Wakes in 3rd Harmonic RF Modules

FLASH

4 cavities
at ~ 130 MV
~ 4 MV / cavity

single bunch effects
multi bunch effects → Rainer Wanzenberg

XFEL

12 .. 24 cavities
at ~ 500 MV
~ 8 (4) .. 10 MV / cavity

single bunch effects
multi bunch effects

summary

3rd harmonic cavities in FLASH

possible working point

1.3 GHz system: 136.39 MV @ 10.82 deg --> 133.66 MeV
3.9 GHz system: 16 MV @ -176.2 deg --> 118 MeV
BC2 r56 = -165.1 mm --> compression factor = 7
1.3 GHz system: 338.15 MV @ 10.98 deg --> 450 MeV
BC3 r56 = -63.8 mm --> compression factor = 7

(r56 values from TESLA-FEL-06, page9)

sensitivity (10% change of compression)

1.3 GHz system before BC2: $|\Delta V| < 0.76$ MV, $|\Delta\varphi| < 0.025$ deg
3.9 GHz system: $|\Delta V| < 0.83$ MV, $|\Delta\varphi| < 0.075$ deg

transverse effects due to rf

a) cavity

rf focusing and rf kick (due to misalignment) are comparable to TESLA cavity

for large gamma: $V_x \to \frac{x'}{2} V_{\mathrm{acc}}$ (independent on frequency)

b) couplers (scaling)

main coupler: $P = \int (\mathbf{E} \times \mathbf{B}) d\mathbf{A} \to E_\perp^2 r_{\mathrm{pipe}}^2 \propto P \propto V_{acc}$

$$V_\perp = \int (\mathbf{E} + \mathbf{v} \times \mathbf{B})_\perp dz \propto E_\perp \cdot \lambda \propto \sqrt{P} \cdot \frac{\lambda}{r_{\mathrm{pipe}} \propto \lambda} \propto \sqrt{V_{\mathrm{acc}}}$$

4x3rd harm. ~ $4\sqrt{4\mathrm{MV}} \leftrightarrow 2\sqrt{16\mathrm{MV}}$ ~ 2xTESLA

HOM coupler:

? $E_\perp \propto E_{\mathrm{acc}}$

$V_\perp \propto E_{\mathrm{acc}} \cdot \lambda \propto \lambda$ 4x3rd harm. ~ 1.33 x TESLA

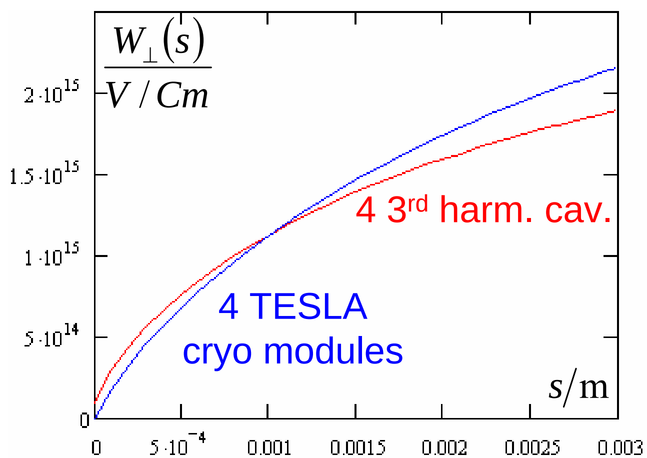
a) cavity

wake field / length scales with fundamental mode frequency ** 3

wake field / cavity scales with fundamental mode frequency ** 2

→ kick of 4 third harmonic cavities corresponds to kicks of 36 TESLA cavities (all between 118 and 134 MeV with a localization that is not long compared to the betatron wavelength)

I. Zagorodnov: TESLA Report 2003-19 (TESLA module)
TESLA Report 2004-01 (LOLA & 3^{rd} harm. cavity)

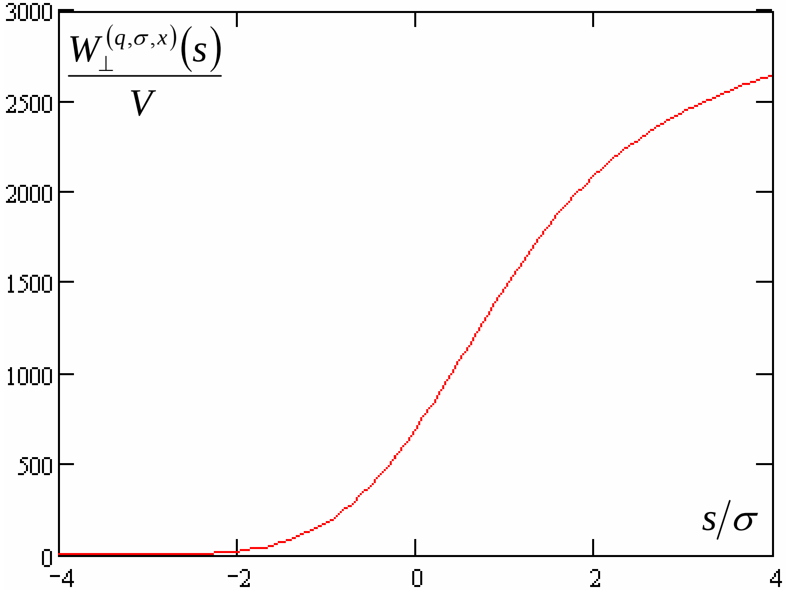


3rd harmonic cavities in FLASH

single bunch effect for $q = 1\,\text{nC}$, $\sigma = 2.4\ \text{mm}$, $x = 1\text{mm}$

(I = 50 A compression to 2.5 kA)

transv. wake of 3rd harm. cavity



$$av\{W_\perp\} = \frac{1}{q}\int W_\perp(s)\lambda(s)ds = 0.8\ \text{kV}$$

$$rms\{W_\perp\} = \sqrt{\frac{1}{q}\int (W_\perp(s) - av\{W_\perp\})^2 \lambda(s)ds} = 0.59\ \text{kV}$$

rms centriod kick:

$$\sqrt{\overline{x_c' x_c'}} \approx \frac{rms\{W_\perp^{q,\sigma,x}\}}{V_\parallel} = \frac{0.59\ \text{kV}}{118\ \text{MV}} = 5\ \mu\text{rad}$$

emittance growth due to centriod kick:
(for $\overline{x_c x_c'} = 0,\ \overline{x_c x_c} = 0$)

$$\tilde{\varepsilon} \approx \varepsilon\sqrt{1 + \frac{\beta}{\varepsilon}\left(\overline{x_c' x_c'}\right)}$$

$$\varepsilon = \frac{2\ \mu\text{m}}{\gamma_L = 235} \qquad \beta \approx 20\ \text{m} \qquad \rightarrow \tilde{\varepsilon} \approx 1.03\,\varepsilon$$

$$\varepsilon = \frac{1\ \mu\text{m}}{\gamma_L = 235} \qquad \rightarrow \tilde{\varepsilon} \approx 1.06\,\varepsilon$$

3rd harmonic cavities in FLASH

multi bunch effects

Higher Order Mode Measurements in Superconducting Accelerating Cavities

22-23 January 2007 | DESY, Hamburg

Asymptotic and rms Kicks due to HOMs in 3.9 GHz cavity

Id: 18
Place: *DESY, Hamburg*

Notkestrasse 85
22607 Hamburg
GERMANY

Room: Bldg. 24, Rm 200
Starting date: 22-Jan-2007 14:00
Duration: 25'
Primary Authors: **Dr. WANZENBERG, Rainer** (DESY)
Presenters: Dr. WANZENBERG, Rainer
Material: Slides

Conclusions

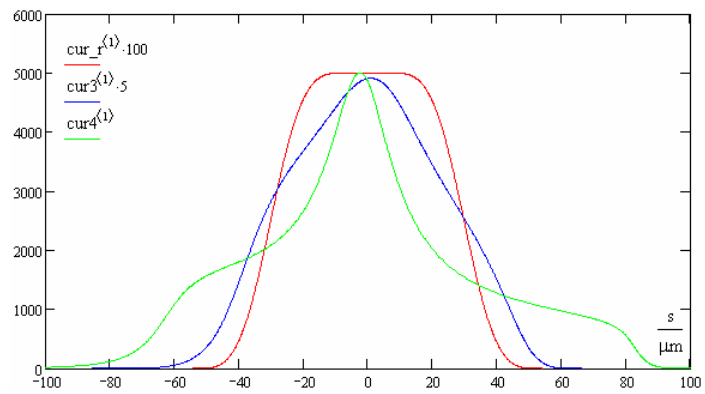
- The kicks due to HOMs in the 3.9 GHz cavity have been calculated for a constant offset of all bunches
- Analytic formulas have been obtain for different cases
  1. Asymptotic kick
  2. Average and rms kick
  3. Average and rms kick with no damping
  4. Average and rms kick with no damping and many bunches $N \to \infty$
- Even an small dumping constant seems to be acceptable, if only short bunch trains are used (say < 100 bunches) Further investigations are required
- The operation with long bunch trains require HOM dampers
- A possible solution if one hits a HOM resonce:
  a small change in the bunch-to-bunch spacing (one 1.3 GHz bucket), say 3903 instead 3900 free 3.9 GHz buckets gives a large change of phase δ)

3rd harmonic cavities in XFEL

12 .. 24 cavities ~ 90 .. 250 MV
(~ 8 .. 10 MV / cavity)

possible working point

1.3 GHz system: 130 MV @ 0 deg --> 130 MeV
447.5 MV @ 0.74 deg --> 577.5 MeV
3.9 GHz system: 97.3 MV @ -142.2 deg --> 500 MeV
BC2 r56 = -103.5 mm --> compression factor = 20
1.3 GHz system: 1500 MV @ 0 deg --> 2000 MeV
BC3 r56 = -20.7 mm --> compression factor = 5



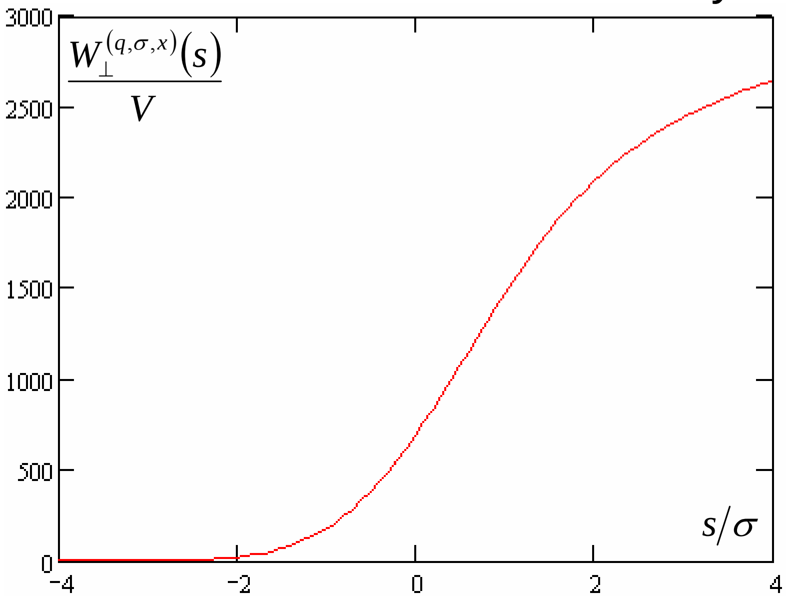
sensitivity (10% change of compression)

1.3 GHz system before BC2: |ΔV| < 0.19 MV, |Δφ| < 0.023 deg
3.9 GHz system: |ΔV| < 0.071 MV, |Δφ| < 0.060 deg

3rd harmonic cavities in XFEL

single bunch effect for $q = 1\,\mathrm{nC}$, $\sigma = 2.4$ mm, $x = 1$mm
(I = 50 A compression to 5 kA), 12 / 24 cavities

transv. wake of 3rd harm. cavity



$$av\{W_\perp\} = \frac{1}{q}\int W_\perp(s)\lambda(s)ds = 2.4\ /\ 4.8\ \mathrm{kV}$$

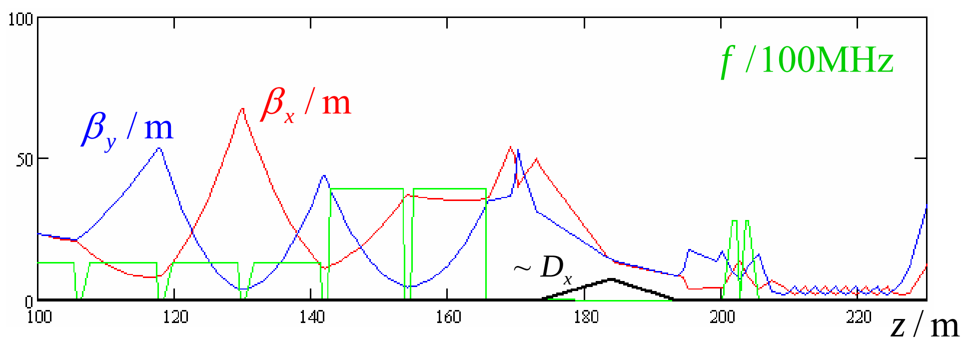
$$rms\{W_\perp\} = \sqrt{\frac{1}{q}\int \left(W_\perp(s) - av\{W_\perp\}\right)^2 \lambda(s)ds} = 1.76\ /\ 3.5\ \mathrm{kV}$$

rms centriod kick:

$$\sqrt{\overline{x_c' x_c'}} \approx \frac{rms\{W_\perp^{q,\sigma,x}\}}{V_\parallel} = \frac{\cdots}{500\ \mathrm{MV}} = 3.5\ /\ 7.0\ \mu\mathrm{rad}$$

emittance growth due to centriod kick: $\tilde{\varepsilon} \approx \varepsilon\sqrt{1 + \frac{\beta}{\varepsilon}\left(\overline{x_c' x_c'}\right)}$
(for $\overline{x_c x_c'} = 0$, $\overline{x_c x_c} = 0$)

$$\varepsilon = \frac{1\,\mu\mathrm{m}}{\gamma_L = 978}$$



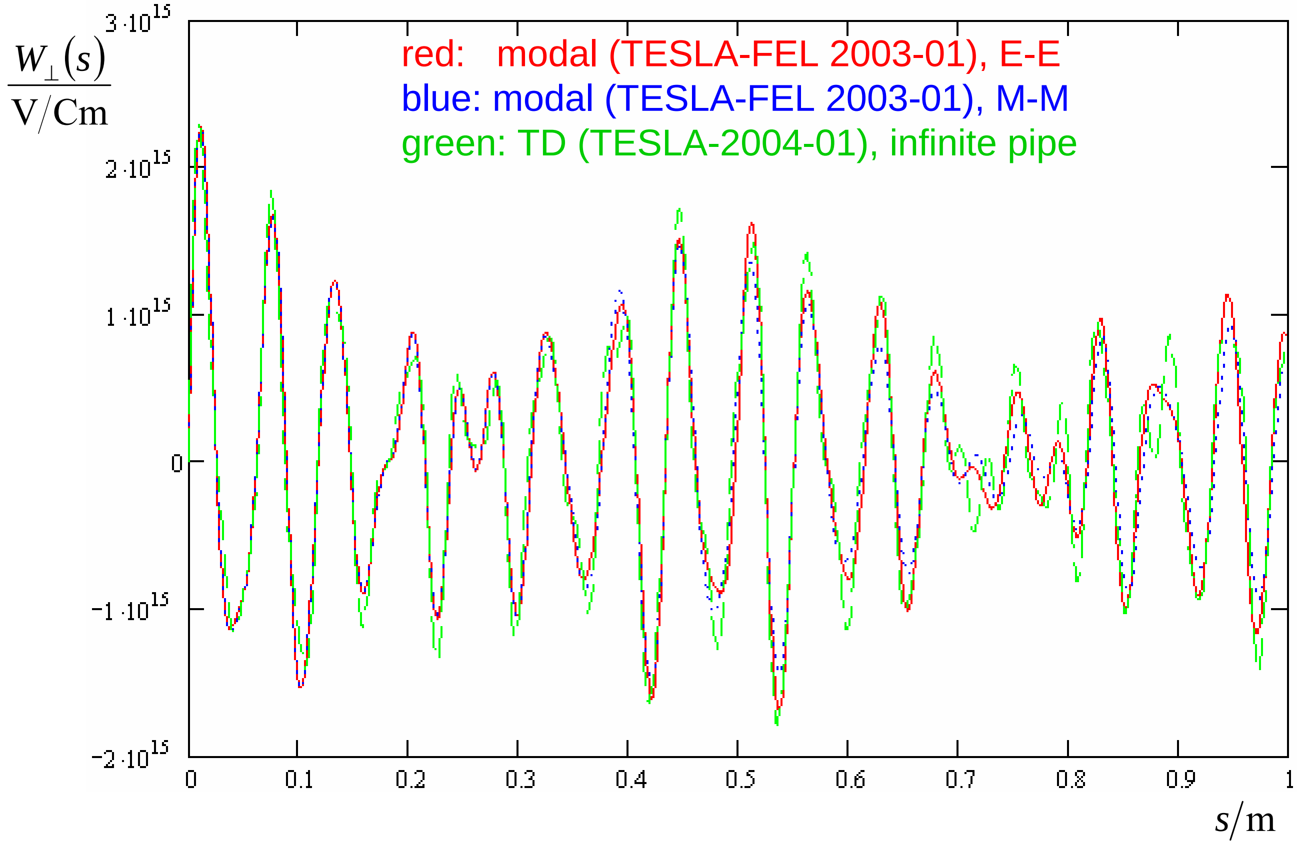
$$\beta \approx 40\ \mathrm{m}$$

$$\rightarrow \tilde{\varepsilon}\cdot\gamma_L \approx 1.22\ /\ 1.72\ \mu\mathrm{m}$$

(BC1@400MeV → ε = 1.27/1.85)

short range ---> longer ---> longer ---> multi-bunch

transv. wake of **four** 3rd harm. cavities

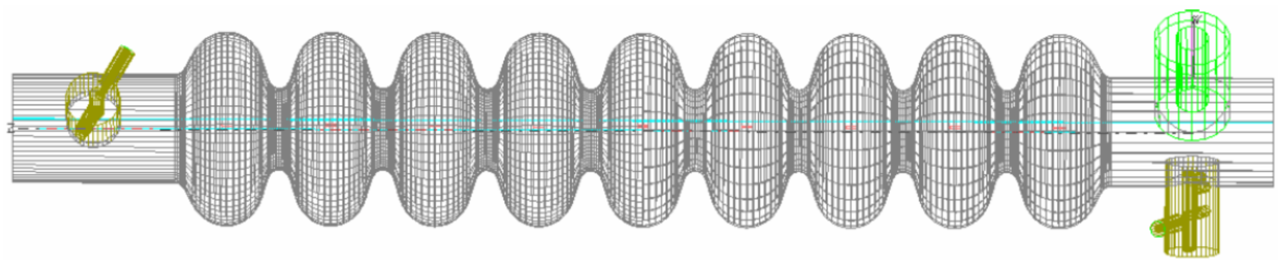


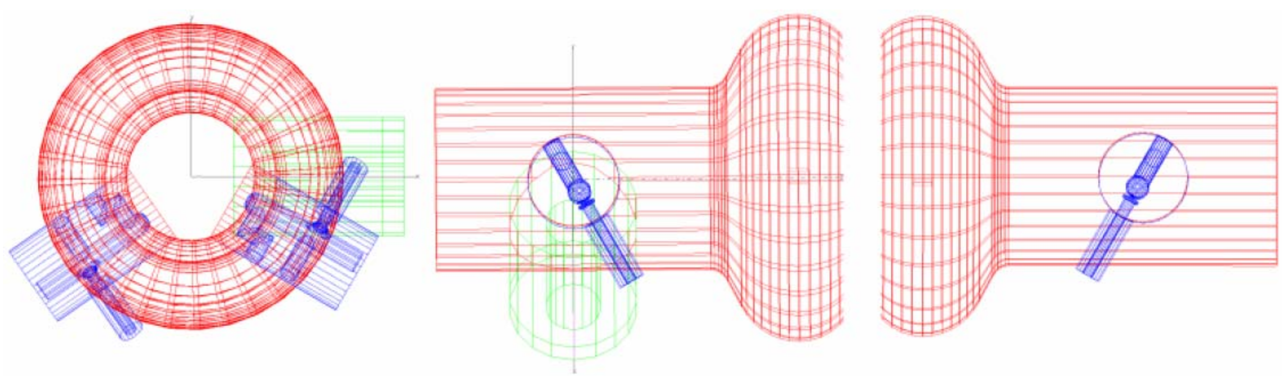
bunch distance:	30 m	or	1nC & 10mA
	60 m		5mA
	300 m		1mA

FERMILAB-TM-2210
TESLA-FEL 2003-01, May 2003

Higher Order Modes of a 3rd Harmonic Cavity with an Increased End-cup Iris

T. Khabibouline N. Solyak R.Wanzenberg





r_{pipe} =20 mm
cutoff frequencies:

dipoles
4.4 GHz (TM)
9.1 GHz (TE)

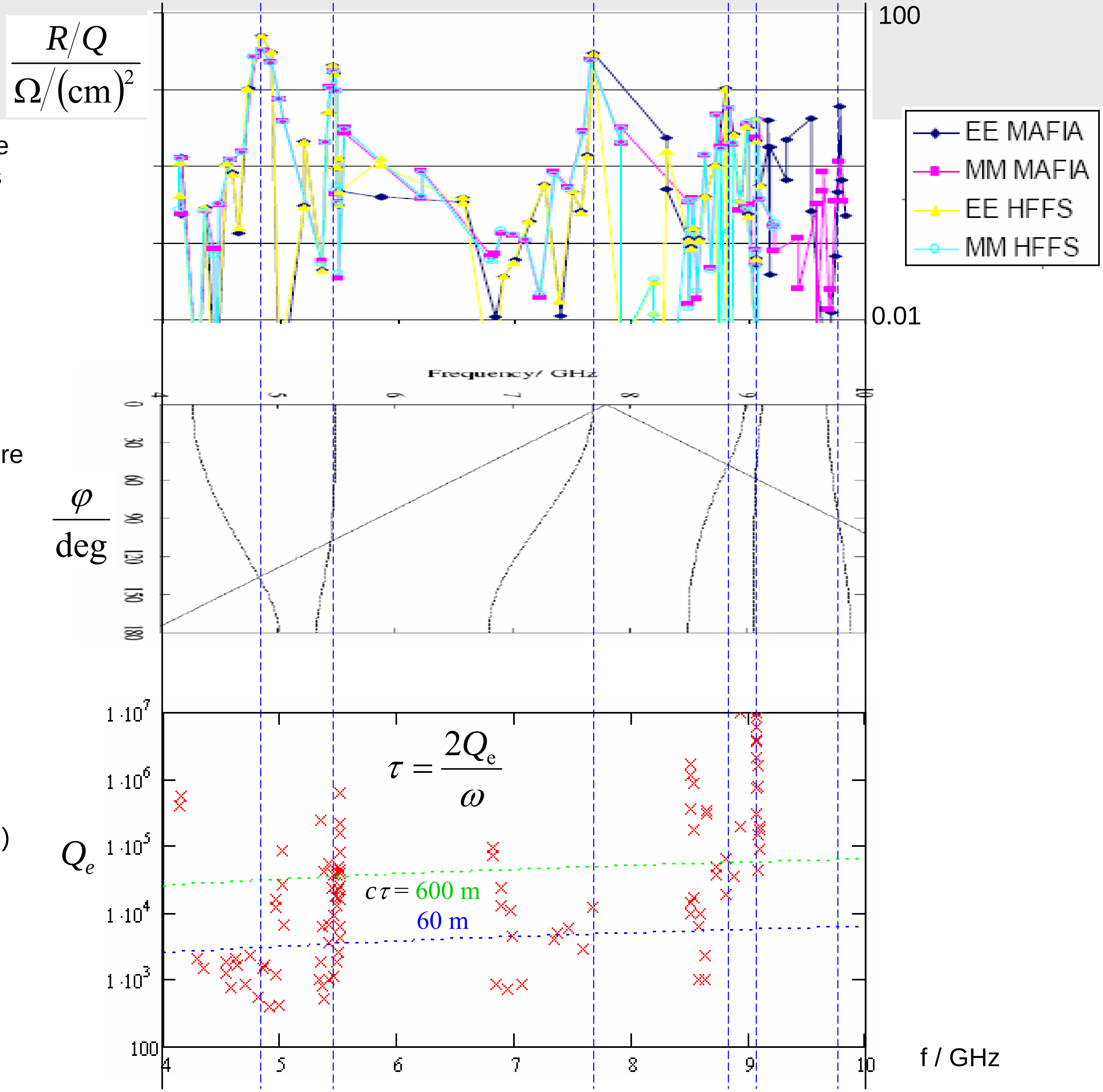
monopole
5.7 GHz (TM)
9.1 GHz (TE)

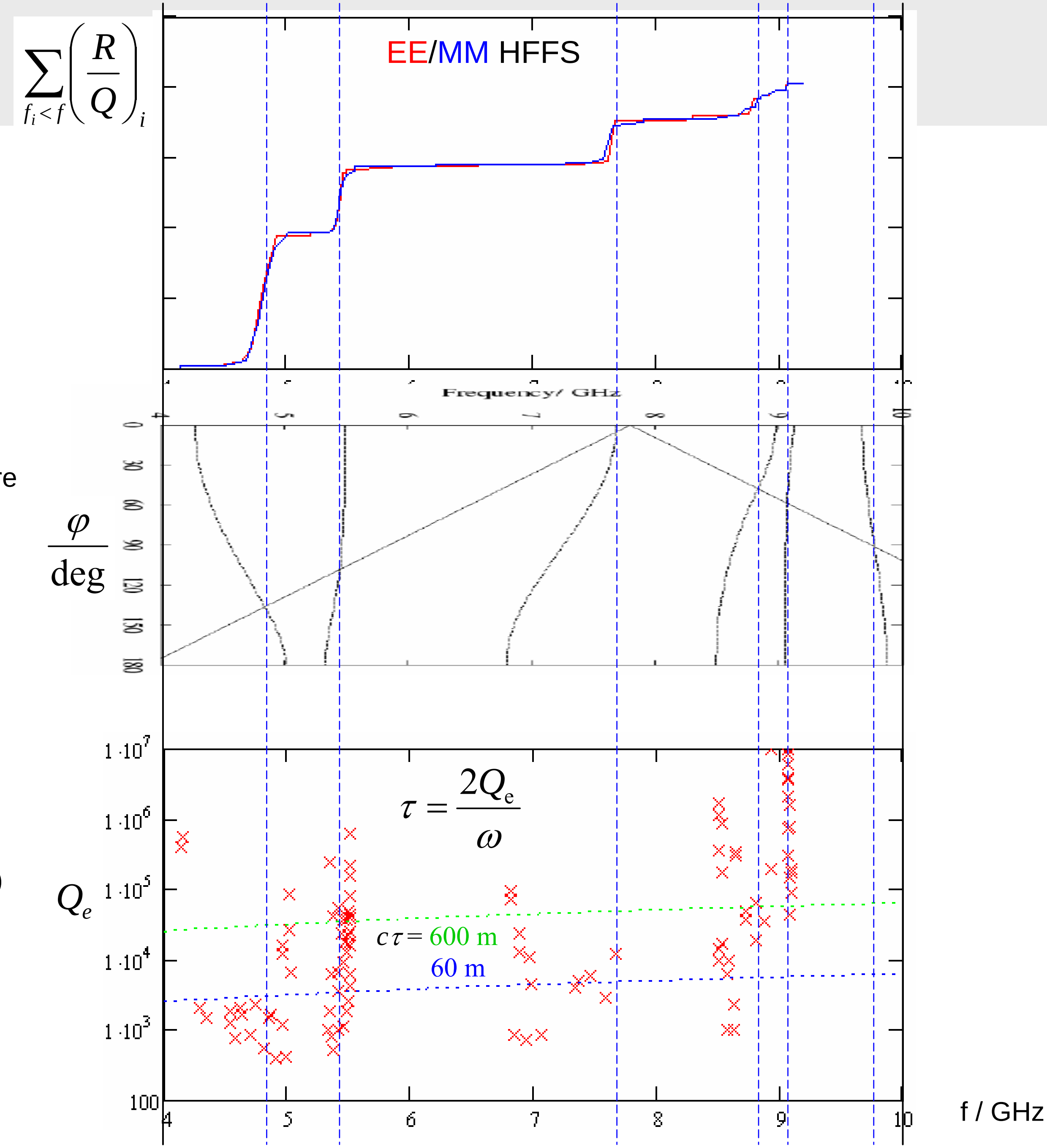
shunt impedance
of dipole modes

phase advance
in periodic structure
of middle cells

quality

(HFSS calc.
with ee or mm
boundary cond.)





phase advance
in periodic structure
of middle cells

quality
(HFSS calc.
with ee or mm
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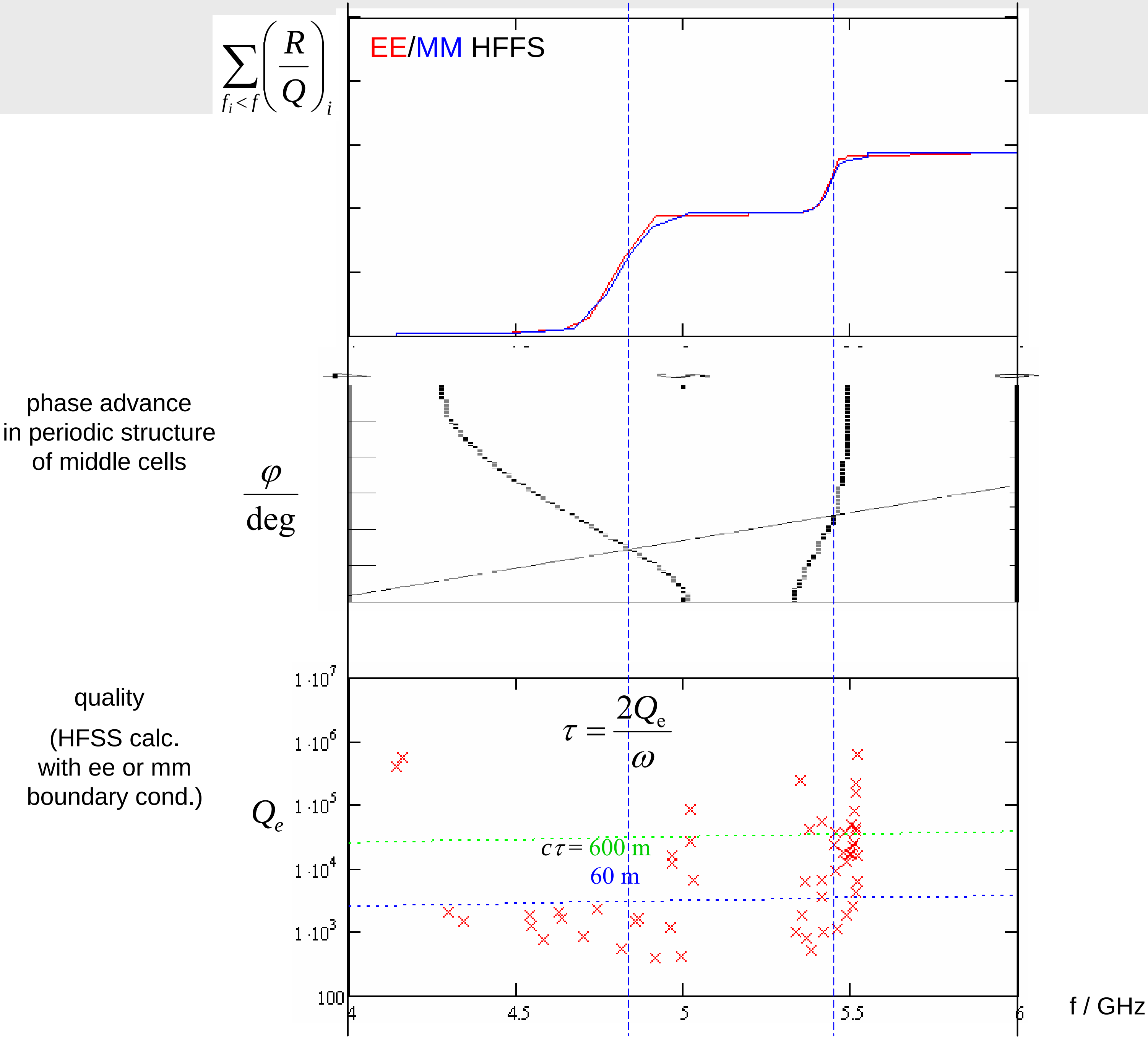
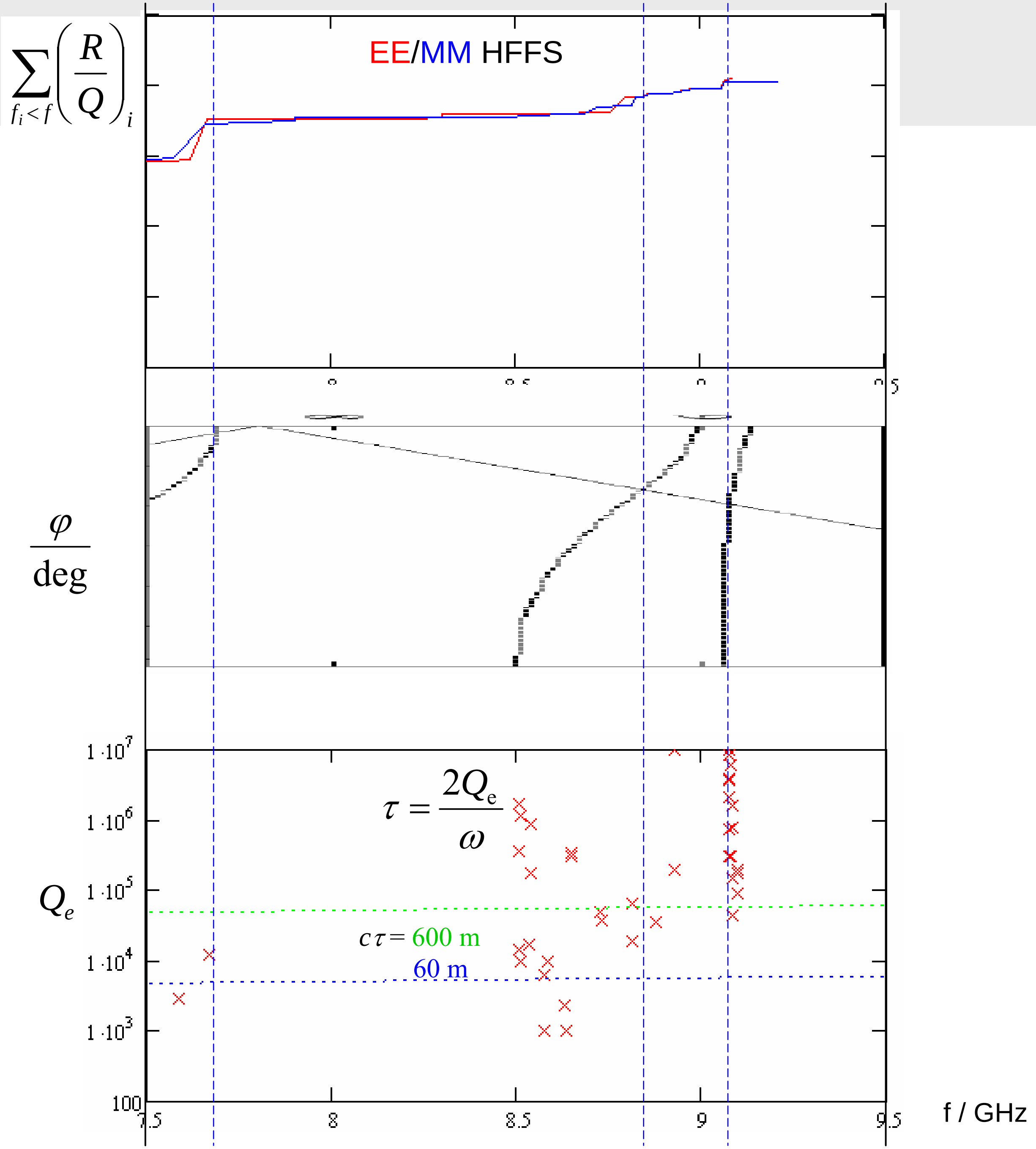


$\sum_{f_i<f}\left(\frac{R}{Q}\right)_i$
EE/MM HFFS
phase advance
in periodic structure
of middle cells
$\frac{\varphi}{deg}$
quality
(HFSS calc.
with ee or mm
boundary cond.)
Q_e
$1\cdot10^7$
$1\cdot10^6$
$1\cdot10^5$
$1\cdot10^4$
$1\cdot10^3$
100
$\tau=\frac{2Q_e}{\omega}$
$c\tau=$ 600 m
60 m
4
4.5
5
5.5
6
f / GHz

phase advance in periodic structure of middle cells

quality

(HFSS calc. with ee or mm boundary cond.)



XFEL summary

number of cavities & possible gradient have to be determined
(so far $\geq$ 100 MV assumed for optimization of WP)

the knowledge of limitations (as gradient, r56 range etc.)
is substantial for further optimizations

single bunch: significant growth of projected emittance
(for 1 mm beam offset to structure axis)
$\rightarrow$ alignment & optics

all dipole modes above fc, most modes are well damped
no investigation of multi-bunch effects (so far)