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 $\text{C}_2\text{F}_4\text{H}_2$ and $\text{SF}_6$. 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; $\text{C}_2\text{F}_4\text{H}_2$ based gas mixtures and the ecological $\text{C}_3\text{F}_4\text{H}_2$ (HFO-1234ze). A small MRPC was used for the tests. It has a sensitive area of $20 \times 20 \text{cm}^2$; it was been built with 6 gaps of 220 $\mu\text{m}$.

In normal operation, the strong space charge created within the gas avalanche limits the avalanche’s growth. $\text{SF}_6$ 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. $\text{CF}_3\text{I}$ is a possible candidate. Tests were performed with this gas added to $\text{C}_3\text{F}_4\text{H}_2$.

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 ($\text{C}_2\text{F}_4\text{H}_2$) and $\text{SF}_6$, that have a high Global Warming 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 \cite{1,2}, this study continues this investigation. The ecological gas $\text{C}_3\text{F}_4\text{H}_2$ has been considered as a substitute for $\text{C}_2\text{F}_4\text{H}_2$, and gas mixtures with the following gases, CO$_2$, $\text{SF}_6$ and $\text{CF}_3\text{I}$, have been tested. Especially, $\text{CF}_3\text{I}$ is introduced as a possible candidate to substitute for $\text{SF}_6$.

2. MRPC
We used a MRPC that has an active area of $20 \times 20 \text{cm}^2$. It consists of 24 pickup strips of $0.7 \times 20.5 \text{cm}^2$ with 6 gas gaps of 220 $\mu\text{m}$. The resistive plates were 280 $\mu\text{m}$ thick soda lime float glass. The measured time resolution in previous tests with gas mixture, $\text{C}_2\text{F}_4\text{H}_2/\text{SF}_6$ (95%/5%) \cite{3} is about 80 ps at 15 kV operating voltage.

The ultrafast NINO amplifier-discriminator \cite{4} is used to readout signals from MRPC. This ASIC has been developed for ALICE TOF detector at LHC experiment \cite{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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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

![Setup at T10 beam facility.](image)

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 × 2 cm² for P1-P2 and 1 × 1 cm² 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 × 2 × 10 cm³); 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 ±3σ 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 × 2 cm² 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 kHz/cm², and two additional flux, 0.5 and 0.9 kHz/cm² are used for the 100% C₃F₄H₂ to check behaviour of the MRPC at various rates. Basically, the operating voltage of C₃F₄H₂ mixtures need an increase of voltage by 4 kV more than the C₂F₄H₂/SF₆ gas mixture. The efficiencies obtained for the efficiency plateau are 95% for C₂F₄H₂/SF₆ and 88% for C₃F₄H₂ at the same particle flux of 1.3 kHz/cm². At lower flux for pure C₃F₄H₂ the efficiency increases and the plateau becomes longer, and in case of 0.5 kHz/cm² we obtained the similar result as the one of C₂F₄H₂/SF₆.

Adding CO₂ to the C₃F₄H₂ 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. SF₆ is known as a very electronegative gas together with the highest known GWP of 23900. Adding this to C₃F₄H₂ the efficiency increases and reaches 98%. The plateaux lengthen even with a small amount of SF₆.

In the second beam period, a new gas CF₃I has been tested, which is a part of the research for finding a new gas in order to replace high GWP gas SF₆. Adding this new gas to the ecological gas increases the efficiency. Increasing the ratio
of CF$_3$I 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$_2$F$_4$H$_2$/SF$_6$ and C$_3$F$_4$H$_2$/CF$_3$I.

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$_2$F$_4$H$_2$ 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
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 $C_2F_4H_2$ are similar to $C_2F_3H_2/SF_6$ 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 $I$, 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 $C_2F_4H_2$ 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...
of streamer, a significant amount of CF₃I is needed unlike the case of adding SF₆.

5. Conclusion

The feasibility of using the ecologcial gas (HFO-1234ze: C₂F₄H₂, GWP < 7) and also the mixture with CF₃I (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 C₂F₄H₂ and SF₆, 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, C₂F₄H₂/SF₆. Adding SF₆ to C₂F₄H₂, the result seems almost same as the commonly used one, except for the operating voltage. Adding CF₃I to the C₂F₄H₂, the efficiency plateaux becomes better depending on the amount. However, the operating voltage slightly increases.

Overall performance of C₂F₄H₂/CF₃I (80/20%) mixture shows a very similar result as the one of C₂F₄H₂/SF₆. It should be noted here that the price of CF₃I gas is currently very expensive.

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