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NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH
Section A

Measurements of light yield, attenuation length and time response of long samples of "blue" scintillating fibers

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Abstract

In connection with the design of the electromagnetic calorimeter of the KLOE detector, we have studied the performance of several samples of commercially available plastic scintillating fibers with a particle beam at the CERN PS. Results on light yield, attenuation length and time resolution measurements concerning 2–4.5 m long samples of those fibers are presented.

1. Introduction

The electromagnetic calorimeter of the KLOE detector consists of scintillating fibers embedded in lead [1–3]. The calorimeter consists of three parts: (a) a central part, the *barrel*, approximating a cylindrical shell of 4 m inner diameter, 4.3 m effective length and 23 cm thickness with fibers running parallel to the beam axis, and (b) two *end-caps*, 4 m diameter and 23 cm thick, with fibers running vertically. Due to the calorimeter dimensions, fibers are longer than 4 m; therefore the choice of the proper fiber type is of major importance to define the calorimeter performance. To match the spectral sensitivity of standard photocathodes, only fibers emitting in the "blue" region of the spectrum ($\lambda_{peak} = 420$–460 nm) are considered. Furthermore, to fulfill the requirements of the experiment the fibers are expected to have: (i) high light yield, (ii) large attenuation length, and (iii) fast time response.

An experimental test of the performance of several types of commercial fibers was carried out in 1993 at the T10 beam of the CERN PS. To test fibers under conditions similar to the KLOE calorimeter, five small calorimeter modules have been built, using fibers produced by different manufacturers [4] as listed in Table 1. Each module is obtained by gluing 1 mm diameter scintillating fibers between grooved lead plates of 0.5 mm thickness: the

Table 1
Tested calorimeter modules

Fiber type	Provided in	Module length [m]
Bicron BCF-12	1992	4
Bicron BCF-12	1993	4
Kuraray SCSF-81	1992	4.5
Pol.Hi.Tech Polifi-0046	1992	4.5
Pol.Hi.Tech Polifi-0046	1993	2

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fiber:lead:glue volume ratio is 48:42:10. The cross section is $3.5 \times 3.5\,\mathrm{cm}^2$ [3].

We present in the following the results of the test of the modules. The experimental setup is described in Section 2, the results on light yield and attenuation length are in Section 3 and time resolution measurements are given in Section 4. The modules tested are listed in Table 1.

2. Experimental setup

The setup of the modules and trigger counters of the T10 beam is shown in Fig. 1.

Four calorimeter modules were tested at once: they were arranged on a movable platform allowing displacements orthogonal to the beam line. Negative pions of 4 GeV energy were used as minimum ionizing particles (mip). Each module was viewed at both ends by fast photomultipliers (PMTs) [5] through 20 cm long light guides. The light collection efficiency of these guides has been measured and is about 85% [6]. A "green" light emitting diode (LED) was mounted on each light guide in order to monitor PMT gain variations during the measurements. Each PMT signal was sent to an ADC [7] and to a TDC [8], both started by a trigger signal. The trigger signal was provided by a threefold coincidence of two crossed scintillators (S_1 and S_2), of $1 \times 1\,\mathrm{cm}^2$ cross area, and a larger one (S_3), of $10 \times 10\,\mathrm{cm}^2$ cross area, placed behind the calorimeter modules. The time and the amplitude of the trigger signals were also recorded and used in the off-line analysis. Several scans of the modules were performed.

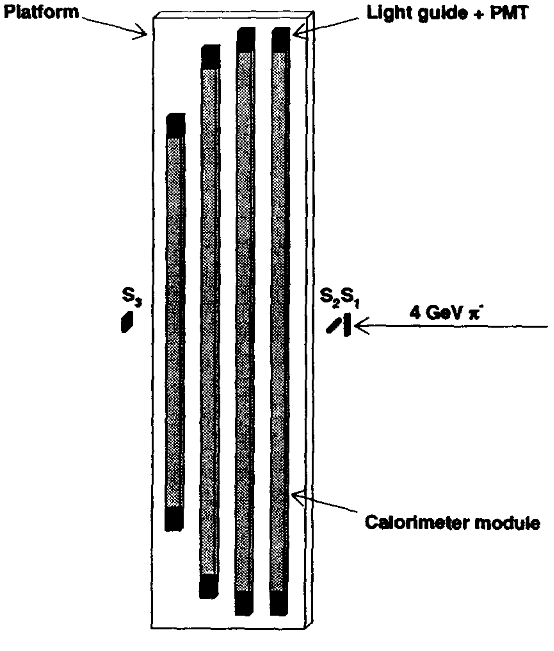

Fig. 1. Experimental setup (not in scale).

For each platform position, a calibration run with LEDs was taken before a beam run (typically of 10^4 events). In these runs the PMT's gain G was measured to ±2% using the relation $G = A/N$ where A is the ADC peak and N the number of photoelectrons evaluated according to the $\sigma(A)/A = 1/\sqrt{N}$.

3. Light yield and attenuation length measurements

According to a Monte Carlo simulation a mip deposits 3.2 MeV in the fibers. In Fig. 2 the dependence of the number of collected photoelectrons per mm of crossed scintillator material N vs z (distance of the beam impact point from the PMT) is shown for the five modules listed in Table 1. N is obtained from the peak A (in counts) of the pulse height spectrum, according to the following relation:

$$N = Af/eGT\,,$$

where e is the electron charge, $f = 0.25\,\mathrm{pC/count}$ is the ADC sensitivity, T is the average scintillator thickness in mm crossed by a mip and G is the gain of the PMT evaluated as explained above.

The light attenuation length λ is obtained fitting the experimental data for $0.5 \leq z \leq 3.7$ m ($0.5 \leq z \leq 2.0$ m for the Polifi-0046 (93) module) with an exponential:

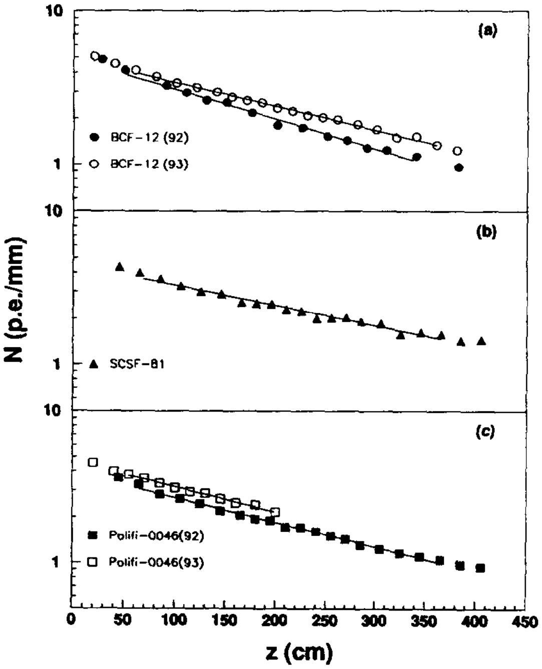

Fig. 2. Dependence of the light yield on the distance z from the PMT: (a) BCF-12, (b) SCSF-81, (c) Polifi-0046. The superimposed curves are the fits according to Eq. (1).

Table 2
Attenuation length and light yield

Fiber type	λ [cm]	N(0.5 m) [p.e./mm]	N(2 m) [p.e./mm]	N(3.7 m) [p.e./mm]
BCF-12 (92)	226±3	4.5±0.6	2.2±0.2	1.1±0.1
BCF-12 (93)	286±8	4.3±0.3	2.4±0.2	1.3±0.1
SCSF-81	321±5	4.2±0.3	2.4±0.2	1.5±0.1
Polifi-0046 (92)	284±5	3.5±0.5	1.8±0.2	1.0±0.1
Polifi-0046 (93)	267±6	3.9±0.5	2.2±0.2	

$$N(z) = N_0 \, e^{-(z/\lambda)} \qquad (1)$$

As Fig. 2 shows, at short distances ($z \leq 50$ cm) the light is attenuated faster. The results are summarized in Table 2: the attenuation length and the number of photoelectrons at three different distances from PMTs are given for each tested fiber.

The measured number of photoelectrons depends on the quantum efficiency of the PMT and on the quality of the optical contacts between the calorimeter module and the light guide, and between the light guide and the PMT. The difference between photoelectrons measured at the two ends of a module gives an estimation of the above mentioned effect, and turns out to be of the order of 10%. In a previous test, we had measured the relative quantum efficiencies of the PMTs using a laser as light source, and we had found no differences in excess of 5%. Therefore, the uncertainty on light yield is mainly due to the optical couplings. To verify this hypothesis, the PMTs of some modules have been interchanged: variations of about 10% in the light yield are observed, while the attenuation length, as expected, remains unchanged.

4. Time resolution measurements

Since pulses have been digitized by means of leading edge discriminators (with 30 mV threshold), the TDC outputs have been corrected off-line for slewing, using the usual parametrization $t_{\mathrm{meas}} = t_{\mathrm{true}} + b/\sqrt{q}$, where q is the ADC integrated charge. For small pulse heights, correction up to 25% has been applied. The TDC start was provided by the trigger: its jitter σ_{tr} can be evaluated from the time difference distribution of the two small identical counters S_1 and S_2. We find $\sigma_{\mathrm{tr}} = 0.15$ ns. The trigger jitter is unfolded from the width of the time distributions in order to calculate the correct time resolution σ_t of each module.

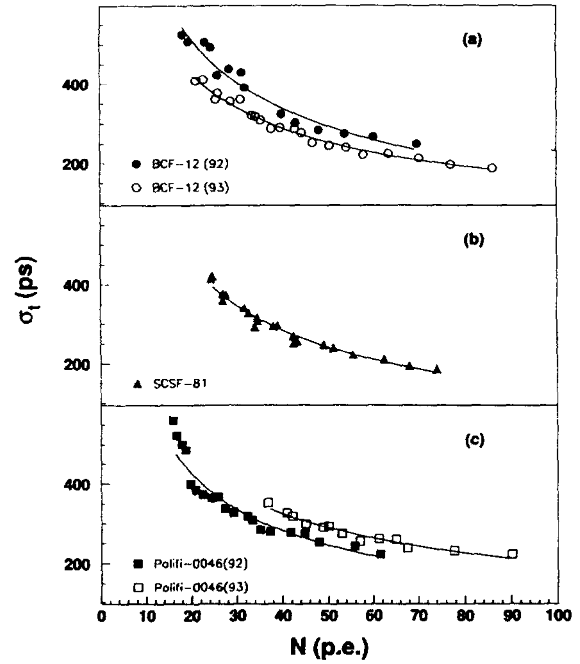

Fig. 3. Time resolution as a function of the light yield: (a) BCF-12, (b) SCSF-81, (c) Polifi-0046. The superimposed curves are the fits according to Eq. (2).

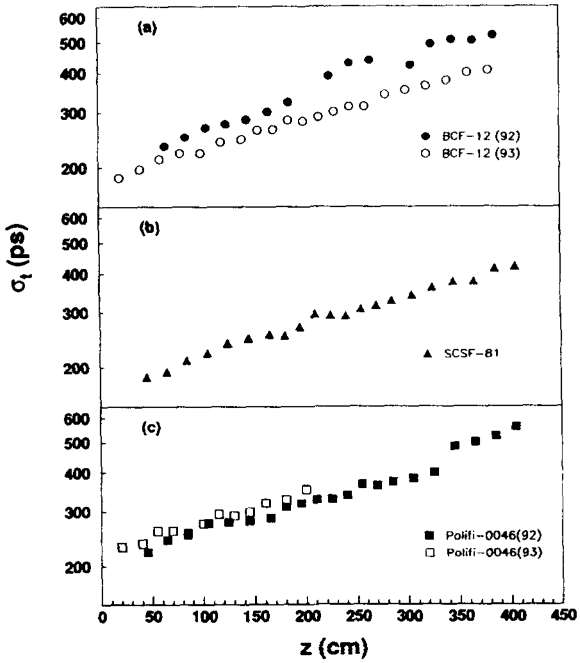

Fig. 4. Time resolution as a function of the distance from PMT: (a) BCF-12, (b) SCSF-81, (c) Polifi-0046.

Table 3
Parameter τ and time resolutions

Fiber type	τ [ns]	σ_t (0.2 m) [ns]	σ_t (2 m) [ns]	σ_t (4 m) [ns]
BCF-12 (92)	2.42±0.08	0.23	0.34	0.52
BCF-12 (93)	2.16±0.03	0.21	0.28	0.40
SCSF-81	2.49±0.03	0.19	0.27	0.40
Polifi-0046 (92)	2.27±0.03	0.23	0.32	0.50
Polifi-0046 (93)	2.23±0.06	0.25	0.35	–

The time resolution σ_t is plotted in Fig 3 as a function of the number of detected photoelectrons for the various types of fibers. The data are well described by the simple parametrization:

$$\sigma_t(N) = \sigma_\infty + \tau/\sqrt{N}, \tag{2}$$

where σ_∞ represents unavoidable inaccuracies and $\tau/\sqrt{N}$ is due to the statistical fluctuations of N. The more relevant contributions to τ are the scintillator decay time, the PMT transit time spread, and the path length dispersion of the photons along the fiber. By fitting Eq. (2) to the data we find that σ_∞ is consistent with zero for all the fits while the values of τ are in the range 2.0–2.5 ns, for all tested fibers, i.e. well inside the decay time expected range for these kinds of scintillating materials [9]; hence the two other contributions are negligible [10]. In Fig. 4 σ_t is plotted as a function of the distance z from the PMT; σ_t values at three distances (0.5, 2, 3.7 m), are given in Table 3. The relative errors associated to σ_t are estimated to be of the order of 10 ps.

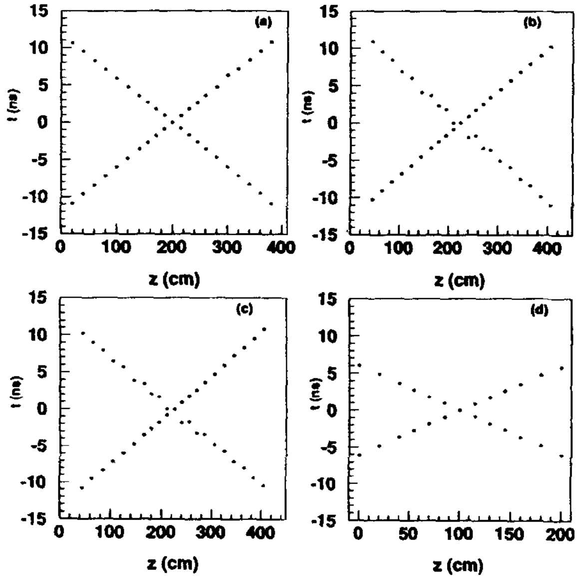

Fig. 5. Dependence of the signal arrival time on the beam impact point: (a) BCF-12 (93), (b) SCSF-81, (c) Polifi-0046 (92), (d) Polifi-0046 (93); left side PMT: open circles, right side PMT: full circles.

In Fig. 5 the signal arrival time vs the beam impact point (z) is shown for both ends of a module; the light propagation velocity in fibers is obtained by means of a linear fit to the data. In the velocity measurements differences up to ±3% are found between right and left side, due to TDC calibration uncertainties. Averaging right and left side measurements we obtain the light propagation velocities given in Table 4.

5. Conclusions

Small calorimeter modules filled with several types of "blue" scintillating fibers have been tested with a minimum ionizing particle beam. The tested fibers show an attenuation length in the range between 2.3 and 3.2 m; a light yield of 3.5 ÷ 4.5 photoelectrons per mm of crossed scintillator material is obtained when fibers are radiated at 0.5 m distance from a "standard" bialkali photocathode PMT. As far as the time characteristics are concerned, all tested fibers give:

(1) a fast time response characterized by a decay constant in the range 2.0 ÷ 2.5 ns,
(2) a time resolution dominated by the photoelectron statistics,
(3) a light propagation velocity of about 17 cm/ns (as expected not dependent on the fiber type).

Acknowledgements

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Table 4
Light propagation velocity in fibers

Fiber type	velocity [cm/ns]
BCF-12 (92)	16.6±0.2
BCF-12 (93)	16.7±0.2
SCSF-81	17.2±0.6
Polifi-0046 (92)	17.2±0.6
Polifi-0046 (93)	16.7±0.1

References

[1] The KLOE Collaboration, A General Purpose Detector for DAΦNE LNF-92/019 (1992).

[2] The KLOE Collaboration, The KLOE detector, Technical Proposal LNF-93/002 (IR) (1993).

[3] A. Antonelli et al., Nucl. Instr. and Meth. A 354 (1995) 352.

[4] The fibers are manufactured by Bicron Corp., Newbury, OH (USA), Kuraray Co. Ltd., Tokyo (Japan) and Pol.Hi.Tech. s.r.l., Carsoli (Italy).

[5] $1\frac{1}{8}$ in. Hamamatsu phototubes, type R1398 with bialkali photocathode.

[6] KLOE Note No. 83, unpublished.

[7] 11 bit LeCroy FERA ADC.

[8] 25 ps/channel CAEN C414 TDC.

[9] C.M. Hawkes et al., Nucl. Instr. and Meth. A 292 (1990) 329.

[10] According to Hamamatsu Photonics K.K., (Japan) data sheet, the R1398 tube transit time spread is 0.65 ns.