

## Production and electroweak couplings of 3rd generation quarks at the ILC

**Y. Okugawa<sup>\*a</sup>, A. Irlles<sup>b</sup>, V. Lohezic<sup>c</sup>, S. Amjad<sup>d</sup>, R. Yonamine<sup>a</sup>, F. Richard<sup>b</sup>,  
H. Yamamoto<sup>a</sup>, and R. Pöschl<sup>b</sup>**

<sup>a</sup>Tohoku University, 6-3 Aoba Aramaki-aza Aoba-ku, Sendai 980-8578, Japan

<sup>b</sup>Laboratoire de l'Accélérateur Linéaire, Bâtiment 200, 91440 Orsay, France

<sup>c</sup>University of Paris-Sud, 15 Rue Georges Clemenceau, 91400 Orsay, France

<sup>d</sup>University College London, Gower St, Bloomsbury, London WC1E 6BT, United Kingdom

E-mail: [okugawa@epx.phys.tohoku.ac.jp](mailto:okugawa@epx.phys.tohoku.ac.jp), [irles@lal.in2p3.fr](mailto:irles@lal.in2p3.fr),  
[victor.lohezic@u-psud.fr](mailto:victor.lohezic@u-psud.fr), [s.amjad@ucl.ac.uk](mailto:s.amjad@ucl.ac.uk),  
[yonamine@epx.phys.tohoku.ac.jp](mailto:yonamine@epx.phys.tohoku.ac.jp), [richard@lal.in2p3.fr](mailto:richard@lal.in2p3.fr),  
[yhitoshi@epx.phys.tohoku.ac.jp](mailto:yhitoshi@epx.phys.tohoku.ac.jp), [poeschl@lal.in2p3.fr](mailto:poeschl@lal.in2p3.fr)

The 3rd generation quarks are, due to their large mass, highly sensitive probes for new physics connected to the electroweak symmetry breaking. Linear  $e^+e^-$  colliders allow for clean measurements of heavy quark final states between the  $Z$ -Pole and the TeV scale, with sensitivities to different aspects of the manifestations of new physics in the extracted electroweak couplings. At the same time, these processes are ideal benchmarks for the optimization of detectors at linear colliders. This includes, for example, the event-by-event distinction between  $b$  and anti- $b$  quarks, which is indispensable for the proper measurement of differential observables. The contribution will outline with full simulation studies the capabilities of the ILD concept. An efficiency of 30% has been achieved for the charge measurements in  $b\bar{b}$  final states, which is about a factor three better than that presented earlier. We will also present new results using the fully hadronic  $t\bar{t}$  final state. Finally quantitative estimations of the reach in detecting the onset of new physics will be given.

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\*Speaker.

## 1. Introduction

The mass hierarchy of fermions cannot be explained within the Standard Model of particle physics. In particular, the top quark is the heaviest elementary particle known today with a mass comparable to the scale of electroweak symmetry breaking [1, 2]. Within the Standard Model the top and the bottom quarks form an iso-doublet and LEP experiments have reported an anomaly in the measurement of the forward-backward asymmetry  $A_{FB}^b$  that is still unresolved today [3]. Many models for physics beyond the Standard Model explain the mass hierarchy by the existence of extra dimensions implying, in particular, the modifications of the left and right handed electroweak couplings of the heavy quarks. A linear collider with polarized beams is the adequate tool to study the electroweak couplings of heavy quarks and to detect the onset of new physics.

At the International Linear Collider (ILC) [4], any anomaly in the coupling between heavy quarks, i.e. between top and bottom quarks, can be explored by studying the exchange of neutral vector bosons,  $Z^0$  and  $\gamma$ . The ILC will first run at  $\sqrt{s} = 250$  GeV, where pair production of  $b\bar{b}$  is abundant. Extension to  $\sqrt{s} = 500$  GeV allows the analysis of the  $t\bar{t}$  production. Through these channels, the asymmetry of electroweak couplings between vector bosons and heavy quarks with left or right handed polarization are investigated.

## 2. Results

To measure the forward-backward asymmetry ( $A_{FB}$ ) requires a precise reconstruction of the polar angle spectrum of the top quark pair. The individual results on  $A_{FB}$  of top and bottom is presented in this section. We studied two variants of ILD [5] - ILD-large and ILD-small - as benchmarks contributing to the ILD Design Report (IDR).

### 2.1 Top quark result

We study the semi-leptonic decays of the top quark pair, i.e.  $e^+e^- \rightarrow t\bar{t} \rightarrow bqq'bl\nu$ , where the decay into  $\tau$  leptons is ignored. Figure 1a shows the polar angle spectrum of the top-quark for left-handed electron beam polarization. The polar angle distribution of b quarks from the top quark decay is shown for the first time in the course of top quark production at  $e^+e^-$  colliders. This spectrum is more sensitive to detector effects than the  $t$  polar angle spectrum and it offers a physics potential as it is e.g. an analyzer of the top quark helicity. When the top quark is left-handed, b quarks are emitted primarily close to the flight direction of the top quark as a consequence of the  $V - A$  type interaction at the  $tbW$  Vertex. This is also apparent in Figure 2a, which demonstrates the similarity of the polar angle spectra of the top and bottom quarks. Top and anti-top quarks are distinguished by means of the isolated lepton, the vertex charge and the charge of the Kaons that are produced in the decay of B-mesons. We require opposite charges at the two respective secondary vertices associated to the decays of the b hadrons.

### 2.2 Bottom quark result

We present a study of  $e^+e^- \rightarrow b\bar{b}$  at 250 GeV that extends the study in [6] to an integrated luminosity of  $2000 \text{ fb}^{-1}$ . Being the iso-partner of the top, the  $b$  is likely to share sensitivities to new physics with the top quark. The different isospin and electrical charges render the polar angle

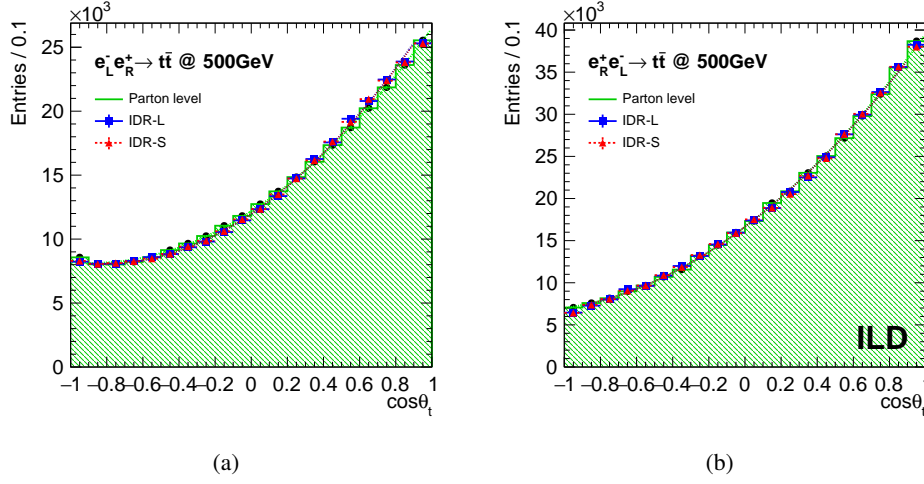


Figure 1: Pair produced top quark polar angle distribution is shown above with (a) left-handed and (b) right-handed polarized electron beam. Gray distribution shows the parton level distribution and the red (blue) points shows the reconstructed polar angle with the small (large) detector model.

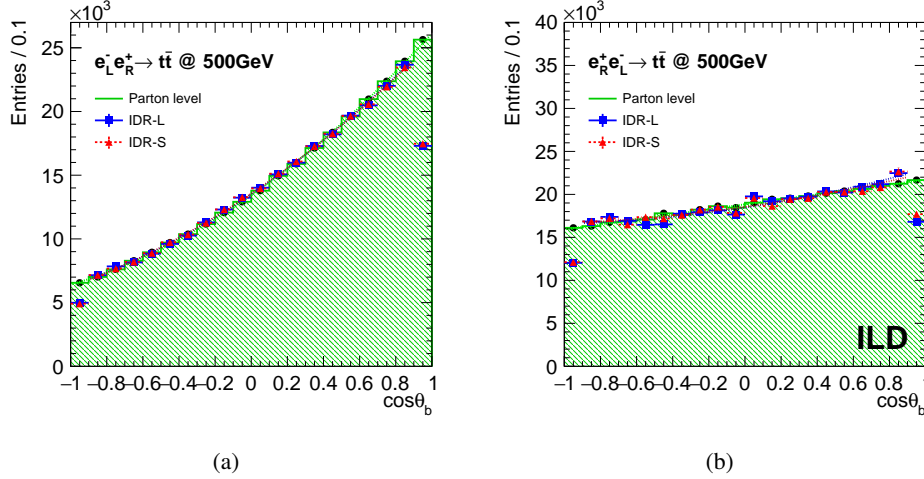


Figure 2: The polar angle distribution of b quarks from top decays is shown above with (a) left-handed and (b) right-handed polarized electron beam. The majority of the distribution agrees with parton level except in the regions closest to the beam-axis, where the power of the b-tagging drops.

Polarization	Left-handed	Events	Right-handed	Events
$A_{FB}^{Gen}$	0.329	1812768	0.430	376690
$A_{FB}^{Reco}$	0.342	277435	0.396	292271
Final Efficiency	30.6%		77.8%	

Table 1: The result of  $A_{FB}$  calculation and the final efficiencies for left and right handed top quark.

spectrum in the case of a left handed electron much steeper than what was the case for the top-quark. Note also that the shape changes drastically when going from the polarization configuration  $e_L^- + e_R^+$  to the configuration  $e_L^+ + e_R^-$ .

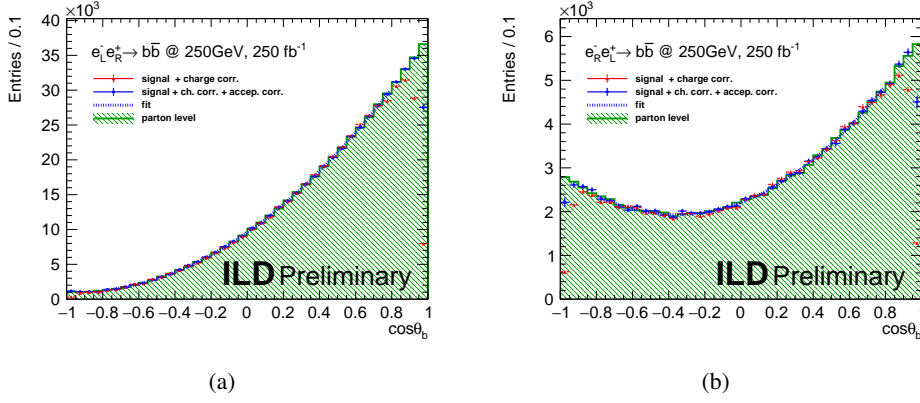


Figure 3: Pair produced  $b$  quark polar angle distribution is shown above with (a) left-handed and (b) right-handed polarized electron beam.

Polarization	Left-handed	Right-handed
$A_{FB}^{Gen}$	0.708	0.263
$A_{FB}^{Reco}$	0.708	0.266
Final Efficiency	30.0%	30.0%

Table 2: The result of  $A_{FB}$  calculation and the final efficiencies for left and right handed  $b$  quark

### 3. Conclusion

Studies of  $e^+e^- \rightarrow t\bar{t}$  at  $\sqrt{s} = 500$  GeV and  $e^+e^- \rightarrow b\bar{b}$  at  $\sqrt{s} = 250$  GeV are presented. Both channels require the measurement of the vertex charge and the Kaon charge to distinguish between the fermion and the anti-fermion. The semi-leptonic top-quark decay offers the isolated lepton as an additional handle. In case of the semi-leptonic top-quark channel, 30% and 77% reconstruction efficiency were obtained for left and right handed electron beam polarization, respectively. The presented results lay the foundation for a precise determination of electroweak couplings of top and bottom quarks well below the 1% level. The extraction of the couplings is left for future studies.

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