Backgrounds and Detectors for High-Energy $\gamma\gamma$ Colliders*

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ABSTRACT

Some of the sources of backgrounds important for studies of $\gamma\gamma$, $e^-\gamma$, and e^-e^- collisions at a next linear collider are reviewed and generic detector requirements for such studies are listed.

I. INTRODUCTION

High-energy collisions of photons with photons, photons with electrons, and electrons with electrons at a second interaction region (IR) of a Next Linear Collider (NLC) provide interesting physics complementary to that of electron-positron collisions. Here, the photon beams are produced by Compton scattering of an intense laser beam off an electron beam at a short distance from the interaction point. While most backgrounds are common to both e^+e^- and $\gamma\gamma$ / $e^-\gamma$ / e^-e^- collisions, the presence of the spent or disrupted electron beam in the latter case presents a particular challenge for the design of the interaction region. Other differences arise from different beam parameters and IR design.

In the following sections the problems posed by the spent electron beam and other background sources are outlined, as well as the requirements for a generic detector.

II. $\gamma\gamma$, $e^-\gamma$, AND e^-e^- LUMINOSITIES

The design of the $\gamma\gamma$ interaction region forsees that very intense laser beams are focused on the high-energy electron beams on both sides at conversion points (CPs) about 5 mm away from a common interaction point (IP). The backscattered high-energy photons then follow approximately the electron orbit to the IP, where they collide. The energies of the scattered photons depend on their angle relative to the incident electrons, with the lowest-energy photons scattering at the highest angles (of still only about a few μrad), and the forward-scattered photons having up to about 81% of the electron beam energy (for an electron beam energy of 250 GeV and laser wave length of about 1 μm). Polarization of the electron and laser beam allows one to adjust the photon energy distribution; it is rather flat for collisions of like-handed electrons and laser photons, and peaks near the maximal energy in collisions of opposite-handed electrons and laser photons[1]. The exact energy-dependent photon-photon luminosity distribution depends sensitively on the distance to the conversion point and the electron beam parameters.

In addition, the spent electron beam colliding with its counterpart and with high-energy photons from the opposite side gives rise to energy-dependent electron-electron and electron-photon luminosities, which represent a background to the photon-photon luminosity. These three luminosity distributions are best determined by simulations, such as those presented at this workshop[3].

The main concern here is the electron-electron luminosity and the disposal of the spent electron beam. If nothing is done, the e^-e^- luminosity is already reduced by a factor of about 5, as the energy-degraded spent electron beam shows a larger disruption. To reduce the e^-e^- luminosity further, several schemes have been studied, among them introducing a small offset in y between the electron beams [4], or installation of a sweeping magnet[5][6]; even the installation of a plasma lens to overfocus the spent electron beam has been proposed[7]. It is clear that the latter two schemes might produce backgrounds of their own from rescattering of synchrotron radiation or the disrupted electron beam on the matter introduced close to the beam in the center of a detector.

The γe luminosity is possibly comparable to the $\gamma\gamma$ luminosity if nothing is done to deflect the spent electron beam, as there is no disruption, but it will be reduced if the e^-e^- luminosity is reduced by one of the schemes mentioned above. Anyway, the degradation in energy of that fraction of electrons which scattered at the CP will reduce the center-of-mass energy of most $e^-\gamma$ events at the IP.

Higher-order multiple Compton scattering at the CP also produces some thousand electrons of 2–3% of the beam energy, which are deflected at an angle of up to about 8 mr due to collision with the opposing electron beam[2]. These particles would present a background source, if allowed to hit the face of the exit quadrupole; to avoid this problem, the crossing angle of the electron beams in the design now considered will be increased to 30 mr (from 20 mr in the e^+e^- IR design) and the acceptance of the exit quadrupole increased to 10 mr (from 3mr).

Finally, while the simultaneous occurence of $\gamma\gamma$,$e^-\gamma$, and e^-e^- collisions might appear disconcerting, it might be possible to sort out the origin of any given event from its detector signals, and thus study all three types of collisions simultaneously, as has been first discussed at this workshop[8]. In that case the problems associated with a sweeping magnet may be avoided.

In any case, for any disposal option for the spent electron beam, further simulations both of the electron and photon spectrum in the IR and its interaction with any structures in it are required.

III. OTHER BACKGROUNDS

Many other background sources will be common to both the e^+e^- and $\gamma\gamma$/$e^-\gamma$/e^-e^- interaction regions. However, there

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are also some differences. In particular, no full-energy charged beams collide in the $\gamma\gamma$ and $e^-\gamma$ case. Also, the beam parameters will be different; the very flat beams used to attain high luminosity at the e^+e^- next linear collider are not needed here, as there are no beam-beam effects in $\gamma\gamma$ collisions. Thus there is also no beamstrahlung (except from the disrupted spent electron beams), which produces electron-positron pairs in e^+e^- collisions from the Breit-Wheeler ($\gamma\gamma \to e^+e^-$) and Bethe-Heitler ($e\gamma \to ee^+e^-$) reactions.

Instead, e^+e^- pairs can be produced (and high-energy photons lost) by the Breit-Wheeler process in the laser focus, when high-energy photons collide with an unscattered laser photon. This might become a problem if the parameter x,

$$x \equiv \frac{4E_b\omega_o}{m_e^2} \approx 15.3 \left(\frac{E_b}{\mathrm{TeV}}\right)\left(\frac{\omega_o}{\mathrm{eV}}\right) , \qquad (1)$$

becomes larger than 4.8; however, a value of 4.8 can be attained for a beam energy E_b=250 GeV and a laser photon energy ω_o corresponding to the Nd:Glass laser wavelength of 1.05 μm. Even then, one expects on the order of ten thousand pairs per bunch crossing, which might radiate and backscatter into the detector. Simulations of the similar number of pairs produced from beamstrahlung in e^+e^- collisions indicate that the background thusly induced is acceptable[9].

The backgrounds from muons produced in upstream collimators are presumably the same as in the well-studied e^+e^- case[9], with differences due to different beam parameters and collimation, and present here no more of a problem than there.

Hadronic backgrounds from so-called minijets are, if hard, a QCD signal. With a total hadronic cross section in $\gamma\gamma$ collisions of no more than 400 nb, and a luminosity of 10^{33}/cm/s, one gets 400 such events per second, or 2-3 events per 90 beam crossings, which should be quite manageable.

IV. SYNCHROTRON RADIATION

Backgrounds from synchrotron radiation (SR) are generated by the same mechanisms as in the e^+e^- case. The beam passing through bends and quadrupoles generates SR, which then might rescatter in the final focus quadrupole magnets, off any structure in the interaction region (e.g. mirrors for laser focussing), and off the face of the exit quadrupole. This rescatterd radiation might then end up in the detector, unless intercepted by a cleverly installed mask. Synchrotron radiation from far-away magnets can be reduced by collimators. Thus only that produced in the final focus needs to be studied. The SR in quadrupole magnets is mainly produced by beam tails, as the on-axis particles do not see any appreciable magnetic field. The nominal beam makes only small contributions in bending magnets, which are far away from the IP and whose contribution can be collimated out. Hence the SR produced by beam tails in final-transformer and final-focus quadrupoles is the dominant contribution to SR in the interaction region. Of course, the size of such beam tails is not well known.

Past measurements of the backgrounds in the Central Drift Chamber of the SLD detector at the Stanford Linear Collider were consistent with a flat 1% beam tail. Based on this experience, the NLC studies also used a 1% flat beam tail. In fact, recent measurements by SLD indicate that when SLC is operating well, a 1% beam tail is an overestimate (and backgrounds in the liquid-Argon calorimetry of SLD are then consistent with a flat tail of only 0.1%).[10] For a conservative estimate, I use in the following a nominal beam with a flat tail containing 1% of the total charge.

For a first study of the direct SR in the $\gamma\gamma/e^-\gamma/e^-e^-$ interaction region, I used the program QSRAD[11], which divides a 2-dimensional gaussian beam into 10,000 rays, follows these through the magnets, generates fans of synchrotron radiation, traces these and tallies the spectrum at prescribed surfaces.

A magnet lattice for the final transformer was kindly provided by A. Zholents [12]. The RMS spot sizes at the IP are σ_x=71.5 nm, and σ_y=9.04 nm; the number of electrons per bunch is $N_e = 0.65 \cdot 10^{10}$. The beam tail with $1\% \cdot N_e$ particles was assumed to be distributed in the transverse coordinates x and y over $7\sigma_x$= 500.5 nm and $35\sigma_y$= 316.4 nm to reflect the collimation used. The synchrotron radiation flux from this tail at the entrance of the exit quad, 2 meters from the interaction point, as function of the radius from the (e^-) beam axis, is shown in the figures below.

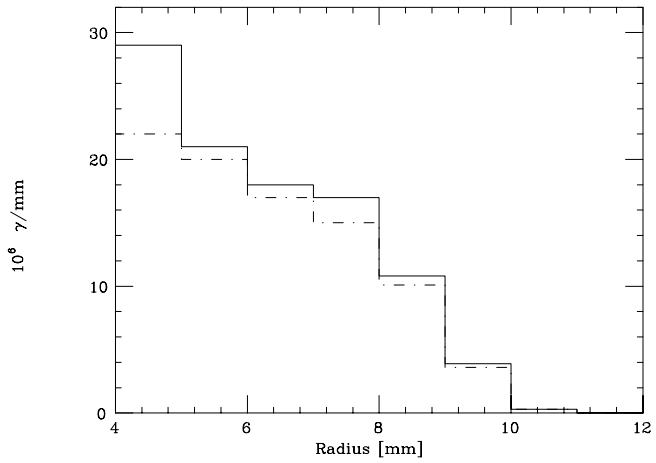

Figure 1: SR photon number flux at face of exit quadrupole.

Figure 1 shows the flux in number of photons per mm bin in radius, the solid line includes all photons, the dot-dashed line only those of energy above 10 keV. Figure 2 shows the total energy deposited per mm radius bin.

One sees that the exit quadrupole aperture should have a radius of at least 11 mm so as to let the synchrotron radiation comoving with the electron beam pass through (rather than rescatter at its face). Most likely the size of the aperture of the exit quadrupole will be set by the requirement to let pass through the disrupted electron beam, and might be as large as 2 cm in radius for that reason, as said in section II above. Hence synchrotron radiation is not a problem here.

For the $\gamma\gamma$ collider, the interaction region will also contain the mirrors which focus the laser beam on the electron beam; they

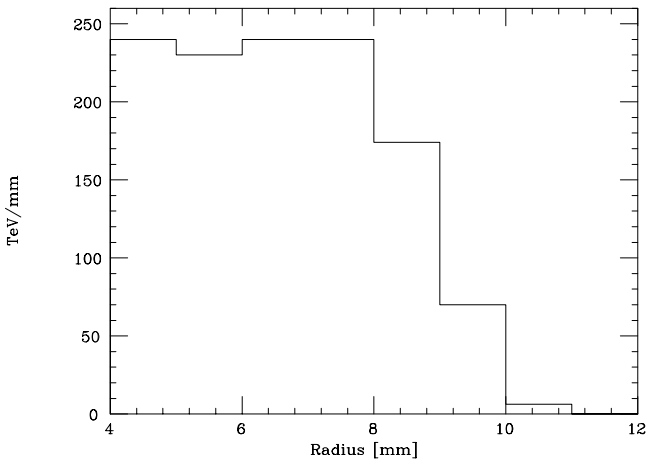

Figure 2: SR energy flux at face of exit quadrupole.

are located at 1.5 meters from the IP, 0.5 m from the entrance and exit quadrupoles. Rescattering of SR from these mirrors might present a problem, as they are about 1 cm thick, which, if made from silicate glass, is about 8.5% of one radiation length. A similar study with QSRAD shows that the hole in the mirror (or similar stay-clear distance) through which the electron beam passes should have a radius of at least 5 mm at the entrance quadrupole side, and 10 mm at the exit quadrupole side, so as to let the SR co-moving with the electron beam pass through. The current design[13] allows for that clearance.

Clearly, more studies are needed, especially EGS4 or Geant studies of rescattering of SR in the last quadrupole magnet into the detector.

V. GENERIC DETECTOR REQUIREMENTS

Requirements for a detector installed in a $\gamma\gamma/e^-\gamma/e^-e^-$ interaction region has been considered before[6]. Essentially, it should be of the same quality as that of the e^+e^- region, as the final states studied are quite similar. As there, the detector should provide precision vertexing for b-quark separation, and accurate measurements of electrons, muons, and jets up to the beam energy over its full-angle coverage. Fine segmentation is needed to reduce the sensitivity to backgrounds. Many new ideas for such a detector have been presented at this conference by the NLC Detector group[14].

One difference is the measurement of the luminosity, which will rely on Bhabha scattering at small angles in the $e+e^-$ case. In e^-e^- scattering, one can similarly use Møller scattering. The two-photon processes $\gamma\gamma \to e^+e^-$ and $\to \mu^+\mu^-$ at small angles would provide a similar measurement for the $\gamma\gamma$ case. For a center-of-mass energy above 200 GeV, the cross section for $\gamma\gamma \to e^+e^-$ is about 10pb; with a 70% efficiency one expects about 70,000 events per 10 inverse femtobarn luminosity.

The process $\gamma\gamma \to W^+W^-$ has also been studied as a means for luminosity monitoring[15]. Here the energy-weighted cross section is about 50 pb; with a 15% 4-jet reconstruction efficiency, one again gets about 75,000 such events per 10 inverse femtobarn.

VI. CONCLUSION

In conclusion, the backgrounds at a a $\gamma\gamma/e^-\gamma/e^-e^-$ interaction region are not worse than in the e^+e^- case. However, more detailed Monte Carlo studies are needed. The detector should be of the same quality as that proposed for the NLC [14]; here, too, more simulations are needed. The interested groups in the U.S., Europe, and Japan will certainly continue to study the challenges posed by the physics, detector, and machine aspects of $\gamma\gamma, e^-\gamma$, and e^-e^- collisions.

VII. ACKNOWLEDGEMENTS

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