Luminosity Monitor Options for TESLA

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Abstract

The feasibility of a luminosity monitor based on a radiative Bhabha, beamstrahlung photons or e^+e^- detectors, is investigated in the context of the TESLA [1] linear collider.

1 INTRODUCTION

During the normal operation of a linear collider, while the beam are in collisions, the detuning of the final focus optics must be controlled in such a way that the luminosity stays maximum. The required on-line tuning procedure should be the least invasive in order to lose the least luminosity up-time. The beam-beam deflection scan method in use at the SLC [2] allows one to measure the convoluted spot sizes of both beams with a limited impact on the machine operation. For TESLA [1] however, the large vertical disruption of the colliding beams (cf. Table 1), characterised by the disruption parameter $D_y = 33$, precludes the measurement of the vertical spot size by this method. However, the combination of beam-beam horizontal deflection scans ($D_x = 0.3$) and luminosity monitoring is a valid procedure to correct both horizontal and vertical aberrations. Luminosity monitoring, recently re-investigated at the SLC [3], offers the advantage that the beam aberrations can be measured in the vicinity of the optimum head-on collision parameters and that a relative measurement of the luminosity is sufficient for its optimization.

Table 1: TESLA parameters at the IP for $\sqrt{s} = 500$ GeV

Beam sizes	σ_x^*, σ_y^* [nm]	558 , 5
Emittances	$\gamma\epsilon_x^*, \gamma\epsilon_y^*$ [μm]	10 , 0.03
Bunch length	σ_z [mm]	0.4
Bunch population	N_e [10^{10}]	2.0
Number of bunch	n_b	2820
Bunch spacing	Δt_b [ns]	337
Luminosity	$\mathcal{L}$ [$10^{33}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$]	32
Beamstrahlung	δ_B [%]	2.5

We study three options to provide such a measurement based on detecting either the bremsstrahlung leptons, the beamstrahlung photons or the e^+e^- pairs. We use the beam-beam program GUINEA_PIG [5] to generate these processes and track the trajectory of the low energy leptons, from pair creation or bremsstrahlung, through the coherent e.m. field of the opposite bunch. The bremsstrahlung cross-section is corrected for the finite beam size effect [4]. It can be artificially multiplied by a factor n_b which allows one, with a single beam-beam simulation, to track the bremsstrahlung particles and integrate the bremsstrahlung signal originating from n_b bunch-crossings assuming that the bunch parameters are fixed and their fluctuations can be neglected. This is a valid assumption since the bunch population is about 6 orders of magnitude larger than the bremsstrahlung one.

The e^+ and e^- bunches are replaced by 320 000 macroparticles with 6-D Gaussian distributions set by the beam parameters given in Table 1. The luminosity for the optimum parameters is about $3.2 \times 10^{34}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$ including a factor about 2.0 from the pinch effect. The statistical relative error on the luminosity is about $7.5 \cdot 10^{-5}$ from numerical origin. This is small enough to be able to identify, from the simulations, rate fluctuations of the order of 10^{-3} as physical fluctuations.

2 BREMSSTRAHLUNG MONITOR

Bhabha monitors are a well proven instruments for luminosity measurement at e^+e^- and e^-p colliders [6]. The radiative Bhabha process $e^+e^- \to e^+e^-\gamma$, also called bremsstrahlung has a much higher event rate at small angles than the elastic Bhabha process $e^+e^- \to e^+e^-$, and is more suitable for on-line monitoring. This rate can be measured by detecting the low-energy lepton emitted away from the intense beamstrahlung cone around the beam axis. Since they are strongly deflected by the opposite beam, the rate of the outgoing low energy bremsstrahlung leptons deflected at angles usable for a luminosity detector is enhanced. This more than counterbalances the finite beam size correction [4] of roughly 1/2 to the total bremsstrahlung rate. Because of its sensitivity to the beam-beam effect, the bremsstrahlung signal *within a fixed kinematical acceptance* is no longer an absolute measurement of the luminosity but it can still be used for measuring luminosity variations induced by beam parameter changes at the interaction point (IP) such that the horizontal beam sizes which control the beam-beam effect, are unchanged. This includes the most important vertical aberrations.

For this study the luminosity monitor, assumed to be a hollow disk around the beam axis with 24 mm inner radius. As shown in Fig.(1) its location, 8.5 m from the IP, is optimised for detecting about 40 GeV particles. The number of hits is about 550 with about 20 TeV deposited per side and per bunch crossing. Integrating over 10 bunch cross-

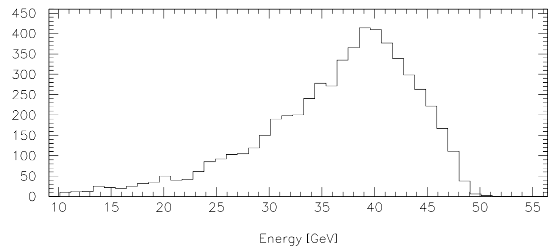

Figure 1: Bremsstrahlung energy distribution on luminosity monitor

ings and both sides leads to over 10,000 hits, enough to reduce the statistical error to the 1% level. The most important vertical beam parameters to be tuned are the beam matrix "rotations" which affect the vertical beam size, namely the vertical waist shift w_y, the vertical dispersion η_y and the yx'-coupling c_y. The definition of these aberrations and the beam matrices associated to them are given in [7]. Fig.(2) displays the results of luminosity optimisations obtained by varying the waist-shift w_y of the electron beam matrix, keeping the positron beam constant. The central configuration is such that

$$w_y^{(0)} = 0.9\,\beta_y^*, \quad \eta_y = c_y = 0 \tag{1}$$

for both beams. It is also the optimal configuration since, due to the pinch effect, the luminosity is maximized when both vertical waists are shifted by $0.9\,\beta_y^*$ in front of the IP. The gain in luminosity is about 16% with respect to the configuration where the waists are centered on the IP. In this figure, the calculated luminosity (right) is compared to the number of hits (left) from bremsstrahlung particles on the luminosity monitors, adding both sides. The scan involves 11 points and therefore a total of 110 bunch-crossings. The "optimum" luminosity as determined by the parabolic fit through the bremstrahlung rate, is less than 10^{-3} relatively smaller than the maximum of the calculated luminosity. This optimum can be determined equally well from the number of hits (counter) or from the energy deposited (calorimeter), and similar resolutions are obtained for the dispersion and coupling scans [7] as well.

In practice, each scan could be implemented with fast quadrupole pairs in the chromatic correction section (CCS) [8]. A vertical waist-scan like in Fig.(2) for instance, would be performed by symmetrically exciting the quadrupoles in the vertical CCS over 110 bunch crossings and measuring the luminosity for 110 monotonically increasing values of the waist-shift w_y at the IP. In this way, a single TESLA bunch train with 2820 bunches would allow one to measure the vertical waist-shift, the vertical dispersion and the coupling of both beams, provided the implementation of the necessary excitations of the fast quadrupoles is manageable within one pulse.

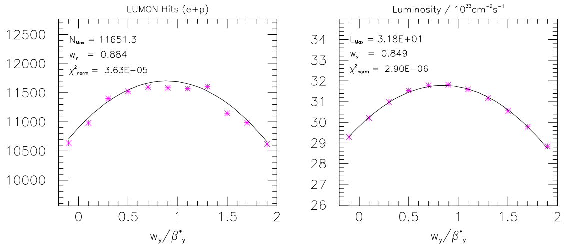

Figure 2: Scan of the vertical waist. Parabolic fits are drawn through the data points

3 BEAMSTRAHLUNG MONITOR

The beamstrahlung photons, with a ratio $N_\gamma/N_e \simeq 1.65$ for TESLA, provide a very strong signal which is directly related to the beam energy loss but less directly to the luminosity. In fact, this signal goes through a maximum when the two beams are vertically offset and deflect each other strongly. In order to decouple this effect from the luminosity optimization, we select the photons emitted in the $\pm 25 \times 5\mu$rad^2 forward cones whose intensities decrease with the beam offset. Fig.(3) shows the dependance of these intensities in the e$^-$ (left) and the e$^+$ (right) directions on the e$^-$-beam vertical waist (up) and dispersion (low). Unlike the bremsstrahlung, the beamstrahlung signal is not e$^-$/e$^+$ symmetric and signs which beam matrix is changing. As can be seen by comparing Fig.(3) to Fig.(2), the e$^-$-beamstrahlung is not effective for the e$^-$-waist tuning. Vertical dispersion, and $x'y$ the coupling as well, can however be tuned with a resolution better than 10^{-3} in terms of relative luminosity. In these scans, the 1% error in the intensity is due to the purely numerical limitation in the number of macro-photons, about 11,000, representing the physical photons contained in the forward cones.

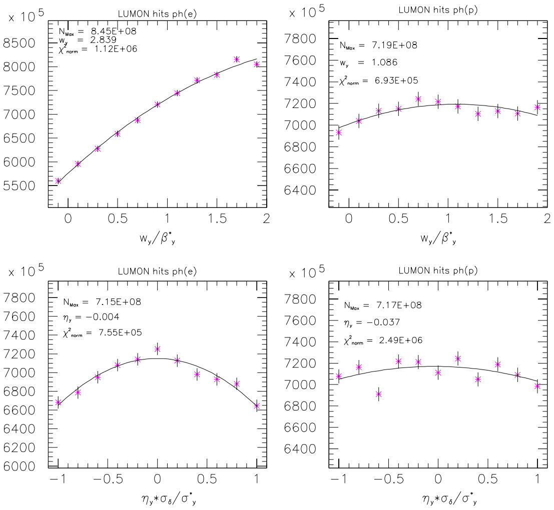

Figure 3: Beamstrahlung photon intensity per bunch-crossing vs. vertical waist (up) and dispersion (low)

4 $E^+ - E^-$ PAIR CALORIMETER

Inside the main mask a combined inner mask and luminosity monitor will be installed. This inner mask will be hit by a large number of pairs deflected by the beams. At small

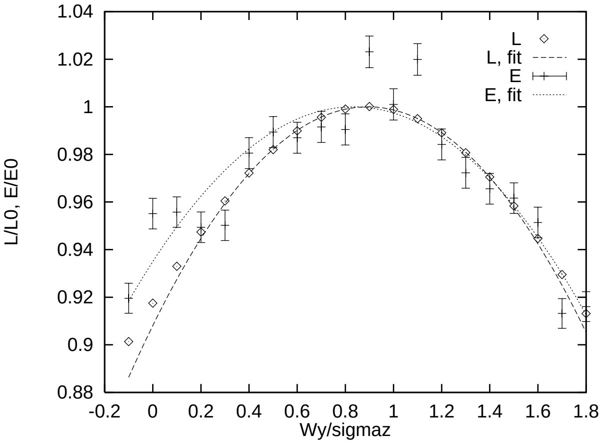

Figure 4: Scan of the vertical waist shift: energy deposited in the calorimeter and luminosity normalised to the maximal values.

radii it is covered with a low-Z material (graphite) to prevent the backscattering of low energy particles. At larger radii, where the background due to the deflected pairs is small, it will be used to measure the Bhabha events with larger angles. The rate of these events will be a few per second, much higher than those measured in the main detector for the reconstruction of the luminosity spectrum but too low for fast monitoring.

The total energy deposited by the pairs in this mask can be measured calorimetrically, but details have to be worked out. This energy is about $12000\,\mathrm{GeV}$ per bunch crossing and per side. This values varies from simulation to simulation due to physical and numerical effects. Running 25 cases with the same initial distribution (read from a file) but different seeds for the random number generators showed an RMS-spread of $1.2\,\%$ and $1.4\,\%$ for the two sides. This is in reasonable agreement with the expectation from the counting rate alone ($\approx\ 1.0\,\%$ from about 9200 hits). In practice one can expect significant contributions to the error from energy leaking out at the inner aperture of calorimeter and from jitter of the beam.

The scan was performed moving the waist of one beam, while the one of the other was about in the right position. For each point only a single bunch crossing was measured. The optimal position of the waist was determined by maximising the sum of the two signals, leading to $w_y = 0.83\,\beta_y^*$ (note that $\beta_y^* = \sigma_z$). The luminosity thus obtained is lower by a fraction of $4 \cdot 10^{-4}$ than the optimal value, which is reached for $w_y = 0.89\sigma_z$. The scan was repeated decreasing the positron bunch charge to $1.5 \cdot 10^{10}$ particles, increasing its horizontal emittance by $50\,\%$ and increasing its vertical emittance by $50\,\%$. In all three cases the luminosity for the found optimal waist position were smaller than the optimal by a fraction of about 10^{-3}.

In contrast to the bremsstrahlung process where the production of particles depends strongly on the luminosity and only weakly on the other beam parameters, the number and energy of pairs produced depends also on the number and energy of the photons produced by beamstrahlung. The deflection is however very different in the two cases. The beam particles which have emitted bremsstrahlung are still relatively high in energy and are focused by the oncoming beam. Most of the particles from pair production that hit the calorimeter are low in energy and are defocused by the same charge oncoming beam. Combining the two methods one could thus hope for reducing possible ambiguities.

5 CONCLUSION

We believe that a luminosity monitor will be a necessary instrument for the fast tuning of the collision parameters of TESLA. In this study we have shown that a radiative Bhabha counter or calorimeter can monitor the luminosity to a 1% resolution by integrating the bremsstrahlung signal over about 10 TESLA bunch-crossings, that is about 3.3 μs. The powerful beamstrahlung signal in a very narrow forward cone can also be used for tuning dispersion and coupling. A promising complementary option is a calorimeter in the masking system around the IP to measure the energy deposited by the pair-created e^+e^- particles. The 1% level can then be reached with one bunch-crossing.

With either monitor, scanning the usual vertical linear aberrations with about 10 points should permit to determine the optimal luminosity to better than 0.1% relative resolution. Implementing such scans within a single TESLA bunch train should be possible: it would reduce considerably the influence of beam jitter on the luminosity measurement errors.

6 REFERENCES

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