KLOE-Note-**142**
March, 1995

HIGH PRECISION LIMITED STREAMER DRIFT TUBES

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ABSTRACT

A tracking telescope employing 6 layers of Al drift tubes 50 cm long, with diameter d=3 cm and wall thickness 500μm, has been built and successfully operated with a 40%Ar$-$60%iC_4H_{10} gas mixture at atmospheric pressure. The tube cells, with a 100 μm thick Cu-Be wire strung along the axis, enter streamer mode operation at V=4.6 kV, and feature full efficiency and local resolution of $\leq 60\,\mu$m.

Presented at the 1995 Vienna Wire Chamber Conference
Vienna, Feb 19-24 1995

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1 — Introduction

The two identical mini-trackers (MT in the following) described here were built to precisely track test beam particles through a prototype of the main drift chamber of the KLOE detector[1,2] exposed to a beam of 50 GeV/c pions from the CERN SPS. In this paper we only discuss the performance of the tracking system, deferring the presentation of prototype data to a forthcoming paper.

2 — Mechanical Construction

The setup consists of the two MT's sandwiched around the KLOE prototype (see fig. 1), plus two (not shown) scintillation counters[3] whose coincidence triggered the acquisition and provided the START to the TDC's.[4] Discriminated signals from the tubes themselves provided individual STOPs.

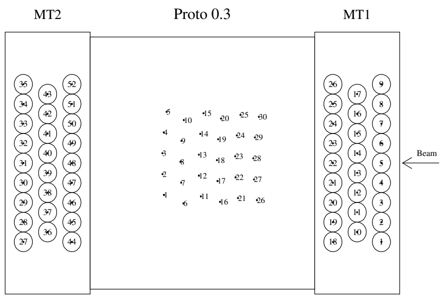

Fig. 1. The test beam setup.

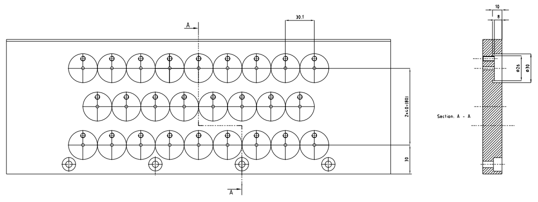

Fig. 2. Drawing of an MT endplate.

Each MT (see fig. 2 for a drawing of the endplate) employs 3 layers of 9+8+9 tubes; the central layer is offset by one tube radius (1.5 cm), and the distance between layers is 4 cm. The Al tubes are cut to the final length from selected $\sim 6\,\mathrm{m}$ long tubes. To avoid electrostatic discharge even in streamer-mode operation, the tube inner surfaces have been polished. The outer frame, also made of Al, has been machined on a digitally controlled mill, ensuring accuracy at the level of $\leq 30\,\mu\mathrm{m}$. The two endplates of each tracker carry the 26 holes for the *delrin* wire feed-throughs, concentric to 26 cylindrical pits that hold the Al tubes in their nominal position. At the bottom of the pits, a cylindrical groove having a $2{\times}2\,\mathrm{mm}^2$ square section, machined around the outer rim, is filled by a slow-hardening, non-running glue[5] providing mechanical strength and excellent gas tightness.

Another set of holes parallel to the feed-throughs and as far as possible from the HV pins accomodates small diameter, fast-on gas connectors[6] for the daisychain carrying the $40\%\mathrm{Ar}-60\%\mathrm{iC_4H_{10}}$ gas mixture serially to each tube. All tubes are glued simultaneously onto a frame consisting of two endplates and two separators. The frame, kept in a known position by several dowel pins, is then tightened with bolts. Other dowel pins are used to mount the two MT's around the KLOE prototype, whose external frame has also been precisely machined. After 48 hours of glue hardening, we strung the $100\,\mu\mathrm{m}$ thick Cu-Be wires through the feed-through holes. The tube signals are sent to discriminators through a HV-decoupling capacitor.

3 — Streamer mode operation

Operating the tubes in limited streamer mode generates large signals which do not need amplification; the very high signal-to-noise ratio reduces the time jitter and improves the resolution of the drift time measurement. The tubes have a very long single plateau that starts at $\sim$4.6 kV and extends to $\sim$6 kV. The signals on a 50Ω load, shown in fig. 3 , have a typical streamer length of $\sim$100 ns. During the test, the tubes were kept at 5.7 kV, to have longer streamers and therefore higher signals, and to bring the drift velocity at the cathode as close as possible to saturation. The maximum drift time, one tube radius, was $\leq$ 300 ns.

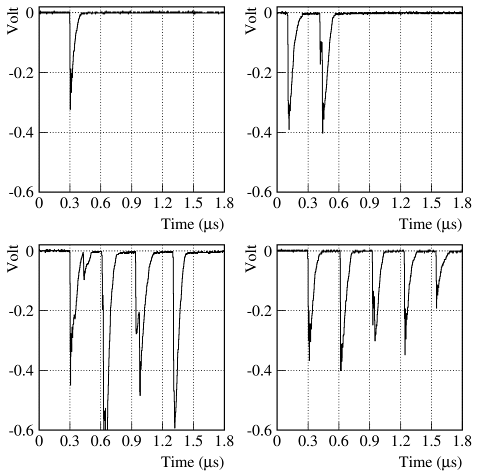

Fig. 3. Typical tube signals at 5.7 kV.

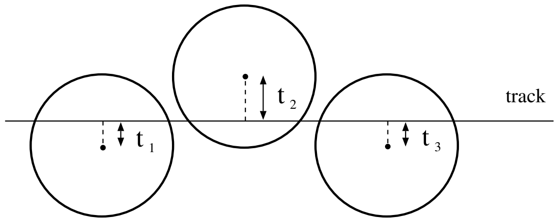

Fig. 4. Symbols in the $t_{\rm stag}$ function.

The presence of afterpulses in the Al tubes (up to 5 or 6 at 5.7 kV) is of no relevance here: we only measure the arrival time of the first pulse. To avoid re-firing discriminators, we set the output gate to $2\,\mu$s. This fixed the maximum rate at 5.7 kV to be in the $\leq$ 500 kHz range. Afterpulses do increase the total charge integrated on the wires. This could lead to a faster ageing of the wires; a study of this aspect has just begun, and we do not have any data at present. At 5.7 kV the charge of a single streamer is $\sim$ 300 pC, which corresponds to a gain of $\sim 6\ 10^6$.

4 — Drift Velocity and Local Resolution

Knowledge and use of the appropriate Space-Time Relation is a major ingredient needed to obtain a good spatial resolution. Neglecting displacements of the wires and imperfections in the manufacturing of the tubes, the electric field in our devices has the simple behaviour $E = \kappa/r$, with $\kappa = 1$ kV with 5.7 kV on the sense wire. The end point of the typical time spectrum around 300 ns indicates for our 1.5 cm tubes an average drift velocity of $\sim 50\,\mu$m/ns, as is expected for typical argon-isobutane mixtures [7] at these electric field values.

The drift velocity is not constant, as can be seen studying the correlation $t_{\rm stag} = (t_1+t_3)/2+t_2$ as a function of t_2, in three adjacent tubes belonging to the same MT. The geometry of the tube triplet and the symbols are illustrated in fig. 4. One would expect a flat $t_{\rm stag}$ for a saturated drift velocity, since this combination of times adds up to the total drift time corresponding to the stagger between the tubes which is 1.505 cm; this flatness is not observed.

To fit the space-time relation, we used the results of a `GARFIELD+MAGBOLTZ` [8,9] simulation to define a 7 parameter space-time relation $x = x(t; \alpha_i), i = 1..7$. The 7 parameters, *the same for every tube*, have been determined requesting the function $x_{\text{stag}} = (x(t_1) + x(t_3))/2 + x(t_2)$ to result, independently of drift times, in the nominal one-radius offset. Applying this procedure to a suitable number of different triplets, the same 7 parameter set was found, within small errors. The quality of the fit can be seen from fig. 5 , where x_{stag} is plotted against t_2: the band around 1.505 cm does not depend appreciably on the drift distance, making the average resolution over the whole tube the same as the local one ($\simeq 65\,\mu$m). Fig.6 shows this local resolution, plotted against the drift distance.

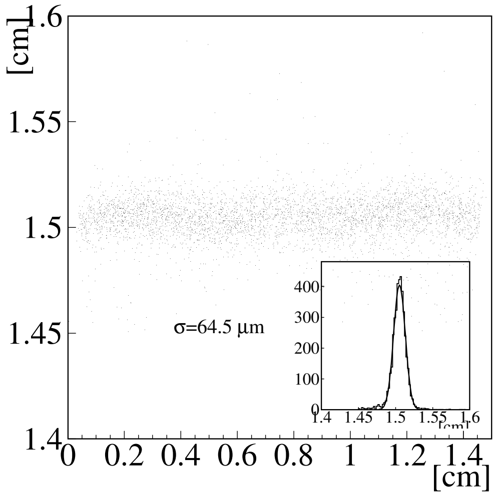

Fig. 5. The function x_{stag} (see text).

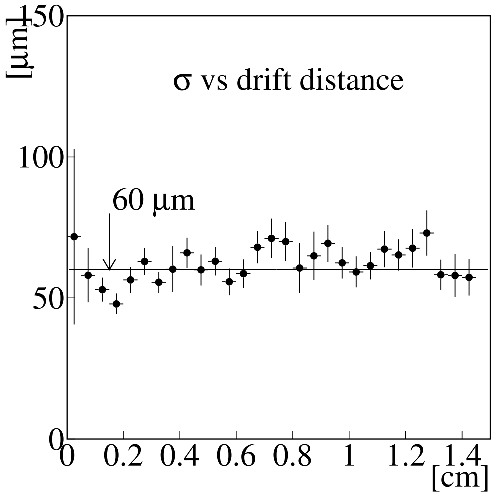

Fig. 6. Tube resolution as a function of r.

Further details on the study of the drift velocity and the space to time relations can be found in ref.10.

5 — Efficiency and Global Resolution

The space-time relation determined as described above was then used to measure particle trajectories inside our setup, performing a linear 6-points fits. The distribution of tubes hit peaks at 6; there is a small tail to lower values due to the dead space introduced by the 500 μm-thick Al walls. The tube efficiency was calculated requiring consistency ($\leq$ 5 ns) between the expected drift time of the track and the drift time actually measured in the tube. The expected drift time was obtained from the time measurement of the tubes in the layer in front (t_1) and behind (t_3) the tube: $(t_1 + t_3)/2 = t_{max} - t_2$, t_2 being the measurement in the tube whose efficiency we are measuring, and t_{max} the maximum drift time. An efficiency of $\geq$ 97% is found at the tube border, and close to 100% elsewere. In fig. 7 the fit residuals are shown, as a function of the distance from the sense wire, for tubes in different layers of the MT structure, and in fig. 8 the corresponding projections.

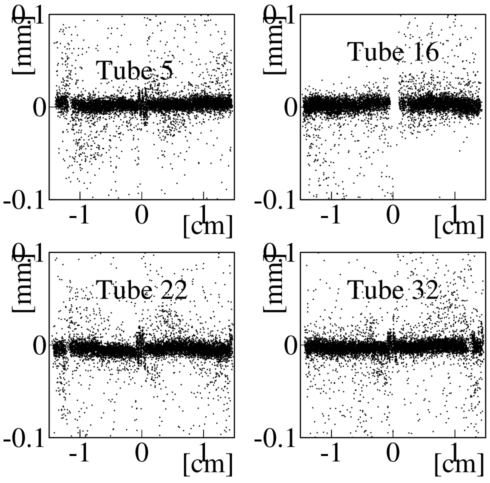

Fig. 7. Fit residuals.

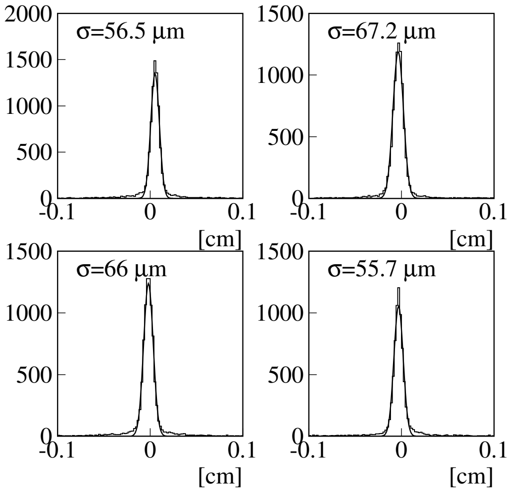

Fig. 8. Projected fit residuals.

Since the tubes were included in the fit, the observed widths must be divided by a coefficient (respectively 0.78, 0.82 and 0.85 for tubes belonging to the outer, central and inner column of each MT) of easy derivation from the formulae of linear least-squares fits. The single wire resolution is $\sim 60\,\mu$m, with deviations of $\leq \pm 10\,\mu$m from tube to tube. It is important to stress the fact that to perform the fit we have used *the same* coefficients for the space-time relation in all tubes.

We fitted the χ^2 of the fit when all six tubes were hit with a χ^2 function with 4 degrees of freedom. The corresponding $P(\chi^2)$ distribution is only flat, when the error in the tubes is set to $70\,\mu$m. This value is slightly worse than the error in the single tube, a difference which we attribute mainly to the displacements (30–50 μm) of the wires with respect to their nominal positions, which were not corrected for.

We have operated the MT's at different high voltage values. In fig. 9 we show the resolution as a function of the drift distance for runs taken at 5.1, 5.4 and 6.0 kV compared to the one at 5.7 kV. We observed no significant degradation in either efficiency or resolution of the device even when running at the lowest high voltage value, where the number of afterpulses is greatly reduced and therefore the device can sustain much higher single counting rates.

We took also data with the setup in a magnetic field $B = 0.6$ T directed parallel to the wires. A complete analysis of these data is not ready yet, but preliminary results show very little performance degradation. Fig.10 has been obtained fitting two track segments in the two MT's and plotting the difference between their directions. The expected track bending, taking into account the separation between MT's, the track momentum and the magnetic field, is correctly reproduced.

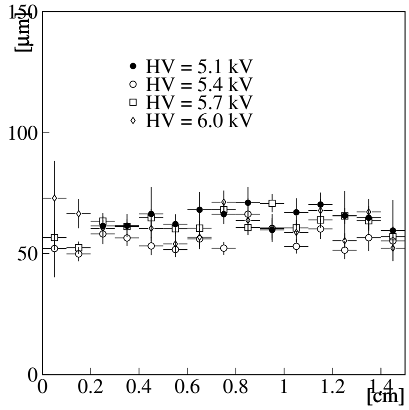

Fig. 9. Resolution for several HV's.

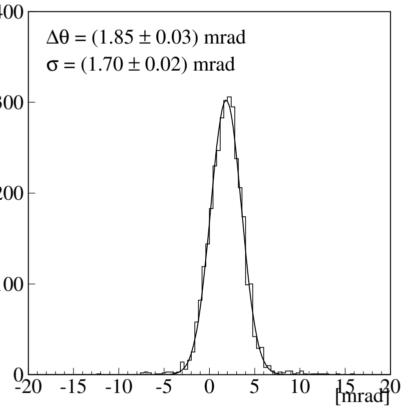

Fig. 10. Bending angle, B=0.6 T.

6 — Further Developments

One open question on the operation of Al limited streamer tubes is the stability of its performances over time, given the significant amount of charge that is produced in the high gas amplification regime of operation. We are planning to make a study of the long term behaviour of these tubes.

ACKNOWLEDGMENTS

We would like to thank L. Iannotti, whose skill and dedication made possible the accurate and fast fabrication of the MT's, and A. Di Virgilio for preparing the scintillation counters.

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