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A demonstrator for the Micro-Vertex-Detector of the CBM experiment

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CMOS sensors are the most promising candidates for the Micro-Vertex-Detector (MVD) of the CBM experiment at GSI, as they provide an unprecedented compromise between spatial resolution, low material budget, adequate radiation tolerance and readout speed. To study the integration of these sensors into a detector module, a so-called MVD-demonstrator has been developed. The demonstrator and its in-beam performance will be presented and discussed in this work.

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1. The CBM experiment @ FAIR

The goal of the Compressed Baryonic Matter experiment (CBM) is to study the QCD phase diagram in the region of moderate temperatures and high net-baryon densities in the vicinity of the predicted critical point. To do so, the fixed target experiment CBM will probe nuclear fireballs produced in heavy ion collisions of 8 to 45 AGeV incident energy with various rare probes, among them open charm. Due to the short life time ($c\tau = 123.0\ \mu$m for D^0-mesons) and the presence of a large background due to particles emitted from the target, the identification of open charm is only possible via their daughter particles considering their displaced decay vertex (secondary vertex). This requires an unprecedented vertex detector performance with a vertex resolution better then $\sim 70\ \mu$m. This implies a detector with minimal material budget (< 0.3 % X_0) and a single point resolution of better than $\leq 5\ \mu$m. In order to reduce multiple scattering the detector has to operate in moderate vacuum. Moreover, the high particle flux (up to 3.5×10^6 hits/mm^2) generated by the ambitioned collision rates of $10^5 - 10^6$/s requires a radiation tolerant sensor ($\gtrsim 10^{13}\ n_{eq}/cm^2$ [1]).

As they provide an optimum compromise between an excellent spatial resolution ($\leq 5\ \mu$m), low material budget (thinned to $\sim 50\ \mu$m Si), adequate radiation tolerance and readout speed, CMOS Monolithic Active Pixel Sensors (MAPS) are currently considered as guideline technology for the CBM Micro-Vertex-Detector (MVD). The so-called "MVD-demonstrator"- project aims at studying the integration of these sensors into an ultra-light and actively cooled detector module using available technologies. This project does not yet meet all ambitious requirements of the CBM MVD, but focused on system integration and material validation based on MAPS.

2. The MVD-demonstrator

The MVD-demonstrator integrates two MAPS-sensors (MIMOSA-20 [2]) on a double-sided module (see figure 1). The MIMOSA-20 sensors were developed by IPHC Strasbourg with a thickness of 750 μm silicon (50 μm after thinning), which corresponds to a material budget of 0.795% X_0. Each sensor hosts 640×320 pixels with a pixel pitch of $30 \times 30\ \mu$m^2. The chip is read out via two differential analogue signal lines in serial mode. The raw data rate of one sensor is 2.4 Gbit/s corresponds to 50 MHz readout frequency and 12-bit ADC-resolution. The sensors are positioned and bonded below to a dedicated three layer flex print cable (0.212 % X_0) and glued hereafter direct onto a highly heat conductive TPG (Thermal Pyrolitic Graphite $\sim$ 1500 W/mK [3]) support. The two TPG layers of the double-sided demonstrator are separated by a very light Reticulated Vitreous Carbon (RVC [4]) layer to increase mechanical stability and to keep the material budget low. The TPG layers transport the dissipated power of the sensors towards a copper heat sink located outside the acceptance of the detector module. This cooling concept allows for operating the demonstrator in vacuum.

It should be noted that it was not yet the goal of this project to achieve the material budget of the final CBM detector, hence the active part of the demonstrator setup has a material budget of ~ 2.452 % X_0. The integration of thinned sensors (50 μm silicon, total thickness of a demonstrator module ~ 1 % X_0) was successfully demonstrated but not applied for the demonstrator used in the beam test in order to reduce the risk of this project.

The readout of the sensors is done via the flex print cable, which is connected via a fine pitch connector to the front-end board (DemoAux). This board converts single-ended signals in differential signal and provides signal amplification. The high data rate of the sensors requires online data processing in a pipeline sequence to avoid dead times. Noise filtering and shaping for signal conditioning is implemented both on the hardware platforms and in the online pipeline sequence to

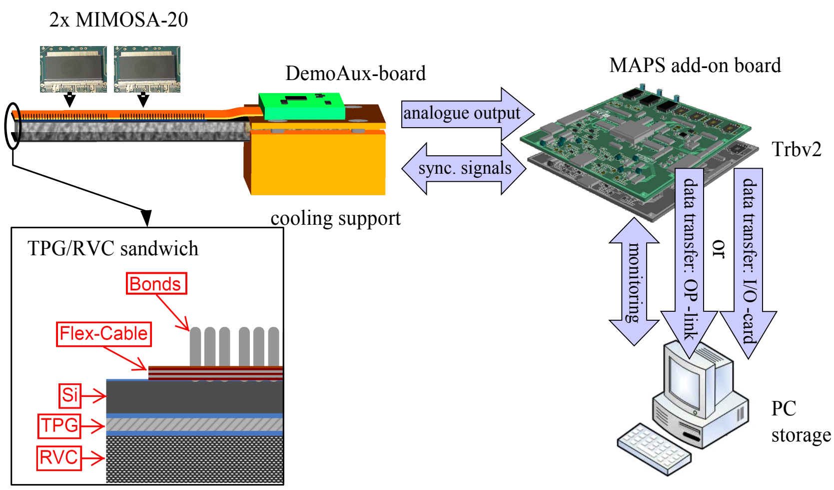

Figure 1: Sketch of MVD-demonstrator setup: Demonstrator module and R/O, DAQ.

improve the spatial resolution of the demonstrator. In order to implement the pipeline algorithms and the protocol, a FPGA (VIRTEX4) is used, which is located on a customized hardware platform. To allow for integrating the demonstrator in the HADES experiment this hardware platform is developed as an add-on concept for the HADES-TRBv2 [5]. This MAPS add-on board allows for an analogue-to-digital conversion of the signals generated by the MIMOSA-20 sensors as well as a deterministic sensor control.

3. Test conditions and in-beam performance

The detector performance of the demonstrator was tested with the 5.9 keV photons of a ^{55}Fe-source. This study focused on validating the hardware and the sensors with respect to noise and gain behaviour at different running conditions like temperature and readout frequency. This allows for calibrating and for tuning online noise filters like an online common mode filter or correlated double sampling. During the tests, we reproduced the known intrinsic noise of MIMOSA-20, which validates our readout system.

In order to examine the in-beam performance regarding to signal/noise-ratio and spatial resolution two demonstrator modules have been tested with 120 GeV/c pions at the CERN-SPS. The modules were arranged in a reference telescope (TAPI [6]) which provided trigger information from two scintillators. The synchronization of the demonstrator modules and the telescope was done by encoding time stamps and trigger flags into the data stream of the freely running devices. This method simulates the freely running CBM-DAQ and enables tracking over multiple stations which are running independently.

The good noise and signal performances observed in the laboratory was reproduced in the beam for both demonstrator stations. Figure 2 shows the noise distribution of one cooled demonstrator station and of one demonstrator station running at room temperature during the beam test.

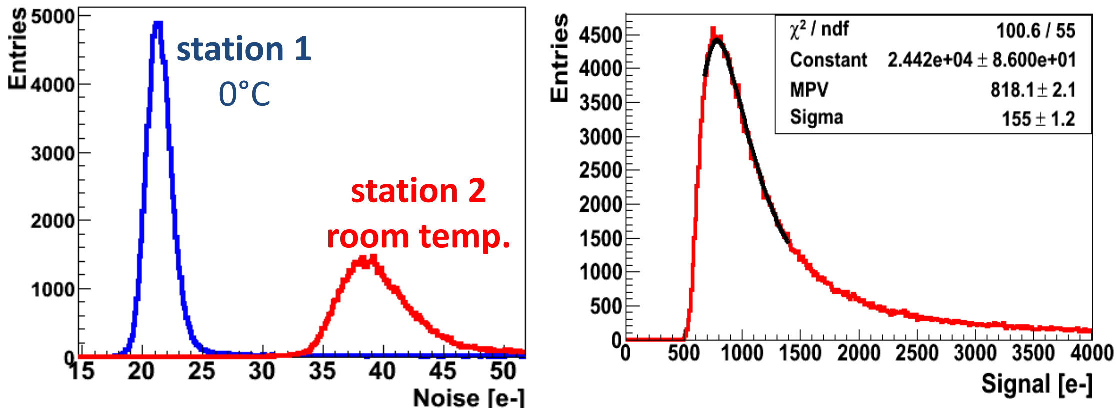

Figure 2: Noise averaged (left) of each pixel over 500 frames during the beam test for station 1 cooled down to 0 °C and for station 2 running at room temperature. The signal distribution (right) of the demonstrator for a 3 × 3 cluster including the seed pixel. The signal cut was set to 5 times the average noise (i.e. ~ 110 e$^-$).

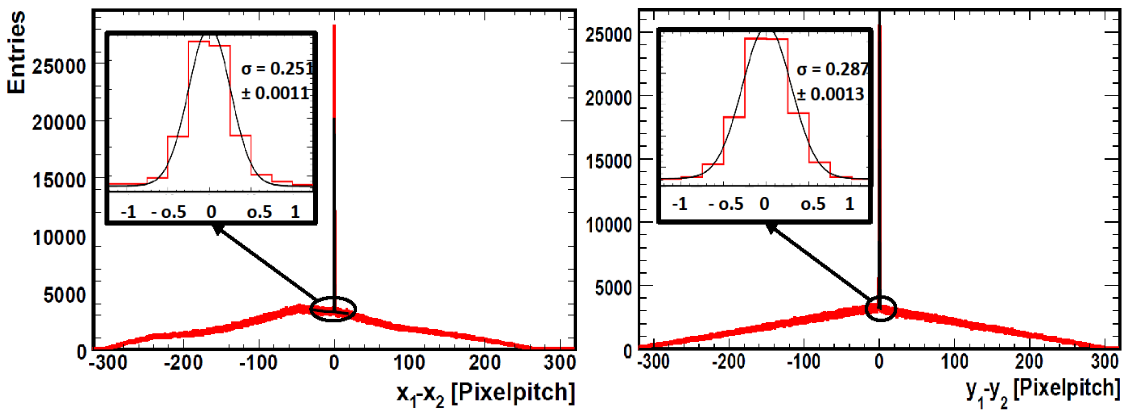

Figure 3: Position residual plot of the two demonstrator stations in x- (left) and y- (right) coordinate with a pixel pitch of 30 μm. The zoomed insert shows details of the position correlation, together with a gauss fit.

Due to an online common mode filter a noise average value of about ~ 21.4 e$^-$ and a noise dispersion of < 1.01 e$^-$ has been achieved for the cooled station.

Assuming straight and parallel tracks for alignment and using a center of gravity method, a first estimate of the spatial resolution was obtained (see figure 3). After an offline alignment by means of both, translation and rotation, as well as correcting for beam inclination, a spatial resolution of ≤ 5.73 μm (x,y) was achieved, which matches the specification of CBM regarding single point resolution. The discrepancy with the ultimate performances of MAPS with 30 μm pitch (2-3 μm spatial resolution) is probably due to additional noise caused by a known and meanwhile fixed mistake during the commercial processing of MIMOSA-20.

4. Conclusion and Outlook

A demonstrator for the Micro-Vertex-Detector of the future CBM experiment has been built and tested in beam. The good signal/noise performance observed in the laboratory could be reproduced in the beam test and validates the readout concept including online noise filters. Moreover, the untriggered online pipeline readout for data processing in combination with the offline data correlation from the two demonstrator stations delivered a spatial resolution in agreement with the chosen sensor parameters. The resolution matches the requirements regarding spatial resolution of the CBM experiments.

The next step is to develop a MVD prototype based on the experiences of the demonstrator. This prototype will operate with a successor sensor, MIMOSA-26 [7] featuring a single point resolution of 4 μm, a time resolution of 110 μs, a material budget of 0.05 % X_0 (sensors only), a radiation hardness of few 10^{12} n_{eq}/cm^2 for non-ionising radiation and > 300 krad for ionising radiation. These sensors will supported by CVD diamond [8] provides at the same time optimum mechanical stiffness and maximum head conductivity ($>$ 1800 W/mK) for cooling purposes. With a new scalable readout concept first arrays with many sensors and a readout network structure will be set up.

Acknowledgments

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