BEAM DIAGNOSTICS FOR CTF3 AT UPPSALA UNIVERSITY

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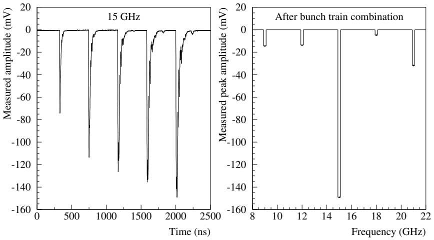
The Uppsala Phase Monitor (PHM)

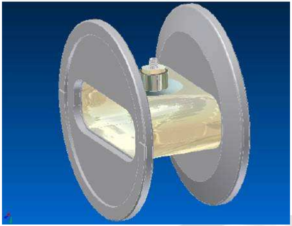
Design of a Nearly Confocal Resonator (NCR)

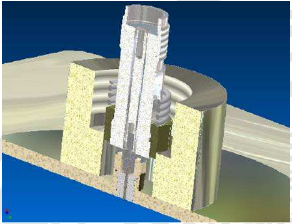
Conclusions

Motivations and old results

The Uppsala Phase Monitor (PHM) was designed in 2001-2002, and it successfully measured the bunch frequency multiplication during the CTF3 Preliminary Phase.





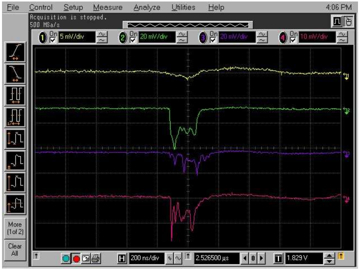


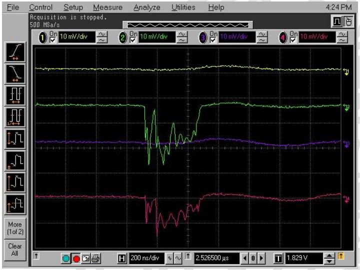
We want to repeat these measurements in the CTF3 Combiner Ring.

Comparison of 1.5 GHz and 3 GHz beams

Until recently, the PHM was placed just after the Delay Loop. Its electronics consists of four band-pass filters (7.5, 9, 10.5 and 12 GHz) with detector diodes.

As expected, a 3 GHz beam leaves no signal in the 7.5 GHz and 10.5 GHz PHM channels. We used the signal disappearance to test the performance of the Delay Loop in 2006.



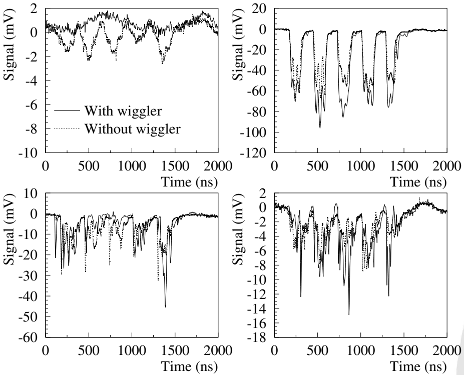


1.5 GHz bunched beam

3 GHz bunched beam

RF combination monitoring in the Delay Loop

PHM signals were recorded while performing the RF combination in the Delay Loop, without/with wiggler.



With wiggler ON:

- smaller signals at 7.5 GHz,
- larger signals at 9.0 GHz,
- not conclusive at 10.5 and at 12 GHz.

The small signal amplitudes at 7.5 GHz are due to the bandwidth of the power splitter upstream of the filters...

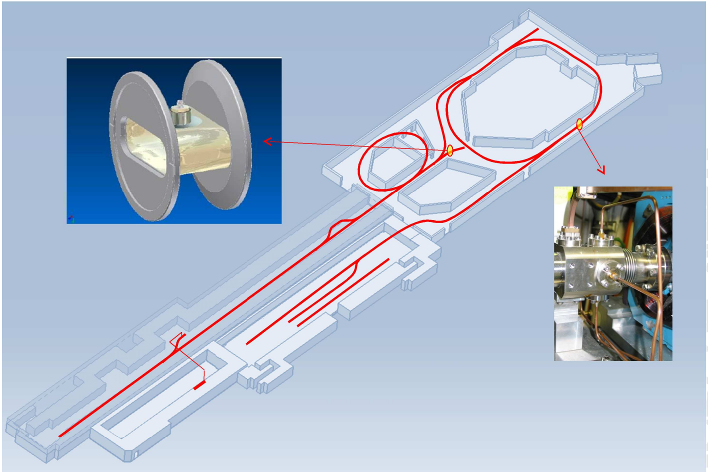
Plans for 2008 (1)

1. More measurements in the Delay Loop:
   - Some improvement of the electronics: new diodes, extra amplification...
   - Study the PHM signals for different wiggler settings.
2. Installation in the Combiner Ring:
   - Use the 4 coaxial pick-up antennas of the BPR in the CTF3 Combiner Ring, and then combine the signals $\longrightarrow$ no sensitivity to the beam position.
   - Modification of the electronics (all components have been delivered).
   - Measure the bunch frequency multiplication with the PHM monitor.

Resources: 140 kSEK from Göran Gustafssons Stiftelse.

Plans for 2008 (2)

Two phase monitors in CTF3 from 2008



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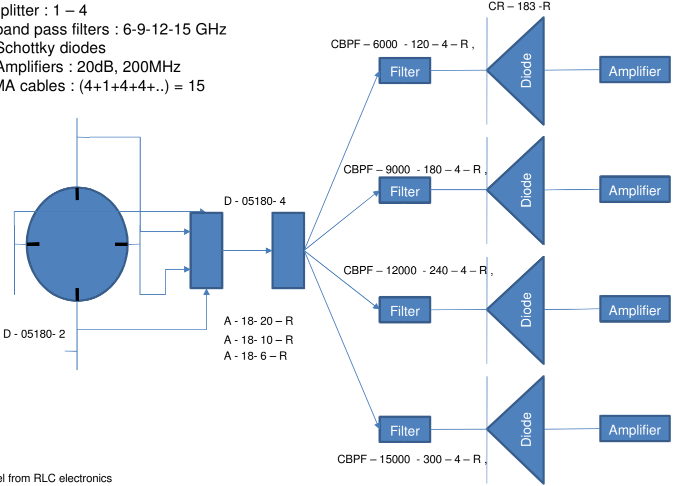
Plans for 2008 (3)

BPR – Phase monitor

- 4 Splitters : 1 – 2
- 1 Combiner 4 – 1
- 4 Attenuators (20, 10, 6dB)
- 1 Splitter : 1 – 4
- 4 band pass filters : 6-9-12-15 GHz
- 4 Schottky diodes
- 4 Amplifiers : 20dB, 200MHz
- SMA cables : (4+1+4+4+..) = 15



Materiel from RLC electronics

1 The Uppsala Phase Monitor (PHM)

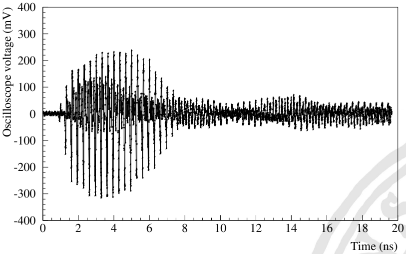
2 Design of a Nearly Confocal Resonator (NCR)

- Goals and analytical design
- Rejection of parasitic wakefields
- Coupling of the NCR to the beam

3 Conclusions

Motivations

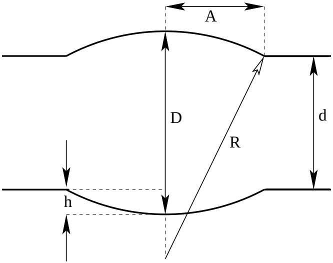
Beam diagnostic devices can be perturbed by microwave fields generated by the beam, that propagate in the wake of the bunches.



An open resonator pick-up with spherical mirrors can have a high quality factor for the diffraction losses.

Reciprocity then suggests that it couples weakly to external TE or TM fields... while keeping anyway a significant coupling to the beam??

Open resonator with spherical mirrors



The solution of the wave equation between the spherical mirrors is described by Gaussian beams modulated with associated Laguerre polynomials.

$$f = \frac{c}{2D}\left[q + 1 + \frac{1}{\pi}(1 + m + 2n)\arccos\left(1 - \frac{D}{R}\right)\right]$$

- $q \rightarrow$ number of nodes between the spherical mirrors
- $m, n \rightarrow$ coefficients of associated Laguerre functions

Design of a nearly confocal resonator

Losses and quality factors:

- Diffraction losses depend on the Fresnel number $N_F = A^2/D\lambda \times \sqrt{(2D/R) - (D/R)^2}$ and (m, n).

$$Q_d = \frac{2\pi D}{\alpha_d \lambda} \text{ with } \alpha_d = \frac{2\pi \, (8\pi N_F)^{1+m+2n} \, e^{-4\pi N_F}}{(m+n)!n!}.$$

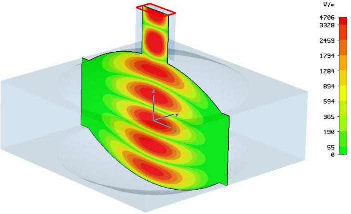
- Resistive losses on the spherical mirrors depend only on the geometry and the material.

$$Q_r = \frac{G}{R_s} \text{ with } G = Z_0 \times \frac{\pi}{2} \times \frac{D}{\lambda}.$$

We use a mirror distance $D = 5.345$ cm and a curvature radius $R = 8.908$ cm. This ensures that there is only one eigen-mode at 12 GHz ($m = n = 0$ and $q = 4$): $Q_d = 3.6 \times 10^6 \gg Q_r = 4.1 \times 10^4$.

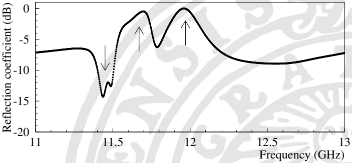
Search for NCR eigen-modes

The CST Microwave Studio simulation package was used to study the electromagnetic properties of the NCR cavity, connected to a waveguide (1.905 cm $\times$ 0.953 cm) through the upper mirror.



Electromagnetic field in the NCR cavity at 12 GHz for the $m = n = 0$ and $q = 4$ mode.

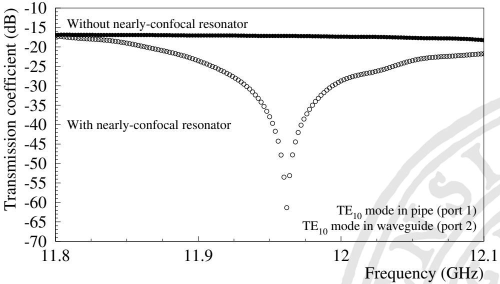
Eigen-modes are identified in the S_{11} spectrum at the waveguide port.



Resonances with a large Q_d translate into a peak close to 0 dB.

Transmission coefficient of incoming modes

The NCR is inserted into a 11 cm $\times$ 3.7 cm rectangular pipe. Below a cut-off frequency of 12.1 GHz, 38 modes can propagate through the pipe.



CST simulations show a clear rejection of the TE_{10} mode of the pipe around the resonant frequency of the NCR.

A similar behaviour is observed for all other incoming TE and TM modes.

Experimental prototype

NCR prototype on a pipe:

The horn antenna allows to inject TE and TM modes into the rectangular pipe.

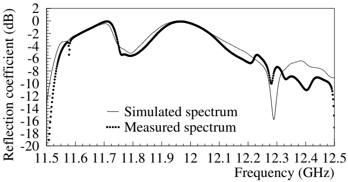
Measurement of reflection and transmission coefficients with a network analyzer in Uppsala.

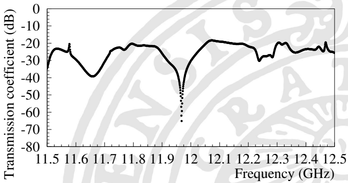
Results with the NCR prototype

Experimental tests confirmed our simulations and provided a clear proof-of-principle for the NCR.

A good agreement between the simulated and measured S_{11} spectrum.

A clear rejection of incoming modes at the NCR resonant frequency.





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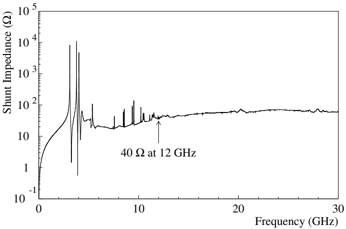
GdfidL simulations of the NCR pick-up (1)

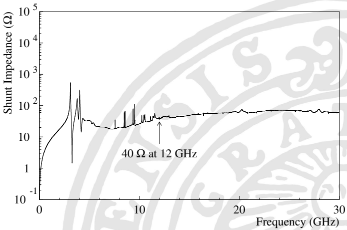
To study the signal induced by the CTF3 beam in the NCR pick-up, simulations are performed with GdfidL.

Shunt impedance as a function of frequency:

Only the NCR pick-up:



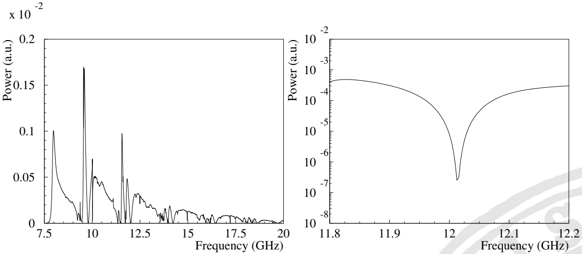
With SiC damping bricks:



Low-frequency modes couple best to the beam and they can be damped with absorbing material in the beam pipe walls (SiC here).

GdfidL simulations of the NCR pick-up (2)

The signal induced by one bunch ($q = 3$ nC, $\sigma = 2$ mm) in the NCR extraction waveguide is $\mathrm{FFT}(E) \times \mathrm{FFT}(H)$:



Minimum at 12 GHz: small transit time factor for the mode with $m = n = 0$ and $q = 4$, which has $E_z(s) \propto e^{-s^2/2w_0^2}$:

$$\Delta E = \int E_z(s) \cos\left(\frac{2\pi f}{\beta c} s\right) ds = \exp\left(-\frac{\pi^2 w_0^2}{\lambda^2}\right) \int E_z(s) ds.$$

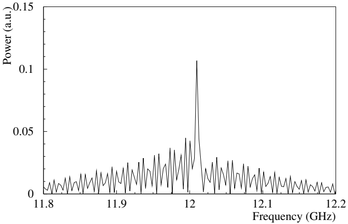
The analytical and computed transit time factors are 0.0048 and 0.0035.

Power spectrum computation (1)

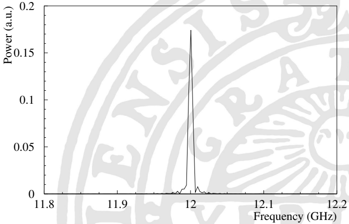
The power induced by N_b bunches (in the right unit) is:

$$P_{bunch}(f) \times \left[\left(\sum_{i=1}^{N_b} cos\,(2\pi f \tau_i) \right)^2 + \left(\sum_{i=1}^{N_b} sin\,(2\pi f \tau_i) \right)^2 \right].$$

With the NCR pick-up after summing up 420 bunches:



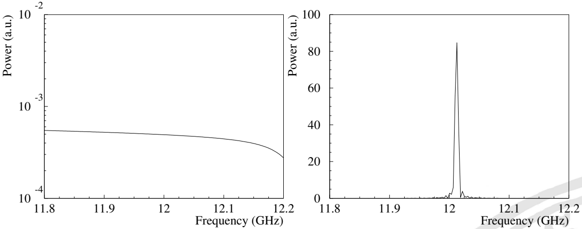
With a 140 ns long unitary sine function at 12 GHz:



With a bandwidth of 50/300 MHz, the power coming from the NCR during the passage of a bunch train is 1.0/3.5 W.

Power spectrum computation (2)

For a pick-up with no NCR cavity:



For a bandwidth larger than 50 MHz, the output power during the passage of a bunch train is 500 W.

The two spherical mirrors in the beam pipe:

- reduce the available signal in the NCR waveguide,
- do not allow a significant improvement of the signal-to-noise ratio.

Summary and outlooks

- The PHM monitor successfully measured the bunch frequency multiplication in the CTF3 Delay Loop (but more tests could be useful).
- A new combined BPR-PHM monitor based on four read-out channels should allow measurement of the bunch frequency multiplication in the Combiner Ring in 2008.
- Simulations and experimental tests of a new NCR pick-up showed a clear rejection of external parasitic modes at the resonant frequency (12 GHz).
- GdfidL simulations show that there is a very weak coupling of the beam to the NCR mode of interest and thereby not a significant improvement of the signal-to-noise ratio.