Beam Instrumentation

Detailed Analysis of Noise Measurement for Orbit Response Matrix Data

JEDI collaboration meeting @ Tbilisi State University

September 1, 2016 | Fabian Hinder (IKP - 4)

Why Orbit Response Matrix Analysis?

- Orbit Response Matrix (ORM) describing the response of the beam position to corrector magnet changes
  - $\begin{pmatrix} \vec{x} \\ \vec{y} \end{pmatrix} = M \begin{pmatrix} \overrightarrow{\theta_x} \\ \overrightarrow{\theta_y} \end{pmatrix}$
  - $M_{i,j}$ with its corresponding error $\sigma_{i,j}$ for BPM i and magnet j

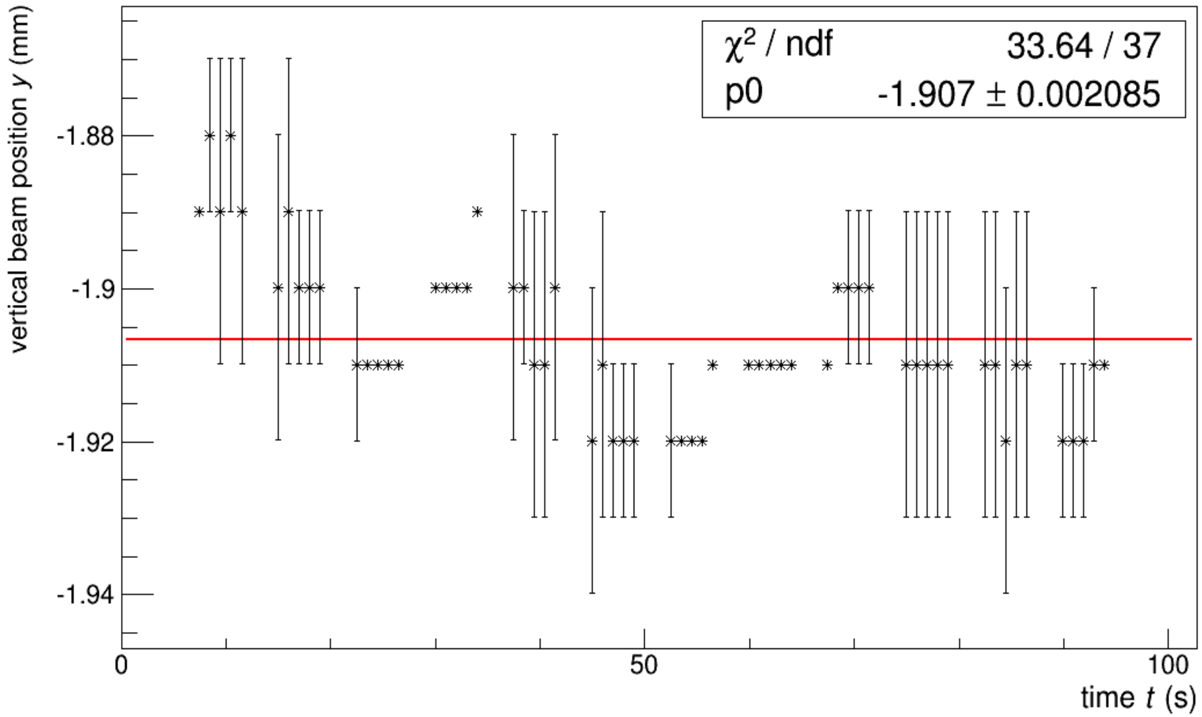
- Why?
  - Orbit correction
  - Analysis of ORM to estimate COSY optics (LOCO)
  - Understand long-term stability of COSY

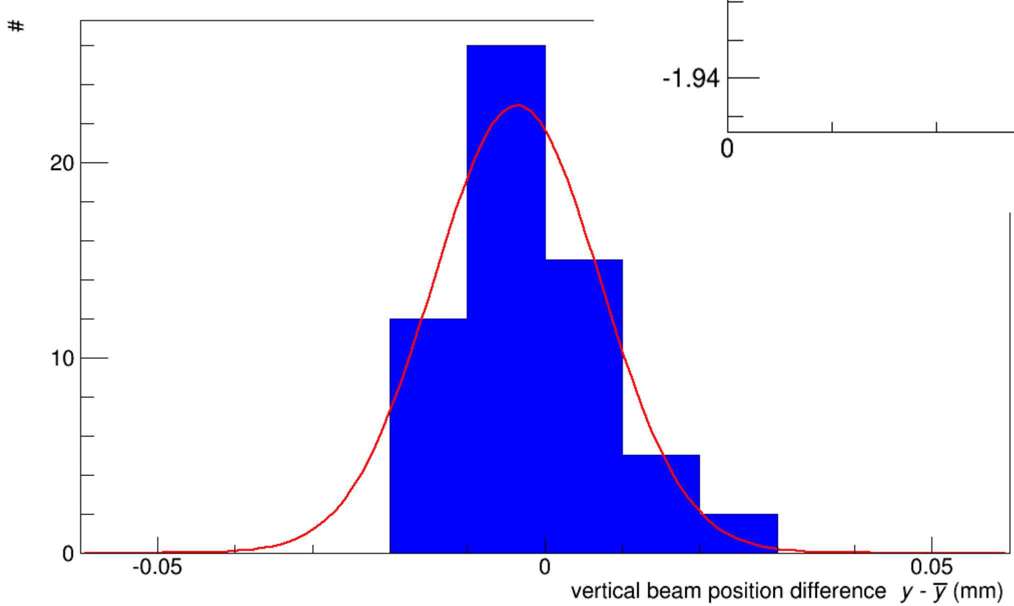
What do we need?

- Estimation of noise of BPMs
- Estimation of stability of COSY
- Measured beam positions for different corrector kick angles
- Combination of everything to calculate ORM including realistic errors
- Now: Interesting details of ONE ORM data set
  - (Protons, 2.6 GeV/c)

Noise Measurement (vertical)

$$\sigma_{Noise} = \frac{1}{\sqrt{N-1}} \sum (y_i - \bar{y})^2$$



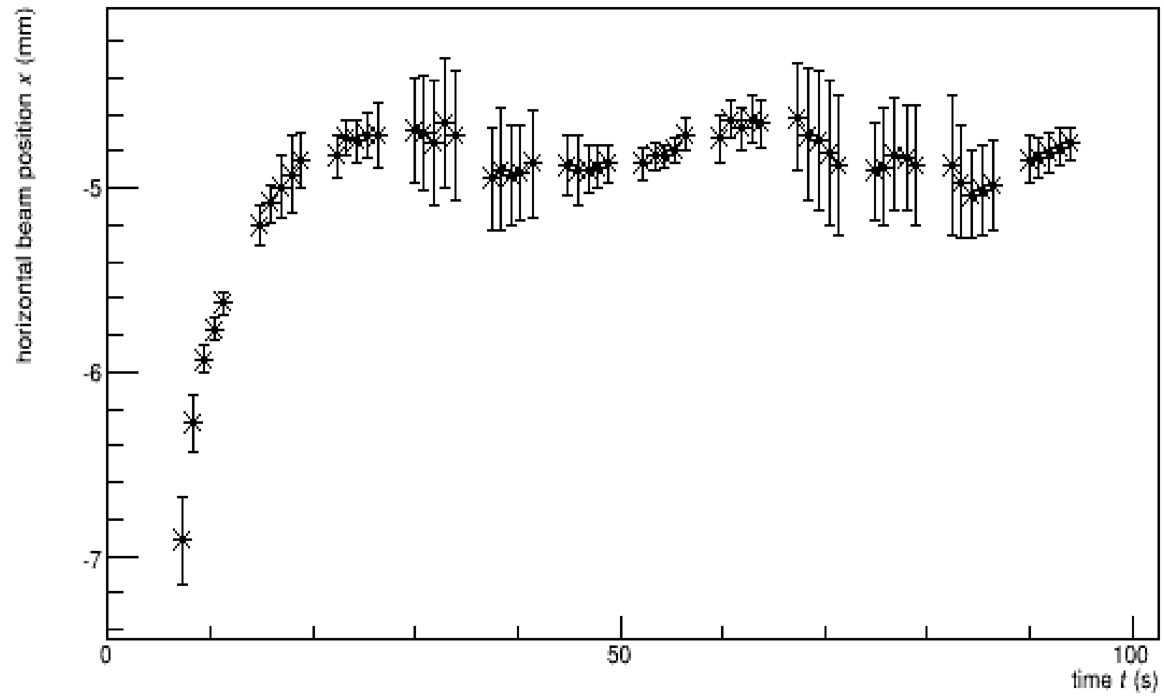


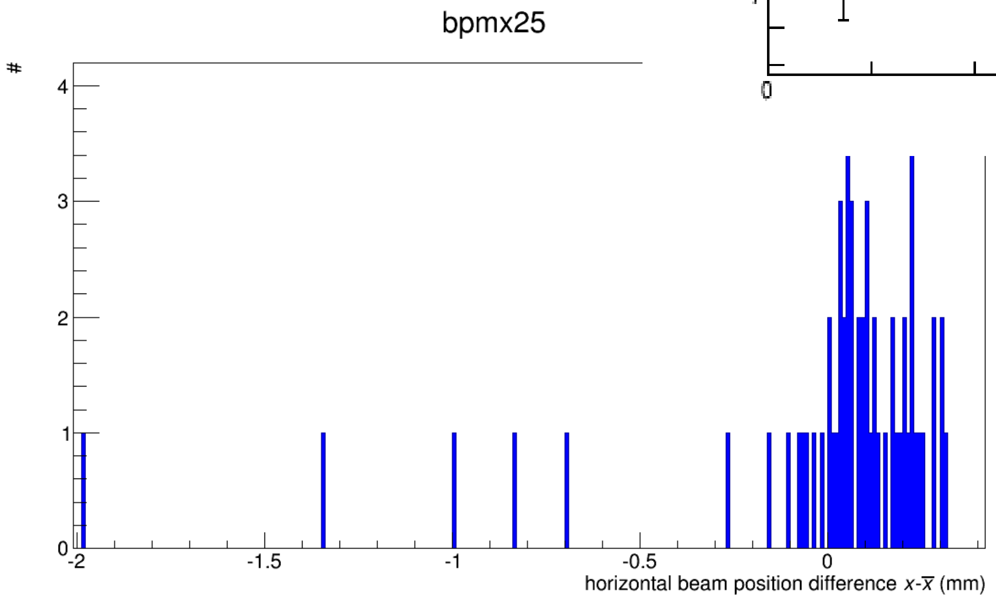
BPMy29:

$$\sigma = 0.01mm$$

Noise Measurement (horizontal)

$$\sigma_{Noise} = \frac{1}{\sqrt{N-1}} \sum (x_i - \bar{x})^2$$





BPMx25:

$$\sigma = 0.39mm$$

But:

systematic movement of beam

Global Noise Fit

The horizontal beam positions can be described by:

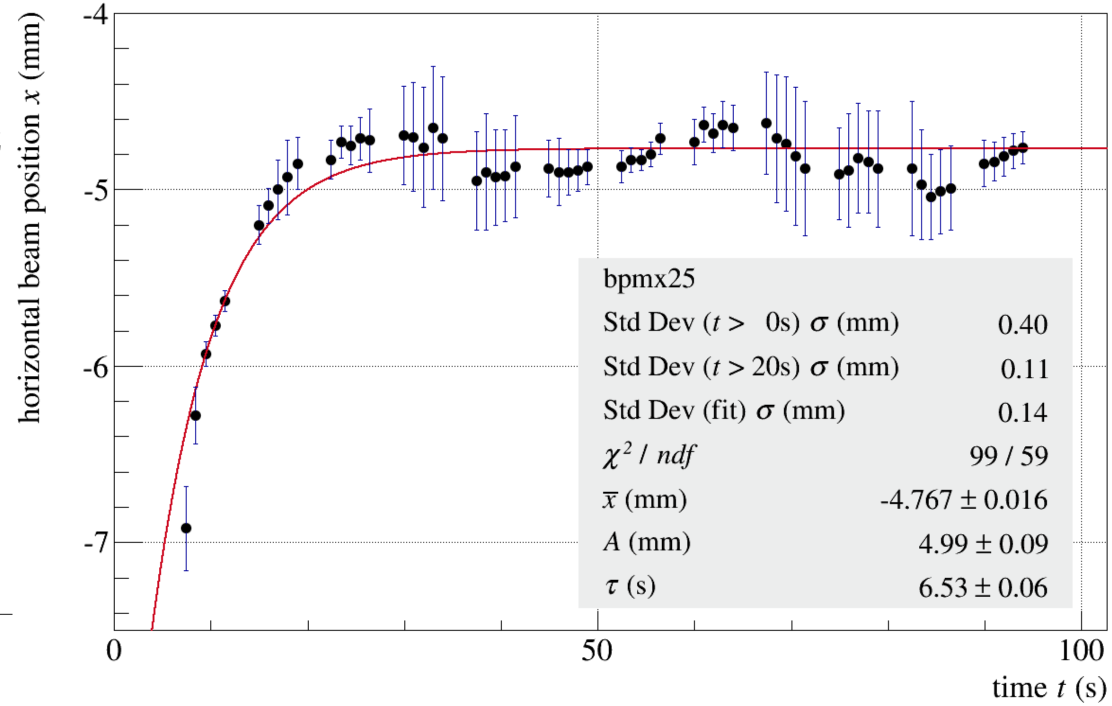
$$x_i(t) = x_{0,i} + A_i e^{-\frac{t}{\tau}}$$

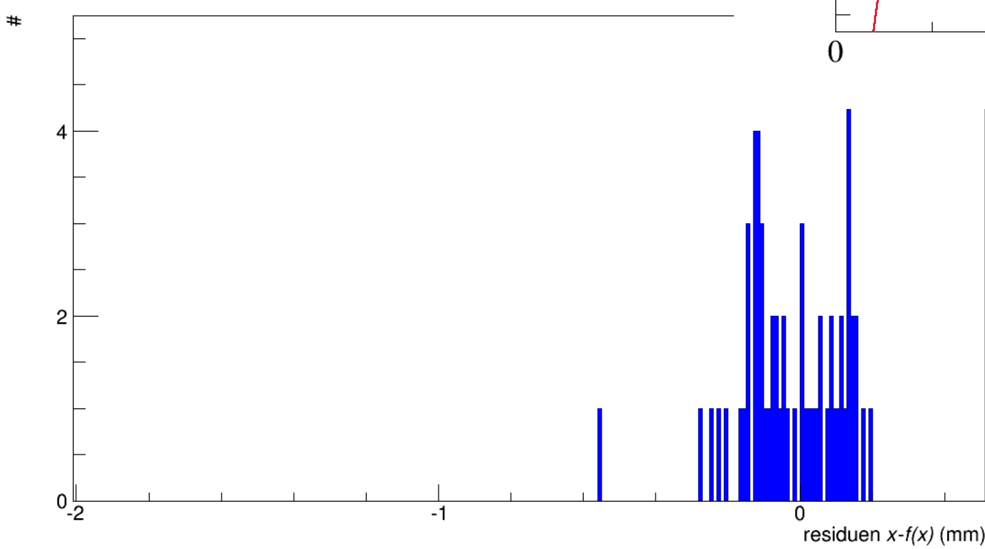
Fit parameters:

- for each BPM: $x_{0,i}$ and A_i
- Common time constant τ
- Results:
  - $\chi^2/_{NDF} = 2077/1528$
  - $\tau = 6.53 \pm 0.06\ s$
  - Amplitudes → following slides

Noise Measurement (horizontal)

$$\sigma_{Noise} = \frac{1}{\sqrt{N-1}} \sum \left(x_i - x_{fit}(t_i)\right)^2$$



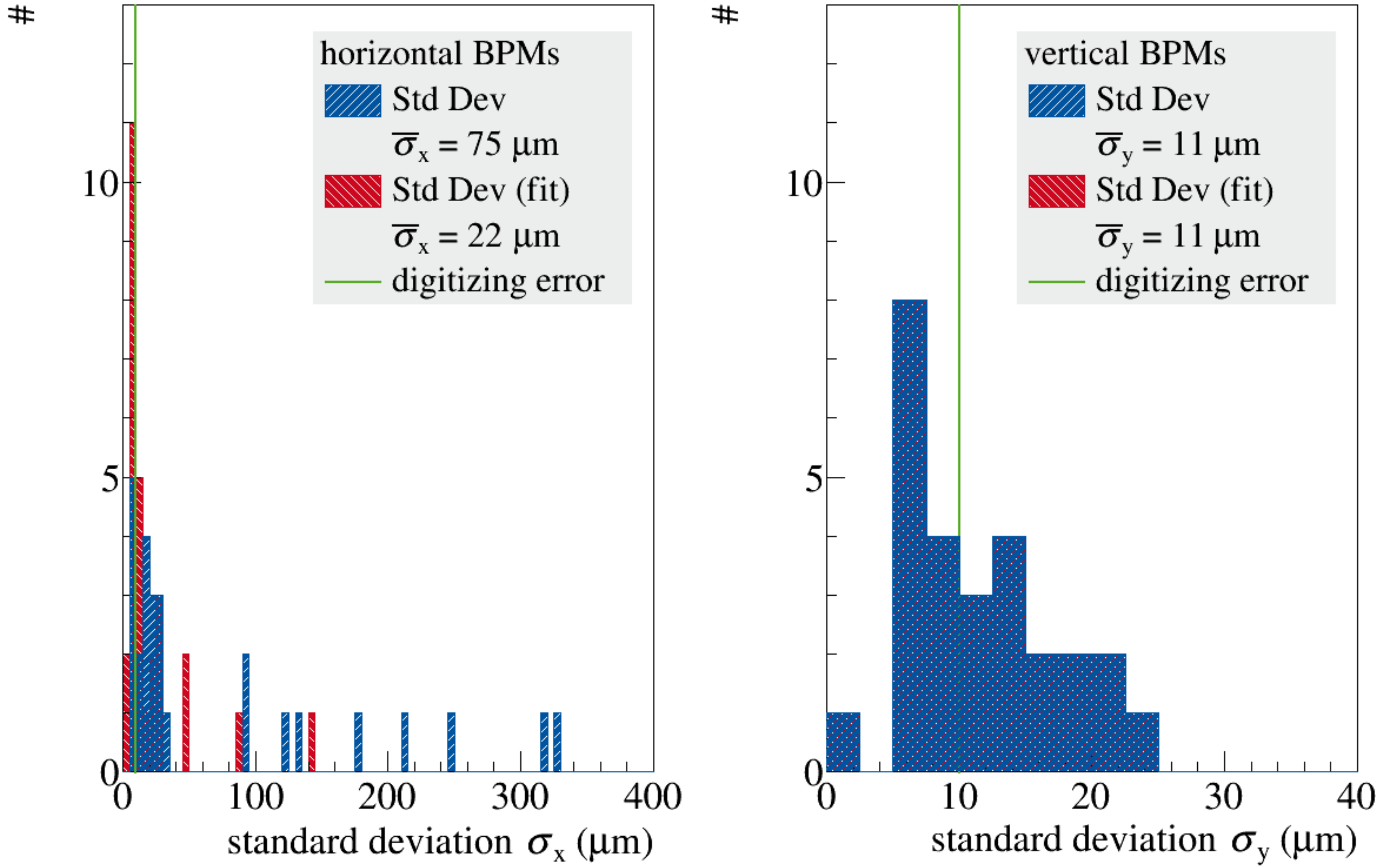


BPMx25:

$$\sigma = 0.14mm$$

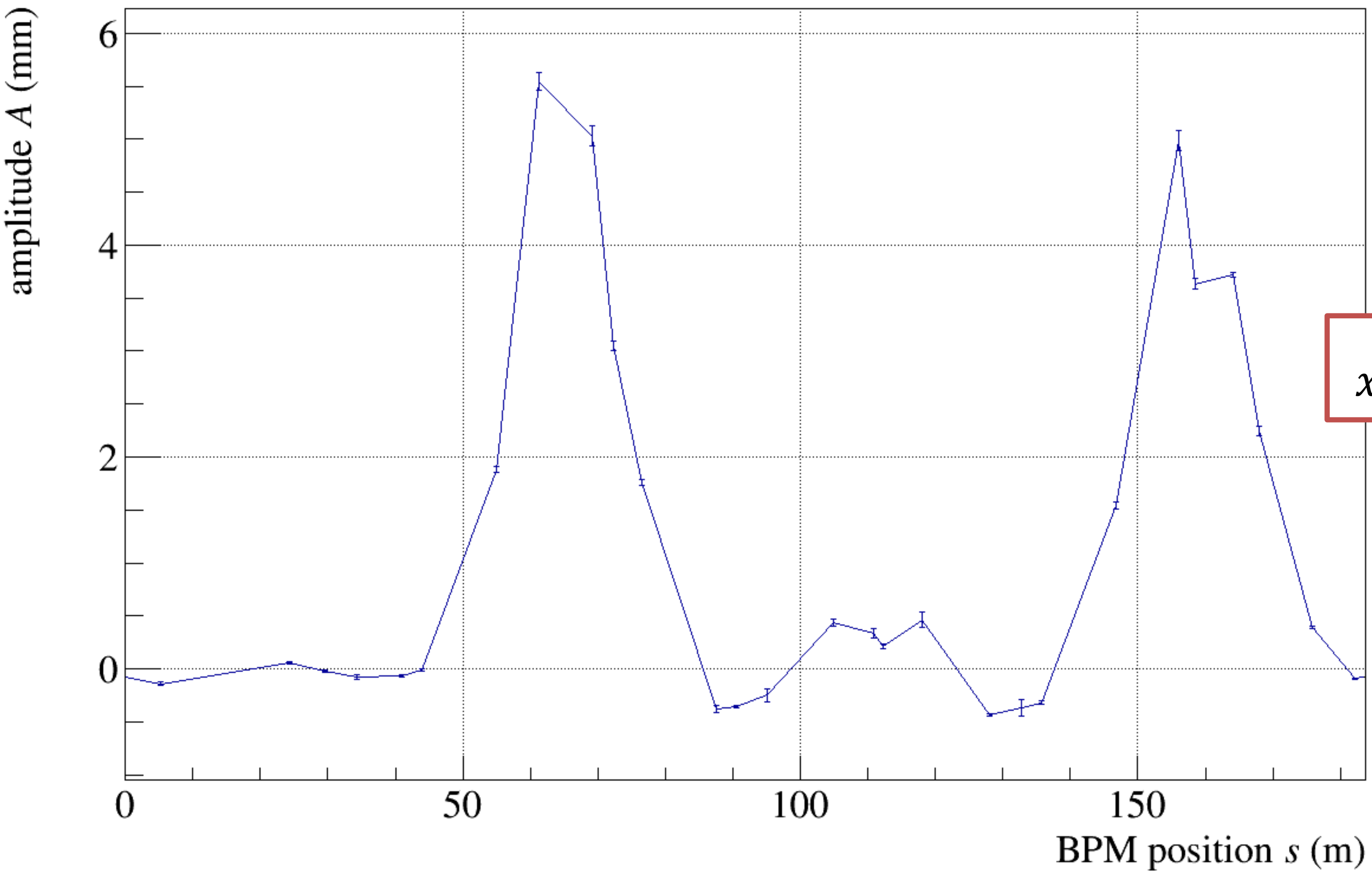
Resolution of other horizontal BPMs is better

Resulting estimated Errors



(Including stability of COSY)

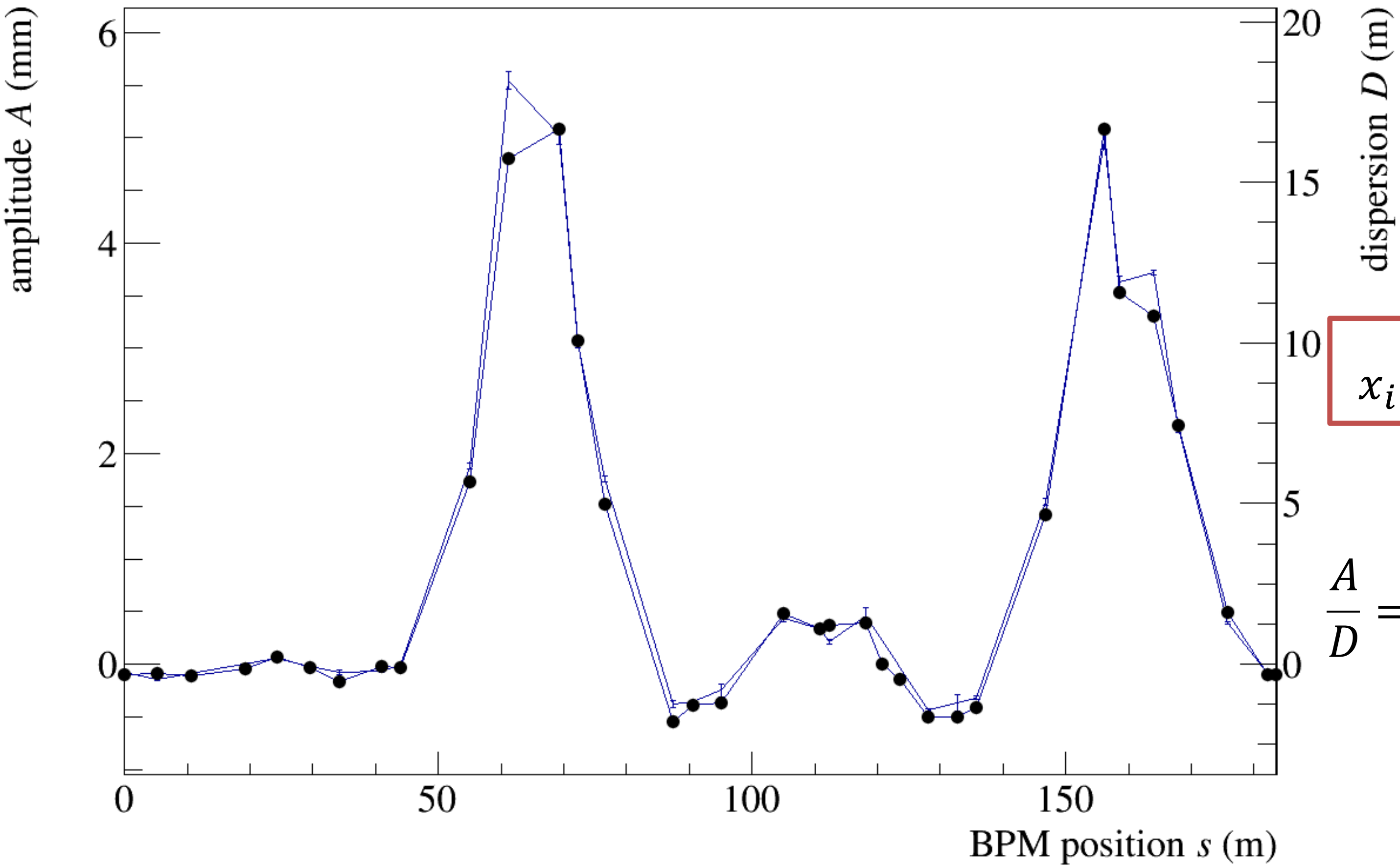
Distribution of Amplitudes



$$x_i(t) = x_{0,i} + A_i e^{-\frac{t}{\tau}}$$

Amplitudes are proportional to dispersion
→ Exponential movement caused by main dipoles

Distribution of Amplitudes



$$x_i(t) = x_{0,i} + A_i e^{-\frac{t}{\tau}}$$

$$\frac{A}{D} = (0.31 \pm 0.03)10^{-3}$$

Amplitudes are proportional to dispersion

→ Exponential movement caused by main dipoles

Explanation for spin tune drift within one cycle??

Simple Explanation ?

$$B(t) \propto I(t)$$
$$I(t) = \frac{U_0}{R} * (1 - e^{-\frac{t}{\tau}})$$

With $\tau = L/R$

Dipoles:

$$L = 15mH, R = 3m\Omega$$
$$\tau = \frac{15H}{3\Omega} = 5s$$

Measured with beam:

$$\tau = 6.5s$$

Other effects in addition + discussion with power-supply group is ongoing…

Small Estimation on Momentum Variation

$$x(t) = x_0 - Ae^{-t/\tau}$$

Definition of dispersion:

$$\Delta x = D \frac{\Delta p}{p_0}$$

$$\Leftrightarrow \frac{\Delta p}{p} = \frac{A}{D} e^{-t_1/\tau}$$

$$\frac{\Delta p}{p} = 0.3 \cdot 10^{-3} \mathrm{e}^{-10s/6.5s} = 6 \cdot 10^{-5}$$

Theoretical relation to spin tune:

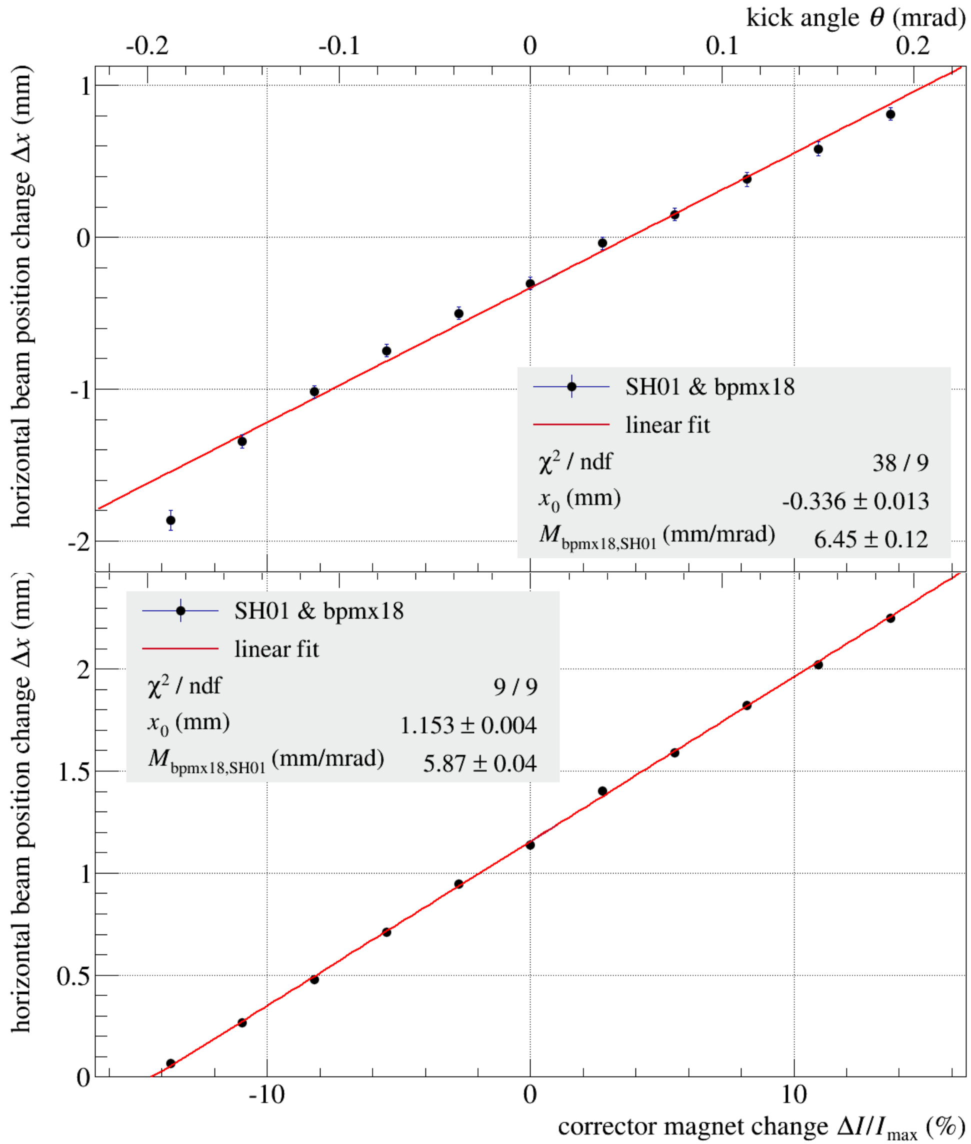
$$\frac{\Delta \nu_s}{\nu_s} = \beta^2 \frac{\Delta p}{p}$$

(need to be confirmed with Deuterons @ 970MeV/c)

ORM calculation

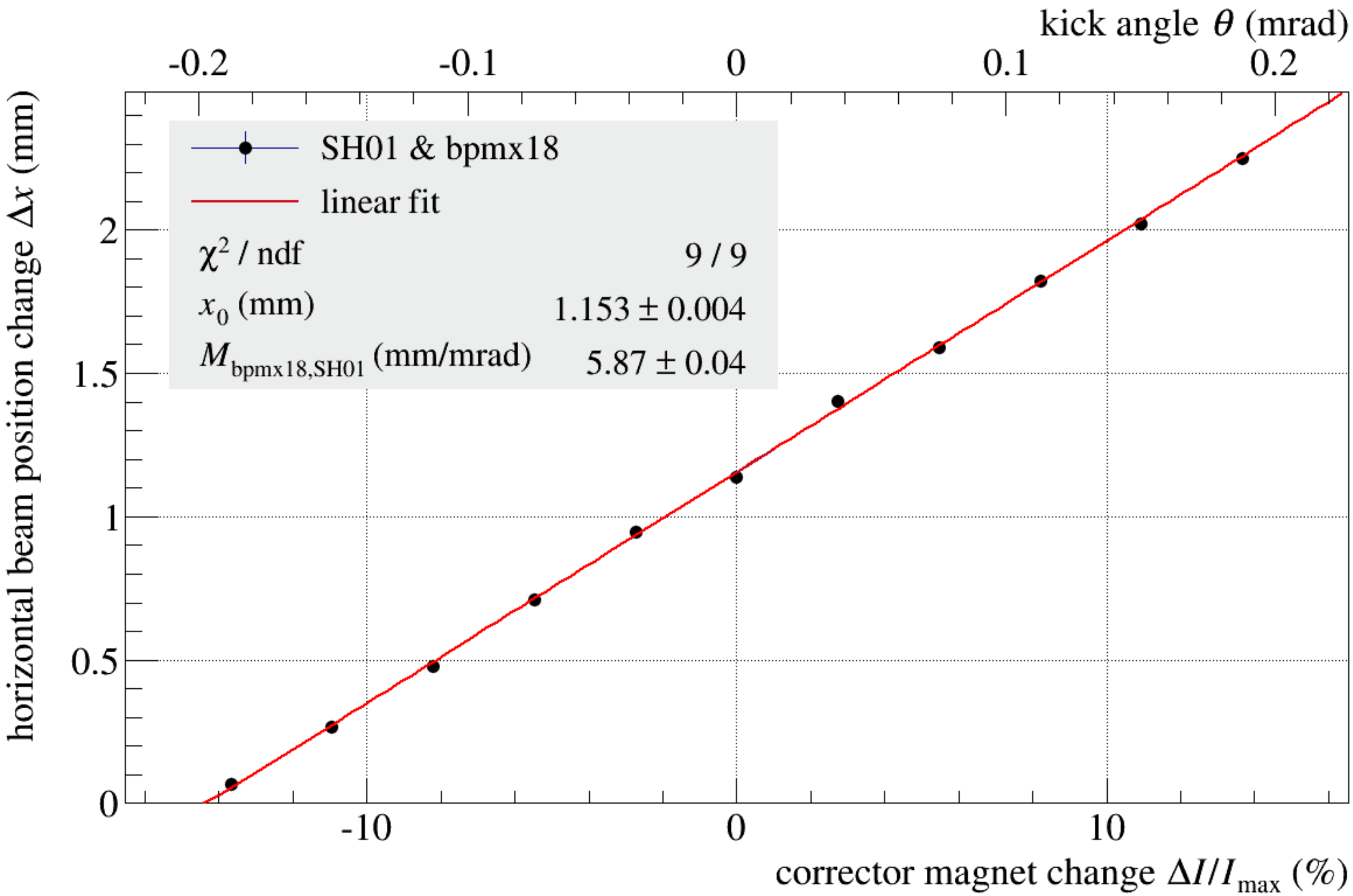
No "$e^{-t/\tau}$" correction

"$e^{-t/\tau}$" correction

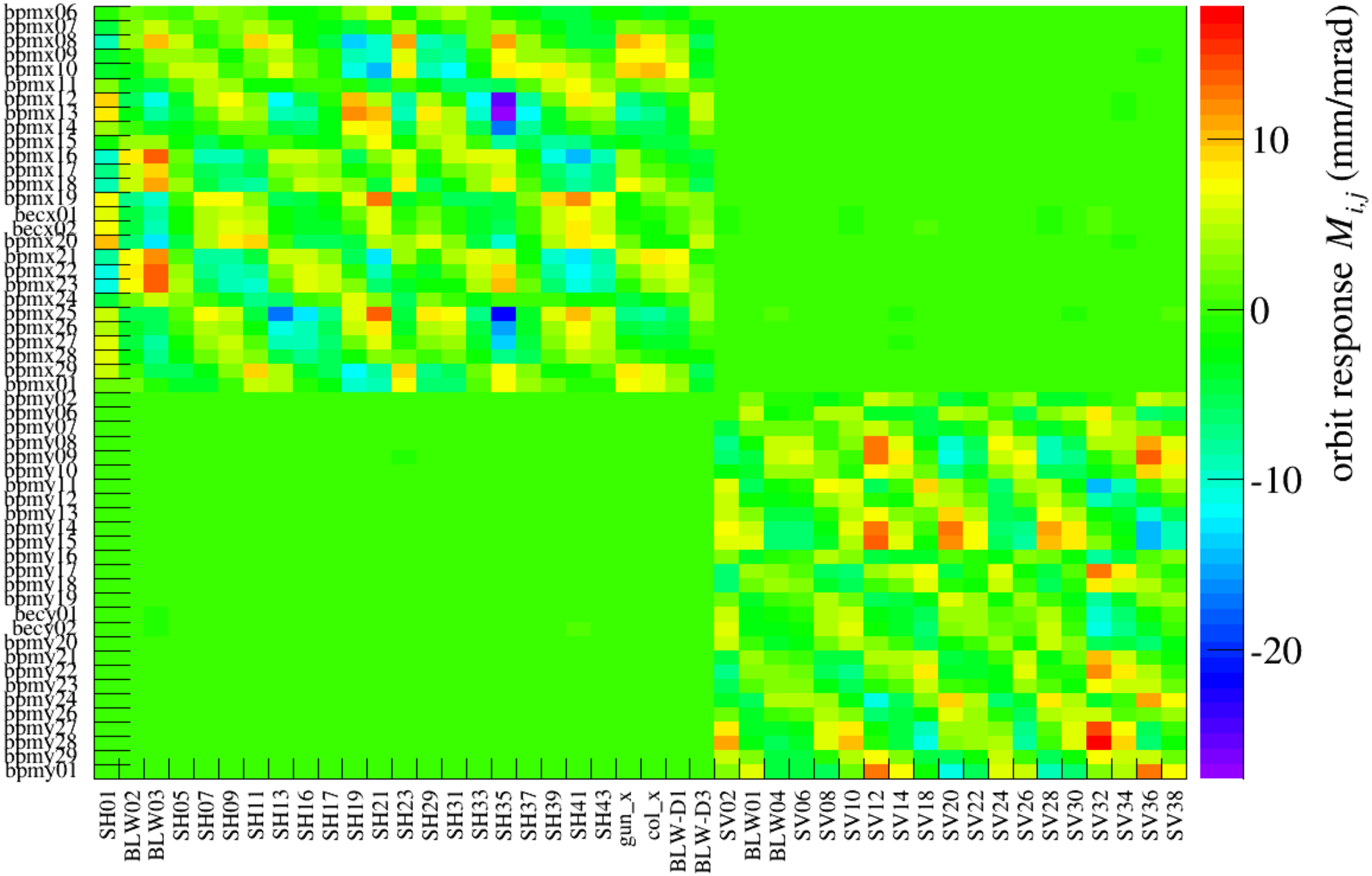


- ORM entry is biased by exponential dipole drift
- 10% higher than true value:
  $M_{unCor} = 1.10 \cdot M_{Cor}$
- After correction:
  - $\frac{\chi^2}{ndf} = 1$
  - ➢ Error on ORM entry is correct
- $\frac{\sigma_M}{M} \approx 1\%$
- Important for
  - LOCO analysis
  - optics calculation
  - orbit correction

ORM calculation



ORM measured at COSY

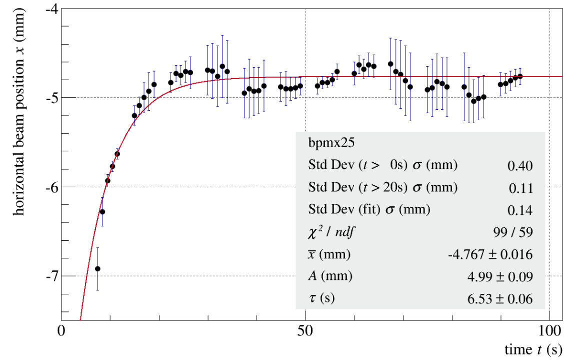


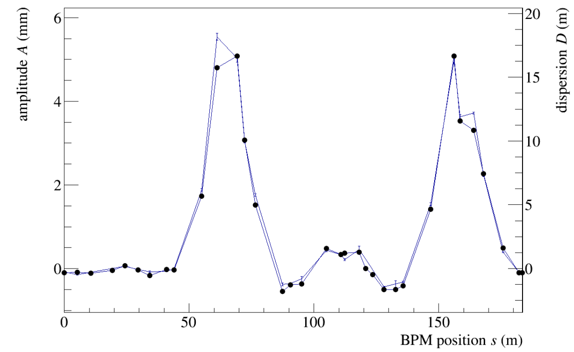
Matrix has the form (decoupled): $M = \begin{pmatrix} M_{xx} & \approx 0 \\ \approx 0 & M_{yy} \end{pmatrix}$

Summary & Outlook

Detailed analysis of BPM data shows interesting effects:

- Hint for dipole drift
  - $\tau = 6s$
  - $A \propto D$





- Further Questions:
  - Correct for dipole drift?
  - Consequence for orbit correction, if ORM is distorted by systematic effects?
  - Consider in spin tune measurements, EDM measurement?