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Anatomy of the Higgs fits: A first guide to statistical treatments of the theoretical uncertainties

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Abstract

The studies of the Higgs boson couplings based on the recent and upcoming LHC data open up a new window on physics beyond the Standard Model. In this paper, we propose a statistical guide to the consistent treatment of the theoretical uncertainties entering the Higgs rate fits. Both the Bayesian and frequentist approaches are systematically analysed in a unified formalism. We present analytical expressions for the marginal likelihoods, useful to implement simultaneously the experimental and theoretical uncertainties. We review the various origins of the theoretical errors (QCD, EFT, PDF, production mode contamination…). All these individual uncertainties are thoroughly combined with the help of moment-based considerations. The theoretical correlations among Higgs detection channels appear to affect the location and size of the best-fit regions in the space of Higgs couplings. We discuss the recurrent question of the shape of the prior distributions for the individual theoretical errors and find that a nearly Gaussian prior arises from the error combinations. We also develop the bias approach, which is an alternative to marginalisation providing more conservative results. The statistical framework to apply the bias principle is introduced and two realisations of the bias are proposed. Finally, depending on the statistical treatment, the Standard Model prediction for the Higgs signal strengths is found to lie within either the 68% or 95% confidence level region obtained from the latest analyses of the 7 and 8 TeV LHC datasets.

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1. Introduction and summary

Besides the historical discovery of a resonance around 125 GeV [1,2] that is most probably the Brout–Englert–Higgs boson responsible for the ElectroWeak (EW) symmetry breaking [3], the ATLAS and CMS Collaborations have provided a set of 88 rate measurements – based on the full dataset collected so far with luminosities of ~ 5 fb^{-1} at the center of mass energy $\sqrt{s} = 7$ TeV and ~ 20 fb^{-1} at $\sqrt{s} = 8$ TeV [4,5] (see also Refs. [6,7]) – that constitutes a new and precious source of indirect information on physics beyond the Standard Model (SM). Indeed, observing deviations of the Higgs boson rates with respect to their SM predictions would reveal the presence of an underlying theory while the absence of such deviations allows one to strongly constrain new models (see for example Ref. [8] for higher-dimensional models, Ref. [9] for composite Higgs theories and Ref. [10] for supersymmetric scenarios). So far, no signs from an unknown world have came out from the data, but this is only the beginning of a long exploration, given the expected LHC upgrades [11].

The fits of the Higgs rates (*cf.* Ref. [12] for the first set of analyses, Refs. [13–16] for the results after the Moriond 2013 winter conference and Refs. [4,5] for the latest official ATLAS and CMS analyses) are thus obviously important. Now certain aspects of these analyses remain to be worked out in order to obtain the final fits for testing new physics. First, the precise likelihood functions associated to the experimental rates (in particular their specific shapes and the complete correlations between channels) are not provided in the present public papers, although they might be expected at some point. Second, a major part of the theoretical uncertainties is due to QCD calculations of the Higgs production rates [17–20] and their treatments in the fits raise questions in the Higgs physics community (see Refs. [21,22] for recent discussions). Taking carefully into account these theoretical uncertainties is crucial for the Higgs fits due to the following reasons.

First, theoretical uncertainties can be sizeable with respect to the experimental ones. The QCD uncertainty on the gluon–gluon fusion mechanism dominantly involved in most of the Higgs discovery channels induces typically an error of $\sim 10\%$ on signal strengths (see Section 6), that is already comparable to the experimental error bars in several Higgs channels which reach values down to $\sim 20\%$ [4–7]. Besides, considering for instance the CMS prospectives at $\sqrt{s} =$ 14 TeV with a luminosity of 300 fb^{-1}, the experimental error bars are around $\sim 5\%$ (with same systematic errors as today) for the diphoton final state and less than $\sim 10\%$ for the τ-lepton, Z and W boson channels [11] so that the theoretical error might even become the dominant one in some channels.

Second, theoretical uncertainties might be of the same magnitude as the main potential deviations due to new physics. For instance the maximal corrections to Higgs couplings estimated in Ref. [23] for characteristic composite Higgs and supersymmetric models[1] lead typically to deviations of the signal strengths between $\sim 2\%$ and tens of percent compared to SM. This is of

[1] In the case of no new states, related to the EW symmetry breaking, directly observed at the LHC.