



EP-DT
Detector Technologies



Gas mixture quality monitoring for the RPC detectors at the LHC experiments

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Outline

Gas recirculation systems for the RPC detectors at LHC

Radiation effects on the RPC gas mixture

Gas analysis techniques for the RPC gas mixture

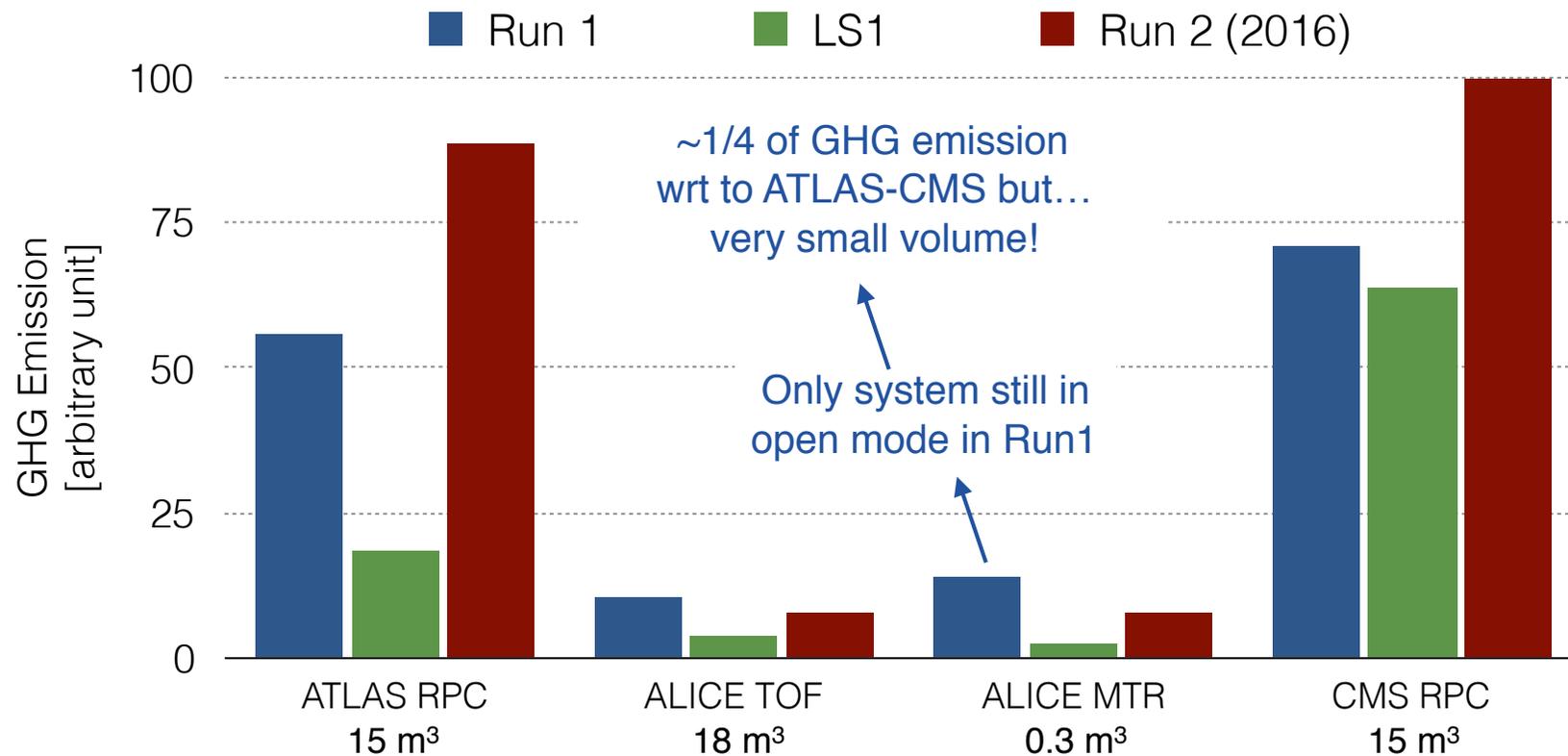
The ALICE MTR gas analysis campaign during LHC Run2

Conclusions

RPC detectors at LHC experiments

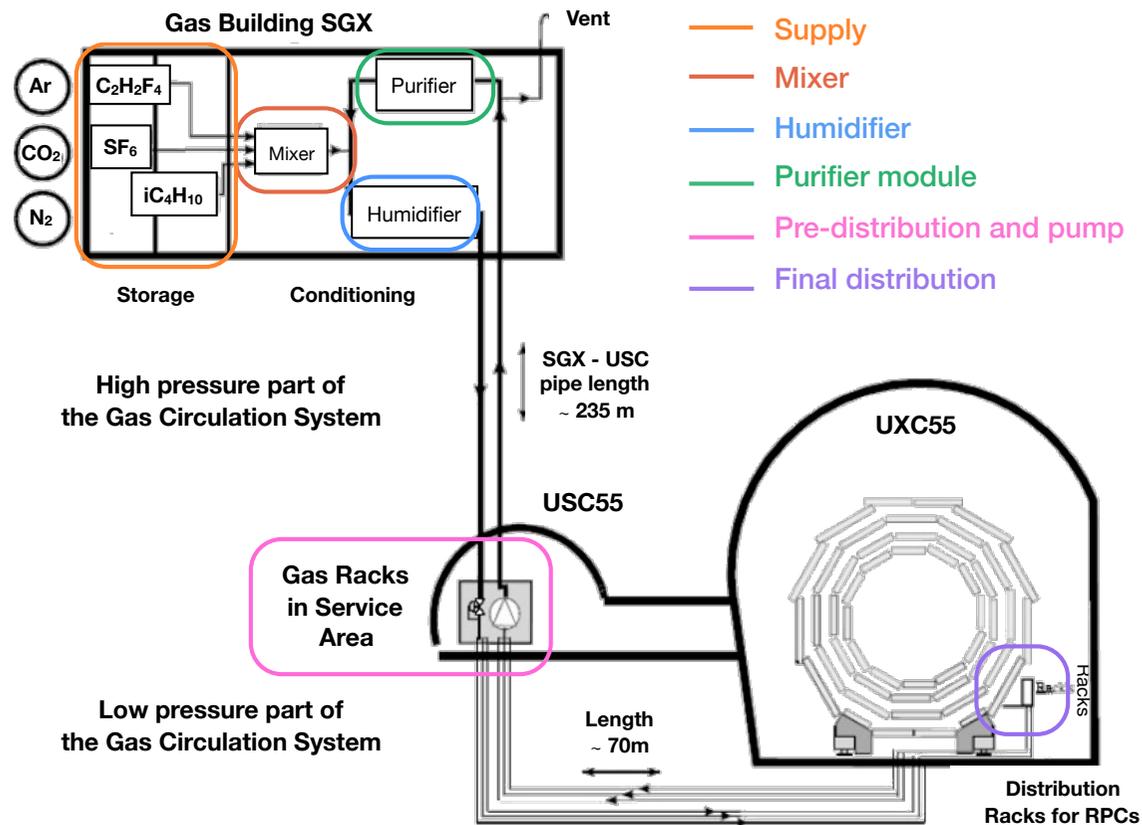
Experiment	ATLAS	CMS	ALICE (MTR)	ALICE (TOF)
Material	Bakelite	Bakelite	Bakelite	Glass
Layout	Single-gap	Double-gap	Single-gap	Multi-gap
Read-out (coordinate)	2	1	2	2
Surface (m ²)	7500	3750	140	171
Volume (m ³)	15	15	0.3	18
Counting rate (Hz/cm ²)	~10	Barrel: ~10 Endcap: ~100	~10	~50
Integrated charge (mC/cm ²)	500	Barrel: 50 Endcap: 500	50	25
Gas system operation	Closed loop	Closed loop	Closed loop*	Closed loop
Gas mixture	R134a/iC ₄ H ₁₀ /SF ₆	R134a/iC ₄ H ₁₀ /SF ₆	R134a/iC ₄ H ₁₀ /SF ₆	R134a/SF ₆

RPC GHG consumption at CERN



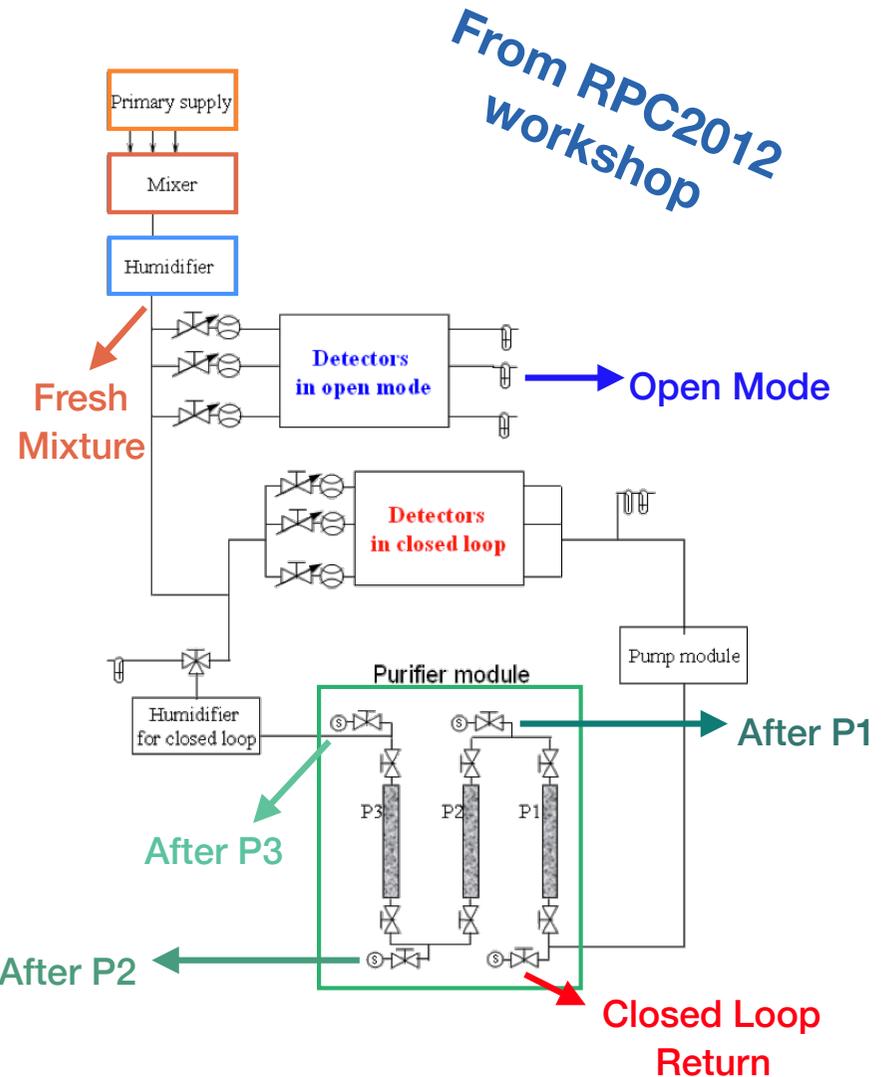
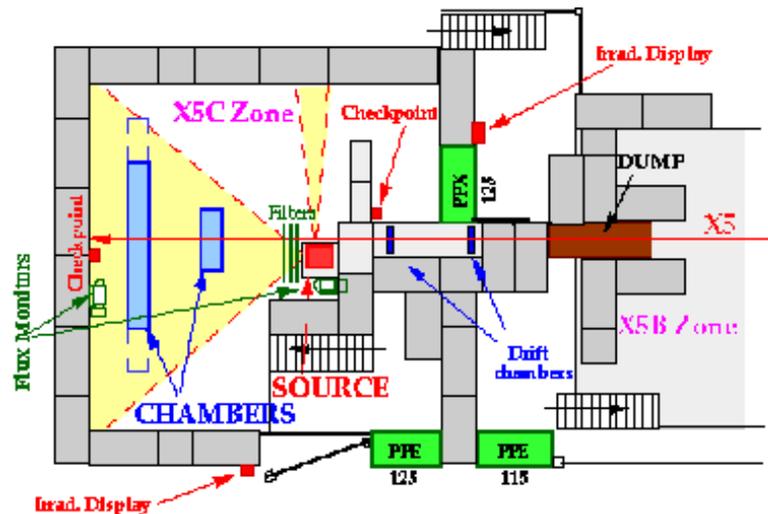
- ATLAS and CMS: GHG emission due to leaks in the detectors
 - Maximum recirculation fraction is set by leaks at ~90%
- ALICE TOF: recirculation >90%
 - No leaks at the detector level
- ALICE MTR: in 2015 upgrade of gas system from open to gas recirculation
 - Very small system but in open mode gas consumption very high wrt other systems
 - In agreement with experiment, gas recirculation fraction between 50 and 70%

Gas Recirculation systems for RPC at LHC



- GHG and expensive gas mixture make recirculation system compulsory
 - ~ 80% of detector GHG emission is from RPC systems
 - CMS and ATLAS RPC gas mixture cost is > 600 euro/day
- **Critical points in recirculation systems**
 - Pressure and flow regulation for each chamber
 - Possible accumulation of **impurities**
 - Use of cleaning agents compulsory

Previous long-term test at GIF: set-up



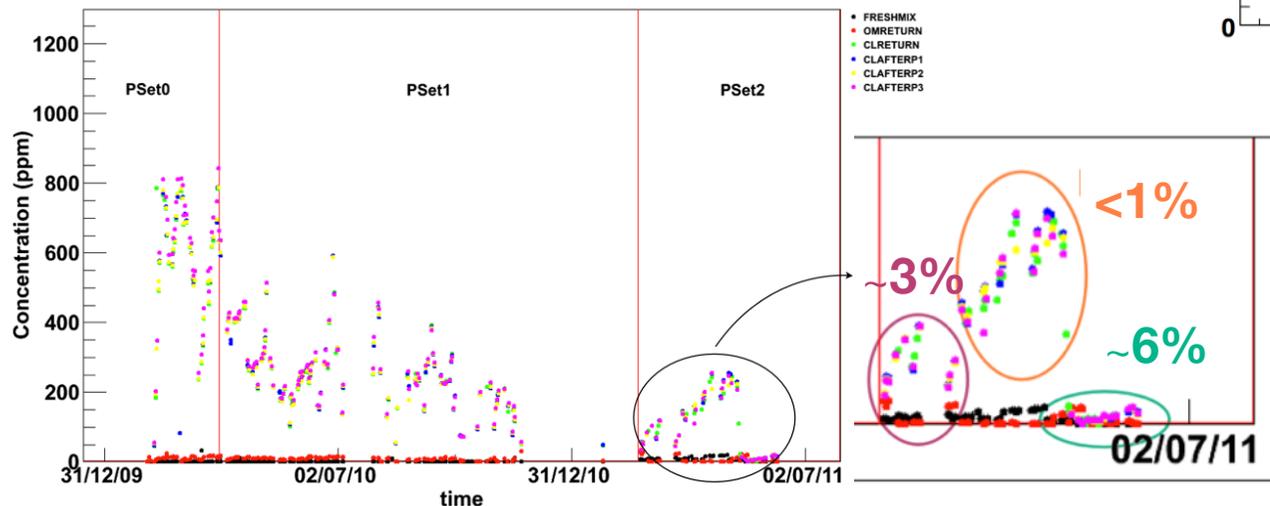
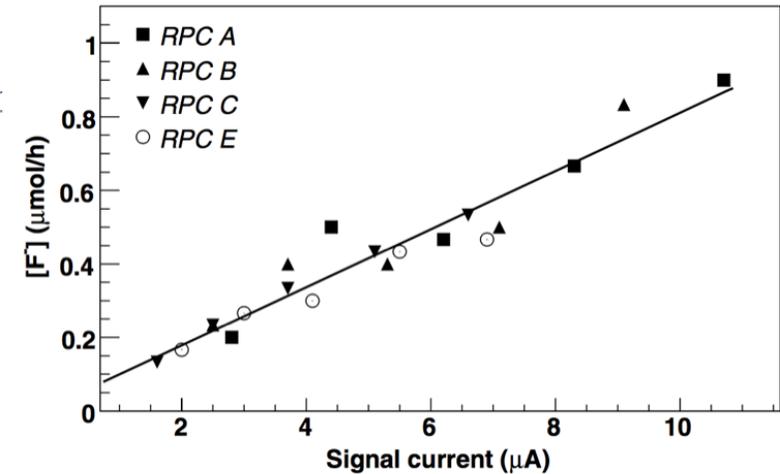
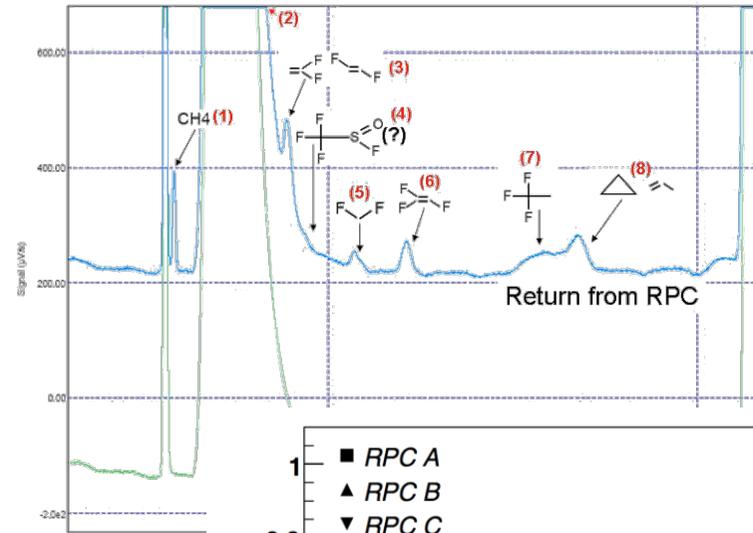
- (Old) GIF (Gamma Irradiation Facility)
- ^{137}Cs source of 590 Gbq
- Accelerator factor: 30
- Operation of RPC detectors in recirculation mode at GIF
 - Small replica of LHC gas system
 - RPC performance in recirculation mode
 - Gas analysis in different gas points
 - RPC counting rate $\sim 200 \text{ Hz/cm}^2$
 - Accumulated $\sim 100 \text{ mC/cm}^2$

For more info:

<https://doi.org/10.1088/1748-0221/8/08/T08003>

Previous long-term test at GIF: results

- Under the effects of high background radiation and electric field, $C_2H_2F_4$ molecule breaks into fluorine radicals
- Creation of $F\cdot$ radical free
- Sub-products in the order of hundreds ppm
- Accumulation in case of closed loop system
- Cleaning agents help in reducing these impurities
- Help but they do not completely remove
- Different types of cleaning agents necessary
- Gas recirculation fraction plays a key role
- With 100% recirculation: high concentration

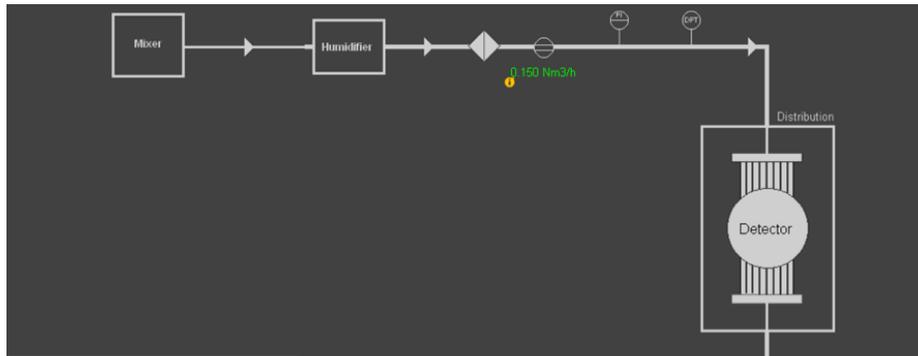


The impurity concentration is relatively high.

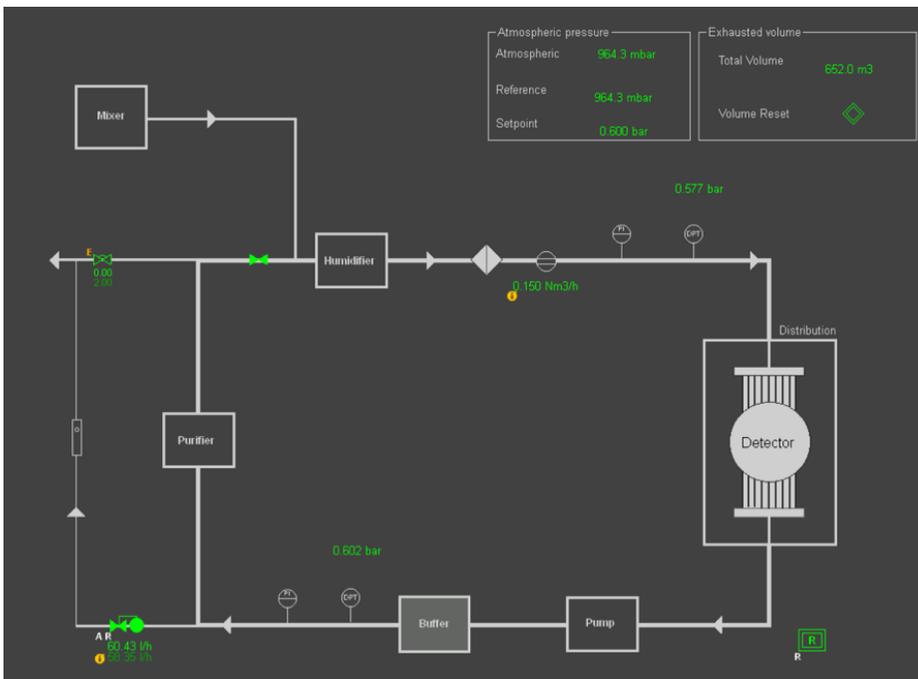
The impurity concentration is high.

The impurity is under control.

Monitoring the MTR transition to gas recirculation



- Open mode very simple
 - Gas mixture humidified and then injected into the detectors
 - Gas mixture exiting the detectors is sent to the atmosphere
 - Few parameters to monitor

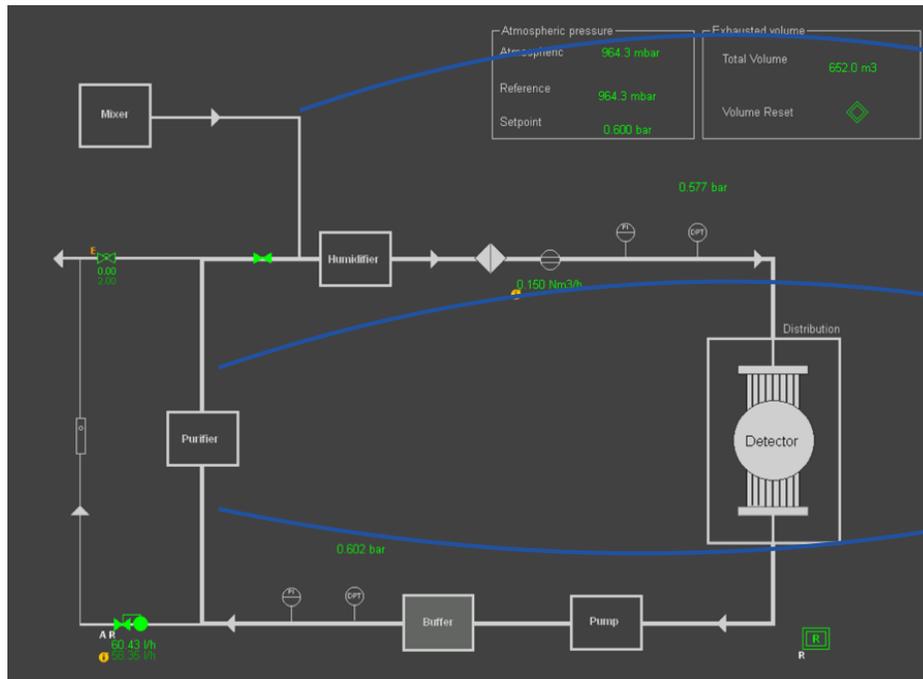


- Upgrade to gas recirculation
 - Addition of several gas modules —> addition of complexity to the system
 - Gas mixture exiting the detectors is recycled
 - Recirculation fraction adjustable
 - Purifier necessary to maintain correct humidity and O₂ level
 - Several parameters to monitor

Monitoring of the gas mixture composition

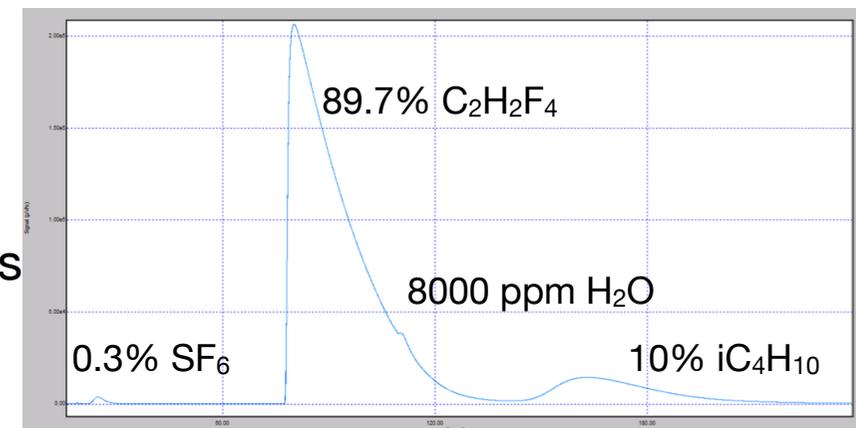
- With respect to ATLAS and CMS RPC, ALICE MTR has higher pulse charge
 - At GIF it was demonstrated that higher charge —> higher probability to create fluorine radicals

Gas analysis for the ALICE MTR gas system

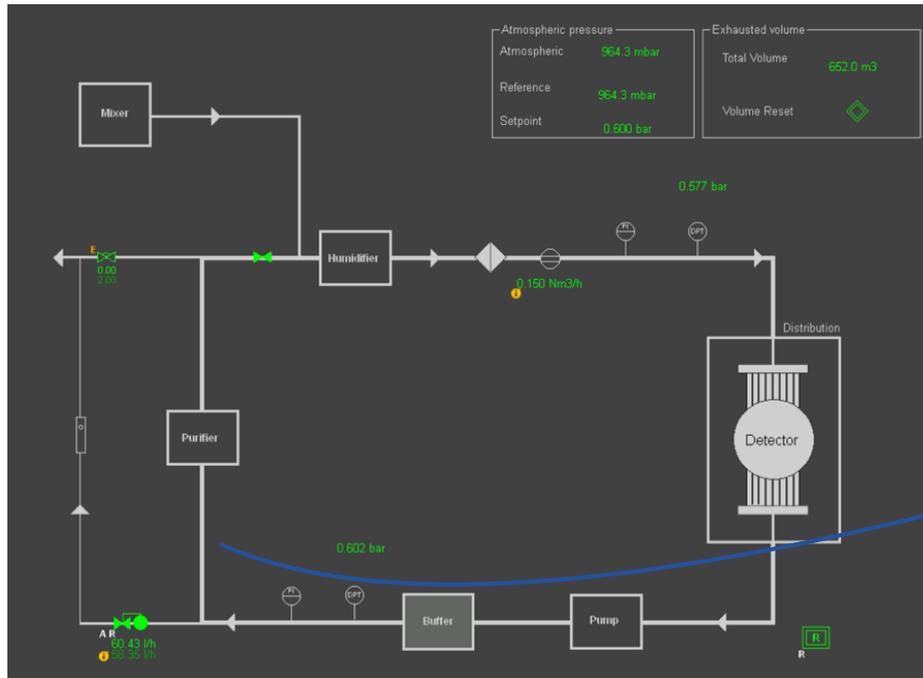


Gas Chromatograph coupled with a Mass Spectrometer

- Gas Chromatograph: it separates and quantifies the gas mixture components
 - Measurements are in uV over time
 - Sensitivity ~ppm
- Mass Spectrometer: it identifies the different gases
 - Very useful in case of unknown components
 - Ions are separated by deflection in a magnetic field according to their m/z

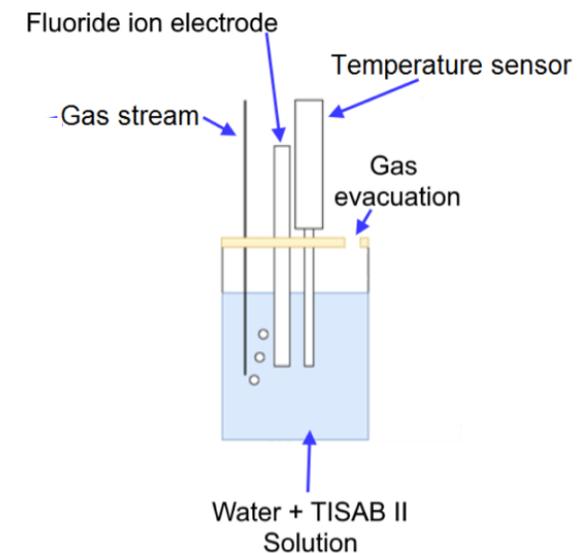


Gas analysis for the ALICE MTR gas system



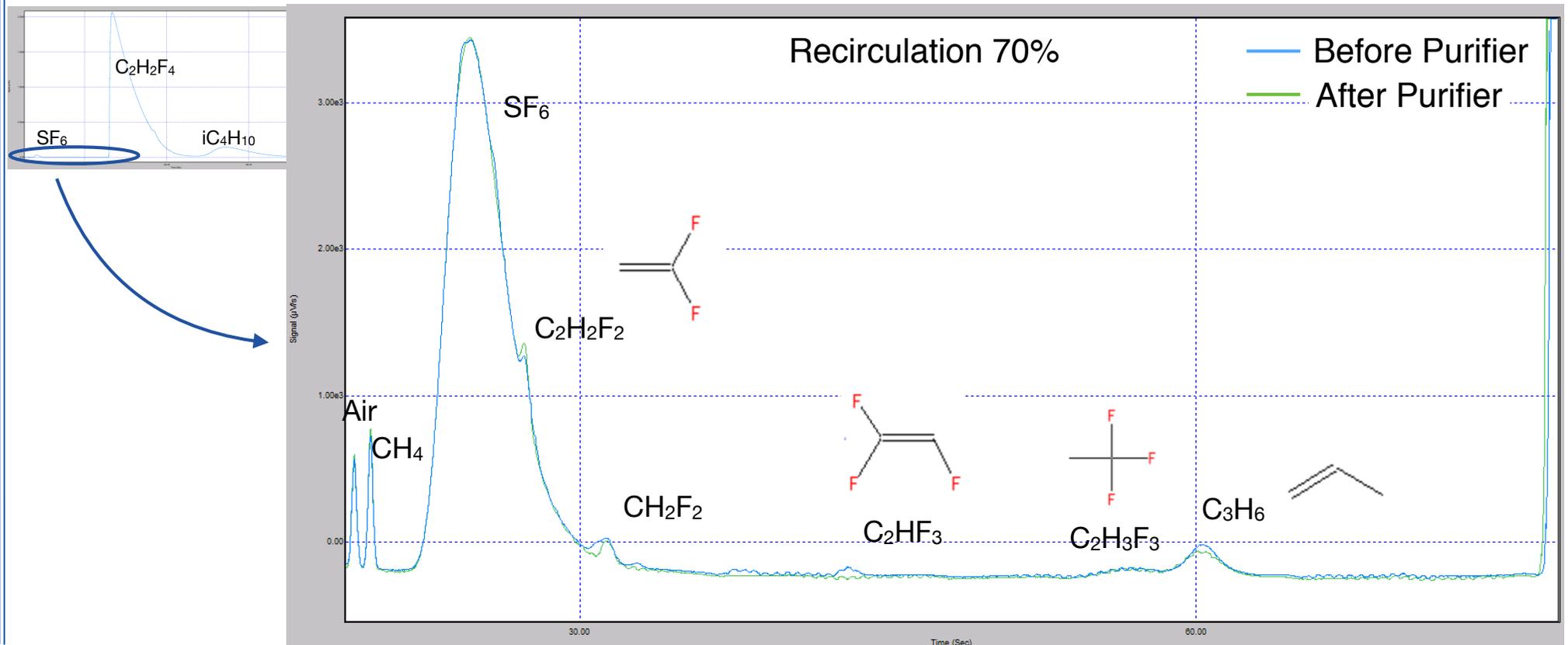
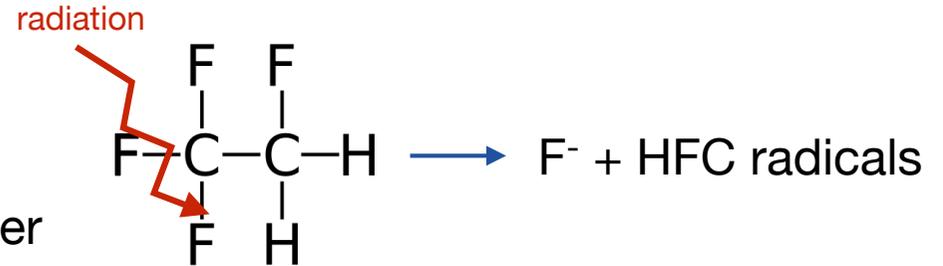
Ion Selective Electrode (ISE) station

- It measures fluoride ions in aqueous solutions
 - When the F^- sensing element is in contact with a solution containing fluoride ions, an electrode potential develops.
 - The potential depends on the level of free fluorine ions in solution (Nernst equation)
- Gas mixture is bubbled in water+TISAB II solution
 - Bubbler efficiency in trapping the HF

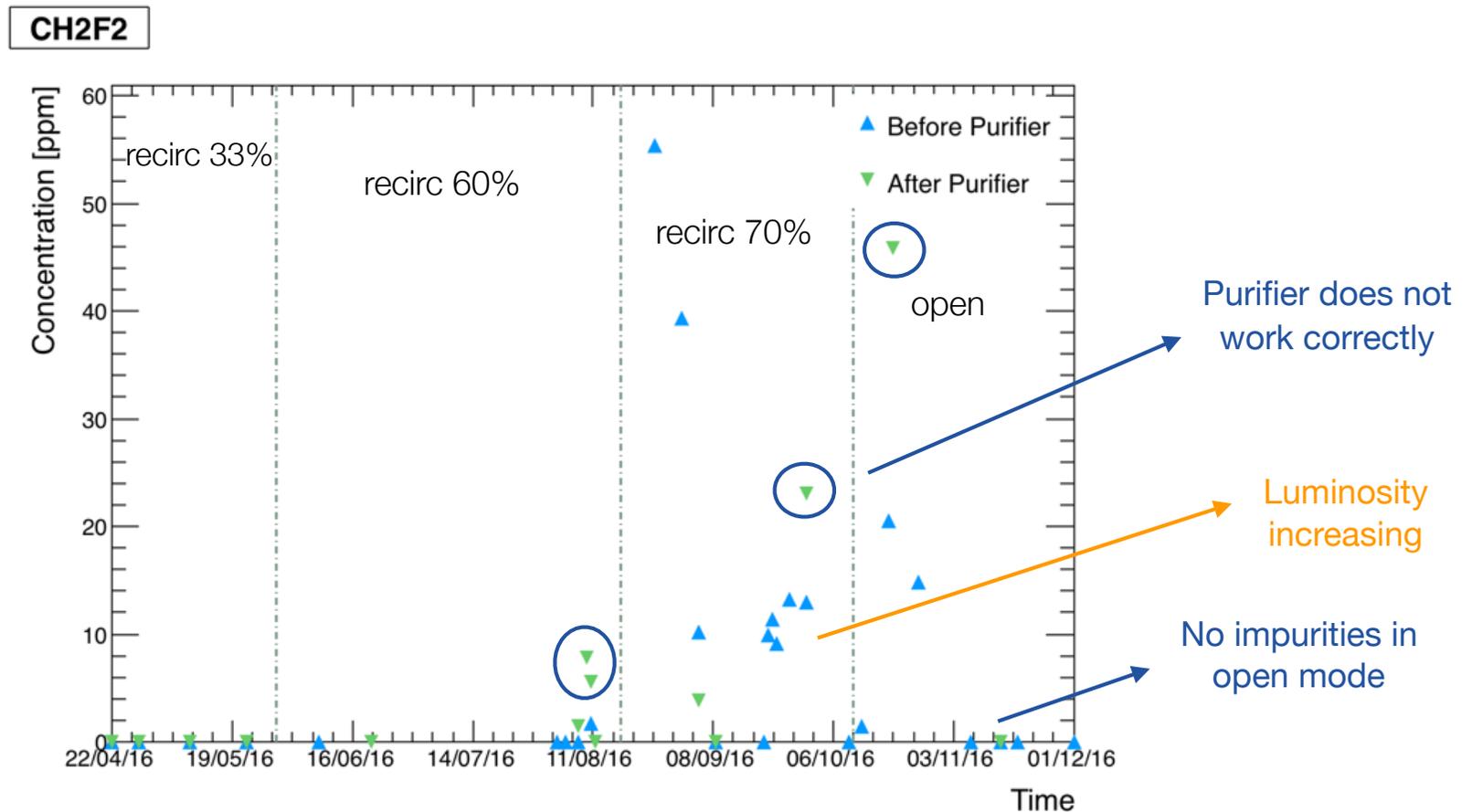


GC/MS analysis of ALICE MTR gas mixture

- Identification and quantification of impurities
 - Clearly created from $C_2H_2F_4$ breaking
 - Concentration is of the order of tens of ppm
 - Same impurities as seen in test at GIF
- Difference between “before” and “after” purifier
 - Purifiers help in eliminating impurities
- GC/MS analyses every 2 weeks in 2016 and 2017

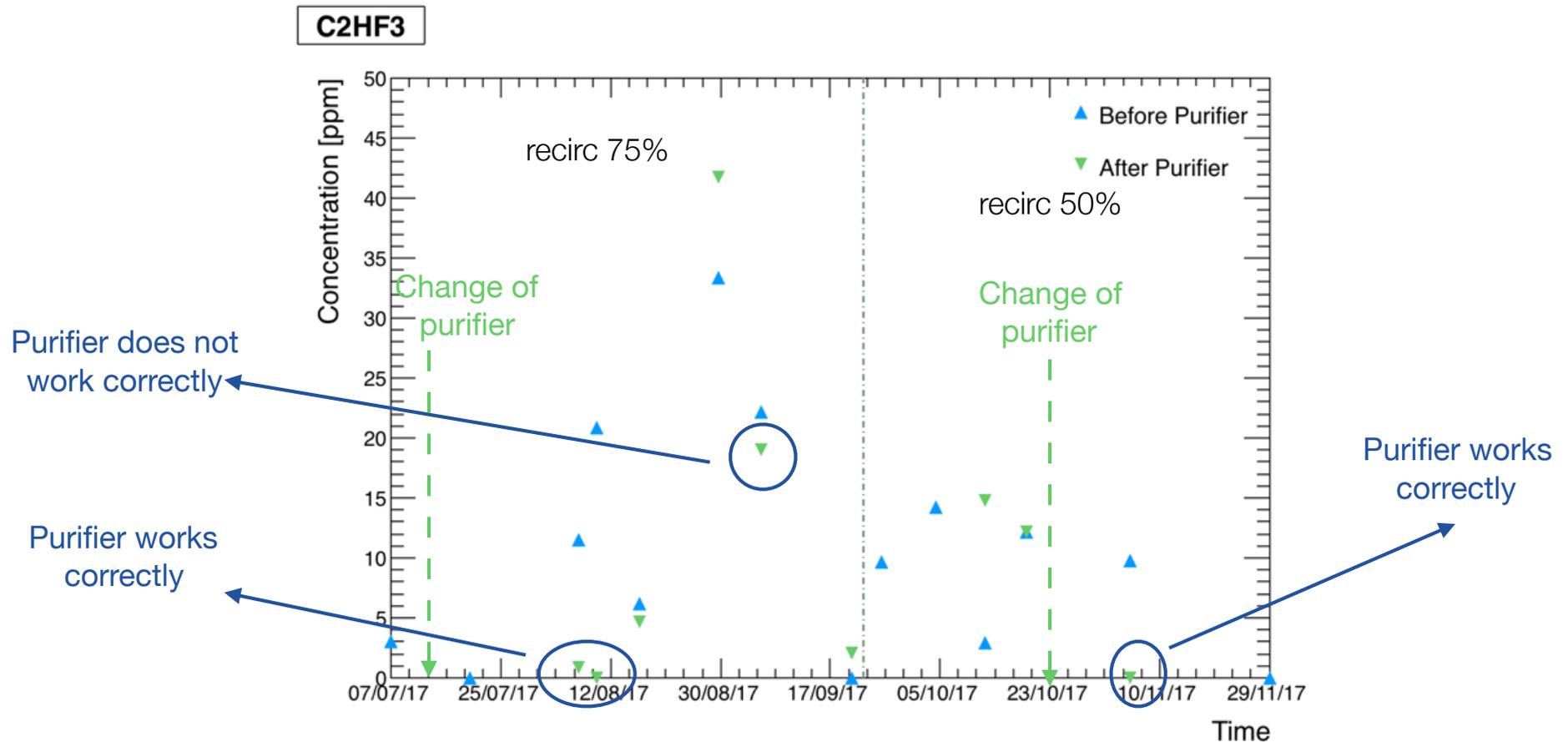


MTR impurities during 2016 Run



- Gas analysis performed before and after the purifier at several gas recirculation fractions
- Purifier absorbs some impurities but its efficiency and working time are limited
- In general, higher concentration with higher recirculation fraction
- But not a well-defined trend for all impurities
- Concentration is at the order of tens ppm for all impurities
- For some impurities, their concentration increases with time: their creation inside the gas gap increases with the increase of radiation

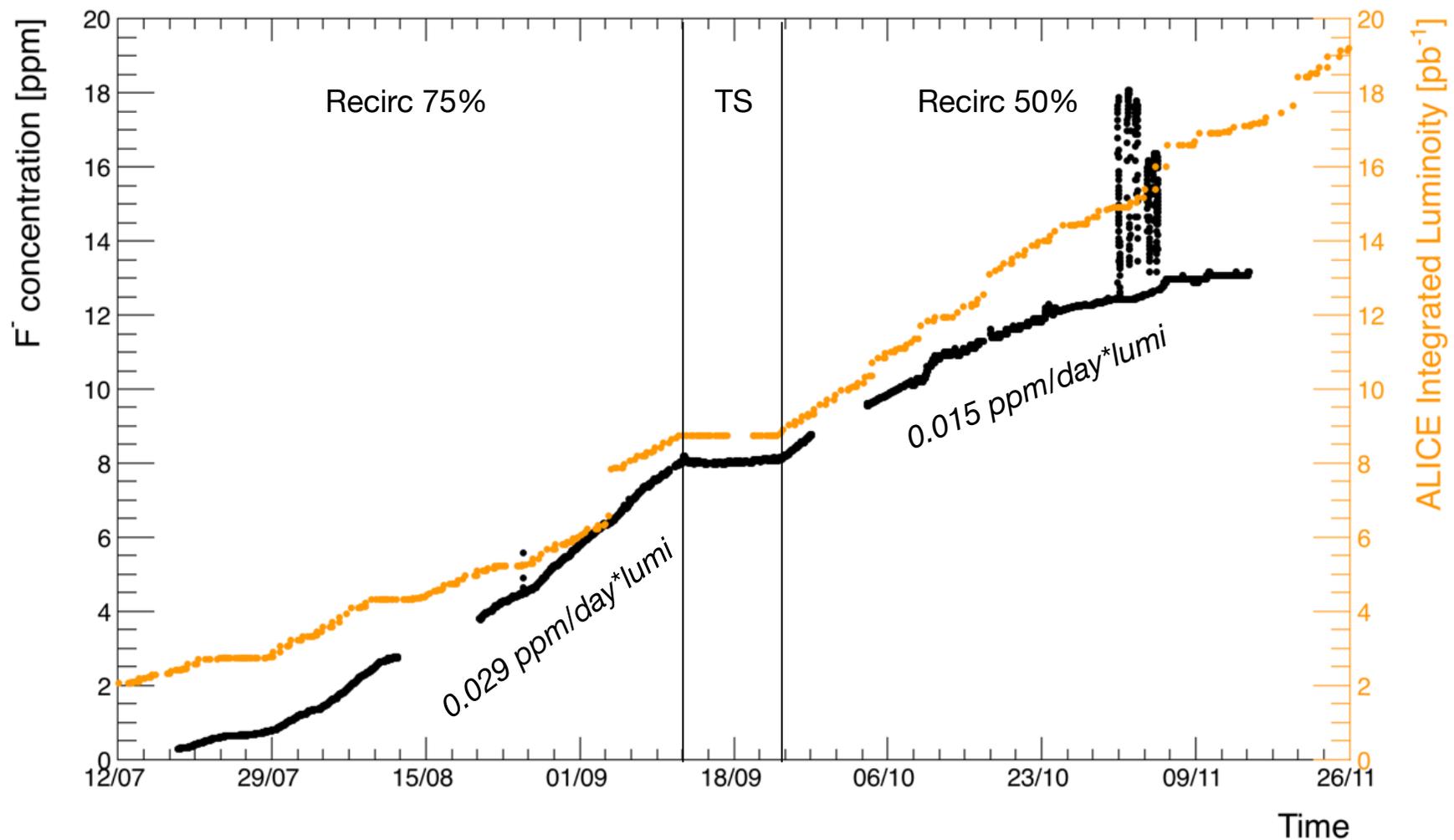
MTR impurities during 2017 Run



- After 2016 results, in 2017 decided to increase the recirculation fraction to 75%
- Impurities as usual around tens of ppm
- Sometimes higher concentration of impurities due to bad quality of gas supply
- Studies on purifier absorption capacity
 - Absorption of water lasts for several months
 - Absorption of impurities last few days or week (depending on the impurity)

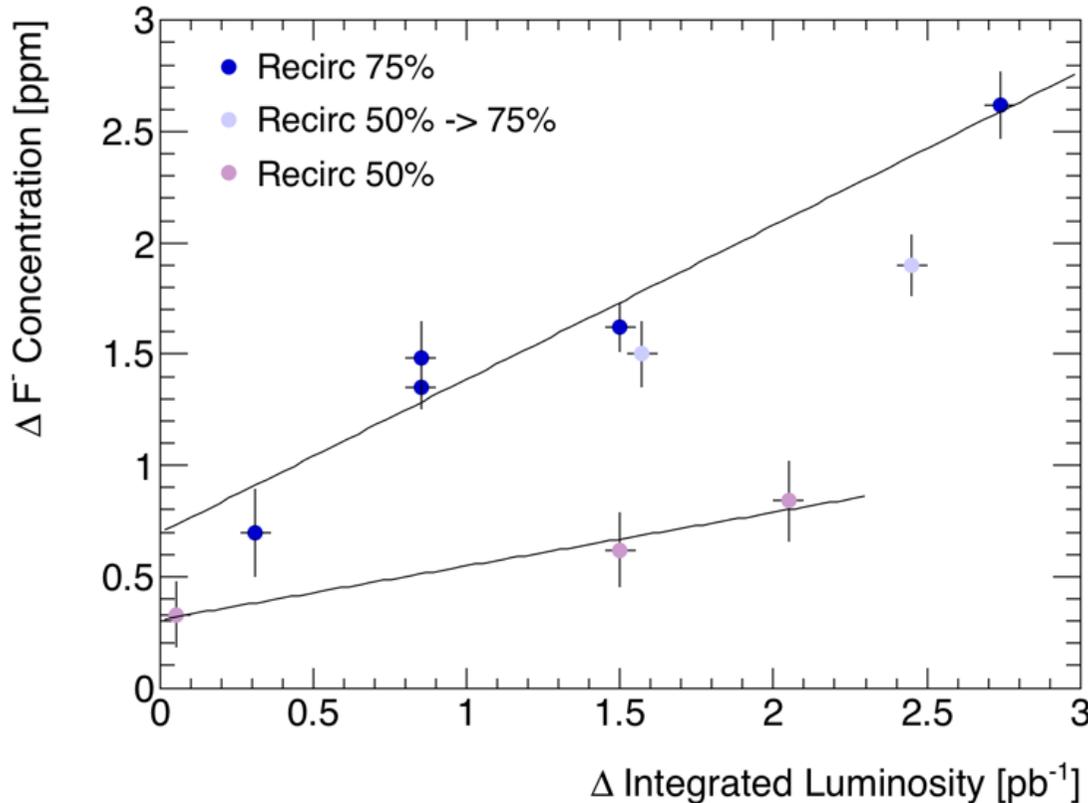
Fluoride concentration in MTR during 2017 Run

- F⁻ concentration measured for the gas returned from the 72 MTR detectors
 - Concentration measured in the H₂O+TISAB bottle
- Effects of luminosity, recirculation fraction and technical stop clearly visible
 - During technical stop F⁻ accumulation stops
 - At higher recirculation: higher F⁻ accumulation



Fluoride concentration in ALICE MTR

- F⁻ concentration evaluated in the detector gas system
 - Not taken into account possible lost of F⁻ in the pipes of the set-up
 - Efficiency of trapping HF in the set-up estimated around 30%
- F⁻ concentration clearly depends on recirculation fraction and integrated luminosity
 - Same effects visible on the accumulation of C₂H₂F₄ impurities



How much is the F⁻ concentration in the detectors?

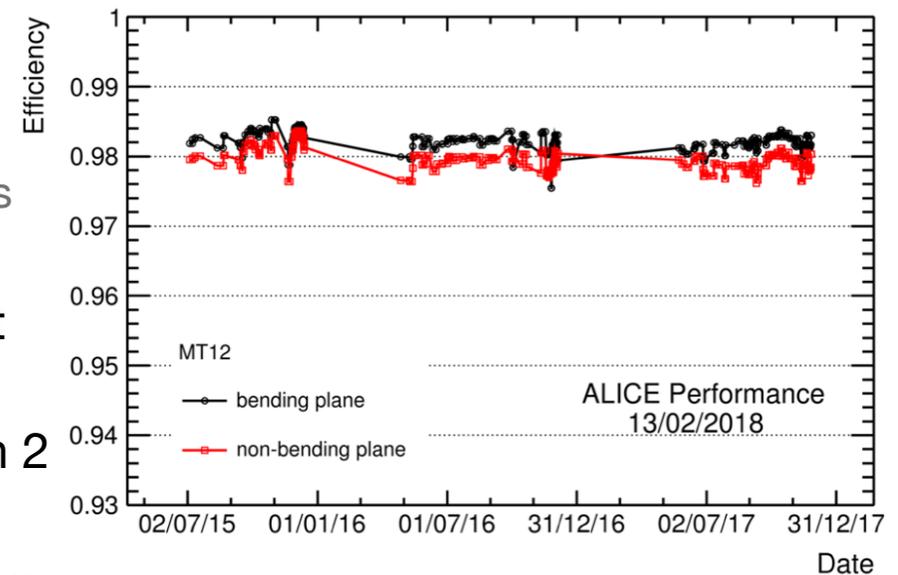
$$F_{ppm} = \frac{V_{H_2O}}{\Delta t \cdot \phi_{gas}} \cdot C_{\Delta t} \cdot \epsilon$$

\swarrow 75 % recirc \searrow 50 % recirc
5 ppb **3 ppb**

F⁻ potential impact on the detectors to be understood!

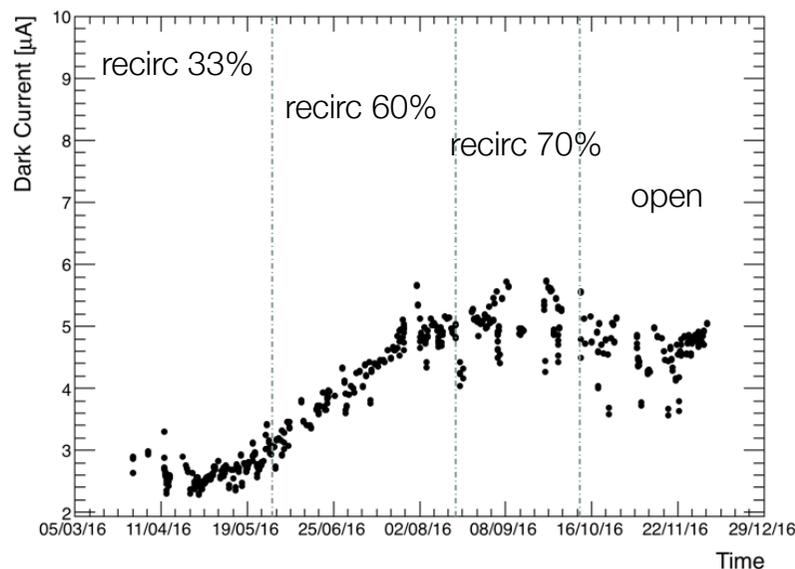
ALICE MTR detector performance

- Check possible correlation between gas system operation and detector performance
- At GIF test on generic RPC detectors, signal currents were stable after 100 mC/cm² accumulated in ~ 3 years
- The MTR RPCs operated in closed-loop mode at the LHC have shown stable efficiency throughout the whole period 2015-17 (see talk by A. Ferretti)
- Dark current increased from the beginning of Run 2
- Gas mixture monitoring will continue during 2018
- No clear evidence of correlation with accumulation of impurities or creation of F⁻

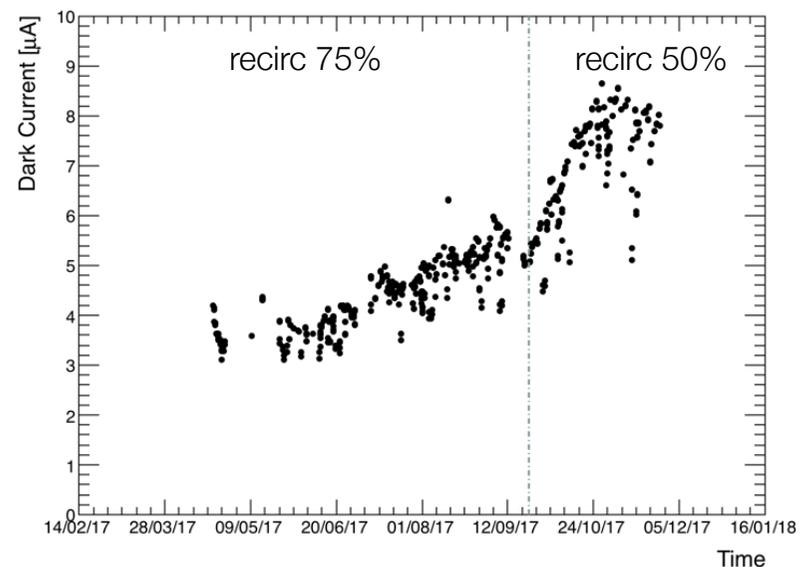


PERF-143059

Average Dark Current 2016



Average Dark Current 2017



Conclusions

All RPC systems are operated under gas recirculation at LHC

- For ATLAS and CMS not possible to increase the recirculation fraction due to leaks
- ALICE MTR gas system upgrade during LS1

Creation of F-radicals due to the $C_2H_2F_4$ breaking

- Electric field and radiation play a key role
- Not all of impurities can be absorbed by the cleaning agents
- Very high recirculation fraction leads to higher impurities concentration

Intensive gas analysis campaign for the ALICE MTR system

- Different gas analysers have been used
- Gas chromatograph analysis also performed for the CMS experiment

Clear correlation of F-radical creation with gas system and integrated luminosity

- Higher recirculation fraction -> higher concentration of impurities
- Impurities concentration increases with integrated luminosity
- F^- concentration of the order of ppb: to understand possible effects on the detector

Efficiency of the MTR RPCs operated in closed-loop high and stable during Run2

- Slight increase of the dark current, but no correlation with the gas recirculation

Cleaning agents in ALICE MTR gas system

	50%			25%		25%	
	<i>MS 3 Å</i>	<i>MS 4 Å</i>	<i>MS 5 Å</i>	<i>Cu R11</i>	<i>Cu/Zn R12</i>	<i>NiAl₂O₃</i>	<i>NiSiO₂</i>
Conditioning (volume changes)	3	10	50	20	20	15	15
Main component filtered	<i>H₂O</i>	<i>H₂O</i>	<i>H₂O</i>	<i>O₂/H₂O</i>	<i>O₂/H₂O</i>	<i>O₂/H₂O</i>	<i>O₂/H₂O</i>
Nominal absorption capacity for the main component filtered (g (O ₂ /H ₂ O) /kg)	140	170	130	5/50	5/50	15/50	15/50
Impurities							
(1) <i>CH₄</i>	Unchanged	Unchanged	Unchanged	Unchanged	Unchanged	Unchanged	Unchanged
(2)	Not present	Not present	Not present	Not present	Present up to 400 volume changes	Not present	Present up to 400 volume changes
(3) <i>C₂H₂F₂</i>	Unchanged	Unchanged	Back after 1000 vol. changes	Unchanged	Enhanced	Unchanged	Unchanged
(4) <i>CF₄SO</i>	Filtered	Filtered	Filtered	Filtered	Filtered	Filtered	Filtered
(5) <i>CH₂F₂</i>	Unchanged	Filtered	Filtered	Unchanged	Unchanged	Unchanged	Unchanged
(6) <i>C₂HF₃</i>	Unchanged	Unchanged	Filtered	Filtered	Filtered	Filtered	Filtered
(7) <i>C₂H₃F₃</i>	Unchanged	Filtered	Filtered	Filtered	Filtered	Present up to 150 volume changes	Unchanged
(8) <i>C₃H₆</i>	Unchanged	Filtered	Filtered	Filtered	Present up to 450 volume changes	Present up to 150 volume changes	Unchanged