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Studies on fast triggering and high precision tracking with Resistive Plate Chambers

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A B S T R A C T

We report on studies of fast triggering and high precision tracking using Resistive Plate Chambers (RPCs). Two beam tests were carried out with the 180 GeV/*c* muon beam at CERN using glass RPCs with gas gaps of 1.15 mm and equipped with readout strips with 1.27 mm pitch. This is the first beam test of RPCs with fine-pitch readout strips that explores precision tracking and triggering capabilities. RPC signals were acquired with precision timing and charge integrating readout electronics at both ends of the strips. The time resolution was measured to be better than 600 ps and the average spatial resolution was found to be 220 μm using charge information and 287 μm only using signal arrival time information. The dual-ended readout allows the determination of the average and the difference of the signal arrival times. The average time was found to be independent of the incident particle position along the strip and is useful for triggering purposes. The time difference yielded a determination of the hit position with a precision of 7.5 mm along the strip. These results demonstrate the feasibility using RPCs for fast and high-resolution triggering and tracking.

1. Introduction

Resistive Plate Chambers (RPCs) [1] have been rapidly adopted in large-scale particle physics experiments due to their excellent timing capabilities, reliability, low cost, and ability to easily scale to large areas. In major collider and neutrino experiments, RPCs are mainly used as trigger or time-of-flight devices with a typical time resolution of $\mathcal{O}(ns)$ [2–8]. They are typically read out with centimeter-wide strips and have spatial resolutions of $\mathcal{O}(cm)$ [9,10]. However, studies have shown that RPCs with narrow readout strips could provide sub-millimeter spatial resolution using classic charge interpolation [11,12] or using timing information from the signal propagating in the graphite layer [13]. Such high resolution and fast RPCs could be useful as trigger and precision tracking detectors in experiments at future lepton and hadron colliders.

To explore the feasibility of using RPCs for high-precision tracking and fast trigger devices, two beam tests were carried out with the 180 GeV/*c* muon beam at CERN. Single gas-gap glass RPCs equipped with fine-pitch strips were used. Both ends of the strips were read out using charge Analog-to-Digital Converters (ADCs) and fast Time-to-Digital Converters (TDCs). The results of the spatial resolution of muon hits in the direction perpendicular to the readout strips (referred to as the “primary coordinate”), are reported in Section 3. The results from the second beam test, focusing on measurements of RPC time resolution, spatial resolution of muon hits in the direction along the readout strips (referred to as the “second coordinate”), and mean signal arrival time from both ends of readout strips, are presented in Section 4. Conclusions are drawn in Section 5.

2. RPC chamber description

The glass chamber was 96×32 cm^2 in size and the structure was depicted in Fig. 1. Two float glass plates, with the volume

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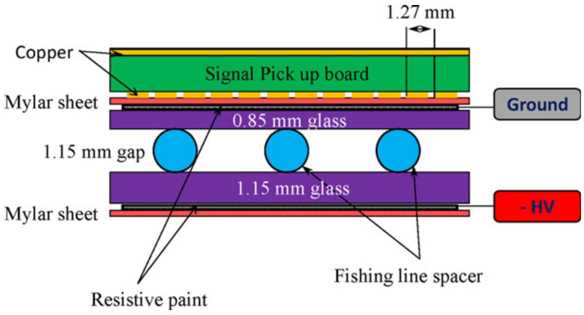

Fig. 1. Cross-sectional view of the glass RPC.

resistivity of about $10^2 \Omega\, cm$, were separated by 1.15 mm using nylon monofilament fishing line placed along the longest dimension. The ground-side glass plate was 0.85 mm thick and the side with the high voltage applied was 1.15 mm thick. The outer surfaces of the glass plates were painted with resistive paint having a surface resistivity of 1–5 MΩ/□.

Signal pickup boards with readout strips of 1.27 mm in pitch were placed on the ground sides of the chambers, and signals were read out via capacitive coupling. Negative high voltages were applied on the opposite-side plates. A three-component gas mixture of Freon(94.7%):iC$_4$H$_{10}$(5%):SF$_6$(0.3%) was used. The dark currents were measured to be less than 0.1 nA/cm^2 under normal operating conditions.

3. Primary coordinate measurements

3.1. Experimental setup and readout electronics

The spatial resolution for the primary coordinate of the RPCs was measured using 180 GeV/*c* muons from the SPS-H8 beam line at CERN. The schematic view of the experimental setup is shown in Fig. 2. The glass RPC, with two closely spaced round scintillators, each 2 cm in diameter, was placed upstream in the beam line. These two scintillators, smaller than the readout area, were mainly used to measure the RPC efficiency. Two Bakelite RPCs and a small-diameter monitored drift tube (sMDT) chamber were installed on the downstream side. The sMDT chamber [14] was made of eight layers of 15 mm diameter drift tubes and was filled with an Ar(93%):CO$_2$(7%) gas mixture at 3 bar absolute pressure. The average spatial resolution of individual drift tubes has been measured to be 120 μm. The sMDT chamber could measure the direction of muon tracks with an angular resolution of 0.4 mrad [15] and thus provided precise measurements of the incident muon tracks. Two additional large-area scintillators were employed to give common trigger signals to all chambers.

In total, 72 strips, terminated with 50 Ω resistors, were read out from both ends in three groups of 24 channels. Each group was connected to a low-noise ATLAS custom MDT “mezzanine” card containing three 8-channel Amplifier-Shaper-Discriminator (ASD) chips [16] and a 24-channel TDC [17] chip which had a least count of 0.78 ns. The injected signals from the strips were first amplified and shaped. The shaped pulses were compared to a programmed threshold to provide the leading edge of a digital pulse. A Wilkinson ADC was used to measure the integrated charge of the shaped pulses. The integrated charge was then encoded into the trailing edge of the discriminator output. Both leading and trailing edges were digitized and stored into the TDC with a large memory buffer and later were sent optically to the DAQ computer via a local processor. The same readout system was used to read out the data from the sMDT chamber using a unique DAQ system.

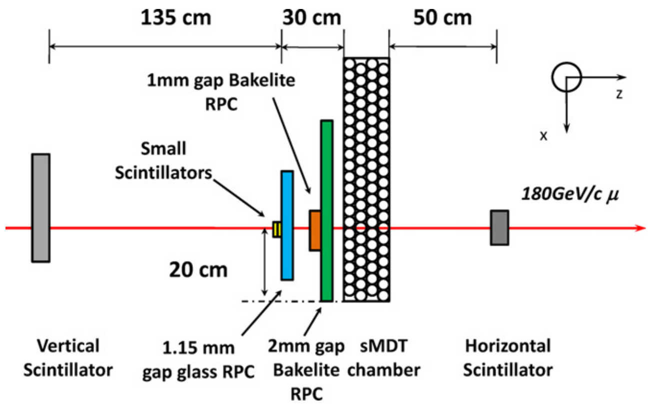

Fig. 2. Side view of the beam line set up for the primary coordinate measurement.

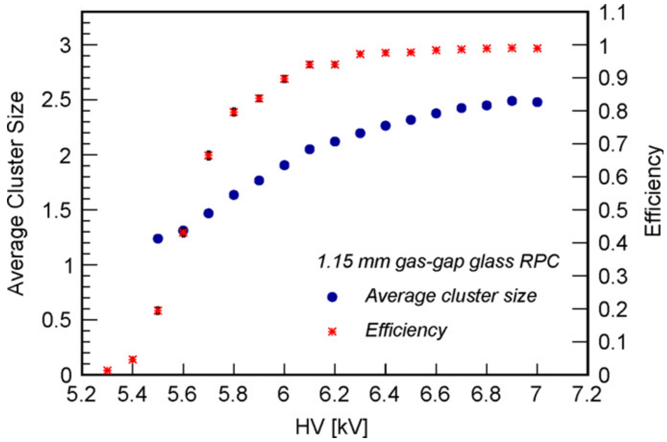

Fig. 3. The average cluster size and efficiency as a function of the applied high voltage.

3.2. Cluster size and efficiency

For events recorded by the glass RPC, the strip with the earliest arrival time was selected, and a 20 ns time window was opened after this earliest arrival time to look for hits on strips associated with the muon tracks. A cluster was defined as a group of adjacent strips or combinations of multiple strips separated by one missing strip. Dependence of the average cluster size on the applied high voltage is shown in Fig. 3. The cluster size increases from 1.2 at 5.5 kV to 2.5 at 7.0 kV. The distribution of the cluster size at the working point of 6.5 kV is shown in Fig. 4. The average cluster size was found to be 2.3 strips.

The glass chamber efficiencies at different high voltages were measured with a threshold of 5 fC on the total charge collected by each strip, and the efficiency curve is also shown in Fig. 3.

3.3. Spatial resolution

Reference tracks from the sMDT chamber were extrapolated to the glass RPC. The spatial resolution was then defined as the difference between the measured position on the RPC and the expected position from the reference track provided by the sMDT.

The track hit positions in the RPC were reconstructed with two different methods. For the first approach, the hit positions were determined as the weighted average of the strip center positions using ADC counts recorded for the strips as weights. Since a dedicated sMDT calibration was not available during the beam test and the RPC was placed almost half a meter away from the sMDT center, a conservative assumption of 100 μm uncertainty for the predicted track hit positions was made. The RPC spatial