A NEW EXTERNAL BEAMLINE FOR DETECTOR TESTS

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Abstract

At the electron accelerator ELSA [1], a new external beamline is under construction, whose task is to provide a primary electron beam for detector tests. In the future, the accelerator facility will not only be offering an electron beam to the currently implemented double polarization experiments for baryon spectroscopy, but to the new "Research and Technology Center Detector Physics" as well. This institution will be located near the accelerator in Bonn and is charged with the development of detectors for particle and astroparticle physics.

The requirement for the new beamline is to be able to vary the beam parameters such as beam current and width over a wide range. With the slow resonance extraction method employed, it is possible to extract electrons with a maximum energy of 3.2 GeV and an energy spread lower than 0.1 % to the test area. A quasi-continuous external beam current of of 1 fA to 100 pA can be offered. A further reduction of the beam current can be realized by utilizing the single-pulse operation mode at ELSA. The beam width can be changed in both transverse directions from 1 mm to 8 mm.

INTRODUCTION

Modern high energy particle detectors are huge devices consisting of a network of many subdetectors gathering information of what particles were detected.

In order to ensure the functionality of those subdetectors it is inevitable to determine and optimize their characteristics. Thus, it is required to perform an intense testing of detector components before they are integrated in the intended experimental setup. Therefore, particle testbeams for detectors—currently only available at CERN and DESY—are an important tool for detector physics.

Detectors can be shooted with charged particles to get information about stability and ageing or if the concept is working. Moreover, components following the detectors like electronics and data processors can be checked.

At ELSA a testbeam with primary electrons is under construction. It is based on a slow extraction of the circulating electrons via excitation of a third integer betatron resonance. The beamline consists of four quadrupole magnets to ensure a variation of the beam width from 1 mm to 8 mm at the test area and one dipole in combination with beam scrapers to further reduce beam halo which is eventually generated by the extraction mechanism and the beam separation in the extraction septum magnets. All magnetic components of the beamline has been used in former experimental set-ups at ELSA. Therefore they were available for the new beamline.

The general set-up of the magnets was designed using the software-package MAD-X [2]. Later, simulations were carried out—also with Elegant [3]—to investigate possible variations of the beam widths at the test area.

THE BEAMLINE

The new beamline at ELSA is located in the former synchrotron light experiments laboratories (see Fig. 1). The extraction septa for the new beamline are placed point symmetrically to the septa of the existing beamline to the hadron physics experiments.

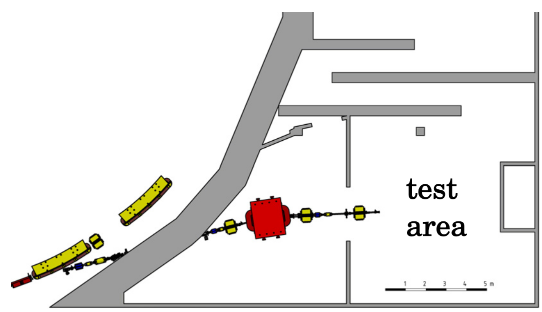

Figure 1: Location of the new beamline.

Layout Concepts

The optimization of the general beamline design was performed with MAD-X (Methodical Accelerator Design, version 10). Considering the spatial limitations, one bending magnet is required to guide the beam to the test area. Furthermore, the shielding wall between ELSA and the laboratory prevents the installation of magnets on a length of four meters. Additionally, the user demands have to be taken into account. A minimum beam size of $\sigma_{x,z} \approx$ 1 mm, expandable up to 10 mm, and a low dispersion at the test area should be foreseen to achieve the user requirements.

Three different optical set-ups have been investigated in detail.

A layout with 3 quadrupoles and hence a short beamline showed a non-vanishing dispersion and beam widths of $\sigma_{x,z}^{\min} \approx 1.5$ mm and $\sigma_{x,z}^{\max} \approx 3.1$ mm.

When adding one quadrupole, the beam width mainly stays below 5 mm over the course of the beamline. Hence the beam pipe diameter can be mostly chosen to 50 mm. Furthermore, two quadrupoles can be soled. This allows

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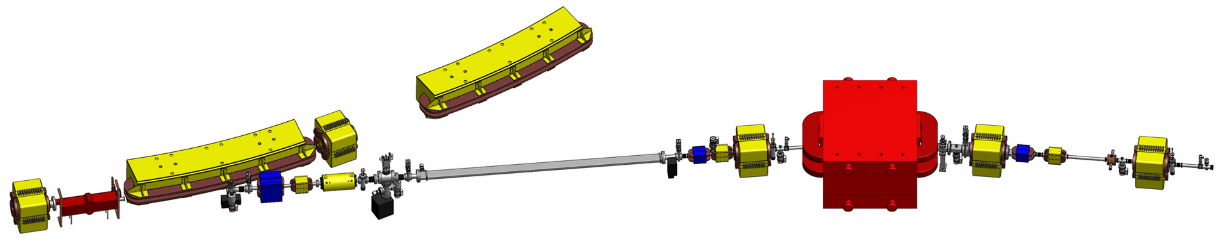

Figure 2: The layout of the beamline. On the left side, the ELSA ring with two quadrupoles and two dipoles as well as the main extraction septum can be seen. The new beamline branches off to the right.

in a simple way to increase their focusing strengths by decreasing the magnets' apertures ("soled quadrupoles"). At the test area, a low dispersion and beam widths of $\sigma_{x,z}^{\min} \approx 1\,\mathrm{mm}$ and $\sigma_{x,z}^{\max} \approx 8\,\mathrm{mm}$ can be achieved.

The case of 5 quadrupoles with a quadrupole triplet located just in front of the test area gives a low focal length but also a considerably large beam width in the triplet. In addition, it shows no significant improvement with respect to the case with 4 quadrupoles.

In general, it turned out that the beam width at the third quadrupole needs to be large in all layouts to achieve a minimal beam width at the test area. Therefore, this quadrupole cannot be soled.

Based on the investigations, the layout with 4 quadrupoles was chosen for the beamline.

Layout

The layout of the beam line is illustrated in Fig. 2. There are four quadrupoles placed in the beamline to focus the electron beam and hence ensuring the desired beam properties in the test area. By means of three horizontal and three vertical correction dipoles, the beam can be shifted in both planes. For beam diagnostics purposes, fluorescence screens are installed after each—except the third—quadrupole and after the bending dipole. The beam current can be measured with an RF cavity [4] located in front of the last quadrupole.

The vacuum system consists of three ion getter pumps (IGPs) and six turbo vacuum pumps (TVPs) and ensures a vacuum in the region of $10^{-7}\,\mathrm{mbar}$ in the first section directly following the ELSA ring and is increasing to $10^{-6}\,\mathrm{mbar}$ in the course of the beamline.

Details of the components of the beamline are depicted in Fig. 3 to Fig. 5.

Simulations

To conceive the design of the beamline, simulations with MAD-X were performed, taking into account the premises as well as the requirements at the test area.

Subsequent simulations focused on investigating possible beam properties at the test area whilst paying regard to the beam pipe aperture $a \geq 5\,\sigma$. For these simulations Elegant (ELEctron Generation ANd Tracking) was used as well to enrich the simulation results of MAD-X.

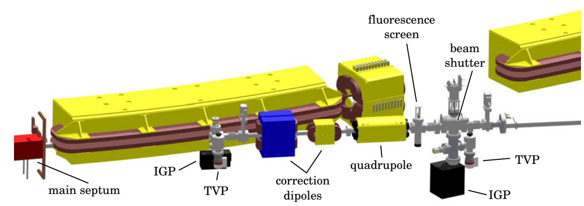

Figure 3: The first section of the beamline. The vacuum is ensured by two IGPs and two TVPs each at the beginning and at the end. A horizontal correction dipole is followed by a vertical one. Hereafter, the first quadrupole—featuring a maximum field gradient of $8\,\mathrm{T/m}$—with a fluorescence screen behind it is installed. A beam shutter prevents electrons and synchrotron radiation to reach the test area.

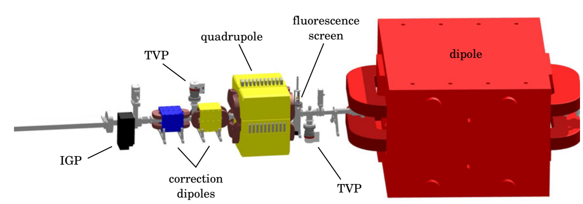

Figure 4: The second section of the beamline. The vacuum is maintained by two TVPs and one IGP. Two correction dipoles—one for each plane—are followed by the second, soled quadrupole with a maximum field gradient of $40\,\mathrm{T/m}$. Once again, a fluorescence screen is installed behind it. The dipole bending magnet comes next, whose task consists in guiding the beam to the test area.

The simulation process for both programs is comparable. The lattice has to be defined. The start parameters for the beam—obtained through simulations of the ELSA lattice or by measurements—are provided. Both programs optimize beam width and divergence at defined positions by changing the quadrupole strength of each quadrupole. To avoid the problem of lingering in a local minimum, this optimization algorithms runs several times, each one with different initial quadrupole strengths. In MAD-X, this loop can be integrated in the program itself, whereas in Elegant, this task has to be done by a higher level program.

After this optimization, any results that physically make no sense, or whose beam widths are bigger than one fifth of the beam pipe aperture as well as those who are very similar

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ISBN 978-3-95450-122-9

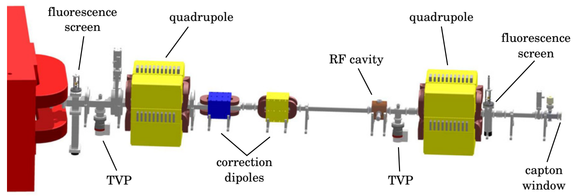

Figure 5: The third section of the beamline. Here, a fluorescence screen is located right after the dipole and is followed by the third quadrupole with a maximum field gradient of $10\,\mathrm{T/m}$. As in the other sections, two correction dipoles are installed here, too. Before the beamline ends at a capton window, the last soled quadrupole with an adjacent fluorescence screen is placed. Two TVPs maintain the vacuum. For being able to measure the beam current, an RF cavity [4] is placed in front of the last quadrupole.

are sorted out. This reduces the data considerably, so that a manually sorting can be done. The resulting quadrupole strengths pose requirements for the quadrupoles' power supply.

Simulation Results

The simulation results that are presented here were computed for an energy of 3.2 GeV. They show that it is possible to vary the beam width in both planes from 1 mm up to 8 mm, therefore allowing for round and elliptical beam profiles.

A minimal beam size is realizable with a round beam of 1 mm radius. In this case, the divergence cannot be adjusted to zero at the test area. This, for example, is possible with a round profile of 2 mm radius, as depicted in Fig. 6.

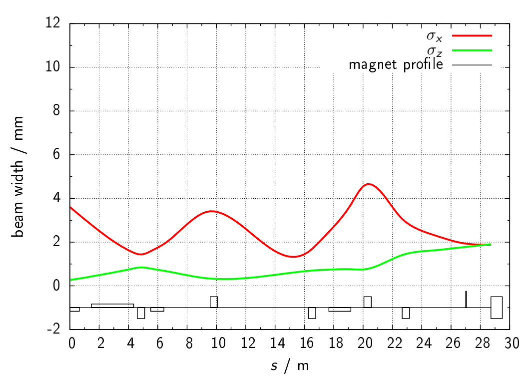

Figure 6: Simulation of the beam width development for a round beam of 2 mm radius at the test area.

Other possibilities are shown in Fig. 7 and Fig. 8, in the first case an elliptic beam and in the latter a beam of maximal size. In both cases, the divergence cannot be adjusted to zero.

There are of course many more beam widths settings possible.

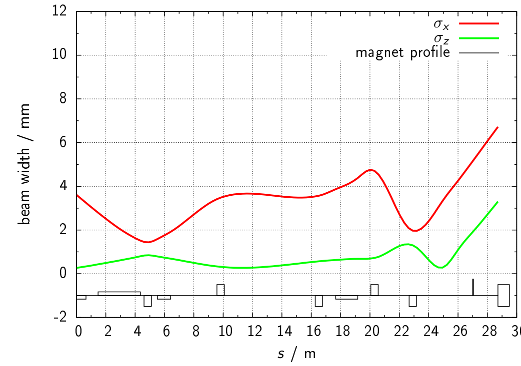

Figure 7: Simulation of the beam width development for an elliptic beam with radii of 5 mm and 2 mm, respectively at the test area.

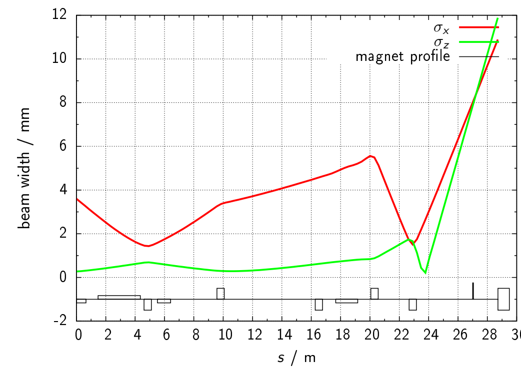

Figure 8: Simulation of the beam width development for a round beam of 8 mm radius at the test area.

SUMMARY AND OUTLOOK

The new beamline at ELSA will offer new possibilities for detector testing.

The extracted electron beam holds an energy spread lower than $0.1\,\%$. Beam energies of up to $3.2\,\mathrm{GeV}$ and beam currents of up to $100\,\mathrm{pA}$ can be offered. The beam width can be varied from $1\,\mathrm{mm}$ to $8\,\mathrm{mm}$ at the test area.

Currently, two thirds of the beamline are completed. The first sector in the ELSA tunnel will be constructed in the next months. The set-up of the technical infrastructure in the laboratories as well as the required radiation safety installations (beam dump and shielding for the operating room) will be finished within this year.

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