FOAM RADIATORS FOR TRANSITION RADIATION DETECTORS

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Abstract

A wide variety of foam radiators, potentially useful in the design of a transition radiation detector, the possible particle identification tool in collider experiments, have been tested in the beam. Various characteristics of these radiators are compared, and the conclusion is reached that certain brands of polyethylene foam are best suited for use in the detector. Comparison is made with a 'traditional' radiator, which is a periodic structure of plastic foils.

(Submitted to Nuclear Instruments and Methods in Physics Research)

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1. INTRODUCTION

The most interesting phenomena to be studied at future colliders [i.e. the Superconducting Super Collider (SSC) and the Large Hadron Collider (LHC)] are thought to be mostly accessible through lepton-mode decays. Thus the development of devices capable of tagging leptons is naturally one of the urgent problems in SSC and LHC detector design.

Transition radiation detectors (TRDs) seem to be the most competitive instruments for electron identification at ultra-high energies [1–5]. In collider experiments the TRDs are placed inside the calorimetric part of the detector along with the tracking devices. It is quite natural to try to combine tracking and electron-tagging capabilities in a single instrument [1–4]. Decent tracking as well as the need to maintain high rates necessitates the fine-grained structure of such a TRD.

Transition radiation (TR) is produced when a charged particle crosses the interface between two media with different dielectric constants. The probability of single-quantum emission is about $\sim 1/100$ per crossing. Thus a large number of surfaces (radiators) are needed to produce enough radiation. The radiators in typical TRDs are followed by proportional chambers with a xenon-enriched gas mixture for the effective detection of X-rays.

As mentioned in ref. [5], at a given TRD thickness the optimal structure of the detector in terms of hadron/electron identification is a multilayer system of comparatively thin elements comprising a radiator and a proportional chamber. For example, the detailed calculation shows that with a 50 cm total geometric thickness of the TRD and 5% radiation length the optimal partial thickness of the xenon in a single chamber is 1.6–2.0 mm, the number of elements being 30–50. This gives an idea of the size of a detector element. The need for fine granularity and technological feasibility brings up the problem of the choice and optimization of the radiator.

2. RADIATORS

Usually the radiators for TRDs are made of 15–20 μm thick polypropylene foils with 200–300 μm spacing between them. This design implies the use of some structure supporting the radiator [5, 6]. Given the stringent limits on the mass and dimensions of the devices inside the calorimeter, such traditional radiators do not look very attractive.

In the D0 experiment the polypropylene foil will be wound to form a roll which will serve as a radiator [7]. In our opinion there is still a disadvantage, because the radiator's parameters (effective foil thickness and spacing) vary with the polar angle of the particle trajectory. Besides, a radiator of this kind cannot serve as a supporting structure for the detector, which would be useful, if, for example, one wants to use straw chambers.

It seems to be important to design a self-supporting radiator, with isotropic structure, which could possibly be used as a construction element. In view of this idea, we believe that foam materials are very promising. At present there exist a great variety of foams that could potentially be useful for TRDs [8].

Some results of the study of foam radiators can be found in refs. [9, 10]. Unfortunately, these results are not comprehensive because the TR yield was measured for a limited range of radiator densities and in the case of thick (~ 30 cm) radiators. Also lacking is an adequate comparison of regular (foil) and foam radiators with identical parameters that could be valuable in making estimates of the TRD performance in the design stage.

We have studied thin-foam radiators of different materials and with different densities. Some parameters of these radiators are given in table 1.

When choosing the materials for our study we paid special attention to their transparency to X-rays. The following materials were chosen: polyethylene, polystyrene, polyurethane, carbon. As a reference we used a regular radiator hereinafter called REG, made of 20 μm polypropylene foils with 280 μm spacing. In order to determine the influence of spacing irregularities on the TR yield we also used a radiator identical to a REG but with the spacing not fixed – NREG.

All radiators were of the same thickness, i.e. 6 mm. Moreover, the radiators REG, NREG, and polyethylene foam with 0.064 g/cm³ density had the same thickness in terms of g/cm². Polyurethane and carbon foams were of special interest because they proved rather rigid and exhibited exceptional radiation hardness [11].

Our measurements of X-ray transparency have shown that foam polyethylene radiators have an absorption length (at 5.95 keV) 20% smaller than that of polypropylene (table 1), owing to impurities introduced during the production of the foam. Whilst polyethylene-foam samples have almost the same absorption, that of polyurethane foams may vary significantly depending on the particular technology of manufacture. We have selected the samples most transparent to X-rays from twenty different kinds. These data are also given in table 1. The carbon-foam absorption is very close to the reference figures for pure carbon.

3. EXPERIMENTAL SET-UP

The measurements have been done using a mixed 3 GeV beam of hadrons and electrons at the Serpukhov accelerator. The separation of hadrons and electrons was accomplished by two Cherenkov counters and a lead-glass calorimeter. In addition, a thick scintillation counter was used to reject multiparticle events by dE/dx measurement. The set-up included 10 elements of the radiator–proportional chamber modules. The chamber was operated at atmospheric pressure. The gas-mixture composition was adjusted so that the electron-collection time was stable and between 68 and 72 ns.

We used multiwire proportional chambers with an anode-to-cathode distance of 3 mm. The current signal width, as measured at the preamplifier output, was 24 ns (FWHM) for 5.95 keV ⁵⁵Fe quanta. The gas gain was 5×10^3 – 10^4 . After preamplification the signal was fed to a QDC module operating with a 250 ns gate. In this case the ionization losses and photoelectron cluster energy are added together over the whole track length; signals with a total charge above certain thresholds (implemented in software) are detected.

The computer read out and stored not only the information from the chamber, but also that from Cherenkov counters and a scintillation counter measuring dE/dx . After off-line data processing the admixture of electrons in a hadron sample and the opposite case was less than 10^{-4} .

4. RESULTS

4.1 Polyethylene

A typical microphotograph of the polyethylene foam slice (which we tested) is shown in fig. 1. Obviously the thickness of the walls of bubbles and their sizes are rather uniform.

Figure 2 shows the results of measurements with polyethylene foam, REG, and

NREG radiators for an Xe partial thickness of 1.6 mm. This figure shows the probability of clusters being produced by electrons above some threshold plotted against the same probability in the case of pions, as a function of the energy threshold. Comparing the curves for REG and NREG reveals that irregularities in foil spacing have practically no effect on the TR yield under these conditions. The probabilities of electron detection using foams with densities of 0.092, 0.064, and 0.052 g/cm³ differ by no more than 4% and are as much as 0.80–0.85 of the value for the REG radiator at 4–5 keV thresholds (typical for TRDs).

The correct comparison of the properties of regular and foam radiators should be made at equal values of the parameters, L , t , and also a or b (see table 1). However, the calculation shows that a regular radiator with a 13 μ m foil (instead of the 20 μ m one in the case of REG) has the same TR properties as REG within 3–5% (having the same thickness in g/cm² and mm), which allows the REG radiator to be considered as a gauge radiator.

The fact that the TR yield does not change significantly when the foam density varies from 0.052 to 0.092 g/cm³ is evidence that in our case the spacings (i.e. pore sizes) between foils are much smaller than the TR formation zone. In this region the TR yield is proportional to the spacing between foils. In this way, decreasing of the yield due to the smaller spacing at higher densities is compensated by a growing number of surfaces crossed (foils).

4.2 Polyurethane

Three samples of polyurethane foam have been tested: the densities were 0.045, 0.055, and 0.059 g/cm³. The second sample (0.055 g/cm³) has a special feature: its effective pore size was about two times smaller than in other polyurethanes. The best results were obtained with this sample (table 1).

4.3 Carbon

Two samples of carbon foam have been tested: their densities were 0.05 and 0.08 g/cm³. The samples had quite different pore-wall thickness (i.e. pore walls). The results are shown in fig. 3 and table 1. The fine-structured carbon foam (0.08 g/cm³) is equivalent to the polyethylene foam of 0.059 g/cm³ density in terms of its radiator properties.

4.4 Polystyrene

Figure 3 also contains the experimental data for polystyrene foam. As previously, the best results were obtained with fine-structured foam (0.11 g/cm³).

Solid curves in fig. 3 correspond to calculations performed for a regular radiator and a polyethylene one (0.059 g/cm³). The TR yield of the foam is smaller, which is mainly due to spread of the effective pore-wall thickness as seen by the particle crossing the surfaces. The best fit of experimental data for foam radiators corresponds to fluctuations of effective pore-wall thickness (as seen by the particle), $\sim 100\%$. The deterioration of TR yield observed in large-pore radiators (polyurethane, polystyrene, some carbon samples) is basically a result of the local density fluctuations between the pores. Note that polyethylene does not have this feature (see fig. 1). The TR yield grows with smaller pore sizes, but this implies higher material density.

In our opinion polyethylene foam is one of the most promising radiators so far. Figure 4 illustrates the isotropy of the parameters of 0.059 g/cm^3 foam. These measurements were made with foam slabs oriented in two different (perpendicular) directions. The difference is only $\sim 3\text{--}5\%$.

As mentioned in ref. [5], the important feature of the TRD is the number of detected clusters per unit of thickness of the device crossed by a particle. Usually this parameter is about $\sim 0.15\text{--}0.20$ clusters per cm [5]. It can be seen from our results that a fine-structured TRD can yield as much as 0.35 clusters per cm with a regular radiator and 0.28 with a foam one.

Acknowledgements

We wish to express our deep appreciation to Dr. Gary H. Sanders from the Los Alamos National Laboratory, who has gone to some trouble to provide us with special carbon-foam samples for our study. We are grateful to our colleagues, V. Bondarenko, I. Markina, V. Ruzheinikov and S. Muravjev, for practical assistance.

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Table 1

Some parameters of tested radiators

Radiator	Bulk density (g/cm ³)	Density of radiator (g/cm ³)	Foam density t (10 ⁻² g/cm ³)	Length, L (mm)	Mass absorption relative to polypropylene	Number of surfaces crossed N	Mean foil thickness a (μ m)	Mean pore size b (μ m)	Relative yield ^{*)}
Polypropylene (CH ₂) REG foils NREG foils	0.91	0.064	3.8	6	1.0	20	20	280	1
	0.91	0.064	3.8	6	1.0	20	20	280	1
	0.93	0.092	5.5	6	1.2	41	14	133	0.84
Polyethylene (CH ₂) foam		0.064	3.8	6	1.2	31	13	180	0.83
		0.059	3.5	6	1.2	29	13	195	0.82
		0.052	3.1	6	1.2	26	13	220	0.8
		0.035	2.1	6	1.2	17	13	335	0.76
	1.05	0.040	2.4	6	1.1	12	18	480	0.65
Polystyrene (CH) foam		0.105	6.3	6	1.1	40	15	130	0.83
Polyurethane (C ₂₀ H ₈₅ O _{1.9} N _{1.3}) foam	1.1	0.0459	2.4	6	1.4	14	15	410	0.64
		0.055	3.3	6	1.4	45	7	130	0.74
		0.059	3.5	6	1.4	20	16	284	0.59
Carbon foam	1.7	0.050	3.0	6	1.05	14	13	420	0.58
		0.080	4.8	6	1.05	45	5	130	0.83

*) Probability of electron detection at the threshold 4–5 keV (probability of pion detection = 0.05)

Figure captions

Fig. 1 A microphotograph of polyethylene foam.

Fig. 2 The comparison of polyethylene foam radiators. Xenon thickness 1.6 mm.
●: REG. Δ : 0.092 g/cm³ foam. ○: NREG. ×: 0.062 g/cm³ foam. +: 0.052 g/cm³ foam.
◇: 0.035 g/cm³ foam.

Fig. 3 The comparison of the best radiators. Xenon thickness 1.6 mm. Solid curves are the calculations. Δ : REG. +: polyethylene foam 0.59 g/cm³. ●: polystyrene foam 0.110 g/cm³. ○: carbon foam 0.080 g/cm³. ▽: polystyrene foam 0.040 g/cm³ (large-pore foam; shown for comparison)

Fig. 4 The comparison of the polyethylene foam-radiator TR yield if exposed to the beam in two perpendicular directions with respect to the foam slab plane. Xenon thickness 1.6 mm. ∴: REG. +: polyethylene foam 0.059 g/cm³. ○: polyethylene foam 0.059 g/cm³.

Figure 1

Figure 2

Figure 3

Figure 4