Preliminary results of Resistive Plate Chambers operated with eco-friendly gas mixtures for application in the CMS experiment

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The "ecological" gas issue

- **The European Community has prohibited the production and use of gas mixtures with Global Warming Power > 150 (GWP(CO_2) = 1)**
  - ✓This is valid mainly for industrial (refrigerator plants) applications
  - ✓Scientific laboratories would be excluded
  - ✓CERN could require to stick to these rules anyhow
- **$C_2H_2F_4$ is the main component of the present RPC gas mixture:**
  - ✓GWP($C_2H_2F_4$) = 1430, GWP(SF_6) = 23900, GWP(iC_2H_{10}) = 3.3
- $C_2H_2F_4$ and SF_6 Crucial to ensure a stable working point in avalanche
- To test molecules similar to $C_2H_2F_4$ but with lower GWP

  $C_3H_2F_4$ – tetrafluoropropene (GWP=4-6)

  - ✓**Should replace $C_2H_2F_4$ as automotive air-conditioning refrigerant**

✓other possibility could be CF_3I – Trifluoroiodomethane with GWP ~ 0 & ODP ~ 0

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The search for an ecogas replacement

Review of possible
Gas present on the market

L. Benussi et al.
Properties of potential eco-friendly gas replacements for particle detectors in high-energy physics
arXiv:1505.00701

Laboratory tests

these slides

Chemical analysis of interactions between new gas and RPC materials

Work ongoing

Choice of few candidate mixtures

Tests under irradiation (GIF++)

Experimental approach in CMS

Compare results from standard gas mixtures vs mixtures with eco-gases

two operational laboratory test stands

The **LNF** test stand:

- Induced charge spectrum
- Efficiency and streamer probability
- Time resolution
- Use of standalone chamber and electronics
- **Use of gas chromatograph**

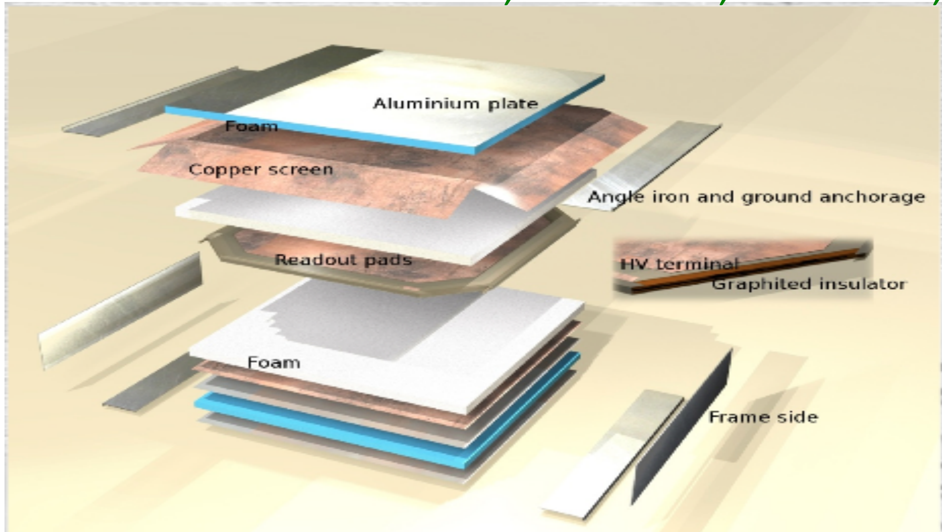
The **Ghent** test stand:

- dark current
- single rate
- efficiency
- Use of the the standard CMS chambers and electronics

Two complementary approaches. Synergies to be explored

Experimental Set-up in Frascati

S. Bianco, L. Benussi, D. Piccolo, L. Passamonti, D. Pierluigi, A. Russo



- 12 single gap RPCs, 2 mm wide gas gap
- 50 x 50 cm^2
- Double Pad readout
  - partial cancellation on single mode noise
  - Expected about x2 induced signal charge
- Scintillator layers on top and bottom for trigger

Data taken with oscilloscope

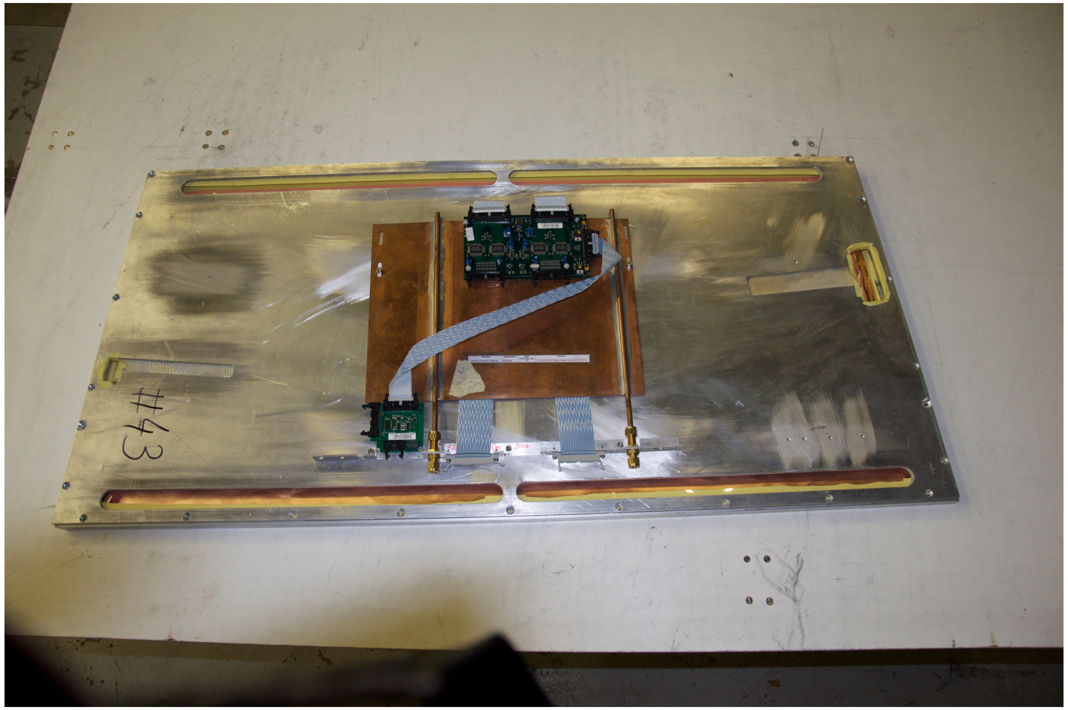
- **Gas chromatograph: for gas mixture analysis**
- 4 channels Oscilloscope lecroy104xi (5 Gsamples, 1 GHz): for signal readout
  - Full digitization of signal

Experimental Set-up in Ghent

Frederik Van Acker   *Simon Cauwenbergh*   *Michael Tytgat*

Double gap: 2mm gas gap x 2

"Alternative" gas mixing unit

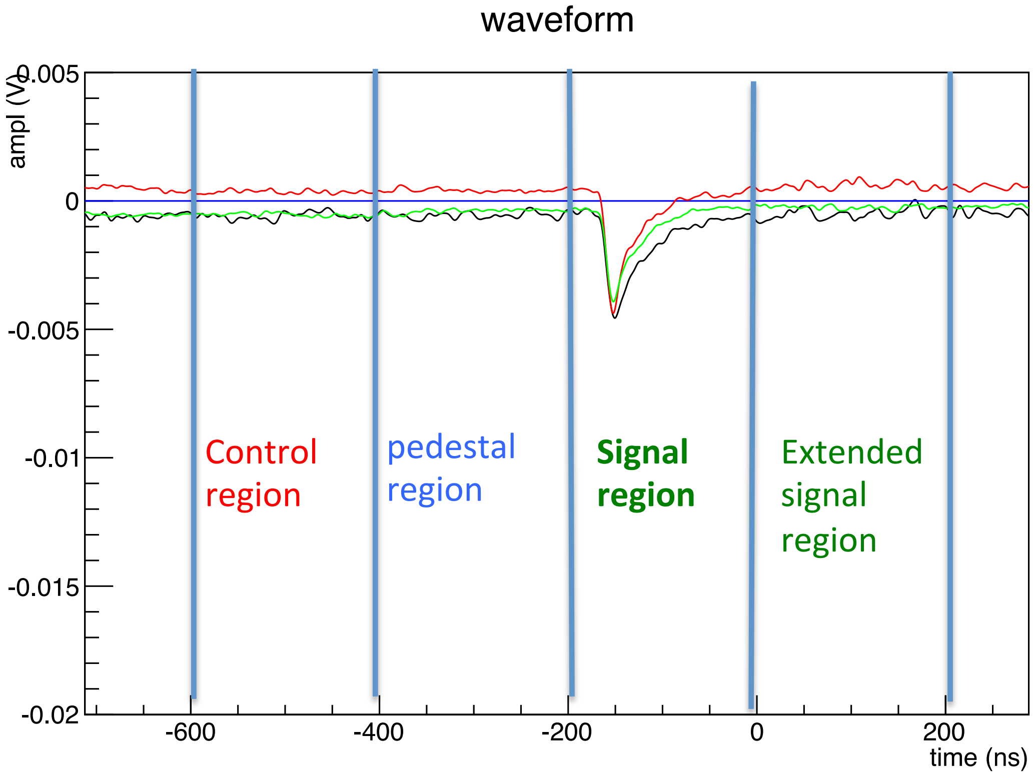


2 CMS-like test chambers equipped with standard cms electornics

Efficiency and cluster size measured with standard CMS electronics

Frascati test stand: Signal analysis

- One RPC is used as offline trigger kept at fixed voltage
- Second RPC used for test



- **Signal region baseline corrected used for analysis**
- Pedestal region used to define voltage baseline
- Extended signal region used to evaluate streamers
- Control region used to define cuts

Waveform in green: signal from software trigger RPC

Waveform in red: signal from test RPC with scale 2 mV/div

Waveform in black: signal from test RPC with scale 20 mV/div

Frascati test station: Notes on the analysis

- Threshold used for analysis of RPC:
  - Efficiency: $Q_{induced}$ > 300 fC (to be divided for ~2 because of double pad readout) && $|V_{max}|$>0.4 mV *(similar to CMS Front electronic threshold)*
  - Streamer: $Q_{induced}$ > 40 pC (to be divided for ~2 because of double pad readout)
- HV corrected at P0=990 mbar, T0 = 20 degrees
- Time resolution is extracted from the difference between time over threshold (0.8 mV) of trigger RPC and test RPC

- CMS standard gas mixture:

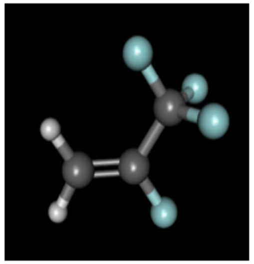
  R134a (95.2 %) i-C_4H_{10} (4.5 %) SF_6 (0.3%)

Possible eco-gas repacements

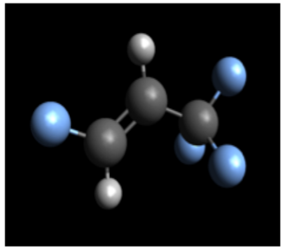
Tetrafluorepropene ($C_3H_2F_4$)

It cames in two allotropic forms

HFO-1234ze



HFO-1234yf



Molecule	CCl_2F2	CF_4	R134a
Ionization energy (eV)	10.24	12.81	12.40
Molecule	R152a	HFO1234ze	HFO1234yf
Ionization energy (eV)	10.78	9.34	9.37

Molecule similar to R134a ($C_2H_2F_4$) BUT

HFO-1234ze GWP=6, HFO-1234yf GWP=4

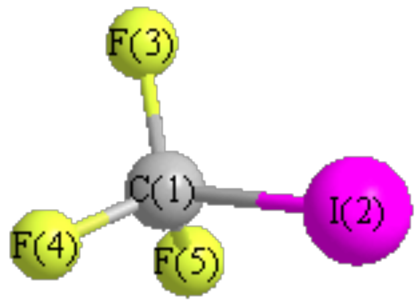
R134a GWP = 1430

HFO-1234yf HMIS code =2
(moderate flammability)

In this talk we concentrate on HFO-1234ze

(HFO in the labels will mean HFO-1234ze)

Trifluoroiodomethane (CF_3I)

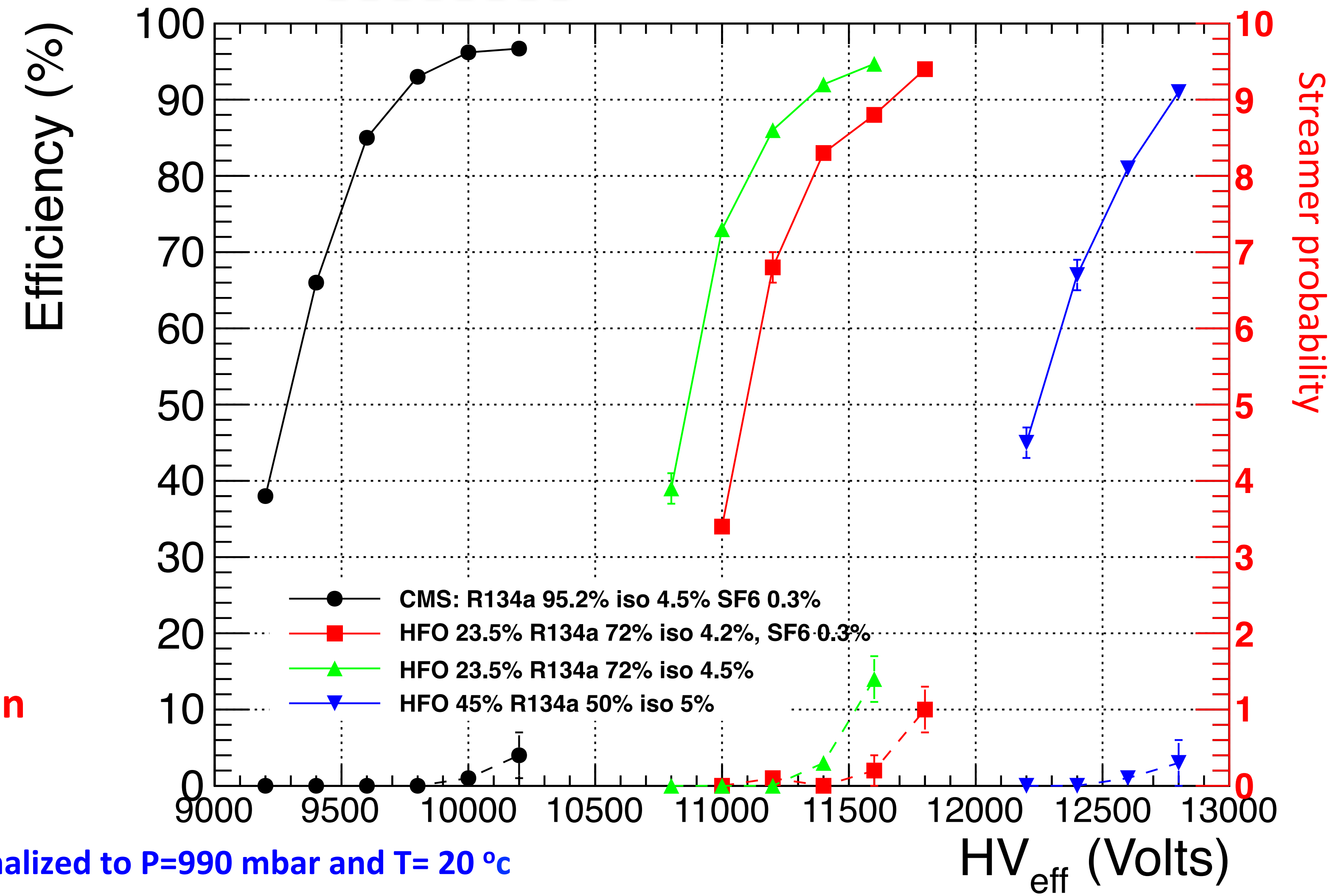


GWP and ODP close to 0

High quenching power

Very expansive ! We were able to buy just a small bottle of 0.5 kg for very few preliminary tests

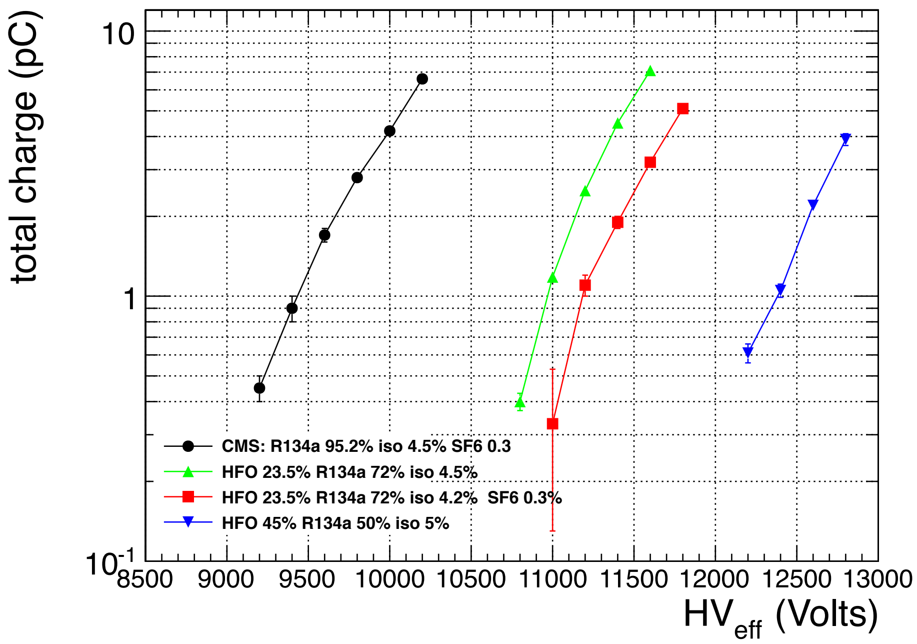
Replacing R134a with HFOze

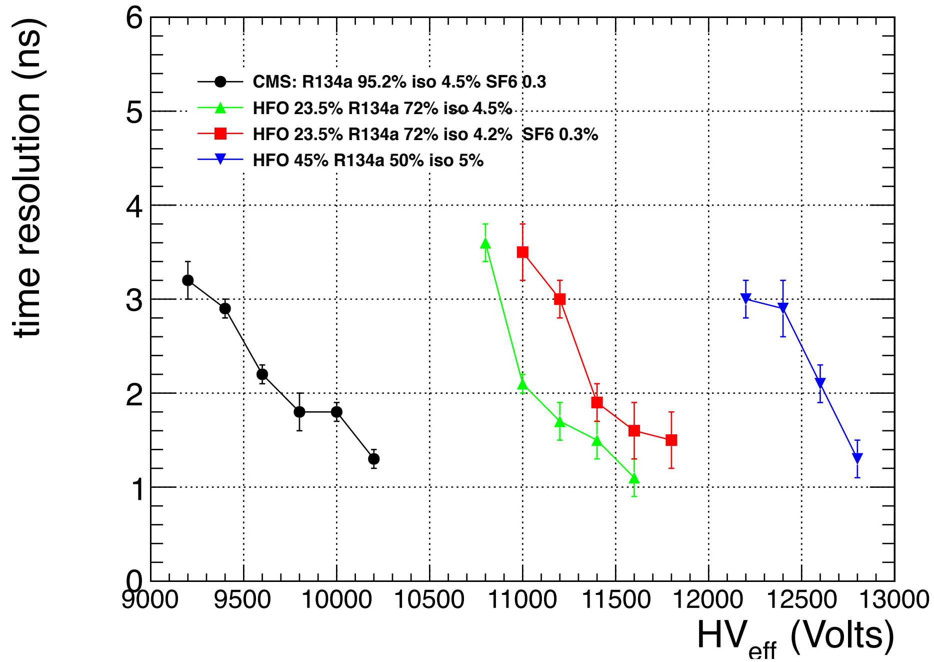


LNF Test station

HV normalized to P=990 mbar and T= 20 °c

Replacing R134a with HFOze





Total Induced charge to be divided by ~2 (double pad readout)

LNF Test station

Summary:

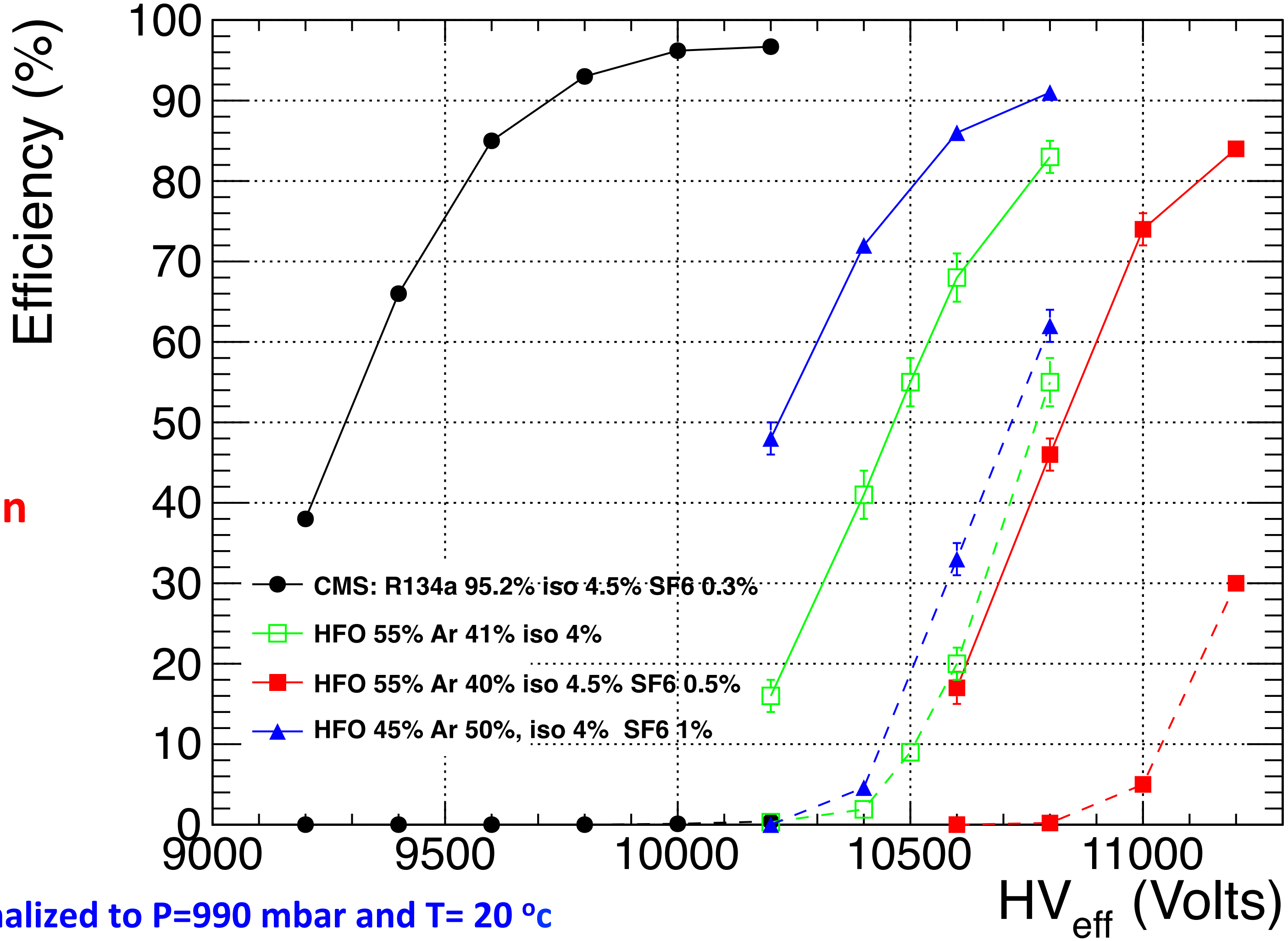
HFO shows interesting quenching properties BUT cannot be used alone to replace R134a (large shifts of working voltage)

Adding Ar to HFOze

efficiency

Streamer probability

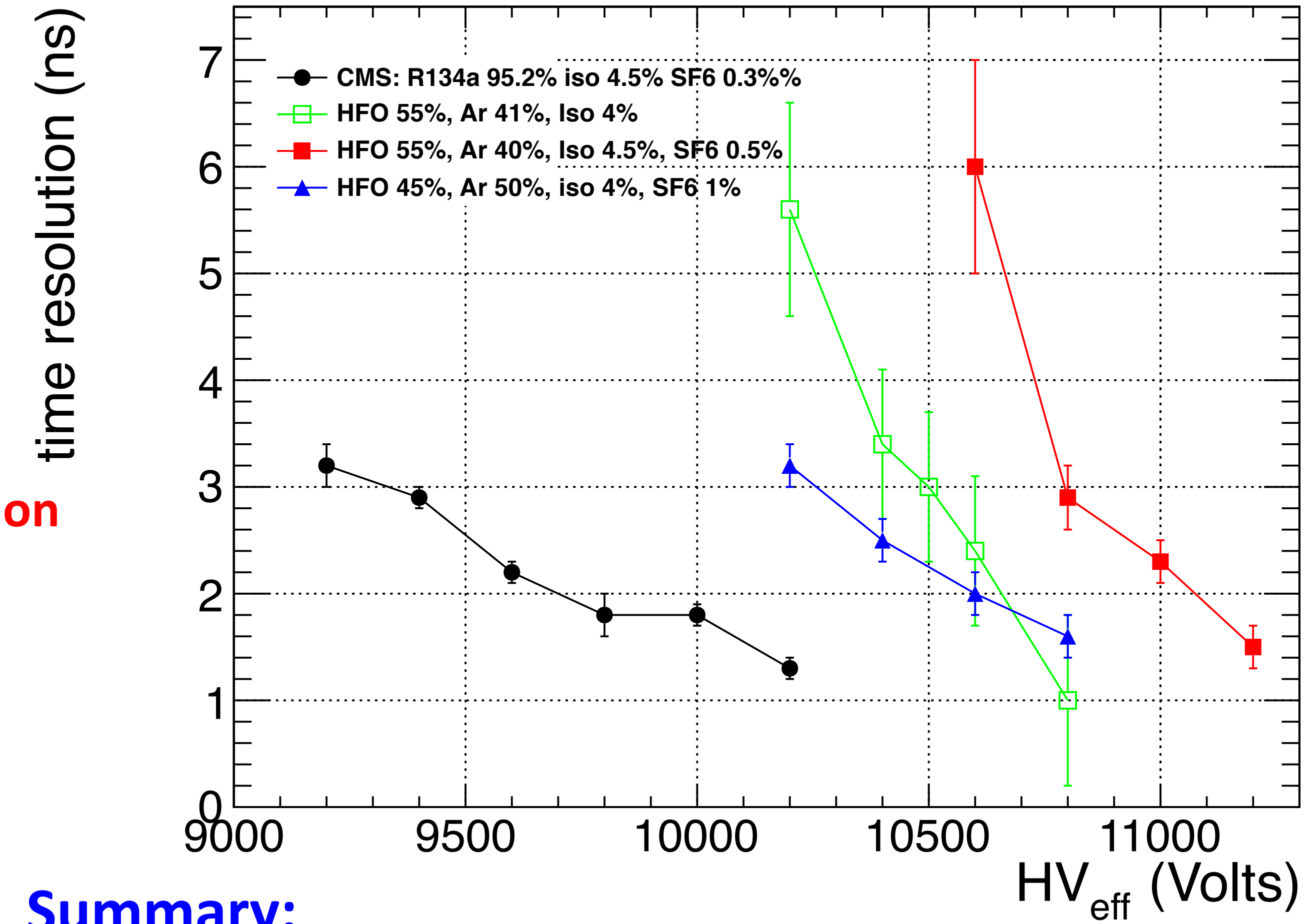
LNF
Test
station



HV normalized to P=990 mbar and T= 20 °c

Adding Ar to HFOze

LNF Test station



INDUCED CHARGE DISTRIBUTION NOT AVAIABLE BECAUSE OF SATURATION DUE TO LARGE SIGNALS

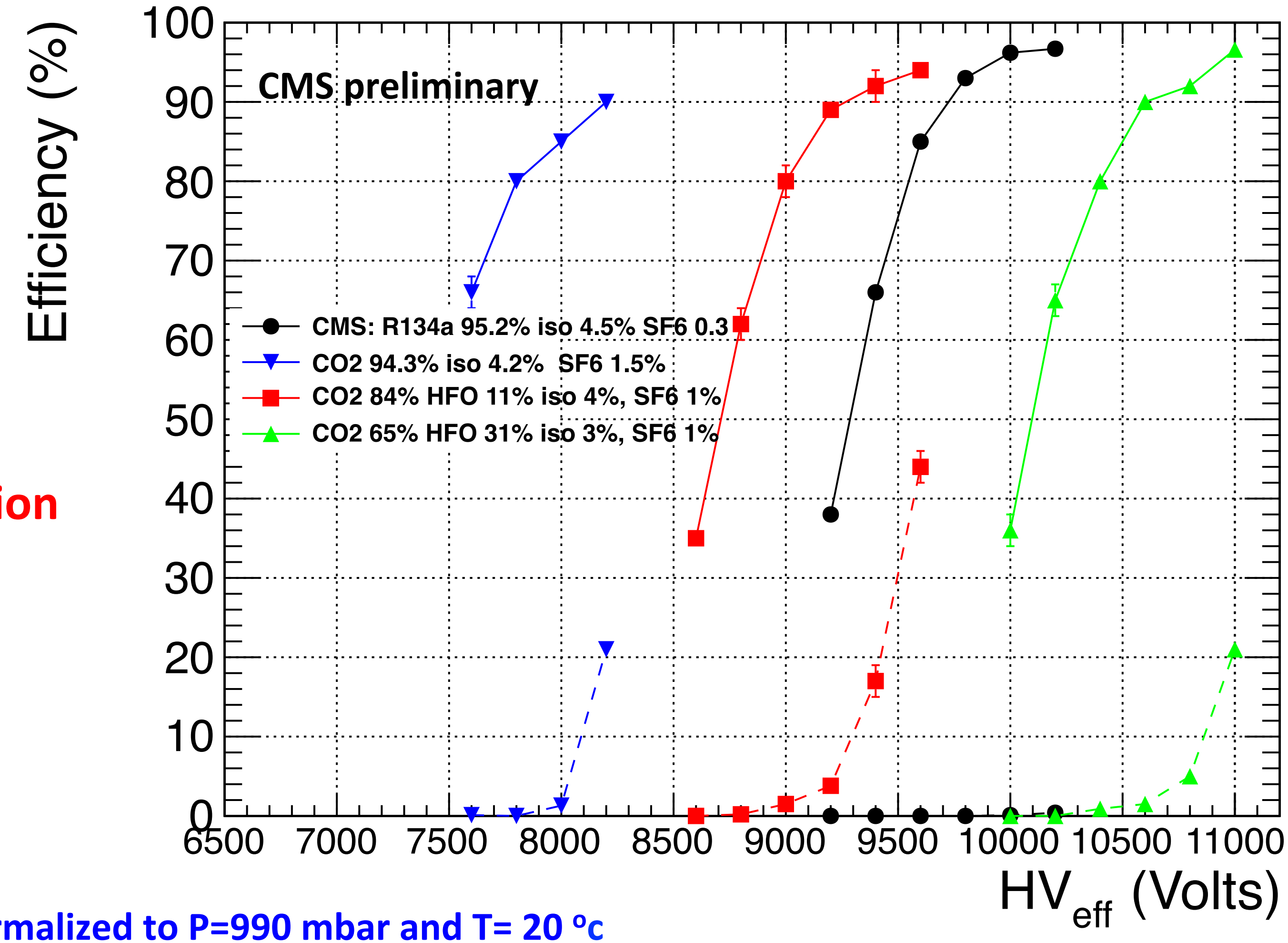
Summary:

Addition of fraction of Argon very soon trigger streamers

CO2/HFO based gas mxitures

efficiency

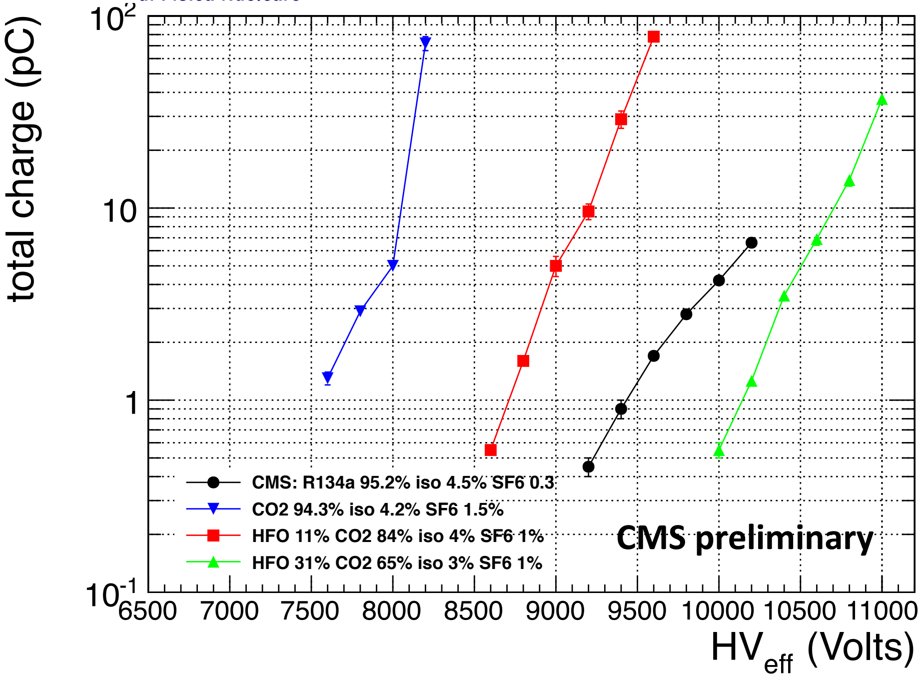
Streamer probability

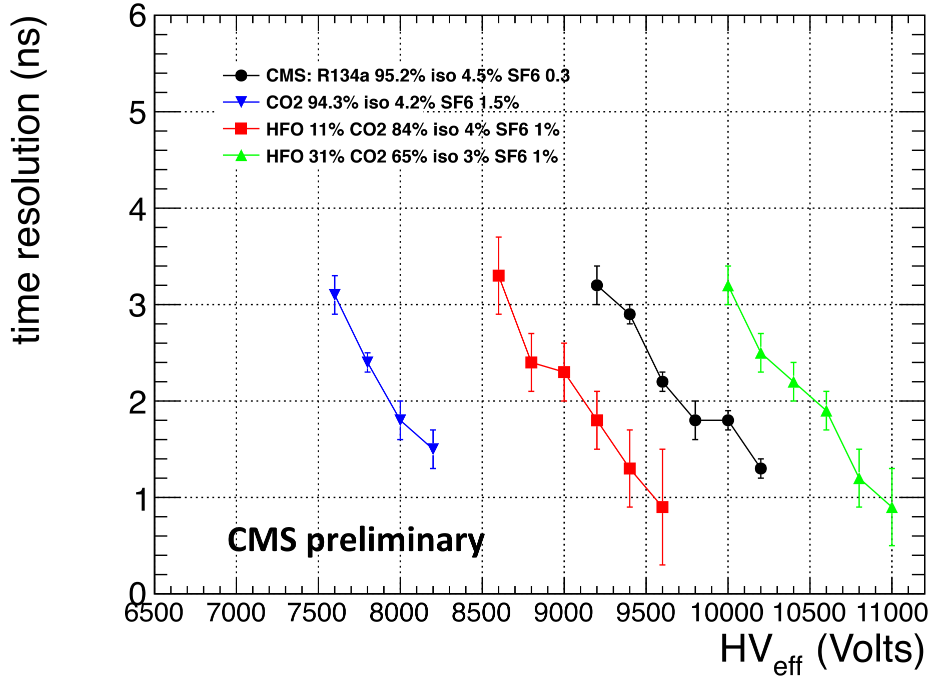


LNF Test station

HV normalized to P=990 mbar and T= 20 °c

CO2/HFO based gas mxitures



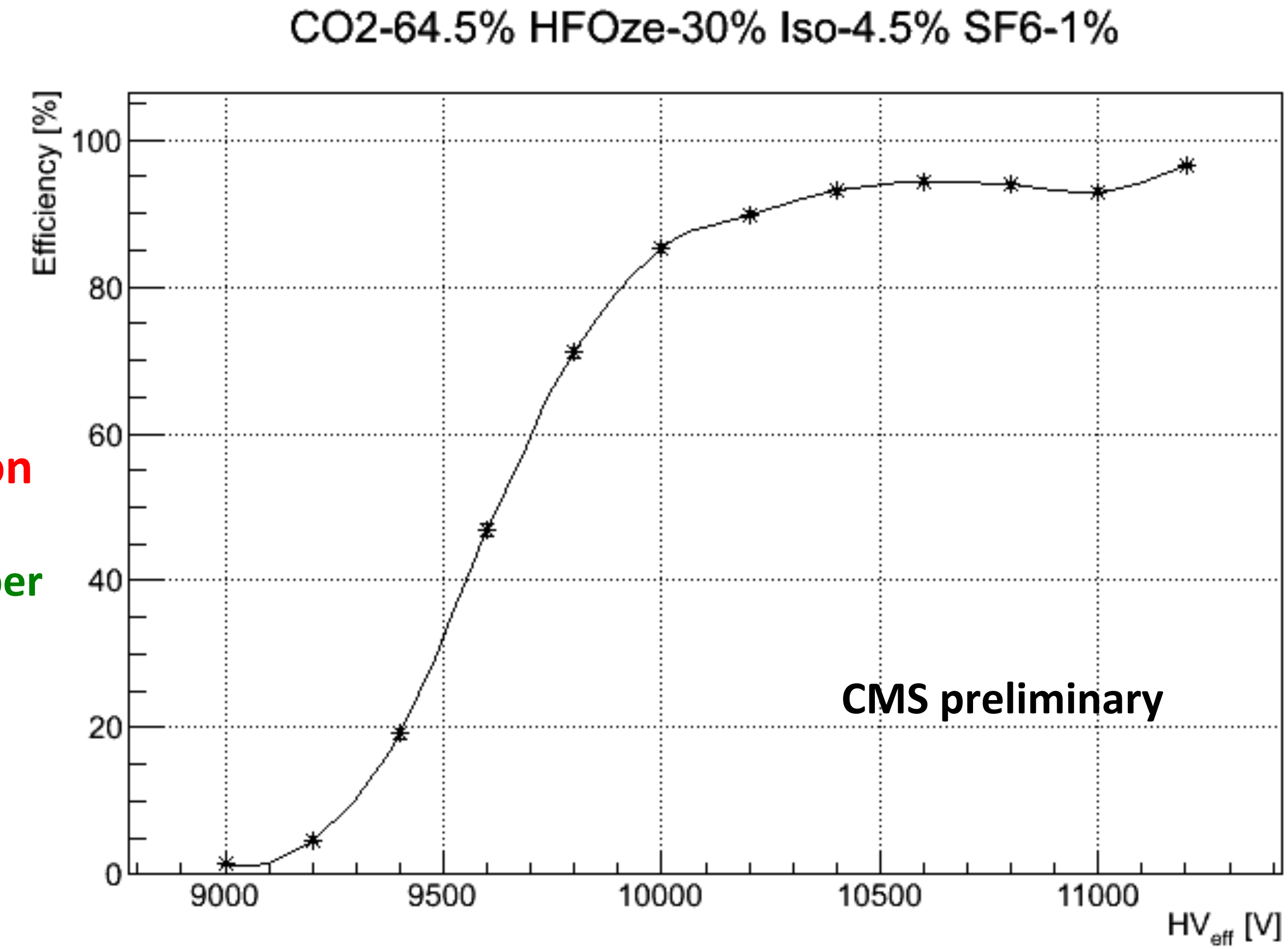


Total Induced charge to be divided by ~2 (double pad readout)

LNF Test station

Summary: Interesting results. More exploration needed.
Caveat: possible presence of multiple pulses to be checked

CO2/HFO based gas mxitures



Ghent Test station

Double gap Chamber

HV normalized to P=990 mbar and T= 20 °c

Working voltage from Ghent tests
About 400 Volts lower
BUT double gap vs single gap
Under investigation

Additional measurements

New gas mixtures for Resistive Plate Chambers operated in avalanche mode

M. Abbrescia, V. Cassano, S. Nuzzo, G. Piscitelli, D. Vadruccio, F. Zaza

M. Abbrescia – University and INFN Bari RPC2010- Darmstadt- 9/12-Feb-2010. p.1

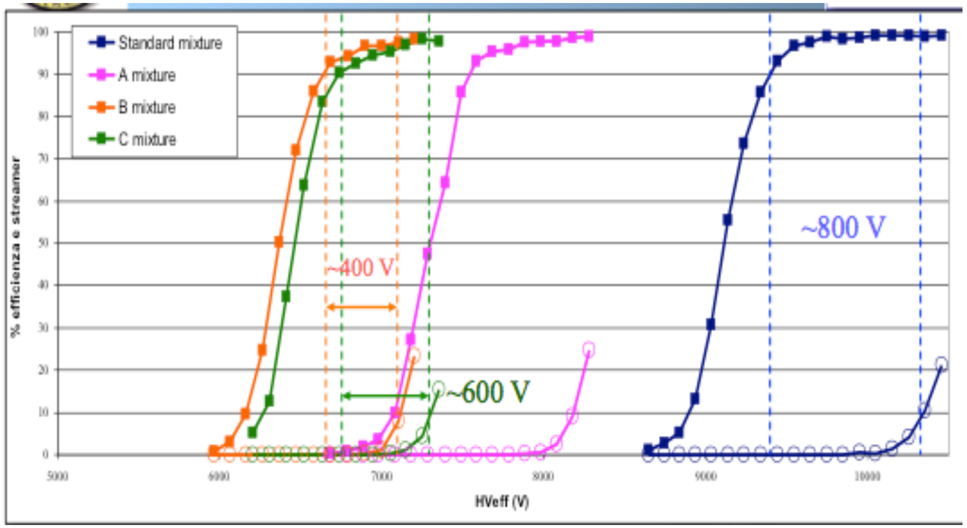
From 2010 RPC conference

Interesting presentation of M. Abbrescia et al.
At RPC2010 conference:
Use of He to reduce working voltage

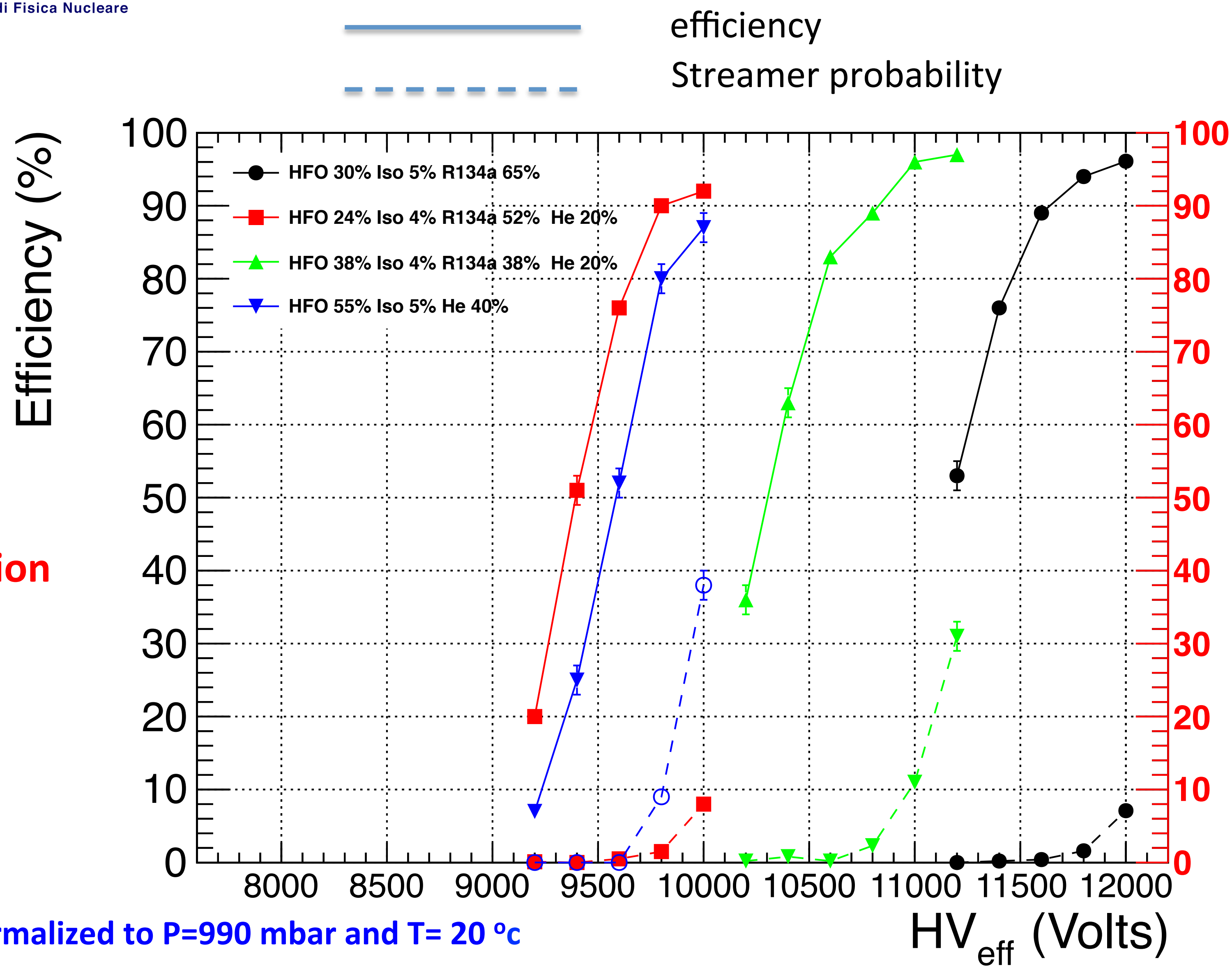
Standard mixture used as a reference… then

- "A" mixture
  - 62.5/2.3/0.2/35 $C_2H_2F_4/C_4H_{10}/SF_6/He$
- "B" mixture
  - 48.1/1.75/0.15/50 $C_2H_2F_4/C_4H_{10}/SF_6/He$
- "C" mixture
  - 48/1.7/0.3/50 $C_2H_2F_4/C_4H_{10}/SF_6/He$

"A" and "B" essentially standard mix. + Helium
"C" increased SF_6 fraction



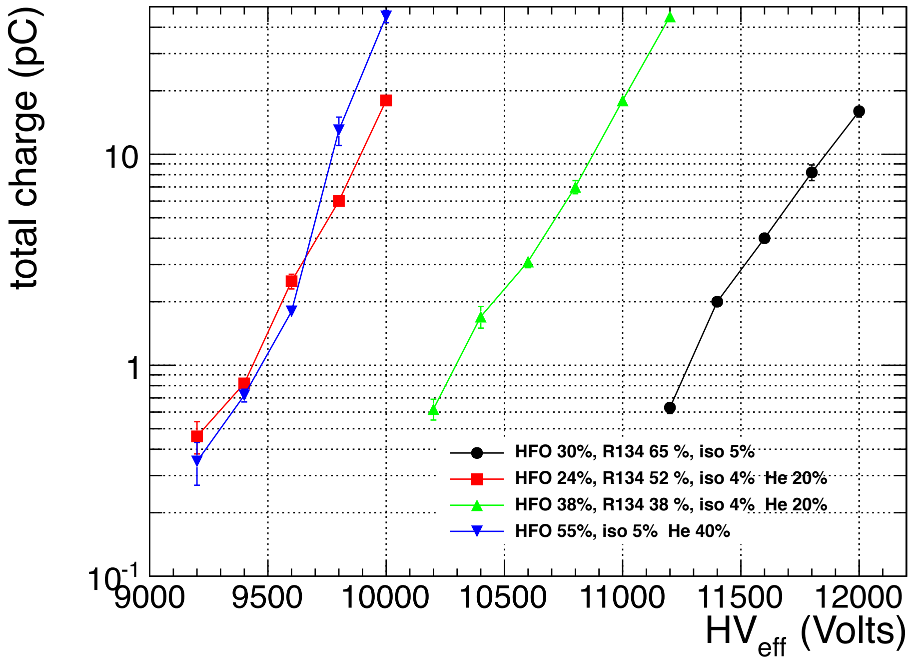
He/HFO based gas mixtures

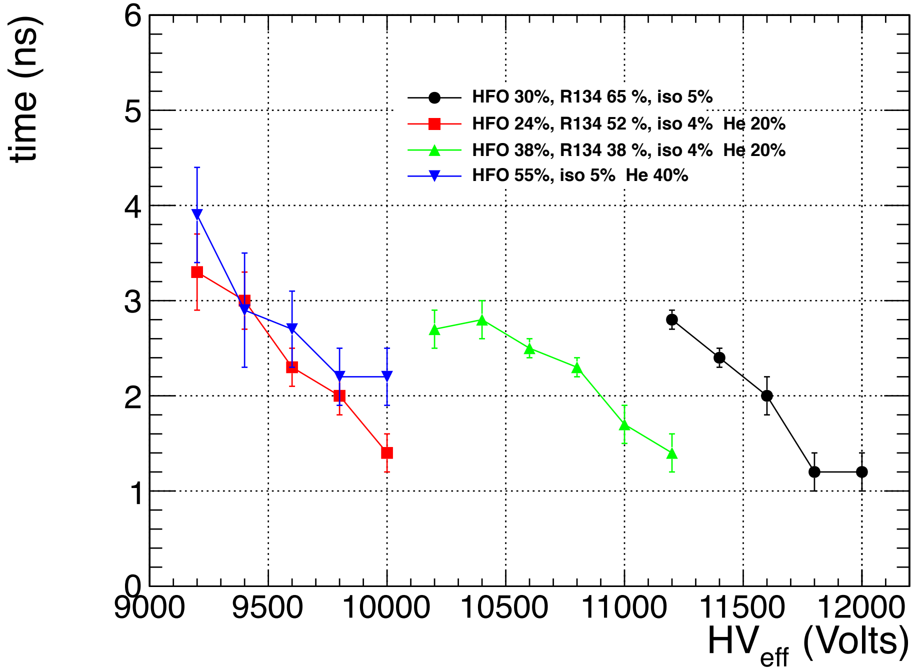


LNF Test station

HV normalized to P=990 mbar and T= 20 °c

He/HFO based gas mixtures



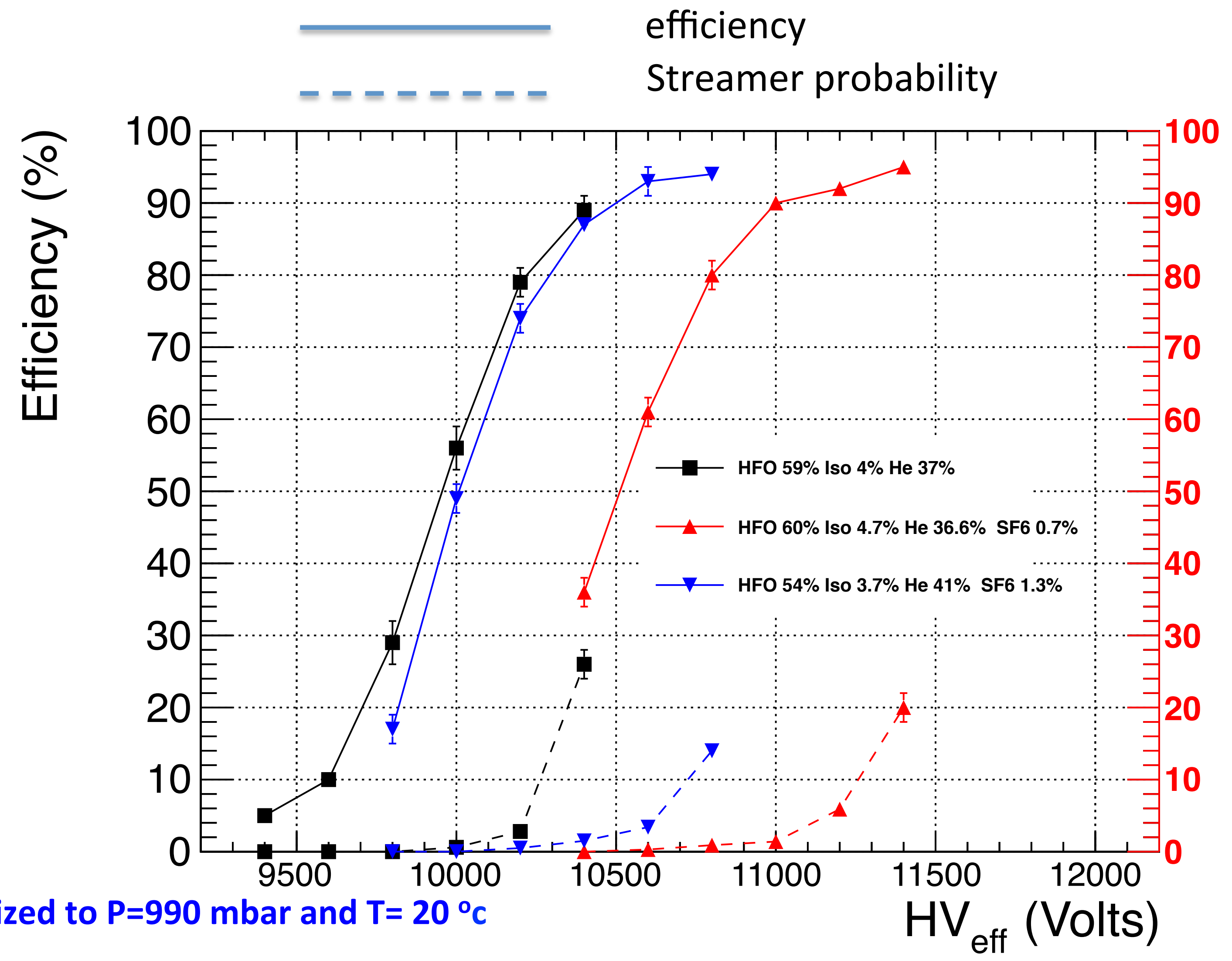


LNF Test station

Total Induced charge to be divided by ~2 (double pad readout)

Adding SF6 to He/HFO based gas mixtures

LNF Test station



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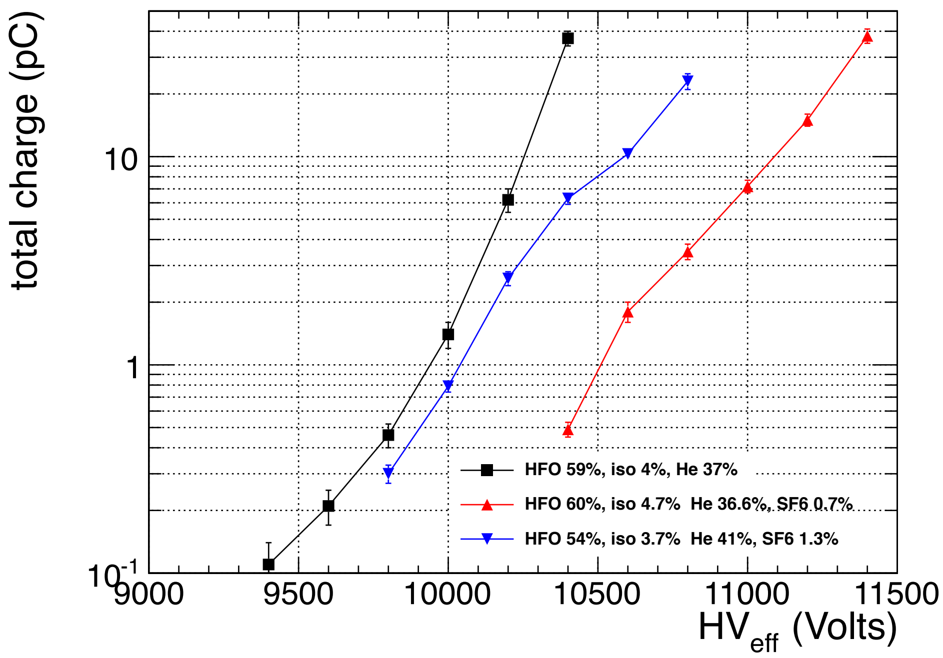
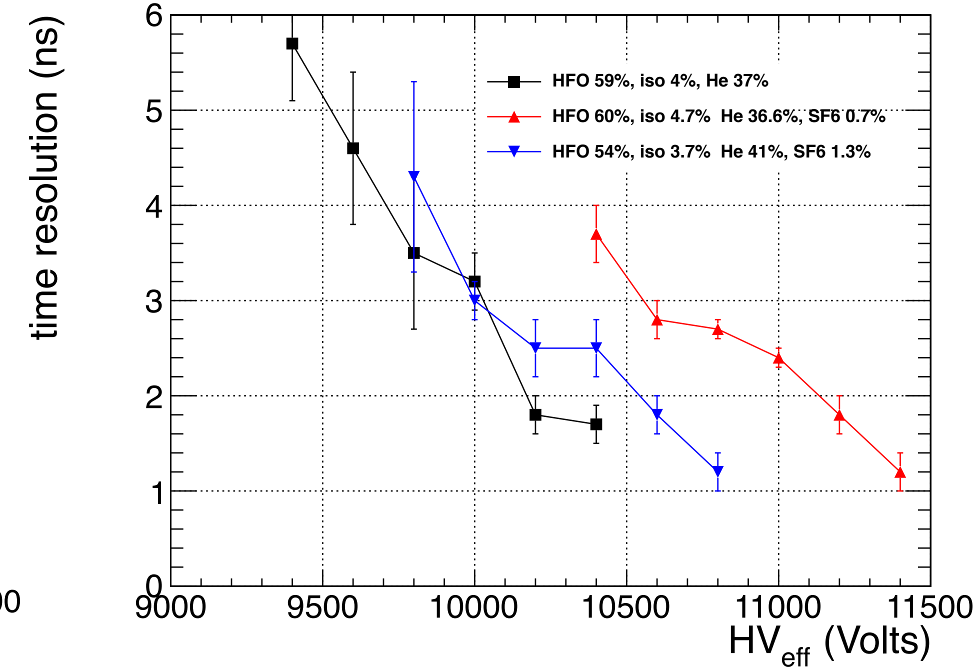
Adding SF6 to He/HFO based gas mixtures



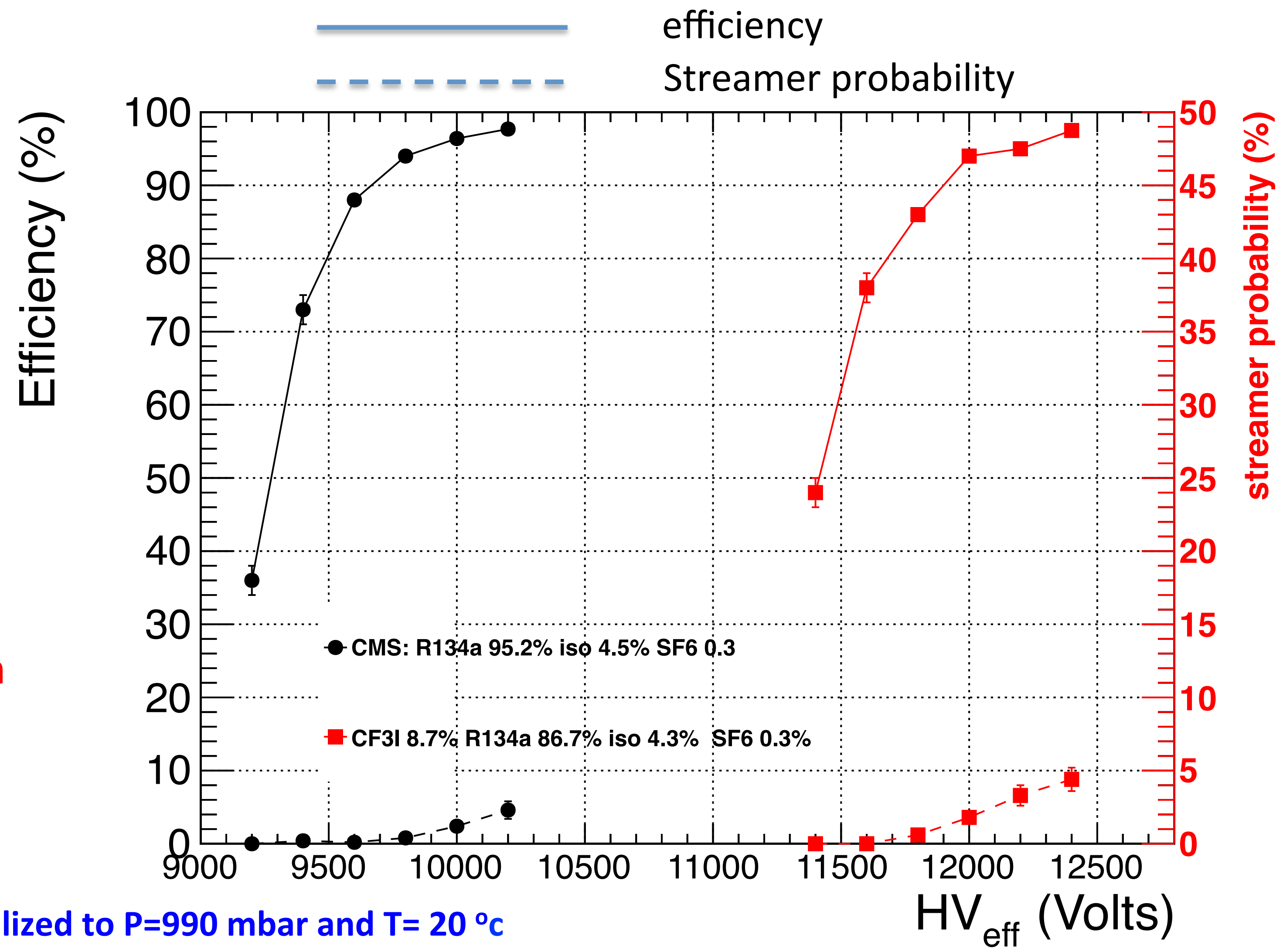


Total Induced charge to be divided by ~2 (double pad readout)

LNF Test station

Summary: Use of Helium to reduce working voltage show Interesting results and is a line to be followed.
Not clear if Helium could be used in CMS

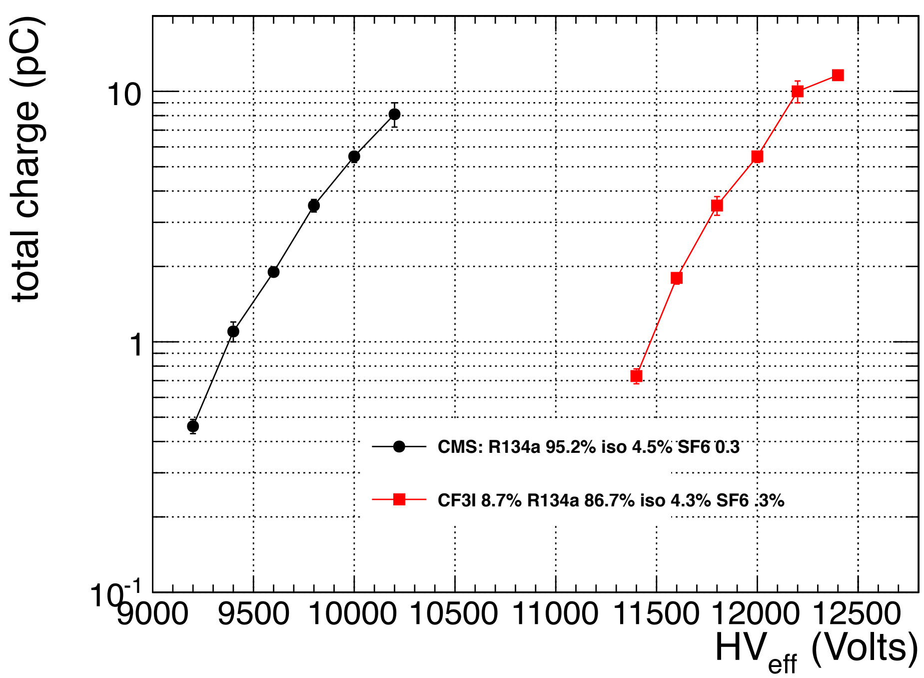
CF_3I vs R134a

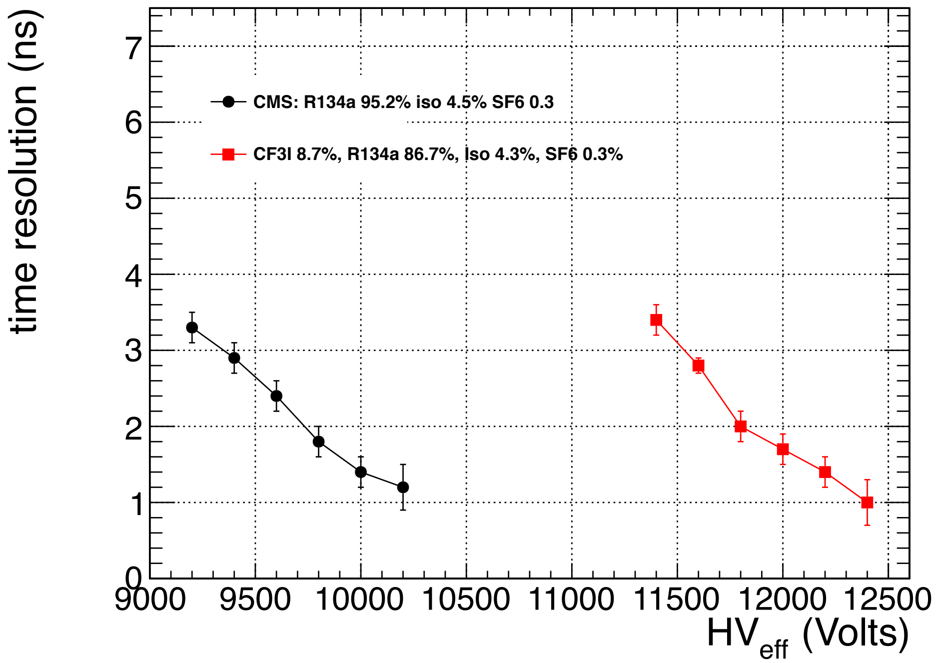


LNF Test station

HV normalized to P=990 mbar and T= 20 °c

CF_3I vs R134a



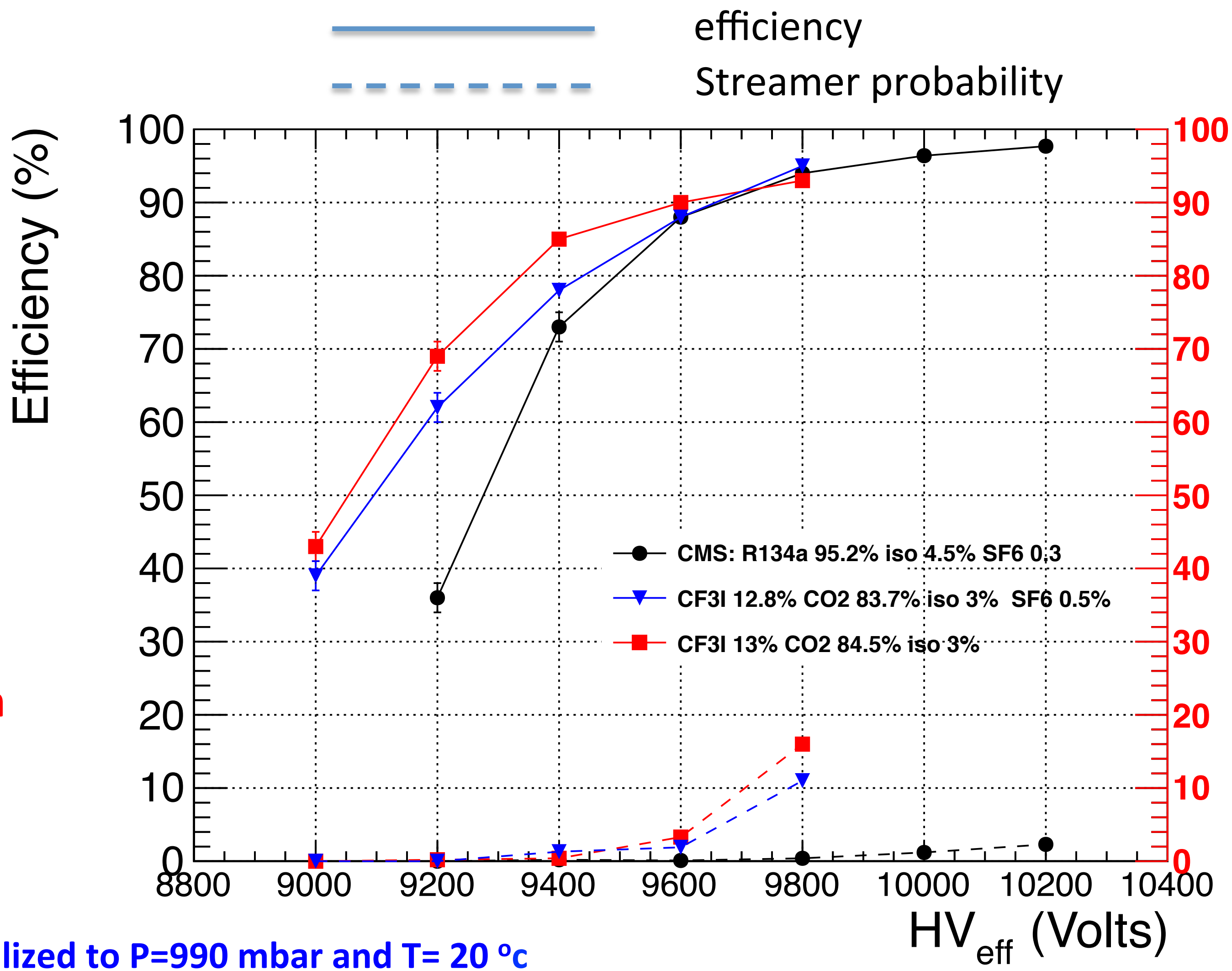


Total Induced charge to be divided by ~2 (double pad readout)

LNF Test station

Summary: very preliminary results.
Large quenching power BUT for the same efficiency average charge and streamer probability seem to be slightly higher

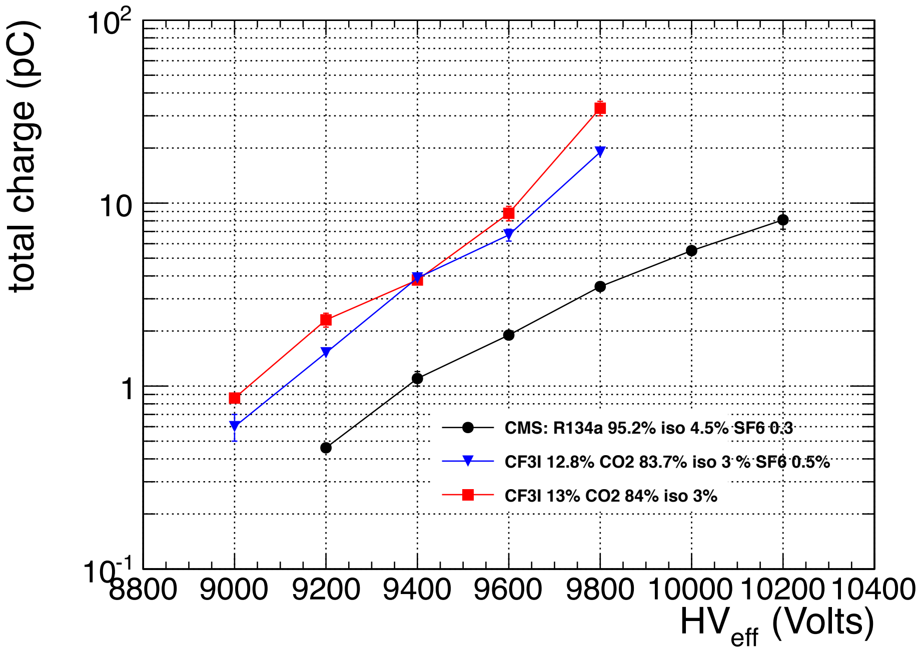
CF_3I-CO_2 based gas mixtures

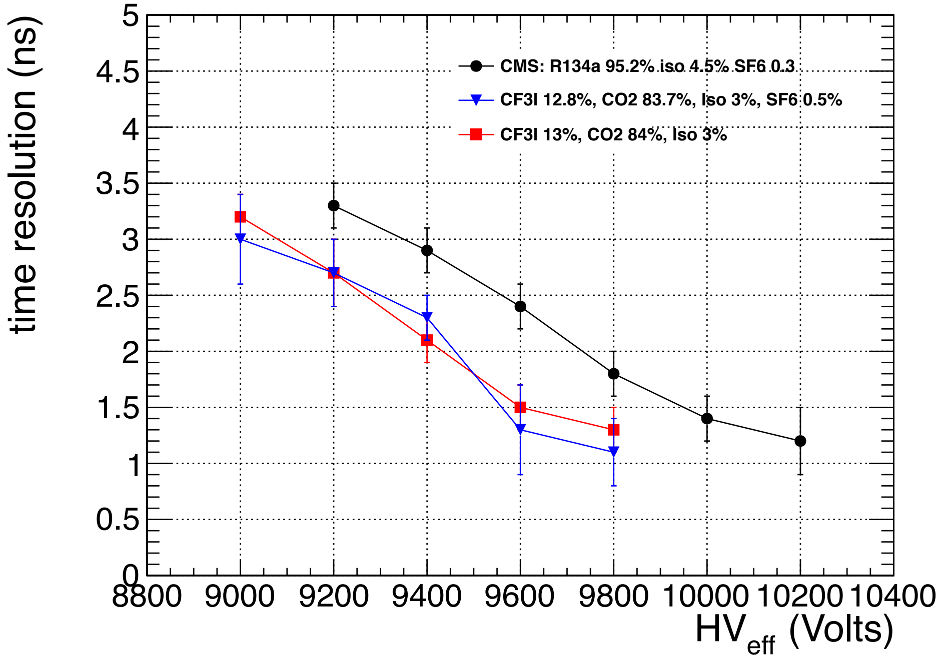


LNF Test station

HV normalized to P=990 mbar and T= 20 °c

CF_3I vs R134a





Total Induced charge to be divided by ~2 (double pad readout)

LNF Test station

Summary: very preliminary results.
More work needed to explore if CO_2/CF_3I gas mixtures could be used.

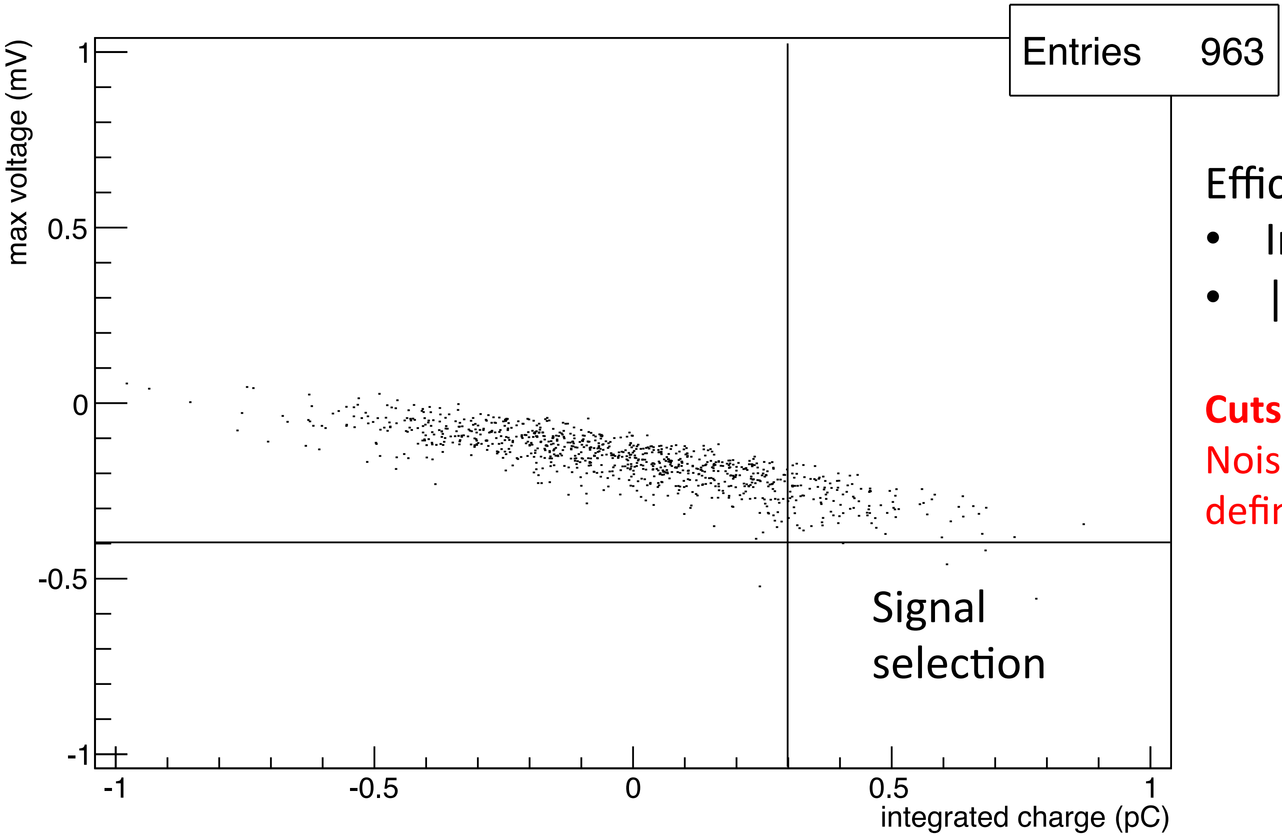
Conclusions

- Several ecological (or semi-ecological) gas mixtures have been tested
- **HFO-1234ze** has interesting quenching properties but cannot be used alone to replace the **R134a** (high working voltage shift)
- Addition of **Argon** trigger suddenly many streamers
- **CO2/HFO-1234ze** gas mixtures seem to give interesting results to be explored deeper (possible presence of multiple pulses)
  - Cross-checking results with Ghent test station
- Use of **Helium** help in reducing working voltage and is a interesting line to be followed
  - Not clear if possible to use in CMS
- **CF_3I** is a very interesting candidate from theoretical point of view
  - Very expensive
  - Very quenching
  - Still the streamer probability and average charge seems to be slightly higher with respect to standard gas mixture for the same Efficiency
  - CO_2/CF_3I based gas mixture studies just started

- **More investigations are needed and are in progress**

Backup

Control region distributions



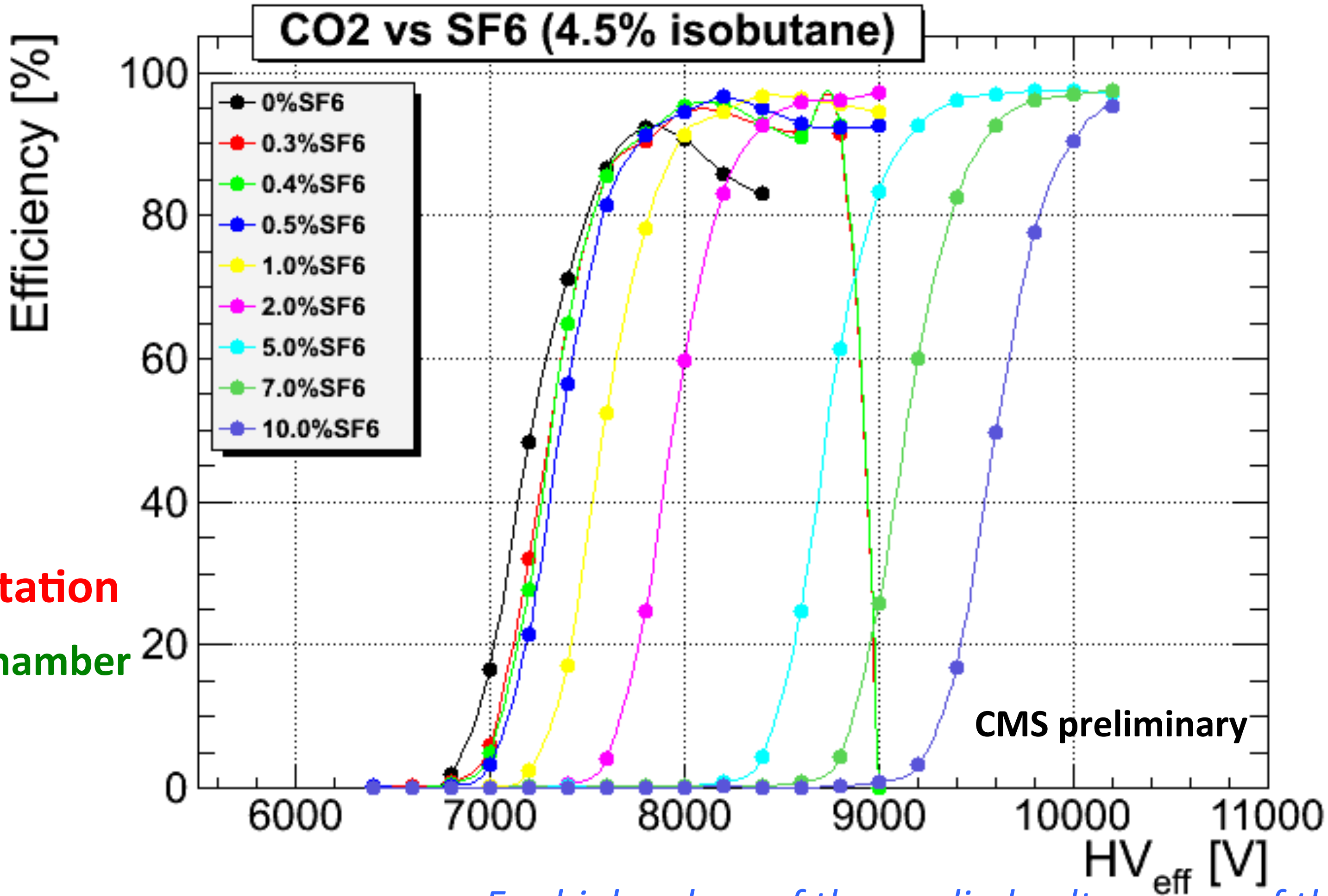
Efficient signal selection:

- Integrated charge > 0.3 pC
- |Vmax|>0.4 mV

Cuts verified un the control region

Noise contamination in efficiency definition lower than 0.5 %

$CO2/SF_6$ based gas mxitures



Ghent Test station

Double gap Chamber

For high values of the applied voltage one of the Gaps trips and the chamber works in single mode.

HV normalized to P=990 mbar and T= 20 °c