I-LHC Beam in the SPS 2012-2013
Present status of the analysis of observations concerning the longitudinal plane

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MSWG 2013-04-23

Contents

Introduction

$^{208}\mathrm{Pb}^{82+}$ Beams

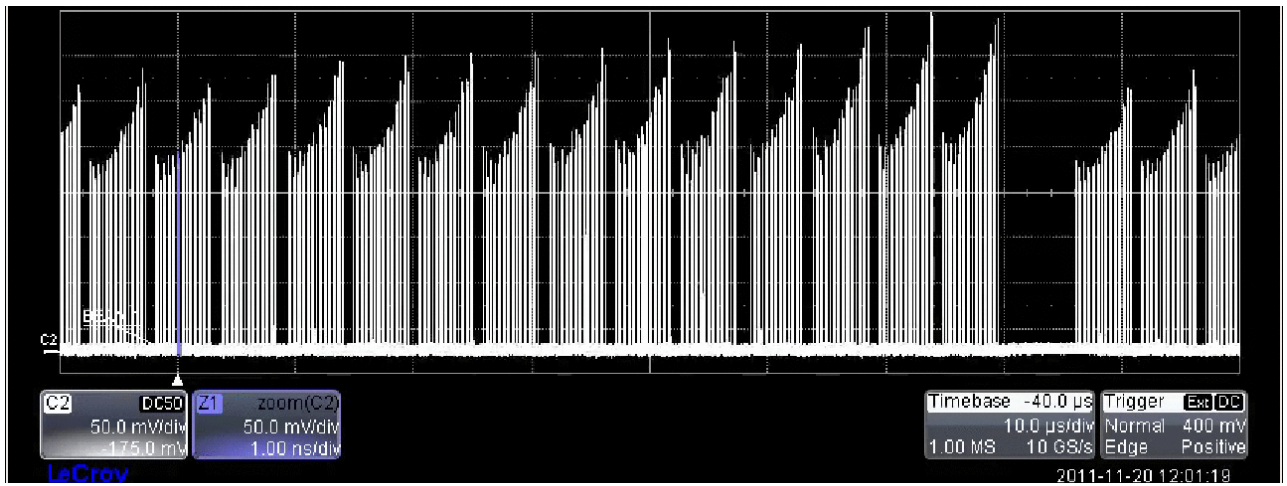
- Early Beam: single bunch, used for LHC filling (iLHC)
- Intermediate Beam: two bunches spaced 200 ns, used for LHC filling (iLHC) and SPS fixed target physics (iFT)

Cycles

- iLHC
  - Q26
    - LHC_ION_1inj_FT1045_short_ext
    - LHC_ION_12inj_FT1045_short_extr
  - Q20
    - LHC_ION_1Inj_Q20
    - LHC_ION_12Inj_Q20
- iFT, all Q26
  - SFT_ION_E36
  - SFT_ION_E52
  - SFT_ION_E80.7

Issue

Problem of dispersion of bunch parameters at flat bottom in LHC (example of 2011-11-20):



- dispersion of bunch parameters (length, peak amplitude, intensity) at end of 40 s long flat bottom of SPS for LHC filling cycles
- results of 2011 and earlier and discussion of possible sources: see MSWG 2011-10-14, LMC 2011-11-23, MSWG 2012-06-01, MSWG 2012-10-26, e.g.
- emphasis on influence of SPS RF on bunch parameters

Flat bottom

Results of September 2012

Comparison of Fixed Frequency Acceleration (FFA) with Fixed Harmonic Acceleration (FHA). With $h = f_{\mathrm{RF}}/f_{\mathrm{rev}}$ we have

- FFA:

$$f_{\mathrm{RF}} = const \text{ and } h = h(f_{\mathrm{rev}}), h \in \mathbb{R} \tag{1}$$

- FHA:

$$h = const \text{ and } f_{\mathrm{RF}} = f_{\mathrm{RF}}(f_{\mathrm{rev}}),\ h \in \mathbb{N} \tag{2}$$

Observations

- cycle iLHC/Q26, $t_{\mathrm{FB}} = 40.220$ s
- 2011: peak amplitude reduction improved by use of a generator instead of FFA low level: no FM, no AM, but also no loops
- 2012:
  - modified LO (similar to pLHC) to replace FF LO
  - no FM, no AM, FHA at $h = 4653$, phase loop and synchro loop on
  - bunch intensity 1/4 or less of operational value

Flat bottom

Results of September 2012

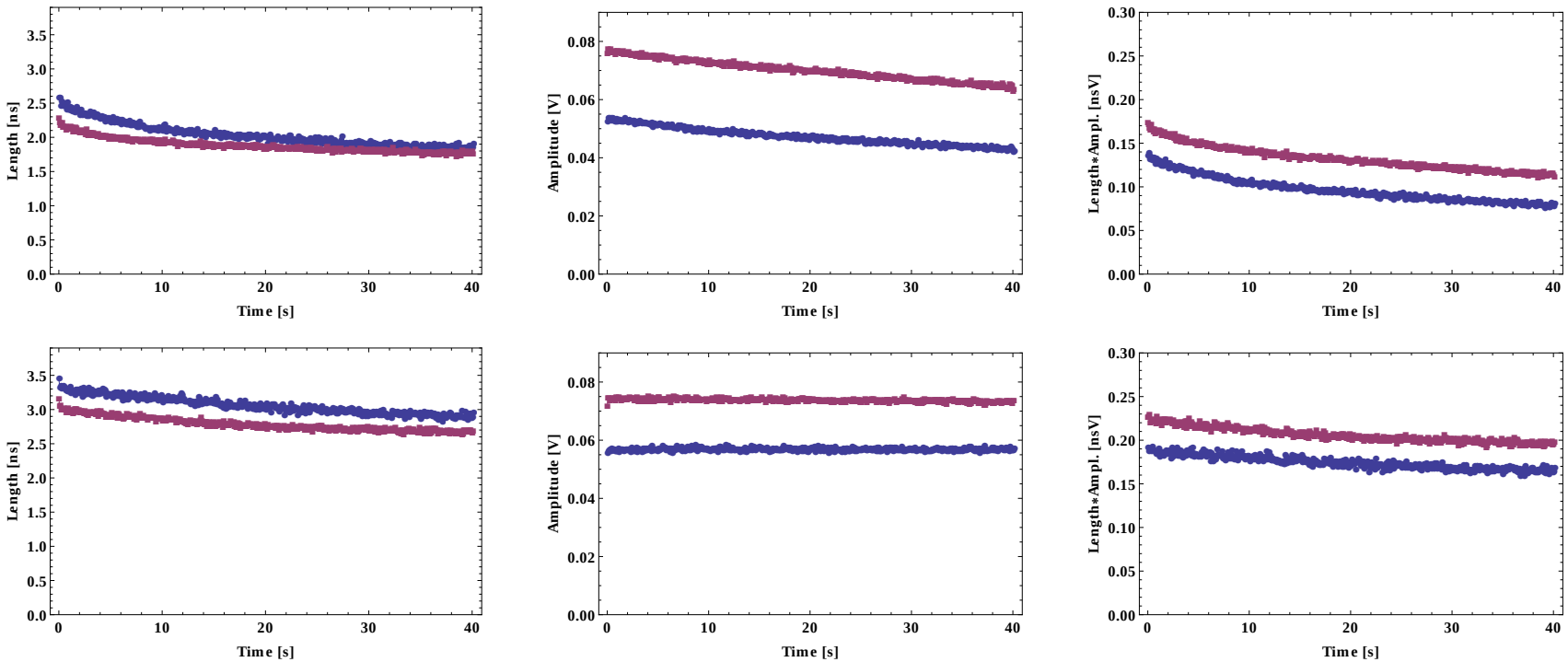


Figure : Comparison of bunch profile data for FFA (top) and FHA (bottom). Left: bunch length, centre: bunch peak amplitude, and right product of both. Blue: Bunch 1, red: Bunch 2. Intermediate Beam. First turn excluded. 2012-09-17.

Flat bottom

Results of September 2012

- only low intensity available, about 1/10 to 1/3 of operational values
- FHA: bunch length reduction (also observed with protons)
- peak amplitude lifetime ($\tau = \tau_{10.8}$)
  - with FFA
    - $N_\mathrm{Q} = 1 \times 10^9$: $\tau = (207 \pm 20)$ s
    - $N_\mathrm{Q} = 4 \times 10^9$: $\tau = (112 \pm 10)$ s
  - with FHA, $h = 4653$: $\tau > 1000$ s ($\tau >>> t_\mathrm{FB}$)
- phase noise
  - with FFA
    - $N_\mathrm{Q} = 4 \times 10^9$: $\sigma_\mathrm{z} = (16.5 \pm 1)$ ps
  - with FHA, $h = 4653$
    - $N_\mathrm{Q} = 4 \times 10^9$: $\sigma_\mathrm{z} = (9 \pm 1)$ ps (limited by meas. set-up)

Flat bottom

Low level modifications

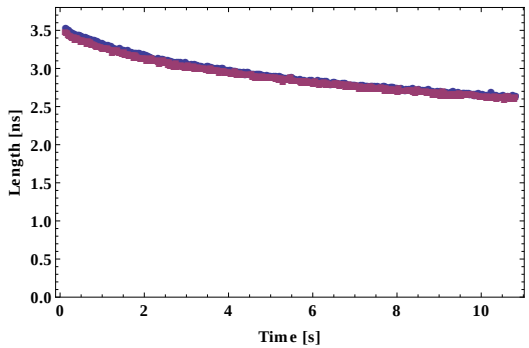
- installation of new New Master DDS/Slave DDS (P. Baudrenghien, J. Bento)
- identification and elimination of
  - 500 MHz reference clock noise
  - other noise sources
- optimisation of gain distribution in phase loop and synchro loop

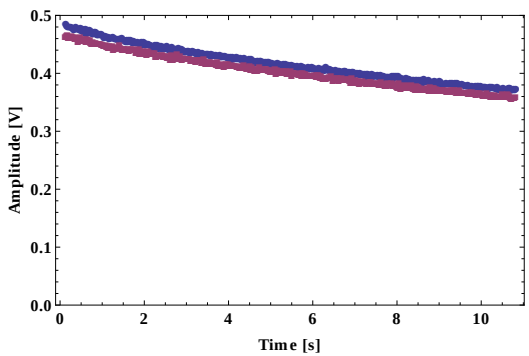
Flat bottom

Low level modifications

2012-12-04: bunch length and bunch peak amplitude versus time, iFT/Q26, $N_{\mathrm{Q}} = 2.2 \times 10^{10}$:

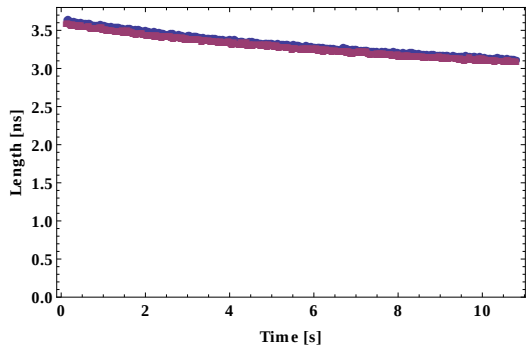
before

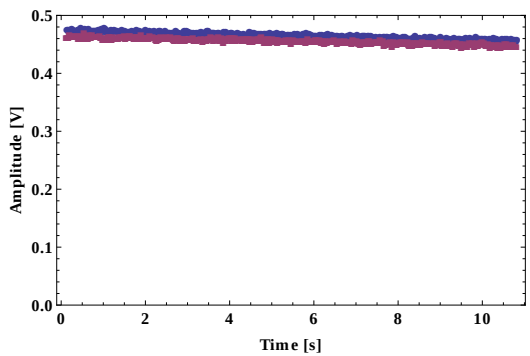




$\tau_{10.8} = 40$ s

after





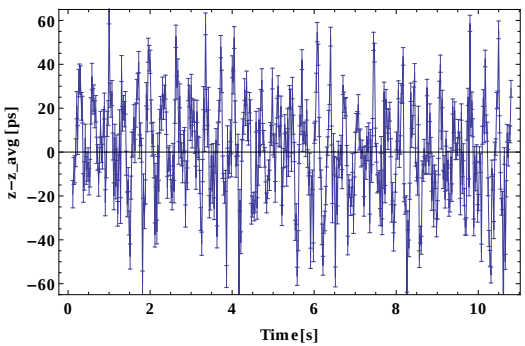
$\tau_{10.8} = 290$ s

Flat bottom

Low level modifications

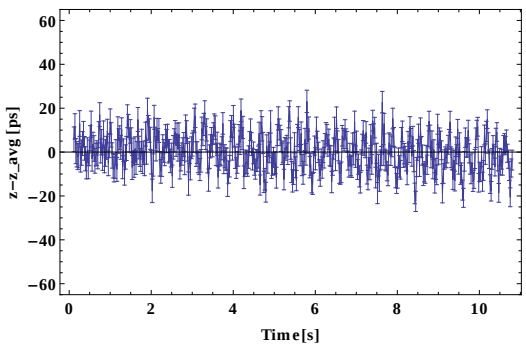
2012-12-04: bunch position versus time and std (phase noise), iFT/Q26, $N_Q = 2.2 \times 10^{10}$:

before



$\sigma_z = 23$ ps

after



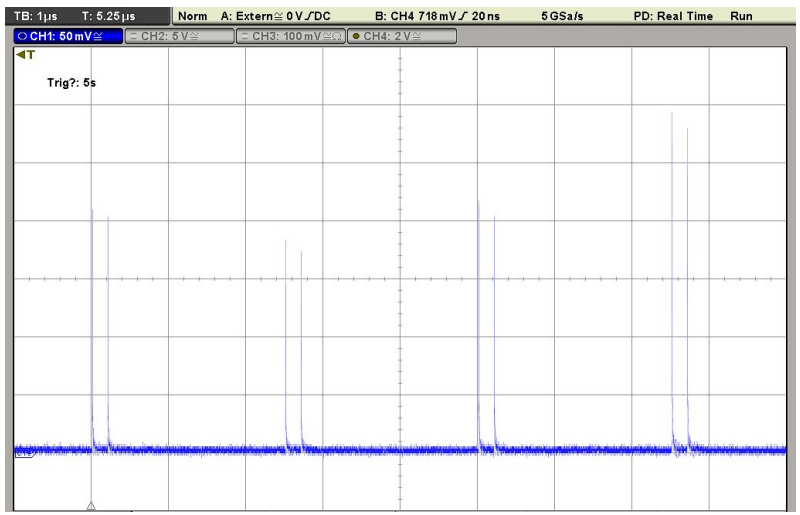
$\sigma_z = 9$ ps

Flat bottom

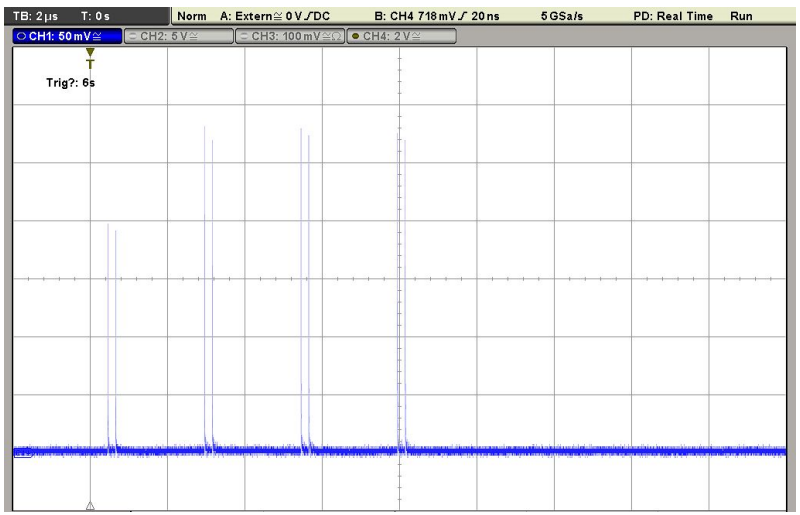
Low level modifications

2012-12-04: bunch peak amplitude at end of flat bottom, iFT/Q26:

before



after



Flat bottom

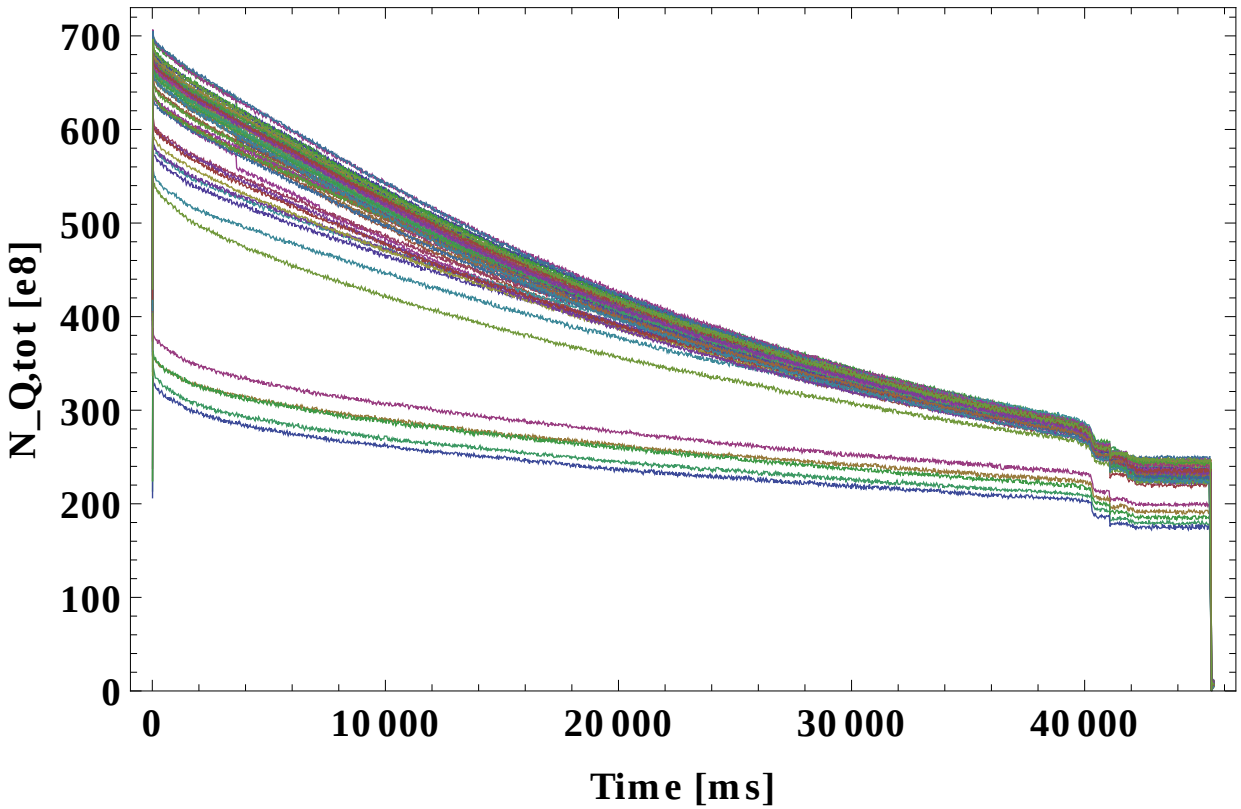
Degradation of performance at flat bottom in 2013 with respect to 2012.

Possible reasons

- consequence of additional low level modifications based on purely electronic noise measurements?
- linked to Q26 versus Q20 optics?
- linked to bunch intensity?

Flat bottom

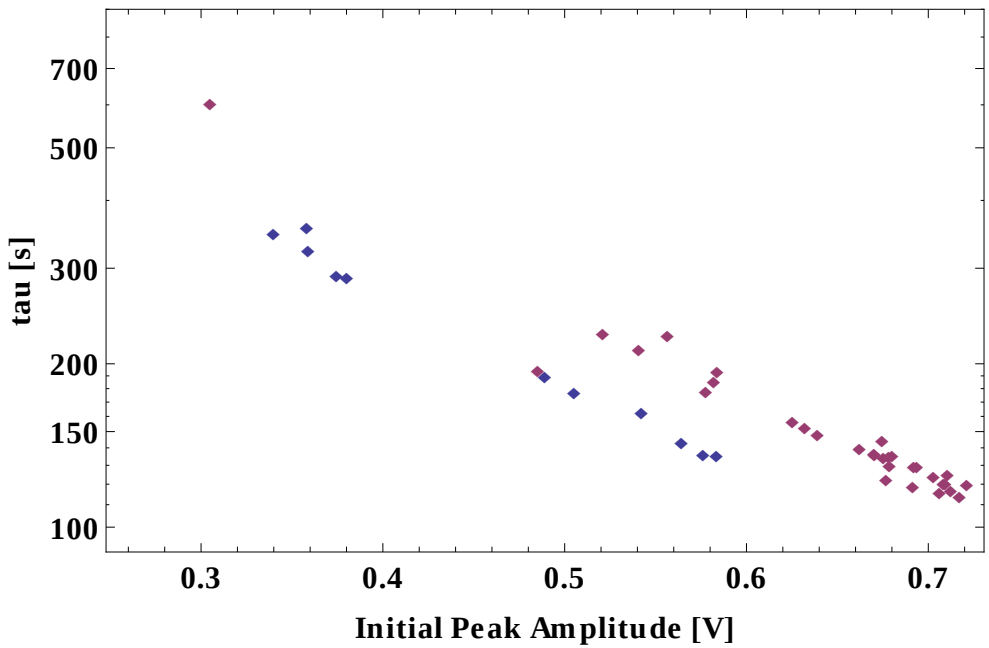
Intensity: BCT for iLHC/Q20



Flat bottom

Bunch peak amplitude lifetime τ

τ for iFT/Q26 (blue) and for iLHC/Q20 (red) [$\tau = \tau_{10.8}$]

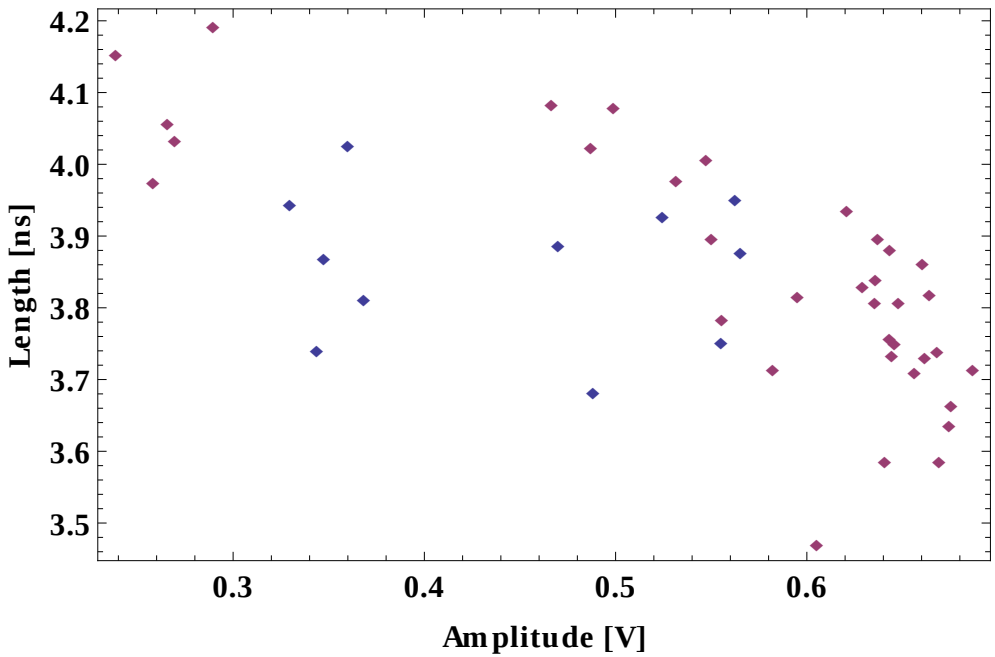


- horiz. axis: 0.1 V about $N_Q = 5 \times 10^9$, $\delta\tau \approx \pm 5$ s
- for initial bunch peak ampl. < 0.3 V: $\tau > 1000$ s
- τ not dominated by RF noise (see also phase noise plot)

Flat bottom

Bunch peak amplitude lifetime τ

Bunch length at injection of data used for determination of τ

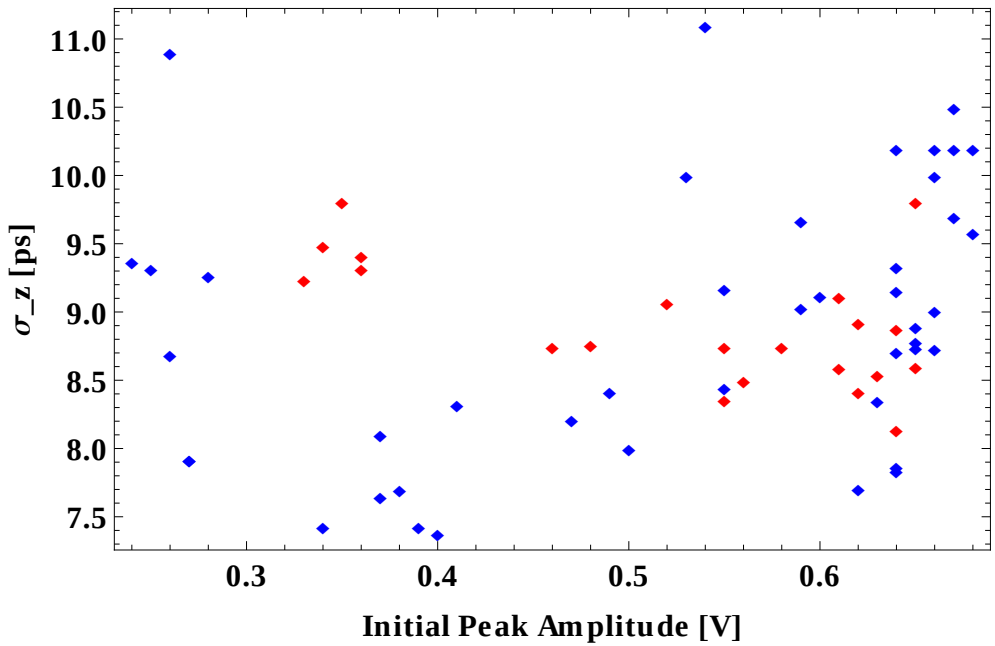


- bunch length variation dominated by bunch shape variation of injected bunches

Flat bottom

Phase noise σ_z

σ_z for iLHC/Q20 (blue) and for iFT/Q26 (red)



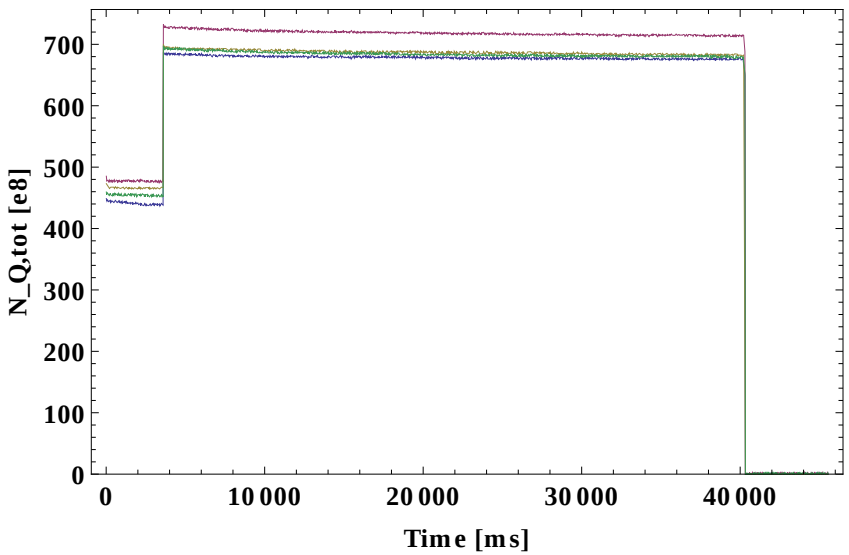
- σ_z independent of bunch peak amplitude

Flat bottom

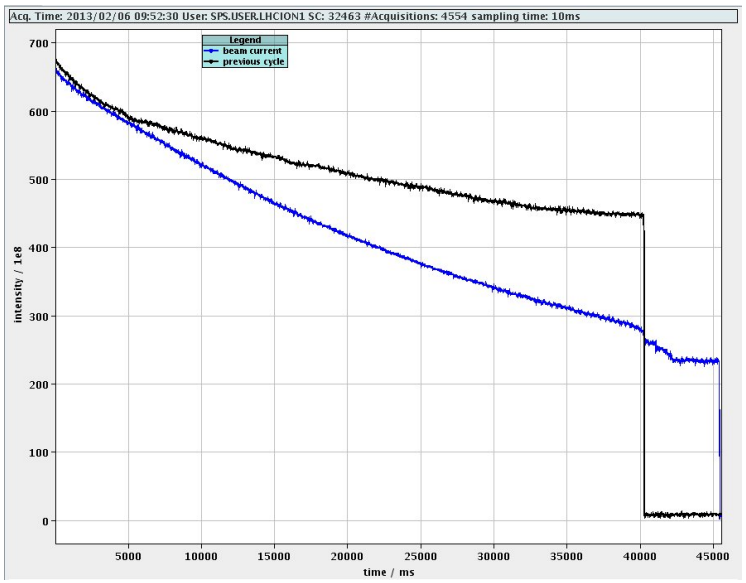
Transmission

Transmission along flat bottom for iLHC cycle Q26/Q20

Q26: RF off



Q20 RF on/off

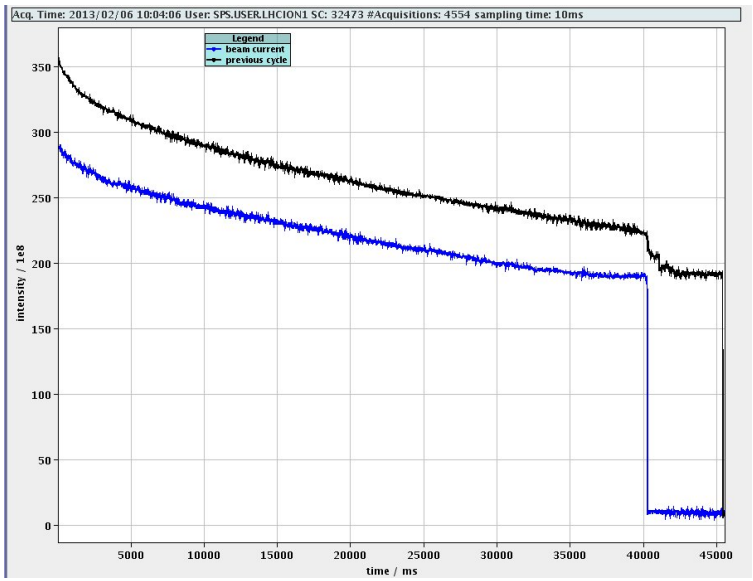


Flat bottom

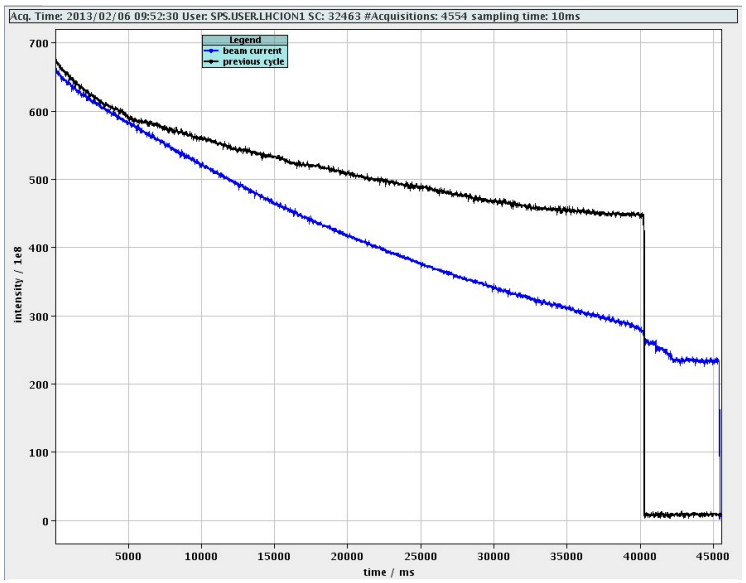
Transmission

RF on/off, Q20

low intensity



high intensity

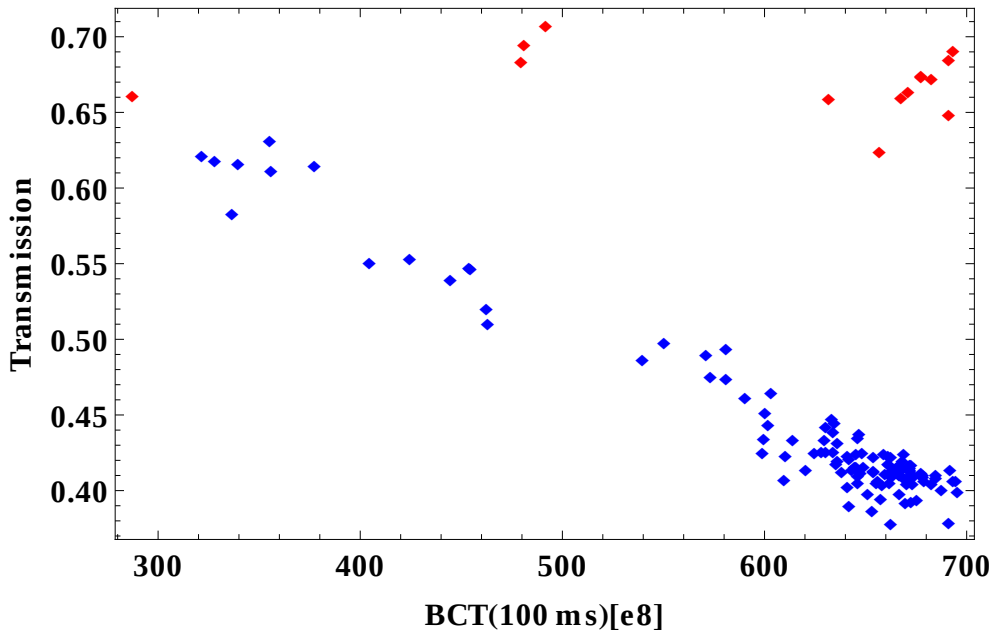


- RF off: in both cases BCT reduction is 66% within about 1%
- no space charge effect/resonance crossing?

Flat bottom

Transmission

BCT(40 000 ms)/BCT(100 ms): iLHC cycle, Q20



- blue: RF on, red: RF off
- RF off: transmission independent of initial bunch intensity
- RF on: transmission converges to RF off value for decreasing initial bunch intensity

Front porch, transition

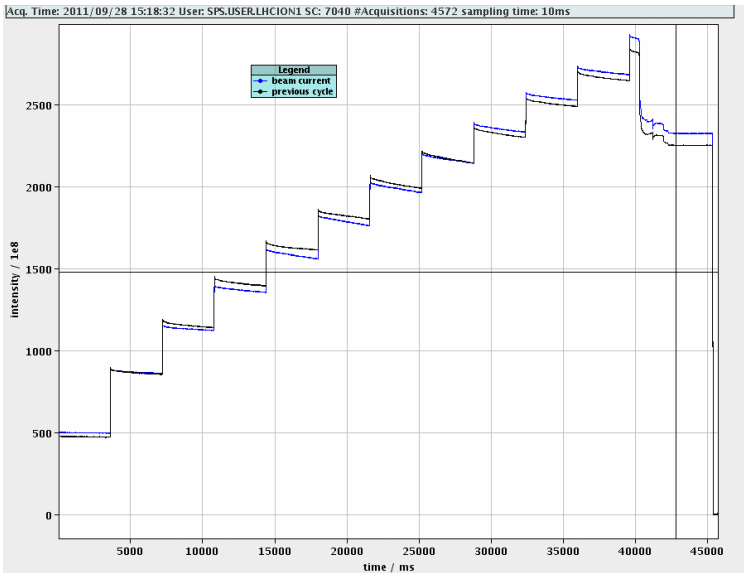
- front porch losses: nothing particular to report
- transition: no special issues, larger losses with Q20 than with Q26?

	Q20	Q26
γ_t	17.95	22.8
t (ACC Beam Process Time) [ms]	846	981
p/Z [GeV/c]	42.5	53.8
dp/dt/Z [GeV/c/s]	76.1	92.6
B-dot [T/s]	0.34	0.42
T_c [ms]	66	97
$\beta\gamma$	17.92	22.77
$d\gamma/dt$ [1/s]	31.9	39.2
η	-4.1×10^{-7}	-1.9×10^{-7}

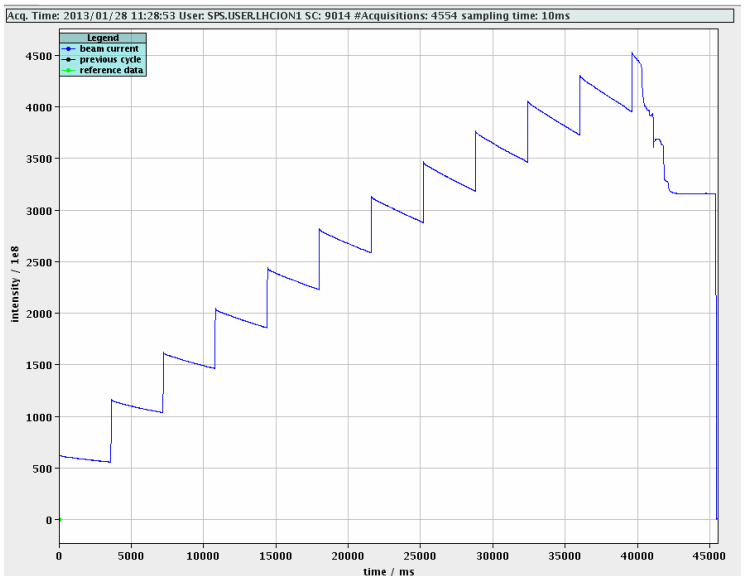
- horizontal aperture limit at γ_t: $\alpha_p = 1/\gamma_t^2$

High energy loss

Q26



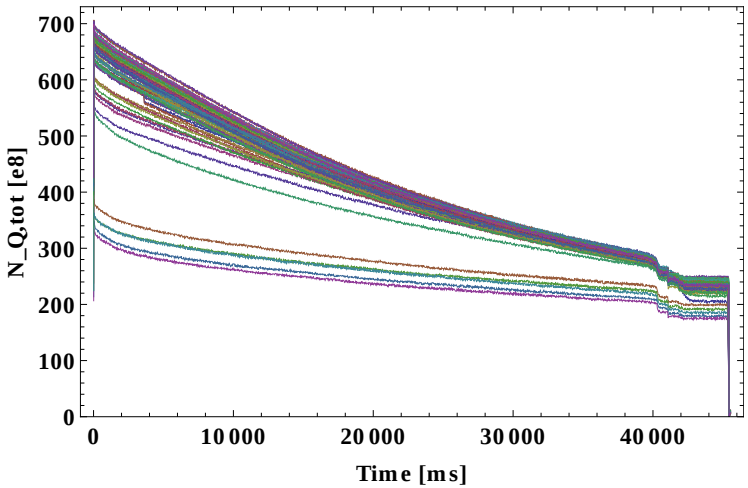
Q20

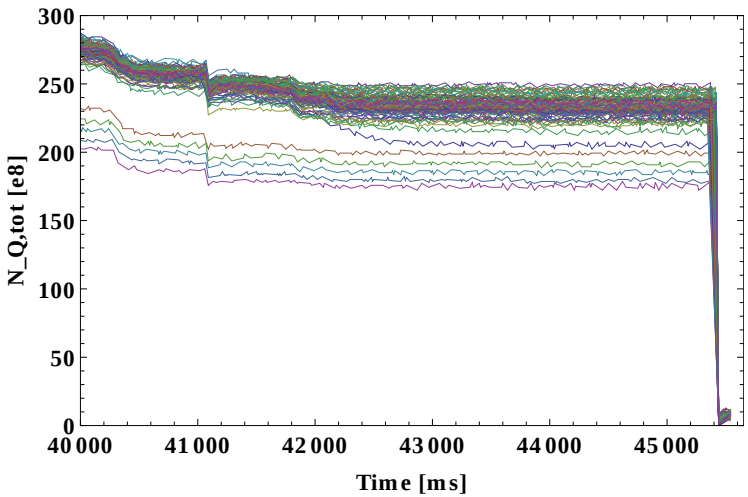


- with Q20 larger loss at transition and at higher p

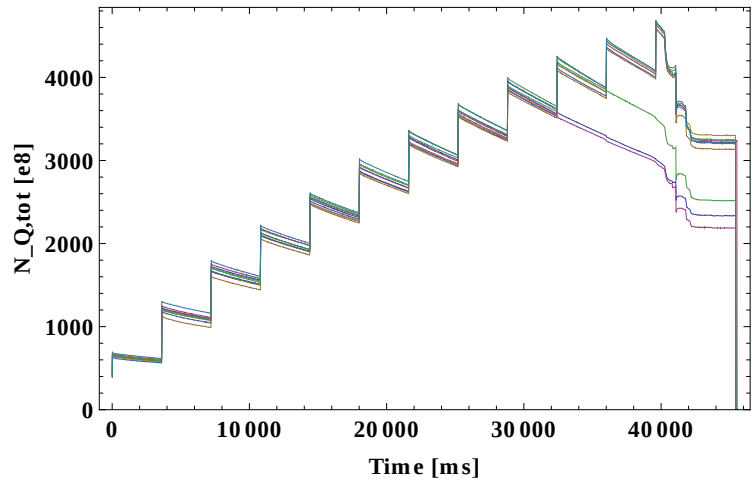
High energy loss

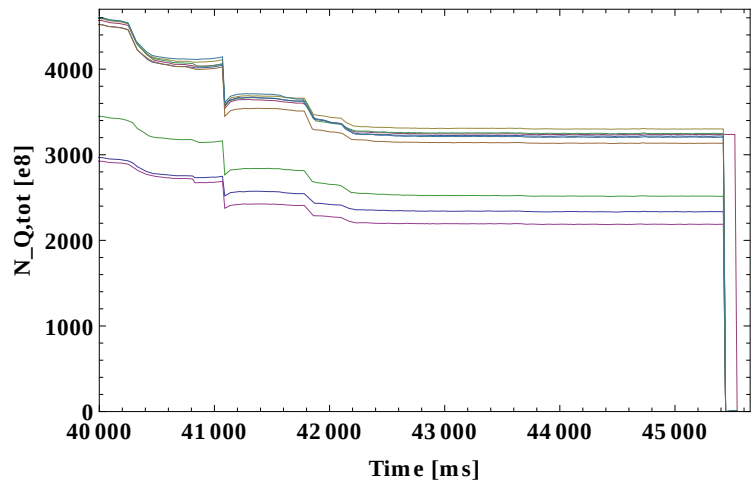
single batch





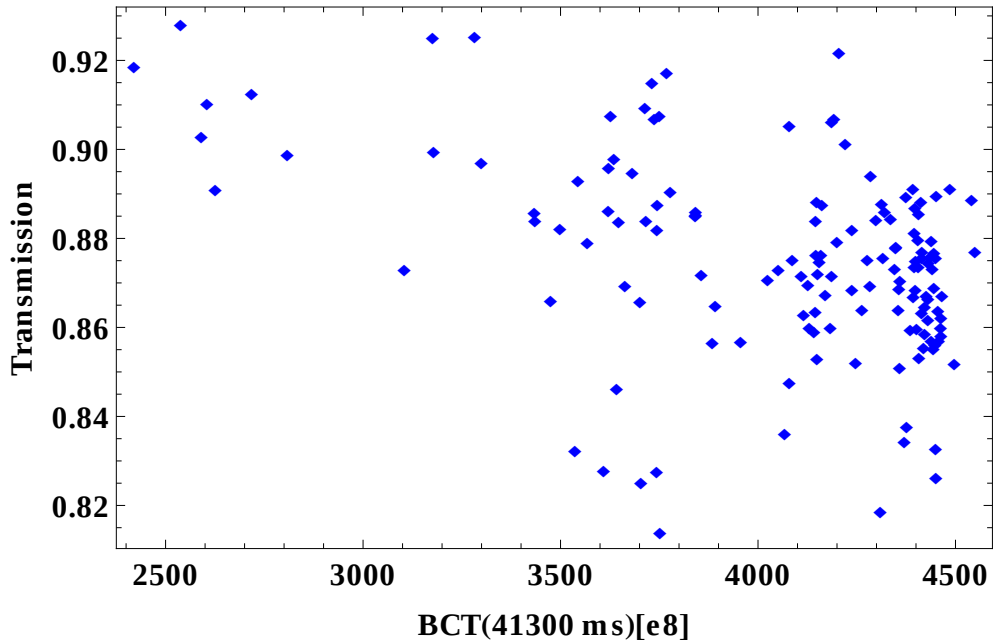
multiple batch



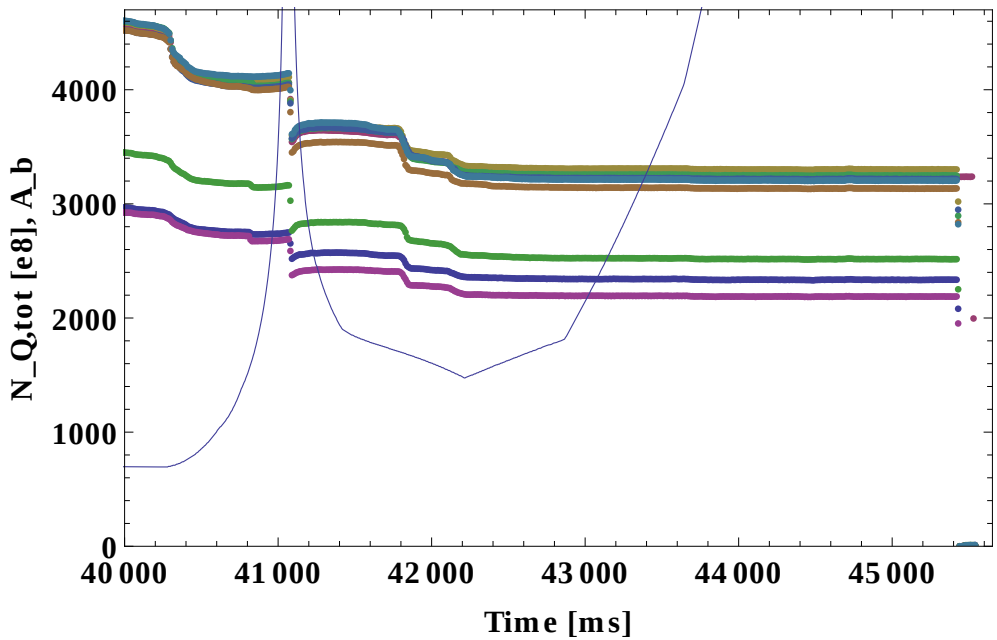


High energy loss

Transmission: BCT(42 500 ms)/BCT(41 300 ms)



High energy loss

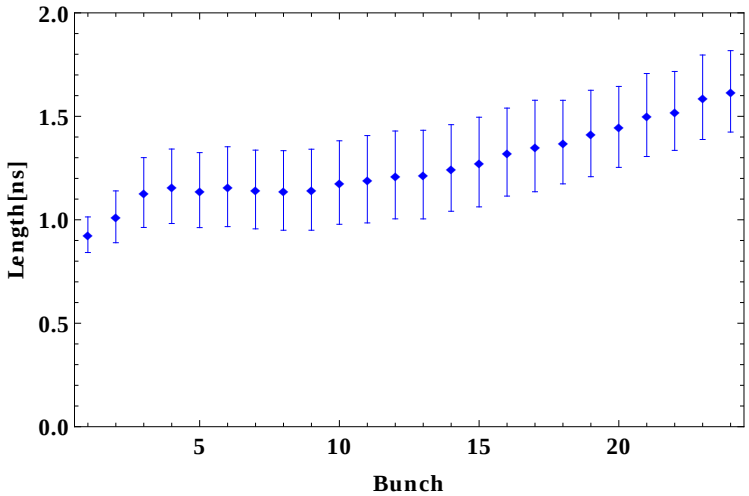


- with Early Beam: influence of phase loop gain
- bucket filling factor
- $A_{\mathrm{b}}(\mathrm{Q20})/A_{\mathrm{b}}(\mathrm{Q26}) = 0.77$, for same A_{b} increase RF voltage by 1.7

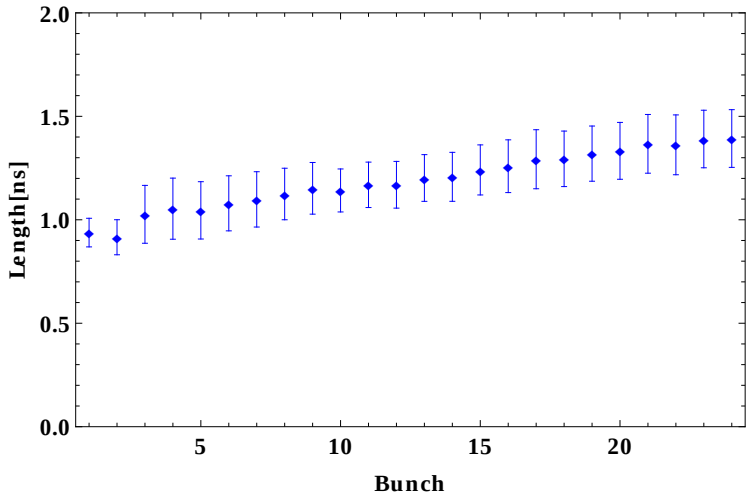
Flat top

Bunch length profile

2011



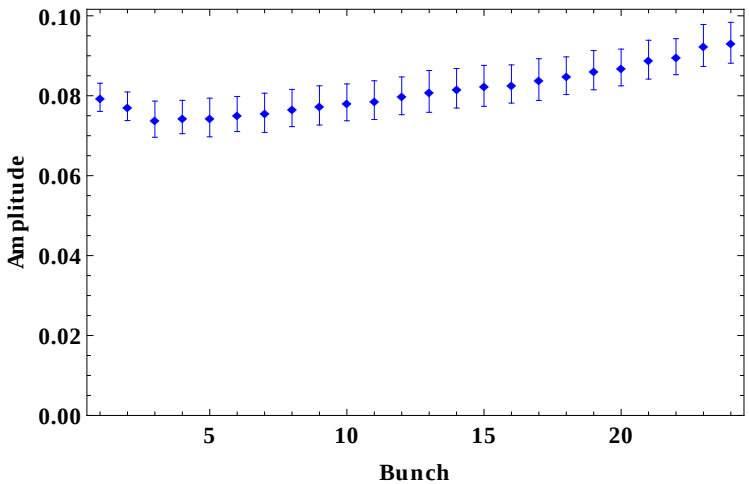
2012 - 2013



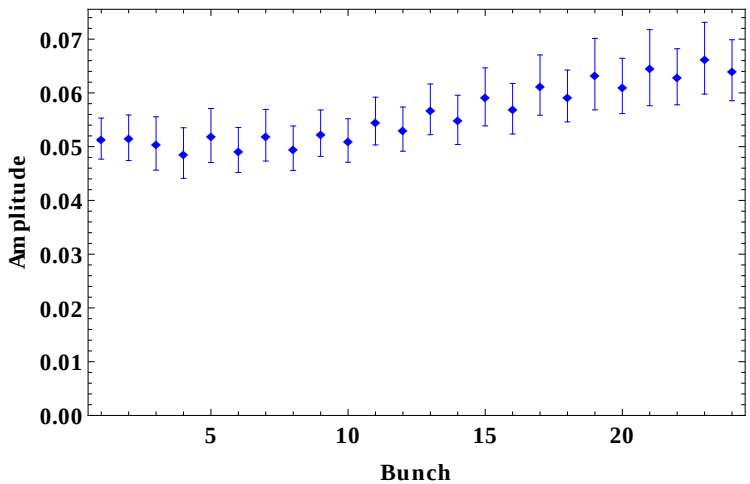
- all cycles with 24 bunches at flat top and destination LHC (2011: $N = 1630$, 2012 - 2013: $N = 647$), no other selection criteria

Flat top

2011



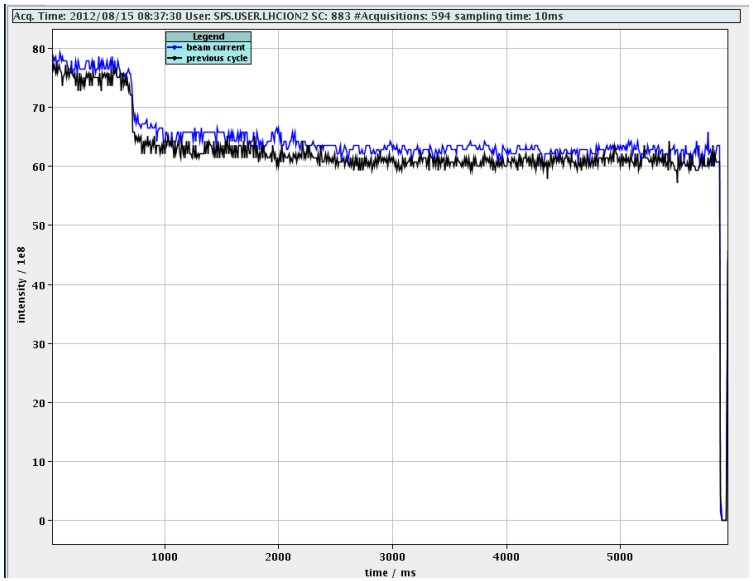
2012 - 2013



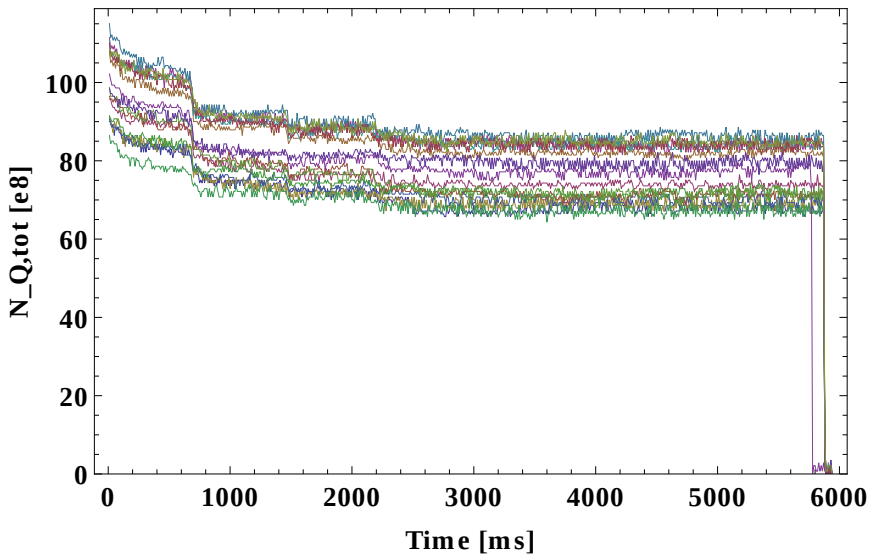
- all cycles with 24 bunches at flat top and destination LHC (2011: $N = 1630$, 2012 - 2013: $N = 647$), no other selection criteria

Early Beam

Q26



Q20

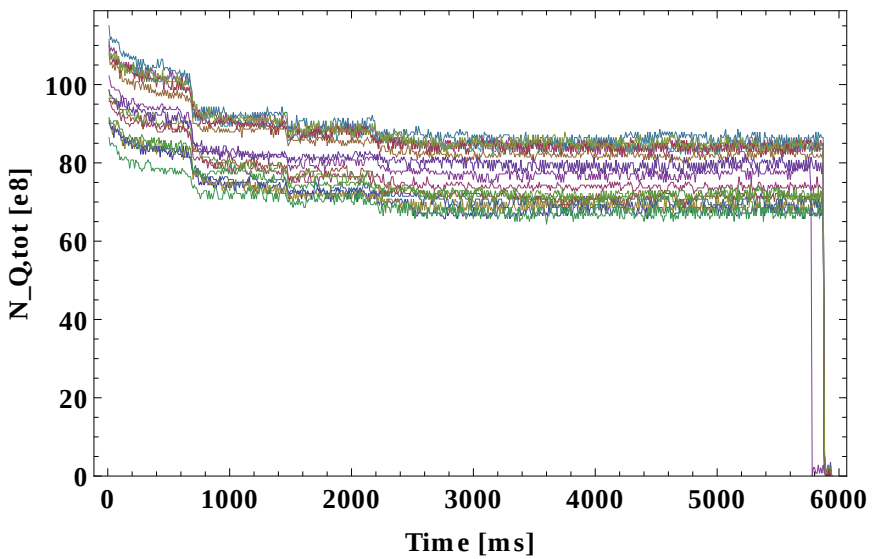


- flat bottom, transition, high energy

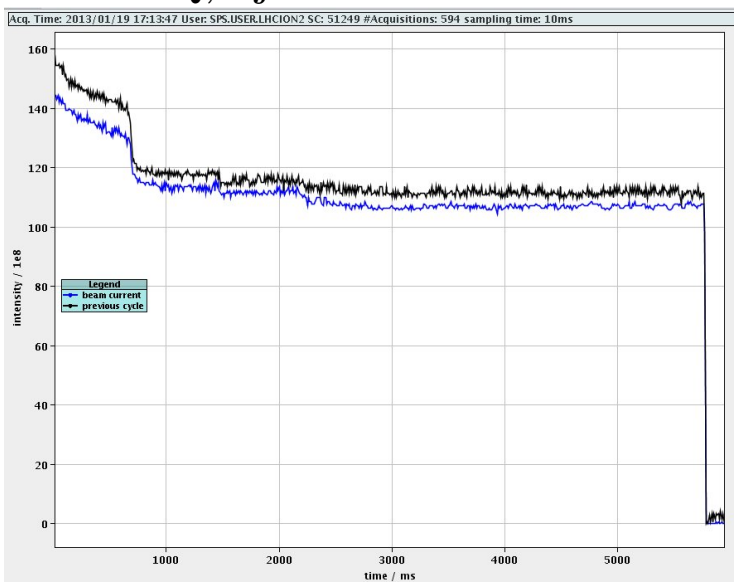
Early Beam

Q20

$N_{\mathrm{Q,inj}} \approx 1.0 \times 10^{10}$



$N_{\mathrm{Q,inj}} \approx 1.5 \times 10^{10}$



- flat bottom, transition, high energy

Status

Discussed: comparison of Q20 and Q26 in view of

- phase noise at flat bottom
- peak amplitude lifetime
- BCT lifetime with RF on/off
- transmission at flat bottom, front porch, transition and high energy

Not discussed

- test of $h = 4653$ with digital LO
- steps taken to obtain optimal gain distribution in phase and synchro loop
- bunch length evolution at flat bottom

To be done

- BCT lifetime at flat bottom
- test of $h = 4653$ with digital LO under improved conditions

Acknowledgements

P. Baudrenghien and J. Bento

- installation of new Master DDS and Slave DDS
- support during search for electronic noise sources

J. Noirjean

- modifications of SLA

K. Cornelis, D. Manglunki and OP crews

- support of measurements