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Resonant Multi-Scalar Production in the Generic Complex Singlet Model in the Multi-TeV Region

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We develop benchmarks for resonant di-scalar production in the generic
complex singlet scalar extension of the Standard Model (SM), which contains two new scalars. These benchmarks maximize di-scalar resonant production: $pp \to h_2 \to h_1h_1/h_1h_3/h_3h_3$, where h_1 is the observed SM-like Higgs boson and $h_{2,3}$ are new scalars. The decays $h_2 \to h_1h_3$ and $h_2 \to h_3h_3$ may be the only way to discover h_3, leading to a discovery of two new scalars at once. Current LHC and projected future collider (HL-LHC, FCC-ee, ILC500) constraints are used to produce benchmarks at the HL-LHC for h_2 masses between 250 GeV and 1 TeV and a future pp collider for h_2 masses between 250 GeV and 12 TeV. We update the current LHC bounds on the singlet-Higgs boson mixing angle. As the mass of h_2 increases, certain limiting behaviors of the maximum rates are uncovered due to theoretical constraints on the parameters. These limits, which can be derived analytically, are $\mathrm{BR}(h_2 \to h_1h_1) \to 0.25$, $\mathrm{BR}(h_2 \to h_3h_3) \to 0.5$, and $\mathrm{BR}(h_2 \to h_1h_3) \to 0$. It can also be shown that the maximum rates of $pp \to h_2 \to h_1h_1/h_3h_3$ approach the same value. Hence, all three $h_2 \to h_ih_j$ decays are promising discovery modes for h_2 masses below $\mathcal{O}(1\mathrm{TeV})$, while above $\mathcal{O}(1\mathrm{TeV})$ the decays $h_2 \to h_1h_1/h_3h_3$ are more encouraging. Masses for h_3 are chosen to produce a large range of signatures including multi-b, multi-vector boson, and multi-h_1 production. The behavior of the maximum rates imply that in the multi-TeV region this model may be discovered in the Higgs quartet production mode before Higgs triple production is observed. The maximum di- and four Higgs production rates are similar in the multi-TeV range.

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