Specifications of Tevatron BPM Upgrade

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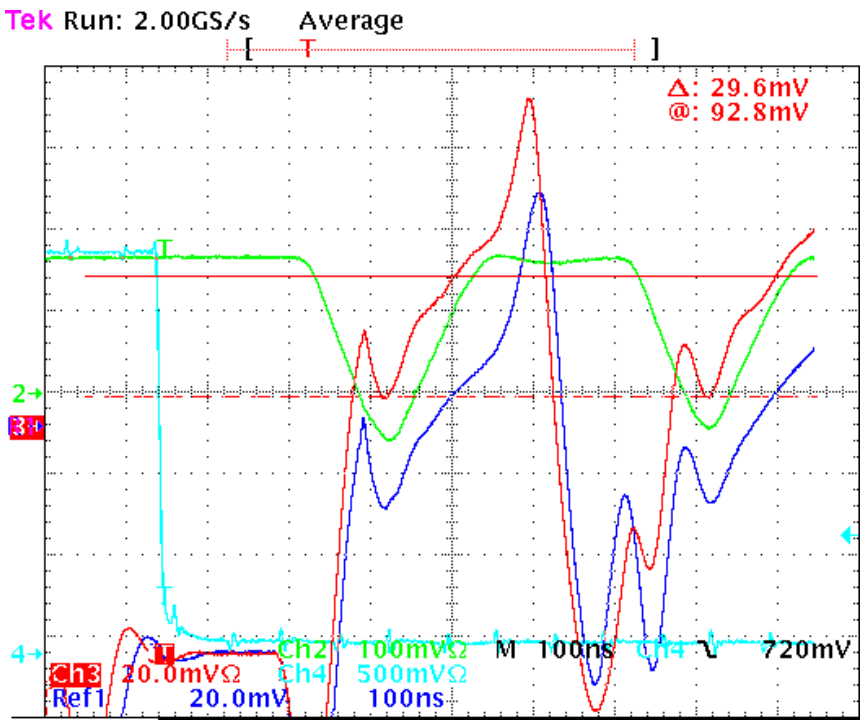
Why an upgrade?

- Accuracy of current system is poor with coalesced bunches.
- Problems with reliable data acquisition (turn-by-turn)
- Blind to pbars.

Current Analog Frontend



- Considerable slope on position signal for coalesced bunches.
- Beam based trigger has jitter.
- Filters optimized for 6x6 operation.
- Always measuring first bunch in train.

Current Data Acquisition

- Only 8 bit ADC for full range.
- Communication uses obsolete GAS protocol. Data retrieval is unreliable and difficult to debug.
- Questions about triggering and correlation of samples for turn-by-turn analysis.

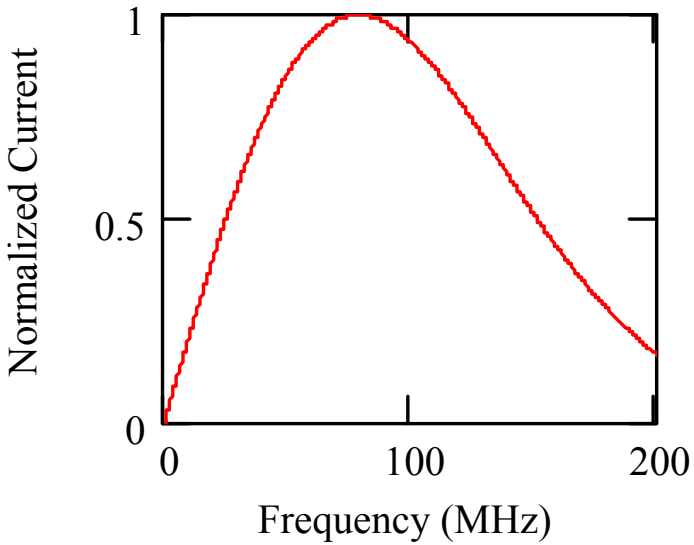
Pbar Sampling Status

- BPMs are externally terminated to allow for directional pickups at both ends.
- Pbar end of BPMs are currently terminated in the tunnel.
- We currently posses boxes with switches to allow changes between pbar and proton ends of BPM, but it interferes with the directionality of the BPM.

Scope of BPM Upgrade

- Cabling and processing hardware for 224 BPMs.
- Data acquisition algorithms for processing hardware.
- Synchronization and triggering system for all BPMs.
- Software for hardware communication, data processing, and user interface.

Stripline Properties



Graph showing the product of the stripline response and the beam form factor for a full bucket.

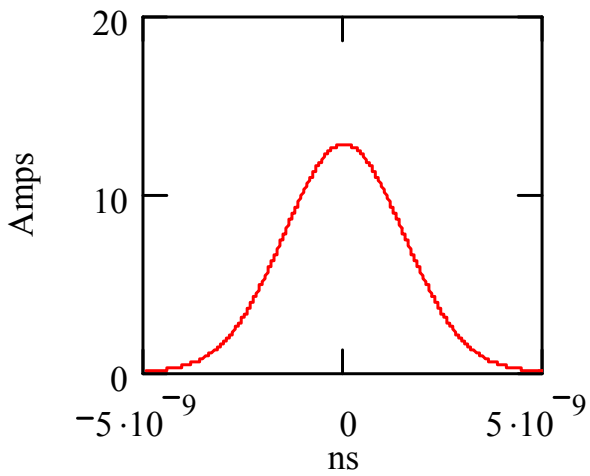
- Directionality ~ 26 dB
- Response peaks at around 375 MHz
- Peak product of response and form factor (for full bucket) at ~80 MHz
- Best fundamental response at 53 MHz or 106 MHz

Bunch Properties

- Coalesced Protons
- Particles/bunch: 30e9 - 350e9
- # of bunches: 1 – 36
- Bunch length 3σ: 4.5ns – 10ns

- Coalesced Pbars
- Particles/bunch: 3e9 - 150e9
- # of bunches: 1 – 36
- Bunch length 3σ: 4.5ns – 10ns

Peak & Average Signal Levels



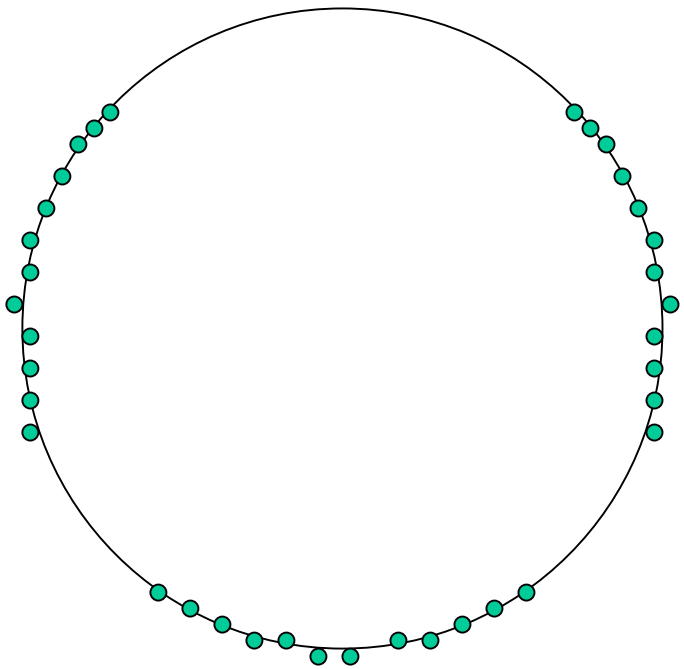
Simulation of peak current from a single Gaussian bunch with 300e9 particles and 1.5ns σ.

- Peak specified current will be ~10A.
- Peak voltage from single stripline will be ~200V.
- Peak DC current of protons ~80mA.
- Peak fundamental sum voltage from BPM ~1.4V.

Beam Distribution

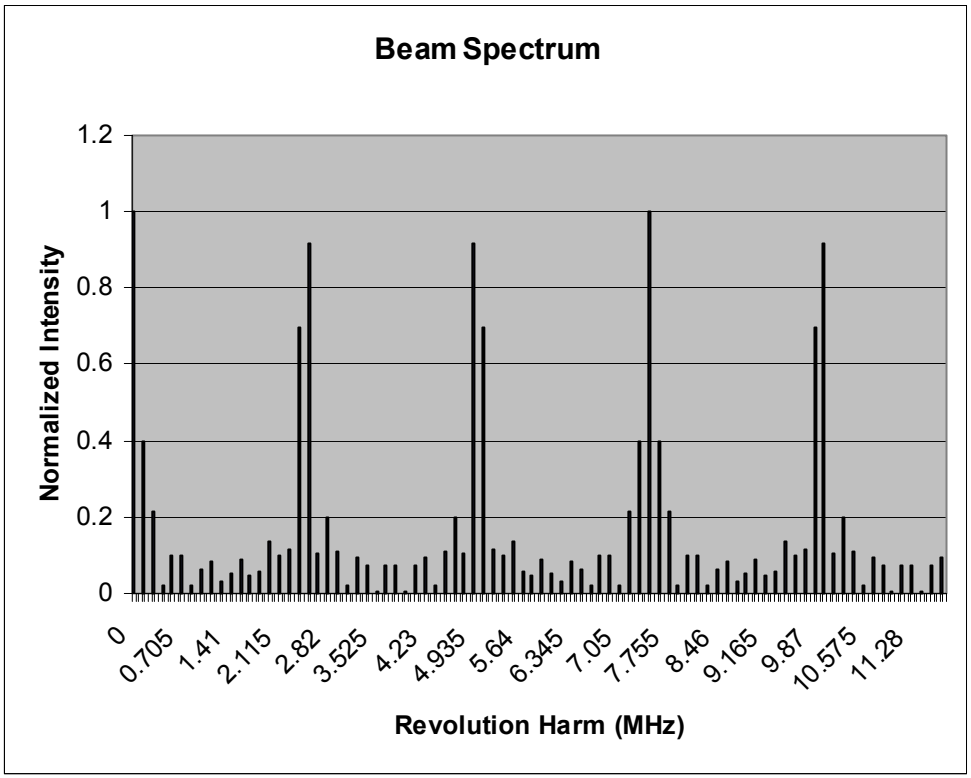
- Standard Store Configuration
- Pilot Tuning
- Injection
- Ramp
- Pbar Only
- Studies

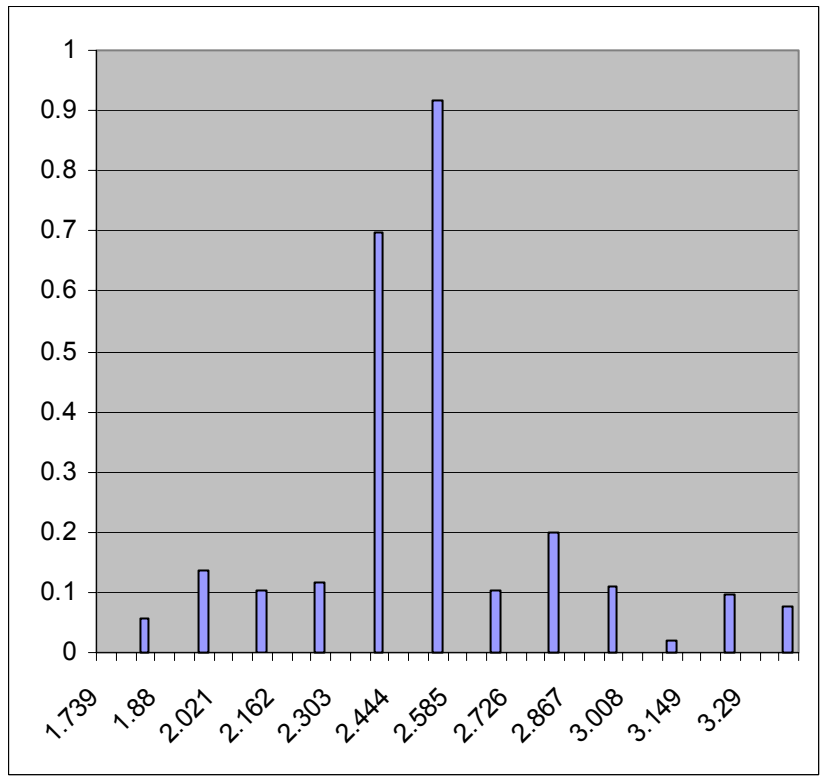
Standard HEP Store



- Bucket spacing is 18.9ns (53.1 MHz)
- Store consists of 3 batches of 12 bunches.
- Within a batch, bunch separation is 21 buckets.
- 140 bucket separation between batches.
- Pbars and protons have same configuration.

Standard Store Spectrum





Pilot Tuning

- Use a single coalesced bunch or uncoalesced batch for tuning.
- Uncoalesced batch consists of 30 low intensity bunches in consecutive buckets.
- Very important to have repeatability between pilot position measurements and 36 bunch position measurements.

Injection

- Protons injected one bunch at a time.
- After protons are injected, pbars are injected 4 bunches at a time and then cogged.
- Important to maintain average position orbit through the injection process.

Ramp

- Protons and pbars are accelerated.
- Magnets and correctors are varying wildly to respond to changes in bending strength as beam accumulates more energy.
- Largest rate of closed orbit position changes in acceleration process.

Studies

- Arbitrary configuration
- Beam may occupy any number of buckets.
- Arbitrary intensity and orbits.
- May involve only protons or only pbars.

Specification Definitions

- Scope: Specifications refer to final data output to user (includes all averaging).
- Absolute Position Accuracy
- Relative Position Accuracy
- Position Linearity
- Orbit Position Resolution
- Long Term Position Stability
- Specification Range

Absolute Position Accuracy

- Creates a limit to the sum of the uncalibrated position offset and the relative error at full range.
- Dictates how well we know the position of the beam relative to the center of the quad for all beam conditions, positions, and time.

Relative Position Accuracy

- Describes the limit of the position error variation as a function of beam displacement.
- Does not include offset errors, but does include scale errors, non-linearities, and random errors.
- Takes precedence over absolute position accuracy for small displacement.

Position Linearity

- Describes how much the relative position can deviate from a linear function.
- Similar to relative position error, but scale errors do not affect it.

Orbit Position Resolution

- Refers to the smallest change in beam position that the BPM system can reliably observe.
- Affected by noise and other random errors.

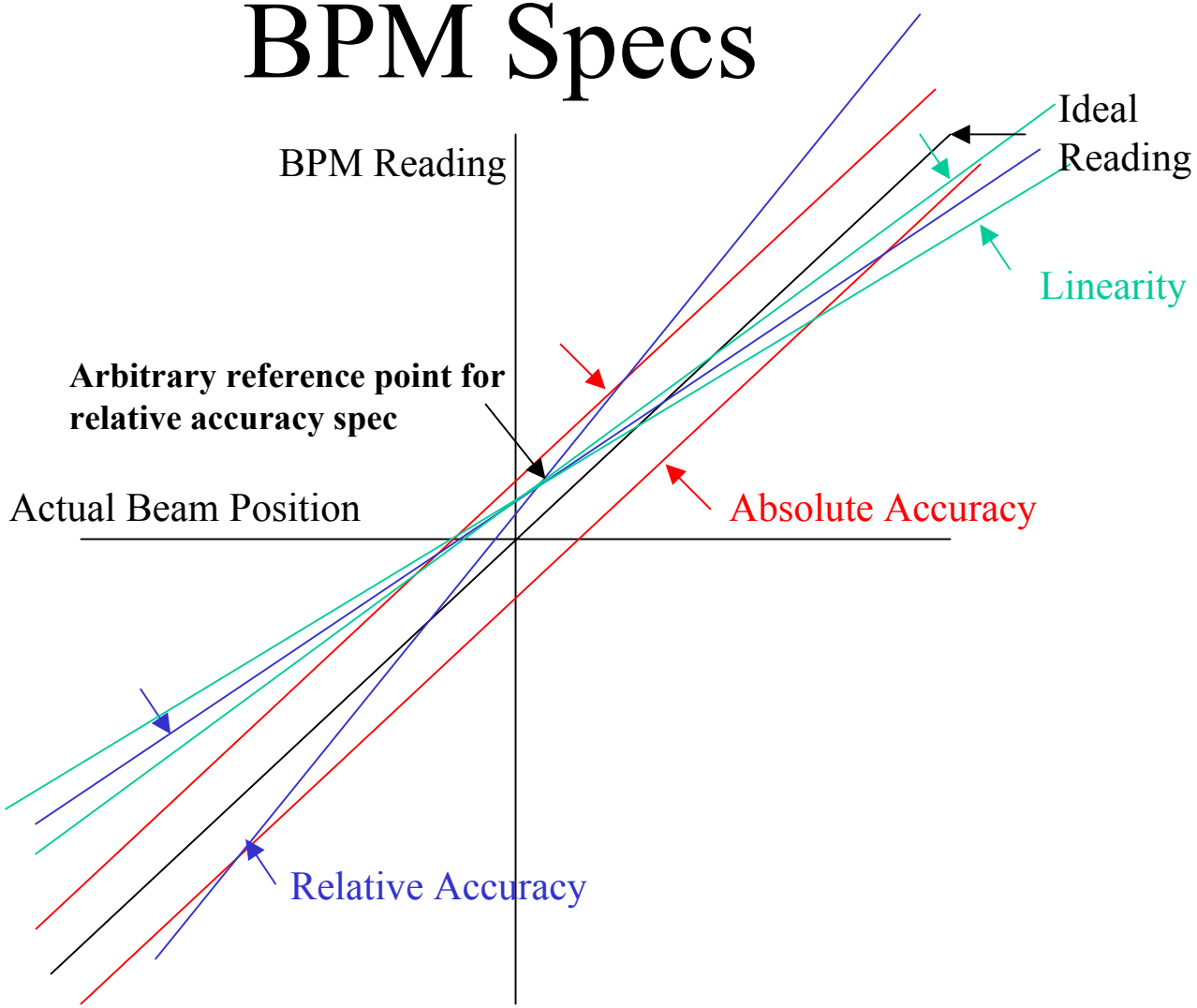
Long Term Position Stability

- Refers to the BPMs' ability to give the same position value for the same beam position and intensity over a time period of multiple stores or one week shutdown.
- The BPM readings should not vary by more than the amount specified over a one week time span.

Specification Range

- Refers to the amount of BPM aperture, relative to center, in which the listed specifications remain valid.
- Beyond these points, the specification becomes more relaxed.

BPM Specs


BPM Reading
Ideal
Reading
Linearity
Arbitrary reference point for
relative accuracy spec
Actual Beam Position
Absolute Accuracy
Relative Accuracy

Processing Definitions

- BPM Frontend
- Bandwidth Modes: Flash
- Bandwidth Modes: Closed Orbit
- Time Stamp

BPM Front End

- Analog combining, filtering, mixing, and amplifying of BPM stripline signals.
- A/D, memory organization
- Single channel internal processing
- Single channel triggering

Bandwidth Modes: Flash

- Take a fast sample of positions relative to a clock event, state change, or manual command.
- Bandwidth must be of the order of or greater than revolution frequency.
- Used to diagnose problems of a fast nature: Injection misteering, kicker misfires.

Bandwidth Modes: Closed Orbit

- Lower bandwidth but more precise mode.
- Will include more internal averaging.
- Data access triggered by clock event, state change, manual command, or continuous update.
- Max 1Hz data request rate.

Time Stamp

- Time value associated with each sample point, used to synchronize data from different channels.
- Time stamp must be synchronized around the ring for successful diagnostic of injection errors and kicker misfires.

Key Specifications

- Absolute Position Accuracy: 1.0 mm
- Relative Position Accuracy: 5%
- Long Term Position Stability: 0.02 mm
- Best Orbit Position Resolution: 0.02mm
- Position Linearity: 1.5%
- Specification Range: ±15mm
- Total number of BPM channels required: 244 x 2

Resolution Requirement Details

- Store and pilot distributions: use key specifications.
- Ramp and injection distributions: Close orbit resolution 0.05mm.
- Studies
- Over range

Studies

- Arbitrary mode, will specify resolution for different dynamic ranges.
- > 200e9 particles or >100e9 particles/bunch – 0.02mm
- 200e9 > particles > 50e9 or 100e9 > particles/bunch > 30e9 – 0.1mm
- 50e9 > particles > 10e9 or 30e9 > particles/bunch > 3e9 – 0.25mm
- Always use least stringent specification.

Over Range

- Specs for beam off center 15mm-25mm
- Absolute Position Accuracy: 2.0 mm
- Relative Position Accuracy: 5%
- Long Term Position Stability: not needed, we need to re-steer immediately
- Best Orbit Position Resolution: 0.2mm
- Position Linearity: part of relative position accuracy spec
- No specs for beam off center more that 25mm

Processing Specifications

- Bandwidth of flash mode: ~50 kHz
- Bandwidth of closed orbit mode: ~100 Hz
- Flash mode time stamp precision: 10 μs
- Closed orbit mode time stamp precision: 500 μs
- Frames of internal storage/mode: 512

Functional Justification

- Tune Orbits
- Injection Diagnostics
- Orbit Smoothing during HEP
- Orbits up the Ramp for Shots
- Abort/Quench Conditions
- Lattice Function Measurements

User Interface Requirements

- User interface must run from a control room console.
- Interface should be multi-user.
- It should set up the BPMs for the appropriate user measurements.
- It should retrieve the data from the BPMs.
- It should correlate and present the BPM data in a usable fashion.

Priority for Multi-user Data Aquisition

- Data acquisition in progress
- Preprogrammed automatic acquisition
- Manual closed orbit acquisition
- Manual flash acquisition

BPM System Settings

- Closed Orbit/Flash Mode Select
- Proton/Pbar Mode Select
- Arm and Trigger Settings for Automated Measurements
- Quantity of Flash Mode Data to Download

BPM Data Cluster

- BPM Azimuthal Position
- Trigger Settings
- Closed Orbit/Flash Mode Setting
- Proton/Pbar Setting
- Size of Data Array
- Trigger Event for Current Data Acquisition
- Arm Event for Current Data Acquisition
- Array of:
- Position readings
- Intensity readings
- Time stamp for each read

Plotting Packages

- Plot Closed Orbit (all BPMs)
- Plot Difference Orbit (closed orbit/all BPMs)
- Plot Flash Orbit (all BPMs)
- Plot Flash Data (single BPM)
- Plot Flash FFT (single BPM)

Calibration & Maintenance

- The calibration system must maintain the specifications.
- Specifications are only required to hold over period given by long term stability. Beyond this calibration required.
- Diagnostics must be good enough to pinpoint fault in any replaceable component.

Misc Notes

- Tune measurement not specified, but feature of system.
- Pbar positions only specified for pbar only stores.
- High intensity pbars will interfere with proton position accuracy and linearity.

Turn-by-turn

- Turn-by-turn operation not specified, but a feature of the system due to first turn orbits.
- Currently, no justification for ring wide turn-by-turn capability.
- Lattice phase advance?
- Local coupling?
- Can turn-by-turn information be collected by a few wide-band systems?

Cost and Schedule

- Keep total cost below $300k
- Have design plan finished by Oct. ‘03.
- Begin ordering components and installing during Fall/Winter ‘03.
- Have system commissioned by April ’04.

Priorities

- Reliability
- Closed orbit position resolution
- Closed orbit position accuracy
- Flash position resolution
- Flash memory depth
- Turn-by-turn synchronization and processing

Questions

- Do we need ring wide turn-by-turn capability?
- Do we need to expand/loosen our specifications on pbar positions?
- Do we need to expand the scope of the project to include a small number of wide-band processors?