Higgs and electroweak symmetry breaking

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One of the major LHC goals is the Higgs boson search. Once found measurements will be performed to establish experimentally the Higgs mechanism. In the following the composite Higgs model will be presented as an alternative to the elementary Higgs. Modifications in Higgs production and decay and implications for Higgs discovery will be discussed.

1 Introduction

In the Standard Model (SM) unitarity in the scattering of longitudinal W, Z bosons is assured by an elementary Higgs boson. The electroweak precision observables and the absence of large flavor-changing neutral currents strongly constrain departures from this minimal Higgs mechanism and support the idea of a light Higgs boson emerging as a pseudo-Goldstone boson from a strongly-coupled sector, the Strongly Interacting Light Higgs scenario [1, 2].

The effective Lagrangian in [1] should be seen as an expansion in $\xi = (v/f)^2$ where $v = 1/\sqrt{\sqrt{2}G_F} \approx 246$ GeV and f is the typical scale of the Goldstone bosons of the strong sector. It can therefore be used in the vicinity of the SM limit ($\xi \to 0$), whereas the technicolor limit ($\xi \to 1$) requires a resummation of the full series in ξ. Explicit models provide concrete examples of such a resummation. Here we refer to the Holographic Higgs models of Refs. [3, 4, 5], which are based on a five-dimensional theory in Anti-de-Sitter (AdS) space-time. The bulk gauge symmetry $SO(5) \times U(1)_X \times SU(3)$ is broken down to the SM gauge group on the UV boundary and to $SO(4) \times U(1)_X \times SU(3)$ on the IR. In the unitary gauge this leads to the following Higgs couplings to the gauge fields ($V = W, Z$) in terms of the parameter ξ

$$g_{hVV} = g_{hVV}^{SM} \sqrt{1-\xi} , \qquad g_{hhVV} = g_{hhVV}^{SM} (1-2\xi) . \tag{1}$$

The couplings to fermions depend on their embedding into representations of the bulk symmetry. In the MCHM4 model [4] the fermions transform as spinorial representations, in the MCHM5 model [5] as fundamental representations of $SO(5)$ and the Higgs fermion interactions read

$$\text{MCHM4:} \quad g_{hff} = g_{hff}^{SM} \sqrt{1-\xi} \qquad \text{MCHM5:} \quad g_{hff} = g_{hff}^{SM} \frac{1-2\xi}{\sqrt{1-\xi}} . \tag{2}$$
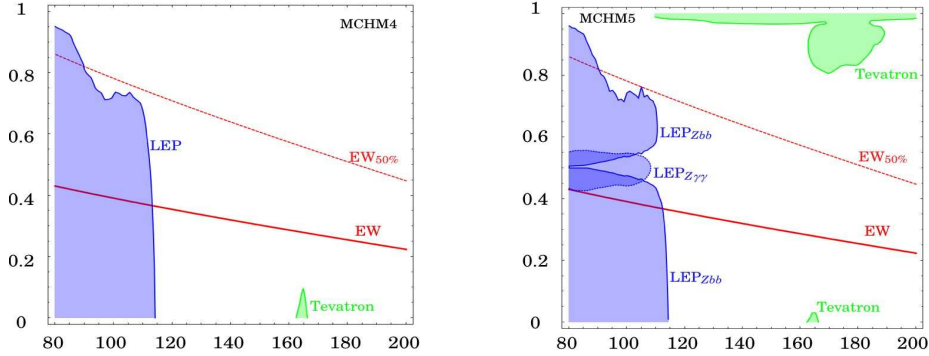
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Figure 1: Limits from Higgs searches at LEP (blue/dark gray) and Tevatron (green/light gray) in the plane (M_H, ξ) for MCHM4 (left), MCHM5 (right). The red continuous line delineates the region favoured at 99% CL by EW precision data (with a cutoff scale of 2.5 TeV), the region below the red dashed line survives for an additional 50% cancellation of the oblique parameters.

2 Constraints from LEP, Tevatron and EW precision data

The (M_H, ξ) parameter region is constrained from Higgs searches at LEP and Tevatron. The excluded regions are shown in Fig.1. In both models the SM Higgs mass LEP limit $M_H \gtrsim 114.4$ GeV is lowered, since at LEP the most relevant search channel is Higgs-strahlung with Higgs decay into $b\bar{b}$ and in both models this production is suppressed compared to the SM. As in MCHM5 at $\xi = 0.5$ the Higgs fermion coupling vanishes, constraints are then set by Higgs-strahlung production with decay into $\gamma\gamma$. At Tevatron, low ξ is excluded by the Higgs decay into a W pair for $M_H \approx 160$ GeV. The exclusion region quickly shrinks to 0, since the relevant Higgs-strahlung production is suppressed compared to the SM for non-zero ξ. In MCHM5, an additional region $M_H \sim 165 - 185$ GeV can be excluded for $\xi \gtrsim 0.8$ through $H \to WW$. Close to $\xi = 1$ the exclusion is set by $H \to \tau\tau$ decays. Further constraints arise from the electroweak precision data. In our set-up they are due to the incomplete cancellation between the Higgs and gauge boson contributions to S and T and low ξ values are preferred. The upper bound on ξ is relaxed by a factor of ~ 2 if one allows for a partial cancellation of the order of 50%.

3 Branching ratios and statistical significances

The partial widths in the composite Higgs models are obtained by rescaling the Higgs couplings involved in the decay. In the MCHM4 model all couplings are multiplied by $\sqrt{1-\xi}$ so that the branching ratios are the same as in the SM. In the MCHM5 model due to different Higgs couplings to gauge bosons and fermions, the branching ratios (BRs) are modified. Fig.2 shows the BRs in the SM and the MCHM5 for three values of $\xi = 0.2, 0.5, 0.8$ in the mass range favoured by composite Higgs models. For $\xi = 0.2$ the behaviour is almost the same as in the SM. The decays into $\gamma\gamma$ and $Z\gamma$ are slightly enhanced, a behaviour which culminates at $\xi = 0.5$. Here, due to the specific Higgs fermion coupling in MCHM5 the decays into fermions and fermion-loop mediated decays into gluons are closed and the BR into $\gamma\gamma$ dominates in the low Higgs mass region. At $\xi = 0.8$ the BRs into fermions dominate at low-Higgs mass and are
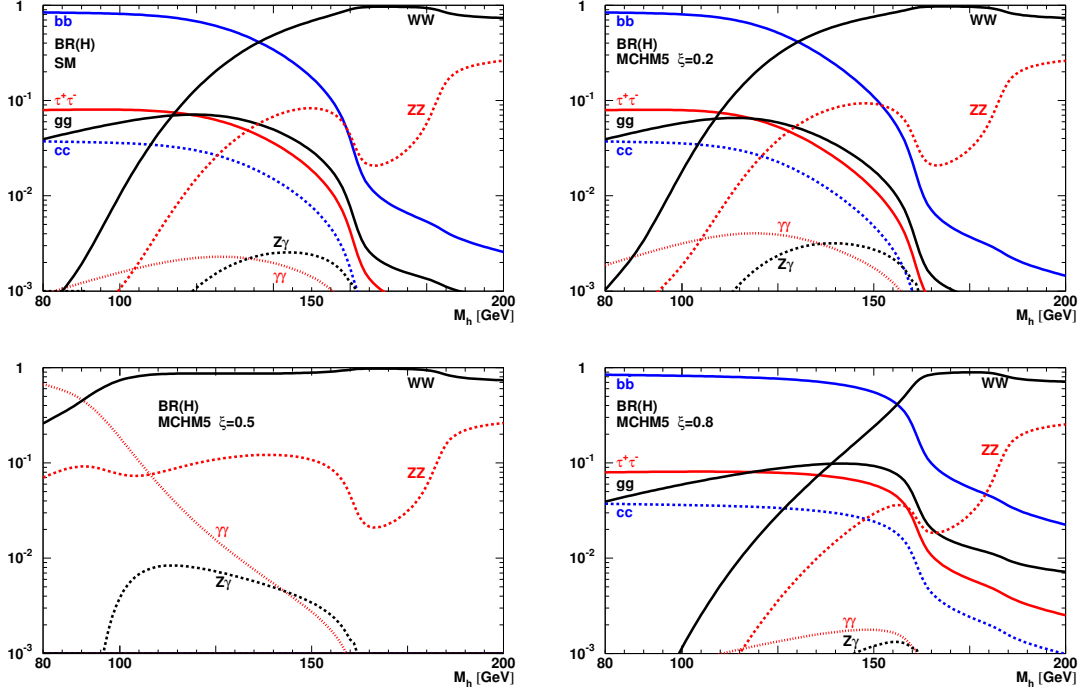
Figure 2: Higgs branching ratios as a function of the Higgs boson mass in the SM ($\xi = 0$, upper left) and MCHM5 with $\xi = 0.2$ (upper right), 0.5 (bottom left) and 0.8 (bottom right).

enhanced compared to the SM above the gauge boson threshold.

In order to study the Higgs discovery prospects, the statistical significances for different LHC search channels have been evaluated by referring to the CMS analyses [6]. The results are not significantly changed for the ATLAS analyses [7]. Assuming that only the signal but not the backgrounds rates are changed, since only Higgs couplings are affected, the significances can be obtained by applying a rescaling factor $\varkappa$ to the number of signal events. Referring to a specific search channel, it is given by taking into account the change in the production process p and in the subsequent decay into a final state X with respect to the SM, hence

$$\varkappa = \frac{\sigma_p \, BR(H \to X)}{\sigma_p^{SM} BR(H^{SM} \to X)} \; . \tag{3}$$

The number of signal events s is obtained from the SM events s^{SM} by $s = \varkappa \cdot s^{SM}$ where s^{SM} after application of all cuts is taken from the experimental analyses. With the signal events s and the background events after cuts, $b \equiv b^{SM}$, the significances in the composite Higgs model are calculated. For more details see Ref. [8]. In Figs.3 the SM significance and the MCHM5 significances for $\xi = 0.2, 0.5, 0.8$ are presented. For $\xi = 0.2$ the reduction in the production channels cannot be compensated by the enhancement in the BRs into $\gamma\gamma$ and massive gauge bosons, so that the significances are below the SM ones. This is even worse for $\xi = 0.5$ where the gluon fusion (and also $Ht\bar{t}$) production vanishes. Only for low Higgs masses the strong
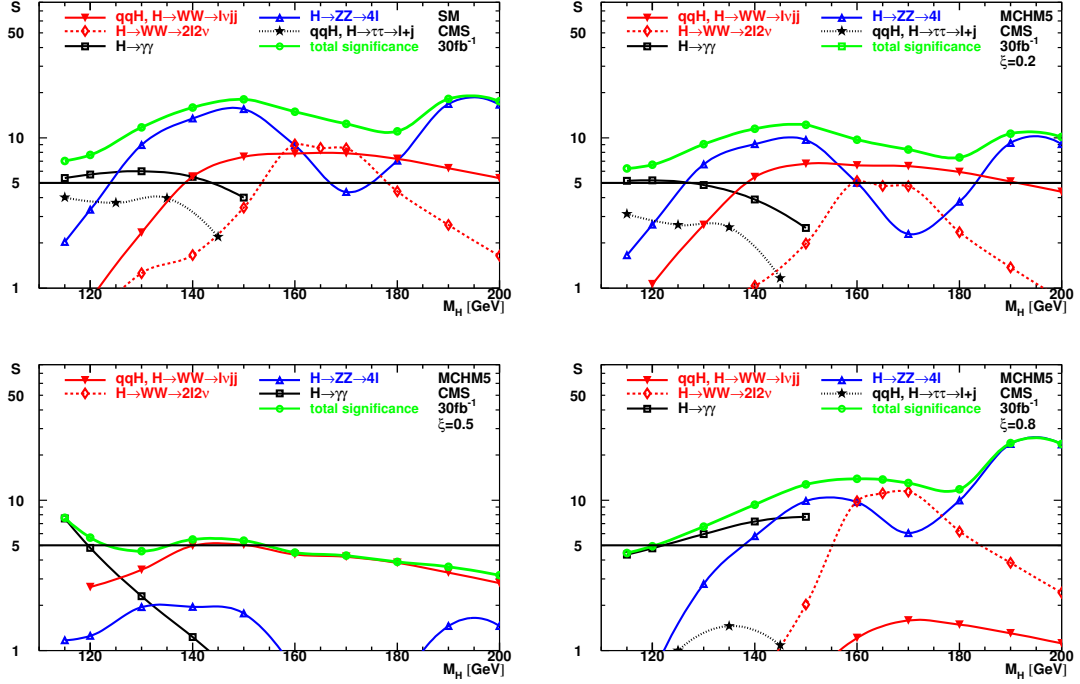
Figure 3: Significances in different channels as a function of the Higgs boson mass in the SM ($\xi = 0$) and for MCHM5 with $\xi = 0.2$, 0.5 and 0.8.

enhancement in the $\gamma\gamma$ BR can raise the significance above 5. For higher Higgs masses one has to rely on weak boson fusion with $H \to WW$ decay. For $\xi = 0.8$ the production is completely taken over by gluon fusion and leads to large significances in the massive gauge boson final states. Also $\gamma\gamma$ final states contribute for $M_H \gtrsim 120$ GeV.

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