Study of eco friendly gas mixtures with low HFO content for the Resistive Plate Chambers

Giorgia Proto, Barbara Liberti, Rinaldo Santonico on behalf the RPC Roma Tor Vergata group

22/04/2021

Introduction (I): Search for an alternative gas mixture for Resistive Plate Chambers

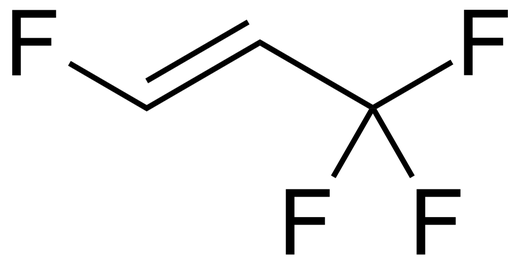
- High gas density, which can ensure a sufficient primary ionization
- Separation between avalanche regime and streamer appearance large enough to allow a sufficient streamer free avalanche operation
- Low average electronic charge but high enough to overcome the front-end electronics threshold
- Average ionic charge, corresponding to about the 90% of the total charge delivered inside the gas, low enough to ensure modest working current and good rate capability, as required by most experiments with high radiation environments.
- Non flammable and made of industrial components as required for very large size detectors

Carbon Dioxide

- GWP =1
- Simple molecule, used as “filler” and target for the primary ionization
- Weak *quenching* power

Tetrafluoropropene (HFO1234ze)

- GWP ~ 6
- Electronegative gas, used as quencher and as target for the ionizing particle



2012-2013

Bachelor thesis

"Studio di Nuove Miscele Gassose per Rivelatori di Ionizzazione", E. Piersanti

Ar/i-C4H10 and Ar/i-C4H10/N2

2014

Bejing

"New RPC gas mixtures for large area apparatuses" [R. Cardarelli *et al* 2014 *JINST* **9** C11003]

Ar/i-C4H10/ HFO1234ze

2014-2015

Bachelor thesis

"Studio di nuove miscele di gas per camere a elettrodi piani resistivi ", G. Rebustini

Ar /HFO1234ze

2016

Ghent

"Further gas mixtures with low environment impact" [B. Liberti *et al* 2016 *JINST* **11** C09012]

- HFO1234ze/CO2
- HFO/CO2 + %SF6
- HFO/He
- Pure HFO

2016-2017

Stage for master thesis

"Studio delle prestazioni di un rivelatore RPC con gap da 2 mm ed elettrodi standard con due diverse miscele gassose: HFO/CO2 e benzina", G.Proto

HFO/CO2 and HFO/CO2 + gasoline

2018

Mexico

"Search for new RPC gases", B. Liberti [https://indico.cern.ch/event/644205/contributions/2862262/]

- HFO/CO2/ Ethylmethylketone (MEK)
- HFO/CO2/Methyl tert-Butyl ether (MTBE)
- CO2/Dimethyl Sulfide (Dims)

2018-2019

Bachelor thesis

"Studio delle performance di un rivelatore RPC con possibili miscele eco-compatibili basate su HFO/CO2 e Metano", M.E. Perruzza

HFO/CO2/Methane mixture based

A LONG JOURNEY...

2020

Rome

"Characterization of new eco friendly gas mixtures based on HFO for RPCs" [G. Proto *et al* 2021 *JINST* **16**

- Effect of HFO1234ze reduction in mixtures composed by HFO/CO2/i-C4H10/SF6
- Effect of i-C4H10 reduction in mixtures composed by HFO/CO2/i-C4H10/SF6
- First studies with a new gas component, HFO1233zd, never tested before in mixtures composed by HFO1233zd/Co2/i-C4H10 + SF6

...TO GET HERE

SIF 2020

16th International Congress of "Società Italiana di Fisica" :"Study of the performance of the RPC detector with new eco friendly gas mixtures"
[Waiting for the publication on Nuovo Cimento C - Colloquia and Communications in Physics]

Topic of this presentation

RPC2020 results suggests that HFO concentration could be lowered below the 28% value.
According to present understanding, less HFO means less Fluorine molecules inside the mixture and a slower detector aging.

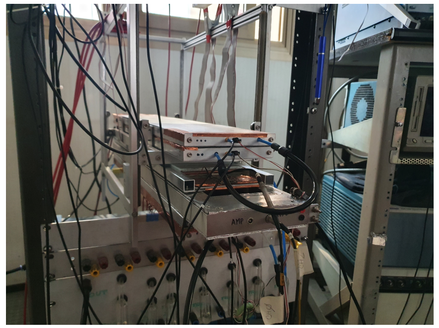
Measurements on mixtures based on HFO/ CO2/i-C4H10/SF6 with low HFO content (GWP ~ 200)

Systematic study of the RPC performance in terms of efficiency, charge delivered inside the detector and separation between avalanche and streamer appearance.

- HFO/CO2 variable ratio : i-C4H10/SF6 (5/1) fixed ratio and HFO/CO2 ratio varies in order to study the effect of the reduction of HFO concentration.
- CO2/i-Butano variable ratio : HFO/Sf6 (5/1) fixed ratio and i-C4H10/CO2 ratio varies, in order to study the effect on charges and avalanche-streamer separation with the increase of i-C4H10.

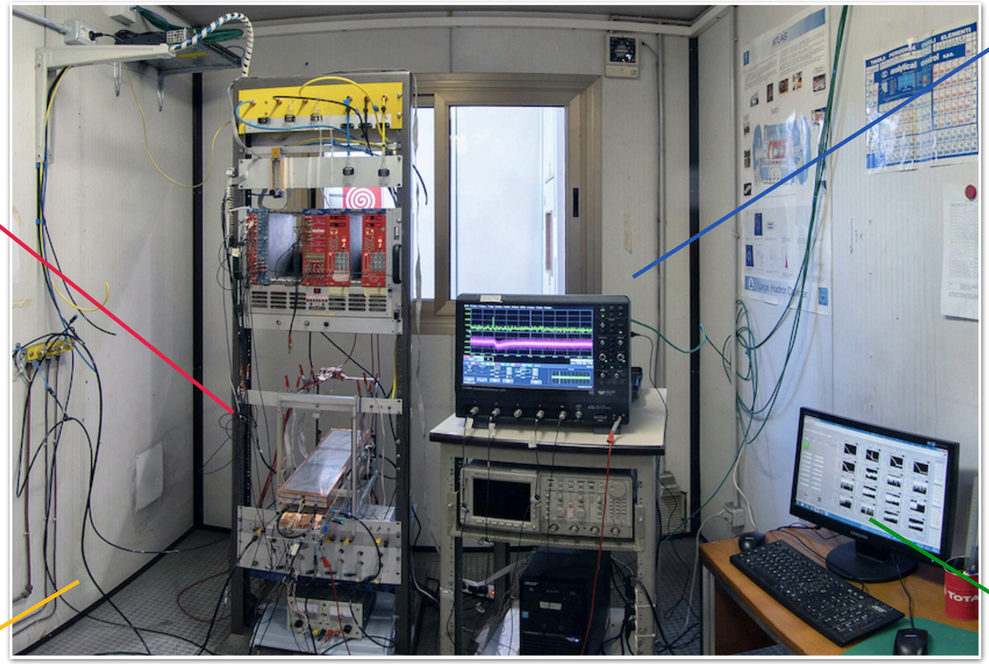
Experimental setup (I): Trigger and DAQ

Trigger



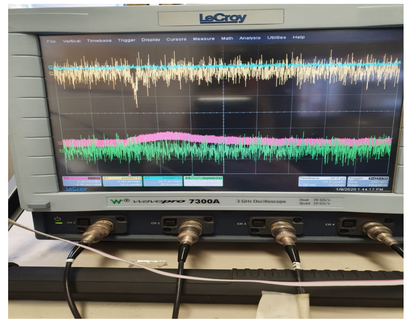
- The amplified signal of the four trigger chambers, are discriminated and sent to a logical unit, which produces the logical AND;
- The prompt signal of the 0.5 mm RPC is inserted as the fifth trigger chamber for the efficiency measurement in the *offline* analysis

Gas system



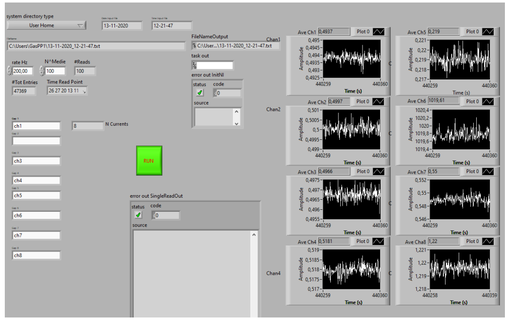
- Four 2 mm gas gap RPCs in coincidence, forming the *trigger*
- One 0.5 mm RPC used as confirmation
- RPC under test
- High Voltage and Low Voltage generators
- Discriminator and coincidence unit
- Oscilloscope
- Gas system (Mass flow meters and controllers, mixer)

Oscilloscope



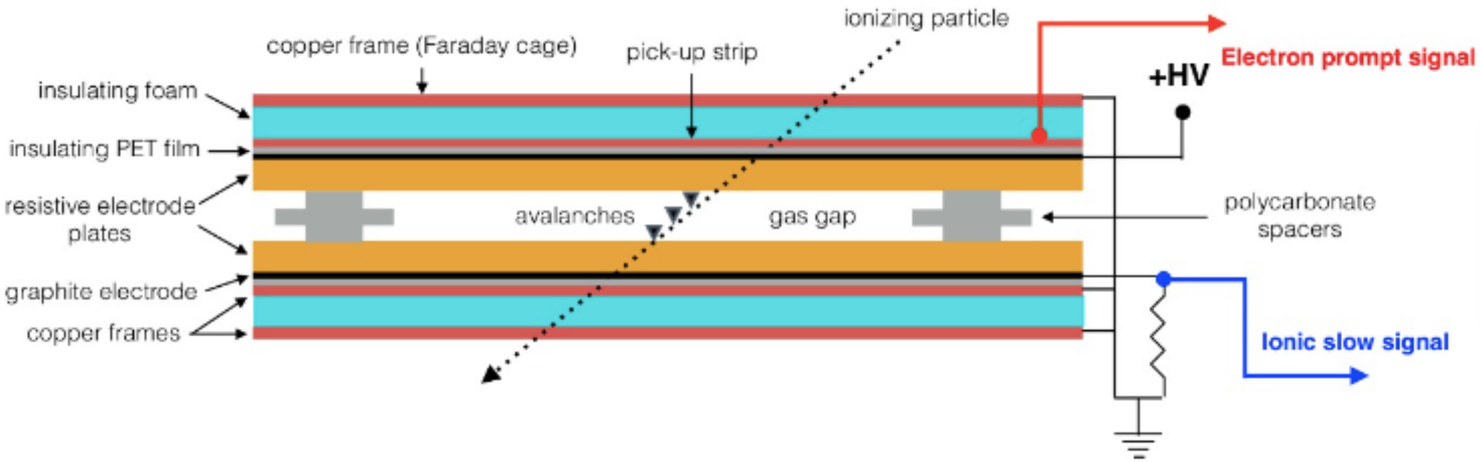
- Bandwidth: 3 GHz
- Sampling velocity : 20 Gs/s
- Acquired time window for the *prompt* signal = 200 ns
- Acquired time window for the ionic signal = 100 μs

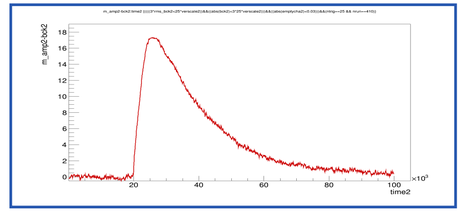
Online and offline analysis



Experimental setup (II): RPC detector under test

- Dimensions : 57 X 10 cm²
- Gas gap width = 2 mm
- Electrode thickness = 1.8 mm

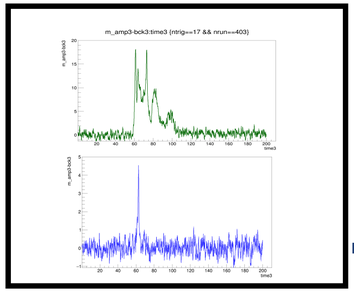


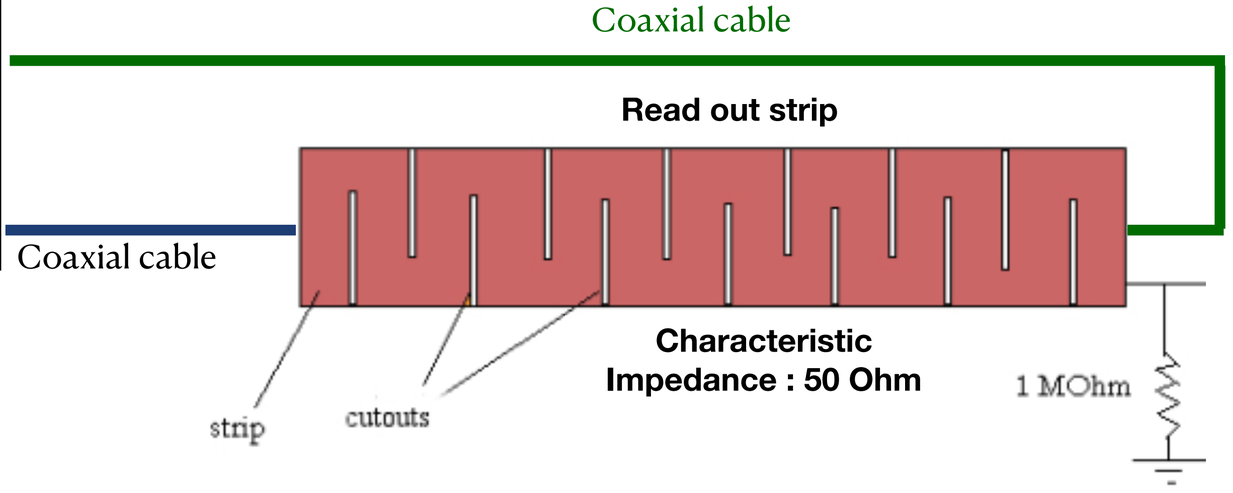


Ionic signal :read out on a resistance on the ground graphite electrode equal to 10 kOhm

- Prompt signal **without amplification** for the streamer analysis
- Oscilloscope scale variable

Oscilloscope

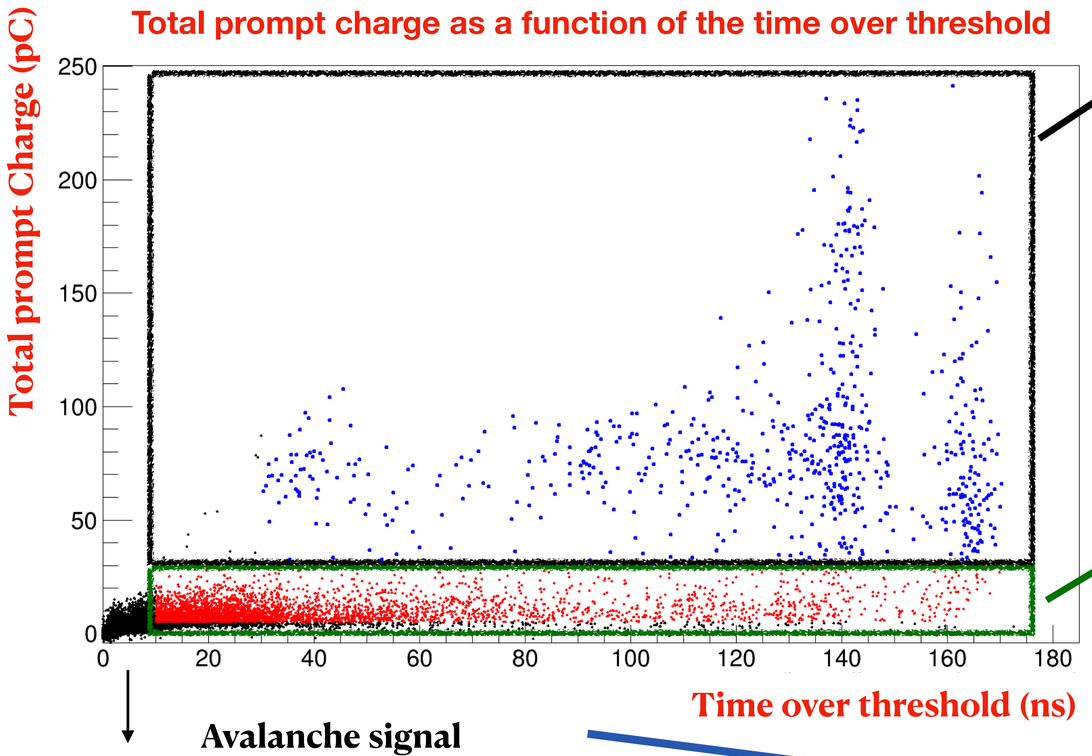




Resistance on both sides of the strip to refer it to ground

- Prompt signal **without amplification** for the efficiency measurement
- Maximum oscilloscope sensitivity

Streamer and extra charge definitions



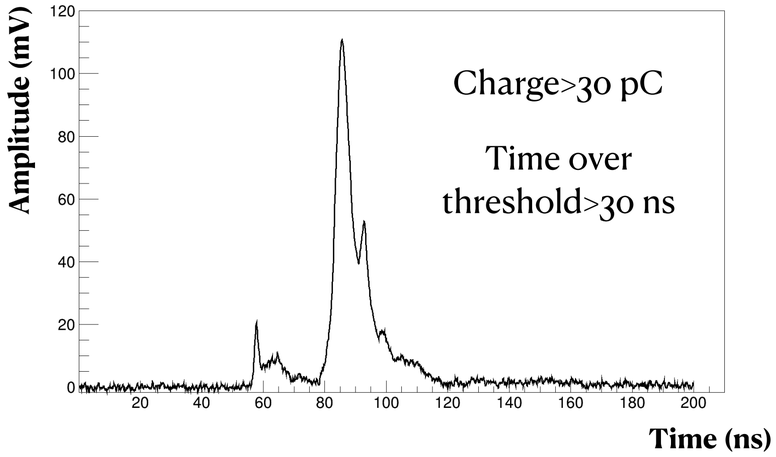
Streamer: signal with a charge content more than 30 pC and a time over threshold more than 30 ns

Extra-charge signal: signal with a charge content more than 5 pC and less than 30 pC with a time over threshold more than 10 ns

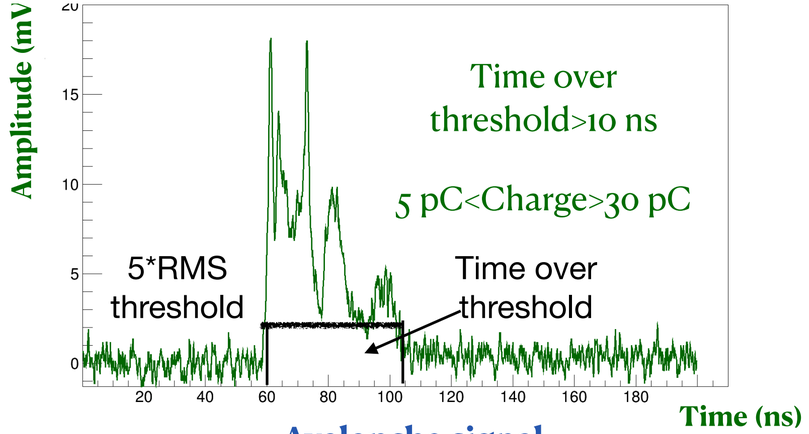
Three band :

- Low charge and low time over threshold signals have been considered as **avalanche signals**
- Medium charge and high time over threshold signals have been considered as **extra-charge signals**
- High charge and high time over threshold signals have been considered as **streamer signals**

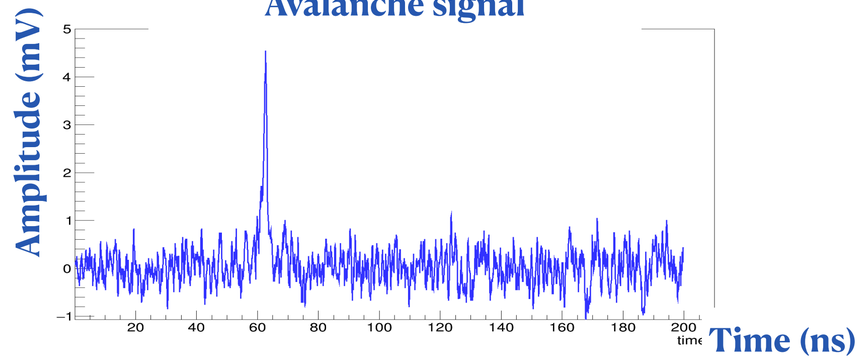
Streamer signal



Extra-charge signal



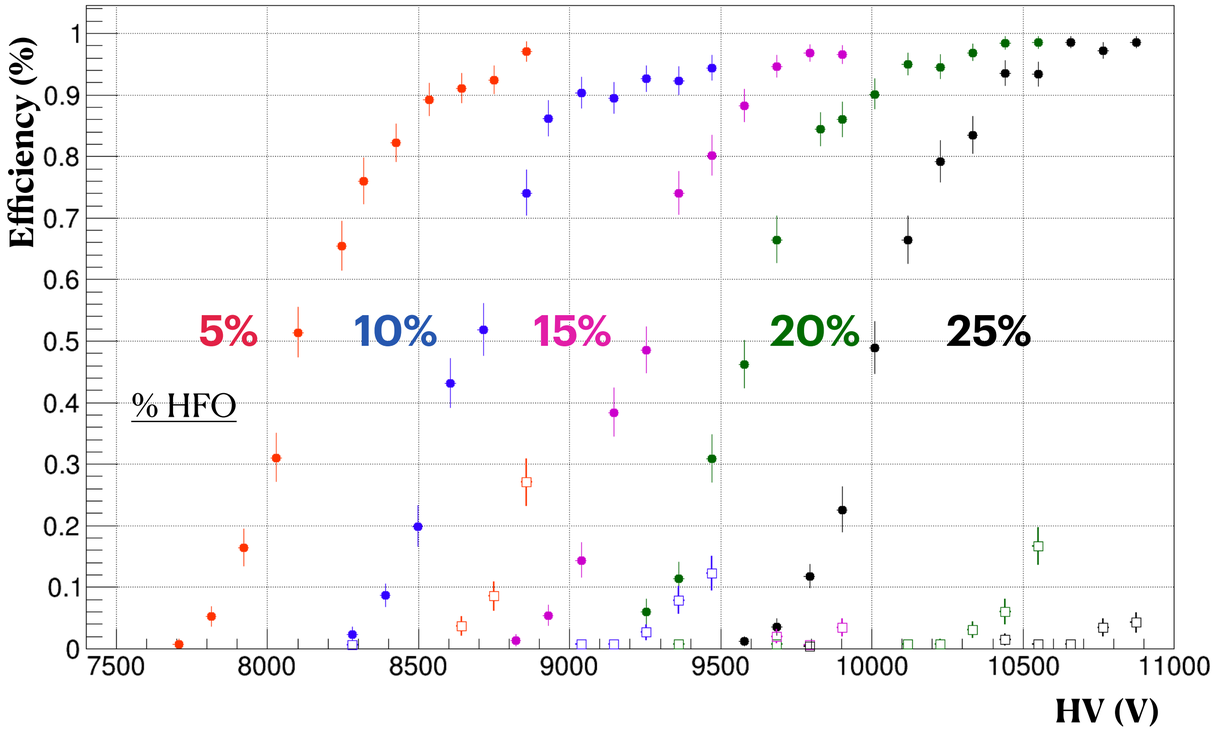
Avalanche signal



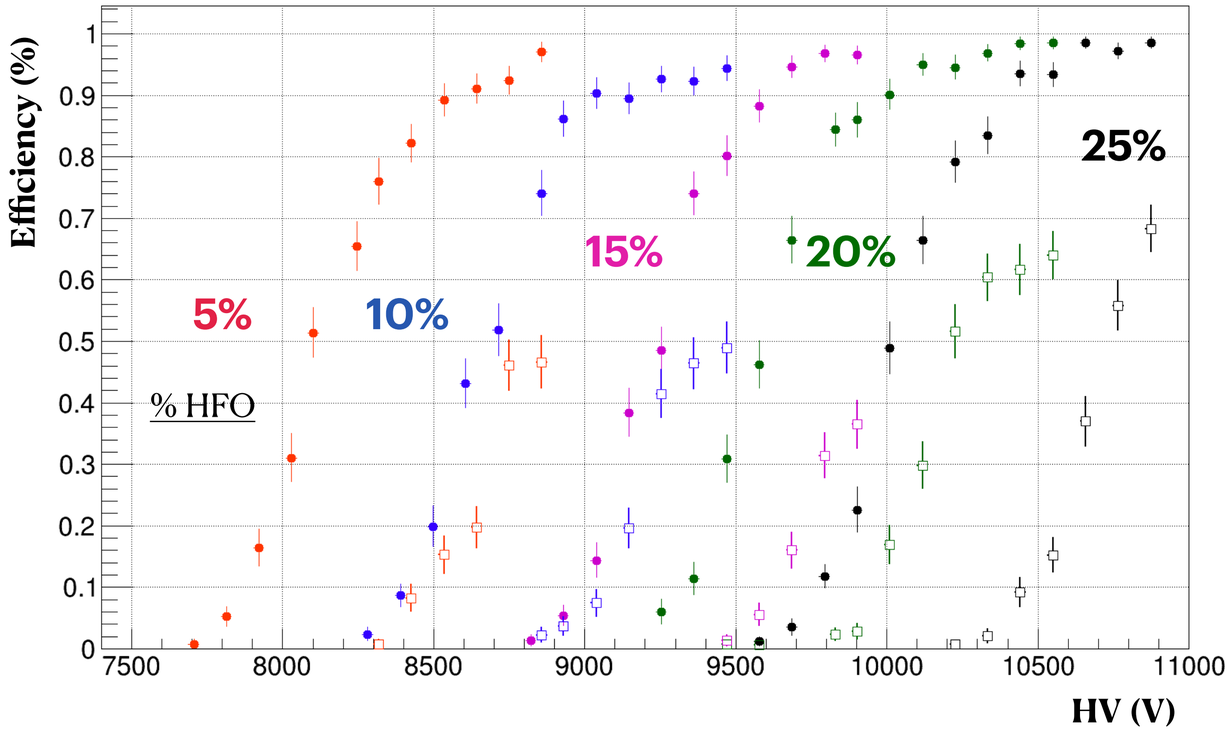
Results

i-Butane/SF_6=constant=5/1 - CO_2=89/84/79/74/69 : Efficiency study

Efficiency and streamer probability



Efficiency and extra charge probability



Efficiency:
signals which cross an amplitude threshold equal to the 5 Root Mean Square of the background window (~1.5 mV) and which produce a signal also in the confirm chamber

Streamer:
signal with a charge content more than 30 pC and a time over threshold more than 30 ns

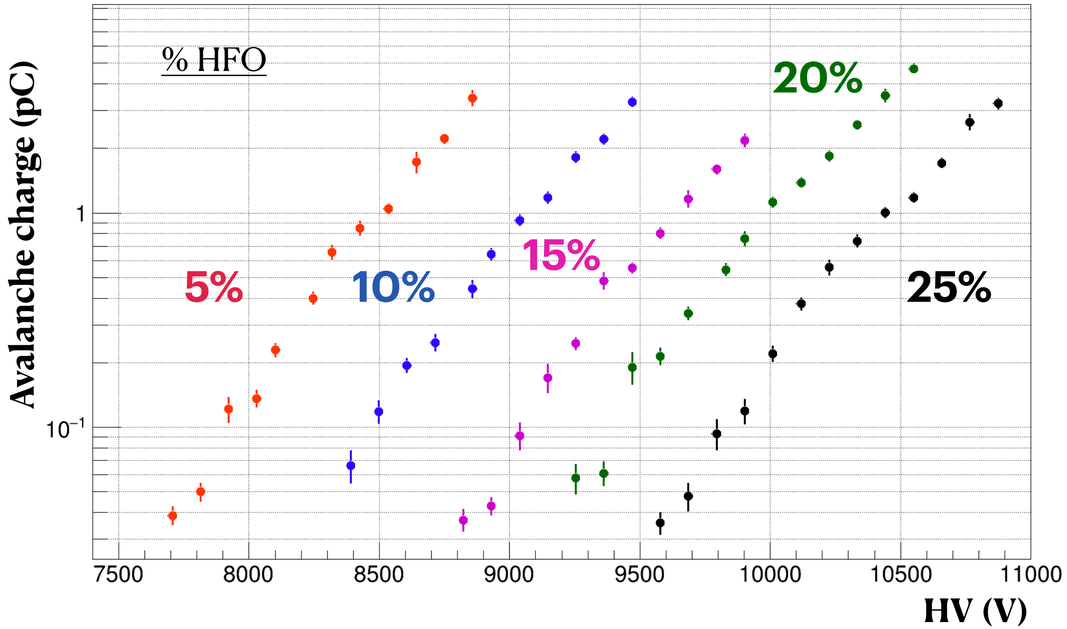
Extra-charge signal:
signal with a charge content more than 5 pC and less than 30 pC with a time over threshold more than 10 ns

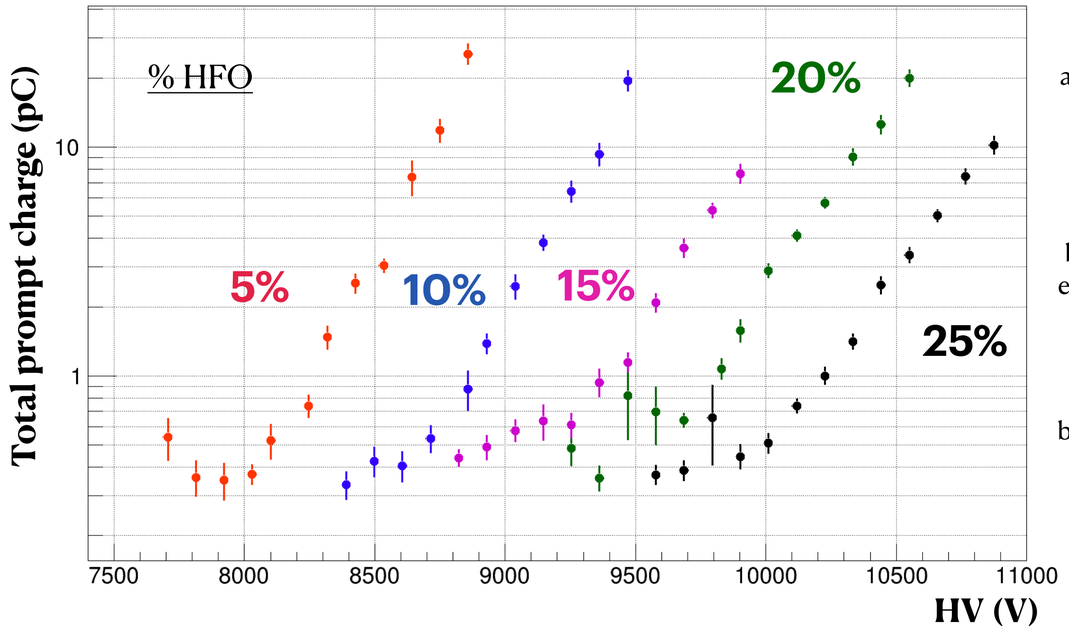
% HFO1234ze	V_{knee}	Efficiency @plateau	%streamer @ V_{knee} + 200 V	%extra charge@ V_{knee} + 200 V
5%	8.5 kV	93%	8.5%	46%
10%	9 kV	93.5%	3%	41%
15%	9.5 kV	96.5%	0.6%	31%
20%	9.9 kV	98%	0.8%	30%
25%	10.4 kV	98%	0.7%	37%

Vknee= High voltage @90% efficiency

THE MIXTURE WITH 15% OF HFO SEEMS TO REPRESENT A MINIMUM (IN THIS SET OF MEASUREMENT) FOR STREAMERS AND EXTRA CHARGES

i-Butane/SF_6=constant=5/1 - CO_2=89/84/79/74/69 : Charge study

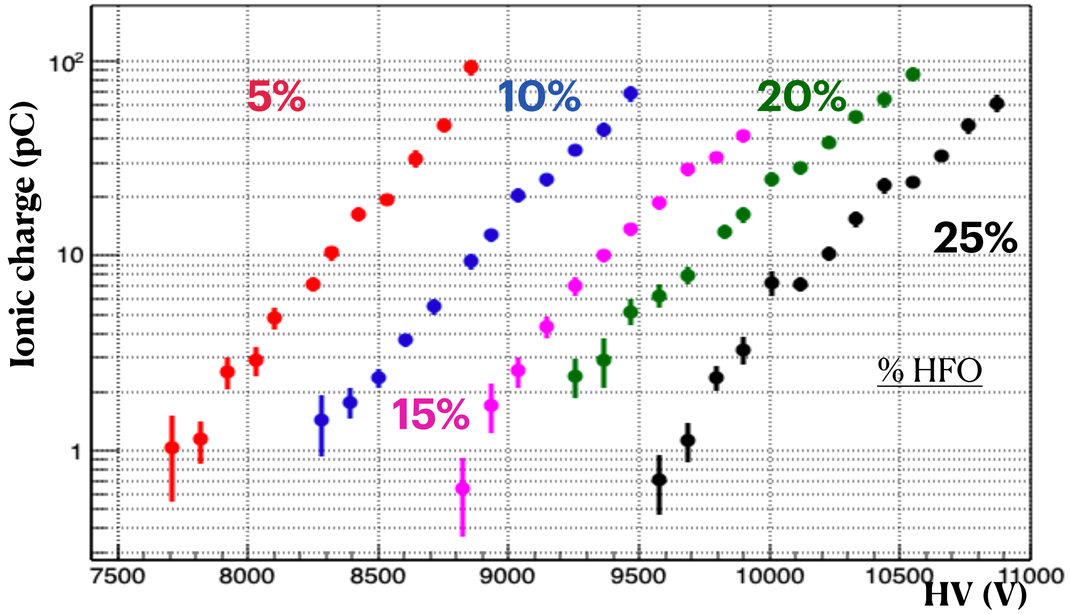




Avalanche charge : integrated charge in 10 ns around the first peak in the time window after the background time (40 ns)

Total prompt charge: integrated charge from the background time (40 ns) to the end of the time window (200 ns)

Total charge (ionic charge): integrated charge from the background time (15 μs) to the end of the time window (100 μs)

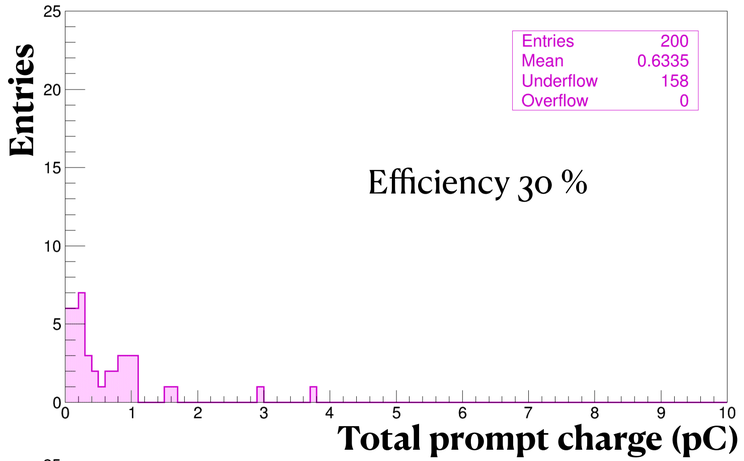


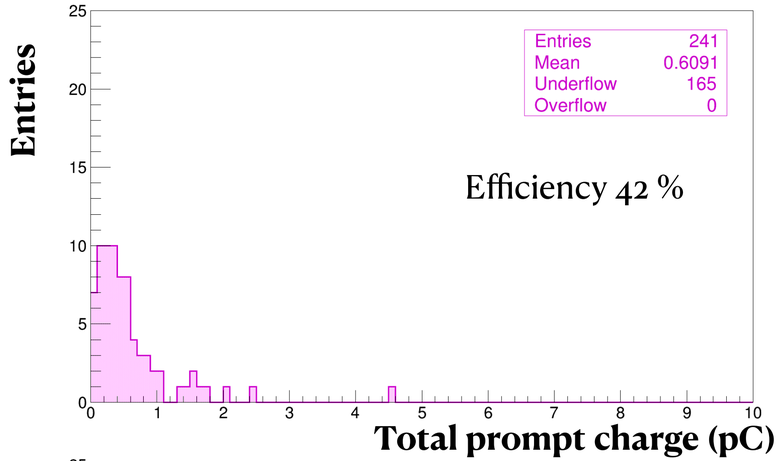
% HFO	V_{knee}	Avalanche charge@ V_{knee} + 200 V	Total prompt charge @ V_{knee} + 200 V	Ionic charge @ V_{knee} + 200 V
5%	8.5 kV	2.1 pC	11.5 p C	50 pC
10%	9 kV	1.9 pC	7 pC	38 pC
15%	9.5 kV	1.6 pC	4.3 pC	32 pC
20%	9.9 kV	1.5 pC	4 pC	31 pC
25%	10.4 kV	1.7 pC	5 pC	34 pC

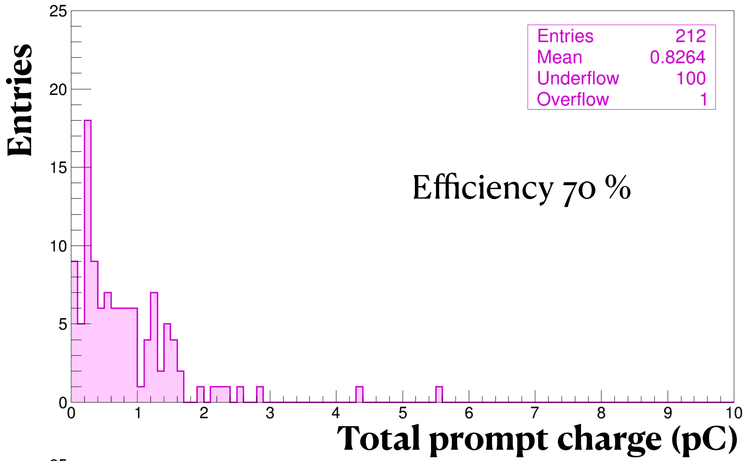
Vknee= High voltage @90% efficiency

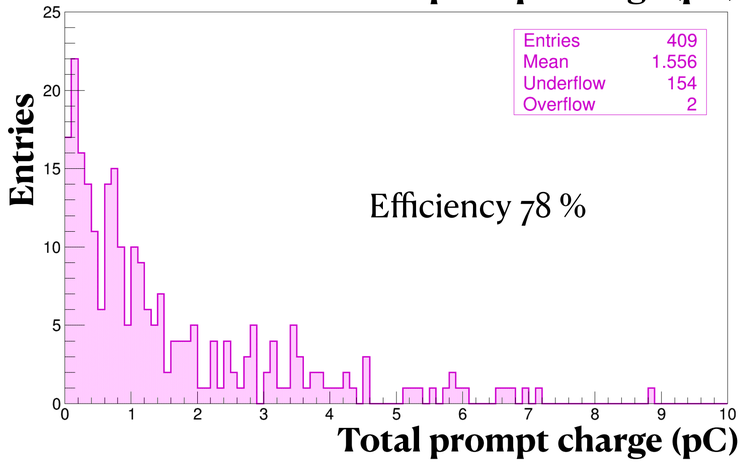
THERE IS NO GAIN IN TERMS OF CHARGE DELIVERED INSIDE THE DETECTOR FROM 15% TO 25% OF HFO CONTENT

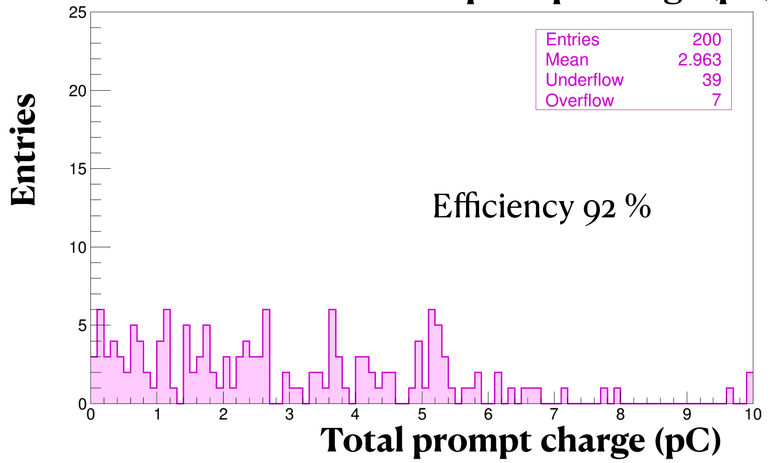
HFO1234ze/i-Butane/CO_2/SF_6=15/79/5/1: Total prompt charge distribution

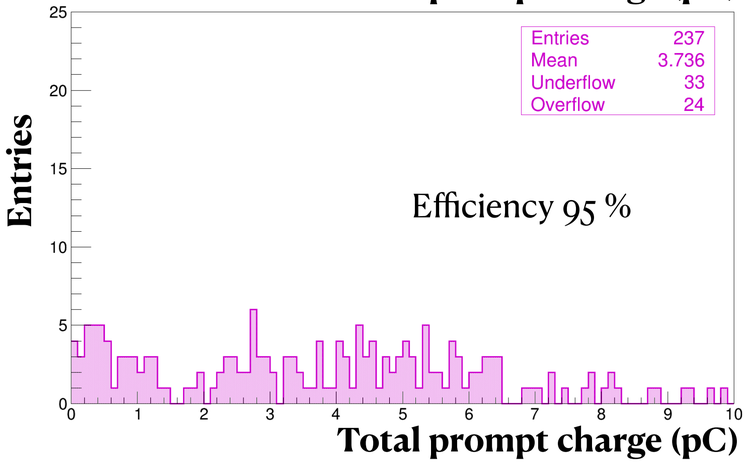








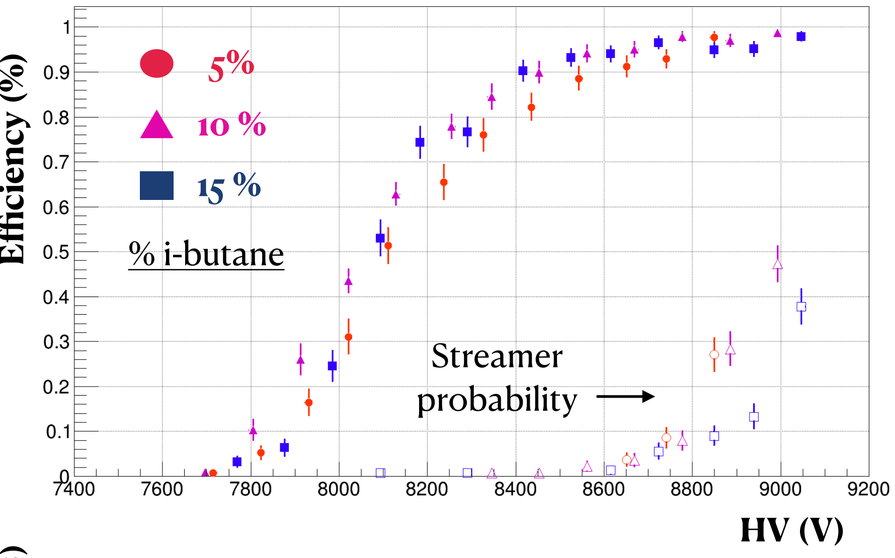


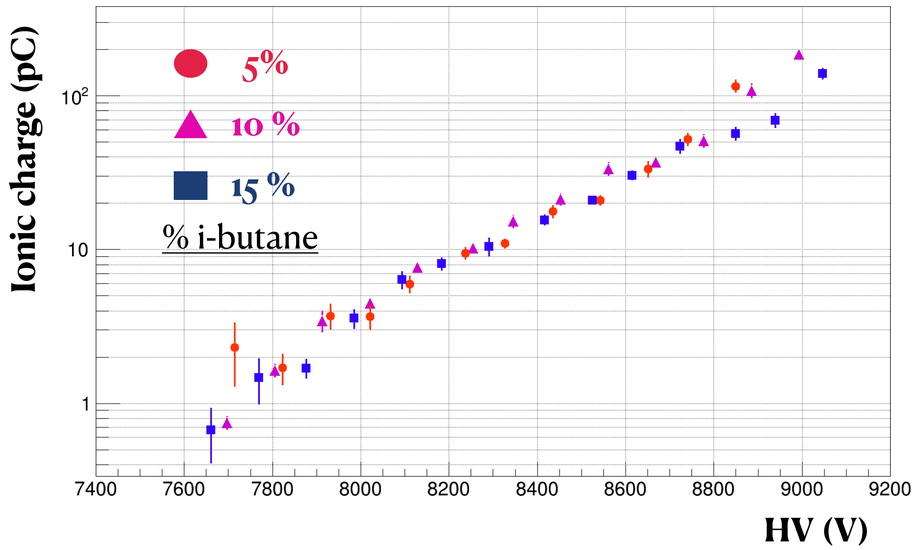


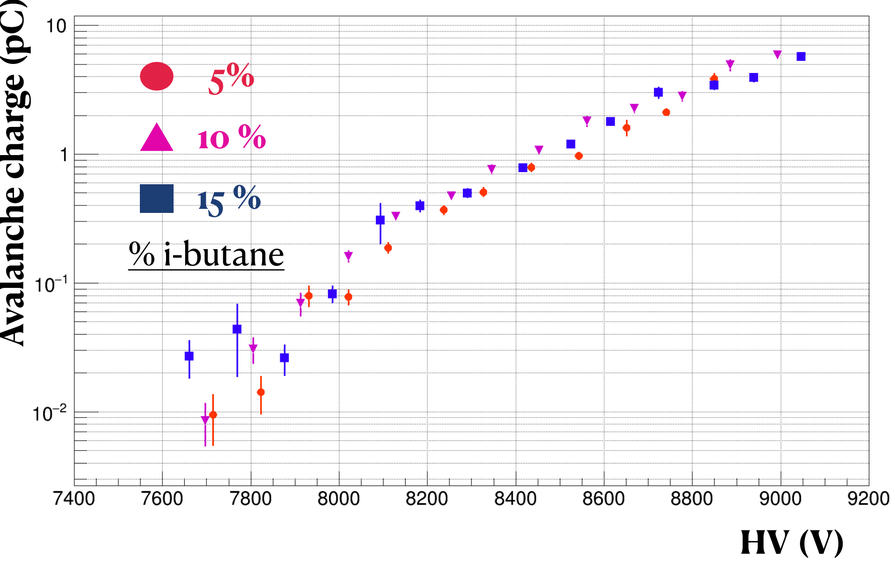
NO SATURATION HAS BEEN OBSERVED AT HIGH EFFICIENCY

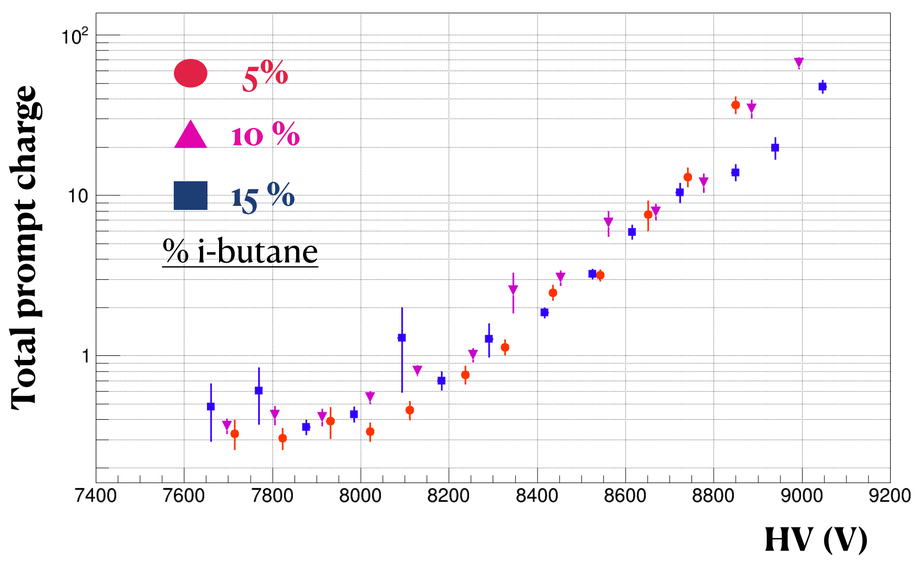
HFO1234ze/SF_6= constant=5/1 - CO_2=89/84/79

Efficiency, streamer probability and charge as a function of the high voltage









Subject to flammability limits

% i-butane	V_{knee}	%streamer @ V_{knee} + 200 V	%extra charge@ V_{knee} + 200
5%	8.5 kV	8.5%	46%
10%	8.45 kV	3.5%	46%
15%	8.4 kV	1%	35%

% i-butane	Avalanche charge@ V_{knee} + 200 V	Total prompt @ V_{knee} + 200 V	Ionic charge @ V_{knee} + 200 V
5%	2.1 pC	11.5 pC	50 pC
10%	2.2 pC	7.3 pC	37 pC
15%	1.8 pC	5.3 pC	30 pC

Vknee= High voltage @90% efficiency

In this work a systematic performance study of a small size RPC operated with four- components gas mixtures $C_3H_2F_4/CO_2/i\text{-}C_4H_{10}/SF_6$ with an HFO content lower than 25% has been performed. The mixtures under study have a Global Warming Potential of about 225 (due to the presence of SF_6).

Two set of measurements have been performed:

- HFO/CO2 variable ratio : i-C4H10/SF6 (5/1) fixed ratio and HFO/CO2 ratio varies
- CO2/i-Butano variable ratio : HFO/Sf6 (5/1) fixed ratio and i-C4H10/CO2 ratio varies

Conclusions

- The decrease of HFO in the HFO/CO2 ratio produces a reduction of the operating voltage and there is not a great gain in terms of avalanche-streamer/extra-charge separation and charge delivered inside the detector when the HFO fraction is increased from 15% to 25%.
- The smaller amount of Fluorine molecules inside the gas mixture could reduce the ageing effects and a higher CO2 content increase the i-C4H10 flammable limit
- The increase of i-C4H10 gives a lot of benefits in terms of avalanche-streamer/extra charge separation and in terms of charge content

- We have not yet selected a mixture which satisfies ATLAS requirements both for performance and ageing, but with this systematic work we are expanding our knowledge on gas mixtures properties

Next steps

- The new HFO (HFO1233zd), $C_3H_2ClF_3$, which has been already presented during RPC2020, can not be used as primary gas, but the addition of small amounts into the mixture could give benefits. To be investigated

→ WORK IN PROGRESS

THANK YOU!!!

BACKUP