Nuclear Instruments and Methods in Physics Research A 435 (1999) 34–43

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A

www.elsevier.nl/locate/nima

The ZEUS microvertex detector

For the ZEUS Microvertex Detector group

A. Garfagnini

Hamburg University, II. Institute of Exp. Physics, Hamburg, Germany

Abstract

A new vertex detector for the ZEUS experiment at HERA will be installed during the 1999–2000 shutdown, for the high-luminosity runs of HERA. It will allow to reconstruct secondary vertex tracks, coming from the decay of long-lived particles with a lifetime of about 10^{-12} s, and improve the global momentum resolution of the tracking system. The interaction region will be surrounded with single-sided silicon strip detectors, with capacitive charge division: three double layers in the central region (600 detectors), and 4 "wheels" in the forward region (112 silicon planes). Due to the high number of readout channels, 512 readout strips per silicon plane in the barrel region and 480 in the forward part, and the large coverage of the vertex detector (almost 1 m long), the front-end electronics has to be placed on top of the detectors and has to be radiation tolerant since doses up to 2 kGy are expected near the interaction region. The HELIX chip has been chosen as analog chip with a low-noise, charge-sensitive amplifier/shaper. The chip integrates 128 read out channels which are sampled in an analog pipeline with the HERA bunch crossing frequency of 10.4 MHz. A review of the status of the project is presented. A test program is underway in order to gain experience in the understanding of the detectors and their performance characteristics (i.e. detection efficiency, noise, large angle track position resolution, irradiation studies).

1. Introduction

ZEUS is a general purpose detector operating in the hadron electron ring collider (HERA), located at DESY in Hamburg, Germany. HERA provides colliding beams of electrons, with an energy of 27.5 GeV, and protons of 920 GeV energy,[1] corresponding to a center-of-mass energy of 318 GeV [1]. A detailed description of the ZEUS detector is given elsewhere [2]. Charged particles are measured by the inner tracking detectors which operate in a magnetic field of 1.43 T. Around the beam pipe is the central tracking detector (CTD), which consists of 72 cylindrical drift chamber layers, organized into nine superlayers covering the angular region $15^\circ < \theta < 164^\circ$.[2] The energy measurement is performed with the high-resolution depleted-uranium calorimeter (CAL) which covers the pseudorapidity region $4.3 < \eta < -3.8$.[3]

The HERA collider will follow a luminosity upgrade during the shutdown starting in year 2000 allowing high-luminosity runs which will provide

E-mail address: alberto.garfagnini@desy.de (A. Garfagnini)

[1] Current values for the 1998 data taking period.

[2] The polar angle θ is defined between the particle track and the proton beam line (defined as z-axis).

[3] $\eta = -\log\tan(\theta/2)$.

PII: S0168-9002(99)00583-5

a high sensitivity to low e–p cross-section physics (see e.g. Ref. [1]).

A silicon microvertex detector (MVD), placed in the vicinity of the beam pipe inside the CTD, would improve the global precision of the tracking system and allow to identify events with secondary vertices originated from the decays of long-lived states (i.e with $ct \approx 100$ μm) like hadrons with charm or bottom quarks or τ leptons. Some of the physics topics accessible with the MVD are:

- *Charm in photoproduction.* From the rate of charm events in direct photoproduction it will be possible to measure the gluon content of the proton.
- *Charm in Deep Inelastic Scattering (DIS).* In particular the measurement of the proton structure function F_2^{charm} will profit from a kinematic range which extends beyond what is currently accessible with the ZEUS detector using D^* mesons tagging.
- *New physics.* The possibility of identifying secondary vertex tracks and improving the resolution of the tracking system will provide a better understanding of the nature of the interaction (e.g. very high Q^2 electrons are scattered in the forward direction).

2. Vertex detector layout

During the design of the MVD, the following requirements have been specified:

- angular coverage of the region $10^\circ < \theta < 160^\circ$ around the interaction point (IP);
- measurement of three points per track, in two projections each;
- 20 μm intrinsic hit resolution;
- two track separation of 200 μm;
- physical space available limited by the inner volume of the CTD ($r = 20$ cm), and by the beampipe volume.

According to the specifications, the MVD has been split into a central (BMVD) and a forward (FMVD) detector (see Fig. 1), requiring a good matching with the existing detectors.

2.1. BMVD layout

The length of the barrel section, 640 mm, is constrained by the longitudinal distribution of the interaction region which at HERA is dominated by the length of the proton beam bunch. A cross section of the BMVD in the r–ϕ plane is shown in Fig. 2; three layers have been chosen for high

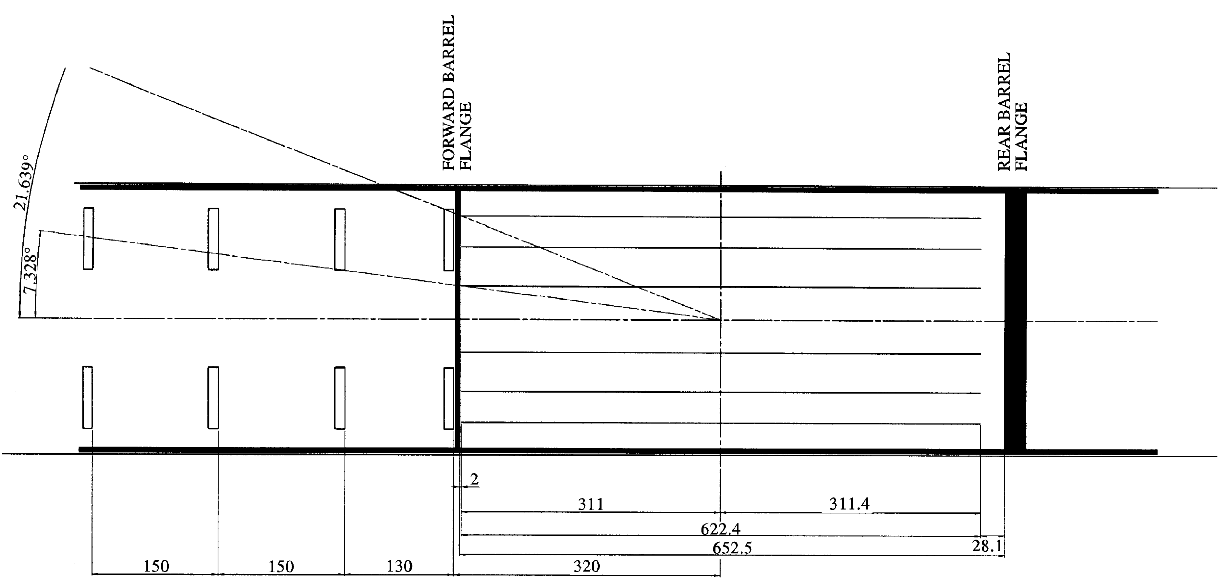

Fig. 1. Layout of the MVD along the beam line (z-axis). Note that the horizontal and vertical scales are different.

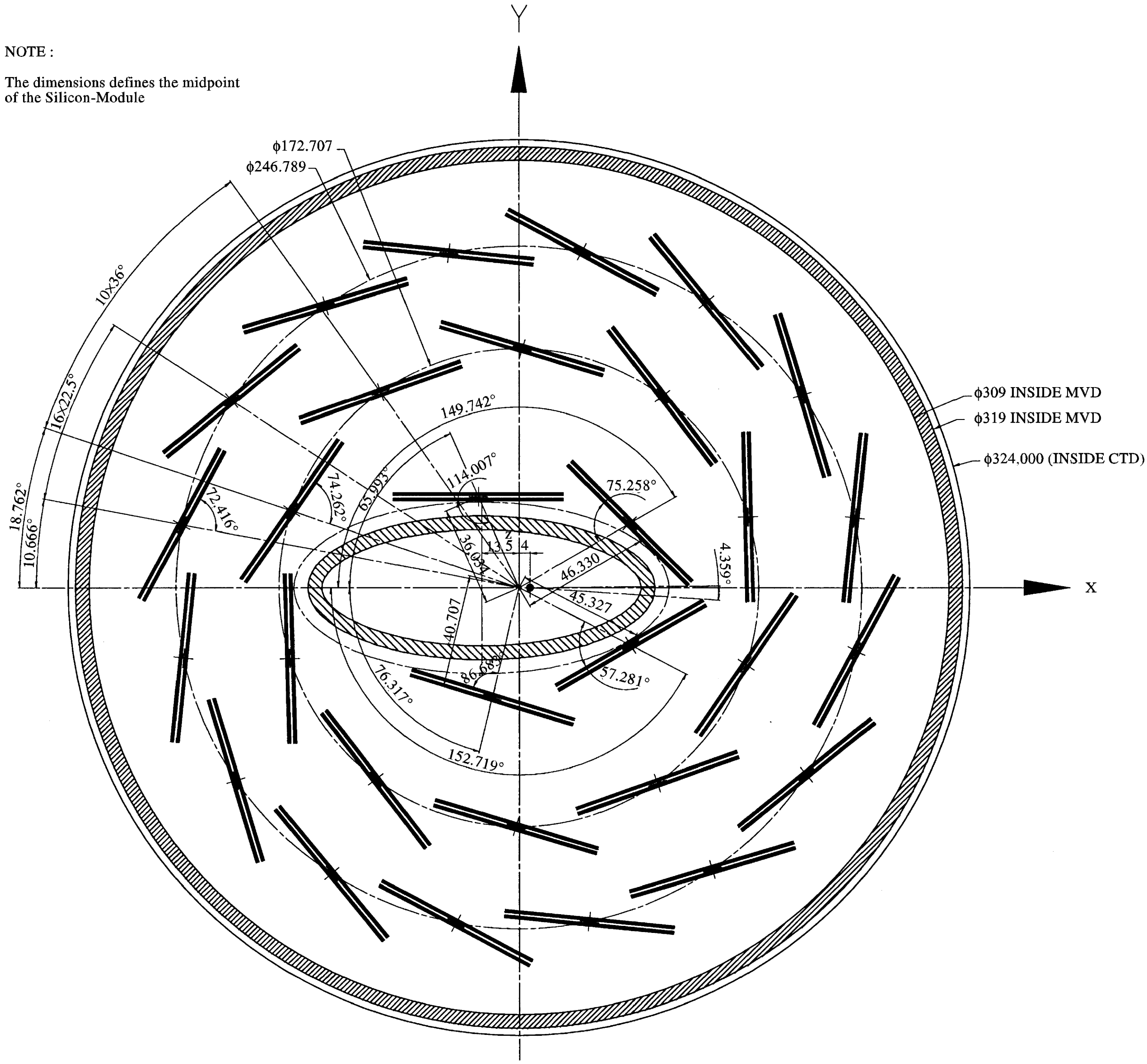

Fig. 2. BMVD cross section in the r–ϕ plane. The silicon sensors are placed in three layers between the beam pipe and the CTD inner volume.

efficiency for pattern recognition and the possibility of using a momentum estimate of the tracks in the trigger. The first layer of detectors, placed at $r = 3$–5 cm from the CTD axis follows the elliptical shape of the beam pipe; the second and third layers are placed around a circle at $r \sim 8.6$ and ~ 12.3 cm. Note that the beampipe is not centered with respect to the CTD axis and that the nominal IP is shifted towards the HERA center (increasing x values), of about 4 mm. The beam-pipe shape and the beam optics are the result of optimization studies on beackground in the interaction region;

Table 1
Average material in percentage X_0 as seen by tracks perpendicular to the beamline in the BMVD section

AlBe alloy beam pipe	1.1	
Ladder (per layer)	2.2	
Module		0.92
Support ladder		0.24
Cooling (water + pipes)		0.26
Cabling		0.78
Outer support	0.9	

Note: Each track traverses 2.8 layers on average.

the biggest contributions are direct and back-scattered synchrotron radiation of the electron beam[4][3].

2.2. BMVD impact parameter resolution

The material distribution of the BMVD is shown in Table 1.

The impact parameter resolution, based on Monte Carlo (where the geometry and material distribution have been simulated with GEANT [4]), is shown in Fig. 3 for tracks perpendicular to the beamline ($\eta = 0$) as a function of momentum.

The improvement in resolution combined with the secondary vertex identification (not available with the current setup of ZEUS) will significantly enrich the heavy flavour physic program. As an example, the MVD will allow charm tagging with an efficiency between 10% and 30%, with purity greater than 30%. (Charm identification is currently performed in ZEUS via D* mesons reconstruction [5], but the analyses suffer from a very low efficiency, around 1% with purity 30%, which limit the available statistics.)

2.3. Silicon sensor design

The detectors are single sided made of high-resistivity (3–6 kΩ cm) n-type silicon, 300 μm thick. One side of the detector (64 mm × 64 mm) is n^+ doped and aluminized. The opposite face is covered by p^+ doped strips, 12 μm wide, with 20 μm pitch. The readout strips (14 μm wide) have 120 μm pitch and are AC coupled with respect to the p^+ implantation and covered by a 10 μm wide aluminization. The total number of readout strips are 512. The coupling capacitance of the readout strips is achieved with a double layer of SiO_2 and Si_3N_4. The biasing of the strips is implemented using poly-Si resistors which alternately connect even and odd strips to either of the two bias lines placed below the resistors, near the detector edges (see Fig. 4); the first and last readout strips complete the bias ring being directly connected to the bias lines. Three guard rings surround the bias line. An additional n^+ doped ring is placed beyond the last guard ring, on the edges of the detector.

Capacitive charge division is used between the readout strips in order to limit the number of readout channels and achieve a 10 μm spatial resolution for minimum ionizing particles traversing the detector with angles up to 30° with respect to the surface. By means of capacitive coupling

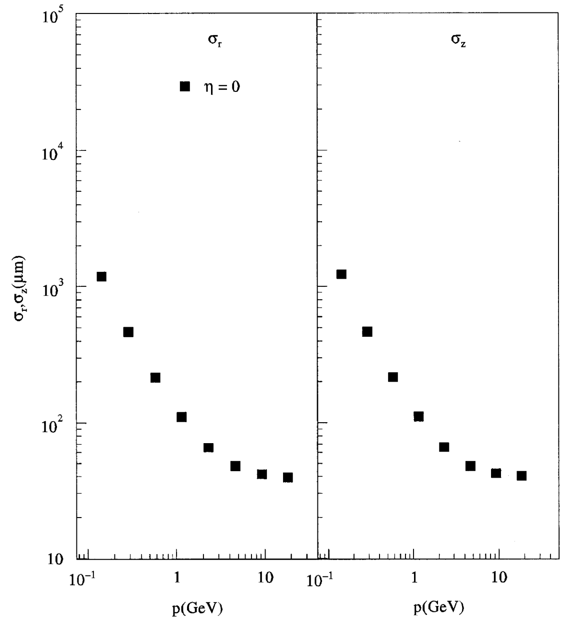

Fig. 3. Impact parameter resolution for $\eta = 0$ tracks as a function of momentum. The points are obtained for tracks traversing three layers of modules.

[4] With respect to the current beam optics, for the high luminosity running, the separation of the two beams will happen nearer to the IP.

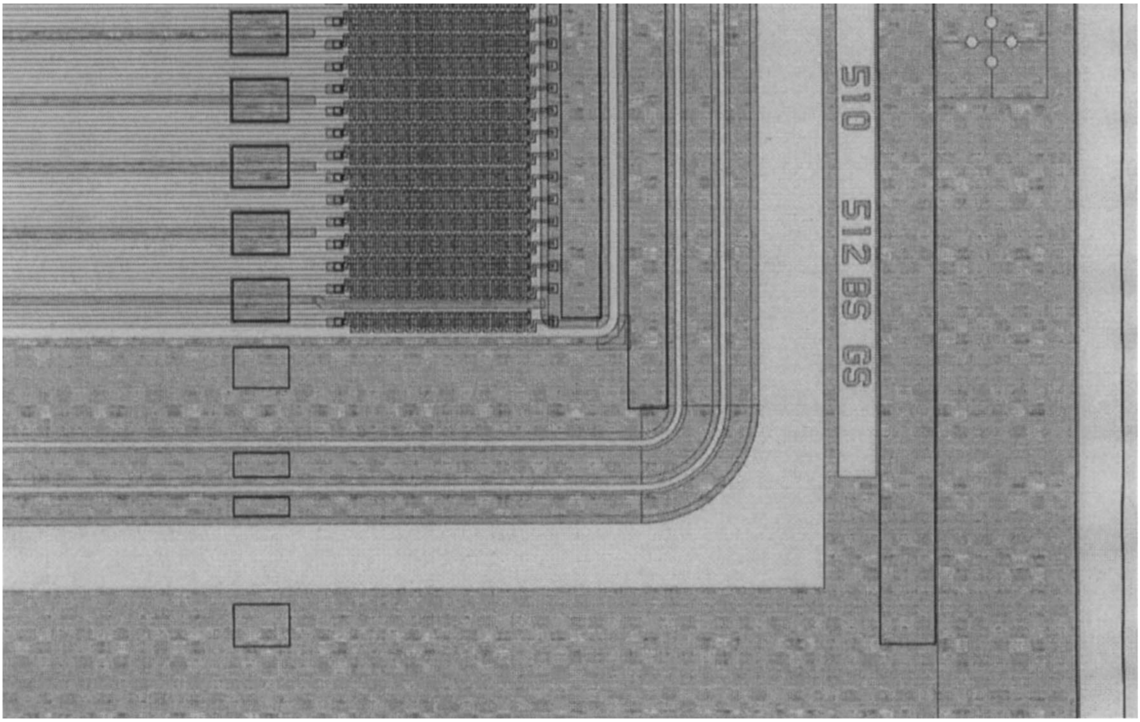

Fig. 4. Mask of one corner of the BMVD prototype. Scanning the figure from right to left: n^+ region, on detector edges, three guard rings, the bias line which is directly connected to the strips via poly-silicon resistors, and probe pads for the readout strips, the guard rings and the n^+ region.

between strips, the charge collection at intermediate strips induces charges on the readout strips which are inversely proportional to the distance between interpolation and readout strips [6]. Uniformity in charge collection can be achieved keeping all the strips (readout and intermediate) at the same potential. Charge losses to the ground planes can be significantly reduced by imposing the interstrip capacitance much larger than the capacitance to the detector backplane [6].

The barrel detectors have been ordered to Hamamatsu. Twenty prototypes have been received and are currently being investigated. Six hundred detectors will be produced starting at the end of the year.

2.4. BMVD ladders

As shown in Fig. 5 the silicon planes are arranged with strips parallel and perpendicular to the beam line (the so-called r–ϕ and r–z planes). Two detectors are read out together via connecting the strips of the two different planes with a Kapton foil of triangular shape, forming a readout cell of approximately $120 \times 60\ \mathrm{mm}^2$. The detectors have a small overlap in order to minimize the dead area of the cell. An additional fanout Kapton, glued to the r–z plane, connects the strips to the front-end electronics. Two readout cells are placed on top of each other forming a readout module of 1024 channels and providing two coordinate reconstruction for a track traversing the module. Five read out modules are placed on a support ladder as shown in Fig. 6(b); due to its triangular shape, the fanout Kapton is bent and the hybrid with the front-end electronics is positioned over the detector (see Fig. 6(a) for a cross section of the ladder). The ladders are made of carbon fiber and besides supporting the detectors and the front-end electronics provide the cooling for the readout chips. Prototypes ladder

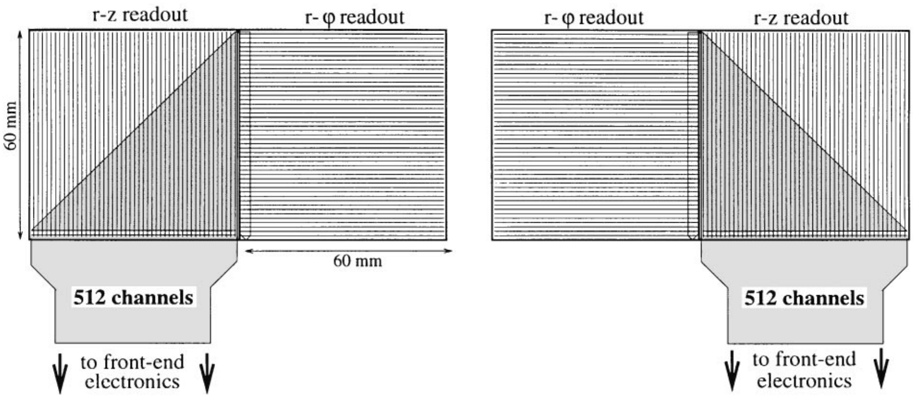

Fig. 5. BMVD readout cell.

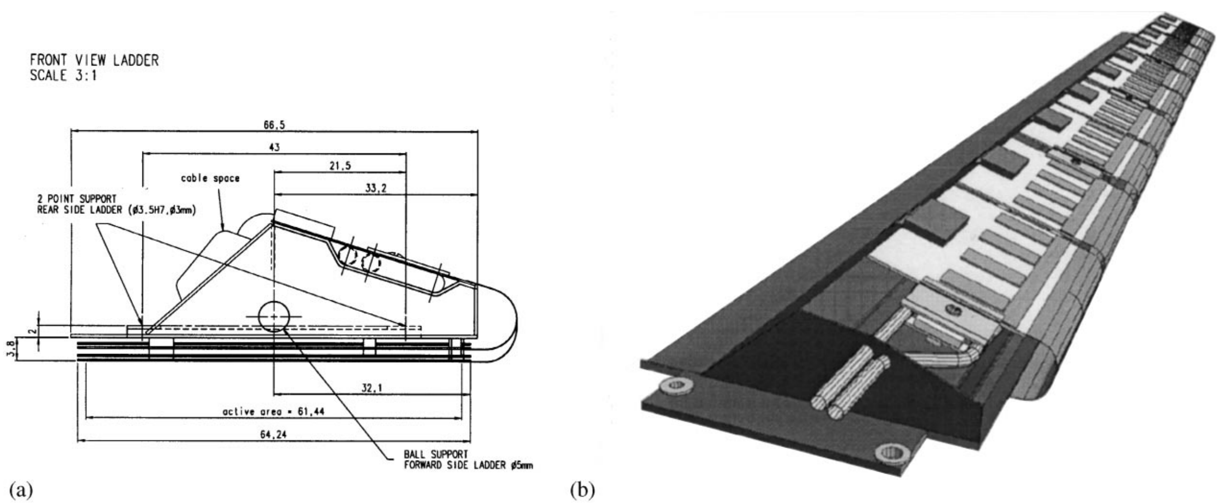

Fig. 6. (a) Cross section of a barrel ladder. The detectors are located on the bottom of the structure while the hybrid is located on one edge of the triangular structure. (b) Layout of a complete ladder with five modules.

have been built and tested. They proved to be light ($\sim$ 70 g) and rigid (deflection $\sim$ 45 μm for 220 g weight, and flatness $\leq$ 100 μm).

2.5. FMVD layout

The forward vertex detector which is arranged in wheels extends to a pseudorapidity range of $\eta = 2.6$. The wheels provide essential tracking and vertexing information in regions which are not covered by the existing tracking system. A wheel is made of by two layers of 14 silicon planes of the same type of the barrel sensors and with a "wedge" shape, two sides being parallel and two tilted by 13° in opposite directions. One plane incorporates 480 readout strips. Fig. 7 shows a cross section of a forward wheel. By using two overlapping planes with strips oriented along the two titled edges, one wheel provides r and ϕ coordinates per track (see Fig. 8). A small overlap between adjacent detectors in a layer is used in order to minimize dead regions. The four wheels are positioned at $z = 32, 45, 47$ and

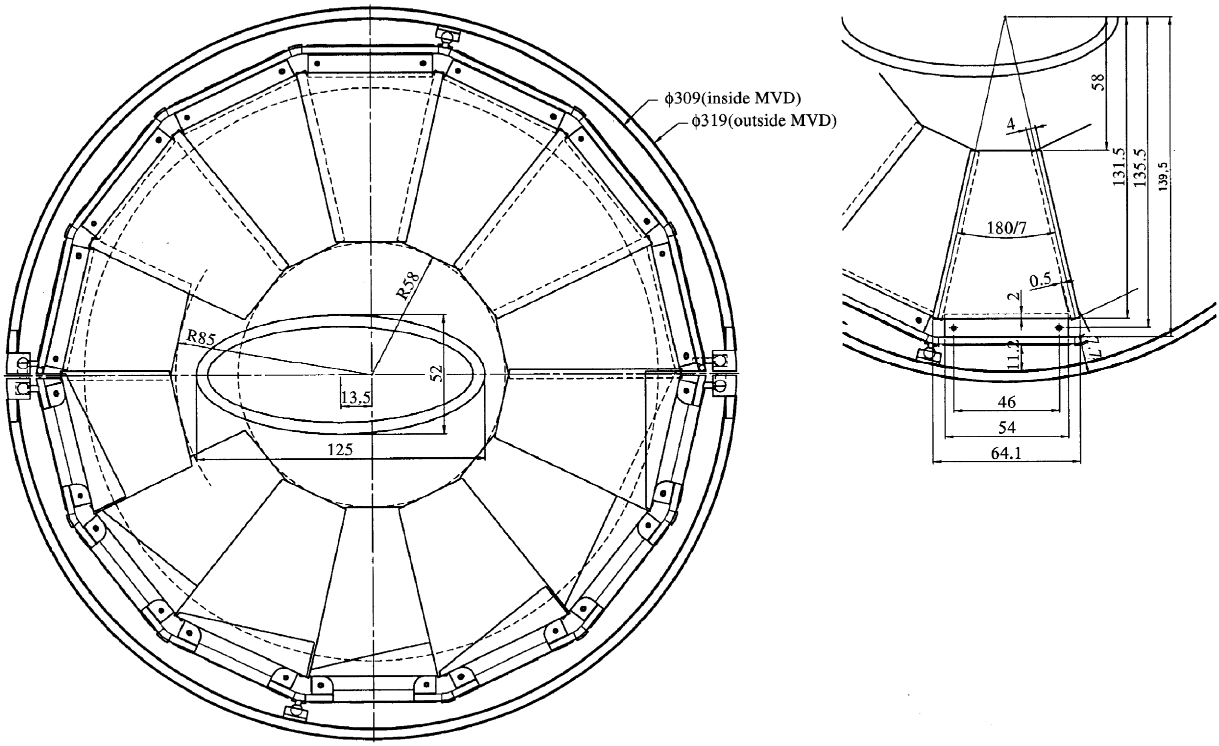

Fig. 7. Arrangements of detectors in a forward wheel.

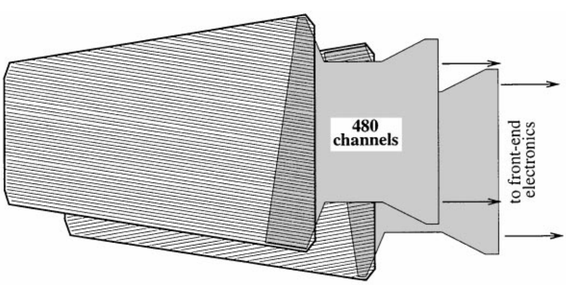

Fig. 8. FMVD readout cell.

75 cm and the first wheel is mechanically attached to the barrel support structure. In order to optimize the space around the beam pipe, two detectors with different dimensions have been designed.

The design of the FMVD detectors have been finalized.

As for the BMVD, a Kapton foil connects the readout strips with the front-end chips (see Fig. 8). Each detector is read separately using the same hybrid structure of the barrel section.

3. Readout electronics

The MVD silicon planes are readout by HELIX [7], an analog chip initially designed by ASIC laboratories in Heidelberg and manufactured in the 0.8 μm CMOS process by AMS. The HELIX 2.2 [8] version, specifically designed for the HERA-B experiment, is currently used for the MVD prototypes. The HELIX 3.0, with design contributions from ZEUS, will be used in the final production. The chip integrates 128 channels with a charge-sensitive amplifier/shaper; the signals are then sampled in an analog pipeline with a maximum latency of 128 sampling intervals. The chip has an additional amplifier per each channel which is used to read the pipeline and is followed by a multiplexer and a buffer used to transfer the data on a serial bus. An important feature of HELIX is the possibility to synchronize the data transfer of more chips on the serial bus using a daisy-chain mechanism; the first chip of the chain sends a token to the next chip after having transmitted all the data. The token moves on the chain and is sent back by the last chip through the chain until it reaches the first chip which generated it. The HELIX 3.0 chip will implement a failsafe token which will allow to exclude a bad chip from the read out chain, without perturbing the functioning of the remaining chips of the chain.

The measured noise figure for the HELIX chip is

$$\mathrm{ENC}\ [\mathrm{e}] = 340 + 40 \cdot \mathrm{C}\ [\mathrm{pF}].$$

The signal coming out of the HELIX chip is transferred via an analog link to the ADC cards about 10 m away from the detector hybrids. The ADC performs the pedestal and common mode subtraction and a first cluster reconstruction. The signal is then transferred to the MVD second-level trigger processors and to the ZEUS event builder.

4. Radiation monitoring

The MVD detector is planned to operate for at least 5 years of HERA running during which an integrated radiation dose up to 3 kGy, including beam loss accident, is anticipated. The H1 detector has measured at the position of the microvertex detector a dose of 50 Gy for the 1996 data taking period [9]. Different detectors, installed to measure the radiation background from HERA near the interaction region, showed higher annual doses of 10 kGy in 1995 and 1996; those high doses occur in very short times when the positron[5] beam is dumped. Without an electron dump in HERA, the beam occurs to be dumped in regions of minimum machine apertures (i.e. close to the experiments). The problem will be solved with a fast electron beam dumping procedure which will be provided for the luminosity upgrade.

A radiation monitor system which takes inspirations from the OPAL radiation monitoring system [10] has been proposed. It uses 16 10×10 mm^2 silicon (PIN) diodes located in the MVD area.

The rates from the diodes and their changes with time will allow to detect beam instability within few revolutions of the beam and induce a fast beam dump in case of danger, protecting the MVD from high radiation doses. Such a system will be able to provide a monitoring over time of the accumulated doses in the region of the MVD.

5. The test program

A test program aimed at the understanding of the acceptance of the detector and defined to measure the performance characteristics of the system has been prepared and is currently underway. The important points of the program are the following:

- *Detector tests.* Prototype detectors have been ordered (20 BMVD prototype have been received, other prototypes of the FMVD-1 and FMVD-2 will be ordered once the former detectors are tested and the specifications with the producer are agreed upon). For each detector, Hamamatsu provides a small test structure which has been produced on the same wafer. Together with the counter it allows to measure several parameters of the detector (e.g. resistance of the p^+ implantation, Al strip and polySi resistance, coupling capacitance, Flat band of field oxide, etc.).
- *Detector plus FE electronics tests.* Prototype read out cells are being assembled and are going to be tested with beam particles. The aim is the measurement of the performance parameters: detection and charge collection efficiency, noise, position resolution as a function of incident track angle up to 80°.
- *Mechanics and cooling tests.* The support structures of the modules have been tested for deflection, torsion and thermal expansion. Long-term tests of the cooling system of a complete ladder have been performed.
- *Quality control during production/assembly/installation.* Several tests are in preparation and will be carried out during all the building steps of the

[5] During the 1995 and 1996 running periods HERA collided 27.5 GeV positrons with 820 protons.

MVD up to the installation in ZEUS. They include quality control of detectors and front-end electronics during and before assembly and long-term tests of assembled ladders including temperature cycling. Those long-term tests will allow the debugging of readout, data acquisition and slow control systems. To ensure a proper functioning of the MVD since the beginning of the data taking, every single installation step will be accompanied with quality control tests.

5.1. Test beam setup

Prototype detectors assembled with the read out electronics are being exposed to a low-energy electron beam (2–6 GeV) of the DESYII accelerator. Charged tracks are measured by three couple of reference detector (silicon planes with 50 μm read out pitch and one intermediate strip) providing x and y coordinates. Fig. 9(a) shows a drawing of the test beam setup; the device under test (DUT) can be moved laterally and rotated selecting tracks with a specific incident angle.

The accuracy in predicting the coordinates of the track on the device under test is given, to a first order, by multiple scattering and by the intrinsic resolution of the detector:

$$\sigma_t^2 \sim \left(\frac{13.6\ \text{MeV}}{\beta c}\frac{d}{p}\sqrt{\frac{X}{X_0}}\right)^2 + \sigma_i^2$$

where p is the beam momentum, X/X_0 is the fraction of radiation length traversed and d the distance between the DUT and the second reference detector. The intrinsic resolution of the reference detectors has been estimated from data as ~ 4 μm. For a 6 GeV electron beam, assuming a distance between the nearest reference detector of 5 cm, and $X/X_0 \sim 0.007$, the resolution of the charged track on the DUT is $\sigma_t = 5$ μm. Fig. 9(b) shows the measured value of 5.4 μm for a 6 GeV electron beam; the result indicates that the setup can be used successfully for the above-mentioned studies.

Concerning radiation studies, a set of detectors and corresponding test structures are going to be irradiated with low-energy electrons, up to 20 kGy. Another set will be irradiated with neutrons (1–2×10^{13} 1 MeV n/cm^2). The electrical characteristics of the detectors will be measured on prober before and after irradiations; the detectors will be assembled and measured with test-beam particles.

6. Conclusions

The ZEUS vertex detector is currently under construction. The first prototypes have been produced and their behavior is being investigated. A test program has been prepared and is underway in order to understand the detector acceptance and measure the performance characteristics. The production phase of the project will start at the

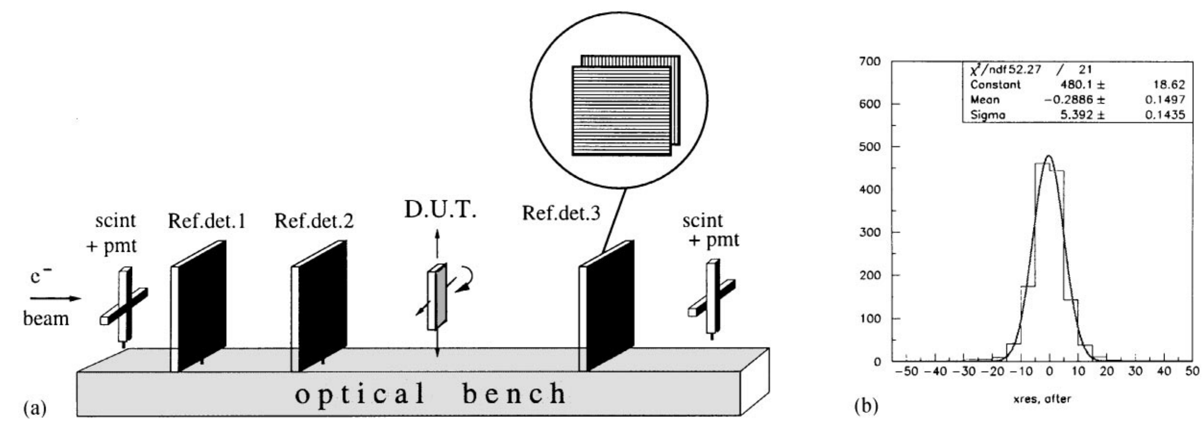

Fig. 9. (a) Test beam setup; (b) measured accuracy in predicting the coordinate of the track on the DUT for a 6 GeV electron beam.

beginning of 1999. The installation of the microvertex detector inside ZEUS is foreseen during the 1999–2000 shutdown.

Acknowledgements

I have presented the status and the test program of the ZEUS microvertex detector. Several people from different institutes are involved in the project. I would like to thank them for their work from which I have drawn the presented material.

References

[1] G. Ingelman, A.De Roeck, R. Klanner, (Eds.), Proceedings of the 1995/96 Workshop 'Future Physics at HERA', 1996.
[2] ZEUS Collaboration, M. Derrick et al., The ZEUS Detector, Status Report 1993, DESY, 1993.
[3] U. Schneekloth (Ed.), The HERA Luminosity Upgrade, DESY HERA 98-05, July 1998.
[4] GEANT 3.13, R. Brun et al., CERN DD/EE-84-1, 1987.
[5] ZEUS Collaboration, Measurement of D^* cross sections and the charm structure function of the proton in deep inelastic scattering at HERA, Paper 768, ICHEP98, Vancouver, 23-29 July 1998, submitted for publication.
[6] U. Koetz et al., Nucl. Instr. and Meth. A 235 (481) 1985.
[7] M. Feuerstack-Raible, Helix128S-2 User Manual Version 1.9, HD-ASIC-33-0697; http://wwwasic.ihep.uni-heidelberg.de/~feuersta/projects/Helix/index.html
[8] K. Riechmann, Nucl. Instr. and Meth. A 408 (221) 1998.
[9] R. Eichler, private communication.
[10] O. Biebel et al., Nucl. Instr. and Meth. A 403 (351) 1998.