F-gases usage in the ALICE detector

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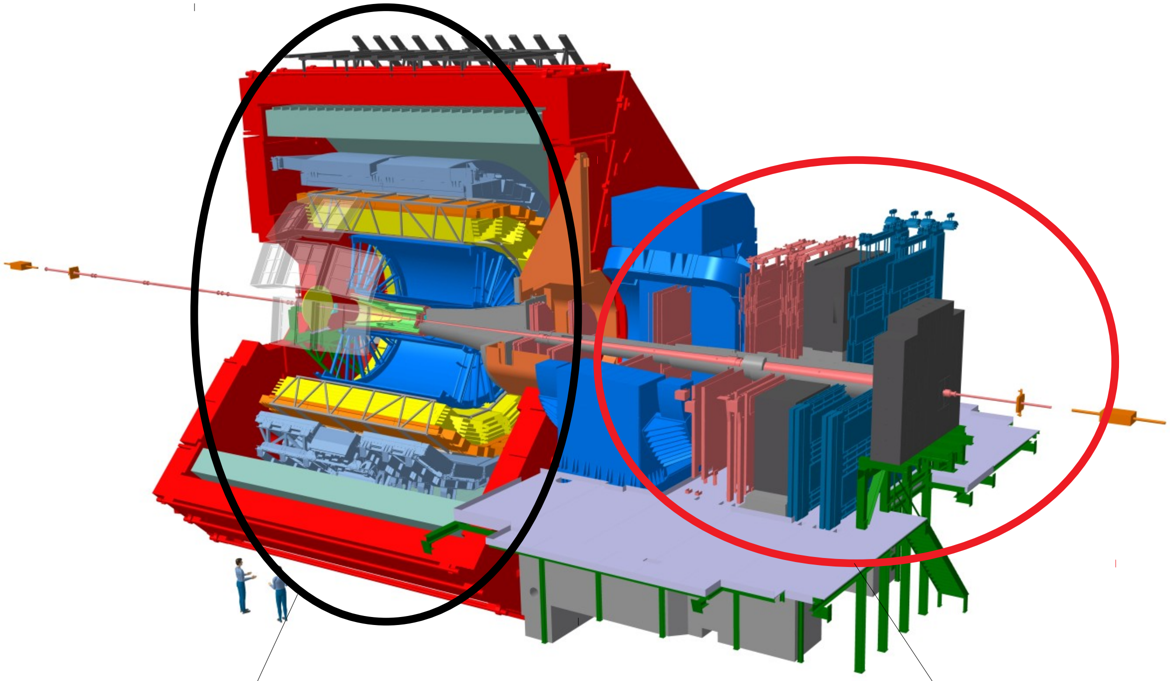
Overview

- The ALICE detector
- F-gases in the ALICE sub-detectors
- Muon Identification (MID) system
- Time Of Flight (TOF) detector
- High Momentum Particle Identification Detector (HMPID)
- Conclusions and remarks

The ALICE detector



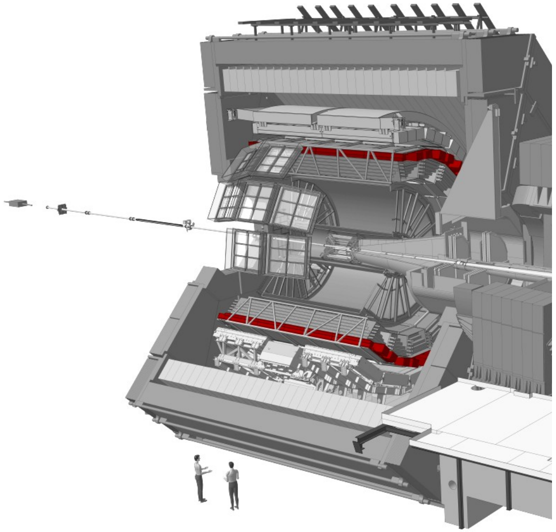
- A Large Ion Collider Experiment (ALICE)
- Multi-purposed particle detector (p-p, p-Pb and A-A collisions) at the CERN LHC
- Focused on the study of the Quark Gluon Plasma (QGP) in heavy-ion collisions

- Central barrel
→ For PID and tracking of hadrons, e and γs

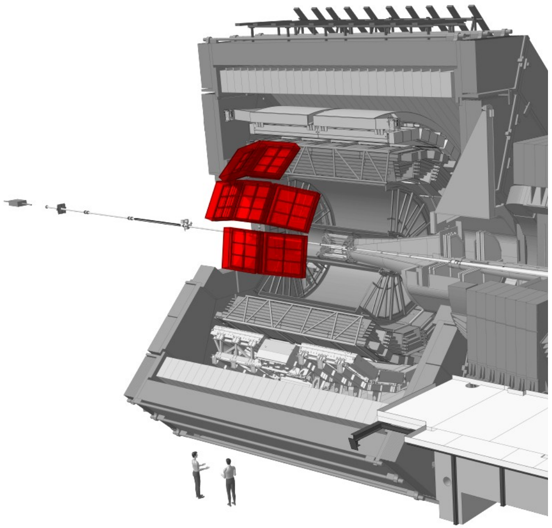
- Forward muon spectrometer
→ For muon tracking and identification

F-gases in the ALICE detector (1)

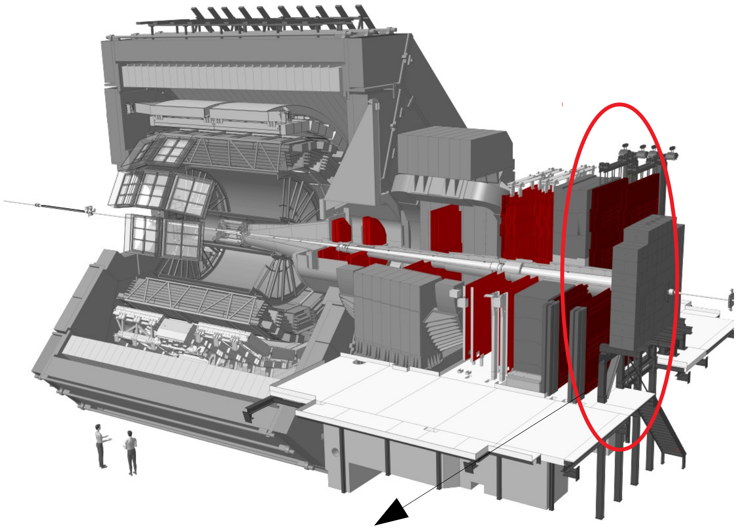
- Total of 18 subdetectors in ALICE
- Various particle detection and identification technologies employed
- Three of the 18 detectors employ F-gases: Time Of Flight (TOF), High Momentum Particle Identification detector (HMPID) and Muon Identification system (MID), highlighted in red in the following figures



TOF



HMPID



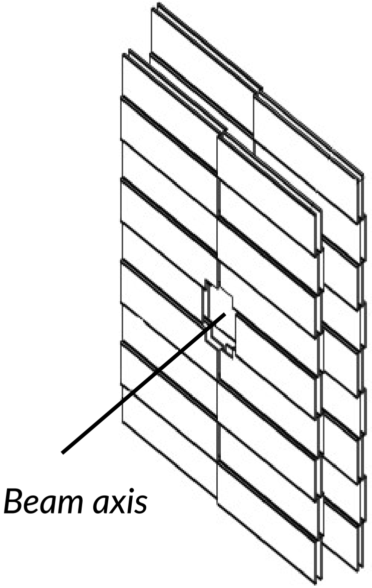
MID

F-gases in the ALICE detector (2)

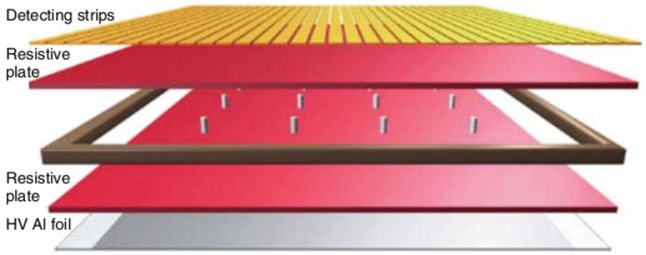
Detector name	Technology employed	Mixture	Aim of the detector
TOF	Multigap Resistive Plate Chambers (MRPCs)	93 % $C_2H_2F_4$ 7 % SF_6	Charged-particle PID in the intermediate momentum range
HMPID	Ring Imaging Cherenkov detector (RICH)	Liquid C_6F_{14} as Cherenkov radiator	PID of high-momentum particles, i.e. π, K and p from 1 to 5 GeV/c
MID	Single gap Resistive Plate Chambers (RPCs)	89.7 % $C_2H_2F_4$ 10% i-C_4H_{10} 0.3 % SF_6	Identification of muons from the decays of heavy flavour and quarkonia

Muon Identification system (MID)

- 72 single gap RPCs covering a total area of ~ 140 m^2
- 2 mm thick gas gap and 2 mm thick low resistivity (10^9-10^{10} Ω·cm) bakelite electrodes
- Arranged in 2 stations of 2 planes each located at ~ 16 and 17 m from the interaction point in the forward rapidity region downstream of a 7 λ_{int} iron wall (muon filter)
- Operated in highly-saturated avalanche mode (maxi-avalanche)
  → Effective high voltage applied ~ 10-10.5 kV, average charge per hit ~ 100 pC
- Gas mixture: 89.7 % $C_2H_2F_4$, 10 % i-C_4H_{10}, 0.3 % SF_6
- Up to run 2: provide a trigger signal for the muon spectrometer
- From run 3 onwards:
  → ALICE will run with continuous readout
  → Muon identification offline



Schematic view of the MID RPCs – ALICE collaboration, *ALICE Technical Design Report*, 2008



Exploded view of a single gap RPC – M. Abbrescia et al., *Resistive gaseous detectors*

Choice of the gas mixture for MID

- $C_2H_2F_4$ (R134a) and SF_6 are the F-gases in the MID gas mixture

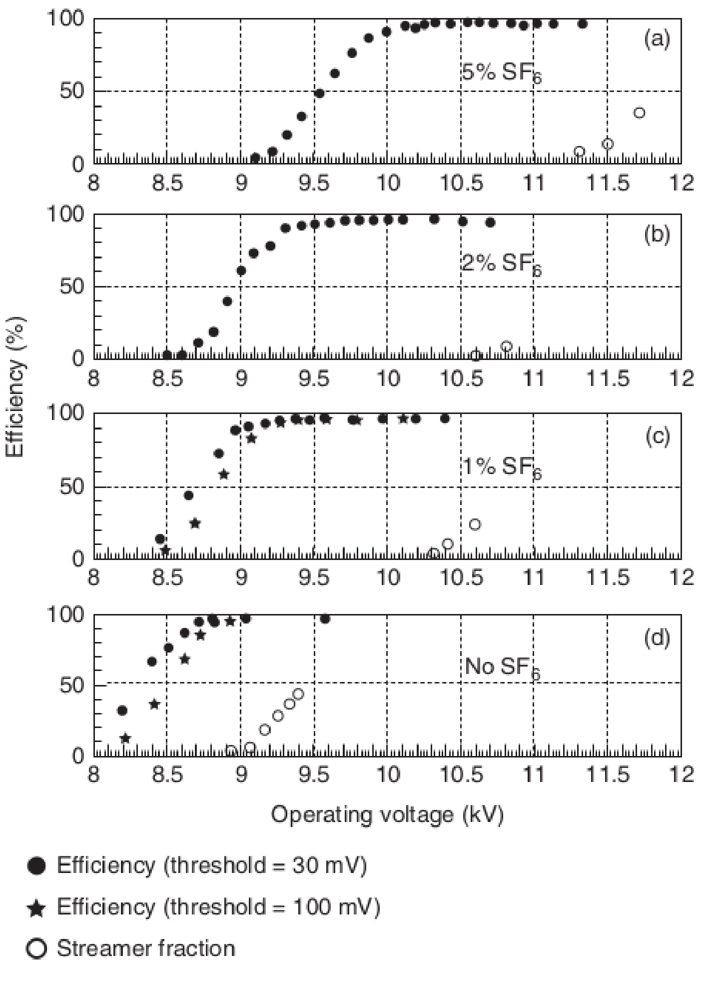
- R134a:
  → Low primary ionization energy, provides primary electrons
  → High electron affinity, helps reducing the size of the avalanche

- SF_6:
  → Highly electronegative, reduces signal charge and streamer contamination
  → Working point shifted to higher voltages

- Initially two gas mixtures were investigated: streamer mixture for Pb-Pb data taking and maxi-avalanche for p-p
  → Streamer: 50.5 % Ar, 41.3 % $C_2H_2F_4$, 7.2 % i-C_4H_{10} and 1 % SF_6
  → Maxi-avalanche: 89.7 % $C_2H_2F_4$, 10 % i-C_4H_{10} and 0.3 % SF_6

- Eventually converged to the single maxi-avalanche mixture for both Pb-Pb and p-p

MID gas mixture R&D



Camarri et al., 1998

- Effects of varying the percentage of SF_6 in the RPC gas mixture ($C_2H_2F_4/C_4H_{10}$ 97/3 relative fraction):

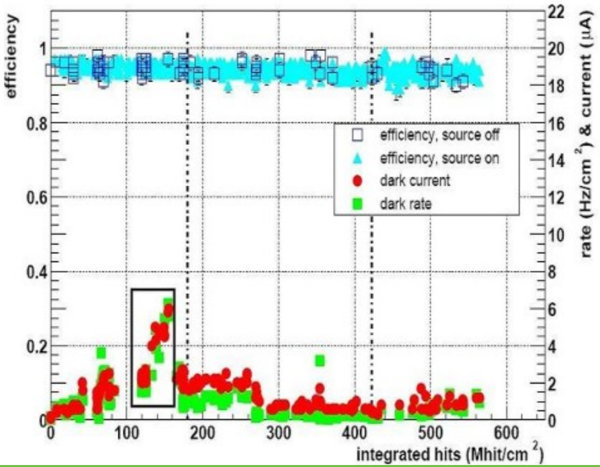
1) Efficiency plateau moves to higher High Voltage (HV) values

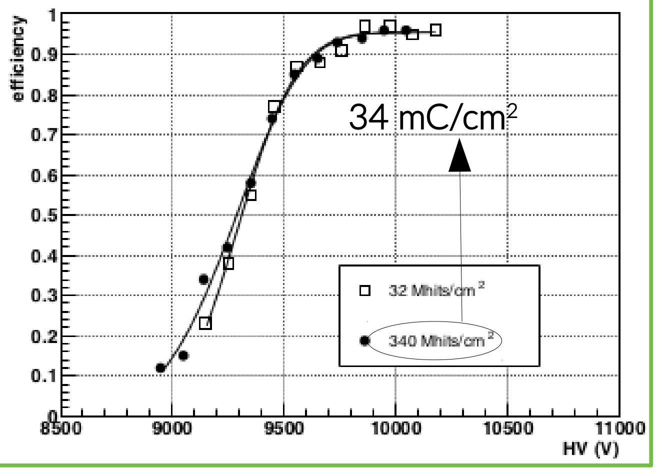
2) Increased "useful plateau", i.e. HV interval where efficiency ~ 90-95 % and streamer probability ~ 10 %

- Aging test carried out at the CERN Gamma Irradiation Facility to validate long-term detector operation with maxi-avalanche gas mixture

1) Stability of efficiency, with and without Irradiation, dark current and counting rate

2) Efficiency curve before and after Irradiation

1) 

2) 

R. Arnaldi et al., *Beam and ageing tests with a highly–saturated avalanche gas mixture for the ALICE p–p data taking*, 2006

Impurities production

- Interaction between gas and radiation has two effects:
  → Signal production
  → **Gas radiolysis** = breakage of gas molecules into impurities (e.g. C_2HF_3 or $C_2H_2F_3$)

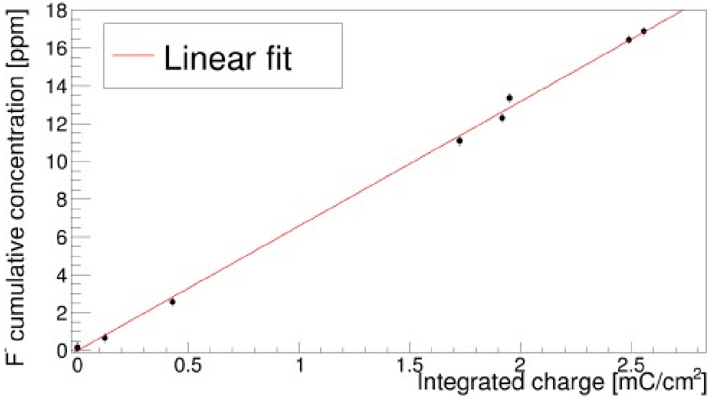
- Main component of gas mixture is $C_2H_2F_4$ (rich in F)
  → It can interact with H_2O (humidified gas mixture) and **form Hydrofluoric acid** (HF)

- HF is highly corrosive
  → **It might deposit on the inner surfaces of the detector** and chemically attack them
  → This may explain the observed dark current increase

- To validate this hypotesis
  → 2/72 RPCs flushed with pure Ar
  → When fully ionizied a plasma is created in the gap
  → *Cleaning* action of the plasma might detach some of the deposited HF

- Measurement of the produced F^- ions resulting from this procedure was carried out
  → **Non-zero concentration** was detected, increasing with the integrated charge
  → Hint of possible fuorinated impurities detachment

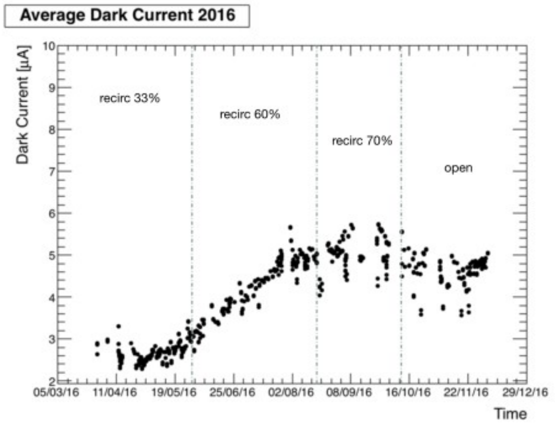
- This procedure had **no effect in reducing the** absorbed **dark current**

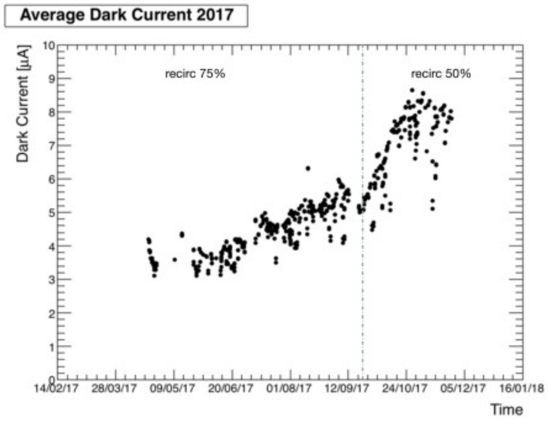


F^- ions cumulative concentration as a function of the integrated charge during the Ar plasma test – L. Quaglia et al., *Performance and aging studies for the ALICE muon RPCS*, 2020

The MID gas consumption

- Average volume of a single RPC: 270 x 70 x 0.2 cm^3 = 3780 cm^3
- Total volume to be flushed with gas mixture = 72 x 3780 cm^3 ≈ **0.3 m^3**
- The gas mixture is toxic for the environment (**GWP**[1]) of around **1230**
  → In Run 2 the detectors were operated in a closed loop system in order to reuse part of the gas mixture
  → Recirculation Fraction (RF) = fraction of the gas mixture recirculated
- The gas mixture is continuosly flushed in the system (total flow of ~ **144 l/h**)
  → A fraction of fresh gas is inserted in the loop ((1-RF) * total flow ≈ **36 l/h if RF = 75 %**) in order to compensate for leaks in the system and try to keep dark currents under control
  → The rest is **circulated through a purifier** to remove impurities formed under irradiation





B. Mandelli, RPC workshop 2018, Puerto Vallarta

-Trend of the absorbed dark current for different recirculation fractions (the % of the gas mixture that is recirculated)

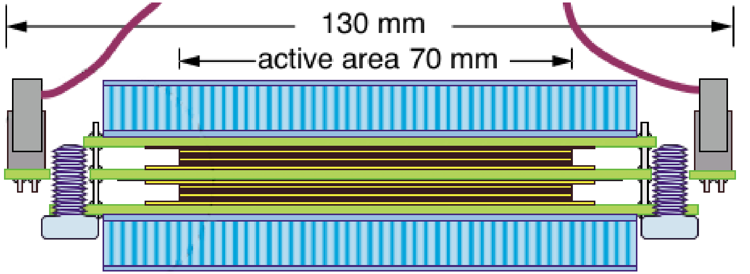
-Dark currents increase when RF from 33 % to 60 % then stable

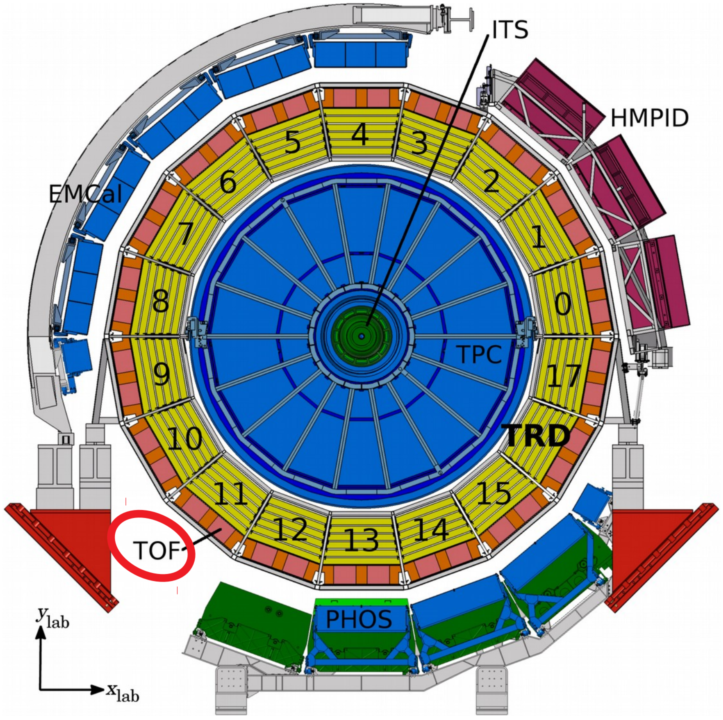
-In 2017 a change in RF did not show improvement in the dark current

[1]GWP = Global Warming Potential = measure of the quantity of heat that can be trapped in the atmosphere by a certain gas, if compared to the same mass of CO 2 (GWP = 1)

Time Of Flight (TOF) detector

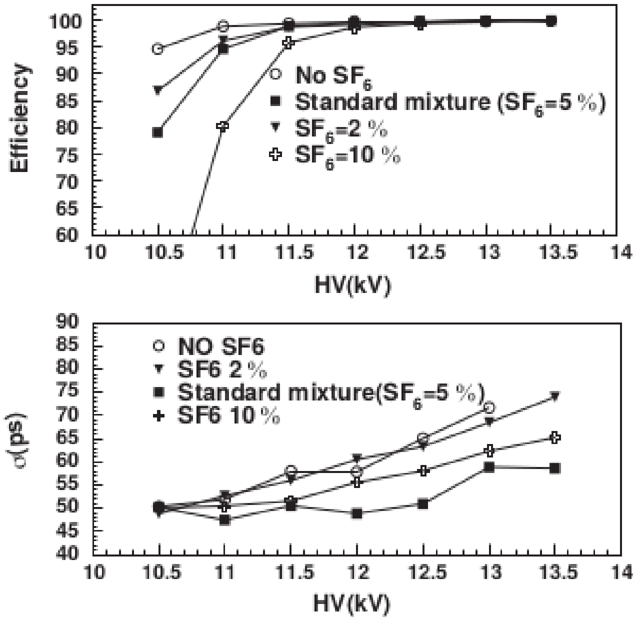
- Covers an area of ~ 150 m^2 and provides a time resolution of ~ 100 ps or less: Multigap Resistive Plate Chambers (MRPCs)
- Located at 3.7 m from the nominal Interaction Point (IP), gives full coverage in φ and [45,135] ° in θ
- TOF MRPCs: strips of 120 x 7.4 cm^2 with 96 readout pads each
- Each strip consists of two stacks of five gaps
  → Total of 10 gaps, 250 μm each
  → Resistive plates made out of *soda-lime* glass
  → TOF = 1638 MRPC strips and ~ 160 k readout channels
- Operated in avalanche mode with a streamer-free gas mixture of 93 % $C_2H_2F_4$ + 7 % SF_6
- TOF provides 3σ separation for π/K in the 0.5-2.5 GeV/c and up to 4 GeV/c for protons





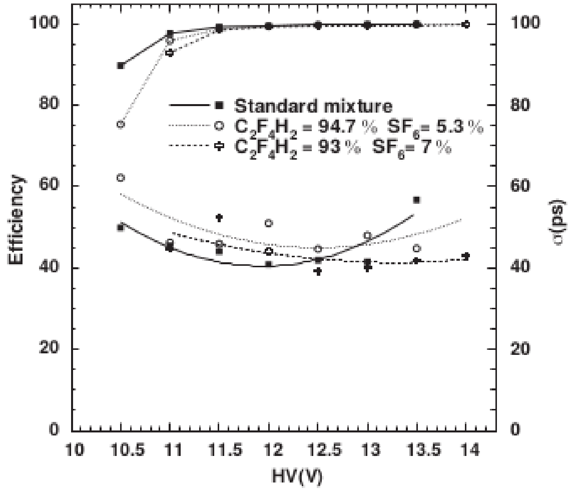
ALICE collaboration, *TOF Technical Design Report*, 2000

Choice of the gas mixture for TOF (1)



- First studies on ternary mixtures: $C_2H_2F_4$, C_4H_{10} and SF_6
- Increasing the SF_6 percentage the efficiency plateau shifts to higher voltages (as for single gap RPCs)
- Two processes affect time resolution:
  1) Higher SF_6 concentration requires higher electric fields
  → higher drift velocity and improved time resolution
  2) SF_6 reduces the ionization clusters and worsens the time resolution
- At 0 % SF_6
  → Degradation of time resolution due to streamers

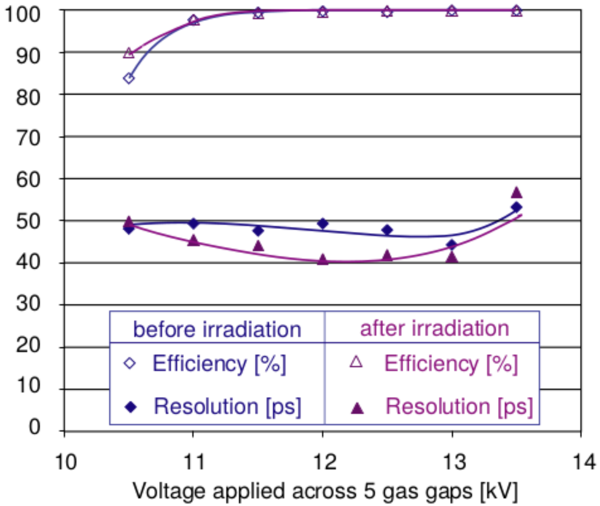
- Studies on binary mixtures
  → No C_4H_{10} = not flammable gas mixture = safer
- Similar performances in efficiency and time resolution
- Plateau where time resolution is best is larger

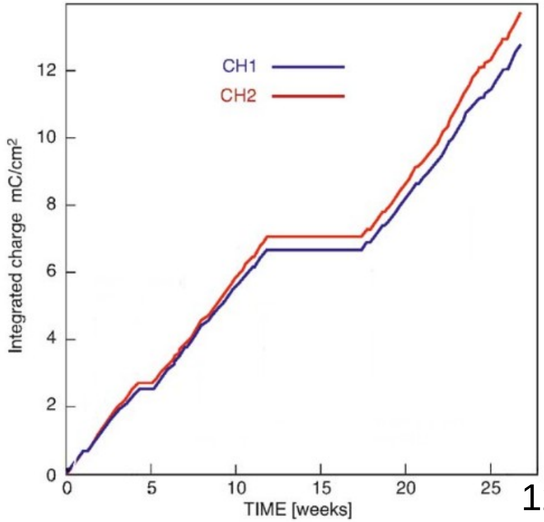


Graphs taken from A.V. Akindinov et al., *Study of gas mixtures and ageing of the multigap resistive plate chamber used for the Alice TOF*, 2004

Choice of the gas mixture for TOF (2)

- Aging studies performed on the ternary gas mixture @ GIF
- Total integrated charge = 14 mC/cm^2
  → Average total charge produced in an event ~ 2 pC
  → 14 mC/cm^2 = 7·10^9 particles/cm^2
  → Average charged particle rate on TOF = 50 Hz/cm^2
  → Aging test = 1620 days of operation
- No HF production was observed under irradiaiton
  → Due to the fact that MRPCs are operated in *streamer-free* mode
- Comparison of efficiency and time resolution before and after irradiation
  → No degradation observed in either quantity
  → Efficiency above 99.5 % and time resolution below 50 ps

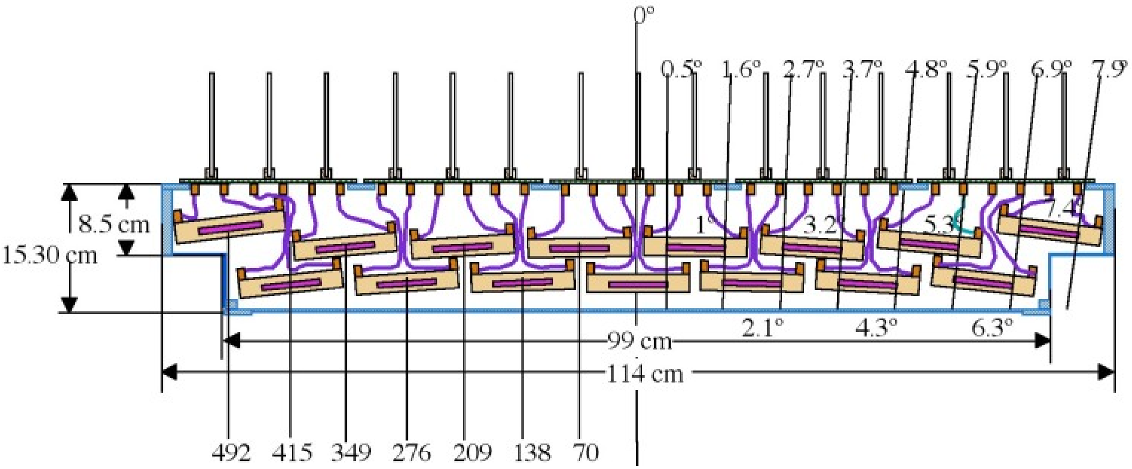




Graphs taken from A.V. Akindinov et al., *Study of gas mixtures and ageing of the multigap resistive plate chamber used for the Alice TOF*, 2004

The TOF gas system

- MRPCs are enclosed in gas-tight boxes
  → The total gas volume is not only the volume of the MRPCs but the one of the boxes ≈ 20 m^3



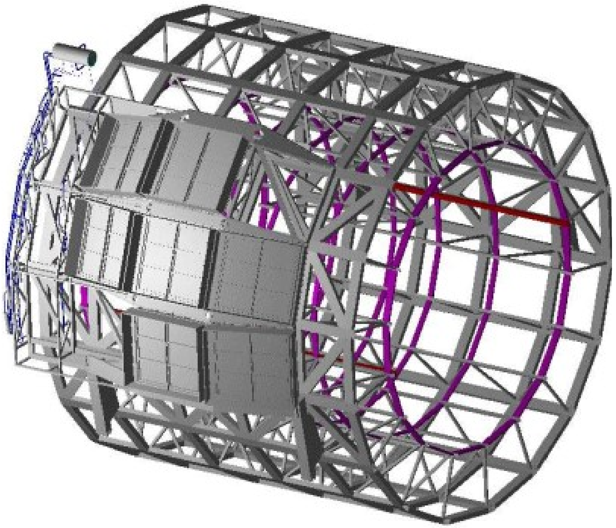
C. Williams, *ALICE TOF Gas System*, 2006

- Since the beginning of operations TOF MRPCs are operated in closed loop
  → 30 % of the total gas volume is refreshed every Δt (initially 8 hours and then increased)
  → Currently there is an entire gas volume change every ~ 30 days
  → 26 l/h of fresh gas

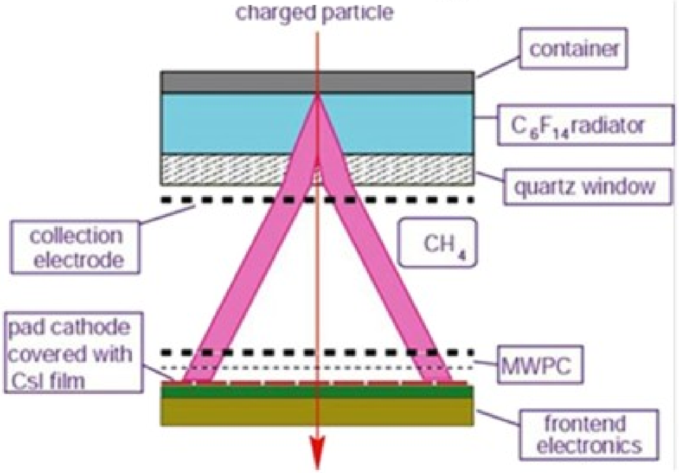
- Purifier used to remove H_2O, O_2 and other impurities from the gas mixture
  → Possible to increase the Δt but keeping in mind that the main goal is to maintain efficiency and time resolutions

High Momentum Particle Identification Detector (HMPID)

- 7 identical proximity focusing Ring Imaging Cherenkov detectors (RICH) covering a total area of ~ 12 m^2
- Located on an independent cradle mounted in the two o'clock position on the ALICE space frame
- Chambers tilted in a cupola-like structure to focus on the nominal interaction point at ~ 4.7 m distance from the detectors



- Cherenkov photons are detected by a photon counter: → Multi Wire Proportional Chamber (MWPC) operated with CH_4 at atmospheric pressure
- The MWPC cathode plane is segmented into pads and coated with a 300 nm photosensitive layer of CsI



A. Di Mauro, *Status of the HMPID CsI-RICH project for ALICE at the CERN/LHC*, 2004

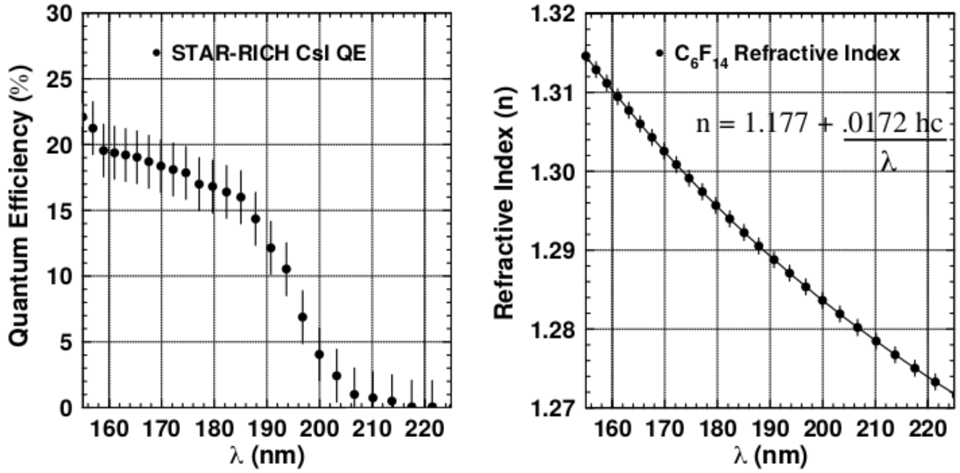
C_6F_{14} as radiator medium

- C_6F_{14} (Perfluorohexane) is a liquid at STP conditions and it is used as radiator medium in the ALICE HMPID

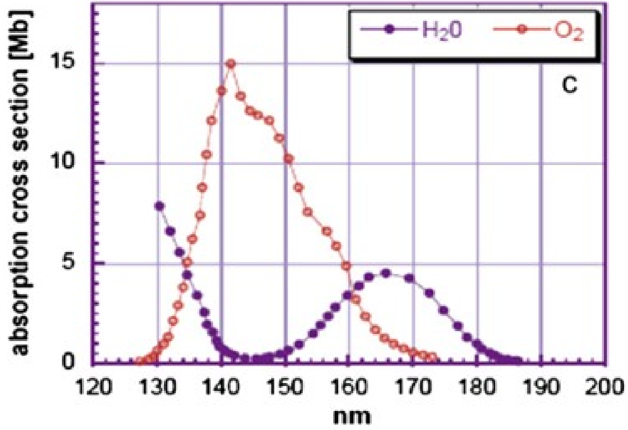
- Refraction index n = 1.2989 at 175 nm
  → Threshold momentum for Cherenkov radiation p_{th} = 1.21 m GeV/c (m = particle mass)

- Great capacity for dissolving gases and water at the ppm level
  → Bad because water and oxygen absorb ultraviolet radiation

- Good transparency to ultraviolet radiation in the region that matches the quantum efficiency spectrum of the CsI photocatode



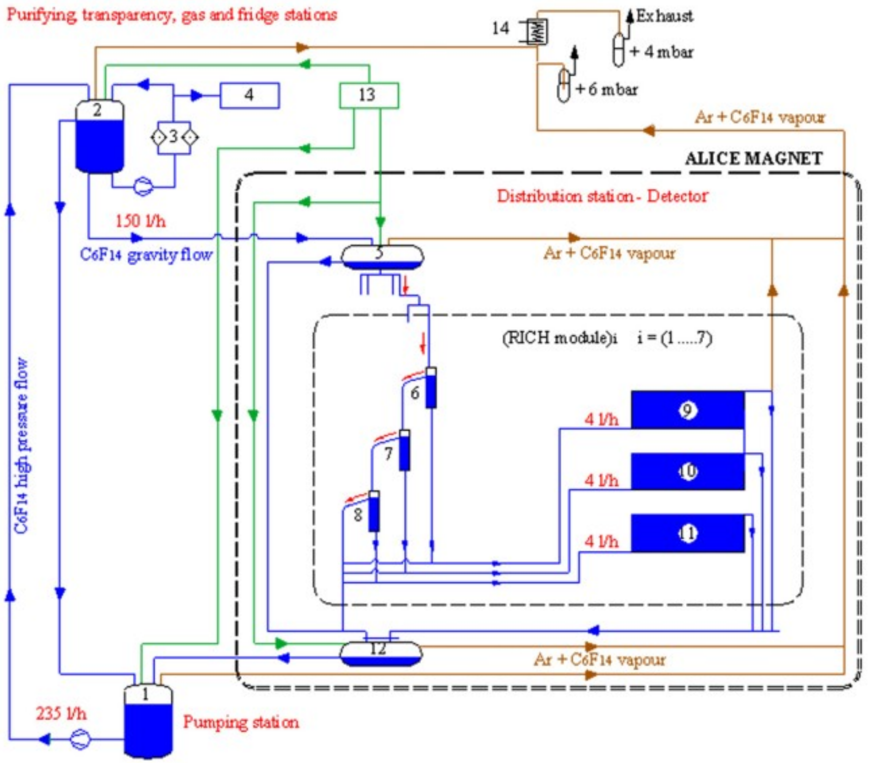
Y. Andres et al., *Cleaning and recirculation of perfluorohexane (C_6F_{14}) in the STAR-RICH detector*, 2002



C. Pastore et al., *The Cherenkov radiator system of the high momentum particle identification detector of the ALICE experiment at CERN-LHC*, 2011

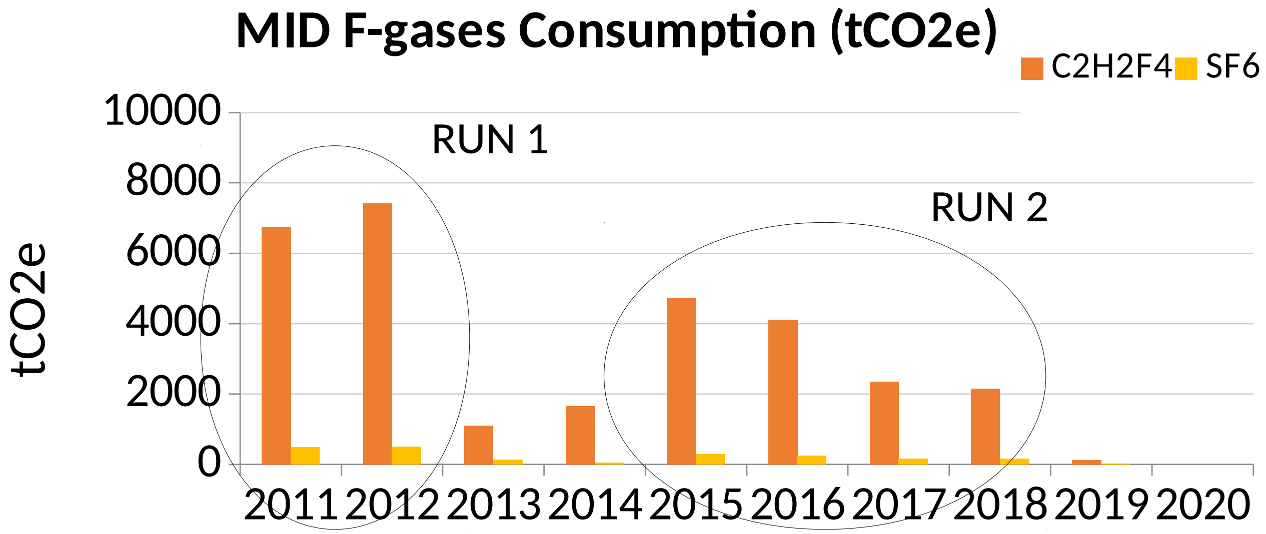
HMPID C_6F_{14} circulation system

- HMPID operates in closed loop mode in order to recover the C_6F_{14} since C_6F_{14} has a GWP of 7910
- Complex system based on gravity in order to:
  → remove contaminants and isolate the radiator liquid from water and oxygen
  → avoid overpressures in the vessels
  → condensate liquid vapour for reuse
- 7 HMPID modules with 3 radiator each = 21 radiator vessels
- Liquid pumped at 6.3 bar from the tank at 235 l/h
- In purifying station: 13x Molecular Sieve filters remove contaminants
  → Best liquid transparency, real time monitoring
- High pressure of the liquid has to be reduced
  → Max over-pressure of vessels = 140 mbar
- Done thanks to a *cascade* distribution system
  → It ensures a laminar flow of 4 l/h in each vessel
- Pure Ar isolates the system from outside air
- The system is stagnant during LHC technical stops



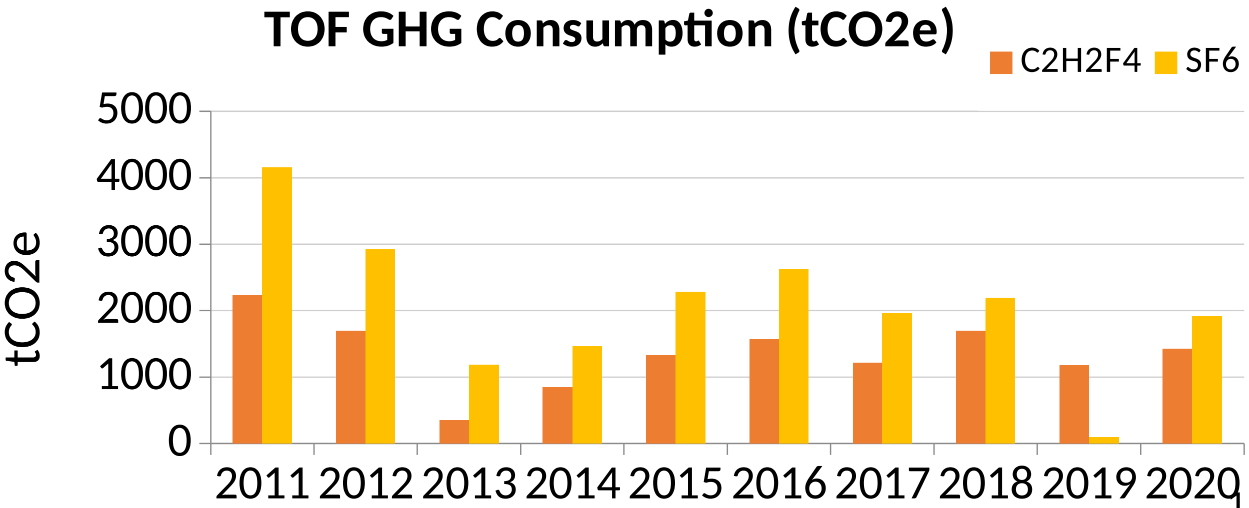
C. Pastore et al., *The Cherenkov radiator system of the high momentum particle identification detector of the ALICE experiment at CERN-LHC*, 2011

Conclusions and remarks (1)



- Gas consumption (ton) in CO_2 equivalent for MID and TOF

- From RUN 1 to RUN 2
→ Reduction in consuption due to close loop gas system for MID



- From RUN 1 to RUN 2
→ Reduction in consuption due an increase in the time for a full change of the gas volume for TOF

Data and graphs by B. Mandelli (CERN EP-DT-FS group)

Conclusions and remarks (2)

- F-gases are an essential part in gas mixture for some of the gaseous sub-detectors in ALICE

- Extensive R&D has been carried out in the past to get to the currently employed mixtures
→ MID gas mixture provides a subcentimeter spatial resoluton and a timing resolution in the order of 1 ns
→ TOF gas mixture provides a timing resolution in the order of 56 ps

- They both have a very high GWP
→ MID gas mixture ≈ 1237
→ TOF gas mixture ≈ 2854

- New Europen Union regulations are pushing for a progressive phase out of F-gases production and usage
→ Prices are already increasing
→ Efforts to find new, more eco-friendly, gas mixtures for RPC detectors (see A. Bianchi, G. Proto and EcoGas@GIF++ talks in the last session)

- A first reduction in F-gases consumption is being carried out by recirculating the gas mixture
→ MID: moved from open to closed loop between RUN 1 and RUN 2
→ TOF: increasing the time taken to change a full gas volume

Thank you for your attention!