IEEE Transactions on Nuclear Science, Vol. NS-28, No. 3, June 1981

VERY LOW INTENSITY STORAGE-RING PROFILE MONITOR

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Introduction

The Fermilab Colliding Beams Group has now accomplished several cooling experiments (electron and stochastic methods) on proton beams in the "electron cooling" synchrotron ring built for this purpose. A key to analyzing the performance of any test cooling system is a complete set of beam diagnostics to measure the beam emittances in all three planes.

For longitudinal emittance we use the well established method of Schottky scans (although our very low intensities make this difficult, necessitating a departure from the conventional method by bunching the beams).

In our experiments the design demands for transverse emittance monitors are extreme:

1. Good time resolution: Original consideration was of cooling e folding times of <100 ms.
2. Good space resolution and dynamic range: Observation of initial "hot" beam and final pencil electron cooled beam is desirable.
3. High Sensitivity: Our experimental $\bar{p}$ beam intensities vary from $2 \times 10^5 \rightarrow 2 \times 10^6$ $\bar{p}$ ($\lesssim 0.1$ mA).
4. Low intercepting mass: Since ring (140m) vacuum is to be 10^{-10} Torr. The intercepting monitor mass must be a reasonable fraction of this.
5. UHV compatible: All parts bakeable to $\sim 400^\circ$C. High reliability and nonconsumable components to reduce opening system to air.

The original concept and design of such a monitor, involving a Mg vapor ribbon slicing the proton beam and an MCP (multi channel plate) telescope with position sensitive readout is described elsewhere.[1,2] Here we describe the MCP telescope and readout which evolved independently as a complete monitor system using residual gas in lieu of Mg vapor. To date all transverse measurements of coasting beam profiles have been obtained in this mode.

MCP Monitor

Figure 1 presents a conceptual view (not to scale!) of the device. Our actual monitors (Figure 2) were designed for operation with a Mg vapor ribbon, tilted 45° from vertical, to allow two dimensional profiles to be measured via a two dimensional resistive anode charge readout. This same design, as in use now, functions as well (except more slowly) with no Mg ribbon. In this case the (presumed uniform) intensity of beam line residual gas ($\sim 5 \times 10^{-10}$ to $\sim 3 \times 10^{-9}$ Torr during the period of use sofar) is ionized by beam collisions. A one dimensional "image" (in ions) of the beam is projected (by transverse sweeping E field) onto a multi-channel plate telescope.

*Operated by Universities Research Association, Inc. under contract with the U.S. Department of Energy.

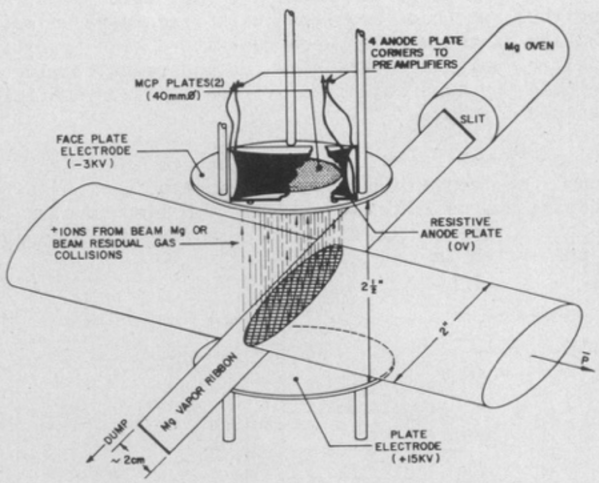
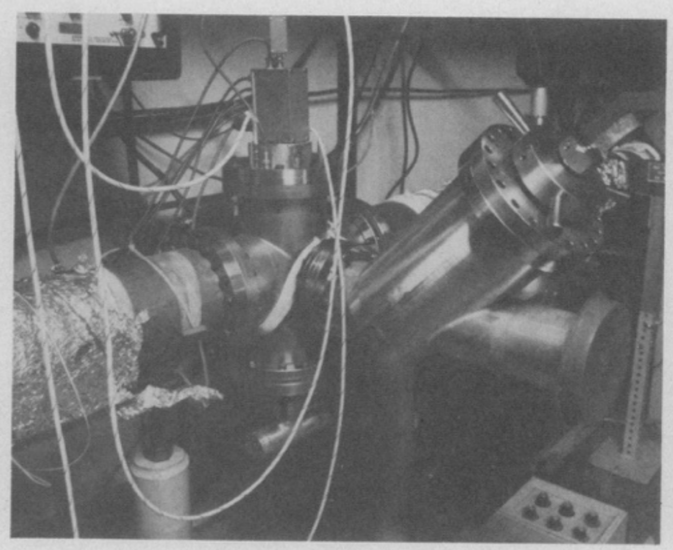


Fig. 1 Conceptual view, MCP monitor.

The device functions on an event by event basis. Each ion formed in the beam initiates a (time) distinct avalanch in the MCP whose charge is divided amongst the resistive anode sheet corners. Each charge is separately digitized and stored for final use in computation of that event's position. In our present case one coordinate (longitudinal) is superfluous. Except for the geometrical distortion due to round plates all distributions in this dimension must be uniform (which operationally becomes a good performance check). Of course, we must use two devices, one for vertical and another for horizontal profiles. The horizontal device is pictured in Fig. 2:



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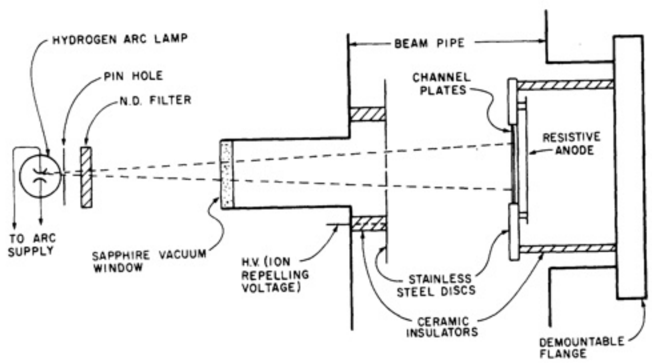
Profile "snapshots" consist of 512 ionization event coordinates. The analog to digital conversion time limits the "exposure" time to ~5 ms. Under typical running conditions (10^{-9} Torr N_2, 2 x 10^6 p circulating) we measure 200 ms elapsed time for snapshots. Calculation of the expected rate from gas cross sections at 200 MeV proton kinetic energy (assuming 100% ion collection efficiency) gives 85 ms exposure time.

Although MCP's are sensitive to both ions and electrons we had problems with secondary emission feedback if the monitor were run with a high positive repeller voltage. The high ion mass also eliminates the need for high collection voltages and/or confining magnetic fields.

Since MCP's are also sensitive to UV light we found it convenient to incorporate an in situo fiducial scheme into the design. The lamp housing is visible on the bottom flange of Figure 2. A schematic of the system is in Figure 3:



UV CALIBRATION SYSTEM

Figure 4 illustrates data taken with UV light through a mask consisting of 5 holes. DATA FWHM is consistant with that calculated from the ray optics umbra.

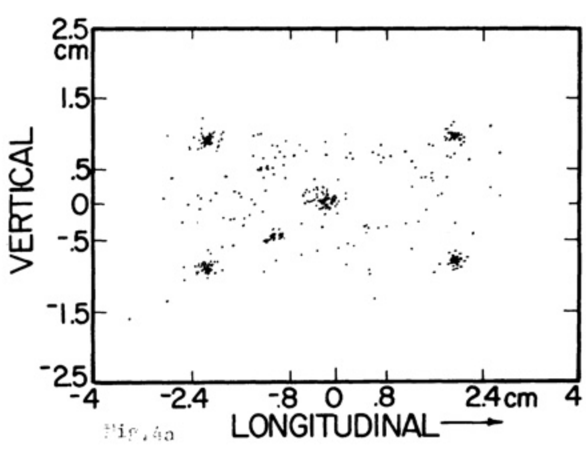
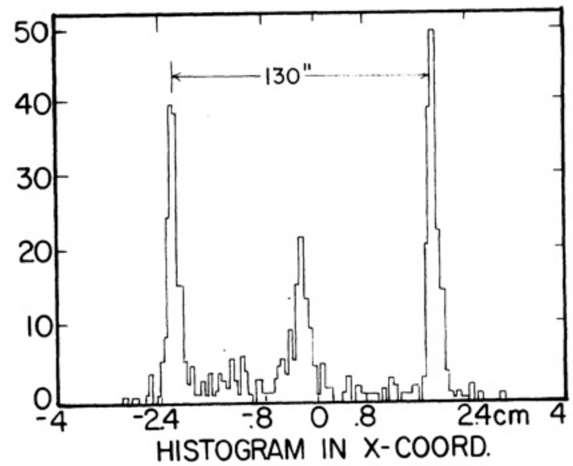
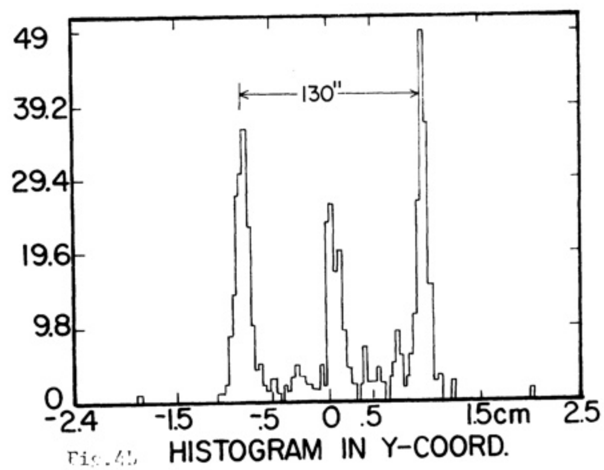


Fig. 4 a. scatter plot of 512 UV initiated events. b. histograms of data in a.

Signal Processing

Figure 5 is a block diagram of the signal processing system utilized for extracting profile data. Heavy lines show the analog signal path, double lines show digital data paths and single lines show control paths.





An event is sensed by sampling the voltage transient which results when charge leaves the last channel plate. This transient is amplified, normalized to logic levels and initiates a data acquisition sequence. Charge is deposited on the resistive anode at a unique point determined by the collision of beam with a residual gas molecule. This charge divides proportionally between the 4 corners of the resistive anode and is converted to voltage pulses by the charge amplifiers. Pulse rise time is determined by the resistivity and capacity to ground of the anode. (Typically 1 μsec for our anode assembly.) The integrating amplifiers are unclamped for 3 μsec then their inputs are grounded and the integrators are allowed to hold at the final value while the analog to digital converters balance. The sample and hold (S/H) blocks in Figure 5 are not actual physical entities but are shown as separate blocks here for clarity. Analog to digital coverters (1 μsec conversion time) produce an 8 bit digital output which is combined along with a 16 bit real time clock to form 3 16 bit time sequentially multiplexed data words. Data frames of 512 data points are then routed to one of 8 memory buffers which communicate via a standard CAMAC bus to the data processing computer. An entire frame of 512 points may be collected in less than 5 μsec.

Several memory buffers may be filled sequentially to provide more data per frame and the system may be triggered at specific times to provide a sequence of

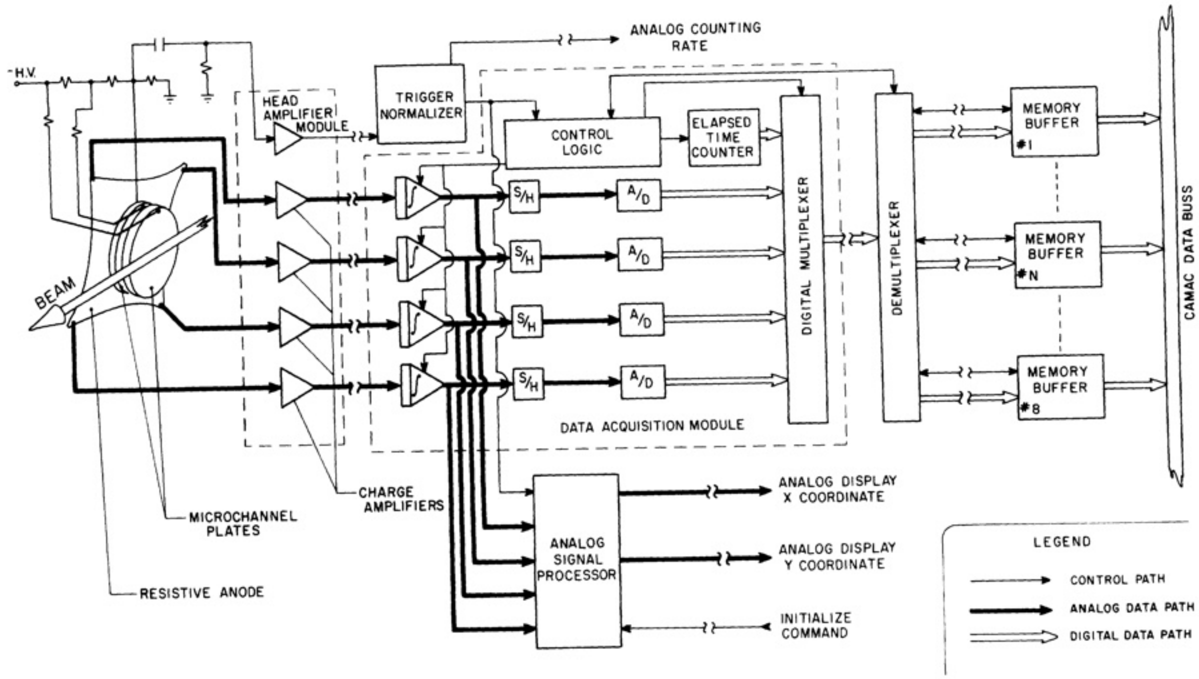
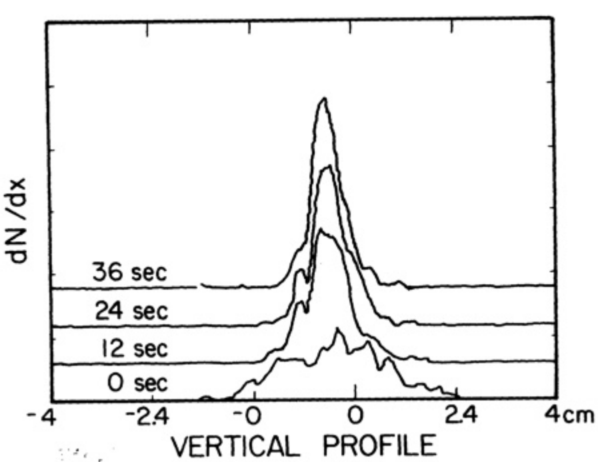


Fig. 5 PROFILE MONITOR SIGNAL PROCESSING DIAGRAM

profiles versus time. Figure 6 is a typical sequence of vertical beam profiles taken during one of our electron cooling experiments. The frames here are 12 seconds apart and each frame took <.5 sec. to obtain (512 events). Off line profile information is also provided by performing the necessary arithmetic operations with an analog signal processor. The resulting information is displayed as a scatter plot on a control room oscilloscope. Analog event rate signals are made available in the control room to serve as relative beam intensity indicators (except at injection where some beam loss occurs) and provide the operator with exposure time information.



The 40 mm active diameter channel plates are smaller than appropriate for our needs. Originally this size was chosen for the economy of a prototype development (we found "reject" quality plates, at $100 each, from Varian associates quite suitable, although the final versions use $400 "non imaging" quality plates). Our original source of hybrid film resistive anodes was limited to this size by fabrication constraints. Subsequently we have developed a monitor using 8 x 10 cm (rectangular) plates with a larger anode.

Acknowledgements

An excellent job was done by Mr. Horton of the EFI Electronics Shop (U. of Chicago) in fabricating the thick film resistive plates. We appreciate continuous and on-going support from E. Gray and J. Klen at Fermilab in the testing, assembly and vacuum setup work connected with the project. J. Michelassi designed the (better!) mechanical construction of the horizontal monitor. R. Hogrefe (ANL) constructed the signal processing electronics. We also received excellent service, advice, and technical help from: Mr. R. Klein (Varian Associates); Mr. M. Kelly (Surface Science Labs developed new large resistive anode plates); various personnel of Galileo Electro Optics for mounting hardware and a complete 8 x 10 cm mounted MCP assembly. We are indebted to M. Lampton for key design advice.[2]

References

1. W. Kells, "Magnesium Jet Profile Monitor", Fermilab p Note 31, unpublished 1979.

2. M. Lampton and F. Paresce, Rev. Sci. Instrum. 45, 1098 (1974).