Study of environment-friendly gas mixtures for the Resistive Plate Chambers

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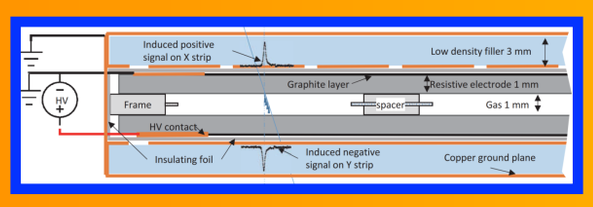
The Resistive Plate Chamber

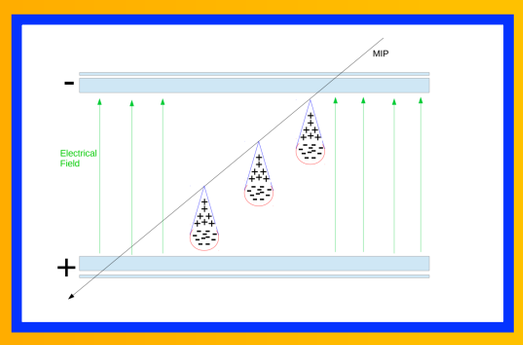
The Resistive Plate Chambers (RPC) are planar gaseous detectors working with a uniform electric field generated by two parallel plates of high-bulk resistivity electrodes.



The uniform field makes them very fast detectors with an excellent time resolution, suitable for timing measurements and for triggering

RPC under test : 2 mm gas gap RPC with 1.8 mm electrode thick

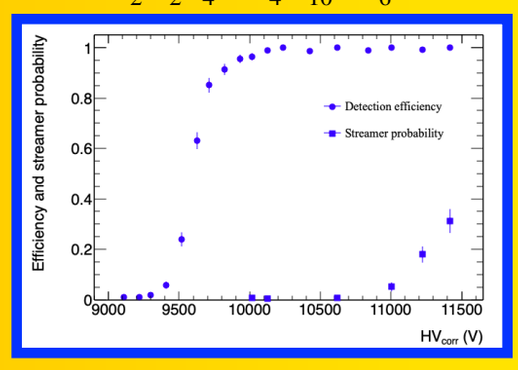
Avalanche and streamer operation mode



- Primary ionization
- Electron acceleration and avalanche charge formation
- Avalanche working mode
- Electron-ion recombination processes with UV photon emission
- Streamer formation

Avalanche mode: the standard gas mixture

$C_2H_2F_4$/i-C_4H_{10}/SF_6



- High gas density ensuring sufficient primary ionization
- Electronic prompt charge slowly increasing with the applied voltage and high enough to overcome the FE threshold
- Total delivered charge, dominated by the ionic charge, low enough to ensure modest working current and good rate capability
- Comfortable avalanche-streamer separation
- Non-flammable and made of industrial components

The standard gas mixture has a high Global Warming Potential (GWP) : search of an environment-friendly gas mixture for RPCs

GWP(CO_2) =1

$C_2H_2F_4$ + i-C_4H_{10} + SF_6 → GWP ~ 1430

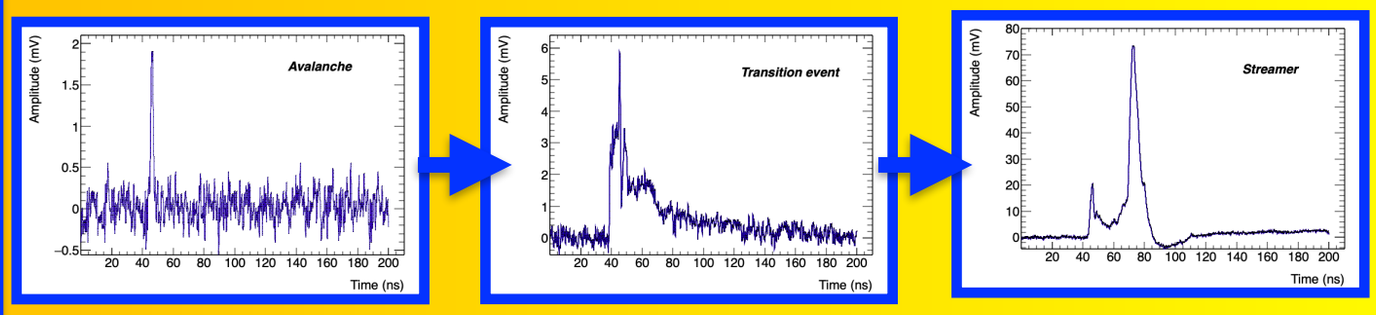
1). Substitution of $C_2H_2F_4$

$C_3H_2F_4/CO_2$ + i-C_4H_{10} + SF_6 → GWP ~ 230

2) Substitution of SF_6

$C_3H_2F_4/CO_2$ + i-C_4H_{10} + $C_3H_2ClF_3$ → **GWP ~ 10**

The transition events



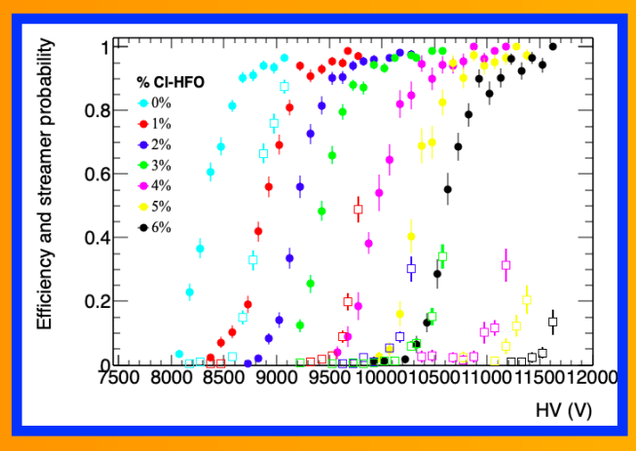
Avalanche : very short signal with low charge content (<12 ns, < 5 pC)

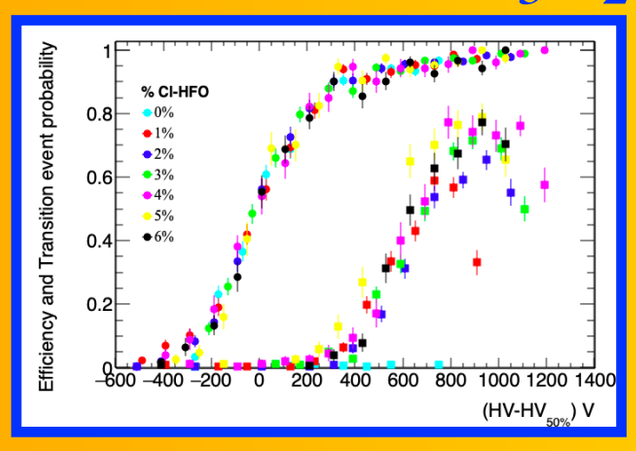
Transition signal : multiple avalanche signal and/or a large tail following the precursor (>12 ns, 5<q (pC)<30)

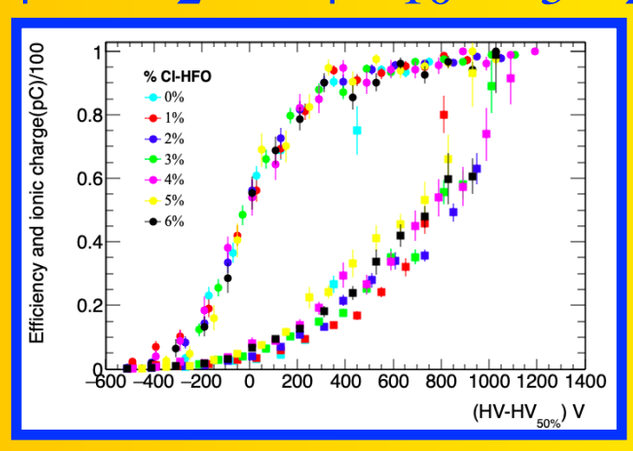
Streamer : avalanche signal precursor followed by a signal lasting tens of ns and with high charge content (>30 ns, > 30 pC).

The transition events are negligible with the standard gas mixture but relevant in the new HFO/CO_2 gas mixtures.
Mixtures studied with cosmic rays: ($C_3H_2F_4$/i-C_4H_{10}) = (15/7)% + CO_2/$C_3H_2ClF_3$ = (71/77) % / (6/0) %

Results on mixtures composed of : $C_3H_2F_4/CO_2$/i-C_4H_{10}/$C_3H_2ClF_3$ (Cl-HFO)



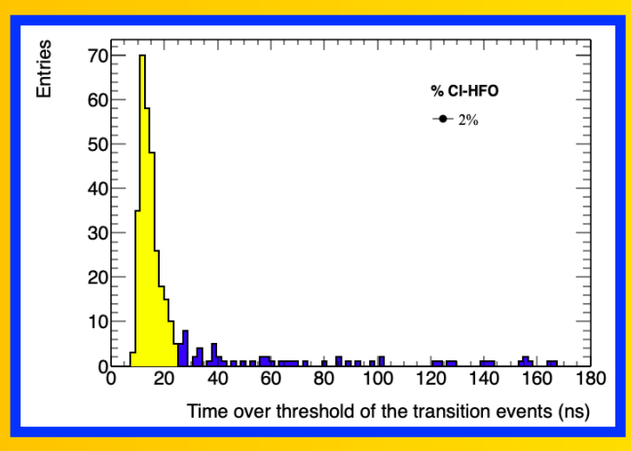


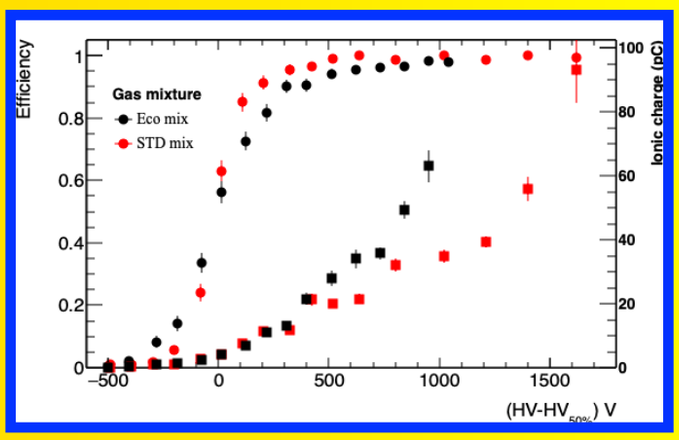


- Very strong quenching effect
- The operating voltage increases at the rate ~ 400 V/1% Cl-HFO
- Good detection efficiency (> 95%) -> exploring the possibility to increase the active target increasing the $C_3H_2F_4$ concentration
- Good separation avalanche-streamer (400 V)
- Total charge delivered (ionic charge) few pC higher with respect to the standard gas

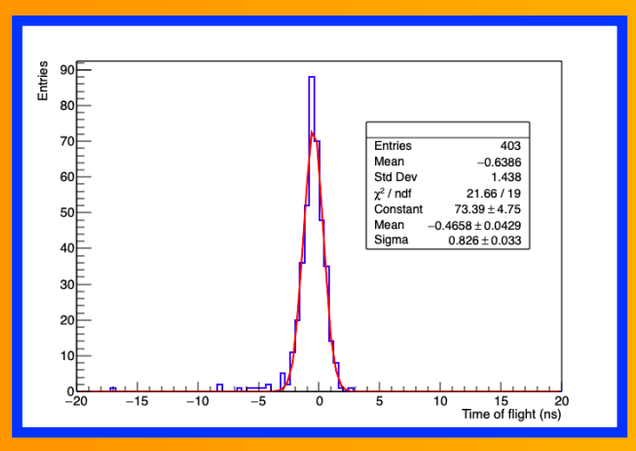
- Transition events less than 20% at the operating voltage with no strong impact on the charge
- The transition event probability decreases when the first streamers start to occur
- The transition events can be interpreted as streamer precursors
- The duration of transition events is within 20 ns

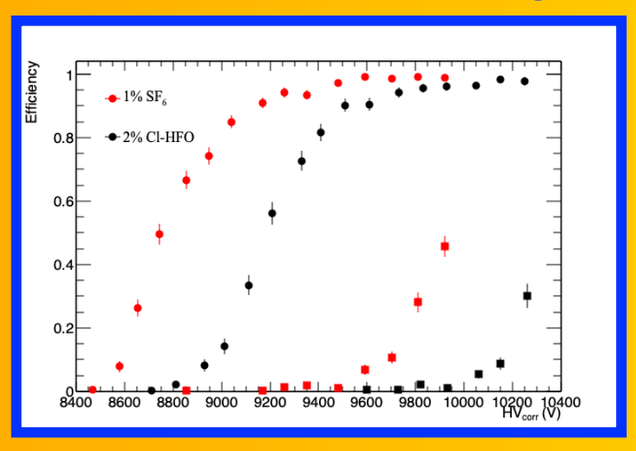
The criterium to select the gas mixture with the best performance is based on the minimization of both streamer contamination and ionic charge

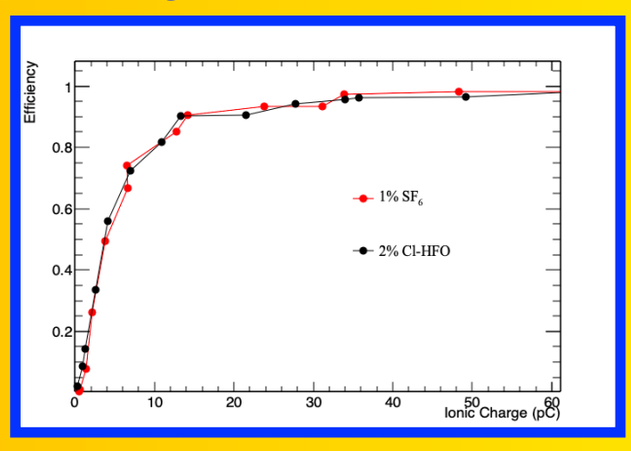




Best gas mixture selected: 2%$C_3H_2ClF_3$







Best improvement : excellent time resolution of about **0.8 ns**, 24% better than that of that of the standard gas (σ_{STD} ~ 1 ns)

The new gas, $C_3H_2ClF_3$, shows the same properties of SF_6:

1) Same detection efficiency
2) Avalanche-streamer separation slightly larger in the mixture with Cl-HFO
3) The mixtures shows the same ionic charge at the same efficiency value

Conclusions

Excellent performance achieved for the first time with a RPC operating with a totally environment-friendly gas mixture (GWP ~ 10)

References :

References : G. Proto *et al* 2022 *JINST* 17 P05005