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G. Barbiellini, A. Martinis, R. Sangoi and F. Scuri

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Light Transport in a Flexible Liquid Scintillator Fiber

G. Barbiellini[1], A. Martinis[1], R.Sangoi[1], F. Scuri[2]

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Abstract

First results on attenuation length and photon yield of a liquid scintillator flexible fiber are presented. Possible applications and systematic effects are also discussed.

[1] Università di Trieste and I.N.F.N., sez. Trieste, Italy
[2] Università di Udine and I.N.F.N., sez. Trieste, Italy

1 Introduction

Several interesting applications of scintillating fiber based detectors have been proposed, e.g. in calorimetry or tracking detectors. Calorimeters with fibers parallel to the incoming particles direction (head–on) have been used by many collaborations and reported in the literature (DELPHI, SPACAL...)[1, 2]. The KLOE collaboration at DAΦNE is proposing a large area imaging calorimeter with fibers oriented normally to the particles direction (side–on)[3]. Tracking applications of fibers are also very well known as vertex detectors for heavy flavour experiments, neutrino physics and for tracking at high luminosity colliders [4]. Large volume detectors using liquid scintillators features have been already extensively studied; recent results from the MACRO collaboration [5] for large bulk detectors and from other collaborations for liquid scintillator filled capillary arrays [6] report attenuation lenghts in the range of meters. The inexpensive liquid scintillator, introduced in plastic pipe of good light transmission property, results on a flexible liquid scintillator fibre (F.L.S.F.). The F.L.S.F. of few meters length can be the basic element for the construction of large volume detectors with fast response and space accuracy of the order of few mm, as, for instance, a muon tracker or an imaging calorimeter with projective geometry. In this note, the results of measurements on attenuation lenght and light yield for a prototype of such a liquid scintillator flexible fiber are reported. For our tests we used the light emitted by the liquid core when excited by ionizing radiation obtained from a Sr^{90} β source since we are interested in the fiber behaviour when it is used in calorimetric or track triggering detectors.

2 The liquid scintillator flexible fiber

Measurements has been performed on a 3 meters long fiber with circular cross-section from the firm LUMATEC [7]; core diameter is 5 mm and plastic cladding thickness is 0.5 mm; the fiber is externally protected by a rubber wrapping and the liquid containement is ensured by quartz endcaps entering 2 cm in the core volume. The fiber core is filled by a mixture of PPO (2.5 g/l), BIS-MSB (2.5 mg/l), BHT (40-80 ppm) in Petroleum Specialties mineral oil with pseudocumine scintillating dye, 6% in concentration [8]. For this fiber the refraction index are: $\eta_{oil} = 1.456$ for the core mixture and $\eta_{cladd} = 1.35$ for the cladding at $\lambda = 580$ nm [9]. For light emitted from a point on the axis of the fiber, the incidence at the core-cladding separation surface is related only to the polar angle ϑ between the fiber axis and the direction of the emitted light. The light will be trapped inside the core if $\vartheta \leq \vartheta_{tr}$, where $cos\vartheta_{tr} = \eta_{cladd}/\eta_{oil}$. Light not trapped in the core is refracted in the cladding and then, depending on the incidence with respect to the critical angle $\overline{\vartheta}_{tr}$ where $cos\overline{\vartheta}_{tr} = \eta_{air}/\eta_{cladd}$ the light can be trapped at the cladding-air surface or lost outside. For the core we obtain $\vartheta_{tr} = 22^o$ and for the cladding $\overline{\vartheta}_{tr} = 42.2^o$; thus the light emitted on the axis of the fiber is trapped in the core-cladding surface if $\vartheta \leq 22^o$ and is trapped in cladding-air surface if $\vartheta \leq \arccos(1/\eta_{core}) = 46.6^o$ (here ϑ is always the initial polar angle of emission in the core before refraction at the core-clad surface). For round fibers the trapping angle does not represent a sharp cutoff because light emitted off the axis has an angle of incidence, with respect to the normal on the fiber surface, which depends on both polar and azimuthal angles of emission. The condition for trapping at the core-cladding surface becomes:

$$\sin\vartheta\sqrt{1-(\frac{\rho}{r}\sin(\phi-\Phi)^2)} < \sin\vartheta_{tr}$$

Here (ρ, Φ) define the position of the scintillation in the core, (ϑ, ϕ) are the polar and azimuthal angles of emission and r is the radius of the core. These off-axis emitted light rays "spiralize" along the fiber with a great number of reflections and a longer path length than that corresponding to the on-axis rays. The resulting attenuation length is an average among all rays paths.

Both core and cladding light give contribution to the total detected light; the light emitted and/or transmitted in the cladding is expected to have a much shorter attenuation length because of worse separation surface between cladding and air (e.g. imperfections and damage due to usage).

The optical coupling of the fiber to the photomultipliers was chosen to have a thin air gap between the end of the fiber and the photocathodes ensuring a better reproducibility than with the fiber coupled directly to the photocathode (with optical grease).

3 Experimental setup

The measurements on the fiber were performed with the setup shown in fig 1. The whole optical apparatus is closed in a black painted wooden box to avoid interferences from external light. Two Philips 2262 phototubes are coupled to the end-caps of the fiber. A movable collimated Sr90 β-source upon the fiber is coupled to a plastic scintillator, 2×2 cm^2 in sensitive surface placed just below the fiber and aligned with the source; in this way, induced scintillation events are selected with a triple coincidence of the scintillator signals with the the signals from the tubes. The accidentals are almost fully suppressed as it is evident from the absence of pedestals in the pulse height spectra in fig. 2. Moreover the mean energy of β particles from Sr90, is about 0.546 Mev and so they are well below Čerenkov threshold. The charge signal from the PM's are digitized by a 2249W LeCroy ADC and a 2228A LeCroy TDC is used for time measurements. Scales are: 0.25 pC/channel for ADC and 100 ps/channel for TDC. Before digitization charge signals are amplified 10 times by a low-noise amplifier (612A LeCroy).

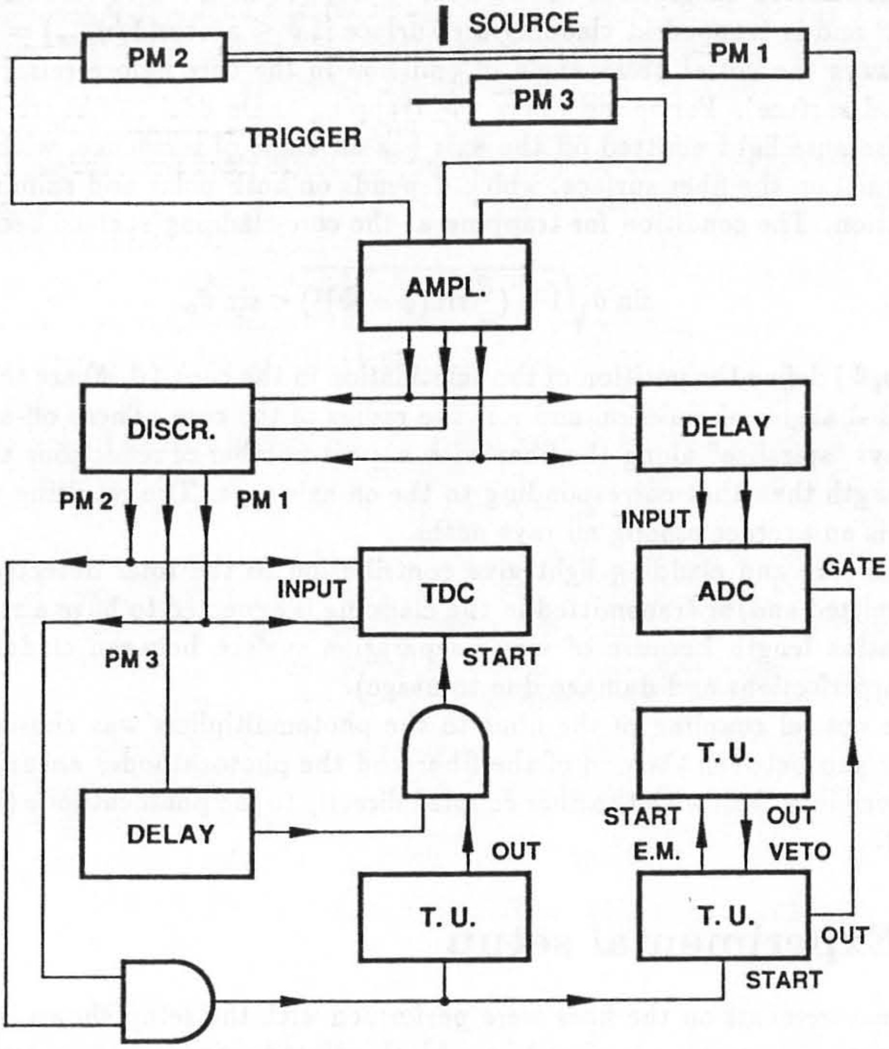

Figure 1: experimental setup

Discriminators widths for PM1 and for PM2 are 70 ns and 10 ns for trigger counter. As shown in fig. 1 the threefold coincidence PM1-PM2-TRIGGER is used to start the TDC conversion and to form the ADC gate signal. Suitable inhibit and timing systems for those units are used in the acquisition driven by a PC with CAMAC interface.

4 Data analysis

Data have been analyzed according to a standard method [10]. As a preliminary measurement the single-photon pulse height distribution for both phototubes at the two end-caps of the fiber is stored. For this purpose spectra are taken with in-

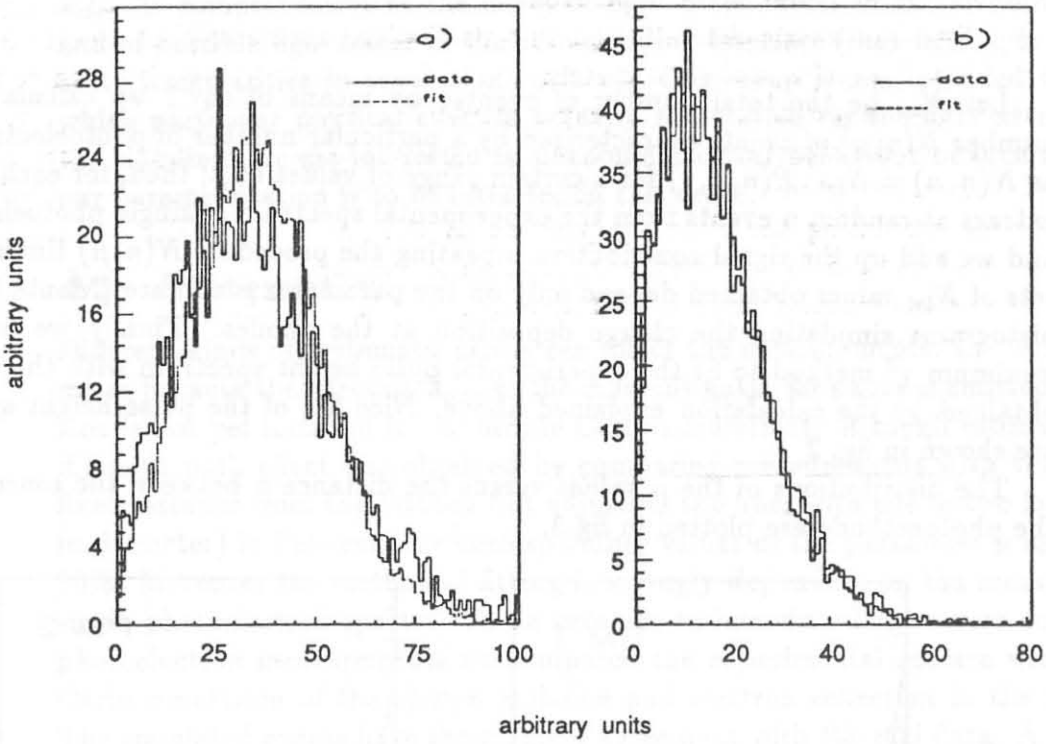

Figure 2: PM1 pulse height spectrum: source at a) 44 cm b) 288 cm from the cathode

creasing number of neutral filters between fiber and cathodes to reduce the intensity of detected light until spectrum shape doesn't change any more; in this measurements the source is positioned at the fiber end-side opposite to the analysed PM. In this situation, the minimum amount of light, just one photoelectron is detected. Then the filters are removed and several spectra, each one of 5000 events, are taken positioning the source at different points along the whole fiber.

The attenuation length measurements is done by estimating the average number of detected photoelectrons corresponding to each pulse height spectrum. The analysis proceeds as follows: we suppose the primary photon emission to be nearly poissonian and we take into account the fact that the charged particle path in the scintillator can vary depending on the angle of emission and on a possible source displacement by convoluting a Poisson distribution with a geometrical form factor; the probability distribution for the number of detected photoelectrons is:

$$P(n,\mu,r) = \int_0^r \frac{x/r}{\sqrt{r^2-x^2}} \frac{e^{-2\mu x}(2\mu x)^n}{n!} dx \qquad (1)$$

where μ is the mean number of detected photoelectrons per unit track length in the fiber, and r is the radius of the scintillating fiber.

phototube	λ_{core} (cm)	λ_{cladd} (cm)	P_{core} (ph/mm)	P_{cladd} (ph/mm)
PM1	239 ± 51	< 23	3 ± 0.5	4.2 ± 3.4
PM2	310 ± 65	< 33	3.3 ± 0.5	< 7
PM1 *fit 1 exp.*	233 ± 34		3.05 ± 0.34	
PM2 *fit 1 exp.*	308 ± 29		3.33 ± 0.18	

Table 1: Attenuation lengths and photon yield

length of ~ 3 m so the F.L.S.F. can be used in large surface detector for projective coordinates measurements.

6 Conclusions

Performing a weighted mean, the measurements on the analysed liquid scintillator flexible fiber result in an attenuation length $\lambda_{core} \simeq 274 \pm 19$ cm and in photon yield $P = P_{core} + P_{cladd} \simeq 6.8 \pm 2.6$ photoelectrons/mm. This error is large and due mainly to the systematic effects connected with the method used in simulating photon emission induced by ionizing particles. The attenuation length and the photon yield measured for the analyzed mixture are compatible with those obtained for other liquid mixtures in capillary arrays and in the same spectral region of emission (around 500 nm)[6]. The relatively long attenuation length, the relatively low systematic effects introduced by bending the fiber, offer the possibility of several application for such a device, in particular for tracking and/or calorimetry detectors to be inserted in complex geometrical structures.

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