THE LIMITED STREAMER TUBES 
FOR EXPERIMENT PS199 AT LEAR

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ABSTRACT

Eight thousand limited streamer tubes have been built for the antineutron detectors of experiment PS199 at LEAR, the Low-Energy Antiproton Ring at CERN. The tubes are arranged in vertical planes and each plane is equipped with two orthogonal sets of strips used as position-sensitive readout elements. The digital readout system is based on the new board ‘streamer interface’ built by SGS.

The construction and testing procedure are described, as well as the performances of the detector and the readout system in a test with cosmic rays.

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1. INTRODUCTION

Experiment PS199 at the Low-Energy Antiproton Ring (LEAR) at CERN [1, 2] is studying the charge-exchange channel of the antiproton–proton interaction ($\bar{p}p \rightarrow \bar{p}p$). The differential cross-section, the asymmetry parameter of the reaction, and the polarization transfer parameter $D$ are measured, employing an antiproton beam from LEAR characterized by high intensity, monochromatism, and small emittance, and a ‘frozen-spin’ polarized-proton target [$\text{CH}_3(\text{CH}_2)_4\text{OH}$]. These measurements require a clear identification of the two neutral particles forming the final state, as well as a good determination of the kinematical parameters of the event to reject the scattering off bounded protons present in the target.

Two identical antineutron counters (ANCs) are used, each being a sandwich of limited streamer tubes (LSTs) arranged in 20 vertical planes, five scintillation counter hodoscopes, and four iron slabs. The material of the slabs acts as antineutron converter. The active elements of the ANCs detect the charged products of the antineutron annihilation, mainly charged pions but also electrons and positrons from the conversion of photons produced in $\pi^0$ decays. The measurement of the charged-particle trajectories allows the identification of the antineutron through the pattern of the annihilation events and the determination of the antineutron trajectory by reconstructing the point where the annihilation has taken place. For these purposes, the LST planes are used as position-sensitive detectors. Each plane is equipped with two sets of orthogonal pick-up strips to measure two orthogonal coordinates. The hodoscopes of scintillation counters are mainly used for triggering purposes and to reject the photons from the target on the basis of time-of-flight (TOF) measurements.

This paper is mainly devoted to describing the LST construction, tests, and performances, and it is organized as follows. A short description of the ANCs is given in section 2. The general layout of these detectors has guided the choice of some construction parameters. The LSTs are described in section 3, where we also give information about their construction. The procedure to test the finished LST is given in section 4. The general features of the readout system and its performances are described in section 5. The performances of the position-sensitive detectors, mainly obtained by measuring cosmic-ray trajectories, are given in section 6.

2. THE ANTINEUTRON DETECTORS OF EXPERIMENT PS199

Figure 1 shows the location in space of the relevant components of the two identical ANCs. The area of the sensitive region of the LST planes and of the scintillation counter hodoscopes as well as of the iron slabs is the same: 1660 $\times$ 2016 mm$^2$. The structure of the detector is modular: each module is forward–backward symmetric and formed by four LST planes and one scintillation counter hodoscope consisting of six vertical scintillation counters, each viewed by two photomultipliers. It is enclosed by two thin (6.3 mm) aluminium slabs to guarantee mechanical rigidity; the overall thickness of the module is 155 mm.

The LST planes are formed by fixing the tubes on an aluminium frame external to their sensitive region to minimize the amount of material inside the module.

The iron slabs (thickness: 30 mm) are placed between the modules, which are mounted at a distance of 35 mm from one another. These slabs, together with the adjacent aluminium ones (i.e. the external walls of the modules), include most of the detector material (about 80% in interaction length).
The ANCs are quite compact detectors, as stressed in the description. This feature allows the detection of the charged products of the antineutron annihilation in a wide solid-angle interval. The mechanical support of the modules and of the iron slabs has been carefully designed to guarantee this compact geometry. On the other hand, the compactness of the working configuration does not allow access to a large portion of the detectors and, in particular, to the readout electronics boards mounted on the LST planes at the strip edges (see section 5). To overcome this problem, couples of adjacent LST planes are suspended on telescopic arms. Arms can be extracted from the side of the mechanical structure supporting the detectors till the whole surface of the planes becomes accessible.

The absence of elements of the supporting structure at one side of each counter is another relevant feature of the mechanical arrangement. This allows positioning of the active region of the detector at very small angle with the outgoing beam direction without inserting material across the beam line and arrangement of the two ANCs in an orthogonal configuration to form a single counter covering a larger angular range without gaps.

Two similar apparatuses (sandwich of LST planes, scintillation counters, and iron slabs) have already been used as antineutron detectors; one was used in a first-generation LEAR experiment (PS178 [3]); the second one has been built for the experiment FENICE [4]) at the ADONE storage ring (Laboratori Nazionali di Frascati of the INFN). In those counters the iron slabs are homogeneously distributed along the detector instead of being concentrated in thicker plates as in the present one. The ANC geometry has been chosen on the basis of previous experience and Monte Carlo calculations to increase the antineutron identification and selection, allowing a clear picture of the annihilation events to be recorded.

3. THE LIMITED STREAMER TUBES

We have built 8320 channels of LSTs. The geometry of these detectors follows the standard design first developed for the NUSEX experiment [5, 6]; the tubes are electrodeless [7], and eight tubes are enclosed in a single chamber. The length of the sensitive portion of the tubes is 1660 mm, while the overall length of a chamber is 1796 mm.

The tubes have been built using the facilities [8] available at the Laboratori Nazionali di Frascati of the INFN.

The PVC eight-tube chambers have been painted with the requirement that the final resistivity of the cathode ranges between 50 kΩ/cm and 500 kΩ/cm. This requirement has raised the rejection rate to 40% of the painted tubes.

At the time of construction, the chambers have undergone a gas-leakage test. The few chambers exhibiting gas leakages have been repaired using an appropriate glue.

One hundred and sixty man-days of work have been necessary for the overall construction of the tubes. The cost of the LSTs, which have been built during 1987, is 300,000 lire per square metre, manpower not included. In this evaluation the discarded components have been taken into account.

4. THE ELECTRICAL TEST OF THE LSTs

It is well known that the major operating problems of the LSTs are due to the electrical instabilities which affect a certain fraction of the chambers. An efficient
diagnostic consists in monitoring the current driven by a chamber while keeping it in working conditions. This diagnostic technique seems more efficient than alternative methods [9] even if it does not guarantee full efficiency in the rejection of chambers which, later, will suffer from electrical instabilities [10]. On the basis of these considerations we have adopted a quite standard test procedure based on the test cycle described below.

A complete cycle includes evacuation of the chambers, fluxing with the proper gas mixture, and application of the high voltage; it lasts 24 hours and forty chambers are tested in parallel. In particular, the high voltage is applied over a period of 20 hours, during which the current is continuously monitored for each chamber individually.

To allow evacuation and gas supply, chambers are serially connected four by four. For the test, chambers were operated with a gas mixture of Ar : isoC₄H₁₀ = 40 : 60, and the pressure is atmospheric at a height of 100 m above sea level (at the Dipartimento di Fisica, University of Trieste). Evacuation and high gas flux (six volumes per hour) are used to speed up the cleaning of the chambers.

The high voltage applied during the active stage of the cycle is about 250 V higher than the knee of the plateau curve. The signals generated on the wires of each chamber by the limited streamer discharges are decoupled from the high-voltage level via a capacitor and are available for parallel checks. The high-voltage and current controls are computerized, and the on-line computer is a Macintosh PLUS. Figure 2 shows the hardware set-up. The current of each chamber is read every 30 s and the chamber undergoes an off-on cycle if the current is higher than a selected value (5 μA). At the end of the cycle, the chamber is rejected if it has been switched off at least three times during the 20 hour cycle or if the mean value of the current is larger than 0.05 μA.

This test procedure has resulted in a rejection rate of 6% of the chambers. Later, the accepted chambers mounted in the experimental set-up, have exhibited a failure rate of 0.7% after an overall operation period of three months (most of the failures have been observed during the first days). This value is compatible with the confidence established for a similar test procedure [10].

5. THE READOUT SYSTEM

In our detectors the LSTs are arranged in planes and equipped with external pick-up strips. Each plane is faced with two orthogonal sets of strips to allow the measurement of two coordinates of the trajectory of the crossing particle. The strips consist of an aluminium ribbon (thickness: 40 μm) glued on a PVC support (thickness: 1 mm). The external face of the PVC support is coated with an aluminium foil (thickness: 40 μm) carefully grounded.

The x (vertical) strips are parallel to the anode wires, have a pitch of 10 mm and a width of 4 mm; the y (horizontal) ones a pitch of 10.5 mm and a width of 8 mm. The graphite-coated side of the tubes is faced with the x strips. The range of values chosen for the resistivity of the cathode is such as to allow full transparency to the signals generated by the limited streamer discharges (see ref. [11]).

The digital readout electronics is serial and based on the new commercial board 'streamer tube interface' provided by SGS. A CAMAC interface is used: a streamer-tube readout controller (STROC) [12]. Data are shifted to the STROC at a speed of 5 MHz.

Chains are used which are formed by 11 boards corresponding to a complete LST plane, with x and y coordinate readout. The choice of relatively short chains increases
the parallelism, speeding up the data transfer from the apparatus to the CAMAC controllers.

Using triangular positive signals to simulate the signal induced by the limited streamer discharges, we have made some preliminary studies of the performances of the SGS boards to calibrate the threshold setting with respect to the signal amplitude (in this paper we refer to the amplitude as measured on a 50 Ω load) and to measure the uniformity of the effective threshold for a given threshold setting within a board and among channels belonging to different boards: we observe deviations up to ±15%, in agreement with what was observed for the first prototypes of the SGS boards [13].

The observed failure rate of the readout electronics is $5 \times 10^{-4}$ per channel per day.

6. TESTS OF THE LSTs

6.1 Preliminary tests

Some preliminary tests have been performed before assembling the LST planes. The working conditions are the same as those used for the active part of the test cycle (section 4).

We have sampled the finished chambers looking at the plateau curves (source of $^{60}$Co) obtained using the decoupled anodic signals. All the measured plateaux start at the same voltage (±25 V) and have a width $\geq 500$ V.

Plateau curves obtained by reading the signal induced on the strips applied to the external wall of the chambers are not displaced with respect to the previous ones when applying threshold cuts around 4 mV.

6.2 Measurement of penetrating cosmic-ray trajectories

The overall performances of the detector in measuring tracks of minimum ionizing particles are tested by reconstructing the trajectories of penetrating cosmic rays. The set-up used for this test is composed of the ANCs themselves as described in section 2. The hodoscopes of scintillation counters are used to provide the trigger.

In data reduction, we define as a hit any strip exhibiting a signal larger than the threshold, as a cluster any isolated hit or group of consecutive hits of any length. For each cluster, we define the cluster centre as the coordinate of the centre of mass of the hits forming the cluster. The cluster size is given by the number of hits forming the cluster. To reconstruct the trajectories, we assume as measured coordinates the cluster centres. The reference frame (x,y,z) for the coordinates is indicated in fig. 1.

The performance of each group of four planes included in a module (five modules per ANC) are analysed separately. For each module, we define four telescopes of three LST planes each, and we reconstruct separately the (z,x) and (z,y) projections of the particle trajectory requiring three aligned coordinates. The plane not included in the telescope is regarded as the plane under test and its performances are checked assuming the parameters of the reconstructed trajectory. Events exhibiting more than one reconstructed track per telescope are rejected.

For each reconstructed trajectory, the angles formed by the trajectory projections with the z axis, $\theta_x$ [(z,x) projection] and $\theta_y$ [(z,y) projection], are evaluated.

The tests have been performed varying the LST operating conditions, i.e. gas mixture, high-voltage supply, and electronics threshold. The tests have taken place at CERN (altitude above sea level: 435 m) at atmospheric pressure.
The starting point to fix the LST operating conditions is obtained from the plateau curves. For this purpose we have selected only trajectories for which $|\theta_y| < 45^\circ$ since the amplitude of the induced signals depends strongly on $\theta_y$. Figure 3 shows the plateau curves obtained for the gas mixture Ar : isoC$_4$H$_{10} = 30 : 70$ using two different values of the threshold cut: 4 mV and 5 mV. The behaviour of the plateau curves is the same (knee at 4400 V), indicating that these values of the threshold are low enough not to modify the intrinsic streamer regime plateau. Similar curves are obtained for the gas mixture Ar : isoC$_4$H$_{10} = 40 : 60$ exhibiting the knee of the plateau curves at 3900 V.

In the following subsections, we present the results obtained using the gas mixture Ar : isoC$_4$H$_{10} = 30 : 70$. The results obtained for the gas mixture Ar : isoC$_4$H$_{10} = 40 : 60$ look similar after proper scaling of the high-voltage values.

6.3 The detection efficiency

The detection efficiency has been studied as a function of the inclination of the particle trajectory and the electronics threshold. Efficiency as a function of trajectory inclination is presented in fig. 4 for data taken at 4500 V and applying a threshold cut value of 5 mV. At this threshold setting, the efficiency depends on $\theta_x$ only and it is lower than the maximum for small $\theta_x$ owing to the dead zones of the detector, the walls present between adjacent tubes and chambers. The detection efficiency for tracks not affected by geometrical inefficiency (large $\theta_x$) is 97%. The detector efficiency as a function of the readout electronics threshold has been measured keeping the supply voltage fixed (4500 V) and selecting trajectories with $|\theta_y| < 45^\circ$. Efficiency decreases for threshold values higher than 5 mV (fig. 5).

The uniformity of the detection efficiency of the LST planes has been studied dividing each plane into a matrix of 120 square cells and determining the efficiency of each cell. Owing to the geometry of the set-up and the cosmic-ray distribution, the trajectories of the particles giving a trigger exhibit different angular spectra for particles crossing the different portions of the detectors, and only trajectories at small $\theta_x$ and $\theta_y$ are measured everywhere. Since the detection efficiency has a strong dependence on $\theta_x$, for this study we have selected only trajectories with $|\theta_x| < 10^\circ$. Figure 6 shows the results obtained for the cells of a single plane using a sample of events collected at 4500 V and applying a threshold cut of 5 mV; owing to the small $\theta_x$ values, the efficiency for this sample of events does not reach the maximum. For the same sample of events, the distribution of the efficiency of the cells of all the 40 LST planes has a standard deviation $\sigma$ = 3%; this value includes the effect of the residual dependence of the measured efficiencies on the angular spectra of the trajectories impinging on the different cells. The same test for a sample of events collected applying a threshold of 9 mV gives a similar value for the standard deviation in spite of the slightly reduced detection efficiency obtained when applying a higher threshold value.

6.4 Noise rate

To obtain an upper limit of the noise rate, we count the number of spurious clusters, i.e. the clusters in the plane under test which do not belong to the trajectory reconstructed using the telescope planes. To remove as far as possible the hits due to any ionizing event in the tubes, we ask for a very clean pattern on the telescope planes: one and only one measured coordinate, i.e. the one belonging to the reconstructed trajectory itself. The spurious cluster rate per readout channel per event is $1 \times 10^{-4}$, both for the x and the y coordinates, for threshold settings higher than 3.5 mV, and the rate increases only at lower threshold values.
The spurious coordinates can be due to limited discharges in the tubes or to electronics noise. Table 1 gives the rates of spurious x clusters per plane per event as a function of the number of spurious y clusters present in the plane. The presence of x and y spurious clusters looks quite correlated even if the correlation is far from being complete. This suggests that part of the spurious signals are generated by discharges in the detector (either caused or not caused by ionizing events) and part are due to the readout electronics.

Table 1

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<thead>
<tr>
<th>Number of spurious y clusters</th>
<th>Number of spurious x clusters</th>
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<tr>
<td></td>
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<tr>
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<td>0.04</td>
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<td>≥ 3</td>
<td>3×10⁻³</td>
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6.5 Cluster size

The length of the cluster is an important parameter for our detectors. In fact, the detectors have to measure multiparticle events characterized by trajectories, all originating from a single point (antineutron annihilation stars): long clusters may spoil the two-track resolution and confuse the event picture.

The average cluster size as a function of $\theta_x$ and $\theta_y$ is shown in fig. 7 for data taken at 4500 V, applying a threshold cut of 5 mV. The length of the x cluster is always quite reduced, whilst the length of the y cluster can reach large values, as already observed for the NUSEX detector [6]. The y cluster size depends weakly on $\theta_x$ and strongly on $\theta_y$, suggesting that the more important parameter is the projection onto the wire axis of the portion of the trajectory included in the active volume of the tube (generation of several limited streamer discharges). Moreover, the average cluster size does not give a complete picture of the phenomenon since the distributions are quite large and have a long tail towards the large values, as can be seen in fig. 8.

Trying to reduce the cluster size, we have studied this parameter as a function of the applied threshold value and we have seen evidence of the strong dependence of the cluster size on the threshold. Figure 9 shows, for comparison, the cluster-size spectra obtained by applying a higher threshold cut (9 mV). These measurements suggest keeping the readout threshold as high as possible, compatible with the requirements of good efficiency and stability of the detector performances.
6.6 Resolution of the position measurement

The resolution of the position measurement has a standard deviation of 4 mm for the x coordinate and 5 mm for the y coordinate (see fig. 10), and it is independent of the trajectory inclination. Also data collected using different values of the threshold always give the same values for the resolution of the position measurement. These facts suggest that the quite large y cluster size (see subsection 6.5) does not spoil the resolution.

7. CONCLUSION

In the present paper we give all the relevant parameters and data about the construction and performances of the LSTs employed as position-sensitive detectors with digital readout in experiment PS199.

The tests have allowed us to gain experience in operating LSTs. The detectors, which, up to now, have been on the floor for 18 months, are reliable; the performances look quite stable in time and reproducible after long periods (months) of power off. Moreover, measuring cosmic-ray trajectories is a powerful method to check and monitor the ANC efficiency and to perform diagnostics. The experimental study of the detector performances has allowed optimization of the experimental parameters, obtaining a clear identification of antineutrons and good antineutron detection efficiency (see ref. [2]).

Limited streamer tubes have gained wide popularity during recent years and, nowadays, are widely employed in large and medium-size experiments. The comparison of their performances in facing different and specific experimental aims is desirable and can be extremely useful in designing future experimental apparatuses.

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Figure captions

Fig. 1: Structure of the antineutron detectors.

Fig. 2: Scheme of the hardware set-up used for the test of the electrical stability.

Fig. 3: Plateau curves, signal from parallel and orthogonal strips; threshold cut: 4 mV and 5 mV; operating conditions: 4500 V, Ar : isoC₄H₁₀ = 30 : 70, atmospheric pressure at 435 m above sea level. Only trajectories exhibiting \(|\theta_y| < 45^\circ\) have been used.

Fig. 4: Efficiency for the x- and y-coordinate measurements as a function of \(\theta_x\) (\(\theta_y\)) for fixed values of \(\theta_y\) (\(\theta_x\)); operating conditions: Ar : isoC₄H₁₀ = 30 : 70, atmospheric pressure at 435 m above sea level.

Fig. 5: Efficiency for the x- and y-coordinate measurements as a function of the readout threshold; operating conditions: 4500 V, Ar : isoC₄H₁₀ = 30 : 70, atmospheric pressure at 435 m above sea level. Only trajectories exhibiting \(|\theta_y| < 45^\circ\) have been used.

Fig. 6: Detection efficiency of the cells of a LST plane; the efficiency measured for the cells belonging to a row is shown; the hatched region indicates the spread of the value measured for all the cells; operating conditions: 4500 V, threshold cut of 5 mV, Ar : isoC₄H₁₀ = 30 : 70, atmospheric pressure at 435 m above sea level. Only trajectories exhibiting \(|\theta_x| < 10^\circ\) have been used.

Fig. 7: Average cluster size versus \(\theta_x\) (\(\theta_y\)) for fixed values of \(\theta_y\) (\(\theta_x\)); operating conditions: 4500 V, threshold cut of 5 mV, Ar : isoC₄H₁₀ = 30 : 70, atmospheric pressure at 435 m above sea level.
Fig. 8: Distribution of x- and y-cluster size in $\theta_x$ and $\theta_y$ bins; operating conditions: 4500 V, threshold cut of 5 mV, Ar : isoC$_4$H$_{10}$ = 30 : 70, atmospheric pressure at 435 m above sea level.

Fig. 9: Distribution of x- and y-cluster size in $\theta_x$ and $\theta_y$ bins, operating conditions: 4500 V, threshold cut of 9 mV, Ar : isoC$_4$H$_{10}$ = 30 : 70, atmospheric pressure at 435 m above sea level.

Fig. 10: Histograms of the resolution of the x- and y-position measurements; operating conditions: 4500 V, threshold cut of 5 mV, Ar : isoC$_4$H$_{10}$ = 30 : 70, atmospheric pressure at 435 m above sea level.
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Fig. 2
Fig. 3
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Fig. 10