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PLASTIC STREAMER TUBE CALORIMETERS

P. CAMPANA
Laboratori Nazionali dell'INFN, Frascati, Italy

The use of streamer tubes in the construction of electromagnetic and hadron calorimeters has been considered by several groups within LEP Collaborations. The results of various tests on these calorimeters is reviewed and the possibility to have an integrated muon–hadron detection system in hadron calorimeters with streamer tubes is discussed, together with possible applications when high energy and high rates are concerned.

1. Introduction

The use of a saturated mode, as the streamer, in calorimeters is based on the assumption that the collected charge is proportional to the number of saturated discharges, which in turn, is linearly related to the number of sampled tracks in the shower. Compared to gas proportional calorimeters, the use of streamer tubes [1] has some advantages:

– the resolution in principle improves due to the absence of Landau fluctuations;

– the saturated mode permits a simple monitoring and less strict tolerances;

– the large signals generated in the streamer process improve the signal/noise ratio.

It should be noticed that, due to saturation effects (i.e. the fact that two or more tracks crossing the dead region of the streamer along the wire are counted as one), the relation between the collected charge and the energy starts to become non linear above a certain energy, so that σ_E/E deviates from the $C/\sqrt{E}$ behaviour. The energy at which this phenomenon occurs depends strongly on the longitudinal and lateral granularity, gas operating conditions and wire dimensions.

The use of graphite coated plastics greatly simplifies the construction of streamer tube calorimeters [1]. On account of the transparency of the cathode [2], the streamer charge can be detected with external electrodes (strips, pads) which are completely separated from the active device and can be arranged in oriented structures (e.g. towers of pads).

2. Electromagnetic calorimeters

The results of an electromagnetic test calorimeter with streamer tubes (Annecy, Frascati, Roma), performed within the ELECTRA–LEP Collaboration [3] are discussed below.

The calorimeter was made of a sampling of 2 mm lead and 9×6 mm^2 active cross section tubes. The anode wire was 60 μm in diameter. The tubes were operated with an Ar + isobutane = 1 + 5 mixture at a working voltage of 3.5 kV, at the beginning of the efficiency plateau. The single streamer charge on wire for orthogonal tracks was 7 pC. The charge response and the energy resolution are shown in fig. 1. The non linearity at 25 GeV is 12%, while the energy resolution is fitted by $\sigma_E/E = 0.10/\sqrt{E} + 0.02$, between 4 and 25 GeV.

From this result, it can be seen that the resolution found in e.m. calorimeters employing streamer tubes is only 20% better than those using proportional tubes,

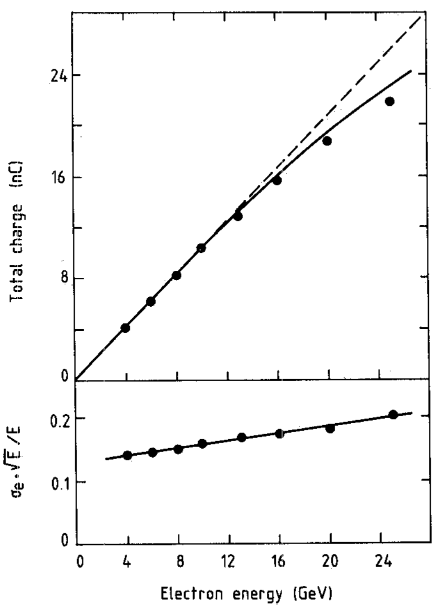

Fig. 1. Charge response and energy resolution for the e.m. streamer tube calorimeter of ref. [3].

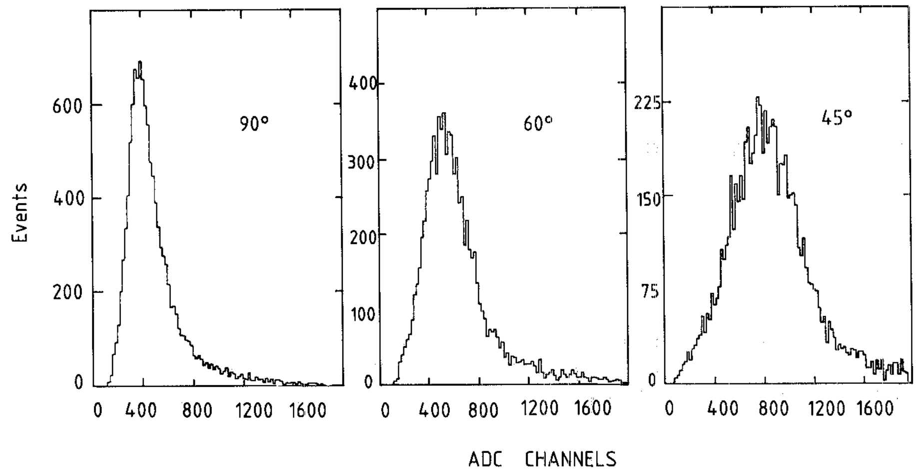

Fig. 2. Streamer charge of tracks at various angles with respect to the wire for 9×9 mm^2 tubes, 100 μm wire, Ar + isobutane = 1 + 3, HV = 4.5 kV.

while it is 50% worse than scintillators with the same sampling. This point has been investigated in detail with a Montecarlo for the PEP4 Limited Geiger Calorimeter [4]. There are two major contributions to the large difference in energy resolution between a saturated mode calorimeter and a scintillator one. On the one hand there is an unavoidable track counting loss in the dense core of the e.m. shower, even in the linear response range, due to the high density of particles in that region. In addition to this, large fluctuations are introduced by tracks in the shower which make large angles with respect to the wire, which can generate, in the case of the streamer mode, multiple streamers. This leads to the conclusion that the hypothesis of counting the number of tracks when collecting streamer charge is only an approximation. The angular dependence of the response of the streamer can be studied, evaluating its obscuration length (i.e. the dead region) along the wire.

In comparing the non linearity of streamer e.m. calorimeters [3,5] with that of the Limited Geiger Calorimeter [4], where the length of the dead region is fixed, and taking into account the different average radiation lengths, efficiencies, etc., the following values for streamer obscuration lengths are obtained: ~ 1 mm in the case of 9 × 6 mm^2 cell, 60 μm wire, Ar + isobutane = 1 + 5, 7 pC single streamer charge for orthogonal tracks (referred to as "9 × 6 mm^2 tubes" below); ~ 2 mm from the data of a previous e.m. test calorimeter [5] with 9 × 9 mm^2 cell, 100 μm wire, Ar + isobutane = 1 + 3, 30 pC single streamer charge for orthogonal tracks ("9 × 9 mm^2 tubes" in the following). The different obscuration lengths obtained depend on the different geometries of the tubes, gas mixture and wire dimension [6]. In general, small tubes need higher quenching mixtures compared to larger ones. This reduces streamer charge and its obscuration length along the wire. The use of thinner wires has the same effect.

The charge distributions obtained [7] when exposing a single layer of 9 × 9 mm^2 tubes to a high energy muon beam at various angles with respect to the wire (90, 60 and 45 degrees) are shown in fig. 2. From the charge distributions, one can calculate [1] obscuration lengths of ~ 3 mm in the "9 × 6 mm^2" case and ~ 4 mm in the "9 × 9 mm^2" case. These values seem to contradict the previous results.

A possible explanation for this is that the streamer dead region depends on the local ionization density; the space charge of a streamer depresses the electric field along the wire so that streamers in the nearby region will fire at distances which are correlated to the local density of tracks. The pulse height will also be affected by the available ionization density. This hypothesis is

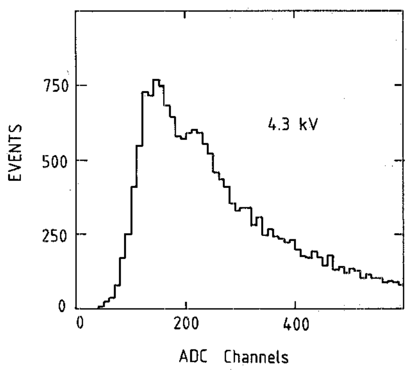

Fig. 3. Streamer charge for uncollimated tracks (^{90}Sr source) in a 9×9 mm^2 tube, 100 μm wire, Ar + isobutane = 1 + 3, HV = 4.5 kV.

confirmed by the fact that the second streamer peak generated from isotropic tracks in a tube (fig. 3) is at less than twice the first one. The fact that no undesired effects appear for non orthogonal incidence is confirmed from the test made on the e.m. calorimeter quoted above, tilting it by 30 degrees [3]. No change in the charge response was found, while the energy resolution changed only for the different sampling thickness ($\sqrt{t}$ scaling).

3. Hadron calorimeters

In this section we consider the results of tests on two streamer hadron calorimeters made by two different LEP collaborations.

The ALEPH hadron test calorimeter (Bari, Frascati, Pisa) was made [7] of a sandwich of 5 cm iron slabs with 9×9 mm^2 plastic streamer tubes of the same type as in the Mont Blanc Nucleon Stability Experiment [8], with 100 μm anode wire, Ar + isobutane = 1 + 3 mixture, operated at 4.3 kV, at the beginning of the efficiency plateau. The charge was collected on external pads (60×60 cm^2) arranged in a single tower, while on the other side of the tube plane, 4 mm wide, 10 mm pitch, strips ran parallel to the wires to give digital patterns of events in the calorimeter. The charge response and the energy resolution are shown in fig. 4. The non linearity at 100 GeV is 10%, with an energy resolution ($\sim 80\%/\sqrt{E}$) which is comparable, in the linear range, with that of an iron-scintillator calorimeter with the same sampling.

The L3 hadron test calorimeter (Firenze, ITEP-Moscow, Madrid, Lausanne, Roma, Vienna, Berlin-Zeuthen, ETH-Zurich) was made [9] with streamer tubes identical in structure, gas mixture, and operation conditions, to those of the e.m. calorimeter quoted above; the planes of streamer tubes were interleaved with 12 mm Cu plates. The module was tested with two different kinds of absorber; 12 mm Cu plates and 3–5.1–3 mm Cu–U–Cu plates. Fig. 5 shows the measured energy resolution: ~ 60% at 1 GeV. Even in this case, a streamer tube hadron calorimeter shows an energy resolution which is comparable with that obtainable with scintillators. This fact is presumably due to the much lower density of particles in a hadron shower with respect to the e.m. one.

In addition to their good energy resolution achievable, hadron calorimeters with streamer tubes can also record the digital pattern of the events with a good spatial granularity. For low energy hadron showers, were hit saturation does not occur (~ 10 GeV in the case of ALEPH hadron calorimeter), the stable hit counting can be used to monitor the charge response against variations of gas or HV, performing a self monitoring of the calorimeter.

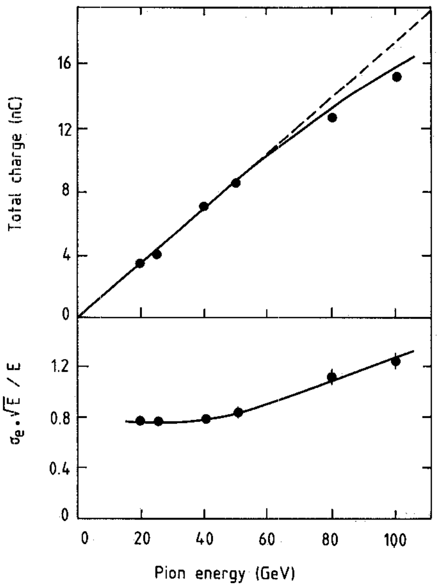

Fig. 4. Charge response and energy resolution for the ALEPH streamer hadron test calorimeter.

Since muons can be tracked through the iron using the digital readout, the requirements on an external muon detector are greatly reduced. A high spatial resolution is no longer necessary, since there are many points in the calorimeter to connect the muon tracks with those in the Central Detector. Taking this into account, layers of streamer tubes can be used as muon chambers with an (x, y) set of strips, giving an integrated muon–hadron detection system, as in the ALEPH hadron calorimeter design [10], for example. The expected spatial resolution is $\sigma_x \cong \sigma_y \cong 2$ mm for a double staggered external layer of 9×9 mm^2 streamer tubes. In any case, when a high resolution is required,

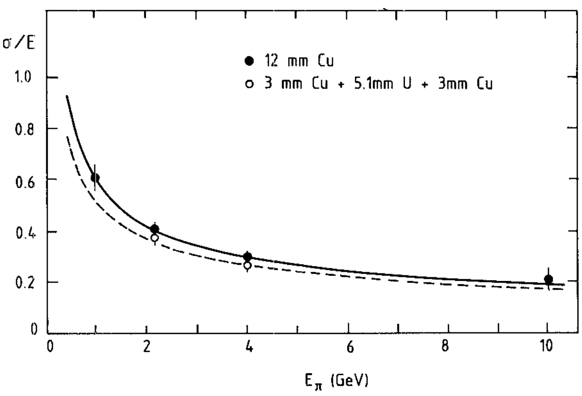

Fig. 5. Energy resolution for the L3 streamer hadron test calorimeter.

one can expect a $\sigma_x \cong \sigma_y \cong 0.5$ mm using the method of charge centroids on strips.

Let us now discuss briefly the possibility of extending the limits of linearity and rates with a view to possible high energy applications of hadron calorimeters with streamer tubes.

From the data on non linearity of electromagnetic test calorimeters [3,5], it can be seen that, scaling for the different average radiation lengths, the use of a thinner wire (60 μm instead of 100 μm), and of a more quenching gas mixture (Ar + isobutane = 1 + 5 instead of 1 + 3), improves the non linearity of about a factor 2. The extrapolation of the ALEPH test calorimeter data for a 5×5 mm^2 tube geometry, 50 μm anode wire, gives a non linearity of ~ 10% at 500 GeV.

There are two limiting effects when operating at high rates:

– the local dead time of streamer (~ 10^{-4} s), which limits the rate of showering particles to ~ 10^5 Hz/m^2 if one does not want the charge response affected;

– the resistivity of the cathode, which can give, in high flux conditions, a local voltage drop, changing the energy response.

For maximum practical tube length (~ 8 m) and typical surface resistivity (~ 200 kΩ/square), the maximum rate tolerable with a local voltage drop which gives a negligible variation in the charge response for 5×5 mm^2 tubes, turns out to be about 10^5 Hz/m^2. From this qualitative evaluation of rate effects, one can see that the limit to the flux of incident particles imposed by the use of a resistive cathode appear of the same order of that set by the process itself.

4. Conclusions

The use of streamer tubes in e.m. calorimetry slightly improves the energy resolution compared to that of proportional gas calorimeters, but does not give as good a resolution as scintillator calorimeters. On the other hand, e.m. calorimeters with plastic streamer tubes have the advantage of simple construction, operation and monitoring.

Hadron calorimeters using streamer tubes have energy resolutions comparable to those of scintillator calorimeters. In addition to this, the pattern of the events can be recorded with a good spatial granularity, which is of relevance for example in muon tagging. The tracking of muons through the iron permits the design of integrated muon–hadron detection systems, where the last planes of the streamer hadron calorimeter, equipped with (x, y) strips, act as muon chambers. Application of streamer hadron calorimeters in high rates and high energy conditions, extrapolating the data on non linearity from previous test calorimeters, seems feasible up to energies of 500 GeV and fluxes as high ~ 10^5 particles/m^2.

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