Center for the Advancement of Natural Discoveries using Light Emission

Difference Orbit Correction in XFEL SASE1

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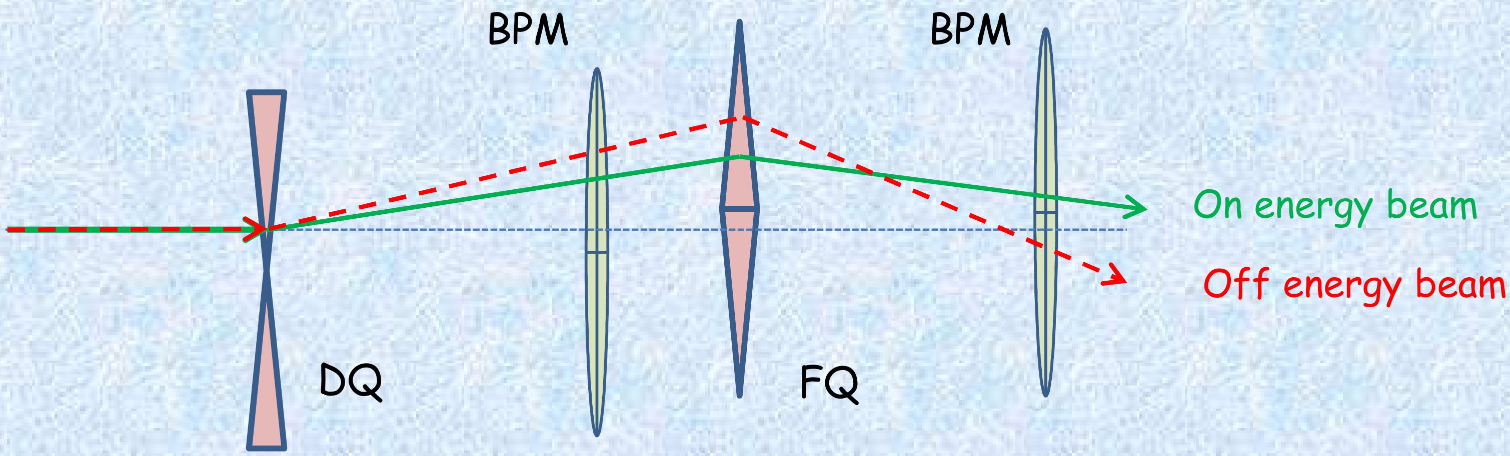
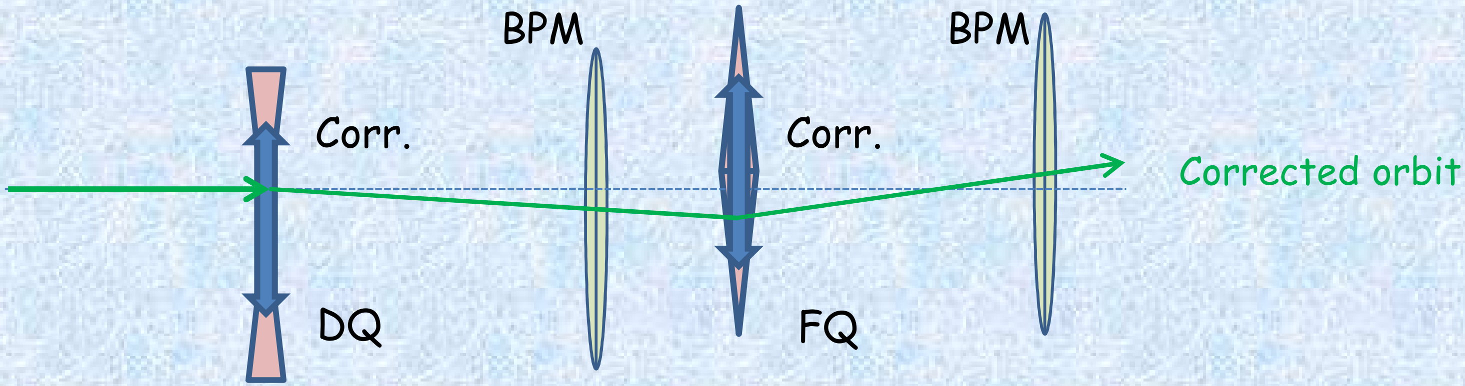
Introduction

- Global orbit correction with SVD.



$$\vec{m} = \begin{pmatrix} m_1 \\ m_2 \\ \vdots \\ m_N \end{pmatrix}, \qquad m_k = \sum_{i<k} \Theta_i M_{12}\left(z_i^{(quad)}, z_k^{(BPM)}\right) - b_k,$$

$$\vec{m} + R\vec{\theta} = 0, \qquad \vec{\theta} = \begin{pmatrix} \theta_1 \\ \theta_2 \\ \vdots \\ \theta_N \end{pmatrix} \xrightarrow[R^{+} - pseudoinverse]{R - response\ matrix} \vec{\theta} = -R^{+}\vec{m} \Longrightarrow X_k \approx b_k$$



- Global difference orbit correction with SVD without BPM resolution errors.

$$\vec{m}^{(on)} = \begin{pmatrix} m_1^{(on)} \\ m_2^{(on)} \\ \vdots \\ m_N^{(on)} \end{pmatrix}, \quad \vec{m}^{(off)} = \begin{pmatrix} m_1^{(off)} \\ m_2^{(off)} \\ \vdots \\ m_N^{(off)} \end{pmatrix},$$

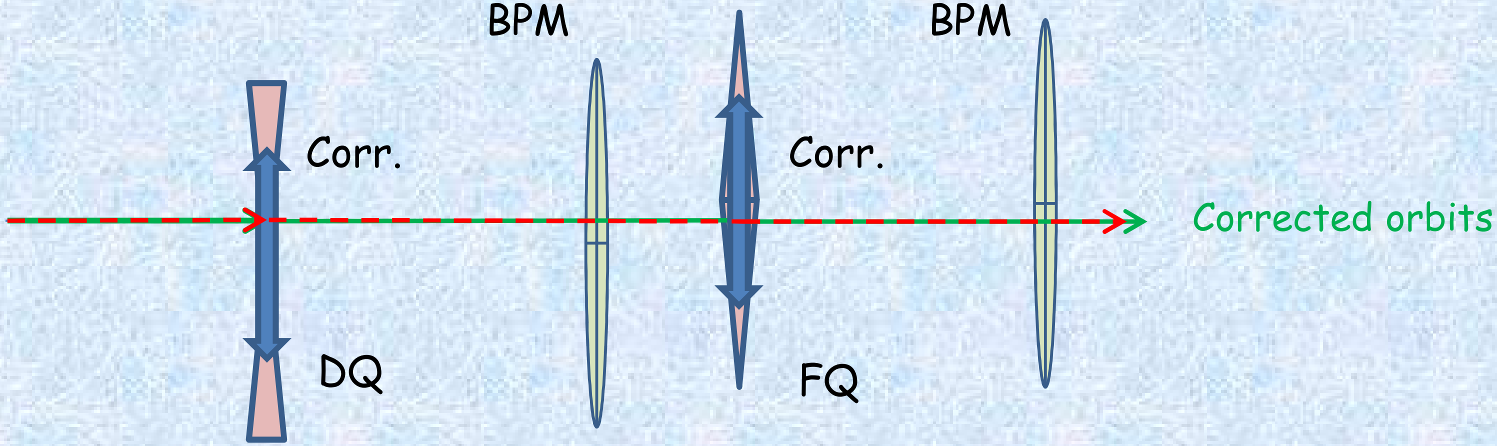
$$m_k^{(on)} = \sum_{i<k} \Theta_i^{(on)} M_{12}^{(on)}\left(z_i^{(quad)}, z_k^{(BPM)}\right) - b_k,$$

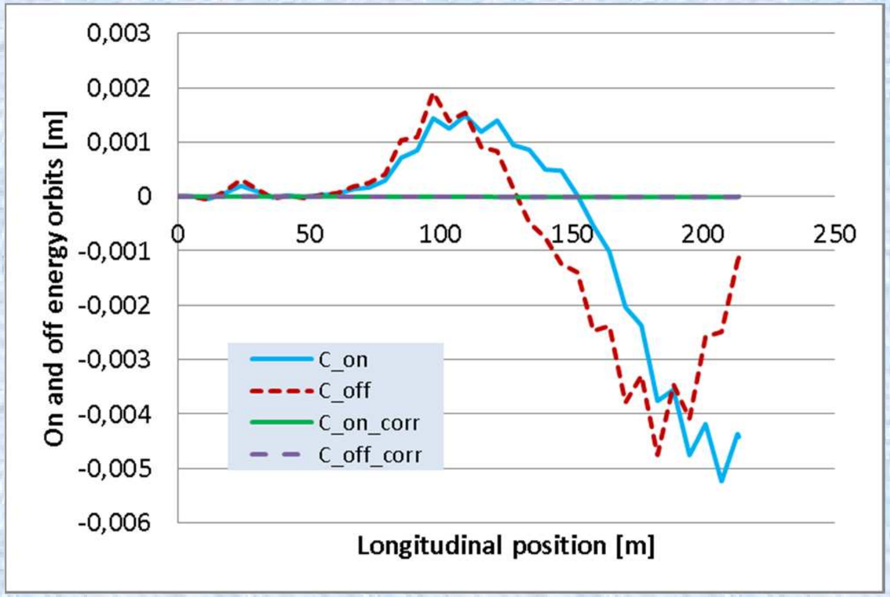
$$m_k^{(off)} = \sum_{i<k} \Theta_i^{(off)} M_{12}^{(off)}\left(z_i^{(quad)}, z_k^{(BPM)}\right) - b_k,$$

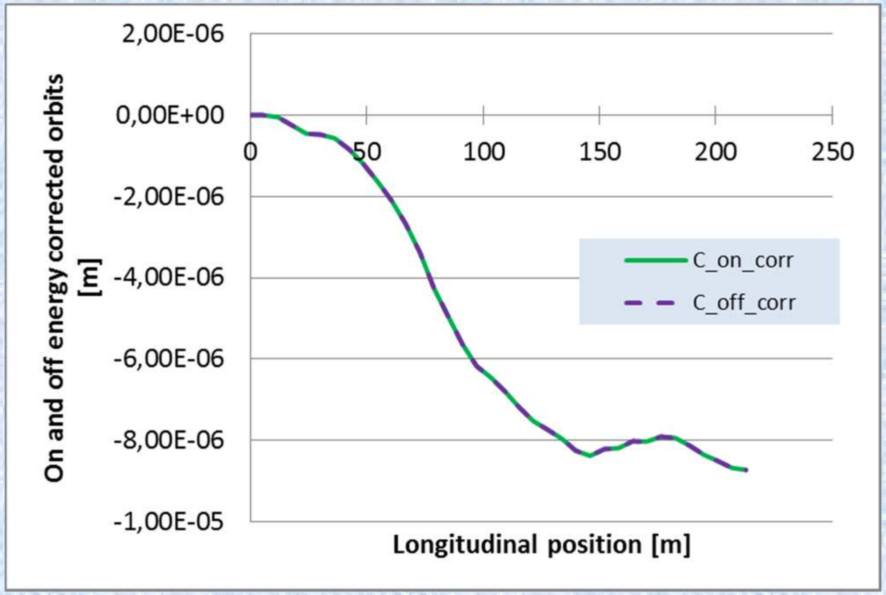
$$\vec{m}^{(off)} + R^{(off)}\vec{\theta} - \left(\vec{m}^{(on)} + R^{(on)}\vec{\theta}\right) = 0, \quad \Longrightarrow \quad \vec{\theta} = (R^{(on)} - R^{(off)})^{+}(\vec{m}^{(off)} - \vec{m}^{(on)})$$

If on- and off- energy beams are nor separated transversely, then

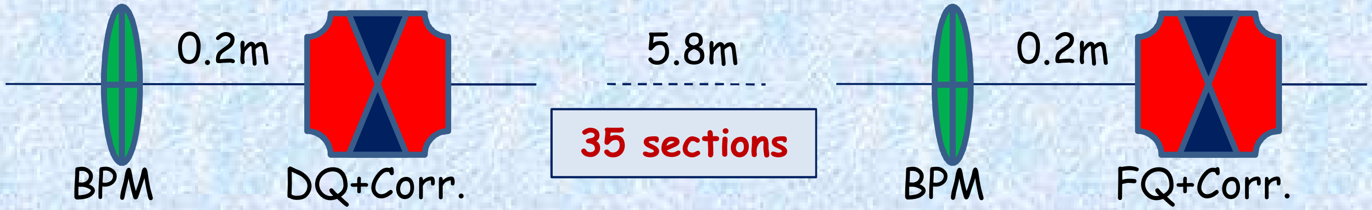
$$\boxed{\frac{\Theta_q^{(off)}}{\Theta_q^{(on)}} = \frac{\theta_c^{(off)}}{\theta_c^{(on)}}}$$







- SASE1 lattice
- 300 µm quad. mis.
- - 40% rel. energy dev.



BPM resolution errors impact

$$m_k^{(on)} = r_k(t_1) + \sum_{i<k} \Theta_i^{(on)} M_{12}^{(on)}(z_i^{(quad)}, z_k^{(BPM)}) - b_k,$$

$$m_k^{(off)} = r_k(t_2) + x_k^{(inj)} + \sum_{i<k} \Theta_i^{(off)} M_{12}^{(off)}(z_i^{(quad)}, z_k^{(BPM)}) - b_k$$

⇒

$$\vec{\theta} = (R^{(on)} - R^{(off)})^{+}(\vec{m}^{(off)} - \vec{m}^{(on)})$$

has errors

Question: what will be the impact on residual orbit?

- Theoretical estimate
  - In smooth focusing approx.
  - For long line of FODO sells

$$x_{rms}(z_k) \sim \frac{\sigma_{res}\mu^2}{|\delta|} k^{3/2},$$

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A. Sargsyan
V. Tsakanov

σ_{res} - rms of BPM resolution errors

δ - relative energy deviation between on- and off- energy beams

μ - the phase advance per FODO sell

- Numerical evaluation
  - Numerical simulations - ELEGANT
  - The global difference orbit correction - MATLAB

σ_{res}	1 μm	10 μm	100μm
δ	-0.02	-0.02	-0.02
μ	0.4 rad	0.4 rad	0.4 rad
a*$k^{1.5}$fit	1.45e-5 $k^{1.5}$	1.45e-4 $k^{1.5}$	1.45e-3 $k^{1.5}$

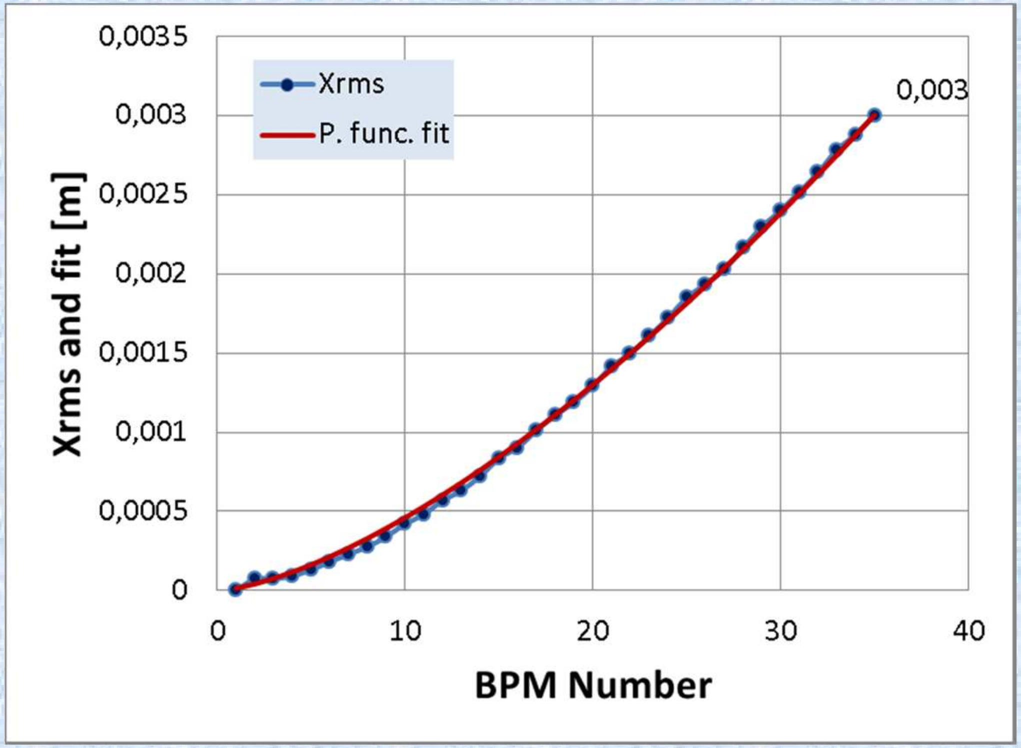
Table 1. σ_{res}-dependence of X_{rms}

σ_{res}	1 μm	1 μm	1μm
δ	-0.02	-0.2	-0.4
μ	0.4 rad	0.4 rad	0.4 rad
a*$k^{1.5}$fit	1.45e-5 $k^{1.5}$	1.7e-6 $k^{1.5}$	1e-6 $k^{1.5}$

Table 2. δ-dependence of X_{rms}

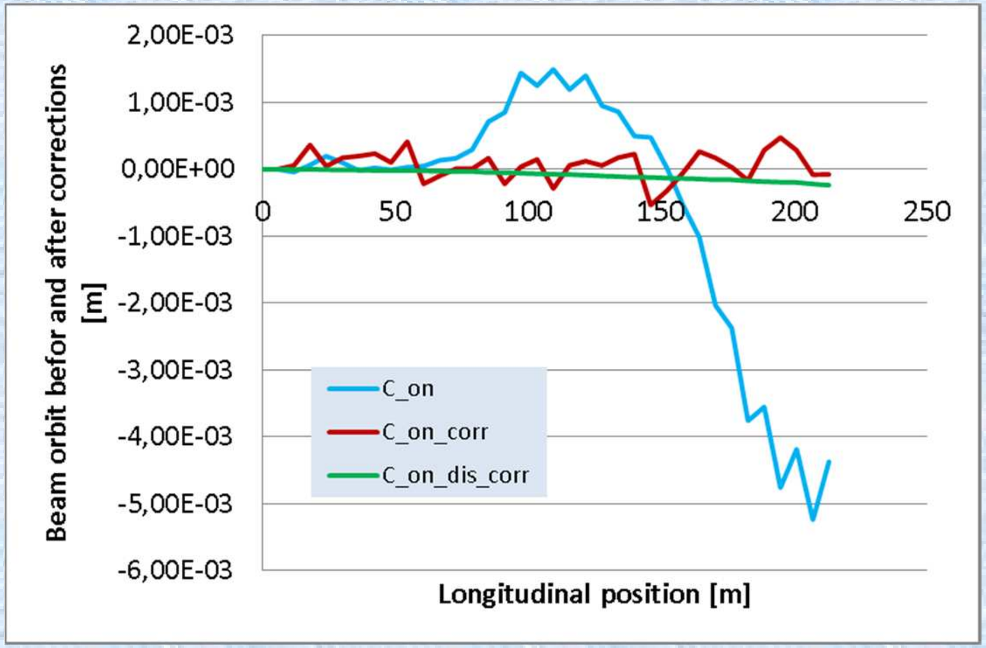
σ_{res}	1 μm	1 μm	1μm
δ	-0.02	-0.2	-0.4
μ	0.2 rad	0.4 rad	0.8 rad
a*$k^{1.5}$fit	7.37e-6 $k^{1.5}$	1.45e-5 $k^{1.5}$	2.78e-5 $k^{1.5}$

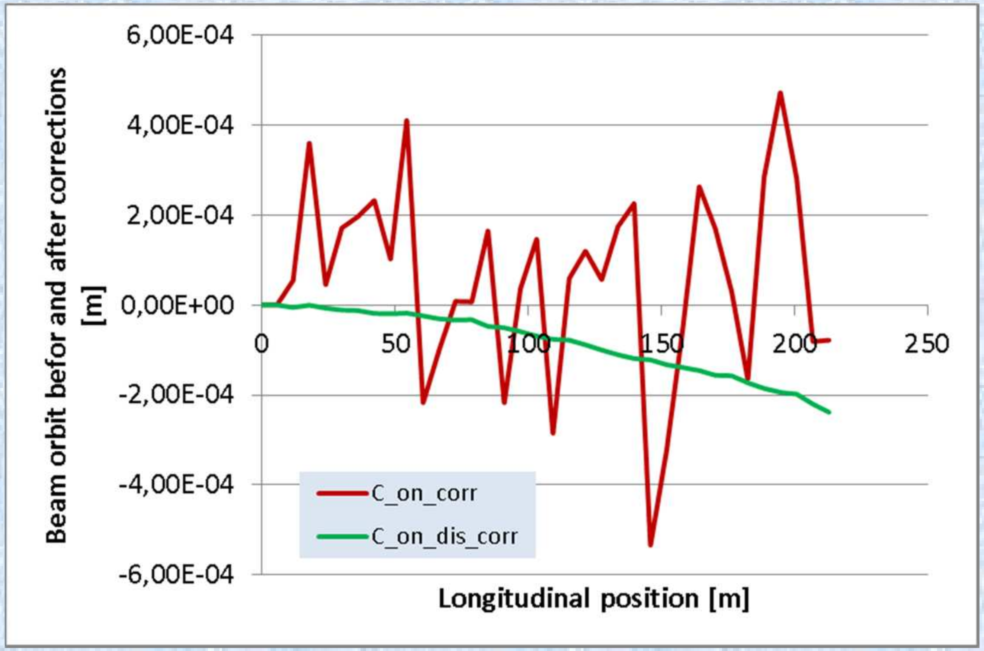
Table 3. μ-dependence of X_{rms}

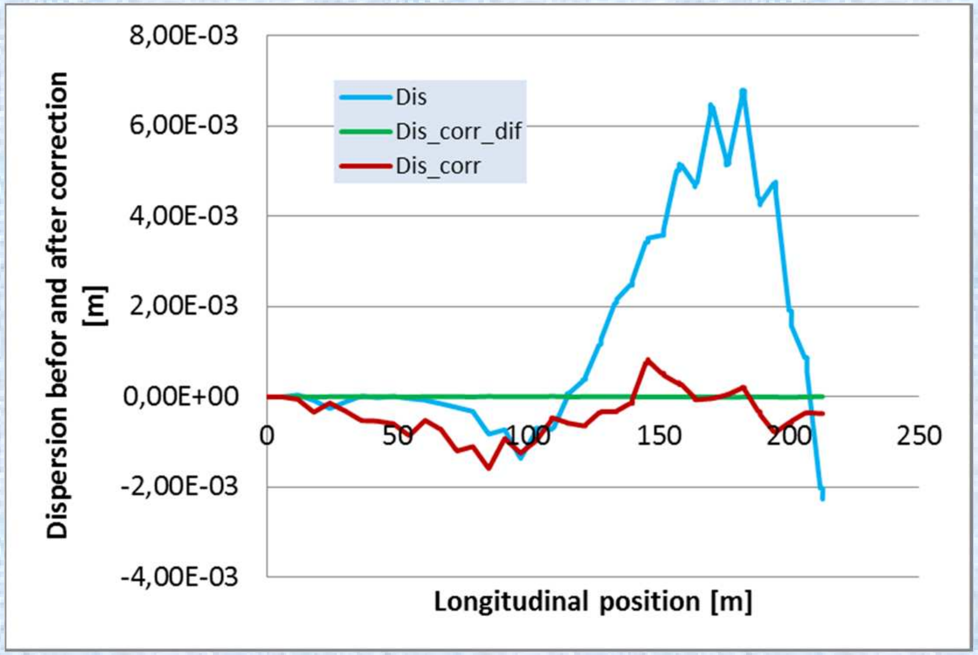


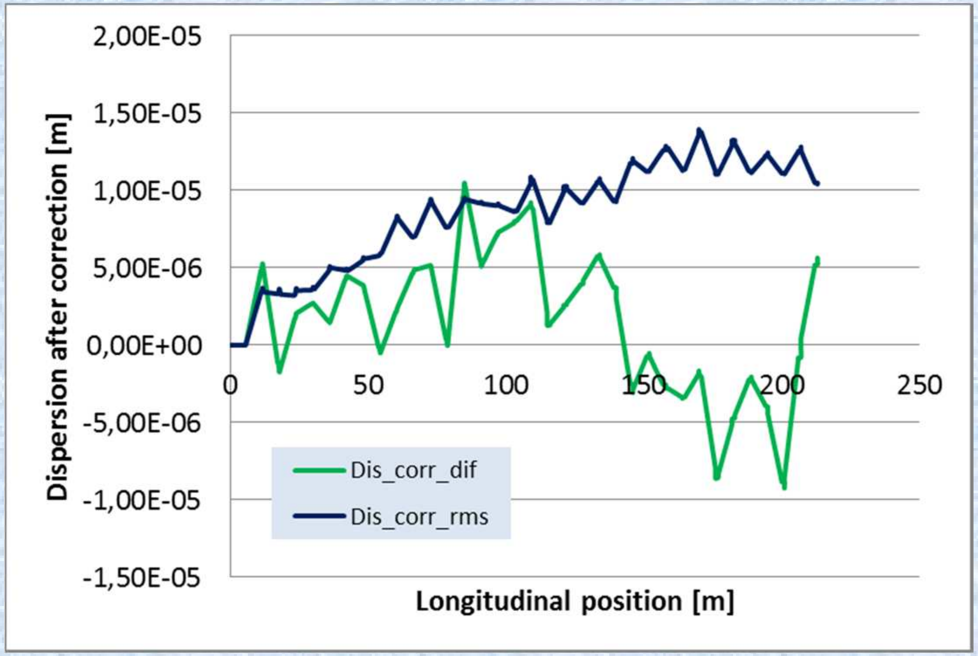
X_{rms} and power function fit a*n^b for SASE1 for σ_{res} = 1 µm, δ =-0.02, μ=0.4rad.

- a=1.46e-5
- b=1.499



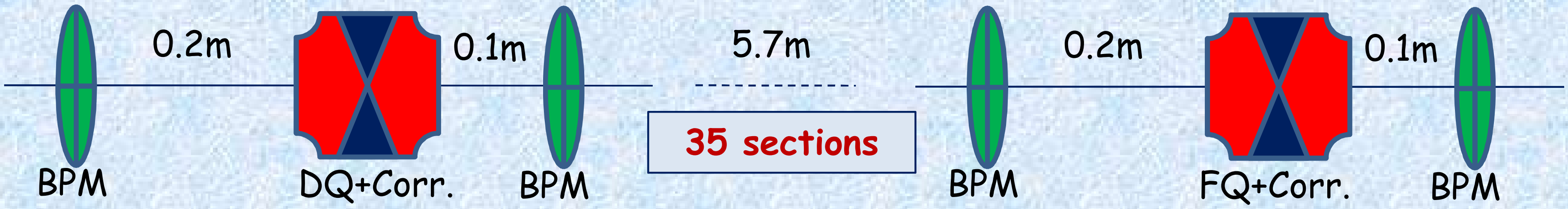






$\sigma_{res} = 1\ \mu m$, $\delta = -0.4$, $\mu = 0.4$ rad

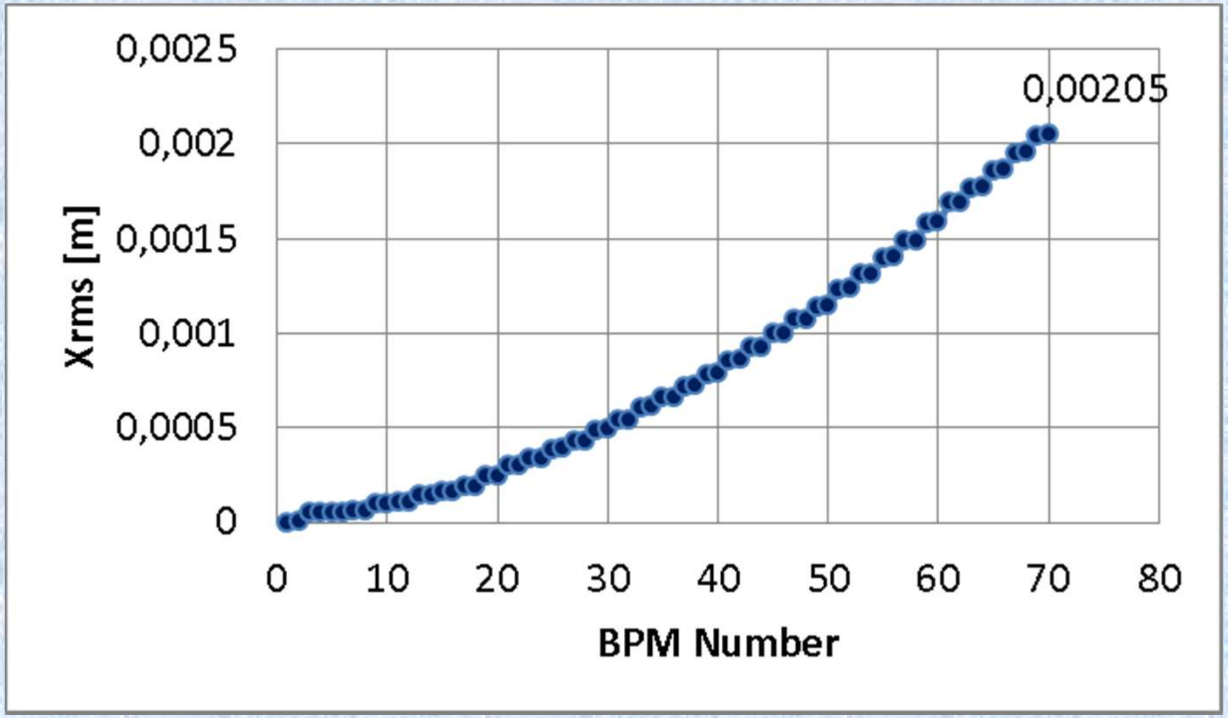
$|\theta_i| < 0.1 mrad$



$\sigma_{res} = 1\mu m$

δ=-0.02

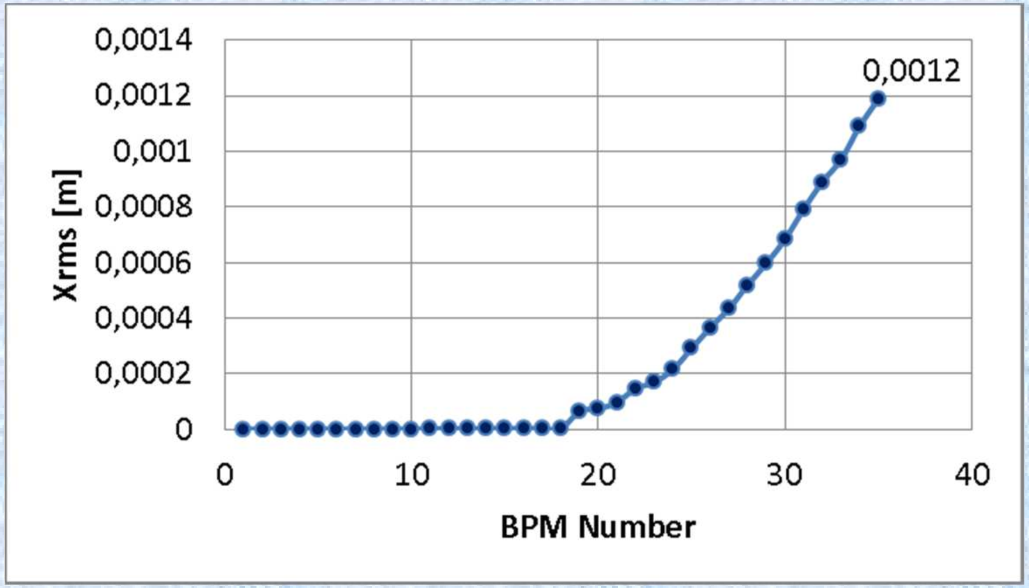
μ=0.4 rad



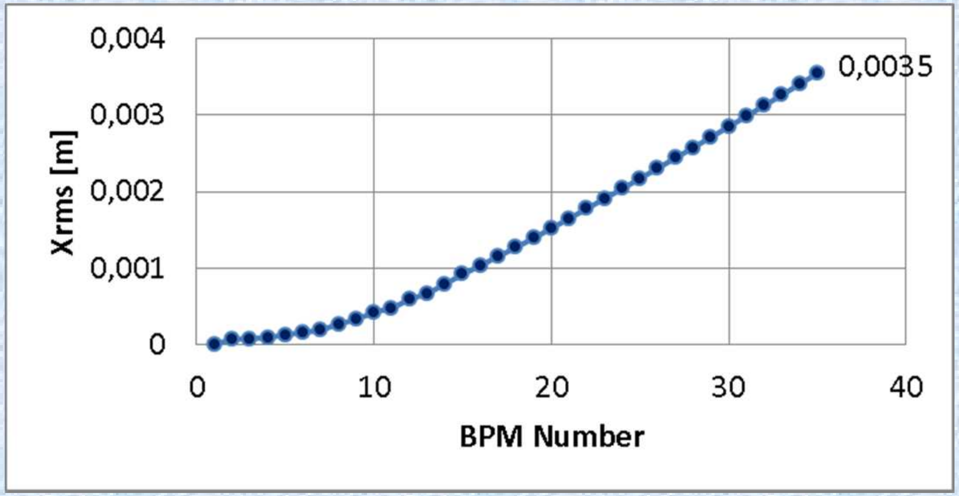
Doubling the quantity of BPMs leads to the reduction of X_{rms} by a factor of about $\sqrt{2}$.

Use of very precise or "perfect" BPMs (by means of resolution)

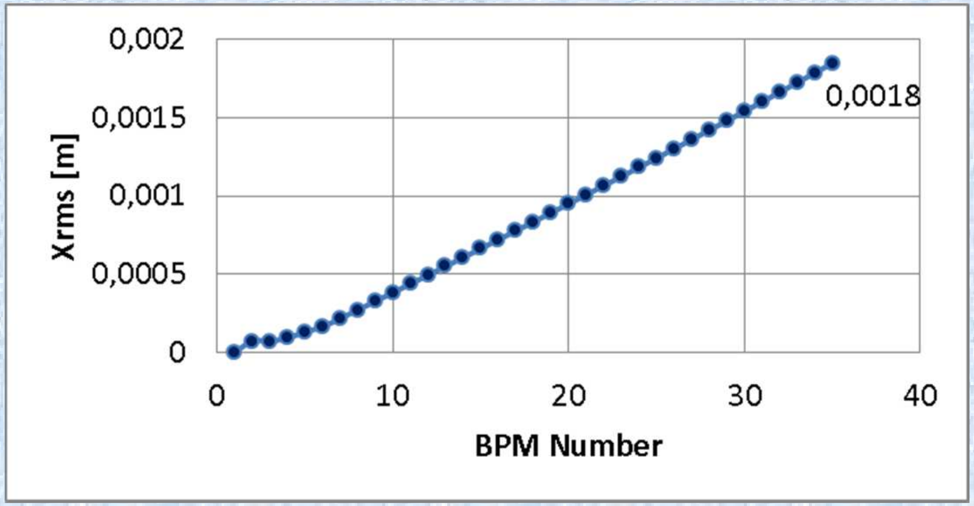
Only the last half of BPMs has $1\mu m$ rms resolution errors



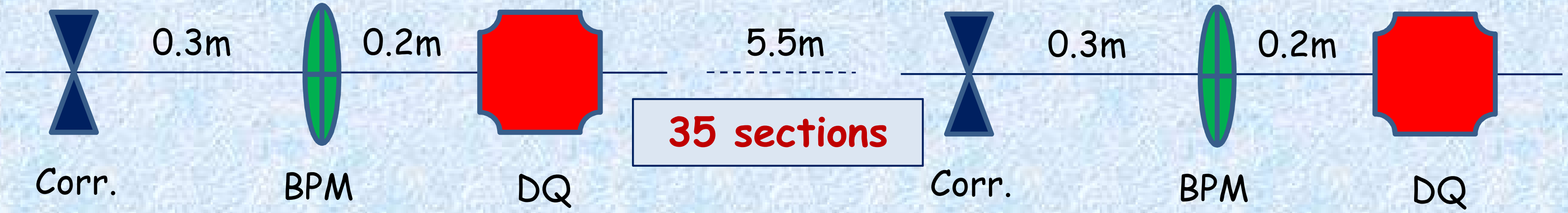
SASE1 lattice
δ=-0.02

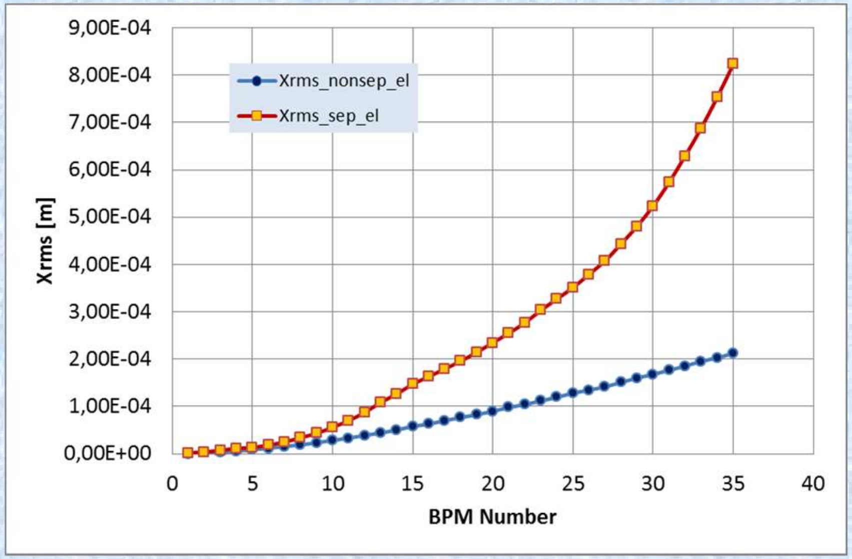


Only the first half of BPMs has $1\mu m$ rms resolution errors

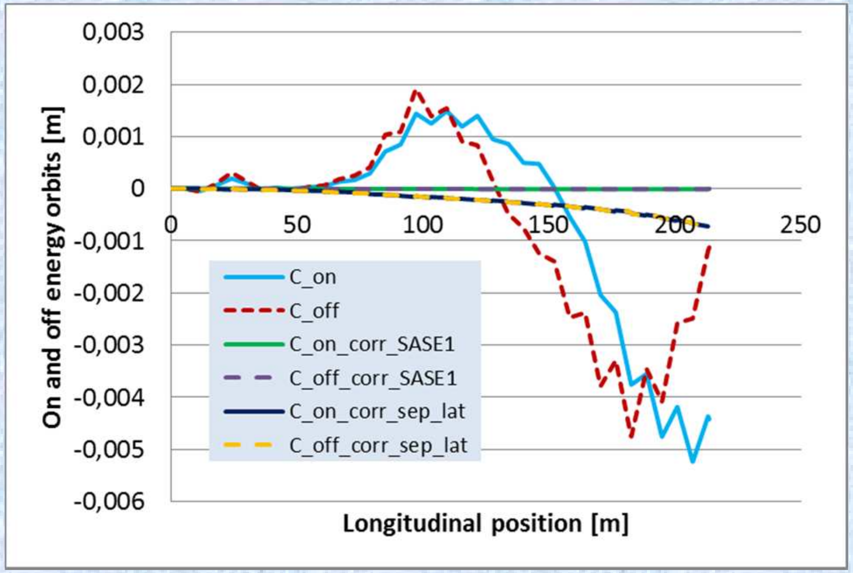


Only the first five BPMs have $1\mu m$ rms resolution errors





Comparison of rms residual orbits for SASE1 and separated elements lattices for σ_{res} = 1μm, δ=-0.4.



For SASE1 ~ -9μm

For sep. el. lattice ~ -700μm

Summary

- Difference orbit correction is considered for XFEL SASE1 section.
- BPM resolution errors impact on rms residual orbit growth is evaluated numerically using ELEGANT and MATLAB.
- Comparison of numerical results with theoretical estimate was performed.
- Possible ways of residual orbit growth reduction are considered.

THANK YOU FOR ATTENTION