Confocal Resonator Monitor

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- Motivation and "The Problem"
- Fritz Caspers idea
- Analytical Design
- Numerical Simulations
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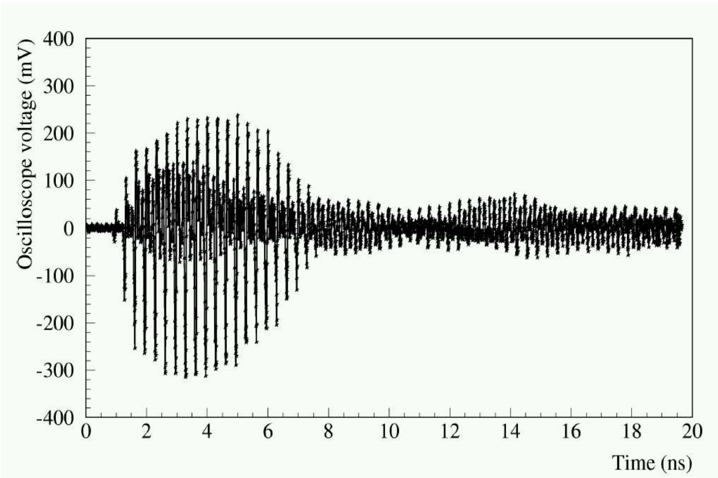
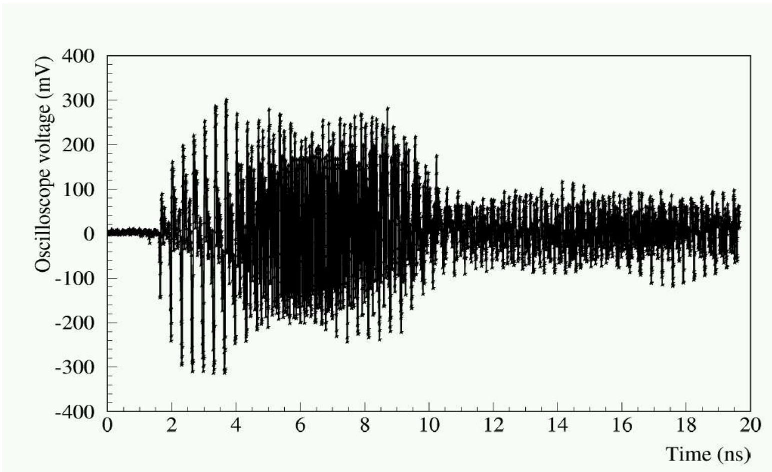
- Position Monitor
- Bunch Length Monitor

Motivation and "The Problem"

- Microwaves (wake-fields) that co-propagate with the beam disturb measurements of beam properties.
- Clearly disturb the bunch frequency measurements in CTF3pre
- One bunch train with 20 bunches (Pictures from CLIC Note 557)
- Bunch train propagates right to left



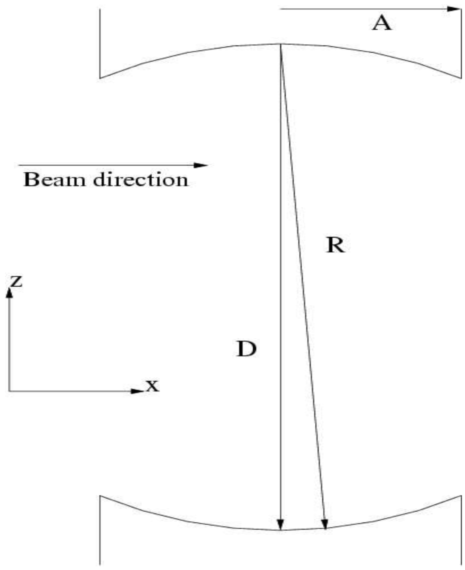
- Five bunch trains interleaved



- No signal before the bunch train arrives.
- Disturbing microwave signals visible within the bunch train and following the bunch train.
- Try to construct monitor insensitive to wake fields.

Fritz Caspers Idea

- A resonator placed perpendicularly to the beam still interacts with the quasi-TEM wave of the beam, but not with the co-propagating microwaves,
- because a resonator does not radiate, i.e. couple to propagating waves, by reciprocity the external fields do not couple to the resonator.
- A sketch:



- Make the domes a confocal resonator by choosing the distance between the domes equal to the radius of curvature.
- Very similar to an optical cavity laser-resonator.
- Same theory applicable (Gauss-Laguerre)
- But wavelength similar to geometric dimensions.

Need to consider:

- Losses and Q-values
- Coupling to the beam
- Suppression of microwaves (S-parameters)

Analytical Design: Modes

- Gauss-Laguerre modes:

$$L_n^m\left(\frac{2r^2}{w^2(z)}\right)\exp\left(-\frac{r^2}{w^2(z)}\right)\cos(m\phi)$$

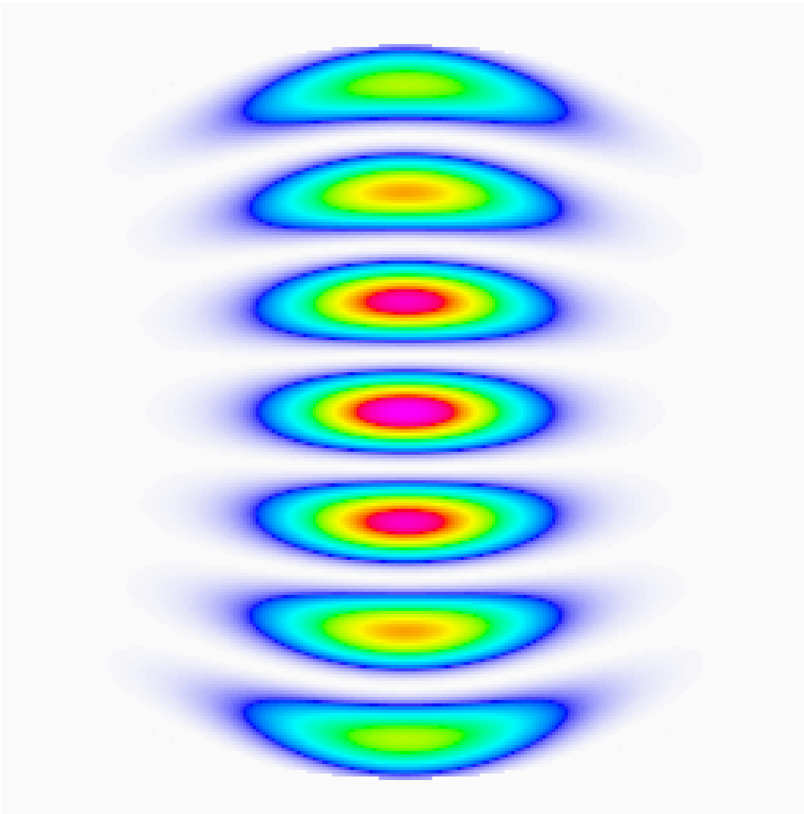
- Choose distance *D* between mirrors to have zero field on mirrors.

$$D=\left(l+\frac{3}{4}\right)\lambda$$

- Waist w_0 is then given by

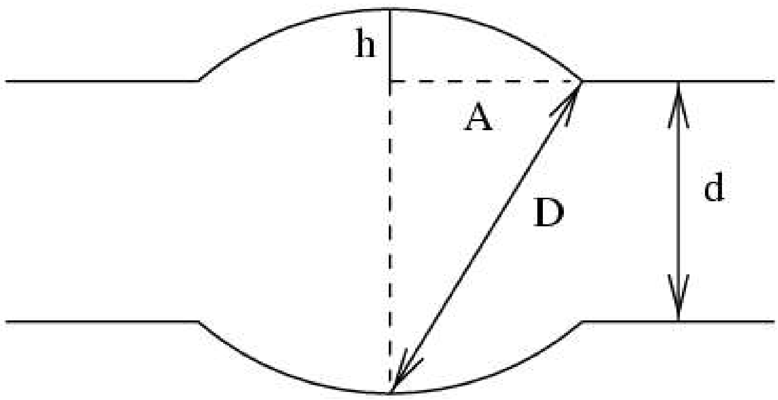
$$w_0^2=\frac{D\lambda}{2\pi}$$

- Choose *l*=3 and λ=2 cm, and *n*=*m*=0:



Analytical Design Equations

- How to fit the resonator into the beam pipe



- Design constraints
  - Make sure that A is large enough to minimize diffraction losses (Fresnel number should be unity -- see below).
  - Fit dome smoothly to vacuum pipe
  - Electric field on mirrors needs to be zero

$$\frac{D}{\lambda} = l + \frac{3}{4}\,,$$

$$\frac{d}{\lambda} = \left(l + \frac{3}{4}\right)\left[2\sqrt{\frac{l - 1/4}{l + 3/4}} - 1\right]\,,$$

$$\frac{A}{\lambda} = \sqrt{l + \frac{3}{4}}\,,$$

- Once the mode number *l* is choosen, the geometry is fixed.

- We use λ = 20 mm (15 GHz) and l =3 and get
  - Resonator diameter D = 75 mm
  - Beam pipe height d = 53.45 mm
  - Dome radius A = 38.73 mm

Analytical Design: Losses

- Follow standard literature about Resonators.
- **Diffraction Losses** are determined by the lateral size of the mirror and how much power in the side lobes is not captured by the mirrors.
- Fresnel Number: $N=A^2/D\lambda$

$$Q = 4.3\times10^4$$

- **Losses due to coupling hole**
- See below how to determine the hole parameters
- use diameter 3 mm and depth 2 mm

$$Q = 1.1\times10^5$$

- **Resistive Losses on the mirror**
- Power dissipated in the upper (skin-depth) layer of the mirror

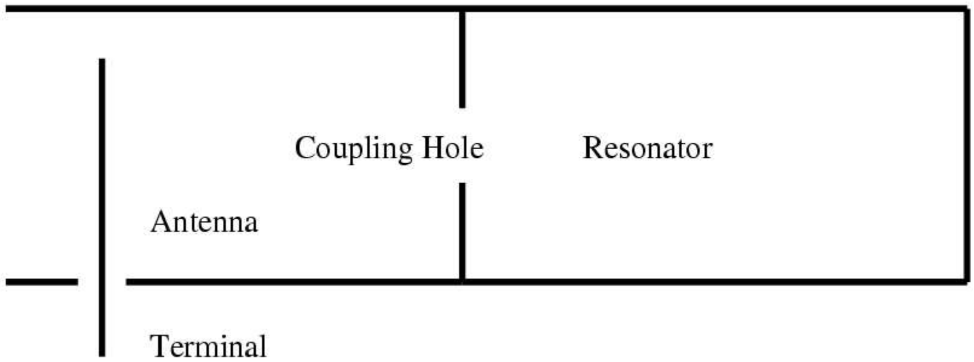
$$Q = 5.7 \times10^4$$

- **Total Q-value** is approximately

$$Q = 2\times10^4$$

Analytical Design: Coupling to Beam

- Calculate coupling impedance backwards and treat monitor as a kicker. Relate current in antenna in extraction waveguide to energy gain of the beam.



- Calculate radiated power of the antenna into waveguide ($\approx I^2$)
- Coupling hole behaves as a shunt inductance coupled to a resonator defined by resonance frequency and Q-value.
- Shunt inductance depends on the hole diameter
- Critical coupling if impedance of "resonator+hole" equals waveguide impedance $\rightarrow$ determines the coupling hole diameter.
- Power U in the resonator changes: $dU/dt = -(\omega/Q)\, U + P_{in}$

$$U = \frac{\varepsilon_0}{2}\int_V E^2 dV \approx \frac{\pi\varepsilon_0}{4} D w_0^2 E_0^2$$

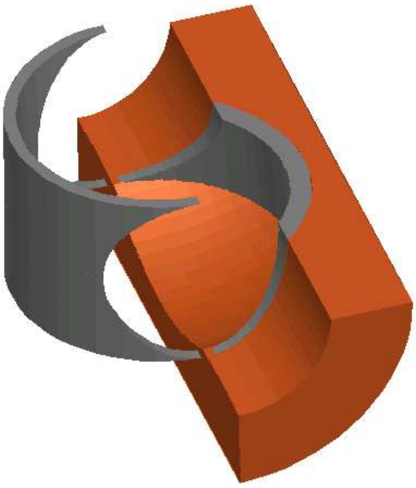
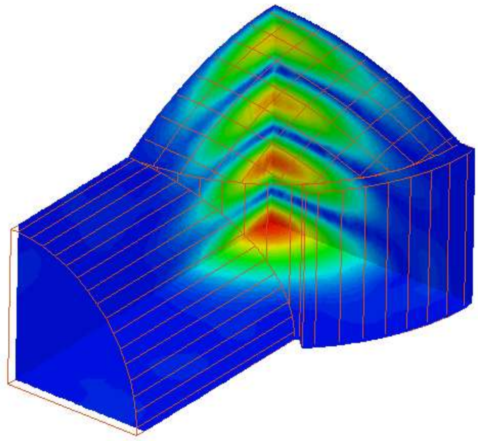
- Equilibrium energy $dU/dt=0$ determines the electric field E_0 on axis.
- Transit time factor (electric field oscillates during beam passage)

$$\Delta E = \int_{-\infty}^{\infty} E_0 e^{-z^2/w_0^2}\cos(2\pi z/\lambda)dz = \sqrt{\pi} w_0 E_0 e^{-(\pi w_0/\lambda)^2}$$

- Depends on the mode number l: $\Delta E \propto e^{-\pi(l+3/4)/2}$
- ...and we have $E_0 \approx I$.
- The constant of proportionality is the coupling impedance.
- We get about 50 Ω for the geometry discussed above.

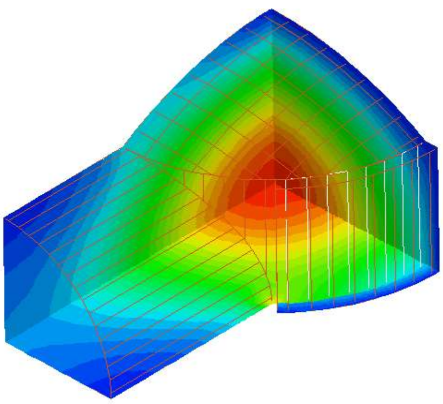
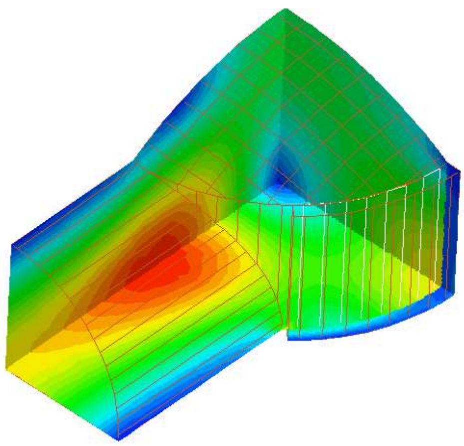
Numerical Simulations 1

- System has a high degree of symmetry and supports many modes beside the wanted one.

- Damping material (SiC) needed to suppress unwanted modes in order to be able to calculate fields in HFSS (I.S.).
- Ideally need to follow contour of the wanted mode by damping material to suppress the unwanted ones.

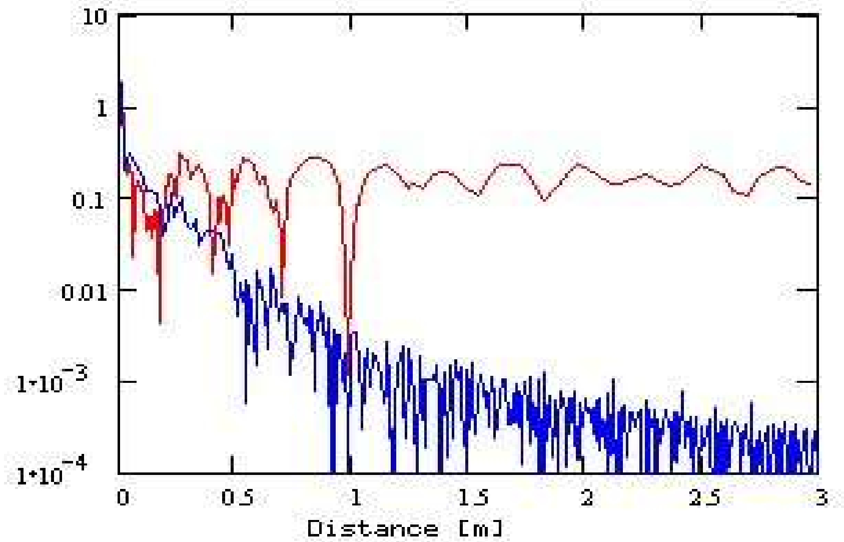
- Two examples of unwanted modes, left: l=0 at 3 GHz, Q=175, right at higher frequency of 4.1 GHz, Q=89.

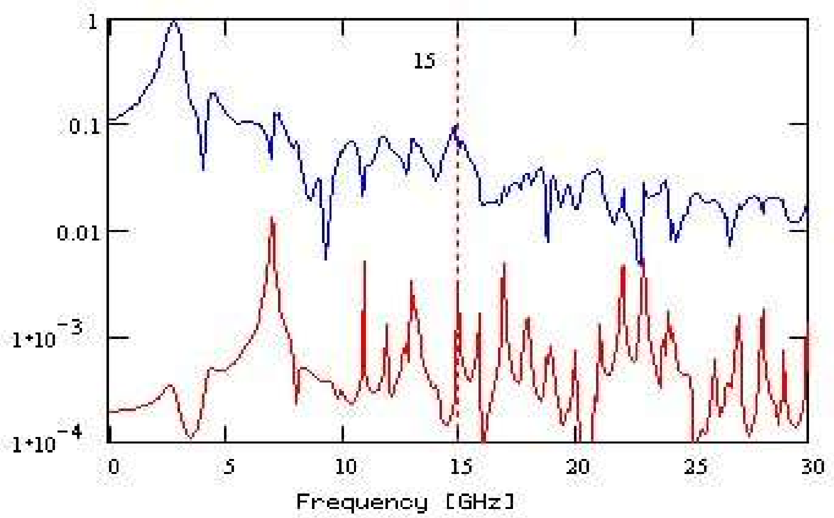
- Q-value of the unwanted modes around 100.

Numerical Simulations 2

- Simulate excitation of the structure by a beam with GDFIDL (I.S.). Wake field following the exciting bunch for damped (blue) and undamped structure (red).



- Fourier transformation of the damped data, blue: starting at 0.1 m, red: starting at 1.7 m.



- In the 1.7 m data the low frequency stuff has decohered.
- The 15 GHz peak is just one among many.
- Working on S-parameters, but not finished (FEMLAB).

Engineering Issues

- Suppress unwanted modes by filters in the extraction wave guide.
- Need circulator to have freedom in the filter choice.
- May need to make dampers in stripes with conducting material inbetween in order to reduce losses due to wall currents.
- Suppress the low frequency modes by making the extraction waveguide small aperture. Then they are below cutoff.
- Select polarization by rectangular waveguide shape.

Position Sensitive Monitor

- Compare excitation of two modes, one with zero field on axis and the other with maximum field on axis, e.g. l=3 and l=4 and relate that to position of the beam.
- Lots of simulation work needed.