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Beam Size Measurements in a Linear Collider using an X-ray Gradient Undulator

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In a recent DESY internal report [1] a novel method using of synchrotron radiation was described for beam size measurements in a linear collider. Synchrotron light from a vertically focusing quadrupole magnet is deflected out of the linac with small mirrors located very close to the beam. The total radiated light power of an electron beam well centred in a quadrupole magnet is proportional to the square of transverse beam size (σ^2). Discrimination of signals due to the vertical beam size (σ_y^2) against the much larger signal from the horizontal beam extent (σ_x^2, $\sigma_x^2 >> \sigma_y^2$) can be achieved by selecting light with the electric vector in the vertical direction with polarisation filters. It was shown that the calculated signal strength is large enough to measure the vertical beam sizes of each of the individual bunches in a single bunch train.

Since publication of [1] it has been discovered that a significant background must be expected from "diffractive radiation", *i.e.* the conversion of the virtual photons accompanying each relativistic electron into real photons as they strike the deflecting mirrors. The effect is described in a note by one of the authors [2]. This diffractive radiation does not make the beam measurement as proposed impossible, but discrimination of the required measurement signal (originating in the vertical focusing quadrupole) against the much larger signal from diffractive processes may turn out to be technically difficult.

Diffractive radiation becomes negligible at higher photon energies. If the signals due to vertical beam size could be produced in the x-ray range or even at higher energies, diffractive radiation would pose no background problems. A convenient source of x-ray radiation sensitive to vertical beam dimensions would be given by an undulator arrangement as shown in figure 1, which we will refer to as a *gradient undulator*.

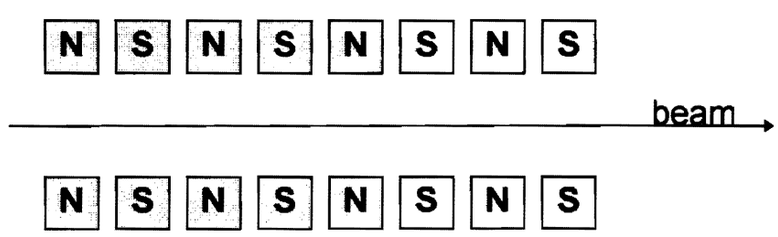

Fig. 1 Gradient undulator arrangement for measuring vertical beam size

Electrons travelling on axis do not see transverse fields and do not radiate. Vertically off-axis electrons will see alternating vertical fields with amplitudes proportional to their displacement. The total power radiated will be proportional to the square of the

particle displacement (similar to the original quadrupole case), but now most of the radiation will be concentrated at a wavelength of $\lambda_u/2\gamma^2$, λ_u being the period length of the undulator. Since there is no field variation in the horizontal plane, the radiated power will be independent of horizontal beam dimensions.

Figure 2 shows how the gradient undulator could be used in a chicane arrangement in the linac of a linear collider. Apart from the obvious advantage of photon extraction, the chicane also laterally displaces the detector away from the main beam axis (6 mm in this example), and hence away from any high energy photons travelling down the linac which could be a source of considerable background.

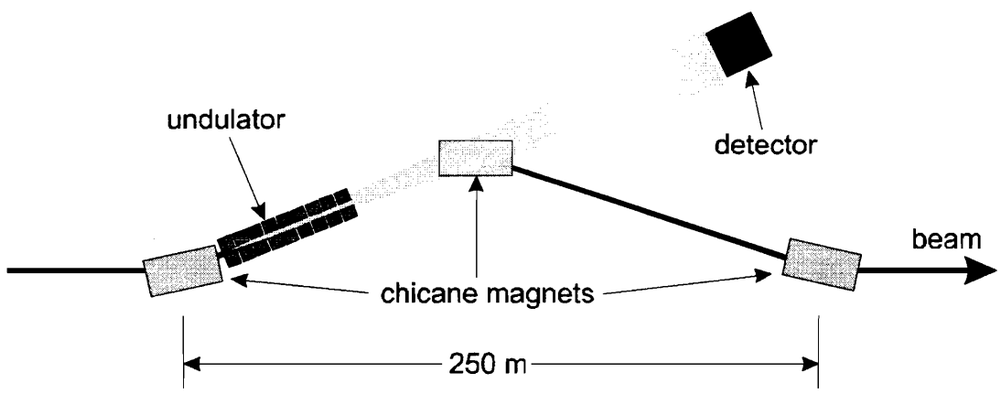

Fig.2 Arrangement of undulator and x-ray detector.

The beam size signal from the undulator must now compete with the synchrotron radiation background produced in the chicane, but since the latter is considerably weaker and softer than the undulator signal, it should be relatively easy to block this with appropriate filters. Table 1 gives typical numerical examples for three different electron energies. The large number of x-ray photons expected is easily enough to measure in a "single shot" the individual beam sizes of all bunches in a bunch train. As in the case of synchrotron radiation from quadrupoles, the signal is proportional to the square of the displacement. In a well centred beam with a Gaussian distribution the signal is proportional to the square of the *rms* height (σ_y^2). By moving the beam through the centre of the undulator with beam bumps, one can easily calibrate the device[1].

The exact determination of the beam width depends on the measurement of the total power output of the undulator when the beam is exactly centred (on axis). Since the power output is a quadratic function of the vertical beam offset, it should be a simple task to adjust the device to give a minimum signal. While the numbers given in table 1 clearly show that a strong measurable signal is expected, the effect of errors and the overall question of tolerances for the device still needs evaluation. However, early estimates of the effects of single pole misalignment suggest that mechanical tolerances may not be too restrictive. Further investigation into the tolerance issue and the expected accuracy of the device is currently underway.

[1] As an alternative to beam bumps, the undulator could be placed on a precision mechanical mover, and the device (not the beam) vertically scanned.

Table 1: Examples of typical numbers for three different electron energies

Electron energy	250	30	3	GeV
Vertical beam size	15	25	45	μm
Undulator radiation power[1)]/ current	2074	83	2.7	V
Photon energy	60000	864	8.6	keV
Number of photons/10^{10} electrons	345	960	3140	$\times 10^3$
Background:				
Chicane field strength[2)]	100	24	2.4	G
Characteristic energy[2)]	412	1.4	0.0014	keV
Chicane synchrotron radiation power/current[3)]	8000	6.6	6.6×10^{-4}	V

1. Assumed here is a samarium-cobalt hybrid undulator with 100 periods, a gap of 3 mm and a length of 1 meter, in which the maximum gradient of the vertical field is 4.8 $T.cm^{-1}$.
2. Assumed here is a 180° beam bump produced by vertical bending magnets of 1, 2 and 1 m length. For the 30 and 3 GeV case the detector will be 6 mm away from the beam axis (3 mm at 250 GeV)
3. Only at high electron energies is the total synchrotron radiation power from the chicane fields comparable with the signal power. Only part of this radiation will hit the detector however, and that part can probably be filtered, since it is so much softer than the signal (undulator radiation).

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References

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2. E. G. Bessonov, Internal Report DESY M 96-15, August 1996.