Position and Collision Point Measurement System For Fermilab's Interaction Regions

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Abstract

A higher resolution beam position monitor system, (BPM) has been developed at FNAL to measure the transverse position of the beam at opposite ends of the Collision Halls. A secondary function is to measure the longitudinal location of the Collision Point. This system is called the Collision Point Monitor, (CPM). The Transverse positions are determined by software rectification and integration of a BPM signal obtained from a sampling oscilloscope. A difference over sum calculation of the A and B signals yields the position. The longitudinal location is obtained by measuring the difference in time between the proton and antiproton bunches at both ends of the Collision Hall. The Downstream difference is then subtracted from the Upstream difference and the result is multiplied by half the speed of light to yield the Collision Point error.

INTRODUCTION

Fermilab has two regions in the Tevatron (B0 and D0) where the proton and antiproton beams Collide. These collision regions are bounded upstream and downstream by horizontal and vertical BPM's as drawn in figure 1. These BPM's are striplines with the same cross section as the standard Tevatron detector but are only half their length, (8.3 cm) (1,2). The detector signals are split and shared with the Tevatron BPM system. To conserve space, the BPM's were built as an integral part of the cryogenic quad magnet. This required 4 meters of cable inside the magnet to transport the signal to the accessible end. The stripline directionality was defeated by placing shorts on the cables attached to one end of the detector. This allowed both proton and antiproton signals to be measured using the same cables and electronics, reducing systematic errors.

A typical store consists of six proton and six antiproton bunches. The proton bunch intensities are three times larger than the antiproton. To reduce the beam-beam tune shift and increase luminosity, separators were installed in the Tevatron to move the protons and antiprotons onto helical orbits that intersect only at B0 and D0. The location of the collision point can be determined by measuring the proton - antiproton position difference upstream and downstream of the Collision Hall and projecting straight lines. This procedure ignores any beam-beam steering. The 150 micron resolution of the existing Tevatron BPM system was not sufficient. The Collision Point Monitor provides 20 micron resolution.

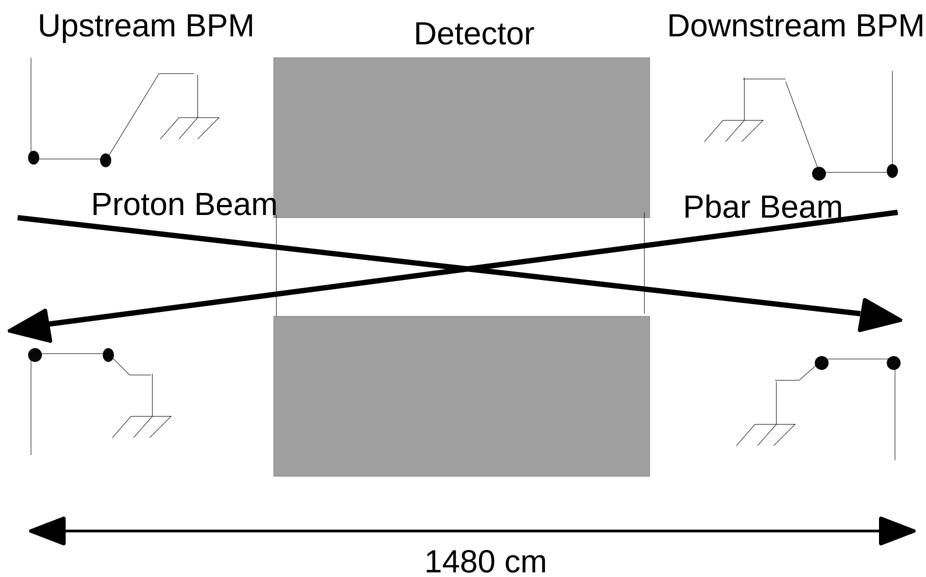


Figure 1. Tunnel Geometry of CPM Pickup Plates

A secondary function of the system is to accurately determine the longitudinal collision point by measuring the arrival time difference between the proton and antiproton bunches at each end of the colliding hall. A resolution of about 50 pSec, or 1.5 cm, has been achieved.

CONFIGURATION

The Collision Point Monitor is composed of a LabVIEW application program operating on a Macintosh computer utilizing a Tektronix TDS520 oscilloscope with a Keithley RF Multiplexer for data acquisition. The Collision Point Monitor is diagrammed in Fig. 2. The interface between the Macintosh and the Accelerator Control System is provided by a Token Ring link (3). The computer communicates with the oscilloscope and the multiplexer through a GPIB interface. The four position detectors are sequentially connected to the oscilloscope's inputs through the Keithley RF Multiplexer. The scope's main sweep is triggered by a Beam Sync pulse generated by a Camac 279 module. The 279 module has a resolution of 7 RF Buckets, so the oscilloscope must be operated in the delay trigger mode to obtain the finer timing resolution required to capture the 20 nano-second bunch signal. The oscilloscope's trigger delay must be changed for each BPM, to compensate for differences in cable lengths and beam flight times. After the beam signal has been acquired, a GPIB read is performed to transfer this information to the computer for processing.

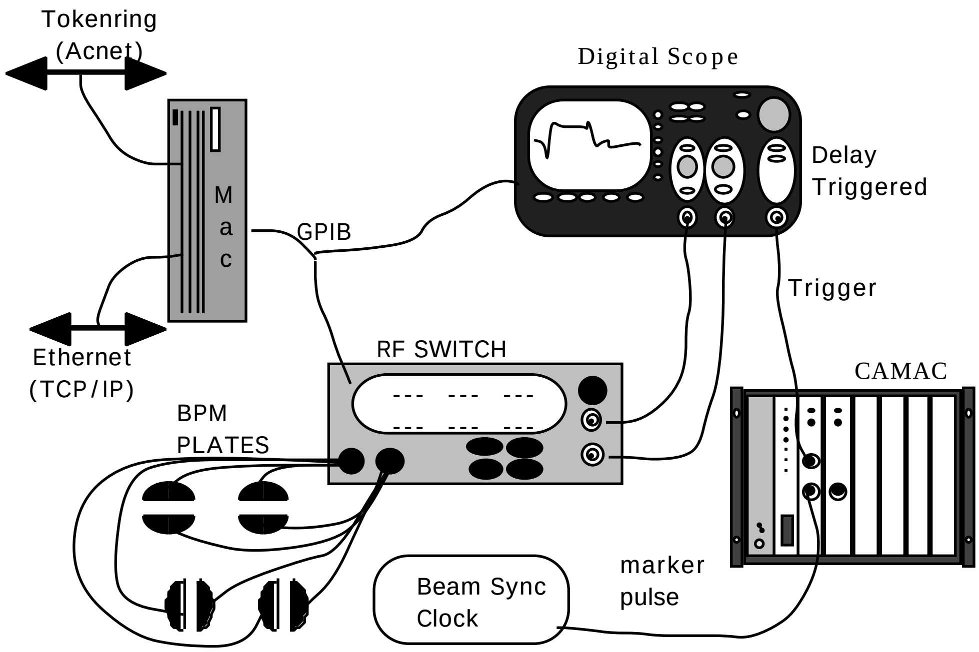


Figure 2. The Collision Point Monitor Configuration.

TRANSVERSE POSITIONS:

At both interaction regions there are six proton antiproton bunch collisions each turn. One of the six collisions is selected with the Acnet parameters; T:B0TRIG or T:D0TRIG. These parameters are referenced to the Tevatron Beam Sync "A-marker" and are in units of RF Buckets.

A beam position resolution of 20 microns can be achieved by setting the oscilloscope to; Single Sweep Averaging mode with 16 averages, 5 nSec per division, delayed trigger mode, and full Band Width.

During each data collection cycle, the CPM program performs four iterations through a loop, one iteration for each of the BPM's. Nested within this outer loop is a second loop that iterates twice, once to obtain the proton position data and again to obtain the antiproton position data. The vertical gain of the scope is set to 2 Volts per division on the proton pass and 500 milli-volts per division on the antiproton pass. Improved performance on lower intensity stores can be achieved by setting the oscilloscope's vertical scale to a more sensitive setting. It is planned to have these scales automatically set in a future revision of the program. The delay for the oscilloscope trigger is automatically set from a look-up table depending upon which bunch is selected, which BPM is being read. The look-up table values have been empirically determined to trigger the oscilloscope about 10 nsec before the bunch arrives.

When the beam traverses the detector, it generates a doublet signal such as the one illustrated in Fig. 3. Two signals, one from the A plate and one from the B plate, are transferred to computer through the GPIB interface.

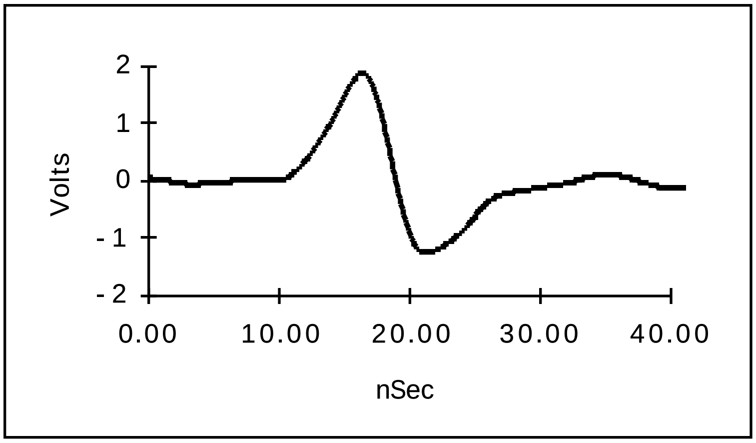


Figure 3. A typical BPM doublet signal

The procedure used to calculate the position is listed below.

1) The digitized signal is passed through a software 5-90 MHz Band Pass Filter to remove unwanted frequency components and optimize the signal to noise ratio.

2) The most positive and most negative points of the trace are found and the points between them are fit to a cubic polynomial. The zero crossing of the polynomial is used as the zero crossing for the signal.

3) The signal is rectified by multiplying all points after the zero crossing by minus 1.

The advantage of steps 2 and 3 over a simple addition of the absolute values is that any offset, noise, ringing, or satellite bunch signals outside the central bunch averages to zero.

4) The signal strength of the A and B doublets is then determined by digitally integrating the rectified signals.

5) A difference over sum calculation is performed to obtain a position reading.

This process repeats until all four Proton and all four Pbar positions have been obtained. A sample Datalog plot of the D0 Downstream Horizontal Proton Position signal is displayed in Fig.4.

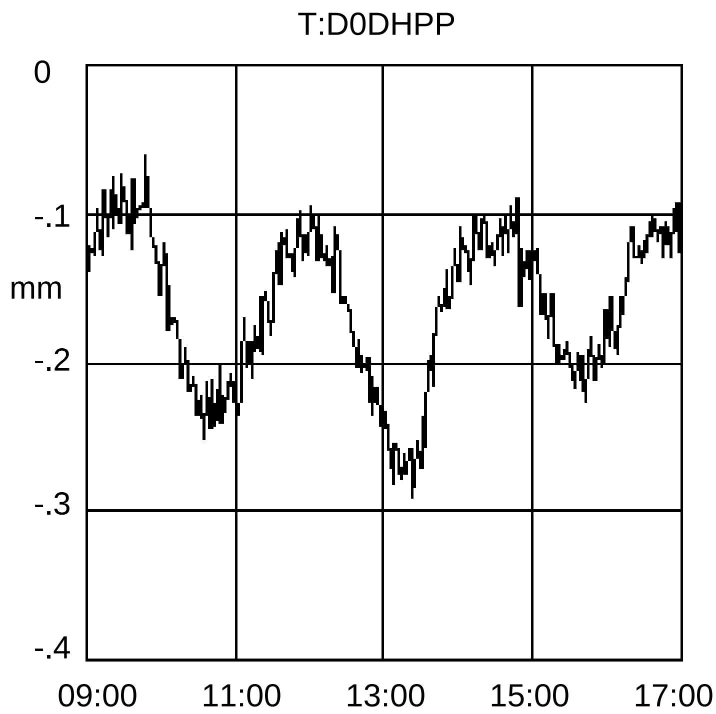


Figure 4. Sample Datalog plot of a transverse Position Reading

LONGITUDINAL POSITIONS:

The longitudinal location of the collision point is measured using another routine that obtains a signal from one plate at each of the four BPM locations. The Scope is set to 20 nSec per division, single channel acquisition, 16 averages, and an appropriate trigger delay. Wave forms, similar to Fig 5, are sent to the computer and processed to determine the zero crossing times of the proton and antiproton doublets. From these Zero crossings, the time of flight differences (Delta-t) is determined. In Fig 6, a sample Datalog plot of the longitudinal positions covering a 16 hour time span is displayed.

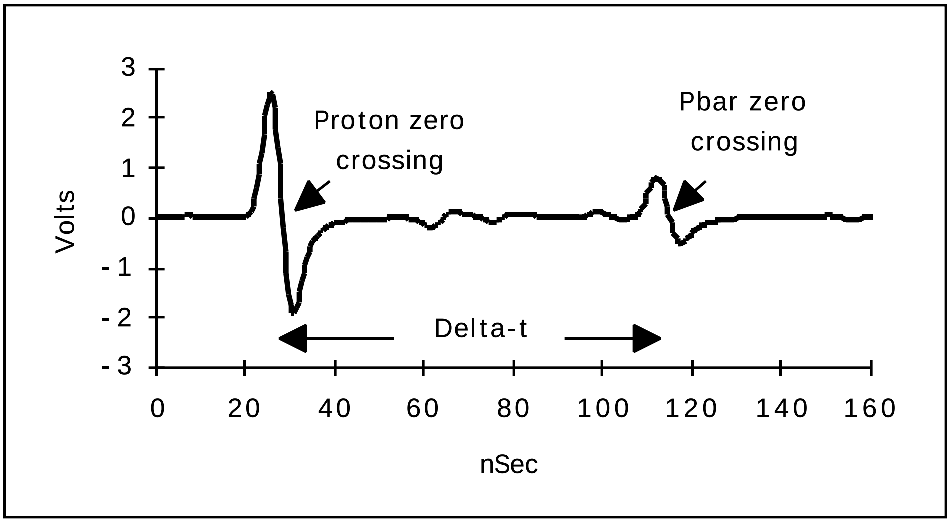


Figure 5. A typical Delta-t Waveform

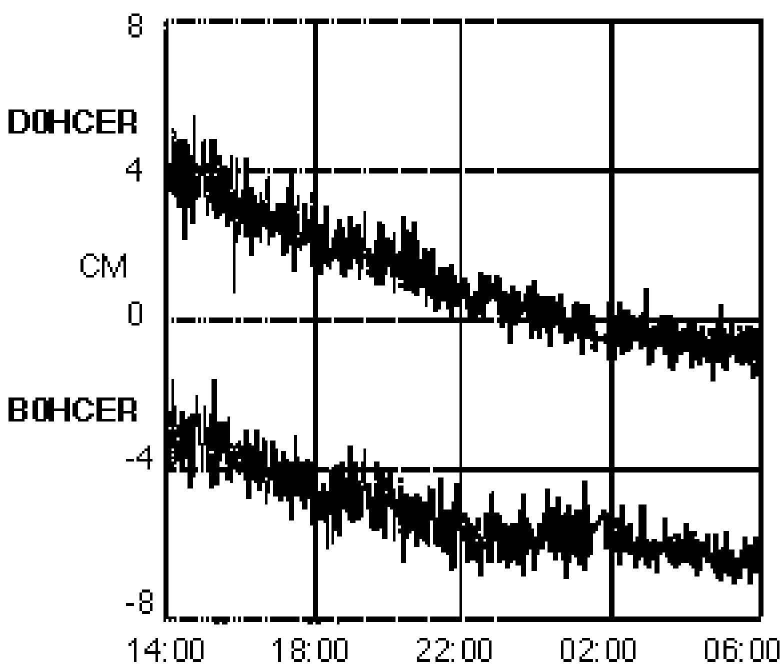
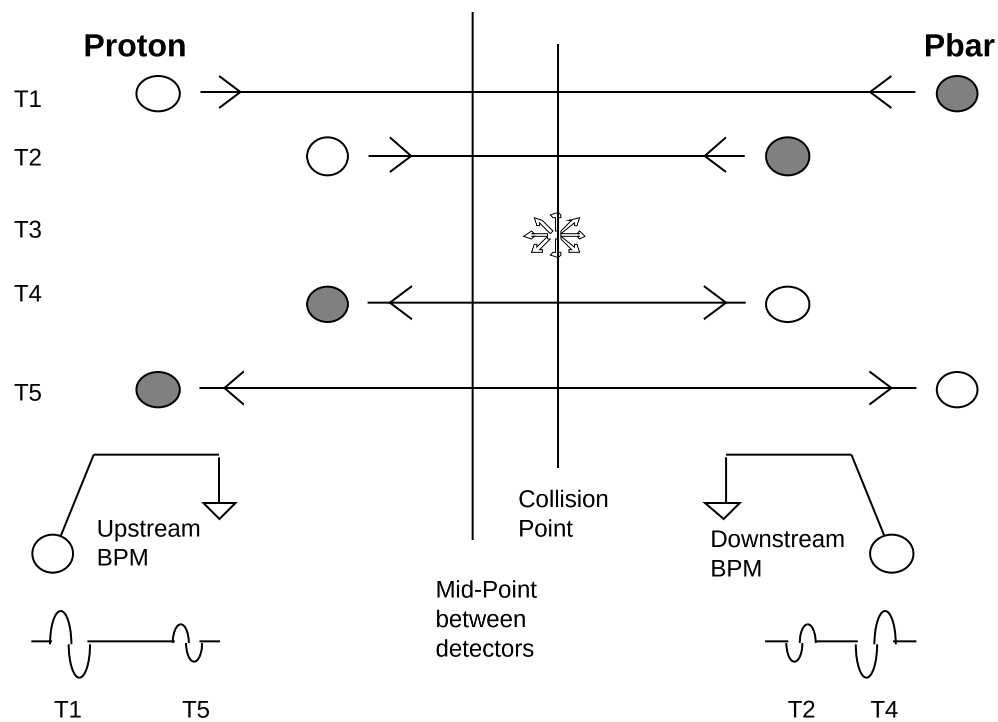


Figure 6. Sample datalog plot of the longitudinal positions

Consider the case diagrammed in Fig. 7 where the collision point is shifted downstream. At T1, the proton bunch crosses the upstream BPM but the antiproton bunch still has an x amount of time before it crosses the downstream BPM. Later, at T4, the proton bunch crosses the downstream BPM but the antiproton bunch still has an x amount of time before it crosses the upstream BPM. This results in delta-t upstream being larger than Delta-t downstream by a factor of 2x. So:

$$\text{Cogging Error} = (\text{Delta-t upstream} - \text{Delta-t downstream})/2*C \qquad (1)$$

The cogging error is calculated using data from either the vertical or the horizontal detectors. The convention has been established that a positive cogging error indicates that the collision point is shifted towards the downstream BPM, with respect to protons.



T1 = Time Proton bunch crosses upstream BPM
T2 = Time Pbar bunch crosses downstream BPM
T3 = Time Bunches collide
T4 = Time Proton bunch crosses downstream BPM
T5 = Time Pbar bunch crosses upstream BPM

Figure 7. Collision point shifted towards the downstream BPM.

CONCLUSIONS:

Using the digital integral of the plate signals to calculate position was thought to offer the ultimate position resolution. Any analog equivalent would clearly suffer from at best the same difficulties as this digital system. An annoyance of the system is the slow cycle rate that makes it awkward to use during separator scans. Approximately 90 seconds is required for a complete set of transverse and longitudinal measurements. The majority of time is used to perform averaging which could be reduced by using a faster scope or a digitizer.

The success of the system was the automatic measurement of the absolute longitudinal beam position. RMS resolutions obtained were about 50 pSec. or 1.5cm. The less-than-successful result was the absolute transverse measurement. Statistically the transverse measurements are good to the 20 micron level. The absolute accuracy is difficult to verify. With the separators turned off, proton and antiproton orbits should be identical, but the measured positions disagreed by up to 0.69 millimeters. Figure 5 illustrates one source of error. Between the proton and antiproton doublets there are reflected signals caused by the shorted end of the pickup delayed by the internal cable. Some ringing is corrupting the antiproton reading. Compensation for this problem in software is possible, but further analysis is required. Rebuilding the BPM with an internally shorted plate to eliminate the internal cable run, would reduce this effect but cost may be prohibitive.

REFERENCES

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