

Micromegas testbeam data analysis and VMM3a chip testing for the New Small Wheel upgrade of ATLAS

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Abstract

This Summer Student project at CERN revolved around the Micromegas gaseous detector for the New Small Wheel upgrade of ATLAS for the High-Luminosity LHC. During July and August, data obtained from the setup at the North Area testbeam were analysed, for muon and pion runs. The resolutions from the Micromegas precision planes as a function of the high voltage applied on the planes were obtained, and the effect of various analysis techniques on these resolutions was studied. Moreover, validation tests were carried out on the VMM3a chips that will be mounted on the frontal electronics (MMFE8) boards of the detector; while most chips showed good behaviour, some exhibited undeniably problematic activity under testing conditions.



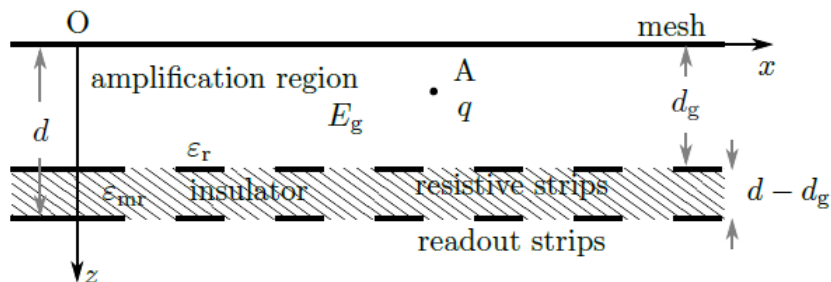
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1 Introduction

The LHC is constantly being upgraded to reach ever higher instantaneous luminosities, in order to accumulate ever more physics data for analysis. It is expected that, after the 2019-2020 long shutdown, the LHC during Run 3 will provide $L = 2 - 3 \times 10^{34} \text{cm}^{-2} \text{s}^{-1}$; after the Phase II upgrade, instantaneous luminosity could reach up to $5 \times 10^{34} \text{cm}^{-2} \text{s}^{-1}$ [1], with 140 pileup events at $\sqrt{s} \geq 7$ TeV. It follows that there will be a multitude of particles whose trajectories lie in the forward region of the detector: the New Small Wheel is designed to replace the existing Small Wheel in the forward region of ATLAS, so that exiting particles in that region may be detected. Of particular interest are any muons leaving the interaction point, since they are in general hard to detect.

The Micromegas gaseous detector exploits the fact that muons are charged particles, and thus may ionise any medium they travel through. A gas mixture (typically Ar and CO_2), which can produce electrons from ionisation by interaction with a charged muon, is introduced in the detector; the resulting ionisation electron then drifts towards a micromesh, accelerated by a voltage difference between the drift electrode and the micromesh. Once the electron enters the amplification gap, a further high voltage difference between the micromesh and resistive strips creates an avalanche of electrons, which induces a signal in the readout strips of the detector [2]. This signal is shaped, and then read out from the detector by means of the VMM chips on the frontal electronics boards (MMFE8), which are mounted on the detector planes (8 VMM chips for every MMFE8 board).

Figure 1: Schematic of the amplification gap of a Micromegas detector[2]



Thus, the charged particle moving through the gaseous detector creates a signal which can be translated into clusters of strips which responded to the track; from the positions of these clusters in the Micromegas planes, the track of the original ionising particle can be reconstructed. The New Small Wheel will therefore incorporate Micromegas detectors in its sectors.

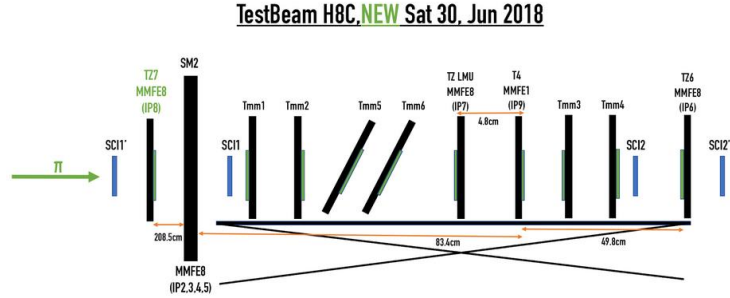
Naturally, the study of spatial resolutions yielded is interesting from both a physics and a technology perspective, as it allows us to determine how reliably a Micromegas detector can reconstruct the track of a charged particle coming

through, as well as to explore whether or not it can distinguish different particle species of the same charge that pass through it, and can thus provide data that contribute to particle identification. Also of considerable interest is the validation of the components of the readout chain, especially the VMM chips: these two tasks formed the bulk of the present summer project.

2 Testbeam data analysis

The experimental setup at the July testbeam consisted of the SM2 Micromegas module, as well as external tracking planes TZ-6, TZ-LMU, TZ-7 (which are themselves gaseous detectors from which data can be extracted via the readout chain). The SM2 module itself is made up of four planes, each of which is filled with an Ar/CO₂ mixture; the mixture in our case is 93% Ar - 7% CO₂. Two of these planes (the U and V planes, or stereo planes) have their strips rotated about the longitudinal (beam) axis, forming an angle with the horizontal axis of $+1.5^\circ$ and -1.5° respectively; the other two (the η and η' planes, or precision planes) have their strips oriented along the horizontal axis. It is the precision planes that yield, typically, better resolutions, and as such the data from these two planes were analysed. Each run varied in a number of parameters; for the analysis carried out in the scope of this project, the free parameters were the high voltage (HV) applied on the precision planes for the amplification gap, as well as the particle species of the beam (muon beam at 120 GeV or pion beam at 180 GeV). The VMM chips provide, for every run, the indices of the strips on which a charge greater than a certain cutoff pedestal was induced, as well as the charge induced on these strips.

Figure 2: Drawing of the setup (distances not to scale)



From these raw data, one can organise the strips into clusters, whose positions can be calculated. From there, once clusterisation has yielded cluster positions on all 5 planes (the three external tracking planes and the two SM precision planes), we implemented the Hough transform that reconstructed the incoming particle track. The reconstructed track was verified to be correct in multiple different events. Then, we picked the cluster on each plane that was

closest to the intercept of the reconstructed track as the "representative" of that plane, to do analysis with. Applying two different methods to extract spatial resolutions as a function of Micromegas strip voltage, one for single-plane resolutions (the geometric mean method) and one for dual-plane resolutions (comparing the cluster positions on SM- η and SM- η'), we found that the resolutions obtained by the Micromegas detector depend primarily on the profile of the incoming beam, more so than the particle species *per se*.

Single-plane resolutions were in the order of $100 - 140\mu m$, and dual-plane resolutions in the order of $65 - 90\mu m$. It was discovered that, given a similar beam profile, pion and muon beams yield practically the same resolutions; interestingly, the pion beam of our run series had had its profile much worsened by interacting with a sheet of metal, placed between our setup and the incoming beam by one of the other groups of the North Area (our group was not a primary user of the testbeam). Thus, it was shown that the pion beam runs contained significantly "noisier" (i.e. higher cluster multiplicity) events than those of the muon beam runs, and the fraction of clean to noisy events was determined in both pion and muon beam runs as a function of the strip voltage. Indeed, pion beam runs only had around 50–55% clean events total, as opposed to the muon beam runs' 70–75%, which indicates that the pions (which are mesons) produce hadronic showers upon interacting with the metal sheet, whereas muons (which are leptons) don't.

Running analysis on a pion beam run taken at 570 V strip voltage from before the metal sheet was installed, we noticed a significant drop in dual-plane resolution to $47 - 49\mu m$, much better than that of the muon beam: this is to be expected, since the pion beam in question was much better collimated. Moreover, the percentage of clean events of the run in question was 80%, confirming our suspicion that the worse resolutions we were seeing was indeed a result of the pion beam interacting with the metal sheet.

Further analysis for various tilts of the SM2 module and more pion/muon runs remains to be undertaken: nevertheless, we have arrived at a series of conclusions which suggest that the Micromegas SM2 precision planes' spatial resolutions lie at a level consistent with the profile of the incoming beam. The ROOT source code that was developed is fully functional, successfully extracting the desired resolutions and plots from raw VMM data; obviously, more work can be done to expand the code's scope, such as including data from the SM2 stereo planes.

3 VMM3a testing

In the second part of this project, a number of VMM3a chips were brought to the Electronics Lab at building 188 to be tested for dead channels and unusual baselines: a functional chip must have no dead channels (for obvious reasons) and baselines tightly clustered around a mean value that is the same for all channels, so that PDO (charge) data from the chip are reliable.

The VMM chip is placed in a board, which is then connected to a voltage

Figure 3: Beam profiles of muons (up) and pions (down) in analysed runs with metal sheet, at strip voltage 570 V

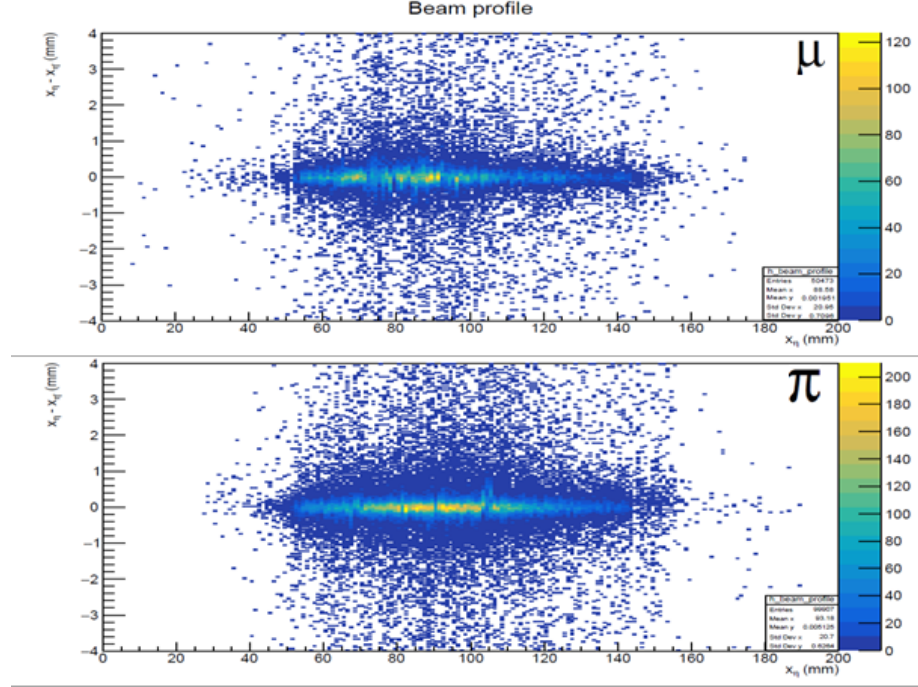


Figure 4: Percentage of events that yielded one cluster on SM- η and one on SM- η' . Pion runs magenta, muon runs yellow.

Retained events in single-cluster analysis, μ vs π

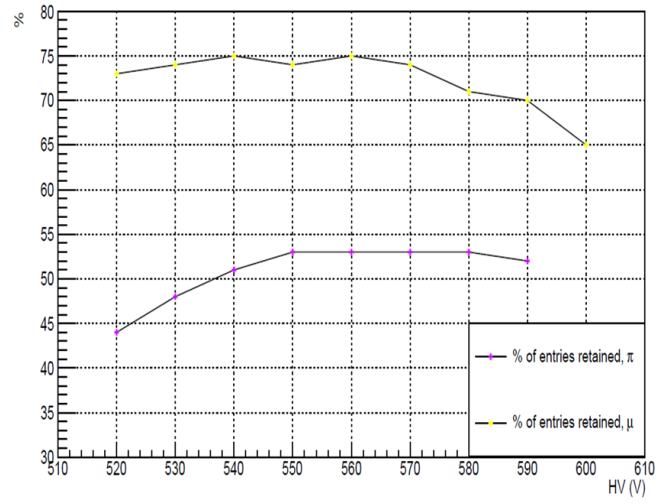
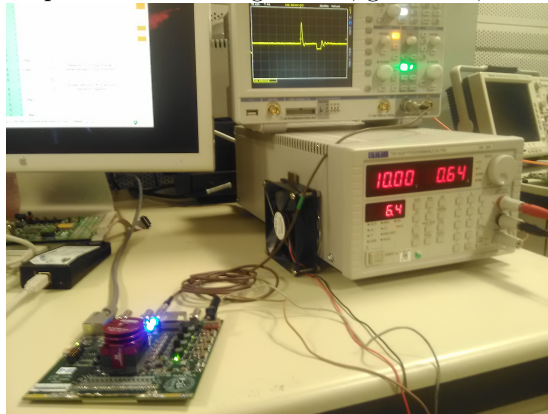


Figure 5: Setup for VMM testing: board, generator, and oscilloscope.



generator, an oscilloscope (for analog monitoring of the test pulses) and a PC where the analog pulser software is installed. By modifying the registers in this software, one can control the pulse height, width, period, and number, as well as enable/disable or mask channels, and specific types of output.

In order to be considered functional, the chip must be configurable, i.e. respond to changes in the pulse settings or the global VMM registers modified in software; typically, a non-functional chip would not produce any output on the oscilloscope when a run was being carried out and ACQ was ON. Moreover, the chip's current draw (displayed on the generator) must not exceed 1.1 A; lastly, the oscilloscope output must not produce any oscillations when the VMM is configured; oscillations imply that the VMM, which is an Application Specific Integrated Circuit (ASIC), does not work properly (some part of the circuit is not functioning as it should).

We carried out channel and baseline tests on a good number of VMM chips, and retrieved the output in the form of plots; ROOT histograms in the case of channel data and pdf files in the case of baselines. The number of baseline deviations and the indices of any dead channels were then recorded, and the statistics of which chips were accepted for use, accepted for conditional use, or rejected were compiled. We noticed that, while most chips behaved remarkably well with at most 1 or 2 dead channels and 1 or 2 baseline problems, there were some that exhibited troublesome behaviour, with as many as half of the channels dead and a tendency to show abnormally high baselines for higher channel indices. This is a problem that our group had seen in previous generations of the VMM chip, and we noticed that these problematic VMMs were part of the same range of serial numbers: we conclude that there must have been some problem with their manufacturing. In any case, most of the VMMs we tested turned out to be suitable for use, at least conditionally.

Figure 6: Channel output of a VMM3a chip: channel 54 is dead.
channel

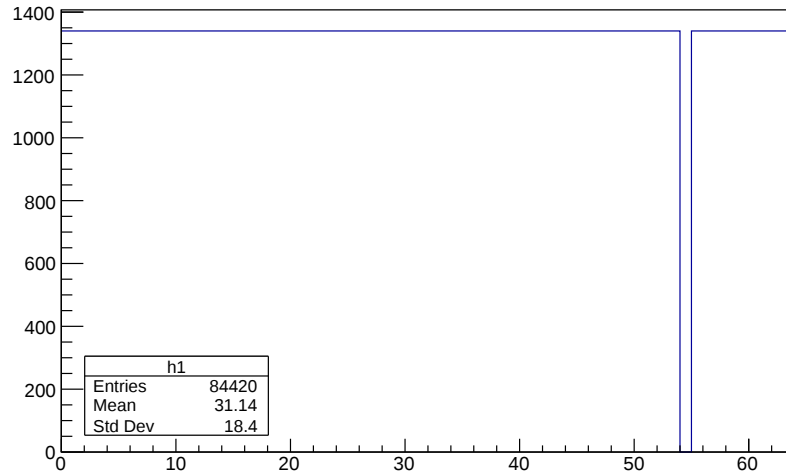
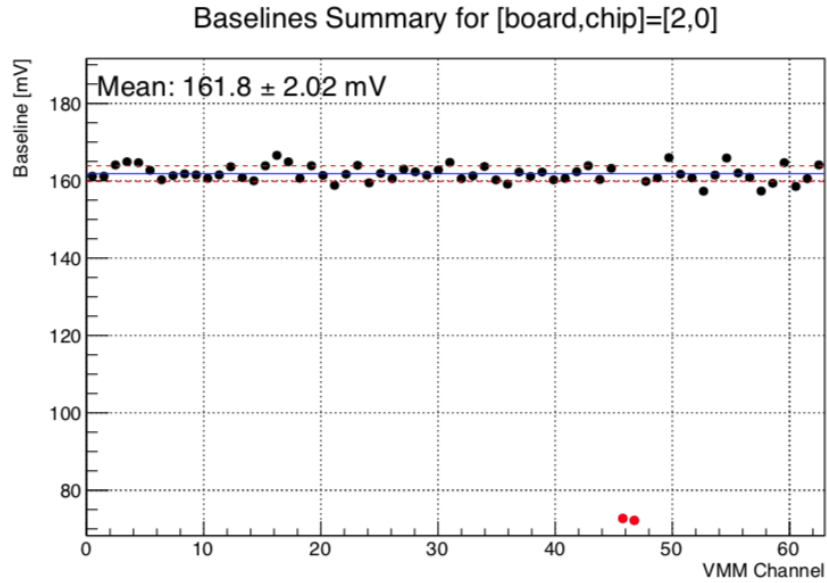


Figure 7: Baselines of a VMM3a chip: channels 46, 47 are showing baseline problems



References

- [1] ATLAS Collaboration. “New Small Wheel Technical Design Report”. In: *CERN-LHCC-2013-006* (2013).
- [2] M. Dris and T. Alexopoulos. “Signal Formation in Various Detectors”. In: *ArXiv e-prints* (June 2014). arXiv: 1406.3217 [hep-ex].