Tests of a fiber detector concept for high rate particle tracking

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\textbf{Abstract.} A fiber detector concept is suggested allowing to registerate particles within less than 100 nsec with a space point precision of about 100 \(\mu\)m at low occupancy. The fibers should be radiation hard for 1 Mrad/year. Corresponding prototypes have been built and tested at a 3 GeV electron beam at DESY. Preliminary results of these tests indicate that the design goal for the detector is reached.

\textbf{INTRODUCTION}

The advantageous use of fiber detectors for particle tracking has been demonstrated for very different conditions e.g. in the UA2-Experiment \cite{1}, CHORUS \cite{2}, for D0 \cite{3} and the H1-Forward Proton Spectrometer \cite{4}. Due to the different experimental situation in this applications three types of optoelectronic read out techniques are applied – Image Intensifier plus CCD’s, Visible Light Photon Counters and Position Sensitive Photomultipliers. However, all have in common that the precision of space point measurements is given by hits of overlapping fibers of several staggered fiber layers. For high rate experiments demanding online tracking of several hundred particles per 100 nsec bunch crossing such a concept may not work due to too high occupancy of single fiber channels.

We propose in the following to use overlapping fiber roads reading out several thin scintillating fibers with one clear optical fiber. The demands and the solutions presented below match to a possible application of the detector as the inner tracker in the HERA-B project at DESY \cite{5}. Similar ideas have been used by others \cite{6} to build a fiber detector for the DIRAC experiment at CERN.

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DETECTOR PRINCIPLE

The fiber detector under discussion is aimed to detect throughgoing particles with more than 90% efficiency within less than 100 nsec and a precision of better than 100 μm. The fibers should not change their characteristics significantly after an irradiation of 1−2 Mrad. The sensitive detector part should have a size of 25 x 25 cm². The scintillating fibers should be coupled to clear optical fibers of about 3 m length guiding the light to photosensors placed outside the experimental area.

It is assumed that most particles of interest hit the detector perpendicular, i.e. with angles less than five degrees with respect to the beam axis. In this case low occupancy and high light yield are guaranteed by using overlapping fiber roads like schematically drawn in fig. 1. One fiber road consists of several thin scintillating fibers arranged precisely behind each other and coupled to one thick light guide fiber. The scintillating fiber diameter determines the space point resolution of the detector. The number of fibers per road is fixed by the scattering angle of particles and the allowed amount of multiple scattering. It will also influence the factor of background suppression for tracks with larger inclination or curvature. The pitch between fiber roads is defined by demanding a homogeneous amount of fiber material across the detector width.

Keeping in mind the conditions at HERA-B, we made the following choices:

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\begin{align*}
\Phi_{fib} &= 480 \mu m \\
L_{fib} &= 30 \text{ cm} \\
\Phi_{lg} &= 1.7 \text{ mm} \\
L_{lg} &= 300 \text{ cm}
\end{align*}
\]

\[
\begin{align*}
N_{fib/road} &= 7 \\
N_{road} &= 640 \\
p_{road} &= 340 \mu m \\
W_{det} &= 217.6 \text{ mm}
\end{align*}
\]

with Φ and L: diameter and length of scintillating and light guide fibers, \(N_{fib/road}\): number of fibers per road, \(p_{road}\): distance between neighboured road centers, \(N_{road}\): number of roads per detector, \(W_{det}\): detector width.

The light guide fibers are read out with the new Hamamatsu\(^6\) 64 channel PSPM R5900–M64 with a pixel size of 2 x 2 mm² [7]. To diminish optical cross talk the thickness of the entrance window of the device was decreased to 0.8 mm.

The coupling between scintillating and light guide fibers is done by loose plastic connectors. The light guides are coupled to the PSPM using a plastic mask fitting the corresponding pixel pattern.

MATERIAL STUDIES

Double clad fibers of three different producers\(^7\) \(^8\) \(^9\) were tested concerning light output, light attenuation and radiation hardness for several fiber diameters and

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\(^6\) Hamamatsu Photonics K.K., Electron tube division, 314–5, Shimokanzo, Tokyooka Village, Iwaguni, Shizuoka-ken, Japan

\(^7\) BICRON, 12345 Kinsman Road, Newbury, Ohio, USA

\(^8\) Pol. Hi. Tech., s.r.l., S.P. Turanense, 67061 Carsoli(AQ), Italy

\(^9\) KURARAY Co. LTD., Nikonbashi, Chuo-ku, Tokyo 103, Japan
wavelengths of the emitted light. Details of these measurements are given in [8]. A few results are summarized below.

The light output of fibers of 500 µm diameter is shown in fig. 2. Generally it can be seen, that the light yield decreases with increasing scintillator emission wavelength because the PM sensitivity curve is not unfolded. There is no remarkable difference between the best materials of the three producers. A mirror at the end of the fiber increases the light output by a factor 1.7.

Several tests were performed to couple scintillating and light guide fibers. Finally the coupling efficiency became better than 95 %, independent of the medium between both parts (air, glue, grease).

The light attenuation of clear fibers was measured coupling them to single scintillating fiber roads excited by a Ruthenium source. The clear fibers were cutted back piece by piece to the length under investigation. Results for two producers are given in fig. 3.

Radiation hardness tests of fibers were made using an intense 70 MeV proton beam at the Hahn–Meitner–Institute Berlin. 1 Mrad radiation was deposited within a few minutes. For all materials investigated we observed a damage of the scintillator and the transparency of the fiber which was followed by a long time recovery of up to 600 h. An example is shown in fig 4. More detailed studies using glued and nonglued fibers and irradiate them in air and nitrogen atmosphere are still ongoing.

Summarizing all results of our material studies we decided to use the KURARAY fibers SCSF-78M with a diameter of 480 µm for the scintillating part of our detector prototypes. For clear fibers still two choices seem to be possible: 1.7 mm fibers from KURARAY or Pol. Hi. Tech..

**DETECTOR PRODUCTION**

Using winding technology as developed for the CHORUS experiment [9] we built a detector production chain at our institute. A drum of 80 cm diameter allows to produce five detectors at once. The production time for winding one drum is about 14 h. Sticking the fibers to the connector holes is still done by hand and rather time consuming. A part of the polished end face of one of our detectors is shown in fig. 5.

Two other detector prototypes are ordered from industry. GMS–Berlin followed a technology proposed by the university of Heidelberg [10] mounting single layers on top of each other using epoxy glue. Each layer is prepared on a v-grooved vacuum table. One layer per day can be produced in this case. The connector is here also added by hand. The production technology used by KURARAY is unknown to us.

To get the precision of the detector geometry quantified we measured the coordinates of all fibers of the polished end face of the three detectors. In fig. 6 the deviation from the ideal position is given per fiber road. Some stronger local effects

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10) GMS - Gesellschaft für Mess- und Systemtechnik mbH, Rudower Chaussee 5, 12489 Berlin, Germany
are visible. Averaging these results characteristic accuracies of 20 µm, 50 µm and 10 µm are calculated for the Zeuthen, GMS and KURARAY detectors respectively.

**TESTRUN RESULTS**

Two testruns were performed to measure the properties of the produced fiber detectors in a 3 GeV electron beam at DESY. The setup used in both cases was very similar and is schematically drawn in fig. 7. Four silicon microstrip detectors are used together with two fiber reference detectors and an external trigger system to predict the position of a throughgoing particle at the detector to be tested. A precision of 50 µm and 80 µm was reached for that prediction using the geometrical arrangements of testrun 1 and 2. The fiber detector signals were registrated after 3m of light guide in the first case using a 16 channel PM R5900–M16 read out with a charge sensitive ADC. In the later run the 64 channel R5900–M64 was used and the signals were transfered via a special multiplexer to a flash ADC.

In April 1997 first small eight road detectors were investigated to measure the light profile across a fiber road. The result is shown in fig. 8. The data can be described simply by taking into account fiber geometry seen by a throughgoing particle. They allow to calculate the detector efficiency for any particular pitch between the fiber roads.

During the testrun in October 1997 the three full size detector prototypes described in section 4 were investigated in detail. Up to now only preliminary results are derived from about 4 Gbyte of data.

A relation of 0.9/1.0/0.8 was found for the average light output of the Zeuthen, GMS and KURARAY detectors. It seems to be due to the different quality of the end face polishing rather than to the mechanical detector precision.

The detector efficiency and resolution is dependent on the hit selection method used. With a maximum amplitude search for all PSPM pixels we calculated rough values of $97 \pm 3 \%$ for the efficiency and about 140 µm for the resolution of the three detectors. (see also figs. 9 and 10). Taking into account the finite resolution of our track prediction of 80 µm and the total mechanical alignment not better than 50 µm this points to a fiber detector resolution of better than 100 µm.

Work is in progress to qualify these results. In addition the detector noise has still to be studied in detail. Optical and electrical cross talk will influence the choice of cuts and the hit selection methods and in this way also efficiencies and resolution.

**SUMMARY**

Three fiber detector prototypes have been tested. They are made out of 640 overlapping roads of seven 480 µm diameter fibers coupled to 1.7 mm diameter light guides of 3 m length read out with 64 channel photomultipliers. For all three detectors a preliminary analysis gives an efficiency of about 97 % and a resolution
of about 100 µm. These results together with radiation hardness studies of the used fiber material seem to make it possible to use a corresponding detector in a high rate experiment like HERA-B. In such case special care has to be taken to keep noise from optical and electrical cross talk at an acceptable level.

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REFERENCES

1. Ansorge, R., et al., NIM 265, 33 (1988)
2. Annies, P., et al., NIM A367, 367 (1995)
3. Bross, A.D., Nucl. Phys. B (Proc.Suppl.) 44, 12 (1995)
   Adams, D., et al., Nucl. Phys. B (Proc.Suppl.) 44, 332 (1995)
4. Bähr, J., et al., Proceedings of the 28th Intern. Conf. on High Energy Physics, Warsaw, Poland, 1996, eds. Z. Ajduk, A.K. Wroblewski V. II, p. 1759
5. Lohse, T., et al., HERA-B Technical Proposal, DESY-PRC 94/02 (1994)
6. Ferro-Luzzi, M., et al., contribution presented by A. Gorin to this workshop
7. Yoshizawa, Y., contribution to this workshop
8. Aschenauer, E.C., et al., preprint DESY 97-174 (1997)
9. Nakano, T., et al., Proceedings of the workshop SCIFI93, Notre Dame, USA, 1993, eds. A. Bross, R. Ruchti, M. Wayne, p. 525
10. Eisele, F., et al., private communication
FIGURE 1. Schematic view of the proposed fiber detector cross section and coupling principle (LG: light guide fiber).

FIGURE 2. Light output from 500 µm diameter fibers for several fiber materials of three producers.

FIGURE 3. Light attenuation in clear fibers of 1.7 mm diameter produced by Kuraray and Pol.Hi.Tech.

FIGURE 4. Time evolution of light output for KURARAY SCSF 78M fibers irradiated with 0.2 and 1.0 Mrad at 10 and 20 cm respectively. The solid, dashed and dotted curves correspond to measurements with a source placed at 10, 20 and 25 cm.
**FIGURE 5.** Photograph of part of the polished end face of a Zeuthen prototype detector.

**FIGURE 6.** Deviation of fibers from ideal position per fiber road for three prototype detectors from Zeuthen, GMS and KURARAY.

**FIGURE 7.** Set up for testruns 1 and 2. M1-M4: silicon microstrip detectors, RD1 and RD2: fiber reference detectors, T1-T4: trigger paddels, FD: detector to be tested.

**FIGURE 8.** Light output across a fiber road of seven 500 μm KURARAY fibers coupled to a 3 m long light guide of 1.7 mm diameter.
FIGURE 9. Efficiency at different positions of three fiber detector prototypes, averaged for 64 channels. Particles hit 5cm from the near (n) or far (f) end of the ordered detector part.

FIGURE 10. Resolution at different positions of three fiber detector prototypes, averaged for 64 channels. Particles hit 5cm from the near (n) or far (f) end of the ordered detector part.