Search of alternative gas mixtures or the Resistive Plate Chambers

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2nd DRD1 Collaboration Meeting & Topical Workshop on Electronics for Gaseous Detectors

Operating RPC in avalanche mode with the "standard" gas mixture

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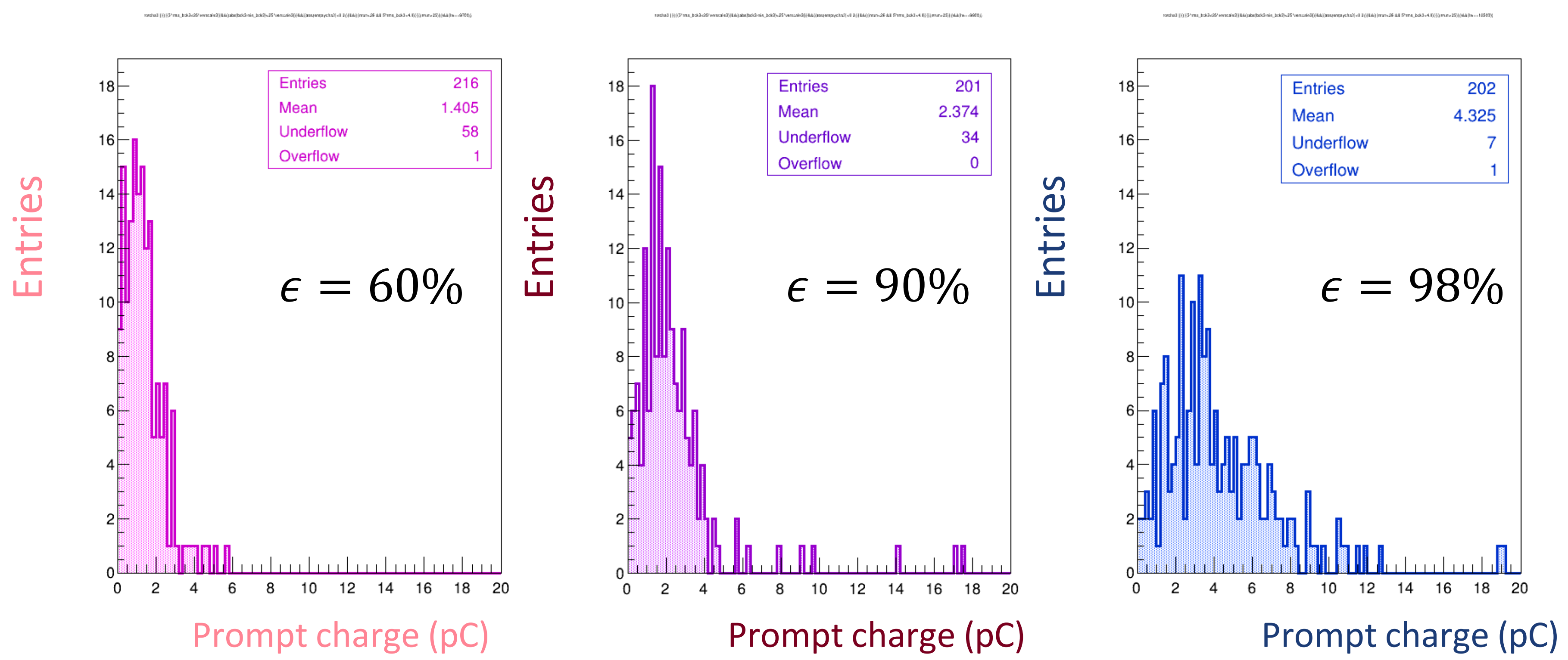
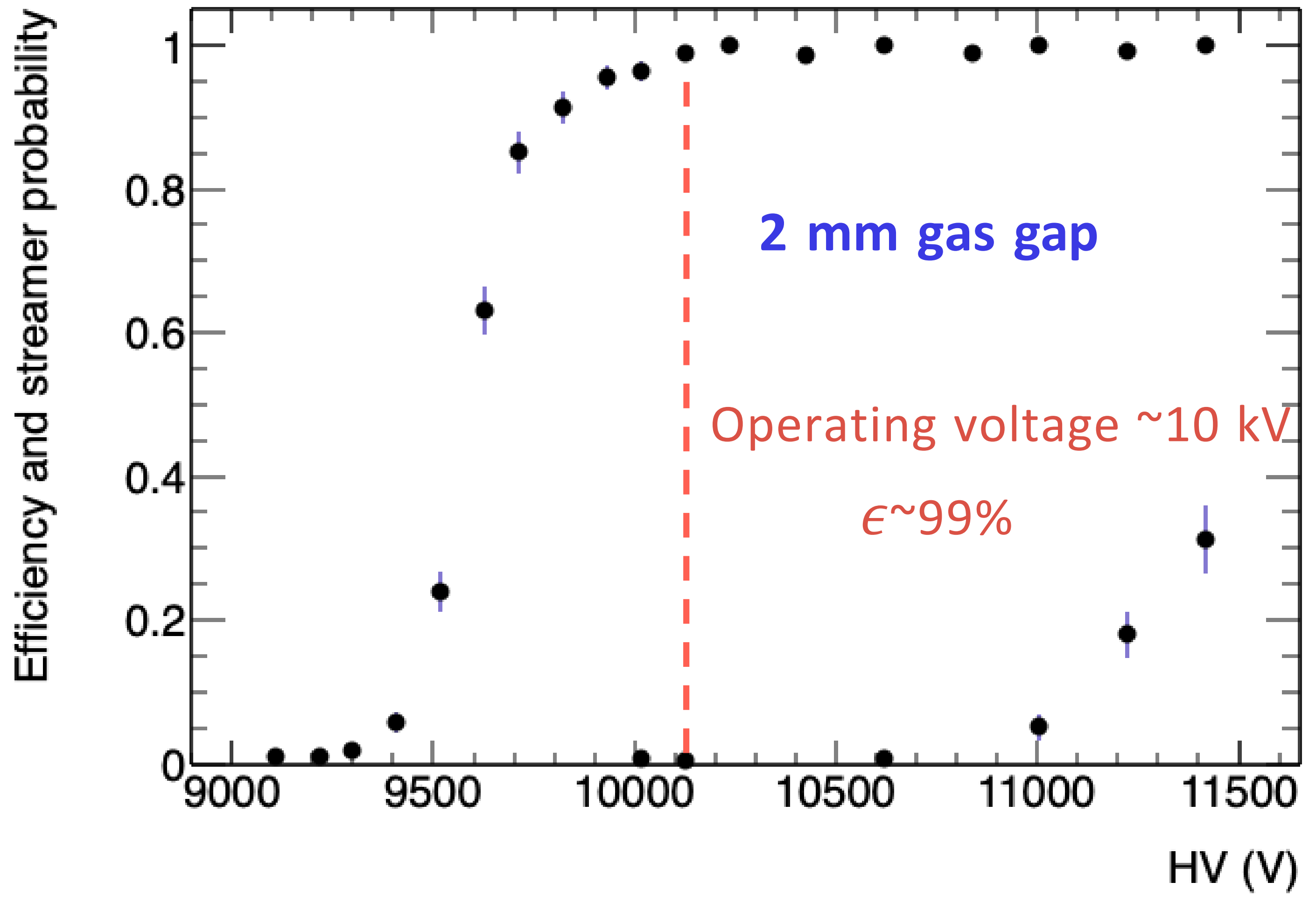
The standard gas mixture is composed of
94.7%$C_2H_2F_4$(TFE)/5%I-C_4H_{10}/0.3%SF_6

Primary target — **"Quencher"** — **Streamer suppressor**

- High gas density ensuring sufficient primary ionization even for gas gaps in the millimeter range size;
- Prompt charge slowly increasing with the applied voltage and high enough to overcome the FE threshold;
- Total delivered charge low enough to ensure modest working current and good rate capability;
- Comfortable avalanche-streamer separation
- Non-flammable and made of industrial components

Used in experiment with high radiation environment because it ensures high rate capability and long term operation





Search of an environment-friendly gas mixture

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The standard gas mixture has a high Global Warming Potential (GWP)

- $C_2H_2F_4$ (GWP ~ 1430) + $i\text{-}C_4H_{10}$ (GWP ~ 5) + SF_6 (GWP ~ 23000) → **GWP ~ 1450**

The European Union regulations have imposed a progressive phase down in the production and use of the F-gases (like $C_2H_2F_4$ and SF_6) in industry :

↓

Reduction of the availability

Increase of the cost

Search for an alternative gas mixture →

- Performance comparable to those of the standard gas (efficiency, current, rate capability, time resolution…)
- Low GWP
- Longevity of the detector for High-Energy Physics experiments (low current, low F^- production …)

Long term and performance

Gas parameters

- Density/cross section → High efficiency
- Capability to suppress streamer (electronegativity, affinity, electron capture cross section) → Low charge/current
- Molecular structure to avoid an excess of F^{-} production → Reduce the probability to damage the surfaces
- non flammable, no toxic

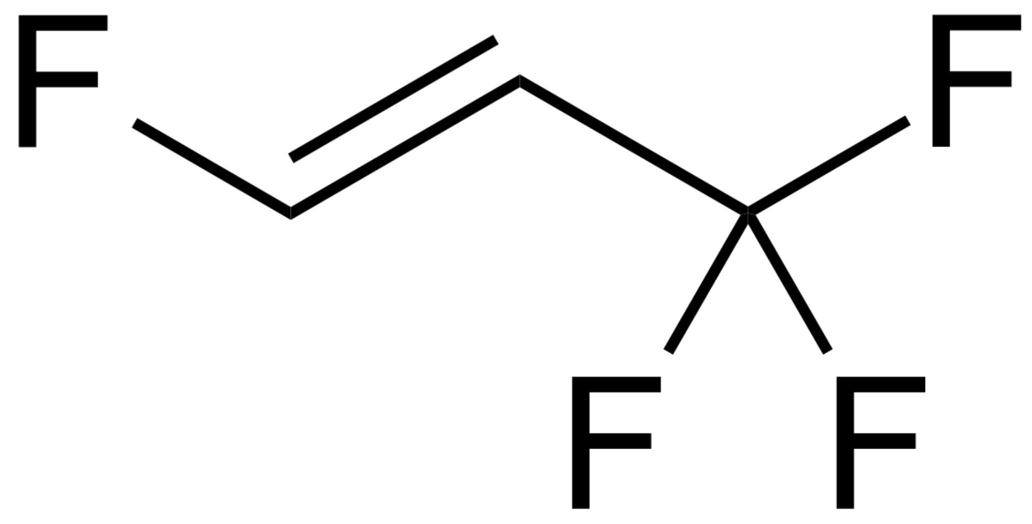
Detector parameters

- Gas gap width : the thinner the gas gap , the higher the density of the gas to achieve good plateau efficiency
- FE electronics threshold: possibility to compensate the F^{-} production by working at lower field, thus current, thanks to low-threshold FE electronics
- Materials and manufacturing

Replacement of the Tetrafluoroethane

1) Total replacement: Replace $C_2H_2F_4$ with an environment-friendly gas mixture

- CO_2 / $C_3H_2F_4$ **(HFO1234ze)** + i-C_4H_{10} + SF_6 → **GWP ~ 200**



1. A high-density gas is needed to ensure high particle detection efficiency → HFO concentration as high as possible
2. Low currents and low fluorine molecules are required to ensure long term operation → HFO concentration as low as possible

2) Partial replacement: Reduction of the $C_2H_2F_4$ concentration introducing the CO_2

- CO_2 / $C_2H_2F_4$ + i-C_4H_{10} + SF_6 → **GWP ~ (1017 -1162) for the CO2 concentrations under study**

1. No large impact expected on aging in terms of fluorine production
2. Higher GWP

Working with CO_2 : the transition events

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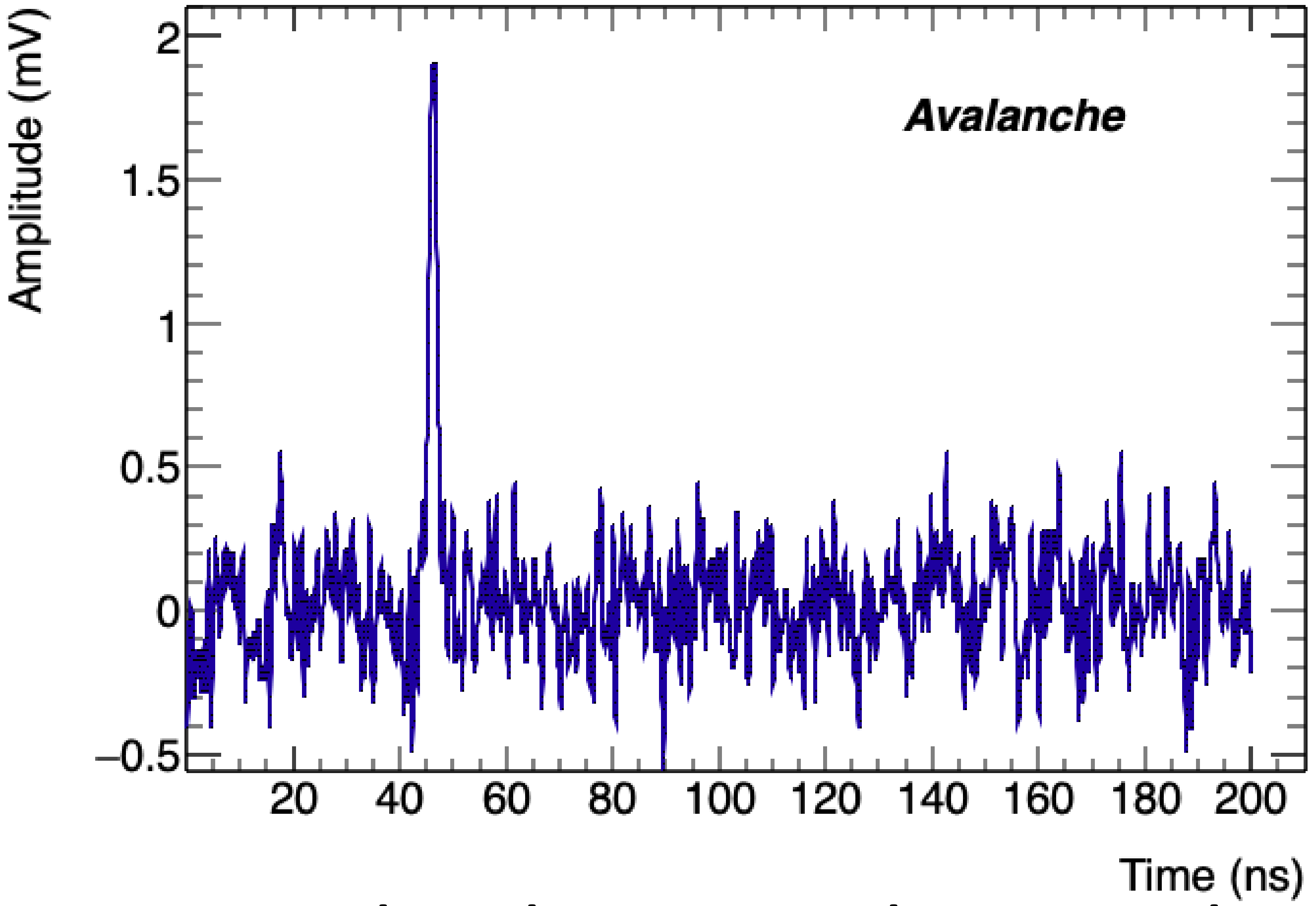

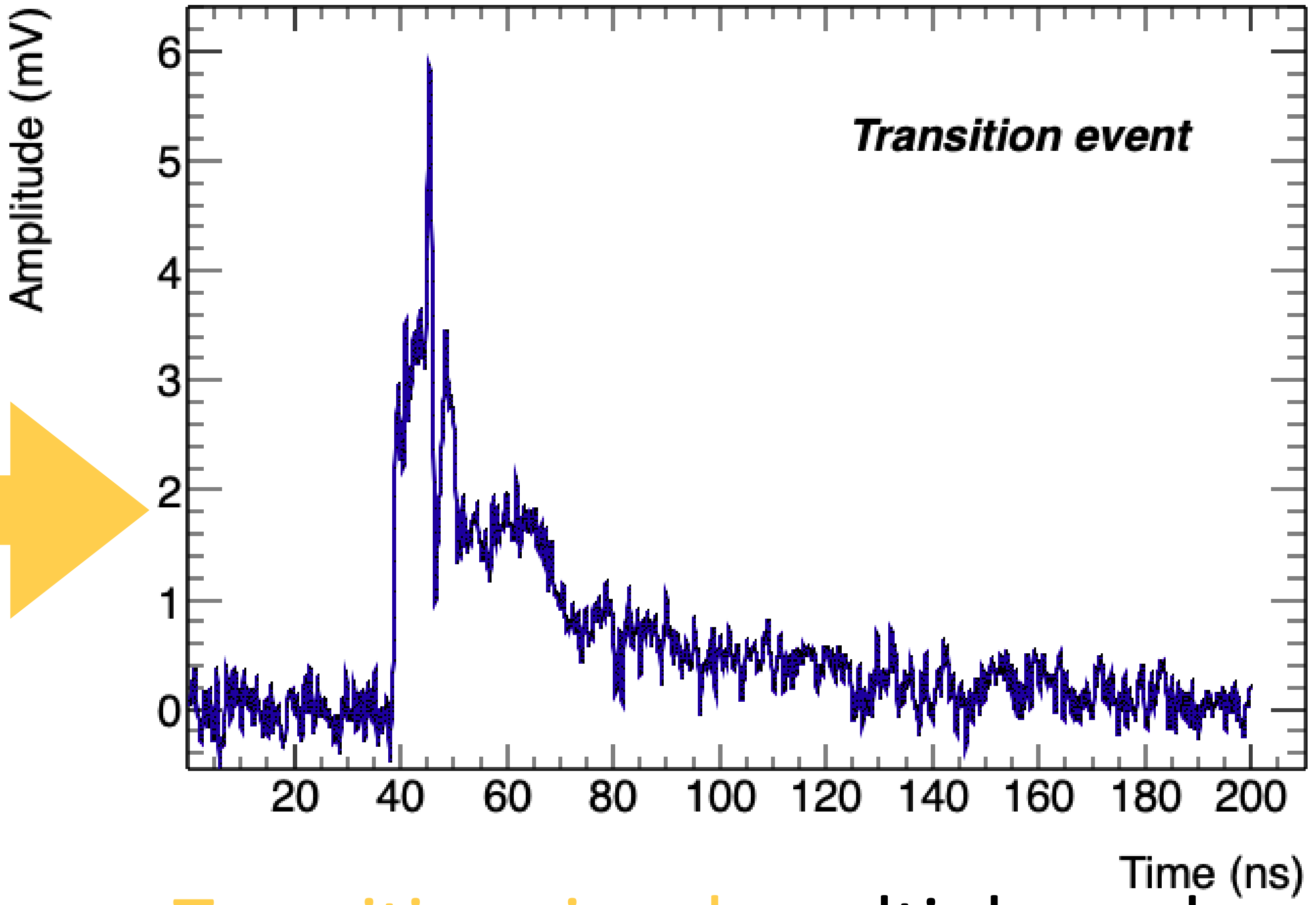

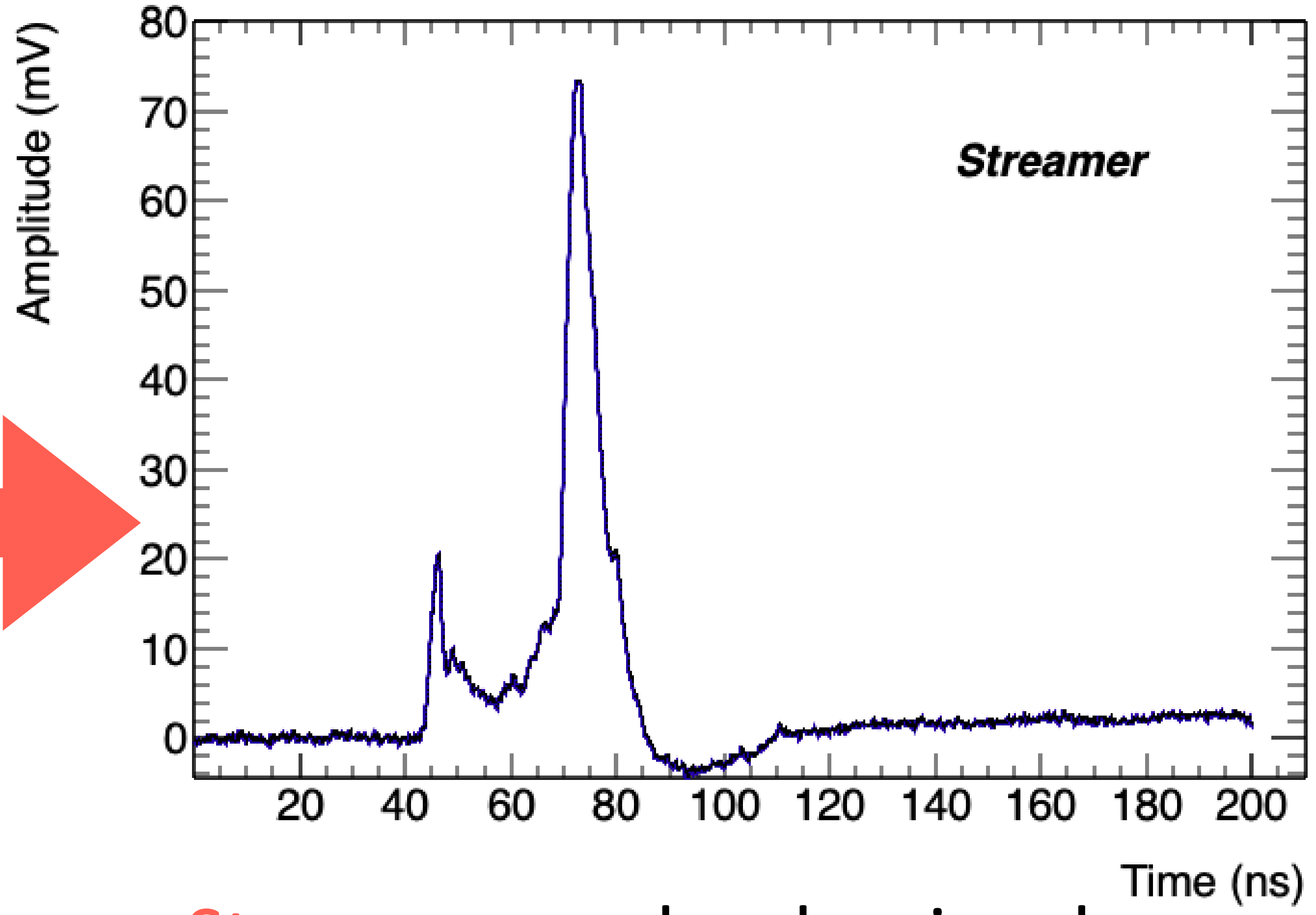

- Avalanche : very short single signal
- Transition signal: multiple avalanche signal and/or a large tail following the precursor
- Streamer: avalanche signal precursor followed by a signal lasting tens of ns.

The transition events are negligible with the standard gas mixture but relevant in the new HFO/CO_2 gas mixtures.

Interpreted as streamers precursor: the delayed avalanche don't merge together and don't trigger the streamer

Total replacement: $CO_2/C_3H_2F_4$/i-C_4H_{10}/ 1% SF_6

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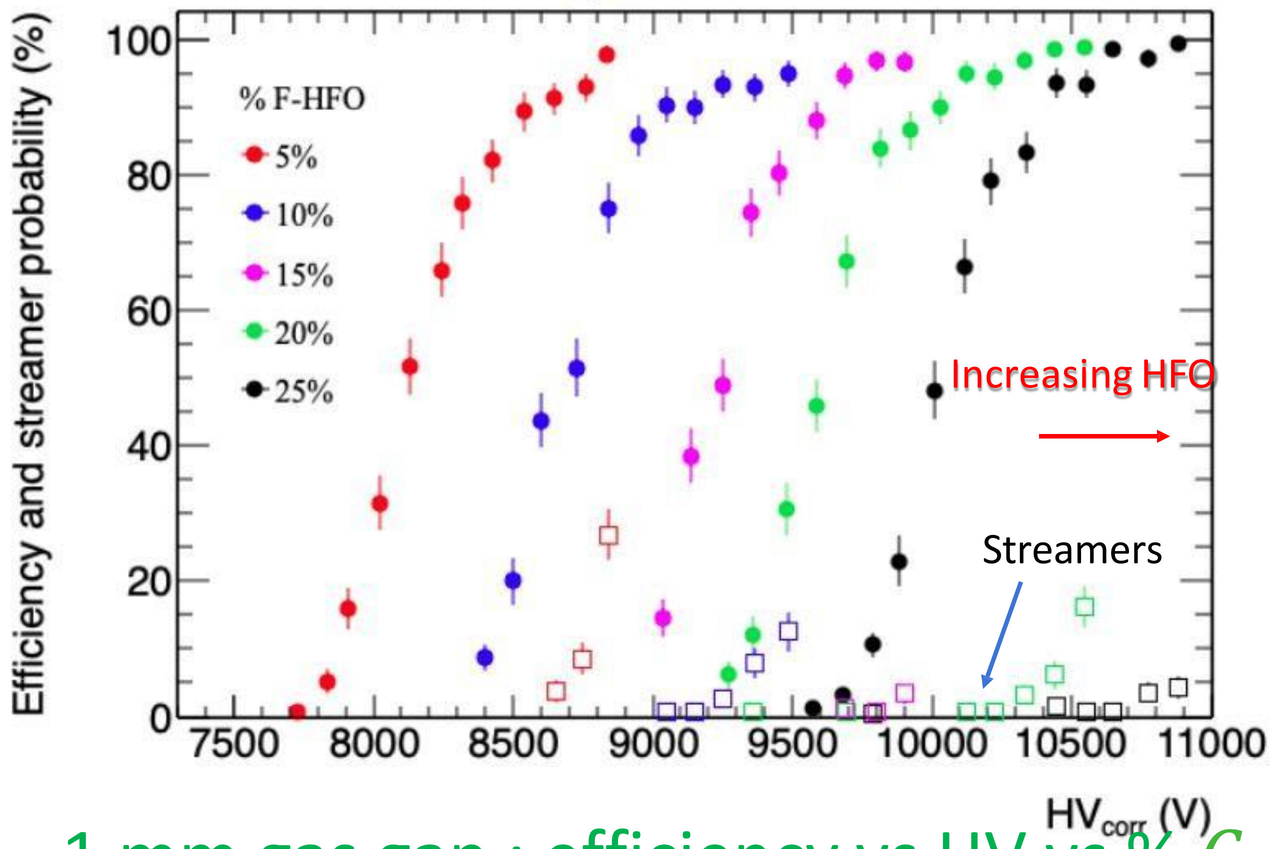
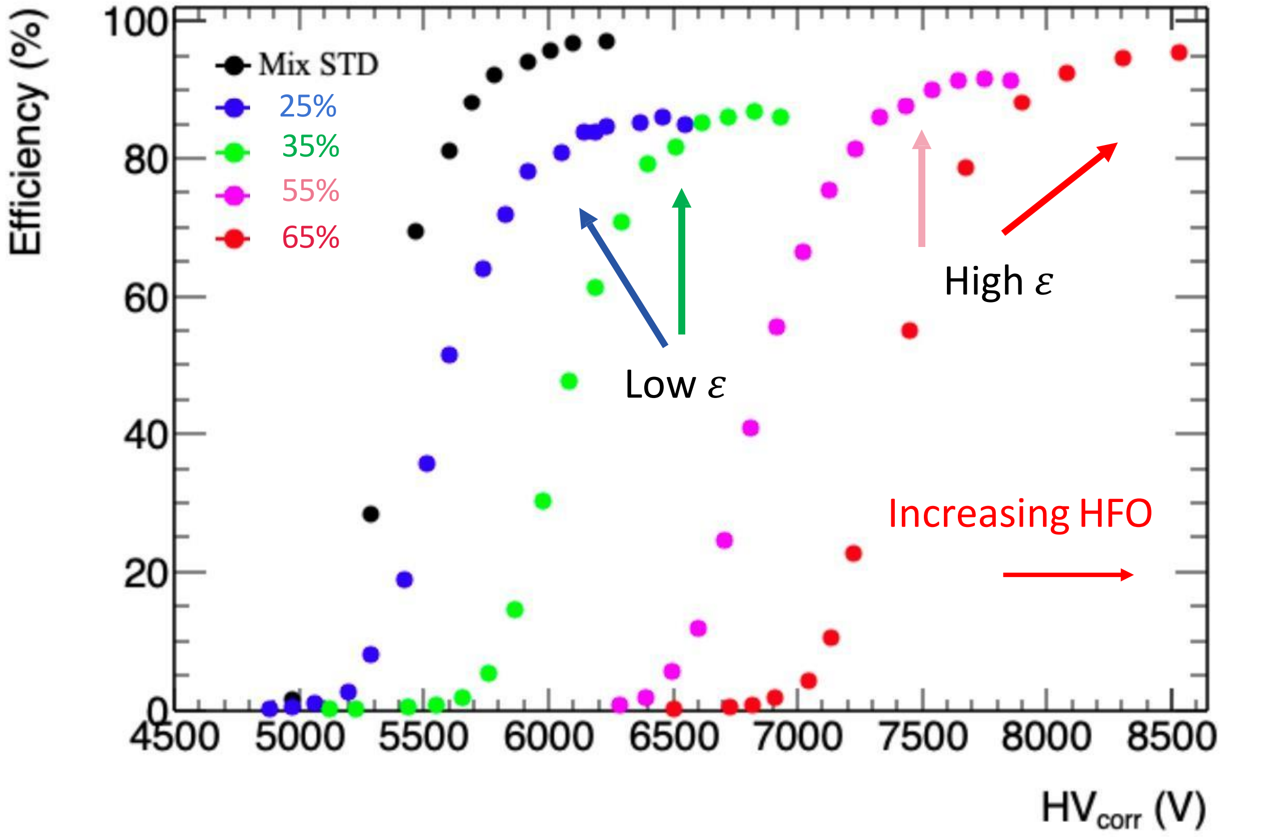
2 mm gas gap : efficiency vs HV vs % $C_3\ H_2\ F_4$



1 mm gas gap : efficiency vs HV vs % $C_3\ H_2\ F_4$



The production of fluorine radicals due to the break of the molecules is strictly correlated to the detector aging: the more is the number of radicals, the faster is the aging

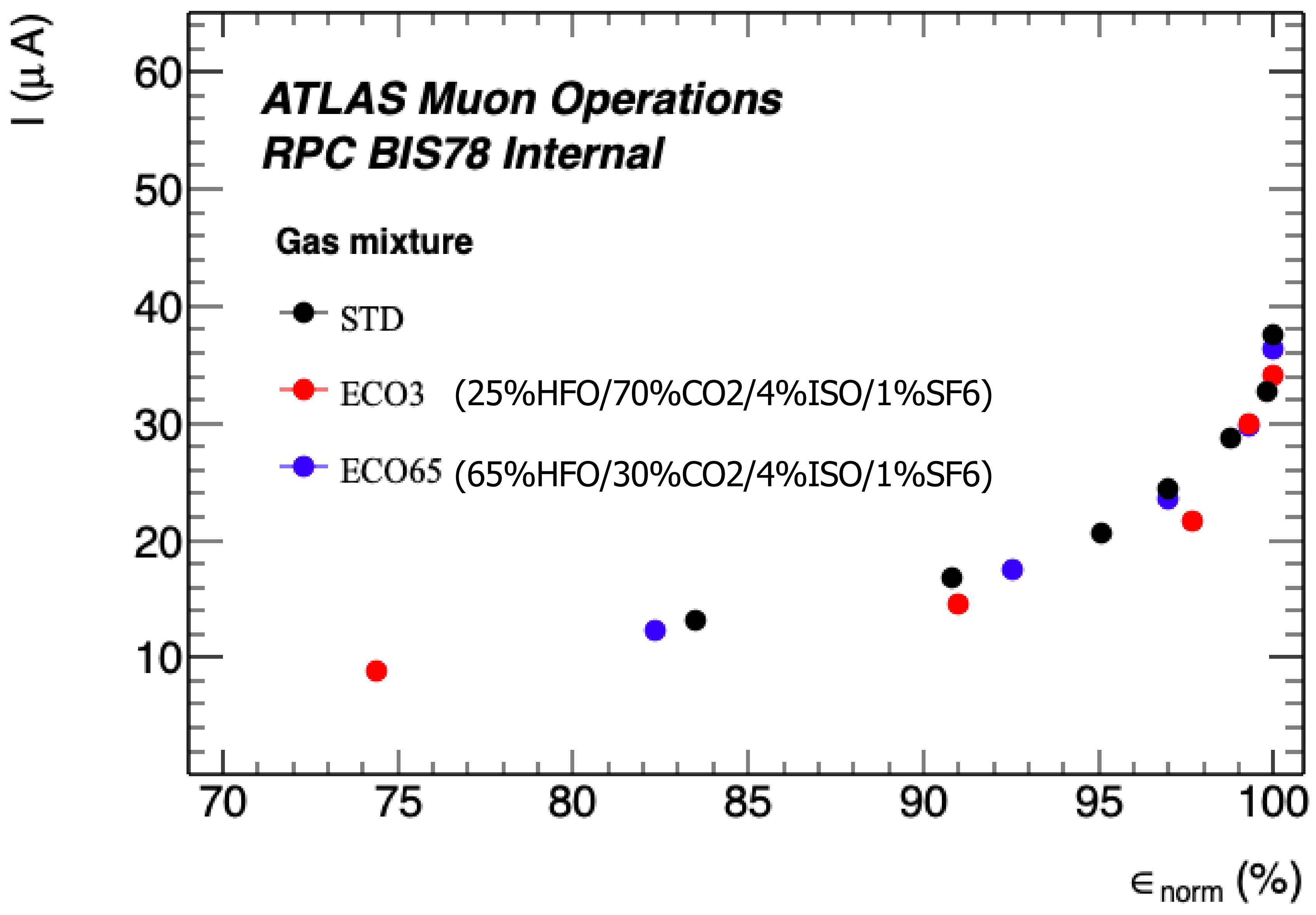
Study the possibility to work with low Tetrafluoropropene concentration :

1. 2 mm gas gap : no degradation of the performance until 15% $C_3\ H_2\ F_4$
2. 1 mm gas gap : need to increase the $C_3\ H_2\ F_4$ fraction due to the less active target. The aging effect can be compensated using a lower threshold (improved FE electronics)

Ecogas and FE electronics

Possibility to balance the larger amount of F^- radicals by lowering the operating electric field, thus current → Work with low FE threshold (1-4 fC) → Same plateau efficiency reached at lower electric field, thus lower current.

γ current vs MIP normalized efficiency



The current due to photons vs MIPs efficiency very similar for different gas mixture, suggesting that the photon contribution to the detector current is independent from the gas mixture at the same normalized efficiency.

ϵ_{STD}~ 97.5%, ϵ_{ECO3}~ 88% , $\epsilon_{\mathrm{ECO65}}$~ 96.5%

ECOGAS might guarantees same aging and same rate capability as the standard gas mixture working with 1 fC threshold → under study

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Prompt charge distribution

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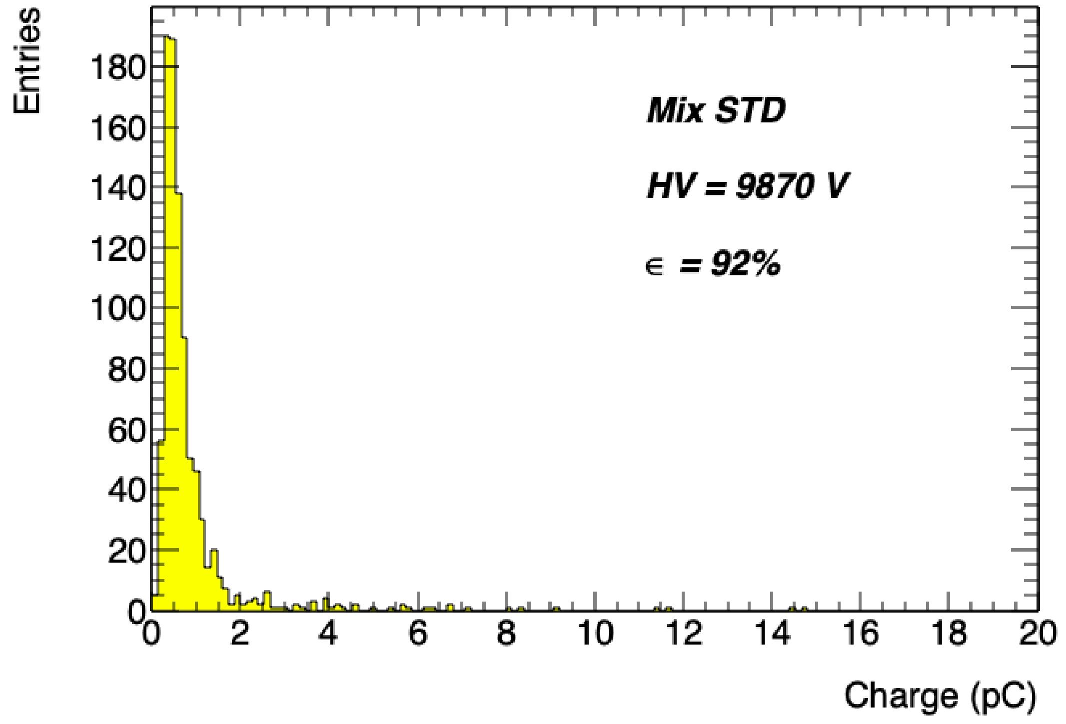
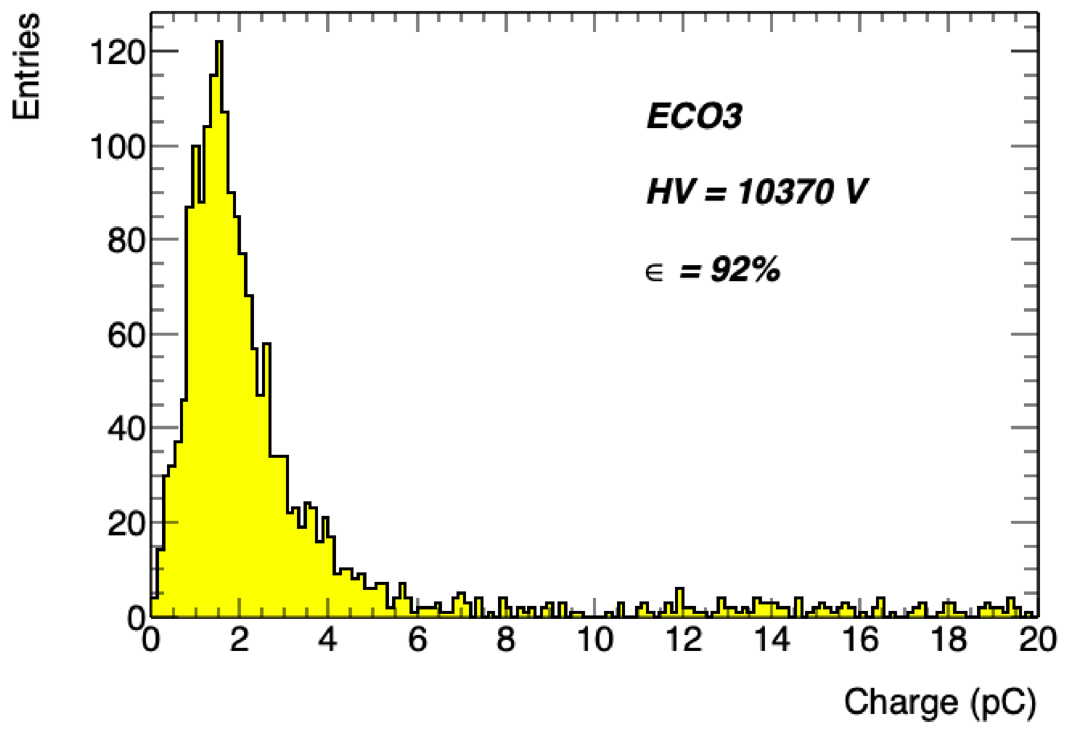
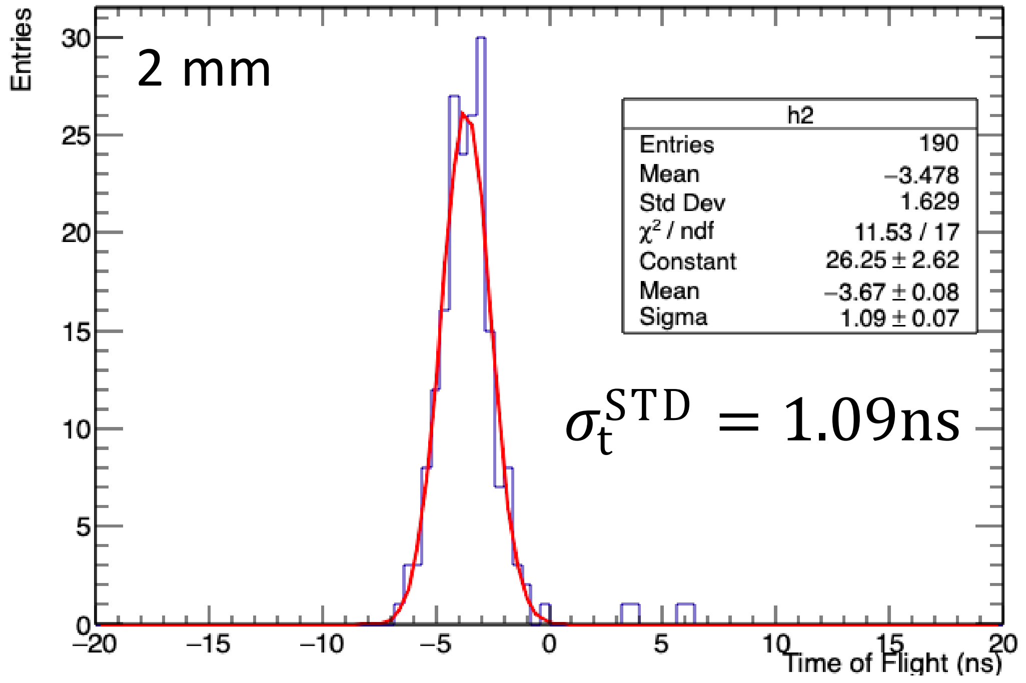
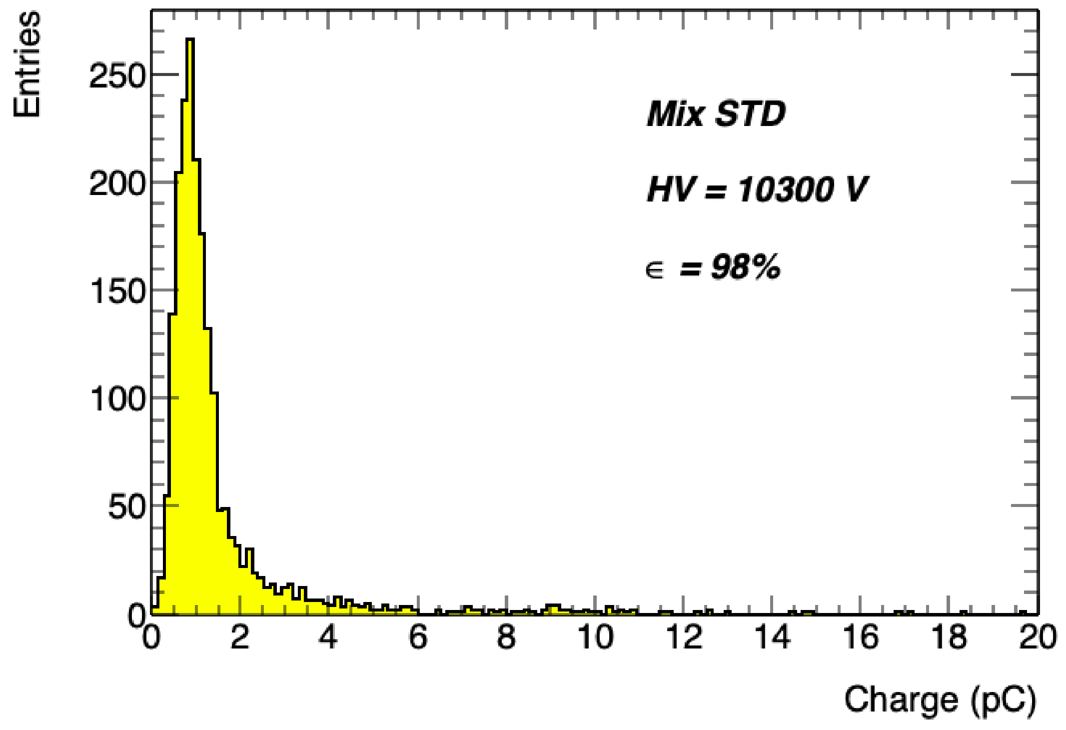
ECO3 = 25%HFO/70%CO2/4%ISO/1%SF6

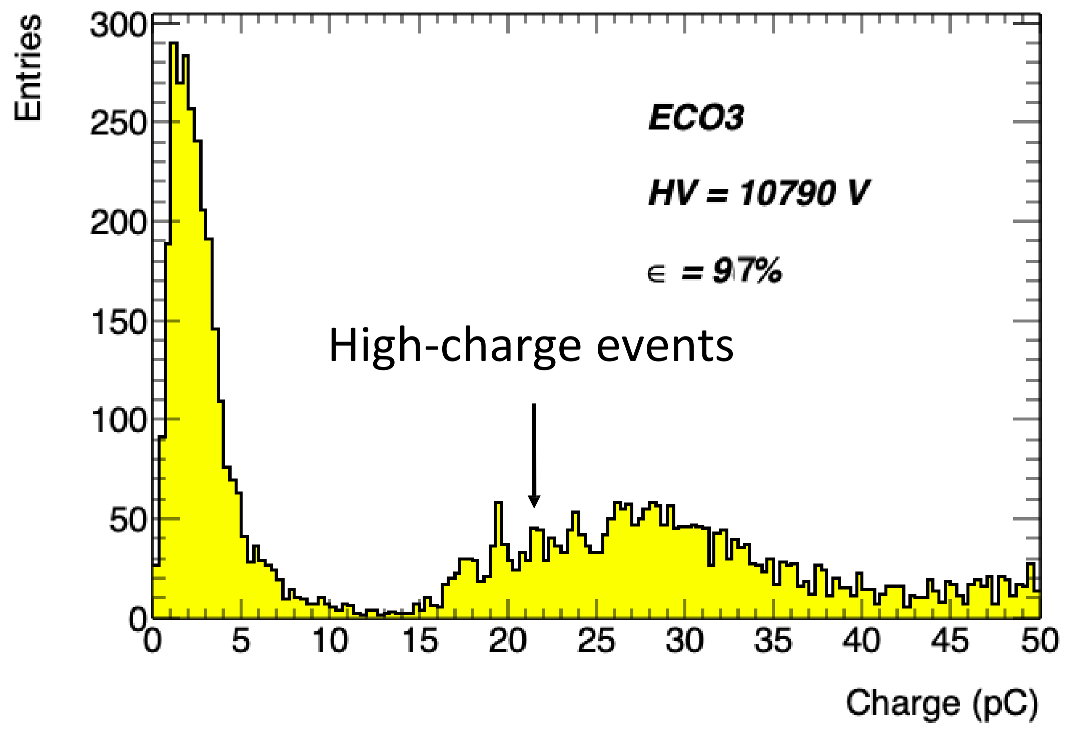




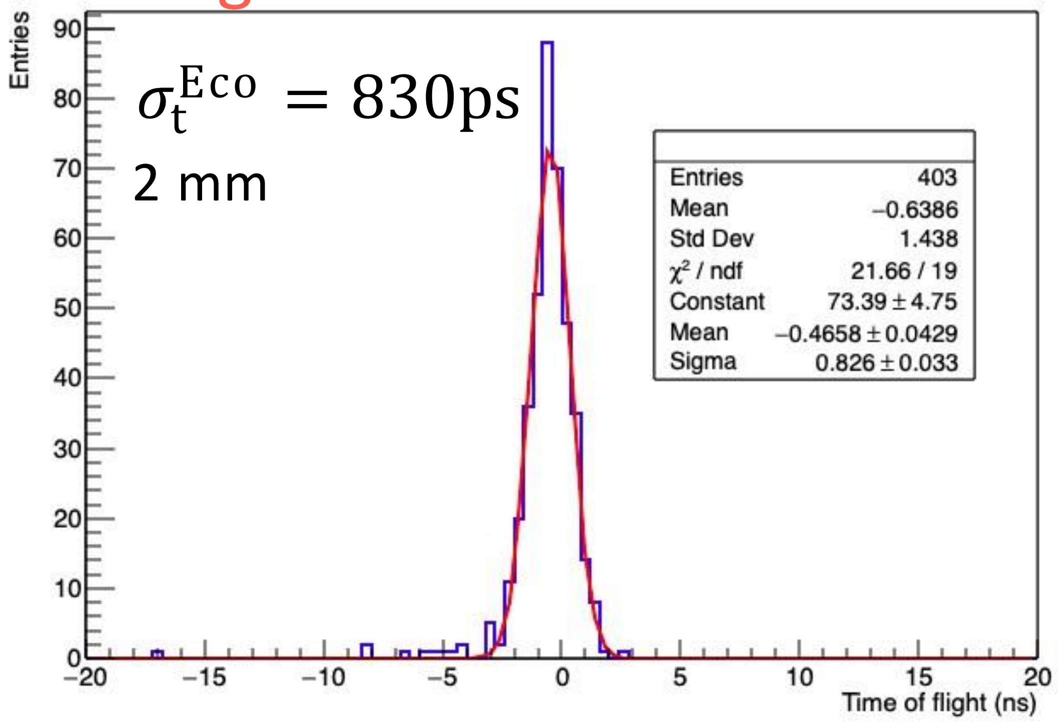
Standard gas time resolution







Eco-gas time resolution

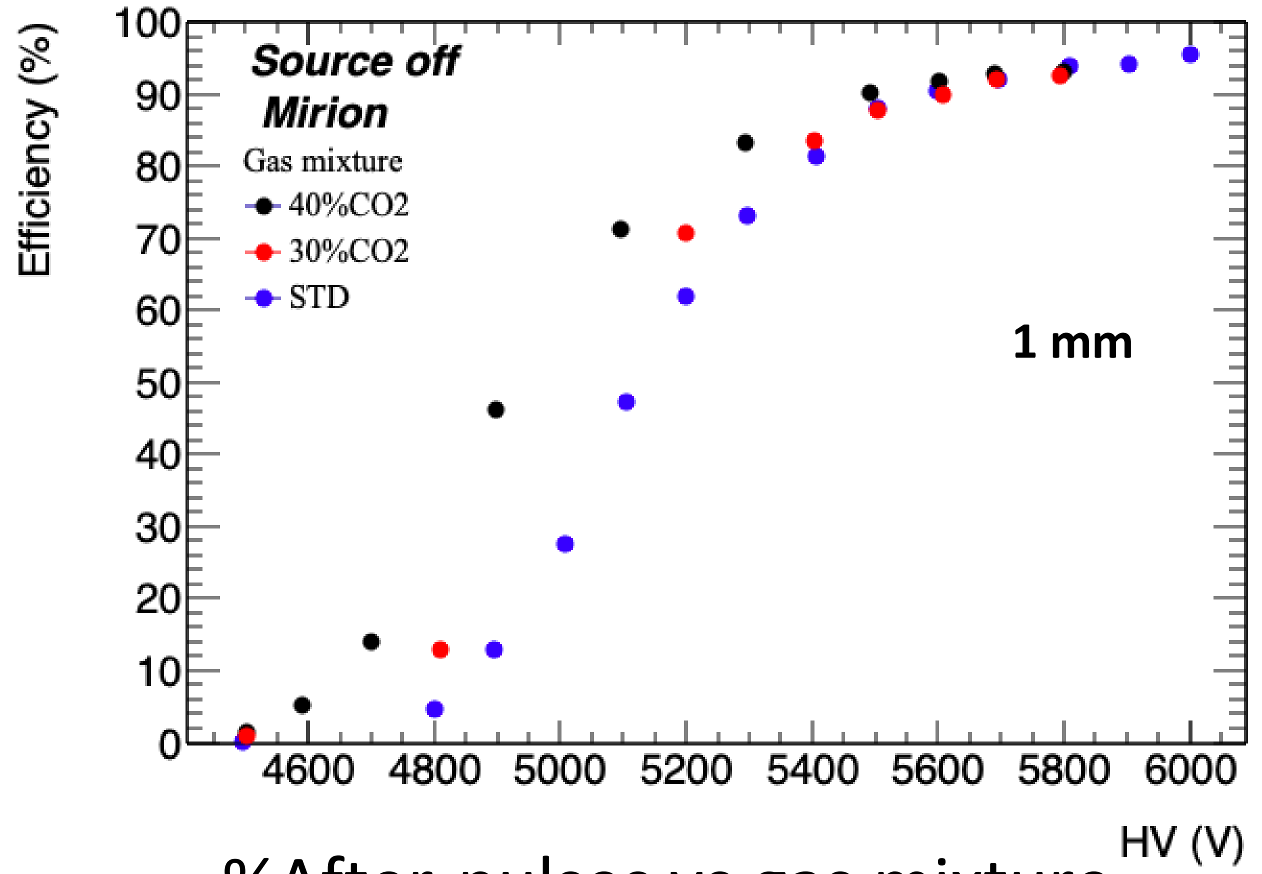


At higher efficiency high-charge events start to occur in the eco gas mixtures (second peak in the charge distribution)

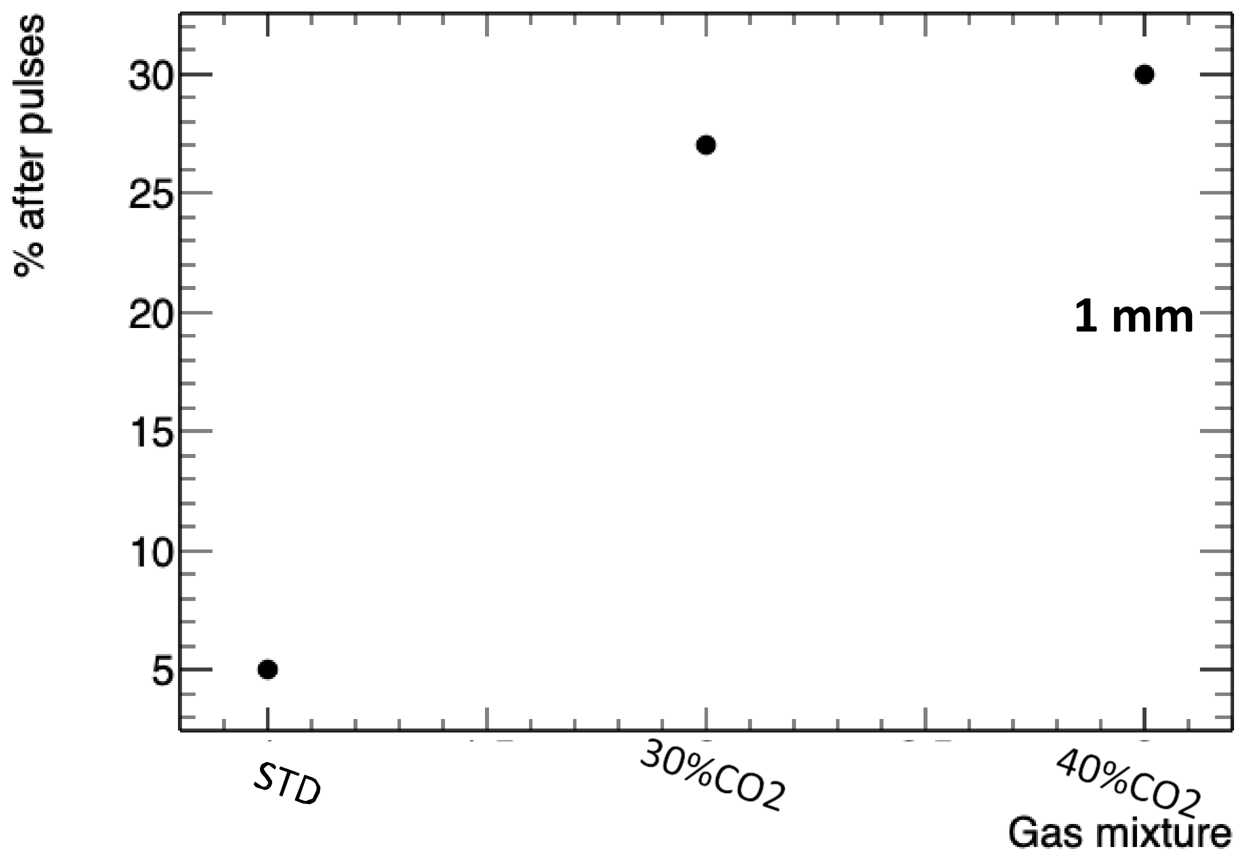
Improved time resolution

Partial replacement: $CO_2/C_2H_2F_4$/i-C_4H_{10}/ 1% SF_6

Efficiency vs high voltage



%After-pulses vs gas mixture



Gas mixture studied

STD gas mixture

30%CO2/65%TFE/4%ISO/1%SF6

40%CO2/55%TFE/4%ISO/1%SF6

Main conclusions

- Efficiency @ plateau: ~ 93% for Co2 gas mixtures, ~96% for the STD gas
- I(40%CO2) ~ 1.7 I(STD), I(30%CO2)~1.5 I(STD)
- "Contamination" at plateau from after-pulses: 5% for the STD, 27% for the 30%CO2 and 30% for the 40%CO2 gas mixtures

Best option : gas mixture with 30% CO_2

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The SF_6 substitute

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The highest GWP molecule in the standard and eco-gas mixtures is the SF6 (GWP ~ 23900).

Reduction of the SF6 fraction in TFE/CO2 gas mixtures from 1% to 0.5%

- **30%**CO_2 **/65.5%**$C_2H_2F_4$ + 4%i-C_4H_{10} + 0.5%SF_6 → **GWP ~ 1041**

- Reduction of the GWP

Possibility to replace this crucial component with a different environment-friendly gas :
the **Chloro-trifluoropropene** , $C_3H_2ClF_3$ (HFO1233zd)

- CO_2 **/** $C_3H_2F_4$ **(F-HFO)** + i-C_4H_{10} + $C_3H_2ClF_3$**(Cl-HFO)** → **GWP ~ 10**

- Possibility to work with a <u>totally</u> environment-friendly gas mixture (G. Proto *et al* 2022 *JINST* **17** P05005))

$CO_2/C_2H_2F_4$/i-C_4H_{10}/ 0.5% SF_6

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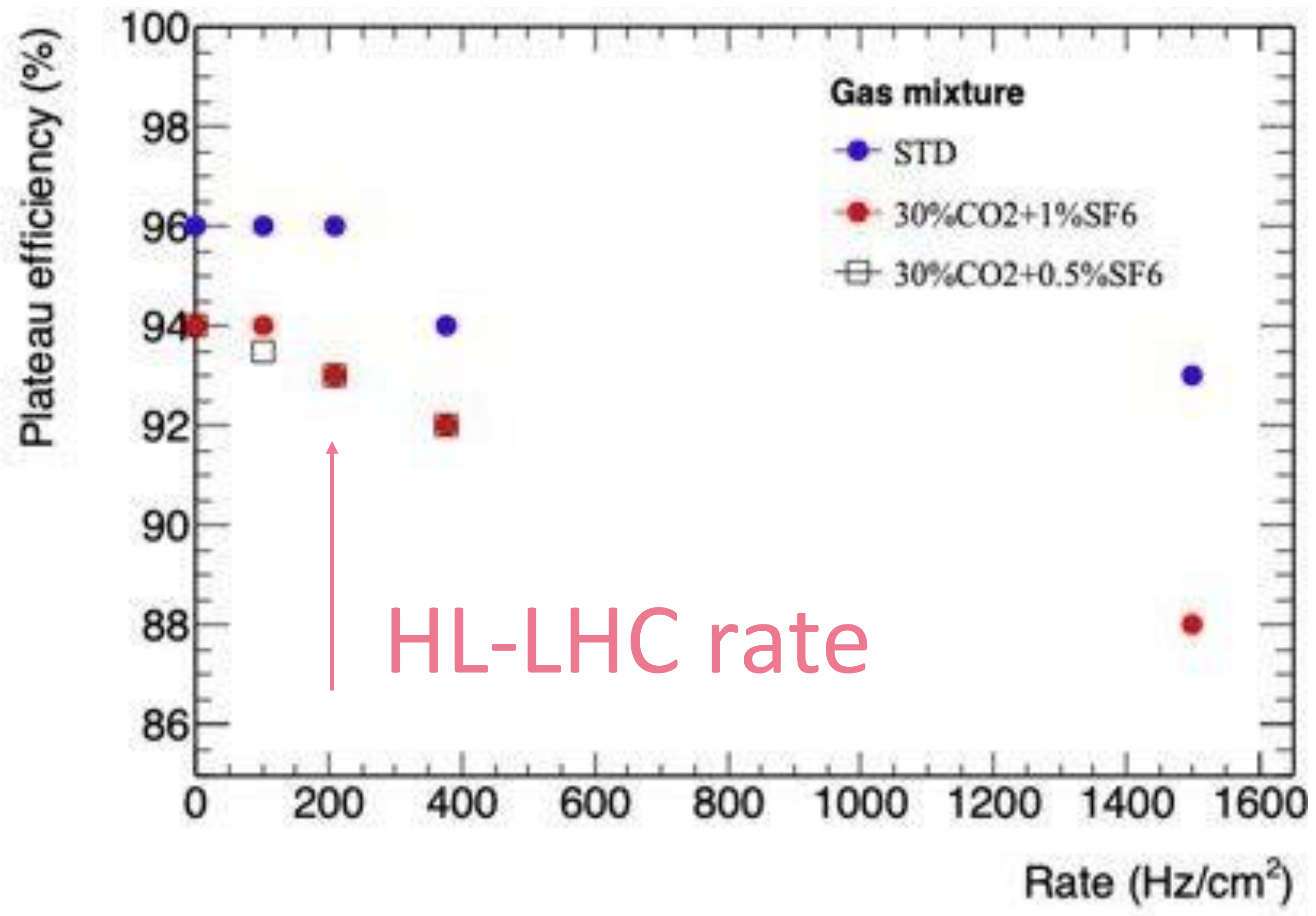
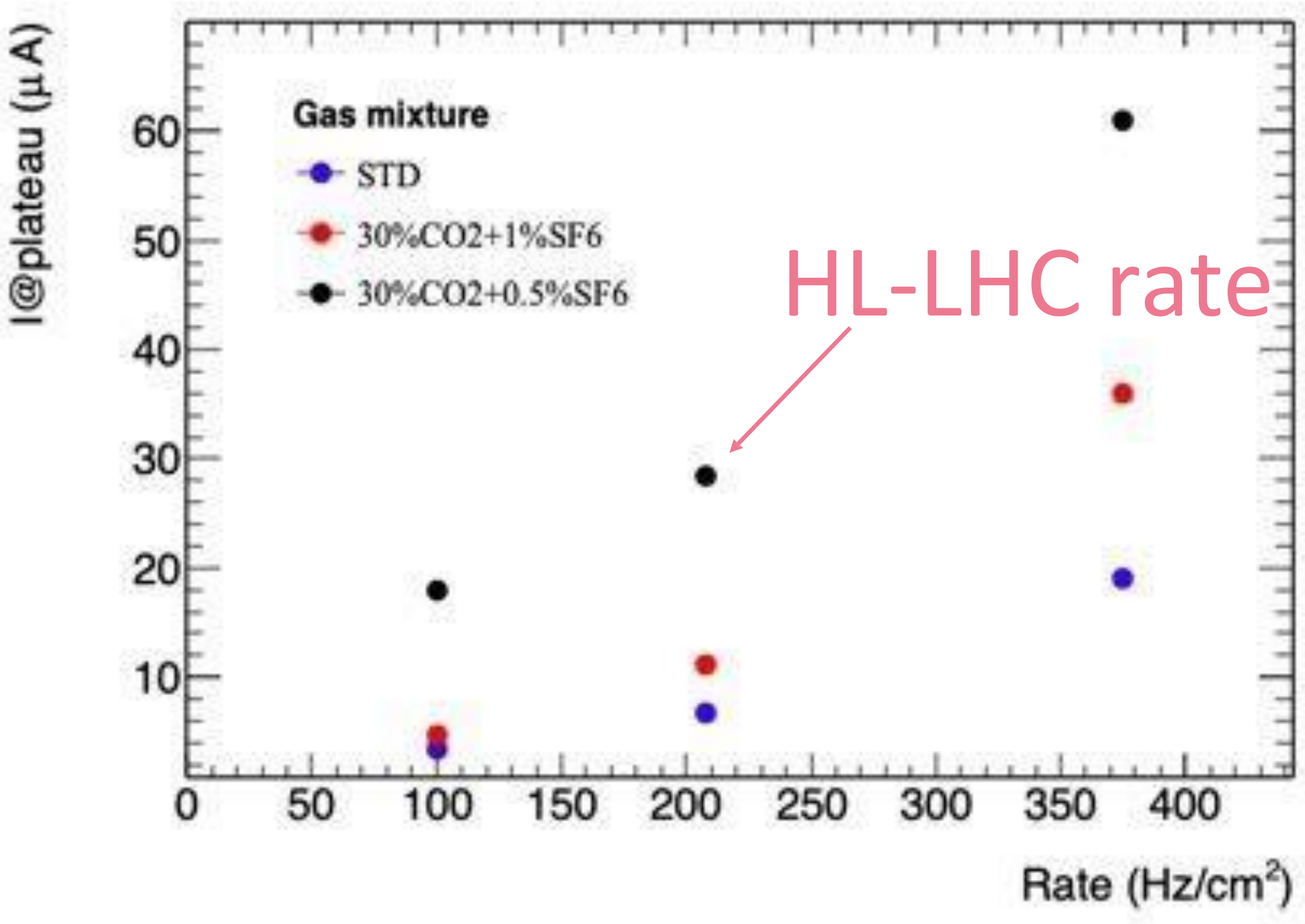
Efficiency vs γ-rate



Plateau current vs γ-rate



Gas mixtures studied

1. STD gas mixture
2. 30% CO_2 /65% $C_2H_2F_4$/4% i-C_4H_{10}/1% SF_6
3. 30% CO_2 /65.5% $C_2H_2F_4$/4% i-C_4H_{10}/0.5% SF_6

Main conclusions

The reduction of the SF_6 fraction leads to an increase in the current due to the premature appereance of streamers

Best option : gas mixture with 1% SF_6

The Chlorotrifluoropropene : $C_3 H_2 ClF_3$

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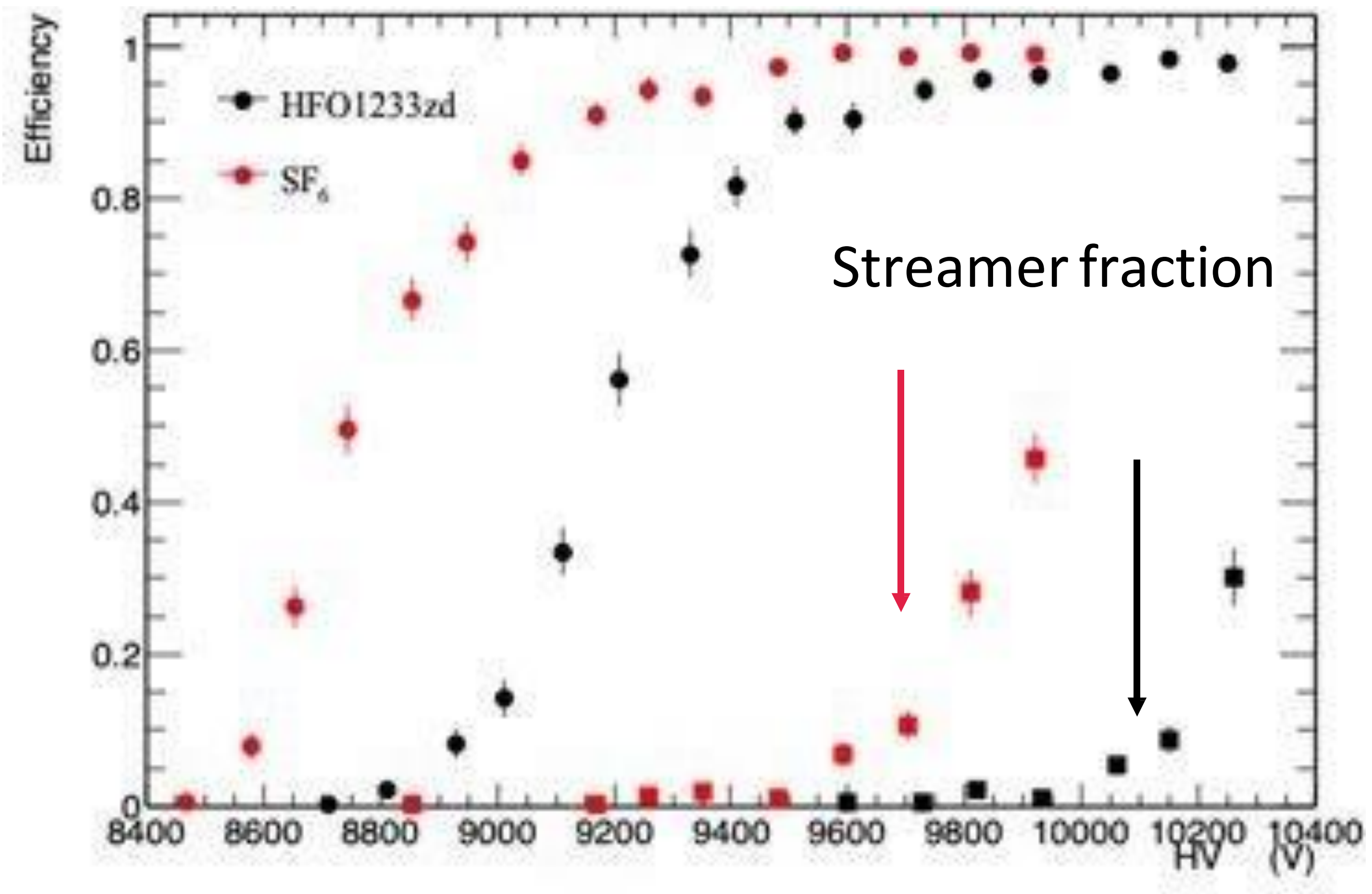
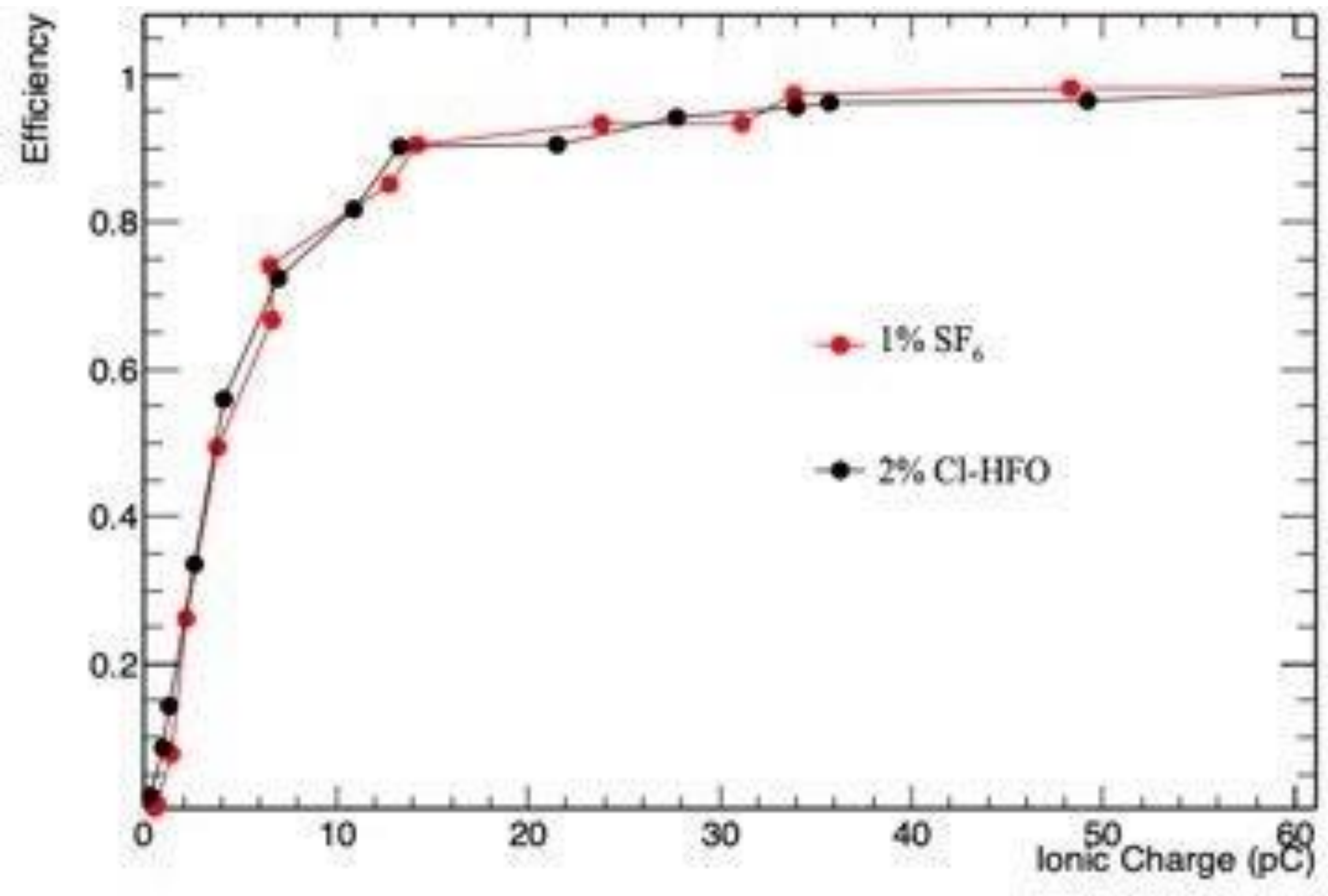
Possibility to replace the highest GWP molecule, the SF_6, with an environment friendly gas: the Chlorotrifluoropropene ($C_3H_2ClF_3$- HFO1233zd)

$CO_2/C_3H_2F_4$ +i-C_4H_{10} + $C_3H_2ClF_3$ → GWP ~ 10 (100 times less than the standard gas!!)

Efficiency vs high-voltage



Efficiency vs current



- Same avalanche-streamer separation
- Same current at the same efficiency → same rate capability

The HFO1233zd can replace the SF_6 in these gas mixtures

Conclusions and next steps

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In this presentation the results on alternative gas mixtures for Resistive Plate Chambers detectors have been presented

- Substitution of the Tetrafluoroethane:
  - HFO1234ze/CO2/i-C4H10/SF6 gas mixtures
  - R134a/CO2/i-C4H10/SF6 gas mixtures

- Substitution of the SF6:
  - HFO1233zd
  - Reduce the amount of SF6 from 1% to 0.5%

Future research

Aging test operating the RPC with gas mixtures containing $C_3\ H_2Cl\ F_3$ to certificate the gas for high radiation environments (HL-LHC and beyond)

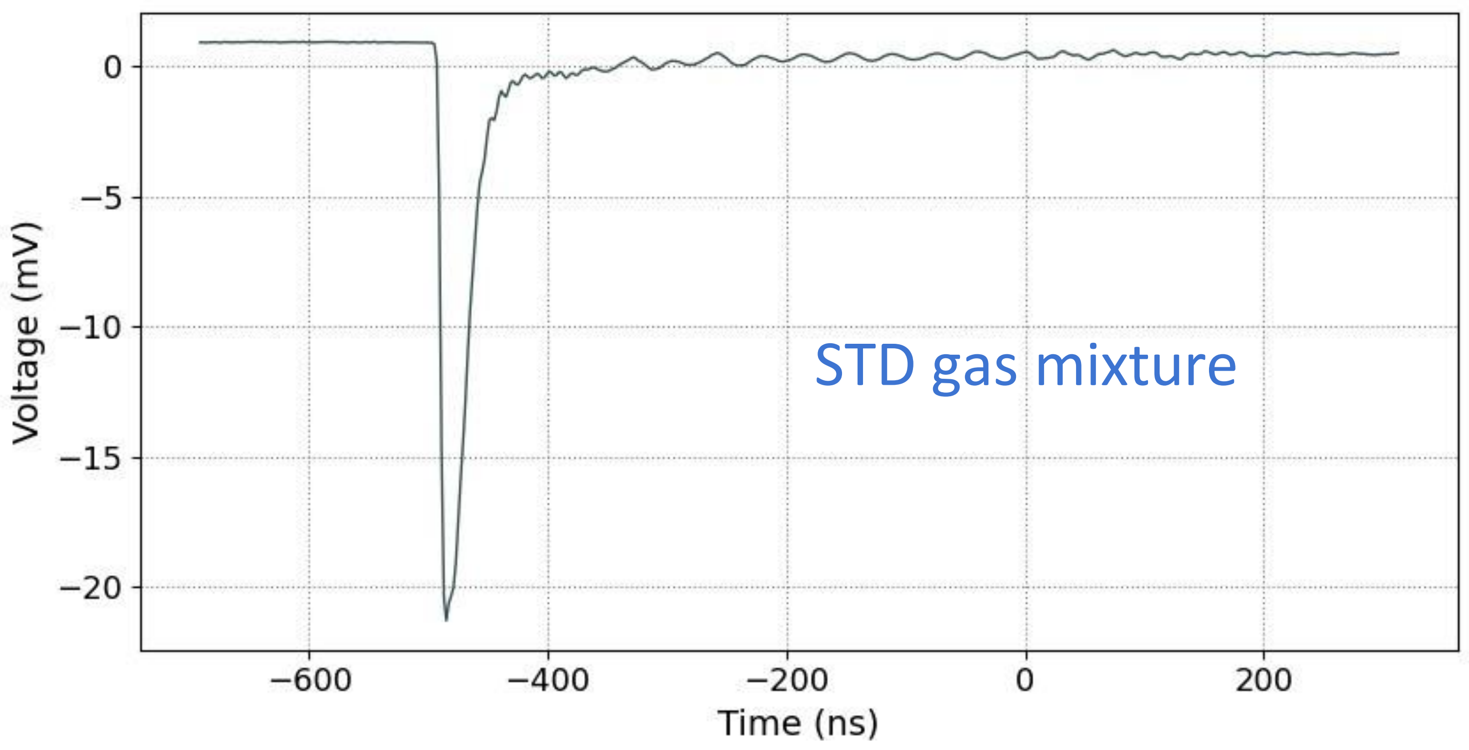
Interplay between detector parameters (FE electronics …) and gas mixture properties

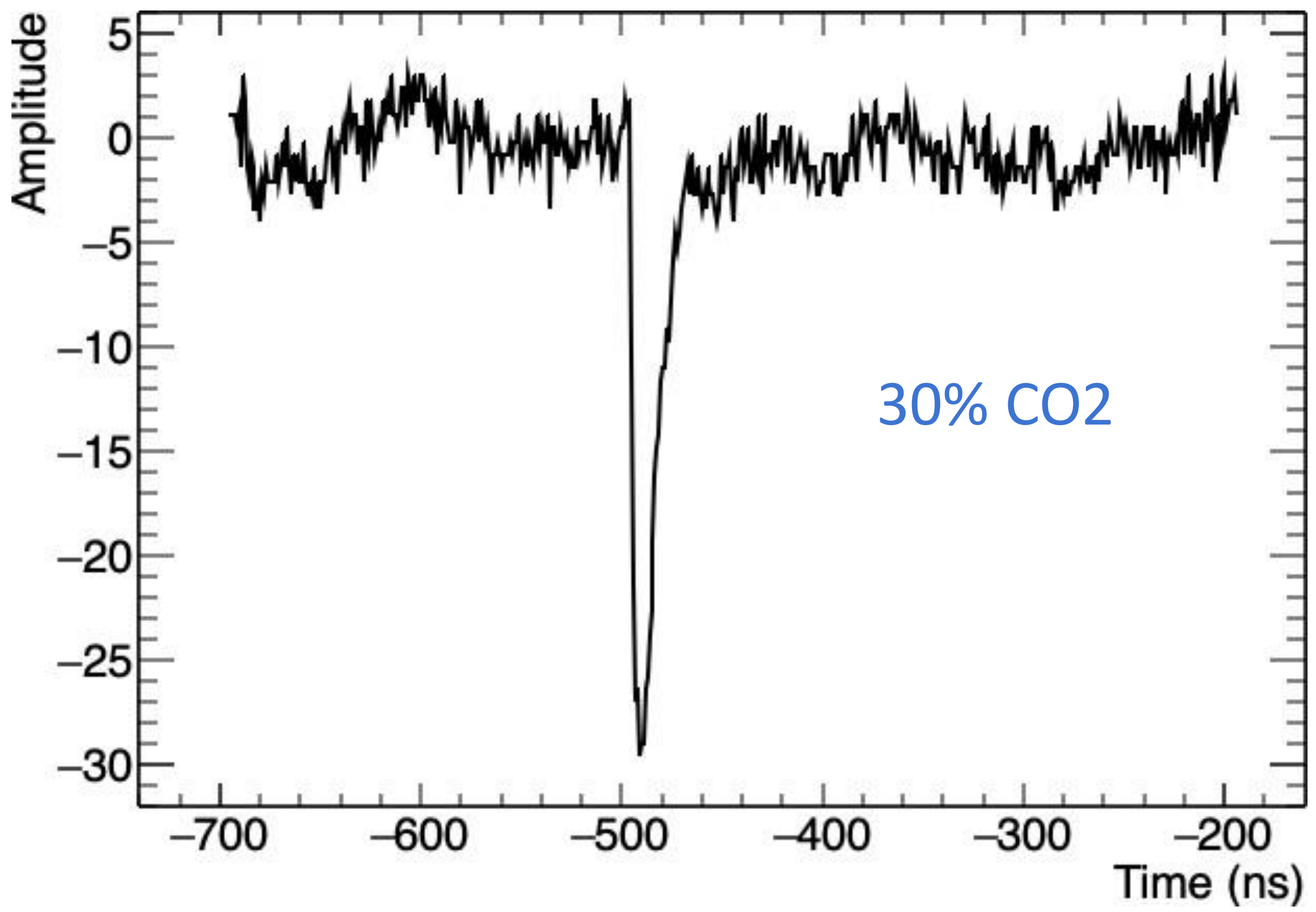
Final goal :

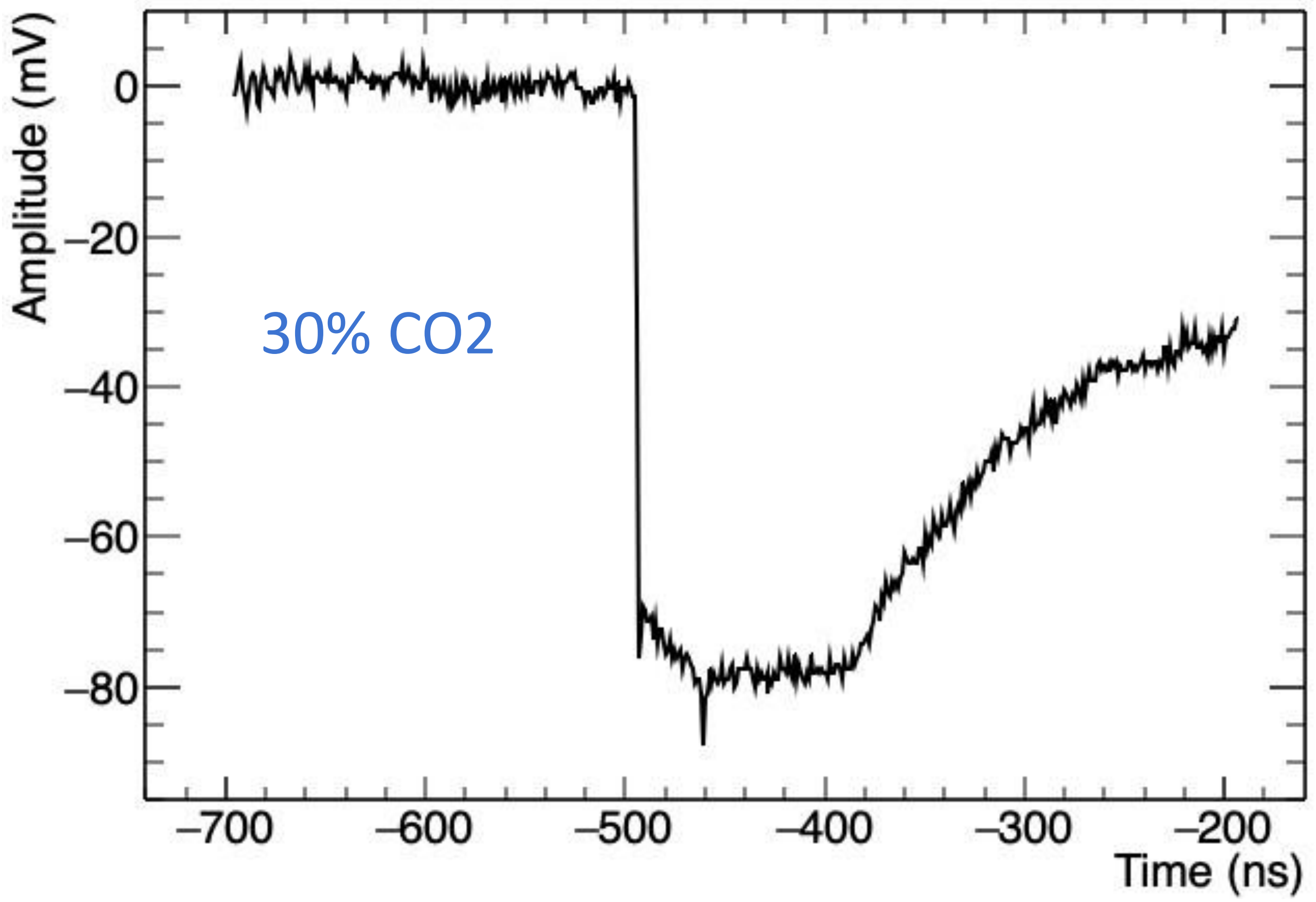
Operate the Resistive Plate Chambers with a completely environment friendly gas mixture in future colliders

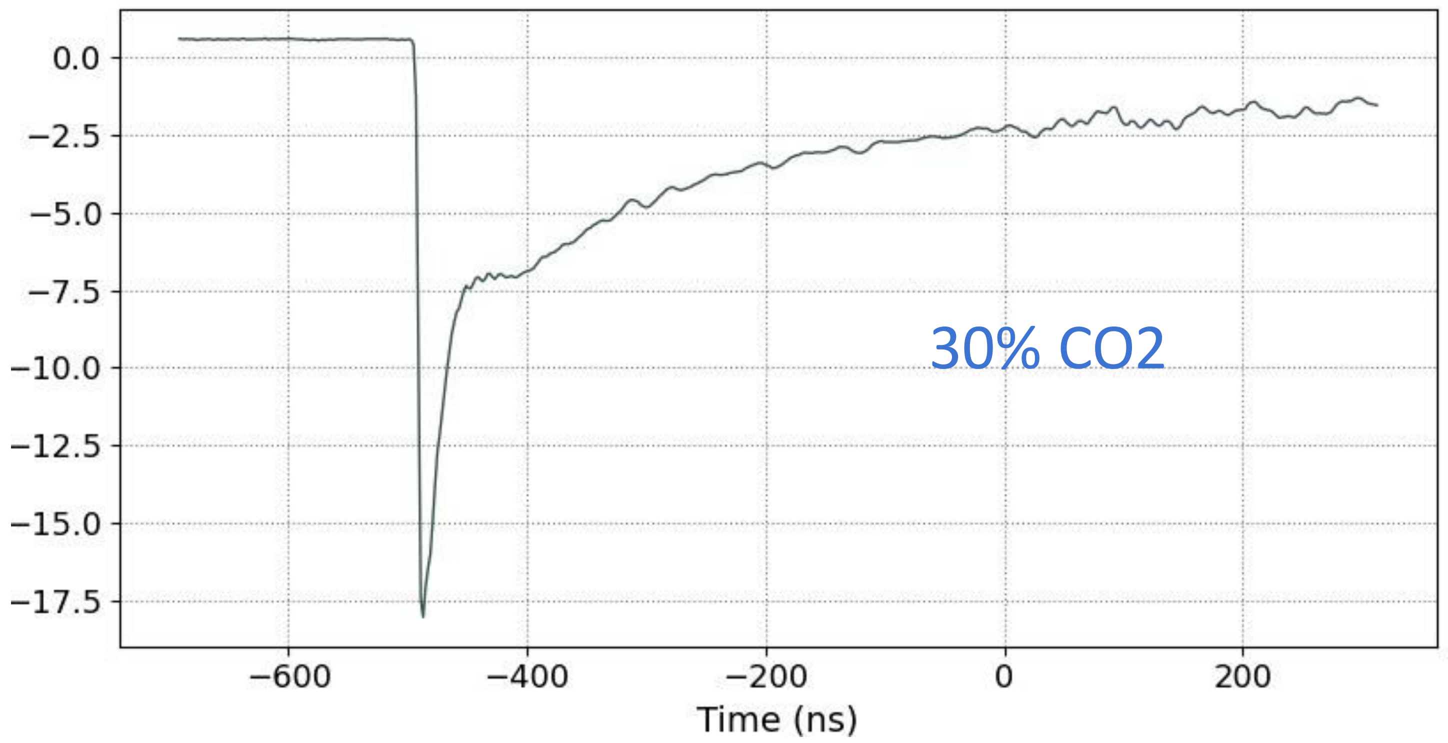
Thank You

Signals shape









- Most of the event in the standard gas have the shape shown in figure.
- The CO2-based gas mixtures shows signals with a tail or very wide signals
- These signals could explain the higher amount of current measured in these alternative gases