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BEAM QUALITY MONITORING SYSTEM IN THE HADES EXPERIMENT AT GSI USING CVD DIAMOND MATERIAL*

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Abstract

In this contribution a beam monitoring system which consists of a chemical vapor deposition (CVD) diamond sensor, a fast readout electronics and a monitoring and visualization software used at GSI will be introduced. The sensor has been designed to measure the reaction time (T0) in the HADES Spectrometer, but also possesses beam quality monitoring capabilities which is of great importance to ensure high efficiency data recording. In the following, the diamond based sensor, its read-out chain and the online analysis and visualization software are described. Special emphasis will be put on an online visualization of important beam parameters namely the beam intensity, its position during extraction and the beam particle time structure.

INTRODUCTION

For experiments with the HADES [1] detector at GSI in Darmstadt and for the future CBM [2] experiment at the FAIR facility, radiation hard and fast beam detectors are required. The detectors should feature high rate capability, low interaction probability and perform precise T0 measurements ($\sigma_{T0} < 50$ ps). In addition, the sensors should offer beam monitoring capabilities. These tasks can be fulfilled by utilizing single-crystal Chemical Vapor Deposition (scCVD) diamond based detectors. This material is well known for its radiation hardness and high drift velocity of both electrons and holes, making it ideal not only as Time-of-Flight (ToF) detectors placed in the beam but also as luminosity monitors. With the help of striped read-out electrodes position information can be obtained for beam monitoring purposes. The main detector system used for this purpose in the HADES experiment consists of two diamond based sensors made of pcCVD and scCVD materials. Both sensors are equipped with a double-sided strip segmented metallization (300 µm width) which allows a precise position determination of the beam position. Those sensors are able to deliver a time precision <100 ps RMS and can handle rate capabilities up to 10^7 particles/channel. Having the precise time measurement and precise position information of the incoming beam ions one can monitor important beam parameters namely the beam intensity, its position during extraction and the beam particle time structure. The read-out of the sensors is based on the NINO [3] chip in combination with the already well established TRB3 (Trigger Readout Board - Version 3) platform [4], developed by the TRB Collaboration [5]. On this platform high precision multi-hit TDCs (up to 264 channels, time precision <10 ps RMS) are implemented inside FPGAs. The TRB3 system serves as a fast and flexible Data Acquisition System (DAQ) with integrated scaler capability. The analysis and online visualization is performed using the Data Acquisition Backbone Core (DABC) [6] framework.

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CVD DIAMOND BASED BEAM DETECTOR

The detector, which is used in HADES in order to construct the reaction time determination (T0) and beam quality monitoring, is made of single crystal chemical vapor deposition (scCVD) diamond material with an active area of 4.7 mm × 4.7 mm. The sample thickness of 70 µm is chosen in order to reduce the nuclear interaction probability of the beam ions in the detector material. For example for an Au beam at 1.25 AGeV the interaction probability is about 0.36 %. The sensor is metalized with a 50 nm Cr layer, annealed at 500 °C for 10 min, deposited on the scCVD diamond and covered by a 150 nm Au layer. A similar detector [7] was used as T0 sensor in HADES for a $^{197}Au^{69+}$ beam, with a kinetic energy of 1.25 AGeV and currents between 10^6–10^7 ions/s delivered from the SIS 18 accelerator. The metallization is arranged in 16 strips (each 300 µm wide) on each side which allows a beam profile measurements in x and y directions. A close-up picture of the multi-strip segmentation of the diamond based sensor is shown on in Fig. 1.

The diamond sensor is glued to a Printed Circuit Board (PCB), which serves as a holder and provides electrical con-

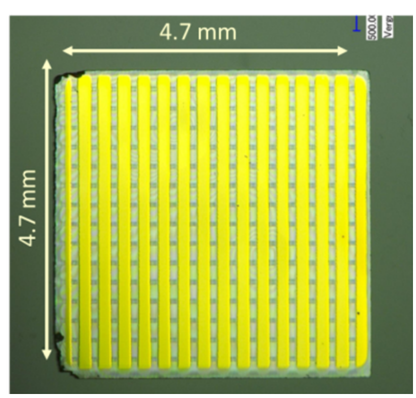

Figure 1: Close-up photography of the scCVD diamond based sensor. The metallization is arranged in 16 strips (each 300 µm wide) on each side which allows beam profile measurements.

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nections to the read-out electronics. The read-out segments of the diamond sensors are bonded, using aluminum wires, to the conducting traces on the PCB. The scCVD diamond sensor mounted on a PCB is shown in Fig. 2.

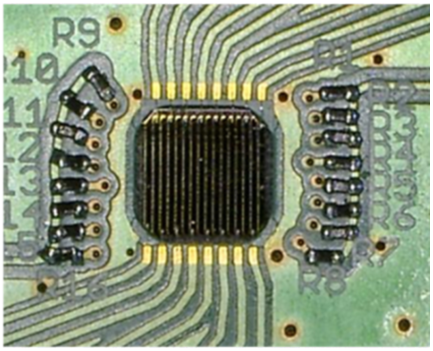

Figure 2: The diamond sensor is mounted on a PCB plates and the read-out electrodes are bonded to the PCB traces using aluminum wires.

As the T0 sensor has to be installed in vacuum very close to the HADES target, an additional mechanical holding structure is used for this purpose. The PCB with the sensor is installed on four PCB rods serving as a mechanical holder and ensures a electrical connection needed for the sensor read-out. The T0 sensor mounted on a holder structure is shown in Fig. 3. The T0 detector is located 2 cm in front of the reaction target. In addition the HADES experiment uses a diamond based veto-detector which is located 70 cm behind the target. Both detectors are aligned with the beam axis and the beam is focused on the target.

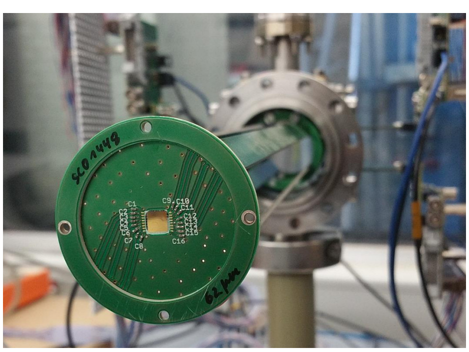

Figure 3: The diamond sensor as it is mounted into the HADES beam tube.

READ-OUT CONCEPT AND ONLINE VISUALIZATION

The read-out electronics of the diamond senor is based on the NINO chip. In Fig. 4 a NINO-based read-out board is shown. Each board offers eight input channels. A fan-out implementation delivers eight fast Low Voltage Differential signals (LVDS) for trigger purposes and eight fast LVDS signals for timing measurements. Timing measurements are performed using the TRB3 platform. A large variety of front-end electronics is available for the TRB3 in order to extend its functionality i.e. discriminator boards [8].

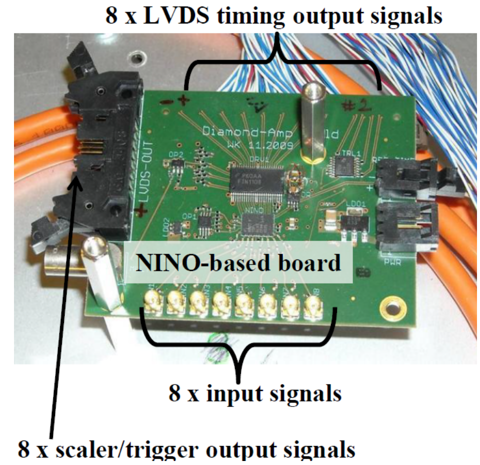

Figure 4: The NINO-based board used for T0 readout in HADES. This board offers LVDS timing outputs and scaler/trigger outputs.

The Data Acquisition Backbone Core (DABC) [6] is a DAQ framework with modular components for data-flow on multiple nodes. It provides a C++ runtime environment with all basic services, such as: threads and event handling, memory management, command execution, configuration, logging and error handling. User written DAQ applications can be executed within this environment by means of a plug-in mechanism. It offers advanced possibilities for on-line analysis of data samples via TCP/IP sockets, and monitoring of run variables via HTTP clients. A specialized web server [9], based on an embeddable Civetweb http server, has been implemented in DABC. This server can deliver data directly from running applications to a web browser where JavaScript-based code powers an interactive web graphics.

For this application DABC collects the data from the TRB3 boards, performs the needed online time calibrations, and carries out online data analysis. Results of the data processing in form of histograms are provided to the DABC web server for visualization. For online beam monitoring purposes trend plots showing the beam position in x- and y-direction, the time structure of the beam, and the beam intensity have been implemented. Those plots are rendered as a live display in any web browser to be used by the accelerator operators.

System Performance

A prototype system consisting of one segmented diamond sensor connected to NINO based discriminator boards and read-out by one TRB3 board has been prepared and tested with very low intensity Ca beam, about 200 Ca ions/s, and with pulse generator signals. Further beam tests are planned and will be conducted soon. The readout system can transfer up to 100 MB/s data without data losses to the linux PC running the DABC analysis system. This amount of data can

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be online analyzed, the preprogrammed histograms can be prepared and visualized on a dedicated web server. In Fig. 5 a trend plot of the spill structure of a calcium beam is shown as an example. The 100 MB/s of data corresponds to the hit rate of about 20 MHz hits in a single TDC channel. At higher hit rates some hits will get lost as the TRB3 can currently transfer only 100 MB/s lossless. In order to increase the data transfer bandwidth one can use several boards in parallel.

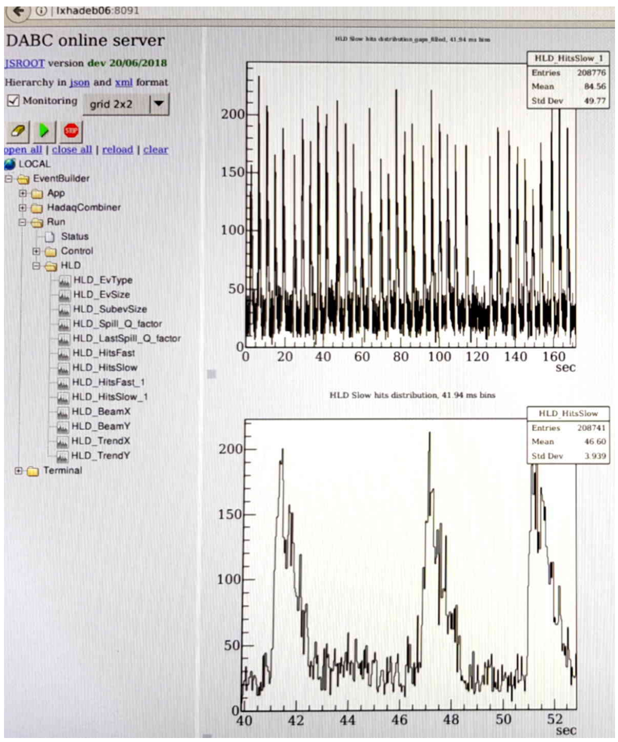

Figure 5: Spill structure of a calcium beam monitored by DABC in a web browser.

SUMMARY AND OUTLOOK

A scCVD diamond based beam sensor was presented in detail. The sensor provides T0 determination for time-of-flight measurements in the HADES spectrometer. Besides that it is used for beam monitoring purposes. A segmented metallization allows a precise determination of the beam position. Utilizing state of the art read-out electronics based on the NINO ASIC and the TRB3 platform and the comprehensive DABC software framework, beam quality trends can be visualized in a web-browser in real-time.

Currently, the HADES collaboration prepares the spectrometer for a production beam time with a 1.65 AGeV silver beam. A four week physics beam time is planned for end of 2018. The introduced beam monitoring concept will be used. For further diamond detector developments a test set-up is currently installed at the Superconducting Darmstadt Electron Linear Accelerator (S-DALINAC) [10] of Technical University Darmstadt. The accelerator is designed for electron beams with an energy of 130 MeV and currents up to 10 µA. It provides an excellent condition for diamond detector research and developments, especially for Minimum Ionizing Particles (MIPS).

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