PROCEEDINGS OF SCIENCE

TIGER/GEMROC: a Versatile and Modular Readout System for Micro-pattern Gaseous Detectors

Stefano Gramigna[a,b,*] **on behalf of the CGEM-IT working group**

[a] *Ferrara Division, National Institute for Nuclear Physics, Via Giuseppe Saragat 1, Ferrara, Italy*

[b] *Department of Physics and Earth Science, University of Ferrara, Via Giuseppe Saragat 1, Ferrara, Italy*

E-mail: gramigna@fe.infn.it

TIGER/GEMROC is a new scalable readout system developed for the CGEM-IT, a novel cylindrical GEM detector designed to replace the inner drift chamber of the BESIII experiment in its upcoming upgrade. The versatility of the system allows it to read other MPGDs with GEM-like signals and seamlessly interface with the many subsystems of a modern physics experiment. The entire system revolves around the TIGER chip, a new 64-channel mixed-signal ASIC capable of simultaneous charge and time measurements, and GEMROC, an FPGA-based off-detector module controlling the chips and managing the data flow during the acquisition. This paper provides an overview of the system and presents the first preliminary results of a test beam with 80 GeV muons on the H4 line at CERN to validate the performance of the readout chain.

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*Speaker

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1. Introduction

The TIGER/GEMROC readout chain was developed to provide the Cylindrical GEM Inner Tracker (CGEM-IT) with a fast, modular readout system for the upgrade of the BESIII experiment at BEPCII [1]. Despite being designed for the typical signals produced by a GEM detector [2], the system is versatile enough to read other kinds of MPGDs having similar signal characteristics. The TIGER/GEMROC readout chain has already been tested on MicroMegas [3] and in the near future it will be used in a test beam for reading micro-RWELL detectors.

2. The TIGER/GEMROC Readout chain

The two cornerstones of the system are the Torino Integrated GEM Electronics for Readout (TIGER) [4], a new ASIC with 64 channels capable of performing simultaneous charge and time measurements, and the GEM Readout Card (GEMROC) [5], an FPGA-based module responsible for configuring the TIGERs and managing the data flow coming from the chips. In a typical application, the TIGERs are mounted in pairs on the Front-End Boards (FEBs), which are directly connected to the detector. Each GEMROC module can handle up to eight TIGERs and serves as an interface to the Low Voltage (LV) power supply, to the computer used for the acquisition, and to the other subsystems of the experiment. The entire system is controlled from the acquisition computer through Ethernet connections using the Graphical User Frontend Interface (GUFI) [6] software, a suit of python scripts for configuration, control, and diagnosis of the chips.

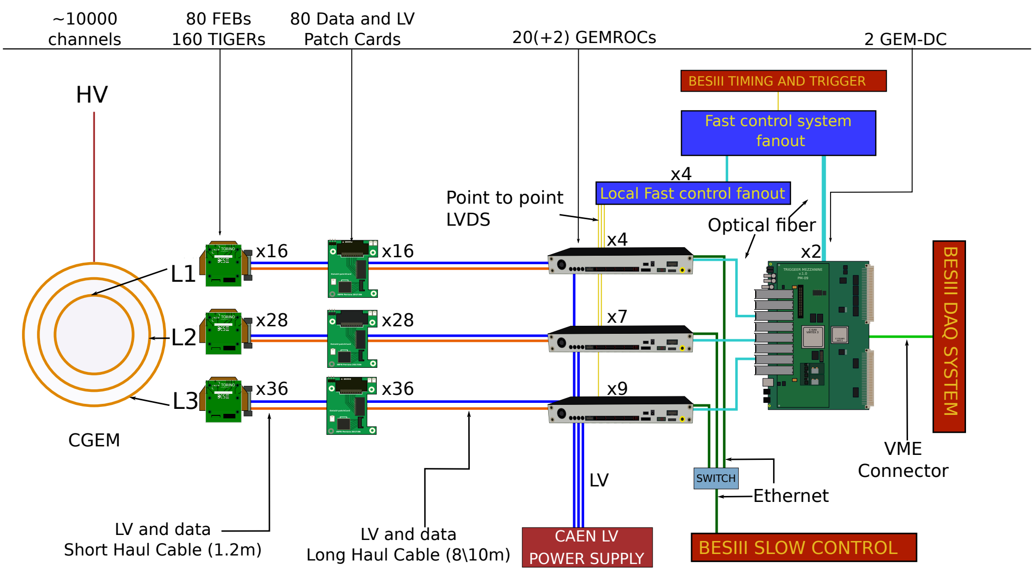


Figure 1: Complete scheme of the CGEM-IT readout chain [5]

Thanks to its modular design, the system can be easily expanded to read a large number of channels while the numerous connectivity options of the GEMROC allow a variety of external systems to be easily connected. Figure 1 shows a realistic TIGER/GEMROC application: the full readout chain of the CGEM-IT [5]. This system will consist of 80 FEBs, 22 GEMROCs and 2 data concentrator modules (GEM-DC), which are necessary to interface with the BESIII DAQ system but not required for standalone operation. The complete readout chain will be able to read the about 10000 channels of the three layers of the CGEM-IT, handle rates of 60 kHz/channel, and interface with the different BESIII subsystems through LVDS, fiber optics, and Ethernet connections.

2.1 On-detector Electronics: TIGER

TIGER is a mixed signal ASIC capable of simultaneous time and charge measurements. The chip is fabricated in 110 nm CMOS technology and its digital logic is protected against single-event upset. TIGER is designed to operate with an input capacitance of up to 100 pF while maintaining a noise level lower than 1800 electrons ENC [4].

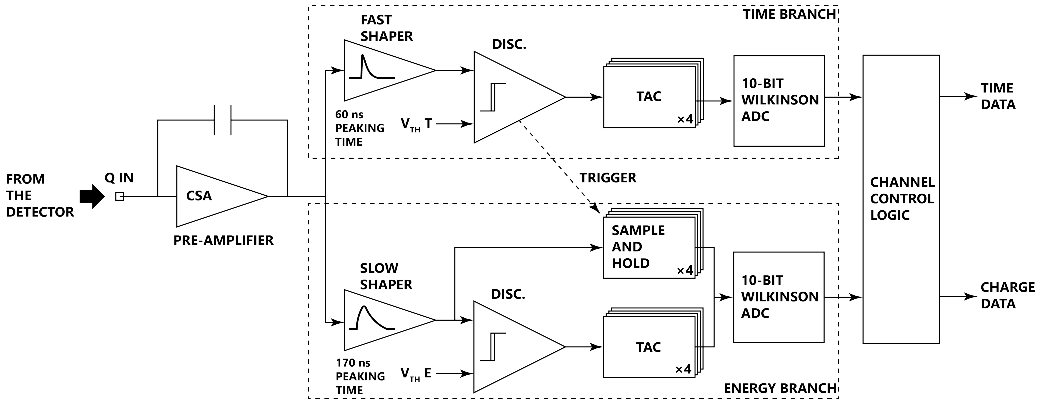


Figure 2: Scheme of a TIGER channel

Figure 2 is a schematic representation a TIGER channel. The current signal from the detector is amplified by a charge sensitive amplifier (CSA), split, and fed to the two branches for time and energy measurements. Both branches feature a shaper, a discriminator and a TDC based on analog interpolation. The peaking time of the fast shaper was set to 60 ns to match the charge collection time of the sensor, thus allowing a measurement with low jitter. The shaper on the energy branch, with a peaking time of 170 ns, provides flatter peaks that are better suited for charge integration by the Sample and Hold (S&H) circuit uniquely present on this same branch. Charge can also be measured by the time over threshold (ToT) method, trading the loss of linearity for the ability to measure above the S&H saturation limit of about 50 fC. The thresholds on each branch can be set independently and they allow TIGER to operate without an external trigger. Once the measurements are performed, digitized data is transmitted off-chip to the GEMROC through 2 LVDS links in single data rate mode.

2.2 Off-detector Electronics: GEMROC

Each GEMROC consists of a commercial FPGA development kit of the Intel/ALTERA ARRIA V GX family and a custom interface card. The modules manage the data flow from the TIGERs towards the acquisition computer. When operating with an external trigger, in trigger-matched mode, the GEMROC receives the trigger signal and parses the continuous data stream into the events to be transmitted and stored, while in trigger-less mode, the GEMROCs forward the entire data stream to the acquisition computer. GEMROCs also carry out a series of other tasks like distributing the voltage levels to supply both the analog and digital power domains of the TIGERs, configuring the chips prior to their operation, and monitoring their currents and temperatures while they are collecting data.

3. Validation

To validate the performance of the readout chain, a test beam of 80 GeV muons was conducted on the H4 line at the CERN North Test Area in July 2021. A TIGER/GEMROC system was employed to read four triple-GEM planar test chambers filled with an $Ar : iC_4H_{10}$ gas mixture in a 90 : 10 ratio. This particular mixture was chosen for the operation of the CGEM-IT to increase avalanche spread and, therefore, improve cluster size and spatial resolution. The analysis of the data was performed using the CIVETTA (Complete Interactive VErsatile Test Tool Analysis) [6] software, which also provided real-time data validation during the data collection. Runs were also taken using a standard APV25/SRS readout chain to benchmark the analysis and have a comparison with previous results [7].

Both the charge and size of the clusters follow the expected behavior. At an angle of incidence of 0°, the two quantities increase with the voltage applied to the GEM electrodes as a result of the larger gain. At larger angles of incidence in the tilted view the avalanche can cover many more strips, increasing the cluster size as shown in fig. 3, while in the non-tilted view the increase is less pronounced and due to the longer path travelled by the particle within the drift region. For this same reason there is also a slight increase in the cluster charge for both views.

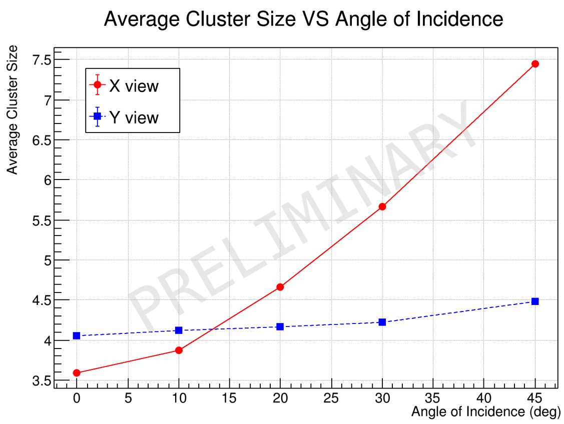
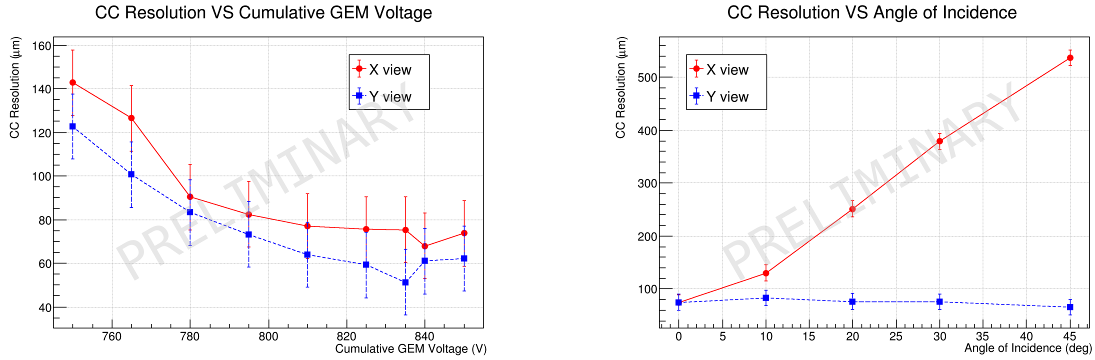


Figure 3: Average cluster size as a function of the angle of incidence with respect to the X view. All the data points in the plot were collected at 835 V cumulative GEM voltage.

The spatial resolution, calculated from the position reconstructed through the Charge Centroid (CC) method, improves with the voltage applied to the GEM electrodes, as shown in fig. 4a, reaching values better than 80 µm at voltages above 810 V. Figure 4b shows another expected difference in the behavior of the two views: the resolution in the non-tilted view remains stable, while in the tilted view it degrades quickly when increasing the angle of incidence due to the poor accuracy of the CC method at large angles. The implementation of µ-TPC algorithms, which are being adapted for the use with the TIGER/GEMROC system, was proven successful in the past to overcome the shortcomings of the CC method and provide good resolution even at larger angles [7].



(a) **(b)**

Figure 4: Behavior of the spatial resolution as a function of the cumulative voltage applied to the GEM electrodes at 0° angle of incidence, on the left, and as a function of the angle of incidence at a cumulative GEM voltage of 835 V, on the right.

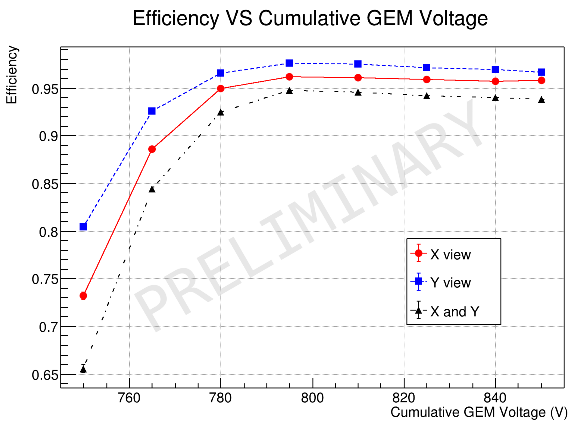


Figure 5: 5σ efficiency as a function of the cumulative voltage applied to the GEM electrodes. All the data points were collected at 0° angle of incidence.

The efficiency was calculated by considering the Detector Under Test (DUT) efficient whenever the reconstructed position falls within 5 standard deviations of the exclusive residuals distribution from the expected position. The exclusive residuals distribution is obtained by excluding the DUT, tracking the particle using the position of the clusters in the other three chambers, and then considering the deviation between the expected position and the measured one in the DUT. The behavior of the 5σ efficiency as a function of the cumulative GEM voltage is represented in fig. 5 and reaches values above 97% for a single view and around 95% when requiring both views to be efficient at the same time.

The observed efficiency losses are attributable to noise spikes generating a large number of low charge hits close in time that saturate the buffering capabilities of the GEMROC modules, and the production of delta rays that travel parallel to the drift region and generate a large number of ionizations along their path. While delta rays are an unavoidable noise source for this kind of detectors, the noise spikes are being addressed by improving the grounding configuration and boosting the buffering capabilities of the GEMROCs.

4. Conclusions

TIGER/GEMROC is a modular, scalable readout system that was designed for GEM detectors but is flexible enough to read similar MPGDs. The system can perform simultaneous charge and time measurements at rates above 60 kHz/channel and provides many connectivity options for interfacing with the different subsystems of a physics experiment. The performance of the readout chain when used to read planar GEM detectors was validated through a test beam of 80 GeV muons, where the cluster charge and size showed the expected behavior as a function of both the HV settings and the angle of incidence of the beam. A resolution of about 60 µm was achieved at 0° angle of incidence, where the CC method used for the reconstruction of the cluster position performed best, while µTPC algorithms are still being implemented to assess resolution at larger angles. The 5σ efficiency for a single view reaches values above 97% while the 2D efficiency is about 95%. Known sources of inefficiency impacting the results are being addressed via grounding and firmware optimizations.

Acknowledgments

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