THE NEW EXTERNAL BEAMLINE FOR DETECTOR TESTS AT ELSA

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Abstract

At the electron accelerator ELSA [1], a new external beam line has been constructed whose task is to provide a primary electron beam for detector tests. Using a slow resonance extraction method, it is possible to extract a quasi continuous electron beam with a maximum energy of 3.2 GeV to the test area. An external beam current of 100 pA to 1 fA can be realized. A further reduction of the beam current is envisaged as well.

The beam width can be changed in both transverse directions from 1 mm to 8 mm. To dump and simultaneously measure the current of the electron beam behind the detector components a Faraday cup consisting of depleted uranium is used. The residual radiation leaving the cup is absorbed in a concrete casing. The radiation protection concept for the entire area of the new beamline was designed with the help of the Monte Carlo simulation program Fluka. In addition to the concrete casing, radiation protection walls were built to allow a safe working environment in the neighboring control room.

INTRODUCTION

Modern high energy particle detectors are large devices consisting of many subdetectors gathering information on the species and momentum of secondary particles being produced in primary collisions.

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 are an important tool for detector physics.

Currently only tertiary testbeams at CERN and DESY are available. At ELSA a testbeam with primary electrons with a variable beam width, a low energy spread and external currents of under 1 fA was built up.

THE BEAMLINE X3ED

The new beamline is located in the former synchrotron light experiments laboratories (see Fig. 1). The extraction septum for the new beamline is placed point symmetrically to the one of the beamline to the hadron physics experiments.

Layout Concepts

The optimization of the general beamline design was performed with MAD-X [2]. 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—a minimum beam size of $\sigma_{x,z} \approx 1$ mm, expandable up to 10 mm, and a low dispersion at the test area—have to be taken into account.

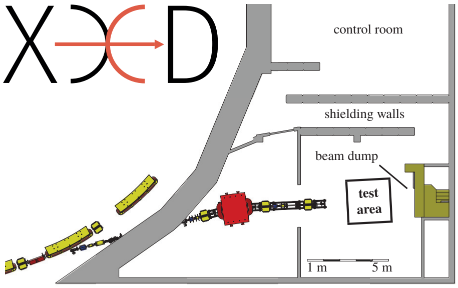

Figure 1: Location of the new beamline.

Three different set-ups have been investigated in detail. A layout with 3 quadrupoles showed a non-vanishing dispersion and beam widths not fulfilling the requirements. Adding one quadrupole features a beam pipe diameter of 50 mm, a low dispersion and desired beam widths at the test area. The case of 5 quadrupoles gives a low focal length but also a large beam width. In addition, it shows no significant improvement with respect to the case with 4 quadrupoles.

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

Layout

The layout of the beam line is illustrated in Fig. 2. Three of the four quadrupoles are placed in the new laboratory to focus the electron beam and hence ensuring the desired beam properties at the test area. By means of three horizontal and three vertical corrector dipoles, the beam can be shifted in both planes. Fluorescence screens are installed as diagnostic elements. The beam current can be measured with a rf cavity [3].

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 [4] was used to enrich the simulation results of MAD-X.

The simulation process for both programs is comparable. The lattice and the start parameters for the beam have to be defined. Both programs optimize beam width and divergence at defined positions by changing the quadrupole strength of each quadrupole. To avoid the problem of lin-

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Table 1: Specifications of the Beamline

beam	$\sigma_{x,z}$	$\sigma'^{\,\mathrm{min}}_{x,z}$	E **/ GeV**	$\frac{\Delta E}{E}$ **/ %**	I_{ext}
primary e^-	1 mm – 8 mm	1 mrad	0.8 – 3.2	0.02 – 0.08	< 1 fA – 100 pA

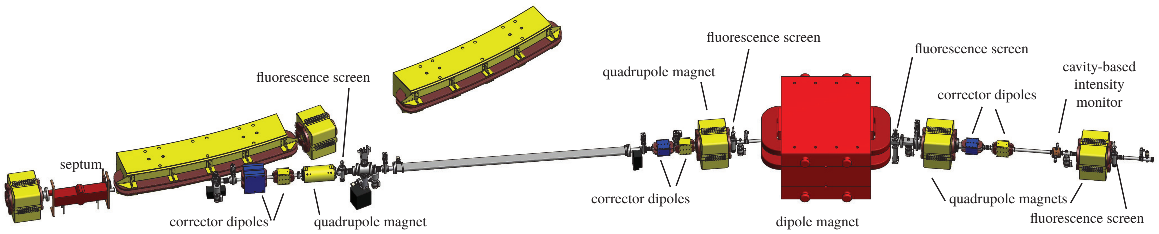

Figure 2: The layout of the beamline. On the left side, the ELSA ring with two quadrupoles and two dipoles as well as the main extraction septum can be seen. The new beamline branches off to the right.

gering in a local minimum, these optimization algorithms run 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 are sorted out. This reduces the data considerably. The resulting quadrupole strengths pose requirements for the quadrupoles' power supplies.

Simulation Results

The simulations were done for an energy of 3.2 GeV. They show that it is achievable to vary the beam width in both planes from 1 mm up to 8 mm, therefore allowing for round and elliptical beam profiles. One of the many result of these simulations is shown in Fig. 3.

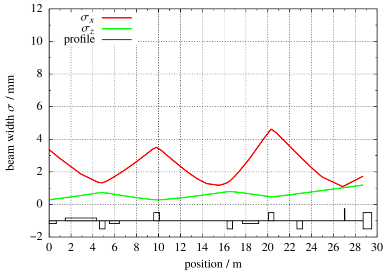

Figure 3: Simulation of the beam width development for a round beam of 1 mm radius at the test area.

THE RADIATION PROTECTION CONCEPT

The starting situation of the location is not suitable for operation, since without dumping of the electron beam in an appropriate way, the radiation level in the laboratories, the surrounding soil and the overlying meadow would raise above limits. However, it is also the structural situation and consequential requirements that have to be respected:

a) Next to the test area a control room as supervised area with an effective dose D_{eff} less than 6 mSv/a needs to be created (see Fig. 4 a)).

b) The geometry of the beam dump casing has to take into account, that the existing emergency exit shaft must be preserved (see Fig. 4 b)).

c) The test area should be as large as possible, so the dump casing should be placed as deep as possible in the emergency shaft (see Fig. 4 c)).

d) The area above the beamline is public area where the effective dose should be $D_{\mathrm{eff}} \leq 1\,\mathrm{mSv/a}$ (see Fig. 4 d)).

e) An existing Faraday cup should be used as beam dump.

Simulation Process

The aim of the simulations is to conceive a possible solution regarding a radiation protection concept, following the constraints mentioned above.

For this purpose FLUKA [5], a Monte Carlo simulation program was used. The user defines an input file containing beam properties, output parameters and the geometry with corresponding materials. The occasionally complex geometry can be built using the interface SimpleGeo. Objects—or regions as combinations of objects—can be created with the help of geometric primitives by using Boolean operators.

After the geometry is generated, materials need to be assigned. Some of them are predefined in FLAIR, others can be defined using the stochiometric composition in units of the mass percentage number. For example baryte or barium sulfate ($BaSO_4$) consists of 27.42 % oxygen, 13.74 % sulfur and 58.84 % barium.

Next, the output parameters of FLUKA are selected. Here, the equivalent dose of all produced particles—calculated out of energy dependant factors—is the quantity of interest to be optimized.

One simulation with user defined primaries consists in general of several cycles. After the simulation process the data files created are merged to create a file containing the average values and statistical errors.

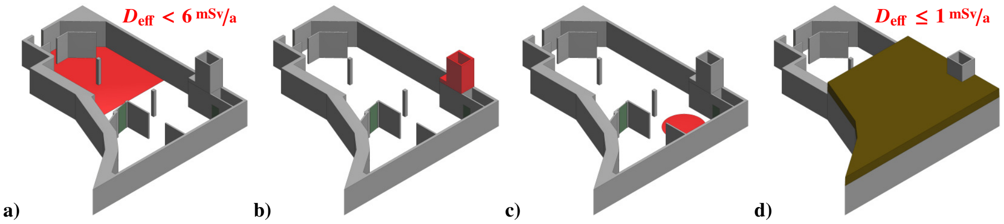

Figure 4: The laboratories with illustrations for the different constraints for the radiation protection concept.

Simulation Geometry

In course of the simulations a geometry fulfilling all demands **a)** – **e)** was developed; it is shown in Fig. 5. Based on the geometry of the laboratories and of the Faraday cup, heavy concrete elements were added.

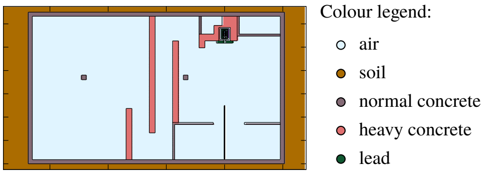

Figure 5: The simulation geometry. A simplified model showing the soil sourounding the basement with its walls consisting of normal concrete. Heavy concrete elements are used for the radiation protection walls dividing the room into two areas, as well as for the beam dump casing.

To fulfill demand **a)**, a radiation shielding wall consisting of baryte concrete is used. The remaining constraints can only be realized by using a beam dump casing with a customised form which assures a further usage of the emergency exit. In this casing—which is positioned as deep as possible into the emergency exit shaft—a hole remains housing the Faraday cup.

The Faraday Cup

To be able to measure the external beam current, a Faraday cup is used as primary beam dump. This cup was used in the 1980s and consists of 81 kg depleted uranium and is sourrounded by a lead casing. The uranium dump is half as large compared to a lead dump, providing the same shielding effect. A slight disadvantage is the higher backscattering of secondary radiation, which increases with heavier elements.

Simulation Results

The simulation result is displayed in Fig. 6. In the simulations the beam had an energy of $E = 3.2\,\text{GeV}$ and the external beam current was $I_{\text{ext}} = 1\,\text{nA}$.

A further reduction of the neutron fluence in the test area could be achieved by using polyethylene as coating of the inner walls of the beam dump casing, which acts as moderator for neutrons. Secondary particles, produced in the moderation process will stay in the lead wall or in the concrete.

The doses in the control room (<2 mSv/a) and above the laboratories (<0.2 mSv/a) comply with the statutory doses.

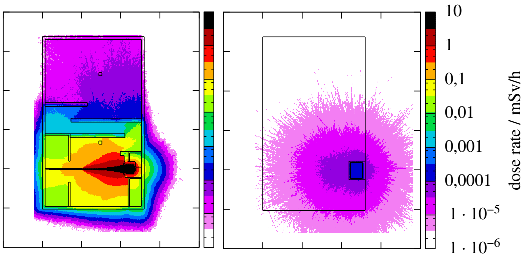

Figure 6: The dose equivalent in the basement (left) and above of it (right).

CONCLUSION

The new beamline offers new possibilities for detector testing. The extracted electron beam holds an energy spread lower than 0.1 %. Beam energies of up to 3.2 GeV and beam currents of up to 1 nA and lower than 1 fA can be offered. A beam width from 1 mm to 8 mm at the test area is possible.

The radiation protection concept of the new beamline was simulated with the particle transport code FLUKA. Starting with the geometry of the laboratories, heavy concrete walls and a casing for the primary beam dump were added to obtain radiation levels that remain under statutory limits in regions where it is required.

The whole beamline including all radiation protection elements was built up completely. The steering of the beamline with an in-house developed, existing control system and new menus is implemented. Currently tests of the steerage are executed, which are followed by the commissioning.

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