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# A High Resolution Beam Profile Monitor Using Bremsstrahlung

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J. Norem*
Argonne National Laboratory, Argonne, IL 60439

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## INTRODUCTION

The development of efficient high energy linear colliders in the 1 TeV range requires final focus systems capable of producing beam spot sizes on the order of 1 - 20 nm, about three orders of magnitude smaller than those produced at the SLC.[1] Although beam line designs exist which can, in principle, produce the required optics, the construction of quadrupoles with the size and precision required will be challanging. Field errors in these quads must be small and should be verified experimentally, which is difficult with existing technology.

This paper describes a proposal to use bremsstrahlung from heavy targets to measure high energy beam profiles and positions with a resolution approaching a few nm.[2] The method is also applicable to tests of other final focus systems (flat beams, plasma lenses[3]) at lower energies.

## METHOD

A design for a final focus system for a 1 TeV linear collider has recently been produced by Oide.[1] This design requires a flat final focus spot with dimensions 41 by 1 nm, and a $\beta^*$ at the focus of 43 microns. Since beams of these dimensions are too small to examine with wavelengths longer than 1nm, and the environment of a collider interaction point will allow minimal mechanical or electrical pickups, bremsstrahlung from a thin flag seems to be the best method of extracting beam profile information.

We describe the system shown in Fig 1. Using this system a fixed collimator downstream of the IP will produce a penumbra whose width will be equal to the beam size at the foil times the magnification $M = L2/L1$. The converter target must have a thickness less than $\beta^*$ to sample the waist. Since the beam density is very high, the foil will probably be destroyed on every pulse. This constraint, plus the difficulty of rigidly mounting the foil edge to nm tolerances inside a high energy physics detector argue against using the edge of the foil to probe the beam shape as shown in Fig 2a, and the method shown in Fig 2b seems more suitable. A sweeping magnet is used to prevent the electron beam from hitting the collimator.

## EXAMPLES

This method has been considered for profile measurements of a final focus spot size in a plasma focus experiment and as a final focus diagnostic in a 1 TeV linear collider. A possible set of parameters are shown in Table 1 for the two cases.

Backgrounds due to synchrotron radiation in the sweeping magnet and slit scattering have been calculated and estimates of thermal heating and mechanical jitter have been considered. Magnification is optimized by decreasing L1 (increasing the sweeping magnet field) or increasing the total length of the system (L2). Since synchrotron radiation from the last quads is unavoidable the sweeping magnet field is assumed to be a few times $B'\sigma$ where $B'$ is the quad gradient and $\sigma$ is the beam size, giving sweep fields of 0.5 T and L1 roughly 1 m. The separation between the beam and the collimator surface

$$d \approx l^2 / 2R - n\sigma$$

where l is the length of the magnet, R is the bending radius, seems tolerable.

The collimator, which absorbs a few joules/pulse must remain flat at the level of the resolution of the device, ideally a few nm. Inexpensive quartz mirrors are made to flatnesses of about 25 nm (1/20 wave) over large areas, and should be better than this over small areas. Beam heating will distort the surface, so it would be desirable to use a material which has a high heat conductivity and low thermal expansion coefficient. Heating from a single 1 TeV pulse assuming an effective shower volume of 1.25 $cm^3$, is 2.6 °C in Pb, and this heating should distort the surface about 2 nm.

Synchrotron radiation can be approximated from the energy loss per turn,

$$dE/E = 8.85\cdot 10^{-5}\, E^3/R,$$

for an electron of energy E in GeV, multiplied by the solid angle of the active area of the detector. The average (critical) energy of these photons is given by

$$E_c = 0.667\cdot 10^{-6} E^2 B,$$

where the B field is in teslas. The photons are quite energetic, nearly 1 GeV for 1 TeV electrons.

Backgrounds due to slit scattering have been examined using EGS4,[4] by calculating a normalized angular distribution, $1/E\ dE/d\Omega$, as a function of secondary photon angle for scattered energy from the slit. These are shown in Fig 3. The fraction of energy directed into the detector is this distribution times the detector solid angle. The corresponding normalized angular distribution for the direct bremsstrahlung beam is given by $1/2\pi\sigma_{x'}\sigma_{y'} \approx 10^9$ at 1 TeV, where $\sigma_{x'}$, $\sigma_{y'}$ are the beam divergences.

The bremsstrahlung must be detected using a technique that samples the total energy, and insensitivity to the low energy photons is highly desirable. A cerenkov calorimeter, preceded by a dense preradiator would give profile information with a resolution of 0.1 radiation lengths,[5] (about 0.3 mm) which is insufficient for high precision measurements. If this detector is preceded by a movable collimator, the penumbra can be differentiated by measuring the detected signal as a function of position of the second collimator, using a number of pulses. In principle, profiles can be extracted from single pulses if the second (diagnostic) collimator is inclined slightly to the primary collimator, making profiles along the collimator surface equivalent to motion perpendicular to it.

Alignment accuracy and jitter could limit the ultimate resolution of the system. Ground noise is frequency and environment dependent, however above a few hertz the amplitude is roughly $A[\mu] = 0.1/f[Hz]$,[6] and externally produced noise should move all nearby components together. Thus measurements taken over short timescales (0.01 sec) should be possible at the level of 1 nm. All components could be aligned with piezotranslators which can produce repeatable

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movements approaching this precision.

## CONCLUSIONS

A preliminary analysis has shown that heavy target bremsstrahlung, collimated by slits, should be capable of producing beam profiles with resolution approaching the beam sizes required in 1 TeV colliders. Problems due to synchrotron radiation and slit scattering backgrounds, jitter, alignment and collimator heating must be evaluated for specific geometries.


## ACKNOWLEDGEMENTS

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## REFERENCES


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TABLE 1

| | | |
|---|---|---|
| E | 50 GeV | 1 TeV |
| $n_e$ | $3 \cdot 10^{10}$ | $0.5 \cdot 10^{10}$ |
| $\varepsilon$ | $3.3 \cdot 10^{-9}$ | $1.2 \cdot 10^{-14}$ m |
| $\beta^*$ | 7 mm | 43 μ |
| Pb radiator | 0.6 mm | 30 μ |
| B | 0.5 T | 0.5 T |
| M = L2/L1 | 10 = 10/1 | 100 = 100/1 |
| Synch/Brem Power | $10^{-4}$ | $10^{-1}$ |

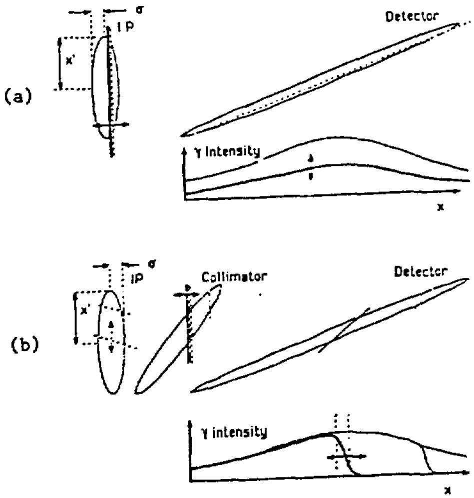


Fig. 2 Photon Phase Space

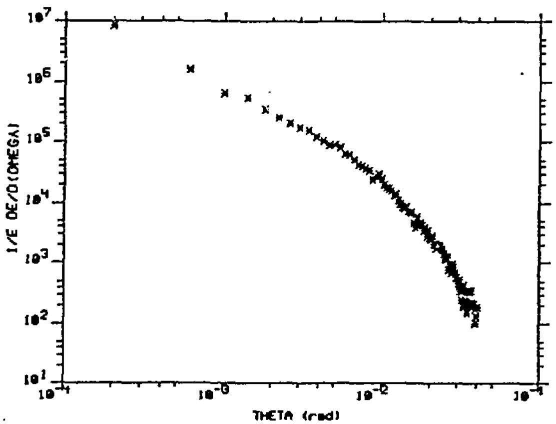


Fig. 3 Angular distribution for slit scattering, 1/E dE/dΩ, for 1 TeV a beam.

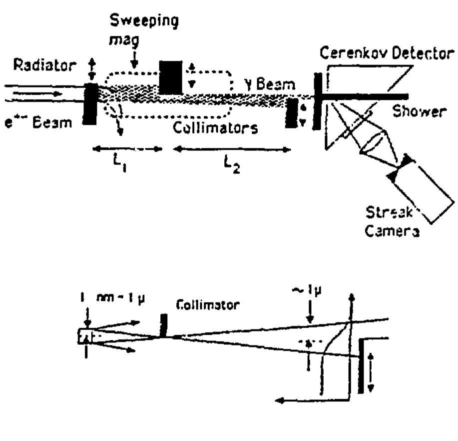


Fig. 1 Plan of Bremstrahlung Monitor