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Combining LEP and LHC to bound the Higgs width

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Abstract

The correlation of on- and off-shell Higgs boson production at the LHC in $gg \to h^* \to ZZ$ has been used to bound the Higgs width. We propose an alternative complementary constraint which is only possible through the combination of LEP and LHC measurements. Precision electroweak measurements at LEP allow for the determination of indirect constraints on Higgs couplings to vector bosons by considering one-loop processes involving virtual Higgs exchange. As the indirect constraint is model dependent we will consider two specific models which modify the Higgs couplings and width, and our results will apply specifically to these models. By combining these LEP constraints with current LHC 8 TeV Higgs measurements a stronger limit on the Higgs width can be achieved than with LHC data alone. Looking to the future, a more robust constraint can be achieved by correlating LEP measurements with WBF Higgs production followed by Higgs decays to WW and ZZ. We will discuss the model dependence of this method in comparison to other proposed methods.

1. Introduction

The discovery of the Higgs boson [1–3] marked a new era of exploration in fundamental physics. Ideally one would like to be able to extract all of the properties of the Higgs, such as the

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mass and individual decay widths, as well as detailed information on the coupling magnitudes and Lorentz structures. In practice such an extensive wish list cannot be met with direct measurements alone, and varying degrees of theoretical assumptions must be imposed in order to map from measurement to Lagrangian.

In this work we will consider the total Higgs decay width, which is a crucial parameter for many scenarios beyond the Standard Model (SM). The total Higgs width has received considerable experimental and theoretical attention recently [4–10] after a recent proposal for correlating on- and off-shell Higgs production at the LHC [11–13]. In this paper we consider two specific models which modify the Higgs width and couplings, and pursue a different strategy, which combines the off-shell Higgs information gathered at the Large Electron Positron Collider (LEP) with LHC Higgs measurements. It is important to realise that, although the discovered Higgs falls outside the *kinematic* coverage of LEP, the high precision results of LEP still provide seminal and complementary information to current and future Higgs physics analyses, especially now that it has been established that $m_h \simeq 125$ GeV.

The implications of the Higgs discovery for the combined electroweak parameter fit was analysed in [14]. Our work takes a different approach and uses the indirect Higgs coupling constraints determined from the LEP results in correlation with LHC Higgs measurements to constrain free parameters in specific models. The limits we obtain particularly highlight the power of a concrete LEP + LHC combination.

We organise this work as follows: First we review recent attempts to set limits on the total Higgs width at the LHC in Sec. 2 and argue further in Sec. 3 that for certain specific models LEP can be considered a superior off-shell Higgs constraint. In Sec. 4 we establish this quantitatively by combining LEP and current LHC 8 TeV results to set a constraint on the total Higgs width in the spirit of Refs. [4,5,11]. Keeping in mind potential theoretical shortcomings that such an approach might involve we discuss the potential improvement of the LEP + LHC combination in Sec. 5. We discuss the relationship of this method in comparison to other methods in Sec. 6 and conclude in Sec. 7.

2. Higgs width overview in light of LHC results

Due to its small couplings to light fields, in the SM the Higgs width satisfies $\Gamma_h \ll m_h$ and the narrow width approximation is appropriate for LHC observations of an on-shell Higgs [15]. Specifically, if σ_i is the SM prediction for Higgs production in some channel 'i' at the LHC and BR_j is the SM prediction for the branching ratio into a final state 'j', then a reasonable approximation for the total cross section in these channels at the LHC is

$$\sigma_{ij} = \frac{c_i^2 c_j^2}{R_h} \sigma_i \mathrm{BR}_j \tag{1}$$

$$= \mu_{ij} \sigma_i \mathrm{BR}_j \tag{2}$$

where we have re-scaled the SM Higgs couplings with some factor which takes the value $c \to 1$ in the SM limit, we have similarly rescaled the total decay width by a factor R_h, and shown these two may be absorbed into a single 'signal-strength' variable μ.[1] We have also assumed that the

[1] In reality a simple coupling rescaling is overly simplistic and ideally the effects of new physics above the weak scale should be encoded in higher dimension operators. However, it is worth noting that the existence of complete models which realise free couplings for the Higgs with SM fields have been demonstrated [16], thus the free-coupling interpretation does have consistent UV-completions.