

A TRANSVERSE BEAM PROFILE MONITOR FOR p-p̄ STUDIES  
IN THE CERN SPS

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1. Introduction

In the SPS collider, counter-rotating beams of protons and antiprotons will be stored at 270 GeV/c for many hours. Each beam will consist of up to 6 bunches of 10<sup>11</sup> particles. A simple device has been developed which allows the transverse profile of each individual bunch to be measured in an almost non-destructive way.<sup>1,2,3</sup> A fine beryllium wire is passed quickly (~4m/s) through the beam. The profile is measured by detecting the high-energy secondary particles produced in the wire. Due to the strong directionality of secondary particle production the profile of each proton and antiproton bunch can be measured simultaneously using two scintillators placed either side of the wire and close to the beam pipe. In addition, profiles of single beams can be obtained by measuring the secondary electron current emitted by the wire. The device has been successfully tested during storage studies with protons.

2. Mechanical considerations

The upper limit of the speed of the wire is governed by the desired precision of the measurement of the profile of a single bunch. To obtain a wire displacement of 0.1 mm during the revolution time of the bunch requires a speed of 4.34 m/s. The prototype device was constructed from existing mechanical components and electronics by modifying a rotating mechanism normally used for moving TV screens. The wire (50μ beryllium) is stretched on a fork (figure 1) which is driven by a DC motor and a reduction gear box through a rotating vacuum seal. The wire rotates through an angle of 120° on a radius of 115 mm. This gives a total displacement of 240 mm and allows ample space for smooth acceleration and deceleration of the fork. A potentiometer mounted on the drive arm of the fork provides the signal for the control of the acceleration and deceleration and at the same time allows the speed to be monitored. With this simple arrangement, a traversal speed of 2.5 m/s has been achieved.

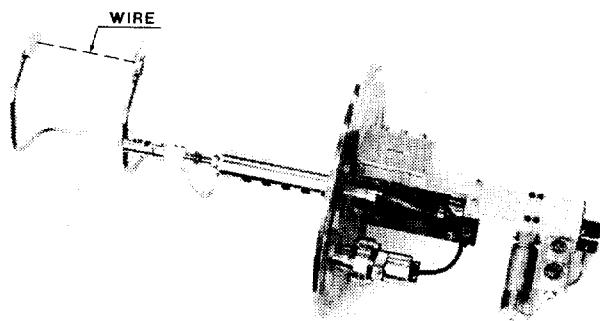


Figure 1. Prototype wire scanner

Production versions of the device now under construction will have speeds continuously variable up to 10 m/s.

3. Effect on the beam

The passage of the wire across the beam produces emittance blowup through multiple Coulomb scattering. The emittance blowup per scan is given approximately by

$$\frac{1}{\pi} \frac{d\epsilon}{dn} = \frac{1.12 \times 10^{-4}}{p^2} \cdot \beta \cdot \frac{d^2 f_r}{v L_{rad}} \left[ \text{m.rad/scan} \right]$$

where p is the beam momentum (GeV/c), d the wire diameter (m) v the speed (m.s<sup>-1</sup>), L<sub>rad</sub> the radiation length (m), f<sub>r</sub> the beam revolution frequency and β the beta value at the position of the wire.

Putting p = 270 GeV/c, β = 50m, d = 50 × 10<sup>-6</sup>m, v = 4.3 ms<sup>-1</sup>, L<sub>rad</sub> = 0.347m, f<sub>r</sub> = 44 × 10<sup>3</sup>Hz, then

$$\frac{1}{\pi} \frac{d\epsilon}{dn} = 5.7 \times 10^{-6} \text{ mm.mrad/scan}$$

This should be compared with the blowup due to gas scattering, given by

$$\frac{1}{\pi} \frac{d\epsilon}{dt} = 1.6 \times 10^3 P_{MS} \cdot \frac{\bar{\beta}}{p^2} \text{ m.rad/h.}$$

Supposing the equivalent pressure for multiple scattering, P<sub>MS</sub> ~ 10<sup>-3</sup> torr and β̄ ≈ 50m then  $\frac{1}{\pi} \frac{d\epsilon}{dt} = 1.1 \times 10^{-3}$  mm.mrad/h., so almost 200 scans/h could be made with the wire to give a blowup equivalent to the residual gas. In practice the device will be used much less frequently so that its influence on the beam is negligible.

4. Heating of the wire

The upper limit of intensity at which the device can be used is governed by the heating of the wire by the beam. Assuming that no conduction occurs during the time of traversal of the beam, the temperature rise during a scan of a single beam is

$$\Delta T = 3.82 \times 10^{-14} N_p \cdot f_r \frac{dE}{dx} \cdot \frac{1}{v h_{eff} s} \text{ } ^\circ\text{C}$$

N<sub>p</sub> is the number of particles in the beam, dE/dx is the energy loss (MeV.cm<sup>2</sup>.gr<sup>-1</sup>), v is the velocity in cm.s<sup>-1</sup>, h<sub>eff</sub> is the effective height (cms) in the direction perpendicular to the scan (h<sub>eff</sub> = √2π σ for a Gaussian beam) and s is the specific heat in cal.gr<sup>-1</sup> °C<sup>-1</sup>.

Putting dE/dx = 1.61 MeV.cm<sup>2</sup>.gr<sup>-1</sup>, v = 430 cm.sec<sup>-1</sup>, s = 0.436 cal.gr<sup>-1</sup> °C<sup>-1</sup>, h<sub>eff</sub> = √πβ/2 = 0.18 cm. for antiprotons (ε = 0.04π mm.mrad, β ~ 50m) then

$$\Delta T = 8 \times 10^{-11} \text{ } ^\circ\text{C/proton.}$$

So for the full charge of 1.2 × 10<sup>12</sup> particles, the temperature rise is acceptable (96°C). The prototype device has already been used at an intensity of 3 × 10<sup>12</sup> protons with a scan speed of only 250 cm.sec<sup>-1</sup>, giving a calculated instantaneous temperature rise of ~ 320°C.

One of these devices will be used in a low beta intersection (h<sub>eff</sub> ≈ 0.35mm). A quartz fibre will be

used instead of beryllium in order to allow a higher temperature rise (480°C at 4.3 m/s).

### 5. The scintillator detector

The distribution of secondary particles produced by interaction of the proton beam with the wire is strongly peaked in the forward direction. Previous calculations<sup>2</sup> showed that the flux density should be sufficiently high that a small scintillator placed close to the beam pipe should intercept a large number of secondaries and so reproduce the incident beam profile with good statistics.

After striking the wire, the secondaries travel in an enlarged vacuum chamber for about 3 metres after which the chamber profile is sharply reduced to the normal magnet vacuum chamber (56mm x 132 mm) (fig. 2). Two slabs of scintillator (NE 110) each of 140mm x 50mm x 10mm were placed above and below the beam pipe touching the vacuum chamber. Plexiglass light guides from both scintillators were fed into a single photomultiplier placed below the beam pipe. This geometry allowed secondary particles to be intercepted within the angular range 9 to 25 mrad with respect to the circulating beam. The photomultiplier was shielded from direct particles by a 1.6 m steel shield.

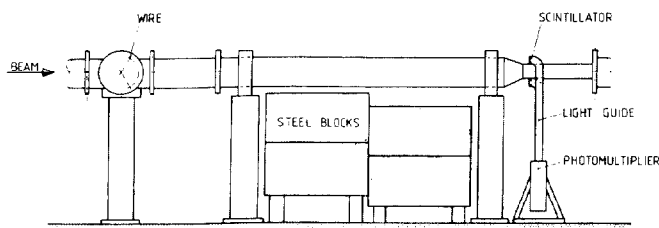


Fig. 2 Layout of scintillator detector

The photomultiplier was chosen for good linearity and high peak current output at the expense of gain. Initial experiments with a Philips XP2020 gave good profiles with a low intensity debunched beam (fig.3) but proved to be far too sensitive with dense single bunches. Much better results were obtained with a PM2243/B. This is a 6-stage tube with a trialkali photocathode. The gain was  $\sim 10^4$  at 2 kV overall voltage.

A typical profile of a single bunch is shown in Figure 4.

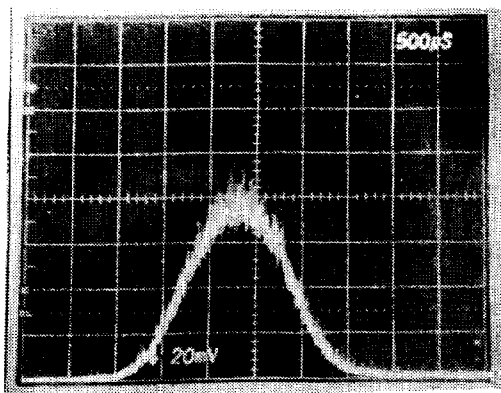


Fig. 3 Profile of a debunched beam of  $10^{10}$  protons

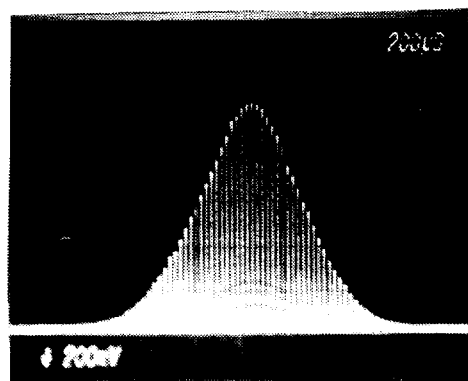


Fig. 4 Profile of a single bunch ( $\sim 5$  nsec duration)  $3 \times 10^{10}$  protons with scintillator telescope.

In order to check the directionality of the device, two identical scintillators were placed at identical positions upstream and downstream of the wire. The ratio of the signals in the two tubes was greater than  $10^4$ .

### 6. Secondary emission detection

The charge created in the wire by the passage of a single bunch is given by

$$\frac{dQ}{dn} = \xi \frac{dN_p}{dx} \cdot d$$

where  $\xi$  is the charge created per traversing proton,  $d$  the wire diameter and  $dN_p/dx$  the particle density as a function of the scanning direction  $x$ . Figure 5 shows a typical profile for a circulating beam intensity of  $10^{10}$  protons/bunch. The vertical r.m.s. height was 1.3 mm. From the output signal and the known parameters of the amplifier and the vertical charge distribution in the centre of  $dN_p/dx = 3 \times 10^9$  protons/mm a charge collection efficiency  $\xi$  of 4.8% is obtained, which is in excellent agreement with the expected value from thin aluminium foils.

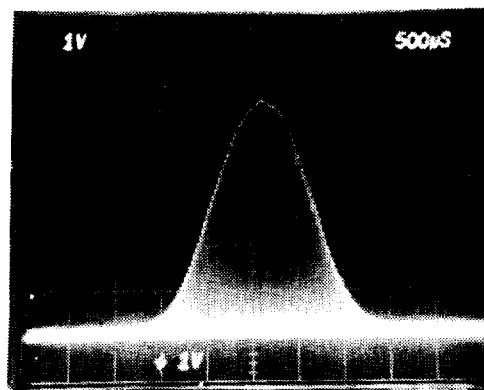


Fig. 5 Profile of a single bunch of  $10^{10}$  protons from secondary electron emission current.

Clearing electrodes were mounted on the fork, on which a voltage of  $\sim 1$  kV could be applied. No influence of bias voltage on the charge signal could be found.

### 7. Computer interface

A simple computer interface was built to allow acquisition of beam profiles and measurement of wire

speed. Figure 6 shows a block diagram of the system. The fast (<50 nsec) signal generated in the scintillator was first passed through a low-pass filter to allow subsequent treatment by slow electronics. This was followed by a sample-and-hold circuit with a reset at the revolution frequency. This converted the fast pulse into a square wave of  $\sim 15 \mu\text{sec}$  duration which could be sampled by a fast ADC followed by a 4K memory. Figure 7 shows a typical profile obtained in this way.

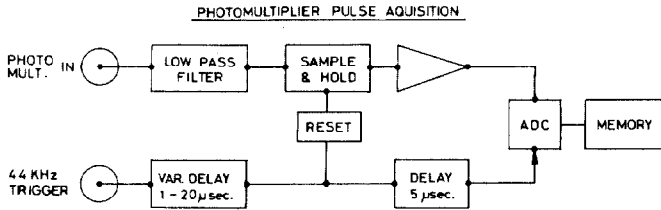


Fig. 6 Computer Interface

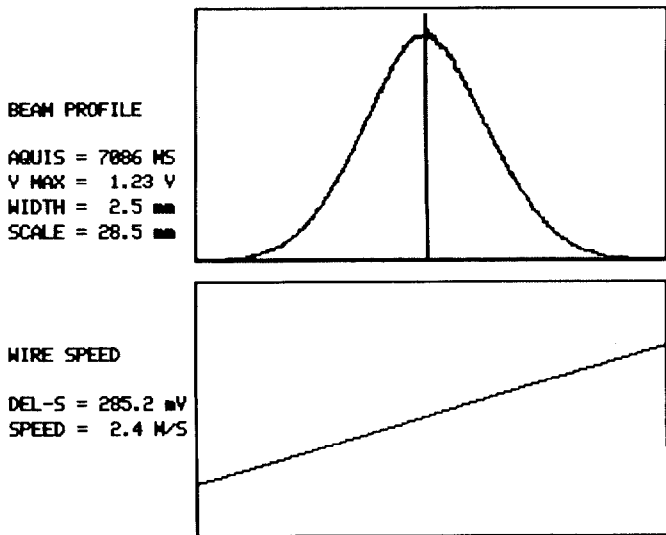


Fig. 7 Computer acquisition of bunched beam profile and wire speed

## 8. Conclusions

The device provides a simple precise means of measuring the profiles of stored protons and anti-proton beam. For a reasonable frequency of scans the effect on the beam is negligible. It works over the whole energy range of the SPS (10 GeV/c to 450 GeV/c) and will provide a valuable tool for beam studies under the conditions of the p-p̄ collider.

## References

1. W. Schnell, CERN ISR-RF/68-19 (1968)
2. L. Evans, R. Shafer, BNL 57236, p. 68 (1979).
3. P. Sievers, Private Communication, (1979).