Experience with the ZEUS Micro Vertex Detector

E.N. Koffeman

Nikhef, Kruislaan 409, 1098 SJ Amsterdam, The Netherlands

Abstract

The HERA accelerator underwent a major upgrade in the year 2000. The upgrade was partly motivated by the desire to determine the contribution of heavy quarks and gluons to the proton structure more accurately. To benefit from the expected increase in luminosity, the ZEUS experiment was equipped with a silicon micro strip detector. This vertex detector was designed to recognize short lived c- and b-hadrons, produced in deep inelastic scattering. After the restart, the HERA collider suffered from severe background problems and therefore the ZEUS experiment collected significant luminosity only since the end of 2004. Until the end of 2006 the integrated luminosity collected by the ZEUS experiment is 350 pb^{-1}, most of it with good vertex detector data (99 %).

Key words: Vertex, Silicon, Zeus.

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1 Introduction

In 2001 a silicon micro strip vertex detector has been installed in the ZEUS experiment at HERA. After a major upgrade of the accelerator complex, it took HERA several years to solve background problems. In 2005 the design luminosity has been reached and ZEUS collected 350 pb^{-1} from until the end of 2006. In July 2007 the HERA accelerator will be closed.

The vertex detector is based on silicon sensors with p-on-n strips, implanted with a pitch of 20 μm, but only every sixth strip is (AC) connected to the readout. The total number of analog readout channels is 208 k. In a test beam a position resolution of 7 μm has been achieved.

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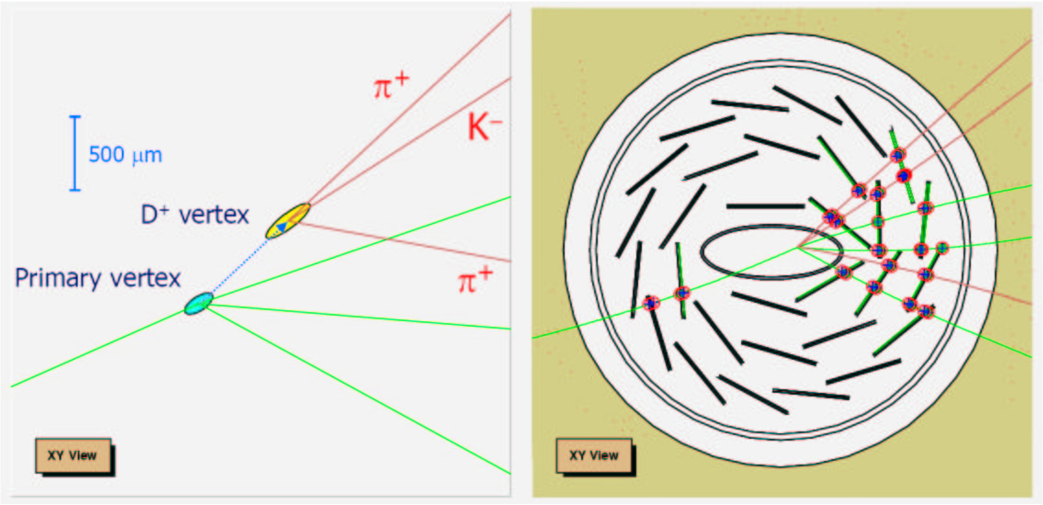

Fig. 1. *Event display of an ep collision with a D meson decaying to $K\pi\pi$. On the left side of the display the reconstructed vertex is shown. On the right the cross section of the vertex detector is displayed with the hits in it.*

2 Detector Description

The silicon detector consists of a 60 cm long barrel with three concentric layers and four circular shaped disks in the forward region. The 30 ladders that make up the barrel are based on identical carbon fiber frames, each holding 10 half modules. A half module carries 2 identical sensors: one provides the $r\phi$ coordinate and the other one is mounted perpendicular to measure the z coordinate. A ladder is a carbon fiber frames that supports sensors, hybrids, cables and cooling pipes and provides stiffness. The wheels are carbon fiber rings that hold 14 sectors with back to back sensors. These forward sensors have parallel strips but are mounted with a respective stereo angle of $360°/14$.

The layout of the detector is asymmetric in the azimuthal direction due the the elliptical shape of the beam-pipe. This beam-pipe allows the synchrotron radiation to traverse the experiment without causing secondary interactions. The cross section of the detector can be seen in the event display in figure 1, which shows the decay of D meson produced in deep inelastic *ep* scattering.

The design and performance of the silicon sensors have been extensively described in references [1,2].

The ladders and the wheels are supported by a carbon cylinder shell that encloses the detector volume. Although the sensors run at room temperature, the front-end chips need to be cooled. On each ladder a stainless steel tube runs underneath the ceramic hybrids that hold four chips each. The coolant is water at a temperature of 15 °C.

The positioning of sensors on a ladder was performed with 10 μm precision and measured afterward with a precision of a few μm. The position accuracy of the ladders with respect to the cylinder frame was estimated to be 10 μm in the vertical and horizontal direction and 0.1 mm in the beam direction.

After the detector was installed in March 2001 no access has been possible and the detector has been running reliably ever since. When HERA restarted in the summer of 2001, the accelerator faced serious problems with the beam and vacuum conditions. There were some beam loss accidents and periods with increased synchrotron radiation backgrounds. The radiation levels in the vertex detector are monitored with three radiation monitoring systems: PIN diodes, radiation sensitive FETs and thermo luminescent detectors. The diodes are used for a fast beam abort signal. Comparison of the absolute dose measured with the different systems is complicated. The radiation dose is expected to have a very asymmetric distribution and the dosimeters are not all at same locations. The average dose is estimated to be 50 kRad, and is well within the foreseen maximum of 200 kRad. Although small radiation damage effects are observable in the sensor characteristics (visible in increased leakage current and noise and a decrease in gain), it has not lead to a significant loss of performance.

The only sign of detector degradation (not related to radiation damage) is an increase in the number of problematic channels. Just after completion of the detector 1 % of all channels were dead. At the end of 2006, a total of 6 % of the modules is dead, noisy or causes problems during readout. Most of the problems seem to be uncorrelated and have different causes.

3 Material Budget

Bookkeeping during the design of the detector provided a detailed list of all detector components. Most components were put on a balance to cross check their size and material descriptions. If the amount of material in one ladder is added and subsequently spread over the active surface of the ladder the approximate material thickness is 3 % of a radiation length.

The material that is used outside the active volume of the vertex detector was underestimated in the original Monte Carlo description. A better description was made in the 2005, based on mechanical design drawings. Recently a study has been performed based on a selection of hadronic interactions. The interactions are characterized by two or more tracks from a common vertex. No mass or pointing constraints are used for the selection. The analysis is performed for both data and Monte Carlo events. The resulting material maps proved that some components were missing (like cooling pipes on the beam-pipe) in

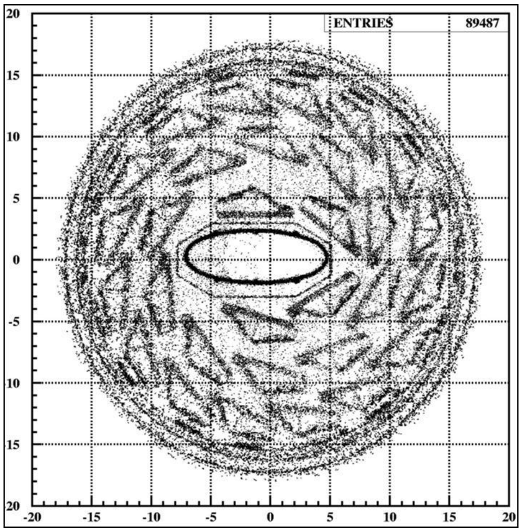

Fig. 2. *Map of the material distribution in the barrel part of the vertex detector recorded with data. Hadronic interactions are used selected by multitrack vertices.*

the Monte Carlo description. A detailed cross section of the material in the barrel is shown in figure 2.

4 Alignment

Although extensive metrology measurements were performed they were only used to help define alignment structures and to interpret the first alignment results that were obtained by the analysis of tracks. Soon after the installation of the vertex detector, cosmic muon data samples were collected and used to get ladder alignment constants. Details on this alignment procedure were reported in the previous workshop [3]. Ladder displacements up to a few hundred μm along the beam direction (z) were found. These numbers are consistent with the expected accuracy of 100 μm for a ladder, combined with the uncertainty in the relative position of the bottom and top half of the barrel. The alignment in the perpendicular (xy) plane (still based on entire ladders) showed smaller shifts (several tens of μm) but these shifts are larger larger than expected from the design specifications. The shifts are likely caused by a small torsion in the overall barrel construction. The sensor positions within a ladder are kept at the default design geometry, and there is still no indication that the deviations are larger than 10μm. The track fit residuals after ladder alignment are down to 47 μm in rz and 64 μm in the $r\phi$ direction.

In 2005 a start was made with detector alignment based on tracks from ep-collisions. Over the last year the alignment has been completed. Refining the clustering algorithm and track reconstruction solved most irregularities. In the design proposal the goal was to design a detector that provides three hits

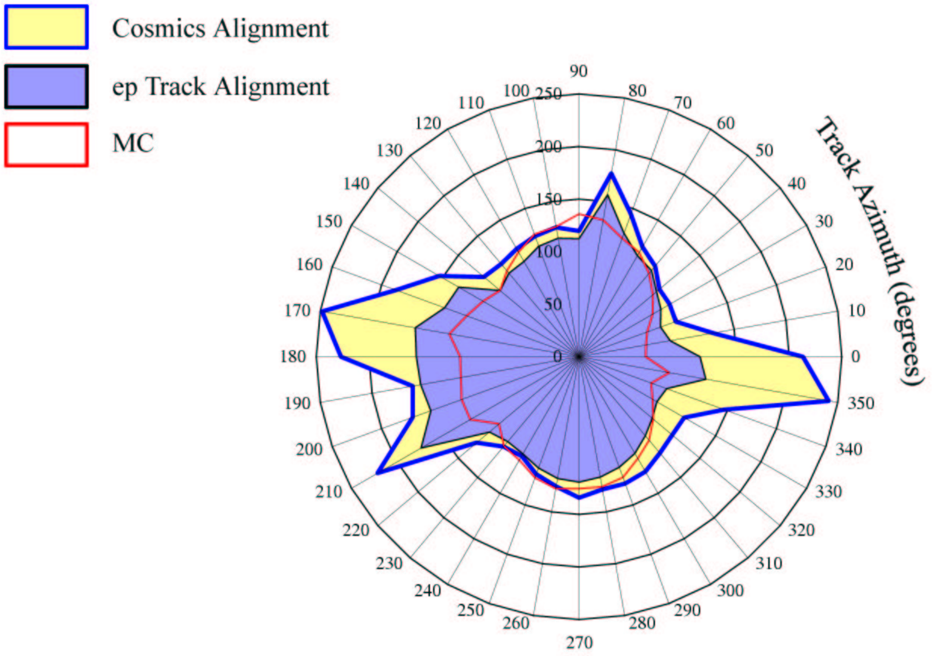

Fig. 3. *The azimuthal impact parameter resolution after the introduction of the ep-track alignment.*

per track with a 20 μm point resolution. At present the achieved resolution is still above this. It seems that multiple scattering and the non-flatness of the silicon sensors are limiting the position reconstruction accuracy. From figure 3 it can be seen that the impact parameter resolution is very close to what is expected from Monte Carlo simulations. Since the beam position in the already asymmetric beam-pipe is at positive x, the region around ϕ equals 180 degrees is problematic due to the long extrapolation length of tracks from the interaction point to the first hit. The design specification of the impact parameter resolution at high transverse track momenta was 100 μm and is reached.

The hardware alignment monitor based on laser beams shining through small transparent laser diodes shows possible movements when the quadrupoles are switched on. These magnets were installed during the HERA upgrade and are quite close to the interaction point. Confirming these movements is difficult since no data with quadrupoles switched off has been recorded.

In part of the available ep-data the D-meson signal has been analyzed. In the decay channel $D \rightarrow K\pi\pi$ the selection on impact parameter significance greatly reduces the background. The results, based on 91 pb^{-1}, are shown in figure 4.

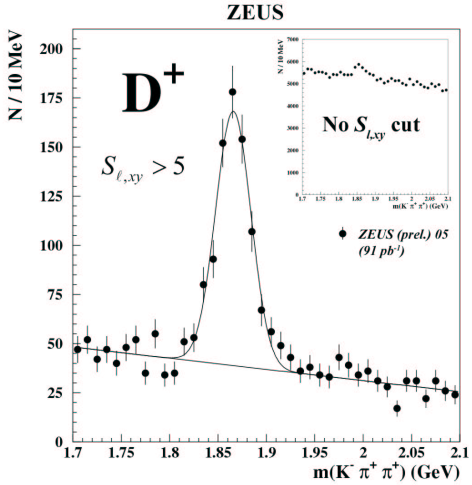

Fig. 4. *Reconstruction of D mesons. The effect of using the impact parameter significance in the selection is clearly visible.*

5 Conclusion

The ZEUS vertex detector has been successfully operated for (nearly) six years without any intervention. Software alignment and calibration procedures have been finalized over the last year, reaching design specifications. We learned that detailed software calibrations are not always readily available. Early data analysis and the need for fast results should be considered in the design of mechanical tolerances and sensor specifications.

References

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