AN IONIZATION PROFILE MONITOR FOR THE TEVATRON*

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Abstract

Primarily to study emittance blowup during injection and ramping, an ionization profile monitor has been developed for the Tevatron. It is based on a prototype installed in the Main Injector, although with extensive modifications. In particular, the electromagnetic shielding has been improved, the signal path has been cleaned up, and provisions have been made for an internal electron source. Due to the good Tevatron vacuum, a local pressure bump is introduced to increase the primary signal, which is then amplified by a microchannel plate and detected on anode strips. For the DAQ, a custom ASIC developed for the CMS experiment is used. It is a combined charge integrator and digitizer, with a sensitivity of a few fC, and a time-resolution that allows single bunch measurement. Digitization is done in the tunnel to reduce noise. Preparations for detector installation were made during the long 2004 shutdown, with the installation of magnets, vacuum chambers, vacuum pumps and cabling. The actual detector will be installated during the fall 2005 shutdown. This paper describes the design of the detector and associated electronics, and presents various bench test results.

INTRODUCTION

For the Tevatron Run II, every effort is made to increase the luminosity of the collider. Part of this process is to preserve the beam emittance to low beta. To study emittance evolution at injection and on the ramp, an Ionization Profile Monitor (IPM) has been developed for the Tevatron.

The Tevatron collider has two counter-rotating beams on helical orbits separated by a few millimeters. The separation is typically small enough that there is some overlap between proton and pbar beam profiles, making it uncertain to rely on the helix alone to separate protons from pbars. For this reason, the possibility of separating protons and pbars by time was investigated. At any given point in the machine, proton and pbar bunches are typically separated by less than 200 ns in time-of-arrival. Collider physics experiments regularly measure charge in the fC range at higher repetition rates, which is why a solution to the DAQ problem was sought there. However, the number of ionizations generated by a single bunch at nominal Tevatron vacuum pressure is too low to accurately reconstruct a beam profile, so a local pressure bump is needed.

DETECTOR DESIGN

The IPM detector design is based on a prototype installed in the Main Injector. Due to the strong space charge forces in the small Tevatron beam, it is imperative to use a magnetic field and collect electrons rather than ions. The long drift time for ions would also have made single bunch resolution impossible, while electrons are collected within a few nanoseconds of being generated.

* Work supported by the US Department of Energy

Detector Interior

The interior of the detector is attached to the vacuum flange for easy installation and removal. To align the detector properly to the beam, the vacuum chamber is mounted on motorized stands.

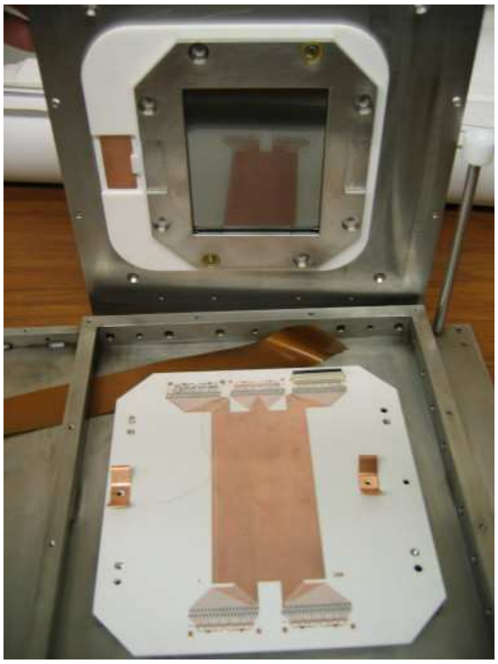

Figure 1: Partial assembly of detector, showing the anode board (bottom), MCP (top) and signal flex circuit (middle)

A sweep field of 115 kV/m accelerates the ionization electrons onto a Microchannel Plate (MCP) used for amplification. Before striking the MCP, the electrons pass thru a grounded screening mesh. This mesh is part of a Faraday cage enclosing the MCP, anode board, all the signal wires, and the vacuum feedthroughs (see Fig. 1) in order to avoid electromagnetic interference from the beam. Measurements in a test stand have shown that the number of electrons able to pass thru the screening mesh is consistent with the open area ratio of the mesh, which in this case is 60% (see Fig. 2). To avoid shadowing effects, the mesh is inclined by 15° with respect to the anode strips.

A single MCP is used instead of a Chevron configuration, since saturation limits the gain to about 10,000. As a

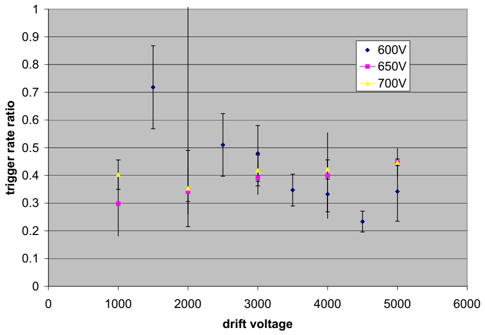

Figure 2: Electron detection rate with screening mesh divided by the rate without mesh, as a function of sweep voltage, for three different source settings (bias voltage on the Electron Generator Array).

rule-of-thumb, the signal current should not exceed 10% of the bias current, but since the signal is concentrated to a relatively small part of the MCP, the limit is effectively much lower than that. MCP gain saturation has been observed in the Main Injector IPMs with relatively low gains. To raise the saturation limit, special Extended Dynamic Range (EDR) MCPs with a bias current above the normal EDR range were purchased.

Due to the small beam size, 0.25 mm anode strip spacing used. The anode board has 200 channels, 128 of which will be instrumented. The strip signals are connected to 50-pin vacuum feedthroughs using flex circuits. These provide a well-defined impedance, while avoiding cross-talk. A 50 Ω series resistor on the anode board provides backmatching, and some level of filtering.

On the air side, an adapter board connects the signals individual minicoax cables. The board also terminates the reference cables needed for the DAQ system. Each adapter board is shielded by a custom-made aluminum housing. From the board, the cables are bundled in sets of four channels. Each bundle is shielded by a braid and connected to the DAQ cards. Three of the air-side 50-pin connectors are cabled to instrument all signals, the other two are sparsely instrumented. By moving connectors around, the densely instrumented area can be relocated if needed.

Magnets

Electro-magnets are used to generate the magnetic field, allowing the system to be completely shut off.This also allows the focusing effect on the electrons to be verified by varying the field strength. Because of space restrictions, a single magnet of opposite polarity is used to compensate the effect on the orbit. Although the resulting two-bump is not perfect, the orbit distorsion is expected to be less than 0.1 mm, which can easily be compensated by one of the adjacent orbit correctors, using a small fraction of its strength. The magnets were installed during the 2004 fall shutdown, along with the new vacuum chambers, vacuum pumps and other infrastructure components (see Fig. 3).

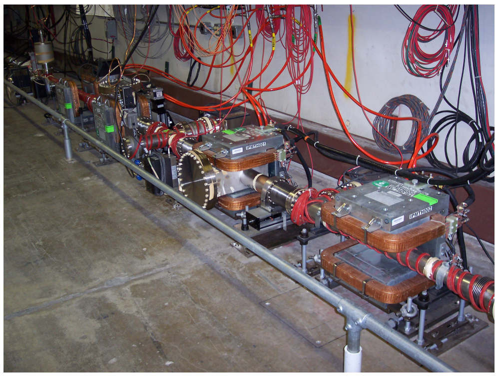

Figure 3: Magnets installed in the tunnel.

Controlled leak

A calibrated nitrogen leak and differential pumping is used to create a local pressure bump. The leak is located on a separate chamber, featuring its own ion pump and gauges, which is then connected to the Tevatron vacuum system by a remote-controlled gate valve. Since the trapped gas volume in the leak shutoff valve is enough to bring the leak chamber pressure out of the ion pump operating range, the leak is permanently left on while the ion pump actively keeps the pressure in the desired range. As a passive safety measure, a small orifice connects to a titanium sublimation pump to keep the pressure down and avoid the need for a tunnel access in case of a power failure. Bench tests of the system have shown it to work well.

ELECTRONICS AND DAQ

Front end card

As mentioned above, an effort was made to leverage the DAQ expertise from the collider detectors. The QIE8 chip[2] was selected for the front end electronics. This is a deadtimeless integrator and digitizer ASIC, designed for the CMS experiment at CERN, which has a resolution of 2.7 fC and a very large dynamic range. It also has a calibration mode with sensitivity of 0.9 fC, but a limited dynamic range. With a MCP gain of about 10,000, this gives close to single-electron sensitivity. To minimize the noise, the signals will be digitized in the tunnel close to the source. The QIE chip has been found to be radiation tolerant, and the radiation levels in the tunnel was measured to be low enough for a satisfactory lifetime. All other components on the front end board were selected to be more radiation resistant than the QIE chip. The rms noise of the system, with a 4 foot cable attached, was measured to 1.8 fC (see Fig. 4). Bench calibration is done by injecting charge with a laser-PMT system (see Fig. 5).

Each front end board has 8 channels. The digitized signals are combined with a "header" containing timing and trigger information into a serial data stream which is sent upstairs on an optical fiber. Another CMS chip (GOL) performs the serialization of the data[3]. In all, 16 front end

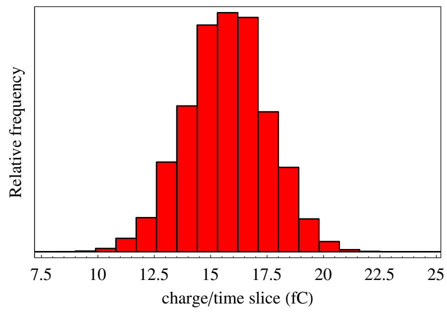

Figure 4: Noise distribution of the QIE front-end card (in calibration mode) with cable attached. The rms width of the histogram is 1.8 fC.

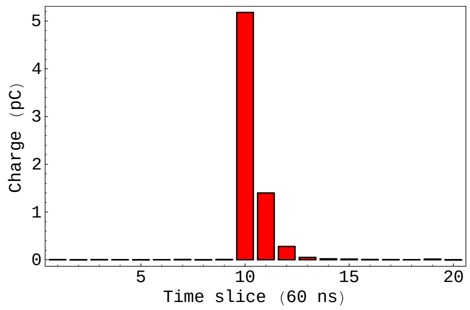

Figure 5: Test pulse injected into QIE front end card using laser-PMT charge injection system.

cards are used per system, giving a total data rate of about 20 Gbps.

Data buffer card

A data buffer board gathers the data from the front-end boards, sorts it on-the-fly and puts it in a temporary memory for later retrieval and analysis. It also does a basic error check on the data, verifying proper synchronization of all channels using information entered into the data stream by the front end card. The board is designed as a PCI card and resides in a standard PC. While the incoming data stream is continuous, the buffer card can be set up to take data in two different ways. Either it can take data immediately upon request (soft trigger mode), or it can wait for specific timing information to appear in the data stream header and then capture data for a set number of turns (hard trigger mode). Each buffer board can handle the signal from eight front-end boards, so two boards are daisy-chained to cope with the full 128 channels in each system.

Timing

The digitizer clock in the front-end cards is 2/7 of the Tevatron RF (15MHz). This makes it synchronous with bunches in all three bunch trains without having to work at the full RF frequency. A PCI timing card generates the clock from the Tevatron RF, and allows for fine tuning of the relative phase. The clock signal is sent to the tunnel on a standard cat-5 cable, along with encoded injection tags and revolution markers from the Tevatron beam sync clock. These tags and markers are simply mirrored in the data stream. The revolution markers enable the buffer card to sort and sparsify the data, as only 72 samples (36+36 bunches) out of 371 in each machine turn will contain interesting data. Injection tags are used to trigger data taking in hard trigger mode. The timing card can also send instructions to the front end card to change its operating mode between normal (2.7 fC/LSB) and calibration (0.9 fC/LSB).

Analysis software

The Labview analysis software is based on the code for the existing IPMs, and has a similar look and feel (see Fig. 6). However, it has been re-written with a proper state machine, and adapted to the new hardware. This program runs on the PC hosting the buffer and timing card, located in a Tevatron service building. For the end user, an ACNET user interface will be provided.

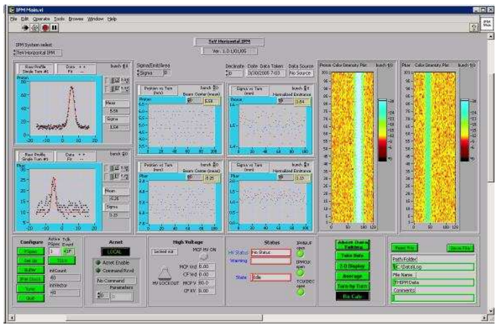

Figure 6: Screenshot of the frontend labview program.

SUMMARY AND STATUS

An ionization profile monitor has been developed for the Tevatron. It uses electronics developed for the CMS experiment, with a time resolution of 60 ns and a sensitivity down to 1 fC, enabling single bunch resolution. Currently, all infrastructure (magnets, ion pumps, valves) is installed. The leak chamber and the actual detectors are scheduled to be installed during the 2005 fall shutdown.

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