DEUTSCHES ELEKTRONEN-SYNCHROTRON
INSTITUT FÜR HOCHENERGIEPHYSIK

DESY 93-200
December 1993

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ISSN 0418-9833

PLATANENALLEE 6 - 15738 ZEUTHEN

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Contribution to the
Workshop on Scintillating Fiber Detectors–SCIFI93,
Notre Dame, 1993

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[1] on leave from JINR Dubna
[2] on leave from Universität Münster

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1 The project

The investigation of diffractive scattering reactions in photoproduction and deep–inelastic scattering is of particular interest since the discovery of about 5 % deep–inelastic events ($Q^2 > 10\,(\mathrm{GeV}/c)^2$) with large rapidity gap [1]. Here may be a chance to learn more about the structure of the Pomeron. The experimental difficulty is that for processes as schematically drawn in fig. 1, the scattered proton or the decay particles of a heavier diffractive excitation state escape through the collider beam pipe. Their detection needs special forward particle detectors added to the central experimental assembly at very small angles i. e. large distances [2].

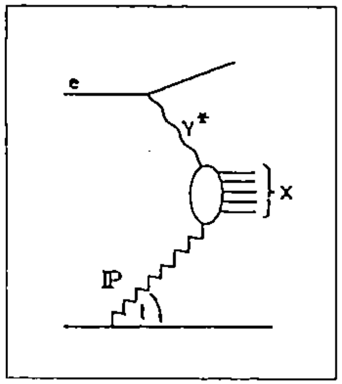

Figure 1: Feynman diagram of a diffractive process in ep–collisions.

A forward proton spectrometer based on scintillating fiber detectors is foreseen in the upgrade programme of the HERA H1 experiment by groups from DESY–Hamburg, DESY–Zeuthen and the Universities of Hamburg, Kiel and Lancaster [3]. For the ZEUS experiment the installation of a similar spectrometer using silicon microstrip detectors as sensitive elements is just being completed [4].

Both experiments use movable vacuum inserts at several positions of the beam pipe (Roman Pots) in which the high resolution track detectors are installed. The

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field of the beam bending magnets is used to determine the proton momentum. High space point accuracy is necessary to get reasonable momentum resolution. An error in particle momentum of 5 GeV/c demands a spatial measurement precision of about 50 μm.

The HERA bunch crossing time of 96 nsec requires a very good time resolution and small dead time for the spectrometer. This was the reason to suggest to use scintillating fibers for the H1 upgrade project. In this case data could even be included in the first level trigger of the experiment. A second advantage is that the expensive readout detectors and electronics can be put far away from the beamline and run no risk to be damaged by radiation or a beam accidentally out of control.

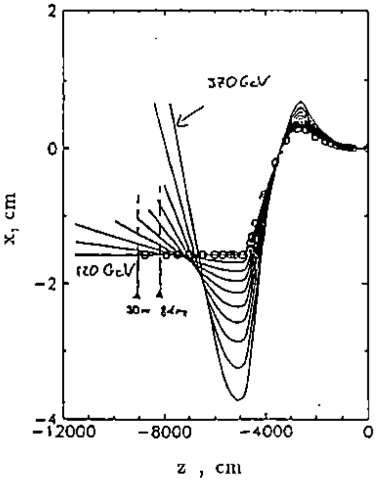

Figure 2: Bending profile of different proton momenta with respect to the HERA proton beam.

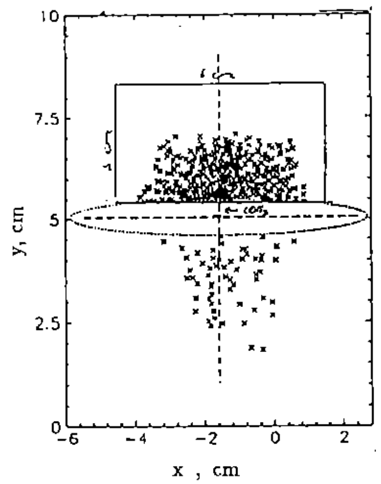

Figure 3: Particle distribution transverse to the HERA proton beam at 81 m distance to the H1 detector for diffractively scattered protons.

In the first phase of the H1 project two Roman Pots are proposed to be installed at distances of 81 m and 90 m downstream from the H1 central detector at the proton beamline. In fig. 2 a bending profile for particles of different momenta is given along the beam direction. Fig. 3 shows a Monte Carlo simulation of the expected particle distribution transverse to the beam at z=81 m for particle momenta 420-820 GeV/c [5]. The flat ellipse gives the 20σ beam profile at this position. A detector of 6 x 3 cm^2 would measure most of the expected particle tracks. The H1 proposal foresees two detectors of this size for each pot measuring 3 coordinates with a precision of 50 μm and a reasonable two track resolution. The installation of two detectors in the

same pot would allow already to determine track gradients with a precision of about 1 mrad.

2 A fiber detector prototype

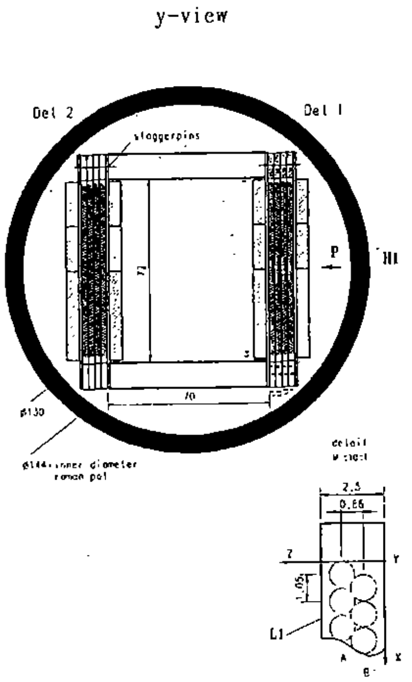

Figure 4: Schematic view of the Roman Pot fiber detector prototype.

To measure real background conditions, get first information about the signal and test the whole detector concept in reality it was decided to mount two Roman Pots during the winter-shutdown 1993/94. One pot will be equipped with a fiber detector prototype and in the other one an additional trigger system will be installed.

The prototype detector was designed and built including the optoelectronic system in DESY-Zeuthen. It will be described in the following in some detail. As can be seen from fig. 4 the prototype consists of two detectors separated by 70 mm and staggered by 125 μm. Each detector has 4 double layers of 32 fibers of 1mm diameter i. e. one coordinate is measured for half of the future detector width. The double layers are staggered by 250 μm. Each single fiber consists of a 3 cm scintillating part thermally spliced to a light guide of about 45 cm length. The fibers are read out by 2 position-sensitive photomultipliers H4139-20 [1]. Four fibers are connected to each of the anode pixels. Two of them are located behind each other in z–direction and used only to increase the efficiency. Fiber numbers different by 16 are also combined. This coordinate multiplexing has to be resolved later by additional trigger information. Details about the readout procedure are described elsewhere in these proceedings [6].

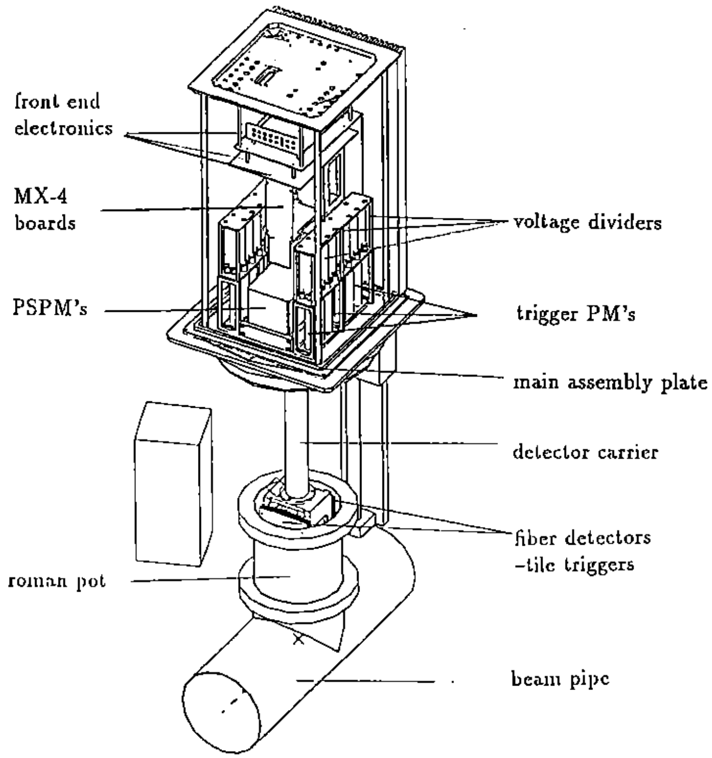

Figure 5: Schematic view of the fiber detector prototype installation at the Roman Pot.

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[1] HAMAMATSU PHOTONICS K. K. Electron Tube Center, 314–5 Shimokanzo, Toyooka village, Iwata-gun, Shizuoka-Ken, 43801, Japan

A trigger system of 4 x 3 scintillating tiles read out by wavelengthshifter fibers connected to light guides coupled to 12 photomultipliers of type XP 1911[1] provides fast information for multiplexing and background discrimination. The same trigger system will be installed in the second Roman Pot at 90 m. Therefore data can be selected demanding tracks to be seen at least for about 9 m in length.

A general view of the detector scheme is shown in fig. 5 where only the light guide fibers are omitted. As can be seen the detectors and trigger tiles are mounted at a detector carrier which is connected to an assembly plate where the photomultipliers couple to corresponding fiber masks. Also the basic front–end electronics is installed at the plate. A bellow (not shown) will connect the assembly plate with the pot. For safety reasons the inner space is afterwards filled with nitrogen gas.

With the fiber arrangement chosen we get theoretically an internal space resolution for one detector of

$$\sigma_x^{D_1,D_2} = = \frac{d}{4\cdot\sqrt{12}} = 72\mu m$$

combining both detectors this diminishes to

$$\sigma_x^{D_1+D_2} = 36\mu m.$$

Using both detectors we will be able to determine a track gradient with

$$\sigma_\theta = 2\mathrm{mrad}.$$

3 Detector technology

To form a double layer with high precision for each fiber position we use a vee groved brass matrix manufactured on a nc–machine with deviations of the order of 1 μm for about 10 cm length. Afterwards precise holes and pins are used to stagger the double layers within the detector. A photograph of a four double layer device is shown in fig. 6. Defining Δ as the difference between nominal and measured fiber position we found very good precision for different fiber diameters in particular within one double layer as can be seen from σ_Δ^l in table 1 and fig. 7.

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[1] PHILIPS Photonique, Avenue Roger Roncier–B. P. 520–19106 Brive la Gaillarde, Cedex–France

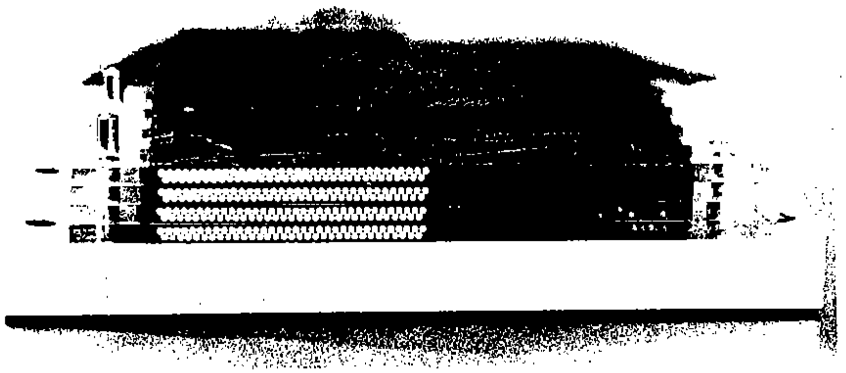

Figure 6: Photograph of a fiber detector made of four double-layers of 1 mm scintillating fibers.

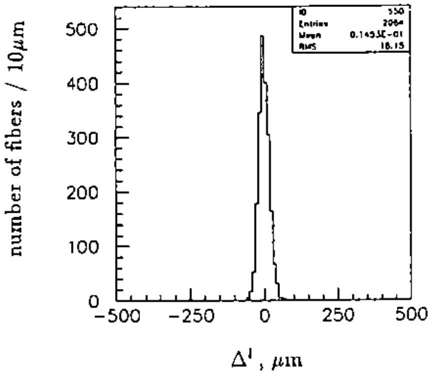

Figure 7: Deviation of fibers from nominal position within one double-layer measured for 512 fibers.

Table 1: Mechanical precision measured for different fiber detectors (see text)

[illegible] / mm	P / mm	S / μm	σ^l_Δ/μm	σ^D_Δ / μm
0.5	0.53	125	7	17
1.0	1.05	250	18	45
1.0	1.05	250	20	

Cutting a detector after assembly into several parts we studied the homogeneity of fiber alignment through the detector. The result for σ^D_Δ is also shown in table 1 and still within our demands.

The single fiber light output measured by the number of photoelectrons seen is given by

$$N^{pe} = N_\gamma \int \frac{dE}{dx} \varepsilon_{tr} \varepsilon_q \exp(-l/\lambda)(1-R)^k \, dx$$

where N_γ is a material constant, dE/dx: the energy loss of the particle at the length dx, ε_{tr}: the light trapping efficiency in one direction, ε_q: the quantum efficiency of the optoelectronic read out device, λ: the light attenuation in the fiber material and R the single reflection loss at the cladding.
Assuming reasonable values for all involved quantities

$$\begin{aligned} N_\gamma &= 10\,\gamma/\mathrm{keV} & \varepsilon_{tr} &= 0.03 \\ \frac{dE}{dx} &= 200\,\mathrm{keV/mm} & \varepsilon_q &= 0.20 \\ dx &= \frac{2}{\pi}\cdot\phi_{\mathrm{fib}} \\ l &= 50\,\mathrm{cm}\ , \quad \lambda = 100\mathrm{cm}, & R &= 5\cdot 10^{-4} \end{aligned}$$

we calculate the number of photoelectrons for different fiber diameters as given in table 2 and confirmed by measurements with BCF-y12 fibers [1] . The measurements were performed using a ^{106}Ru source precisely collimated to the fibers. The reproducibility of the measurement was better than 2 %.

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[1] BICRON Corporation, 12345 Kinsman Road, Newbury, Ohio 44065-9677

Table 2: Average number of calculated and measured photoelectrons from 0.5 and 1 mm diameter BCF-12 Fibers. The corresponding average amplitudes in number of ADC-channels are given for comparison with the results in table 3.

⌀/ mm	$< N_{pe}^{calc.} >$	$< N_{pe}^{meas.} >$	$< A^{meas} >$
0.5	2.0	2.0	115
1.0	4.2	4.7	225

Table 3: Average light amplitudes in number of ADC-channels measured for 20 cm scintillating fibers of different cross sections for various producers

$< A >$	⌀ = 0.5 mm	⌀ = 1.0 mm	sq = 0.5 mm	sq = 1.0 mm
BCF 12	148	308	129	253
SCSF 38[1]	153		145	
P.H. 042[2]	150	306		
P.H. 046[2]	145	287		
P.H. 048[2]	127	249		

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[1] KURARAY Co. Ltd, Tokyo, Japan

[2] Pol. hi. tech. S.P. Turanense Km. 44,400-67061 Carsoli (AQ), Italy

Comparing standard samples of 20 cm length round- and square scintillating fibers from different producers, we found for the average light amplitudes the values given in table 3. For the connection of scintillating fibers to light guides we investigated two different methods: glueing and thermal splicing. The results are given in table 4 and 5 where R is the ratio of the measured amplitudes from 6.5 cm scintillating fibers coupled to 13.5 cm light guides, to the amplitude measured with 20 cm scintillating fibers.

Table 4: Light output of scintillating fibers of 6.5 cm length glued to 13.5cm light guides relative to 20 cm scintillating fibers from different producers

R	⌀ = 0.5 mm	⌀ = 1.0 mm
BCF-12	0.78	0.79
SCSF 38	0.78	-
P.H. 042	0.89	0.97
P.H. 046	0.77	0.79
P.H. 048	0.89	1.07

Table 5: Light output of 1 mm scintillating fibers of 6.5cm length thermally spliced to 13.5 cm light guides relative to 20 cm scintillating fibers from different producers

	R
BCF-12	0.80
P.H. 042	1.01
P.H. 042[1]	1.12

[1] spliced by Pol. hi. tech.

All results are stable for a large number of fibers. Both techniques allow to register particle crossing with high efficiency. We decided to use the splicing technology for future detector construction.

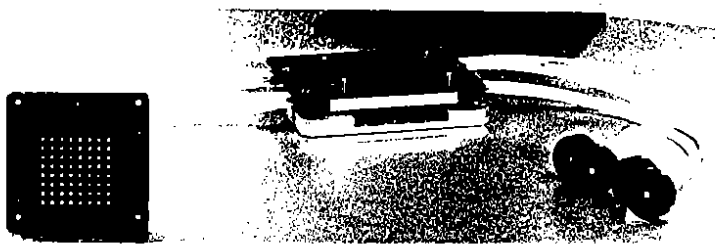

Figure 8: Photograph of a "self-triggering" fiber detector made of 2x4 double-layers of 500 μm scintillating fibers.

4 Cosmic particle Tests

In addition to the efficiency tests for 1 mm fiber detectors described in [5] we wanted to study the space resolution in reach for our detector concept. Therefore we built two detectors made from 4 double-layers staggered by 125 μm. The double layers consist of two times 16 fibers of 500 μm diameter. The first and last layers are connected to four XP2020 photomultipliers for triggering the readout of the position sensitive photomultiplier H4139-20. Each pixel of this device is used for 4-fold multiplexing. A photograph of the detector is displayed in fig. 8.

With this detector arrangement we obtain from 2 000 cosmic particle triggers an average efficiency per double layer of 93 %. This corresponds to an average number of active double-layers per trigger of 3.8. Removing background hits by a special fit procedure we still detected 66 % of all tracks. The average point resolution comes out to be $< \sigma_x > = 63$ μm.

5 Future activities

In a testrun at DESY in November 1993 we want to study the described fiber detector prototype including the trigger system in a 5 GeV electron beam. As previously [7,8] we will use an independent reference measurement with a precision of 12 μm per space point to test several types of fiber-PSPM arrangements.

During the period January to March we will install the prototype at the HERA collider. In May 1994 first data can be expected. A technical proposal for the final project will be ready in summer of next year.

Acknowledgement

The kind support of A. Pevsner and J. Spangler from Johns Hopkins University by lending us several complete readout boards developed originally for the L3-Fiber detector at CERN is gratefully acknowledged. We thank P. Söding for a critical reading of the manuscript.

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