**CTFF3 TECHNICAL NOTE**

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# CTF3 Bunch Length Measurement with the 1.3 GHz RF Deflector

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## 1. Introduction

We measured the bunch length of the CTF3 Linac Test Facility [1] with the 1.5 GHz RF Deflector [2] using the “0 crossing method”. The RF deflector is designed to select every other bunch in a train and deflect its trajectory into the CTF3 Delay Loop to be then rearranged in the following bunch train.

The RF deflector can be used as a diagnostic device to measure the bunch length by operating it at the same frequency and at the zero-crossing phase of the linac, where the time derivative is maximum. Under these conditions, the field in the RF cavity induces a strong correlation between particle longitudinal position in the bunch and transverse position after the kick, so that a measurement of the beam profile downstream of the RF cavity gives direct information of the bunch longitudinal length before the kick.

In the case of CTF3, the linac has a 3 GHz bunch structure while the RF deflector working frequency is 1.5 GHz. Therefore, if we work it at the zero-crossing phase all the bunches will be “streaked” in the same way (Fig. 1, top panel), while if we work it out of the zero-crossing phase the odd and even bunches will receive different kicks and we will see two separated images in the monitor downstream (Fig. 2, bottom panel). We carried out measurements in both these regimes, in particular at the zero-crossing phase and at ±5 deg, ±10 deg and ±15 deg with respect to the zero-crossing.

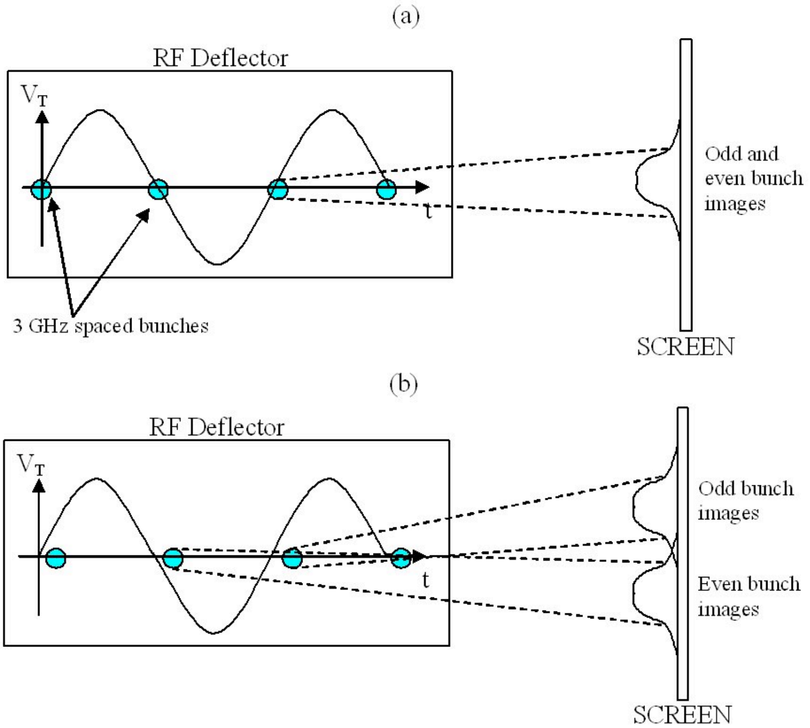


**Figure 1: A schematic view of the RF deflector action on the bunches, at the zero-crossing phase (top) and out of the zero-crossing (bottom).**

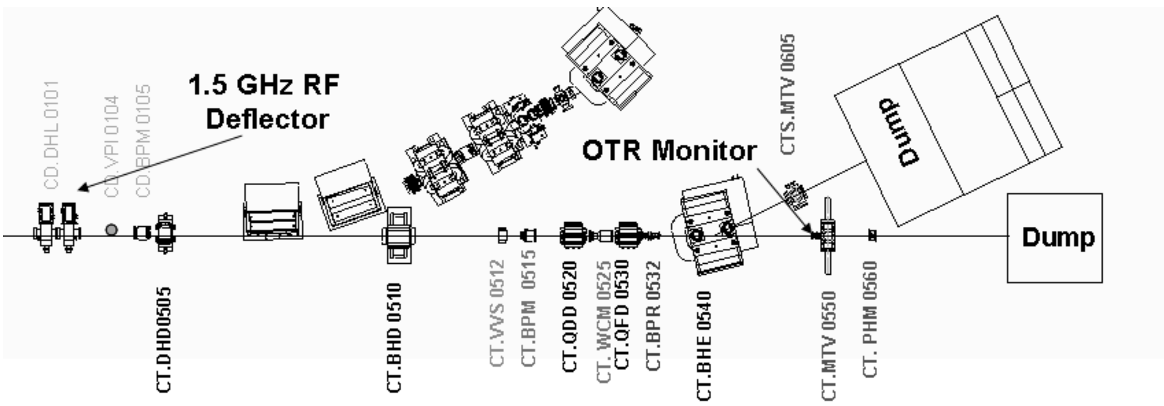


**Figure 2: The CTF3 layout in the RF deflector area.**

## 2. Accelerator parameters and images acquisition

The data used for this analysis were acquired during the CTF3 Commissioning in December 2005. The beam energy was ~100 MeV and the electric charge was ~0.3 nC per bunch. Each train had a maximum duration of about ~300 ns (and variable depending on the particular measurement) and was composed of about 1000 bunches.

The beam images were acquired using the first OTR after the RF deflector (see Fig. 2) and the optics between the RF deflector and the OTR were optimized for the latter's resolution.

As mentioned above, we took sets of images of the bunch at the zero-crossing and at ±5 deg, ±10 deg and ±15 deg with respect to it and with ~10 MW of input power in the device. We determined the zero-crossing condition by observing the beam image on the OTR and choosing the RF cavity phase that produced the smallest image. We also took a set of reference image with the RF deflector turned off. Fig. 3 shows an example of these unprocessed images for each of the cases. The images show clearly the separation of the odd and even bunches when the RF deflector phase is different from the zero-crossing condition, and how this separation becomes more obvious as this difference increases. We can also notice that the beam images are slanted with respect to the longitudinal direction. This effect could be due to two different kinds of causes (or to both at the same time): the camera orientation and the linac optics. In the first case, an error in the camera orientation would produce a camera field of view that is oblique with respect to the beam reference frame, and the oblique image would be only an effect of this different orientations. In the second case, the optics after the deflector could have an effect on the bunch that depends on the transverse direction.

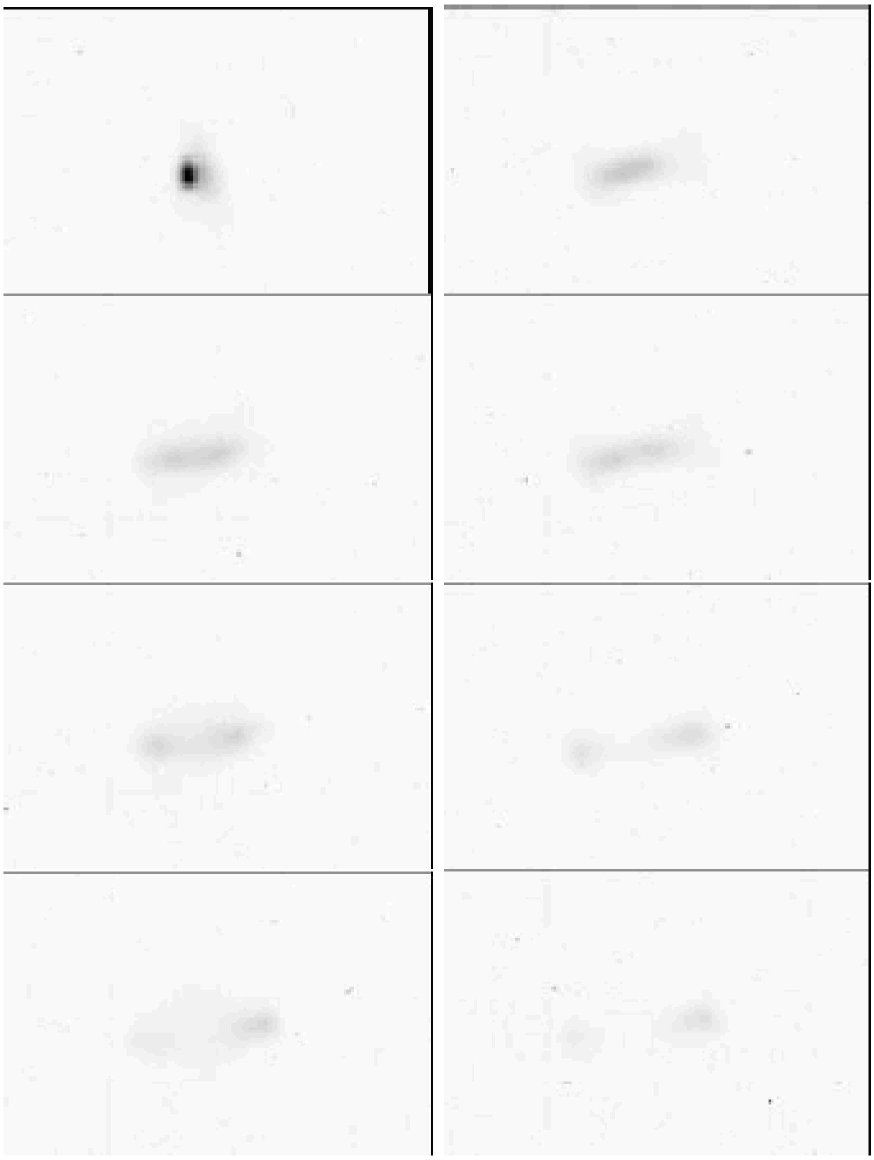

**Figure 3: Unprocessed bunch images. From top left: with the RF switched off, at zero crossing, 5 deg up, 5 deg down, 10 deg up, 10 deg down, 15 deg up, 15 deg down.**

## 3. Image Analysis

In order to obtain the bunch size from the images shown in Fig. 3, we had to correct them for the diagonal effect discussed above before performing the analysis.

The first step in the processing consisted in subtracting the noise from the whole image, that is removing the hot spots and evaluating the signal level in the image areas that were not illuminated by the beam. Then we rotated each beam image in order to obtain the maximum size in the transverse direction (each image required its own optimization) and we projected it on the transverse direction. Finally, depending on the particular image shape, we fitted the obtained beam profiles with either a single or a double Gaussian profile plus a constant noise level to estimate their size. Fig. 4 shows an example of such a fit. The widths for each image were then averaged with the homologous ones to obtain a beam size estimate for each value of the RF cavity phase, and having more than one image allows us also to obtain an estimate of the error on the measured width.

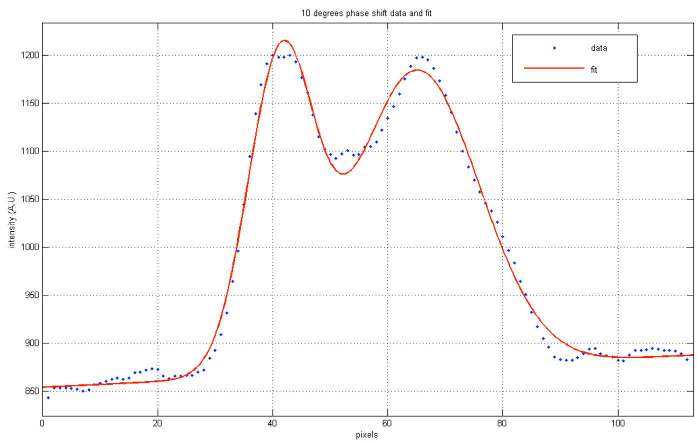


**Figure 4: An example of an analyzed image. After noise subtraction, the image was rotated and projected in the transverse direction to obtain the blue dots profile. This profile was then fitted with two different gaussians plus a constant value to the red curve.**

## 4. Calibration and Results

From the image analysis described above we obtained the FWHM size in image pixels of the beam with the RF turned off ($\sigma_{x\_noRF}$) and at the zero-crossing phase ($\sigma_{x\_zc}$):

$$\sigma_{x\_noRF} \cong 5.8\,px$$

$$\sigma_{x\_zc} \cong 15.09\,px$$

To obtain the actual bunch length, we calibrated the screen. We plotted the position of the beam centroids in image pixels as a function of the phase difference with the zero-crossing (Fig. 5), separating the images of the even and odd bunches were they were split (Fig. 5 shows also that what we considered the zero-crossing situation is -1.67 deg from the actual one).

The resulting fitted lines give an average parameter of $|B|\cong 1.45px/deg$, and considering the RF frequency of 1.5~GHz, the calibration coefficient of the measurement is: $CAL\cong 0.393mm/px$.

To obtain the actual bunch length we have subtracted quadratically the two dimensions (at the zero crossing and with the RF power off, [3]) in pixels and then we have multiplied the result by the factor *CAL*:

$$\sigma_z = CAL \cdot \sqrt{\sigma_{x\_zc}^2 - \sigma_{x\_noRF}^2} \cong 5.45mm$$

From the previous results it is possible to calculate the resolution of the measurement in terms of the minimum bunch length that gives, on the OTR screen, a $\sigma_{x\_zc}$ exactly equal to $\sigma_{x\_noRF}$:

$$\sigma_{x\_zc\_MIN} = \sigma_{x\_noRF} \cong 2.28mm$$

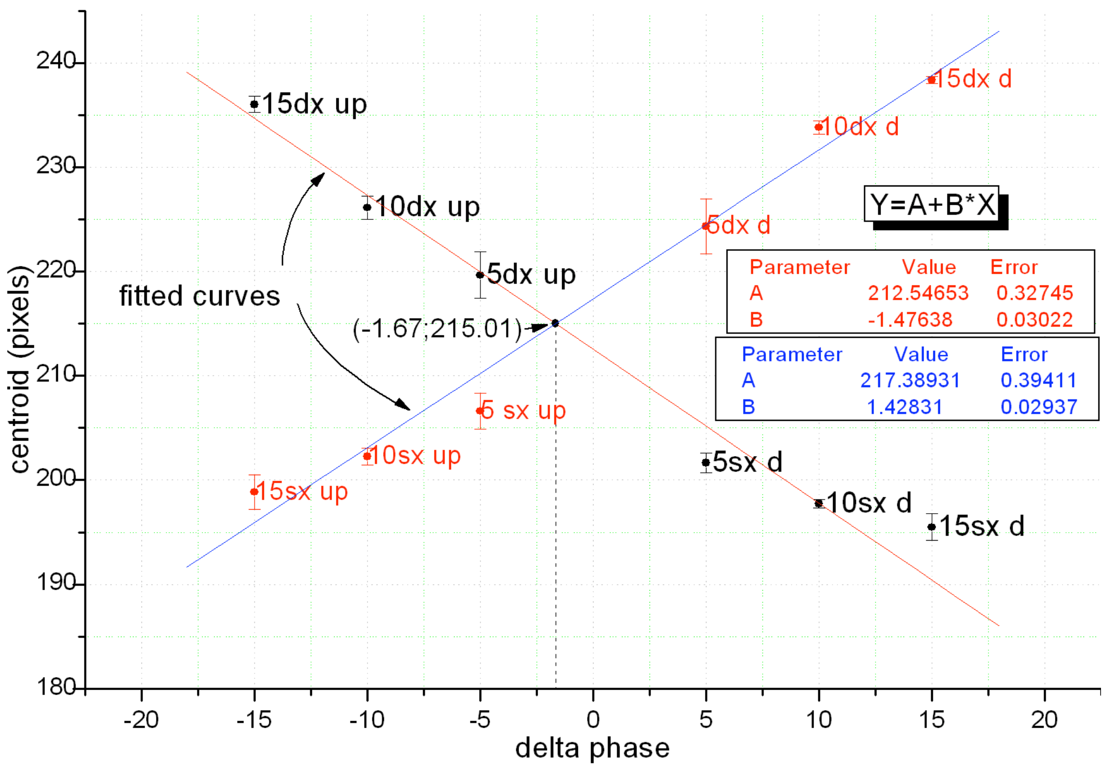


**Figure 5: The phase/centroid position relation. The dx and sx labels refer to the even and odd bunches in each image, where they were split. The fitted lines provide the parameters for the pixels/millimetres conversion.**

## 5. Conclusions

We have measured the CTF3 bunch length with the 1.5~GHz RF deflector, which at this stage of machine commissioning is ~5.45 mm. We have developed image analysis dedicated tools to perform correction and noise subtraction, and we have shown that this technique is also a powerful diagnostic device to check on camera orientation and possibly beam optics.

## References

[1] http://ctf3.home.cern.ch/ctf3/CTFindex.htm.

[2] F.Marcellini, D.Alesini, "Design Options for the RF Deflector of the CTF3 Delay Loop", EPAC 2004 , Lucerne, 2004

[3] P. Emma, et al., "Transverse RF deflecting structure for bunch length and phase space diagnostics", 2000.