4.1.6 Performance

During operation typically 0.1 % of the digital channels (wires, strips) are noisy and $1-2$ % are dead.

Calibration data were taken during cosmic runs. One result is the efficiency of the chambers, which is shown in Figure 43. It agrees well with the expected values. Figure 44 shows the number of wires and strips per event for events triggered by the muon system. The wire data show a signal starting at a multiplicity of 13 which is roughly the mean number of wires expected for single penetrating muons with a plane efficiency of 80 %.

With cosmic muons the chambers of all modules have been aligned to each other with an accuracy of a few mm. In the barrel region cosmic muons can be used to determine the reconstruction efficiency by extrapolating jet chamber tracks. Geometrical acceptance limits this efficiency to 89 % in the plateau region above the threshold of 2 GeV as shown in Figure 45.

4.2 Forward muon spectrometer

4.2.1 General description

The purpose of the forward muon spectrometer is to measure high energy muons in the range of polar angles $3° \leq \theta \leq 17°$. The detector consists of drift chamber planes mounted on either side of a toroidal magnet. The design aim was to measure the momenta of muons in the range between 5 GeV/c and 200 GeV/c, the lower limit being given by the amount of material the muons have to penetrate and the influence on the momentum resolution of the multiple Coulomb scattering in the magnet iron. The upper limit is set by the magnetic field strength of the toroid together with the spatial resolution of the drift chambers. The expected momentum resolution at 5 GeV/c is 24% and deteriorates slowly to 36% at 200 GeV/c. Muon momenta below 5 GeV/c are measured in the forward tracker.

Figure 46a shows schematically the detector arrangement and the toroid magnet. The latter is described in Section 3.4 of reference [1]. The drift chamber planes, which increase in size from about 4 m diameter for the first detector plane to 6 m diameter for the last, are all divided into octants of individual drift cells mounted on Al-frames. The orientation of the drift cells is such that four of the planes essentially measure the polar angle (θ) and thereby provide the momentum of the traversing muon while the remaining two measure the azimuthal angle (ϕ). Each plane consists of a double layer of drift cells staggered by half a cell width (Figure 46b). This arrangement enables the resolution of left-right ambiguities and also the determination of t_0 as will be explained below. The total number of drift cells is 1520.

4.2.2 Chamber design

All drift cells have a rectangular cross-section with a depth of 2 cm, a width of 12 cm and lengths between 40 cm and 240 cm. With a central sense wire the maximum drift distance is 6 cm. The cells have 50 μm thick Nichrome wires except for the inner short cells where the diameter is 40 μm. For cells longer than 1.5 m there is a wire support in the middle. More details can be found in reference [114].

The chamber signals are amplified, digitized and read out using the same components as all other drift chambers within the H1 detector (see Section 2.4).

4.2.3 The chamber gas and high voltage system

The choice of gas for the drift chambers was determined by several requirements. One is the desire to work in a drift voltage range where the drift velocity is constant. Further the gas has to be fast enough for the pulse to arrive in time for the trigger and finally it should be non-flammable for safety reasons. Currently a mixture of 92.5% argon, 5% CO_2 and 2.5% methane (FMS gas) has been chosen for the chambers. The gas is mixed and purified in a recirculator. The chambers have a total gas volume of 4 m^3, and with a small overpressure of about 0.2 hPa measured at the output, the return gas flow is typically 90% of the input and the oxygen content is of order 100 ppm. More details can be found in [114].

A 120-channel high voltage system [112] supplies distribution boxes on the detector with high voltage via 50 m long coaxial cables. Two different modules are used, one (6 kV, 1 mA) supplies the drift voltage and the other (8 kV, 200 μA) supplies the sense voltage. One drift channel supplies voltage to an entire octant, feeding 20-40 individual resistor chains. One sense channel supplies voltage to all but the 12 innermost cells of a θ-octant and the central section of the ϕ-octants. These cells have another sense channel, which can be set to a lower voltage in case of bad beam conditions. Additionally, for the ϕ-octants, the central section which is close to the beam tube can be moved outwards mechanically, if necessary.

There is a continuous monitoring of the gas composition and flow rates as well as of the high voltage and the toroid magnet, communicated via an Apple Macintosh II ci in the control room. From this work station it is also possible to control the high voltage of the detector.

4.2.4 The charge-time analysis

Only the rising edge and peak region of a pulse are used to get the time and charge information. A pulse is said to start when there are two successively rising digitizings above threshold (see also Section 2.4.5).

The end of a pulse is taken as the second successive digitizing after the peak which is below threshold, or eight 9.6 ns time bins from the start of the pulse, whichever occurs first. The arrival time of the pulse is obtained by extrapolating a line fitted to the steepest part of the leading edge back to the intercept with the background level. With a test set up, looking at cosmic muons, this method gave a resolution of < 200 μm. This result was obtained with a gas mixture of 90% argon and 10% propane providing a drift velocity of 4 cm/μs [114]. However, to satisfy the gas requirements specified in Section 4.2.3 we have chosen the FMS-gas with a drift velocity of $\sim$5 cm/μs, resulting in an expected resolution of $\sim$250 μm. Pairs of pulses which originate from the same hit are associated by requiring the difference of their arrival times to be less than the full propagation time through the two sense wires and the linking resistor.

The collected charge is found by integrating the digitizings of the pulses from the two wire ends over intervals of the same length, with subtraction of a constant background. A correction for fractional time bins was found to be important since the start times for the two pulses are subject to variable propagation delays. With cosmic muons in the test set up we found a charge-division versus distance characteristic linear to about 1%, which is well matched to the resolution.

4.2.5 Track reconstruction

The space points obtained from the charge-time analysis of the chamber hits are used in a three step procedure for track reconstruction which starts with the pairing of hits in each double layer followed by association of pairs into straight track segments and finally the linking of track segments through the toroid to form full tracks and thus provide a momentum measurement. Pair finding in the double layers is decisive due to the displacements of cells which results in the sum of drift times being a constant (compare Figure 46b). A vertex pointing requirement is applied as selection criteria, but also unpaired hits are kept to be considered in the track segment finding where we demand 3 out of 4 hits in the θ-layers. The measuring errors of the space points for a pair define a cone which is extrapolated to the other θ-layer on the same side of the toroid. In the area defined by the cone, hits are tried for segment fits and are selected by a χ^2-cut.

For the linking procedure each pre-toroid segment is tracked through the magnetic field of the toroid, taking into account energy loss and multiple Coulomb scattering in the magnet iron. By doing this for a minimal reconstructible momentum of 2.5 GeV/c in the spectrometer and for either of the two muon charges possible, regions in the θ-layers after the toroid are defined inside which segment candidates for linking are considered. From the crossing angle of two linked segments an estimate of the momentum is made. Starting from the pre-toroid segment and the estimated momentum the tracking is repeated as the momentum is changed in small steps around the estimated value. Each post-toroid segment obtained from the tracking is compared to the actual segment found and a χ^2 is calculated. The minimum of the χ^2 variation with momentum defines the momentum corresponding to the best fit.

4.2.6 Drift velocity and t_0-determination

Beam halo muons are used to determine the drift velocity. From the uniform population of the total number of tracks (N) over the full drift distance (Δy), recorded in a run, a rectangular distribution is expected if the drift velocity is constant. However, due to field variations close to the sense wire, dependence on the angle of the track, the possibility of tracks traversing only the corner of a cell etc., the drift velocity will be altered and cause a smearing of the distribution.

t_0 is determined from the specific geometry of the detector, making true specific check sums for each track, as detailed in reference [114]. The widths of the check sum distributions can be used to find the spatial resolution of the chambers.

4.2.7 Chamber alignment

The drift chambers must be aligned with respect to each other and to the rest of the detector. The cells of a θ-layer are positioned on its supporting Al-frame to a precision of $\sim$50 μm along the drift direction and to $\sim$1 mm in the two other directions. This is better than the achievable resolution and therefore we only have to consider the alignment of the full octants.

Simulation studies and analysis of a small sample of real data have shown that beam halo tracks are suitable for providing the two translational and one rotational quantities which are needed to specify the position of the octant in the plane transverse to the beam direction. Further studies with angle tracks together with the survey will determine the relative positions of the octants along the direction of the beam.