A TRANSVERSE ELECTRON TARGET FOR HEAVY ION STORAGE RINGS*

S. Geyer# 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 for storage rings to investigate electron-ion interaction processes relevant for heavy ion accelerators. In comparison with an internal gas target, it promises a better energy resolution and has the advantage, in contrast to an electron cooler, of access to the interaction region for photon and electron spectroscopy under large solid angles.

The new electron target is suited for the UHV requirements of a storage ring and realizes an open geometry for spectroscopy. A simple design based on electrostatic fields was chosen. The sheet beam application provides a higher perveance limit and a smaller potential depression than a cylindrical gun arrangement. The adjustable electron energy ranges between several 10 eV and a few keV. The setup will be installed applying the so-called animated beam technique.

The electron target is dedicated to the FAIR storage rings. First measurements are planned at a test bench and subsequent tests at the Frankfurt Low Energy Storage Ring (FLSR) are envisages.

EXPERIMENTAL PERSPECTIVE

A transverse target of free electrons promises a better energy resolution than an internal gas target by one order of magnitude. It additionally allows the detection of emitted photons and electrons under large solid angles. Therefore a transverse electron target opens the perspective to new types of experiments. One application of the target will be the measurement of the absolute cross sections in the low energy regime for astrophysical data as well as for plasma. In addition data for ion beam physics (eg. for beam lifetimes in storage rings and beam transport, like from an ECRIS to the subsequent LINAC at the FAIR facility) are objectives. Due to its design, the influence of electrostatic fields on the different interaction processes can be examined.

Interaction Rates

To approximate the rates expected for the electron target, calculations for the direct electron impact ionization (DI) and the radiative recombination (RR) have been performed using semi-empirical expressions for the cross sections $\sigma(E)$ [1,2]. The interaction rates can be expressed according to [3] with

$$R = \frac{L\, I_e\, I_i \left(j_0/I_e\right)}{e^2\, \zeta_0\, v_i}\, \sigma\left(v_e\right). \qquad (1)$$

v_i is the ion velocity, L is the length of the interaction path, I_e and I_i stand for the electron and ion current, e is the elementary charge and ζ_0 the initial charge state of the ion beam. For a 50 keV argon beam with a current of 1 µA interacting in a 10 cm long electron beam region assuming an electron beam density of 0.5 A/cm^2, different charge states are depicted in Fig.1. The rates amount to ~10^3 kHz for the direct electron impact ionization and ~10^2 Hz for the RR.

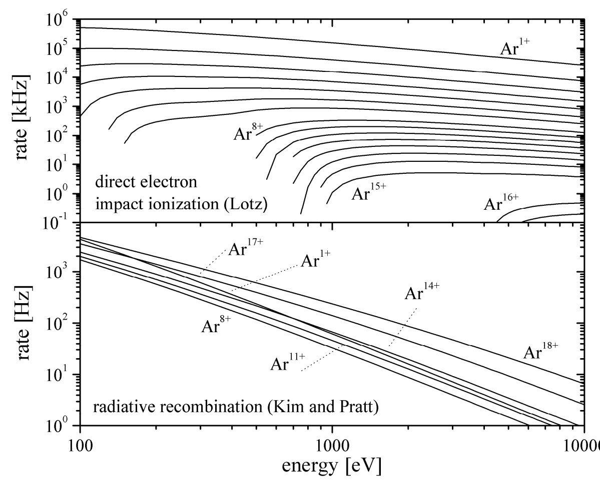

Figure 1: Energy dependence of the rates for the DI and the RR for different charge states of Ar.

Energy Resolution

The collision energy E_{rel} for two colliding particles is given for the relativistic treatment by

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

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 with 0° for parallel movement like in an electron cooler, in a transverse target is θ = 90°. A deviation in the angle $\Delta\theta$ causes a deviation in the collision energy and therewith determines the energy resolution ΔE [4]. From the electron target side the $\Delta\theta$ can be divided into an electron-optical part determined by the focussing electrical fields and into a fraction determined by the width of the thermal energy distribution of the electrons. For typical cathode temperatures of ~ 1200 K this value is expected to be in

*Work supported by HIC for FAIR
#geyer@iap.uni-frankfurt.de

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the order of $k_B T \approx 0.1$ eV and therewith should deliver only a small contribution to the total energy resolution. The access to simulations including thermal effects combines these two aspects. The results for $\Delta\theta$ have been calculated from simulations with the Advanced Charged-particle Design Suite AMaze©. Under the assumption of a perfect parallel ion beam only the angle between y- and z-axis contribute to $\Delta\theta$. The example in Fig. 2 gives for $\Delta\theta$ a value in the order of ~ 220 mrad for the boundary area. The inner part of the target produces a beam with $\Delta\theta \approx 50$ mrad. The boundary value corresponds to a contribution to the total energy resolution of $\Delta E \approx 50$ eV for $T_e = 1$ keV and a $T_i = 50$ keV/q Ar^{16+} beam. Around 95% of the current has an angle deviation of $\Delta\theta < 50$ mrad, corresponding to an energy resolution of $\Delta E \approx 10$ eV. These values refer to a preliminary design of the target and also depend on the applied voltage setting (here: potential at the electrodes around interaction region in [kV] : 5:4:1:1:4:5).

Another point for the energy resolution is the potential depression of the beams which results in different kinetic energies of the electrons depending on their position in the beam. The potential depression dominates the energy resolution with several ten eV. Due to the influence of the compensation degree by positive ions in the electron beam, a higher resolution is expected to be achievable for high compensation degrees. Another problem here is the determination of the overall reduction of the applied voltages in the interaction region. Both aspects will be investigated more closely in characterization measurements. In flight direction of the ion beam the space charge will act as lens and focus the ion beam, so that the storage parameter of the storage ring have to be adjusted accordingly. This point is also under investigations.

TARGET DESIGN

The electron beam is produced by an indirectly heated BaO cathode, providing electron current densities up to ~2.5 A/cm^2. The cathode has a length of 100 mm in ion beam direction (z-axis) and a height of 12 mm. This rectangular geometry allows in comparison to a cylindrical one not only a higher perveance limit but also leads to a smaller potential depression. This is important for a good energy resolution (see previous section). To focus the sheet beam the target relies on a simple concept using electrostatic fields only (see Fig. 3 and Fig. 5). Therefore the cathode is surrounded by a Wehnelt electrode, set on negative potential relative to the cathode. The beam is extracted by an anode, which is at the same time the first electrode of the einzel lens, transporting the electron beam to the interaction region. Another einzel lens is placed mirrored on the other side of the interaction region to create a symmetrical potential configuration. This design allows a decoupling of the electron current from the electron beam energy in the interaction region by applying different voltage settings to the electrodes. The adjustable electron energy in the interaction region ranges between several 10 eV and a few keV depending on deflection due to space charge and the range of the used voltage supplies. Behind the second einzel lens the electron beam is defocused, decelerated and dumped in a collector. For collision measurements in a storage ring all voltages will be set relative to the grounded interaction region.

The dissipated power from electron losses at the Wehnelt, at the anode and at the collector, these electrodes will be water-cooled. The different electrodes are isolated by aluminium oxide ceramics. To gain a large solid angle for spectroscopy the electrodes next to the interaction region are shaped accordingly.

Control System and Setup

A control and interlock system will be installed to protect the cathode and the electrodes. It will monitor the water-cooling system as well as the loss currents on the different electrodes. The last aspect is also import for the estimation of the effective electron current in the

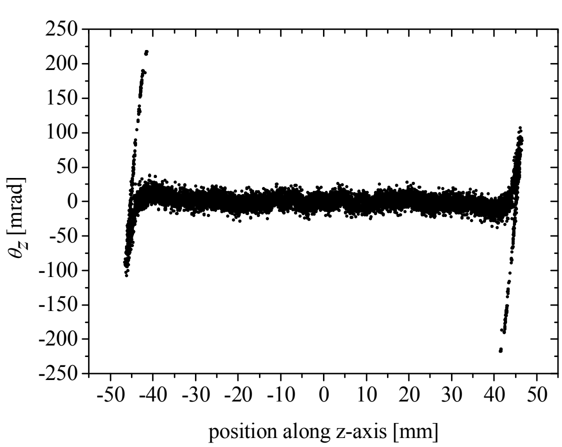

Figure 2: Divergence angle of the electron beam in the interaction region from 3D-simulations with a cathode temperature of $T_c = 0.1$ eV.

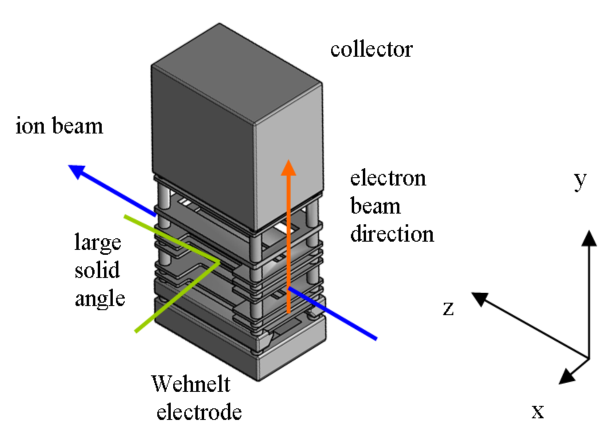

Figure 3: Schematic drawing of the transverse electron target (preliminary).

interaction region. The control system will be able to perform energy scans using different relative electrode voltage settings over certain energy ranges. For absolute cross section measurements of electron-ion interaction processes, the overlap factor of electron and stored ion beam has to be determined. Therefore a manipulator system with a stepper motor will be integrated in the setup (see Fig. 4). The target is vertically mounted on a CF150 flange with the collector upside. A bellow allows the stepper motor to mechanically move the whole target and therewith the electron beam through the ion beam.

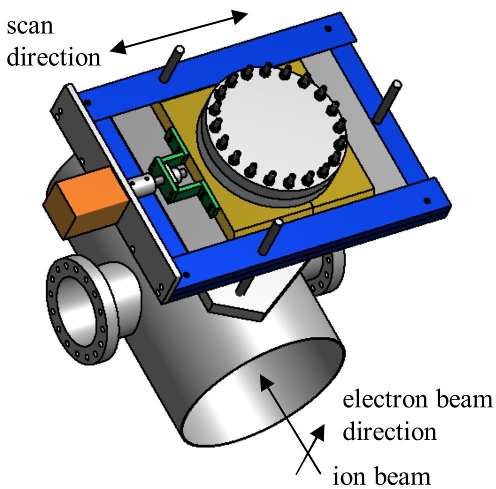

Figure 4: Manipulation system of the transverse electron target.

SIMULATIONS

To optimize the beam optics for electron trajectories as parallel as possible in the interaction region, simulations with EGUN [5] and the 3D simulation code AMaze© have been performed. The EGUN simulations give a perveance for the electron target of ~ 4.2 × 10^{-6} A/V$^{3/2}$. For anode voltage of 5 kV currents of ~ 1.5 A can be extracted. 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.

The transverse electron target has been optimized in 2D EGUN simulations in its x-direction, where beam losses would cause much energy deposition to the guiding electrodes. The consideration of a limited expansion in z-direction is part of ongoing investigations, since it is of interest for the energy resolution. A preliminary result of the 3D simulations is shown in Fig. 2 and Fig. 5. The aberration in Fig. 2 results from the focus at the Wehnelt electrode.

SUMMARY

The transverse electron target will open new experimental perspectives for the investigation of electron-ion interaction processes in storage rings. The application for example of coincidence techniques or/and in combination with other ring tools such as an electron cooler or an internal gas jet target will be possible.

After finalizing the design and the setup of the target, characterization measurements will be performed comprising investigations at a test bench and later at the Frankfurt Low Energy Storage Ring (FLSR) [6]. The experimental setup for the first characterization of the target is under preparation now. Subsequent measurements at the FLSR are envisaged for the end of this year.

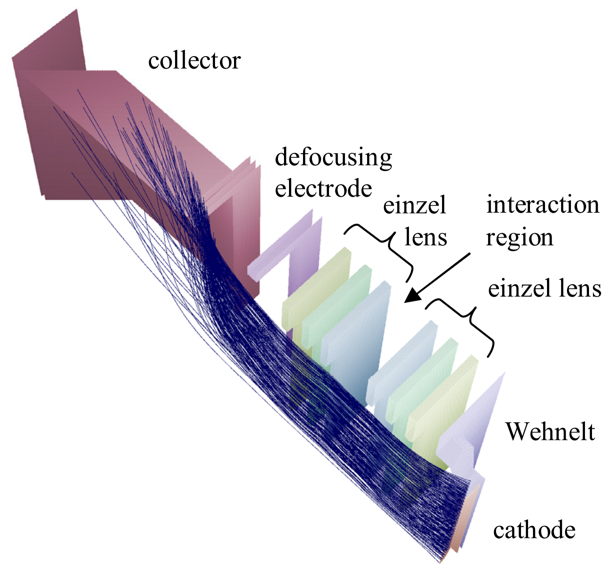

Figure 5: Example for 3D-simulations for the transverse electron target.

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