PROCEEDINGS OF SCIENCE

Review on Higgs Tools

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A plethora of tools for the investigation of properties of Higgs bosons in the Standard Model and beyond is available nowadays. The aim of this proceedings contribution is to give an overview about the existing tools starting with high-precision tools for Standard Model Higgs-boson analyses. Tools addressing specific extensions of the Standard Model are as well mentioned as tools that can be applied to develop missing components for one's own Higgs study.

Computational Tools for High Energy Physics and Cosmology (CompTools2021)
22-26 November 2021
Institut de Physique des 2 Infinis (IP2I), Lyon, France

*Speaker

PoS(CompTools2021)008

1. Introduction

The discovery of a Higgs boson 10 years ago was a milestone in particle physics [1]. Meanwhile, the investigations of the discovered Higgs boson turn into a precision-physics program and tools to describe the behaviour of this particle become even more important. Since small deviations of the Higgs boson's properties from the Standard Model (SM) expectations can hint for new physics, precise experimental measurements of these properties as well as accurate theoretical predictions are needed.

There is a plethora of tools that can be used in different investigations of Higgs bosons. The aim of this proceedings contribution is to give an overview about the broad spectrum of tools. Details about the tools and the tools themselves can be found in the references and links. The list of tools, which is presented, is however not exhaustive.

The reader interested in tools for the SM should focus on the Sect. 2 and 3 where in the former tools are discussed that only address the SM while in the latter, the focus is on tools that provide precise predictions in the Standard Model as well as extensions of the Standard Model. For the reader with focus on specific SM extensions the Sect. 3 as well as 4 are most relevant, since in Sect. 4, tools are discussed that are dedicated to Beyond SM physics models. In addition, Sect. 5 addresses tools that can be used to test SM extensions against experimental data. In Sect. 6 tools are presented that can be applied in effective-field-theory calculations where effective-field theory (EFT) is understood in a broad sense as a model that is describing the physics at collider energies with and without higher-dimensional operators. Finally, in Sect. 7, tools are collected that can be useful when performing a calculation of Higgs-boson mass spectra, cross sections or decay widths within a SM extension.

2. Tools for Standard Model Higgs predictions

The most precise production cross sections are implemented in tools that only address the SM. The production cross sections include up to next-to-next-to-leading order (NNLO) QCD corrections for differential production cross sections and contributions up to next-to-next-to-next-to-leading order (N^3LO) in QCD for inclusive production cross sections.

The production cross section of the SM Higgs boson at hadron colliders in gluon fusion can be generated with

- `iHixs 2`: Inclusive production cross section including up to N^3LO QCD corrections in the heavy top quark effective theory [2];

- `ggHiggs`: Inclusive production cross section including contributions up to N^3LO in QCD [3–5] including top-quark mass effects [6]. Large threshold resummation can be taken into account via the tool `Troll` [5, 7] up to next-to-next-to-next-to-leading-logarithmic (N^3LL) accuracy;

- `fehipro`: Differential and inclusive production cross section at NNLO in QCD in the heavy top-mass limit [8] including decays into leptonically decaying W and Z bosons as well as in photons;

- HNNLO: Differential and inclusive production cross sections for hadron colliders at NNLO in QCD including Higgs decays via W or Z bosons into four leptons as well as into photons [9, 10]. Large logarithms occurring when the Higgs-boson transverse momentum is much smaller than the Higgs mass can be resummed and are included in the corresponding tool HRes [10] up to next-to-next-to-leading log (NNLL) accuracy;

- HqT: Transverse momentum distribution for Higgs production in pp collisions up to next-to-leading (NLO) combined with NNLL accuracy. The normalization is fixed to the corresponding total cross section at fixed order [11].

The differential production cross section via Higgs Strahlung can be evaluated with the help of the tool MCFM [12] at NNLO in QCD. The Higgs production processes in MCFM are only a subset of the implemented processes. The differential production cross section of one or a pair of Higgs bosons via vector boson fusion (VBF) can be studied with the help of the tools ProVbfH [13, 14] and ProVbfHH [14, 15] up to NNLO QCD. For both processes, the corresponding inclusive cross sections are implemented up to an order of N^{3}LO in QCD in the respective tools.

For a review of the status of the calculations within the Standard Model, see e.g. Ref. [16].

3. Tools for Higgs predictions in the Standard model and its extensions

Besides the development towards higher precision of the predictions, there is also advances towards including extensions of the Standard Model. In this section, tools are covered that started out from the SM but evolved, partly already at publication time, into a tool including also SM extensions.

For the gluon fusion production cross section of Higgs bosons, there is the tool HIGLU [17–19]. It provides the gluon fusion production cross section for scalar and pseudoscalar Higgs bosons including up to NNLO corrections for the SM; the Two-Higgs-Doublet Model (2HDM); the Minimal Supersymmetric Standard Model (MSSM); a SM extended by a fourth generation and by the dimension-5 operator $G^{a\mu\nu}G^{a}_{\mu\nu}H/v$. For Higgs pair production via gluon fusion, the tool HPAIR can be applied to evaluate the corresponding cross sections in the infinite top-quark mass limit for the SM, the MSSM and for a SM extension including dimension-6 operators [20].

Another computer tool providing predictions for the production cross section via gluon fusion but also production cross sections via bottom-quark annihilation in the SM, the 2HDM and the (N)MSSM is SusHi [21]. It includes the extension SusHiMi, which allows for CP-violating effects in the Higgs sector. The N^{3}LO results in the heavy top-limit employing the threshold expansion [4] are also implemented.

For the evaluation of the hadronic Higgs production cross section in association of a weak gauge boson, the tools vh@nnlo [22] and HAWK [23, 24] are available. The former provides an inclusive cross section for the SM, the 2HDM and the MSSM including corrections at NNLO in QCD taking also the gluon-induced channel into account. The latter tool is a Monte Carlo program that takes QCD as well as electroweak corrections at NLO into account and provides also differential cross sections. Via an interface to the tool Recola2 [25, 26], the Higgs production can be calculated for the 2HDM and the Higgs-singlet extension of the SM. Recola2 can compute any process at one-loop order. The generation of the model files used in Recola2 is done with the help of the tool REPT1L [25]. Different renormalization schemes are available for the processes contained in HAWK [24]. The implementation of HAWK also comprises Higgs production via VBF. A further parton-level Monte-Carlo tool is VBFNLO [27–30], where, among other processes, Higgs boson production via VBF is implemented. The VBF Higgs cross section without decay of the Higgs boson includes QCD and electroweak NLO corrections. Most other processes are at the NLO QCD level of precision. For VBF the SM extensions considered are the MSSM [29] and the SM including anomalous HVV couplings [30]. For SM only, also VBF Higgs pair production is available [31]. In addition, Higgs production in association with a W boson are implemented including the possibility of anomalous couplings [32]. Higgs plus 2 jets production processes via gluon fusion are only available at LO for the SM, the MSSM, anomalous couplings or, for some decay possibilities, the general 2HDM [33].

A Monte Carlo program from the early days is ISAJET [34], which was originally developed to describe processes, some of them involving Higgs bosons, at the collider ISABELLE, a proton-proton collider. Later on, it was extended to include also proton-antiproton processes and extensions of the Standard Model, in particular the MSSM taking into account partial decay widths of Higgs bosons and supersymmetric partner particles within the additional module ISASUSY, mostly at tree level.

For the partial decay widths of the Higgs boson, the program HDECAY [19, 35–37] is available. It evaluates the different partial decay widths including all relevant QCD and partly electroweak corrections as well as off-shell decays for the SM, the 2HDM and the MSSM. A fourth generation of fermions is also allowed. HDECAY also serves as a basis for a whole family of decay tools for different extensions. While electroweak corrections are neglected, the QCD corrections and the off-shell decays can be taken over for these extensions: sHDECAY [38] for the SM extended by a real or a complex Higgs singlet; N2HDECAY [39] for the 2HDM extended by a real Higgs singlet; C2HDM_HDECAY [40] for the complex 2HDM; and CN2HDM_HDECAY [41] for a 2HDM extension with a complex Higgs singlet. Furthermore, based on the SILH Lagrangian, Higgs decay widths for an effective-field theory as well as for composite Higgs models are implemented in eHDECAY [42]. The tools 2HDECAY [43], ewNHDECAY [44] and NMSSMCALCEW [45] include also electroweak corrections to partial decay widths of decays that are not loop-induced within the CP-conserving 2HDM, the real Higgs singlet extended 2HDM and the complex NMSSM. Different renormalization schemes have been implemented in these tools. The decay part of NMSSMCALC [46] is also based on HDECAY.

The tool Prophecy4f [37, 47] is a Monte Carlo generator for decays of the Higgs boson into 4 fermions including QCD and electroweak NLO corrections. It was originally developed for the SM but then extended to include a fourth generation of fermions, to a Higgs singlet extension [48] and to the 2HDM [49]. For the two latter extensions, different renormalization schemes are available [24, 48, 49]. A further tool addressing the decay of the Higgs boson into four charged leptons at NLO is Hto4l. It includes parton-shower effects and provides predictions for the SM and the SM extended by dimension-six operators [50].

4. Tools for Higgs predictions within specific extensions of the SM

There is a plethora of tools that have been developed in order to investigate specific extensions of the Standard Model. I will discuss them here starting with models with only an extended

Higgs sector, then covering supersymmetric models and finally tools that allow to study "general" extensions of the Standard Model.

4.1 Extended Higgs sectors

Several tools that allow for investigations of an extended Higgs sector have already been discussed in the previous section. For the 2HDM, there is, in addition, the tool `2HDMC` [51] which permits different parametrization of the Higgs potential and for generic Yukawa sectors. Theoretical constraints such as the positivity of the potential, tree-level unitarity constraints, oblique parameters or the anomalous magnetic moment of the muon as well as decay widths partly including QCD corrections can be evaluated. A further tool, addressing four types of the 2HDM, the inert Higgs doublet model as well as the Higgs singlet model, is `H-COUP` [52] evaluating Higgs-boson branching ratios taking into account NLO electroweak as well as NNLO QCD corrections.

The Georgi-Machacek model can be studied with the help of the tool `GMCALC` [53]. The Georgi-Machacek model extends the Higgs sector by two Higgs triplets in such a way that custodial symmetry is preserved in the Higgs potential at leading order. The model contains neutral, singly- and doubly-charged Higgs bosons. The tool allows for the evaluation of the particle spectrum, theoretical and indirect constraints and partial and total decay widths of the Higgs bosons. It also includes the possibility to study EFT effects.

4.2 Supersymmetric extensions of the Standard Model

So far, the majority of tools dedicated to a specific extension are directed to the Minimal Supersymmetric Standard Model (MSSM). It had been noticed early that radiative corrections in the Higgs sector are particularly important in the MSSM, since the upper Higgs-mass bound is shifted to higher values when radiative corrections are taken into account. Hence, a lot of work went into the precise calculation of the Higgs-mass spectrum. There are several approaches towards this calculation, see also Ref. [54]: the fixed-order, the EFT, and the hybrid approach. In the following three paragraphes, the tools are ordered with respect to the followed approach. It should however be noted that the tools exploiting the hybrid approach contain an implementation of the pure fixed-order as well as of the EFT approach.

Pure fixed-order approach: In the fixed-order approach, radiative corrections up-to a certain order are taken into account. The majority of codes follows this approach. `SOFTSUSY` [55], `SPheno` [56], `SuSeFLAV` [57], `SUSPECT` [58] include two-loop corrections at vanishing external momenta in the gaugeless limit. In `CPSuperH` [59], leading-logarithmic two-loop contributions in the gaugeless limit are taken into account. The tool `H3m` [60] is the only code in the category "pure fixed order" including three-loop corrections.

Pure EFT approach: In the EFT approach, first a tower of effective field theories is defined depending on the mass hierarchy of the particles occurring in the considered SM extension. It is assumed that the MSSM is suited as a description at high-energy scales. Below a matching scale, a corresponding EFT provides the correct predictions. The parameters of this EFT are determined in such a way that, at the matching scale, the MSSM and the EFT describe the same physics. The parameters of the EFT are then evolved down to lower energy scales with the help of the corresponding renormalization group equations (RGE). At the lower scale, the EFT might be matched to a further EFT with fewer active degrees of freedom repeating the procedure of matching and evolution of the parameters until the energy scale is reached at which the observables are calculated. There are two tools that follow only this approach, `SUSYHD` [61] and `MhEFT` [62].

The hybrid approach: The fixed-order approach has the advantage that all contributions up to a fixed-order are taken into account. It is straightforward to take into account the individual particle masses as long as the mass differences are not too large. The EFT approach, however, resums potentially large logarithms of mass ratios, which is important if large mass differences occur in the considered scenario. In order to make use of the advantages of both, the fixed-order approach and the EFT approach, the hybrid approach was invented: Via this approach, both, the resummation of the logs and the additional fixed-order contributions, are taken into account. Such a hybrid approach has been implemented in the code `FeynHiggs` [63]. `FeynHiggs` also allows for switching between a pure fixed-order approach including two-loop corrections, a pure EFT result with different EFT options as well as the hybrid approach. Also `Himalaya` [64], using the results of `H3m` [60], exploits a hybrid approach and evaluates the mass of the light CP-even Higgs boson including N^3LO and N^3LL corrections. The tools `FlexibleSUSY` [65, 66] with the module `FlexibleEFTHiggs` and `SARAH` [67] together with `SPheno` [56] have also implemented a hybrid approach.

While an important feature of the tools mentioned in the previous paragraph is that they evaluate the mass spectrum of the MSSM, most of them include further predictions such as Higgs partial decay widths, flavour-physics observables, and constraints from theoretical considerations. In addition, some of these tools also cover further supersymmetric extensions such as the Next-to Minimal Supersymmetric Standard Model (NMSSM), which is for example available in `SOFTSUSY`.

The tools for predictions of production cross sections in the MSSM have already been mentioned in Sect. 3, since they also include SM cross section predictions.

For the evaluation of the Higgs mass spectrum in the NMSSM and the corresponding branching ratios of the Higgs bosons, `NMSSMTOOLS` [68] and `NMSSMCALC` [46] are available. `NMSSMTOOLS` allows for both, a Z_3 symmetric NMSSM or an NMSSM without Z_3 symmetry, while `NMSSMCALC` supports only the Z_3 symmetric version. Both tools permit the investigation of additional constraints, such as those coming from electric dipole moments. Recently, in `NMSSMCALC`, the two-loop corrections for the Higgs-mass spectrum have been extended to include not only $O(\alpha_t\alpha_s + \alpha_t^2)$ but also $O(\alpha_t\alpha_s + (\alpha_t + \alpha_\lambda + \alpha_\kappa)^2)$ corrections. Here, α_s is the strong coupling constant and $\alpha_t = y_t/(4\pi)$, $\alpha_\lambda = \lambda/(4\pi)$, $\alpha_\kappa = \kappa/(4\pi)$ with y_t, λ, and κ being the top Yukawa coupling, the coupling between the Higgs singlet and doublet superfields, and the coupling between the Higgs singlet superfields, respectively.

The code `numuMSSM` [69] addresses an extension of the NMSSM, the $\mu\nu$SSM, where the singlet superfield of the NMSSM is interpreted as a right-handed neutrino superfield. It provides the mass spectrum of the model as well as partial decay widths of all non-coloured scalars.

4.3 Tools for arbitrary extensions of the Standard Model

In addition to the codes that address a choice of specific models, there are also tools that can be used for arbitrary renormalizable models. These tools are sometimes called 'generators of spectrum generators', since they provide a code to evaluate the mass spectrum of a user-defined model. One of the tools is `SARAH` [67], which allows not only for the evaluation of the particle-mass spectrum but also provides model files for other tools. A further tool of this type is `FLEXIBLESUSY` [65, 66].

It applies SARAH for the generation of analytic formulas for tadpoles, self energies and RGE and some components from SOFTSUSY [55] in order to calculate the mass spectrum of a user chosen model. It recently was extended by the module FlexibleDecay [66], which provides partial decay widths of scalar particles. While in FlexibleDecay known higher-order corrections are taken into account, pure beyond-SM effects are taken into account at leading order, including, however, loop-induced processes.

5. Tools for investigating parameter spaces of Higgs sectors

One important feature of a viable parameter-space point is that it contains a SM-like Higgs boson, i.e. a Higgs boson with properties that do not deviate much from the properties of the SM Higgs boson. A further characteristic is that experimental bounds originating from searches for Higgs bosons are not violated. The tools HiggsSignals [70] and HiggsBounds [71], which are currently combined into a new tool HiggsTools [72], is developed for checking the considered parameter point with regard to these characteristics. The user has to provide certain Higgs predictions of a particular model and will obtain an answer about the viability of the considered parameter point. A further tool that serves the same purpose as HiggsSignal is Lilith [73]. It requires Higgs-signal strengths as an input.

The tool ScannerS [38, 39, 74] employs HiggsBounds and HiggsSignals together with further build-in constraints and Dark Matter bounds from MicrOMEGAs[1] [75] in order to generate parameter-point samples that are viable. In contrast, the tool HEPfit [76] provides fits of parameters of a given particle-physics model to a set of experimental observables. It also evaluate predictions for observables for a given parameter point.

6. Tools for Higgs-boson studies involving Effective-Field Theories

If Higgs-boson properties are investigated in the framework of the SM EFT where the SM Lagrangian is extended by operators of higher-mass dimensions, a tool like Rosetta [77] might be needed to translate from one operator basis to another in order to combine results from different Monte-Carlo event generators consistently. The operator bases called Warsaw, SILH, and Higgs bases and corresponding translations are implemented in Rosetta.

If specific theories are matched to an EFT at a high-energy scale and predictions are needed at a low-energy scale, then tools providing RGE for the respective EFT are helpful. In Sect. 4, the tool SARAH [67] was already introduced: It can provide RGE for a user-defined model at two-loop order and is based on Mathematica. PyR@te [78, 79] is written in Python and can calculate RGE for non-supersymmetric models at two-loop order and, for gauge couplings, at three-loop order. A new Mathematica-based tool, RGBeta [79, 80], provides 4-loop gauge, 3-loop Yukawa and 2-loop quartic beta functions.

[1] MicrOMEGAs is also interfaced to a variety of tools discussed in Sect. 4.

7. Tools for Higgs-boson studies and beyond

In this section, we turn to tools that are not specifically developed for Higgs-boson studies but can be used for the calculation of observables also related to Higgs bosons.

One class of tools are the so-called model-file generators: The model-files provided by these generators contain the information about the particle content and the correponding couplings of a user-defined model. They are input files for tools that can generate and evaluate Feynman amplitudes. In Sect. 3, the tool REPT1L [25] was already addressed, which produces model files for Recola2 [25, 26], a tool for calculating processes at one-loop order, see also Recola [81]. The tool SARAH [67], see Sect. 4 and 6, can build model files for several tools. Similarly, FeynRules [82] can provide model-files for different tools including also counterterm information in the model file. Further development of FeynRules focussing in particular on the generation of model files at NLO led to the code MoGRe [83]. Finally, LanHEP [84] is a model-file generator for the tool CompHep [85], which can evaluate Feynman diagrams, integrate over a multi-particle phase space and generate events. CompHep has been further developed and turned into the tool CalcHEP [86]. Tools serving similar purposes are for example GRACE [87] or HELAS [88]. For a numerical evaluation of scattering amplitudes at NLO including both QCD and electroweak corrections, the tool OpenLoops [89] can be employed, which applies a special algorithm leading to a fast and numerically stable evaluation. OpenLoops can be interfaced to the Monte Carlo event generators Sherpa [90] and Herwig++ [91] for the simulation at hadron level. At that point, a further Monte Carlo event generator, Pythia [92], providing events at hadron level should be mentioned.

The model files generated by SARAH and FeynRules can be used for the packages FeynArts [93] and FormCalc [94] where the former is used for the generation of the Feynman amplitudes and the latter for the processing of the FeynArts output returning analytical results for amplitudes and squared amplitudes or corresponding fortran code for the numerical evaluation. Also the tool Whizard [95], a tool for the calculation of multi-particle scattering cross sections and generation of event samples, can be interfaced to FeynRules and SARAH. Finally, the tool MadGraph [96], which can generate parton-level events for processes at NLO QCD, can also process model files from SARAH and FeynRules.

A further tool to generate Feynman diagrams is QGRAF [97], which is based on fortran. For the symbolic evaluation of Feynman amplitudes the Mathematica package FeynCalc [98] is available. A very recent tool is MARTY [99], which also calculates amplitudes, cross sections and Wilson coefficients symbolically using C++.

To conclude this section, two computer tools combining several of the above mentioned codes shall be addressed. One of them is FeynMaster [100] making use of FeynRules, QGRAF and FeynCalc in order to generate Feynman rules, diagrams and amplitudes and to perform loop calculations applying an $\overline{\text{MS}}$ renormalization scheme. The second tool is SloopS [101], which combines LanHEP, FeynArts and FormCalc in order to provide cross sections and other observables at one-loop level employing an on-shell renormalization scheme.

8. Summary

There is a plethora of tools related to Higgs physics covering many aspects: High-precision predictions are provided for Higgs-boson cross sections within the SM. Mass spectra, partial decay widths and cross sections are provided for a variety of extensions of the SM. For the investigation of extended Higgs sectors, tools are available to find viable parameter points. In addition, there are many tools that, though not specifically developed for Higgs physics, can be useful for the calculation of Higgs observables or for phenomenological Higgs studies. Though a broad range of tools was addressed in this proceedings contribution, the list is not exhaustive—and the development of tools is continuing.

Acknowledgements

H.R. would like to thank the organizers for the invitation to give this overview talk at the Computational Tools for High Energy Physics and Cosmology (CompTools2021) workshop and for the organization of this interesting workshop. H.R.'s research is funded by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation)—project no. 442089526.

References

[1] G. Aad *et al.* [ATLAS], Phys. Lett. B **716** (2012), 1-29 doi:10.1016/j.physletb.2012.08.020 [arXiv:1207.7214 [hep-ex]]; S. Chatrchyan *et al.* [CMS], Phys. Lett. B **716** (2012), 30-61 doi:10.1016/j.physletb.2012.08.021 [arXiv:1207.7235 [hep-ex]].

[2] F. Dulat, A. Lazopoulos and B. Mistlberger, Comput. Phys. Commun. **233** (2018), 243-260 doi:10.1016/j.cpc.2018.06.025 [arXiv:1802.00827 [hep-ph]]; https://github.com/dulatf/ihixs

[3] R. D. Ball, M. Bonvini, S. Forte, S. Marzani and G. Ridolfi, Nucl. Phys. B **874** (2013), 746-772 doi:10.1016/j.nuclphysb.2013.06.012 [arXiv:1303.3590 [hep-ph]]; M. Bonvini, R. D. Ball, S. Forte, S. Marzani and G. Ridolfi, J. Phys. G **41** (2014), 095002 doi:10.1088/0954-3899/41/9/095002 [arXiv:1404.3204 [hep-ph]]; M. Bonvini and S. Marzani, Phys. Rev. Lett. **120** (2018) no.20, 202003 doi:10.1103/PhysRevLett.120.202003 [arXiv:1802.07758 [hep-ph]]; M. Bonvini, Eur. Phys. J. C **78** (2018) no.10, 834 doi:10.1140/epjc/s10052-018-6315-x [arXiv:1805.08785 [hep-ph]]; B. Mistlberger, JHEP **05** (2018), 028 doi:10.1007/JHEP05(2018)028 [arXiv:1802.00833 [hep-ph]]; Marco Bonvini, https://www.ge.infn.it/~bonvini/higgs/

[4] C. Anastasiou, C. Duhr, F. Dulat, E. Furlan, T. Gehrmann, F. Herzog and B. Mistlberger, JHEP **03** (2015), 091 doi:10.1007/JHEP03(2015)091 [arXiv:1411.3584 [hep-ph]]; C. Anastasiou, C. Duhr, F. Dulat, E. Furlan, T. Gehrmann, F. Herzog, A. Lazopoulos and B. Mistlberger, JHEP **05** (2016), 058 doi:10.1007/JHEP05(2016)058 [arXiv:1602.00695 [hep-ph]].

[5] M. Bonvini, S. Marzani, C. Muselli and L. Rottoli, JHEP **08** (2016), 105 doi:10.1007/JHEP08(2016)105 [arXiv:1603.08000 [hep-ph]]; T. Ahmed, M. Bonvini,

M. C. Kumar, P. Mathews, N. Rana, V. Ravindran and L. Rottoli, Eur. Phys. J. C **76** (2016) no.12, 663 doi:10.1140/epjc/s10052-016-4510-1 [arXiv:1606.00837 [hep-ph]].

[6] R. Bonciani, G. Degrassi and A. Vicini, JHEP **11** (2007), 095 doi:10.1088/1126-6708/2007/11/095 [arXiv:0709.4227 [hep-ph]]; R. V. Harlander and W. B. Kilgore, Phys. Rev. Lett. **88** (2002), 201801 doi:10.1103/PhysRevLett.88.201801 [arXiv:hep-ph/0201206 [hep-ph]]; R. V. Harlander and K. J. Ozeren, JHEP **11** (2009), 088 doi:10.1088/1126-6708/2009/11/088 [arXiv:0909.3420 [hep-ph]]; R. V. Harlander, H. Mantler, S. Marzani and K. J. Ozeren, Eur. Phys. J. C **66** (2010), 359-372 doi:10.1140/epjc/s10052-010-1258-x [arXiv:0912.2104 [hep-ph]].

[7] M. Bonvini and S. Marzani, JHEP **09** (2014), 007 doi:10.1007/JHEP09(2014)007 [arXiv:1405.3654 [hep-ph]]; M. Bonvini and L. Rottoli, Phys. Rev. D **91** (2015) no.5, 051301 doi:10.1103/PhysRevD.91.051301 [arXiv:1412.3791 [hep-ph]]; M. Bonvini, S. Marzani, J. Rojo, L. Rottoli, M. Ubiali, R. D. Ball, V. Bertone, S. Carrazza and N. P. Hartland, JHEP **09** (2015), 191 doi:10.1007/JHEP09(2015)191 [arXiv:1507.01006 [hep-ph]]; M. Bonvini and S. Marzani, JHEP **06** (2018), 145 doi:10.1007/JHEP06(2018)145 [arXiv:1805.06460 [hep-ph]]; https://www.ge.infn.it/~bonvini/troll/

[8] C. Anastasiou, K. Melnikov and F. Petriello, Nucl. Phys. B **724** (2005), 197-246 doi:10.1016/j.nuclphysb.2005.06.036 [arXiv:hep-ph/0501130 [hep-ph]]; C. Anastasiou, S. Bucherer and Z. Kunszt, JHEP **10** (2009), 068 doi:10.1088/1126-6708/2009/10/068 [arXiv:0907.2362 [hep-ph]]; C. Anastasiou, A. Lazopoulos, F Stoeckli, https://people.phys.ethz.ch/~pheno/fehipro/

[9] S. Catani and M. Grazzini, Phys. Rev. Lett. **98** (2007), 222002 doi:10.1103/PhysRevLett.98.222002 [arXiv:hep-ph/0703012 [hep-ph]]; M. Grazzini, JHEP **02** (2008), 043 doi:10.1088/1126-6708/2008/02/043 [arXiv:0801.3232 [hep-ph]].

[10] M. Grazzini and H. Sargsyan, JHEP **09** (2013), 129 doi:10.1007/JHEP09(2013)129 [arXiv:1306.4581 [hep-ph]]; . D. de Florian, G. Ferrera, M. Grazzini and D. Tommasini, JHEP **06** (2012), 132 doi:10.1007/JHEP06(2012)132 [arXiv:1203.6321 [hep-ph]]; https://www.physik.uzh.ch/en/groups/grazzini/research/Tools.html

[11] G. Bozzi, S. Catani, D. de Florian and M. Grazzini, Phys. Lett. B **564** (2003), 65-72 doi:10.1016/S0370-2693(03)00656-7 [arXiv:hep-ph/0302104 [hep-ph]]; G. Bozzi, S. Catani, D. de Florian and M. Grazzini, Nucl. Phys. B **737** (2006), 73-120 doi:10.1016/j.nuclphysb.2005.12.022 [arXiv:hep-ph/0508068 [hep-ph]]; D. de Florian, G. Ferrera, M. Grazzini and D. Tommasini, JHEP **11** (2011), 064 doi:10.1007/JHEP11(2011)064 [arXiv:1109.2109 [hep-ph]]; https://www.physik.uzh.ch/en/groups/grazzini/research/Tools.html

[12] J. M. Campbell and R. K. Ellis, Phys. Rev. D **60** (1999), 113006 doi:10.1103/PhysRevD.60.113006 [arXiv:hep-ph/9905386 [hep-ph]]; J. M. Campbell, R. K. Ellis and C. Williams, JHEP **07** (2011), 018 doi:10.1007/JHEP07(2011)018 [arXiv:1105.0020 [hep-ph]]; J. Campbell and T. Neumann, JHEP **12** (2019), 034

doi:10.1007/JHEP12(2019)034 [arXiv:1909.09117 [hep-ph]]; R. Boughezal, J. M. Campbell, R. K. Ellis, C. Focke, W. Giele, X. Liu, F. Petriello and C. Williams, Eur. Phys. J. C **77** (2017) no.1, 7 doi:10.1140/epjc/s10052-016-4558-y [arXiv:1605.08011 [hep-ph]]; T. Becher and T. Neumann, JHEP **03** (2021), 199 doi:10.1007/JHEP03(2021)199 [arXiv:2009.11437 [hep-ph]]; https://mcfm.fnal.gov/

[13] M. Cacciari, F. A. Dreyer, A. Karlberg, G. P. Salam and G. Zanderighi, Phys. Rev. Lett. **115** (2015) no.8, 082002 [erratum: Phys. Rev. Lett. **120** (2018) no.13, 139901] doi:10.1103/PhysRevLett.115.082002 [arXiv:1506.02660 [hep-ph]]; F. A. Dreyer and A. Karlberg, Phys. Rev. Lett. **117** (2016) no.7, 072001 doi:10.1103/PhysRevLett.117.072001 [arXiv:1606.00840 [hep-ph]].

[14] F. A. Dreyer, A. Karlberg and L. Tancredi, JHEP **10** (2020), 131 doi:10.1007/JHEP10(2020)131 [arXiv:2005.11334 [hep-ph]]; https://provbfh.hepforge.org/

[15] F. A. Dreyer and A. Karlberg, Phys. Rev. D **98** (2018) no.11, 114016 doi:10.1103/PhysRevD.98.114016 [arXiv:1811.07906 [hep-ph]]; F. A. Dreyer and A. Karlberg, Phys. Rev. D **99** (2019) no.7, 074028 doi:10.1103/PhysRevD.99.074028 [arXiv:1811.07918 [hep-ph]].

[16] G. Heinrich, Phys. Rept. **922** (2021), 1-69 doi:10.1016/j.physrep.2021.03.006 [arXiv:2009.00516 [hep-ph]].

[17] M. Spira, A. Djouadi, D. Graudenz and P. M. Zerwas, Nucl. Phys. B **453** (1995), 17-82 doi:10.1016/0550-3213(95)00379-7 [arXiv:hep-ph/9504378 [hep-ph]]; M. Spira, [arXiv:hep-ph/9510347 [hep-ph]]; http://tiger.web.psi.ch/proglist.html

[18] G. Passarino, C. Sturm and S. Uccirati, Phys. Lett. B **706** (2011), 195-199 doi:10.1016/j.physletb.2011.11.012 [arXiv:1108.2025 [hep-ph]]; M. Mühlleitner and M. Spira, Nucl. Phys. B **790** (2008) 1 [arXiv:hep-ph/0612254].

[19] S. Actis, G. Passarino, C. Sturm and S. Uccirati, Nucl. Phys. B **811** (2009) 182 [arXiv:0809.3667 [hep-ph]]; S. Actis, G. Passarino, C. Sturm and S. Uccirati, Phys. Lett. B **670** (2008) 12 [arXiv:0809.1301 [hep-ph]]; S. Actis, G. Passarino, C. Sturm and S. Uccirati, Phys. Lett. B **669** (2008) 62 [arXiv:0809.1302 [hep-ph]].

[20] T. Plehn, M. Spira and P. M. Zerwas, Nucl. Phys. B **479** (1996), 46-64 [erratum: Nucl. Phys. B **531** (1998), 655-655] doi:10.1016/0550-3213(96)00418-X [arXiv:hep-ph/9603205 [hep-ph]]; S. Dawson, S. Dittmaier and M. Spira, Phys. Rev. D **58** (1998), 115012 doi:10.1103/PhysRevD.58.115012 [arXiv:hep-ph/9805244 [hep-ph]]; R. Gröber, M. Mühlleitner, M. Spira and J. Streicher, JHEP **09** (2015), 092 doi:10.1007/JHEP09(2015)092 [arXiv:1504.06577 [hep-ph]]; http://tiger.web.psi.ch/proglist.html

[21] R. V. Harlander, S. Liebler and H. Mantler, Comput. Phys. Commun. **184** (2013), 1605-1617 doi:10.1016/j.cpc.2013.02.006 [arXiv:1212.3249 [hep-ph]]; R. V. Harlander, S. Liebler and

H. Mantler, Comput. Phys. Commun. **212** (2017), 239-257 doi:10.1016/j.cpc.2016.10.015 [arXiv:1605.03190 [hep-ph]]; S. Liebler, Eur. Phys. J. C **75** (2015) no.5, 210 doi:10.1140/epjc/s10052-015-3432-7 [arXiv:1502.07972 [hep-ph]]; R. V. Harlander, Eur. Phys. J. C **76** (2016) no.5, 252 doi:10.1140/epjc/s10052-016-4093-x [arXiv:1512.04901 [hep-ph]]; S. Liebler, S. Patel and G. Weiglein, Eur. Phys. J. C **77** (2017) no.5, 305 doi:10.1140/epjc/s10052-017-4849-y [arXiv:1611.09308 [hep-ph]]; https://sushi.hepforge.org/

[22] O. Brein, R. V. Harlander and T. J. E. Zirke, Comput. Phys. Commun. **184** (2013), 998-1003 doi:10.1016/j.cpc.2012.11.002 [arXiv:1210.5347 [hep-ph]]; R. V. Harlander, J. Klappert, S. Liebler and L. Simon, JHEP **05** (2018), 089 doi:10.1007/JHEP05(2018)089 [arXiv:1802.04817 [hep-ph]]; https://web.physik.rwth-aachen.de/~harlander/software/vh@nnlo/

[23] M. Ciccolini, A. Denner and S. Dittmaier, Phys. Rev. Lett. **99** (2007), 161803 doi:10.1103/PhysRevLett.99.161803 [arXiv:0707.0381 [hep-ph]]; M. Ciccolini, A. Denner and S. Dittmaier, Phys. Rev. D **77** (2008), 013002 doi:10.1103/PhysRevD.77.013002 [arXiv:0710.4749 [hep-ph]]; A. Denner, S. Dittmaier, S. Kallweit and A. Mück, JHEP **03** (2012), 075 doi:10.1007/JHEP03(2012)075 [arXiv:1112.5142 [hep-ph]]; A. Denner, S. Dittmaier, S. Kallweit and A. Mück, Comput. Phys. Commun. **195** (2015), 161-171 doi:10.1016/j.cpc.2015.04.021 [arXiv:1412.5390 [hep-ph]]; https://hawk.hepforge.org/

[24] A. Denner, S. Dittmaier and J. N. Lang, JHEP **11** (2018), 104 doi:10.1007/JHEP11(2018)104 [arXiv:1808.03466 [hep-ph]].

[25] A. Denner, J. N. Lang and S. Uccirati, JHEP **07** (2017), 087 doi:10.1007/JHEP07(2017)087 [arXiv:1705.06053 [hep-ph]].

[26] A. Denner, J. N. Lang and S. Uccirati, Comput. Phys. Commun. **224** (2018), 346-361 doi:10.1016/j.cpc.2017.11.013 [arXiv:1711.07388 [hep-ph]]; https://recola.gitlab.io/recola2/

[27] K. Arnold, M. Bahr, G. Bozzi, F. Campanario, C. Englert, T. Figy, N. Greiner, C. Hackstein, V. Hankele and B. Jager, *et al.* Comput. Phys. Commun. **180** (2009), 1661-1670 doi:10.1016/j.cpc.2009.03.006 [arXiv:0811.4559 [hep-ph]]; J. Baglio, J. Bellm, G. Bozzi, M. Brieg, F. Campanario, C. Englert, B. Feigl, J. Frank, T. Figy and F. Geyer, *et al.* [arXiv:1107.4038 [hep-ph]]; J. Baglio, J. Bellm, F. Campanario, B. Feigl, J. Frank, T. Figy, M. Kerner, L. D. Ninh, S. Palmer and M. Rauch, *et al.* [arXiv:1404.3940 [hep-ph]]; https://www.itp.kit.edu/vbfnlo/wiki/doku.php?id=overview.

[28] T. Figy, C. Oleari and D. Zeppenfeld, Phys. Rev. D **68** (2003), 073005 doi:10.1103/PhysRevD.68.073005 [arXiv:hep-ph/0306109 [hep-ph]]; T. Figy, V. Hankele and D. Zeppenfeld, JHEP **02** (2008), 076 doi:10.1088/1126-6708/2008/02/076 [arXiv:0710.5621 [hep-ph]]; K. Arnold, T. Figy, B. Jager and D. Zeppenfeld, JHEP **08** (2010), 088 doi:10.1007/JHEP08(2010)088 [arXiv:1006.4237 [hep-ph]].

PoS(CompTools2021)008

[29] T. Figy, S. Palmer and G. Weiglein, JHEP **02** (2012), 105 doi:10.1007/JHEP02(2012)105 [arXiv:1012.4789 [hep-ph]].

[30] T. Figy and D. Zeppenfeld, Phys. Lett. B **591** (2004), 297-303 doi:10.1016/j.physletb.2004.04.033 [arXiv:hep-ph/0403297 [hep-ph]].

[31] T. Figy, Mod. Phys. Lett. A **23** (2008), 1961-1973 doi:10.1142/S0217732308028181 [arXiv:0806.2200 [hep-ph]]; J. Baglio, A. Djouadi, R. Gröber, M. M. Mühlleitner, J. Quevillon and M. Spira, JHEP **04** (2013), 151 doi:10.1007/JHEP04(2013)151 [arXiv:1212.5581 [hep-ph]].

[32] F. Campanario, R. Roth and D. Zeppenfeld, Phys. Rev. D **91** (2015), 054039 doi:10.1103/PhysRevD.91.054039 [arXiv:1410.4840 [hep-ph]].

[33] V. Del Duca, W. Kilgore, C. Oleari, C. Schmidt and D. Zeppenfeld, Phys. Rev. Lett. **87** (2001), 122001 doi:10.1103/PhysRevLett.87.122001 [arXiv:hep-ph/0105129 [hep-ph]]; V. Del Duca, W. Kilgore, C. Oleari, C. Schmidt and D. Zeppenfeld, Nucl. Phys. B **616** (2001), 367-399 doi:10.1016/S0550-3213(01)00446-1 [arXiv:hep-ph/0108030 [hep-ph]]; V. Del Duca, G. Klamke, D. Zeppenfeld, M. L. Mangano, M. Moretti, F. Piccinini, R. Pittau and A. D. Polosa, JHEP **10** (2006), 016 doi:10.1088/1126-6708/2006/10/016 [arXiv:hep-ph/0608158 [hep-ph]]; F. Campanario, M. Kubocz and D. Zeppenfeld, Phys. Rev. D **84** (2011), 095025 doi:10.1103/PhysRevD.84.095025 [arXiv:1011.3819 [hep-ph]].

[34] F. E. Paige and S. D. Protopopescu, BNL-29777;
F. E. Paige, S. D. Protopopescu, H. Baer and X. Tata, [arXiv:hep-ph/0312045 [hep-ph]]; http://www.nhn.ou.edu/~isajet/

[35] A. Djouadi, J. Kalinowski and M. Spira, Comput. Phys. Commun. **108** (1998), 56-74 doi:10.1016/S0010-4655(97)00123-9 [arXiv:hep-ph/9704448 [hep-ph]]; A. Djouadi, J. Kalinowski, M. Mühlleitner and M. Spira, Comput. Phys. Commun. **238** (2019), 214-231 doi:10.1016/j.cpc.2018.12.010 [arXiv:1801.09506 [hep-ph]]; http://tiger.web.psi.ch/proglist.html

[36] G. Passarino, C. Sturm and S. Uccirati, Phys. Lett. B **655** (2007), 298-306 doi:10.1016/j.physletb.2007.09.002 [arXiv:0707.1401 [hep-ph]].

[37] A. Bredenstein, A. Denner, S. Dittmaier and M. M. Weber, Phys. Rev. D **74** (2006), 013004 doi:10.1103/PhysRevD.74.013004 [arXiv:hep-ph/0604011 [hep-ph]]; A. Bredenstein, A. Denner, S. Dittmaier and M. M. Weber, JHEP **02** (2007), 080 doi:10.1088/1126-6708/2007/02/080 [arXiv:hep-ph/0611234 [hep-ph]].

[38] R. Costa, M. Mühlleitner, M. O. P. Sampaio and R. Santos, JHEP **06** (2016), 034 doi:10.1007/JHEP06(2016)034 [arXiv:1512.05355 [hep-ph]]; https://www.itp.kit.edu/~maggie/sHDECAY/

[39] M. Mühlleitner, M. O. P. Sampaio, R. Santos and J. Wittbrodt, JHEP **03** (2017), 094 doi:10.1007/JHEP03(2017)094 [arXiv:1612.01309 [hep-ph]]; https://www.itp.kit.edu/~maggie/N2HDECAY/

[40] D. Fontes, M. Mühlleitner, J. C. Romão, R. Santos, J. P. Silva and J. Wittbrodt, JHEP **02** (2018), 073 doi:10.1007/JHEP02(2018)073 [arXiv:1711.09419 [hep-ph]]; https://www.itp.kit.edu/~maggie/C2HDM/

[41] M. Mühlleitner, J. Müller, S. L. Williamson and J. Wittbrodt, [arXiv:2110.06680 [hep-ph]]; https://www.itp.kit.edu/~maggie/CN2HDM_HDECAY/

[42] R. Contino, M. Ghezzi, C. Grojean, M. Mühlleitner and M. Spira, JHEP **07** (2013), 035 doi:10.1007/JHEP07(2013)035 [arXiv:1303.3876 [hep-ph]]; R. Contino, M. Ghezzi, C. Grojean, M. Mühlleitner and M. Spira, Comput. Phys. Commun. **185** (2014), 3412-3423 doi:10.1016/j.cpc.2014.06.028 [arXiv:1403.3381 [hep-ph]]; https://www.itp.kit.edu/~maggie/eHDECAY/

[43] M. Krause, M. Mühlleitner and M. Spira, Comput. Phys. Commun. **246** (2020), 106852 doi:10.1016/j.cpc.2019.08.003 [arXiv:1810.00768 [hep-ph]]; https://github.com/marcel-krause/2HDECAY

[44] M. Krause and M. Mühlleitner, Comput. Phys. Commun. **247** (2020), 106924 doi:10.1016/j.cpc.2019.106924 [arXiv:1904.02103 [hep-ph]]; https://github.com/marcel-krause/ewN2HDECAY

[45] J. Baglio, T. N. Dao and M. Mühlleitner, Eur. Phys. J. C **80** (2020) no.10, 960 doi:10.1140/epjc/s10052-020-08520-8 [arXiv:1907.12060 [hep-ph]]; T. N. Dao, M. Mühlleitner, S. Patel and K. Sakurai, Eur. Phys. J. C **81** (2021) no.4, 340 doi:10.1140/epjc/s10052-021-09129-1 [arXiv:2012.14889 [hep-ph]]; https://www.itp.kit.edu/~maggie/NMSSMCALCEW/

[46] J. Baglio, R. Gröber, M. Mühlleitner, D. T. Nhung, H. Rzehak, M. Spira, J. Streicher and K. Walz, Comput. Phys. Commun. **185** (2014) no.12, 3372-3391 doi:10.1016/j.cpc.2014.08.005 [arXiv:1312.4788 [hep-ph]]; K. Ender, T. Graf, M. Mühlleitner and H. Rzehak, Phys. Rev. D **85** (2012), 075024 doi:10.1103/PhysRevD.85.075024 [arXiv:1111.4952 [hep-ph]]; T. Graf, R. Gröber, M. Mühlleitner, H. Rzehak and K. Walz, JHEP **10** (2012), 122 doi:10.1007/JHEP10(2012)122 [arXiv:1206.6806 [hep-ph]]; M. Mühlleitner, D. T. Nhung, H. Rzehak and K. Walz, JHEP **05** (2015), 128 doi:10.1007/JHEP05(2015)128 [arXiv:1412.0918 [hep-ph]]; T. N. Dao, R. Gröber, M. Krause, M. Mühlleitner and H. Rzehak, JHEP **08** (2019), 114 doi:10.1007/JHEP08(2019)114 [arXiv:1903.11358 [hep-ph]]; T. N. Dao, M. Gabelmann, M. Mühlleitner and H. Rzehak, JHEP **09** (2021), 193 doi:10.1007/JHEP09(2021)193 [arXiv:2106.06990 [hep-ph]]; S. F. King, M. Mühlleitner, R. Nevzorov and K. Walz, Nucl. Phys. B **901** (2015), 526-555 doi:10.1016/j.nuclphysb.2015.11.003 [arXiv:1508.03255 [hep-ph]]; https://www.itp.kit.edu/~maggie/NMSSMCALC/

[47] A. Bredenstein, A. Denner, S. Dittmaier and M. M. Weber, Nucl. Phys. B Proc. Suppl. **160** (2006), 131-135 doi:10.1016/j.nuclphysbps.2006.09.104 [arXiv:hep-ph/0607060 [hep-ph]]; A. Denner, S. Dittmaier and A. Mück, Comput. Phys. Commun. **254**

(2020), 107336 doi:10.1016/j.cpc.2020.107336 [arXiv:1912.02010 [hep-ph]]; https://prophecy4f.hepforge.org/

[48] L. Altenkamp, M. Boggia and S. Dittmaier, JHEP **04** (2018), 062 doi:10.1007/JHEP04(2018)062 [arXiv:1801.07291 [hep-ph]].

[49] L. Altenkamp, S. Dittmaier and H. Rzehak, JHEP **09** (2017), 134 doi:10.1007/JHEP09(2017)134 [arXiv:1704.02645 [hep-ph]]; L. Altenkamp, S. Dittmaier and H. Rzehak, JHEP **03** (2018), 110 doi:10.1007/JHEP03(2018)110 [arXiv:1710.07598 [hep-ph]].

[50] S. Boselli, C. M. Carloni Calame, G. Montagna, O. Nicrosini and F. Piccinini, JHEP **06** (2015), 023 doi:10.1007/JHEP06(2015)023 [arXiv:1503.07394 [hep-ph]]; S. Boselli, C. M. Carloni Calame, G. Montagna, O. Nicrosini, F. Piccinini and A. Shivaji, JHEP **01** (2018), 096 doi:10.1007/JHEP01(2018)096 [arXiv:1703.06667 [hep-ph]]; https://www2.pv.infn.it/~hepcomplex/hto4l.html

[51] D. Eriksson, J. Rathsman and O. Stål, Comput. Phys. Commun. **181** (2010), 189-205 doi:10.1016/j.cpc.2009.09.011 [arXiv:0902.0851 [hep-ph]]; https://2hdmc.hepforge.org/

[52] S. Kanemura, M. Kikuchi, K. Sakurai and K. Yagyu, Comput. Phys. Commun. **233** (2018), 134-144 doi:10.1016/j.cpc.2018.06.012 [arXiv:1710.04603 [hep-ph]]; S. Kanemura, M. Kikuchi, K. Mawatari, K. Sakurai and K. Yagyu, Comput. Phys. Commun. **257** (2020), 107512 doi:10.1016/j.cpc.2020.107512 [arXiv:1910.12769 [hep-ph]]; http://www-het.phys.sci.osaka-u.ac.jp/~hcoup/

[53] K. Hartling, K. Kumar and H. E. Logan, [arXiv:1412.7387 [hep-ph]]; K. Hartling, K. Kumar and H. E. Logan, Phys. Rev. D **90** (2014) no.1, 015007 doi:10.1103/PhysRevD.90.015007 [arXiv:1404.2640 [hep-ph]]; K. Hartling, K. Kumar and H. E. Logan, Phys. Rev. D **91** (2015) no.1, 015013 doi:10.1103/PhysRevD.91.015013 [arXiv:1410.5538 [hep-ph]]; C. Degrande, K. Hartling and H. E. Logan, Phys. Rev. D **96** (2017) no.7, 075013 [erratum: Phys. Rev. D **98** (2018) no.1, 019901] doi:10.1103/PhysRevD.96.075013 [arXiv:1708.08753 [hep-ph]]; https://people.physics.carleton.ca/~logan/gmcalc/index.html

[54] P. Slavich, S. Heinemeyer, E. Bagnaschi, H. Bahl, M. Goodsell, H. E. Haber, T. Hahn, R. Harlander, W. Hollik and G. Lee, *et al.* Eur. Phys. J. C **81** (2021) no.5, 450 doi:10.1140/epjc/s10052-021-09198-2 [arXiv:2012.15629 [hep-ph]].

[55] B. C. Allanach, Comput. Phys. Commun. **143** (2002), 305-331 doi:10.1016/S0010-4655(01)00460-X [arXiv:hep-ph/0104145 [hep-ph]]; B. C. Allanach and T. Cridge, Comput. Phys. Commun. **220** (2017), 417-502 doi:10.1016/j.cpc.2017.07.021 [arXiv:1703.09717 [hep-ph]]; B. C. Allanach, P. Athron, L. C. Tunstall, A. Voigt and A. G. Williams, Comput. Phys. Commun. **185** (2014), 2322-2339 [erratum: Comput. Phys. Commun. **250** (2020), 107044] doi:10.1016/j.cpc.2014.04.015 [arXiv:1311.7659 [hep-ph]]; B. C. Allanach and M. A. Bernhardt, Comput. Phys. Commun. **181** (2010), 232-245 doi:10.1016/j.cpc.2009.09.015

PoS(CompTools2021)008

[arXiv:0903.1805 [hep-ph]]; B. C. Allanach, C. H. Kom and M. Hanussek, Comput. Phys. Commun. **183** (2012), 785-793 doi:10.1016/j.cpc.2011.11.024 [arXiv:1109.3735 [hep-ph]]; B. C. Allanach, A. Bednyakov and R. Ruiz de Austri, Comput. Phys. Commun. **189** (2015), 192-206 doi:10.1016/j.cpc.2014.12.006 [arXiv:1407.6130 [hep-ph]]; B. C. Allanach, S. P. Martin, D. G. Robertson and R. Ruiz de Austri, Comput. Phys. Commun. **219** (2017), 339-345 doi:10.1016/j.cpc.2017.05.006 [arXiv:1601.06657 [hep-ph]]; https://softsusy.hepforge.org/

[56] W. Porod, Comput. Phys. Commun. **153** (2003), 275-315 doi:10.1016/S0010-4655(03)00222-4 [arXiv:hep-ph/0301101 [hep-ph]]; W. Porod and F. Staub, Comput. Phys. Commun. **183** (2012), 2458-2469 doi:10.1016/j.cpc.2012.05.021 [arXiv:1104.1573 [hep-ph]]; F. Staub and W. Porod, Eur. Phys. J. C **77** (2017) no.5, 338 doi:10.1140/epjc/s10052-017-4893-7 [arXiv:1703.03267 [hep-ph]]; https://spheno.hepforge.org/

[57] D. Chowdhury, R. Garani and S. K. Vempati, Comput. Phys. Commun. **184** (2013), 899-918 doi:10.1016/j.cpc.2012.10.031 [arXiv:1109.3551 [hep-ph]]; https://github.com/debtosh/SuSeFLAV

[58] A. Djouadi, J. L. Kneur and G. Moultaka, Comput. Phys. Commun. **176** (2007), 426-455 doi:10.1016/j.cpc.2006.11.009 [arXiv:hep-ph/0211331 [hep-ph]]; http://suspect.in2p3.fr/

[59] J. S. Lee, A. Pilaftsis, M. Carena, S. Y. Choi, M. Drees, J. R. Ellis and C. E. M. Wagner, Comput. Phys. Commun. **156** (2004), 283-317 doi:10.1016/S0010-4655(03)00463-6 [arXiv:hep-ph/0307377 [hep-ph]]; J. S. Lee, M. Carena, J. Ellis, A. Pilaftsis and C. E. M. Wagner, Comput. Phys. Commun. **180** (2009), 312-331 doi:10.1016/j.cpc.2008.09.003 [arXiv:0712.2360 [hep-ph]]; J. S. Lee, M. Carena, J. Ellis, A. Pilaftsis and C. E. M. Wagner, Comput. Phys. Commun. **184** (2013), 1220-1233 doi:10.1016/j.cpc.2012.11.006 [arXiv:1208.2212 [hep-ph]]. https://www.hep.manchester.ac.uk/u/jslee/CPsuperH.html

[60] R. V. Harlander, P. Kant, L. Mihaila and M. Steinhauser, Phys. Rev. Lett. **100** (2008), 191602 doi:10.1103/PhysRevLett.101.039901 [arXiv:0803.0672 [hep-ph]]; P. Kant, R. V. Harlander, L. Mihaila and M. Steinhauser, JHEP **08** (2010), 104 doi:10.1007/JHEP08(2010)104 [arXiv:1005.5709 [hep-ph]]; D. Kunz, L. Mihaila and N. Zerf, JHEP **12** (2014), 136 doi:10.1007/JHEP12(2014)136 [arXiv:1409.2297 [hep-ph]]; https://www.ttp.kit.edu/Progdata/ttp10/ttp10-23/

[61] J. Pardo Vega and G. Villadoro, JHEP **07** (2015), 159 doi:10.1007/JHEP07(2015)159 [arXiv:1504.05200 [hep-ph]]; http://users.ictp.it/susyhd/

[62] P. Draper, G. Lee and C. E. M. Wagner, Phys. Rev. D **89** (2014) no.5, 055023 doi:10.1103/PhysRevD.89.055023 [arXiv:1312.5743 [hep-ph]]; G. Lee and C. E. M. Wagner, Phys. Rev. D **92** (2015) no.7, 075032 doi:10.1103/PhysRevD.92.075032 [arXiv:1508.00576 [hep-ph]]; https://gabrlee.com/code/

[63] S. Heinemeyer, W. Hollik and G. Weiglein, Comput. Phys. Commun. **124** (2000), 76-89 doi:10.1016/S0010-4655(99)00364-1 [arXiv:hep-ph/9812320 [hep-ph]]; S. Heinemeyer, W. Hollik and G. Weiglein, Eur. Phys. J. C **9** (1999), 343-366 doi:10.1007/s100529900006 [arXiv:hep-ph/9812472 [hep-ph]]; G. Degrassi, S. Heinemeyer, W. Hollik, P. Slavich and G. Weiglein, Eur. Phys. J. C **28** (2003), 133-143 doi:10.1140/epjc/s2003-01152-2 [arXiv:hep-ph/0212020 [hep-ph]]; M. Frank, T. Hahn, S. Heinemeyer, W. Hollik, H. Rzehak and G. Weiglein, JHEP **02** (2007), 047 doi:10.1088/1126-6708/2007/02/047 [arXiv:hep-ph/0611326 [hep-ph]]; S. Heinemeyer, W. Hollik, H. Rzehak and G. Weiglein, Phys. Lett. B **652** (2007), 300-309 doi:10.1016/j.physletb.2007.07.030 [arXiv:0705.0746 [hep-ph]]; T. Hahn, S. Heinemeyer, W. Hollik, H. Rzehak and G. Weiglein, Phys. Rev. Lett. **112** (2014) no.14, 141801 doi:10.1103/PhysRevLett.112.141801 [arXiv:1312.4937 [hep-ph]]; W. Hollik and S. Paßehr, Phys. Lett. B **733** (2014), 144-150 doi:10.1016/j.physletb.2014.04.026 [arXiv:1401.8275 [hep-ph]]; S. Borowka, T. Hahn, S. Heinemeyer, G. Heinrich and W. Hollik, Eur. Phys. J. C **74** (2014) no.8, 2994 doi:10.1140/epjc/s10052-014-2994-0 [arXiv:1404.7074 [hep-ph]]; W. Hollik and S. Paßehr, JHEP **10** (2014), 171 doi:10.1007/JHEP10(2014)171 [arXiv:1409.1687 [hep-ph]]; W. Hollik and S. Paßehr, Eur. Phys. J. C **75** (2015) no.7, 336 doi:10.1140/epjc/s10052-015-3558-7 [arXiv:1502.02394 [hep-ph]]; S. Borowka, T. Hahn, S. Heinemeyer, G. Heinrich and W. Hollik, Eur. Phys. J. C **75** (2015) no.9, 424 doi:10.1140/epjc/s10052-015-3648-6 [arXiv:1505.03133 [hep-ph]]; H. Bahl and W. Hollik, Eur. Phys. J. C **76** (2016) no.9, 499 doi:10.1140/epjc/s10052-016-4354-8 [arXiv:1608.01880 [hep-ph]]; H. Bahl, S. Heinemeyer, W. Hollik and G. Weiglein, Eur. Phys. J. C **78** (2018) no.1, 57 doi:10.1140/epjc/s10052-018-5544-3 [arXiv:1706.00346 [hep-ph]]; H. Bahl and W. Hollik, JHEP **07** (2018), 182 doi:10.1007/JHEP07(2018)182 [arXiv:1805.00867 [hep-ph]]; H. Bahl, T. Hahn, S. Heinemeyer, W. Hollik, S. Paßehr, H. Rzehak and G. Weiglein, Comput. Phys. Commun. **249** (2020), 107099 doi:10.1016/j.cpc.2019.107099 [arXiv:1811.09073 [hep-ph]]; H. Bahl, S. Heinemeyer, W. Hollik and G. Weiglein, Eur. Phys. J. C **80** (2020) no.6, 497 doi:10.1140/epjc/s10052-020-8079-3 [arXiv:1912.04199 [hep-ph]]; H. Bahl, I. Sobolev and G. Weiglein, Eur. Phys. J. C **80** (2020) no.11, 1063 doi:10.1140/epjc/s10052-020-08637-w [arXiv:2009.07572 [hep-ph]]; H. Bahl and I. Sobolev, JHEP **03** (2021), 286 doi:10.1007/JHEP03(2021)286 [arXiv:2010.01989 [hep-ph]]; H. Bahl, N. Murphy and H. Rzehak, Eur. Phys. J. C **81** (2021) no.2, 128 doi:10.1140/epjc/s10052-021-08939-7 [arXiv:2010.04711 [hep-ph]]; http://www.feynhiggs.de/

[64] R. V. Harlander, J. Klappert and A. Voigt, Eur. Phys. J. C **77** (2017) no.12, 814 doi:10.1140/epjc/s10052-017-5368-6 [arXiv:1708.05720 [hep-ph]]; R. V. Harlander, J. Klappert, A. D. Ochoa Franco and A. Voigt, Eur. Phys. J. C **78** (2018) no.10, 874 doi:10.1140/epjc/s10052-018-6351-6 [arXiv:1807.03509 [hep-ph]]; R. V. Harlander, J. Klappert and A. Voigt, Eur. Phys. J. C **80** (2020) no.3, 186 doi:10.1140/epjc/s10052-020-7747-7 [arXiv:1910.03595 [hep-ph]]; https://github.com/Himalaya-Library/Himalaya

[65] P. Athron, J. h. Park, D. Stöckinger and A. Voigt, Comput. Phys. Commun. **190** (2015), 139-172 doi:10.1016/j.cpc.2014.12.020 [arXiv:1406.2319 [hep-ph]]; P. Athron, J. h. Park, T. Steudtner, D. Stöckinger and A. Voigt, JHEP **01** (2017), 079 doi:10.1007/JHEP01(2017)079 [arXiv:1609.00371 [hep-ph]]; P. Athron, M. Bach, D. Harries, T. Kwasnitza, J. h. Park,

D. Stöckinger, A. Voigt and J. Ziebell, Comput. Phys. Commun. **230** (2018), 145-217 doi:10.1016/j.cpc.2018.04.016 [arXiv:1710.03760 [hep-ph]]; https://flexiblesusy.hepforge.org/

[66] P. Athron, A. Büchner, D. Harries, W. Kotlarski, D. Stöckinger and A. Voigt, [arXiv:2106.05038 [hep-ph]].

[67] F. Staub, [arXiv:0806.0538 [hep-ph]]; F. Staub, Comput. Phys. Commun. **181** (2010), 1077-1086 doi:10.1016/j.cpc.2010.01.011 [arXiv:0909.2863 [hep-ph]]; F. Staub, Comput. Phys. Commun. **182** (2011), 808-833 doi:10.1016/j.cpc.2010.11.030 [arXiv:1002.0840 [hep-ph]]; F. Staub, T. Ohl, W. Porod and C. Speckner, Comput. Phys. Commun. **183** (2012), 2165-2206 doi:10.1016/j.cpc.2012.04.013 [arXiv:1109.5147 [hep-ph]]; F. Staub, Comput. Phys. Commun. **184** (2013), 1792-1809 doi:10.1016/j.cpc.2013.02.019 [arXiv:1207.0906 [hep-ph]]; F. Staub, Comput. Phys. Commun. **185** (2014), 1773-1790 doi:10.1016/j.cpc.2014.02.018 [arXiv:1309.7223 [hep-ph]]; M. D. Goodsell, K. Nickel and F. Staub, Eur. Phys. J. C **75** (2015) no.1, 32 doi:10.1140/epjc/s10052-014-3247-y [arXiv:1411.0675 [hep-ph]]; M. D. Goodsell and F. Staub, Eur. Phys. J. C **77** (2017) no.1, 46 doi:10.1140/epjc/s10052-016-4495-9 [arXiv:1604.05335 [hep-ph]]; F. Staub and W. Porod, Eur. Phys. J. C **77** (2017) no.5, 338 doi:10.1140/epjc/s10052-017-4893-7 [arXiv:1703.03267 [hep-ph]]; M. D. Goodsell, S. Liebler and F. Staub, Eur. Phys. J. C **77** (2017) no.11, 758 doi:10.1140/epjc/s10052-017-5259-x [arXiv:1703.09237 [hep-ph]]; M. D. Goodsell and F. Staub, Eur. Phys. J. C **78** (2018) no.8, 649 doi:10.1140/epjc/s10052-018-6127-z [arXiv:1805.07306 [hep-ph]]; M. Gabelmann, M. Mühlleitner and F. Staub, Eur. Phys. J. C **79** (2019) no.2, 163 doi:10.1140/epjc/s10052-019-6570-5 [arXiv:1810.12326 [hep-ph]]; https://sarah.hepforge.org/

[68] U. Ellwanger, J. F. Gunion and C. Hugonie, JHEP **02** (2005), 066 doi:10.1088/1126-6708/2005/02/066 [arXiv:hep-ph/0406215 [hep-ph]]; U. Ellwanger and C. Hugonie, Comput. Phys. Commun. **175** (2006), 290-303 doi:10.1016/j.cpc.2006.04.004 [arXiv:hep-ph/0508022 [hep-ph]]; G. Degrassi and P. Slavich, Nucl. Phys. B **825** (2010), 119-150 doi:10.1016/j.nuclphysb.2009.09.018 [arXiv:0907.4682 [hep-ph]]; S. Narison, Phys. Lett. B **236** (1990), 474-478 doi:10.1016/0370-2693(90)90386-K; F. Domingo, JHEP **03** (2017), 052 doi:10.1007/JHEP03(2017)052 [arXiv:1612.06538 [hep-ph]]; F. Domingo, U. Ellwanger and M. A. Sanchis-Lozano, Phys. Rev. Lett. **103** (2009), 111802 doi:10.1103/PhysRevLett.103.111802 [arXiv:0907.0348 [hep-ph]]; M. Drees and K. i. Hikasa, Phys. Rev. D **41** (1990), 1547 doi:10.1103/PhysRevD.41.1547; F. Domingo and U. Ellwanger, JHEP **06** (2011), 067 doi:10.1007/JHEP06(2011)067 [arXiv:1105.1722 [hep-ph]]; U. Ellwanger and C. Hugonie, Comput. Phys. Commun. **177** (2007), 399-407 doi:10.1016/j.cpc.2007.05.001 [arXiv:hep-ph/0612134 [hep-ph]]; U. Ellwanger, C. C. Jean-Louis and A. M. Teixeira, JHEP **05** (2008), 044 doi:10.1088/1126-6708/2008/05/044 [arXiv:0803.2962 [hep-ph]]; B. Allanach, M. Badziak, C. Hugonie and R. Ziegler, PoS **PLANCK2015** (2015), 012 [arXiv:1510.03143 [hep-ph]]; M. Badziak, N. Desai, C. Hugonie and R. Ziegler, Eur. Phys. J. C **79** (2019) no.1, 67 doi:10.1140/epjc/s10052-019-6590-1 [arXiv:1810.05618 [hep-ph]]; F. Domingo, JHEP **06** (2015), 052 doi:10.1007/JHEP06(2015)052 [arXiv:1503.07087 [hep-ph]]; D. Das,

U. Ellwanger and A. M. Teixeira, Comput. Phys. Commun. **183** (2012), 774-779 doi:10.1016/j.cpc.2011.11.021 [arXiv:1106.5633 [hep-ph]]; M. Mühlleitner, A. Djouadi and Y. Mambrini, Comput. Phys. Commun. **168** (2005), 46-70 doi:10.1016/j.cpc.2005.01.012 [arXiv:hep-ph/0311167 [hep-ph]]; https://www.lupm.univ-montp2.fr/users/nmssm/

[69] T. Biekötter, S. Heinemeyer and C. Muñoz, Eur. Phys. J. C **78** (2018) no.6, 504 doi:10.1140/epjc/s10052-018-5978-7 [arXiv:1712.07475 [hep-ph]]; T. Biekötter, S. Heinemeyer and C. Muñoz, Eur. Phys. J. C **79** (2019) no.8, 667 doi:10.1140/epjc/s10052-019-7175-8 [arXiv:1906.06173 [hep-ph]]; T. Biekötter, Comput. Phys. Commun. **264** (2021), 107935 doi:10.1016/j.cpc.2021.107935 [arXiv:2009.12887 [hep-ph]]; T. Biekötter, S. Heinemeyer and G. Weiglein, [arXiv:2112.12132 [hep-ph]]. https://gitlab.com/thomas.biekoetter/munussm

[70] P. Bechtle, S. Heinemeyer, O. Stål, T. Stefaniak and G. Weiglein, Eur. Phys. J. C **74** (2014) no.2, 2711 doi:10.1140/epjc/s10052-013-2711-4 [arXiv:1305.1933 [hep-ph]]; P. Bechtle, S. Heinemeyer, O. Stål, T. Stefaniak and G. Weiglein, JHEP **11** (2014), 039 doi:10.1007/JHEP11(2014)039 [arXiv:1403.1582 [hep-ph]]; P. Bechtle, S. Heinemeyer, T. Klingl, T. Stefaniak, G. Weiglein and J. Wittbrodt, Eur. Phys. J. C **81** (2021) no.2, 145 doi:10.1140/epjc/s10052-021-08942-y [arXiv:2012.09197 [hep-ph]]; https://gitlab.com/higgsbounds/higgssignals

[71] P. Bechtle, O. Brein, S. Heinemeyer, G. Weiglein and K. E. Williams, Comput. Phys. Commun. **181** (2010), 138-167 doi:10.1016/j.cpc.2009.09.003 [arXiv:0811.4169 [hep-ph]]; P. Bechtle, O. Brein, S. Heinemeyer, G. Weiglein and K. E. Williams, Comput. Phys. Commun. **182** (2011), 2605-2631 doi:10.1016/j.cpc.2011.07.015 [arXiv:1102.1898 [hep-ph]]; P. Bechtle, O. Brein, S. Heinemeyer, O. Stål, T. Stefaniak, G. Weiglein and K. Williams, PoS **CHARGED2012** (2012), 024 doi:10.22323/1.156.0024 [arXiv:1301.2345 [hep-ph]]; P. Bechtle, O. Brein, S. Heinemeyer, O. Stål, T. Stefaniak, G. Weiglein and K. E. Williams, Eur. Phys. J. C **74** (2014) no.3, 2693 doi:10.1140/epjc/s10052-013-2693-2 [arXiv:1311.0055 [hep-ph]]; P. Bechtle, S. Heinemeyer, O. Stål, T. Stefaniak and G. Weiglein, Eur. Phys. J. C **75** (2015) no.9, 421 doi:10.1140/epjc/s10052-015-3650-z [arXiv:1507.06706 [hep-ph]]; P. Bechtle, D. Dercks, S. Heinemeyer, T. Klingl, T. Stefaniak, G. Weiglein and J. Wittbrodt, Eur. Phys. J. C **80** (2020) no.12, 1211 doi:10.1140/epjc/s10052-020-08557-9 [arXiv:2006.06007 [hep-ph]]; H. Bahl, V. M. Lozano, T. Stefaniak and J. Wittbrodt, [arXiv:2109.10366 [hep-ph]]; https://gitlab.com/higgsbounds/higgsbounds

[72] https://gitlab.com/higgsbounds/higgstools/-/tree/develop/

[73] J. Bernon, B. Dumont and S. Kraml, Phys. Rev. D **90** (2014), 071301 doi:10.1103/PhysRevD.90.071301 [arXiv:1409.1588 [hep-ph]]; J. Bernon and B. Dumont, Eur. Phys. J. C **75** (2015) no.9, 440 doi:10.1140/epjc/s10052-015-3645-9 [arXiv:1502.04138 [hep-ph]]; S. Kraml, T. Q. Loc, D. T. Nhung and L. Ninh, SciPost Phys. **7** (2019) no.4, 052 doi:10.21468/SciPostPhys.7.4.052 [arXiv:1908.03952 [hep-ph]]; https://lpsc.in2p3.fr/projects-th/lilith/

[74] R. Coimbra, M. O. P. Sampaio and R. Santos, Eur. Phys. J. C **73** (2013), 2428 doi:10.1140/epjc/s10052-013-2428-4 [arXiv:1301.2599 [hep-ph]]; P. M. Ferreira, R. Guedes, M. O. P. Sampaio and R. Santos, JHEP **12** (2014), 067 doi:10.1007/JHEP12(2014)067 [arXiv:1409.6723 [hep-ph]]; M. Mühlleitner, M. O. P. Sampaio, R. Santos and J. Wittbrodt, Eur. Phys. J. C **82** (2022) no.3, 198 doi:10.1140/epjc/s10052-022-10139-w [arXiv:2007.02985 [hep-ph]]; https://scanners.hepforge.org/

[75] G. Belanger, F. Boudjema, C. Hugonie, A. Pukhov and A. Semenov, JCAP **09** (2005), 001 doi:10.1088/1475-7516/2005/09/001 [arXiv:hep-ph/0505142 [hep-ph]]; G. Belanger, F. Boudjema, A. Pukhov and A. Semenov, Comput. Phys. Commun. **174** (2006), 577-604 doi:10.1016/j.cpc.2005.12.005 [arXiv:hep-ph/0405253 [hep-ph]]; G. Belanger, F. Boudjema, A. Pukhov and A. Semenov, Comput. Phys. Commun. **176** (2007), 367-382 doi:10.1016/j.cpc.2006.11.008 [arXiv:hep-ph/0607059 [hep-ph]]; G. Belanger, F. Boudjema, A. Pukhov and A. Semenov, Comput. Phys. Commun. **185** (2014), 960-985 doi:10.1016/j.cpc.2013.10.016 [arXiv:1305.0237 [hep-ph]]; G. Bélanger, F. Boudjema, A. Goudelis, A. Pukhov and B. Zaldivar, Comput. Phys. Commun. **231** (2018), 173-186 doi:10.1016/j.cpc.2018.04.027 [arXiv:1801.03509 [hep-ph]]; https://lapth.cnrs.fr/micromegas/

[76] J. De Blas, D. Chowdhury, M. Ciuchini, A. M. Coutinho, O. Eberhardt, M. Fedele, E. Franco, G. Grilli Di Cortona, V. Miralles and S. Mishima, *et al.* Eur. Phys. J. C **80** (2020) no.5, 456 doi:10.1140/epjc/s10052-020-7904-z [arXiv:1910.14012 [hep-ph]]; https://hepfit.roma1.infn.it/

[77] A. Falkowski, B. Fuks, K. Mawatari, K. Mimasu, F. Riva and V. Sanz, Eur. Phys. J. C **75** (2015) no.12, 583 doi:10.1140/epjc/s10052-015-3806-x [arXiv:1508.05895 [hep-ph]]; https://rosetta.hepforge.org/

[78] F. Lyonnet, I. Schienbein, F. Staub and A. Wingerter, Comput. Phys. Commun. **185** (2014), 1130-1152 doi:10.1016/j.cpc.2013.12.002 [arXiv:1309.7030 [hep-ph]]; F. Lyonnet and I. Schienbein, Comput. Phys. Commun. **213** (2017), 181-196 doi:10.1016/j.cpc.2016.12.003 [arXiv:1608.07274 [hep-ph]]; L. Sartore and I. Schienbein, Comput. Phys. Commun. **261** (2021), 107819 doi:10.1016/j.cpc.2020.107819 [arXiv:2007.12700 [hep-ph]]; https://github.com/LSartore/pyrate

[79] C. Poole and A. E. Thomsen, JHEP **09** (2019), 055 doi:10.1007/JHEP09(2019)055 [arXiv:1906.04625 [hep-th]].

[80] A. E. Thomsen, Eur. Phys. J. C **81** (2021) no.5, 408 doi:10.1140/epjc/s10052-021-09142-4 [arXiv:2101.08265 [hep-ph]]; A. G. M. Pickering, J. A. Gracey and D. R. T. Jones, Phys. Lett. B **510** (2001), 347-354 [erratum: Phys. Lett. B **535** (2002), 377] doi:10.1016/S0370-2693(01)00624-4 [arXiv:hep-ph/0104247 [hep-ph]]; A. Bednyakov and A. Pikelner, Phys. Rev. Lett. **127** (2021) no.4, 041801 doi:10.1103/PhysRevLett.127.041801 [arXiv:2105.09918 [hep-ph]]; J. Davies, F. Herren and A. E. Thomsen, JHEP **01** (2022), 051 doi:10.1007/JHEP01(2022)051 [arXiv:2110.05496 [hep-ph]]; https://github.com/aethomsen/RGBeta

[81] S. Actis, A. Denner, L. Hofer, A. Scharf and S. Uccirati, JHEP **04** (2013), 037 doi:10.1007/JHEP04(2013)037 [arXiv:1211.6316 [hep-ph]]; S. Actis, A. Denner, L. Hofer, J. N. Lang, A. Scharf and S. Uccirati, Comput. Phys. Commun. **214** (2017), 140-173 doi:10.1016/j.cpc.2017.01.004 [arXiv:1605.01090 [hep-ph]]; https://recola.gitlab.io/recola2/

[82] N. D. Christensen and C. Duhr, Comput. Phys. Commun. **180** (2009), 1614-1641 doi:10.1016/j.cpc.2009.02.018 [arXiv:0806.4194 [hep-ph]]; N. D. Christensen, P. de Aquino, C. Degrande, C. Duhr, B. Fuks, M. Herquet, F. Maltoni and S. Schumann, Eur. Phys. J. C **71** (2011), 1541 doi:10.1140/epjc/s10052-011-1541-5 [arXiv:0906.2474 [hep-ph]]; N. D. Christensen, C. Duhr, B. Fuks, J. Reuter and C. Speckner, Eur. Phys. J. C **72** (2012), 1990 doi:10.1140/epjc/s10052-012-1990-5 [arXiv:1010.3251 [hep-ph]]; C. Duhr and B. Fuks, Comput. Phys. Commun. **182** (2011), 2404-2426 doi:10.1016/j.cpc.2011.06.009 [arXiv:1102.4191 [hep-ph]]; C. Degrande, C. Duhr, B. Fuks, D. Grellscheid, O. Mattelaer and T. Reiter, Comput. Phys. Commun. **183** (2012), 1201-1214 doi:10.1016/j.cpc.2012.01.022 [arXiv:1108.2040 [hep-ph]]; A. Alloul, J. D'Hondt, K. De Causmaecker, B. Fuks and M. Rausch de Traubenberg, Eur. Phys. J. C **73** (2013) no.2, 2325 doi:10.1140/epjc/s10052-013-2325-x [arXiv:1301.5932 [hep-ph]]; N. D. Christensen, P. de Aquino, N. Deutschmann, C. Duhr, B. Fuks, C. Garcia-Cely, O. Mattelaer, K. Mawatari, B. Oexl and Y. Takaesu, Eur. Phys. J. C **73** (2013) no.10, 2580 doi:10.1140/epjc/s10052-013-2580-x [arXiv:1308.1668 [hep-ph]]; A. Alloul, N. D. Christensen, C. Degrande, C. Duhr and B. Fuks, Comput. Phys. Commun. **185** (2014), 2250-2300 doi:10.1016/j.cpc.2014.04.012 [arXiv:1310.1921 [hep-ph]]; C. Degrande, Comput. Phys. Commun. **197** (2015), 239-262 doi:10.1016/j.cpc.2015.08.015 [arXiv:1406.3030 [hep-ph]]; https://feynrules.irmp.ucl.ac.be/

[83] S. Frixione, B. Fuks, V. Hirschi, K. Mawatari, H. S. Shao, P. A. Sunder and M. Zaro, JHEP **12** (2019), 008 doi:10.1007/JHEP12(2019)008 [arXiv:1907.04898 [hep-ph]]; https://feynrules.irmp.ucl.ac.be/wiki/MSSMatNLO

[84] A. V. Semenov, [arXiv:hep-ph/9608488 [hep-ph]]; A. V. Semenov, [arXiv:hep-ph/0208011 [hep-ph]]; A. Semenov, Comput. Phys. Commun. **180** (2009), 431-454 doi:10.1016/j.cpc.2008.10.012 [arXiv:0805.0555 [hep-ph]]; A. Semenov, Comput. Phys. Commun. **201** (2016), 167-170 doi:10.1016/j.cpc.2016.01.003 [arXiv:1412.5016 [physics.comp-ph]]; https://theory.sinp.msu.ru/~semenov/lanhep.html

[85] A. Pukhov, E. Boos, M. Dubinin, V. Edneral, V. Ilyin, D. Kovalenko, A. Kryukov, V. Savrin, S. Shichanin and A. Semenov, [arXiv:hep-ph/9908288 [hep-ph]]; A. S. Belyaev, E. E. Boos, A. N. Vologdin, M. N. Dubinin, V. A. Ilyin, A. P. Kryukov, A. E. Pukhov, A. N. Skachkova, V. I. Savrin and A. V. Sherstnev, *et al.* AIP Conf. Proc. **583** (2002) no.1, 211-213 doi:10.1063/1.1405306 [arXiv:hep-ph/0101232 [hep-ph]]; https://theory.sinp.msu.ru/doku.php/comphep/start

[86] A. Pukhov, [arXiv:hep-ph/0412191 [hep-ph]]; A. Belyaev, N. D. Christensen and A. Pukhov, Comput. Phys. Commun. **184** (2013), 1729-1769 doi:10.1016/j.cpc.2013.01.014 [arXiv:1207.6082 [hep-ph]]; https://theory.sinp.msu.ru/~pukhov/calchep.html

[87] H. Tanaka, T. Kaneko and Y. Shimizu, Comput. Phys. Commun. **64** (1991), 149-166 doi:10.1016/0010-4655(91)90058-S; J. Fujimoto, T. Ishikawa, M. Jimbo, T. Kaneko, K. Kato, S. Kawabata, K. Kon, M. Kuroda, Y. Kurihara and Y. Shimizu, *et al.* Comput. Phys. Commun. **153** (2003), 106-134 doi:10.1016/S0010-4655(03)00159-0 [arXiv:hep-ph/0208036 [hep-ph]]; G. Belanger, F. Boudjema, J. Fujimoto, T. Ishikawa, T. Kaneko, K. Kato and Y. Shimizu, Phys. Rept. **430** (2006), 117-209 doi:10.1016/j.physrep.2006.02.001 [arXiv:hep-ph/0308080 [hep-ph]]; https://minami-home.kek.jp/

[88] H. Murayama, I. Watanabe and K. Hagiwara, KEK-91-11.

[89] F. Cascioli, P. Maierhofer and S. Pozzorini, Phys. Rev. Lett. **108** (2012), 111601 doi:10.1103/PhysRevLett.108.111601 [arXiv:1111.5206 [hep-ph]]; S. Kallweit, J. M. Lindert, P. Maierhöfer, S. Pozzorini and M. Schönherr, JHEP **04** (2015), 012 doi:10.1007/JHEP04(2015)012 [arXiv:1412.5157 [hep-ph]]; F. Buccioni, S. Pozzorini and M. Zoller, Eur. Phys. J. C **78** (2018) no.1, 70 doi:10.1140/epjc/s10052-018-5562-1 [arXiv:1710.11452 [hep-ph]]; F. Buccioni, J. N. Lang, J. M. Lindert, P. Maierhöfer, S. Pozzorini, H. Zhang and M. F. Zoller, Eur. Phys. J. C **79** (2019) no.10, 866 doi:10.1140/epjc/s10052-019-7306-2 [arXiv:1907.13071 [hep-ph]]; https://openloops.hepforge.org/index.html

[90] E. Bothmann *et al.* [Sherpa], SciPost Phys. **7** (2019) no.3, 034 doi:10.21468/SciPostPhys.7.3.034 [arXiv:1905.09127 [hep-ph]]. https://sherpa-team.gitlab.io/

[91] M. Bahr, S. Gieseke, M. A. Gigg, D. Grellscheid, K. Hamilton, O. Latunde-Dada, S. Platzer, P. Richardson, M. H. Seymour and A. Sherstnev, *et al.* Eur. Phys. J. C **58** (2008), 639-707 doi:10.1140/epjc/s10052-008-0798-9 [arXiv:0803.0883 [hep-ph]]; J. Bellm, S. Gieseke, D. Grellscheid, S. Plätzer, M. Rauch, C. Reuschle, P. Richardson, P. Schichtel, M. H. Seymour and A. Siódmok, *et al.* Eur. Phys. J. C **76** (2016) no.4, 196 doi:10.1140/epjc/s10052-016-4018-8 [arXiv:1512.01178 [hep-ph]]; J. Bellm, G. Bewick, S. Ferrario Ravasio, S. Gieseke, D. Grellscheid, P. Kirchgaeßer, M. R. Masouminia, G. Nail, A. Papaefstathiou and S. Platzer, *et al.* Eur. Phys. J. C **80** (2020) no.5, 452 doi:10.1140/epjc/s10052-020-8011-x [arXiv:1912.06509 [hep-ph]]. https://herwig.hepforge.org/ https://github.com/hep-mirrors/herwig

[92] T. Sjostrand, S. Mrenna and P. Z. Skands, JHEP **05** (2006), 026 doi:10.1088/1126-6708/2006/05/026 [arXiv:hep-ph/0603175 [hep-ph]]; T. Sjöstrand, S. Ask, J. R. Christiansen, R. Corke, N. Desai, P. Ilten, S. Mrenna, S. Prestel, C. O. Rasmussen and P. Z. Skands, Comput. Phys. Commun. **191** (2015), 159-177 doi:10.1016/j.cpc.2015.01.024 [arXiv:1410.3012 [hep-ph]]; T. Sjöstrand, Comput. Phys. Commun. **246** (2020), 106910 doi:10.1016/j.cpc.2019.106910 [arXiv:1907.09874 [hep-ph]]; https://pythia.org/

[93] J. Küblbeck, M. Böhm and A. Denner, Comput. Phys. Commun. **60** (1990), 165-180 doi:10.1016/0010-4655(90)90001-H; T. Hahn, Comput. Phys. Commun. **140** (2001), 418-431 doi:10.1016/S0010-4655(01)00290-9 [arXiv:hep-ph/0012260 [hep-ph]]; T. Hahn

and C. Schappacher, Comput. Phys. Commun. **143** (2002), 54-68 doi:10.1016/S0010-4655(01)00436-2 [arXiv:hep-ph/0105349 [hep-ph]]; T. Fritzsche, T. Hahn, S. Heinemeyer, F. von der Pahlen, H. Rzehak and C. Schappacher, Comput. Phys. Commun. **185** (2014), 1529-1545 doi:10.1016/j.cpc.2014.02.005 [arXiv:1309.1692 [hep-ph]]; http://www.feynarts.de/

[94] T. Hahn and M. Perez-Victoria, Comput. Phys. Commun. **118** (1999), 153-165 doi:10.1016/S0010-4655(98)00173-8 [arXiv:hep-ph/9807565 [hep-ph]]; T. Hahn, Comput. Phys. Commun. **178** (2008), 217-221 doi:10.1016/j.cpc.2007.09.004 [arXiv:hep-ph/0611273 [hep-ph]]; http://www.feynarts.de/formcalc/

[95] M. Moretti, T. Ohl and J. Reuter, [arXiv:hep-ph/0102195 [hep-ph]]; W. Kilian, T. Ohl and J. Reuter, Eur. Phys. J. C **71** (2011), 1742 doi:10.1140/epjc/s10052-011-1742-y [arXiv:0708.4233 [hep-ph]]; https://whizard.hepforge.org/

[96] T. Stelzer and W. F. Long, Comput. Phys. Commun. **81** (1994), 357-371 doi:10.1016/0010-4655(94)90084-1 [arXiv:hep-ph/9401258 [hep-ph]]; F. Maltoni and T. Stelzer, JHEP **02** (2003), 027 doi:10.1088/1126-6708/2003/02/027 [arXiv:hep-ph/0208156 [hep-ph]]; J. Alwall, R. Frederix, S. Frixione, V. Hirschi, F. Maltoni, O. Mattelaer, H. S. Shao, T. Stelzer, P. Torrielli and M. Zaro, JHEP **07** (2014), 079 doi:10.1007/JHEP07(2014)079 [arXiv:1405.0301 [hep-ph]]; R. Frederix, S. Frixione, V. Hirschi, D. Pagani, H. S. Shao and M. Zaro, JHEP **07** (2018), 185 [erratum: JHEP **11** (2021), 085] doi:10.1007/JHEP11(2021)085 [arXiv:1804.10017 [hep-ph]]; http://madgraph.phys.ucl.ac.be/

[97] P. Nogueira, J. Comput. Phys. **105** (1993), 279-289 doi:10.1006/jcph.1993.1074; P. Nogueira, Comput. Phys. Commun. **269** (2021), 108103 doi:10.1016/j.cpc.2021.108103; http://cfif.ist.utl.pt/~paulo/qgraf.html

[98] R. Mertig, M. Böhm and A. Denner, Comput. Phys. Commun. **64** (1991), 345-359 doi:10.1016/0010-4655(91)90130-D; V. Shtabovenko, R. Mertig and F. Orellana, Comput. Phys. Commun. **207** (2016), 432-444 doi:10.1016/j.cpc.2016.06.008 [arXiv:1601.01167 [hep-ph]]; V. Shtabovenko, R. Mertig and F. Orellana, Comput. Phys. Commun. **256** (2020), 107478 doi:10.1016/j.cpc.2020.107478 [arXiv:2001.04407 [hep-ph]]; https://feyncalc.github.io/

[99] G. Uhlrich, F. Mahmoudi and A. Arbey, Comput. Phys. Commun. **264** (2021), 107928 doi:10.1016/j.cpc.2021.107928 [arXiv:2011.02478 [hep-ph]]; https://marty.in2p3.fr/

[100] D. Fontes and J. C. Romão, Comput. Phys. Commun. **256** (2020), 107311 doi:10.1016/j.cpc.2020.107311 [arXiv:1909.05876 [hep-ph]]; https://porthos.tecnico.ulisboa.pt/FeynMaster/

[101] N. Baro, F. Boudjema and A. Semenov, Phys. Rev. D **78** (2008), 115003 doi:10.1103/PhysRevD.78.115003 [arXiv:0807.4668 [hep-ph]]; N. Baro and F. Boudjema, Phys. Rev. D **80** (2009), 076010 doi:10.1103/PhysRevD.80.076010 [arXiv:0906.1665 [hep-ph]]; http://code.sloops.free.fr