High-Precision Field-Maps of TESLA Cavity
some conclusions

computation by W. Ackermann:

- field maps (ASTRA format)
- different resolution, different coupling (pen = 0 ..10mm)
- decay-mode

preparation for ASTRA:

- center of cavity to origin
- conversion to fill-mode and sw-mode
- easy to use --> http://www.desy.de/fel-beam/s2e/codes.html

discrete coupler kicks:

extensive simulations: of XFEL-ACC1, all working-points (20pC .. 1nC)

data reduction: discrete coupler kicks

normalized complex coupler kick

$$\tilde{\mathbf{V}}(x,y) = \int dz \times \left(\mathbf{E}(x,y,z) + c\mathbf{e}_z \mathbf{B}(x,y,z)\right) \exp(j\omega z/c)$$

$$\mathbf{V}(x,y) = \frac{\tilde{\mathbf{V}}(x,y)}{\tilde{V}_z(0,0)}$$

$$V_x(x,y) \approx V_x + V_{x,x}x + V_{x,y}y$$
$$V_y(x,y) \approx V_y + V_{y,x}x + V_{y,y}y$$
$$V_z(x,y) \approx 1 + V_{z,x}x + V_{z,y}y$$

(normalized) coupler kick coefficients

V_x	horizontal kick
V_y	vertical kick
$V_{x,x} = -V_{y,y}$	dipole kick (from Maxwell Eq.)
$V_{x,y} = V_{y,x}$	skew kick (symplecticity)

kicks per coupler

naive upstream/downstream splitting does not work

$$\tilde{\mathbf{V}}(x,y) = \tilde{\mathbf{V}}_{\mathrm{up}}(x,y) + \tilde{\mathbf{V}}_{\mathrm{down}}(x,y)$$

with $\tilde{\mathbf{V}}_{\mathrm{up}}(x,y) = \int_{-\infty}^{\mathrm{center}} \times(\cdots)\exp(j\omega z/c)$

$$\tilde{\mathbf{V}}_{\mathrm{down}}(x,y) = \int_{\mathrm{center}}^{\infty} \times(\cdots)\exp(j\omega z/c)$$

sensitive to position of center (if off axis)

solution: extract monopole part

$$\Delta\mathbf{E} = \mathbf{E}(\mathbf{r}) - \mathbf{E}_m(\mathbf{r})$$

$$\Delta\mathbf{B} = \mathbf{B}(\mathbf{r}) - \mathbf{B}_m(\mathbf{r})$$

with $\mathbf{E}_m(\mathbf{r}) = \frac{1}{2\pi}\int \mathbf{Q}_z(-\varphi)\mathbf{E}_m(\mathbf{Q}_z(\varphi)\mathbf{r})d\varphi$

$$\mathbf{B}_m(\mathbf{r}) = \frac{1}{2\pi}\int \mathbf{Q}_z(-\varphi)\mathbf{B}_m(\mathbf{Q}_z(\varphi)\mathbf{r})d\varphi$$

$$\Delta\tilde{\mathbf{V}}_{\mathrm{up}}(x,y) = \int_{-\infty}^{\mathrm{center}} \times(\Delta\mathbf{E}\cdots\Delta\mathbf{B}\cdots)\exp(j\omega z/c)$$

$$\Delta\tilde{\mathbf{V}}_{\mathrm{down}}(x,y) = \int_{\mathrm{center}}^{\infty} \times(\Delta\mathbf{E}\cdots\Delta\mathbf{B}\cdots)\exp(j\omega z/c)$$

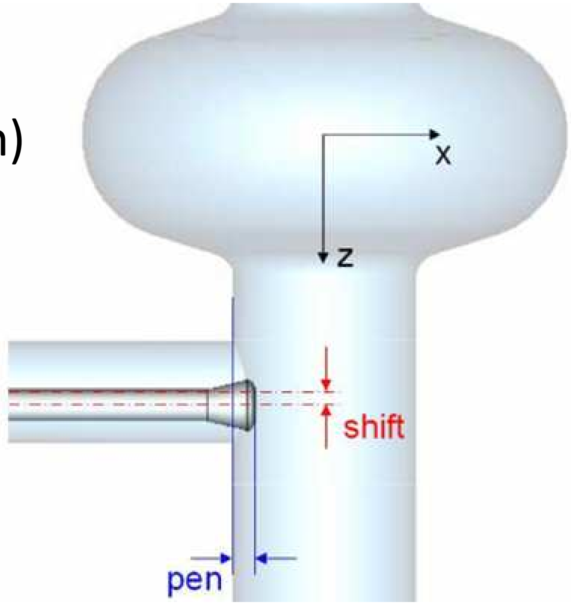
insensitive !

normalization to $\tilde{V}_z(0,0)$!!!

cavity operation

a) penetration depth of power coupler (downstream)

pen/mm	Q_e/1E6
0	12.6
2	8.3
4	5.57
6	3.81
8	2.67
10	1.90



close to standard operation conditions

b) fill mode

decay mode (no forward power), simulated by W.A.

"perfect" fill mode (no reflected power)

standing wave mode

approximation:

$$\mathbf{E}^{\mathrm{SW}} \approx \mathrm{Re}\left\{\mathbf{E}^{\mathrm{decay}}\right\} \qquad \mathbf{E}^{\mathrm{fill}} \approx \mathrm{Re}\left\{\mathbf{E}^{\mathrm{decay}}\right\} - j\,\mathrm{Im}\left\{\mathbf{E}^{\mathrm{decay}}\right\}$$

$$\mathbf{B}^{\mathrm{SW}} \approx j\,\mathrm{Im}\left\{\mathbf{B}^{\mathrm{decay}}\right\} \qquad \mathbf{B}^{\mathrm{fill}} \approx -\mathrm{Re}\left\{\mathbf{B}^{\mathrm{decay}}\right\} + j\,\mathrm{Im}\left\{\mathbf{B}^{\mathrm{decay}}\right\}$$

independent of cavity operation

upstream coupler kick

$$V_x \times 10^6 = -56.80 + j10.76$$
$$V_y \times 10^6 = -41.08 + j0.58$$
$$V_{x,x} \times 10^6 \,\mathrm{mm} = 1.009 - j0.785$$
$$V_{x,y} \times 10^6 \,\mathrm{mm} = 3.456 - j0.422$$

compensation of vertical kick is not bad !

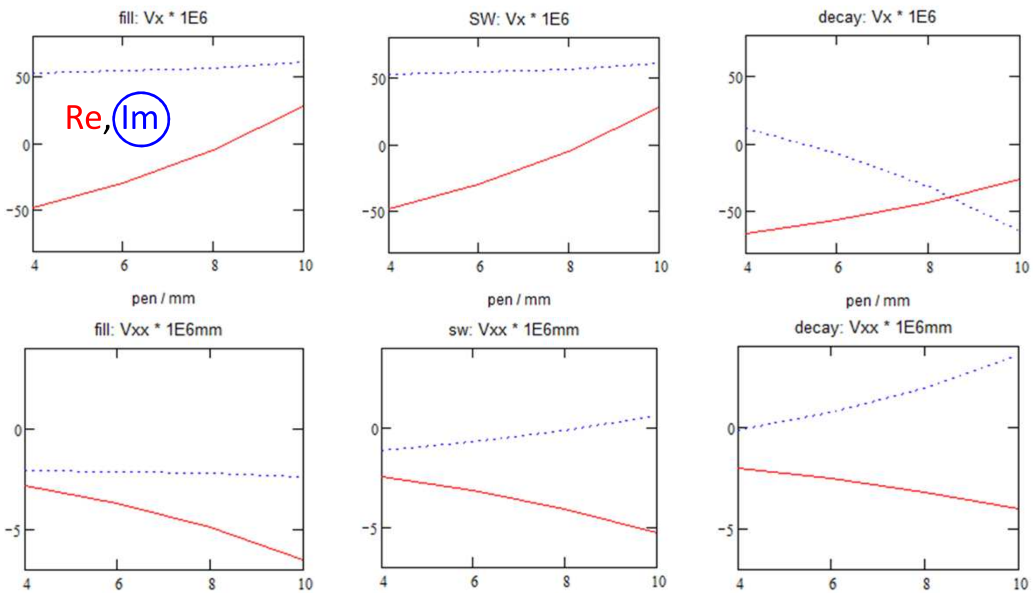
downstream: vertical and skew kick

$$V_y \times 10^6 = 36.55 + j7.95$$
$$V_{x,y} \times 10^6 \,\mathrm{mm} = 2.88 - j0.009$$

dependent on cavity operation

horizontal, downstram – no wonder!

time dependent !



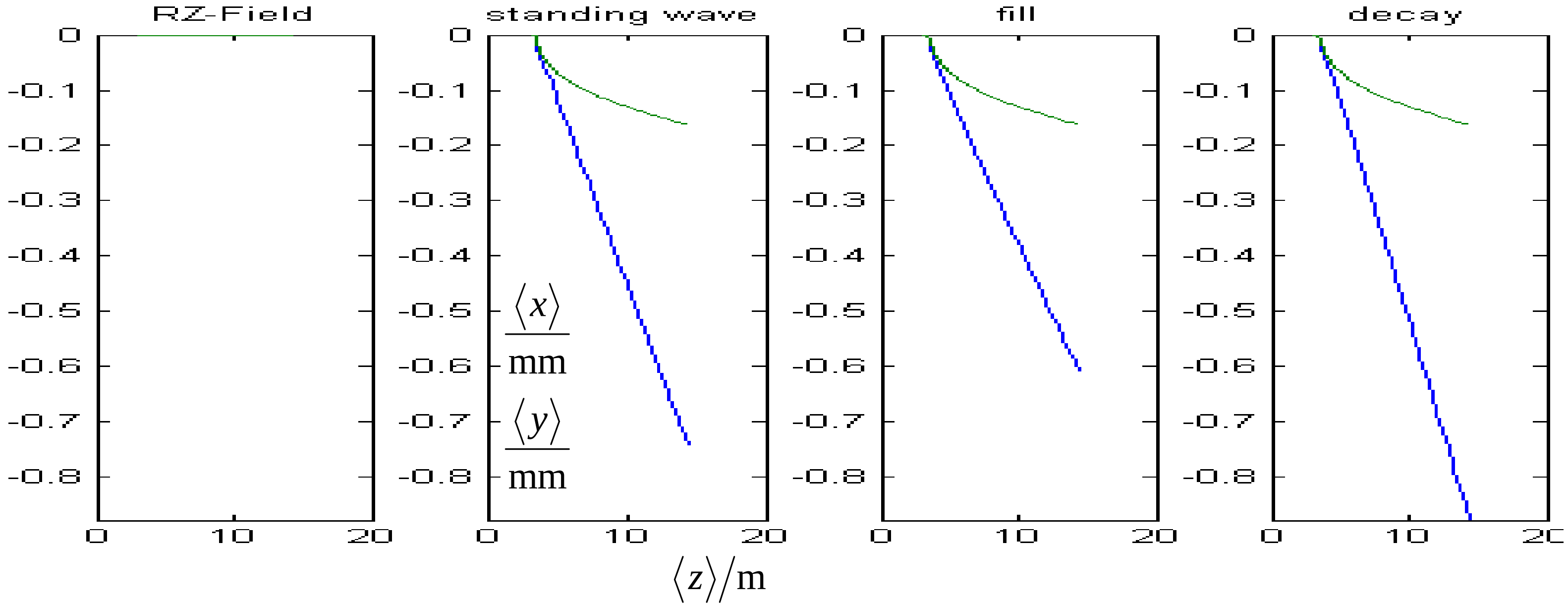
hor. kick, no comp.

dipole kick

beam dynamics simulation with full field map

ASTRA, XFEL-ACC1, 1nC case
penetration depth 8mm

average horizontal and vertical offset



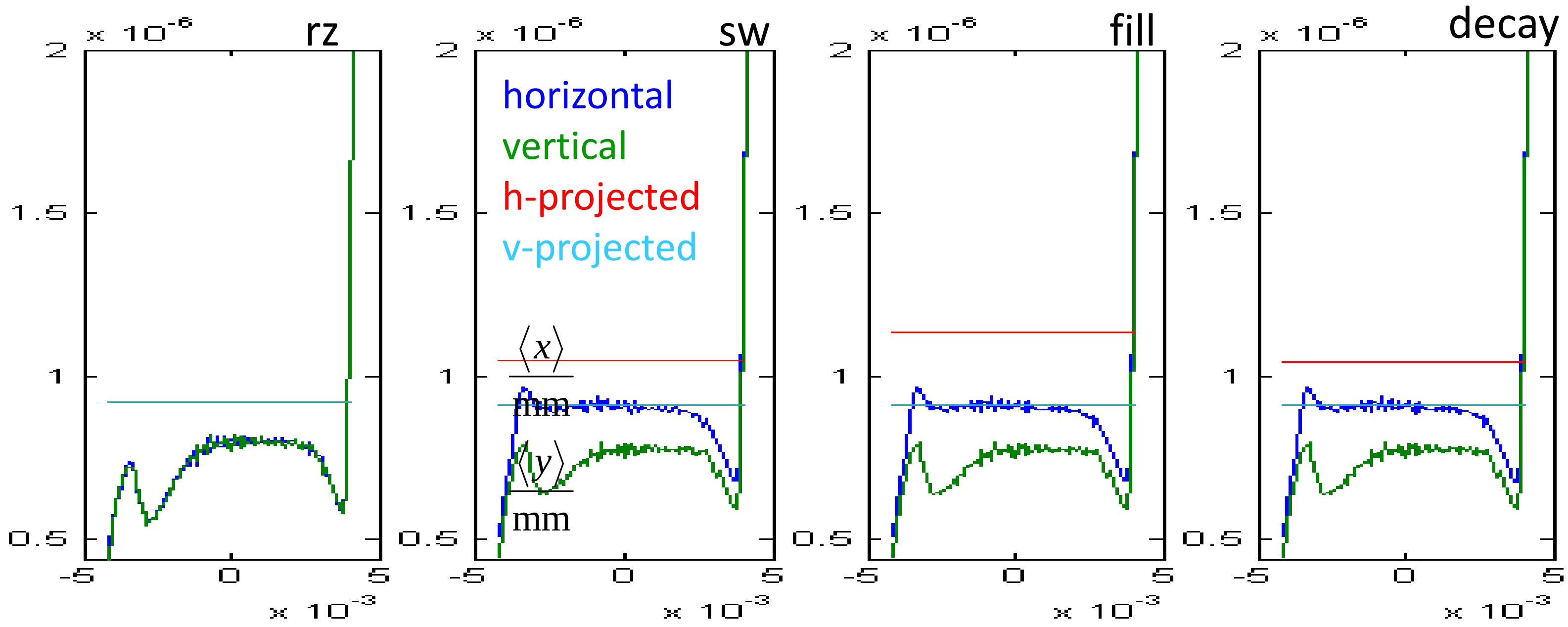
vs. beamline coordinate

length of ACC1 with 8 cavities is ~ 10m

beam dynamics simulation with full field map

ASTRA, XFEL-ACC1, 1nC case
penetration depth 8mm

after ACC1: normalized slice emittance



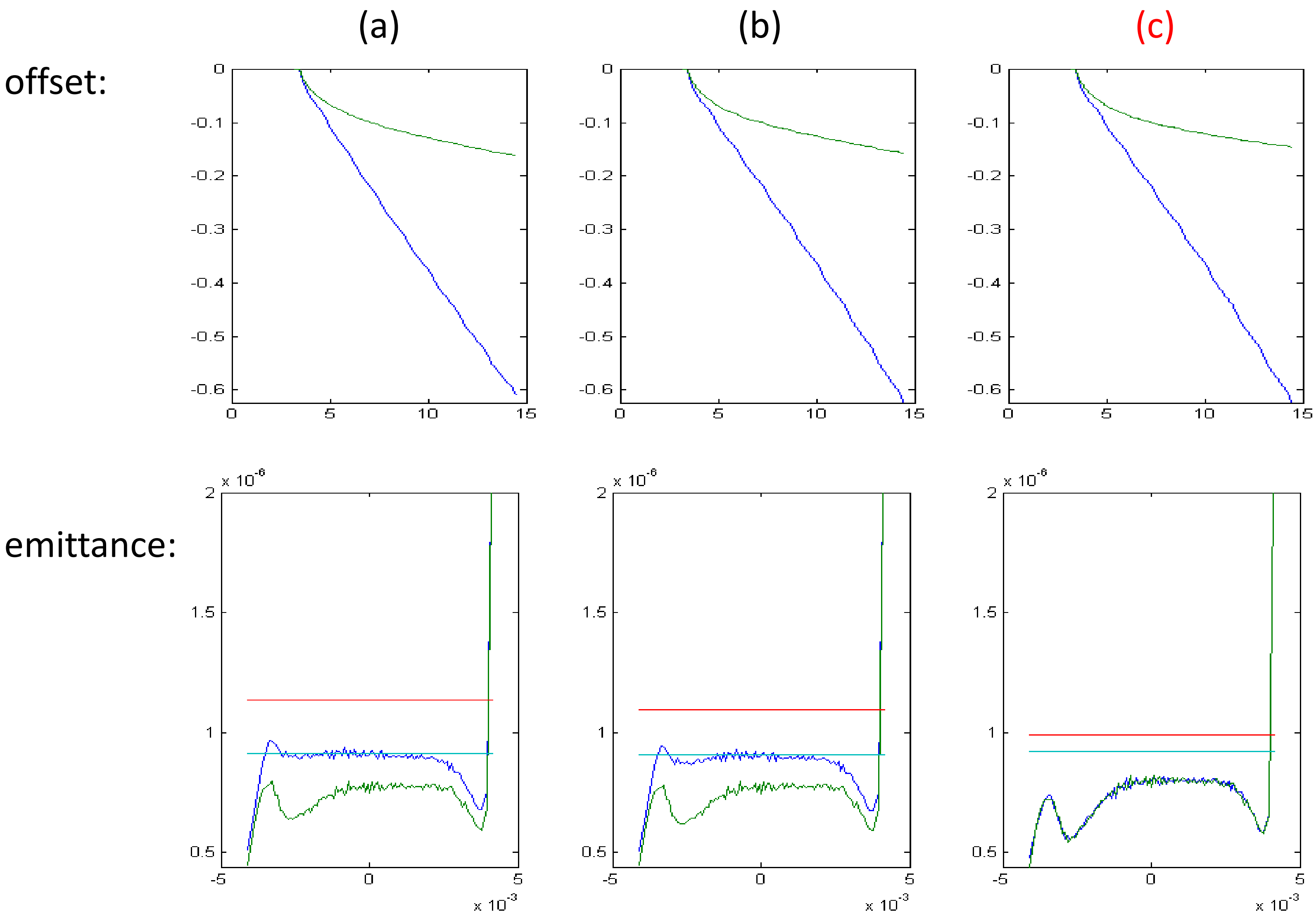
vs. bunch coordinate

comparison

(a) complete 3D fields

(b) rz-field + coupler kicks

(c) rz-field + offset-independent coupler kicks



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discrete coupler kicks:

- upstream/downstream – horizontal/vertical/dipole/skew-kicks
- mode and coupling dependent: downstream: horizontal & dipole

extensive simulations: of XFEL-ACC1, all working-points (20pC .. 1nC)

- 0^{th} order: x_{av}, x'_{av}, y_{av} and y'_{av} depend on mode, coupling and working point
- 1^{st} order: growth of proj. emittance (time- & offset-dependence)
  growth of vert. slice emittance (offset-dependence)