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PERFORMANCE OF THE CVD DIAMOND BASED BEAM QUALITY MONITORING SYSTEM IN THE HADES EXPERIMENT AT GSI*

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Abstract

This contribution depicts a beam monitoring system consisting of a chemical vapor deposition (CVD) diamond sensor, a fast read-out electronics and a monitoring and visualization software which is used in the HADES experiment at the SIS 18 accelerator of GSI Helmholtzzentrum (Darmstadt, Germany). The sensor has been designed to measure the reaction time (T0) in the HADES spectrometer, but also possesses beam quality monitoring capabilities. In the following the performance of the system, which was used in order to evaluate an Ag ion beam delivered by the SIS18 accelerator will be discussed.

INTRODUCTION

The beam quality monitoring of extracted beams from Heavy-Ion-Synchrotron (SIS18) at GSI, transported to the HADES experiment [1] is of great importance to ensure a high efficient data recording. 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. The 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 a position information can be obtained for beam monitoring purposes. Having the precise time measurement and precise position information of the incoming beam ions one can monitor important beam parameters such as the beam intensity, its position during extraction and the beam particles time structure.

CVD DIAMOND BASED BEAM DETECTORS AND READ-OUT CONCEPT

The main detector system [2] for beam quality monitoring in the HADES experiment consists of two diamond based sensors made of scCVD material. The first scCVD sensor is designed to measure the reaction time (T0) in the HADES Spectrometer and is located 2 cm in front of the reaction target. In addition the HADES experiment uses a second scCVD sensor as a 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. The arrangement of the detectors in respect to the target foils is shown in Fig. 1.

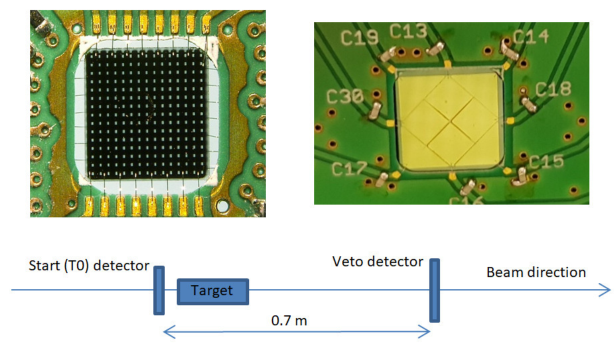

Figure 1: Arrangement of the scCVD diamond sensors in the HADES experiment. In the upper left a close-up picture of the T0 sensor is shown. The metallization which is arranged in sixteen stripes is clearly visibly. The upper right corner shows a close-up picture of the scCVD diamond based veto detector with a boxed shaped metallization.

The scCVD detector which is used for T0 measurement and most beam diagnostic purposes has an active area of 4.7 mm × 4.7 mm and a sample thickness of 70 µm. The sensors is equipped with a double-sided strip segmented metallization (16 strips, each 300 µm wide). In total sixteen channels in x-direction and sixteen channels in y-direction allow beam profile measurements. The sensor is able to deliver a time precision <100 ps RMS and can handle rate capabilities up to 10^7 particles/channel. In Fig. 1 a close-up picture of the sensor is shown. The second diamond based veto detector, is made of 8 mm × 8 mm scCVD material with a thickness of 107 µm. A boxed shaped metallization was chosen in order to allow a fragment identification in order to exclude events without a reaction in the target from the HADES trigger generation. A close up picture of the sensor one can find in Fig. 1.

The read-out of the sensors is based on the NINO [3] chip in combination with the TRB3 (Trigger Readout Board - Version 3) platform [4, 5]. The TRB3 platform implements high precision multi-hit TDCs (up to 264 channels, time precision <10 ps RMS) inside FPGAs and serves as a fast and flexible Data Acquisition System (DAQ) with integrated scaler capability. Data analysis and online visualization

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is performed using the Data Acquisition Backbone Core (DABC) [6] framework.

The Data Acquisition Backbone Core (DABC) [6] is a DAQ framework with modular components for data-flow on multiple nodes. It provides a C++ run-time 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 [7], 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. An Example of such a live, display showing important beam properties, one can find in Fig. 2.

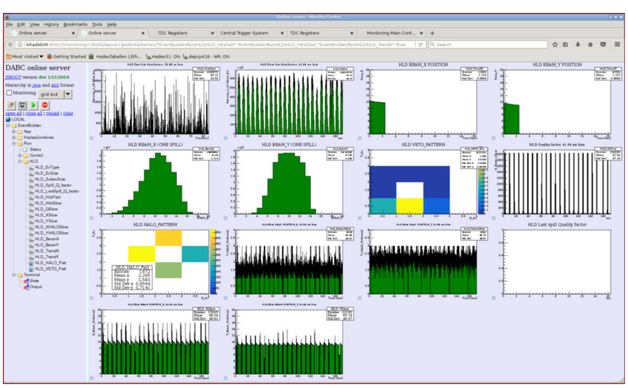

Figure 2: Important beam properties (i.e. x- and y- profile macro- and micro-spill structure) can be displayed live in any web browser.

SYSTEM PERFORMANCE

The introduced system was used during a four week physics production beam time of the HADES experiment in March 2019. An $^{107}Ag^{45+}$ ion beam with an energy of 1.58 A GeV was delivered by the SIS18 accelerator. The main purpose of the system, besides defining the reaction time (T0) in HADES, was the beam diagnostics. The online monitoring histograms of important beam parameters, which can be visualized in any web-browser, have been a powerful tool for accelerator experts in the SIS18 control room. This provided a fast and efficient tuning of the beam and during data taking they have been used for beam quality monitoring. In the following, the performance of the system will be discussed.

Beam Profile and Position Measurement

The segmented metallization of the scCVD sensor allows a beam profile and position of the ion beam with an resolution of 300 µm. The HADES experiment requires a focused beam on the target with a beam size of about $\sigma_{x,y}$ =1 mm. An example of a typical beam profile measurement in x-direction is shown in Fig. 3. An average beam size of about $\sigma_{x,y}$ =0.8 mm could be achieved.

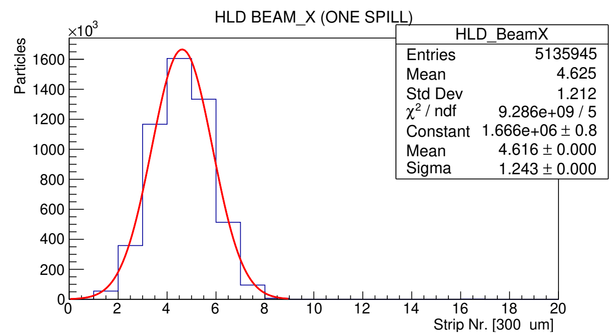

Figure 3: Beam profile measurement of an $^{107}Ag^{45+}$ ion beam with an energy of 1.58 A GeV using a scCVD with a metallization segmented into sixteen stripes. Each bin corresponds to a width of 300 µm.

Spill Profile and Time Structure

The ion beam was extracted from the SIS18 accelerator via a so called "slow extraction" with a typical extraction time of 19 s. In order to ensure an efficient data taking the macro spill profile is required to be almost flat with out spikes. The multi-wire drift chambers which are used in the HADES spectrometer for tracking of the reaction particles limit the maximal beam intensity to 10^6 particles/s. Any rate above this value could potentially be harmful for the HADES spectrometer. The typical macro-spill time structure during the beam time is shown in Fig. 4. Figure 5 shows the corresponding micro-spill time structure.

In a joint collaboration between the GSI accelerator and HADES groups, the physics run of the HADES experiment was used to improve the cycle-to-cycle feedback on the slow-extraction macro-spill structure [8, 9] under nominal beam conditions. The introduced monitoring system and the associated HADES data acquisition (DAQ) infrastructure has been used, via a new prototype link to directly drive the relevant SIS18 accelerator extraction parameters. The event data recording efficiency could be improved by about 15% on top of what has been already established by expert-driven manual fine-tuning of the SIS18 accelerator.

A quality factor of the beam has been introduced by the ratio between the peak and average event rates. The Q-factor

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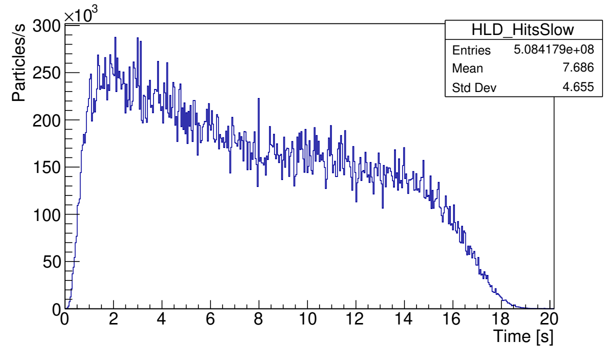

Figure 4: Macro-spill time structure measured by the scCVD diamond sensor in font of the HADES target. The ion particles are extracted from the SIS18 accelerator via a so called "slow extraction" in about 19 s. The maximal average rate should not be above 10^6 particles/s.

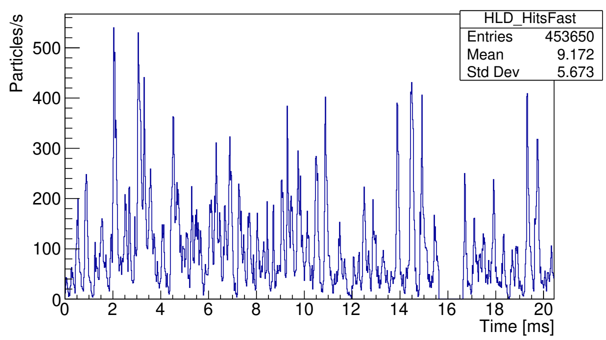

Figure 5: Micro-spill time structure of the particle rates.

is defined by

$$Q = \frac{N_{\mathrm{max}}(20\,\mu\mathrm{s})}{N_{\mathrm{mean}}(40\,\mathrm{ms})} \tag{1}$$

with with the maximal number of hits in a 20 µs binning $N_{\mathrm{max}}(20\,\mu\mathrm{s})$ and the average number of hits in a 40 ms binning $N_{\mathrm{mean}}(40\,\mathrm{ms})$. In ideal case the Q-factor should be as close to 1 as possible and constant during the slow-extraction. The Q-factory during for the time of a complete macro-spill is shown in Fig. 6.

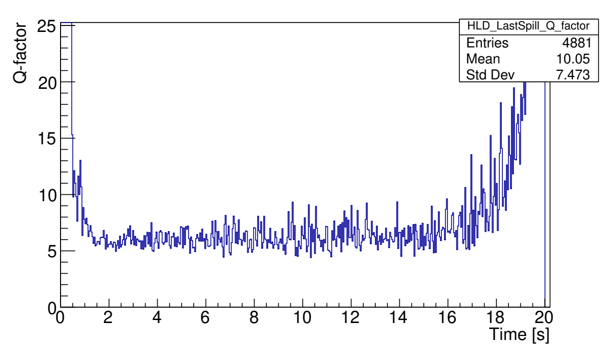

Figure 6: Quality factor of the Ar beam, which is defined by the ratio between the peak and average event rates.

SUMMARY AND OUTLOOK

During the four weeks long HADES physics production beam time in March 2019 a successful operation of the scCVD diamond based beam quality monitoring system could be shown. In a close collaboration of the HADES and GSI accelerator groups the beam-properties i.e. the macro-spill structure could be significantly improved. For the future this close collaboration will continue in order to improve further the beam properties. Beside this the implementation of a fast beam-abort-system in HADES is ongoing.

ACKNOWLEDGEMENTS

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