

LHC Beam Operation Workshop – Evian, 7th December 2010

Beam quality and availability from the injectors

Giulia Papotti

after discussion with

G. Arduini, T. Bohl, A. Butterworth, H. Damerau, J. Emery,
S. Gilardoni, S. Hancock, W. Hofle, L. Jensen, G. Rumolo,
E. Veyrunes, J. Wenninger...

outline

- list of delivered and available beam parameters in 2010
- transverse size
 - transverse blow up (PS and SPS)
 - scraping
 - measurements: wire scanners
- intensity
- bunch-to-bunch equality
 - intensity
 - bunch lengths
- longitudinal plane
 - BQMSPS
 - RF improvements (rephasing, 800 MHz, ...)
- satellites
- timing
- communication
- statistics

delivered beam parameters

- 2010 roadmap:
 - March 30th: 2+2 fat pilots
 - May: ramp nominal bunches
 - July: 4 bunches per LHC injection
 - September: 150 ns spacing (8-16-24-32 bunches per LHC injection)
 - early November: 50 ns and 75 ns spacing short runs
 - ions: 1, 4 or 8 per LHC injection
 - that meant:
 - LHC bunch spacing: pilot, 50, 75, 150, 500, 1000, 1250, 2500 ns
 - PS batches: 1 to 4
 - PSB rings: 1 to 3
 - different batch spacing at the SPS
 - while trying to increase bunch intensity, decrease emittance, and play around with longitudinal emittance
-
- ...a lot of flexibility!
 - PSB: $\varepsilon_{x,y}$, N ppb
 - PS: bunch spacing, transverse blow up
 - SPS: transverse + longitudinal blow up, and packing together bunches

PSB parameters

Type of LHC beam (multibunch)	ρ / ring @ PSB ($\times 10^{10}$)	ρ / bunch @ SPS ($\times 10^{11}$)	$\epsilon_x + \epsilon_y$ (μm) (at booster extr)
150ns	50	1.1	2.5
75ns	100	1.1	3.5
50ns (single batch)	160	1.1	5
25ns (double batch)	160	1.1	5
Ultimate 50ns	230	1.6	7
Ultimate 25ns	250	1.7	8
50ns (double batch)	80	1.1	3

Beams injected into LHC

Beams sent to PS/SPS

(G. Rumolo)

- remarks:
 - 75/150 ns: produced with $\epsilon \ll \text{nominal}$ + PS/SPS blow up
 - 50 ns double batch allows lower ϵ , operational until 2008
 - 50 ns single batch for nominal ϵ (25 ns is the only double batch now)
 - ultimate 25/50 ns up to SPS, in MDs
 - losses at SPS still significant, big emittances (x,y,z)
 - compatible with TMCI threshold at inj of about $1.6e^{11}$ ppb
 - SPS optic with lower γ_t pushes the threshold higher, studies ongoing
 - more electron cloud was measured with higher intensity 25ns beams, no clear trend was observed with 50ns beams

transverse blow up

- from LHC Design Report: $\varepsilon_{x,y} = 3.5 \mu\text{m rad}$ at LHC injection
 - but $\varepsilon_{x,y}$ produced is smaller
- at PS done by changing the tune and coupling the two planes
 - only 1 knob, very reproducible, PPM for free
 - but tried also:
 - mis-steering injection trajectories, and injection optics
 - not enough blow up obtained
 - transverse damper + octupoles (used for MTE)
 - would be best, but controls not PPM
 - always counted on additional blow up at the SPS
- at SPS done with transverse damper + octupoles
 - now not PPM, not integrated into control system
 - PPM needed due to different intensities, emittances, ramp rates in the different users
 - verifications on orbit, tune and octupoles to be done prior to blowing up
 - plan: use of CVORG board developed by BE-CO
 - already chosen for new long. blow-up in SPS
 - in the pipeline of BE-RF-CS projects (but after long. blow up)
 - will still need reproducible tunes, tune spread and chroma

scraping

- “cleaning of the tails of the beam distribution down to $3-3.5\sigma$ by means of fast scrapers”
 - LHC Design Report vol III, chapter 12
- issues/stops in 2010
 - only one scraper (BA5)... some cables broke 4 times
 - as it was fragile, at some point turned on only when filling
 - too close at injection, and so already scraping
 - for nominal LHC protons
- foreseen improvements for 2011
 - add one + spare: in BA1
 - cables that broke will become springs – should be less fragile
 - will try and move in as late as possible in cycle
 - to avoid scraping at injection
 - add BLM for scraper protection
- extra transverse blow up needed due to scraper
 - not really tails only: often scraped 5% of beam
 - try and measure tails before and after scraping

(E. Veyrunes)

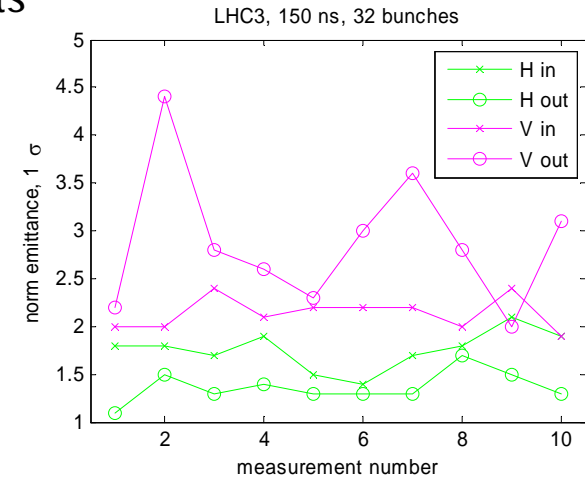
transverse size measurement

- now:
 - no continuous, online, non-destructive measurements
 - i.e. why not “Ionization Profile Monitor”
 - no bunch-by-bunch measurement
- wire scans
 - not precise enough on small ε and low intensity: need the linear (517)
 - known systematic differences between IN and OUT
 - plan upgrade the SW for 416 and 517
 - include the saturation detection (from PSB)
 - PS: mechanical fatigue on bellow
 - impact on statistics
 - OP happy about support
 - but measurements difficult for shift crew

517 system full upgrade:

- Mechanical (position sensor exchange)
- LHC electronics installation
- New crate with MEN-A20 CPU
- Software porting on Linux platform

(J. Emery, A. Guerrero)

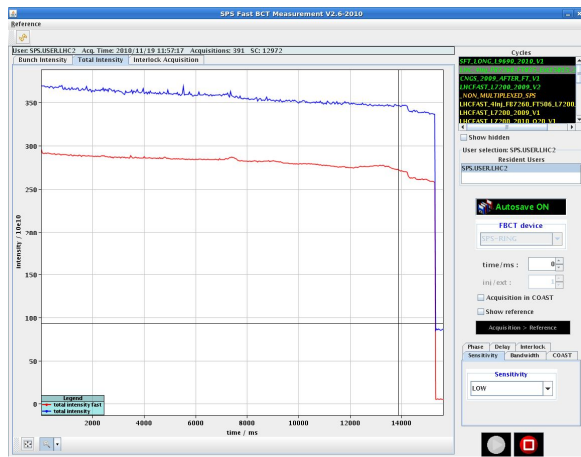


sample 10 wires per plane by SPS crews

SPS Device	Scanner Type	Electronics	Status	2011 run
414 H & V	Rot long	90's	H: Motion card issue V: OK	
416 H & V	Rot short	LHC	OK	SW upgrade & 40MHz test
517 H & V	Linear	90's	Unavailable	HW & SW upgrade & 40MHz test
519 H & V	Rot long	90's	OK	
521 H & V	Linear	90's	OK	

intensity

- 2010 “request path”: LHC talks to SPS, SPS talks to PSB, PSB regulates
- PS
 - more sensitive electronics for low-intensity beams to be commissioned
 - BI follow-up: remove auto-calibration feature
 - causes precision not to be better than 5%
 - improve cross calibration between ring and TT2 transformers
- SPS
 - used DC-BCT for absolute values
 - agrees well with PS measurement (ring to ring)... and divide by n bunches to get ppb
 - threshold on DC noise level is an expert setting
 - then F-BCT for bunch-to-bunch equality



extra noise integrated (signal also after dump)

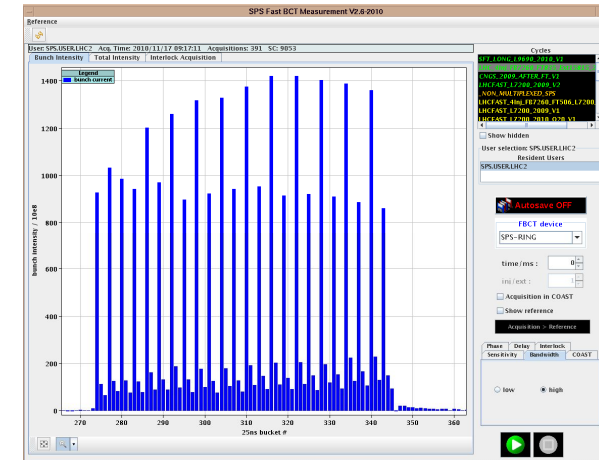
DC BCT
fast BCT



noise threshold regulated (fast and dc overlap well)

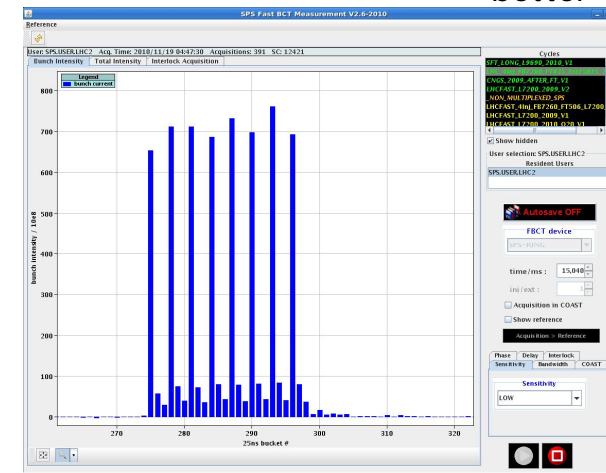
bunch-to-bunch equality – 1 –

- design tolerance: +/-10 %
 - due to transient beam loading at PS splittings
 - beams produced within the design spec for nominal intensity
- transverse emittance
 - no way to measure bunch-by-bunch in injectors
- intensity
 - look at SPS F-BCT, in relative terms
 - F-BCT absolute calibration wrt DC not obvious
 - need to scan sampling phase (40 MHz only)
 - impossible to use it for satellite detection
 - not enough bandwidth gives tails (up to 10%, 2 slots)
 - long cables to the surface?
 - interlock in LHC SIS with F-BCT data in place
 - not operational yet
 - absolute values / tolerances are tricky
 - manual interlock (MKI switch) in the meanwhile
- possibility to add checks in BQMSPS
 - for standard deviation on bunch lengths or peaks



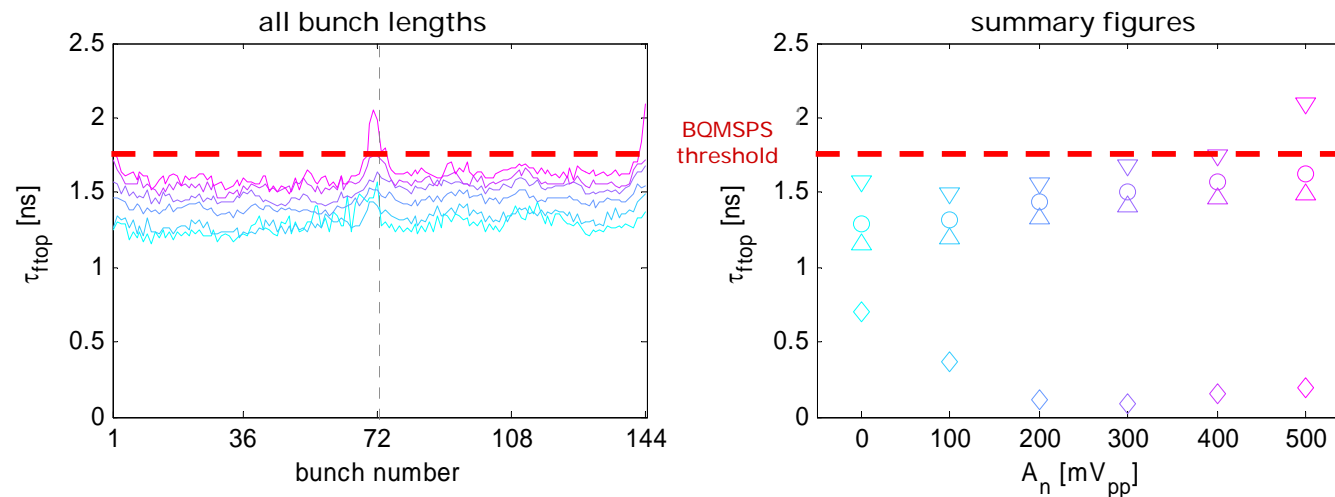
not so equal

better



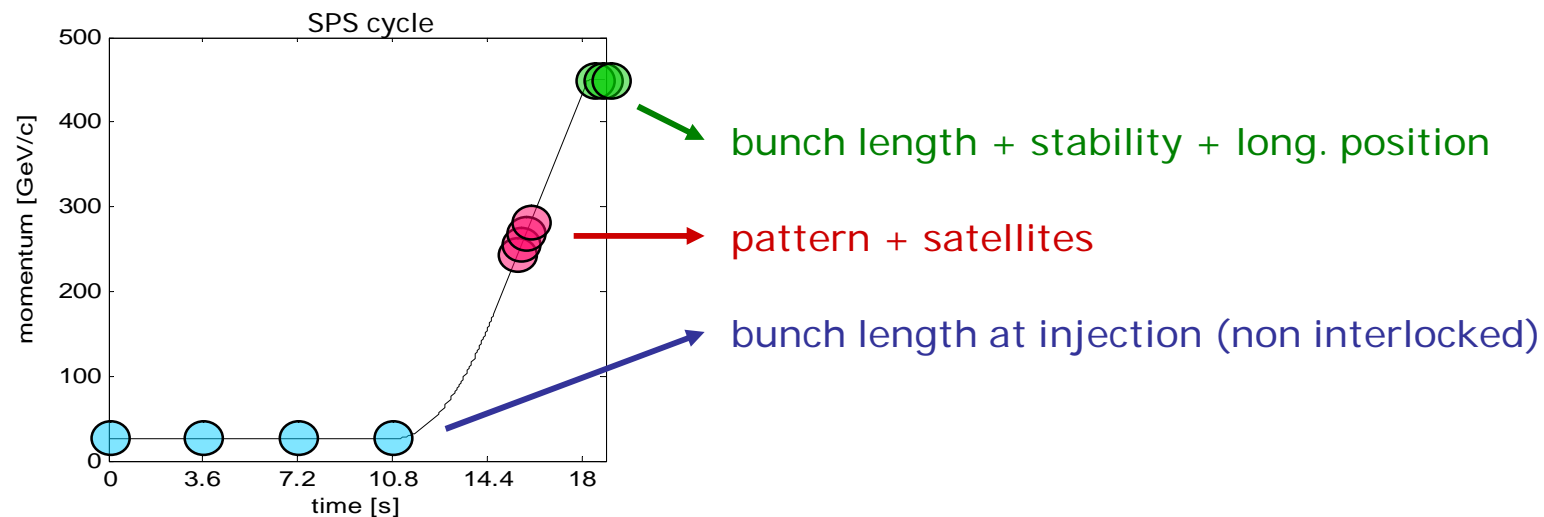
bunch-to-bunch equality – 2 –

- bunch length example
 - $1.1e^{11}$ ppb, 25 ns spacing, 2 batches,
 - data from BE-RF-BR SPS MD on July 9th 2008
- increasing controlled noise increases bunch length and improves stability
- bunch lengths get more equalized
 - but some spread always remains
- too much noise makes bunches too long



BQMSPS -1-

- automated analysis of longitudinal beam profile
 - wall current monitor beam profile
 - FESA class controls ADC and performs analysis
 - connected to emergency beam dump
 - if beam not good, dump already at SPS
 - rather than at the LHC



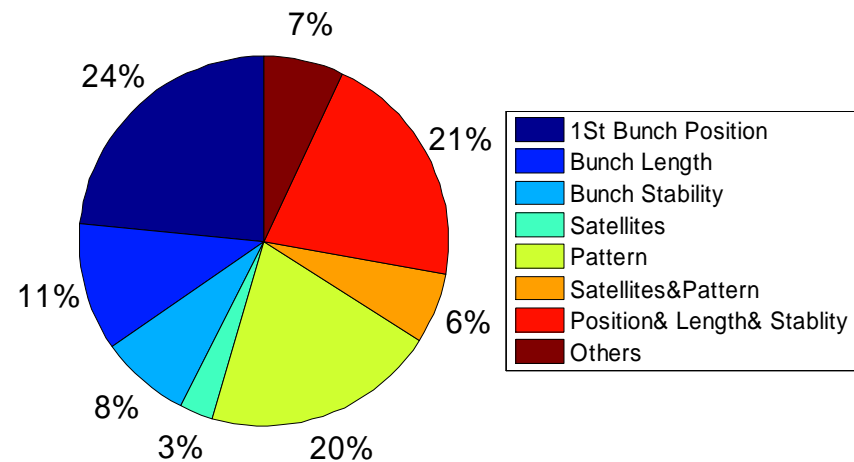
BQMSPS -2-

- it caught:
 - rephasing not working correctly
 - fully debunched beam, missing PS LHC-cavities
 - or no beam at all
 - not enough or too much long. blow up
 - very bad injection phase or bad PS splittings
 - injections in the wrong bucket, missing injections

BEAM.OK: logical "and" of all others

Time	Cycle Name	Dump	Beam	1st Bu pos	Bu length	Stability	Satellites	Pattern
18:04:43	LHCION2	Enabled	Ok	Ok	Ok	Ok	Ok	Ok
18:00:02	LHCION2	Enabled	Error	Error	Ok	Ok	Ok	Ok
18:01:36	LHCION2	Enabled	Error	Error	Error	Error	Error	Error
18:10:57	LHCION2	Enabled	Error	Ok	Ok	Error	Ok	Ok
18:10:26	LHCION2	Enabled	Error	Ok	Error	Ok	Ok	Ok
18:02:38	LHCION2	Enabled	Error	Ok	Ok	Ok	Error	Ok
17:59:00	LHCION2	Enabled	Error	Ok	Ok	Ok	Ok	Error
18:00:02	LHCION2	Enabled	Error	Error	Ok	Ok	Ok	Error

- statistics
 - by G. Trad, A. Apollonio
 - thanks also to the database people
 - calculated on fills 1000-1535 for modes injection probes and physics
 - 20% of the incoming beam are stopped



- new in the CCC jargon: "On a eu un BQM"
 - possible translation: "the beam did not come, try again"

RF improvements: SPS

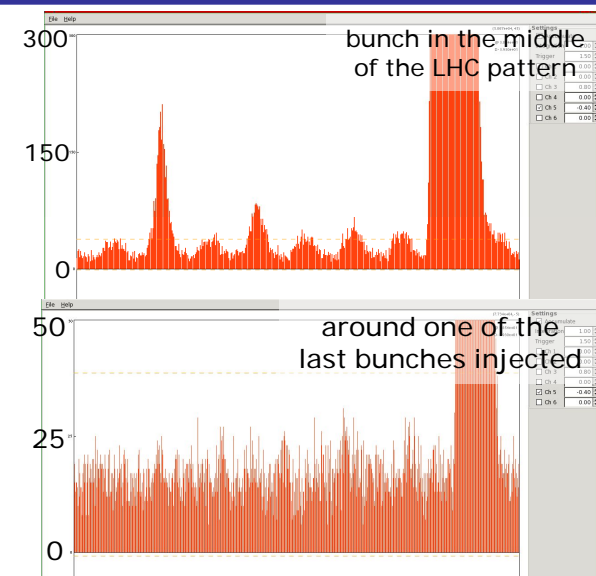
- BQMSPS
 - pattern to be sent via LHC Inj. Sequencer or set via SPS GUI
 - at the moment use handwritten file
 - satellite sensitivity 3% now, new hardware required for better performance
 - will need time to test, while old system operational
 - components being ordered
- LHC-SPS rephasing
 - training always a pain, especially at overinjection!
 - best found for this year: b1 training on SPS dump, b2 different training + playback
 - late pilot injection next year?
 - next year: same settings for b1/2 while LHC b1/2 frequencies are locked
 - small software change needed, and promised
- longitudinal blow up
 - now: not PPM, settings not readable, Labview interface
 - FESA version being tested and operational for sometime next year
 - many settings from LSA (f-synch, noise amplitude, spectrum shape)
 - new GUI
- 800 MHz system
 - present difficulty: no diagnostics in CCC
 - sometimes locked on the wrong harmonic, or not locking at all
 - coming up
 - alarm if free running frequency too far, at flat bottom and flat top
 - 800 MHz LL + amplifiers upgrade (also remote control), for later
- plan to make SPS frequency program playback PPM (to be tested later in 2011)

RF improvements: PS

- 80 MHz cavities
 - 3 cavities: 2 operational and one spare
 - spare re-tuned to a different frequency for ion operation
 - problem during parallel operation of ion and protons if one cavity has problems
 - 1-hour stop between ion and proton operation to tune, frequent trips...
 - mechanical tuner foreseen to become automatic
 - for pressure and temperature changes
 - two streams of thought
 - some think one extra 80 MHz cavity at the PS would not be bad
 - others don't want extra impedance
 - better to improve reliability of the existing system
- ideas for a "PS Beam Quality Monitor"
 - continuous / online monitoring of longitudinal parameters
 - some information could be fedforward to LHC SIS
 - do not let in LHC if bad shot
 - could even look at OTR screens for transverse emittance?

satellites

- JJ.Gras and the LHC Long. Density Monitor
 - explains difference between the 2 BCTs
 - measurement integrated over 50 min during stable beams, fill 1515, b2 only available
 - bunch peaks are around 80000 counts
 - noise baseline around 10 counts per bin
 - many 2.5 ns buckets populated due to RF gymnastics at flat bottom
 - some 5 ns structure from injectors
 - from experiments (VdM scans)
 - presented at “Bunch Current Normalisation Working Group Meeting”, Nov 29th 2010
 - ATLAS, fill 1386
 - some events are present at 75.0cm (and less at 37.5cm)
 - contribution $< 10^{-3}$
 - ALICE, fill 1514/1515
 - structures with 37.5 cm spacing, up to 3-4 m from IP
 - charge $\sim 10^{-3}$ of main pea/k
 - ALICE, fill 1522:
 - Charge at 1.5 and 2.25 m, $\sim 1\%$ of main bunch
- (75 cm \Leftrightarrow 2.5 ns)
- down to 3% checked in BQMSPS
 - no complaints so far ... and remember: will have to live with some!



others

- # of booster rings not automatic
 - for now manual, delays experienced mostly during scrubbing tests
 - main problems with PS RF settings which need fine tuning
 - mostly for number of batches for 50 and 75 ns spacing
 - 25 ns and 150 ns less problems
 - could be stored in different users, or same user but “double” or “triple PPM” settings
- SPS batch spacing only programmed through MMI
 - long promised upgrade: new software foreseen for next year
- change supercycle, faster if sequence ready
 - tradeoff with || MDs
- optimization of SPS supercycle length is non negligible for efficiency
 - needs to take into account:
 - time for request to injectors
 - time for IQC analysis
 - e.g.
 - 2 x MD1 + LHCION2 works: 12 BP = 14.4s
 - 2 x CNGS + LHCION2 does not work : 10 BP = 12s
 - could avoid padding if interaction Injection Sequencer was “per beam”
 - request for b2 now awaits response for b1, and viceversa (serial operation)

communication

- shift crew level:
 - improvement over time, as shift crews learn the tricks:
 - first injections: PS cavities off
 - first overinjections: MKEs disabled
 - etc etc
 - all OP is learning!
- coordination level
 - did not always allow time to set up injectors properly
 - also improved towards the end of the year
 - feedback from SPS: difficulties in getting latest expected parameters
- new Monday meeting:
 - LHC-coordinators
 - open to LHC and SPS OP members
 - maybe MD coordinator, and BI, CO, RF representatives

statistics & conclusions

- statistics (for LHC OP elogbook, expanded from Walter's)
 - 2.3% downtime due to injectors, of which:
 - 14.6% to PSB
 - 17.5% to PS
 - 68.0% to SPS
 - do we blame them as last in the line!?
- very high availability
- plenty of times problems were kept in the shade
 - shade of stable beams, of LHC access
- plenty of work coming up & room for improvement
 - equipment to become PPM, upgrades etc...