Main Injector commissioning for NuMI

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AAC Review, Nov. 17-19, 2004

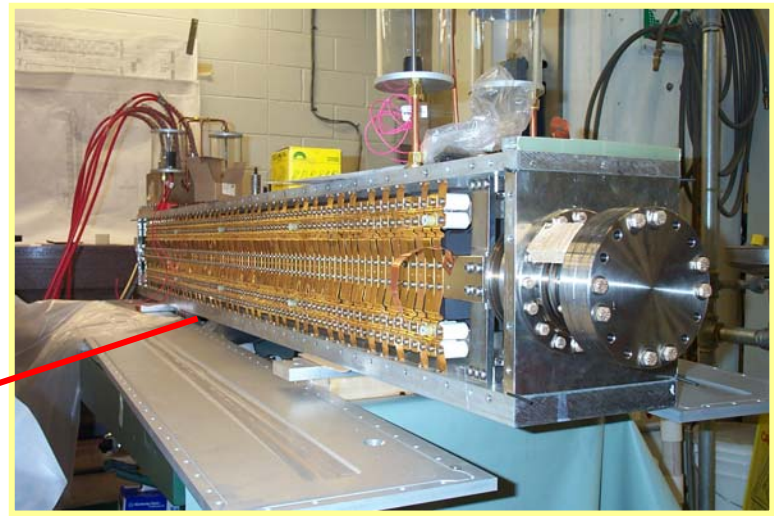
- Main Injector goal
- Commissioning plan components
  - Extraction elements
  - Bunch by bunch digital dampers
  - High intensity studies
  - Operational implementations
  - Instrumentation upgrades
- Closing remarks

Main Injector Goal

- **Antiproton stacking and NuMI will share a same Main Injector cycle, with a flattop energy of 120 GeV**
  - a 2 s long Main Injector cycle will accommodate injections of 6 batches, with a total intensity of 3.3×10^{13} protons/cycle
    - the Antiproton Source requires 1 batch of 0.8×10^{13} protons
    - an intensity of 0.8×10^{13} protons will be achieved by slip-stacking two batches in 3 Booster ticks (200 ms)
  - 5 batches, for a total intensity of 2.5×10^{13} protons, will be single-turn extracted to the NuMI target
  - beam quality requirements:
    - 95% normalized transverse emittance $\leq 25\ \pi$ mm-mrad
    - 95% bunch length on the pbar target (after bunch rotation) $\leq$ 1.5 ns
- **The goal**
  - run NuMI at a 2 s cycle time with 2.5×10^{13} protons/cycle by Spring

MI extraction magnets for NuMI

NuMI kicker region



NuMI extraction Lambertsons

Bunch-by-bunch Digital Damper System

B. Foster, P. Adamson, B. Ashmanskas, H. Kang, A. Marchionni, D. Nicklaus, A. Semenov, D. Wildman

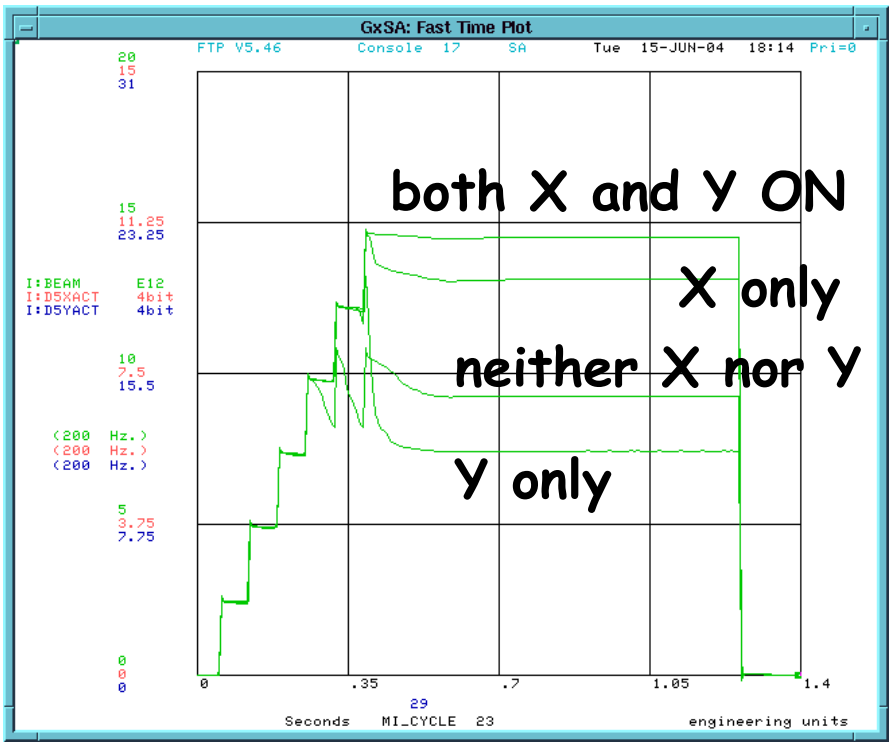
- The system consists of beam pickup signals (RWM, stripline) with corresponding kickers and a single digital board serving both transverse and longitudinal dampers
  - **pickup signals digitized at 212 MHz, with 12 bit resolution**
  - **digital pipelined processing in a large FPGA**
  - **damper kicks digitally synthesized by a 424 MHz DAC**
- **FPGA prototype board installed in spring '03**
  - **first tested with transverse dampers**
    - **have been essential to achieve an intensity of 3.3×10^{13} in MI at 8 GeV**
  - **after '03 shutdown longitudinal dampers have been made operational for proton transfers to the Tevatron and for pbar stacking cycles**

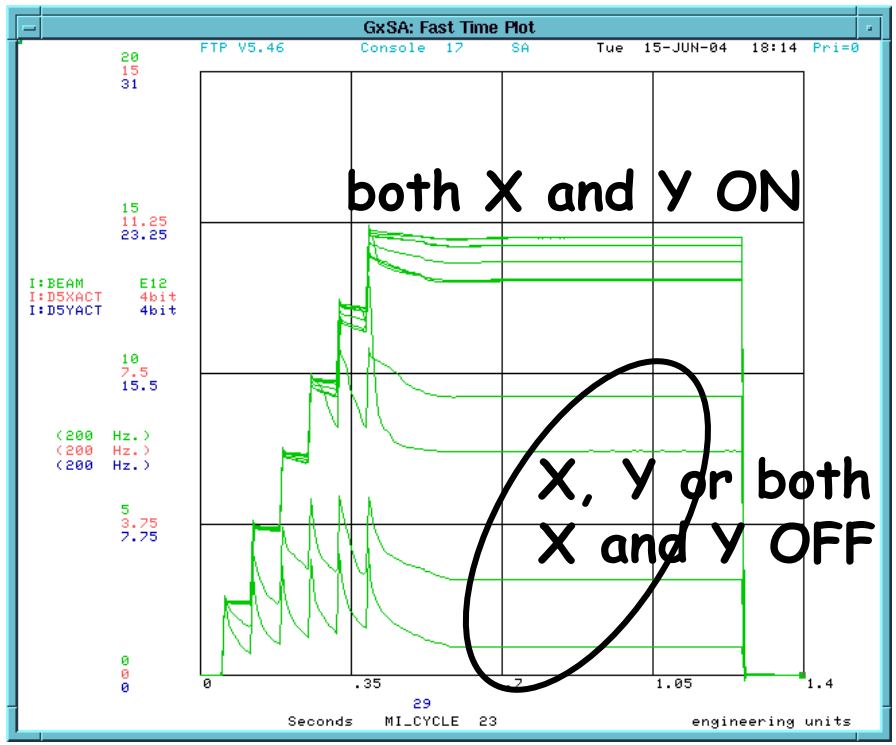
- **Final FPGA boards brought into operation in early summer '04**
  - **both transverse and longitudinal dampers implemented for 53 MHz bunches**
  - **added code for transverse and longitudinal damping of 2.5 MHz bunches**

cycle	operational before shutdown
pbar stacking cycle	53 MHz longitudinal
proton shots to Tevatron	53 MHz longitudinal
pbar shots to Tevatron	2.5 MHz longitudinal
2.5 MHz proton studies	2.5 MHz transverse and longitudinal
NuMI high intensity studies	53 MHz transverse and longitudinal

- **We will resume operations after the shutdown with a system operational for all modes of operation**
  - added an external amplifier to the stripline signal to enable damping of transverse injection oscillations of 2.5 MHz pbar
  - damping 2.5 MHz and 53 MHz bunches in the same cycle
  - ***finalized all the diagnostic tools: fast time plots, FIFO readout***

Transverse dampers



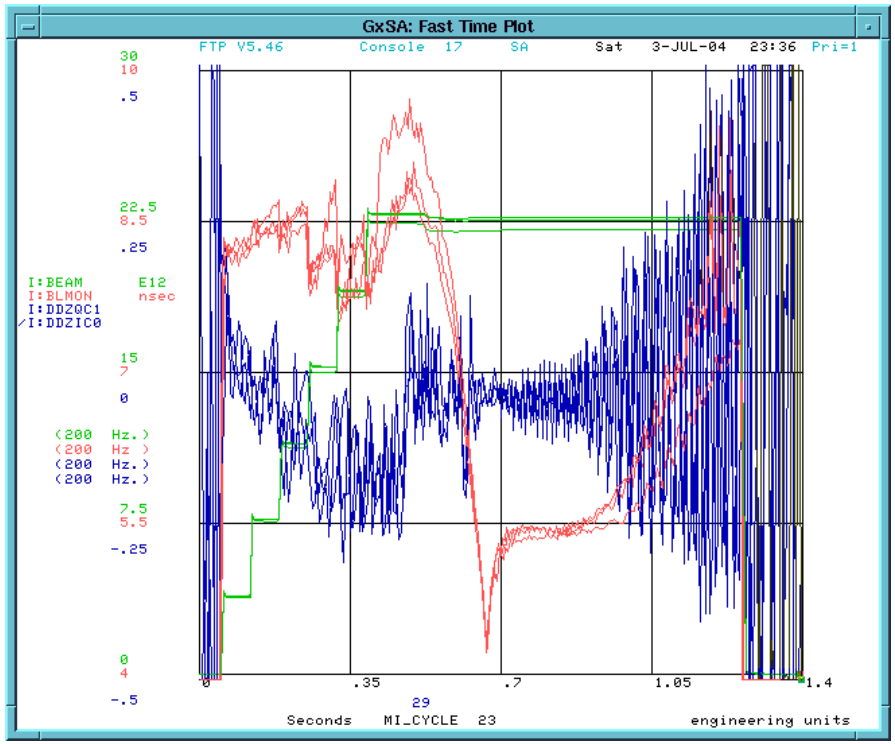


χ=-10

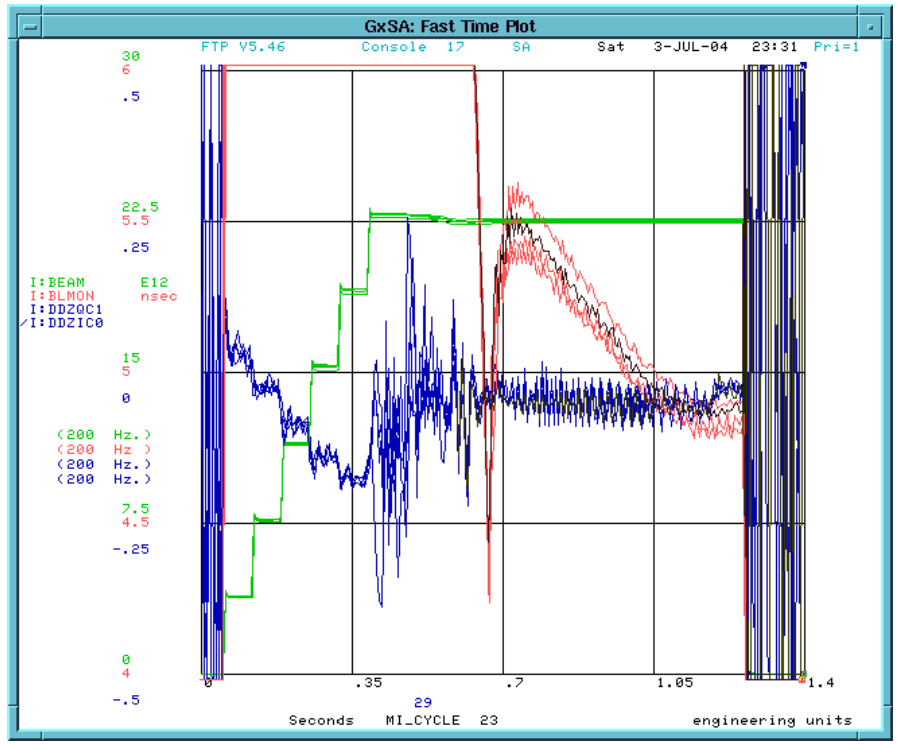
χ up to +5

Longitudinal dampers

Longitudinal dampers OFF

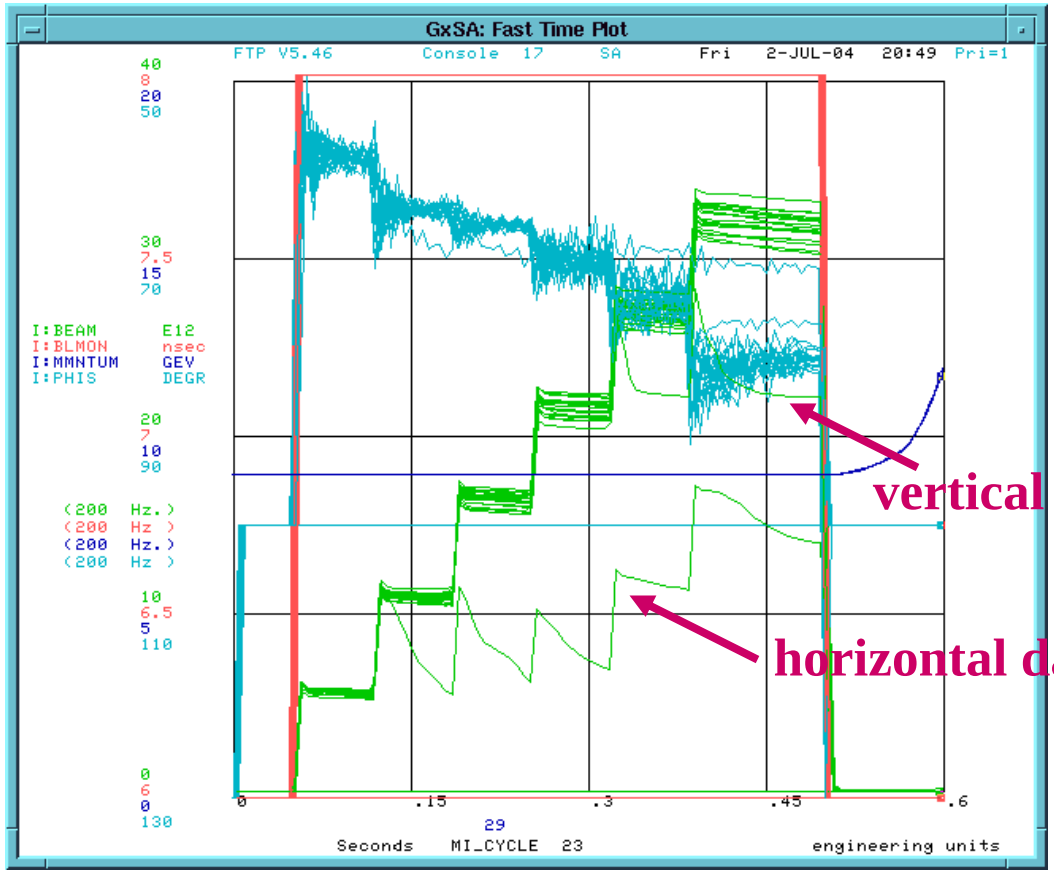


Longitudinal dampers ON



High intensity operation at 8 GeV

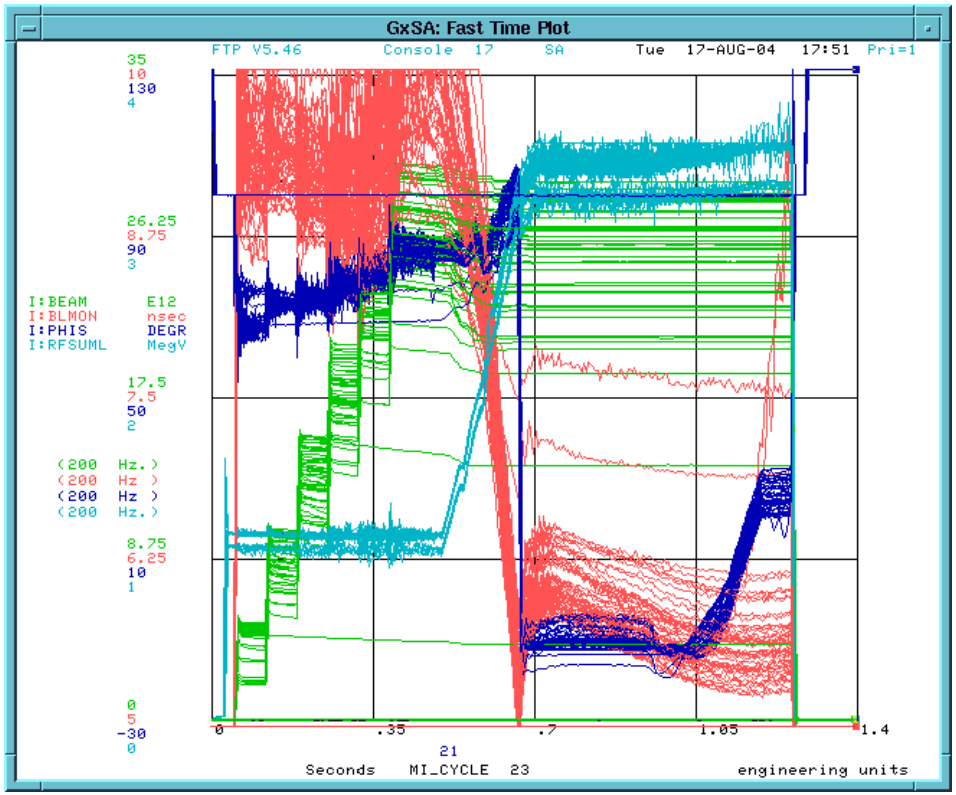
Both horizontal and vertical dampers ON, longitudinal OFF



We also experimented with turning off one of the two amplifiers on the X or Y coordinates, and there was a small effect, but the beam stayed in the machine.

High intensity …middle of August

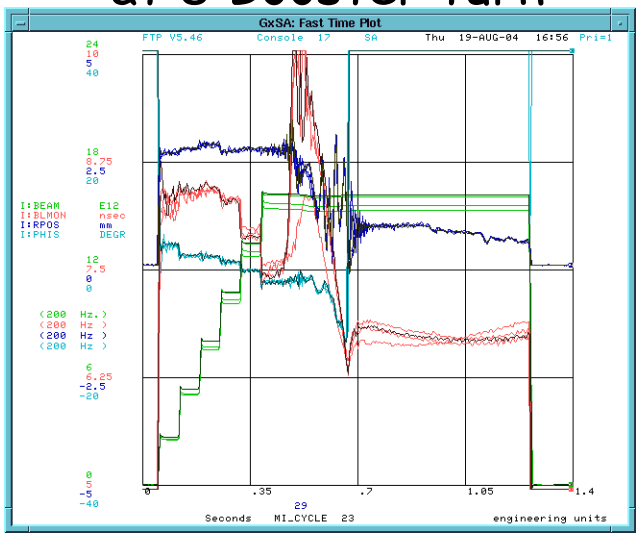
from 13 to 15 Booster turns (dampers ON)



- **max beam intensity at 120 GeV: 2.9×10^{13} protons**
- at the highest intensity we have beam losses in MI up to 1×10^{12} protons
- not yet achieved beam quality requirements above ~ 2×10^{13} protons

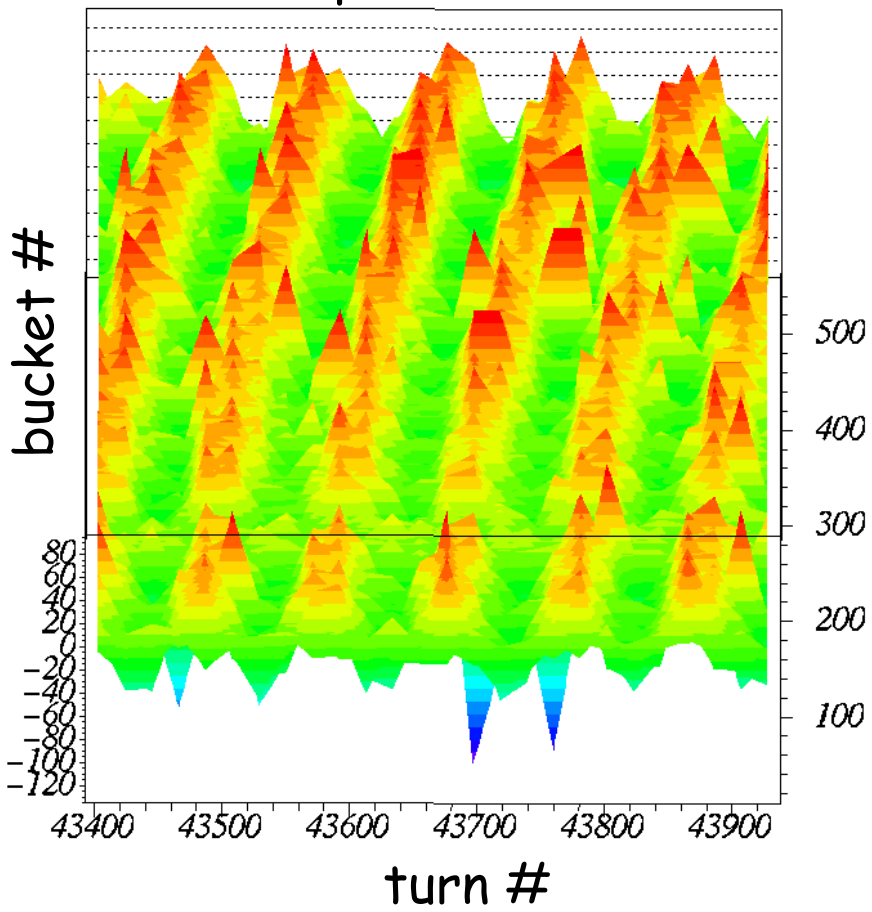
Mode 1 oscillation

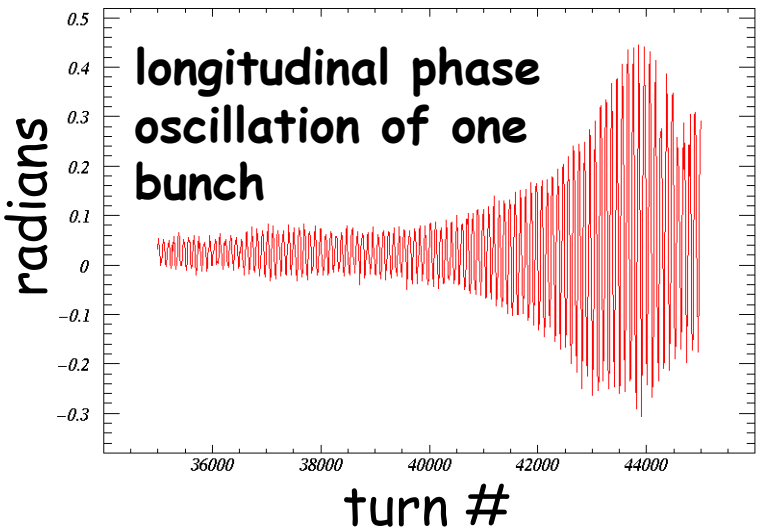
at 8 Booster turn



after tuning of injection phases

from damper FIFO readout

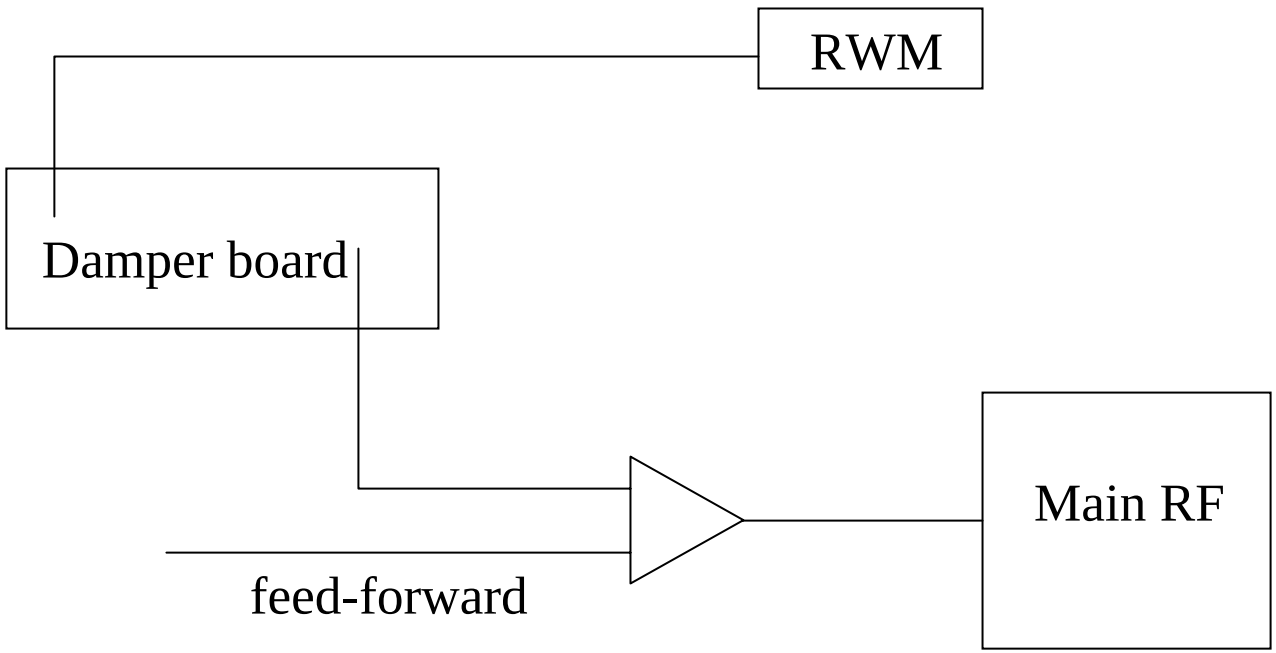




- evidence for mode 1 oscillations
- not enough power in the longitudinal kickers to damp the oscillation !

Mode 1 damper implementation

- We are implementing a mode 1 damper using the current damper board, which will provide a feedback signal to the main RF system
  - ***ready to be tested in the first month of operation***



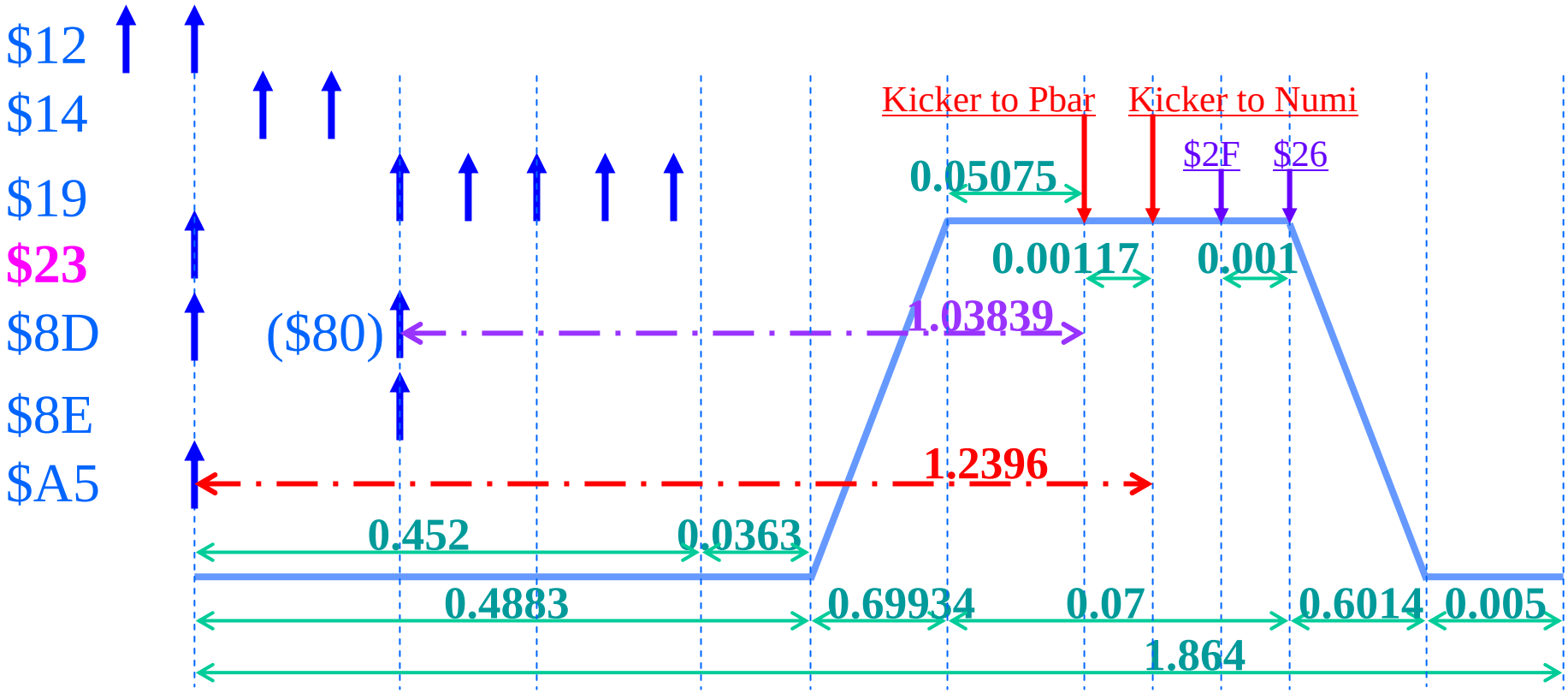
RF issues

- Work done during the shutdown
  - fixed a faulty current detector on the transformer side of one the anode power supplies, which was intermittently causing RF trips at the highest intensity
  - replaced several ‘weak’ power tubes in the modulator power supplies, which were causing RF voltage sagging at transition at high intensity
- ***The present system is capable to accelerate up to ~ 4×10^{13} protons/cycle***

Operational implementations

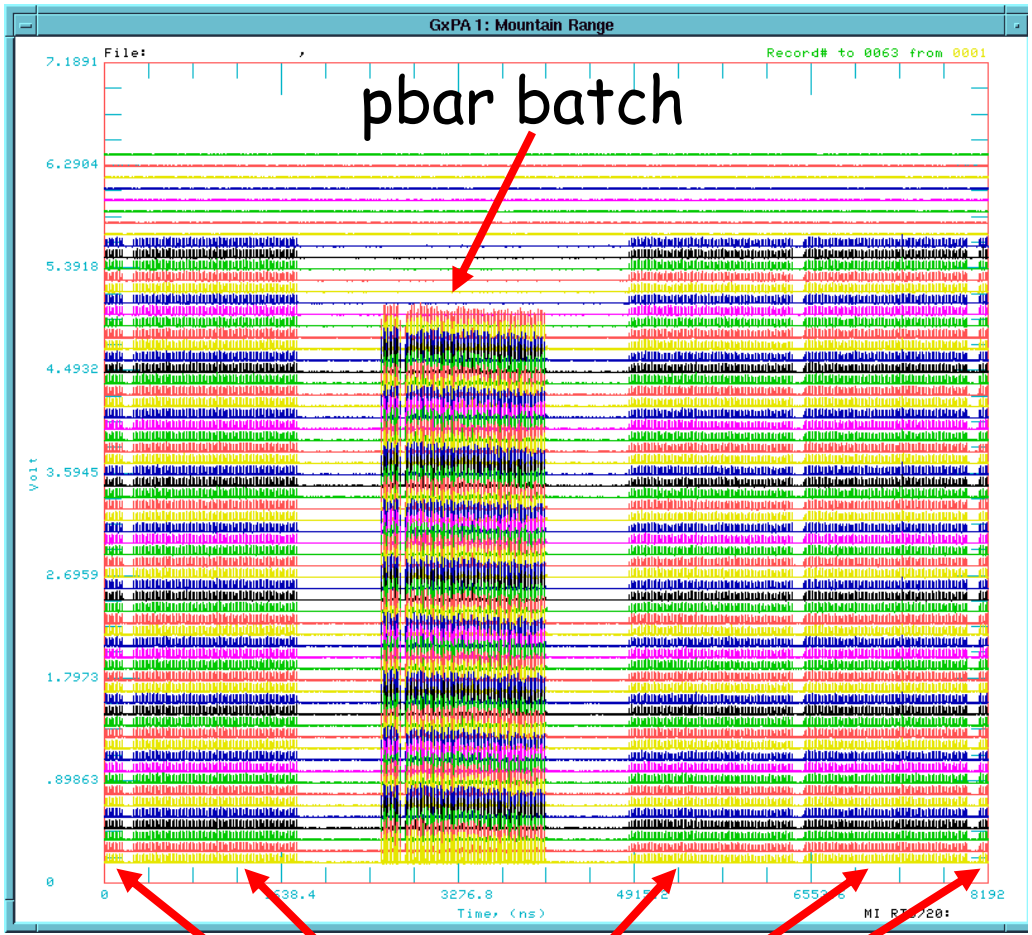
- **We have set up an operational cycle for simultaneous antiproton stacking and NuMI operation**
  - a single MI magnet ramp will accommodate all the different modes of operations: NuMI study, NuMI only, NuMI + stacking, NuMI + slip-stacking
  - we still need to test the cycle combining slip-stacking and NuMI multi-batch operation
  - ***we already did a test where we extracted successfully 1 batch to the pbar target, keeping the remaining 5 in MI***
- **TCLK timing scheme of MI to accommodate NuMI has been revised**
- **Setting of extraction bumps around NuMI Lambertsons and kickers**
  - ***final bumps checked OK***

NuMI + slip-stacking

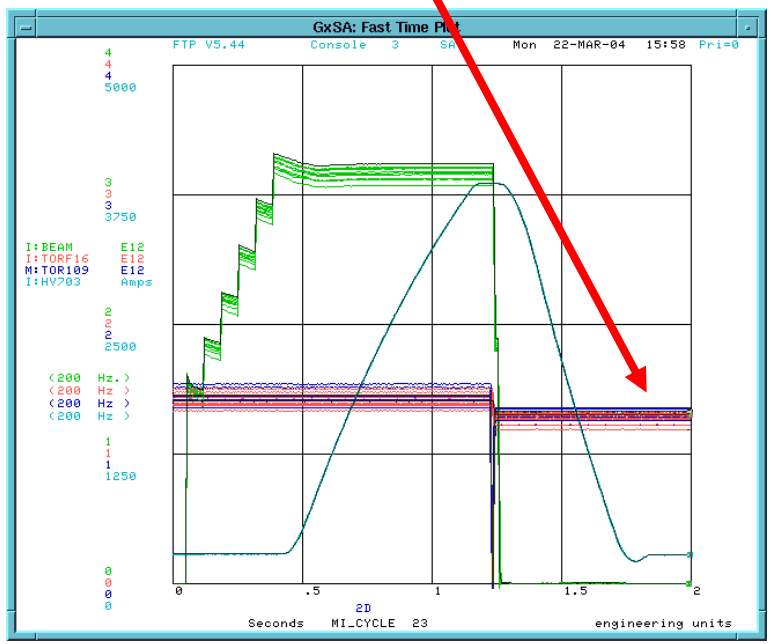


K. Koba

One batch to pbar, the rest to NuMI

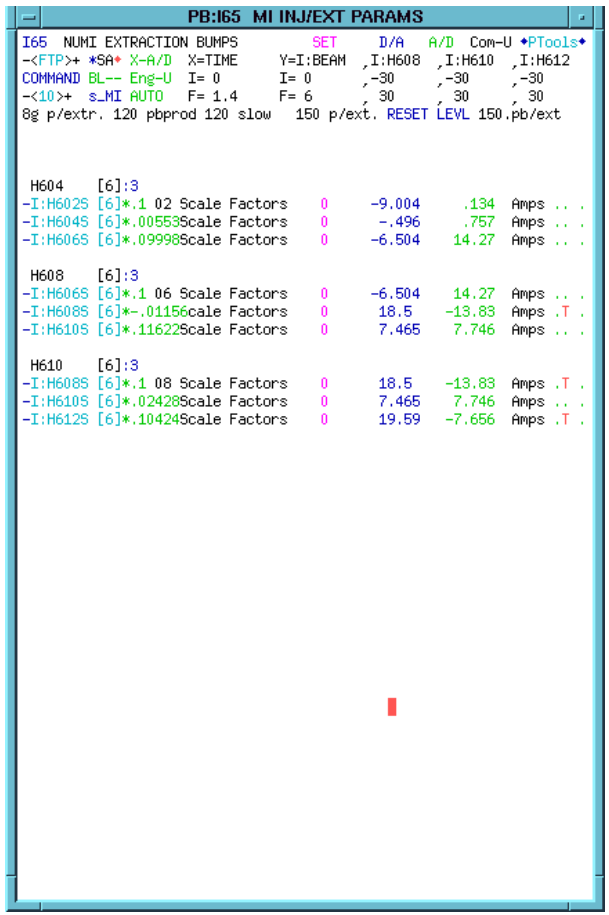


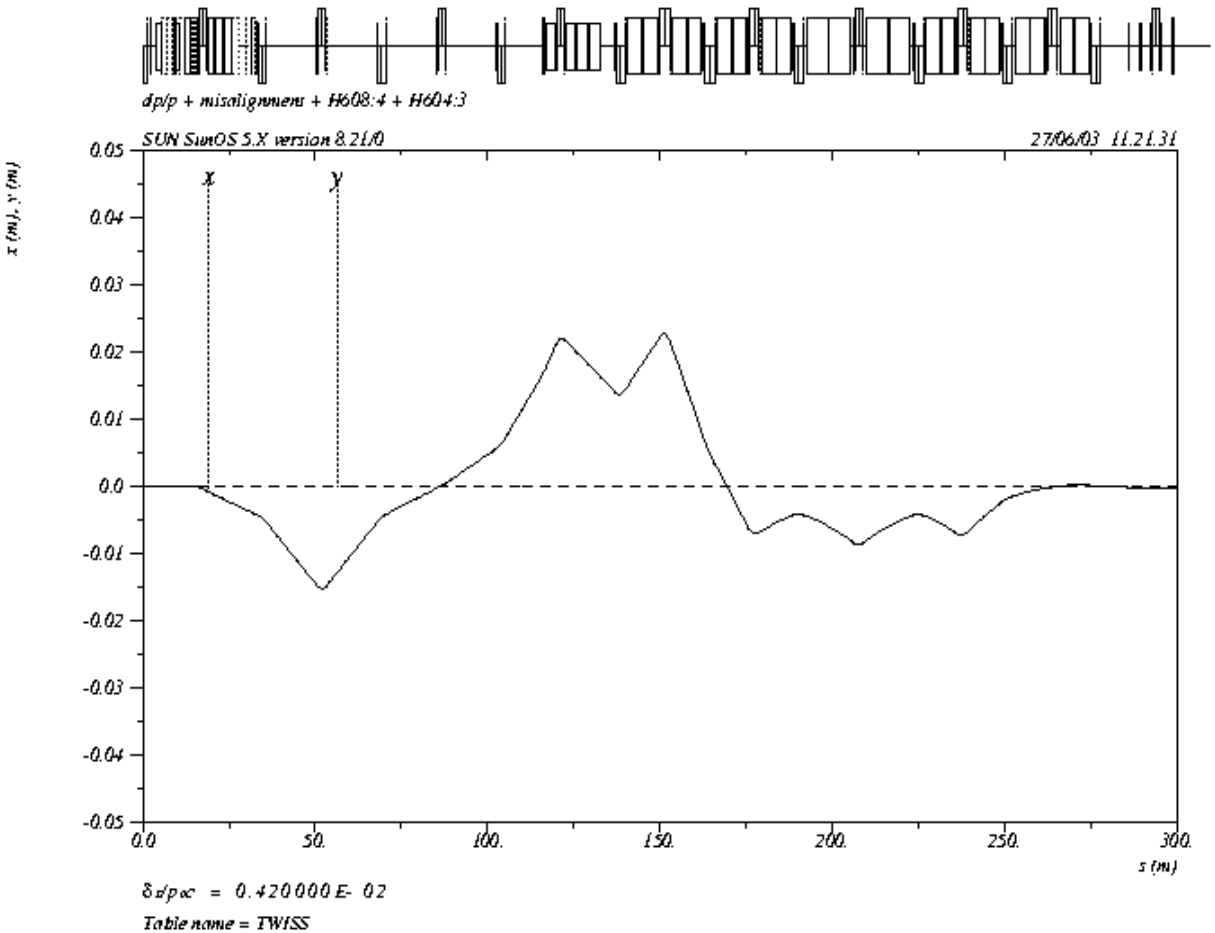
Beam on the pbar target



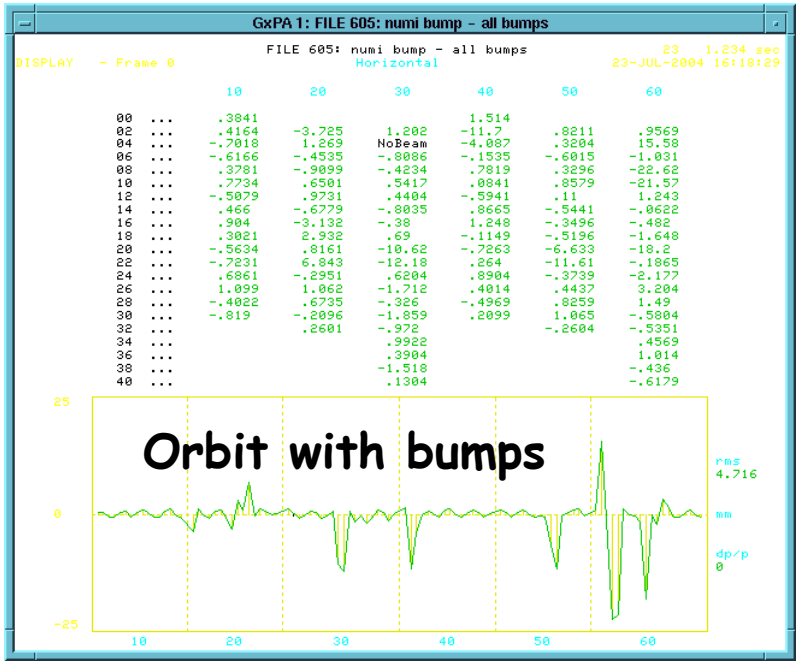
NuMI batches

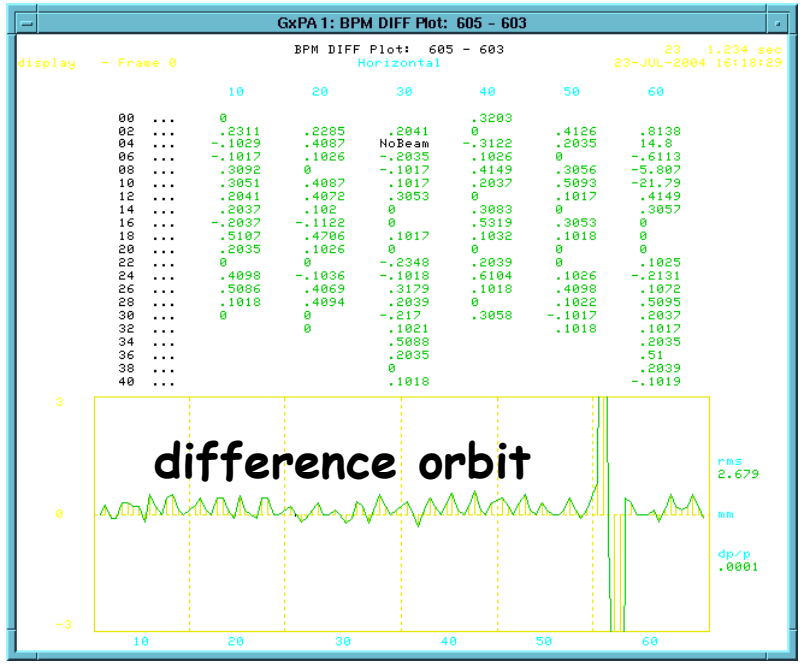
NuMI extraction bumps





Dave Johnson


GxPA 1: FILE 605: numi bump - all bumps
FILE 605: numi bump - all bumps
Horizontal
Orbit with bumps
rms
4.716
mm
dp/p
0


GxPA 1: BPM DIFF Plot: 605 - 603
BPM DIFF Plot: 605 - 603
Horizontal
difference orbit
rms
2.679
mm
dp/p
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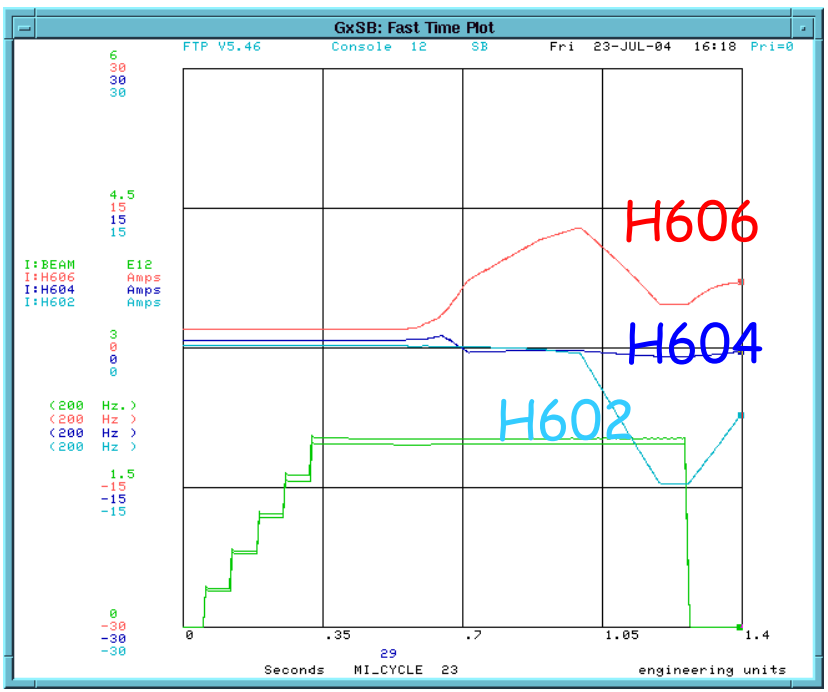
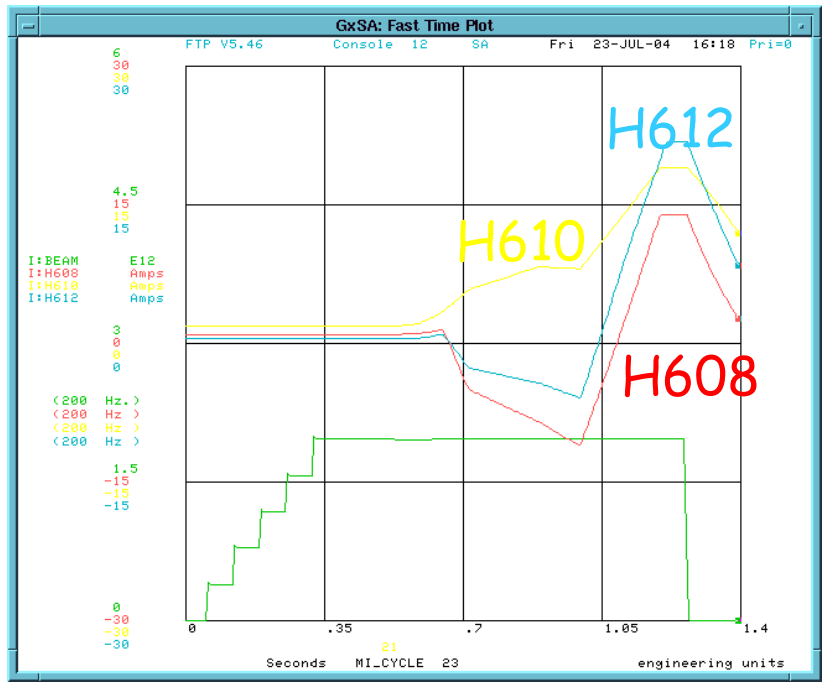

GxSB: Fast Time Plot
FTP V5.46 Console 12 SB Fri 23-JUL-04 16:18 Pri=0
H606
H604
H602
Seconds MI_CYCLE 23 engineering units


GxSA: Fast Time Plot
FTP V5.46 Console 12 SA Fri 23-JUL-04 16:18 Pri=0
H612
H610
H608
Seconds MI_CYCLE 23 engineering units

- **First look at MI orbit distortions at 8 GeV due to NuMI Lambertsons: they are small**
- **The pbar batch and the NuMI batches will occupy fixed bucket positions in MI, and it will be possible to control either portion of the beam with its own "beam switch" (pbar and NuMI beam switches)**
  - MI52 and MI602 kicker timings will be kept "fixed"
  - LLRF now supports feedback loops for beam positioned anywhere in the machine (it has been tested successfully).
- **Main Injector beam safety envelope has been modified to 9.6×10^{16} p/hr (it was 3.9×10^{16} p/hr) (part of the NuMI SAD)**
  - since operational limits are set to 10% below the safety envelope, the new limit corresponds to 4.8×10^{13} ppp with a repetition rate of 0.5 Hz.

Instrumentation upgrades

❖ ***We need to upgrade some of the instrumentation. It's a matter of reliability of operation***

❖ **using the total beam intensity signal from DCCT, Instr. Dept. has implemented a "beam loss watt-meter"**

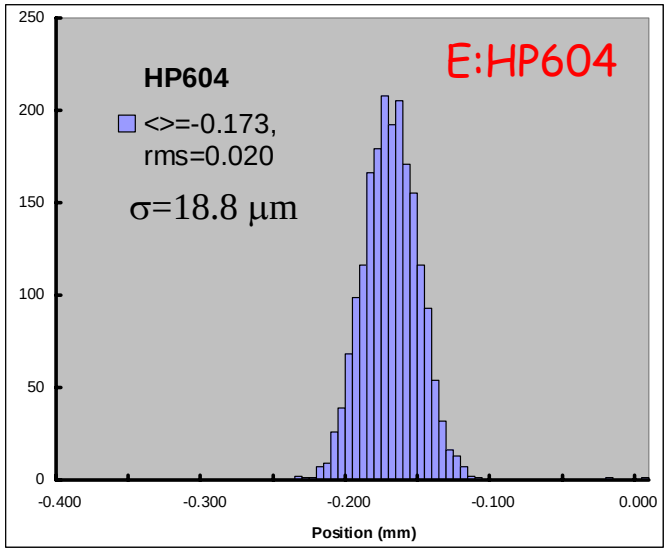
- ➢ to be made operational when we resume operations
- ➢ 1 watt/m $\Rightarrow$ 6.6 kJ/cycle for 0.5 Hz rep rate in MI
  - loss $\leq 4.6\times10^{12}$ protons at 8 GeV
  - loss $\leq 3.4\times10^{11}$ protons at 120 GeV
  - ***… but the limit will be probably due to scattered hot spots***

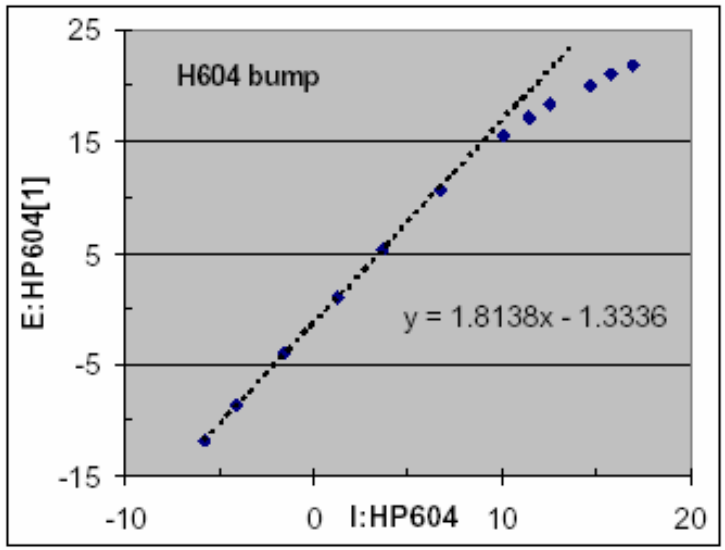
❖ we are in the process of upgrading the **MI Beam Loss Monitor system**, coordinating this effort with the similar one which is in process for the Tevatron system (RunII project)

- ➢ ***when running multi-batch at high intensity we need reliable records of integrated losses in the machine***

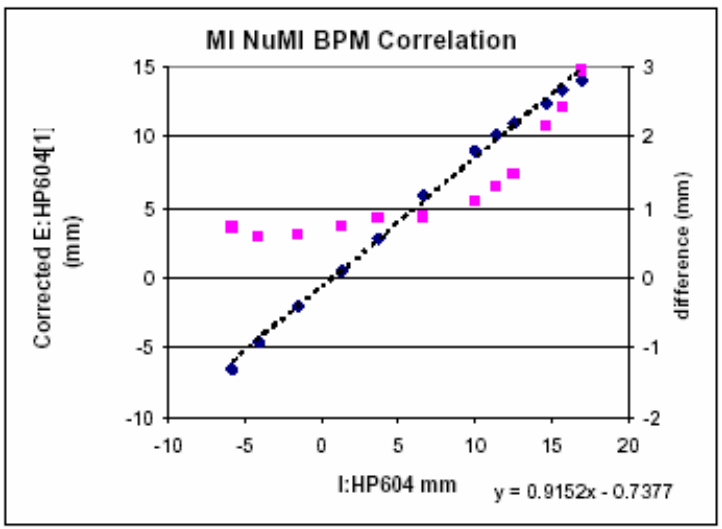
- Since ~ 1 year we are taking regular ***radiation surveys*** of Main Injector. Several hot spots have been identified and we have realigned MI beam pipe during the shutdown in several locations
- ***Instr. Dept. has implemented a batch-by-batch intensity monitor that will provide intensity measurements for each batch along the acceleration ramp***
  - to be made operational when we resume operations
- ***we plan to establish a tune measurement system utilizing the digital damper system***
- according to the RUN II plan, **MI Beam Position Monitor upgrade** will start at the end of ’04 and finish by the end of ’05
- ***Instr. Dept. has instrumented 4 horizontal BPM’s, along with a vertical one, located in the NuMI extraction region, with NuMI BPM electronics, capable of batch-by-batch position measurements, to be used for last turn measurement in MI***

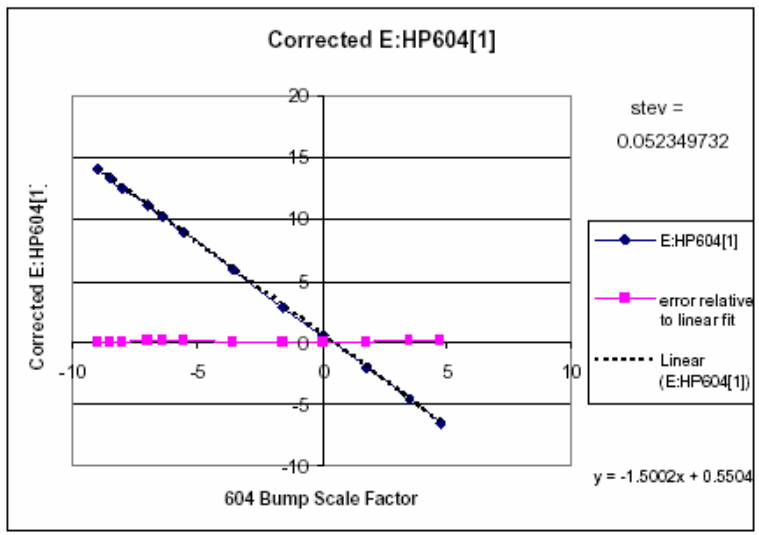
MI BPMs with NuMI electronics





after the fix (Bob Webber)





MI beam quality inputs to NuMI Beam Permit System

- We have implemented a "**beam quality**" signal from Main Injector to be fed into the NuMI beam permit system
  - this is needed to minimize beam losses in the NuMI beamline due to poor quality beam extracted from MI, because of some accident conditions in MI
  - to be made operational when we resume operations
- "Beam quality" signal built from the following requirements
  - no beam present during the rise time of the NuMI kickers
    - use signal from batch-by-batch intensity monitor
  - NuMI kicker repeatability within 2%
  - extraction position, both horizontal and vertical, within 2 mm
  - central momentum regulation at flattop within 1×10^{-3} (already taken care of by LLRF and MECAR)
  - MI beam quality (no losses at flattop in the 608 and 612 regions)

Closing remarks

- **Achieved a max intensity of 2.9×10^{13} protons @ 120 GeV in MI**
  - ***the goal is 3.3×10^{13} protons/cycle***
  - the digital damper system is essential for this mode of operation
  - ***beam losses and beam quality issues still to be worked on above ~ 2×10^{13} protons***
  - we are implementing a mode 1 damper system
  - ***we are paying special attention to beam losses in MI***
- All operational issues **OK for initial NuMI commissioning**
  - we developed a detailed start-up plan working closely with NuMI Dept. personnel