Tevatron BPM and BLM requirements

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Requirements

First,

Determine the uses of the BPM system.

Then,

Use

+ Type of Measurement (Closed Orbit, TBT, etc.)
+ Mode of Data Collection (Manual or Triggered)
+ Beam Structure and Intensity
+ Accuracy and Precision

= Set of Requirements (for that particular use.)

Requirements (Example #1)

Use: Measure the orbits during a shot setup.

Then,

Orbits during shot setup
+ Closed Orbit Measurement
+ Collected on TCLK event and saved in a buffer
+ 36 p bunches (300e9) + 36 pbar bunches (150e9)
+ 0.05 mm error

= One of the requirements (out of several dozen)

Requirements (Example #2)

Use: Measure the orbit on the first revolution
for injection tune up.

Then,

1st turn injection orbit
+ Single Turn Measurement
+ Collected on TCLK event (Injection event)
+ 30 uncoalesced proton bunches (3e12 total)
+ 0.1 mm error

= Another of the requirements

Uses of the BPM system

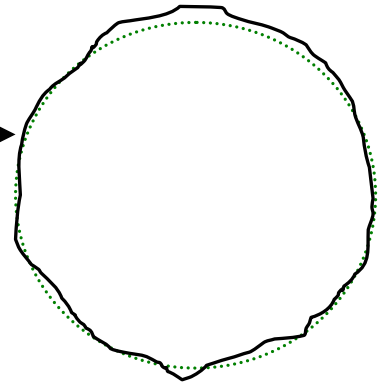
- Measuring the closed orbit positions during collider operations.
- TCLK triggered closed orbit data collection for orbit smoothing.
- Maintaining the orbit positions at CDF and D0 during a collider store.
- 1st turn orbit and intensity data for commissioning and diagnostics.
- Multi-turn orbit and intensity data for commissioning.
- 1st turn and TCLK triggered closed orbit data for injection closure.
- Last turn data for tune up and diagnostics of the A0 beam dump.
- Diagnosing aborts using a circular buffer of closed orbits.
- Archiving orbits during shot setups with the (SDA.)
- Fast time plotting (FTP) of orbits positions during aperture scans.
- Lattice measurements using the 1-bump technique.
- Lattice and coupling measurements using turn-by-turn (TBT).
- Closed orbit measurements during accelerator studies.

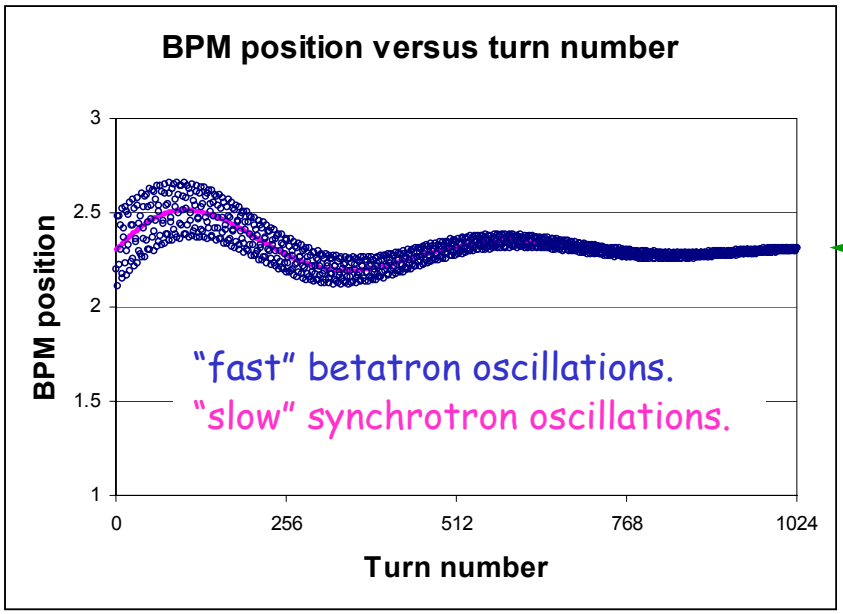
Types of Orbits
The Closed Orbit

Closed orbit:

A particle with no betatron or synchrotron oscillation returns to the same position every turn.

Not necessarily in the center of the BPM!





BPM position settles on the closed orbit.

Can use "averaging" to improve signal/noise.

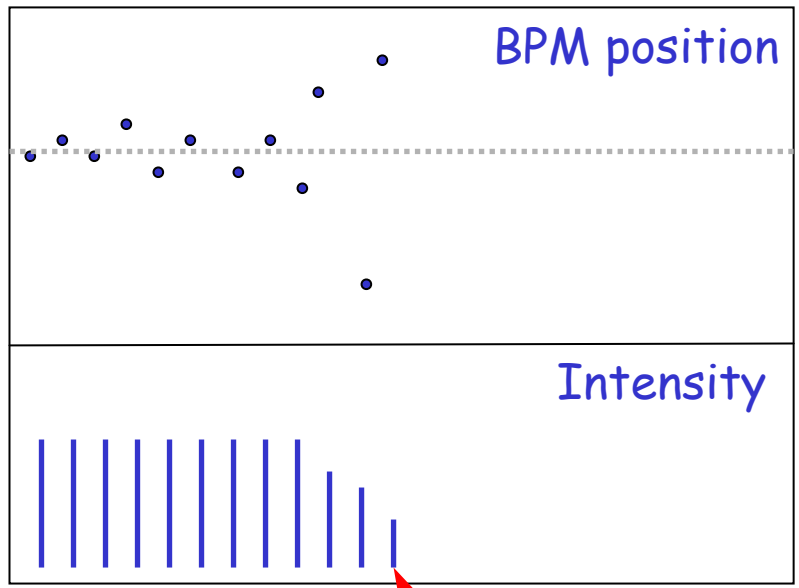
Types of Orbits
The Single Turn Orbit

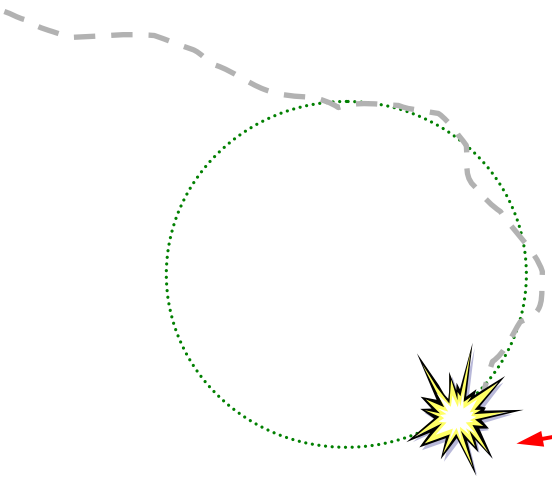
Single turn measurement:

Measure the position from a single pass of beam.

Include the intensity measurement.

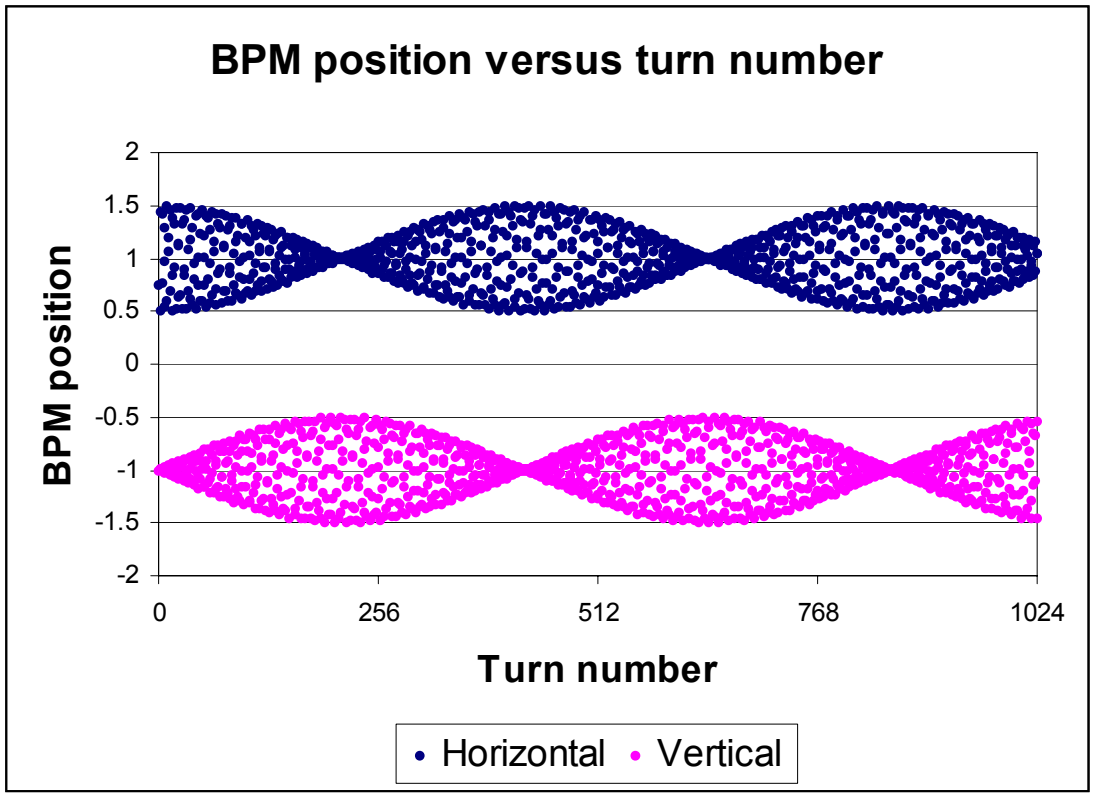
BPMs synchronized to get orbit on the same turn.





Restriction in the beamline!

Types of Orbits
The Turn-By-Turn (TBT)



Turn-by-turn measurement:

Measure the position from a single pass of beam.

Measure the position on consecutive turns.

BPMs synchronized to get orbit on the same turn.

Shows the coupling.

Energy transferred from horizontal to the vertical plane and back.

Methods of data collection.

Not all methods used in all cases.

In closed orbit mode: (the default measurement type.)

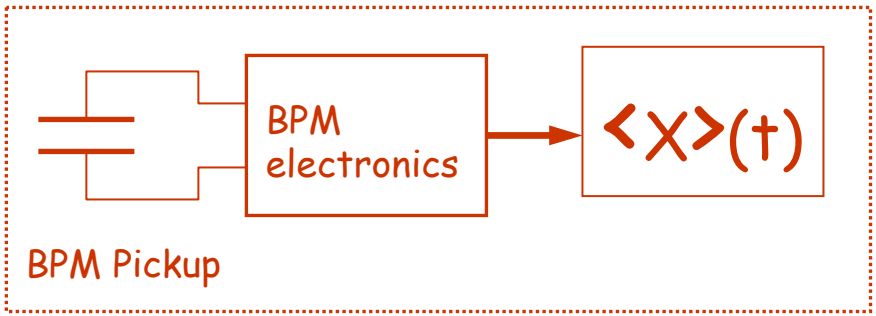
- Position of each BPM available as an ACNET parameter. (T:HPE11)
- Position can be plotted with FTP.

- Positions of all BPMs on manual request. (i.e. request orbit from T39.)

- Positions of all BPMs saved in a buffer when triggered by a TCLK event.
- Positions stored in a circular buffer that is halted by a Tev abort.

Methods of data collection.

In closed orbit mode: (the default measurement type.)



<X>(t) can be:

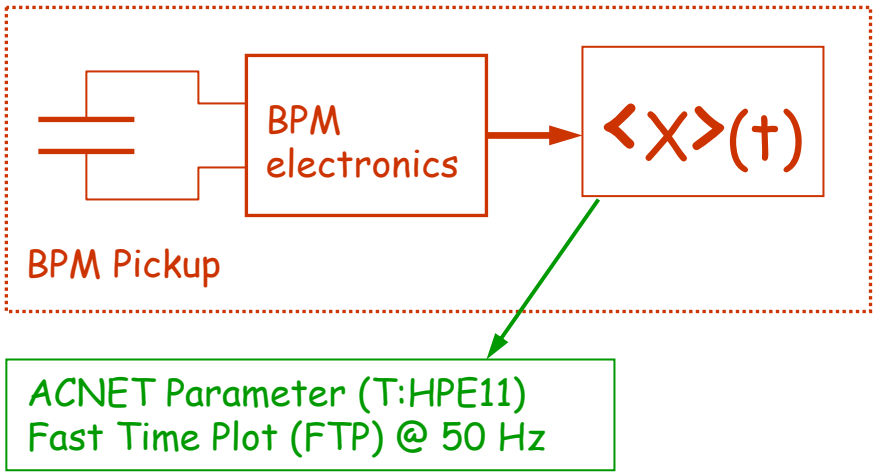
Protons OR Pbars

Batch OR Bunch

No requirement for separate channels.

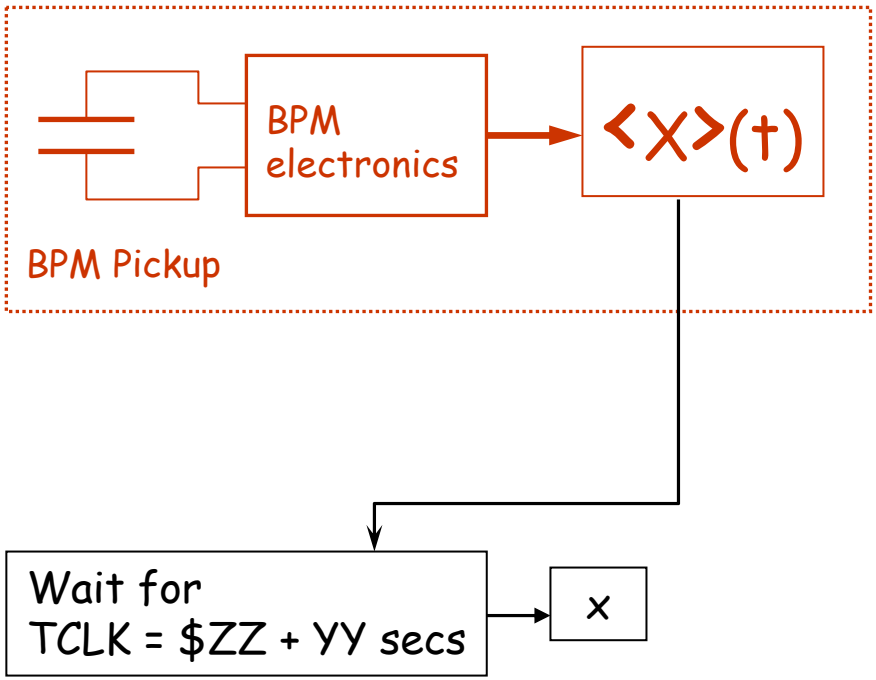
Methods of data collection.

In closed orbit mode: (the default measurement type.)



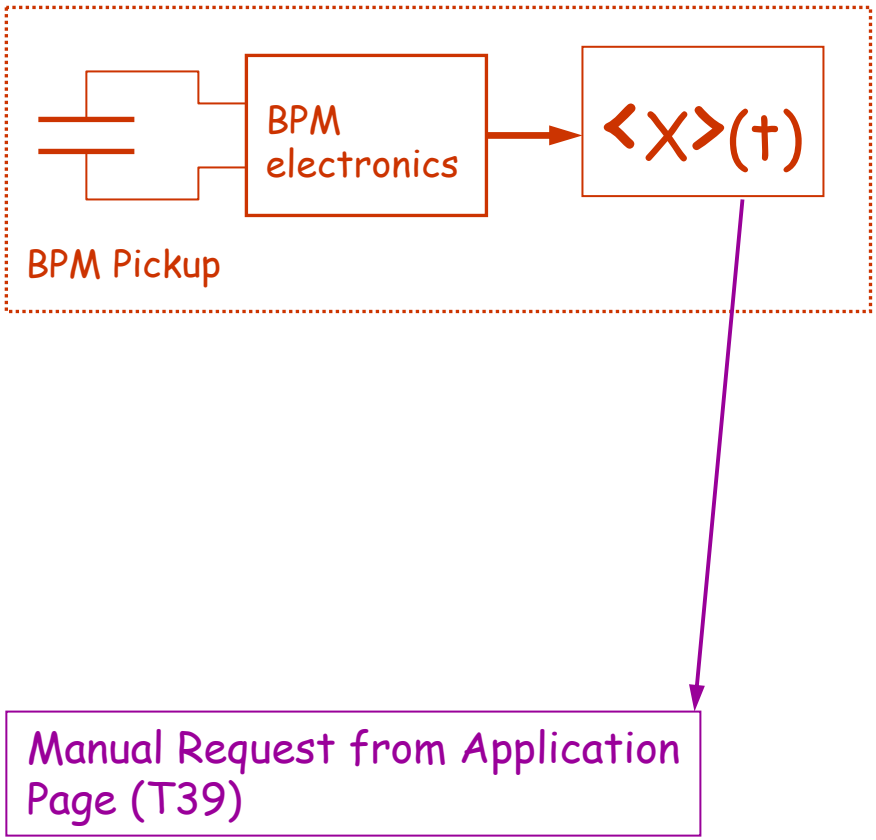
Methods of data collection.

In closed orbit mode: (the default measurement type.)



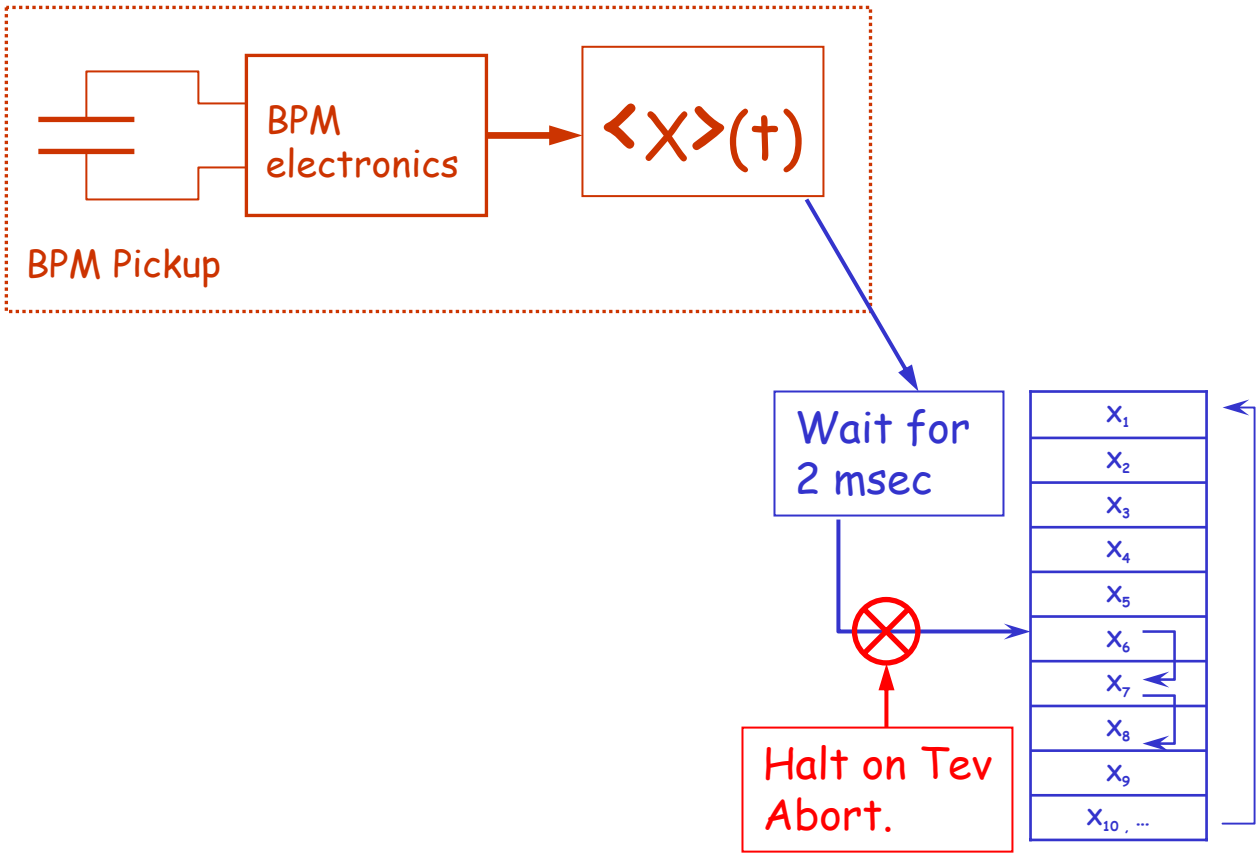
Methods of data collection.

In closed orbit mode: (the default measurement type.)



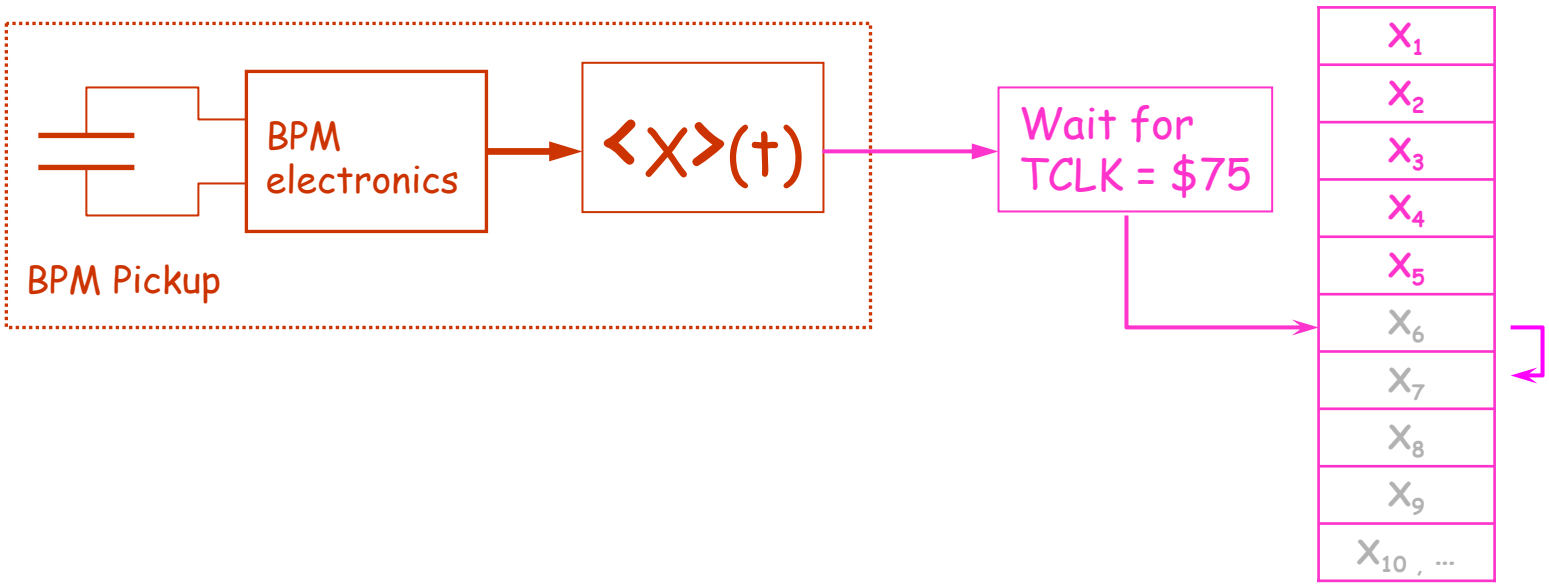
Methods of data collection.

In closed orbit mode: (the default measurement type.)

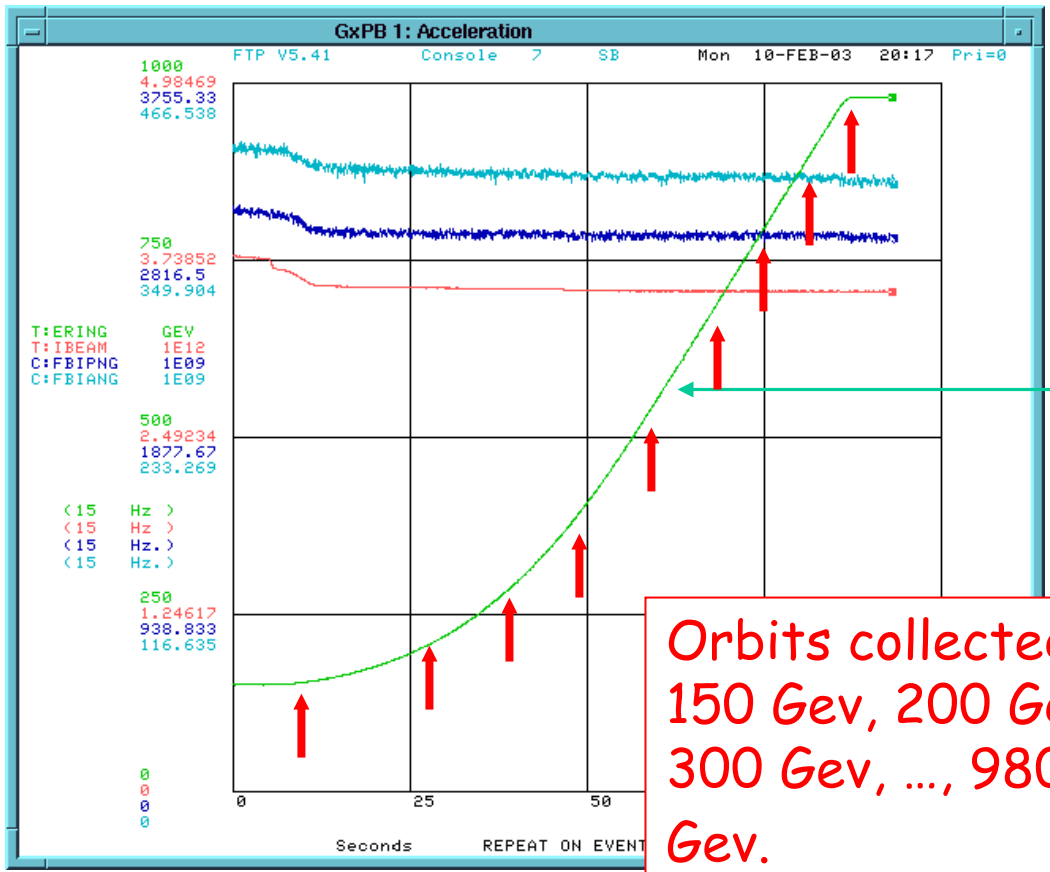


Methods of data collection.

In closed orbit mode: (the default measurement type.)



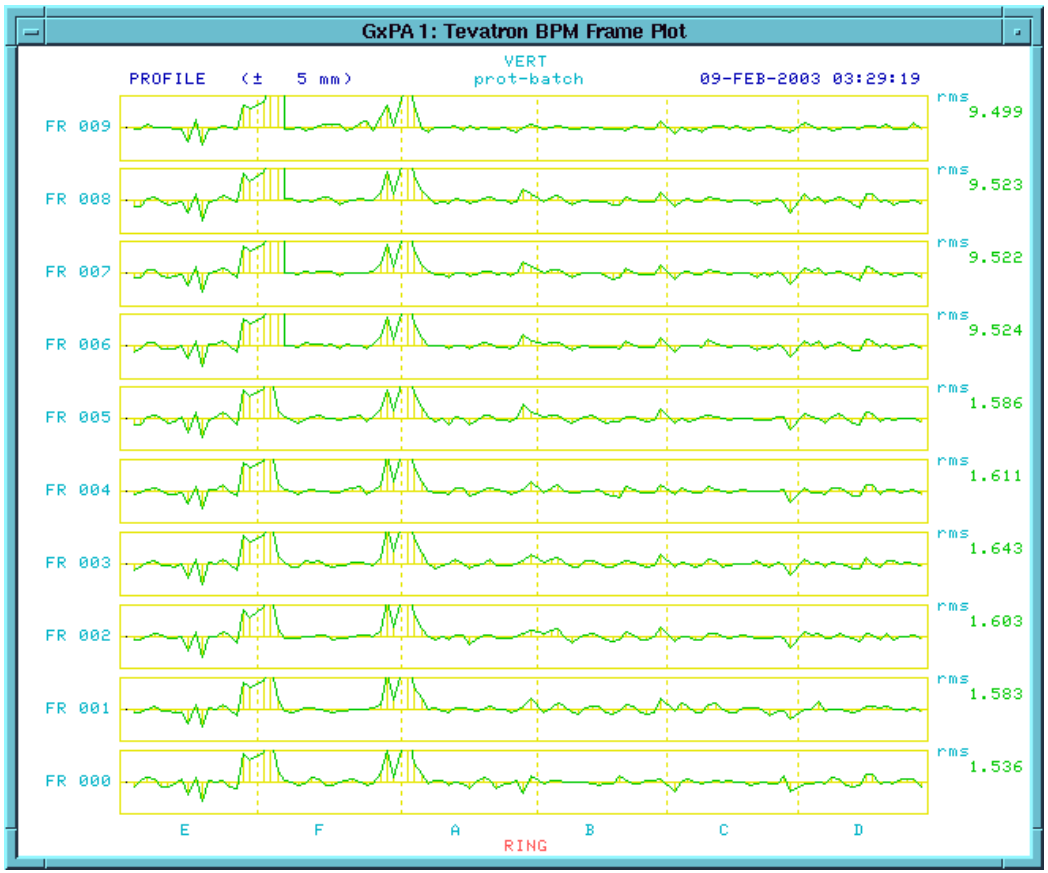
Accelerate



Tevatron accelerates beam from 150 GeV to 980 GeV.

Orbits collected at 150 Gev, 200 Gev, 300 Gev, …, 980 Gev.

Orbits up the ramp



980 Gev

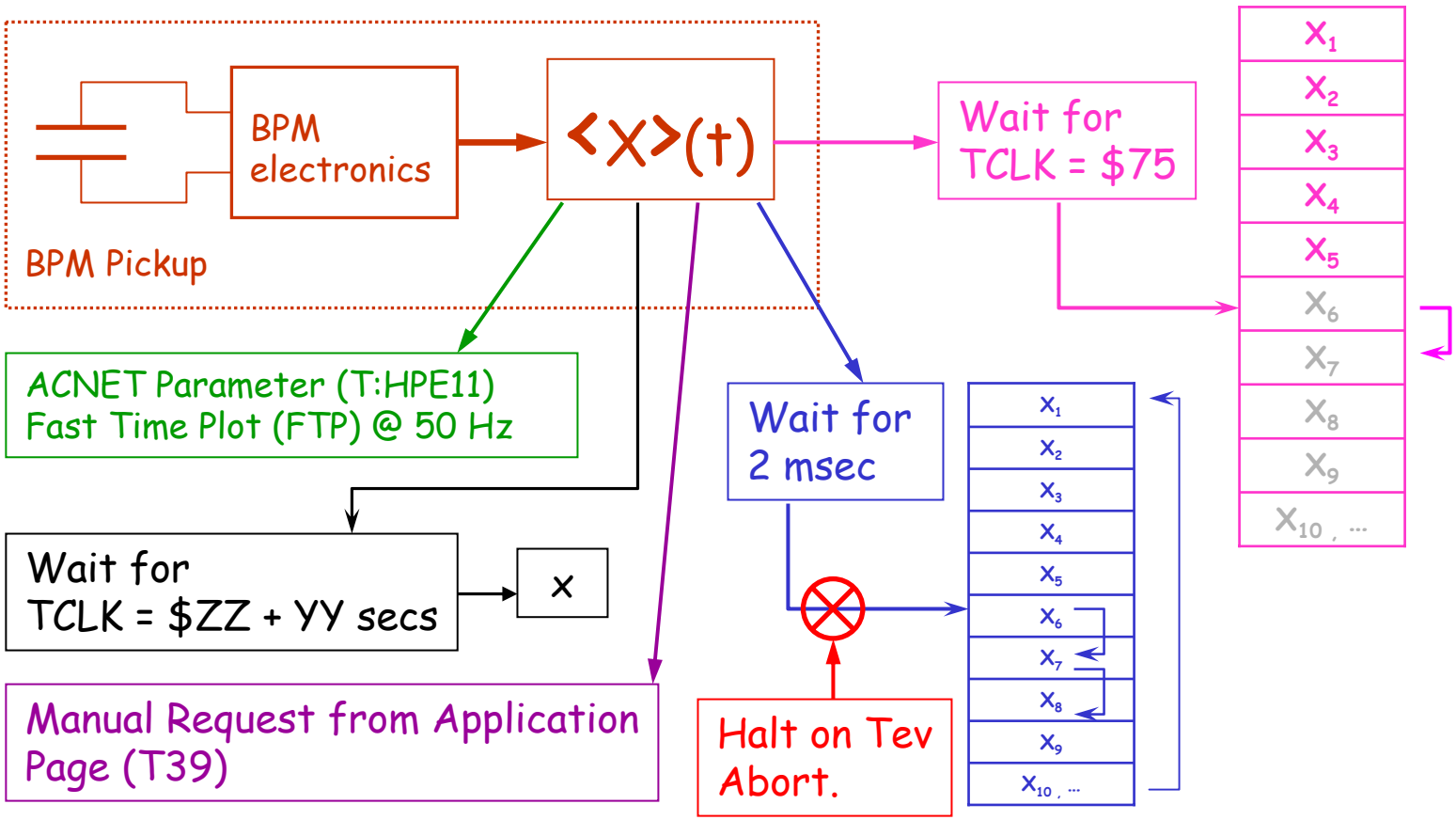
900 Gev

200 Gev

150 Gev

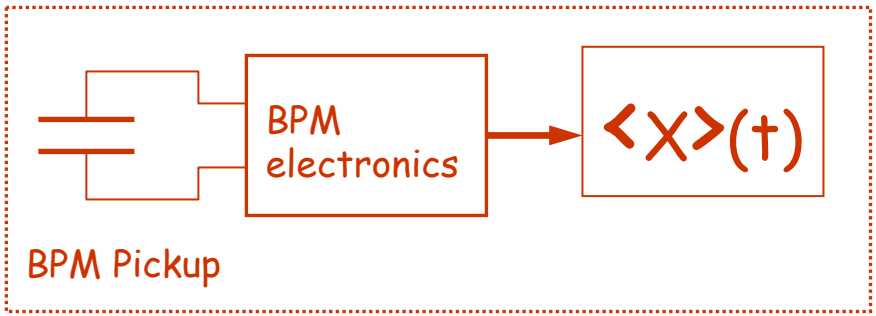
Methods of data collection.

In closed orbit mode: (the default measurement type.)



Methods of data collection.

In single-turn mode:

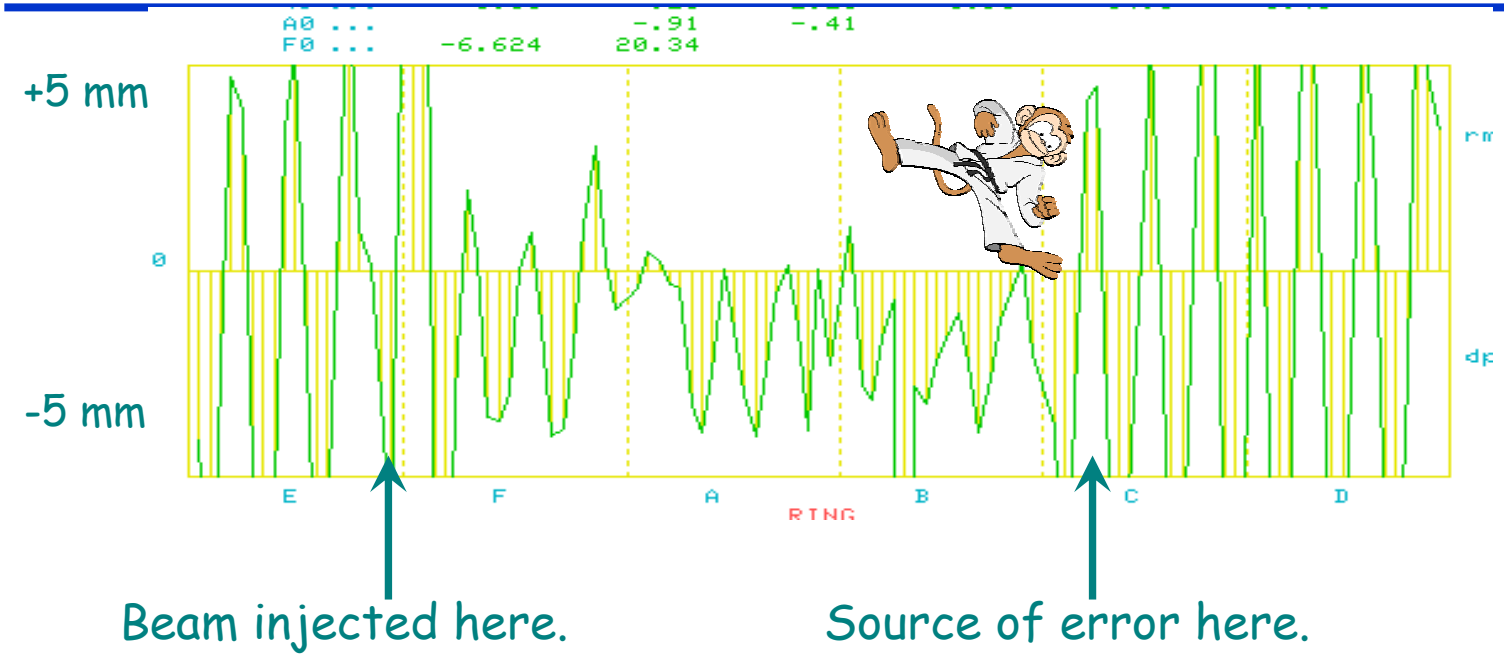


Arm can be on TCLK, State Device Transition, or Manual Request.

1. Arm for single turn measurement.
2. BPM "electronics" ready in 1 msec.
3. Wait for TCLK trigger
4. Collect single-turn position and intensity
5. Store data in buffer
6. Return to Closed Orbit Mode in 1 msec.

All BPMs must collect position and intensity on the same revolution.

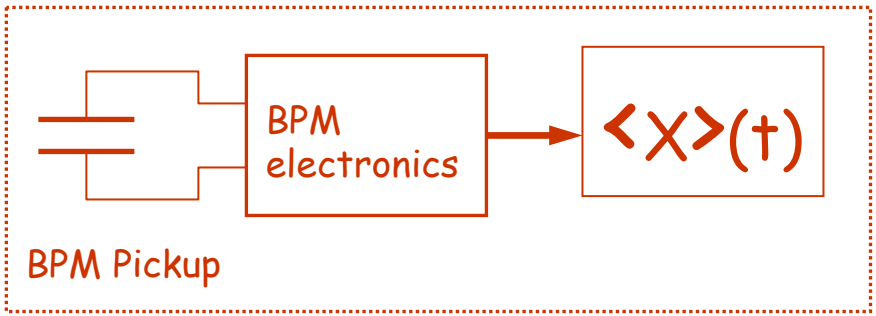
First turn orbits during startup



This plot shows the proton orbit on the 1st turn after injection after a startup.

Methods of data collection.

In TBT mode:



Arm can be on TCLK, State Device Transition, or Manual Request.

1. Arm for TBT measurement.
2. BPM "electronics" ready in 1 msec.
3. Wait for TCLK trigger
4. Collect position and intensity for 1024 turns
5. Store data in buffer
6. Return to Closed Orbit Mode in 1 msec.

All BPMs must collect position and intensity on the same revolution.

Data in an Orbit Frame

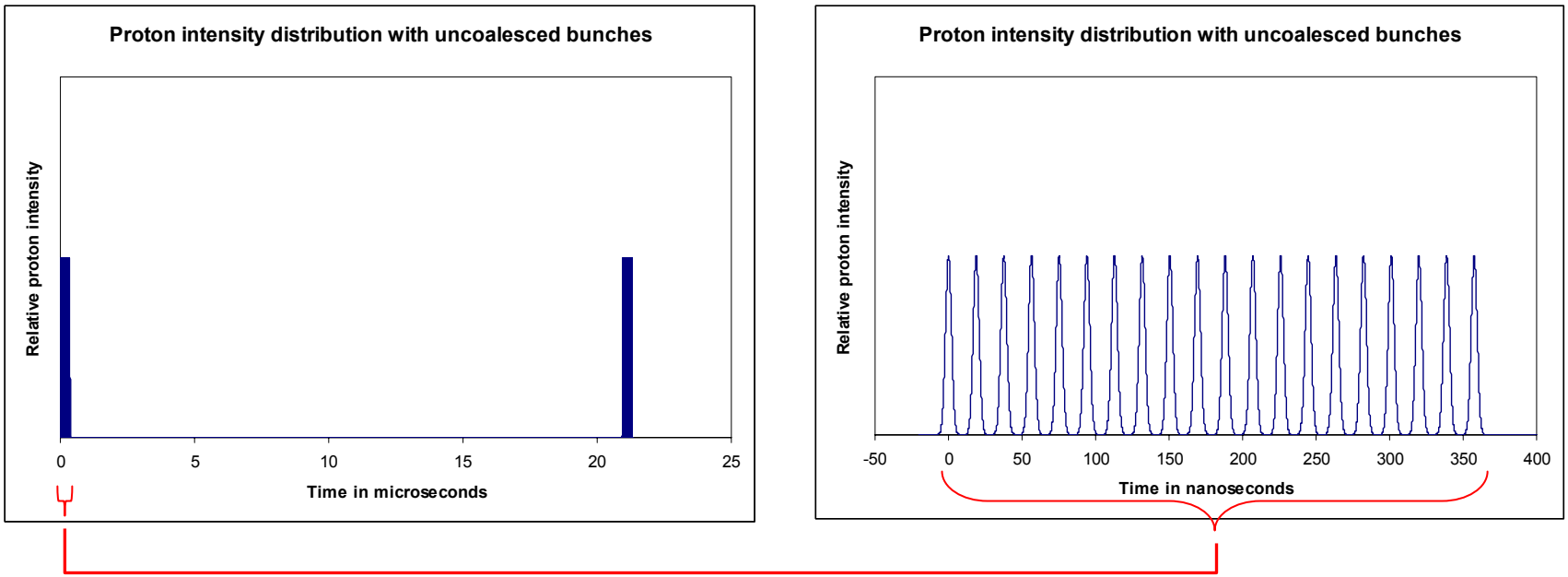
Information Contained in the Orbit Frame Data.

- Status or Error Code
- BPM Azimuthal Position
- Trigger Settings
- Closed Orbit/Flash Mode Setting
- Proton/Pbar Setting
- Batch/Bunch Setting
- Size of Data Array
- Trigger Event for Current Data Acquisition
- Arm Event for Current Data Acquisition
- Array of:
  - Position readings
  - Intensity readings
  - Time stamps

The precision of the time stamps are

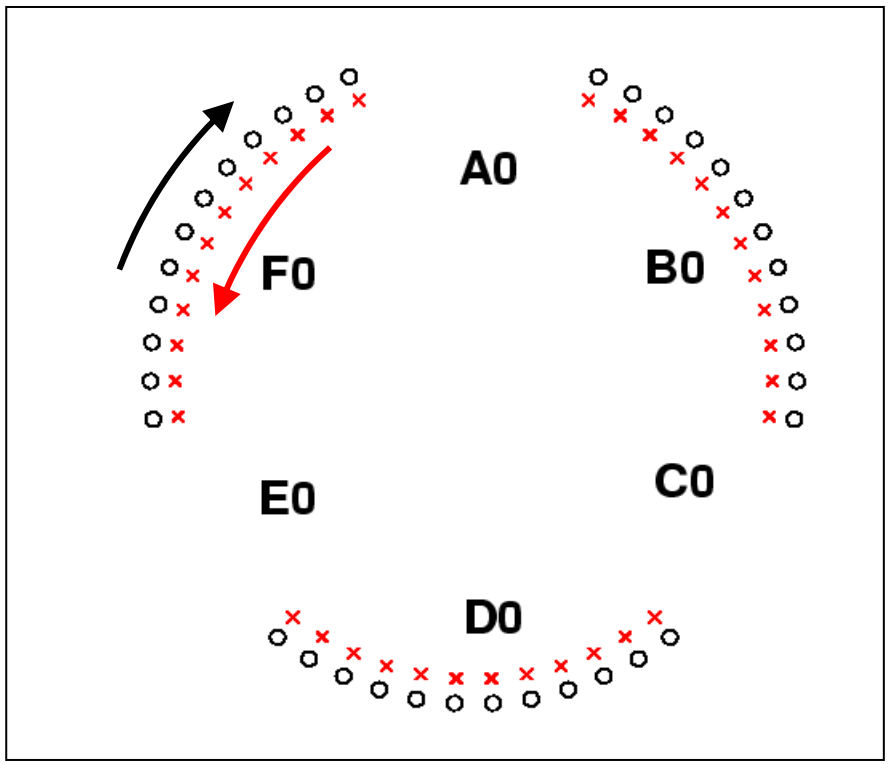
- Single turn or TBT mode: 1 μs (3σ rms)
- Closed orbit mode: 500 μs (3σ rms)

Uncoalesced Beam



Bunch structure with uncoalesced protons in the Tevatron. There is a group of 20 to 30 consecutive bunches spaced one RF bucket (18.8 nsec) apart followed by a gap of ~20 μsec without beam before the group returns after one revolution. The lower figure shows the beam over a little more than one revolution and the upper figure zooms in on the consecutive bunches.

Coalesced Beam



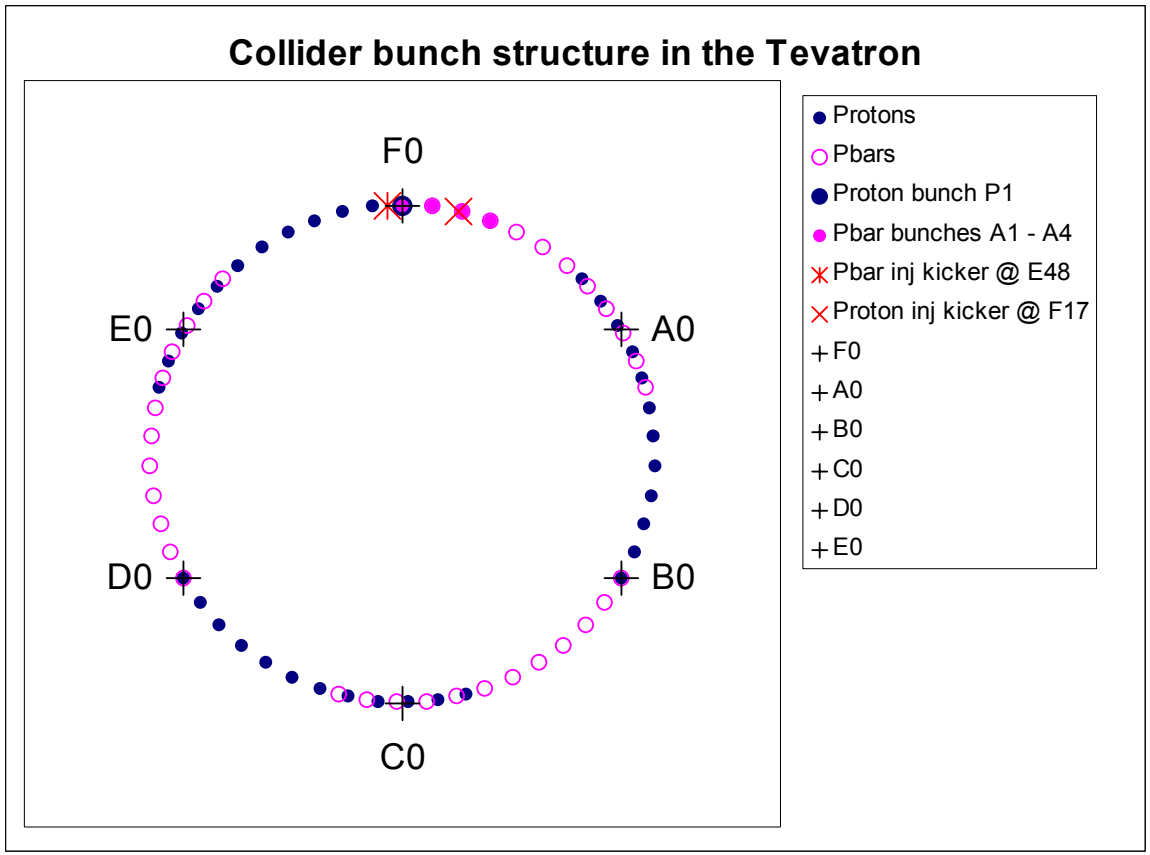
36 x 36 configuration

396 nsec bunch spacing

3 x 12 proton bunches

3 x 12 pbar bunches

Collision point cogging

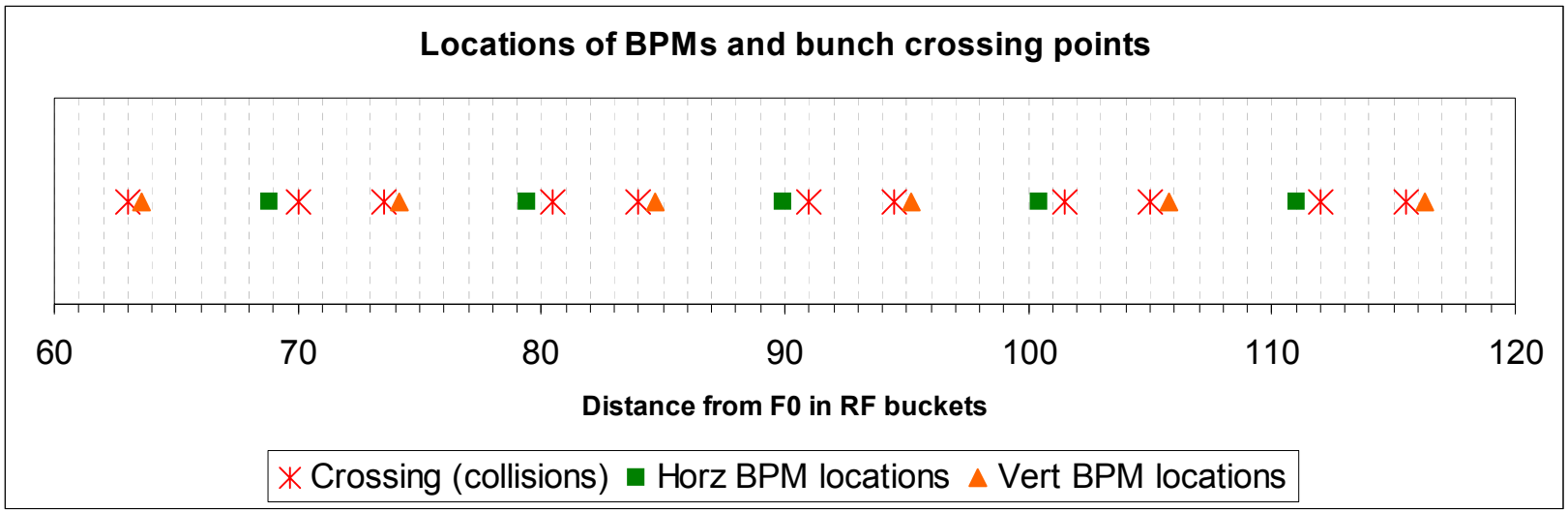


After accelerating, the relative timing of the protons and pbars is changed.

This is done by a process called cogging.

Proton and pbar bunches now cross at CDF and D0.

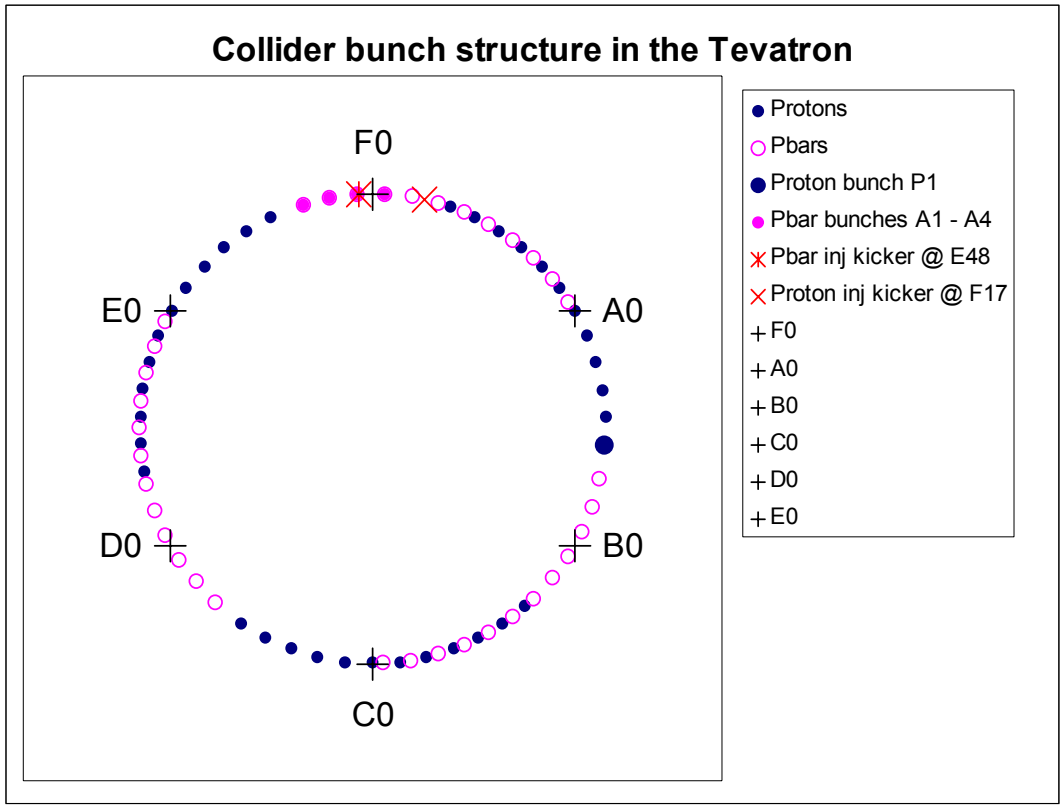
Cogging, crossings, BPMS



Cogging affects locations of proton and pbar bunch crossings.

Has implications for separating proton and pbar signals at the locations of the BPMs

Inject final pbars

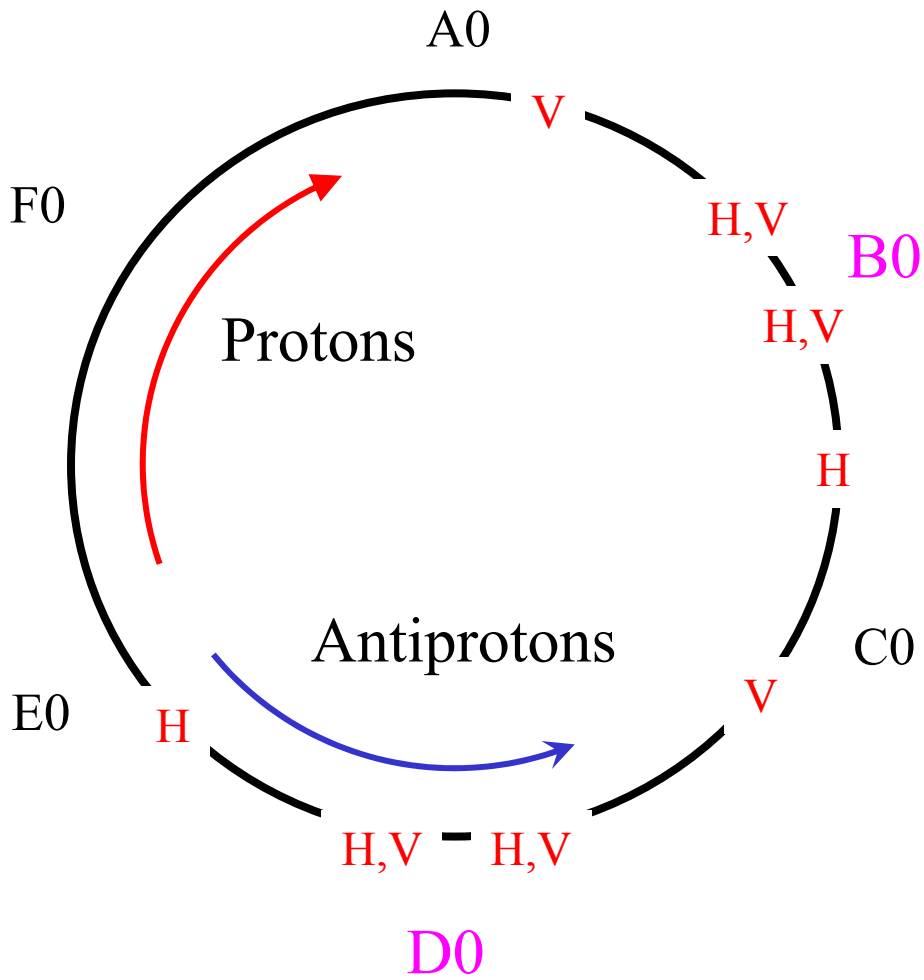


36 bunches of coalesced pbars injected for bunches at a time.

Bunches are in three groups of 12.
Bunches are spaced 21 RF buckets (396 nsec) apart.

Injected on the helical orbit (with separators on.)

Tevatron Separators

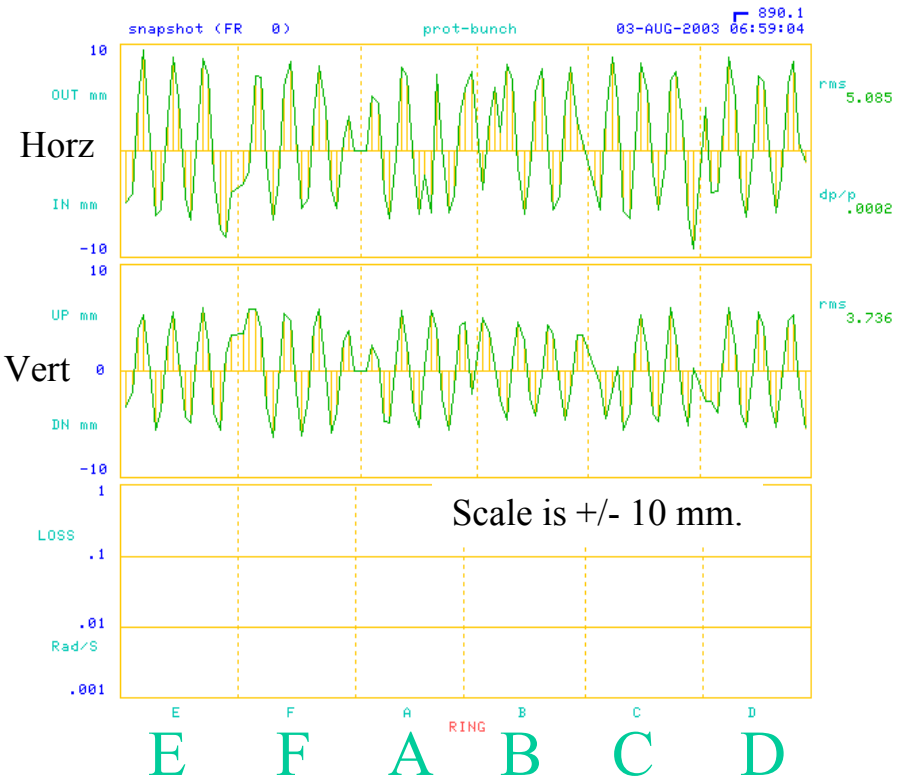


Electrostatic separators are used to separate the proton and pbar orbits transversely

…

except at the IPs where the protons and pbars collide head-on.

Helical orbits



Six sectors in the Tevatron

Orbit changes for protons when the electrostatic separators are used.

Pbar orbits change in other direction.

~100 BPMs in each plane

Intensities

Range of intensities and bunch lengths expected in Collider Run II.

	Particles/bunch	Number of bunches	Bunch length (3σ value in nsec)
Uncoalesced Protons	3e9 to 30e9	30	3.5 to 10
Coalesced Protons	30e9 to 350e9	1 to 36	4.5 to 10
Coalesced Antiprotons	3e9 to 150e9	1 to 36	4.5 to 10

Accuracy

Measurement range

Range of positions, relative to the BPM center, over which the BPM measurement must be valid and meet the accuracy requirements.

BPM system accurate over a range of $\pm$15 mm from the center.

…. beyond this range -> get the sign right

Accuracy

Absolute position accuracy

Determine how accurately the BPM system measures the position of the beam for all beam conditions, for the entire range of positions, for long periods of time (years), and when parts of the BPM system or BPM electronics are replaced.

It is sufficient for the BPM system to have a 3σ absolute position accuracy of 1 mm.

Hard to actually confirm this measurement.

Accuracy

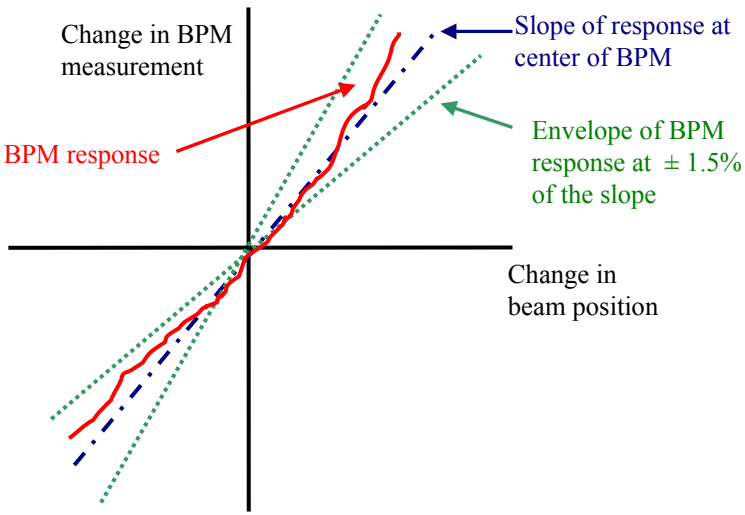
Long term position stability

Essentially this requirement limits the amount of drift allowed by a BPM over the period of a week, for consecutive stores, or after a shutdown.

The requirement on the long term positions stability is a 3σ drift of 0.02 mm per week.

Maybe should be 0.05 mm per week?

Accuracy



Definition of the linearity requirement for the Tevatron BPM. Note that the requirement on the linearity of the BPM response does not constrain the slope of the BPM response.

Change in BPM measurement ± 1.5% of the slope

Accuracy

Relative position accuracy should be 5%.

Δxa is then change in the actual position of the beam,
Δxm is the measured position change of the beam,

then $\Delta xm = \Delta xa \pm 5\%$.

There should be a requirement stating that all BPMs have the same gain to within 1?%, 2%?

Accuracy

Orbit position resolution

The smallest change in beam position that the BPM system can reliably measure.

For the most precise measurements the orbit position resolution is 3σ of 0.02 mm.

What is meant by resolution?

Requirements

Measurement Purpose	Beam Structure	Data Acquisition Type	Position accuracy and resolution
Proton closed orbit during a store.	36x36.	Manual. Buffered on TCLK. ACNET variable. FTP variable.	As in Table 2
Pbar closed orbit during a store.	36x36.	Manual. Buffered on TCLK. ACNET variable. FTP variable.	Position resolution of 0.05 mm.
Proton closed orbit during ramp and LB squeeze	36x36. Prot coal. Prot uncoal.	Buffered on TCLK. ACNET variable. FTP variable.	Position resolution of 0.05 mm.
Pbar closed orbit during ramp and LB squeeze	36x36. Pbar coal.	Buffered on TCLK. ACNET variable. FTP variable.	Position resolution of 0.05 mm.

Requirements

Measurement Purpose	Beam Structure	Data Acquisition Type	Position accuracy and resolution
Proton single turn for injection commissioning.	Prot uncoal.	Single turn, triggered on TCLK.	Position resolution of 0.1 mm.
Proton closed orbit for injection commissioning.	Prot uncoal.	Buffered on TCLK	Position resolution of 0.05 mm.
Proton single turn for injection tune up.	Prot uncoal.	Single turn, triggered on TCLK.	Position resolution of 0.05 mm.
Proton closed orbit for injection tune up.	Prot uncoal.	Buffered on TCLK.	Position resolution of 0.02 mm.

Requirements

Measurement Purpose	Beam Structure	Data Acquisition Type	Position accuracy and resolution
Closed orbit circular buffer.	36x36. Prot coal. Prot uncoal. Pbar coal.	Circular buffer halted on Tevatron Abort.	
Aperture scans	Prot coal. Prot uncoal.	Manual. Buffered on TCLK. ACNET variable. FTP variable.	As in Table 2
Lattice measurements	Prot uncoal. Prot coal.	Manual. Buffered on TCLK. ACNET variable. FTP variable.	As in Table 2
Lattice and coupling measurements	Prot coal. Prot uncoal.	TBT buffer.	

Conclusion

- Structure for defining requirements exists
- Number of issues (i.e. average out synchrotron oscillation?)
- Lots of questions to answer!
- Justification is weak.