

A transverse electron target for the FAIR storage rings

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Electron-ion interaction processes are of fundamental interest for several research fields like for atomic and astrophysics as well as for plasma physics. To address this topic, a transverse electron target, dedicated to the FAIR storage rings, is under development.

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, left). The electron beam is produced by an indirectly heated BaO cathode. The cathode has a length of 100 mm in ion beam direction and a height of 12 mm. To focus the sheet beam only electrostatic fields are used. For beam formation the cathode is surrounded by a Wehnelt electrode on negative potential relative to the cathode. The anode is the first of three electrodes placed in front of the interaction region. Another three electrodes with mirrored potential configuration are installed behind it. This design gives independency of the electron current from the electron beam energy and assures a symmetric potential distribution in the interaction region. 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 defocused, decelerated and dumped in a collector. For critical electrodes - such as the Wehnelt, the anode and the collector - water-cooling has been implemented. The other electrodes are cooled indirectly by their isolating aluminium oxide ceramics.

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 will be integrated in the setup (fig. 1, right). The target is vertically mounted on a CF160 flange upside down. A bellow allows the stepper motor to mechanically scan the electron beam through the ion beam.

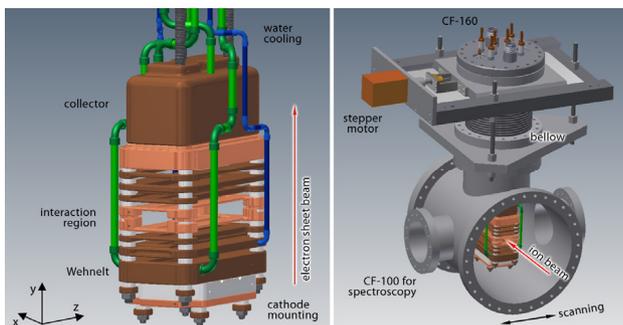


Fig. 1: The design of the transversal electron target (left). The mounted target with its manipulator system (right).

A control and interlock system monitors the water-cooling system, the vacuum system and the beam losses on the different electrodes to protect the target parts from heating by beam losses.

Simulation and beam parameter

To optimize the beam optics in the interaction region, simulations with the Amaze© code have been performed. They give a perveance for the electron target of $5.1 \mu\text{A}/\text{V}^{3/2}$. In the interaction region the beam has a height of ~ 5 mm and a density of up to 10^9 electrons/cm³ (fig. 2), both depending on the voltage setting. The example in figure 3 depicts the emittance of the beam for the direction of the crossing ion beam angle in direction toward the ion beam. Also investigations concerning the energy resolution and the line width in collisions experiments have been performed.

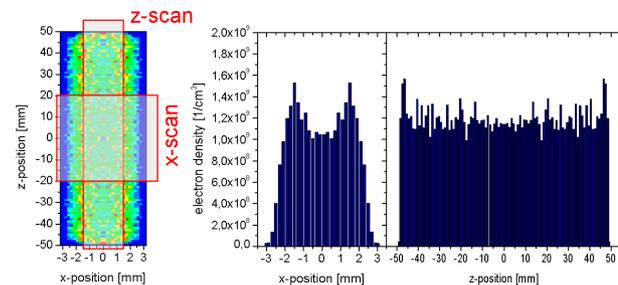


Fig. 2: Simulated cross section (left) and electron density profiles for the marked regions (right).

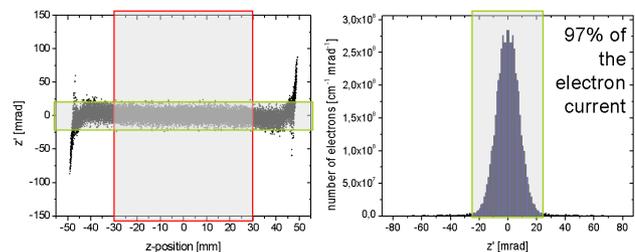


Fig. 3: Simulated emittance in direction of the ion beam (left) and the corresponding density distribution (right).

Summary and Outlook

All parts of the target are currently built at the IAP (Institut für Angewandte Physik) workshop. A test beam line for first characterization measurements of the target is already prepared. Experiments with molecule and ion beams from a volume source and an XEBIS are envisaged. Also the influence of the space charge of the electron beam on the ion optics in storage rings is part of further studies by simulations as well as subsequent measurements.

Simulation study of TNSA from a double-layer target

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For intensities of the PHELIX laser [1] the Target Normal Sheath Acceleration (TNSA) is the relevant acceleration mechanism. In our simulation work we found that the phase-space distribution of the accelerated proton beam strongly depends on the thickness of the contamination layer, deposited on the target surface. In this report we present a parameter-scan over the layer thickness in 1D geometry. The simulations were performed using the VORPAL PIC code [2].

The laser-produced relativistic electrons create strong charge separation field at the plasma surface. The spatial profile of the electric field is known analytically [3] and it allows us to set up the initial electron density profiles with thermal Boltzmann distribution. The temperature ratio of hot (h) and cold (c) electrons is $T_h/T_c = 20$ and the density ratio is $n_c/n_h = 5$. The target consists of heavy ions and a proton layer on the surface.

The electric field penetrating into the target can be approximated with an exponential function [3] with the scale length: λ_D/r where $\lambda_D = (\epsilon_0 T_h / (e^2 n_h))^{1/2}$ and $r = \sqrt{1 + (n_c/n_h)(T_h/T_c)}$. The proton layer thickness should be compared to this length, therefore we introduce the dimensionless parameter:

$$D = \frac{rd}{\lambda_D} \quad (1)$$

where d is the layer thickness. The quantity D characterizes the layer and defines in which regime will the protons be accelerated.

In Fig. 1 the resulting proton energy distribution is shown for different initial layer thicknesses. The main features of the two extreme cases are clearly visible: quasi-monoenergetic beam in the case of thin layer ($D \ll 1$, quasi-static acceleration [3]) and exponential energy distribution with large energy spread [4] in the case of thick layer ($D \gg 1$, plasma expansion).

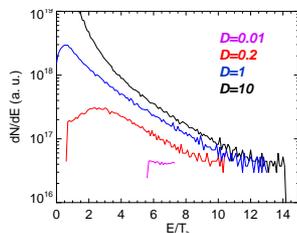


Figure 1: The energy spectrums of protons for different normalized layer thicknesses.

In the intermediate regime the proton layer detaches from the target and expands in the Debye sheath, while it traps electrons, which means that the energy spread increases. Based on the work of Albright et al. [5] we could deduce an expression for the potential drop between the heavy target and the proton layer after detachment:

$$\varphi_d = 2 \ln \left(e^{-\varphi_0/2} + \frac{\sqrt{2}n_h}{n_p(D/r + d_{min}/\lambda_D)} \right) \quad (2)$$

where $d_{min} = \lambda_D n_p^{-1} \sqrt{2} / (e^{-\varphi_{min}/2} - e^{-\varphi_0/2})$, $n_p = n_c + n_h$ is the initial proton density and φ_0 is the potential at the surface of the heavy ion plasma. The minimum potential is defined by the maximum electron energy (ϵ_{max}): $-\varphi_{min} = \epsilon_{max}/T_h - 1$. In our simulations $\epsilon_{max} = 7.5T_h$ is arbitrary chosen. The potential is normalized to T_h/e .

The comparison of simulation results with our analytical estimation is shown in Fig. 2. We performed simulations with two plasma lengths: $L_p = 4\lambda_D$ (blue) and $L_p = 20\lambda_D$. The discrepancy at larger layer thicknesses is due to the different cooling time of the hot electrons.

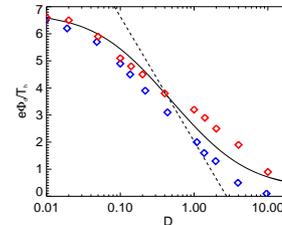


Figure 2: Potential drop measured from 2T simulations with $L_p = 4\lambda_D$ (blue) and $L_p = 20\lambda_D$ (red). The black full line represents Eq. (2) and the dashed line corresponds to the case, when $\epsilon_{max} \rightarrow \infty$.

The expression given in Eq. 2 can be used to estimate the energy conversion from the hot electrons to protons. If $D \ll 1$ the mean energy of the short bunch will be $-\varphi_{min}T_h/e$, while in the expansion regime the total energy of protons is the integral of the hot electron energy distribution form φ_d up to ϵ_{max} .

References

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