Nuclear Instruments and Methods in Physics Research A 623 (2010) 954–959

Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research A

journal homepage: www.elsevier.com/locate/nima

Calibration of the TWIST high-precision drift chambers

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ARTICLE INFO

Article history:
Received 12 February 2010
Received in revised form
30 July 2010
Accepted 25 August 2010
Available online 8 September 2010

Keywords:
Drift chambers
Drift times

ABSTRACT

A method for the precise measurement of drift times for the high-precision drift chambers used in the TWIST detector is described. It is based on the iterative correction of the space–time relationships by the time residuals of the track fit, resulting in a measurement of the effective drift times. The corrected drift-time maps are parametrised individually for each chamber using spline functions. Biases introduced by the reconstruction itself are taken into account as well, making it necessary to apply the procedure to both data and simulation.

The described calibration is shown to improve the reconstruction performance and to extend significantly the physics reach of the experiment.

1. Introduction

The TRIUMF Weak Interaction Symmetry Test (TWIST) experiment measures momentum and angle distributions of positrons from the decay of highly polarised positive muons to obtain an accurate measurement of the decay parameters.

High-precision planar drift chambers are employed to reconstruct the positron tracks in the momentum and polar angle range of $15 \lesssim p \lesssim 55\,\mathrm{MeV}/c$ and $0.5 \lesssim |\cos\theta| \lesssim 1.0$, respectively. The chambers are contained in a solenoidal spectrometer with a 2 T magnetic field, and arranged symmetrically around a central target foil that stops the low energy muon beam (Fig. 1). Following the decay of the muon, the positron is tracked in the chambers and a high statistics decay distribution is acquired. The decay parameters are then extracted by comparing the measured spectrum with a simulation.

TWIST's physics goal is an improvement in the accuracy of the decay parameters by one order of magnitude over previous measurements. Intermediate results, obtained from data taken before 2005, have been published [1–4]. To further reduce the uncertainties for the analysis of the final data sets acquired in October–December 2006 and May–August 2007, a detailed understanding of the response of the drift chambers, in particular the space–time relationships (STRs), was required.

While the determination of drift-time maps is a common problem, the chamber setup and the precision requirements for TWIST made it necessary to calculate accurate STRs directly from data. Consequently, a method was devised to measure the drift times individually for each chamber, taking into account construction inaccuracies, environmental parameters and interplay with the track reconstruction algorithms.

2. TWIST drift chambers

The 44 planar drift chambers (DCs) are the main tracking devices of the TWIST spectrometer. A more complete description of the design and construction of the DCs than is given here can be found in Ref. [5].

2.1. Chamber design

A primary design requirement for the DCs was to minimise their total thickness, thereby reducing the amount of material that particles have to cross when passing through the detector. This minimises the uncertainties from the calculation of energy loss and multiple scattering. At the same time, the chambers had to obtain single-hit reconstruction efficiencies of above 99% and a spatial resolution of significantly better than 100 μm to achieve the physics goals of the experiment.

An individual chamber is composed of two parallel cathode foil discs of 320 mm radius, separated by 4 mm, and a wire plane with 80 parallel sense wires stretched across the disc at a pitch of 4 mm. The foils are located at 1.85 and 2.15 mm distance, defining asymmetric half-cells.[2] No field wires are used. The schematic layout of one drift cell is shown in Fig. 2. A drift cell is defined as

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[2] The original design called for equal foil distances of 2 mm. However, a systematic shift of the foil position resulted from the construction process. The wire planes are not affected.

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doi:10.1016/j.nima.2010.08.105

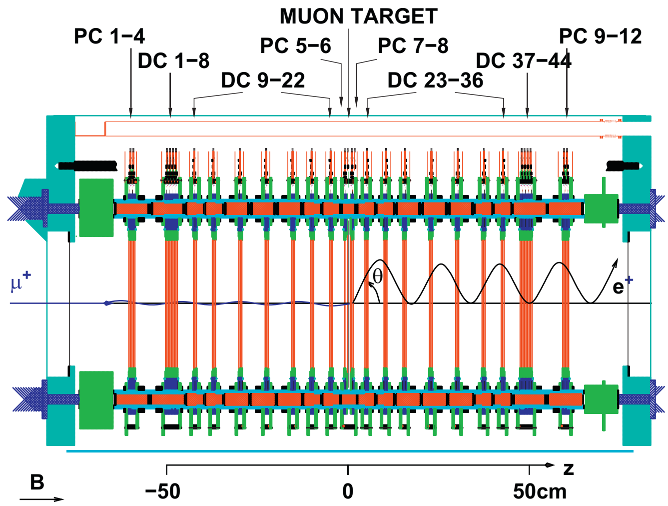

Fig. 1. Side view of the TWIST detector. It consists of two symmetric stacks of drift and proportional chambers (DCs and PCs) surrounding the muon stopping target and is immersed in a 2 T magnetic field. A typical event is shown with the helical track of the decay positron.

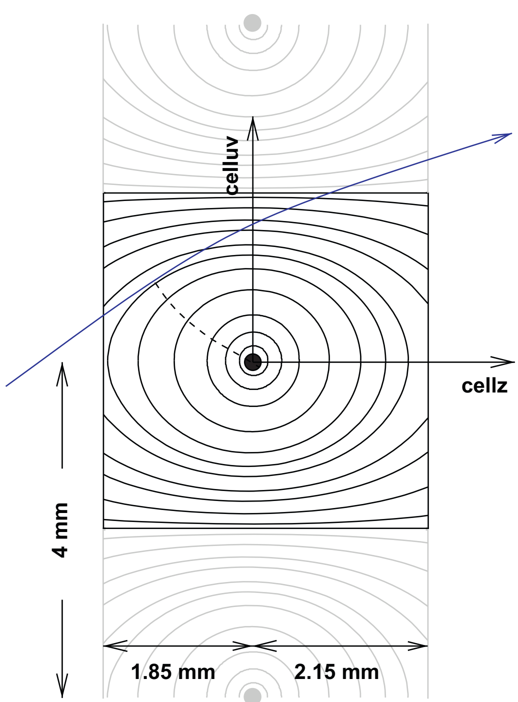

Fig. 2. Schematic layout of one drift cell and a projected particle trajectory. The cell coordinate system is defined with the origin at the wire and *cellz* and *celluv* ranging from −1.85 to 2.15 mm, and −2.00 to 2.00 mm, respectively. The isochrones for drift times of 2, 5, 10, 25, 50, 75, 100, 150, 200, 300, 500 ns are shown. As can be seen, the point of the charge deposit that reaches the wire first depends on the entry point and angle of the track. Its approximate path to the wire is indicated.

the projection of the drift space along all wires of a particular plane. Sense wires are 15 μm diameter gold-plated tungsten/rhenium with the initial distance between wires accurate to approximately 3.3 μm and the absolute wire positions known to better than 20 μm. The foils are aluminised Mylar with a nominal thickness of 6.35 μm. As drift gas dimethyl ether (DME) at atmospheric pressure is used. In addition to having a low mean atomic number, DME has a small Lorentz angle, a good cluster yield ($\approx 30\,\mathrm{cm}^{-1}$) and a relatively low drift velocity, with the maximum drift times being below 1 μs for the given geometry.

2.2. Stack assembly

As shown in Fig. 1 most DCs are assembled into modules of two chambers, with the central cathode foil shared, and the outer foils serving as gas containment windows. The two wire planes of such a module are rotated by $\pm 45^\circ$ with the detector axis to reduce gravitational sag. The wire orientations then define the $u/v/z$ coordinate system, with z being the detector axis. Fourteen such modules are symmetrically arranged around the target, with irregular spacing to reduce ambiguities in the reconstruction. At the very upstream and downstream these modules are complemented by two stacks of eight DCs that have all inner foils shared. Upstream and downstream DCs are flipped with respect to each other so that the smaller half-cell is always oriented toward the target. In addition, proportional chambers (PCs) surround the DCs at the very upstream and downstream end of the detector, and around the target. They provide trigger and timing information and are not used for the track fit.

The precise z-positioning of all modules is implemented with ceramic spacers that have an extremely low thermal expansion coefficient. They stabilise the distances between two wire planes to an accuracy of better than 5 μm. The positioning of the foils is accurate to about 100 μm with respect to the wire planes and is expected to vary from chamber to chamber. The space between the individual chamber modules is filled with a (97:3) mixture of helium[3] and nitrogen at atmospheric pressure.

2.3. Operation

The pressures of the DME and He/N input lines are carefully adjusted and monitored to avoid differential pressure that would bulge the cathode foils. In particular, fast temperature changes of the detector environment have to be avoided to allow the control systems to adapt. The dynamic bulging of the foils was not bigger than 35 μm at the centre and does not constitute a considerable source of reconstruction uncertainties.

With unavoidable variations in the atmospheric pressure the density of the drift gas varies as well. This effect is accounted for in the determination and usage of the STRs (see below).

The chambers operate at a voltage of 1950 V, providing efficiencies of above 99% with no significant risk of sparking. Signals on the wires of all chambers pass through preamps and post-amplifier-discriminators before being read out by LeCroy 1877 multi-hit TDCs with 0.5 ns time resolution.

2.4. Drift times

Initially, the drift properties of the chambers have been studied using the GARFIELD [6] program. GARFIELD calculates the drift times expected for a given setup, including the specifications of the gas, and the electric and magnetic fields. While an accurate drift-time map can be obtained this way, there are inevitable differences with the real chambers, arising from construction inaccuracies, local variations of the electric field, and temperature and pressure variations. The impact of each of these effects on the drift times can be quantified using GARFIELD with modified chamber parameters, however, a comparison with the real drift times of all 44 chambers cannot be obtained this way. This lack of

[3] Helium is used in order to reduce the amount of material beam muons and decay electrons have to traverse. The use of air would significantly increase the energy loss and associated systematic uncertainties.