PROCEEDINGS OF SCIENCE

Development of a new large-area Micromegas detector and its ToRA ASIC-based readout electronics for the AMBER experiment at CERN

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As part of the AMBER (NA66) upgrade program, we have designed and built a resistive bulk Micromegas detector with a total active area of $1.0 \times 0.5\ m^2$ per module, intended to replace selected Multi-Wire Proportional Chambers in the spectrometer. The detector comprises three independent side-by-side modules. Each module hosts two readout planes in a face-to-face configuration sharing a central cathode, enabling XUV tracking. For the lateral modules, a uniform Diamond-Like Carbon (DLC) resistive layer was adopted to mitigate discharge probability while preserving efficiency at high gas gain. The first module-currently the largest operating resistive bulk Micromegas of its kind was completed in October 2024 and is under test. Meanwhile, considering the need for new triggerless compatible readout electronics, we are developing a 64-channel mixed-signal front-end ASIC (Torino Readout for AMBER - ToRA), optimized for time and energy measurements. This article review the detector design, production, first operation, and ongoing development of the ToRA-based readout chain.

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1. Introduction

AMBER (NA66) [1] is a fixed-target experiment at CERN's M2 beamline in the EHN2 hall, fed by the Super Proton Synchrotron (SPS) and a production target that delivers $\mu^{\pm}$, $p^{\pm}$, $\pi^{\pm}$, and $K^{\pm}$ beams with momenta from 50 GeV/c to 280 GeV/c. The physics program for the approved phase-1 includes: antiproton production for indirect dark matter searches, a proton radius measurement (PRM), and pion/kaon parton distribution functions through the Drell-Yan process. A transition from a COMPASS-derived triggered DAQ [2] to a fully streaming architecture (AMBER FriDAQ) [3] is underway to support the medium and long-term program. Within this framework, we are replacing parts of the aging MWPC system with large-area Micromegas detectors and developing a dedicated, triggerless-capable front-end electronics.

2. Large-area Micromegas detector

2.1 Detector concept

To cover a total active area of $1.0 \times 1.5\ m^2$, the system consists of three staggered side-by-side modules to minimize dead zones between adjacent units [4]. Each module is an independent detector featuring two readout anodes facing a common central cathode. One readout plane features X-oriented strips, while the second consists of two layers implementing U- and V-oriented strips tilted by 10° with respect to the X direction. A 3D model of the lateral module and its exploded view are shown in Fig. 1. The green FR-4 frames act as the gas vessel and host suspension and alignment elements.

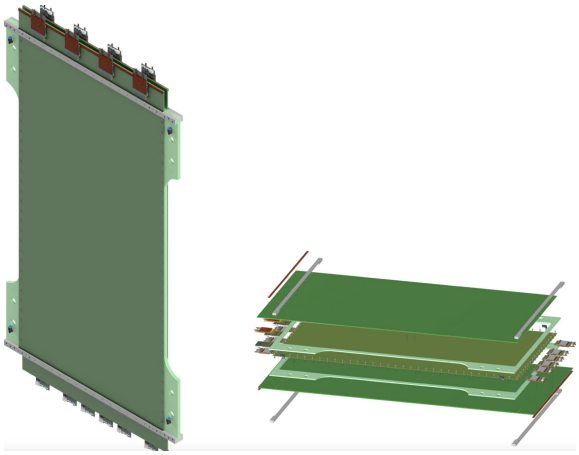

Figure 1: 3D model of the first prototype of the lateral module of the new large-area micromegas of AMBER experiment

2.2 First lateral module: design and production

Each readout plane is built on a 3.2 mm PCB with an external ground plane and an internal copper readout. The X anode uses 512 strips with 1 mm pitch and 750 µm width. The UV plane employs a two-layer copper structure (stackup in Fig. 2), with U-strips of 250 µm and V-strips of 80 µm arranged at a ±10° stereo angle relative to the Y axis (Fig. 3, 4).

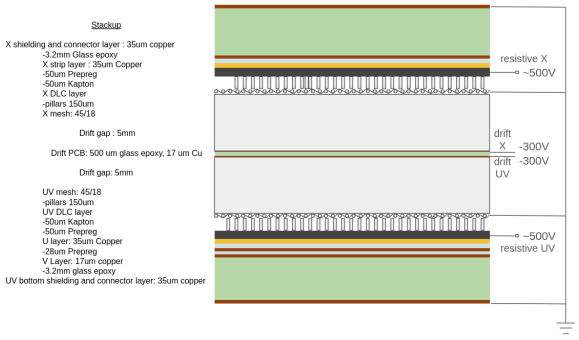

Figure 2: Lateral module stackup with dimension

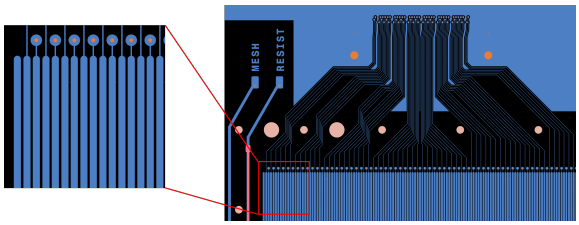

Figure 3: X plane strips

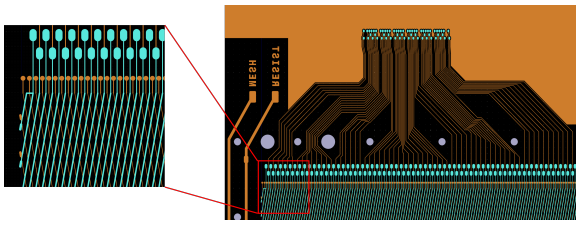

Figure 4: UV plane strips

To mitigate discharge effect in the Micromegas detectors, a uniform resistive layer made of Diamond-Like Carbon (DLC) foil with a surface resistivity of 10 MΩ is deposited on top of a thin insulating layer above the readout electrode. The readout is no longer directly exposed to the charge created in the amplification region; instead the signals are capacitively coupled to it. This configuration leads to a moderate reduction in signal amplitude and it enables stable detector operation at higher gas gains preserving the front-end (FE) electronics from damage.

A 18-45 stainless steel mesh is implemented with bulk technology, embedded in a photoresist polyimide film to maintain a uniform 150 µm amplification gap on the active surface. The first lateral module (Fig. 5) was fully assembled in October 2024 and tested with the beam using TIGER-based readout electronics [5].

2.3 High-voltage scheme and stability

We bias the resistive layer at the positive potential and the cathode at the negative, keeping the mesh at ground; the same configuration implemented in the ATLAS NSW system [6]. Stable detector operation was achieved with multiple gas mixtures: Ar–CO_2 70:30, Ar–CO_2 93:7 and

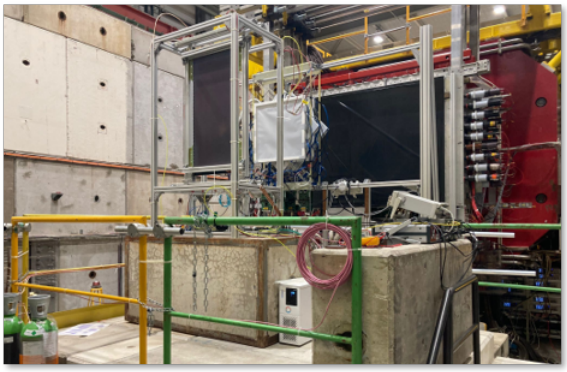

Figure 5: Test setup area downstream SM2

Ar–CO_2–iC_4H_{10} 93:5:2.

The leakage currents measured in the resistive layers remained below 15 nA, while the drift electrode current is below 1 nA.

This first prototype was tested with several grounding and shielding configurations to investigate and optimize the signal-to-noise ratio. This aspect is particularly critical for large-area detectors, where strip capacitance significantly influences the performance of electronic noise (Fig. 6).

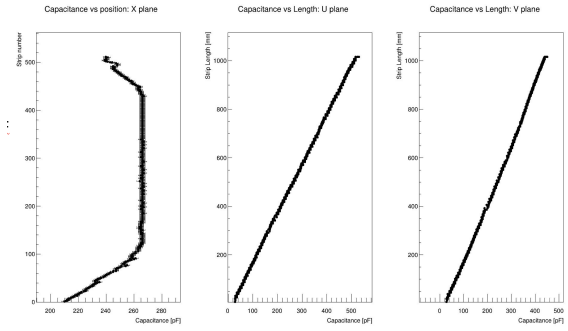

Figure 6: Measured strip capacitance. Left: capacitance versus strip number for the X-plane. Center and right: capacitance versus strip length for the UV-plane. X-strips show capacitance ranging from 210 pF to 250 pF, while UV-plane capacitance reaches up to 500 pF

3. Front-end electronics toward continuous readout

The new ASIC, named *Torino Readout for AMBER* (ToRA) [7], is a 64-channel front-end chip with a fully digital interface that operates at clock frequencies up to 200 MHz. This R&D activity focuses on the development of a new custom ASIC designed for Micromegas and wire chamber detectors, optimized for the operating conditions of the AMBER experiment. Performance enhancement was carried out using Garfield++ simulations.

The ultimate goal is to implement a unified and triggerless-compatible readout architecture across multiple detector technologies.

The analog front-end (Fig. 7) section consists of:

Table 1: Main characteristics and operating parameters of the lateral Micromegas module prototype.

Item/Parameter	**Value**
Mesh	Stainless steel, 400 wires/inch
Amplification gap	150 µm
Drift/conversion gap	5 mm
Resistive layer	DLC, R $\approx 10 - 20 M\Omega/cm$
Readout strip pitch	1 mm
Stereo angle (UV layers)	±10°
Total number of strips	1792
Gas	Ar:CO_2 70:30; Ar:CO_2 93:7; Ar:CO_2:iC_4H_{10} 93:5:2
HV on resistive layer	Positive polarity, up to 550 V
Amplification field	36.7 kV/cm
Drift field	600 V/cm

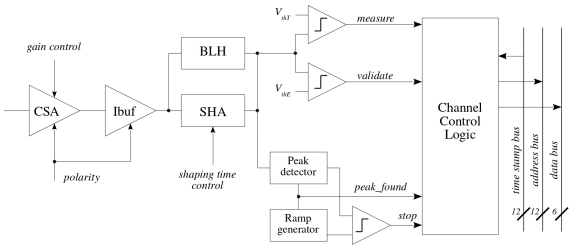

Figure 7: Block diagram of the front-end of ToRA ASIC

- a programmable charge-sensitive amplifier (CSA) with a current buffer to handle both input signal polarities,
- a third-order programmable shaper with adjustable shaping time,
- a discriminator stage implementing a dual-threshold signal detection architecture, complemented by a peak detector and peak-holder for Time-over-Threshold (ToT) measurements.

The digital back-end architecture is derived from the (Fig. 8) ToASt ASIC [8] originally designed in 110 nm CMOS technology and has been adapted for ToRA, which will be implemented using 65 nm TSMC CMOS technology. A common time-stamp is distributed across all 64 channels, each channel containing four data registers for time measurement and two configuration registers (Fig.7). The data output consists of one or two 32-bit words transmitted over 200 Mb/s serial links, with the option of operating in single- or dual-link mode. The stream of hit words includes headers and trailers that define time frames. The first version of the ToRA layout design is currently being finalized and submitted in May 2025.

4. Conclusions

We reported on the design and first operation of a large-area resistive bulk Micromegas module for AMBER and on the development of the ToRA front-end ASIC for triggerless readout. The

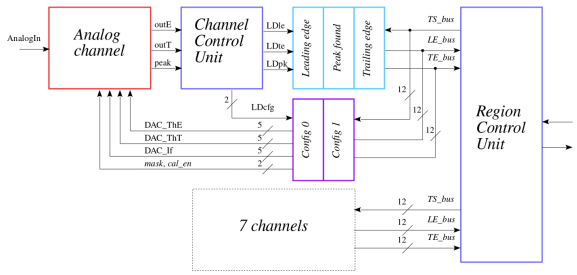

Figure 8: Block diagram of the back-end of ToRA ASIC

ongoing tests of the first lateral module will determine the design of the central one. The ToRA ASIC, produced in 65 nm CMOS, aims at unifying readout of the Micromegas and wire chamber detectors within the streaming DAQ paradigm [9].

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this paper.

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