Investigating MRPC Detector Performance with Eco-friendly Gas Mixtures

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STA Team

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1. Why do we want to go CERN?

We're a group of students at STA. STA is a high school dedicated to teaching science to its students. CERN is the leading laboratory for particle physics and attracts the cream of physicists from all over the world. Detectors developed at CERN and used in the beam lines for experiments are at the cutting edge of technology. At STA we work at the nanosecond level - but at CERN they are working with detectors and electronics that are working at the picosecond level. We're at the beginning of our journey in science: a visit to CERN (plus working in a test beam) will inspire us that science research is a something interesting and motivating. Also, this chance will enable us to interact with other young researchers - from a variety of universities/countries. Especially important for women in science [Girls represent 50% of our team].

2. Project Objectives

The issue of climate change caused by global warming has become a serious issue that needs immediate solutions. That is why we're keen in this proposal to find ecofriendly gas mixtures that can be used in MRPCs detectors while maintaining high performance and efficiency.

3. Introduction

SF_6 and $C_2H_2F_4$ gas mixtures are used in MRPCs due to their high electronegativity, attachment coefficient, Arc quenching and insulation properties and the ability to work under relatively low voltage (14.5kV). which enhances both time resolution and efficiency. But SF_6 and $C_2H_2F_4$ have very high global warming potential (GWP) values 23900 and 1430 respectively. So, our proposal aims to investigate the performance of MRPCs when replacing harmful gas mixtures by eco-friendly mixtures (CF_3I added to $C_3H_2F_4$). Table 1 shows Comparison of properties of different gases [2-4].

Table 1. Comparison of properties of different gases.

	CF_3I	CF_4	CO_2	N_2	O_2	SF_6
ODP	**0.0001**	**0**	**0**	**0**	**0**	**0**
GWP	**0.45**	**6300**	**1**	**0**	**0**	**23900**
LIFETIME	**<1 day**	**50 kyr**	**<15 yr**	**Infinity**	**Infinity**	**3200 yr**
$T_{BOILING}$	**-22.5**	**-128**	**-78.5**	**-195.8**	**-183**	**-64**

Note: ODP, ozone depleting potential; Lifetime, lifetime in the atmosphere; $T_{BOILING}$, boiling temperature at 0.1MPa (°C)

The weak chemical bond C-I in CF_3I means that it can be decomposed quickly in the atmosphere, and therefore the ODP of CF3I for surface release is less than 0.0001[2-4].

4. Methods

Why CF_3I? We've focused through our research on three main factors to specify the most suitable eco-friendly gas mixture which're discussed below;

- **Ionization coefficient;**

For the following formula derived by Riegler [1];

$$\sigma(t) = \frac{1.28}{(\alpha - \eta)\upsilon}$$

Where;

υ: electron drift velocity η: Attachment Coefficient. α: Townsend Coefficient=1/λ (λ Lambda is the mean distance between ionising collisions).

To reduce jitter and make better timing measurement, we need to have the smallest possible lambda λ. This can be done by growing avalanche over very small gas gap. But the small gap means there is a chance that through going charged particle does not have an ionising collision with a molecule of gas. This can highly reduce the efficiency of the detector. To solve the problem of efficiency: many gas gabs are needed: hence the multigap RPC. It was subsequently found that gas gabs of 250 micron operated with a Townsend coefficient that corresponded to a gas gain of 10^{16} for a single electron. Electron avalanche grows according to Townsend law;

$$N = N_O e^{\alpha x}$$

Shows how the Townsend and the gap distance governs the avalanche growth. Such high gain can lead to sparks. But it doesn't happen due to space charge which limits the avalanche growth when it grows to~10^7 electrons [5]. Then the resultant electric field, affected by electrons of the head of avalanche, drops towards zero. The electric field is so modified that the attachment coefficient is dominant. This means electrons are captured by CF_3I to form negative ions and thus the growth of avalanche is turned off. It is necessary to have high attachment coefficient at low electric field [6-7] to prevent sparks production. Figure 1 indicates that $(\alpha - \eta)$ of CF_3I with its mixtures are higher than a pure SF_6 which is good for timing measurement.

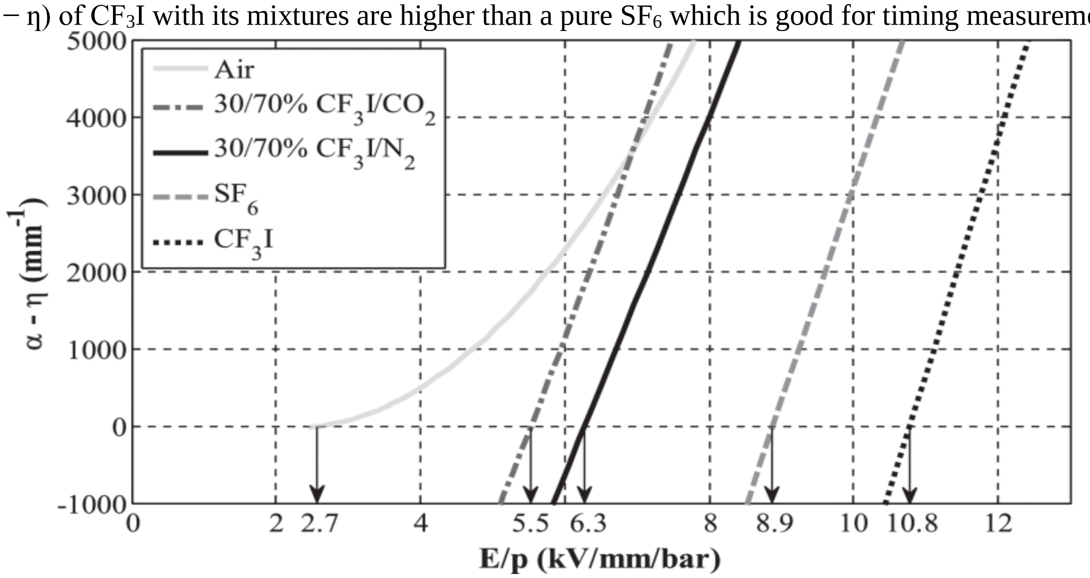

Figure 1: Effective ionisation coefficients in pure gases (Air, SF6 and CF3I,) and gas mixtures (30/70% CF3I/N2 and 30/70% CF3I/CO2). Arrows indicate the critical E/p at (α−η)=0.

- **<u>Electronegativity;</u>**

  the Higher electronegativity of gas mixture, the higher chance of electron being captured by a molecule (thus forming a negative ion). The importance of electronegativity of gas mixture is to switch off the avalanche growth above a certain size. CF_3I is highly electronegative gas that can be used to switch off the avalanche [5-7].

- **<u>Insulating capacity and arc quenching</u>;**

  After the avalanche the space between the plates is filled with positive and negative ions. Then they recombine to form neutral ions generating photons. They can go off and hit the cathode knocking out an electron initiating a new avalanche. So, quenching property is important. SF_6 has arc quenching property 3to4 times better than air [8]. The insulation capability makes CF_3I a feasible alternative to SF_6 as an insulation medium where arc quenching is not required. trifluoro iodomethane (CF_3I) has a 1.2 times insulation strength higher than SF_6 under a uniform electric field [8-9], which indicates a great potential of CF_3I or its mixtures as alternative to SF_6 for high-voltage apparatus.

4.1 Experimental setup and Procedures

The MRPC that can be used for the beam test is 220micron meter with 6 gaps as shown in figure2.

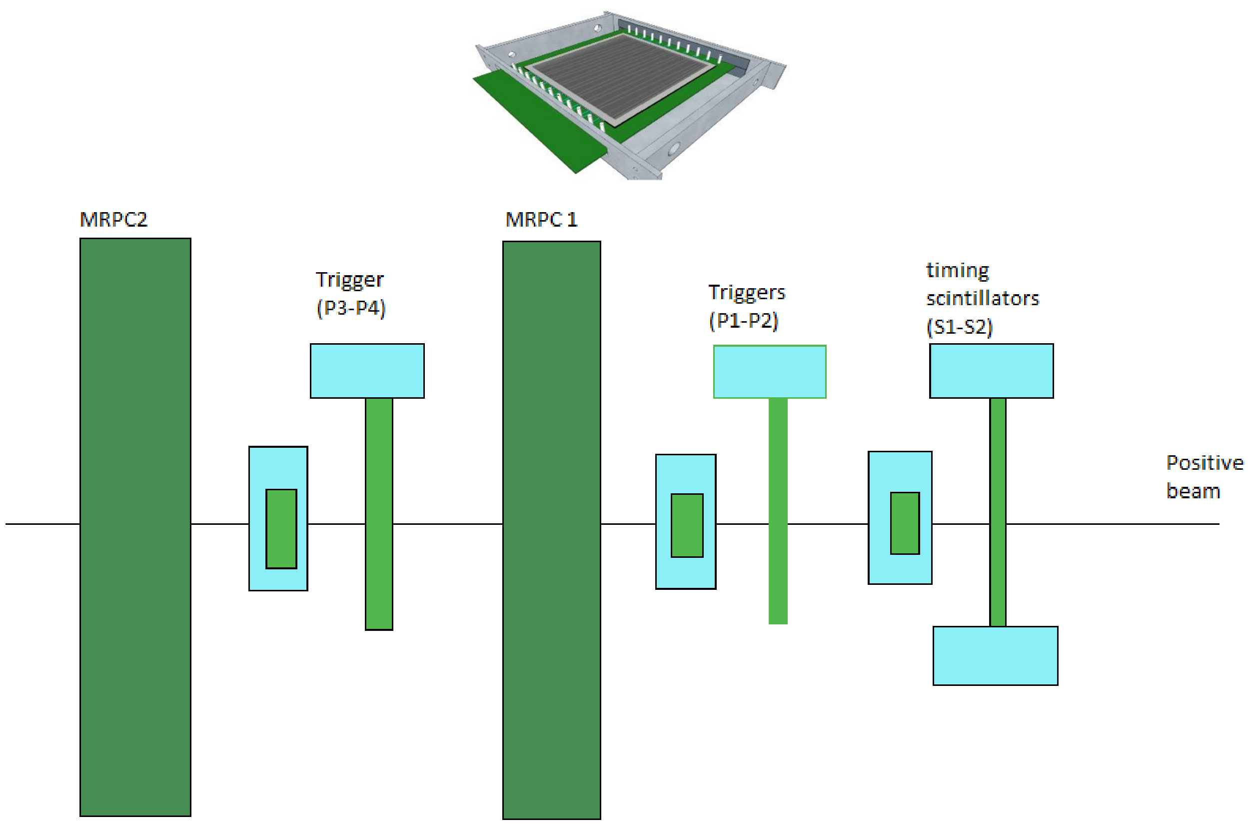

Figure 2: Setups of testing MRPC with alternative gas mixtures.

Testing MRPC1(with ecofriendly gas)

We can test MRPC detector with a positive beam with different momenta(3GeV/c,4GeV/c,5GeV/c). The two-timing scintillators are equipped with photomultiplier. The signal of trigger is created from coincidence with these scintillators. The distance between scintillator(S1-S2) and MRPC2(calibrating device) is 2meters and MRPC1(tested device with eco gas mixture) is in the middle between them.

- **<u>Testing efficiency</u>**

  - calculating efficiency can be determined by the total number of events divided by the events counted by MRPC. To calculate the total number of events we can use two layers scintillators to cover the active area of MRPC.
  - Two layers of scintillators are upstream and MRPC2 is downstream.
  - Plastic scintillators are used due to its high efficiency for counting total number of events.
  - Then connecting the two signals of photomultiplier from two the scintillator with (or gate) that any signal read by any of two photomultiplier is counted. The total number of events enter MRPC1 is counted. MRPC2 counts the number of events leave MRPC1
  - Then we take the number signals from MRPC1 readouts.
  - The mean total number of events= $\frac{\text{total number of events(S1−S2)+total number of events (MRPC2)}}{2}$
  - we divide the mean total number events by the number of events counted by MRPC1 calculating efficiency.

$$\eta(efficiency) = \frac{the\ number\ of\ events\ counted\ by\ MRPC1 \times 100}{the\ mean\ total\ number\ of\ events\ calculated\ by\ MRPC2\ and\ (S1 - S2)}$$

- **<u>Testing time resolution</u>**

  - In our experiment we will calibrate the time reference using plastic scintillators. The beam of particles goes through (S1-S2) crossing MRPC1 and then through MRPC2
  - Then we calculate the mean value of the time difference distribution from two trigger scintillators; (S1+S2)/2 – MRPC2. The mean time is used as reference time.

- **<u>Steps for measuring time resolution</u>**

  - we determine the time of (S1-S2) and the time of MRPC1. The time of MRPC2 =(S1-S2)+(T1)time that positive beam spends to cut distance(s) between (S1-S2) and MRPC2
  - Because the MRPC1 is in middle distance between scintillators (S1-S2) and MRPC2. The actual time of MRPC1 =(S1-S2) + (T1/2) (actual value). Because MRPC1 is not as much efficient as scintillators, then The time measured time by MRPC1 =(S1+S2)+(T_2) (T_2 is the measured value by MRPC).
  - Then we calculate Absolute Error = Measured Value - Actual Value.

    $\text{the asolute error} = (\text{T2}) - (\frac{\text{T1}}{2}).$
  - The lower absolute error, the better CF_3I mixture for timing

In case we have enough time, we may calculate the fraction of protons and kaons using TOF measurement as a side activity. Which allows us to understand more about particle physics

For example: to calculate the fraction of protons in beam, we can set the beam at fixed momentum (5GeV/c). then calculate what is velocity protons travel with this momentum. By following equation:

$$p = \frac{m_0 v}{\sqrt{1-\frac{v^2}{c^2}}} \qquad \therefore 5 = \frac{0.938 \times v}{\sqrt{1-\frac{v^2}{(1)^2}}} \text{ then } v = 0.983c = 3 \times 10^8 \times 0.983 \text{ m/s}$$

m_0: rest mass (invariant mass=0.938 GeV/c^2), v: velocity of the body and c: speed of light.
by gauss distribution analysis (got from TOF measurement) we can know How many particles travels at $0.983c$.

the fraction of protons in beam$= \frac{total\ number\ of\ particles\ travel\ at\ 0.983c}{total\ number\ of\ particles\ in\ beam}$

4.2 Main measuring Devices

1- Four Triggers.
2- Four Fast scintillators each one equipped with Photomultiplier.
3- MRPC2

5. Previous Results

The CF_3I gas mixtures were experimentally evaluated by [5]. The results showed promising performance and dielectric properties comparable to SF6. Through previous results in figures 3,4,5, it's preferred, to get comparable time resolution and efficiency by CF_3I similar to SF6, when use CF_3I and $C_3H_2F_4$ mixture with concentration 20% CF_3I and 80% $C_3H_2F_4$ and at higher operating voltage 20.5 kV.

Table 2: Summary of Previous Researches results

PERCENTAGES OF CF_3I IN GAS MIXTURES	OPERATING VOLTAGE	TIME RESOLUTION	EFFICIENCY	STREAMERS RATE
0.5%	**19 kV**	**85- 90 ps**	**90- 95%**	**0.4%**
1%	**19 kV**	**90 ps**	**95- 97.5%**	**0.3%**
5%	**20 kV**	**85- 90 ps**	**95%**	**0.4%**
10%	**20 kV**	**80- 82 ps**	**95- 97.5%**	**0.3%**
20%	**20.5 kV**	**77.5- 80 ps**	**98%**	**0.5%**

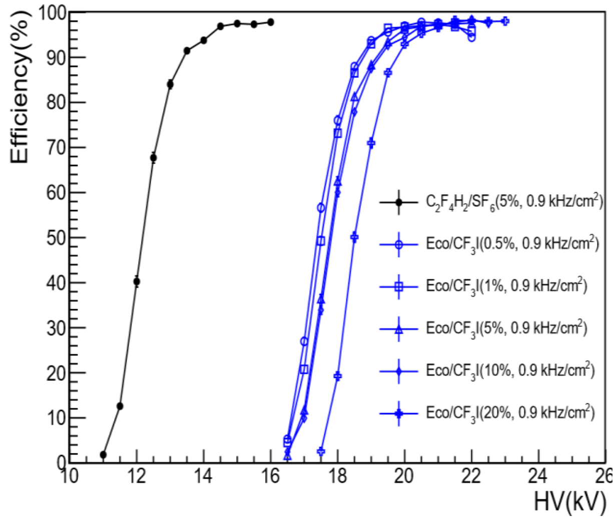

Figure 3: Efficiencies measured with various gas mixtures

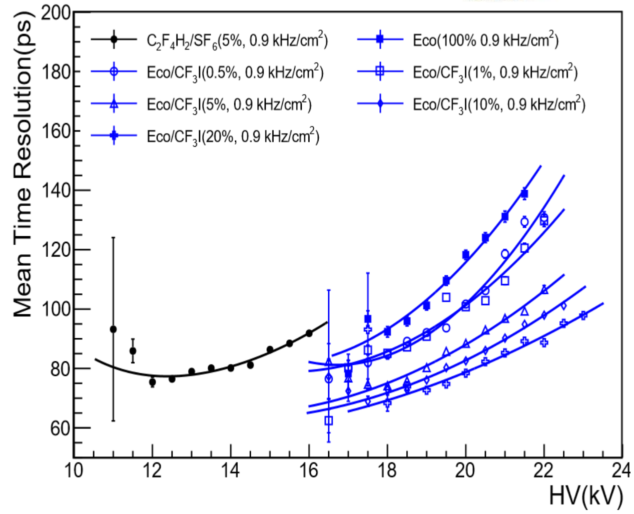

Figure 4: Time resolutions of various gas mixtures at 0.9kHz/cm^2.

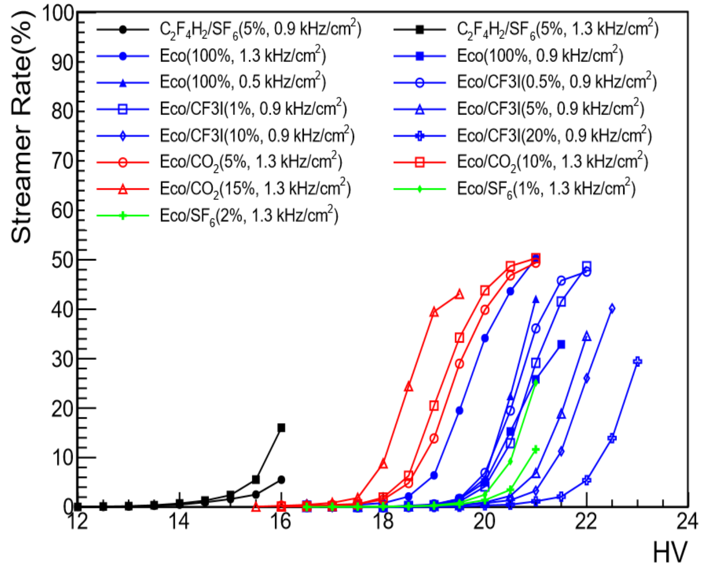

Figure 5: Streamer probability for gas mixture

What we hope to take away.

We hope that our ecological gas gives a high efficiency and good timing that it will be used in CERN`s experiments. And if there is enough time it will be good chance to be taught How to measure the fraction of protons and Kaons in positive beam. In our country, we don`t have the facilities to carry out. In case we have, it will be hard for high school student to use these facilities. Especially, we are students of programming technical high school which focus only on software development and computer science. it was a passion toward knowledge and science (especially particle physics) led us to this competition. We think it is a priceless opportunity unleash that passion. having contact with particle physicist will enhance us to learn and know more about the latest discoveries in particle physics.

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Outreach activity

Marie Curie said, “I knew that the path to progress was neither quick nor easy.” This quote shows us that progress in science is neither easy nor fast, but we can make it somewhat easy when receiving science through online platforms and creating an app for science to learn it better. We intend to make a YouTube channel that introduces theories in particle physics and astrophysics. Especially we will be the first YouTube channel to talk about theories like QFT, QCD, Quantum mechanics, and astrophysics in a simplified way in our mother language(Arabic) that a high school student can understand. Winning the competition will enhance us to have contact with scientists at CERN to introduce the right information and get in touch with the latest discoveries in physics.

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