

TEST OF A NON-INVASIVE BUNCH SHAPE MONITOR AT GSI HIGH CURRENT LINAC*

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Abstract

At the heavy ion LINAC at GSI, a novel scheme of a non-invasive Bunch Shape Monitor has been tested with several different ion beams at 11.4 MeV/u. The monitor's principle is based on the analysis of secondary electrons as liberated from the residual gas by the beam impact. These electrons are accelerated by an electrostatic field, transported via a sophisticated electrostatic energy analyzer and an rf-deflector, acting as a time-to-space converter. Finally a MCP amplifies electrons and the electron distribution is detected by a CCD camera. For the applied beam settings this Bunch Shape Monitor is able to obtain longitudinal profiles down to a width of 440 ps with a maximum resolution of 135 ps, corresponding to 2° of the 36 MHz accelerating frequency. Systematic parameter studies for the device were performed to demonstrate the applicability and to determine the achievable resolution.

MOTIVATION

Within the FAIR-Project [1] a proton LINAC [2] is scheduled as a new injector for the SIS18 synchrotron at GSI. The p-LINAC will provide 70 MeV and 70 mA current in addition to a compact construction. Due to the high energy deposition for conventional intersecting Bunch Shape Monitors [3] a novel design is foreseen. The new detector for the longitudinal bunch structure with a phase resolution of 1°, with respect to the 325 MHz acceleration frequency, is intended to ensure proper longitudinal matching of the accelerating structures. The presented device is a re-commissioning of a non-invasive Bunch Structure Monitor [4].

WORKING PRINCIPLE

The non-invasive Bunch Shape Monitor (BSM) prototype is based on secondary electrons, which are freed by the interaction of beam ions and the residual gas. Figure 1 provides a schematic illustration. These electrons are accelerated towards an aperture by an external homogeneous electrostatic field of 4.2 kV/mm. Using side strips parallel to the electrodes the electric field is leveled. The aperture slit has a width of 1.5 mm in beam direction. To further reduce the divergence of the secondary electrons (SEs) two apertures with a distance of 70 mm are used. The aperture width can be remotely adjusted between 0.1 mm and 2 mm. After passing these apertures the electrons are filtered by an 90° cylindrical electrostatic energy analyzer with a bending radius of 30 mm. A second similar analyzer bends

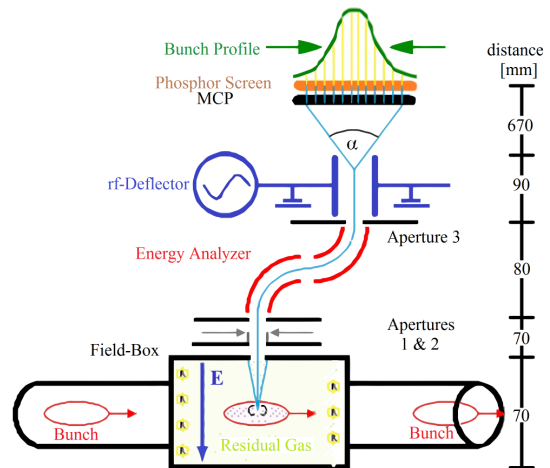


Figure 1: Schematic illustration of the non-invasive BSM.

the SE beam back in its original direction for mechanical reasons.

The applied voltages are ± 5.5 kV for the opposite cylinder segments. A third aperture is placed 10 mm away from the edge of the second analyzer to enable a point-to-point focusing from the entrance to the exit slit. After a drift of 90 mm the SEs reach an rf driven deflector coupled to the acceleration frequency. The rf-deflector works as a time-to-spatial converter, due to a specific angle each electron is deflected in dependence to its time of arrival. Two types with different resonance frequencies are available. The first one is operating at a frequency of 36 MHz for long bunches and another one for short bunches at the third harmonic at 108 MHz. Both deflectors are 800 mm long parallel wires corresponding to $\lambda / 4$ to get the maximum amplitude where the SEs pass the deflector. The maximum power applicable to the resonator is 100 W at 36 MHz and 50 W at 108 MHz in pulses of 6 μ s duration. The deflected SEs form a spatial distribution. This distribution arrives after a flight of 670 mm at a Chevron MCP (Hamamatsu F2226-24P) with an effective diameter of 77 mm, which is also equipped with a P20 phosphor screen. The illuminated spots on the phosphor screen are observed by a CCD-Camera (PCO 12Bit SensiCam) with a resolution of 640×480 pixels. In addition the deflector has a second function as a focusing electrostatic einzel-lens by a common DC-voltage on the deflector's plates.

Due to a technical defect, the three apertures could not be moved and were manual opened. The first and the second aperture are 1 mm opened and the third is 2 mm opened, respectively.

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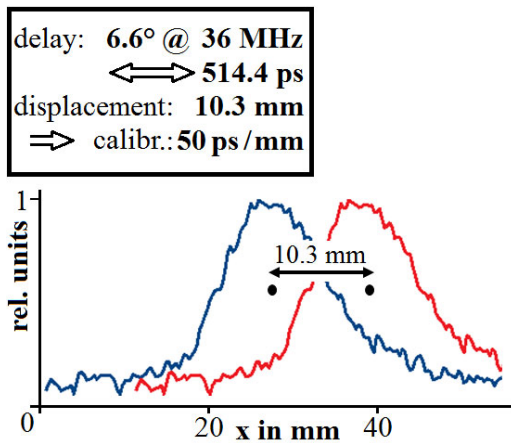


Figure 2: Example for calibration measurement for an rf power fed to the deflector of $P = 1$ W. This calibration was used for the measurement displayed in Fig. 4.

CALIBRATION AND RESOLUTION

In order to determine the longitudinal time structure of a bunch, a calibration has to be done and the resolution has to be determined. The deflection angle and therefore the position of a detected electron depends on the amplitude and phase of the driving frequency of the rf-deflector. By obtaining the electron distribution, the CCD-Camera assigns each event a specific pixel (see Fig.2). For a given amplitude the rf-phase is shifted by a preset degree corresponding to a certain time delay and regarding the displacement of the distribution, the phase calibration is done.

With only DC voltage applied to the rf-deflector, working as an electrostatic einzel-lens, the image properties can be investigated. This is performed by using the bottom plate of the BSM as a reference electron source with no time alteration, due to the long drift time of positive charged gas atoms traveling to the negative bottom plate and creating there SEs. The DC voltage setting with the narrowest distribution is taken. Using the afore mentioned phase calibration the resolution of the BSM is determined for the fixed aperture setup of 1 mm and 2 mm, respectively. Figure 3 shows a measurement to determine the resolution. The SEs from the bottom plate are focused on the MCP. A minimal focus width of 2.7 mm FWHM is obtained. Using the phase calibration of 50 ps / mm, as valid for Fig. 4, a phase resolution of 1.75° at 36 MHz corresponding to 135 ps is achieved.

The effect of resolution is illustrated for an example: Assuming a beam with Gaussian profile width of 800 ps FWHM, the broadening of the image, due to the resolution of 135 ps, is a few percent, allowing reliable bunch profile measurements.

MEASUREMENTS

A test measurement using the BSM yielded a bunch profile with 780 ps FWHM displayed in Fig. 4. The obtained bunch shape shows a basic Gaussian shape with a slight

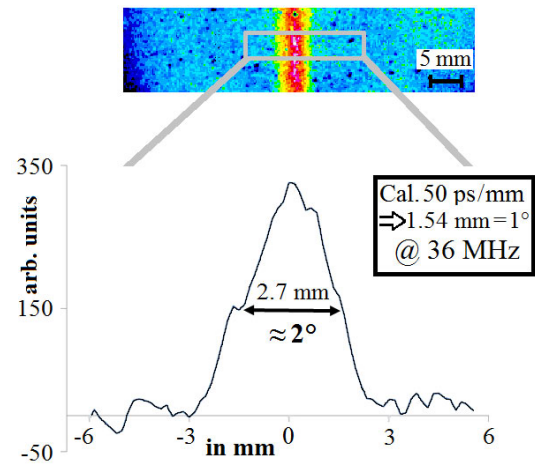


Figure 3: Determination of the resolution, see text. All events in an region-of-interest are projected and plotted for evaluation.

tilt. Currently a reliable measurement requires at least 64 macro pulses and can last several minutes depending on the repetition rate of the accelerated beam.

The BSM is based on the creation of electrons as a signal transmitter. Therefore any kind of charged particles can create a signal or just contribute to a background. In an environment, such as the high current heavy ion LINAC, the BSM is quite receptive for measuring artifacts or scattered electrons, which do not belong to the bunch profile. Although using apertures and an energy analyzer this occurrence cannot be excluded, the measurements have to be verified.

If the BSM is sensitive to the alterations of the bunch length, the device is credible. By applying rf power to a

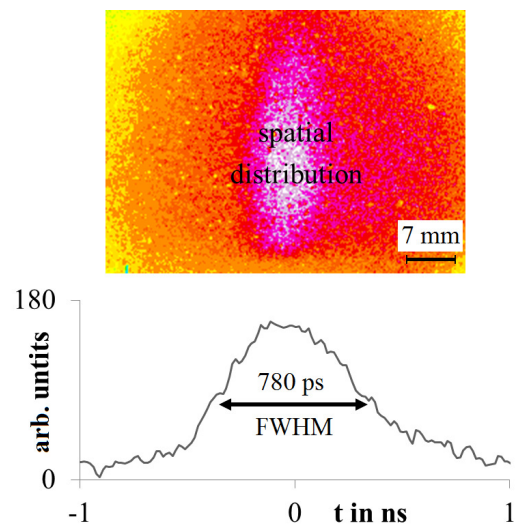


Figure 4: Measurement of a longitudinal bunch profile of 780 ps FWHM. Parameters: U^{28+} , current $I = 200 \mu A$, macro pulse length $\tau = 180 \mu s$, $p = 5 \cdot 10^{-6}$ mbar, averaged over 64 macro pulses, rf power $P \approx 1$ W.

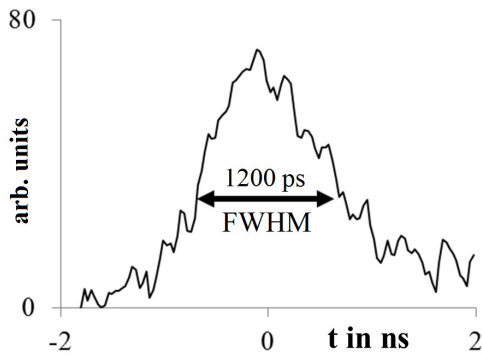


Figure 5: A measurement for a stretched bunch profile of 1200 ps FWHM. Parameters: U^{36+} , $I = 100 \mu A$, $\tau = 180 \mu s$, $p = 5 \cdot 10^{-6}$ mbar, 128 pulses, rf power $P \approx 0.1$ W.

buncher cavity upstream of the monitor location, the bunch length can be strongly affected. The BSM has been tested for reliability for three different bunch lengths with all other beam parameters left constant. The device is able to measure a stretched profile of 1200 ps FWHM and is still sensitive enough to distinguish between the reference shape of 480 ps FWHM and a compressed bunch of 440 ps FWHM.

DISCUSSION OF ACHIEVEMENTS

The non-invasive BSM has performed high quality measurements for longitudinal bunch profiles from 1200 ps FWHM down to 440 ps FWHM. The resolution for the longer bunch shape were 3.7° at 36 MHz, corresponding to 285 ps and 1.75° at 36 MHz corresponding to 135 ps for the shorter bunch shape. There are options to improve the performance of the device which will be discussed:

- Increasing the applied power to the rf-deflector will increase the absolute occupied space of the SE distribution on the MCP and therefore increase the time resolution. At the same time the intensity on the MCP will drop to a point where the signal level is too low to distinguish it from the background. The installed electronic amplifier is able to provide two orders of magnitude higher power than used in Fig. 6.
- A recently installed new aperture control will allow for future experiments different aperture setups to significantly improve the absolute resolution. By closing the apertures, the intensity decreases until the signal level might be too low for proper detection.

As a beam diagnostics tool the usability of the BSM has to be improved. Background, parasitic signal contributions and resolution were investigated and improved, therefore decreasing the acquisition time and the dependence of the device for adjusting beam parameters for high quality measurements. By accomplishing these objectives, the non-invasive BSM principle will be operational for the com-

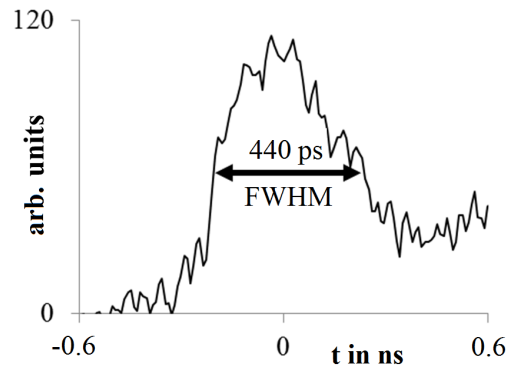


Figure 6: Image of a shorter bunches with 440 ps FWHM. Parameters: see Fig. 5, rf power $P \approx 1$ W.

missioning of the FAIR proton LINAC, having a phase resolution of 1° .

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