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Linear Collider contribution to a very Heavy Higgs

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Current data does not rule out a Higgs with Standard Model couplings up to the triviality bounds. We consider the contribution of a linear collider if in fact the Higgs is very heavy, $\mathrm{M_H} > 350$ GeV/c^2. A very heavy Higgs would require the existence of a non-Standard Model effect; however, that effect could exist at an experimentally inaccessible mass scale so that the very heavy Higgs could act with couplings indistinguishable from Standard Model couplings.

In this discussion, we assume that the LHC would be the discovery machine since a signal greater than 5 sigma is claimed by both ATLAS and CMS for 30 fb^{-1} for $\mathrm{M_H} \sim 1$ TeV/c^2. We ask the question, "What measurements could a linear collider contribute to better the understanding of a very heavy Higgs candidate?"

We consider the specific case for $\mathrm{M_H} = 500$ GeV/c^2 and the Higgs has couplings that are equal to those expected in the Standard Model. The natural width of this Higgs can be calculated to be 70 GeV/c^2 and the branching ratios into the dominant decay modes are: 55% in W^+W^-, 25% in Z^0Z^0, and 20% in $t\bar{t}$.

At the LHC, the production cross section is 4 pb^{-1} for $\mathrm{M_H} = 500$ GeV/c^2. The decay of the Higgs into pairs of Z^0's and the subsequent decay of the Z^0's into either e^+e^- or $\mu^+\mu^-$ gives a cross section times branching ratio into the four lepton final state, "4 l" (the *golden* mode), of 3.2 fb. In 300 fb^{-1} and assuming an acceptance times efficiency of 40%, the ATLAS TDR states that 390 events in this *golden* mode can be used to measure the mass to a relative error better than 0.3%, the width to 6%, and production cross section times B to 12% (assuming a 10% uncertainty on the luminosity determination). The LHC should be able to make a precision measurement on the ratio of branching ratio's into W-pairs relative to Z^0-pairs. Other measurements such as the CP-nature of the Higgs is not discussed here.

One can look at several measurements that could potentially benefit from a linear collider. There is no obvious physics case that would require the mass measurement to be better. The measurement of the width comes from a direct fit to the data to the 4 lepton mass (recall that the natural width is large and directly measurable) and has an uncertainty dominated by the statistical precision of the fit. The machine with the largest statistics should be able to make the most precise width measurement. The LHC appears unlikely to be able to make a precise measurement of a branching ratio both due to uncertainties in the normalization of luminosity and due to the inability of precisely determining the production cross section.

At a linear collider, the production of a very heavy Higgs requires both high energy and high luminosity. We consider the "super-"TESLA machine running at an energy of 800 GeV with a luminosity of 5×10^{34} so that five years of running at 10^7 seconds per year gives a data sample of 2500 fb^{-1}. At his energy, the production cross section of $H\nu\nu$ dominates at 10 fb, but the production cross section of HZ^0 also contributes significantly at 6 fb. In all, approximately 40,000 Higgs would be produced. Even with such a glorious data set, the number of expected *golden* mode events is only 46 events assuming 100% acceptance and efficiency and no backgrounds. We assume that in the case of a linear collider, the *golden* mode will not contribute to a high precision measurement due to limited statistics.

The expected event sample that would be produced for Higgs decaying into W^+W^- where either one or both W's decay leptonically is 7,700. For Higgs decaying into Z^0Z^0 with at least one Z^0 decaying into a lepton pair (e or μ) and the other Z^0 decaying either into neutrinos or $b\bar{b}$ is 480 events. Other decay modes of the vector bosons appear to either have large backgrounds or have great difficulties in their reconstruction (c-tagging could help, for instance). Unlike the LHC, it is possible that the linear collider could observe and measure the branching ratio of Higgs into $t\bar{t}$. Final state modes that involve at least one lepton and two b-jets number would provide a sample of 2750 events. Assuming that 10% of this sample is usable (within the acceptance, found efficiently over background, correctly b-tagged), the relative error on the branching ratio could be 6%. For a very heavy Standard Model-like Higgs, assuming that a sufficiently large data sample could be obtained, the linear collider could be the best place to measure the coupling of the Higgs to fermion pairs and perhaps give insight into the exact nature of the Higgs and the origin of mass.