Beam jitter studies at ATF and ATF2

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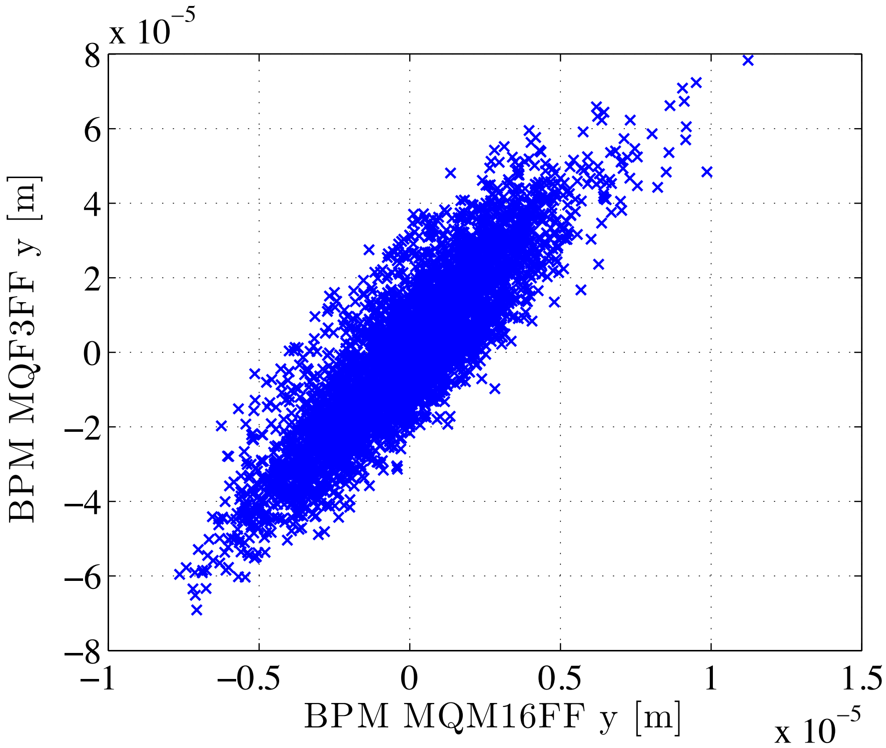
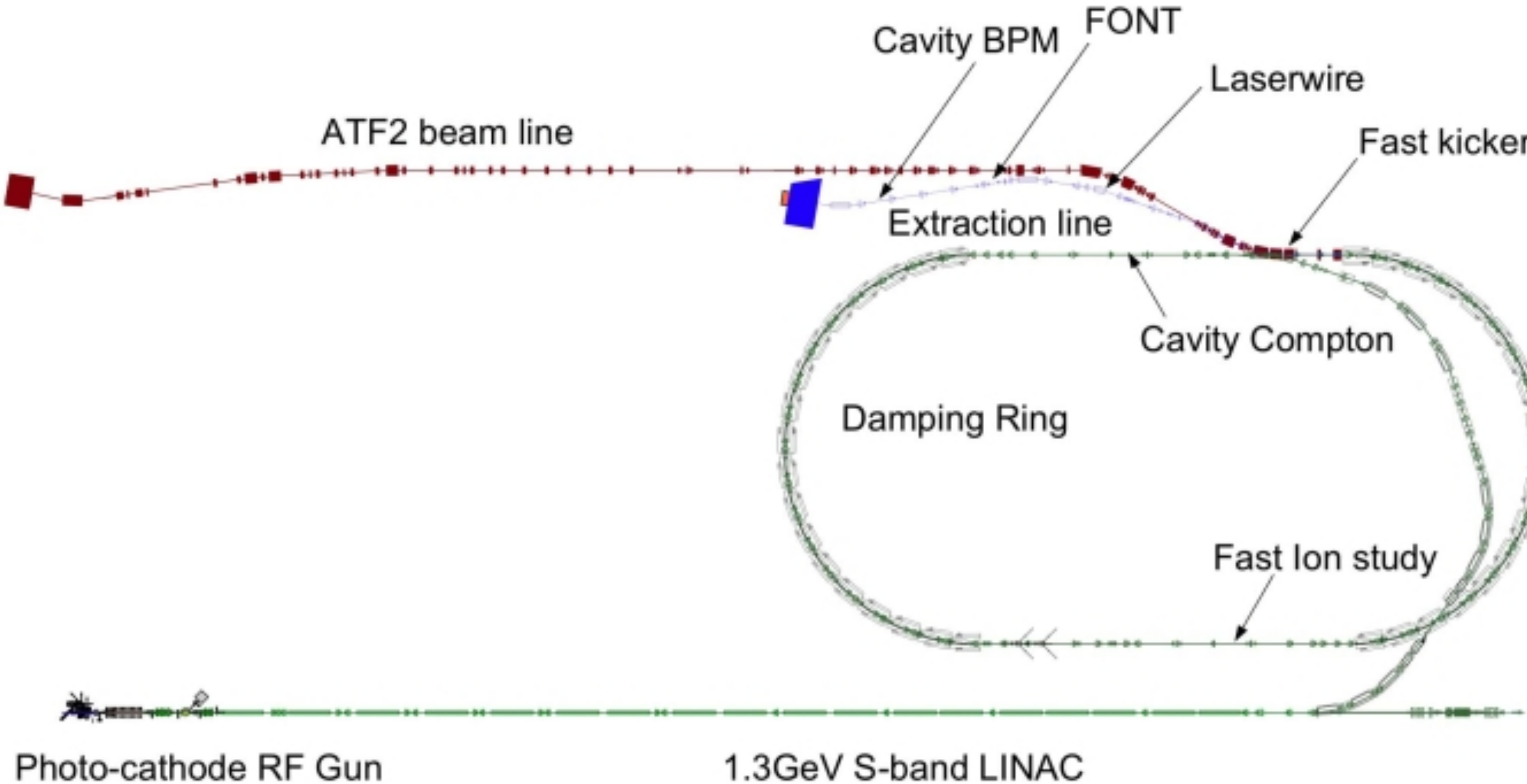
Content



Many thanks to Y. I. Kim, J. Snuverink, G. White and M. Woodley for supporting us with all necessary information at ATF and for the many very helpful discussions!

1. ATF and ATF2

ATF and ATF2 complex



ATF and ATF2 intention and goals

- The Accelerator Test Facility (ATF) is a test facility located at KEK to verify and improve key concepts of the International Linear Collider (ILC).
  - With the ATF linac and damping ring, beams with the smallest ever already reached emittance have been created (within the ILC specifications).

- The ATF2 beam line is an extension of ATF to test the ILC final focus system
  - Goal 1: Test the chromatic correction scheme by creating beams of the size of 37nm
  - Goal 2: Ensure a beam jitter of less than 5% of the beam size.

2. Measurement and analysis setup

Intention of the jitter studies

- Intention:
  1. Study beam motion in damping ring and ATF2 beam line
  2. Locate beam motion and especially beam jitter sources
  3. Study the performance of already operating orbit feedback systems and try to make suggestions for possible improvements if necessary

- Setup:
  1. Some scripts to read BPM data in the damping ring and the ATF2 beam line have been written
  2. Several data set have been taken under different conditions between the 13th and 18th of December 2012

Used BPM systems and EPICS

- Used BPM systems
  1. 96 button-BPMs in the damping ring, resolution of 20μm, only 90 used since others did not work properly
  2. 12 strip-line BPMs at the beginning of the ATF12beam line, resolution 5μm
  3. 34 cavity BPMs in the end of the ATF2 beam line, resolution 0.1μm

- EPICS system
  1. The *Experimental Physics and Industrial Control System* (EPICS) is a collection of software tools to create distributed soft real-time applications for large scientific applications.
  2. EPICS data (PVs) of BPMs have been accessed via Matlab commands

Analysis tools

- Correlation coefficient:

$$r = \frac{\sigma_{ij}}{\sigma_i \sigma_j}$$

σ_i … standard deviation σ_{ij} … cross correlation

- Power spectral density (PSD) estimated as:

$$\hat{P}[\omega_n] = \frac{T_0}{N^2} \left| X[n] \right|^2$$

$X[n]$ … DFT of x_k

T_0 … acquisition time of x_k

N … sample number in x_k

- Integrated root mean square (IRMS):

$$I[\omega_m] = \sqrt{\frac{2}{T_0} \sum_{\omega=\omega_m}^{\omega_{MAX}} \hat{P}[\omega]}$$

- Full and differential motion:

x_k … full beam motion data $\tilde{x}_k = x_k - x_{k-1}$ … differential beam motion data

Beam motion source search method (for beam lines)

Search method

- Correlate BPM with all others (correlation coefficient)
- If correlation starts at BPM, there is a jitter source close by
- Remove detected correlation (see talk of Hector) and search for next jitter source
- Especially good if correlation starts between BPMs with same phase advance. Otherwise one BPM does not sample full oscillation and several BPMs have to be used for one source

Source types

1. Dipole kicks

Location of the source is upstream of the BPM where correlation is detected -> kick needs a phase advance to become an offset.

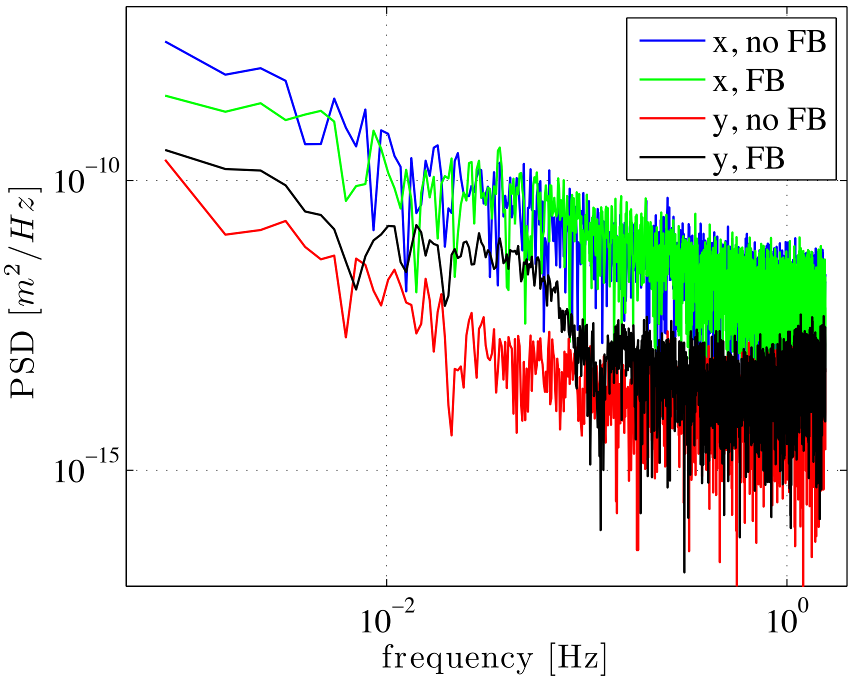
2. Wakefield kicks:

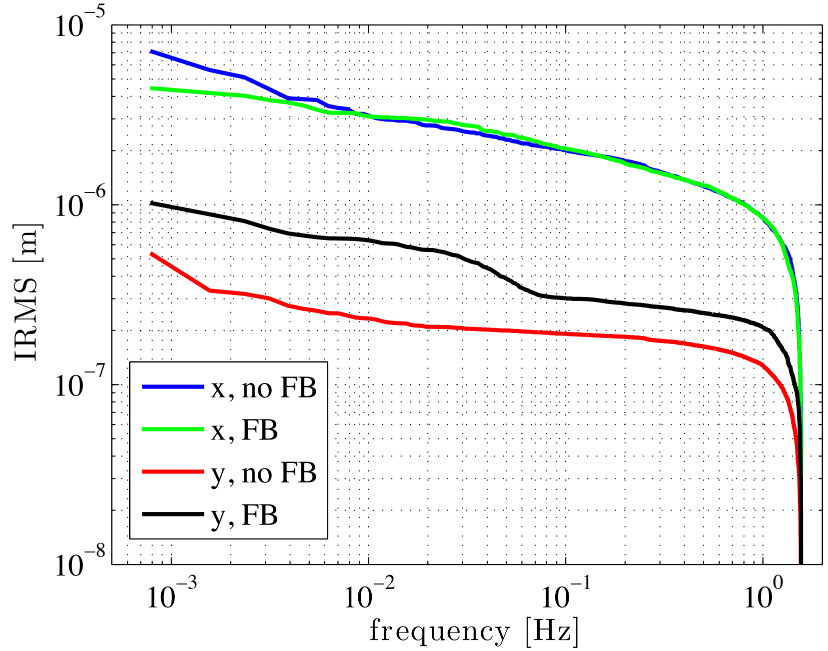
Location of the source is close to the BPM where correlation is detected -> kick is proportional to beam offset in source

We have to search up- and down-stream of the BPM and cannot predict exact location.

3. Results: damping ring

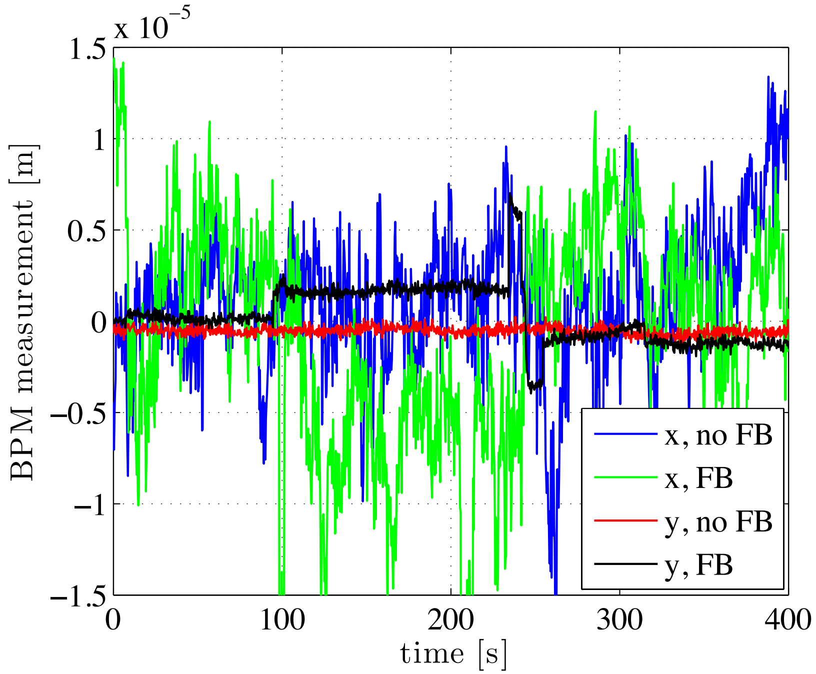
Full beam motion in the damping ring 1/3





Plots based on data from BPM MB52R (number 30)

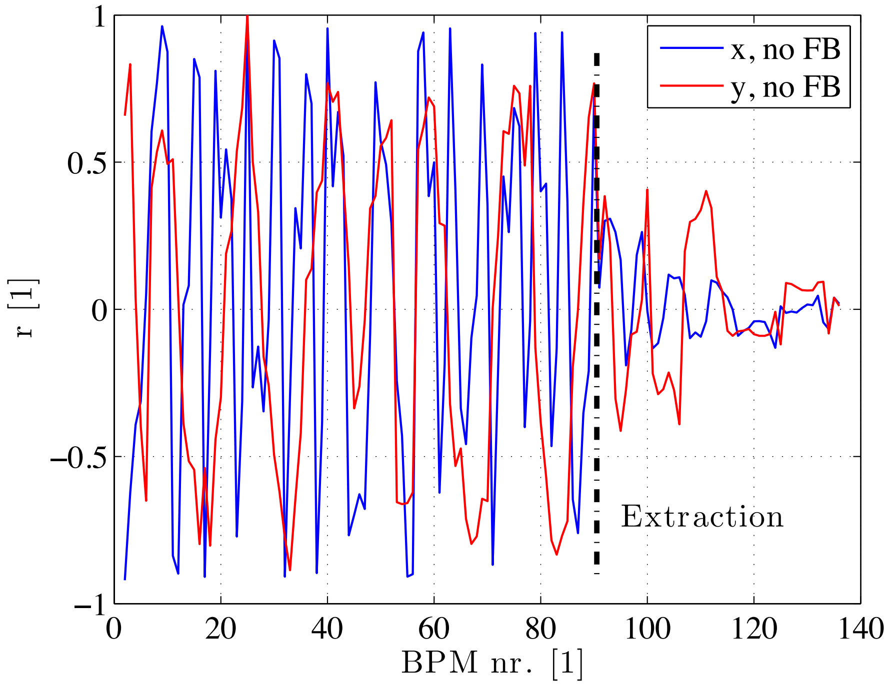
Full beam motion in the damping ring 2/3



Plots based on data from BPM MB52R (number 30)

- Damping ring feedback system suppresses low frequencies, but creates new frequencies between 0.01 and 0.1 Hz due to a step-like feedback action.
- A bit more stronger feedback action and a smoother actuation would be beneficial.
- Mode-like excitation changes could be overcome with an adaptive controller based on a on-line PSD estimation.

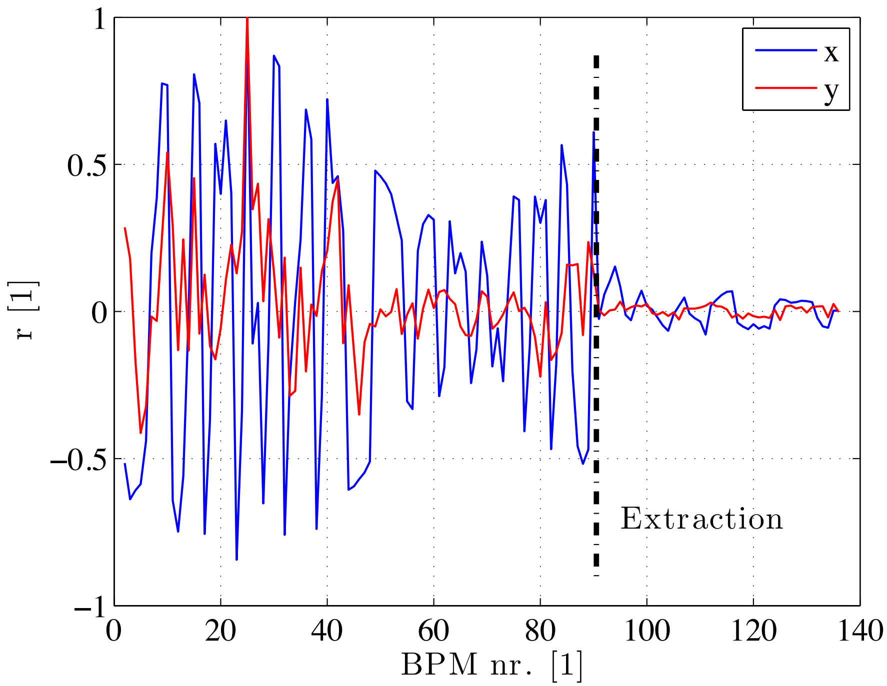
Full beam motion in the damping ring 3/3



Correlation coefficient of BPM MB46R (number 25) with all other BPMs

- Strong correlation of the full beam motion in the damping ring.
- Correlation coefficient propagates with the phase advance.
- Only little correlation has been observed in the ATF2 beam line.

Differential beam motion in the damping ring

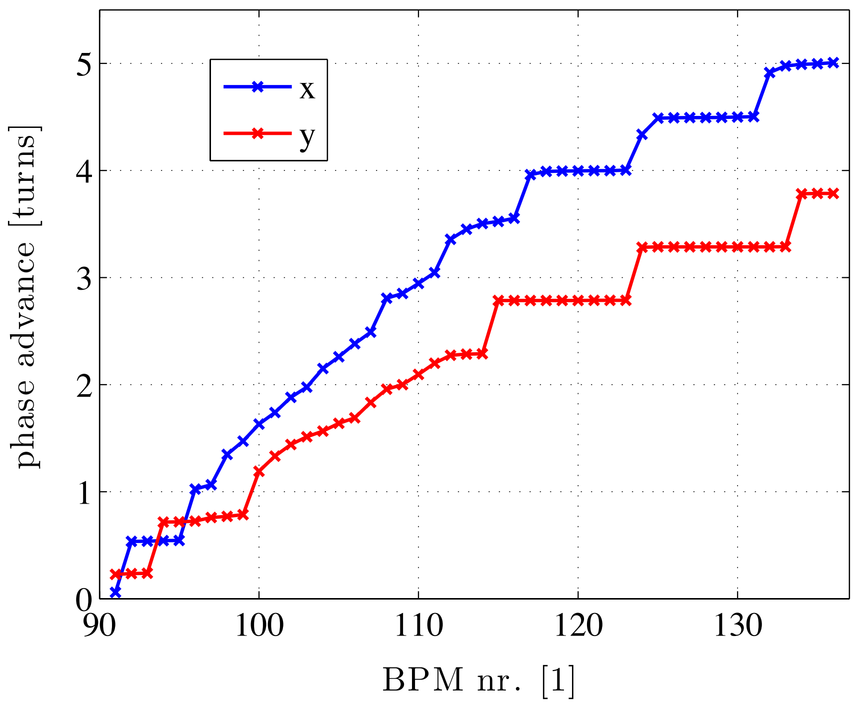


Correlation coefficient of BPM MB46R (number 25) with all other BPMs

- Differential beam motion is only slightly correlated in the damping ring (strong signal contribution of BPM noise).
- In the ATF2 beam line hardly any effect has been observed -> no orbit jitter from the damping ring (but only orbit data used)

4. Results: ATF2 beam line

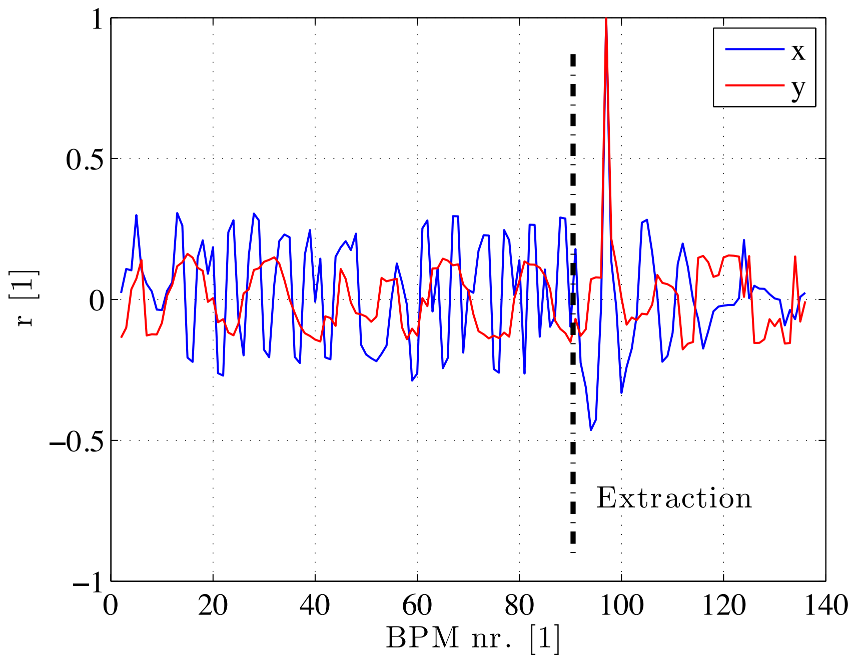
Method to detect beam motion/jitter sources

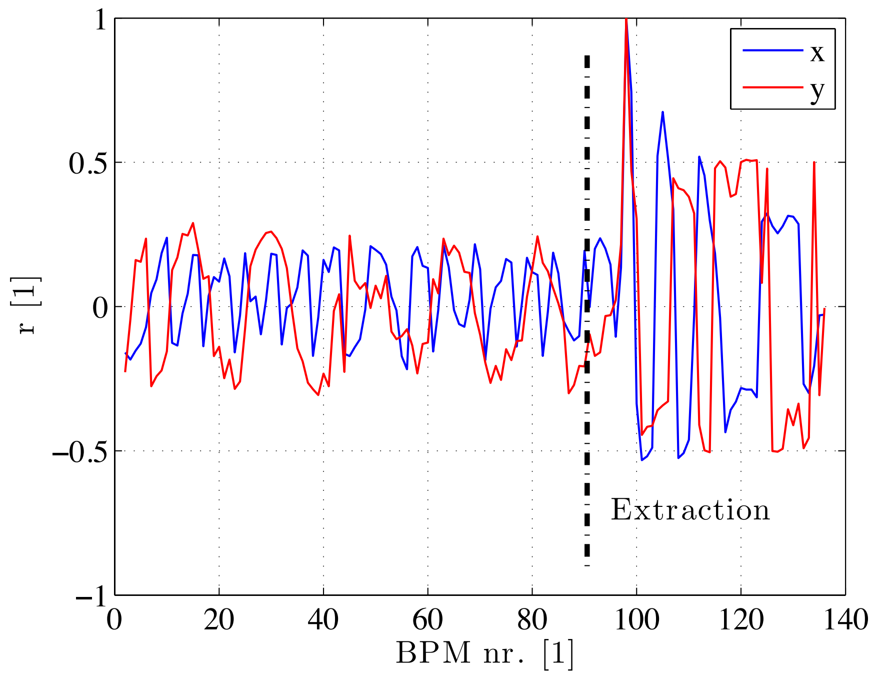


Phase advance in the ATF2 beam line:
left … extraction kicker, right … IP

- Look at two BPMs that have nearly the same phase advance.
- If there are strong differences in the correlation behavior with the other BPMs, there is a source between these BPMs.

Full beam motion in the ATF2 beam line

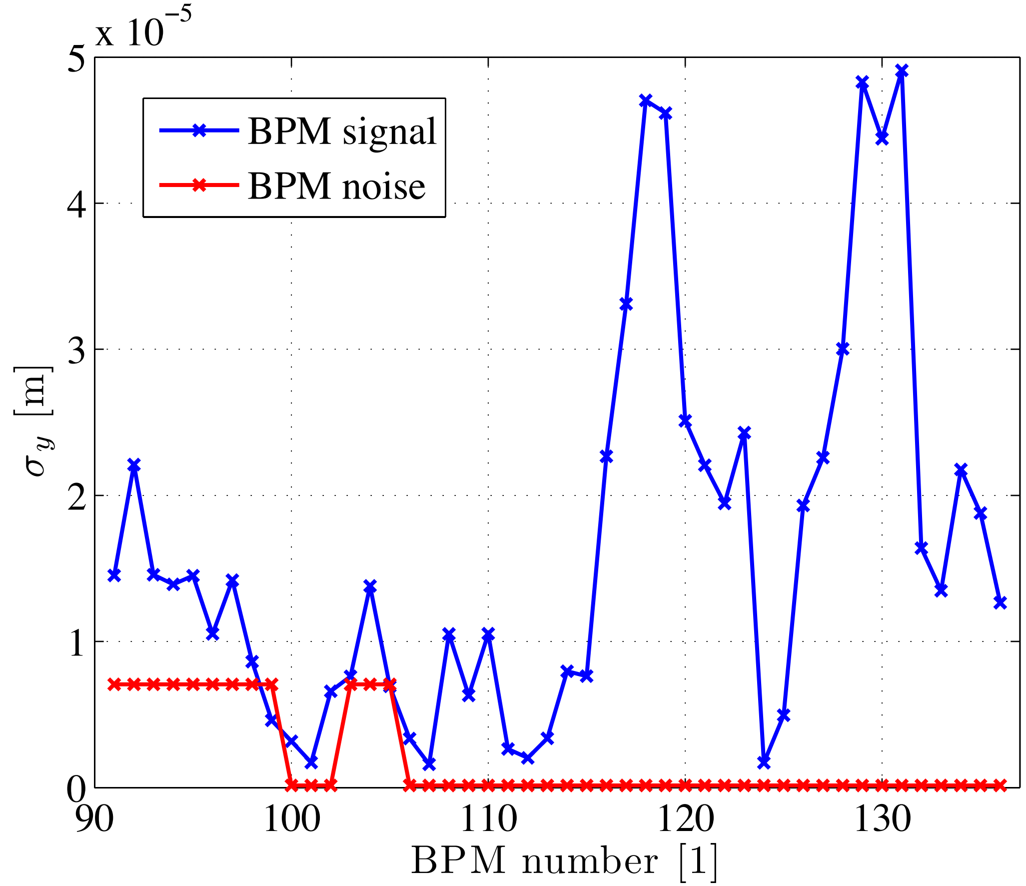




Correlation difference between BPMs MQF7X (number 97) and MQD8X (number 98); candidates: QF7X, QD8X, ZH3X or dipole BH3X

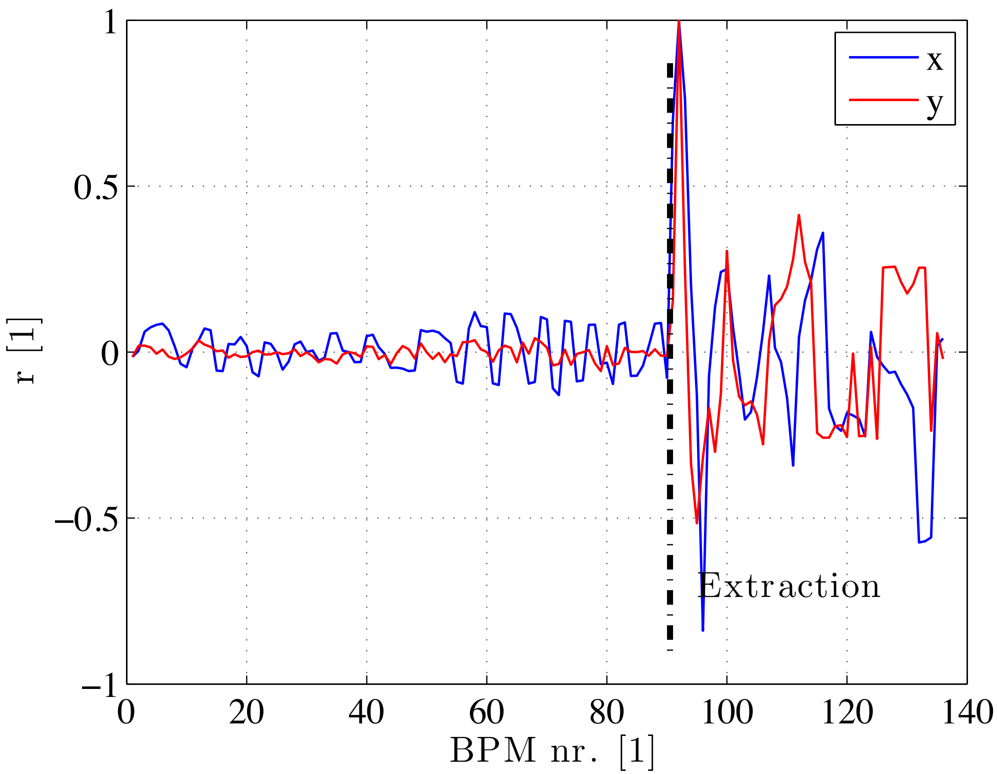
Differential beam motion in the ATF2 beam line (beam jitter)

Signal and noise levels



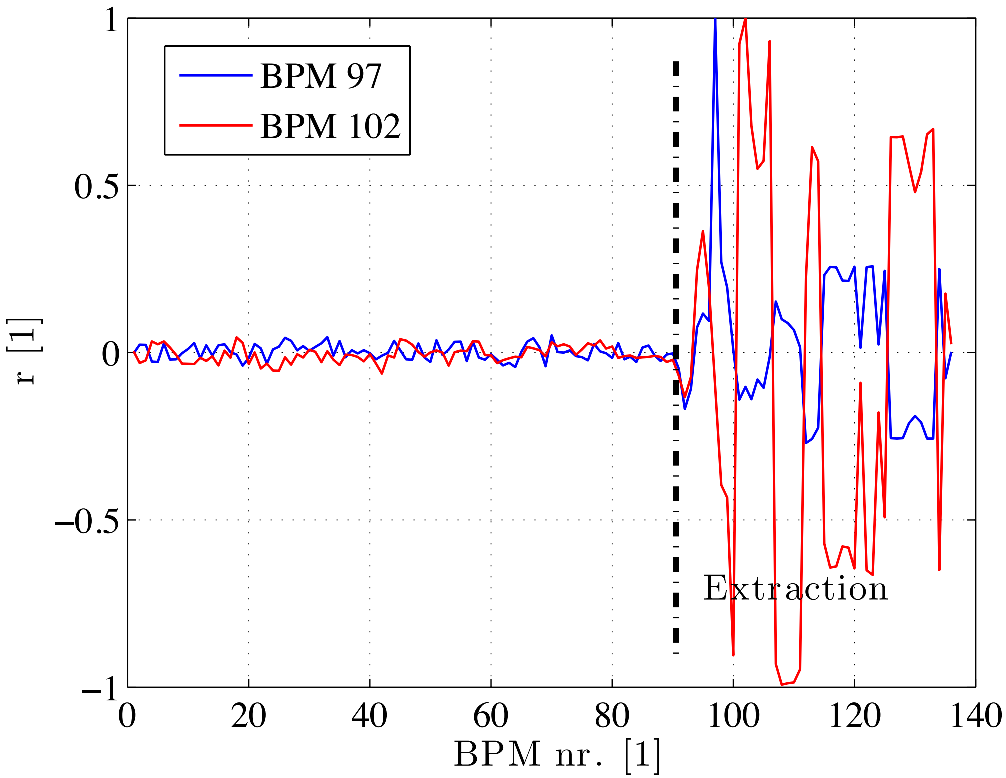
From this plot it is questionable if the data measured by the strip-line BPMs are just noise.

Small correlation from the start of the beam line (kicker?)



- It seems that the data are not only noise
- Data of strip-line BPMs had to be shifted by one time step wrt. Cavity BPMs.
- Correlation can be assigned to begin of beam line, maybe the kicker
- Only small effect for the beam jitter at the end of the beam line

First beam jitter source



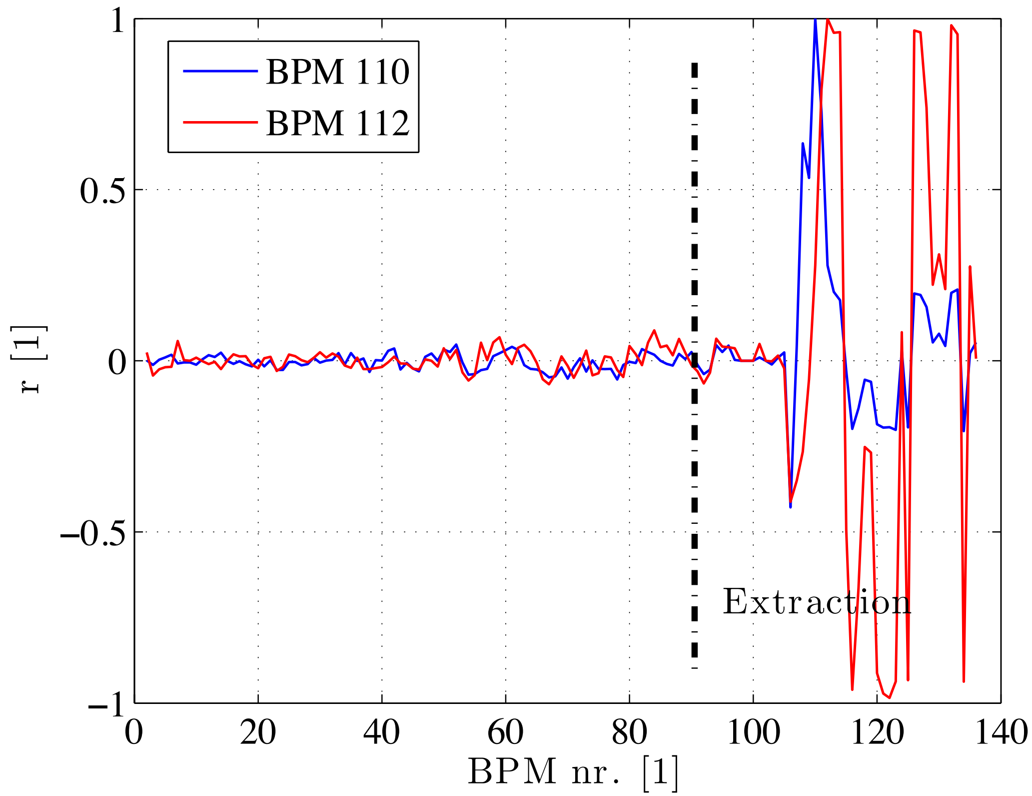
Located between BPMs 97 and 102 (MQF7X and MQD12X)

Probably several sources but strongest signal from BPM 102

Candidates:

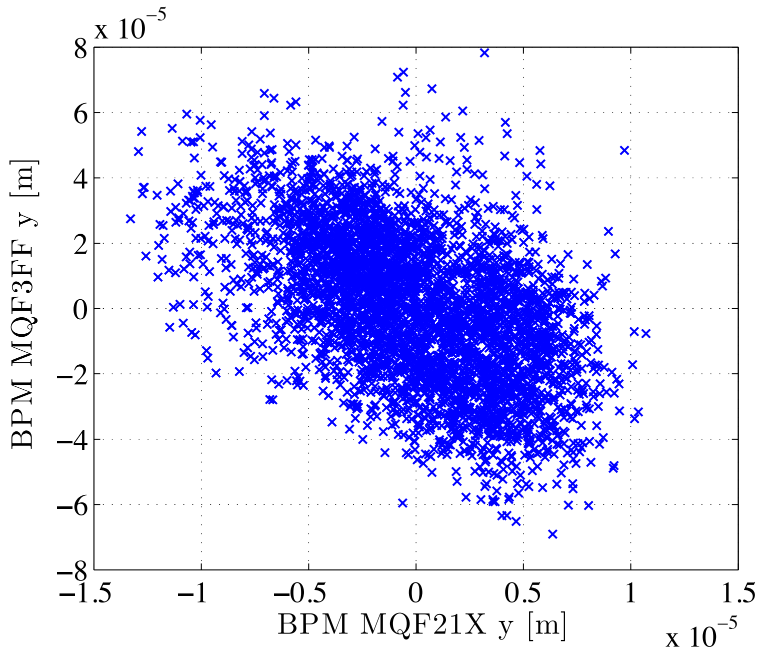
- FONT equipment
- Correctors: ZH5X, ZH6X, ZV8X
- QPs: QF11X, QD12X, QD13X, QD14X, QK2X

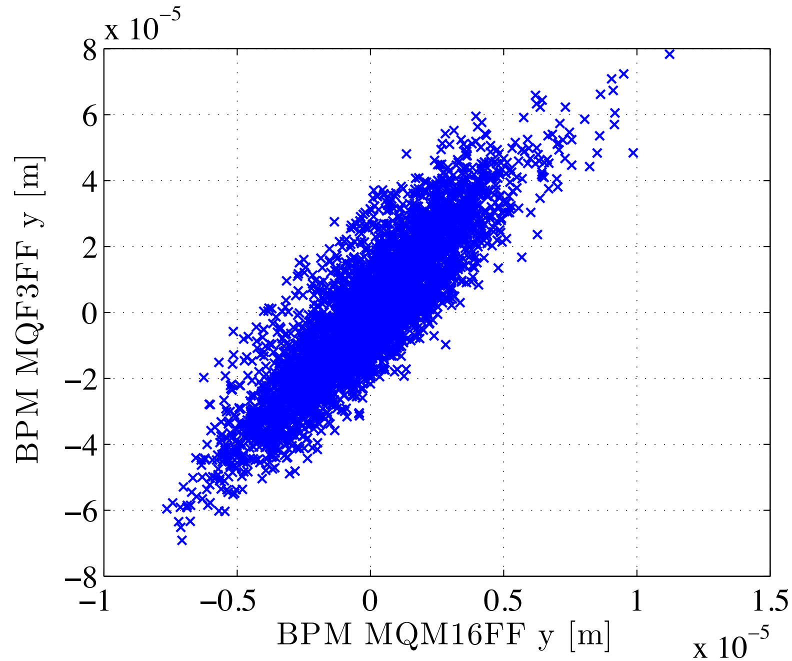
Second beam jitter source 1/2



- Located at BPM 112 (MQM16FF)
- Very strong source
- Candidates:
  - Wire scanner: MW3X, MW4X
  - Profile monitor: OTR3X
  - Correctors: ZH1FF, ZV1FF
  - QP: QM16FF

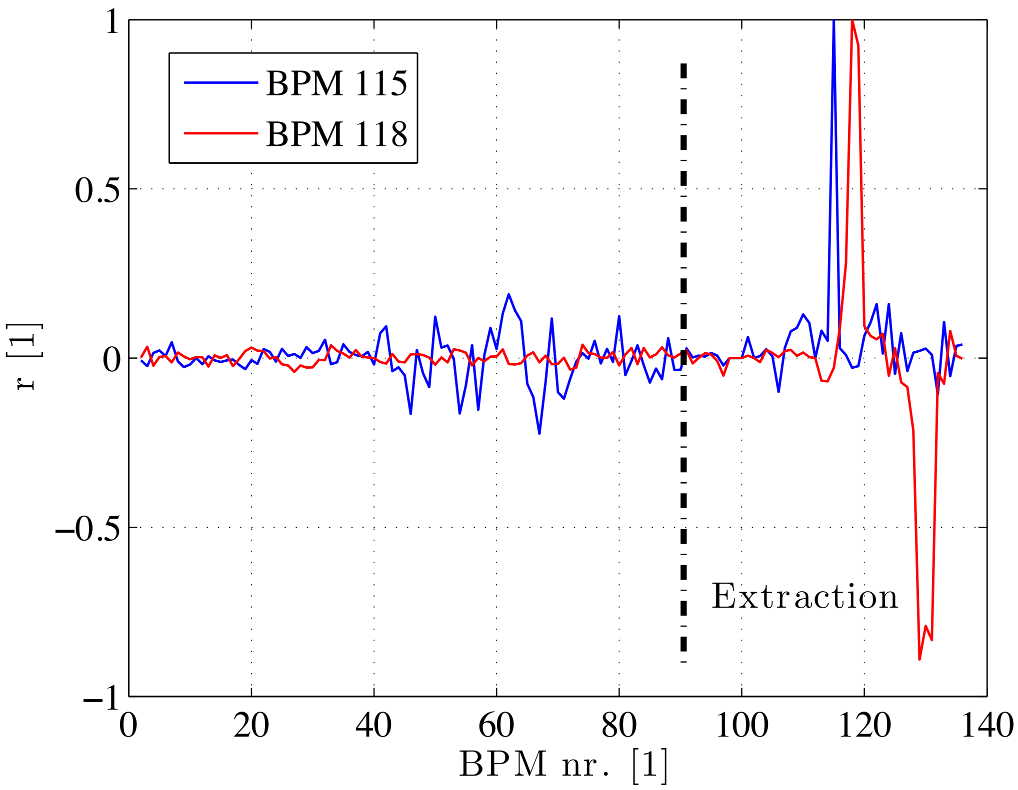
Second beam jitter source 2/2





Measured vertical beam position data of the BPMs 111 (left) and 112 (right) versus BPM 134. A strong change in correlation can be seen.

Third beam jitter source



- Located at BPMs 118 and 119 (MQD10BFF and MQD10AFF)
- Candidates:
  - Ref. cavity mover
- Wakefield effect observed?

ATF2 beam line orbit feedback system

- Works very well under usual beam motion conditions
- Remaining beam motion PSD is nearly flat

- Also in the ATF2 beam line, mode-like changes of the beam excitation have been observed
- A controller that changes its parameters e.g. based on an on-line estimation of the current PSD could be beneficial (adaptive controller).

5. Conclusions

- Beam motion/jitter
  1. No significant effect of beam motion in the damping ring on the beam motion in the ATF2 beam line has been observed. However, only orbit data have been used instead of single turn data.
  2. Three locations in the ATF2 beam line have been identified in which most likely beam motion/jitter is created
  3. No dispersive patterns have been observed. Therefore, the influence of the beam energy seems to be negligible.
  4. No indications have been found that the extraction kicker creates a significant amount of beam jitter.
- Feedback performance
  1. The damping ring feedback system could act slightly stronger and the actuation itself could be smoother.
  2. The ATF2 beam line feedback works very well, but an adaptive controller with e.g. PSD estimation could improve mode-like changes.

Thank you for your attention!