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Towards a precise measurement of the top quark Yukawa coupling at the ILC

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A precise measurement of the top quark Yukawa coupling is of great importance, since it may shed light on the mechanism of EWSB. We study the prospects of such measurement during the first phase of the ILC at $\sqrt{s} = 500$ GeV, focusing in particular on recent theoretical developments as well as the potential benefits of beam polarization. It is shown that both yield improvements that could possibly lead to a measurement competitive with the LHC.

1. INTRODUCTION

The top quark Yukawa coupling (λ_t) is the largest coupling of the Higgs boson to fermions. A precise measurement of it is very important since the it may help unravel the secrets of the Electroweak Symmetry Breaking (EWSB) mechanism, in which the top quark could possibly play a key role. For $m_h < 2m_t$, a direct measurement of λ_t is possible via associated $t\bar{t}h$ production, both at the LHC and a future e^+e^- International Linear Collider (ILC). At the LHC, the expected accuracy [1] is $\delta\lambda_t/\lambda_t \sim 12 - 15\%$ for $m_h \sim 120 - 200$ GeV, assuming an integrated luminosity of 300 fb^{-1}. Existing feasibility studies at the ILC [2] predict an accuracy of $\delta\lambda_t/\lambda_t \sim 6 - 10\%$ for $m_h \sim 120 - 190$ GeV, assuming $\sqrt{s} = 800$ GeV and 1000 fb^{-1}. However, currently the baseline design for the ILC only contemplates a maximum center-of-mass energy of 500 GeV. Therefore, it is very relevant to explore the prospects of this measurement during the first phase of the ILC, especially in view of the limited accuracy expected at the LHC: for a number of years, the combination of results from the LHC and ILC would yield the most precise determination of λ_t.

A preliminary feasibility study at $\sqrt{s} = 500$ GeV was performed in Ref. [3], which we briefly overview here. Indeed, the measurement of λ_t at $\sqrt{s} = 500$ GeV is more challenging than at $\sqrt{s} = 800$ GeV. On the one hand, the reduced phase-space leads to a large reduction in $\sigma_{t\bar{t}h}$ (e.g. $\sigma_{t\bar{t}h}^{Born} \simeq 0.16(2.5)$ fb at $\sqrt{s} = 500(800)$ GeV, for $m_h = 120$ GeV). On the other hand, the cross section for many background processes is significantly increased. This analysis assumed $m_h = 120$ GeV and focused on the $t\bar{t}h \to (\ell\nu b)(jjb)(b\bar{b})$ decay channel ($BR \sim 30\%$). The dominant background is $t\bar{t}jj$, followed by $t\bar{t}Z$, although other non-interfering backgrounds (e.g. W^+W^-) were also considered. Signal and backgrounds were processed through a fast detector simulation. After basic preselection cuts, the signal efficiency was found to be $\simeq 50\%$ and the $S : B \simeq 1 : 100$. In order to increase the sensitivity, a multivariate analysis using a Neural Network (NN) with 23 variables was performed. The final selection consisted on an optimized cut on the NN distribution. Assuming an integrated luminosity of 1000 fb^{-1}, the expected total number of signal and background events was 11 and 51, respectively, resulting in $(\delta\lambda_t/\lambda_t)_{stat} \simeq 33\%$. Based on previous experience [2], the addition of the fully hadronic decay channel was expected to ultimately lead to $(\delta\lambda_t/\lambda_t)_{stat} \simeq 23\%$. While this analysis is already rather sophisticated, significant improvements are expected from e.g. the usage of a more efficient b-tagging algorithm or a more optimal treatment of the kinematic information. In the next sections we discuss additional sources of improvement which are currently under investigation.

2. THE IMPACT OF RESUMMATION EFFECTS

The precise measurement of λ_t requires accurate theoretical predictions for $\sigma_{t\bar{t}h}$. Currently, one-loop QCD and electroweak corrections are available. However, at $\sqrt{s} = 500$ GeV and for $m_h \geq 120$ GeV, the kinematic region