We present the prototype of a Resistive Plate Counter equipped with electrodes made from Pestov Glass (\(\sim 10^{10} \Omega \text{cm}\)). It is aimed as solution for TOF subdetector of CBM experiment at the future FAIR facility in Darmstadt. Details of the design and the construction are introduced. Results of tests with radioactive sources and of in-beam investigations on time resolution and counting rate capability are discussed.

1. INTRODUCTION

The Compressed Baryonic Matter (CBM) experiment [1] at the future Facility for Antiproton and Ion Research (FAIR) in Darmstadt [2] is aimed at the investigation of highly compressed nuclear matter at moderate temperature produced in relativistic heavy-ion collisions. CBM will measure rare probes for studying fundamental issues of strongly interacting matter. For hadron identification, CBM foresees a time-of-flight (TOF) wall equipped with Resistive Plate Chambers (RPCs) installed about 10 m downstream from the target. The inner part of the TOF shall cover solid angles of 50 - 100 mrad around the beam axis where fluxes of charged particles of \(\sim 2 \cdot 10^4 \text{s}^{-1} \text{cm}^{-2}\) are expected. Conventional timing RPCs with standard float glass electrodes are efficient only up to fluxes of \(10^3 \text{s}^{-1} \text{cm}^{-2}\) [3]. Higher rate capabilities require electrode materials with lower bulk resistivity. These demands have to be fulfilled without deterioration of the desired time resolution.

Recently, we developed a glass resistive plate chamber prototype based on a symmetric multi-gap architecture with a multi strip central electrode [4, 5]. Such a configuration offers the possibility to build large area TOF systems with excellent time resolution (<100 ps), a detection efficiency larger than 95% and high granularity, for modern nuclear and particle physics experiments. The TOF - upgrade of the FOPI experiment is based on such a multi-gap multi-strip RPC architecture [6].
The successful commissioning of the FOPI TOF barrel [7] confirmed that large area detectors based on such architecture with an average time resolution of the order of 80 ps and very good position resolution is achievable.

For experiments at high counting rates, we designed, built and tested a new prototype of a multi-gap multi-strip RPC based on a special low-resistivity glass (in the following called Pestov glass). As for previous RPCs with similar architecture, the strip readout is done in single-ended mode. Timing and rate performances of this prototype with resistive electrodes made from this special glass were tested with $^{60}$Co source and with an electron beam at the ELBE facility at FZ Dresden-Rossendorf [8].

2. RPC PROTOTYPE DESCRIPTION

The RPC architecture is displayed in Fig. 1. The resistive electrodes of the present prototype are made from Pestov glass with a resistivity of $10^{10} \, \Omega \cdot \text{cm}$ [9]. Four plates of this glass of 2 mm thickness and 40.6 x 300 mm$^2$ total area are stacked, two on each side, relative to the central read-out electrode made from 0.5 mm double sided printed circuit board.

![Fig. 1 – Left: Schematic drawing of RPC with resistive electrodes made from Pestov glass. Right: The detector housed in the gas-tight Al box.](image)

The central anode has 14 strips on each side of 2.54 mm pitch and 1.4 mm gap width. The glass plates are separated by fishing line of 0.3 mm thickness which defines the gas gap size. Highly polished aluminium plates of 2 mm thickness were used to apply high voltage to the stack. The detector is housed in a gas-tight aluminium box of 40 x 80 x 330 mm$^3$.

3. $^{60}$Co SOURCE TESTS

3.1. EXPERIMENTAL SETUP

The experimental setup used for $^{60}$Co source tests is presented in Fig. 2. The signals of three strips read-out at both sides have been recorded. Time spectra have
been obtained from $\gamma - \gamma$ coincidences of the $^{60}$Co source between the two ends of each measured strip and a plastic scintillator (NE102 cylinder of 1 cm diameter and 1 cm height) coupled to a photomultiplier XP2972. The RPC detector was supplied with a high voltage yielding 2.9 kV per gas gap. The counter volume was flushed with a gas mixture of 85% C$_2$H$_2$F$_4$+ 5% iso-C$_4$H$_{10}$+10% SF$_6$ at atmospheric pressure. The first generation of a four-channels card (FEE1) developed for FOPI experiment at GSI [10] was used for signal amplification. The amplified signals were split and sent to the ADCs and the discriminators, respectively; their logic output went to the TDCs. The charge information was recorded using a Le Croy 2249W ADC. The time information was processed by a leading-edge discriminator CAEN N840. These logic signals were fed as stop signals (two per strip) to a Le Croy 2228A TDC. The phototube signals were discriminated in a constant fraction CAEN N842 discriminator. A coincidence between phototube signal and - at least - one RPC signal, was used as common start for the TDC and as gate for the ADC. An OR of the leading edge discriminator outputs from one end of each measured strip and also the output of the coincidence unit were fed into a scaler.

3.2. RESULTS AND DISCUSSIONS

The time of flight information, for each measured strip, was obtained as the mean of the time information of the two ends, $(t_{left} + t_{right})/2$, relative to the plastic scintillator time. The mean time is independent of the location of the avalanche along the strip. From the time difference of the same two timing signals, the position information on avalanche location along the strip can be derived.

The correlation between the TOF and charge distributions for one of the measured strips is shown in the left panel of Fig.3. The finite dependence of the time information on the signal height (walk effect) was corrected using a polynomial fit. The resulting walk-corrected correlation between the TOF and charge distributions is
shown in the right panel of Fig. 3. The corrected data were then used to estimate the RPC time resolution. In order to minimize the spreading of the time of flight distribution given by the different trajectories the scattered $\gamma$ quanta follow from the $^{60}$Co source to the counter, a 3 cm cut in position along the strip (as derived from the time difference of the signal from both strip ends), centered on the position of the source, was applied. Removing the small signals, as can be seen in the charge distribution shown in the left part of Fig. 4, the TOF spectrum displayed in the right panel of Fig. 4 is derived. As time resolution we denote the $1\sigma$ width taken from a Gaussian fit to

Fig. 3 – Correlation between the time of flight and signal charge distributions before (left) the slewing correction, after (right) the slewing correction.

the time of flight distribution yielding 3.7 channels. With the TDC-slope calibration of 42 ps per channel and subtracting quadratically the time resolution (125 ps) of the

Fig. 4 – Left: Charge distribution of RPC prototype at a counting rate of 160 Hz/cm$^2$. Right: Time of flight spectrum at the same counting rate.
plastic scintillator, the obtained intrinsic RPC time resolution is 93 ps ± 10 ps. Note that the time resolution of the scintillation detector was measured in a separate run using two identical plastic scintillators and phototubes.

We investigated the effect of high counting rates on the RPC prototype performance. At low particle flux densities, detection efficiencies for minimum ionizing particles beyond 95% were obtained for this type of counters [4, 5]. With the aim to obtain information on the detection efficiency in high counting rate environment using radioactive sources, we studied the rate of $\gamma - \gamma$ coincidences using a $^{60}\text{Co}$ source (Co-Co) as a function of particle flux density.

In order to investigate this effect we used a high activity (800 MBq) $^{137}\text{Cs}$ source to generate a high counting rate environment and a weak activity $^{60}\text{Co}$ source for timing information, as can be followed in Fig. 5. The measured rate of $\gamma - \gamma$ coincidences using only the $^{60}\text{Co}$ source (Co-Co) was 0.4 Hz at a counting rate of 30 Hz/cm$^2$. The $^{137}\text{Cs}$ source was shielded by lead bricks and aligned relative to the center of the counter in order ensure a close-to-uniform exposure over the whole surface of the counter. The counting rate was changed by variation of the distance between the RPC and the high activity source.

Within this configuration, when the counter is exposed to both radioactive sources, we have three types of coincidences, i.e. Co-Co which we would like to extract in a background of Co-Cs and Cs-Cs random coincidences. From the experimental data we obtained the rate of all these coincidence types as a function of the single counting rate when the counter is exposed to both radioactive sources and the rate of Cs - Cs coincidences only when the $^{137}\text{Cs}$ source is used, respectively. In order to get the Co-Co coincidences as a function of counting rate, we need to subtract from all coincidences the Cs-Cs and the Cs-Co coincidences. Because Co-Cs coincidences cannot be measured in any configuration we tried to estimate them using the experimental data. It is known that, at present, the RPC rate capability is limited at 1 kHz/cm$^2$ by the use of high resistivity ($10^{12}$-$10^{13}$ $\Omega$cm) float glass for resis-

![Fig. 5 – Experimental setup for high counting rate tests.](image)
Fig. 6 – Rate of coincidences (left) and time resolution (right) as a function of counting rate.

tive electrodes [3]. The high rate application requires electrodes of lower resistivity. Using for this prototype Pestov glass with a resistivity of the order of 10^{10} \, \Omega cm, we supposed that up to 1 kHz/cm\textsuperscript{2} the counter performance is not affected and consequently, the number of Co-Co coincidences stay unchanged at 0.4 Hz, as mentioned above. Hence, we subtracted them from the difference between all coincidences and Cs-Cs coincidences obtaining in this way only the mixed coincidences Co-Cs for the region of counting rates up to 1 kHz/cm\textsuperscript{2}. We fitted the resulting dependence with a polynomial function and extrapolated it to high counting rates in order to get the information about Co-Cs coincidences for the corresponding counting rate range (cf. left panel of Fig. 6). Finally, having all types of coincidence known, we subtracted from the all coincidences (Co-Co + Co-Cs + Cs-Cs) the contribution of random coincidences (Co-Cs + Cs-Cs). Thus, we obtained the Co-Co coincidences as a function of counting rate (left panel of Fig. 6). The Co - Co coincidences, open circles, do not change with the counting rate up to about 3 kHz/cm\textsuperscript{2}, the maximum counting rate reachable with the used \textsuperscript{137}Cs source. The particle flux density was calculated as the number of events given by the RPC divided by the measurement time and by the active area of the three strips in use. Simultaneously, we recorded the time information at each counting rate. Applying the procedure described above, the corresponding time resolution as a function of counting rate was determined (right panel of Fig. 6). Note that the position cut made in our analysis does not eliminate completely the random coincidences of types Cs-Co and Cs-Cs. Therefore the apparently deterioration of the time resolution with the counting rate is mainly due to the effect of the random coincidences.
4. IN - BEAM TESTS

4.1. EXPERIMENTAL SETUP

The experiment has been performed at the electron linac ELBE at the Forschungszentrum Dresden-Rossendorf [8]. The accelerator produces a quasi-continuous electron beam with a micro-pulse repetition rate of 13 MHz and a corresponding beam current up to 1mA, making it attractive for detector tests at high rates. The R.F. signal of ELBE can be used as time reference for TOF measurements due to the short micro-pulse duration of less than 5 ps. The electron energy was chosen to 30 MeV. The geometry of the test setup is shown in Fig. 7. The electron beam is scattered by a 18 µm thick Al foil (placed in a scattering chamber) in order to reduce the beam intensity and to distribute it over a large area. The test setup is located at 45° and 2 m from the target. Three scintillators of size 2 x 2 cm² are used as active collimators. They have thicknesses of either 1 mm (coupled to photomultiplier S5 of type Philips XP2972) or 5 mm (viewed by two photomultipliers S1/S2 and S3/S4 of type Philips XP2020). The whole setup is covered by a lead shielding (not displayed). The trigger requires a coincidence between all scintillator signals and, at least, one strip of the RPC detector under test. The position of the counter in the experimental setup can be followed from the right panel of Fig. 7. We employed the same preamplifier/discriminator cards, gas composition and high voltage settings as used for the tests with radioactive sources. The signals of four strips read out at both sides were recorded. The corresponding time (charge) signals were digitized using a CAEN TDC V1290N (ADC V965).

4.2. RESULTS AND DISCUSSIONS

Results obtained for each of four measured strips are presented. The TOF distributions, for the involved strips, were obtained as described in Sec. 3.2, i.e. the
arithmetic mean of the time signals derived from both ends, of a strip relative to the R.F. signal provided by ELBE.

Fig. 8 – Upper left side: Correlation between the time of flight and signal charge distributions for raw data. Upper right side: the same as left but after time-slewing correction. Lower left: Time of flight spectrum after slewing correction. Lower right: The same as left for events with maximum charge on analyzed strip.

The dependence of the time of flight on the integrated charge before the slewing corrections, for one of the measured strips, is presented in Fig. 8 (upper left panel). The same correlation but for walk-corrected data using a polynomial fit, is given in the upper right panel of the figure. The obtained TOF spectrum fitted with a Gaussian function is shown in the lower left panel. The time resolution obtained for this strip amount to 58 ps. By selection of the events with the highest charge on the analyzed strip the time resolution improves to 52 ps. The finite size of the plastic scintillators used for collimation (2 x 2 cm²) allowed for investigation of the position dependence
of the time information. The position was obtained as the time difference \((t_{\text{left}} - t_{\text{right}})\) of the signals from both ends of a strip. Only for one strip the correction of the position dependence was necessary, improving the time resolution from 70 ps to 66 ps. The resolutions obtained for the four measured strips are shown in the left part of Fig. 9.

The difference in the time resolutions of the strips quite probable comes from the difference in time resolution between the electronic channels. It should be stressed that these results have been obtained under a uniform illumination of the counter at a particle flux density of 975 Hz/cm\(^2\) in contrast with tests performed with minimum ionizing hadron beams when only a small part of the active area is exposed.

The right panel of Fig. 9 displays the RPC counting rate versus the electron beam current. A clear linear dependence is visible over the investigated intensity range. Thus, any saturation effect, if present, should occur at higher intensities.

5. CONCLUSIONS

In summary, a four-gap multistrip RPC prototype based on Pestov glass was built and tested using radioactive sources in IFIN-HH and with 30 MeV electron beam at ELBE facility at FZ Dresden - Rossendorf.

The results of the source tests show that the RPC prototype has a time resolution better than 100 ps. This time resolution, accompanied by a constant detection efficiency, was found up to fluxes of about 3 kHz/cm\(^2\), the maximum rate reachable with the available sources.

The counter performance in terms of time resolution (\(~65\) ps) was confirmed by the tests performed in real conditions using a 30 MeV electron beam. We empha-
size that this time resolution was obtained on the condition of a uniform exposure of the active area of the counter with a particle flux of $\sim 1 \text{ kHz/cm}^2$.

The linear behavior of the RPC rate as function of electron beam current shows that the electric field inside the gas gaps is not significantly reduced by a possible perturbation of the electrical potential of the resistive electrodes at high counting rates, up to $9 \text{ kHz/cm}^2$.

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