Strange Quark Pair Production in High Energy Electron Positron Collisions

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The process $e^+e^- \to q\bar{q}$ with $q\bar{q} = s\bar{s}, c\bar{c}, b\bar{b}, t\bar{t}$ plays a central role in the physics programs of high energy electron-positron colliders operating from the $\mathcal{O}$(100 GeV) to $\mathcal{O}$(1 TeV) center of mass energies. Furthermore, polarised beams as available at the International Linear Collider (ILC) are an essential feature for the complete measurement of the helicity amplitudes that govern the production cross section. Quarks, specially the heaviers, are likely messengers to new physics and at the same time they are ideal benchmark processes for detector optimisation. All four processes call for superb primary and secondary vertex measurements, a high tracking efficiency to correctly measure the vertex charge and excellent hadron identification capabilities. We will show with detailed detector simulations of the International Large Detector (ILD) that production rate and the forward backward asymmetries of the the different processes can be measured at the 0.1% - 0.5% level and how systematic errors can be controlled to reach this level of accuracy. The importance of operating at different center of mass energies and the discovery potential in terms of Randall-Sundrum models with warped extra dimensions will be outlined.

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1. Introduction

Ever since the discovery of Higgs boson in 2012, the mass hierarchy of fermions was left to be explained within the framework of the Standard Model. Top quark, for example, has the heaviest mass among all the other quarks, which lies on a scale comparable to the vacuum expectation value of electroweak symmetry breaking. Such investigation requires precise measurements on the coupling between fermion pair and a weak boson, and can be measured by seeking forward and backward asymmetry as an observable (A_{FB}). The measurement of electroweak coupling for $e^+e^- \to s\bar{s}$ process is essentially an extension of such analysis to the lighter quark.

International Linear Collider (ILC) [1], is a perfect experiment to conduct such investigation, which is expected to run at the center of mass energy of 250 GeV at the beginning. It does not suffer from the synchrotron radiation, and initial states of electron and positron beams can be controlled by beam polarization. ILC can also make a full use of Particle Flow Objects (PFO) which is an object created by the particle flow algorithm, which attempts to reconstruct individual final state particle from the detector records. After the run at the 250 GeV, the accelerator will be extended to achieve the energy of 500 GeV and beyond. Through these channels, the asymmetry of electroweak coupling between vector bosons and heavy quarks with left handed electron beam polarization is investigated.

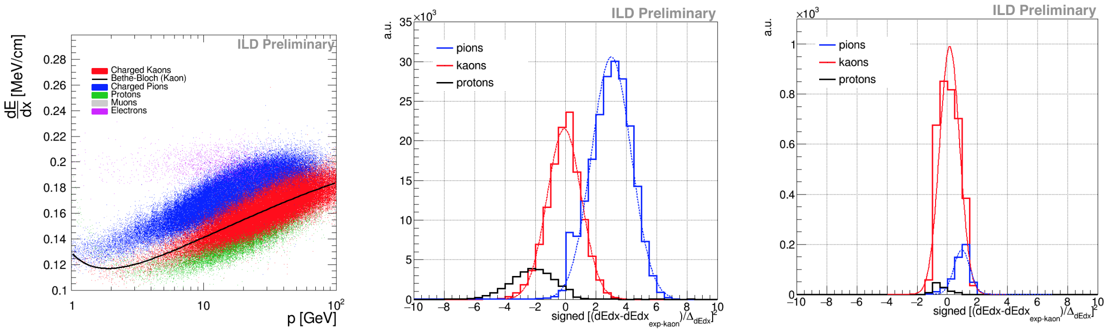
2. Methods

$s\bar{s}$ process has a characteristic, where it will mostly hadronize into a pair of kaons. This is advantageous compared to the other fermion pair production process, as each jet in the process will possess less constituents, which gives us less ambiguity upon selecting kaons to reconstruct $s\bar{s}$. This essentially demonstrates the significance of using the Time Projection Chamber (TPC) [2], since kaon identification requires information on ionization energy loss of each particle, also known as dE/dx. For the analysis step, the particle with highest momentum among the constituents inside the jet is chosen at the beginning, which is called the leading PFO (LPFO). Consequently, the identification of this particle as a charged kaon is performed using dE/dx and compare its charge with the other one from the opposite hemisphere. These charges should be opposite to one another. In order to identify the particle as kaon, we defined the following parameter (2.1) as dE/dx distance.

$$\text{dE/dx distance} = \text{signed}\left[\left(\frac{(dE/dx - dE/dx_{exp-Bethe})}{\Delta_{dE/dx}}\right)^2\right] \tag{2.1}$$

where $dE/dx_{exp-Bethe}$ is dE/dx value expected from Bethe-Bloch formula, $\Delta_{dE/dx}$ is statistical error for dE/dx measurements, and the +/- sign that was lost upon squaring the quantity will be retained afterwards (thus "signed"). Each PFO has 3 dE/dx distance parameters, i.e. dE/dx distance from proton, pion and kaon Bethe-Bloch formulae. In order to maximize the purity for the kaon identification, we required kaon dE/dx distance is smaller than those for proton and pion.

In this analysis, we simulated $e^+e^- \to s\bar{s}$ production at high effective center of mass energy, 250 GeV, with integrated luminosity of 100 fb^{-1}. Full Geant4 detector simulation of the ILD was used in this analysis.

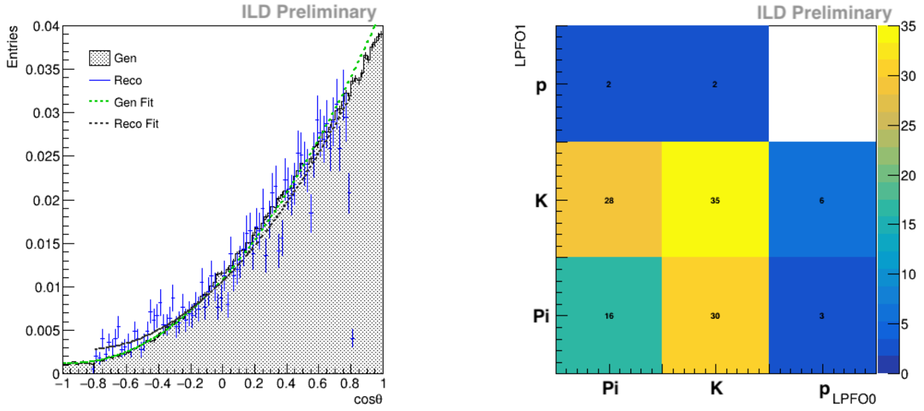


(a) (b) (c)

Figure 1: Left shows dE/dx plotted against momentum for each particle ($e, \mu, K^{\pm}, p, \pi$), middle plot shows those dE/dx distances from kaon Bethe-Bloch formula, and right plot shows after the minimizing particle dE/dx distance to kaon Bethe-Bloch formula

3. Results

Precise reconstruction of angle spectrum of the $s\bar{s}$ is necessary for the precision measurement of the A_{FB}. In this analysis, we used K^- polar angle to estimate the original s quark flight direction.



LPFO1 \ LPFO0	Pi	K	p
p	2	2	
K	28	35	6
Pi	16	30	3

(a) (b)

Figure 2: Polar angle distribution of LPFOs after the selection (left) and true PDG information of LPFO with wrongly reconstructed charge (right). Note that due to the TPC detector acceptance (# of hits), there is little to no sensitivity at the forward region. ($|\cos\theta| > 0.8$)

In the final results we have calculated the purity to be 85% after using the reconstruction method we used, as well as the polar angle distribution which is vital distribution to seek the forward and backward asymmetry parameter. The purity here is defined as ratio of correctly identified charged kaons among the total number of reconstructed leading kaons (3.1). The charged kaons are regarded as correctly identified if its flight direction coincide with those of generated $s\bar{s}$.

$$\text{purity} = \frac{\text{\# of correctly identified K}^{\pm}}{\text{Total \# of Leading K}} \tag{3.1}$$

There are also few events where the kaon candidates failed to reconstruct its original MC charge. We also focused on such events to get an idea on what are the problems that causes the migration. Migrated event happens when the LPFO satisfies the selection criteria yet still identifies the charge wrong.

4. Conclusion

Reconstruction of strange quark pair charges at ILC for 250 GeV scenario was examined. Such process requires precise selection in Kaons using dE/dx information. For this analysis, we were able to achieve 85% purity for the kaon identification in pure $s\bar{s}$ samples. Prospects include of full background samples (u,d,c) and optimization of kaon selection as currently sacrifice efficiencies in exchange of purity.

References

[1] H. Baer, T. Barklow, K. Fujii, Y. Gao, A. Hoang, S. Kanemura et al., *The International Linear Collider Technical Design Report - Volume 2: Physics*, `1306.6352`.

[2] H. Abramowicz et al., *The International Linear Collider Technical Design Report - Volume 4: Detectors*, `1306.6329`.