

Development of an 1-m long prototype TOF-RPC for the J-PARC $\pi 20$ beam line

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Abstract

We have developed a prototype multi-gap Resistive Plate Chamber (RPC) for a time-of-flight (TOF) detector at the J-PARC $\pi 20$ beam line. It is a double stack RPC with five 0.26-mm gas gaps in each stack. Its readout strips are 25 mm wide and 940 mm long. We have also developed an amplifier board which can be used for TOF-RPCs in general and carried out a beam test to evaluate the performance of the RPC and this new board. Timing measurements and a time-walk correction using a time-over-threshold (TOT) method were found to work well without stretching signals. We obtained time resolutions of 60-70 ps when the test particle's position was determined using 5 mm $\times$ 10 mm trigger detectors and 65-80 ps without this position determination.

Keywords: Resistive Plate Chamber (RPC), Time-Of-Flight (TOF), Time-Over-Threshold (TOT)

1. Introduction

Multi-gap resistive plate chambers (RPCs) are powerful detectors for precise timing measurements. A multi-gap RPC consists of resistive glass plates with gas gaps of 200-300 μm between the plates. Electron avalanches in the gas gaps induce electric signals in readout strips located outside the glass planes. Compared to other time-of-flight (TOF) counters based on scintillators and photomultipliers, RPCs offer superior time resolution, are operable in magnetic fields, and can be produced at lower cost. However, covering a large area with timing RPCs using a small number of readout channels requires enlarging area covered by each single readout strip. This is problematic since induced signals deteriorate during propagation along longer readout strips, degrading the timing information before arriving at the end of strips for readout. It has been shown that 20-30 mm wide long readout strips are well-suited to good timing performance [1]. Various experimental groups have developed multi-gap RPCs for TOF measurements with long readout strips: the R3B experiment at GSI (20 mm $\times$ 1,000 mm strip) [2], the BGOegg (25 mm $\times$ 1,000

mm strip) and the LEPS2 (25 mm $\times$ 2,000 mm strip) experiments at SPring-8 [3, 4, 5] and the SHiP experiment at CERN (29 mm $\times$ 1,600 mm strip) [6]. Another important item for RPCs using long strips is development of a high gain amplifier. The R3B, BGOegg and LEPS2 collaborations developed customized amplifier boards for their RPCs [7, 3], whereas the SHiP-RPC uses the front-end electronics board developed for the HADES-RPC [8]. Finally, a gas-tight enclosure for each RPC is also important for covering a large area with a large number of gas chambers.

We have developed TOF-RPCs for the multi-purpose spectrometer at the $\pi 20$ beam line in J-PARC [9]. At the $\pi 20$ beam line, $\pi/K/p$ beams up to 20 GeV/c will be provided to a variety of measurements, such as a charmed baryon spectroscopy experiment (E50 experiment), a cascade baryon spectroscopy measurement (E97 experiment) and high isospin di-baryon search (E79 experiment), as well as cross section measurements of the Drell-Yan processes and Λp scattering [10, 11, 12, 13, 14, 15]. The TOF-RPC is used for particle identification ($\pi/K/p$) at large scattered angles. A schematic drawing of the spectrometer is shown in

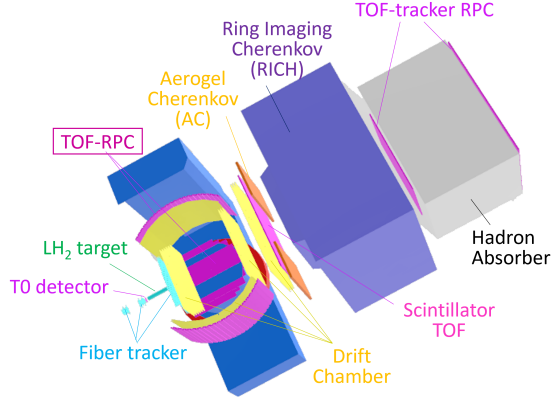


Figure 1: Schematic drawing of the spectrometer at the J-PARC $\pi 20$ beam line. The TOF-RPC covers the side wall and pole faces inside the FM magnet.

Fig.1. The TOF-RPC system will cover the side wall as well as the pole faces inside the FM magnet and will have a total coverage area of 11 m². RPCs longer than 1,600 mm will be installed. The start timing of the TOF system is measured by the T0 detector which has timing resolution below 40 ps [16]. Since the total TOF resolution needs to be less than 75 ps, 60 ps resolution is required for the RPC. Further, particle detection efficiency greater than 99% is also required.

We have developed an 1-m-long prototype RPC, starting from the BGOegg-RPC [3, 4] design. However, we improved the gas enclosure of the RPCs as well as the connection between readout strips and amplifiers. In addition, we have developed a new amplifier board that can be used for timing RPCs in general. In this article, we describe performance of the prototype RPC and the amplifier board following a beam test performed at the LEPS2 beam line at the SPring-8 synchrotron in Japan.

2. Description of the prototype RPC and the amplifier

Figure 2 shows the cross section of the prototype RPC. It is a double stack RPC in which each stack has five gas gaps. The 0.26 mm gas gaps are maintained by fishing lines between glass plates. These resistive soda glass plates are 230 mm wide, 940 mm long and 0.4 mm thick. There are eight readout strips, each of which is 25 mm wide, 26 mm in pitch and 940 mm long. They are formed of 0.018mm-thick copper printed on a 0.8 mm-thick PCB. An anode plane is formed from one of these PCBs placed in between the two stacks and two cathode

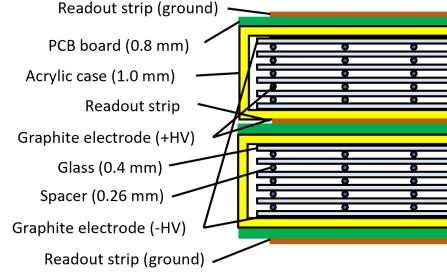


Figure 2: The cross section of the prototype TOF-RPC.

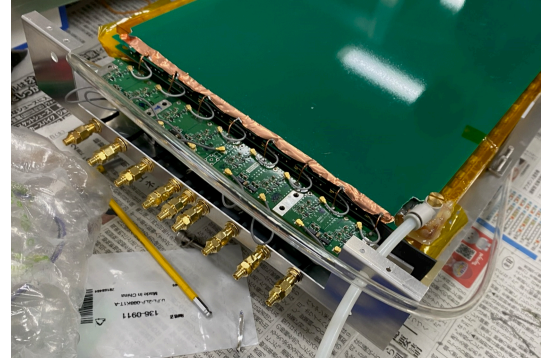


Figure 3: The amplifier board connected to the prototype RPC.

planes are placed on the outside of those stacks. Amplifiers are connected to the anode plane for signal readout with the cathode planes connected to ground. An acrylic case is used to seal each stack, surrounding only the glass plates (c.f the SHiP-RPC design [6]). This design enables us to place the readout strip boards and amplifier boards outside of the gas, reducing the total gas volume consumed by the RPC and generally making it easier to install and operate. The thickness of the top and bottom plates of the acrylic case is 1 mm. A resistive graphite tape, EEE T-9188, is placed on the inner side of the acrylic plates to form the voltage electrode.

The new amplifier has been designed so that it can be used with different timing RPCs: the TOF-RPC and the TOF-tracker RPC at the $\pi 20$ beam line, the TOF-RPC for the E88 experiment in J-PARC [17], the TOF-RPC for the LEPS2 experiment at SPring-8, and the TOF-RPC for the EMPHATIC experiment in Fermilab [18]. A photo of the amplifier board connected to the prototype RPC is shown in Fig.3. The amplifier consists of monolithic microwave integrated circuit chips arranged in two stages; BGA2866 and BGA2869. The band width of these chips is 2 GHz and the gain is 24 dB and 31 dB, respectively, resulting in a total gain of 55 dB (amplification factor of 550). A 50 Ω U.FL cable is used

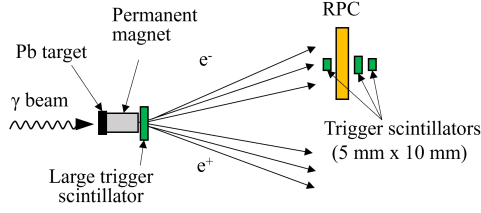


Figure 4: Experimental set up of the beam test at the LEPS2 beam line in SPring-8.

to connect each readout strip and the amplifier board. At the end of strips, we place two 100 Ω (strips 3-6), 200 Ω (strips 2,7) and 300 Ω (strips 1,8) resistors in parallel with the U.FL connectors to test different impedance matching. We tested strips 3 and 5 during the beam test at SPring-8.

3. Experimental setup

We carried out a test experiment at the LEPS2 beam line [19] in order to evaluate the performance of the prototype RPC. The experimental setup is shown in Fig.4. At the LEPS2 beam line, gamma rays up to 2.4 GeV produced via the backward Compton scattering of a UV laser with 8 GeV electrons from the SPring-8 storage ring were delivered to the experimental area. These gamma rays impinged on a lead target to create e^+e^- then passed through a dipole magnet to select and direct electrons toward the RPC. A gas mixture of $C_2H_2F_4(R134a):SF_6:butane=90:5:5$ was flowed through the RPC and ± 6.8 kV was applied to the electrodes. We used one finger scintillator on the upstream side of the RPC and two finger scintillators downstream to define a 5 mm $\times$ 10 mm trigger area. Additionally, we took data using a large trigger scintillator located just downstream of the magnet without these finger scintillators to evaluate the RPC performance when particle hit positions are not predetermined. The RF signal (resolution is below 15 ps) for the SPring-8 storage ring was used for the start timing of the TOF and the beam rate was around 10 Hz/cm². Signals from the RPC were sent to a fast discriminator, whose PECL output width is the same as input signal [3]. The threshold was optimized using the data taken at the center of a strip and set to -140 mV. An FPGA-based high resolution TDC card based on a Hadron Universal Logic (HUL) module [20] was used for the timing measurement. This TDC card accepts logic signals with widths greater than 1 ns, so the discriminator output was read without need for additional stretching.

4. Experimental results

4.1. Time walk correction

In Fig.5(a) we show the distribution of the difference between the RF signal and the mean timing of the left and right ends of the RPC as a function of the sum of the time-over-threshold (TOT) of the left and right ends for the measurement with the 5 mm $\times$ 10 mm trigger placed -50 mm from the center of strip 5. We observed a second peak in the TOT distribution which comes from a reflection at the end of strips. To carry out a time-walk correction we adopted the method in Ref.[21], which utilizes the fraction of TOT normalized by the integrated TOT of all events. In Fig.5(b), we show the relationship between the nominal TOT and this integrated TOT. The distributions of the RF-RPC timing as a function of the integral TOT before and after the time-walk correction are shown in Figs.5(c) and (d).

4.2. Position dependence

We examined the time resolution and efficiency using the 5 mm $\times$ 10 mm trigger along strip 5. In Fig.6(a) we show the time resolutions before time-walk correction of the right end (green) and left end (blue) of the RPC. The time resolution deteriorates as the signal propagation length increases. Figure 6(b) shows the time resolutions of the mean of the timing from the left and right ends before (yellow) and after (red) time-walk corrections. Time resolutions between 60 and 70 ps were obtained. The particle detection efficiency is shown in Fig.6(c) and is greater than 99% in most positions. Around the end of the strip we observed slight deterioration of the RPC performance, which may be attributed to setting the discriminator threshold too high (-140 mV). This will be investigated at a future beam test.

4.3. Whole detection area analysis

We also analyzed data triggered with the large trigger scintillator located just downstream of the magnet. Under these conditions the detector performance should be close to that of the actual experiment where particles continually strike the whole area of the RPC. Unfortunately, during this measurement the RPC developed a gas leak which increased the ratio of streamer events relative to normal avalanche events. Since the time-walk correction does not work properly with streamer signals, streamer-like events were removed from the analysis whose signal widths were greater than 8 ns. We observed cross-talk hits in several strips. To define the strip through which the particle passed, we selected the

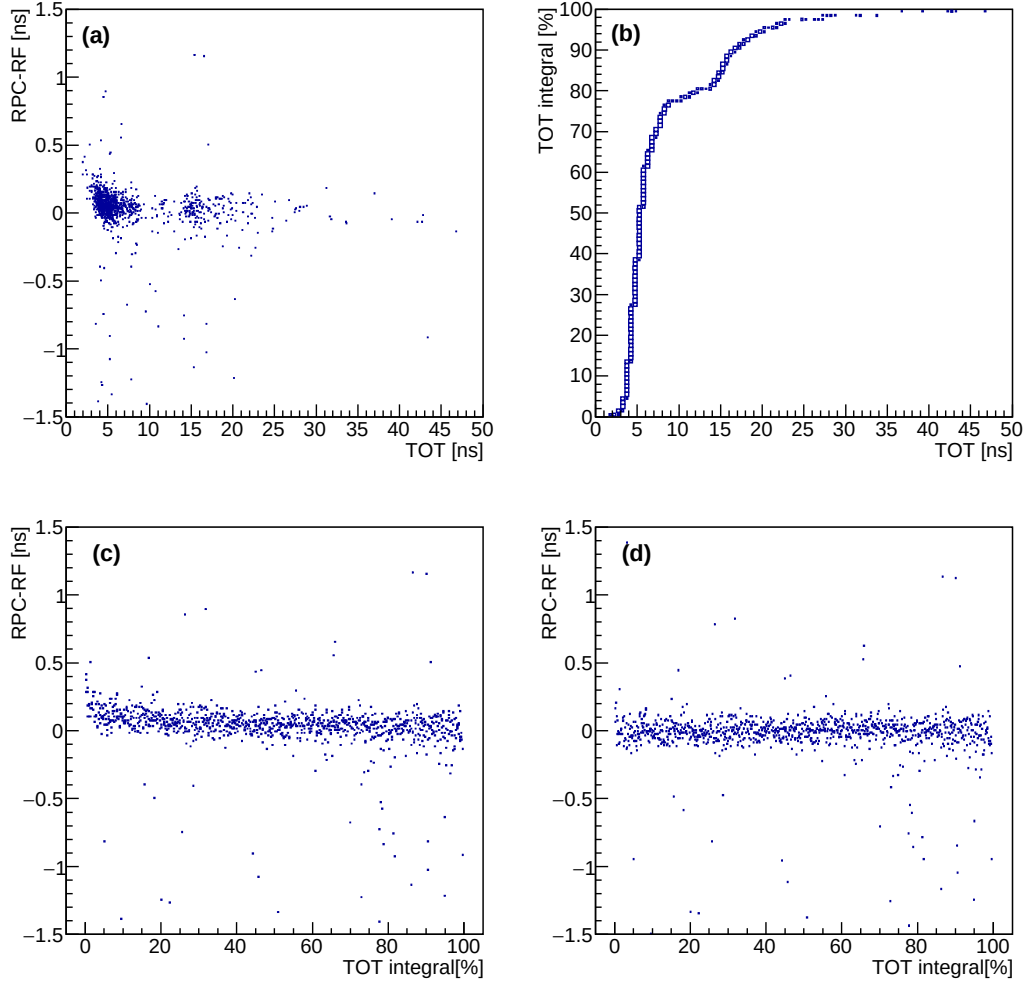


Figure 5: Experimental data from the $5 \text{ mm} \times 10 \text{ mm}$ trigger placed -50 mm from the center of strip 5. (a) The timing of RPC-RF vs TOT, (b) TOT vs TOT integral, (c) RPC-RF vs TOT integral before a time-walk correction and (d) RPC-RF vs TOT integral after a time-walk correction.

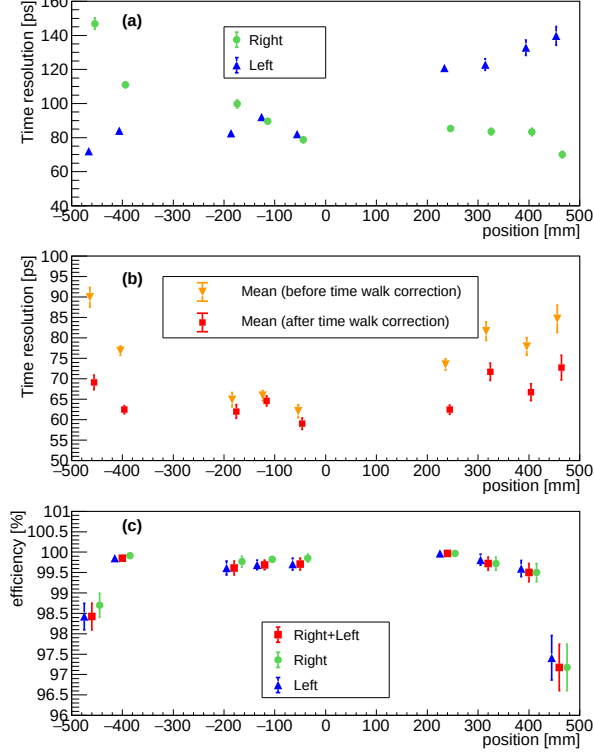


Figure 6: Position dependence of the performance of strip 5 using the $5 \text{ mm} \times 10 \text{ mm}$ trigger. (a) The time resolutions of left and right ends before time walk corrections, (b) the time resolution of the mean of the timing from the left and right ends before and after the time-walk correction, (c) the detection efficiency.

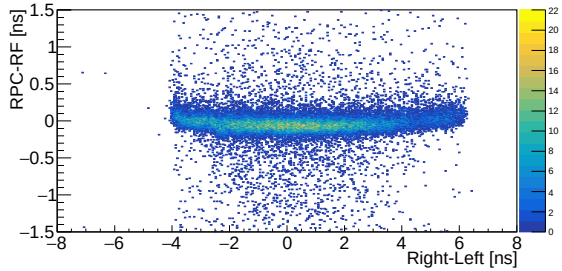


Figure 7: Distribution of the time difference between the RF signal and the mean of the RPC left and right ends as function of the time difference of the right and left ends.

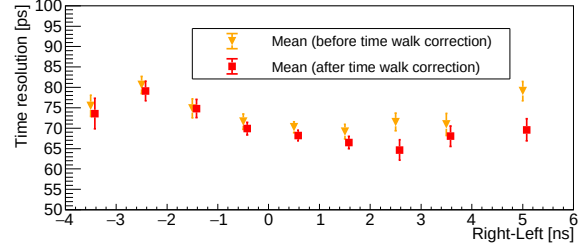


Figure 8: Time resolutions at different positions along strip 3 with the large trigger.

strip with the largest TOT. In Fig.7, we show the timing difference between the RPC (mean of left and right ends) and the RF signal and the time difference of the left and right ends of strip 3 when strip 3 had the largest TOT among all strips. The time difference between the left and right end corresponds to the hit position along the strip. As can be seen in Fig.7, the timing distribution depends on the hit position. We carried out hit-position-dependent time-walk corrections by dividing the data into 1 ns regions based on the time difference between left and right amplifier signals. In Fig.8 we show the time resolutions along strip 3. Time resolutions between 65 and 80 ps were achieved, which is slightly worse than the results with small-size trigger detectors. After fixing the gas leak in the chamber, this resolution will be investigated again at a future beam test.

5. Summary and prospects

We have developed a prototype RPC and amplifier board for the TOF detector at the J-PARC $\pi 20$ beam line. We carried out a beam test at the LEPS2 beam line in SPring-8 to evaluate the performance of the prototype RPC and the amplifier boards. We have demonstrated that the TDC measurement and time-walk correction using TOT works well without stretching signals. The small scintillator trigger data shows the time resolutions of 60-70 ps and efficiency greater than 99% except at the end of RPC readout strips. Analyzing data with only the large trigger scintillator resulted in resolutions between 65 and 80 ps. This prototype RPC and the amplifier boards will be sent to Fermilab and used for the TOF-RPC of the EMPHATIC experiment [18]. As a next step we will build a 1,800 mm long prototype RPC and evaluate its performance to optimize the threshold level and impedance matching resistors.

Acknowledgments

The experiment was performed at the BL31LEP beam line of SPring-8. We thank the Japan Synchrotron Radiation Research Institute (JASRI) and the LEPS2 staff for the stable operation of the beam line. This research was partly supported by the RCNP International Joint Usage Program No. J001, J002 and J007 (Q040 and Q044). This research was supported in part by the Ministry of Education, Culture, Sports, Science and Technology of Japan (MEXT) Grant-in-Aid for Scientific Research on Innovative Areas Grant No. JP18H05402 and No. JP21H00122, Japan Society for the Promotion of Science (JSPS) Grant-in-Aid for Scientific Research (A) Grant No. JP19H00684, No. JP22H00124, Grant-in-Aid for Early-Career Scientists Grant No. JP21K13939, and the Natural Science and Technology Council Grant No. 108-2112-M-001-020, No. 109-2112-M-001-034 and No. 110-2112-M-001-027.

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