# Eco-gas studies: report from laboratories

D. Piccolo

*On behalf of CERN, Ghent, LNF, PKU HEP groups*

# Introduction

Eco gas studies are based on three legs:

- **Theoretical approach:**
  - to identify most interesting eco-gas candidates and to find/simulate basic parameters

- **experimental approach:**
  - test in laboratories of most promising candidate mixtures
    - Measurements of efficient, charge, time resolution, cluster size, noise, dark current

- **long term aging test:**
  - test at GIF++ of RPCs with few finally selected eco-gas mixtures
  - Long term aging test of interactions between new gases and RPC materials

# 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)**

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

✓$C_2H_4F_2$ – difluoroethane (GWP=120)

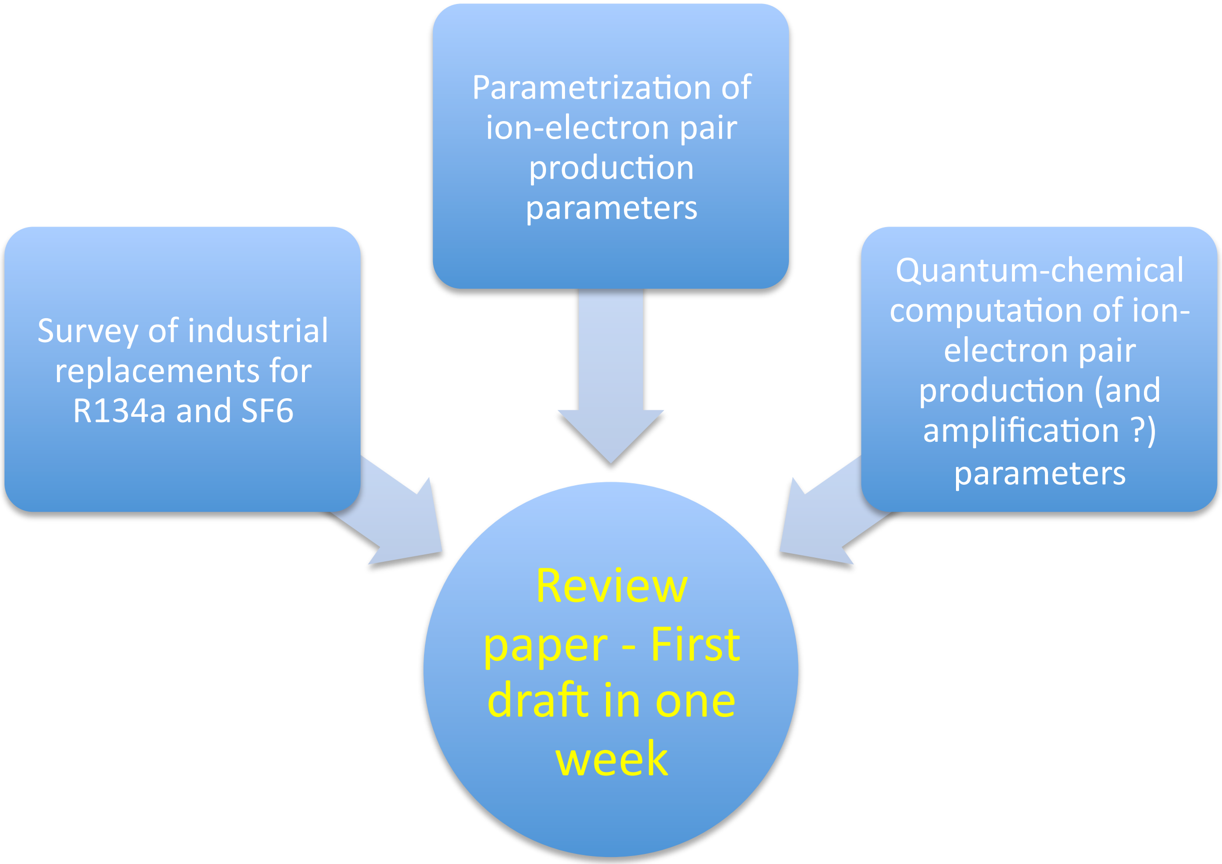
✓Also studied to replace $C_2H_2F_4$ as a refrigerant

✓$C_2HF_3Cl_2$ (GWP=93), others…

# The search for an ecogas replacement: computations and simulations

Y.Ban L.Benussi S.Bianco G.Chen S.Colafranceschi M.Ferrini J.Kjølbro, Q.Li D.Piccolo G.Saviano A.Sharma D.Yang,

*Cern – Frascati – PKU – Univ. Roma Sapienza*



# A theoretical approach

To study the main parameters of possible eco-gases to replace R134 and SF6.
Study of interaction with materials used in RPCs is also part of the issue

Summer Student Project 2014

Jógvan Kjølbro Technical University of Denmark (DTU)

Supervisors: A.Sharma (CERN) and G.Saviano (INFN Frascati and Univ. Roma La Sapienza)

The program is mainly devoted to analysis of GEM materials but clear sinergy with RPC issues for eco-gas studies

…………………

Results on interaction of materials with gas mixtures will also contribute to study and to determine alternative environmentally-friendly eco-gas mixtures to replace the banned gas mixtures presently in use.

# A Gas Chemical Properties Study

Daneng Yang, Geng Chen (PKU), Stefano Colafranceschi,
Archana Sharma (CERN), Yong Ban, Qiang Li (PKU)

High Energy Physics Group, School of Physics, Peking University

## Quantum chemical calculation

1. Applying quantum mechanics in physics models
2. Computer programs used in computaional chemistry
3. Both open source and commercial softwares available

## Main methods

1. Hartree-Fock (HF) Theory, self-consistent field (SCF) method
2. Density functional theory (DFT), Real-time time-dependent density functional theory (RT-TDDFT)
3. High-level Coupled-Cluster methods (Not used in for this study)

NWCHEM
HIGH-PERFORMANCE COMPUTATIONAL CHEMISTRY SOFTWARE

http://www.nwchem-sw.org/index.php/Main_Page

## Main methods

1. We used an open source software, **NWCHEM**, to do the calculation
2. Several other tools used for generating input structures, i.e. **Avogadro**
3. **PyMOL** used for visualization

## Goals

1. We want to find gases whose properties are similar as the Freon
2. $CCl_2F_2$ is tested as a representative Freon gas
3. Other gases calculated in the study: HFO1234yf, HFO1234ze, R134a, R152a

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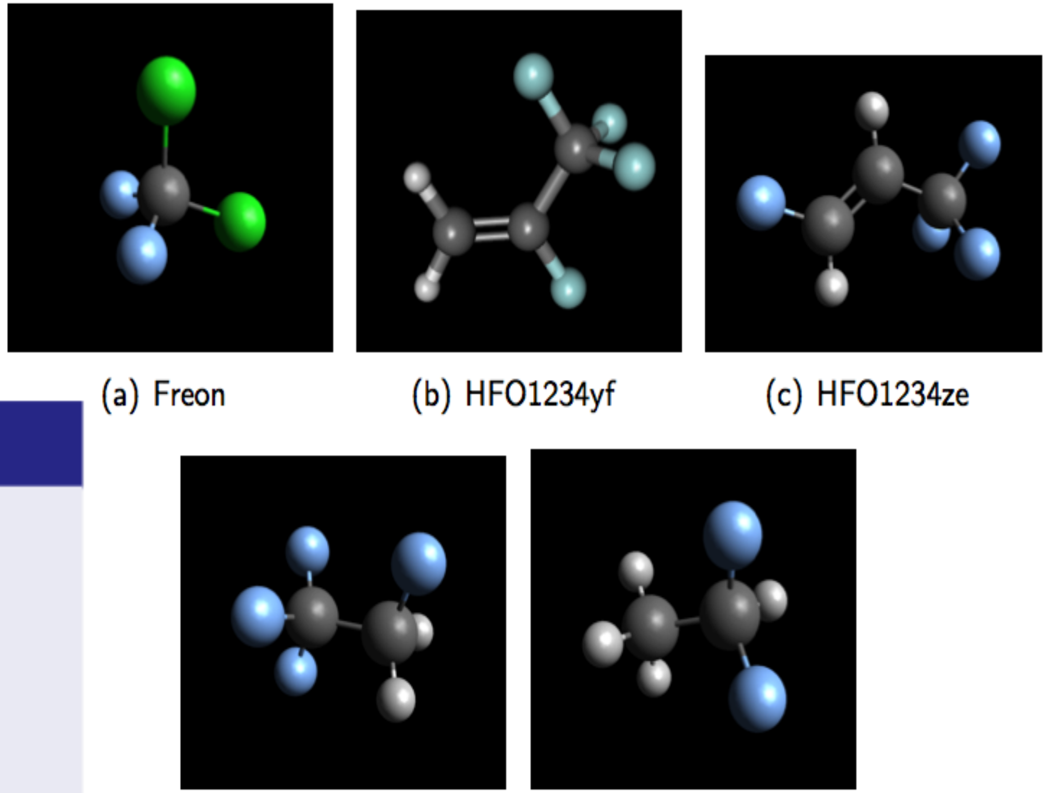


(a) Freon (b) HFO1234yf (c) HFO1234ze

(d) R134a (e) R152a

## Calculated results

1. Optimized geometry and center of mass
2. Charged density and molecular obital
3. Ground state energy and nuclear Dipole moment
4. Excitations of electronic modes and absorption spectrums

# Ionization change the molecular orbits

Daneng Yang, Geng Chen (PKU), Stefano Colafranceschi, Archana Sharma (CERN), Yong Ban, Qiang Li (PKU)

High Energy Physics Group, School of Physics, Peking University

Comparison of R134a

Comparison of HFOze

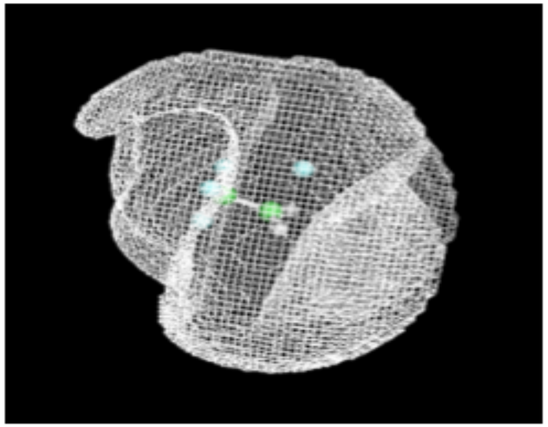


Figure : $CH_2FCF_3^+$ molecular orbital

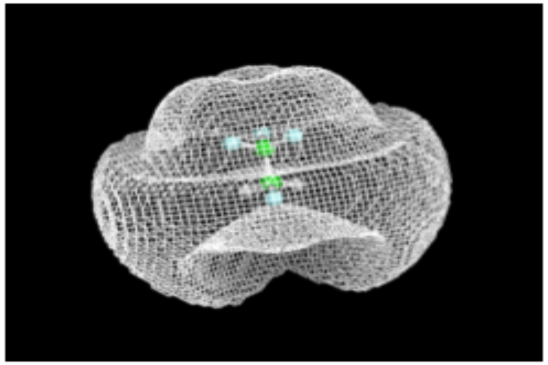


Figure : $CH_2FCF_3$ molecular orbital

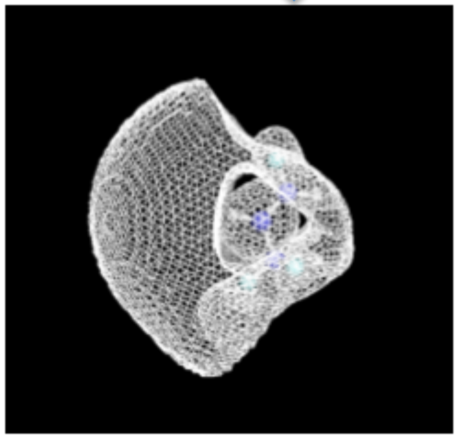


Figure : $CFHCHCF_3^+$ molecular orbital

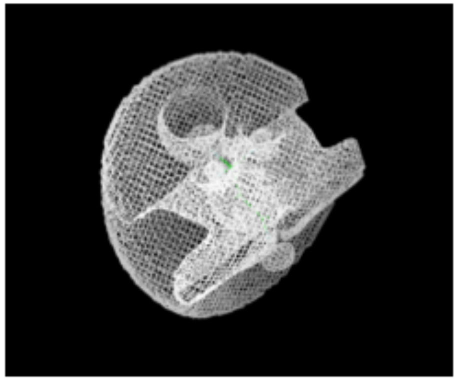


Figure : $CFHCHCF_3$ molecular orbital

Ionization energy of several gases have been calculated

| 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 |

NEW

# Experimental approach

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

Tetrafluorepropene:
**HFO-1234ze bottle already available in Frascati and Ghent**
**HFO-1234yf also available**

The LNF plan is to analyze:
- induced charge spectrum
- streamer probability
- time resolution
- signal shape
- Use of standalone electronics

The Ghent plan is to analyze:
- dark current
- single rate
- efficiency
- Use of the the standard CMS electronics

**Two complementary approaches. Synergies to be explored**

# Experimental Set-up in Ghent

- Setup from RE4 construction for characterization of chamber performance, ie. efficiency, cluster size, cluster multiplicity, timing (?)

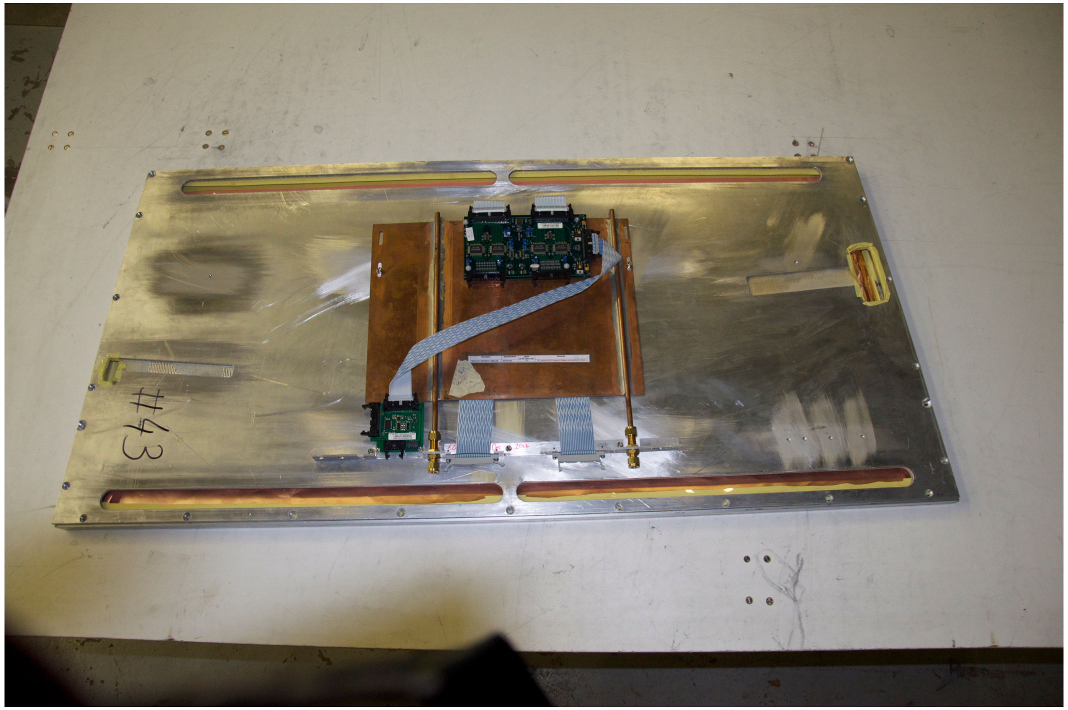
- 2 gas mixing units available:
  - "standard" gas mixer: 95.2% R134a, 4.5% isobutane, 0.3% $SF_6$ + 40% humidity
  - "alternative" gas mixer: std RPC gases, Ar, $CO_2$, $CF_4$, $N_2$ … + humidity

- 2 test chambers have been constructed in the standard CMS-way, with spare RE4 gaps and materials, however A-partition only (32 channels), double layer

- Alternatives to R134a to be tested:
  - $CO_2$
  - HFO-1234ze (GWP=6, ODP=0), available in Ghent
  - HFO-1234yf (GWP=4, ODP=0)

*Frederik Van Acker*
*Simon Cauwenbergh*
*Michael Tytgat*

# Gas Studies @ UGent

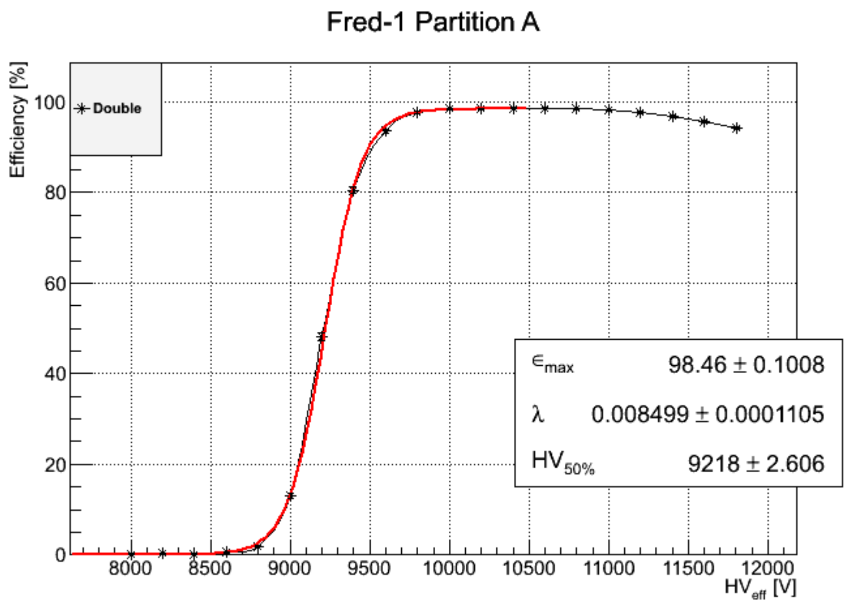



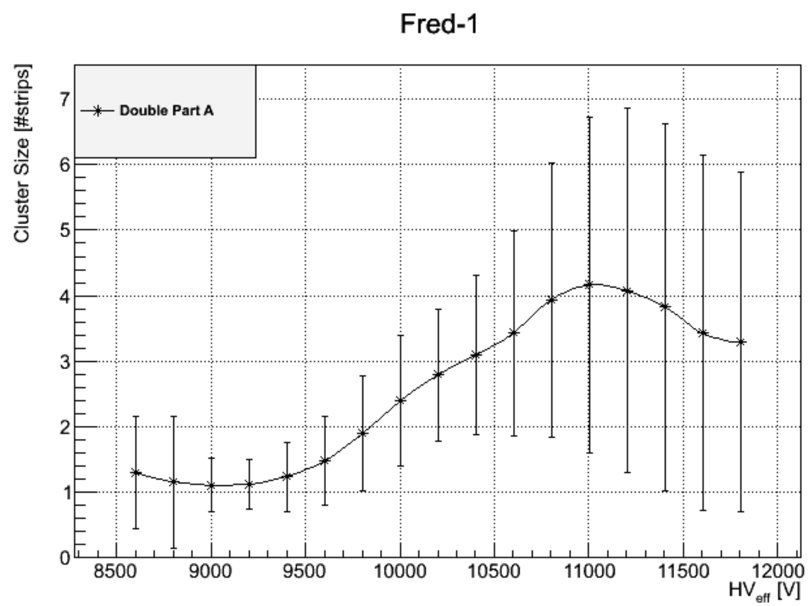

**One of the 2 CMS-like test chambers**

**“Alternative” gas mixing unit**

# Standard Gas Mixture @ Ghent

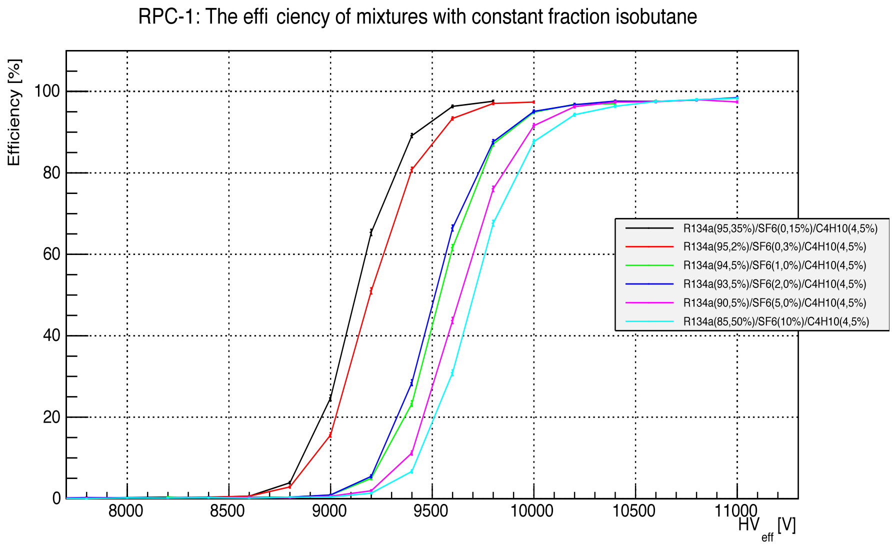
- Characterization of the test chambers with the standard RPC gas mixture
- Pushing them into the streamer regime to see the range of operation

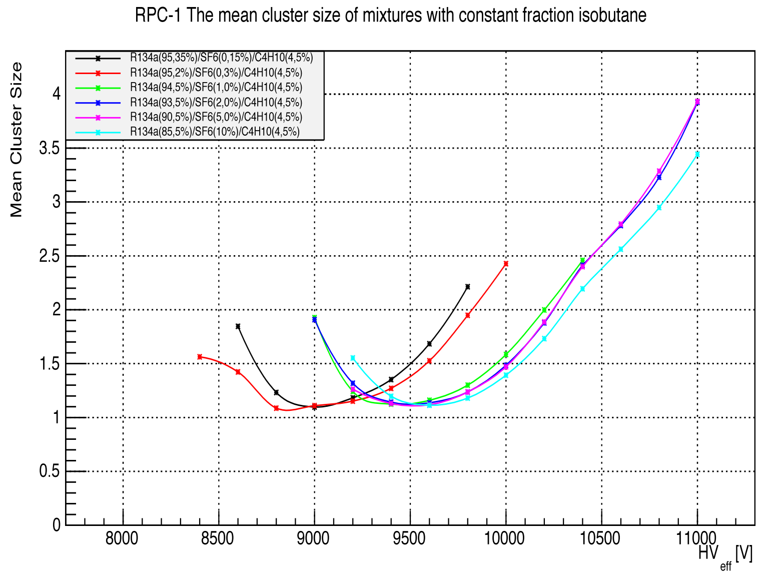


# R134a-based Mixtures

- **Checking effect of $SF_6$ in standard gas mixture: clear shift in plateau and working point**



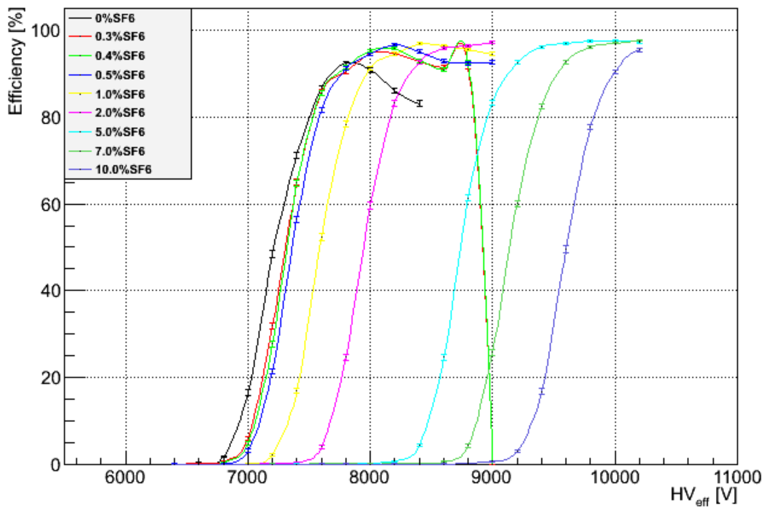




| Mixture | Voltage (kV) | Efficiency (%) | Mean Cluster Size | Noise Hits* |
|---|---|---|---|---|
| 0.15% SF6 | 0.98 | 97.60±0.25 | 2.21 | 0.02 |
| 0.3% SF6 | 1.00 | 97.40±0.24 | 2.43 | 0.006 |
| 1.0% SF6 | 1.02 | 96.86±0.27 | 2.00 | 0.01 |
| 2.0% SF6 | 1.04 | 97.65±0.24 | 2.41 | 0.36 |
| 5.0% SF6 | 1.06 | 97.45±0.24 | 2.79 | 0.09 |
| 10.0% SF6 | 1.08 | 98.00±0.22 | 2.95 | 0.27 |

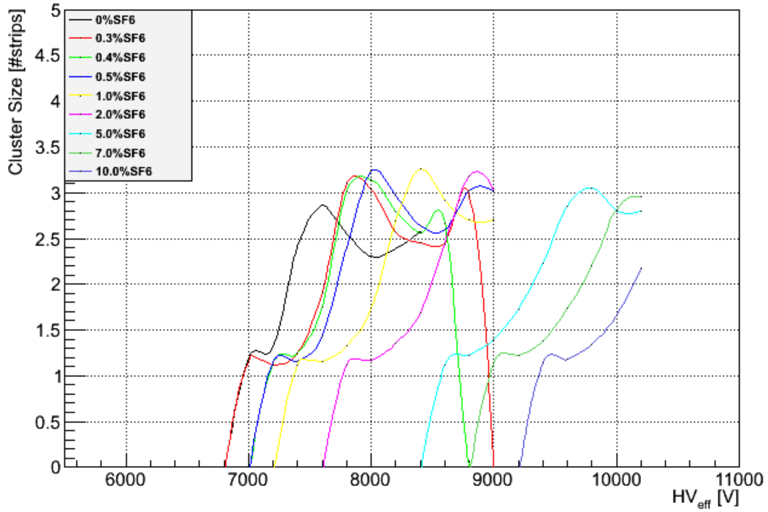
# $CO_2$-based Mixtures

- $CO_2$ based mixtures (as replacement of R134a)
- Chamber performance for various $SF_6$ percentages; effect of $SF_6$ clearly visible
- Full, stable chamber efficiencies can be recovered for >1-2% $SF_6$ however, cluster size is higher wrt. standard gas mixture

CO2 vs SF6 (isobutane @ 4.5%)

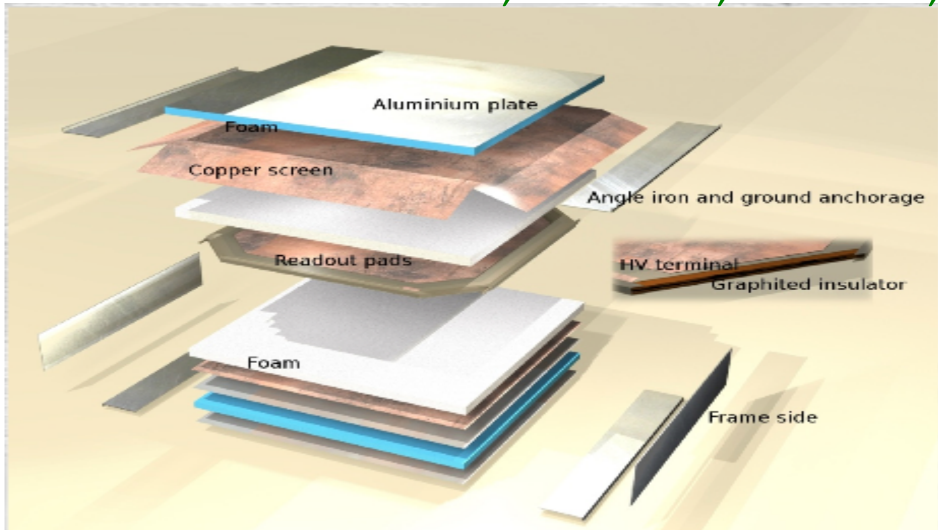



CO2 vs SF6 (isobutane @ 4.5%)



# Experimental Set-up in Frascati

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



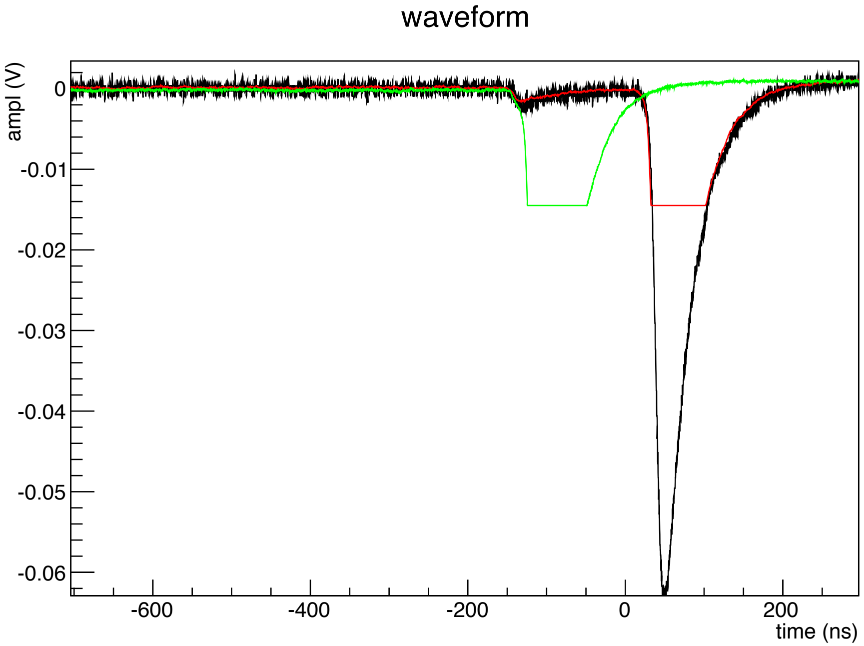

- 12 single gap RPCs, 2 mm wide gas gap
- 50 x 50 $cm^2$
- Double Pad readout
  - partial cancellation on single mode noise
  - Expected about x2 induced signal charge
- Scintillator layers on top and bottom for trigger

**Data taken with oscilloscope**

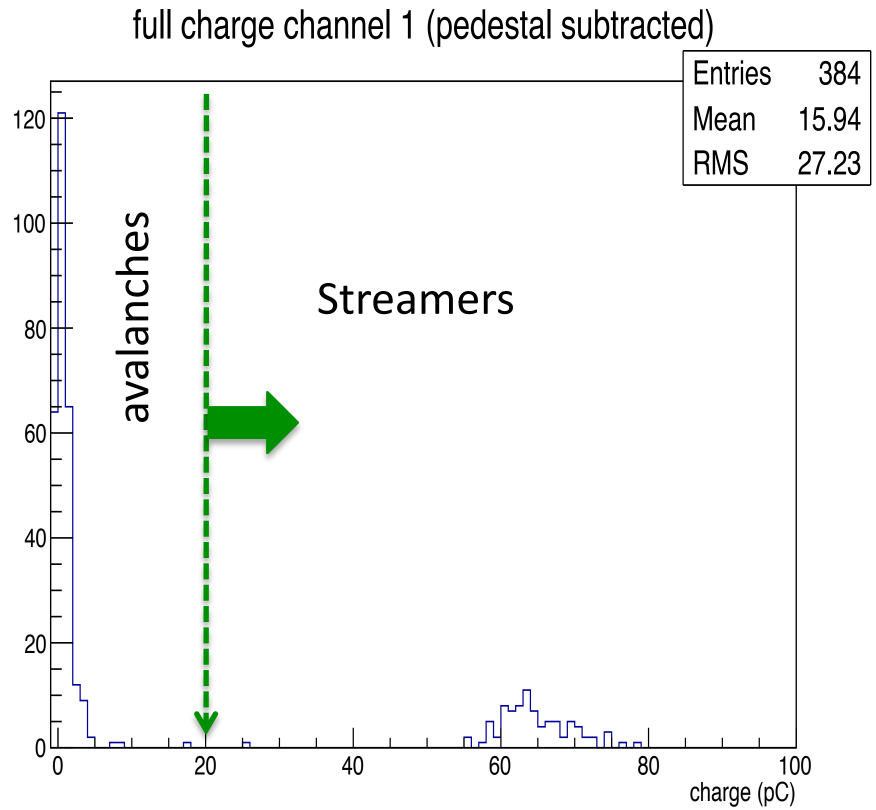
- Gas chromatograph: for gas mixture analysis
- 4 channels Oscilloscope lecroy104xi (5 Gsamples, 1 GHz): for signal readout
  - Full digitization of signal
  - By hand measurement

See https://indico.cern.ch/event/337691/ for previews presentation

# Typical distributions




RPC signal sent to the oscilloscope on two different channels with different y scale (avalanche and streamer)




**Streamer probability defined as fraction of events above threshold and below 20 pC**

# Results Summary

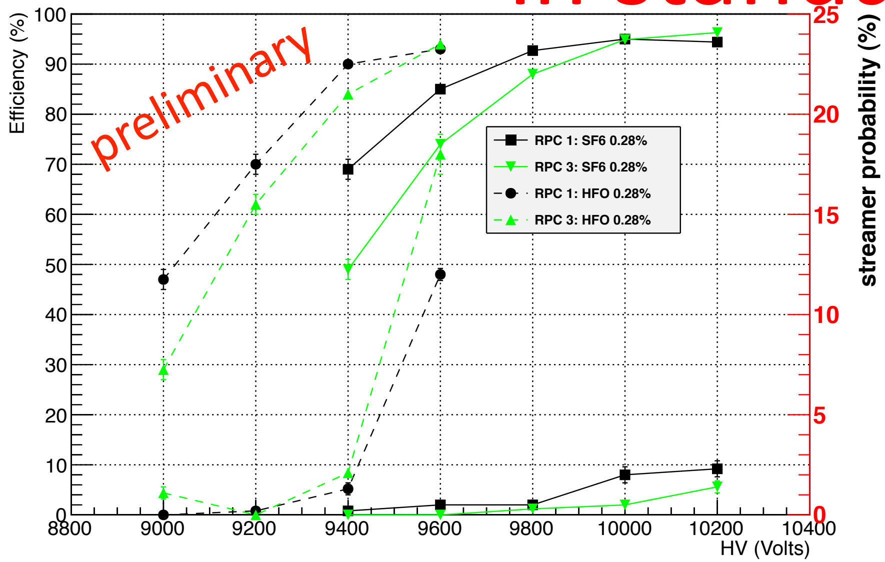
- Efficiency vs HV
  - RPC is defined efficient if q > 0.3 pC && $V_{peak}$<-0.4 mV
- Streamer probability
  - Total charge evaluated in 300 ns time window: streamer is declared if q>20 pC
- Time resolution
  - Time difference of the time over threshold (0.4 mV) between two RPCs
  - Division for ~ sqrt(2) should be applied
- Old set of results used q>0.5 pC
- New set of measurement concentrate on one single RPC channel (lower noise)

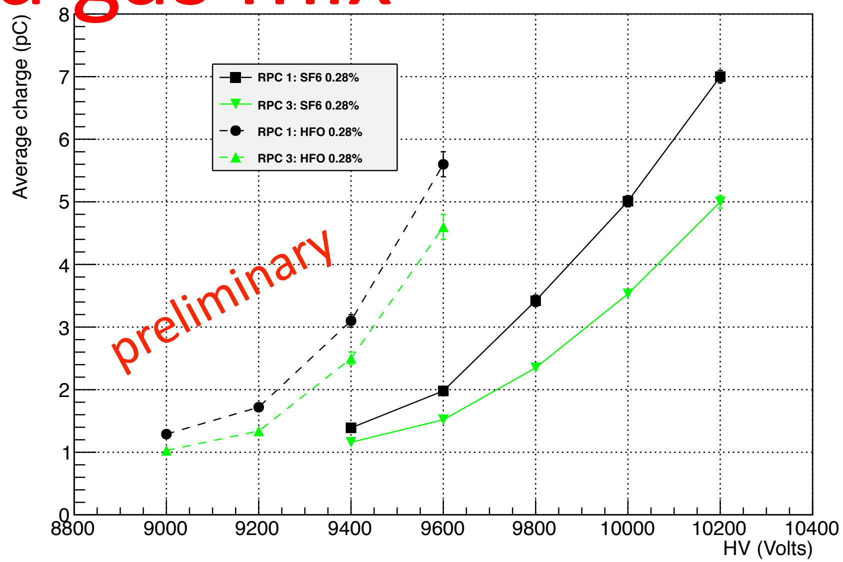
# Old results

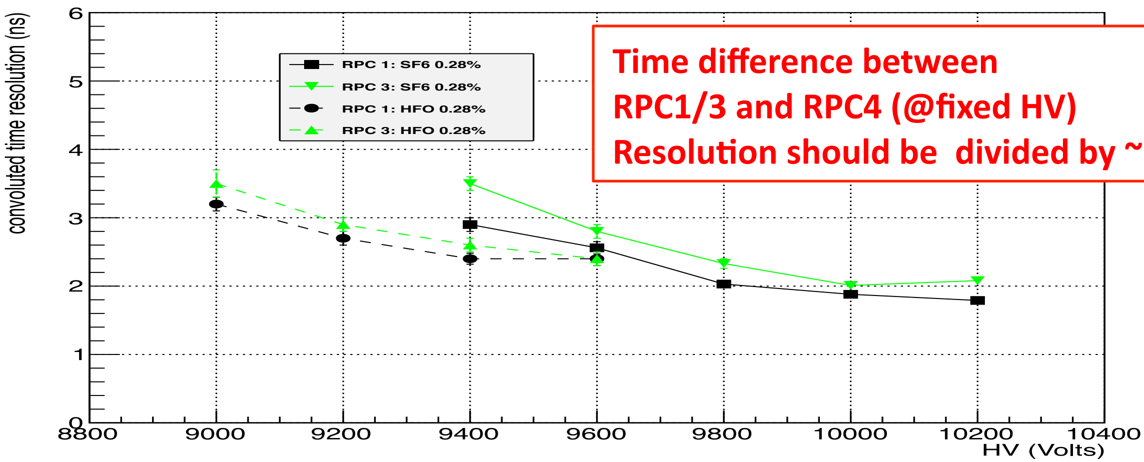
- See https://indico.cern.ch/event/337691/

Istituto Nazionale
di Fisica Nucleare

# Replacing SF6 with HFOze in standard gas mix

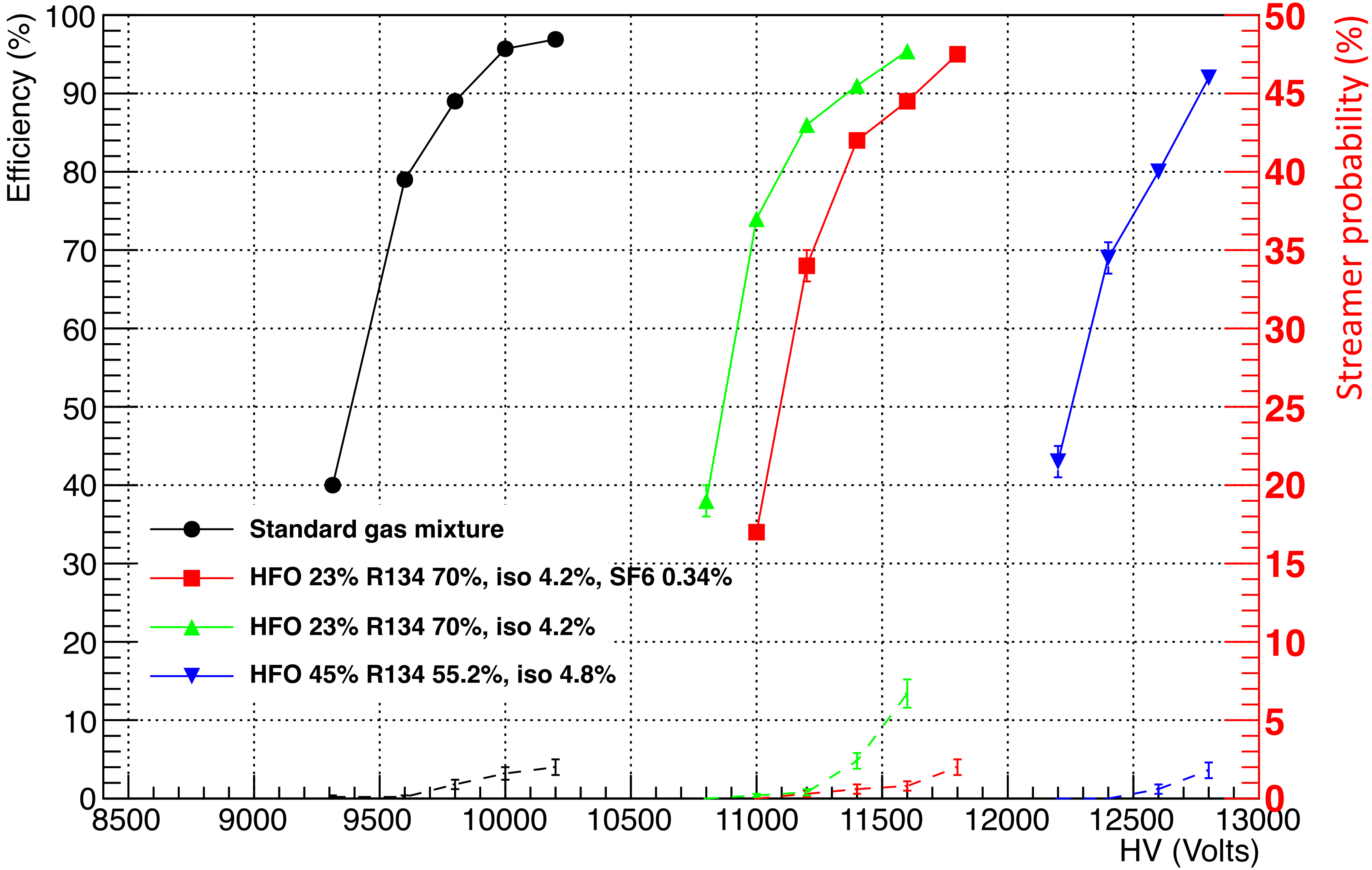


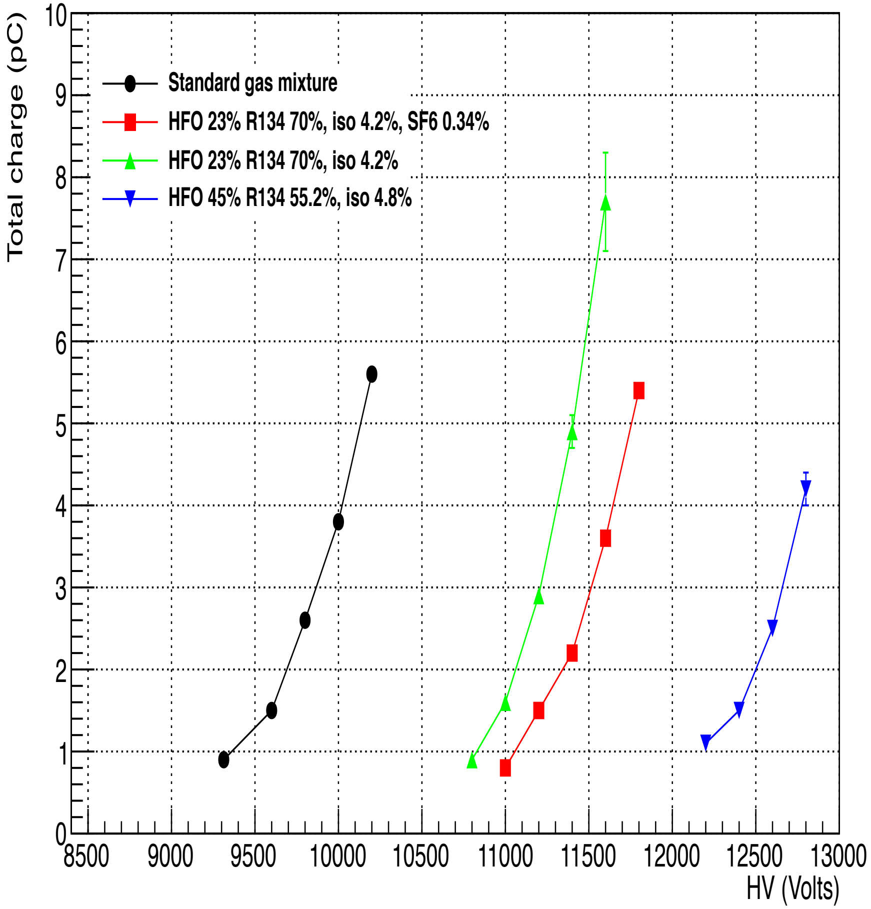



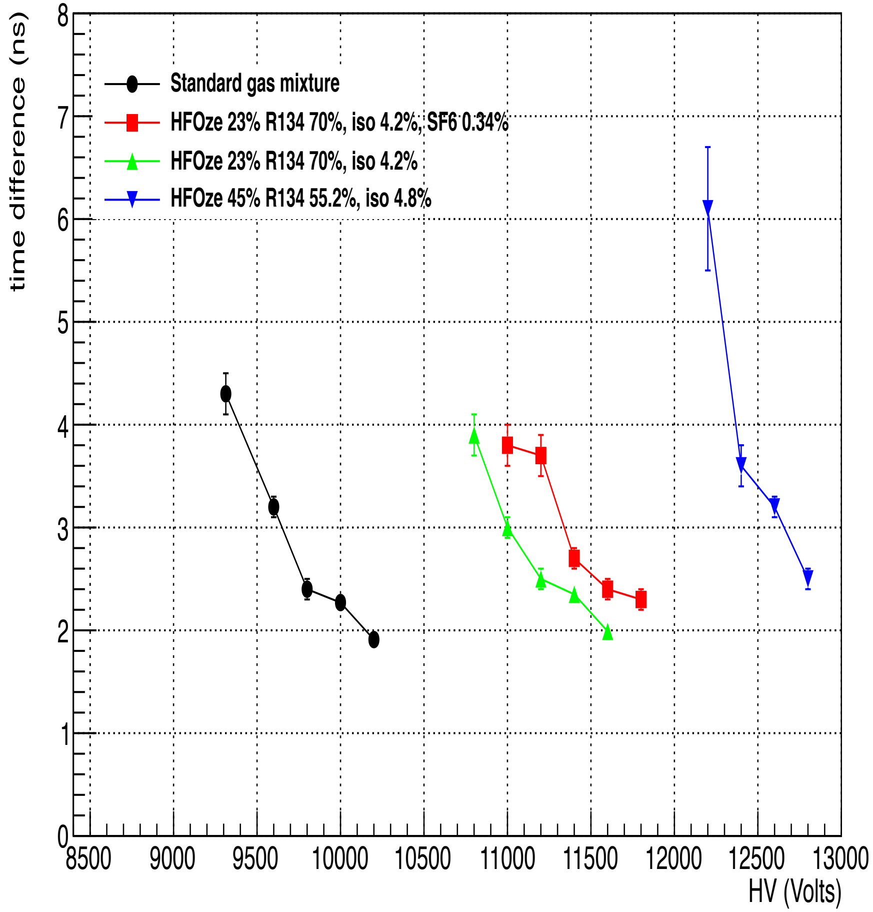

**Time difference between RPC1/3 and RPC4 (@fixed HV)**
**Resolution should be divided by ~ sqrt(2)**

# Replacing R134 with HFOze

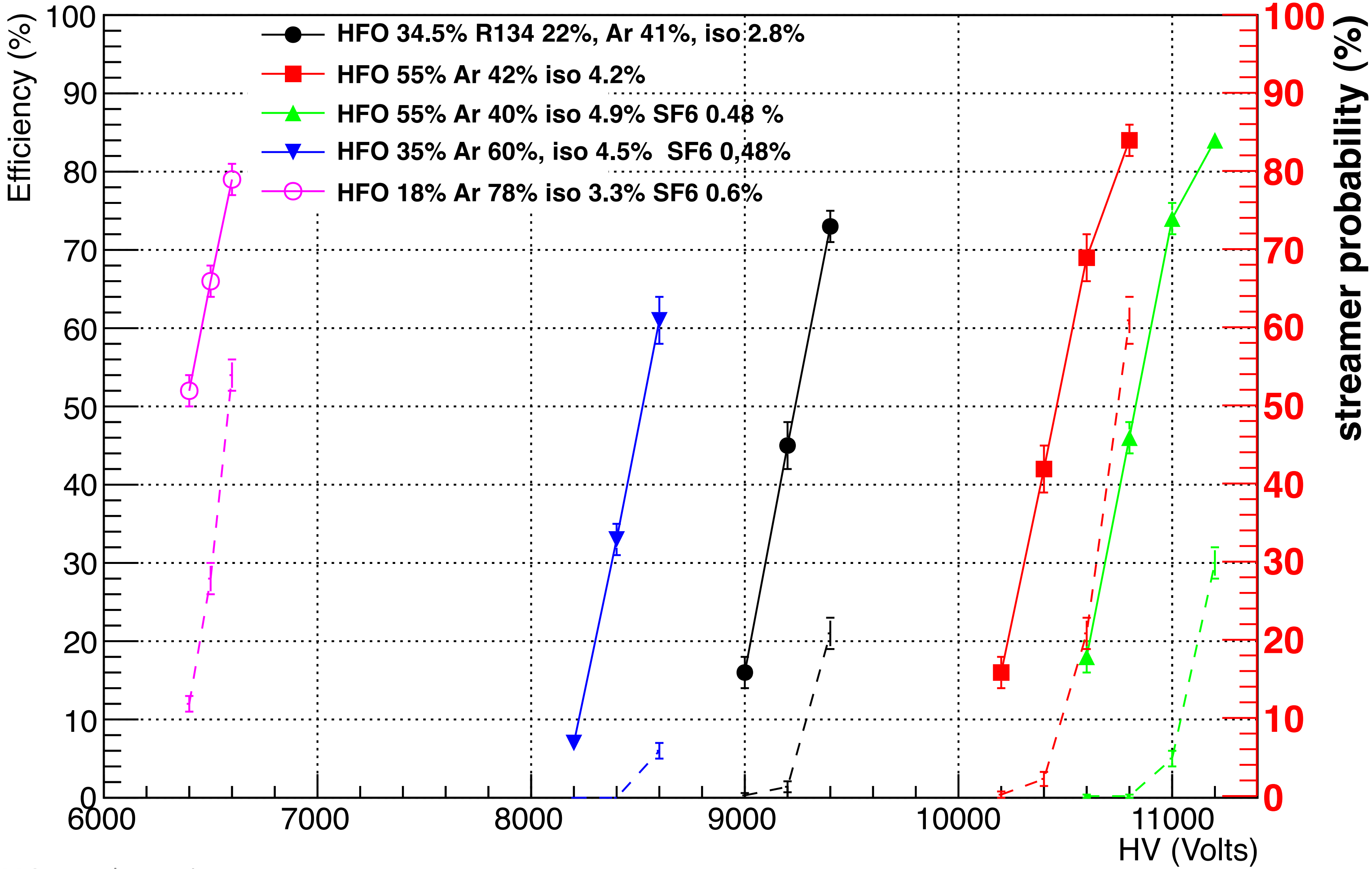


# Replacing R134 with HFOze - 2

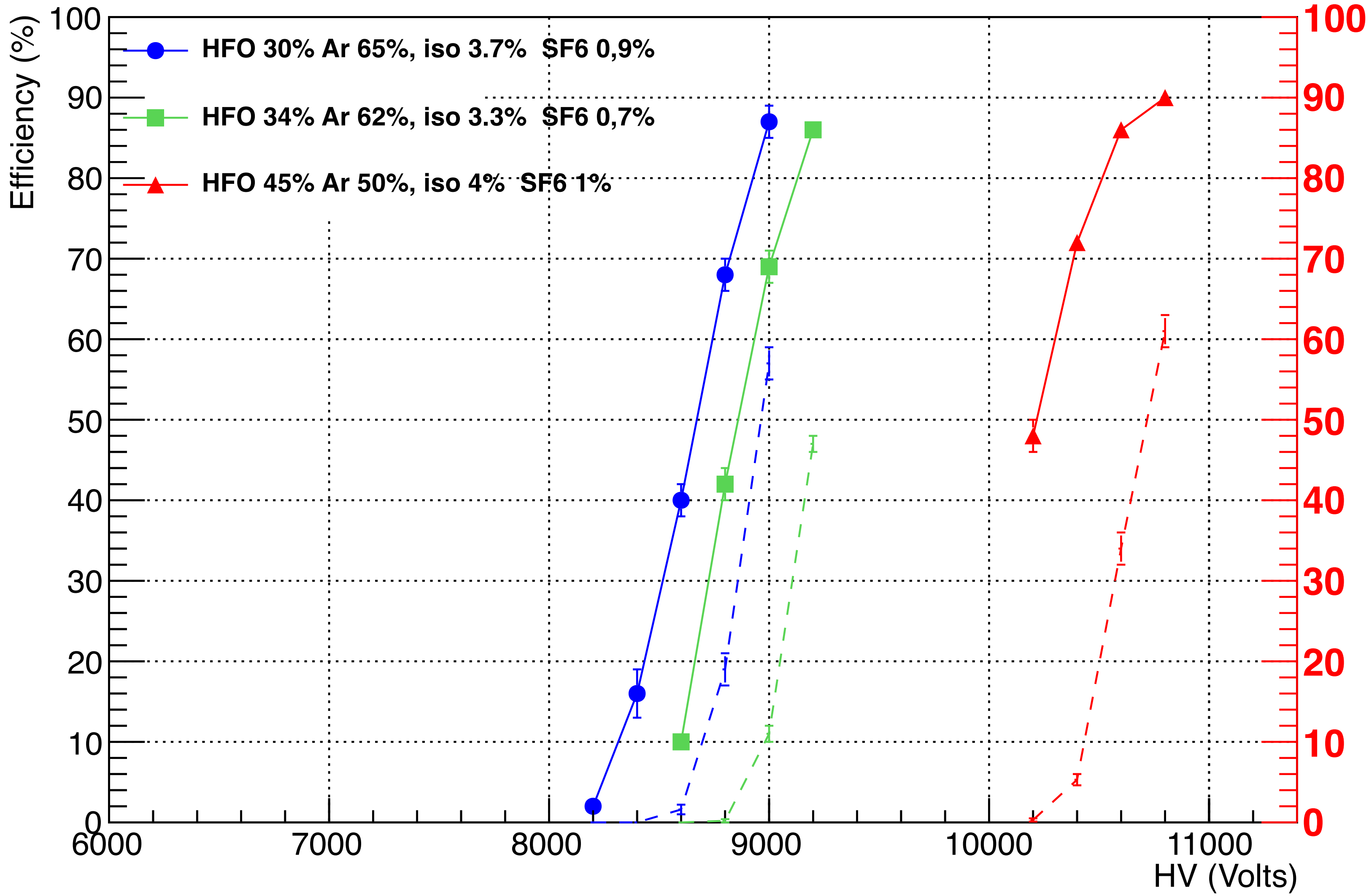


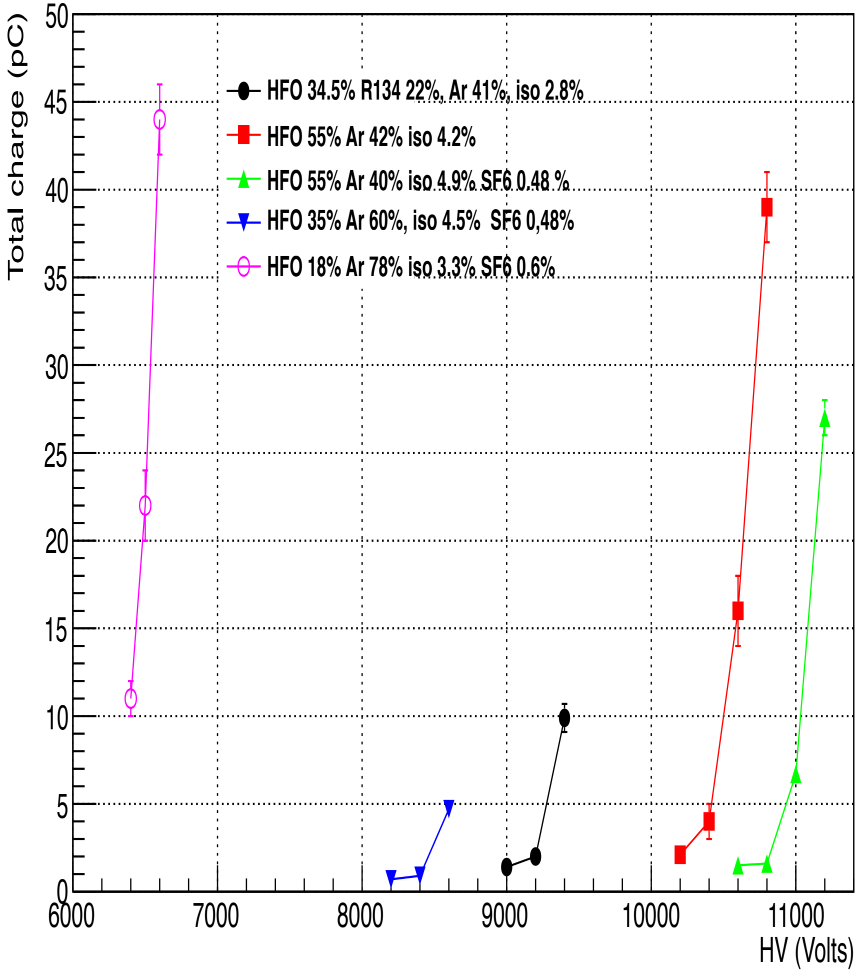
# Adding Argon to HFOze mix

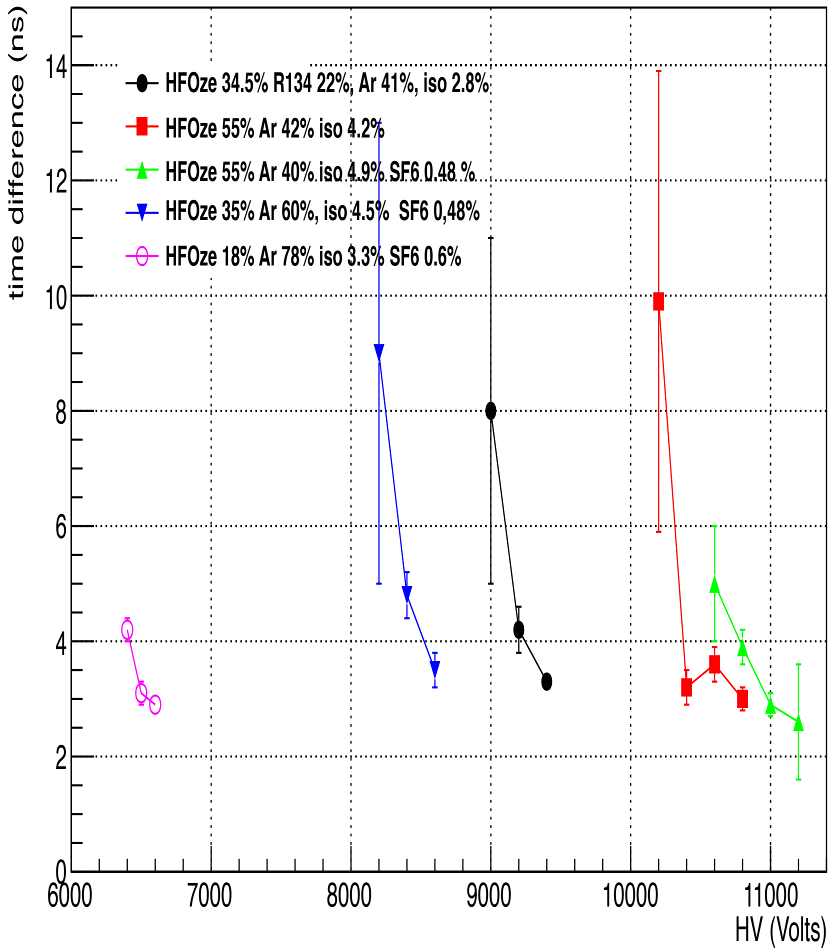


# Adding Argon to HFOze mix - 2

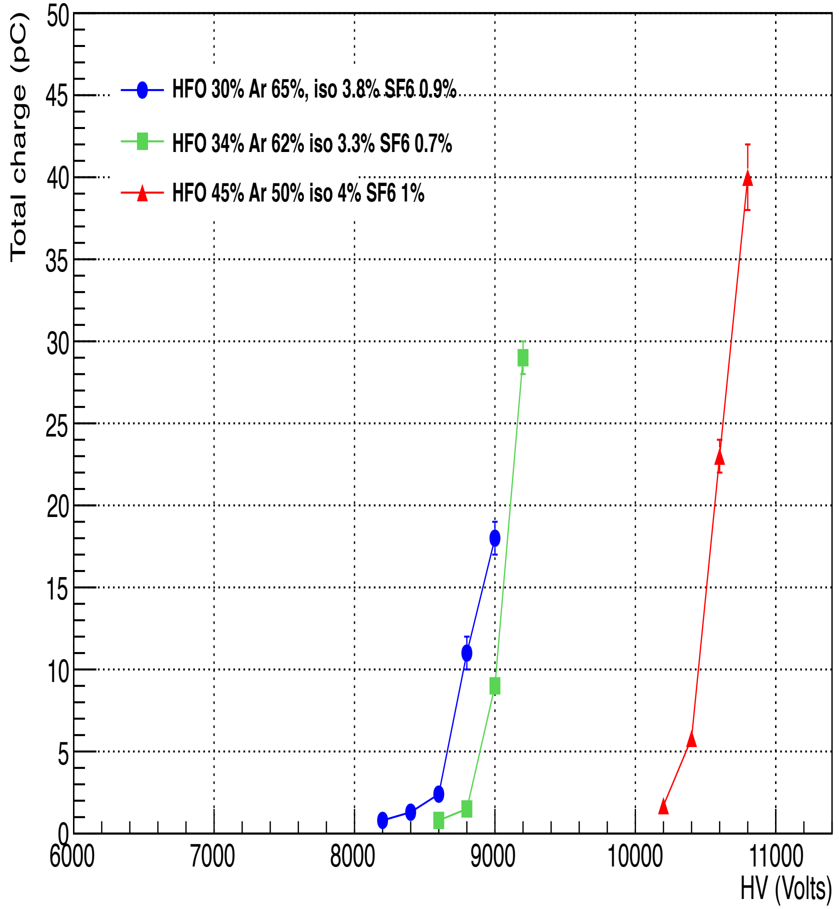


# Adding Argon to HFOze mix - 3



# Adding Argon to HFOze mix - 4




Time resolution in preparation

# Conclusions

- Theoretical studies started and give first feedbacks
  - Note in preparation: first draft ready by the end of week
- Experimental setup ready in Ghent and LNF
- First test on HFOze in LNF (LNF internal note ready and published by the end of this week)
  - Replacing all R134 with HFOze move HV point to working voltage too high
  - Adding Argon promising but streamer probability increase very soon (lower thresholds could help)
- First results from Ghent
  - Dependence of efficiency and cluster size from SF6 percentage, for R134a and CO2 mixtures
- Synergies and collaboration between LNF and Ghent will start soon

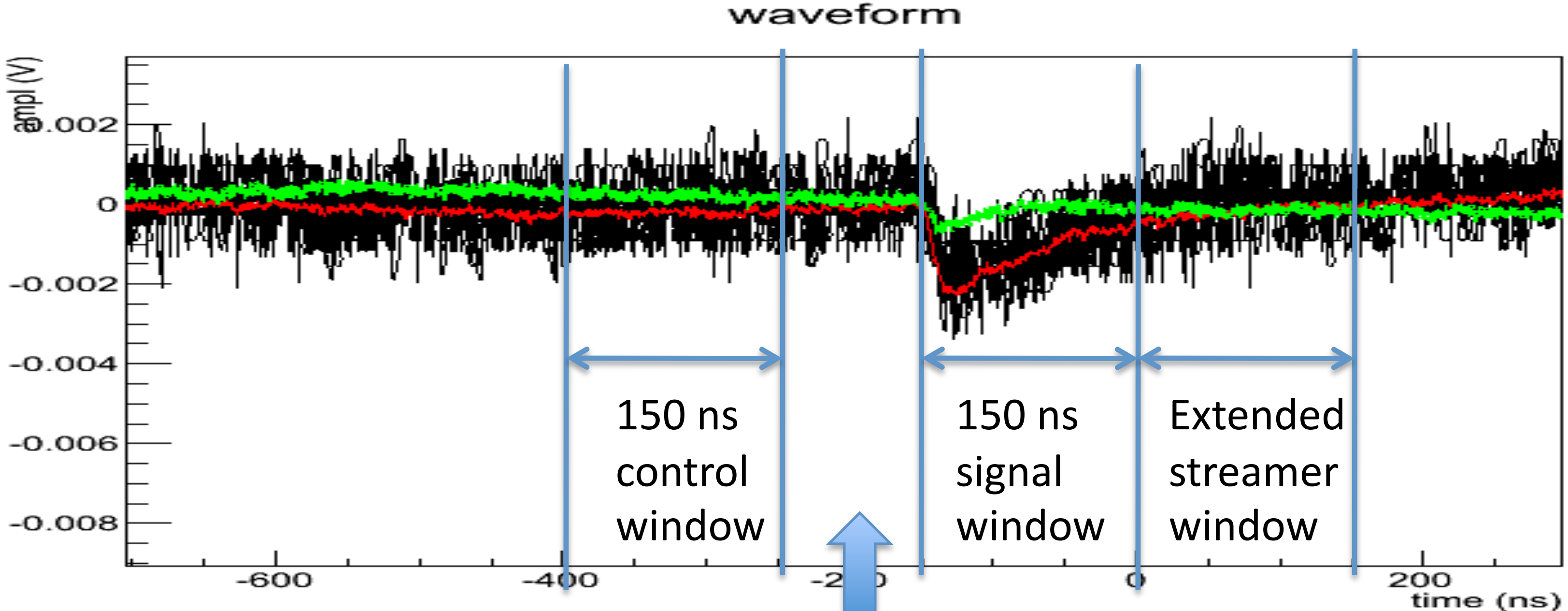
- Synergies to be started between different groups and with ATLAS , Alice

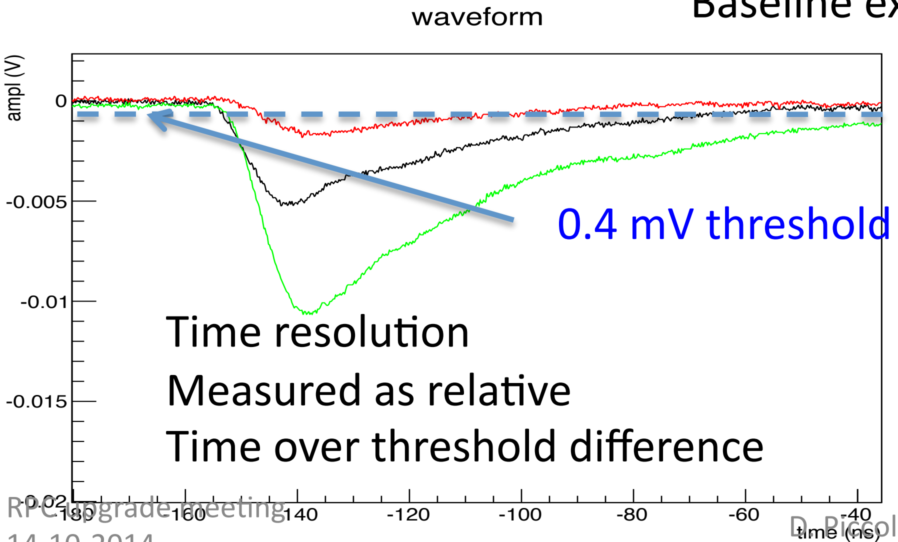
# spares

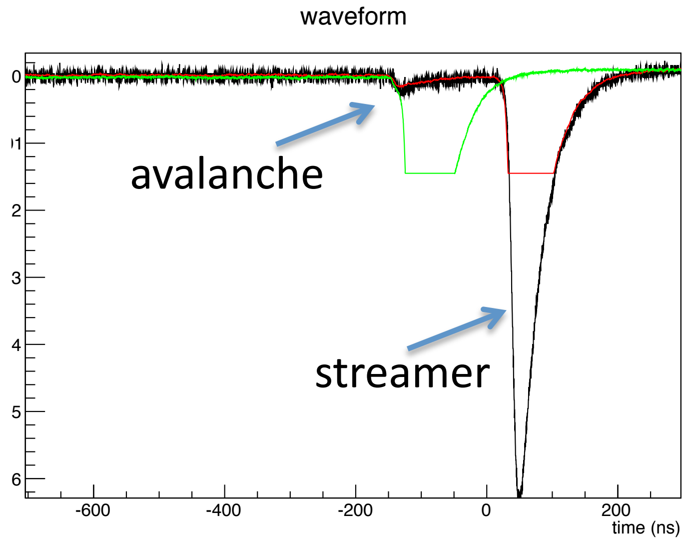
# Data analysis

- 4 RPCs connected to the gas line but just 2 sent to oscilloscope channels
- Scintillator signal used to trigger the event
- One RPC at fixed voltage used as additional offline trigger
- 1000 waveforms collected for each RPC at each HV point
- HV normalized to 990 mbar and 290 °K
- Due to environmental noise 20 Mhz filter applied to oscilloscope channels
  - Xcheck of results with and without filters
- Use of filter and readout of signal through pad will increase rise and fall time
  - Total charge not affected
  - Timing of signals affected in the same way for all the channels and cancel out in the relative differences

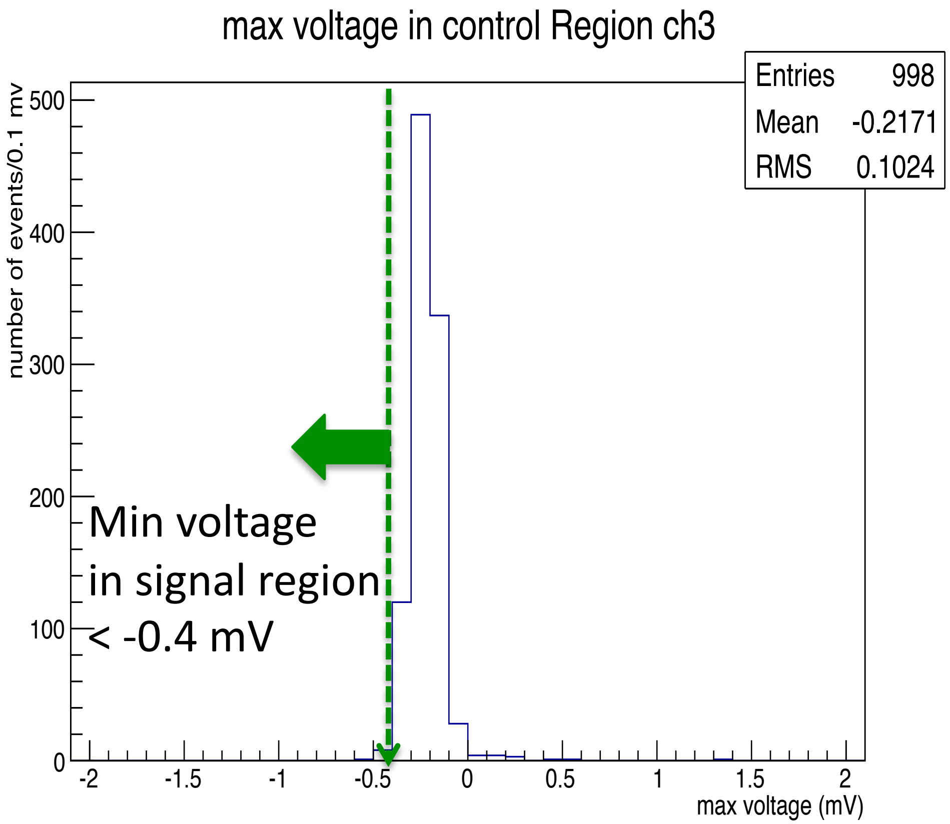
# Oscilloscope measurements

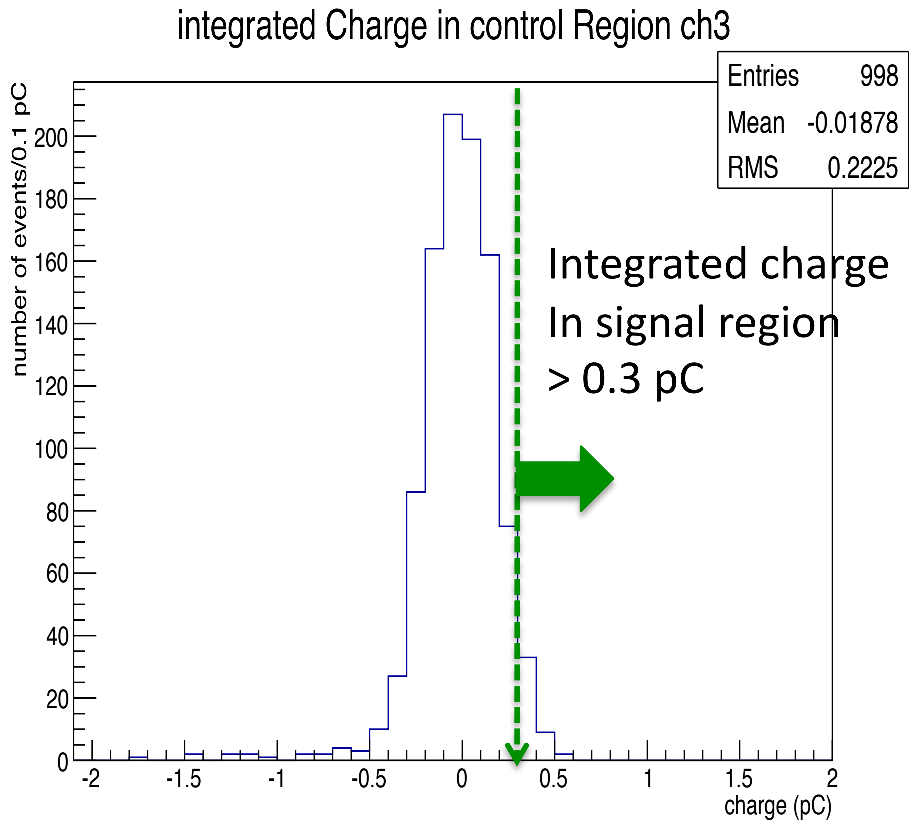


# Threshold definition




**RPC defined as efficient if: signal peak < -0.4 mV && Integrated Charge > 0.3 pC**

# RPC Streamers

- **TDC also records pulses arriving late wrt. trigger signal**

- **Try to extract information on streamers …**

In time events

Late events, streamers