Ecological gas mixture studies in CMS experiment

D. Piccolo (INFN Frascati)
for CMS group

66th INFN ELOISATRON WORKSHOP: New gas mixtures for RPC and MRPC detectors

The search for an ecogas replacement at CMS

Review of possible Gas present on the market

L. Benussi, D. Piccolo et al.
Properties of potential eco-friendly gas replacements for particle detectors in high-energy physics
JINST **13** P03012 (2018)

Laboratory tests started in 2014

A study of HFO-1234ze (1,3,3,3-Tetrafluoropropene) as an eco-friendly replacement in RPC detectors,
arXiv:1505.01648

Eco-friendly gas mixtures for Resistive Plate Chambers based on Tetrafluoropropene and Helium
***JINST* 11 P08019 (2016)**

Preliminary results of Resistive Plate Chambers operated with eco-friendly gas mixtures for application in the CMS experiment
***JINST* 11 C09018 (2016)**

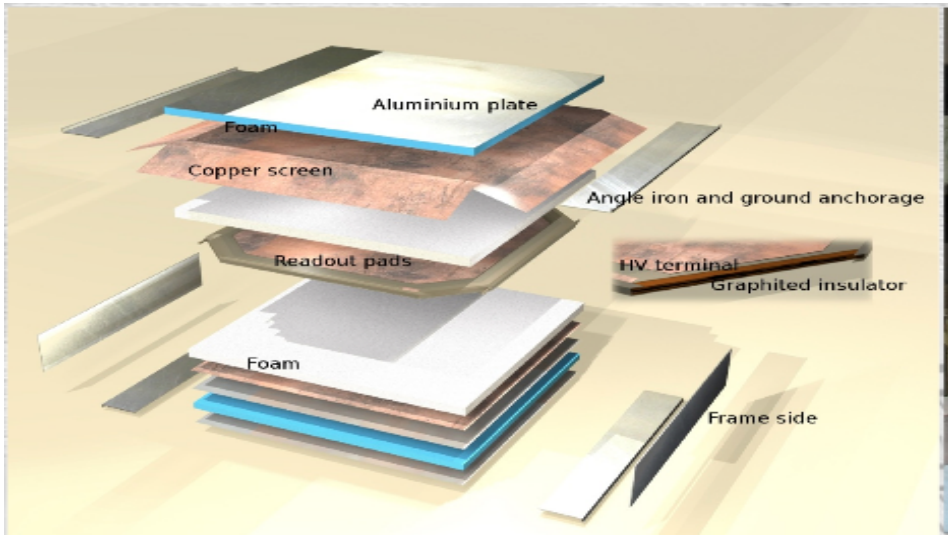
Choice of few candidate mixtures

Tests under irradiation (GIF++)

RPC ECOGAS@GIF++ Collaboration

Laboratory test

Experimental Set-up in Frascati



- 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

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) and $|V_{max}|$>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 P_0=990 mbar, T_0 = 20 degrees
- Time resolution is extracted from the difference between time over threshold (0.8 mV) of trigger RPC and test RPC

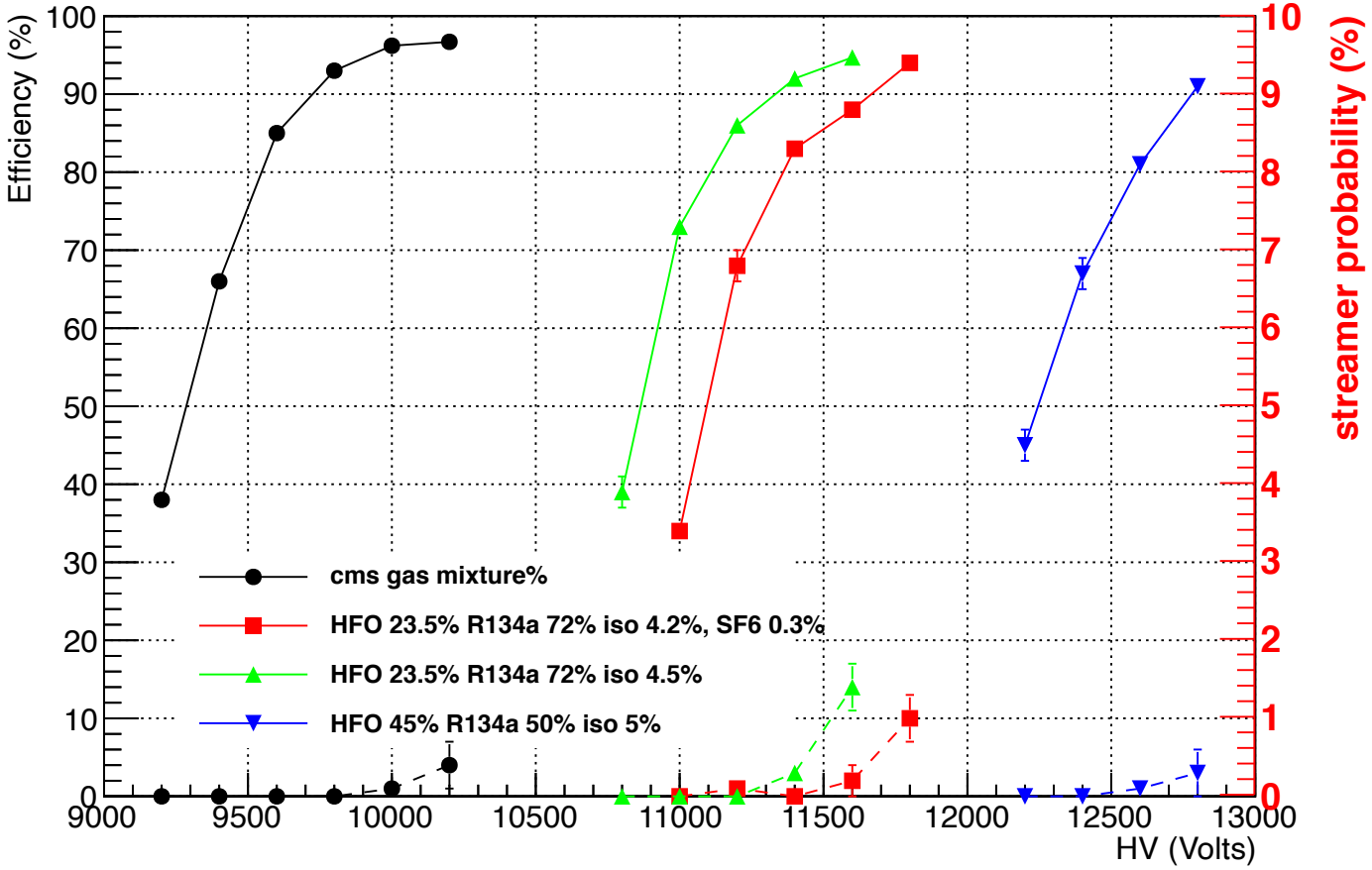
- CMS standard gas mixture:

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

Replacing R134a with HFOze

efficiency

Streamer probability

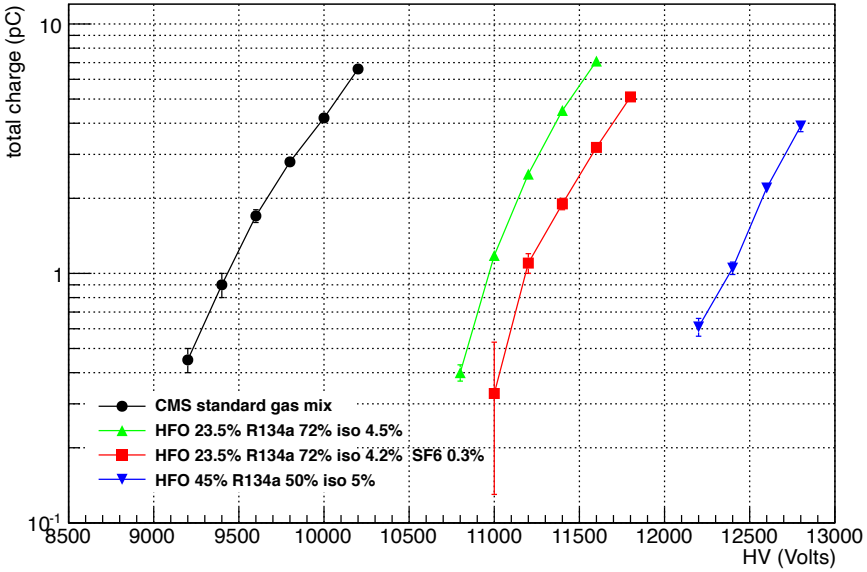


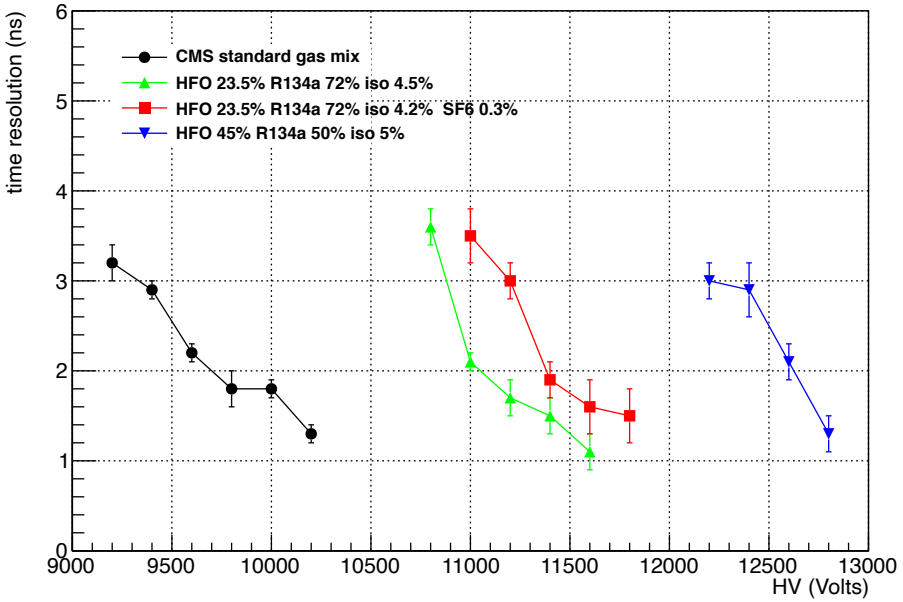
LNF Test station

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

About 900 Volt shift
For each 10% of HFO vs R134a

Replacing R134a with HFOze





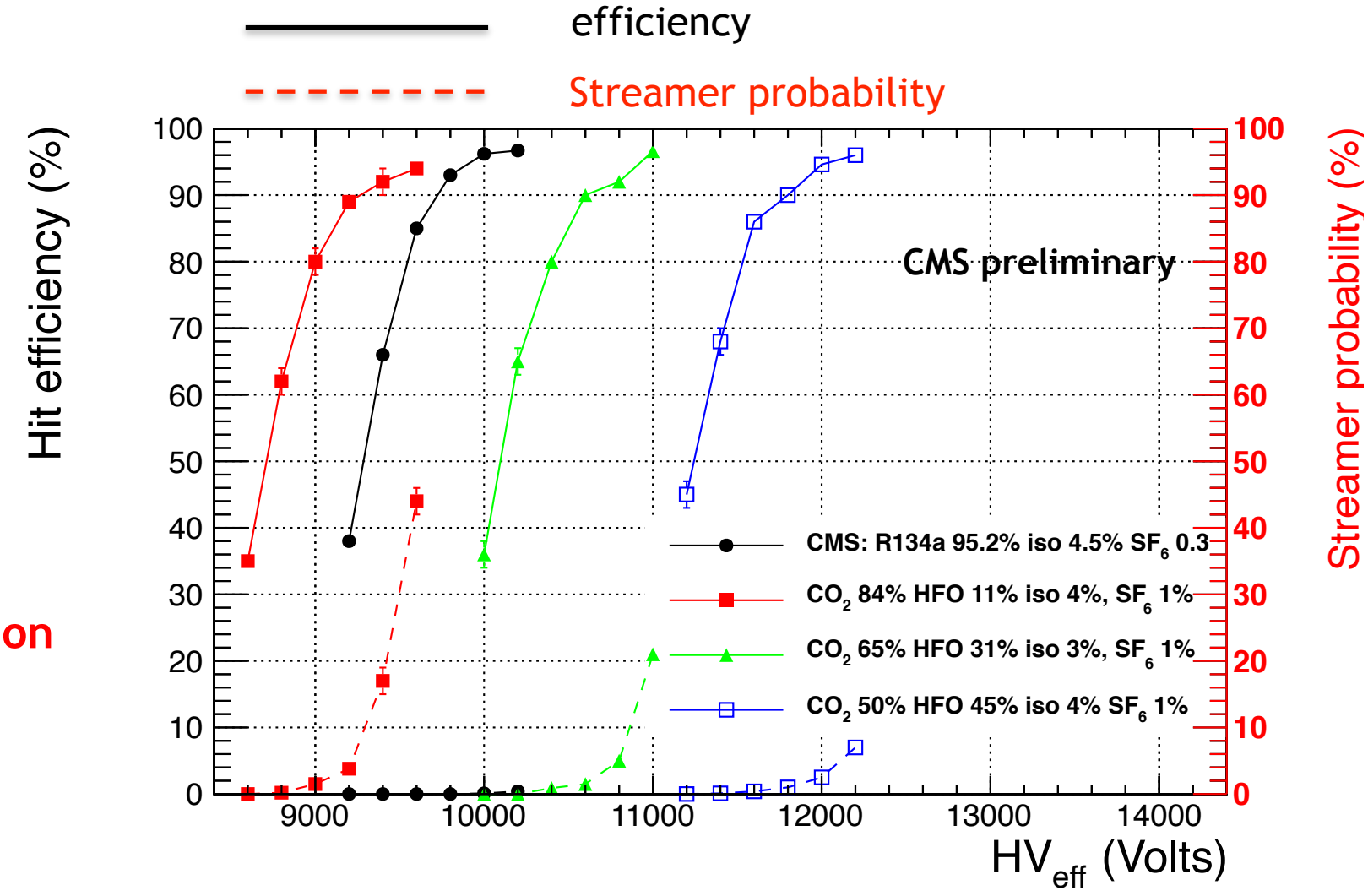
Pad Induced charge to be divided by ~2 (double pad readout)

LNF Test station

Summary:

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

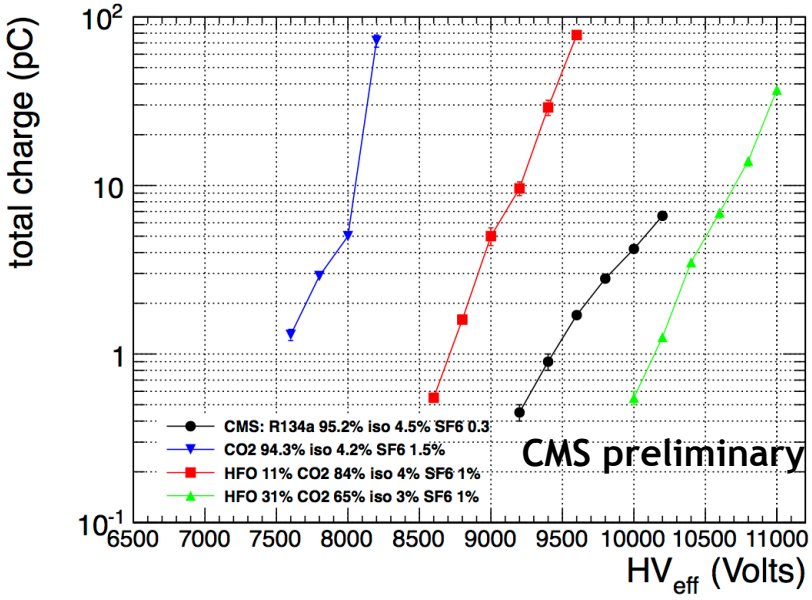
CO_2/HFO based gas mxitures

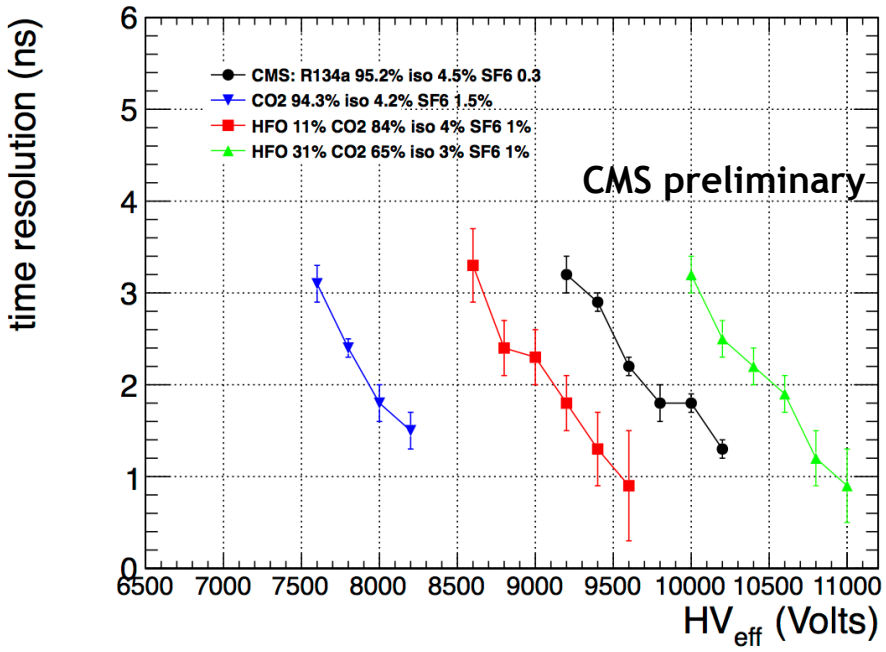


LNF Test station

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

CO2/HFO based gas mxitures



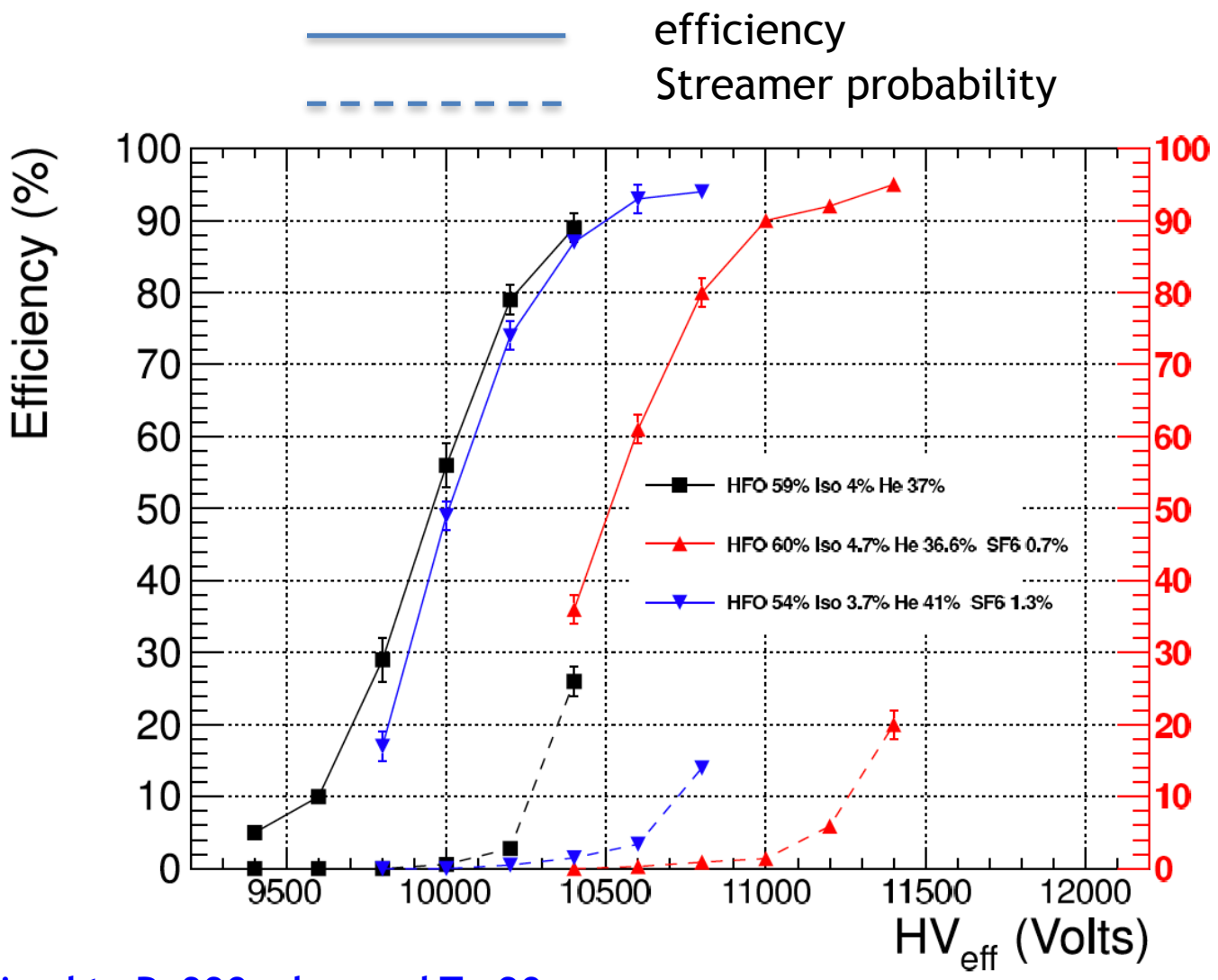


Total Induced charge to be divided by ~2 (double pad readout)

LNF Test station

Charge and time resolution for HFO at 45% not available

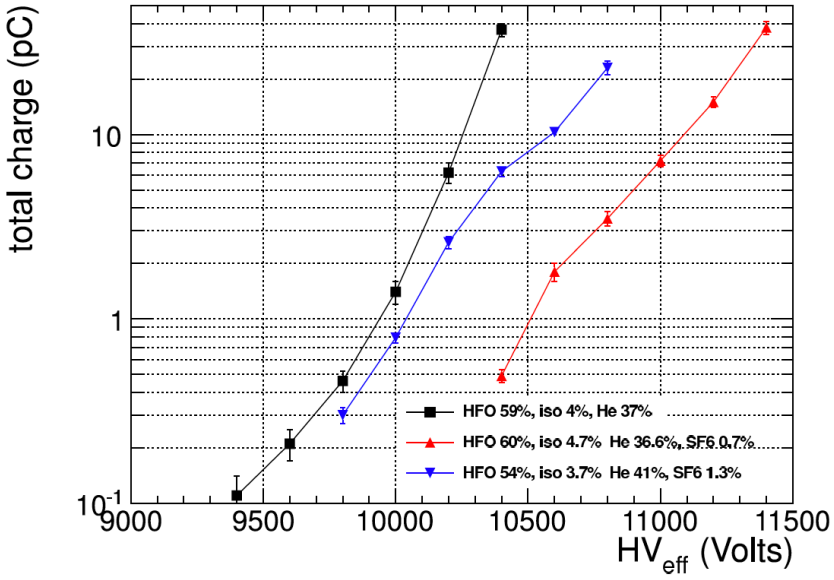
He/HFO based gas mixtures

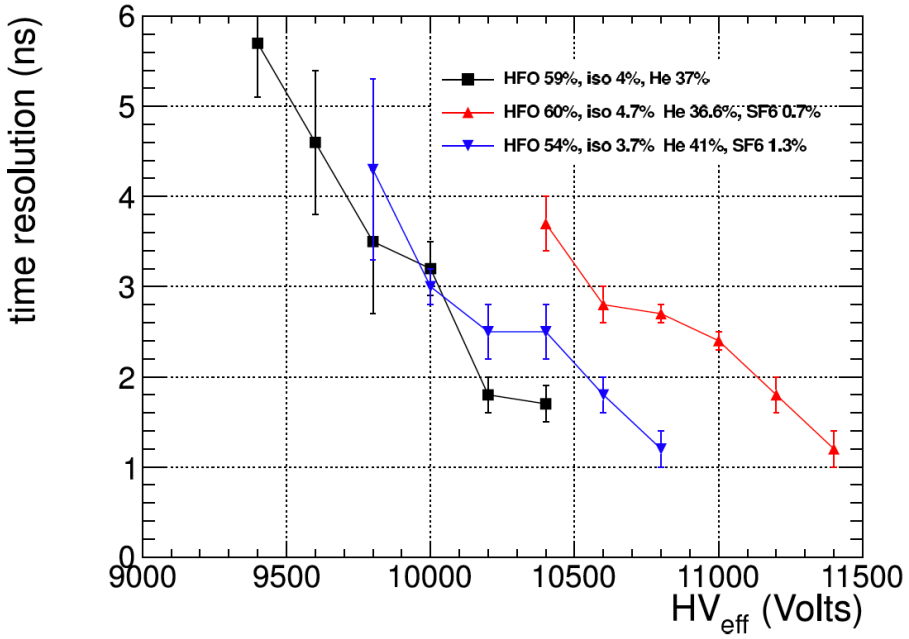


LNF Test station

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

He/HFO based gas mixtures



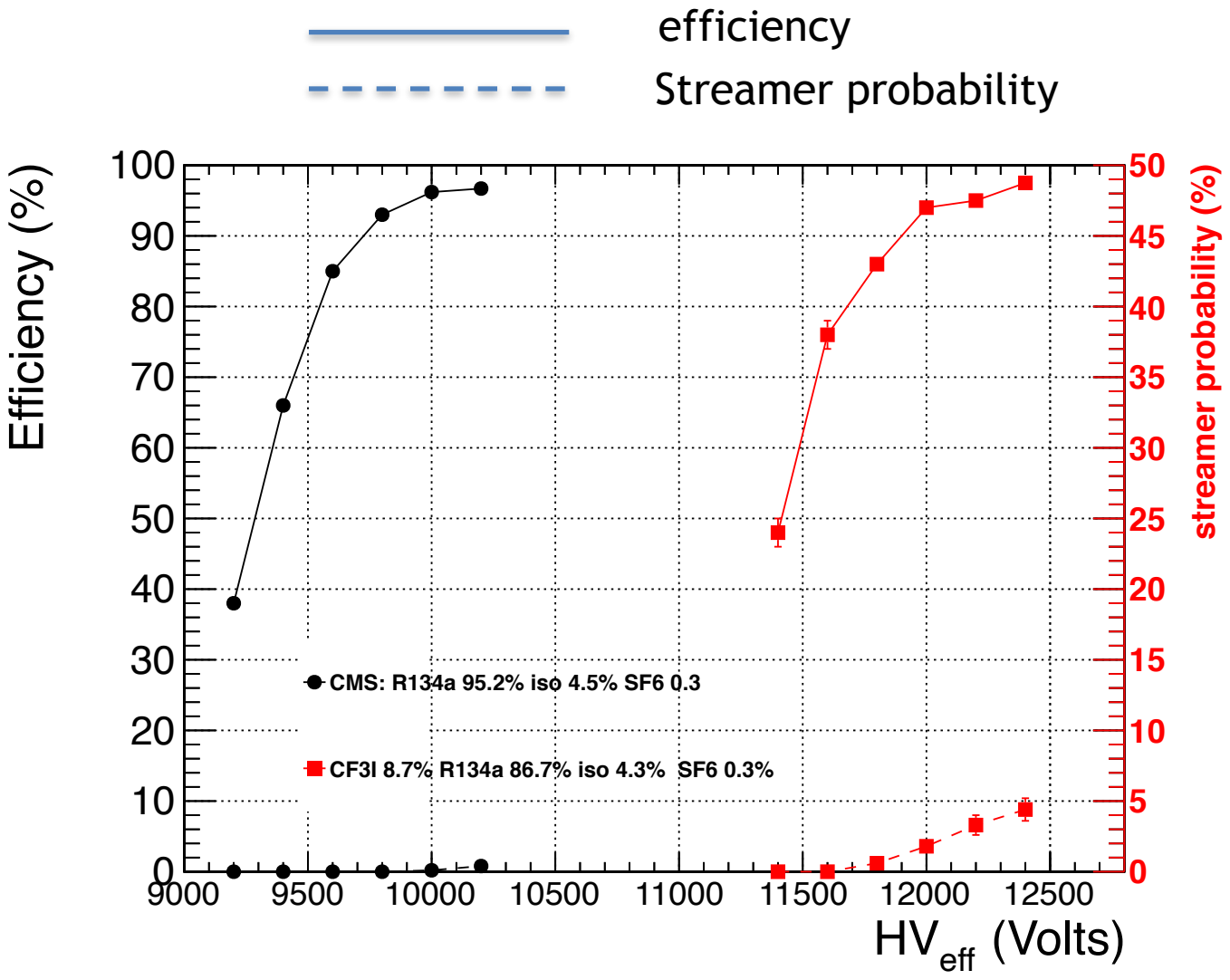


Total Induced charge to be divided by ~2 (double pad readout)

LNF Test station

Summary: Use of Helium to reduce working voltage shows reasonable results, but not clear if Helium could be used in CMS

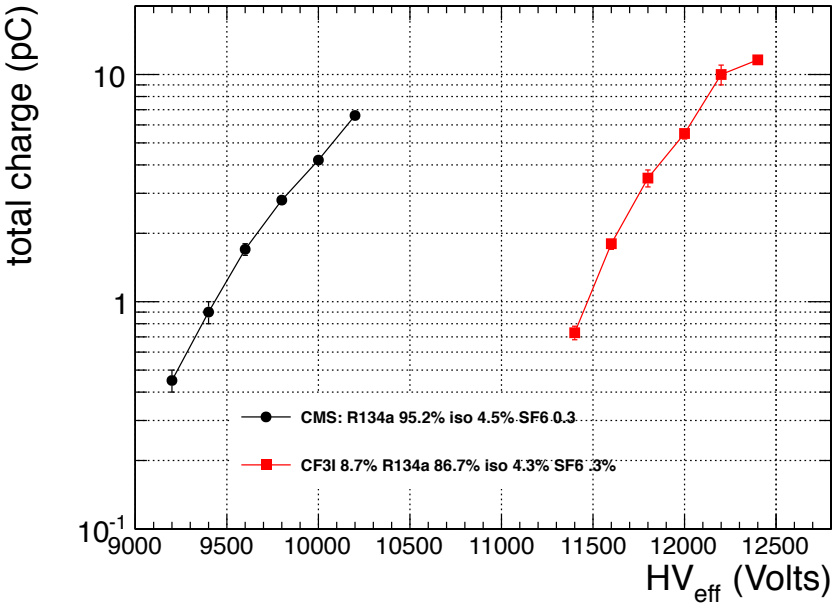
CF_3I vs R134a

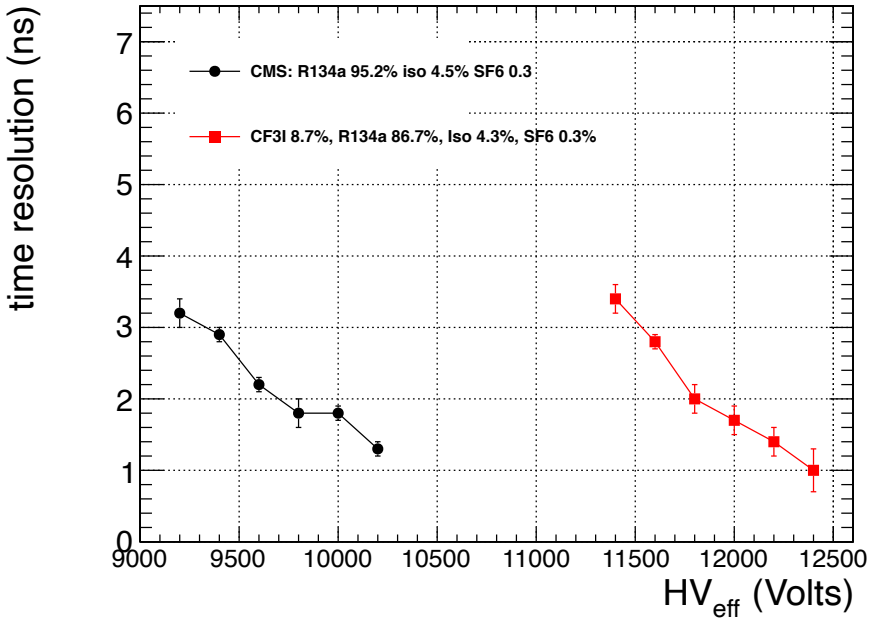


LNF Test station

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

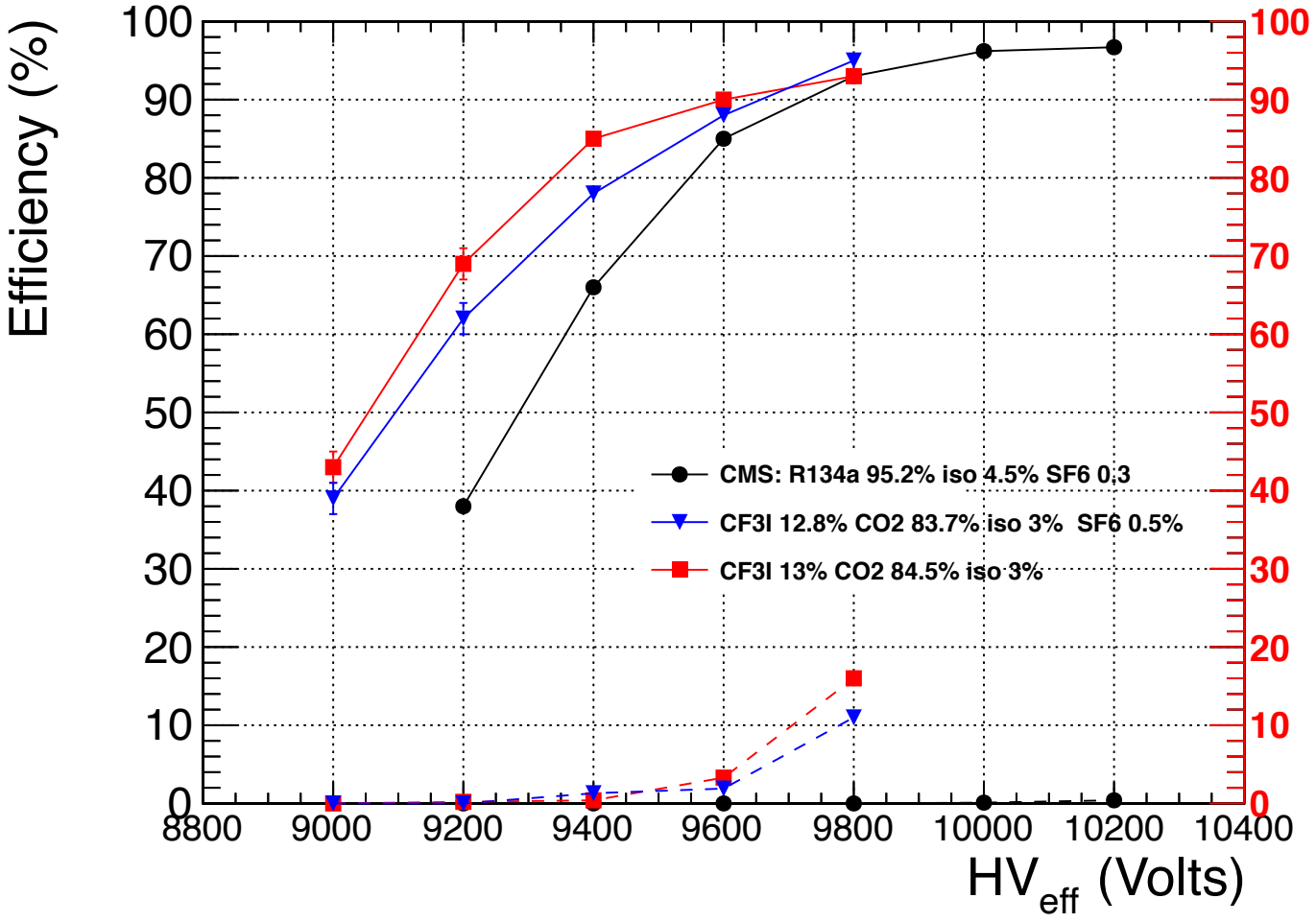
Summary:

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

efficiency

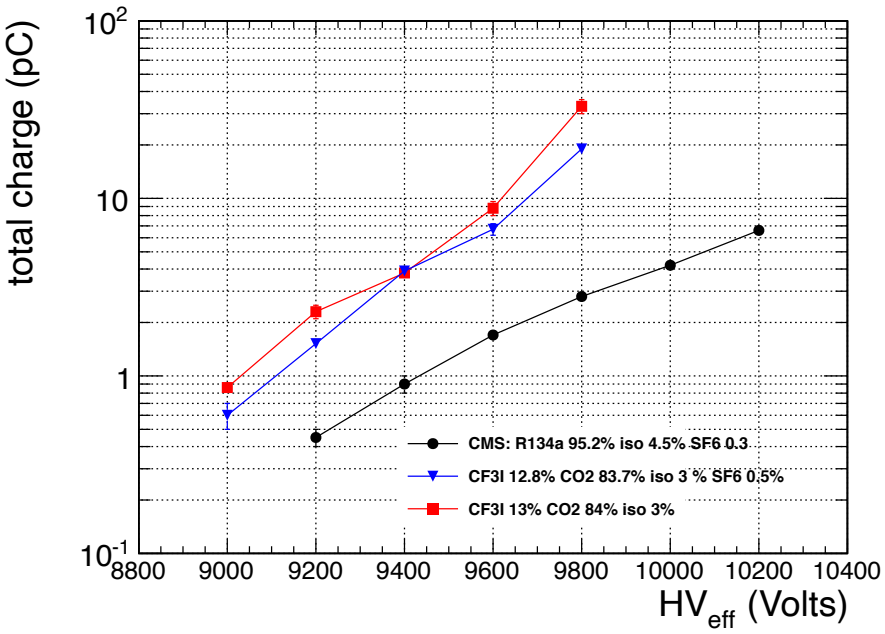
Streamer probability

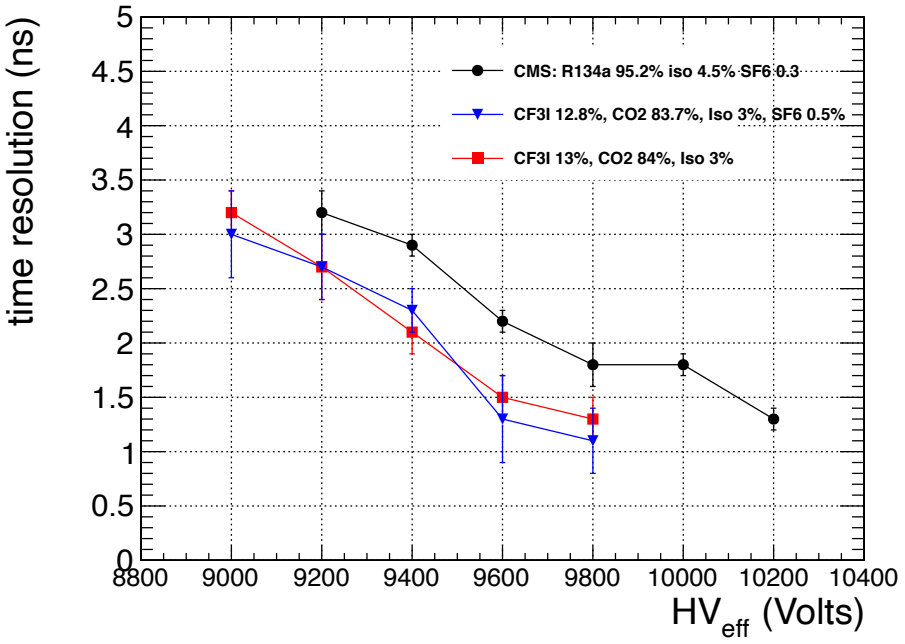


LNF Test station

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

CF_3I-CO_2 vs R134a





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

LNF Test station

Summary: preliminary results.

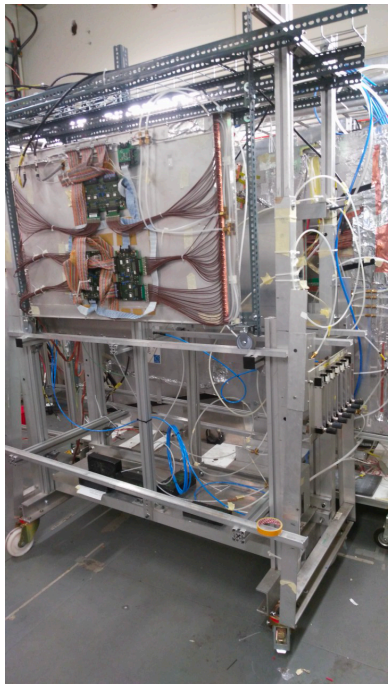
More work needed to explore if CO_2/CF_3I gas mixtures could be used. BUT the CF_3I is very toxic

The RPC ECOGas@GIF++ Collaboration

- In 2019 a proto Collaboration between Atlas-CMS-Alice-EPDT and later LHCb/ Ship has been set up

- Goal of the Collaboration: To study RPC performance with EcoGas mixtures under irradiation at GIF++

- Chambers from Atlas, CMS, EPDT, Alice, LHCb/Ship and with different gas thickness (2 mm , 1.6 mm , 1.4 mm, 1 mm)



AIDA INNOVA
WP 7
Task 7.2.2

Study of eco-friendly gas mixtures
for Resistive Plate Chamber detectors

- EcoMix2: CO_2 60%, HFO 35%, C_4H_{10} 4%, SF_6 1%

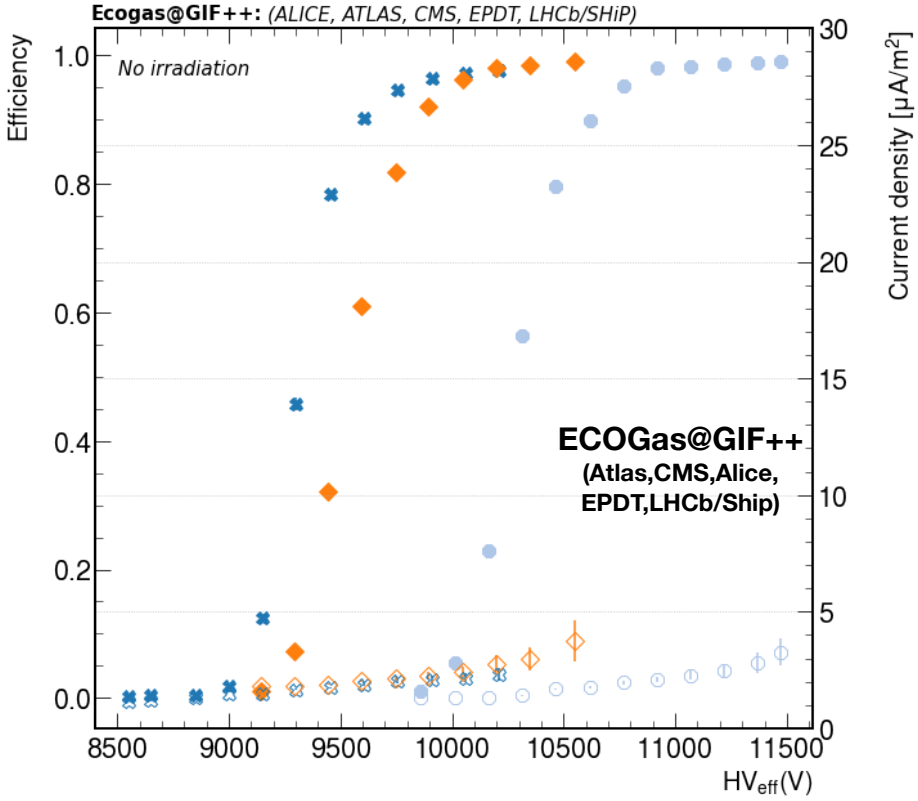
- EcoMix3: CO_2 69%, HFO 25%, C_4H_{10} 5%, SF_6 1%

Test Beam results
2 mm CMS chamber

70 x 100 cm² size
2 mm Gap
Resistivity 2-3 10¹⁰ ohm cm
CMS electronics

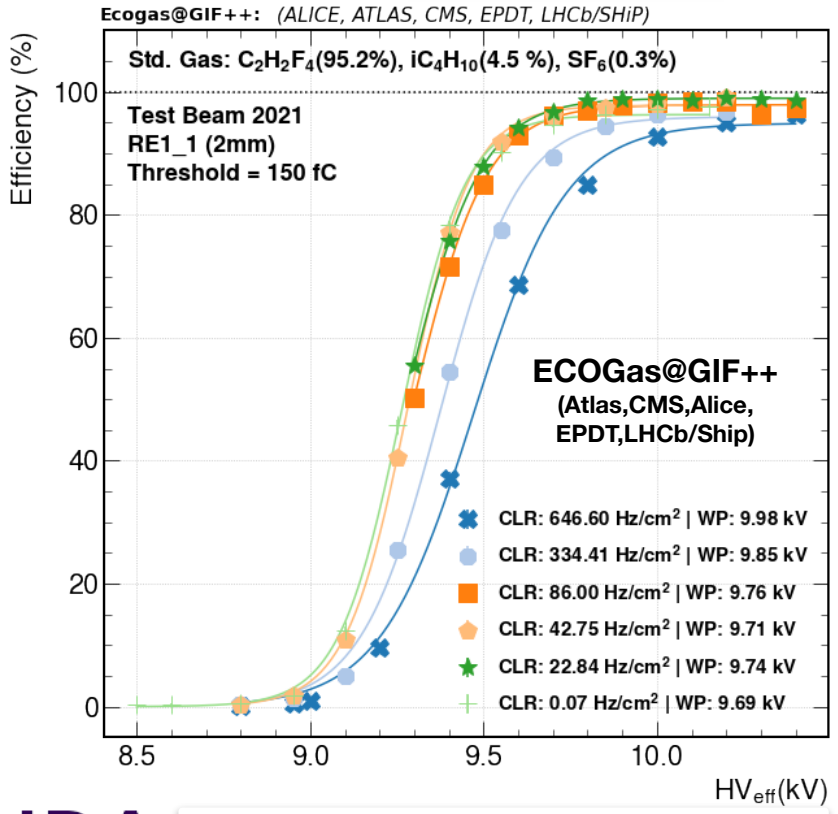
PRELIMINARY

- Standard Gas: WP 9686.9 V | eff(WP) 95.8 % | max. eff. 96.8 %
- Ecomix-2: WP 10715.3 V | eff(WP) 97.3 % | max. eff. 98.6 %
- Ecomix-3: WP 9979.8 V | eff(WP) 97.2 % | max. eff. 98.5 %



Efficiency vs HV (Std, ECO2, ECO3)

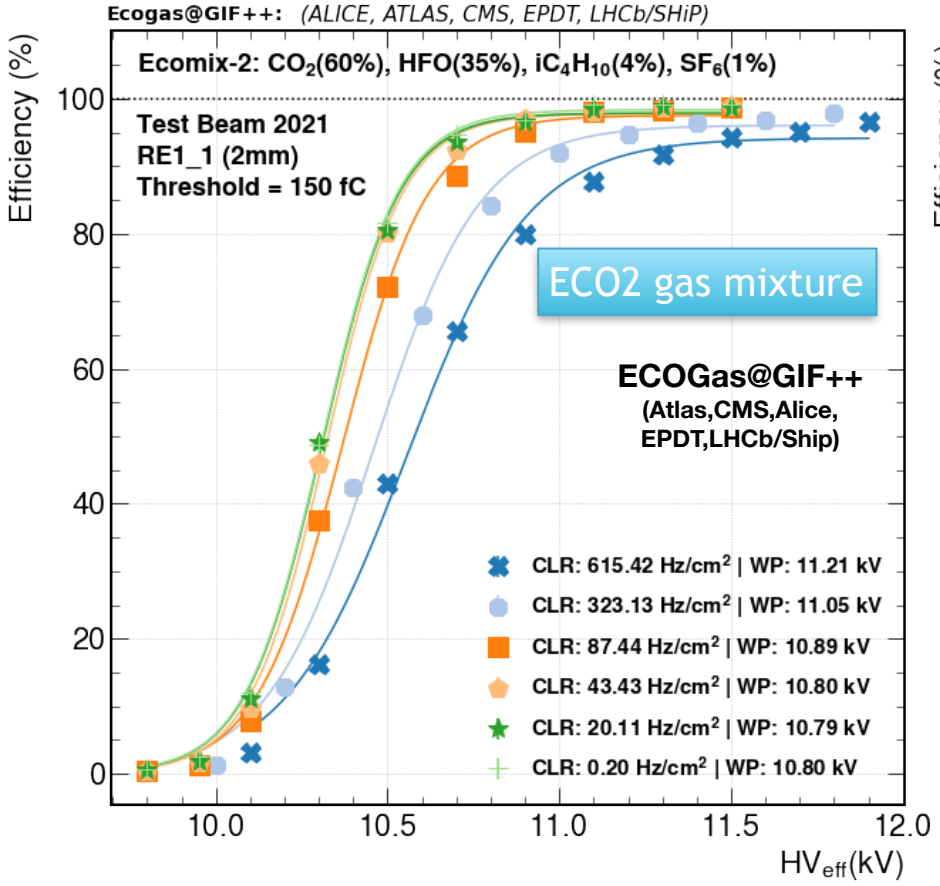
STD gas mixture

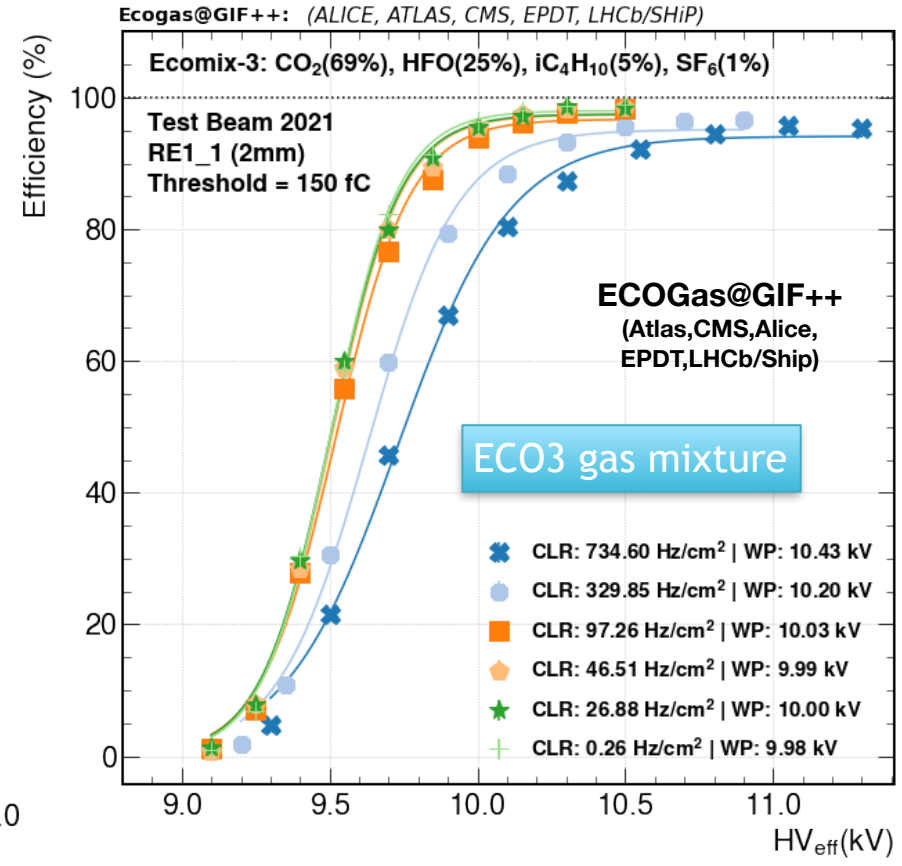


Efficiency vs HV (different rate)

Test Beam results
2 mm CMS chamber

PRELIMINARY





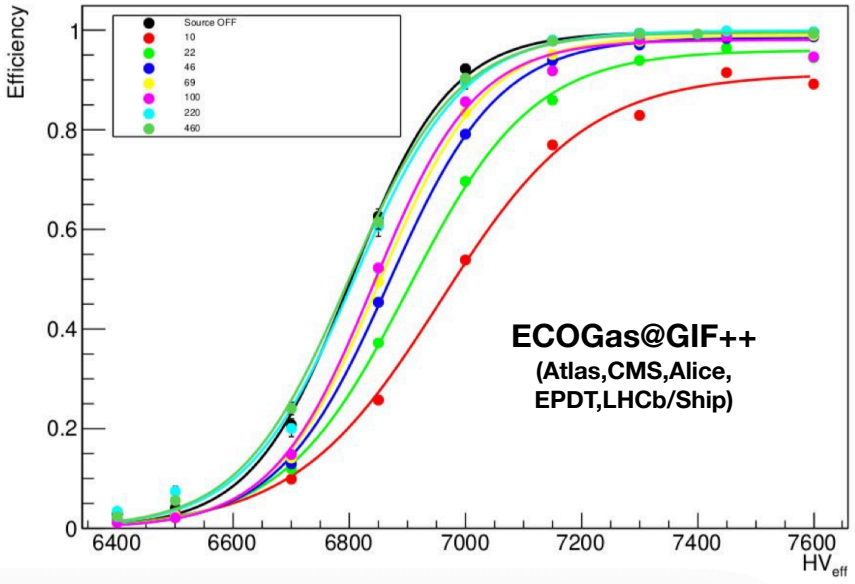
Efficiency vs HV (different rate)

Test Beam results
1.4 mm CMS chamber

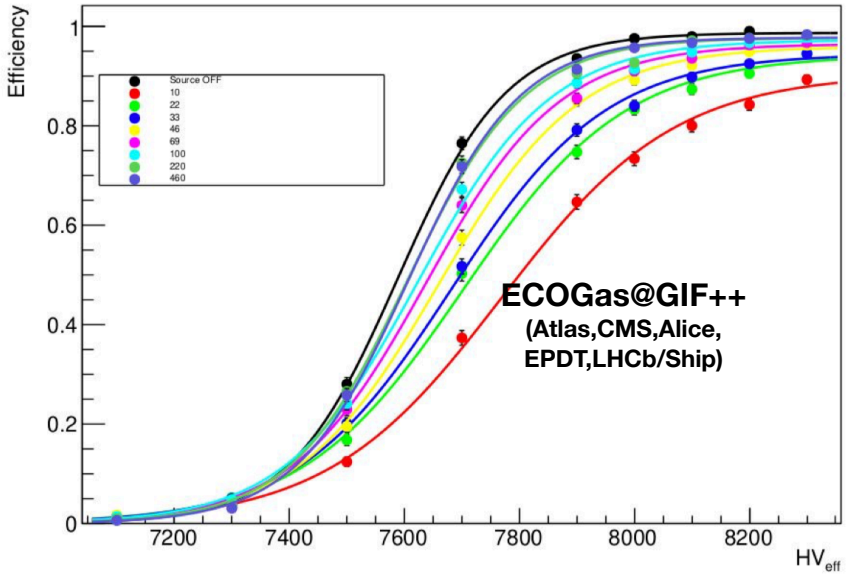
70 x 100 cm² size
1.4 mm Gap
Resistivity 2-3 10¹⁰ ohm cm
Kodel Standalone electronics: Not the official one

PRELIMINARY

STD gas mixture

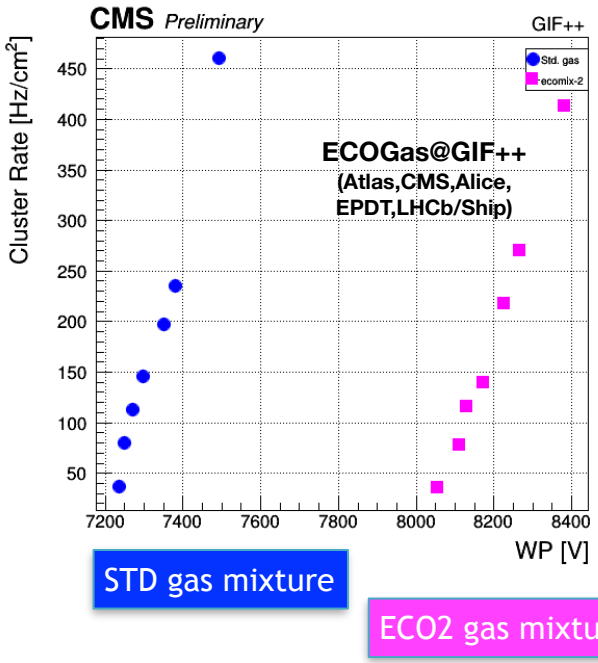


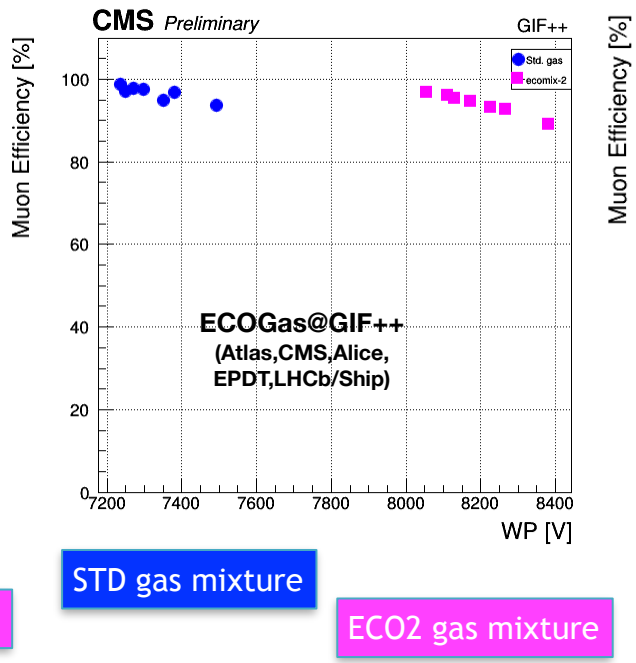
ECO2 gas mixture

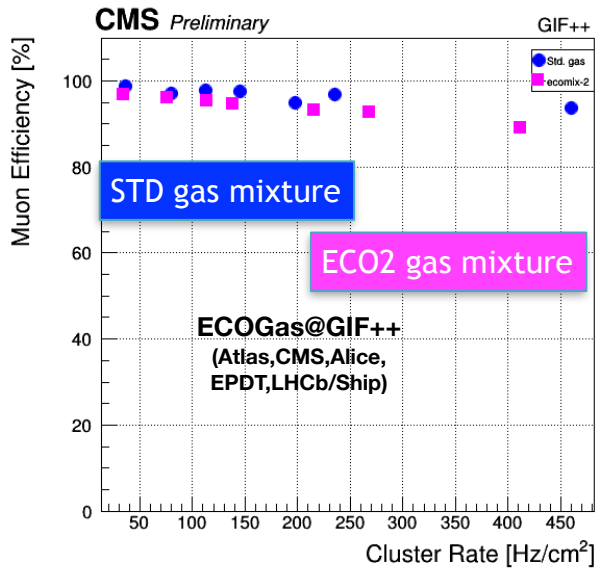


Efficiency vs HV (different ABS/rates)

Test Beam results
1.4 mm CMS chamber



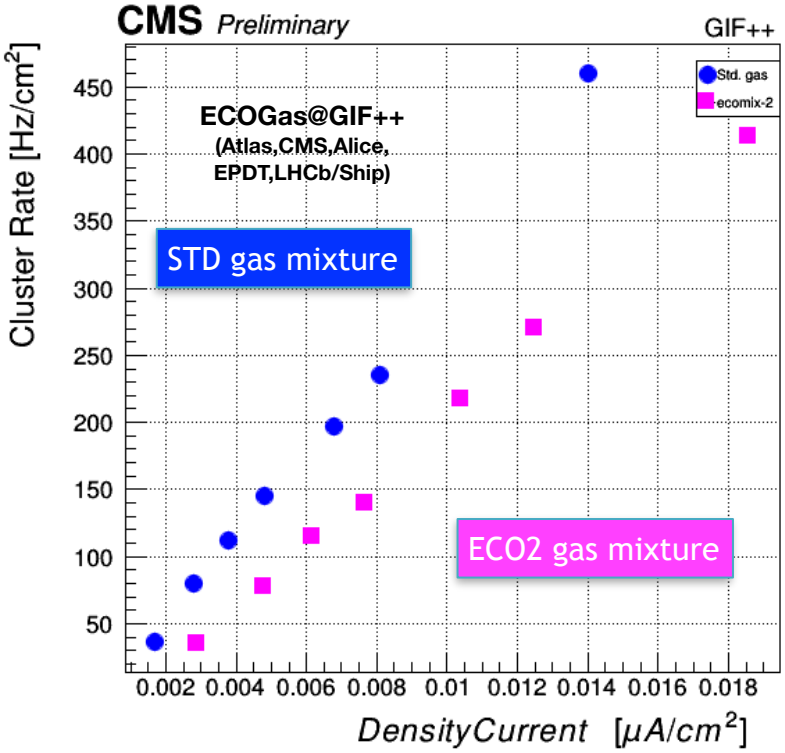


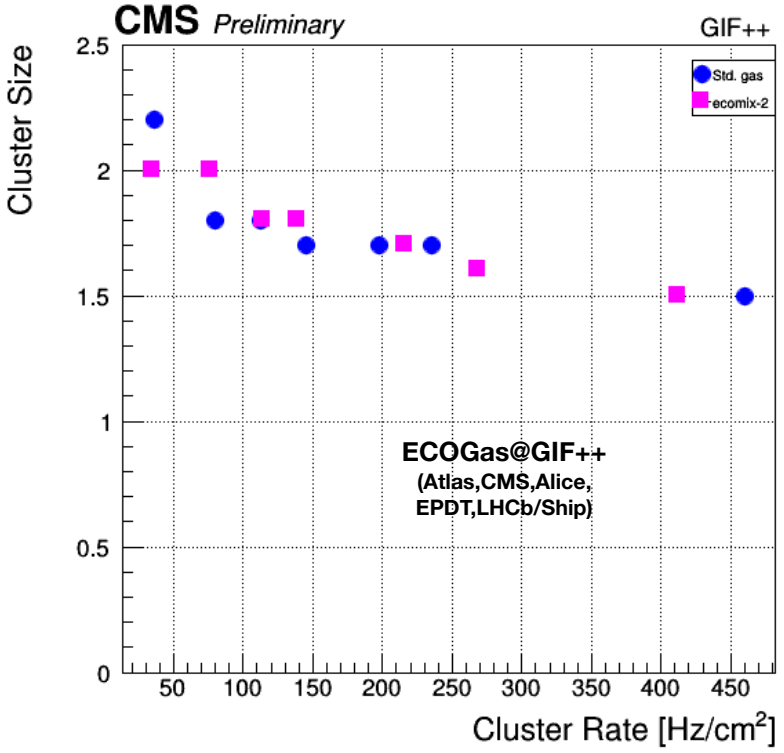


PRELIMINARY

- **For the same ABS different WP but almost same rate**
- **Front end electronics not optimized for 1,4 mm gap**
- **ECO2 mixture show slightly lower efficiency for the same rate**

Test Beam results
1.4 mm CMS chamber



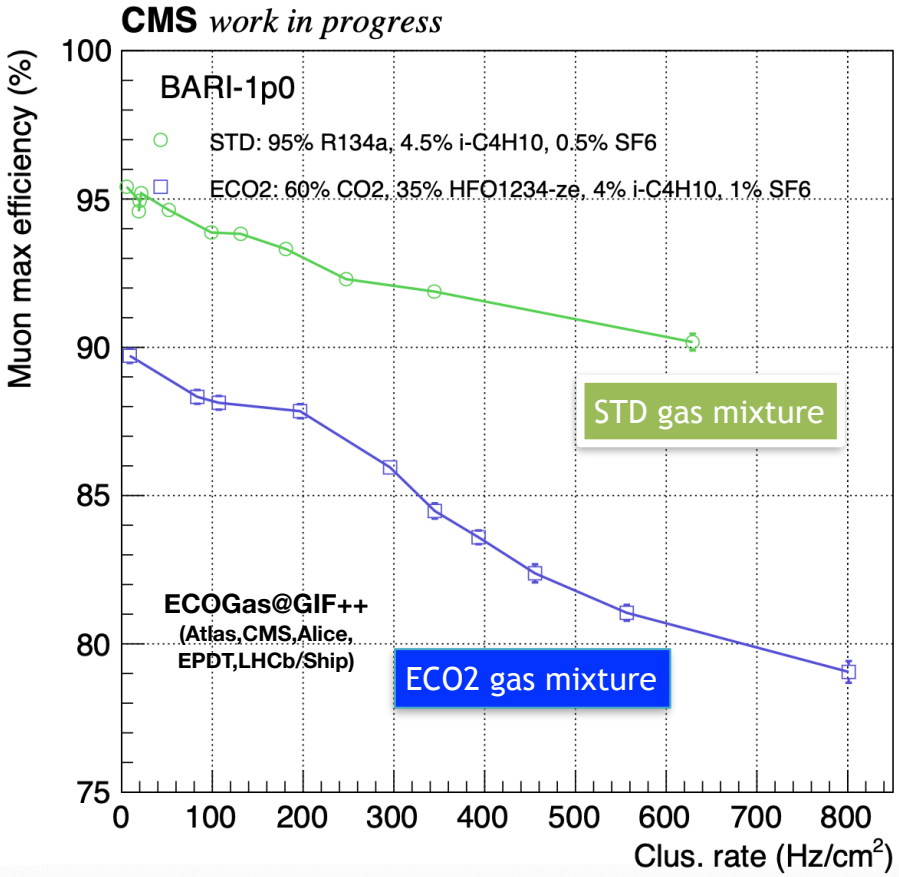


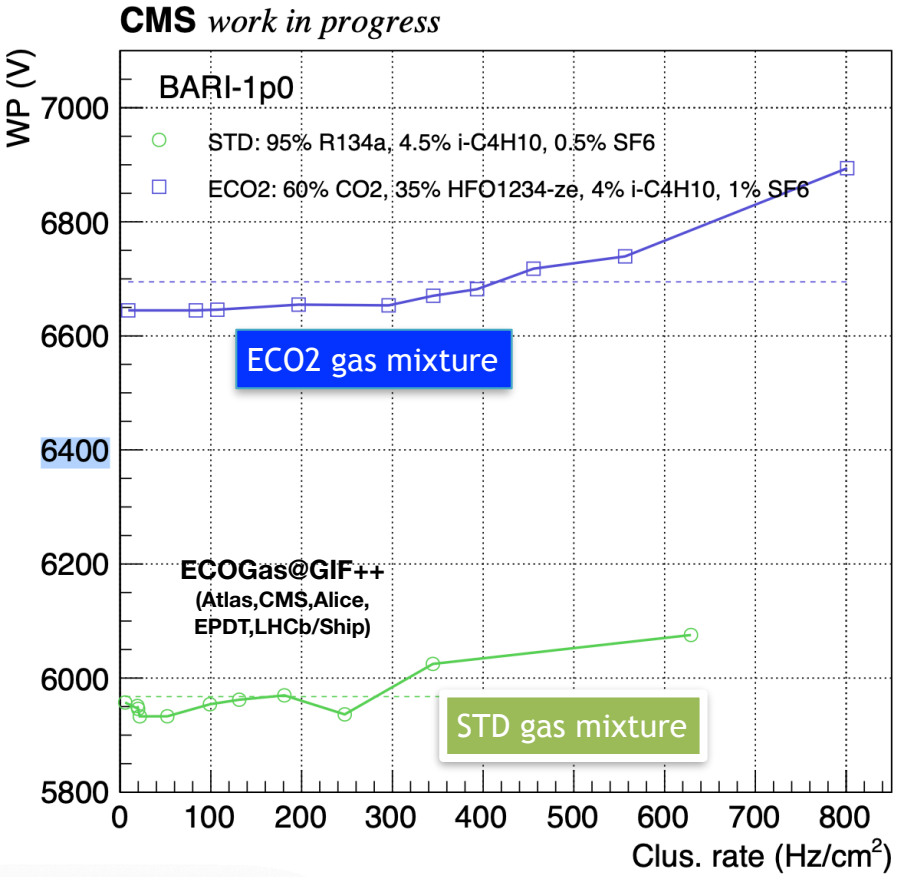
PRELIMINARY

- **Higher density current for ECO2 vs STD**
- **Similar cluster size well under control**

Test Beam results
1 mm CMS chamber

PRELIMINARY



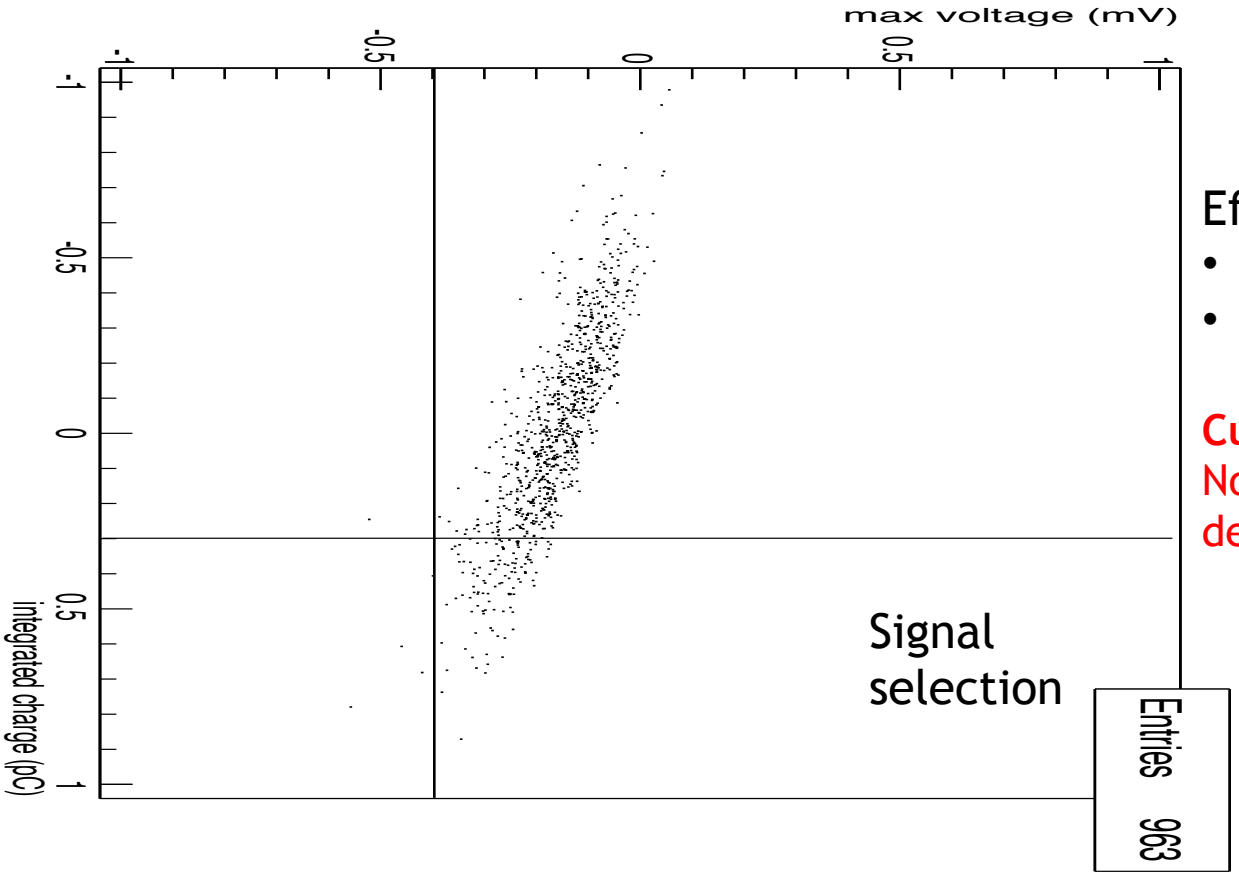


Conclusions

- Several ecological (or semi-ecological) gas mixtures have been tested at LNF lab
- **HFO-1234ze** has interesting quenching properties but cannot be used alone to replace the **R134a** (high working voltage shift)
- **CO2/HFO-1234ze** gas mixtures seems to give interesting results
- **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
  - Toxic
  - CO_2/CF_3I based gas mixture studies are only preliminary
- **Tests at GIF++ started in the context of ECOgas@GIF++ Collaboration and AidaInnova program**
  - **Results from test beams presented for 1, 1.4 and 2 mm gap RPCs**
  - **Long term aging will follow**

Backup

Control region distributions

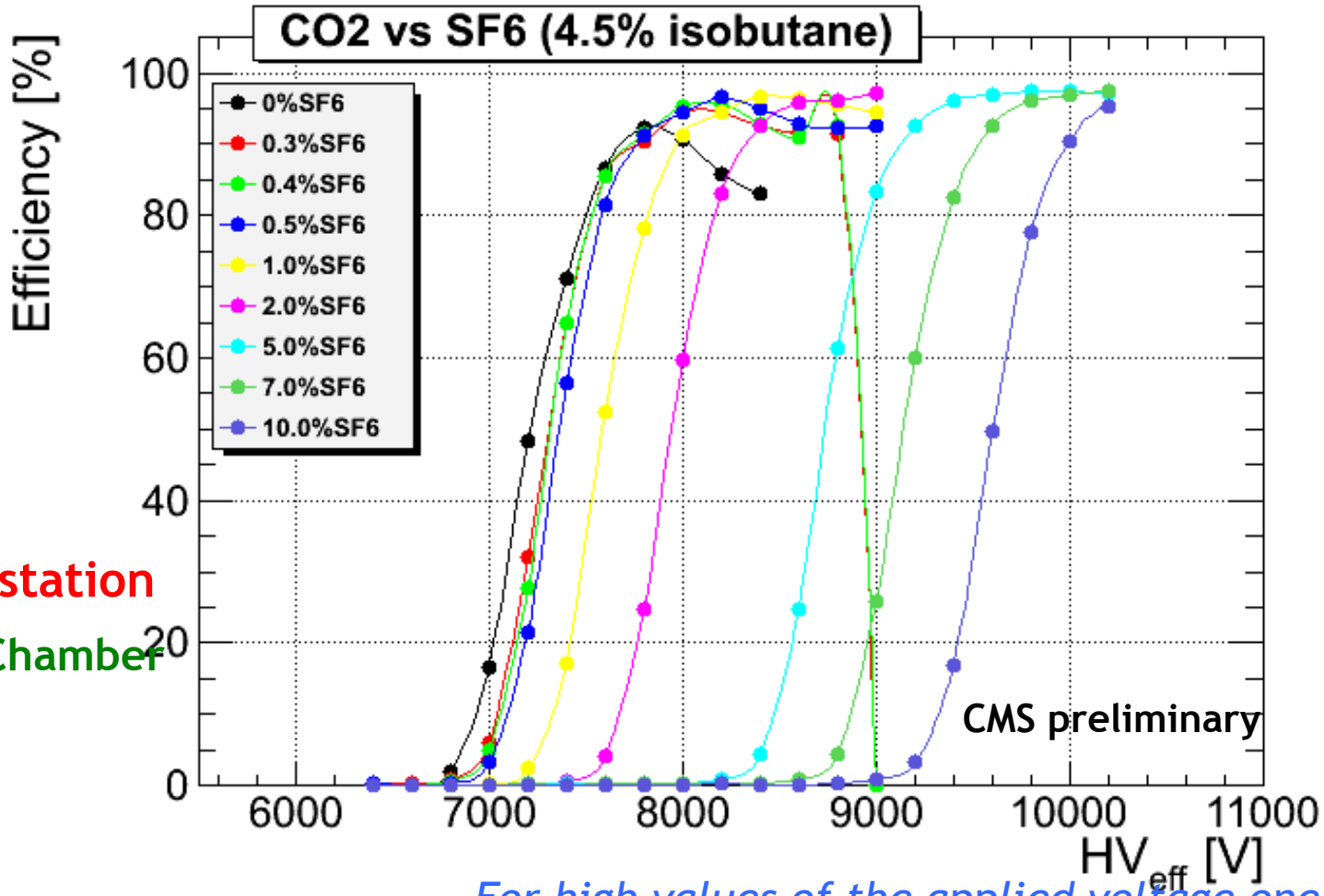


Efficient signal selection:

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

Cuts verified un the control regior
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

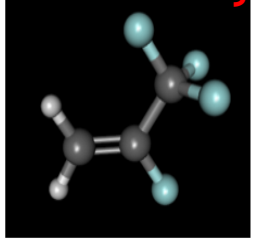
Possible eco-gas repacements

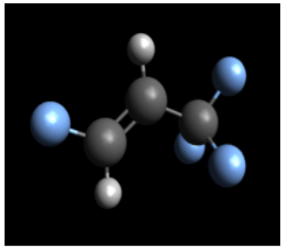
Tetrafluor ... $_3$I)

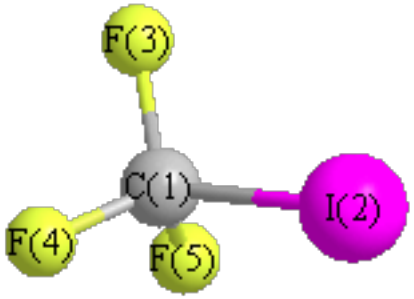
It cames in two allotropic forms

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

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

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)

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)

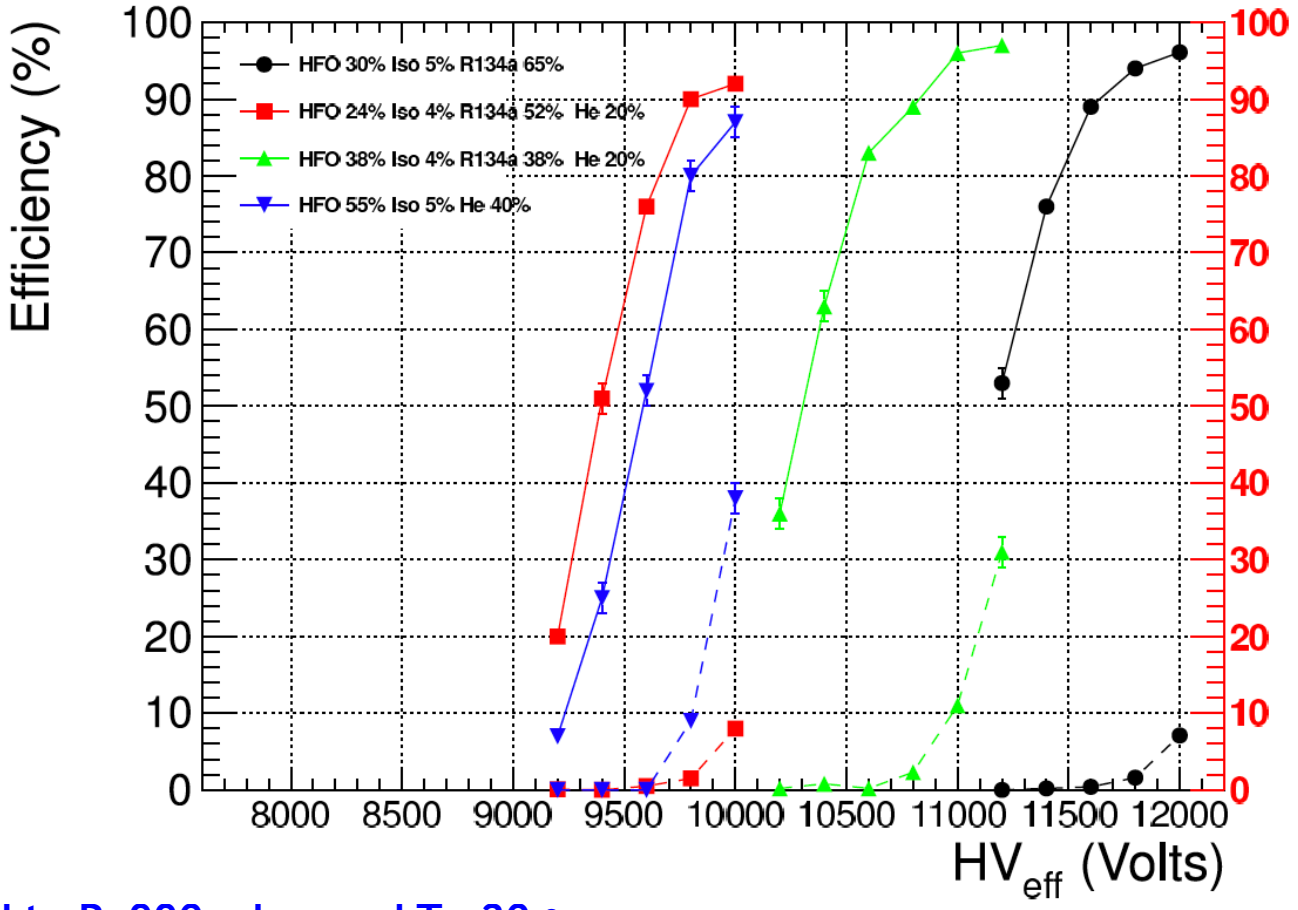
- ✓**Should replace $C_2H_2F_4$ as automotive air-conditioning refrigerant**

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

He/HFO based gas mixtures

efficiency

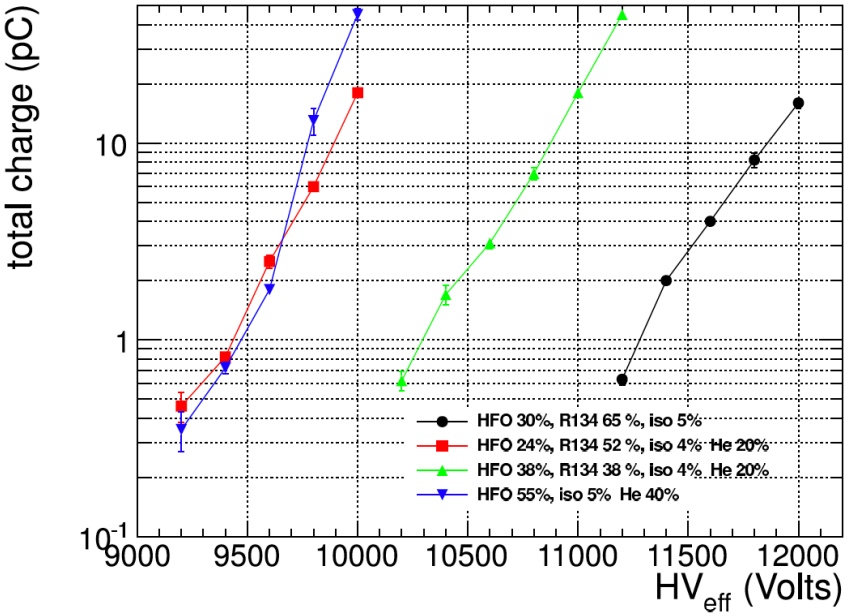
Streamer probability

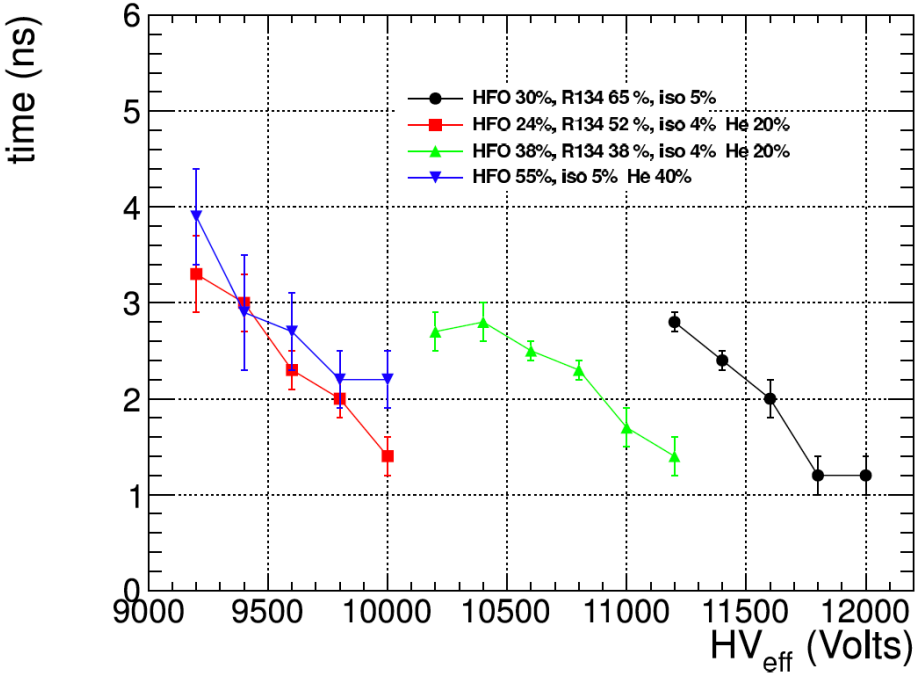


LNF Test station

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

He/HFO based gas mixtures





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

LNF Test station