Beam quality: 50 ns beam in the SPS
– Injection/Flat Top –

2012-06-21

Contents

Introduction

- familiarity with SPS cycle and LHC beams is assumed
- data is of style “analysed” and “latest news”
- analysis of data acquired after 2012-05-25 is ongoing

BQM data

- 50 variables
- 13 thresholds
- at injection: bunch length, bunch peak amplitude
- satellite detection during ramp
- at flat top
  - bunch length: min, mean, max, std
  - bunch peak amplitude: pk-pk
  - dipole, quadrupole instability parameters at flat top

Patterns

Data

- LHC_50ns_D_2011_V1 (ID: 387)
- cycles with 144 bunches at flat top, plus other selection criteria
- at injection: bunch peak amplitude, bunch length
- at flat top: bunch peak amplitude, bunch length, longitudinal bunch position

Information about

- coupling (bunch, batch), single bunch
- beam loading

Data analysis 2012-03-02 to 2012-05-24 I

The aim is to describe the bunch to bunch variations of bunch peak amplitude, bunch length and bunch position.
Therefore the bunch parameters peak amplitude, a_{pk}, and bunch length, λ, were analysed as follows. For each acquisition $i \in \{1, ..., N\}$, where N the total number of acquisitions, the mean value per acquisition was obtained as

$$\langle x_i \rangle = \frac{\sum_{j=1}^{N_{\mathrm{b}}} x_{ij}}{N_{\mathrm{b}}}$$

where $x \in \{a_{\mathrm{pk}}, \lambda\}$, N_{b} the number of bunches, and from this the normalised value

$$\tilde{x}_{ij} = \frac{x_{ij} - \langle x_i \rangle}{\langle x_i \rangle} \ .$$

Data analysis 2012-03-02 to 2012-05-24 II

For each bunch, $j \in 1, ..., N_\mathrm{b}$ a mean value was then obtained as

$$\langle \tilde{x}_j \rangle = \frac{\sum_{i=1}^{N} \tilde{x}_{ij}}{N}$$

and the standard deviation $\sigma(\tilde{x}_j)$.
The bunch position, z, is understood as the relative bunch position with respect to the nominal position. For the bunch positions the mean value, $\langle z_j \rangle$ and the standard deviation, $\sigma(z_j)$, were calculated for each bunch the same way as for the $\tilde{x}_j$.

Data analysis 2012-03-02 to 2012-05-24 III

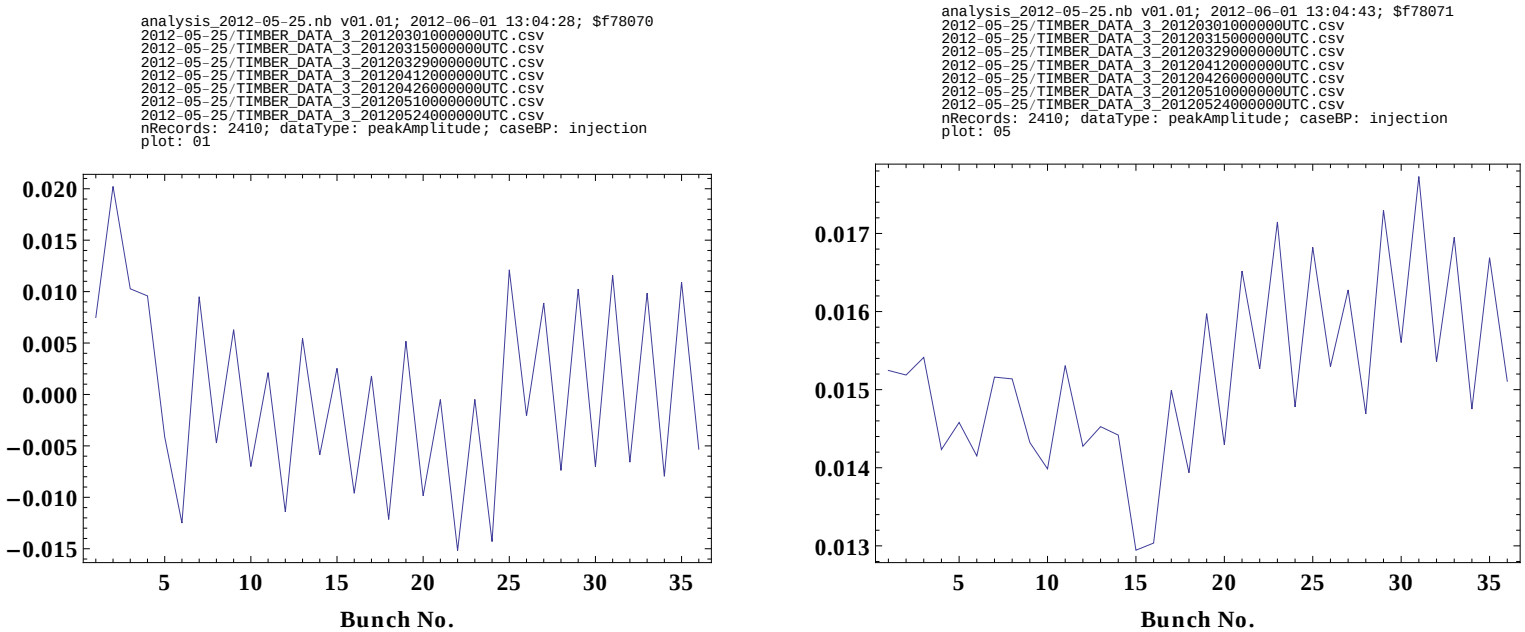


Figure : Left: $\langle \tilde{a}_{\mathrm{pk}} \rangle$ versus bunch number. Right: $\sigma(\tilde{a}_{\mathrm{pk}})$ versus bunch number. $N = 2412$. Based on BQM data BUNCH_PEAKS_INJ.

Data analysis 2012-03-02 to 2012-05-24 IV

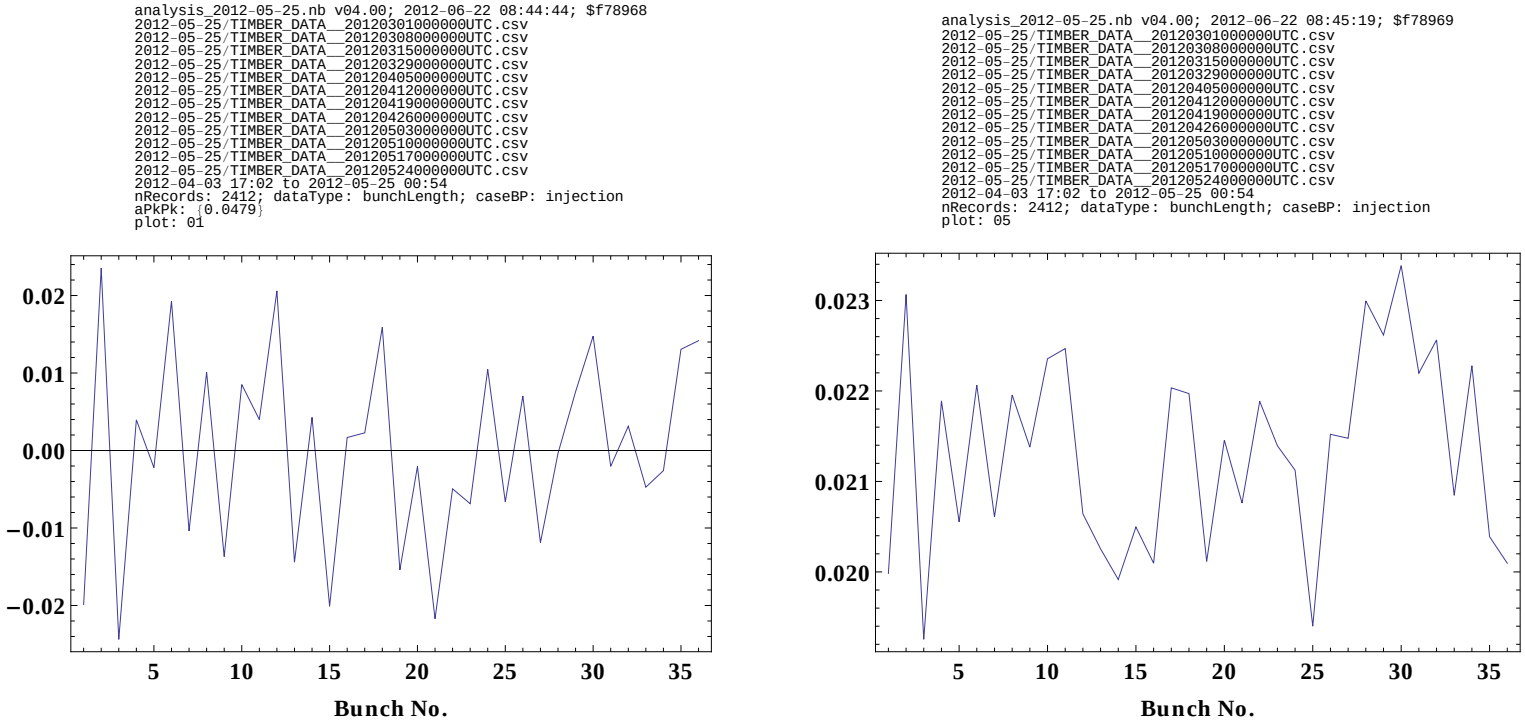


Figure : Left: $\langle\tilde{\lambda}\rangle$ versus bunch number. Right: $\sigma(\tilde{\lambda})$ versus bunch number. $N = 2412$. Based on BQM data BUNCH_LENGTHS_INJ.

Data analysis 2012-03-02 to 2012-05-24 V

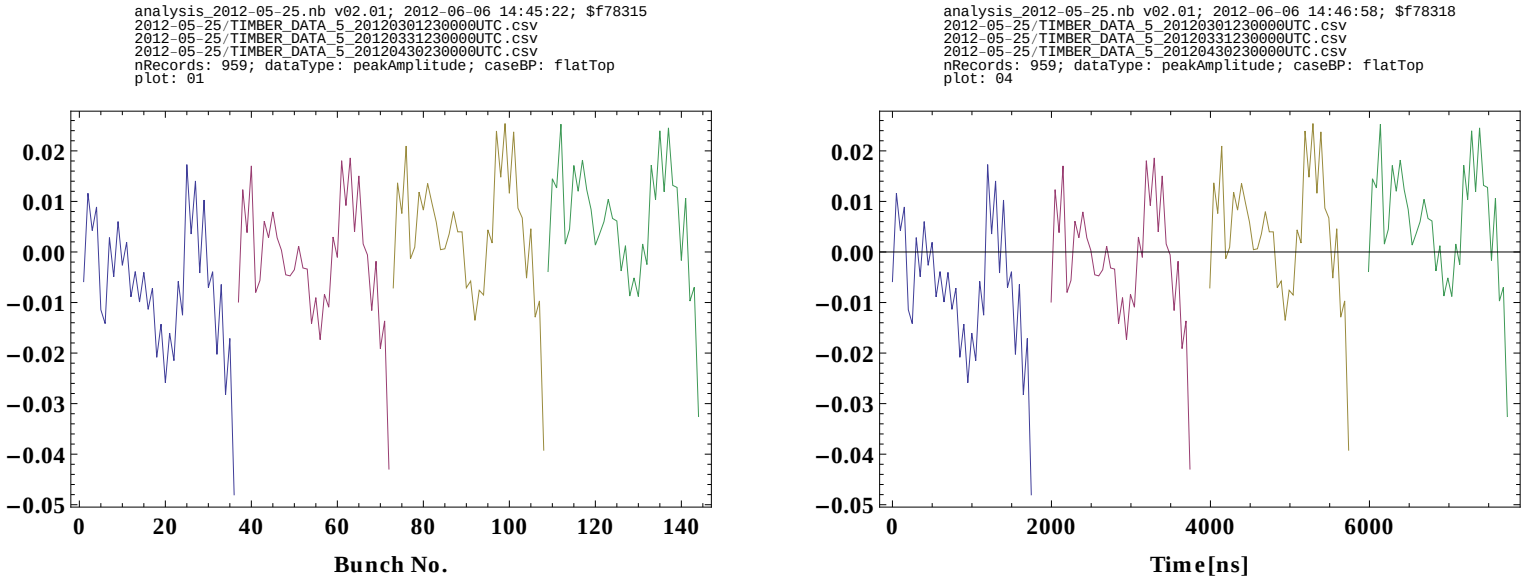


Figure : Left: $\langle \tilde{a}_{\mathrm{pk}} \rangle$ versus bunch number. Right: $\langle \tilde{a}_{\mathrm{pk}} \rangle$ versus time. Based on BQM data BUNCH_PEAKS.

Data analysis 2012-03-02 to 2012-05-24 VI

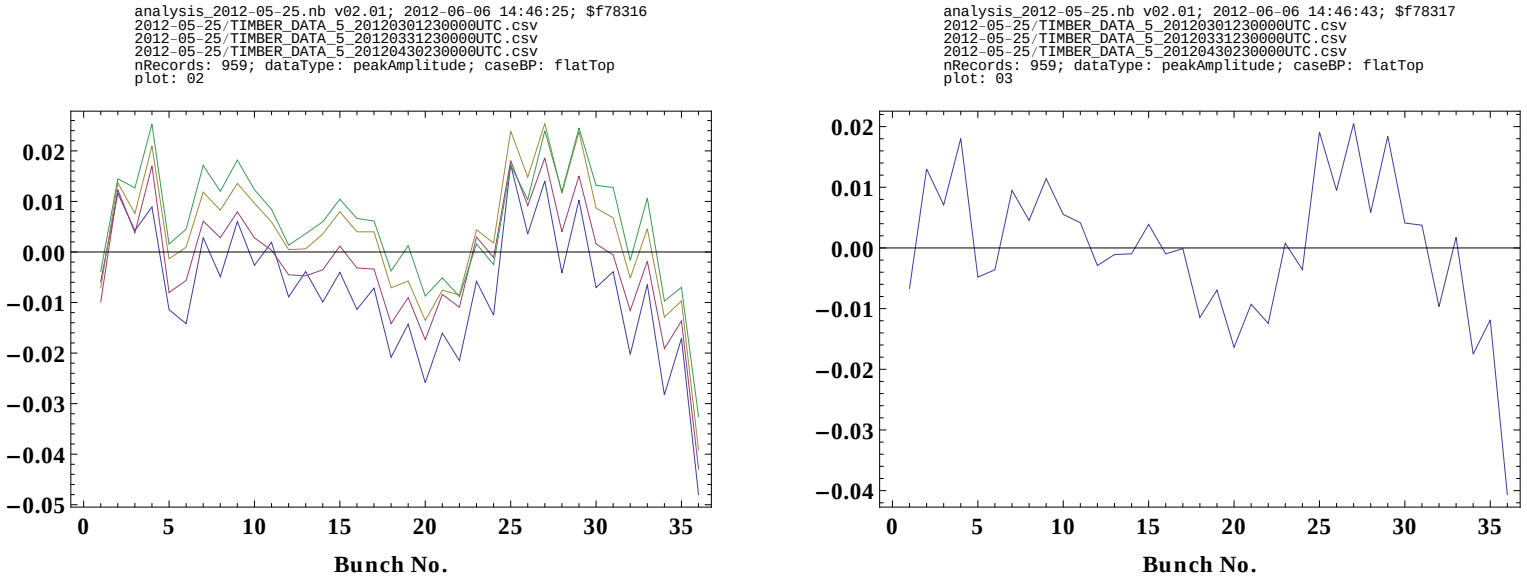


Figure : Left: $\langle \tilde{a}_{\mathrm{pk}} \rangle$ versus bunch number; folded, same colour code for batches as used in previous Fig. Right: average of data shown left. Based on BQM data BUNCH_PEAKS.

Data analysis 2012-03-02 to 2012-05-24 VII

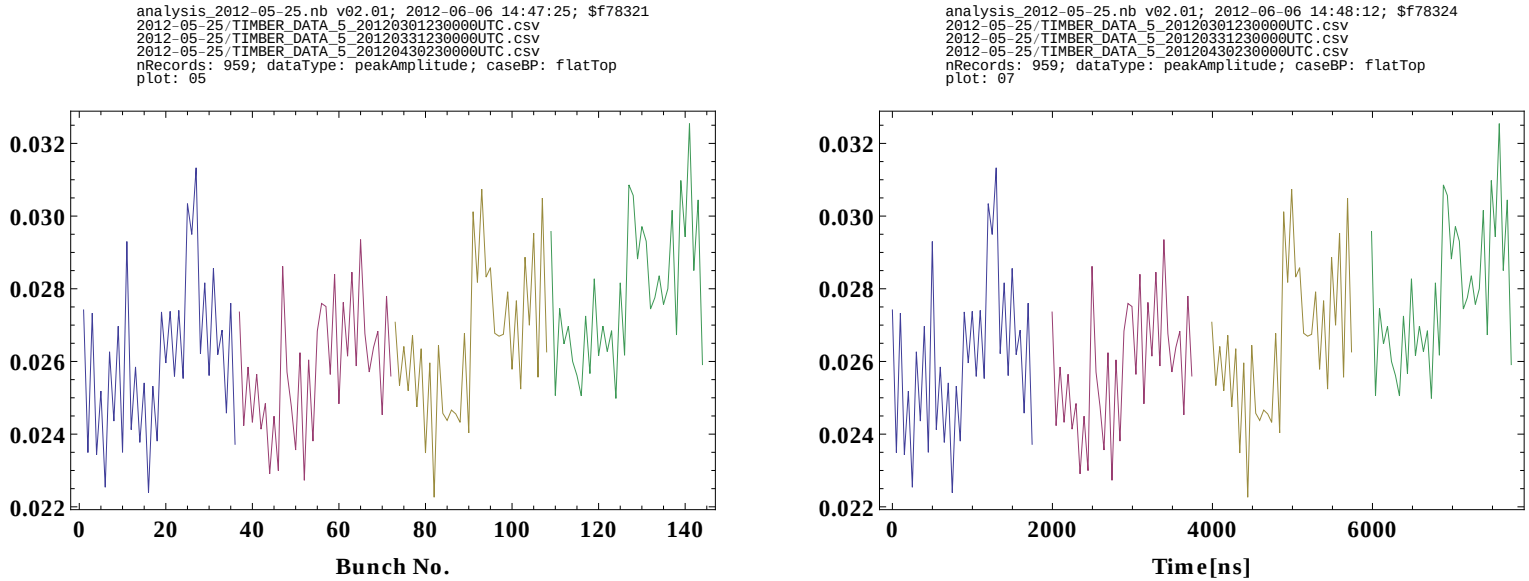


Figure : Left: $\sigma(\tilde{a}_{\mathrm{pk}})$ versus bunch number. Right: $\sigma(\tilde{a}_{\mathrm{pk}})$ versus time. Based on BQM data BUNCH_PEAKS.

Data analysis 2012-03-02 to 2012-05-24 VIII

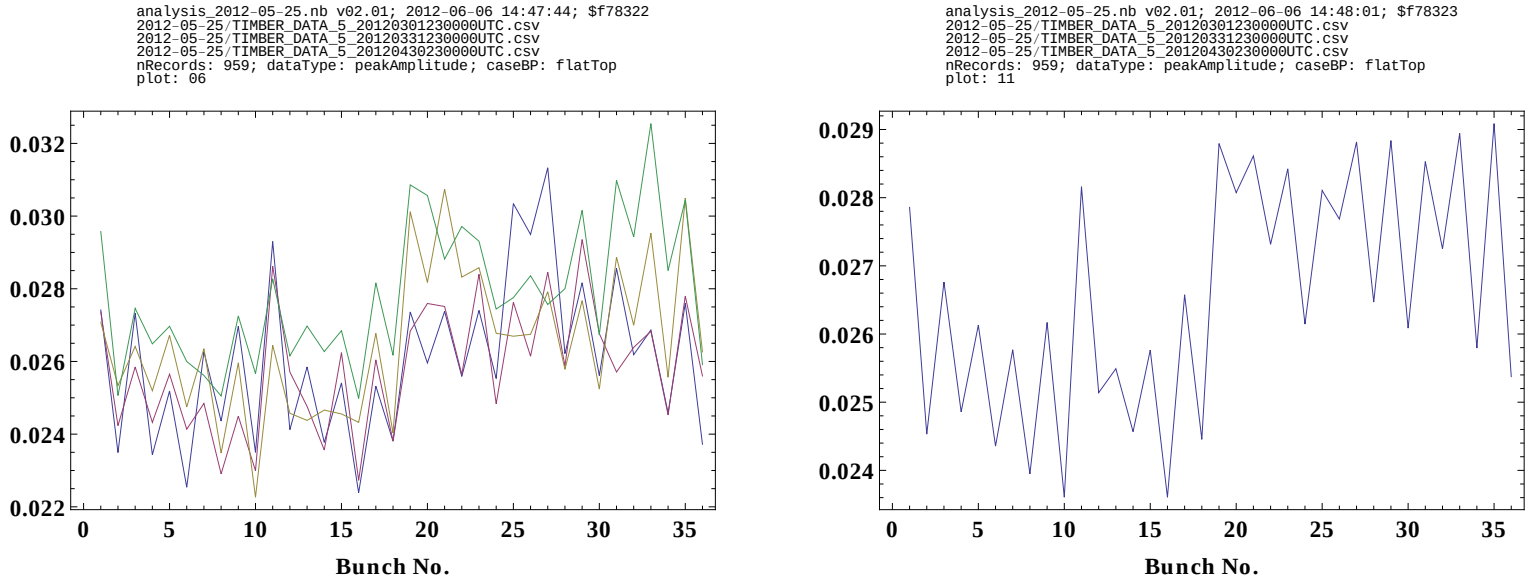


Figure : Left: $\sigma(\tilde{a}_{\mathrm{pk}})$ versus bunch number; folded, same colour code for batches as used in previous. Right: average of the data shown left. Based on BQM data BUNCH_PEAKS.

Data analysis 2012-03-02 to 2012-05-24 IX

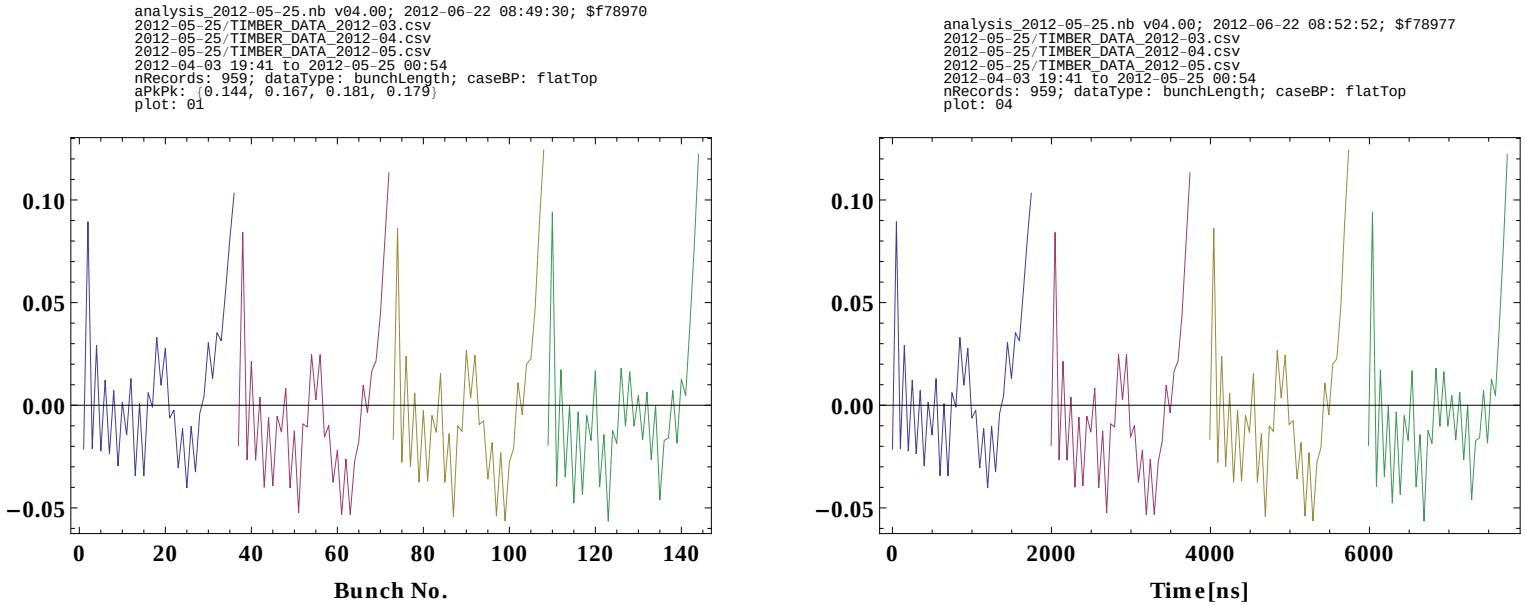


Figure : Left: $\langle\tilde{\lambda}\rangle$ versus bunch number. Right: $\langle\tilde{\lambda}\rangle$ versus time. Based on BQM data BUNCH_LENGTHS.

Data analysis 2012-03-02 to 2012-05-24 X

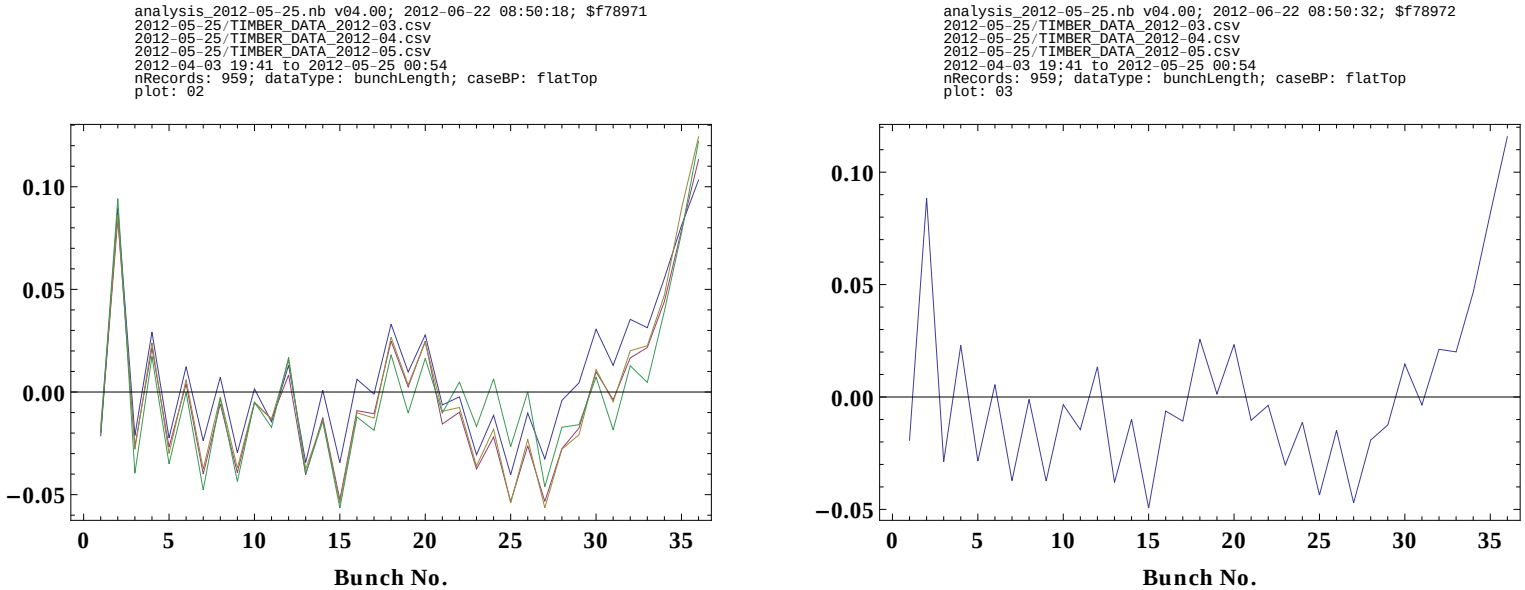


Figure : Left: $\langle\tilde{\lambda}\rangle$, folded; same colour code for batches as for previous Fig. Right: average of data shown on the left. Based on BQM data BUNCH_LENGTHS.

Data analysis 2012-03-02 to 2012-05-24 XI

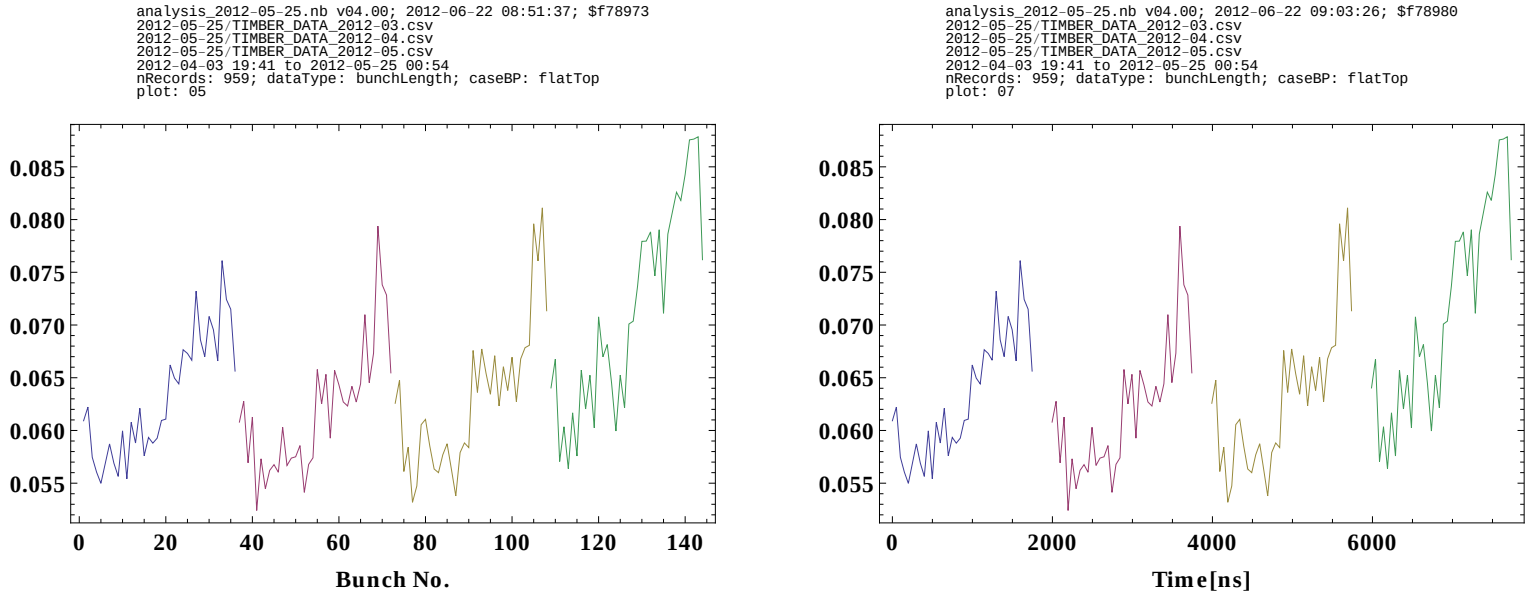


Figure : Left: $\sigma(\tilde{\lambda})$ versus bunch number. Right: $\sigma(\tilde{a}_{\mathrm{pk}})$ versus time. Based on BQM data BUNCH_LENGTHS.

Data analysis 2012-03-02 to 2012-05-24 XII

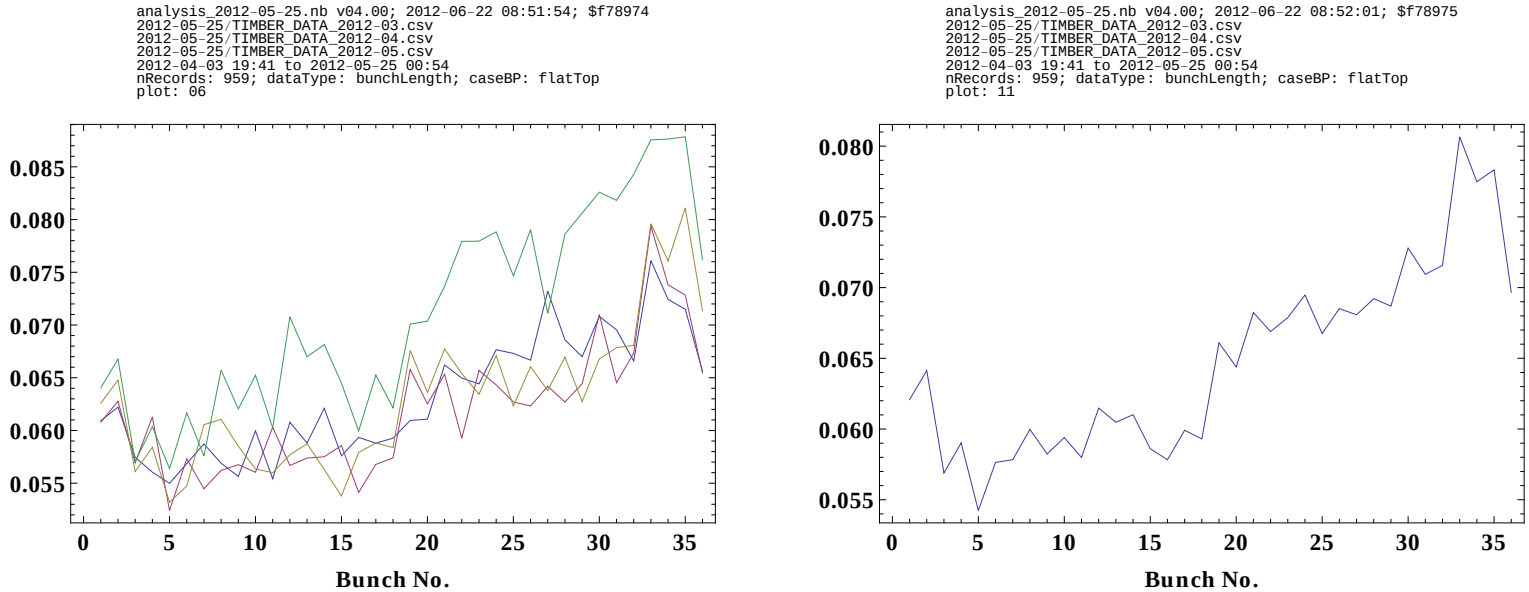


Figure : Left: $\sigma(\tilde{\lambda})$ versus bunch number; folded, same colour code for batches as used in previous Fig. Right: average of the data shown left. Based on BQM data BUNCH_LENGTHS.

Data analysis 2012-03-02 to 2012-05-24 XIII

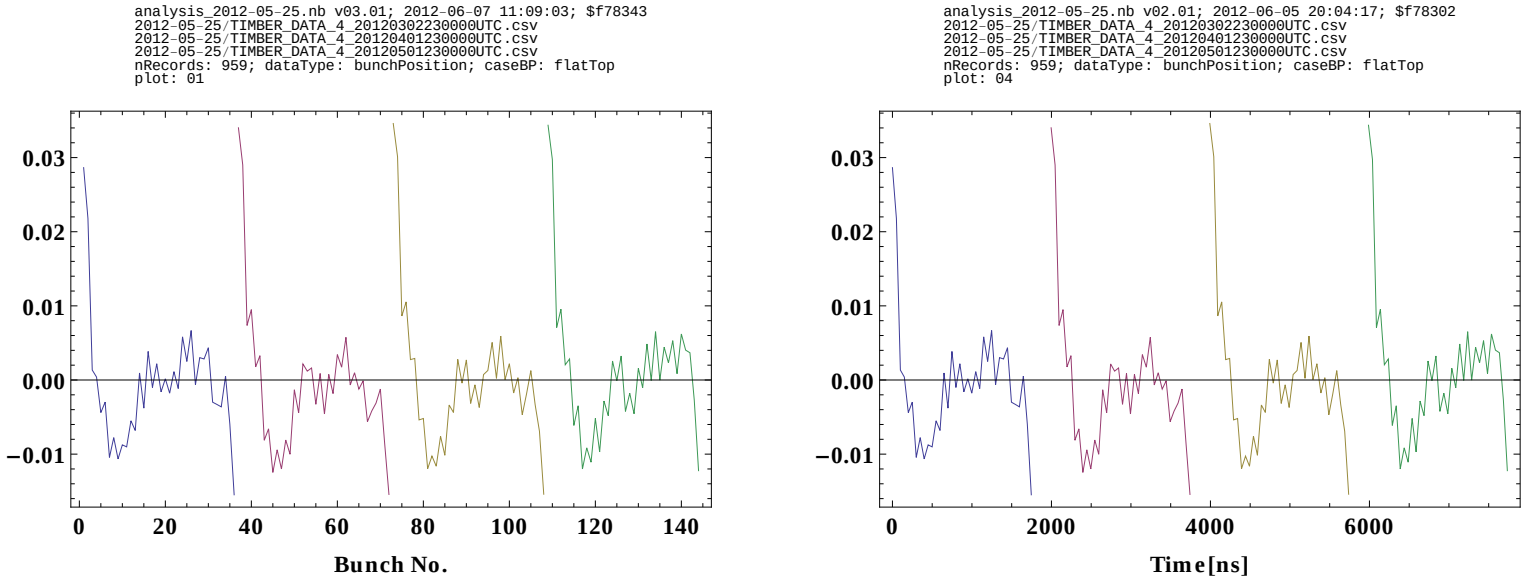


Figure : Left: $\langle z \rangle$ [ns] versus bunch number. Right: $\langle z \rangle$ [ns] versus time. Based on BQM data BUNCH_MEANS.

Data analysis 2012-03-02 to 2012-05-24 XIV

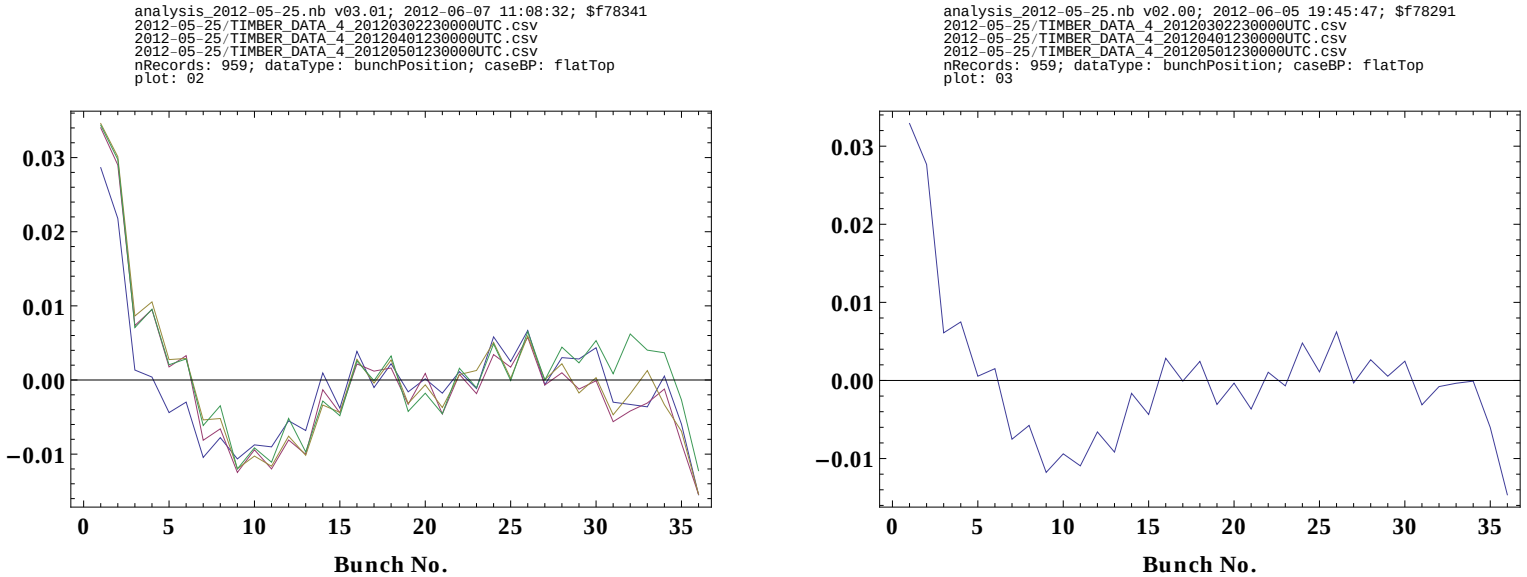


Figure : Left: $\langle z \rangle$ [ns] versus bunch number; folded, same colour code for batches as used in previous Fig. Right: average of the data shown left. Based on BQM data BUNCH_MEANS.

Data analysis 2012-03-02 to 2012-05-24 XV

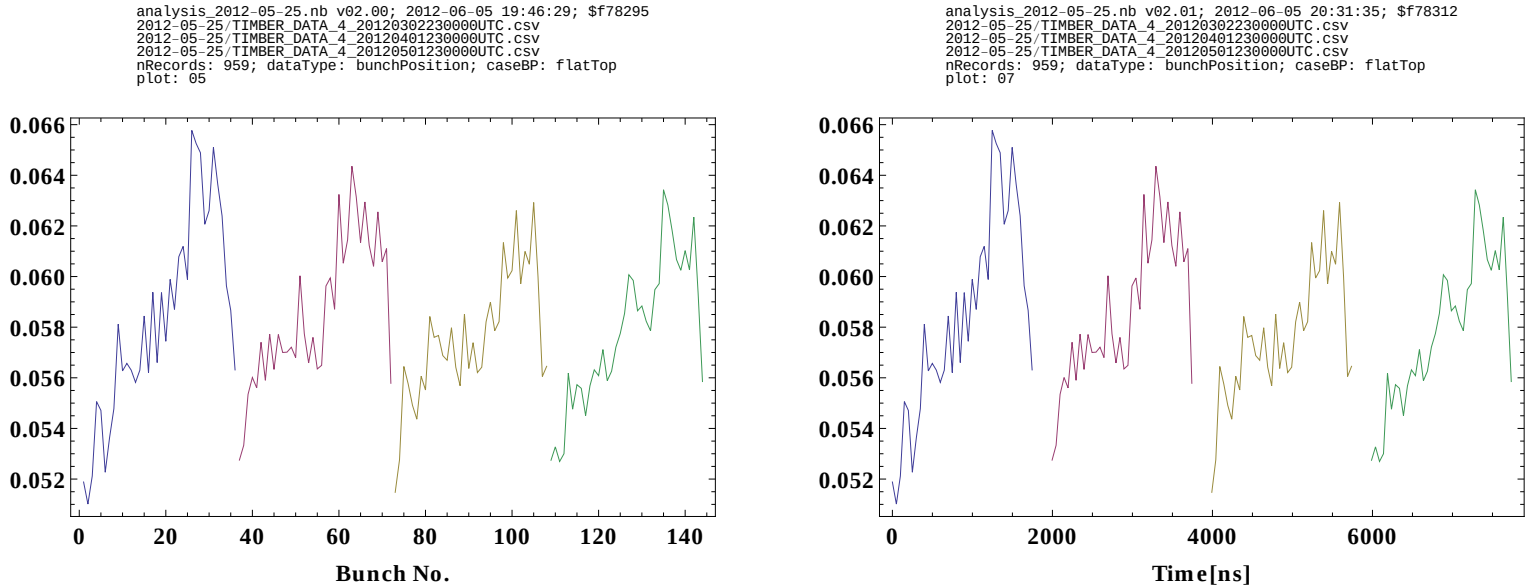


Figure : Left: $\sigma(z)$ [ns] versus bunch number. Right: standard deviation of $\sigma(z)$ [ns] versus time. Based on BQM data BUNCH_MEANS.

Data analysis 2012-03-02 to 2012-05-24 XVI

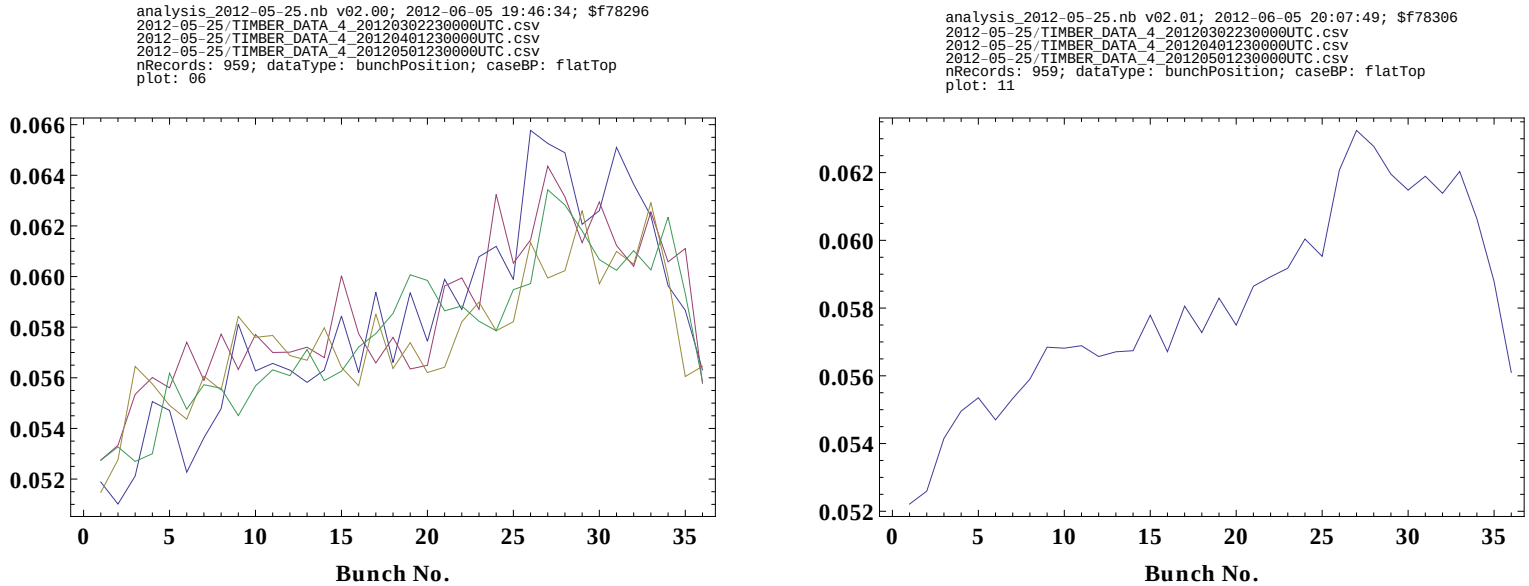


Figure : Left: $\sigma(z)$ [ns] versus bunch number; folded, same colour code for batches as used in previous Fig. Right: average of the data shown left. Based on BQM data BUNCH_MEANS.

Shortest/longest bunches

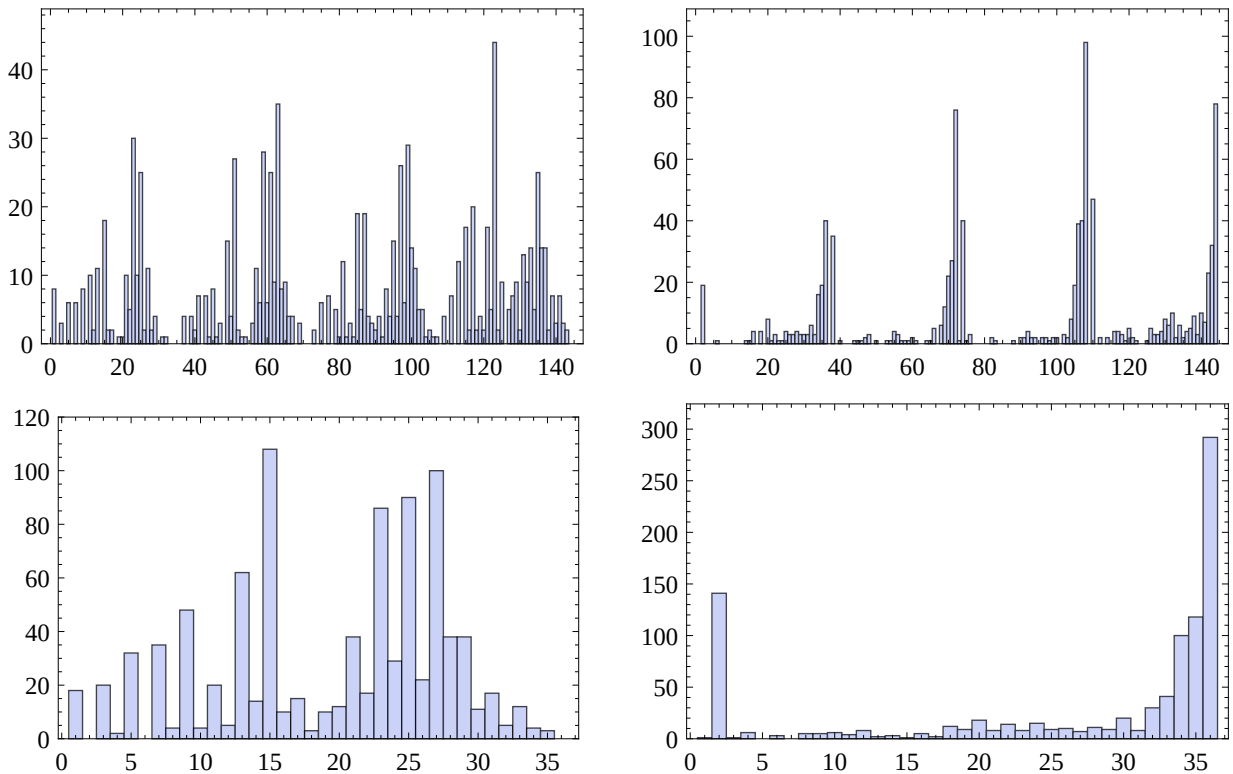
Shortest/longest bunches

- stability
- BQM rejection

Shortest/longest bunches

May

```
analysis_2012-05-25.nb v03.08; 2012-06-13 20:57:37; $f78541
2012-06-12/timber_injphys_05/analysis_2012-05-25_extremaCycle.dat
N(cycles): 932
start: 2012-05-06 10:53
stop : 2012-05-31 21:19
```

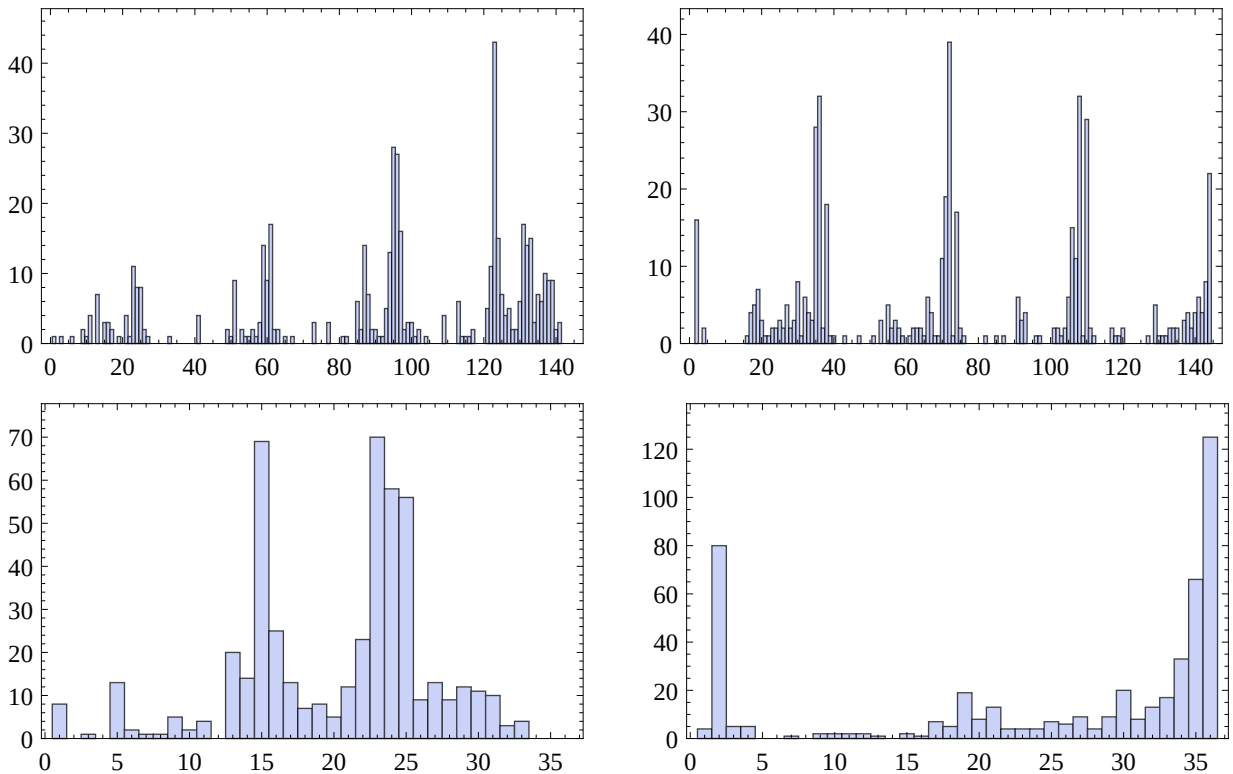


Shortest/longest bunches

June (up to 2012-06-13)

June (up to 2012-06-13)

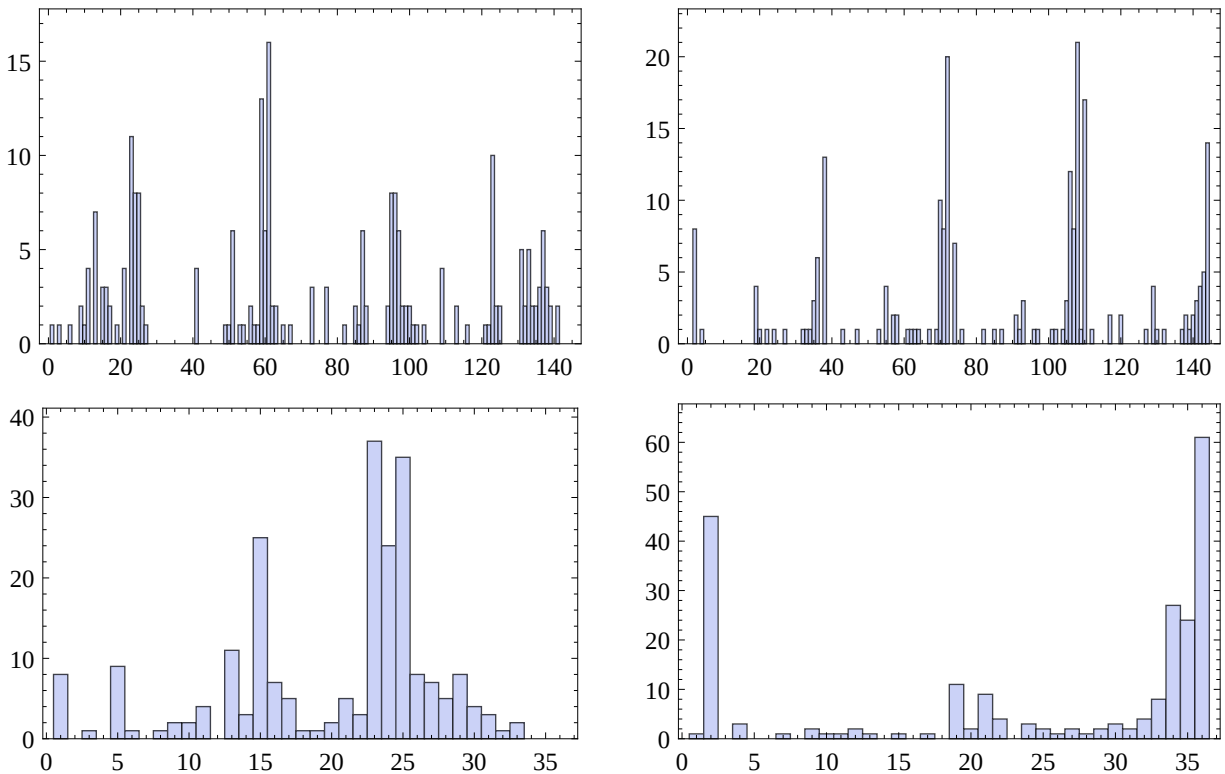
```
analysis_2012-05-25.nb v03.08; 2012-06-13 20:48:06; $f78533
2012-06-13/timber_injphys_06/analysis_2012-05-25_extremaCycle.dat
N(cycles): 488
start: 2012-06-01 02:30
stop : 2012-06-13 10:57
```



Shortest/longest bunches I

June in detail

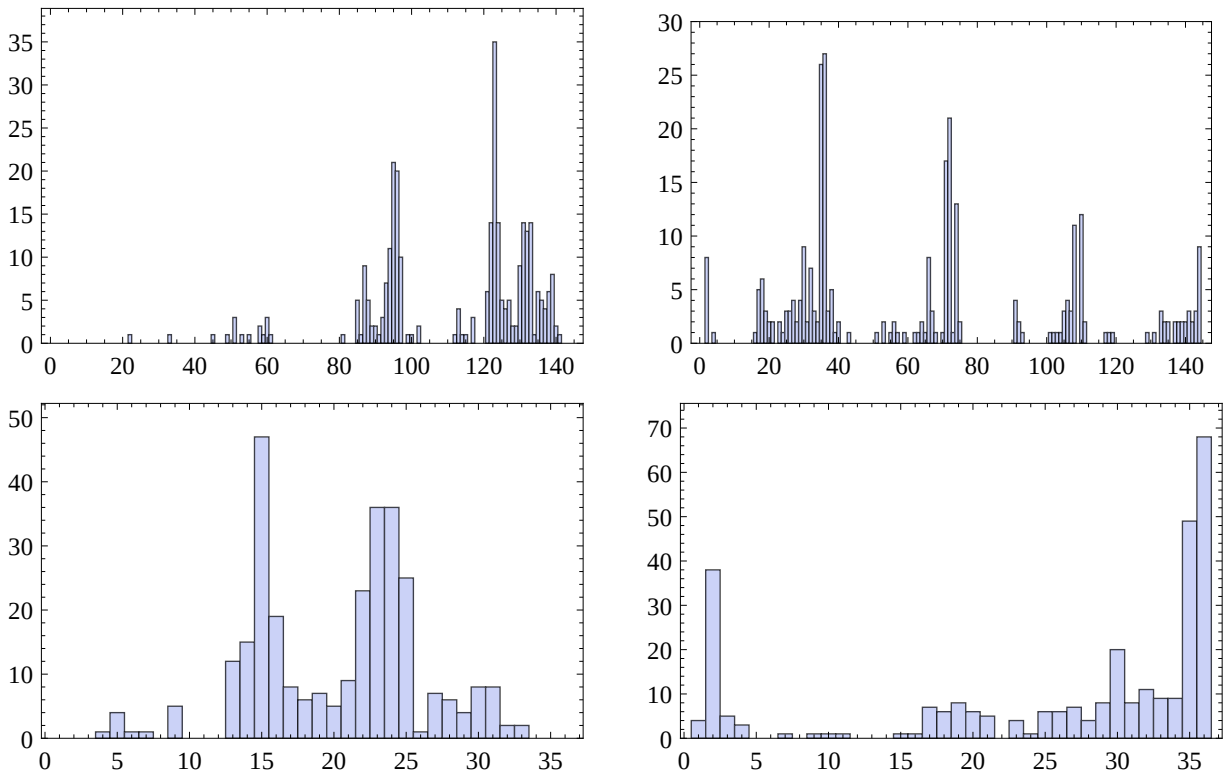
```
analysis_2012-05-25.nb v03.10; 2012-06-19 17:25:13; $f78930
analysis_2012-05-25_extremaCycle.dat
N(cycles): 225
start: 2012-06-01 02:30
stop : 2012-06-06 19:17
```



Shortest/longest bunches II

June in detail

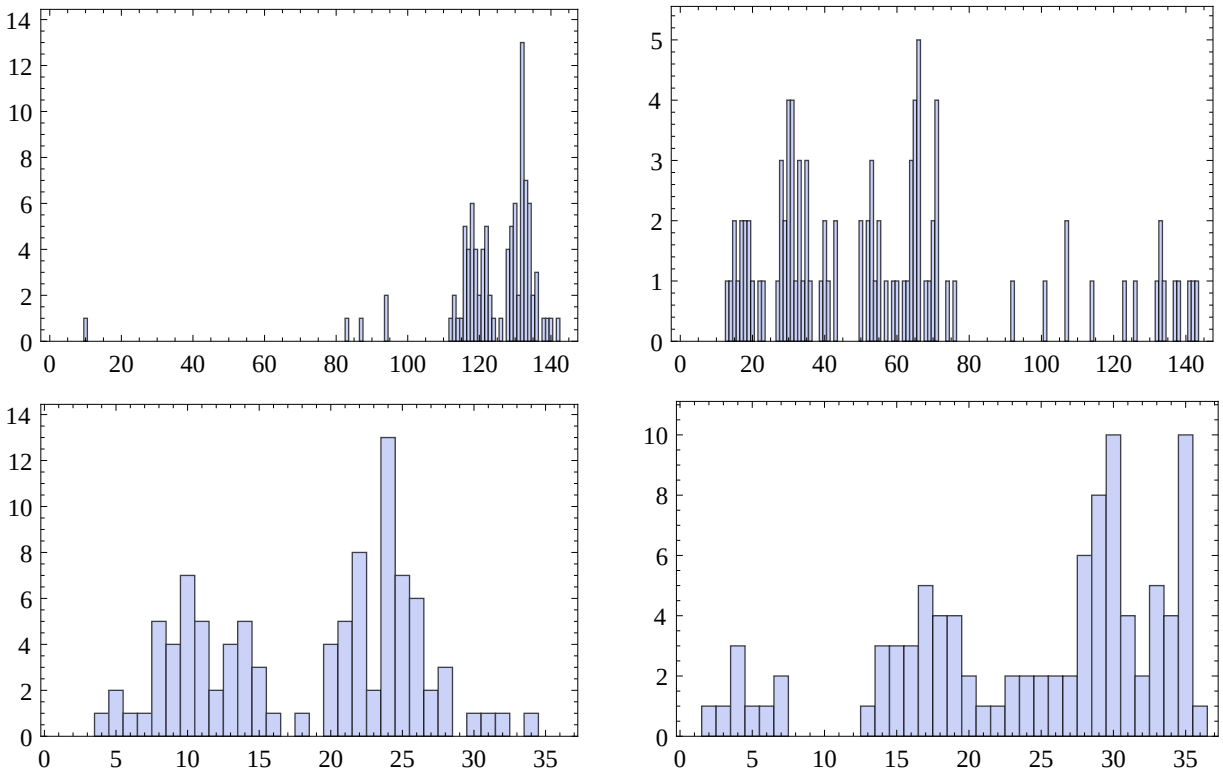
```
analysis_2012-05-25.nb v03.10; 2012-06-19 17:27:17; $f78938
analysis_2012-05-25_extremaCycle.dat
N(cycles): 298
start: 2012-06-07 15:45
stop : 2012-06-14 13:13
```



Shortest/longest bunches III

June in detail

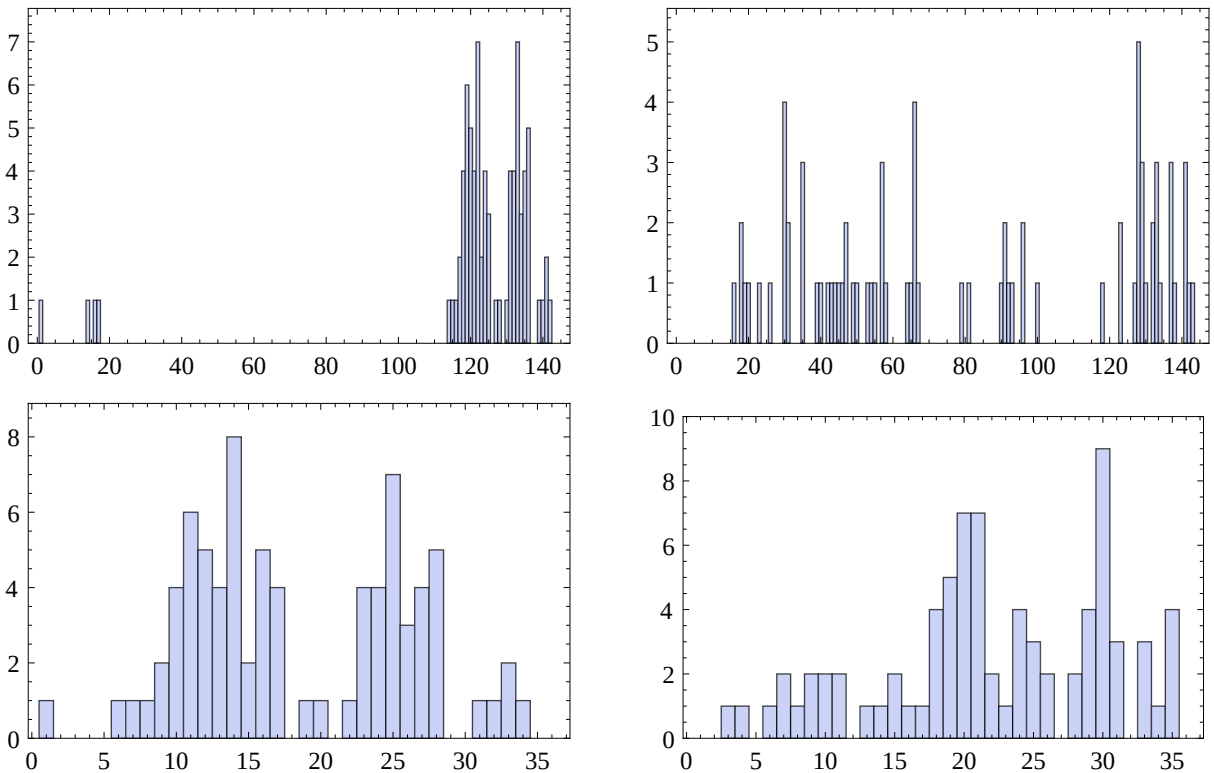
```
analysis_2012-05-25.nb v03.10; 2012-06-19 17:28:41; $f78946
analysis_2012-05-25_extremaCycle.dat
N(cycles): 96
start: 2012-06-14 19:05
stop : 2012-06-16 19:11
```



Shortest/longest bunches IV

June in detail

```
analysis_2012-05-25.nb v03.10; 2012-06-19 17:29:35; $f78954
analysis_2012-05-25_extremaCycle.dat
N(cycles): 79
start: 2012-06-17 19:18
stop : 2012-06-18 09:34
```



Shortest/longest bunches V

June in detail

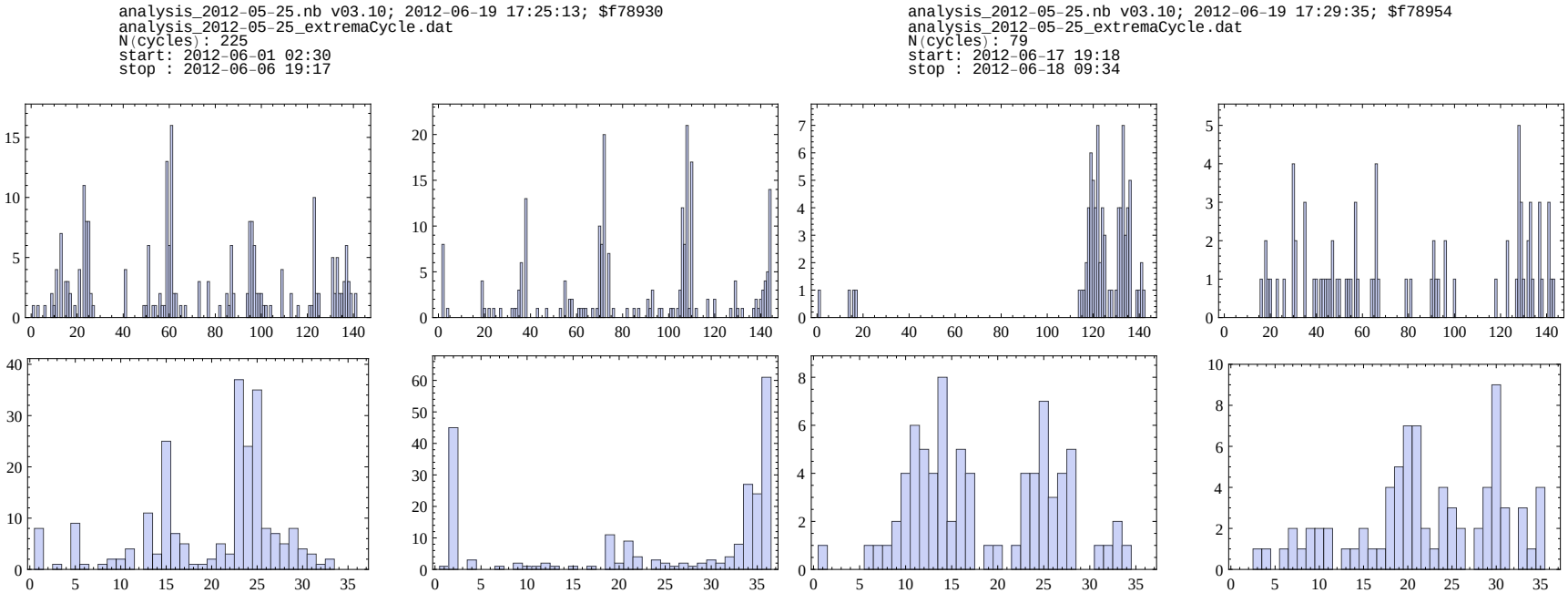
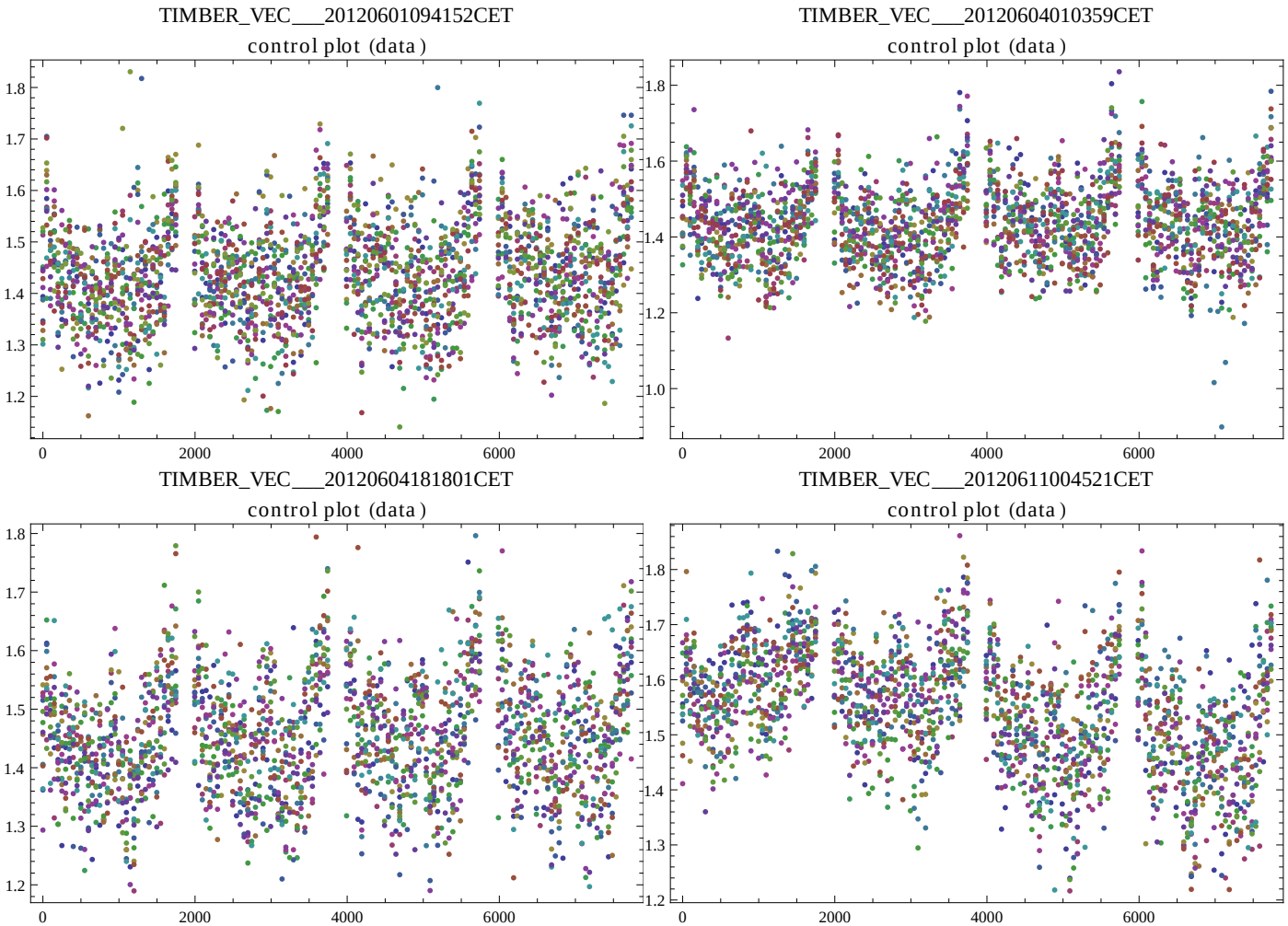


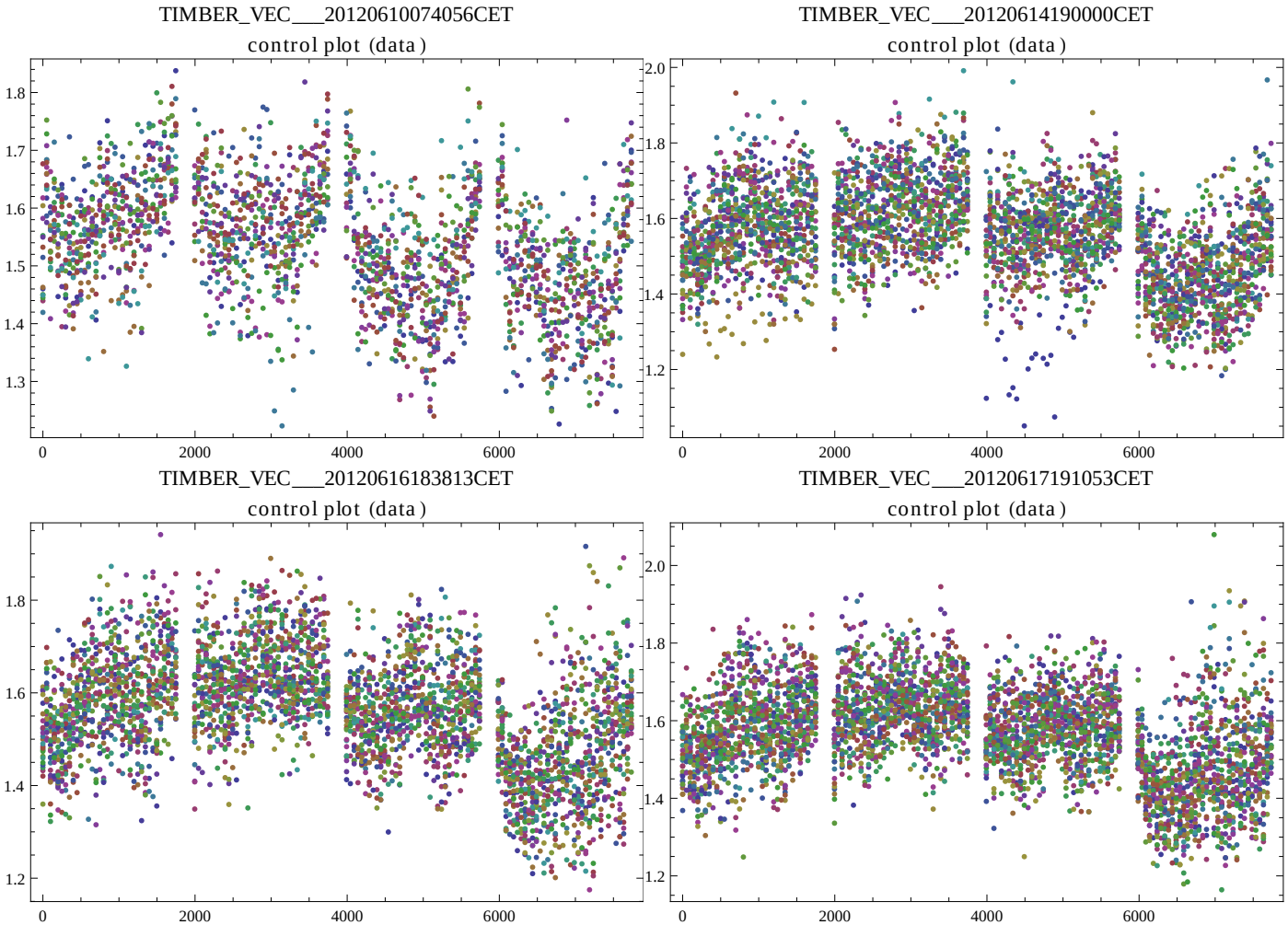
Figure : Left: 2012-06-01 to 2012-06-06. Right: 2012-06-17 to 2012-06-18.

Bunch length at flat top I

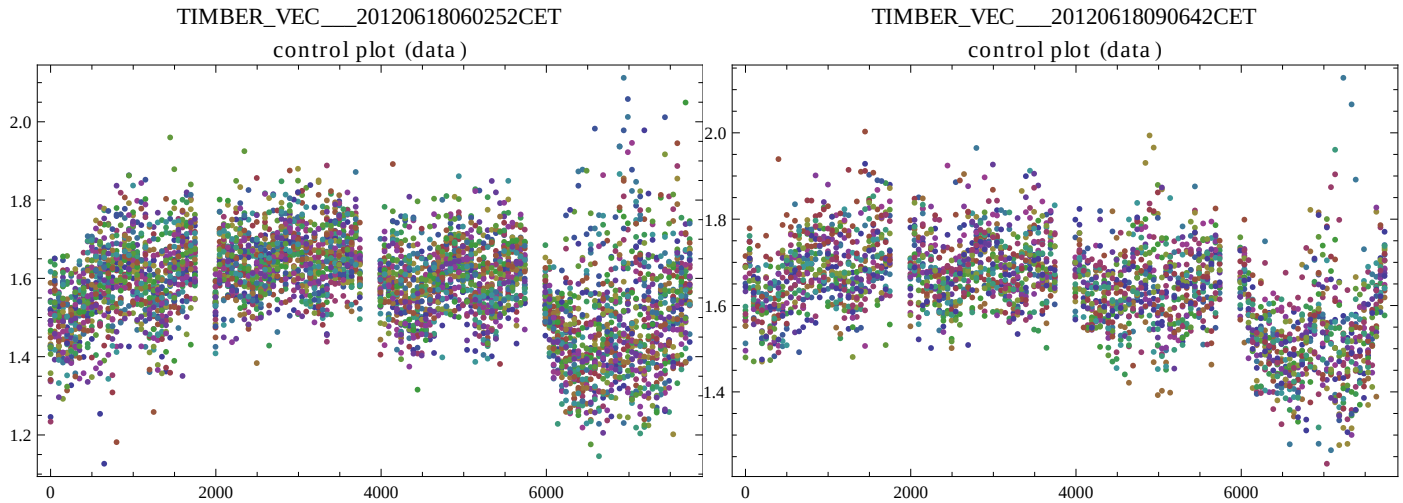
- bunch length data at flat top
- all cycles of a particular LHC fill



Bunch length at flat top II

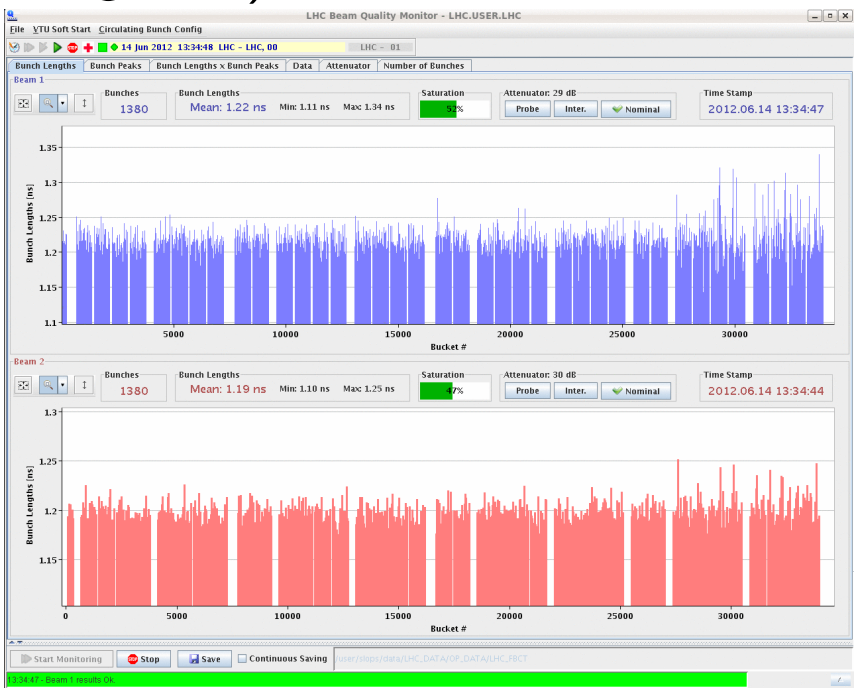


Bunch length at flat top III



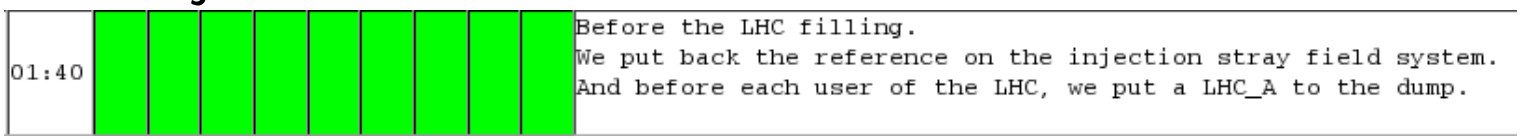
Comparison of two consecutive fills I

- LHC filling ok, 2 batches for LHC missing
- intervention on 80 MHz cavity in CPS
- inject last 2 batches into LHC, problems there "Bunch lengths and intensities bunch-by-bunch, end of ramp. Some spread in the last two injections of beam 1 in bunch length, due to the cavity that was just back from the trip probably." (LHC eLogbook)



Comparison of two consecutive fills II

- try to refill, BQM rejections
- verification of coupled bunch feedback in CPS
- 2012-06-14 19:00: rocky filling, especially for the 2 batch cycles
- look for improvements until about 01:00H: no breakthrough
- PSB adjustment

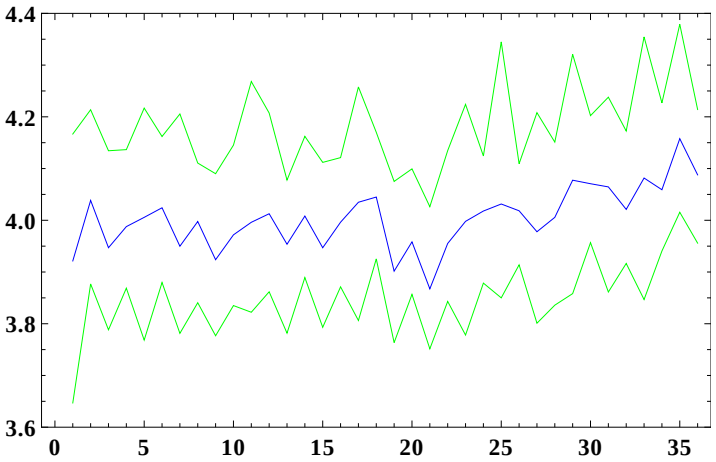


- 2012-06-15 01:34: no problems to fill!
- difference: uniformity of CPS spill: $\lambda_{\mathrm{pp}} = 0.29$ ns versus $\lambda_{\mathrm{pp}} = 0.13$ ns (see also FBCT)

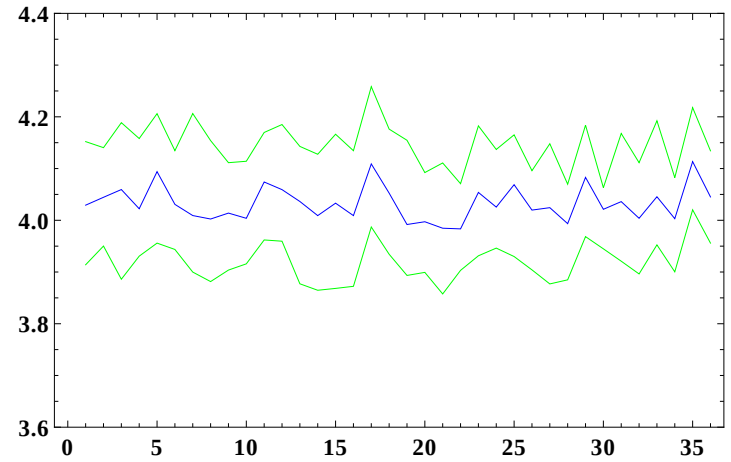
Comparison of two consecutive fills III

```
analysis_2012-05-25.nb v03.10; 2012-06-21 11:08:04; $f78959
2012-06-18/timber_injphys_06/TIMBER_VEC_2_20120614190000CET.csv
isoTime01(3.95848) <> to <> isoTime01(3.98572)
nRecords: 45; dataType: bunchLength; caseBP: injection
{yMin, pos(yMin), pos_mod(yMin): {3.65, 1, 1}
{yMax, pos(yMax), pos_mod(yMax): {4.38, 35, 35}
mean: min:3.87; mean: 4.; std: 0.0586; max: 4.16; max-min: 0.29
aPkPk: 0.732
plot: 16
```

```
analysis_2012-05-25.nb v03.10; 2012-06-21 11:06:19; $f78958
2012-06-18/timber_injphys_06/TIMBER_VEC_2_20120615013415CET.csv
isoTime01(4.08841) <> to <> isoTime01(4.12176)
nRecords: 25; dataType: bunchLength; caseBP: injection
{yMin, pos(yMin), pos_mod(yMin): {3.86, 21, 21}
{yMax, pos(yMax), pos_mod(yMax): {4.26, 17, 17}
mean: min:3.98; mean: 4.03; std: 0.0336; max: 4.11; max-min: 0.13
aPkPk: 0.401
plot: 16
```

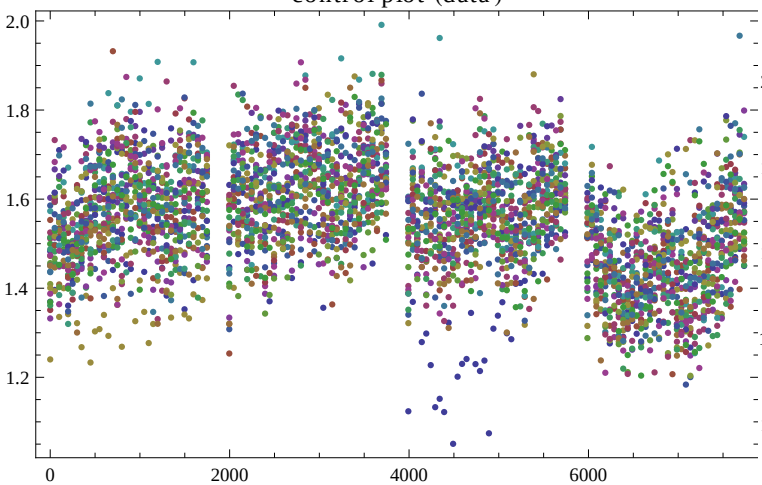


TIMBER_VEC___20120614190000CET

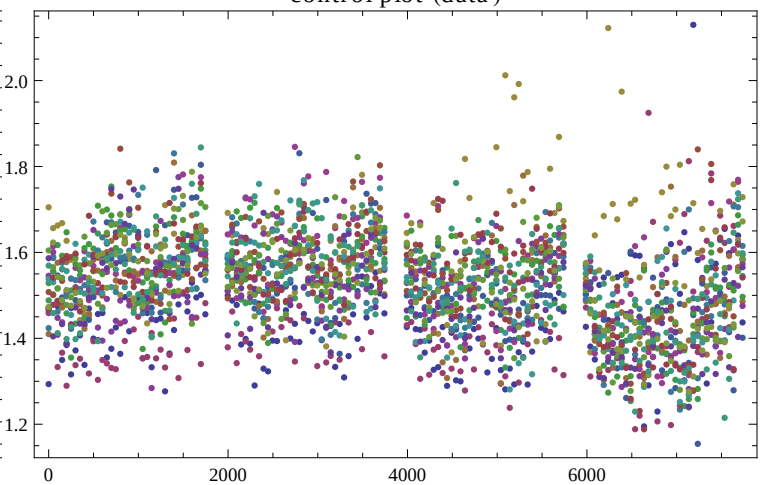


TIMBER_VEC___20120615013415CET

control plot (data)



control plot (data)



Last Monday, 2012-06-18

Observations

- bunch intensity 1.6×10^{11}, higher than for LHC filling
- observations typical for injected beams over weekend but not earlier this month
- Batch 1, Batch 2 unstable in SPS at flat bottom
- bunch shape change (Batch 1) at time of 2nd injection, long. shaving?
- $\lambda(\mathrm{Batch}\ 4)$ shorter than for other batches after contr. long. emittance BUP in SPS (and about equal before)
- Batch 4 unstable at end of SPS ramp
- extra longitudinal emittance blow-up in CPS helped to stabilise Batch 4 at end of ramp in SPS

Next

For next LHC fills

- larger BUP in CPS with optimal rotation timing
- optimise RF voltage dips at injection and at flat top
- different BUP methods, MARGIN settings, ... (problem: no SPS time available)

Requirements

- uniform spill (see FBCT)
- allow larger avg/max bunch length at flat top
- BQM threshold improvement: n/N bunches above threshold