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Development of the new large area Micromegas detector and its readout electronics for the AMBER experiment at CERN

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ABSTRACT

For the AMBER (NA66) experiment several upgrades of the COMPASS (NA58) spectrometer are foreseen for the medium and long-term AMBER program. Among this R&D program the replacement of a part of the Multi-Wire Proportional Chambers (MWPCs) is planned, to face up the aging of some of the structural elements of the MWPC chambers. The preferred technology for substituting the most aged MWPCs is the well-established Micro-Pattern Gaseous Detectors (MPGD). This R&D project started with testing our non-resistive floating mesh MM detector with the TIGER-based front-end initially designed for the Cylindrical GEM detector of BESIII experiment. Those tests comprised laboratory tests and test beam campaigns. The main difficulty we had to address was regarding the Electro-Static Discharge (ESD) protection circuit of the FE cards. For this reason, we designed a new revision of the front-end board with a new protection circuit which aims on a single channel discharge quenching, thus enhancing the detector stability. The ongoing work on the development and testing of a prototype of a Micromegas (MM) detector and its front-end electronics is presented. Moreover, a first insight on the development of a new ASIC for the MM readout will be provided.

1. Introduction

In the context of the Physics-Beyond Colliders (PBC) initiative at CERN, AMBER (NA66) is a newly proposed fixed-target experiment at the M2 beam line of the SPS, devoted to various fundamental QCD measurements. The experimental proposal was approved in December 2020 by the CERN Research Board for a Phase-1 program and the Letter of Intent made public for a longer term program [1].

Three different measurements are foreseen for the AMBER Phase-1: the Proton Radius Measurement (PRM), the proton-induced antiproton production cross sections for dark matter searches and the Drell–Yan measurement (DY). For the PRM, a test run and a pilot run were carried out respectively in September 2022 and in September 2023; run 1 is scheduled for 2026. Concerning the antimatter production cross-section measurement, a test run was carried out in October 2022 and the 2023 data acquisition period was successfully finished in July 2024. For the DY measurement, the first test run is planned for mid-2026 and the first run is currently scheduled for after LS3.

The AMBER experiment is located in the same experimental hall (EHN2) of the COMPASS experiment; therefore the whole COMPASS spectrometer [2] would be upgraded by using all the experience and benefits from the past setup and combining them with state-of-the-art technology to optimize the performance for the newly proposed measurements. For this reason an important work of R&D is foreseen for the medium and long term programs.

Presently, Multi Wire Proportional Chambers (MWPC) are used as one of the main large area trackers and it is planned they will continue to be operated in the first part of the AMBER program. Unfortunately, due to aging of some of the structural elements of the MWPC chambers only a part of them could be operated for the whole expected life span of the experiment. Several refurbishment campaigns had been carried out on the MWPCs to substitute the external aluminized Mylar. In fact, the external aluminized Mylar is subject to Al delamination, creating shorts which in turn break the Faraday cage and open the gas volume of the chamber to air. To overcome this, the substitution of the most

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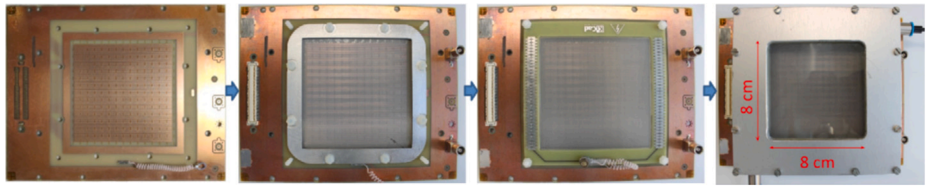

Fig. 1. The first MM detector prototype. From left to right: the readout plane, mesh electrode, drift electrode and the gas vessel.

3 aged MWPC stations (each station made of 2 MWPC detectors) with Micromegas detectors is planned.

2. Design of the new large area Micromegas detector for AMBER

Production and testing of the first MM prototypes was carried out in collaboration with a research group from Dzhelepov Laboratory of Nuclear Problems (DLNP) at Joint Institute for Nuclear Research (JINR), Dubna [3]. Those prototypes were designed in Torino; photoresistive pillars and mesh were produced in JINR laboratories, while the drift electrodes and the mechanical components were built in parallel in Turin. In Fig. 1 the prototype construction stages are shown.

For this first MM detector prototype the non-resistive approach was chosen due to our experience with the COMPASS MMs [4]. The main purpose of the first prototype was on one hand to define the production chain details and on the other to test a simple detector with the new TIGER-based Front-End Electronics (FEE) [5].

The second step of the project foresees the design, development and test of the first module of the new large area Micromegas detector, the development is being carried out within the Micro-Pattern Technologies workshop (MPT) under the supervision of Rui De Olivera [6]. The final detector geometry will consist of three Micromegas detector, as shown in Fig. 2 top, two lateral modules and a central one. Each module will have two strip readout planes in a "face-to-face" configuration: one of them for the X-coordinate and the other one with the double UV coordinate (a 2D capacitive-sharing U-V strips layout); then, a common drift cathode will be used for the two conversion gaps. In the bottom part of Fig. 2 the Micromegas detector structure is shown, the bulk technology [7] has been chosen for the mesh placement and a uniform resistive Diamond-Like Carbon (DLC) layer of 10 MΩ will be placed above the readout strips.

In Fig. 3 the design of the X and UV coordinates is shown.

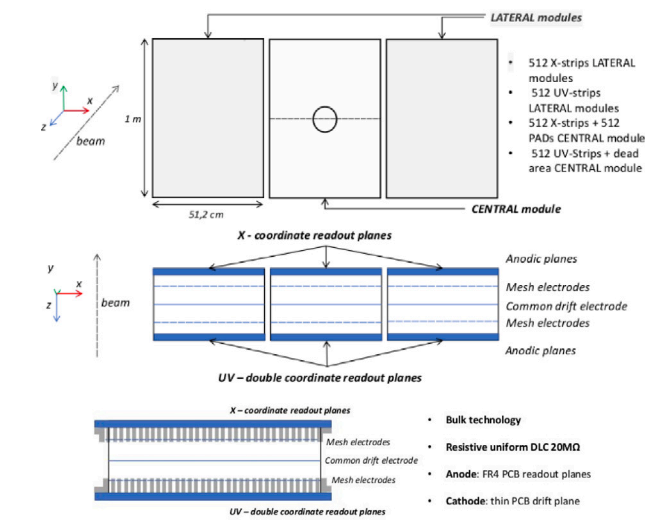

Fig. 2. MM final detector concept. From top image the 3 modules are shown, the readout planes "face-to-face" configuration is shown.

3. Readout electronics

3.1. TIGER ASIC-based readout system

The main purpose of the test with our first MM prototype was to validate the experimental setup composed by the front-end electronics based on the TIGER ASIC with our Micromegas detector. The experimental setup which has been used for one of the test beam is shown in Fig. 4 : the Micromegas detector is connected via FX10A-144S-SV Hirose Connector to the Front-End Board (FEB) TIGER-based, the data transmission and the low voltage supply are provided via an intermediate front-end card (Data LV Patch card, DLVPC) which is then connected to the off-detector electronics, namely the GEM-ReadOut Card (produced by INFN Ferrara section) [8]. The GEMROC module is finally controlled by the General User Front-End Interface (GUFI) DAQ software [9].

This test with the first MM prototypes allowed us to validate the data transmission, reconstruction, analysis and all the mechanical and the readout elements. At that time the main issues were related to the loss of readout channels due to the detector discharge. Exploiting the results of these tests we designed a new TIGER-based FEB with the possibility to have additional data lines in order to enhance the data acquisition and with a new discharge protection circuit in order to face up the intense discharges of our first MM detector (non-resistive) (Fig. 5). The new readout chain elements are shown in Fig. 6. The testing procedure of the complete readout system with the new FEB and a new adapted DLVPC card is currently ongoing in Turin.

Studies are ongoing regarding a new custom ASIC for MM detectors optimized for AMBER experimental conditions. The new chip will be based on the Torino Amplifier for Strip detectors (ToASt) ASIC [10] which has been developed for double-sided silicon strip sensors that will equip the micro-vertex detector of the PANDA experiment [11].

TIGER ASIC is still considered a backup option for our Micromegas readout but it is not a suitable solution for AMBER due to its limited dynamic range. Indeed, for AMBER we are searching to design a new ASIC aiming the compatibility with both Micromegas and MWPCs signals. Nonetheless, TIGER front-end electronics will be used to carry out the first tests of the first module of the Micromegas detector.

The new ASIC will be implemented in a commercial 65 nm CMOS technology. Currently the design of the amplification and shaping stages is ongoing in order to optimize the architecture to MM detector signals.

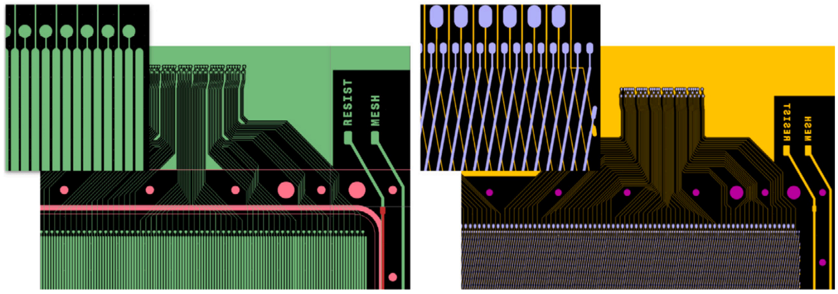

Fig. 3. The X-coordinate readout pattern on the left. On the right, the UV-coordinate readout plane is shown.

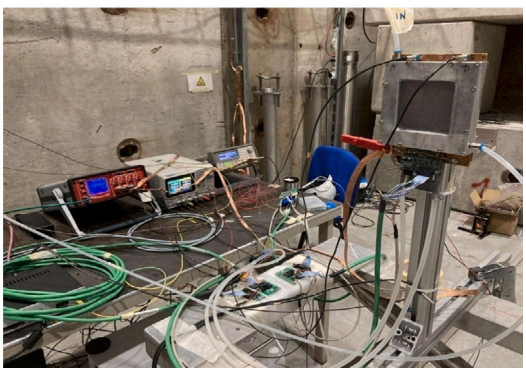

Fig. 4. The AMBER setup for the RD51 H4 test beam, north area CERN.

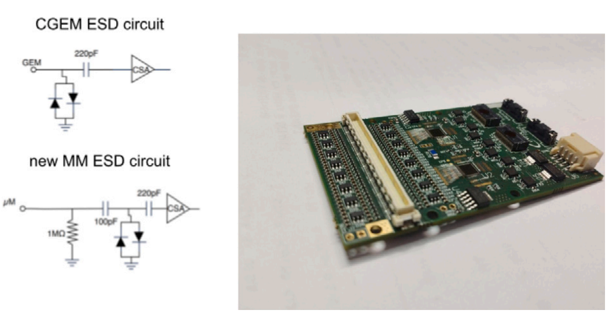

Fig. 5. On the left comparison between the old and the new ESD protection circuit: 1MOhm resistor to ground and another 100pF capacitance added, thus allowing for a single channel quenching mechanism. When a discharge occur the amplification field drop locally and the discharge is immediately quenched. New FEB after TIGER bonding on the right side.

Fig. 6. New FEE readout chain in Turin laboratory, from left to right the AMBER Micromegas FEB, DLVPC board and the GEMROC module.

4. Conclusions

The design of a new MM detector with an active area of 100×50 cm^2, is currently in progress. This new detector will be an upgrade of the first prototype (single coordinate readout strips) with a new design featuring two readout planes in “face-to-face” configuration with a single coordinate readout for one plane (X) and a dual-coordinate strip readout on the other (UV). The resistive technique will be exploited with a standard single DLC layout. Regarding the front-end development, further studies will be conducted on a new custom ASIC for MM detectors optimized for AMBER experimental conditions exploiting the results gained with TIGER-based readout tests.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Chiara Alice reports administrative support, equipment, drugs, or supplies, and travel were provided by University of Turin. Chiara Alice reports administrative support, equipment, drugs, or supplies, and travel were provided by National Institute of Nuclear Physics Turin Branch. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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