SPS Beam Quality Monitor: recap & cheat sheet

T. Bohl, G. Papotti, F. Follin, U. Wehrle
outline

• system specifications
• block diagram and acquisition structure
• algorithms
• examples of rejection criteria
• GUI screenshots
• Q&A, cheat sheet
system specification

- decision in the SPS whether to extract to the LHC, aiming at
  - reducing losses at the LHC
  - avoiding stressing LHC Machine Protection components
  - ultimately improving LHC luminosity
  - optimize efficiency (tens of seconds vs tens of minutes!)

- decide as late as possible in the SPS cycle
  - instabilities not to develop after the measurement
  - time available: “few” $T_{\text{synchrotron}}$
    - $T_{\text{synchrotron}} \approx 3.5 \text{ ms at the flat top with Q20}$

- connected to BA3 BIC
  - final decision pull emergency beam dump, or not
  - also clock selection interlock in on BA3 BIC

- acceptance thresholds given through user interface
  - for some criteria can improve quality or reduce LHC filling time
SPS BQM specifications

- **Level 1**: protect the LHC machine against equipment damage
  - successful synchronization between the SPS and LHC
    - avoid the injection of an SPS batch on top of a batch already circulating in LHC, or injecting an SPS batch into the abort gap

- **Level 2**: avoid extraction of beam outside a given specification
  - although not harmful, would unnecessarily stress LHC machine elements or degrade the LHC luminosity
    - if these parameters are outside specifications the beam will not be fully captured in LHC, stressing the momentum collimation system
  - individual bunch phase, bunch length and longitudinal emittance, ghost bunches, stability of individual bunches

- **Level 3**: ease operator’s life
  - not in LHC Design Report!
  - reject too weak or too different bunches

1 & 2: straight out of LHC design report
reasons not to extract

• Level 1: protect the LHC machine against equipment damage
  – first bunch position wrt LHC reference
  – pattern (any one bunch missing, extra or misplaced)
  – max number of bunches
  – acquisition missing or saturated (then can’t judge!)

• Level 2: avoid extraction of beam outside specification
  – bunch length: min, max, spread
    • accept a certain number of too long bunches
  – satellite bunches (2 algorithms): max
  – stability (2 algorithms): max

• Level 3: ease operator’s life
  – bunch peak: min, max, spread
  – bunch intensity: min, max (+doublets)
- ADC for digitizing the Wall Current Monitor bunch profile (8 GS/s, ~8 bits)
  - plus 2 attenuators, one PPM and one non-PPM
  - operators to act on the PPM one only
- VME Trigger Units (VTU) for synchronization to the exact bucket ($f_{RF}$)
- CTRI for synchronization to machine cycle
- CTRI for output to Beam Interlock System
acquisition structure

- beam profile acquisitions and evaluation:
  - after each injection for initial bunch parameters (no interlock)
    - bunch length, peak amplitude, fine position
  - after capture for beam pattern and satellites
  - at flat top for final bunch parameters and stability
    - check also 1st bunch position w.r.t. $f_{RF,LHC}$ and $f_C$

8 profiles (10 us), 26 turn spacing (fast analysis)

25 profiles (10 us), 1 turn spacing (longer analysis)

1 profile at first turn (warnings, no interlocks)
software: FESA class

- FESA for synchronization to machine cycle
- ABQMSPS class contains 4 Real Time Actions (RTAs)
  - i.e.: download ADC data, perform analysis, setup next acquisition
  - on automatic restart on cfi-ba3-allbqm

![Graph showing momentum and time relationships with RTAs highlighted]

RTA: bunch parameters at flat top + stability + 1st bunch position
RTA: pattern + satellites
RTA: bunch length at inj
RTA: setup first acquisition
what can cause dump?

- no beam, including beam out of acquisition window
  - also refuses saturated acquisitions (high or low)
- wrong beam pattern
  - any one bunch missing, extra or misplaced, wrong PS batch spacing
    - pattern reference information from GUI when SPS mastership, from LHC Injection Sequencer when LHC mastership
  - 1st bunch in wrong position at the flat top
    - checks rephasing and injection bucket from PS
  - any number of satellites (2 algorithms)
- bunch parameters
  - too long or too short bunches, too different length (rms)
    - allowed number of bunches above threshold
  - ADC waveform peak min/max, rms spread
  - intensity min/max (integral of ADC waveform in units of ADC counts)
- beam unstable (2 algorithms)
- doublets: min/max intensity split
  - but no check of stability
- note: can be disabled via software
algorithms: full width half max

- for bunch parameters
  - bunch length
  - peak amplitude
  - fine position
  - bunch length
    - standard measure is $4\sigma$ on gaussian fit
    - for ideal gaussian can scale fwhm to $4\sigma$
      - $\tau_{\text{fwhm}} \sim 0.5887 \tau_{4\sigma}$
    - scaling done internally
      - user sees only $4\sigma$ values in the FESA class interface
      - n.b.: $4\sigma$ is not 100% of particles, threshold should not be 2.5 ns
algorithms: stability

- 8 acquisitions spaced a fraction of $T_{synchrotron}$
  - method 1: subtraction algorithm
    - good especially for dipole oscillation detection
  - method 2: peak amplitude stability
    - good for quadrupole oscillation
- very fast, but only $\sim 0.4$ ns precision
algorithms: satellites

- from main bunches reconstruct bucket structure
  - use bucket edges to cancel baseline wander due to WCM and cables
    - n.b.: assumes no debunched beam -> acquisition during ramp
  - interpolate to have integer number of points per bucket
- method 1: data point at mid-bucket
- method 2: signal integration within buckets
GUI screenshots - 1

- GUI master: Fabio Follin

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• history for bunch length, peak, intensity statistics

...can use this to set reasonable thresholds on peak or intensity!
GUI screenshots - 3

- bunch length, peak, intensity per bunch for the latest cycle

![Graphs showing bunch length, peak, and intensity](image)

- e.g. 8b+4e
  - can use these to talk back to PS and PSB in case of too big differences
• history of number of bunches, satellites and oscillations
• raw ADC waveforms available (if enabled):
  – flat bottom, ramp, flat top
  – ramp after averaging among waves
    • only if analysis successful, good to verify satellites by eye
other tabs, not shown here:

- injection beam parameters:
  - length and peak, bunch-by-bunch
  - length and peak statistics history
- satellites per bucket
- doublets:
  - doublet intensity split per pair
  - doublet intensity split statistics history
warning messages: examples

• at the bottom of the GUI: **read them**!
• from signal levels:
  – no beam
    • also if beam out of acquisition window!
  – not enough dynamic range
  – scope saturated (high/low)
  – can increase sensitivity
• at injection
  – too long or too short bunches from PS
  – wrong injection bucket
• misc:
  – acquisition not done (setup problem, call me or Thomas!)
  – analysis failed (software crash)
  – doublets expected (if verify doublets = enabled)

Thomas’ note:
all data is logged, and
often used for offline analysis...
a bad setup is lost information!
cheat sheet

• no measurements (all red)?
  – check if acquisition saturated or attenuation too high
    • pattern and satellite measured in the ramp, all others measured at flat top
  – check in console messages if setup is correct
    • eg VTU, acquisitionTimeOut: to be setup by experts
    • eg number of injections: max number to be set in sequence editor
      – there is a warning in the GUI

• pattern?
  – check if pattern setup correctly in GUI (number of injections, bunches, PS batch spacing for all injections)
  – check injection bucket and its increment (batch spacing), number of requested injections
  – check if there are some very low intensity bunches on fBCT (<20-30%)
  – for ions, might have a bucket jump at transition

• satellites?
  – check injection phase, injected bunch length
  – check averaged waveform in the ramp for visual cross-check
  – check if total voltage is too low, or voltage dips are too deep
cheat sheet

• all measurements at flat top are missing?
  – check if beam dumped earlier in the cycle
  – check if acquisition saturated, or attenuation too high
  – check rephasing (beam out of acquisition window?)

• only fail is first bunch position at flat top?
  – check rephasing, also vs extraction bucket monitor

• beam unstable?
  – check controlled emittance blow up
  – check 800 MHz (e.g. on or off?)
  – check rephasing

• intensity or peak?
  – check if there is too much spread (talk to PSB, PS?)
  – check with LHC what is “too much” spread (is it acceptable or not?)
  – note that changes in attenuation affect the measurement

• if *not* on local clock (on LHC clock, and LHC not at inj frequency)
  – likely to get first bunch position, stability, beam out of acquisition range, no beam at flat top
any questions?