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The third generation quark and the electroweak boson couplings at the 250 GeV stage of the ILC

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Abstract

The first stage of the ILC at a center-of-mass energy of 250 GeV can perform precision measurements of bottom quark pair production, thereby settling the long standing 3σ tension between the LEP experiments and SLD. This study shows the 250 GeV ILC has its good potential capability to measure the right-handed bottom quark couplings, which are keys in many BSM scenarios. Another important precision probes for new physics are the triple gauge boson couplings. Thanks to a high luminosity of the ILC and a possibility to polarize beams, a significant increase in precision is expected at the 250 GeV ILC, in particular for TGCs involving W bosons.

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1 Introduction

The third generation quarks are, due to their large mass, highly sensitive probes for new physics connected to the electroweak symmetry breaking. There are some tantalizing hints for non-standard behavior of the right-handed bottom quark. There is a long-standing 3σ discrepancy between the value of $\sin^2\theta_W^\ell$ derived from the bottom quark forward-backward asymmetry, A_{FB}^b, at LEP experiment and the value obtained at the SLC experiment using polarized beams[1]. An issue of particular interest is the measurement of the electroweak (EW) coupling to the right-handed bottom quark, g_R^Z, because new physics can explain the LEP anomaly on $\sin^2\theta_W^\ell$ where a large correction for g_R^Z is expected while the deviation of the EW coupling to the left-handed bottom quark, Δg_L^Z, remains small.

Precise measurements of the γW^+W^- and ZW^+W^- triple gauge boson couplings (TGCs) can be a test of the SU(2)×U(1) gauge boson self-coupling structure of the Standard Model (SM) and thus a probe for physics beyond the Standard Model (BSM). The primary focus of TGC studies is the search for modifications to the TGCs from BSM at energy scales well beyond the e^+e^- center-of-mass energy. This process is also important to measure in-situ beam polarization by making use of the strong dependence of the cross sections and angular distributions on the beam polarization[2].

As described above, the polarized beams are of special importance for both A_{FB}^b measurement and the TGC measurements. The International Linear Collider (ILC)[3] is a proposed linear electron-positron collider which will provide the beam polarization with high luminosity. The studies presented in this paper assume the first stage of the ILC at a center-of-mass energy of 250 GeV and are based on the International Large Detector (ILD)[4], which is one of concept detectors at the ILC.

2 $e^+e^- \to b\bar{b}$

To measure g_R^Z, b-quark polar angular spectrum is studied using WHIZARD[5] and the ILD full detector simulation[4], where beam spectrum and initial state radiation are taken into account. The b-quark polar angle reconstruction requires an accurate b-quark charge sign identification. The b-quark charge sign can be measured by summing up all charges associated to the B-hadron and/or identifying the charges of kaons found in the b-jet[6]. A correction technique of b-quark charge assignment was implemented to correct for the b-quark charge mis-assignments, which requires no external inputs and uses number of events in which only one of b-quark charges is correctly assigned[6]. Figure 1 shows potential capability of 250 GeV ILC with beam polarizations $(e_L^-, e_R^+) = (\pm 0.8, \mp 0.3)$ to constrain models by measuring right-handed coupling to Z. The integrated luminosity assumed here is 250 fb^{-1} for each beam polarization.

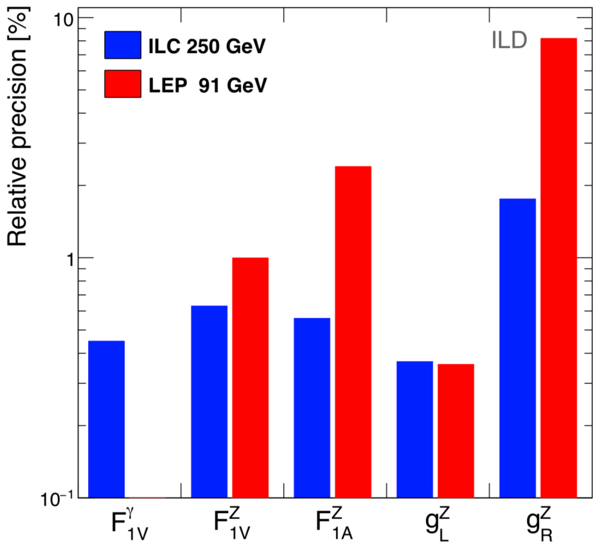

Figure 1 – Comparison with the LEP measurements[7]. The results of the ILC assume an integrated luminosity of 250 fb^{-1} for each beam polarization, $(e_L^-, e_R^+) = (\pm 0.8, \mp 0.3)$. The beam polarization and high luminosity are essential.

3 $e^+e^- \to W^+W^-$

BSM physics at energy scales well beyond the e^+e^- center-of-mass energy is parameterized by an effective Lagrangian with dimension-6 operators that respects SU(2)×U(1) gauge symmetry. The most general Lorentz invariant γW^+W^- or ZW^+W^- vertex contains 14 complex parameters, denoted by g_1^V, g_4^V, g_5^V, κ_V, λ_V, $\tilde{\kappa}_V$, $\tilde{\lambda}_V$, where $V = \gamma, Z$. At tree-level, in the SM, $g_1^V = \kappa_V = 1$ and all other parameters are zero. In this study the CP-conserving operators are considered, and after requiring SU(2)×U(1) constraints only g_1^Z, κ_γ and λ_γ remain as free parameters[8].

TGCs are measured at the ILC through $e^+e^- \to W^+W^-$ process and $e^-\gamma \to \nu_e W^-$ process, where the initial state γ refers to either a virtual or beamstrahlung photon. Five angles, the W^- production polar angle, and the rest frame fermion polar and azimuthal angles associated with the decays of the $W^\pm$, are to be measured. A full simulation study, which includes luminosity-weighted beam energy spectra and beam-beam background event overlay, has been done for the center-of-mass energy of 500 GeV [9], and the one for 250 GeV is work in progress. In this report, the 500 GeV results is extrapolated to 250GeV by using the scaling factors : (1) Statistics, $1/\sqrt{\sigma L}$, (2) Energy dependence of SU(2)×U(1) diagram cancellation, 1/s. Figure 2 shows precision estimations.

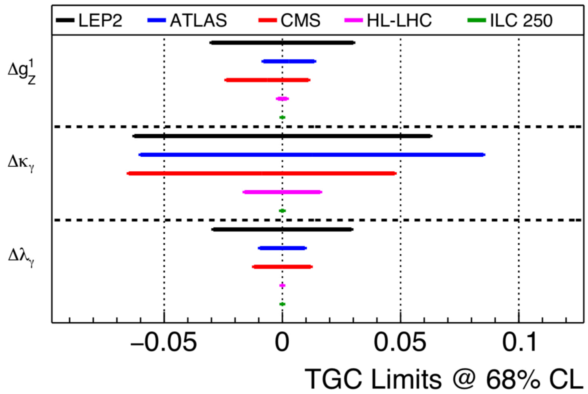

Figure 2 – Comparison of the reachable TGC precision using one parameter fits, where the other two anomalous couplings are set to be zero[8]. The results of the ILC assume an integrated luminosity of 2 ab^{-1}.

4 Conclusion

The ILC will measure precisely not only Higgs couplings but also the other SM parameters for BSM, which are complementary to searches at the LHC. The polarized beams of the ILC are essential for both g_R^Z and TGC measurements. Regarding third generation quarks, the 250GeV ILC can investigate the couplings for the left-handed and the right-handed bottom quarks and shows its good potential capability to measure g_R^Z, which is a key in many BSM scenarios. The ILC can shed light on the long-standing 3σ discrepancy between value of $\sin^2\theta_W$ derived from the bottom forward-backward asymmetry at LEP and the value obtained at the SLC. For the electroweak boson coupling, 10^{-3} level or better TGC measurements are feasible according to the extrapolation from the 500 GeV full simulation study. A full simulation for TGC measurement at 250 GeV is work in progress.

Acknowledgments

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