

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

2012-06-21

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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 |

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 $i \in \{1, \dots, N\}$, where N the total number of acquisitions, the mean value per acquisition was obtained as

$$\langle x_i \rangle = \frac{\sum_{j=1}^{N_b} x_{ij}}{N_b}$$

where $x \in \{a_{\text{pk}}, \lambda\}$, 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, $j \in 1, \dots, N_b$ 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

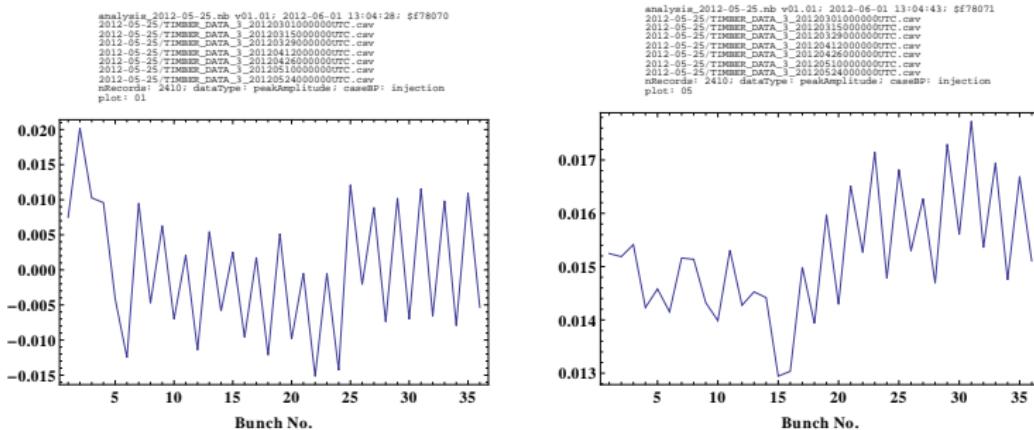
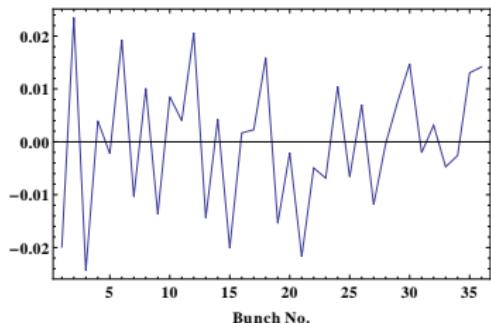


Figure : Left: $\langle \tilde{a}_{pk} \rangle$ versus bunch number. Right: $\sigma(\tilde{a}_{pk})$ versus bunch number. $N = 2412$. Based on BQM data BUNCH_PEAKS_INJ.

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

```
analysis_2012-05-25.nh v04.00: 2012-06-22 08:44:44; #E78968
2012-05-25/TIMMER_DATA_20120308000000UTC.csv
2012-05-25/TIMMER_DATA_20120309000000UTC.csv
2012-05-25/TIMMER_DATA_20120315000000UTC.csv
2012-05-25/TIMMER_DATA_20120321000000UTC.csv
2012-05-25/TIMMER_DATA_20120405000000UTC.csv
2012-05-25/TIMMER_DATA_20120412000000UTC.csv
2012-05-25/TIMMER_DATA_20120418000000UTC.csv
2012-05-25/TIMMER_DATA_20120426000000UTC.csv
2012-05-25/TIMMER_DATA_20120503000000UTC.csv
2012-05-25/TIMMER_DATA_20120510000000UTC.csv
2012-05-25/TIMMER_DATA_20120517000000UTC.csv
2012-05-25/TIMMER_DATA_20120524000000UTC.csv
2012-05-25/TIMMER_DATA_2012-05-25 00:15:44
nrecords: 2412; dataType: bunchLength; caseMP: injection
aPPk: [ 0.0479];
plot: 01
```



```
analysis_2012-05-25.nh v04.00: 2012-06-22 08:45:19; #E78969
2012-05-25/TIMMER_DATA_20120310000000UTC.csv
2012-05-25/TIMMER_DATA_20120308000000UTC.csv
2012-05-25/TIMMER_DATA_20120316000000UTC.csv
2012-05-25/TIMMER_DATA_20120323000000UTC.csv
2012-05-25/TIMMER_DATA_20120405000000UTC.csv
2012-05-25/TIMMER_DATA_20120412000000UTC.csv
2012-05-25/TIMMER_DATA_20120419000000UTC.csv
2012-05-25/TIMMER_DATA_20120426000000UTC.csv
2012-05-25/TIMMER_DATA_20120503000000UTC.csv
2012-05-25/TIMMER_DATA_20120510000000UTC.csv
2012-05-25/TIMMER_DATA_20120517000000UTC.csv
2012-05-25/TIMMER_DATA_20120524000000UTC.csv
2012-04-03 17:02 to 2012-05-25 00:54
nrecords: 2412; dataType: bunchLength; caseMP: injection
plot: 05
```

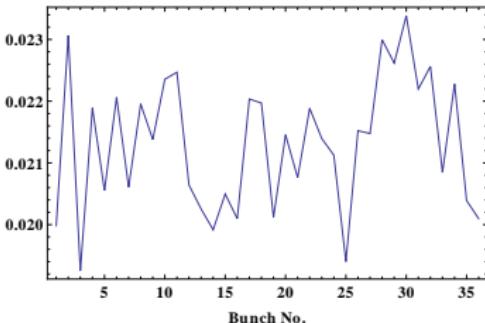


Figure : Left: $\langle \tilde{\lambda} \rangle$ versus bunch number. Right: $\sigma(\tilde{\lambda})$ versus bunch number. $N = 2412$. Based on BQM data BUNCH_LENGTHS_INJ.

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

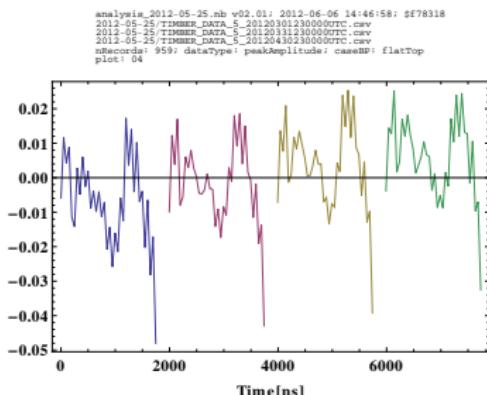
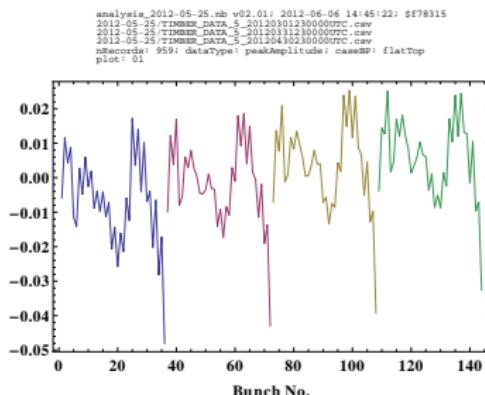
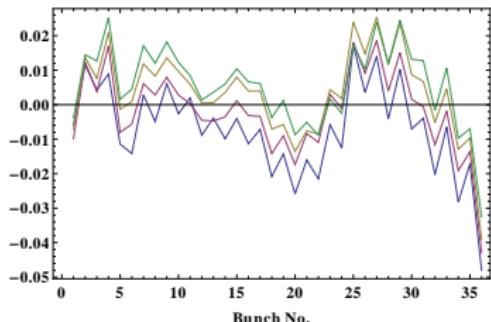


Figure : Left: $\langle \tilde{a}_{pk} \rangle$ versus bunch number. Right: $\langle \tilde{a}_{pk} \rangle$ versus time.
Based on BQM data BUNCH_PEAKS.

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

```
analysis_2012-05-25.nb v02.01: 2012-06-06 14:46:25; $f78316
2012-05-25/TIMBER_DATA_5_2012043012300000UTC.csv
2012-05-25/TIMBER_DATA_5_2012043013300000UTC.csv
2012-05-25/TIMBER_DATA_5_2012043023000000UTC.csv
nSeconds: 959; dataType: peakAmplitude; caseBP: flatTop
plot: 02
```



```
analysis_2012-05-25.nb v02.01: 2012-06-06 14:46:43; $f78317
2012-05-25/TIMBER_DATA_5_2012043012300000UTC.csv
2012-05-25/TIMBER_DATA_5_2012043013300000UTC.csv
2012-05-25/TIMBER_DATA_5_2012043023000000UTC.csv
nSeconds: 959; dataType: peakAmplitude; caseBP: flatTop
plot: 03
```

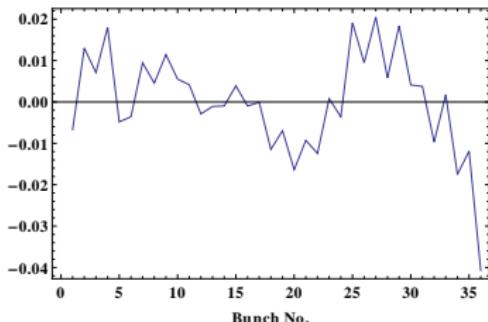
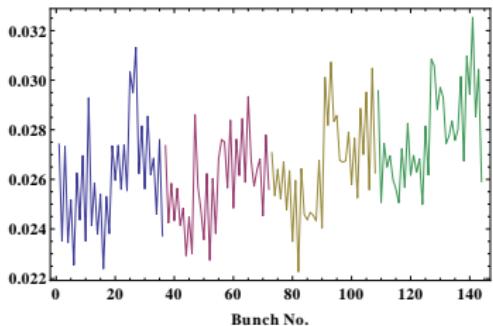


Figure : Left: $\langle \tilde{a}_{pk} \rangle$ versus bunch number; folded, same colour code for batches as used in previous Fig. Right: average of data shown left. Based on BQM data BUNCH_PEAKS.

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

```
analysis_2012-05-25.nb v02.01; 2012-06-06 14:47:25; $f78321  
2012-05-25/TIMBER_DATA_3_20120301230000UTC.csv  
2012-05-25/TIMBER_DATA_3_20120301230000UTC.csv  
2012-05-25/TIMBER_DATA_3_20120430230000UTC.csv  
nRecords: 959; dataType: peakAmplitude; caseHP: flatTop  
plot: 05
```



```
analysis_2012-05-25.nb v02.01; 2012-06-06 14:48:12; $f78324  
2012-05-25/TIMBER_DATA_5_20120311230000UTC.csv  
2012-05-25/TIMBER_DATA_5_20120311230000UTC.csv  
2012-05-25/TIMBER_DATA_5_20120430230000UTC.csv  
nRecords: 959; dataType: peakAmplitude; caseHP: flatTop  
plot: 07
```

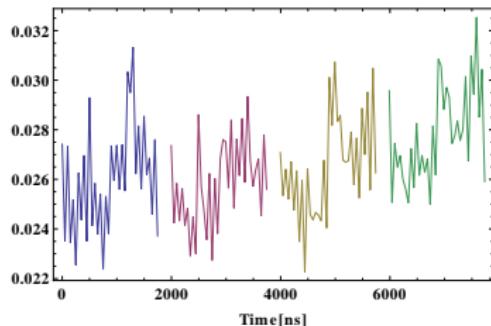


Figure : Left: $\sigma(\tilde{a}_{\text{pk}})$ versus bunch number. Right: $\sigma(\tilde{a}_{\text{pk}})$ versus time.
Based on BQM data BUNCH_PEAKS.

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

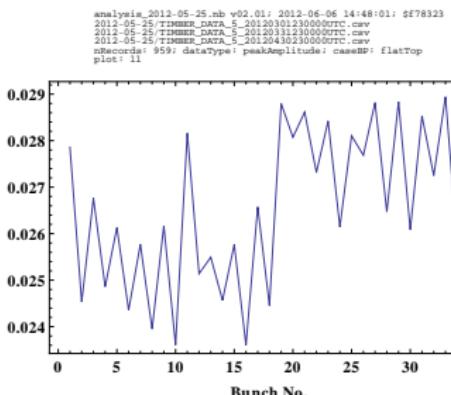
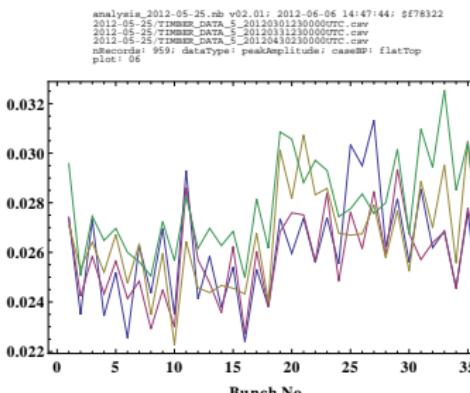


Figure : Left: $\sigma(\tilde{a}_{pk})$ versus bunch number; folded, same colour code for batches as used in previous. Right: average of the data shown left.
Based on BQM data BUNCH_PEAKS.

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

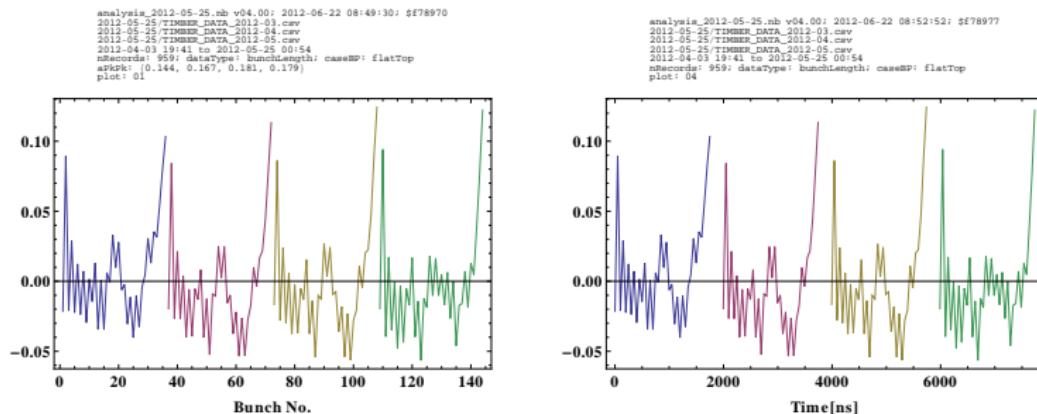
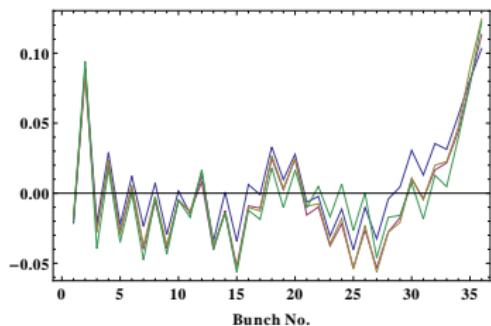


Figure : Left: $\langle \tilde{\lambda} \rangle$ versus bunch number. Right: $\langle \tilde{\lambda} \rangle$ versus time. Based on BQM data BUNCH_LENGTHS.

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

```
analysis_2012-05-25.nb v04.00: 2012-06-22 08:50:18: $f78971
2012-05-25/TIMMER_DATA_2012-04.csv
2012-05-25/TIMMER_DATA_2012-04.csv
2012-05-25/TIMMER_DATA_2012-05.csv
2012-05-01 09:41 to 2012-05-25 00:54
nRecords: 959; dataType: bunchLength; caseBP: flatTop
plot: 02
```



```
analysis_2012-05-25.nb v04.00: 2012-06-22 08:50:32: $f78972
2012-05-25/TIMMER_DATA_2012-04.csv
2012-05-25/TIMMER_DATA_2012-04.csv
2012-05-25/TIMMER_DATA_2012-05.csv
2012-05-01 09:41 to 2012-05-25 00:54
nRecords: 959; dataType: bunchLength; caseBP: flatTop
plot: 03
```

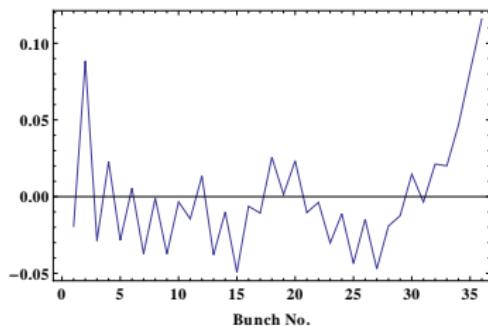
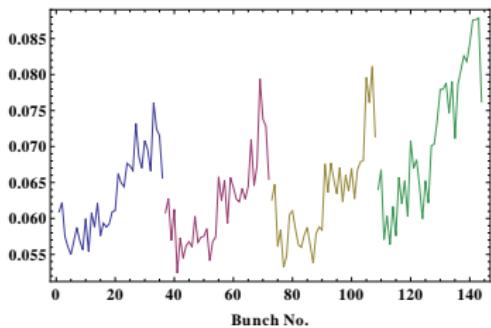


Figure : Left: $\langle \tilde{\lambda} \rangle$, folded; same colour code for batches as for previous Fig. Right: average of data shown on the left. Based on BQM data BUNCH_LENGTHS.

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

```
analysis_2012-05-25.nb v04.00; 2012-06-22 08:51:37; $E78973
2012-05-25 /TIMMER_DATA_2012-03.csv
2012-05-25 /TIMMER_DATA_2012-04.csv
2012-05-25 /TIMMER_DATA_2012-05.csv
2012-05-01 09:41 to 2012-05-25 00:54
nRecords: 959; datatype: BunchLength; caseEP: flatTop
plot: 05
```



```
analysis_2012-05-25.nb v04.00; 2012-06-22 09:03:26; $E78980
2012-05-25 /TIMMER_DATA_2012-03.csv
2012-05-25 /TIMMER_DATA_2012-04.csv
2012-05-25 /TIMMER_DATA_2012-05.csv
2012-05-03 09:41 to 2012-05-25 00:54
nRecords: 959; datatype: BunchLength; caseEP: flatTop
plot: 07
```

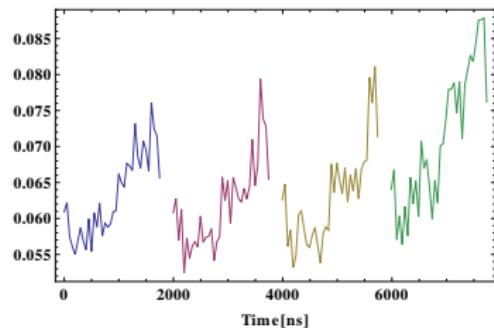
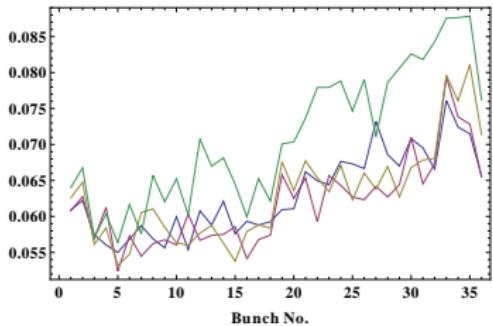


Figure : Left: $\sigma(\tilde{\lambda})$ versus bunch number. Right: $\sigma(\tilde{a}_{pk})$ versus time.
Based on BQM data BUNCH_LENGTHS.

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

```
analysisim_2012-05-25.nb v04.00; 2012-06-22 08:51:54; $E78975
2012-05-25 /TIMMER_DATA_2012-03.csv
2012-05-25 /TIMMER_DATA_2012-03.csv
2012-05-25 /TIMMER_DATA_2012-05.csv
2012-05-01 09:41 to 2012-05-25 00:54
nRecords: 959; datatype: BunchLength; caseEP: flatTop
plot: 06
```



```
analysisim_2012-05-25.nb v04.00; 2012-06-22 08:52:01; $E78975
2012-05-25 /TIMMER_DATA_2012-03.csv
2012-05-25 /TIMMER_DATA_2012-03.csv
2012-05-25 /TIMMER_DATA_2012-05.csv
2012-05-01 09:41 to 2012-05-25 00:54
nRecords: 959; datatype: BunchLength; caseEP: flatTop
plot: 11
```

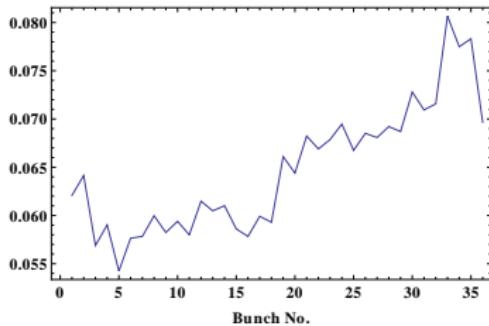
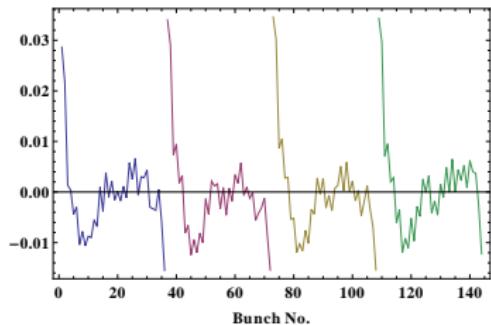


Figure : Left: $\sigma(\tilde{\lambda})$ versus bunch number; folded, same colour code for batches as used in previous Fig. Right: average of the data shown left. Based on BQM data BUNCH_LENGTHS.

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

```
analysis_2012-05-25.nb v03.01: 2012-06-07 11:09:03: $f78343  
2012-05-25/TIMBER_DATA_4_20120502230000UTC.csv  
2012-05-25/TIMBER_DATA_4_20120503000000UTC.csv  
2012-05-25/TIMBER_DATA_4_20120505123000UTC.csv  
nRecords: 959; dataType: bunchPosition; caseBP: flatTop  
plot: 01
```



```
analysis_2012-05-25.nb v02.01: 2012-06-05 20:04:17: $f78302  
2012-05-25/TIMBER_DATA_4_20120502230000UTC.csv  
2012-05-25/TIMBER_DATA_4_20120503000000UTC.csv  
2012-05-25/TIMBER_DATA_4_20120505123000UTC.csv  
nRecords: 959; dataType: bunchPosition; caseBP: flatTop  
plot: 04
```

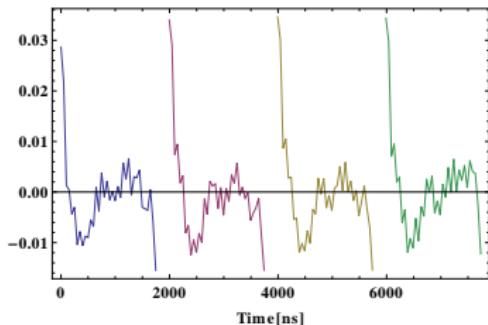
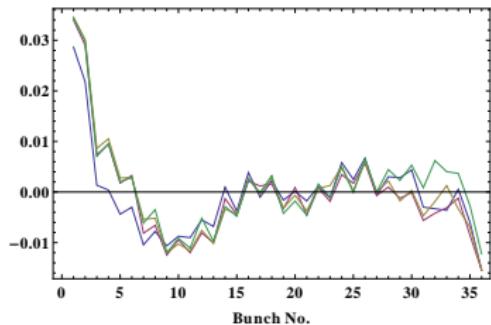


Figure : Left: $\langle z \rangle$ [ns] versus bunch number. Right: $\langle z \rangle$ [ns] versus time.
Based on BQM data BUNCH_MEANS.

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

```
analysis_2012-05-25.nb v03.01: 2012-06-07 11:08:32; $f78341  
2012-05-25/TIMBER_DATA_4_20120302230000UTC.csv  
2012-05-25/TIMBER_DATA_4_2012030512300000UTC.csv  
2012-05-25/TIMBER_DATA_4_20120501230000UTC.csv  
nSeconds: 959; dataType: bunchPosition; caseBP: flatTop  
plot: 02
```



```
analysis_2012-05-25.nb v02.00: 2012-06-05 19:45:47; $f78291  
2012-05-25/TIMBER_DATA_4_20120302230000UTC.csv  
2012-05-25/TIMBER_DATA_4_2012030512300000UTC.csv  
2012-05-25/TIMBER_DATA_4_20120501230000UTC.csv  
nSeconds: 959; dataType: bunchPosition; caseBP: flatTop  
plot: 03
```

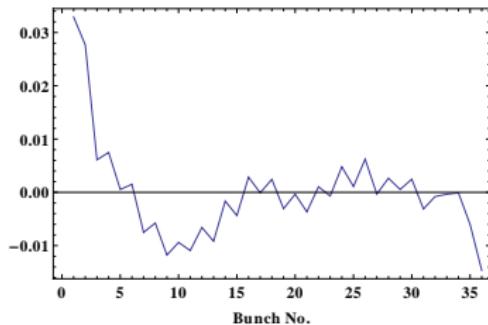
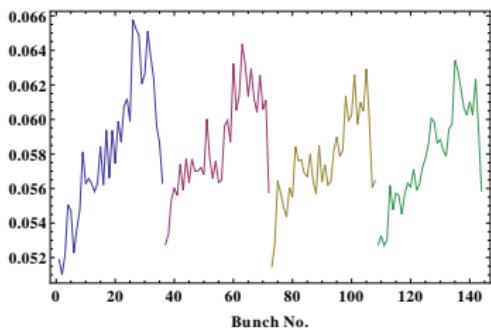


Figure : Left: $\langle z \rangle$ [ns] versus bunch number; folded, same colour code for batches as used in previous Fig. Right: average of the data shown left. Based on BQM data BUNCH_MEANS.

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

```
analysis_2012-05-25.nb v02.00; 2012-06-05 19:46:29; $f78295
2012-05-25 /TIMMER_DATA_4_201205102230000UTC.csv
2012-05-25 /TIMMER_DATA_4_201205102230000UTC.csv
2012-05-25 /TIMMER_DATA_4_201205102230000UTC.csv
2012-05-25 /TIMMER_DATA_4_201205102230000UTC.csv
nRecords: 959; dataType: bunchPosition; caseHP: flatTop
plot: 05
```



```
analysis_2012-05-25.nb v02.01; 2012-06-05 20:31:35; $f78312
2012-05-25 /TIMMER_DATA_4_20120512230000UTC.csv
2012-05-25 /TIMMER_DATA_4_20120512230000UTC.csv
2012-05-25 /TIMMER_DATA_4_20120512230000UTC.csv
2012-05-25 /TIMMER_DATA_4_20120512230000UTC.csv
nRecords: 959; dataType: bunchPosition; caseHP: flatTop
plot: 07
```

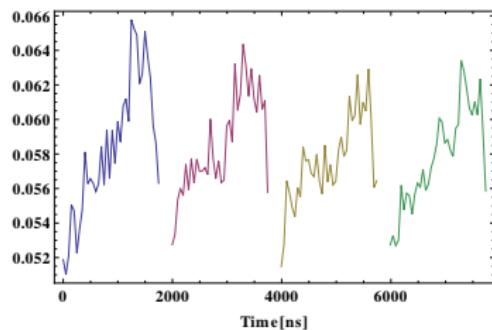
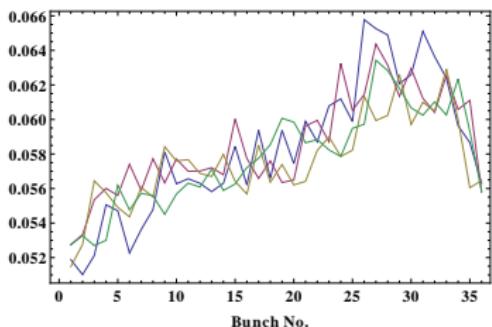


Figure : Left: $\sigma(z)$ [ns] versus bunch number. Right: standard deviation of $\sigma(z)$ [ns] versus time. Based on BQM data BUNCH_MEANS.

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

```
analysis_2012-05-25.nb v02.00; 2012-06-05 19:46:34; $E78296
2012-05-25/TIMMER_DATA_4_20120510223000UTC.csv
2012-05-25/TIMMER_DATA_4_20120510230000UTC.csv
2012-05-25/TIMMER_DATA_4_20120511230000UTC.csv
nRecords: 959; dataType: bunchPosition; caseHP: flatTop
plot: 06
```



```
analysis_2012-05-25.nb v02.01; 2012-06-05 20:07:49; $E78306
2012-05-25/TIMMER_DATA_4_20120510223000UTC.csv
2012-05-25/TIMMER_DATA_4_20120510230000UTC.csv
2012-05-25/TIMMER_DATA_4_20120511230000UTC.csv
nRecords: 958; dataType: bunchPosition; caseHP: flatTop
plot: 11
```

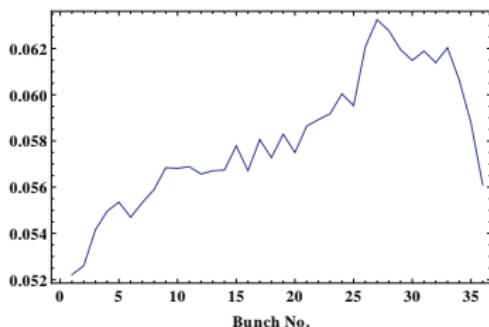


Figure : Left: $\sigma(z)$ [ns] versus bunch number; folded, same colour code for batches as used in previous Fig. Right: average of the data shown left. Based on BQM data BUNCH_MEANS.

Shortest/longest bunches

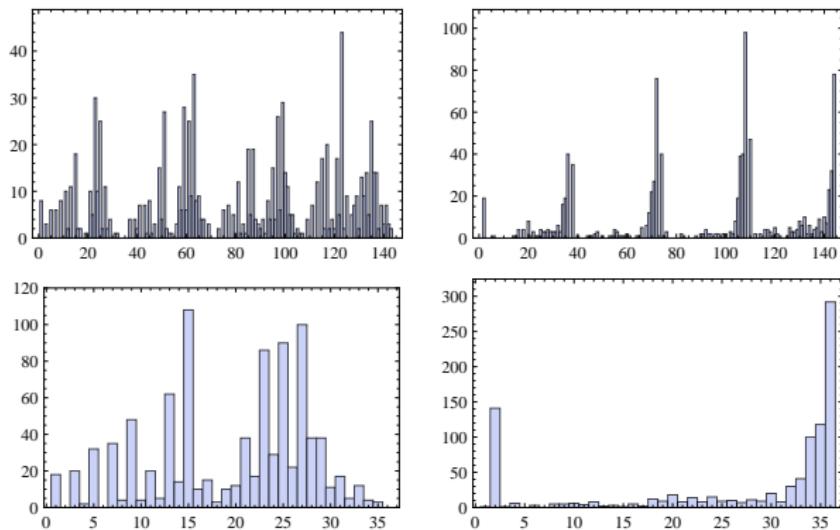
Shortest/longest bunches

- ▶ 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
```

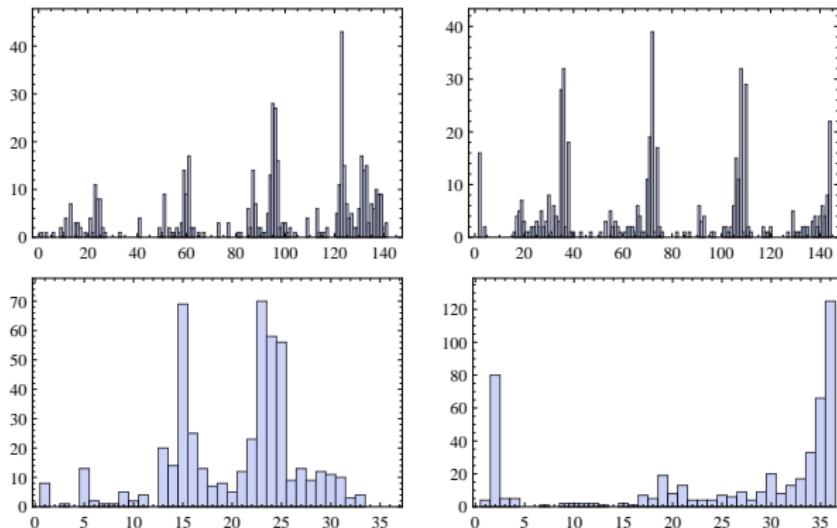


Shortest/longest bunches

June (up to 2012-06-13)

June (up to 2012-06-13)

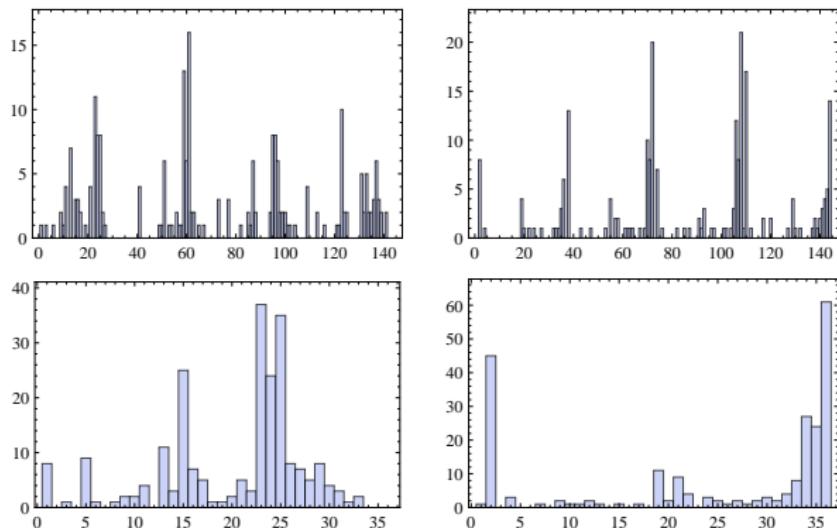
```
analysis_2012-05-25.nb v03.08; 2012-06-13 20:48:06; $f78533
2012-06-13/timber_injphys_06/analysis_2012-05-25_extremaCycle.dat
N(cycles): 488
start: 2012-06-01 02:30
stop : 2012-06-13 10:57
```



Shortest/longest bunches I

June in detail

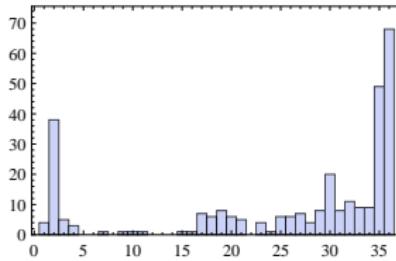
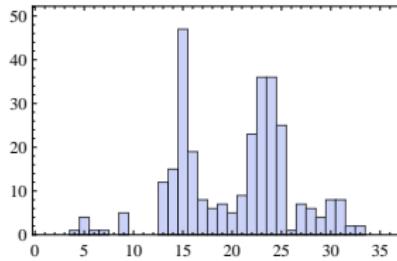
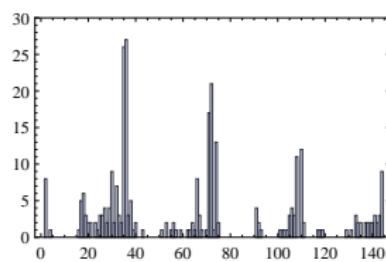
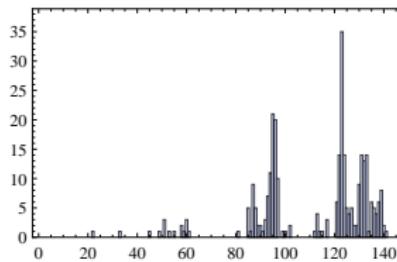
```
analysis_2012-05-25.nb v03.10; 2012-06-19 17:25:13; $f78930
analysis_2012-05-25_extremaCycle.dat
N(cycles): 225
start: 2012-06-01 02:30
stop : 2012-06-06 19:17
```



Shortest/longest bunches II

June in detail

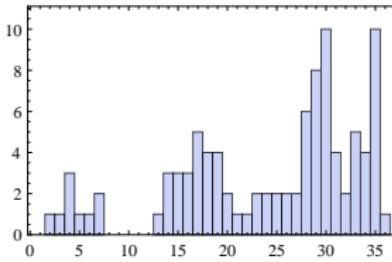
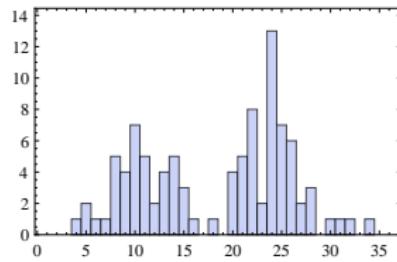
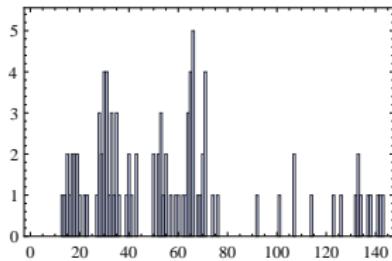
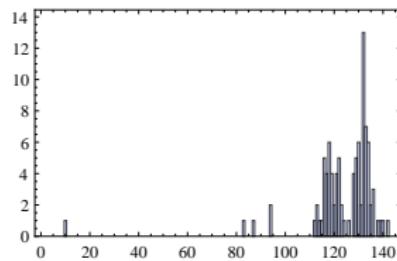
```
analysis_2012-05-25.nb v03.10; 2012-06-19 17:27:17; $f78938
analysis_2012-05-25_extremaCycle.dat
N(cycles): 298
start: 2012-06-07 15:45
stop : 2012-06-14 13:13
```



Shortest/longest bunches III

June in detail

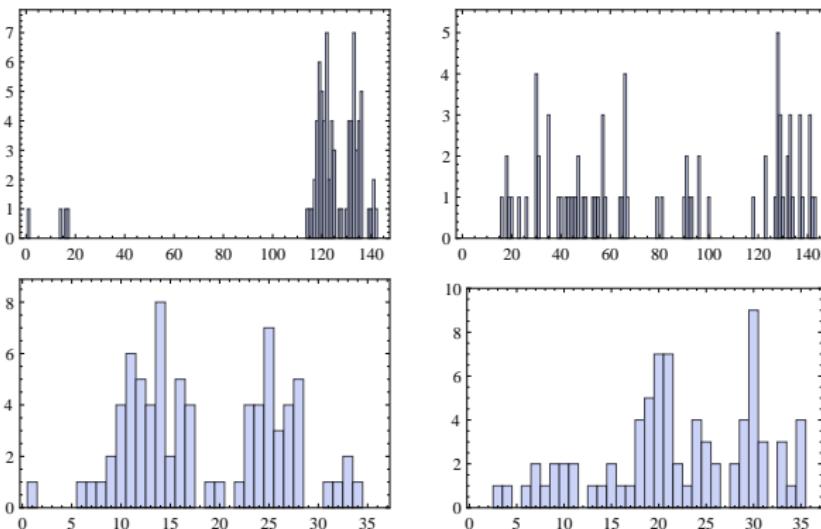
```
analysis_2012-05-25.nb v03.10; 2012-06-19 17:28:41; $f78946
analysis_2012-05-25_extremaCycle.dat
N(cycles): 96
start: 2012-06-14 19:05
stop : 2012-06-16 19:11
```



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 19:18:24
stop : 2012-06-18 09:34
```



Shortest/longest bunches V

June in detail

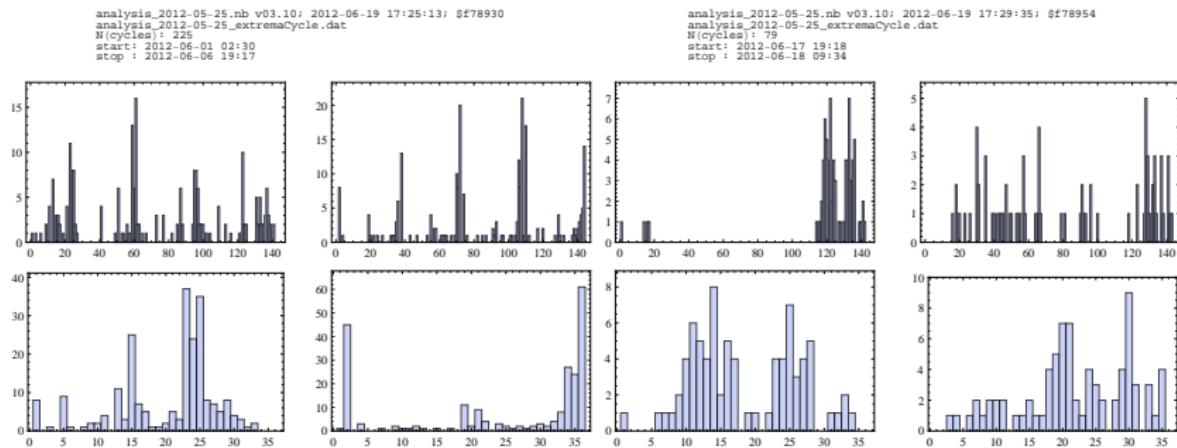
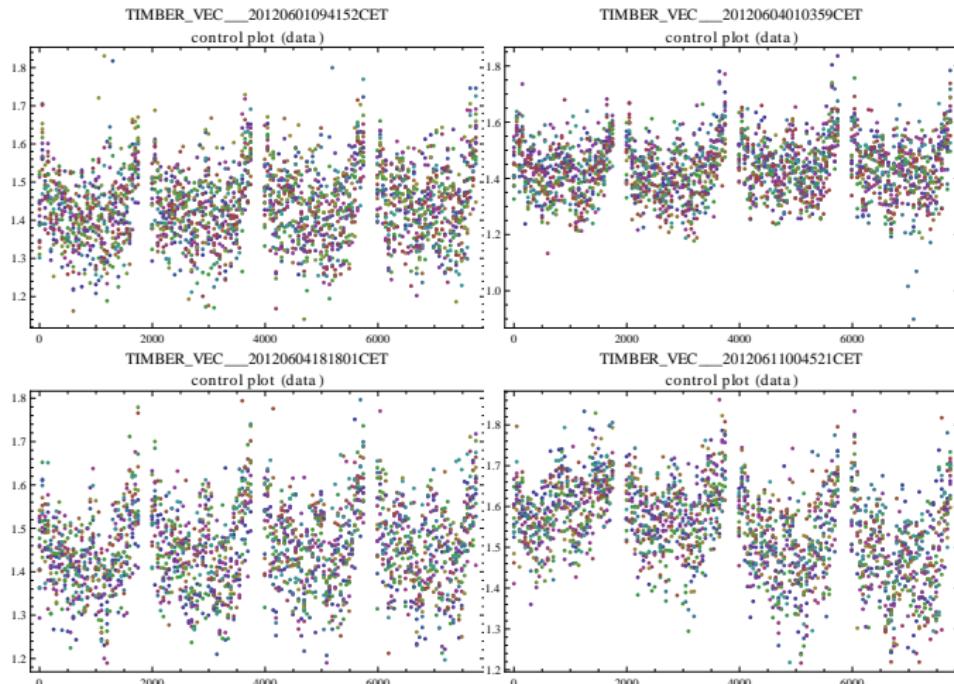


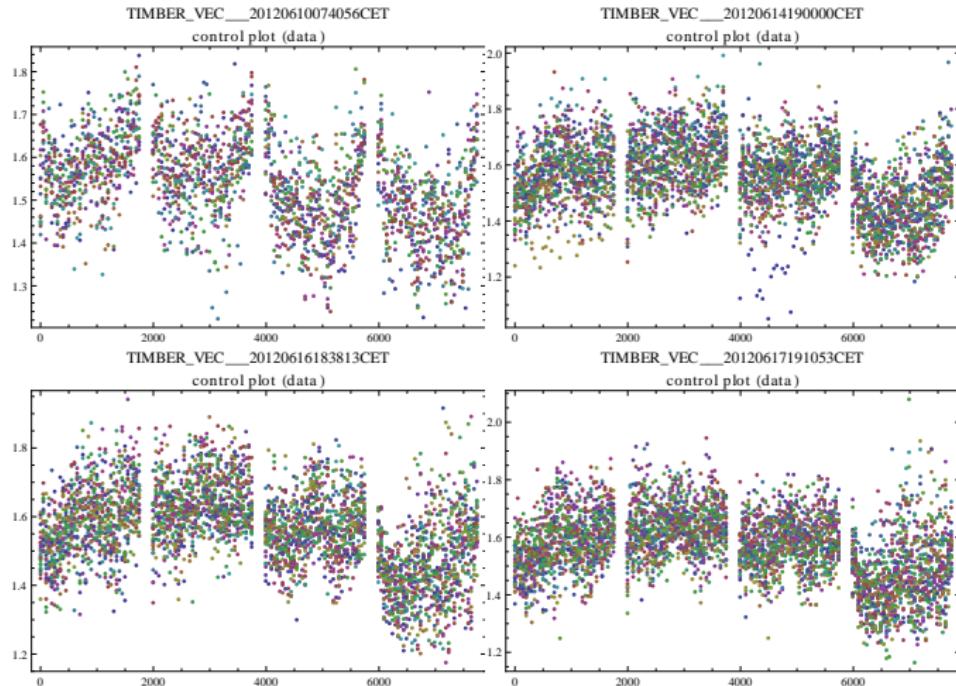
Figure : Left: 2012-06-01 to 2012-06-06. Right: 2012-06-17 to 2012-06-18.

Bunch length at flat top I

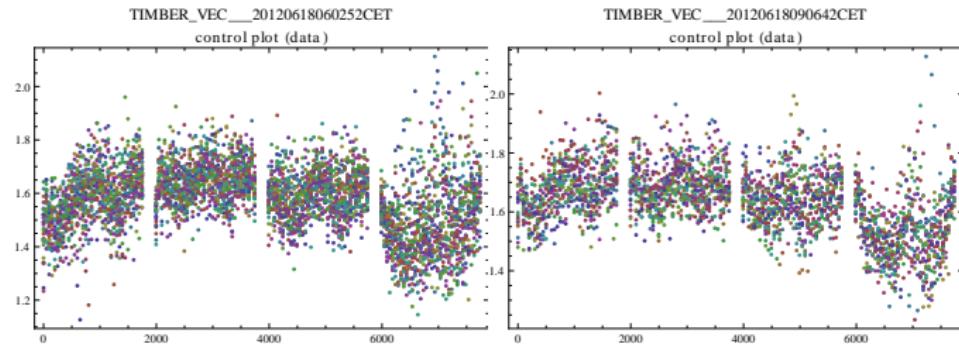
- ▶ bunch length data at flat top
- ▶ all cycles of a particular LHC fill



Bunch length at flat top II

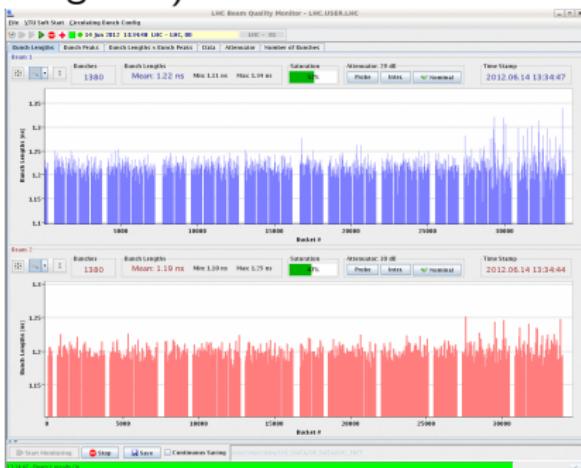


Bunch length at flat top III



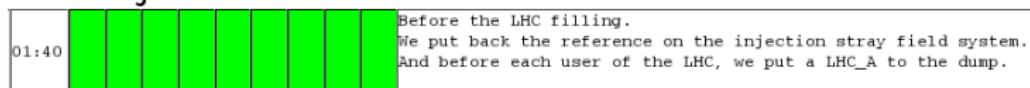
Comparison of two consecutive fills I

- ▶ 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

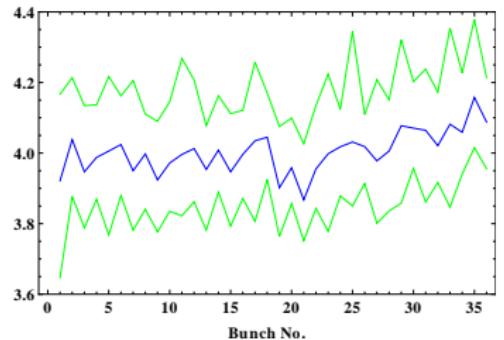


- ▶ 2012-06-15 01:34: no problems to fill!
- ▶ difference: uniformity of CPS spill: $\lambda_{pp} = 0.29$ ns versus $\lambda_{pp} = 0.13$ ns (see also FBCT)

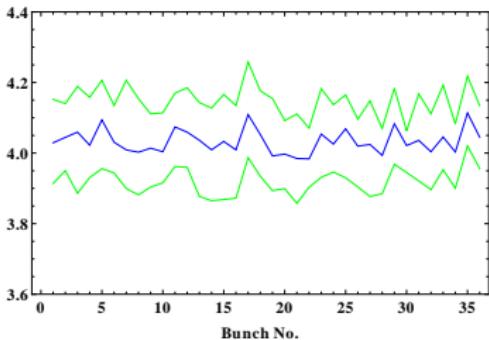
Comparison of two consecutive fills III

```
analysis_2012-05-25.nb v03.10: 2012-06-21 11:08:04; #E78959
2012-06-21 11:08:04; /injtrig_06/TimeSeries/2_20120614190000CET.csv
isotri_01[1, 0.95846] -> isotri_01[1, 0.98846]
nrecords: 45; dataType: bunchlength; caseIDP: injection
ymin, ymax: [3.6, 4.4]; pos_mod(ymin): [4.15, 35.1];
yMax, posMod(yMax): [4.15, 35.1];
mean: min:3.87; mean: 4.15; std: 0.0586; max: 4.16; max-min: 0.29
apRMS: 0.732
plot: 16
```

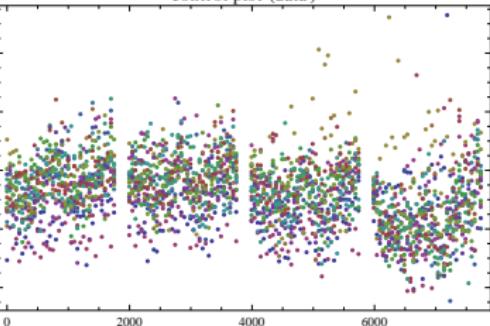
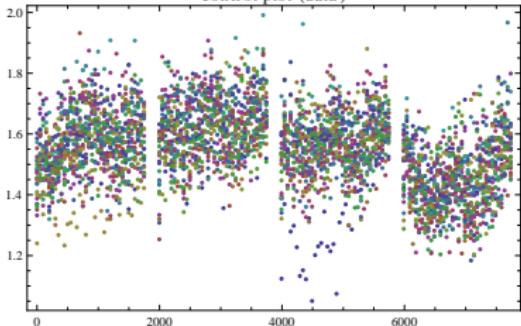
```
analysis_2012-05-25.nb v03.10: 2012-06-21 11:06:19; #E78958
2012-06-21 11:06:19; /injtrig_06/TimeSeries/14_12/20120615013415CET.csv
isotri_01[1, 0.98846] -> isotri_01[14, 1.1276]
nrecords: 25; dataType: bunchlength; caseIDP: injection
ymin, ymax: [3.6, 4.4]; pos_mod(ymin): [3.98, 17.1];
yMax, posMod(yMax): [3.98, 17.1];
mean: min:3.98; mean: 4.03; std: 0.0336; max: 4.11; max-min: 0.13
apRMS: 0.401
plot: 16
```



TIMBER_VEC____20120614190000CET
control plot (data)



TIMBER_VEC____20120615013415CET
control plot (data)



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?
- ▶ λ (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