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Technical Notes

Front-end electronics and data acquisition system for a multi-wire 3D gas tracker

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ABSTRACT

This paper presents the design and implementation of the front-end electronics and the data acquisition (DAQ) system for readout of multi-wire drift chambers (MWDC). Apart of the conventional drift time measurement the system delivers the hit position along the wire utilizing the charge division technique. The system consists of preamplifiers, and analog and digital boards sending data to a back-end computer via an Ethernet interface. The data logging software formats the received data and enables an easy access to the data analysis software. The use of specially designed preamplifiers and peak detectors allows the charge-division readout of the low resistance signal wire. The implication of the charge-division circuitry onto the drift time measurement was studied and the overall performance of the electronic system was evaluated in dedicated off-line tests.

1. Introduction

Precision measurements in neutron and nuclear decay offer a sensitive window to search for new physics beyond the standard electroweak model and allow also the determination of the fundamental weak vector coupling. Recent analyses based on the effective field theory performed in e.g. [1,2] show that in processes involving the lightest quarks the neutron and nuclear decay will compete with experiments at highest energy accelerators. For instance, data taken at the LHC is currently probing these interactions at the 10^{-2} level (relative to the standard weak interactions), with the potential to reach the $\simeq 10^{-3}$ level. In some of the β decay correlation measurements there are prospects to reach experimental sensitivities between 10^{-3} and 10^{-4} making these observables interesting probes for searches of new physics originating at TeV scale. The most direct access to the exotic tensor interaction in β decay is to measure the Fierz term (coefficient b) or the beta-neutrino correlation coefficient a in a pure Gamow–Teller transition [3]. The b coefficient shows up as a tiny energy dependent $(1/E)$ departure of the β spectrum from its V–A (standard model) shape. The smallness of the potential b contribution requires that other corrections to the spectrum shape of the same order are included in the analysis. Indeed, according to [4,5] the recoil terms also affect the spectrum shape with their main contribution being proportional to E. In order to disentangle these effects the detector efficiency for β particle as a function of energy must be known with the precision better than 10^{-3} [6]. The dominating contribution in the systematic uncertainty comes from back-scattering and out-scattering of electrons from the detector. Monte Carlo simulation of this effect is helpful, however, it introduces its own uncertainty as the input parameters are known with limited accuracy. Monte Carlo simulation would reflect the real situation better after it is adjusted to real experimental data of a particular measurement setup.

Electronics described in this paper was designed for a spectrometer capable of direct registration of the back-scattering events, thus providing reference data for the Monte Carlo calculation of the detector efficiency. The spectrometer itself is still in an R&D phase undergoing detailed tests and tuning. It will be a subject of a separate paper together with the performance benchmark [7]. In this paper, its concept will be described only in a minimum extent at the beginning of Section 2 to explain the requirements imposed onto the front-end electronics and DAQ. The rest of Section 2 is devoted to the electronic system architecture. The test results were obtained with a help of a signal generator and are presented in Section 3. Therein the resulting time spectrum and the charge asymmetry distribution representing the typical performance are shown. The asymmetry spectra were obtained using a dedicated tester to simulate the hit position on the wire with adjustable resistance division (potentiometer). Conducting the electronic benchmark tests without a detector was chosen by purpose. The

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detector itself is still not fully understood. Therefore it was important to assess the purely electronic contribution to the performance parameters of the spectrometer. The paper ends with a short summary and outlook for the future experiment.

2. System architecture

In order to facilitate the identification of the electrons impinging onto and scattered from the energy detector (e.g. Si detector, scintillator) a low-Z and low-mass tracker must be applied. One of the attractive options is a low pressure multi-wire drift chamber with minimum number of necessary wires in order to maximize the detector transparency. This condition can be fulfilled by a hexagonal wire geometry and the charge division technique allowing for a 3D track reconstruction without major distortion of the electron energy measurement. The hexagonal wire geometry is not the only one considered in the project. The rectangular (planar) wire configuration is the next suitable alternative. The multi-wire drift chamber is based on the small prototype described in Ref. [8] and will be operated with He/Isobutan gas mixture (ranging from 70%/30% to 90%/10%) at lowered pressure (down to 300 mbar). It consists of 10 sense wire planes (8 wires for each plane) separated with 24 field wire planes forming the double F–F–S–F–F–S–F–F–S–F–F–S–F–F–S–F–F structure (F- denotes a field wire plane, S- denotes a signal wire plane). The distance between neighboring signal planes is 15 mm, with wires within a plane being separated by 17.32 mm. This wire plane structure leads to the hexagonal cell geometry as shown in Fig. 1.

Each cell consists of a very thin anode wire (NiCr alloy, 25 μm diameter) with resistance of about 20 Ω/cm surrounded by 6 cathode field wires forming a hexagonal cuboid. All wires are soldered to pads of the printed circuit board (PCB) frames. The chamber is equipped with a two-dimensional positioning system for a beta source installed in the central region of the detector, between both parts of the MWDC structure. In the initial configuration, the electrons detected in two plastic scintillators installed at both sides of the MWDC provide the time reference signal for the drift time measurement. The PMT signals are also used as a trigger for the MWDC and electron energy detector readout. Acquiring the drift time and the pulse height asymmetry at both ends of the responding signal wire one can establish the electron path across the chamber cell. The system provides charge-division position sensing in the direction parallel to the wires as well as precise drift time measurement. The expected position resolution across wires is limited by angular straggling of primary electrons travelling in the gas and accounts to about 450 μm as shown in Ref. [8]. In this situation, the precision of the drift time measurement of about 200 ps is more than needed as it corresponds to about 50 μm for the operating conditions in view. The MWDC will be operated in homogenous magnetic field oriented parallel to wires providing a rough electron transverse momentum filter. The position information along the wires will be used for the identification of the sequence of the cells passed by the electrons and for distinguishing between the electrons impinging onto and scattered from the energy detector. This is why the modest position resolution of a few mm is sufficient for that direction.

Crucial in the design is the analog part of the system. In principle, commercial digitizers (TDC, ADC) could be applied at the end of the acquisition chain. However, it has been decided to equip the data channels with custom digital boards with adjusted specifications such that the whole system is handy, cost effective and scalable. The applied on board processing (FPGA) allows for acquiring up to 15,000 triggered events per second which gives a comfortable factor of 10 reserve as compared to the application in view.

The described modular electronic system consists of three main parts: (i) preamplifiers, (ii) analog cards containing the peak detector and constant fraction discriminator (CFD), and (iii) the digital boards containing analog to digital converters, ADC and TDC. The data logging software on the PC constitutes the data receiver. The signal from each signal plane is processed by means of one electronics module, which consists of two analog cards and one digital board providing 16 ADC and 8 TDC channels. A corresponding block diagram is shown in Fig. 2.

The signals from both ends of a signal wire are fed to inputs of preamplifiers located directly on the detector frames (see Fig. 3) in order to minimize the input noise and protect the signal from EM interferences. The signals from the preamplifiers are received by the analog cards which drive the ADC inputs and produce the TDC STOP signals. The digital data is transmitted via a LAN port to the back-end computer where the process of receiving, sorting and formatting to a complete physical event is accomplished by the data logging software. The card configuration settings and control is done via a RS485 port. Detailed description of each part of the system is presented in the following sections.

2.1. Preamplifiers

Signal readout from both ends of the relatively low resistance wire requires application of dedicated preamplifiers. Low resistance wires force the use of fast preamplifiers with low input

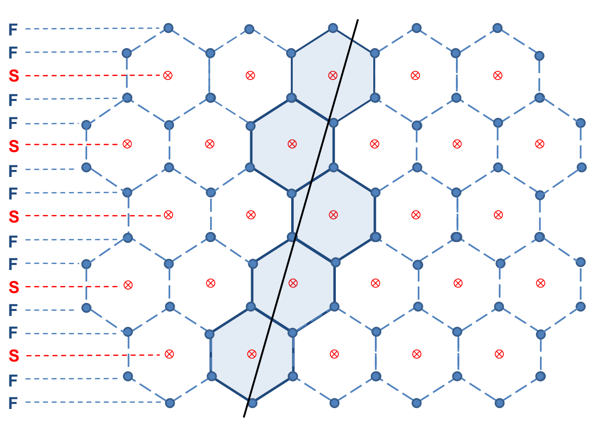

Fig. 1. Fragment of the hexagonal wire structure. The blue (solid) circles denote the field wires and the red circles (crossed) correspond to signal wires. The field and signal wire planes are indicated with F and S, respectively. The shaded areas illustrate the responding cells after an electron passed along the black solid line.

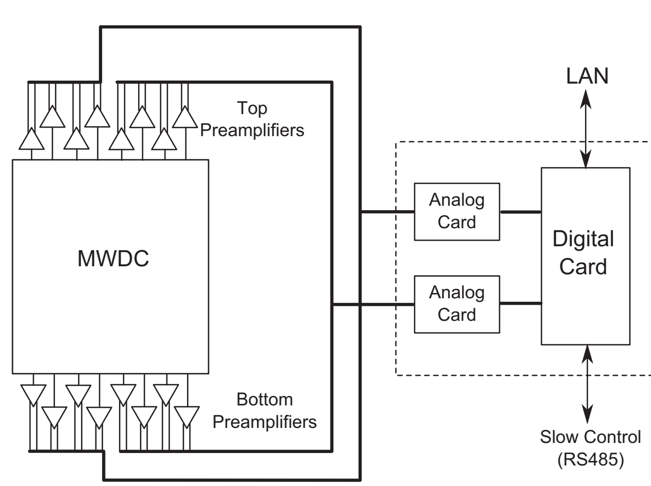

Fig. 2. Schematic of the data acquisition architecture.