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The MONOLITH prototype

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Abstract

MONOLITH (Massive Observatory for Neutrino Oscillation or LImits on THeir existence) is the project of an experiment to study atmospheric neutrino oscillations with a massive magnetized iron detector. The baseline option is a 34 kt iron detector based on the use of about 50 000 m^2 of the glass Resistive Plate Chambers (glass RPCs) developed at the Laboratori Nazionali del Gran Sasso (LNGS). An 8 ton prototype equipped with 23 m^2 of glass RPC has been realized and tested at the T7-PS beam at CERN. The energy resolution for pions follows a $68\%/\sqrt{E(\mathrm{GeV})} + 2\%$ law for orthogonally incident particles, in the energy range between 2 and 10 GeV. The time resolution and the tracking capability of the glass RPC are suitable for the MONOLITH experiment. © 2000 Elsevier Science B.V. All rights reserved.

Keywords: RPC; Neutrino; Underground

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1. Introduction

The physics goals of the Massive Observatory for Neutrino Oscillation or LImits on THeir existence (MONOLITH) experiment are to establish or disprove the evidence of neutrino oscillations reported by the Super-Kamiokande collaboration [1–3], to measure the oscillation parameters and to clarify the nature of the oscillation mechanism. This program can be accomplished by exploiting the high-energy component of the atmospheric neutrino fluxes, using a high-density, large-mass tracking calorimeter. Briefly, the proposed detector consists of 120 horizontal magnetized iron planes 8 cm thick, 30 m long and 15 m wide. The iron slabs are interleaved by sensitive planes for a total active

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area of about 50 000 m^2. The proposed experiment requires the use of a detector with a spatial accuracy of 3 cm and a time resolution of 2 ns, in order to recognize the particle direction by means of the tracking and the time-of-flight techniques. An average energy resolution for the hadronic 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 [4]. The energy response and the resolution of a hadron calorimeter test module have been studied between 2 and 10 GeV. The prototype is equipped with the glass Resistive Plate Chambers (glass RPCs) developed at the Laboratori Nazionali del Gran Sasso (LNGS), that have been proposed as basic detectors for the MONOLITH experiment [4].

2. The MONOLITH prototype

The test module is made of 20 iron plates (100×100 cm^2) 5 cm thick, 2 cm apart, interleaved with 21 layers (100×110 cm^2) consisting of four glass RPCs 110 cm long, 25 cm wide and 9 mm thick; the total calorimeter depth is about 6 interaction lengths. The glass RPC (Fig. 1), consists of a pair of electrodes 245 mm wide, 1.85 mm thick, 108 cm long. The electrodes are made of commercially available float glass, having a volume resistivity at room temperature of about $\rho = 10^{12}$ Ω cm, suitable for operation in streamer mode in low particle rate environments. The 2 mm distance between the electrodes is ensured by NORYL injection molded spacers clamped at the edge of electrodes. As shown in Fig. 1, the shape of the spacers optimizes the gas flow. The high voltage (HV) supply is applied to the glass by means of water-based graphite, with a surface resistivity of about 400 kΩ/square. The glass plates and the spacers are inserted in a 250 mm wide NORYL envelope. The detector is closed by two NORYL end caps, in which are located the gas connectors.

This detector is conceived for a large and fast production: in fact, unlike bakelite, the float glass does not require any surface treatment [5]; the spacers are applied without gluing; the HV contacts are realized without soldering; the use of an envelope for the gas containment instead of a glued frame speeds up the assembling and prevents leakage.

The glass RPC has a gap precision of at least 0.5%, which ensures a good time resolution and uniform working conditions. In fact, the sticks of the spacers have a tolerance of ± 5 μm and are inserted without gluing. The glass sagitta due to the gravity and due to the electrostatic attraction between the electrodes (assuming an electric field of 4 kV/mm) is at the level of a few μm for each electrode. Finally, the pressure of the flowing gas cannot change the distance between the plates because the gas containment is ensured by the

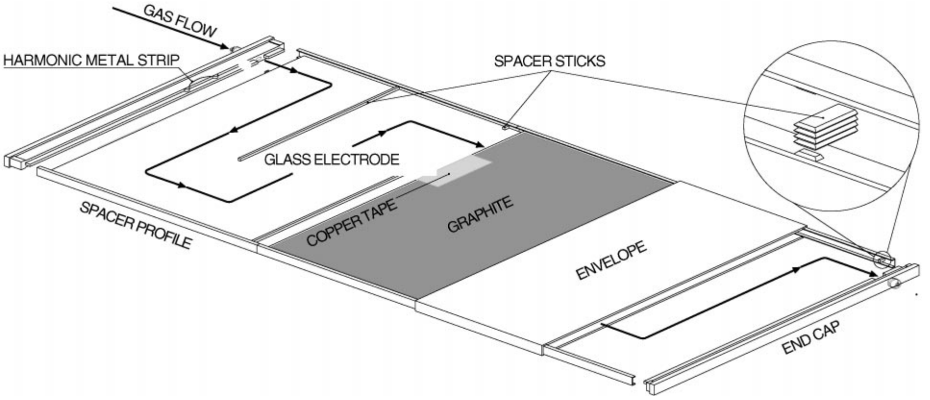

Fig. 1. Sketch of a glass RPC.

envelope and not by the electrodes themselves. The details of the glass RPC developed at the LNGS can be found in Ref. [6].

The readout system, developed at the LNGS, is based on the use of halogen-free flat cables acting as pick-up strips. The strips are coupled to the detector plane and are connected to ground by means of a $100 \times 100\ \mathrm{cm}^2$ FR4 vetronite foil acting as a shield. The other side of the detector plane faces a $100 \times 100\ \mathrm{cm}^2$ aluminium sheet connected to ground. The digital readout system of the ALEPH hadron calorimeter has been used for the event pattern in one view. The flat cables are connected on one side to the front end discriminators to obtain 1 cm wide strips. The other side is connected to cards developed at LNGS that perform charge and time measurements.

3. Experimental results

The measurements reported here have been done at the T7-PS facility at CERN. This beam provides particles (mainly pions) in the range between 2 and 10 GeV. The prototype was operated with argon + isobutane + R134A = 48% + 4% + 48% at 9.0 kV (single streamer signal ~ 200 pC), 400 V above the efficiency knee. The overall plane efficiency for muons by using the digital chain was about 94% with a mean multiplicity of 1.8 hits/plane. The efficiency measured by using the LNGS cards was about 96%, essentially due to the geometrical dead zone of the planes.

Fig. 2 shows a typical time distribution for 10 GeV muons crossing a plane. The time resolution is 1.7 ns. Although this result is adequate for our final experiment, a better result can be obtained by eliminating the electronic noise generated by the ALEPH digital cards (5 MHz clock freely running on board). Fig. 3 shows a typical induced charge distribution for 10 GeV muons crossing a plane. The sigma of the distribution is 12% of the peak and the distribution shows very little high charge tail.

Figs. 4–6 show the typical pattern for 10 GeV muons, pions and electrons taken from the online event display. The analog information for each plane is shown in the lower part of the display (without pedestal subtraction). The shower energy can be measured by hit counting, because the hit number is proportional to the total track length and therefore to the energy released. The mean

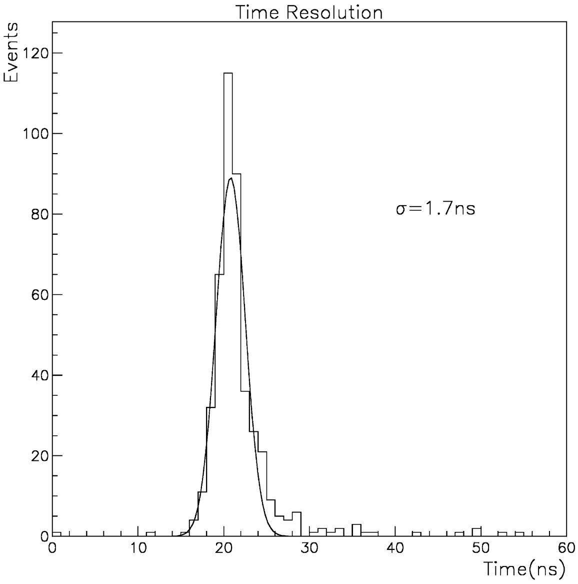

Fig. 2. Time distribution for 10 GeV muons crossing a plane.

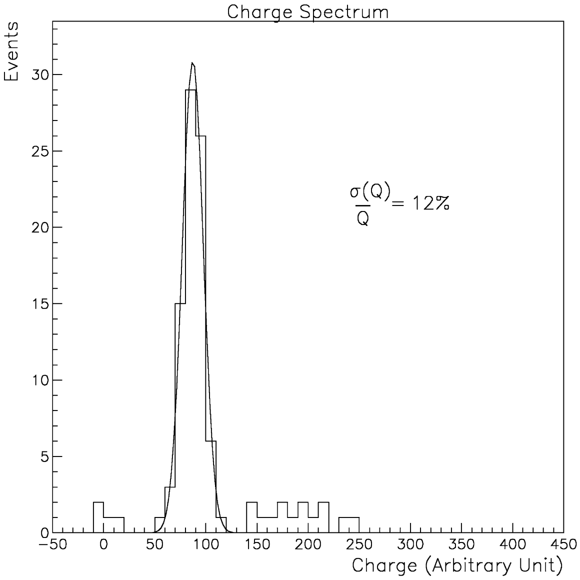

Fig. 3. Induced charge distribution for 10 GeV muons crossing a plane.

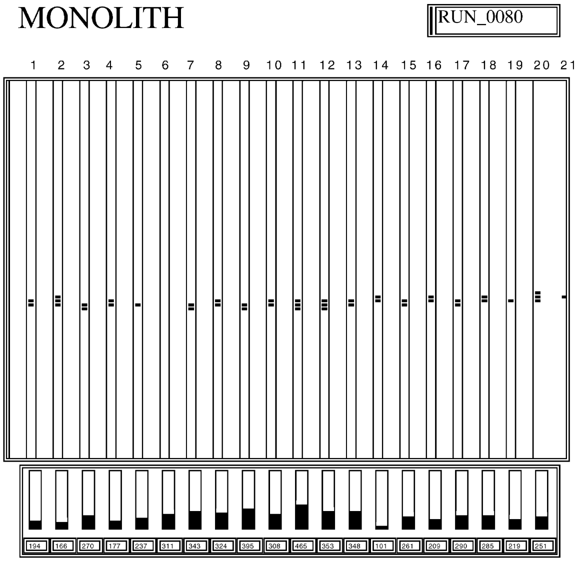

Fig. 4. Typical digital pattern of a 10 GeV muon.

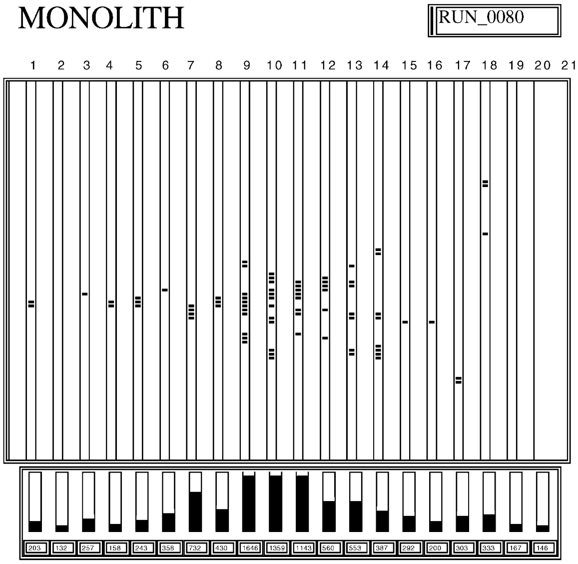

Fig. 5. Typical digital pattern of a 10 GeV pion.

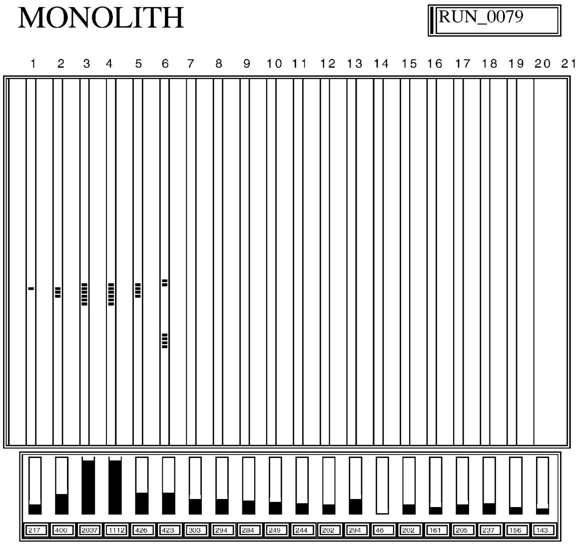

Fig. 6. Typical digital pattern of a 10 GeV electron.

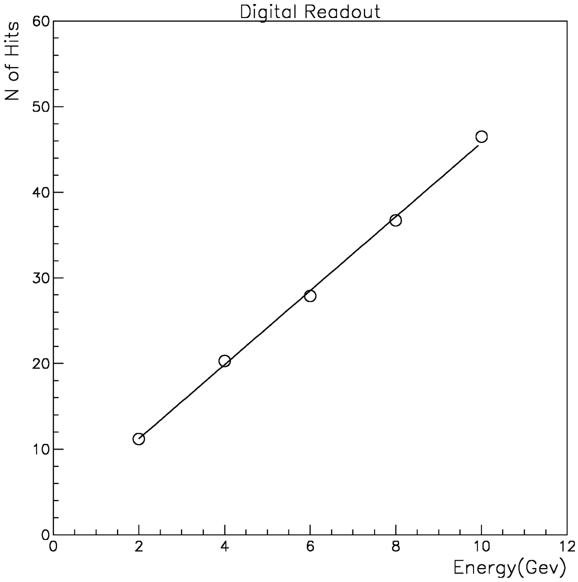

Fig. 7. Digital response for pions.

number of hits produced by pions as a function of the energy is given in Fig. 7; no saturation effects were found in the investigated energy range and a calibration value of 4.4 hits/GeV was obtained. As shown in Fig. 8, the energy resolution can be parameterized as $68\%/\sqrt{E(\mathrm{GeV})} + 2\%$. The shower resolution for different sampling densities was obtained offline by appropriately selecting the detector planes. Fig. 9 shows that the resolution is better than $100\%/\sqrt{E(\mathrm{GeV})}$ up to shower sampling of 20 cm of iron. In the MONOLITH project,

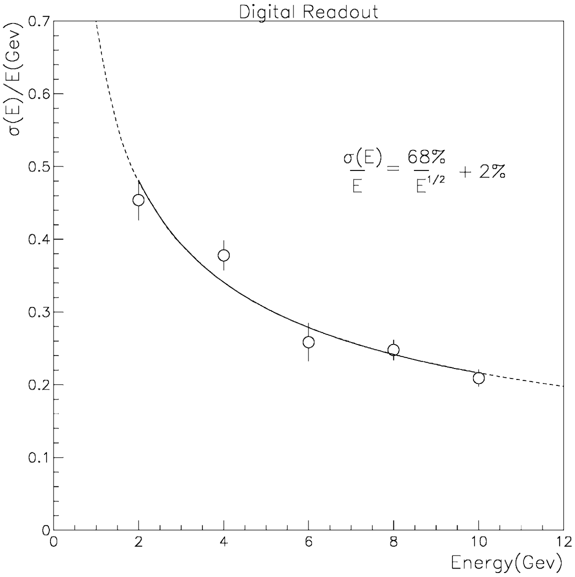

Fig. 8. Digital resolution for pions.

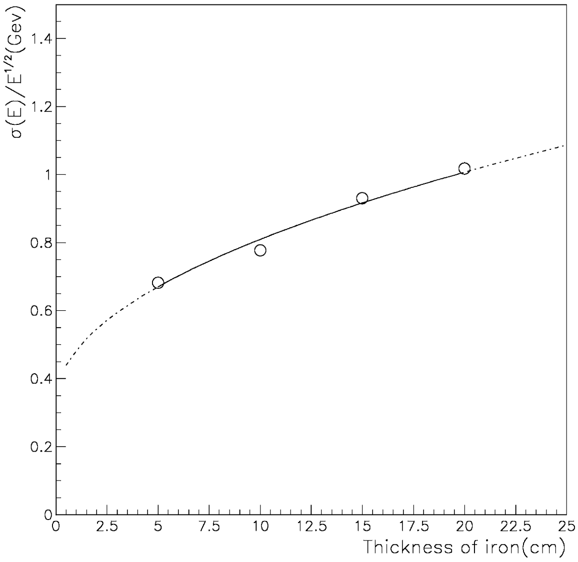

Fig. 9. Digital hadronic resolution as a function of the iron thickness.

20 cm sampling corresponds to showers developing at 66° with respect to the zenith angle.

It is worth observing that, in a digital calorimeter, a good linearity and resolution is possible only if the probability to have more than one track on the same strip is negligible. A high track density (due to high energy and/or electromagnetic showers) determines a loss of linearity with the worsening of the resolution. The same effect occurs when using wide pick-up strips.

Concerning the analog readout, the total charge is proportional to the total number of streamers and therefore to the total track length. Thus the charge collected can be used to measure the energy released by the shower. The energy resolution obtained with the analog readout follows a $96\%/\sqrt{E(\mathrm{GeV})}$ law. It is worse than expected mainly because the analog method strongly depends on the precision of the coupling between pick-up and detector planes [7], while the intrinsic charge spread of the single streamer (see Fig. 3) gives a negligible effect on the resolution.

In conclusion, the digital readout is weakly dependent on the working conditions, but it suffers effects of saturation at high track density. On the contrary, the analog readout is linear up to higher energies, but presents more difficulties when used in a large apparatus (gas mixture stability, precision in construction, etc.).

4. Conclusion

The time resolution, the tracking capability and the energy response of the glass RPC calorimeter tested are adequate for an atmospheric neutrino experiment. We point out the strength and reliability of these detectors that were transported from LNGS to CERN without any particular care. The use of commercially available materials and the simple assembling make the glass RPC suitable for mass production. The modularity of the detector and its easy operation meet the requirements for a feasible large neutrino experiment.

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