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Comparing Event Generators for Radiative Bhabha Interaction at CEPC

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Abstract

Small-Angle Bhabha Scattering is a traditional process used for high-precision luminosity measurement at electron-positron colliders, known for its clean event signature and large cross section. The Circular Electron Positron Collider (CEPC) is a Higgs factory that will produce millions of HZ events at $\sqrt{s} = 240\text{GeV}$, and 0.7 trillion Z bosons at the Z-pole energy. In order to improve precision on measurements of Standard Model processes, the luminosity systematic with an accuracy of 10^{-4} is required. This study focuses on the measurement of radiative Bhabha interaction using the event generators ReneSANCe and BHLUMI, aiming to achieve a systematic uncertainty of 0.01% for the Bhabha cross-sections. The radiative photons from NLO processes are compared in terms of momentum and opening angles relative to the electrons, considering the luminometer acceptance at CEPC.

Introduction

The cutting-edge methods for calculating luminosity theoretically using BabaYaga [1] and BHLUMI [2] have been identified as the most advanced codes. The Monte Carlo (MC) BHLUMI generator, which is solely based on QED principles, has a theoretical uncertainty of around 0.037% (refer to Table 2 in [3]). The study also outlined the potential for achieving a theoretical precision of 10^{-4} in future collider experiments at the Z peak for luminosity measurements.

The latest version of BabaYaga now includes considerations for a range of radiative corrections, such as QED, (electro)weak, and higher-order effects. This generator is primarily designed for large-angle Bhabha scattering, with theoretical uncertainties estimated to be around 0.1% [4]. As our study focused on Small-Angle Bhabha Scattering (SABS), we opted not to utilize the BabaYaga generator.

Besides, we also made use of the Monte Carlo event generator RenSANCe (Renewed SANC Monte Carlo event generator) in our research. This generator provides a precise electroweak (EW) description at next-to-leading order (NLO) for important processes at electron-positron colliders, considering polarization effects [5].

The poster is structured as follows. In the section "SABS cross sections" we compared the numerical results for the cross sections with MC generator BHLUMI and ReneSANCe. In the section “Angular distributions," we discussed angular event distributions of experimental significance and analyzed the impact of the minimum cut-off on the electron scattering angle with MC generator ReneSANCe.

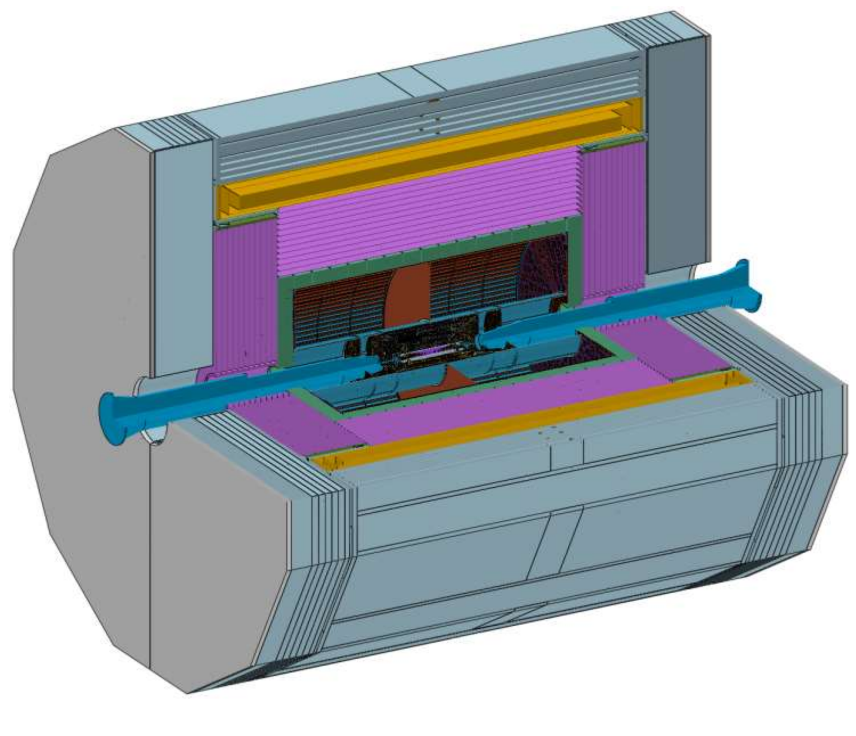

Figure 1. The conceptual design of CEPC detector.

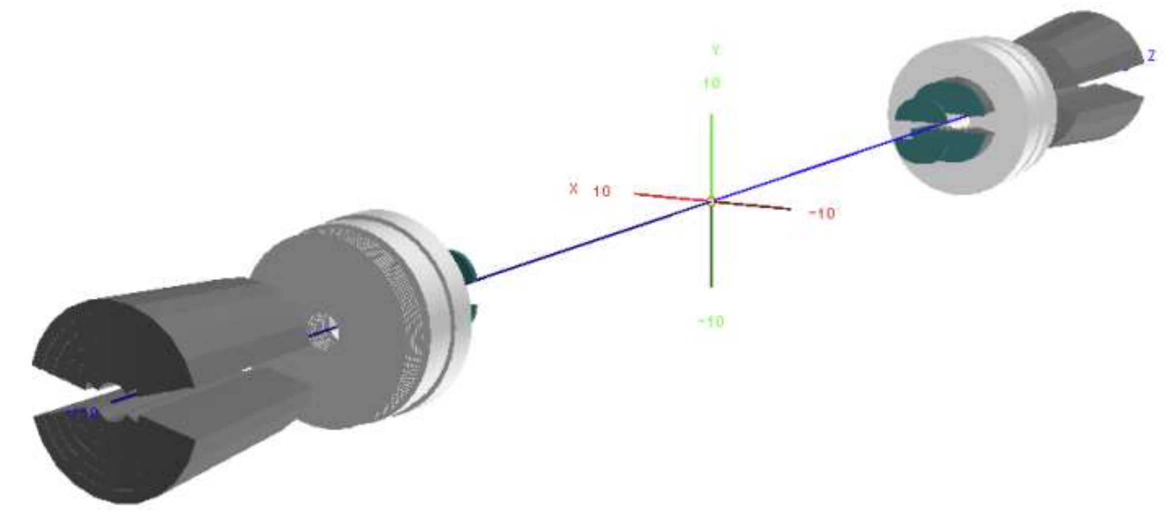

Figure 2. The geometry of LumiCal.

SABS cross sections

The results were obtained within the $\alpha(0)$ electroweak scheme. Additionally, the luminosity acceptance was set at θ > 30 mrad (1.72 degrees).

In order to showcase the capabilities of the two programs, we generated 1 million events for the Bhabha cross section at center-of-mass (c.m.s.) energies ranging from 100 GeV to 300 GeV. The results are presented in Table 1 and Figure 5.

```
# Process id:
pid : 101
    # 101 - e^+e^-  --> e^-e^+
    # 102 - e^+e^-  --> ZH
    # 103 - e^+e^-  --> mu^-mu^+
    # 104 - e^+e^-  --> tau^-tau^+
#!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
# ALR:
alr  : 0
    # 0 - sigma, 1 - sigma_RL-sigma_LR, 2 - sigma_RL+sigma_LR,
    # 3 - sigma_0L-sigma_0R, 4 - sigma_0L+sigma_0R
#!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
# Longitudinal polarization of initial particles:
lamep :    0 # e^+ polarization
lamem :    0 # e^- polarization
#!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
# EW scheme:
gfscheme : 0
 # 0 - alpha(0)
```

Figure 3. Example ReneSANCe settings file.

```
prod2 prod2 llog2 obis2   =========Data set for BHLUM2 test=========
 0 1 0 0 0 0 0 0    KAT1,KAT2,KAT3,KAT4,KAT5,KAT6,KAT7,KAT8
   1000000      NEVT
      3001      KEYOPT = 1000*KEYGEN +100*KEYREM +10*KEYWGT +KEYRND
      1022      KEYRAD =              100*KEYUPD +10*KEYMOD +KEYPIA
         2      KEYTRI  Obsolete!!!
     240D0      CMSENE
       .03      Tming   theta_min [rad]    genaration
1.57079633      Tmaxg   theta_max          generation
   0.9999D0     VMAXG   v_max              generation
      1D-5      XK0     eps_CMS            generation
      .024      TminW   theta_min sical    trigger wide
      .058      TmaxW   theta_max sical    trigger wide
      .024      TminN   theta_min          trigger narrow
      .058      TminN   theta_max          trigger narrow
     0.5D0      VMAXE   v_max              trigger maximum v
        32      NPHI    nphi      sical    trigger no of phi   sect.
        16      NTHE    ntheta    sical    trigger no of theta sect.
================ the end of data set BHLUM2 ================
```

Figure 4. Example BHLUMI settings file.

Table 1. The cross section.

$\sqrt{s}$, GeV	σ, nb (ReneSANCe)	σ, nb (BHLUMI)
100	120.33(3)	120.59(8)
120	83.80(2)	84.14(5)
140	61.75(2)	61.96(4)
160	47.37(1)	47.58(3)
180	37.50(1)	37.67(2)
200	30.42(1)	30.59(2)
220	25.19(1)	25.34(2)
240	21.19(1)	21.32(1)
260	18.08(1)	18.20(1)
280	15.62(1)	15.71(1)
300	13.61(1)	13.71(1)

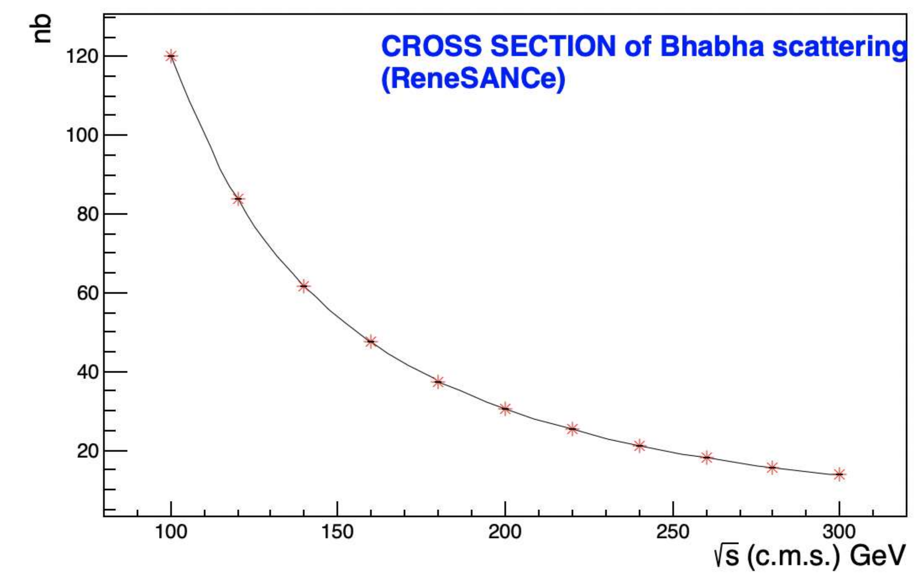

Figure 5. Variation of the cross section with c.m.s..

Angular distributions

Next, we examined the distribution of lepton scattering angles between the outgoing and incoming positrons, as well as the distribution based on the angle at which the photon was emitted.

We generated 1 million Bhabha events at $\sqrt{s} = 240\text{GeV}$ for the acceptance of the luminometer θ > 30 mrad (1.72 degrees). The sharp edges at 1.72 degrees correspond to the acceptance limits of the luminometer. The results are shown in Figure 6-8.

And then we set the range of luminosity measurement from 30 mrad to 174.5 mrad, and assumed electrons were allowed to scatter by any angle, down to zero. We discovered that the total fraction of events within the angular range of (0, 30) mrad for θ_{14} is approximately 1-2 permille. In the angular range of (0, 10) mrad, the relative event yield is about less than 10^{-4}.

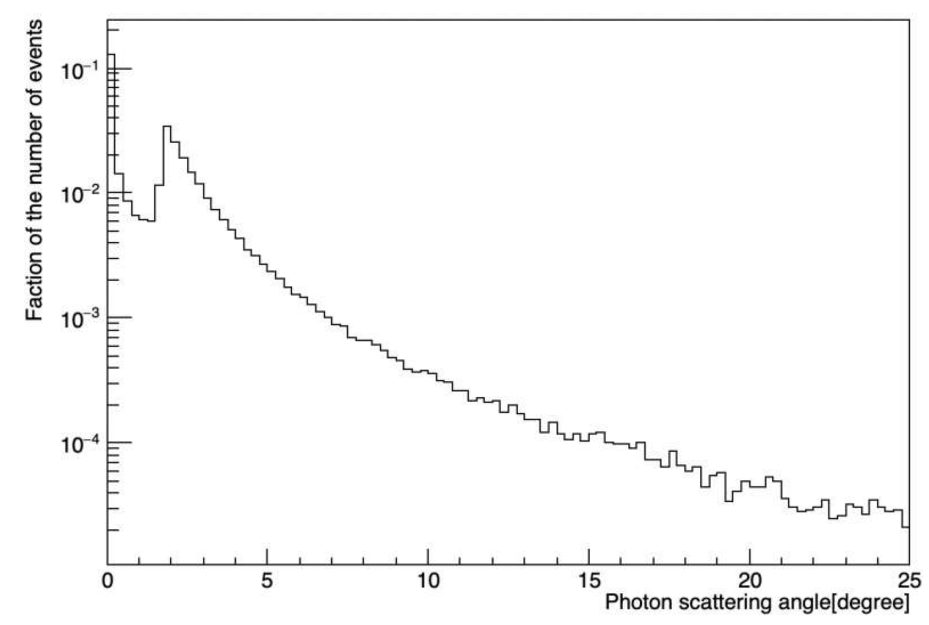

Figure 6. Angular distribution θ_{15} between the initial positron p_1 and the photon p_5 .

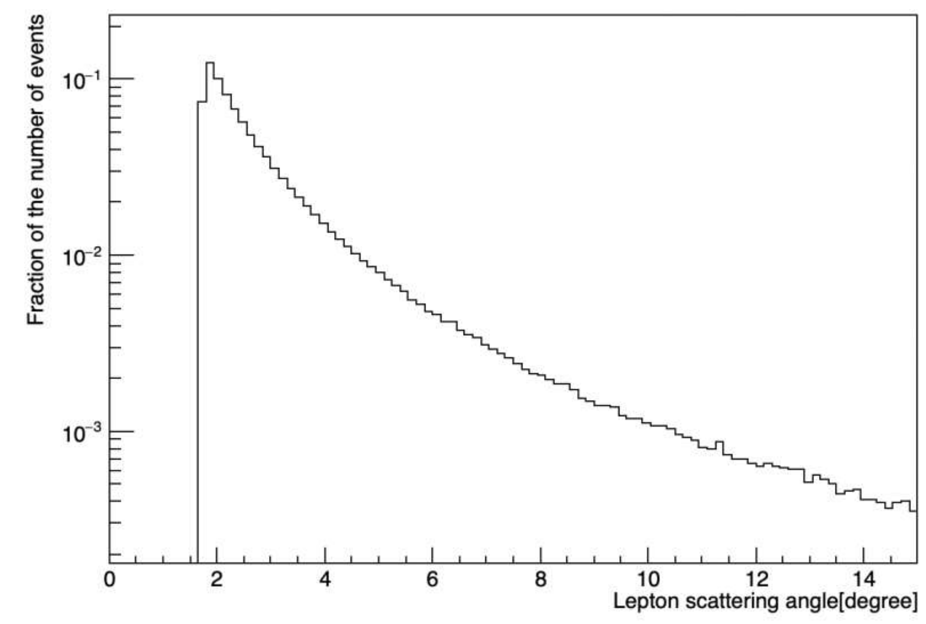

Figure 7. Angular distribution θ_{14} between the initial positron p_1 and the final positron p_4 .

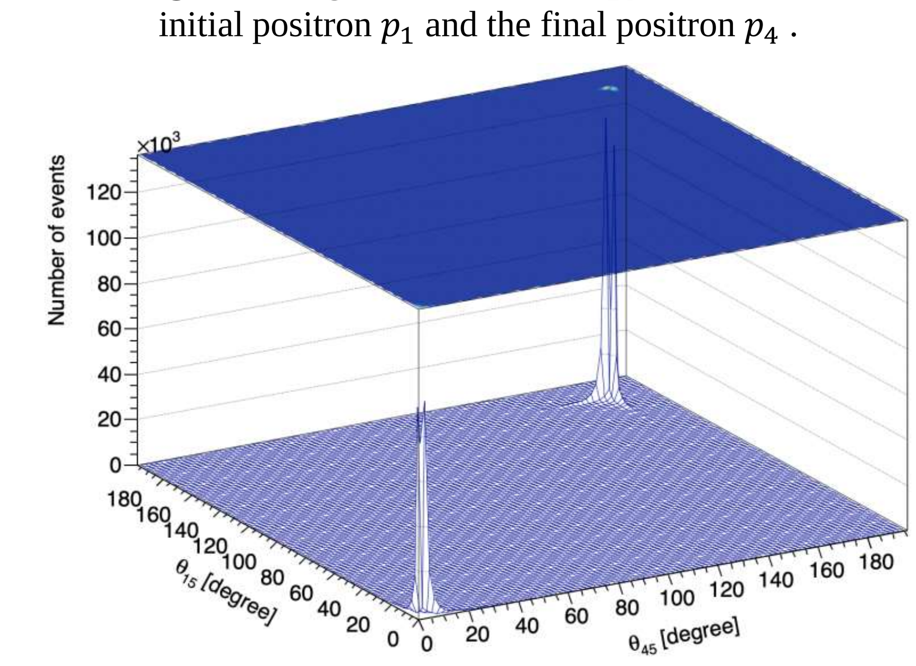

Figure 8. Angular distribution θ_{45} vs θ_{15}, indicating FSR and ISR photons with small opening angles to p_4 and p_5, respectively.

Conclusions

We utilized the BHLUMI and ReneSANCe generators to simulate small-angle Bhabha scattering. Comparisons of scattering cross sections were made at the luminosity acceptance greater than 30 mrad, and the results from both generators showed a rough match. We plan to further optimize the parameter settings of the two programs. In terms of studying the angular distribution, we exclusively employed the ReneSANCe generator and intend to extend this analysis to BHLUMI. Detailed statistics on the fraction of the number of events at the lepton scattering range of (0, 30) mrad and (0, 10) mrad with the acceptance of the luminometer (30, 174.5) mrad will be conducted. Our study suggests that the detection of Small-Angle Bhabha Scattering events is a viable approach to achieving a precision of 10^{-4} for the luminosity measurement at CEPC.

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