Precise tracking of cosmic muons using the Time-over-Threshold property of NINO ASICS

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ABSTRACT: This work reports on a cost-effective, simple front-end readout and data-acquisition system for a muon scattering tomography system based on Resistive Plate Chambers. The Time-over-Threshold (TOT) property of NINO ASICs has been exploited to extract position information and achieve precise tracking capability. Initial test measurements with a prototype Resistive Plate Chamber were performed using a low-cost FPGA coupled to the NINO ASIC for the event selection and handling of the TOT data. The relation between input pulse width and TOT has been established by analyzing the waveforms of the RPC signals. The TOT profile at different working voltages has been obtained by the FPGA and it has been fitted with the Gaussian distribution whose standard deviation represents an estimate of the tracking precision.

KEYWORDS: Front-end electronics for detector readout; Gaseous detectors; Resistive-plate chambers; Portal imaging

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1 Introduction

Muon Scattering Tomography (MST) exploits the deviation of cosmic muons from their path due to their interaction with atomic nuclei and electrons of the target material whose physical properties one wants to probe. Gaseous detectors have proven to be versatile means for tracking the cosmic muons [1–3] and are therefore widely used in MST applications. The Resistive Plate Chamber (RPC) is one of the popular gaseous detectors which is found suitable for this purpose due to its simple design, ease of construction, cost-effectiveness, large-scale producibility, along with very good temporal, spatial resolutions, and detection efficiency. The spatial resolution of the RPC determines the precision in tracking and hence the quality of image formation. This is demonstrated by the example of the images produced by a MST setup for two different spatial resolutions as shown in figure 1. An elaborate study on the effect of spatial resolution on image formation is available in a previous simulation work [4]. Controllable operational parameters such as, applied electric field, gas mixture, etc. are a few factors that influence the detector spatial resolution. But most importantly, it is determined by the readout granularity as the position information is extracted from the distribution of charge induced on the readout strips. Finer strips can predict the center of a charge distribution with a better resolution which helps to achieve pin-pointed position information. For a readout with finer strips a larger number of channels are required and hence the cost of electronics increases significantly. A multi-channel readout ASIC which also serves the purpose of an ADC, can be a possible solution for precise tracking as well as inexpensive electronics.

In this work, we suggest a reliable option for extracting charge information based on the Time-Over-Threshold (TOT) property of NINO [5], which is a low power, ultra-fast front-end ASIC designed for ALICE-TOF detectors [6, 7]. By virtue of its TOT property, the NINO ASIC can represent charge in terms of time which can be obtained from the width of its output pulse [8, 9]. The data-acquisition (DAQ) system has been designed with an FPGA for the time measurement using a high-frequency clock. The objective of this work is to study the performance of the proposed
scheme of readout and DAQ for extracting position information. This has been investigated using a prototype RPC detector and the results have demonstrated that this can be useful for building readout electronics of a RPC-based MST set-up.

Figure 1. A MST system consisting of 6 detectors (3 above and 3 below the region of interest), cubes of Fe and Pb of side 5 cm have been placed on the central plane. The reconstructed images obtained for two different spatial resolutions has been shown: (a) 500 μm, (b) 1 mm.

2 Components of the readout & DAQ

The proposed scheme comprises two components: a NINO ASIC for the front-end readout and a FPGA in the back-end for acquiring the data. These two are briefly described below.

2.1 NINO in front-end

The NINO is a 8-channel LVDS input/output discriminator, pre-amplifier ASIC. It has been designed with the TOT property, i.e. the output pulse width of NINO is related to the input detector pulse width above a pre-set threshold. For a particular detector and working conditions, it is assumed that the TOT is related to the amplitude of the detector signal which is in turn a measure of the induced charge [10, 11]. Therefore, the charge deposit can be related to time which can be digitized using a TDC. Although for a RPC detector the relation between charge deposit and NINO TOT is not one-to-one, the TOT technique is still useful to locate the center of the charge distribution and hence pinpoint the particle track.

2.2 FPGA in back-end

Taking advantage of the low rate of cosmic muons, a low-end FPGA has been used in the present work to design a TDC of coarse resolution. A developer board based on ALTERA MAX-10 FPGA has been used for pulse width measurement [12]. It has been programmed using the Intel Quartus Prime platform [13]. The TOT output of NINO has been measured by a 500 MHz clock (maximum recommended clock for the selected FPGA) generated using a Phase Locked Loop (PLL) mechanism [14] applied on the 50 MHz on-board clock. Therefore, a resolution of 2 ns has been achieved in this scheme. It has been tested by measuring the pulse width of a known 60 ns pulse using both an oscilloscope and our FPGA. It has been observed that, the measurement technique has a
maximum probable inaccuracy of 2 ns. This value has been added to the FPGA measured pulse width to counter the inaccuracy. The difference in measurements obtained from FPGA and oscilloscope has been shown in figure 2 (a). The following logical operation has been programmed in the FPGA for collecting data from the RPC: the TOT values for seven readout strips (center strip, three on the right, three on the left) are temporarily stored in a memory array; these data are serially transmitted to the computer via UART protocol when a coincidence of three scintillators and the central strip of RPC is found. The schematic workflow of the FPGA has been illustrated in figure 2 (b).

Figure 2. (a) Difference of pulse widths measured by the oscilloscope and the FPGA, obtained after adding 2 ns to FPGA measured pulse width to counter the measurement inaccuracy, (b) Schematic diagram of the operation inside the FPGA.

3 Experimental setup

A 30 cm × 30 cm prototype RPC detector made with Bakelite electrodes has been used to test our proposed readout electronics scheme. A mixture of R134a (95%) and iso-butane (5%) gases has been used to operate the RPC. The readout strips are made of copper and have width 1 cm, pitch 1.2 cm, and length 30 cm. The RPC has been placed in a vertical cosmic ray hodoscope of three plastic scintillators with an overlapped area that matches the width of a single (central) readout strip of the RPC. The finger scintillator among the three has been kept as close as possible to the RPC to trigger only a single strip. However, waveforms from three strips from either side have been studied to obtain the charge spread of a signal. An image of the experimental setup has been shown in figure 3 (a). Two key aspects have been investigated in this experiment. Firstly, the raw pulses of the RPC and NINO TOT outputs have been compared by analyzing their waveforms using a Tektronix MSO 4104-b oscilloscope. This process has been illustrated in figure 3 (b). Secondly, the profile of induced charge on the strips has been obtained using the TOT measured by the FPGA.

In figure 4, two typical RPC pulses at a given voltage and their corresponding NINO outputs as obtained with the oscilloscope, have been shown. The following criteria have been used for selecting the RPC pulses for comparison to the NINO output; a) The RPC pulse generally arrives around the same position in the time window defined by the scintillator trigger. Therefore, the first 200 ns of the RPC signal readout window has been considered as background electronic noise. The average amplitude of the noise window has been used to remove fluctuations in the baseline of the RPC pulse. b) Those pulses which last at least 8 ns above the threshold are taken as a valid pulse.
c) If a signal has multiple rises and falls along with the existence of several valid pulses, the signal is considered to have multiple pulses. In such cases the width of the all the pulses are summed up to obtain the resultant value. The occurrence of multiple pulses indicates the existence of streamers.

Figure 4. RPC pulse (bottom) and NINO TOT output (top) for (a) large pulse and (b) a smaller pulse.

4 TOT measurement results

The TOT output of NINO has been found to increase with input pulse width linearly as shown in figure 5. For a given signal with multiple strip hits, the maximum amount of charge is induced on the strip which covers the detector region where the particle has actually passed through. Therefore, the output of that strip would give the largest pulse width and hence the largest TOT among all the strips. This can provide the position information of the event. The TOT measurement has been carried out at three different working voltages (10.2 kV, 10.6 kV, 11.6 kV) to evaluate the tracking ability of this DAQ technique. The distribution of TOT received by the central strip for these voltages has been shown in figure 6. It may be noted that the larger tail of the distribution at 11.6 kV suggests transition to streamer mode. Moreover, the streamer signals have shown larger spread than the avalanche signals, as shown in figure 7. It has been demonstrated that the multiplicity increases as the working voltage is raised. Finally, the fraction of TOT spread (ratio of TOT obtained from a given strip to total TOT obtained from all the strips) on the central strip and six neighboring strips
has been shown in figure 8. The standard deviations of the distributions have been found to increase with the rise in working voltage. At an avalanche working voltage (10.2 kV), the standard deviation of the spread of the TOT obtained is 4.5 mm with 1.2 cm strip pitch.

![Figure 5](image.png)

**Figure 5.** Variation of the output TOT for varying input pulse widths.

![Figure 6](image.png)

**Figure 6.** TOT of the central strip for working voltages: (a) 10.2 kV, (b) 10.6 kV and (c) 11.6 kV.

5 Conclusion

A novel scheme of readout electronics for a RPC-based MST setup has been proposed using NINO ASIC in the front-end and an FPGA-based DAQ in the back-end. The TOT measurement of the NINO with a resolution of 2 ns has been achieved using a 500 MHz clock pulse derived using PLL on the on-board clock of FPGA. The preliminary tests have indicated that the present scheme can be utilised for retrieving position information with spatial resolution of the order of mm with the current design parameters of the RPC. It has been demonstrated in [4] that 500 μm is a reasonable resolution for material discrimination using MST. We plan to fabricate a set of new readout panel with narrower strips. This can be useful for achieving the goal of building an MST setup for material discrimination.
Figure 7. The strip multiplicity for working voltages: (a) 10.2 kV, (b) 10.6 kV and (c) 11.6 kV.

Figure 8. TOT fraction received by all the seven strips for three different working voltages.

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