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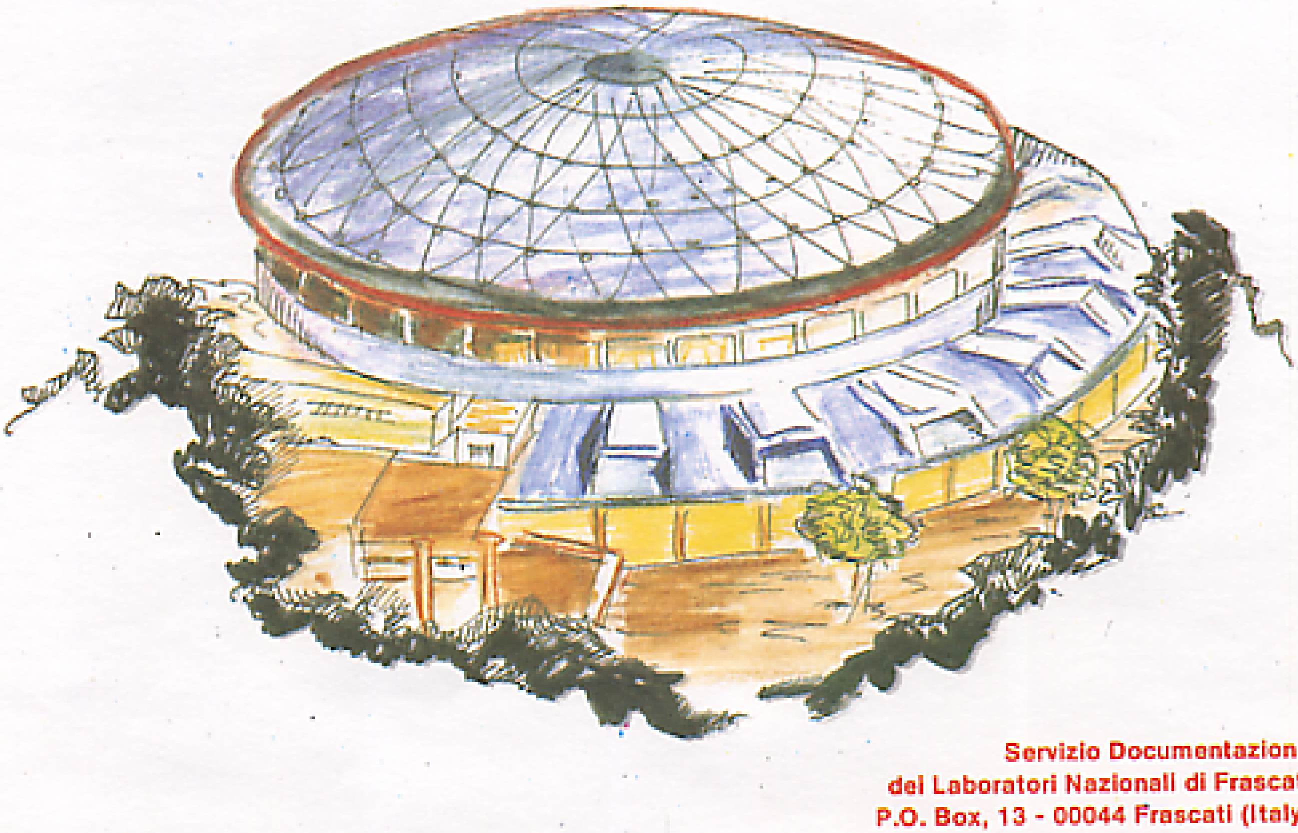

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A DOSE COMPARISON BETWEEN GAS BREMSSTRAHLUNG AND SINGLE BEAM–BEAM BREMSSTRAHLUNG AT HIGH LUMINOSITY $e^+ e^-$ STORAGE RINGS

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Abstract

It is well known that the gas bremsstrahlung produced by the electron and positron beams circulating in a storage ring is one of the main photon radiation source for this kind of machines.

However, at high luminosity e^+e^- storage rings, another considerable photon source should be taken into account: the so called radiative Bhabha scattering or single beam-beam bremsstrahlung.

According to the luminosity, to the residual gas pressure and to the length of the straight sections where e^+e^- beams are made to collide, the latter process can become as important as gas bremsstrahlung.

The dose-rates due to the radiative Bhabha scattering have been evaluated in the case of the Main Rings of the DAΦNE Project, the e^+e^- Φ-factory presently under construction at the Frascati National Laboratories (Italy). A comparison is made with the expected dose-rates due to gas bremsstrahlung.

1 Introduction

It is well known that the gas bremsstrahlung produced by the electron and positron beams circulating in a storage ring is one of main radiation source for this kind of machines. Bremsstrahlung on residual gas is also one of the main cause of beam-losses in the electron-positron storage rings. Although the interactions of the primary particles with residual gas molecules or ions take place all around the machine, the photon intensity is high especially in straight sections. The narrow "jet" of bremsstrahlung X-rays from a straight section may represent a serious radiation hazard when channeled outside the ring through the shield or when the shield itself is not thick enough.

At high luminosity e^+e^- storage rings, as those dedicated to the Φ-factories, another considerable photon source should be taken into account, the so called radiative Bhabha scattering or single beam-beam bremsstrahlung:

$$e^+ + e^- \rightarrow e^+ + e^- + \gamma \tag{1}$$

This source is localized in the crossing point where the beams are made to collide. According to the various parameters involved (luminosity, beam currents circulating, residual gas pressure, straight section length), the radiative Bhabha scattering can become as important as gas bremsstrahlung. This process is often exploited in designing luminosity monitors for this kind of machines. In the case of DAΦNE, the e^+e^- Φ-factory presently under construction at the Frascati National Laboratories (Italy), the counting rate due to the single beam-beam bremsstrahlung is expected to be for such a monitor larger than the one due to the gas bremsstrahlung [1].

2 The radiative Bhabha scattering or single beam-beam bremsstrahlung

From the point of view of the performances of an electron-positron collider, the radiative Bhabha scattering, because of its large cross section, plays an important role in at least two respects:
i) one may reach a situation where the process alone determines the maximum attainable luminosity;
ii) the measurement of the rate of the process furnishes a good method to determine the beam luminosity, if one can rely on a precise calculation of the process.

Furthermore, in many kinematic regions it provides a background for several other processes actually investigated in colliding beam experiments.

A detailed study of the radiative Bhabha scattering has been performed in the past. Independent calculations of the differential cross section in the energy and angle of the emitted particles for small angle photon emission are avalaible in literature [2, 3]. In these analysis, the evaluation of the squared matrix element of the process has been made simpler by neclecting the electron mass. This approximation must be removed if we want to study the process in the very forward direction, where the e, γ scattering angles $\theta_{e,\gamma} \leq 1/\gamma$ $(= mc^2/E)$ and the momentum transfer is of order of m^6c^{12}/E^4.

An expression for the squared matrix element including the finite mass corrections is reported in Ref.[5]. However, this expression is not accurate enough and it leads to unphysical negative result in the very forward region. This extreme kinematic condition has been studied in Ref.[6], where the $O(m^2c^4)$ finite mass corrections, absent in Ref.[5], are explicitly obtained. In addition, the authors of Ref.[6] have also developed a Fortran code [7] designed for a complete study of the radiative Bhabha scattering at the energy of the Φ-factory DAΦNE. This code allows for the calculation of various differential and total cross sections of experimental interest at DAΦNE with the possibility of taking into account realistic cuts on the energies and angles of the final state particles.

The obtained results are in agreement, in the regions where they overlap, with the results of ref. [1, 2, 3, 4] and with a simple analytical formula for the total cross section derived using the no-recoil approximation [5].

We have used the LS (light spot) option of this computer program to evaluate the differential cross section $d\sigma/dE_\gamma d\theta_\gamma$.

3 Dose rates expected at DAΦNE

The DAΦNE accelerator complex consists of two storage rings and of an injector for topping-up at 510 MeV. In the storage rings electrons and positrons circulate in opposite directions, interacting in two interaction points. The interaction regions are 10 m long.

As part of the radiation protection estimates for DAΦNE, the expected dose rates due to both the processes, gas bremsstrahlung and single beam-beam bremsstrahlung, have been evaluated.

The calculations have been done for the nominal DAΦNE parameters. The initial luminosity is expected to be $1.3 \cdot 10^{32}\ cm^{-2}s^{-1}$, while the ultimate target is $\approx 10^{33}\ cm^{-2}s^{-1}$ [8, 9], or perhaps $\approx 5 \cdot 10^{32}\ cm^{-2}s^{-1}$ [10]. The main ring vacuum system is dimensioned for an operating mean pressure of $1.33 \cdot 10^{-7}\ Pa$ ($10^{-9}\ torr$) with 5 A of circulating current. The residual gas is supposed to be biatomic of atomic number 6.5 [1].

The dose rates due to the two processes have been compared in a point located 1 m from the end of the straight section where the stored beams are made to collide.

3.1 Gas bremsstrahlung dose rates

Recently the gas bremsstrahlung emission in the electron storage rings has been extensively studied in the intermediate energy region ($100 - 1000\ MeV$) by the FLUKA Monte Carlo code [11]. Furthermore, the ability of the FLUKA code to predict the doses from gas bremsstrahlung has been checked by means of a specific experiment, carried out at the storage ring Adone, just before the decommissioning of this machine [12].

On the basis of the results of the simulation, the following expression relating the fluence rate φ ($cm^{-2}s^{-1}$), the primary electron energy E (MeV), the beam current I (e/s), the residual gas pressure p (Pa), the straight section length L (m) and the distance d (m), has been proposed [11]:

$$\varphi = 1.9 \times 10^{-18}\left(\frac{E}{mc^2}\right)^2 \frac{L}{d(L+d)} I \frac{p}{p_0} \tag{2}$$

where $mc^2 = 0.511\ MeV$ and $p_0 = 1.33 \cdot 10^{-7}\ Pa$ ($10^{-9}\ torr$).

Likewise, based on the conversion coefficients suggested by Rogers [13], an expression for the absorbed dose rate $\dot{D}$ (Gy/h) has been also proposed [11]:

$$\dot{D} = 2.5 \times 10^{-27}\left(\frac{E}{mc^2}\right)^{2.67} \frac{L}{d(L+d)} I \frac{p}{p_0} \tag{3}$$

where the symbols have the same meaning as in eq. (2).

Eq. (2) and (3) have been obtained considering the residual gas as air. When this is not the case, the results have to be multiplied for $(Z/Z_0)^2$, Z and Z_0 being the atomic numbers of residual gas and air respectively.

The gas bremsstrahlung emission for the storage rings of DAΦNE has been extensively treated on the basis of eq. (2) and (3) [14]. The absorbed dose rate 1 m from a straight section 10 m long, operating at a mean pressure of $1.33 \cdot 10^{-7}$ Pa (10^{-9} $torr$), has been found 6.89 Gy/h with 5 A of circulating current and a residual gas equivalent to air. This figure decreases to 5.4 Gy/h in the case of a biatomic residual gas of atomic number 6.5.

3.2 Radiation Bhabha scattering dose rates

The photon energy spectra in the forward direction, due to the single beam-beam bremsstrahlung at 510 MeV, in a location 1 m distant from the end of a straight section 10 m long, have been simply obtained multiplying the differential cross section of the process (see paragraph 2) by the luminosity of the machine. As an example, fig. 1 shows the spectra, in terms of photon flux per unit of energy and of solid angle, evaluated for angles of emission between [0-0.1/γ] and [0.9/γ-1.0/γ], respectively.

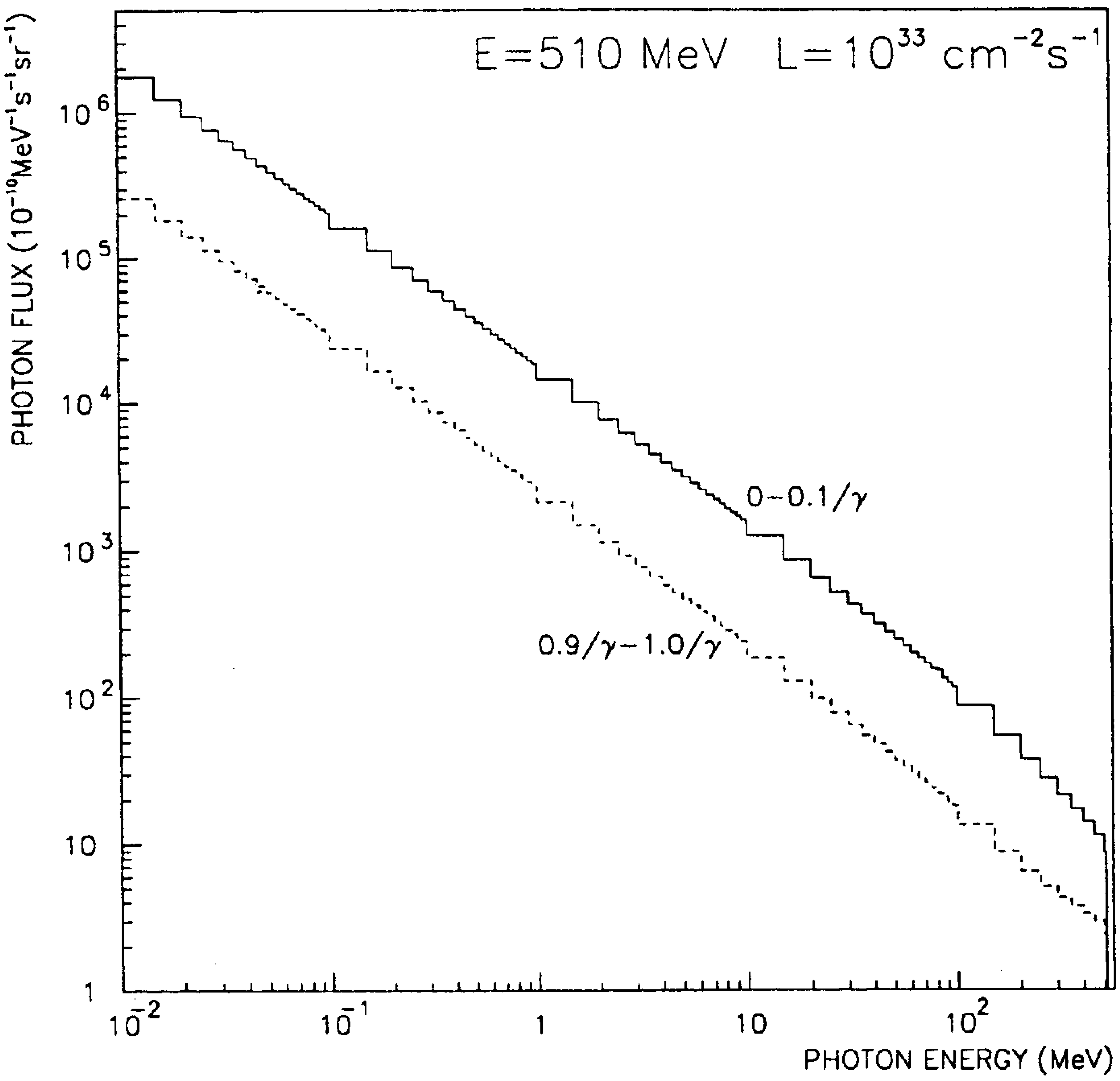

Figure 1: Photon energy spectra in the forward direction, due to the single beam-beam bremsstrahlung, in a location 1 m distant from the end of a straight section 10 m long.

Absorbed dose rates have been estimated from the spectra by means of the conversion coefficients suggested by Rogers [13]. Fig. 2 shows a plot of the absorbed dose rate as a function of the angle of emission, for a gas residual pressure of $1.33 \cdot 10^{-7}$ Pa (10^{-9} $torr$) and a luminosity of 10^{33} $cm^{-2}s^{-1}$.

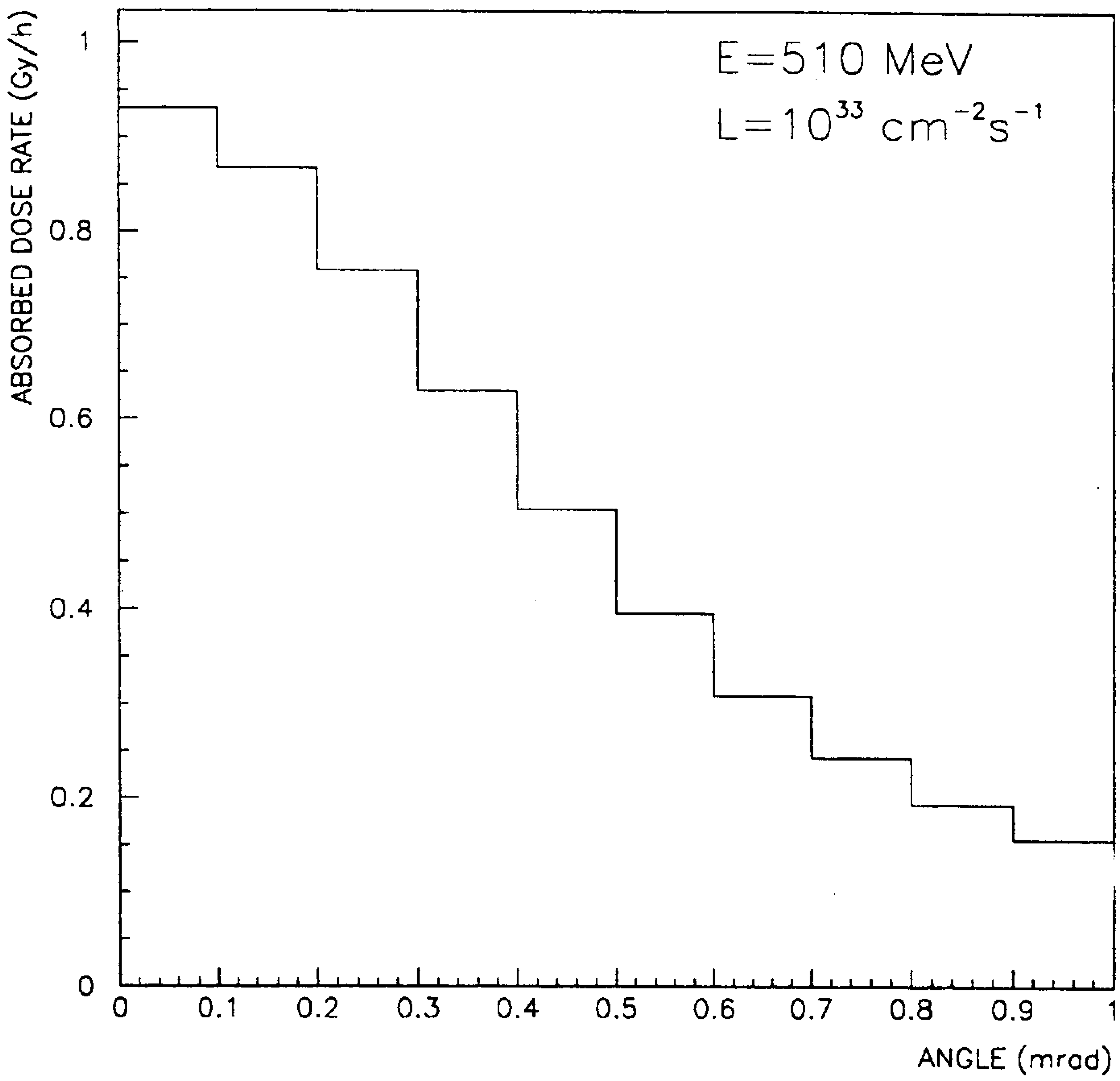

Figure 2: Absorbed dose rate due to the single beam-beam bremsstrahlung as a function of the angle of emission.

3.3 Comparison between gas bremsstrahlung and single beam-beam bremsstrahlung dose rates

On the basis of the data presented in the previous paragraphs, the absorbed dose rate due to the single beam-beam bremsstrahlung in the forward direction ($\theta_{e,\gamma} \leq 0.1\ mrad$), at a point 1 m from a straight section 10 m long, results about a factor 5-10 lower than the one of the gas bremsstrahlung, in the case of the machine parameters of DAΦNE. Of course this figure could increase if the target luminosity is not reached, or decrease if the vacuum pressure is better than $1.33 \cdot 10^{-7}$ Pa (10^{-9} $torr$).

In general it should be noted the key role played by the lenght of the straight section too. Fig. 3 shows, in this connection, the ratio of the gas bremsstrahlung to single beam-beam bremsstrahlung absorbed dose rates as a function of the straight section length, for some sets of machine parameters, in the case of machines operating with performances comparable to those of DAΦNE. The dose rates are always estimated in points 1 m distant from the end of the straight section considered.

As you can see, the importance of the single beam-beam bremstrahlung increases as the straight section length and/or the residual gas pressure decrease.

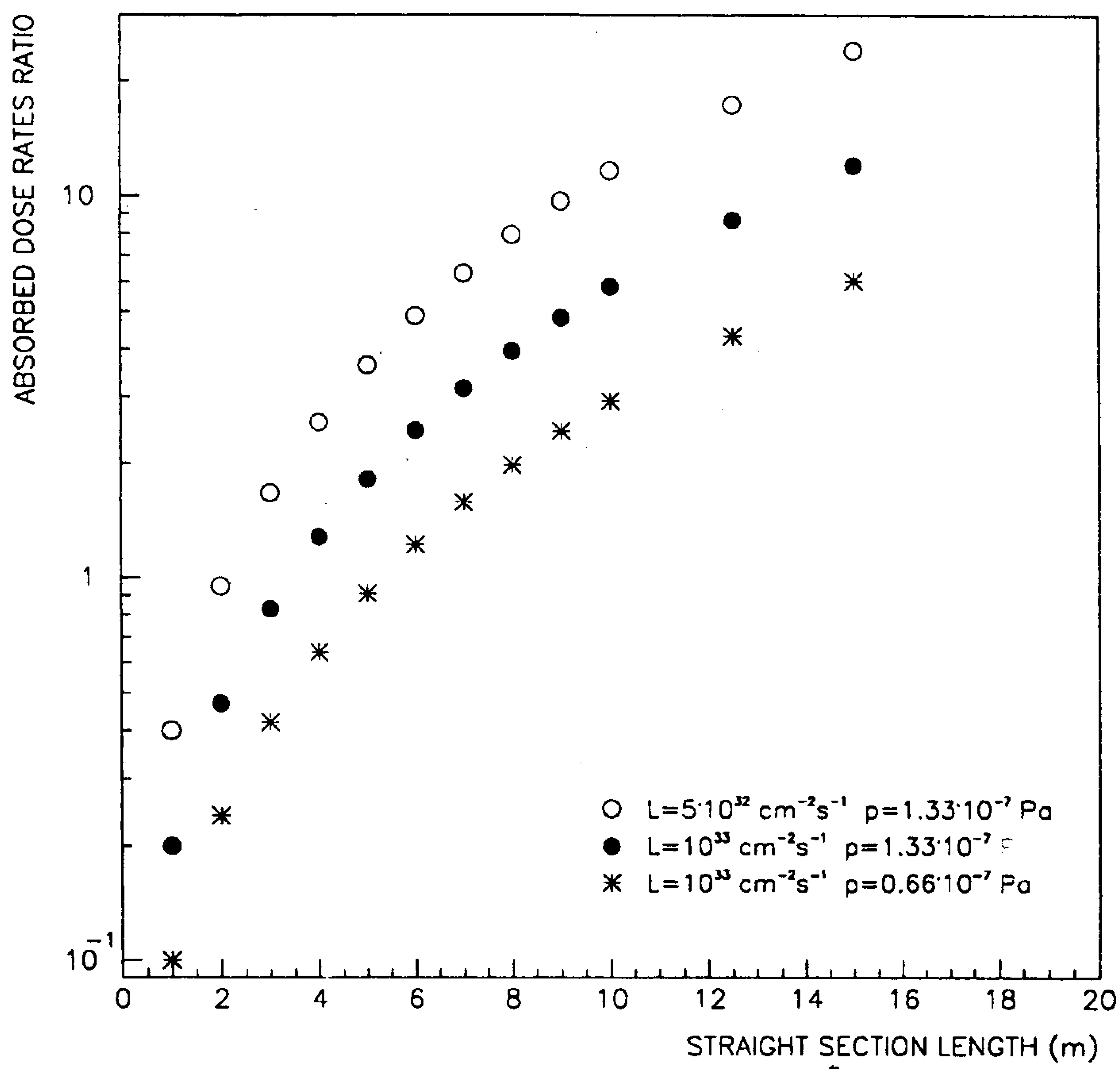

Figure 3: Ratio of the gas bremsstrahlung to single beam-beam bremsstrahlung absorbed dose rates as a function of the straight section length, for some sets of machine parameters.

4 Conclusion

At the high luminosity e^+e^- storage rings, the dose contributions of the single beam-beam bremsstrahlung could be comparable with those of gas bremsstrahlung. As a general rule, at least over the range of machine performances here examined, the latter prevails, in spite of the larger intensity of the former source. Therefore the radiation protection precautions taken on the basis of the gas bremsstrahlung emission should be efficacious also for the single beam-beam bremsstrahlung. In any case some estimates regarding the latter process is advisable, expecially for those high luminosity storage rings where the crossing points are located in short straight sections.

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References

[1] M. Preger, DAΦNE Technical Note IR-3 (1993).

[2] G. Altarelli and F. Buccella, Nuovo Cimento, **34** (1964) 1337.

[3] V.N. Baier, V.S. Fadin, V.A. Khoze and E.A. Kuraev, Physics Report, **78** (1981) 293.

[4] F.A. Berends, R. Kleiss, P. De Causmaeker, R. Gastmans, W. Troost and T.T. Wu, Nuclear Physics, **B206** (1982) 61 and references therein.

[5] G. Pancheri, Internal Note LNF-93/024 (1993).

[6] M. Greco, G. Montagna, O. Nicrosini and F. Piccinini, Physics Letters, **B318** (1993) 635.

[7] G. Montagna, O. Nicrosini and F. Piccinini, Computer Physics Communications, **78** (1993) 155.

[8] M. Serio, Presented at the VI International Conference of High Energy Accelerators, Hamburg, 20-24 July (1992).

[9] G. Vignola, Presented at XXVI International Conference on High Energy Physics, Dallas, 6-12 August (1992).

[10] G. Vignola, Presented at 1993 Particle Accelerator Conference, Washington DC, May 17-20 (1993).

[11] A. Ferrari, M.Pelliccioni and P.R. Sala, Nucl. Instr. Meth., **B83** (1993) 518.

[12] A. Esposito, A. Ferrari, L. Liberatori and M. Pelliccioni, submitted to Nucl. Instr. Meth.

[13] D.W.O. Rogers, Health Physics, **46** (1984) 891.

[14] A. Ferrari, L. Liberatori, M. Pelliccioni and P.R. Sala, Internal Note LNF-93/056 (1993).