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DEVELOPMENT OF A NEW CLUSTERIZATION METHOD FOR THE GEM-TPC DETECTOR

M. Luoma*[1], F. García, T. Grahn[1], A. Jokinen[1], R. Turpeinen, J. Äystö[1]
Helsinki Institute Of Physics, Helsinki, Finland
S. Rinta-Antila, University of Jyvaskyla, Jyvaskyla, Finland
T. Blatz, H. Flemming, K. Götzen, C. Karagiannis, N. Kurtz, S. Löchner
C. Nociforo, C.J. Schmidt, H. Simon, B. Voss, P. Wieczorek, M. Winkler
GSI, Darmstadt, Germany
D. Chockeli, Georgian Technical University, Tbilisi, Georgia
[1]also at University of Jyvaskyla, Jyvaskyla, Finland

Abstract

The GEM-TPC detector in a twin field-cage configuration will be used as one of the Super-FRS particle identification detectors. It aims to provide the position information at up to a 1 MHz counting rate, with a position resolution less than 1 mm, and with close to 100 % tracking efficiency. In a single field-cage configuration, the GEM-TPC was tested at the FRS with a newly integrated AWAGS ASIC readout electronics, with a uranium beam at 850 MeV/u. The obtained results show that the new clusterization method developed for the analysis works on an event-by-event basis. The spatial resolution of 0.80 - 0.82 mm and cluster strip multiplicity of 14.3 - 8.6 strips were obtained for digitization with a decreased number of bits, starting from 13 bits which was the original number of bits during data taken, and then applying software conversion to 8 and 4 bits. The presented paper describe the methodology followed to reach such results in detail.

INTRODUCTION

Superconducting FRagment Separator (Super-FRS) [1] will be an extremely powerful in-flight magnetic separator for producing, separating, and delivering high-energy radioactive beams. It will be one of the main parts of the Facility for Antiproton and Ion Research (FAIR) [2] at GSI in Darmstadt, Germany.

In the future, the tracking at the Super-FRS will be done in an event-by-event basis by Time Projection Chambers (TPC) with a Gas Electron Multipliers (GEM-TPC) in a twin field-cage configuration [3] to cope with the high particle rate. The GEM-TPC in twin configuration will provide position information of traversing particles.

The twin GEM-TPC includes two single GEM-TPCs inside the same vessel, with one of them rotated 180 degrees with respect to the other in such a way that the electric fields of the field-cages are in opposite directions (see Figure 1). The GEM-TPC detector consists of a field cage and Gas Electron Multiplier (GEM) [4] stack, a pad plane, and readout electronics.

It is required at the Super-FRS that such tracking detectors have a position resolution <1 mm, dynamic range suitable for particles from protons up to uranium, and tracking efficiency >95 %.

In the present in-beam test, the GEM-TPC prototype in the single field-cage configuration [5] was tested with a newly integrated Low Noise Amplifier With Adaptive Gain Settings - (AWAGS) ASIC [6] readout electronics. One of the goals was to test a newly developed clusterization method for its data analysis, which can be integrated into the analysis framework of future experiments. The following chapters describe the experimental setup, the clusterization method, and the results of the data analysis for different digitization of the signal amplitude.

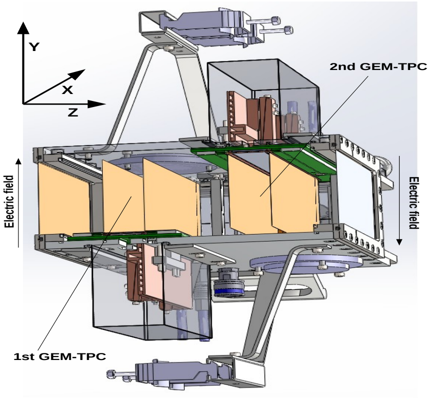

Figure 1: The layout of the GEM-TPC detector in the twin field-cage configuration.

EXPERIMENTAL

The setup of the present in-beam test included a plastic scintillator for triggering, thus setting the starting time of each event, and two conventional Time Projection Chambers (TPC) [7] used as reference trackers. The whole setup was located at the final focal plane S4 of the GSI FRagment separator (FRS) [8].

The primary beam used was ^{238}U at 850 MeV/u, with a varied intensity of 100 - 1k ions/s and with a spill length of 2 s to 8 s. The detector was filled with P10 gas (90% Ar, 10% CH4), and the electric field strength varied from 90 V/cm to 320 V/cm.

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* mianmalu@jyu.fi

The GEM-TPC readout plane consists of 512 strips in parallel with the incoming beam. The signals generated by the GEM-TPC were read out by the AWAGS and passed to the FEBEX3b digitizers [9]. The FEBEX3b ADC uses 14 bits to cover the whole dynamic range from 16 channels at up to a 50 MHz sampling rate. Fourteen-bit data digitization corresponds to 16384 ADC counts, but since the signals generated by the GEM-TPC are of a single polarity, the resulting conversion has a maximum of ADC counts of 8192 i.e., effectively having 13 bits for the data digitization.

DATA FLOW AND ANALYSIS METHOD

The collected signals from the GEM-TPC were saved as waveforms. Figure 2 (left) shows an example of the recorded waveform with 1000 samples. The signal amplitude was extracted from the difference between the baseline and signal samples together with its time of arrival at a threshold. The next step was to merge the signals with respect to their physical position and carry out a cluster reconstruction to determine the position of the hit in the horizontal and vertical planes. During this procedure, the number of strips fired in a single cluster determined the cluster strip multiplicity. In addition, cluster multiplicity for a single trigger was also obtained.

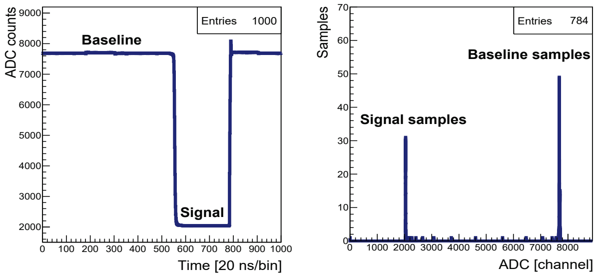

Figure 2: On the left figure is an example of a waveform of the one event of one strip of GEM-TPC, and on the right is shown the extracted ADC channel distribution of baseline and signal samples.

From each waveform, ADC channel distribution of the baseline and signal samples were extracted as shown in Figure 2 (right). By using a Gaussian fit, mean values of the baseline and signal distribution were determined, and the difference of these mean values was assigned as the signal amplitude of that strip.

Timing of the cluster was needed to determine the vertical coordinate of the hit. The time of arrival was extracted from the strip located at the mean of reconstructed cluster charge, at a threshold of 100 ADC counts, which was calculated from the baseline fluctuations in order to be well above the noise.

Cluster Reconstruction

From each primary interaction, the cluster reconstruction was carried out. Because the cluster includes all the information about the incoming particle. For instance, the horizontal position is determined by the following equation

$$X = M \cdot P - D, \tag{1}$$

where X is the determined horizontal position at the GEM-TPC, M is the mean channel value of the cluster (defined with the Gaussian fit), P is a pitch width of 0.4 mm, and D = 51.2 mm is a distance from the edge of the detector to the center.

To study further the effect of the reduced signal discretization to know how much the data transmission can be reduced without losses of the position information, the cluster reconstruction was carried out for 8 bits and 4 bits and then compared to the initial 13 bits. Examples of the reconstructed clusters with different bits are shown in Figure 3. It can be seen that the mean value of the cluster is almost the same in all three cases, with the mean channel amplitude decreasing from 6016 ADC counts to 95 ADC counts.

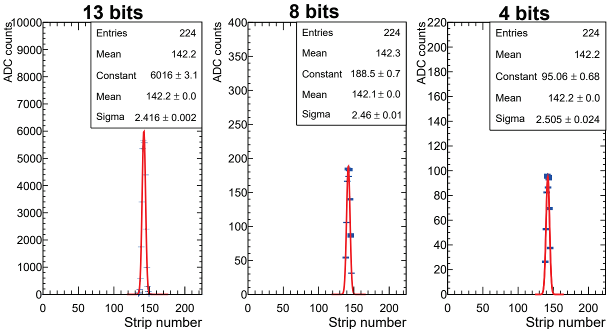

Figure 3: Example of one reconstructed cluster with 4 bit, 8 bit, and 13 bit data digitization.

Since the position of the cluster remained almost the same, the position distribution of the GEM-TPC did not drastically change for 8 and 4 bits, as shown in Figure 4. The bars indicate the standard deviation of the distribution, which is a good indicator of the estimated error on the position reconstruction. The calculated horizontal position of the beam at the GEM-TPC varied from -17.52 mm to -17.56 mm, and the sigma between 0.757 - 0.735 mm. As a conclusion, the position remained effectively the same.

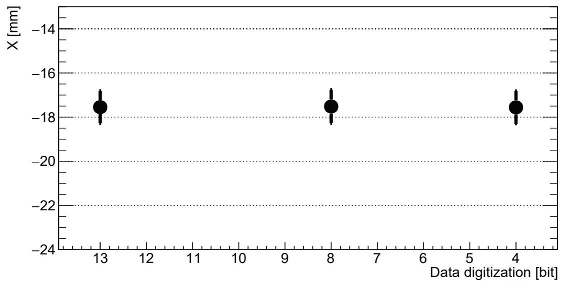

Figure 4: Measured position at the GEM-TPC with 13 bit, 8 bit, and 4 bit data digitization. The bars represent the standard deviation of the position distribution.

CLUSTER STRIP MULTIPLICITY

Further investigation deals with the effect of digitization on the cluster strip multiplicity. The cluster strip multiplicity is the number of fired strips within a single cluster. In Figure 5 are shown the cluster strip multiplicity distributions for all three cases. With 14.33 strips for 13 bits which represent the starting point, followed by 10.51 strips for 8 bits, and 8.63 strips for 4 bits. It can be seen that it decreased when the number of bits decreased, as expected.

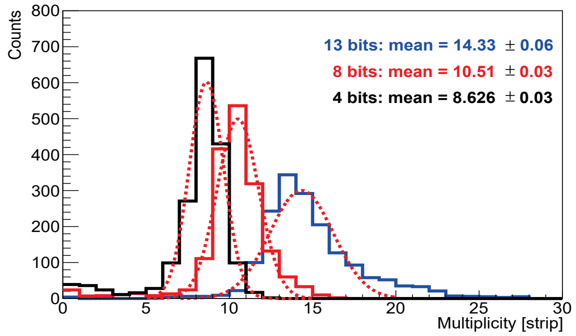

Figure 5: Extracted cluster strip multiplicity distributions with the Gaussian fits with 13 bit, 8 bit, and 4 bit data digitization.

SPATIAL RESOLUTION

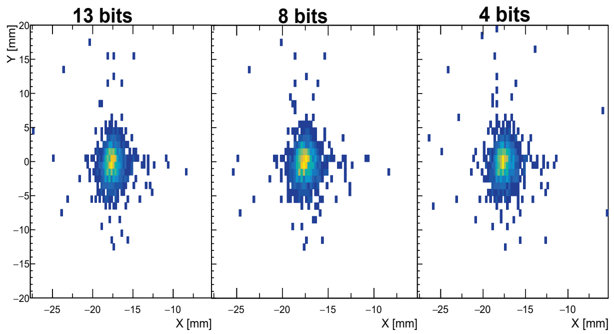

Figure 6: Beam profiles at the GEM-TPC with different data digitization.

In order to study the spatial resolution, calibrations and alignments were done for the TPCs and the GEM-TPC. For the TPCs, the standard calibration method described in the reference [7] was used. The same calibration method as for the TPC was utilized to calibrate the vertical position of the GEM-TPC. With the calibration grid, which was located at the closest TPC in the upstream direction of the GEM-TPC. Moreover, to align the trackers in the beam coordinate system, a residual distribution was used as explained in the reference [10].

After the calibrations and the alignments, the beam profiles at the GEM-TPC were computed for all three cases (see Figure 6). It can be seen that there are no significant differences between them, giving good indications that the reduced digitization of the signals does not contribute to any significant degradation of the beam profiles.

Following the beam profile determination, the spatial resolution was computed using the TPCs as reference trackers. The spatial resolution of the GEM-TPC with the single field-cage configuration can be obtained from the standard deviation of a residual distribution between the extrapolated and measured positions, which is the difference between the extrapolated and measured positions and corresponds to the quadratic sum of the resolutions of the two TPCs and the GEM-TPC. In this in-beam test, the extrapolated position was calculated using measured positions of TPCs [11].

The spatial resolution for different data digitization is shown in Figure 7. Only a slight variation from 0.80 mm to 0.82 mm can be seen, which corresponds to 20 micrometers as an overall shift i.e. causing a negligible effect on the spatial resolution. In conclusion, by reducing data digitization from 13 bits to 4 bits, the spatial resolution changes only by 3 % with a reduction by a factor of 3.25 in the data transmission.

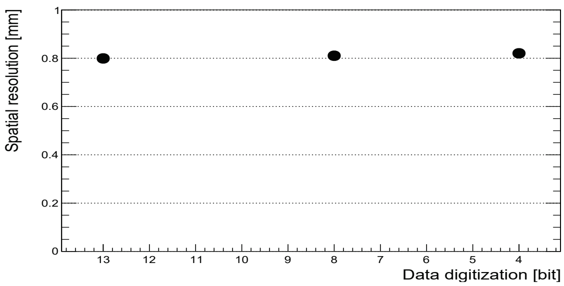

Figure 7: Measured spatial resolution with different data digitization.

CONCLUSION

The presented results show that the new clusterization method for the GEM-TPC works on the event-by-event basis. From the study of the reduced sampling digitization, the spatial resolution of 0.80 - 0.82 mm, and the cluster strip multiplicity of 14.3 - 8.6 strips were obtained. This analysis shows that by reducing the digitization from 13 bits to up to 4 bits and the data transmission by a factor of 3.25, the position reconstruction in the horizontal and vertical planes did not drastically change, demonstrating that the implementation of such a digitization scheme is needed, and further investigation will be carried out in future tests.

Furthermore, it was demonstrated that the newly integrated readout electronics can be used with the GEM-TPC detector.

ACKNOWLEDGEMENTS

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REFERENCES

[1] H. Geissel *et al.*, "The Super-FRS project at GSI", *Nucl. Instr. and Meth. in Phys*, vol. 204, pp. 71-–85, May 2003. `doi:10.1016/S0168-583X(02)01893-1`

[2] G. Rosner, "Future Facility: FAIR at GSI", *Nucl. Phy. B (Proc. Suppl.)*, vol. 167, pp. 77–81, May 2007. `doi:10.1016/j.nuclphysbps.2006.12.089`

[3] F. Garćıa *et al*, "GEM-TPC prototype for beam diagnostics of Super-FRS in NUSTAR experiment — FAIR", *2009 IEEE Nuclear Science Symposium Conference Record (NSS/MIC)*, pp. 269–272, 2009. `doi:10.1109/NSSMIC.2009.5401762`

[4] F. Sauli, "GEM: A new concept for electron amplification in gas detectors", *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment*, vol. 386, no. 2, pp. 531-–534, Feb. 1997. `doi:10.1016/S0168-9002(96)01172-2`

[5] F. Garćıa *et al*, "A GEM-TPC in twin configuration for the Super-FRS tracking of heavy ions at FAIR", *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment*, vol. 884, Mar 2018, pp. 18–24. `doi:10.1016/j.nima.2017.11.088`

[6] P. Wieczorek, H.Flemming, H.Deppel, "Low Noise Amplifier with Adaptive Gain Setting - (AWAGS) ASIC", *TWEPP 2021 Topical Workshop on Electronics for Particle Physics*, 21. Sep 2021, online event, `https://indico.cern.ch/e/twepp2021`

[7] R. Janik *et al.*, "Time Projection Chambers with C-pads for heavy ion tracking", *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment*, vol. 640, no. 1, pp. 54–57, June 2011. `doi:10.1016/j.nima.2011.02.052`

[8] *H. Geissel, et al.*, "The GSI projectile fragment separator (FRS): a versatile magnetic system for relativistic heavy ions", *Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms*, vol. 70, no. 1, pp. 286–297, August 1992. `doi:10.1016/0168-583X(92)95944-M`

[9] FEBEX3b, `https://www.gsi.de/work/forschung/experimentelektronik/digitalelektronik/digitalelektronik/module/font_end_module/febex/febex3b`

[10] R. Farinelli *et al.*, "GRAAL: Gem Reconstruction And Analysis Library", *Journal of Physics: Conference Series*, vol. 1525, no. 1, p. 012116, Apr 2020. `doi:10.1088/1742-6596/1525/1/012116`

[11] M. Luoma *et al.*, "Results of the Super-FRS GEM-TPC detector prototype test with uranium projectiles", under submission, unpublished.