BACKGROUND PROBLEM AT INTERACTION POINT FOR AN e^+e^- TeV LINEAR COLLIDER

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I. INTRODUCTION

There are two major backgrounds at interaction region for high energy experiments in e^+e^- TeV linear colliders. First is synchrotron radiations from last bending magnet and several quadrupole magnets in final focus system. The radiated photons may be reflected on the inner surface of beam pipes and the pole face of the magnets, then go through detectors. Second one is e^+e^- pairs created in beam-beam interactions. In subsequent sections we describe them in some detail together with proposing mask systems against these backgrounds. For the estimation we take the parameters of JLC (Japan Linear Collider) designs[1,2] as an example for TeV colliders.

II. SYNCHROTRON RADIATIONS

A. From Last Bending Magnet

The $10\sigma_{x(y)}$ beam envelops[2] near the interaction point (IP) of JLC (E_{beam} =500GeV) are shown in Fig.1. The figure shows also the locations of last bending magnet(B04) and four quadrupole magnets(QX1, QC2, QC3 and QC4). Since B04 is placed at ~88m from IP and its total bending angle is 0.13mrad, the synchrotron radiations emitted in it will be distributed horizontally up to 1.2cm from the beam axis. Their critical energy is 5.6MeV. The total number of radiated photons is similar to that of beam particles, 10^{10}/bunch. Considering a half aperture of the nearest quarupole magnet(QX1), just 1m from IP, is 0.5mm, the amount of the photons hitted to QX1 is not tolerable for detectors with no mask because $10^{10} \cdot 10^{-1}$ (reflection coefficient)$\cdot 10^{-3}$(acceptance) $\cdot 10^{-2}$ (conversion efficiency of photons to electrons in a gas chamber) $\cdot 10^{1}$(bunch#/train) = 10^5 signals will appear in the detector. In order to reduce these backgrounds to negligibly small level, a proper collimation is neccessary with a suppression factor of more than 10^{-5}. It is essential to have a mask just upstream of QC3, $\sim$ 40m from IP, whose half aperture is $220\mu m$ as shown in Fig.1 and which can be made of lead in 20cm thickness corresponding to 10λ (photon attenuation length) for photons of a few MeV energies as most severe case. The mask can be constructed as horizontally moving one, whose minimum aperture from the beam axis should be $220\mu m$.

Fig.1 Horizontal and vertical beam envelops of 10σ indicated by solid and dash lines, respectively.

B. From Quadrupole Magnets

We consider the synchrotron radiations only from the four quadrupole magnets in the straight line of the final focus system(Fig.1), which are downstream of B04, because no direct photons reach to IP from quarupole magnets upstream of the B04. The best way to avoid the background problem due to these synchrotron radiations is not to shadow their spatial profile near IP. Since a half aperture of QX1 is very small to be 0.5mm, the photons radiated from the quadrupole magnets upstream of QX1 may be scattered by edges of its magnetic pole faces. On the other hand there is no such problem in the opposite side QX1 forcussing an opposing beam, if we can make a large exit hole for these photons. With a finite crossing angle of two beams, $6 \sim 30$mrad, a beam pipe of 6mmϕ can be placed at QX1 for a disrupted beam* and the

*Under beamstrahlung the maximum deflection angle of the disrupted beams is calculated to be 5.9mrad for JLC by the equation given in [11], therefore no disrupted particles cause the background problem for >6mrad crossing angle cases.

photons. So we do not consider the background due to the aperture of QX1 in the opposite side. We estimate the spatial distributions of the photons from three upstream quadrupole magnets in front of QX1 by Monte Carlo simulation using MQRAD program[3]. In the MQRAD, macro particles are transfered by linear matrices corresponding to the optics[2]. Each macro particle emits synchrotron radiations in tangential direction to the trajectory if it is transfered in a quadrupole magnet. The emitted photons are linearly extraporated to QX1 for their spatial distribution.

The calculations have been done for three different asumptions of spatial distributions of beam particles which are (i) Gaussian, (ii) Gaussian up to $3\sigma_{x(y)}$ adding flat tail up to $5\sigma_{x(y)}$ (5σ flat beam) and (iii) same as (ii) except for flat tail up to $10\sigma_{x(y)}$ (10σ flat beam) where a population in the tail is 1% of the total. The total number of beam particles is 10^{10}(/bunch). The results are shown in Figs.2(a) and (b) for horizontally and vertically projected ones, respectively. As clearly seen in the figures and especially from the amounts of photons at the half aperture of QX1,0.5mm, the 10σ flat beam can not be tolerable for detectors as the discussions in the previous section and the 5σ flat beam is barely maginal for detectors. If the beam is really Gaussian as (i), there is no problem at all. However there is experimental evidence of non-Gaussian beam produced in linear accelerators[4].

Fig.2 Synchrotron radiation profiles from upstream quadrupole magnets in front of QX1 for three different beam distributions. (a) and (b) are horizontally and vertically projected ones, respectively.

Fig.3 Synchrotron radiation profiles from QC2,QC3 and QC4 in front of QX1 for the 5σ flat beam. (a) and (b) are the same as Fig.2.

So it is very important to controll beam tails and to sharply collimate beams at $\pm 5\sigma$. Assuming the 5σ flat beam, Fig.3 shows individual contributions of QC2,QC3 and QC4 to the synchrotron radiation profile in front of QX1. As seen in Figs.3(a) and (b), QC2 and QC4 are dominant ones at 0.5mm from the beam axis in horizontal and vertical directions, respectively. Since there will be no mask for synchrotron radiations because of the very near location of QC2 to IP, careful optimization between the optics and the aperture of QX1 is further necessary regarding the background.

III. e^+e^- PAIRS

Since both beams are focused into a very small spot of O(1nm) at IP, radiative loss of the beam itself becomes a major problem for detectors. While two beams are colliding, positrons and electrons in the beams are bent to radiate photons (beamstrahlung) by the very strong electromagnetic field which is produced by the opposing beam. In the same electromagnetic field, the photons are converted into e^+e^- pairs, then these electrons (positrons) are bent into detectors and final focusing magnets, thereby creating a background problem in experiments. The amount of the background strongly depends on beam parameters at IP, and it can significantly be reduced by flattening beams with a large aspect ratio. Nevertheless it is impossible to suppress the background completely and a quantitative estimation is necessary.

Since the final focusing magnets are located at $\sim \pm 1$m from IP and their minimum opening aperture is $\sim$1mm, *the secondary background* produced by collisions between the bent electrons, positrons (*primary background*) and the magnetic poles should also be considered. For the secondary background, the crossing angle of the two beams is a key parameter because the primary background concentrates along the beam axes. If the crossing angle is needed to be as large as 30 $\sim$ 40mrad, the crab crossing method[5] has to be employed in order to avoid luminosity loss. This suggests the need for construction of two tunnels and therefore might change the accelerator design completely. If $\sim$5mrad of the crossing angle, which corresponds to $\frac{\sigma_x}{\sigma_z}$, is enough for preventing the background from endangering detectors, the design constraint can be largely relaxed since it is easy to make such angle in the final focusing system without losing much luminosity.

A. Primary background

The primary background of e^+e^- pair creations occur via coherent and incoherent processes. The former is the beamstrahlung photon conversion by the strongly collective magnetic field produced by the opposing beam. Its probability depends mainly on a beamstrahlung parameter(Υ).† The former equals the latter at $\Upsilon \sim 0.4$ and becomes two order of magnitude higher than the latter at $\Upsilon > 1$. The coherent process produces $10^6(10^8)$ pairs per pulse crossing in our case of $\Upsilon = 0.45(1.12)$ for $E_{beam}=$ 200(500)GeV[1] . Although this number is enormous, there is an energy threshold ($E^{th}_{e\pm} = \frac{E_{beam}}{2\Upsilon}$)[6] in the produced $e^\pm$ spectrum. Since the number of $e^\pm$'s below this threshold is suppressed exponentially, the amount of $e^\pm$'s bent outside the beam pipe is negligible. On the contrary the incoherent process consisting of (a) $\gamma e^\pm \rightarrow e^\pm e^+ e^-$, (b) $e^+e^- \rightarrow e^+e^-e^+e^-$ and (c) $e^+e^- \rightarrow \gamma e^+e^-$ has no such energy threshold and the energy distribution of produced $e^\pm$'s is inversely proportional to their energies. The subprocesses (a) and (b) dominate the incoherent process and have total cross sections of about 10^{-26}cm^2 in the TeV region. Energy dependence of the cross sections is only logarithmic.

The background due to the incoherent process is mainly discussed since the background from the coherent process is negligible unless $\Upsilon > 10$. As the e^+e^- pairs are created and deflected during collisions between two very thin beams, we employ a Monte Carlo method to estimate these effects by ABEL program[7]. Figs.4(a) and (b) show scatter plots of $e^\pm$'s created by the incoherent process at $E_{beam} = 200$GeV in a plane of their energies ($E_{e^\pm}$) versus scattering angles in the horizontal(θ_x) and vertical(θ_y) directions, respectively. the scattering angles are sums of intial direction of the beam and the bending angles by the electromagnetic field which the opposing beam produces. In the present study, we approximate zero production angles of the pairs and "zero" impact parameters for the interactions. As is clearly seen in these figures,

Fig. 4 Scatter plot of $e^\pm$ created by the incoherent process in a plane of their energies versus their scattering angles(bending angles by the electromagnetic field which the opposing beam produces), where E_{beam} and the beam intensity are 200GeV and $10^{10}e^+(e^-)$'s per bunch crossing, respectively, corresponding to $\Upsilon =$ 0.45, (a) in horizontal direction(θ_x) and (b) in vertical one(θ_y).

†The condition of $\Upsilon \sim 1$ corresponds to a threshold for a photon of the same energy as the beam to convert into an e^+e^- pair in the magnetic field produced by the opposing beam.

there is a strong correlation between the scattering angles and the energies. For instance, it suffices to consider the $e^{\pm}$'s of $E_{e^{\pm}} < 10(20)^{\rm a}{\rm nd}^{1}(2)$GeV for $\theta_{x(y)} > 5^{\rm a}{\rm nd}^{3}0$mrad, respectively. Our detector will cover a solid angle of more than 0.15rad from the beam axis. The angular region less than this angle has to be occupied by the final focusing magnets and is irrelevant for most physics requirements. The primary background can not enter directly into our detector because their transverse momenta($<$ 16MeV)‡ are small enough for a typical solenoid field of 1.5 Tesla to trap them in a cylinder of $|r| <$ 7cm around the beam axis. Therefore it is enough to consider the secondary background of photoneutrons and backscattered photons from the final focusing magnets for the moment.

B. Secondary Background

To estimate the secondary background, the total energy ($\Sigma_{>\theta} E_{e^{\pm}}$) and the number ($\Sigma_{>\theta} n_{e^{\pm}}$) of the primary background $e^{\pm}$'s, which are integrated over angles above a certain scattering angle(θ), are shown in Figs.5(a) and (b), respectively. In these figures the values are for a single bunch crossing, where the beam intensity is $10^{10} e^{+}(e^{-})$'s/bunch. Since there are 10 bunches in a 14nsec bunch train which is considered to be a pulse and collides at 200Hz, we have to multiply the above values by 10 to get values for a single pulse crossing.

The photoneutrons are emitted from giant resonances of nuclei in the final focusing magnet poles which are photo-excited by the primary background of $e^{\pm}$'s. The number of photoneutrons is proportional to the total energy deposit in the poles with a rate of $8.2 \times 10^{8} n$/Joule for iron[8] (*i.e.* 0.13 photoneutrons per 1GeV). As seen in Fig.5(a) the total energy deposit is $10^{6}(10^{5})$ GeV in each pulse collision for $\theta >$ 5(30)mrad if the primary $e^{\pm}$'s are totally absorbed in the poles. Thus $1.3 \times 10^{5}(10^{4})$ photoneutrons are produced at 200Hz, and their total energy is 200(20)GeV per pulse collision because their average energy is 1.5MeV. However it is necessary for the photoneutrons to make signals in the detector in order to become real backgrounds. Fig.6 shows a typical detection efficiency for neutrons of a similar energy(1.65MeV) by a liquid scintillator[9] .. The efficiency is about 5% for an energy threshold of 0.3MeV and becomes nearly zero for a 1MeV threshold. These neutrons scatter uniformly over the detectors. They can be completely suppressed by setting an appropriate energy threshold($\sim$ 1MeV) for all channels of electromagnetic and hadron calorimeters whose total channel number is about 5×10^{4}. Even if the threshold is set to zero, the total energy deposit of the neutrons in the calorimeters will be as low as 10(1)GeV. Timing information is also very effective to remove them because of their slow velocity.

Fig.5 (a) Total energy of the primary background particles per bunch crossing, which is integrated over their scattering angles above $\theta \equiv \sqrt{\theta_x^2 + \theta_y^2}$ as a function of θ. (b) Their total number integrated in the same way as (1), where the beam conditions are the same as Fig.4.

The backscattered photons were estimated by a simulation using EGS4 codes[10] which traced down to 1keV photons with fluorescence and Rayleigh scattering. In the simulation a mixture of Fe-Co-V(49-49-2%) was chosen as the material of the magnet poles. The simulated results are shown in Fig.7(a) for energy spectrum of photons and in Fig.7(b) for their number per electron (positron) as a function of the

‡For the primary background $e^{\pm}$ of $\theta_{x(y)} > 0.03$ their energies and their transverse momenta are expressed as $E_{e^{\pm}} < (\frac{0.03(0.04)}{\theta_{x(y)}})^2$ and $E^{t}_{e^{\pm}} \sim E_{e^{\pm}} \cdot \theta_{x(y)} < \frac{0.03^2(0.04^2)}{\theta_{x(y)}}$, respectively.

incident energy, respectively. The sharp energy peak at 0.5MeV corresponds to e^+ annihilation. Most of the photons have energies of more than 0.1MeV. The number of backscattered photons increases slowly with the incident $e^\pm$ energy, which reaches about $5/e^+(e^-)$ at $E_{e^\pm} = 10$GeV. As the integrated number of $e^\pm$'s for $\theta > 5(30)$mrad is $4(1) \times 10^5$ per pulse collision (see Fig.5(b)), the corresponding number of photons is $2(0.5) \times 10^6$ at most.

Fig.6 Integral detection efficiency of 1.65MeV neutrons in a liquid scintillator (NE213) as a function of energy threshold which is normalized to electron energy.

Fig.7 (a) Energy spectrum of photons backscattered from Fe-Co-V(49-49-2%), which is simulated by EGS4, where the energy distribution of incident electrons is uniform in the energies from 0.5GeV to 10GeV. The spectrum of the photons is insensitive to the incident energy. (b) Number of backscattered photons per electron (positron) as a function of the incident energy in GeV.

IV. MASKING SYSTEM AROUND IP

We propose a masking system mainly for the secondary background of backscattered photons. Fig.8 shows a schematic view of the masking system. The mask is made of a heavy metal like as tungsten covering the polar angle from 0.1 to 0.15 radian. Thus the shape of the mask is a cone and the distance of its front face to IP (ℓ_{mask}) determines an acceptance (η_{acc}) of the photons escaping from the mask, *e.g.* $\eta_{acc} = 5 \cdot 10^{-4}$ and $6 \cdot 10^{-3}$ for $\ell_{mask} = 0.3$ and 0.6m, respectively. Outside the mask is a detector region for experiments. As described in the previous section, the beam pipe for the disrupted beam and the synchrotron radiations must have a diameter of at least 6mm as shown in Fig.8(b). Inside the mask there will be a luminosity monitor which is also able to measure the total energy of deflected e^+e^- pairs for an online monitor of beam-beam interaction during collisions. A separation between Bhabha scattering events and the deflected pairs can be done by longitudinally segmentanting the monitor.

Fig.8 (a) Schematic view of a masking system in IP region. Besides the finite crossing angle the system is cylindrically symmetric around the beam axis. (b) Cross sectinal view of the beam line in front of QX1.

The flux of the backscattered photons can be reduced by a factor of 10^{-5} with proper shielding for $E_\gamma < 0.5$MeV (*e.g.* 5cm thickness of tungsten for 0.5MeV photons). However, there is a tail in the energy distribution as shown in Fig.7(a) for $E_\gamma >$1MeV, which amounts to 10% of the total. For these photons ($E_\gamma >$ 1MeV), the suppression factor relative to the total photon flux is 10^{-1}(tail)$\cdot 10^{-3}$(shielding) $=10^{-4}$ because of their two times larger attenuation length than those of $E_\gamma < 0.5$MeV. Therefore there are at most 10^2 photons penetrating the shielding. In addition $\sim 10^3$ photons are escaping from the mask assuming the position of front face of the mask is 0.3m from IP, however most of them are hitting on the outer surface of the opossing mask. Taking account of 1% probability for these photons to convert into electrons in usual tracking chamber gas, total number of hits in a detector is a few $\times 10^1$ even if we assume 100% rescattering probability on the opossing mask. Thus the estimated background rate is apparently acceptable for our experiments.

V. SUMMARY

Since the physical aperture of QX1 is very small to be 0.5mm (half aperture), the magnet poles of QX1 is a potential scatterer of the tremendous synchrotron radiations from the last bending magnet(B04) and the upstream quardupole magnets. For the former radiations the mask around $\sim$ 40m from IP is definitely needed with the horizontal aperture of 220μm. As no mask works for the latter radiations, it is very important to sharply collimate beams within $\pm 5\sigma$. Also further optimization between the optics of the final focus system and the physical aperture of QX1 is necessary regarding this background because the situation is barely marginal even for the 5σ flat beam. To sweep off the disrupted beam and the synchrotron radiations, the beam pipe of at least 6mmϕ is required in QX1.

Under the condition of $\Upsilon < 1$ the background of $e^{\pm}$ pairs from the coherent process can be neglected because they are confined in the beam pipe, thanks to their high energy threshold. We consider the three reactions of e^+e^- pair creations for the incoherent process. Under the assumption of zero production angles for the pairs, there is no serious problem in the primary background. The secondary background of photoneutrons and backscattered photons could be a serious problem. Their amounts strongly depend on the crossing angle between two beams. With the proposed masking system in the IP region, the crossing angle of 5mrad is found to be enough for avoiding the background problem, while the background rate for 30mrad is less by a factor of 10 than that of 5mrad. Although the numerical calculations have been carried out at $E_{beam} = 200$GeV, these conclusions are valid for $E_{beam} = 500$GeV because the energy dependence of the incoherent background is logarithmic and results in an increase of only 20%.

REFERENCES

[1] K. Yokoya, "Beam parameters for JLC" in the procceedings of "The First Whorkshop JLC", KEK, Japan, Oct.1989.

[2] K. Oide, "Final Focus System for the JLC"(KEK Preprint 89-190, Feb. 1990), in the same procceedings as [1].

[3] T. Morimoto, MQRAD,"Monte Carlo Sumilation for Synchrotron radiation from quadrupole magnets", INS-TH-158, 1984.

[4] R.Jacobsen et.al., Invited talk presented at the Vth International conference on Instrumentation for Colliding Beam Physics, Novosibirsk, USSR, March 15-21, 1990, SLAC-PUB-5205, April 1990.

[5] R.Palmer, Linear Collider Workshop Group Reports from Snowmass'88, SLAC - Report - 344(1989).

[6] P. Chen and V.I. Telnov, SLAC-PUB-4923, July 1989.

[7] K. Yokoya, ABEL,"A Computer Simulation Code for the Beam-Beam Interaction in Linear Colliders", KEK-Report-85-9, Oct. 1985, also *Nucl. Instr. Meth.* **B251**, 1 (1986).

[8] W.P. Swanson, SLAC-PUB-2211, Oct. 1978.

[9] V.V. Verbinsky *et al.*, *Nucl. Instr. Meth.* **B65**, 8 (1968).

[10] W.R. Nelson, H. Hirayama and D.W.O. Rogers, SLAC-265, Dec. 1985.

[11] P. Chen, "Disruption, Beamstrahlung, and Beamstrahlung Pair Creation" in proceedings of 1988 Snowmass Summer Study.