EDIT 2011 - Drift Tubes

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Abstract

Drift tubes are used in many high energy physics experiments as precision tracking detectors, reaching spatial resolutions of better than 100 μm. The moderate channel density with a granularity of several cm, the low production cost and the mechanical robustness predestine their use whenever large areas need to be covered, as e.g. in the muon spectrometers of the LHC experiments. The determination of the spatial position of a hit inside a drift tube is based on the measurement of the electron drift time from the traversing track to a central anode wire. Therefore, to reach the ultimate performance, the space-to-drift time relation and its dependence on parameters such as gas composition, applied voltage and the environment (temperature, magnetic field etc.) has to be well understood. The EDIT setup uses drift tubes which are currently being developed for high rate capable muon chambers for the LHC upgrade. The students can modify certain parameters to study their effect on the space-to-drift time relation and gain an understanding in the operation of the detector.

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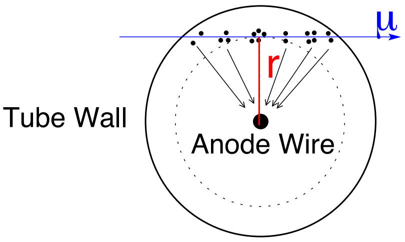

Figure 1: Principle of a drift tube position measurement. A muon passes at the distance r from the anode wire, creating ionization clusters along its path. The primary electrons will drift to the anode wire.

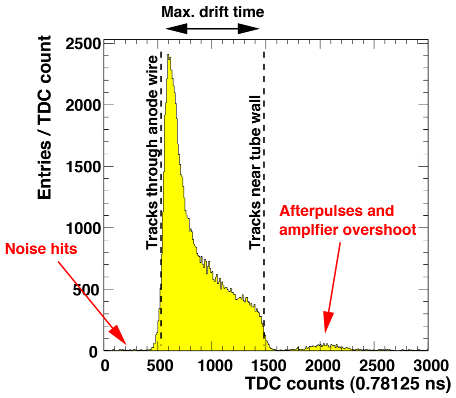

Figure 2: Drift time spectrum of drift tube of 29.8 mm inner diameter with a 50 μm diameter anode wire, using an Ar/CO$_2$ (93/7) gas mixture at 3 bar absolute pressure with a high voltage of 3080 V.

1 Introduction

1.1 Principle of Drift Tube Operation

A drift tube consists of a cylindrical cathode with a tensioned anode wire in the middle of the tube. The tube is flushed with a suitable gas mixture and an electrical potential is applied between the anode wire and the cathode. If an ionizing particle traverses the tube electron-ion pairs are created along its path, see fig 1. Under the influence of the electric field between the anode wire and the cathode and in the absence of a magnetic field, the primary electrons from the ionization drift radially towards the wire and in the high electrical field close to the wire initiate an avalanche, multiplying the initial charge by a factor called the gas gain. The gas gain depends on the gas composition and the operating conditions. The avalanche leads to a usable induced signal from the ions created in it and drifting towards the tube wall [1]. This signal can be read-out by electronics and further processed. The leading edge of the signal coincides with the arrival of the primary electrons which were created at a radial distance closest to the wire.

The drift time of the primary electrons to the anode wire depends on the geometry of the drift tubes, the drift gas composition and pressure, and operational and environmental parameters such as applied high voltage, temperature and magnetic field. Therefore, assuming the drift tube is homogeneously illuminated, the distribution of all measured drift times (drift time spectrum), has a characteristic shape. An example of a drift time spectrum is given in fig. 2.

To determine the distance of a track from the anode wire the drift times of the electrons needs to be measured. The signal of the drift tube created by the arrival of the primary electrons at the wire is used to stop the time measurement. The time measurement itself has to be started by an external source, the trigger. To convert the measured drift time to a radius, the space-to-drift time (rt) relation is used. The rt-relation can either be derived by integration from the drift time spectrum, it can be determined in-situ from the data of the measured particle tracks (auto-calibration) or it can be simulated with programs like Garfield/Magboltz [2,3].

The spatial resolution of a drift tube is a function of the drift radius due to the dependence of the electron drift velocity on the electric field, the clustering of the primary ionization and the diffusion of the electrons along their drift path to the anode wire.

A careful optimization of all parameters is necessary to ensure the optimal performance of a drift tube detector.

1.2 ATLAS Monitored Drift Tube Chambers

The vast majority of the 1200 precision tracking detectors which constitute the muon spectrometer of the ATLAS experiment [4] are Monitored Drift Tube (MDT) chambers. They consist of two multilayers, each built of 3 or 4 layers of densely packed drift tubes mounted on an intermediate lightweight support frame; the chamber sizes vary from about 1 m^2 to 11 m^2 with tube lengths ranging from 1 to 6 m, see fig. 3. The drift tubes have an outer diameter of 30 mm and a wall thickness of 0.4 mm. A single anode wire of 50 μm diameter is centered in the middle of each tube by precision endplugs. Operated with an Ar/CO_2 (93/7) gas mixture at a pressure of 3 bar absolute and a potential of 3080 V applied between the tube wall and the anode wire, the individual drift tubes reach an average spatial resolution of 80 μm and have a maximum drift time of 700 ns at low background rates; in conjunction with the wire positioning accuracy of better than 20 μm, the MDT chambers reach a spatial resolution of 35 μm. To reach the ultimate precision of the spatial tube resolution, the rt-relation is calibrated every few hours during data taking. The calibration method uses the deviation of the measured muon hits from fitted track segments inside a chamber to correct the rt-relation iteratively (autocalibration) [5–7]. An optical alignment system continuously monitors the deformations of the chamber and their relative positions in the spectrometer to allow for geometric corrections in the tracking algorithms.

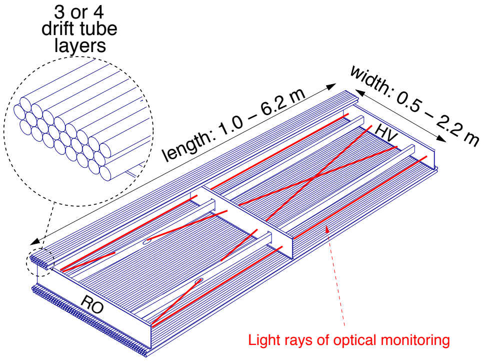

Figure 3: Schematic view of an ATLAS MDT chamber.

The drift tube chamber design offers several advantages: modularity in the construction and mechanical robustness, operational independence of each tube leading to negligible inefficiencies in case of failures, and the independence of the spatial resolution from the angle of incidence of the particle track due to the symmetry of the tubes.

The ATLAS MDT chambers were designed to cope with counting rates up to 300 kHz per tube, corresponding to an occupancy of about 20%. With the planned luminosity upgrade of the LHC beyond its design luminosity of 1×10^{34} $cm^{-2}s^{-1}$, leading to an increase in the background, the chambers will exceeded these counting rates in the forward regions of the spectrometer.

Research and Development on High Rate Capable Drift Tubes

At high counting rates, the detection efficiency of the drift tubes of the ATLAS MDT chambers suffers from the increased occupancy [8] and the spatial resolution is degraded by the high space charge within the tubes [9, 10]. Both effects can be suppressed by reducing the tube diameter while

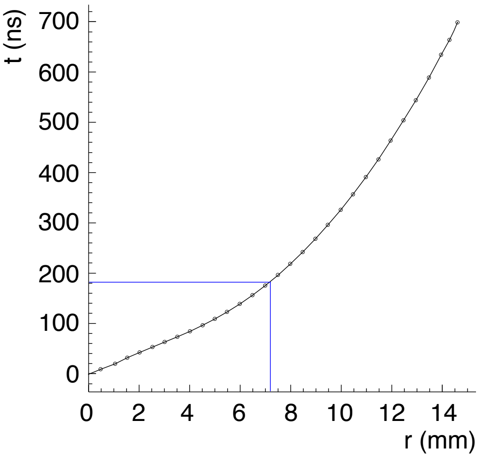

Figure 4: Space-to-drift time relation of 30 mm diameter drift tubes. If the tube diameter is reduced to 15 mm, the maximum drift time is reduced from 700 ns to about 200 ns (blue lines).

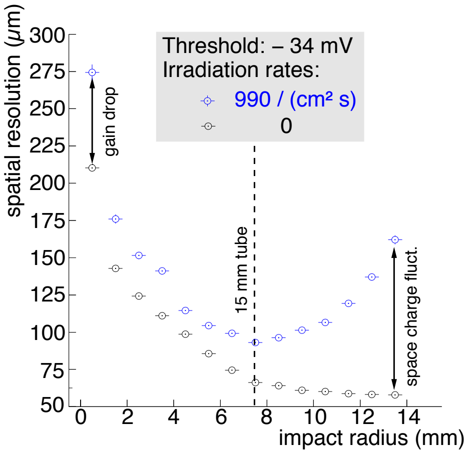

Figure 5: Resolution of 30 mm diameter drift tubes for different photon irradiation rates, measured at the Gamma Irradiation Facility at CERN with an ^{137}Cs source [8]. The degradation of the resolution by space charge fluctuations is reduced for drift drift distances below 7.5 mm, corresponding to 15 mm tubes (dashed line). See text for a discussion of the gain drop effect.

keeping the other operating parameters, in particular the gas mixture, the pressure and the gas gain, unchanged.

A decrease of the drift tube diameter from 30 mm to 15 mm and of the operating voltage from 3080 V to 2730 V leads to a reduction of the maximum drift time by a factor of 3.5 from about 700 ns to 200 ns [11], see fig. 4. In addition, the background counting rate, dominated by the conversion of the neutron and gamma background radiation in the tube walls, decreases proportional to the tube diameter, i.e. by a factor of two per unit tube length. Both effects together lead to a reduction of the occupancy by about a factor of 7.

The space charge of the ion clouds created in the avalanches and drifting towards the tube wall lowers the effective potential near the anode wire, leading to a reduction of the gas gain. The resulting loss in signal height and, therefore, spatial resolution grows with the inner tube diameter d proportional to $d \cdot \ln(d/d_{\mathrm{wire}})$ [12] where d_{wire} is the wire diameter. Therefore, the signal height reduction due to space charge is 10 times smaller in 15 mm compared to 30 mm diameter tubes. Fluctuations of the space charge and, consequently, of the electric field in the tube lead to variations of the drift velocity in nonlinear drift gases like Ar/CO_2 (93/7) causing a deterioration of the spatial resolution which increases rapidly with the drift distance above a value of about 7.5 mm [9, 10], cp. fig. 5. In addition, the space-to-drift time relation for the Ar/CO_2 (93/7) drift gas is more linear at drift distances below 7.5 mm (see fig. 4), reducing the sensitivity of the position measurement to environmental parameters such as gas composition and density, magnetic field and, in particular, irradiation rate.

With the smaller drift tube diameter the cell density can be increased by a factor of 4 in the same detector volume, allowing for additional improvement of the detection efficiency and spatial resolution of the cham-

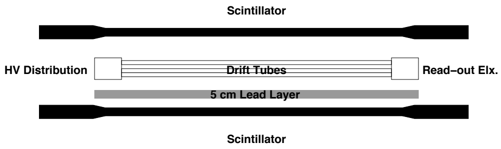

Figure 6: Schematic drawing of the detector setup, consisting of the drift tube chamber between the two scintillators used for triggering.

Figure 7: Photograph of the drift tube chamber and part of the read-out electronics.

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For further information see [13,14].

2 The Drift Tube Setup

Fig. 6 shows a schematic view of the drift tube setup. A small chamber, consisting of 4×6 densely packed drift tubes of 15 mm diameter and 1 m length has been built (see fig. 7), using the same procedure as for the present chambers for high rate drift tube R&D [13]. The chamber is equipped with standard ATLAS MDT read-out electronics [15] on one side and a high voltage distribtion system on the other side. In addition to the time measurement, the front-end electronics also allow a measurement of the charge at the beginning of the signal. A trigger for muons from cosmic rays is formed by two plastic scintillators, situated above and below the drift tube chamber. The lower scintillator is shielded by a layer of 5 cm of lead to stop very low energetic cosmic muons and reduce the effect of multiple scattering on the data.

Figure 8: Photograph of the gas system used to mix the Ar/CO_2 drift gas. On the top the NIM and VME crates containing the trigger logic and read-out modules are vissble, on the right side the low voltage and high voltage power supplies for the drift tube chamber and the trigger scintillators.

The trigger logic is based on NIM-modules and the signal is distributed by a standard LHC trigger, timing and control (TTC) VME module to the drift tube chamber. The read-out uses a combination of VME modules to measure the exact trigger time of the scintillators and a custom PCI card to acquire data from the drift tube chamber. Fig. 8 shows a photograph of the electronics on top of the gas system rack. A DAQ program combines both data sources and prepares a common data file for the analysis.

The gas system (fig. 8) allows the mixture of arbitrary Ar/CO_2 and is computer controlled, as are the HV power supplies during standard operation.

Details of the setup will be explained during the session.

3 Session Programme

The aim of this session is to gain an understanding on how different parameters change the gas gain, the space-to-drift time relation and the spatial resolution of a gaseous detector. The drift tube setup allows the variation of the high voltage, the gas pressure and the gas mixture.

The following session programme is foreseen:

1. Study the difference between signals from cosmic muons and signals created by photons from an ^{55}Fe source.

   The ionization mechanism between the two particle source is different: muons undergo energy loss by electromagnetic interaction along their path, creating many statistically separated clusters of a few electron-ion pairs. Interactions of the 5.9 keV photons from the ^{55}Fe source with the drift gas via the photo effect lead to low energetic electrons with a very small range, creating a single large ionization cluster.

2. Study the dependence of the pulse height of the ^{55}Fe signals on the high voltage applied to the anode wire.

   Changing the applied high voltage changes the gas gain in the avalanche and therefore the pulse height. Photon sources are often used to calibrate the gas gain and its dependence on the high voltage as the primary ionization is well known and localized.

3. Measure the length of the drift time spectrum at standard operating conditions (gas mixture Ar/CO_2 (93/7), pressure 3 bar absolute, high voltage 2730 V). Use the provided analysis programmes to determine the rt-relation and the spatial resolution of the drift tubes.

   Included is a discussion on the influence of multiple scattering on the result and how to estimate the drift tube resolution from a simple geometric approach.

4. Vary either the high voltage or the gas mixture and measure the effects on the drift time spectrum. Compare the rt-relation and the spatial resolution to the ones with standard operating conditions.

5. If time: Study the necessity of a quencher in the drift gas by operating the drift tubes with pure argon.

Note: The parameters and results of steps 3 and 4 can be used as input in the simulation session by Rob Veenhof.

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