Main Injector BPM system upgrade

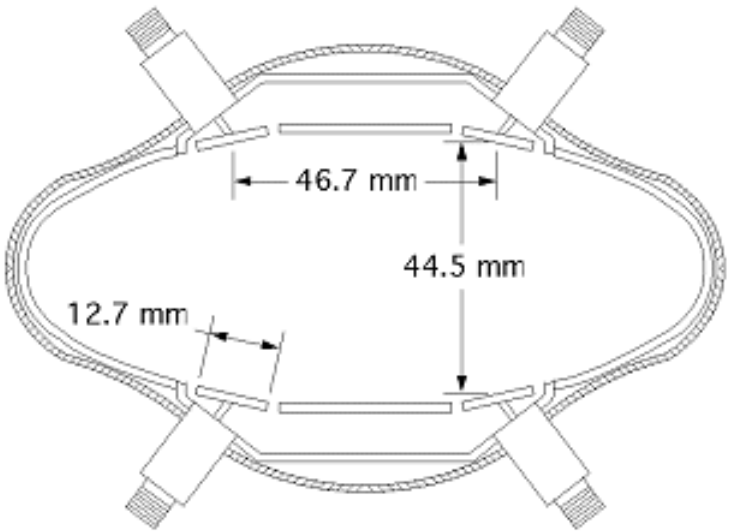
A. Marchionni, MI department

RunII DoE Review, July 2003

- The present system
- Motivations for an upgrade
- System requirements document
- Internal review committee report
- Present schedule, cost, resources

The present system

- The Main Injector has a total of 208 BPMs. There are 203 "Main Injector" style BPMs and 5 "Booster" style BPMs.



Main Injector style BPM

The "Main Injector" style detectors were designed in order to fit inside the downstream end of each quadrupole and have an aperture of 4.625"×1.9".

The 5 "Booster" style detectors, with an aperture of 4.625" are placed in the injection/extraction regions, adjacent to the Lambertsons.

- Each detector has 4 striplines connected in pair to measure either horizontal or vertical position at each quad.

- The system provides 4 detectors per betatron wavelength in both the horizontal and vertical planes.

- Bipolar signals from the beam detectors are passed through front-end filters to extract the 53 MHz component and then to amplitude-to-phase converters.

- Resolutions for beam positions within ±5 mm are ~ 100μm. The system has limited resolution beyond ±10 mm, because of non-linearities in the amplitude-to-phase conversion and the limited dynamic range of the present ADC (8 bit).

Available application programs

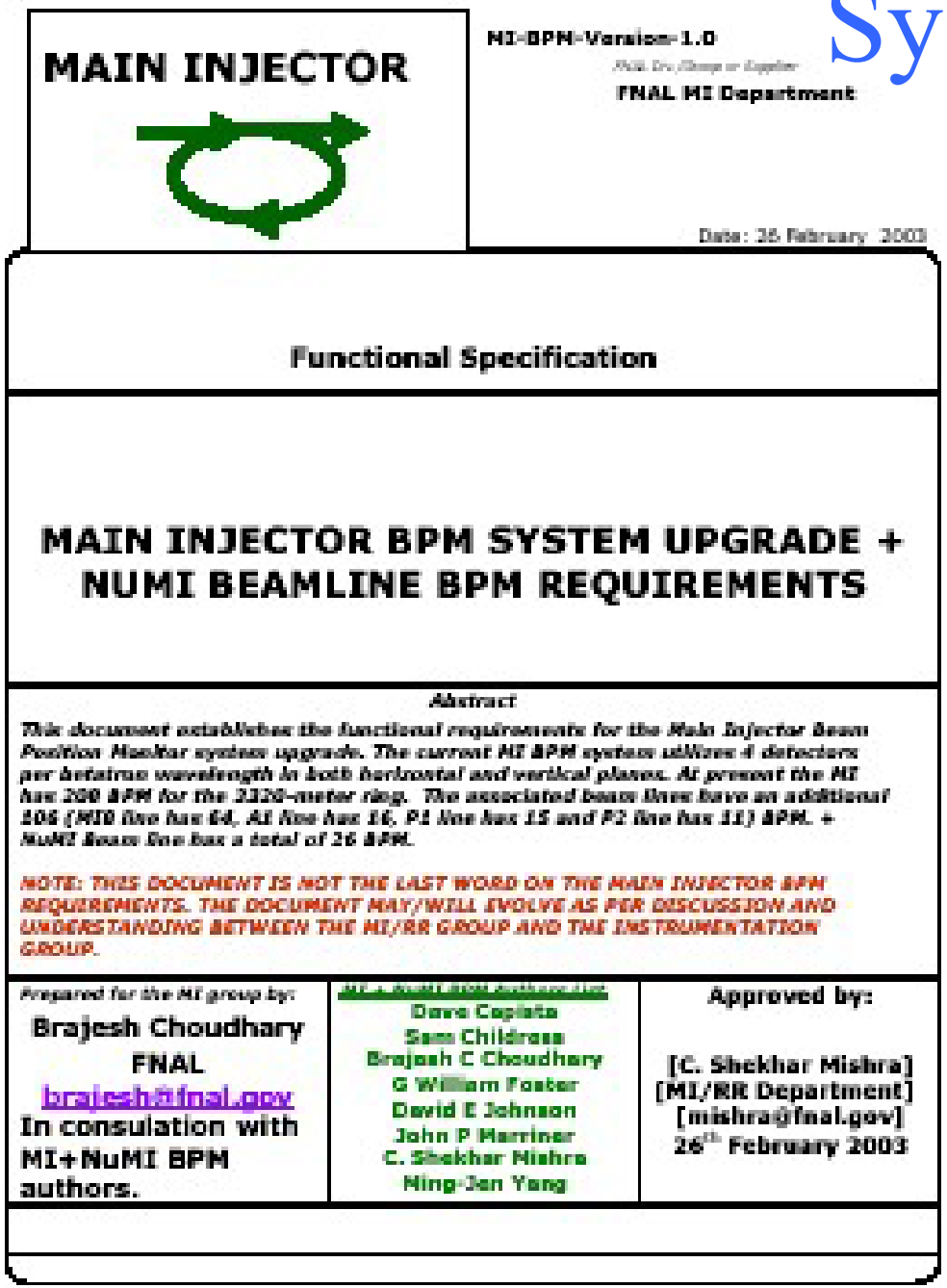
- **Control and diagnostics**
  - I37 ➡ BPM control parameters
  - I38 ➡ BPM hardware tests
  - I53 ➡ BPM rms noise
- **Machine operation**
  - I39 ➡ single turn and closed orbit display
  - I50 ➡ MI orbit smoothing
  - I52 ➡ MI injection closure
- **Accelerator physics studies**
  - I42 ➡ Tune measurement from Turn-By-Turn BPM data, by pinging the beam
  - I92 ➡ TBT data acquisition program and analysis, lattice function measurements

Motivations for an upgrade of the front-end system

- The present front-end system is 20+ years old. Some parts are no longer commercially available (e.g. clock-chips used to decode MI events, we have ~ 200 in hand). The computer interface is based on Z80s.
- The system does not cover all the different beam conditions (intensity and time structure) currently used in the day to day operation of the machine
  - it is essentially blind to single coalesced 53 MHz bunches, as well as to short bunch trains (less than 20-30 bunches). This mode of operation is the one currently used for proton and antiproton transfers to the Tevatron.
  - the present electronics is blind to 2.5 MHz time structure. This mode of operation would be required when/if the 2.5 MHz acceleration for antiprotons becomes operational.

- The system is self-triggered (beam intensity threshold). It does not have a general purpose beam synch clock based trigger.
- The system is not capable to operate when the Main Injector is loaded with 6 batches. It requires all detectors at a house to be below threshold before arming will begin. This mode of operation is required for simultaneous antiproton stacking and NuMI operation, which is schedule to start in January 2005.
- The user interface is quite limited. It is essentially a single user, single buffer system. The data in the buffer gets overwritten each time any valid MI reset occurs.

System requirement document



MAIN INJECTOR

MI-BPM-Version-1.0

FNAL MI Department

Date: 26 February 2003

Functional Specification

MAIN INJECTOR BPM SYSTEM UPGRADE + NUMI BEAMLINE BPM REQUIREMENTS

Abstract

This document establishes the functional requirements for the Main Injector Beam Position Monitor system upgrade. The current MI BPM system utilizes 4 detectors per betatron wavelength in both horizontal and vertical planes. At present the MI has 208 BPM for the 3320-meter ring. The associated beam lines have an additional 206 (MI8 line has 64, A1 line has 16, P1 line has 15 and P2 line has 11) BPM. + NuMI Beam line has a total of 26 BPM.

NOTE: THIS DOCUMENT IS NOT THE LAST WORD ON THE MAIN INJECTOR BPM REQUIREMENTS. THE DOCUMENT MAY/WILL EVOLVE AS PER DISCUSSION AND UNDERSTANDING BETWEEN THE MI/RR GROUP AND THE INSTRUMENTATION GROUP.

Prepared for the MI group by:

Brajesh Choudhary

FNAL

brajesh@fnal.gov

In consulation with MI+NuMI BPM authors.

MI + NuMI BPM Hardware Group

Dave Capista

Sam Childress

Brajesh C Choudhary

G William Foster

David E Johnson

John P Marriner

C. Shekhar Mishra

Ning-Jen Yang

Approved by:

[C. Shekhar Mishra]

[MI/RR Department]

[mishra@fnal.gov]

26th February 2003

Beams-doc-471-v1

2/26/2003

The requirements

- **Beam time structure**
  - The MI BPM electronics should be functional with 53 MHz and 2.5 MHz time structures. It should give reliable position measurements either with a single Booster bunch, or a single coalesced bunch, as well as with multiple bunches, and up to 6 Booster batches loaded in the machine.
- **Dynamic range**
  - From 0.5×10^{10} particles/bunch up to 30×10^{10}/bunch (this is for a single coalesced bunch of protons)
- **Beam position precision**
  - The position accuracy requested is, at the 3σ level, 400 μm+5% of the actual position. This has to cover long term stability and resolution.

- **Beam intensity measurements**
  - Every BPM has to provide a measurement of the amplitude of the common mode signal ("sum signal") proportional to the "beam intensity". BPM-to-BPM rescaling capabilities shall be incorporated so that relative location-to-location beam intensities can be determined to a precision of 5% on a Flash, Turn by Turn or Profile mode.
- **System calibration**
  - A calibration system must be provided to verify and maintain the required position and intensity precision. The accuracy of the calibration system must be adequate to assure a maximum error in position accuracy of 200 μm+1.25% of the actual position, and 2% in intensity.

- **Operational modes**
  - Flash mode: a single turn position of the beam around the ring at a specific time (e.g. injection orbit, last turn orbit, …). This allows to study deviations from the closed orbit.
  - Turn by turn mode: flash data at every BPM simultaneously over a large number of consecutive turns (up to 16384 if cost is small). This is a way to try to identify causes for beam losses, onset of coherent instabilities,… up the ramp. This mode is also used for lattice functions and phase advance measurements.
  - Closed orbit mode: averaged position data over a programmable number of flash mode measurements from 1 to 256 turns. This is used for closed orbit measurement, orbit smoothing, …
- **Front-end functionality**
  - The system is expected to support multiple users (more than an application program at a time) and multiple MI resets, with separate data buffers for each MI reset. The system shall be self triggered (beam intensity threshold) as well as beam synch clock triggered.

From the Internal Review Report, on March `03

- The committee fully supports the proposed upgrade of the MI BPM system. The documentation was complete and covered not only the specifications required for designing the BPM electronics, but also documented the operational aspects.
- The level of accuracy was requested over the full dynamic range of beam intensity and all types of beam (independent of beam type structure).
  - we suggest that a single specification for the accuracy may be too stringent over the full dynamic range.
  - the committee suggests a higher priority be given to repeatability from measurement-to-measurement, or day-to-day, with the same type of beam than to the repeatability of the same orbit measurement with different beam structures.

- There might be trouble building a BPM system that can report the intensity of the beam to 5% accuracy with single turn measurement.
- We anticipate the specifications for a calibration system with accuracy of ± (0.2 mm +1.25%) will not be considered feasible by the engineers designing the system. We still recommend that a calibration system be designed “as well as reasonably possible”.

New developments

- The Run II luminosity upgrade plan assigned to the Tevatron BPM project a higher priority than to the Main Injector BPM upgrade.
- Manpower and budgetary limitation suggested as conservative starting date for the Main Injector BPM upgrade the completion date of the Tevatron BPM project.
- The requirements on the 2.5 MHz capability of the Main Injector BPM is linked to a successful implementation of the 2.5 MHz antiproton acceleration project (WBS 1.3.1.3.3). A review for this project is scheduled in August ’03.
- Recent experience with restarting multi-batch operation of the Main Injector for the NuMI project shows the importance of batch by batch position measurements.

- Also following the suggestions of the Review Committee, some of the requirements will have to be reexamined, with input from the design engineers.
- The hardware implementation of the Main Injector BPM system will benefit from and likely adopt some of the technical solutions implemented in the Tevatron and Recycler BPM system.

Present MI BPM schedule, cost, resources

WBS		Start	Duration	M&S ($K)	M&S Cont
Main					
1.3.1.3.2	**MI BPM Systems**	**6/4/04**	**290 days**	**900**	**+60%**
1.3.1.3.2.1	MI BPM system design	6/4/04	44 days	0	
1.3.1.3.2.2	MI BPM: Review (Milestone)	8/4/04	0 days	0	
1.3.1.3.2.3	MI BPM system fabrication	8/5/04	180 days	900	60%
1.3.1.3.2.4	MI BPM system installation	4/14/05	22 days	0	
1.3.1.3.2.5	MI BPM system commissioning	5/16/05	44 days	0