A simulation of Interaction Region in a Photon Photon Collider

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Abstract

The status and initial performance of a simulation program for interaction region of Linear Colliders is described. The program is developed to be applicable for e^+e^-, e^-e^-, $e^-\gamma$ and $\gamma\gamma$ Linear colliders. As an example of an application, simulation of a $\gamma\gamma$ collider option of NLC is reported.

1 Introduction

As options of e^+e^-linear colliders, feasibility studies for e^-e^-, $e^-\gamma$ and $\gamma\gamma$ colliders have become active in resent years. For linear colliders, detail knowledge of beam-beam interaction is important to estimate background to the detector as well we to calculate realistic luminosity. In order to study these effects, a Monte Carlo simulation program for beam-beam interaction in e^+e^-colliders,ABEL,was developed[1]. The original ABEL included beam disruption and beamstrahlung and was later modified to include electron position pair creation which is potentially a serious source of background to the detector(ABELMOD)[2, 3]

For e^-e^-, $e^-\gamma$ and $\gamma\gamma$ colliders, the same kind of simulation is necessary to understand beam-beam interaction but the situation is much more complicated due to complicated scheme of the beam collision. In $e^-\gamma$ and $\gamma\gamma$ colliders, an intense laser beam is flashed to the incoming electron beam just before interaction point to convert the high energy electron beam to the high energy photon beam by Compton scattering. A simulation program for these colliders is required to implement laser-electron interaction at the conversion point which is typically order of cm before the interaction point. In addition to the conversion point, the simulation of beam-beam interaction at the interaction point is more complicated than the e^+e^-collider case, since 1), the initial state includes not only electrons and positron but photons 2), as a consequence of Compton interaction at the conversion point, electron and photon beams have wider spectrum in both energy and spatial distribution than those of e^+e^-colliders. According to these feature of new type linear colliders, it is necessary to develop a new simulation program for beam-beam interaction. To meet this requirement, a project to make a new comprehensive beam-beam simulation program named CAIN has started[4] which should include, Compton and Breit-Wheeler processes at conversion point, transportation of particles from conversion point to interaction point and interaction of all possible combination of electrons/positrons and photons

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at the interaction pint. By using the Compton scattering part of CAIN, the effect of Breit Wheeler process in a photon photon collider is discussed in in previous paper[5].

In this paper, we report the first version of the comprehensive simulation program which can treat conversion, transportation and interaction region by a single set of the program and is applicable for for all 4 type of e^+e^-, e^-e^-, $e^-\gamma$, $\gamma\gamma$ colliders. As an example of the simulation, energy distribution of generated photons and differential luminosity distribution of a photon photon collider option of NLC is described with putting emphasis on the nonlinear QED effect.

2 Processes in CAIN

A schematic of a $\gamma\gamma$ collider is illustrated in fig.1. Simulations in CAIN can be divided to three parts as is shown in fig.1, i.e, conversion point, transportation and interaction point. The laser beam is introduced to electron beam at conversion point and low energy laser photon beam is converted to high energy photon beam. All particles coming out from the conversion point are transported to the interaction point accordingly and then meet with particles from opposite side.

At the conversion point, Compton and Breit-Wheeler interaction between the laser and the electron beam is simulated. As is described later, primary concept of the design of the laser parameters is to keep effect of nonlinear QED processes as small as possible, however, it not possible to avoid such effect completely to get enough luminosity. The nonlinear Compton processes is expressed as

$$e + n\gamma(laser) \rightarrow e + \gamma$$

where $n\gamma(laser)$ means that more than one laser photons are absorbed coherently by one electron. Since this process makes higher tails in scattered photon spectrum and lowers peak energy of photon spectrum due to the increasing of effective electron mass[6], it has to be kept small to get good photon beams. For the purpose of $\gamma\gamma$ and $e^-\gamma$ collider application, proper treatment of helicity of electron and laser beam is essential since produced photon energy spectrum depends on the helisity state of incoming electrons and photons. In the simulation, cross section formula by Tsai[7] is used in which the polarization of electrons and lasers are taken into account in nonlinear QED calculation. The nonlinear Breit-Wheeler process can be written as

$$\gamma(Compton) + n\gamma(laser) \rightarrow e^+e^-$$

where more than one laser photons are absorbed by (Compton scattered) high energy photons and generates electron positron pairs. This processes produce electron positron pairs even if the center of mass energy of $\gamma(Compton)\gamma(laser)$ system is lower than e^+e^-threshold and could be an additional source of the background in high laser field environment. We also adopt the formula by Tsai[7] for this process.

The transportation process takes care drift of spent electrons, Compton photons and electron positron pairs come out from the conversion point. Photons are simply drifted to the interaction point by their angular divergence. For electrons and positrons, it is

possible to insert sweeping magnet to sweep them out from the interaction point. In the current version of CAIN, a sweeping magnet and synchrotron radiation in the sweeping process is included.

Phenomena at the interaction point is the same as ABELMOD, i.e.; disruption, beamstrahlung, and production of low energy pairs. The difference from ABELMOD is that CAIN needs to take care mixture of electrons and photons in its initial state while , by definition, only electron and positron beam is its initial condition in ABELMOD. The detail of the description of this process are found in [1, 3].

3 Simulation

3.1 Parameters

Simulation was performed with the reference parameters for a $\gamma\gamma$ collider option of NLC[8]. Table 3.1 summarize the parameters.

With these parameters, geometric luminosity of electron electron collision is $8.7 \times 10^{33} cm^{-2} s^{-2}$ which is larger than the typical NLC e^+e^-collider ($5.3 \times 10^{33} cm^{-2} s^{-2}$). Since the luminosity of photon photon colliders is approximately proportional to the geometric luminosity and, unlike e^+e^-collider, these is no strong beamstrahlung at the interaction, the higher geometric luminosity is preferable. For laser parameters, it is chosen that conversion efficiency of incoming electron in a laser pulse is about 0.65. The peak laser power density is about $10^{18} W/cm^2$ which correspond to nonlinear QED parameter

$$\xi^2 = \left(\frac{eE}{\omega mc}\right)^2 \approx 0.4 \left[\frac{I}{10^{18} W/cm^2}\right] \left[\frac{\lambda}{1.054 \mu m}\right]^2 \approx 0.4$$

where e, E, ω, m, c, I and λ are electric charge, strength of laser field, laser photon energy, electron mass, speed of light, laser intensity and laser wave length respectively. In this parameter, we assumed the laser profile is the Gaussian shape in 3 dimension and it can be focused to diffraction limit.

With this set of electron and laser parameter, the Compton kinematic parameter is $x = 4E\omega/m_e^2 = 4.47$ and the maximum photon energyE_{max} in linear Compton limit is;

$$E_{max} = \frac{x}{x+1} E \approx 200 GeV.$$

3.2 Simulation Results

The energy spectrums of Compton scattered photons are plotted in fig. 2 for linear and nonlinear QED calculation. In the simulation, it is assumed that the laser beam is 100% circularly polarized and the electron beam is 100% longitudinally polarized. The combination of the polarization of the laser(λ_γ) and the electron(λ_e) beam is chosen to $\lambda_\gamma \lambda_e = -1$ so that one get relatively narrow peak at high energy edge. Comparing nonlinear with linear Compton spectrum, the maximum energy exceeds $E_{max} = xE_e/(x+1) \approx 200 GeV$ due to multiple laser photon absorption. It is also seen that the high energy peak energy that is about 200GeV in linear Compton spectrum is shifted to lower value

Table 1: Parameters for a photon-photon collider

Electron beam parameters	
Beam energy	250GeV
Number of Particles per bunch	0.65×10^{10}
Repetition rate	180Hz
Number of bunches per pulse	90
Bunch length σ_z	100μm
Bunch sizes (C.P.)	
σ_x	718nm
σ_y	91nm
Bunch sizes (I.P.)	
σ_x	91nm
σ_y	9.1nm
Beta functions (I.P.)	
β_x	0.5mm
β_y	0.5mm
Emittances	
$\gamma\varepsilon_x$	5.0×10^{-6} m·rad
$\gamma\varepsilon_y$	8.0×10^{-8} m·rad
Distance C.P-I.P	5mm
Laser parameters	
Wave length	1.17 μm
Pulse energy	1 J
Pulse length	0.23 mm
Peak power density	$1{\times}10^{18}$ W/cm^2
Repetition rate	180×90 Hz
r.m.s spot size	2.9 μm

Table 2: Summary of the lumonosity

Linear Compoton Simulation	
$L_{\gamma\gamma}$	$0.98L_{geometric}$
	$0.10L_{geometric}$ $(z = E_\gamma/E_e > 0.65)$
$L_{e\gamma}$	$0.71L_{geometric}$
	$0.16L_{geometric}$ $(z = E_\gamma/E_e > 0.65)$
L_{ee}	$0.10L_{geometric}$
	$0.05L_{geometric}$ $(z = E_\gamma/E_e > 0.65)$
Nonlinear Compoton Simulation	
$L_{\gamma\gamma}$	$0.88L_{geometric}$
	$0.08L_{geometric}$ $(z = E_\gamma/E_e > 0.65)$
$L_{e\gamma}$	$0.71L_{geometric}$
	$0.16L_{geometric}$ $(z = E_\gamma/E_e > 0.65)$
L_{ee}	$0.11L_{geometric}$
	$0.06L_{geometric}$ $(z = E_\gamma/E_e > 0.65)$

in nonlinear spectrum. This is the another effect of nonlinear interaction,i.e; increasing of effective electron mass and the peak energy. The peak energy is consistent with expected value,

$$E_{max} = \frac{xE_e}{x + \xi^2 + 1} \approx 190GeV.$$

A differential luminosity spectrum is shown in fig.3 with linear and non linear Compton calculation. In this parameter, there is no sweeping magnet in transportation but $1\sigma_y$ offset collision scheme is adopted to reduce background by beam-beam interaction at the interaction point. In $L_{\gamma\gamma}$ distribution, high c.m.s energy part is made by collision of Compton photons. In the low energy region, a large low energy tail is seen in the spectrum. The source of the tail is beamstrahlung, i.e, collision of beamstrahlung photons and of beamstrahlung and Compton photons. With nonlinear calculation, high energy peak is shifted to lower value due to the shift in Compton photon spectrum and the peak became broader than the linear Compton case. $\gamma\gamma$ luminosity in high energy region is about 8% of geometric luminosity which is 10% in linear Compton calculation reflecting broadness of the high energy peak. The nonlinear effect lower the peak energy and broaden the peak, however, with this parameter ,$\xi^2 = 0.4$ the effect is not appeared to be significant and is tolerable level. Obtained luminosity is summarized in table 2.

Since there is overlap electron beams and of electron and photon beams at the interaction point , some amount of $L_{e\gamma}$ and L_{ee} is observed. From the experimental point of view, the initial state of the interaction should be simple but needs high luminosity as the same time. These requirement are conflicting and more study is needed to find an optimum solution.

4 Summary

We developed a simulation program for phenomena in interaction region for linear colliders which allow us to estimate realistic luminosity distribution and detector background. This simulation program can be used for various type of linear colliders such as $\gamma\gamma$, $e^-\gamma$, $e^-e^-e^+e^-$by just switching input parameter.

The program was used for a photon photon collider option of the NLC and a realistic luminosity distribution was obtained. It was also found that nonlinear QED effect is not negligible in typical parameters for a $\gamma\gamma$ collider. Since characteristic of physics as well as background events depends of the luminosity distribution, it gives us useful information for further study.

5 acknowledgment

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Figure Captions

Fig.1 A Schematic view of a photon linear collider and physical processes.

Fig.2 Simulated photon energy spectrum from Compton conversion point without (a) and with(b) nonlinear QED effect.

Fig.3 Simulated luminosity distribution of a $\gamma\gamma$ collider without (a) and with (b) nonlinear QED effect. Solid, dots and dashed line corresponds to $\gamma\gamma$, $e^-\gamma$ and e^-e^-luminosity respectively.

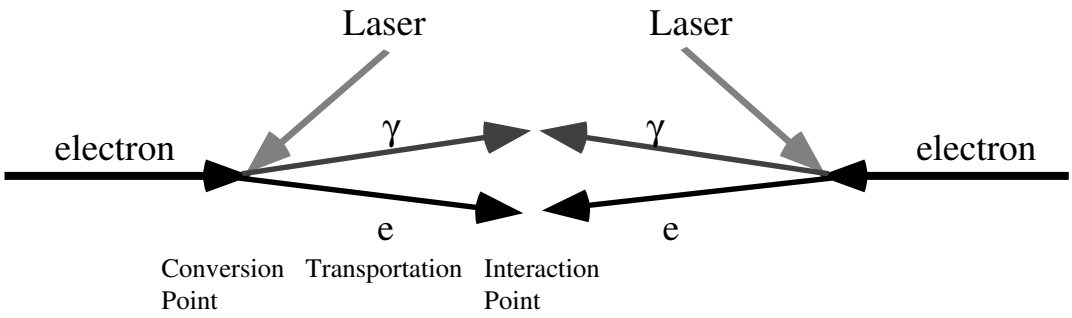

Laser
Laser
electron
γ
γ
electron
e
e
Conversion Point
Transportation
Interaction Point

Fig. 1

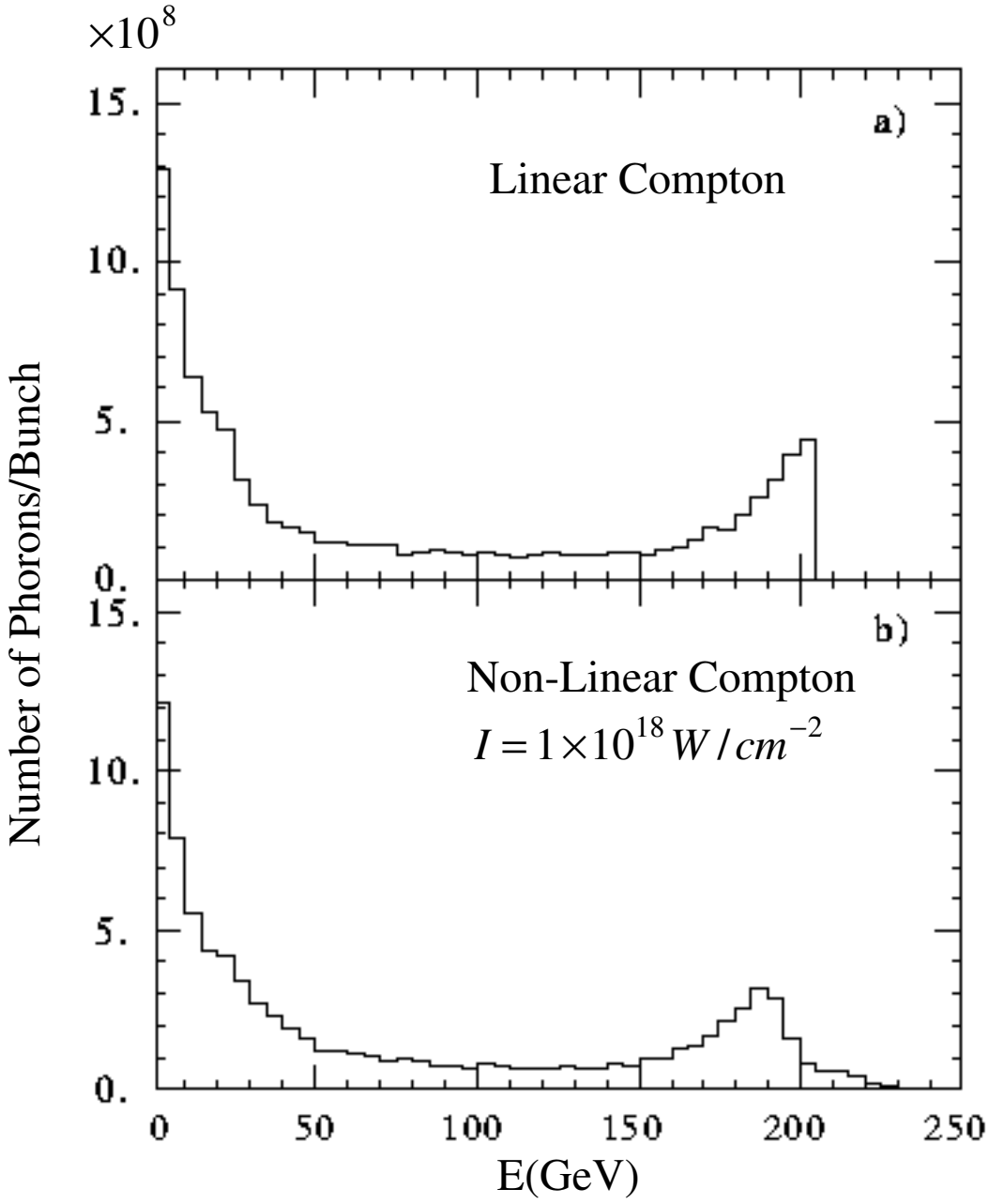
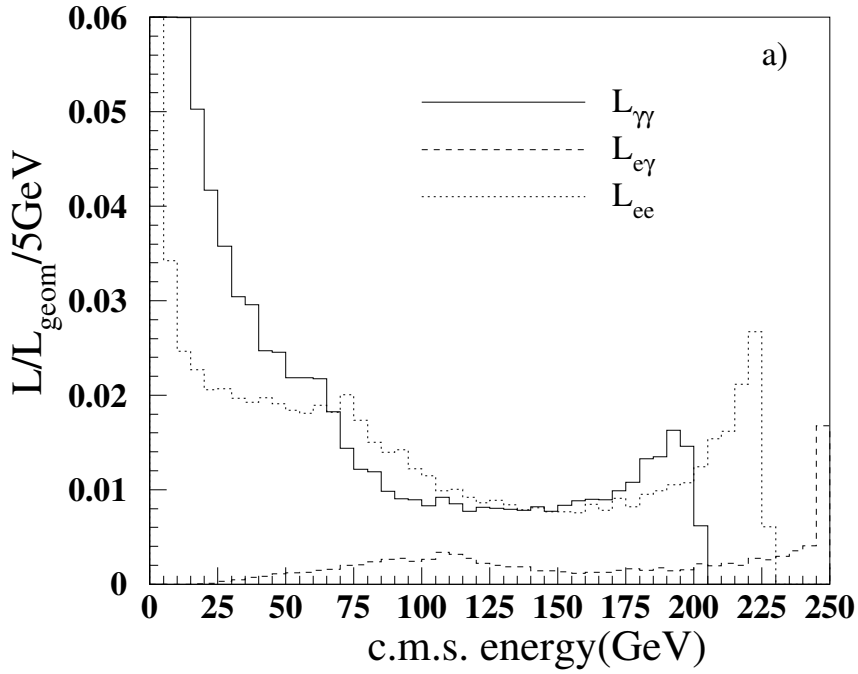

×10^8
15.
10.
5.
0.
a)
Linear Compton
15.
10.
5.
0.
b)
Non-Linear Compton
$I = 1\times10^{18}\,W/cm^{-2}$
0
50
100
150
200
250
E(GeV)
Number of Phorons/Bunch

Fig. 2


a)
$L_{\gamma\gamma}$
$L_{e\gamma}$
L_{ee}
L/L_{geom}/5GeV
0.06
0.05
0.04
0.03
0.02
0.01
0
0 25 50 75 100 125 150 175 200 225 250
c.m.s. energy(GeV)

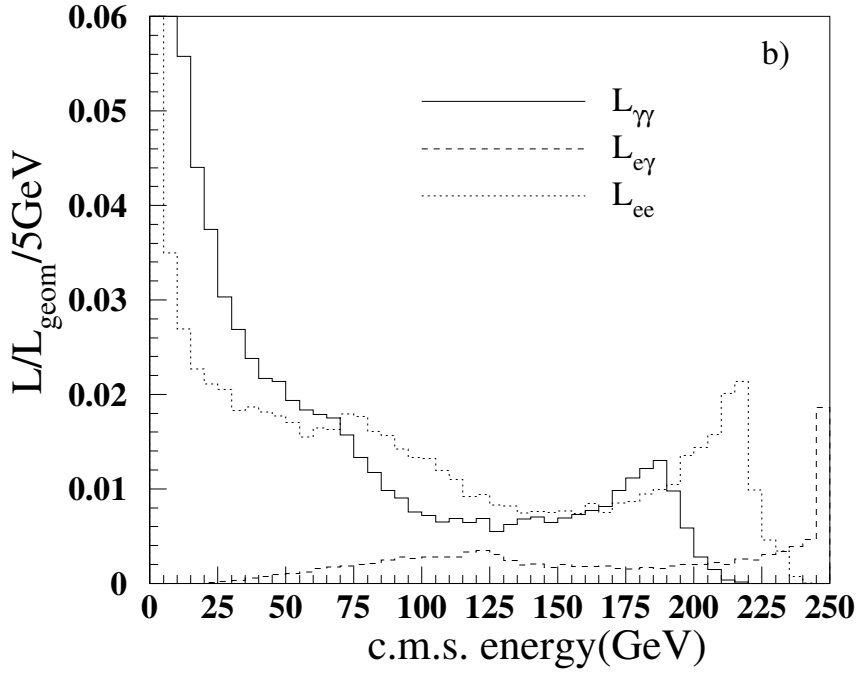

b)
$L_{\gamma\gamma}$
$L_{e\gamma}$
L_{ee}
L/L_{geom}/5GeV
0.06
0.05
0.04
0.03
0.02
0.01
0
0 25 50 75 100 125 150 175 200 225 250
c.m.s. energy(GeV)

Fig.3