Study of the ecological gas for MRPCs

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Abstract

The Multigap Resistive Plate Chamber (MRPC) is a gaseous detector; the performance depends very much on the gas mixture as well as the design. MRPCs are used as a timing device in several collider experiments and cosmic ray experiments thanks to the excellent timing performance. The typical gas mixtures of RPC-type detectors at current experiments are based on the gases $C_2F_4H_2$ and SF_6. These gases have very high Global Warming Potential (GWP) values of 1430 and 23900 respectively.

The present contribution has been performed as a part of efforts to reduce the amount of greenhouse gases used in high energy experiments. The performance of MRPC has been measured with two different gas mixtures; $C_2F_4H_2$ based gas mixtures and the ecological $C_3F_4H_2$ (HFO-1234ze). A small MRPC was used for the tests. It has an sensitive area of 20 × 20 cm^2; it was been built with 6 gaps of 220 μm.

In normal operation, the strong space charge created within the gas avalanche limits the avalanche's growth. SF_6 plays an important part in the process due to its high attachment coefficient at low electric fields. It is thus necessary to find another gas that has a similar attachment coefficient. CF_3I is a possible candidate. Tests were performed with this gas added to $C_3F_4H_2$.

Keywords: LHC, ALICE-TOF, MRPC, eco-friendly gas

1. Motivation

The advantage of using the Resistive Plate Chamber (RPC) is due to its low cost and high detection efficiency. Most RPC-type detectors have been operating with gas mixtures containing R134a ($C_2F_4H_2$) and SF_6, that have a high Global Warning Potential (GWP). As a way of reducing an amount of harmful gases emitted to the atmosphere, closed loop gas systems have been introduced, however the construction cost is not negligible. A better way is to replace these high GWP gases with more ecological gas mixtures.

Searching for new ecological gases has been carried out by various groups [1, 2], this study continues this investigation. The ecological gas $C_3F_4H_2$ has been considered as a substitute for $C_2F_4H_2$, and gas mixtures with the following gases, CO_2, SF_6 and CF_3I, have been tested. Especially, CF_3I is introduced as a possible candidate to substitute for SF_6.

2. MRPC

We used a MRPC that has an active area of 20 × 20 cm^2. It consists of 24 pickup strips of 0.7 × 20.5 cm^2 with 6 gas gaps of 220 μm. The resistive plates were 280 μm thick soda lime float glass. The measured time resolution in previous tests with gas mixture, $C_2F_4H_2/SF_6$ (95%/5%) [3] is about 80 ps at 15 kV operating voltage.

The ultrafast NINO amplifier-discriminator [4] is used to readout signals from MRPC. This ASIC has been developed for ALICE TOF detector at LHC experiment [5]. A differential signal is derived from anode and cathode readout strips which is used as input to the NINO card. The width of the output signal from the NINO is related on the amplitude of the input signal through a time-over-threshold (TOT) technique.

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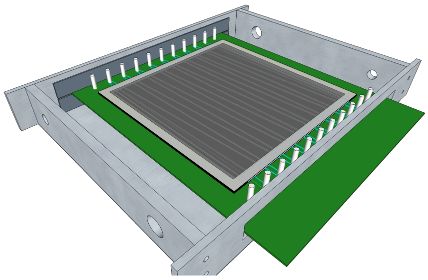

Figure 1: Schematic view of the small MRPC used for the beam test. It has a $20 \times 20\,\text{cm}^2$ active area with 6 gaps of $220\,\mu$m.

The signals at both ends of a strip of the small MRPC have been readout by NINO cards. The threshold control voltage was set at 160 mV; this threshold setting corresponds to the discriminator being set to fire for 40 fC signals. The NINO's LVDS signal has been connected to two CAEN V1290 TDCs which have a time resolution of 30 ps for the two edges of the LVDS pulse.

3. Experimental layout

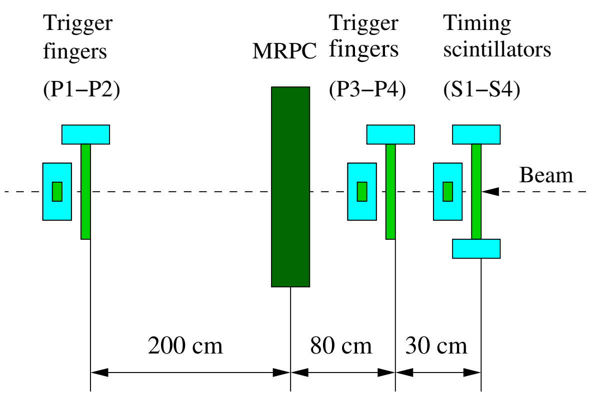

Figure 2: Setup at T10 beam facility.

T10 is a test beam in the East hall; it provides a pion beam with a momentum up to 6 GeV/c. The setup at T10 is shown in figure 2. Two sets of trigger scintillators with active areas of $2 \times 2\,\text{cm}^2$ for P1-P2 and $1 \times 1\,\text{cm}^2$ for P3-P4. A trigger signal is created from the coincidence of these scintillators. The accurate time information of triggered event is provided by two fast scintillator bars ($2 \times 2 \times 10\,\text{cm}^3$); each bar is read out with two photomultipliers. These are shown as S1-S4 in figure 2.

4. Results

4.1. Event selection

The preliminary stage of event selection has been done by accepting events within $\pm 3\sigma$ from the mean value of the time difference distribution from two trigger scintillators; (S1+S2)/2 - (S3+S4)/2. The mean time, (S1+S2+S3+S4)/4, is used as reference time. Its precision is estimated from the time difference distribution of two timing scintillators giving a time resolution of the reference time of 47 ps. When we quote the time resolution of the MRPC this 47 ps is subtracted in quadrature. The data was collected in two test beam periods with the beam intensity set at various low flux. The flux is estimated from the coincidence of the scintillators S1-S4 with a sensitive area $2 \times 2\,\text{cm}^2$ and the beam spill period of 350 ms.

4.2. Efficiency

The chamber efficiency is defined as a ratio between the number of events detected by MRPC and the number of triggered events. The figures 3 and 4 show efficiencies as a function of applied voltages, obtained with various gas mixtures and particle flux.

In the first period, the default particle flux was $1.3\,\text{kHz/cm}^2$, and two additional flux, 0.5 and $0.9\,\text{kHz/cm}^2$ are used for the 100% $C_3F_4H_2$ to check behaviour of the MRPC at various rates Basically, the operating voltage of $C_3F_4H_2$ mixtures need an increase of voltage by 4 kV more than the $C_2F_4H_2/SF_6$ gas mixture. The efficiencies obtained for the efficiency plateau are 95% for $C_2F_4H_2/SF_6$ and 88% for $C_3F_4H_2$ at the same particle flux of $1.3\,\text{kHz/cm}^2$. At lower flux for pure $C_3F_4H_2$ the efficiency increases and the plateau becomes longer, and in case of $0.5\,\text{kHz/cm}^2$ we obtained the similar result as the one of $C_2F_4H_2/SF_6$.

Adding CO_2 to the $C_3F_4H_2$ and increasing the ratio up to 15%, the operating voltage reduced by 1 kV, however the efficiency does not improved and the efficiency plateaus shortened. SF_6 is known as a very electronegative gas together with the highest known GWP of 23900. Adding this to $C_3F_4H_2$ the efficiency increases and reaches 98%. The plateaux lengthen even with a small amount of SF_6.

In the second beam period, a new gas CF_3I has been tested, which is a part of the research for finding a new gas in order to replace high GWP gas SF_6. Adding this new gas to the ecological gas increases the efficiency. Increasing the ratio

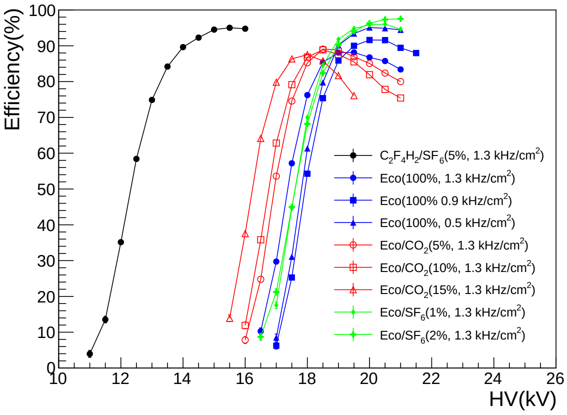

Figure 3: Efficiencies measured with various gas mixtures at 1.3 kHz/cm^2 of particle flux and 100% $C_3F_4H_2$ is tested at additional particle flux, 0.5 and 0.9 kHz/cm^2.The error bars are contained within the size of the symbols.

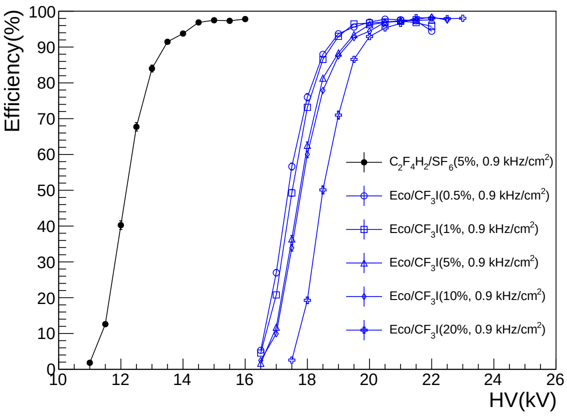

Figure 4: Efficiencies measured with various gas mixtures that includes CF_3I mixed with $C_3F_4H_2$.

of CF_3I gas needs higher operating voltage. The plateaux are improved by becoming longer, shown in figure 4. The efficiencies are 98% for both gas mixtures; $C_2F_4H_2/SF_6$ and $C_3F_4H_2/CF_3I$.

4.3. Time resolution

To obtain position independent time resolution, the mean time of signals at both ends is used to calculate the time resolution. The measured mean time distribution and the mean width distribution for the pure $C_3F_4H_2$ is shown in figure 5 and 6. Using the time-of-threshold technique (TOT) of NINO chip can derive a time-slewing correction that depends on an amount of charge. To correct this time-slewing effect a fourth order polynomial fit function

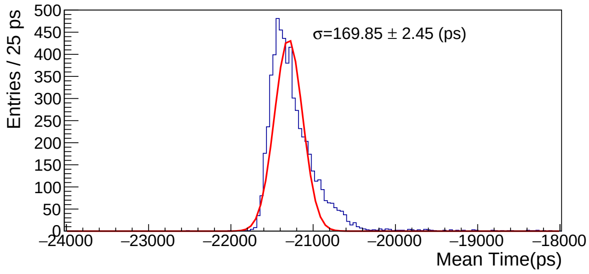

Figure 5: Measured mean time distribution for the data taken at 19 kV, 1.3 kHz/cm^2 and with 100% $C_3F_4H_2$.

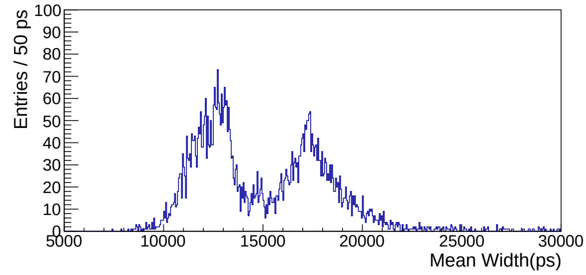

Figure 6: Time-over-threshold (average of two ends) 100% $C_3F_4H_2$ distribution for the data taken at 19 kV, 1.3 kHz/cm^2.

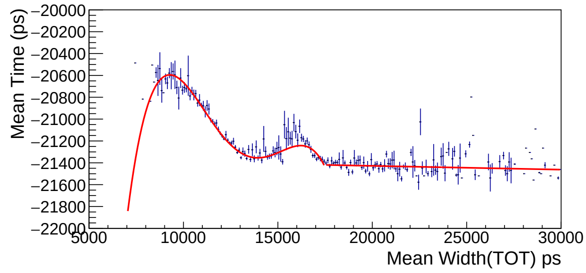

Figure 7: Profile of time vs. time-over-threshold 100% $C_3F_4H_2$ and a fourth and a first order polynomial fit function lines for the time-slewing correction are shown.

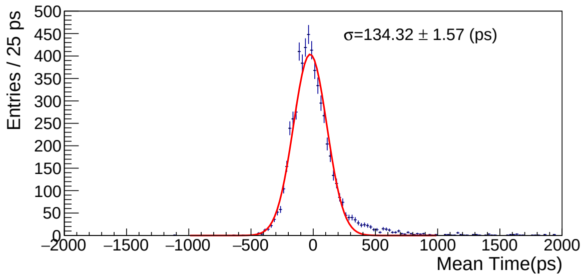

Figure 8: Time-slewing corrected mean time distribution for the 100% $C_3F_4H_2$.

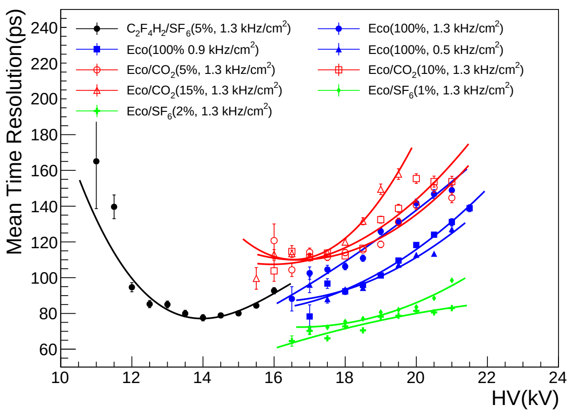

Figure 9: Time resolutions of various gas mixtures at 1.3 kHz/cm^2 and of different particle flux on $C_3F_4H_2$.

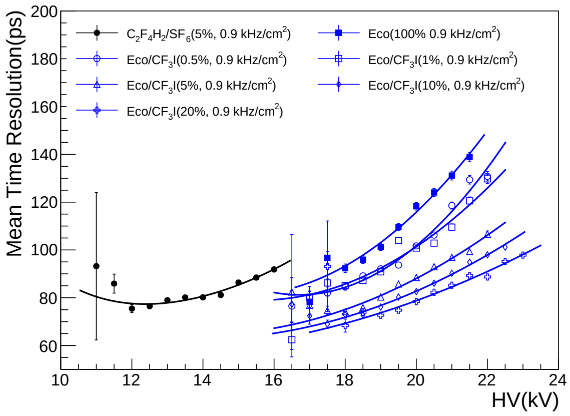

Figure 10: Time resolutions of various gas mixtures at 0.9 kHz/cm^2.

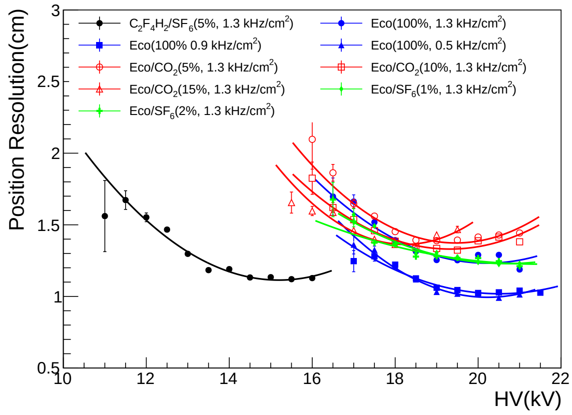

Figure 11: Position resolution at 1.3 kHz/cm^2.

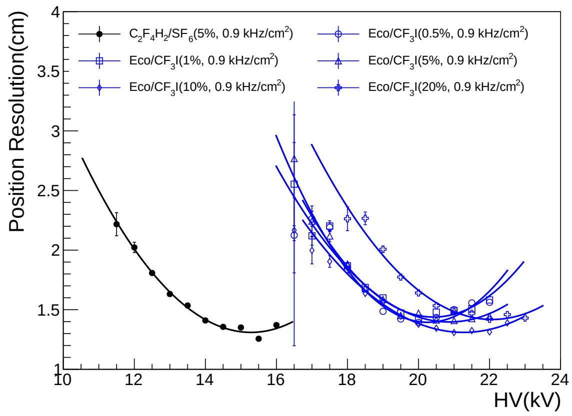

Figure 12: Position resolution at 0.9 kHz/cm^2.

is used.

The measured time resolutions for different gas mixtures are shown in figure 9 and 10. At the knee voltage of the efficiency plateau the time resolution is 88 ps for $C_2F_4H_2/SF_6$ and $C_3F_4H_2/SF_6$. Others are between 115 and 125 ps at 1.3 kHz/cm^2. A better resolution is obtained for the $C_3F_4H_2$, which is between 95 and 120 ps depending on the ratio of CF_3I.

4.4. Position resolution

The position resolution can be estimated from the difference in time measured at both ends of a hit strip. The position resolution of all the gas mixtures of $C_3F_4H_2$ are similar to $C_2F_4H_2/SF_6$ in the same particle flux, shown in figure 11 and 12. At the lower particle flux, it is improved to 1.1 cm.

4.5. Streamer probability

It is difficult to define and count the number of streamers directly. In this analysis, a signal firing more than 5 neighbouring strips is used to define streamer event. The ratio of streamer events over the triggered events is defined as the streamer probability. It is assumed that the high value of streamer probability will accelerate ageing.

The observed probability is shown in figure 13. Comparing values at their operating voltages and 4), most gases have streamer probabilities less than 5%, except for the gas mixtures of $C_3F_4H_2/CO_2$, which increased its value proportional to the amount of CO_2. Adding CF_3I to $C_3F_4H_2$ shows an tendency of increase of the operating voltage. It suppresses the streamer production at the knee of the efficiency plateau when increasing its ratio. To have the effective suppression

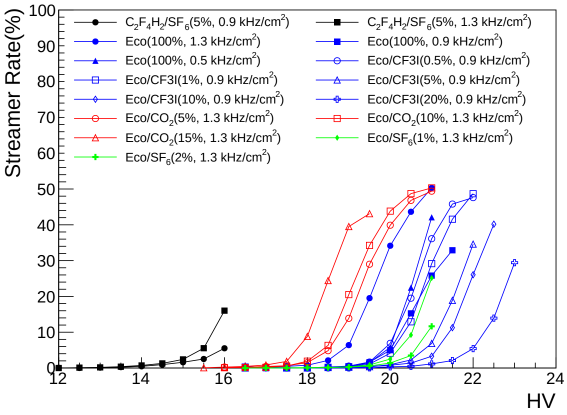

Figure 13: Streamer probability for gas mixtures.

of streamer, a significant amount of CF_3I is needed unlike the case of adding SF_6.

5. Conclusion

The feasibility of using the ecological gas (HFO-1234ze: $C_3F_4H_2$, GWP < 7) and also the mixture with CF_3I (GPW < 1) have been tested using a small MRPC with 6 gaps of 220 μm, for the purpose of finding ecological gases to substitute for greenhouse gases, namely $C_2F_4H_2$ and SF_6, being currently used in many experiments.

For the performance of MRPC with ecological gas mixture, it needs an operating voltage of 25% higher to reach the plateau compared with the more commonly used gas mixture, $C_2F_4H_2/SF_6$. Adding SF_6 to $C_3F_4H_2$, the result seems almost same as the commonly used one, except for the operating voltage. Adding CF_3I to the $C_3F_4H_2$, the efficiency plateaux becomes better depending on the amount. However, the operating voltage slightly increases.

Overall performance of $C_3F_4H_2/CF_3I$ (80/20%) mixture shows a very similar result as the one of $C_2F_4H_2/SF_6$. It should be noted here that the price of CF_3I gas is currently very expensive.

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