HOM Studies in the TESLA Cavities with Intensity Modulated Beam

Nicoleta Baboi, DESY, Hamburg

Studies with Intensity Modulated Beams

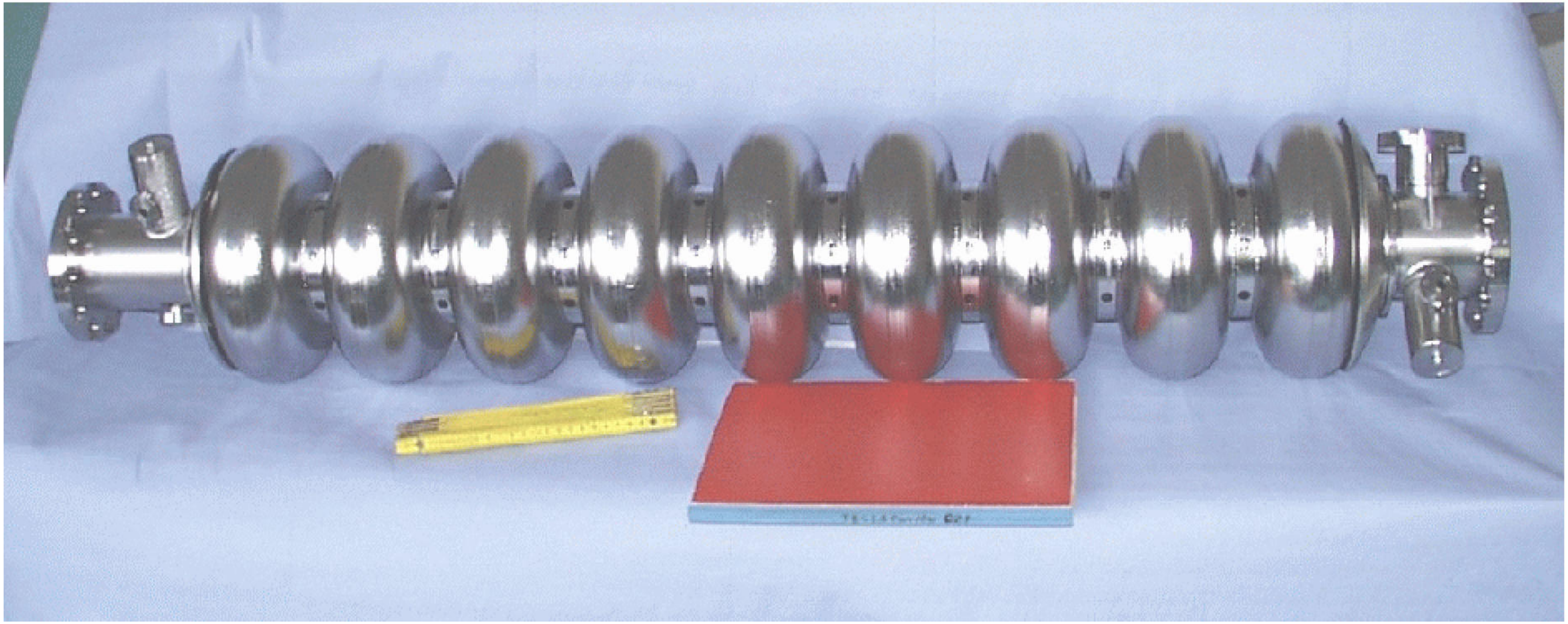
- Proposed by S. Fartoukh
- Some of the first measurements on HOMs with beam
  - 1998-2002
- performed in the TESLA cavities and later in the superstructures (tested at TTF)

- Performed at the TESLA Test Facility
  - meanwhile partially user facility :FLASH (previously VUV-FEL)

The TESLA cavity

- 1 m long, 9-cell
- 1.3 GHz (π mode)
- standing waves

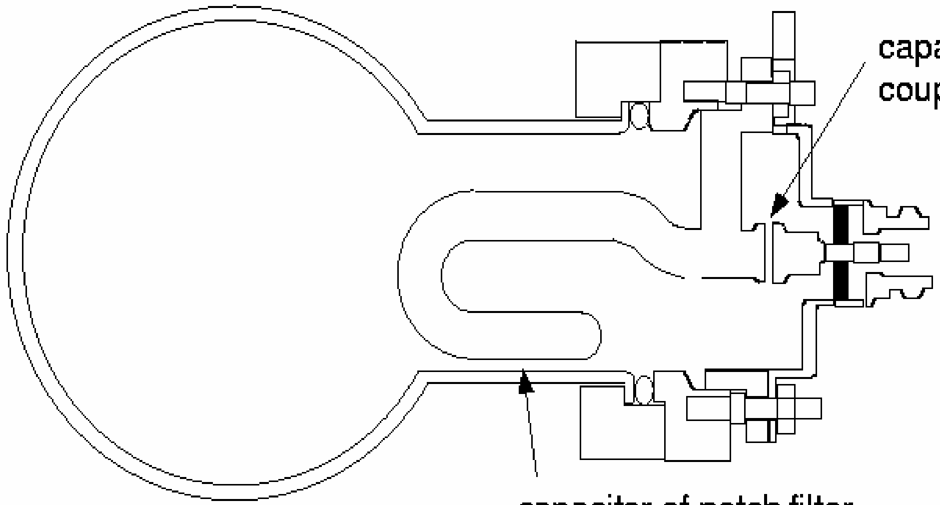
- 2 HOM coupler for damping, at either side, at 115 deg



HOM damping

- Extract mode energy ⇒
  - reduce Q
  - reduce damping time $$\tau = \frac{2Q}{\omega}$$

- with HOM couplers



Higher Order Modes (HOMs)

- The long range wakefield = ∑ resonant fields (HOMs)
- Transverse dipole wakefield:

$$W_\perp^\delta(\zeta) = \sum_l 2k_l \frac{c}{\omega_l} \sin\left(\omega_l \frac{\zeta}{c}\right) \exp\left(-\frac{\omega_l}{2Q_l}\frac{\zeta}{c}\right)$$

($\zeta > 0$)
l: HOM index

loss factor — frequency — quality factor

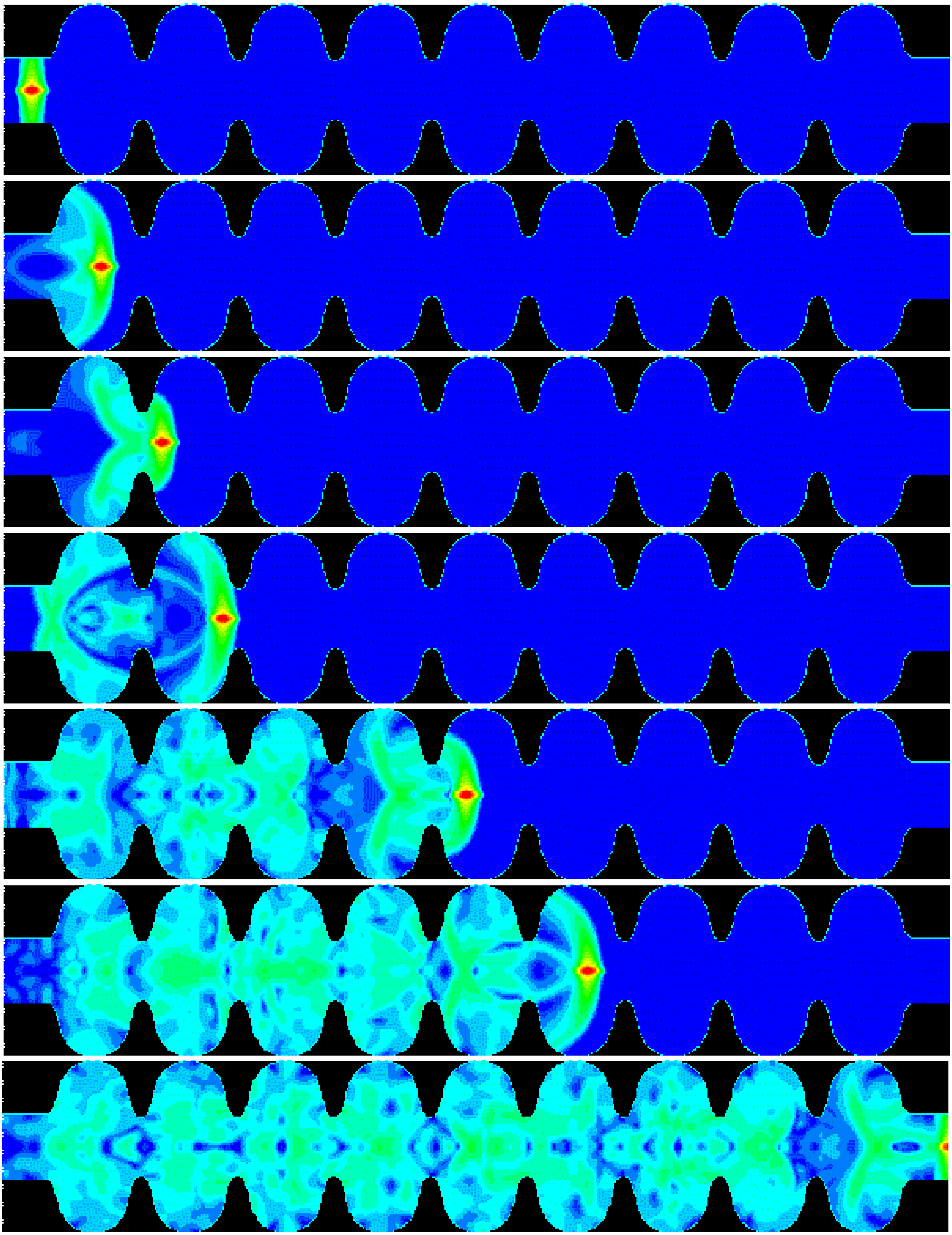
$$k_{\perp l} = \frac{|V_l|^2}{4W_l a^2} \Leftrightarrow \left(\frac{R}{Q}\right)_l = \frac{4k_l}{\omega_l}$$

(for dipole modes)

$$Q_l = \frac{\omega_l W_l}{P_{\mathrm{loss}\,l}} \Rightarrow \tau_l = \frac{2Q_l}{\omega_l}$$

- Calculated with the help of simulation programs (MAFIA, URMEL)

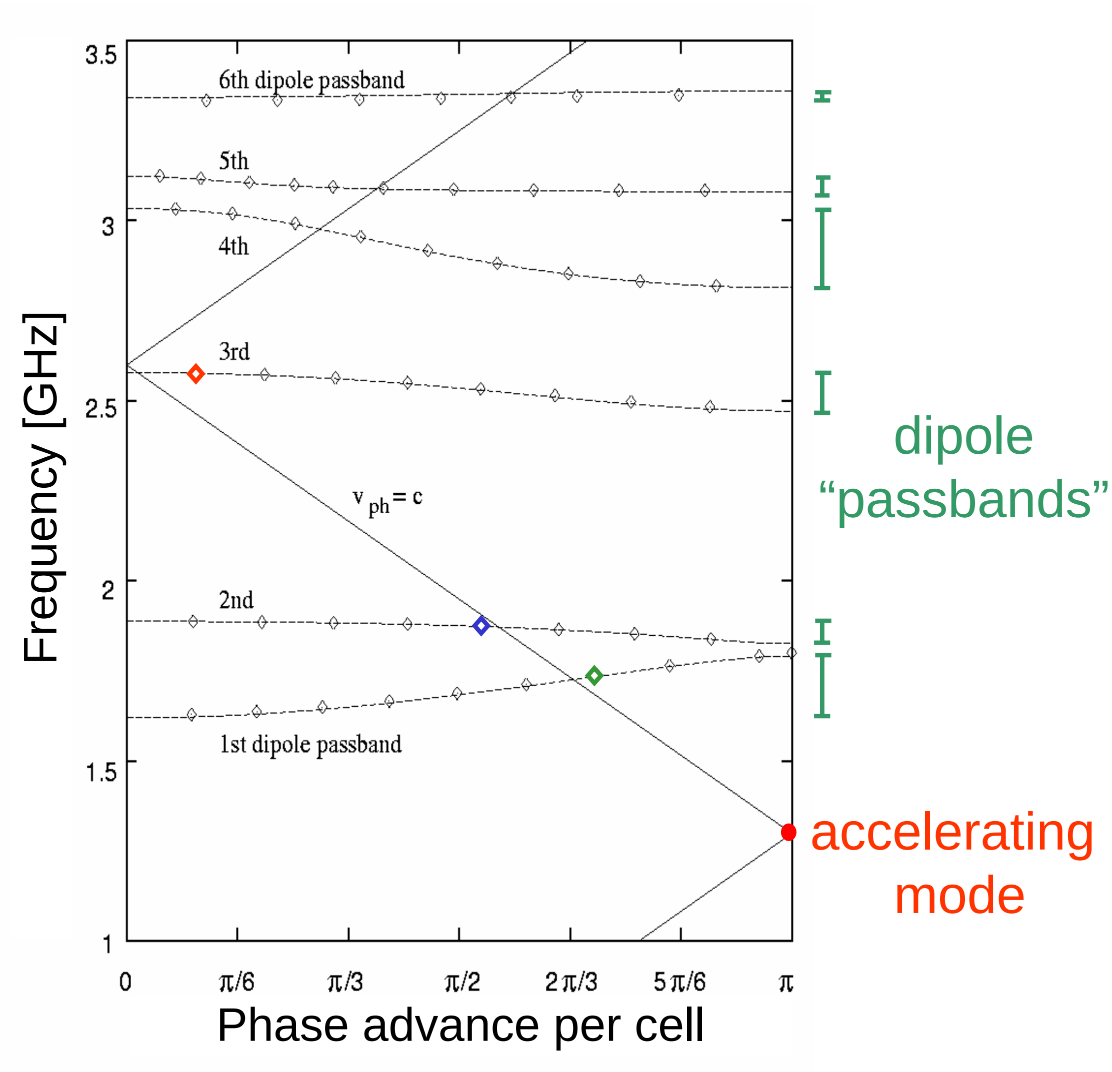
Wake fields in TESLA cavities



R. Wanzenberg

Wakefields and Dipole modes

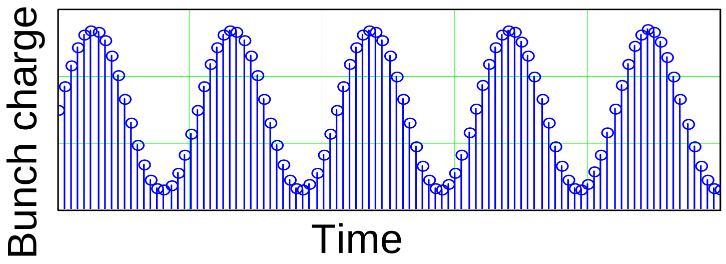
Dispersion diagram

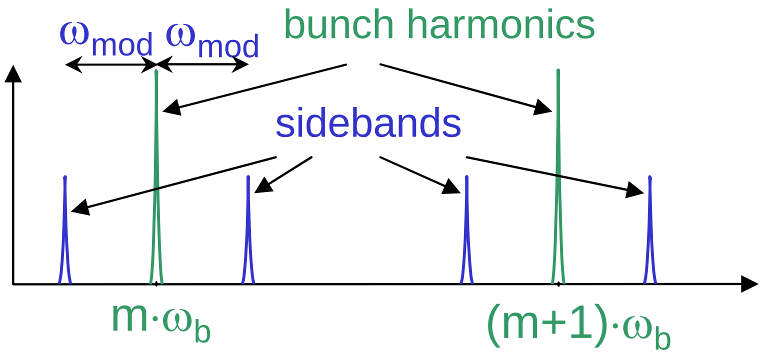


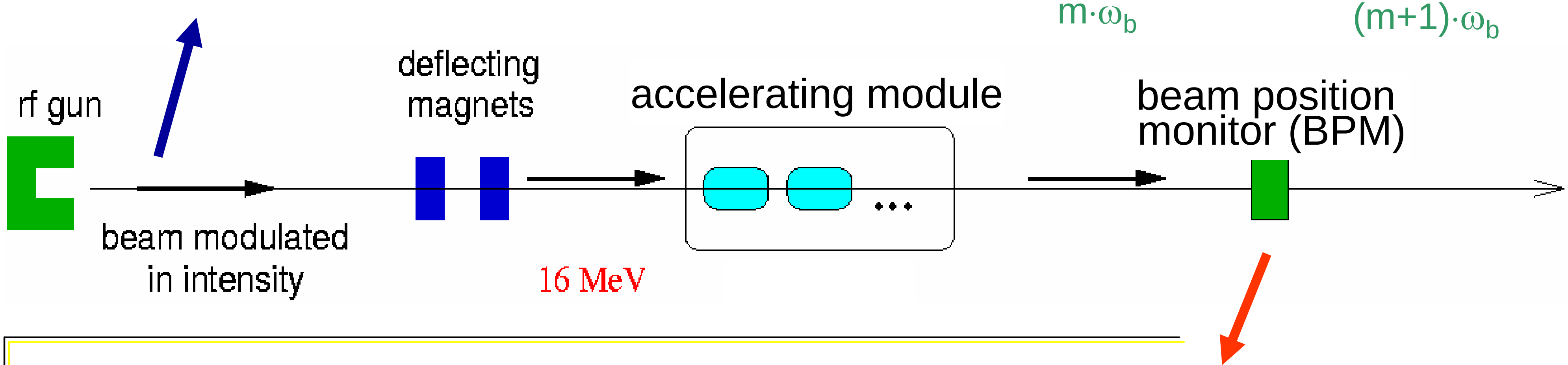
Modes with highest R/Q

$\omega_l/2\pi$ [GHz] (measurement)	$(R/Q)_l$ [Ω/cm^2] (simulation)	Q_l (measurement)
1st dipole passband		
1.6506	0.76	$7.0 \cdot 10^4$
1.6991	11.21	$5.0 \cdot 10^4$
1.7252	15.51	$2.0 \cdot 10^4$
1.7545	2.16	$2.0 \cdot 10^4$
1.7831	1.75	$7.5 \cdot 10^3$
2nd dipole passband		
1.7949	0.77	$1.0 \cdot 10^4$
1.8342	0.46	$5.0 \cdot 10^4$
1.8509	0.39	$2.5 \cdot 10^4$
1.8643	6.54	$5.0 \cdot 10^4$
1.8731	8.69	$7.0 \cdot 10^4$
1.8795	1.72	$1.0 \cdot 10^5$
3rd dipole passband		
2.5630	1.05	$1.0 \cdot 10^5$
2.5704	0.50	$1.0 \cdot 10^5$
2.5751	23.80	$5.0 \cdot 10^4$

Excitation of single modes



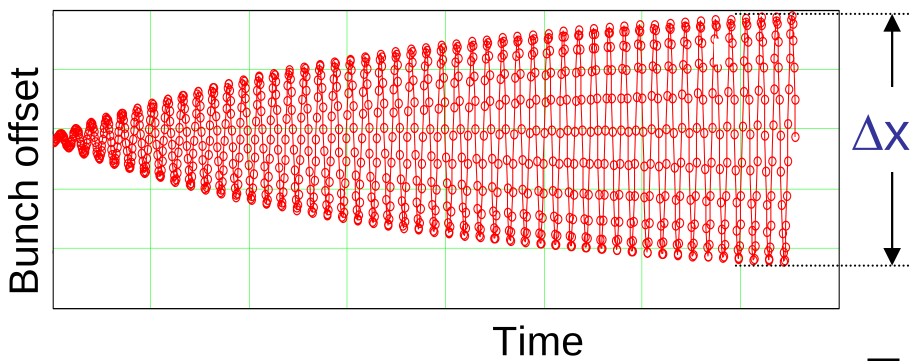




If $\omega_{\text{mod}} = \left|\omega_l - m\cdot\omega_b\right| \leq \omega_b/2$:

$$\Delta x'_{res\max} = c\frac{e}{E}\delta x_0\left(q_0\frac{\omega_b}{2\pi}\right)\lambda\frac{1}{\omega_l}\left(\left(\frac{R}{Q}\right)Q\right)_l$$

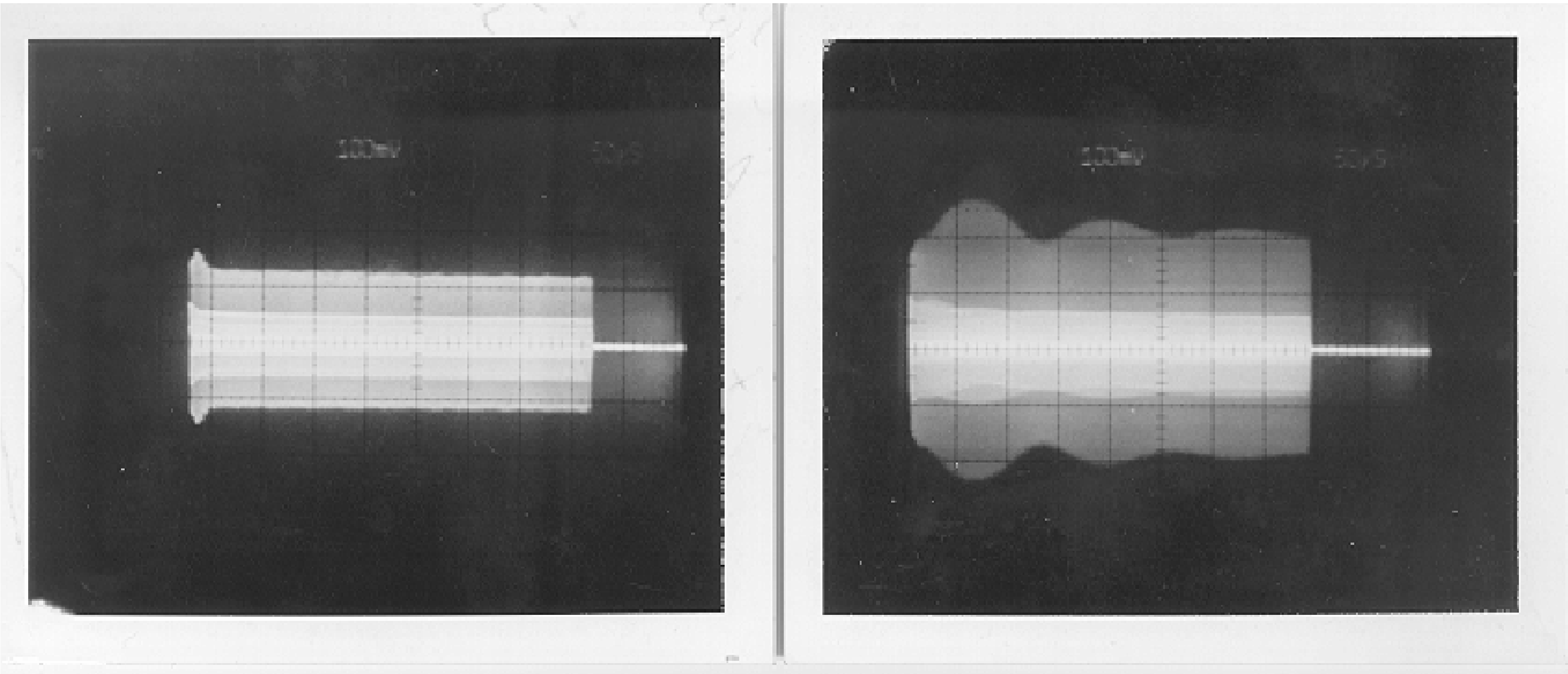
(for long bunch trains)



High-Q mode found

- High-Q mode in the 3rd dipole passband excited resonantly by a beam with modulated intensity
  - $\omega_l/2\pi$ = 2.584 GHz, $(R/Q)_l$ = 23.8 Ω/cm^2, $Q_l = 10^6$

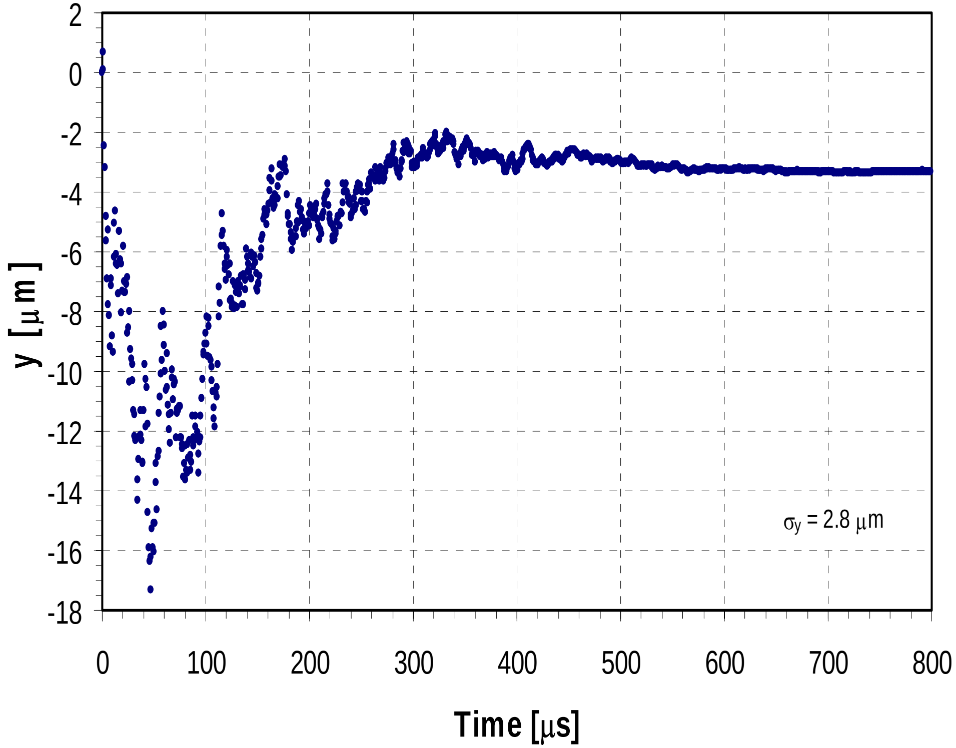
no HOM resonance HOM resonance

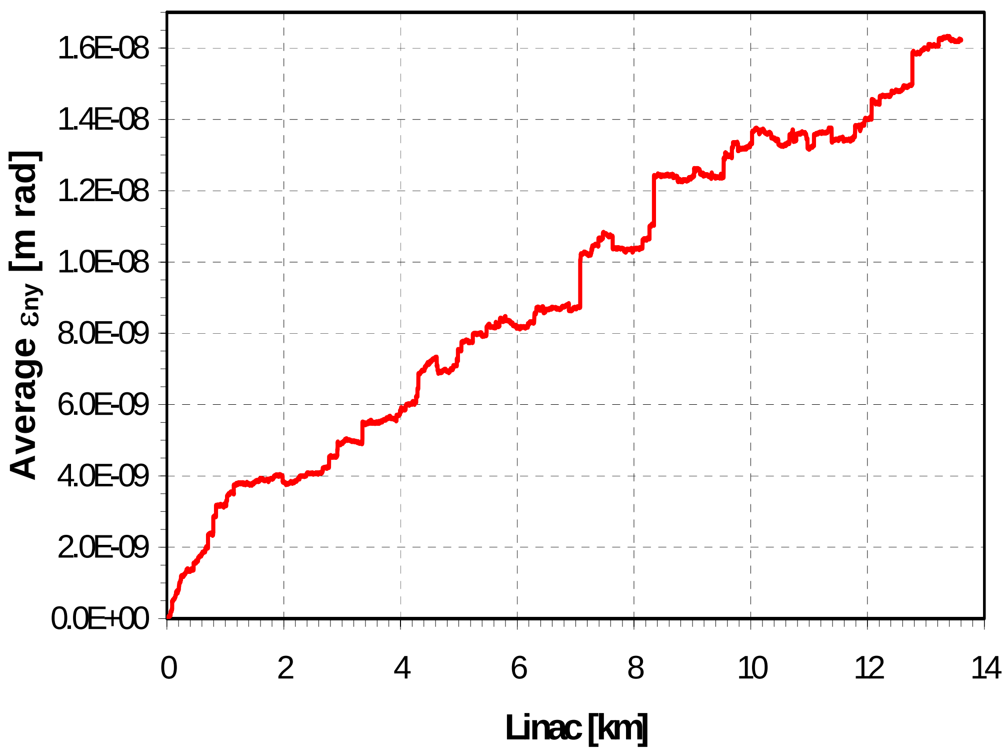


Beam dynamics with high-Q mode

- 1 cavity in each cryo-module → high Q mode in 3rd passband:

   ⇒ average $\Delta\varepsilon/\varepsilon_0$ > 50% ⇒ stronger damping is needed

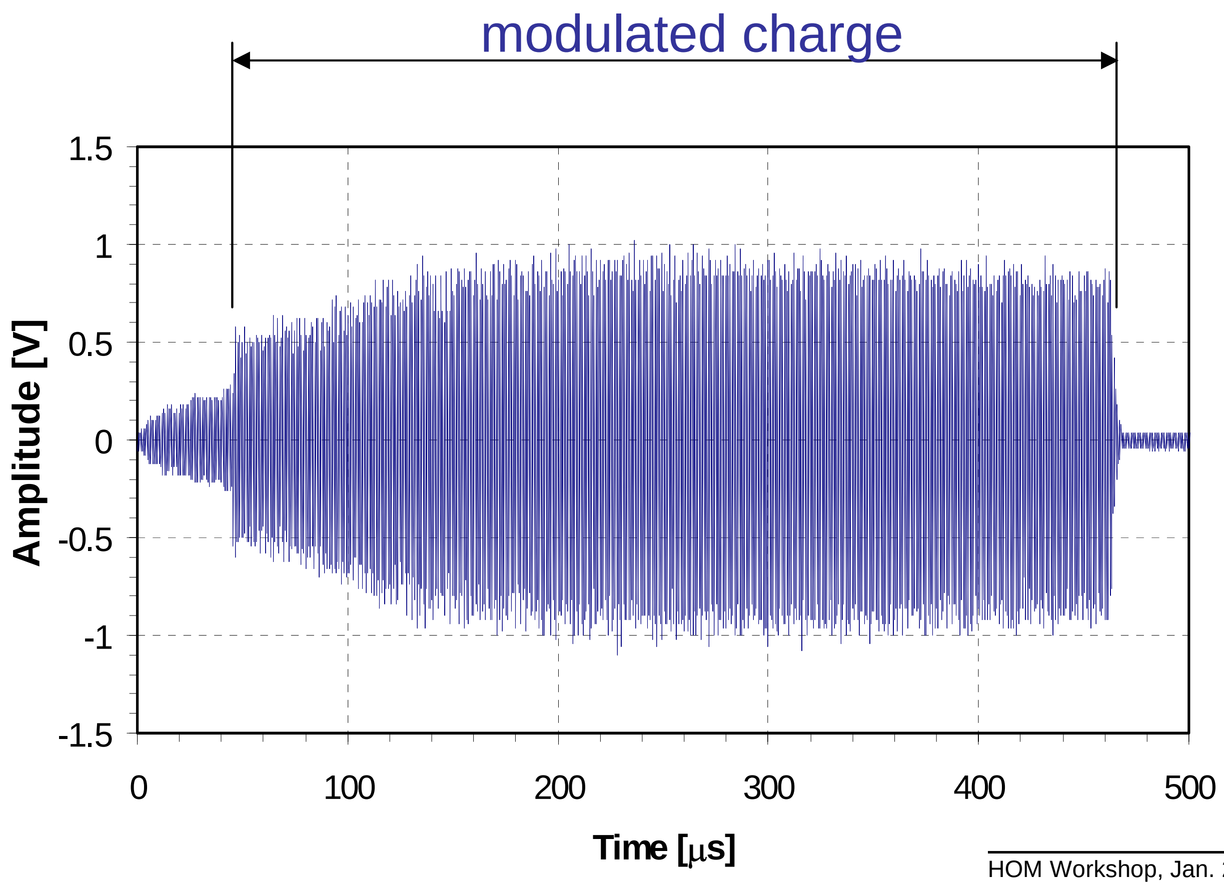




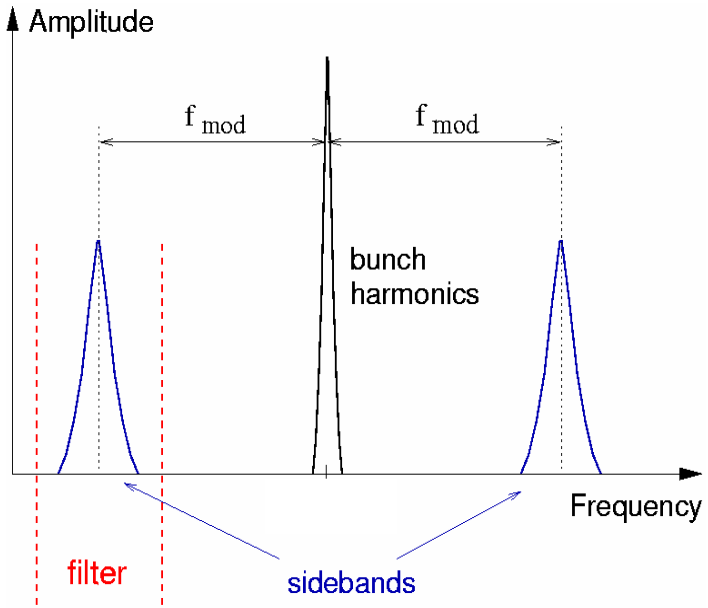
BPM difference signal

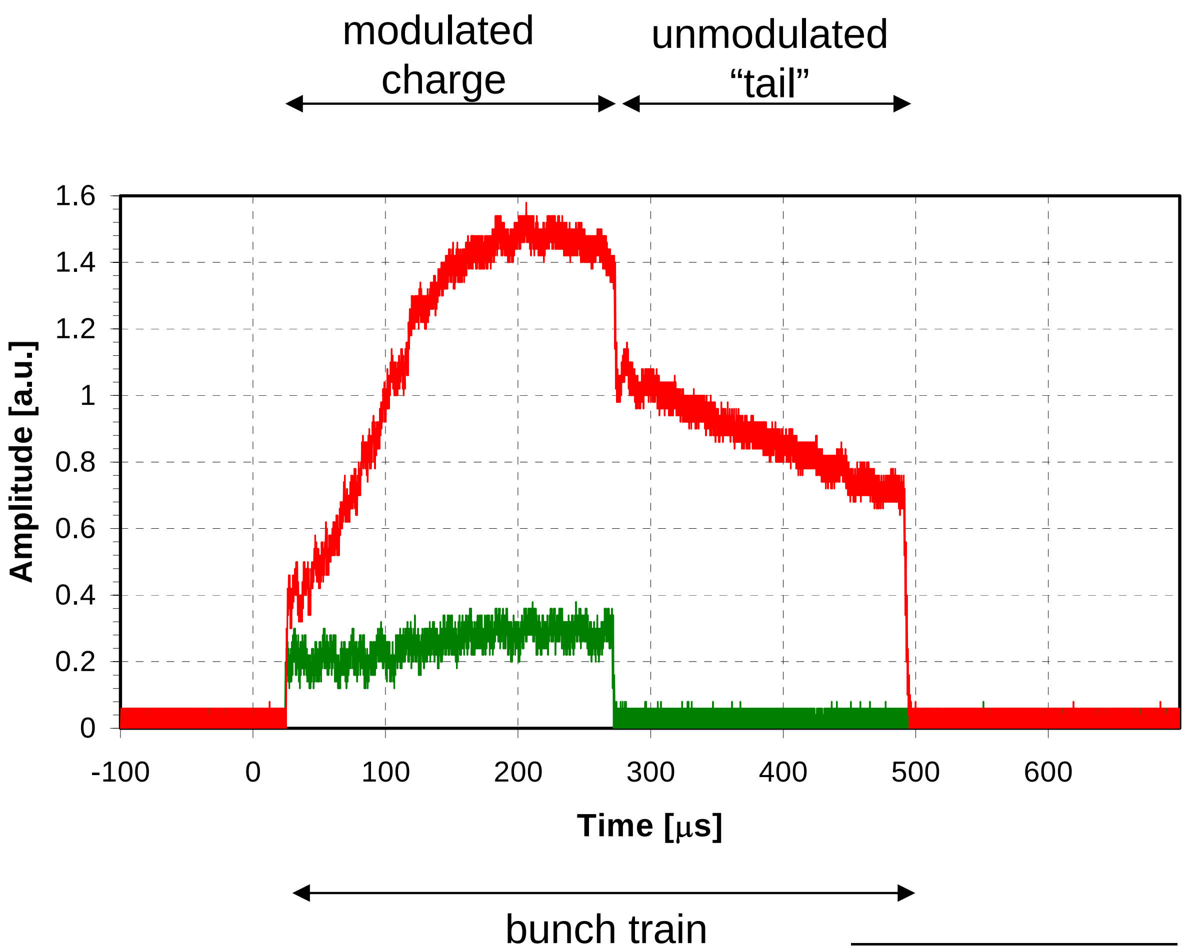
- change with ω_{mod} are comparable to the fluctuations in beam charge and position
- rejection of sum signal in difference signal

$\omega_{mod}/2\pi = 23.775$ MHz



BPM filtered signal

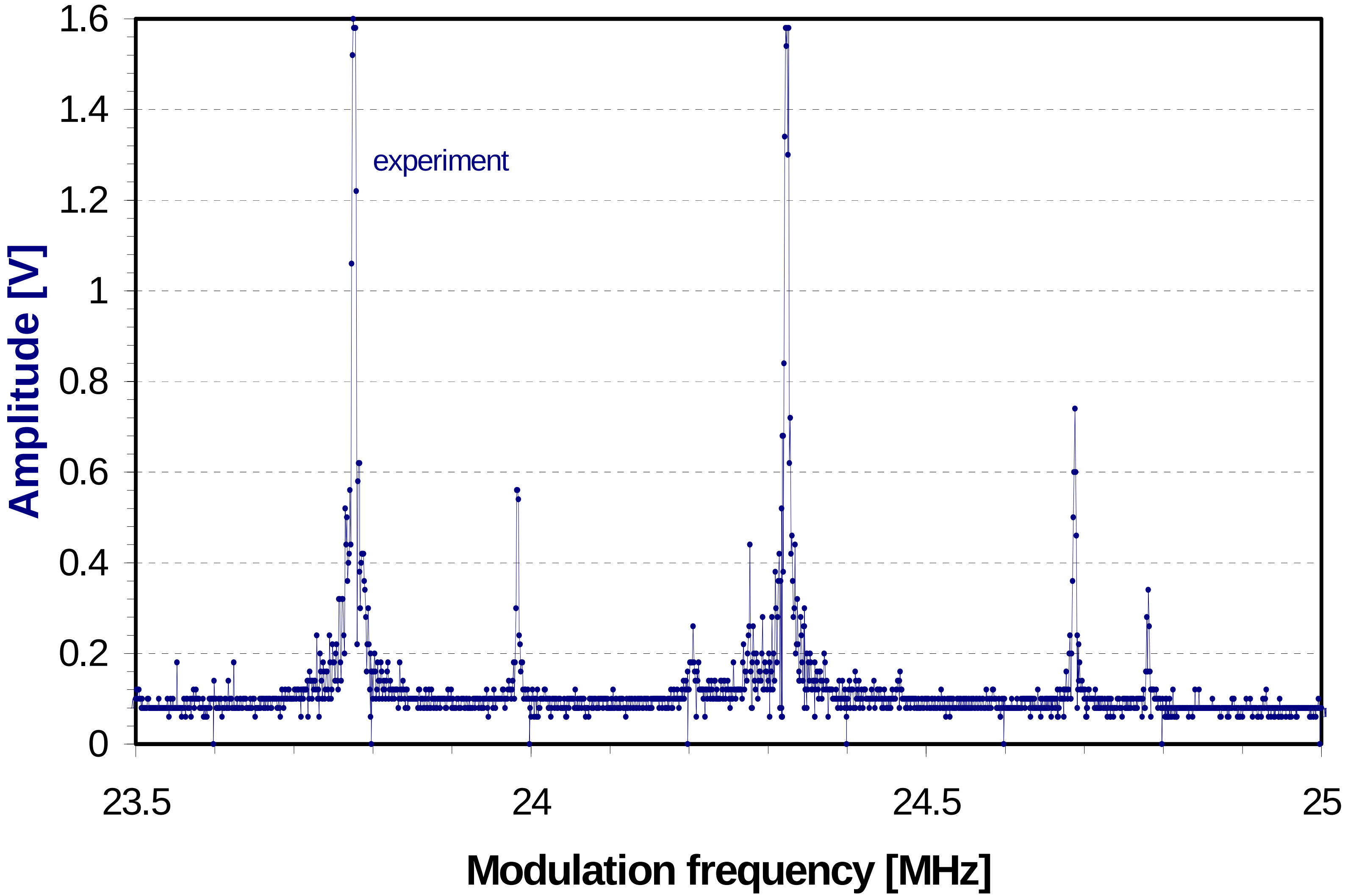




$\omega_{mod}/2\pi = 23.629$ MHz (off resonance)

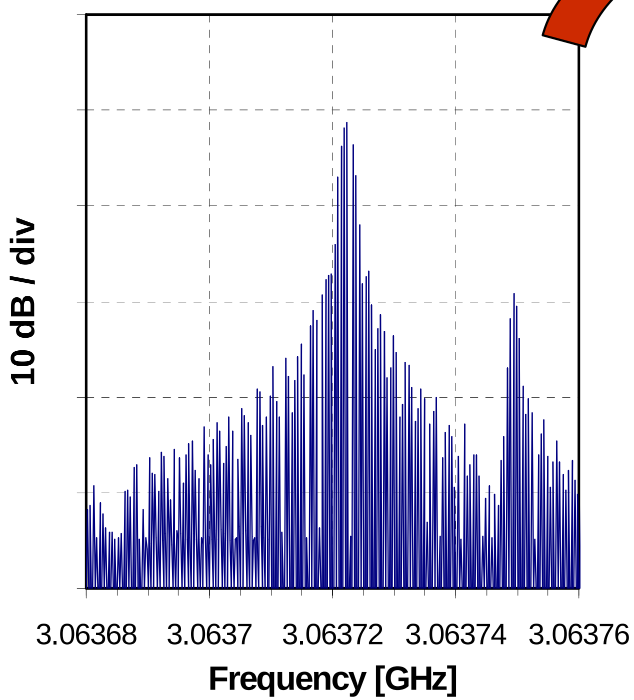
$\omega_{mod}/2\pi = 23.776$ MHz (on resonance)

Modulation frequency scan



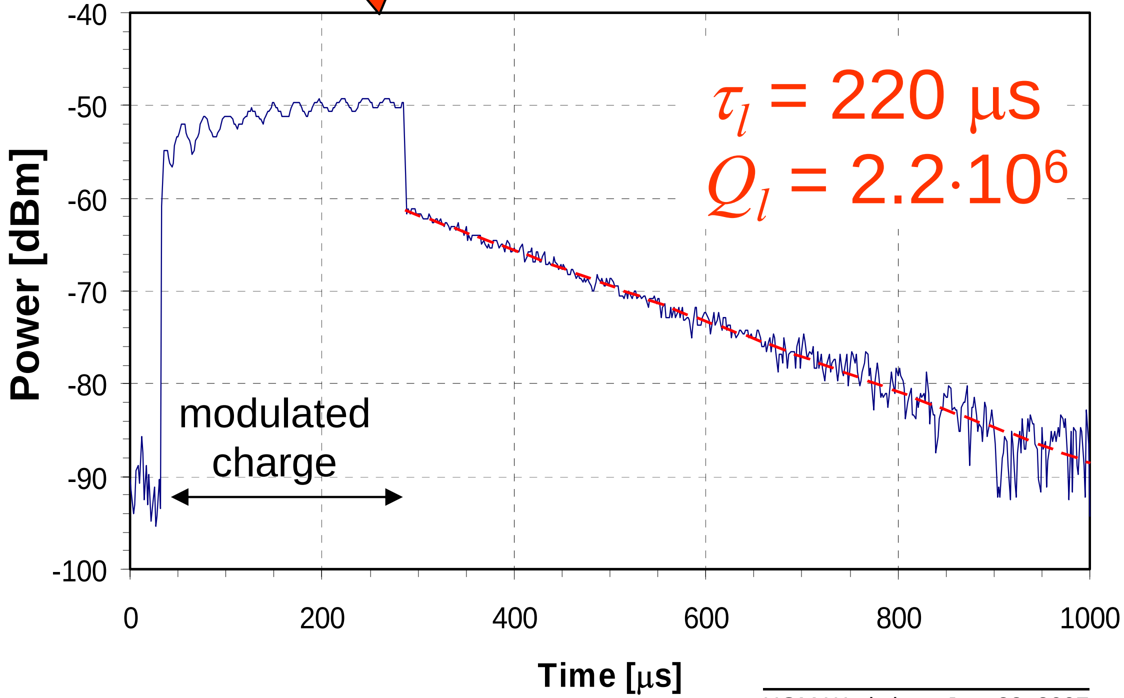
Spectrum from HOM couplers

$\omega_{mod}/2\pi = 23.775$ MHz, $\omega_l/2\pi = 3.063724$ GHz $= (57\cdot\omega_b - \omega_{mod})/2\pi$



filter 1 MHz

$$\propto \exp\left(-\frac{1}{\tau}t\right), \quad \tau = \frac{2Q}{\omega}$$



$\tau_l = 220\ \mu s$

$Q_l = 2.2\cdot 10^6$

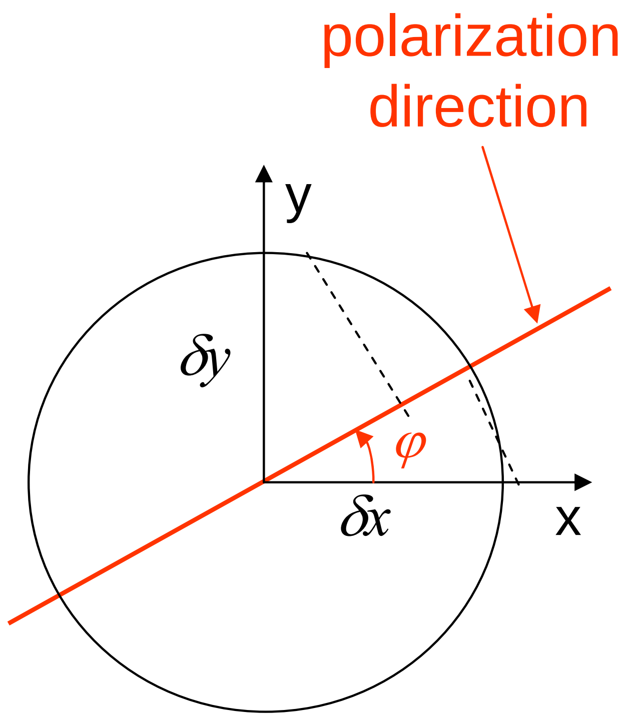
$(R/Q)_l = 1\ \Omega/cm^2$ (simulations)

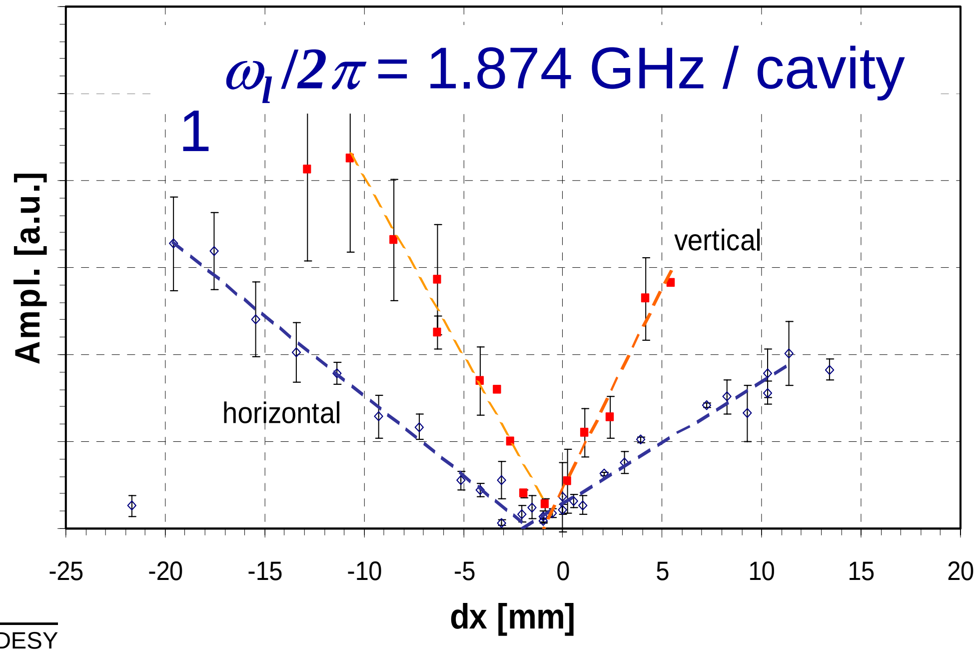
Polarization angle

- Signal amplitude at coupler

$$A(\delta x, \delta y = 0) \propto \delta x \cdot \cos\varphi; \quad A(\delta x = 0, \delta y) \propto \delta y \cdot \sin\varphi$$

$$\delta x = \delta y \quad \Rightarrow \quad \tan\varphi = \frac{A(\delta x = 0, \delta y)}{A(\delta x, \delta y = 0)}$$





$\Rightarrow \varphi = 70° \pm 7°$

Measure R/Q

- Kick amplitude: $$\Delta x'_{\max} = c\frac{e}{E}\delta x_0\left(q_0 f_b\right)\lambda\frac{1}{\omega_l}\left(\left(\frac{R}{Q}\right)Q\right)_l \cos\varphi$$

polarization angle

- For $\omega_l/2\pi$ = 1.874 GHz / cavity 1:

Δx = 1.8 mm $\Rightarrow$ $\Delta x'$ = 200 μrad $\Rightarrow$ $(R/Q)_l \cos\varphi$ = 3.3 Ω/cm^2

$\Rightarrow$ **$(R/Q)_l$ = 9.3 Ω/cm^2** $\pm$ **3 Ω/cm^2**

(simulations: 8.7 Ω/cm^2)

Conclusions

- Studies with modulated beam intensity:
  - some of the first HOM studies with beam in superconducting accelerating cavities
  - method to study modes individually
  - modes excited and identified in 3rd and 5th dipole passbands
  - *R/Q* can be measured; also polarization
- Other methods:
  - one could use beam position modulation instead of charge modulation (used for normal conducting structures)
  - Active HOMs excitation (J. Sekutowicz et al.):
    - performed on the superstructures