European XFEL Undulator Focusing Lattice Errors and FEL Performance

Vitali Khachatryan
CANDLE

Beam based quadrupole magnets alignment method will be applied in FEL undulator section to correct focusing lattice quadrupoles initial alignment errors [1]. Precision movers are used to correct quadrupole magnets misplacements instead of traditional dipole field stirrers.

The study was conducted aimed at definition of the after correction error orbit influence on the European XFEL radiation parameters.

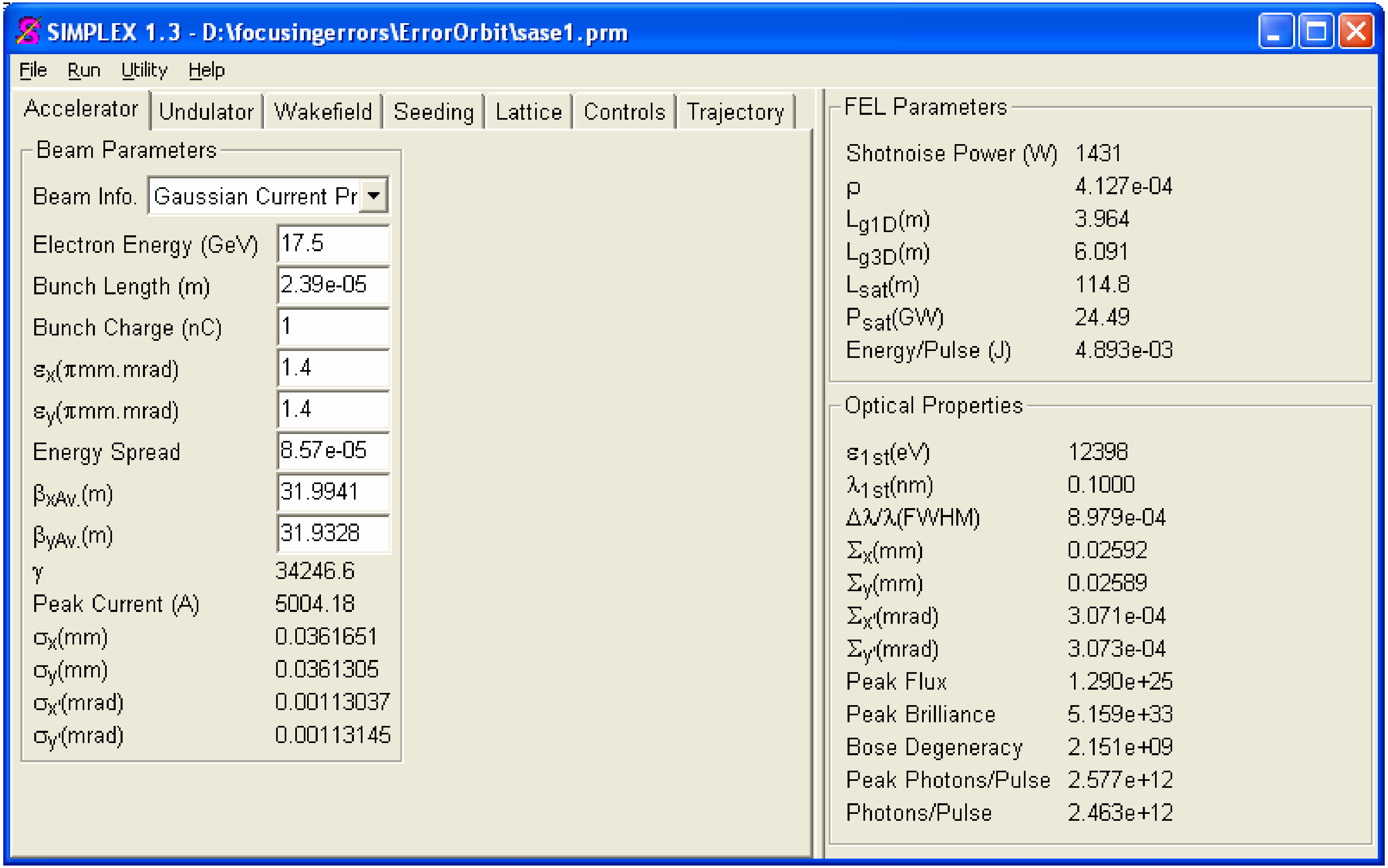
The study should be continued further together with simulation of the beam based alignment scenarios to find out the requirements for quadrupole magnets alignments errors, movers' precision, BPM resolution, their alignment accuracy and optimal arrangement.

Beam parameters at the entrance of the undulator system SASE1

Electron energy [GeV]	17.5
Bunch length (RMS) [m]	$2.5\text{x}10^{-05}$
Bunch charge [nC]	1
Emittance, ε_x [mm-mrad]	1.4
Emittance, ε_y [mm-mrad]	1.4
Energy spread [MeV]	1.5 ($8.57\ \text{x}10^{-05}$)
Peak current [kA]	5
γ	34246.6

SASE1 FEL design parameters

K value	3.3
Period length [cm]	3.56
Segment length [m]	5
Number of segments	33
Segment interval [m]	6.1
Inter-segments drift space [m]	1.1
Periods per segment	140
Total length [m]	201
Resonant radiation wavelength [nm]	0.1
# of quadrupole magnets	34
Total length [m]	201
FODO period length [m]	12.2
Av. Beta function [m]	32
Quad. Magnet's integrated field [T-m]	3.6



SIMPLEX GUI with SASE1 parameters

Undulator section field errors` effects:

E. Gluskin et al, ANL report ANL/XFD/CP-102080 , 2000.

$$I_{1x}(z)=\frac{e}{mc^2}\left[\int_0^z B_x(z')dz'-\frac{1}{L}\int_0^L\int_0^{z'} B_x(z'')dz''dz'\right],\qquad I_{1y}(z)=\frac{e}{mc^2}\left[\int_0^z B_y(z')dz'-\frac{1}{L}\int_0^L\int_0^{z'} B_y(z'')dz''dz'\right],$$

1.Trajectory deviation from the strait line

$$x(z)=\frac{1}{\gamma}\int_0^z I_{1x}(z')dz'\ ,\ \ y(z)=\frac{1}{\gamma}\int_0^z I_{1y}(z')dz'$$

2. Zero-angle radiation spectral intensity of the zero-angle radiation is $\frac{e^2k^2|A|^2}{2\pi c\gamma^2}$

where

$$A=\int_0^L I_{1y}(z)e^{-i\frac{k}{2\gamma^2}\left[z+\int_0^z I_{1x}^2(z')dz'+\int_0^z I_{1y}^2(z')dz'\right]}dz$$

3. The calculated particle phase deviation from the design value

$$\varphi=\frac{k}{2\gamma^2}\left[L+\int_0^L I_{1x}^2(z)dz+\int_0^L I_{1y}^2(z)dz\right]$$

T. Tanaka, H. Kitamura, and T. Shintake, Nucl. Instrum. Methods Phys. Res., Sect. A **528**, 172 (2004).

After the kick gain length increases:

$$L_G \to L_G / \left(1 - \frac{\vartheta^2}{\vartheta_c^2} \right)$$

where the critical angle corresponds the kick that completely destroys further radiation growth

$$\vartheta_c = \sqrt{\frac{\lambda_R}{L_G}}$$

A gain length is calculated for SASE1 at =0.1nm is about 6.1m, and real real gain length is ~9m , that gives $\vartheta_c \approx 3 \mu rad$

Corresponds to quad. misalignment $x_Q \approx 50 \mu m$

Best

A300em6_B300em6_X001em6t20_D005em7t20_M001em6_vi01_x.txt

D=5x10^-7m

Intermediate

A300em6_B300em6_X001em6t20_D002em6t20_M001em6_vi01_x.txt

D=2x10^-6m

Worst

A300em6_B300em6_X001em6t20_D050em6t20_M001em6_vi05_x.txt

D=5x10^-5m

Intermediated005

D=5x10^-6m

Intermediated010

D=10x10^-6m

A=300x10-6m --- quad initial rms misalignment

B=300x10-6m --- BPM offsets

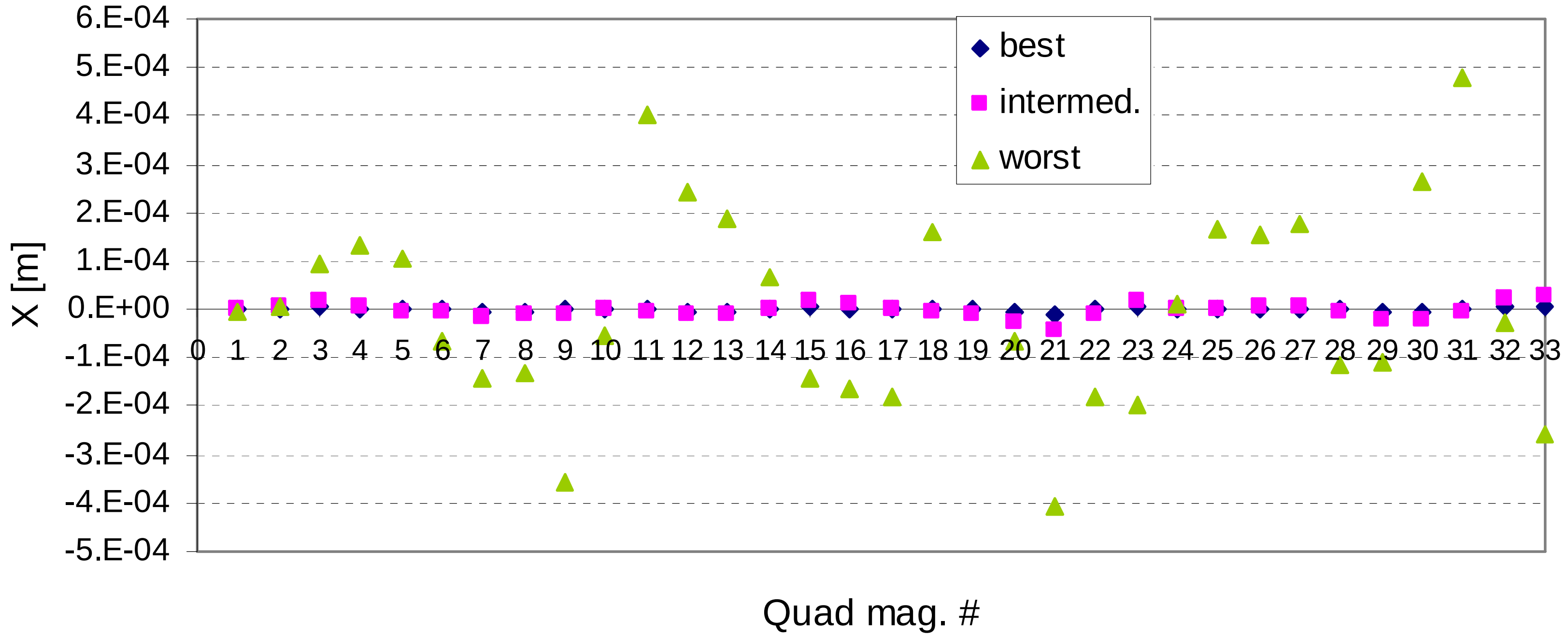
X=1.0x10-6m --- BPM X/Y resolution

D=5x10-7m --- rms dispersion [x/max(dE/E)]

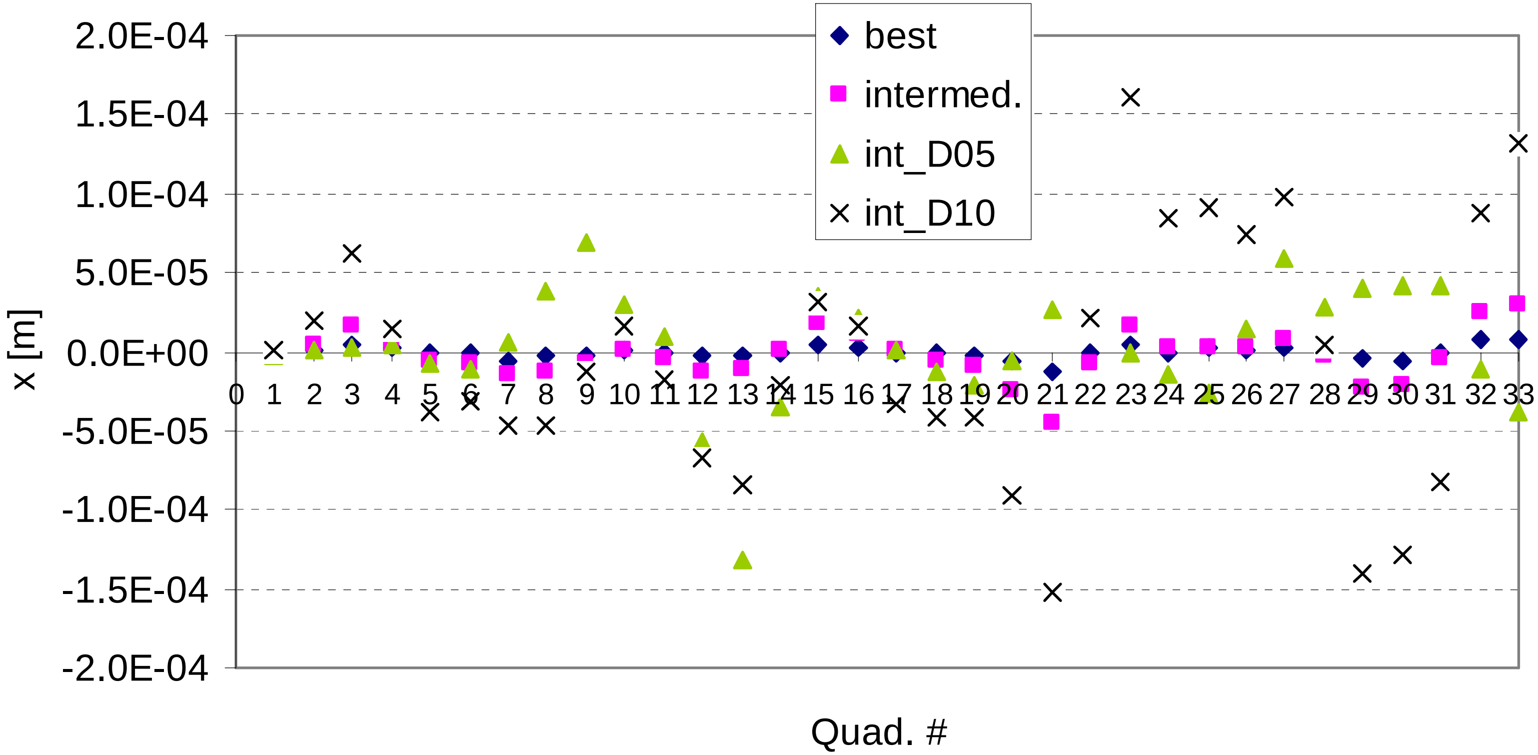
M=1.0-6m – mover (corrector) rms error

Dispersion-free correction method was applied

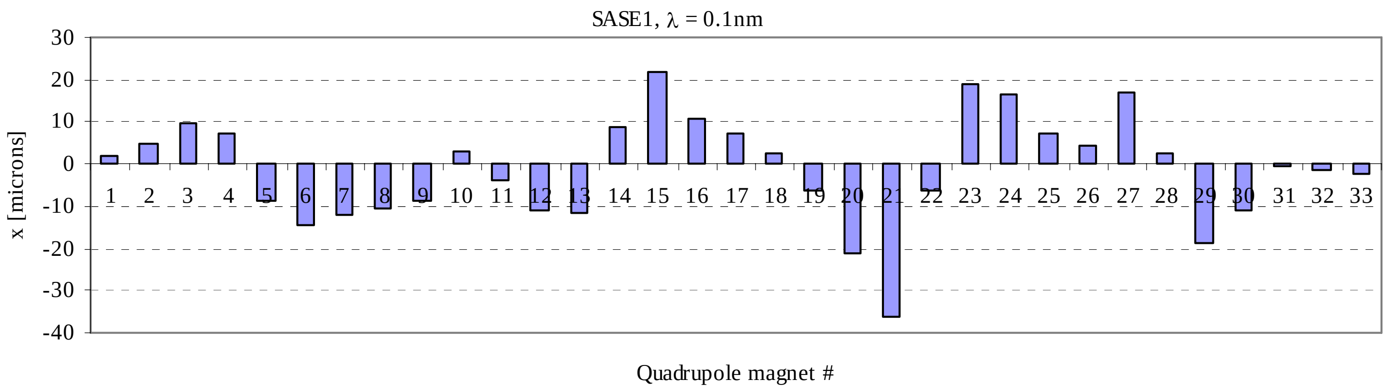
(M. Vogt, http://www.desy.de/xfel-beam/talks_2009.html)

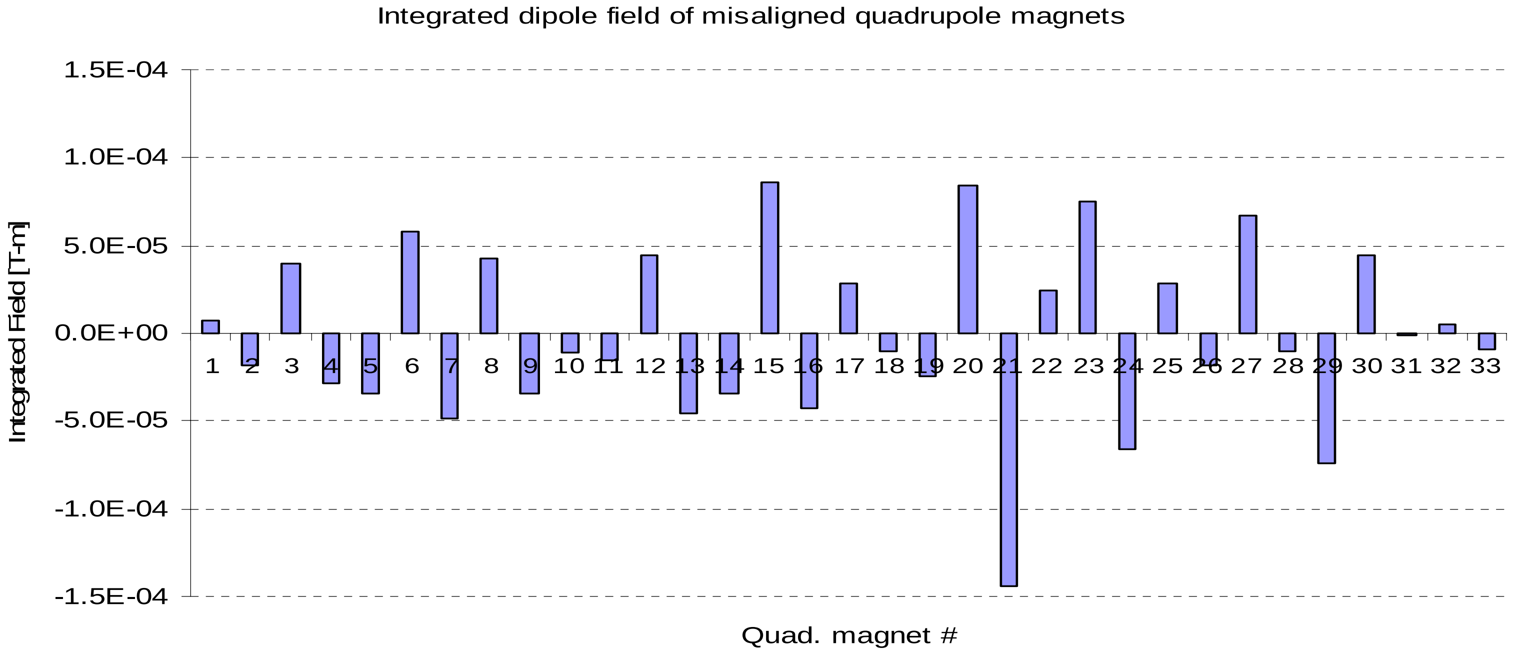


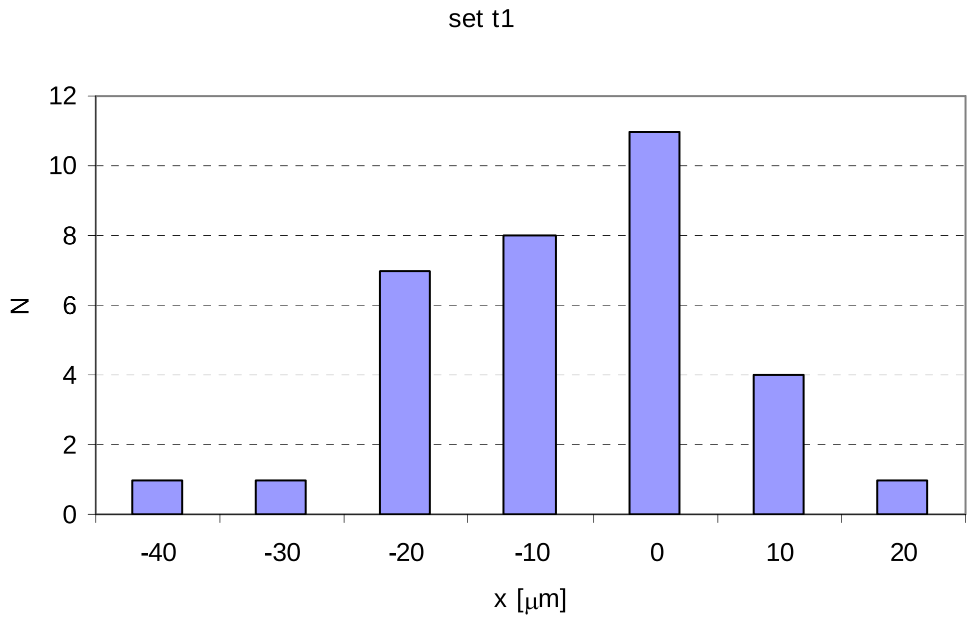
Quadrupole magnets residual misalignments



Quadrupole magnets residual misalignments

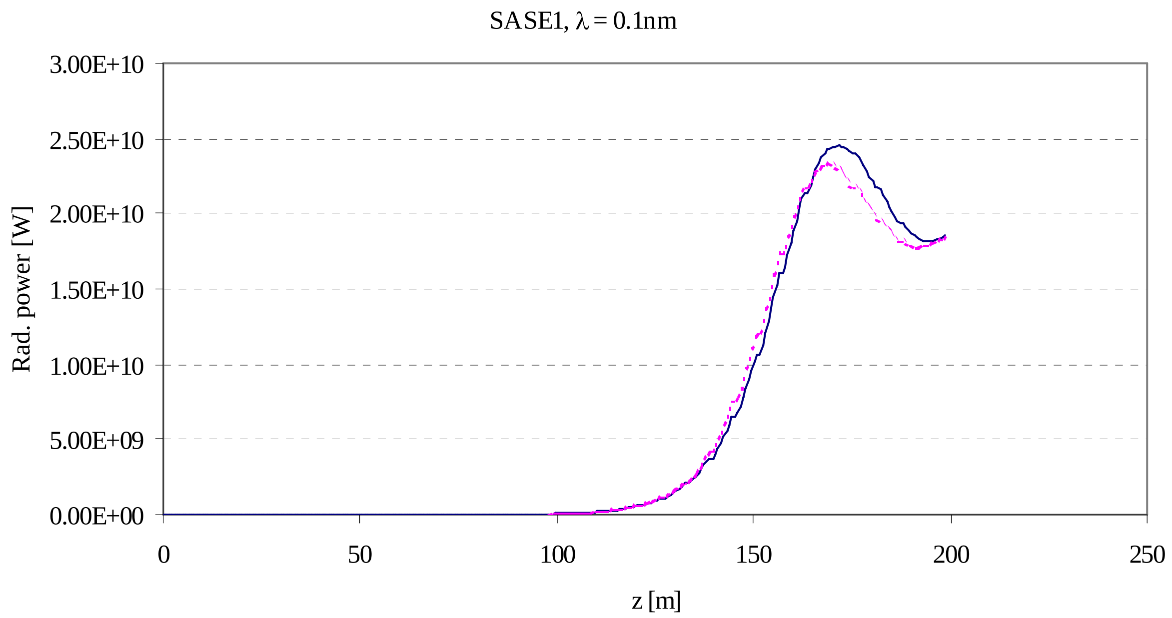

SASE1, λ = 0.1nm
30
20
10
0
-10
-20
-30
-40
x [microns]
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33
Quadrupole magnet #


Integrated dipole field of misaligned quadrupole magnets
1.5E-04
1.0E-04
5.0E-05
0.0E+00
-5.0E-05
-1.0E-04
-1.5E-04
Integrated Field [T-m]
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33
Quad. magnet #



Misalignments distribution

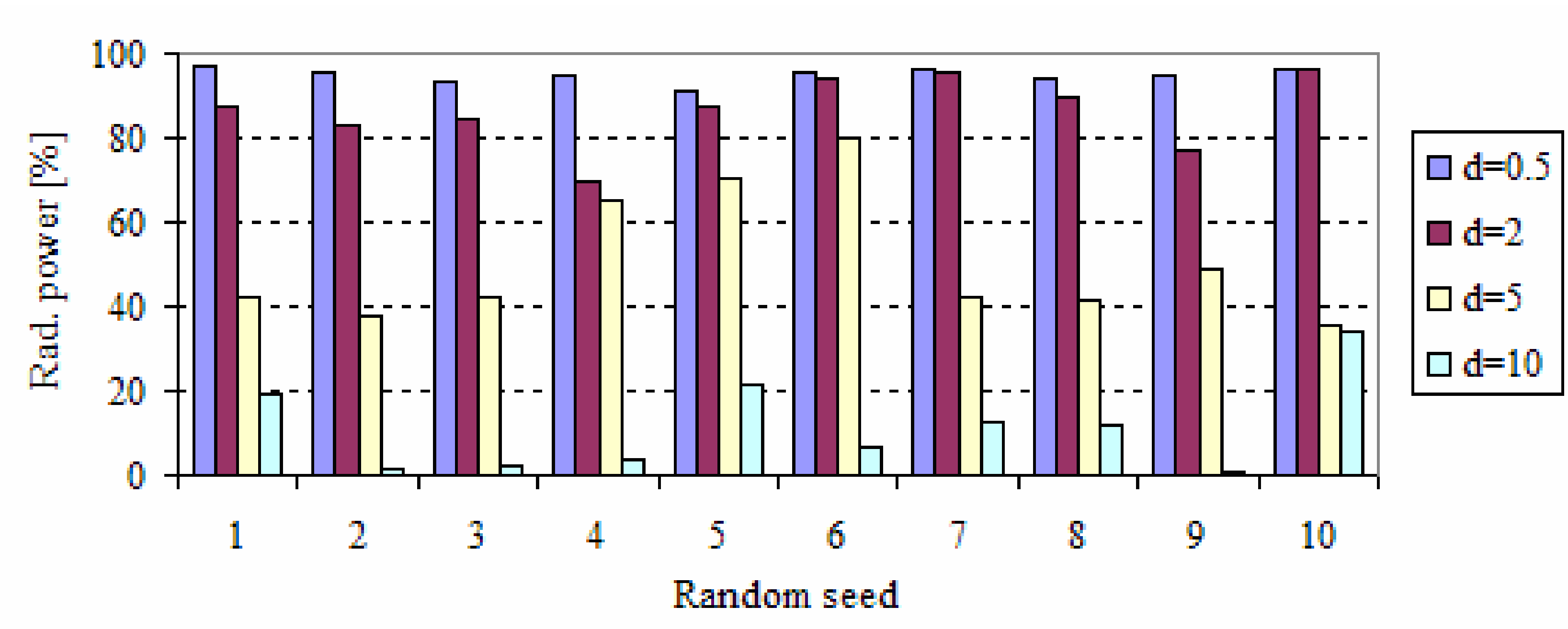
	Best [m]	Intermediate [m]	Interm.d_05 [m]	Interm d_10 [m]	Worst [m]
Dispersion	5E-7	2E-6	5E-6	10E-6	5E-5
Av. Misalign.	-3.40E-07	-2.41E-06	3.90E-06	-5.05E-06	1.50E-05
RMS misalign.	3.92E-6	1.47E-5	1.22E-5	7.61E-5	2.17E-5



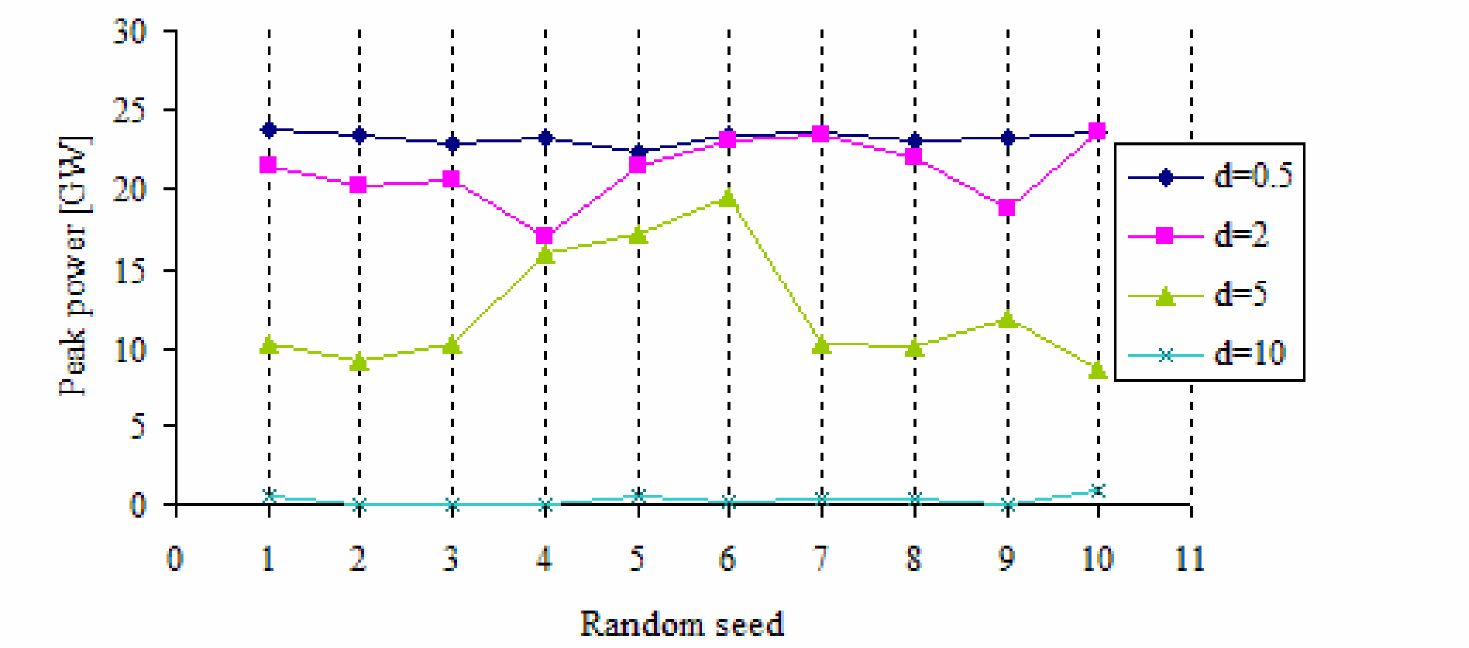
SASE1, λ = 0.1nm
3.00E+10
2.50E+10
2.00E+10
1.50E+10
1.00E+10
5.00E+09
0.00E+00
Rad. power [W]
0
50
100
150
200
250
z [m]

Peak power [%] for 12 different random seeds

best	intermediate	int.d05	int. d10
97.14286	88.11475	42.04082	1.897751
95.5102	83.19672	37.7551	0.023149
93.46939	84.42623	42.04082	0.235583
80.40816	56.14754	82.85714	0.353374
91.02041	88.11475	85.30612	2.130879
95.91837	94.67213	80	24.66258
96.32653	96.31148	42.04082	1.263804
94.28571	90.16393	41.63265	1.173824
94.69388	77.45902	48.57143	0.050307
91.02041	69.67213	35.26531	3.431493
96.32653	96.72131	70.20408	0.182004
95.10204	0	64.89796	0.658487

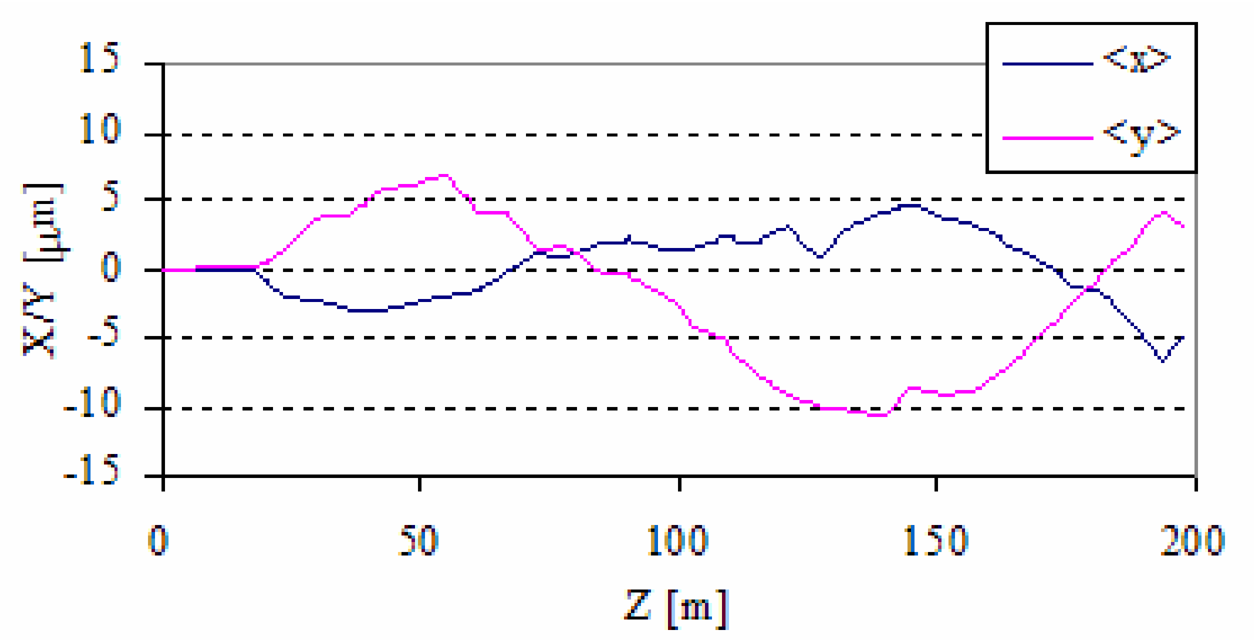


SASE radiation normalized peak power for the 10 different sets of random residual misalignments. Bars with four different colours correspond to for various values of RMS dispersion (d = 0.5, 2, 5, 10 [µm]). Bars representing d=10 µm case are scaled up by factor of 1000seeds

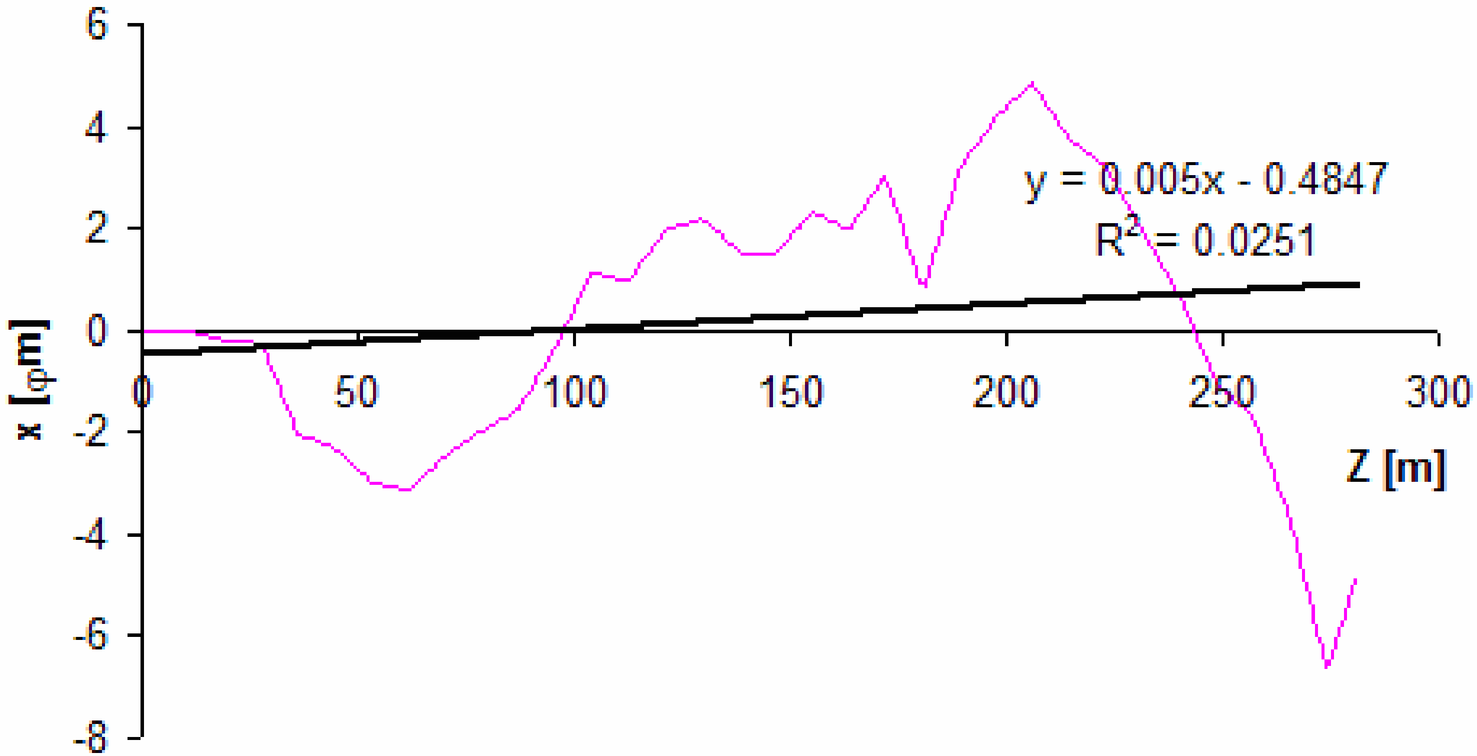


SASE radiation peak power average values and RMS dispersion for the 10 different sets of random residual misalignments

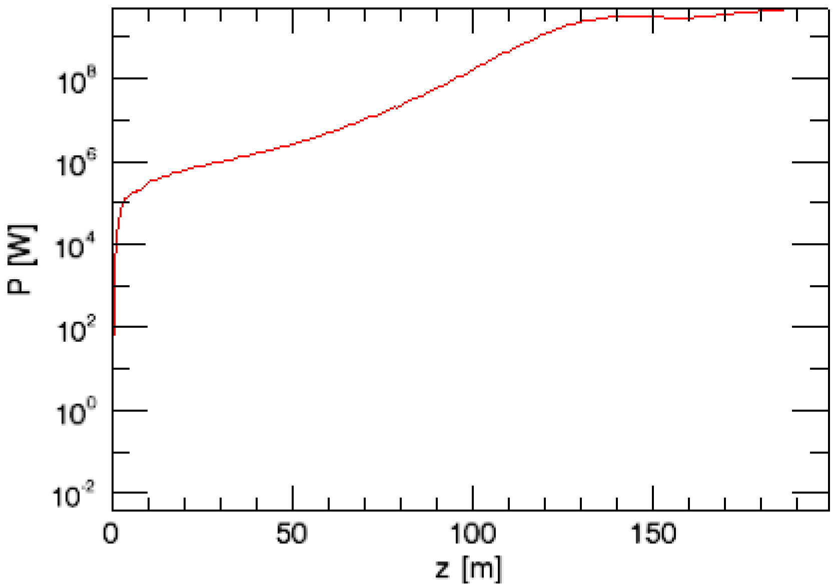
RMS dispersion resolution [µm]	0.5	2	5	10
Orbit deviation from strait line	0.73	1.3	1.7	
Average [GW]	23.3	21.2	12.4	0.278
RMS deviation [GW]	0.432	2.1	3.79	0.265

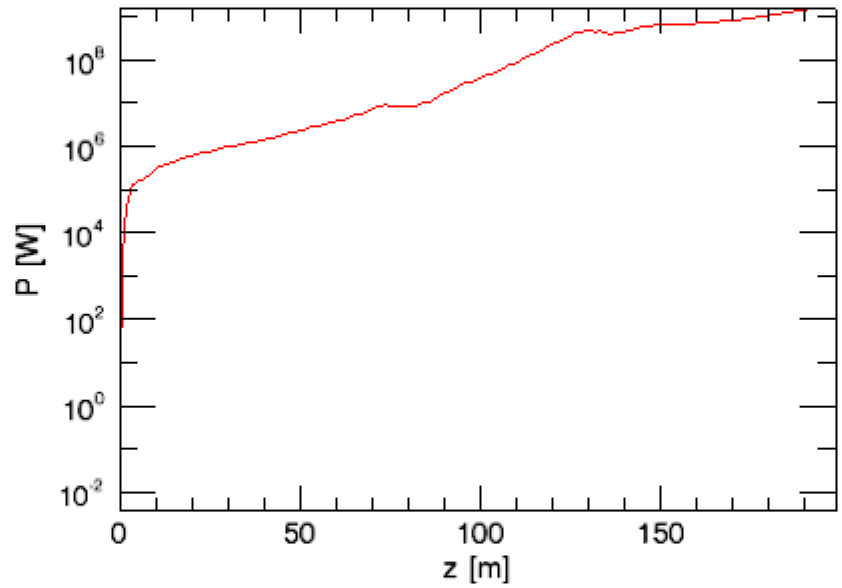


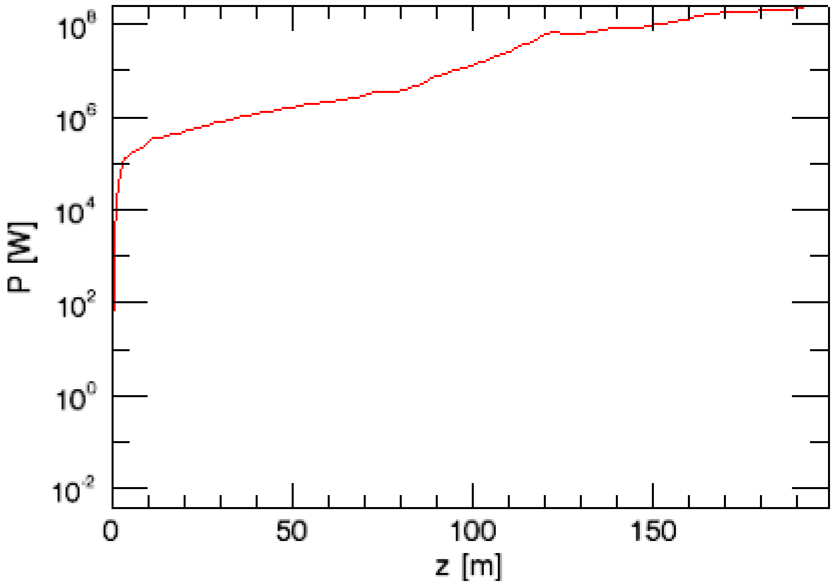
: Beam error orbit due to quadrupole magnets residual misalignments

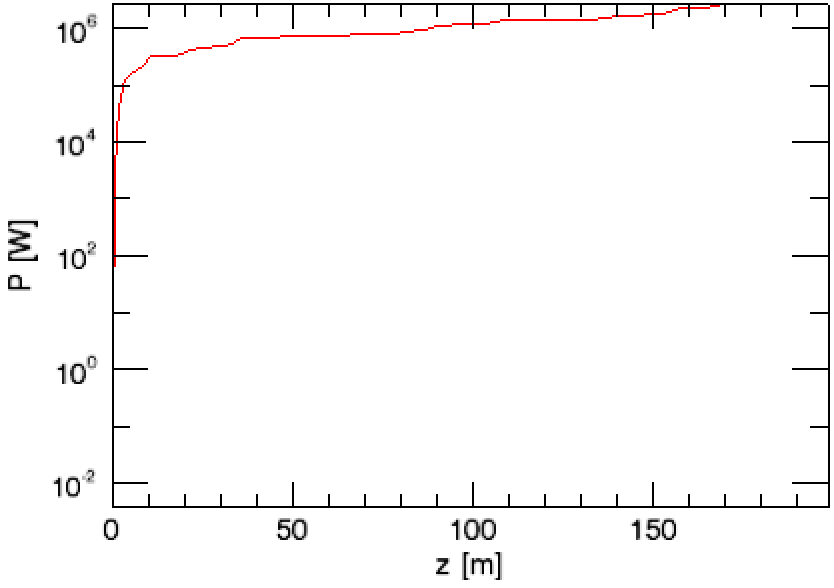


Strait line fitted to the beam error orbit

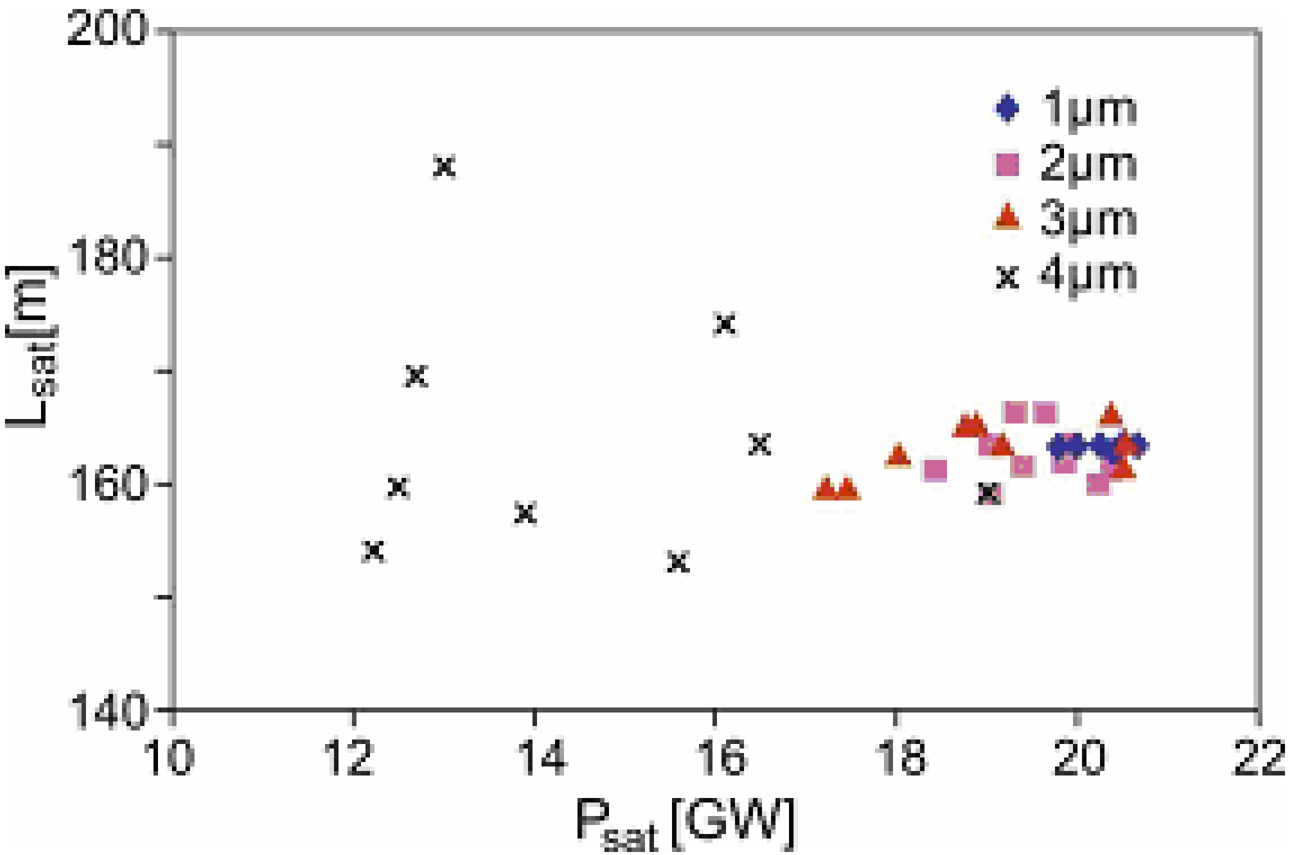




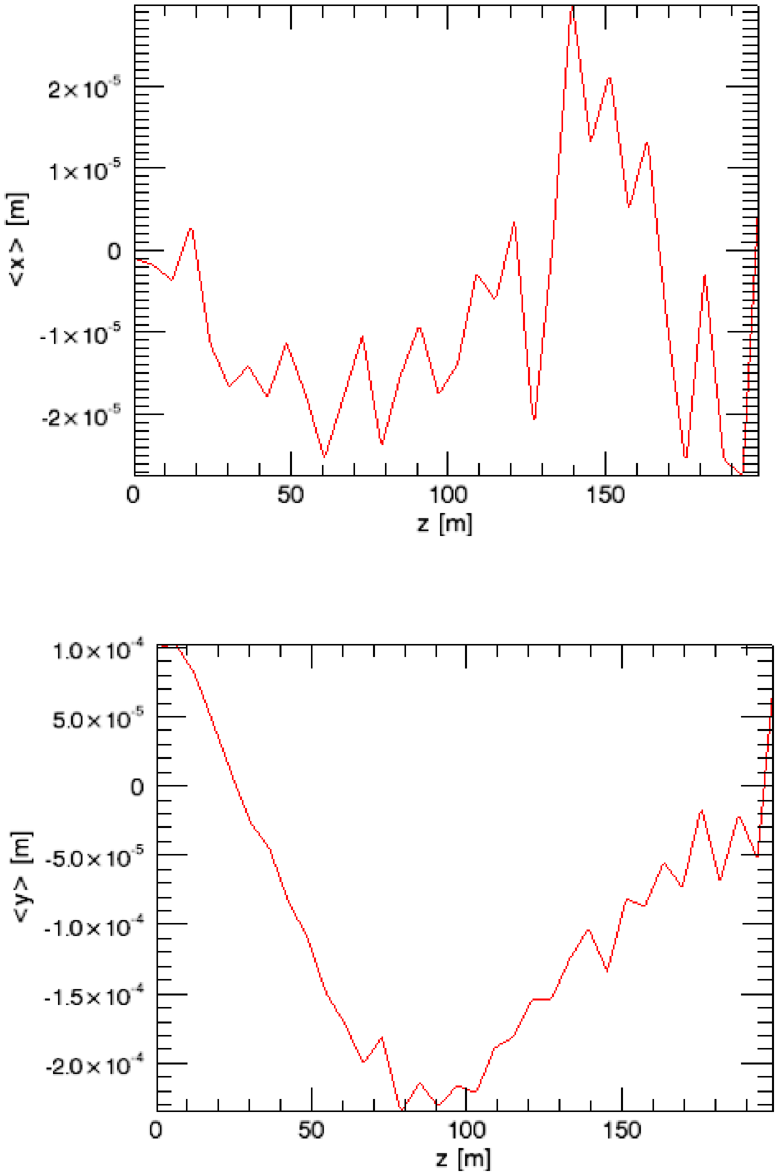




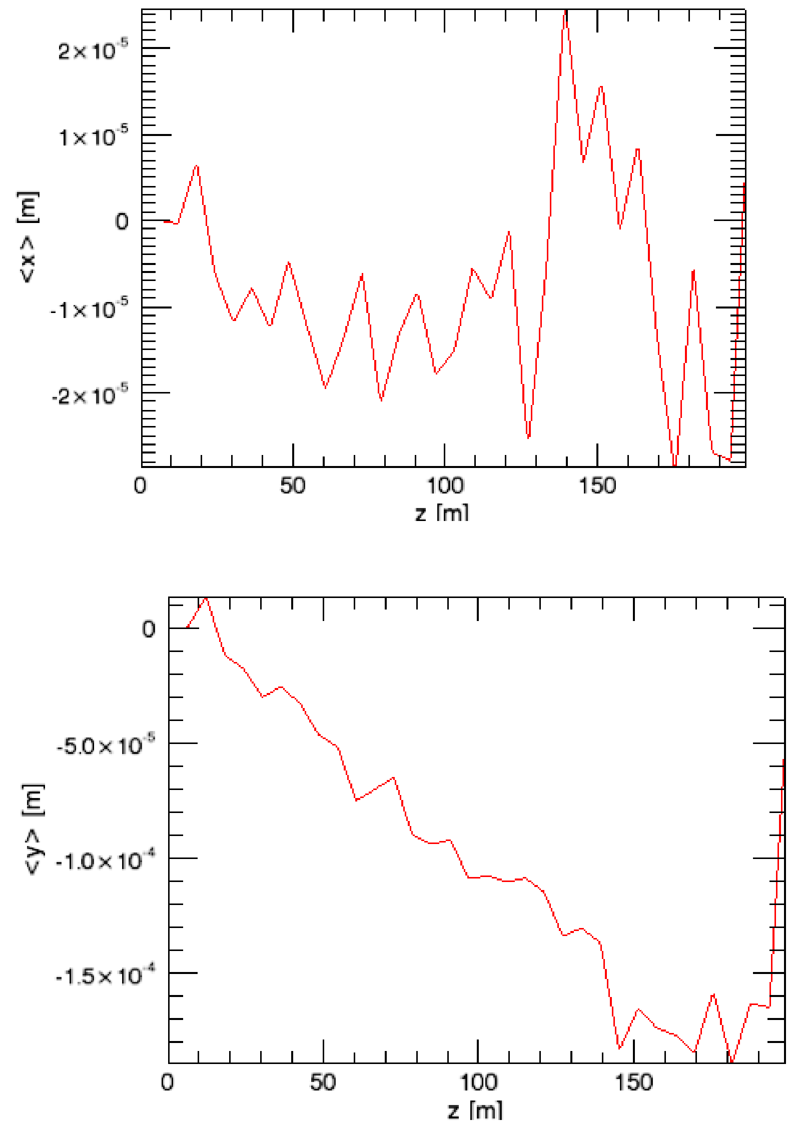
Time –dependent simulations



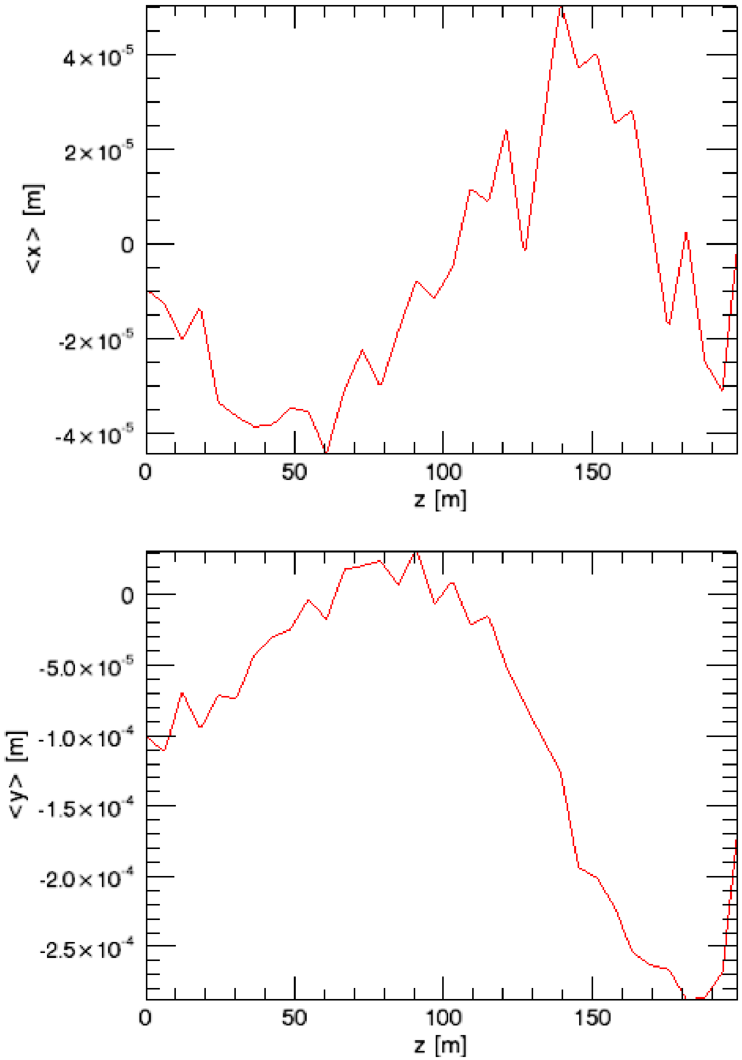
Saturation power and saturation length for various BPM rms offsets (10 different seeds).



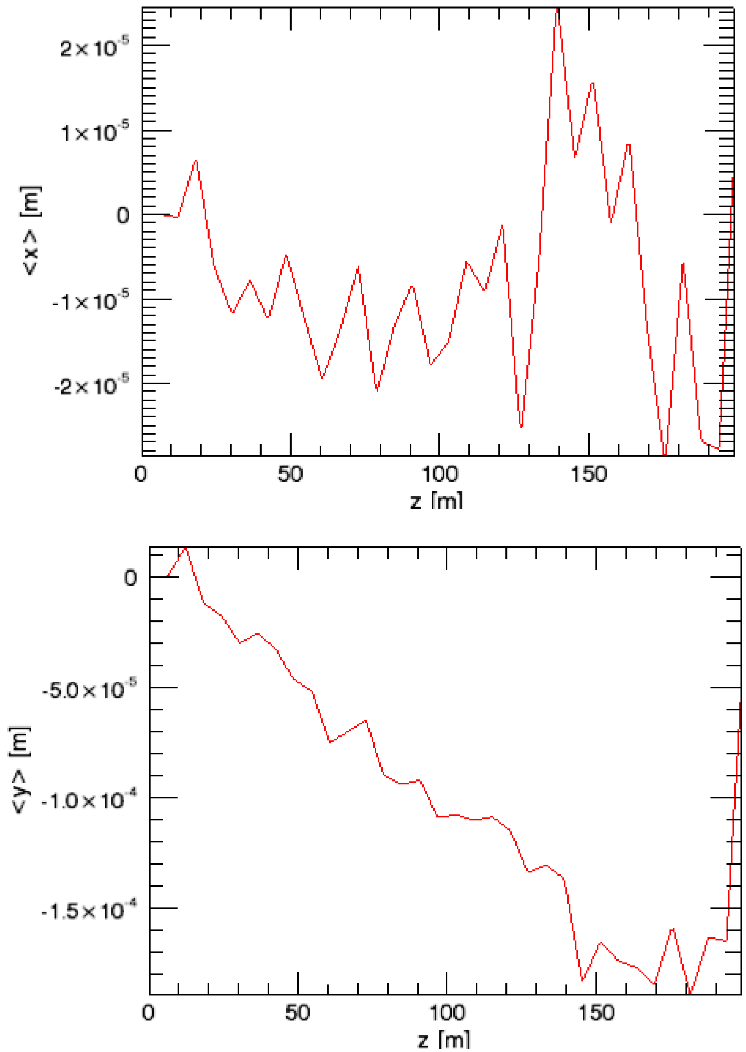
Orbit with optimal beam launch



Beam error orbit



Orbit with optimal beam launch



Beam error orbit

conclusions

- SASE FEL simulations has been performed to define the impact of beam trajectory errors due to quadrupole magnets residual (after correction) misalignments on the FEL radiation.
- Trajectory errors arise from the technically feasible requirements of quadrupole magnets and BPM alignments, BPM resolution in the result of realization of the different DF stirring scenarios.
- 0.5 micron rms dispersion resolution should be provided to ensure that radiation power reduction is ~ 5%.
- No beam offset and tilt at the undulator entrance have been considered.