Gas mixture studies for streamer operated RPCs

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Why streamer ?

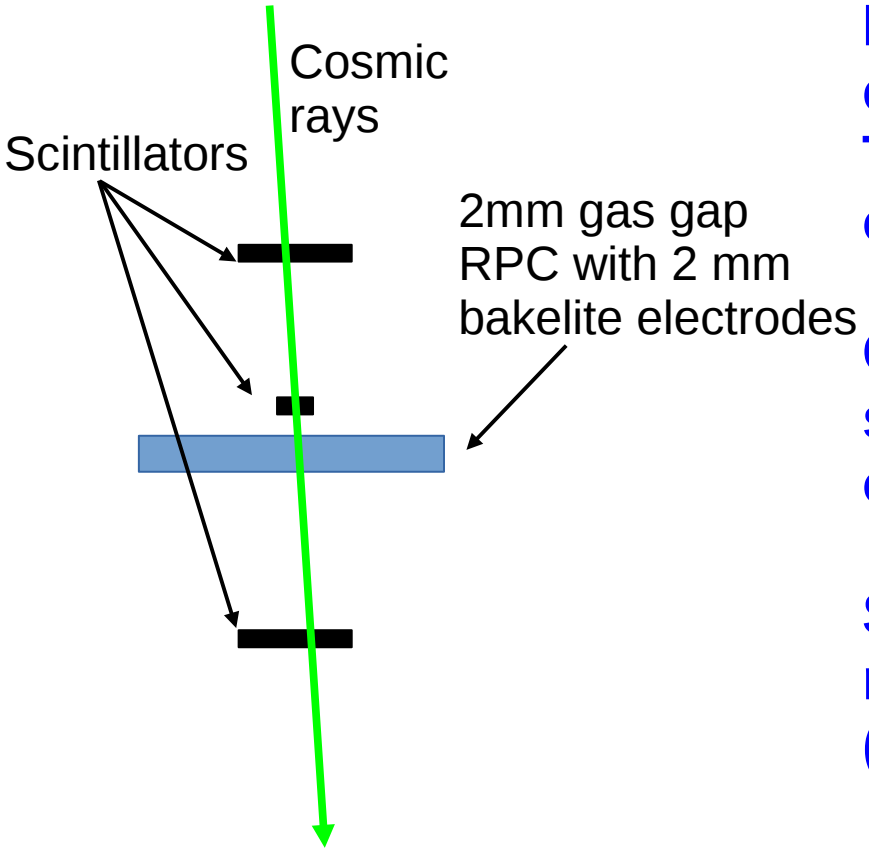
Streamer operated RPCs can be used:

- **in low rate experiments (in underground laboratories or at cosmic ray fluxes)**
- **if time resolutions worse than 1 ns are acceptable,**

because of FE electronics simplicity.

Examples in neutrino and astro-particle physics: OPERA, ARGO.

Experimental set-up



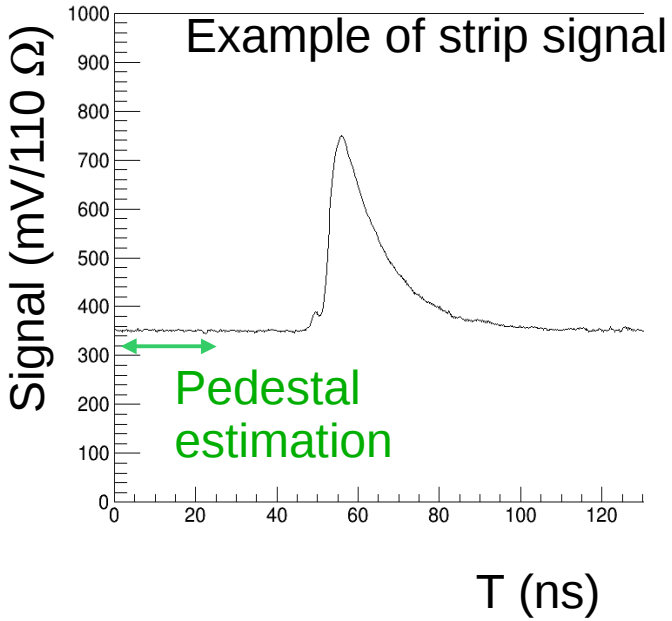
RPC under test read-out by 3.5 cm wide copper strips of 70 cm length. Terminated on 110 Ω on the read-out side, on 25 Ω on the opposite side.

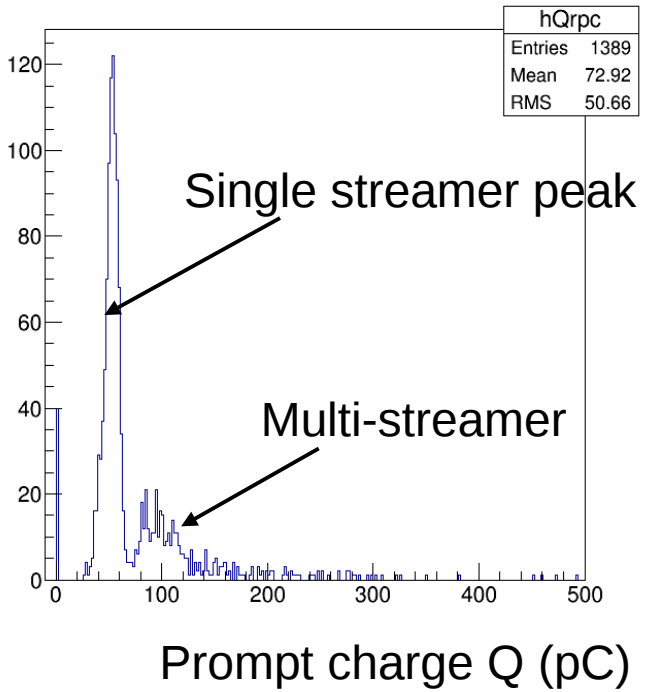
Cosmic ray trigger made by three scintillators coincidence (the central one used also as time reference).

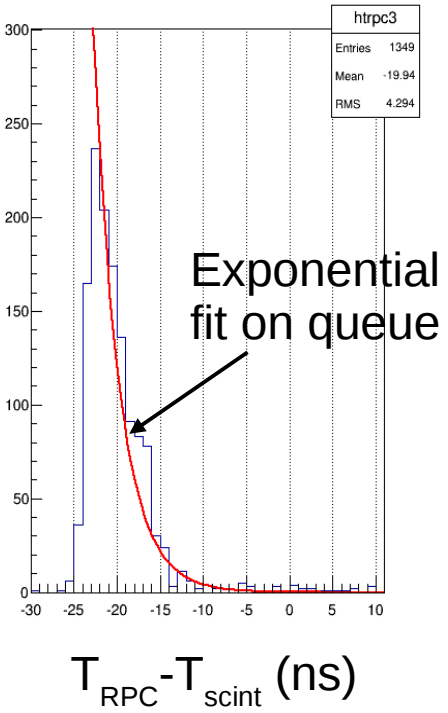
Signals from 11 strips acquired by means of N6742 CAEN digitizer (5 Gsamples/sec).

Strip signals discriminated at 50 mV/110 Ω.

Analysis techniques description







Signal treatment:
Pedestal subtraction channel by channels using first 100 samples.
Common mode noise estimation using strips without signals.

RPC and streamer properties from measured distributions:
Prompt charge: efficiency, multistreamer probability, single streamer charge.
Single strip events: streamer amplitude, FWHM, risetime (10% - 90% of amplitude).
T_{RPC}-T_{scint}: streamer arrival time (relative to the scint.), time resolution (exp fit on the queue).

Basic things...

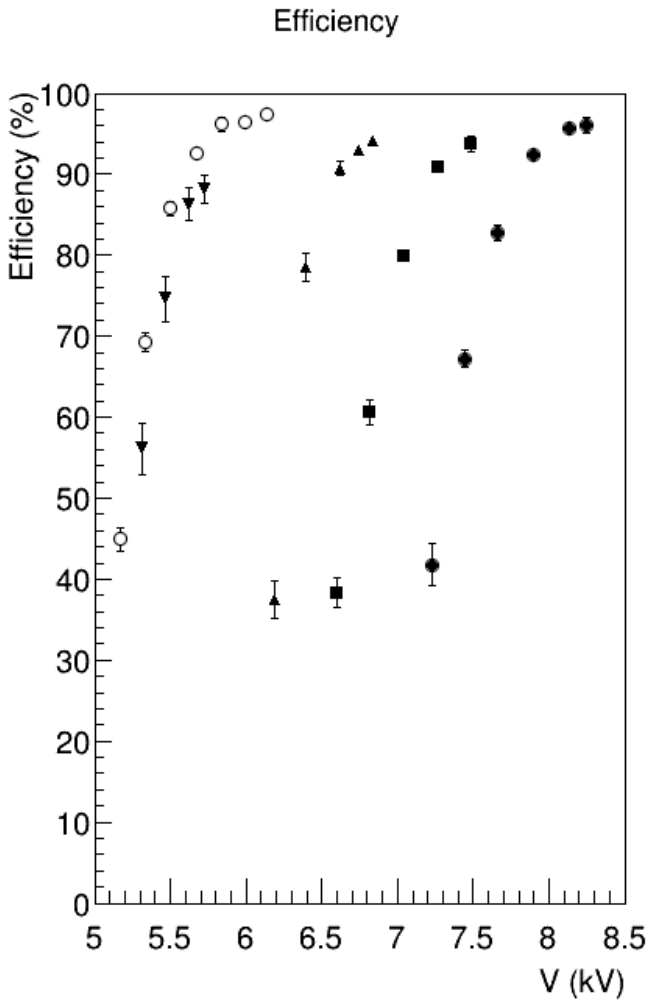
Gas mixtures for present generation of experiments made of:
Argon (noble gas, good for electron multiplication)
Iso-butane (UV quencher, but percentage limited to few % because of flamability issues)
R134a (TetraFluoroEtane, UV quencher in addition to iso-butane)
SF_6 (eventually added to reduce the charge, making stable economic mixture with low concentrations of quenching gases)

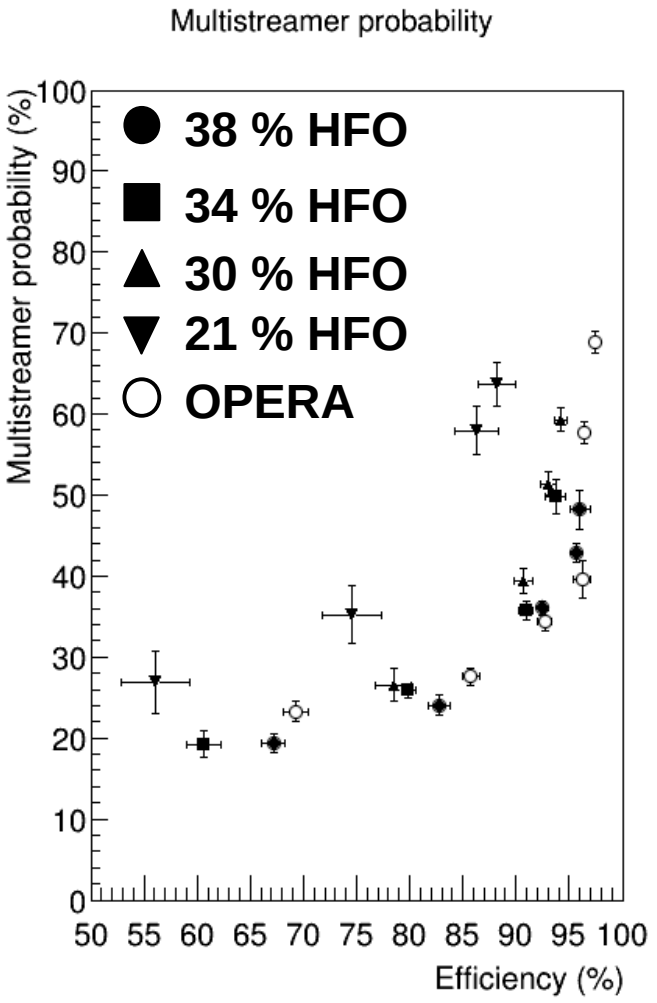
OPERA-like gas mixture: Argon/R134a/iso-butane=76/20/4 + 0.3% SF6.
Will be used as a reference mixture in the following.
Mixtures with Argon, Iso-butane, R134a, SF_6 will be indicates as "standard" in the following slides.

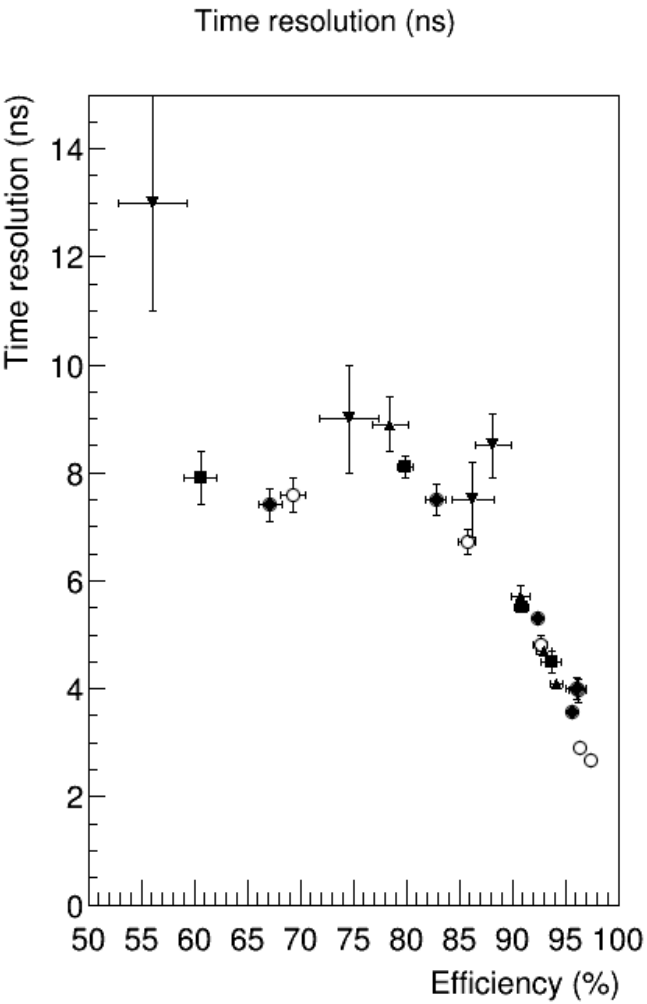
R134a and SF6 are gases with high Global Warming Power (GWP): they could be banned for ecological reasons.

Last RPC workshop (talk by B. Liberti, 2014 JINST 9 C11003):HFO-1234ze (Tetrafluoropropene, $C_3H_2F_4$) proposed for replacement of R134a and Iso-butane.

Ar/HFO-1234ze binary mixtures

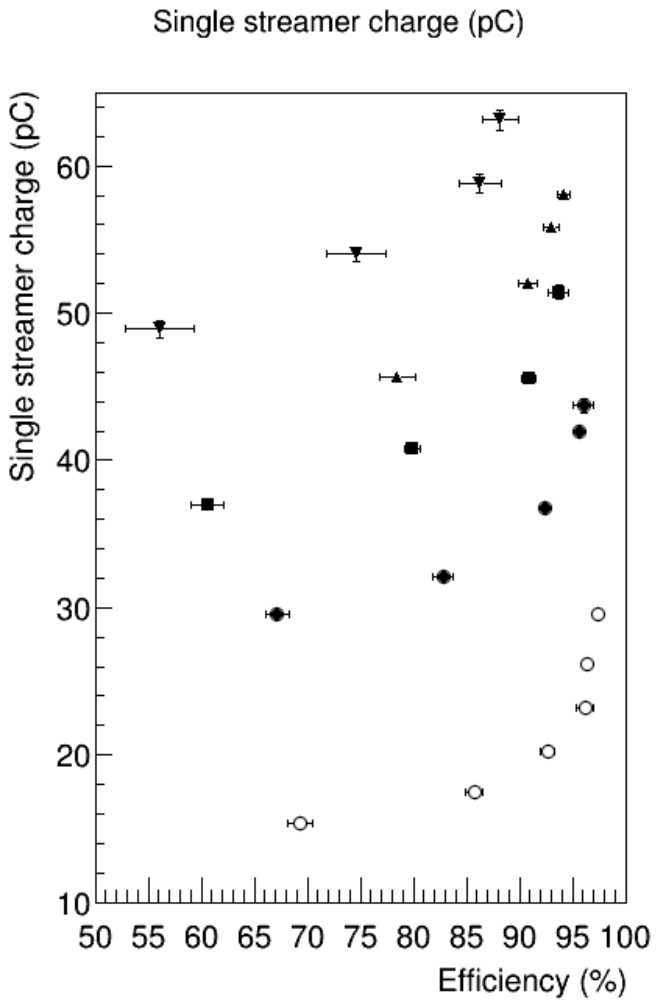


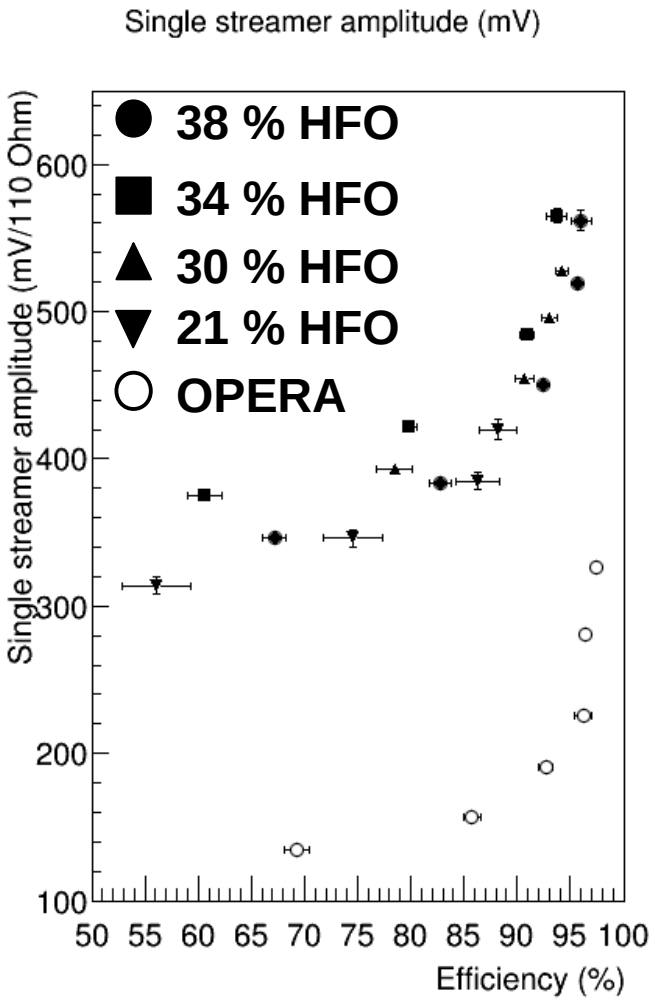


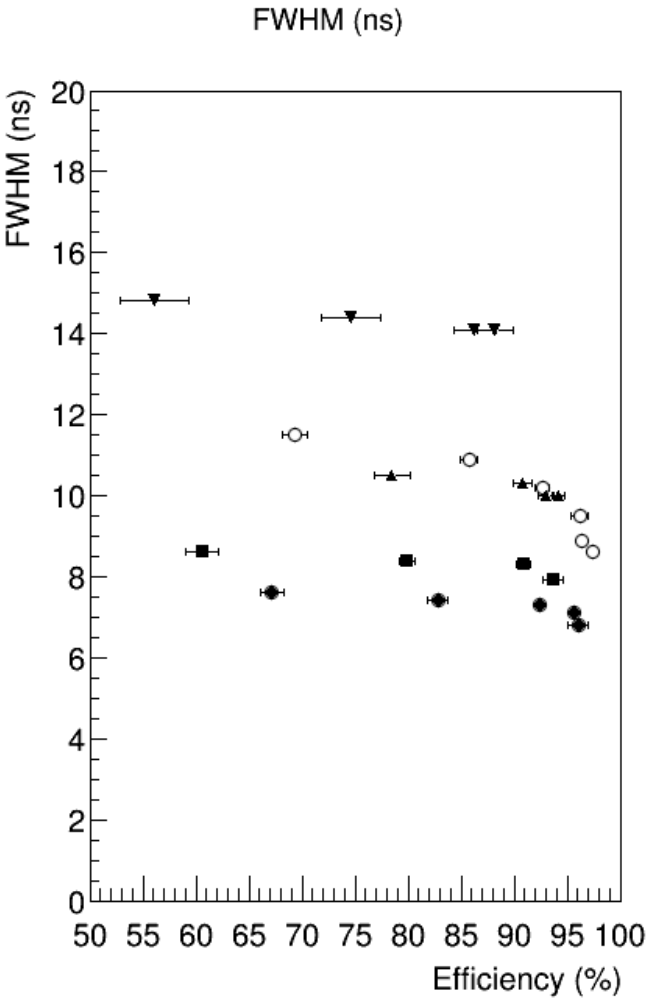


The higher the HFO concentration, the higher the operating voltage and the quenching power.
Better to keep HFO concentration to 30%, to limit multistreamers.

Ar/HFO-1234ze binary mixtures



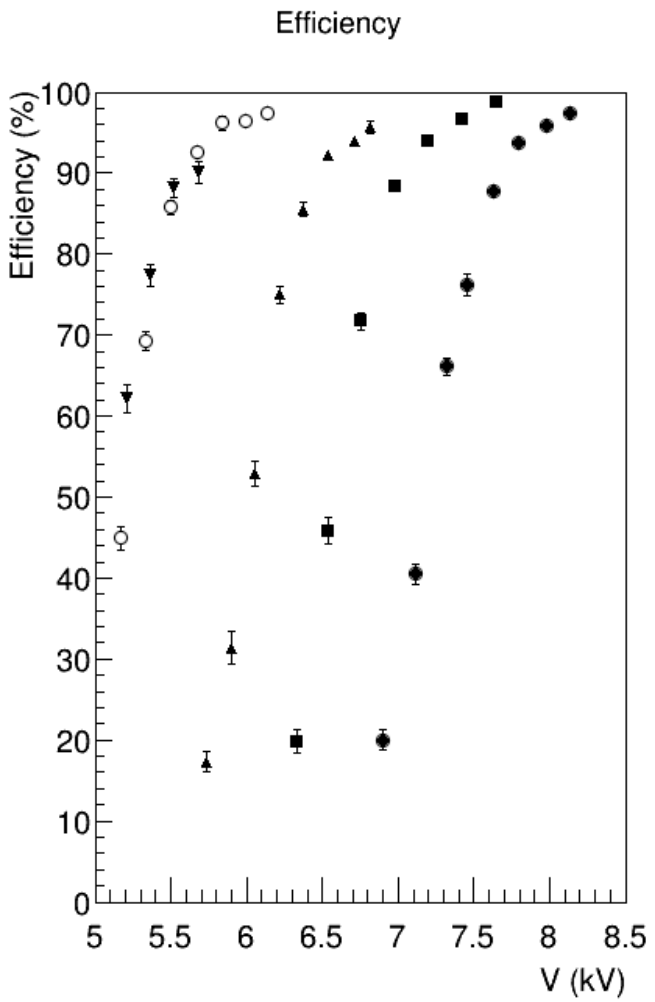


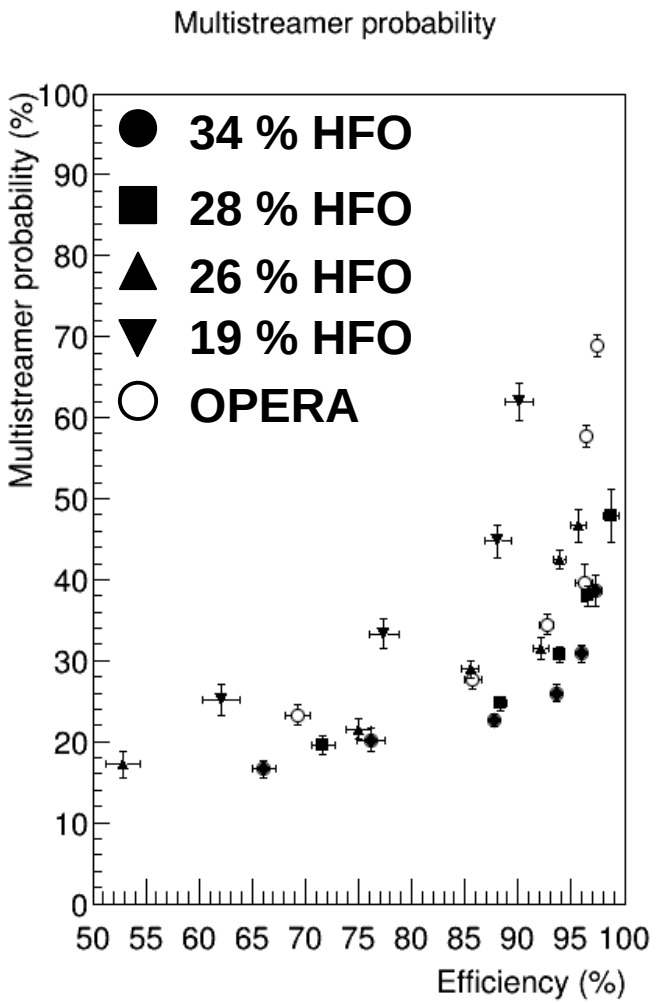


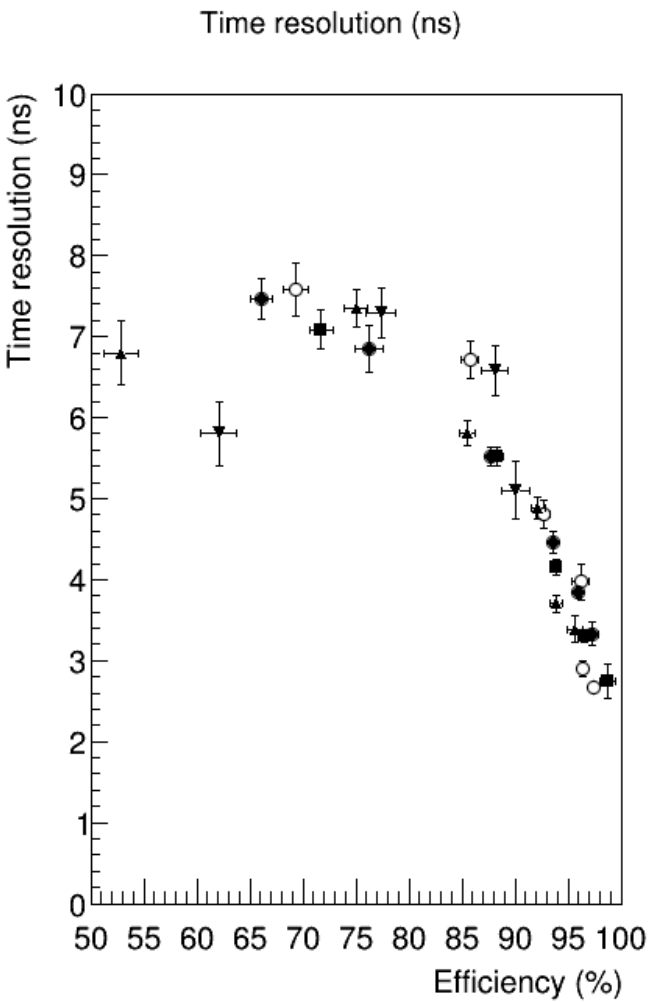
The higher the HFO concentration, the higher the operating voltage and the quenching power.
Better to keep HFO concentration to 30%, to limit multistreamers.

The higher the HFO concentration, the lower the prompt charge (FWHM smaller).

Ar/HFO-1234yf binary mixtures



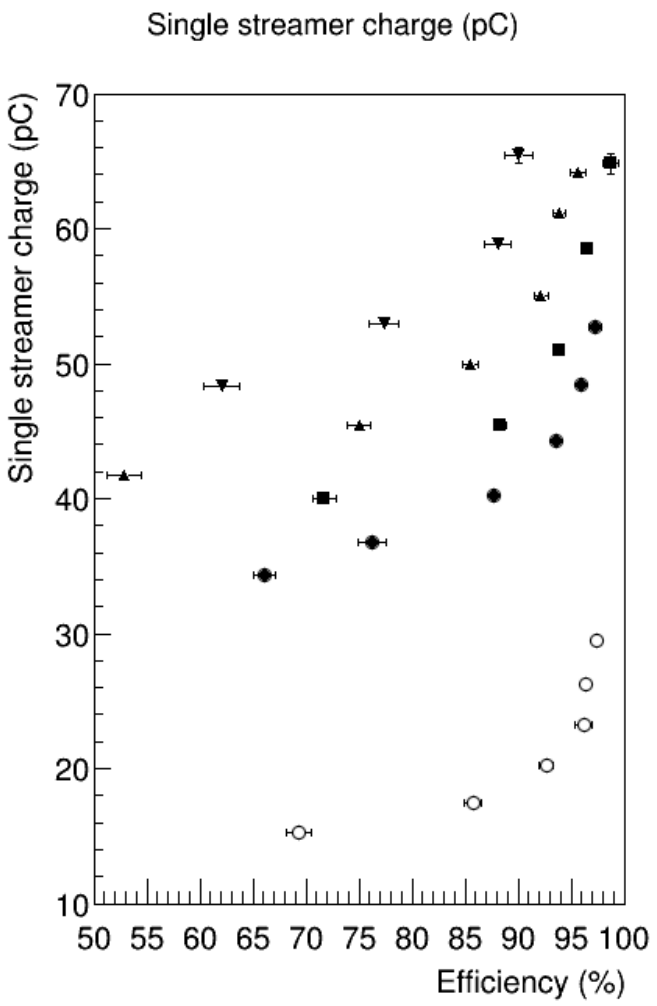


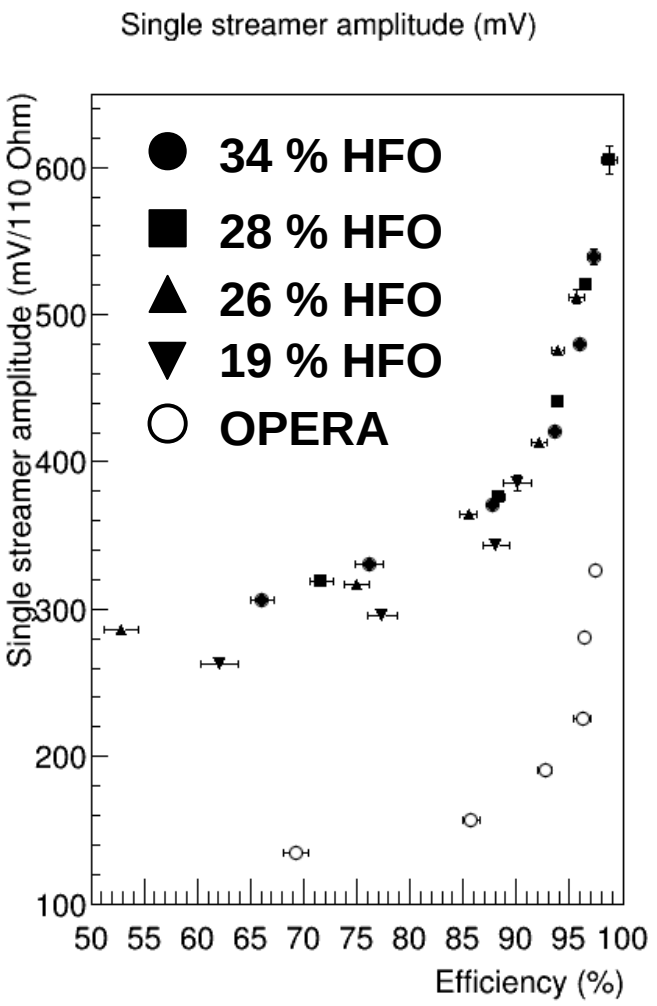


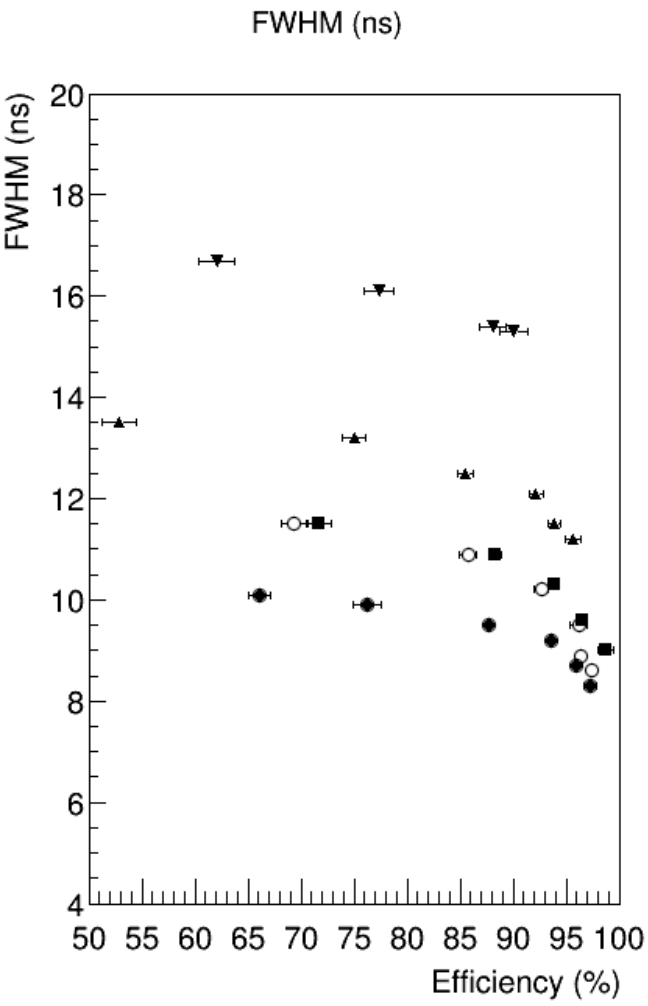
Remark: HFO-1234yf is flamable.
Qualitatively similar to HFO-1234ze.

Good quenching power also with concentrations of 26% and 28%.

Ar/HFO-1234yf binary mixtures







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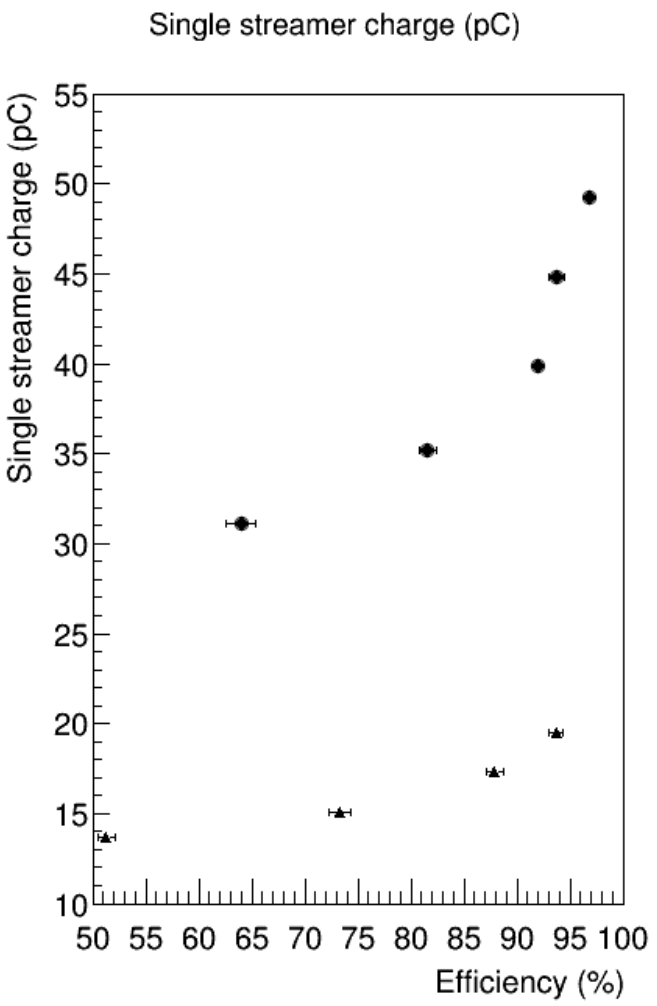
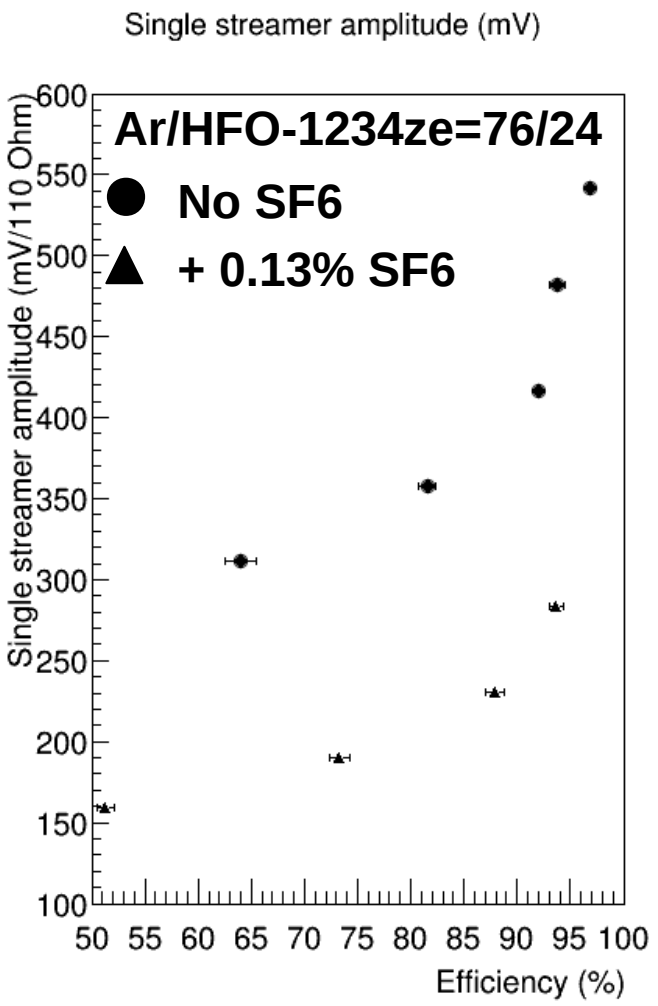
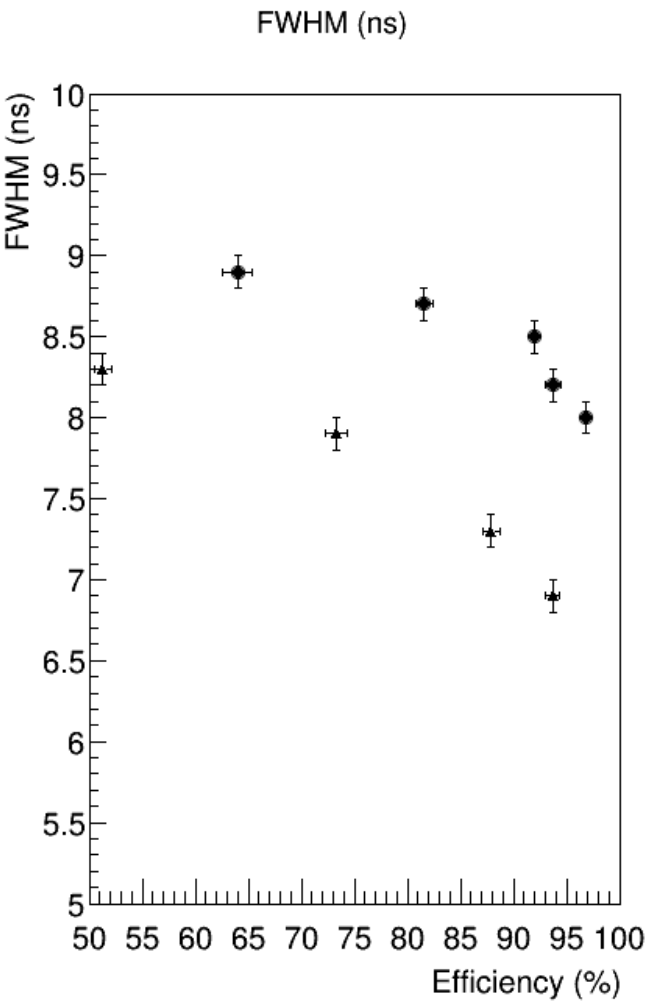
SF_6 addition



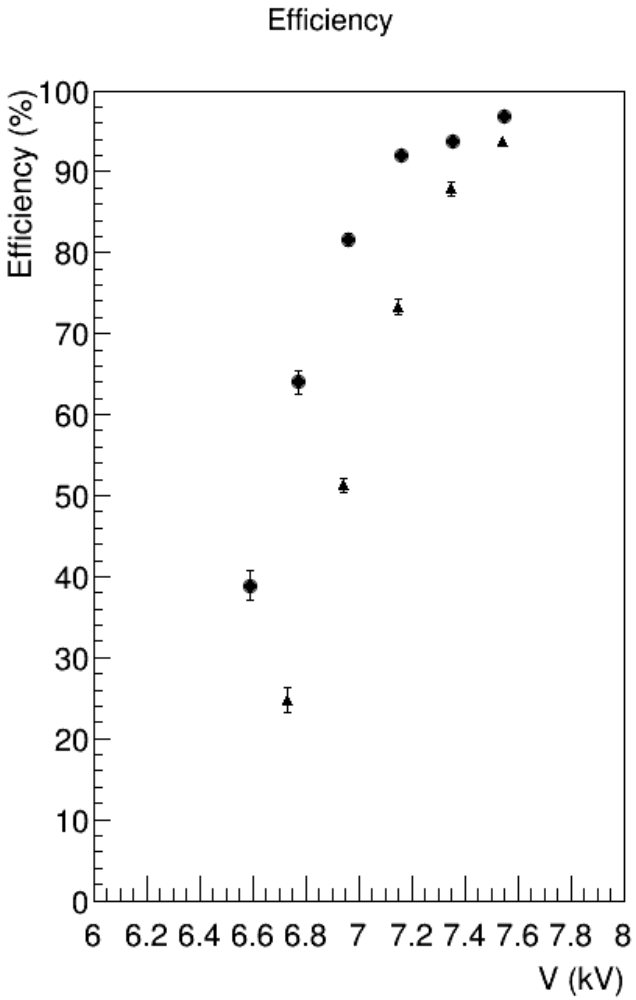


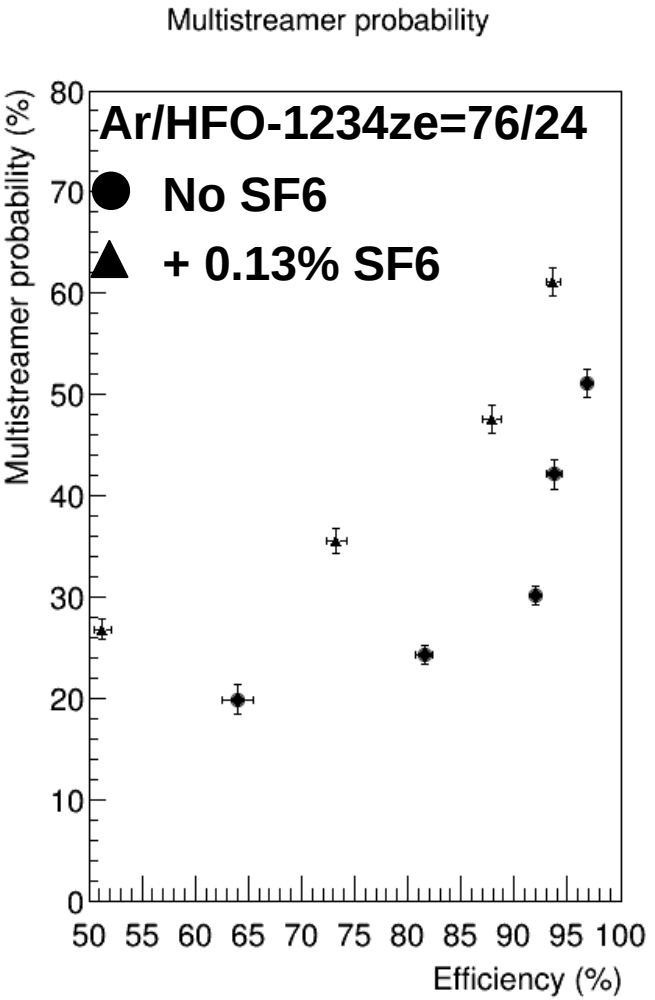


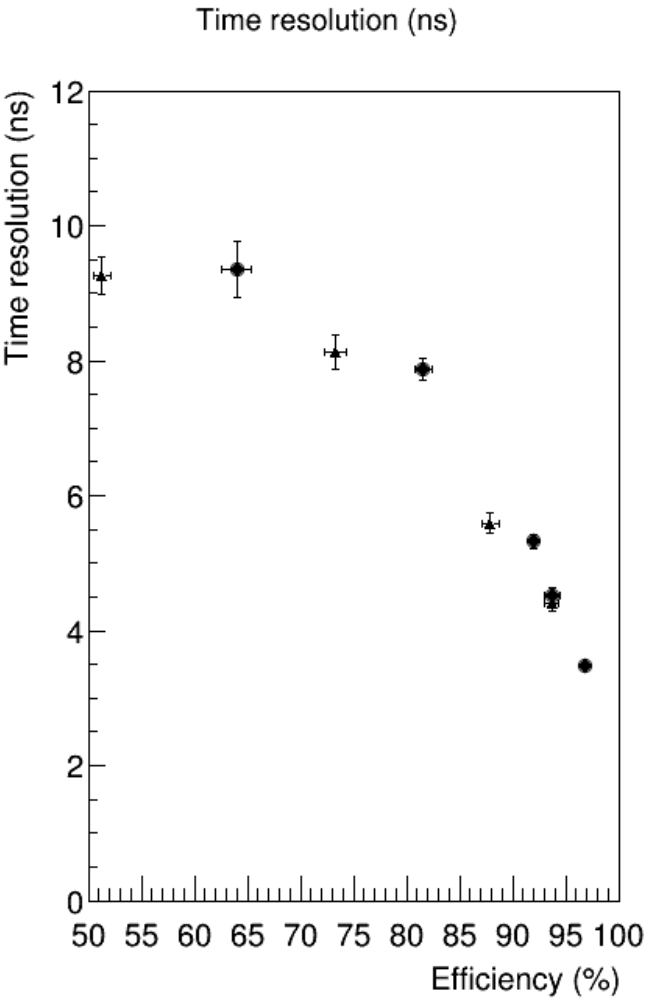
Similar to “standard” mixtures. Even with small additions

Strong charge suppression (both in signal amplitude and FWHM).

SF_6 addition

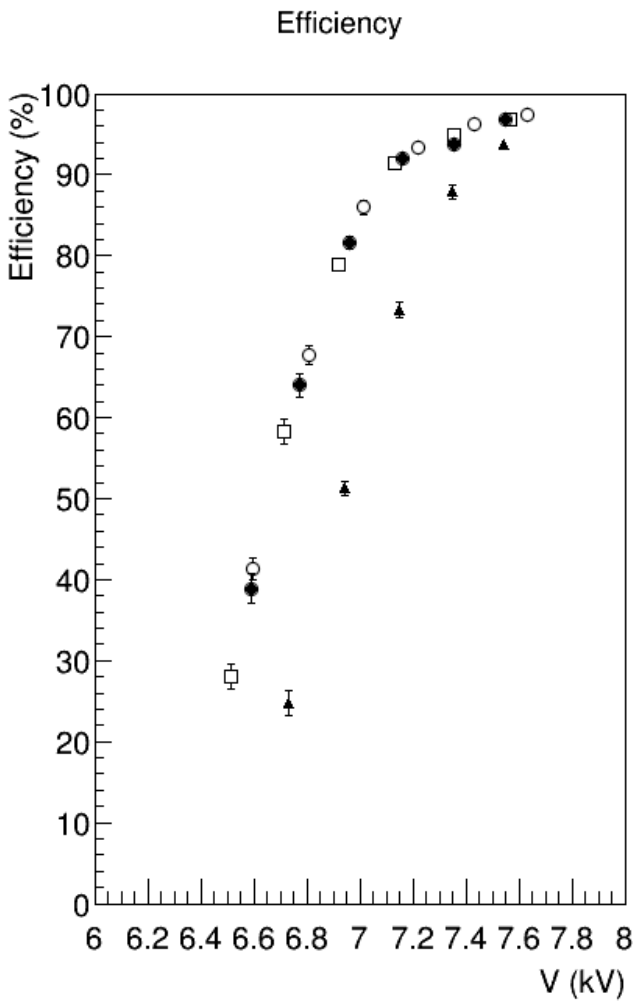


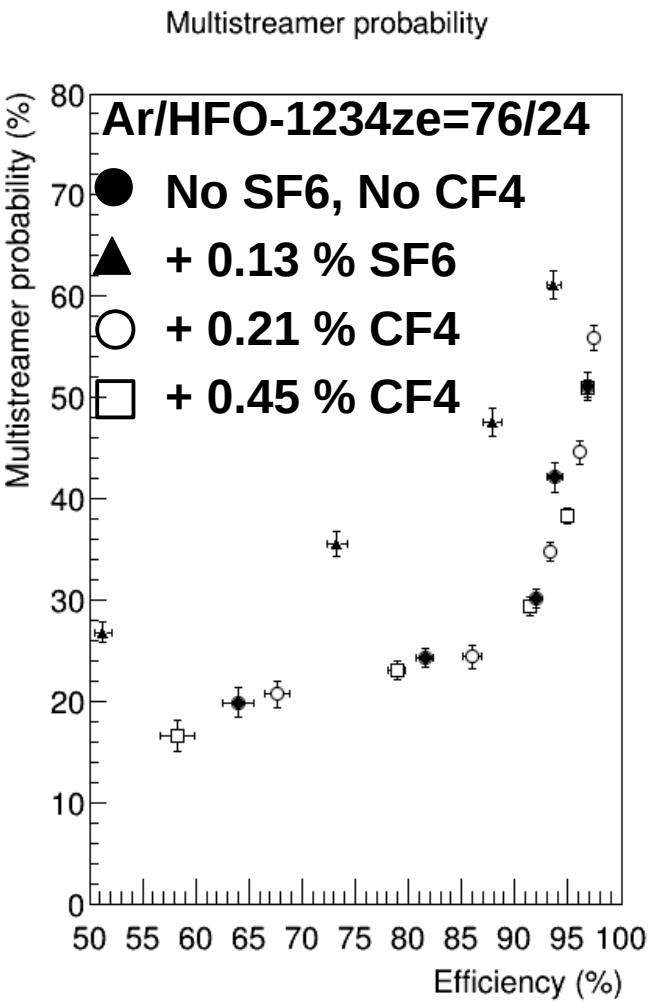


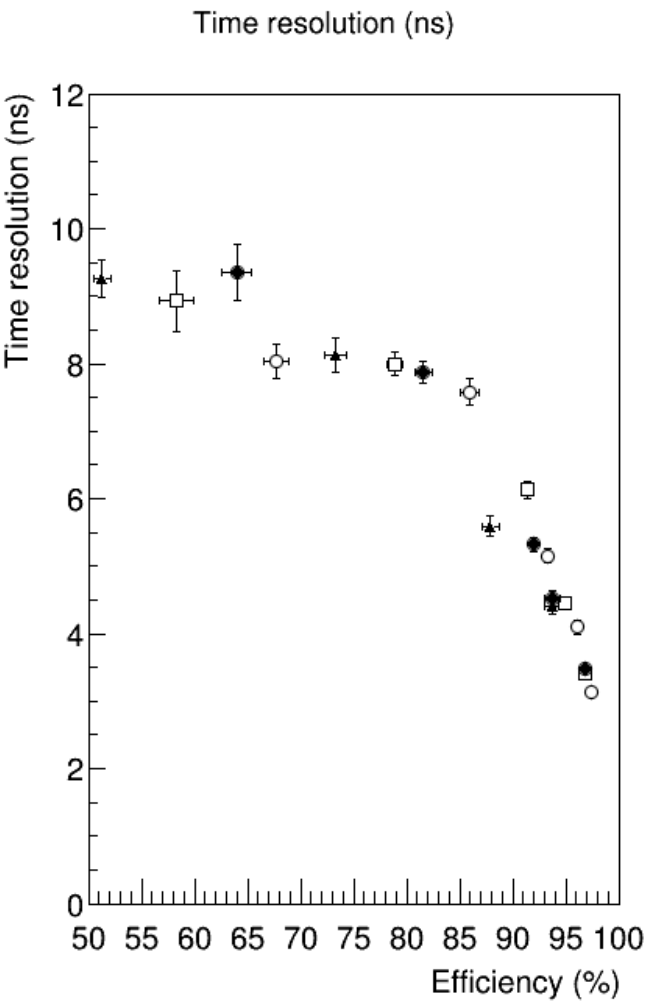


Similar to "standard" mixtures. Even with small additions
Strong charge suppression (both in signal amplitude and FWHM).
Observed also an increase of multistreamer probability.
Tested also on Ar/HFOyf=74/26,70/30 Ar/HFOze=70/30 Ar/HFOyf/ibut=63/34/3.
In the following slides, try to repeat the SF6 "miracle" with CF_4, CO_2, N_2.

CF_4 replacement of SF_6

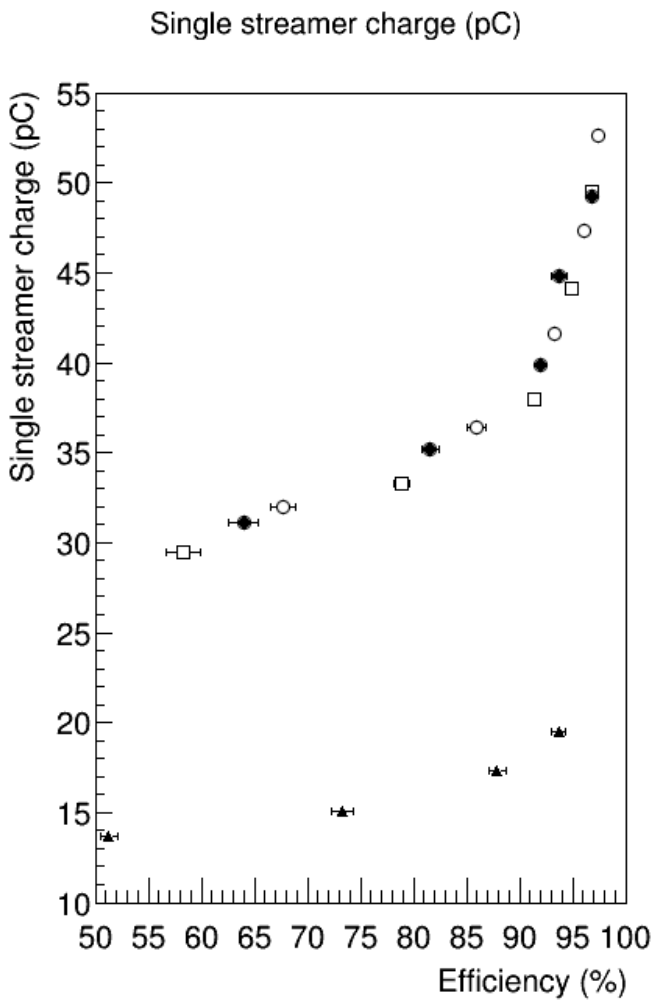


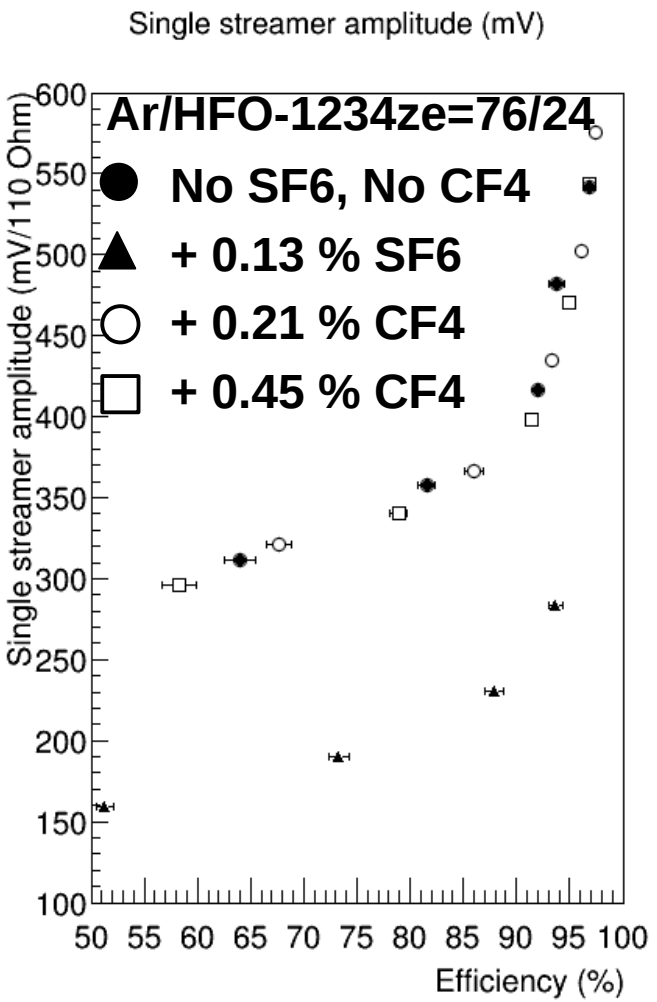


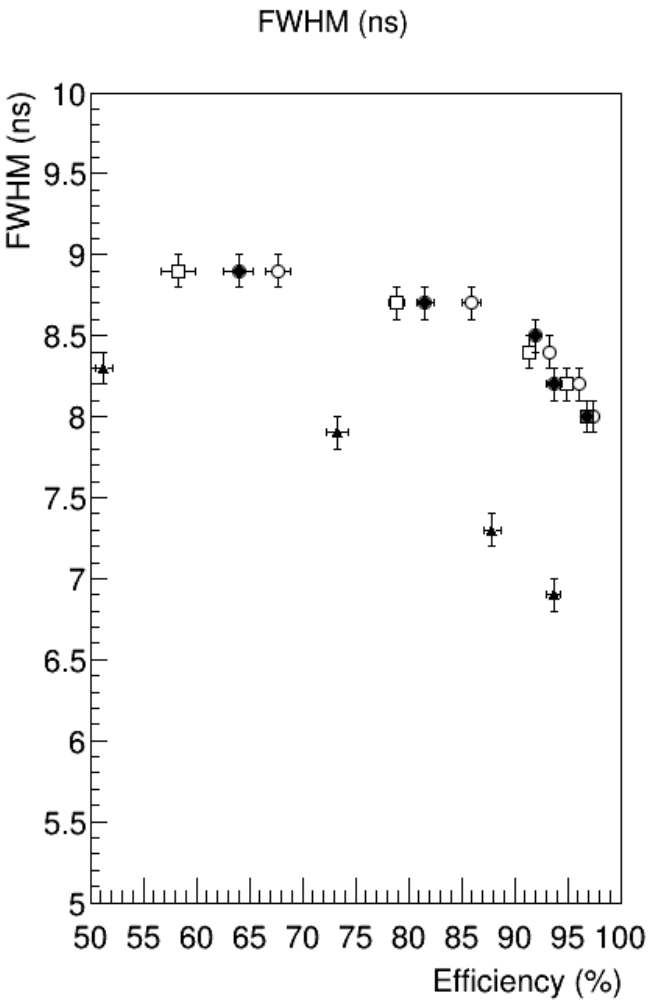


Effects observed with SF_6 addition, are completely absent with CF_4.
Tested also for Ar/HFOze=70/30 base mixture.

CF_4 replacement of SF_6







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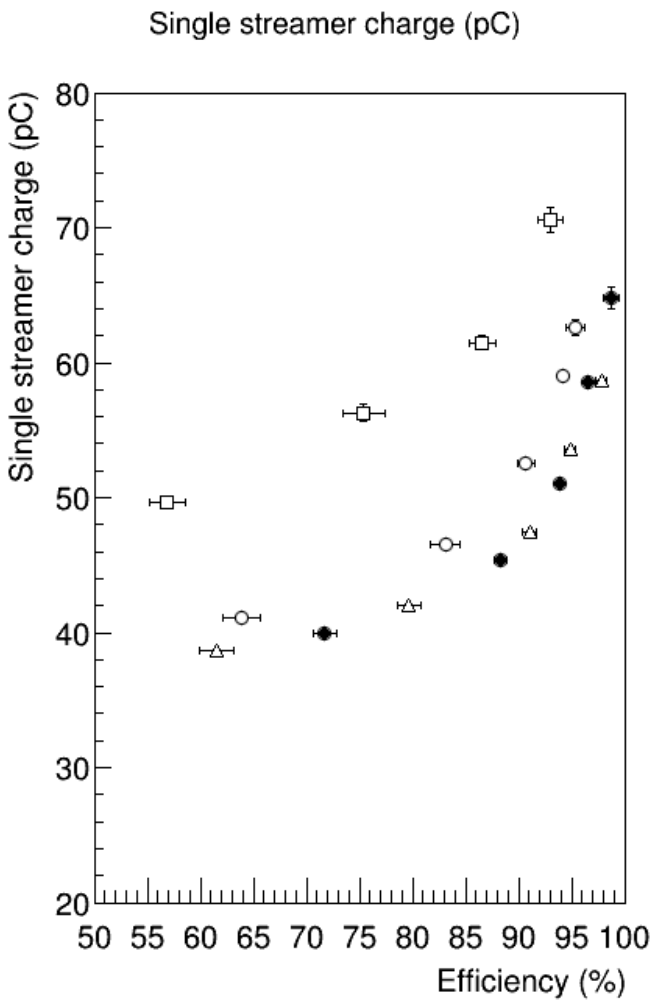
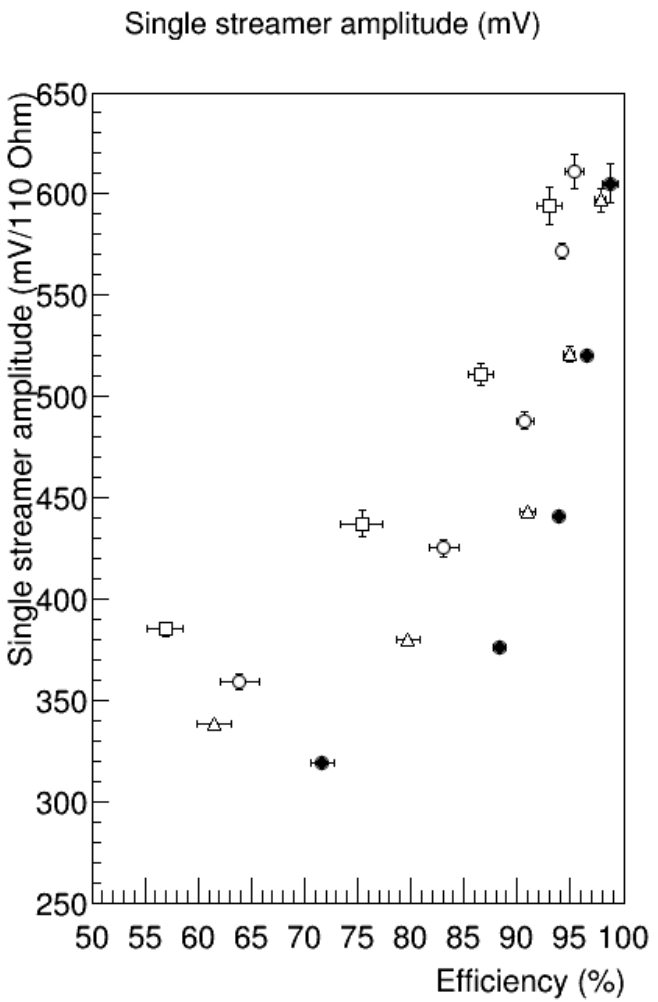
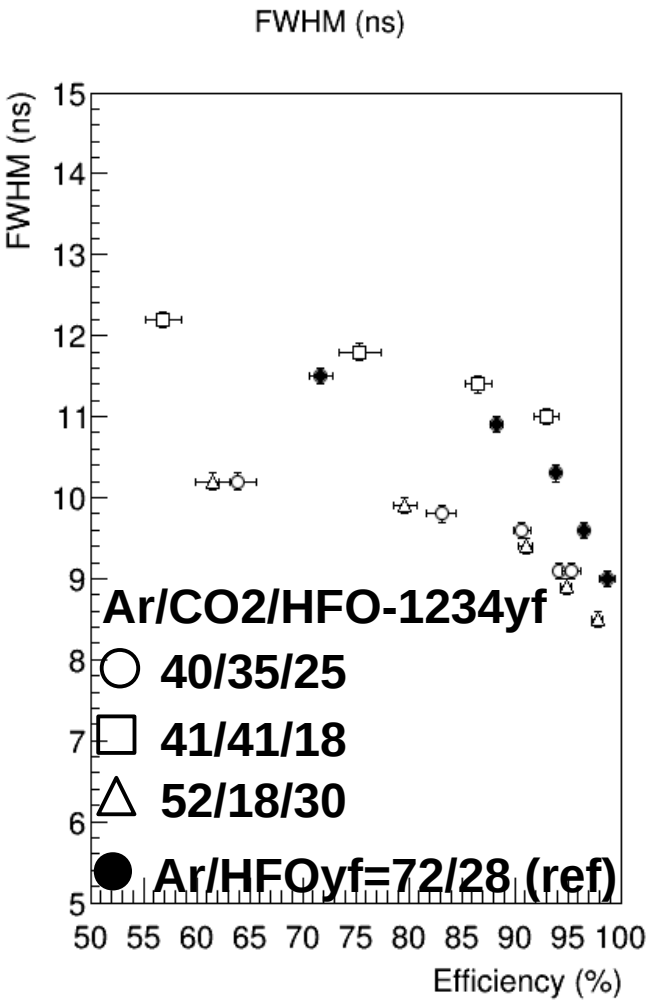
CO_2 addition

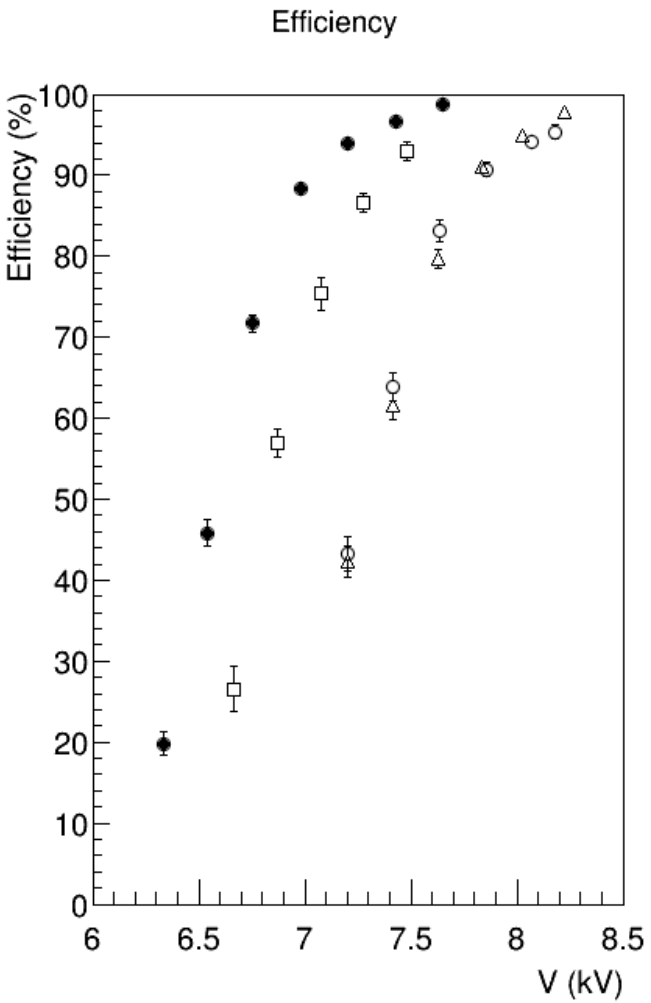


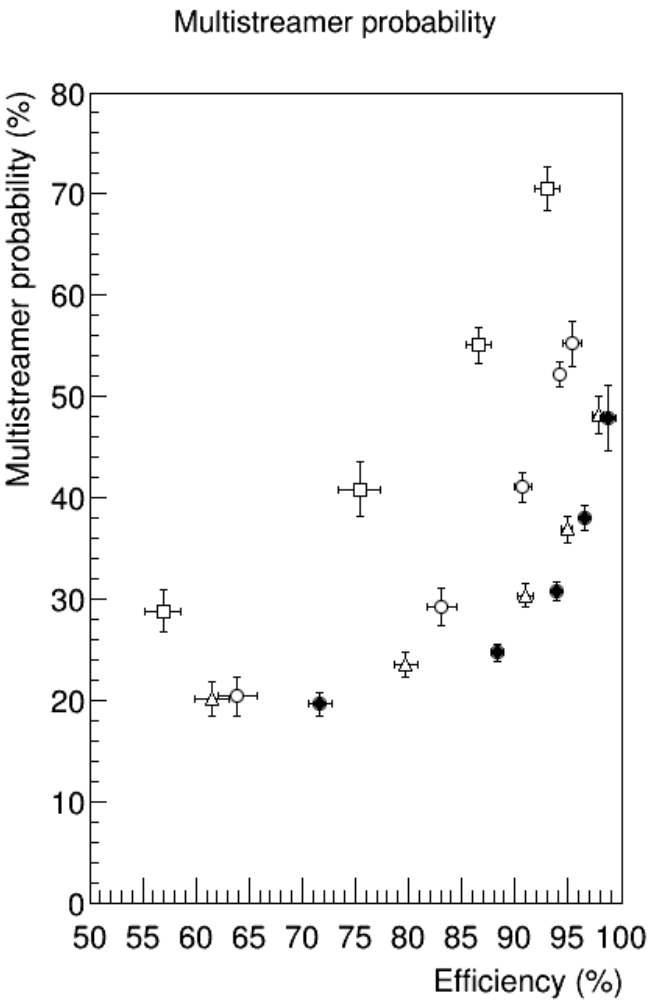


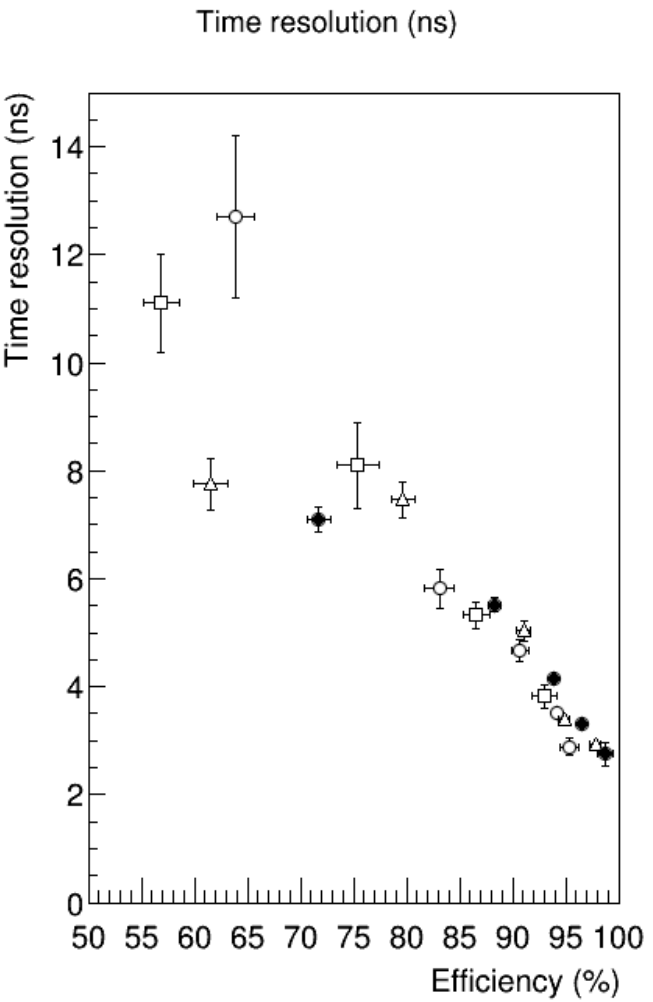


No streamer charge suppression.

CO_2 addition







No streamer charge suppression.

CO_2 shows also a low quenching power.

Its addition increases the operating voltage.

Several tests performed also with CO_2 addition to "standard" mixtures.

Ar/CO2/HFO-1234yf

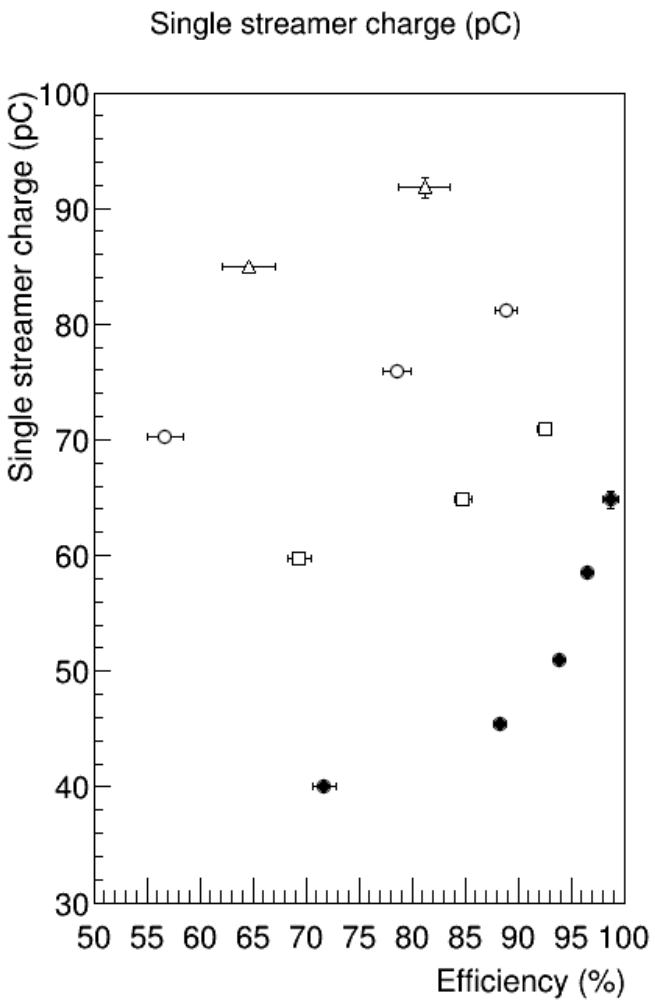
○ 40/35/25

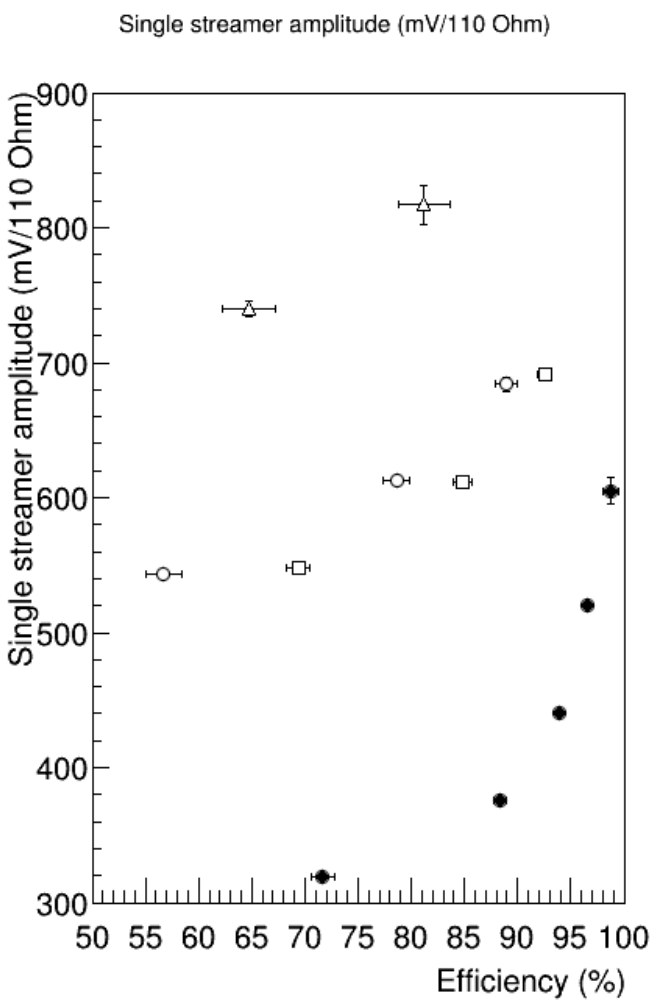
□ 41/41/18

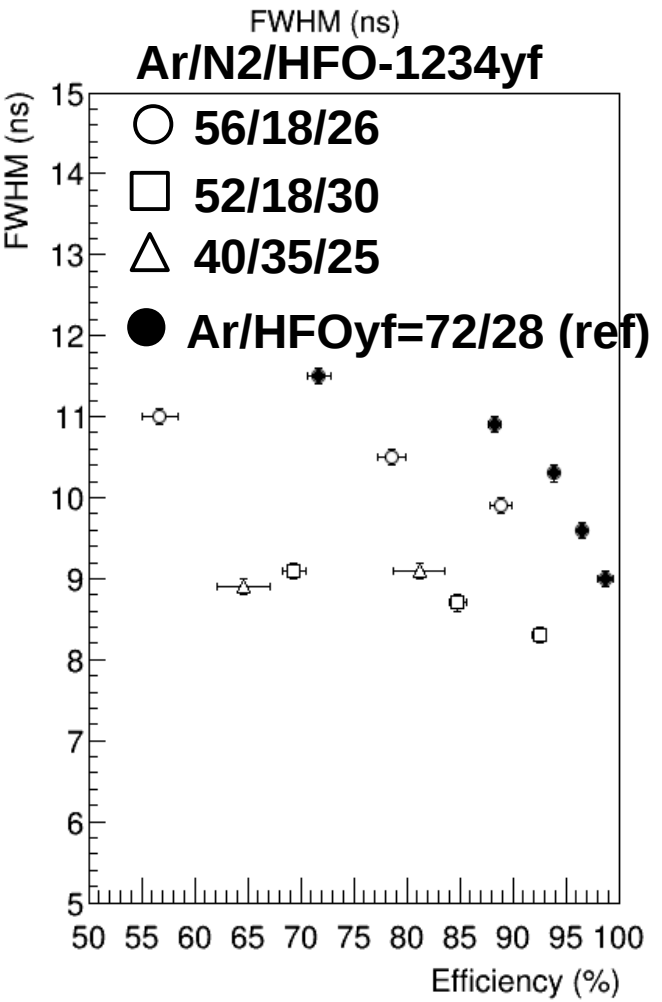
△ 52/18/30

● Ar/HFOyf=72/28 (ref)

N_2 addition

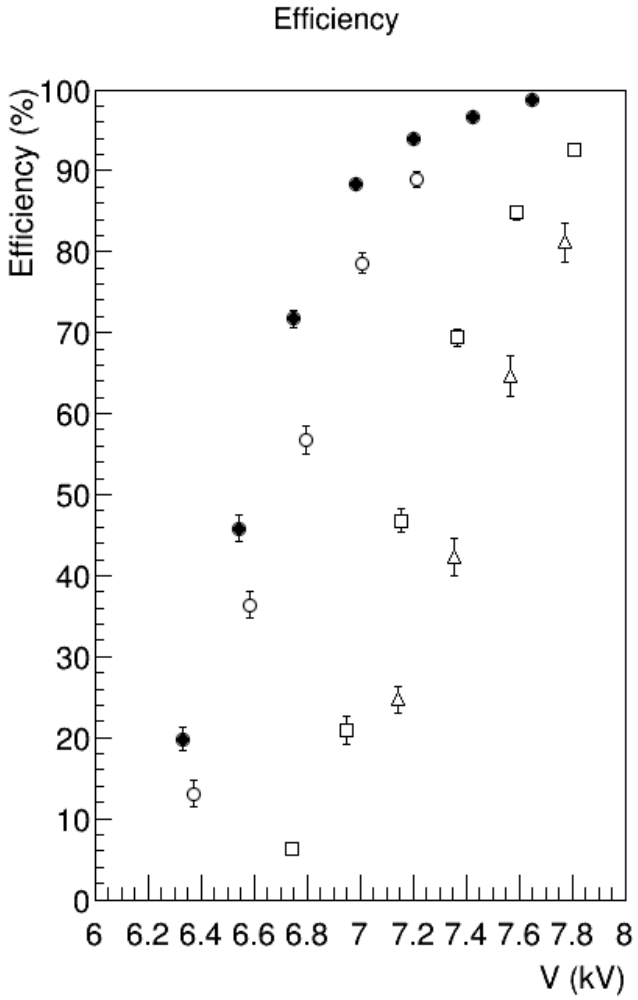


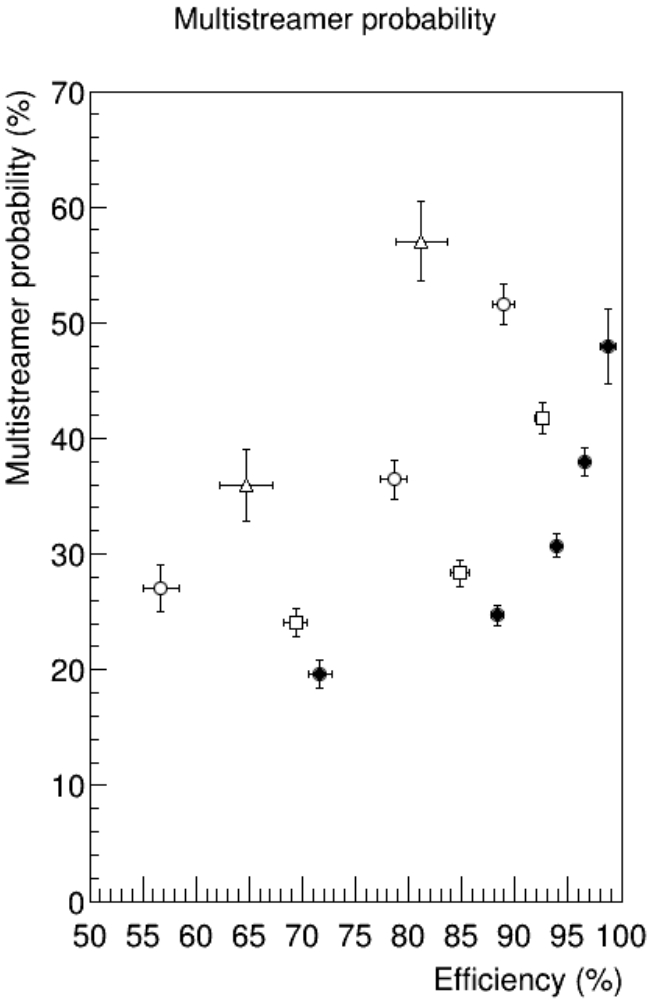


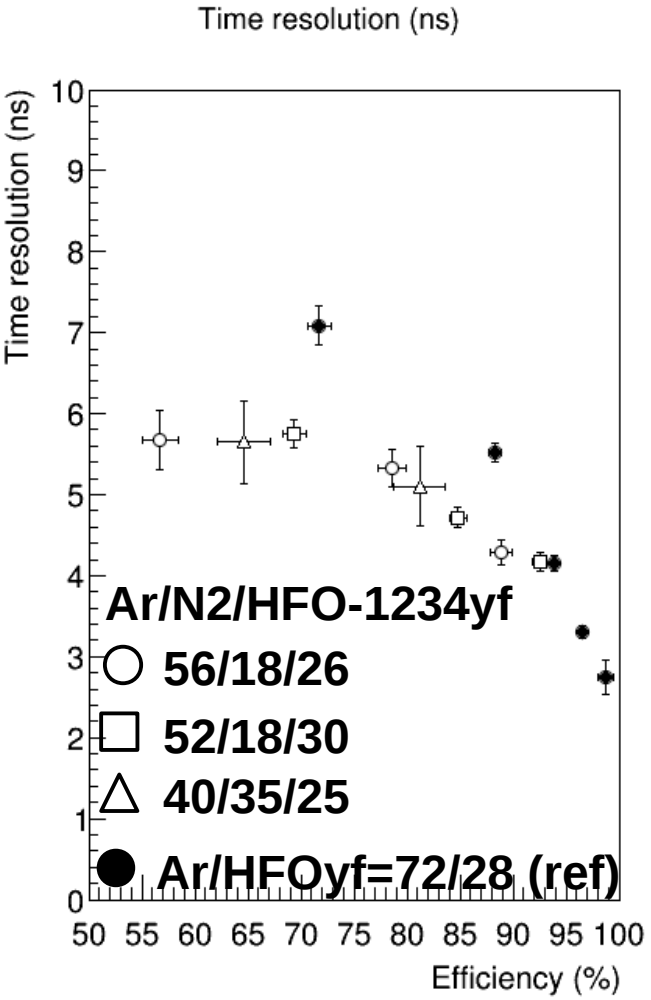


The considered mixtures have almost the same HFO concentration.
They differ because of the N2/Ar ratio.
The higher the N2 content, the higher the streamer charge and amplitude (the highest among all tested mixtures),

N_2 addition







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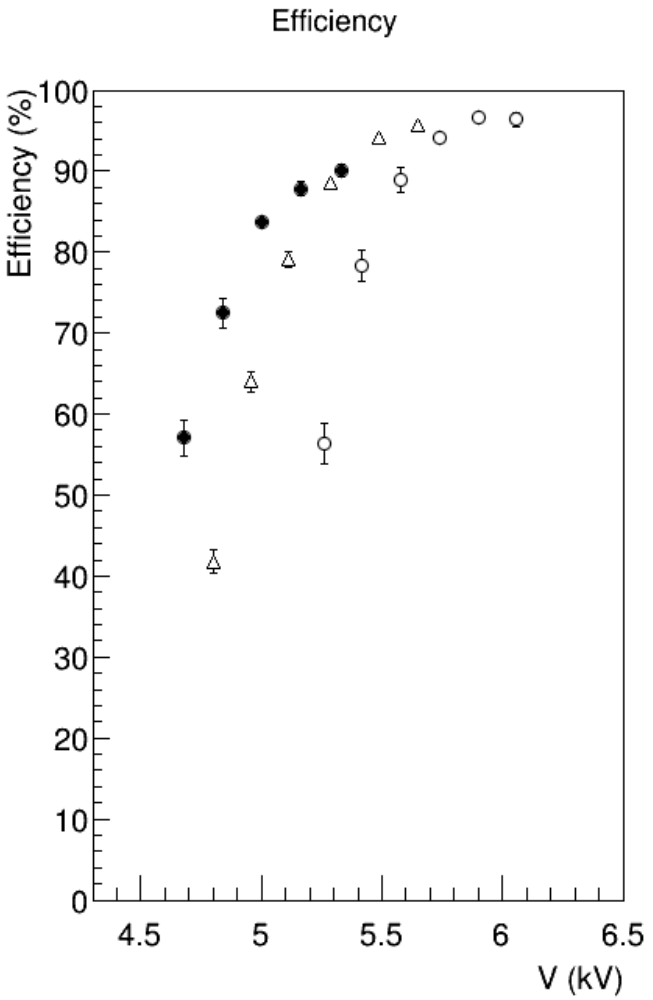
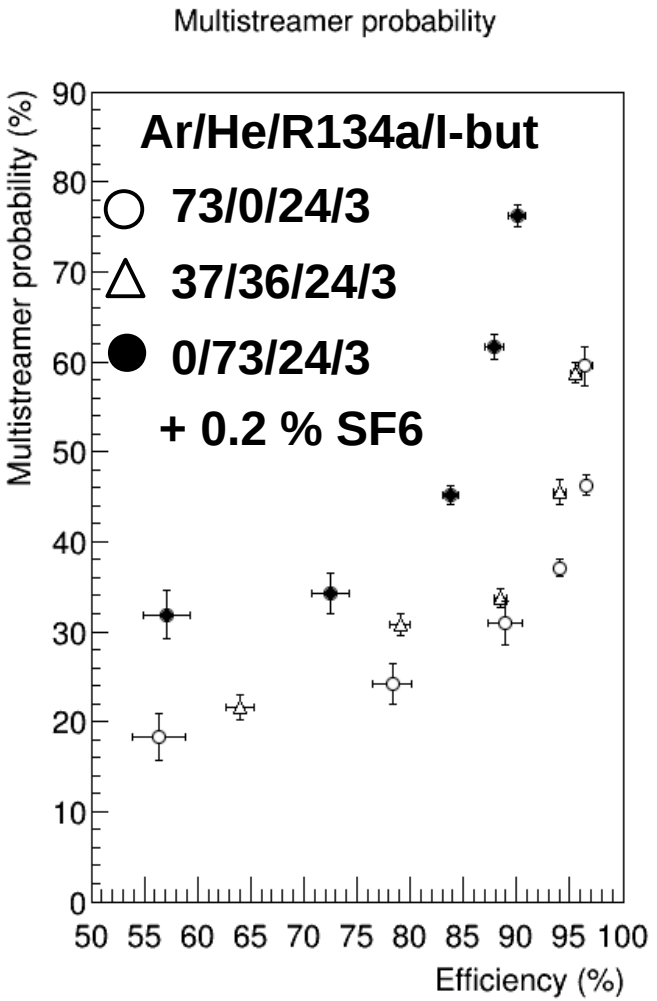
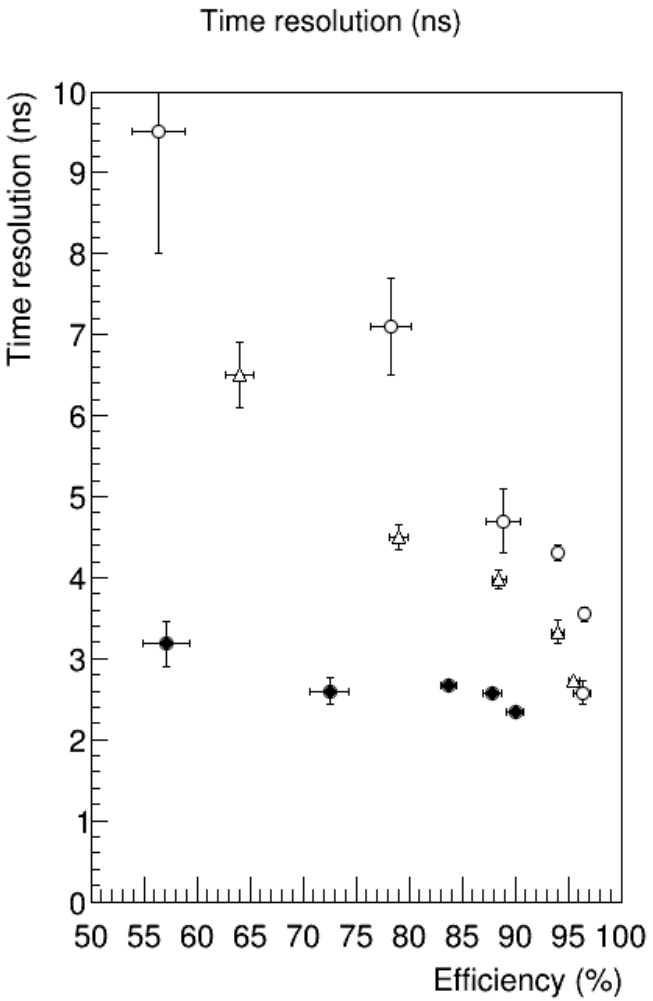
The higher the N2 content, the higher the streamer charge and amplitude (the highest among all tested mixtures), the operating voltage and the multistreamer probability.

He based gas mixtures

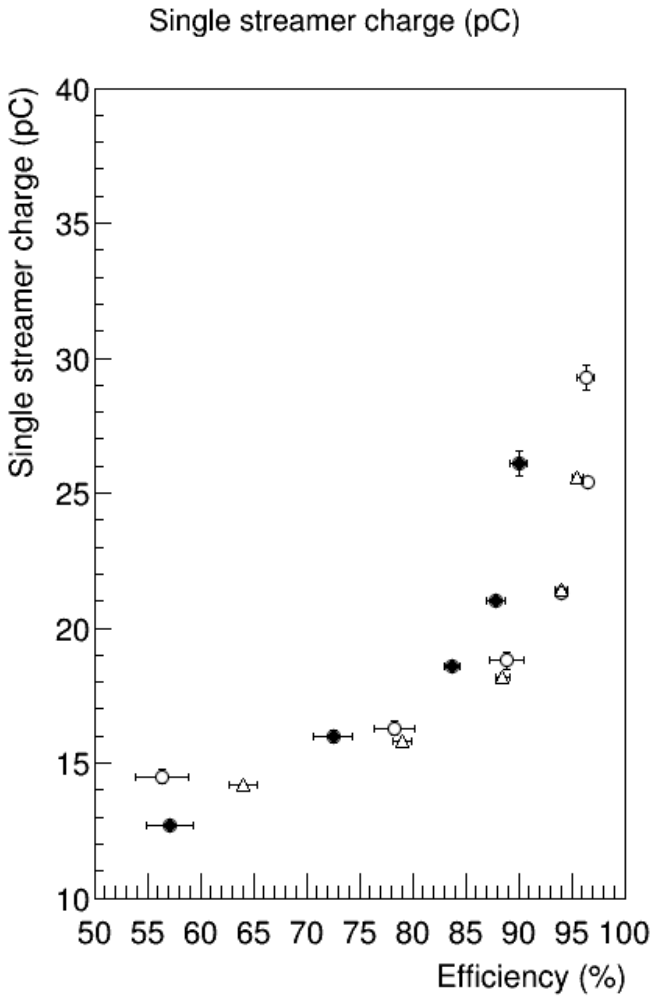


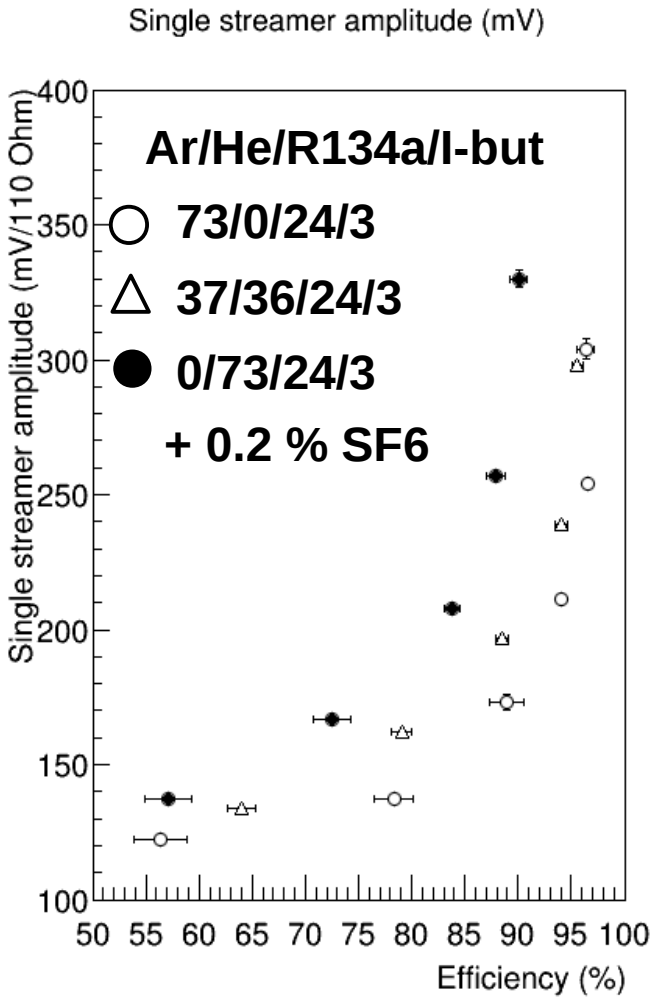


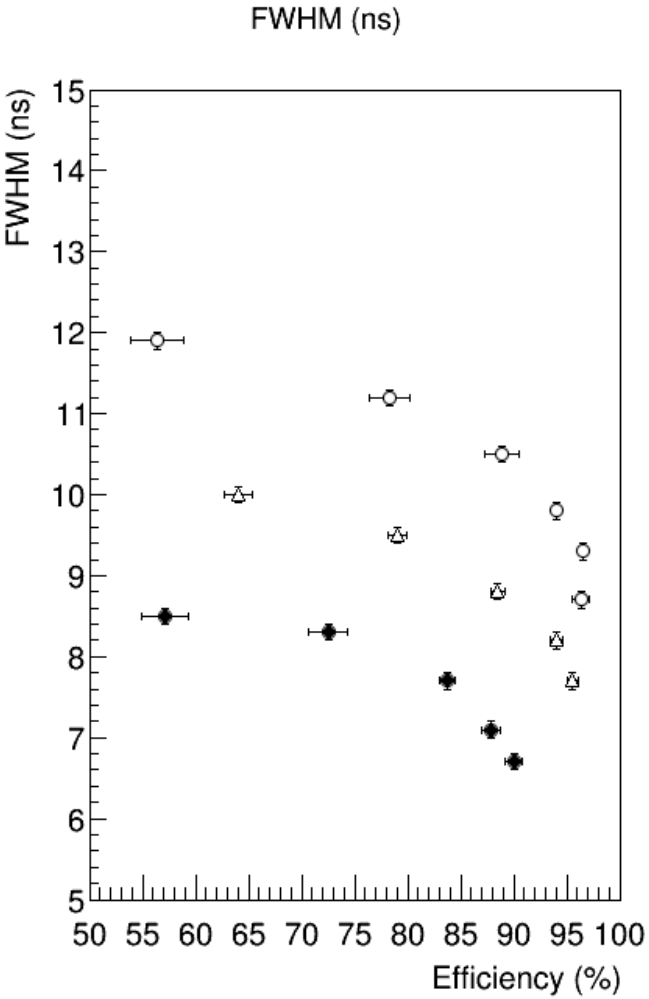


The most striking feature of mixtures with He (instead of Ar) is the improvement in time resolution (also at low efficiency values).
A lower efficiency is also observed (probably because of the lower primary ionization).

He based gas mixtures







The most striking feature of mixtures with He (instead of Ar) is the improvement in time resolution (also at low efficiency values).

A lower efficiency is also observed (probably because of the lower primary ionization).

A decrease of the signal FWHM is observed.

Also tested on Ar/R134a/ibut=48/48/4 (with and without SF6).

Conclusions

The presented tests started a couple of years ago, aimed at replacing gases of the “standard” mixtures with already known and used (in other detectors) ones.

New ecological Ar/HFO-1234ze binary mixtures are good for streamer operation (HFO concentration > 30% not to have a high multistreamer probability). HFO-1234yf, the flamable isomer, has similar properties.

Unfortunately no substitute has been found for SF_6, whose addition strongly diminishes the streamer charge.

CO_2 neither reduces the charge nor lower the multistreamer probability.

N_2 is even worsening the mixture properties.

Ar replacement with He seems interesting, improving the time resolution.