Study of alternative gas mixtures for RPCs

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RPC 2020 conclusions

Mixtures under test: HFO1234ze/CO_2/i-Butane/SF_6:

- 29/56/14/1
- 33/56/10/1
- 38/56/5/1
- 28/66/5/1
- 33/61/5/1

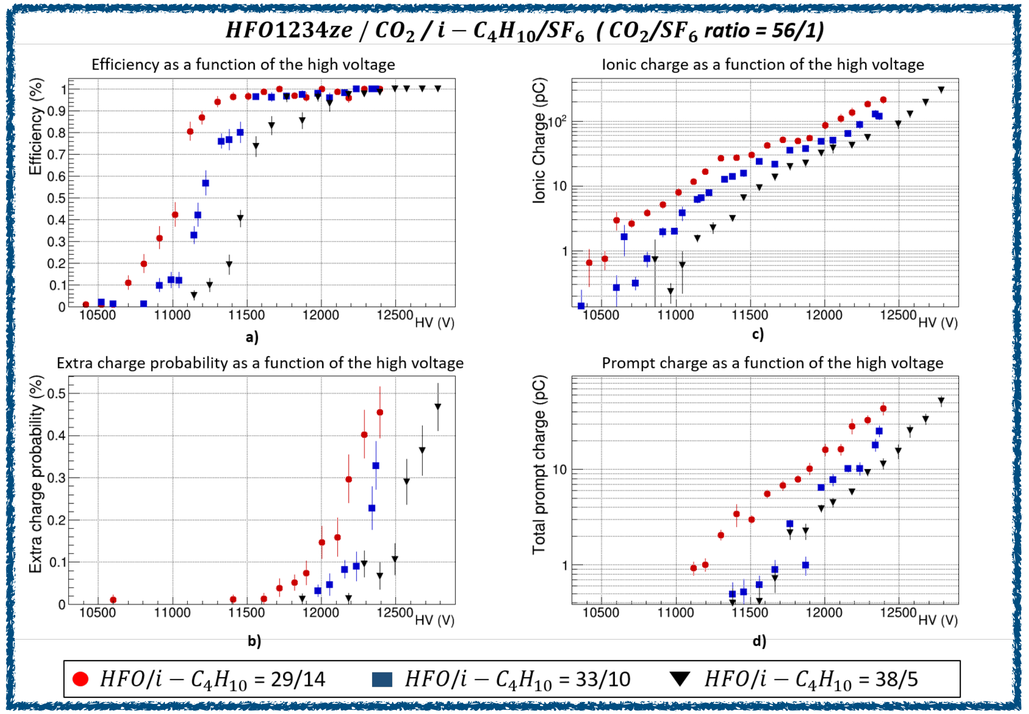
- **HFO/i-C_4H_{10} variable ratio:** the decrease of the HFO in the mixture produces a decrease of the operating voltage but does not change the delivered charge, which is the same in the three mixtures and has a value of ~30 pC. Also the avalanche-extra charge separation is the same in the three mixtures

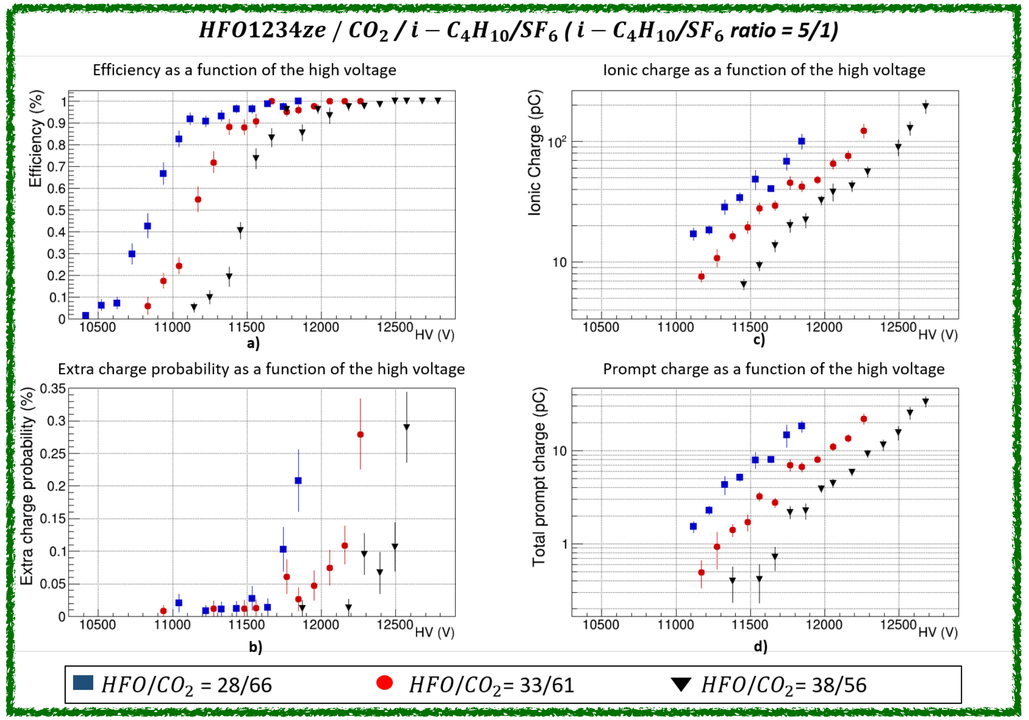
- **HFO/CO_2 variable ratio:** The decrease of the HFO has the effect to decrease both the operating voltage and the delivered charge. The voltage decrease is ~400 V every 5% of HFO reduction and the delivered charge decrease is ~ 10 pC comparing the mixture with more HFO with the mixture with less HFO

What's new

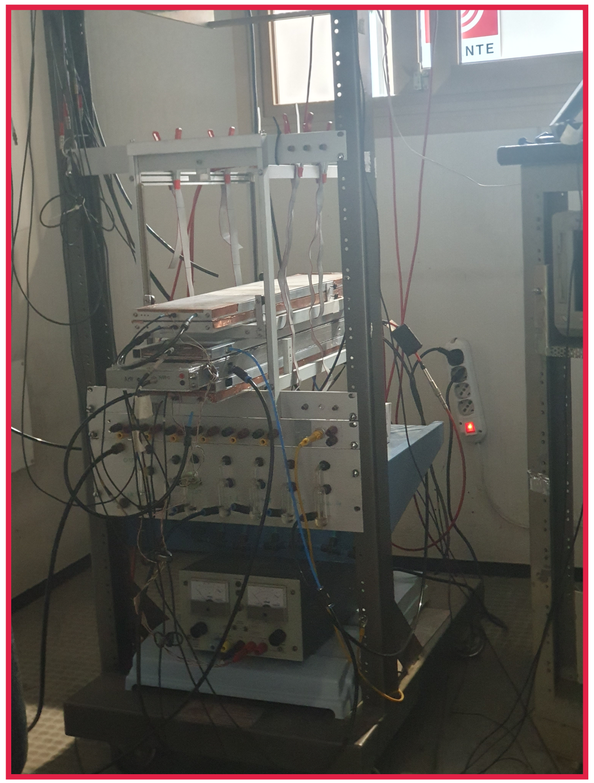
RPC2020 results suggests that HFO concentration could be lowered below the 28% value. According to present understanding, less HFO means less Fluorine molecules inside the mixture and a slower detector ageing

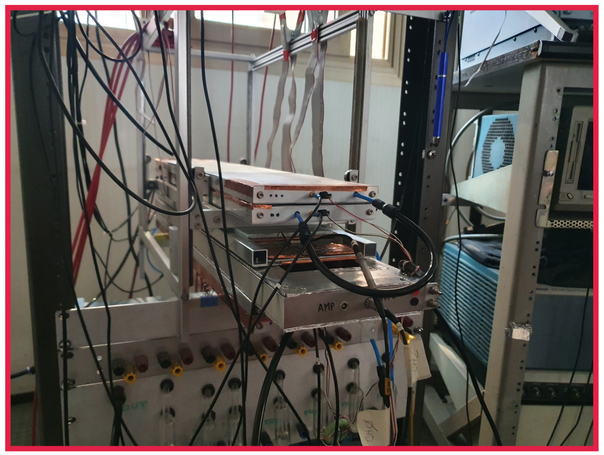
Test with mixtures with low HFO content

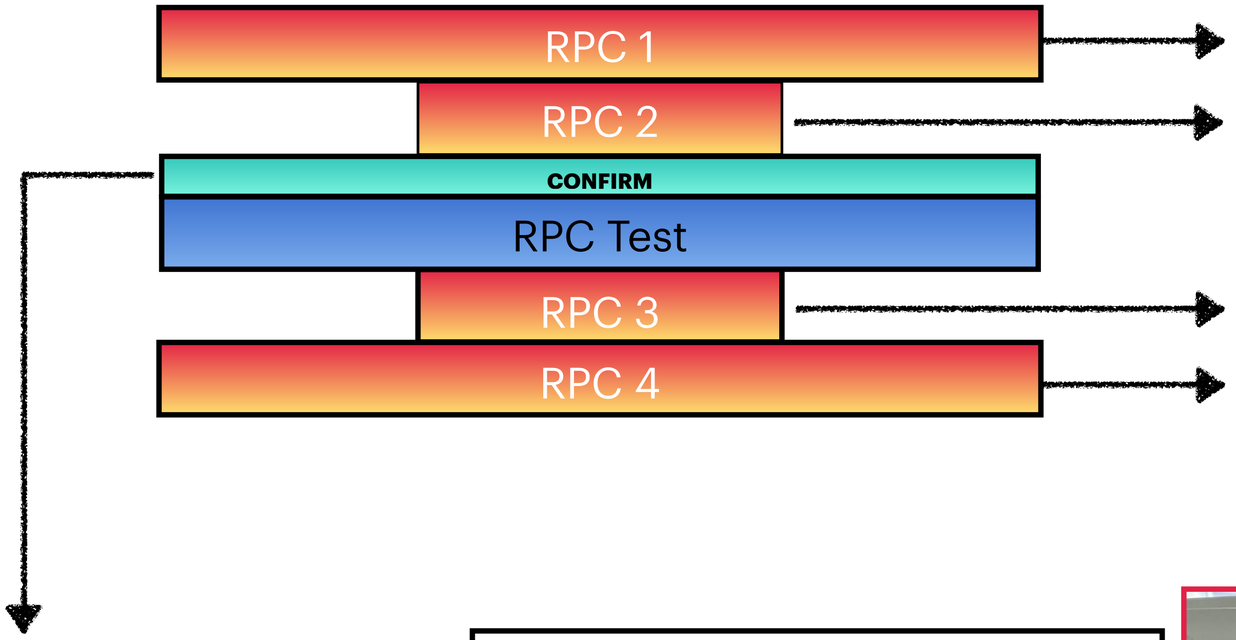




Experimental setup: Trigger and DAQ







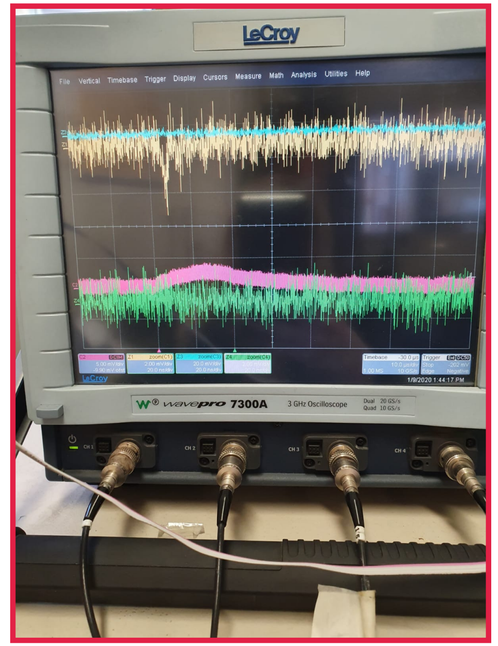
Amplified signals are discriminated and sent to the logic unit, which produces the logic AND

Confirm chamber

- RPC (0.5 mm gas gap)
- Prompt signal
- In the *offline* analysis is inserted as the fifth trigger chamber for the efficiency measurement

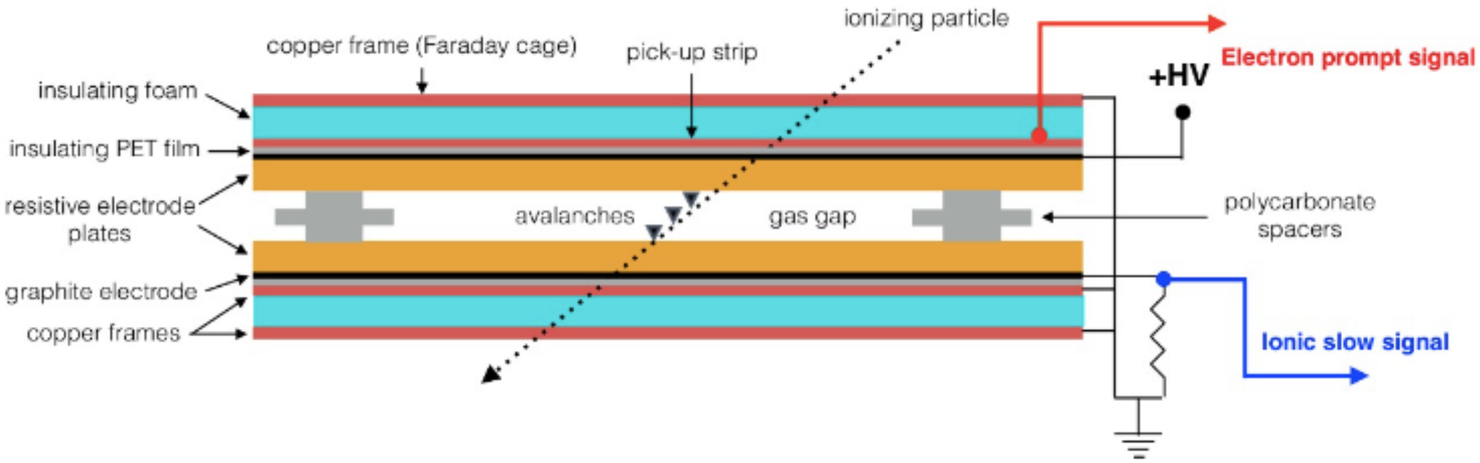
Oscilloscope

- 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



Experimental setup: RPC chamber under test

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

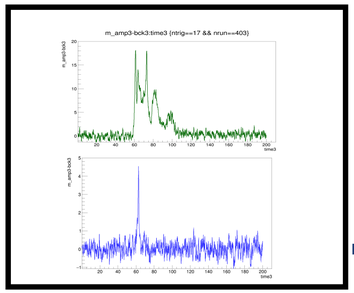


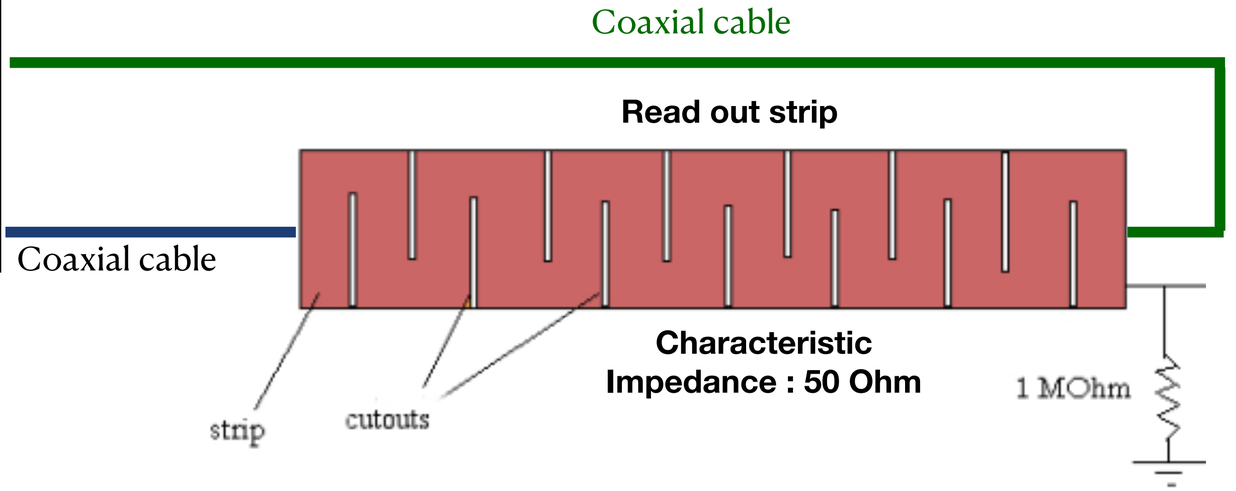
Ionic signal :read out on a resistance on the ground graphite electrode equal to 10 kOhm

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

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

Oscilloscope



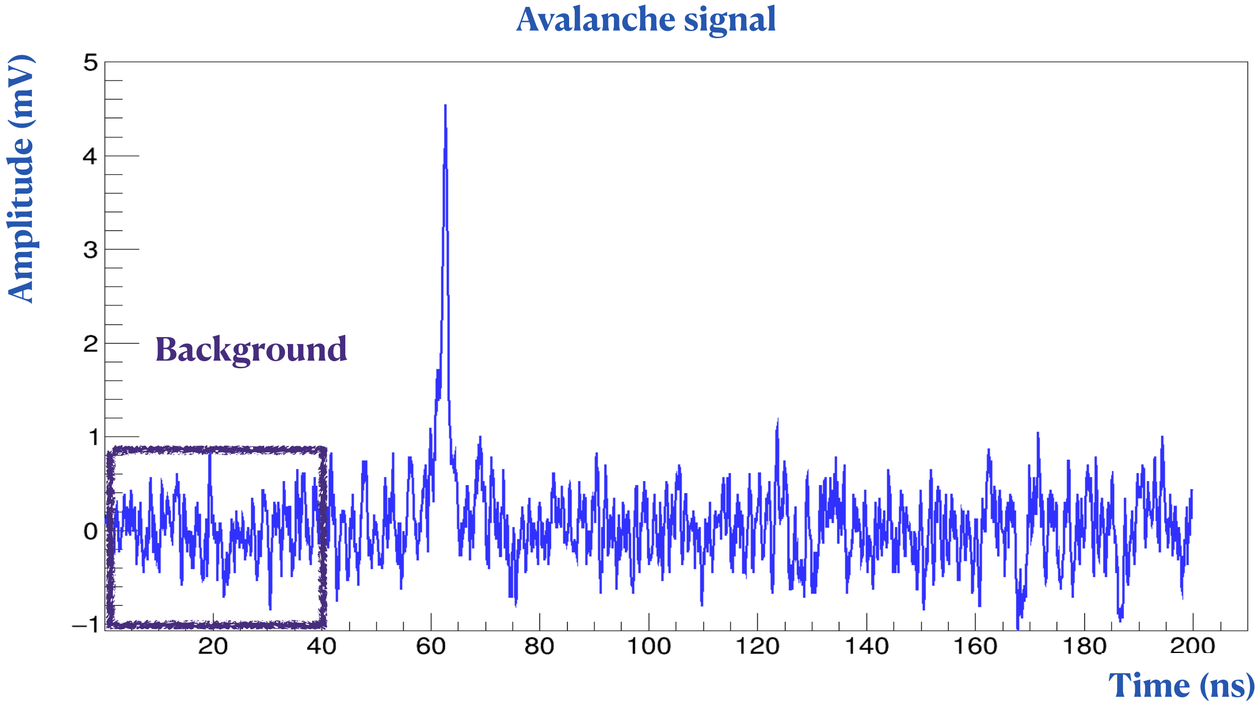


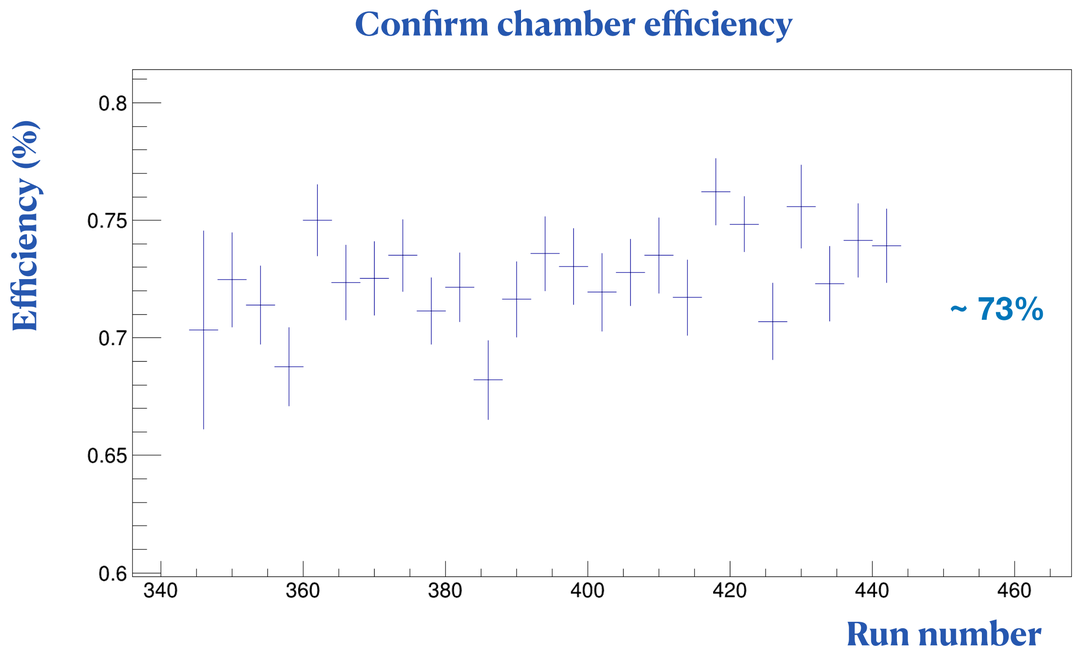
Resistance on both sides of the strip to refer it to ground

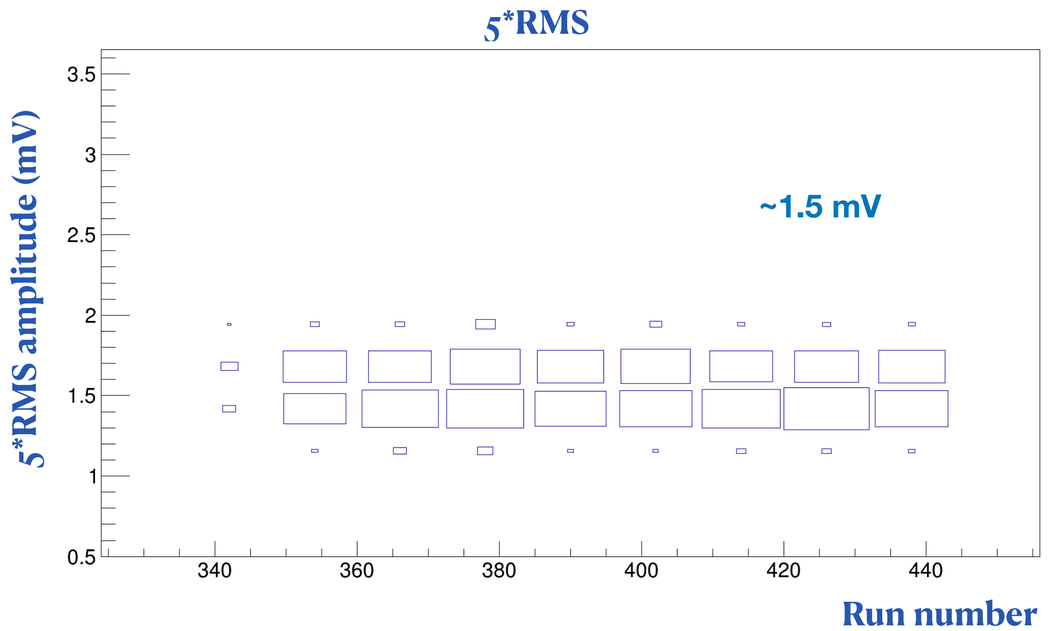
Definition of the analysis Parameter

Efficiency criteria

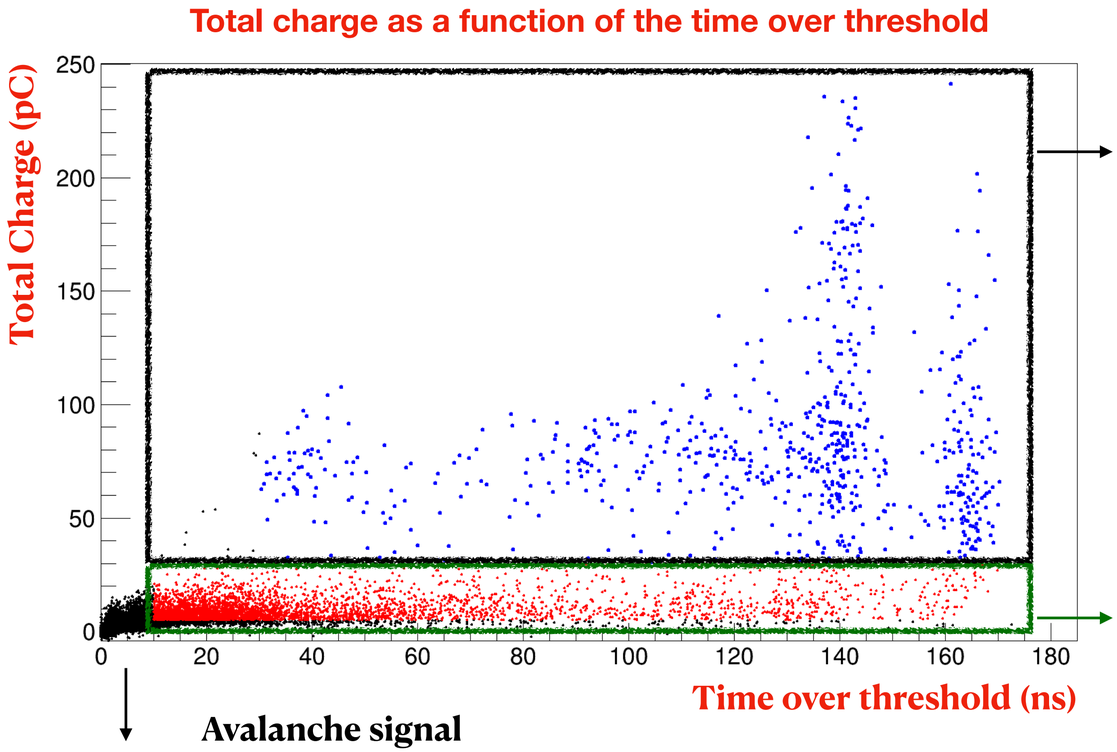
- signals which cross an amplitude threshold equal to the 5 Root Mean Square of the background window;
- The background is calculated in a time window of 40 ns which anticipates the avalanche signal;
- The average value of the RMS over all the HV scans is ~ 1.5 mV
- Only the events in which the confirm chamber has been efficient have been considered in the analysis





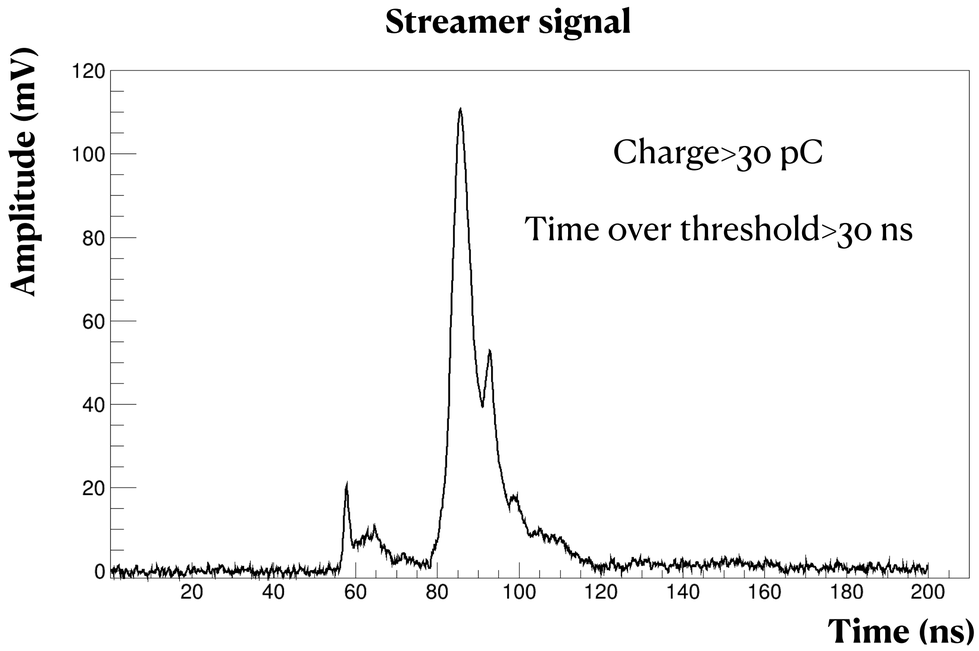


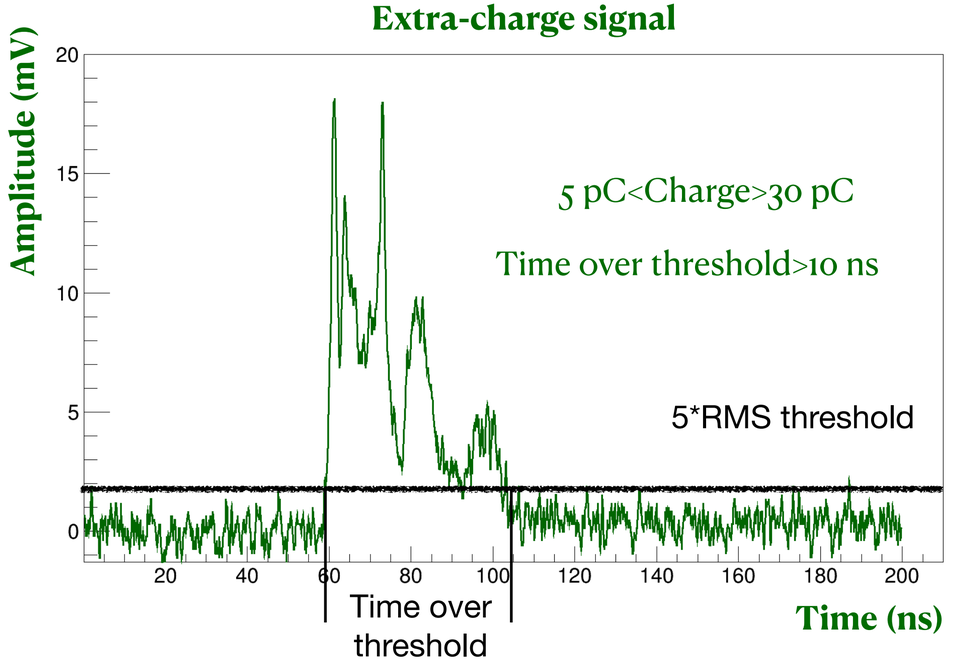
Streamer and extra charge definition



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 :

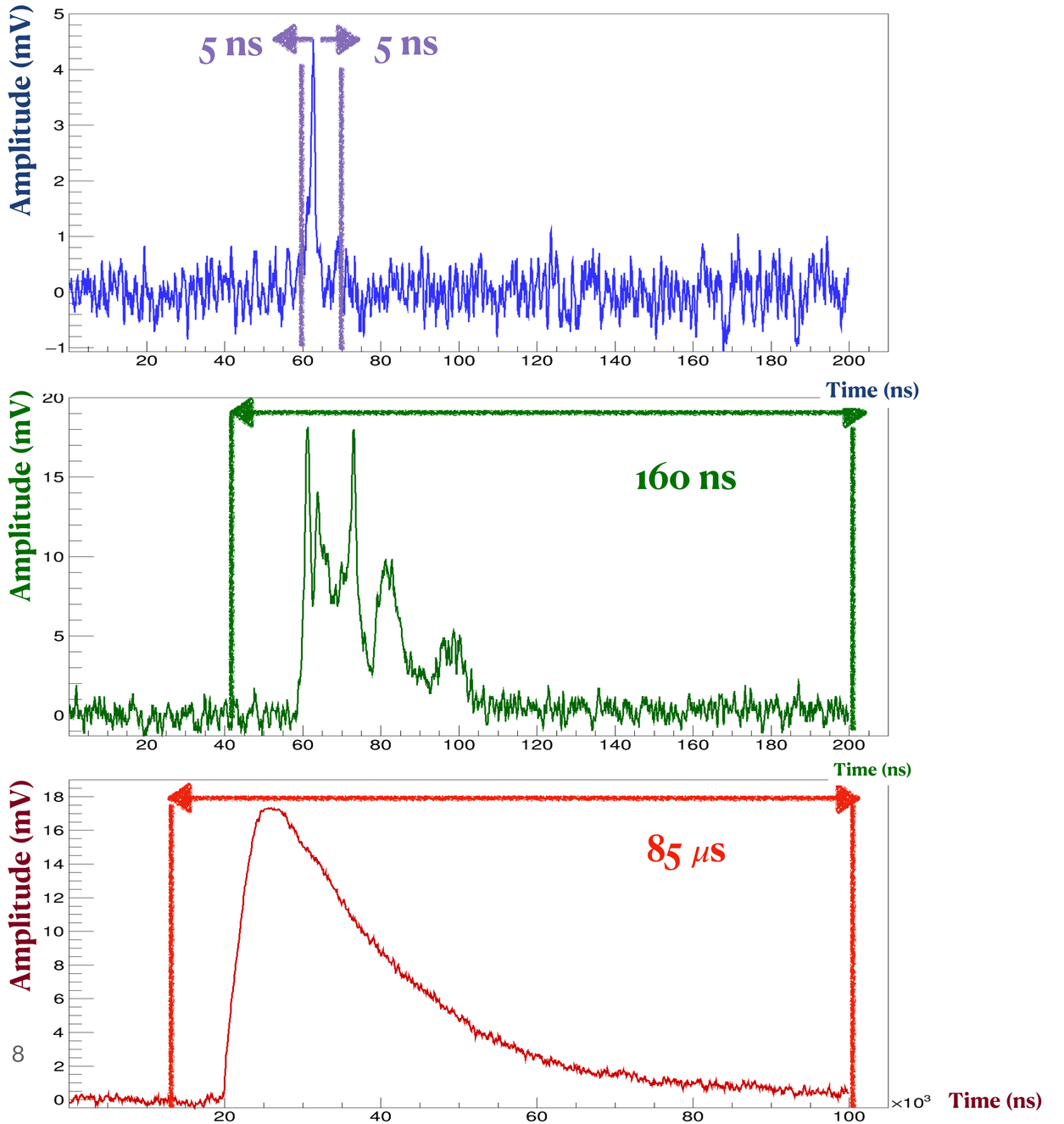
- Low charge and low time over threshold signals have been considered as **avalanche signals**
- Medium charge and high time over threshold signals have been considered as **extra-charge signals**
- High charge and high time over threshold signals have been considered as **streamer signals**

Charge Definition

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)



Mixtures under study

HFO/CO2 Variable Ratio (constant i-butane/SF6=5/1)

HFO/CO2/i-C4H10/SF_6 =

- **25/69/5/1**
- **20/74/5/1**
- **15/79/5/1**
- **10/84/5/1**
- **5/89/5/1**

CO2/i-C4H10 Variable Ratio (constant HFO/SF6=5/1)

HFO/Co2/i-C4H10/SF6 =

- **5/84/15/1**
- **5/79/10/1**
- **5/89/5/1**

Efficiency study

- Absolute efficiency plateau value
- High voltage working point
- Study of the streamer and extra charge probability
- Separation between avalanche regime and streamer/extra charge appearance

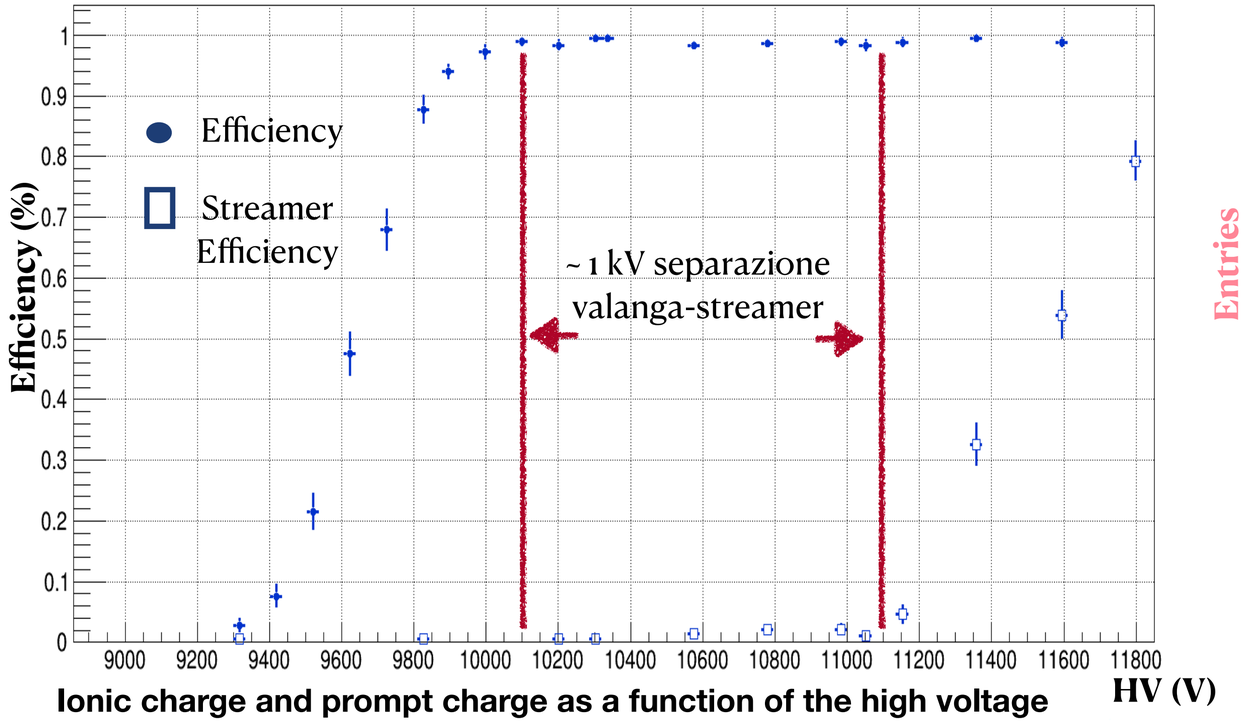
Charge study

- Avalanche, total prompt and ionic charge value in HV point of interest
- Study of the charge distributions

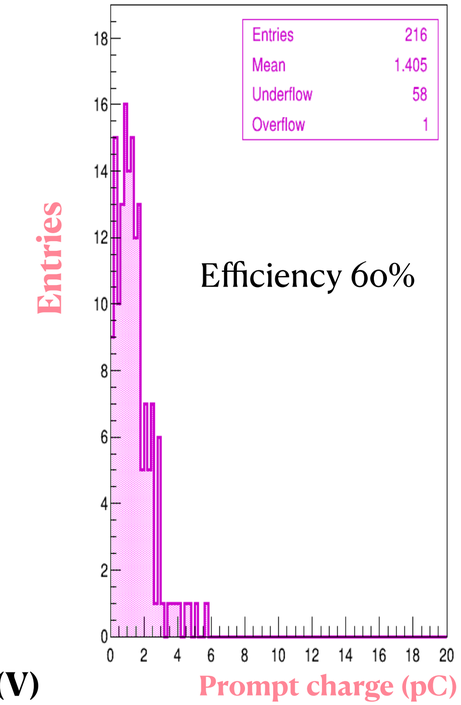
Results

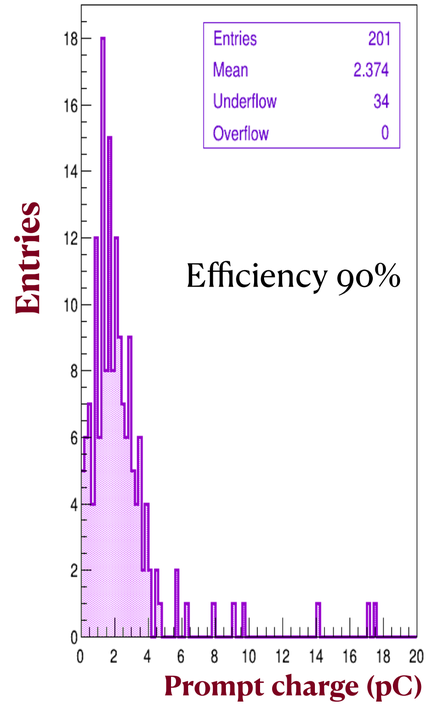
Standard mixture as reference

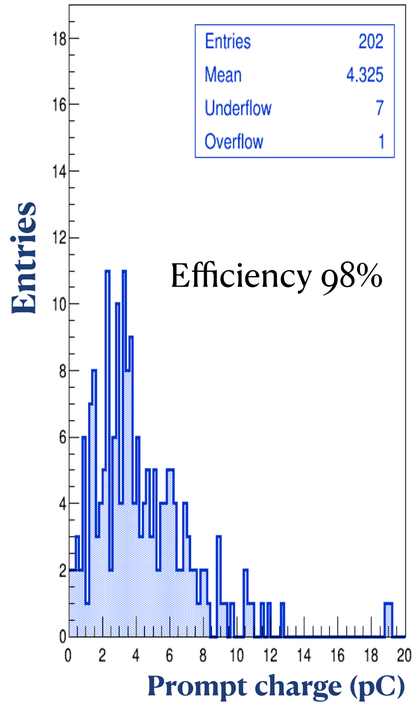
Efficiency and streamer probability as a function of the high voltage



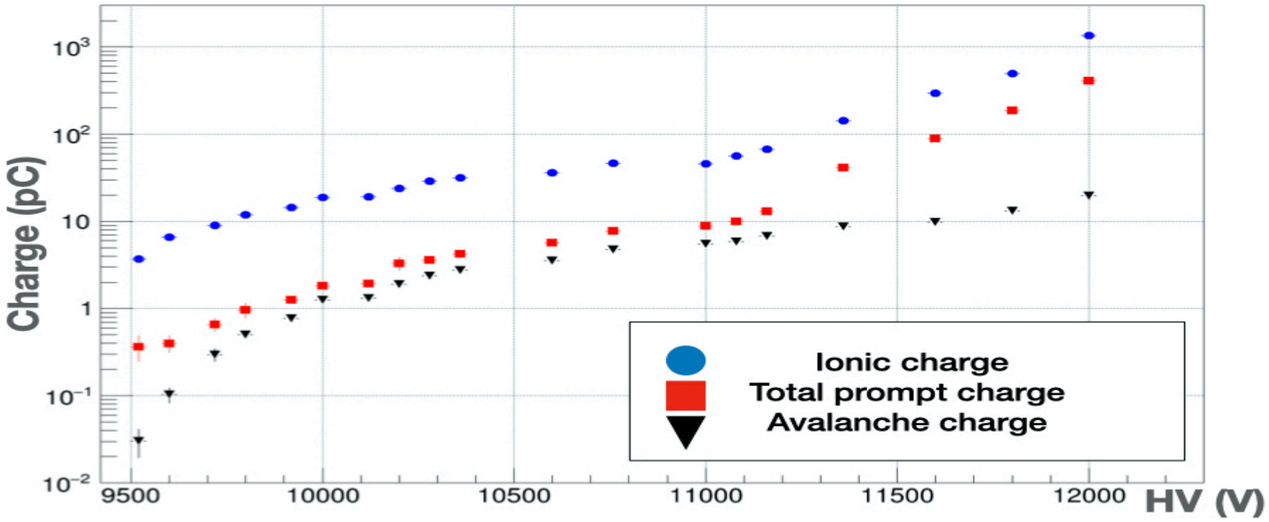
Charge distribution at different efficiency values







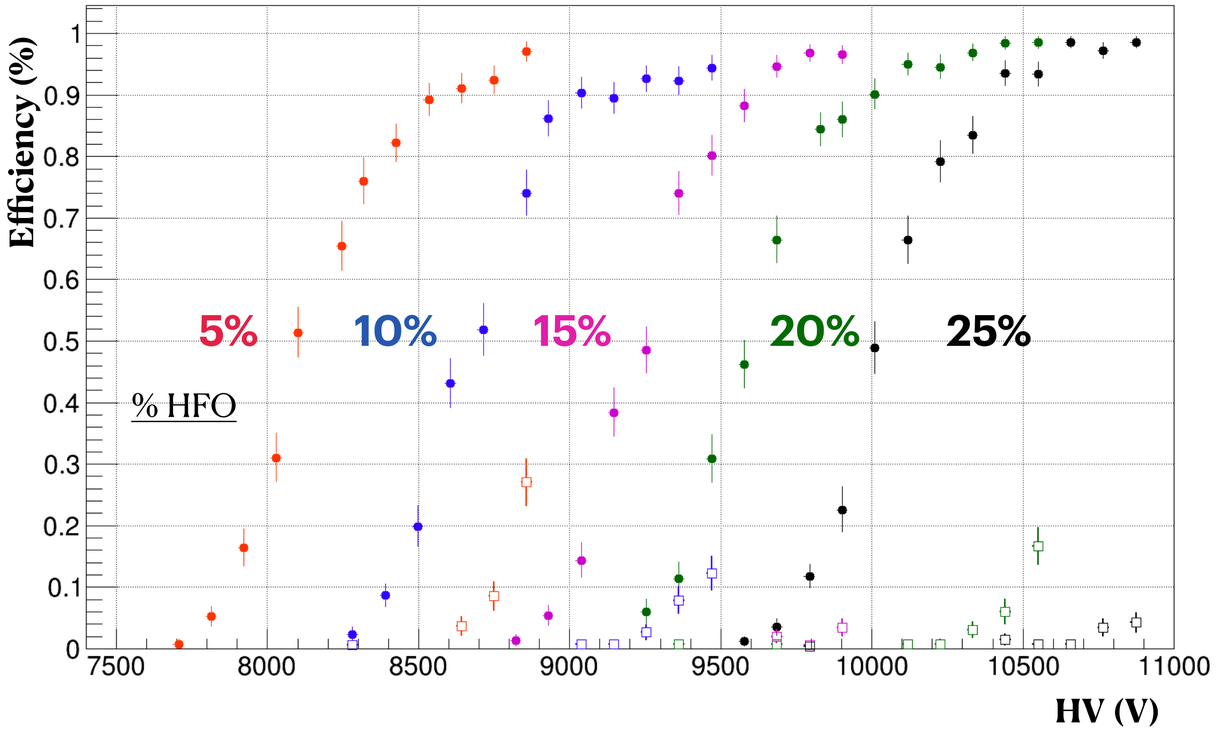
Ionic charge and prompt charge as a function of the high voltage



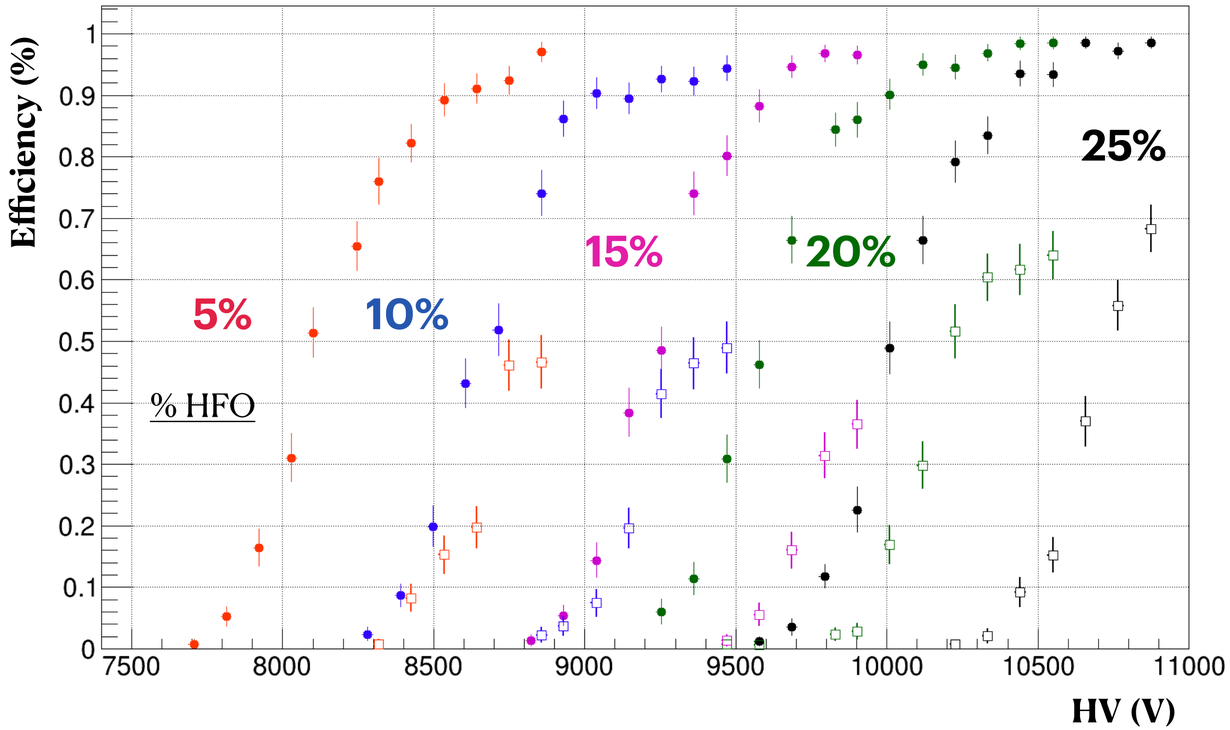
- Ionic charge @10.1 kV = 20 pC
- Total prompt charge @10.1 kV = 2 pC
- Avalanche charge @10.1 kV = 1.2 pC

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

Efficiency and streamer probability



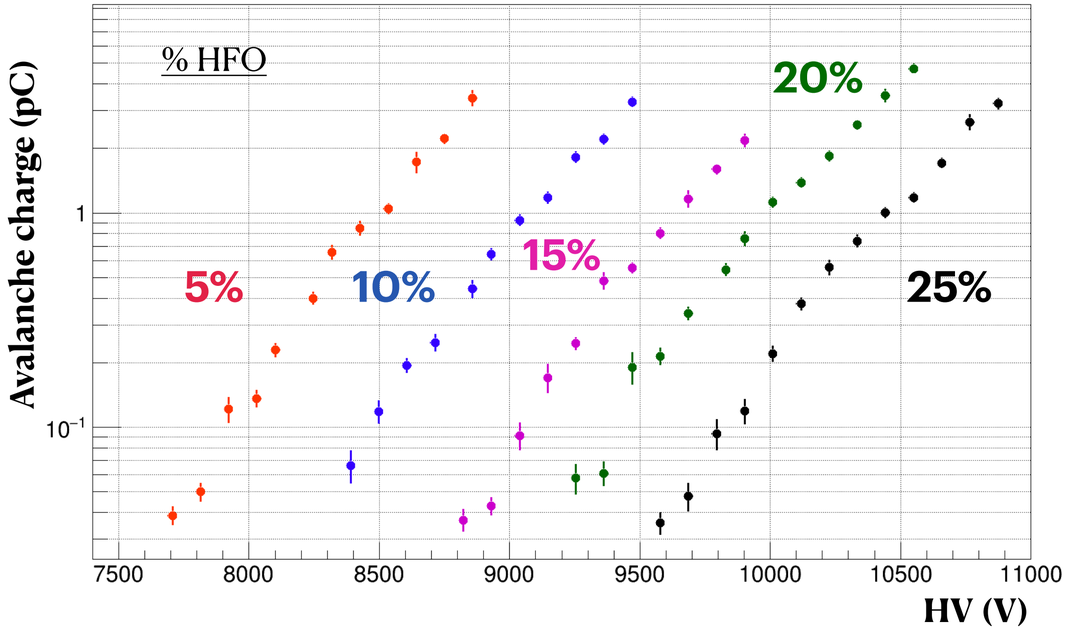
Efficiency and extra charge probability

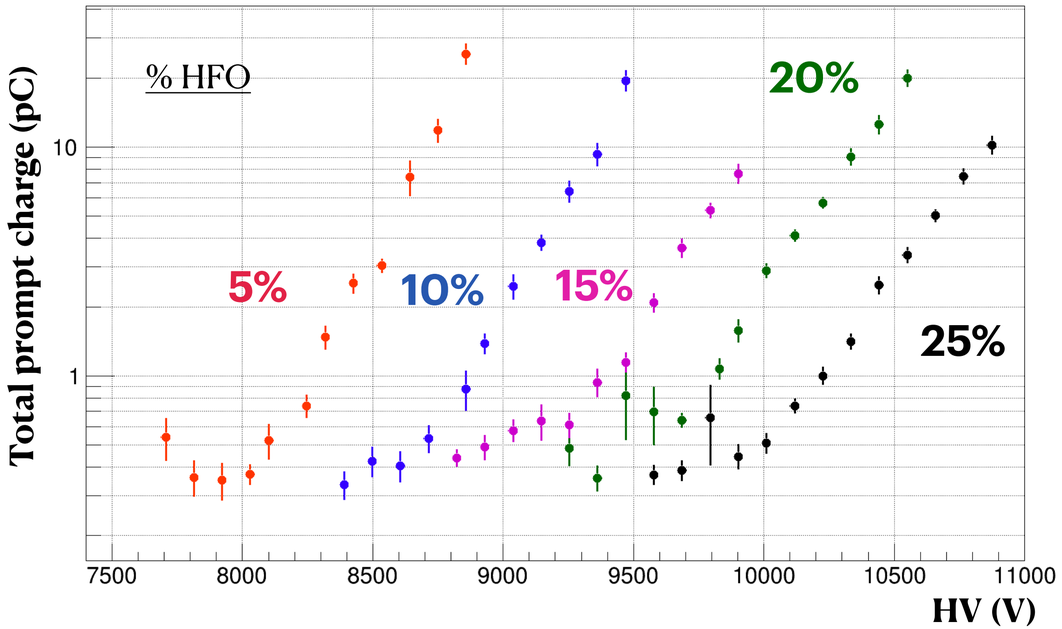


% HFO1234ze	V_{knee}	Efficiency @plateau	%streamer @ V_{knee} + 200 V	%extra charge@ V_{knee} + 200 V
5%	8.5 kV	93%	8.5%	46%
10%	9 kV	93.5%	3%	41%
15%	9.5 kV	96.5%	0.6%	31%
20%	9.9 kV	98%	0.8%	30%
25%	10.4 kV	98%	0.7%	37%

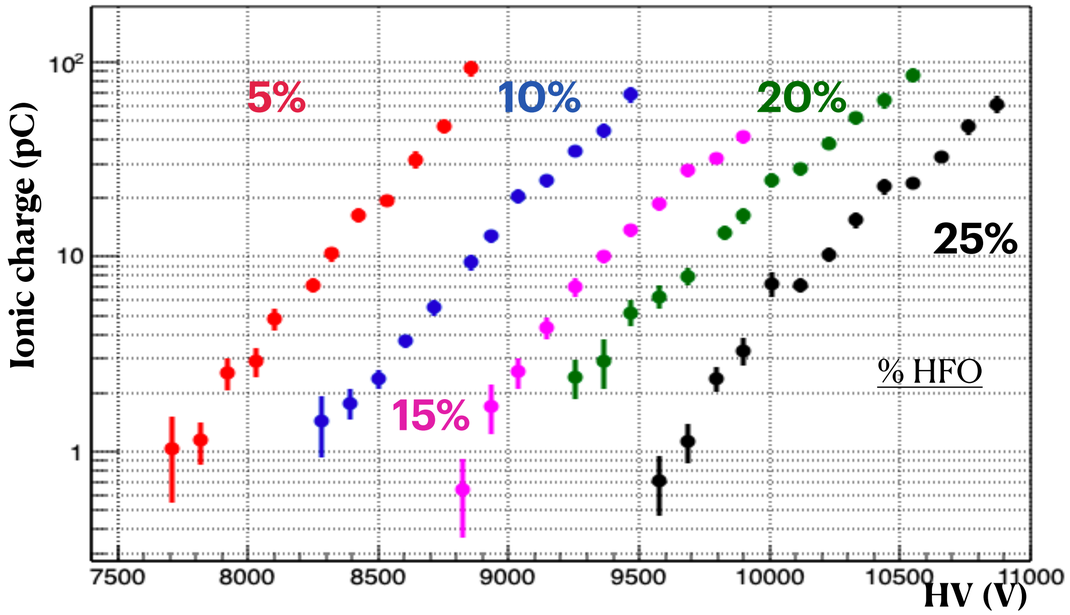
Vknee= High voltage @90% efficiency

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



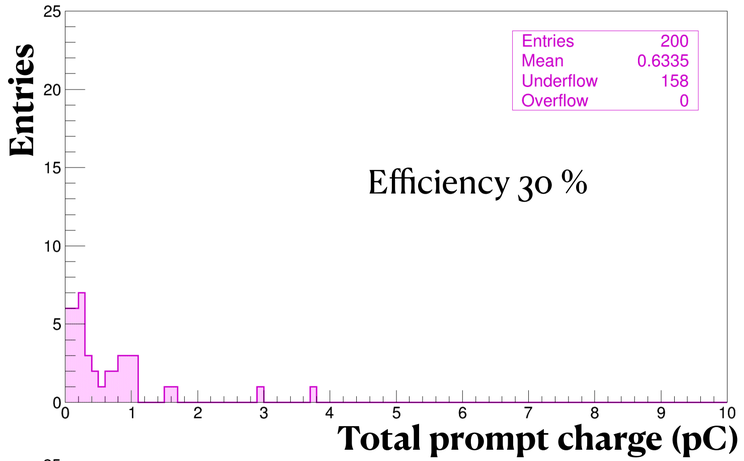


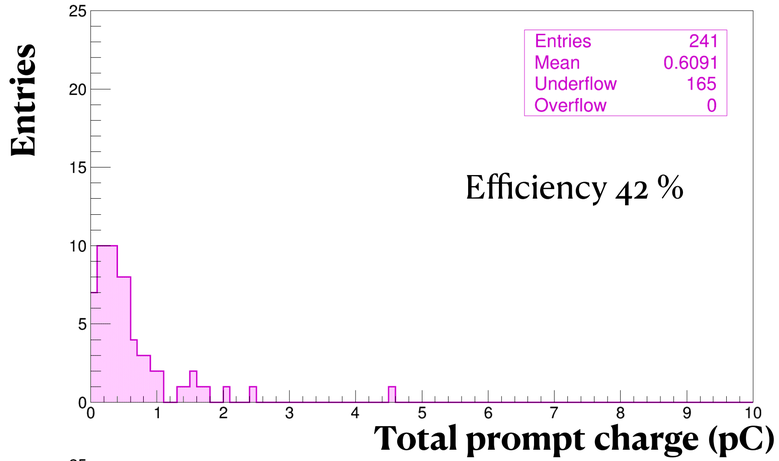
Vknee= High voltage @90% efficiency

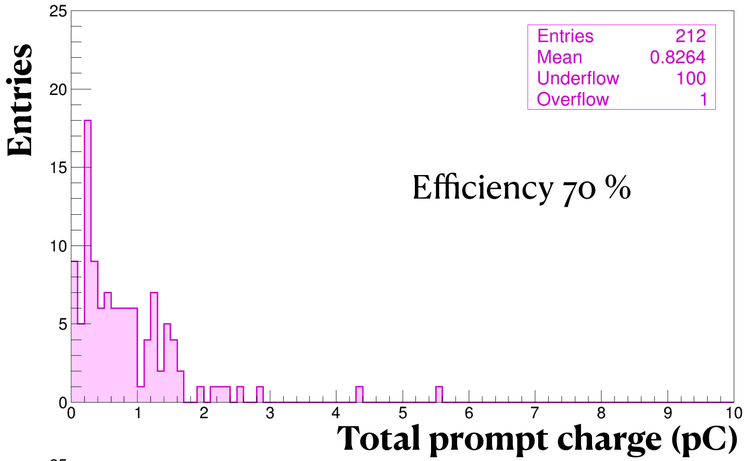


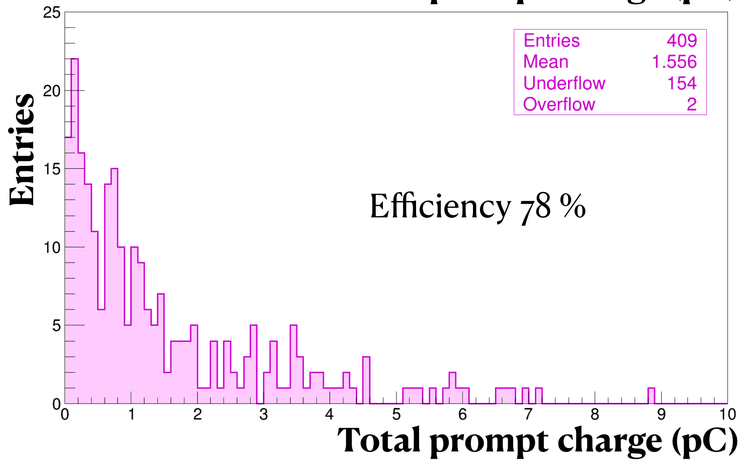
% HFO	V_{knee}	Avalanche charge@ V_{knee} + 200 V	Total prompt charge @ V_{knee} + 200 V	Ionic charge @ V_{knee} + 200 V
5%	8.5 kV	2.1 pC	11.5 p C	50 pC
10%	9 kV	1.9 pC	7 pC	38 pC
15%	9.5 kV	1.6 pC	4.3 pC	32 pC
20%	9.9 kV	1.5 pC	4 pC	31 pC
25%	10.4 kV	1.7 pC	5 pC	34 pC

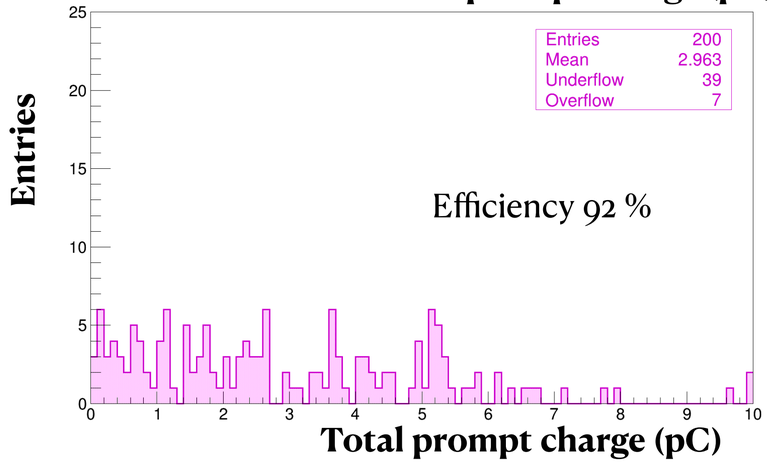
HFO1234ze/i-Butane/CO_2/SF_6=15/79/5/1: Total prompt charge distribution

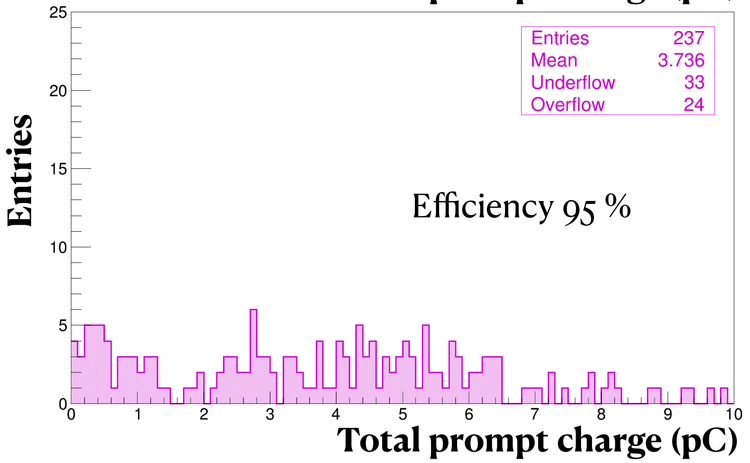






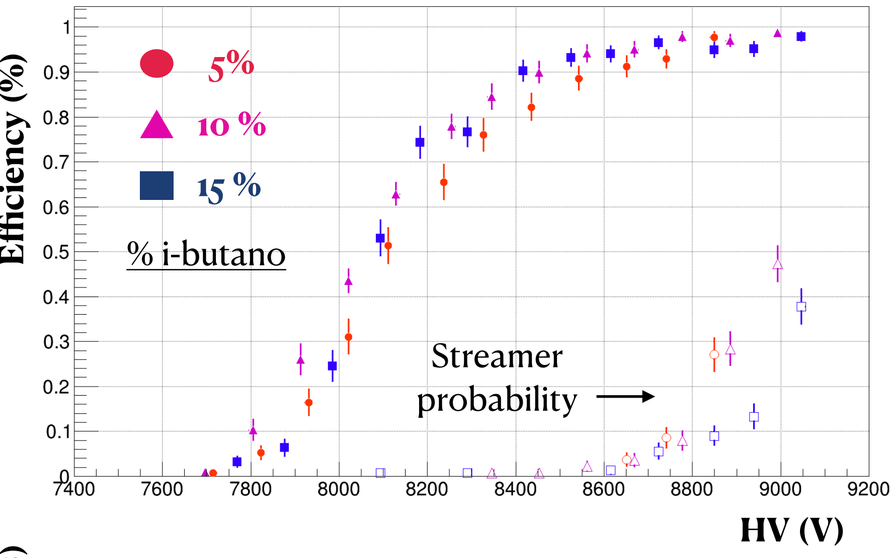


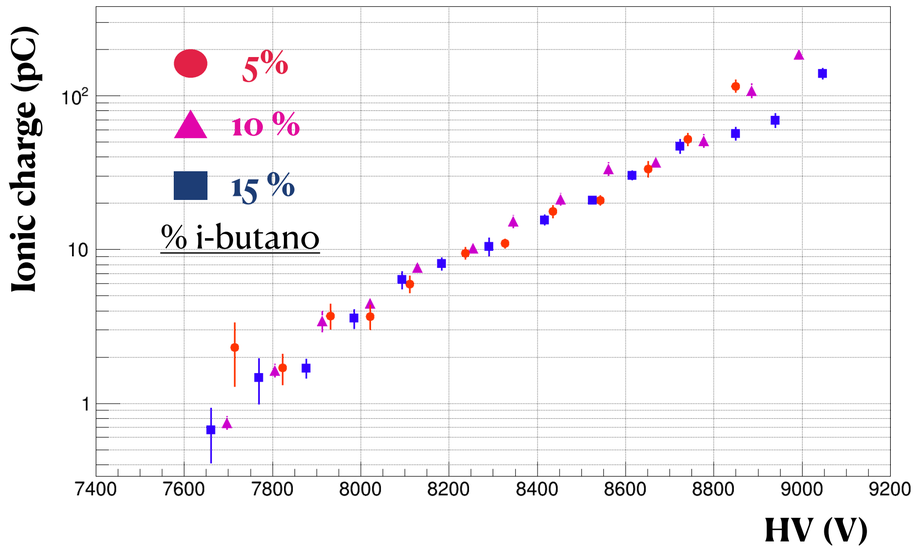


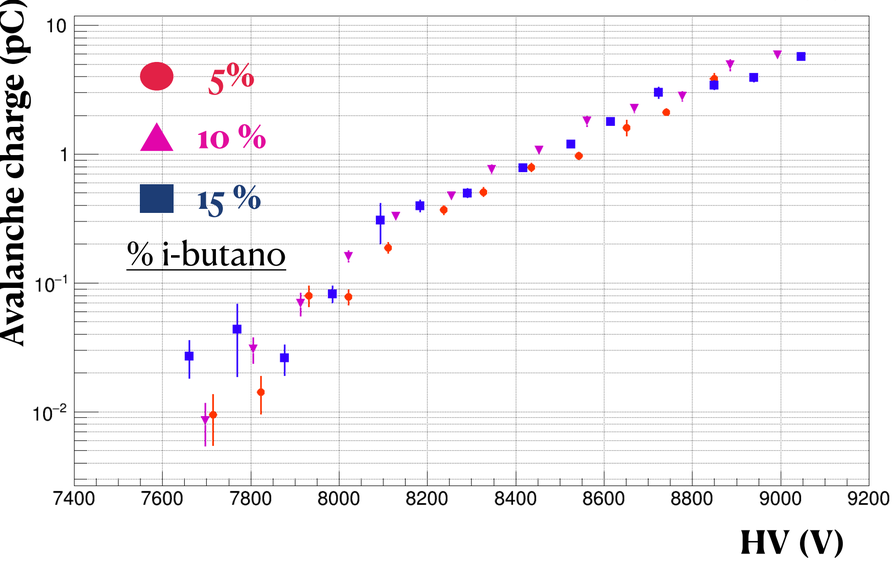


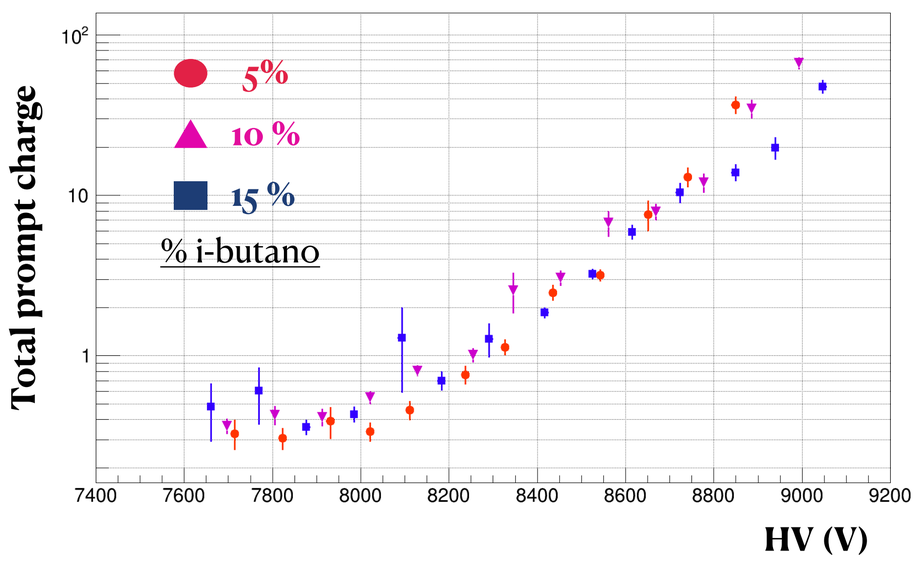
HFO1234ze/SF_6= constant=5/1 - CO_2=89/84/79

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









Subject to flammability limits

% i-butano	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-butano	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

Conclusions

- These results have been presented at the SIF 2020 conference but there is not a publication;
- 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 to the mixture could give benefits. To be investigated

To be discussed

- Could be a good idea to test the mixture composed by HF/CO2/i-butane/SF6= 25/69/5/1 under irradiation?
- If we want to continue with the ECOGAS2 mixture we will test it here in Rome using cosmic rays

Thank you!!

Backup