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Abstract

Steel tubes of approximately 8 mm O.D., filled with Argon gas to ∿200 bar, are considered as the active element for a charge collecting sampling calorimeter readout system. The tubes are permanently sealed and operated in the ion chamber mode, with the charge collection on a one-millimeter concentric anode. We present the motivation for such a device, including Monte Carlo predictions of performance. The method of construction and signal collection are discussed, with initial results on leakage and ageing of the filling gas. A prototype electromagnetic calorimeter is described.

I. Introduction

Among the several readout techniques employed for sampling calorimeters at colliding beams, liquid argon systems stand out for two important reasons:

i) They provide excellent energy and space resolution.

ii) They have demonstrated control of instrumental effects (calibration and uniformity of response) at the 1% level required to achieve the intrinsic precision of calorimetric measurements at very high energies.

The drawback of these devices is the high fabrication costs of the cryogenic construction, and inevitable dead spaces in detectors covering large solid angles.

We describe here a new read-out system for calorimeters, presently under development, in which the active sampling elements are sealed tubes of high pressure argon gas operating as individual ion chambers. The motivation for this approach is to achieve a relatively inexpensive, well-segmented calorimeter structure of design similar to proportional wire devices, with energy measurement capability and control of systematics comparable to liquid argon systems.

II. The HARP Concept

Our approach has evolved from recent studies of a "high density" proportional wire calorimeter:[1,2] a structure in which individual sampling channels penetrate bulk absorber, in contrast to the conventional geometry of multiwire planes sandwiched between sheets of absorber. A test device of this type is shown in Fig. 1. It was found that acceptable energy resolution can be achieved with very sparse sampling volumes, and that the high net density of the device (which limits the lateral shower development), coupled with a fine-grain array of sampling channels can be exploited to give excellent space resolution, separation of near-by showers and discrimination between electromagnetic and hadronic showers. In addition, this type of structure lends itself to a number of interesting options for construction methods. (We return to this point in Sec. IV.)

Figure 2 shows the calculated energy resolution of such a device for electromagnetic showers, as a function of the sampling ratio, R = sampling volume/total volume. These results are obtained for argon sampling gas at 1 atmosphere.[2] The resolution width is dominated by Landau fluctuations, which in principle can be reduced by increasing the gas pressure. In Fig. 3 we show the same calculation, comparing the net resolution for a range of gas pressures and for liquid argon. The performance figures of liquid argon are approached at pressures which are not difficult to achieve in practice. Hence the concept of HARP (High Pressure Argon Pipes): we replace the proportional wire sampling channels in such a structure with sealed tubes of argon gas pressurized to ∿200 atmospheres. For sampling channels of 25 mm^2 cross section in an iron structure with R = .25 (a practical packing fraction for such tubes) the calculated energy resolution for 1 GeV electrons is 15% at 250 atmospheres, as compared with 13% for liquid argon. The signal charge at this pressure (∿10^6 electrons per GeV of shower energy) is sufficient to allow operation in the ion chamber mode, with no avalanche gain: i.e., in nearly exact analogy with liquid argon readout.

III. Charge Collection in Ion Tubes

The tube construction which we have adopted is illustrated in Fig. 4. It consists of a standard steel pipe with 8 mm outside diameter and 5.6 mm inside diameter. The gas tightness is achieved by two plastic stoppers which are crimped at the two ends of the pipe in such a way that the gas pressure helps ensure the gas tightness. The stopper at one end of the pipe serves as an insulating feed-through for the central electrode.

These tubes are permanently sealed with the aim of being operational for ≳ 10 years. In tests carried out with the collaboration of the CERN HS Dept. the breaking pressure was found to be ∿850 atm., which allows a safe working pressure up to 250 atm. The leakage rate, measured at 200 atm., corresponds to a maximum drop in pressure of 3% (i.e., 6 atm.) over a period of five years.

The thick central electrode (≲ 1 mm diameter) is held in the center of the pipe by thin plastic spacers; it carries both the operating voltage (3-4 kV) and the signal, the external wall of the pipe being grounded. The electrical capacitance of a 1 meter long tube is about 50 pF.

The time development of signal charge in cylindrical ion tubes is closely analogous to that of the familiar parallel plate geometry used in liquid argon calorimeters. This is illustrated in Fig. 5, for a gas mixture of 90% argon, 10% CH_4. (For the illustrated geometry, with an applied voltage of 4 kV and 250 atm. pressure, the reduced electric field ranges from E/P = .25 V/cm/mm Hg at the anode to .05 V/cm/mm Hg at the cathode. In this range the small admixture of methane increases the electron drift velocity by a factor of 5 over purge argon.)

The readout electronics requires little development as the needs are similar to those of several other charge collection devices now in operation (e.g., liquid argon calorimeters, low-gain wire chambers,

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silicon strip detectors). The electronics chain illustrated in Fig. 6 has been implemented for initial tests, using existing components, and yields a measured equivalent noise charge of 350 electrons RMS.

A series of tests have been initiated with tubes constructed with α-emitting radioactive sources sealed inside. These are being kept continuously at operating voltage and the pulse-height spectrum monitored to investigate the stability of response and possible ageing effects due, e.g., to degradation of the gas mixtures. Results to date for the two earliest tubes are shown in Fig. 7. It will be seen that there is a "conditioning" period in each case lasting for a few days, after which the response remains very much constant.

IV. Possible Application and Plans for a Prototype Detector

With each tube being an independent, self-contained detector, which operates at room temperature and should perform well in a magnetic field, one has a great deal of flexibility for configuring them in some matrix of absorber. We mention two classes of applications:

a) Pole Tip Calorimeters (see discussion in Ref. 1): Here we envisage the pipes to be inserted into channels drilled into the steel, as illustrated schematically in Fig. 8a. Drilling of such holes in iron (8 mm diameter, 1 m length) can be done without great difficulty, and at reasonable cost, by specialized companies. We have evaluated test drillings in magnet iron and found them to be satisfactory, with deviations from straightness $\lesssim$ .001 m over 1 m lengths.

b) Large Angle (EM or Hadronic) Calorimeters: Here a great variety of geometries can be realized with either magnetic or non-magnetic materials. Fig. 7b visualizes a close-packed array of hexagonal tubes, as an example. Arrays of tubes may also be imbedded in molded castings. An interesting possibility is to consider these tubes in a matrix of heavy metal oxides cast in plastic.[3] This approach offers the possibility of uranium calorimeters using powdered oxides (which are plentiful and easily cast in plastic) rather than metallic uranium, which is difficult and expensive to machine.

We are presently constructing a prototype electromagnetic shower detector for test beam studies. This device will incorporate 150 tubes inserted in 8 mm diameter holes drilled in an iron block. The tubes will be 30 cm long, with readout electronics as illustrated in Fig. 6.

References

1. T. Ludlam et al., IEEE Trans. Nucl. Sci. NS-28, 517 (1981).
2. T. Ludlam et al., BNL Report 30607, 1981 (to be published, Nucl. Instr. and Methods).
3. H. Gordon et al., Physica Scripta 23, 564 (1981).

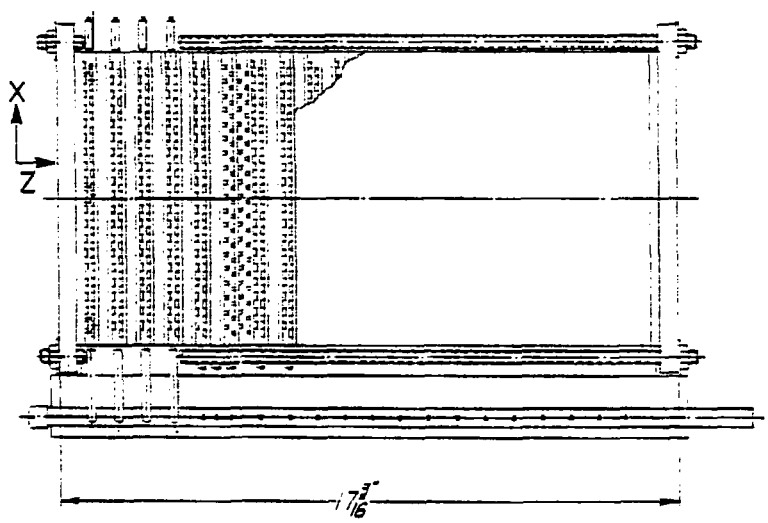

Figure 1. The test calorimeter of Refs. 1, 2. The module is assembled from steel plates. Machined slots in alternate plates form the sampling channels, which are 2 mm x 5mm and 2 mm x 2 mm in cross section. In this device, which was operated with proportional wires, the sampling gas occupies only 10% of the total volume.

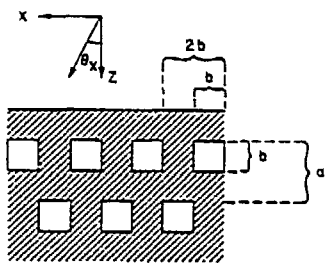

Figure 2a. Sampling geometry used for the Monte Carlo results shown below. The absorber material is iron; the sampling medium is argon gas at atmospheric pressure; the beam is parallel to the Z direction and randomly distributed in X. For this configuration the ratio of sampling volume to total volume is given by

$$R = \frac{b}{2a}$$

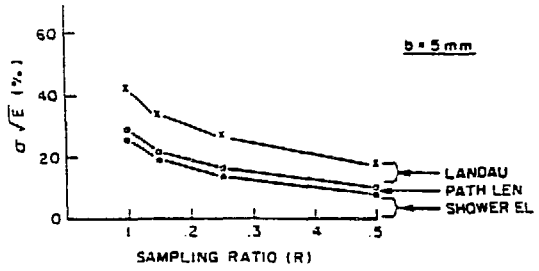

Figure 2b. Energy resolution for incident electrons, as a function sampling ratio, for 5 x 5 mm^2 sampling channels. The lowest curve corresponds to fluctuations in the number of sampled shower electrons, the next incorporates path length fluctuations, and the top curve gives the net resolution (Ref. 2).

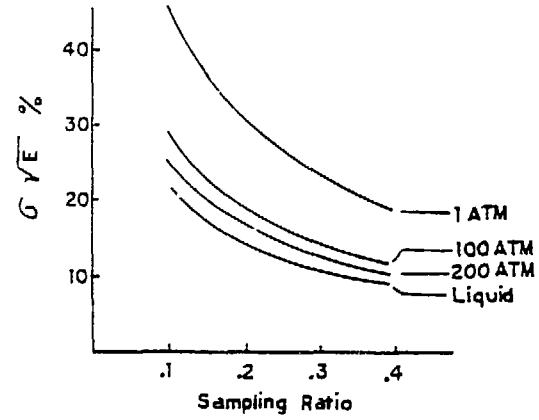

Figure 3. The net energy resolution, calculated as in Fig. 2, for various pressures of the sampling gas.

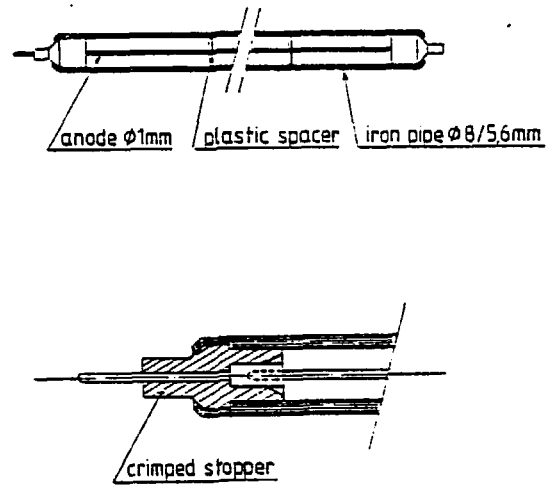

Figure 4. Construction details of the ion tube.

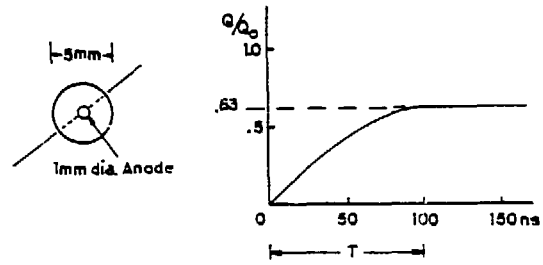

Figure 5. Time development of the signal charge for a track crossing an ion tube in the illustrated geometry, producing ionization charge Q_0. The gas mixture is 90% argon/10% methane, with the central anode at +4 kV. The time (T) for full signal collection is 100 nsec.

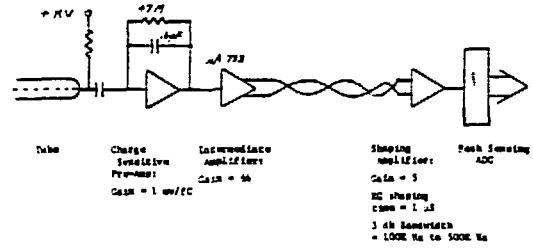

Figure 6. Electronics chain for ion tube readout.

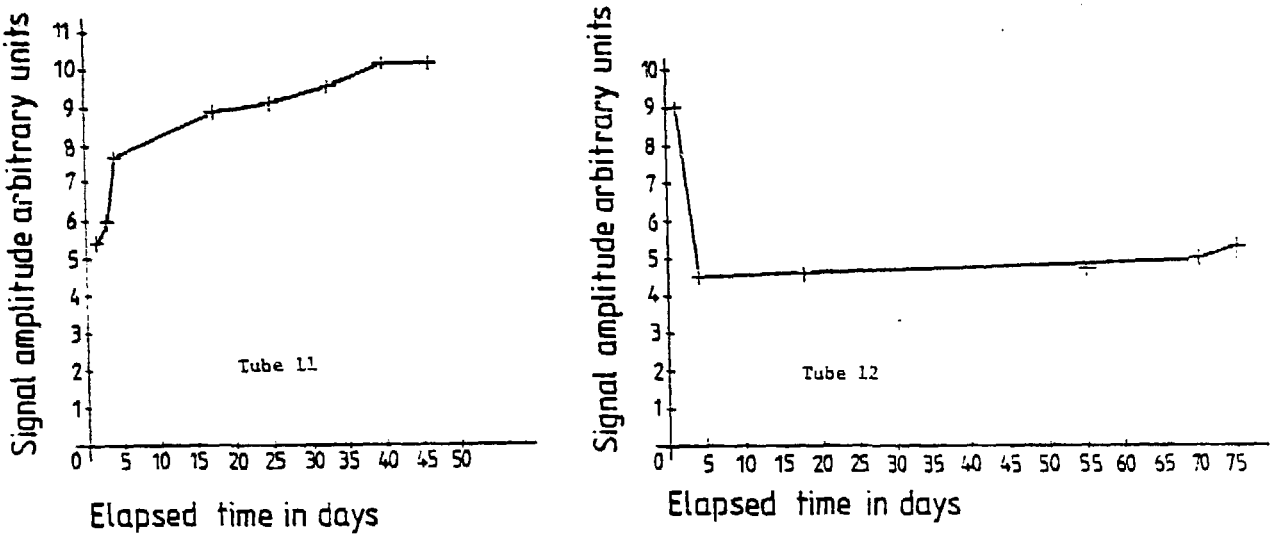

Figure 7. Time history of pulse-height measurements with two tubes in which α-emitting radioactive sources have been imbedded. Due to the high ionization density produced by the α particles they provide a more sensitive check on impurity effects than minimum ionizing tracks. Tube 11 was operated with an ^{241}Am source with an applied voltage of 1 kV; tube 12 had a ^{238}U source and was operated at 3 kV.

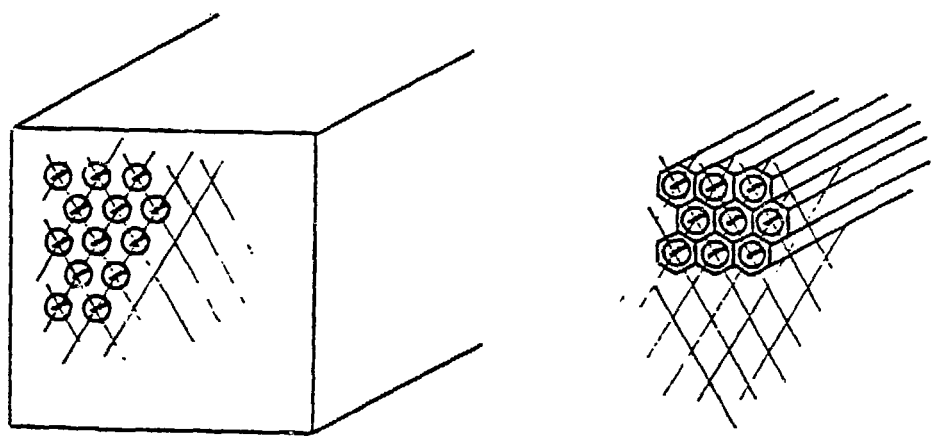

Figure 8. Possible detector configurations (see text).