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Experimental Data on GEM LAC FCAL Tube Design

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Abstract:

While ionization sampling calorimetry using liquid argon is a well tested technique, the particular tube electrode design proposed for GEM forward calorimetry is unique. This paper reports experience with such tube electrodes which suggests that this electrode configuration will behave just as expected.

GEM Calorimetry Note

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Ionization sampling calorimetry using cryogenic noble liquids, in particular liquid argon, is a well proven technique. Both electromagnetic and hadronic calorimeters have been used in large experiments with very good results. D0 at Fermilab, SLD at SLAC, H1 at HERA, and R806 and NA31 at CERN are prominent examples.

The liquid argon forward calorimeter (LAC FCal) option for GEM has one unique feature which is different from the conventional LAC, the electrode structure. In order to avoid the problem of positive ion buildup in the liquid argon gap which will occur at the highest SSC luminosities and at large values of eta, we must employ argon sampling gaps which are of order 100 μm across. A technique for realizing such narrow gaps without undue cost is inherent in our tube design. In addition the electronic readout with very fast shaping is quite straightforward. A single tube is shown in Fig. 1 and an engineering drawing of a part of the front face of one module of the LAC FCal is shown in Fig. 2.

While liquid argon calorimetry is a well established and successful technology, there is no experience with our particular electrode structures. A beam test is not practical now but an extensive test is planned for the summer of '93.

This report summarizes the experience we have gained in working with these tubes over the last few months. These results, coupled with Monte Carlo work to be described separately, indicate that the tube design will work as expected and will meet the GEM physics objectives. We have results on three different types of measurements; 1) precision measurements of the dielectric constant for argon in the readout gap, 2) high voltage breakdown measurements, and 3) measurement of recombination in the gap as a function of electric field in the gap. Each of these will be described and the results presented here.

We have constructed three generations of tubes. In all cases the construction was quite easy and the electrical properties, e.g. breakdown potential, were suprisingly good. The first generation used a 60 μm gap since that was what was conveniently available at the local hardware store in brass tubing. We tried various fibers spiralled about the inner tube to maintain the gap. Ordinary cotton thread did not work very well since it is too coarse and doesn't compress as much as we expected. We eventually found that surgical suture (a monofilament of polypropylene) worked well and was easy to handle. While we have samples of quartz fiber coated with polyimide (Kapton) we do not yet have enough to use

as spacers. A glossy photograph of the present generation is inadequately reproduced in Fig. 3. It consists of 21 tubes arranged in an hexagonal close-packed array of three rows of 7 tubes each. The gaps are 100 μm.

Dielectric Constant of Liquid Argon

Precision measurements of the capacitance of six of the tubes in the array of Fig. 3 were made in order to determine whether liquid argon had properly filled the tube gaps. Measurements of the capacitance made with the tubes immersed in liquid argon were compared to measurements made in cold argon gas and the ratio of the two was used to determine the dielectric constant. Based on earlier measurements of this type, it was believed that sufficient accuracy was possible to measure the variation of dielectric constant with temperature as described in the CRC Tables. Temperature of the liquid argon was varied by decreasing the pressure (stepwise) in the cryostat and waiting until boiling ceased at each new pressure setting. Temperature was then read from a graph of the vapor pressure of liquid argon vs. temperature.

Fig. 4 shows our data along with the parameterization of previous measurements quoted in the CRC Tables. It should be noted that the value 1.53 quoted in the tables is at a temperature of 82 K (which is, curiously, below the triple point for argon at T_{tr}=83.78 K). The tables also quote the temperature dependence of this value as -0.0034 K^{-1}.

The good agreement of our results with the published data, in addition to the high voltage breakdown results, strongly indicates that the tube gaps do reliably fill with liquid argon.

High Voltage Breakdown

Charge collection in a liquid argon gap is generally in an electric field of order 10 kV/cm. For the standard, parallel plate gap of 2 mm, the potential across the gap is 2 kV. For the 100 μm gap we are using, the potential is 100 V. Electrical breakdown can be a problem at such electric fields if the electrode structure is not engineered with care. The tube electrode structure is one which is fairly easy to construct without dangerous points which induce breakdown.

Using the same six tubes of the array of 21 described above, we ran the high voltage up until a measureable current was drawn from the supply. No particular care was taken to avoid breakdown in the construction of these tubes. With positive potential on the inner tube the breakdown point occured at 575 V. With negative potential on the inner tube the breakdown occured at 560 V. We regard these as roughly identical so we see no significant dependence on the sign of the potential. These breakdown potentials are at least a factor 5.6 above the operating potential which leaves a much larger margin than in conventional, parallel plate geometries. Further the electrode structure is so robust that breakdown does not seem to damage anything.

Recombination in Liquid Argon

At electric fields well below the operating point in liquid argon, the ions produced by charged particles traversing the gap will recombine before the field can separate them. Measuring the charge collected as a function of the potential across the gap is a well-established test of an ionization calorimeter. The collected charge should plateau at a potential well below the operating point.

We have performed such a measurement with our tube electrode structure. But without a readily available test beam we altered the measurement slightly. We attached a 5 mCi ^{90}Sr beta source (end-point energy of 2.283 MeV) to the side of the tubes and measured the current as a function of the potential across the gap. The results are shown in Fig. 5. Measuring currents in the nanoAmpere range requires great care and we worked hard to reduce pickup and leakage currents to managable levels. We performed the same set of measurements without the ^{90}Sr source in place. We do not show these results because the data points lie on the horizontal axis with error bars so small that the data points would not show outside the thick line demarking the axis. In all cases the current was below 10 pA.

We made an attempt to predict the current we would see due to the ^{90}Sr source. Such a calculation is difficult because of lack of knowledge of the beta spectrum and a host of other effects. Our estimate was in the nanoAmpere range. The measurement is consistent with this estimate.

We were a bit surprised at the very low value of electric field at which the current plateaued. It is our experience that this plateau point is considerably higher in test-beam measurements where charge is collected rather than a current. However one would expect such a difference if attachment were a problem. The current measurement determines recombination independent of attachment while the charge measurement depends on both effects. (We intend to do both types of measurements when performing purity studies to pin down the nature of contaminants.)

Conclusions

The three measurements reported here suggest that a tube electrode structure in a liquid argon calorimeter behaves as expected. And there are some considerable advantages when such small gaps are required. The tube structure is relatively easy to construct and the tolerances are easily maintained. An added advantage results from the fast collection time. The ions in the gap drift out in about 20 ns. Coupled with new techniques for transferring the charge from the electrodes to the electronics, this structure will be particularly fast, an advantage in the forward direction.

There are many other issues that must be faced by this technology as applied to GEM forward calorimetry. We have addressed many of these in talks and other papers and continue to pursue the remaining outstanding questions identified to date. With the success

of the above tests we can be much more confident that such remaining questions can be answered via careful simulation.

Figure Captions

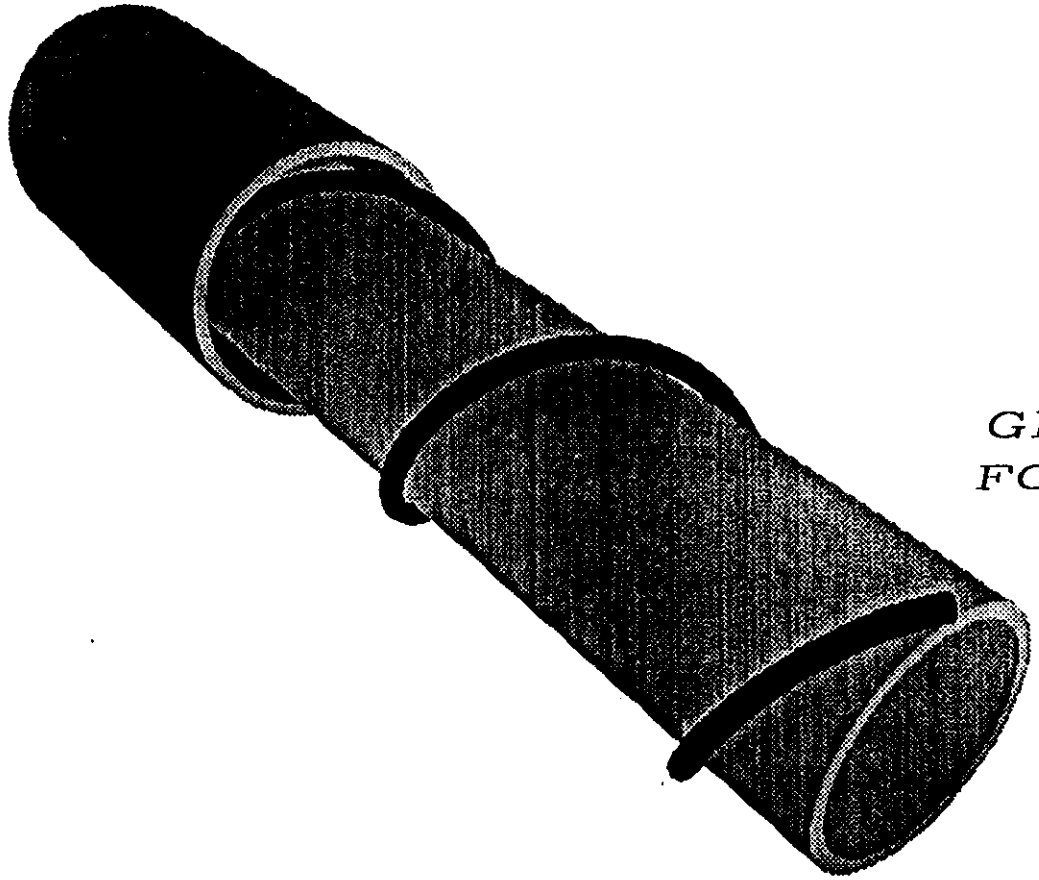
1) Drawing of one tube electrode for the GEM liquid argon forward calorimeter. The 100 μm gap between the inner and outer tubes is maintained by a spiralled fiber which we imagine will eventually be quartz, perhaps with a Kapton coating, in order to withstand radiation damage. These tubes are oriented parallel to the beam line. In this drawing the inner tube is partially withdrawn from inside of the outer tube in order to show the spiral fiber spacer.

2) Engineering drawing of a part of the front face of one longitudinal section of the GEM liquid argon forward calorimeter. The depth of the "EM"section is 25 cm and the absorber material is Tungsten or heavymet. Rather than electrodes with an inner tube filled with absorber this design shows an inner Tungsten rod. One such rod, seen in cross section, is shaded. The Tungsten absorber in the region between the stainless steel outer tubes will be assembled in truncated triangular segments. One such segment is also shown in cross section and shaded.

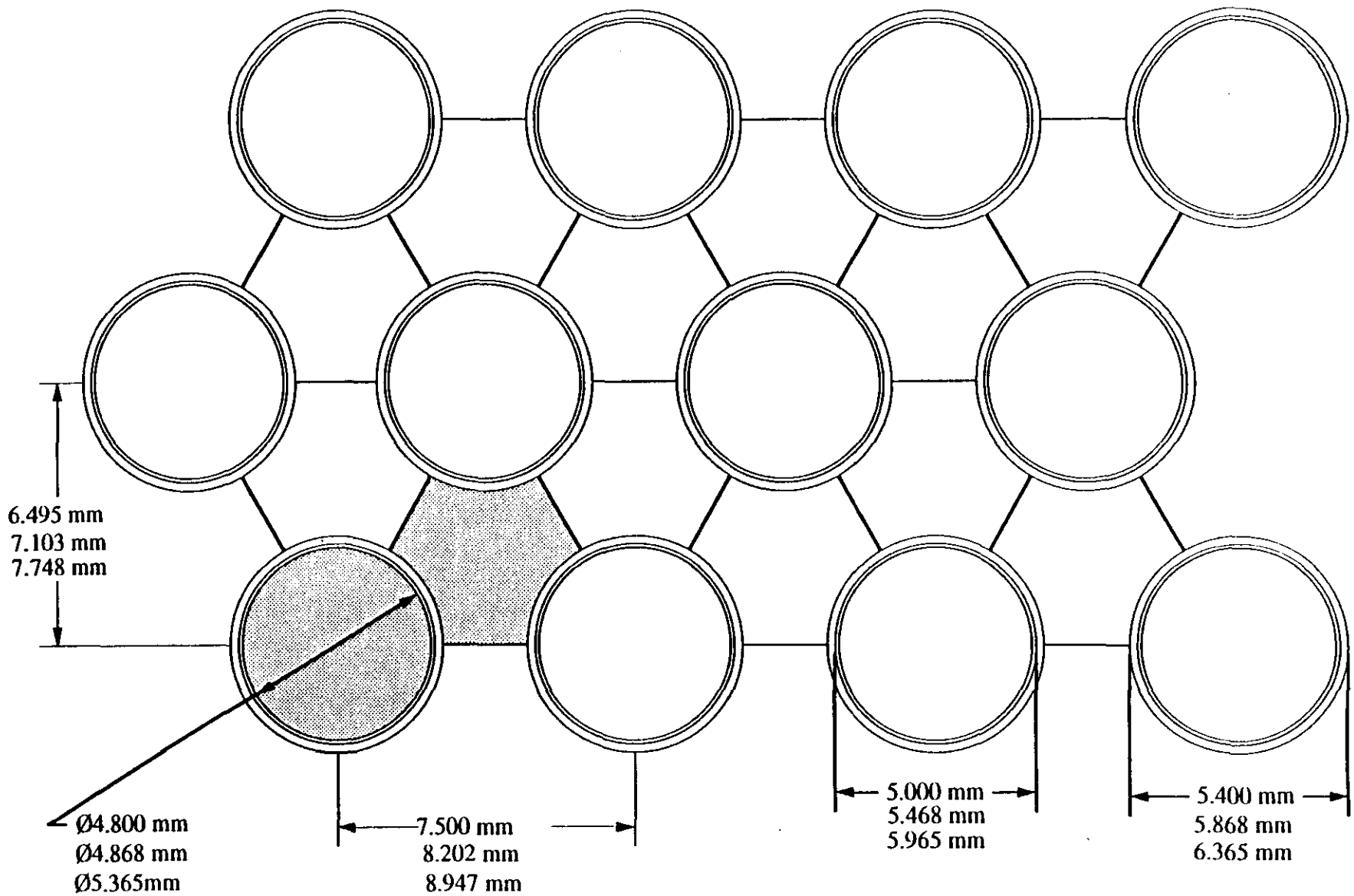
3) Photocopy of a glossy photograph of an array of 21 tube electrodes used in the tests described in this paper.

4) Measured value of the dielectric constant for liquid argon as a function of temperature. The solid line represents the values in the CRC handbook.

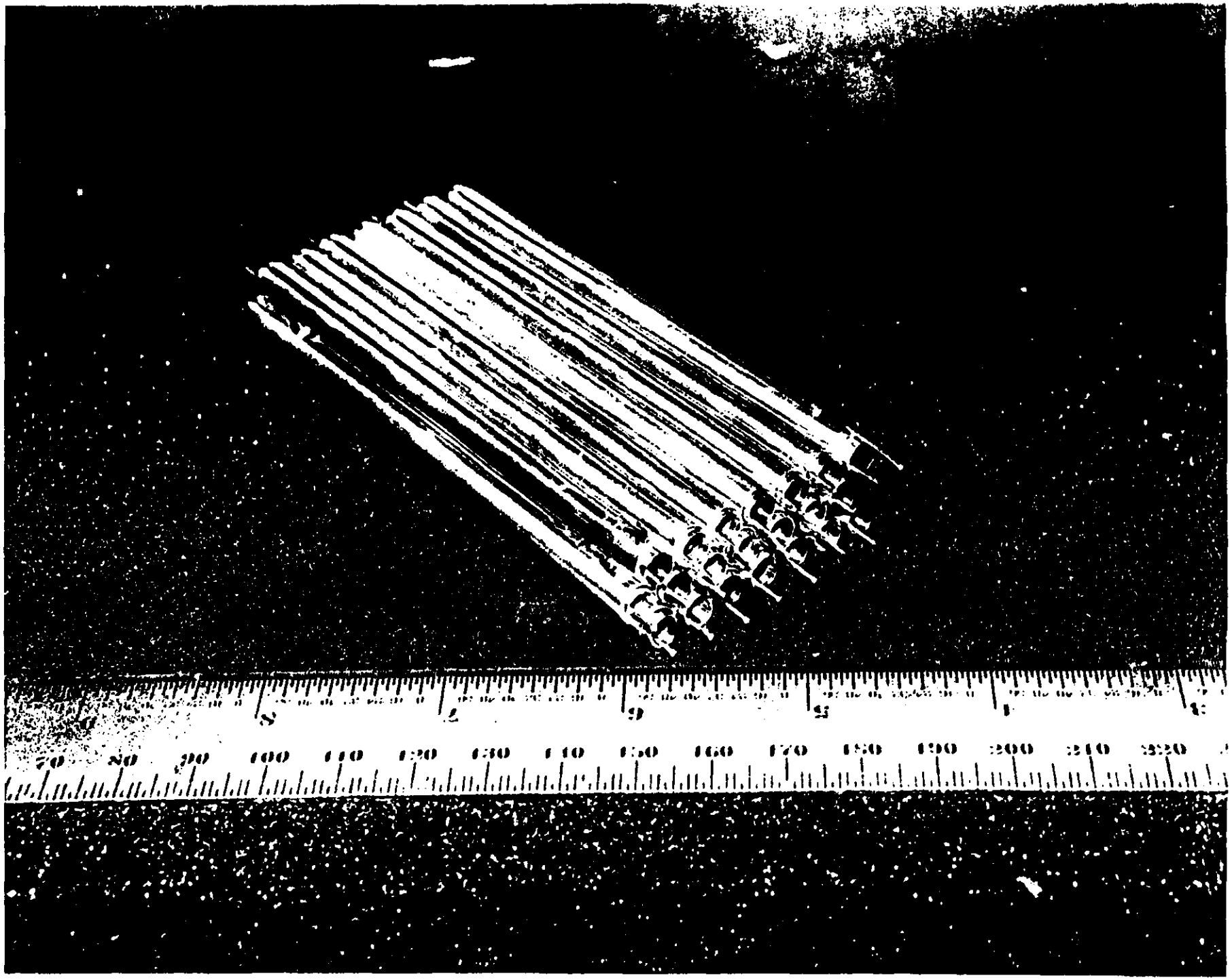
5) The current across the gap of six of the tubes in the photograph of Fig. 3 as a function of the potential across the gap. A ^{90}Sr beta source was the origin of the free charges in the argon gap.



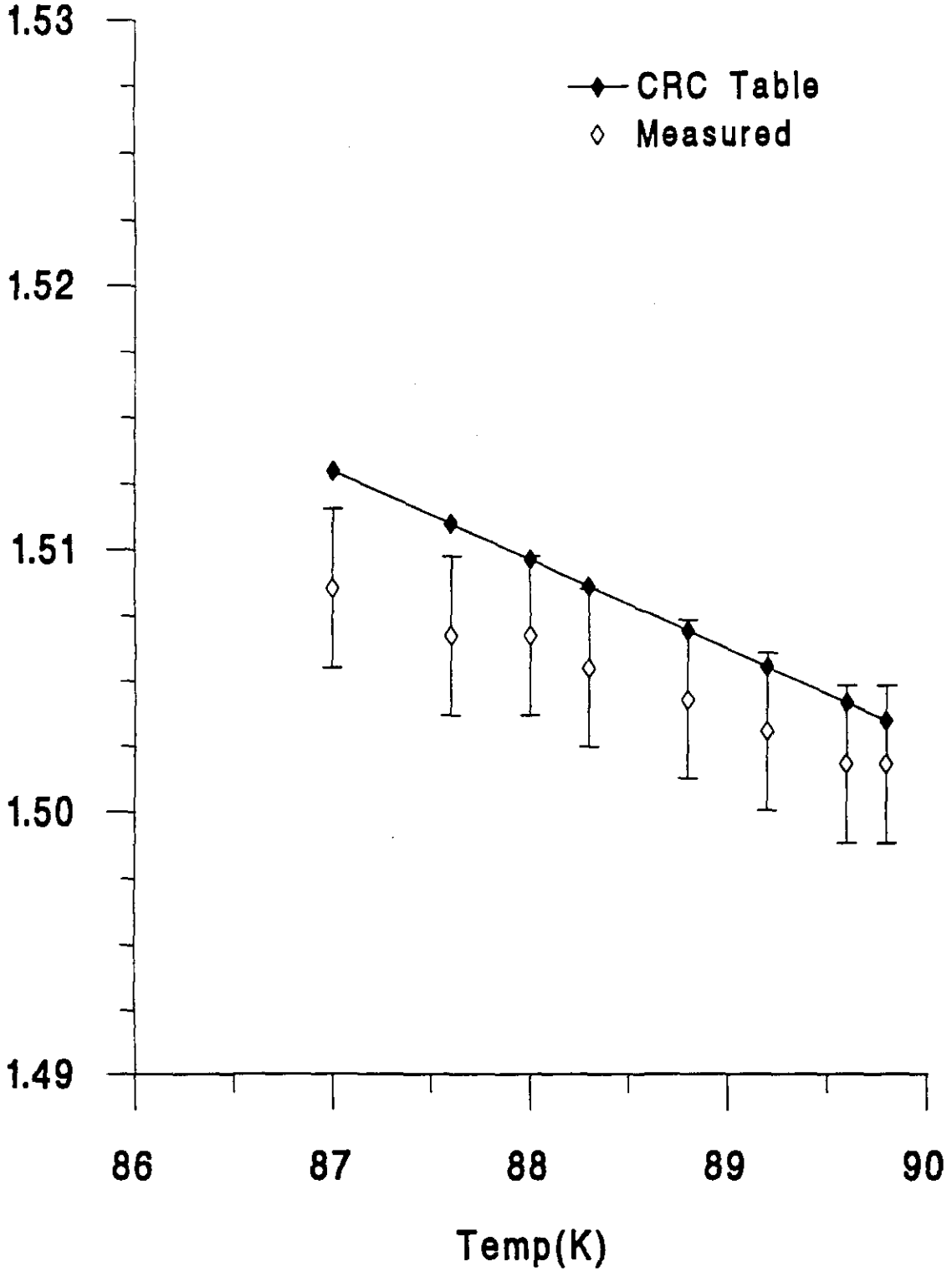
GEM LAC
FCal Tube

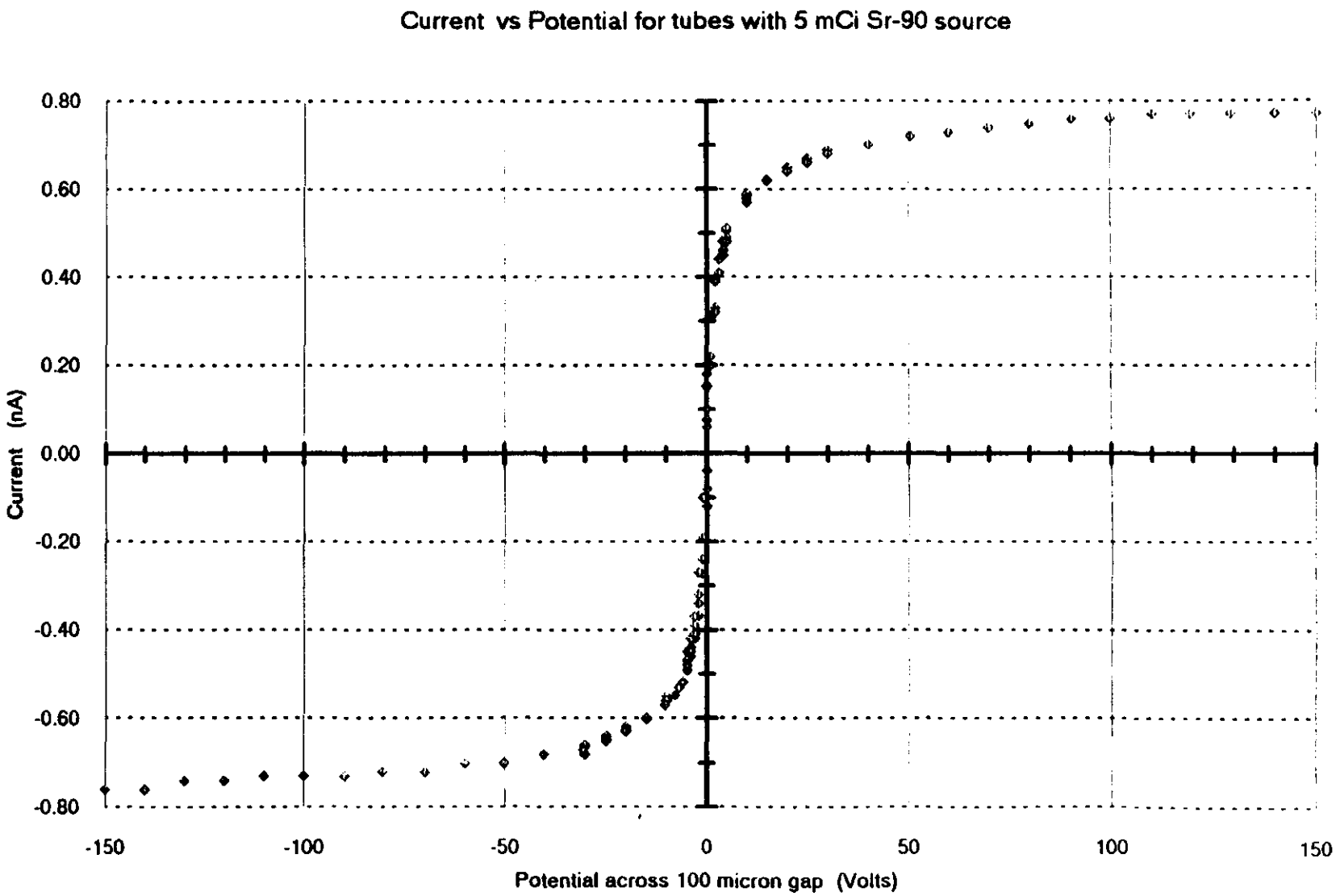


FCAL MODULE - TUNGSTEN ARRAGEMENT



Dielectric Constant of Liquid Argon




Current vs Potential for tubes with 5 mCi Sr-90 source
0.80
0.60
0.40
0.20
0.00
-0.20
-0.40
-0.60
-0.80
Current (nA)
-150
-100
-50
0
50
100
150
Potential across 100 micron gap (Volts)