



XXXIV Annual Meeting of the Particles and Fields
Division of the Mexican Physics Society



Eco Gas Studies for the CMS Improved RPC Detector for the High Luminosity Large Hadron Collider

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Definition and Motivation

Data from unpublished gas mixtures studies in CMS were analyzed. The analysis was approved by the collaboration and presented at an international conference.

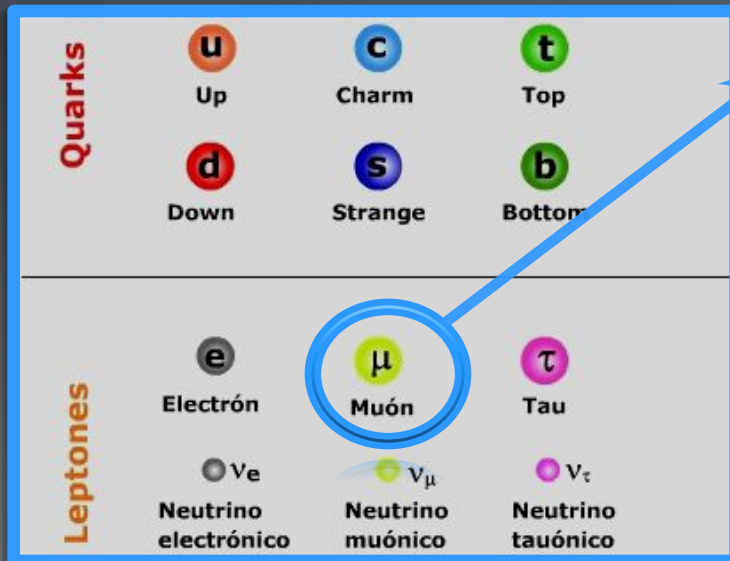
- **RPC** (Resistive Plate Chamber) detectors are particle detectors whose active medium is a mixture of different gases that make it possible to detect a particle when it passes through it.
- CMS, one of the four main experiments at the LHC at CERN (Switzerland), uses RPC detectors as a "trigger" system for data acquisition.

Motivation

- Mixtures with a high **GWP** (Global Warming Potential) index are harmful to the environment, for this reason it is necessary to find an alternative whose index is lower and allows optimal operation of the detector. The GWP index is an index that uses CO₂ as a reference.
- The officially approved blend for the past 10 years, for both the CMS experiment and the ATLAS experiment has a GWP value of, $GWP_{\text{CMS-Mix}} = 1434.55$. The aim of this work is to search for a gas which can be used for the same detectors but having a lower GWP index.

Theoretical framework

- Interaction of radiation with matter: Particles can be charged or neutral and depending on this they will behave differently when interacting with matter:
 - ✓ Charged: Ionization and excitation, Bremsstrahlung emission and electron-positron annihilation.
 - ✓ Neutrals: Compton effect, photoelectric effect and pair production

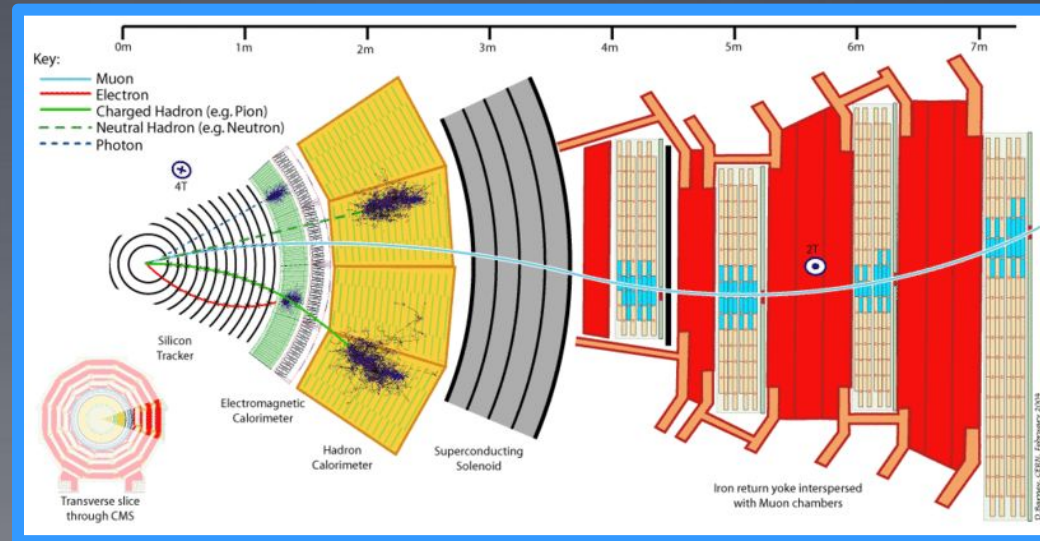


Muons are charged electron-like particles (200 times the mass of the electron) and can pass through matter almost without interaction.

Theoretical framework

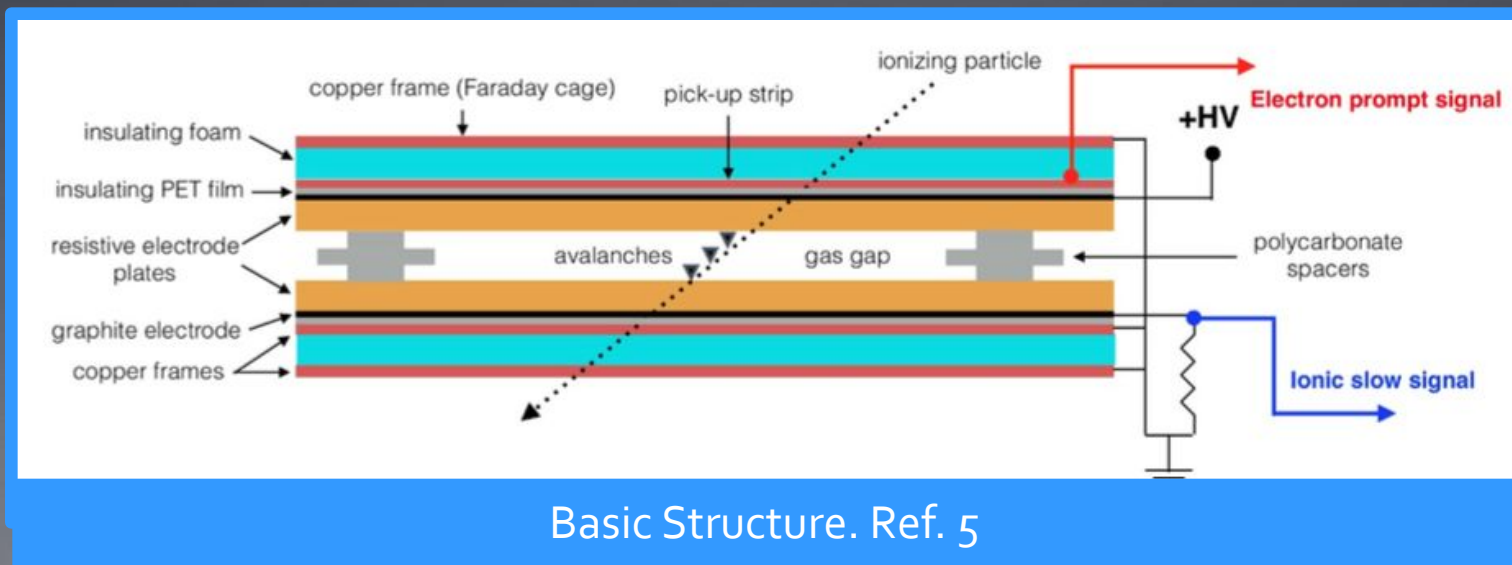
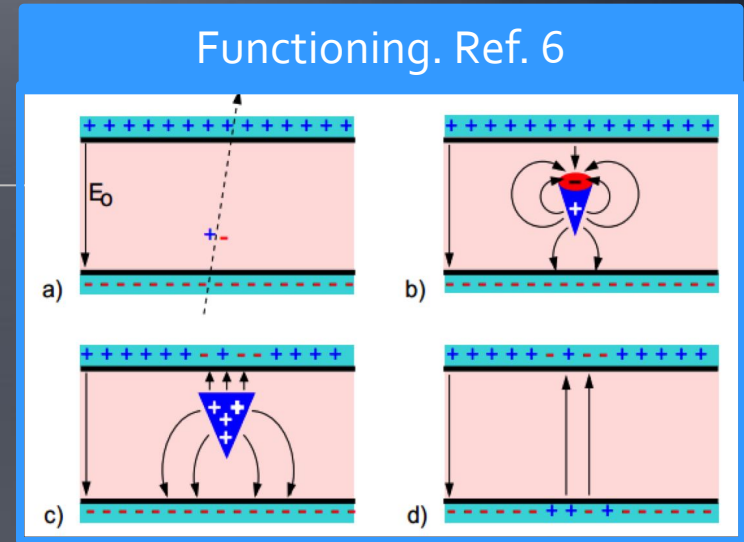
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Quarks	u Up	c Charm	t Top
	d Down	s Strange	b Bottom
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	e Electrón	μ Muón	τ Tau
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RPC Detectors

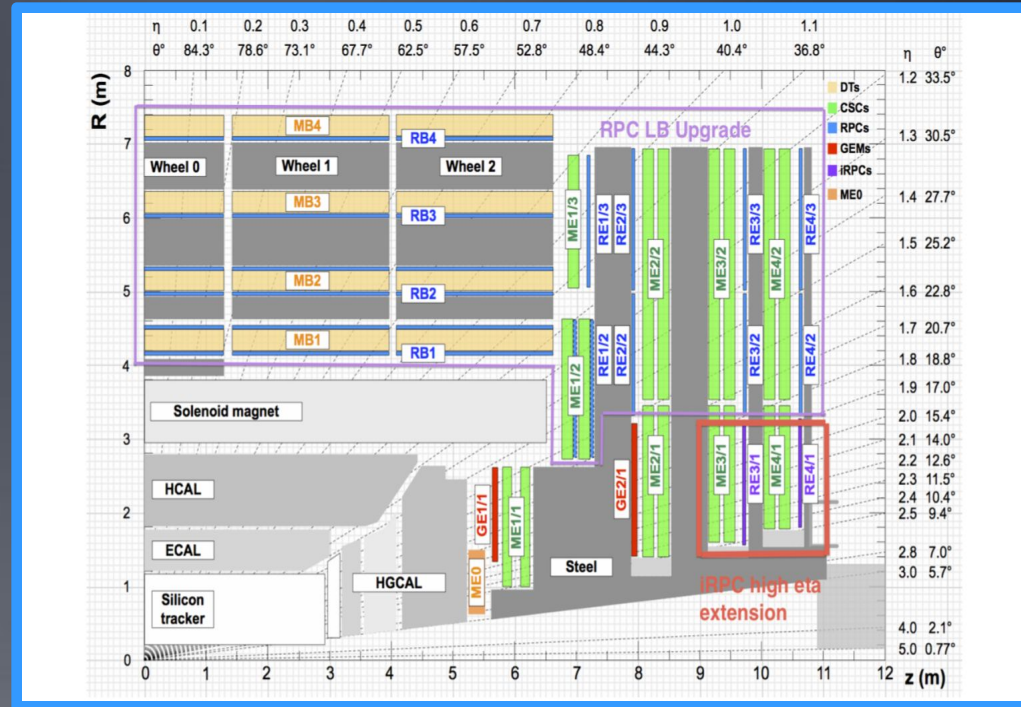
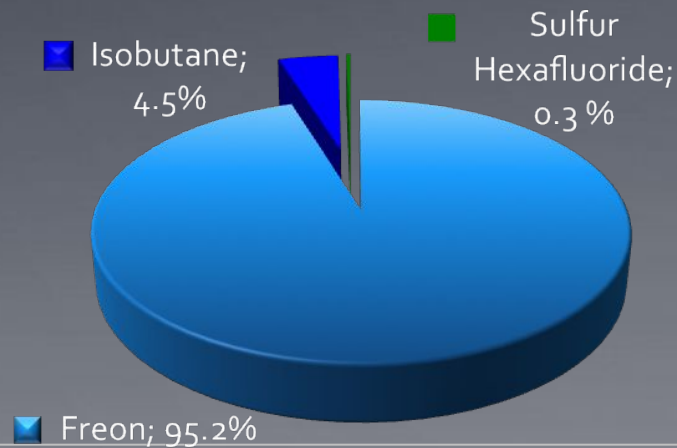
- Gaseous
- Its simplest form consists of:
 - ✓ Two highly resistive flat electrodes (10⁹ and 10¹² Ohms).
 - ✓ Filling gas.
 - ✓ Graphite paint coating.
 - ✓ Two planes of conductive lines.



Actual System at CMS

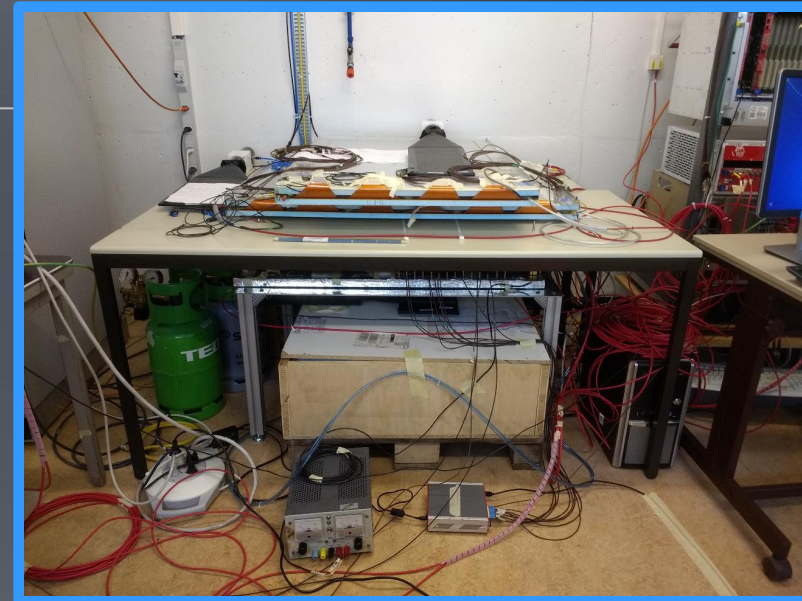
- Double gap camera system
- 480 cameras in the barrel
- 576 cameras on the outer cover
- Avalanche mode
- 2 mm thick Bakelite
- Gaps 2mm thick
- Relative humidity 40% -50%
- $GWP_{CMS-Mix} = 1434.55$

Gas Mixture



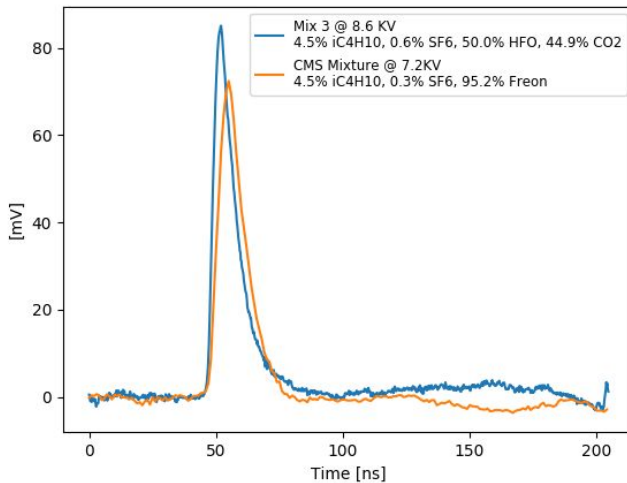
Cross section of the CMS RPC detectors. Considering the implementation of the new RPC detectors (red box), as well as the region of interest for the link system (purple region). Ref. 3.

Experimental Arrangement



- During the spring semester, the data analysis of the results obtained in the summer of 2017 in the CERN CMS experiment was performed.

- The experimental setup consisted of two scintillation detectors as trigger system and a $97 \times 54 \text{ cm}^2$ RPC, with 2 gaps 1.4 mm thick and 32 analog channels 2.5 cm wide, from which only 8 channels corresponding to the area covered by scintillation detectors.



- ✦ The signals obtained were digitized using a CAEN DT5742 module.
- ✦ Example of an analog signal obtained with an RPC using the CMS gas mixture (orange) and mixture number 3 (50% HFO, 44.9% CO₂, 0.6 SF₆ and 4.5 isobutane) at 8.6 kV.

At IBERO we have a detector with the same characteristics to reproduce the results and to test more mixtures.

Gas Components

Gas Component	Characteristics	GWP Index
SF6 Sulfur Hexafluoride	Colorless, odorless, non-toxic and non-flammable gas, used as quenching gas. It is considered as a high contributor to the green-house effect.	23900
i-C ₄ H ₁₀ Isobutane	The deterioration of the ozone layer has led to an increase in the use of isobutane in refrigeration systems and as a propellant, replacing chlorofluorocarbons.	3.3
Freon	Is a refrigerant composed of chlorofluorocarbons, harmful for the ozone layer.	1430
CO ₂ Carbon Dioxide	Colorless gas, it is a green house effect gas and the GWP index is related to this gas.	1
HFO	Are non flammable and non-toxic refrigerants characterized by having zero ozone depletion potential (ODP) and low GWP.	3

Gas Blends

- 5 different gas mixtures and the mixture currently used by the CMS experiment were analyzed.
- Freon was replaced by a mixture of HFO and CO₂ in different proportions for the different mixtures.
- The GWP index values of each of the mixtures were obtained, from where we can observe a notable decrease of about an order of magnitude, in the CMS mixture to the 5 proposed mixtures.
- The operating voltage is greater than the voltage for the CMS mix, approximately around 8,000 and 8,600 V.

Component	CMS	1	2	3	4	5
SF6	0.3%	0.3%	0.6%	0.6%	0.6%	0.6%
Isobutane	4.5%	4.5%	4.5%	4.5%	5%	4.5%
HFO	-	50%	55%	50%	50%	45%
CO ₂	-	45.2%	39.9%	44.9%	44.4%	49.9%
Freon	95.2%	-	-	-	-	-

Blend	GWP	Color*
CMS	1434.55	■
1	75.14	■
2	154.6	■
3	145.5	■
4	145.51	■
5	146.73	■

*Code color used for the next results

Example of the GWP Calculation:

$$GWP_{SF6} = 23900$$

$$GWP_{Iso} = 3.3$$

$$GWP_{Freon} = 1430$$

$$SF6 \rightarrow 0.3\% \rightarrow GWP = 71.7$$

$$Iso \rightarrow 4.5\% \rightarrow GWP = 1.49$$

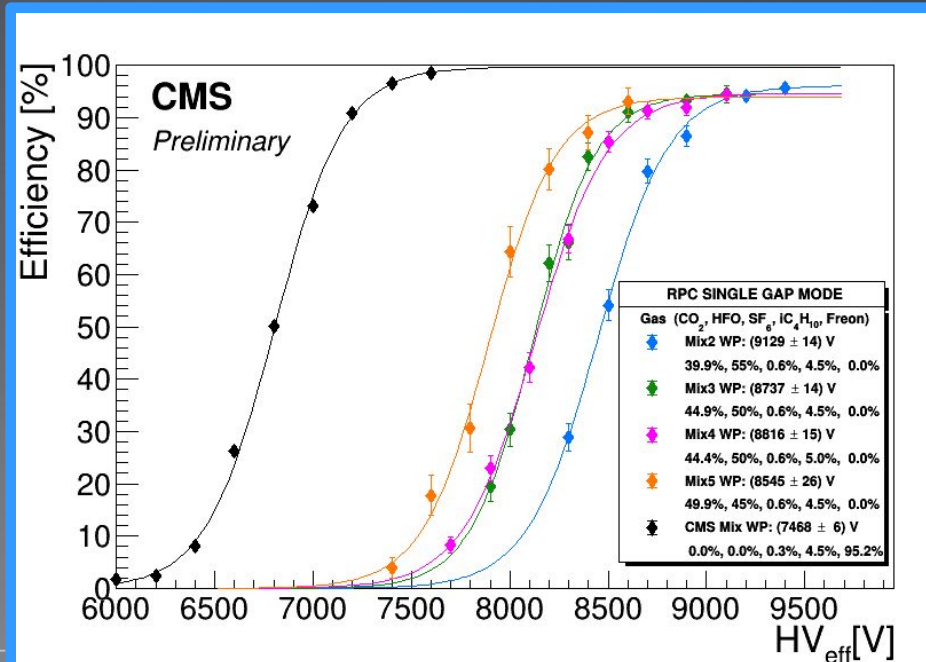
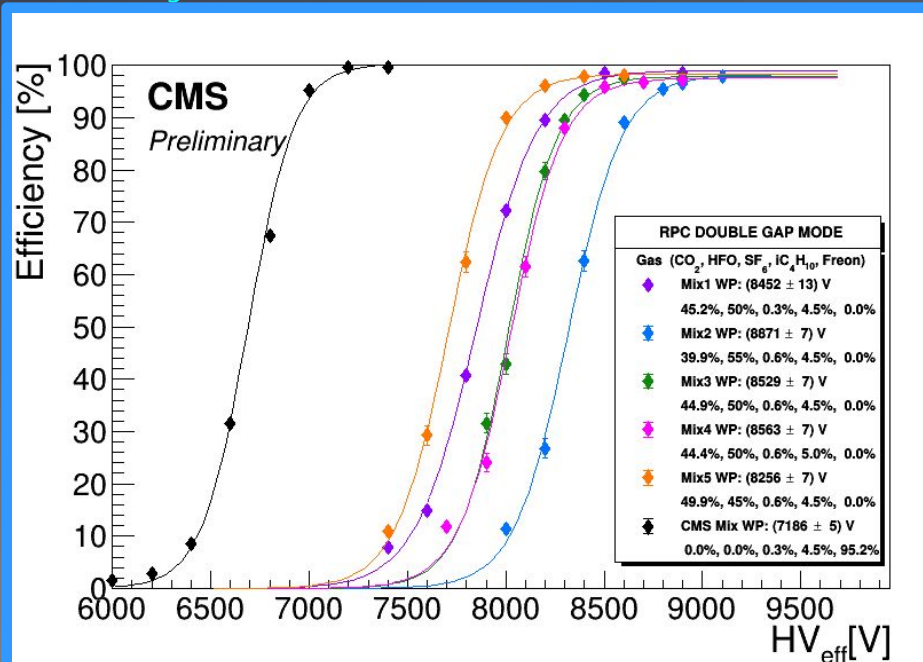
$$Freon \rightarrow 95.2\% \rightarrow GWP = 1361.55$$

$$GWP_{CMS-Mix} = 1434.55$$

Ref. [9]

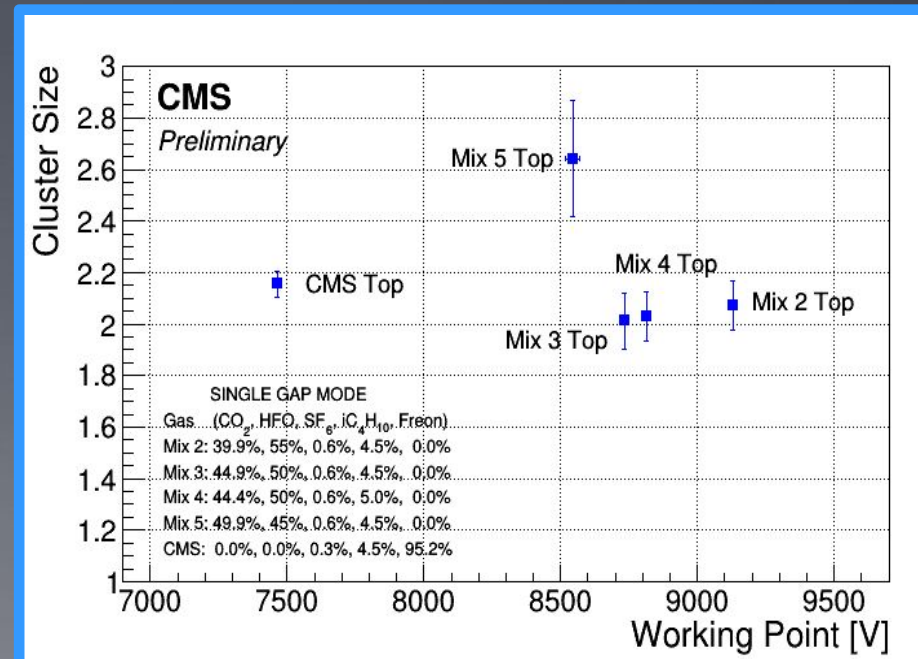
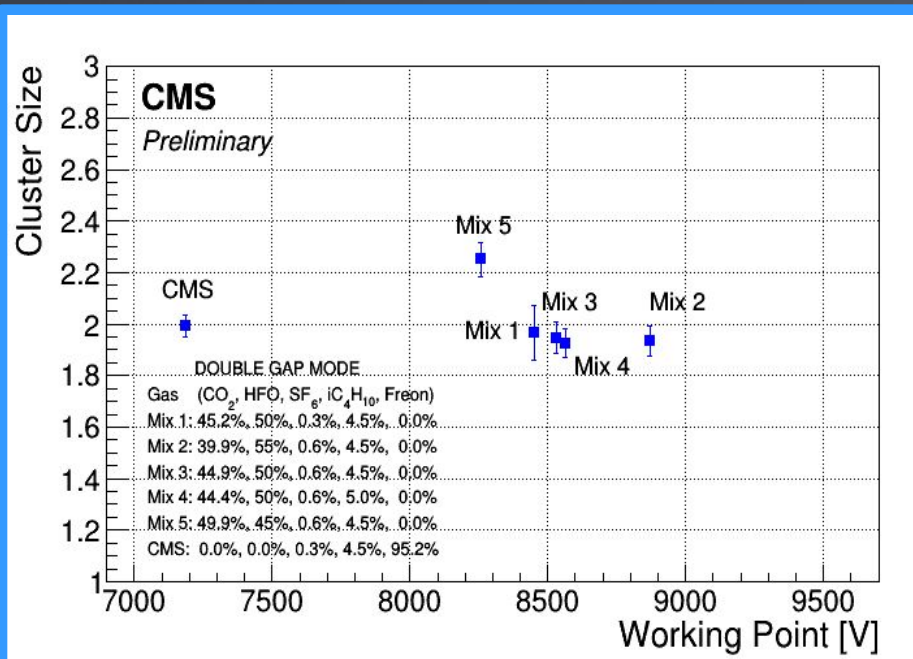
Efficiency

- Signals were considered if they exceed a threshold defined as 10 times the standard deviation of the offset size of the digitized signal of the first 100 points of the signal.
- Efficiency was calculated as the quotient of the number of events with signal in at least one channel divided by the total number of events.
- The working point (WP) of the RPC detector is defined as the high voltage value at which the efficiency is 95% plus 150 V.
- ✓ A similar behavior between all mixtures is observed and, although the efficiency curve is shifted to higher HV values, the Working Point is still acceptable.
- ✓ Mixtures 3 and 4 show almost the same behavior, the difference between the two mixes is an increase of isobutane of 0.5%.
- ✓ Increasing HFO in 5% (from mix 5 to 3 and from 3 to 2) while decreasing CO₂, we get an increase in the HV_WP of around 300 V.



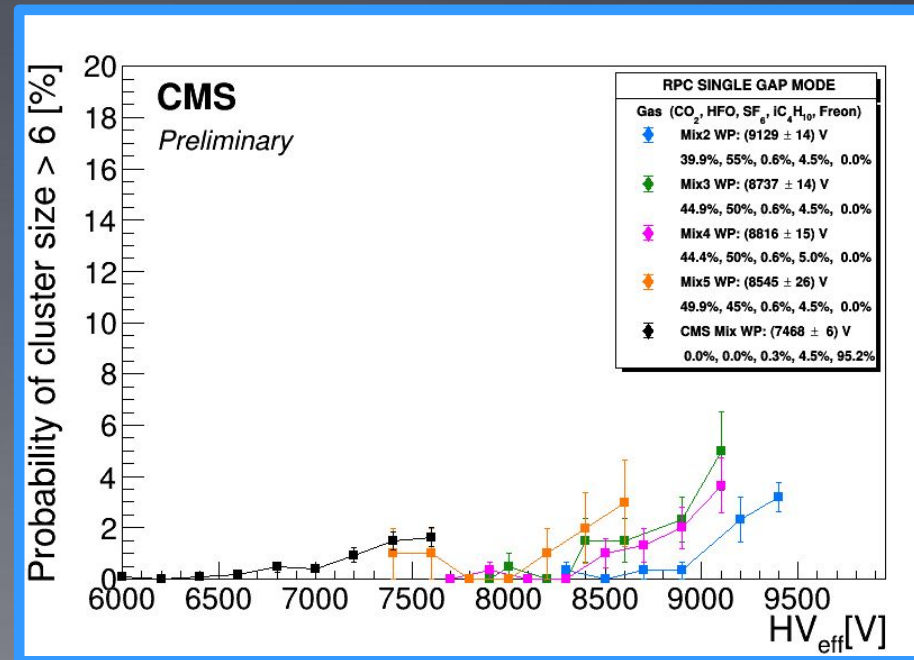
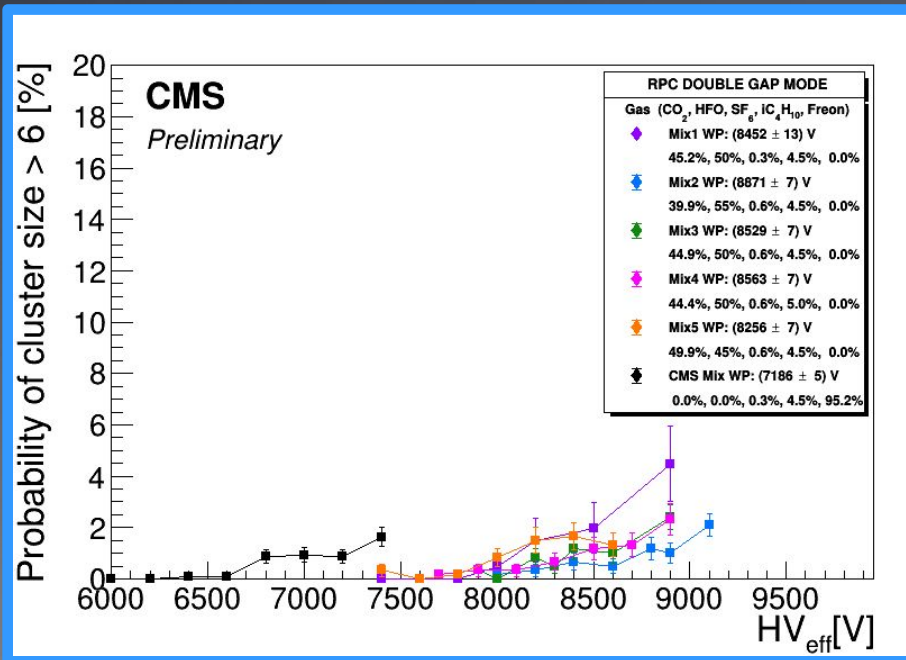
Cluster Size

- The "Cluster Size" was defined as the number of consecutive channels with a signal above the threshold.
- For each mix, the "cluster size" is shown depending on the working point, considering double-gap and single-gap modes.
- ✓ We can observe that the Cluster Size is almost constant with a value of about 2, for all the mixtures except for the mixture number 5.



Probability of having a Cluster Size greater than 6

- Here the cluster size greater than 6 consecutive channels is considered. In both RPC operating modes this probability is shown to be less than 10%.
- ✓ We can observe that the probability of Cluster Size variation above 6 strips is much lower than 10% for all mixtures.



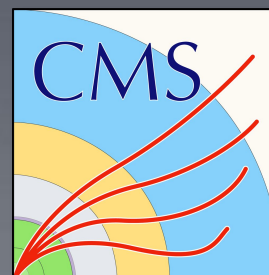
Summary

- This study has already been submitted to the CMS Collaboration and was approved to be presented at National and International Conferences (see next slide).
- Promising mixtures have been found that reduce the GWP index by an order of magnitude, therefore they are considered as ecological mixtures.
- Efficiency was shifted to higher values but the WP is still acceptable. Mixtures 3 and 4 show good behavior.
- Cluster Size remains constant for all mixtures, with a value approximately of 2.
- Probability of having a Cluster Size greater than 6 is much lower than 10% for all mixtures.

Future Work

- These blends must be validated at a cluster rate of at least 2.0 kHz/cm², and this can be done at Gamma Irradiation Facility (GIF++) at CERN.
- A detailed study of the Streamer Probability is needed. The study of Cluster greater than 6 is only a first approach.

- In May 2019, these first results were presented during "The 7th Conference on Large Hadron Collider Physics"
- With a more detailed approach to data analysis, it was presented during the "LXII National Physics Congress 2019"



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