One-loop electroweak radiative corrections to polarized

\(e^+e^- \rightarrow ZH\)

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Abstract

The paper describes high-precision theoretical predictions obtained for the cross sections of the process \(e^+e^- \rightarrow ZH\) for future electron-positron colliders. The calculations performed using the \textsc{SANC} platform taking into account the full contribution of one-loop electroweak radiative corrections, as well as longitudinal polarization of the initial beams. Numerical results are given for the energy range \(E_{cm} = 250\) GeV — 1000 GeV with various polarization degrees.
1 Introduction

The clean signatures of the reactions at $e^+e^-$ colliders (eeC) combined with the effect of polarization of initial particles can greatly improve the precision of theoretical predictions for various observables of the Standard Model processes [1]. The future linear eeC projects such as FCCee, ILC [2], CLIC [3] are designed to provide polarized beams (up to 80% for electrons and up to 60% for positrons). For the future circular eeC – CEPC [4] and FCC-ee [5] the prospects for beam polarizations are also considered. Energy range for future eeC will be 250 – 1000 GeV, while 250 GeV is the optimal energy for the Higgs production through the Higgs-strahlung $e^+e^-\rightarrow ZH$, which is most important to get the precision measurements of Higgs mass, spin, CP nature, coupling of Higgs to ZZ and various branching ratios. Thus, it is important to take beam polarization into account in theoretical calculations.

At eeC the three main Higgs production processes are the Higgs-strahlung $e^+e^-\rightarrow ZH$, the W-fusion $e^+e^-\rightarrow \bar{\nu}_e\nu_e(W^+W^-)\rightarrow \bar{\nu}_e\nu_eH$ and the Z-fusion $e^+e^-\rightarrow e^+e^-(ZZ)\rightarrow e^+e^-H$ [6, 7, 8, 9, 10, 11].

In this paper we present results of the full one-loop electroweak (EW) corrections to the process

$$e^+(p_1) + e^-(p_2) \rightarrow Z(p_3) + H(p_4),$$

for arbitrary longitudinal polarizations $P_{e^+}$ and $P_{e^-}$ of the positron and electron beams, respectively. Numerical results are evaluated for the following longitudinal polarizations: (0.0;-0.8,0;-0.8,-0.6;-0.8,0.6) and for the energies: 250, 500, 1000 GeV.

The radiative corrections (RC) to $e^+e^-\rightarrow ZH$ with unpolarized initial particles were extensively considered in the literature [12, 13, 14]. The effect of polarization on the virtual and soft photonic contributions to electroweak (EW) RC to Higgs-strahlung process was previously calculated in [15, 16]. The present paper also takes into account the hard Bremsstrahlung contribution.

Numerical estimates are presented for the correction of the total cross section, of the differential distribution in the Z boson scattering angle $\cos \vartheta_Z$ and for the left-right asymmetry $A_{LR}$ as a function of $\cos \vartheta_Z$. The relevant contributions to the cross section are calculated analytically and then evaluated numerically.

For the numerical evaluation of the process we use the extended version of our Monte Carlo (MC) generator of unweighted events, that is based on the SANC [17] platform, and was previously used for Bhabha process [18]. The polarized virtual and soft Bremsstrahlung contributions are compared with the results of [16]. The cross sections for polarized Born and hard Bremsstrahlung are cross-checked with the corresponding results of the WHIZARD [19] and CalcHEP [20] programs.

The structure of the paper is the following. In Sect. 2 we describe the cross section calculation technique at the EW one-loop level. Expressions for covariant (CA) and helicity amplitudes (HA) are presented. The approach to taking into account the polarization effects is discussed. In Sect. 3 we give our numerical results for the total and differential cross sections and relative corrections. Sect. 4 contains conclusion and discussion of obtained results.
2 Differential cross section

Let us consider scattering of longitudinally polarized $e^+$ and $e^-$ with polarization degrees $P_{e^+}$ and $P_{e^-}$, respectively. Then the cross section of the generic process $e^+e^- \rightarrow ...$ can be expressed as

$$\sigma_{P_{e^-}P_{e^+}} = \frac{1}{4} \sum_{\chi_1, \chi_2} (1 + \chi_1 P_{e^-})(1 + \chi_2 P_{e^+}) \sigma_{\chi_1 \chi_2},$$

where $\chi_i = -1(+1)$ corresponds to lepton with left (right) helicity state. Thus the cross section with arbitrary longitudinal polarization is a linear combination of four contributions:

$$\sigma_{--(++,+,++)} \equiv \sigma_{LL, (LR, RL, RR)}.$$

At one-loop the cross section of the process can be divided into four parts:

$$\sigma^{1\text{-}\text{loop}} = \sigma^{\text{Born}} + \sigma^{\text{virt}}(\lambda) + \sigma^{\text{soft}}(\lambda, \omega) + \sigma^{\text{hard}}(\omega),$$

where $\sigma^{\text{Born}}$ — Born level cross-section, $\sigma^{\text{virt}}$ — contribution of virtual(loop) corrections, $\sigma^{\text{soft}}$ — contribution due to soft photon emission, $\sigma^{\text{hard}}$ — contribution due to hard photon emission (with energy $E_\gamma > \omega$). Auxiliary parameters $\lambda$ ("photon mass") and $\omega$ are cancelled out after summation.

We count all contributions through helicity amplitudes approach.

The virt(Born) cross section of the $e^+e^- \rightarrow ZH$ process can be written as:

$$d\sigma^{\text{virt(Born)}}_{\chi_1 \chi_2} = \frac{\sqrt{\lambda(s, M_Z^2, M_H^2)}}{32\pi s^2} \left| H^{\text{virt(Born)}}_{\chi_1 \chi_2} \right|^2,$$

where

$$|H^{\text{virt(Born)}}_{\chi_1 \chi_2}|^2 = \sum_{\chi_3 = 0, \pm 1} |H^{\text{virt(Born)}}_{\chi_1 \chi_2 \chi_3}|^2.$$  

The soft term is factorized to Born-level cross section:

$$
\frac{d\sigma^{\text{soft}}_{\chi_1 \chi_2}}{d \cos \theta_Z} = \left. \frac{d\sigma^{\text{Born}}_{\chi_1 \chi_2}}{d \cos \theta_Z} \right|_{\lambda = 0} \frac{\alpha}{2\pi} \left( -L_s^2 + 4L_s \ln \frac{2\omega}{\lambda} - \frac{2\pi^2}{3} + 1 \right), \quad L_s = \ln \frac{s}{m_e^2} - 1. 
$$

The cross section for hard Bremsstrahlung $e^+(p_1) + e^-(p_2) \rightarrow Z(p_3) + H(p_4) + \gamma(p_5)$ is

$$
\frac{d\sigma^{\text{hard}}_{\chi_1 \chi_2}}{ds'd \cos \theta_4 d\phi_4 d\cos \theta_5} = \frac{s - s'}{8(4\pi)^4 s s'} \sqrt{\lambda(s', M_Z^2, M_H^2)} \left| H^{\text{hard}}_{\chi_1 \chi_2} \right|^2,
$$

where $s' = (p_3 + p_4)^2$, and

$$|H^{\text{hard}}_{\chi_1 \chi_2}|^2 = \sum_{\chi_3 = 0, \pm 1} \sum_{\chi_5 = 0, \pm 1} |H^{\text{hard}}_{\chi_1 \chi_2 \chi_3 \chi_5}|^2.$$  

Here $\theta_5$ is an angle between 3-momenta of the photon and the positron, $\theta_4$ — an angle between 3-momenta of the $Z$-boson and the photon in the rest frame of $(Z,H)$-compound, $\phi_4$ — an azimuthal angle of $Z$-boson in the rest frame of $(Z,H)$-compound.
2.1 Covariant amplitude for virtual parts and Born level

The covariant amplitude neglecting the masses of initial particles can be written as [21]:

$$A_{\text{eeZH}} = N(s) \left\{ \bar{v}(p_1) \left( \gamma_0 \gamma_+ \sigma_e \mathcal{F}_0^+(s, t) + \sum_{i=1,2} \phi_3 \gamma_+(p_i) \gamma_0 \mathcal{F}_i^+(s, t) \right) u(p_2) \varepsilon_\nu(p_3) \right\} + \left[ \sigma_e \rightarrow \delta_e, \gamma_+ \rightarrow \gamma_-, \mathcal{F}_i^+(s, t) \rightarrow \mathcal{F}_i^-(s, t) \right]$$

(10)

where

$$N(s) = \frac{ig^2}{4c_w^2 s - M_Z^2 + iM_Z \Gamma_Z}.$$  

(11)

We also use various coupling constants

$$\sigma_e = v_e + a_e, \quad \delta_e = v_e - a_e, \quad c_W = \frac{M_W}{M_Z}, \quad g = \frac{e}{s_W}, \quad \text{etc.}$$  

(12)

2.2 Helicity amplitudes for virtual parts and Born level

• HA for virtual part

There are 6 non-zero HAs for virtual contribution:

$$\mathcal{H}_{++} = N(s) \sqrt{s} c_+ \left\{ \sqrt{\lambda} c_- \left[ \mathcal{F}_2^+(s, t) - \mathcal{F}_1^+(s, t) \right] - 4\mathcal{F}_0^+(s, t) \right\},$$

(13)

$$\mathcal{H}_{+-} = N(s) \sqrt{s} c_- \left\{ \sqrt{\lambda} c_+ \left[ \mathcal{F}_2^+(s, t) - \mathcal{F}_1^+(s, t) \right] - 4\mathcal{F}_0^+(s, t) \right\},$$

$$\mathcal{H}_{+0} = N(s) \sin \theta_Z \left\{ \sqrt{\lambda} \left[ \beta_+ \mathcal{F}_1^+(s, t) + \beta_- \mathcal{F}_2^+(s, t) \right] + 4\sigma_e L \mathcal{F}_0^+(s, t) \right\},$$

where

$$L = s + M_Z^2 - M_H^2, \quad \lambda = \lambda(s, M_Z^2, M_H^2),$$

$$\beta = \beta(s, M_Z^2, M_H^2) = \frac{\sqrt{\lambda}}{L}, \quad \beta_\pm = \beta \pm \cos \theta_Z, \quad c_\pm = 1 \pm \cos \theta_Z.$$  

(14)

Expression for the amplitude $\mathcal{H}_{+++}$ is obtained from the expression $\mathcal{H}_{++}$ by the replacement $(\sigma_e \rightarrow \delta_e, c_+ \rightarrow c_-, \mathcal{F}^+ \rightarrow \mathcal{F}^-)$, the same procedure is applied to obtain $\mathcal{H}_{+-}$ from $\mathcal{H}_{+-}$. To obtain amplitude $\mathcal{H}_{+0}$ from $-\mathcal{H}_{+-}$ the replacement $(\sigma_e \rightarrow \delta_e)$ works.

• HA for Born level

In order to get helicity amplitudes for the Born level one should set $\mathcal{F}_i^+(s, t) = 0$ and $\mathcal{F}_0^+(s, t) = 1$. 

4
2.3 Helicity amplitudes for hard Bremsstrahlung

For massless particle with light-like momentum $k$, we are using following notations for spinors:

\[ u_+(k) = \gamma_+ u(k) = v_-(k) = \gamma_- v(k) = |i\rangle, \]
\[ u_-(k) = \gamma_- u(k) = v_+(k) = \gamma_+ v(k) = |i\rangle, \]
\[ \bar{u}_+(k) = \bar{u}(k) \gamma_- = \bar{v}_-(k) \gamma_+ = |i\rangle, \]
\[ \bar{u}_-(k) = \bar{u}(k) \gamma_+ = \bar{v}_+(k) = \bar{v}(k) \gamma_- = |i\rangle. \] (16)

Using them we able to construct polarization wave-functions for other particles, including massive.

We project all massive momenta with $p_i^2 = m_i^2$ to the light-cone of photon $p_5$ and introduce associated “momenta”:

\[ k_i = p_i - \frac{m_i^2}{2p_i \cdot p_5} p_5, \quad k_i^2 = 0, \quad i = 1..4, \] (17)
\[ k_5 = - \sum_{i=1}^{4} k_i = K p_5, \quad K = 1 + \sum_{i=1}^{4} \frac{m_i^2}{2p_i \cdot p_5} = 1 + \sum_{i=1}^{4} \frac{m_i^2}{2k_i \cdot p_5}, \]
\[ p_5 = - \sum_{i=1}^{4} p_i = K' k_5, \quad K' = 1 - \sum_{i=1}^{4} \frac{m_i^2}{2p_i \cdot k_5} = 1 - \sum_{i=1}^{4} \frac{m_i^2}{2k_i \cdot k_5}. \] (18)

Vector $k_5$ appears to be light-like, so we are left with “momentum conservation” of associated vectors.

Construction of photon polarization vector needs introduction auxiliary massless vector $q$ for gauge fixing. Physical amplitudes are independent of it. We use following parametrization:

\[ \varepsilon_\mu^+(k_5) = \frac{\langle q|\gamma_\mu|5\rangle}{\sqrt{2} \langle q|5\rangle}, \quad \varepsilon_\mu^-(k_5) = \frac{[q|\gamma_\mu|5\rangle}{\sqrt{2} [q|5\rangle} = (\varepsilon_\mu^+(k_5))^*, \]
\[ \tilde{\varepsilon}^+(k_5) = \gamma^\mu \varepsilon_\mu^+(k_5) = \sqrt{2} \frac{|q|5\rangle + |5\rangle[q]}{[q|5\rangle}, \quad \tilde{\varepsilon}^-(k_5) = \sqrt{2} \frac{|q|5\rangle + |5\rangle[q]}{[q|5\rangle}. \]

There are 20 non-zero HAs for hard contribution:

\[ A_{---} = 2e m_1 M_Z N(s') \left( \frac{\delta_e}{s_{15}} + \frac{\sigma_e}{s_{25}} \right) \frac{[12]}{[35]} \frac{\langle 3|5\rangle}{[3|5]}, \]
\[ A_{+++} = 2e m_1 M_Z N(s') \left( \frac{\sigma_e}{s_{15}} + \frac{\delta_e}{s_{25}} \right) [12] \frac{\langle 3|5\rangle}{[3|5]} \frac{[15]}{[25]}, \]
\[ A_{---} = -2e M_Z N(s') \frac{\sigma_e}{s_{15}} \frac{[12]}{[35]} \frac{\langle 3|5\rangle}{[3|5]} \frac{[15]}{[25]}, \]
\[ A_{+++} = -2e M_Z N(s') \frac{\delta_e}{s_{25}} \frac{[12]}{[35]} \frac{\langle 3|5\rangle}{[3|5]} \frac{[15]}{[25]}, \]
\[ A_{-0+} = \sqrt{2} e m_1 N(s') \left( \frac{\delta_e}{s_{15}} \frac{[23]}{[35]} \frac{[13]}{s_{25}} \frac{[15]}{[25]} \right) \frac{[12]}{[35]}, \]
\[ A_{-++} = -2e M_Z N(s') \sigma_e \left( \frac{[1|2 \langle 2|3 \rangle \langle 2|5 \rangle}{s_{25} [3|5]} + \frac{[1|5 \langle 3|5 \rangle}{[2|5 ] [3|5]} \right), \]
\[ A_{++-} = -2e M_Z N(s') \delta_e \left( \frac{[1|2 \langle 1|3 \rangle \langle 1|5 \rangle}{s_{15} [3|5]} - \frac{[2|5 \langle 3|5 \rangle}{[1|5 ] [3|5]} \right), \]
\[ A_{+0+} = \sqrt{2} e m_1 N(s') \left( \frac{\sigma_e}{s_{15}} [1|2 \langle 1|5 \rangle \langle 2|3 \rangle + \frac{\delta_e}{s_{25}} \langle 2|5 \rangle \langle 1|3 \rangle \right) + [3|5] \left( \sigma_e - \delta_e \right), \]
\[ A_{-0+} = -\sqrt{2} e N(s') \left( \frac{\sigma_e}{s_{15}} \left[ \frac{[1|3 \langle 2|3 \rangle \langle 1|5 \rangle}{s_{25}} + \frac{[1|3 \langle 3|5 \rangle}{[1|2] \left[ \frac{M_Z^2 \langle 2|5 \rangle}{s_{45}} \right) + \frac{\delta_e}{s_{15} s_{25}} \langle 2|5 \rangle \langle 1|5 \rangle \right) \right], \]
\[ A_{+0+} = -\sqrt{2} e N(s') \left( \frac{\delta_e}{s_{25}} \left[ [2|3 \langle 1|3 \rangle \langle 2|5 \rangle - \frac{[2|3 \langle 3|5 \rangle}{[1|2] \left[ \frac{M_Z^2 \langle 1|5 \rangle}{s_{45}} \right) + \frac{\sigma_e}{s_{15} s_{25}} \langle 2|5 \rangle \langle 1|5 \rangle \right) \right], \]

where
\[ s_{15} = 2k_i \cdot p_5 = K' \langle i|5 \rangle [5|i]. \]  

Other ones can be obtained using CP-symmetry:
\[ A^{\text{hard}}_{\chi_1 \chi_2 \chi_3 \chi_4} = -\chi_1 \chi_2 \chi_3 \chi_5 A^{\text{hard}}_{-\chi_1 -\chi_2 -\chi_3 -\chi_5} |p_1 \leftrightarrow p_2|. \]

Freedom in the light-cone projection choice corresponds to arbitrariness of spin quantization direction. We exploit it to make expressions compact.

To obtain amplitudes \( \mathcal{H} \) with definite helicity state spin-rotation matrices should be applied for each index \( \chi \) of incoming particles independently:
\[ C^{\chi_i} = \left[ \begin{array}{c} k_{i^*} p_5 \\ |p_i p_5| \\ m_i [k_{i^*} p_5] \\ [k_{i^*} k_{i^*}] [p_i p_5] \end{array} \right] = \left[ \begin{array}{c} \langle k_{i^*} p_i \rangle \\ \langle k_{i^*} k_{i^*} \rangle \langle p_i p_5 \rangle \\ m_i [k_{i^*} p_5] \\ [k_{i^*} k_{i^*}] [p_i p_5] \end{array} \right], \]

where
\[ k_{i^*} = \{|p_i|, -p_i^x, -p_i^y, -p_i^z\}, \quad k_{i^*}^2 = 0, \]
\[ k_{i^*} = p_i - \frac{m_i^2}{2p_i \cdot k_{i^*}}, \quad k_{i^*}^2 = 0. \]
3 Numerical results and comparison

In this section, we present the numerical results for the EW RC to $e^+e^-\rightarrow HZ$ obtained with help of SANC. We work in $\alpha(0)$-scheme and use the following set of input parameters:

\[
\begin{align*}
\alpha^{-1}(0) &= 137.03599976, \quad \Gamma_Z = 2.49977 \text{ GeV} \\
M_W &= 80.4514958 \text{ GeV}, \quad M_Z = 91.1876 \text{ GeV}, \quad M_H = 125 \text{ GeV}, \\
m_e &= 0.51099907 \text{ MeV}, \quad m_\mu = 0.105658389 \text{ GeV}, \quad m_\tau = 1.77705 \text{ GeV}, \\
m_d &= 0.083 \text{ GeV}, \quad m_s = 0.215 \text{ GeV}, \quad m_b = 4.7 \text{ GeV}, \\
m_u &= 0.062 \text{ GeV}, \quad m_c = 1.5 \text{ GeV}, \quad m_t = 173.8 \text{ GeV}.
\end{align*}
\tag{20}
\]

For the real photon emission we apply the cut on the photon energy $E_\gamma > 1 \text{ GeV}$.

In [21] we compared the results for one-loop EW corrections (excluding hard Bremsstrahlung) with the results of [16] and the program Grace-Loop [22].

In this paper in order to cross-check the results of hard and Born cross sections we produce the results for these contributions with the help of the WHIZARD and CalcHEP programs. We receive complete agreement in all digits.

- Energy dependence

Tables 1 – 3 show our results for polarized Born, hard Bremsstrahlung and 1-loop cross sections and relative correction $\delta$ in percents, which is defined as

\[
\delta = \frac{\sigma^{\text{1-loop}} - \sigma^{\text{Born}}}{\sigma^{\text{Born}}} \cdot 100%.
\tag{21}
\]

for various energies and polarization degrees of initial particles.

| $P_e^-$ | $P_e^+$ | $\sigma^{\text{hard}}$, fb | $\sigma^{\text{Born}}$, fb | $\sigma^{\text{1-loop}}$, fb | $\delta$, % |
|-------|-------|------------------------|------------------------|------------------------|--------|
| 0     | 0     | 82.0(1)                | 225.59(1)              | 206.91(1)              | -8.28(1) |
| -0.8  | 0     | 47.6(1)                | 266.05(1)              | 223.52(2)              | -15.99(1) |
| -0.8  | -0.6  | 46.3(1)                | 127.42(1)              | 111.76(2)              | -12.29(1) |
| -0.8  | 0.6   | 147.1(1)               | 404.69(1)              | 335.28(1)              | -17.15(1) |

Table 1: Hard, Born and 1-loop cross sections in fb of the process $e^+e^-\rightarrow ZH$ and relative correction $\delta$ in percents for energy 250 GeV and various polarizations of initial particles produced by SANC.

As it can be seen in Table 1, taking into account the polarization significantly affects the value of the observed cross section: at zero beam polarization the correction value is negative and equal to $-8.28(1)$%, and with different set of the polarization beams the correction remains negative and is two time bigger, up to $-17.15\%$.

From Tables 2 and 3 we see that at zero beam polarization the correction value is positive and equal $16.17(1)$ for 500 GeV and $20.97(1)$ for 1000 GeV, and with different set of the polarization beams the correction remains positive and varies greatly, up to 6.43% for 500 GeV and 9.57 for 1000 GeV.
\[
\begin{array}{|c|c|c|c|c|c|c|}
\hline
P_{e^-} & P_{e^+} & \sigma^{\text{hard}}, \text{fb} & \sigma^{\text{Born}}, \text{fb} & \sigma^{\text{1-loop}}, \text{fb} & \delta, \% \\
\hline
0 & 0 & 38.95(1) & 53.74(1) & 62.43(1) & 16.17(1) \\
-0.8 & 0 & 45.92(1) & 63.38(1) & 68.32(1) & 7.80(1) \\
-0.8 & -0.6 & 22.10(1) & 30.35(1) & 34.04(1) & 12.16(1) \\
-0.8 & 0.6 & 69.74(1) & 96.40(1) & 102.60(1) & 6.43(1) \\
\hline
\end{array}
\]

Table 2: Hard, Born and 1-loop cross sections in fb of the process \(e^+e^- \to ZH\) and relative correction \(\delta\) in percents for energy 500 GeV and various polarizations of initial particles produced by SANC.

\[
\begin{array}{|c|c|c|c|c|c|c|}
\hline
P_{e^-} & P_{e^+} & \sigma^{\text{hard}}, \text{fb} & \sigma^{\text{Born}}, \text{fb} & \sigma^{\text{1-loop}}, \text{fb} & \delta, \% \\
\hline
0 & 0 & 11.67(1) & 12.05(1) & 14.58(1) & 20.97(1) \\
-0.8 & 0 & 13.75(1) & 14.217(1) & 15.824(1) & 11.31(1) \\
-0.8 & -0.6 & 6.65(1) & 6.809(1) & 7.955(1) & 16.84(1) \\
-0.8 & 0.6 & 20.85(1) & 21.62(1) & 23.69(1) & 9.57(1) \\
\hline
\end{array}
\]

Table 3: Hard, Born and 1-loop cross sections in fb of the process \(e^+e^- \to ZH\) and relative correction \(\delta\) in percents for energy 1000 GeV and various polarizations of initial particles produced by SANC.

• Angular dependence

Figure 1 shows the distributions of left-right asymmetry \(A_{LR}\) for three different energies \(\sqrt{s} = 250, 500, 1000\) GeV, where \(A_{LR}\) is defined as

\[
A_{LR} = \frac{\sigma_{LR} - \sigma_{RL}}{\sigma_{LR} + \sigma_{RL}}. \tag{22}
\]

At Born level the \(A_{LR}\) is constant:

\[
A_{LR}^{\text{Born}} = \frac{-3M^4_Z + 4M^2_Z M^2_W}{5M^4_Z - 12M^2_Z M^2_W + 8M^4_W} = 0.2243. \tag{23}
\]

4 Conclusion

In the paper we investigate the process \(e^+e^- \to ZH\) at one-loop level with longitudinal polarizations of the positron and electron beams.

HA approach to the calculation of all components of the cross section: Born, virtual, soft part and hard Bremsstrahlung makes it easy to take into account any polarization of the beams.

Table 1-3 summarizes the estimation of the the correction value \(\delta\) in percent for the set (0,0;0.8,0.7;0.8,0.6;0.8,0.6) of longitudinal polarizations \(P_{e^+}\) and \(P_{e^-}\) of the positron and electron beams, respectively, and for the energies: 250, 500, 1000 GeV. Estimation of correction \(\delta\) amounts significant value: 6-20 \% for our set of the polarization value.

The asymmetry analysis shows a significant increase in \(A_{LR}\) at high angles with the increasing energy (from 250 GeV to 1000 GeV).
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