Precision Higgs physics — Once Vision, Now Mainstream

Tilman Plehn

Universität Heidelberg

Spira-Fest, September 2024

Modern LHC physics

Discovery machine

- Higgs, delivered in 2012
- dark matter particle?
- baryogenesis conditions?
- some reason for the Higgs VEV?
- SUSY particles? new scalars? new light particles?

$\to$ Precision predictions crucial!

Modern LHC physics

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$\to$ Precision predictions crucial!

Precision machine

- modelled after LEP analyses
- start with particle couplings and bad QFT
- grow up and move to EFTs as proper QFT
- combine rate, energy and precision

Modern LHC physics

Discovery machine

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$\to$ Precision predictions crucial!

Precision machine

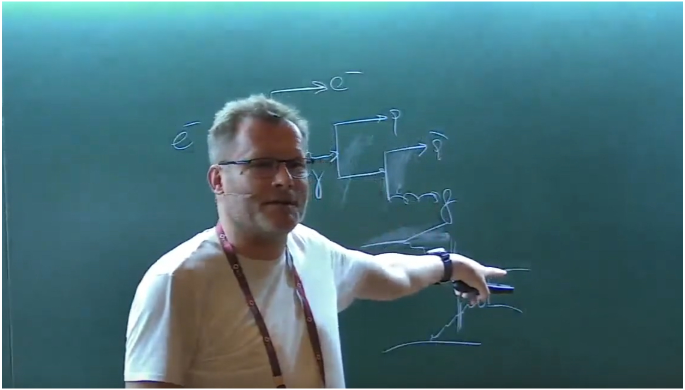
- modelled after LEP analyses
- start with particle couplings and bad QFT
- grow up and move to EFTs as proper QFT
- combine rate, energy and precision
- transforming theory and experiment
- precision-driven discoveries
- model-based vs simulation-based inference

$\to$ Precision predictions crucial!

Happy birthday, Spirix!

Behind every great experiment...

...are a those few people who build its science

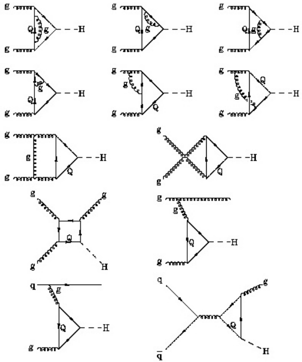


→ LHC as the first precision-hadron collider

The Higgs production years: 1991 - today

Higgs production

- leading order $gg \to H$ already one-loop
- top mass matters, so top-loop
- kinematics crucial
- all master integrals by hand
- effortlessly covering SUSY-Higgs
- QCD-corrections strictly too big...



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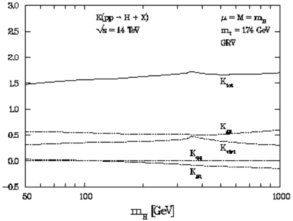

→ Serious and lasting breakthrough!

DESY 94–123
GPP–UdeM–TH–95–16
CERN–TH/95–30
hep-ph/9504378
February 1995

HIGGS BOSON PRODUCTION AT THE LHC

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[2] Groupe de Physique des Particules, Université de Montréal, Case 6128 A, H3C 3J7 Montréal P.Q., Canada

[3] Deutsches Elektronen–Synchrotron DESY, D-22603 Hamburg, FRG

[4] Theoretical Physics Division, CERN, CH–1211 Geneva 23, Switzerland

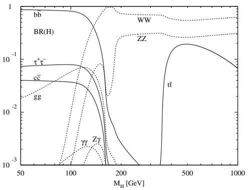
Abstract

Gluon fusion is the main production mechanism for Higgs particles at the LHC. We present the QCD corrections to the fusion cross sections for the Higgs boson in the Standard Model, and for the neutral Higgs bosons in the minimal supersymmetric extension of the Standard Model. The QCD corrections are in general large and they increase the cross sections significantly. In two steps preceding the calculation of the production processes, we determine the QCD radiative corrections to Higgs decays into two photons and gluons.

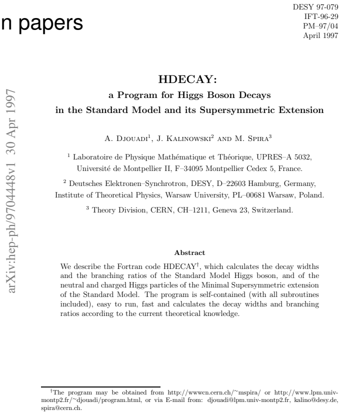
The HDecay years: 1997 - today

Higgs decays

- event count = $\sigma \times$BR
- more structure in decays than in production rates
- off-shell effects and higher orders relevant
- corrections to loop-decays from production papers
- long-lived and fast public code



$\rightarrow$ Intermediate masses we want(ed)!



DESY 97-079
IFT-96-29
PM–97/04
April 1997

arXiv:hep-ph/9704448v1 30 Apr 1997

HDECAY:

a Program for Higgs Boson Decays

in the Standard Model and its Supersymmetric Extension

A. Djouadi[1], J. Kalinowski[2] and M. Spira[3]

[1] Laboratoire de Physique Mathématique et Théorique, UPRES–A 5032, Université de Montpellier II, F–34095 Montpellier Cedex 5, France.

[2] Deutsches Elektronen–Synchrotron, DESY, D–22603 Hamburg, Germany, Institute of Theoretical Physics, Warsaw University, PL–00681 Warsaw, Poland.

[3] Theory Division, CERN, CH–1211, Geneva 23, Switzerland.

Abstract

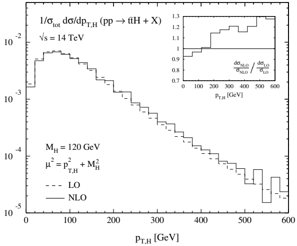
We describe the Fortran code HDECAY[†], which calculates the decay widths and the branching ratios of the Standard Model Higgs boson, and of the neutral and charged Higgs particles of the Minimal Supersymmetric extension of the Standard Model. The program is self-contained (with all subroutines included), easy to run, fast and calculates the decay widths and branching ratios according to the current theoretical knowledge.

[†]The program may be obtained from http://wwwcn.cern.ch/~mspira/ or http://www.lpm.univ-montp2.fr/~djouadi/program.html, or via E-mail from: djouadi@lpm.univ-montp2.fr, kalino@desy.de, spira@cern.ch.

The $t\bar{t}H$ years: 2001 - today

Better Higgs production

- gluon fusion for discovery
  top-Higgs for measurements
- top-Higgs our best renormalization group
  triviality, vacuum stability, fixed-points, etc
- more particles means more information
  Lorentz/CP-structure of top Yukawa?



→ Again, kinematics the key

DESY 02-177
Edinburgh 2002/18
MPI-PhT/2002-70
PSI-PR-02-22
hep-ph/0211352

NLO QCD corrections to $t\bar{t}H$ production in hadron collisions†

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[2] *Deutsches Elektronen-Synchrotron DESY, D-22603 Hamburg, Germany*
[3] *Max-Planck-Institut für Physik (Werner-Heisenberg-Institut), D-80805 München, Germany*
[4] *School of Physics, The University of Edinburgh, Edinburgh EH9 3JZ, Scotland*
[5] *Paul Scherrer Institut PSI, CH-5232 Villigen PSI, Switzerland*

Abstract

The Higgs boson H of the Standard Model can be searched for in the channels $p\bar{p}/pp \to t\bar{t}H + X$ at the Tevatron and the LHC. The cross sections for these processes and the final-state distributions of the Higgs boson and top quarks are presented at next-to-leading order QCD. To calculate these QCD corrections, a special calculational technique for pentagon diagrams has been developed and the dipole subtraction formalism has been adopted for massive particles. The impact of the corrections on the total cross sections is characterized by K factors, the ratios of the cross sections in next-to-leading order over leading order QCD. At the central scale $\mu_0 = (2m_t + M_H)/2$ the K factors are found to be slightly below unity for the Tevatron ($K \sim 0.8$) and slightly above unity for the LHC ($K \sim 1.2$). Including the corrections significantly stabilizes the theoretical predictions for total cross sections and for the distributions in rapidity and transverse momentum of the Higgs boson and top quarks.

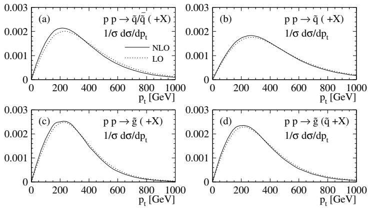
November 2002

†This work has been supported in part by the Swiss Bundesamt für Bildung und Wissenschaft and by the European Union under contract HPRN-CT-2000-00149.

The Prospino years: 1996 - really today???

Branching out to SUSY [quiet]

- dark matter means SUSY pair production
- starting with squarks and gluinos [Thank you to Roland Höpker and Wim Beenakker]
- always consider kinematics



DESY 96-150
CERN-TH/96-215
October 1996

Squark and Gluino Production at Hadron Colliders

W. Beenakker[1*], R. Höpker[2], M. Spira[3] and P. M. Zerwas[2]

[1] *Instituut-Lorentz, P.O. Box 9506, NL-2300 RA Leiden, The Netherlands*
[2] *Deutsches Elektronen-Synchrotron DESY, D-22603 Hamburg, Germany*
[3] *TH Division, CERN, CH-1211 Geneva 23, Switzerland*

ABSTRACT

We have determined the theoretical predictions for the cross-sections of squark and gluino production at $p\bar{p}$ and pp colliders (Tevatron and LHC) in next-to-leading order of supersymmetric QCD. By reducing the dependence on the renormalization/factorization scale considerably, the theoretically predicted values for the cross-sections are much more stable if these higher-order corrections are implemented. If squarks and gluinos are discovered, this improved stability translates into a reduced error on the masses, as extracted experimentally from the size of the production cross-sections. The cross-sections increase significantly if the next-to-leading order corrections are included at a renormalization/factorization scale near the average mass of the produced massive particles. This rise results in improved lower bounds on squark and gluino masses. By contrast, the shape of the transverse-momentum and rapidity distributions remains nearly unchanged when the next-to-leading order corrections are included.

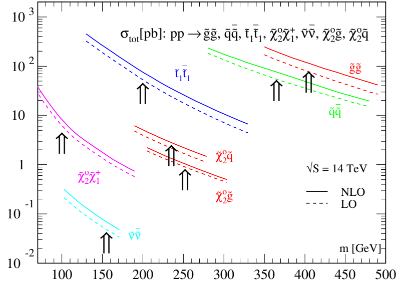
*Research supported by a fellowship of the Royal Dutch Academy of Arts and Sciences.

The Prospino years: 1996 - really today???

Branching out to SUSY [quiet]

- dark matter means SUSY pair production
- starting with squarks and gluinos [Thank you to Roland Höpker and Wim Beenakker]
- always consider kinematics
- moving on to tops, electroweakinos, sleptons, etc
- and then data hit us all...
- *Wir kommen so langsam aus dem pandemischen Rahmen heraus - ich habe heute wieder die erste Vorlesung ohne Maske gehalten und prompt ueber Prospino geredet ;-). Jaja, war'n Zufall.*

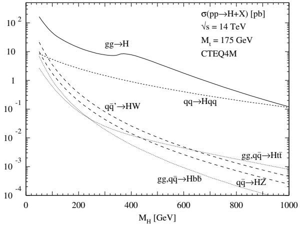
→ Sorry for dropping out!



The Higgs bible: 1997

Higgs production and decay [first]

– assume: narrow CP-even scalar
Standard Model operators



CERN-TH/97-68
hep-ph/9705337

QCD Effects in Higgs Physics

Michael Spira

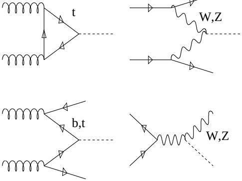
Theoretical Physics Division, CERN, CH-1211 Geneva 23, Switzerland

Abstract

Higgs boson production at the LHC within the Standard Model and its minimal supersymmetric extension is reviewed. The predictions for decay rates and production cross sections are updated by choosing the present value of the top quark mass and recent parton density sets. Moreover, all relevant higher order corrections, some of which have been obtained only recently, are included in a consistent way.

CERN-TH/97-68
hep-ph/9705337
April 1997

The Higgs bible: 1997



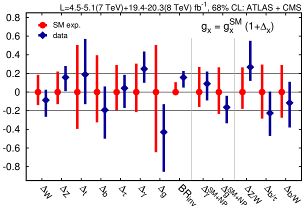
Higgs production and decay [first]

- assume: narrow CP-even scalar
  Standard Model operators
- fundamental physics in terms of Lagrangian

$$\mathcal{L} = \mathcal{L}_{\text{SM}} + \Delta_W \, g m_W H \, W^\mu W_\mu + \Delta_Z \frac{g}{2c_w} m_Z H \, Z^\mu Z_\mu - \sum_{\tau,b,t} \Delta_f \frac{m_f}{v} H \left(\bar{f}_R f_L + \text{h.c.} \right)$$
$$+ \Delta_g F_G \frac{H}{v} \, G_{\mu\nu} G^{\mu\nu} + \Delta_\gamma F_A \frac{H}{v} \, A_{\mu\nu} A^{\mu\nu} + \text{invisible} + \text{unobservable}$$

Production		Coupling		Decays
$gg \to H$ $gg \to H+j$ (boosted) $gg \to H^*$ (off-shell) $qq \to qqH$ $gg \to t\bar{t}H$ $qq' \to VH$	$\longleftrightarrow$	$g_{HXX} = g_{HXX}^{\text{SM}} \; (1 + \Delta_X)$	$\longleftrightarrow$	$H \to ZZ$ $H \to WW$ $H \to b\bar{b}$ $H \to \tau^+\tau^-$ $H \to \gamma\gamma$ $H \to$ invisible

$\to$ All ingredients to global Higgs analyses



The Higgs-pair years: 1996 - today

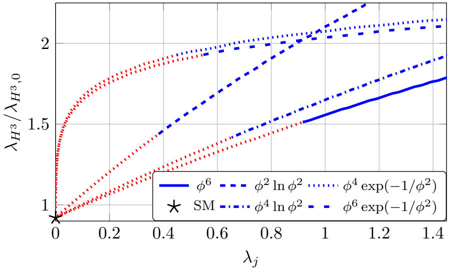
Higgs self-coupling the Universe

- baryon number violation
  C and CP violation
  1st-order e-w phase transition
- D6-Higgs potential, generalized [Grojean, Servant, Wells]

$$\Delta V_6 = \lambda_6 \frac{\phi^6}{\Lambda^2}$$

$$\Delta V_{\ln,2} = -\lambda_{\ln,2} \frac{\phi^2 \Lambda^2}{100} \ln \frac{\phi^2}{2\Lambda^2} \qquad \Delta V_{\ln,4} = \lambda_{\ln,4} \frac{\phi^4}{10} \ln \frac{\phi^2}{2\Lambda^2}$$

$$\Delta V_{\exp,4} = \lambda_{\exp,4} \phi^4 \exp\left(-\frac{2\Lambda^2}{\phi^2} + 23\right) \qquad \Delta V_{\exp,6} = \lambda_{\exp,6} \frac{\phi^6}{\Lambda^2} \exp\left(-\frac{2\Lambda^2}{\phi^2} + 26\right)$$



The Higgs-pair years: 1996 - today

Higgs self-coupling the Universe

- baryon number violation
  C and CP violation
  1st-order e-w phase transition
- D6-Higgs potential, generalized [Grojean, Servant, Wells]

→ requiring 50% enhanced λ_{HHH}

DESY 95–215
December 1995
hep-ph/9603205

Pair Production of Neutral Higgs Particles in Gluon–Gluon Collisions

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[1] Deutsches Elektronen–Synchrotron DESY, D–22603 Hamburg, FRG

[2] II. Institut für Theoretische Physik[†], D–22761 Hamburg, FRG

Abstract

Pair production processes of neutral Higgs particles will allow us to study the trilinear Higgs couplings at future high–energy colliders. Several mechanisms give rise to multi–Higgs final states in hadron interactions. In the present paper we investigate Higgs pair production in gluon–gluon collisions. After recapitulating pair production in the Standard Model, the analysis of the cross sections is carried out in detail for the neutral Higgs particles in the minimal supersymmetric extension.

*Address after Jan.1,1996: TH Division, CERN, CH–1211 Geneva 23, Switzerland

†Supported by Bundesministerium für Bildung und Forschung (BMBF), Bonn, under Contract 05 6 HH 93P (5), and by EU Program *Human Capital and Mobility* through Network *Physics at High Energy Colliders* under Contract CHRX–CT93–0357 (DG12 COMA).

Precision LHC

Tilman Plehn

Production

Decays

Wrong turns

Global Higgs

Higgs pairs

EFT

Party

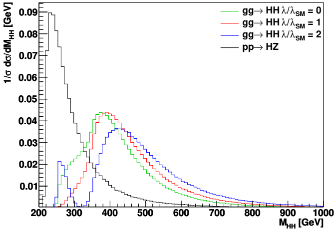
The Higgs-pair years: 1996 - today

Higgs self-coupling the Universe

- baryon number violation
  C and CP violation
  1st-order e-w phase transition
- D6-Higgs potential, generalized [Grojean, Servant, Wells]

State of the (theory) art

- destructive interference
- m_{HH} for signal process
  bringing us back to top mass effects



→ Kinematic measurement, means theory!

KA–TP–44–2012
SFB/CPP–12–102
LPT–ORSAY–12–124
PSI–PR–12–10

arXiv:1212.5581v2 [hep-ph] 18 Jul 2013

The measurement of the Higgs self–coupling at the LHC: theoretical status

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M.M. Mühlleitner[1], J. Quevillon[2] and M. Spira[3]

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[2] Laboratoire de Physique Théorique, U. Paris–Sud and CNRS, F–91405 Orsay, France.
[3]Paul Scherrer Institute, CH-5232 Villigen PSI, Switzerland.

Abstract

Now that the Higgs boson has been observed by the ATLAS and CMS experiments at the LHC, the next important step would be to measure accurately its properties to establish the details of the electroweak symmetry breaking mechanism. Among the measurements which need to be performed, the determination of the Higgs self–coupling in processes where the Higgs boson is produced in pairs is of utmost importance. In this paper, we discuss the various processes which allow for the measurement of the trilinear Higgs coupling: double Higgs production in gluon fusion, vector boson fusion, double Higgs–strahlung and associated production with a top quark pair. We first evaluate the production cross sections for these processes at the LHC with center–of–mass energies ranging from the present $\sqrt{s}$ = 8 TeV to $\sqrt{s}$ = 100 TeV, and discuss their sensitivity to the trilinear Higgs coupling. We include the various higher order QCD radiative corrections, at next–to–leading order for gluon and vector boson fusion and at next–to–next–to–leading order for associated double Higgs production with a gauge boson. The theoretical uncertainties on these cross sections are estimated. Finally, we discuss the various channels which could allow for the detection of the double Higgs production signal at the LHC and estimate their potential to probe the trilinear Higgs coupling.

1

The EFT years: 2013 - today

Renormalizable D6-Lagrangian

– Higgs operators

$$\mathcal{O}_{GG} = \phi^\dagger \phi G^a_{\mu\nu} G^{a\mu\nu} \qquad \mathcal{O}_{WW} = \phi^\dagger \hat{W}_{\mu\nu} \hat{W}^{\mu\nu} \phi \qquad \mathcal{O}_{BB} = \cdots$$

$$\mathcal{O}_{BW} = \phi^\dagger \hat{B}_{\mu\nu} \hat{W}^{\mu\nu} \phi \qquad \mathcal{O}_{W} = (D_\mu \phi)^\dagger \hat{W}^{\mu\nu} (D_\nu \phi) \qquad \mathcal{O}_{B} = \cdots$$

$$\mathcal{O}_{\phi,1} = (D_\mu \phi)^\dagger \phi \, \phi^\dagger (D^\mu \phi) \qquad \mathcal{O}_{\phi,2} = \frac{1}{2} \partial^\mu \left(\phi^\dagger \phi\right) \partial_\mu \left(\phi^\dagger \phi\right) \qquad \mathcal{O}_{\phi,3} = \frac{1}{3} \left(\phi^\dagger \phi\right)^3$$

– one more TGV operator $\mathcal{O}_{WWW} = \mathrm{Tr}\left(\hat{W}_{\mu\nu} \hat{W}^{\nu\rho} \hat{W}^\mu_\rho\right)$
plus Yukawa sector $f_{\tau,b,t}$

→ Many, many theory questions...

CERN-PH-TH/2013-047
KA-TP-06-2013
PSI-PR-13-04

arXiv:1303.3876v4 [hep-ph] 13 Mar 2014

Effective Lagrangian for a light Higgs-like scalar

Roberto Contino[a], Margherita Ghezzi[a], Christophe Grojean[b,c],
Margarete Mühlleitner[d] and Michael Spira[e]

[a] *Dipartimento di Fisica, Università di Roma La Sapienza and INFN, Roma, Italy*
[b] *ICREA at IFAE, Universitat Autònoma de Barcelona, E-08193 Bellaterra, Spain*
[c] *Theory Division, Physics Department, CERN, Geneva, Switzerland*
[d] *Institute for Theoretical Physics, Karlsruhe Institute of Technology, Karlsruhe, Germany*
[e] *Paul Scherrer Institut, CH–5232 Villigen PSI, Switzerland*

Abstract

We reconsider the effective Lagrangian that describes a light Higgs-like boson and better clarify a few issues which were not exhaustively addressed in the previous literature. In particular we highlight the strategy to determine whether the dynamics responsible for the electroweak symmetry breaking is weakly or strongly interacting. We also discuss how the effective Lagrangian can be implemented into automatic tools for the calculation of Higgs decay rates and production cross sections.

The EFT years: 2013 - today

Renormalizable D6-Lagrangian

– Higgs operators

$$\mathcal{O}_{GG} = \phi^\dagger \phi G^a_{\mu\nu} G^{a\mu\nu} \qquad \mathcal{O}_{WW} = \phi^\dagger \hat{W}_{\mu\nu} \hat{W}^{\mu\nu} \phi \qquad \mathcal{O}_{BB} = \cdots$$

$$\mathcal{O}_{BW} = \phi^\dagger \hat{B}_{\mu\nu} \hat{W}^{\mu\nu} \phi \qquad \mathcal{O}_{W} = (D_\mu \phi)^\dagger \hat{W}^{\mu\nu} (D_\nu \phi) \qquad \mathcal{O}_{B} = \cdots$$

$$\mathcal{O}_{\phi,1} = (D_\mu \phi)^\dagger \, \phi \, \phi^\dagger \, (D^\mu \phi) \qquad \mathcal{O}_{\phi,2} = \frac{1}{2} \partial^\mu \left(\phi^\dagger \phi \right) \partial_\mu \left(\phi^\dagger \phi \right) \qquad \mathcal{O}_{\phi,3} = \frac{1}{3} \left(\phi^\dagger \phi \right)^3$$

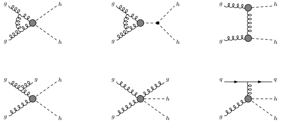
– one more TGV operator $\quad \mathcal{O}_{WWW} = \mathrm{Tr} \left(\hat{W}_{\mu\nu} \hat{W}^{\nu\rho} \hat{W}^{\mu}_{\rho} \right)$

plus Yukawa sector $\quad f_{\tau,b,t}$

→ Many, many theory questions...

Same for Higgs pairs

· $\lambda_{HHH} \to \mathcal{O}_{\phi,3}$, but more operators



KA-TP-08-2015
PSI-PR-15-03
RM3-TH-15-5

arXiv:1504.06577v1 [hep-ph] 24 Apr 2015

NLO QCD Corrections to Higgs Pair Production including Dimension-6 Operators

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[2] Institute for Theoretical Physics, Karlsruhe Institute of Technology, 76128 Karlsruhe, Germany

[3] Paul Scherrer Institute, CH-5323 Villigen PSI, Switzerland

Abstract

New Physics that becomes relevant at some high scale Λ beyond the experimental reach, can be described in the effective theory approach by adding higher-dimensional operators to the Standard Model (SM) Lagrangian. In Higgs pair production through gluon fusion, which gives access to the trilinear Higgs self-coupling, this leads not only to modifications of the SM couplings but also induces novel couplings not present in the SM. For a proper prediction of the cross section, higher order QCD corrections that are important for this process, have to be taken into account. The various higher-dimensional contributions are affected differently by the QCD corrections. In this paper, we provide the next-to-leading order (NLO) QCD corrections to Higgs pair production including dimension-6 operators in the limit of large top quark masses. Depending on the dimension-6 coefficients entering the Lagrangian, the new operators affect the relative NLO QCD corrections by several per cent, while modifying the cross section by up to an order of magnitude.

The EFT years: 2013 - today

Renormalizable D6-Lagrangian

– Higgs operators

$$\mathcal{O}_{GG} = \phi^\dagger \phi G^a_{\mu\nu} G^{a\mu\nu} \qquad \mathcal{O}_{WW} = \phi^\dagger \hat{W}_{\mu\nu} \hat{W}^{\mu\nu} \phi \qquad \mathcal{O}_{BB} = \cdots$$

$$\mathcal{O}_{BW} = \phi^\dagger \hat{B}_{\mu\nu} \hat{W}^{\mu\nu} \phi \qquad \mathcal{O}_{W} = (D_\mu \phi)^\dagger \hat{W}^{\mu\nu} (D_\nu \phi) \qquad \mathcal{O}_{B} = \cdots$$

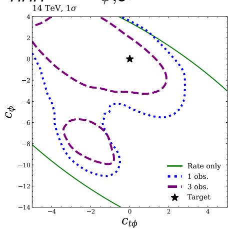
$$\mathcal{O}_{\phi,1} = (D_\mu \phi)^\dagger \phi \, \phi^\dagger \left(D^\mu \phi\right) \qquad \mathcal{O}_{\phi,2} = \frac{1}{2} \partial^\mu \left(\phi^\dagger \phi\right) \partial_\mu \left(\phi^\dagger \phi\right) \qquad \mathcal{O}_{\phi,3} = \frac{1}{3} \left(\phi^\dagger \phi\right)^3$$

– one more TGV operator $\mathcal{O}_{WWW} = \text{Tr}\left(\hat{W}_{\mu\nu} \hat{W}^{\nu\rho} \hat{W}^\mu_\rho\right)$
plus Yukawa sector $f_{\tau,b,t}$

→ Many, many theory questions...

Same for Higgs pairs

· $\lambda_{HHH} \to \mathcal{O}_{\phi,3}$, but more operators



→ Higgs potential vs D6?

KA-TP-08-2015
PSI-PR-15-03
RM3-TH-15-5

NLO QCD Corrections to Higgs Pair Production including Dimension-6 Operators

R. Gröber[1]*, M. Mühlleitner[2]†, M. Spira[3]‡ and J. Streicher[2]§

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Abstract

New Physics that becomes relevant at some high scale Λ beyond the experimental reach, can be described in the effective theory approach by adding higher-dimensional operators to the Standard Model (SM) Lagrangian. In Higgs pair production through gluon fusion, which gives access to the trilinear Higgs self-coupling, this leads not only to modifications of the SM couplings but also induces novel couplings not present in the SM. For a proper prediction of the cross section, higher order QCD corrections that are important for this process, have to be taken into account. The various higher-dimensional contributions are affected differently by the QCD corrections. In this paper, we provide the next-to-leading order (NLO) QCD corrections to Higgs pair production including dimension-6 operators in the limit of large top quark masses. Depending on the dimension-6 coefficients entering the Lagrangian, the new operators affect the relative NLO QCD corrections by several per cent, while modifying the cross section by up to an order of magnitude.

Precision LHC

Tilman Plehn

Production

Decays

Wrong turns

Global Higgs

Higgs pairs

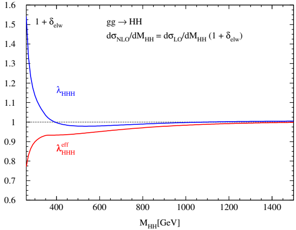
EFT

Party

Still hard at work...

More Higgs pairs

- there are always more perturbative contribution
- top-Yukawa potentially dangerous
- did we talk about kinematics?



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Top-Yukawa-induced Corrections to Higgs Pair Production

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Abstract

Higgs-boson pair production at hadron colliders is dominantly mediated by the loop-induced gluon-fusion process $gg \to HH$ that is generated by heavy top loops within the Standard Model with a minor per-cent level contamination of bottom-loop contributions. The QCD corrections turn out to be large for this process. In this note, we derive the top-Yukawa-induced part of the electroweak corrections to this process and discuss their relation to an effective trilinear Higgs coupling with integrated out top-quark contributions.

1 Introduction

The discovery of a bosonic particle with a mass of (125.09 ± 0.24) GeV [1] turned out to be in agreement with the Standard-Model (SM) Higgs boson within the present uncertainties of all production and decay modes. Its coupling strengths to SM gauge bosons, i.e. ZZ, W^+W^-, and fermion pairs as τ, μ leptons and bottom quarks as well as the loop-induced couplings to gluon and photon pairs, have been measured with accuracies of $10-50\%$. All measurements are in agreement with the SM predictions within their uncertainties [2]. In addition, there are very strong indications that the newly discovered boson carries zero spin and positive CP-parity, i.e. possible deviations from these hypotheses are strongly constrained by the accuracy of present experimental data. Thus, there is increasing evidence that this particle is indeed the long-sought SM Higgs boson. Its discovery is of vital importance for the consistency of the SM and the success of the predictions for the precision electroweak observables which are in striking agreement with measurements at LEP and SLC [3]. The discovery of a SM-like Higgs boson at the LHC completed the SM of electroweak and strong interactions. The existence of the Higgs boson is inherently related to the mechanism of spontaneous symmetry breaking while preserving the full gauge symmetry and the renormalizability of the SM [4], since the Higgs boson permits the SM particles to be weakly interacting up to high-energy scales [5]. However, with the knowledge of the Higgs-boson mass all its properties within the SM are uniquely fixed, i.e. the SM does not allow the Higgs couplings to the SM particles to deviate from their unique predictions.

The minimal model as realized in the SM requires the introduction of one isospin doublet of Higgs fields that leads after spontaneous symmetry breaking to the existence of one scalar Higgs boson. A crucial experimental goal is the measurement of the Higgs potential, since the formation of a non-trivial ground state with a finite vacuum expectation value of the Higgs field causes electroweak symmetry breaking so that the experimental verification of the Higgs potential itself is of highest interest. The parameters describing the Higgs potential

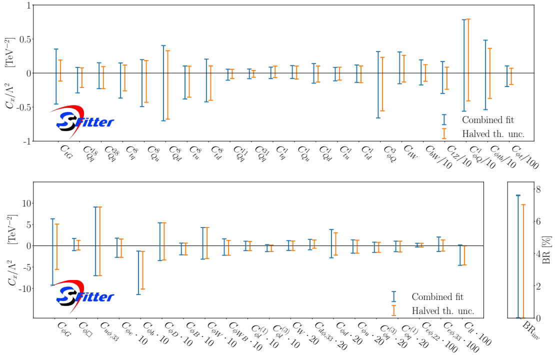
1

Congratulations!

A research dream come true

- Higgs was discovered
- LHC the first precision-hadron collider
- Higgs sector at heart of the LHC program
- precision theory crucial
- still many things to learn and understand

$\rightarrow$ Those results are to you, Spirix! [ee]



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$\to$ Let's go party!