DAΦNE TECHNICAL NOTE

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A LUMINOSITY MONITOR FOR DAΦNE

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1. Introduction

A fast and precise luminosity monitor, based on the direct measurement of an electromagnetic reaction, is one of the possible tools for real time optimization and check of a storage ring collider performance, particularly in the case where the beams are stored in two independent rings, so that the overlap at the crossing point (IP) is a function of both transverse and longitudinal position of the two beams. Although the sensitivity of the signal to beam superposition is poor, since its derivative vanishes around the optimum, this is the only absolute measurement of the luminosity.

A measurement of the transverse position cannot be performed at DAΦNE by means of a synchrotron radiation device, because the solenoidal field at the IP is longitudinal. An electrostatic system based on pick-up buttons cannot be proposed, because the two beams cross in the IP at the same time with opposite charges; a directional strip-line detector could overcome this difficulty, but it would be in any case an unwanted obstruction for the experimental detector.

Relative luminosity measurements could also be envisaged, which can provide alternative tools to optimize machine parameters relevant to beam-beam interactions: examples of such methods are the direct measurement of the beam-beam tune shift, shaking one of the beams with a small perturbation while observing the effect on the other one, or measuring the beam-beam deflection on beam position monitors[1]. However, these methods could help in reaching the best obtainable luminosity, but one should rely on the experimental detectors to know its absolute value.

Fast luminosity measurements, based on well established electromagnetic cross sections, are small angle elastic scattering, double and single beam-beam bremsstrahlung. The first method, quite sensitive to detector geometry, is strongly discouraged by the layout of the KLOE experimental setup, which covers the maximum possible solid angle around the IP. Moreover, the solenoidal field influences the trajectories of the scattered electrons and, as a consequence, the estimate of the solid angle subtended by the counters is not trivial.

Double beam-beam bremsstrahlung is based on the detection in coincidence of two photons travelling in the direction of the colliding beams. The layout of the DAΦNE interaction region is such that the emitted photons can travel through the vacuum chamber up to the splitter magnet (see Fig. 1) and they can be extracted through a thin window at its end and detected by a proportional counter where the two rings begin to separate. However, the angular distribution of the photons at the low operating energy of DAΦNE (± 11 mrad are necessary @ 0.51 GeV to collect 80% of the total cross section) is too large to extract the photon beam efficiently, and therefore single beam-beam bremsstrahlung, which exhibits a much sharper distribution in the forward direction seems to be the most effective measurement method, if the gas bremsstrahlung background can be efficiently subtracted.

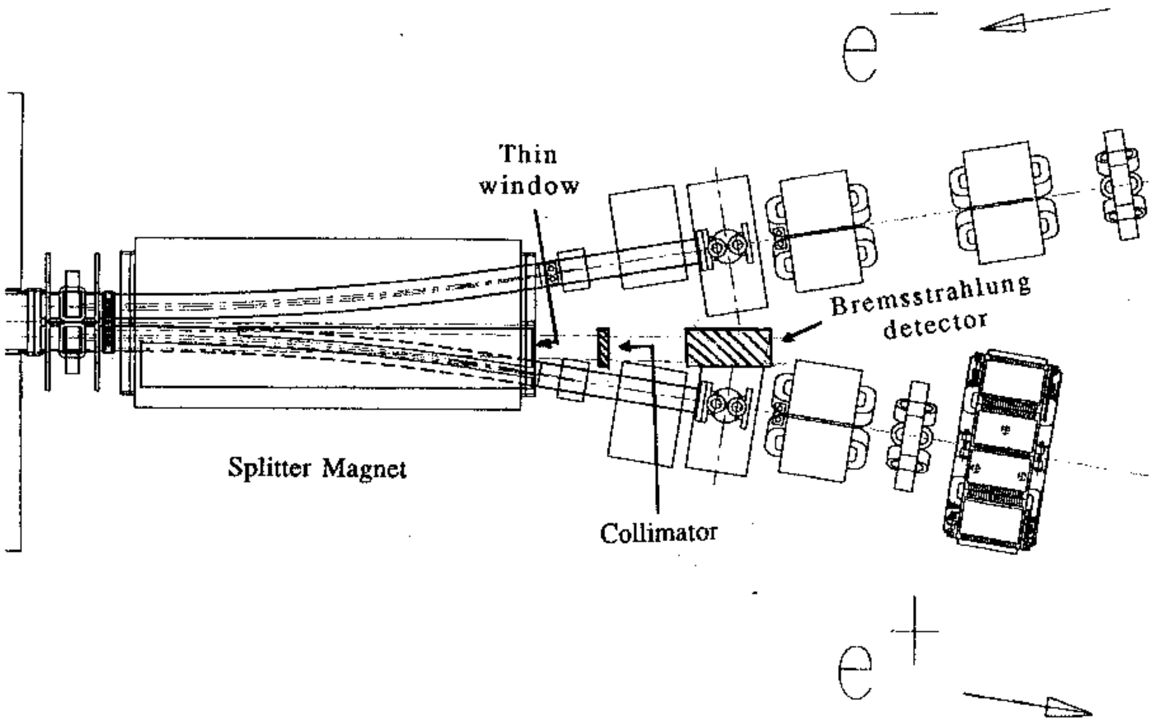

Fig. 1 - Bremsstrahlung detector layout.

2. Luminosity measurement by single bremsstrahlung

An extensive description of the physics problems related to a luminosity measurement based on single beam-beam bremsstrahlung can be found in [2,3]. I will recall here the results at the Φ-factory energy, in order to give an estimate of the expected counting rate and signal-to-background ratio.

Figure 2 shows the foreseen total rates for both beam-beam and gas bremsstrahlung photons as a function of the detector energy threshold, normalized to the beam energy (ε). The rates are calculated for the nominal single bunch DAΦNE parameters, namely:

Bunch current (mA)	44
Single bunch luminosity ($cm^{-2}s^{-1}$)	$4.0x10^{30}$
Straight section length (m)	10
Residual gas pressure (nTorr)	1
Residual gas atomic number (biatomic)	6.5

and are obviously proportional to the number of bunches. It is clear that the counting rate (in the order of 100 KHz) is sufficiently large to allow a very fast measurement, and that the foreseen background is at least one order of magnitude smaller. The gas bremsstrahlung rate in Fig. 2 is overestimated, since it has been calculated as if the electrons were following a straight path from the IP exactly as the photons, while they are deflected by the low-β quadrupoles and the solenoidal field. The actual electron trajectory is therefore quite different from a straight line and only a small fraction of the emitted gas bremsstrahlung photons are expected to reach the detector.

It should be pointed out that the beam-beam bremsstrahlung rate scales with the square of the bunch current (at constant beam transverse size at the IP), while the background rate is proportional to the bunch current. Moreover, the measurement should be reliably performed also when the luminosity is much lower than its design value (e.g. when the beams are not properly aligned), and in this case a background subtraction procedure could be necessary.

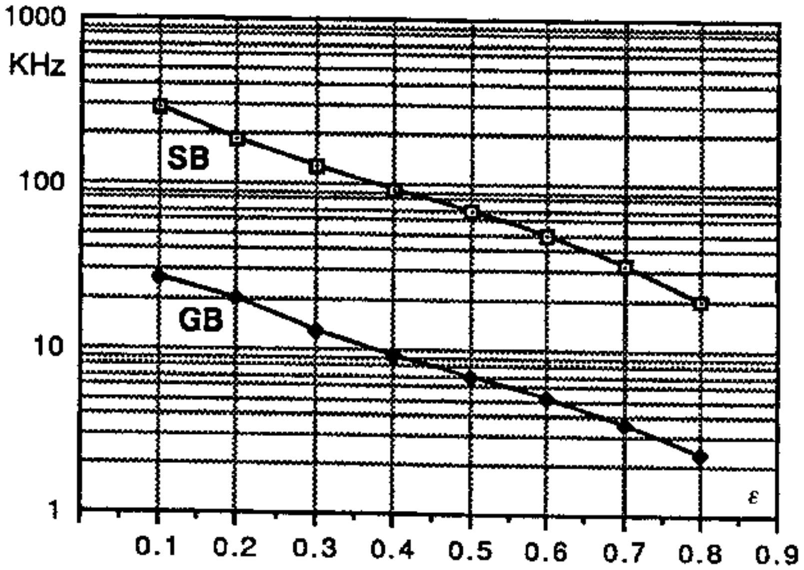

Fig. 2 - Single beam-beam bremsstrahlung and gas bremsstrahlung counting rates as a function of photon energy divided by beam energy.

The gas bremsstrahlung background can be easily subtracted in DAΦNE, where the beams are stored in two independent rings: with the detector placed downstream the IP in the direction of the positron beam (see Fig. 1), a small gap of few missing bunches in the electron beam can be created. The positron bunches passing through the IP at the same time of the electron missing bunches will produce only gas bremsstrahlung photons; the background can therefore be subtracted, the statistical error being negligible, provided all the positron bunches have the same charge or the current in each bunch can be measured, e.g. by a second bremsstrahlung detector looking at a non-interaction point. A second possibility is a small vertical separation of the beams at the IP, which allows a direct measurement of the background rate.

At the design luminosity, the probability of detecting a bremstrahlung photon in a single passage of one bunch at the IP is ≈4% at a detector threshold ε=0.3. The probability of having two beam-beam events from the same bunch crossing is therefore $\approx 2x10^{-3}$. However, the time resolution of a detector based on fast photomultipliers is in the range of 10 ns, corresponding to 3÷4 crossings at the IP when all 120 buckets are filled. In this case the probability of detecting more than one photon during the detector time resolution increases to ≈3%. This gives a systematic error on the luminosity, which, anyway, can be easily estimated from the beam-beam and background rates.

3. Detector layout

The detector layout consists essentially of one proportional counter placed downstream the IP in the direction of any of the two outcoming bunches. The crossing angle in DAΦNE can be varied between ±10 and ±15 mrad in the horizontal plane, and the photons travel through the vacuum chamber of the interaction region until they reach the splitter magnet (see Fig. 1). Here a special vacuum chamber has been designed with a slot towards the axis of the magnet, to allow the photons to escape from the ring through a $\approx 90^o$ thin window at the magnet exit, but still preserving the continuity of the chamber wall as seen by the beam. The slot is 24 mm high.

Fig. 3 shows the fraction of single beam-beam bremsstrahlung photons emitted within the half-angle displayed on the horizontal axis. The 24 mm slot height corresponds to ±1.8 mrad vertical acceptance at the thin window position. A 20 mm diameter thick collimator in front of the detector will determine a 1.5 mrad half aperture acceptance, corresponding to ≈65% efficiency in photon collection. The collimator should be provided with bidi-rectional movements in order to find the optimum alignment with the photon beam. The thin window in the vacuum chamber is designed to cope with the luminosity measurement for any choice of the crossing angle within the above quoted limits.

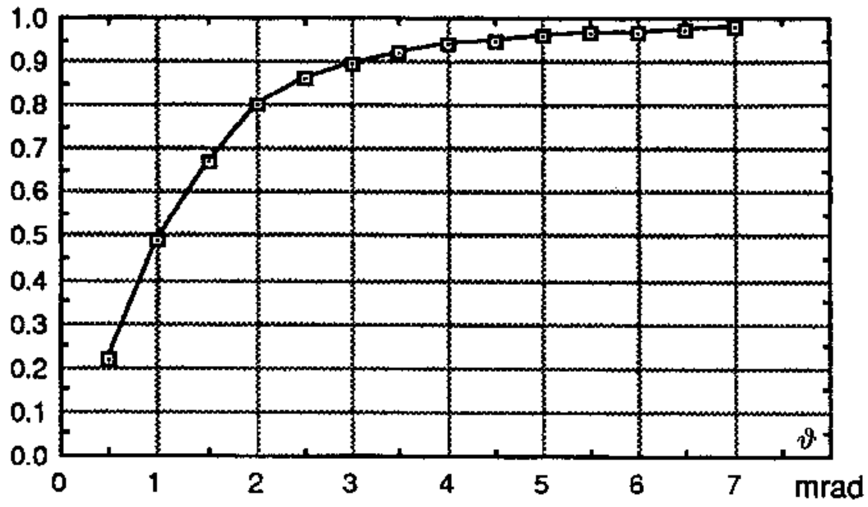

Fig. 3 - Fraction of accepted beam-beam bremsstrahlung photons as a function of collimator half-angle.

Good energy resolution is required from the detector, in order to precisely measure the photon energy threshold, which is directly related to the integrated cross section. The relative resolution $\Delta E/E$ improves typically with the square root of the photon energy, and it has been shown[4] that FWHM below 30% can be obtained for 0.5 GeV photons with a "sandwich" counter realized with 10 lead plates, one radiation length thick ($\approx$ 5 mm) interleaved with 10 mm thick plastic scintillators. To improve resolution, it is better to increase the total thickness to at least 15 radiation lengths and to decrease, after the first cells, the lead thickness while increasing the scintillator one. A compromise could be a modular structure, where the first section consists of 5 cells realized with 5 mm lead and 10 mm plastic scintillators; the second is made with 10 cells of 3 mm lead with 15 mm scintillators. With a resolution better than 30%, it should be possible to set the threshold around 0.25 GeV (ε=0.5), thus decreasing the counting rate and the probability of unwanted double events. The threshold will be calibrated at low beam intensity, with a dead time system built into the electronics which generates the gate for a charge integrating ADC, by comparing the measured energy distribution of the signals with the theoretical beam-beam bremsstrahlung spectrum.

Much better resolution (<10%) can be reached with a new type of proportional counters, the same used for the KLOE calorimeter. It consists of very thin lead layers (0.5 mm) interleaved with scintillating optical fibers. For the same number of radiation lengths, the overall size of such a counter should not exceed $\approx$30 cm in the direction of the incoming photons. The size of the layers in the direction perpendicular to the beam should be at least 20 cm horizontally and 15 cm vertically to avoid the shower escaping from the counter due to multiple scattering.

It should be remarked that the detector for the luminosity measurement is required also by the γ-γ experiment[5] to serve as a veto, since beam-beam bremsstrahlung is the major source of background for this kind of measurement. Being the electrons tagged on both sides of the IP, a second bremsstrahlung detector should be placed in the electron beam direction. With two detectors it will be possible to check the reliability of the single bremsstrahlung measurement (the two detectors should deliver the same luminosity value) and perform an independent measurement with double bremsstrahlung (with the detectors in coincidence).

Acknowledgments

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References

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