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CyMBal : MPGDs for the ePIC detector at EIC

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R&D efforts are ongoing to develop the Cylindrical Micromegas Barrel Layer (CyMBaL) for the central region of the ePIC detector, the first experiment at the future Electron Ion Collider (EIC). The Micromegas detectors will be part of a multi-technology tracker located inside a 1.7 T solenoid, bringing stringent limits on space. Constraints on momentum reconstruction performances also impose a low-material budget in order to not degrade the measurements of detectors placed behind. As such, a light resistive Micromegas equipped with a 2D readout is needed. The R&D goal is to optimise the readout system to limit the number of channels while keeping a spatial resolution of about 150 μm.

The first prototypes for CyMBaL were designed to compare different readout patterns. This work presents the beam test of the prototypes at the MAMI facility in Mainz on a 880 MeV electron beam.

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[*] Speaker

1. The ePIC detector at EIC

The Electron Ion Collider (EIC) will be built at Brookhaven National Lab with the first beam expected around 2034. The goal of the facility is to probe nuclear matter and to study the strong interaction over a wide kinematic range. The EIC will be able to collide highly polarised electron and ion beams, with up to 70% beam polarisation at luminosities up to 10^{34} cm^{-2}s^{-1}. The collider will operate in a range of centre-of-mass energies, from 20 to 140 GeV in electron proton collisions. The first experiment to take data at the EIC will be ePIC, a large acceptance detector organised around a 1.7 T solenoid magnet with an inner diameter of 3 m and length of 5 m. The tracking system will fit inside the solenoid and will be made of multiple layers of high resolution silicon detectors close to the beam and two layers of MPGDs (Micro Pattern Gas Detectors) further out (fig. 1). The MPGD layers will provide a time resolution of the order of 10 ns, and they will be used to find the tracks in the silicon and for redundancy purposes.

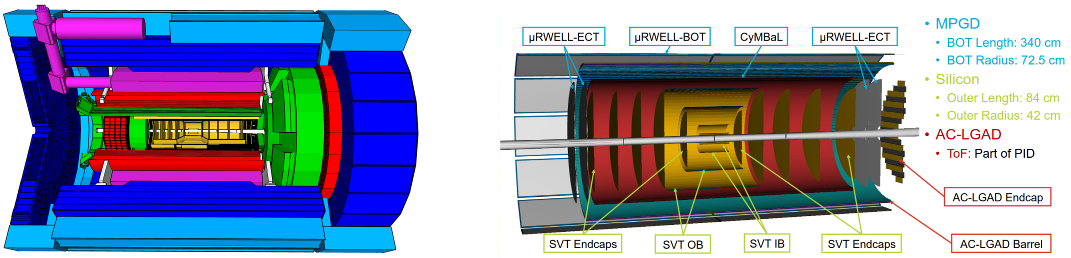


Figure 1: Left: Diagram of the ePIC detector. Right: Diagram of the tracking system inside the solenoid.

2. CyMBaL

The Cylindrical Micromegas Barrel Layer (CyMBaL) will be part of the MPGD system of ePIC. It is a single cylindrical layer of Micromegas detectors, 2.4 m in length and 55 cm in radius, built of overlapping curved tiles to cover the full barrel acceptance. Micromegas detectors are made of two gas volumes separated by a metallic mesh. A drift region above the mesh that is 3-5 mm thick where a low electric field is applied, and below the mesh a high field amplification region 128 μm wide (fig. 2). When a charged particle crosses the detector, it ionises the gas in the drift region, the electrons are then guided to the mesh by the field. Once in the amplification region, electrons gain enough momentum to start ionising the gas, creating electron avalanches which amplify the signal that is then collected on a readout layer.

The ePIC detector requires CyMBaL to have a spatial resolution of about 150 μm with a material budget below 0.5% X_0. The CyMBaL R&D is based of the CLAS12 barrel Micromegas detector [1] which is also made of cylindrical tiles and operates in a high magnetic field (5 T), withstanding particle rates ten times larger than the ones expected in ePIC. However, the CLAS12 tiles measure the 1D position of the track, requiring multiple detector layers to measure the 2D position. Therefore, the current R&D is focused on developing a 2D readout to satisfy the ePIC space and material budget constraints.

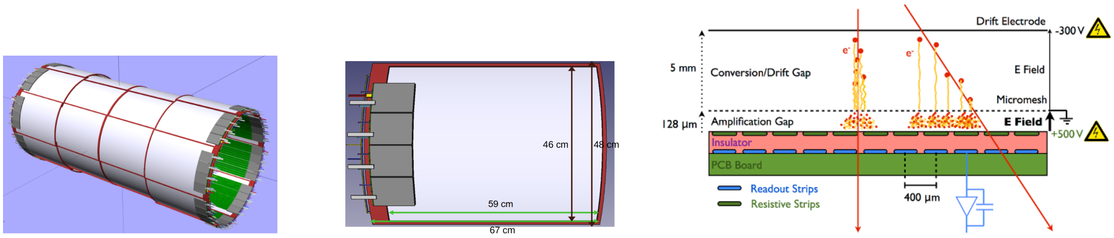


Figure 2: Drawing of the CyMBaL detector and of a single Micromegas tile. Right: Cross-section of the CLAS12 Micromegas tiles [1].

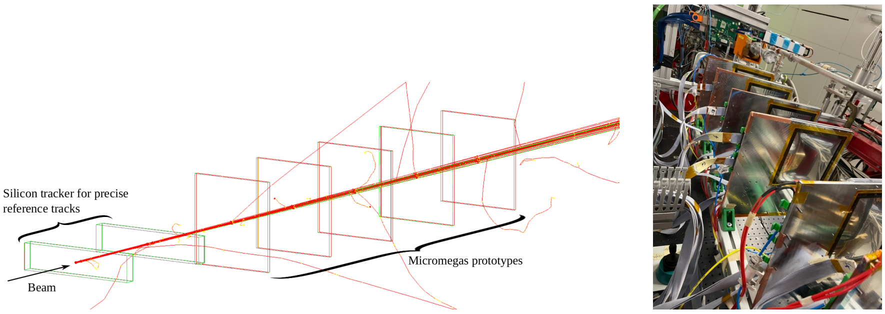


Figure 3: Beam test setup with the reference silicon detector closest to the beam pipe, and the prototypes behind. Left: Geant4 simulation of the setup. Right: Picture of the setup installed at MAMI.

3. Beam test at MAMI facility

The first prototypes for the CyMBaL project were build at the CEA-Saclay MPGD laboratory to test different readout designs. In June 2023 they were tested at the MAMI facility in Mainz with a 880 MeV electron beam. The beam test setup consisted of a high resolution reference detector close to the beam, then the prototypes, and downstream, a scintillator to trigger the data acquisition (fig. 3). The prototypes were read by DREAM electronic cards, the same used for the CLAS12 Micromegas detectors [1]. The reference detector is made of four layers of MAPS ladders from the ALICE MFT, equipped with ALPIDE sensors with $29 \times 27\ \mu\text{m}^2$ pixels, offering a good resolution to build reference tracks [2].

The prototypes are equipped with two different types of readout, each using a different strategy to achieve the same goal: measuring the 2D position of the track while keeping a limited number of channels in order to reduce the cost of the detector. For that reason they both rely on using two sets of readout strips, one in each direction, rather than pads.

3.1 Two plane strip readout prototypes

The readout for the D1 and D2 prototypes is made of three layers, a resistive layer (DLC of $\sim 10\ \text{M}\Omega/\square$) on top of two layers of orthogonal strips. Charges in the amplification gap induce a signal on the resistive layer that is then read out by the strips through capacitive coupling (fig. 4). There are two parameters to optimise in the design: the pitch, the distance between the centre of two adjacent strips, and the inter-strip, the size of the gap between strips on the top layer. The latter is essential to avoid screening the signal for the bottom strips. Prototype D1 has three different

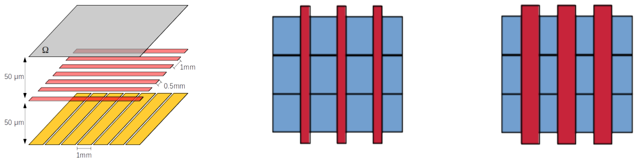


Figure 4: Left: Diagram of the 2D readout. Middle: D1 prototype with narrow top strips. Right: D2 prototype with wide top strips.

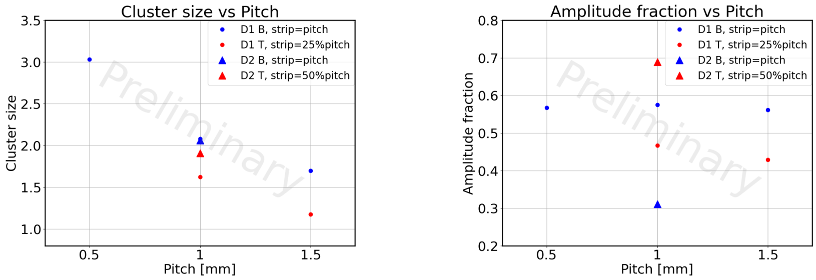


Figure 5: Cluster size and amplitude fraction of D1 and D2 prototypes. B and T stand for bottom and top strips respectively.

pitches (0.5, 1, 1.5 mm) for the top and bottom strips with the top strips covering 25% of the pitch, whereas D2 has a fixed pitch at 1 mm and a 500 μm inter-strip on the top strips (50% of the pitch).

Hits in the detectors are recorded if the signal amplitude on a strip exceeds a threshold of 5σ above the noise. Then hits on adjacent strips in a given direction are put together to form clusters, with the position of the cluster computed as the average position of all strips in the cluster weighted by their signal amplitude. Then, the largest clusters in each direction are associated to find the 2D position of the track. In the rest of the analysis, events are only considered if the 2D position is less than 2 mm away from the reference track in order to remove any noise.

The average number of strips in a cluster (cluster size) is found to increase as the pitch decreases as expected (fig. 5), but the wide bottom strips for D1 have a significantly larger cluster size than the narrow top strips. On the other hand, the D2 prototype with wider top strips has a more uniform cluster size between the two layers.

To measure how evenly the signal is shared between the two layers, we look at the average cluster amplitude fraction. It is defined as the signal amplitude collected on one layer divided by the total amplitude summed on both layers, and we aim for a fraction of 0.5 to have a similar behaviour on each layer. In D1 the bottom layer is carrying a higher fraction of the charge, but the difference doesn't exceed 15 %pt. Whereas in D2 the top layer is carrying about 70% of the charge due to the larger top strips being both able to collect more charge, and screen more of the signal for the bottom strips (fig. 5).

The charge sharing and cluster size evenness should be improved in future prototypes by choosing an inter-strip between D1 and D2, a detector with top strips covering 33% of the pitch is currently being tested.

Figure 6: Diagram of the interconnected pad design, on the left prototype D3 with the strip resistive pattern on top of the readout, and on the right D4 with the full resistive layer.

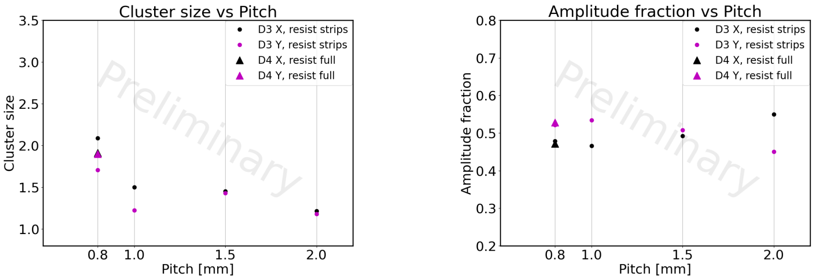


Figure 7: Cluster size and amplitude fraction of D3 and D4 prototypes. X and Y are the two strip directions, for D4 Y strips run along the resistive strips.

3.2 Interconnected pad readout prototypes

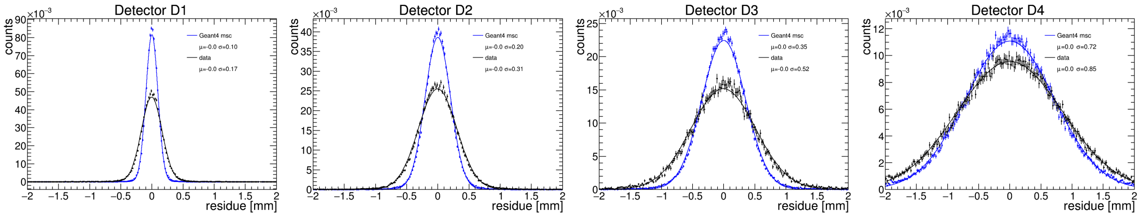
Prototypes D3 and D4 use a different readout strategy, they have a single layer of square pads interconnected to form strips, both detectors have regions with different strip pitch ranging from 0.8 mm to 2 mm. D3 has a full resistive layer on top of the readout and D4 has resistive strips running in the Y direction (fig. 6). The resistivity used is of the order of 300 MΩ/□.

The average cluster size is smaller on the interconnected pad design than with D1 and D2 for the same pitch because of the difference in readout patterns. Only the smallest pitch at 0.8 mm can come close to an average cluster size of 2 (fig. 7). The X direction strips in D3 have a larger cluster size than the Y direction strips because the charges are able to spread along the resistive strips in the Y direction reaching more X strips.

D3 and D4 both have uniform charge sharing between the two directions because they are on the same layer avoiding any screening effect. The Y direction strips carry a slightly higher fraction because the pads are connected over the board whereas the X direction strips are connected with vias under the board, which makes the surface of the Y direction strips larger.

3.3 Residues

The resolution of the prototypes can be estimated from the residues, defined as the difference between the position of the reference track extrapolated to the prototype and the position measured on the prototype. Figure 8 shows the residues for each prototype, all measured in a region with 1 mm pitch strips. The width of the distribution increases rapidly as we get further away from the reference detector situated at $z = 0$ mm. That is clear evidence of multiple scattering, the beam electron is scattered between the reference tracker and the detectors. To evaluate this contribution, we perform a Geant4 [3] simulation of 880 MeV electrons crossing the beam test setup, and compute the residues not smeared by the detector resolution. We find that multiple scattering is the



z = 305 mm z = 425 mm z = 545 mm z = 785 mm

Figure 8: Residue distributions on 1 mm strips for all four prototypes, the multiple scattering contribution estimated with Geant4 is overlaid in blue.

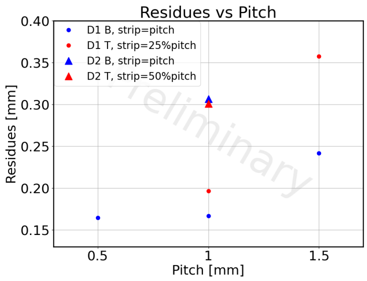


Figure 9: Residues as a function of the pitch for prototypes D1 and D2. The Geant4 estimated multiple scattering contribution is 96 μm for D1 and 205 μm for D2.

dominant contribution to the residues, especially for the D3 and D4 prototypes, therefore we can only accurately estimate the resolution of D1 and D2.

Figure 9 shows prototypes D1 and D2 residues as a function of the pitch, D1 with a 1 mm or smaller pitch is able to meet the ePIC requirements, but top strips offer a worse resolution than bottom ones. The D2 prototype with the wide top strips has a smaller difference in resolution between the two directions, which suggests that a prototype with an inter-strip size in between D1 and D2 will provide a more uniform resolution.

4. Conclusion

The first prototypes for the CyMBaL detector in the ePIC experiment have been tested at the MAMI facility in Mainz. The results show that the 2D readout with a resistive layer is a viable solution to achieve the project goals. Further testing is ongoing at CEA Saclay to explore more resistive layer patterns and to measure precisely the prototypes resolution using cosmic muons.

References

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[2] *Technical design report for the muon forward tracker*, *CERN-LHCC-2015-001, ALICE-TDR-018* `https://cds.cern.ch/record/1981898` (2015) .

[3] GEANT4 collaboration, *GEANT4-a simulation toolkit*, *Nucl. Instrum. Meth. A* **506** (2003) 250.