Feasibility of short pulses at ESRF

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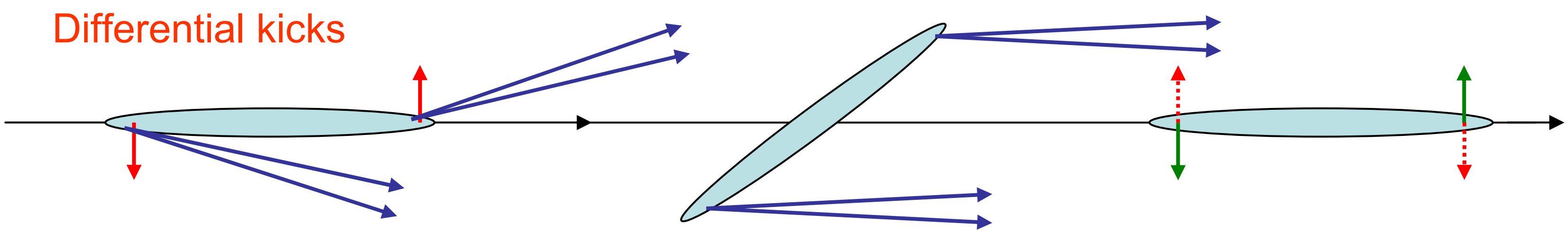
0. Motivation

- Scientific case: ESRF- ID9 beamline:
  - Main single or few bunch user
  - Top specialist in time resolved experiments (Dynamical study of Laser triggered reactions in biological molecular structures)
  - Dream: Improve time resolution down to a ps at still reasonable flux, first step towards what could become this science with X-FEL
  - Experiments use a chopper at 1 to 3 kHz $\Rightarrow$ defines optimum repetition rate of short pulses
  - Refocusing by means of assymmetrically cut crystal is considered by the beam line to maximize flux

- Most other ESRF users prefer high intensity high brilliance beam
  - Differential Head-Tail vertical kick should be limited to ID9
  - Produce as low distortion as possible, avoid blow up

1. Principle: vertical differential kick

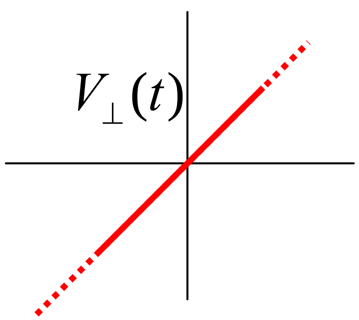


Photons separated in <u>ANGLE:</u>
Probably easier to exploit

Photons separated in <u>POSITION:</u>
Is optics resolution sufficient to exploit it ?

d = $\lambda_\beta/2$

⇔ 2 kickers enough

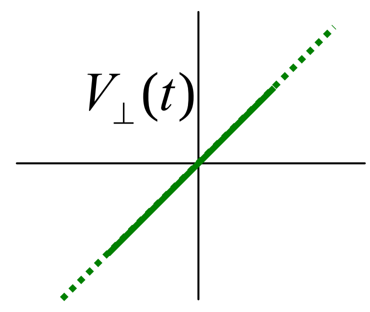


Kicker 1: generates differential kicks

$$\left.\frac{\Delta V_\perp}{\Delta t}\right|^{max} = 2\pi f \hat{V}_\perp$$

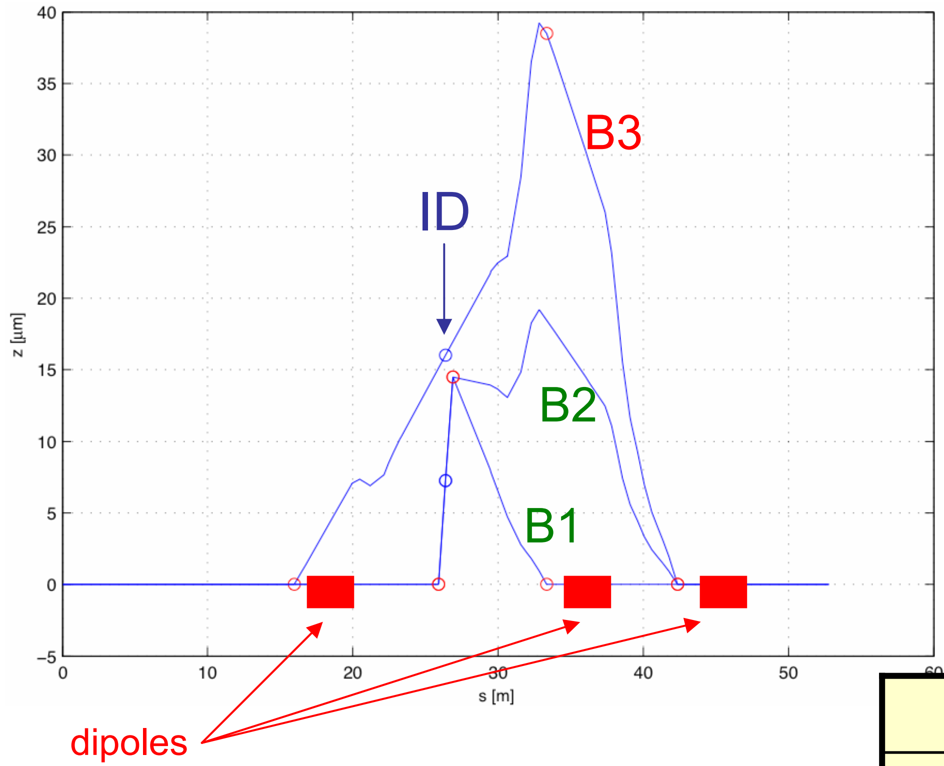
$\Downarrow$

High frequency crab cavities optimized on E110 deflecting mode



Kicker 2: generates kicks to cancel previous kicks

2. Required kicks at ESRF



- Realistic closed vertical bumps need 3 crab cavities
- Bumps closed before next straight section
- B1 & B2 = minimum bumps for full vertical angular separation of X-ray beam
- B3 = minimum bump for full X-ray beam separation in vertical position

	B1	B2	B3
Kick 1 [µrad]	14.84	14.84	1.78
Kick 2 [µrad]	-17.36	-15.06	-1.67
Kick 3 [µrad]	1.81	1.56	3.26
Position [µm]	7.25	7.25	**16.02**
Angle [µrad]	**14.84**	**14.84**	1.86

3. Minimum transverse RF kicks

Assuming no further distortion, full separation of $\Delta\tau$ = 1 ps slices can be obtained with crab cavities delivering:

	B1: angular separation	B2: angular separation	B3: separation in position
$(f \times V_\perp)_1$ [MV x GHz]	14.17	14.17	1.70
$(f \times V_\perp)_2$ [MV x GHz]	-16.58	-14.38	-1.59
$(f \times V_\perp)_3$ [MV x GHz]	1.73	1.49	3.11

($f \times V_\perp$) is simply obtained from kick *k* as: $f \cdot \hat{V}_\perp = \frac{k}{\Delta\tau} \frac{E/e}{2\pi}$

- Angular separation:
  - less demanding on X-ray optics
  - requires high RF deflection: **15 to 17 MV x GHz**
- Separation in position:
  - not clear if possible with resolution of existing x-ray optics
  - requires reasonable RF deflection: **3.1 MV x GHz**

4. Definition of transverse impedance

- Accelerating Cavity: E010 mode
- Deflecting cavity:
  - 1st transverse HOM → E110 deflecting mode

$$\frac{R_{\perp}^{defl}}{[\Omega]} = \frac{\hat{V}_{\perp}^{\,2}}{P} = \frac{\left|\int_0^L (E_r - Z_0 H_\varphi)\cdot e^{j\frac{\omega}{c}s}\,ds\right|^2}{P} = \frac{2}{(\omega/c)}\,\frac{R_{\perp}^{usual}}{[\Omega/m]}$$

  - E010 mode becomes a LOM (Lower Order Mode)
  - LOM & HOMs must be damped
  - TCBI & LCBI, also from E110 Crab mode need to be investigated

Some scaling

- Deflecting Cavity: $V_\perp \bullet f \geq 3\ MV\ GHz$
  - Impedance: $(R_\perp^{usual}/Q) \propto f$

    $$(R_\perp^{defl}/Q) \propto 1 \Rightarrow (R_\perp^{defl}/Q \times f) \propto f$$

  - Q factor for $\rightarrow$ NC: $Q \propto 1/\sqrt{f}$

    $\rightarrow$ SC: $Q = Qext = f\ (beam\ loading)$

  - SC Cavity: electron field emission $\rightarrow$ limits E_{peak}

    $$V_\perp \sim E_{peak} \bullet L \sim E_{peak}/f \Rightarrow [V_\perp \bullet f]^{max} \sim E_{peak}$$

    Given $[V_\perp \bullet f]^{max}$, $L \sim 1/f$: *higher f → shorter structure*

SC cavity – cw operation

- Example CESRB / KEKB SC Crab cavities

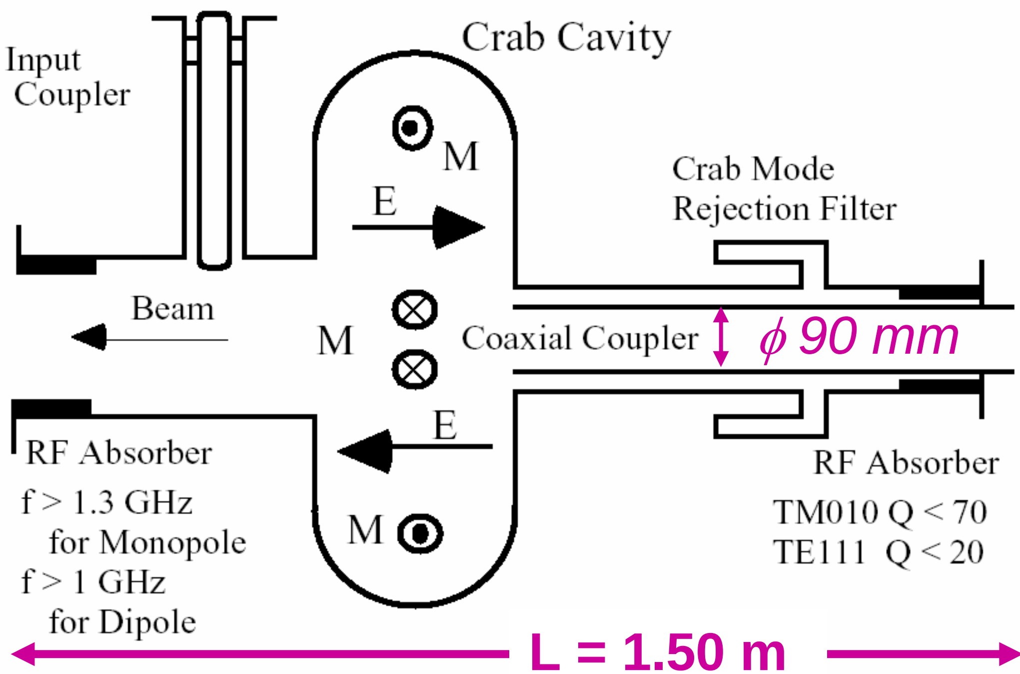


Fig. 2 Conceptual design of the crab cavity

- 500 MHz, $R_\perp/Q \approx 50\ \Omega$
- Max field: 30 MV/m

$\Rightarrow V_\perp^{max} \times f \approx 1$ MV GHz

$\Rightarrow$ 3 cavities required for only 3 MV GHz!

$\Downarrow$

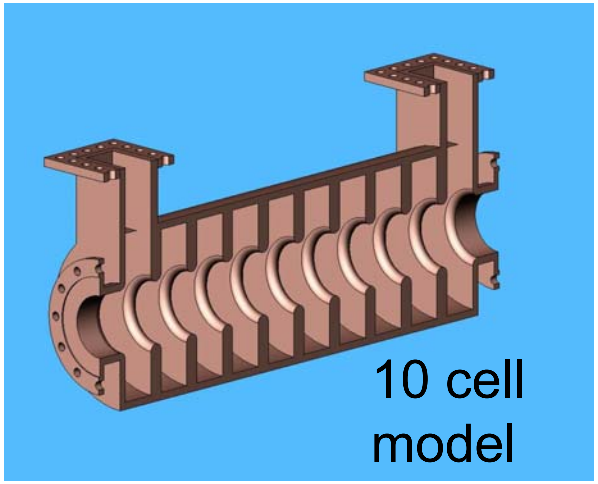
- Scaling to 2817.6 MHz using 3 cavities
- $L_{tot} \approx 1$ to 2 m ?
- Beam tube *ϕ 15 mm !!*
- $V_\perp max \times f \approx 3$ MV GHz

NC cavity – pulsed mode

- 3 GHz - S band cavities: 2π/3 backward traveling wave structure
  - SLAC, L = 2.44 m, P = 20 MW → $V_\perp$ = 17.5 MV
    (corresponds to $R_\perp/Q\ /L_{cell}$ = 1000 Ω/m)
  - Or CTF3 deflecting cavity: $R_\perp/Q\ /L_{cell}$ = 1380 Ω/m

- Tentative ESRF dimensioning:
  - 20 cells ⇔ Length = 0.66 cm
  - Fits into machine
  - Wave attenuation has only small impact on achieved deflection

  ⇒ Possible to add a lot of damping against LOM and HOMs



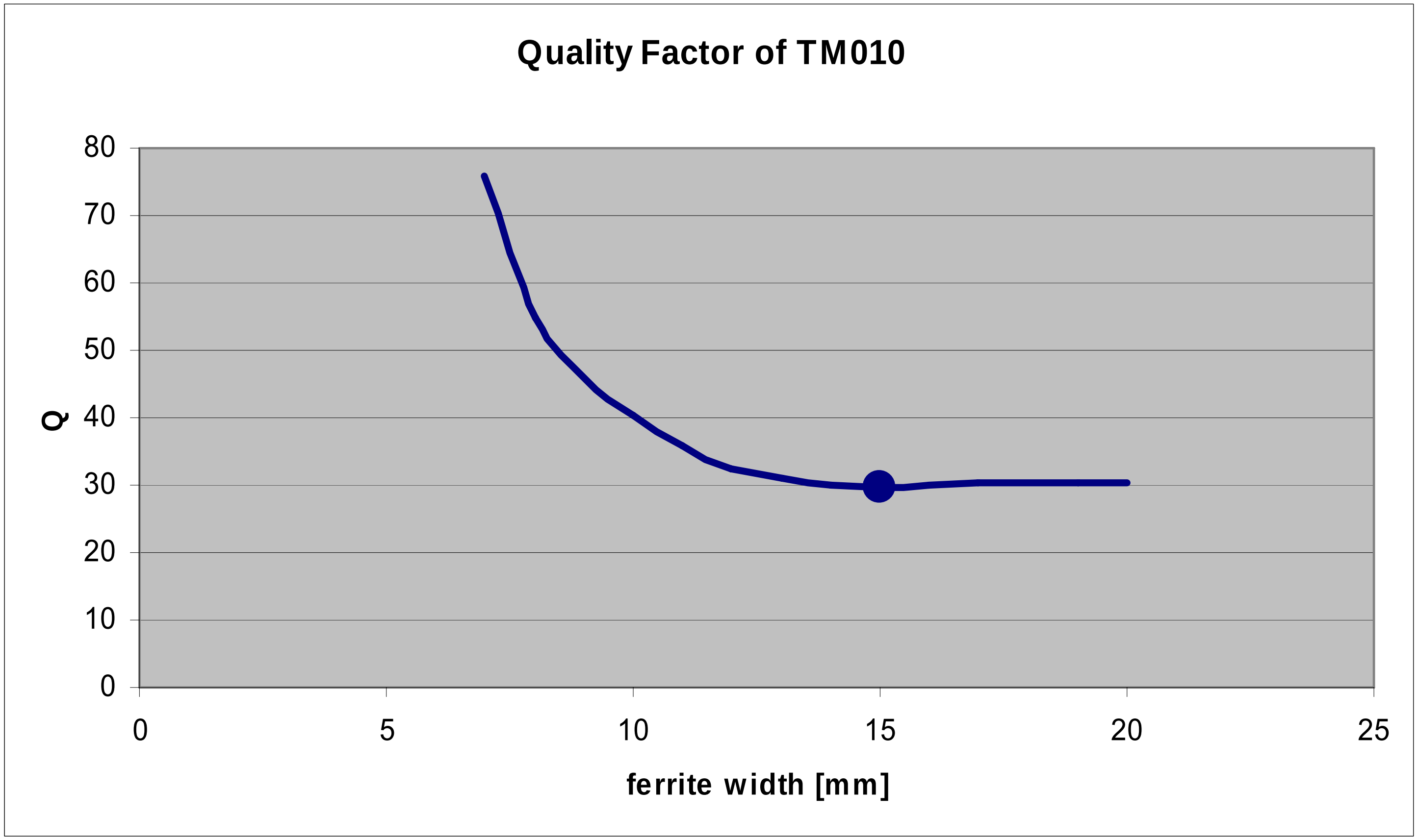
☞ Very preliminary study and results !

NC cavity: deflecting mode / LOM

		f [GHz]	Q for Copper	Q for stainless steel
TM010	LOM	2.1516	22000	1700
TM110	Deflecting mode	2.998	11500	1600

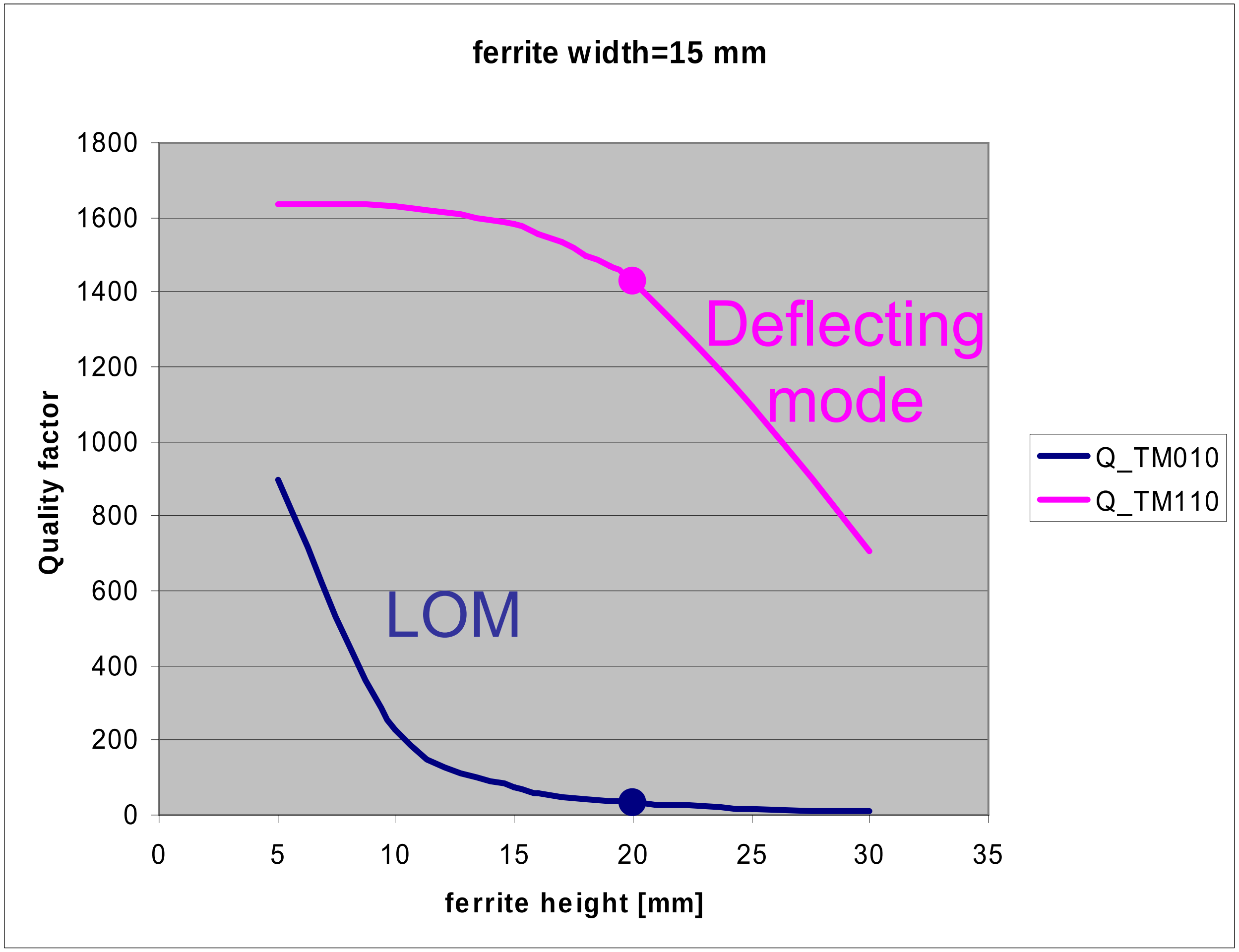
NC cavity: additional HOM / LOM damping

Selective damping of LOM

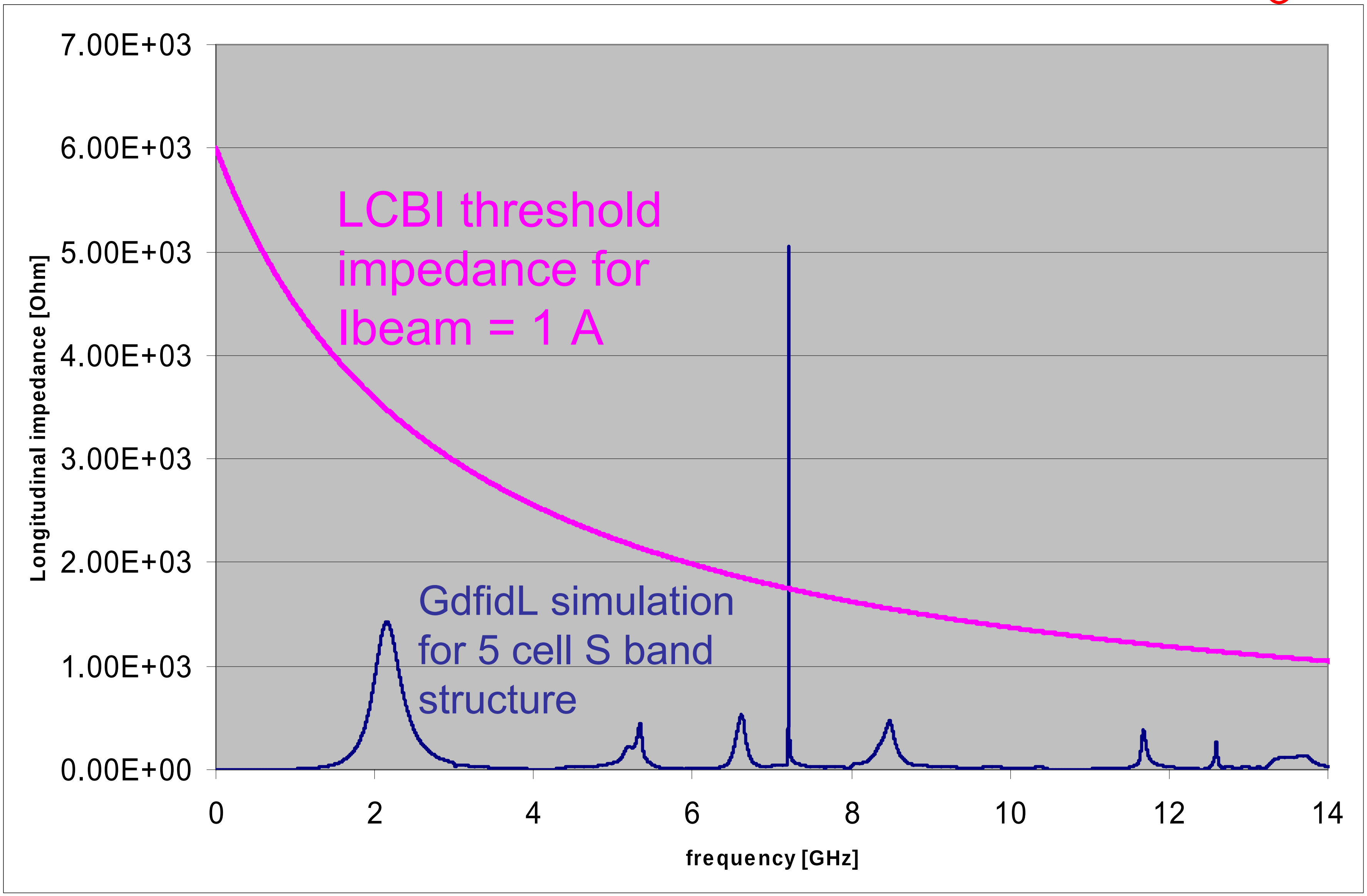


Ferrite height = 20 mm

Selective damping of LOM



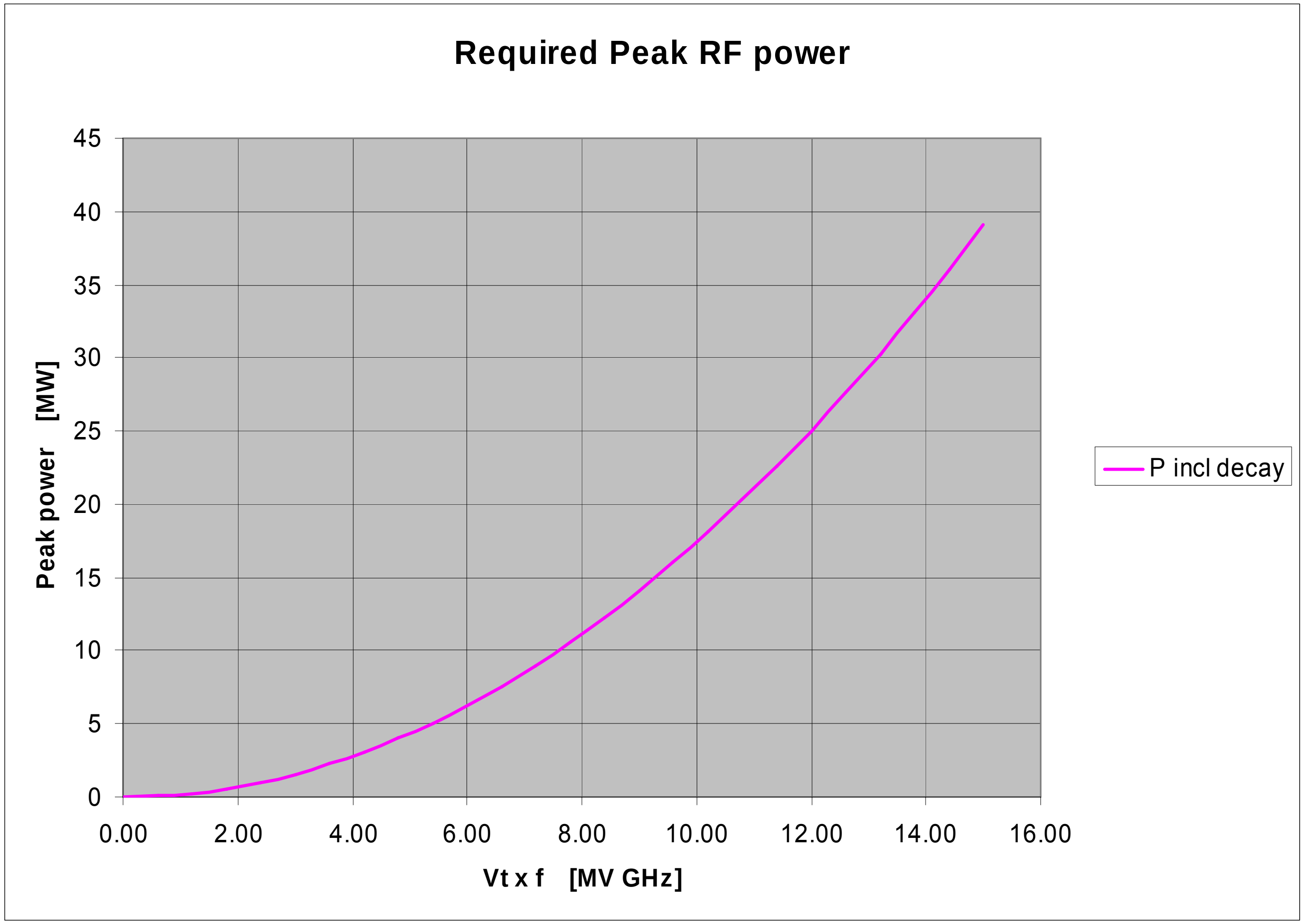
HOM & LOM damping



Expected deflection performance

Deflecting mode with ferrite (h = 20mm,w = 15 mm):

- R/Q/L = 1000 Ω/m (pessimistic)
- Q = 1400
- L = 0.66 m
- T_{fill} = 0.09 μs
  (T_{rev} = 2.84 μs)



Preliminary conclusions

- Minimum requirement for ps separaion in position: 3 MV GHz
- Easier ps angle separation needs: 17 MV GHz
- SC cavity: already 3 MV GHz:
  - Much space: 3 x 1…2 m
  - Huge R&D effort
- NC pulsed TW S-band structure
  - HOM damping seems feasible with bad conductivity stainles steel and additional ferrite absorbers
  - Even for only 20 cells with a total length of 0.66 m:
    - 3 MV GHz requires only 1.6 MW pulse
    - 14 MV GHz achievable with less than 40 MW pulses
    - RF pulse length of several filling times: still well below T_{rev}
  - Question: modulators for 0.5 μs pulses at 1 to 3 kHz rep. rate??