A TRANSVERSE ELECTRON TARGET FOR HEAVY ION STORAGE RINGS*

S. Geyer[#], D. Ries and O. Meusel, IAP, Goethe-University Frankfurt, Germany
O. Kester, GSI, Helmholtzzentrum für Schwerionenforschung, Darmstadt, Germany

Abstract

A transverse electron target is a well suited concept under discussion for storage rings to investigate electron-ion interaction processes relevant for heavy ion accelerators. Using a sheet beam of free electrons in crossed beam geometry promises not only a high energy resolution but allows access to the interaction region for photon and electron spectroscopy under large solid angles as well. To realize a compact and multi-purpose applicable design, only electrostatic fields are used for beam focussing. The produced electron beam has a length of 10 cm in ion beam direction and a width of around 5 mm in the interaction region with densities of ~10^9 electrons/cm^3. The target geometry allows the independent adjustment of the electron beam current and energy in the region of several 10 eV and a few keV. The setup meets the high requirements for an operation in the UHV environment of a storage ring and is installed applying the so-called animated beam technique. The electron target is dedicated to the FAIR storage rings.

TARGET DESIGN

The transverse electron target uses a sheet beam of free electrons in crossed-beam geometry. This allows the realization of a small and flexible design with access to the interaction region for spectroscopy (Fig. 1). The electron beam is produced by an indirectly heated BaO cathode. The cathode is surrounded by a thermal shield of Macor, which itself is placed into an electrically insulated Wehnelt electrode. The anode of the gun system is the first of three electrodes in front of the interaction region which act as electrostatic lens. Another three electrodes with mirror symmetric voltage configuration are installed behind the interaction region. This design gives in a certain range independency of the electron current from the electron beam energy. The adjustable electron energy in the interaction region ranges between several 10 eV and a few keV. To gain a large solid angle for spectroscopy the electrodes next to the interaction region are shaped accordingly. Behind the second lens the electron beam is decelerated and defocused in a collector. For critical electrodes - such as the Wehnelt, the anode and the collector - water-cooling has been implemented.

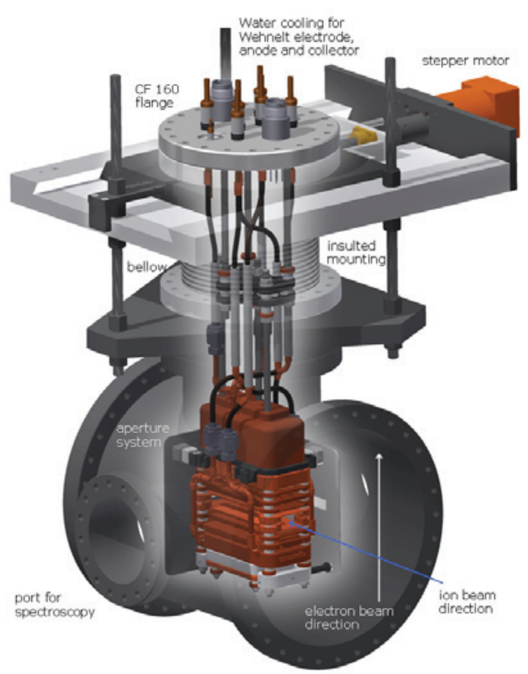

Figure 1: Design of the transversal electron target with manipulator system.

For absolute cross section measurements, the overlap between the electron and the stored ion beam has to be determined. Therefore a manipulator system with a stepper motor is integrated in the setup.

CHARACTERISTIC PARAMETERS OF THE ELECTRON BEAM

To optimize the beam optics in the interaction region of the target and to investigate the relevant electron beam parameters, simulations using the three-dimensional finite-element code AMaze have been performed. The calculated perveance for the gun system of the electron target is about 5.1 $\mu A/V^{3/2}$. In the interaction region the beam has a height of ~ 5 mm and a density of up to 10^9 electrons /cm^3, both depending on the voltage setting. A cross section for the electron density profile for a potential setting of [5 keV : 5.5 keV : 1 keV], referring to the electrodes around the interaction region, is shown in Fig. 2. The density increase at the beam edges is a result of the strong beam focussing in the gun which leads to aberration in the interaction region.

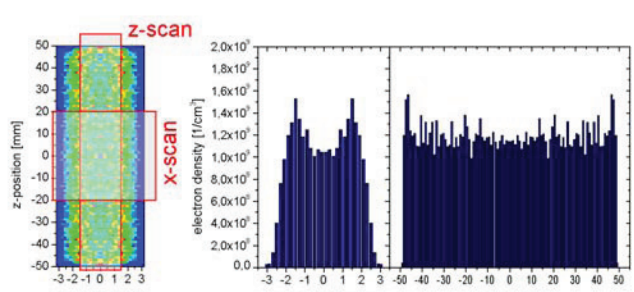

Figure 2: Cross section (left) and averaged electron density profiles for the marked regions (right).

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For energy dependent cross section measurements the knowledge of the collision energy is of high relevance. As already discussed in [1,2] it is given by the expression

$$E_{rel} = -(E_e + E_i)\cdot\left[(E_i + E_e) + 2\left(T_e T_i + T_e E_i + T_i E_e - \sqrt{T_e(T_e + 2E_e)}\sqrt{T_i(T_i + 2E_i)}\cos\theta\right)\right]^{1/2}, \quad (1)$$

where T_e and T_i denote the kinetic energy of the electron and ion and E_e and E_i stand for their rest energy. θ is the collision angle between the two particles. To investigate the distribution of the collision energy, simulated results for the divergence angle and the electron energy distribution in the beam have been used. Figure 3 depicts the

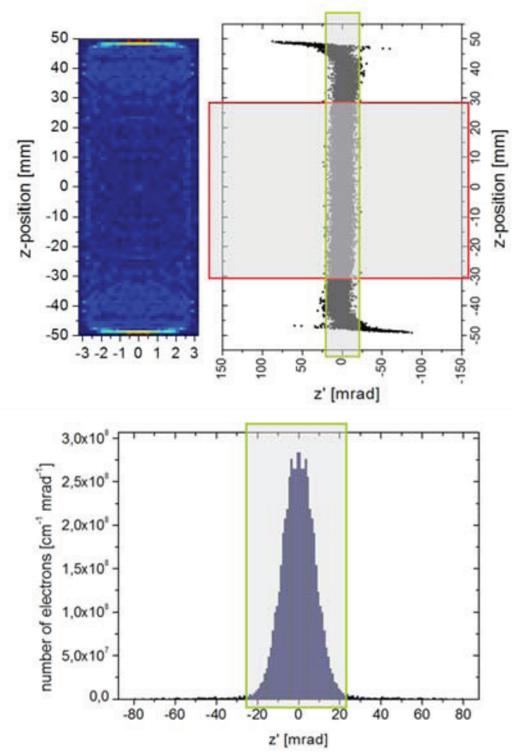

Figure 3: Cross section of the deviation angle in the electron beam and its emittance in ion beam direction. Bottom: Distribution of angle z'.

distribution of the divergence angle in the electron beam and the corresponding density distribution over the angle. The distribution of the electron energy over the beam cross section is shown in Fig. 4. There the electron energy with the highest abundance corresponds to the yellow area in the 2D plot. It is expected that the electron energy in the middle of the beam is compared to the applied voltage decreased by the space charge. In fact the penetration of the potentials of the neighboring electrodes into the interaction region increases the resulting electron energy. The distribution of the collision energy under the assumption of a parallel ion beam with emittance = 0 is presented in Fig. 5 for two different examples. In the first case is $\Delta E_{coll}/E_{coll} \approx 0.07$ with $\Delta E_{coll} \approx 74.6$ eV while in the second $\Delta E_{coll}/E_{coll} \approx 0.04$ with $\Delta E_{coll} \approx 8.0$ keV.

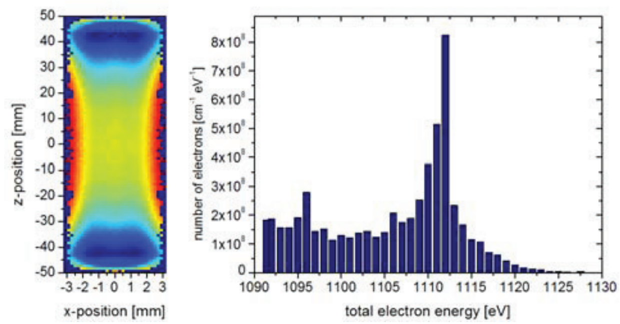

Figure 4: Cross section of the kinetic energy T_e (left) and the corresponding energy distribution (right).

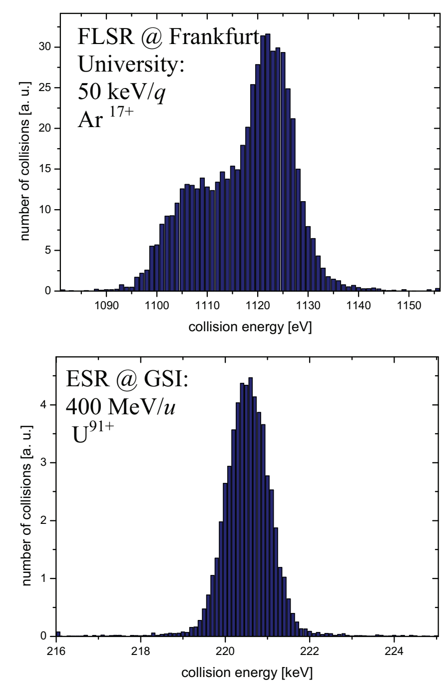

Figure 5: Relative distribution of the collision energy for different ion beams.

TEST BEAMLINE

For first characterization measurements of the transverse electron target a test beam line has been designed and constructed (Fig. 6). It consists of two electrostatic quadrupole duplets in front and behind the designated target position. A volume ion source provides different ions and molecules with extraction energies of up to 6 keV/q. To reach UHV conditions in the target area, a differential pumping stage separates the ion source from the subsequent beam line. Behind the second duplet a diagnostic tank with a Faraday Cup is placed. For cross section measurements a magnetic momentum spectrometer is used. Simulations with the Code COSY Infinity [3] have been performed as well as measurements to optimize the beam transport into the spectrometer. Systematic studies for matching the ion beam parameters to the experimental requirements are under investigation by characterizing the ion source properties.

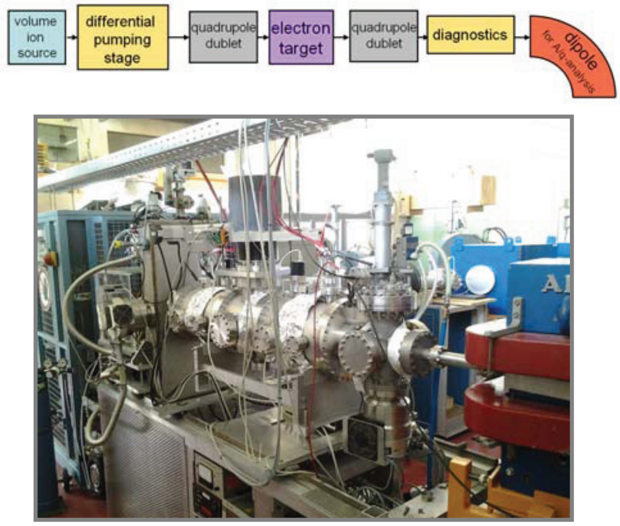

Figure 6: Scheme of the test beam line at Frankfurt University

INFLUENCE ON CROSSING ION BEAM

Measurements with the electron target are envisaged at the Frankfurt low-energy storage ring (FLSR) [4] to evaluate the target performance under storage ring conditions. Implementing a target of charged particles into a ring for low-energetic ions will cause a distortion of the ring tune, since the target will act as a space charge lens for the stored particles. Therefore investigations on the target's beam-optical behavior have been performed with AMaze using the 3D electrical field maps including the contribution of the electrode potentials and from the electron beam space charge. Several fields and settings of the electrodes were tested for emittance dominated ion beams whose species and charge states can be provided. Simulations showed that ion beam matching to the electron target, an additional aperture in front and behind the target electrodes is required in order to shield the electrode potentials and to avoid a steering of the ion beam. Figure 7 depicts the crossing ion beam in the z-y-plane (left) of the target with apertures and the z-x-plane (right). The target has an astigmatic focusing behavior, which gives for this particular voltage setting the appearance of three focus points: one in the direction vertical to the electron beam direction, two in electron beam direction.

To determine the contribution of the space charge potential and of the electrical fields from the neighbor electrodes to the focus points, simulations of the ion beam propagating through the target with and without electron beam have been compared (Fig. 8). Due to the flexibility in the voltage setting, also a set with nearly no potential penetration into the interaction region was found.

The next step will be the determination of the target's transfer matrix to include it into ion-optical simulations of the test beam and of the FLSR. Also an experimental setup to verify the ion-optical behavior of the target is planned.

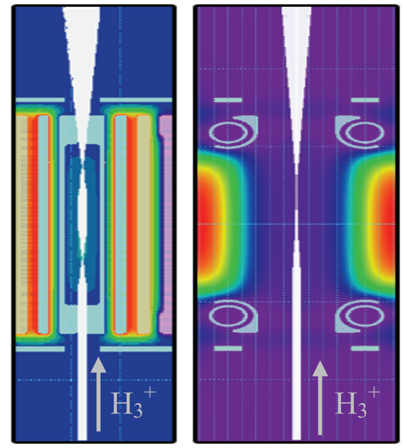

Figure 7: H_3^+ beam with 3 keV propagating through the target. Left: Electron beam direction from left to right side. Right: Electron direction into paper plane.

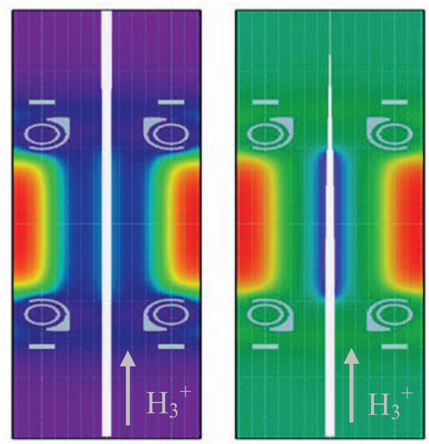

Figure 8: H_3^+ beam with 10 keV through the target. Left. Only electrical fields of the electrodes, no electron beam. Right: Additional superposed fields of electron beam.

SUMMARY

For the investigation of electron-ion interaction processes in storage rings with a transverse electron target the knowledge of the electron beam parameters is mandatory. Therefore detailed studies have been carried out by simulations including their influence on cross section measurements as well as on beam optics. After the assembly of the target, characterization measurements will be performed comprising investigations at a test bench and later at the FLSR, before the target will be prepared for its operation at the storage rings of the FAIR facility.

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