PROCEEDINGS OF SCIENCE

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

Sviatoslav BILOKIN* **on behalf of ILD concept group**
Institut Pluridisciplinaire Hubert CURIEN, Strasbourg, France
E-mail: sviatoslav.bilokin@iphc.cnrs.fr

The 3rd generation quarks are, due to their large masses, 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 SLC experiment. For this measurement, 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 is triple gauge boson couplings. Thanks to the polarised beams and a 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.

ICHEP 2018, International conference on High Energy Physics
4-11 July 2018
Seoul, Korea

*Speaker.

© Copyright owned by the author(s) under the terms of the Creative Commons Attribution-NonCommercial-NoDerivatives 4.0 International License (CC BY-NC-ND 4.0).

PoS(ICHEP2018)422

The International Linear Collider (ILC) [1] is a linear electron-positron collider with initial center-of-mass energy of $\sqrt{s} = 250\,\mathrm{GeV}$, which is extendable 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 polarization. This contribution concentrates on one of the ILC detectors, the International Large Detector (ILD). The high-granularity of all ILD subdetectors allows for an individual particle reconstruction using the Particle Flow approach. The central tracker of the ILD is chosen as Time Projection Chamber (TPC) with particle identification capabilities.

1. Measurement of b-quark electroweak couplings

The LEP 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 [2] away from the very precise value from SLD using beam polarisation. 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 [3].

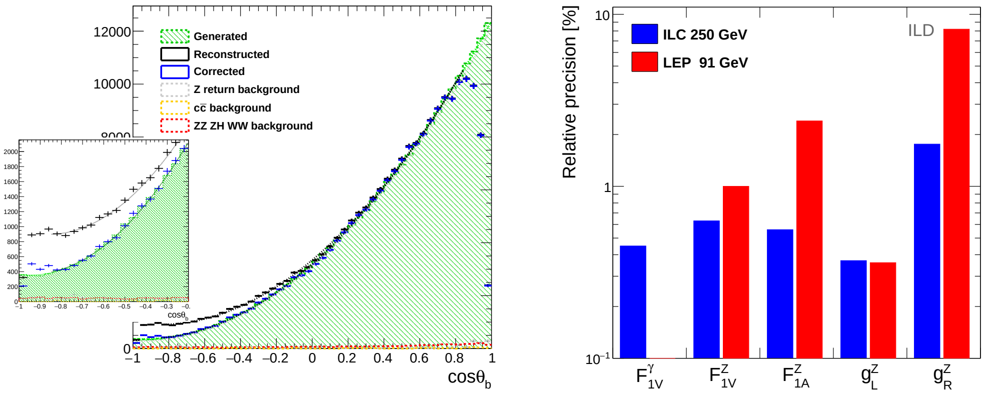

Figure 1: *Polar angle distributions of generated b-quarks and reconstructed b-quarks in left-handed case with overlaid background processes (left) and comparison of the LEP measurements to the expected precision at the ILC (right). More details are given in [4].*

In this work, the ILC precision on electroweak b-quark couplings is studied using b-quark polar angle analysis, which requires an accurate b-quark charge sign assignment. The b-quark charge is identified using two basic signatures: vertex charge, which is defined as a sum of all reconstructed charges associated to the B-hadron vertices and kaon charge, which is the charge of the charged kaons found in b-hadron vertices. The charged kaons are identified using the specific energy-loss dE/dx in the TPC of ILD. The reconstructed b-quark polar angle distributions at $\sqrt{s} = 250\,\mathrm{GeV}$ using a combination of kaon and vertex charge signatures are shown in Fig. 1. The events with reconstructed kaon or vertex charges, which are incompatible between jets, allow defining the kaon and vertex charge purity in-situ [4]. Using the in-situ purities, the reconstructed spectrum is corrected using a data-driven procedure.

PoS(ICHEP2018)422

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 computed using the b-quark polar angle spectra, shown in Fig. 1. The assumed integrated luminosity of $\mathcal{L}_I = 500\,\mathrm{fb}^{-1}$ is shared between each beam polarization according to the ILC physics program and rescaled to the expected beam polarization $e_L^-, e_R^+ = \pm 0.8, \mp 0.3$. The ILC precision on the g_R^Z coupling is enough to confirm or discard New Physics influence on the LEP I anomaly of the b-quark electroweak coupling measurements.

2. Measurement of charged Triple Gauge Couplings at the ILC

At the e^+e^- colliders the TGCs are measured using mainly the $e^+e^- \to W^+W^-$ process. The polarization of the initial state is used to separate the photon and Z^0 boson couplings to W^+W^-. To analyse and separate out the different combination of longitudinally and transversely polarized $W^\pm$ bosons in the final state up to five reconstructed angles can be 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.

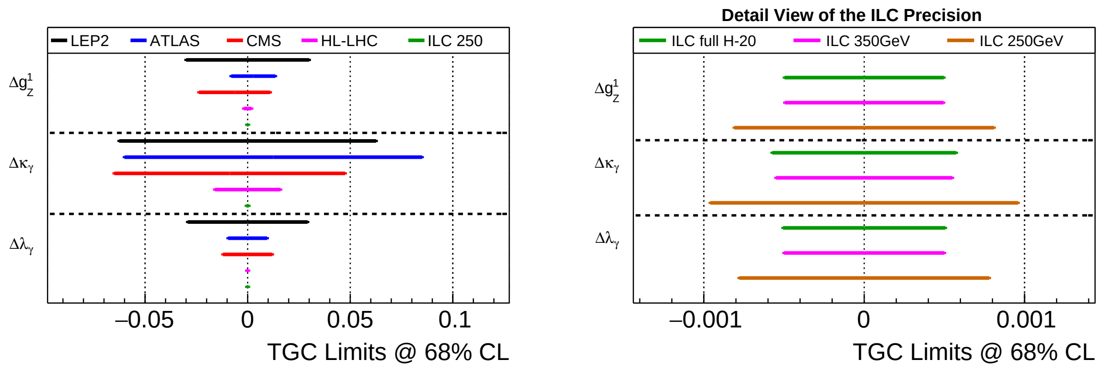

Figure 2: *Comparison of the reachable TGC precision of the ILC with LEP and LHC experiments. From [5].*

The simultaneous measurement of the beam polarization and the three TGCs g_1^Z, k_γ, λ_γ was studied using W-pair production in the semileptonic channel at $\sqrt{s} = 500$ GeV, and another study was done at a $\sqrt{s} = 1$ TeV. Both studies were performed with a full detector simulation of the ILD detector concept, and, due to the limited MC statistics available in full simulation, used only the information of three out of the five sensitive angles in a binned fit.

A full simulation study of TGC measurements at $\sqrt{s} = 250\,\mathrm{GeV}$ has not been yet finalized. Therefore, the existing full simulation results at 500 GeV and 1 TeV were extrapolated to lower center-of-mass energies, considering (i) the statistical scaling f_{stat} which is just given by the different cross sections and integrated luminosities, (ii) the change in actual sensitivity to the TGCs f_{theo}, which is assumed to scale with M_W^2/s, and (iii) a scaling factor f_{det} related to the energy dependence of the detector acceptance. The latter factor has been determined by the comparison between the 500 GeV and 1 TeV results. The final scaling factors are described in [5]. The results of the full simulation studies and the extrapolations are compared to LEP2 and LHC results as well as to HL-LHC projections in Fig. 2.

PoS(ICHEP2018)422

		total error ($\times 10^{-4}$)			correlation		
Exp	N_{par}	g_1^Z	κ_γ	λ_γ	$g_1^Z\ \kappa_\gamma$	$g_1^Z\ \lambda_\gamma$	$\kappa_\gamma\ \lambda_\gamma$
LEP 2	3	516	618	376	-0.17	-0.62	-0.15
ILC 250	3	4.4	5.7	4.2	0.63	0.48	0.35
LEP 2	1	300	626	292	–	–	–
LHC	1	319	1077	198	–	–	–
HL-LHC	1	19	160	4	–	–	–
ILC 250	1	3.7	5.7	3.7	–	–	–

Table 1: *TGC precisions for LEP 2, Run1 at LHC from ATLAS, HL-LHC and the ILC at $\sqrt{s} =$ 250 GeV with 2000 fb^{-1} luminosity (ILC 250). From [6].*

The additional relative improvement expected when moving from a 3-angle binned fit to an unbinned fit using all five angles (or an optimal observable technique) was estimated in a toy setup to be about a factor of 2. This was confirmed by extrapolating LEP2 results to higher center-of-mass energies. Considering this additional improvement, the currently most up-to-date ILC projections, which are also used in the EFT-based Higgs coupling fit [6] are summarized in Tab. 1, both for simultaneous extraction of all three couplings ($N_{par} = 3$), and for fixing two of them ($N_{par} = 1$) in order to compare to LHC.

Regardless of the exact assumptions in the extrapolation in can be concluded that constraints in the order of 10^{-4} can already be reached in the first stage of the ILC with $\sqrt{s} = 250$ GeV. This is roughly two orders of magnitude better than the current best limit on anomalous TGCs.

ACKNOWLEDGEMENTS: We would like to thank the LCC generator working group and the ILD software working group for providing the simulation and reconstruction tools and producing the Monte Carlo samples used in this study. This work has benefited from computing services provided by the ILC Virtual Organization, supported by the national resource providers of the EGI Federation and the Open Science GRID.

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] 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].

[3] 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].

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

[5] R. Karl, "Prospects for Electroweak Precision Measurements and Triple Gauge Couplings at a Staged ILC, 2017." , published in https://pos.sissa.it/314/763/ and references therein.

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

PoS(ICHEP2018)422