left(M_A^2+M_Z^2\right) s_\beta c_\beta \\ -\left(M_A^2+M_Z^2\right) s_\beta c_\beta & M_Z^2 s_\beta^2 + M_A^2 c_\beta^2 + \frac{T_2}{\sqrt{2}v_2} \end{pmatrix}$$

$$\begin{pmatrix} T_H \\ T_h \end{pmatrix} = \begin{pmatrix} c_\alpha & s_\alpha \\ -s_\alpha & c_\alpha \end{pmatrix} \begin{pmatrix} T_1 \\ T_2 \end{pmatrix} \qquad [1]$$

$$\frac{tan(2\beta)}{tan(2\alpha)} = \frac{M_A^2 - M_Z^2}{M_A^2 + M_Z^2}$$

For higher order corrections we have to compute the renormalized self-energy:

$$\left[\Sigma(p^2=0)^{(3Loop)}_{hh} - \delta^{(3)} M^2_{hh}\right]_{O(\alpha_t \alpha_s^2)}, \qquad [2]$$

$$\delta^{(3)} M^2_{hh} = Re\ \Sigma(p^2=0)^{(3Loop)}_{AA} + T_h^{(3Loop)} + T_H^{(3Loop)}$$

Use of **DRED** as variant of **DREG** without **evanescent** couplings.

Technical Details

FeynArts [1] Generation of diagrams and their amplitudes as well as selection of the contributions at order O($\alpha_t\alpha_s^2$).

FeynCalc [1] Dirac and Color algebra on the numerators was implemented with the help of a modification of the functions **DiracTrace** and **SUNSimplify**.

Reduze [2] C++ program, which implements the Laporta algorithm. Scalar integrals are reduced to a small basis of Master Integrals by repeated application of the Integration by Parts identities (IBPs).

TVID [3] Master Integrals U4, U5 and U6 were evaluated using the method of dispersion relations. Numerical results were checked with the help of the program **3VIL** [4].

$$B_{0,m_1}^{(p^2,m_1,m_2)} B_0^{(p^2,m_3,m_4)} = \int_0^\infty ds \frac{f(s)}{s-p^2-i\epsilon} \qquad [3]$$

SoftSUSY [5] We set the SUSY spectrum and the SM input parameters in the $\overline{DR}$ scheme using the spectrum generator SoftSUSY. **FeynHiggs** [6] reads the SoftSUSY output and evaluate the one and two loop Higgs mass value corrections. **H3m** [7] gives the three-loop contributions for some specific mass hierarchies and SUSY breaking scenarios.

References

[1] T. Hahn 2013, V. Shtabovenko et al. 2016.
[2] C. Studerus et al. 2010, 2012.
[3] A. Freitas et al. 2017.
[4] S. P. Martin et al. 2016.
[5] B. C. Allanach. 2002.
[6] Frank et al. 2006, 2010.
[7] P. Kant et al. 2008, 2010.

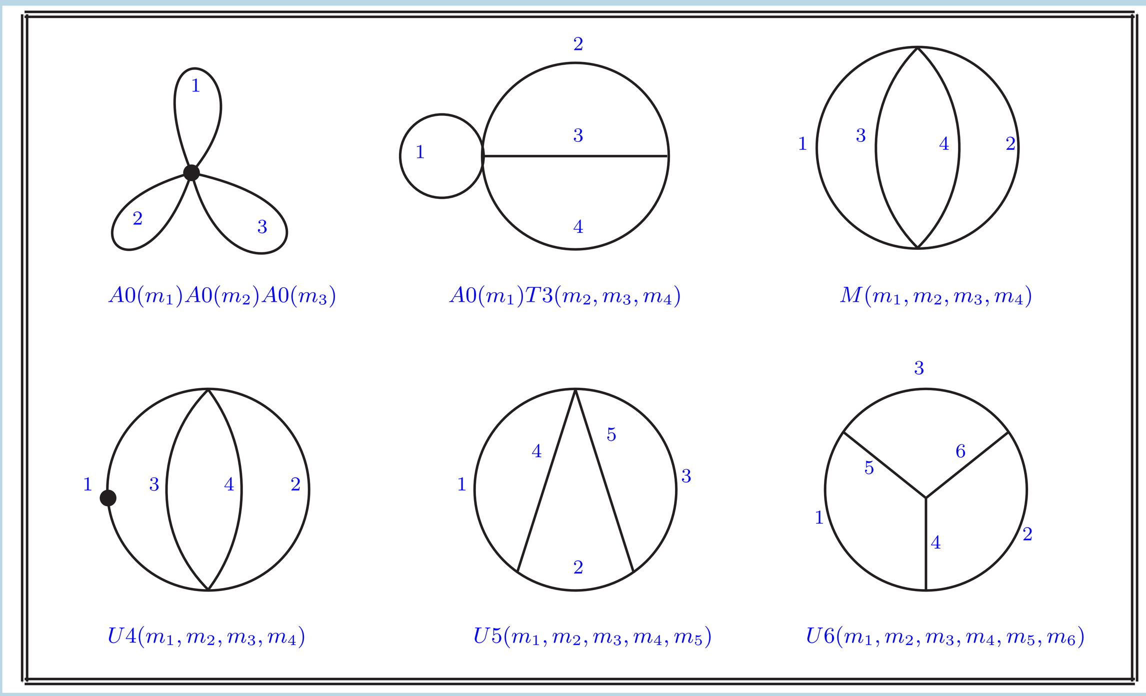
Evaluation of Renormalized Topologies

There are 80 three-loop 1PI self-energy topologies. At O($\alpha_t\alpha_s^2$) 40 self-energy topologies make contributions. In total there are 3869 x 3 amplitudes to evaluate. There are 15 3L 1PI tadpoles. At O($\alpha_t\alpha_s^2$) 11 of them make contributions. In total there are 3590 x 2 amplitudes. This set of about 20000 amplitudes can be reduced to a superposition of 4313 scalar integrals with the structure:

$$\left\langle \frac{1}{\left(q_1^2-m_1^2\right)^a \left(q_2^2-m_2^2\right)^b \left(q_3^2-m_3^2\right)^c \left((q_1-q_2)^2-m_4^2\right)^d \left((q_1-q_3)^2-m_5^2\right)^e \left((q_2-q_3)^2-m_6^2\right)^f} \right\rangle_{3-Loop}, \qquad [4]$$

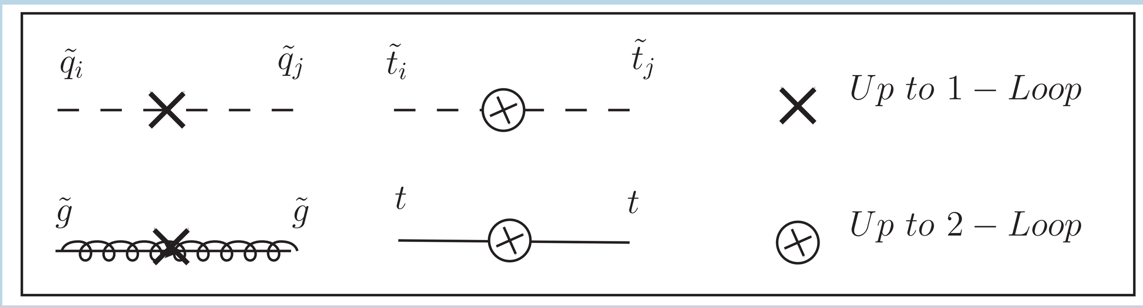
where a, b, c, ... are positive or negative integer numbers or even zero.

These sets of scalar integrals are related by the IBP identities and the tensor reduction. By solving the constraints one can reduce each scalar integral to a linear combination of the master integrals:



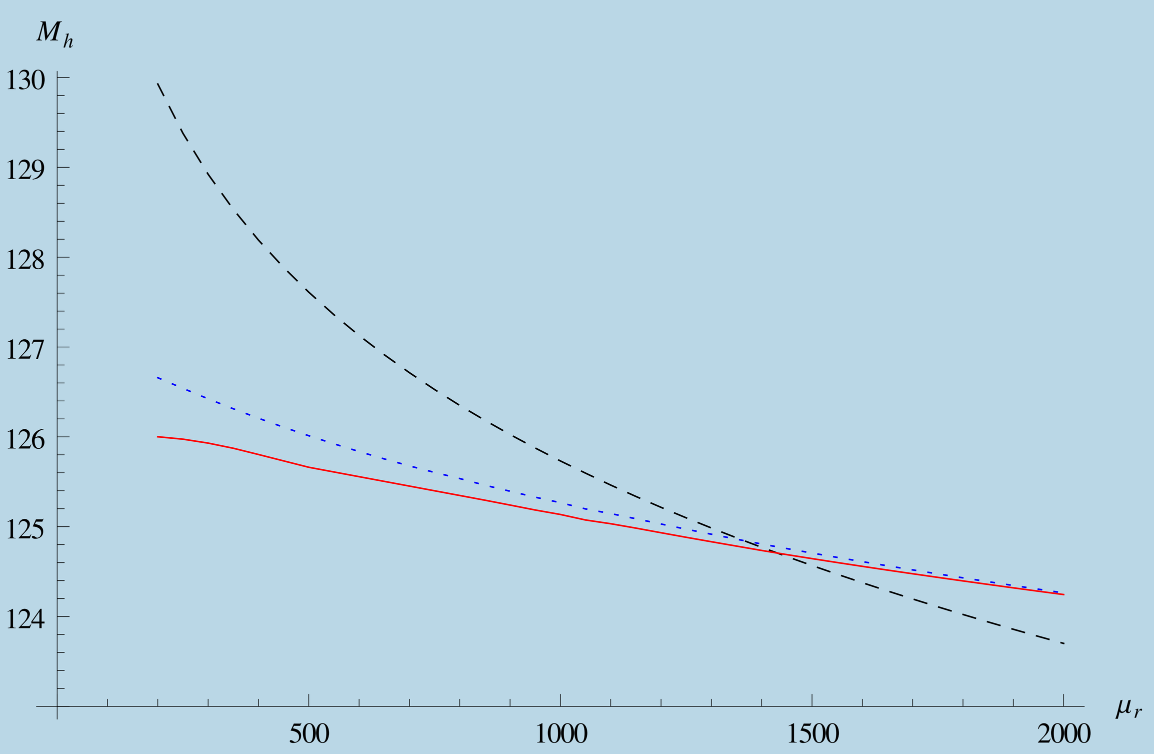
with coefficients that are ratios of polynomials in the space-time dimension and the squared masses. Master integrals could have at most four independent mass scales. In general, an analytical solution for an arbitrary configuration of the masses is unknown. Then, we have used numerical methods, **TVID** and **3VIL**, to evaluate the master integrals of our basis.

Besides, there are sub-divergences that have to be removed with additional one and two -loop diagrams with the counter-terms insertions:



Numerical Results

We have studied the dependence of the Higgs boson mass M_h (GeV) on the renormalization scale μ_r (GeV). The black dashed and the blue dotted lines are the one and two -loop predictions of FeynHiggs, while the red solid line corresponds to our three-loop prediction. Here we have used for the soft breaking parameter $A_t = 1500$ GeV and for $tan\beta = 10$.



We have also investigated the dependence of M_h (GeV) on A_t (GeV) (with $\mu_r = 200$ GeV and $tan\beta = 10$) and the ratio of the vacuum expectation values of the two CP-even Higgs boson fields $tan\beta$ (with $A_t = 1500$ GeV and $\mu_r = 250$ GeV).