Photon Yields in 3HF Scintillating Fibers as a Function of Doping Concentration with Visible Light Photon Counters[1]

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Abstract

The photon yield in polystyrene fibers as a function of 3HF fluor concentration was systematically studied using Visible Light Photon Counters (VLPCs) and collimated gamma ray sources. The tests were done with long fibers to determine optimum concentration of 3HF as a function of fiber length. The fibers were produced in ribbons using 0.835 mm diameter of single clad (PMMA) with white reflective paint. The test procedures, results and applications for High Energy Particle tracking will be discussed.

I. INTRODUCTION

Scintillating fibers have recently become one of the widely used components of detectors for High Energy Physics. However, there have not been many attempts to optimize fluor concentration which greatly affects the performance of the fibers, directly or indirectly.

One of the uses of scintillating fibers is as a tracking device in which a small diameter is preferable for good spatial resolution and multitrack resolution in a high rate and high particle multiplicity environment. Small diameter scintillating fibers provide a fast digital signal which can be used to extract excellent spatial resolution without any preprocessing or tuning of other parameters which are necessary for wire based tracking devices.

However to make such small diameter fibers fully efficient, a proper type of fluor with optimized concentration has to be chosen for high photon yield. The 3HF fiber is the best known and has been the most studied up to this time.

The aim of this study is to determine the optimum concentration of 3HF in terms of the transmitted photons which depend on the length of the fiber and other factors discussed below.

3HF (3 Hydroxyflavone) as the secondary fluor with PTP (p-terphenyl) being the primary fluor has a distinctively long attenuation length due to its large Stokes shift as a result of the proton transfer excitation mechanism. Most other known fluors result in a shorter attenuation length caused by the substantial overlap between the emission and the absorption spectra. There have been numerous studies to search for other fluors with large Stokes shift with good photon yield, but so far none have been found. The emission spectrum of 3HF that peaks around 530 nm wavelength is also advantageous for transmitting photons in clear polystyrene optical fibers which have sharp absorption below 500 nm. Such long wavelength also results in a further benefit: that the possibility of radiation damage to polystyrene is significantly less for transmitting photons of longer than 500

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nm wavelength. [1] At this time, 3HF fiber is the best solution with long attenuation lengths, high photon yields and long term stability. [2]

This study was done using the VLPCs as the photon detector. Single clad scintillating fibers of different fluor concentrations were produced by Kuraray Company of Japan.

II. EXPERIMENTAL ARRANGEMENT

The experimental arrangement is shown in Figure 1. Four scintillating plastic fiber ribbons of different 3HF fluor concentration in each ribbon were stacked in a rectangular plastic channel. Each ribbon is composed of eight scintillating fibers, four in one layer and another four on top of the first four with half diameter staggering. The fiber ribbons were coated with white reflective acrylic paint to improve the reflectivity and for optical isolation of the individual fibers. The scintillating fibers, of 0.83 mm thickness, have polystyrene cores containing 1% PTP (primary fluor) and 500, 1000, 2000 and 5000 ppm 3HF (3-Hydroxyflavone) in each ribbon, respectively. The scintillating fibers were connected to the same diameter, 3 meter long, clear optical fibers through which the photons were transmitted to the VLPCs in the cryogenic unit. Four out of 8 fibers in each ribbon were read out for the study.

A collimated Co^{60} source was positioned over the 3HF fibers at 20 , 100, 200 and 300 cms. from the joint to the clear optical fibers for photo excitation during the experiments.

Though VLPC characteristics were published earlier, we will describe them here briefly. [3] The VLPC is an impurity conduction band (IBC) semiconductor photodetector operated at ~ 6.5^0 K. It was jointly developed by the Rockwell International Science Center and UCLA, and later by FermiLab. [3] The VLPCs are unique due to their very high quantum efficiency with high avalanche gain and extremely low noise level. With proper thickness of silicon oxide anti reflective coating, the quantum efficiency reaches to ~ 80%. With the operating voltage at approximately 6.5V, the gain is close to 10^5 with a gain dispersion of ~ 10%. Because of the low noise level, it can be operated at a threshold of 1 photoelectron or lower without significant disturbance to the experimental conditions. The rise and fall time is faster than 1 ns and the rate per unit cell can be as high as 5 x $10^7/mm^2$. The linearity per unit is practically unlimited.

In this study the pulses from the VLPCs were amplified using transimpedance amplifiers, AD3554-AM. The pulse gain uniformity was within 10% with a common bias applied to the VLPCs. The amplified pulses were then read out using LeCroy 1885 Fastbus ADCs. The ADCs with dual dynamic ranges provided a good linearity up to 1000 pC.

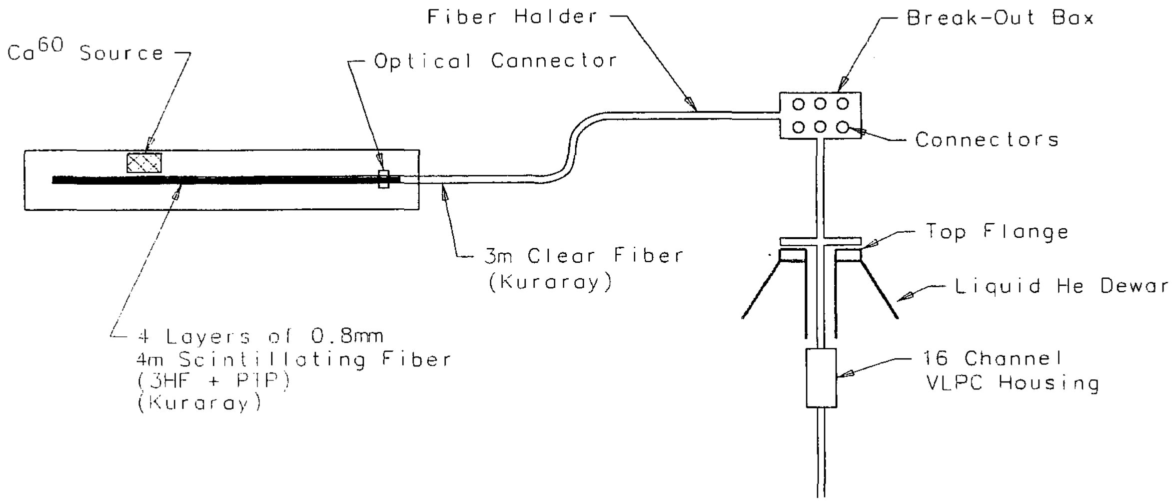

Figure 1
Experimental Arrangement

III. EXPERIMENTAL RESULTS

Compton electrons produced by 1.1 and 1.2 MeV gamma rays from the Co^{60} source resulted in a sufficient number of photons in the scintillating fibers as seen in Figure 2. The multiple photoelectrons detected by the VLPCs are clearly identified up to a multiplicity of 6. The photoelectrons that are detected from each were computed using a calibration plot as shown in Figure 3. The results are plotted in Figure 4 showing that the detected photons increase as the fluor concentration of 3HF is increased. The curves go through a peak value and fall at 2000 ppm. Once the fiber length is longer than 15 cm, there is not much change in the output spectrum due to the large Stokes shift of the 3HF fibers. We see from these curves that 1500 ppm is an optimum fluor concentration for all cases except for very short lengths. The fall beyond 1500 ppm and especially 5000 ppm can be explained by the absorption in 3HF and also by possible impurity contamination at high fluor concentrations. It should be noted that before this experiment (conducted in 1992), the concentration of the commercial 3HF fibers had traditionally been 500 ppm. From our results, we see that this would result in 20% to 30% less light yield than the optimum point.

After this experiment, a more recent study and the cosmic ray test by the D0 Group used 3HF fibers of 1500 ppm and good results were obtained as expected. [4,5]

Given the present results with high quality double clad fibers recently developed by Kuraray and further refined VLPCs, one can expect wider application of small diameter scintillating fibers for tracking devices as well as for other applications.

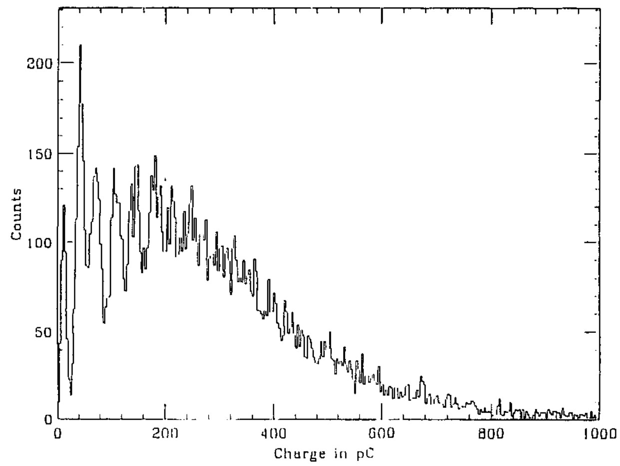

Figure 2
Photoelectron calibration using a cobalt source. The multiple photoelectron peaks were produced by the Compton electrons creating photons in one of the 3HF fibers.

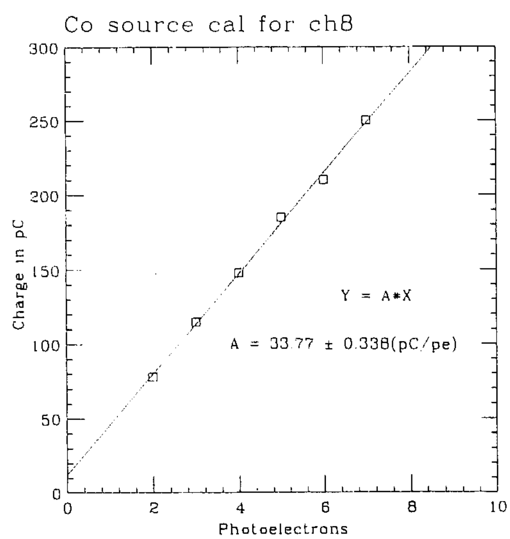

Figure 3
The multiple photoelectrons versus the charge in picocoulombs. This was determined for all fibers.

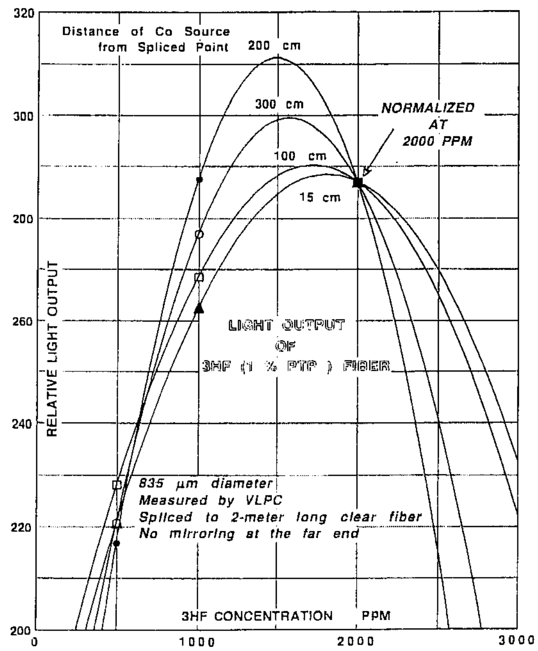

Figure 4
The number of detected photons as a function of 3HF concentration at the given source positions along the fibers.

IV. ACKNOWLEDGMENTS

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V. REFERENCES

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