Electroweak Couplings of Light Quark at Future Linear Colliders

2nd ECFA Workshop on e^+e^- Higgs/EW/Top Factories

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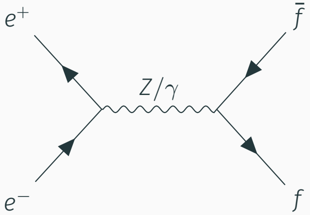
Introduction

Fermion Pair Production

Quark Pair Production

- $e^+e^- \to u\bar{u}, d\bar{d}, s\bar{s}$
- $\sqrt{s} = 250$ GeV
- $\mathcal{L}_{int} = 4.2$ ab^{-1}



Observable

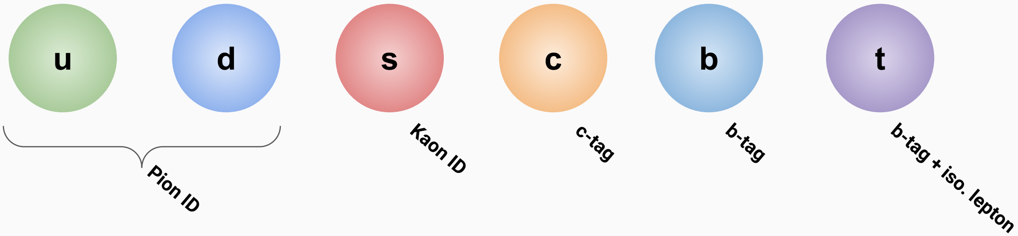
- Differential Cross section

$$\frac{d\sigma}{d\cos\theta} = S(1 + \cos^2\theta) + A\cos\theta$$

- Extracted via A_{FB}

$$A_{FB} = \frac{N_F - N_B}{N_F + N_B}$$

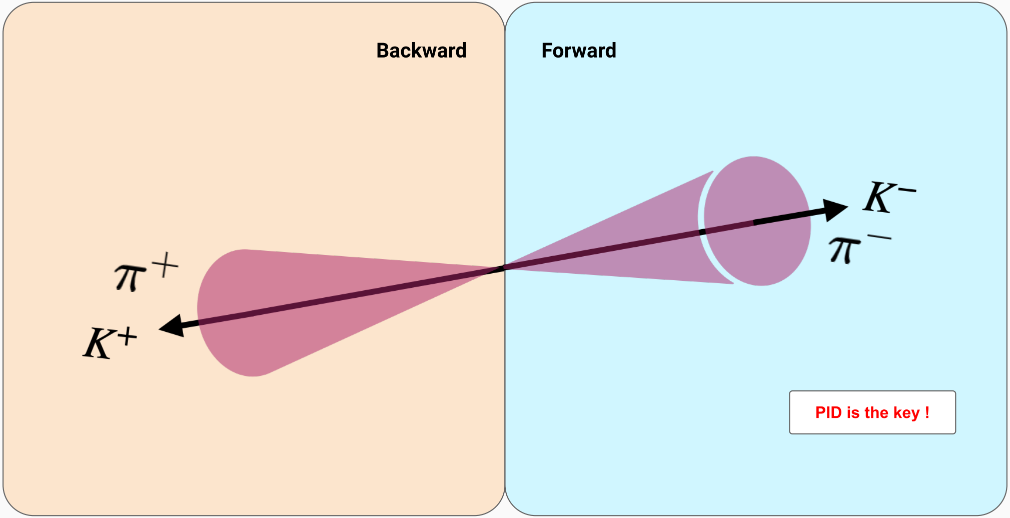
Energy	Process	Goal of measurements
91 GeV	$e^+e^- \to Z^0$	Z^0 physics and calibration
250 GeV	$e^+e^- \to Z^0H$	Higgs couplings
	$e^+e^- \to f\bar{f}$	Z^0/γ couplings
350 GeV	$e^+e^- \to t\bar{t}$	Top mass precision
	$e^+e^- \to \nu\bar{\nu}H$	Higgs couplings
500 GeV	$e^+e^- \to t\bar{t}$	Top couplings
	$e^+e^- \to t\bar{t}H$	Higgs self-coupling
	$e^+e^- \to Z^0HH$	Higgs self-coupling
1 TeV	$e^+e^- \to \nu\bar{\nu}HH$	Higgs self-coupling



Quark pair production

- Extraction of A_{FB} requires dedicated PID process.
- Each flavor has unique method to identify the original hard process.
- $K^{\pm}$ can be used as an imprint of the $s\bar{s}$ process.
- $\pi^{\pm}$ can be used for $u\bar{u}$ and $d\bar{d}$.

Leading PFO



International Large Detector

- Multi-purpose 4π detector designed for the ILC.
- Composed of multiple sub-detectors:
  - Vertex Detector (VXD)
    - b, c-tagging
  - Time Projection Chamber (TPC)
    - dE/dx measurements
  - Electromagnetic Calorimeter (ECAL)
  - Hadronic Calorimeter (HCAL)
  - Muon Yoke
- Optimized for the application of Particle Flow Algorithm (PFA).

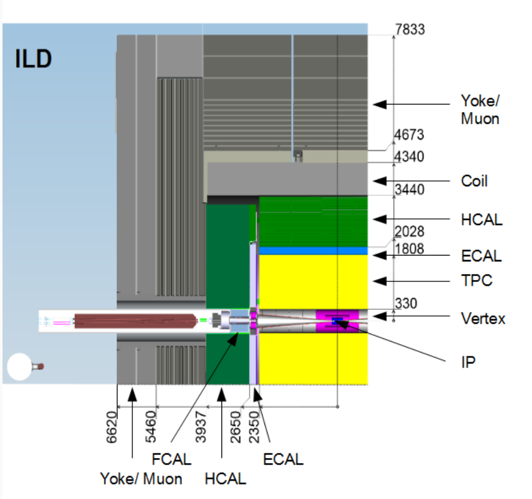
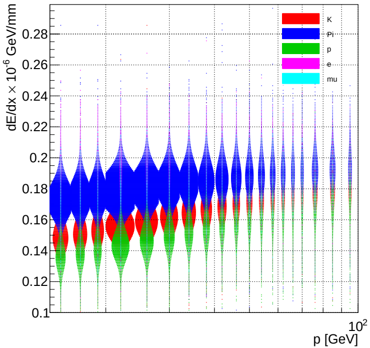
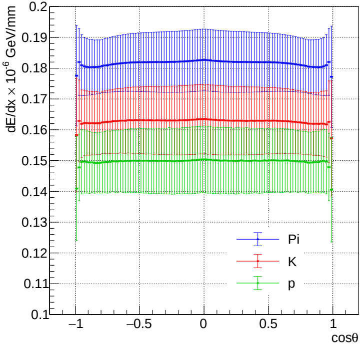


Figure 1: Cross sectional view of the ILD [Abramowicz et al., 2013].

dE/dx Particle Identification

- TPC provides dE/dx information for each track.
- Bethe-Bloch formula separates individual particles.





Event Selection

Event Reconstruction

- Jet/vertex reconstruction
- Flavor tagging

Background Rejection

- Photon veto
  - $E_\gamma < 115\,\text{GeV}$
  - $|\cos\theta_\gamma| < 0.97$
- Acolinearity
  - $\sin\Psi_{acol} < 0.3$
- Invariant mass
  - $M_{j_1,j_2} > 140\,\text{GeV}$
- Jet y_{23}
  - $y_{23} < 0.02$

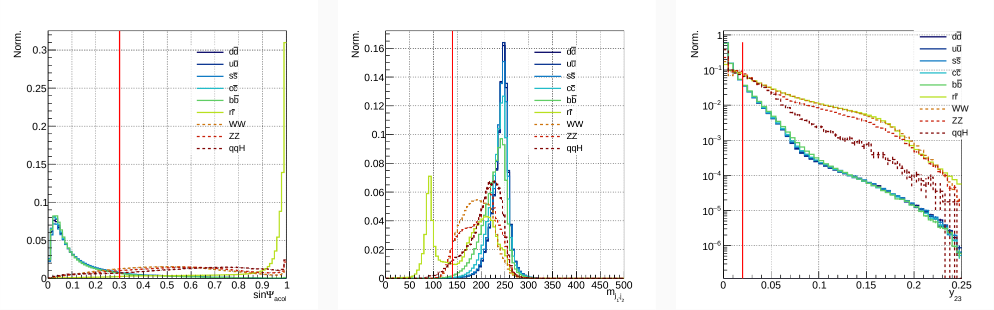
Signal Definition

- Acolinearity of $q\bar{q}$
  - $\sin\Psi_{acol,q} < 0.3$
- Invariant mass
  - $M_{q\bar{q}} > 140\,\text{GeV}$

Backgrounds

- Radiative return
- $e^+e^- \to WW \to 4f$
- $e^+e^- \to ZZ \to 4f$
- $e^+e^- \to q\bar{q}H$

Preselection



(a) (b) (c)

Figure 2: Three histograms illustrating the variable ($\sin\Psi_{acol}$, m_{j_1,j_2}, y_{23}), each successively refined by applying a cut on the right histogram. Red line shows the cut.

	Signal					Background			
Process	$d\bar{d}$	$u\bar{u}$	$s\bar{s}$	$c\bar{c}$	$b\bar{b}$	Rad. Ret.	WW	ZZ	$q\bar{q}H$
$e_L^- e_R^+$	59.00%	59.96%	58.08%	60.22%	59.89%	0.23%	3.98%	2.88%	1.00%
$e_R^- e_L^+$	58.88%	60.07%	57.96%	60.35%	59.76%	0.22%	1.65%	3.26%	1.02%

Table 1: Percentage of remaining events after the entire background removal with left and right-handed electron beam polarization.

- All backgrounds including radiative return can be reduced down to few percent level.
- Signal processes all remain constantly around 60 % of the entire events.

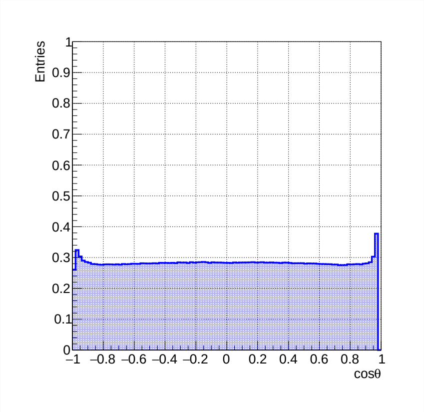
Selection

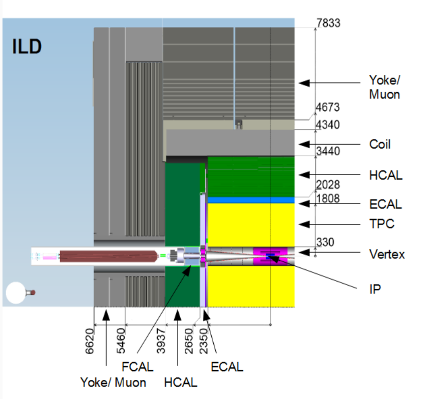
Name	Quantity	Description
Leading momentum	$p_{LPFO} > 15\,\mathrm{GeV}$	Leading momentum cut
Offset	$V_0 = \sqrt{d_0^2 + z_0^2} < 1\,\mathrm{mm}$	Offset cut to reject Λ_0 contribution
dE/dx PID	$dE/dx > 0.178 \times 10^{-6}\,\mathrm{GeV\,mm^{-1}}$	π and K identification
SLPFO	Veto $p_{SLPFO} > 10\,\mathrm{GeV}$ and charge opposite to LPFO.	Attenuate the charge migration by rejecting oppositely charge LPFO competitor
Charge	$Q_{LPFO1} \times Q_{LPFO2} < 0$	Charge of LPFOs from both sides has opposite charge.

Table 2: Each selection criteria for this analysis.

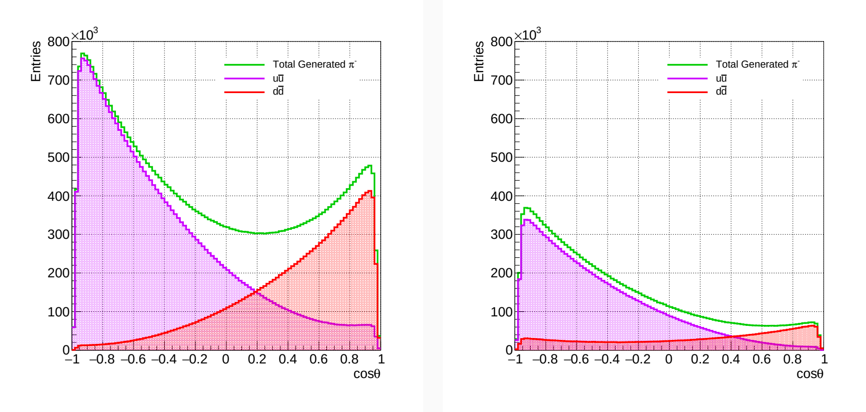
Selection and Acceptance

- Due to the barrel coverage of the TPC, acceptance influences the performance of the dE/dx PID.
- Acceptance safe region of $|\cos\theta| < 0.8$ was chosen to determine the A_{FB}.



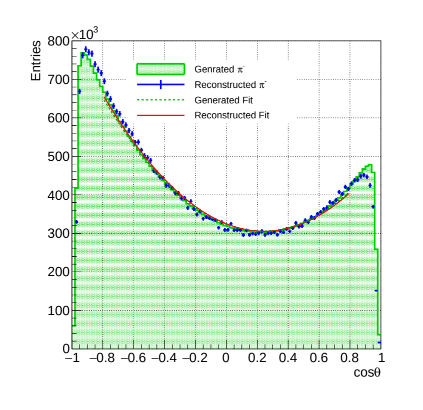


Results

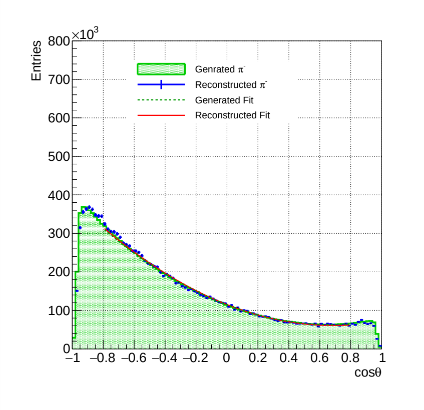


(a) (b)

Figure 3: Generated polar angle distribution for the *u* **and** *d* **mixed samples** with (a) left-handed and (b) right-handed electron beam.



(a)



(b)

Figure 4: Reconstructed polar angle distribution for the *u* **and** *d* **mixed samples** with (a) left-handed and (b) right-handed electron beam.

Differential Cross section

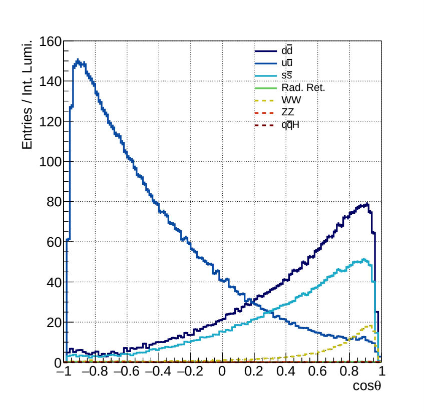
$$\frac{d\sigma}{d\cos\theta} = S(1+\cos^2\theta) + A\cos\theta$$

		S	σ_S	A	σ_A
$e_L^- e_R^+$	Gen	1.14786e+05	3.41247e+01	-1.54663e+05	8.90167e+01
	Reco	1.15086e+05	2.83637e+02	-1.57997e+05	7.71496e+02
$e_R^- e_L^+$	Gen	3.23565e+05	5.63279e+01	-1.51642e+05	1.55409e+02
	Reco	3.24989e+05	5.11509e+02	-1.58961e+05	1.44454e+03

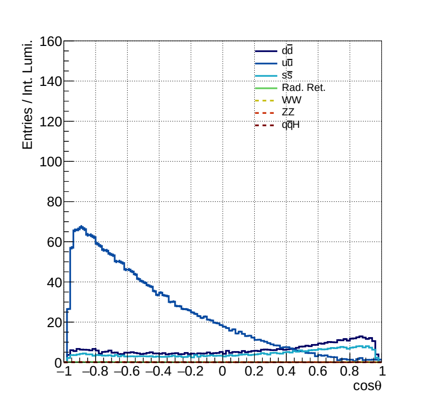
Forward-Backward Asymmetry

- A_{FB} parameter was extracted using the number of entries in the polar angle distribution.
- Comparing with the generated and reconstructed values, reconstruction well fits the parton level.
- Calculation of the systematic and statistical error for the A_{FB} ongoing.
- Next step is to compare with other backgrounds.

	$e^-_L e^+_R$	$e^-_R e^+_L$
Gen	-0.175747	-0.505278
Reco	-0.183423	-0.514824



(a)



(b)

Figure 5: Final polar angle distributions of Pions for seven different processes with (a) left-handed and (b) right-handed electron beam.

Mode	Data Events	MC prediction
K^+K^-	1290	1312.2
$K^+\Lambda^0, K^-\bar{\Lambda}^0$	219	213.5
$\Lambda^0\bar{\Lambda}^0$	17	13.7
$K^\pm K_s^0$	1580	1617.3
$\Lambda^0 K_s^0, \bar{\Lambda}^0 K_s^0$	193	194.1
Total	3299	3350.8

Table 3: Summary of the selected event sample for 5 tagging modes in data and simulation at SLAC experiment [Stängle, 1999].

- Contamination from $s\bar{s}$ process can be attenuated by requesting strict cut on the LPFO momentum.

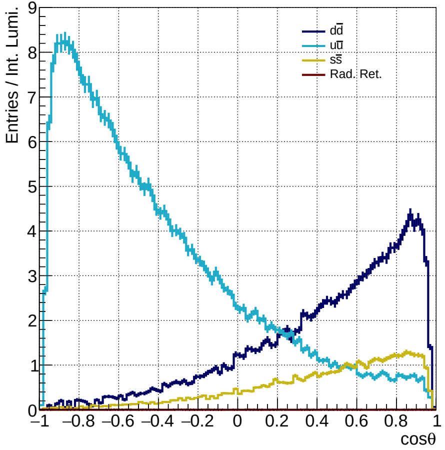


Figure 6: Polar angle distribution for $e_L^- e_R^+$ polarization after requiring $p_{LPFO} > 40$ GeV. (Background omitted)

Summary & Outlook

Summary

- Using the Full detector simulation of the ILD, light quark pair production process was first investigated.
- The study demonstrated the possibility to extract SM parameter $\mathbf{A_{FB}}$ through the $e^+e^- \to q\bar{q}$ with light quarks, using polarized electron and positron beams.
- Both final fit result and A_{FB} value showed excellent consistency with the parton level.

Outlook

- Systematic and statistical error must be calculated to quantitatively tell the ILC precision.
- $s\bar{s}$ is considered background to the light quark production process. This need to be attenuated by various methods. (e.g. requiring tighter cut towards the LPFO momentum.)

Bibliography

- Abramowicz, H. et al. (2013).
  The International Linear Collider Technical Design Report - Volume 4: Detectors.
- Bilokin, S. (2017).
  Hadronic showers in a highly granular silicon-tungsten calorimeter and production of bottom and top quarks at the ILC.
  PhD thesis, Saclay.
- Stängle, H. (1999).
  Measurement of the $Z^0 \rightarrow s\bar{s}$ *coupling at the SLD.*
  PhD thesis, Stanford U.

Backup

Migrations

- Migration occurs when reconstructing a particle charge opposite to its true charge in the parton level.
    - Mis-reconstruction from dE/dx PID
    - Acceptance
    - ...
- Such migration flips the reconstructed quark angle (assuming back-to-back scenario)
- *pq*-method
    - Uses double tag property [Bilokin, 2017].

$$N_{acc} = N(p^2 + q^2)$$
$$N_{rej} = 2pqN$$
$$p + q = 1$$

$$p = \frac{N \pm \sqrt{N(N - 2N_{rej})}}{2}$$
$$q = \frac{N \mp \sqrt{N(N - 2N_{rej})}}{2}$$

Polar Angle Distribution with Backgrounds

- Preliminary result on polar angle distribution with event higher p_{LPFO} cut (60 GeV)
- Contribution from the $s\bar{s}$ process gets attenuated while the efficiency is significantly degraded.
- Sensitivity towards the forward region will be reduced as well.
- Other background contributions also get significantly lower.

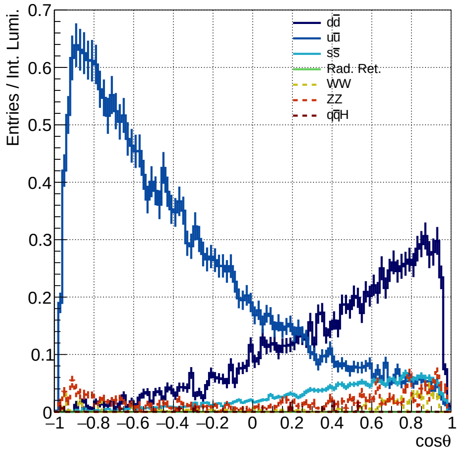


Figure 7: Polar angle distribution for $e_L^- e_R^+$ polarization after requiring $p_{LPFO} > 60$ GeV.