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DEVELOPMENT OF SMALL HIGH-GAIN TUBES FOR THE
ELECTROMAGNETIC CALORIMETER OF THE CPLEAR EXPERIMENT

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The CPLEAR Collaboration

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ABSTRACT

We have designed small rectangular cross-section tubes, $4 \times 4.5 \text{ mm}^2$, working in a high-gain mode. Two of the four cathode walls are coated with high-resistivity graphite, allowing the detection of the induced pulses on external strip boards. At 3.2 kV, the collected charge on the wires, which is due to a minimum-ionizing particle, is 10 pC and can be read out without preamplification. The small size of the tubes makes them particularly suitable for use in gas-sampling calorimeters.

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1. INTRODUCTION

The aim of the CPLEAR experiment, which is installed at the Low-Energy Antiproton Ring (LEAR) at CERN, is to study the CP-violation effects in the various decay channels of the neutral kaons. The principle of this experiment and its layout have been described elsewhere [1]. Several of the K^0 decays to be studied include π^0 's, and therefore photons, in the final state. Because of the low momentum of the initial K^0 (on the average 500 MeV/c), the photons also have a low energy. For example, the photons from the decay $K^0 \rightarrow 2\pi^0$ have a mean energy of 160 MeV, and a good detection efficiency is required down to 50 MeV.

To study the time-dependent interference effects due to CP violation, it is necessary to reconstruct the decay vertex of the K^0 into purely neutral states ($K^0 \rightarrow 2\pi^0$ or $K^0 \rightarrow 3\pi^0$). Monte Carlo studies have shown that a good resolution on this vertex can be obtained if the impact points of the photons are accurately measured, even if the resolution on their energy measurement is poor. For this reason, it has been decided to construct a high-granularity calorimeter located inside the magnet coil, built with successive layers of wire chambers interleaved with lead sheets. The same studies have also shown that, at such a low energy, the best energy resolution is obtained by counting track segments in a purely digital way rather than by measuring the energy deposited in the gas. Finally, it can be shown that the optimal spatial resolution is obtained by measuring the shower as close as possible to the conversion point of the photon; therefore, an independent readout of each layer is necessary.

The classical $1 \times 1 \text{ cm}^2$ plastic limited-streamer tubes [2] seem *a priori* ideally suited to such an application. However, several factors prohibited their use:

- i) the spatial accuracy in the detector ($< 5 \text{ mm}$) could be only marginally obtained with 1 cm^2 tubes used in a digital way;
- ii) the high rate in the experiment requires fast collection of the charges on the resistive cathodes;
- iii) the total thickness devoted to the calorimeter in the experiment is only 22 cm since the whole detector had to fit inside an already existing magnet coil; one could not fit the necessary ~ 20 layers with 1 cm thick tubes;
- iv) the mechanical structure of the detector requires tubes that are stiffer than the classical PVC tubes.

For all these reasons, we decided to develop new tubes of smaller cross-section, typically $5 \times 5 \text{ mm}^2$, but still working in a high-gain mode. Our initial effort was encouraged by the success encountered by the Israel-OPAL group in building small gap chambers that produce large pulse heights [3]. To measure the coordinate along the wire, we decided to read, in addition to the wires themselves, the induced pulses on a system of strips running at $\pm 30^\circ$, located above and below the tubes. This allows the determination of a spatial point that is free of two-track ambiguity.

In this paper we report on the outcome of the study. In Section 2 we describe the design of the tubes. Section 3 is devoted to the description of their performances, Section 4 to the signals observed on the strips.

2. TUBE DESIGN

Figure 1a shows a cross-section of a single tube, $4 \times 4.5 \text{ mm}^2$. The top and bottom cathodes, on which the pick-up strips will be pressed, are made of 1 mm

thick G10 epoxy, coated with a graphited paint^{*)} adjusted to have a resistivity around 1 M Ω per square. The left and right cathodes are 0.5 mm thick brass wings. The reason for choosing these metallic cathodes will be explained in Section 4.

A gold-plated 40 μ m tungsten wire is stretched through the centre of the tube, with a tension of $\sim$ 150 g. In the case of long tubes, the wire is maintained in a central position by gluing it, every 36 cm, to plastic supports similar to those used in the electromagnetic calorimeter of the ALEPH experiment [4].

The tubes are constructed in units of eight; in the following these units are called chambers. Figure 1b shows a detailed view of a chamber. The chamber is built with two, 42 mm wide, epoxy plates, which are machined for later insertion of the metallic wings. After machining, the epoxy plates are polished and graphited. Compared with the classical U-shaped profiles, this technique has the great advantage that the graphited paint is deposited on a flat area, allowing a better control and uniformity of the resistivity [5]. Using a specially made jig, the brass wings are then glued to one of the two epoxy plates with a conductive glue made of Araldite (70%) and graphite powder (30%)^{**) [6]}, so that the resistance from any point of the graphited cathode to the neighbouring brass wing is a few megohm. This allows good collection of the charges on the resistive cathode, which is necessary for a high-rate detector. The epoxy plate and the nine wings then make up a kind of profile.

At the end of this profile are glued printed circuit boards on which the eight wires will be soldered. The nine metallic wings are electrically linked together by a 5 mm wide, 0.5 mm thick brass strip. A plastic end-piece with nine feedthroughs is glued on both extremities of the chamber: eight of them are connected to the eight wires; the ninth one is linked to the brass wings and will later be connected to the grounding of the system.

After the chamber has passed all the construction tests [5], a G10 epoxy plate is glued on top of the wings with the same conductive glue. Finally, a thick Araldite film is applied on both sides to make the chamber gas-tight.

The final appearance of the chamber is that of a closed box, 42.5 $\times$ 6 mm² in cross-section and 2.75 m long, which can never be reopened. It is exceedingly stiff and can withstand high mechanical pressure.

The high voltage is fed to the wires via feed resistors mounted on a thin printed-circuit board on which are also soldered eight decoupling (680 pF) high-voltage capacitors, for reading the wire signals. The overall dimensions of this card are 42 mm width, 100 mm length, and 6 mm thickness.

The chambers are operated with a gas mixture of CO₂ and pentane, 55% and 45% in volume respectively, obtained by bubbling the CO₂ through liquid pentane at 14 °C at atmospheric pressure.

3. TUBE PERFORMANCES

Figure 2 shows pulses observed at 3.2 kV on a 50 Ω probe with the β -rays emitted by a ¹⁰⁶Ru source. The typical pulse height is 20 mV and the pulse width

^{*)} G33 mit verminderte Leitfähigkeit, Kontakt Chemie, Technische Aerosol GmbH, Postfach 1609, 7550 Rastatt, Fed. Rep. Germany.

^{**) [6]} Araldite: 90% AY103, 10% HY95, Ciba Geigy AG, 4001 Basel, Switzerland.
Graphite: KS75 Lonza AG, 5643 Sins, Switzerland.

30 ns. This high pulse height allows the wire signal to be read with 'classical' proportional chamber readout modules (for example, the receiver on memory hybrid (RMH) system [7]) without any amplification.

In fig. 3 are shown plateau curves for the increasing high voltage on the wires at a fixed discriminator threshold of 10 mV, obtained by measuring the count rate in a chamber either with a radioactive source or with the ambient cosmic background. In both cases the chambers have a nice (more than 300 V) plateau starting at 3.1 kV.

A spectrum of the collected charge is displayed in fig. 4a. The mean collected charge is 10 pC, and the distribution is rather narrow ($\text{FWHM}/\text{mean} \approx 0.9$). An important feature is that the same charge is collected for a minimum-ionizing particle and for the 5.9 keV X-rays of a ^{55}Fe source, although the latter deposits about 2.5 times more energy in the gas (fig. 4b). This seems to indicate that we are in a saturated mode. A similar indication comes from the fact that the plateau is insensitive to displacements of the wire in the tube up to 1 mm.

The tube efficiency has been measured in a test beam with muon tracks at small incidence. Most of the inefficiency is due to the geometry of the chamber (the dead space due to the brass wings and to the Araldite film on the side amounts to 14% of the total area). A detailed Monte Carlo simulation reproduces the data well if a $(4 \pm 1)\%$ inefficiency, in addition to the geometrical losses, is assumed.

The pulse height does not vary by more than 15% along the 2.64 m of the wire, except in a small region located around the wire supports where we observe a loss of efficiency as shown in fig. 5.

We have repeated our efficiency tests and plateau curves with a stronger source, delivering about 5000 β -particles per second along a wire length of 5 mm (a factor of 100 higher than the rate expected in our experiment), without seeing any dead-time effect. This source has been maintained in operation for 11 days at the same position, corresponding to a total collected charge of 0.1 C. Figure 6 shows that the collected charge has varied by less than 10% during this test.

Finally, we have searched for possible after-pulses on the wire by measuring the time between two successive pulses. Such after-pulses have been observed in the past with aluminium cathodes [8]. We do not see such an effect with our brass wings (fig. 7). Above 100 ns time difference, the number of pulses is very small (3×10^{-4}) and is well compatible with the expected accidental rate.

During the design phase of our chambers we varied several parameters, some of which we would like to mention here:

- When the diameter of the wire is increased to 50 μm and 65 μm , the high-voltage plateau is shifted by 100 V and 300 V, respectively. On the other hand, the chambers become unstable when the wire diameters are smaller [3].
- We have tried to operate our chambers with other gas mixtures based on argon and isobutane. When operating with pure isobutane, the HV plateau is shifted up by 400 V. Also the chambers sometimes show instabilities, in particular in the presence of a strong radioactive source.

4. PERFORMANCES OF THE STRIPS

The pick-up strips are made of 0.7 mm thick G10 circuits, coated with 35 μm copper on both sides. On the side that will be in contact with the chamber, 5.3 mm wide bands are drawn, interspaced by 1 mm, running at $+ \text{ or } -30^\circ$ with respect to

the chamber wire direction. The other side is the reference ground. The thickness of the board is a compromise between the compactness of the detector and the strip capacitance; the characteristic impedance of a strip is $20\ \Omega$. At one end of the board, the strips come together in groups of 16 to make 50 mm wide connectors onto which the preamplifier card will be plugged. At the other end, each strip is terminated to ground via a $20\ \Omega$ resistor in order to avoid signal reflections.

For a strip board well pressed onto the chamber, the observed pulse height and collected charge are typically 10 times lower than with the chambers. For this reason, we have built preamplifiers that have a gain of ~ 10 , which allow the same readout electronics to be used for both strips and wires.

During the design phase, we have measured the charge distribution on the strips located around the source position. Figure 8 shows how the mean charge varies for different cathode resistivities. The cathode resistivity has to satisfy two opposing criteria:

- i) it must be low enough to enable good collection of the charges produced in the presence of a high flux;
- ii) it has to be high enough to obtain a high pulse height on the strips.

As a compromise, we have chosen a resistivity of the order of $1\ \text{M}\Omega$ per square.

One specific requirement for our digital system is that a threshold be set on the pulse height, which would result in a small number of hit strips but with a high efficiency. It has been previously shown [9] that the tail of the charge distribution is sensitive to the value of the resistivity of the profile wings. This is clearly confirmed in fig. 9, where we show the mean charge on the various strips:

- a) for our final tube design;
- b) for tubes of exactly the same size, but with resistive (10 to $100\ \text{k}\Omega$ per square) instead of metallic wings.

In the first case, the charge collected on the central strips is lower by a factor of 2, but the tails of the distribution are suppressed by one order of magnitude. This is, in addition to the mechanical stiffness, the main reason for the choice of the tube design.

In the case where the strips are not well pressed onto the chamber, the pulse height on the strips varies rapidly with the distance between the tubes and the strips. Air gaps of $0.4\ \text{mm}$ and $1\ \text{mm}$ produce a loss of a factor of 1.6 and 3.2 in pulse height, respectively.

The strip multiplicity and efficiency have been measured with muon tracks. An average multiplicity of 1.4 strips hit is obtained for an efficiency of better than 95%.

The coordinate perpendicular to the strip is obtained by taking the barycentre of all the hit strips. Using both the lower and upper strip system, we have obtained a spatial resolution along the wire direction of better than $3\ \text{mm}$ [5].

5. CONCLUSIONS

We have developed $4 \times 4.5\ \text{mm}^2$ tubes working in a high-gain mode. Their small size allows the construction of very compact detectors. We have found good working conditions that allow the wire signal to be read with classical MWPC electronics without any preamplification, and the signal induced on pick-up strips needs only moderate preamplification. The design has been optimized in view of digital readout. In a forthcoming paper [5], we will describe the construction and tests of a large series of these new detectors in more detail, as

well as the performance of a multilayer photon calorimeter in which they are used as the active elements.

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Figure captions

- Fig. 1: a) Cross-section of a single tube.
b) Perspective view showing the construction of a chamber.
- Fig. 2: Typical pulses obtained with a ^{106}Ru source on a $50\ \Omega$ probe, recorded by a 9450 LeCroy storage oscilloscope (vertical scale: 5 mV/div; horizontal scale: 20 ns/div).
- Fig. 3 Plateau curves for increasing high voltage at a fixed electronics threshold of 10 mV.
- Fig. 4 a) Spectrum of the charge collected on the wire with minimum-ionizing electrons emitted by a ^{106}Ru source.
b) Same for the 5.9 keV X-rays of a ^{55}Fe source.
- Fig. 5 Count rate measured with a ^{106}Ru source along the wire in the vicinity of a wire support.
- Fig. 6 a) Count rate measured at a fixed high voltage of 3.2 kV with a strong ^{106}Ru source, as a function of the time (see text).
b) Charge measured on the wire during the same test.
- Fig. 7 Ratio of the coincidence rate between the direct pulse and the delayed pulse on a wire, to the total rate on the same wire as a function of the delay. A schema of the electronics set-up is also shown.
- Fig. 8 Collected charge on strips perpendicular to the wire for various cathode resistivities.
- Fig. 9 Collected charge on the various strips
a) for our final chamber with metallic wings,
b) for a similar chamber with resistive wings (see text).
The strips run at 30° relative to the wire direction. The strip-to-strip distance is 4.5 mm.

Fig. 1

Fig. 2

Fig. 3

Fig. 4

Fig. 5

Fig. 6

Fig. 7

Fig. 9

Fig. 8