PROCEEDINGS OF SCIENCE

The Higgs singlet extension at LHC Run 2

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We discuss the current status of theoretical and experimental constraints on the real Higgs singlet extension of the Standard Model. For the second neutral (non-standard) Higgs boson the full mass range from 1 GeV to 1 TeV accessible at past and current collider experiments is considered. We present benchmark scenarios for searches for an additional Higgs state in the real Higgs singlet extension of the Standard Model in Run 2 of the LHC. We furthermore discuss electroweak corrections to the $H \to hh$ partial decay width within this model.

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1. The model and dominant constraints on the parameter space

The simplest extension of the Standard Model (SM) Higgs sector, where an additional real scalar field is added [1, 2, 3], is a widely explored benchmark scenario for experimental searches at the LHC [4]. The model contains a complex $SU(2)_L$ doublet, denoted by Φ, and a real scalar S which is a singlet under the SM gauge group. The most general renormalizable Lagrangian compatible with an additional Z_2 symmetry contains the scalar potential $V(\Phi,S) = -m^2\Phi^\dagger\Phi - \mu^2 S^2 + \lambda_1(\Phi^\dagger\Phi)^2 + \lambda_2 S^4 + \lambda_3\Phi^\dagger\Phi S^2$. In the unitary gauge, the Higgs fields are given by $\Phi \equiv \left(0 \;\; \frac{\tilde{h}+v}{\sqrt{2}}\right)^T$, $S \equiv \frac{h'+v_s}{\sqrt{2}}$, with v, v_s denoting the non-zero vacuum expectation values of the doublet and singlet, respectively. The above potential leads to mixing between the gauge eigenstates via the mixing angle α, such that $h = c_\alpha\tilde{h} - s_\alpha h'$, $H = s_\alpha\tilde{h} + c_\alpha h'$, with $s_\alpha\,(c_\alpha) \equiv \sin\alpha\,(\cos\alpha)$. We here use the convention that $m_h \leq m_H$, and choose as input parameters m_h, m_H, $\sin\alpha$, v, $\tan\beta \equiv \frac{v}{v_s}$, where $v \sim 246\,\mathrm{GeV}$. One of the scalar masses is fixed to $\sim 125\,\mathrm{GeV}$. The above mixing induces a rescaling of the SM-like Higgs couplings at tree level by $\sin\alpha$ $(\cos\alpha)$ for h (H), with respect to the couplings for a SM Higgs boson of that mass. Furthermore, it features a genuinely new decay mode whenever the channel $H \to hh$ opens up kinematically. See e.g. [5, 6, 7] for further details.

Both theoretical and experimental constraints determine viable regions of the models parameter space, cf. [5, 6, 7]. Limits on the mixing angle for cases where the second scalar is heavier than 125 GeV mainly result from *(i)* direct search limits, which we implemented using `HiggsBounds` (version 4.3.1) [8, 9, 10], *(ii)* Higgs signal strength measurements, either implemented via `HiggsSignals` (version 1.4.0) [11] or taken as a direct limit from the combined Higgs signal strength measurement [12], *(iii)* the precision calculation of the W-boson mass within this model [13], as well as *(iv)* limits from perturbativity of the couplings. A summary of all constraints is given in Fig. 1. Production cross-sections for the 14 TeV LHC, after all constraints have been taken into account, can reach up to 10 pb for the total rate of all SM final states and up to 0.5 pb for hh final states. Specific benchmarks for all mass ranges allowed by the limits in Fig. 1 have been presented in [7, 4].

2. Renormalization

The complete electroweak renormalization of the model has been discussed in [16], where we applied a non-linear gauge fixing prescription implemented within the SLOOPS framework (see e.g. [17, 18]), to study gauge-parameter dependence of several schemes. We found that an *improved* On-shell scheme, specified by the off-diagonal mass counterterm $\delta m^2_{hH} = \mathrm{Re}\,\Sigma_{hH}(p^2_*)\big|_{\xi_W=\xi_Z=1,\tilde{\delta}_i=0}$ with $p^2_* = \frac{m_h^2+m_H^2}{2}$, exhibits the cleanest theoretical and numerical properties. We apply it to compute the one-loop electroweak corrections to the decay width $\Gamma_{H\to hh}$. Once all present constraints on the model are included, we find mild NLO corrections, typically of few percent, with theoretical uncertainties on the per mille level. Sample results are displayed in Fig. 2.

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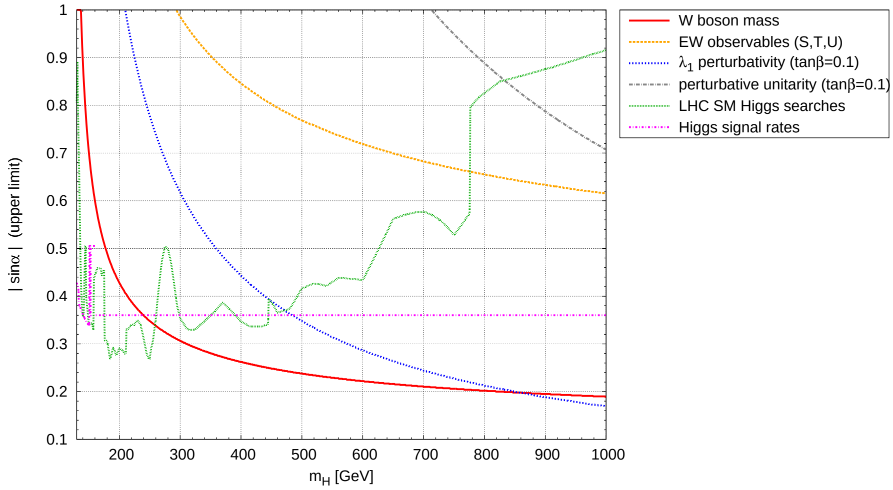
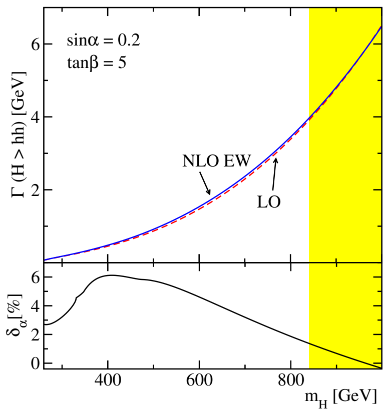
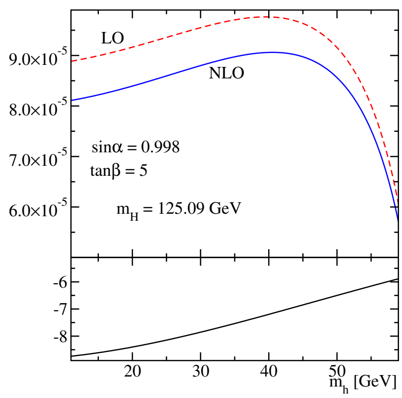


Figure 1: Maximal allowed values for $|\sin\alpha|$ in the high mass region, $m_H \in [130, 1000]\,\text{GeV}$, from precision calculations of the W-boson mass (*red, solid*) [13], electroweak precision observables (EWPOs) tested via the oblique parameters S, T and U (*orange, dashed*), perturbativity of the RG-evolved coupling λ_1 (*blue, dotted*), evaluated for an exemplary choice $\tan\beta = 0.1$, perturbative unitarity (*grey, dash-dotted*), direct LHC Higgs searches (*green, dashed*), and the Higgs signal strength (*magenta, dash-dotted*). Taken from [7]. More recent collider results (see e.g. [14, 15]) are not included and can potentially influence the region where $m_H \lesssim 400\,\text{GeV}$.



(a) $m_h = 125.09\text{GeV}$



(b) $m_H = 125.09\text{GeV}$

Figure 2: NLO corrections to the $H \to hh$ partial decay width, for fixed $\sin\alpha$, $\tan\beta$ values and m_h *(left)* or m_H *(right)* being the 125 GeV resonance measured at the LHC, as a function of the second scalar mass. We display the total decay width for $H \to hh$, we display the total decay width, along with its relative one-loop correction. The yellow region is excluded by perturbativity. *Note:* $\tan\beta$ is defined as $\frac{v_s}{v}$ in this case, in contrast to the definitions given above. Taken from [16].

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