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A Fine Grained Scintillating Optical Fiber Hodoscope for use

at ISABELLE

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A FINE GRAINED SCINTILLATING OPTICAL FIBER HODOSCOPE FOR USE AT ISABELLE

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Abstract

In order to exploit the high event rates at ISABELLE, it will be necessary to have fast detection with fine spatial resolution. The authors are currently constructing a prototype fine-grained hodoscope, the elements of which are scintillating optical fibers. The fibers have been drawn from commercially available plastic scintillator which has been clad with a thin layer of silicone. So far it has been demonstrated with one mm diameter fibers, that with a photodetector at each end, the fibers are more than 99% efficient for lengths of about 60 cm. The readout will be accomplished either with small diameter photomultiplier tubes or avalanche photodiodes used either in the linear or Geiger mode. The program of fiber development and evaluation will be described. In addition an account of the progress on the prototype hodoscope will be given.

Introduction

When ISABELLE, the colliding beam accelerator, comes on line with a luminosity of $2 \times 10^{32} \text{ cm}^{-2} \text{ sec}^{-1}$, there will be about 10^7 pp interactions per second with an average multiplicity of about 20. Between 5.7° and 45° , about 80 Mhz sr^{-1} is the expected rate.¹ To exploit this high rate, fast high resolution detectors made from scintillating optical fibers have been developed. Early attempts² to produce long bare scintillating filaments of one mm diameter yielded maximum useful lengths of about 15 cm, presumably due to cumulative losses at the scintillator to air interface.³ In order to increase the useful length of the scintillating fiber the experience and expertise of the fiber optics industry was used to draw a fiber from a heated preform of polished PVT scintillator, and to coat this with a cladding of lower refractive index. The principle is illustrated in Figure 1 where those rays of light making an angle, relative to the fiber axis, of less than the numerical aperture angle of the fiber are trapped and guided to the end of the fiber where they are detected by a photodetector. A desirable candidate for the photodetector is the avalanche photodiode (APD) which has the virtue of small size and immunity from magnetic fields. It has a photon to electron quantum efficiency about 4 times greater than that of a photomultiplier tube; however, the probability that the photoelectron will propagate to a usable signal is correspondingly lower. Thus the sensitivity of the APD is comparable to that of the PMT.

Hodoscope Description

A section of a hodoscope constructed from such scintillating fibers is shown schematically as a bilayer of fibers imbedded in a protective isolating matrix. The centers of the fibers are offset by one radius from one layer to the next to assure that there are no cracks through which a particle might pass without penetrating a reasonable depth of scintillator.

(b)

Figure 1 (a) Scintillating optical fiber, principle of operation; (b) Bilayer of fibers, encapsulated in isolating matrix.

Fiber Evaluation Procedure

Experimental Setup

In order to establish the feasibility of such a hodoscope, Brookhaven National Laboratory entered into a contract with Galileo Electro-Optical Corporation⁴ to undertake an experimental program to draw and clad scintillating fibers. Various commercially available scintillators, several cladding materials, curing methods, temperatures, tensions, and draw speeds were tried. The scintillators NE102, NE110 and NE161, were obtained from Nuclear Enterprises. The cladding materials have been a proprietary ultraviolet cured acrylic and a heat cured silicone. The best results to date have been obtained with silicone coated NE161. The layout of the test facility⁵ appears in Figure 2. An electron from Ruthenium 106 penetrates two small telescope counters T_1 and T_2 which sandwich the fiber. Upon a coincidence from $T_1 T_2$, the signal from S1 is detected by an RCA 8850 photomultiplier with single photoelectron resolution. From the resultant spectrum in Figure 2 we can calculate the mean number of photoelectrons (4 in the example shown).

Test Results

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The highlights of the results obtained so far are

CHARGE SPECTRA OF SCINTILLATING FIBER USING RCA 8850 PHOTOMULTIPLIER

Figure 2 (a) Fiber measurement setup: electron from source penetrates scintillators T_1 and T_2 as well as the fiber whose output signal S_1 is analyzed; (b) Charge spectrum of fiber pulse using RCA 8850.

Figure 3. Attenuation curves for various fibers.

shown in the curves of Fig. 3, and in the accompanying table where each fiber is characterized by an attenuation length and an effective photoelectron yield at the origin. The data were obtained from fibers whose diameter varied from .032" to .090" but the results have all been scaled to a diameter of .054" or 1.37 mm. The progression of curves 1 through 3 show a steady improvement due in part to choice of material, and in part to gradually improved technique. Curve No. 4 underscores the drastic attenuation suffered at the scintillator to air surface. Thus, we have successfully produced scintillating fibers 1 mm in diameter of lengths approaching 1 meter, with detection efficiency approaching 100%.

Avalanche Photodiode Readout

We are building a barrel hodoscope for use at CERN experiment ISR 807 in which a half cylinder of radius 18 cm will be fitted with 60 cm long fibers of 2 mm diameter to form a hodoscope with about 500 readout channels. The photodetector under development for readout is a cooled APD operated in the saturated mode at about -100°C .

In this mode of operation with the APD biased above the breakdown voltage, a photoelectron has a small (on the order of 20%) probability of causing a breakdown signal. This probability is an increasing function of the overvoltage, but the signal size is independent of the number of photoelectrons that contributed to it so that the signal contains no analog information, and it occurs with a probability which depends upon the overvoltage as well as the number of photoelectrons. On the other hand, there is a dynamic dark count proportional to the true counting rate, which also increases with overvoltage. Thus, there is an optimum overvoltage obtained by trading off required photoelectron input versus acceptable dark count as shown in Figure 4 which shows required photoelectron input versus overvoltage for a detection efficiency of 99.9%. The other curve shows the total to input counting ratio as a function of the overvoltage, thus for an acceptable dynamic dark count of 20% the required input is 22 photoelectrons per pulse.

Figure 4. APD operation as a function of overvoltage.

If we relax the efficiency requirement to 99% the photoelectron requirement is reduced by 25%. Similarly if we allow the dynamic dark count to increase to 30%, the photoelectron budget can be reduced by 25%. Referring back to Figure 3, and scaling to 2 mm fibers of length 60 cm, we find the number of photoelectrons would be about 15×4 (for the superior quantum efficiency of an APD) or 60 photoelectrons if the optical coupling from fiber to APD were as good as from fiber to PMT. Because of the small size of the APD, and the need to interpose a lens between the fiber and the detector, the margin of safety will be smaller. We are presently optimizing the light coupling from fiber to detector.

Conclusion

Having demonstrated the feasibility of the scintillating fiber as a fine grained hodoscope element, we are proceeding to build such an instrument while at the same time, continuing with the program of improvement of fiber performance. To this end we do not expect to see any major improvement in scintillator light yield. We are not aware of a suitable cladding with a lower refractive index than the heat cured silicone, so the effective photon yield at the origin may not be increased much more. An improvement in the bonding between cladding and core should extend the attenuation length to approach that of the bulk scintillator. It should also make the fibers more rugged and resistant to deterioration as a result of handling. Thus, our future efforts will be concentrated upon improved bonding methods as well as upon hodoscope fabrication technique.

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