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DEVELOPMENT OF A SILICON STRIP DETECTOR FOR NOVEL ACCELERATORS AT SINBAD

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Abstract

At the SINBAD facility (DESY Hamburg), novel particle acceleration techniques like dielectric laser acceleration (DLA) structures will be tested using the ARES linac. Due to the small size of these structures, the accelerated electron beams only have a very low (sub-pC) charge. To determine the energy distribution of these beams, a silicon strip detector for the ARES linac spectrometer is currently under development. This detector fulfils the requirements of high spatial resolution for low charge density beams. The detector consists of two 1 cm × 1 cm silicon strip sensors and readout components. The design of the detector, its components and an estimate of its behaviour for a specific electron beam distribution are presented and discussed.

INTRODUCTION

SINBAD (Short and INovative Bunches and Accelerators at Desy) [1] is a dedicated accelerator R&D facility at DESY hosting ARES (Accelerator Research Experiment at Sinbad) [2], a 100 MeV S-band electron linac which is currently under commissioning. The ARES linac is designed to test novel acceleration techniques, such as plasma acceleration or dielectric laser acceleration (DLA), which are characterized by small (μm scale) apertures and acceleration periods. ARES therefore aims at delivering electron beams with unique properties such as ultra short bunches with fs to sub-fs duration and low charges (0.3 - 30 pC) [1] with an arrival time jitter of ~ 10 fs [3]. It will run in single bunch mode with a repetition rate up to 50 Hz [1]. First experiments at ARES include studies of DLAs in the scope of the ACHIP (Accelerator on a Chip International Program) [4] collaboration. ACHIP foresees to use dual grating type DLA structures to accelerate electrons produced at the ARES linac. The DLA structures have an aperture in the μm range and transmit electron bunches in the pC range [5]. The shortness of the ARES bunches allows electron injection to a limited accelerating phase range in the dielectric, resulting in net acceleration. One considered working point at ARES foresees injection to the DLA with a ~ 52 MeV and 0.5 pC charge beam. The minimum expected energy gain is 450 keV [6]. The beam energy spectrum after the DLA can be measured with the ARES spectrometer setup. The electron distribution in x and y dimensions at the position of the detector for the 0.5 pC case as well as the number of electrons integrated over the whole y range and the corresponding charge of the electron spectrum at a certain x position is shown in Fig. 1. Downstream of the spectrometer dipole, where the beam energy spectrum is spatially spread out, electron densities below 7 electrons per μm^2 area are expected. To measure these energy spectra with a good spatial resolution a dedicated detector based on silicon strip sensors is currently under development.

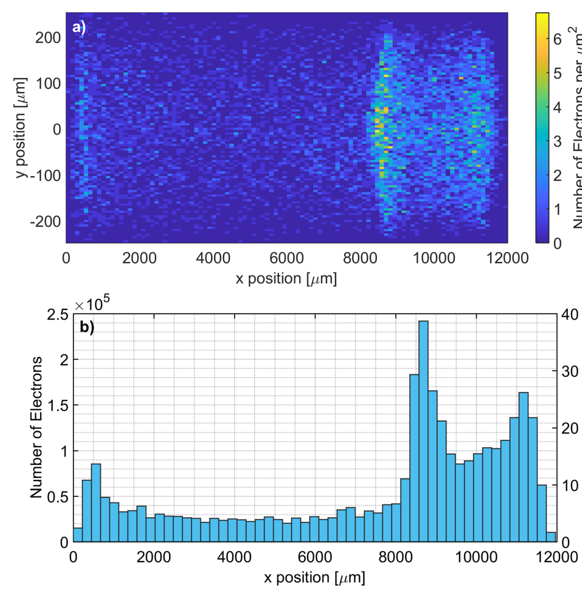

Figure 1: a) Electron beam distribution in x and y dimensions. The number of electrons per μm^2 is displayed with a bin size of (120 × 5) μm^2. b) Electron beam distribution in x dimension integrated over the whole y range. A bin width of 225 μm was chosen to match the detector readout channel width. Both distributions are displayed at the position of the detector for a 0.5 pC ACHIP working point.

DESIGN OF THE STRIDENAS DETECTOR

The STRIDENAS (STRIp DEtector for Novel Accelerators at Sinbad) detector is being developed as an internal DESY collaboration, combining the expertise of the accelerator R&D, detector and different manufacturing groups. It uses two sensors which are mounted and bonded to a printed circuit board (PCB). The readout is done by four charge-to-digital converters which can be connected to a computer. The detector aims at measuring electrons in an area of around 2 cm × 1 cm with a spatial resolution in the 100 μm range and a dynamic range for incoming electrons between ~ 10 - 234 000 electrons (1.6 ×10^{-3} fC - 37.5 fC) per 224 μm width.

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Sensors

The sensors used for the STRIDENAS detector are ATLAS12EC miniature sensors [7] which were designed for the high luminosity ATLAS inner tracker upgrade. These sensors are silicon strip sensors. Their specifications are listed in Table 1. A microscopic picture of the sensor is shown in Fig. 2. For operation, the readout is done via the AC coupled pads on the sensor. This ensures the suppression of leakage current reaching the readout electronics. The high voltage is applied on the backside of the sensor while the strips are set to ground potential. The depletion voltage of the employed sensors was determined by a capacitance-voltage measurement. A current-voltage measurement was performed to determine the leakage current (Fig. 3). The measurement results are shown in Table 2. The sensors are designed to be radiation-hard up to a maximum fluence of $1.2 \times 10^{15} \cdot 1\mathrm{MeVn_{eq}/cm^2}$. In addition, the sensors are equipped with a punch-through protection. This prevents large voltages on the strip implants in case of a high number of charge carriers in the bulk material of the sensor. The survival of the ATLAS miniature sensors under 10^{11} protons in a 2 mm radius beam was studied in [8] and the observed damage was considered acceptable [9]. For the beam charge at ARES ($2\times10^6 - 2\times10^8$ electrons) no damage is expected.

Table 1: ATLAS12EC Miniature Sensor Specifications

	Unit	Value
Sensor Size	mm × mm	10.02 × 10.02
Strip Material		n
Bulk Material		p
Number of Strips		103
Strip Pitch	μm	74.5
Sensor Thickness	μm	300

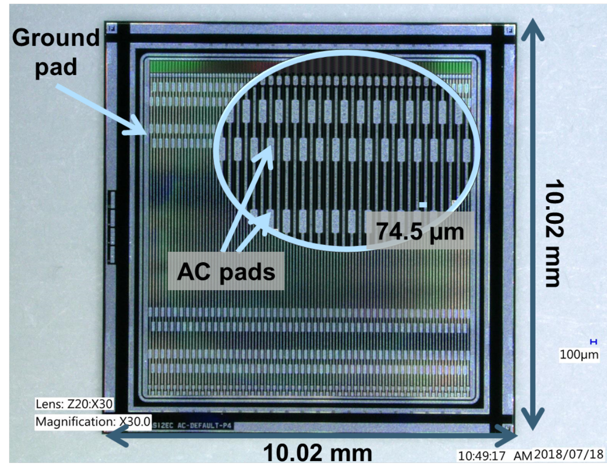

Figure 2: Microscopic picture of one ATLAS12EC miniature sensor. The AC-bonding pads and ground pad are indicated.

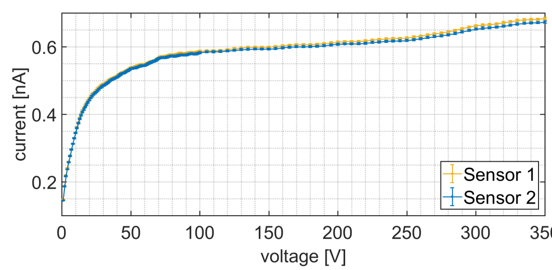

Figure 3: Current-voltage measurements for the two ATLAS12EC miniature sensors. The measurements are displayed in absolute values.

Table 2: Results of Sensor Measurements

	Unit	Sensor 1	Sensor 2
Depletion Voltage	V	- 285 ± 3	- 284 ± 3
Leakage Current	pA	- 662 ± 3	- 652 ± 3

Printed Circuit Board

The PCB of the STRIDENAS detector has a total size of 127 mm × 140 mm. Two silicon microstrip sensors for electron detection are glued to the PCB. The PCB contains 70 LEMO-00 connectors which are connected to 70 bonding pads. The sensor strips are wirebonded to the PCB. Three strips are grouped together to one pad. This design was chosen to reduce the number of readout channels and therefore the required space for connectors on the PCB as well as the number of channels for the readout electronics. The PCB was designed such that independent operation of the two sensors is possible. Therefore, two spatially separated copper biasing plates were implemented. The high voltage supply can be provided by two LEMO-00 connectors on the side of the PCB. A picture of the PCB hosting the sensors is shown in Fig. 4.

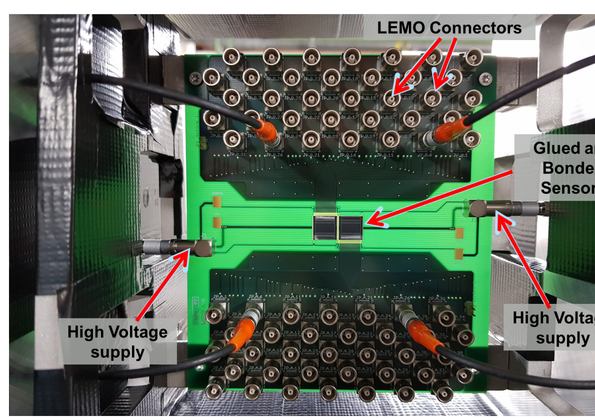

Figure 4: Picture of the printed circuit board hosting two ATLAS12EC miniature sensors. The sensors are bonded to the PCB and connected to LEMO connectors for readout. The high voltage supply is provided on the side of the PCB.

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Readout Electronics

The strip signals are read out by charge-to-digital converters (QDCs) V965 produced by CAEN. Four QDCs with 16 channels each are used. The QDCs have two implemented dynamic ranges. Range 1 is a low charge range between 0 pC and 100 pC with a resolution of 25 fC. Range 2 is a high charge range between 0 pC and 900 pC with a resolution of 200 fC. Both ranges acquire data in parallel. The dead time of the QDCs is 6.9 μs. To start the charge integration a negative gate signal between 30 ns - 900 ns is needed. The QDCs are placed in a VME crate (see Fig. 5) which is connected to a readout computer with dedicated software via an optical link.

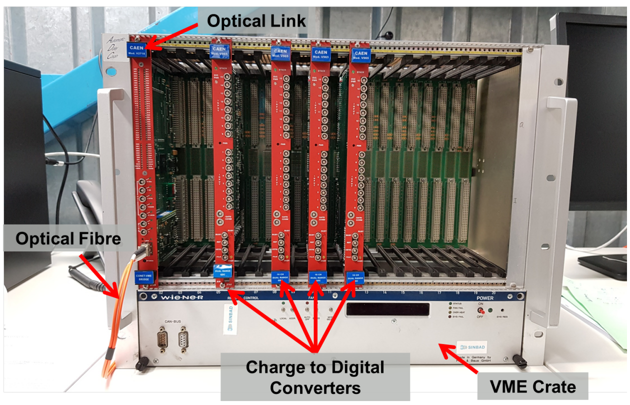

Figure 5: VME crate hosting the four charge-to-digital converters and the optical link which is connected to a computer via an optical fibre.

SIMULATION OF CHARGE PRODUCTION IN THE SENSORS

When electrons hit the depleted area of a silicon sensor, electron-hole pairs are produced and induce a current on the readout electrodes. The number of created electron-hole pairs depends on the amount of incoming electrons, the thickness of the sensor and the deposited energy in the sensor. For a minimum ionizing particle (MIP) the deposited energy follows a Landau-Vavilov distribution. The duration of the induced charge pulse depends on the electric field inside the sensor and on the mobility of the electrons and holes. Thermal diffusion, as well as electrostatic repulsion in the case of a high charge carrier density, spread the pulse in the transverse direction. This might influence the final resolution of the strip detector. To investigate these effects simulations based on ROOT [10] libraries were performed. The aim of these simulations was to estimate the charge production inside the sensor and explore the effect of transverse signal spread. For the simulations, all incoming electrons were treated as MIPs with an energy deposition following a Landau distribution. In silicon, MIPs produce about 80 electron-hole pairs per traversed μm [11]. The transverse signal spread is expected to be ~4 μm, if only thermal diffusion is taken into account. However, due to a high charge carrier density in the sensor, this spread will increase [12]. Thus, a safe limit of $\sigma = 300$ μm for a Gaussian distribution was chosen.

With these estimations and the assumption of the electrons entering the sensor perpendicular to its surface, the number of produced electron-hole pairs per incoming particle was determined by applying a random number generator to the Landau distribution. Each incoming particle has a spatial position x assigned. This signal position was smeared out by applying the Gaussian spread. The result was then filled into histogram bins with a bin size corresponding to the readout channels of the sensor. The whole process was repeated for each incoming particle. A lower threshold of the readout electronics was applied and set to twice the minimum resolution of the QDC range 1.

As an example, the ACHIP 0.5 pC working point beam distribution as shown in Fig. 1 was studied. The simulation results are shown in Fig. 6. Despite the assumption of a big transversal smearing of the signal, the beam features of interest, i.e. the double peak structure, are well resolved, as seen in channels 40 to 60.

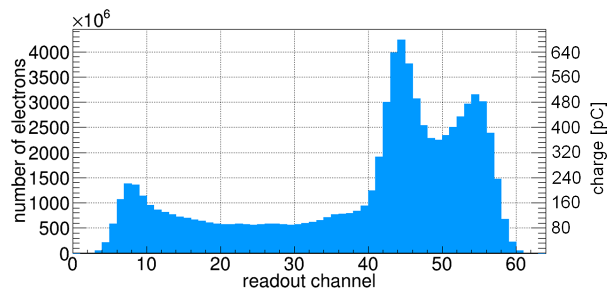

Figure 6: Estimated charge distribution after the sensor for the 0.5 pC ACHIP working point.

CONCLUSION AND OUTLOOK

A silicon strip detector for measuring low charge density electron distributions has been developed and presented. The properties of the different components were listed. The estimated performance, including a transversal spread of the signal, was estimated with a simulation of an expected beam distribution at the detector. The result was found to be sufficient for the desired position measurement. First functionality tests of the setup were performed at the DESY II Test Beam facility [13]. However, due to the low electron incoming rate and an early breakdown of the sensors, no clear signal was observed. This problem is currently under investigation and possible solutions are being explored.

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