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Performance of the readout system for MONOLITH

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Abstract

In this paper, we describe the performance of the readout system for MONOLITH developed at the LNGS. This system is based on the use of flat cables as readout elements, instead of the conventional copper strips. The advantages of flat cable strips are the good performance, the easy installation and the possibility to realize complex readout systems. The X-coordinate readout system (X-system) is composed by 15 m long, Flat Cable Strips (FCS). The distribution of the time difference between the streamer signals transmitted at both the ends of the X-system FCS has a sigma resolution of the order of 100 ps. This resolution allows the measurement of the particle direction by means of the time-of-flight technique and can be exploited to measure the Y-coordinate with a resolution in the order of 1 cm. The Y-coordinate system is composed by short FCS connected together by a flat cable acting as a bus line. It allows the installation of the electronics outside the apparatus minimizing the number of channels.

Keywords: MONOLITH; RPC; Flat cable; Readout strip

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1. Introduction

The readout system described in this paper is based on the use of commercial flat cables as pick-up elements instead of the usual copper strips. The first measurements performed with this innovative readout system have been done with the MONOLITH prototype made of 20 iron plates 100 × 100 cm^2, 5 cm thick, 2 cm apart, interleaved with 20 active planes [1–4]. Fig. 1 shows a plane, composed of 4 Glass RPCs 110 cm long and 25 cm wide [1]. The Glass RPCs are coupled to the readout plane made of flat cables glued on a 110 × 100 cm^2 FR4 sheet coppered on one side. Fig. 2 shows the flat cable strips connected with commercial wiremount socket connectors to the LNGS card [5]. From this figure it is apparent that the width of the strips is determined by the number of flat cable wires connected to a single channel input stage.

The measurements made with the MONOLITH prototype equipped with the FCS are reported in Refs. [1–4]. The aim of this paper is to show that the FCS can also be used on a larger scale, matching all the requirements of the MONOLITH experiment.

2. The FCS readout system for MONOLITH

MONOLITH consists of two modules [7]. Each module is a stack of 125 horizontal 8 cm thick iron planes, with a surface area of 15 × 14.5 m^2, with 2.2 cm gaps housing the Glass RPC planes and the related readout planes. Each module plane is composed by 8 *roads*, 1.8 m wide and 14.4 m long,

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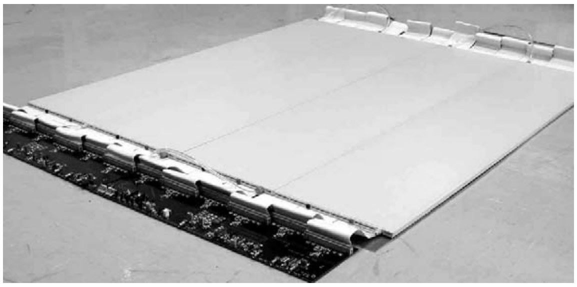


Fig. 1. Picture of 4 Glass RPCs coupled to the readout plane.

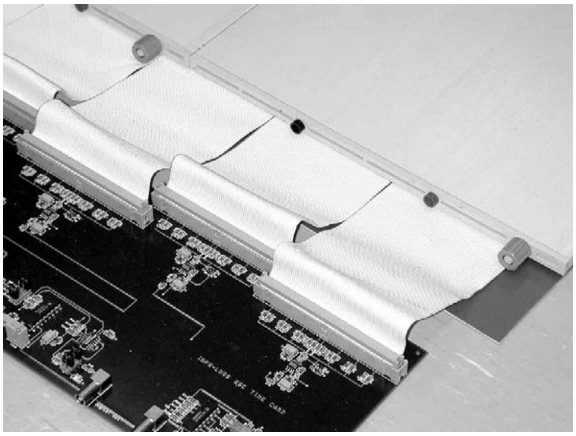
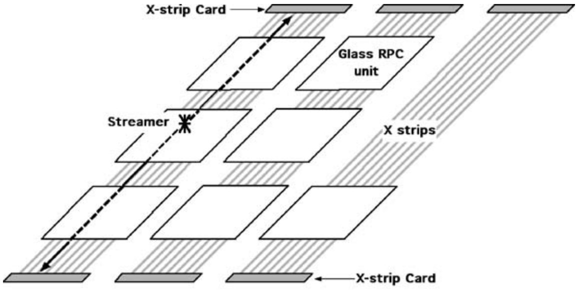


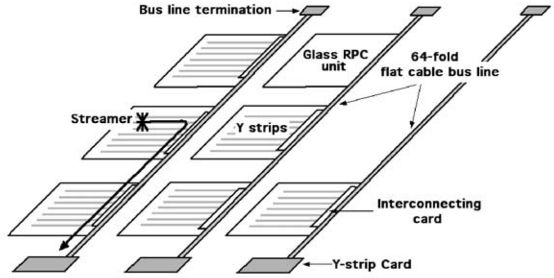
Fig. 2. Magnification of the flat cable strip connected with the LNGS card by means of wiremount socket connectors.

filled with 8 *plate units* of 1.80 × 1.80 m^2. Fig. 3a shows a sketch of one 15 × 14.5 m^2 plane with the LNGS X-system. Please note that for sake of clarity only 3 roads instead of 8 are reported, also only 3 Glass RPC units for each road instead of 8 are shown.

The X-system is based on 14.5 m long and 2.8 cm (22 conductors) wide strips, faced to the 8 Glass RPC units of a *road* (64 strips per road). The X-strips are connected to the FEE cards that provide the digital pattern of the X-view, the fast digital OR t_1 for timing and the analog OR [2]. The FEE cards on the other strip end provide only the fast digital OR t_2 (see Fig. 3a).



(a) X-system



(b) Y-system

Fig. 3. Sketch of LNGS readout system.

The mechanical structure of MONOLITH does not allow the use of long strips to read the Y-coordinate. In the Y-system each Glass RPC unit is coupled with a 1.8 × 1.8 m^2 pick-up plane. As shown in Fig. 3b, each readout plane consists of 1.8 m long flat cables, orthogonal to the flat cables of the X-system. Interconnecting cards (see Fig. 3b) rearrange the flat cable wires of a pick-up plane into 64 strips 2.8 cm wide and 180 cm long. These cards are connected to a 15 m long flat cable acting as a bus line for the analog signals. The bus line is composed by 64 signal +64 ground flat cable conductors. The connection of the cards to the bus is obtained by means of flat cables and wiremount socket connectors. Eight strips, one for each unit, are connected with a single electronic channel through the bus line. The other end of the bus is properly terminated to obtain a uniform response. The Y-system identifies the Y-coordinate of the particle crossing the Glass RPC unit, but cannot identify which unit in that road has been hit. The actual Glass RPC unit is identified by means of the $t_1 - t_2$ measurement performed with the X-system.

3. Performance of the MONOLITH readout system

The measurement reported in this section has been done by using the shielded flat cables developed by the LNGS and the 3M corporation [6]. This FCS is composed of a 3M halogen free flat cable, having 1.27 mm pitched conductors. The flat cable is glued to a plastic liner 2 mm thick. A copper foil 100 μm thick is glued on the other side of the liner. At present, 30 m long, 25 cm wide (i.e. 186 conductors) flat cable strip rolls have been realized. The measured characteristic impedence Z_0 for the 2.8 cm (i.e. 22 conductors) strips is about 12 Ω and the propagation constant is about 5.6 ns/m. Finally, the attenuation in amplitude of triangular signals 30 ns wide at the base is about 0.052 db/m. The timing performance of the X-system has been tested with a Glass RPC coupled with the 15 m long, 25 cm wide FCS. Each end of the 15 m long FCS is connected with one LNGS card [5]. The card thresholds are set at 100 mV. The trigger is provided by two 5 cm wide, 15 cm long plastic scintillators, placed orthogonally with respect to the FCS conductors. When a particle crosses the RPC, a streamer is generated and a pulse is induced on the FCS. Starting from the FCS point facing the streamer location, two pulses propagate along the FCS in opposite directions, reaching the FEE cards in a time proportional to the FCS length travelled. Fig. 4 shows the pulses from the card #1 (scope channel #1) and from the card #2 (scope channel #2). The triggering muon induces the pulse on the FCS at a distance $x_1 = 0.5$ m ($x_2 = 14.5$ m) from the card #1 (card #2). The time interval $t_1 - t_2$ between the two pulses is about 80 ns due to the different FCS length travelled by the two pulses.

As an example, the $t_1 - t_2$ distribution for $x_1 = x_2 = 7.5$ m is shown in Fig. 5 (125 ps/channel, $\sigma = 215$ ps). Assuming a flat distribution of the triggering particles over the 5 cm wide scintillator telescope we have:

$$\sigma_{\text{true}} = \sqrt{\sigma_{\text{exp}}^2 - \sigma_{\text{scint}}^2}, \tag{1}$$

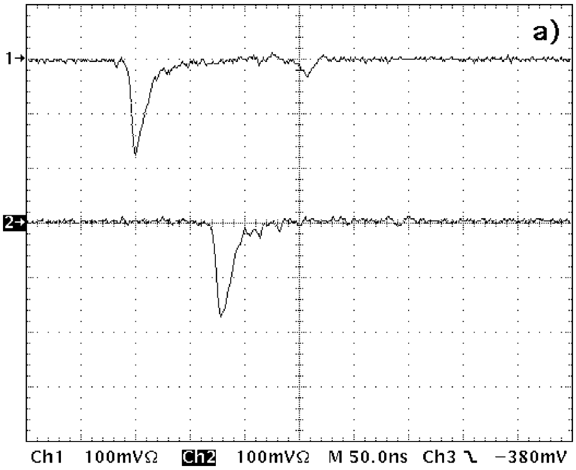


Fig. 4. Pulses from the LNGS cards connected at the ends of the 15 m long FCS. The card #1 and #2 are connected to the oscilloscope channel #1 and #2, respectively. the streamer is generated at 0.5 m to the card #1.

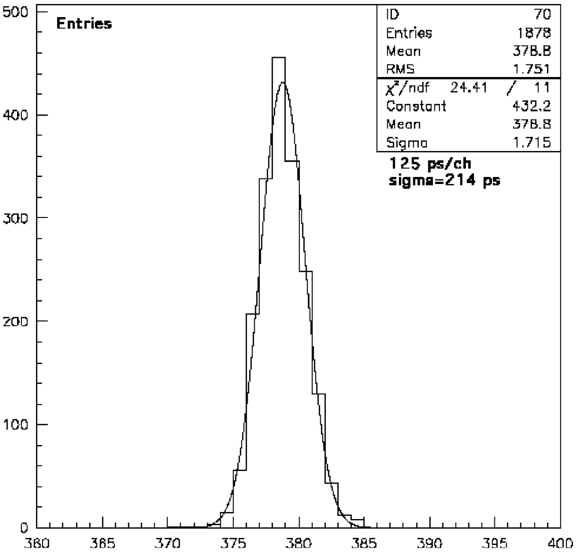


Fig. 5. $t_1 - t_2$ distribution for $x_1 = x_2 = 7.5$ m.

where

$$\sigma_{\text{scint}} = \frac{2\tau w}{\sqrt{12}}, \tag{2}$$

where τ is the propagation time = 5.6 ns/m and w the scintillator width = 5 cm.

Subtracting quadratically the broadening due to the 5 cm width of the scintillator telescope from the raw data distribution, the 215 ps resolution improves to 138 ps.

Taking into account the FCS propagation constant of 56 ps/cm, the spatial (standard) resolution is about 1.23 cm = 138 ps/(2 × 56)cm. The cross-talk between adjoining strips in each pick-up is less than 5%.

The Y-system prototype is composed by 8 FCS 1.8 m long. The conductors of each FCS are sent to an interconnecting card that rearrange the flat cable wires into 8 strips 2.8 cm wide (22 wires) and 180 cm long. Each interconnecting card is connected to the 15 m long, 8-*fold* flat cable bus. All the links are obtained by using commercial wiremount socket connectors. The card at the end of the bus has a driver for each channel, with an input impedance of about 70 Ω. To improve the response uniformity of the 8 pick-up elements, the other end of the bus is terminated with 70 Ω resistors. As in the X-system measurements, the signals are generated by a Glass RPC and the triggering cosmic ray muons are selected with a pair of scintillators. The bottom side of the Glass RPC is faced with one of the 8 pick-up panels of the Y-system prototype. The top side of the Glass RPC is faced to a pick-up directly connected to the FEE card, acting as the reference. The efficiency ε_n of the nth pick-up is defined by the following formula:

$$\varepsilon_n = \frac{S_1 \otimes S_2 \otimes P_0 \otimes P_n}{S_1 \otimes S_2 \otimes P_0}, \tag{3}$$

where $S_1 \otimes S_1$ = scintillator coincidence; P_0 is the signal from the reference pick-up and P_n the signal from the nth pick-up.

Fig. 6 shows the efficiency of the Y-system as a function of the pick-up number. The overall efficiency is at the 98.5% level on the average. As for the X-system, the cross-talk between adjoining strips is less than 5% in all the cases.

4. Discussion and conclusions

The LNGS readout system is conceived to permit easy mounting. The use of commercial connectors instead of soldering allows a safe and fast mounting. All the electronics are outside the apparatus, allowing an independent installation and an easy maintenance.

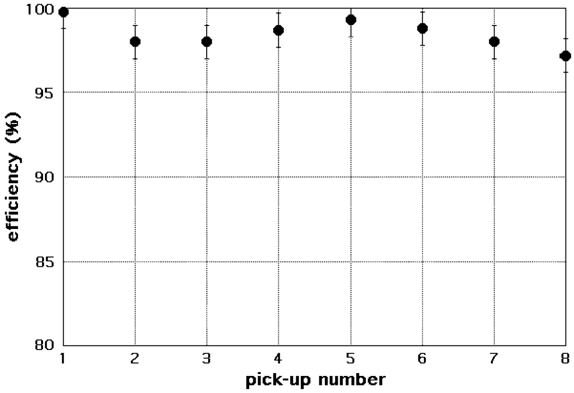


Fig. 6. Efficiency of the Y-readout system as a function of the pick-up unit.

The time performance of the X-system, of the order of 100 ps, shows that 15 m long FCS can be used without a worsening of the intrinsic time resolution of the Glass RPC, which is about 1 ns. All the more reason, as required for the Y-coordinate measurement, the $t_1 - t_2$ resolution is adequate to identify the Glass RPC unit crossed by the particle. In fact, the time separation between consecutive units is 20.16 ns = 1.8 m × (2 × 5.6 ns/m). The $t_1 - t_2$ measurement can be exploited to measure (with a resolution of the order of 1 cm) the Y coordinate, without the use of the Y-system. It is worthwhile to point out that the goal of the measurement was to achieve a resolution just below 1 ns, so that no particular care was taken to push the time resolution beyond this value. We believe that a further improvement of the $t_1 - t_2$ resolution can be obtained improving the FEE cards, optimizing the threshold level and so on. A detailed experimental and simulation study is needed to understand the performance of the system on a large scale and to evaluate the effects of multistreamer and/or particle showering on the $t_1 - t_2$ measurement. The advantage of this technique is the complete elimination of the Y-system, which means the halving of the total pick-up surface and thus the number of channels as well.

The main advantage of using the Y-system is the safe and stable digital system to determine the *Y* coordinate. The performance of the Y-system prototype with the digital readout is very satisfying even though it has not been optimized. In fact, a high efficiency has been obtained with a threshold of 15 mV. This value is far from typical noise levels of few mV and thus allows a wide working region. This work was supported by Istituto Nazionale di Fisica Nucleare (INFN).

References

[1] C. Gustavino, et al., Nucl. Instr. and Meth. A 457 (2001) 558.

[2] M. Ambrosio, et al., Nucl. Instr. and Meth. A 456 (2000) 67.

[3] G. Bencivenni, et al., Nucl. Instr. and Meth. A 461 (2001) 319.

[4] G. Bari, et al.: Analysis of the performance of the MONOLITH prototype at LNGS, Nucl. Instr. and Meth. A (2003) these proceedings.

[5] A. Candela, et al., MONOLITH memo 004/2000.

[6] S. Blo, G. Lamperti, 3M Italia S.p.A.

[7] N.Y. Agafonova, et al., LNGS P26/98, CERN/SPSC 2000/031, SPSC/M657, Aug. 2000.