Optics measurements using TxT data for the SLS

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Outline

Refined Fourier analysis with the NAFF Algorithm

- Measurements of many accelerator parameters can be carried out with frequency analysis of beam position data
- NAFF algorithm: A method of determining the fundamental frequencies of a hamiltonian system (introduced by Jacques Laskar)
- Quasiperiodic approximation of a numerical sequence over a time span [-T T] $\longrightarrow f(t) = \sum_{n}^{\infty} \alpha_k e^{i\omega_k t}$
- Very accurate signal represantation with a precision of $\frac{1}{T^4}$ whereas standard FFT tools have $\frac{1}{T}$

The SLS storage ring

The SLS is a third generation light source which provides photon beams of high brilliance to 20 beam lines.

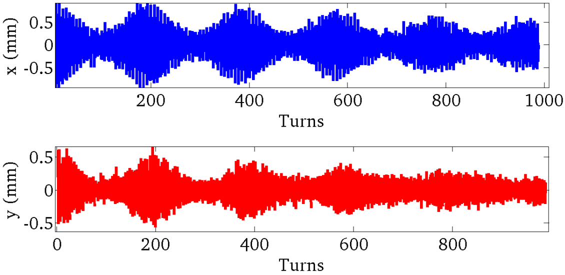
Table : Main Parameter of the SLS storage ring.

Parameter	**Value**
Circuference	288 m
Beam energy	2.4 GeV
Lattice	12 TBA
No. of BPMs	73
Betatron tunes (H/V)	20.44 / 8.74

- In order to estimate the transverse tunes and other ring parameters, the bunches are kicked transversally by a kicker magnet to induce coherent betatron oscillations
- The resulting transverse position data are analysed with NAFF method

Data and decoherence

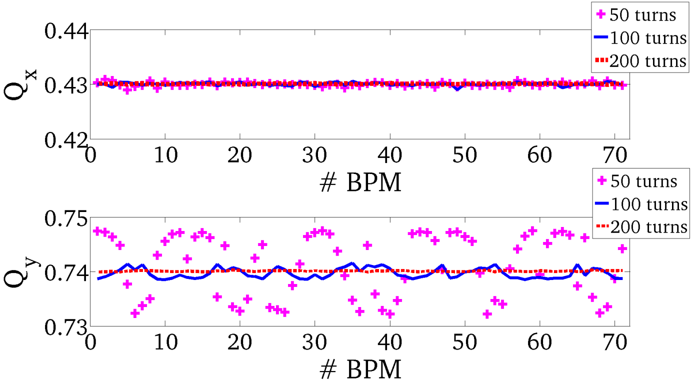
- Some sample TBT data:



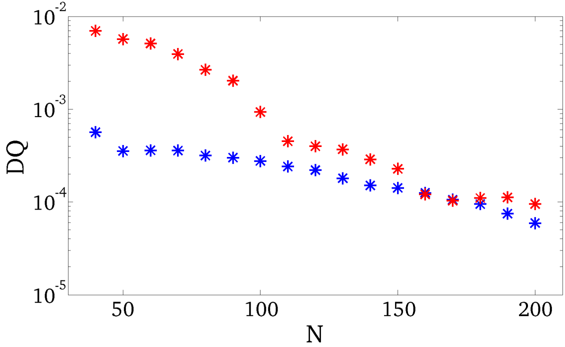
- In the presence of chromaticity and amplitude dependent tune-shift, the BPM signal decoheres leaving a limited number of turns to be analysed

Tune measurement

- BPMs 16 and 43 were noisy and they had to be ignored leaving a total of 71 BPMs for the analysis



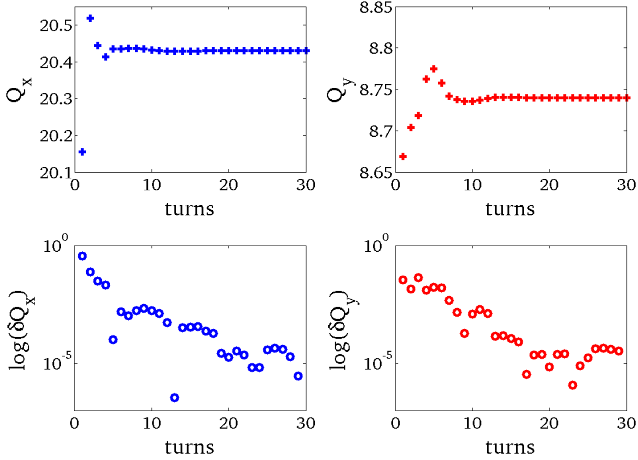
Measurement error



- Horizontal plane$\Longrightarrow$less than 10^{-3} from only 40 turns and gets even less towards 200 turns
- Vertical plane$\Longrightarrow$less than 10^{-3} from 100 turns.

Tune from symmetric to the optics BPM data

Measurement by mixing the beam position data



- $10 \sim 20$ turns needed with error $10^{-5} \Longrightarrow$ speed & accuracy

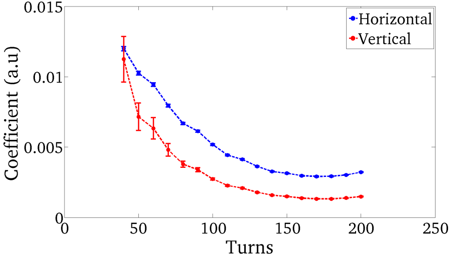
Fit to the machine model

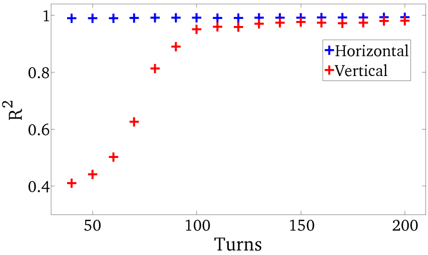
- Fourier component amplitude associated to the main tunes is:

$$A_z^i = c\sqrt{\beta_z^i} \tag{1}$$

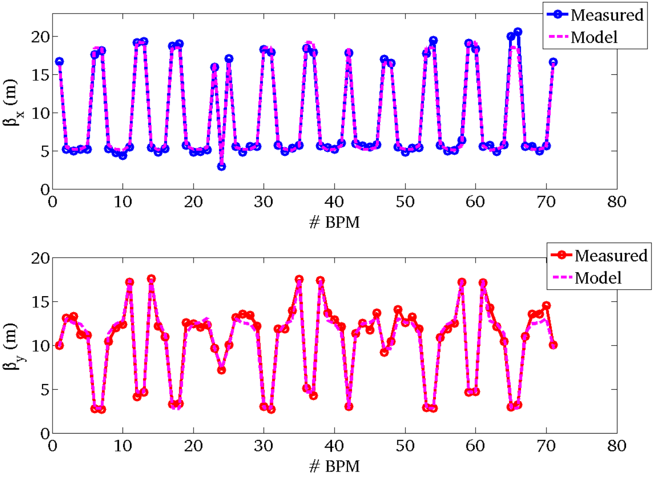
- Beta functions can be estimated by a linear fit of $(A_z^i)^2$ to the linear machine model

Coefficient from the fit

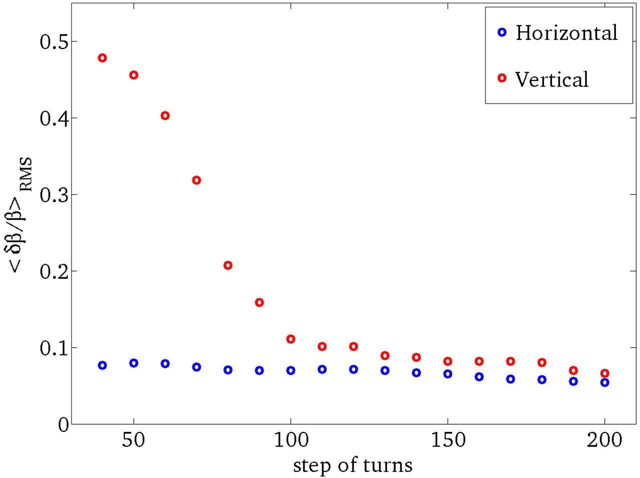




Betas measurements with linear fit method



Normalised error in betas measurements

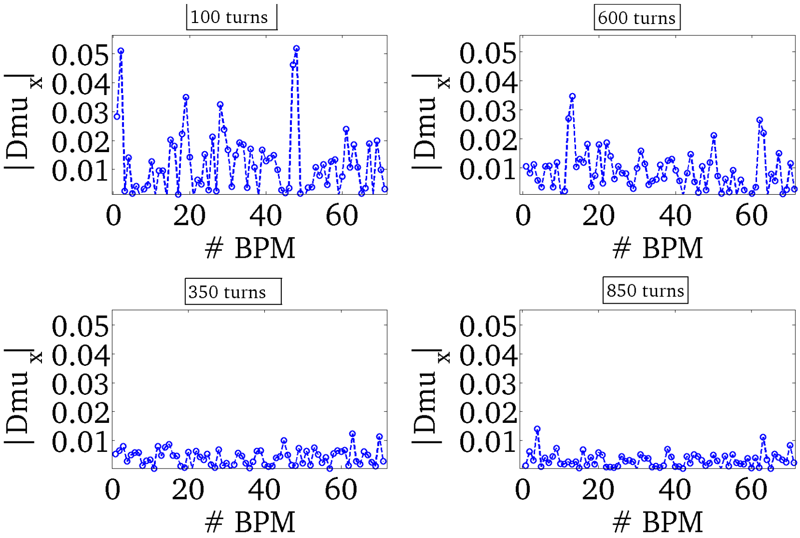


Beta functions from BPM phase advances

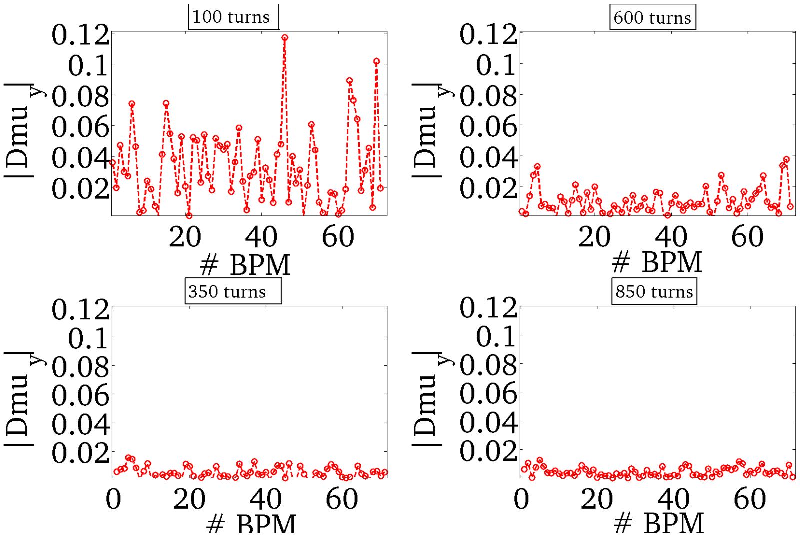
Beta functions can be measured using 3 consecutive BPMs and the measured phase advances (see P.Castro-Garcia Doctoral Thesis)

$$
\begin{aligned}
\tilde{\beta}_1 &= \beta_1 \frac{\cot \tilde{\phi}_{12} - \cot \tilde{\phi}_{13}}{\cot \phi_{12} - \cot \phi_{13}} \\
\tilde{\beta}_2 &= \beta_2 \frac{\cot \tilde{\phi}_{12} - \cot \tilde{\phi}_{23}}{\cot \phi_{12} - \cot \phi_{23}} \\
\tilde{\beta}_3 &= \beta_3 \frac{\cot \tilde{\phi}_{23} - \cot \tilde{\phi}_{13}}{\cot \phi_{23} - \cot \phi_{13}}
\end{aligned} \tag{2}
$$

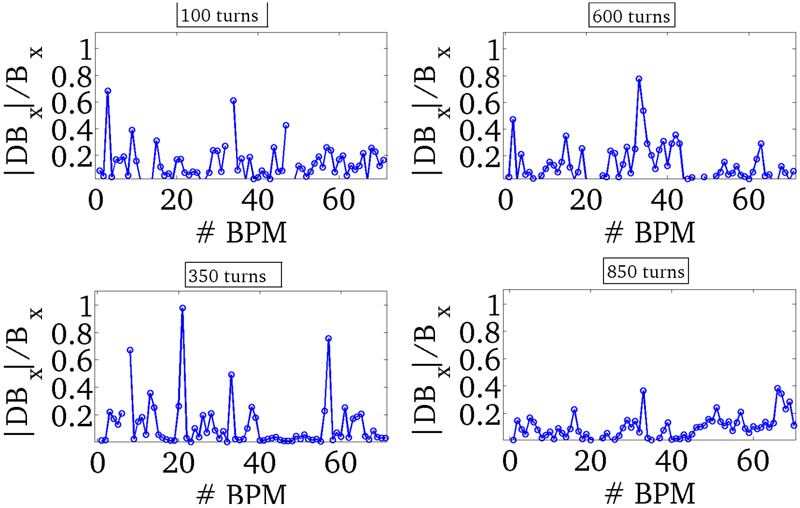
Difference between model and measurements (Horizontal)



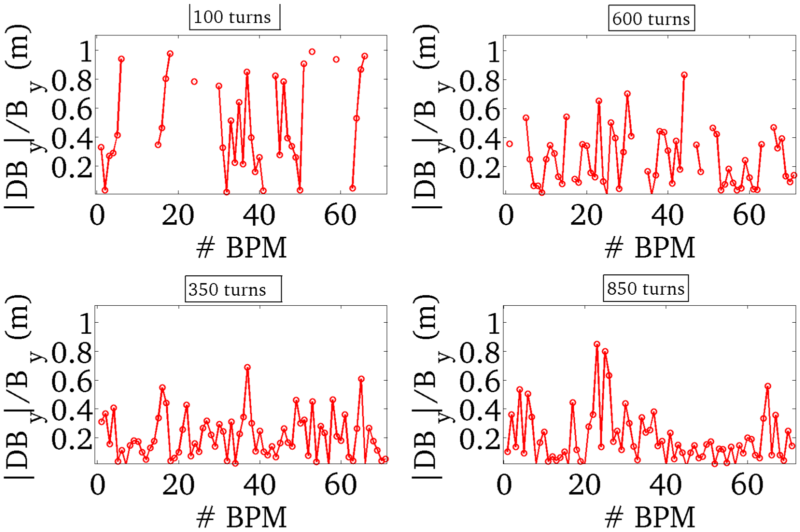
Difference between model and measurements (Vertical)



Error between model and measurements(Horizontal)



Beta beating between model and measurements (Vertical)



RMS momentum spread measurement from chromatic sidebands

- The amplitudes A_q of the chromatic sidebands of order q are

$$A_q = e^{-s^2}|\bar{a}|\left|I_q(s^2) + \frac{\Delta\beta_1}{4i\beta}\sigma_\delta(is)[I_{q-1}(s^2) - I_{q+1}(s^2)]\right|$$

where $s = \frac{Q'_x \sigma_\delta}{Q_s}$

- Use $I_{q-1}(z) - I_{q+1}(z) = \frac{2q}{z} I_q(z)$ and this becomes

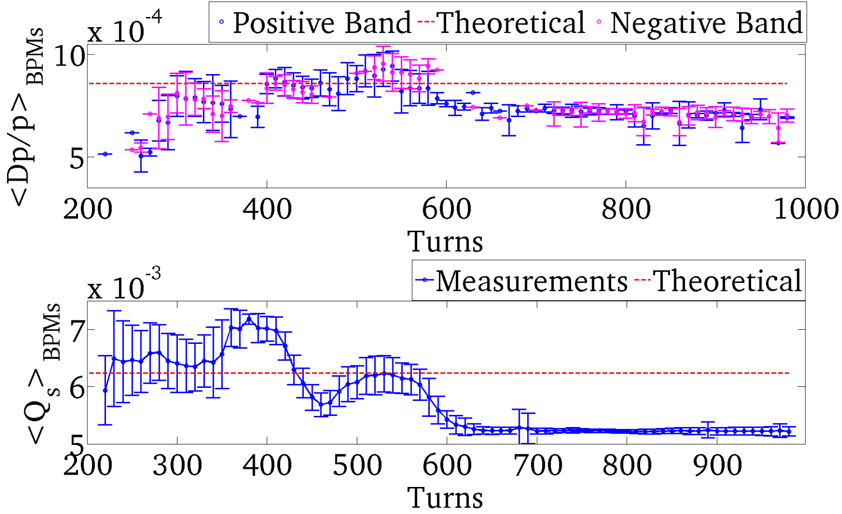
$$A_q = e^{-s^2}\bar{a} I_q(s^2)(1 + \frac{\Delta\beta_1}{2\beta}\frac{Q_s}{Q'_x}q)$$

- One gets rms momentum spread and chromatic beta beat by using $I_q(z) \approx \frac{1}{\Gamma(q+1)}(\frac{z}{2})^q$

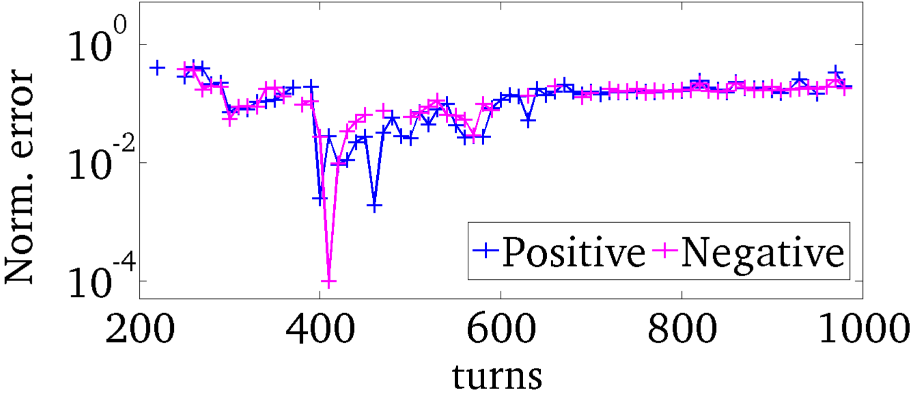
$$\sigma_\delta = \pm\frac{Q_s}{Q'_x}\sqrt{\frac{A_1 + A_{-1}}{A_0}}$$

$$\frac{\Delta\beta_1}{\beta} = \frac{2Q'_x}{Q_s}\left(\frac{A_1 - A_{-1}}{A_1 + A_{-1}}\right)$$

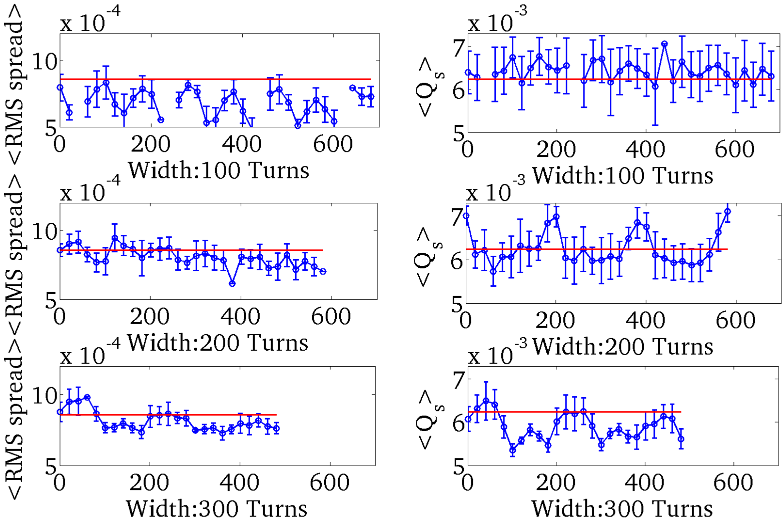
σ_δ measurement with an increasing window of turns



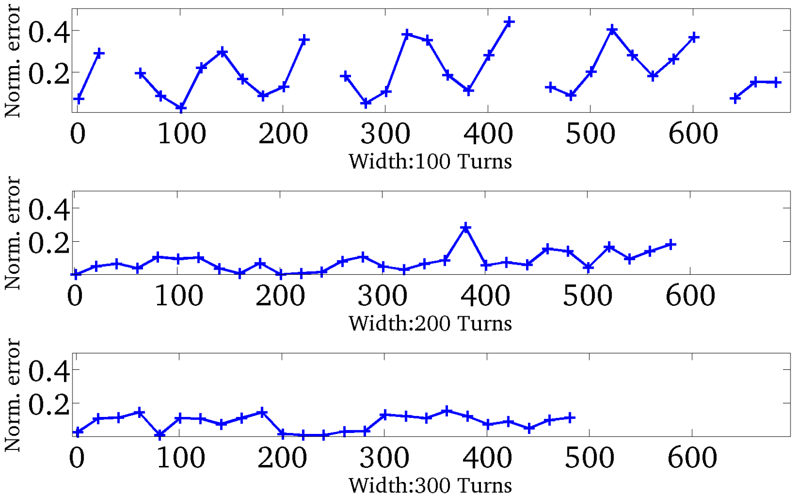
Error in σ_δ measurements



σ_δ measurement with constant window on consecutive data



Absolute error in σ_δ measurement with constant turn window



Conclusions

- NAFF algorithm is a powerful refined Fourier analysis tool which reduces the computation time and reveals many details of the beam dynamics
- The measured fractional tune was measured quite accurately in around 200 turns using the traditional method and at around 10 to 20 turns with the mixed BPM scheme
- Beta functions were measured with two methods. Both methods were succesful but the linear fit method revealed better precision. The phase advance method needs correction for "dangerous" angles
- An RMS momentum spread measurement method was shown and the results are in accordance with the theoretical values. Choice of turns is vital due to decoherence.

Prospects

There are many open subjects under investigation using the capabilities of the NAFF algorithm:

- Finish the chromatic beta beat measurements. Check accordance with MADX
- Derive a method to measure chromaticity using TxT data
- Possibility of estimating the beta functions by only using the measured phase advances
- Produce the Fourier spectrum of decoherence-Maybe decoherence can be filtered out from the TxT data?

What is next in the list?

There are many open subjects under investigation using the capabilities of the NAFF algorithm:

- Finish the chromatic beta beat measurements. Check accordance with MADX
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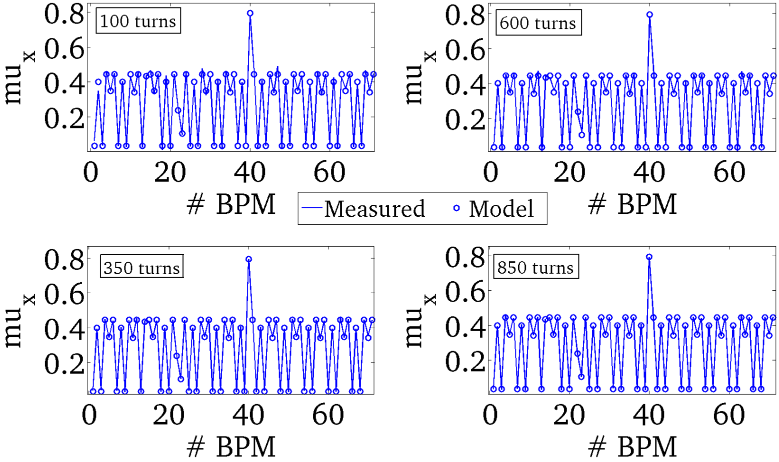
Thank you!

How does it work?

- The amplitudes and frequencies are found using an iterative scheme
- First frequency (fundamental) is found from the maximum of $< f(t), e^{i\sigma t} >= \frac{1}{2}\int f(t)e^{-i\sigma t}e^{i\sigma t}w(t)dt$ with $\frac{1}{2}\int_{-1}^{1} w(t)dt = 1$.
- In most cases $w(t)$ is the Hanning window filter Precision scales with $\frac{1}{N^4}$ than $\frac{1}{N^2}$ without a filter
- Main Amplitude measurement from orthogonal projection on $e^{i\omega_1 t}$
- If desired more frequencies and amplitudes can be found using $f(t)' = f(t) - \alpha_1 e^{i\omega_1 t}$

Measuring phase advances with NAFF

A comparison between the measured phase advances and the model ones gives a first impression of the accuracy of the method in the SLS case



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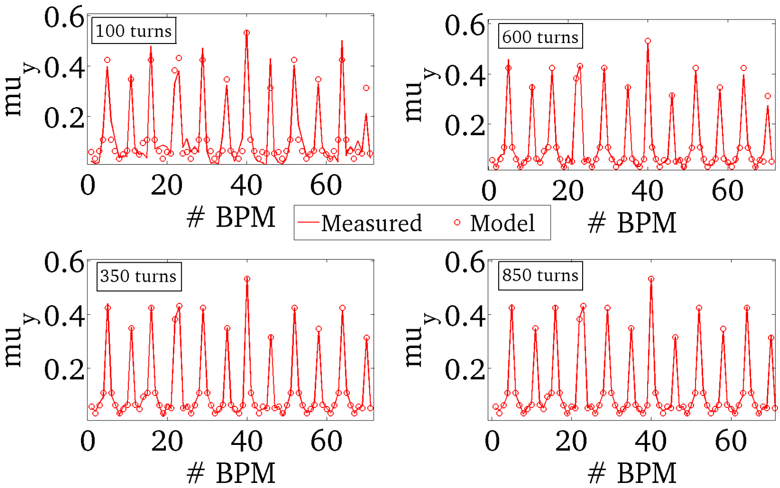
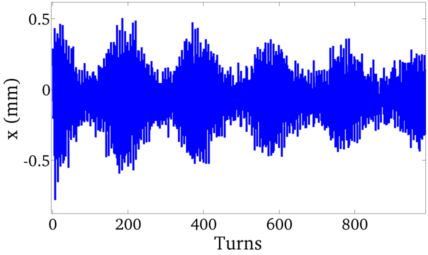
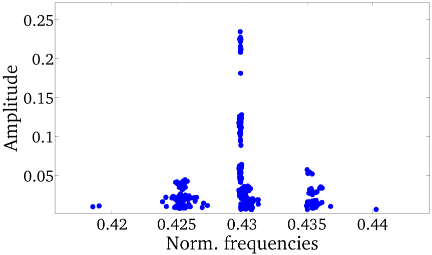


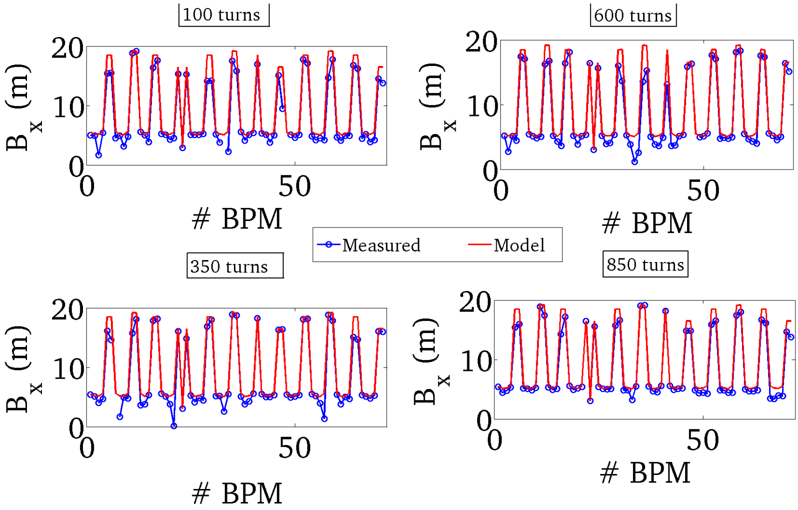
Fourier Analysis

- Measurements of many accelerator parameters can be carried out with frequency analysis of beam position data
- FFT $\rightarrowtail$ Many turns needed for good measurements$\sim$Precision scales with $\frac{1}{N}$





Betas measurements using 3 BPMs' phase advances (Horizontal)



Betas measurements using 3 BPMs' phase advances (Vertical)