HITRAP Low Energy Diagnostics and Emittance Measurement*

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Abstract

The Heavy Ion TRAP (HITRAP) facility at GSI Helmholtzzentrum für Schwerionenforschung in Darmstadt is in the commissioning phase. Highly charged ions up to U^{92+} provided by the GSI accelerator complex will be decelerated and subsequently injected into a large Penning trap for cooling to the meV/u energy level. A combination of an inversely operated IH- and and RFQ-structure decelerates the ions from 4 MeV/u to an intermediate energy of 500 keV/u and then down to 6 keV/u [1]. This contribution concentrates on construction of two new low energy diagnostics, use of a diamond detector as well as some emittance measurements.

THE HITRAP LINAC

After deceleration and cooling of the mainly bare or H-like ions down to 4 MeV/u in the experimental storage ring (ESR), they are ejected every 30-50 seconds via the transport line towards the HITRAP linac (see fig. 1). The Double-drift buncher is the first cavity of the HITRAP linac and is used for phase focussing. It was commissioned during two beam times in 2007. The following structure is the interdigital H-Mode structure (IH) - a special kind of drift-tube linac - that decelerates the ions down to 500 keV/u. Its initial commissioning took place in August 2008 with a partially cooled heavy $^{197}Au^{79+}$ beam [2] and was continued with various Nickel and Xenon beams. The RFQ and Cooler trap are still waiting for commissioning. Regarding beam diagnostics new devices had to be developed for being able to measure these low energy and low intensity beams during the deceleration process. A single-shot pepper pot emittance meter and a diamond detector were installed for transversal emittance and longitudinal bunch structure measurements.

NEW LOW ENERGY DIAGNOSTIC DEVICES

Due to the mixture of energies behind the IH-structure, new low energy and low intensity diagnostics had to be developed.

MCP-based Single-shot Emittance Meter

A new pepperpot emittance meter for low energy and low intensity beams has been designed and built. As the amplifying element a micro channel plate (MCP) has been chosen. It is only single plate for reaching the best spacial resolution possible. The gain of about 10^4 is enough to detect the predicted intensities. The pepperpot aperture is a 100 μm thick Tungsten foil. The 29x29 holes with a diameter of 100 μm were drilled with a laser. The spacing between the holes is 1 mm in both directions x and y. The transmitted ions are drifting 31.8 mm before hitting the MCP and then being detected on the backside on a phosphor screen which is captured with a CCD camera from outside the vacuum vessel. A picture of the measurement head is shown in fig. 2

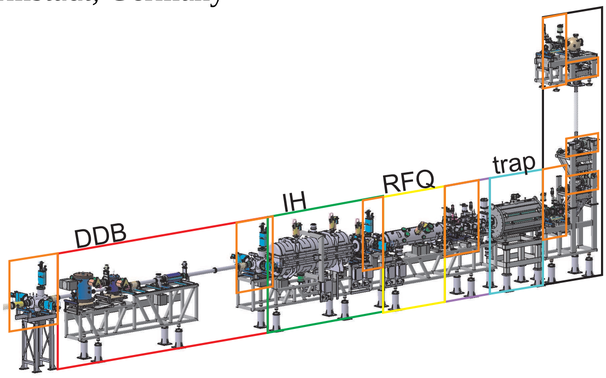

Figure 1: HITRAP linac. All sections are titled: Double-drift buncher (red), IH-structure (green), RFQ (yellow), Cooler Penning trap (cyan), beamline to experiments (black) and diagnostics (orange).

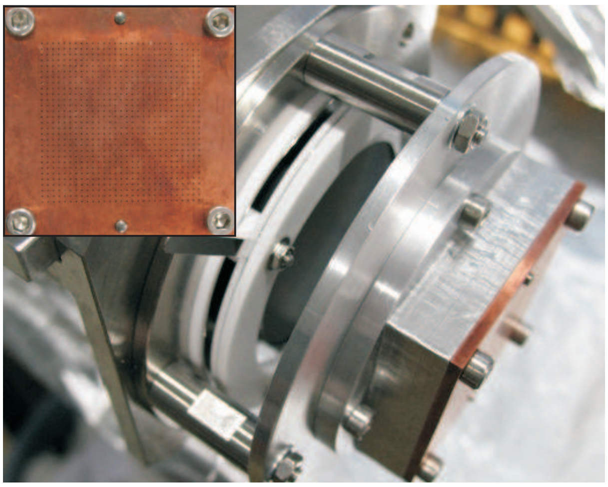

Figure 2: MCP pepperpot device. Copper: holder of the pepperpot, white rings: isolators of the MCP

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An evaluation software was previously developed. Some smaller adjustments have been done, though. The user has several possibilities for substraction of noise during the evaluation process. Nevertheless the software can be operated in free-run mode with predefined settings.

The pepperpot measurement head is also equipped with a Faraday cup, which can also be used for current measurements in order not to destroy the MCP with too high current.

Diamond Detector

The complete diamond detector setup is built on a electronic printing circuit board. Four different diamonds are integrated. They are are used according to their physical properties. Figure 3 shows the setup used at HITRAP.

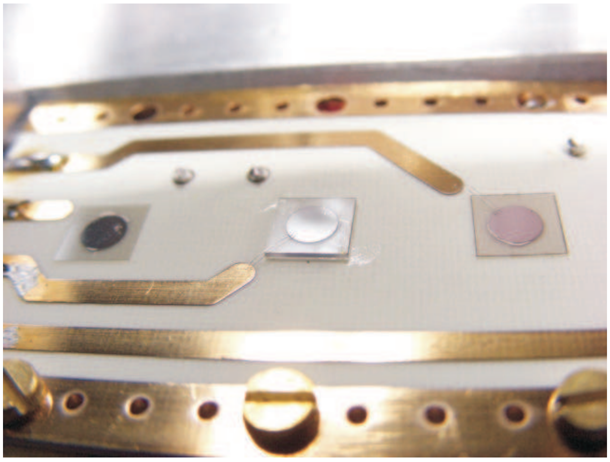

Figure 3: Diamond detector with three active areas. CVD-PC 10μm, CVD-SC 480μm and CVD-PC 15μm (left to right). Diameter of metalization area: 3 mm. Diamonds are 5x5 mm^2 each.

Single-crystal diamonds are thicker than the poly-crystallines. They incorporate a better charge collection efficiency and therefore they are used for particle energy determination through analysis of the peakheight of the detected signal. In contrast poly-crystalline structures are often thinner, which makes the charge collection efficiency worse than with single-crystals, because these structures act like small traps. Only charges created near the electrodes are collected effectively, that means that the signal is very fast but not proportional to the particles energy. Therefore poly-crystals are used for time-structure measurements [3]. At HITRAP the following types and thicknesses of the diamonds are used:

- poly-crystalline chemical vapour deposition (CVD) 10μm,
- single-crystal CVD 480μm,
- poly-crystalline CVD 15μm and
- poly-crystalline CVD 600μm.

Each detector has an effective area of 3 mm in diameter. Results of these measurements are presented below.

Single-shot Energy Analyzer

The construction of the single-shot energy analyzer was triggered by the fact that not only decelerated ions exiting the IH-structure but also a big portion of non-decelerated particles reaching the intertank section. This makes analysis of beam properties difficult since the high energy signal is always overlaying the desired low energy signal. Since there is not enough space for installation of a big dipole magnet for scanning the energy spectrum, a single-shot energy analyzer was constructed and built. It consists of an horizontal slit (width 0.3 mm) and a permanent magnet of 0.5 T that is able to seperate the 500 keV/u beam from all particles with energy higher than 1.3 MeV/u. This is not critical since the main energies that are transmitted are at 2.3 and 4 MeV/u. The particles then hit a Chevron-type micro channel plate, they are amplified and the resulting single-shot distribution is captured by a CCD camera. The setup is shown in figs. 4 and 5.

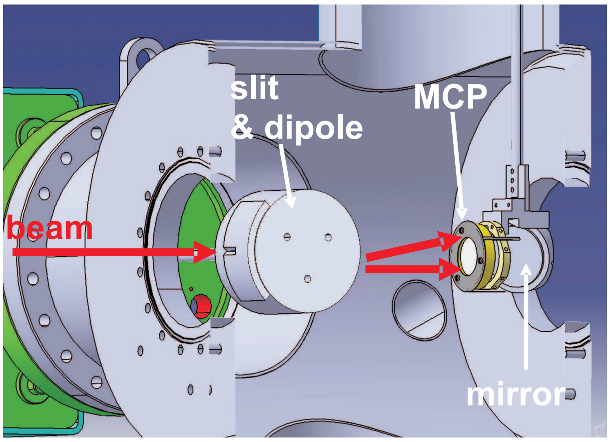

Figure 4: Schematic drawing: cut through the vacuum vessel housing the single-shot energy analyzer.

The dipole field was measured with a hall probe and was determined to be very homogenous (see fig. 6).

The influence of the permanent magnet on the beam, if moved out, is smaller than 0.1 mT on axis, which is a reasonable value.

MEASUREMENTS

During the last beam times three different kind of measurements had been performed. The emittance of the 500 keV/u beam behind the IH-structure was measured with the gradient method and the diamond detector, a test measurement with the new MCP-based pepperpot device

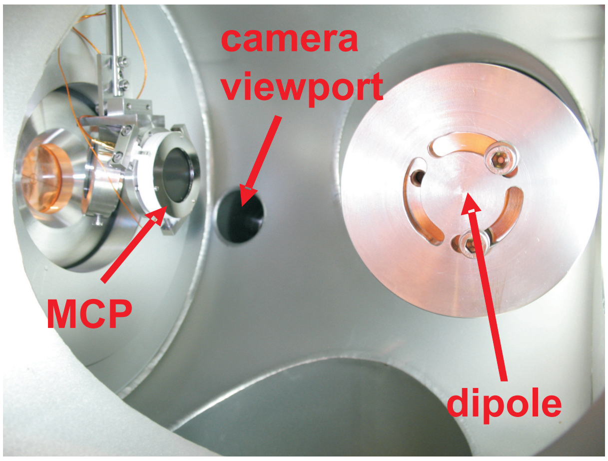

Figure 5: View of the single-shot energy analyzer.

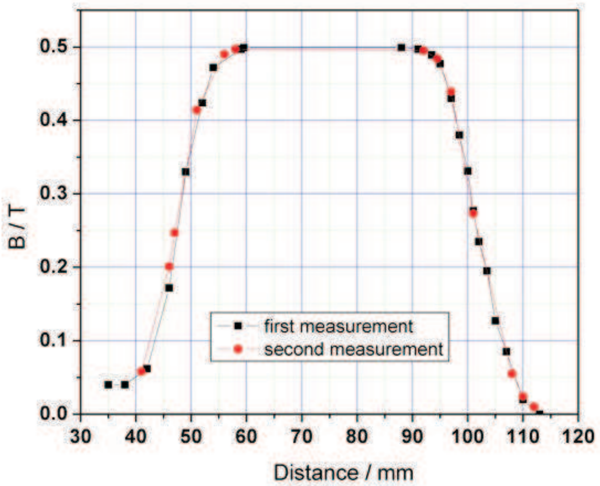

Figure 6: Homogenity of the dipole field for the energy analyzer.

behind the RFQ and a bunch structure measurement in front of the IH.

3-Gradient Method

During commissioning of the IH-structure we were able to measure the emittance of the decelerated 500 keV/u ions behind the cavity. This was difficult because the structure also transports part of the beam non-decelerated which then causes troubles by detecting the underlying decelerated beam with no spatial separation. A steerer was used to seperate the two beams by some mm and a 3-gradient emittance analysis was performed. The count rate on the sensitive diamond detector was always averaged over three consecutive shots. The determined beam radii together with the quadrupole gradients of the doublet are shown in table 1. With this data together with the beam transport matrices the vertical emittance of the decelerated beam is calculated to be $9.3\,mm \cdot mrad$. The twiss parameters are calculated to be $\alpha = 1.15$, $\beta = 7.80\,mm/mrad$ and $\gamma = 0.30\,mrad/mm$. The phase space ellipse as well as restricting straight lines are ploted in fig. 7.

Table 1: Quadrupole gradients B' for emittance evaluation behind the IH in $[T/m]$ for $A/q = 3$. Radii are given in $[mm]$ and contain 90% of the particles.

gradients of quadrupole doublet	**beam radius**
33.6807 / 34.2925	6.22
30.3126 / 30.8633	3.89
26.9445 / 27.4340	2.11

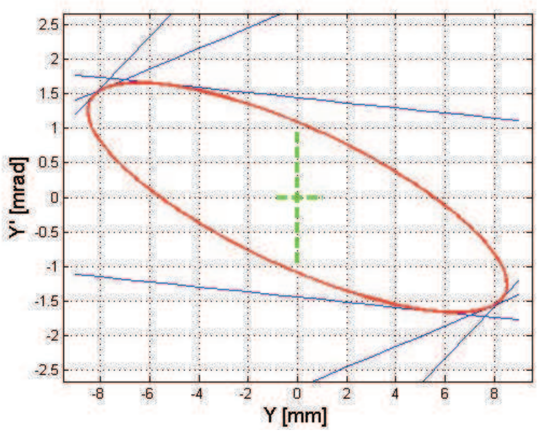

Figure 7: Phase space ellipse of 500 keV/u beam behind the IH-structure.

The three parallel line pairs in fig. 7 represent one gradient measurement each. The distance between the lines is equal to the beam diameter of each individual measurement and the rotation of the line pair is calculated from the transport distance from the lens to the target and the focussing strength of the lens.

Pepperpot Measurement

The MCP-Pepperpot emittance meter was placed behind the RFQ in a vessel of the low energy beam transport line. Some measurements were done with RFQ switched on and off and diffrences in emittance were measured. A sample of the captured images is shown in fig. 8.

Evaluation of this data resulted in the numbers given in table 2.

Table 2: Emittances measured behind the RFQ with RF on and off.

RF_{RFQ}	$\varepsilon_{x,90\%}$	$\varepsilon_{y,90\%}$
off	21.3	18.3
on	27.8	24.6

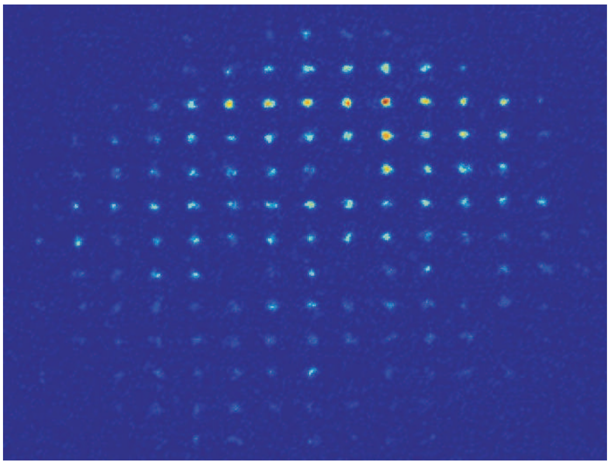

Figure 8: First picture from the MCP-Pepperpot behind the HITRAP-RFQ.

Since emittance grows with deceleration it seems that at least a part of the ions was decelerated by switching on the RF of the RFQ. A sample picture of the phase spaces is given in fig. 9

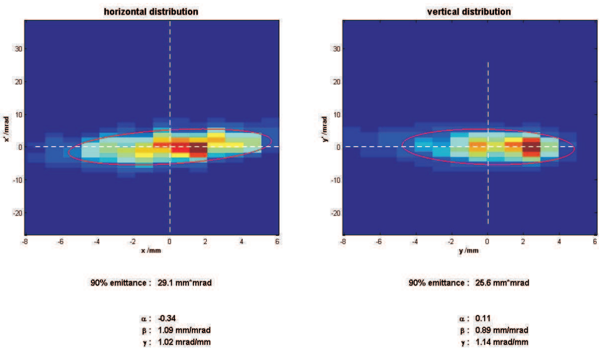

Figure 9: Phase space distributions from the first pepperpot measurement behind the RFQ.

Longitudinal Bunch Structure

The longitudinal bunch structure was measured only qualitatively. The diamond detector was used to show the arriving ions at the entrance of the IH-structure. The pictures of the macro bunch from ESR as well as the bunched ions are shown in figures 10 and 11.

OUTLOOK

Tests of the single-shot energy analyzer are ongoing and first online operation should occur during the next beamtime in spring 2010. This tool should make a fine tuning of the IH-structure possible in a fast and efficient way. During and after commissioning of the RFQ the MCP-based pepperpot emittance meter will measure again the emittance of the entirely decelerated beam.

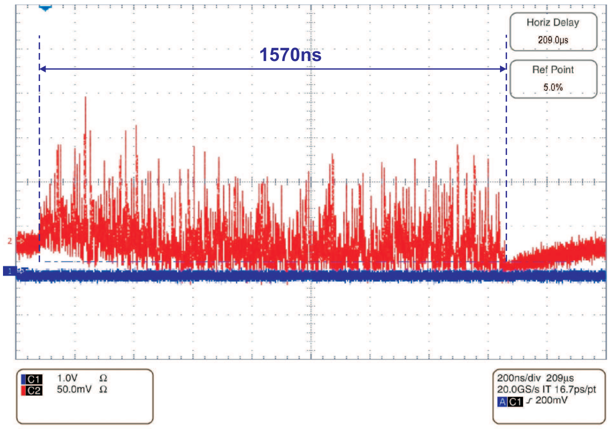

Figure 10: Macro bunch from ESR.

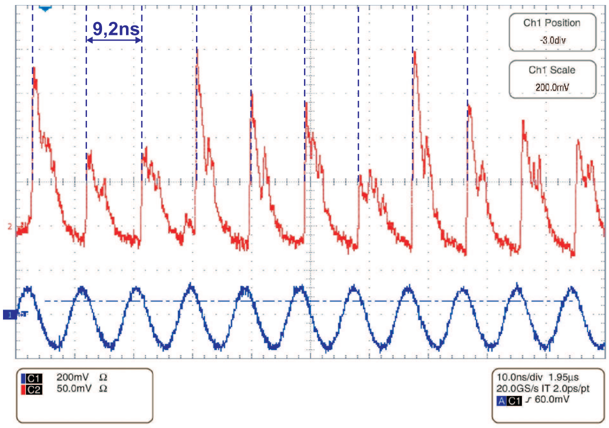

Figure 11: Bunched signal from diamond detector. Diamond signal of incoming ions on the diamond's surface (red) and 108 MHz RF-phase (blue).

REFERENCES

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