A Fast Residual-Gas Ionization Monitor for Intense Stored Heavy Ions

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Abstract

A non-destructive beam profile monitor based on the detection of ions from the residual-gas ionization in the ultra high vacuum of the heavy ion synchrotron SIS has been designed. The beam profile monitor is provided to measure the beam emittance shrinkage of the newly installed electron cooler. Extraction of the beam profile is based on an amplification of the collected residual-gas ions with micro-channel plates and an one-dimensional position readout using a delay-line anode structure. The detector handles ion rates up to 10^6 per second. A combination of CAMAC time-to-digital converters, VME memories and VME processors has been chosen for fast data acquisition of some 10^5 events per second.

1 INTRODUCTION

In 1997/98 an electron cooler has been installed in the heavy ion synchrotron SIS [1], [2]. The effects on the transversal distribution of the ions, the emittance shrinkage and space charge effects during the cooling process should be studied in time intervals of 1 msec to 1 sec. For this application a fast, non-destructive beam profile monitor was designed. The design parameters are:

- transversal position sensitivity over an aperture of 150 mm
- rate capability from some 10^2 to 10^6 events per second
- bakeable up to 300^0C
- position resolution of 0.2 mm
- measuring in various time intervals with nearly no deadtime

Residual-gas ions produced along the beam trajectory are projected by a homogeneous electric field of $E = 100V/mm$ onto a position sensitive micro-channel plate detector [3], [4].

The detector system consists of four 2 inch micro-channel plates in chevron configuration as illustrated in figure 1. In front of the detector two different slits are mounted. With a high voltage, the slits can be switched to give a position sensitive area of $150 \times 1mm^2$ and $150 \times 18mm^2$, respectively. In case of high residual-gas ion rates, one can use the 1 mm slit system otherwise the 18 mm slit is used.

Due to the high count rates, a special type of delay-line anode [5] is used to provide timing measurement instead of charge integration as used with e.g. wedge and strip anodes.

To adapt this delay-line technique to ultra high vacuum conditions ($p \simeq 10^{-11} mbar$) and to guarantee stable operation conditions even after many baking procedures, a delay-line anode based on meander shaped conductor structures on a glass substrate is used. The meander has a active width of 0.25 mm and a spacing of 0.55 mm. The charge cloud from the micro-channel plate is collected on a thin Ge-layer with defined high resistance. The image charge emerging from this resistive sheet is collected on the meander shaped structure on the rear side of the glass plate. By measuring the time difference between the signals at both ends of the meander shaped structure, the position of each ion from the residual-gas can be determined for one dimension. The total signal propagation time along the whole structure is about 150 nsec.

An estimation of the expected residual-gas ion rates N_{Ion} can be given with the relation between the number of injected ions N_{Beam} with a revolution frequency f, the density of residual-gas atoms n_{Atom}, the length of the target l and the total ionization cross section σ.

$$N_{Ion} = N_{Beam} \cdot n_{Atom} \cdot f \cdot l \cdot \sigma \qquad (1)$$

The number of residual-gas atoms is about $2 \cdot 10^5 cm^{-3}$ ($10^{-11} mbar$) and the number of injected ions is currently 10^8 for $^{238}U^{73+}$ and will raise to nearly 10^{10} in near future. The total ionization cross section for 10 MeV/u U^{73+} is about $5 \cdot 10^{-15} cm^{-3}$ [6]. Thus we expect for 10^9 stored U^{73+} ions about 10^6 residual-gas ions per second.

2 DATA ACQUISITION

2.1 *Analog electronics*

From the micro-channel plates a pulse is taken to start the timing measurement. This start pulse is taken with a high pass filter, amplified and discriminated with constant fraction discriminator Ortec CF 935.

The stop pulses for the timing measurement are taken from each side of the meander structure, amplified and discriminated like the start pulse.

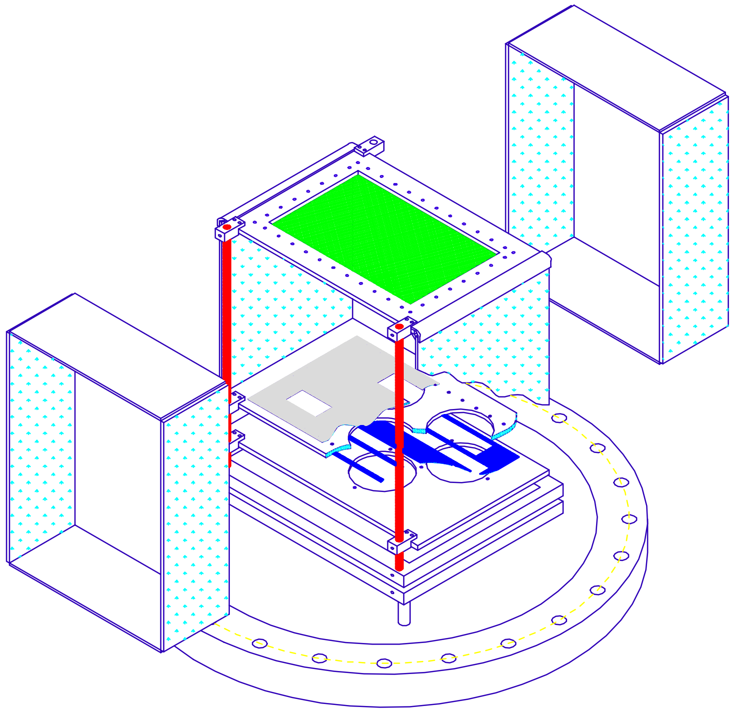

Figure 1: Schematic drawing of the SIS residual-gas beam profile monitor. Two of these monitors are used, one for horizontal and one for vertical measurements. One sees the plates for the back-bending fields in front the detector as well as behind the detector. For simpler assembly, the complete detector is mounted on a flange. The Germanium coated glass plates at the edge of the detector as well as at the edges of the compensation plates serve as voltage dividers.

The conversion is done by LeCroy 3371 TDCs, having a resolution of 50 psec. Due to a modification (the conversion of the upper six from eight available channels is suppressed) a total conversion time of $7\mu sec$ per event is realized, which corresponds to a maximum rate of more than 100 kHz.

2.2 *Digital electronics*

Due to the high residual-gas ion rates of up to several 10^6 per second a fast data acquisition system had to be applied. The converted data from the TDC are transfered via the LeCroy FERA data bus [7] to a VME high speed memory, the CES HSM 8170. The cycle time is about $0.15\mu sec$; CAMAC is only used for initialization of the TDCs and controlling of some timing and monitoring parameters.

Two HSM 8170 memories are used in a flip-flop mode for each direction: Data from one integration interval are stored in one memory, then an external logic switches the FERA data bus to the second memory and the data are stored there as shown in figure 2.2. During this integration interval the first memory is read out by the slave front-end processor.

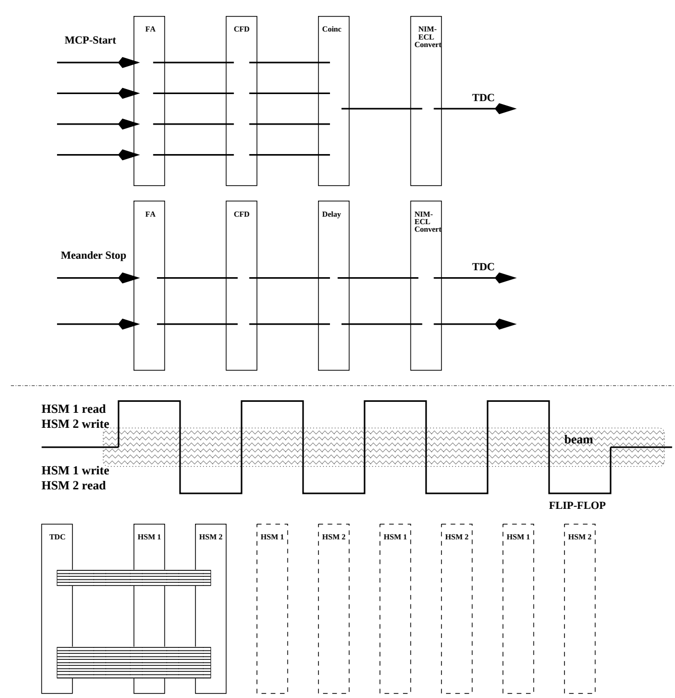

Figure 2: Schematic drawing of the analog electronic and the data acquisition system.

2.3 *Software*

For data acquisition a GSI product called **M**ulti **B**ranch **S**ystem [8], [9] is used. Currently two ELTEC E7 VME processors are used running under Lynx-OS which share a 16 MByte VME/VSB memory. The slave processor collects data from all kinds of VME and CAMAC modules and writes them to the shared memory via VME. The master processor reads data from the shared memory via VSB, formats events and handles all kind of transport e.g. network, tape, disk. With this hardware setup the MBS system can handle up to $2.5 \cdot 10^5$ events per second if data are stored to a tape drive. The limiting factor is the network. If all data are transmitted via the network, the maximum rate is $7.5 \cdot 10^4$ events per second.

For controlling measurements and display acquired data, a home build software is in use; it is written in IDL [10]. Data exchange via TCP/IP and histogramming data is handled with a GSI software called LEA [11] that provides an IDL interface.

3 MEASUREMENTS

First calibration measurements have been done with an UV-light source. Figure 3 shows a projection of the shadow of a calibration mask; dimensions: 20 slits, each 2 mm wide, 5 mm space between the slits. The measured position resolution is about 0.1 mm. The time sum for each signal pair from the meander structure is drawn in figure 3 and shows a narrow peak of 150 psec fwhm equals three channels of the TDC as expected for proper signal processing.

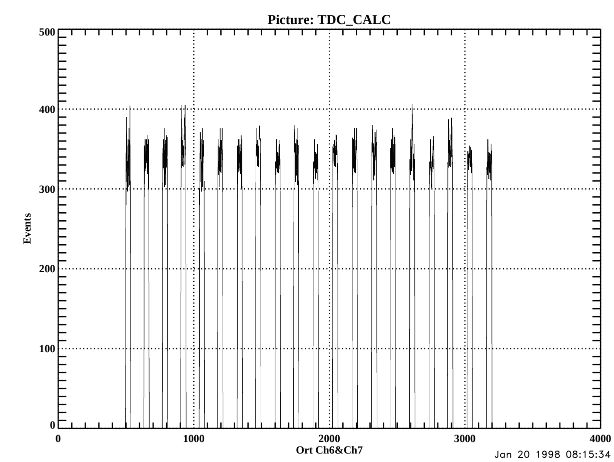

Figure 3: Projection of the shadow of a calibration mask.

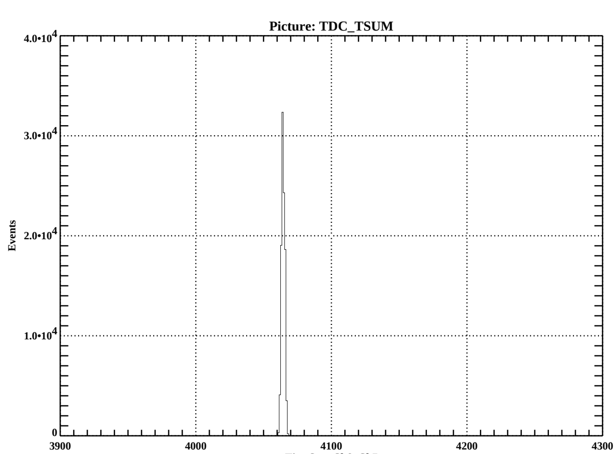

Figure 4: Time sum for each signal pair.

At present measurements with the ion beam in SIS are only in a very reduced manner possible. Some problems occurred since the last calibration tests. High-frequency disturbances in direct environment of the beam profile monitor cause a bad signal to noise ratio. Due to an maladjustment the attenuation through the structure is too large; the geometry has an impedance of 250Ω, amplifier inputs have an impedance of 50Ω. This mismatch did not disturb during the test measurements since no high-frequency drop-ins were present.

4 OUTLOOK

The RF pickup has to be shielded from the beam profile monitor. Internal wires must be replaced by screened cables.

The delay-line structure has to be modified. Currently simulations of the meander structure are made with a finite element software MAFIA [12].

Some software development is necessary to include the whole beam profile monitor system into the GSI main control system [13].

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