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A Compact Beam Profile Probe Using Carbon Fibres*

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A beam profile monitor based on the use of carbon fibres is described. It has been designed to be compatible with the operation of the Mark II particle detector at the SLC, including high resolution secondary vertex detectors mounted 25 mm radially from the beam.

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1. Introduction

Thin wire or fibre probes are in use at many accelerators to allow the measurement of beam profiles and positions [1]. In particular, at the Stanford Linear Collider (SLC) it is frequently necessary to measure the beam spot dimensions — in the range of microns — at the interaction point of the colliding electron and positron beams. Since this must be done at the centre of a large and densely packed experiment, the design of the fibre probe presents some challenges.

The difficulties have been compounded by the recent development of high spatial resolution solid state or drift chamber detectors placed close to the beam line. These are designed to detect and measure the decay vertices of short lived species, such as particles bearing charm or beauty quantum number. In this paper we report on a mechanism that inserts a fibre probe on to the SLC beam line at the interaction point, and is compatible with the small radius vertex apparatus in the Mark II detector [2].

2. Environment

The spatial constraints imposed by Mark II are typical of large solid angle detectors. At azimuthal angles of 15 to 25 mrad from the beam line are detectors for electron-positron elastic (Bhabha) scattering. A minimum of material is allowed in front of these. This is true also between 50 and 120 mrad., where the solid angle is devoted to the principal luminosity monitor. To the extent possible, only thin sections of the beam pipe intervene between the interaction point and these detectors. Above 25° also, the resolution of the secondary vertex detectors and main drift chamber must be preserved by keeping the multiple scattering to a minimum.

The central thin section of the beam pipe, illustrated in fig. 1, extends ± 4.8 cm about the collision point, and its radius is 25 mm. The materials are 0.41 mm of aluminum with an internal deposit of 0.025 mm copper to suppress scattered synchrotron radiation, for a total of 0.65% of a radiation length. Immediately outside it is mounted a silicon strip vertex detector.

For the next section, 6.2 cm long, the beam pipe is slightly thicker, 0.84 mm, but of the same radius. However, by 17 cm from the collision point, the pipe has widened to an internal radius of 37 mm, and this is maintained, with minor variations, out to 50 cm.

It is not permissible to position material too close to the actual beam axis. Although the beam dimensions are a few tens of microns in the worst case, and it may be steered not much more than a millimeter, there is a substantial flux of synchrotron radiation. This comes mostly from the final focussing quadrupoles, has a mean critical energy of about 600 keV, and is constrained within about 20 mm radius by masks, although variation in tuning conditions can affect this limit slightly. Rescattering of this radiation into the Mark II by material inside the beam pipe cannot be tolerated. Under less than ideal beam operating conditions, there may also be in the pipe a flux of Bremsstrahlung gamma rays from scraping of the beam on collimators far upstream. This could also scatter from material placed at too small a radius.

In this space, it was required to be able to insert fine fibre probes on to the beam line at the interaction point, so that both horizontal and vertical profiles of the beam could be measured. Since the beam position at the interaction point must, of necessity, be controllable with sub-micron resolution, it is not necessary for the fibre probe to move across the beam. Once the fibres are positioned on the nominal beam line, the beam can be steered to find the fibres, and then to be stepped across a fibre to establish the beam's profile. This stepping is normally carried out at a beam pulse repetition rate of 10 Hz, allowing time for the beam to be resteered between pulses.

3. Construction of the probe

The design makes use of space inside the beam-pipe about 18 cm from the beam-beam collision point. In this region the radius is 12 mm larger than in the central thin section, to accommodate a tantalum synchrotron radiation mask. A pivoting arrangement at this point permits a cantilever to rock, so that the fibres at its tip can be placed on the beam line close to the collision point. In the other direction, the cantilever can be retracted to within 0.5 mm of the beam pipe. One mechanism is mounted on either side of the collision point, rotated so that one set of fibres is horizontal, the other vertical. This permits both profiles of the beam to be probed.

Because of frictional difficulties with bearings in ultra high vacuum, the mechanism uses flexural pivots [3], which have no sliding or rolling parts. As seen in fig. 2, an aluminum cylindrical yoke is supported diametrically by two flexural pivots which, in turn, are clamped to the inner wall of the beam pipe. Movement of the yoke is effected by a pair of diametrically opposed miniature bellows [4]. The stainless steel welded bellows, closed at one end, are pressurized with air by a stainless steel hypodermic pipe on the side away from the collision point. As one bellows is pressurised and expands, the air supply to the other is opened to the atmosphere, so that it can compress. To hold them conservatively within their parameters, the stroke of the bellows is kept short by mounting them, at the opposite ends of a diameter, at 45° from the pivoting axis. The expanding bellows follows a circular path, and care was taken that the shape under pressure would not bulge significantly to a larger radius, and possibly, in a severe case, become unstable. The circular expansion paths at the 45° points added substantially to the difficulty of fabricating the device. Tests of the arrangement showed that it could be actuated through at least ten thousand cycles without failure of the bellows or the pivots.

The ends of the motion are determined by stops. Each stop has a ceramic button with a conducting head mounted on the yoke, and this makes contact with a stainless steel plate fixed to the beam pipe. The thicknesses of the "in" and "out" plates were set, by trial and error, to position the fibre probe on the beam line, and their holder within 0.5 mm of the beam pipe, respectively. Repeatability was surveyed to within 25 μm.

A wire is threaded from each button, insulated by ceramic tubing, or in some sections woven glass fibre. They go through the flexural pivot, where the 7° twist of the motion is easily absorbed, and through miniature coaxial cables for 70 cm along the inside of the beam pipe. At this point they can be fed through to the atmosphere without the feedthrough mass infringing the detector's clear view of the collision point. The "in" or "out" condition is monitored by the short-to-ground of a 24 V level applied on these lines to the stop buttons, and is incorporated in the SLC machine protection system.

The cantilever holding the fibre probes is attached, at its base, to the yoke. The design is illustrated in fig. 3. The body is made of aluminum, 0.75 mm thick. It is formed cylindrically to an outer radius of 24.5 mm, and so stays as far as possible from the unmasked area around the beam. The piece takes the form of a two-prong fork, whose gap is wide enough to prevent damage to surrounding detectors from synchrotron radiation scattered by the prongs when the probe is on the beam line. The cantilever material contributes, on average, an extra 12% to the scattering mass of the aluminum beam pipe in front of the secondary vertex detectors.

The fibre material is carbon, which is unsurpassed in its ability to withstand the heating of the beam. The fibres are positioned on terraces machined in the edge of the prongs. The terraces are 150 μm in depth and breadth. To align the very stiff fibres more accurately, and to reduce the chance of breakage at the edge, it was necessary to bend the tips of the prongs more sharply than the body of the fork, so that the take-off angle of the fibres is kept small. The prongs are anodized, so that the fibres are insulated from them. The ends of the fibres are attached by solder to gold plated copper tabs, rivetted to the prong. The anodization in the rivet holes allows the tabs to remain insulated from the body of the cantilever, although the production yield of fully insulated tabs was low. There are facilities to connect two of the four fibres on a cantilever to the outside world *via* miniature coaxial cables along the cantilever, and then parallel to the stop connections described earlier. For safety and diagnostic reasons, high resistance connections between the fibres and the electrically grounded cantilever were formed by graphite films, over the surface of the anodization, to bare metal.

Fibres of 35 μm and 4 μm nominal diameter were installed. The larger diameter is used in the early stages of beam tuning. The fibres — one thick and three thin — are too close together to be resolved in the drawing. Multiple thin fibres are used because of a history of unexplained breakage of 4 μm fibres, and the possibility of destruction of the thinner fibres by a well focused beam. The retention of the fibres in their terraces is facilitated by minute quantities of sodium silicate, used as a vacuum- and radiation-compatible adhesive.

It was found that when the cantilever was attached to the very stiff and resonant body of the beam pipe, the fibres were susceptible to failure if the pipe received an accidental sharp impact. It was necessary to attach a thread of about 100 fibres of 7 μm diameter across the gap. This restrains the prongs from resonating in such a way as to stretch the sensing fibres, and so the fibres remain within their breaking strain. These threads are held by a combination of a wrap of aluminum foil and some sodium silicate. The structure of the fork permits the thread to be placed about 1 mm radially outside the probe fibres, and it does not interfere with beam measurements.

The pneumatic controls, outside the Mark II, have been described before [5]. Under control of the SLC computer network, air pressure at about 45 psi is valved to one of the positioning bellows inside the vacuum, while the other is valved open to the atmosphere. The two forks can be moved independently. Air pressure is maintained constantly to hold the devices either on the beam line or fully retracted.

The present device was designed also to make use of the available instrumentation for measuring the interaction of the beam with the fibres [5]. Because of systematic complications in the interpretation of surface emission signals [5], the Bremsstrahlung flux is normally measured, using a converter plate and a gas Cherenkov counter [6].

4. Beam Scan Examples

In fig. 4 are plotted the Bremsstrahlung signals resulting from scanning an electron beam across 4 μm fibres in steps of 1 μm. Scans across orthogonal fibres are illustrated, and the peaks have Gaussian widths of 2.21±0.03 μm horizontal by 2.54±0.11 μm vertical. The diameter of the fibres effectively contributes 0.33 μm and 0.28 μm respectively to the width of the peaks, and so the actual beam widths at the time were 1.9 μm and 2.3 μm. Unlike the case of surface emission of electrons, Bremsstrahlung has no complications related to the fields of the beam bunch, and so the interpretation of the profiles is uncomplicated.

5. Operational Experience

The fibre probes are easily and routinely used for beam diagnostics. While this beam tuning is going on, the Mark II detector voltages are reduced to safe levels. With the probes withdrawn from the beam, the detector can return quickly to data collection. The synchrotron radiation does not rescatter at a significant level from the internal components of the device.

It must be emphasized that there is a beam intensity limit to the fibre probe technique. Although approximately 45% of the dE/dx energy loss in the fibre escapes as delta rays, the remainder degrades into heat. For example, at approximately 10^{10} electrons per bunch, and a round beam spot of gaussian width σ=2.8 μm, the fibre would overheat and fail. Fibres of materials other than carbon would, of course, fail at lower intensities. At higher beam intensities, other techniques for beam measurement must be used [7].

6. Summary

We have described a system of thin fibre probes, mounted at the collision point of the SLC, and compatible with the precision secondary vertex detectors of the experiment at the collision point. The probes are easy to use and are continuously available for use as needed, subject to the fundamental limitations of survival of solids in intense beams.

Acknowledgements

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Figure Captions

1. Longitudinal section of the beam pipe at the SLC interaction point. D: drift chamber inner wall; S: silicon strip vertex detector; V: vacuum pipe wall; P: pivot axes. The positions and relative orientations of the two fibre support forks and their pivoting mechanisms are illustrated.
2. Oblique view of the rocking mechanism. B: the actuation bellows; S: one of the two ceramic precision stops; P: flexural pivots. The base of the fibre support fork is shown attached to the cylindrical rocking yoke. Parts shown dashed are the support and reaction members that attach to ribs in the beam vacuum pipe.
3. A fork. The beam probe fibres are indicated, as are the tabs to which they are attached. The rigidising band of fibres is shown alongside the probe fibres. The two thin coaxial cables stretch longitudinally from two of the tabs nearly to the end of the fork. The head-on view illustrates that the fork is radially thin.
4. Beam scan profiles, measured by the Bremsstrahlung yield, from an electron beam with horizontal (X) width 1.9 μm and vertical (Y) width 2.3 μm.

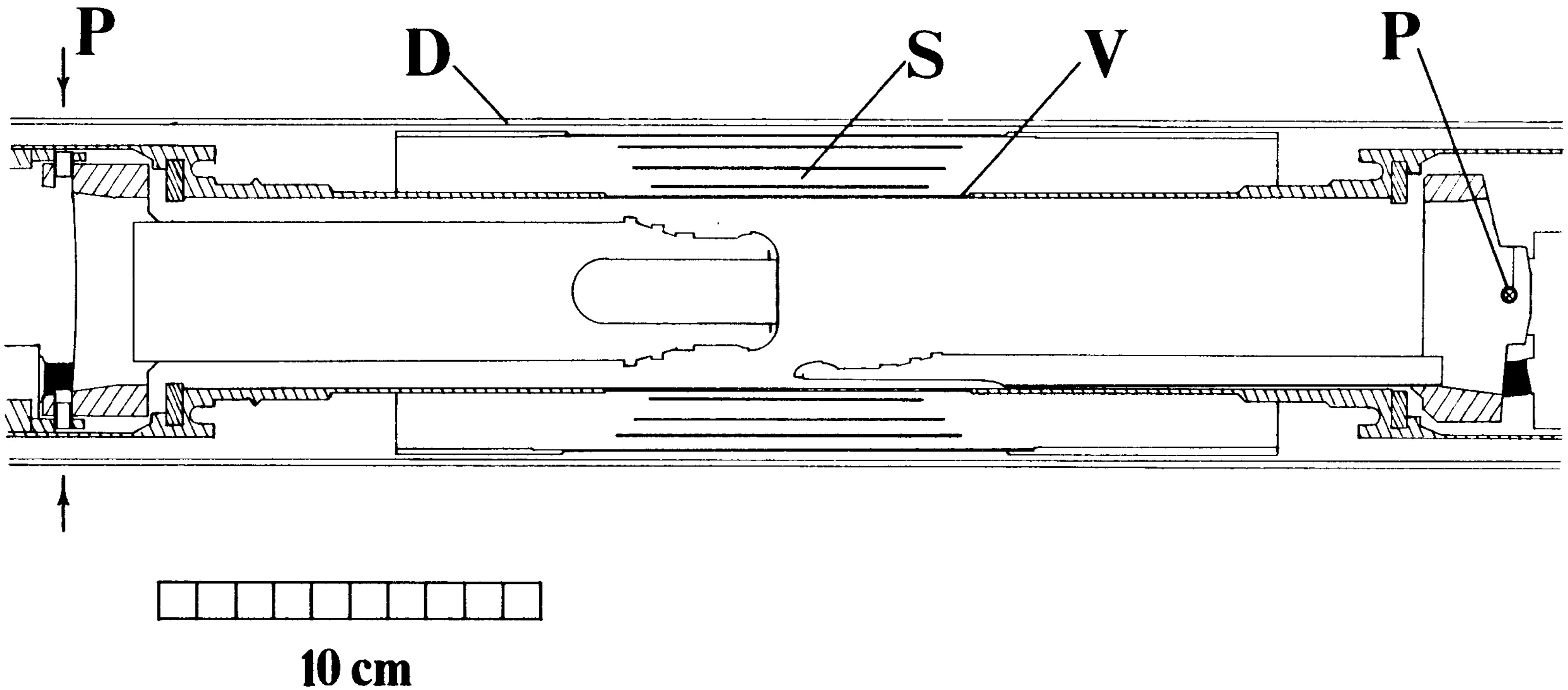

Fig.1

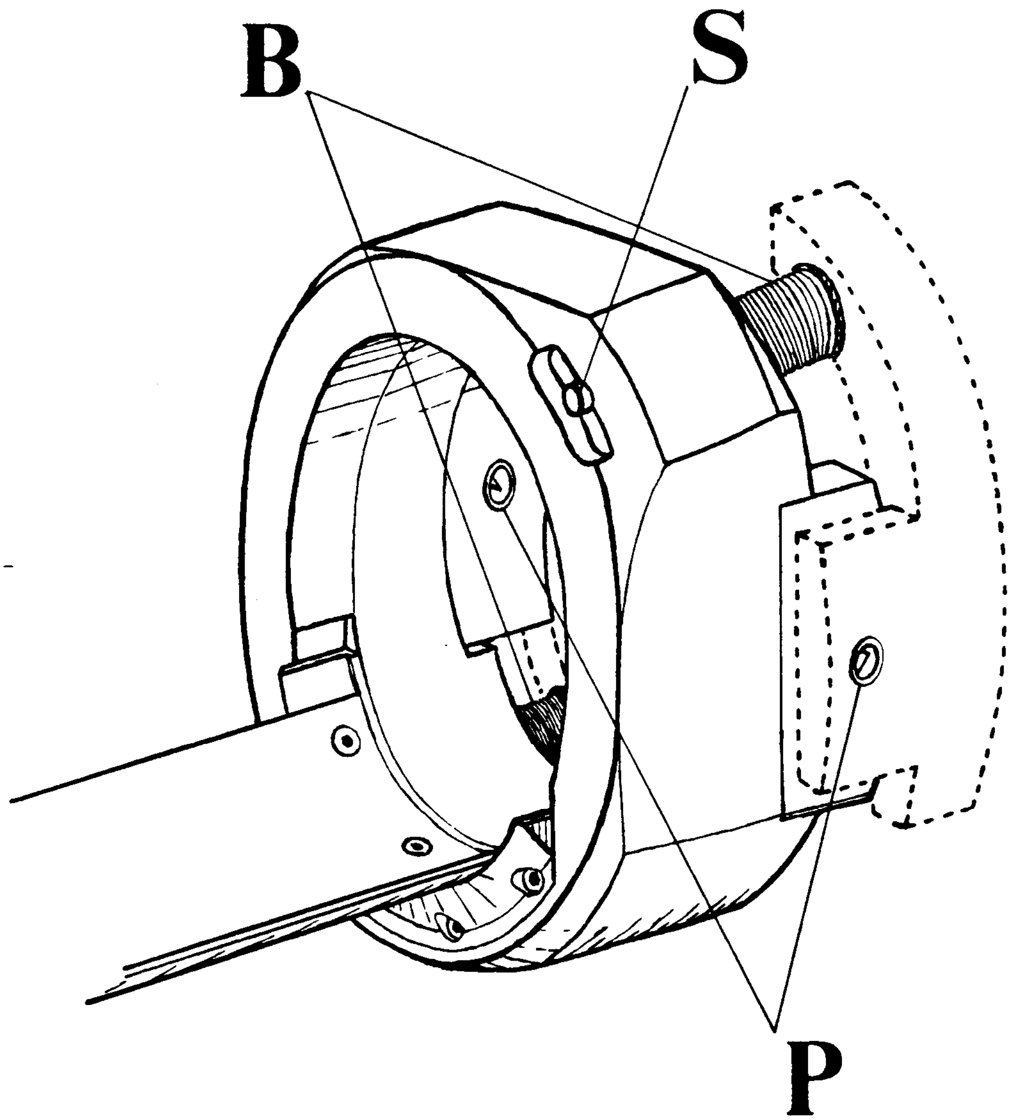

Fig.2

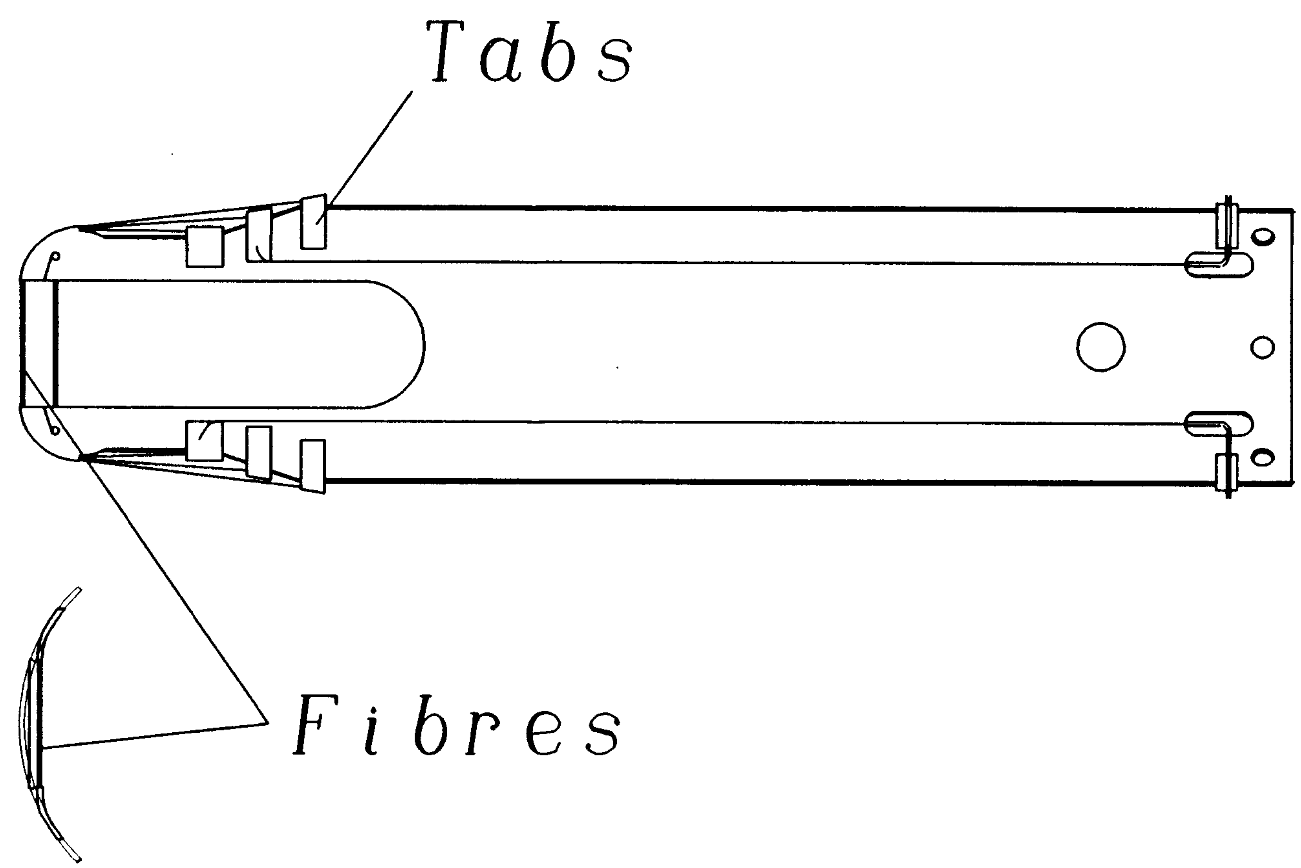

Fig.3

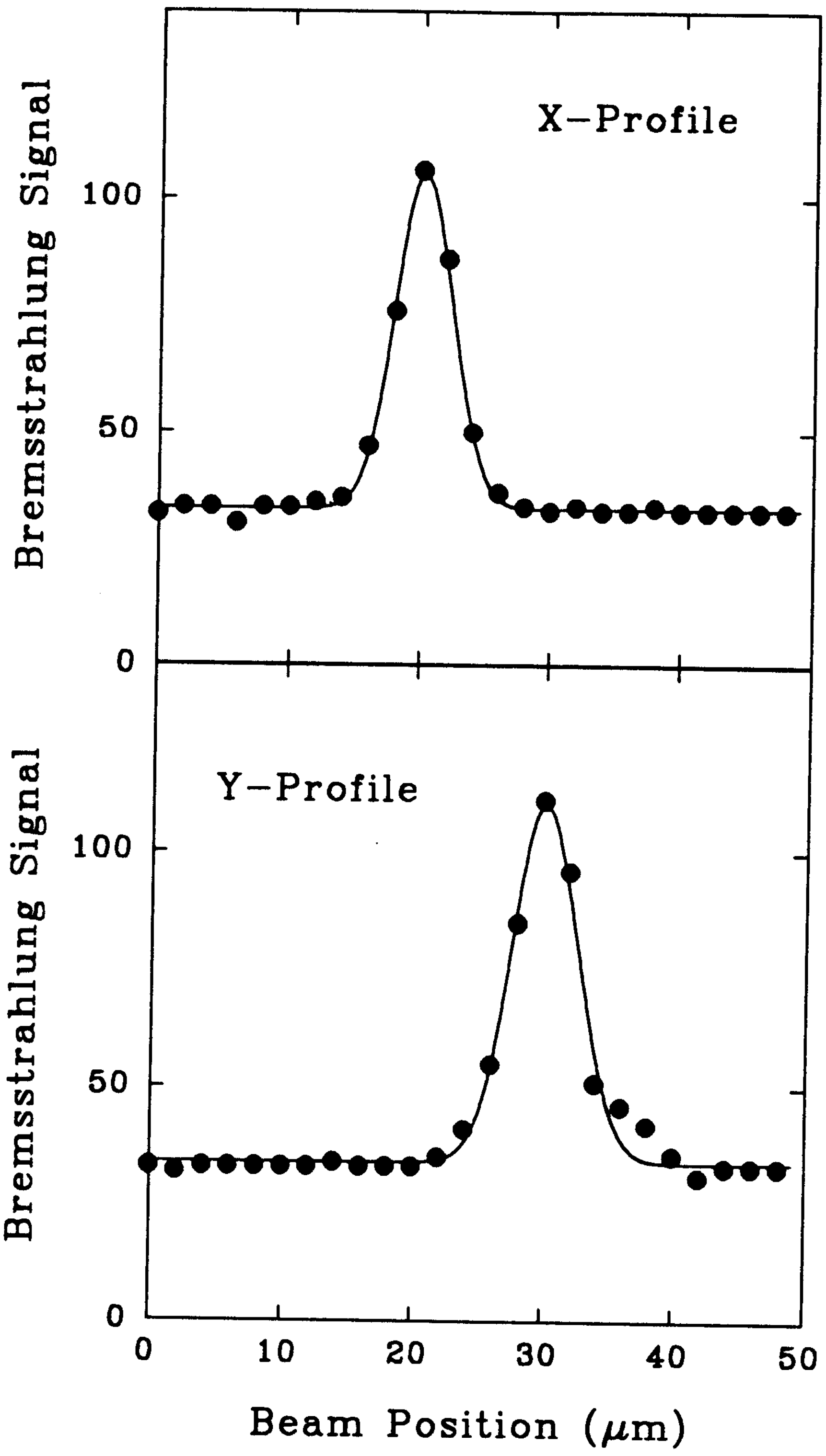
X-Profile
Y-Profile
Bremsstrahlung Signal
Bremsstrahlung Signal
0
50
100
0
50
100
0
10
20
30
40
50
Beam Position (μm)

Fig.4