SCINTILLATING FIBER ARRAYS FOR PARTICLE TRACKING

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presented by Peter Lendermann

Abstract

Scintillating fiber arrays offer interesting possibilities for massive active target detectors in high and low energy neutrino physics. A very promising technique in this context is the use of coherent glass capillary arrays filled with liquid scintillator of high refractive index, since suitable scintillators have been developed and reflection losses at the capillary walls are very small. For 120 μm - capillary bundles an attenuation length λ_{att} = 110 cm has been obtained, essentially limited by self absorption of the scintillating core. The possibility of surrounding each fiber with an extramural absorber allows sufficient reduction of crosstalk.

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1. Introduction

In this report we describe recent progress in the development of a high resolution active target detector based on coherent scintillating fiber arrays, and especially the application of liquid scintillator filled capillaries. These results have been obtained in a Research & Development - Project in the frame of the CHARM II - Collaboration at CERN. Originally this work was initiated by the search for new techniques for efficient ν_τ - detection [1].

2. Scintillating fiber detectors for neutrino physics

Several important requirements have to be fulfilled by future neutrino detectors. Because of very small cross sections in ν-induced reactions and therefore low event rates, a detector mass of at least 10^2 kg is necessary, as well as a sufficiently good time resolution ($10\ \text{ns} \leq \Delta t \leq 1\ \text{ms}$) for background suppression. Since particles with short decay times (e. g. τ - lepton, D - meson) have to be detected, a spatial resolution better than 100 μm is needed. Taking into account these requirements, detectors built of coherent arrays of scintillating fibers can in many respects be superior to other common tracking techniques.

Applications of scintillating fiber detectors in neutrino physics are explained in detail in [2]. Possible detector designs especially in view of the search for $\nu_\mu - \nu_\tau$ - oscillations are discussed in [3] and [4].

3. Tracking with scintillating fibers

In a coherent fiber detector each fiber consists of a high refractive scintillating core ($n_{core} \approx 1.6$) surrounded by a cladding of lower refractive index ($n_{clad} \approx 1.5$). In this case total reflection inside the fiber occurs for a certain fraction ($\varepsilon_{trap} \approx 5\ \%$) of scintillation light, which will be trapped and travel towards the fiber endface [5]. As a result the projected track image in an array can be recorded (fig. 1). In order to preserve a good spatial resolution, a fiber array must have a coherency better than a single fiber diameter. For reduction of crosstalk it is important to surround each fiber with an extramural absorber (EMA).

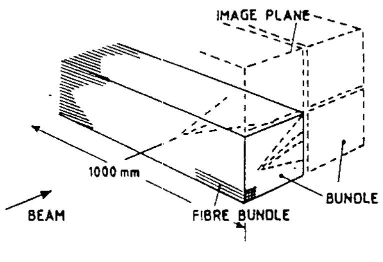

fig. 1. Tracking with scintillating fibers.

In comparison with plastic and glass fibers, liquid scintillator filled capillaries offer several advantages: Binary liquid scintillator systems exist with short fluorescence decay times ($\tau \approx 5$ ns), high refractive indices up to $n \approx 1.66$, good light transmittance and high light yields (10 γ/keV, i. e. comparable with the common plastic scintillator NE 102 A). Reflection losses are by 1 - 2 orders of magnitude smaller than for plastic microfibers.

Furthermore, a technique has been developed, which allows the production of capillary bundles with lengths up to 2 m, a sensitive volume of $\sim 60\ \%$ and excellent coherency (fig. 2) [*]. The capillary walls consist of a multicomponent borosilicate glass ($n = 1.487$), which is transparent above 380 nm. Pore diameters from 1000 μm down to 5 μm are possible. Details concerning their fabrication – especially in view of the performance of EMA – can be found in [6].

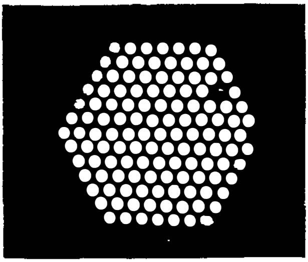

fig. 2. Coherent capillary bundle (fiber-Φ = 120μm), 60 cm long, illuminated from the opposite end.

4. Recent progress in development of new liquid scintillators

The feasibility of capillary targets is essentially dependent on a suitable scintillator, as well as on careful preparation, cleaning and filling of micro-capillaries [6]. Among the available solvents Isopropylbiphenyl and 1-Methylnaphthalene can best meet the demands for high refractive index ($n_{IBP} = 1.582$, $n_{1MN} = 1.617$) and good transmittance. Concerning promising dyes, 1-phenyl-3-mesityl-pyrazoline (PMP, $\lambda_{max} = 430$ nm) and 3-Hydroxyflavone (3 HF, $\lambda_{max} = 540$ nm) have not only a satisfying quantum fluorescence efficiency [7], but also a large Stokes' shift, which makes the light attenuation properties being limited rather by the solvent transmittance itself.

Light yield and attenuation length have been measured for various liquid scintillators by exposure of 1 m long single capillaries (Φ = 2 mm) in a 5 GeV-π-beam (fig. 3). The light output was measured with a standard bialkaline photocathode (exception: S 20 photocathode for the green emitting dye 3 HF). For comparison the results of a standard plastic fiber (Polystyrene/Butyl-PBD/POPOP, UA 2 type, Φ = 1 mm) are added. The best result was found for 1 MN + PMP (0.01 mole/l): 4.2 detectable photoelectrons per mm of traversed scintillator were recorded after 1 m light pathlength in the capillary.

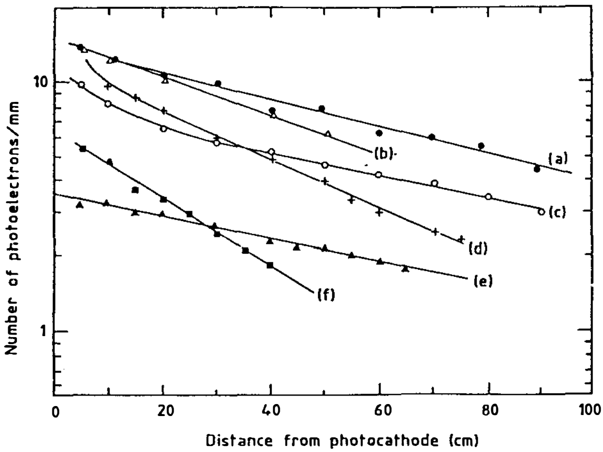

fig. 3. Light output of liquid scintillators in single capillaries:

(a) 1MN+PMP, 0.01mole/l
(b) IBP+PMP, 0.015mole/l
(c) UA 2 plastic fiber (for comparison, see text)
(d) 1MN+PMP, 0.1mole/l
(e) IBP+3HF, 0.06 mole/l
(f) IBP+BBQ, 0.08 mole/l

Capillary bundles of various diameters have also been tested in beam exposures. Fig. 4 shows the attenuation curve for IBP + 3 HF (0.008 mole/l) in a 120 μm-capillary bundle. For comparison data obtained with a single capillary are also displayed. The weak dependance of the attenuation length on the fiber diameter proves that reflection losses at the core/cladding - interface are very small (1 part in 10^5).

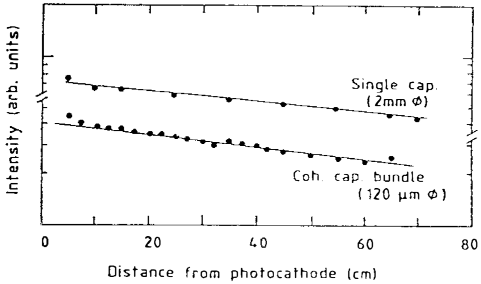

fig. 4. Comparison of light attenuation (IBP+3HF, 0.008 mole/l) in a 2 mm diameter single capillary to that in a bundle of 120 µm diameter capillaries. The attenuation lengths are 130 cm and 110 cm, respectively.

The dye concentration was optimized for PMP with a Monte - Carlo calculation, requiring maximum light yield after 1 m light pathlength [6]. An optimum concentration of 0.01 mole/l was found for 1 MN as well as for IBP. For lower concentrations the decrease in light output is due to a lower primary light yield, for higher concentrations it is due to light yield saturation and increasing dye absorption (fig. 5)

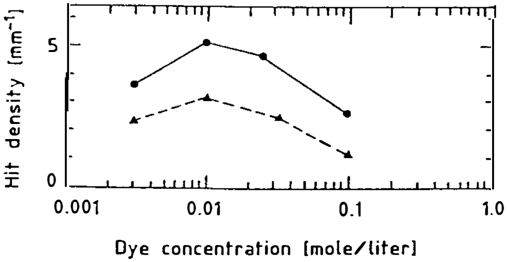

fig. 5. Light yield for 1 MN + PMP / IBP + PMP as a function of dye concentration, expected after 1 m light pathlength in a single capillary with 2 mm diameter (based on a Monte - Carlo calculation).

5. Track imaging with optoelectronic readout chains

In a recent test run, track images produced by 5 GeV - pions in 20 µm - bundles filled with 1 MN + PMP / IBP + PMP, could be viewed for the first time with an optoelectronic readout chain. Details can be found in [8]. Very remarkable are an excellent track resolution ($\sigma_{tr} \approx 15\,\mu m$) and a strong suppression of crosstalk due to the presence of EMA in the capillary target.

6. References

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