Ionization Profile Monitoring

at the Tevatron

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Fermilab

Also thanks to:

• Instrument Design
• First beam results
• Results after recent shutdown
GOAL:
Measure protons and pbar beam size turn by turn at injection and ramp to diagnose and mitigate emittance blow-up.
Challenge:

- Two small beams separated by helix.
- Separate protons from pbars, injected from circulating beam.
- Beam induced parasitic signals.
- Low vacuum pressure.

Solutions:

- Fine granularity and many channels.
- Single bunch resolution and gating.
- Improved shielding and matched cables.
- Local pressure bump with controlled leak.
All signal cables are enclosed in a Faraday cage!
• ¼ mm strip pitch
• 200 channels (128 instrumented)
• Board mounted series resistor for back-termination and LP filtering.
• In-vacuum signal cabling using UHV-compatible flex-circuits
• High resolution area can be moved by swapping connectors
• Max gain with 36 proton bunches is ~1e4 to avoid saturation.
• Can be achieved with single plate
• With dual plates, each plate would run at a very low gain and low bias current.
• Use single MCP with extra-high bias current.
Magnets, vacuum chambers etc installed during 2004 shutdown.

First detector installed December 2005.

Both detectors (re)installed spring 2006 shutdown.
• CMS-QIE chip digitizes signal in tunnel.
• Serial data uplink on optical fiber.
• Receiver and data buffer in upstairs PC
• Timing + QIE clock + QIE clock supplied from PC thru cat-5E cable
• Charge Integrating Encoder (QIE) developed at Fermilab. Used by KTeV, CDF, Minos, CMS...
• Frequency range 7-53 MHz
• Essentially no deadtime.
• LSB 2.6fC (16000e) in logarithmic mode, 0.9fC (6000e) in linear mode
• Dynamic range >10^4 in logarithmic mode
• Noise of O(1fC)
• Radiation “tolerant”

design: T. Zimmerman
- 8 channels (CMS QIE8) per board.
- Achieved noise ~1.8fC with 4’ cable.
- Data is combined with timing information, serialized by CERN GOL ASIC (rad hard) and sent thru optical fiber at 1.1Gbps data rate

- Timing fanout board cleans up and distributes clock and timing signals
• Handles 8 incoming optical links (64 channels, 1.1 GB/s of data)
• Can sparsify data on-the-fly based on timing masks
• 512MB RAM allows for
  - 20,000 turns of continuous data
  - 90,000 turns for 72 bunches
  - 6 million turns for a single bunch
• Read out thru PCI64 bus.
• Two boards are used to handle 128 channels.

• IPM buffer board doubled as prototype for BTeV L1 data buffer.
• Considered for use in MICE experiment.
• Produces the 15MHz (2/7 RF) QIE clock
• Decodes and transmits beamsync revolution marker + injection and trigger events
• Controls QIE settings.
Setup for initial tests

- 2005 shutdown moved to 2006
- Took advantage of magnet failure to install the vertical detector in Dec '05.
- Test DAQ system with 40 channels, 1cm active width, single buffer board

E0 straight section

E0 service building
• First data taken at 980GeV during store 4634 without magnetic field.
• Sparking problems prevented running at full fields (25% B, 70% E).
• Profile widening due to large Larmor radius of electrons
• Measured resolution at 50A is 0.5 mm
Protons during store

Store #4641
Magnet at 50A
(nominal 200A)

Single turn profiles for 36 proton bunches!

Measured profile widths at 980: 0.7-0.9 mm
consistent with flying wires taking into account the low B-field

June 26, 2006
Store #4641
Magnet at 50A
(nominal 200A)

NOTE: Detector centered on proton orbit
Proton during injection

Store #4642
Magnet at 50A

Single turn profiles for 36 bunches!

Proton profiles 16 turns before injecting P36

June 26, 2006
Bunch #36 turn-by-turn

Raw profile width

Corrected for low B-field

Store #4642 Magnet at 50A

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• Vertical detector removed to fix vacuum and sparking problems. Reinstalled.
• Horizontal detector installed.
• Both systems initially instrumented with 40 out of 128 channels (1cm active width).
First profiles after shutdown

- Proton bunch #22 at 150GeV during store #4772.
- Measured beam size 1.05mm, turn-by-turn variation ~50um.
- Total signal per bunch ~1.7pC.

Magnet at 200A
Protons at low beta

- Proton bunch #1 at low beta during store #4758.
- Measured beam size 0.55mm, turn-by-turn variation (noise) 20µm.
- Total signal per bunch ~1.3pC.
Injection – Full B field

Proton bunch #21 turn-by-turn

RMS profile width

Store #4772 Magnet at 200A

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• Measured beam size and total signal as a function of magnet current.
• Resolution due to Larmor radius ~0.1mm at 200A (2% effect for a 0.5mm beam).
• Signal increase with B-field may be due to detection efficiency (threshold is >1 primary electron per channel).
- Measured beam size and total signal as a function of drift field (voltage).
- Negligible effect on profile width.
- Maximum signal at ~7kV drift voltage (MCP sensitivity peaks at ~3keV for electrons)
• Measured beam size and total signal as a function of tilt angle.
• No observable effect within a few mrad.
Comparison of vertical beam size from IPM and nearby Flying Wire. Tuning of abort gap cleaner timing had caused blow-up of certain bunches. From MAD lattice file, expect a 13% wider beam at Flying Wire. See ~1%.
Summary and conclusions

• The Tevatron IPMs can measure single proton bunches turn-by-turn both at injection and top energy.
• Uses custom electronics developed for Particle Physics experiments.
• Observed sensitivity of ~20µm at 980GeV, 50-60µm at 150GeV.
• Good relative agreement with Flying Wires.
• Still some work to be done (e.g. install full readout system, measure pbars, make system more user friendly, correct the observed mismatch...).