



# Bhabha Event Acceptance of the LumiCal at CEPC

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## Abstract

Small-angle Bhabha scattering (SABS) is the best calculated QED process as a reference channel for achieving ultra-high-precision luminosity measurements at electron-positron colliders. The event topology for detecting a pair of back-to-back scattered electron and positron has well defined detector acceptance, with precisely calculated cross-section. The “Circular Electron Positron Collider” (CEPC) is proposed to operate as a Higgs factory with  $\sqrt{s} = 240$  GeV to deliver  $1.2 \times 10^6$  Higgs boson events. It will also be running at Z-pole energy to produce  $7 \times 10^{11}$  Z boson events. The systematic uncertainties on luminosity must be contained to  $10^{-4}$  to meet the stringent demands on Standard Model measurements. In this study, we have employed the BHLUMI event generator to evaluate detection of Bhabha scattering final state particles within the geometric acceptance of the LumiCal. The analysis focuses on characterizing the kinematics distributions of electrons and radiative photons for luminosity measurements.

## Introduction

The design of the LumiCal is dedicated to ultra-precise forward-angle measurements with sub-millimeter spatial resolution, targeting the detection of Bhabha scattering events in the forward region. And currently, the only Monte Carlo tool with well-predicted behavior near the z-pole for SABS events is BHLUMI[1], developed based on the LEP experiment. It is solely based on QED principles and has a theoretical uncertainty of around 0.037% (refer to Table 2 in [2]). Therefore, BHLUMI is our preferred choice for predicting the physical outcomes obtained from the LumiCal.

The poster is structured as follows. In the section "SABS cross sections", we compared the numerical results obtained for different LumiCal acceptance ranges and also examined the angular distribution of electrons. In the section “Radiative SABS”, we analyzed the proportion of radiative SABS events and the behavior of radiated photons, aiming to control the errors inherent in QED theory itself through NLO measurements, thereby further enhancing the precision of CEPC luminosity measurements.

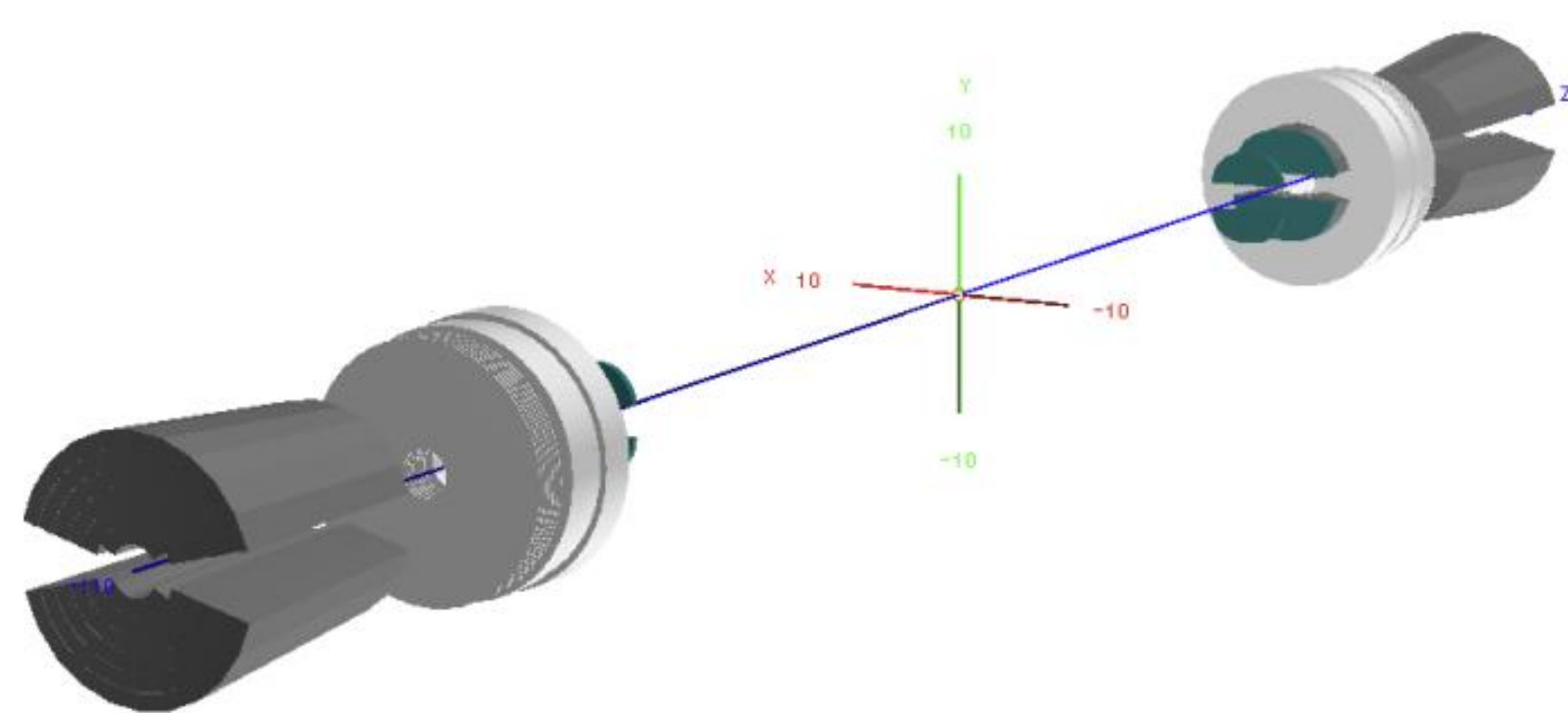


Figure 1. The geometry of LumiCal.

## SABS cross sections

We generated  $10^7$  SABS events using BHLUMI, distributed across the ranges of 10–80 mrad and 10–120 mrad according to the CEPC operation plan.

Considering the 33 mrad cross-angle, Table 1, 2, and 3 present the corresponding cross section information at  $z = 1000$  mm. Here,  $r$  represents the distance from the beam pipe for boosted particles, and  $y$  denotes the y-coordinate of particles when the z-axis coordinate is set to 1000 mm.

To ensure the accuracy of the cross section information, we also examined the distribution of electrons, as shown in Figure 2.

|               | CMS generated<br>Th1, Th2(mrad) | $e^-$ or $e^+$ to pipe<br>centers (mm) | Single $e^-$ in<br>(mm) | Both $e^-$ and $e^+$ in<br>(mm)   |
|---------------|---------------------------------|----------------------------------------|-------------------------|-----------------------------------|
| $\sigma$ (nb) | 10 to 80<br>1206.67             | $10 < r,  y  < 80$<br>1279.09          | $20 < r$<br>299.21      | $\text{and. }  y  > 20$<br>141.52 |
| $\sigma$ (nb) | 10 to 80<br>1206.67             | $10 < r,  y  < 80$<br>1279.09          | $25 < r$<br>184.40      | $\text{and. }  y  > 25$<br>84.64  |
| $\sigma$ (nb) | 10 to 120<br>1216.68            | $10 < r,  y  < 120$<br>1288.97         | $25 < r$<br>195.90      | $\text{and. }  y  > 25$<br>94.14  |

Table 1. The cross section at  $\sqrt{s} = 91$  GeV.

|               | CMS generated<br>Th1, Th2(mrad) | $e^-$ or $e^+$ to pipe<br>centers (mm) | Single $e^-$ in<br>(mm) | Both $e^-$ and $e^+$ in<br>(mm)  |
|---------------|---------------------------------|----------------------------------------|-------------------------|----------------------------------|
| $\sigma$ (nb) | 10 to 80<br>390.94              | $10 < r,  y  < 80$<br>416.14           | $20 < r$<br>97.21       | $\text{and. }  y  > 20$<br>46.07 |
| $\sigma$ (nb) | 10 to 80<br>390.94              | $10 < r,  y  < 80$<br>416.14           | $25 < r$<br>59.93       | $\text{and. }  y  > 25$<br>27.56 |
| $\sigma$ (nb) | 10 to 120<br>395.03             | $10 < r,  y  < 120$<br>420.23          | $25 < r$<br>63.83       | $\text{and. }  y  > 25$<br>30.70 |

Table 2. The cross section at  $\sqrt{s} = 160$  GeV.

|               | CMS generated<br>Th1, Th2(mrad) | $e^-$ or $e^+$ to pipe<br>centers (mm) | Single $e^-$ in<br>(mm) | Both $e^-$ and $e^+$ in<br>(mm)  |
|---------------|---------------------------------|----------------------------------------|-------------------------|----------------------------------|
| $\sigma$ (nb) | 10 to 80<br>174.33              | $10 < r,  y  < 80$<br>186.10           | $20 < r$<br>43.48       | $\text{and. }  y  > 20$<br>20.58 |
| $\sigma$ (nb) | 10 to 80<br>174.33              | $10 < r,  y  < 80$<br>186.10           | $25 < r$<br>26.81       | $\text{and. }  y  > 25$<br>12.31 |
| $\sigma$ (nb) | 10 to 120<br>175.99             | $10 < r,  y  < 120$<br>187.75          | $25 < r$<br>28.51       | $\text{and. }  y  > 25$<br>13.72 |

Table 3. The cross section at  $\sqrt{s} = 240$  GeV.

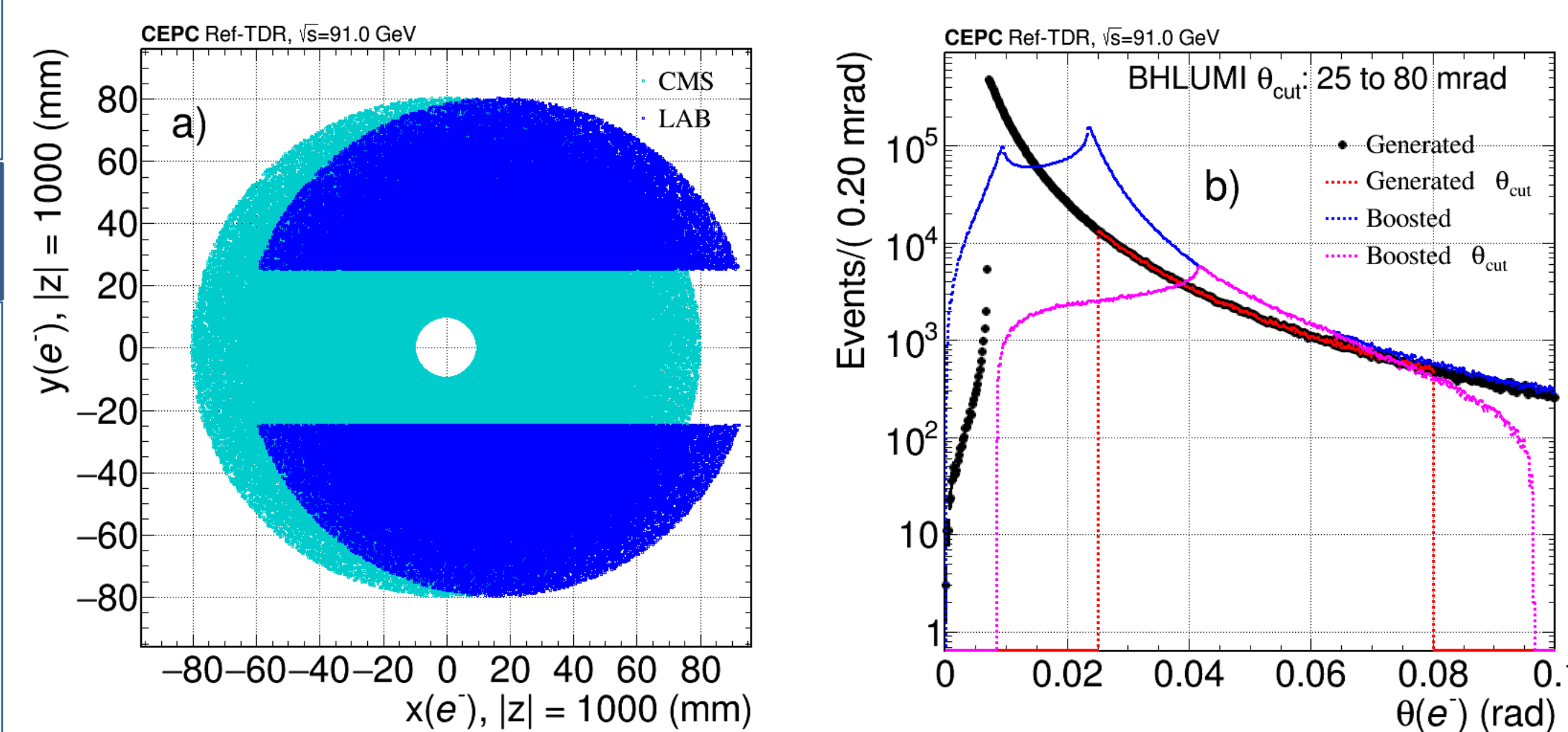


Figure 2. (a) The distribution of scattered electrons.

(b) The back-to-back angles between  $e^+$  and  $e^-$  for both the generated and boosted events.

## Radiative SABS

Next, we will focus on the Radiative SABS event.

When estimating cross section information, we also employed an alternative Monte Carlo event generator ReneSANCe[3]. The total cross section results from both methods differ only slightly, but they diverge in their description of radiative photons, as shown in Figure 3. As shown in Figure 3b, BHLUMI permits multi-photon generation, whereas ReneSANCe allows at most a single photon to be produced. This discrepancy also leads to inconsistencies in the behavior of high transverse momentum electrons between them (in Figure 3c).

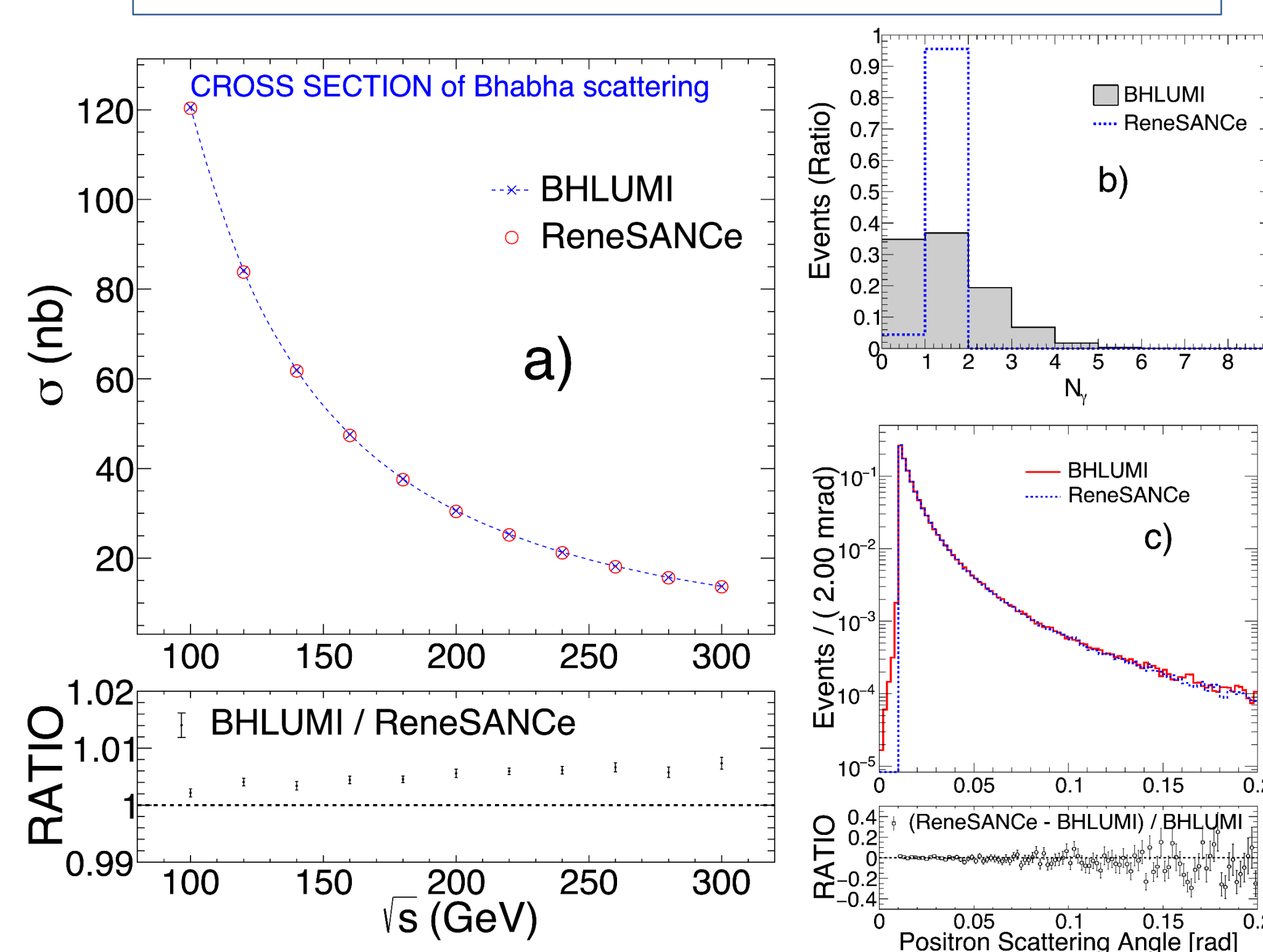


Figure 3. (a) Variation of the cross section with  $\sqrt{s}$ .

(b) The distribution of the radiative photon number.

(c) The angular distribution of positrons.

Given the practical constraints of the detector, we focus solely on the two photons with the highest energy. The corresponding angular distributions of photons relative to electrons are shown in Figure 4.

To better understand the radiative Bhabha process, we utilized BHLUMI to analyze the rate of multiphoton events at different working energy points for CEPC with the mentioned LumiCal structure.

At the same time, we require that the photon's energy  $E_\gamma > 0.1$  GeV and the angle between the photon and the adjacent electron  $\theta_{e\gamma} > 5$  mrad. The corresponding results are shown in Table 4 and Figure 5. Figure 5 illustrates the distribution of photons to ensure the accuracy of the cross section.

As can be seen, the cross section of the radiative SABS event is quite small within the luminosity monitoring range of the LumiCal. However, due to the extended operation of CEPC at z-pole, this presents a potential opportunity for NLO measurements.

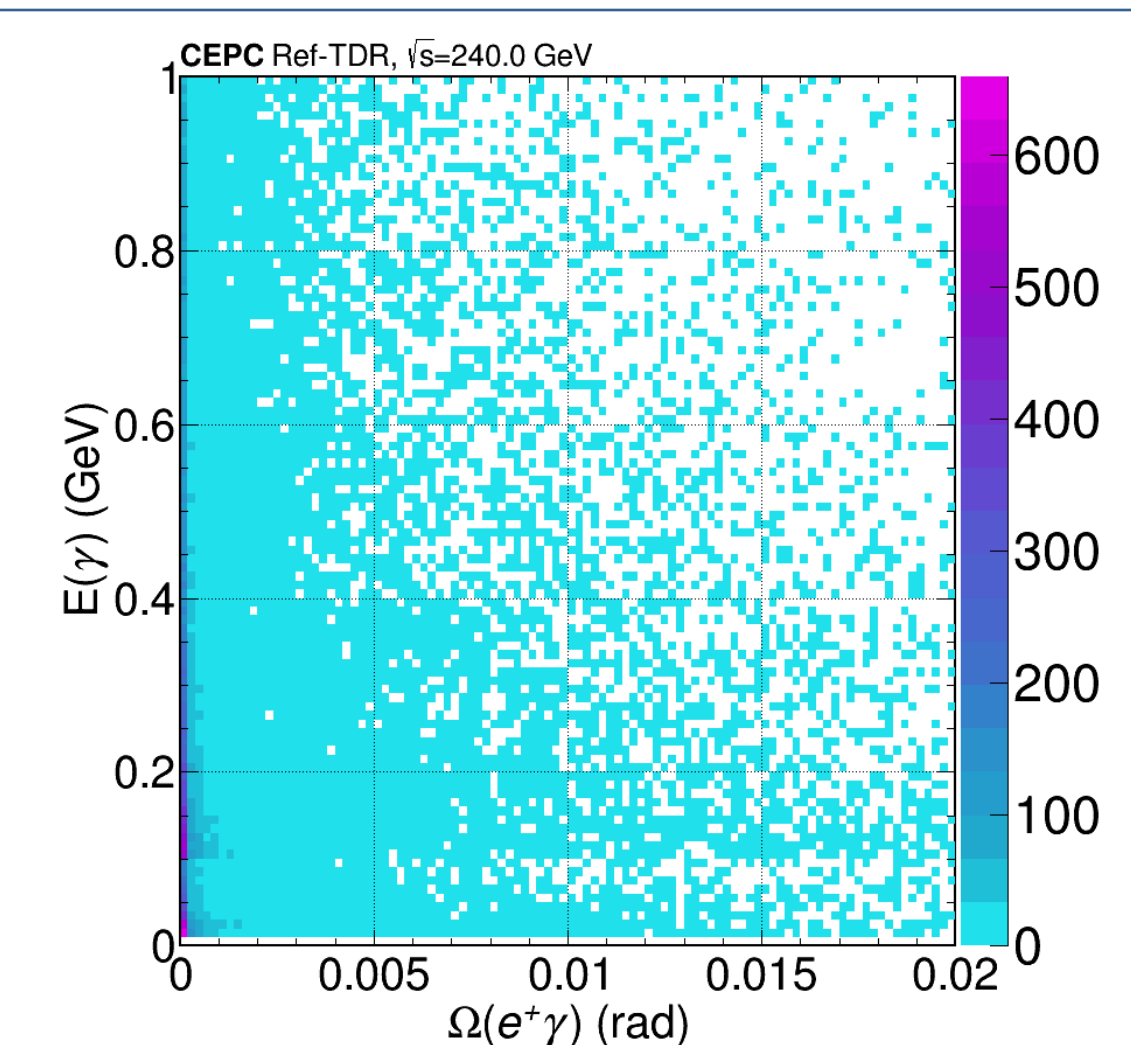


Figure 4. The angle between the photon and the adjacent positron  $\theta_{e^+\gamma}$  vs the energy of photon  $E_\gamma$ .

|               | CMS<br>(GeV) | Both $e^-$ and $e^+$ in<br>(mm) |                                   | ONE<br>PHOTON   | TWO<br>PHOTON   | NONE               |
|---------------|--------------|---------------------------------|-----------------------------------|-----------------|-----------------|--------------------|
| $\sigma$ (nb) | 92.3         | $20 < r$<br>278.31              | $\text{and. }  y  > 20$<br>131.11 | 7.97<br>(6.08%) | 0.22<br>(0.17%) | 122.91<br>(93.75%) |
| $\sigma$ (nb) | 160          | $20 < r$<br>92.96               | $\text{and. }  y  > 20$<br>43.90  | 2.88<br>(6.56%) | 0.09<br>(0.21%) | 40.93<br>(93.23%)  |
| $\sigma$ (nb) | 240          | $20 < r$<br>41.49               | $\text{and. }  y  > 20$<br>19.56  | 1.35<br>(6.91%) | 0.04<br>(0.20%) | 18.17<br>(92.89%)  |

Table 4. The cross sections and event rates for single and double photon radiation at different  $\sqrt{s}$ .

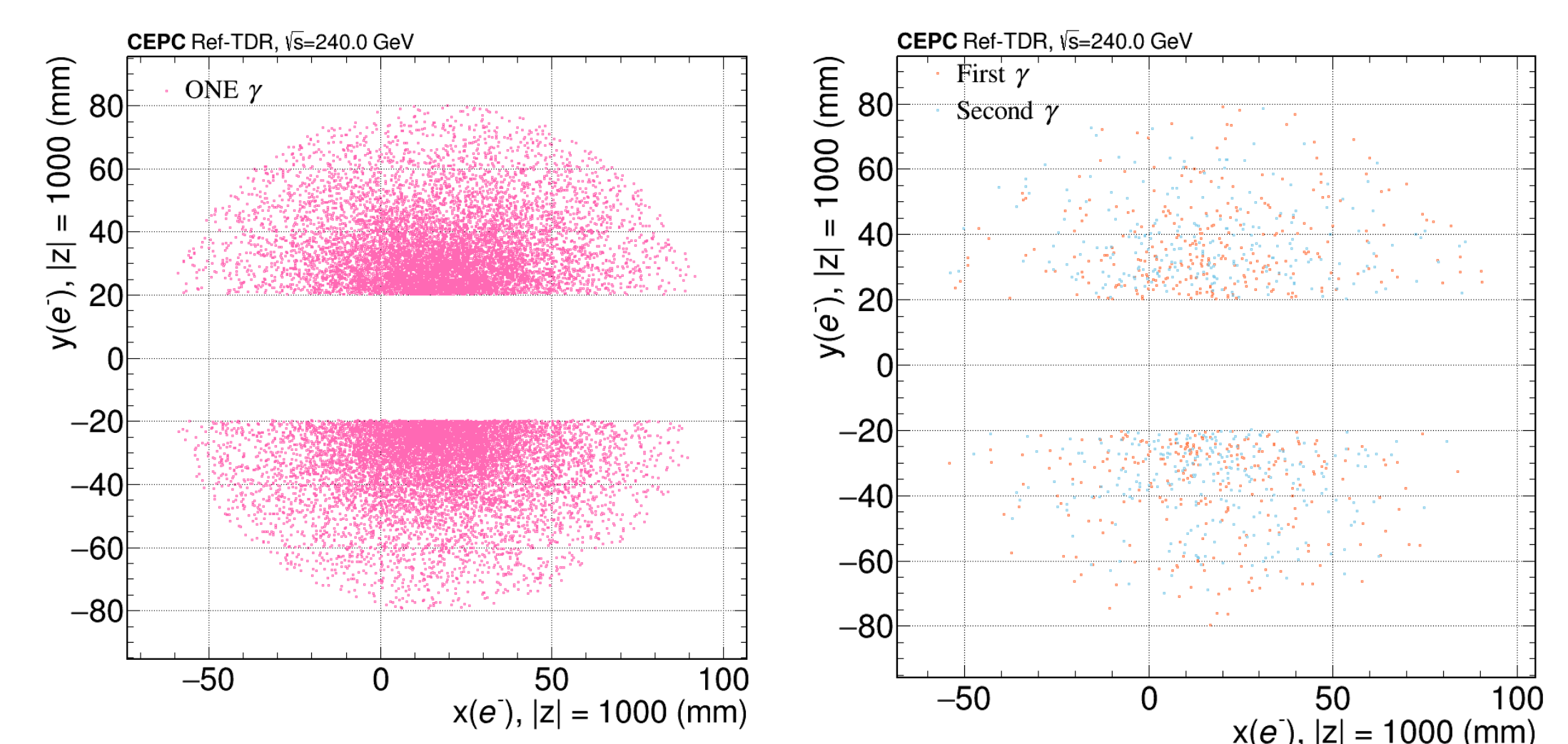


Figure 5. The distribution of photons for the single-photon events at  $z = 1000$  mm (left) and the distribution of photons for the double-photon events at  $z = 1000$  mm (right).

## Conclusions

By integrating the design parameters of the LumiCal with the BHLUMI simulation framework, we accurately predict the cross-section information of Small-angle Bhabha Scattering events under the CEPC operation plan. Concurrently, addressing discrepancies in modeling radiative SABS processes with different generators, we preliminarily evaluate the measurability of radiative photon events. Furthermore, we propose an iterative optimization strategy for program parameters and detector calibration to enhance measurement precision. This work demonstrates that radiative SABS detection will set a new benchmark for precision luminosity monitoring at CEPC while advancing quantum electrodynamics (QED) validation through high-field electromagnetic interaction measurements.

## Contact

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## References

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