PROCEEDINGS OF SCIENCE

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

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The top and bottom quarks plays a central role in the quest for new physics. The complementarity between studies of electroweak top quark production and bottom quark production is therefore intuitively clear and pointed out in the literature. 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.

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1. Introduction

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 [1] away from the very precise value from SLD using beam polarisation, see Fig. 1. Redoing precisely this measurement is therefore a priority for future e^+e^- colliders.

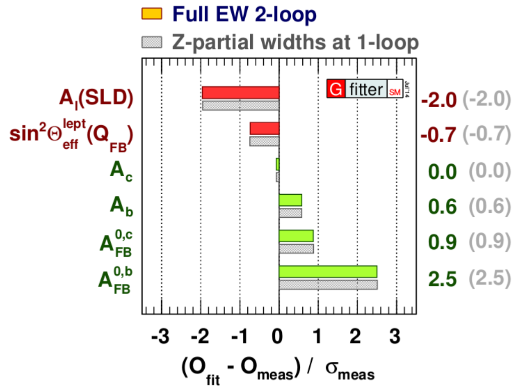


Figure 1: *Deviations of the electroweak precision observables in the Standard Model. Extracted from [1].*

In this study, we intend to prove that the International Linear Collider (ILC) [2], 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 [3]. 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 [4].

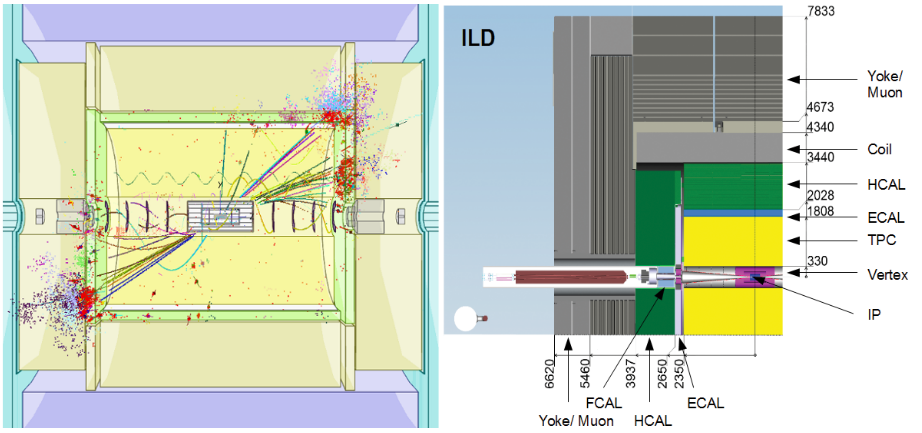


Figure 2: *Example of the event display of the $e^+e^- \to b\bar{b}$ process in a full simulation of the ILD detector (left) and schematic view of the ILD concept [5] (right).*

In this work, the $e^+e^- \to b\bar{b}$ channel is studied at $\sqrt{s} = 250\,\mathrm{GeV}$ using full simulation of the ILD experiment [5], which include beam spectrum and initial state radiation modelling. The high-granularity of the ILD subdetectors allows for an individual particle reconstruction using the Particle Flow approach [6]. The schematic view of the ILD concept and the subdetector layout is presented in Fig. 2.

2. *b*-quark charge sign assignment

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.

Figure 3 shows a schematic view of a b-hadron decay-chain as seen in the ILD vertex detector.

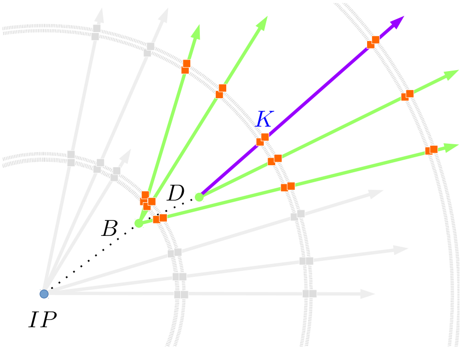


Figure 3: *Illustration of b-hadron decays.*

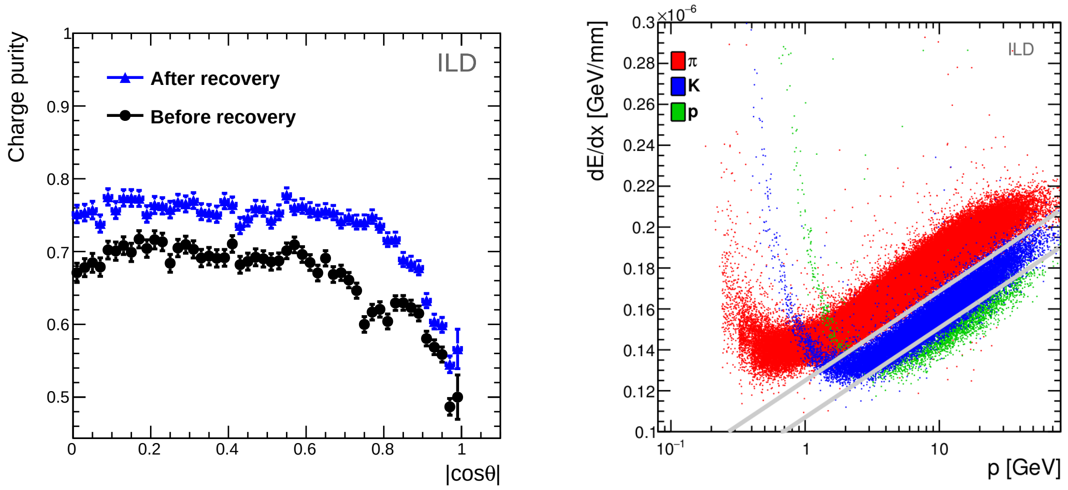
It was found that vertexing algorithms can miss one or more *b*-hadron decay particles from the reconstructed vertices, which decreases the purity of the reconstructed vertex charges. A vertex recovery procedure has been developed to identify the missed tracks and to add them back to the vertices. Figure 4a shows that this improves the vertex charge reconstruction considerably.

The charged kaons are identified using the specific energy-loss dE/dx in the TPC. After correcting for the angular dependence of dE/dx, 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 plots of the dE/dx as function of particle momentum for different hadrons are shown in Fig. 4b.

3. *b*-quark polar angle spectrum

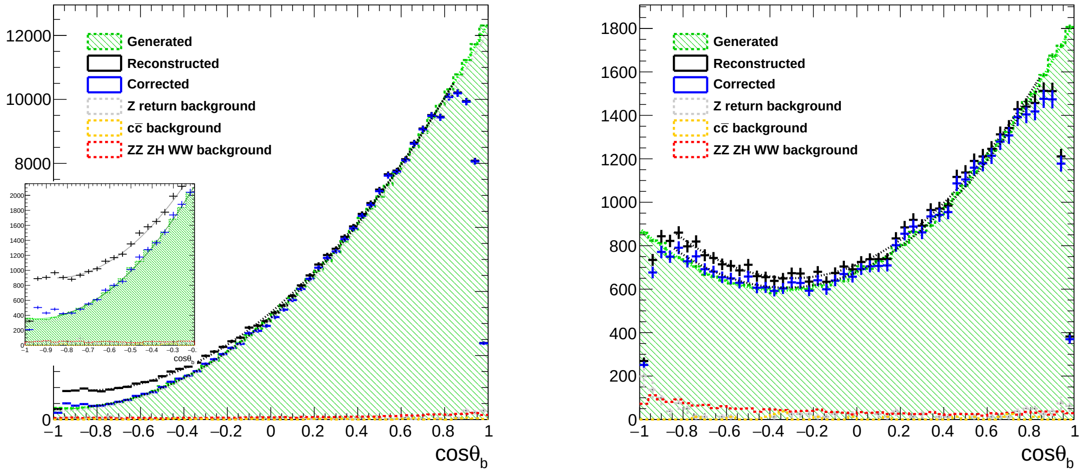
The reconstructed *b*-quark polar angle distributions at $\sqrt{s} = 250\,\mathrm{GeV}$ using a combination of kaon and vertex charge signatures are shown in Fig. 5. The integrated luminosity $\mathscr{L}_I = 250\,\mathrm{fb}^{-1}$ is assumed for each beam polarisation.

The events with reconstructed kaon or vertex charges, which are incompatible between jets, allow to define the kaon and vertex charge purity in-situ. Using the in-situ purities, the reconstructed



(a) (b)

Figure 4: *Vertex charge sign assignment purity as function of $|\cos\theta|$ (left) and energy deposition per unit of length dE/dx as function of particle momentum p (right).*



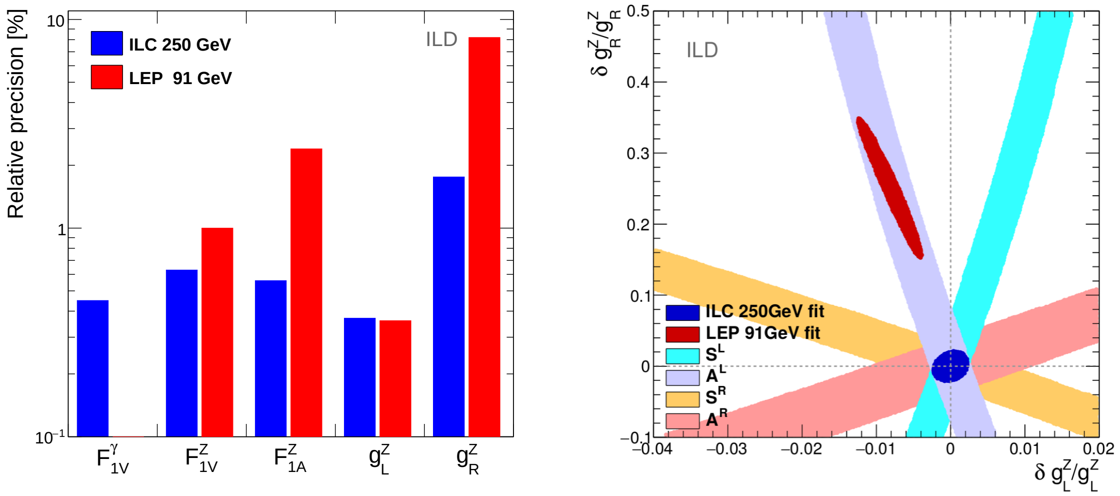
(a) (b)

Figure 5: *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.*

spectrum is corrected using a data-driven procedure. 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. 5, the contribution of the diboson background processes is small.

4. Interpretation

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. 6. 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.



(a) (b)

Figure 6: *Comparison of the LEP measurements to the expected precision at the ILC. The results of the ILC assume an integrated luminosity of $\mathcal{L}_{\mathcal{I}} = 500$ fb^{-1} shared between beam polarizations at $\sqrt{s} = 250$ GeV.*

Conclusions

- The developed procedure of the b-quark charge reconstruction allows for measuring the b-quark polar angle. The residual impurity is corrected by a data-driven procedure;
- The b-quark polar angle fit allows for an independent determination of four electroweak couplings of the b-quark. The fit can be extended to also include a term proportional to $\sin^2\theta$, giving access to an independent determination of the tensorial couplings;
- 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.

Forthcoming Research

The b-quark charge technique can be applied to the fully hadronic $t\bar{t}$ decays and combine the results with semileptonic $t\bar{t}$ channel. The kaon charge method can be extended on the c-quark polar angle analysis, where one can improve on the LEP I results on the c-quark couplings precision.

Acknowledgements

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