

The Orsay Spot Size Monitor for the Final Focus Test Beam

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Abstract

The principle of the ionization spot size monitor built at Orsay and installed at the focal point of the FFTB line of SLAC is reviewed. Its constituents (pulsed gas target, MCP ion detector and electronics) and their performances are briefly described, together with preliminary background tests performed at Orsay.

I. INTRODUCTION

A beam size monitor of a new type [1] built at Orsay to measure the beam dimensions at the focal point of the Final Focus Test Beam [2] (FFTB) has been installed at SLAC. The goal is to measure a spot size of about one micron horizontally and that can be vertically decreased down to 60 nm r.m.s. in a flat beam operation. The principle of the measurement [3,4] is based on the transverse kick given to ions by the space charge field of the electron beam. The ions will be produced by ionization of a pulsed gas target at the focus. In a first measurement with an Argon gas, the heavy Ar^+ ions receive a kick proportional to the electric space charge field. The maximum velocity of these ions is proportional to the maximum field that is inversely proportional to the beam dimensions. The time of flight of the ions to reach a detector has a minimum value that scales linearly with the radius of a round beam (see Fig. 1). For a flat beam, this quantity is also slightly dependent on the beam aspect ratio.

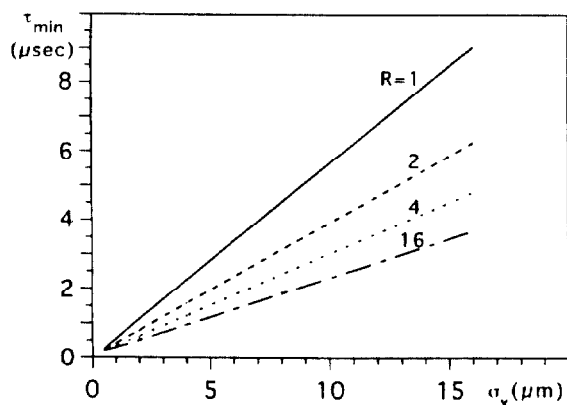


Figure 1: The minimum time of flight $\tau_{\min}$ of Ar^+ ions vs. the r.m.s. horizontal beam dimension σ_x for several aspect ratios $R = \sigma_x / \sigma_y$.

A second measurement, with a Helium gas, will allow to obtain the aspect ratio and to resolve the ambiguity of the first measurement. The light He^+ ions are trapped and oscillate in the space charge field during the passage of the beam pulse. In the case of a horizontally flat beam, the mean oscillation amplitude is larger in the horizontal direction than in the vertical one. After passage of the beam the ions are

emitted in the transverse plane with an azimuthal distribution peaked along the horizontal direction. On the contrary, the azimuthal distribution is isotropic in the case of a round beam. The anisotropy of the azimuthal distribution (see Fig. 2) will then give the beam aspect ratio.

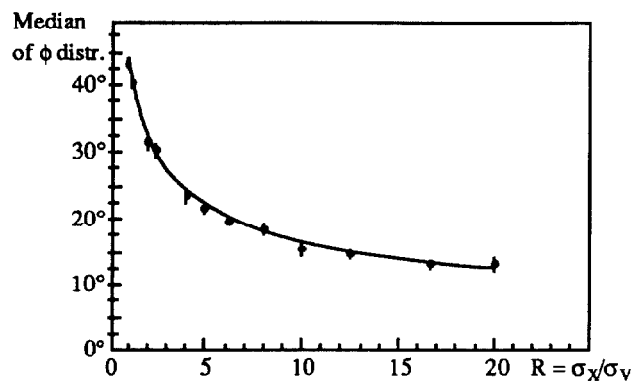


Figure 2: The median of the He^+ azimuthal ϕ -distribution between 0° (hor. direction) and 90° (vert. direction) in the transverse plane vs. the beam aspect ratio σ_x / σ_y , as given by a Monte-Carlo simulation.

Schematically, the Orsay beam size monitor comprises a pulsed gas injection and pumping device, and an array of multichannel plates with spatial and time resolution to detect the ions (see Fig. 3). Two gas inlets allow to inject Helium and Argon gas into the beam pipe at the focal point. The injected gas is pumped rapidly between two successive electron bursts. The ions kicked by the space charge field of the beam pass through a narrow slit inside a thick shielding. They hit an octagon of microchannel plate (MCP) detectors. The hit signals, collected on read-out anodes, are analyzed in time by fast ADC's. The anodes are divided in 8 strips, parallel to the electron beam, for each of 6 MCP detectors and 16 ones for the two MCP detectors hit by the ions emitted near the horizontal plane. The azimuthal distribution will be given by the counting rate of these 80 strips. The ions are also longitudinally deflected by an electric field applied between two small electrodes at the exit of the slit. The strips are made resistive and are read at each end so that the charge division of a signal between the two ends gives the longitudinal position and the deflection. Its correlation with the measured time of flight allows to discriminate ions of different electric charges.

II. THE PULSED GAS TARGET

The two gas injectors are modified fast valves of General Valve Co with a minimum opening time of about 150 μsec . Their shutter needles open two 1 mm diameter nozzles in the wall of the beam pipe. The injected gas expands in the pipe

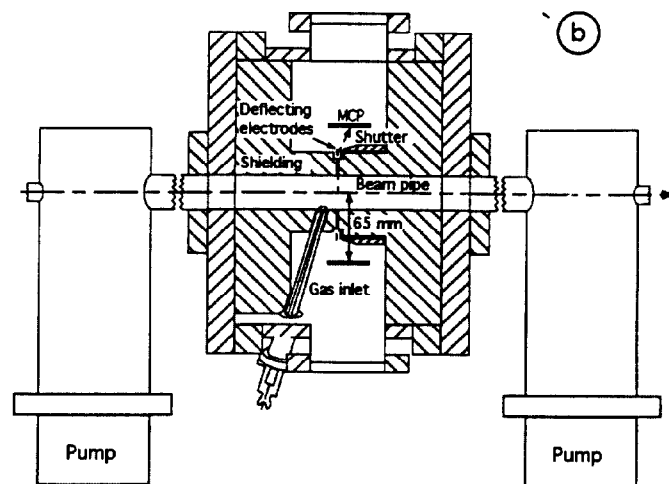
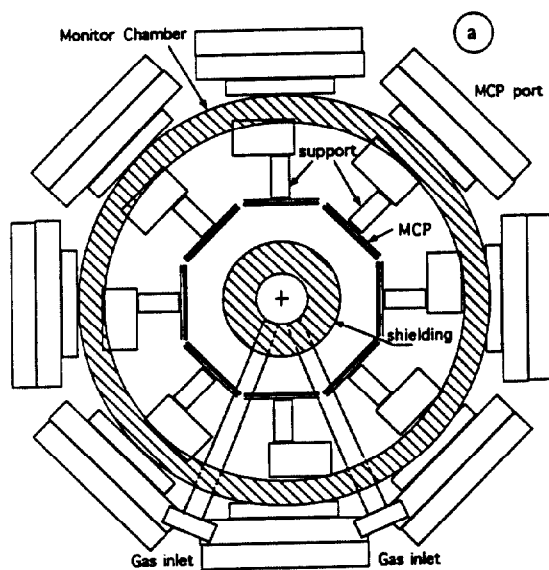


Figure 3: Schematic view of the beam size monitor : a) Transverse section at the FFTB focus, b) Longitudinal section along the beam line.

and its pressure reaches a maximum at the shutter closure when the electron bunch passes through. The maximum value is controlled by the opening time. It can be varied in the range 10^{-6} – 10^{-3} Torr. The upstream gas pressure is set around one bar. The pulse of gas is then pumped through the beam pipe by the two 150 l/sec turbopumps on each side of the monitor. The pressure decreases exponentially with a characteristic time of a few milliseconds (see Fig. 4). The mean increase of the pressure in the beam pipe has been measured, at the point where the pump pipes are connected, and has been found to be about a factor 200 lower than the maximum pressure at the focal point.

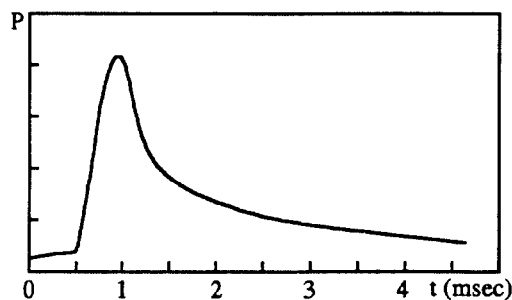


Figure 4: The variation of the pressure P (in arbitrary units) at the focal point in the beam pipe as a function of the time, when a pulse of Helium is injected. The pressure has been measured on a full-size model of the monitor with a fast gauge ($P_{\text{max}} = 1.4 \times 10^{-3}$ T, $P_{\text{upstream}} = 450$ T).

III. THE MCP ION DETECTOR

Each detector is made of 8 pairs of rectangular 40x50 mm MCP's from Hamamatsu Co. They deliver fast signals (≈ 5 nsec) of a few picocoulombs. To calibrate them four radioactive α -sources will be located in front of the MCP's. Fig. 5 shows a pulse height spectrum obtained with these α -rays. The position of the peak is controlled by the high

voltage applied on the MCP's. It allows to adjust the gain and the electronic efficiency of the 8 pairs as required to obtain the ion azimuthal distribution.

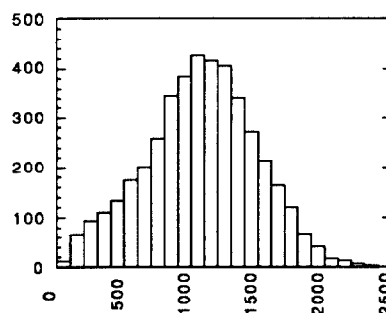


Figure 5: A pulse height spectrum (arbitrary units) of α -ray signals. The resolution is 77% FWHM.

Preliminary tests of the charge division between the two ends of each anode strip have indicated a longitudinal resolution of about 0.5 mm r.m.s. (see Fig. 6). It will be enough to discriminate ions of different charges that are separated by a few millimeters when a DC potential of about 1500 V is applied between the two small deflecting electrodes.

IV. ELECTRONICS AND ACQUISITION

Each of the 160 electronic channels (see Fig. 7) is made of a charge preamplifier located near the monitor followed by an amplifier and a shaper at a remote location. They have a smooth gain saturation that avoids long dead time, after the background pulse accompanying the beam (see Section 5), that would prevent the detection of the first ions arriving on the MCP's. The gain can also be rapidly changed by steps. The shaper pulses (30 nsec long) are sampled by HAMU chips [5] (analog pipelines) followed by 8-bit ADC's and

triggered at each electron burst. They run at 200 MHz, delivering 512 samples, each 5 nsec long. They give the time of each ion hit and the amplitude of its signal. A Macintosh microcomputer is used for data acquisition and treatment. It is also used to control the monitor hardware in connection with the general control of the FFTB line.

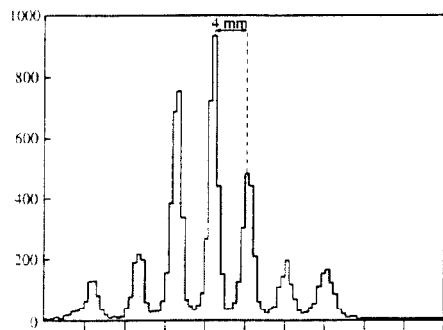


Figure 6: The spectrum of the longitudinal positions obtained with ions passing through thin slits 4 mm apart.

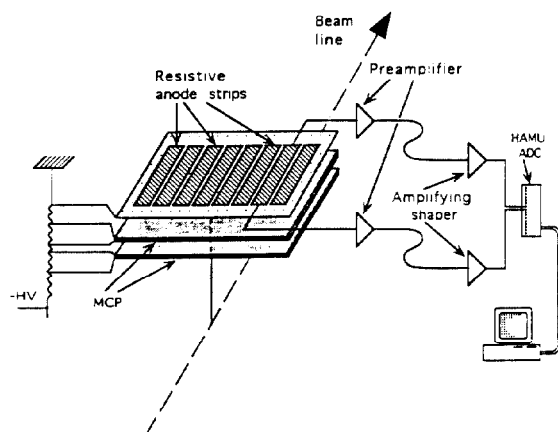


Figure 7: Schematic diagram of a MCP pair with the resistive anode strips and the associated electronics. Two read-out channels of only one strip are shown.

V. LINAC TESTS

The ability of MCP's to detect ions in the environment of a high-energy electron beam has been tested on the Orsay linac at 1 GeV and bursts of a few 10^8 electrons. The background conditions were severe, probably more severe than it can be expected at the FFTB. However, the background level in the MCP detection set-up has been found very small after the passage of an electron bunch. Ions were produced by the electron beam in a low-pressure gas target, composed of a residual gas with some addition of Helium. The beam space charge was negligible and a DC electric field was used to drift and collect the ions on a MCP. Figure 8 shows the time of flight spectrum of these ions, showing two peaks due to H^+ and He^+ ions respectively. The first peak at ≈ 200 ns is observed even without drifting field. It is attributed to background particles associated with the long tail of the beam, arriving after the applied cut off and extending up to ≈ 400 ns.

The only problem is the high background signal at the time of the bunch passage that is 10-100 times larger than an individual ion signal (see Fig. 9). It saturates the electronics

and can lead to a long dead time preventing to detect ions arriving 200 nsec later or less. Several means to reduce the dead time have been developed. The first one is to cut the gain of the MCP pairs during the passage of the beam by applying a blocking pulse between the two MCP's that reverses the potential on the gap between them. Most of the electrons getting out of the front MCP are repulsed and cannot reach the second MCP. It reduces the background signal by a factor 3. In another means, the preamplifiers have been designed to have a smooth saturation curve with nearly logarithmic increase of their gain up to an about 100 pC charge. Finally, the width of the shaper pulses has been reduced to 30 nsec FWHM. In conclusion, the electronic improvements made after the linac tests, show that even the fastest ions (arriving with a delay of about 70 nsec) could be detected if the background would be as high as at the Orsay linac.

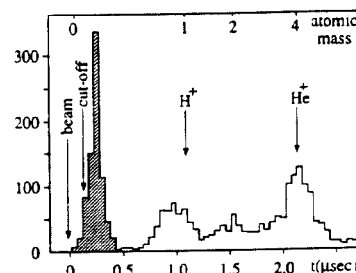


Figure 8: Time spectrum of MCP signals obtained with and without (hatched) a DC drifting voltage of 100 V.

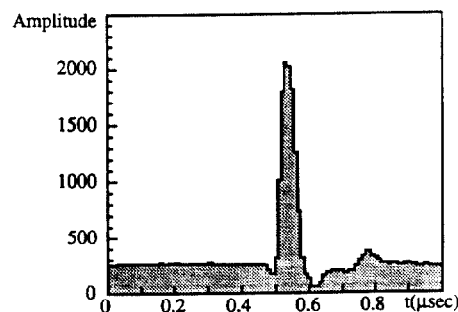


Figure 9: A record of a beam background pulse (≈ 50 pC) collected on a MCP anode after amplification, and digitized by a "HAMU" chip (The bin width is 10 nsec). The small pulse, arriving 240 nsec later and corresponding to about 1 pC, is due to an individual particle.

VI. REFERENCES

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- [3] P. Chen, D.L. Burke, M.D. Hildreth and R.D. Ruth : "A Plasma Beam Size Monitor", SLAC-AAS-41, 1988; presented at the International Workshop on the Next Generation of Linear Colliders, Stanford, 1988.
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