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"Silver" Mode for Heavy Higgs Search in the Presence of a Fourth SM Family

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Abstract

We investigate the possible enhancement to the discovery of the heavy Higgs boson through the possible fourth standard model family heavy neutrino. Using the channel $h \rightarrow \nu_4 \bar{\nu}_4 \rightarrow \mu W \mu W \rightarrow \mu j j \mu j j$ it is found that for certain ranges of the Higgs boson and ν_4 masses, LHC could discover both of them simultaneously with 1fb^{-1} integrated luminosity.

Key Words: heavy Higgs, LHC, fourth family

1. Introduction

The hunt for the Higgs boson is the main aim of the LHC to complete the validation of the basic principles of the Standard Model (SM). The main production mechanism of the Higgs boson at hadron colliders is the gluon fusion via heavy quark loop. Therefore the number and nature of the quarks contributing to that loop play a crucial role. In the realm of the SM as we know it today, with 3 families, the main contribution is from the top quark. However, the number of families in the SM is a free parameter and the LEP-1 data fixes only the number of fermion families with a light ($m_\nu < m_Z/2$) neutrino. The EW precision data, on the other hand, favor the 3 and 4 family cases equally [1]. Moreover a fifth and even a sixth family may be allowed depending on the precision measurements on W boson properties. On the other hand, the upper limit on the number of families comes from the asymptotic freedom property of the QCD as 8.

If there is a fourth SM family, as also implied by the flavour democracy hypothesis (see [2] and references therein), its quarks are expected to be heavier than 200 GeV [3], (a recent experimental result pushes the limit to 250 GeV [4]) contributing to the Higgs boson production loop in addition to the top quark. Such a contribution enhances the production cross section for the Higgs boson and makes the gluon fusion channel sensitive to new physics. Recently at the Tevatron, the process $gg \rightarrow h \rightarrow WW^*$ is investigated after taking into account the possible enhancement due to a fourth SM family [5]. This mode is the most promising for the Higgs masses between 130 and 190 GeV both at the Tevatron and the LHC. However, its observation at the Tevatron requires the enhancement from the fourth family.

At the LHC, in three SM family case, for a heavy Higgs of mass between 200 and 500 GeV the most prominent mode is the "golden" mode: $gg \rightarrow h \rightarrow ZZ \rightarrow \ell\ell\ell\ell$. For an even heavier Higgs, between 500 and 800 GeV, the "semi-golden" mode, $gg \rightarrow h \rightarrow ZZ \rightarrow \ell\ell\,\nu\nu$ becomes the preferred mode of discovery. Above 800 GeV, the discovery channel has to be the $gg \rightarrow h \rightarrow WW \rightarrow \ell\nu jj$ [6]. The fourth SM family quarks

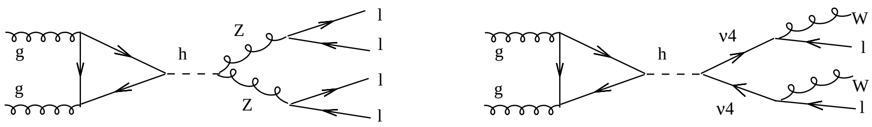

Figure 1. The "golden" (left) and the "silver" (right) modes for heavy Higgs boson discovery.

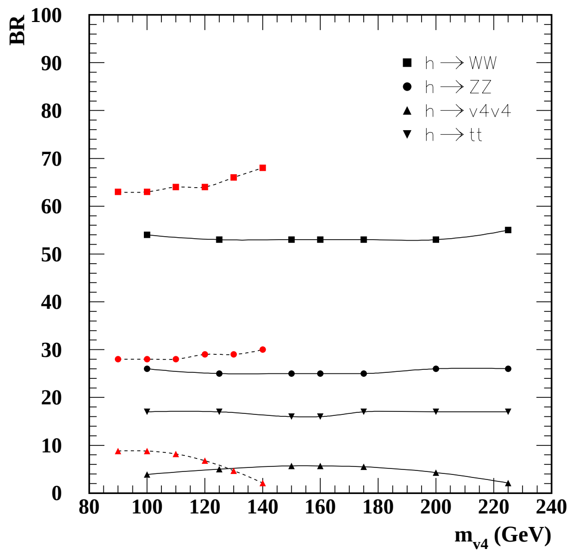

Figure 2. The heavy Higgs branching ratios as a function of the heavy neutrino mass for two example m_h values 300 GeV (dashed lines) and 500 GeV (solid lines).

would increase the production cross section by a factor between 5 - 8 depending on the Higgs boson mass [7] decreasing the required luminosity for a 5σ discovery. This effect is also recently studied in the context of the warped extra-dimensional models with additional heavy quarks [8].

The other fourth family members, depending on their mass, could also allow new search channels for the Higgs boson. The mass of the fourth SM family neutrino, ν_4, is bound from below by the LEP-2 data: $m_{\nu_4} > 90.3$ GeV for the Dirac case and $m_{\nu_4} > 80.5$ GeV for the Majorana case [3]. In this note, we argue that the $gg \to h \to \nu_4\bar{\nu}_4 \to \ell W \ell W$ channel, called hereafter the "silver" mode, could be competitive with the golden mode for some region of the Higgs and ν_4 masses. Figure 1 contains the Feynman diagrams of the "golden" and "silver" channels for the Higgs boson discovery.

2. Fourth family neutrino pair production and decay as the "silver" mode

The fourth family neutrino, ν_4, couples to the Higgs boson with a vertex coefficient proportional to its mass providing a new decay channel. The branching ratios as a function of the ν_4 mass for two Higgs mass values, 300 and 500 GeV, are presented in Figure 2. As seen $\mathrm{Br}(h \to \nu_4\bar{\nu}_4)$ is maximized between 90 and 100 GeV as 8.8% for m_h =300 GeV and between 150 and 160 GeV as 5.7% for m_h =500 GeV. Below we compare the "golden" and "silver" modes in these mass ranges.

The decays of the ν_4 are governed by the 4x4 MNS mixing matrix. For numerical calculations, we consider the parameterization in [9] which is compatible with the experimental data on the masses and the mixings in the SM leptonic sector. In this case, the $\mathrm{Br}(\nu_4 \to \mu W) \simeq 0.68$ and $\mathrm{Br}(\nu_4 \to \tau W) \simeq 0.32$ which imposes the main discovery signal as two muons and four jets considering the hadronic decays of the W bosons in the final state. Note that, the primary "silver" mode contains only muons compared to both electrons and muons of the "golden" mode. This scenario with $m_h = 300$ GeV, leads to Br($h \to \nu_4\bar{\nu}_4 \to \mu^+\mu^- jjjj$)=1.88×10^{-2} which should be compared to the "golden" mode branching ratio of 1.35×10^{-3}, giving an enhancement factor about 14. Corresponding numbers for $m_h = 500$ GeV are 1.22×10^{-2} and 1.12×10^{-3} respectively, yielding an enhancement of about 11 times. We believe that an order of magnitude higher statistics would compensate the possible inefficiencies associated with jet detection and hadronic W boson reconstruction.

An associated channel to the primary "silver" mode is the case where one of the W bosons decays leptonically: $W \to \ell\,\nu$ ($\ell = \mu, e$). The final state in this case will be $\mu^+\mu^-\,\ell jj\not{E}_T$. The number of such events is 63% of the main "silver" mode discussed above, bringing the total enhancement factor up to 23 (18) compared to the "golden" mode for a Higgs boson of m_h=300 (500) GeV.

If the fourth family neutrino is of Majorana nature, an experimentally clear signature would be available, namely same sign muons as decay products of ν_4s. Although in this case the number of expected signal events is halved, the background is practically negligible as there are no tree level diagrams in the SM yielding same sign leptons alongside with the two W bosons in the final state, making this mode deserve the name "platinum" mode. The direct backgrounds to the primary "silver" mode originate from quark anti-quark annihilation and involve only electroweak interactions, including triple and quartic gauge boson couplings, yielding $W^+W^-\mu^-\mu^+$ final state. The indirect backgrounds originate from the possible mis-identification of a Z boson as a W and hence are composed of the processes with $ZW^\pm\mu^+\mu^-$ and $ZZ\mu^+\mu^-$ final states. Compared to the signal process originating from QCD interactions, the total cross section from the above cited background processes is expected to be much smaller.

3. Conclusion

This paper considers a four family SM interacting with the Higgs boson. In this scenario, if Nature allows, a double discovery in the first year of the LHC start up is in the realm of the possible: the fourth family neutrino and a heavy ($m_h > 300$ GeV) Higgs boson. For $m_h = 300$ (500) GeV the fourth family quarks increase the Higgs production cross section to 2×10^4 (8×10^3) fb compared to 4×10^3 (2×10^3) fb in the 3 family SM case [10]. The so called "silver" mode, using both μ and τ involving leptonic decays of the ν_4, allows about 1760 (470) Higgs bosons (and obviously twice as many ν_4) to be reconstructed with 1fb^{-1} luminosity for $m_h = 300$ (500) GeV and $m_{\nu_4} = 100$ (150) GeV. The Monte Carlo simulation to verify this statement is under progress.

A recent arXiv entry, mentioning an enhancement to Higgs discovery from $h \to \nu_4\bar{\nu}_4 \to \ell W \ell W \to 4\ell + \not{E}_T$ channel was brought to our attention [11]. However, this decay channel has two disadvantages: reduction in the event number due to leptonic branching ratio of W boson decay and the impossibility of full event reconstruction due to two neutrinos.

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