Ionization Profile Monitoring at the Tevatron

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Fermilab

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Talk Outline

- Instrument Design
- First beam results
- Results after recent shutdown

Goal

GOAL:

Measure protons and pbar beam size turn by turn at injection and ramp to diagnose and mitigate emittance blow-up.

Challenges in the Tevatron

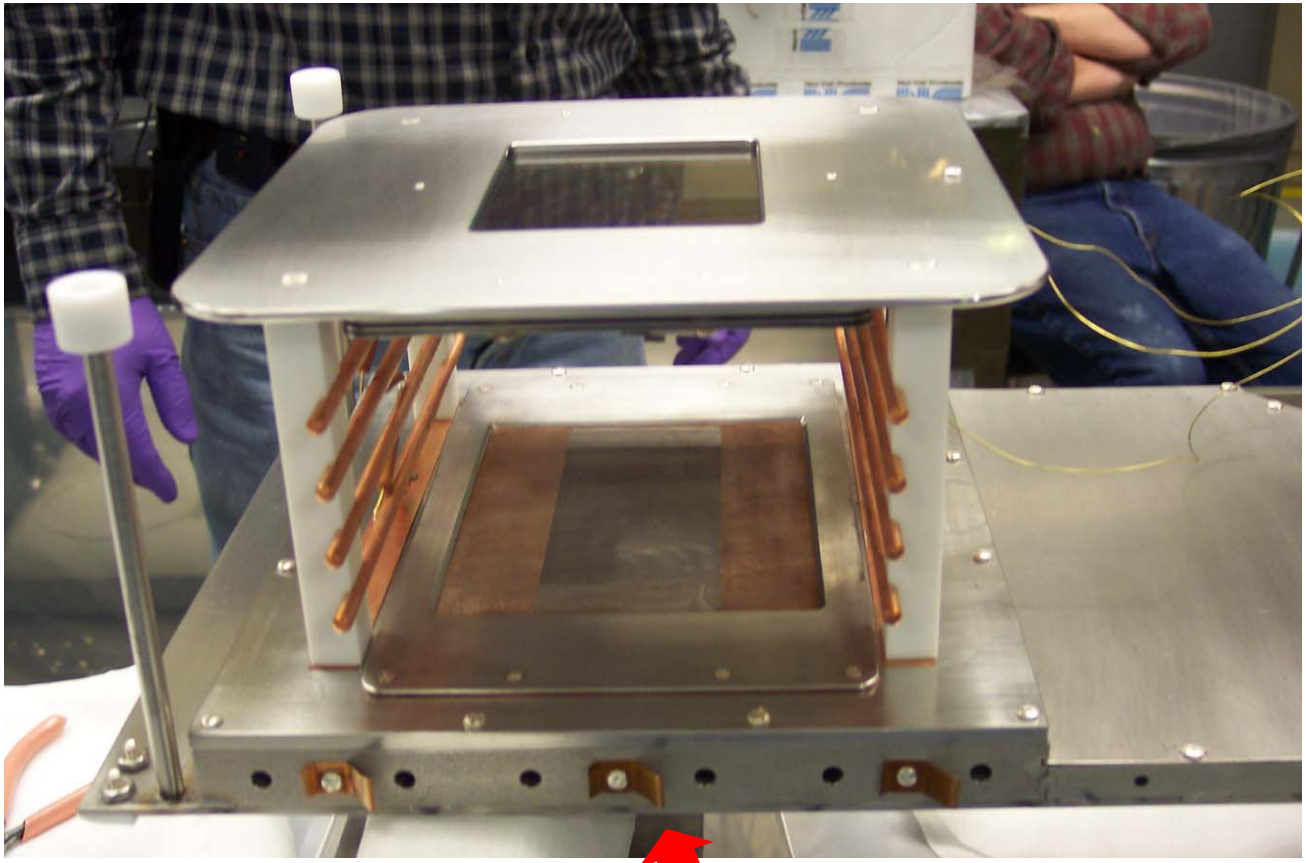
Challenge:

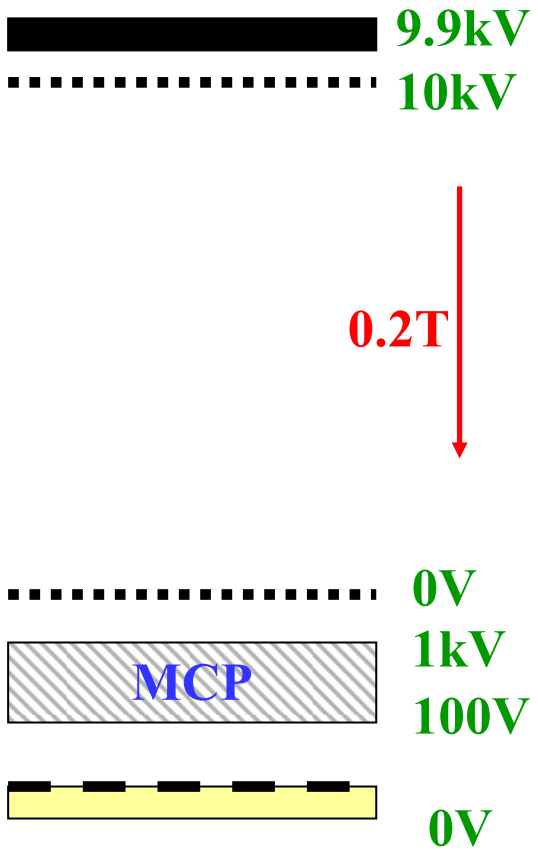
- Two small beams separated by helix.
- Separate protons from pbars, injected from circulating beam
- Beam induced parasitic signals.
- Low vacuum pressure

Solutions:

- Fine granularity and many channels
- Single bunch resolution and gating
- Improved shielding and matched cables
- Local pressure bump with controlled leak

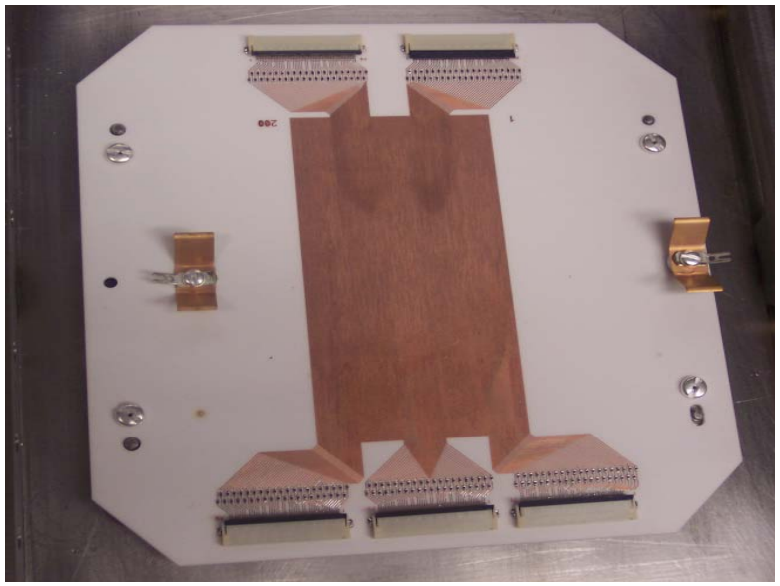
IPM detector

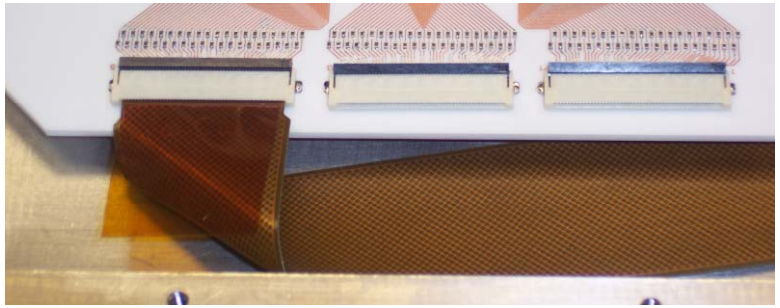




All signal cables are enclosed in a Faraday cage!

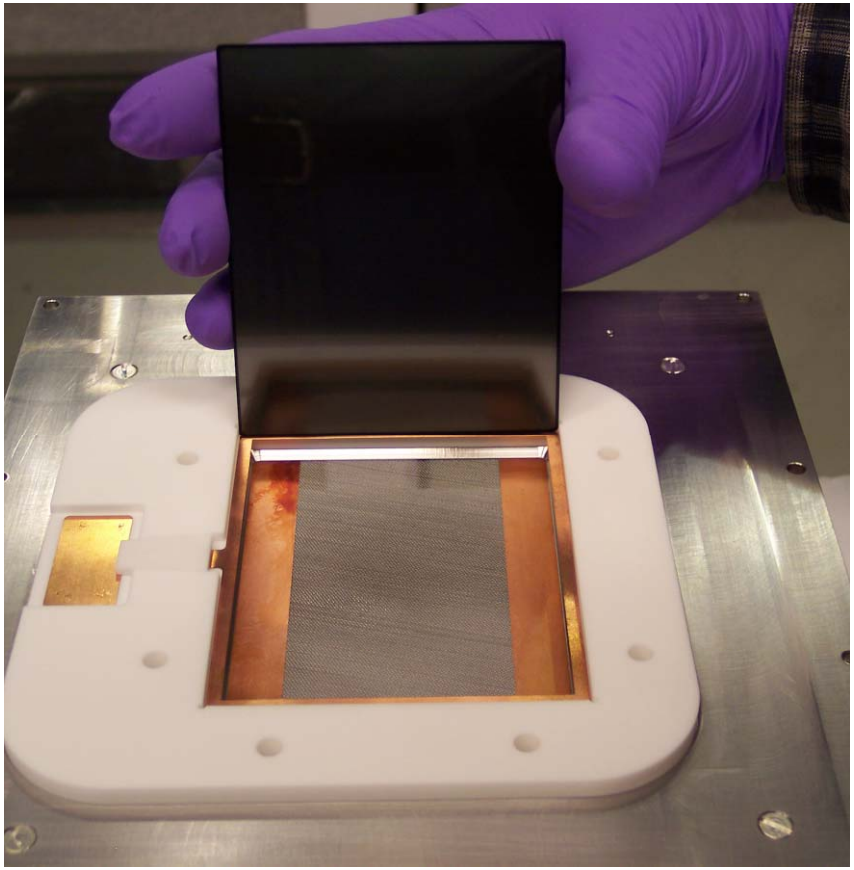
Anode board





- 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

Microchannel plate



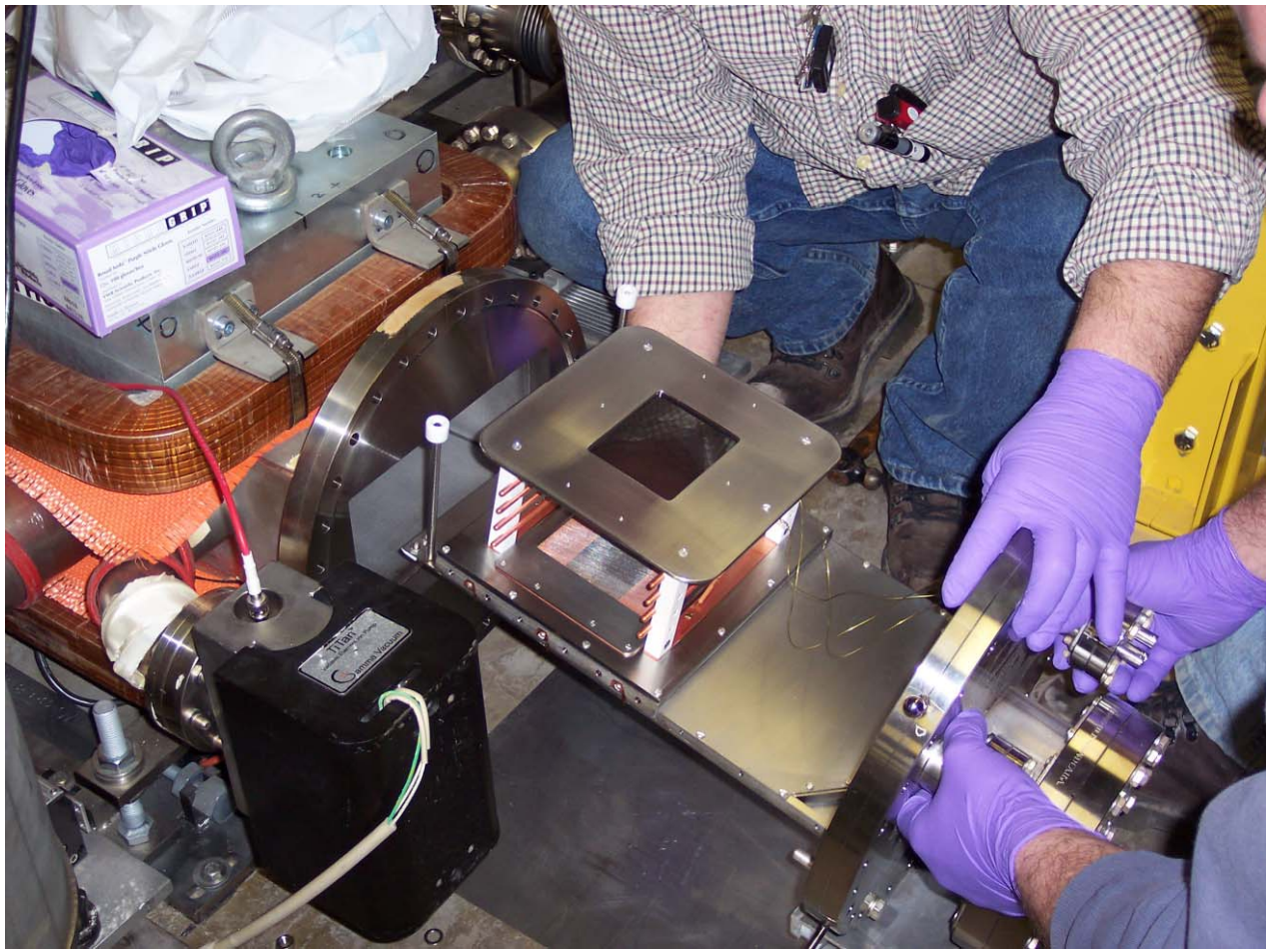
- Max gain with 36 proton bunches is ~1e4 to avoid saturation.
- Can be achieved with single plate
- With dual plates, each plate would run at a very low gain and low bias current.
- Use single MCP with extra-high bias current.

Detector installation

Magnets, vacuum chambers etc installed during 2004 shutdown.

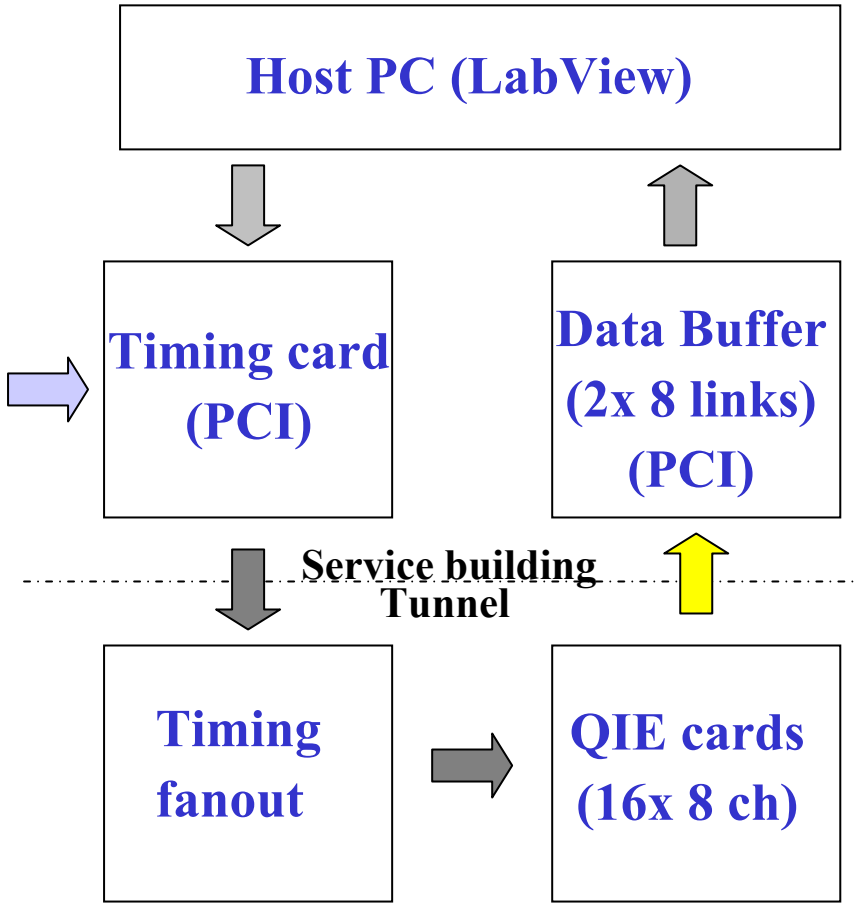
First detector installed December 2005.

Both detectors (re)installed spring 2006 shutdown.



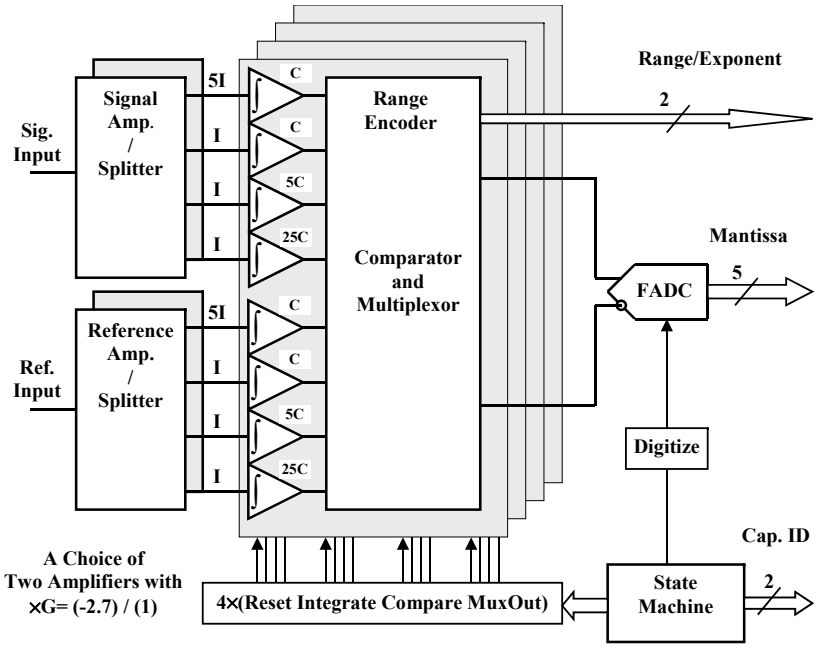
DAQ system

- 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



Fermilab QIE8 ASIC

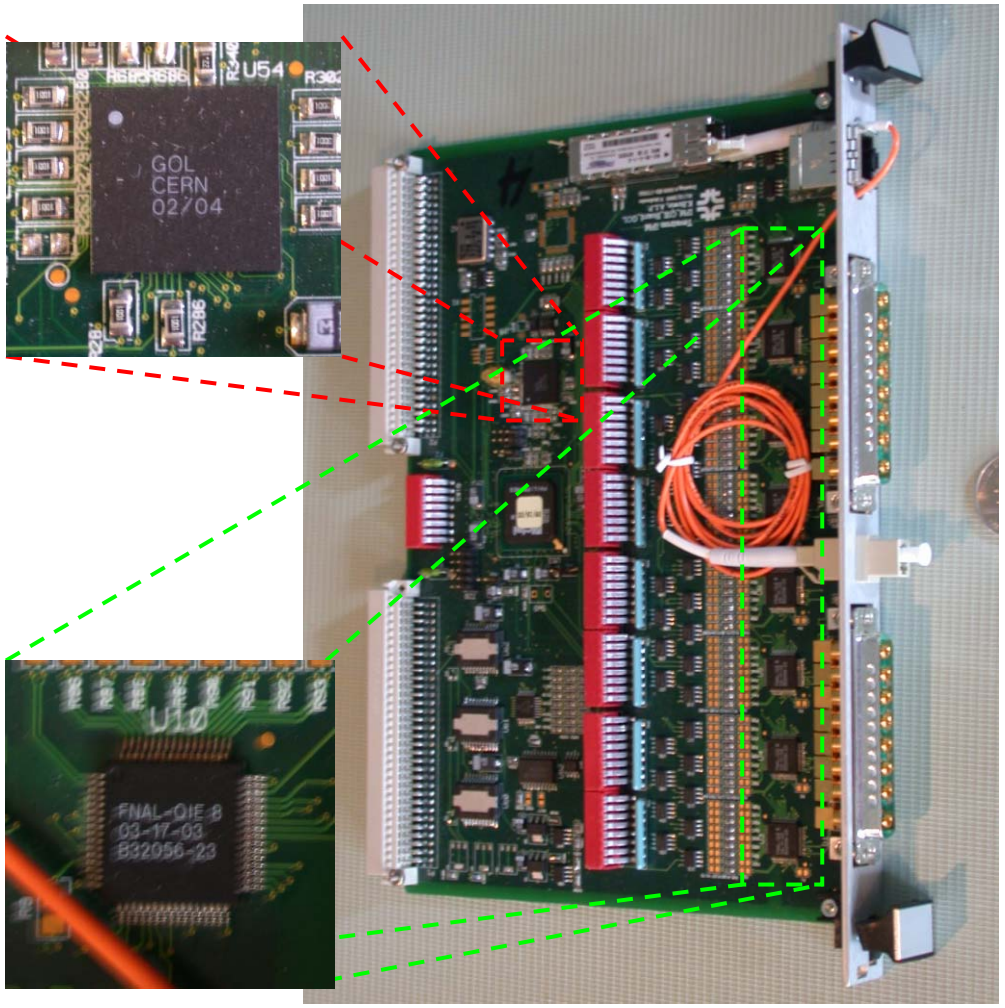
- Charge Integrating Encoder (QIE) developed at Fermilab. Used by KTeV, CDF, Minos, CMS…
- Frequency range 7-53 MHz
- Essentially no deadtime.
- LSB 2.6fC (16000e) in logarithmic mode, 0.9fC (6000e) in linear mode
- Dynamic range >10^4 in logarithmic mode
- Noise of O(1fC)
- Radiation "tolerant"



design: T. Zimmerman

QIE card

- 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



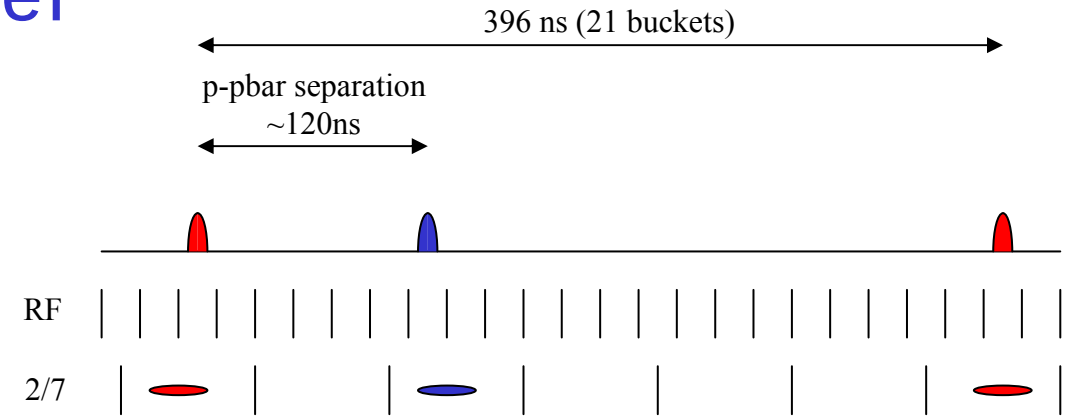
Data buffer card

- 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.

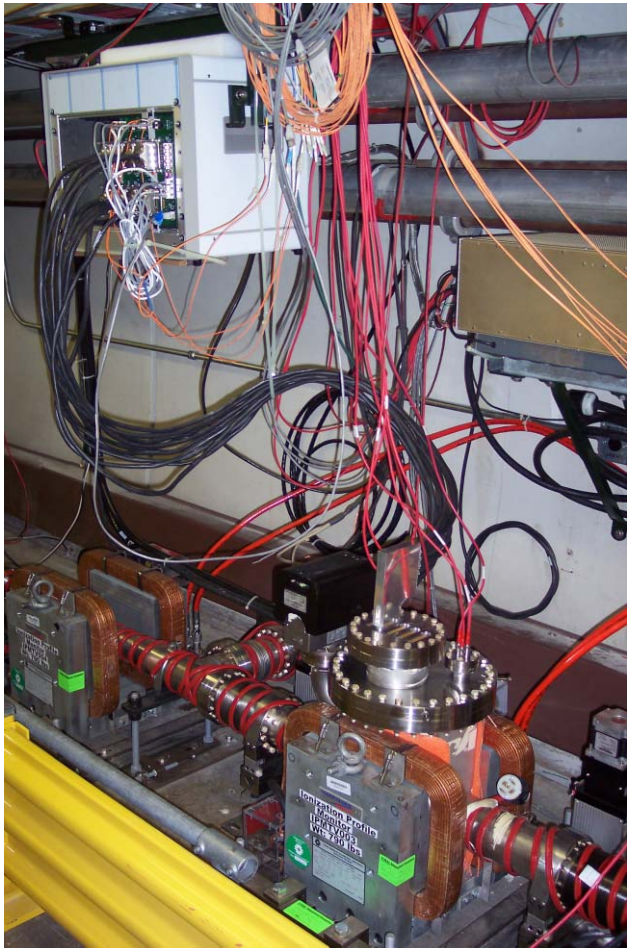
Timing card

- 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

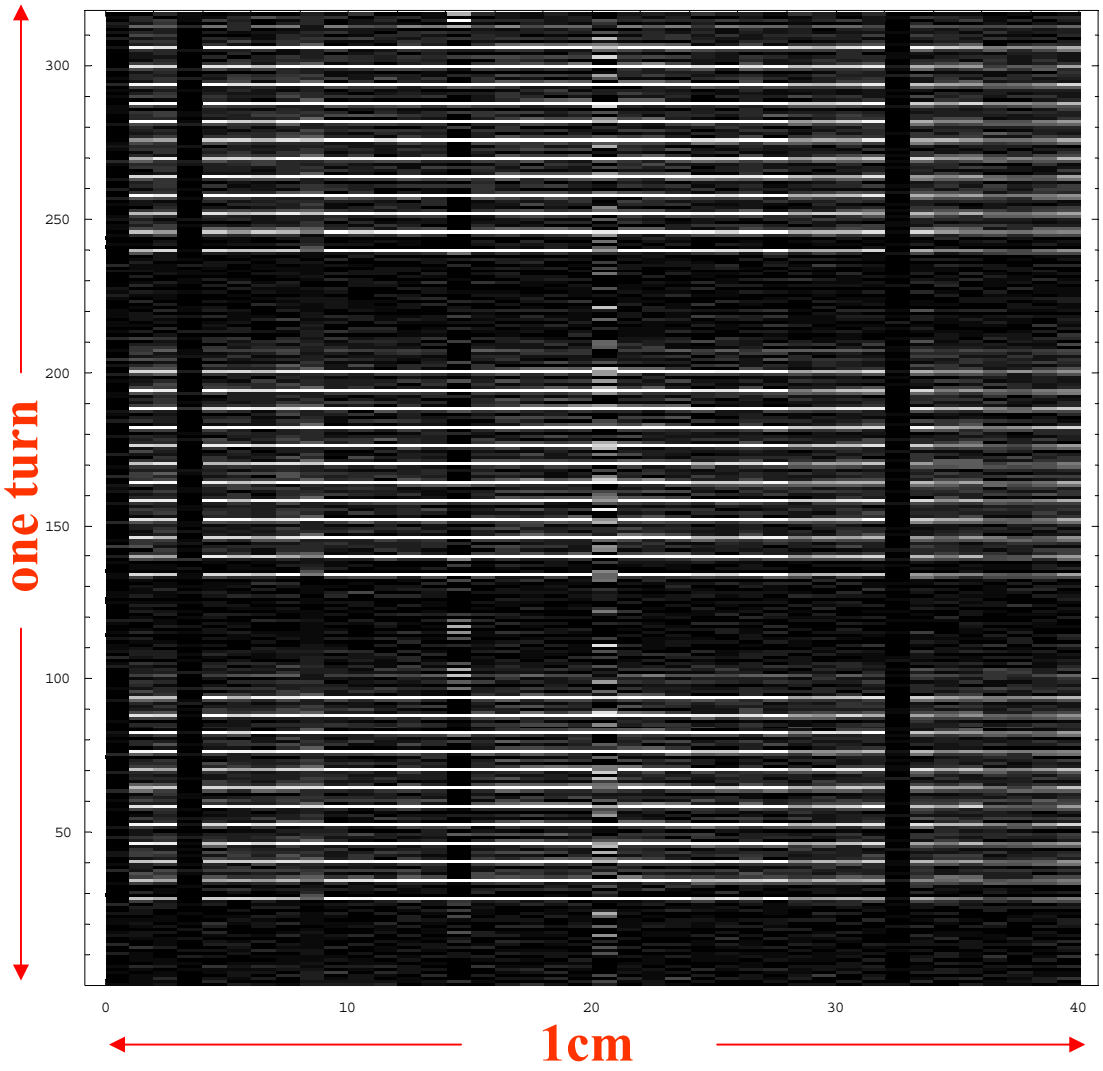


E0 straight section

E0 service building

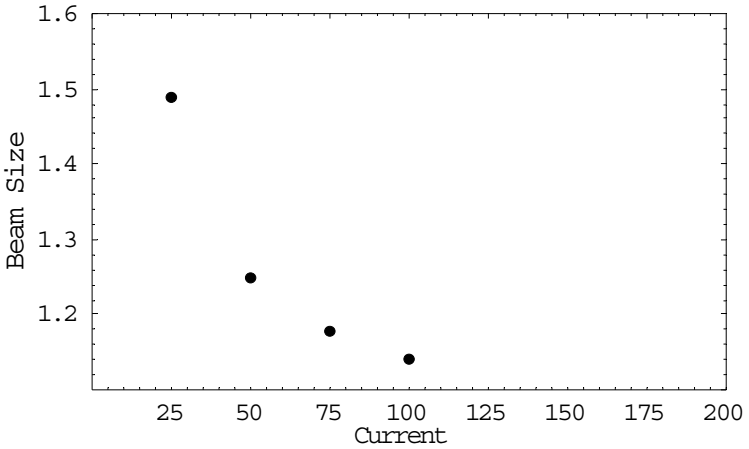
Very first beam results

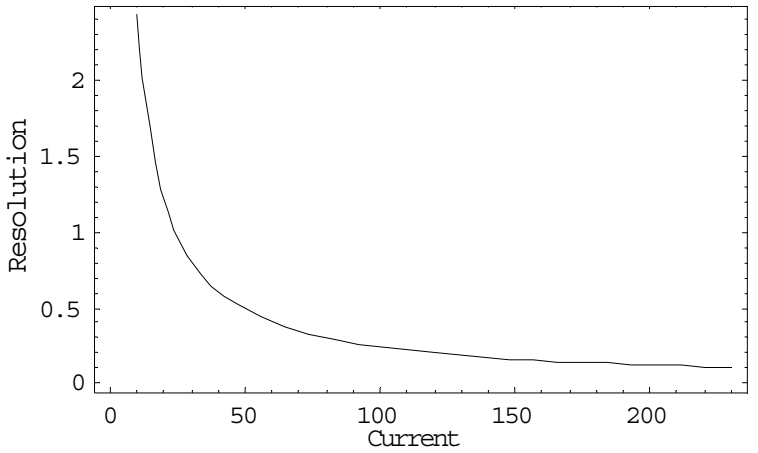
- First data taken at 980GeV during store 4634 without magnetic field.



Effect of reduced 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



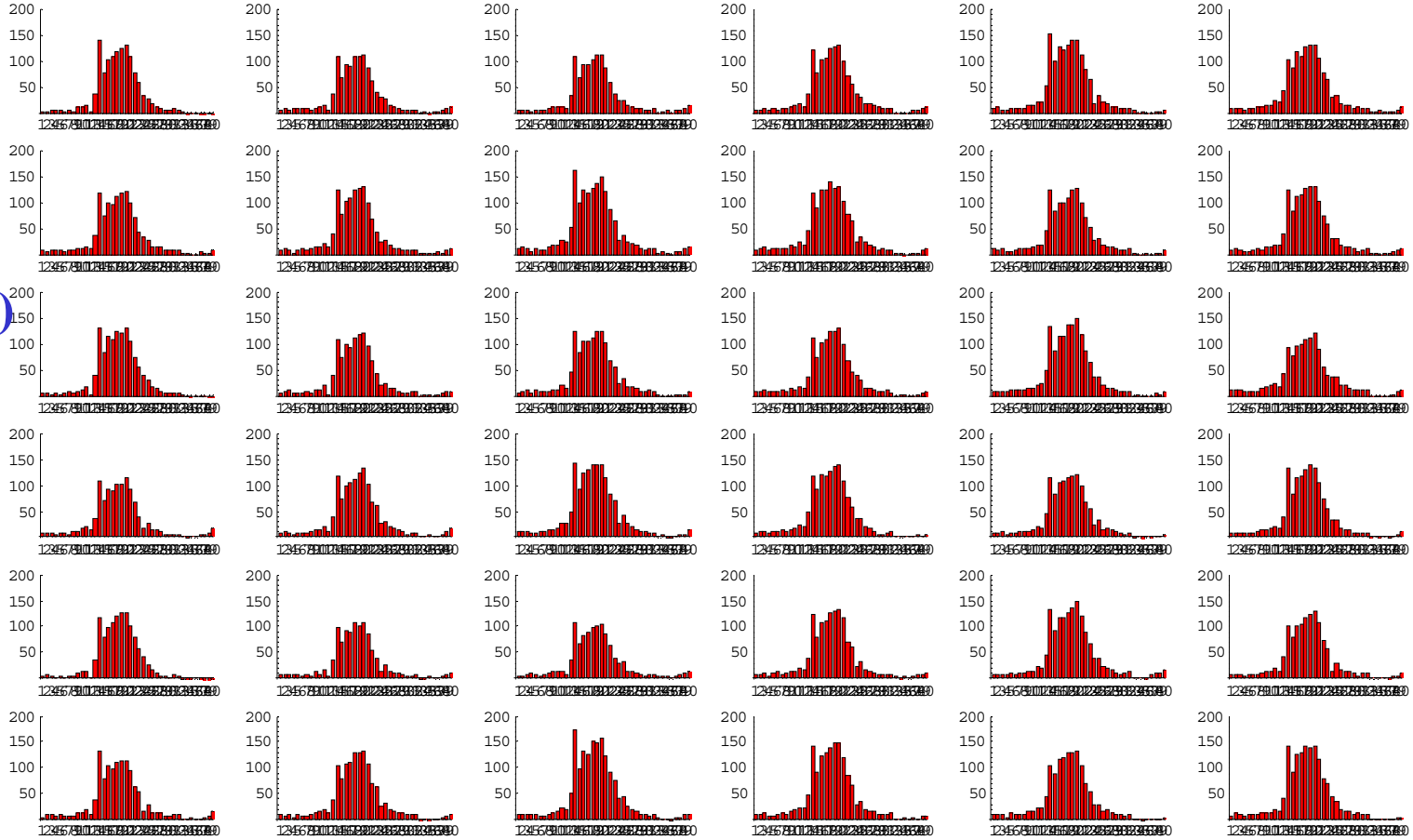


Protons during store

Store #4641

Magnet at 50A (nominal 200A)

Single turn profiles for 36 proton bunches!



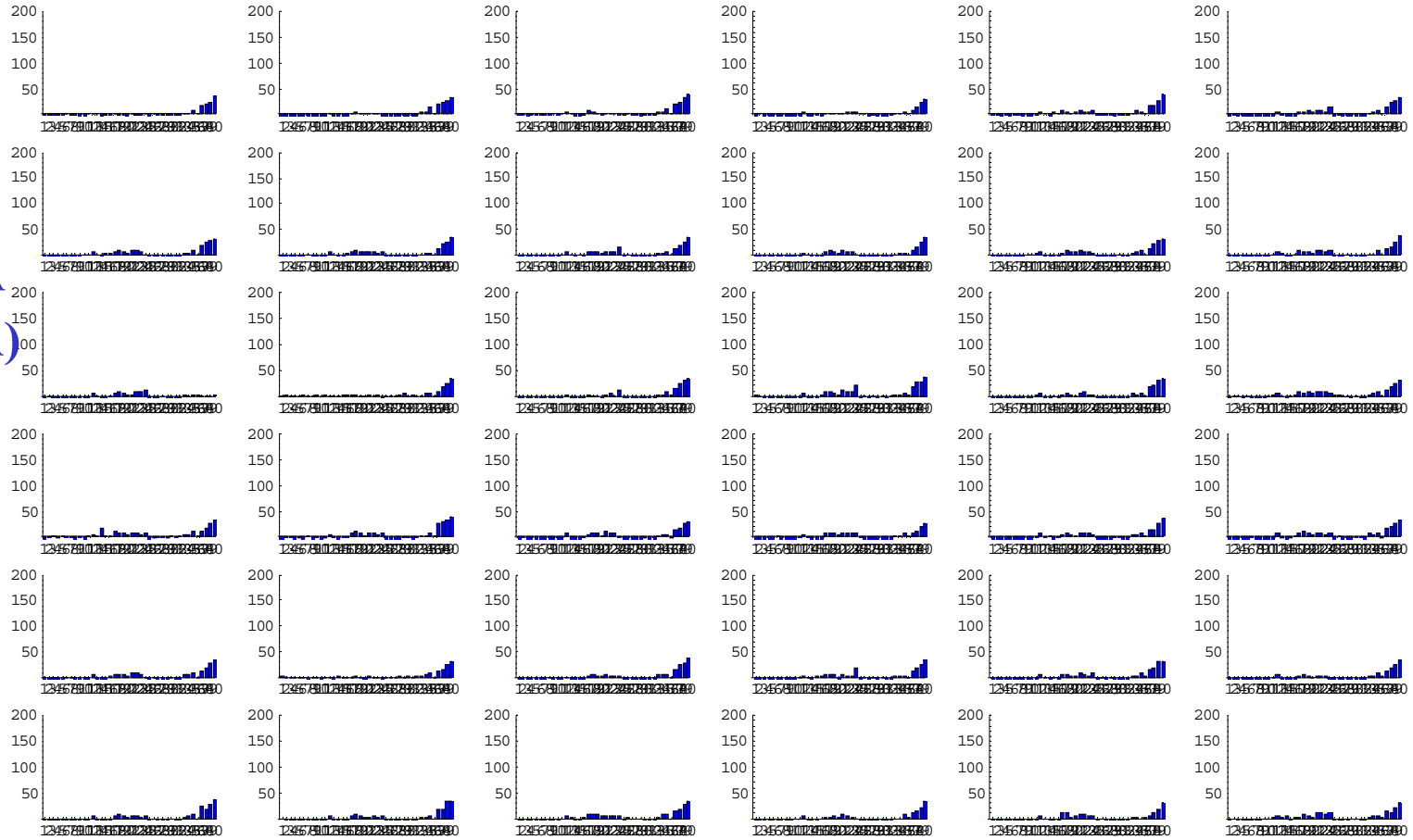
Measured profile widths at 980: 0.7-0.9 mm

consistent with flying wires taking into account the low B-field

Hint of pbars during store

Store #4641

Magnet at 50A (nominal 200A)



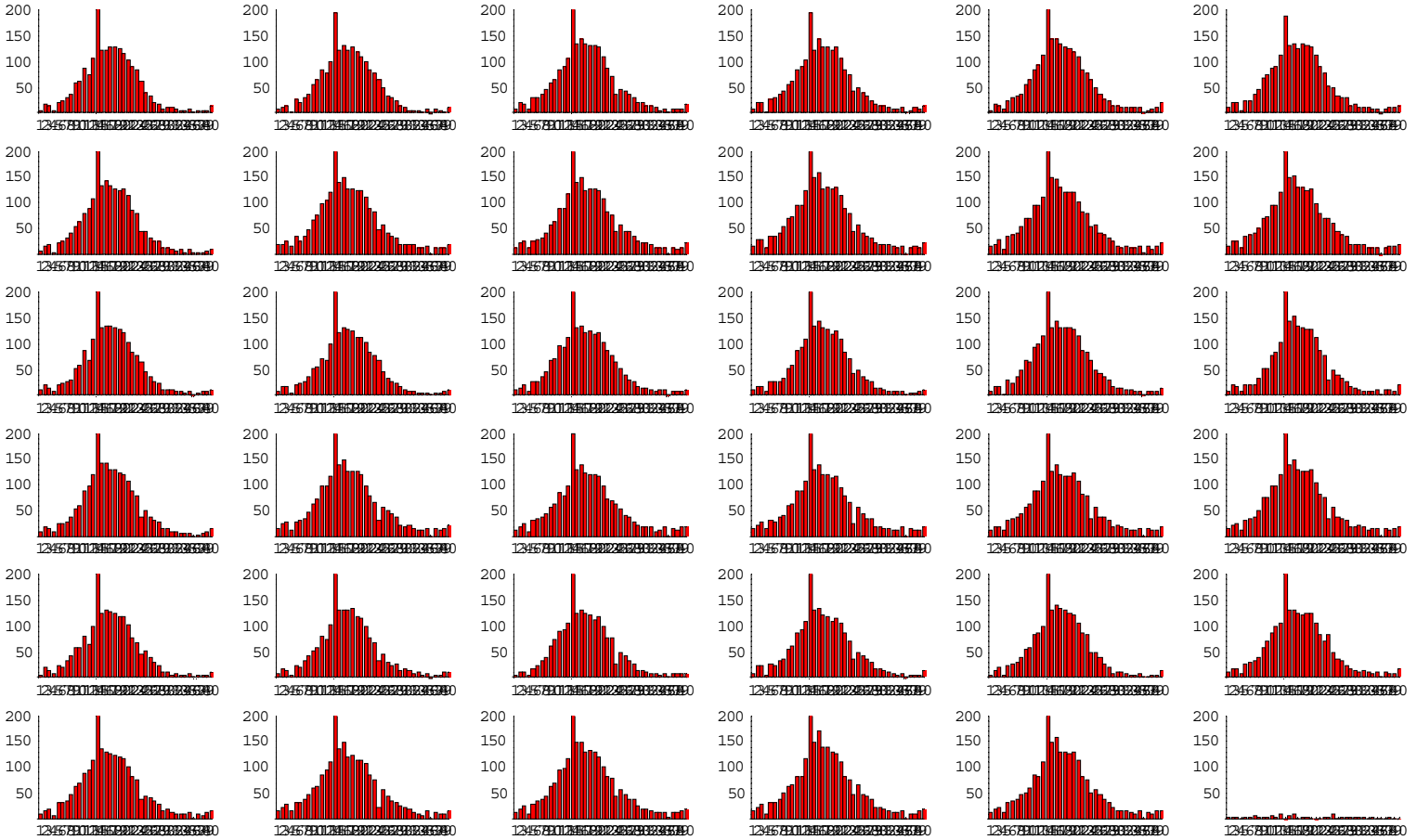
NOTE: Detector centered on proton orbit

Proton during injection

Store #4642

Magnet at 50A

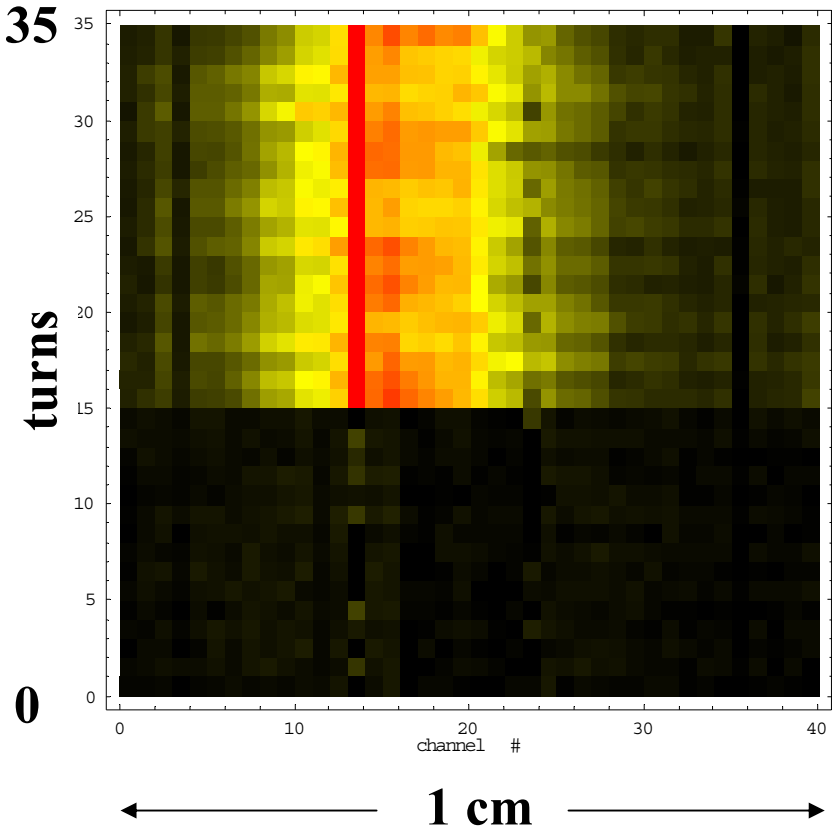
Single turn profiles for 36 bunches!



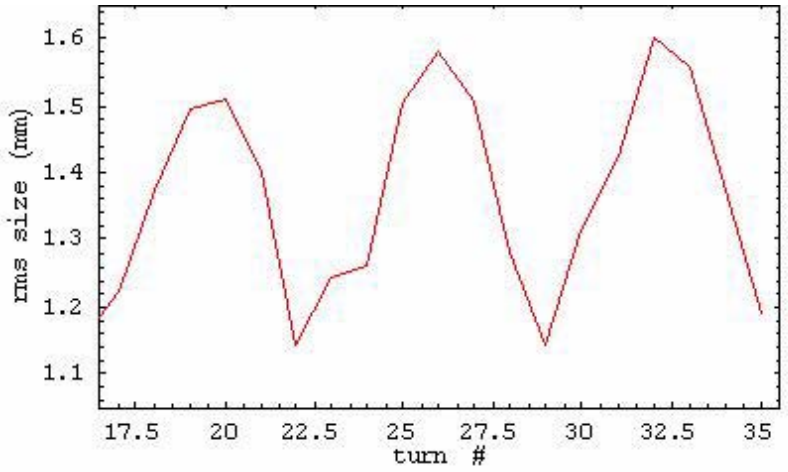
Proton profiles 16 turns before injecting P36

Protons at injection

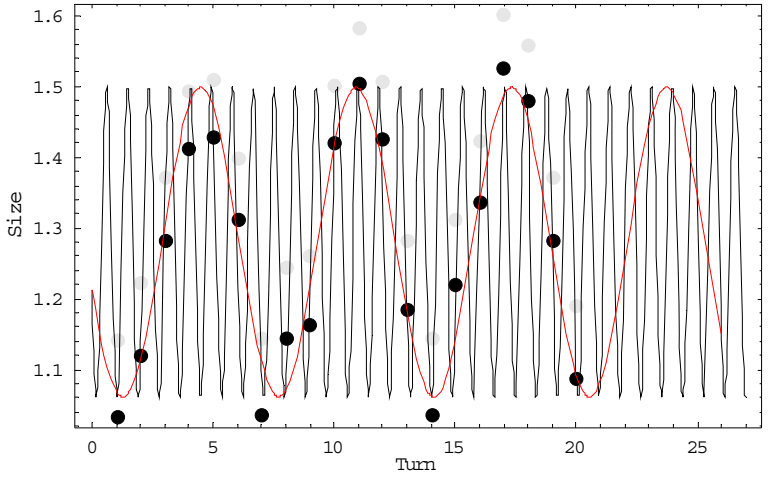
Bunch #36 turn-by-turn



Raw profile width



Corrected for low B-field



Store #4642 **Magnet at 50A**

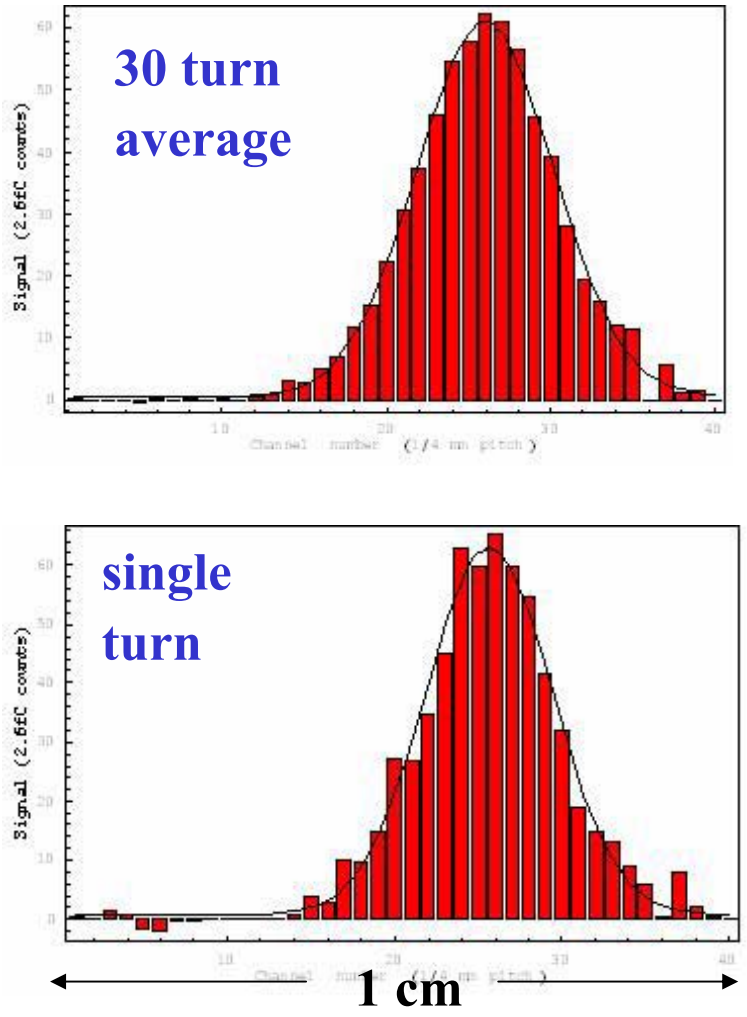
2006 shutdown work

- 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.

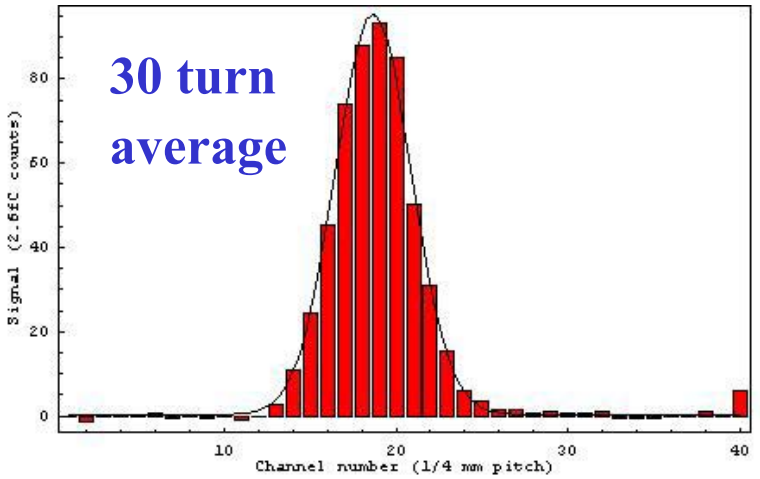
Single bunch proton profiles

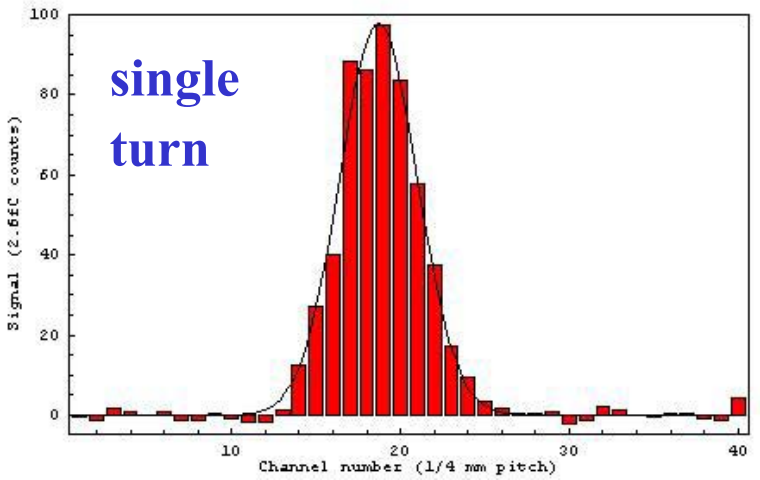


Magnet at 200A

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.

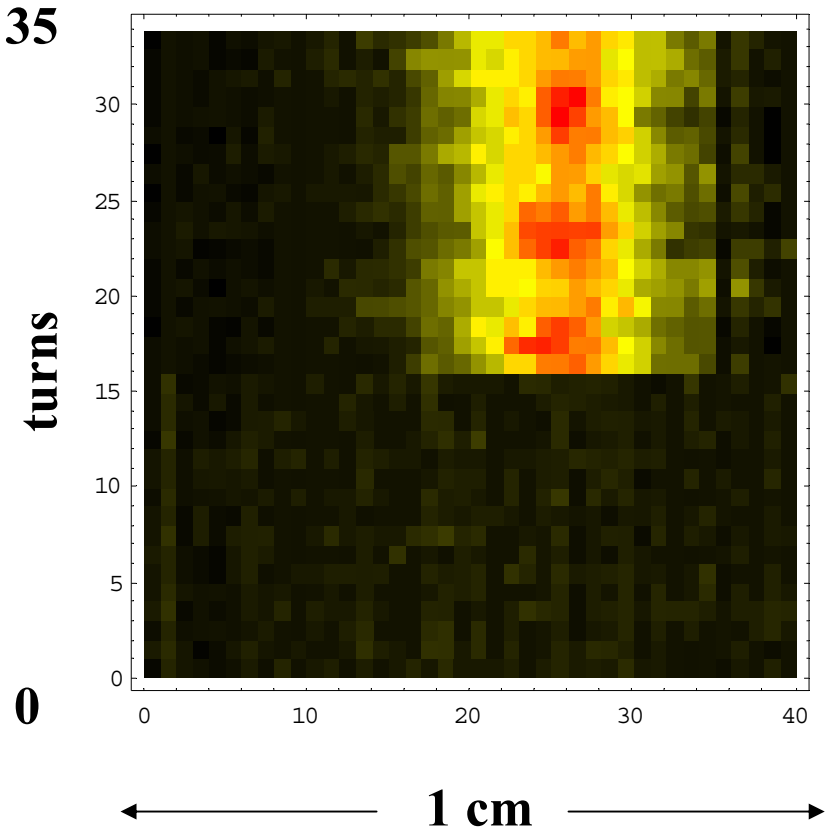




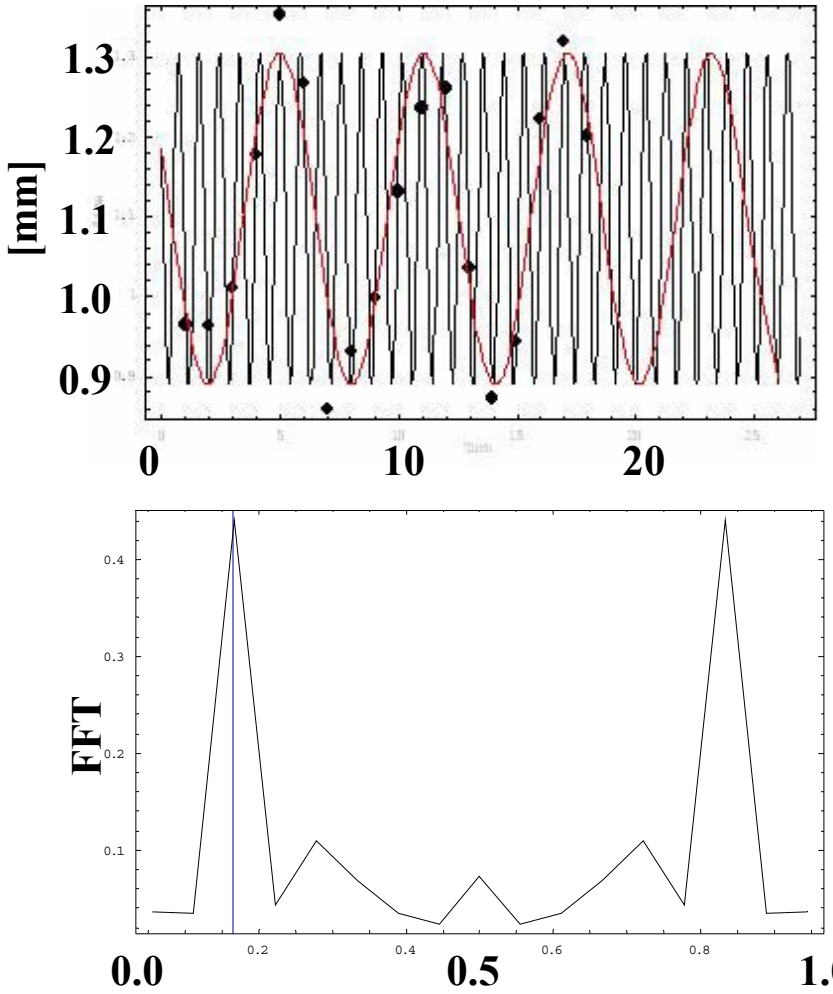
Magnet at 200A

Injection – Full B field

Proton bunch #21 turn-by-turn



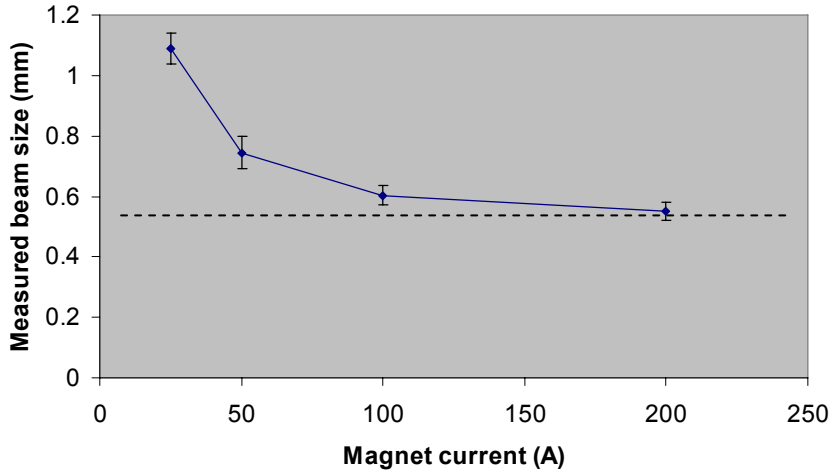
RMS profile width

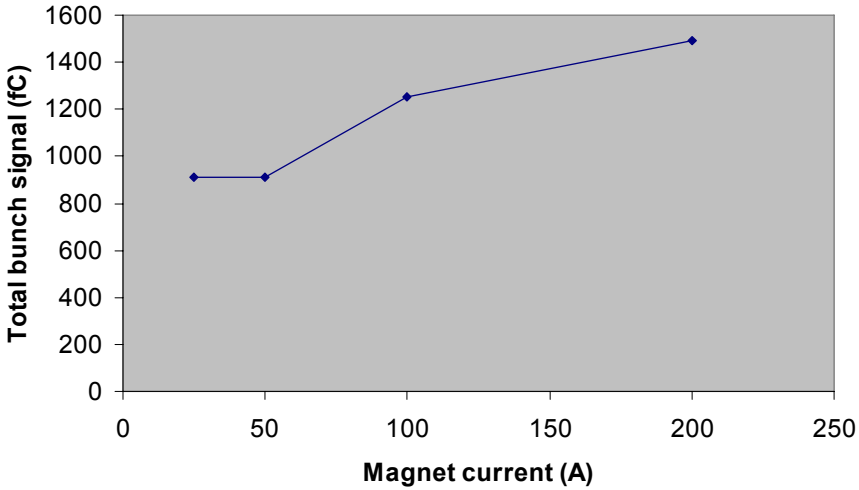


Store #4772 **Magnet at 200A**

Effect of magnetic field strenght

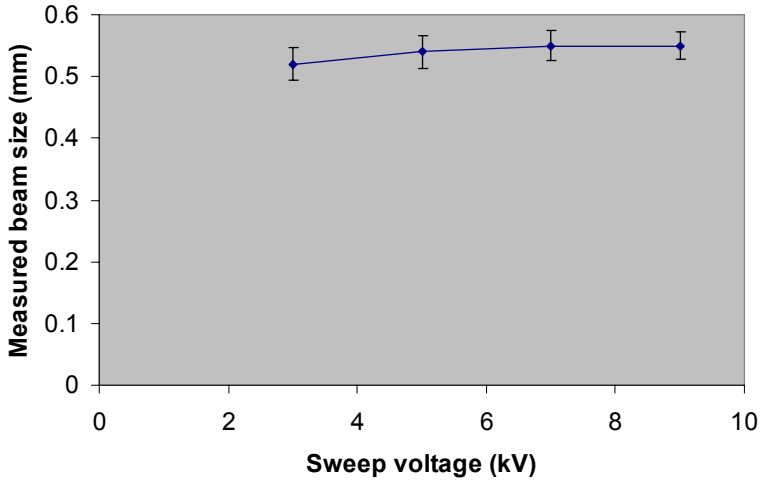
- Measured beam size and total signal as a function of magnet current.
- Resolution due to Larmor radius ~0.1mm at 200A (2% effect for a 0.5mm beam).
- Signal increase with B-field may be due to detection efficiency (threshold is >1 primary electron per channel).

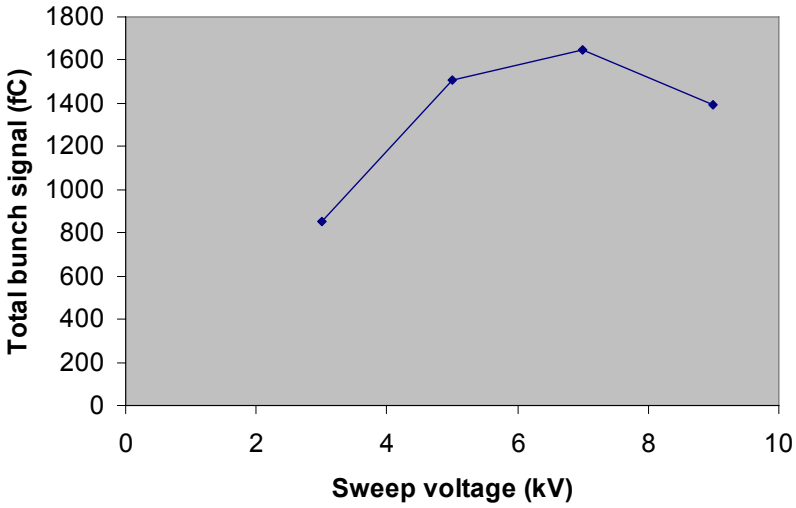




Effect of drift field strength

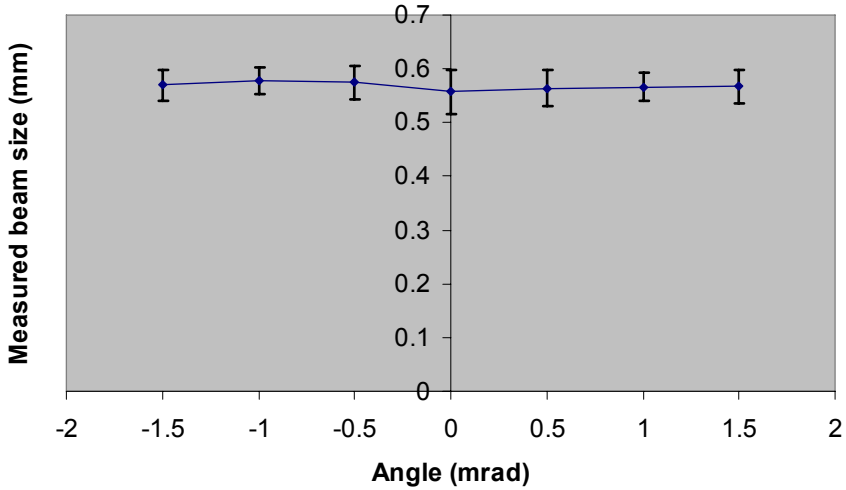
- Measured beam size and total signal as a function of drift field (voltage).
- Negligible effect on profile width.
- Maximum signal at ~7kV drift voltage (MCP sensitivity peaks at ~3keV for electrons)

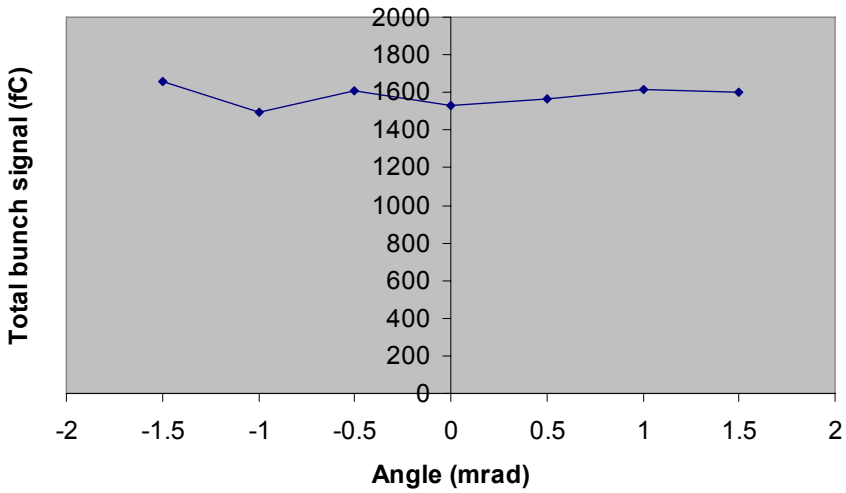




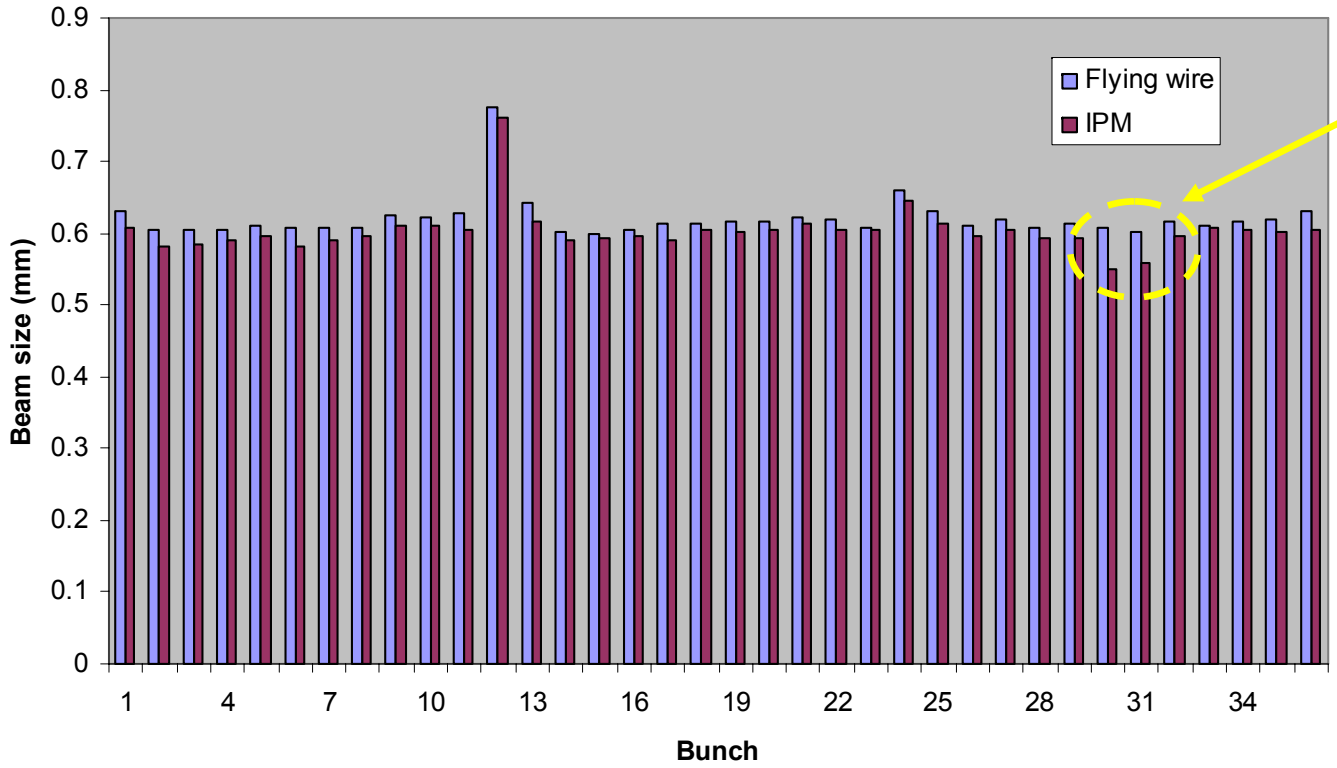
Effect of alignment

- Measured beam size and total signal as a function of tilt angle.
- No observable effect within a few mrads.

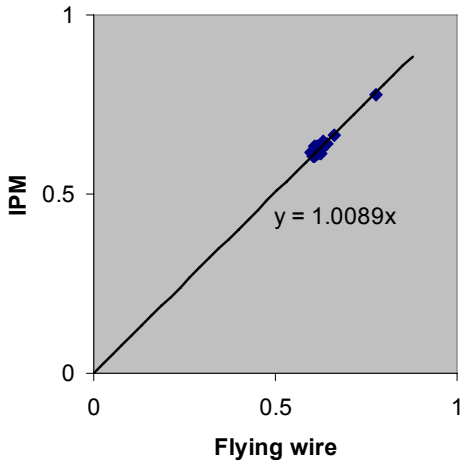




Flying wire comparison



Known electronics problem (cross talk from revolution marker pulse)



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…).