BI WP13 Task Meeting #13 - BPM Electronics (#2/2020)
13 July 2020

The indico site for the meeting can be found here:
https://indico.cern.ch/event/934174/

HL-BPM Specification Update (M. Wendt)
Latest version 02-06-2020
Beam parameters from WP2 presentation on BPM. Riccardo, Davide & Rogelio presented specifications for HL-LHC BPM:

Particle	Bunch charge		# of bunches		Min. bunch spacing [ns]	Bunch length FWHM [ns]	
	min	max	min	max		min	max
Protons	5e9	2.3e11	1	2760	25	0.7	1.2
Ions	5e9	1.6e10	1	1232	50	0.7	1.2
Pilot (p or ions)	5e9	1e10	1	3	(25)	0.7	1.2

Discussion with D. Gamba, R. de Maria & R. Tomas

- Doublets not foreseen
- Bunch length given in FWHM
    - FWHM stated regardless of distribution, used as in synchronous loop and ~= 4 sigmas. The rms will depend on the stage of the fill.
    - Expected at beginning becoming more Gaussian like at the end

BPMs concerned:

Type	Two beams	Operation range (OP) [mm]	Max. range for studies	Bunch spacing [ns]
Arc	no	±9	±18	25
Matching section	no	±12	±24	25
Triplet point 2/8	yes	±14	±27	6
Triplet point 1/5	yes	±29†	±58‡	3.8

† For BPMQSTZA: ±25 mm

‡ For BPMQSTZA: ±50 mm

- Accuracy will be considerably reduced at maximum range.
- Almost full aperture will be filled at triplets. Where beam +-50 mm we may have trouble to cover with type B BPM.
    - Riccardo: this case will be when we want to measure aperture, to approach aperture with orbit bumps with safe beam. So less important not to have a good number.
    - Davide: refer to operating range at the end of document.

Measurement modes:

Measurement	Frequency	Quantity
Orbit mode (CO)	25 Hz	Continuous
Trajectory mode (TR)	~0.1 Hz	1-2 pilots, 20 k turns, on demand

Reproducibility:

Reproducibility timescale	Usage	Class
Bunch-by-bunch	Optics measurement and correction, steering at injection	TF
Stable Beam (~10 h)	Keep orbit during optic changes, IP position stabilization	CO
Fill to flll (~24 h)	Find collisions after a refill, ensure machine reproducibility	CO

Timescale added for various reproducibility requirements

Timescale	Arc and MS BPMs	Triplet BPMs	
		Point 1/5	Point 2/8
Stable beam (~10 h)	±20 µm	±2 µm	±10 µm
Fill to fill (~24 h)	±28 µm	±28 µm	±28 µm

+-2um a real challenge

BPM Errors:

- Offset - Valid for all beams.
  - Declared in document as between mechanical & electrical offset of the BPM pickup (final accuracy wrt a given reference, e.g. magnetic centre not included), but should include “electronics” offsets.
- NEW - B1 v B2 relative accuracy
  - Position difference for crossing and separation: ±1 % (~±40um)
- Long term stability in orbit mode:
  - Most stringent for triplet BPMs in IP1 & 5, to keep lumi as high and stable as possible (+- 2um within a fill ≈ 0.2 sigma of beam!), necessary if BPM used for feedback on lumi.
- Calibration error
  - Single pilot bunch between two calibrations
- Polynomial correction = zero term + BPM tilt effect + nonlinearities.
  - Tilt and calibration error are defined over a given range for these errors.
  - If calibration error ≤ 1.6% in IP1 & 5, then higher order terms in polynomial required
  - What is the difference between noise and resolution? You cannot have better noise than resolution; resolution is uncorrelated noise.

Specifications retained as "challenging":

- Calibration error ±1.6 % (TR, P 1/5)
- 2 x Std($xerror$) ±2 µm (CO, 10 h, P 1/5)
- Noise n.a. ±30 µm (TR, P 1/5)

- Resolution ±15 µm (TR, P 1/5)

Make sure we have enough beam time to test!

Discussion:

- Rhodri: Single pilot calibration? Davide: we need pilot because orbit adjustment done with pilot.
- Manfred: calibration is based on single bunch between 2 runs.
    - We check for electronics offset from fill to fill.
    - Non-linearity is not included. We use wire-based measurements to correct for BPM pickup non-linearity's, but this is done only once. We have to assume they do not change. True if no issue with mechanics. To be tested to confirm this assumption.

- Noise v resolution & precision
    - **ACTION: BI to provide ABP with glossary to agree on terms**

- Can DOROS be retained?
    - We should not run with 2 readout systems in parallel, this may alter result
    - Not for specification, DOROS has a negative effect on the performance due to additional unwanted signal reflections
    - Will depend on performance of new system & final specifications, but in principle we should get to the same resolution as with DOROS for a similar overall bandwidth.
- Thibaut comments that Van de Meer scan requirement need to be included (where DOROS used today)
    - ± 5um in IP1 & 5 seems large wrt what is currently requested
    - **ACTION: Riccardo to contact Anne Dabrowski for VdM scans**

- Calibration repetition between pilot?

- Doug: Charge differences specs for charge varying from 5e9 to 2e11? What is the time scale? What important for electronics is the charge imbalance. Manfred: either you have pilots, or nominals, but when nominals one cannot measure a pilot bunches in the beam with high accuracy and resolution. Attenuated settings will be used, but the measurement performance degrades if the bunch intensity dynamic range within the filling is larger than ~ factor 3.
    - Riccardo: Decay of bunch population during fill up to 2-3 for some bunches
    - Special filling schemes studies/special runs
        - Weak-strong MD
        - p-Pb x10?
    - **ACTION: ABP Extreme conditions (upper & lower intensity bounds) to be included in specification**

Update on Electronic Development (D. Bett)

Open Actions follow-up:

- Electronics being simulated
- Bunch length variations to be considered
  - Now included in the simulation. 0.7 – 1.2 ns (FWHM) of Gaussian assumed for the moment.
- Can VNA style corrections be used?
  - Unlikely. A method of recovering the individual beam signals from the set of waveforms was implemented but performed less well than the other methods. Also, very computation resources intensive.
- Use on-board DACs to generate bunched beam calibration signals
  - Pending
- RF full detuning effects to be considered
  - Pending **ACTION: Rhodri to send Doug references to this**
- Can an algorithm be found that does not need beam signal based correction
  - The VNA method, but it has already been ruled out

Corrections considered

- Waveform correction
  - Sample-by-sample adjustment of the amplitude of the waveform samples
  - Requires template waveforms making assumptions about the undisturbed bunch signal waveform
- Power correction
  - Adjustment of the calculated power of the waveforms
  - Requires template waveform to calculate power correction parameters
- VNA-style correction
  - Beam-independent, but requires precise knowledge of the stripline S-parameters

Power compensation retained as most promising
Looking to achieve 2um stability in orbit over a fill

- For 1 beam
  - Factors affecting position (everything else remaining constant)
    - Bunch length < 10 um change
    - Bunch charge <10 um change
- For 2 beams - BPM closest to IP
  - Without compensation up to 180um shift
  - With correction reduced to ~1um
    - Adding non-linearity this shift likely to already be at 2um
  - Changing bunch length <0.5um effect
  - Changing beam charge
    - Worst case factor 10 difference - e.g. p-Pb
      - Large charge beam OK

- Small beam 100um shifted

Conclusion that any static offset not too critical, what counts is change relative to this "static offset" position during the fill

- **Other sources of drift to be considered at later stage - cables, temp, …**

ACTION (Doug):

- **Study nominal beam positions at these BPMs**
- **Look at normal conditions with a up to factor 2 variation in bunch charge**
- **Look at effect of small position changes of 1 beam from nominal**