Available online at www.sciencedirect.com
SCIENCE DIRECT®

Nuclear Instruments and Methods in Physics Research A 508 (2003) 170–174

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH
Section A

www.elsevier.com/locate/nima

Analysis of the performance of the MONOLITH prototype

G. Bari[a], A. Candela[b], M. De Deo[b], M. D'Incecco[b], M. Garbini[a], P. Giusti[a], C. Gustavino[b,*], M. Lindozzi[b], H. Menghetti[a], G. Sartorelli[a], G. Satta[c], M. Selvi[a]

[a] *Bologna University and INFN, Bologna, Italy*
[b] *Laboratori Nazionali del Gran Sasso, INFN, S.S. 17 bis 18,910 Assergi 67010, Italy*
[c] *Laboratori Nazionali di Frascati, INFN, Frascati, Italy*

Abstract

In the framework of the study for a large magnetic detector suitable for the physics at a neutrino factory, the data collected with the MONOLITH prototype at the T7-PS facility at CERN has been analyzed. The hadron shower angular resolution for pions followed a $10.4/\sqrt{E(\mathrm{GeV})} + 10.1/E$ law for orthogonally incident particles. For a baseline of 732 km, this performance would allow the rejection of wrong sign muon background at the level of 10^{-6}, and a capability to measure $\sin\theta_{13}$ down to 10^{-3}. A preliminary analysis of about 10^6 downward going muons collected at LNGS is also presented. The readout system upgrade allowed the monitoring of each glass RPC with a granularity of 1 cm^2.

Keywords: RPC; Neutrino; Underground

1. Introduction

MONOLITH is a high-density and large mass tracking calorimeter to detect atmospheric neutrinos and to measure the oscillation parameters, for clarifying the nature of the oscillation mechanism [1]. It mainly consists of 120 horizontal magnetized iron planes 8 cm thick, 30 m long and 15 m wide. The iron slabs are interleaved by Glass RPC planes [2] for a total active area of about 50,000 m^2. In order to recognize the particle direction by means of the tracking and the time-of-flight techniques, the experiment requires a spatial accuracy of 3 cm and a time resolution of 2 ns. An average energy resolution for the hadron showers of the order of $100\%/\sqrt{E(\mathrm{GeV})}$ is also required for a full reconstruction of the energy and direction of the neutrinos that interact inside the apparatus.

A prototype made of 20 iron plates (100×100 cm^2) 5 cm thick, 2 cm apart, interleaved with 20 active planes (100×110 cm^2) was constructed. The capability to measure the particle direction by means of the tracking and time-of-flight techniques was tested at the Gran Sasso National Laboratory, where about 30,000 downward through going muons were analyzed [3]. The energy resolution for pions was a $68\%/\sqrt{E(\mathrm{GeV})} + 2\%$, as measured at the T7-PS beam facility at CERN [4]. In the following, we

*Corresponding author. Tel.: +39-0862-437586; fax: +39-0862-437588.
E-mail address: gustavino@lngs.infn.it (C. Gustavino).

0168-9002/03/$ - see front matter © 2003 Elsevier Science B.V. All rights reserved.
doi:10.1016/S0168-9002(03)01345-7

discuss a new analysis of the test beam data. This analysis showed that the large magnetic detector for physics at a neutrino factory can use Glass RPC as basic device. We also present a preliminary analysis of about 10^6 downward going muons recently collected at LNGS, where a readout system for the Y-coordinate has been implemented in the prototype. The new configuration allowed a detailed study of the prototype performance, as each RPC can be monitored with a granularity of 1 cm^2.

2. Test beam measurements

The MONOLITH prototype was made of 20 iron plates (100×100 cm^2) 5 cm thick, 2 cm apart, interleaved with 20 active planes (100×110 cm^2) [4]. Each plane was composed by 4 Glass RPCs 110×25 cm^2 operating in streamer mode [2,5]. Fig. 1 shows a Glass RPC. In this picture the graphite coating has not yet been applied to the upper glass electrode in order to show the 15 mm long, 2 mm thick, 2 mm wide stick spacers inserted between the electrodes. The readout system was based on the use of halogen-free flat cables acting as pick-up strips [6]; the readout system consisted of 96 flat cable strips 120 cm long and 1 cm wide for each plane. The strips were connected to the SGS cards (already used on the ALEPH hadron calorimeter) which provide the digital pattern of the event in the x–z view. The prototype was tested at CERN T7-PS beam facility, which provided e, μ and π in the range between 2 and 10 GeV. The energy response of the prototype is reported in Ref. [4].

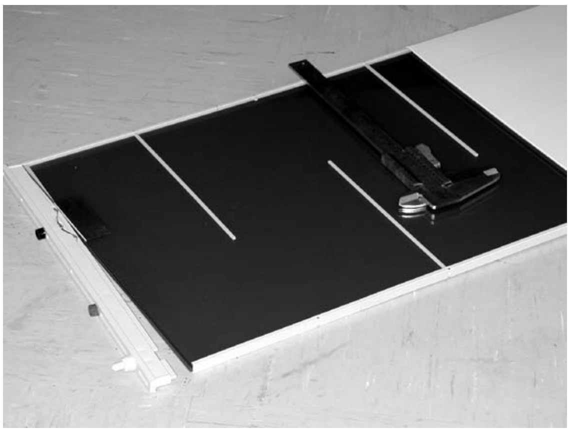

Fig. 1. Picture of a Glass RPC.

In the framework of neutrino oscillation physics, we studied the possibility of using the Glass RPC in a large magnetic detector as a target for a ν-factory beam [7]. Accelerating μ^+ in a muon storage ring, we have

$$\mu^+ \rightarrow e^+ \nu_e \bar{\nu}_\mu$$

and if ν_e oscillates into ν_μ there is a CC interaction producing μ^-; the remaining $\bar{\nu}_\mu$ will give μ^+, so the presence of μ^- in the detector is a very clear signature of oscillation. The investigation of wrong sign muons events gives the opportunity to measure θ_{13}, the sign of Δm^2_{23}, CP violation and matter effects [8]. The background due to the wrong sign muon events is given by secondary negative muons from hadron decays in NC events and in $\bar{\nu}_\mu$ CC and ν_e CC events, where the primary lepton is not detected. These backgrounds can be efficiently suppressed by selecting the events where only one energetic muon is present and there is a large separation between the muon track and the hadronic shower axis, which must be measured with an adequate angular resolution [9]. The hadronic shower angular resolution θ_0 can be parametrized as follows [10]:

$$\theta_0 = \frac{A}{\sqrt{E}} + \frac{B}{E} \quad (1)$$

where θ_0 is the r.m.s. angular resolution in degrees and E is the shower energy in GeV; with $A = 16.67$ $GeV^{1/2}$ and $B = 12.15$ GeV, i.e. the MINOS parameters, the background rejection is of the order of 10^{-6} [9].

We applied the same procedure of [10] on the experimental data to evaluate the hadronic angular resolution of the prototype. For each selected pion event, the shower center of gravity was calculated summing over the hits; a vector was then drawn from the event vertex, reconstructed as the first hit. The shower center and its direction was compared with the true one, as shown in Fig. 2. The shower angular resolution as a function of the incident pion energy is shown in Fig. 3.

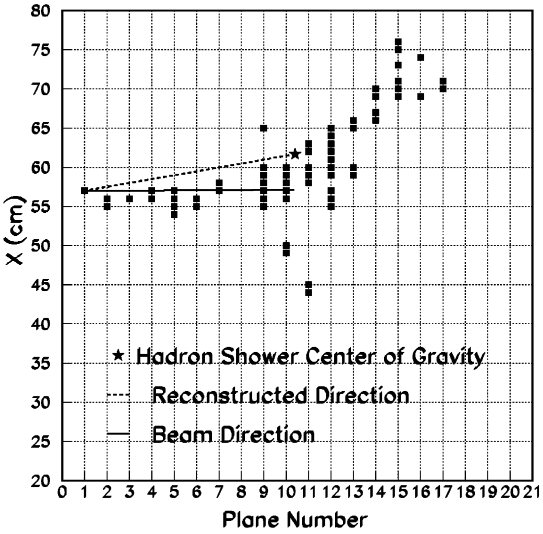

Fig. 2. Hadronic shower direction as reconstructed in a pion event.

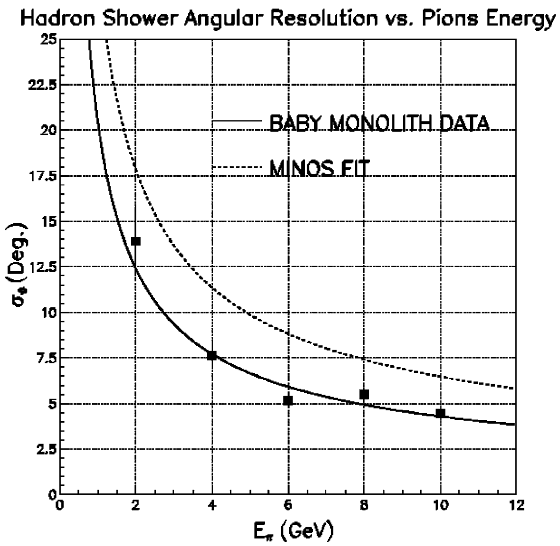

Fig. 3. Hadronic shower angular resolution of the MONOLITH prototype as a function of the pion energy. The MINOS fit is also reported.

The experimental data were fitted using Eq. (1) and were compared with the reference MINOS fit. In our case, we found $A = 10.4\ \mathrm{GeV}^{1/2}$ and $B = 10.1$ GeV, i.e. better than the MINOS parameters. In conclusion, the measured hadronic angular resolution was found to be adequate for a large magnetic detector dedicated to the study of neutrino physics [11].

3. Cosmic ray measurements

Cosmic ray measurements were performed at the Gran Sasso Laboratory. The first 10 planes were equipped with one Glass RPC ($25 \times 110\ \mathrm{cm}^2$) placed orthogonally to the x strips. Besides the x–z view readout system described in the previous section, the measurements described in this section were also done with a readout system for the event reconstruction in the y–z view, obtaining a three-dimensional event reconstruction. Each plane was equipped with 24 flat cable strips, 120 cm long and 1 cm wide, placed along the glass RPC. The strips were connected to the digital cards already used on the MACRO experiment, which provided the digital pattern of the event in the y–z view. The other side of the y strips was connected to the LNGS cards that provided a fast NIM signal to measure the muon crossing time [12].

Vertical through going muons were selected with 2 scintillators, 100 cm long and 25 cm wide, positioned along the Glass RPCs. The RPCs were operated in streamer mode with an Argon/isobutane/R134A = (46%/8%/46%) gas mixture.

The applied voltage was 7.8 kV, about 400 V above the efficiency knee. We collected a sample of about 1.2×10^6 events during 24 days of detector operation. Fig. 4 shows the distribution of the time difference of signals coming from 2 planes crossed by the same particle. The standard deviation of the gaussian fit of the distribution was about $\sigma_{\mathrm{Tot}} = 1.8$ ns. Assuming that the time resolution of the two planes was the same, the sigma resolution of a single detector was found to be $1.3 = \sigma_{\mathrm{Tot}}/\sqrt{2}$ ns. The non-gaussian tails, of the order of 10% of the total, are due to delayed signals [13].

To study the efficiency we selected events with a single track reconstructed on both x–z and y–z view; for each plane (and each projection) we evaluated the coordinate of the hit according to the best straight line fit $((x_{\mathrm{BF}}, z_{\mathrm{BF}}), (y_{\mathrm{BF}}, z_{\mathrm{BF}}))$, excluding the plane under consideration. Then we checked if we had a hit detected $((x_{OB}, z_{OB}), (y_{OB}, z_{OB}))$ within 3 cm from the straight line fit. The ratio between the numbers of detected and reconstructed points gave the plane efficiency.

Combining the information coming from the x–z and y–z view, we could study the efficiency with a granularity of 1 cm^2. Fig. 5 shows the two-dimensional view of the efficiency of one detector. Far from the chamber edges the measured efficiency was about 97%; the drop of efficiency every 10 cm in Fig. 5 was due to the stick spacers between the glass plates (see Fig. 1).

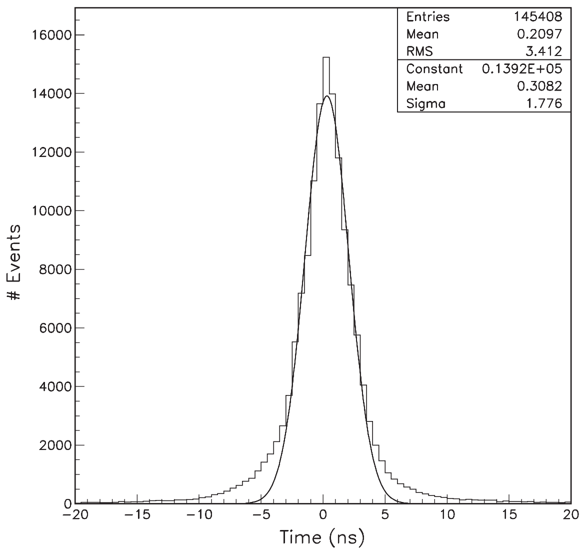

Fig. 4. Distribution of the time difference between two planes.

To evaluate the up/down discrimination we selected a sample of through going muons requiring a single cluster of fired strips with multiplicity $\leqslant 5$ in all the planes. The algorithm used for the $1/\beta$ analysis consisted in fitting the time measurements of each plane with a straight line in the t–z plane:

$$t(z) = \frac{z}{\beta} + q$$

z = vertical coordinate of a plane,

$\beta = v/c(c = 1)$,

discarding planes until the χ^2/d.o.f. is $\leqslant 0.5$ or the number of surviving planes was 3. With our sample of through going muons crossing the detector for a total length of 0.70 cm, we obtained a $1/\beta$ distribution with 14.6% of the events in the up going muon region (negative β), as shown in Fig. 6. It is worthwhile to point out that a rejection factor of $\geqslant 3 \times 10^{-5}$ is achievable with 4 m tracks, 10 planes crossed and operating the glass RPC at 8.4 kV [3]. All 20 planes of the MONOLITH prototype are presently being equipped with the new glass RPC described in this conference [5], for a systematic study of the up/down discrimination as a function of the number of planes, of the track length and of the applied voltage.

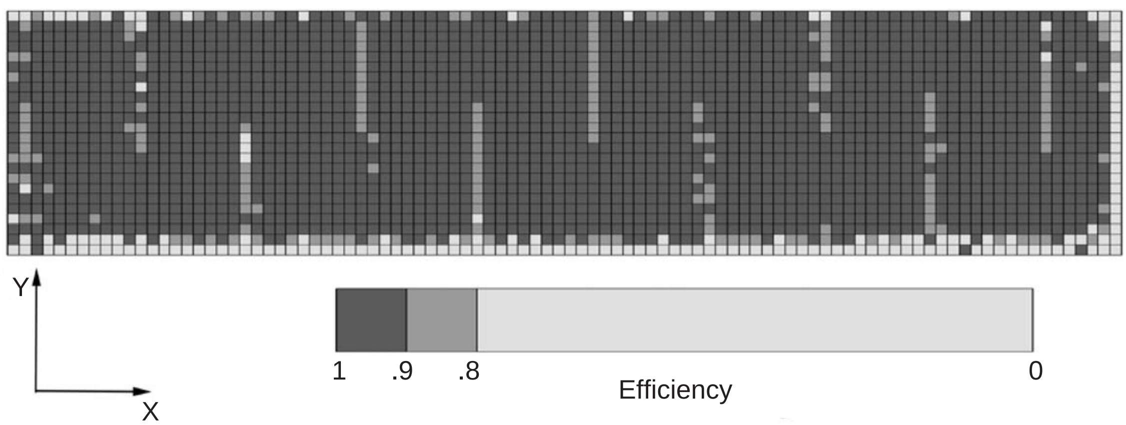

Fig. 5. Two-dimensional plot of the efficiency for one plane as a function of the position (top), and efficiency table (bottom).

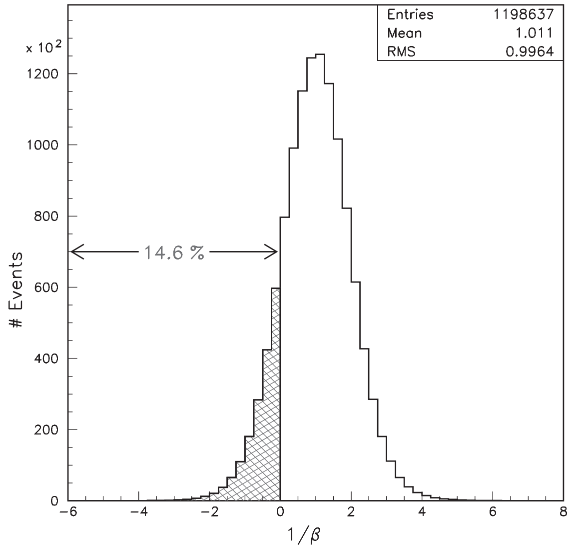

Fig. 6. $1/\beta$ distribution for 0.70 m long tracks.

4. Conclusion

Our present and previous measurements show that glass RPCs fulfill the requirements of large underground experiments [1,9]. The use of commercially available materials, the simple assembling and the possibility to exploit industrial procedure [14] make the Glass RPC suitable for mass production.

Acknowledgements

This work was supported by Istituto Nazionale di Fisica Nucleare (INFN).

References

[1] N.Y. Agafonova, et al., LNGS P26/2000 CERN/SPSC 2000-031, SPSC/M657, August 2000.
[2] C. Gustavino, Nucl. Instr. and Meth. A 457 (2001) 558.
[3] G. Bencivenni, et al., Nucl. Instr. and Meth. A 461 (2001) 319.
[4] M. Ambrosio, et al., Nucl. Instr. and Meth. A 456 (2000) 67.
[5] M. Ambrosio, et al., Performance of glass RPC with industrial silk-screening coated electrodes, Nucl. Instr. and Meth. (2003), these Proceedings.
[6] A. Candela et al., Performance of the readout system for MONOLITH, Nucl. Instr. and Meth. (2003), these Proceedings.
[7] A. Blondel, et al., Nucl. Instr. and Meth. A 451 (2000) 102.
[8] G.L. Fogli, et al., Phys. Rev. D 59 (1999) 033001.
[9] A. Cervera, et al., Nucl. Phys. B 579 (1–2) (2000) 17.
[10] MINOS proposal Chapter 7: Simulation of Detector Response.
[11] M. Selvi, Ph.D. Thesis, Bologna University, 2002.
[12] A. Candela et al., Monolith Memo 004/00.
[13] H. Menghetti, Thesis, University of Bologna, 2000.
[14] G.C. Trinchero et al., A study of new techniques for large scale glass RPC production, Nucl. Instr. and Meth. (2003), these Proceedings.