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THE LIMITED STREAMER TUBE SYSTEM OF THE CHARM COLLABORATION

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ABSTRACT

A new detector system of 20,000 aluminium tubes, working in the limited streamer mode, has been added to the existing fine-grained neutrino calorimeter of the CHARM Collaboration in order to improve its spatial resolution. The system has been operational for nearly two years. The characteristics and performance of the streamer tubes are described and some results obtained in a test beam are presented.

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1. INTRODUCTION

In the last few years new wire devices working in the so-called "limited streamer regime" have been developed. This paper describes the use of limited streamer tubes in a neutrino experiment at the CERN 400 GeV SPS¹⁾. The detector of the CHARM Collaboration²⁾ consists of a fine-grained target calorimeter and a surrounding shell of magnetized iron; a schematic diagram is shown in fig. 1. Seventy-eight plates of 8 cm thick marble constitute the passive material. The calorimeter is instrumented with scintillation counters and proportional drift tubes (PDT). Both scintillators and tubes are used for measuring the energy and the direction of the hadronic and electromagnetic showers which are produced in the interaction of neutrinos. Moreover, the PDT are also used for (i) the determination of the shower vertex, (ii) the measurement of the muon direction, and (iii) for sampling the hadron shower energy between the plates of the iron shell. We have recently added to this detector 77 layers of 256 streamer tubes, each layer covering 285 x 265 cm², which are inserted between the scintillator planes and the marble plates. The main aim was to achieve a better spatial resolution in the measurement of the direction of electromagnetic showers, in the study of the neutral current reaction³⁾

$$\bar{\nu}_{\mu}^{(-)} + e^{-} \rightarrow \bar{\nu}_{\mu}^{(-)} + e^{-}.$$

Of course the streamer tubes provide information on other parameters of hadronic and electromagnetic showers. Some of the results obtained in a test beam are reported in Section 5.

The use of streamer tubes in calorimetry for high-energy electromagnetic and hadronic shower detection is new. Two experiments⁴⁾ have already used streamer tubes (with resistive cathodes) as detectors for low or intermediate energy γ rays. After completion of the present detector, 50,000 plastic streamer tubes were built and are at present running in a proton-decay experiment⁵⁾.

2. A SHORT HISTORY OF THE LIMITED STREAMER REGIME

The limited streamer mode, characterized by large wire signals and wide high voltage operating range, was at first thought to be a limited Geiger regime⁶⁾. In later studies⁷⁾⁸⁾ it turned out to be characterized by a streamer discharge mostly on one side of the wire, while the propagation towards the cathode is limited by the reduction of the electric field due to cylindrical geometry.

The first attempt to use the limited streamer mode in building detectors was made in connection with the development of tubes with resistive cathode by Iarocci and collaborators⁹⁾. Layers of plastic tubes with external strips to pick up the induced pulses for the longitudinal coordinate readout were then used in the already-quoted experiments⁴⁾⁵⁾.

An extensive study of all the parameters that influence the streamer regime (wire diameter, gas composition, and cathode materials) is reported in refs. 8 and 10. It is shown there that the dead-time is of the order of 100 μ s, and affects only a small region of the wire near the streamer. This is not a limitation for a neutrino detector or any other device in a low-intensity environment.

3. THE CHAMBER SYSTEM

3.1 CATHODE MATERIAL AND TUBE DIMENSIONS

Different metals can be used as cathode; for the CHARM calorimeter aluminium tubes were chosen, for reasons of mechanical stability and as cheap extruded multicell profiles are readily available. Particular care was taken to study possible deterioration of the inner surfaces of the tubes which could be caused by the presence of isobutane and/or by high rate discharges. About 6×10^9 pulses were induced on a small region (≈ 1 cm) of a tube filled with a high concentration of isobutane (argon:isobutane = 1:3), at a rate of 10 kHz. During and after this test no change of the tube behaviour was found; the total charge

collected was 2.5 C. However, a tube may be irreversibly spoilt if the high tension is applied before a good gas equilibrium is established. Tubes made of different alloys were tested by irradiating them with intense radioactive sources. Some of them remained in a discharge regime when the source was removed. In many cases the correct behaviour was restored by switching off the high voltage; otherwise the tube was permanently damaged. The effect was attributed to the quality of the aluminium surface and, in particular, to the percentage of magnesium present on the inner surface; however, no systematic studies were carried out. With the chosen alloy*) we did not find this problem.

A good spatial resolution requires a tube with a small cross-section, but when the wire-cathode distance decreases, a higher percentage of the quenching gas is needed to reach a stable regime. In this case the working high voltage increases and the centring of the wire becomes critical. The minimum dimensions tested were $7 \times 7 \text{ mm}^2$, but for a safe mass production we chose $9 \times 9 \text{ mm}^2$.

The centring of the wire over the whole length was ensured by inserting mylar spacers every 50 cm. With this solution a tube works normally even with a 2 cm sagitta on 285 cm length. No electrical problems, discharges, or dead zones were found to arise from the presence of the spacers.

3.2 WIRE DIAMETER AND HIGH VOLTAGE

For a given tube geometry, the width of the high voltage plateau increases and its centre moves to a higher value when one increases either the relative concentration of the quenching component of the gas mixture (isobutane in our case) or the wire diameter. Figure 2 shows a curve of a typical single counting rate for three different compositions of the argon-isobutane mixture in an $8 \times 8 \text{ mm}^2$ tube with $100 \mu\text{m}$ sense wire. Single rate curves for the same gas mixture and different wire diameters, 40, 50 and $100 \mu\text{m}$, are shown in Fig. 3. The

*) Alloy 3569TA, Pandolfo Alluminio Spa, Padova, Italy.

pulse height does not change drastically as a function of the wire diameters: at a high voltage corresponding to 100 V above the knee of the plateau curve, the pulse height increases by about a factor of 1.5 in going from 40 to 100 μm . By changing the isobutane concentration with fixed wire diameter the pulse duration decreases from about 100 ns with 50% isobutane to less than 50 ns with 80% isobutane.

At higher voltages, after-pulses occur. They are responsible for the rise of the counting rates of Figs. 2 and 3 beyond the plateau. As discussed in ref. 10, these after-pulses are due to secondary discharges contiguous to the primary ones generated by electrons extracted from the cathode. The presence of the after-pulses influences only the recovery time of the tube, since the length of wire covered by the discharge is longer.

As a compromise between mechanical and electrical reliability it was decided to use stainless steel wires (50 μm diameter) and 1:3 argon-isobutane gas composition, in order to achieve uncritical operating conditions. Under these conditions the plateau starts at ≈ 3.6 kV and has a width of more than 500 V.

3.3 CHAMBER CONSTRUCTION TECHNIQUE

The construction technique was imposed by two restrictions: (i) only a 13 mm gap was available in the existing detector for insertion of $3 \times 3 \text{ m}^2$ planes, and (ii) the extremities of the chambers were not accessible because of the iron shell surrounding the marble plates. To cope with the second restriction, and in particular to allow for possible repairs, the decoupling high-voltage capacitors were placed outside the detector in an accessible location with the voltage applied to the wires through 1.25 m long 50 Ω cables. It was also decided that broken wires would not be repaired and an irreversible closed construction was adopted.

The elements of a chamber and their details are shown in Figs. 4 and 5. A single chamber is built by gluing together two aluminium profiles of eight cells each; 16 such chambers are assembled together to form a plane. The wire, stainless steel 50 μm in diameter, is clamped with conic pins in two brass blocks situated in two plastic end boxes under a tension of 1 N. One of the end boxes contains the gas inlet and outlet, and a small circuit board on which each wire is connected to its cable. At the other extremity of the cables, a second printed-circuit board supports the capacitors, the high-voltage line, and the test input. The electronics card for readout is plugged on this board. In Table 1, we summarize the main characteristics of the assembly.

Table 1
Properties of one streamer tube

Tube material	extruded Al alloy
Inner cell dimensions	9 x 9 mm ²
Wall thickness	1 mm
No. of tubes per chamber	16
Wire material	stainless steel*)
Wire diameter	50 μm
Wire tension	1 N
Spacers (material)	mylar 0.2 mm thick
Spacers (central hole)	0.4 mm diameter
No. of spacers per tube	6
End caps (material)	rynite 530**)

*) Microfil Lausanne

**) Du Pont de Nemours

3.4 GAS SYSTEM

Owing to the uncritical conditions, the gas system can be kept simple. The 77 planes of streamer tubes represent a gas volume of 4500 l. This system has been divided into 4 identical subsystems and each plane can be isolated individually by valves to allow easy repair. Details can be seen in the circuit diagram of Fig. 6.

The mixing ratio is determined by flow-meters with optical limiters. The gas flow into each subsystem is set at about 0.8 l/min; the overpressure inside the chambers is kept at around 30 mbar. These values are measured by flow meters at the inlet and outlet to each subsystem. Note that the gas flow can be interrupted for more than one day without changing the performance of the system.

The isobutane/argon mixture and the outgassing impurities of the chamber walls are homogenized with the help of a membrane pump parallel to each subsystem which circulates the gas through the system once every hour.

4. ELECTRONICS

4.1 CONSTRAINTS FOR THE ELECTRONICS

In order to be compatible with the other electronics of the detector, the streamer-tube electronics has to perform within the following constraints.

1. Mean number of hits per event: 660.
2. Maximum number of tubes hit per plane per event: 210.
3. Maximum number of events accepted before a CAMAC transfer: 40.
4. Minimum time between two events: 10 μ s.
5. Possibility of rejecting an event by a slow trigger (second level decision).

These constraints imply that local event buffering is necessary. Zero suppression is performed at the readout phase and clustering during data analysis, thus considerably simplifying the electronics system.

4.2 LOGIC SYSTEM

The logic interconnections are based on a hierarchical system, as shown in fig. 7a. Sixteen channels are mounted on a "daughter" card to accept and buffer the signals from the wires of one chamber. A "mother" card groups the outputs from 16 daughter cards. A "grandmother" card groups the outputs from 12 "mother" cards and finally the CAMAC readout module treats the outputs from 7 grandmother cards. The mother, grandmother, and readout box multiplex the data to the event buffer, which is located in the readout box, and perform the fan-out of the control signals needed for the logic system.

4.3 FRONT-END ELECTRONICS

The front-end electronics is shown in Fig. 7b. The signals from the streamer tubes are transmitted to the daughter cards via 125 cm long coaxial cables of 50Ω . These cables load the signals with a capacity of ≈ 100 pF. The $1.8 \text{ k}\Omega$ input resistance of the daughter cards is in parallel with this capacitance. With this load the mean tube signal is ≈ 50 mV, with a FWHM duration of ≈ 100 ns. With a signal of this size a simple comparator can be used for the front end. The comparator (LM311) is wired as a monostable with a mean threshold of 20 mV. The output pulse length is $\approx 1 \mu\text{s}$, which gives a dead time of $\approx 2 \mu\text{s}$. This is a good compromise to avoid after-pulsing and recording previous tracks.

The outputs from the comparator are latched by a signal derived from the scintillators. The output of the latches are written into a FIFO memory buffer $5 \mu\text{s}$ after the trigger if no slow veto has occurred. Thus the data for a maximum of 40 events are stored in the FIFOs.

At the end of the machine burst, the FIFOs are read in parallel and then their outputs scanned by the readout box, suppressing zeros and loading the event buffer with one event from the tubes. Approximately 1K words of 32 bits are necessary to buffer one event. Once an event is buffered a CAMAC transfer can take place.

5. TESTS AND RESULTS

5.1 TESTING PROCEDURE

For each of the 20,000 tubes a high voltage plateau was made using a cosmic ray telescope. The standard chain daughter card/mother card was used for the readout. In addition, the following tests were made:

- i) Visual inspection of the pulse shape for each tube: in this manner we looked for anomalous after pulses and for the presence of low-rate discharges due to improper cleaning of the tube.
- ii) Measurement of the current consumption of each subunit: the value of the current is about 0.3 nA per tube per Hz.
- iii) Single rate plateau: this test was made only on about 5% of the tubes. The single rate of each tube is 9 Hz when the tube is completely unscreened and is reduced to ≈ 5 Hz when the chamber is installed in the set up and screened by the iron and the marble of the detector.

The efficiency curve for a chamber is shown in Fig. 8; the band in the rising part is the total spread over the whole population of chambers tested and includes: differences among the chambers due to their constructional details (for example variations in the diameter and the centring of the wire), the unc-

ertainty in the gas mixture setting, and the spread in response of the electronic cards.

A charge spectrum at 3.7 kV, the chosen working voltage, is shown in Fig. 9: the mean charge is ≈ 30 pC for an integration time of 500 ns. We note that the cosmic-ray trigger accepted very inclined tracks which produce ionization over a large region of wire. Owing to the lengthening of the wire region covered by the multiplication process for such inclined tracks and the generation of multiple streamers, the charge distribution extends to very high values.

At higher voltages (≥ 3.9 kV) the tail of high pulses induces some cross talk in adjacent channels. With the threshold used in our electronics the cross talk level is less than a few per cent in the two channels adjacent to the firing one and is mainly due to the inclined tracks mentioned above.

5.2 OPERATING EXPERIENCE

One third of the whole system, 24 planes making a total of more than 6000 wires, was installed in the CERN SPS neutrino beam two years ago and used for the normal experimental neutrino runs. The rest was installed during an SPS shutdown, i.e. between June 1980 and October 1980. The whole system has operated stably and reliably since the beginning and neutrino data were collected starting in Spring 1981. The mean pulse height, the single rates, and the current drain remained constant, showing that no degenerative processes were occurring. The spurious hit probability was checked in events containing only a single traversing muon and was found to be lower than 10^{-4} per tube. The detection efficiency of a plane for traversing muons is 85%, almost totally explained by the geometrical efficiency of 87%.

5.3 FIRST RESULTS IN A TEST BEAM

Part of the calorimeter, 36 planes in total, was put in a test beam line for calibration. The beam contained electrons and pions from a minimum energy of 5 GeV up to 140 GeV. We report here first results concerning the performance of the streamer system. The data were obtained using only the information given by the 36 streamer planes interleaved with 8 cm of marble, 0.4 cm of aluminium, and 3 cm of plastic scintillator. All results, concerning the scintillator, the PDT systems, and the streamer tubes, will be reported in a later paper. The energy of the incoming particle can be estimated from the total number of the tubes fired, N_{tot} ; the dependence of N_{tot} on the energy is reported in Fig. 10, both for pions and electrons. The data refer to showers fully contained in the calorimeter. Owing to the digital readout, the response for high-energy pions is not linear, because on an average, more than one particle hit the tubes in the central part of the shower. The electromagnetic showers are so dense, i.e. the particles are so close to each other, that for electrons saturation already appears at low energy. In Fig. 11 the energy resolutions are shown: deviations from the $1/\sqrt{E}$ dependence are evident in the region of non-linearity as expected.

The difference in density between electromagnetic and hadronic showers may be used for separating electrons from pions. We have developed an algorithm that counts the non-fired tubes (holes), in the shower region, and compares the "longitudinal profile of holes" with an average electromagnetic shower of the same energy. The result is shown in Fig. 12: the efficiencies for electrons and pions are reported as a function of the energy. The pion rejection rate is large, taking into account that for a light calorimeter ($\langle Z \rangle \approx 13$) the lengths of hadronic and electromagnetic showers of equal energy are very similar³⁾, so that the e/π separation power has to be based essentially on the transverse properties of the showers.

6. CONCLUDING REMARKS

We have built a large-scale system of limited streamer tubes and installed them in an existing neutrino detector. The construction and assembly turned out to be rather cheap and simple. The working parameters are not critical and the system operates stably and reliably with a very satisfactory uniformity of response.

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9. FIGURE CAPTIONS

- Fig. 1 Partial view of the CHARM fine-grain calorimeter and of the muon spectrometer.
- Fig. 2 Single counting rates for different gas mixtures. The tube dimensions were $8 \times 8 \text{ mm}^2$ with a $100 \text{ }\mu\text{m}$ sense wire; the electronics threshold was $30 \text{ mV}/50 \text{ }\Omega$, the dead time $1.5 \text{ }\mu\text{s}$.
- Fig. 3 Single counting rates for different wire diameters in an argon-isobutane mixture 1:3. Tube dimensions: $9 \times 9 \text{ mm}^2$; electronics threshold: $20 \text{ mV}/50 \text{ }\Omega$, dead time $1.5 \text{ }\mu\text{sec}$.
- Fig. 4 Elements of a chamber.
- Fig. 5 Assembly of a layer formed of 16 chambers.
- Fig. 6 The gas system.
- Fig. 7a) The logic of the daughter card.
 b) The data-reading system.
- Fig. 8 Efficiency of the tubes versus the high voltage. The band indicates the range of about 1000 tubes tested.
- Fig. 9 Charge distribution for cosmic rays traversing one tube. Integration time: 500 ns ; high voltage: 3.7 kV .
- Fig. 10 Energy response of the streamer-tube calorimeter. The total number of tubes fired is reported as a function of the beam energy for pions and electrons.
- Fig. 11 Energy resolution of the streamer-tube calorimeter pions and electrons.
- Fig. 12 Efficiencies for electrons and pions of the algorithm which selects electromagnetic showers.

Fig. 1

Fig. 2

Fig. 3

Fig. 4

Fig. 5

Fig. 6

a)

b)

Fig. 7

Fig. 8

Fig. 9

Fig. 10

Fig. 12