rf kick of 3rd harmonic cavities

about kick factors, symmetries & compensation

FLASH setup

XFEL assumptions

calculation of rf kick factors

tracking (based on XFEL EXCEL table)

summary

about kick factors, symmetries & compensation

discrete coupler kick:

$$V_z(x,y,s) \approx V_{\mathrm{cav}} \cos(\varphi_{\mathrm{cav}} - ks)$$

$$V_x(x,y,s) \approx \mathrm{Re}\left\{ V_{\mathrm{cav}} e^{i(\varphi_{\mathrm{cav}} - ks)} \cdot V_x^{(n)}(x,y) \right\}$$

$$V_y(x,y,s) \approx \mathrm{Re}\left\{ V_{\mathrm{cav}} e^{i(\varphi_{\mathrm{cav}} - ks)} \cdot V_y^{(n)}(x,y) \right\}$$

Taylor expansion:

$$V_x^{(n)}(x,y) \approx d_0 + d_x x + d_y y$$

$$V_y^{(n)}(x,y) \approx f_0 + f_x x + f_y y$$

compensation of s- (or time-) dependent fields:

$$V_x(0,0,s) \approx \mathrm{Re}\left\{ V_{\mathrm{cav}} e^{i(\varphi_{\mathrm{cav}} - ks)} \cdot d_0 \right\} = \mathrm{Re}\left\{ V_{\mathrm{cav}} d_0 e^{i\varphi_{\mathrm{cav}}} \right\} \cos ks + \mathrm{Im}\left\{ V_{\mathrm{cav}} d_0 e^{i\varphi_{\mathrm{cav}}} \right\} \sin ks$$

$$\rightarrow \mathrm{Im}\left\{ V_{\mathrm{cav}} d_0 e^{i\varphi_{\mathrm{cav}}} \right\} = 0$$

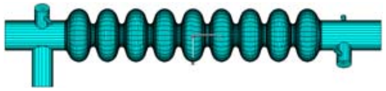
$$\arg\{d_0\} = -\varphi_{\mathrm{cav}}$$

depends on cavity phase

depends on compression scenario

summary – complex coupler kick:

cav

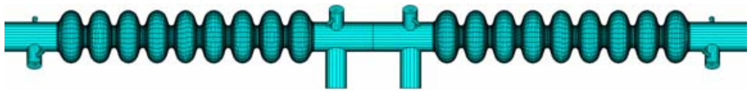


a,b arbitrary: $d_0 = d_0(a,b), \cdots$

$$V_x^{(n)}(x,y) \approx d_0 + d_x x + d_y y$$

$$V_y^{(n)}(x,y) \approx f_0 + f_x x + f_y y$$

cav+mirror-z

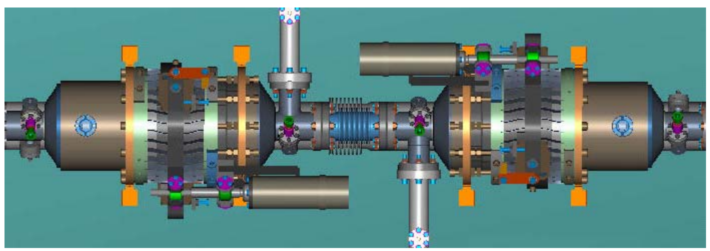


SW: a=b, (equal for sub-structures)

$$V_x^{(\Sigma,n)}(x,y) \approx 2i\,\mathrm{Im}\{d_0 + d_x x + d_y y\}$$

$$V_y^{(\Sigma,n)}(x,y) \approx 2i\,\mathrm{Im}\{f_0 + f_x x + f_y y\}$$

cav+rot | y-axis

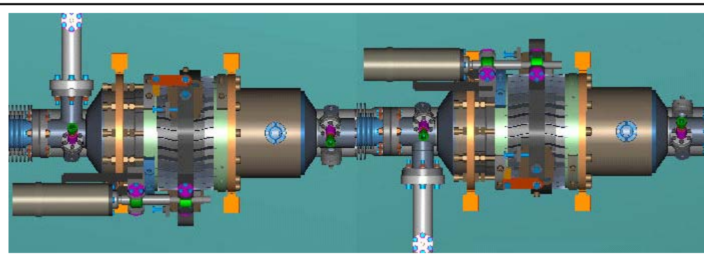


SW: a=b, (equal for sub-structures)

$$V_x^{(\Sigma,n)}(x,y) \approx 2\,\mathrm{Re}\{d_0\} + 2i\,\mathrm{Im}\{d_x\}x + 2\,\mathrm{Re}\{d_y\}y$$

$$V_y^{(\Sigma,n)}(x,y) \approx 2i\,\mathrm{Im}\{f_0\} + 2\,\mathrm{Re}\{f_x\}x + 2i\,\mathrm{Im}\{f_y\}y$$

cav+mirror-y

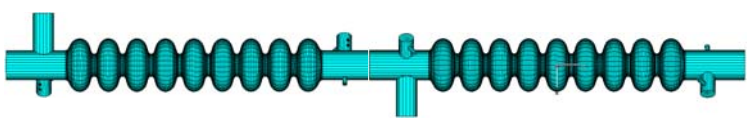


a,b arbitrary (but equal for sub-str.)

$$V_x^{(\Sigma,n)}(x,y) \approx 2 d_x x$$

$$V_y^{(\Sigma,n)}(x,y) \approx 2 f_0 + 2 f_y y$$

cav+rot | z-axis



a,b arbitrary (but equal for sub-str.)

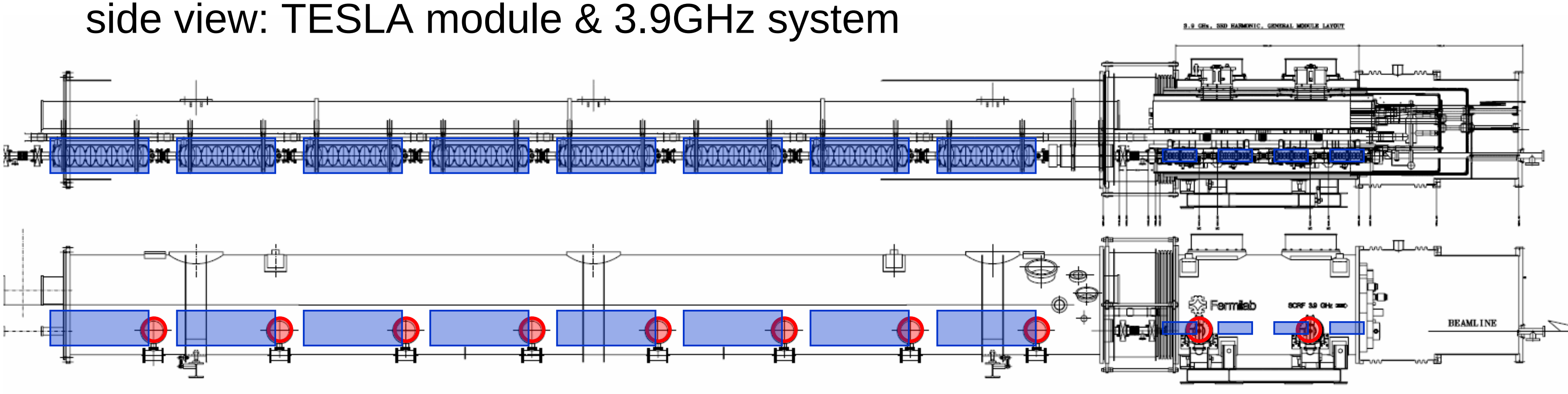
$$V_x^{(\Sigma,n)}(x,y) \approx 2 d_x x + 2 d_y y$$

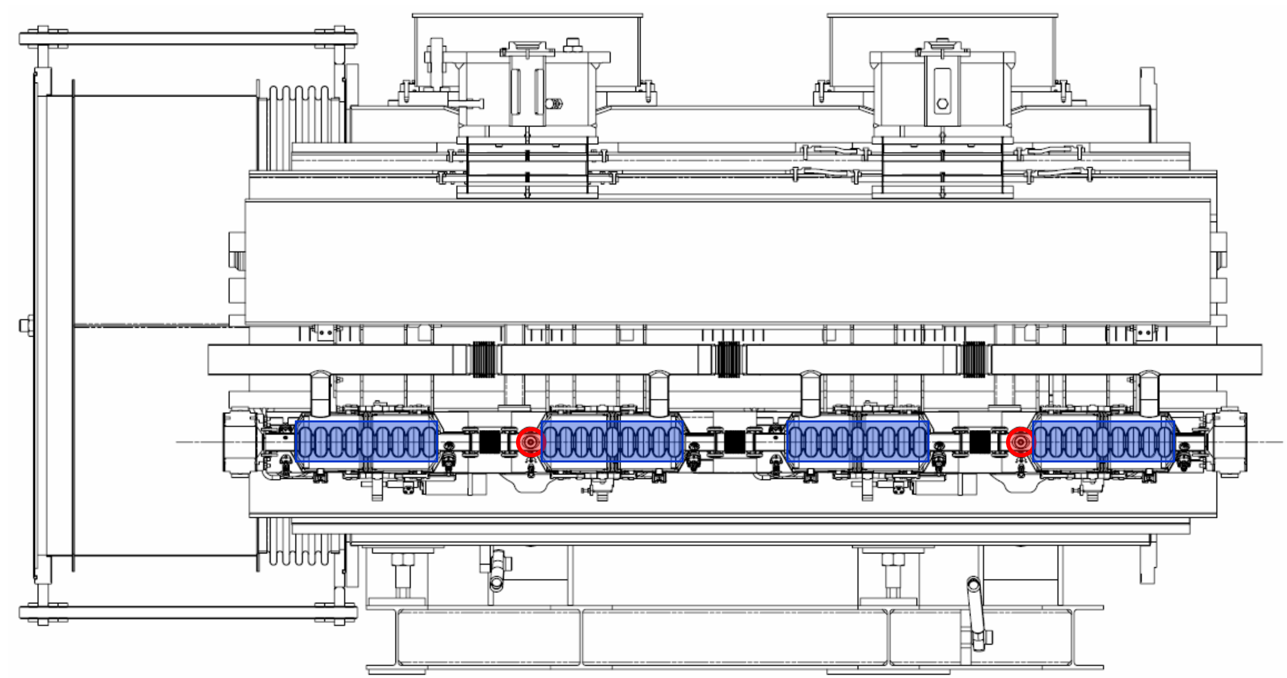
$$V_y^{(\Sigma,n)}(x,y) \approx 2 f_x x + 2 f_y y$$

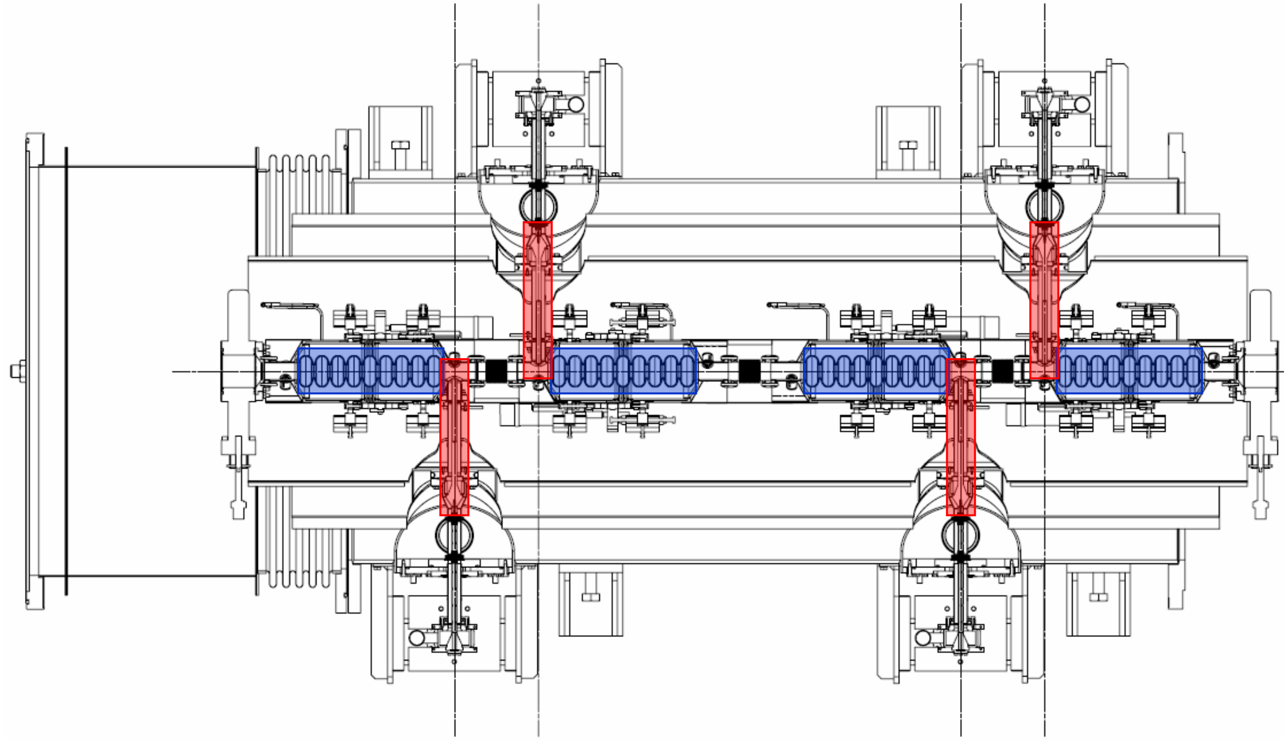
from http://www.desy.de/~dohlus/2007/2007.07.ckick/ckick2.pdf

FLASH setup

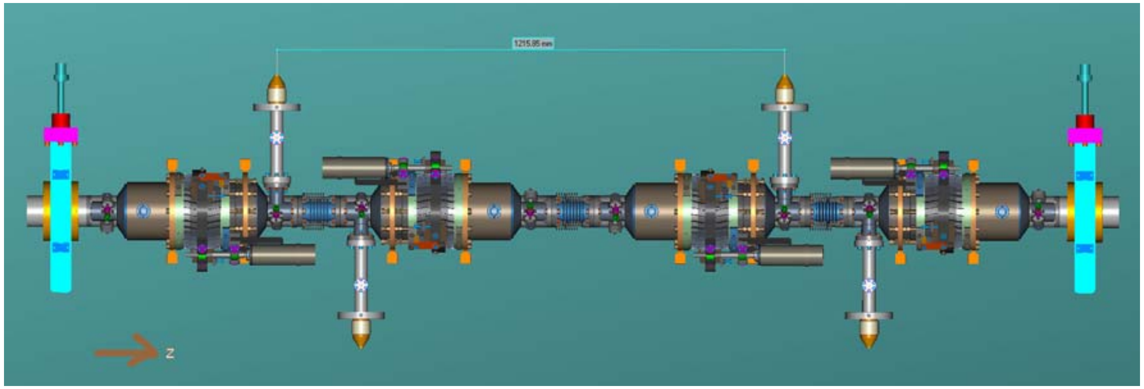
side view: TESLA module & 3.9GHz system







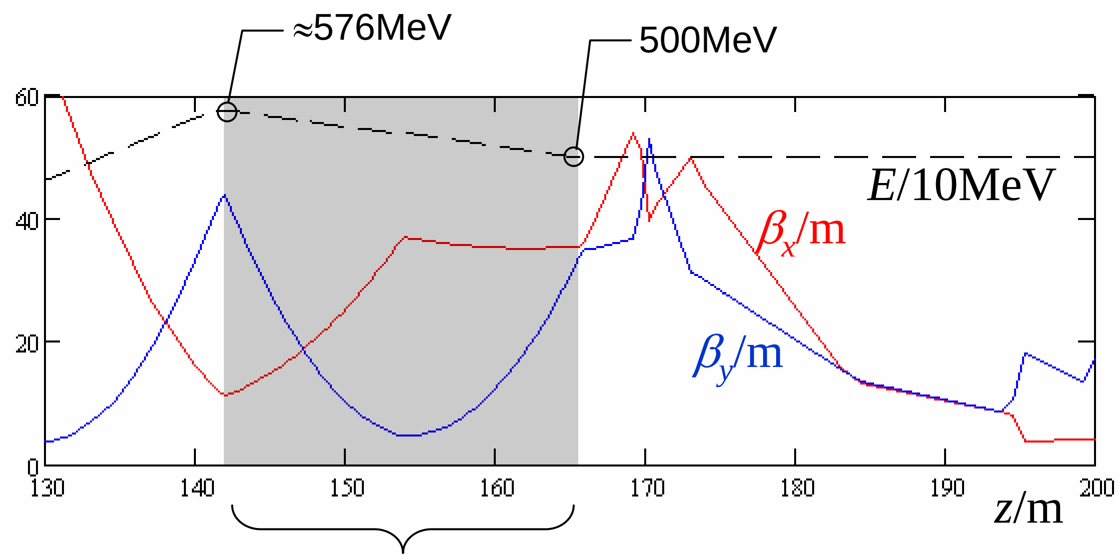
→ horizontal rotation
= “yrot”



XFEL assumptions

initial particle distribution: tracked with ASTRA as described in
http://www.desy.de/xfel-beam/data/talks/talks/dohlus_-_comp_of_ckick_3_20080225.pdf
25. Feb. 2008, beam dynamics seminar
reference solution without coupler kicks in TESLA modules

≈ parameters for 20 x 5 compression (= present design)
$\varphi_{1st} \approx$ 2deg; $\varphi_{3rd} \approx$ 146.6deg (spatial phases); $V_{3rd} \approx$ 92 MV



3rd harmonic section
EXCEL table: 2 modules = 24 cavities
discrete kicks of 48 couplers
(effect depends on field not on number of cavities)

XFEL assumptions

Considerations on the third harmonic rf of the European XFEL

E. Vogel[2], M. Dohlus[2], H. Edwards[1], E. Harms[1], M. Huening[2], K. Jensch[2], T. Khabiboulline[1],
A. Matheisen[2], W.-D. Moeller[2], A. Schmidt[2] and W. Singer[2]

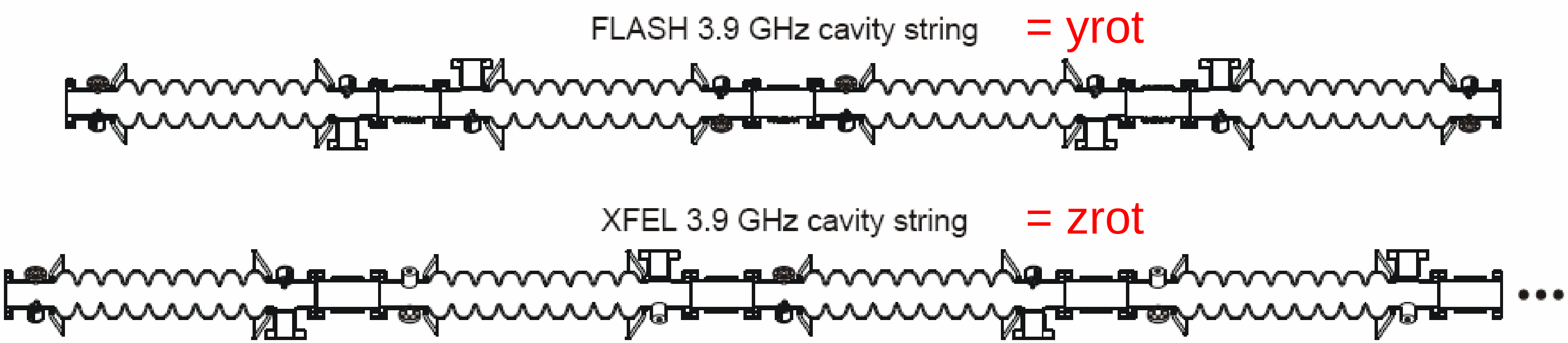


Figure 4: Possible cavity arrangements for installing the power couplers alternately opposite to each other.

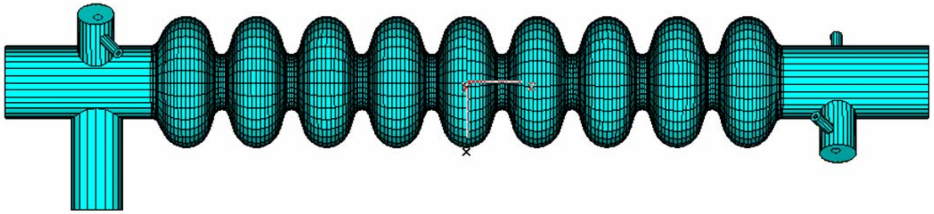
calculation of rf kick factors

a) Timergali's HFSS calculation

source of information, fields and geometry

= Timergali Khabiboulline
Fermilab

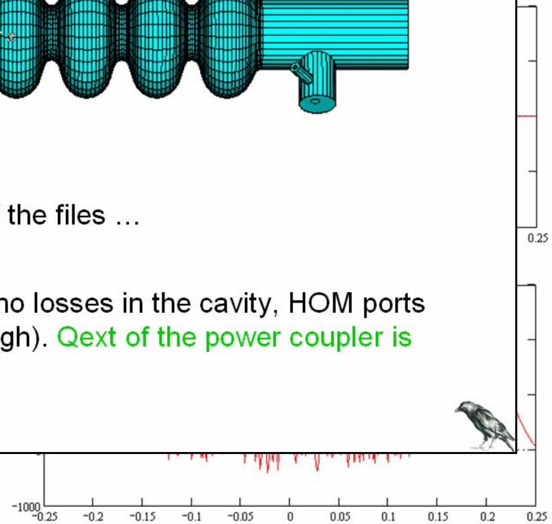
- 3D solid model sat file, similar was used for a HFSS calculations. It can be not optimal for Mafia/MWS and I will prepare smooth shaped solid model for you.



- 4 files ReE, ImE, ReH and ImH. Format of the files …
  Let me know, if you need other format.

  range: … . Power 1W from main coupler, no losses in the cavity, HOM ports are loaded (but Qext for them are pretty high). Qext of the power coupler is 1e6.

…egrals
…habiboulline)



$$\mathbf{V} = \int (\mathbf{E} + \mathbf{v} \times \mathbf{B}) \exp(iz\omega/c)\, dz$$

$|V_z| = 52\,\mathrm{kV}$

$P_f = 1\,\mathrm{W}$

$Q_e = 10^6$

$$W_{tot,SW} = 4 \times \frac{Q_e P_f}{\omega}$$

$$(R/Q) = \frac{|V_z|^2}{2\omega W_{\mathrm{tot}}} = 340\,\Omega$$

for comparison TESLA-FEL 2003-01: 375Ω

$$\frac{1}{V_z}\begin{pmatrix} V_x \\ V_y \end{pmatrix} = \begin{pmatrix} -416 - j219 \\ -36 + j144 \end{pmatrix} \cdot 10^{-6}$$

all couplers!
for comparison TESLA cavity:

$$\frac{1}{V_z}\begin{pmatrix} V_x \\ V_y \end{pmatrix} = \begin{pmatrix} -82 + j58 \\ -9.2 + j1.7 \end{pmatrix} \cdot 10^{-6}$$

(zpen=6mm, new geometry)

from FEL Beam Dynamics Group – Talks
1st Estimation of RF Coupler Kicks of 3rd Harmonic Cavity
18.06.2007

calculation of rf kick factors
a) Timergali's HFSS calculation - in detail

only forward wave (a=0):

upstream $$\frac{1}{V_z}\begin{pmatrix}V_x\\V_y\end{pmatrix}=\begin{pmatrix}-339+j44\\-61+j45\end{pmatrix}\cdot 10^{-6}$$

downstream $$\frac{1}{V_z}\begin{pmatrix}V_x\\V_y\end{pmatrix}=\begin{pmatrix}-78-j263\\26+j99\end{pmatrix}\cdot 10^{-6}$$

only backward wave (b=0):

the numbers deviate less than 10^{-7} from the values for forward wave

therefore:

the coupler kick depends essentially on the SW part of the field
it does not depend on the reflection coefficient at the input coupler

calculation of rf kick factors

b) MWS calculation for 2 cells, scaled

only forward wave (a=0):

upstream $\frac{1}{V_z}\begin{pmatrix} V_x \\ V_y \end{pmatrix} = \begin{pmatrix} -496 + j202 \\ -96 + j222 \end{pmatrix} \cdot 10^{-6}$ downstream $\frac{1}{V_z}\begin{pmatrix} V_x \\ V_y \end{pmatrix} = \begin{pmatrix} -267 - j672 \\ 45 + j340 \end{pmatrix} \cdot 10^{-6}$

rf kick factors

a) Timergali's HFSS calculation - in detail

only forward wave (a=0):

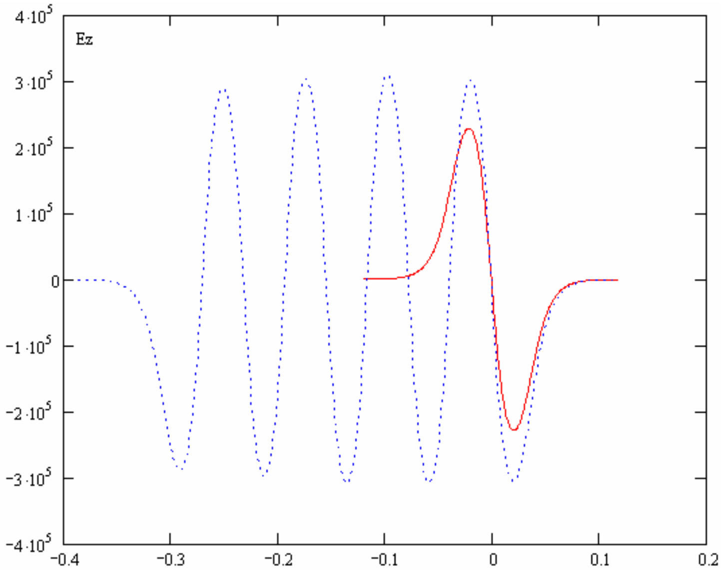
upstream $\frac{1}{V_z}\begin{pmatrix} V_x \\ V_y \end{pmatrix} = \begin{pmatrix} -339 + j44 \\ -61 + j45 \end{pmatrix} \cdot 10^{-6}$ downstream $\frac{1}{V_z}\begin{pmatrix} V_x \\ V_y \end{pmatrix} = \begin{pmatrix} -78 - j263 \\ 26 + j99 \end{pmatrix} \cdot 10^{-6}$

results are quite uncertain:

HFSS very noisy
MWS two cells are not enough
both calculations: discretized beam pipe is too short
(cancellation effects in integrated kick)
systematic difference in accelerating field and in Qext

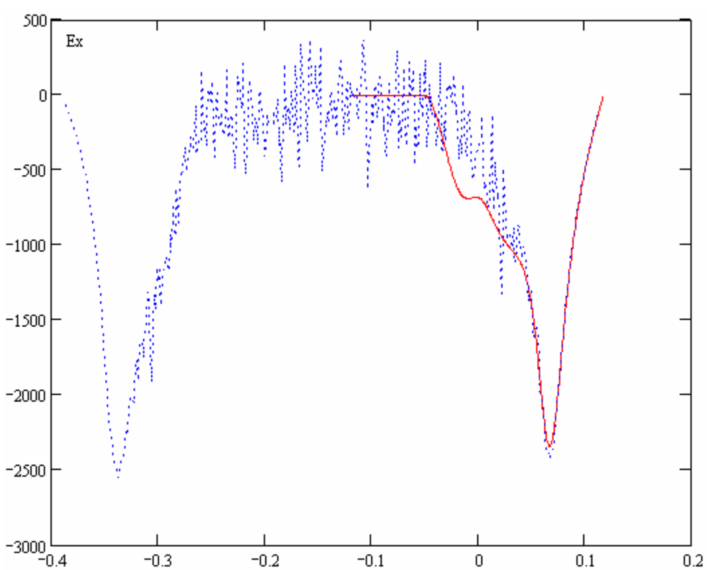
calculation of rf kick factors

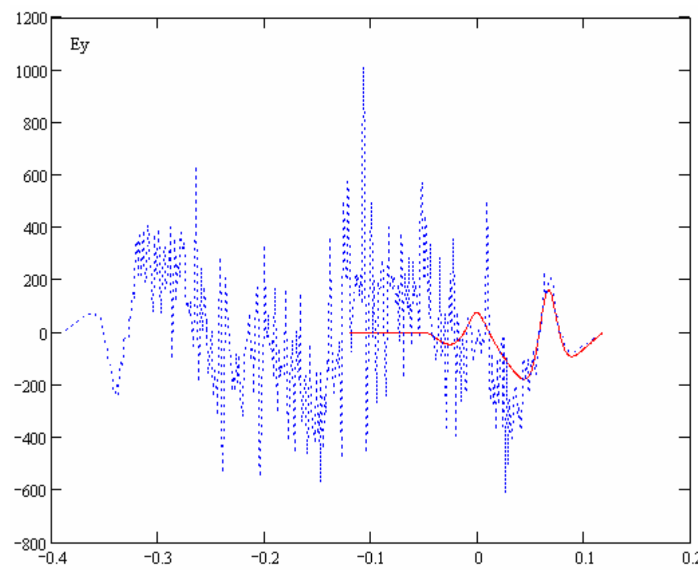
comparison of HFSS & MWS fields



MWS, 2 cells, Cartesian mesh

HFSS, 9 cells, tetraeder grid





calculation of rf kick factors

b) MWS calculation for 2 cells, scaled

but MWS results are smooth enough to estimate spatial derivatives of kicks:

upstream $$\frac{1}{V_z}\frac{\partial}{\partial x}\begin{pmatrix}V_x\\V_y\end{pmatrix}\approx\begin{pmatrix}-44-j34\\28-j67\end{pmatrix}\cdot\frac{10^{-3}}{\mathrm{m}}$$ downstream $$\frac{1}{V_z}\frac{\partial}{\partial x}\begin{pmatrix}V_x\\V_y\end{pmatrix}\approx\begin{pmatrix}-3.5-j53\\33+j75\end{pmatrix}\cdot\frac{10^{-3}}{\mathrm{m}}$$

$$\frac{1}{V_z}\frac{\partial}{\partial y}\begin{pmatrix}V_x\\V_y\end{pmatrix}\approx\begin{pmatrix}28-j66\\44+j34\end{pmatrix}\cdot\frac{10^{-3}}{\mathrm{m}}$$ $$\frac{1}{V_z}\frac{\partial}{\partial y}\begin{pmatrix}V_x\\V_y\end{pmatrix}\approx\begin{pmatrix}33+j75\\3.5+j53\end{pmatrix}\cdot\frac{10^{-3}}{\mathrm{m}}$$

for comparison: TESLA cavity

upstream $$\frac{1}{V_z}\frac{\partial}{\partial x}\begin{pmatrix}V_x\\V_y\end{pmatrix}\approx\begin{pmatrix}1.0-j0.7\\3.4+j0.2\end{pmatrix}\cdot\frac{10^{-3}}{\mathrm{m}}$$ downstream $$\frac{1}{V_z}\frac{\partial}{\partial x}\begin{pmatrix}V_x\\V_y\end{pmatrix}\approx\begin{pmatrix}-3.7-j2.0\\3.0+j0.5\end{pmatrix}\cdot\frac{10^{-3}}{\mathrm{m}}$$

$$\frac{1}{V_z}\frac{\partial}{\partial y}\begin{pmatrix}V_x\\V_y\end{pmatrix}\approx\begin{pmatrix}3.4+j0.2\\-1.1+j0.6\end{pmatrix}\cdot\frac{10^{-3}}{\mathrm{m}}$$ $$\frac{1}{V_z}\frac{\partial}{\partial y}\begin{pmatrix}V_x\\V_y\end{pmatrix}\approx\begin{pmatrix}3.0+j0.5\\3.8+j1.9\end{pmatrix}\cdot\frac{10^{-3}}{\mathrm{m}}$$

$\frac{1}{V_z}\begin{pmatrix}V_x\\V_y\end{pmatrix}$ for one 3rd harm. cavity is about 5…10 times larger than for one TESLA cavity

total kick (=∑) of all 3rd harm cavities before BC1 is about 100 to 200% of that of all TESLA cavities

$\frac{1}{V_z}\frac{\partial}{\partial x}\begin{pmatrix}V_x\\V_y\end{pmatrix}$ for one 3rd harm. cavity is about 10…50 times larger

tracking (based on XFEL EXCEL table)

calculation with HFSS kicks, offset independent

upstream $$\frac{1}{V_z}\begin{pmatrix} V_x \\ V_y \end{pmatrix} = \begin{pmatrix} -339 + j44 \\ -61 + j45 \end{pmatrix} \cdot 10^{-6}$$

$$\frac{1}{V_z}\frac{\partial}{\partial x}\begin{pmatrix} V_x \\ V_y \end{pmatrix} = \begin{pmatrix} 0 \\ 0 \end{pmatrix} \cdot \frac{10^{-3}}{\mathrm{m}}$$

$$\frac{1}{V_z}\frac{\partial}{\partial y}\begin{pmatrix} V_x \\ V_y \end{pmatrix} = \begin{pmatrix} 0 \\ 0 \end{pmatrix} \cdot \frac{10^{-3}}{\mathrm{m}}$$

downstream $$\frac{1}{V_z}\begin{pmatrix} V_x \\ V_y \end{pmatrix} = \begin{pmatrix} -78 - j263 \\ 26 + j99 \end{pmatrix} \cdot 10^{-6}$$

$$\frac{1}{V_z}\frac{\partial}{\partial x}\begin{pmatrix} V_x \\ V_y \end{pmatrix} = \begin{pmatrix} 0 \\ 0 \end{pmatrix} \cdot \frac{10^{-3}}{\mathrm{m}}$$

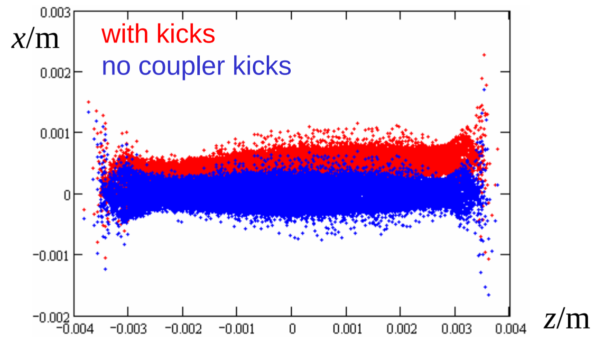
$$\frac{1}{V_z}\frac{\partial}{\partial y}\begin{pmatrix} V_x \\ V_y \end{pmatrix} = \begin{pmatrix} 0 \\ 0 \end{pmatrix} \cdot \frac{10^{-3}}{\mathrm{m}}$$

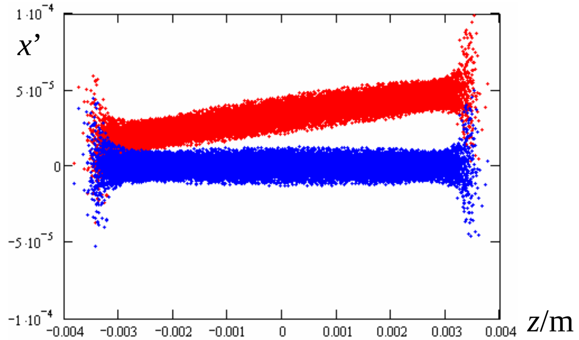
	ε_{xn} / µm	ε_{yn} / µm
no coupler kicks	0.926	0.969
identical orientation	1.812	1.002
yrot of each second	1.278	1.010
zrot of each second	0.940	0.984

tracking (based on XFEL EXCEL table)

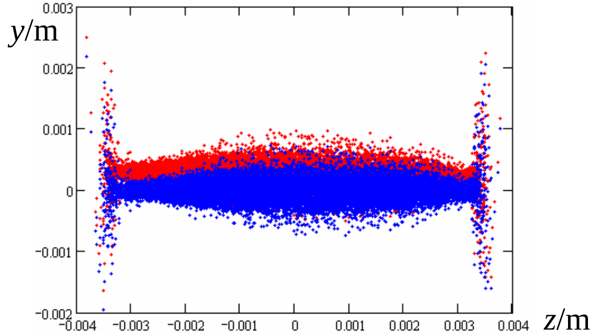
calculation with HFSS kicks, offset independent
identical orientation

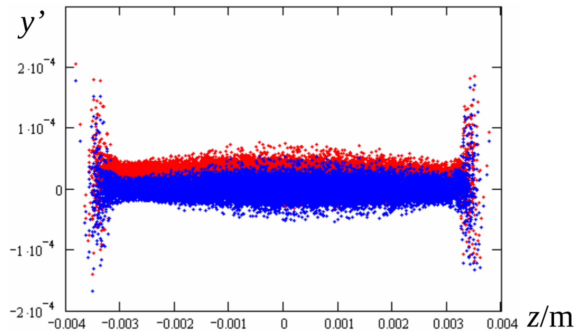
$\varepsilon_{xn} / \varepsilon_{xn0} = 1.96$





$\varepsilon_{yn} / \varepsilon_{yn0} = 1.03$

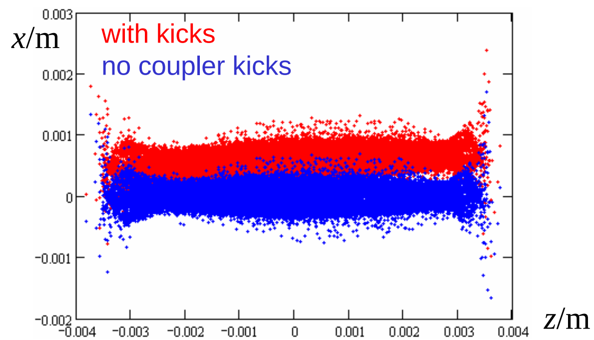


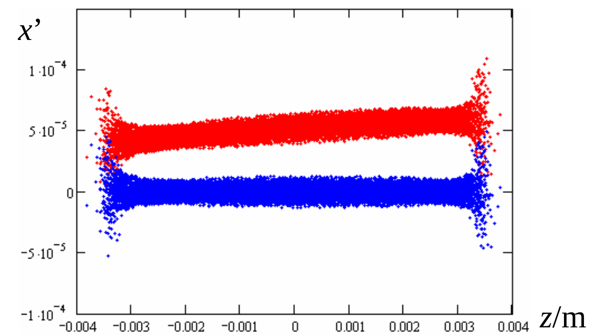


tracking (based on XFEL EXCEL table)

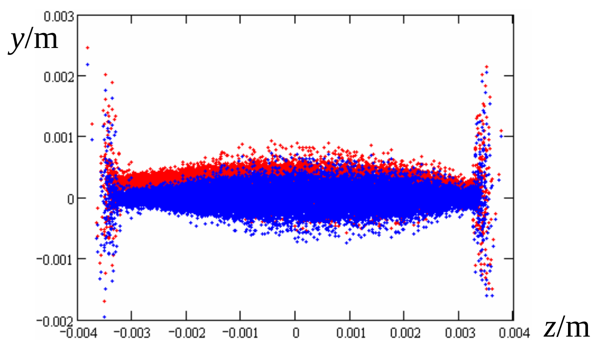
calculation with HFSS kicks, offset independent
yrot of each 2nd

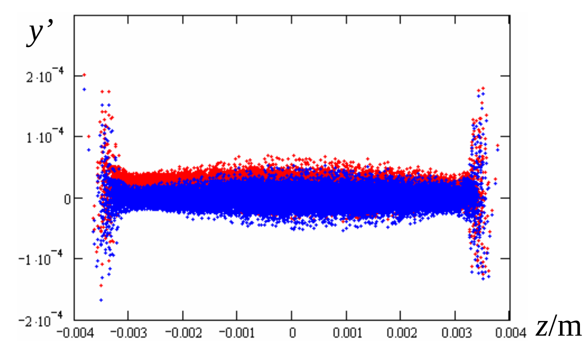
$\varepsilon_{xn} / \varepsilon_{xn0} = 1.38$





$\varepsilon_{yn} / \varepsilon_{yn0} = 1.04$

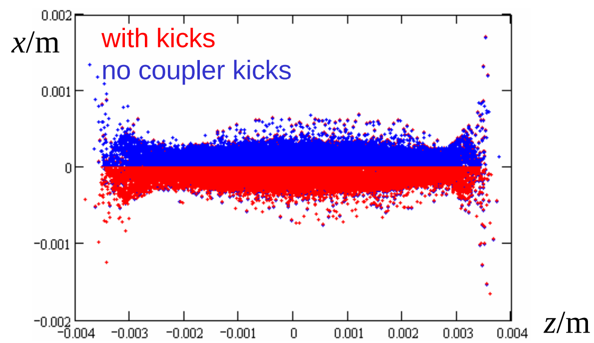


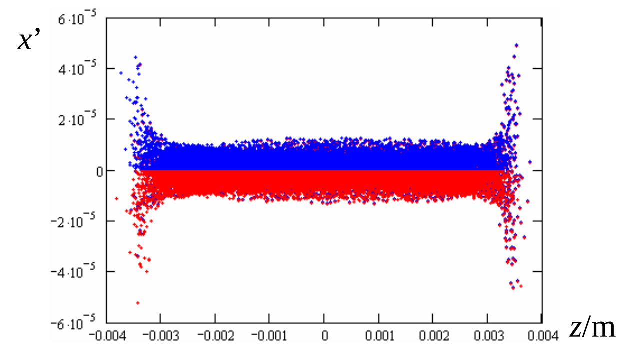


tracking (based on XFEL EXCEL table)

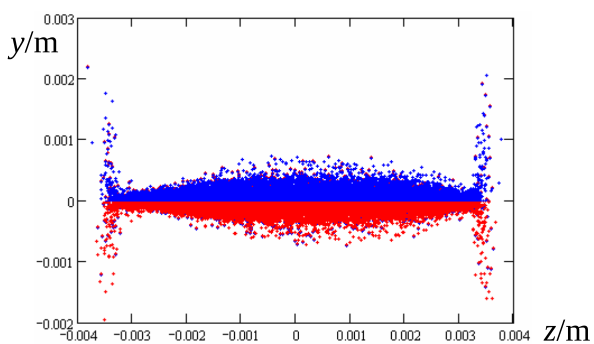
calculation with HFSS kicks, offset independent
zrot of each 2nd

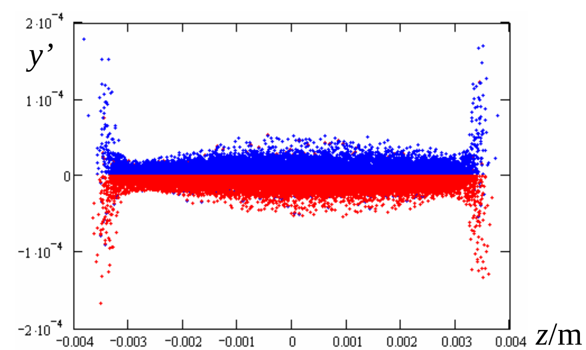
$\varepsilon_{xn} / \varepsilon_{xn0} = 1.02$





$\varepsilon_{yn} / \varepsilon_{yn0} = 1.02$





tracking (based on XFEL EXCEL table)

calculation with MWS kicks

upstream $$\frac{1}{V_z}\begin{pmatrix} V_x \\ V_y \end{pmatrix} = \begin{pmatrix} -496 + j202 \\ -96 + j222 \end{pmatrix} \cdot 10^{-6}$$

downstream $$\frac{1}{V_z}\begin{pmatrix} V_x \\ V_y \end{pmatrix} = \begin{pmatrix} -267 - j672 \\ 45 + j340 \end{pmatrix} \cdot 10^{-6}$$

$$\frac{1}{V_z}\frac{\partial}{\partial x}\begin{pmatrix} V_x \\ V_y \end{pmatrix} = \begin{pmatrix} -44 - j34 \\ 28 - j67 \end{pmatrix} \cdot \frac{10^{-3}}{\mathrm{m}}$$

$$\frac{1}{V_z}\frac{\partial}{\partial x}\begin{pmatrix} V_x \\ V_y \end{pmatrix} = \begin{pmatrix} -3.5 - j53 \\ 33 + j75 \end{pmatrix} \cdot \frac{10^{-3}}{\mathrm{m}}$$

$$\frac{1}{V_z}\frac{\partial}{\partial y}\begin{pmatrix} V_x \\ V_y \end{pmatrix} = \begin{pmatrix} 28 - j66 \\ 44 + j34 \end{pmatrix} \cdot \frac{10^{-3}}{\mathrm{m}}$$

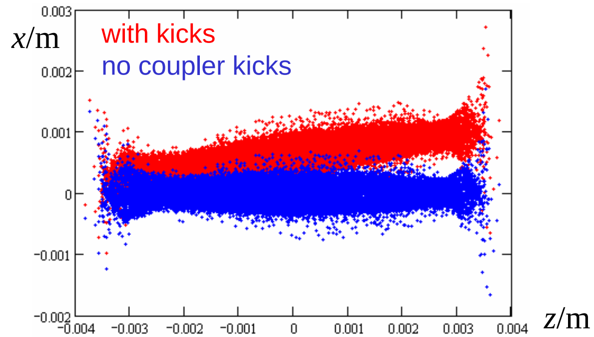
$$\frac{1}{V_z}\frac{\partial}{\partial y}\begin{pmatrix} V_x \\ V_y \end{pmatrix} = \begin{pmatrix} 33 + j75 \\ 3.5 + j53 \end{pmatrix} \cdot \frac{10^{-3}}{\mathrm{m}}$$

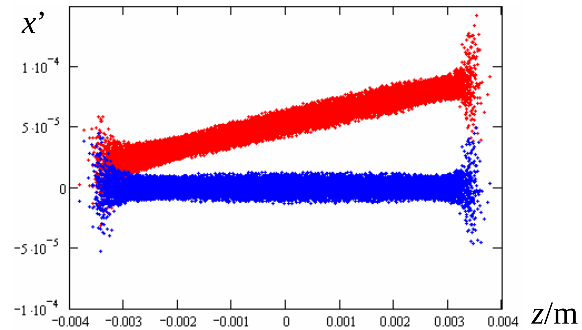
	ε_{xn} / µm	ε_{yn} / µm
no coupler kicks	0.926	0.969
identical orientation	3.304	1.377
yrot of each second	1.948	1.417
zrot of each second	0.953	0.988

tracking (based on XFEL EXCEL table)

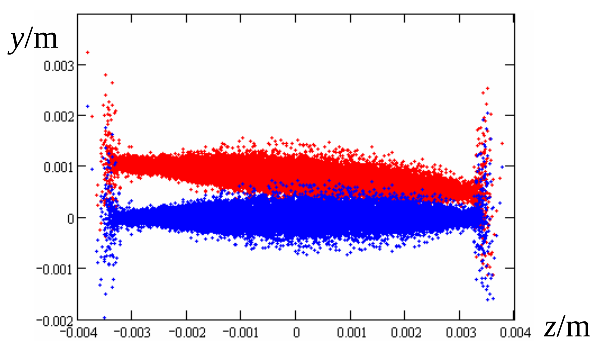
calculation with MWS kicks
identical orientation

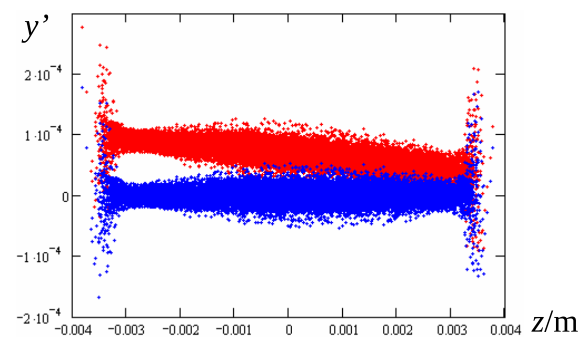
$\varepsilon_{xn} / \varepsilon_{xn0} = 3.57$





$\varepsilon_{yn} / \varepsilon_{yn0} = 1.42$

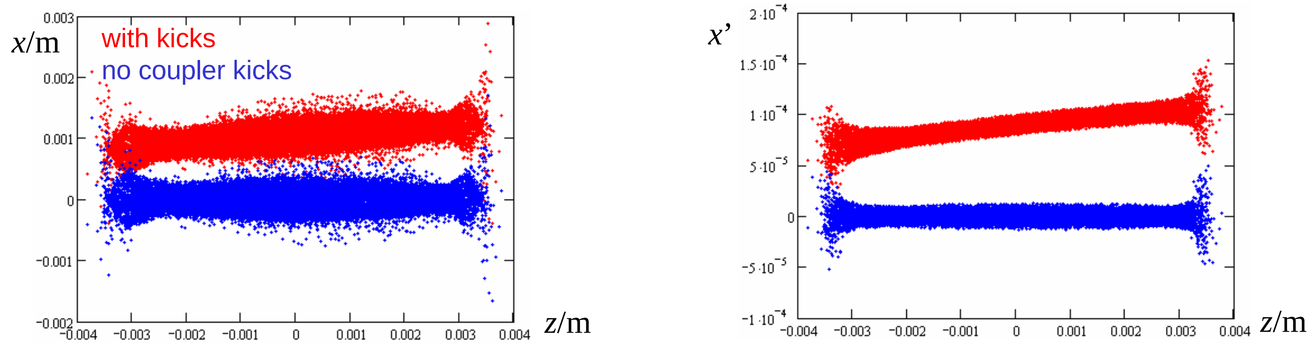




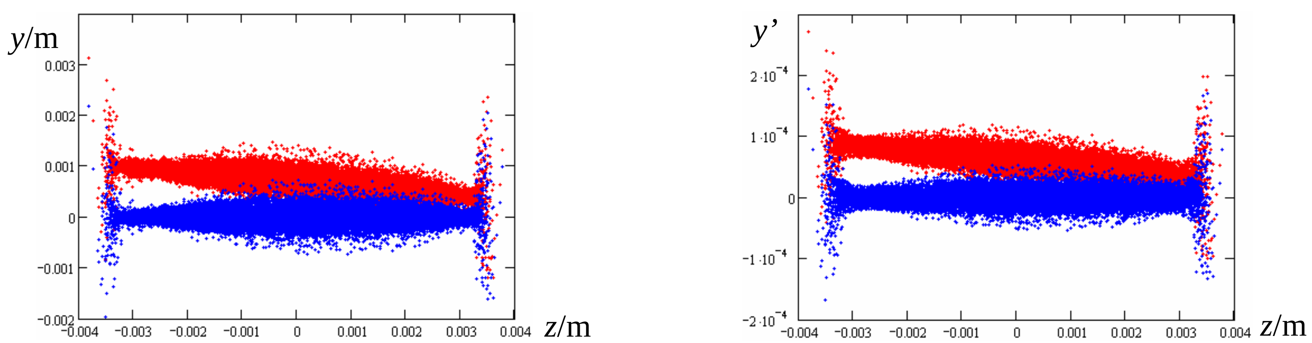
tracking (based on XFEL EXCEL table)

calculation with MWS kicks
yrot of each 2nd

$\varepsilon_{xn} / \varepsilon_{xn0} = 2.10$



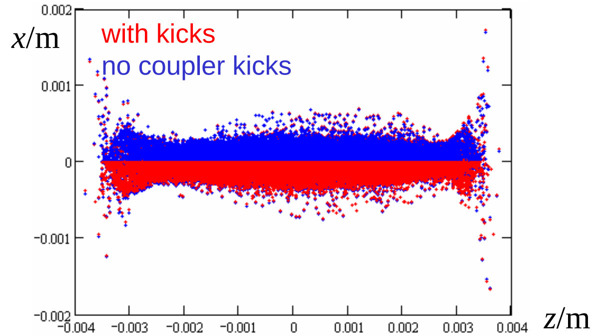
$\varepsilon_{yn} / \varepsilon_{yn0} = 1.46$

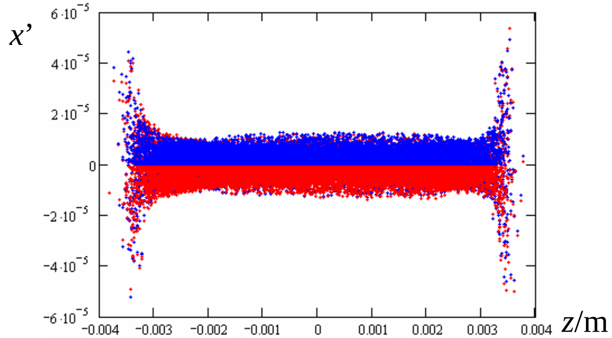


tracking (based on XFEL EXCEL table)

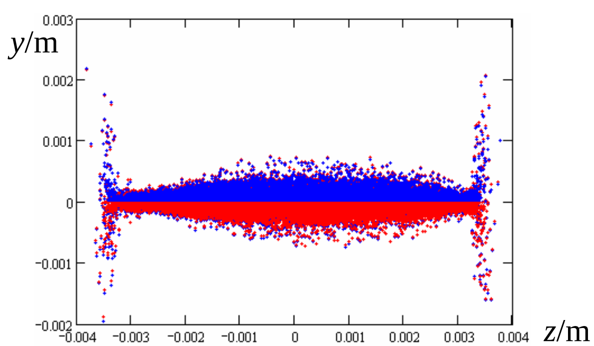
calculation with MWS kicks
zrot of each 2nd

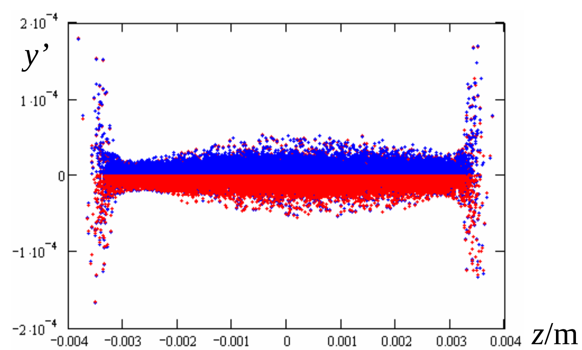
$\varepsilon_{xn} / \varepsilon_{xn0} = 1.03$





$\varepsilon_{yn} / \varepsilon_{yn0} = 1.02$

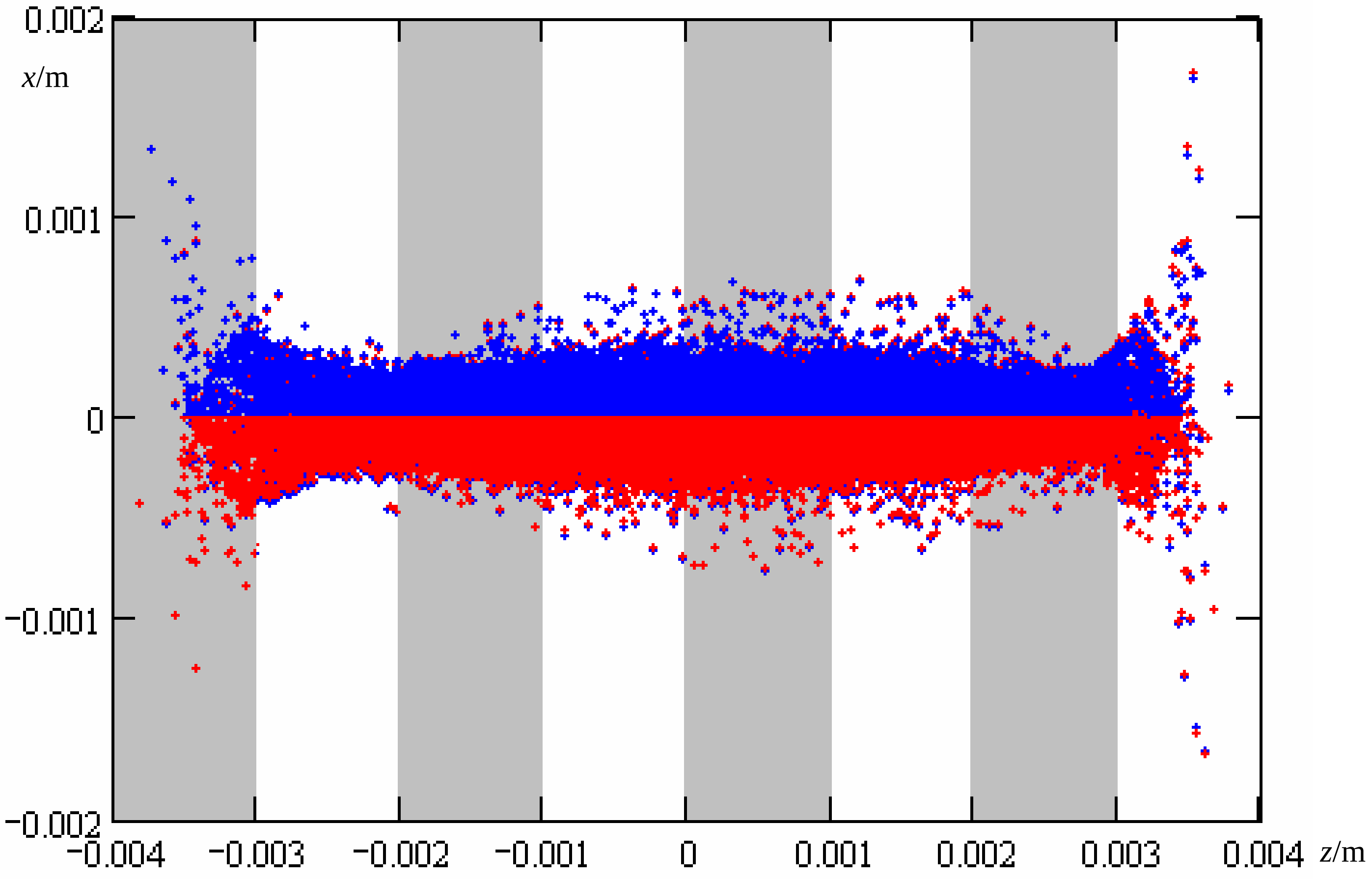




tracking (based on XFEL EXCEL table)

calculation with MWS / HFFS
zrot of each 2nd

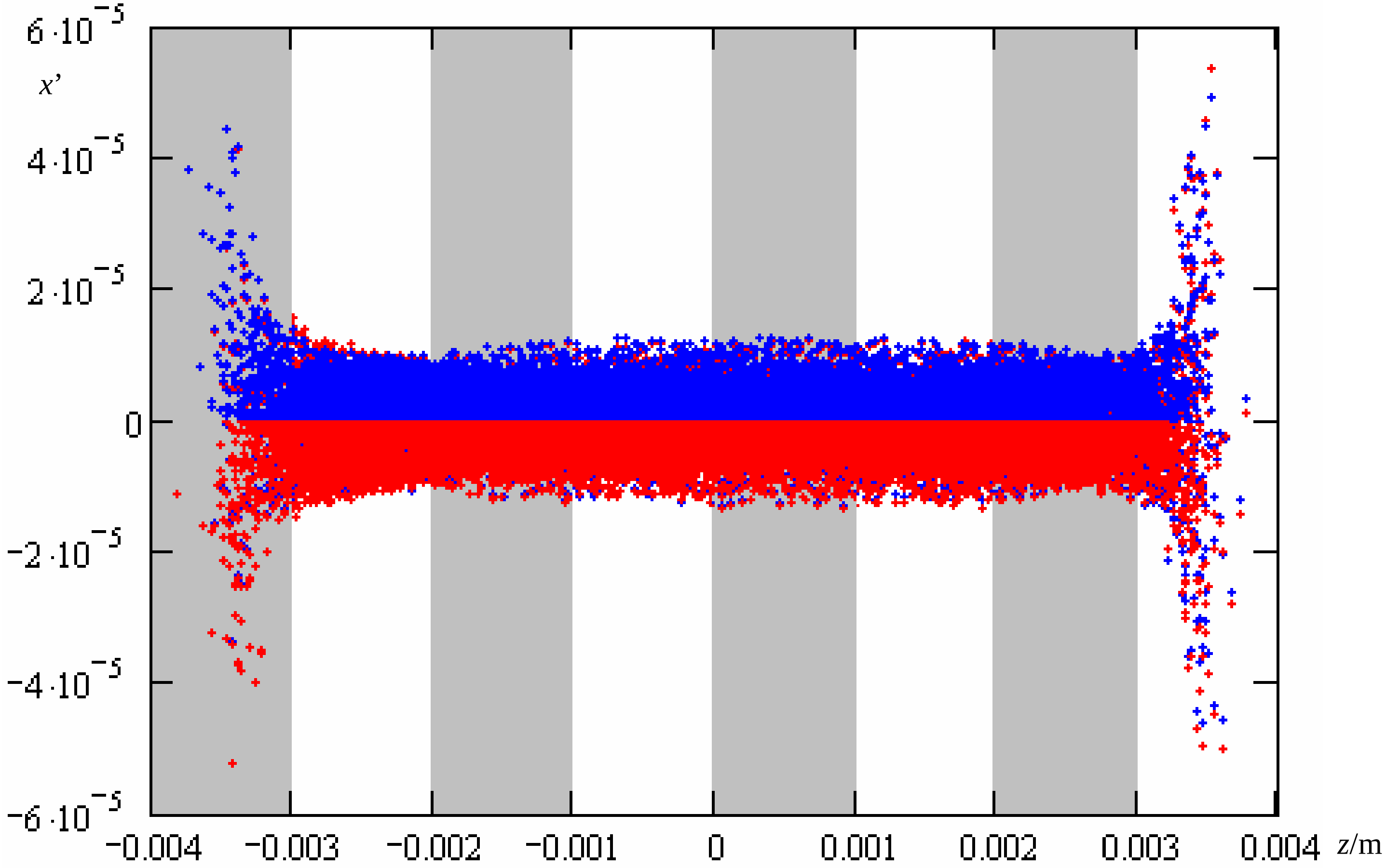
with kicks, MWS
with kicks, HFFS – offset independent
no coupler kicks



tracking (based on XFEL EXCEL table)

calculation with MWS / HFFS
zrot of each 2nd

with kicks, MWS
with kicks, HFFS – offset independent
no coupler kicks



tracking (based on XFEL EXCEL table)

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with kicks, MWS
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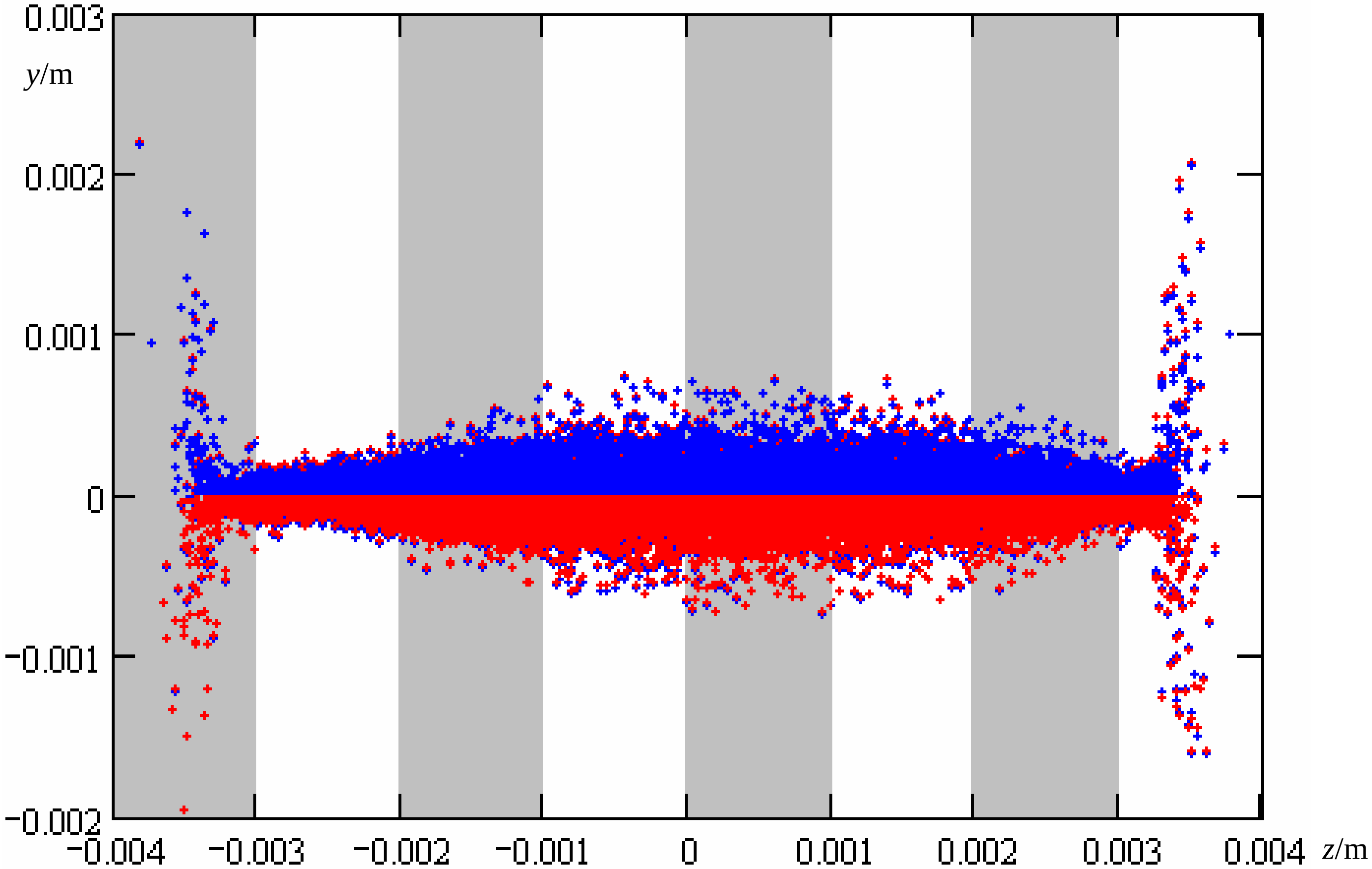

tracking (based on XFEL EXCEL table)

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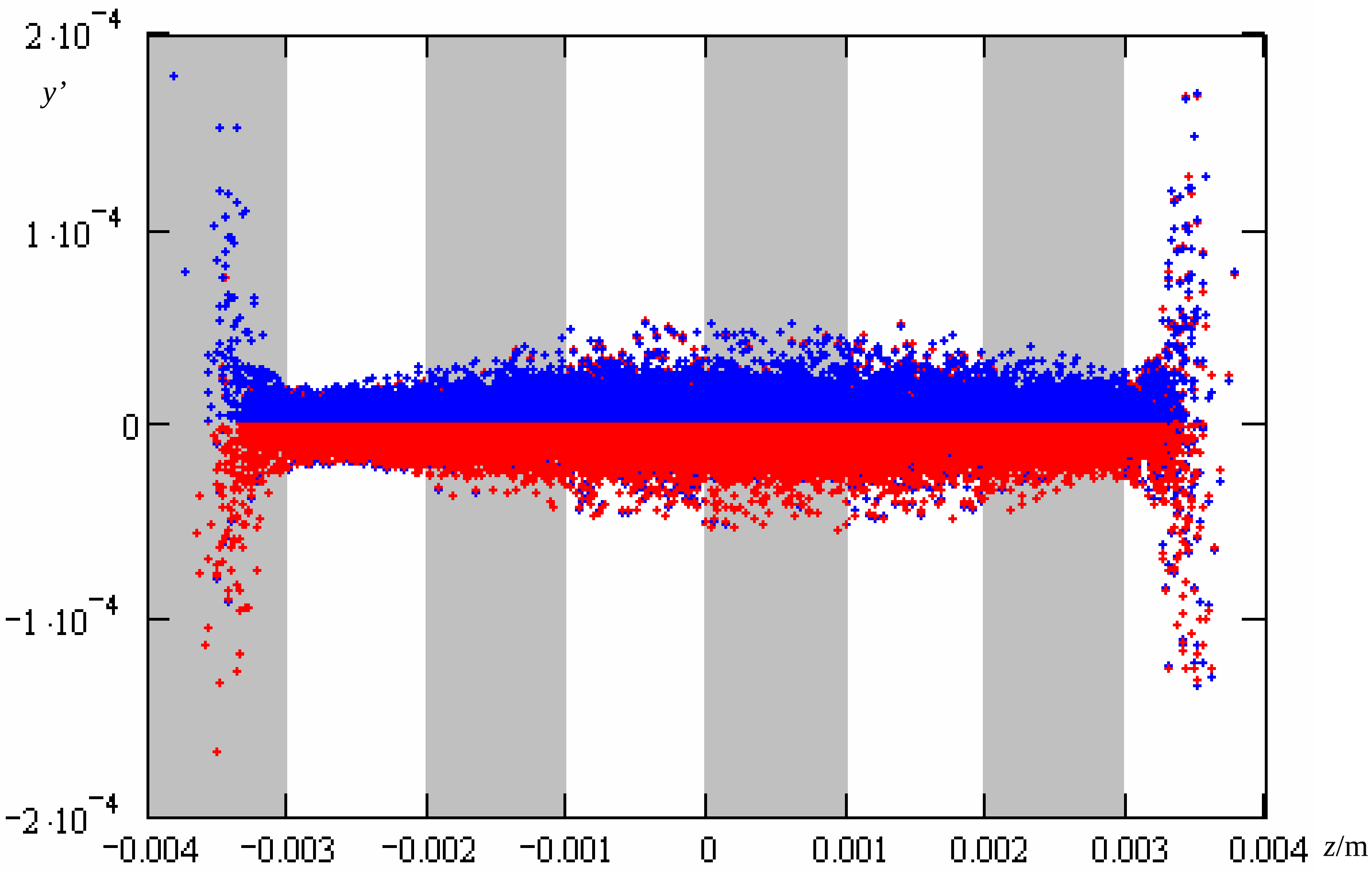

summary

off crest operation of cavities: only “zrot” setup compensates offset independent kick completely; reduction of Re or Im does not help in general!

imprecise & uncertain calculation of rf kick factors
offset independent kicks ~ 5..10 x larger than in TESLA cavities

tracking (based on XFEL EXCEL table)
significant emittance growth for “identical orientation” and yrot setup
below 3% emittance growth for zrot setup even for the worst kick numbers
weak influence of offset dependency

“yrot” setup foreseen in FLASH; effects not investigated here

“zrot” setup recommended for XFEL