TUNE MEASUREMENTS FOR THE ALS BY MIXING TBT DATA

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Tune measurements by mixing the BPM data

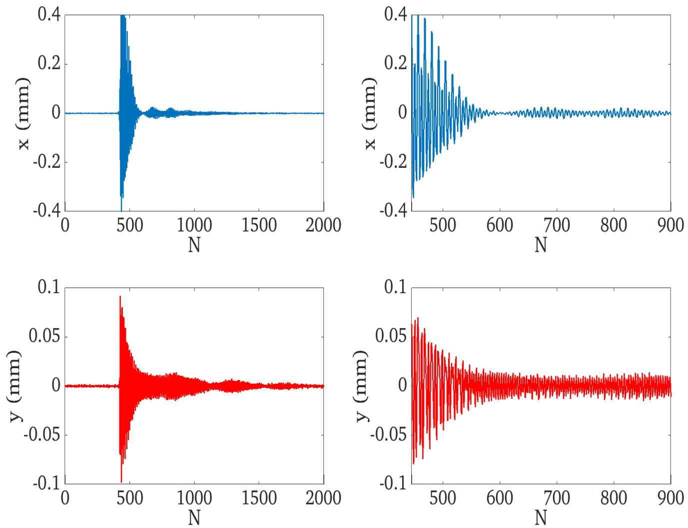
- Fact 1: In the presence of decoherence due to chromaticity and/or amplitude dependent tune-shift, the available number of turns for analysis is limited.

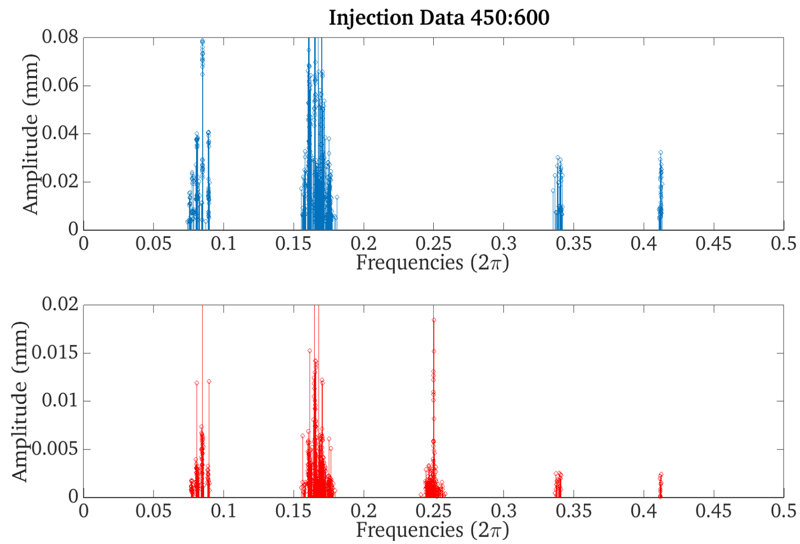
- Fact 2: Aliasing effects allows the only determination of the fractional part of the tunes at the BPMs location.

- Method: Mix the TBT data from all the BPMs together and then let NAFF do the analysis. The sampling period from 1 sample per turn becomes M samples per turn, where M the number of BPMs. Rescaling the measured tunes with M, determines the fractional and integer part of the tune (see Y. Papaphilippou et al. Experimental Frequency Maps for the ESRF storage ring, EPAC 2004)

- Note: The method can be described as recording of the betatron oscillations from one single virtual BPM in the machine **but** with a perturbation in the sampling time. The sampling intervals are not constant because the original BPMs are not equally distributed around the ring. This generates a modulation which is 1-turn periodic, thus it does not affect the measurements.

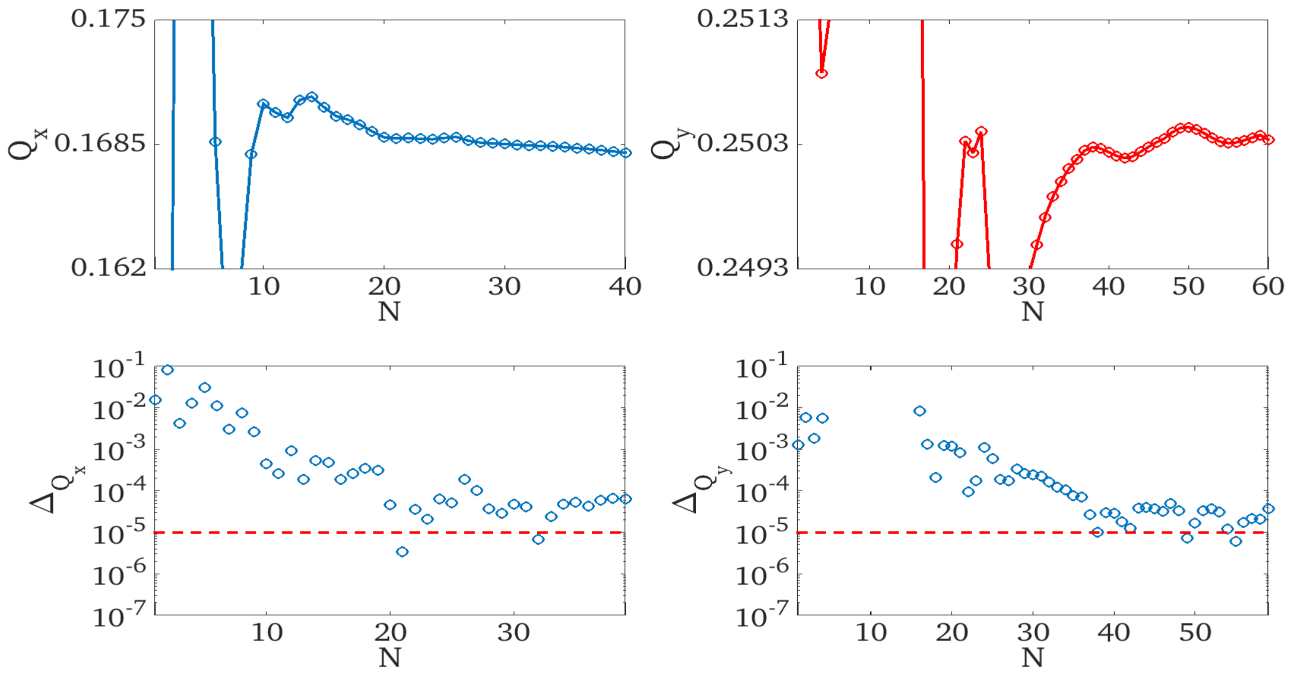
Results for the ALS (1)





- Horizontal plane: Q1=0.0849, Q2=0.3405,Q3=0.4122, Q4=Qx=0.1652
- Vertical plane: Q1=0.0847, Q2=0.3373, Q3=0.4121, Q4=Qx=0.1652,Q5=Qy=0.2505

Results for the ALS (2)

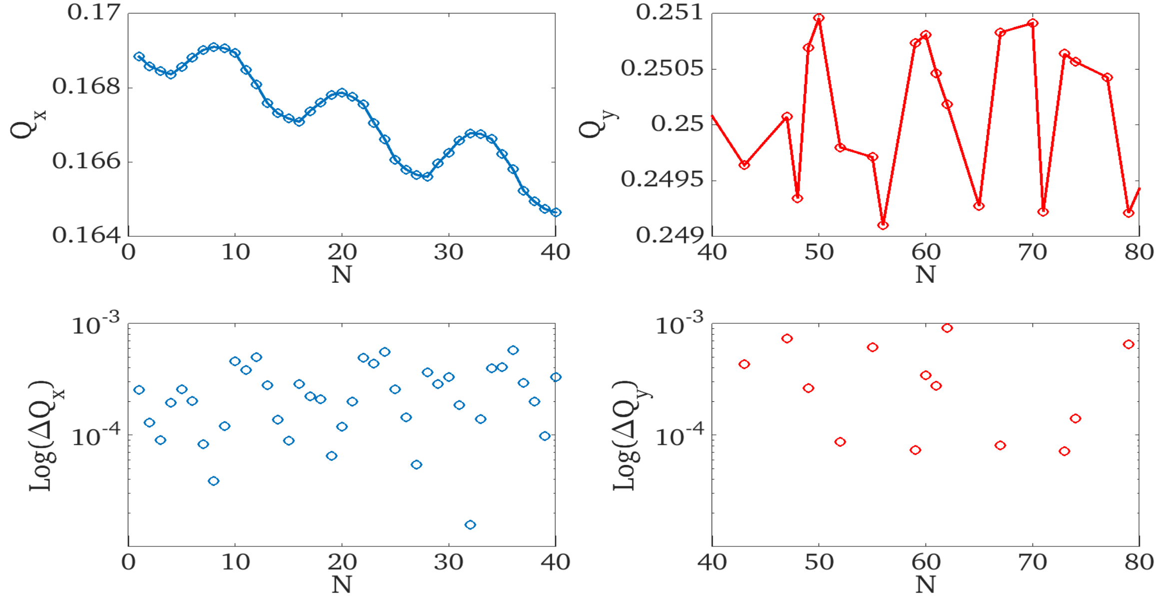


Starting from the 1st turn with an increasing TxT window

- Horizontal tune: Less than 15 turns to be determined

- Vertical tune: Due to coupling, at around 40 turns

Results for the ALS(3)



Using a sliding window of 20 turns

- Horizontal tune: Determined accurately from the first turn
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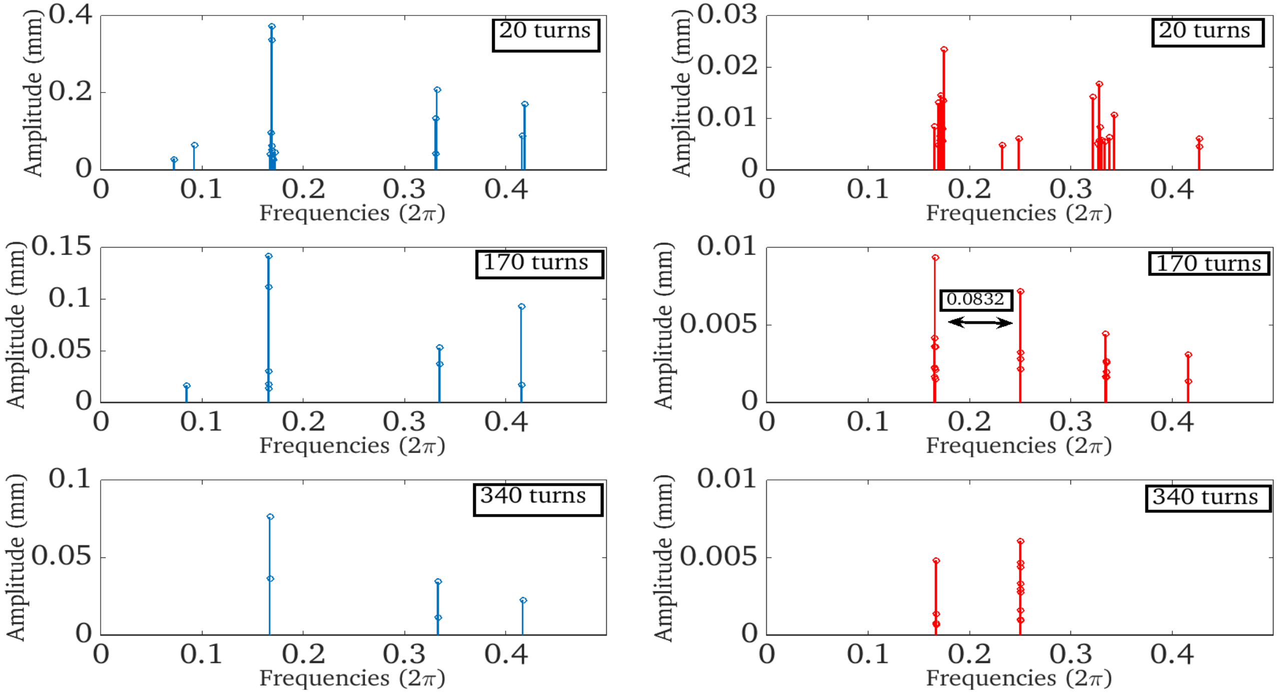
- Vertical tune: Again due to coupling, at around 40 turns
-
- The sliding window reveals certain pattern in the tune evolution in time e.g 12 turns modulation~ Our familiar resonance at 0.0833

Results for the ALS(4)

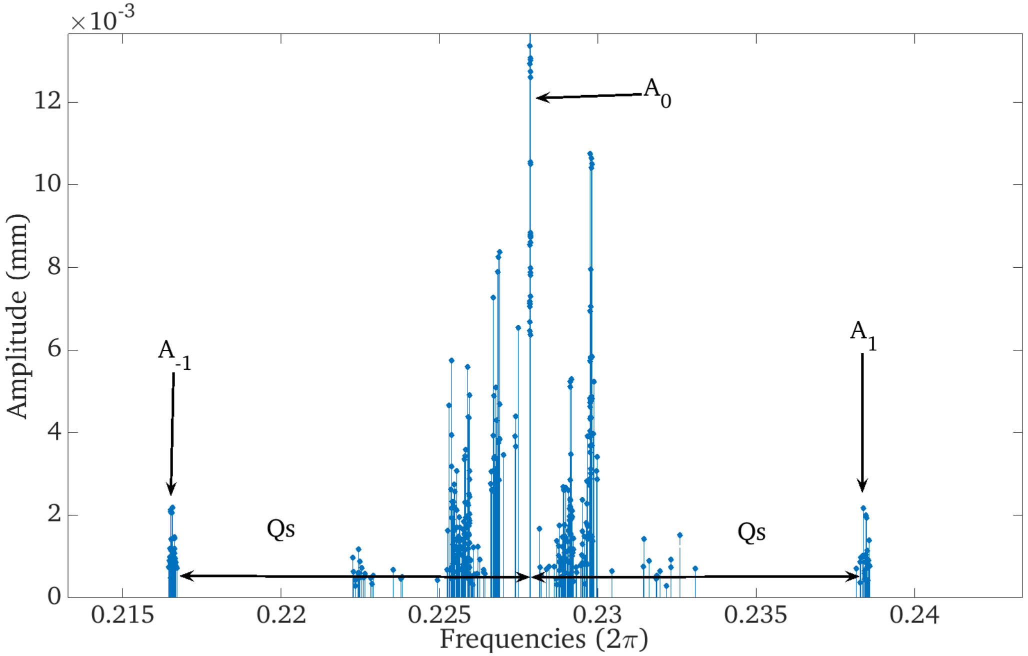


- As the number of turns increases the harmonics are gathered around the resonances more tightly
- Spacing of the harmonics is at 0.0833~12 turns

RMS Momentum Spread Measurements

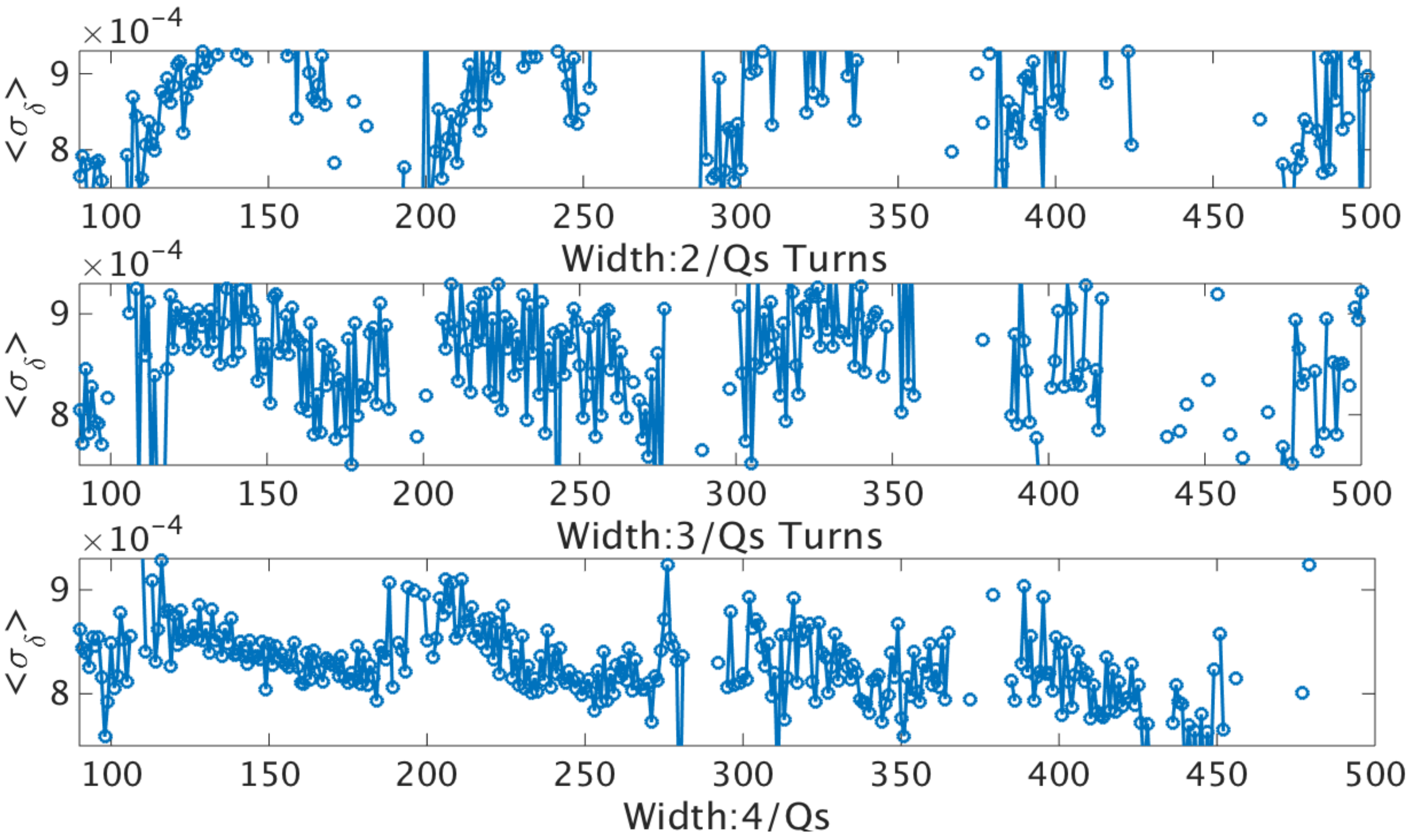
- Assuming Gaussian bunches, measurements for the RMS momentum spread can be performed by using the synchrotron sidebands (see P. Zisopoulos et al. "Frequency Maps Analysis of tracking and experimental data for the SLS storage ring), IPAC 2014"

$$\sigma_\delta = \frac{Q_s}{Q'_x}\sqrt{\frac{A_1 + A_{-1}}{A_0}}$$



RMS Momentum Spread Measurements

- Results from ANKA ring using a sliding window to compute sidebands and the synchrotron tune and applying the formula for the RMS energy spread



Conclusions-Prospects

- The betatron tunes of the ALS ring were successfully measured using the mixed BPM method
- The vertical plane due to coupling needs a greater number of turns to show results.
- The RMS momentum spread has been successfully measured for the SLS and ANKA by just using turn by turn data. Maybe this is of interest for the ALS ?

The NAFF Algorithm

- See J. Laskar, Frequency analysis for multi-dimensional systems. Global dynamics and diffusion)

- Outline of the method
  1. Given a numerical sequence f(t) i.e. BPM signal, perform standard FFT to locate approximately the maximum of power spectra

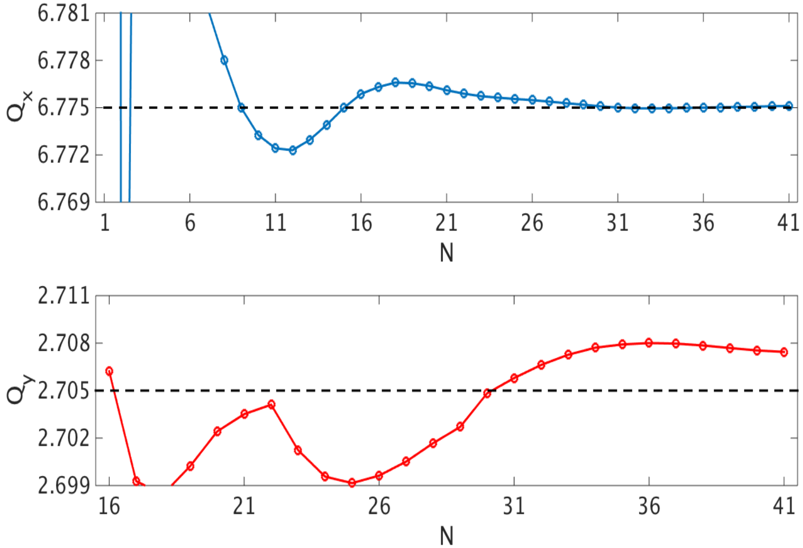
  2. Use quadratic interpolation method to find exactly the maximum of $\varphi(\omega)=<f(t), e^{i\omega t}>$ in the vicinity of the previously found frequency. This gives the first frequency v_1. Applying a window filter also increases precision.

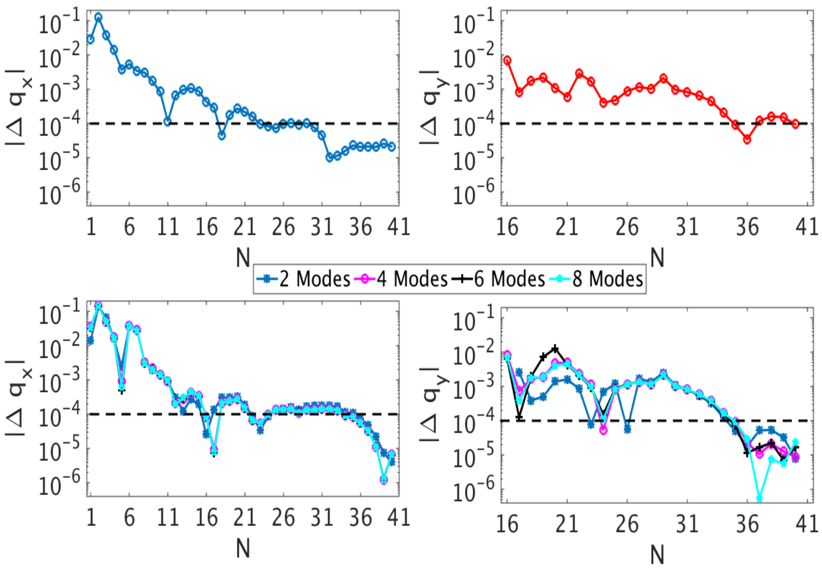
  3. Perform orthogonalization of the basis function e^{iv_1t} so we can project f(t) on it . Substract the first term from f(t) and iterate until desired number of frequencies is obtained.

What we gain?: Precision of $1/T^4$

Compare that to FFT’s 1/T

Example: Results for ANKA ring





- Horizontal tune: Less than 10 turns to be determined
- Vertical tune: Due to coupling, it is determined above 16 turns
- Precision below 10^{-3} in less than 20 turns for both planes
- Overall the same precision for filtered data and results do not seem to change dramatically with the addition of extra modes

RMS Momentum Spread Measurements

- Second order chromatic effects can cause turn by turn modulation of the synchrotron tune with the synchrotron frequency. The centroid motion can be expanded in a Fourier series:

$$x(N) = |a||G|e^{-s^2}\left(\sum_{q=-\infty}^{\infty} I_q(s^2)e^{i(2\pi(Q_x+qQ_s)N+\Omega+\phi)}\right)$$

$$\Omega = s^2 s_2 N(cos\Theta - 1)(1+\frac{sin\Theta}{\Theta}) \qquad \phi = ArcTan(\frac{2s2N}{1 \mp \sqrt{1+4s_2^2N^2}})$$

$$G = \sqrt{1+\frac{2s_2^2N^2}{(1+4s_2^2N^2)(1+\sqrt{1+4s_2^2N^2})}}$$

$$s_2 = \pi^2\sigma_\delta^2 Q_x''$$

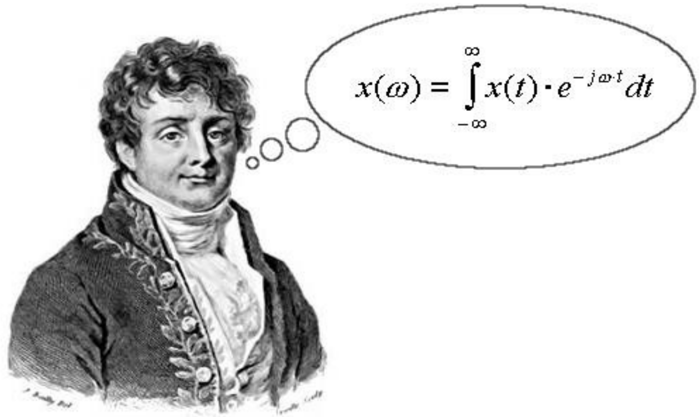
$$\Theta = 2\pi Q_s N$$

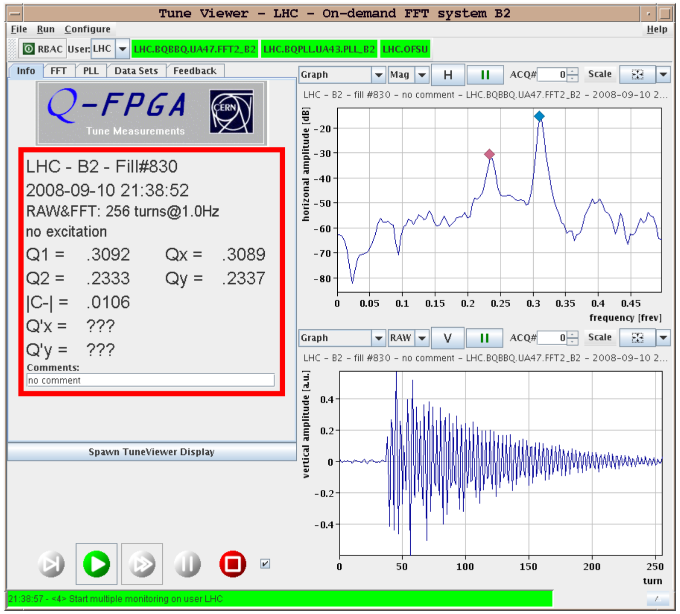
Frequency analysis of TBT data

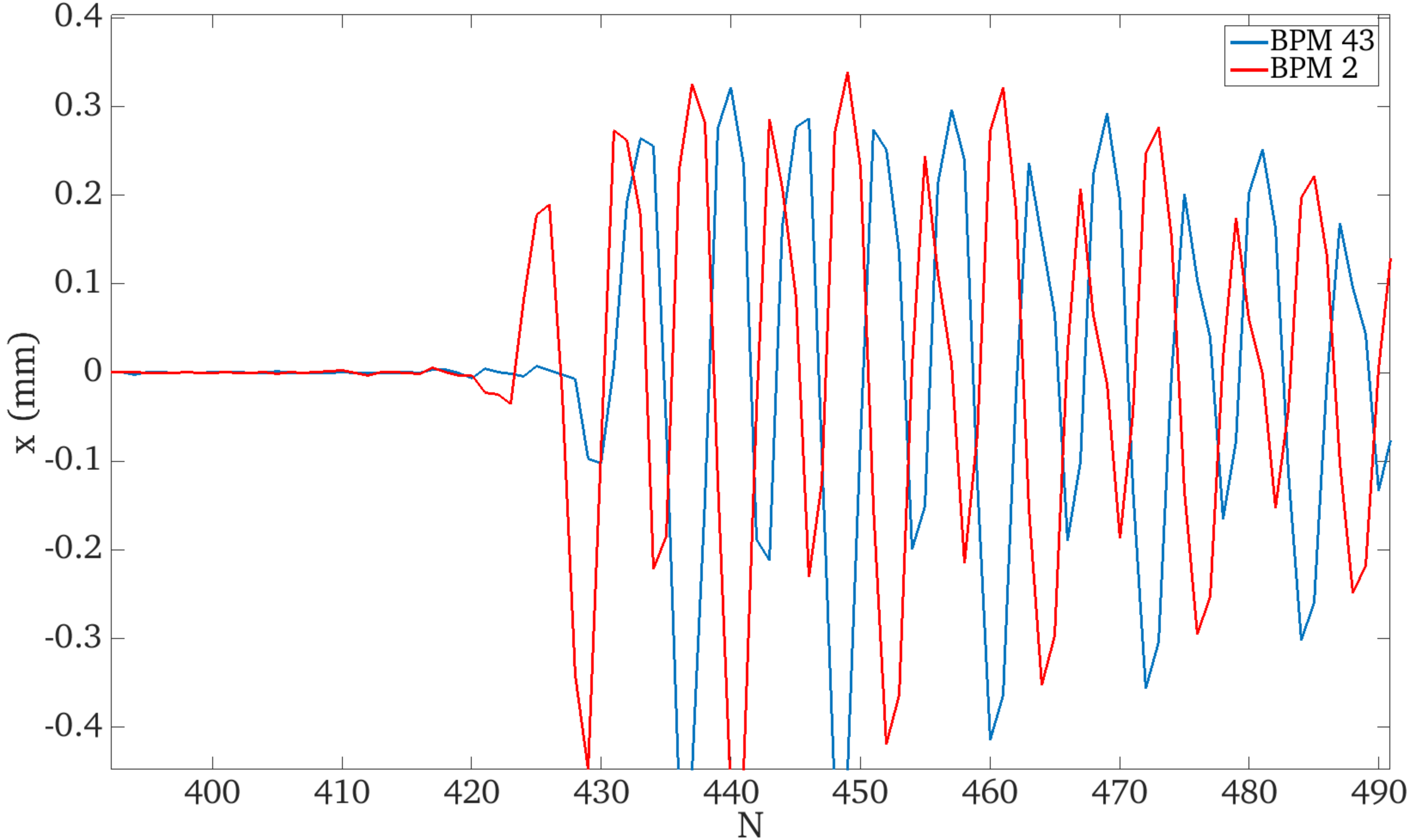
- The Fourier spectra of TBT BPM data can provide valuable information for the status of the accelerators

- The procedure is standard: Excite coherent betatron oscillations, record the TBT data and use refined Fourier methods to determine the frequencies

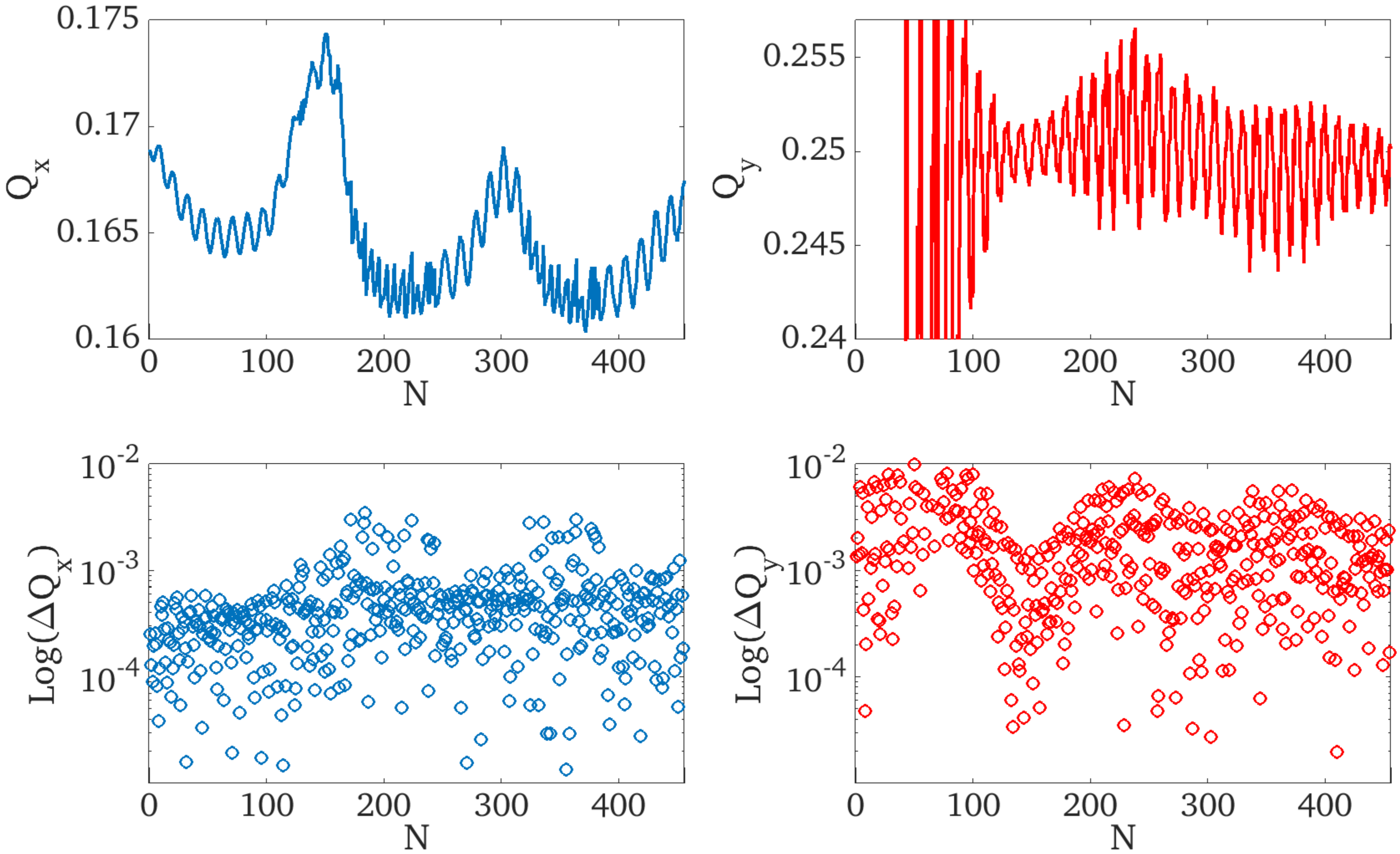
Jean-Baptiste Joseph Fourier







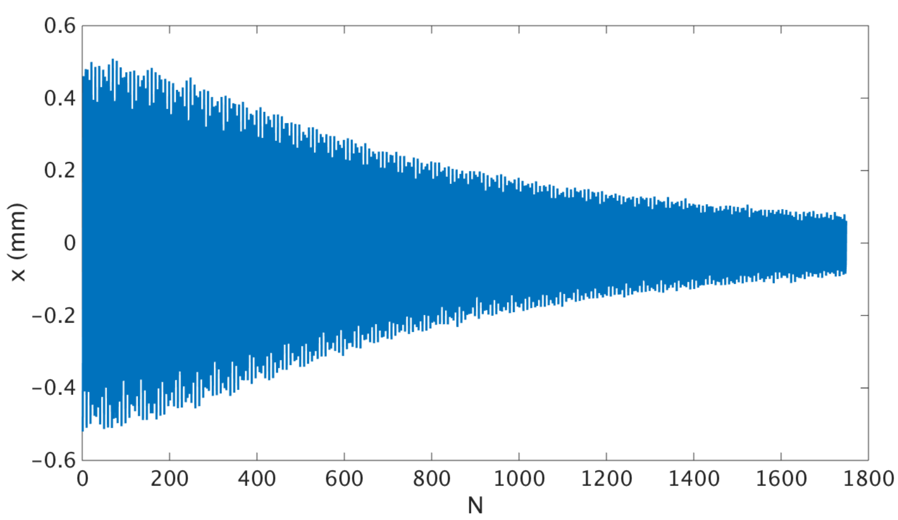
BPM 43
BPM 2
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
x (mm)
400
410
420
430
440
450
460
470
480
490
N

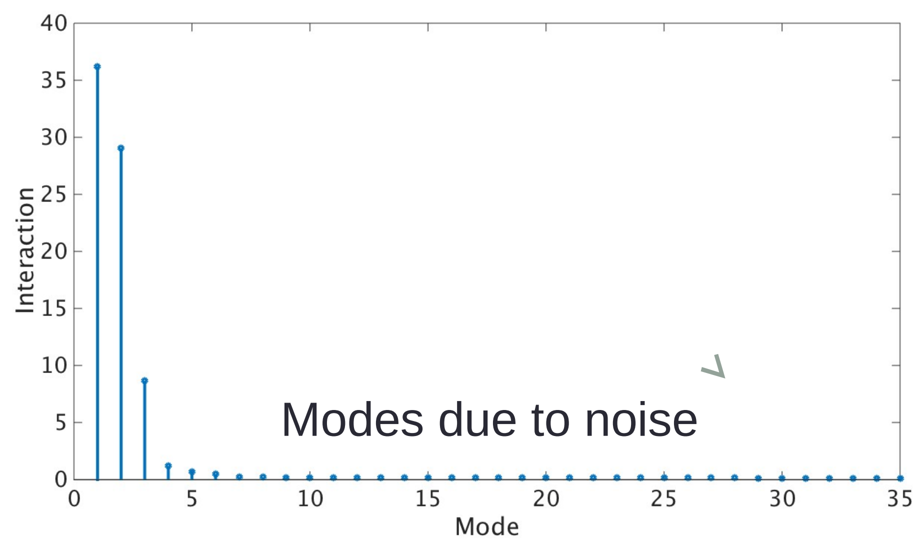


0.175
0.17
0.165
0.16
Q_x
0
100
200
300
400
N
0.255
0.25
0.245
0.24
Q_y
0
100
200
300
400
N
10^{-2}
10^{-3}
10^{-4}
$Log(\Delta Q_x)$
0
100
200
300
400
N
10^{-2}
10^{-3}
10^{-4}
$Log(\Delta Q_y)$
0
100
200
300
400
N

Tune measurements by mixing the BPM data

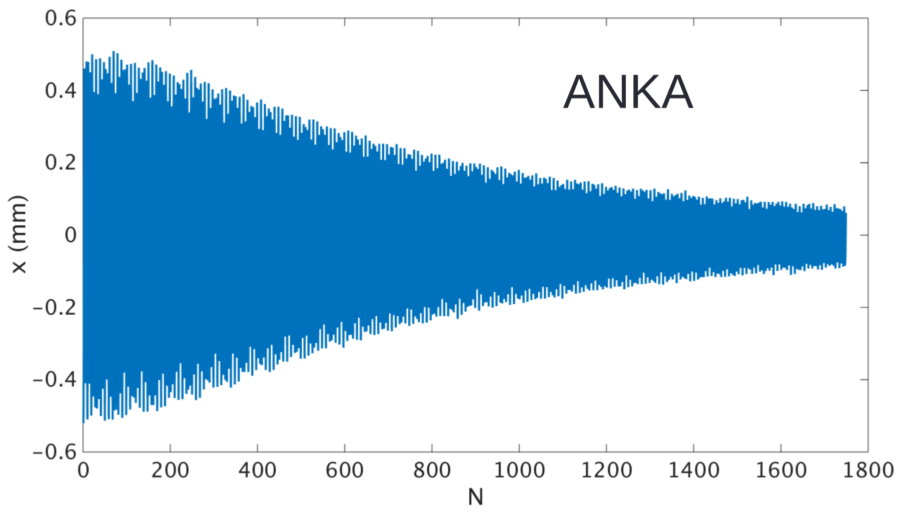
- Furthermore noise level can be significantly reduced by decomposing the TBT data to its' singular modes and discard the modes that have no information (see C.X.Wang, Ph.D. thesis (1999) "Model Independent analysis of beam centroid dynamics", Stanford University)

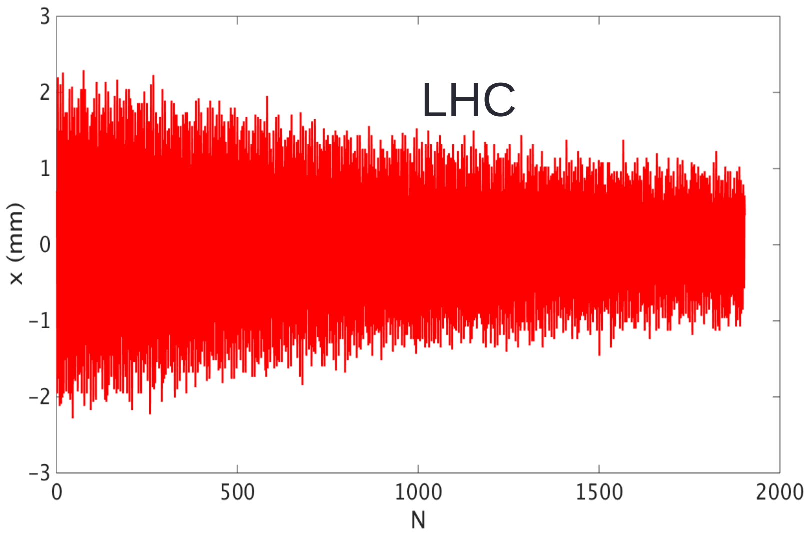




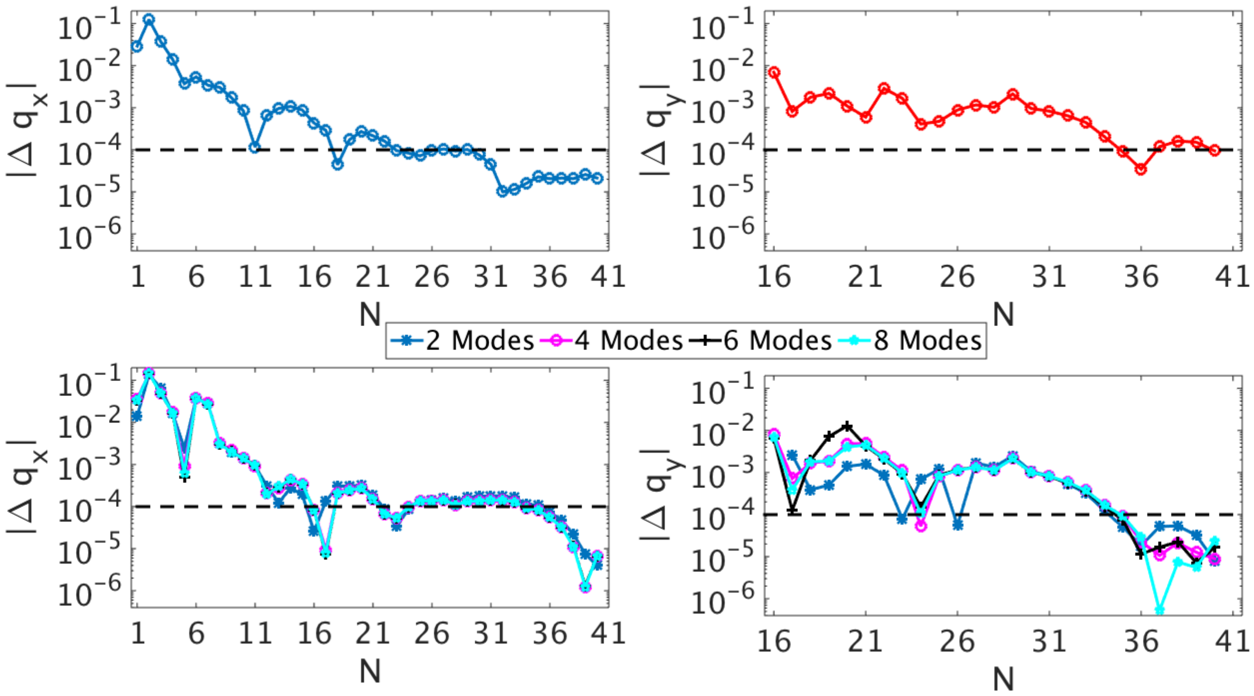
Tune measurements by mixing the BPM data

- The method was applied on TBT data from ANKA storage ring and the LHC
- ANKA ring has tunes of Qx=6.77, Qy=2.70 and 35 BPMs were used
- The LHC has tunes of Qx=64.28, Qy=59.31 at injection and 515 BPMs were used





Results for ANKA



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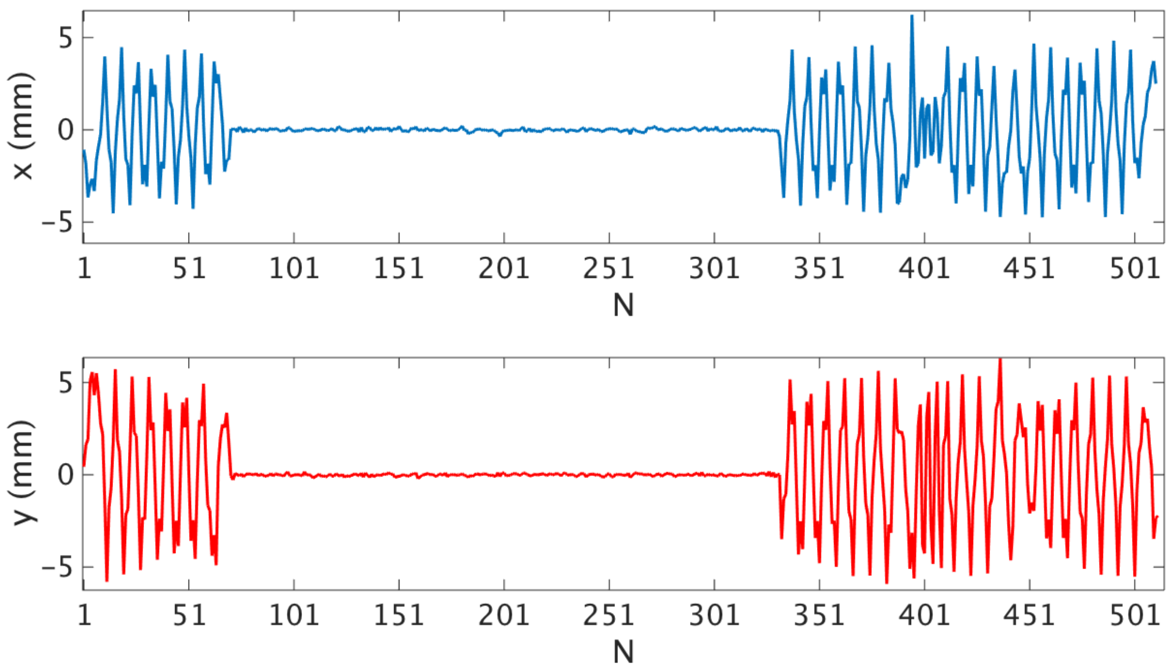
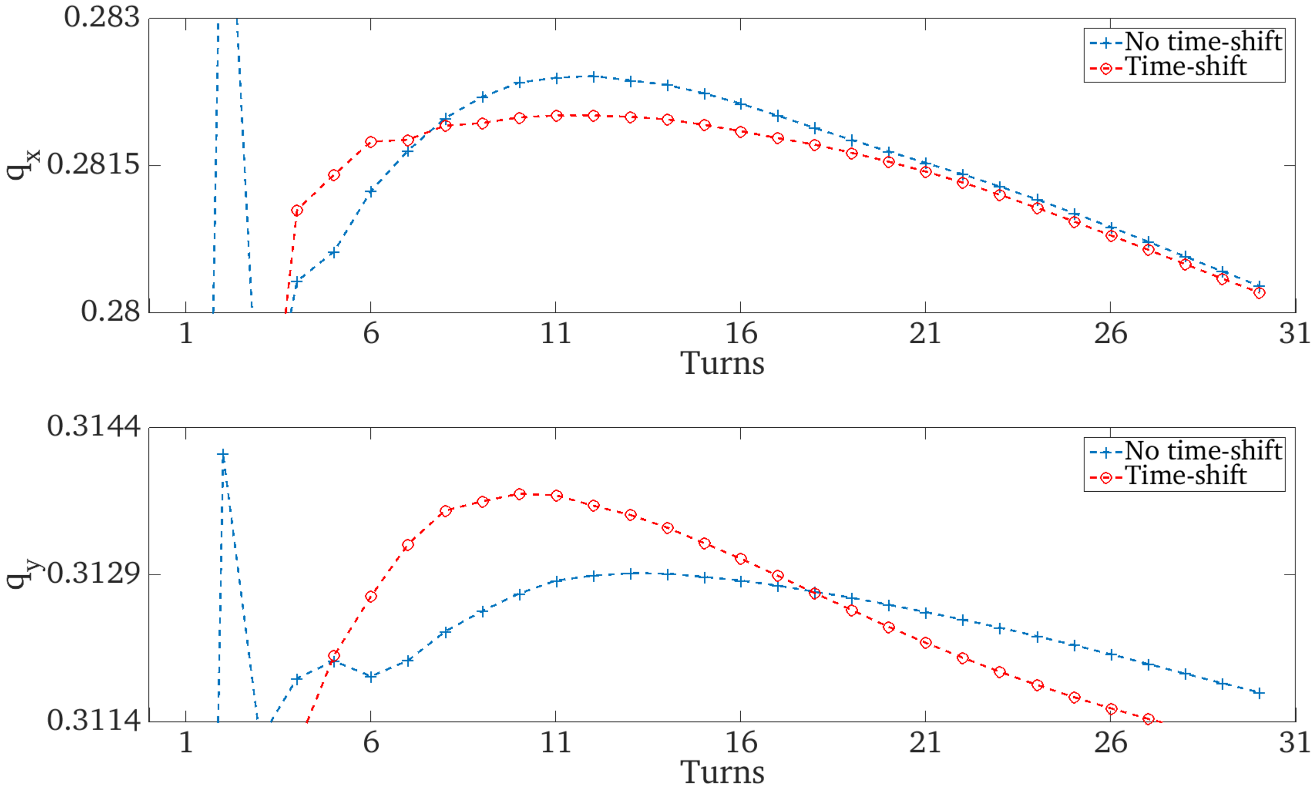
Results for LHC

- In the case of LHC, desynchronization was observed between almost half of the BPMs
- However shifting the TBT data accordingly while comparing the phase advance measurements to the model ones, is a method to treat this problem



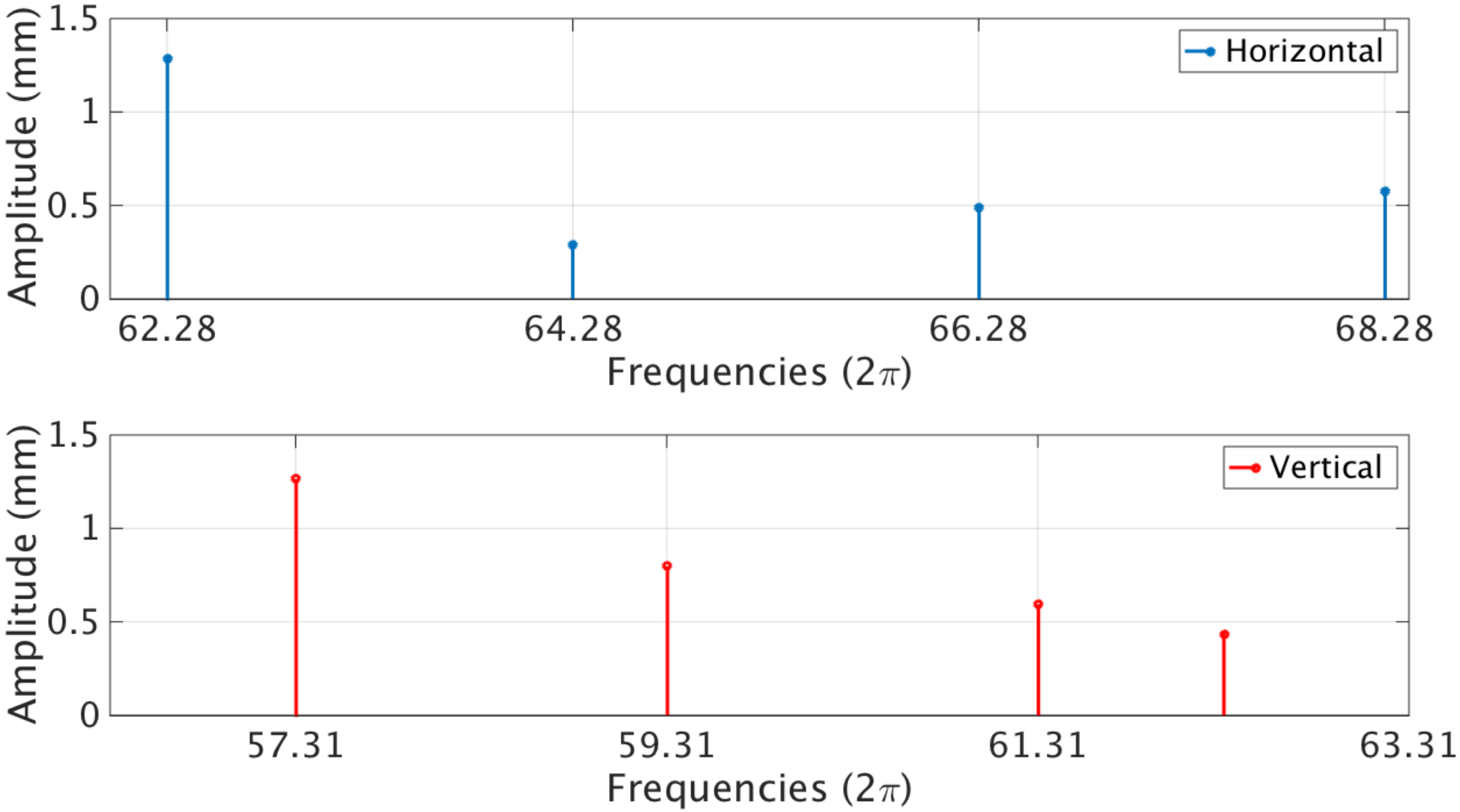
Results for LHC

- Even with the synchronization issue present in the data the method can still determine the fractional part quite accurately and fast



Results for LHC

- Spectral analysis of the measurements gives the correct integer part



RMS Momentum Spread Measurements

- Second order chromatic effects can cause turn by turn modulation of the synchrotron tune with the synchrotron frequency. The centroid motion can be expanded in a Fourier series:

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$$\Omega = s^2 s_2 N(cos\Theta - 1)(1 + \frac{sin\Theta}{\Theta}) \qquad \phi = ArcTan\left(\frac{2s2N}{1 \mp \sqrt{1+4s_2^2N^2}}\right)$$

$$G = \sqrt{1 + \frac{2s_2^2N^2}{(1+4s_2^2N^2)(1+\sqrt{1+4s_2^2N^2})}}$$

$$s_2 = \pi^2\sigma_\delta^2 Q_x''$$

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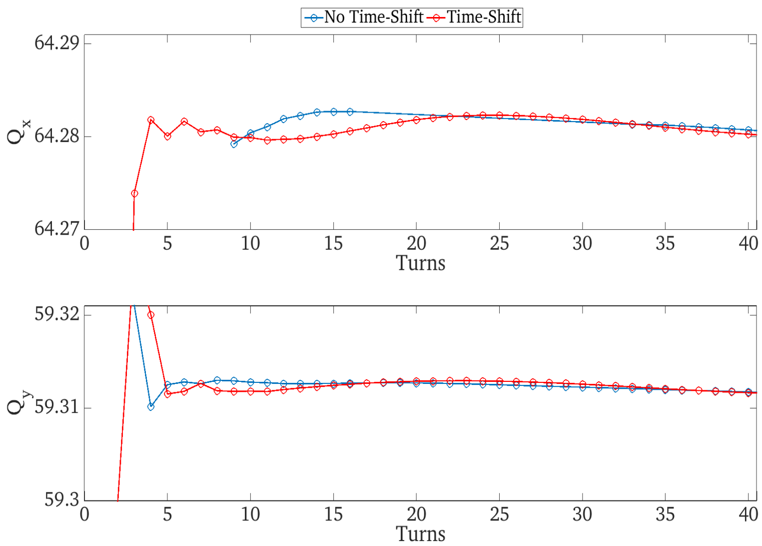
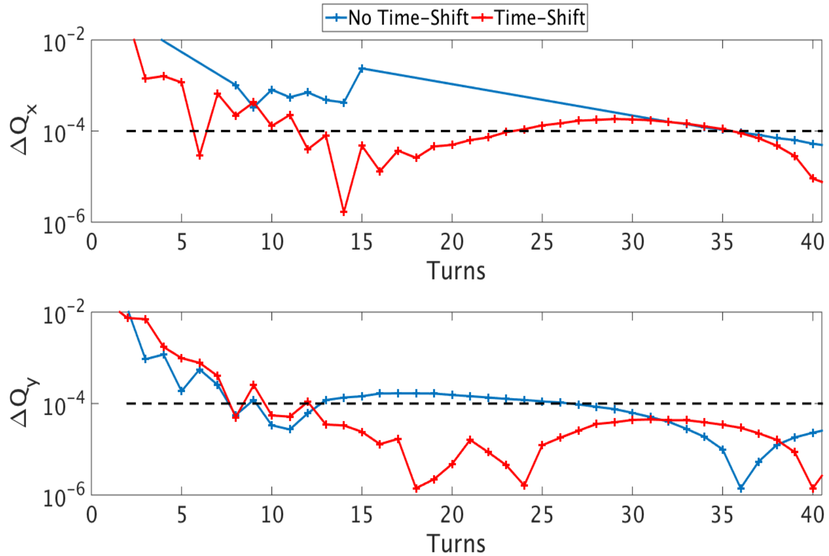
Results for LHC

Accuracy and Speed



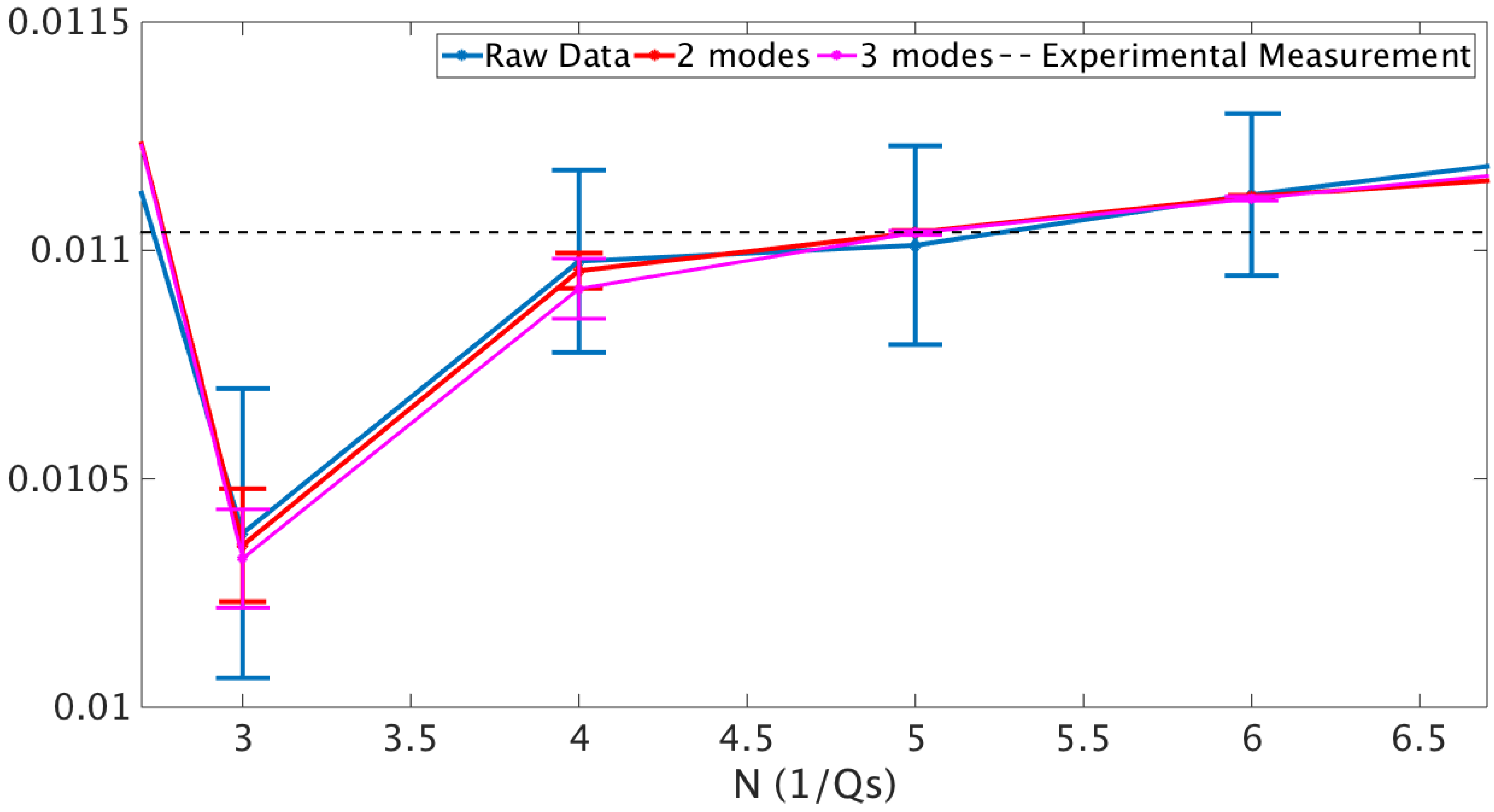
- The tunes are determined in around 5 turns for the all planes and converge to a value fast
- For the horizontal uncorrected data 10 turns are needed for the measurement

Precision



- Precision below 10^{-3} in less than 10 turns for both planes

RMS Momentum Spread Measurements for ANKA



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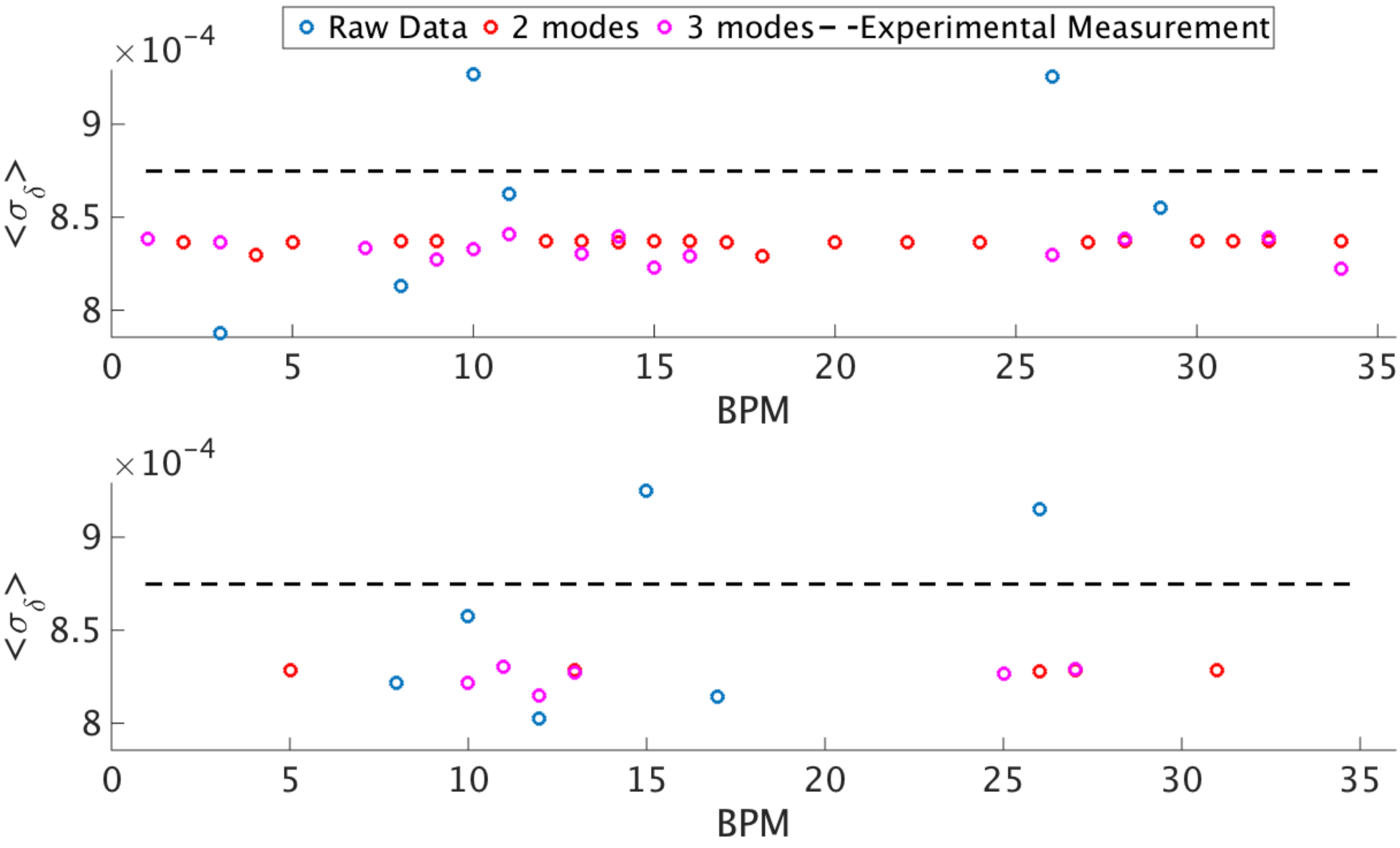

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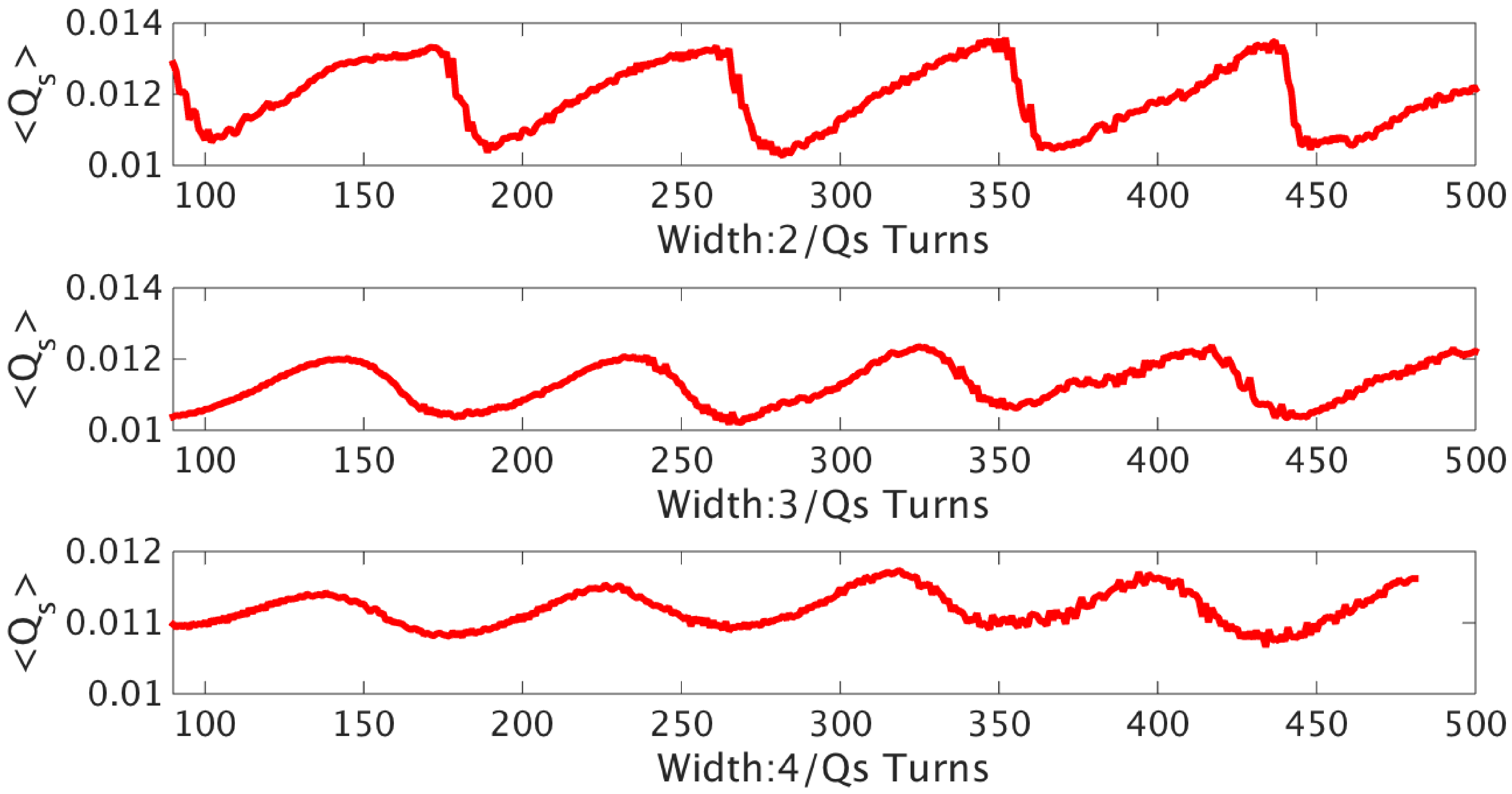
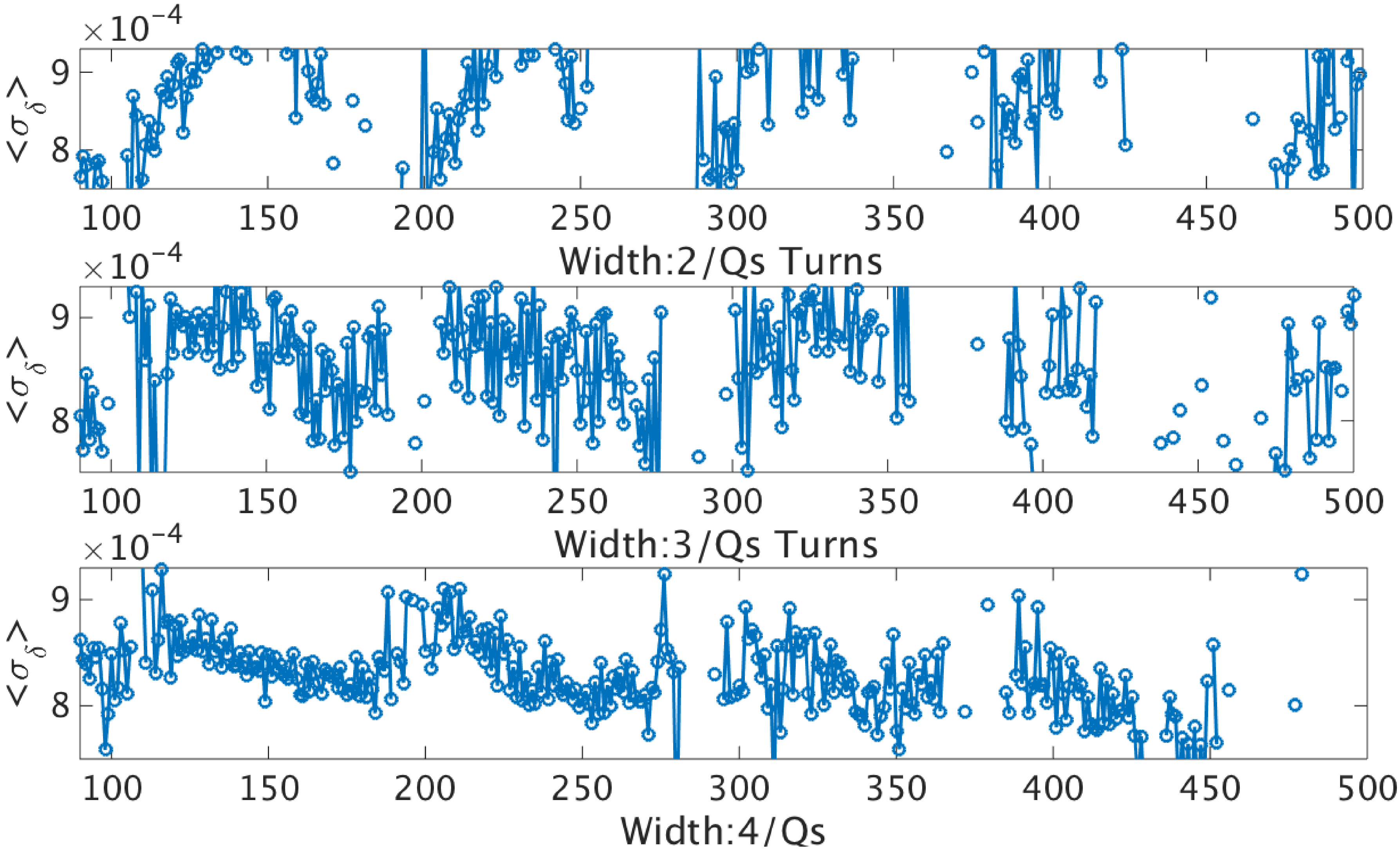
RMS Momentum Spread Measurements



RMS Momentum Spread Measurements



RMS Momentum Spread Measurements for ANKA

- The Fourier amplitudes can be written as

$$A_q = |G||\bar{a}|e^{-s^2} I_q(s^2)(1 + \frac{\Delta\beta_1}{2\beta}\frac{Q_s}{Q'_x}q)$$

- A measurement of A_0 leads to the measurement of |G|. And from there, second order chromaticity can be determined:

$$Q''_x = \sqrt{\frac{M}{\sigma_\delta^2 \pi^2 \mathrm{N}^2}}$$

$$M = \frac{1-5(|G|^2-1)}{8(|G|^2-1)} - \frac{1}{24}\sqrt{\frac{(|G|^2-\frac{10}{9})(|G|^2-2)}{(|G|^2-1)^2}}$$

Summary

- The method of the mixed BPM data was used for the cases of ANKA and LHC rings with success. It was shown that even with a turn-desynchronization issue between the BPMs the tunes can still be measured. NAFF algorithm provides an ultra-fast determination of the tunes.

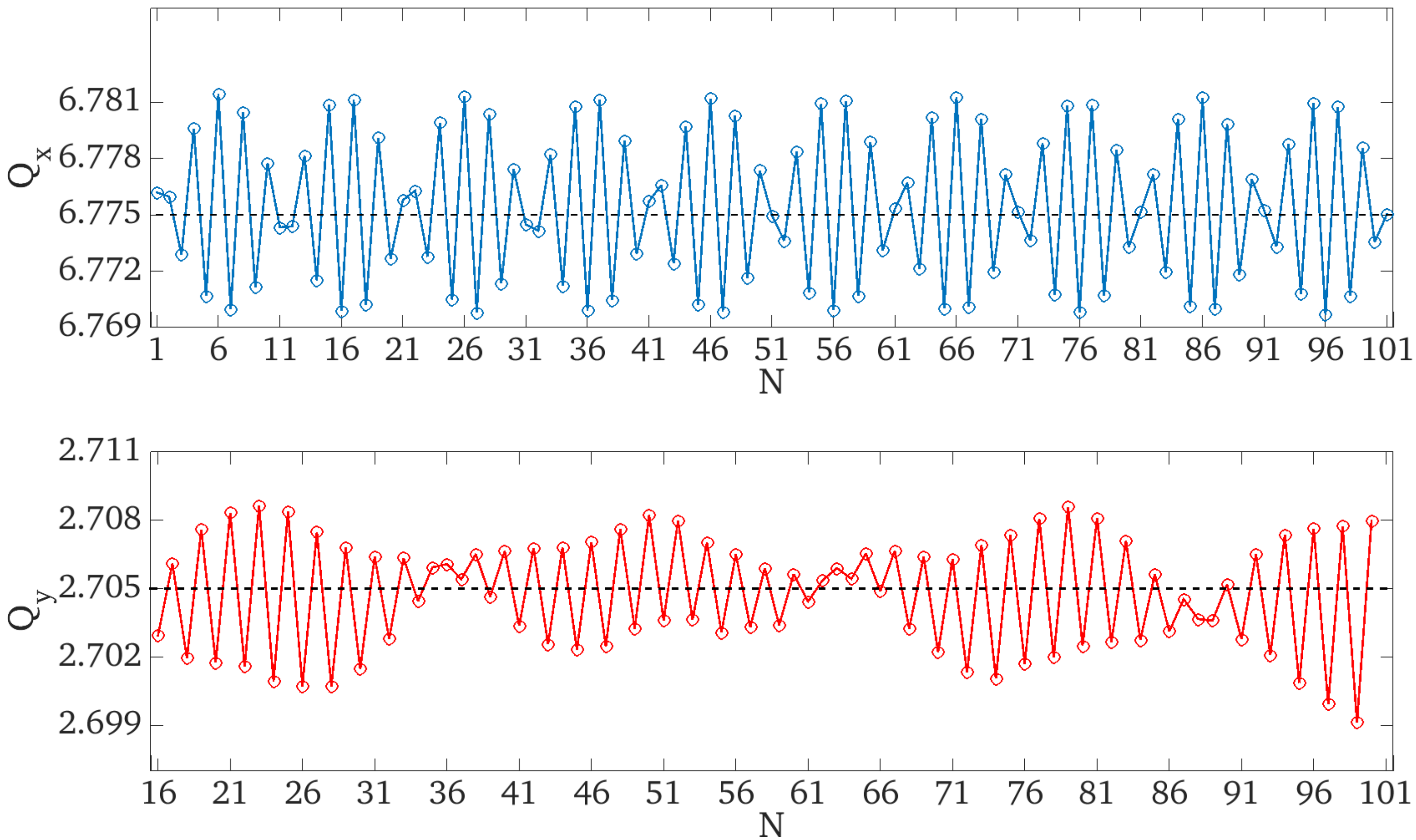
- The RMS momentum spread was measured by using the synchrotron sidebands. The method requires to choose the appropriate number of turns for analysis due to turn dependent effects

- It was shown that second order chromatic effects drive a modulation of the synchrotron tune with. This should be also taken into account in the determination of the RMS momentum spread.

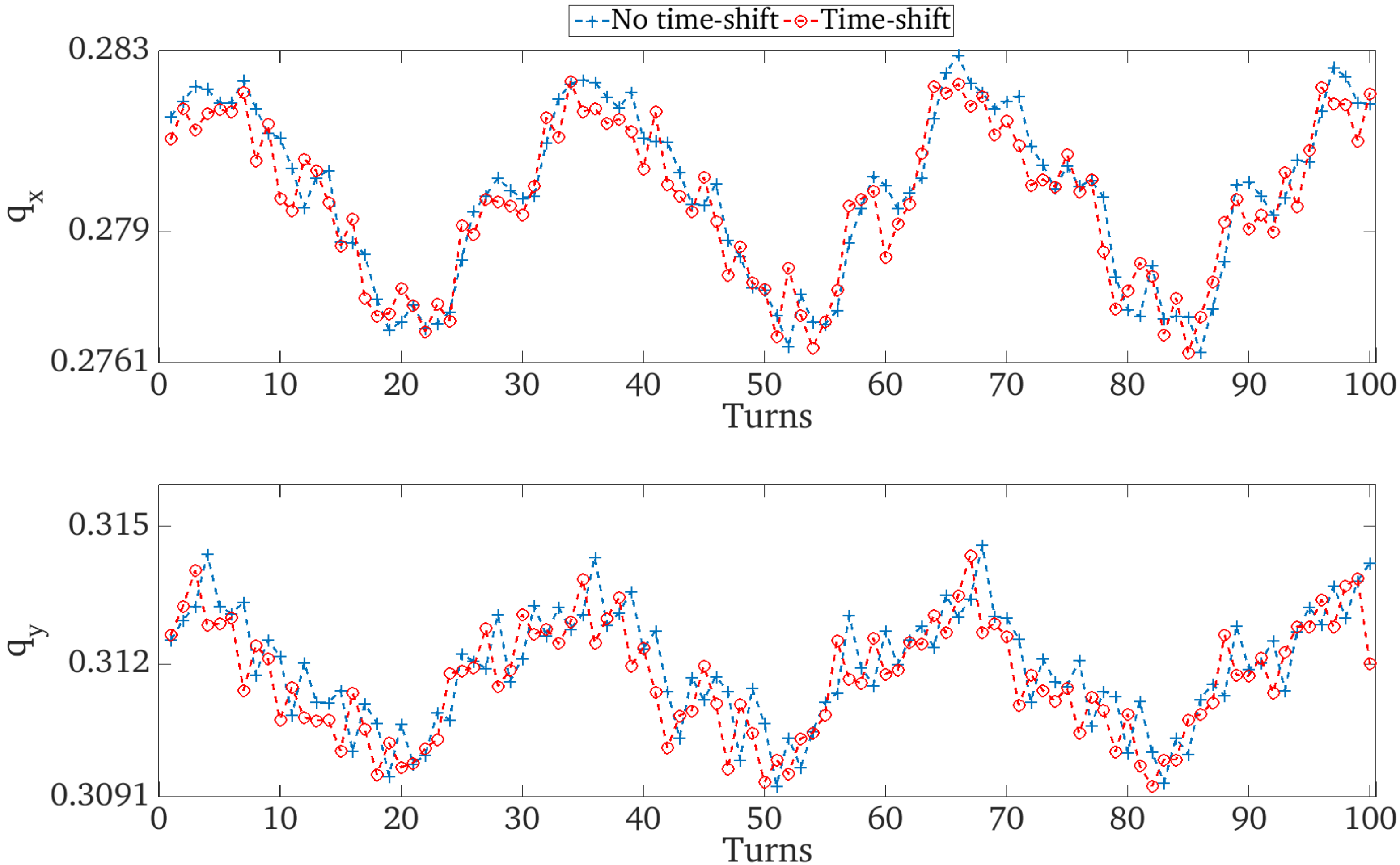
- A method to measure the second order chromaticity from TBT data is under investigation.

Backup

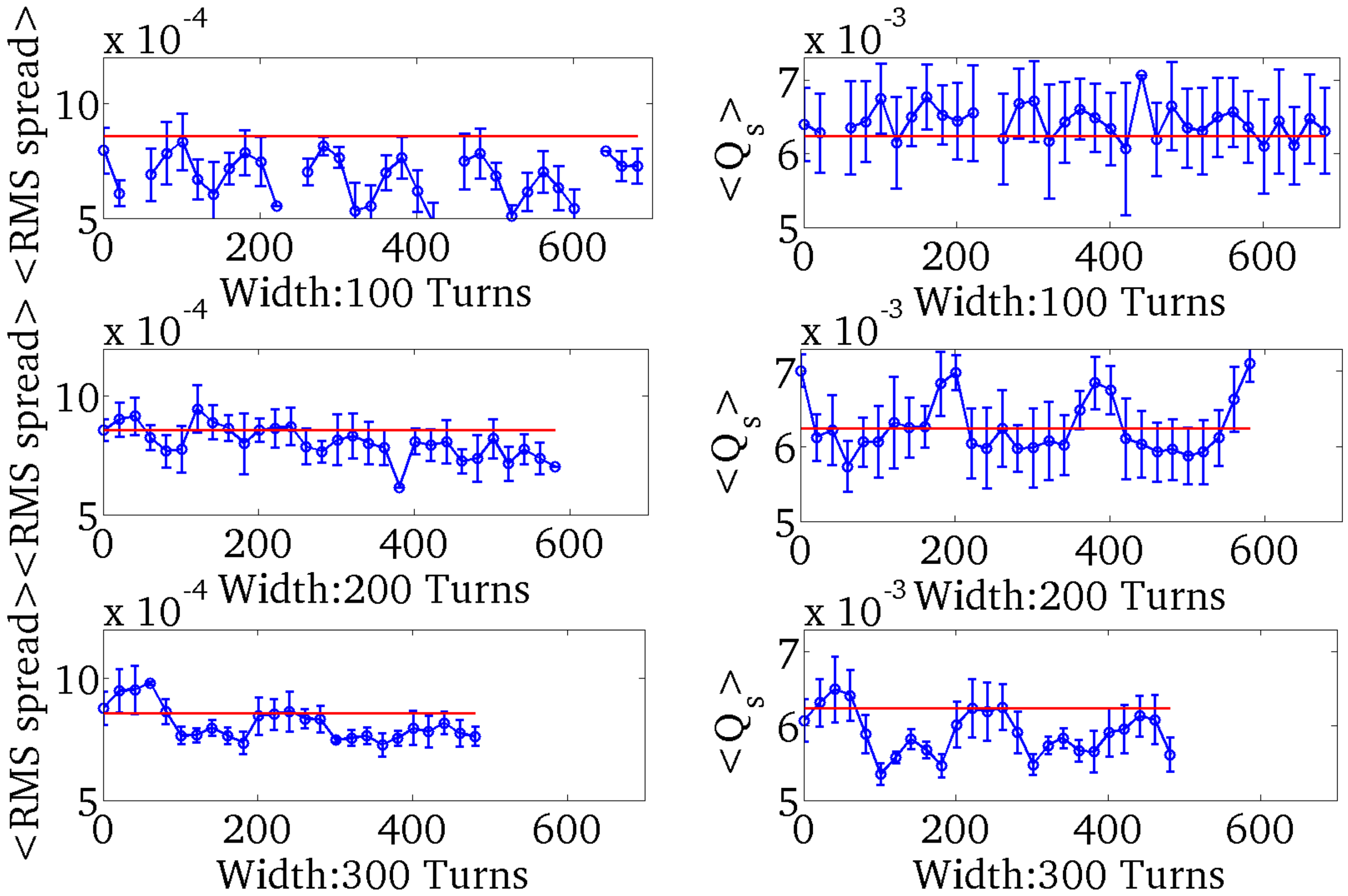
Backup


6.781
6.778
6.775
6.772
6.769
Q_x
1 6 11 16 21 26 31 36 41 46 51 56 61 66 71 76 81 86 91 96 101
N
2.711
2.708
2.705
2.702
2.699
Q_y
16 21 26 31 36 41 46 51 56 61 66 71 76 81 86 91 96 101
N

Backup


No time-shift
Time-shift
0.283
0.279
0.2761
q_x
0
10
20
30
40
50
60
70
80
90
100
Turns
0.315
0.312
0.3091
q_y
0
10
20
30
40
50
60
70
80
90
100
Turns

SLS case


x 10^-4
x 10^-3
<RMS spread>
<Q_s>
Width:100 Turns
Width:200 Turns
Width:300 Turns
0
200
400
600
5
10
5
6
7