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STATUS OF DIAMOND AND LGAD BASED BEAM-DETECTORS FOR THE mCBM AND CBM EXPERIMENTS AT GSI AND FAIR

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Abstract

The Compressed Baryonic Matter (CBM) experiment is currently under construction at the Facility for Antiproton and Ion Research (FAIR) in Darmstadt. The aim of the experiment is the exploration of the Quantum Chromodynamics (QCD) phase diagram of matter at high net-baryon densities and for moderate temperatures.

In this contribution a beam monitoring (BMON) system will be presented which will include a high-speed time-zero (T0) detector. The detector system must meet the requirements of the CBM time-of-flight (ToF) measurement system for proton and heavy-ion beams and should also allow for beam monitoring. The detector technology is planned to be based on chemical vapor deposition (CVD) diamond basis but also new Low Gain Avalanche Detector (LGAD) developments are evaluated. In this contribution the beam detector concept will be presented and the results of first prototype tests in the mini-CBM setup will be shown.

INTRODUCTION

The future CBM Experiment [1] at the Facility for Antiproton and Ion Research (FAIR) in Darmstadt will be a fixed-target multi-purpose detector with the aim to explore the QCD phase diagram of nuclear matter at high net-baryon densities and for moderate temperatures. The detectors will detect hadrons, photons, electrons and muons in elementary and heavy-ion collisions over the entire energy range provided by the heavy-ion synchrotron SIS100, i.e. 3 - 11*A* GeV for heavy-ion and 29 GeV for proton beams. The measurements will be performed at event rates from 100 kHz up to 10 MHz using free-streaming readout electronics and fast online event reconstruction. The miniCBM (mCBM) programme at the already existing heavy-ion synchrotron SIS18 provides ideal experimental conditions in order to benchmark CBM sub-detectors at realistic beam conditions.

In this contribution the current development status of the high-speed time-zero (T0) and beam monitoring system (BMON) for the CBM experiment will be presented. This detector must meet the requirements of the time-of-flight (ToF) measurement system for beams of protons and heavy ions. The system should have a time precision of better than 50 ps (sigma) and allow stable long-term detector operation at high interaction rates of 10^7 particles/s with a detection efficiency of almost 100%. The detector technology is currently planned on chemical vapour deposition (CVD) diamond [2] basis but also new Low Gain Avalanche Detector (LGAD) [3] developments are under consideration.

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THE CBM BEAM MONITORING SYSTEM

The BMON system will consist of two detector stations located in front of the CBM target chamber. The T0-station is foreseen to measure the start time of the reaction, while the halo-station will be used for beam halo monitoring. Both detectors will be mounted inside a beam-pipe using commercially available vacuum elements, as schematically shown in Fig. 1.

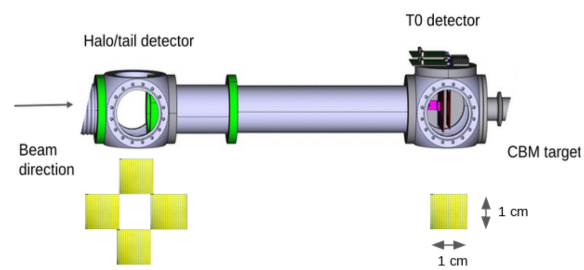

Figure 1: Schematic illustration of the CBM BMON system. Two stations of beam detectors will be used for beam halo and T0 measurement and are mounted in standard CF 100 vacuum chambers. For the T0 measurement a single sensor will be used and for the halo measurement a mosaic structure of four sensors is foreseen.

The sensor of the T0-station, currently planned on poly-crystal CVD (pcCVD) diamond technology, will cover the area of $1 \times 1\ \mathrm{cm}^2$ and is equipped with a metallization arranged in 16 strips on both sides. The strip segmentation and orientation, aligned in x and y-directions, will allow to extract a position information of the beam particles.

The halo-station is foreseen to be used as an independent beam monitoring system. The halo detector will consist of a mosaic arrangement of four sensors, each metallized with four strips on both sides. The sensor arrangement is schematically shown in Fig. 1. This arrangement allows to monitor the beam position and its rate during the extraction process. This information will be used for securing sensible CBM detectors as part of a fast beam-abort-system.

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PROPOSED SENSOR TECHNOLOGY

Experiments with high-intensity heavy ion beams require fast and radiation-hard beam detection systems. For these purposes, pcCVD and single-crystal CVD (scCVD) diamond sensors are widely used. Its radiation hardness and excellent timing characteristics make the diamond material an almost ideal choice for in-beam application. Beside diamond material we are actively investigating the Low Gain Avalanche Diode (LGAD) technology, which is attractive because of possible bigger sample sizes for relative low production costs.

Utilizing pcCVD Diamond Material for Heavy Ion Beams

In physics production experiments with heavy ions, it could be shown [2] that a CVD diamond-based time-zero-start detector fulfilled the requirements in terms of time resolution and radiation hardness. Currently, we plan to use commercially available electronic grade pcCVD diamond material, produced by Element Six [4].

A prototype sensor which is foreseen to be used for T0 measurement has been prepared using pcCVD material. It has an active area of $1 \times 1\,\text{cm}^2$ 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 on the other side allow beam profile measurements. The sensor should be able to deliver a time precision below 100 ps (RMS) for heavy ions and can handle rate capabilities up to 10^7 particles/channel·s, which is the limit of the planned read-out system. A close-up picture of the sensor is shown in Fig. 2.

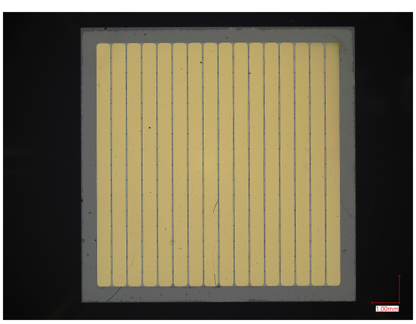

Figure 2: Close-up photography of the pcCVD diamond based prototype sensor for the T0 measurement. The metallization is arranged in 16 strips (each 300 µm wide) on the front and back side which allows beam profile measurements.

Utilizing LGADs for Proton Beams

Beam detectors based on Low Gain Avalanche Diode (LGAD) technology allow high precision timing and position measurements paired with a high radiation hardness and low production costs. These properties make them a promising possible further candidate for in-beam detectors. Using highly segmented LGADs, timing precision below 50 ps could be demonstrated [5]. Recently a successful operation of LGADs as a T0 and beam-monitor detector in the HADES experiment, utilizing a 4.5 GeV proton beam, was achieved [6]. At the moment we are actively investigating the possibility to use LGAD technology especially for proton beams in the CBM experiment.

READ-OUT CONCEPT

It is foreseen to operate the T0 detector up to beam intensities of 10^7 particles/s. By assuming a beam spot diameter of 0.5 cm on the T0 sensor, a rate of 1 MHz per read-out channel is expected. It has turned out that the read-out system used for the CBM TOF detector [7] shows similarities in analogue signal shapes and rate capability and therefore could be adapted for the BMON system.

The T0 sensor will be bonded on a dedicated [5] Printed Circuit Board (PCB) which serves as a sensor holder. A photography of a prototype board is shown in Fig. 3. In order to compensate for radiation damage, which will result in a decrease of the signal amplitude, two analogue amplification stages are realized close to the sensor. This PCB will be mounted inside the vacuum chamber. Analog signals and high- and low-voltage cables will be guided through vacuum elements using standard vacuum feed-through elements.

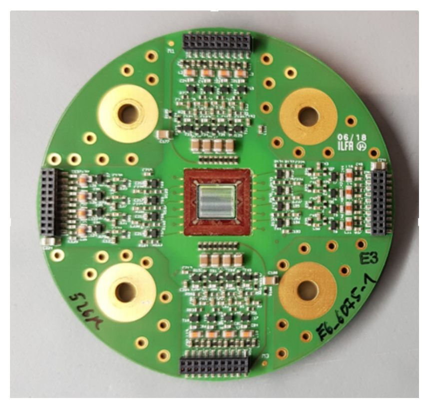

Figure 3: Possible front-end board with two amplification stages close to the sensor.

The analog signals of the sensors are sent to dedicated discriminator and time-to-digital converter (TDC) front-end boards, developed by the CBM TOF group. The read-out scheme of the CBM T0 detector is schematically shown in Fig. 4. As discriminator, the PADI ASIC [8] is used and as a Time-to-Digital-Converter (TDC), the Get4 ASIC [9]. In total, 32 analogue detector channels of the T0, and the halo detector, are read out by 32 GET4 ASICs in order to achieve the maximum rate capability, which is 14 MHz per ASIC. Data of the eight GigaBit Transceiver ASICs (GBTx) is sent to a single Common Readout Interface (CRI) board. It is planned to implement a fan-out functionality after the PADI discriminator in order to provide a beam monitoring functionality, which can run independently from the CBM

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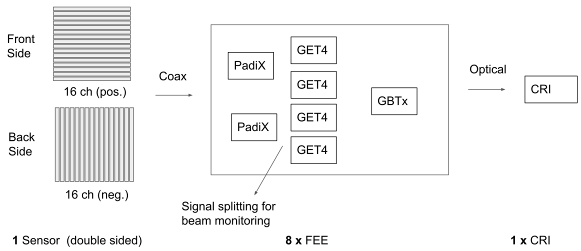

Figure 4: Planned readout scheme of the double sided T0 sensor. In total, 32 detector channels are read out by 16 GET4 ASICs in order to achieve the maximum rate capability. Data of the eight GBTx is sent to a single CRI board. An LVDS fan-out of the detector signal is needed for an "stand-alone" beam monitoring system.

DAQ system, using a "stand-alone" DAQ system which was presented in [10].

T0 DETECTOR PROTOTYPE TESTS AT THE mCBM EXPERIMENT

The mCBM experiment at SIS18 is an ideal place in order to test future CBM detector system under realistic beam conditions. A prototype T0 detector has been build and tested during a benchmark run in May 2022. The T0 detector is based on the pcCVD diamond prototype sensor which was introduced a previously. A photography of the detector is shown in Fig. 5. The sensor was irradiated for eight hours with a Ni beam with an energy of 1.93A GeV using a slow extraction of SIS18 with a duration of 10 s and $4{\times}10^7$ ions per spill. The T0 detector was successfully used as a beam monitoring tool located in front of the mCBM target. An online beam profile is shown in Fig. 6. A detailed systematic data analysis of the recorded T0 data is currently being prepared.

Figure 5: Prototype T0 detector build for the mCBM experiment. The diamond sensor is bonded on a PCB which is pneumatically driven into the beam-line in front of the target.

SUMMARY AND OUTLOOK

The concept of the CBM BMON detector consisting of T0- and halo-station has been prepared. Currently the system is planned to be based on pcCVD diamond technology. It will be used for T0 measurement and beam monitoring purposes. A prototype T0 detector based on pcCVD diamond

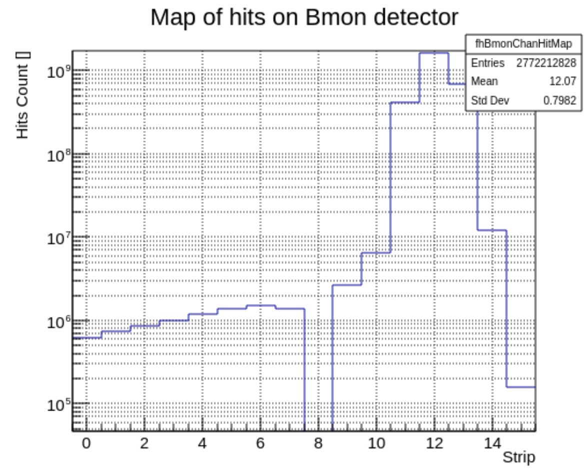

Figure 6: Beam profile measurement using the prototype T0 detector in mCBM. The focused beam has its maximum at strip no. 12, a beam halo is visible on strips no. 0-9. Strip no. 8 shows not data due to a bulk material problem.

material has been prepared and installed in the mCBM setup. The detector was successfully used for beam monitoring purposes and to provide a T0 information in the data stream of the mCBM experiment. A systematic data analysis is currently ongoing. For the future we plan further tests at the mCBM facility. In parallel to the development of CVD diamond based sensors we will evaluate LGAD technology for its use in the CBM experiment.

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