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Third Generation Quark and Electroweak Boson Couplings at the 250 GeV stage of the ILC

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The 3rd generation quarks are, due to their large mass, highly sensitive probes for new physics connected to the electroweak symmetry breaking. While top quark pair production requires center-of-mass energies of larger than 350 GeV, 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. For this measurement, the polarised beams of the ILC are of special importance as they enable the separation of the vector and axial-vector couplings of the b-quark to Z^0 boson and photon. Another important precision probe for new physics are triple gauge boson couplings. Thanks to the polarised beams and the much higher luminosity, a significant increase in precision beyond past and present experiments is expected at the first stage of the ILC for the TGCs involving $W^{\pm}$ bosons.

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1. Introduction

Precision measurements of electroweak couplings is one of the key approaches in indirect searches of the Beyond Standard Model physics. In this contribution we review two of such studies: electroweak couplings of the b-quark and triple gauge couplings (TGCs) measurements, and we describe how these measurements can be done at future e^+e^- colliders, particularly at the International Linear Collider.

The International Linear Collider (ILC) [1] is a linear electron-positron collider planned for high-precision measurements and direct New Physics searches. The linear design of the ILC allow to extend initial center-of-mass energy of 250 GeV to 500 GeV or 1 TeV collisions. Another advantages of the ILC are high luminosity, well-known initial state of the collisions and control of the electron and positron beam polarisation, which plays a key role in measurement of the electroweak physics processes. The ILC will be equipped by two general-purpose particle physics detectors, which can be switched by using push-pull technology of the interaction region. This contribution concentrates on one of these detectors, the International Large Detector (ILD). The high-granularity of all ILD subdetectors allows for an individual particle reconstruction using the Particle Flow approach [2]. The central tracker of the ILD is chosen as Time Projection Chamber (TPC) with particle identification capabilities.

2. Measurement of b-quark electroweak couplings

The LEP I collaborations have determined the b-quark couplings to the Z^0 boson by measuring the b partial width and the forward-backward asymmetry called A^b_{FB}. These quantities provide the most precise value of $\sin^2\theta_W$ at LEP I. It turns out that this value is about three standard deviations [3] away from the very precise value from SLD using beam polarisation. Redoing precisely this measurement is therefore a priority for future e^+e^- colliders.

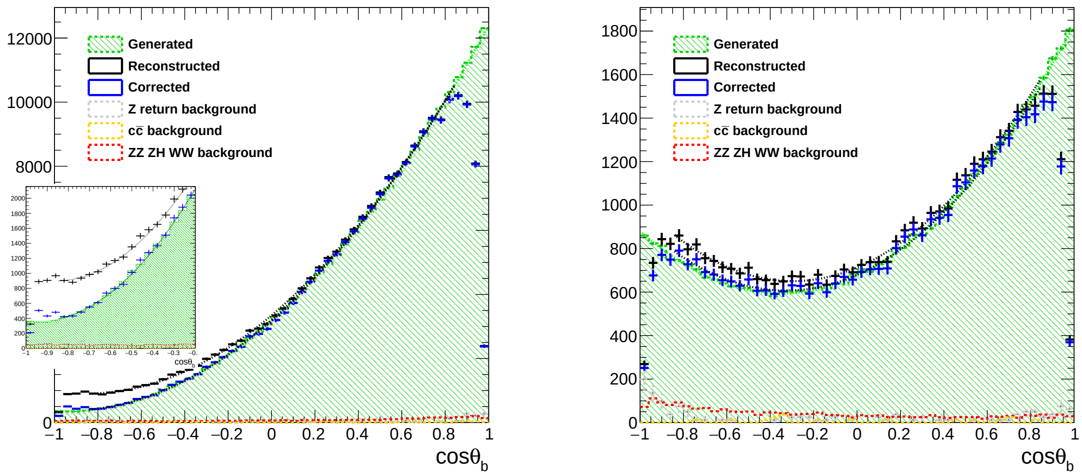
In this study, we intend to prove that the International Linear Collider (ILC) [1], with polarised beams and high luminosity, offers a unique opportunity for precise measurements well above the resonance, where both Z^0 and photon exchanges are present. This additional complexity turns out to be of a great advantage since it allows, through $\gamma - Z^0$ interference, to be sensitive to the sign of Z^0 couplings and fully solve the LEP I puzzle in an unambiguous way. More details are given in [4]. Recall that the LEP I anomaly can be interpreted up to a sign ambiguity for what concerns the right-handed coupling $Z^0 b\bar{b}$, referred hereafter as g^Z_R, which shows the largest deviation [5].

In this work, the ILC precision on electroweak b-quark couplings is studied using b-quark polar angle analysis. The b-quark polar angle reconstruction requires an accurate b-quark charge sign assignment. The b-quark charge is identified using two basic signatures:

- Vertex charge is a sum of all reconstructed charges, which are associated to the B-hadron vertices;
- Kaon charge is a charge of charged kaons found in b-hadron vertices.

The charged kaons are identified using the specific energy-loss dE/dx in the TPC of ILD. After correcting for the angular dependence of dE/dx [4], the charged kaons from b-hadron vertices can be identified with 97% purity and 87% efficiency, assuming 5% precision on the energy loss value.

The reconstructed b-quark polar angle distributions at $\sqrt{s} = 250\,\text{GeV}$ using a combination of kaon and vertex charge signatures are shown in Fig. 1. The integrated luminosity $\mathscr{L}_I = 250\,\text{fb}^{-1}$ is assumed for each beam polarisation.



(a) (b)

Figure 1: *Generated b-quark polar angle distribution compared to the final reconstructed b-quarks polar angle in left-handed case (a) and right-handed case (b) with overlaid background processes.*

The events with reconstructed kaon or vertex charges, which are incompatible between jets, allow defining the kaon and vertex charge purity in-situ. Using the in-situ purities, the reconstructed spectrum is corrected using a data-driven procedure [4]. The corrected distributions are fitted by a general cross section function, defined as $S(1+\cos^2\theta)+A\cos\theta$. The extracted precision on the S and A parameters is rescaled to the expected polarisation $e_L^-, e_R^+ = \pm 0.8, \mp 0.3$ and to the luminosity sharing of the ILC physics program. As one can see from Fig. 1, the contribution of the diboson background processes is small.

The relative precisions on the $Z^0 b\bar{b}$ couplings, g_L^Z and g_R^Z, for the LEP I measurements and for the expected ILC performance are shown in Fig. 2. The ILC precision on the g_R^Z coupling is enough to fully confirm or discard any New Physics influence on the b-quark electroweak couplings.

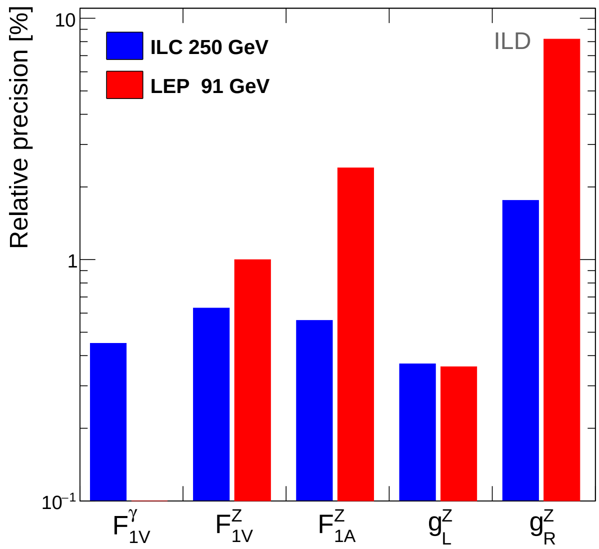


Figure 2: *Comparison of the LEP measurements to the expected precision at the ILC. The results of the ILC assume an integrated luminosity of* $\mathscr{L}_{\mathscr{I}} = 500\,fb^{-1}$ *shared between beam polarizations at* $\sqrt{s} = 250\,GeV$.

3. Measurement of Triple Gauge Couplings at the ILC

Lepton colliders are also ideally suited to measure electroweak TGCs, like $Z^0W^+W^-$ or γW^+W^-. The TGC may reveal the presence of additional heavy gauge bosons and their measurement is an important input to the analysis of Higgs couplings in the EFT framework. However, the measurement of these couplings also has a large sensitivity to the actual beam polarization. Thus, the uncertainty of polarization measurement would significantly affect the precision of TGC determination and vice versa. Therefore, it is necessary to measure anomalous TGC and the beam polarization simultaneously.

In general, $Z^0W^+W^-$ or γW^+W^- vertices are described by 14 complex parameters. Using the $SU(2)\times U(1)$ gauge symmetry constraints and considering only CP conserving parameters, one can reduce the number of considered parameters to 3: g_1^Z, k_γ, λ_γ.

At the e^+e^- colliders the TGCs are measured using $e^+e^- \to W^+W^-$ and $e^-\gamma \to \nu_e W^-$ processes, where the photon is either virtual or beamstruhlung photon. The polarization of the initial state is used to separate photon and Z^0 boson to W^+W^- couplings. To analyze the and separate out the different combination of longitudinally and transversely polarized $W^\pm$ bosons in the final state 5 reconstructed angles are used: The W^- production polar angle θ and the rest frame fermion polar and azimuthal angles, (θ^*, ϕ^*) and $(\bar{\theta}^*, \bar{\phi}^*)$, associated with the decays of the W^- and W^+, respectively.

In this contribution, the full simulation ILC results at $\sqrt{s} = 500$ GeV [6] are extrapolated down to $\sqrt{s} = 250$ GeV in order to obtain the three parameter simultaneous fit result. A factor k_{ex} is used

Experiment	Total uncertainty ($\cdot 10^{-4}$)		
	g_1^Z	k_γ	λ_γ
ILC 250 GeV	4.4	5.7	4.2
LEP 2	300	626	292
LHC 8 TeV	319	1077	198
HL-LHC	19	160	4

Table 1: *Triple Gauge Couplings precision for the ILC at $\sqrt{s} = 250\,\text{GeV}$ with $\mathcal{L}_I = 2000\,\text{fb}^{-1}$ luminosity, for LEP 2, for LHC at $\sqrt{s} = 8$ TeV and for HL-LHC. The ILC precision is computed using 3 parameter fit, while for other facilities only one coupling is varied at the time. Table is taken from [9].*

to extrapolate TGC statistical error from energy A to energy B:

$$k_{ex} = \left(\frac{\sigma_A \mathcal{L}_{IA}}{\sigma_B \mathcal{L}_{IB}}\right)^{1/2} \left(\frac{s_A}{s_B}\right), \tag{3.1}$$

and systematic uncertainties are scaled by the same factor k_{ex}. This factor incorporates statistical error scaling and the $SU(2) \times U(1)$ diagram cancellation [8].

The achievable precision of the TGC measurement is shown in Table 1. At the ILC, a subpermille-level on anomalous TGC precision can already be reached in the first stage of the ILC with 250 GeV. This is roughly 2 orders of magnitude better than the current best limit on anomalous TGCs, as shown in Fig 3.

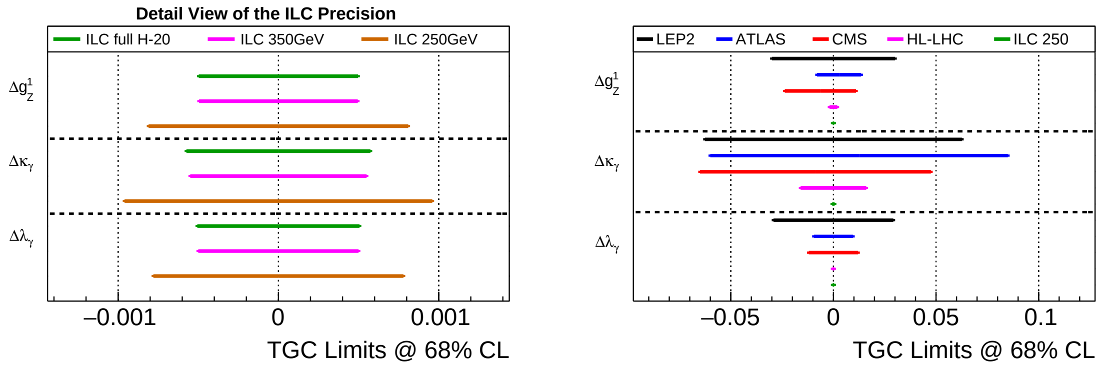


Figure 3: *Comparison of the reachable TGC precision of the ILC, shown in Table 1, with the final results from LEP combined from ALEPH, L3 and OPAL results [10] and the LHC TGC limits for $\sqrt{s} = 8$ TeV data and an integrated luminosity of $\mathcal{L} = 20.3\,\text{fb}^{-1}$ and $\mathcal{L} = 19.4\,\text{fb}^{-1}$ for ATLAS and CMS, respectively [11].*

Conclusions

In this contribution the ILC precision on electroweak b-quark and triple gauge couplings is described. The developed procedure of the b-quark charge reconstruction allows for measuring the b-quark polar angle. The b-quark polar angle fit allows for an independent determination of four electroweak couplings of the b-quark. The relative precision on the right-handed coupling $dg_R^Z/g_R^Z \approx 2\%$ at the ILC is sufficient to confirm at $> 5\,\sigma$ or to discard the LEP I effect, which is at the 25% level. The Triple Gauge Couplings at the ILC will be measured simultaneously with the beam polarization with precision which will be two orders of magnitude better than at LEP.

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References

[1] T. Behnke, J. E. Brau, B. Foster, J. Fuster, M. Harrison et al., *The international linear collider technical design report - volume 1: Executive summary*, 1306.6327.

[2] J. S. Marshall and M. A. Thomson, *The Pandora Software Development Kit for Pattern Recognition*, *Eur. Phys. J.* **C75** (2015) 439 [1506.05348].

[3] GFITTER GROUP collaboration, M. Baak et al., *The global electroweak fit at NNLO and prospects for the LHC and ILC*, *Eur.Phys.J.* **C74** (2014) 3046 [1407.3792].

[4] S. Bilokin, R. Pöschl and F. Richard, *Measurement of b quark EW couplings at ILC*, 1709.04289.

[5] A. Djouadi, G. Moreau and F. Richard, *Resolving the A(FB)$_b$ puzzle in an extra dimensional model with an extended gauge structure*, *Nucl. Phys.* **B773** (2007) 43 [hep-ph/0610173].

[6] I. Marchesini, *Triple Gauge Couplings and Polarization at the ILC and Leakage in a Highly Granular Calorimeter*, 2011.

[7] A. Rosca, *Measurement of the charged triple gauge boson couplings at the ILC*, .

[8] R. Karl, *Prospects for Electroweak Precision Measurements and Triple Gauge Couplings at a Staged ILC*, .

[9] K. Fujii et al., *Physics Case for the 250 GeV Stage of the International Linear Collider*, 1710.07621.

[10] ALEPH, DELPHI, L3, OPAL, and the LEP TGC Working Group, *A combination of results on charged triple gauge boson couplings measured by the LEP experiments*, 2005.

[11] LHC collaborations, "LHC limits on anomalous triple and quartic gauge couplings in comparison of the running experiments."