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LARGE-SERIES TEST OF LIMITED STREAMER TUBES

M. Caria¹⁾, A. Ereditato²⁾, W. Flegel³⁾, C. Gatto²⁾, E. Gorini²⁾, F. Grancagnolo²⁾, R. Iasevoli²⁾,
A. King³⁾, V. Palladino²⁾, A. Seiden⁴⁾ and P. Strolin²⁾

ABSTRACT

A detailed description of the set-up and of the procedure used for the large-scale quality test of the 154,560 limited streamer tubes which compose the CHARM II calorimeter is given. The size of the project has imposed the adoption of a procedure that is simple and fast, yet dependable. The high reliability of the test has been proven by the stability of the system after 20 months of continuous operation.

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- 1) Dipartimento di Scienze Fisiche, University of Cagliari, Italy.
 - 2) Dipartimento di Fisica, University of Naples, and INFN Naples, Italy.
 - 3) CERN, Geneva, Switzerland.
 - 4) CERN, on leave from the University of California at Santa Cruz, Calif., USA.

1. INTRODUCTION

The CHARM II Collaboration has recently completed the construction and the assembly of a massive, fine-grained, low-density calorimeter dedicated to the study of $\langle \bar{\nu}_\mu \rangle e$ scattering. The main physics aim of the experiment is to arrive at a precise determination ($\pm 2\%$) of the electroweak mixing angle $\sin^2\theta_w$ by means of the measurement of the ratio between the cross-sections for elastic scattering of ν_μ and $\bar{\nu}_\mu$ off electrons [1].

The major requirements for the detector are: a) fine transverse and longitudinal granularities, both for precise shower vertex and direction measurements, and for e/π separation (transverse) and e/γ separation (longitudinal); b) large fiducial mass because of the smallness of the cross-section.

The very large number of channels (154,560 tubes arranged in 19,320 profiles or 9,660 chambers) and the high production rate (60 chambers per day) imposed a strong constraint on the amount of time that could be dedicated to testing a single chamber. Moreover, because of the very dense packing of the chamber planes in the final calorimeter assembly, which makes the replacement of a single chamber in the apparatus extremely difficult, the reliability of the test was one of the main goals when designing the test stand.

Similar situations are being encountered in other large experiments making use of limited streamer tubes, and the question whether fast and dependable tests can be carried out successfully on a large scale is of crucial importance for the new generation of experiments which make use of these tubes.

2. DESCRIPTION OF THE CALORIMETER

The calorimeter is composed of 420 modules with a $3.7 \times 3.7 \text{ m}^2$ active area; these modules are grouped into 21 identical units. Each module consists of a glass target-plane, 48 mm (0.5 radiation length) thick, followed by a plane of 352 plastic streamer tubes (1 cm wire spacing). The readout of the wire signal is digital, whilst the pick-up cathode strips (21 mm spacing), oriented in a projection orthogonal to the wires, have analog readout in order to determine the centroid position of single tracks and the total energy of showers.

A low-Z target material has been chosen for optimizing the angular resolution of electromagnetic showers, which is proportional to Z. Moreover, since the ν_μ and $\bar{\nu}_\mu$ fluxes will be monitored by means of the quasi-elastic processes $\nu_\mu n \rightarrow \mu^- p$ and $\bar{\nu}_\mu p \rightarrow \mu^+ n$, the target material had to be isoscalar. Glass fulfils these requirements.

The consecutive planes have their wire orientation alternately rotated by 90° . Planes with the same orientation are staggered, in the direction orthogonal to the wires, by half-wire spacing, and in the direction orthogonal to the pick-up strips, by half-strip spacing.

A set of 5 such modules is followed by one plane of 20 scintillators ($3 \times 3 \text{ m}^2$ sensitive area), and each set of 20 modules is followed by one plane of streamer tubes with wires inclined by $\pm 7^\circ$ with respect to the vertical direction.

One module of the calorimeter arrangement is illustrated in fig. 1. The total mass of the calorimeter is 692 tonnes.

The streamer-tube system contains 154,560 wires and digital readout channels, and 73,920 strips grouped in 9,240 readout channels. The scintillator system is composed of 1,540 analog channels.

The streamer-tube system has already been described in detail elsewhere [2, 3]; it consists of extruded PVC profiles with eight open cells, each of $9 \times 9 \text{ mm}^2$ inner dimension, and with a $100 \mu\text{m}$ diameter silver-plated Cu-Be wire in the centre of each cell. The cells are closed with a PVC cover sheet. Two eight-cell profiles, closed with two such covers, are mounted in a gas-tight PVC envelope and form one single chamber unit. The centring of the wire along the whole length is ensured by inserting wire-holders, made of polyethylene, every 47.5 cm. The position of the wire-holders is shifted along the wire by 10–15 cm with respect to the preceding plane that has the same wire direction. This arrangement repeats itself every 10 planes, thus assuring a uniform detection efficiency for particles traversing the whole detector. The inner surfaces of both the profile and the cover are coated with a layer of low conductivity material. This allows the detection of the streamer signal by the pick-up strips placed outside the PVC envelope containing the streamer cells. The conducting layer used for the profiles is a graphite paint; its resistivity varies between $20 \text{ k}\Omega/\text{square}$ and $20 \text{ M}\Omega/\text{square}$. The covers are coated with a mixture of carbon black in PVDC (Polyvinylidene chloride)*); its resistivity, of $\approx 1 \text{ M}\Omega/\text{square}$, varies by only a few per cent. The analog strips face the covers, whose uniform resistivity guarantees a constant transparency for streamer signals.

During a calibration run, part of the calorimeter (about 20% of it) was exposed to electron and pion beams. The results of this test, together with cosmic-ray test results, are reported in refs. [2] and [3].

3. TEST STAND, GAS, AND HV SYSTEMS

The test proceeded in parallel for 64 chambers (128 profiles, 8 wires each) per test session. Each session lasted 48 hours. Two test stands (A and B) were operating simultaneously but independently of each other, with the test procedure shifted in time by 24 hours, thus giving a continuous output of 64 chambers per day and matching the production rate. The set-up had therefore to be designed in such a way as to allow fast connections of the chambers to the gas, HV, and readout systems.

The chambers were placed horizontally, one on top of the other up to a maximum of eight, on strong, flat, iron-supported shelves (small bendings of the profiles could alter the electric field distribution inside the cell). They were separated from each other by grounded aluminium foils in order to prevent the accumulation of static charges on the outside of the PVC envelopes, and to shield each chamber from possible mutually induced discharges.

The gas connectors were fixed to a panel attached to one end of the testing table. In order to allow for tolerances of gas end-caps, these connectors could pivot about their axis, thus facilitating and speeding-up the connecting and disconnecting of the gas inputs and outputs by sliding the chambers along the table towards insertion (fig. 2). Four chambers were connected in series for the gas flow, and sixteen such series were connected in parallel on each stand in order to ensure a

*) This was done by the firm Aerni-Leuch, Berne, Switzerland.

uniformity of gas exchange between the chambers that was compatible with the gas flow-rate used. The 64 chambers at the 'gas filling' stage of the test procedure (for example, stand A), each received a flow rate of about 2 NI/h, equivalent to a change in volume every 3 hours, whilst those at the 'HV conditioning' stage (stand B) had a flow rate of 0.5 NI/h—a total of about 160 NI/h for both stands. Figure 3 shows details of the gas system.

The HV system connected each profile to a single high-voltage channel. The large number of HV inputs and ground returns (128) made it necessary to develop multiple fast connectors, as illustrated in fig. 4. The current drawn off and the actual voltage of each profile were monitored through a minicomputer and a system of CAMAC-controllable HV modules. In addition, the history of each HV channel was recorded during the conditioning stage in order to help classify the profiles in cases of marginal behaviour.

4. TEST PROCEDURE

The test of each chamber was performed right after construction in order to have an immediate feedback on the quality of the production.

The already mentioned time constraint was such that one had to rule out the possibility of making efficiency curves, of looking at pulse-height spectra (induced either by cosmics or by radioactive sources), and of scanning along the wires for uniformity of external pick-up of the signal in every single chamber.

It turns out that the most representative parameter describing the performance of a chamber is the current generated by the passage of cosmic rays at a fixed value of high voltage and for a given gas mixture. Typical values of the current are of the order of 50 nA per eight-wire, 3.7 m long profile, at a voltage of 4.4 kV and with a gas mixture of argon (27%) + isobutane (73%).

The test proceeded as follows.

4.1 Gas-leak test

The chambers were inflated with compressed air at an overpressure of about 100 Torr and immersed for several seconds in a water bath. The sensitivity of the leak search, performed by visual inspection, was calculated to be of the order of 10^{-2} Torr 1/s. Almost all the leaks found were located in the welding between the end-caps and the PVC envelope, indicating a wearing away of the Teflon jaws used for the thermal welding.

4.2 Gas filling and flushing

The chambers were first evacuated to a residual pressure of about 50 Torr, to speed up the establishing of the correct gas mixture, then flushed with pure argon while still being pumped off, in order to rinse away eventual residual impurities.

The chambers were then filled with the proper gas mixture [argon (27%) + isobutane (73%)] and flushed for a length of time corresponding to at least five volume changes (about 20 hours).

4.3 Short-circuit search

Before starting the HV conditioning, a search for short circuits was performed by looking for ohmic losses at low voltages. These were almost always due to faulty HV or signal connectors and only rarely ($< 0.2\%$ of all profiles) to loose wires (generally because of defective weldings of the plastic spacer around the wire).

4.4 HV conditioning

This step was performed with the help of a minicomputer which ran the conditioning program.

Each profile was first brought up to 3500 V in coarse steps of 500 V (with a ramp-up voltage of 100 V/s), then, with finer and finer steps (from 100 V at 50 V/s to 50 V at 20 V/s), up to the final value of 4550 V, which safely corresponded to about 300 V above the onset of the singles rate plateau.

The profiles were kept for ≈ 10 min at each voltage step, and their average currents were recorded during this period. The subsequent step was undertaken if the last reading was below $2 \mu\text{A}$ and the current had not been increasing during that period. This whole procedure lasted about 4 hours, leaving about 20 hours for the chambers to be burnt in at the highest HV value.

If a profile did not satisfy the criteria which would allow the conditioning to proceed, its voltage was switched to zero and raised again, following the stepping procedure described, until these criteria were satisfied.

Chambers not reaching the value of 4550 V, or recording a current $> 1 \mu\text{A}$ at that value, were tagged as 'bad' and retested at least once more.

4.5 Inspection of failures

Chambers which had failed the conditioning test at least twice were carefully inspected and grouped into different classes of failures.

5. FAILURE RATES

During production of the chambers, a lot of attention was devoted to trying to avoid what were thought to be the main causes of failure, such as lack of cleanliness of the assembly factor, faulty geometry of the PVC extruded profiles, bad quality of solderings (of the wires to the holding PC boards) and of weldings (of the wires to the polyethylene spacers), wrong mechanical tension of the strung wires, etc. Therefore, *a posteriori*, it is now difficult to single out quantitatively the fractions that these parameters might have contributed to the global failure rate. However, after having cured these problems, we were left with a failure rate per profile of about 12% (it was 18% after the first trial, 1/3 of which passed a second test and could therefore be accepted).

An inspection of the failed profiles showed that in 40% of the cases (5% of the total) the failure could be ascribed to faulty painting of the profiles (barely visible spots or stripes with missing paint, mostly in the corners or on the side walls). A 'naked eye' inspection of the remaining 60% (7% of the total) did not show any apparent cause of failure; however, after having been completely repainted, they still had a failure rate compatible with 12%, hence of 1% of the total.

The 1% failure rate is indicative of the limitation of the applied procedure, and represents the 'confusion' between 'bad' and 'good' profiles. In fact, a further test on good profiles also gave a failure rate of about 1%.

6. CONCLUSIONS

The size of the project for testing the 154,560 limited streamer tubes of the CHARM III calorimeter has necessitated the use of a rugged, simple, and rapid control procedure, which would, at the same time, be highly reliable.

Twenty hours of careful monitoring of the current drawn off at different high voltages has proved to be sufficient for singling out malfunctioning profiles.

In a very large number of cases, the cause of the profiles being faulty was the imperfect application of the graphite paint. If this is avoided, a failure rate of the order of 1% can be reached.

The reliability of the test is demonstrated by the stability of the system. About 20% ($\approx 30,000$) of the calorimeter tubes have been continuously in operation since August 1985 at voltages in the range 4300–4450 V (the operating value is set at 4300 V), whereas the rest of the calorimeter tubes ($\approx 120,000$) have been gradually switched on from April to August 1986. The average current drawn off is of the order of a few microampere per plane of streamer tubes (44 profiles; 8 wires each, 3.7 m long).

Up to 19 December 1986 we had about 60 profiles (out of 19,320) with a current such as to require them to be disconnected ($> 25 \mu\text{A}$); most of them started discharging right at the inception of their operation. We are investigating the possibility to recuperate part of them for which we can isolate the sick wire.

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Figure captions

Fig.1: Schematic drawing of a calorimeter module.

Fig. 2: Particulars of the chamber insertion.

Fig. 3: Schema of the gas system.

Fig. 4: View of the multiple HV connector.

Fig. 1

Fig. 2

Fig. 3

Fig. 4