A TRANSITION RADIATION DETECTOR FOR LEP EXPERIMENTS*

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Summary

We are planning to build a transition radiation detector TRD for the identification of prompt electrons in one of the proposed LEP detectors. Tests to be described in this paper show that rather little space is required for such a TRD to achieve a π/e rejection of at least 20 : 1 at 95% acceptance for electrons with momenta in excess of ∿ 2 GeV/c. Combining the TRD with an additional electromagnetic shower calorimeter in the LEP detector, a total hadron rejection of the order of 10^3 : 1 or better can be obtained.

Introduction

Transition radiation TR is emitted when a fast charged particle crosses the boundary between two materials of different dielectric constants, e.g. a dense material and a gas. Highly relativistic particles produce these TR quanta in the x-ray-region (typically 5 - 15 keV) in a narrow forward cone. Unfortunately the average energy loss per interface is very low: $E = \frac{\alpha}{3}\hbar\omega_p\gamma$, where ω_p is the plasma frequency of the dense material and $\gamma = E/mc$. To overcome the small factor $\alpha/3$ one needs several hundred interfaces of alternating slabs of material (typically ∿ 10 μm thick) and gas (e.g. air or helium ∿ 200 μm thick) to produce sizeable TR signals in a subsequent xenon wire chamber. Optimum materials for such radiators have to combine high electron density (large ω_p), on one hand, with low atomic number Z, on the other, to reduce self absorption of TR quanta in the radiator. Some choices of materials more or less fulfilling both conditions are listed in Table 1.

Table I

Material	$\hbar\omega_p$	Comments (availability)
Li	14	best radiators
LiH	19	but safety
Be	27	problems
B	31	not available
B_4C	32	in thin form
C	28	fibres, foam etc.
mylar ($C_5H_4O_2$)	24	inexpensive but
polyethylene (CH_2)	19	less efficient

The TRD model set up

Lithium as one of the best radiator materials has been used with good success by the Willis group[1] in a practical TRD at the CERN ISR. Lithium, Beryllium and their compounds are, however, highly toxic, particularly in finely distributed form. Therefore, their application in large quantities, of the order of tons, in an underground hall at LEP appears to be prohibitive. A reasonable and not too expensive compromise in efficiency is carbon, being available in form of fibres of 6 - 12 μm diameter at densities between 1.6 and 1.85 g/cm^3. The radiators of the model TRD to be described below have been produced from irregularly stacked short cut fibres pressed to overall densities between 0,06 and 0,15 g/cm^3 to keep average fibre to fibre distances in the 100 - 200 μm range (formation zone in air). A problem arises from the fact that the fibres tend to stick together to form clusters of aligned filaments, thereby reducing the required air gaps. The problem is worse for high density fibres which, due to their brittleness, can only be delivered with a thin (rather adhesive) coating.

Fig. 1 shows an experimental set-up recently tested at DESY in an electron beam at momenta between 1 and 6 GeV/c. The TRD is composed of 5 carbon radiators, each followed by a 1 cm thick multiwire proportional chamber filled with 95% xenon plus 5% CH_4, or with 90% xenon plus 10% C_2H_4 during different parts of the

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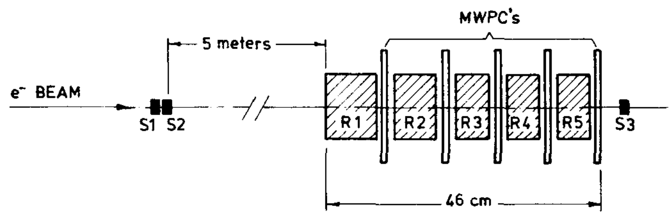

Fig. 1. Schematic view of the test set-up showing 5 carbon radiators R1-R5, each followed by a xenon chamber in a beam defined by counters S1-S3.

run. The chambers are identical to those described in reference [2]. The radiators were not of equal length but staggered with 10, 6 and 3 x 5 cms for the 5 units, respectively, giving the detector a total length of 46 cm (including gaps at the chambers). Staggering reduces the detector length and makes average signals in all chambers equal, since the TR produced in one of the radiators is not fully absorbed by the subsequent chamber but partly added to that of the following unit.

The finger counters S_1, S_2 and S_3 defined a beam size of 1 cm^2 in the chambers. In the so defined beam region four wires in each chamber (5 mm wire spacing) were connected in parallel to a fast charge sensitive preamplifier with two outputs feeding two separate channels, one for integral pulse height measurements and the other - with sharp differentation - for cluster counting. Both informations were transferred via CAMAC into a PDP11. The gas gain was monitored by means of Fe^{55} sources attached to each chamber. The electronic stability was regularly checked with artificial pulses induced on the sense wire.

Results

Fig. 2 shows measurements of the mean (integral) pulse height per chamber as function of the electron momentum. All errors (not indicated) are of the order to 0.2 - 0.4 keV and result from uncertainties in the pulse height calibration. The points on the central curve (c) were obtained with all radiators taken out of the beam; i.e. they represent the mean ionization loss -dE/dx and are well compatible with a Fermi Plateau as shown by the horizontal line. Different symbols of points represent different types of radiators and/or of quenching gases (CH_4 or C_2H_4).

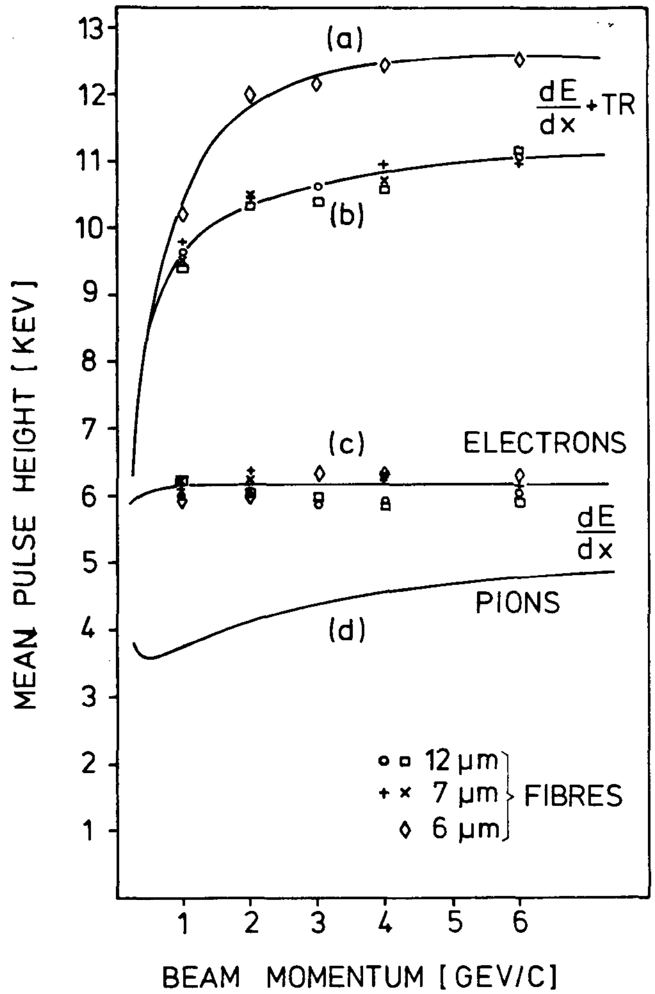

Fig. 2. Mean pulse height as function of the beam momentum. Points on the curves (a) and (b) are measured with radiators in the beam, those on curve (c) without radiators. Curve (d) is taken from reference [4].

Corresponding points on the two upper curves (a) and (b) were measured during neighbouring running hours with radiators in place. Points marked "+" were taken with the full set of 5 radiators, whereas for all other measurements only one radiator of 10 cm length in each case and one chamber were used. The upper two curves are eyeball fits through the points with partial adjustment to former measurements taken below 1 GeV/c.[2] The points on curve (a) are obtained with our best radiator made of 6 μm high density (1.85 g/cm^3) fibres which, to avoid clustering, have been treated specially[3] by washing in acetone and by blowing up in an air stream (a method probably not applicable in case of large quantities). All other radiators show a very similar performance, in spite of so different fibre diameters as 7 and 12 μm. The 12 μm fibres were, however, of low density, i.e. 1.6 g/cm^3 as compared to 1.7 g/cm^2 in case of the 7 μm type. Other low density materials like carbon foam and hollow spheres have also been tested and gave poor results.[3]

The shape of the lower curve (d) in fig. 2 marked "pions" is taken from measurements of Walenta et al.[4] of the ionization loss in xenon at atmospheric pressure. It has been normalized to the Fermi plateau of our electron data (curve c) and will be used in the following part to calculate the π/e discrimination. (A pion beam was not available during our tests.)

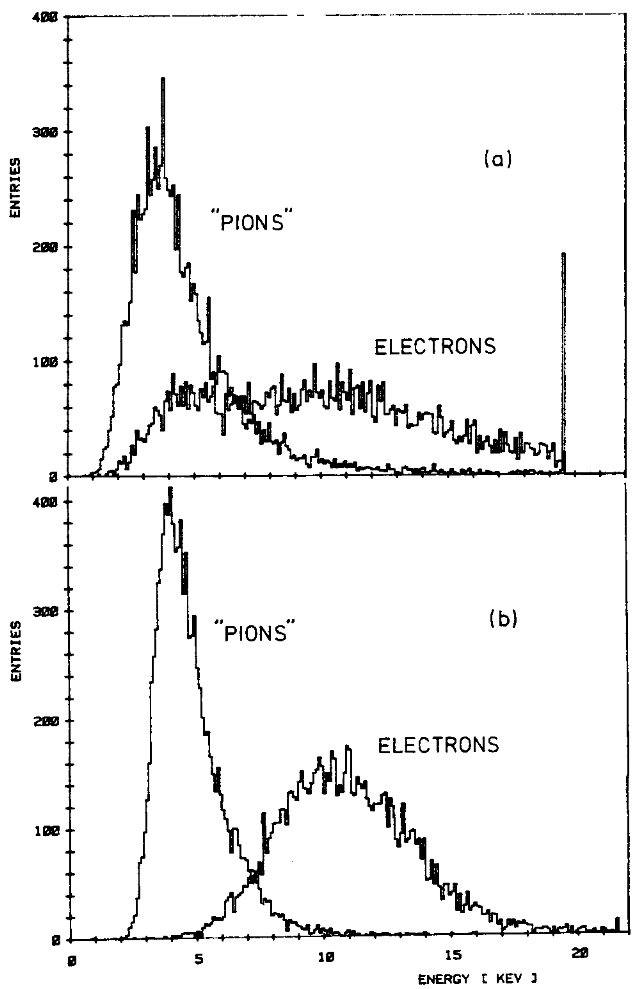

Fig. 3. Pulse height distributions: (a) single hits, (b) the arithmetic mean over 5 chambers. Corresponding histograms contain equal numbers of entries.

Fig. 3 shows in its upper part (a) pulse height distributions from measurements with and without radiators at 6 GeV/c electron momentum. The Landau distribution marked "pions" originates from our electron data without radiators scaled down in the abscissa by a factor of 0.71 as obtained from the normalization in fig. 2. The effect of transition radiation by electrons is clearly seen, although the two distributions still strongly overlap. The overlap is reduced to about 5% in the lower subfigure (b) where the arithmetic mean over the five chambers is plotted.

Applying simple pulse height cuts in distributions of the type shown in fig. 3b we obtain in fig. 4 the pion contamination as function of the electron acceptance. The vertical position of both curves is subject to systematic errors resulting from the above mentioned uncertainties of the pulse height calibration. The figure shows that e.g. at 95% electron acceptance and for momenta above 2 GeV/c the contamination by pions is of the order of 5%.

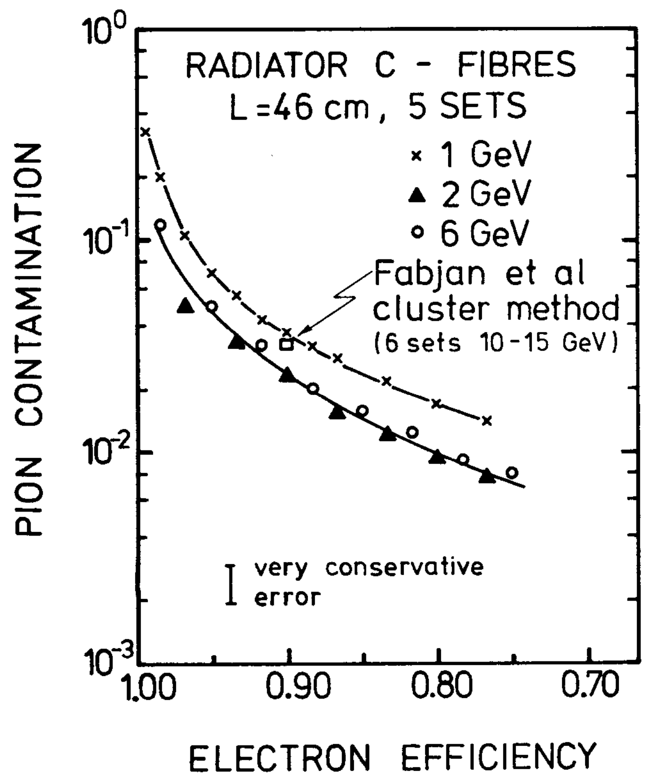

Fig. 4. The pion contamination as function of the electron acceptance.

Fig. 4 also shows a single point from a publication of Fabjan et al.[5] which compares well with our data. It is obtained with a similar set-up but with the cluster method and is valid for 6 sampling units at somewhat higher momenta of 10 - 15 GeV/c.

We should mention that our results on electron versus pion discrimination by means of the cluster method are roughly comparable to those found with the (integral) pulse height method but show a tendency to be somewhat inferior. We therefore do not present them here.

It is interesting to see which e/π discrimination would result with our best radiator made of high density fibres. Having only one radiator available we simulated a set of 3, 4 and 5 sampling units by taking consecutive independent events. The result is shown in fig. 5. Comparing with fig. 4 one sees that an improvement by a factor of ∿ 5 could be achieved.

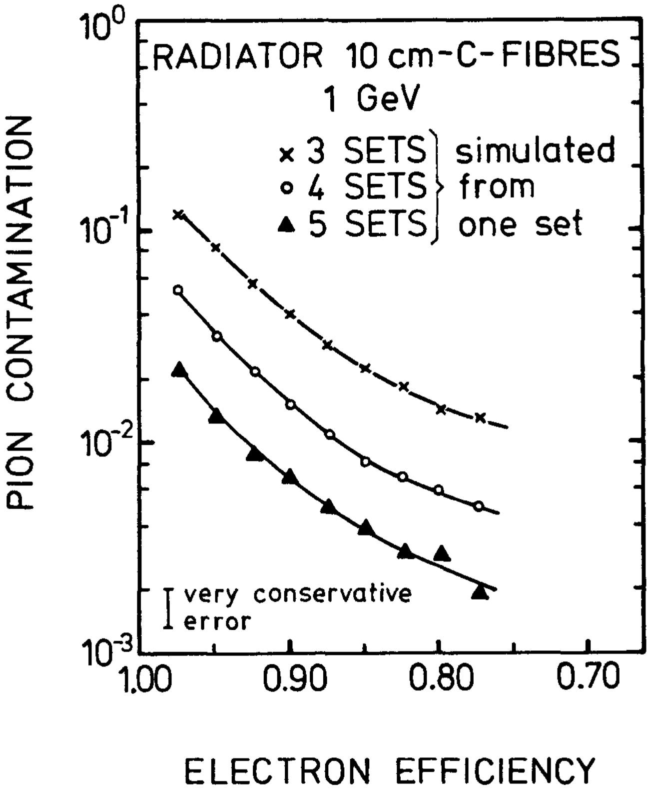

Fig. 5. Same as fig. 4 but from measurements with one radiator (6 μm fibres) only, simulating 3 - 5 sampling units

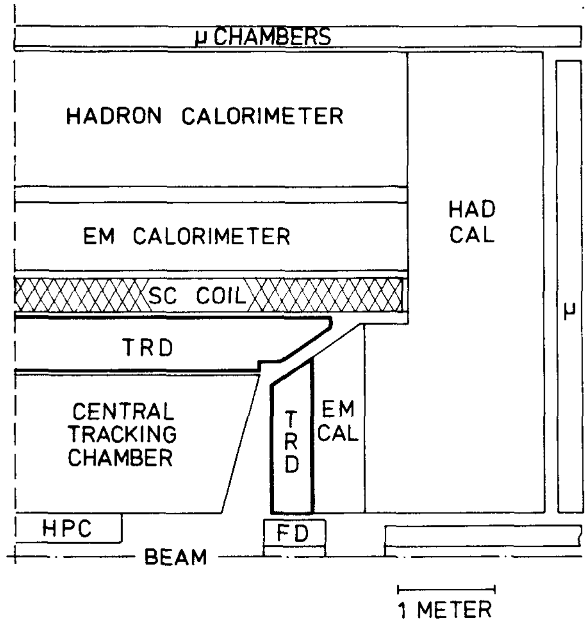

Fig. 6. Schematic view of one quarter of the proposed ELECTRA detector for LEP.

The TRD for LEP Experiments

Fig. 6 is a schematic view of the ELECTRA detector recently proposed[6] for experiments at the large electron-positron storage ring LEP. One of the salient features of this detector will be good lepton identification and high precision in charged particle tracking and photon measurement. The figure shows that inside a superconducting coil (1 Tesla) of 4.6 meter inner diameter two types of transition radiation detectors, a barrel TRD and two endcap TRD's will be arranged to cover ∿ 85% of the full solid angle. According to actual plans, the barrel TRD will be arranged in form of 16 segments and each endcap TRD will consist of 4 quadrants. Both types of TRD will be composed of 5 sampling units and will be ∿ 46 cm thick, i.e. most probably they will be structured according to our test set-up shown in fig. 1.

The intention is to identify prompt electrons by two fully independent methods, the TRD's and the electromagnetic shower calorimeters, whose positions are shown in fig. 6. As the two devices are expected to provide electron versus hadron discriminations at the few percent level, the total hadron rejection will be of the order of 10^3 : 1 or better.

References

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