ISBN: 978-3-95450-262-2 ISSN: 2673-5350 doi: 10.18429/JACoW-IBIC2025-MOPMO31

QUANTUM EFFICIENCY MEASUREMENTS AND BEAM DIAGNOSTICS TEST STAND DESIGN FOR A DUAL-MODE ELECTRON GUN AT ELSA

S. Kronenberg*, K. Desch, B.Gatzsche, P. Hänisch, D. Proft, Y. Schober, M. Switka
Physikalisches Institut, University of Bonn, Germany

Abstract

To support both routine operation and accelerator research at ELSA, a dual-mode dispenser-cathode based electron gun capable of thermionic emission and thermally assisted photoemission (TAPE) is being developed. A dedicated gun test stand is being designed to measure beam properties and quality, as well as quantum efficiency in the TAPE mode under operational conditions. Instrumentation will include a pepper pot emittance stage, quadrupole scan capabilities, profile measurements using screens and wire-scans or SEM grids, and bunch charge and energy spread determination. In a basic test environment, experiments were carried out at low accelerating voltages using a setup consisting of the dispenser cathode, a pickup anode, and a simple laser system with an optical shutter. The shutter enables alternating measurements of photocurrent and dark current at the anode, allowing first estimations of quantum efficiency. The influence of different cathode heating cycles on both the absolute quantum efficiency and its temporal stability was investigated with this setup. Quantum efficiency measurements under different conditions and simulations of the test beamline are presented.

INTRODUCTION

The injector at ELSA (Electron Stretcher Accelerator, operated by the University of Bonn), requires modernization due to aging infrastructure and limited diagnostic capabilities. A new dual-mode electron gun is being manufactured to maintain current operational capabilities while enabling single-bunch operation for machine studies in the stretcher ring. This mode should offer such short electron pulses, that only one bucket in the stretcher ring is filled, this will be assured by only filling one bucket in the Linac and the booster synchrotron. The design of this new gun has been previously presented in detail [1].

Existing Injector Infrastructure

The ELSA facility (shown in Fig. 1) employs a 3 GHz travelling wave LINAC2 with both spin-polarised (GaAs photocathode) and non-polarised (thermionic cathode) electron sources, the latter delivers up to 0.5 A current. The aging beamline connecting the thermionic gun to the linac has resulted in loss of diagnostic capabilities in favor of additional vacuum pumps. Spatial constraints in the injector area complicate replacement planning.

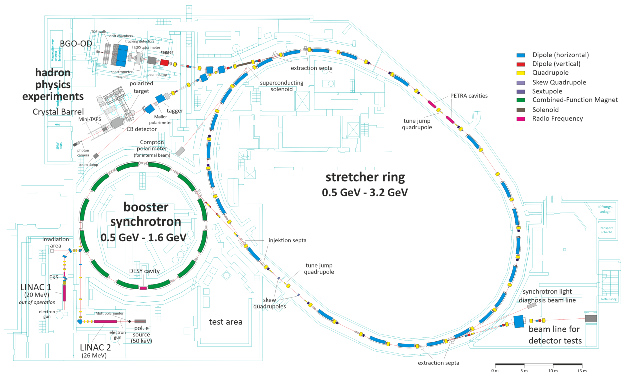

Figure 1: Overview of the ELSA facility.

Electron Gun Upgrade

The thermionic gun design is chosen for reliability and durability. Due to spatial constraints, a hybrid design has been chosen, combining thermionic emission and thermal-assisted photoemission within a single assembly. This ensures that the space constraints are met whilst enabling short-pulse generation via laser pulsing. The gun follows an inverted triode geometry based on the Pierce design.

The upgrade extends the operational range and enhances maintenance ease while addressing age-related issues. This involves increasing the electron current to 2 A, offering the possibility to increase the current in the Linac and reducing required injections into the stretcher ring. Beam quality equal to the current setup with transverse emittance of 8.3 mm mrad or lower is targeted.

THERMALLY ASSISTED PHOTOEMISSION

The TAPE effect enables dispenser cathodes to function as photocathodes. Heating shifts the electron energy distribution, increasing the population of electrons with sufficient energy for photoemission at longer wavelengths including the visible range [2, 3]. This is more convenient than UV wavelengths required for metal cathodes.

For caesium dispenser cathodes, thermal operation causes caesium emission that reduces the surface work function. This effect is expected to further enhance quantum efficiency (QE) even with reduced caesium deposition in TAPE mode. The specific cathode (EIMAC Y845) planned for this application is not yet characterized under TAPE conditions.

* s.kronenberg@uni-bonn.de

ISBN: 978-3-95450-262-2 ISSN: 2673-5350 doi: 10.18429/JACoW-IBIC2025-MOPMO31

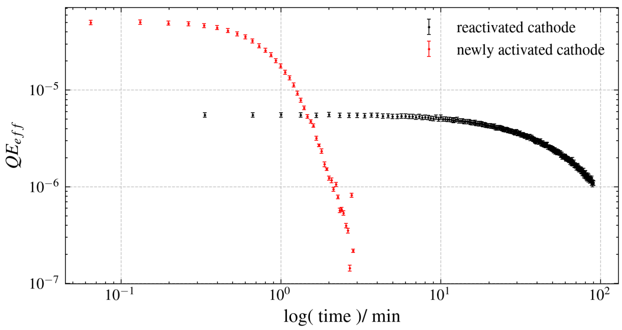

Figure 2: Quantum efficiency measurements of a reactivated cathode as well as a newly activated cathode.

QUANTUM EFFICIENCY MEASUREMENTS

Initial measurements characterized EIMAC Y646B caesium dispenser cathodes (similar to Y845 cathodes planned for the new gun) using a simplified teststand. The setup consists of a vacuum chamber with laser window, pickup anode with central aperture for beam passage, and pyrometer for temperature measurement. Mechanical shuttering enables quasi-simultaneous dark current and photocurrent measurements. Depending on the achievable QE, the expected photocurrent with the current laser setup is on the order of 100 nA or lower, with the initial measurements yielding values around 10 nA.

From the previous investigations of the TAPE effect off dispenser cathodes it was known that the effect only has a limited lifetime but can be restored by further heating the cathode and then let it cool down again. Therefore the goal of the measurements beside estimating a QE was to figure out a mode of operating the cathode as a photocathode.

On the reactivated cathode a QE of 5.6×10^{-6} was observed at a laser wavelength of 405 nm and accelerating voltage of 20 V. Depending on the activation scheme and heating power a half-life time of around 45 min was achieved with a reactivation time of approximately 10 min.

Measurements on a newly activated cathode did not yet result in a stable operation. The TAPE effect could be observed with a significant higher QE in the order of 5×10^{-5}, but with only very short lifetimes in the order of 1 min (compare Fig. 2). The measured QE could be improved by turning off the heating voltage for 20 minutes or longer after a heating cycle. This improvement, along with the strong influence of overall vacuum quality on measurements, suggests that vacuum conditions or caesium oxide buildup at the surface may be critical factors. These hypotheses will be investigated during the measurement campaign at the dedicated gun test stand.

Future characterization at the gun test stand will provide improved conditions including vacuum planned to be at least an order of magnitude better, higher laser power for enhanced measurement accuracy, and additional diagnostics such as residual gas analysis. While a QE of $\approx 2 \times 10^{-4}$ has been reported for similar cathodes [3] at 405 nm, it is unclear how our specific cathode will compare. Vacuum improvements and higher accelerating voltages (Schottky effect) may enable reaching this reference value. The higher QE observed on the fresh cathode motivates these studies to understand stability-limiting factors and optimize TAPE operation.

GUN TEST-STAND

To be able to both characterize the gun's beam properties as well as the performance of the cathode in TAPE operation it was decided to construct a gun-test stand capable of those measurements. Furthermore it was decided to build the test-stand in analogy to the injection beamline at LINAC2.

Therefore the test-stand will be divided into two parts. The first part will house solenoids for initial focusing. At the end an α-magnet will be used as in the injection beamline to deflect the beam dispersion-free by 90° into the second part. This also offers the opportunity to use the vacuum chamber in the alpha-magnet as a laser port for the TAPE operation, this necessitates that all devices used in part one are not blocking the laser. The second part is reserved for additional beam diagnostics, here luminescence screens can be used. Figure 3 shows the conceptual layout of the test stand.

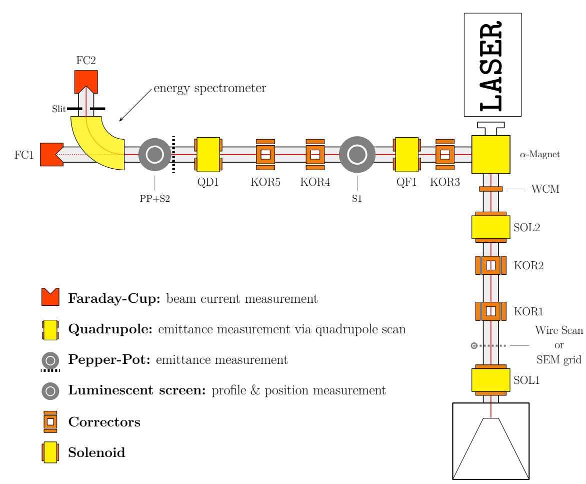

Figure 3: Initial concept of the test stand. Dimensions are not to scale.

Planned Beam Diagnostics

As has been outlined, exclusively non-blocking diagnostics devices can be utilised in the first section. Consequently, the employment of either a wire-scan or a SEM-grid is intended for the measurement of position and beam profile. Furthermore, the longitudinal beam shape will be measured using a wall current monitor, which could also be used to measure the beam position at a second position. In the second part of the test stand, luminescence screens are employed in conjunction with quadrupoles to facilitate a quadrupole scan. The purpose of the scan is to accurately measure

ISBN: 978-3-95450-262-2 ISSN: 2673-5350 doi: 10.18429/JACoW-IBIC2025-MOPMO31

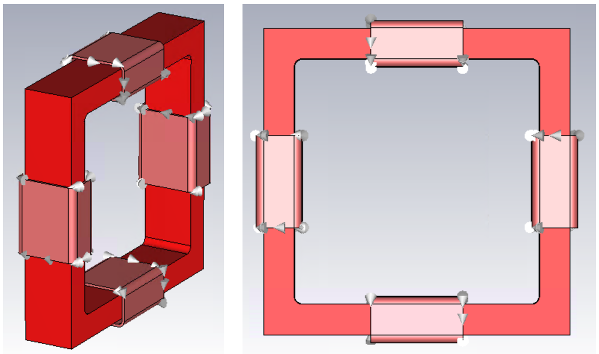

Figure 4: Corrector magnet design following the O-type design using 4 coils around an iron yoke. Modelled and simulated using CST [4].

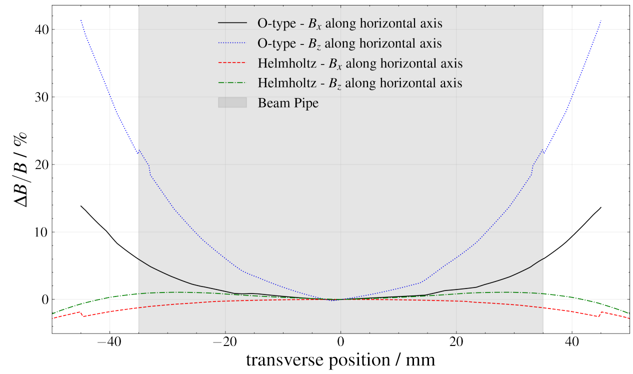

Figure 5: Comparison of the transverse field uniformity for the O-type magnet and two sets of helmholtz coils.

the beam emittance. The implementation of at least two quadrupoles is planned to allow cross validation of the results. In order to ensure optimal reliability, the measurement of the emittance will be conducted in a second instance through the utilisation of a pepper-pot device. The pepper-pot is to be configured on a single piston, with the capability of insertion into two positions, in conjunction with a luminescence screen. This configuration is intended to minimise the length of the test stand and the number of vacuum ports necessary. The final component of the test stand will be an energy spectrometer, which will utilise a bending magnet and a Faraday cup with an aperture in front. It is possible to measure the total beam current by utilising a second Faraday cup, with the bending magnet being deactivated.

Corrector Magnet Design

It is planned to always use pairs of correctors to be able to not only kick the beam but to ensure a parallel displacement. Several corrector designs were tested and evaluated based on transverse field homogeneity and physical compactness. It was decided to employ the O-type magnet design shown in Fig. 4 since it offers very good transverse homogeneity while being far more compact than a dual helmholtz coil setup. As depicted in Fig. 5 it offers a region of at least 25 mm × 25 mm with a variability of less than 10 %. Improvements to the design to enlarge the near-uniform region are currently undertaken.

Beamline-Simulations using ASTRA

Simulations of the injector beamline are conducted using the ASTRA [5] particle tracking code. The code is widely adopted especially for photo-injectors. It offers inclusion of space-charge along the whole beamline. This is of special interest for us due to the rather low energy in combination with our expected bunch charge. This simulations are used to determine the optimal beam optics setup. Although alpha magnets are not inherently supported, the simulation can be conducted by implementing additional steps in the simulation flow. The majority of these steps have now been completed, thereby enabling the entire test stand to be simulated.

CONCLUSION

A hybrid electron gun enabling both thermionic and photoemission modes is being manufactured to replace the existing LINAC2 gun at ELSA. Prior research has demonstrated the feasibility of dispenser cathodes as photocathodes utilizing the TAPE effect. With manufacturing already underway, a dedicated gun test stand is being designed, and initial QE measurements have been performed. Initial measurements showed a QE of 5.6×10^{-6} for a reactivated cathode and 5×10^{-5} for a newly activated cathode, though the latter lacked operational stability. Vacuum limitations in the preliminary setup motivate repeating these measurements at the dedicated test stand under improved conditions and with higher laser power. The test stand will be used to measure both general beam properties and the characteristics of the TAPE effect. Its design will incorporate multiple diagnostic techniques to allow cross-validation of experimental results. The final setup is expected to provide measurements of beam current, emittance, transverse and longitudinal profiles, as well as the beam energy distribution.

REFERENCES

[1] S. Kronenberg, D. Proft, K. Desch, and P. Haenisch, "Development of a hybrid thermionic and photoemission electron gun and dedicated test stand for ELSA", in *Proc. IPAC'24*, Nashville, TN, USA, pp. 2050–2052, 2024. `doi:10.18429/JACoW-IPAC2024-WEPC40`

[2] S. Thorin, N. Čutić, F. Lindau, S. Werin, and F. Curbis, "Photocathode operation of a thermionic RF gun", *Nucl. Instrum. Methods Phys. Res. A*, vol. 606, no. 3, pp. 291–295, 2009. `doi:10.1016/j.nima.2009.05.004`

[3] S. M. Gierman *et al.*, "Operating a Tungsten Dispenser Cathode in Photo-Emission Mode", in *Proc. PAC'09*, Vancouver, Canada, May 2009, pp. 575–576. `https://jacow.org/PAC2009/papers/MO6RFP088.pdf`

[4] CST Studio Suite: Electromagnetic field simulation software, Dassault Systèmes, 2023. `https://www.3ds.com/products/simulia/cst-studio-suite`

[5] K. Floettmann, *Astra, A space charge tracking algorithm*, Version 3.2, DESY, 2017. `https://www.desy.de/~mpyflo/Astra_manual/Astra-Manual_V3.2.pdf`