Studies of $e^+e^- \to b\bar{b}$ channel at the International Linear Collider

Final word on LEP A^b_{FB} anomaly

BILOKIN S., PÖSCHL R., RICHARD F.

Laboratoire de l'Acceleráteur Linéare

bilokin@lal.in2p3.fr

Abstract

The heavy quark doublet plays a central role in the quest for new physics. The complementary between studies of electroweak top quark production and bottom quark production is therefore intuitively clear and pointed out in the literature. Let us remind that the tension between the LEP measurement and the Standard Model prediction of the forward-backward asymmetry A^b_{FB} is still one of the unsolved questions in the field and may be interpreted as a first manifestation of new physics in the heavy quark sector. The process $e^+e^- \to b\bar{b}$ at the ILC offers a unique opportunity for a final word on the tension. Polarised beams allow for a large disentangling of the coupling constants or form factors that govern the $Z^0/\gamma b\bar{b}$ vertex.

This poster presents a detailed simulation study of the process $e^+e^- \to b\bar{b}$ at 250 GeV with the ILD Detector. Besides the phenomenological implications, the studies demonstrate that with a careful analysis of the final state the charge of the b-quarks can be determined on an event-by-event basis with the ILD Detector. Such a capability is unprecedented by past and present particle physics experiments.

Introduction

So far, LEP I has 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 at three standard deviation away from the very precise value from SLD using beam polarization [1]. 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 [2], with polarized 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 may turn up 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. Recall that the LEP I anomaly can be interpreted up to a sign ambiguity for what concerns the righthanded coupling $Z^0 b\bar{b}$, referred hereafter as g^Z_R, which shows the largest deviation [3].

The $e^+e^- \to b\bar{b}$ channel is studied at $\sqrt{s} = 250$ GeV using full simulation of the ILD experiment. The high-granularity of the ILD subdetectors allows for an individual particle reconstruction using the Particle Flow approach. The schematic view of the ILD concept and the subdetector layout is given in Fig. 1.

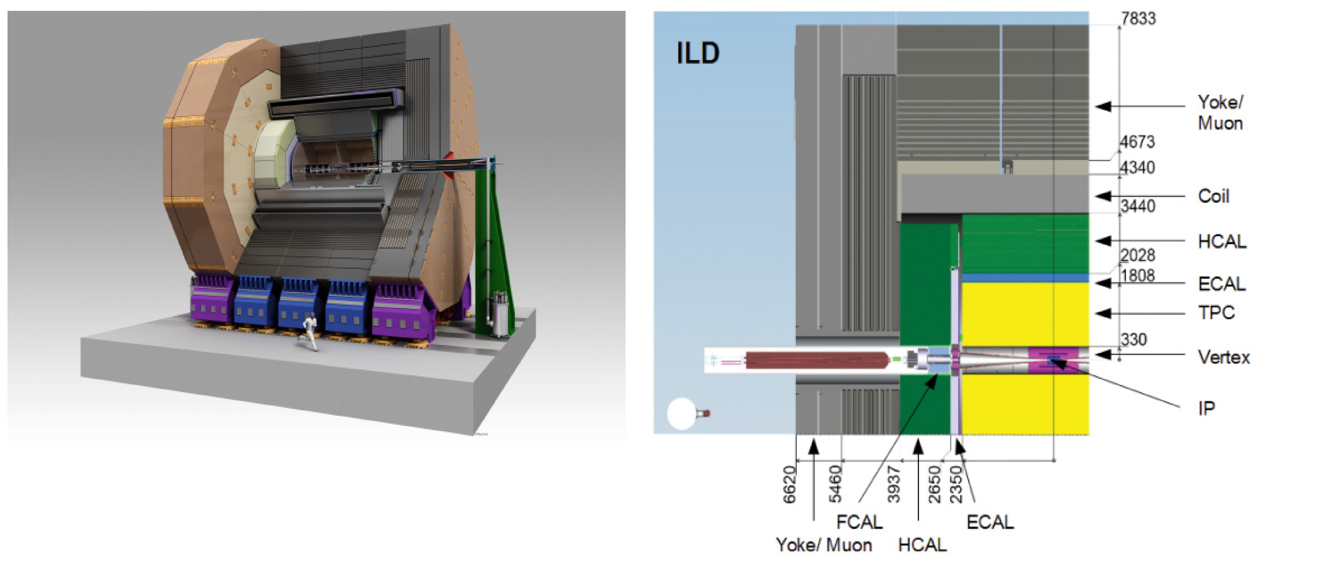

Figure 1: *Schematic view of the ILD concept [2].*

The Vertex Detector (VXD) has 3 double layers equipped with silicon pixels, which allows for an excellent accuracy of the track impact parameter measurement. This enables a highly efficient b- and c-tagging of the jets and a detailed b-hadron vertex reconstruction. The central tracker of the ILD detector is Time Projection Chamber (TPC), which provides up to 224 points per track and allows dE/dx-based particle identification.

The main goal of the study is to reconstruct the b-quark polar angle distributions for both beam polarization cases. These histograms are used to determine the precision on the b-quark electroweak couplings, which are compared to the LEP I anomaly.

B-quark charge measurement

The b-quark polar angle reconstruction requires an accurate b-quark charge measurement. The b-quark charge is identified using two basic signatures:

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

Sometimes, the vertex reconstruction algorithms may fail and lose one or several particles form reconstructed b-hadron vertices. This leads to a wrong vertex charge measurement. The reasons behind the missing b-hadron particles are connected to reconstruction shortcomings or to a low momentum or a low offset of the b-hadron particles. The developed Vertex Charge Recovery procedure enhances the vertex charge purity by adding the missing particles back to the reconstructed vertices.

The kaon identification is possible using the TPC dE/dx information. After equalizing the dE/dx in angular spectrum, the kaons from b-hadron vertices can be identified with 97.% purity and 87% efficiency. However, the $B - \bar{B}$ oscillations will degrade the kaon charge signature purity for neutral b-hadrons.

The plots of the vertex charge purity and the dE/dx as function of particle momentum for different hadrons are shown in Fig. 2.

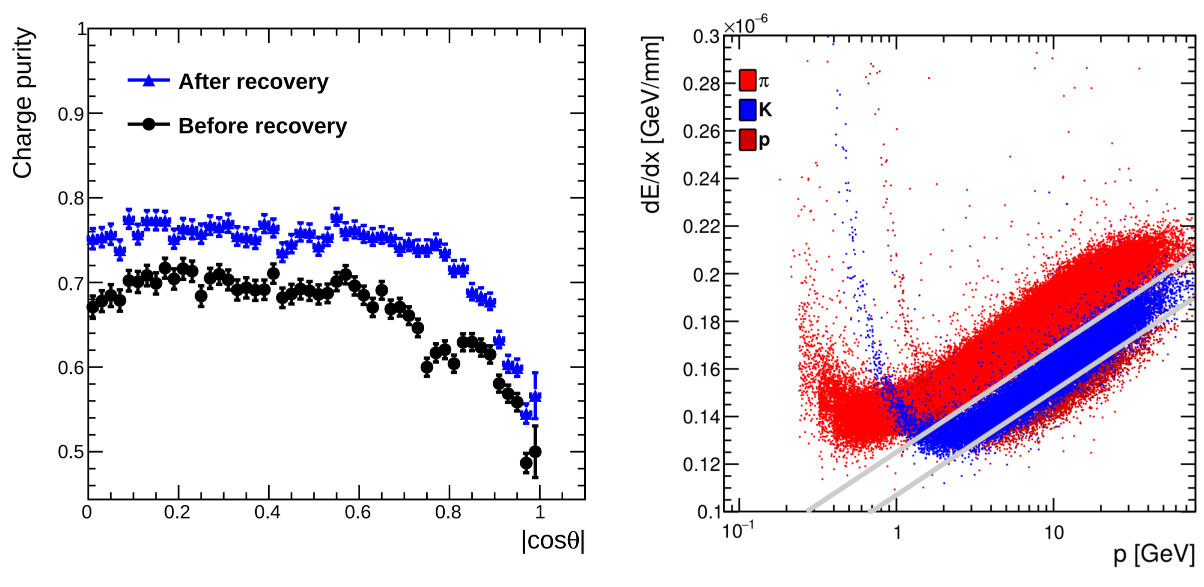

Figure 2: *Vertex charge purity as function of $\cos\theta$ (left) and energy deposition per unit of length dE/dx as function of particle momentum p (right).*

B-quark polar angle reconstruction

The reconstructed b-quark polar angle distributions at $\sqrt{s} = 250$ GeV using a combination of kaon and vertex charge signatures are demonstrated in Fig. 3.

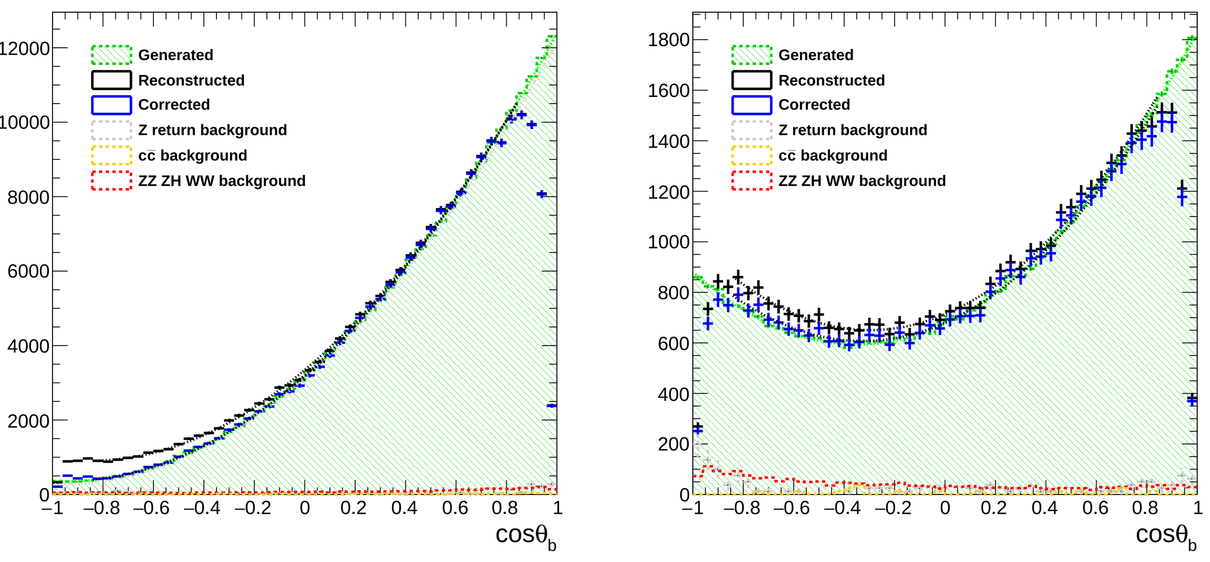

Figure 3: *Generated b-quark polar angle distribution compared to the final reconstructed b-quarks polar angle in left-handed case (left) and right-handed case (right) with overlaid background processes.*

The kaon and vertex charge purity is defined using the measured events with misreconstructed charges. Using the measured purities, the reconstructed spectrum is corrected using a data-driven procedure. The background contribution is small. The distributions are fitted by the general cross section function, defined as

$$S(1+\cos^2\theta) + A\cos\theta, \qquad (1)$$

where the fitted S and A parameters are proportional to the total cross section and A^b_{FB} respectively. The b-quark elecroweak couplings are derived using the fitted parameters.

Interpretation

The relative precisions on the $Z^0 b\bar{b}$ couplings, g^Z_L and g^Z_R, for the LEP I measurements and for the expected ILC performance are shown in Fig. 4.

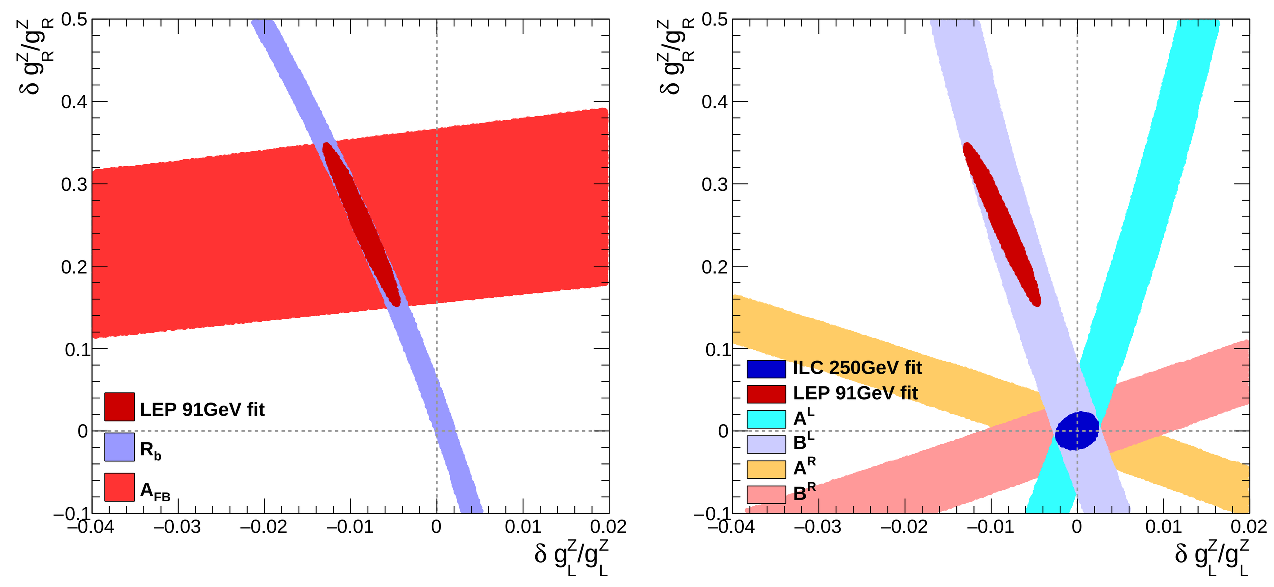

Figure 4: Tree level $\pm 1\,\sigma$ allowed regions defined by the forward-backward asymmetry and total cross section measurements at LEP (left) and ILC via the differential cross section fit (right). Dashed guidelines show the Standard Model value. The allowed region expected at the ILC is centered at Standard Model values of couplings.

Conclusions

- Pellentesque eget orci eros. Fusce ultricies, tellus et pellentesque fringilla, ante massa luctus libero, quis tristique purus urna nec nibh. Phasellus fermentum rutrum elementum. Nam quis justo lectus.
- Vestibulum sem ante, hendrerit a gravida ac, blandit quis magna.
- Donec sem metus, facilisis at condimentum eget, vehicula ut massa. Morbi consequat, diam sed convallis tincidunt, arcu nunc.
- Nunc at convallis urna. isus ante. Pellentesque condimentum dui. Etiam sagittis purus non tellus tempor volutpat. Donec et dui non massa tristique adipiscing.

Forthcoming Research

Vivamus molestie, risus tempor vehicula mattis, libero arcu volutpat purus, sed blandit sem nibh eget turpis. Maecenas rutrum dui blandit lorem vulputate gravida. Praesent venenatis mi vel lorem tempor at varius diam sagittis. Nam eu leo id turpis interdum luctus a sed augue. Nam tellus.

References

[1] M. Baak, J. Cth, J. Haller, A. Hoecker, R. Kogler, K. Mnig, M. Schott, and J. Stelzer. The global electroweak fit at NNLO and prospects for the LHC and ILC. *Eur. Phys. J.*, C74:3046, 2014.

[2] T. Behnke, J. E. Brau, B. Foster, J. Fuster, M. Harrison, J. M. Paterson, M. Peskin, M. Stanitzki, N. Walker, and H. Yamamoto. The International Linear Collider Technical Design Report - Volume 1: Executive Summary. 2013.

[3] A. Djouadi, G. Moreau, and F. Richard. Resolving the A^b_{FB} puzzle in an extra dimensional model with an extended gauge structure. *Nucl. Phys.*, B773:43–64, 2007.

Acknowledgements

Etiam fermentum, arcu ut gravida fringilla, dolor arcu laoreet justo, ut imperdiet urna arcu a arcu. Donec nec ante a dui tempus consectetur. Cras nisi turpis, dapibus sit amet mattis sed, laoreet.