Development of a Bunch Frequency/Length Monitor for CTF3

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1. Beam power spectrum calculations
2. Design of a coaxial pick-up
3. Bunch frequency monitor in the CTF3 Preliminary Phase
4. Bunch length monitor in the CTF3 Initial Phase

Beam power spectrum calculations (1)

Time distribution of a train of N_b bunches = convolution of the field for one single bunch with a train of Dirac pulses:

$$(\vec{E};\vec{H})_{train} = (\vec{E};\vec{H})_{bunch} \otimes \sum_{i=1}^{N_b} \delta(t-\tau_i)$$

with $E_r, H_\theta \propto \frac{Ne}{\sqrt{2\pi}\sigma_t} exp\left(-\frac{t^2}{2\sigma_t^2}\right)$ **for each bunch.**

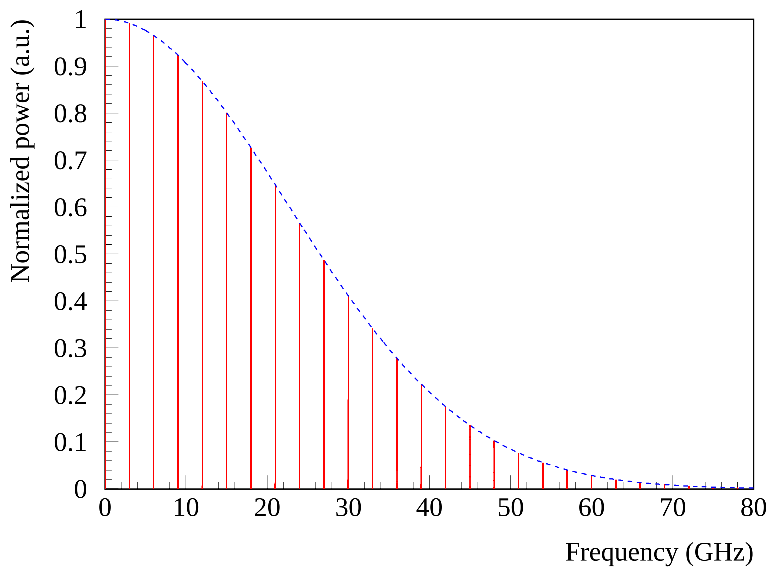
The electromagnetic power is proportional to the square of the modulus of the Fourier transform of the bunch train longitudinal charge distribution:

$$\begin{aligned} P(f) &\propto exp(-4\pi^2 f^2 \sigma_t^2) \\ &\times \left[\left(\sum_{i=1}^{N_b} cos(2\pi f \tau_i)\right)^2 + \left(\sum_{i=1}^{N_b} sin(2\pi f \tau_i)\right)^2\right] \end{aligned}$$

The beam power spectrum is completely determined by the rms bunch length, the number of bunches and the time location of these bunches in the train.

Beam power spectrum calculations (2)

In the CTF3 Preliminary Phase before bunch train combination, or now in the CTF3 Initial Phase, bunches are spaced by 333 ps.



Normalized power spectrum for a train of 4200 bunches with σ_t = 5 ps (CTF3 Initial Phase).

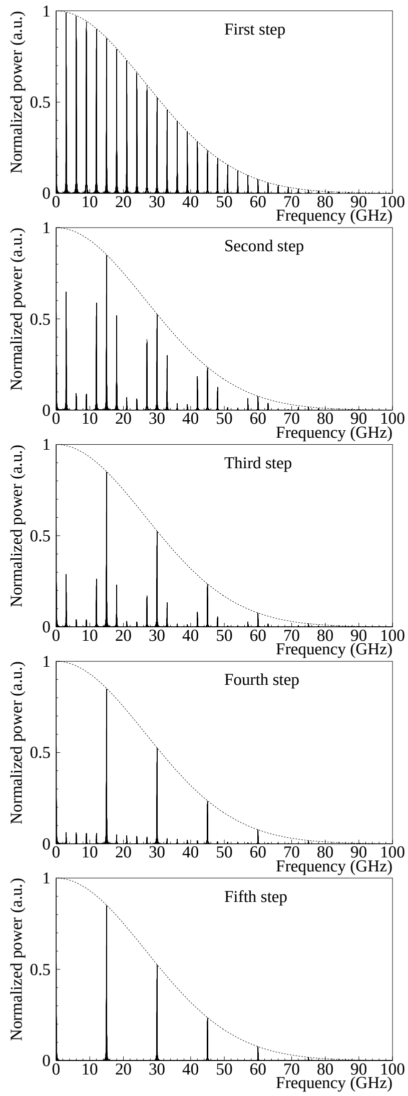
Let f_1 and f_2 be two harmonics of 3 GHz. Let P_1 and P_2 be the corresponding powers, measured by a sensitive device on the beam pipe. If the bunches have a gaussian charge distribution, then one can show that:

$$\sigma_t = \sqrt{\frac{ln(P_2/P_1)}{4\pi^2(f_1^2 - f_2^2)}}$$

⟹ Bunch length monitor

Beam power spectrum calculations (3)

In CTF3 Preliminary Phase, during bunch train combination, the number of bunches and their spacing evolve from 20 to $20 \times N$, and from 333 ps to $333/N$ ps, respectively.

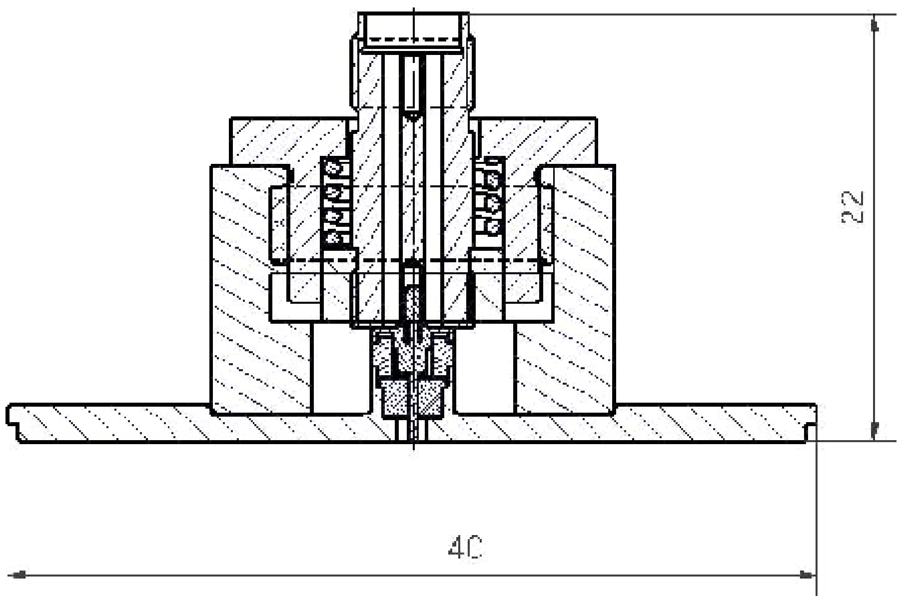


Normalized power spectrum during the bunch train combination (CTF3 Preliminary Phase).

$\Longrightarrow$ **Bunch frequency monitor**

Design of a coaxial pick-up (1)

A coaxial pick-up is used to extract the information contained in the bunch trains. It was designed to include a miniature ultrahigh vacuum feedthrough, while meeting various technical constraints.

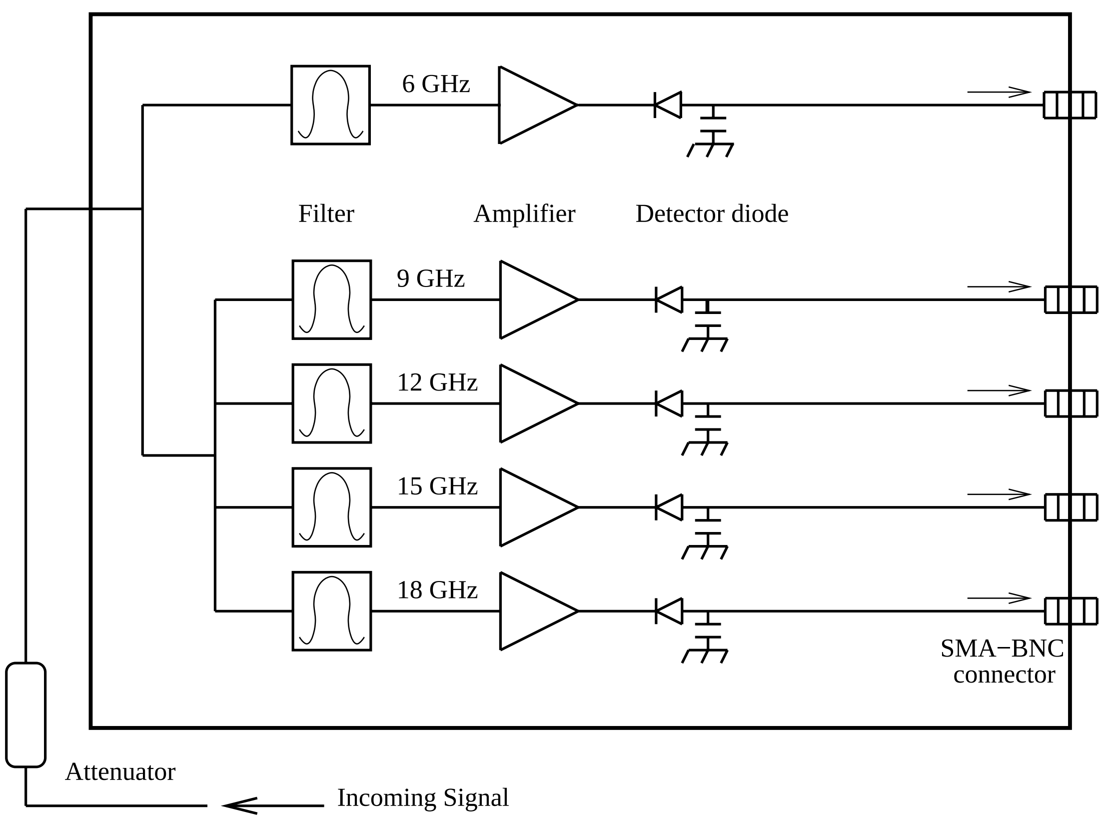


The transfer impedance Z_{tr} between the beam current and the voltage at the pick-up output was estimated with MAFIA.

f (GHz)	6	9	12	15	18	21
$Z_{tr}\,(\Omega)$	0.047	0.085	0.131	0.122	0.110	0.141

Design of a coaxial pick-up (2)

The detection system was designed to analyze various harmonics contained in the signal coming from the pick-up. It consists of five channels with a bandpass filter, a low-noise amplifier and a detector diode.

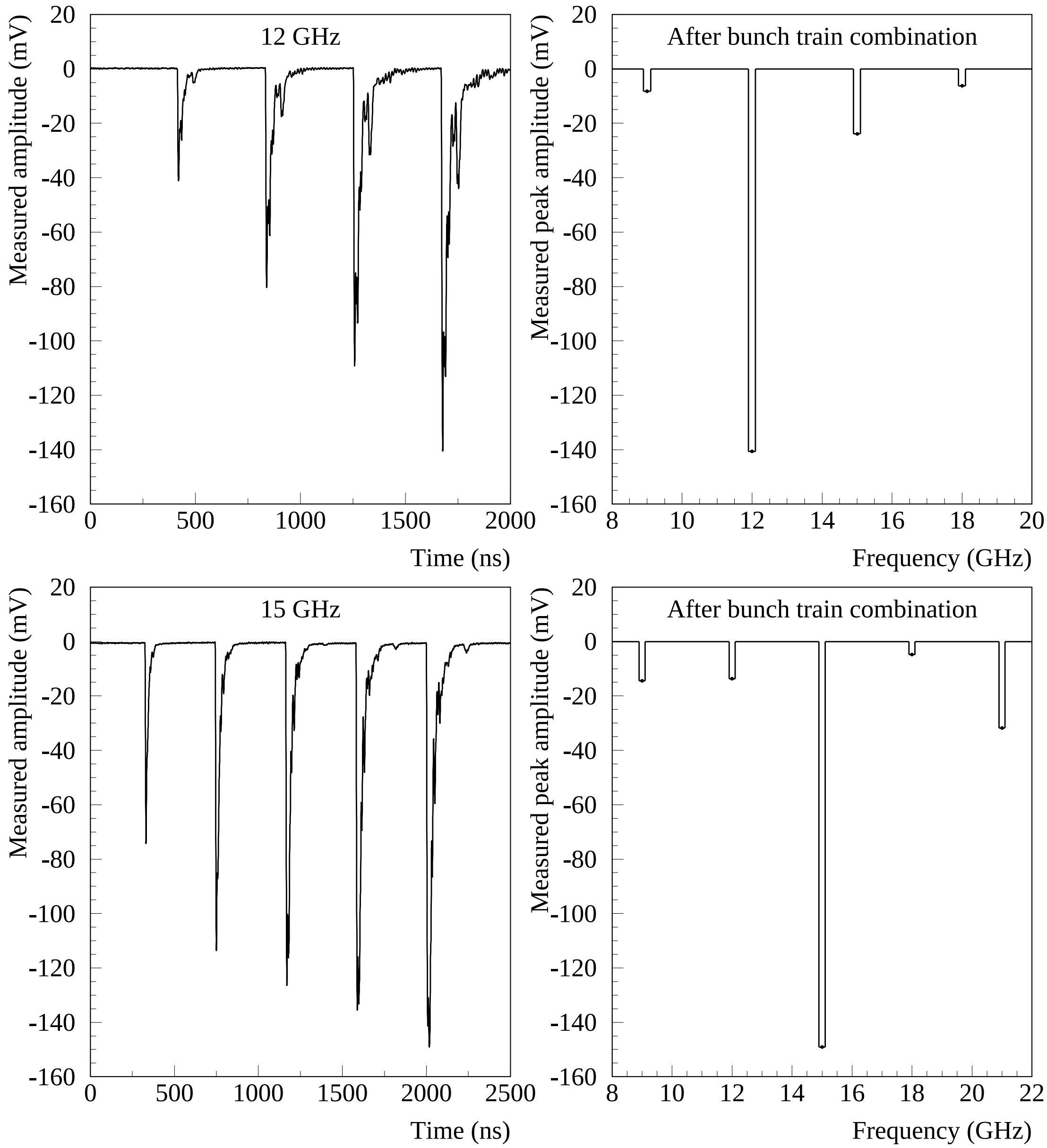


Layout of the detection system for the CTF3 Initial Phase. During the CTF3 Preliminary Phase, the 6 GHz channel was replaced by a 21 GHz channel, and the signal was further amplified (the charge per bunch was 0.1 nC instead of 1.17 nC).

Bunch frequency monitor (1)

In the CTF3 Preliminary Phase, the monitor was used to follow the evolution of the power contained in five harmonics (9, 12, 15, 18 and 21 GHz) while combining bunch trains ($N = 4$ or 5).

$\Longrightarrow$ **Successful proof of principle!!**

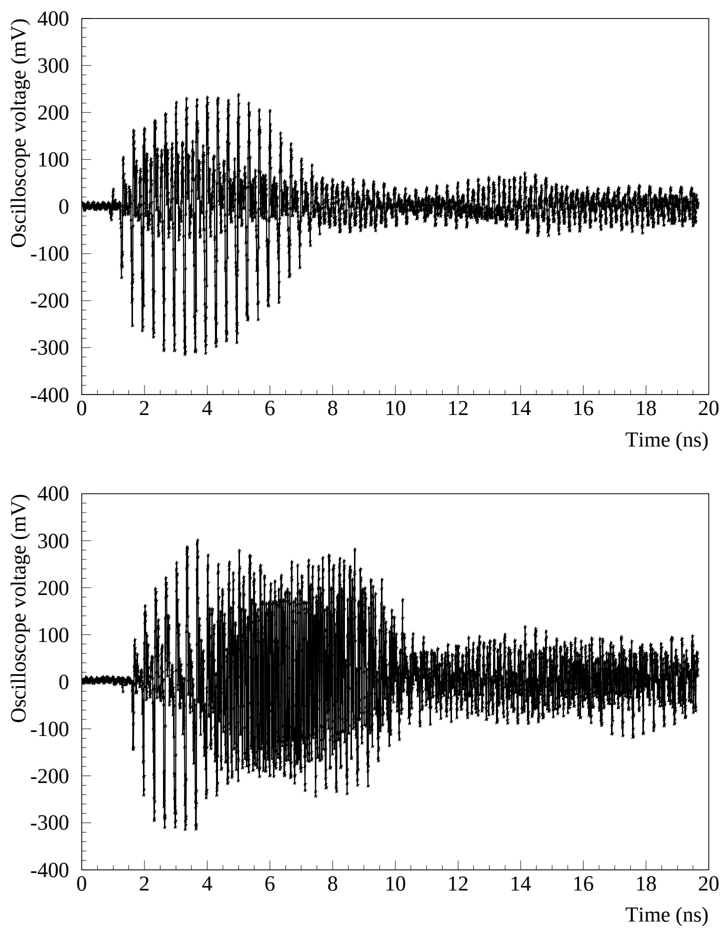


Bunch frequency monitor (2)

Two major limitation was identified:

- **The trains are shorter than the time response of the detection system, so a careful calibration is not possible and one becomes very sensitive to train-to-train variations in position or length, which can explain some discrepancies.**
- **Presence of waveguide modes in the wake of the bunches, which lead to a distorsion of the signal.**

This was confirmed by time-domain measurements, before and after bunch train combination:

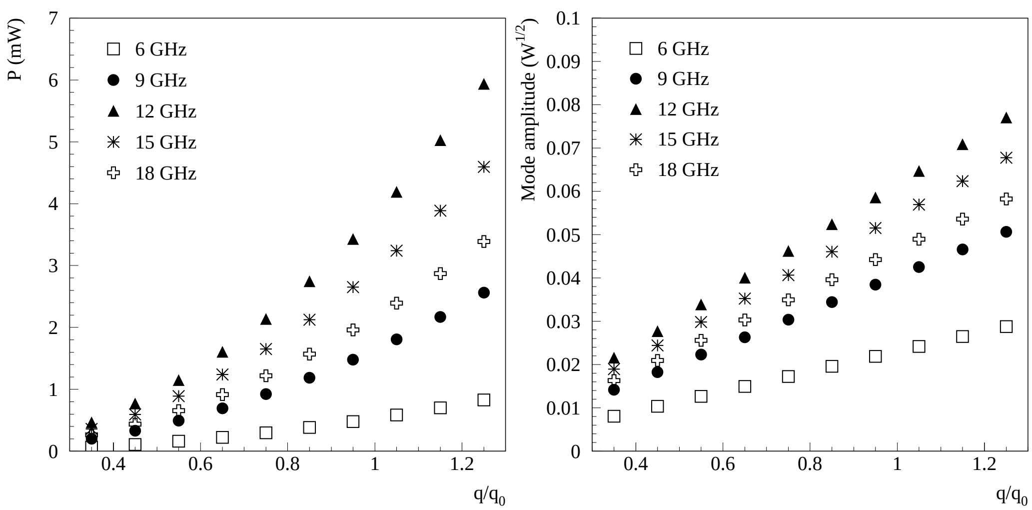


Bunch length monitor (1)

During the CTF3 Initial Phase, the trains are much longer than the time response of the detection system (1.4 μs vs 20-30 ns). No bunch train combination can be monitored. However, some other measurements need to be performed.

- **With SHORT bunches: estimate the transfer impedance by measuring the harmonic amplitude vs the beam current:**

$$\frac{d\sqrt{P(f)}}{dq/q_0} = \frac{N_b q_0}{\delta t\sqrt{R}} \times |Z_{tr}(f)| \times exp(-2\pi^2 f^2 \sigma_t^2)$$

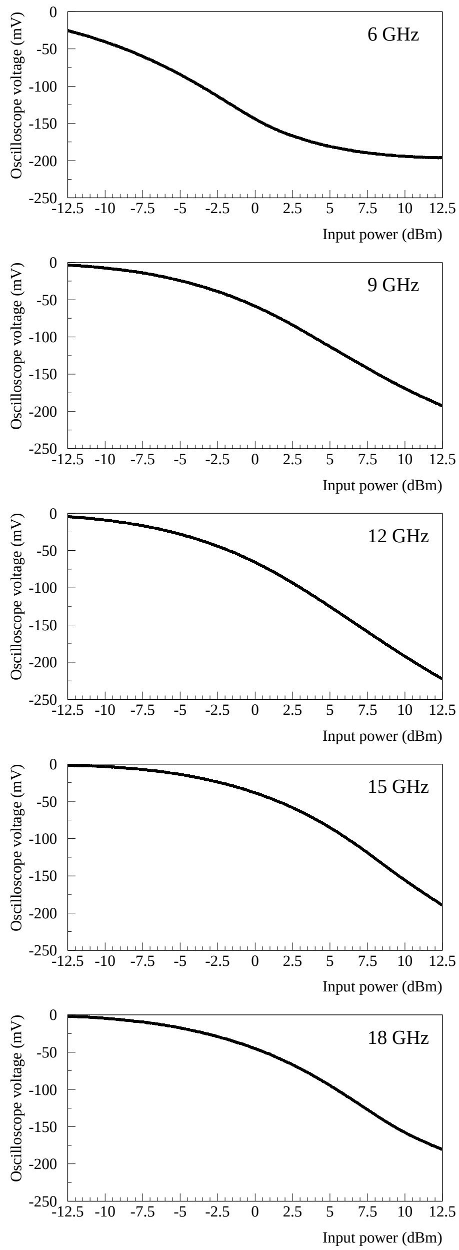


- **With longer bunches: measurement of σ_t.**

- **Better observation of the waveguide modes.**

Bunch length monitor (2)

Recently, the pick-up has been installed at the end of the injector linac and the detection system has been calibrated:



Looking forward to having beam for measurements!!!

Conclusion

A new method, based on beam frequency spectrum analysis, is currently under development to monitor the bunch frequency multiplication and the bunch length in CTF3.

A first series of test was performed during the CTF3 Preliminary Phase and it was a successful proof of principle. However, two major limitations were also identified: short bunch train length and presence of wakefields.

During the present and future stages of CTF3, the extension of the bunch train should not limit use of the instrument for the monitoring of the bunch frequency and length. New tests will be performed during the Initial Phase.

A new type of monitor (confocal resonator) is presently under investigation in order to reject the waveguide modes and have a much cleaner signal. Presently, an analytical design is under consideration, MAFIA simulations will be started soon.