Aspects of Bunch Shape Measurements for Slow, Intense Ion Beams

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Abstract

For the characterisation of the ion beam delivered by the new High Current LINAC at GSI, the time structure of bunches and the knowledge concerning their intensity distribution in longitudinal phase space is of great importance. At least 100ps time resolution and the capability of measuring long tails in the distribution were design parameters. Taking advantage of Rutherford-scattering to reduce the count rate, a direct time of flight measurement technique using diamond detectors can be applied. First results are reported. Plans for determine the energy of individual ions by detecting secondary electrons emitted from a thin C foil using 1m drift are discussed.

1 DESIGN OF BUNCH SHAPE MEASURING DEVICES

Knowledge of the distribution of ions within a bunch and longitudinal emittance is needed for the matching between different LINAC acceleration components as well as for the comparison to calculations, in particular in the case where space charge effects play a role. For the new high current heavy ion LINAC developed at the GSI, which consist of a 36 MHz RFQ (energy 120 keV/u) and two IH-structures (final energy 1.4 MeV/u) [1] space charge effects have to be considered. The commissioning just started in spring 1999 and will be continued until the end of '99 and a maximum pulse current of 15 emA for heavy ions like U^{4+}, corresponding to 10^9 ions per bunch is expected. Having a typical phase spread of ±15° corresponding to 2ns in time, a resolution of at least 100ps is needed to visualise mismatch or space charge effects. Due to the low velocities, capacitive pick-ups cannot be used.

During the commissioning a movable test bench is installed behind each section [2, 3]. To measure the time structure and the longitudinal emittance of the bunches a new designed device is mounted there, which is based on a time-of-flight method using diamond particle detectors [5], where the arrival time of the ions is measured relative to the acceleration rf, see Fig. 1. The excellent time resolution of a diamond detector is used, but one has to make sure, that less than 1 ion per bunch hits the detector. For this purpose Rutherford-scattering by a thin gold foil is used as an attenuator. The technical outline and preliminary results are discussed.

In addition a second method is under development, which is suitable for the bunch time structure measurement within one macro pulse. This is an adaption of the well known method by Ostroumov et al. [6], but instead using secondary electrons from an intersecting wire, the electrons of the residual gas atoms will be used. The time information carried by the electrons is converted to spatial differences by an rf-deflector and detected with a spatial resoluting MCP. The reader is referred to [3] for further details.

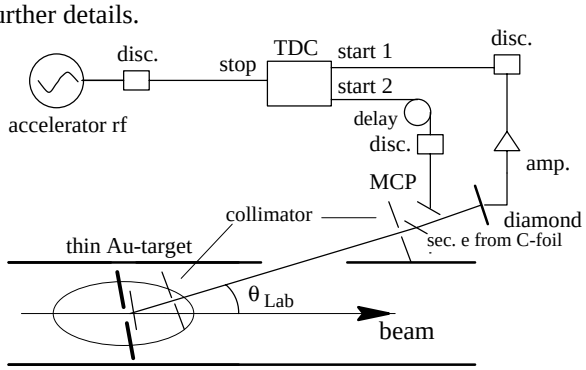

Figure 1: Schematic sketch of the designed TOF method with particle detectors far the bunch shape measurement (see Sec. 2) and phase space distribution (see Sec. 5).

2 RUTHERFORD-SCATTERING CONSIDERATIONS

The precise timing signal from particle detectors is used since several decades for the determination of the bunch structure and the energy spread of slow ion beams. But the direct bombardment of the detector can only be used for very low ion currents to prevent multiple ion hits within one bunch. We like to study space charge effects and therefore the count rate on the detector is reduced by Rutherfordscattering, see Fig. 1. A 120 μg/cm^2 (equals to a thickness of ≈60 nm) gold foil is used as the target. We choose a laboratory angle Θ_{Lab} = 7.5° together with a collimator having ∅ 0.5 mm holes and 16 cm distance on pneumatic feed-throughs. The attenuation of this system is shown in Fig. 2 as a function of the laboratory angle for the RFQ output energy for different ions. The chosen angle prevents from multiple hits for moderate ion currents, while for the highest possible ion currents the count rate can be varied by de-focusing the ion beam. For these considerations, the centre-of-mass energy as well as the broadening of the centre-of-mass solid angle due to the target recoil has been taken into account [4], which depend on the scattering angle, the projectile energy and the ratio between the projectile and target masses. As shown in the figure, the attenuation for the gold target

varies only by a factor of 2 for the interesting projectiles for a fixed specific energy. The attenuation scale with the inverse specific energy squared.

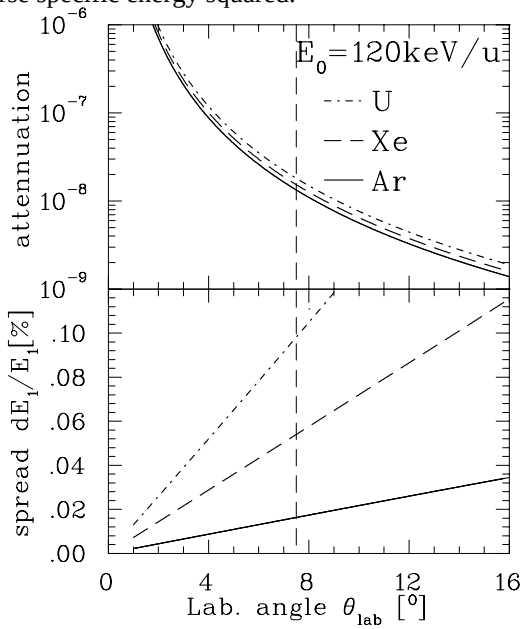

Figure 2: The fraction of scattered ions (top) within the chosen solid angle $\Delta\Omega_{lab}$ = 2.5 - 10-4) for an ion beam diameter of 10 mm and the energy spread of the projectile dEi /Ei (bottom) by Rutherford scattering for a 120µg/cm^2 gold target as a function of the scattering angle θ_{lab}.

A finite solid angle is equivalent to an energy spread dE_1/E_1 of the projectile, shown in Fig. 2, due to different energy releases to the target atoms, also shown in Fig. 2. The effect depends strongly on the projectile/target mass ratio and a heavy nuclei target is preferred here. For the chosen gold target, the energy spread for light ions is much lower than the needed resolving requirements of the beam energy spread of $\Delta W/W = 0.1\%$. But for heavier ions, like U, the resolution is limited. The relative energy spread dE_l/E_l by the target is independent of the projectile energy.

One might think of an other limiting factor, that is the multiple scattering inside the gold target, but according to an estimation in Ref. [4] the probability of multiple scattering is below 1.5 % for the 120 keV/u U projectiles and decreases for lower masses and higher energies; in the case of 120 keV/u it is about 0.75 °%.

Beside the projectile, the target nuclei can also leave the interaction zone due to the energy release by the collision. But the fraction of recoils inside the chosen solid angle around θ_{lab} = 7.5° is below 3x10^{-4} of the scattered projectiles. Therefore it is to low to spoil the resolution.

One drawback of this method is the sensitivity of the gold foil: One has to be very carefull not to heat the foil to the melting point. For our case we have to make sure by beam defocusing, that the beam intensity is below a factor of 1000 compared to the expected maximum. In addition the mechanical stability of the ∅5 mm self-supporting foil is low.

3 DETECTORS AND ELECTRONICS

The scattered ions are detected by diamond detectors; 3 detectors are mounted on feed-throughs downstream at spacing of about 20 cm, 61 cm and 102 cm, respectively. These fast detectors are used in our laboratory since several years for high energy ion detection [5], but so far not for ions, having a range much lower than the detector thickness.

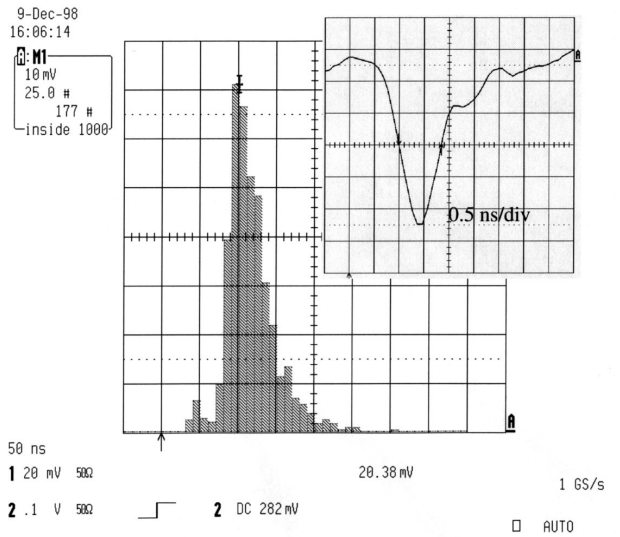

Figure 3: Pulse-height distribution of a diamond detector with 300 keV/u C^{4+} and one typical pulse as an inlet.

Beside the very low radiation damage, we gain mainly from the very fast signals, having a rise time below 1 ns, as shown in Fig. 3. This is important for the high timing requirements. A high voltage biased amplifier with more than 2 GHz bandwidth was developed at GSI [5]. To suppress the 36 MHz pick-up from the acceleration frequency careful shielding and a Notch-filter is needed. The conversion to logical pulses is done by a double threshold discriminator developed at GSI [7]. Via two thresholds the onset of the pulse is extrapolated. With careful adjustment, a timing error of less than 30 ps is expected with this equipment.

The logical pulses serve as a start of a VME time-to digital converter (CAEN V488), having a resolution (least significant bit) of 25 ps. It is stopped by the signal from the 36 MHz rf master oscillator, which drives the power amplifiers for the acceleration rf. A standard leading edge discriminator is used to get logical pulses, a division to 12 MHz is used for fitting to the TDC range. The converted data are stored in a FIFO for reading after the end of the macro-pulse, so a digitisation rate of 250 kHz is reached. In addition the counts can be stored in a FIFO based scaler (SIS 3801) for making off-line cuts with respect to

the time within the macro-pulse. The data are send from the VME to a VMS workstation for storage and analysis.

4 FIRST RESULTS

First test measurements have been done recently at the RFQ test bench with 120 keV/u Ar^+ ions with non-optimized beam setting.

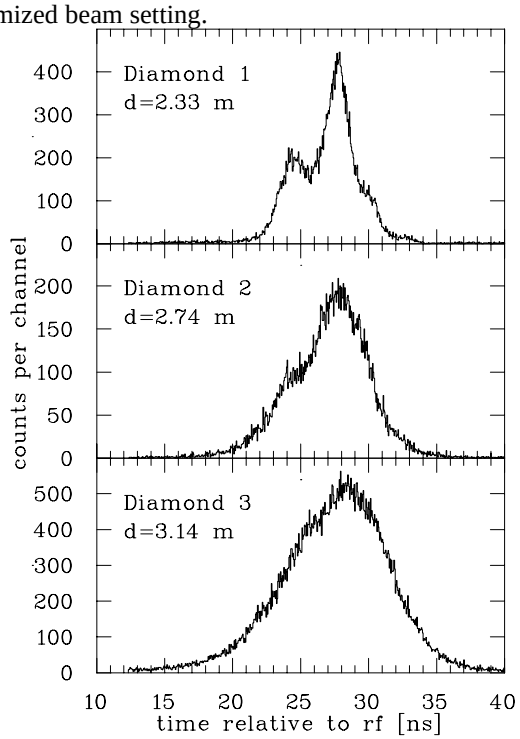

Figure 4: Bunch shape signal from a 120 keV/u Ar^+ beam observed on three diamond detectors with the given distance form the RFQ output, recorded with a time resolution of 48 ps per bin.

The bunch shape is plotted in Fig. 4, showing the functionality and the resolving power of the new device. With the three detectors the dispersion of the bunches can be visualised. The distance from the RFQ output to the gold target is 2.12 m and to the three detectors 2.33 m (Diamond 1), 2.74 m (Diamond 2) and 3.14 m (Diamond 3), respectively. Like expected from numerical simulations [1] the bunch shape is non-Gaussian. The width of the central peak measured with the closest diamond is about 2.2 ns and has pronounced side peaks. These side peaks are smeared out by the beam energy width $\Delta W/W$ after the drift of 1 m, as expected from calculations. The measurements have been done with a 100 times lower beam current as the design current, where the longitudinal emittance is larger. The low current was used to avoid destruction of the gold foil. A measurement with the shown statistics needs several minutes, corresponding to some 10^3 macro-pulses having 1 ms length. The time is limited by the 5 µs conversion time of the TDC. During the ion bombardment a drop of the efficiency (more precisely of the pulse-height) of the diamond was detected with unknown reason.

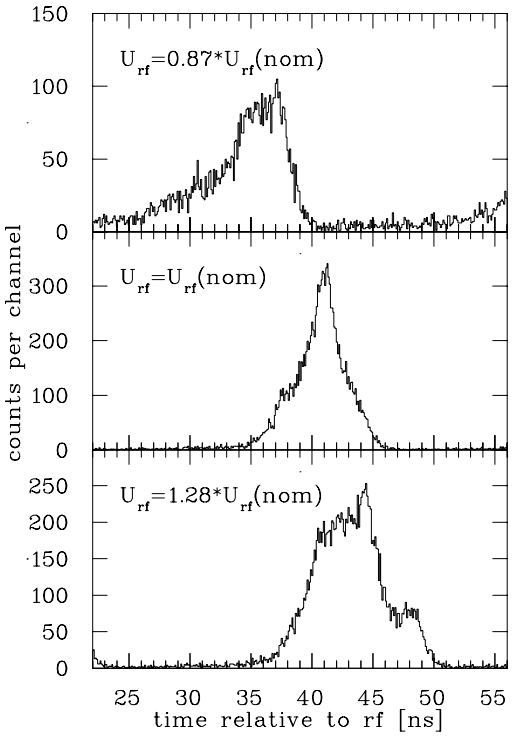

Figure 5: Bunch shape signal from a 120 keV/u Ar^+ beam with different amplitudes of the RFQ rf field.

In Fig. 5 the effect on the bunch shape for different amplitudes of the RFQ tank is shown. The amplitude is varied by ±10% of the nominal value, where the acceleration to the nominal energy is still possible; a different setting as compared to the previous figure is used. Besides a shift of the bunches center-of-mass a strong influence on the structure is visible using the first diamond detector. As expected no significant change on the mounted capacitive pick-up is visible due to the very low velocities, showing the high capability of the applied time-of-flight method.

The data shown are from first tests and are quite encouraging. More careful investigations have to be done, in particular concerning the limits of the resolution, given by the energy spread at the target and the discriminators setting. More measurements, in particular with higher currents, and comparison to theoretical calculations are needed.

5 MEASUREMENT OF PHASE SPACE DISTRIBUTION

With the setup not only the projection to the time axis of the bunches seems to be measurable, but also the energy distribution by determination of the time-of-flight. As an upgrade a second foil made of 5 µg/cm^2 (equals to ≈25 nm) is inserted between the scattering target and the diamond detector. Several secondary electrons are emitted by each ion from this surface [8]. The electrons are accelerated by a electric field of ≈1 kV/cm to a MCP (Hamamatsu F4655-10) 2 cm apart, equipped with a 50Ω

anode giving pulses with ≈1 ns width. For the time difference of the arrival here and at the diamond detectors 2 or 3 the time-of-flight and therefore the relative energy of an individual particle is calculated and the full phase space distribution could be plotted from a series of measurements. Again the resolution is limited by the scattering process: Here the total energy straggling is important, which amounts e.g. 0.1% in the case of Ar ions. The timing of the electronics is quite critical as a first test has shown.

Acknowledgment

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6 REFERENCES

[1] U. Ratzinger, Proc. XVlllntern. Lin. Acc. Conf., Geneva, Switzerland, p. 288 (1996), W Barth et al., Proc. XIX Intern, Lin. Acc. Conf., Chicago, USA, (1998).

[2j P. Forck, P Stiehl, this proceedings.

[3] P. Forck, A. Peters, P. Stiehl, Proceeding of 6th EPAC. Stockholm, Sweden, p. 1500 (1998).

[4] see e.g. J.R.Tesmer, M. Natstasi Handbook of Modem Ion Beam Material Analysis, Material Research Society, Pittsburgh (1995).

[S] P. Moritz et al., Proceeding of 3th DIRAC, Frascati, Italy, p. 153 (1997), E. Berdermann et al., Proc. XJDWllnt. Winter Meeting ofNucl. Phys., Bormio (1998).

[6] YV Bylinsky et al., Proc. 4th European Part. Acc. Conf., London, p 1702 (1994) and references therein.

[7j C. Neyer, 3rd Workshop on Electronics for LHC Experiments, London, CERN/LHCC/97-60 (1997).

[8] P. Koschar et al., Phys. Rev A 40, 3632 (1989)