RPC operation at the LHC experiments in an optimized closed loop gas system

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CERN, Switzerland

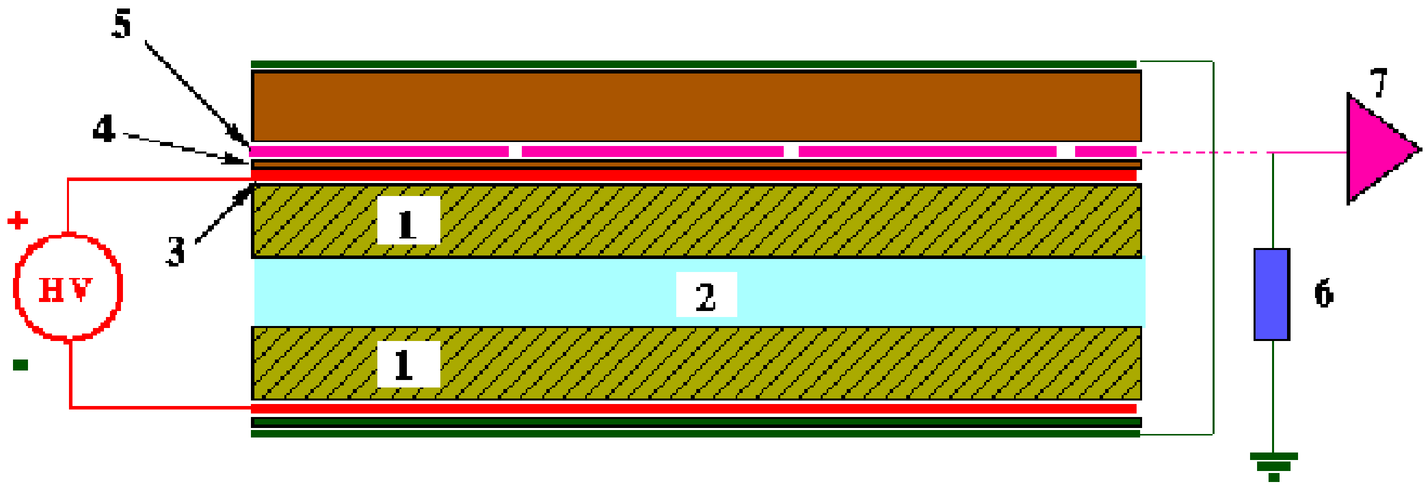
Nuclear Science Symposium
Medical Imaging Conference
25-31 October 2009 · Orlando, Florida, USA

Outline

- RPC detectors at LHC: main parameters and working conditions
- Closed loop operation and gas filtering:
  - Test set-up
  - Identification of the main impurities
  - Characterization of several cleaning agents
  - Impurities in closed loop operation
- Gas flow distribution in RPC
- Conclusions

The RPC detector

Resistive Plate Counters ➔ resistive parallel plate gaseous detector
Developed around 1980 in Italy by R. Santonico et al. NIM 187 (1981) 377-380



- **1. Electrodes: HPL made with melamine/phenol resins; Glass; Ceramic**
- Resistive electrodes: 10^{10}- 10^{12} Ωcm
- Internal electrode surface covered with a thin linseed oil layer (~µm)
- **2. Gap width: 2 mm**
- **3. High Voltage contacts: graphite paint (~100 µm)**
- **Operating pressure: atmospheric pressure**
- **Gas mixture: Ar, $C_2H_2F_4$, iC_4H_{10}, SF_6**
- **Gas flow: 0.2 vol/h**
- **Dimensions: Surface: ~ m^2, thickness: 1 cm**
- **Read-out strip: Al/Cu, ~cm**

+ In a parallel plate geometry the charge multiplication starts immediately (all the gas volume is active).

+ good time resolution (~ 1 ns)

+ not very expensive (~ 25 €/m^2)

However:

-Smaller active volume
-Electrical discharge may start more easily
-Relatively expensive gas mixture
-Environmental conditions (T and RH)

RPCs for LHC experiments

Experiment	ATLAS	CMS	ALICE MTR	ALICE TOF
Material	Bakelite	Bakelite	Bakelite	Glass
Layout	Single-gap	Double-gap	Single-gap	Multi-gap
Read-out (coordinate)	2	1	2	2
Surface (m^2)	4000	4000	140	171
Volume (m^3)	16	16	0.3	18
Expected Background rate (Hz/cm^2)	10	Barrel: 10 Endcap:100	10	50
Integrated charge (mC/cm^2)	500	Barrel: 50 Endcap: 500	50	
Gas system operation	Closed loop	Closed loop	Open mode	Closed loop
Gas mixture	$R134a/iC_4H_{10}/SF_6$	$R134a/iC_4H_{10}/SF_6$	$R134a/iC_4H_{10}/SF_6$ $Ar/ R134a/iC_4H_{10}/SF_6$	$R134a/iC_4H_{10}/SF_6$

RPCs for LHC experiments

Why RPCs for application in LHC experiments need a particular “care”?

- Huge (~4000 m^2 of sensitive area) and very expensive (6 10^6 CHF) systems (for comparison BaBar was about 2000 m^2)

- Very long period of operation expected (at least 10 years)

- Very high level of background radiation expected

- Integrated charge never reached before:
  - 50 mC/cm^2 for ALICE and CMS
  - 500 mC/cm^2 in ATLAS

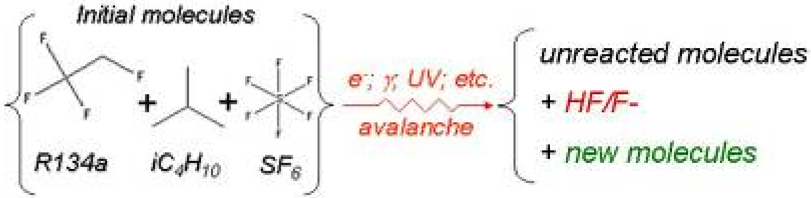
- Large detector volume → basically impossible to operate the gas system in open mode → closed loop operation → gas mixture quality

Closed loop gas circulation

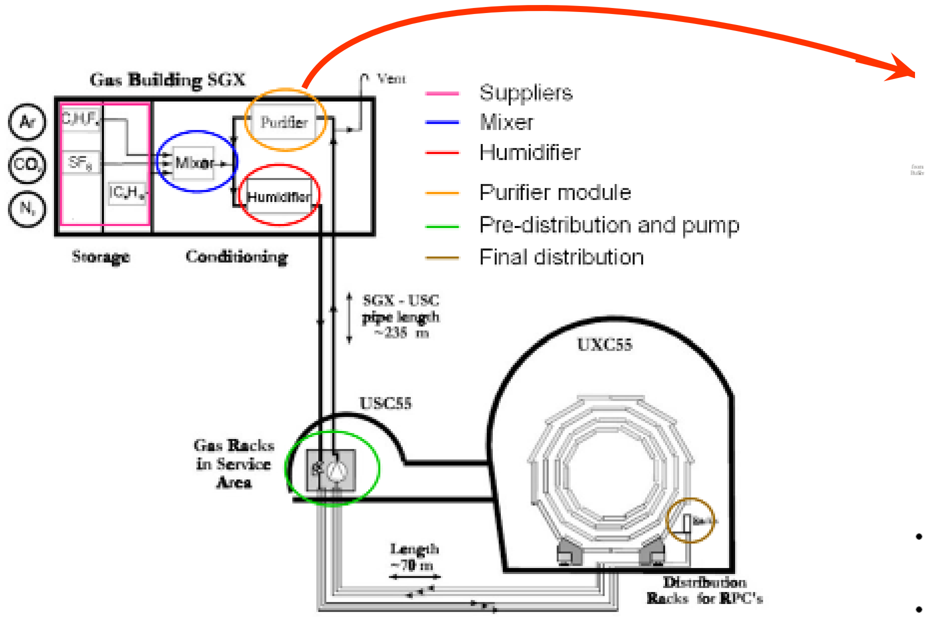
➢Large detector volume (~16 m^3 in ATLAS and CMS)
➢use of a relatively expensive gas mixture
→closed-loop circulation system unavoidable.

<u>Nowadays with 5-10 % of fresh gas replenishing rate → cost is ~700 €/day</u>

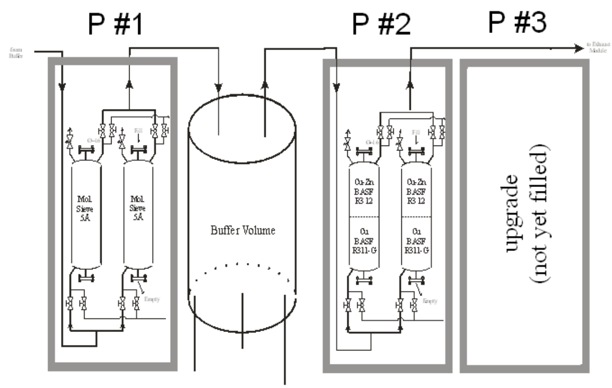
But….



❑Several extra-components appear in the return gas of irradiated RPCs
❑Detector performances can be affected if impurities are not properly removed

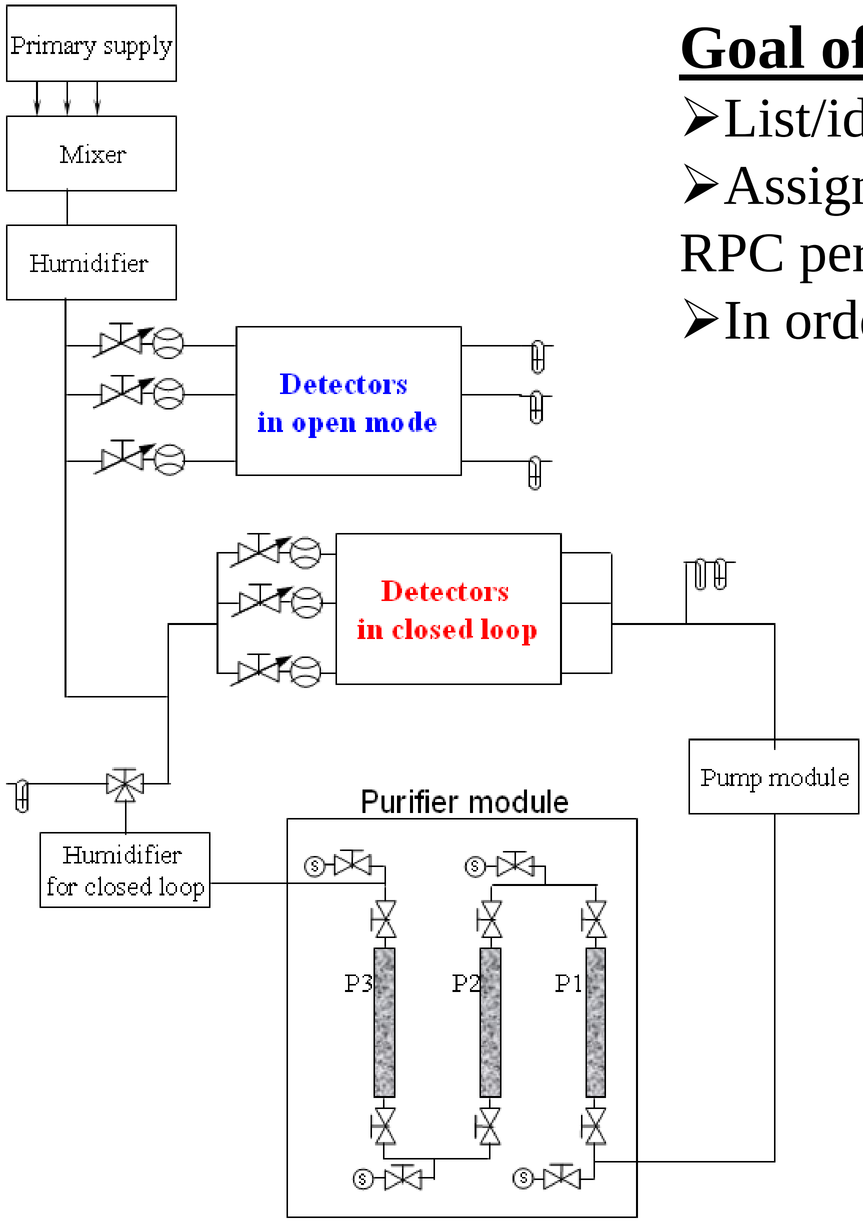


Purifiers:



- Purifier #1: Molecular Sieve (10% 5 Å + 90% 3 Å); Expected lifetime 1.5 day
- Purifier #2: Cu-Zn/Cu and Ni-Al_2O_3; Expected lifetime 15 day

RPC mixture study: test set-up



Goal of the test:

➢List/identify the impurities

➢Assign to each a danger factor according to the RPC performance

➢In order to optimize the mixture purification

➢Two sets of chambers:

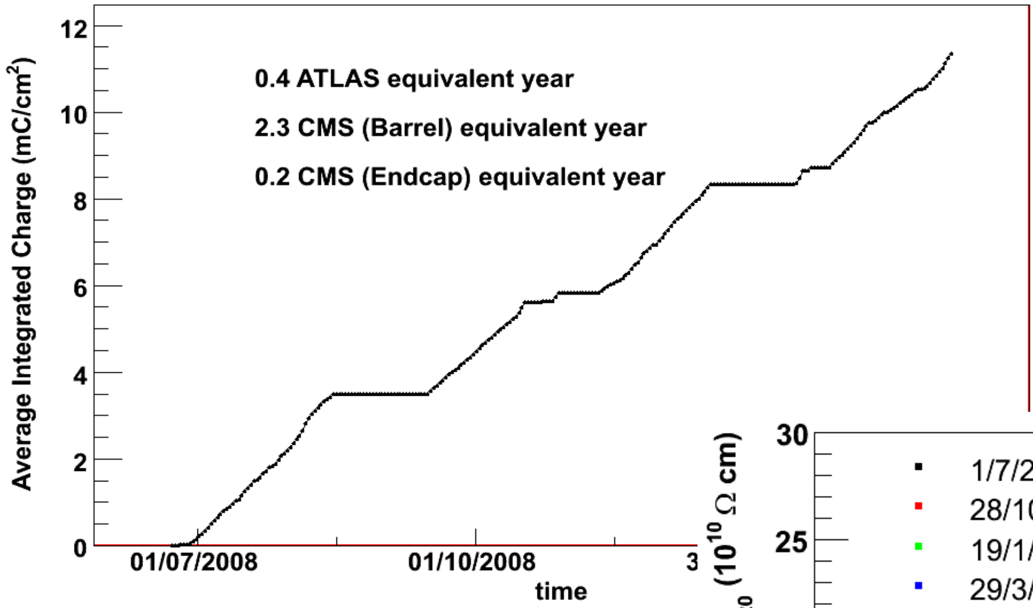
❑**open mode:** characterization of the purifiers

❑**closed loop**: filtering and/or accumulation of impurities – long term operation for validation in closed loop mode

➢High gamma radiation flux (1 cGy/h; RPC counting rate ~200 Hz/cm^2) over a large area at the CERN Gamma Irradiation Facility (GIF)

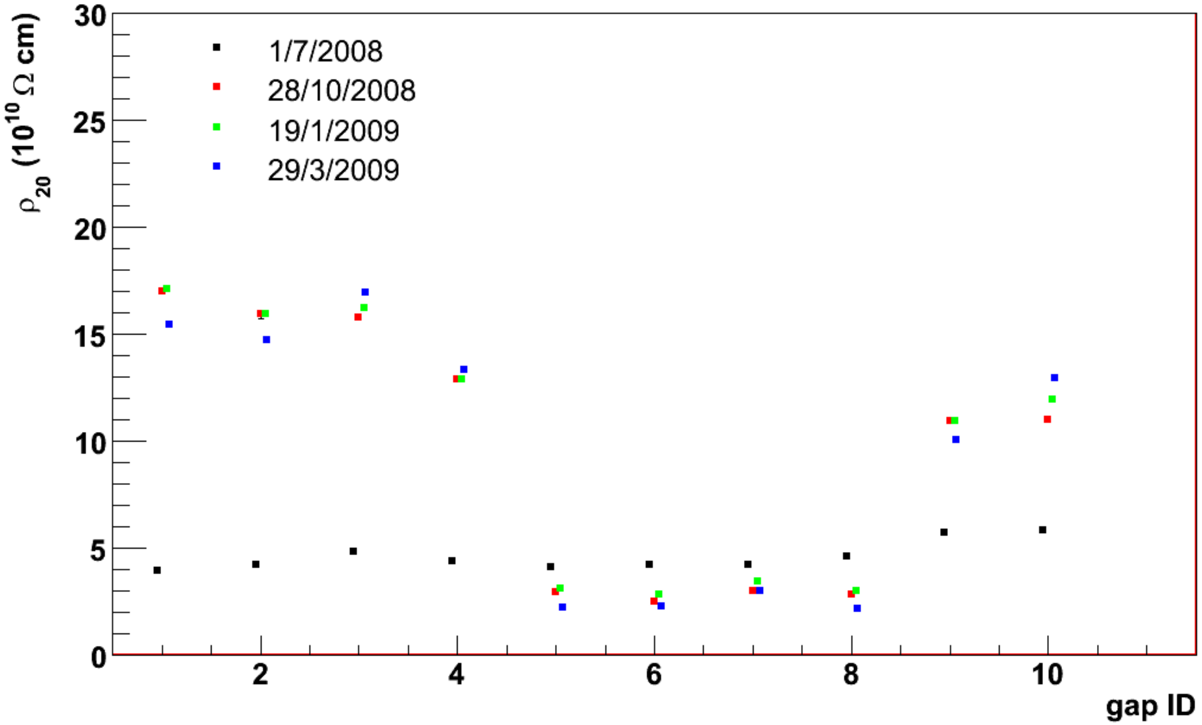
RPCs performance checks

RPC performance monitored in terms of current, HV stability, Bakelite resistivity

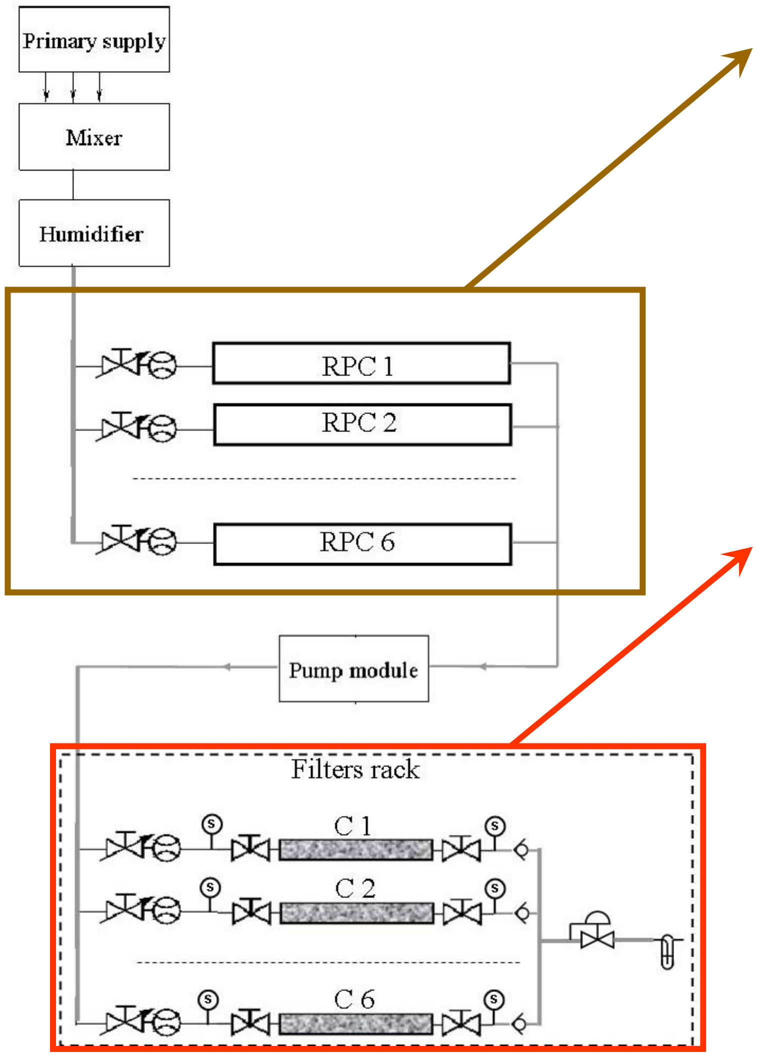


Integrated charge

Bakelite resistivity
vs time



Characterization of the purifiers



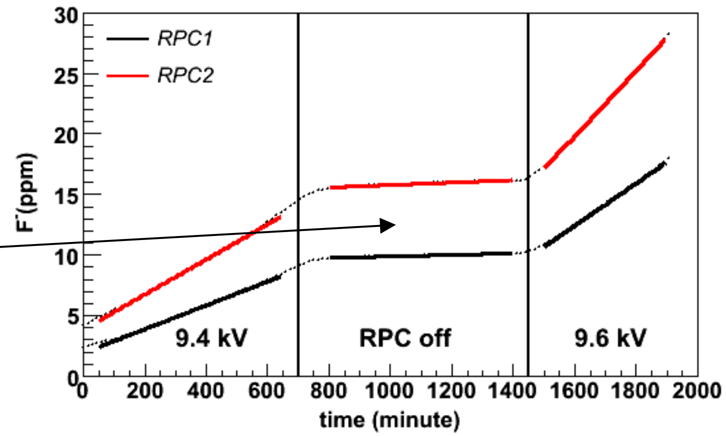
- The return gas from RPC operated under high gamma radiation
- is collected and distributed among several small cartridges.
- Each cartridge contains a specific cleaning agent
- The gas is analysed at the input and at the output of each cartridge

Gas analysis results: Fluoride

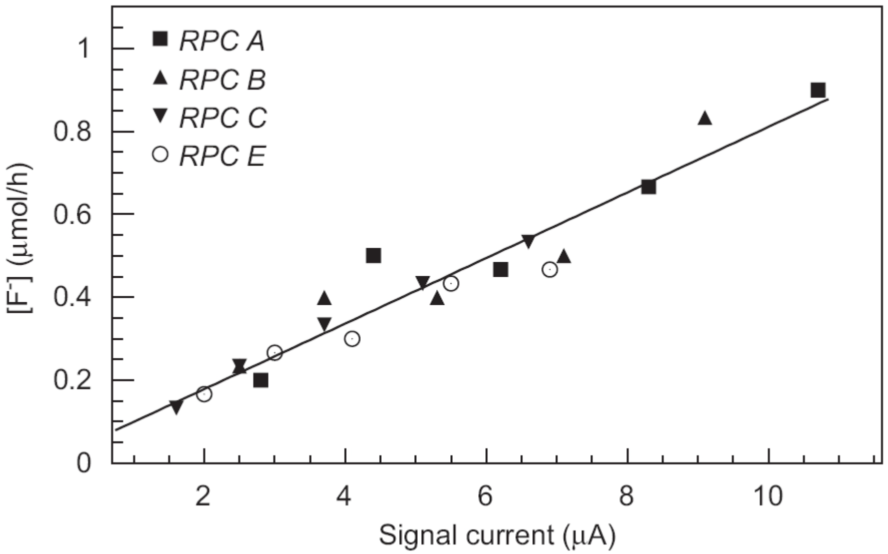
Two method used to evaluate the Fluoride concentration in the exhausted gas:

- Fluoride specific electrode
- HPLC (liquid chromatography)

Measured concentration as a function of time: basically no HF produced with radiation On and RPC Off

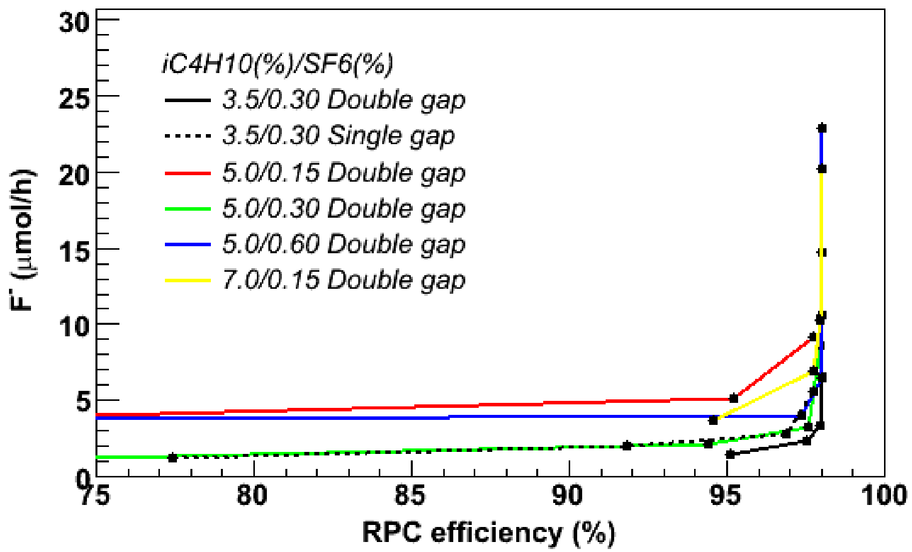


F^- production rate is proportional to the current



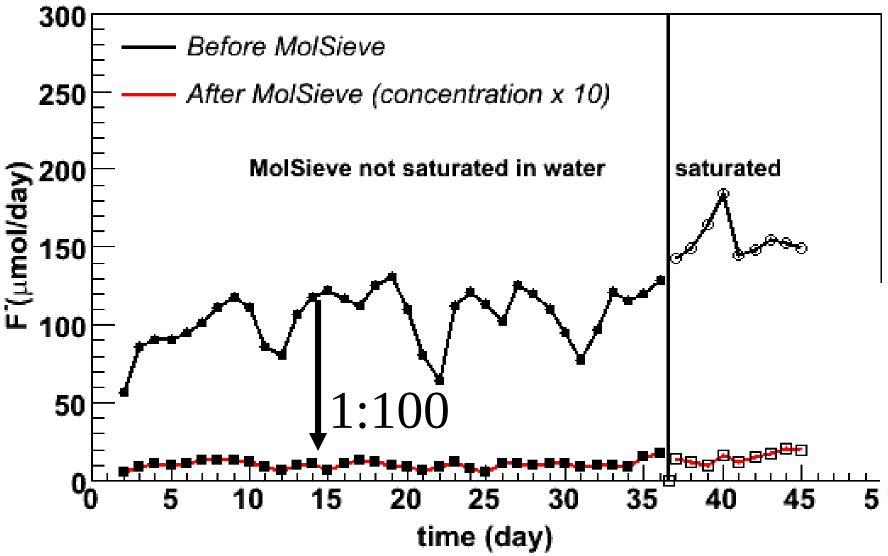
Several mixtures have been tested. Results are reported vs detector efficiency.

No real differences on a short time test.



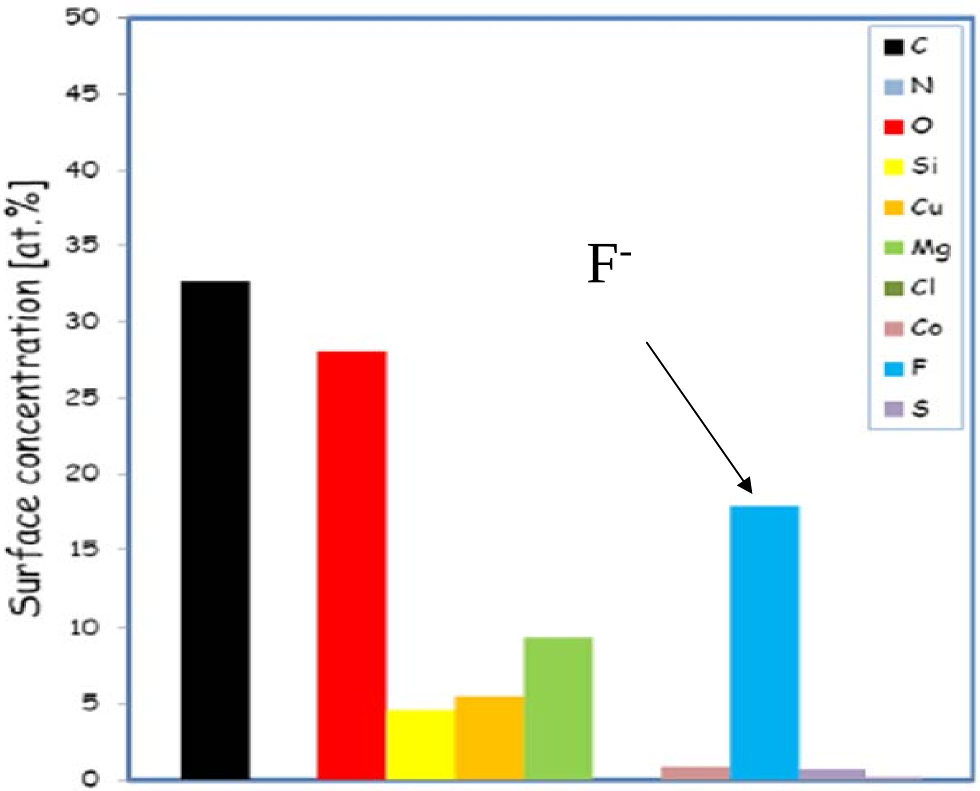
Gas analysis results: Fluoride

F^- are effectively filtered in the combination of Molecular Sieve currently in use.



We plan to study the behaviour of the other cleaning agents and the saturation level in F-

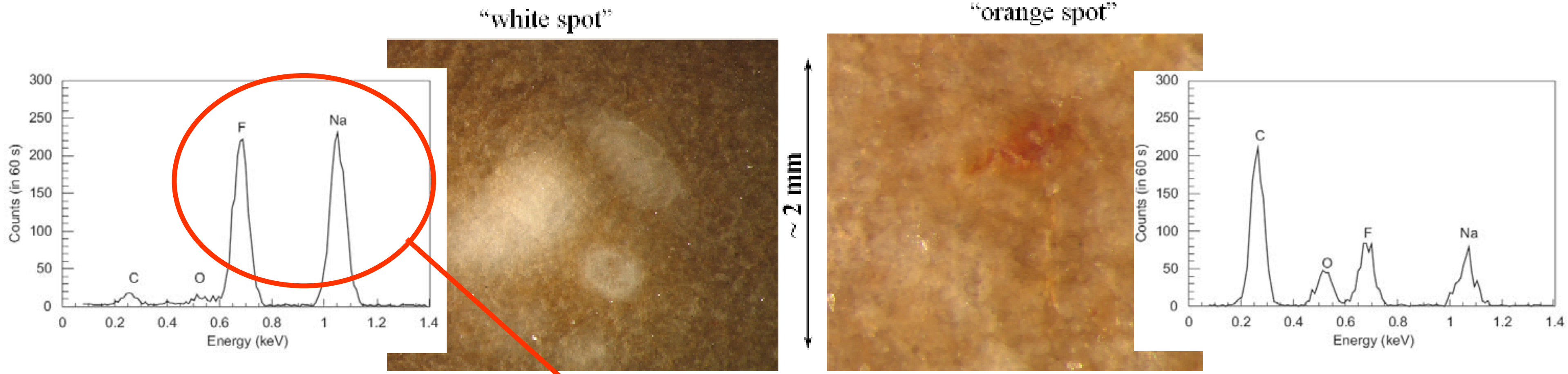
Analysis of the composition of **used absorbers** show the presence of F^-. To verify if this affects the purification effectiveness at long-term.

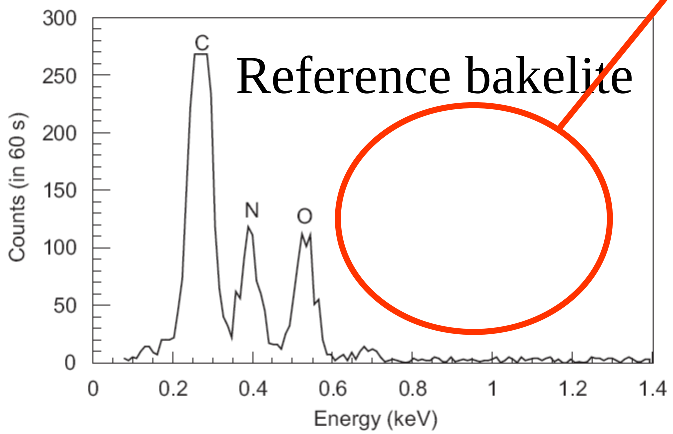


D. Letant-Delrieux, M. Taborelli (TE-VSC)

Bakelite SEM results

We analyzed few bakelite samples from an RPC with relatively high current (after an accumulated charge equivalent to 10 LHC year). The visual inspection of the surface shows at least two different kinds of surface defects:





Reference bakelite

<u>With respect to reference Bakelite surface:</u>

❖High fluorine concentration

❖Na signal appeared

❖N signal disappeared

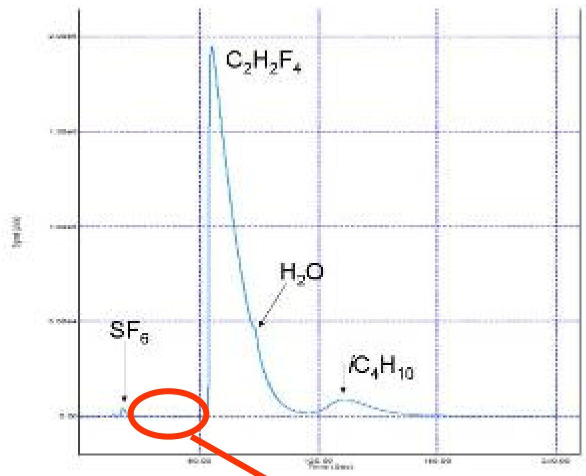
→

➢Linseed oil and melamine layer etched:

✓Na is used as a catalyser for phenolic resin (bulk)

✓Normal surface layer (made on melamine resin) contain N (not present in the “bad” spot)

Gas analysis results: chromatography



Many extra components identified in the return mixture from detector

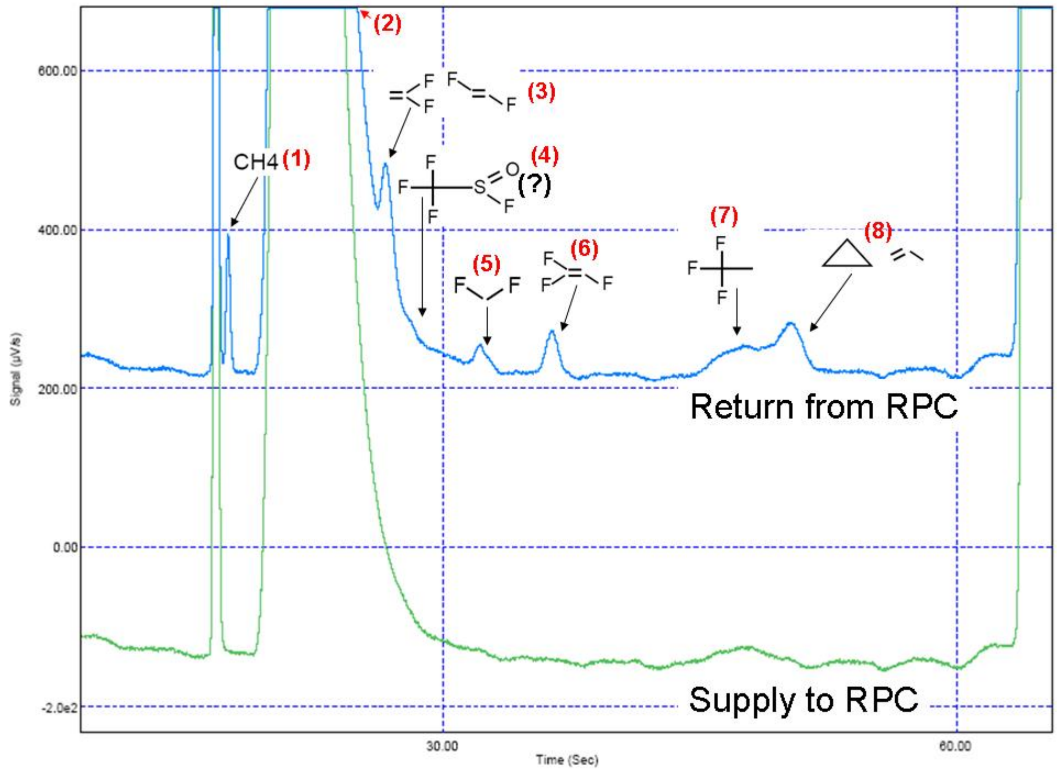
➢Operated with open mode gas system

➢Under high gamma radiation (x 30 acceleration factor)

✓Concentration at the ppm level

✓Mainly hydrocarbons

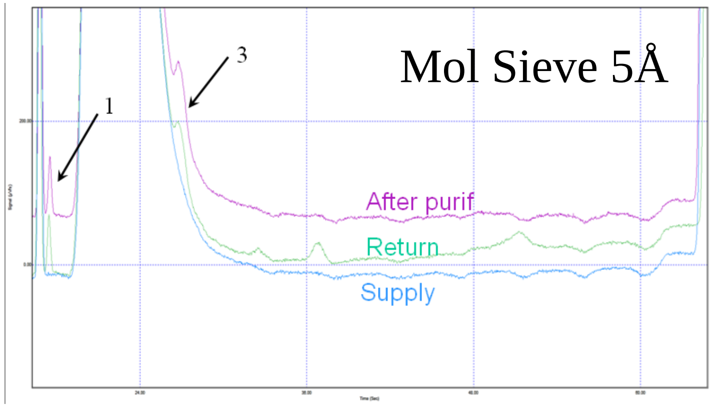
✓other Freon

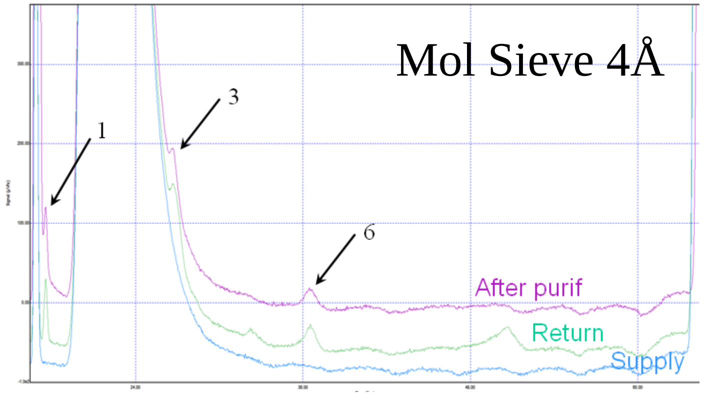


Characterization of the purifiers

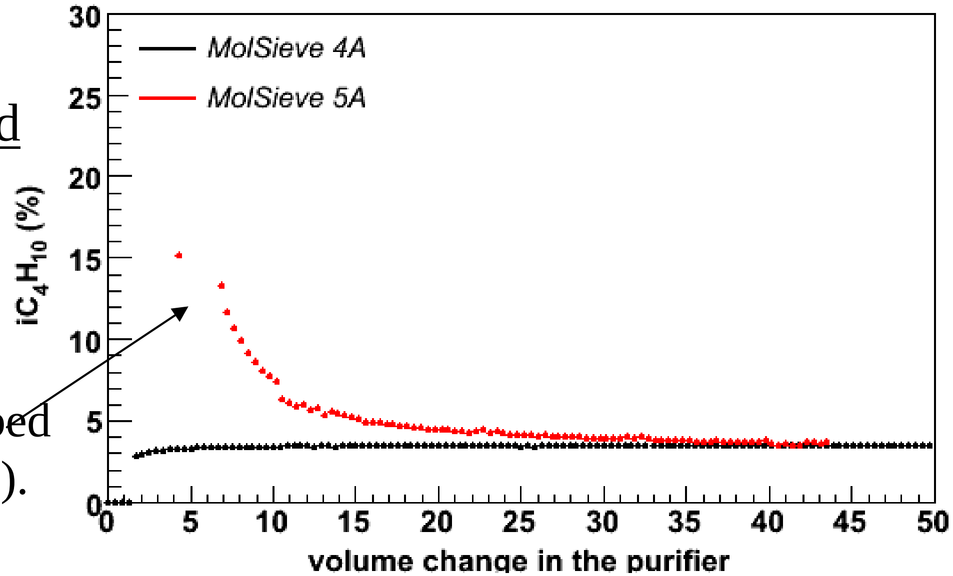
Filtering Capacity of Molecular Sieve 5Å and 4Å

Mol Sieves: filter as they should H_2O (capacity ~ 150 g(H2O)/kg(MolSieve)) +
filter some extra impurities + Absorb part of the RPC mix (need conditioning)





However, many impurities are removed (for a certain time equivalent to ~2000 volume change in the purifier cartridge)



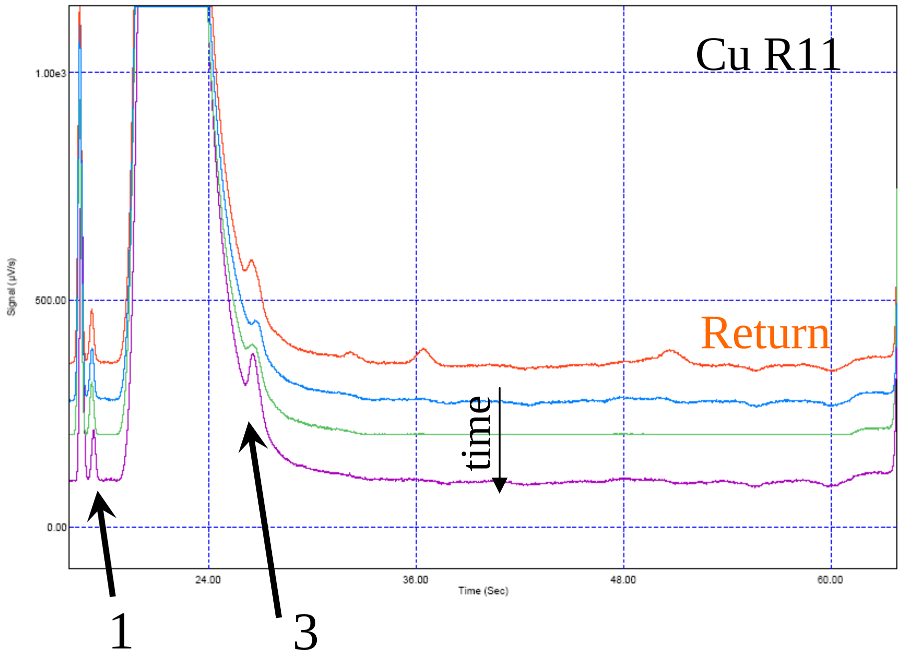
When a mixture component is also absorbed → Conditioning phase:

Some purifiers (see example of mol.sieve 5 Å) need a preparation time (conditioning phase) because at start-up they absorb a mixture component (in the example the $C_2H_2F_4$ is absorbed and as a result the iC_4H_{10} concentration increase).

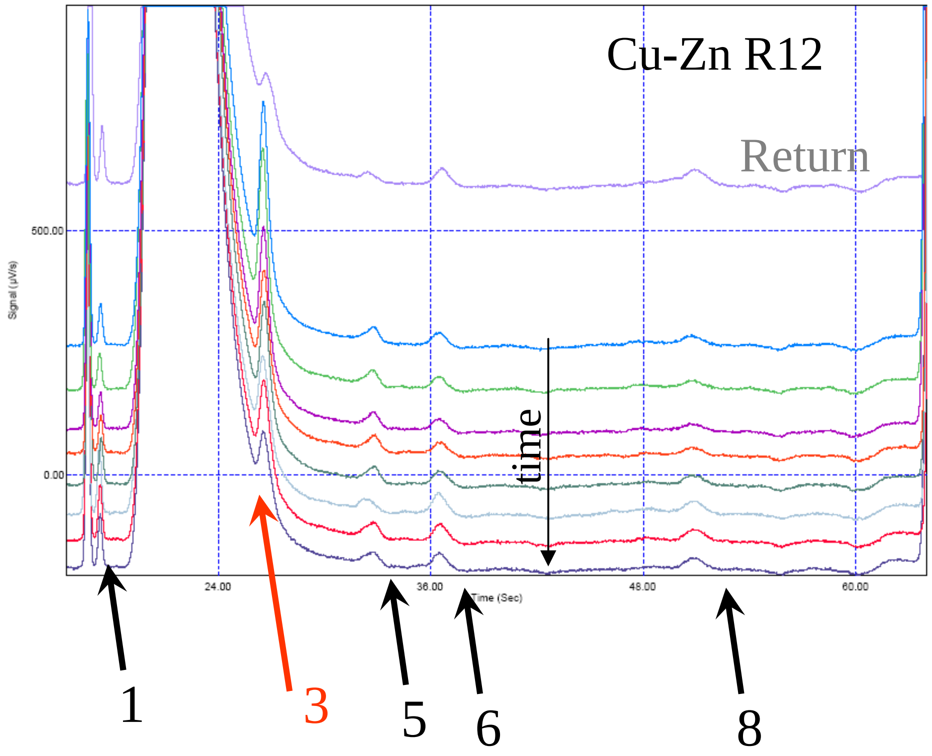
Characterization of the purifiers

Filtering Capacity of R11(Cu catalyst) and R12 (Cu-Zn catalyst)

Filter as they should O_2 (capacity ~ 5 g(O2)/kg(catalyst)) +
H_2O (capacity ~ 50 g(H_2O)/kg(catalyst)) .
R11 filters additional impurities, R12 does not and it enhance an extra component



R11 seems to be quite effective



R12: basically no extra component filtered
comp. #3 is even enhanced

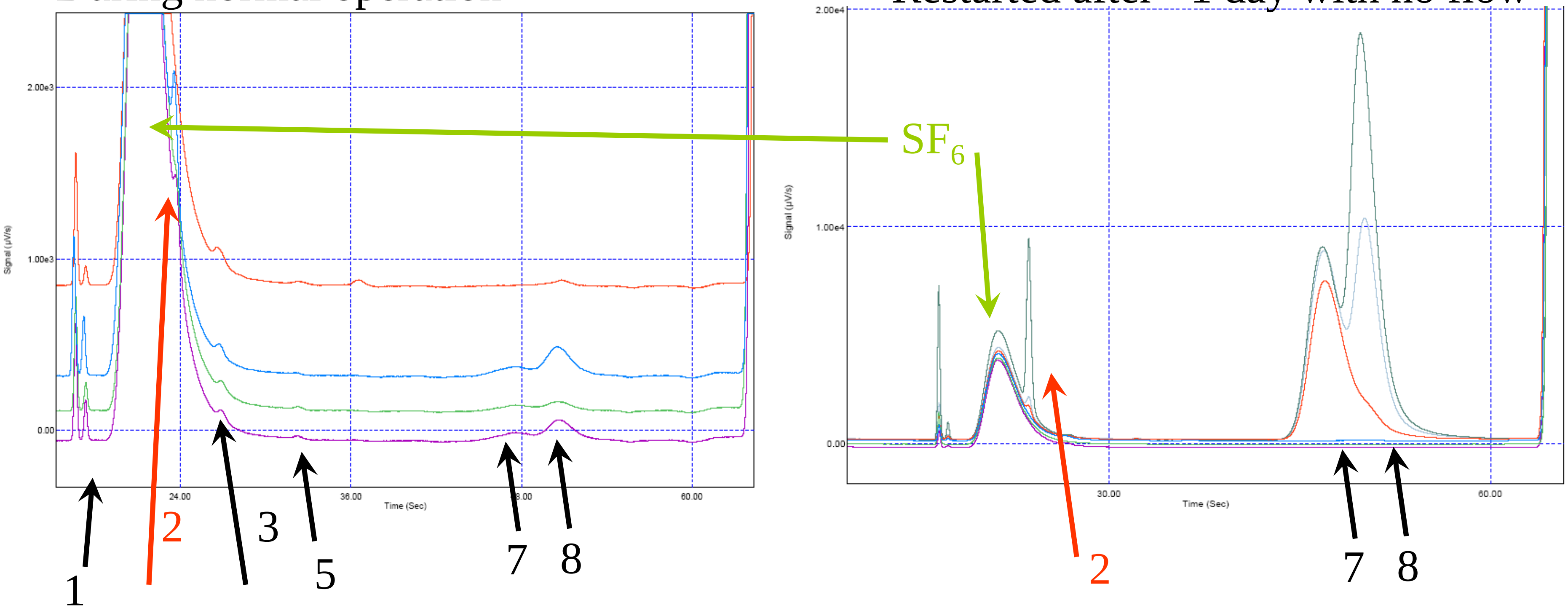
Characterization of the purifiers

Filtering Capacity of Ni-Al_2O_3 catalyst

Filter as it should O_2 (capacity ~ 15-20 g(O2)/kg(catalyst)) +
H_2O (capacity ~ 50 g(H_2O)/kg(catalyst)) .
Filters additional impurities, but it enhance also an extra component

During normal operation

Restarted after ~1 day with no flow



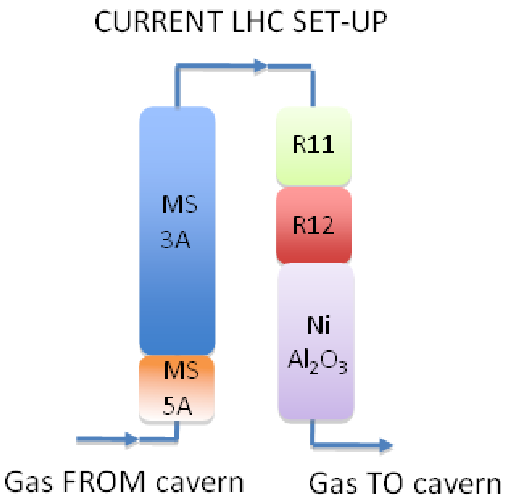
Component #2 (not present in return mixture) is strongly enhanced
After a short stop, the catalyst is releasing important concentration of extra-components (in the plot they can be compared with the SF_6 signal)

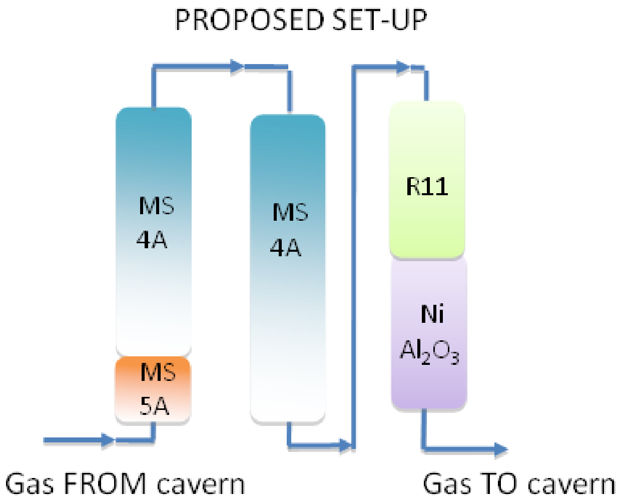
Characterization of the purifiers

Systematic understanding of a set of purifiers vs some impurities

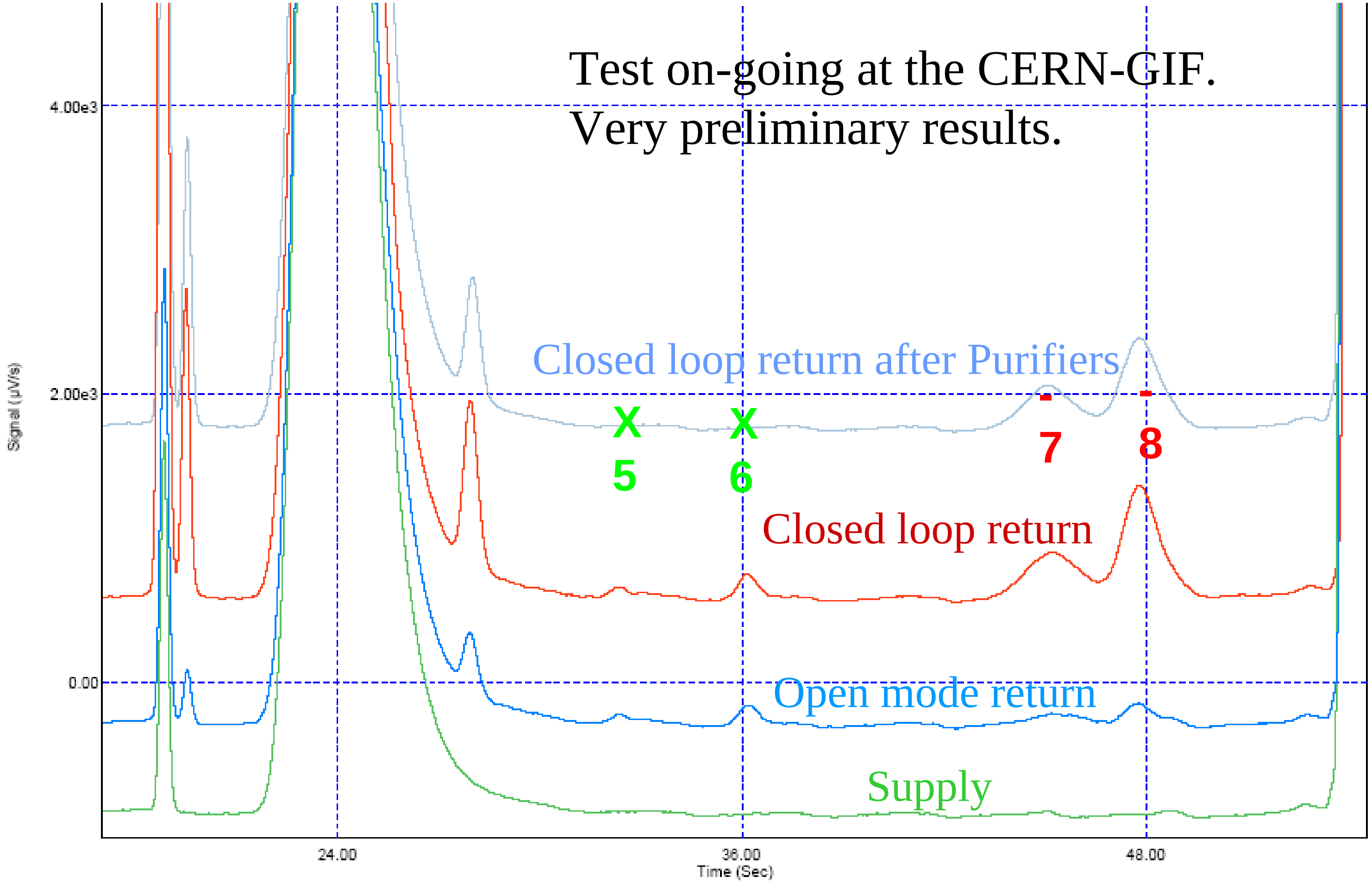
	Conditioning (volume change)	Main component filtered	Saturation (g/kg)	1 CH_4	3 $C_2H_2F_2$	5 CH_2F_2	6 C_2HF_3	7 $C_2H_3F_3$	8 C_3H_6
MS3A	3	H_2O	140	Unch.	Unch.	Unch.	Unch.	Unch.	Unch.
MS4A	10	H_2O	170	Unch.	Unch.	Rem.	Unch.	Rem.	Rem.
MS5A	50	H_2O	130	Unch.	Back after 1000 vol change	Rem.	Rem.	Rem.	Rem.
Cu R11	20	O_2	4	Unch.	Unch.	Unch.	Rem.	Rem.	~Rem.
Cu/Zn R12	20	O_2	4	Unch.	Enhanced	Unch.	Rem.	Rem.	450 vol change
Ni Al2O3	15	O_2	15	Unch.	Unch.	Unch.	Rem.	150 vol change	150 vol change
Ni SiO2	15	O_2	15	Unch.	Unch.	Unch.	Rem.	Unch.	Unch.

MS5Å, MS4Å; Cu-R11; Ni-Al_2O_3 selected for the test in closed loop…..





Closed loop operation



➢After few days of operation, only impurities 5 and 6 are still removed.

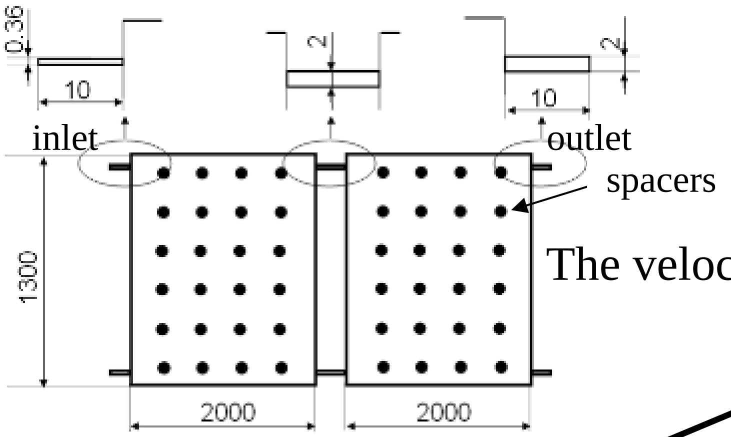
➢Some extra-components show higher concentration in closed loop return wrt open mode return (as expected if not completely filtered)

➢RPC performances do not show any degradation

Gas flow distribution

Experience says that the gas flow has to be at least ~ 0.3 vol/h even without radiation
Is the gas distribution inside the gap the origin of this limit?
Is there a room for future improvements?
Can we remove more effectively the impurities from the gas volume?

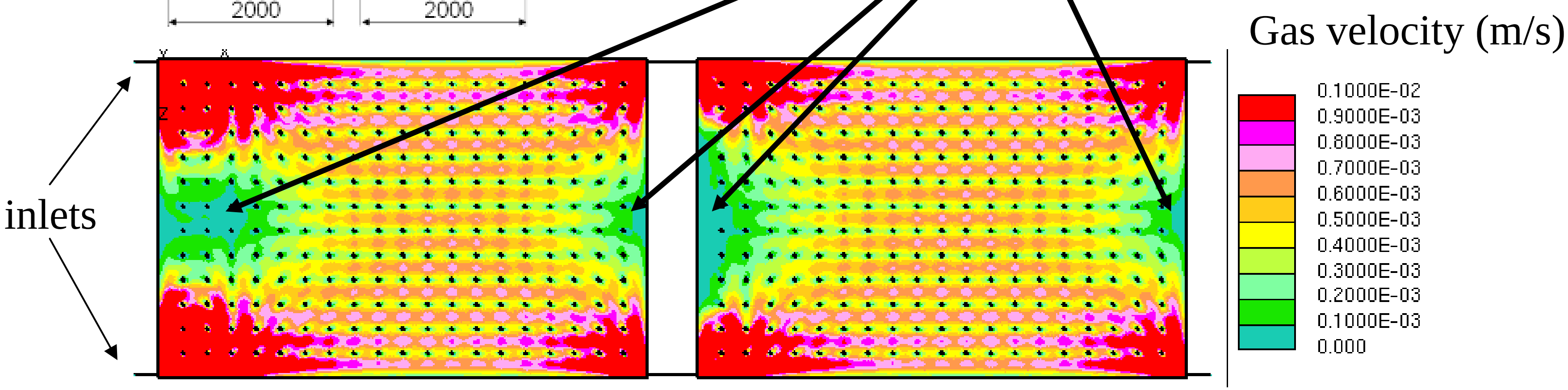
Some preliminary results coming from a finite element simulation:



Thanks to CFD team

Waldemar Maciocha
Antonio Romanazzi

The velocity field shows areas in which the gas is hardly moving



Conclusions

- Two sets of RPCs (one working in open mode and the other in closed loop) are being operated under a high gamma radiation at the CERN-GIF (Gamma Irradiation Facility).

- Many impurities, present in the RPC return gas mixture, have been identified (Fluoride ion, hydrocarbons, other Freon,..).

- A systematic study of cleaning agents has been performed: allowing to select the "best" combination for a long-term closed loop operation under high gamma radiation (long-term validation on-going).

- Simulation studies of the gas flow in RPCs show regions where gas molecules move very slowly. This can lead to a local accumulation of impurities that can define the overall RPC performance. We are studying realistic ways to optimize the flow gas distribution.