MEASUREMENTS WITH A NOVEL NON-INTERCEPTING BUNCH SHAPE MONITOR AT THE HIGH CURRENT GSI-LINAC*

P. Forck, C. Dorn, Ges. für Schwerionenforschung GSI, Darmstadt, Germany, p.forck@gsi.de

Abstract

For bunch length determination in the range of 0.3 to 5 ns at the GSI heavy ion LINAC a novel, non-intercepting device has been realized. It uses the time spectrum of secondary electrons created by atomic collisions between beam ions and residual gas molecules. These electrons are accelerated by an electric field of 420 V/mm toward an electro-static energy analyzer, which is used to restrict the effective source region. Then the electrons are deflected by an rf-resonator running in phase with the acceleration frequency (36 or 108 MHz) to transform the time spectrum into spatial separation. The detection is done with a Ø 70 mm multi-channel plate. The achieved time resolution is about 50 ps, corresponding to 2 degree of 108 MHz phase.

MONITOR OVERVIEW

The determination of the longitudinal density distribution of a bunched beam is an important issue because it is required for an optimal matching between different LINAC-modules as well as for the comparison with numerical calculations. At proton and ion LINACs the bunch structure cannot be determined by capacitive pick-ups due to the non-relativistic beam velocities ($\beta < 20\%$ at the GSI-LINAC) causing a faster propagation of the electric field of the bunches. At most LINACs the bunch structure is determined by secondary electrons emitted from a wire crossing the beam [1, 2]. The wire is biased with about -10 kV to pull the secondary electrons toward a slit outside the beam path. An rf-deflector follows, where the electrons are modulated in transverse direction by an electric rf-field. The deflection angle depends on their relative phases, i.e. the device transforms the time information into a spatial distribution.

For the high current beam operation at GSI with heavy ions and currents up to 20 mA [3], the beam power is sufficient to melt intersecting materials. The described principle is adapted to a non-intersecting device by performing the time spectroscopy of secondary electrons created by atomic collisions between beam ions and residual gas molecules. The electrons are accelerated by a homogeneous electrical field formed by electrodes outside of the beam pass, as usually used for Ionization Profile Monitors. To restrict the source region for the secondary electrons, an aperture system and an electro-static energy analyzer is used. The time-to-spatial transformation is performed with an rf-deflector developed at INR (Moscow) [2].

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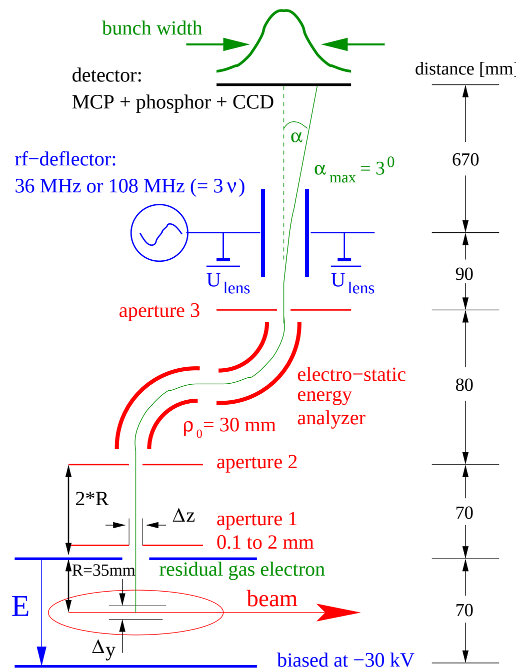

Figure 1: Schematic sketch of the bunch shape monitor.

MONITOR HARDWARE

The schematic layout of the monitor is displayed in Fig. 1: At the detector location, the beam passes a static electric field region generated by a 160×60 mm^2 electrode biased up to -30 kV. With the help of field forming strips, a homogeneous field of 420 V/mm perpendicular to the beam direction guides the secondary electrons toward a grounded plate with a horizontal slit of 1.5 mm in beam direction, see Fig. 2. To shorten the source length Δz in beam direction and the corresponding divergence of the secondary electron beam, two apertures with a distance of 70 mm are used. Their opening can be varied remotely between 0.1 and 2 mm by dc-motors. The second aperture serves as entrance slit of a 90^0 cylindrical electro-static energy analyzer with a bending radius of $\rho_0 = 30$ mm. The nominal voltages are ± 5.5 kV for the opposite cylinder segments. Two similar devices are installed to place the electron detector perpendicular to the beam pipe. A third aperture is located 10 mm downstream from the second cylinder edge to enable a point-to-point focusing from the entrance- to the exit-slit [5]. Using ± 0.25 mm opening for aperture 1 and 2 as well as ± 0.5 mm for aperture 3, the vertical source prolongation is restricted to about $\Delta y = \pm 0.2$ mm [4], which is comparable to the wire thickness in the standard method [1].

After a drift of 90 mm the time information is transferred into spatial distribution by the rf-deflector synchronized

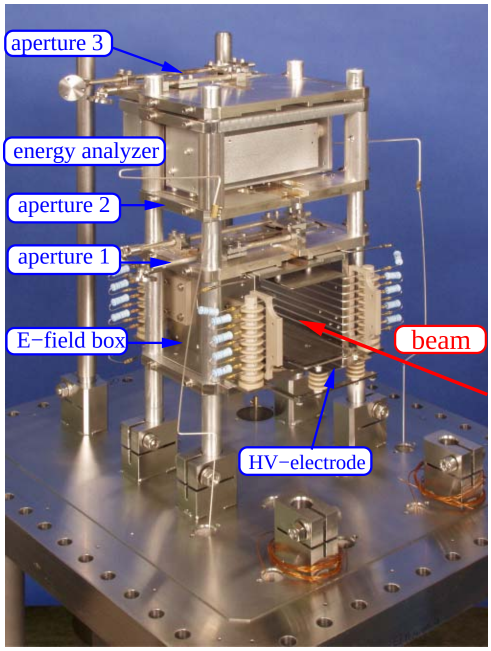

Figure 2: Photo of the electric field box and the energy analyzer. The parts are mounted on a rectangular flange of 340×400 mm^2, which can be mounted to a vacuum chamber. The opening for the beam is 70×70 mm^2.

with the LINAC rf. Two types of rf-deflectors are available, one running at the base-frequency of 36 MHz for the measurement of long bunches and one for short bunches at the third harmonics at 108 MHz. The deflectors are built as 800 mm long parallel-wire $\lambda/4$-resonators [2] having a quality factor of $Q_0 = 290$ and $Q_0 = 370$ for the 36 and 108 MHz device, respectively. The 108 MHz type has straight parallel-wires, while spiraled wires are used for the 36 MHz device. The maximum rf-power fed into the resonator is 100 W and 50 W for the 36 MHz and 108 MHz, respectively. A 6 ms pulse length for the rf-power is sufficiently longer than the maximum macro beam pulse. After this transverse deflection of maximum $\alpha_{max} = 3^0$ and a flight path of 670 mm the single electrons are detected by a Ø 70 mm Chevron MCP (Hamamatsu F2226-24P) equipped with a P20 phosphor screen. The light spots are read out with a 12 bit digital CCD camera (PCO SensiCam) having a 480×640 pixel VGA-resolution and a fiber optic link for digital data communication.

BEAM-BASED MEASUREMENTS

Systematic test measurements at a target location were performed at 11.4 MeV/u for several ion beams. Without applying rf-power to the deflector the optics of the energy analyzer was checked. The parallel wires of the rf-deflector can be biased with maximal $U_{lens} = -7$ kV acting as a electro-static einzel-lens [1]. As shown in Fig. 3 the electron beam can be focused on the MCP and a spot size of 1 mm can be reached corresponding to about 6 pixels.

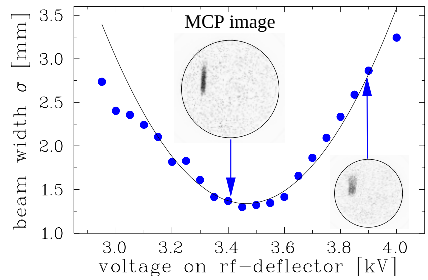

Figure 3: Determination of the monitor resolution by variation of the electro-static lens voltage without applying rf to the deflector for the nominal aperture setting of ± 0.25 mm for aperture 1 and 2 and ± 0.5 mm for aperture 3.

This coincides with the optical calculations for the nominal aperture settings of the energy analyzer. Due to the 70 mm active diameter of the MCP this width contributes by only a few % to the monitor resolution; for the measurements of Fig. 5 and 6 it corresponds to a time resolution of about 50 ps. The beam spot size can be even reduced by a smaller aperture opening, but than also the signal strength decreases.

To illuminate the full MCP the rf-power of the rf-deflector can be varied. Therefore, quite different bunch lengths can be measured. A calibration of the bunch center position at the MCP with respect to the rf-phase is required to achieve an absolute time or phase scale. An example is shown in Fig. 4 using an digital rf-phase shifter with $\sim 0.3^0$ accuracy. In addition, the plots proves the linearity of the transverse deflection as long as the rf-phase difference between deflection voltage and the bunch stays within an interval of $\sim 45^0$. For large phase differences, the non-linear behavior of the sine-wave starts to contribute.

A typical raw image of the bunch as recorded by the CCD camera is shown in Fig. 5. The deflection with a frequency of 108 MHz is displayed horizontally spanning 3.6 ns. The projection of the light intensity on this axis gives the bunch shape. This measurement proves the general functionality of this novel device, where short bunches down to $\sigma = 125$ ps were monitored [4].

It is required to subtract a homogeneous distributed background. This background is only present during beam delivery and is not influenced by the aperture opening. Presently, its origin is not well understood. It might be due

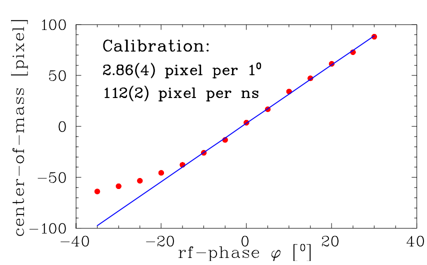

Figure 4: The central position of the bunch as a function of the relative phase shift.

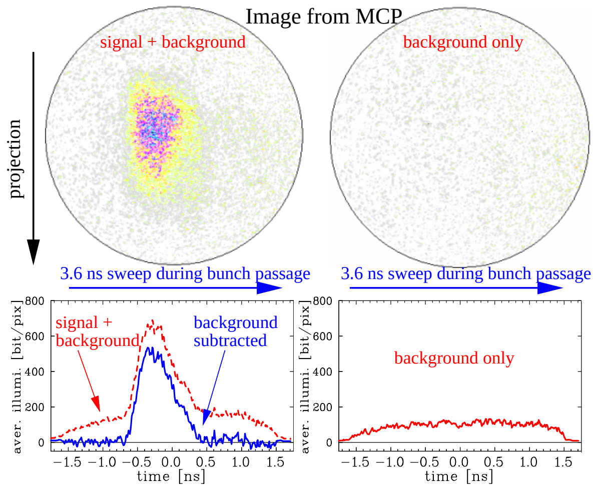

Figure 5: Typical image (inverted color) from the MCP for a 2 mA Ni^{14+} beam averaged over 8 macro-pulses with 0.2 ms duration and a vacuum pressure of $2 \cdot 10^{-6}$ mbar. 15 W had been fed to the 108 MHz rf-deflector.

to x-rays from secondary electrons accelerated by the electric field and hitting the stainless steel plate of the electric field box. But the installation of a 5 mm thick steel shielding behind the energy analyzer for x-ray absorption (maximum energy 30 keV) did not lead to a significant reduction. We will install a biased grid close to the HV-electrode to prevent for secondary electrons entering the interaction region. Other reasons for the background might be neutrons or γ emitted at the nearby beam dump. A nearly background-free measurement is intended to allow single macro-pulse monitoring. Moreover, with an enhanced signal quality the monitor resolution can be increased by a smaller aperture opening and possible non-Gaussian bunch structure contributions can be detected within a single macro-pulse. The image of the bunch can than be spread over the full MCP area and a resolution down to $\sim$ 20 ps would be achievable.

The displayed measurement had been performed with a high current setting of 2 mA Ni^{14+} beam. But the same signal quality can be reached for low current settings [4]. If the amount of secondary electrons does not result in a sufficient statistic, the vacuum pressure can be raised by a regulated gas inlet system. It has been proved, that a local pressure bump up to 10^{-4} mbar in the transfer lines at GSI does not influence the beam properties. Due to the statistical nature, averaging also improves the signal-to-noise ratio leading to a large dynamic range.

An application of the bunch shape monitor is to determine the longitudinal emittance. By varying the voltage amplitude of a buncher cavity and measuring the bunch width, the longitudinal emittance in a linear approximation can be calculated by fitting a parabola through the square of the bunch width, as displayed in Fig. 6.

Compared to the 'standard' method by an intercepting wire a larger contribution for the bunch space charge is expected for the following reason: Close to the wire the elec-

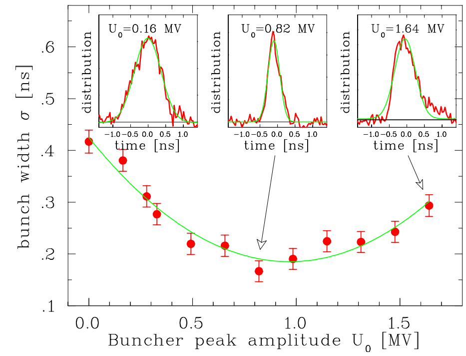

Figure 6: Measurement of the bunch width (one standard deviation) as a function of the buncher voltage 31 m upstream of the detector performed with the same beam as of Fig. 5.

tric field for the secondary electron acceleration is large, while for our setup the electric field is constant during the whole acceleration process. Therefore the influence of the beam's electric field on the detected electrons is more important. Model calculations for the measured beam parameters are discussed in [4] proving the applicability for the high current operation at GSI with a bunch length in the ns range.

CONCLUSION

A novel, non-intersecting device for the bunch structure determination has been successfully tested. It can be used in a wide current range and offers a direct determination of parameters that are difficult to measure. For high currents and moderate bunch-length in the ns range, the bunch structure is reproduced faultlessly. Presently, the origin of the diffuse background is not well understood and limits the achievable resolution. After its reducing a high resolution single macro-pulse observations seems to be possible.

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REFERENCES

[1] A. Feschenko, *Proc. PAC 2001, Chicago*, p. 517 (2001) and references therein.

[2] N.E. Vinogradov et al.,*Nucl. Instrum. Meth.*, **A 526**, p. 206 (2004), Y.V. Bylinsky et al., *Proc. EPAC 1994, London*, p 1702 (1994).

[3] W. Barth et al., *Proc. PAC 2001, Chicago*, p. 3281 (2001), W. Barth et al, *Proc. XX LINAC Conf. 2000, Monterey*, p. 1033 (2000).

[4] P. Forck et al., *Proc. EPAC 2004, Lucerne*, p. 2541 (2004).

[5] See e.g. H. Wollnik, *Optics of Charged Particles*, Academic Press (1987).