Development of a Scintillating Fiber Detector for Experiment E835 at FNAL

D.Bettoni, D. Bonsi, R.Calabrese, B.Camanzi, E.Luppi
University of Ferrara and INFN (Italy)
R.Mussa, M.Onorato, N.Pastrone
University of Torino and INFN (Italy)

Abstract

A tracking detector made of scintillating fibers is being developed at FNAL, for the experiment E835. The tracker will be used for the measurement of the polar angle θ, i.e. of the coordinate along the beam.

The small amount of light from the fibers will be detected by solid state devices (Visible Light Photon Counters) with very high quantum efficiency.

This paper reports the performance of a fiber tracker prototype, as measured at FNAL. We present results on light yield/mip, attenuation and homogeneity of response.

We measured an average number of 14 photoelectrons per mip and a very low noise level.

I. INTRODUCTION

The experiment E760 at FNAL has studied the spectroscopy of $c\bar{c}$ bound states, formed in $p\bar{p}$ annihilations. An upgrade of the detector is in progress, in preparation for the next data taking period (experiment E835 [1]), scheduled to start in early 1996. In order to be able to withstand the proposed factor 5 increase in luminosity, the existing inner tracking detectors have to be replaced or modified.

The possibility of using a scintillating fiber tracker to have a good θ measurement has been successfully tested: due to the recent improvements in both fiber technology and photon detection techniques, a double layered tracker with efficiency $\epsilon > 99\%$, high rate capability (up to $3 \cdot 10^4$ mips/sec per fiber at a peak luminosity $L=5 \cdot 10^{31}cm^{-2}sec^{-1}$) is feasible.

The final detector will be made of a double cylinder with $\sim$ 15 cm radius and $\sim$ 50 cm length, full azimuthal coverage, and θ acceptance from 15 to 65 degrees. Digital signals from the fibers will be OR-ed together in order to have a first level trigger based on θ.

II. PROTOTYPE COSTRUCTION

In order to understand the mechanical problems arising from the design, and to verify light output and reliability of such a detector, we built a prototype with one tenth the number of channels.

The prototype (fig.1) is composed of two layers of $\sim$ 50 scintillating fibers each, wrapped on two concentric cylinders, made of acrylic material. In order to ensure the proper positioning of the fibers, V-shaped grooves have been dug on the cylinder surface. The groove depth is linearly increasing with ϕ, so that, after one turn, each fiber overlaps itself radially: in other words, each scintillating fiber will describe a spiral on the plane normal to the cylinder z axis. The inner cylinder has 56 fibers, 93.5 cm long, 1.016 mm pitch; the outer one has 48 fibers, 98.5 cm long, 1.196 mm pitch. The thickness of the cylinders on the prototype is 3.175 mm and the maximum groove depth is 1.524 mm. The fiber outer diameter is 0.835 mm, with a core diameter of approximately 0.74 mm.

The scintillating fibers being used (Kuraray SCSF-3HF Multiclad) consist of a polystyrene

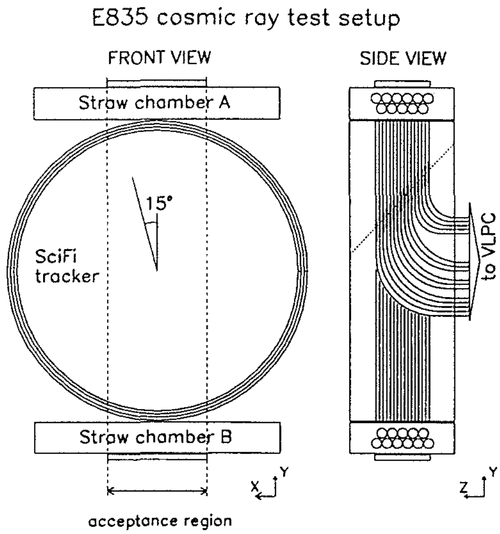

Figure 1: Layout of the apparatus for the cosmic ray test: dashed lines show the acceptance constraints imposed by the trigger counters; a dotted line indicate the junction between scintillating and clear fibers

core, doped with 1.25% paraterphenyl (pTp), and 1500 ppm 3-hydroxyflavone (3HF). The latter acts also as a wavelength shifter ($\lambda_{em} \approx 530$ nm), minimizing self-absorption of the light in the fiber core: the attenuation length has been measured [2] by the D0 collaboration on both scintillating ($L_{att} = 5.5$m) and clear ($L_{att} = 10.4$m) fibers.

In order to increase the amount of light trapped inside the fiber, the far end of 46 fibers (22 in the inner cylinder, 24 in the outer one) has been polished and a thin aluminum layer has been deposited on the surface.

Each fiber is coupled to a 4 meter long Kuraray Clear Multiclad lightguide, 835 μm in diameter. The optical connection between scintillating and clear fiber is a critical point: in order to achieve the highest possible transmission efficiency across the junction, the two fiber ends were polished with a diamond fly cutter [3] and thermally spliced together by a flash lamp. To protect the junction from transversal stresses, the splicing point has been covered with a 2 cm long heat-shrinking sleeve. Two types of sleeve are being used: fibers on the outer cylinder use a 180 μm thick TFE sleeve, while fibers on the inner cylinder use a 75 μm thick FEP sleeve, resulting in a dead zone of about 38% and 27% respectively (including the cladding).

Due to the physical constraints imposed by the detector geometry, the clear fibers have to be bent a few centimeters downstream of the junction, with a bending angle of 90 degrees, and curvature radii from 2 cm to 6 cm. Fibers were assembled in a clean room, where the ambient light was screened using Kodak 0302 filters, to avoid UV damage of the SCSF-3HF fibers [4]. After the assembly, fibers were checked with a movable UV source: 2 fibers were reported to be broken (one due to mishandling, one due to a bad splicing quality), and the precision of fiber positioning was measured to be better than 100 μm.

III. Cosmic Ray Tests

GaAs or silicon based photosensitive devices are needed to ensure high quantum efficiency in the green region of the visible spectrum, and very interesting results have been achieved in recent years [5, 6]. The Visible Light Photon Counters (VLPC), manufactured by Rockwell International, are solid state devices with very high quantum efficiency ($\simeq 60\%$) and a gain in the range $10^4 \div 10^5$. Their operational principles have been extensively described elsewhere [7, 8]

The VLPCs used in this test, labeled HISTE-IV, are produced in chips with 8 round pixels each (1mm diameter), are mounted in modules (*cassettes*), with 128 channels each, and all the 24 cassettes are put in a liquid helium dewar, to maintain the devices at an operating temperature between 6 K and 7 K.

Two independent setups (prototype, trigger hodoscopes, and additional tracking detectors), sharing a common data acquisition system, have been installed by the D0 and E835 collaborations, maximizing the acceptance overlap between the detectors. Each recorded cosmic track is expected to intersect twice both fiber cylinders, in two regions corresponding to $\sim 20\%$ of the entire active

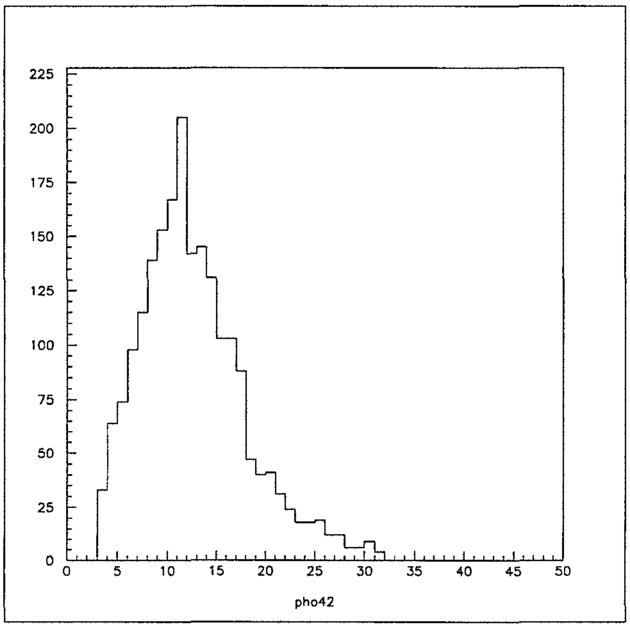

Figure 2: Signal distribution from a single fiber. The horizontal scale is in photoelectrons.

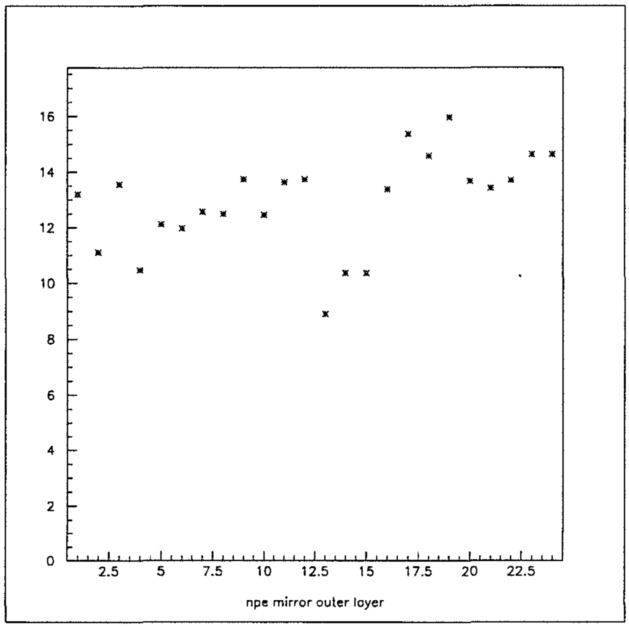

Figure 3: Average number of photoelectrons from all the fibers with mirrored end

area of the prototype (see fig. 1).

We report here the results of the analysis of cosmic rays signals collected over a period of several months this year, when our prototype was connected to one VLPC cassette. The data were all taken at constant VLPC temperature (T=6.5 ^{o}K) and 3 different bias voltages (V_{bias}=6.5, 6.8, 7.0 V). In this paper only the data taken at 6.5 V will be discussed.

Signals from the VLPCs were amplified using QPA02 preamplifiers [9]. The VLPC system is calibrated sending light pulses to each fiber, from a LED source.

Fig. 2 shows a typical signal distribution from a single fiber, with a cut at 3.5 photoelectrons. This cut removes all the noise, while leaving the efficiency unaltered. From such a distribution we can extract the average number of photoelectrons and its dispersion.

The average number of photoelectrons from all fibers of the outer cylinder as a function of fiber number is shown if fig. 3 for the fibers with aluminized end and in fig. 4 for those with non aluminized end. A linear fit to these plots yields :

$$< npe >= 13.4 \pm 1.6$$

for the aluminized fibers and :

$$< npe >= 11.0 \pm 1.7$$

for the non aluminized ones. Thus the fibers with aluminized end show a 20 % increase in light yield.

The data in figg. 3 and 4 show a spread of less than 20 % in the average number of photoelectrons, which is consistent with the width of the signal distribution (see fig. 2). This indicates a very good homogeneity in the detector response. Furthermore, since these data come from fibers with different curvature radii (from 2 cm to 6 cm), we can exclude, at the present level of accuracy, significant bending effects.

To check if the scintillating fibers were damaged during this year, we measured their attenuation length and we compared it with the measurement done by the *D0* Fiber Tracking Group on new fibers.

Considering that the hodoscopes do not cover all the detector along x (acceptance region from 0^o to 15^o in ϕ, see fig. 1), it was possible to divide the data in two subsamples: signals coming from the upper and lower parts of the prototype.

The decreasing in the signals going from the upper to the lower part of the cylinders is due to

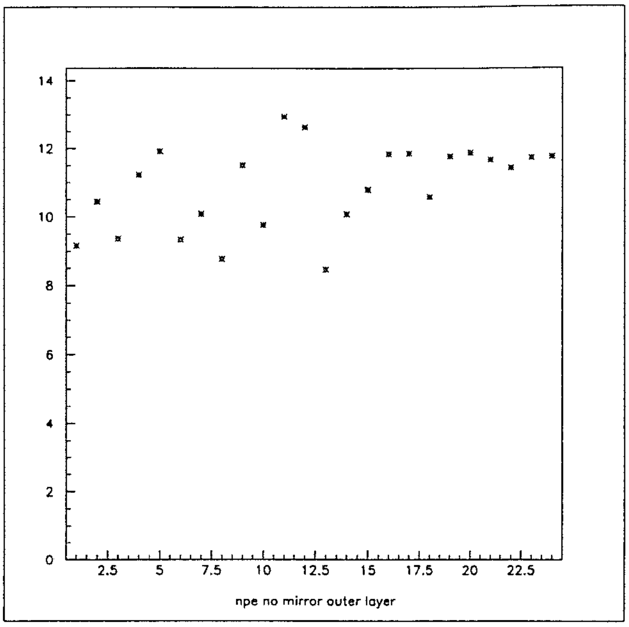

Figure 4: Average number of photoelectrons from all the fibers with non mirrored end

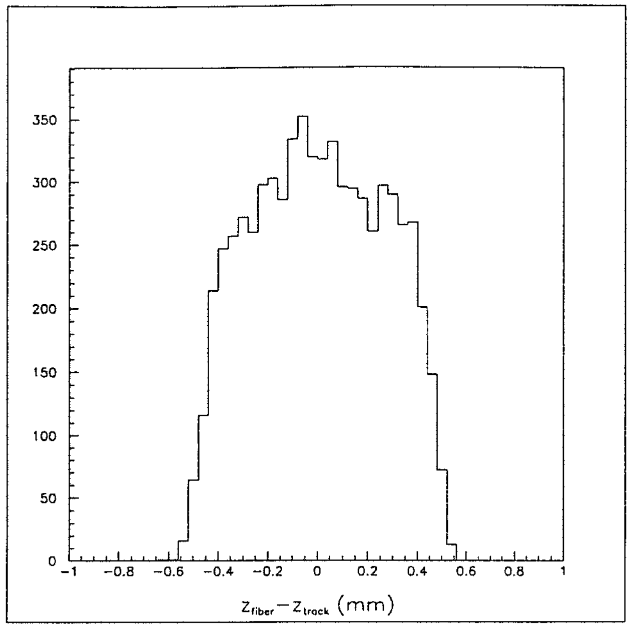

Figure 5: Track residuals (Montecarlo)

the attenuation of the light in a path of approximately 50 *cm*. The ratio of the 2 signals gives the attenuation length :

$$< npe_{down} > / < npe_{up} > = \; exp(-path/\lambda_{att})$$

The measured attenuation length is $\lambda_{att} = (4.8 \pm 0.6)m$. This value is in agreement with the above quoted measurement by the *D0* Fiber Tracking Group (5.5 *m*), meaning that the fibers are not damaged.

Montecarlo simulations have been made to evaluate efficiency and resolution of the detector in the final design. This consists of two layers with radii of 144 mm and 152 mm, with pitches between fibers of 1.1 mm and 1.16 mm respectively. Tracks originating from a non pointlike interaction region ($\sigma_{x,y} = 2.5mm, \sigma_z = 3.0mm$) were generated, and the interactions with the 2 layers of the detector were simulated.

The single track efficiencies of the inner and outer layers were found to be 92.2 % and 90.7 % respectively, yielding a combined efficiency of 99.8 %, with the requirement of at least one hit.

The resolution has been evaluated from the distribution of the residual $z_{fiber} - z_{track}$. Such a distribution, for the case of one hit fiber, is shown in fig. 5. A fit to this plot gives a value $\sigma = 250\mu m$.

IV. Acknowledgments

The authors would like to acknowledge the technical staff of Fermilab Physics Department for technical support, and the Fiber Tracking Group of the D0 Collaboration for providing fibers, VLPCs and much of the data acquisition system for the test of the prototype. We would like to thank J.Mansour, B.Tannenbaum and R.Richards for providing the MSU splicing machine. We finally would like to acknowledge A.Bross, S.Pordes, M.Atac, M.Mishina, J. Warchol and Y.M. Park for many useful suggestions and discussions.

References

[1] T.Armstrong et al., proposal Fermilab-P-835 (1992)

[2] C.L.Kim et al., Proc. Workshop SCIFI 93, Notre Dame Univ. (1993), World Scientific

[3] M.Mishina et al., Fermilab-TM-1869

[4] M.Chung et al., Proc. Workshop SCIFI 93 (see ref.[2])

[5] R.DeSalvo et al., Nucl.Instr. and Meth. A315(1992),375

[6] P. Cushman, R.Rusack, Nucl.Instr. and Meth. A333(1993),381

[7] M.D. Petroff et al., Appl.Phys.Lett. 51 (1987),406
M.D. Petroff, M.G.Stapelbroek, IEEE Trans.on Nucl.Sci.36(1989),158

[8] M.Atac, M.D.Petroff, IEEE Trans.on Nucl.Sci.36(1989),163
M.Atac et al., Nucl.Instr. and Meth. A314,56 (1992)
M.Atac et al., Nucl.Instr. and Meth. A320,155 (1992)
E.W.Atkins et al., Proc. Workshop SCIFI 93 (see ref.[2])

[9] T.Zimmermann et al., IEEE Trans. Nucl. Sci NS-37 (1990),339