Computer Physics
Communications

Experience with the ZEUS central tracking detector

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Abstract

The central tracking detector of the ZEUS experiment has been in operation since 1992. It is a cylindrical drift chamber, approximately 2m in length and 1m in diameter, and has operated reliably in a magnetic field of 1.43T using a gas mixture of 83:12:5 Argon/CO_2/Ethane with a trace (~0.5%) of ethanol. Initial studies conducted between 1995 and 2000 using *dE/dx* to search for a long-term loss of gain were inconclusive. During the course of 2000, operational problems caused by repeated trips of the high voltage in the outer superlayers of the detector were experienced. These were attributed to the Malter effect, which has shown to be alleviated by the addition of water to the gas mixture. Consequently, a trace of water (~0.15%) was added to the gas and has, to date, proved to be a successful remedy. Changes in the chamber performance due to the additional water are covered and solutions to the problems encountered are detailed.

Keywords: ZEUS;High energy physics; Charged particle;Tracking;Wire chamber;Aging;Water

1. Introduction

The ZEUS experiment is one of two general-purpose colliding-beam detectors at the HERA accelerator at DESY, Hamburg [1]. The ZEUS Central Tracking Detector (CTD) is a cylindrical wire chamber. The design concept is similar to other “vector” drift chambers (Mark II, SLD, CDF [2][3][4][5][6][7][8][9]). The CTD outer and inner walls are constructed from aluminium alloy, whilst the end plates are aluminium. The anode and cathode wires are grouped in radial planes known as superlayers. There are also two cylindrical copper shields between the innermost and outermost

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superlayers and the CTD walls, which optimise the electric fields. The CTD is designed to operate in a high magnetic field (1.43T in ZEUS) to achieve high precision momentum measurements. The high magnetic field produces large deviations from radial electron drift. The CTD was designed to operate with an angle between the electron drift velocity and electric field (the Lorenz angle) of 45°. Consequently the cell structure of the CTD is rotated through 45° with respect to the radial direction

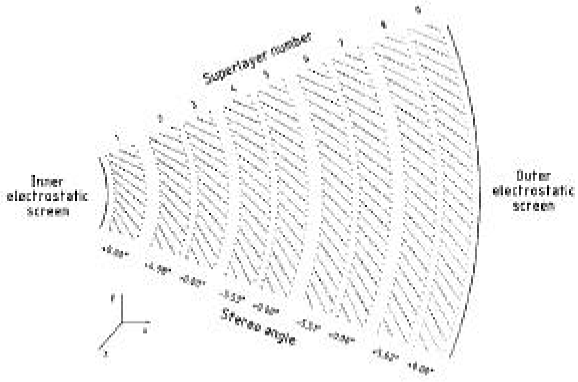

Figure 1: Layout of wires in the CTD. One octant is shown. Wire positions are shown at the end plates – at the chamber centre the stereo layers are displaced by two cells and the mean radius is smaller.

The design goals of the CTD were threefold; to give precise measurements of charged particle momenta, to provide tracking information to all three levels of the ZEUS trigger and to measure *dE/dx* of charged particles. The momentum measurement relies on precise position reconstruction. The resolution on transverse momentum, p_t, is

$$s\left(p_t\right)/p_t = 0.0058\,p_t \otimes 0.0065 \otimes 0.0014/p_t\,. \qquad (1)$$

The CTD wires are arranged into nine concentric superlayers numbered consecutively from the inside out. The odd-numbered superlayers have sense wires running parallel to the chamber axis while those in the even-numbered superlayers have a 5° stereo angle. Three-dimensional information is calculated using these small angle stereo layers. Each superlayer contains eight sense wire layers – there are 4608 sense wires in total. Figure 1 shows the layout of the wires in the CTD. Each sense wire is read out by a 104MHz flash analogue-to-digital converter (FADC). The FADC data are then further processed by a digital signal processor (DSP), which extracts arrival time and pulse height information from the raw hit signals.

The rotation of the CTD cells has the additional benefit of ensuring a prompt timing signal for the tracking trigger as a high-p_t track will cross at least one sense wire plane. The ZEUS trigger is operationally divided into three levels. The first level operates in dedicated hardware within the readout electronics of each sub-component of the detector. The CTD first level trigger (FLT) provides 3D tracking information to the ZEUS FLT. These tracks use hit data from another readout system that instruments all the wires in superlayer one and the odd numbered wires in superlayers three and five – the z-by-timing system [10]. It measures the z position of a hit by calculating the difference in arrival time of a chamber pulse at either end of a wire. The timing resolution is ~300ps, which translates into a z resolution of 3.5cm.

The CTD sense wires are made from 30μm tungsten, chosen for its low dispersion for electrical signals in order to optimise the z measurement for the trigger. The high-voltage field, sense and shaper wires are all copper-beryllium alloy, ranging in diameter from 70μm to 200μm. The high-voltage settings are chosen to give a gas gain of approximately 10^5 whilst keeping negative surface fields below -30KVcm^{-1} to avoid whisker growth.

The CTD was designed to use a 50:50 Argon:Ethane gas mixture. In practice a different mixture was used – 83:12:5 Argon:CO_2:Ethane with a trace (~0.5%) of ethanol – as this was considered to be a safer mixture for long-term running. Ethanol is added to the gas using a precision injector system. The properties of this mixture are similar to Argon:Ethane in terms of Lorenz angle and drift velocity although the single hit resolution and *dE/dx* measurements are slightly degraded.

The CTD has operated reliably since the start of ZEUS in 1992. Under normal operating conditions the typical sense wire currents in the innermost superlayers range from approximately 1.5–0.5 μA over the course of a HERA fill. Sense wire currents in the outer layers are lower at around 0.5 μA. Currents in the outer layers are much less sensitive to the HERA beam as the wires lie further away from the interaction point. The total accumulated charge over the lifetime of ZEUS is around 0.1 $\mathrm{Ccm^{-1}}$.

2. Initial Aging Study

The first aging study of the CTD used the *dE/dx* measurement to search for any signs of long-term loss of gain. *dE/dx* was chosen as the test variable as it is more robust against environmental factors and track sample composition than using raw pulse height information. Since the CTD operates at ambient pressure, the chamber pulse heights are sensitive to atmospheric pressure variations. *dE/dx* can be corrected for these effects. Furthermore, by selecting a set of tracks with high momentum, any variation due to the sample composition can be minimised.

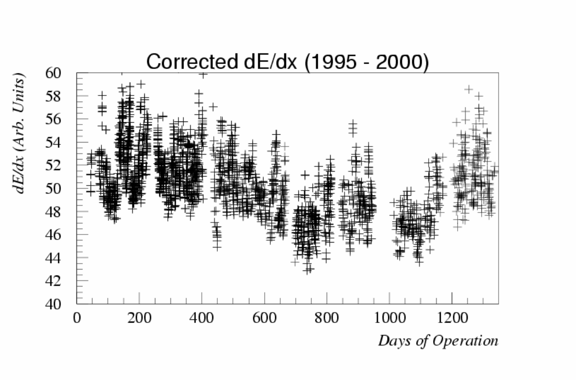

Figure 2: *dE/dx* measurements from 1995 to 2000. The *dE/dx* measurement is corrected for environmental factors such as atmospheric pressure.

Figure 2 shows the *dE/dx* measurements over five years from 1995 to 2000. The large spread in the data over the years makes it difficult to draw any definite conclusions on long-term trends. Any variation is less than 10% over the duration of the study.

3. Operational difficulties experienced in 2000

Towards the end of the 2000 data-taking period the CTD high voltage became unstable, tripping off continuously in some sectors of superlayers eight and nine (the outermost superlayers). The only way to recover the affected area was to remove the high voltage from it for a number of days, after which it could successfully be operated again. At the onset of the problems, the affected regions could be operated for several weeks before re-occurrence, but this interval reduced to days as the problem worsened. The high voltage problems were unrelated to any external environmental factors or beam conditions in the HERA accelerator. Anecdotal evidence did, however, suggest that the high voltage trips were correlated with the integrated luminosity that the detector had been exposed to. The problems were initially confined to the outermost superlayers, where due to the cell geometry the electric fields are higher, but moved in towards the centre of the detector over the course of a number of weeks.

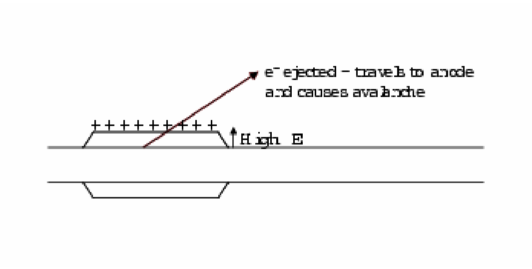

Figure 3: Schematic representation of the Malter effect.

The suspected cause of the problem is the Malter effect [11], where thin insulating deposits on the cathode wires leads to the accumulation of a positively charged ion layer which causes high electric fields resulting in the emission of electrons from the wire surface. These electrons then cause avalanches at the anodes, resulting in exponential growth of standing currents in the chamber – even when no beams are present. Figure 3 shows a schematic representation of this process. Removing the high voltage allows the accumulated charge to slowly leak away to ground, allowing the affected region to be operated again for a limited period of time until sufficient charge builds up again.

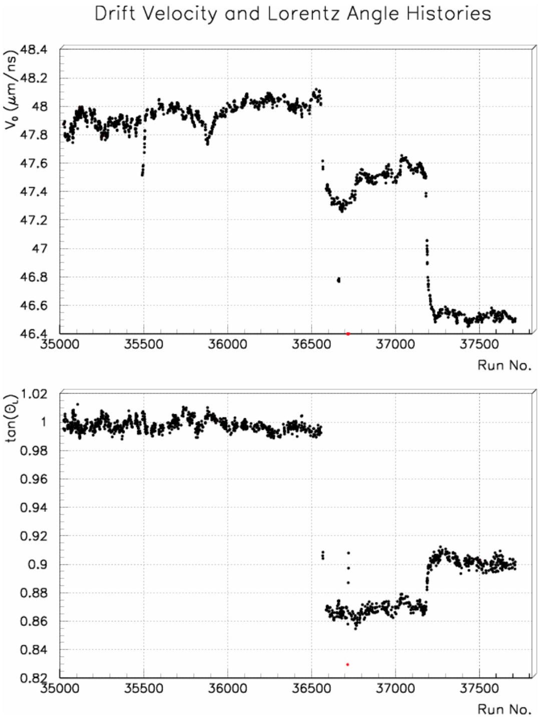

Figure 4: Changes to the CTD operating parameters after the addition of water to the gas mixture. The first large shift is due to the addition of water; the second results from further changes made to the chamber gas mixture to return the Lorenz angle back to 45°

3.1. Solution and Effects

The effects seen in the CTD are very similar to the problems experienced with the TASSO vertex detector [12]. In that case the addition of a small amount of water to the gas mixture alleviated the problems and allowed the detector to operate successfully. It was therefore decided to add water to the CTD gas mixture.

To avoid any major modifications to the existing CTD gas system it was decided to simply replace the 100% ethanol mixture in the injector system with a mixture of ethanol and distilled water. The final mixture chosen was 27:73 H_2O:Ethanol. Since the gas analysis equipment available at DESY is unable to measure such small concentrations, the best estimate of the water concentration in the gas is around 0.15%.

Water was added to the CTD gas mixture in July 2000. The chamber operated without high voltage problems from then until the beginning of the long HERA shutdown in September 2000. There were, however, significant shifts in the operating parameters of the chamber due to the addition of water. The following sections outline the problems experienced and the solutions adopted.

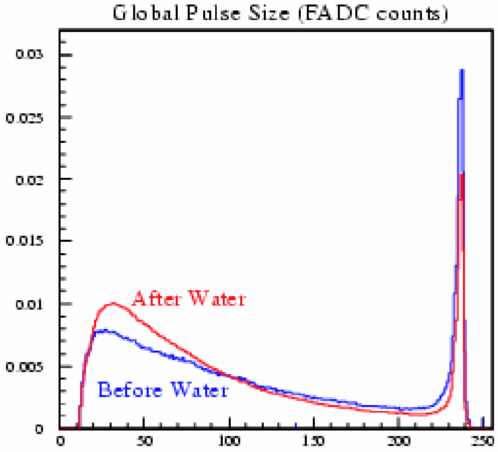

Figure 5: CTD pulse height spectrum before and after the addition of water to the gas mixture. The peak to the right is caused by pulses that saturate the FADC system. Both histograms have unit area to allow a shape comparison to be made.

3.2. Changes to CTD Operating Parameters

Figure 4 shows the changes to the electron drift velocity and Lorenz angle due to the addition of water to the gas mixture. Two large changes can be seen – the first is due to the water; the second will be discussed later and results from the changes made to return the operating parameters to their nominal values. The main changes after adding water were a reduction in the electron drift velocity and a large shift from the design operating point of $\tan\left(q_{Lorenz}\right) = 1.0$. This shift in the Lorenz angle had other undesirable effects, namely a reduction in the single wire efficiency and a worsening of the hit position resolution. Figure 5 shows the effect of adding water on the pulse height distribution in the chamber. There was a measurable drop in the gas gain after the water was added. Both the shift in Lorenz angle and drop in gain are undesirable side effects of adding water. The next section covers the further changes that were made to the CTD gas and high voltage settings to return it to optimal operation.

3.3. Remedies

It is possible to change the drift velocity and Lorenz angle simply by adjusting the high voltage. Figure 6 shows the drift velocity and Lorenz angle variations with applied voltage. The curves and solid symbols show previous measurements made in a small test chamber [13] and the open symbols show measurements made in the CTD after adding water to the gas. Clearly there has been a shift in the drift velocity/Lorenz angle relation, and there was no possibility to return the Lorenz angle to 45º by adjusting the high voltage alone. Instead it was decided to increase the high voltage settings by 10% to return the pulse height spectrum to that of the pre-water gas and to investigate changes to the gas composition to return the Lorenz angle to 45º.

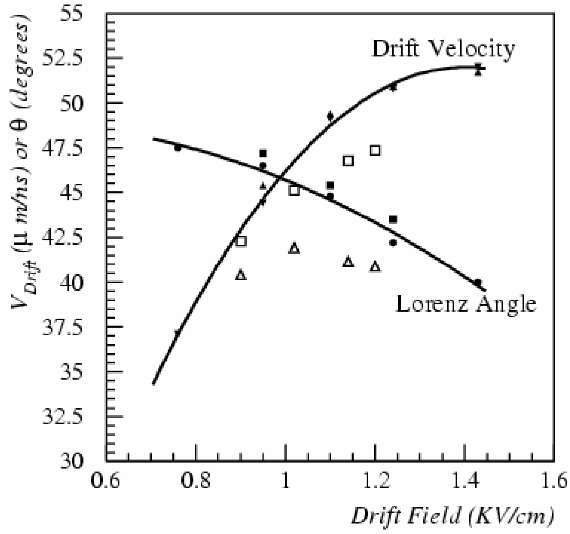

Figure 6: Drift velocity/Lorenz angle variations with applied drift field. The solid points were measured using the test chamber and the solid lines are fits to these points. The open symbols are measurements made using the CTD after water had been added to the gas mixture. The open squares are drift velocity measurements and the open triangles are Lorenz angle measurements.

3.4. Further changes to the gas mixture

The Garfield [14] program was used to investigate the variation of the Lorenz angle with gas composition. The simulations were carried out without any admixtures of ethanol or water as these were found to give inconsistent results when compared to the nominal gas mixture. Figure 7 shows the results of the simulations. Each run was taken by keeping one of the three CTD gas components constant and varying the other two, e.g. keeping CO_2 constant and increasing the ethane by 1% would

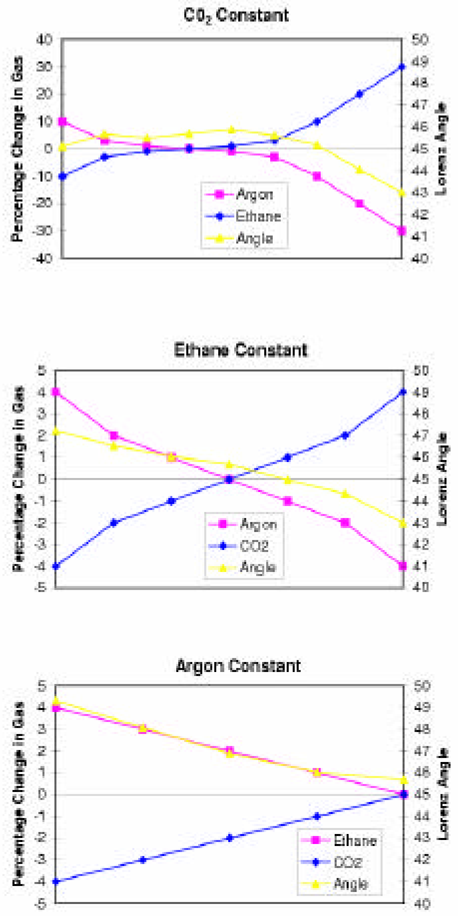

Figure 7: Results of the Garfield simulations. The left axes show the % change in gas composition from the nominal mixture. The right hand axes show the predicted value of the Lorenz angle.

require decreasing the argon by 1%. It is clear from the simulation that the only possible way to change the Lorenz angle significantly was to change the CO_2 concentration. The option chosen was to reduce the CO_2 by 2% and increase the ethane concentration by 2% keeping the Argon constant. This change maintains the required operating properties of the gas whilst keeping below the explosive limit.

The second change in the CTD operating parameters seen in Figure 4 is the result of the gas change detailed above. The drift velocity drops further but remains within acceptable tolerances. The Lorenz angle does return towards 45º as predicted by the simulation, but the change is only 1.2º (from 40.9º to 42.1º). Operational concerns prevented the composition being changed any further. However, the improvement in Lorenz angle was sufficient to restore the single hit efficiency and position resolution to pre-water values.

4. Summary and Conclusions

The ZEUS CTD has operated reliably for more than eight years. Initial aging studies using *dE/dx* have shown no conclusive evidence for a significant gain loss. Operational difficulties with the Central Tracking Detector high voltage system in 2000 have been attributed to the Malter effect. The chosen solution – to add a small quantity of water to the gas mixture – has, to date, been successful and the chamber continues to perform well. Some shifts in its operating parameters, caused by adding water to the gas, were investigated and partially corrected by changing the gas composition – increasing the ethane content of the mixture by 2% with a commensurate drop in CO_2 whilst keeping the argon concentration constant. The high voltage settings were also increased by 10% to correct a reduction in gain caused by the water.

The long HERA shutdown is now coming to an end. The CTD will, once again, be at the heart of ZEUS physics. It is hoped that the operating conditions outlined here will permit successful operation until the end of ZEUS running.

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