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High Energy Particle Tracking Using Scintillating Fibers and Solid State Photomultipliers*

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Abstract

The Solid State Photomultiplier (SSPM)[1] recently developed at the Rockwell International Science Center, coupled with fast scintillating fibers can have a rate capacity of 10^8 tracks per second per cm^2 of fiber cross section in systems for tracking of high energy ionizing particles. Relative to other approaches the SSPM can provide substantial improvements in spatial and temporal tracking accuracy. Results of preliminary experiments with 0.225 x 0.225 mm^2 cross section step-index-of-refraction fibers exposed to electrons from a beta source are presented. The experiments involved pulse height analysis of SSPM photon detection pulses induced by coincident scintillations in two adjacent fibers traversed by the same electron. The data for two different scintillating fibers tested indicate that meter long fibers of this type, optimally coupled to SSPMs, will be effective in detecting minimum ionizing particles.

Scintillating fibers provide fast timing with impressive spatial resolution for the tracking of particles produced in collision regions of high-luminosity colliders. A key component of such tracking systems is the means for detection of the small number of photons guided to the end of each fiber penetrated by a particle. The Solid State Photomultiplier[1] (SSPM) developed at Rockwell International is well suited for this purpose. For example, a tracking

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system using scintillation fibers and SSPMs implemented around the Fermi National Accelerator CDF collision region could provide spatial accuracies better than 0.08 mm. The system would also be suitable for Superconducting Supercollider vertex tracking due to the SSPM's capability of high detection rates and very good time resolution. Such performance is based on the nanosecond pulse risetime of SSPMs and achievable 90% SSPM quantum efficiency at scintillation light wavelengths near 500 nm, allowing use of fibers having a cross section less than 0.25 x 0.25 mm^2. Fig. 1 shows a possible vertex tracking scheme using one group of straight and two groups of stereo layers of scintillating fibers at $\pm 30^o$. The amount of materials in the way of the tracks normal to a total of 12 layers of fibers would be about 0.8% of the radiation length of the particle. Four layers of fibers in each group would provide a high probability of detecting several photons per particle track.

Other devices, such as avalanche photodiodes (APDs)[2], considered as scintillating fiber photon detectors have given disappointing results in experimental tests. The use of scintillation fibers as an active target coupled to an image intensifier with CCD readout has been successful[3]. However, the slow readout speed of the CCD precludes the use of such an arrangement at high rates. Furthermore, the relatively low quantum efficiency of image intensifiers (less than 25%) limits this approach to fibers about 1 mm in diameter with a corresponding spatial accuracy of only 0.35 mm.

A preliminary test of the SSPM's effectiveness as a light detector for scintillating fibers was performed using step-index-of-refraction square 0.225 x 0.225 mm^2 fibers with a 0.18 x 0.18 mm^2 core[4]. Two fibers having different emission wavelengths, $\lambda = 440$ and 530 nm, were investigated. The experiment, illustrated schematically in Fig. 2, involved exposure of two adjacent fibers to a partially collimated beam of electrons, with a 2.25 MeV maximum energy, from a strontium-90 beta source. Coincident photon detection pulses were pulse height analyzed to obtain distributions such as those plotted in Fig. 3 for one of the fibers. The distributions are for two fiber lengths between the point irradiated and the SSPM. Because the amplitude of SSPM pulses is proportional to the number of simultaneously-detected photons with very little amplitude dispersion, such distributions allow determination of the average number of photons detected per electron that passes through the fiber. The first n peaks correspond to 1.2...n detected photons per electron through the fiber, and their areas A(n) are expected to approximately follow the Poisson distribution, $p(n, < n >) = < n >^n \exp(- < n >)/n!$. The average number of electrons detected per electron passing through the fiber, $< n >$, is therefore equal to the ratio $(n+1)A(n+1)/A(n)$. It is noted that the distribution for photon numbers greater than three may contain enough events from electrons scattered through large angles, resulting in long paths in the fiber and therefore may deviate from Poisson statistics.

The first five columns of Table 1 give the parameters for two fibers of different wavelength coupled to an SSPM with no special provisions to reduce reflection losses. λ is the peak wavelength of the fiber emission band. The $\lambda = 440$ nm fiber cores are polystyrene containing Butyl PBD and POPOP and the $\lambda = 530$ nm fibers use 3HF (3-hydroxy flavone) in polystyrene. The parameter n_1 is the core index of refraction, n_2 that of the cladding, and f is the percentage of isotropically-emitted photons that are within the angle for total internal reflection in one direction along a fiber. The actual values of f may be smaller if the fibers have small radius bends of deviate otherwise from the perfect geometry assumed in the estimates.

The last three columns of Table 1 give the average number of detected photons and photon attenuation length from the pulse height data and the expected number of detectable photons assuming that for minimum ionizing particles (MIPs), in plastic scintillators, on the average, about 400 eV of particle energy is consumed in creating one photon. Some of the scattered electrons and the low energy (< 0.5 MeV) part of the beta electron distribution may produce somewhat larger scintillations than those of MIPs created in a collider. The calculated photon yield may therefore exceed the average number of photons that would be detected if heavy MIPs were used in the same experiment. Nevertheless, the photon yields in Table 1 are probably quite close to the yield per collider MIP in a system where the fibers would be aluminized, terminated with a reflecting surface, and optically matched to an SSPM. It should be noted that none of these provisions were employed in the experiments reported here, and several 1.5 cm radius 60° bends in the fibers could not be avoided inside the dewar. Further experiments using MIPs in a set-up with improved SSPM-fiber coupling and with no fiber bends of radius less than 2.5 cm are indicated.

Acknowledgments

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References

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3. R. E. Ansorge et al., Nucl. Instrum. and Methods in Physics Research, A265, 33-49, North-Holland, Amsterdam (1988).

4. Fibers were provided by A. Bross, Fermilab. They were produced for scintillating fiber calorimetry.

Table 1

λ nm	SSPM Q.E. at λ	n_1	n_2	f %	Average Photons/e from data	Measured Attenuation Length (m)	Calculated Detectable Photons/MIP
440	0.4	1.60	1.48	3.5	0.9	1.8	1.08
530	0.6	1.56	1.48	2.6	0.95	1.06	0.90

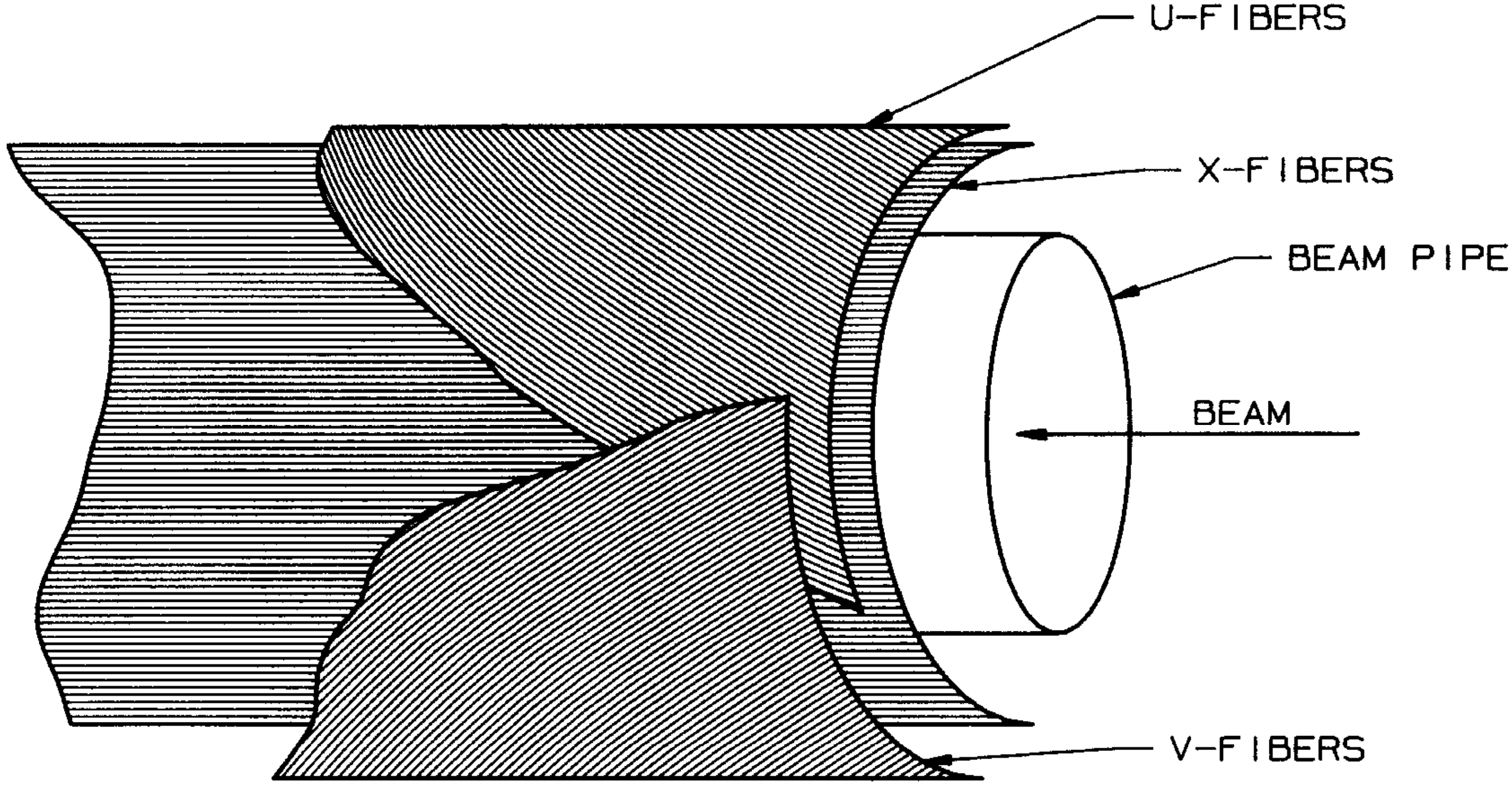

Fig. 1

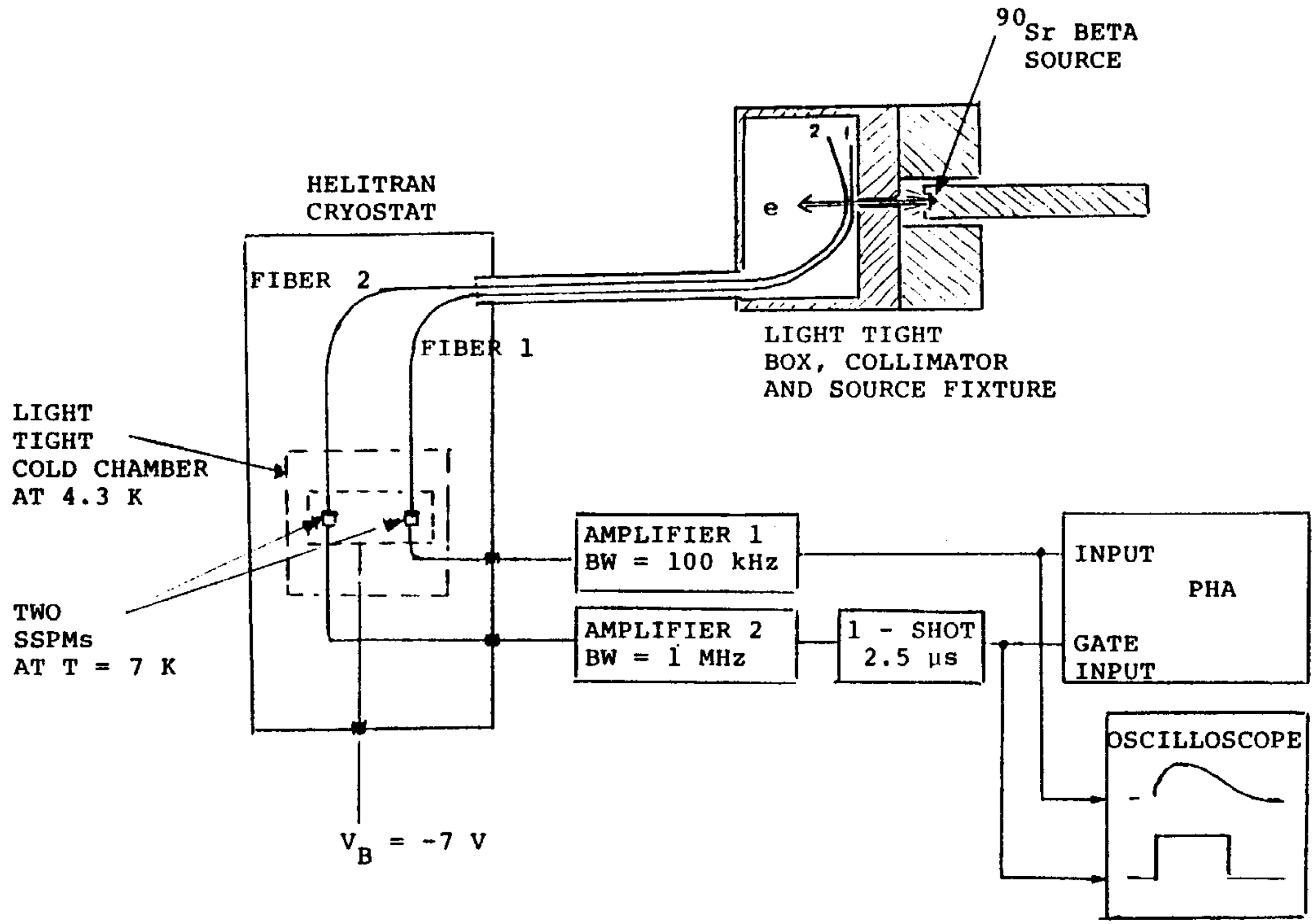

Fig. 2 **Experimental Arrangement for Detection Of Fiber Scintillations**

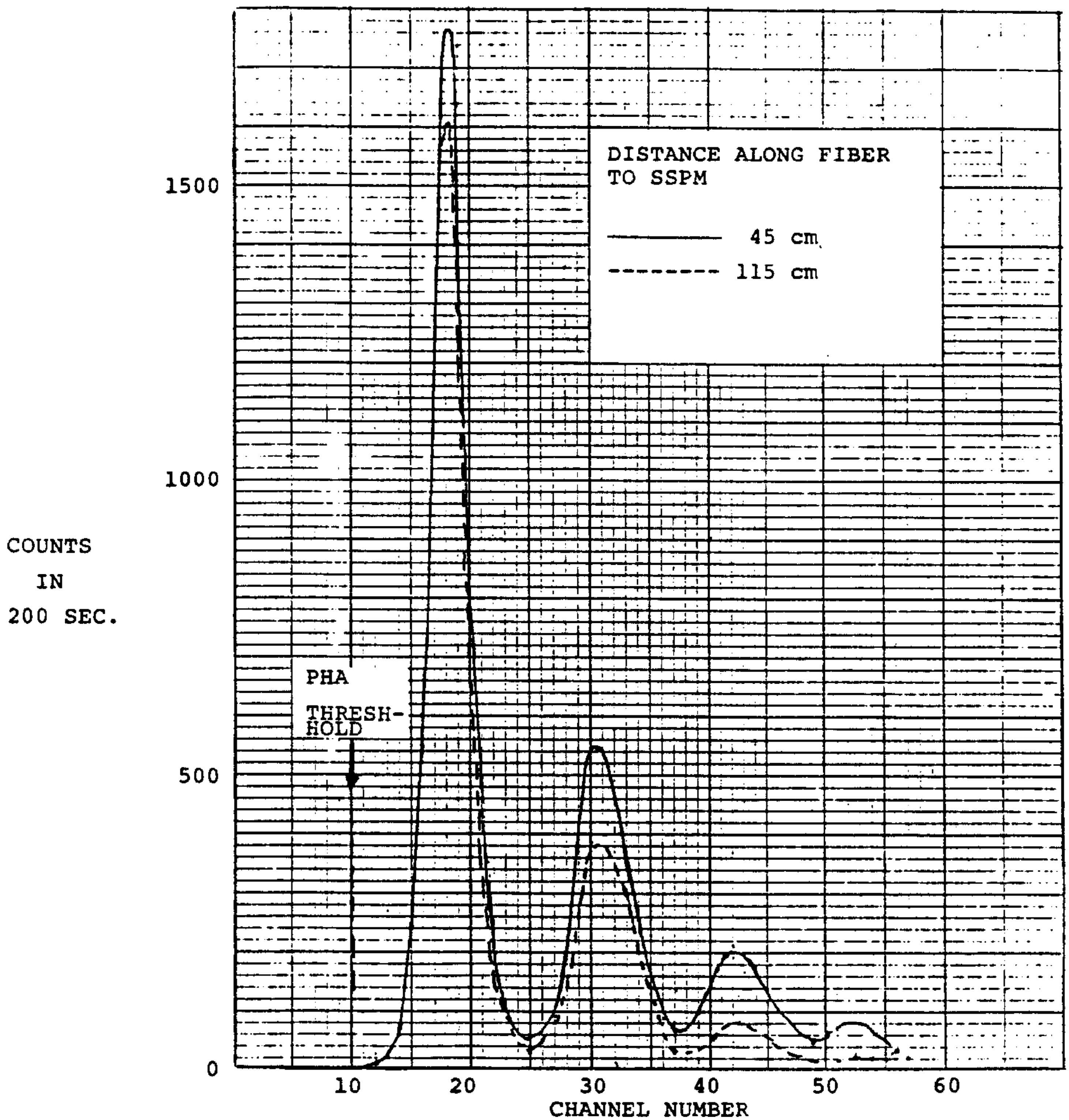

Fig. 3 SSPM Pulse Height Distributions for Fiber Scintillations at two Positions of Beta Beam