Calibration of the Upgraded Tevatron BPM System

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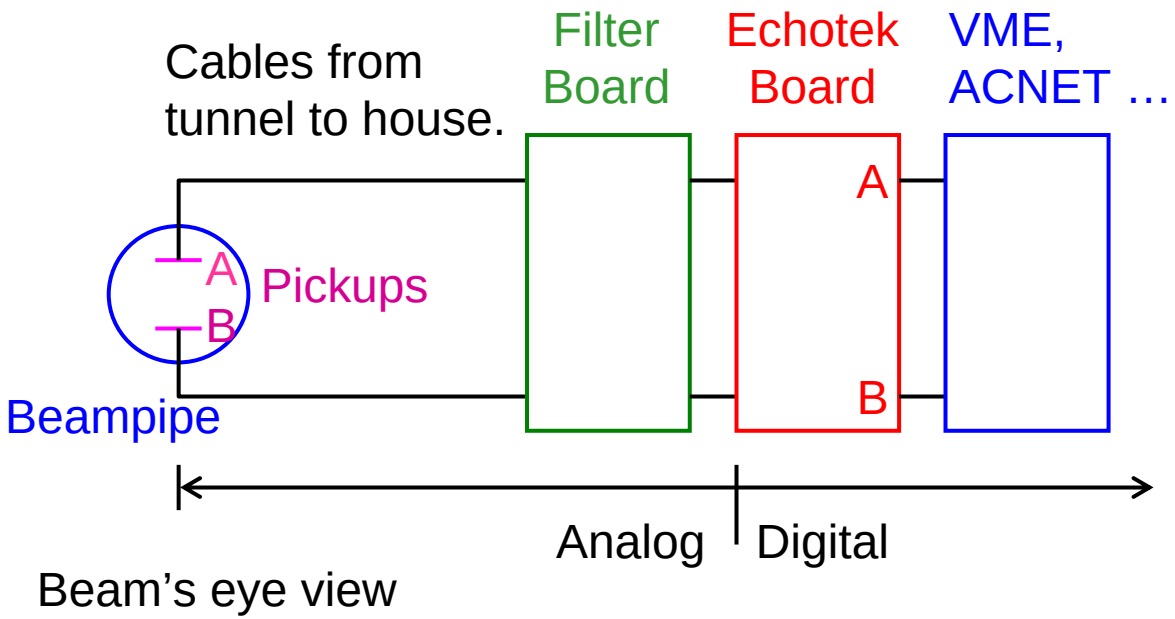
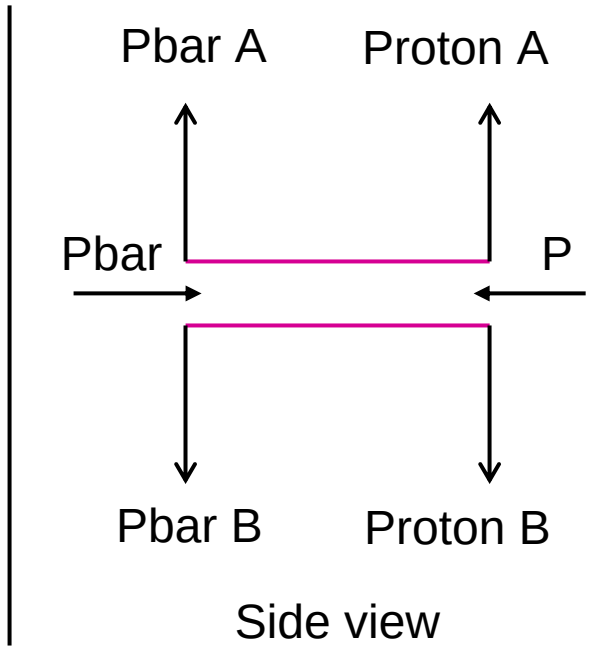
Goals of the Upgraded System

- Must be more robust than the old one.
  - Old system sometimes delivered stale data.
  - Margaret's group will ensure this is correct.
- See Pbars simultaneously with P.
  - Has been demonstrated.
- Improved resolution.
  - Has been demonstrated.
- We are still working on the final calibration methods to get the best precision and accuracy.

Cartoon of the System





- A and B are complex numbers.
- Given measured $(A,B)_{Proton}$ and $(A,B)_{Pbar}$
  - Compute the position and intensity for both protons and Pbars.

Overview of Calibration

- Survey offset (mechanical offset).
- Response of the pickup when there is a single beam species in the machine.
- Differential attenuation and delay of A and B in the analog sections, up to and including the digitizers.
- Imperfect directionality of pickups: important when both beam species are in the machine.
- Digital world should have no measurable channel to channel variation.
- Some calibrations depend on operating mode and the pattern of bunches in the machine.

Operating Modes

- Closed Orbit Mode (CO)
  - Average position over many orbits and all bunches.
    - If betatron or synchrotron motion is present, average it out.
  - Compute both P and Pbar positions.
- Turn by Turn Mode (TBT)
  - Average proton position for each turn.
  - Single bunch of protons only.
  - Typical use is to kick the beam and to watch its motion.
- Injection Turn by Turn Mode (ITBT)
  - Special case of TBT, triggered by injection.
  - Automatically enters closed orbit mode on completion.
- Short gate Mode (SG)
  - Average position over a small number of bunches (2?).
  - Compute both P and Pbar positions.
  - Separate Pbar from P by timing. Not always possible.

Requirements: Beams-Doc-554

Property	Proton	Pbar
Measurement Range	±15 mm	±15 mm
Absolute Position Accuracy	< 1.0 mm	< 1.0 mm
Long Term Position Stability	< 20 μm	< 20 μm
Best Orbit Position Resolution	< 20 μm	< 50 μm
Position Linearity	< 1.5%	< 1.5%
Relative Position Accuracy	< 5%	< 5%
Intensity Stability	< 2%	< 2%

- Numbers are "3σ" requirements (normal AD practice).
- Requirements above are for closed orbit mode.
  - Some requirements are relaxed for other modes.

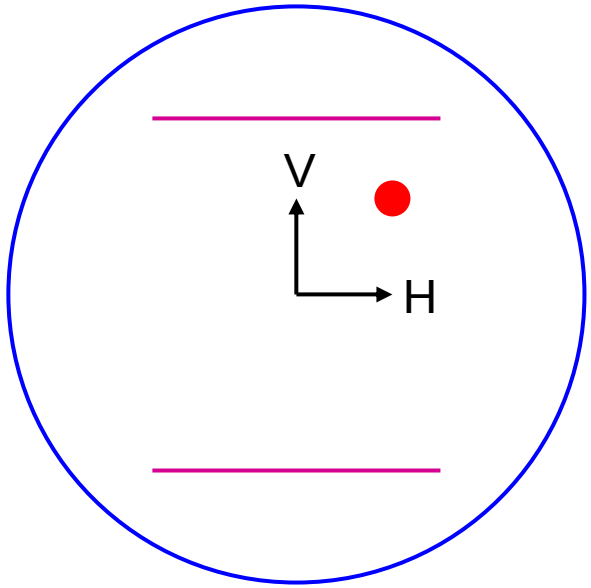
My Comment on Requirements

- If we miss the requirements by a little bit, the system will still work.
  - I am not aware of any cliffs that we can fall off of if we miss the specs by a little.

Precision and Accuracy

- Absolute accuracy is a much, much poorer than the resolution (precision):
  - Resolution on any one closed orbit measurement is of the order of 10 μm (1σ).
  - Spec for absolute accuracy is 330 μm (1σ).
- Absolute accuracy is probably dominated by the physical alignment of the pickup plates wrt the quadrupoles.
  - Known from surveys done during assembly 20 years ago.
  - I have the measured offsets but I have not yet found anyone who can tell me the error on these measurements!
- Tevatron department knows how to use a superb stability monitor, even if the absolute calibration is poor.
- Must avoid the temptation to chase small but irrelevant effects.

The Orthogonal Coordinate



- This BPM measures V.
- Response also depends on H.
- The effect of H is, at most, a few hundred microns in V.
  - Beams-doc-1076
- The plan:
  - Will not correct online.
  - Will correct offline.

Model of Pickup Response

$$A = I_0(1 + \frac{P}{g}) + kP^2$$

$$B = I_0(1 - \frac{P}{g}) + kP^2$$

- Model is valid when on axis in orthogonal coordinate.
- I_0 = true beam intensity
- P = true beam position
- g,k parameters of the pickups.
  - There are 4 classes of pickups.
  - Parameters are believed to the same for all BPMs within a class.
- Given A,B,g,k: solve for I_0 and P.

Differential Attenuation

$$A = I_0(1 + \frac{P}{g}) + kP^2$$

$$B = t\left[I_0(1 - \frac{P}{g}) + kP^2 \right]$$

- t = differential attenuation.
- 0.1 db error in t gives to 150 μm position error.
- Using a grid study one can solve for t.
- Old system parameterized this as an “electrical offset”, not a multiplicative correction.

Cancellation of Proton Signal on the Pbar Cables

$$A'_{Pbar} = A_{Pbar} - aA_P - bB_P$$
$$B'_{Pbar} = B_{Pbar} - cB_P - dA_P$$

- a,b,c,d are complex numbers which change from one BPM to the next.
  - Depend on properties of pickups, cables, fitlers.
  - Scale is mm early in Pbar injection.
- Scale of Pbar contaminating Protons is currently of O(50 μm); will worry about this later.

What We Have Done (1)

- Proof of principle measurements: CO, TBT, SG.
  - Only injection TBT is missing.
- Measured the resolution in CO and SG
  - Actually we bound resolution from above since there is true beam motion that we cannot remove.
  - Demonstrated stability throughout a store.
- Demonstrated Pbar measurements in presence of protons for both CO and SG.
  - Results differ by 600 μm.
  - Need to track this down.

What We Have Done (2)

- Observed the effect of the parameter k (the quadratic term in the intensity).
- Observed the effect of differential attenuation and learned how to remove it using a grid study.
- Demonstrated CO mode for:
  - A batch of 30 uncoalesced bunches in RF consecutive buckets.
  - Standard 36x36 coalesced bunches.
  - Single coalesced bunch of protons.
  - These all give the same position.

What We Have Done (3)

- 1113/5 is not an integer
  - Gives rise to phase artifacts when trying to combine several measurements into one.
  - We know when this hurts us and how to work around it.

What Am I Doing Now

- I am preparing a summary of all of the effects we know about:
  - How big are they?
  - On what time scale do they change?
- Expect to be done in < 2 weeks.
- From this I will develop a plan for the remaining work.
  - Some things will be ignored because they are masked by larger effects.
  - We will have to make some decisions about what is on-project and what is off-project.

Later On (Maybe off project?)

- My guess is that anything which requires non-trivial knowledge of beam physics to correlate data from multiple BPMs is off project.
  - Effect of beam not being parallel to the pickups.
  - Lebedev effect: bunch axis has a yaw and pitch wrt its direction of travel.