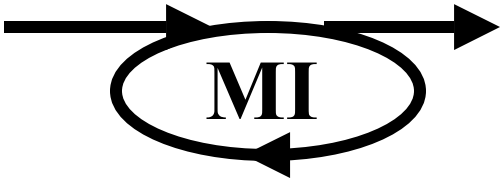

REQUIREMENTS FOR THE MAIN INJECTOR & ASSOCIATED TRANSFER LINES BPMs INCLUDING THE NuMI BEAM LINE

Brajesh Choudhary for the MI Dept.

4th March 2003

ACKNOWLEDGEMENTS

Thanks are due (in alphabetical order) to:

- Mark Averett
- Alan Baumbaugh
- Chandrashekhara Bhat
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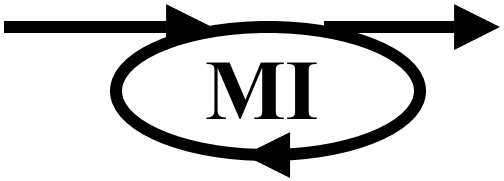
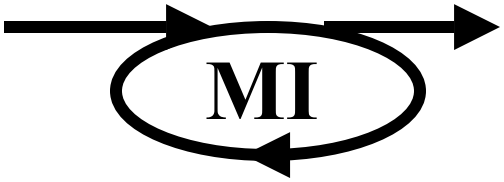
- Bill Foster
- Dave Johnson
- Paul Kasley
- Sharon Lackey
- John Marriner
- Shekhar Mishra
- Marvin Olson
- Stanley Pruss
- Vic Scarpine
- Ming-Jen Yang

OUTLINE OF THE TALK



- Introduction (Description of the existing MI BPM system)
- Why an Upgrade
- What is Needed?
- Definitions
- Measurements
- System Calibration
- Beams in the MI
- Time Structures
- Dynamic Range
- Measurement Precisions
- Data Buffers
- Number of BPMs in the MI and Associated Transfer Lines
- NuMI Beam Line BPMs and Requirements
- Application Program
- New Software
- Schedule
- Summary
- Acknowledgements(First)

MI BPM SYSTEM



➢The MI ring has a total of 208 BPMs. Out of these, 203 are MI style ring BPMs and 5 are large aperture BPMs.

➢The ring BPM is formed from 4 transmission line strips, or strip-lines, located on the perimeter of the beam pipe as shown in the picture. It is elliptical in shape with long face 4.625”(11.7cm) and short face 1.9”(4.8cm) in size. It has a characteristic impedance of 50Ω which is determined by the gap between the strip and the beam pipe. The RF module input impedance is matched to 50Ω within a 5 MHz bandwidth centered at 53 MHz. The outputs are combined in pairs, externally to form either a horizontal, or a vertical detector. Each strip-line is shorted at one end and connected to a ceramic feed-through at the other end, which makes these BPMs non-directional. This design does not have separate horizontal or vertical detectors. (MI-Note 96, & MI TDR).

➢The large aperture BPMs with 6” long plates and a 4.625” aperture (provides 0.52db/mm) are located adjacent to the Lambertson magnets and require large aperture detectors mounted external to the quadrupole.

MI BPMs

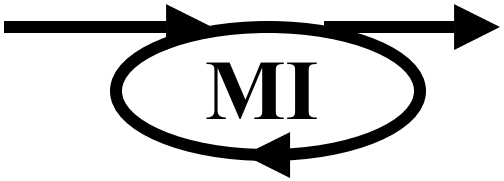
Long face outer/inner size 4.75”/4.625”
Short face outer/inner size 2.1”/1.9”

MI Ring BPM

Large Aperture BPM

Plate diameter outer/inner 4.75”/4.625”

WHY AN UPGRADE ?



- Present MI BPM electronics is blind to 2.5MHz time structure, and unreliable for position measurement of a single coalesced 53MHz bunch, as well as for ≤20-30 bunches of 53MHz beam.

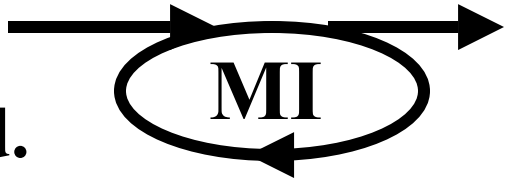
- The system is quite limited. It is essentially a single user, single buffer system. The data in the buffer gets overwritten every time any valid MI reset occurs.

- Computer interface is a multi-bus based system with 8 bit ADC. Design and measured resolution is shown on page 8, and 9, & 10, respectively.

- The system has limited resolution (beyond ±10 mm) because of the non-linearity of AM to PM detection, the BPM geometry, and the 8-bit ADC used in the present electronics.

- The firmware is written in Z80 machine code, which is now obsolete. **Only one person (Alan Baumbaugh) at the laboratory is familiar with the code.** Sharon Lackey used it ~15yrs ago for switchyard, and if it is really needed she can be called to help.

WHY AN UPGRADE ? Contd.



- The control interface is in GASP, an obsolete protocol that is being phased out by the controls department. This is one of the reasons to replace the switchyard BPM.
- The system is self (beam intensity threshold) triggered. It does not have a general purpose beam-synch clock based trigger. **For FLASH, it has been made to work with beam synch clock.**
- It is a ~20+ years old system. The system is approaching its end-of-life and one can expect increasing failure rates. Some spare parts are no longer commercially available.

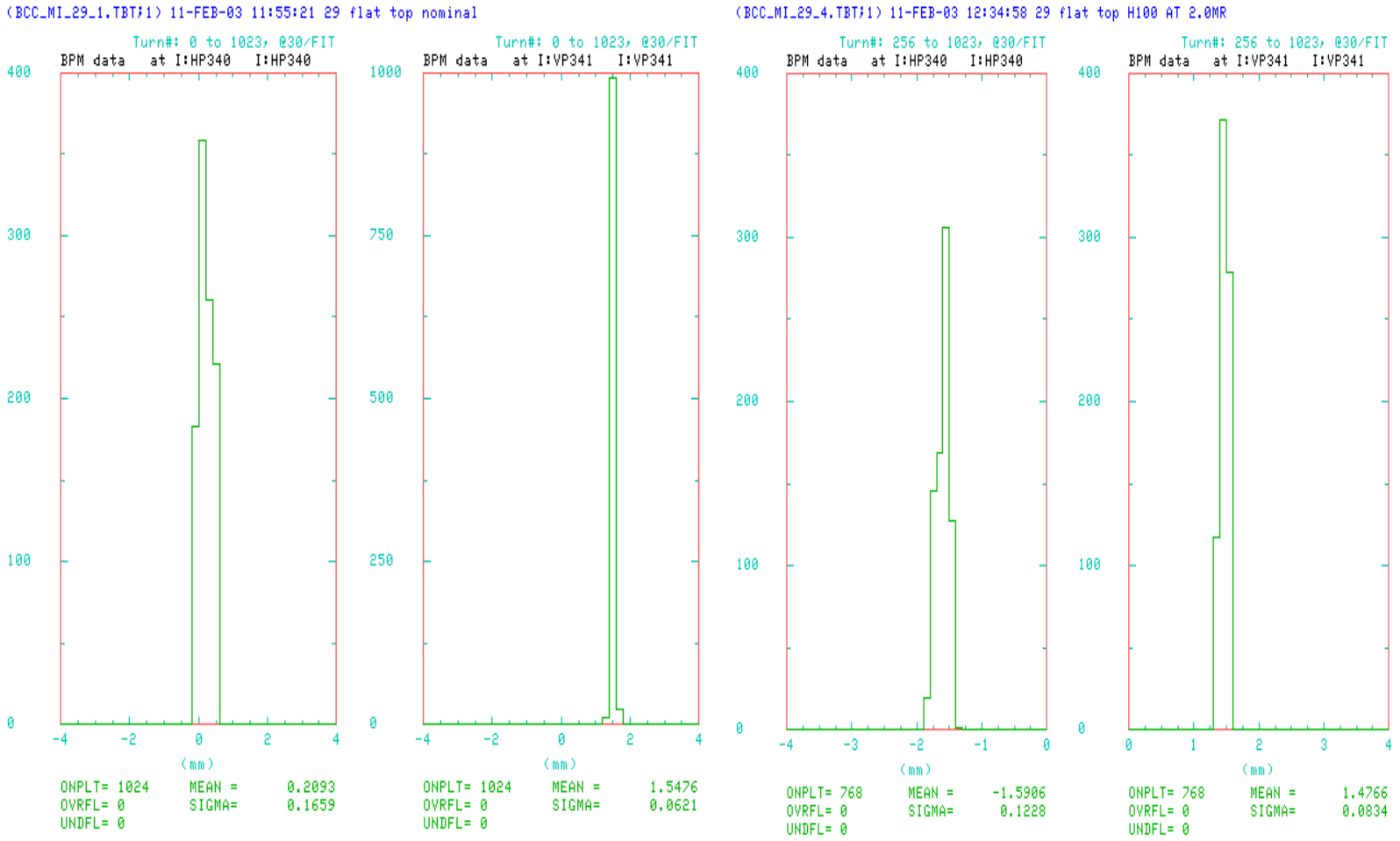
DESIGN RESOLUTION

MI

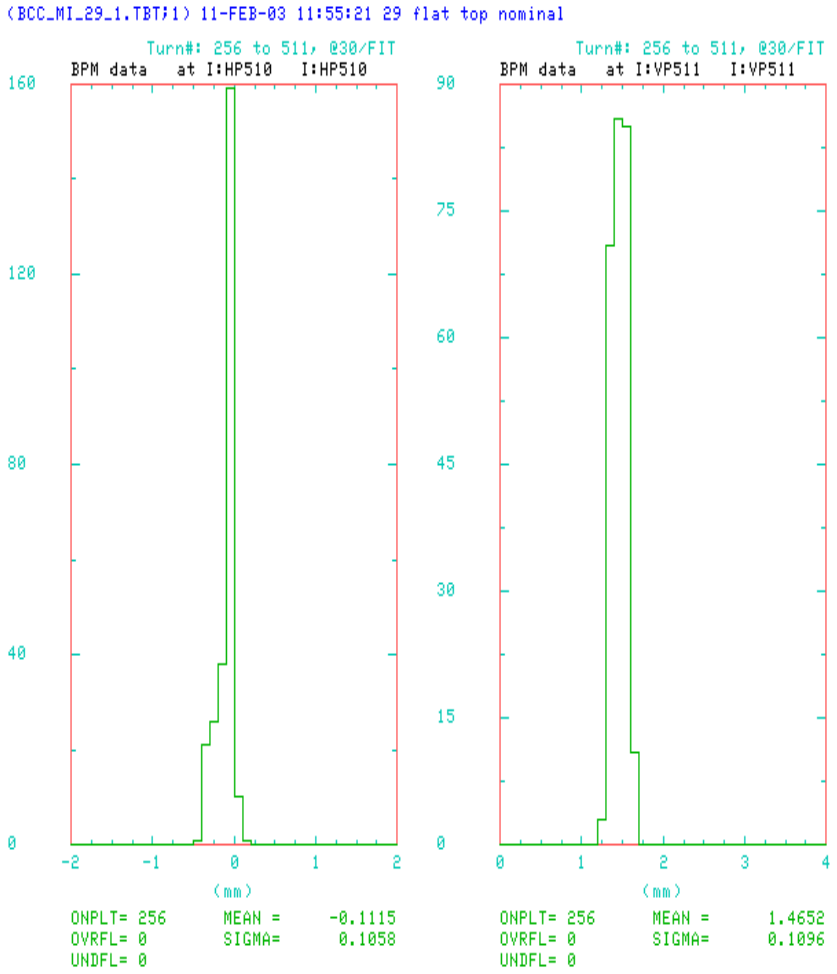
Beam Position	Horizontal(μm)	Vertical(μm)
≤ ± 5mm	~100μm	~150μm
5mm ≤ x ≤ 10mm	~150μm	150-200μm
10mm ≤ x ≤ 15mm	200-300μm	200-300μm
15mm ≤ x ≤ 20mm	300-600μm	300-600μm
≥ ± 20mm	1-4 mm	----------

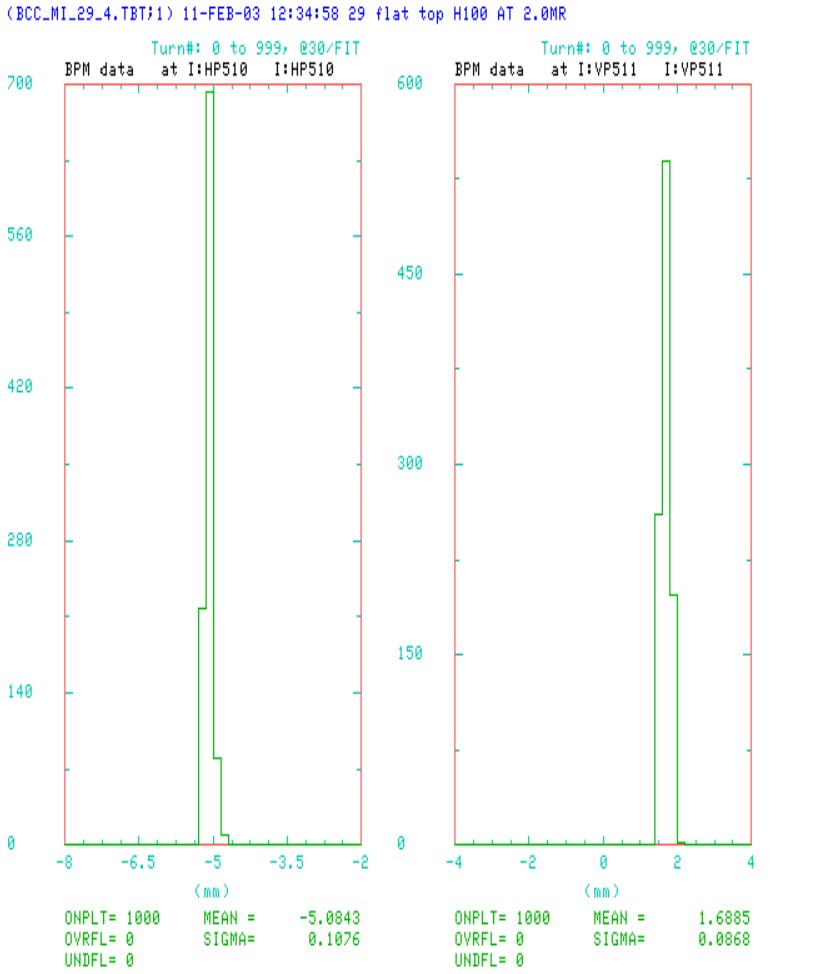
Measured Resolution for beam position ≤ ± 5mm varies between ~50-150 μm. Lets preserve the level of resolution.

MEASURED RESOLUTION

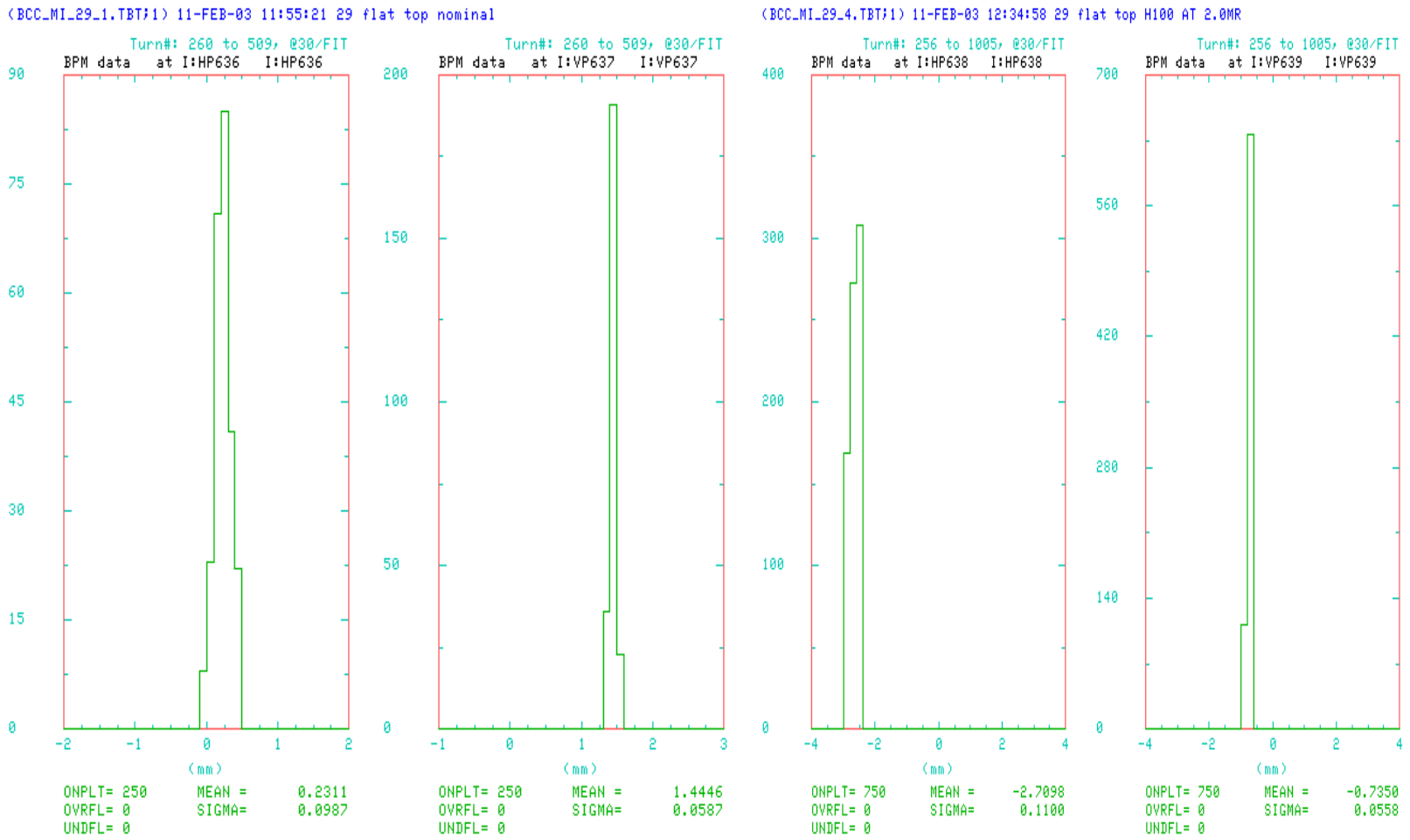


MEASURED RESOLUTION

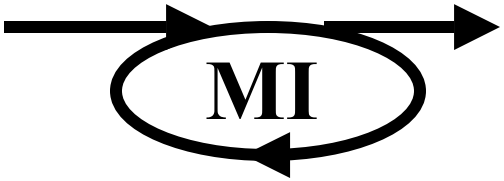




MEASURED RESOLUTION

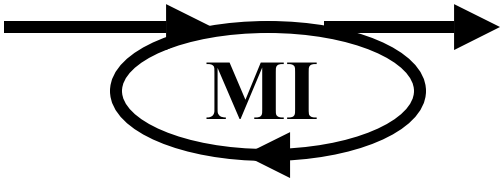


WHY AN UPGRADE ? Contd.
SPARE PART AVALIBILITY



- There are about 24 spare RF modules. It is used for both the MI, and the Tevatron BPM. One RF module is needed for each BPM. Inside the RF module there are matched filters, limiters, and resonators.
  - The vendor does not produce the limiters anymore. We lose about 2 to 3 limiters every year. The failed limiters can't be fixed. There are no spares outside the spare RF modules.
  - Spare resonators are also not available, but the FNAL engineers can make the replacement.
- The clock-chip that decodes the MI event, although doesn't fail regularly, could be a problem. About 100 more available. New clock chips (~100) have been bought and will be tested. Although it is not a problem at this stage, it could be a problem if one wishes to add more MI clock events.
- Power-supply failure rate is about 5% per year in the MI.

WHY AN UPGRADE? Contd.
MULTI-BUS SYSTEM



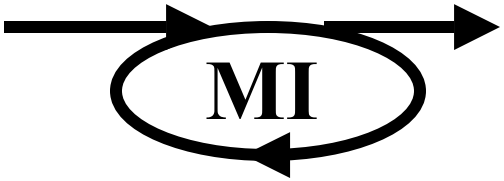
- The multi-bus system was designed in 1981. It is 20+ years old. Carl Wegner from the Research Division designed it. Alan Baumbaugh worked on the firmware, and also designed the first TBT card.

- The person who inherited it from Carl Wegner was transferred. The person who inherited next left the laboratory. Bob Marquard inherited it next. He retired. The person in charge these days is **Mark Averett/Paul Kasley.**

- The system is not very robust. One of the in-house built cards in the system fails frequently. Some spares are left, and the system can be made to work while spares last. There may be programmable parts in the system which are not available anymore. Not many experts left at the laboratory. Alan Baumbaugh has been called to consult on the system but cannot spend 100% of his time supporting the system. Memory also getting sketchy. Recently Roger Tokarek called couple of meetings to understand and discuss errors observed related to a TBT card (designed by someone who is no longer at the laboratory). People are not very familiar with the errors. It takes longer to figure out the problem than to fix the problem.

- According to Alan Baumbaugh the system could at best last another ~5yrs.

WHAT IS NEEDED ?



- The MI BPM electronics should be functional at 2.5MHz, & 53MHz time structure. It should be reliable for position measurement either with a single Booster bunch, or a single coalesced bunch (53 MHz), as well as with multiple bunches, and multiple batches in the MI.

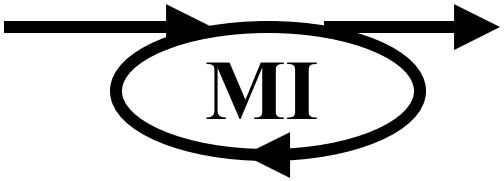
- The system should be event driven to support multi-user with multi-buffer, so that different type of data can be taken during the same MI cycle, and the data taken with a particular MI reset does not overwrite the data taken with other MI reset.

- Attenuation due to varying cable lengths, limits the "dynamic range" of the system and thus detection of small bunch intensities. Gain should be adjusted to account for this variation.

- The system should at user option be self (beam intensity threshold) triggered as well as beam synch. clock triggered.

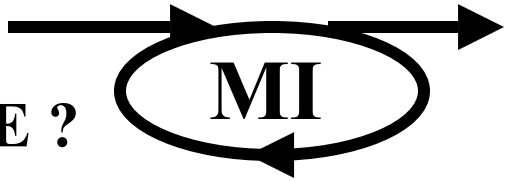
- The present**(old)** multi-bus based system with 8-bit ADC computer interface should be replaced by a modern and better supported architecture (for ex: with a VME contained system) using 12/14-bit ADCs (for a bit resolution of ~50μm) . **[Engineers to determine how this condition will be met].**

DEFINITIONS



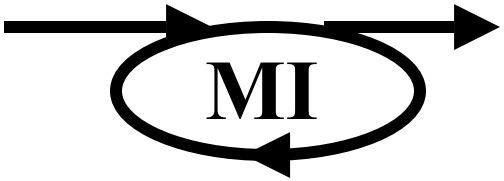
- Flash Mode – Single turn position of the beam around the ring at a specified time/turn.
  - Injection Orbit – First turn position of the beam around the ring.
  - Last Turn Orbit – Last turn position of the beam around the ring before the kicker kicks out the beam.
- Turn by Turn Mode - Flash data at every BPM simultaneously for up to 16,384 consecutive turns. [Motivation for number of turns to be discussed later].
- Snapshot/**Profile**/Display Mode – Averaged position data (from 8 to 64 turns) stored in a buffer for **closed orbit** measurement, orbit correction program, display, and many such utilities. **We recommend that the BPM signals be an average of a programmable number between 1 to 256 turns.**

WHAT DO WE NEED TO MEASURE ?



- Closed Orbit:
  - To understand where the beam is
  - To maximize the aperture, and
  - To control the orbit during energy ramp
- Flash Orbit - Deviations of the beam from the Closed orbit for
  - Injection (First Turn) Orbit
  - Extraction (Last Turn) Orbit
  - Injection Lattice match, and
  - Fast perturbations of beam for any particular turn

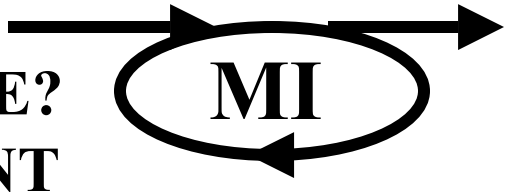
WHAT DO WE NEED TO MEASURE? – Cont.



Turn-by-Turn measurement simultaneously at every BPM

- To measure the lattice functions of the machine by observing the betatron oscillation caused by a ping.
- To measure non-linear properties of the lattice.
- To observe evolution of unpredictable events such as sudden beam loss or oscillations.
- Study beam dynamics
- Measure Injection Oscillations.

WHAT DO WE NEED TO MEASURE? – Contd. - LATTICE MEASUREMENT



Lattice functions can be measured using TBT or Closed orbit.

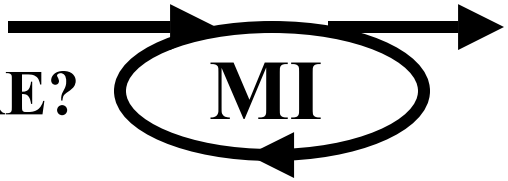
Turn-by-Turn

- Measure β & α lattice function at each BPM.
- Get **phase advance** measurement directly from TBT data per BPM (errors are uncorrelated and systematic free)
- Insensitive to the accuracy of kick magnitude.
- Injection Oscillation or kick source needed.

Closed Orbit

- Measure **phase advance** and β lattice function at each BPM
- Potentially better position resolution (due to averaging)
- Need minimum of two kick sources, beta at the kickers and phase advance between them.
- Systematic errors also include kick strengths & BPM calibration.

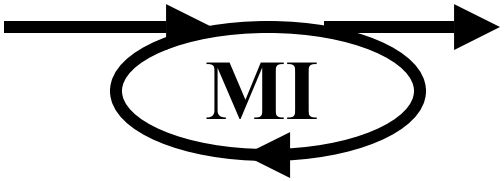
WHAT DO WE NEED TO MEASURE? - Cont. – BEAM INTENSITY



Every BPM shall provide a measure of the magnitude of the common mode signal ("sum signal") called "**beam intensity**". BPM-to-BPM scaling capability shall be incorporated so that relative location-to-location beam intensities can be determined to a precision of ±5% on a FLASH, TBT, and Closed orbit measurements. It will allow:

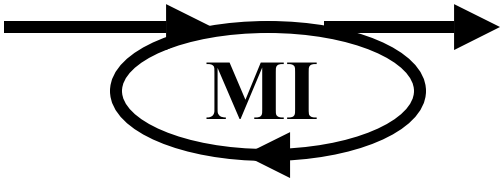
- To diagnose position of beam losses,
- Can be used as a useful cross check on the validity of the other measurements, and
- Can be used to diagnose non-functioning BPMs.

SYSTEM CALIBRATION



- A calibration system must be provided to allow the required position and intensity precision to be verified and maintained. It can also be used to compensate cable lengths.
- The system shall provide means to check and calibrate hardware from the BPM to the front-end electronics in the service buildings, to testing the software, and to store calibration data in a user friendly manner.
- The calibration system must be capable of delivering an equivalent charge (as defined later in the "Dynamic Range" table) to the BPM electrodes to simulate positions of ±20mm and 0mm, to be readout through the entire chain.
- Accuracy of the calibration system must be adequate to assure a position accuracy of 0.20mm ±1.25% of the actual position, and an accuracy of ~2% in intensity **[Discussion to follow].**

BEAMS IN THE MI



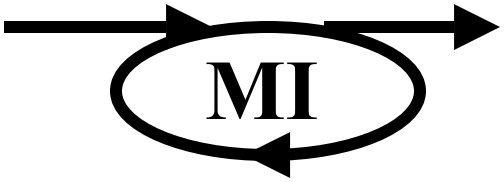
At any particular instance there will be only one kind of beam in the MI. It will be:

- Either Protons
- Or Anti-Protons

Protons and anti-protons do not circulate simultaneously in the MI.

The beam energy will vary between 8.9GeV to 150GeV.

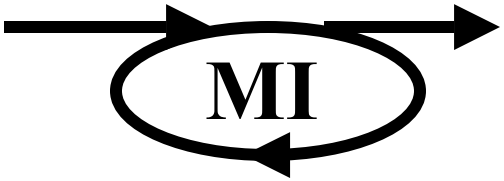
TIME STRUCTURES



- **53 MHz :** Protons or Anti-protons. Up to 84 bunches in successive 84, 53MHz buckets (19 ns apart). Full width/bunch = 1ns to 19ns. σ(t)/bunch = 0.3ns to 5ns. [0.3ns is expected near transition, and 5ns is for a single coalesced bunch][Includes single coalesced bunch, short batch (between 5-13 bunches), long batch (up to 84 bunches) and multi batch (6 batches) operation.]

- **2.5 MHz :** Protons or Anti-protons. 1 to 4 bunches in successive 1 to 4, 2.5MHz buckets (396 ns spacing). σ(t) = 25ns to 50 ns.

DYNAMIC RANGE

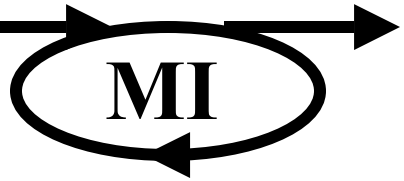


1.	**Protons or anti-protons to/from the RR, and anti-protons from the Accumulator (2.5 MHz)**	**0.5E10/bunch (2.0E10 total) to 7.5E10/bunch (30E10 total). σ(t)= 25ns to 50ns.**
2.	**Protons from the Booster (53MHz) (19ns spacing)**	**From 1 to 84 bunches. Min. Intensity = 0.5E10/bunch. Max. Intensity = 12E10/bunch**
3.	**Protons to the Tevatron (5-9 bunches, typically 7) (53 MHz) (19 ns spacing)**	**Up to 30 Booster bunch for tune up. Each bunch intensity between 1-12E10. For Collider running – up to 4.5E10/bunch or 30E10 after coalescing. (27E10 – TeV Run IIB doc.)**
4.	**Anti-Protons to(from) the Tevatron. (53 MHz bunch in 2.5 MHz spacing).**	**36 single bunches, 4 bunches each in 9 separate batch (4X9), each bunch with intensity of ≤11E10(5E10). (9.4E10 – TeV Run IIB doc.)**
5.	**For the Fixed Target Running. (including NuMI/MINOS) (53MHz)**	**0.5E10 to 12E10 per bunch for 50-504 bunches.**

DYNAMIC RANGE OF 24

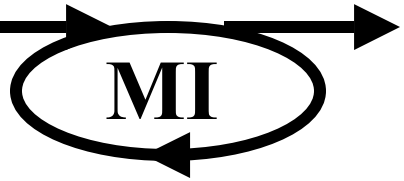
The BPM system should be capable of measuring beam position with 6 batches in the MI.

INTENSITY CALCULUS FOR DYNAMIC RANGES



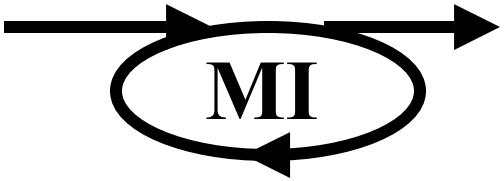
- 2E10 total- pbars - 2.5 MHz - requires 3E10, a reasonable number to use for tuning and pilot shots, given the expected stacking rate.
- 30E10 total – pbars - 2.5 MHz - maximum pbar extracted from Accumulator without degrading emittances.
- 0.5E10/bunch – protons - 53 MHz - For test beam and NuMI commissioning.
- 12E10/bunch – protons - 53 MHz - with ~80 bunches, one gets ~1E13 protons/batch. One hopes to accelerate ~6E13 protons with 6 batches in MI, for simultaneous operation of NuMI, pbar production for collider running, and other possible physics.
- 30E10 total - protons - 53 MHz - protons after coalescing for collider running.

MEASUREMENT PRECISION OVER THE FULL DYNAMIC RANGE



This is a 3σ requirement, or 99.73% of the measurements should be within these limits.
Position Accuracy – 0.40mm ± 5% of the actual position. **Difference between two measurements on pulses with stable beam. It covers long term stability and resolution.**
Calibration precision of – 0.20mm ± 1.25% of the the actual position

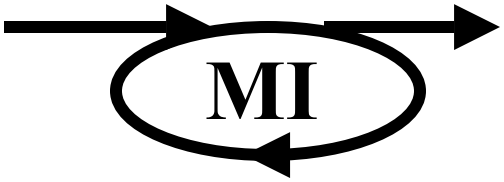
PRECISION CALCULUS



MI beam pipe is elliptical in shape, with long face 117mm wide, and short face 48mm high. 1mm beam position error loses ~10 % of the acceptance.

We use orbit differences to study the lattice. The orbit differences are limited to ~ 3mm to avoid beam losses, and non-linear effects. We need 5% resolution to achieve 10% in β.

DATA BUFFERS

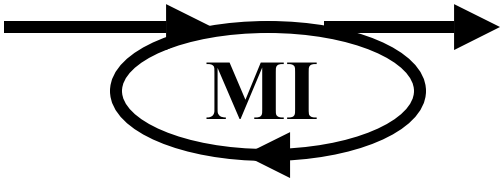


- **FLASH Frame:** Contains a single turn position and intensity measurements of the beam at all the BPMs. This is needed to look at:
  - First turn after the injection, and the
  - Last turn before the extraction

The measurement requires a unique timing which is orchestrated through a beam synch clock triggered T-clock event. The clock and the data information is put in a dedicated FLASH buffer. The data in the buffer is replaced with new data each time a new injection or extraction event is issued.

At present,14 FLASH frame buffers, and 13 FLASH triggers (as shown on the next page) exists in the MI.

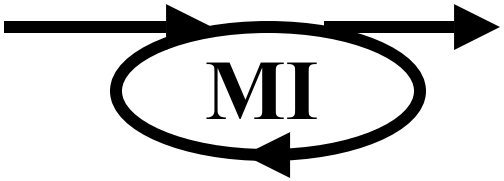
DATA BUFFERS – Contd.
FLASH FRAME TRIGGERS



- Booster → Main Injector BEX
- Main Injector → Debuncher $79
- Main Injector → TeV Fixed Target $78
- Main Injector → TeV Proton Bunch $7C
- Tev (Proton) → Main Injector $D8
- Main Injector → TeV Anti-proton Bunch $7B
- Tev (Anti-Proton) → Main Injector $D6
- Main Injector → Accumulator @ 8 GeV $7E
- Accumulator → Main Injector $7A
- Main Injector → Recycler (Protons) $A2
- Recycler → Main Injector (Protons) $A3
- Main Injector → Recycler (Anti-protons) $A0
- Recycler → Main Injector (Anti-protons) $A7

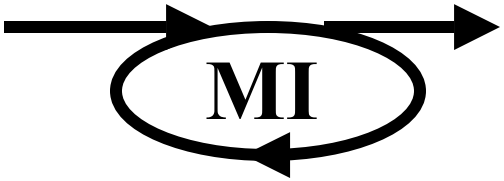
There are two more general purpose events, called "Beam Position Flash Trigger Timer "1" and "2".

DATA BUFFERS – Contd.
MORE ON FLASH FRAME



- For FLASH measurement, a sample of beam must be measured at each BPM location as it moves through the ring.
- There exists beam sync. clock event for different purposes including for the injection and the extraction kickers.
- A delay set by a CAMAC card(T-clock event) waits for a specified number of turns before triggering the BPMs.
- After the delay is complete, a FLASH trigger fans out simultaneously to all the service buildings.
- Local delays (internal to the BPM processor) are implemented at the service buildings to ensure that the trigger arrives precisely when the sample of beam is passing through the BPM.

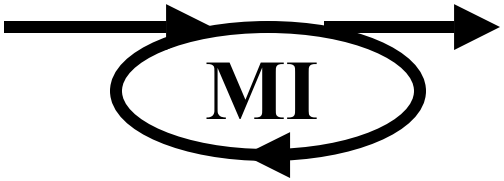
DATA BUFFERS – Contd.



➢**SNAPSHOT BUFFER (CLOSED ORBIT):** At any instance in time this buffer contains the most recent 512 sets of averaged position data in 512 snapshot data frames. The buffer is a circular buffer, and entry 0(zero) is the most recent entry. The SNAPSHOT frames do not need to be timed quite as stringently as FLASH . The BPM signals are averaged over several turns (typically between 8 and 64 measurements), before being put into a frame. The data for the next frame is usually taken after several milliseconds. **We recommend that the BPM signals be an average of a programmable number between 1 to 256 turns.**

➢The primary purpose of this buffer is for abort analysis as the buffer stops being written at the end of each abort. The buffer also freezes at the end of a beam cycle saving the last set of data. **Although not very important for the MI itself, this buffer may prove very useful to understand any possible NuMI accident.**

DATA BUFFERS – Contd.

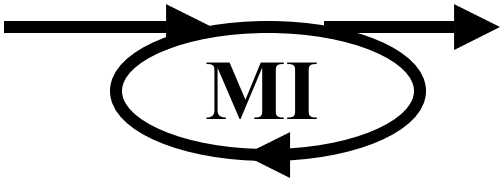


➢**PROFILE BUFFER (CLOSED ORBIT) :** The profile buffer contains up to 128 snapshot data frames taken from the snapshot buffer, and are spaced at intervals chosen by the user. The buffer refreshes once every cycle. These 128 frames are written when the "profile clock event" is decoded by the BPM. When the first profile clock event occurs, the BPM processor retrieves the most recently written snapshot data from the snapshot buffer (both position and intensities) and copies it to the profile buffer the pointer points to. Pointer begins to increment at this stage.

➢The profile buffer is used as an input for the "orbit correction program". It can also be used to understand the history of the acceleration cycle.

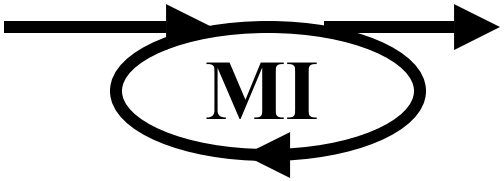
➢Profile buffer is not used for examining aborts.

DATA BUFFERS – Contd.



- **DISPLAY BUFFER:** The display frame buffer is a single snapshot data frame buffer written after the BPM decodes a "write display frame". When this event occurs the most recently written snapshot frame from the snapshot buffer (positions and intensities) is copied to the display frame buffer.
- A display frame buffer can be selected once every machine cycle and displayed for every pulse.
- It refreshes once every cycle.

DATA BUFFERS – Contd.



➢**TURN-BY-TURN (TBT) BUFFER:** In MI the TBT buffer exists for every single BPM. The TBT buffer for each BPM contains the data for up to 8192 consecutive turns. There are two such buffers, so data for 16,384 consecutive turns could be written. The TBT data mode is the highest priority and preempts all other data acquisition mode.

➢NOTE ON 16,384 TBT REQUIREMENT - In the Main Ring days, there were several occasions when beam would fall out while being accelerated at slightly varying times. One of the speculations for a cause was a sparking turn-to-turn fault in a quadrupole which would cause a tune shift. The turn-by-turn data was a good way to look for that. It is not the only way and it may not justify the cost of such a large buffer (8,192/16,384 turns) , if the cost is significant. If the cost is small, it could be very useful, if the software supports looking at the data easily. **The minimum number of turns required for TBT is 2,048, to measure tune with a precision of 10^{-3}.**

DATA BUFFERS – Contd.
WHAT DO WE WANT?

MI

LIST OF CLOCK EVENTS IN THE MACHINE

20	21	23	29	2A	2B	2D	2E	SPARE	SPARE

CLOCK EVENT	DESCRIPTION
20	Pbar Deaccleration.
21	SWITCHYARD
23	NuMI
29	Pbar STACKING
2A	COLLIDER Pbar
2B	COLLIDER P.
2D	8 GeV BEAM. RR/Pbar Tune-up.
2E	STUDIES
SPARE (2)	For FUTURE

FLASH BUFFER 14

SNAPSHOT BUFFER

PROFILE BUFFER

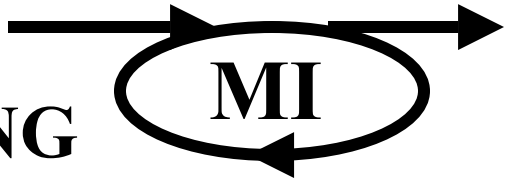
DISPLAY BUFFER

TBT BUFFER

BUFFER DESCRIPTION

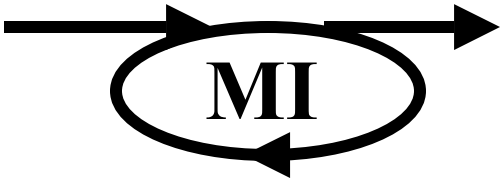
FLASH(10,14/10)
SNAPSHOT (10,512)
PROFILE(10,128)
DISPLAY(10,1)
TBT(10,16,384/2,048)

NUMBER OF BPMs IN MI RING



- At present the MI ring has a total of 208 non-directional BPMs. It uses 4 detectors per betatron wavelength in both the horizontal and the vertical planes. The plate length was selected to be an odd multiple of $\lambda/4$ at 2 GHz.
- Out of these, 203 are MI ring BPMs and are located in the downstream end of every MI quadrupole.
- The other 5 are large aperture BPMs and are adjacent to the Lambertson magnets. The wide aperture BPMs are located at Q101, 402, 522, 608, 620.
- At present each BPM only measures either the horizontal or the vertical position/cycle at each quad. They can be switched to the orthogonal mode.

BPM IN ASSOCIATED BEAM TRANSFER LINES



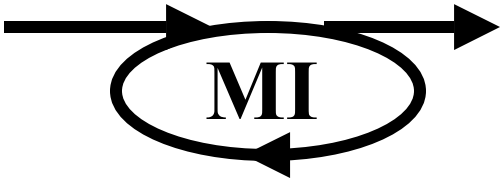
- **MI8 LINE:** Has 33 Horizontal and 31 Vertical BPMs. At 6 locations there are both H&V BPMs. These should have the same qualifications as the FLASH requirement for the MI Ring BPMs.
- **A1 LINE:** Has 9 Horizontal and 7 Vertical BPMs. These will have the same qualifications as the FLASH requirement for the MI Ring BPMs.
- **P1 LINE**: Has 8 Horizontal and 7 Vertical BPMs. These will have the same qualifications as the FLASH requirement for the MI Ring BPMs.
- **P2 LINE**: Has 5 Horizontal and 6 Vertical BPMs. At 2 locations there are both H&V BPMs. These will have the same qualifications as the FLASH requirement for the MI Ring BPMs.

TRANSFER LINE - EXISTING BPM PROPERTIES

	TRANSFER LINE	BPM DESCRIPTION	ELECTRONICS & FRONT-END
1.	MI8	MI8 style split-pipe round BPM.	Uses an AD640 log-amp. Sample and hold, & MADC.
2.	A1	MI8 style split-pipe round BPM.	Uses an AD8307 log-amp. Recycler front-end. [Being replaced with modified log-amps].
3.	P1	MI8 style split-pipe round BPM.	Uses an AD648 log-amp. Recycler front-end. [Being replaced with modified log-amps].
4.	P2	MR style split box rectangular BPM.	AM to PM system, and MI style multi-bus crate.

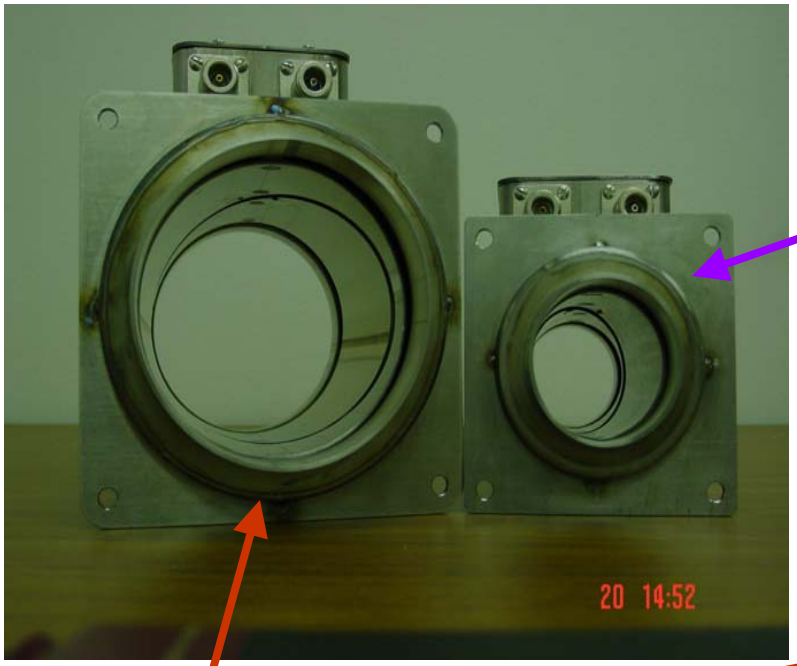
Large aperture BPM is used at Lambertson in all of these beam lines.

BPMs in NuMI BEAM LINE



- **The NuMI beam line will have a total of 26 BPMs**
  - A large aperture BPM with 6” long plates and a 4.625” aperture, at Q608 near Lambertson,
  - 21 split pipe BPM called the transport BPM. The outer/inner diameter of the split pipe is 4”(10.1cm)/3.875”(9.8cm, aperture) , and
  - 4 split pipe BPM called the target BPM. The outer/inner diameter of the split pipe is 2.125”(5.4cm)/2”(5.1cm, aperture)
- The position accuracy, and the stability(calibration) requirement for the transport and target BPM differ (as shown in table later).
- Every BPM needs to measure the beam position individually for each batch of the proton beam.
- For at least one house (for the 4 target BPM), the BPM system should be capable of making multiple measurements within at-least one batch of the proton beam.

NuMI SPLIT PIPE BPMs



Target BPM

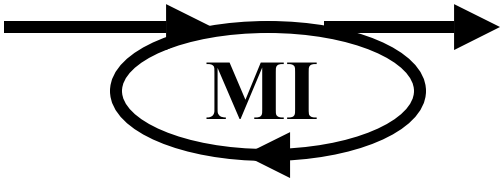
Transport BPM

NuMI MEASUREMENT PRECISION/BATCH (3σ REQUIREMENT)

	Transport BPM (particle/bunch)	Target BPM (particle/bunch)
Position Accuracy	0.50mm@≥1E10 1.00mm@≥0.5E10 (over ± 20mm)	0.25mm@≥1E10 0.50mm@≥0.5E10 (over ± 6mm)
Calibration Accuracy	0.20mm@≥1E10 0.25mm@≥0.5E10 (over ± 20mm)	0.10mm@≥1E10 0.15mm@≥0.5E10 (over ± 6mm)
Intensity Precision	±5% for Position ±2% for Calibration	±5% for Position ±2% for Calibration

If the transport BPM meets the MI BPM precision requirement, NuMI will be satisfied.

NuMI PRECISION

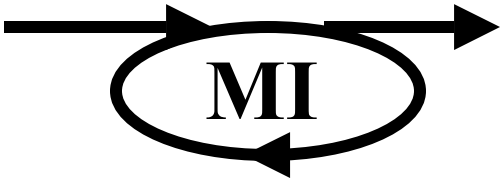


- The precision for "Transport BPM" comes from the knowledge of beam control requirements based on previous usage of 'Autotune' beam control, as to be used in NuMI. For example, the corresponding numbers for some experiments were:
  - Switchyard system - activate tuning for 0.4 mm deviation from nominal (0.2 mm for septa lineup); then, correct to < 0.2mm (0.1 mm) accuracy. **(NuMI has no septa).**
  - KTeV (with a very large targeting optics magnification) - activate for 1.0 mm deviation along the transport (0.05 mm deviation at target)

The precisions were determined initially from detailed calculations of error functions using transport matrices, and verified in beam operation.

- The precision for "Target BPM" comes from MINOS target width of 6.4mm, and the upstream baffle beam hole diameter of 11mm.

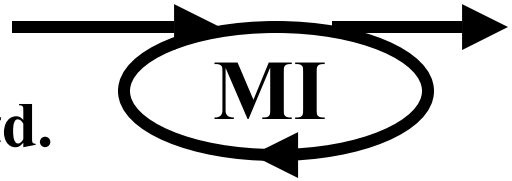
APPLICATION PROGRAMS



At present the following application programs exist:

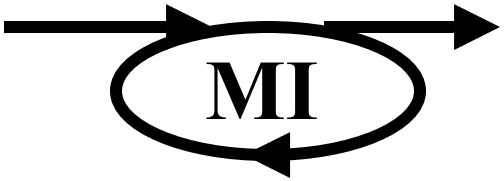
- **I37 :** sets the BPM control parameters.
- **I38 :** performs BPM/BLM hardware tests
- **I39 :** displays measured positions & intensities
- **I40 :** sets the BLM control parameters
- **I42 :** displays turn-by-turn measurement (measures tune)
- **I49 :** 8 GeV line orbit smoothing program
- **I50 :** orbit smoothing program. Uses data from every BPM to calculate orbit correction and move the beam to the desired orbit position. Calculates magnet changes to smooth the closed orbit.

APPLICATION PROGRAMS - Contd.



- **I52** : orbit correction program. Uses position data to calculate corrections. Capable of reducing first turn oscillations and closing the orbit for the second turn.
- **I53 :** BPM rms noise (diagnostic)
- **I90 :** beam line analysis
- **I92 :** TBT data analysis (calculates α and β functions)
- **D40:** generic BPM diagnostics between TeV, MI, and Switchyard.

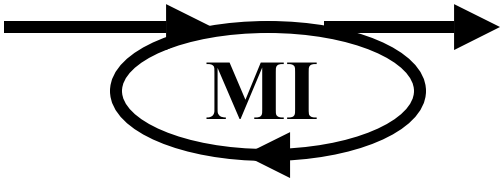
NEW SOFTWARE



We are trying to minimize the software effort required by adopting the present software as much as possible. The major expected change are:

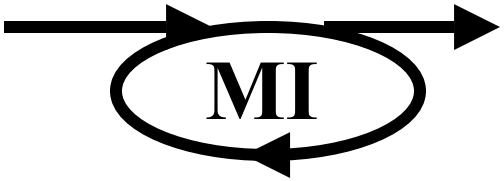
- Separate data buffer for FLASH, TBT, SNAPSHOT, PROFILE, and DISPLAY mode for each MI reset.
- Closed Orbit measurement for programmable number of turns (between 1 to 256).
- A simple to use test of the integrity of the system. A combination exercise of the calibration and a list of non-functioning BPM.
- Intensity

SCHEDULE



- We would like the new system to be fully functional by the end of FY2003. The order of preference is:
  - Replace the MI BPMs
  - Followed by the beam line BPMs
- NuMI time frame is independent of the MI needs. The technology decision for the NuMI BPM must be taken before the DOE review in 6/2003, and the system should be ready by spring of 2004.

SUMMARY



- The MI BPM electronics, and the front-end readout needs to be replaced to meet the scientific demands on the MI, and for the coordinated improved performance of various accelerators at the Fermilab.
- The DOE review committee has asked for it.
- The physics requirements have been laid out in detail in the preceding slides and in the document provided.
- Lets have the system ready by the end of FY2003, or at the earliest possible, with a tested technology available in the market.
- NuMI BPM is needed to commission the beam line.