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


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## Introduction

The heavy quarks have mass regime comparable to the electroweak vacuum expectation value. Top quark, in particular, has higher mass than those for the massive gauge boson. Its partner quark, bottom quark, also showed its properties on deviation from the current framework of the Standard Model. Therefore, the precise measurements on the heavy quark properties is essential for the indirect searches of the new particle beyond the Standard Model predictions to differentiate them from the various other theories.

## Theory

Pair production of fermions through electroweak interactions is proceeded with interacting neutral vector bosons, photon and $Z^0$.

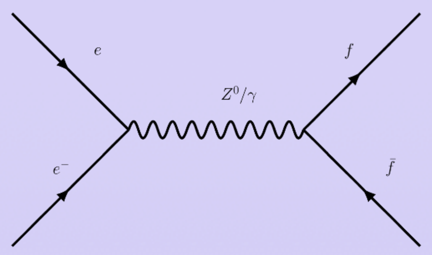

**Figure 1** *Feynman diagram for quark pair production at e+e- collision through $Z^0/\gamma$ for the Leading Order.*

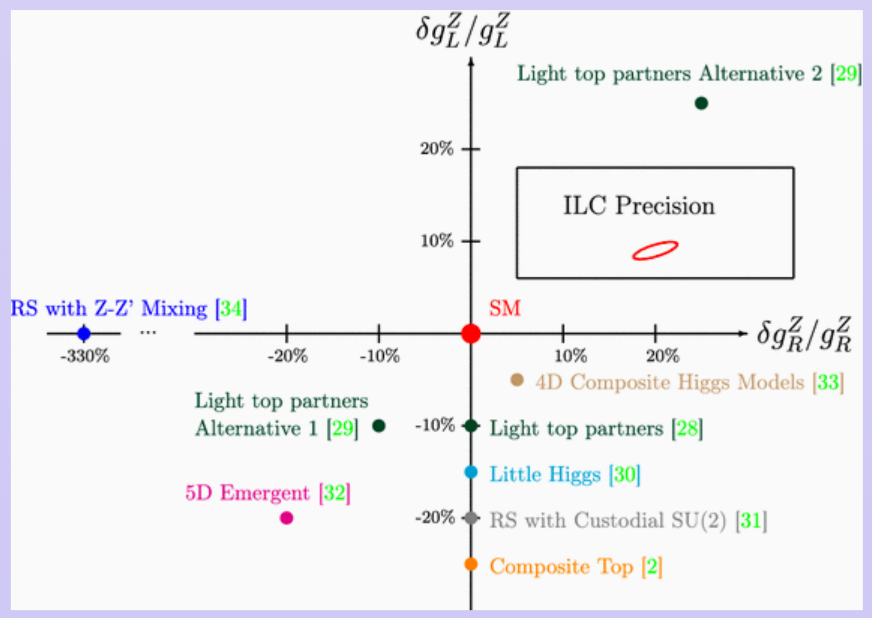


**Figure 2** *Deviation of ttZ coupling for right and left handed top quark. [1]*

### Form Factors

Anomaly in electroweak coupling between neutral vector boson and the fermion pairs are prominent especially among heavy quarks. This quantity can be deduced from the current at the ffZ vertex, which can be expressed in terms of axial form factors, $\mathscr{F}^I_{1,2V}$

$$\mathscr{L}_{int} = \frac{g}{2\sqrt{2}}\bar{\Psi}\gamma^\mu(1-\gamma^5)W^\pm_\mu\Psi + \frac{g}{2\cos\theta_w}\bar{\Psi}\gamma^\mu(g_V - g_A\gamma^5)Z_\mu\Psi \quad (1)$$

$$A^I_{FB} = \pm\mathscr{A}N_c\frac{3\beta\mathscr{F}^I_{1A}(\mathscr{F}^I_{1V}+\mathscr{F}^I_{2V})}{\sigma^I_{total}} \quad (2)$$

where $\mathscr{A} = 4\pi\alpha^2/3s$, with α as the electromagnetic running coupling, $N_C$ is number of quark colors. Therefore it is essential to precisely measure the observable $A^I_{FB}$.

### $A_{FB}$ Calculation

Observable we measure from this investigation is forward-backward asymmetry, $A_{FB}$.

$$A_{FB} = \frac{N(\cos\theta > 0) - N(\cos\theta < 0)}{N(\cos\theta > 0) + N(\cos\theta < 0)} \quad (3)$$

where *N* is the number of events either in the forward or backward direction respect to the electron beam, and *θ* is measured from the beam direction.

## ILC & ILD

### International Linear Collider

- Linear ee collider with 20 km.
- Center of mass energy of 250 GeV. Extension of the linac will enable us to achieve 500 GeV and beyond.
- Beam polarization also plays important role for enhancing the precision measurements!!

### International Large Detector

- High tracking efficiencies.
- Great ability in vertex identification both for primary and secondary vertices.
- Excellent beam IP constraints.
- Two different models, small (s5) and large (l5) are considered.

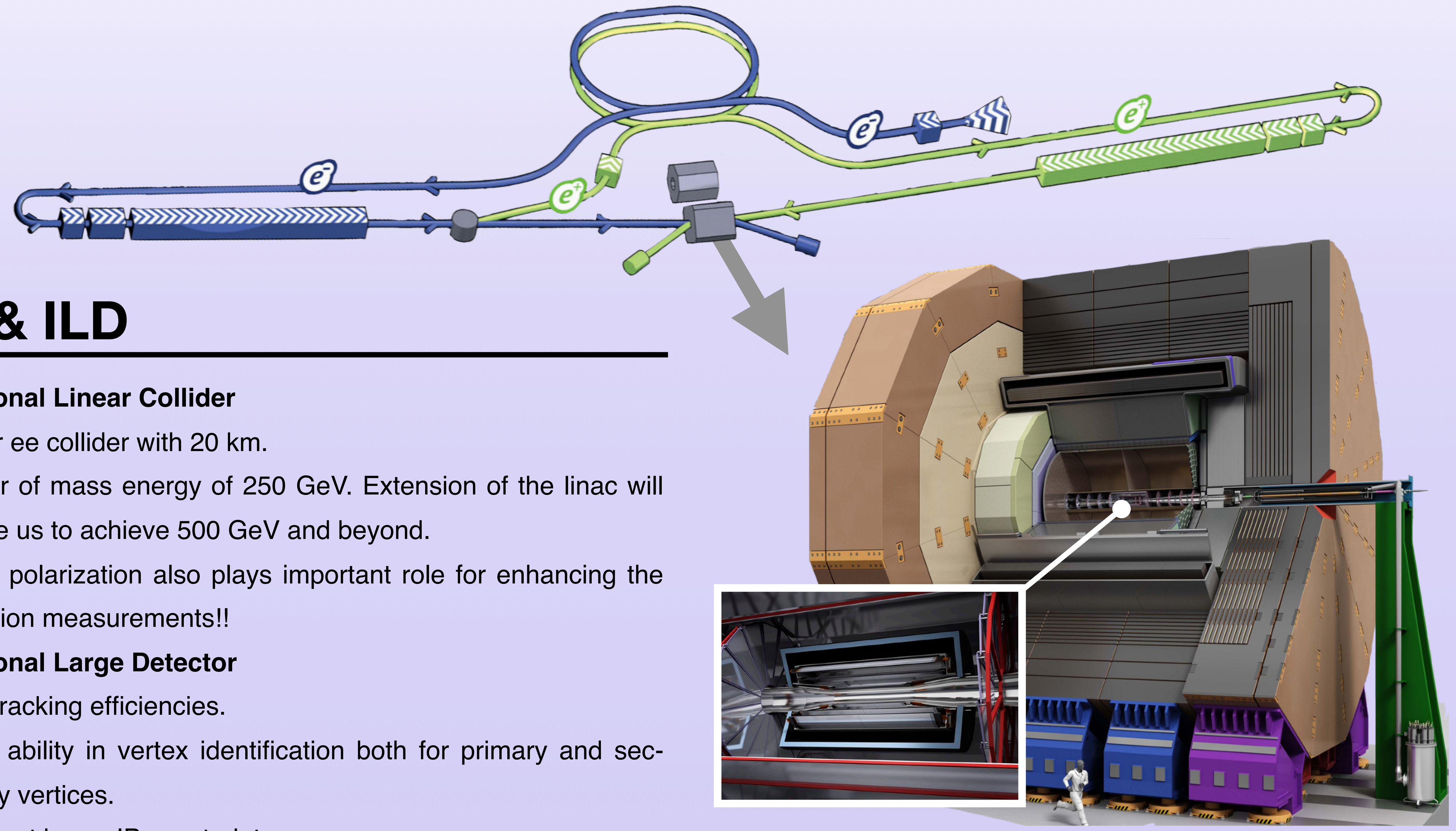

**Figure 3** *Schematics of the ILC (top left) and ILD (bottom right). Vertex detector resides at the center of the ILD which allows us to precisely measure the vertex positions.*

## Vertex Charge Measurement

Vertex charge information is computed as sum of reconstructed particle charges, associated to the reconstructed vertices, which belongs to the associated jets.

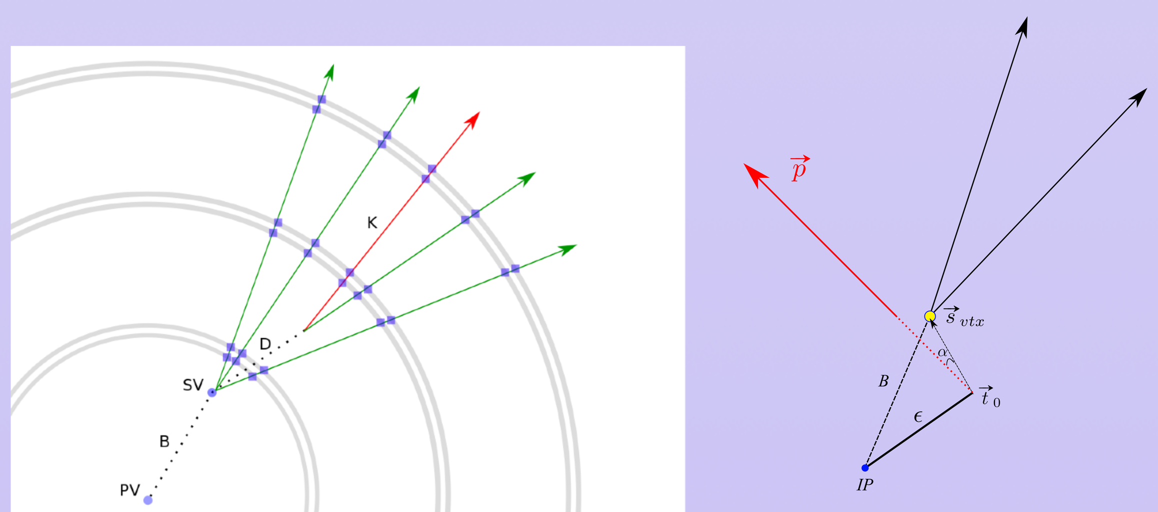

**Figure 4** *Schematic diagram of the disintegration of B hadron (left) within ILD. Right diagram shows the restoration process of secondary vertex using track information.*

### Vertex Charge Recovery

Prongs inside the jets get missing upon particle reconstruction, even when there's a track information involved. Vertex restorer takes this track information and add to the list of particles when reconstructing vertices.

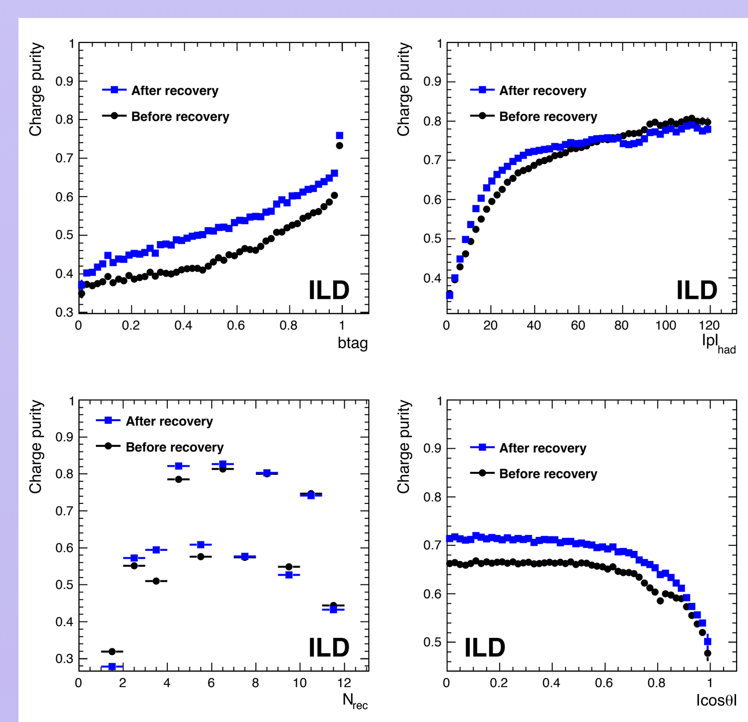

**Figure 5** *Comparison of b quark charge identification purity between before (blue) and after (black) the vertex restoration, by varying different btag, hadronic momentum, number of prongs and the polar angle.*

## Kaon Identification

Charges of kaons, which are disintegrated from b-jets, are also used to identify qq. This information will extracted by comparing dE/dx distributions of generated and reconstructed kaons.

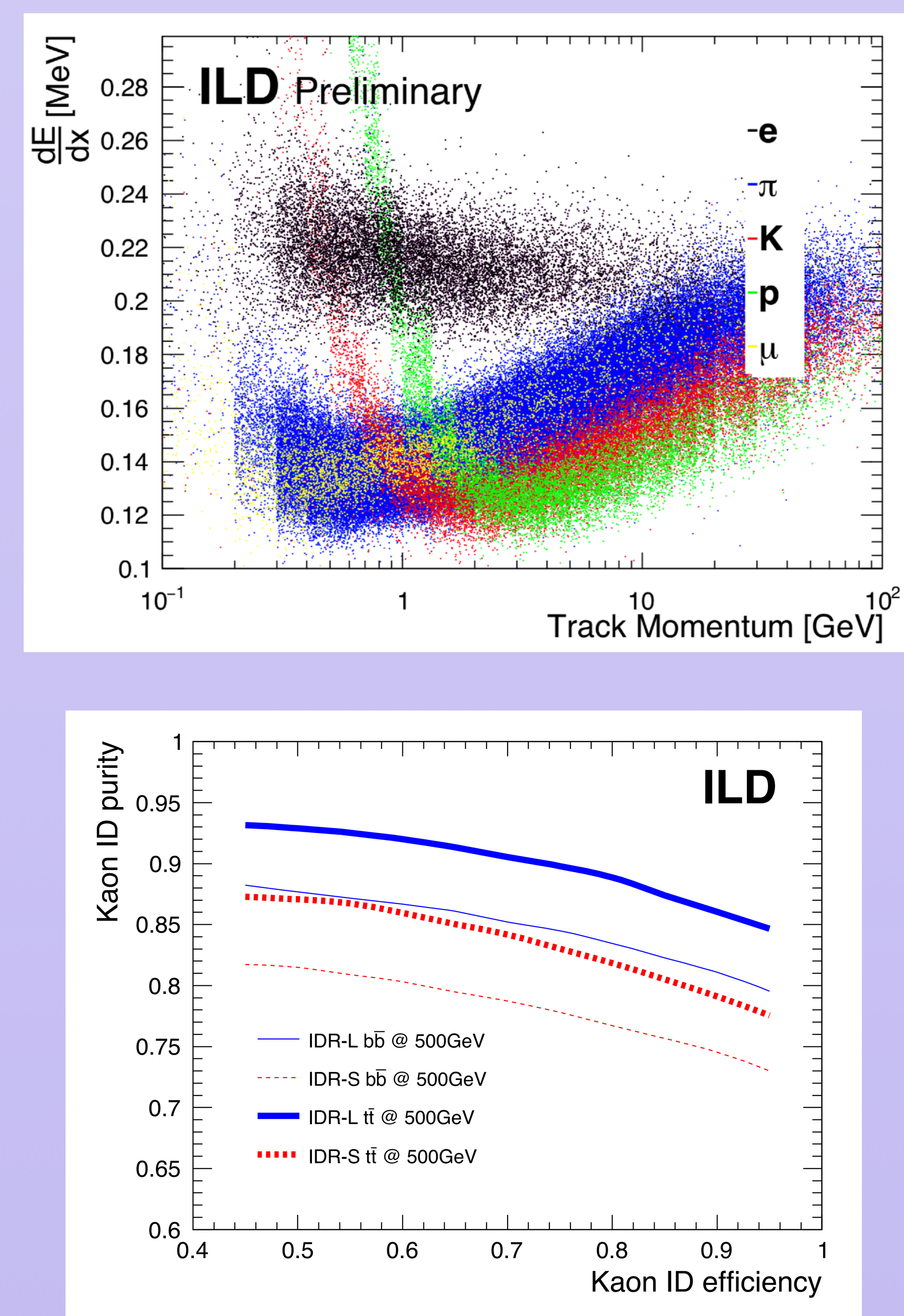


**Figure 6** *dE/dx distribution of pion, kaon and proton are shown (top). Bottom plot shows how purity of kaon selection evolve by varying kaon ID efficiency.*

## Results

### Top Pair Production

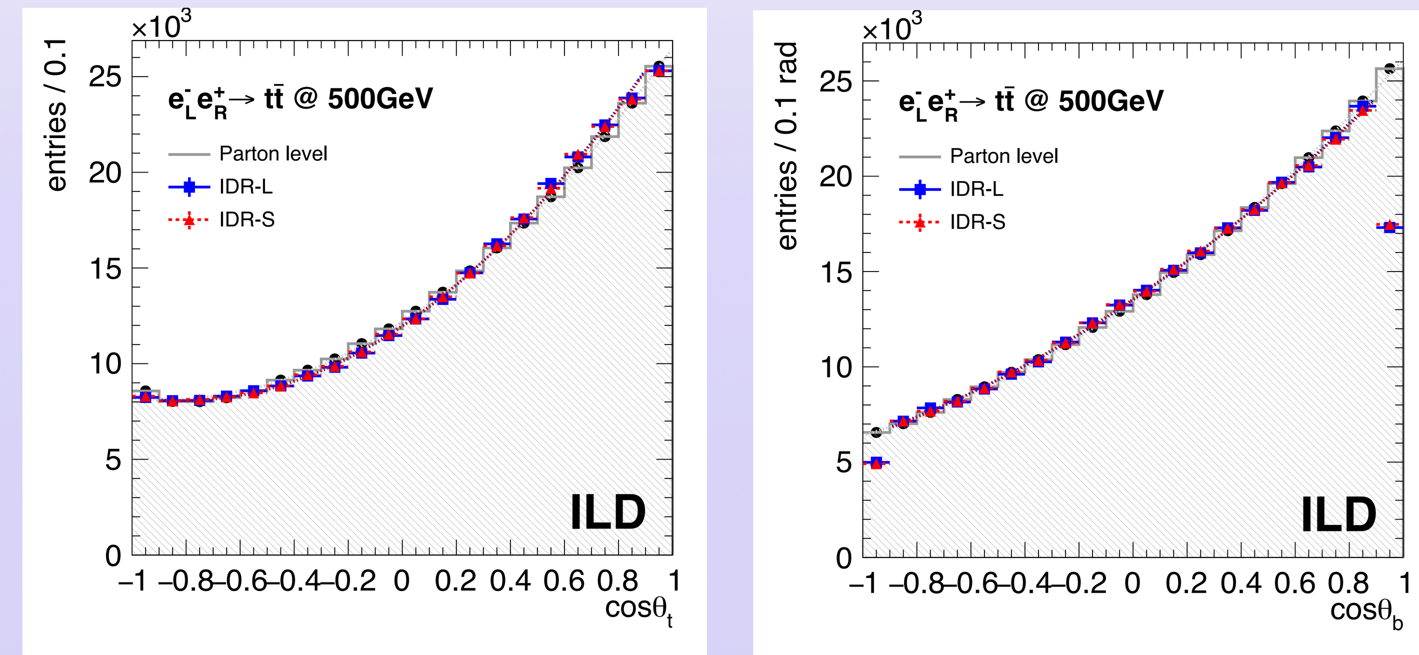

**Figure 7** *Polar angle distributions for left-handed top quarks (left) and its decay product, bottom quarks (right) is presented. Both of which are scaled with its efficiencies.*

### Bottom Pair Production

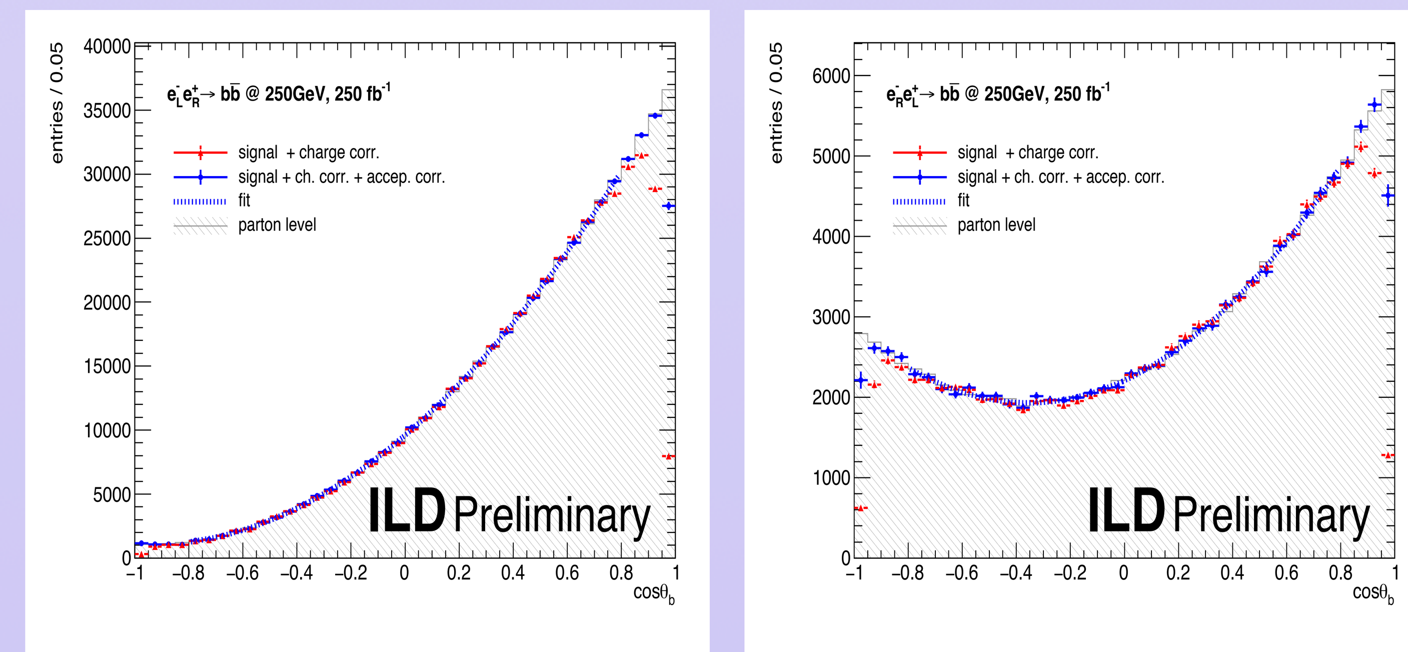

**Figure 8** *Polar angle distributions for left-handed (left) and right-handed (right) bottom quarks.*

### Final Results

| | $t\bar{t}$ | $b\bar{b}$ |
|---|---|---|
| $A_{FB}$ Gen | 0.329 | 0.708 |
| $A_{FB}$ Reco | 0.342 | 0.708 |
| Final Efficiency | 30.6% | 30.0% |

**Table 1** *Result for AFB calculation for both generated and reconstructed particles are presented. Final efficiency shows the efficiency after event selection.*

## Conclusion

Reconstruction of bottom and top quark pair charges at ILC for both 250 GeV and 500 GeV scenario was done. Vertex Charge Recovery algorithm was implemented to assist the purity of the b and top charge. As a result, 30% of reconstruction efficiencies were achieved for both top and bottom pair production.

## Reference


[1] F. Richard, Present and future constraints on top EW couplings. arXiv: 1403.2893 [hep-ph]

[1] Abramowicz, Halina, and etal. The International Linear Collider Technical Design Report - Volume 4: Detectors arXiv:1403.2893 [hep-ph]


## Acknowledgement


*On behalf of the ILD Group*