Measuring the initial electron beam polarization in \( e \gamma \) collisions

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November 19, 2018

Abstract

The investigation of \( e \gamma \rightarrow \nu W \) process is crucial for a possible high energy \( e\gamma \) or \( \gamma\gamma \) collider since it offers the possibility for both new physics discovery and precision measurements. The polarization of the initial beam is a limiting factor for the systematic errors in both cases. This note addresses the feasibility of making a measurement of the initial electron beam polarization with relative statistical error of one percent. Generator and detector level MC tools are used to obtain a realistic event selection for the signal process at the future CLIC test facility running at \( \sqrt{s} = 150 \) GeV.

1 Introduction

The next high energy \( ee \) colliders or their precessor test facilities will also be capable of achieving highly polarized \( \gamma\gamma \) and \( e\gamma \) collisions at high luminosities due to recent advancements in laser technology. In the \( e^-\gamma \) collisions which can uniquely be identified due to the net (-1) charge in the final state, one of the very interesting processes is

\[
e^- \gamma \rightarrow \nu_e W^-. \tag{1}
\]

Depending on the center of mass energy (\( \mathcal{E} \)), the luminosity (\( \mathcal{L} \)) of the collider and the polarization (\( \mathcal{P} \)) of the beams, this process can be used to investigate

*Adapted from the talk given in Chicago LC Workshop, 2002
- Anomalous trilinear gauge boson couplings at high $E$ with polarized beams [3].
- Leptoquarks and composite charged gauge bosons [4].
- An estimation on the value of the beam polarization at high $L$ [5].

The initial electron beam polarization will contribute to the systematic error on any measurement and will thus be a limiting factor on the total error. This note, therefore, focuses on the measurement of the initial electron beam polarization with a small relative error of about 1 percent. After putting down the requirements on the polarization measurement, the properties of the “signal” process and the source for the direct background events will be presented. The second section summarizes the Monte Carlo tools used during this study. The results for event selection efficiency and background rejection will be shown for different final states in section three. Finally, in the proposed CLIC1 [5] accelerator, some time estimates for the intended electron polarization measurement are presented using different $W$ decay channels. Since CLIC1 will solely be an electron accelerator, the positron channel is not considered in this work.

![Feynman diagrams](image)

**Figure 1:** channels yielding the $\nu_e W^-$ final state

The lowest order Feynman diagrams that would yield a $\nu_e W^-$ final state are shown in Figure (1). In the Standard Model, with massless neutrinos, the helicity of the incoming $e^-$ is fixed by the $\nu_e$, implying zero contribution to the total cross section ($\sigma_T$) from a the right handed electrons ($e_R$). Therefore the $s$ channel diagram can even be turned off by choosing 100% opposite $e^-$ and $\gamma$ polarizations. This concept will be the key point to measure beam polarizations. The surviving $t$ channel diagram is of particular interest since, the trilinear gauge boson coupling allows testing, among other things, the V-A structure of the standard model [6], extra charged gauge bosons [7].

If one assumes a fixed laser photon beam polarization, the change in the total cross section of
the signal events due to the change in electron beam polarization is given in Figure 2. We note that in order to determine the electron polarization with an error of 1.0 %, one has to measure the cross section with an accuracy of 5 permille. For the estimation of the required data taking time for such a measurement, only statistical errors and direct backgrounds will be considered. The contributions from the misidentifications and systematic errors are detector dependent and are not included in this note.

**Figure 2:** The signal cross section changes due to the electron Polarization. [5]

Naturally, the $W^{-}\nu_e$ final state will be identified through $W^{-}$'s decay products. The possible tree level background to the final states will arise from the photon structure [8] and invisible $Z$ decays. Figure 3 shows these background diagrams coming from the leptonic and hadronic structure of the photon for the non-electron channels. The Figure 4 shows the background diagrams for the electron final states including the additional backgrounds from the the invisible decays of $Z$. 

\[ e^+\gamma \rightarrow \nu_e W^- \]
2 MC tools and Backgrounds

As event generators, two different programs are used:

Pandora V2.21 This is a tree level generator [9]. It takes into account the beam polarization. It can only calculate $2 \rightarrow 2$ processes. The generated events can be fed into pythia (v6.128) [10] for fragmentation through the pandora-pythia interface [11].

CompHEP V41.10 This is also a tree level generator [12]. Comphep is for unpolarized electron beams only, but it can simulate $2 \rightarrow 3$ processes, which are crucial for the background study. The interface to pythia (v6.128) for fragmentation is cpyth [13].

The beamline parameters can be tuned in both generators for realistic beamstrahlung estimation. For the computations in this note, the proposed CLIC Higgs Experiment’s parameters (based on CLIC1) are used [5]: Bunch size (x+y)=157nm, Bunch length=0.03mm, $N_{e}/bunch=4 \times 10^{9}$.
The photon spectrum in both generators is pure laser spectrum, without the Williams Weizsacker \cite{14} contribution. For Pandora, the laser is assumed to be 100% polarized.

![Figure 5: Laser spectra used in the two MC generators. The shaded band is the 1 sigma statistical error as computed in pandora.](image)

A Higgs particle of mass about 120GeV \cite{15}, requires the optimization of the photon beams in the intended CLIC\textsuperscript{1} machine with $E_{ee}$ of 150 GeV. The parameter $x$, commonly known as Telnov's $x$, becomes different than the conventional value of 4.83. The maximum photon beam energy is then given with the formula:

$$E_\gamma = \frac{x}{x+1}E_e, \quad x = 4.0507 \quad (2)$$

To get a converging value of the effective cross section a minimum set of cuts are applied at the generator level. These are:

- $P_T(W^-) > 5$ GeV
- $E_{cm} > 2$ GeV,
- $\Theta > 1^\circ$.
Table 1: Cross sections times Br (in fb) of signal and background events for the leptonic decays of $W^-$ from CompHEP.

| channel | $\sigma_{\text{signal}}$ (fb) | $\sigma_{\text{backg.}}$ (fb) |
|---------|------------------|------------------|
| $e \gamma \rightarrow \nu W, (W^- \rightarrow \tau \nu)$ | $276.0 \pm 1.24$ | $35.68 \pm 0.08$ |
| $e \gamma \rightarrow \nu W, (W^- \rightarrow \mu \bar{\nu}_\mu)$ | $276.1 \pm 1.65$ | $36.44 \pm 0.09$ |
| $e \gamma \rightarrow \nu W, (W^- \rightarrow e \bar{\nu}_e)$ | $276.8 \pm 1.9$ | $1116 \pm 4$ |

The total effective cross sections obtained from both generators are:

$$\sigma(\text{CompHEP}) = 2661 \pm 2\text{ fb},$$

$$\sigma(\text{Pandora}) = 2495 \pm 2\text{ fb}.$$
Figure 6: *kinematic distributions of signal and background muons.*

Figure 6 has the distributions of selected kinematic quantities for signal (left) and background (right) muons. The red vertical lines in the top four plots represent the optimized cut values. The bottom two plots are the transverse momentum distributions of the remaining signal and background events. The muons from the resolved photon are soft and along the photon’s momentum. These two properties allow a reduction on the background of about 91 % for a signal loss of about 32 %. For the muon channel, the used cuts and their efficiencies are given in Table 2. The results of the similar studies for the electron channel are presented in Table 3.
### 3.2 Hadron channels

Final states containing \( \bar{c}s \) and \( \bar{u}d \) are the major contributors for both the signal & background cross sections. The contribution from \( b \) quark is practically null due to smallness of \( V_{cb} \) and \( V_{ub} \). The jets are reconstructed with DURHAM algorithm, with a typical rapidity cut, \( y \), of 0.04. The required signature is a two jet event (2j) + \( E_T \). Figure 7 contains distributions for selected quantities for the signal in shaded red and in blue for the backgrounds. The black vertical lines are the optimized cut values. The main property of the background jets is to follow the photon direction with small transverse momenta. In each plot the additive effect of the selected cuts are shown. The optimized value for each cut and the cumulative efficiencies are presented in Table 4. With these cuts, about 90% of the background can be eliminated with a signal loss of about 50%. These ratios will be assumed to hold for the other hadronic channels as well.
Figure 7: Hadronic signal and background kinematic distributions. One of the two dominant channels, $\bar{c}s$, is shown as an example. The vertical dotted lines represent the applied cut values.
Table 4: With significance optimized cuts, \( \approx 51\% \) signal vs \( \approx 9.6\% \) background events survive in the \( \bar{c}s \) channel.

### 4 Conclusions

After the cuts, the effective cross section for the signal and background events in the muon and electron channels is given in Table 5. The error on the cross section is calculated with the number of events after background subtraction, assuming a Snowmass year of \( 10^7 \) seconds. The decrease of the statistical error in the signal cross section as a function of data taking time is shown in Figure 8 for electron and muon channels both separately and combined. If the events from two channels are combined, a measurement of \( P_e \) with \( 1\% \) statistical error can be obtained in less than a year of nominal operation with the Snowmass efficiency of about 30 percent.

| applied cut | signal loss | background reduction |
|-------------|-------------|----------------------|
| 2 Jets only events | 2.6 % | 7.4 % |
| \( \cos(\theta) \) both jets < 0.9 | 16 % | 45 % |
| \( P_{jet} > 11 \mathrm{GeV} \) | 39 % | 80 % |
| \( 53 < M_{inv,2jets} < 89 \mathrm{GeV} \) | 49 % | 90.4 % |

Table 5: Effective \( \sigma s \) in \( \mathrm{fb} \) in lepton channels
Figure 8: Precision on the cross section measurement with surviving signal events in leptonic channels is shown both separately and combined.

For the hadronic final states, only one main channel was considered to find the optimal cuts. The obtained signal survival probability is then extended to all hadron channels to compute the total number of events necessary to make a precision measurement on the cross section. The effective cross sections of the signal and background processes after the applied cuts are presented in Table 6. The results of a precision measurement on the cross section to obtain the polarization is presented in Figure 9. We see that if the hadron channel can be used, the polarization of the initial electron beam can be obtained with a one percent statistical error can be obtained in about 3-4 months.

| $qq'$ | signal | background |
|-------|--------|------------|
| $\sigma_{\text{eff}} (\text{fb})$ | 837    | 28         |

Table 6: Effective cross sections in fb for signal and background processes in the hadron channels
Figure 9: Precision on $\sigma$ measurement with surviving signal events using hadron channel

For this study we only have considered the statistical errors and the direct backgrounds. The study of misidentifications and fakes is not yet considered. Nevertheless, it is shown that the initial electron beam polarization is measurable with a good precision using the $e\gamma \rightarrow \nu W$ process.

Acknowledgements: The author is grateful to M. Velasco and M. Schmitt for introduction to the subject and to M. Karagoz Unel for fruitful discussions.

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