The dRICH monitoring gas system

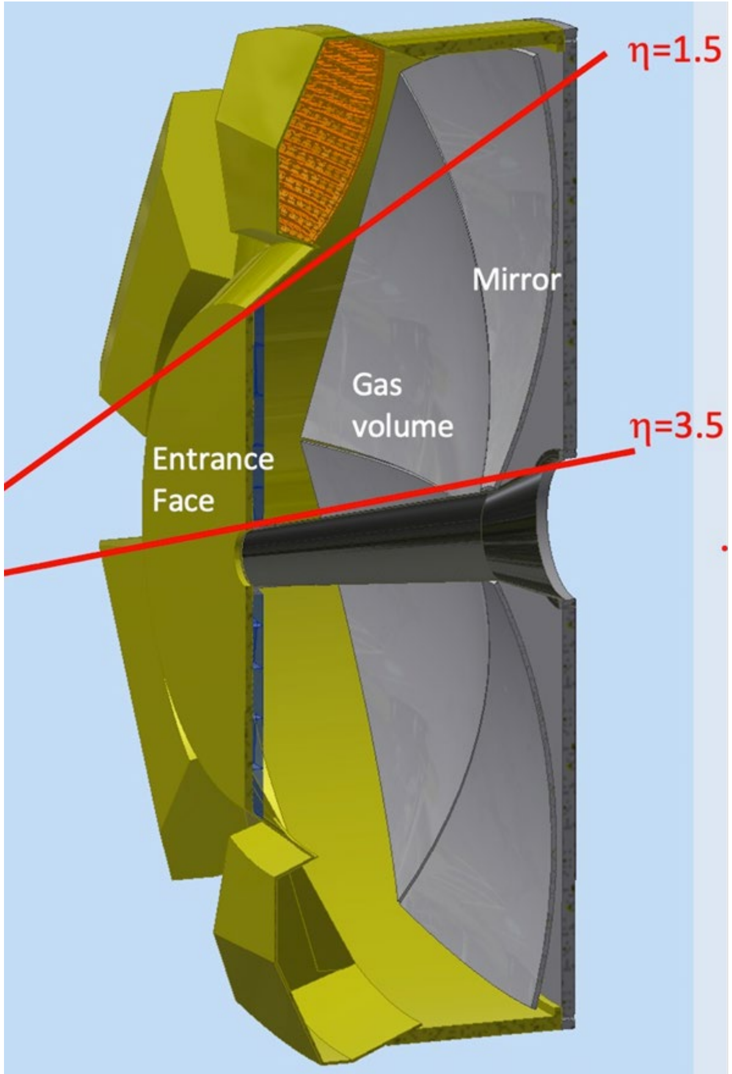
ePIC dRICH radiator gas choice

radiator gas system: the COMPASS RICH1 case

C_2F_6 separation

Possible future ban of fluorocarbons

ePIC dRICH



Momentum range: 3-50 GeV/c

Angular acceptance: 1.5 < η < 3.5

Magnetic field: ~ 1 T

Limited space: diam. ~3600 mm, L ~1200 mm

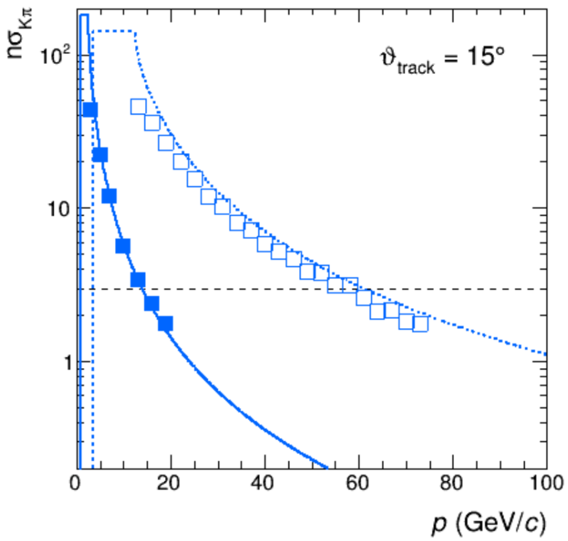
Aerogel

C_2F_6

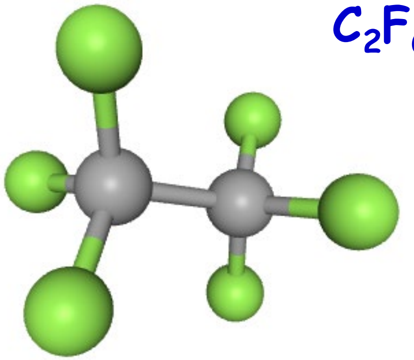
6 mirrors

Curved detectors

Cold SiPMs



hexafluoroethane physical properties



1 covalent bond

6 hydrogen bonds

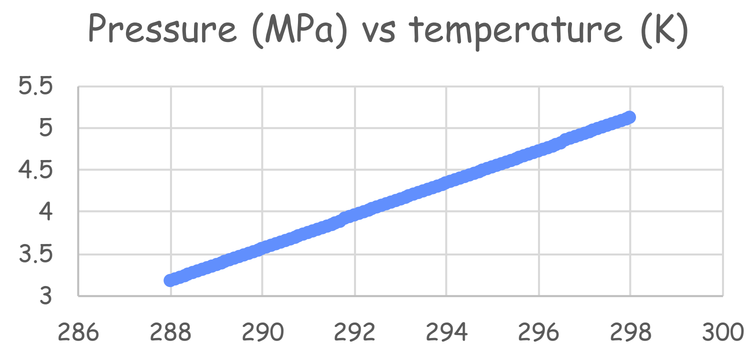
C_2F_6 molecular weight: 138.01 g/mol

boiling point: -78.1 °C

melting point: -100.6 °C

density: 5.734 kg/m^3 at 24 °C

density: 16.08 kg/m^3 at -78 °C



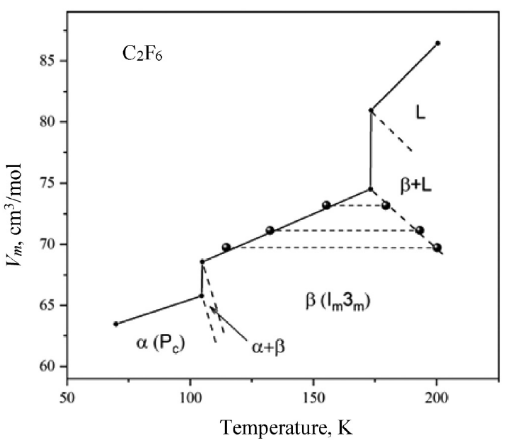
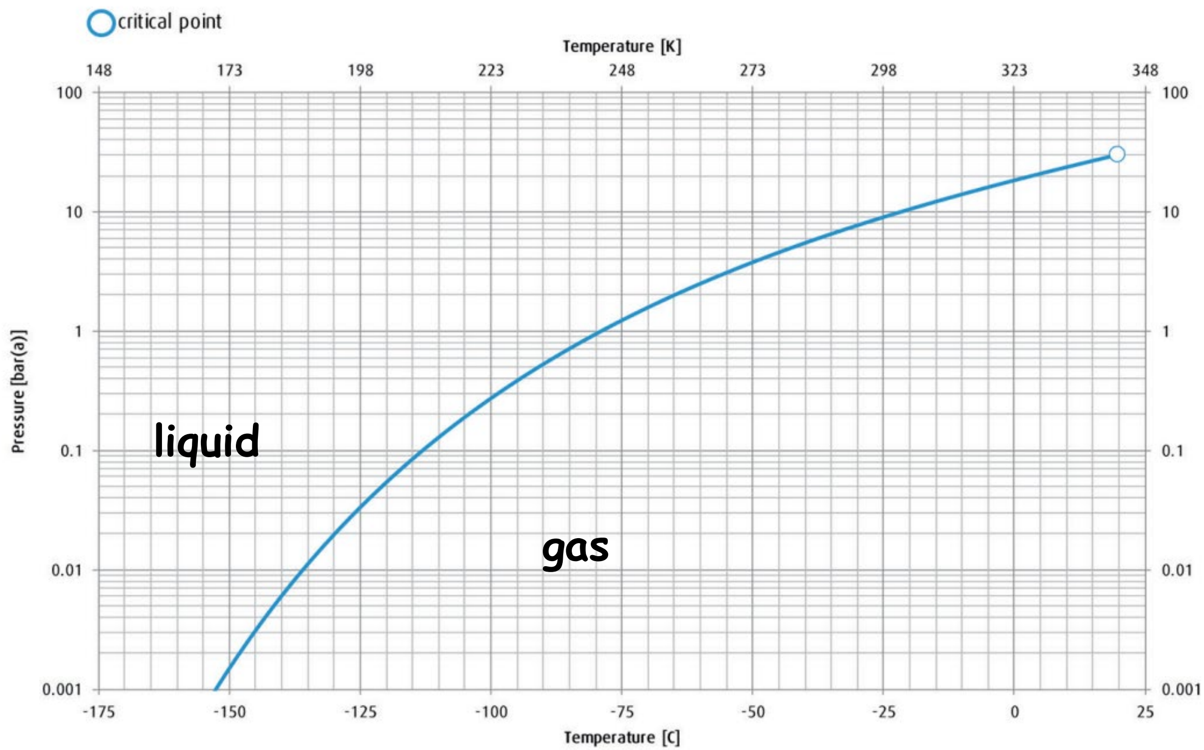
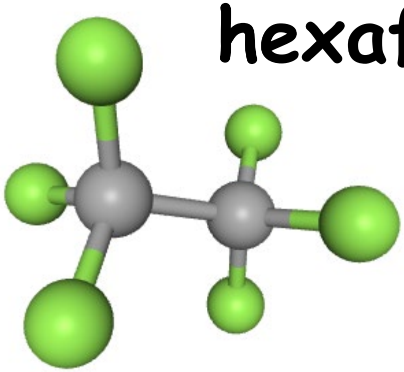


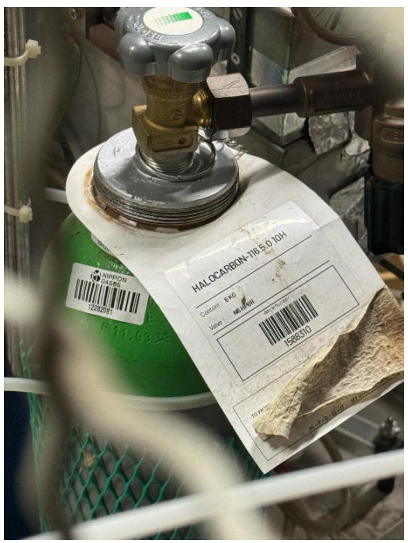
FIG. 2. Phase V–T diagram of hexafluoroethane (freon F-116). The short-dashed lines show the molar volumes of the studied samples, the solid line is the dependence of the molar volume on the temperature at saturated vapor pressure,[11] dashed lines represent the boundaries of the existence of phases, and circles are our experimental data.

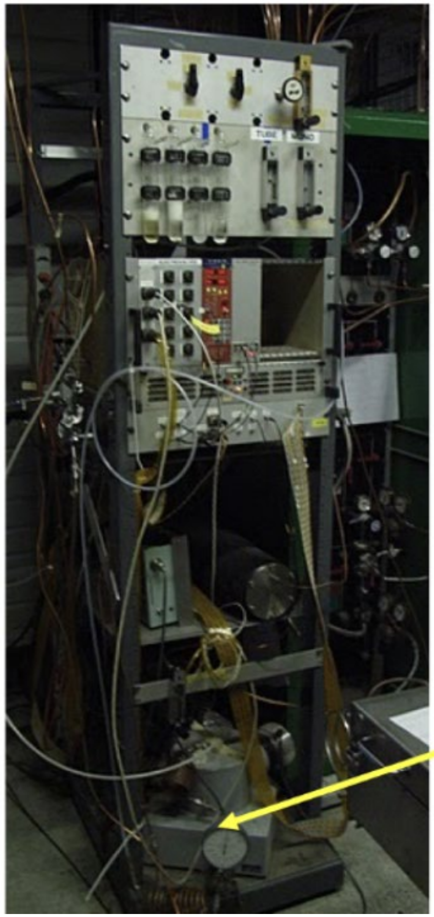


C_2F_6 UV transparency

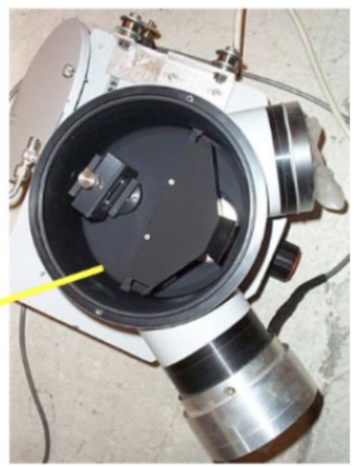


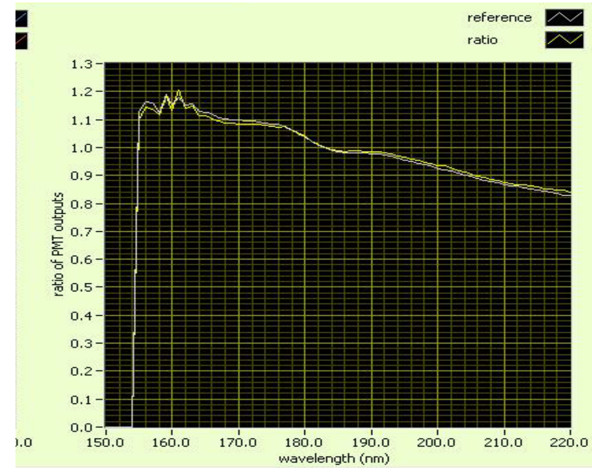
hexafluoroethane

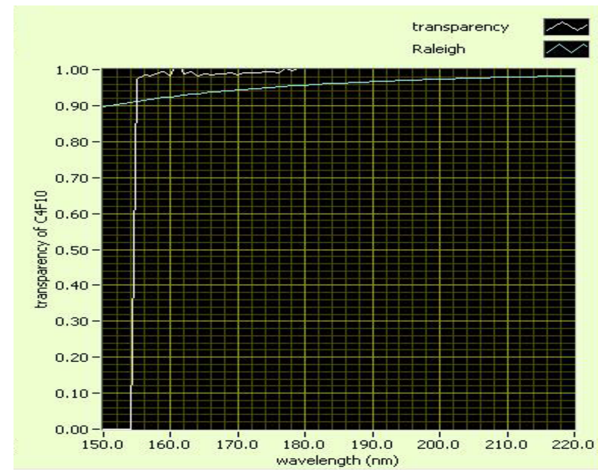




Deuterium UV lamp, Monochromator system, 1.6 m column for gas transparency measurement

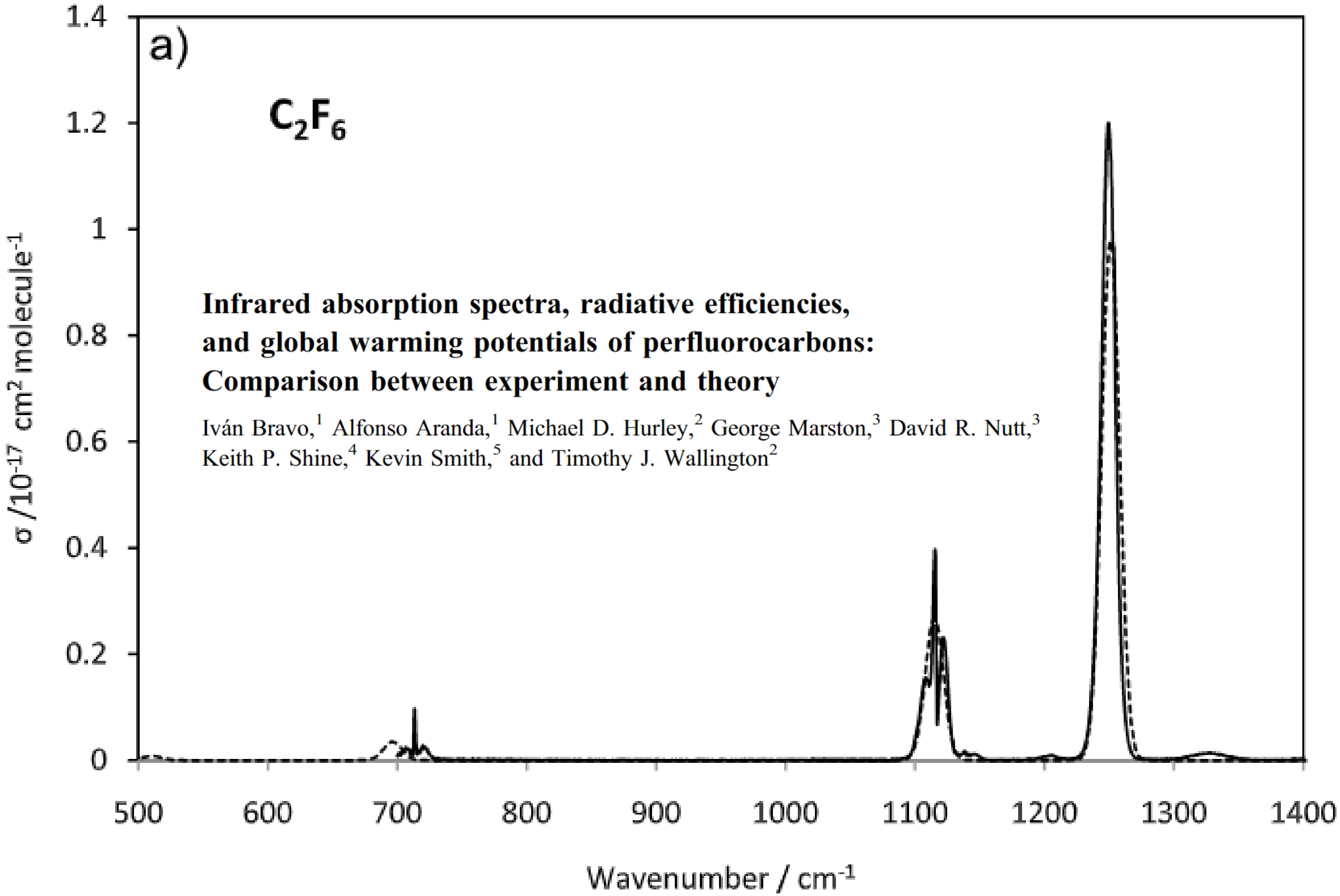






transparency > 98%
for 170 nm < λ < 220 nm

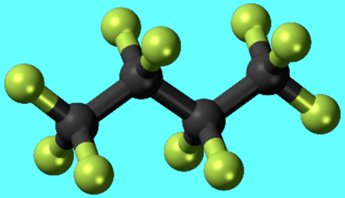
C_2F_6 absorption spectrum



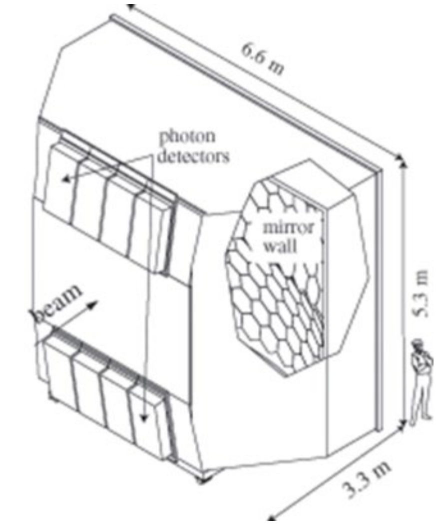
Infrared absorption spectra, radiative efficiencies, and global warming potentials of perfluorocarbons: Comparison between experiment and theory

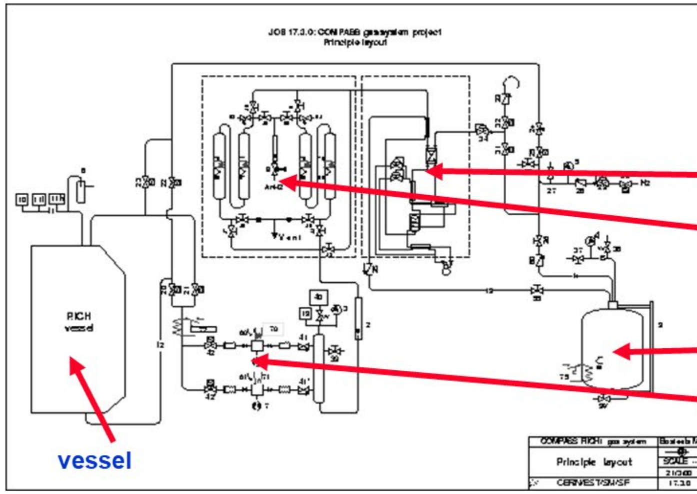
Iván Bravo,[1] Alfonso Aranda,[1] Michael D. Hurley,[2] George Marston,[3] David R. Nutt,[3] Keith P. Shine,[4] Kevin Smith,[5] and Timothy J. Wallington[2]

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 115, D24317, doi:10.1029/2010JD014771, 2010

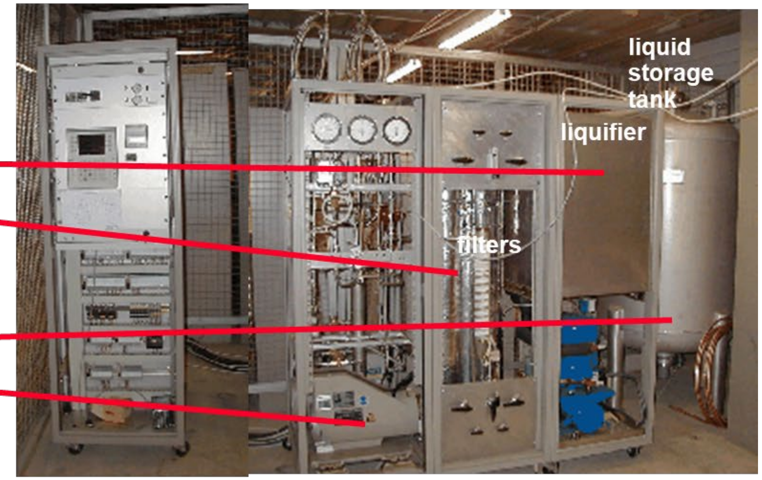


COMPASS radiator gas: C_4F_{10}



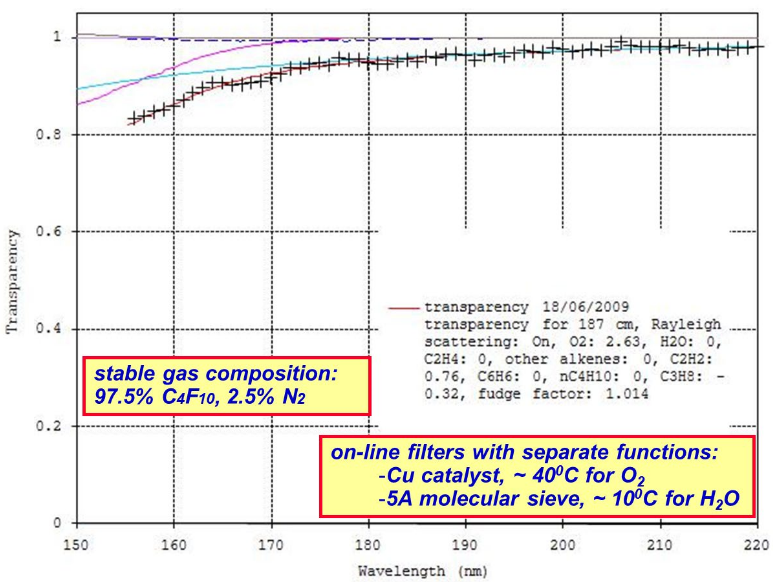


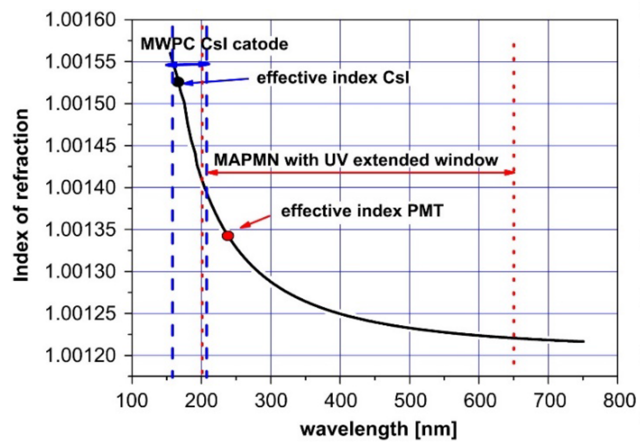
vessel

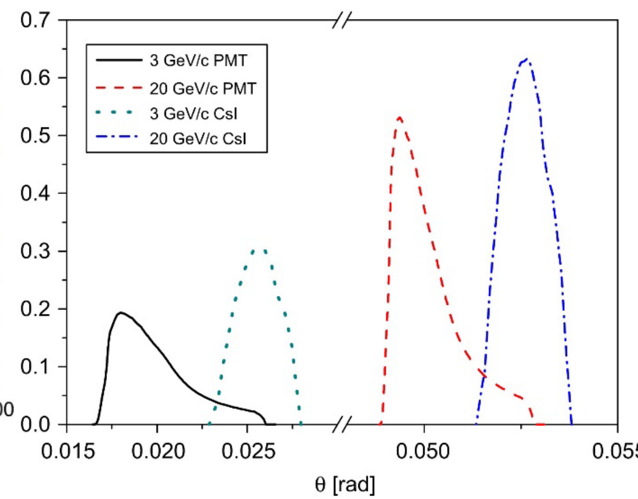


PLC and electrical installation

compressors







Chromaticity

If we work near the chromatic limit, the choice is limited.

The best gas is helium, at the appropriate pressure.

For an intuitive comparison:

	He	Ne	Ar	Kr	Xe	C2F6	C4F10
(n-1)@300 nm	35.54	67.6	295.44	455.68	762.26	850	1280
(n-1)@600 nm	34.86	66.1	282	427.23	688.6	820	1220
Theta@300 nm)	8.4309	11.6276	24.308	30.1887	39.0451	41.2311	50.5964
Theta@300 nm)	8.34985	11.4978	23.7487	29.2311	37.1106	40.4969	49.3964
Delta Theta	0.08105	0.12973	0.55934	0.95759	1.93446	0.73414	1.20009
(Delta Theta)/Theta	0.00961	0.01116	0.02301	0.03172	0.04954	0.01781	0.02372

$\Delta\theta = \theta_{\check{C}}(\lambda=300nm) - \theta_{\check{C}}(\lambda=600nm)$; $\rho = \Delta\theta/\theta_{\check{C}}(\lambda=300nm)$

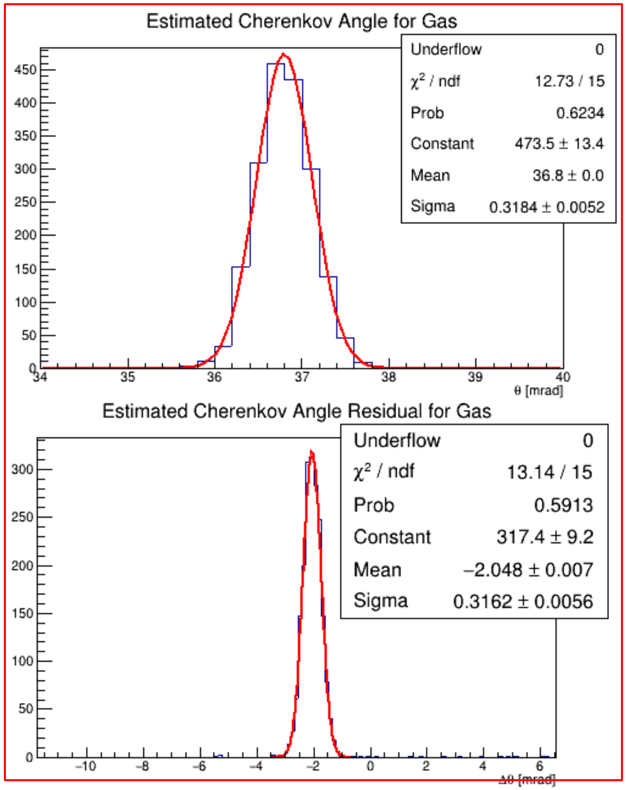
$\rho_{He} = 0.96\%$; $\rho_{Ne} = 1.1\%$; $\rho_{Ar} = 2.3\%$; $\rho_{Kr} = 3.2\%$; $\rho_{Xe} = 4.9\%$;

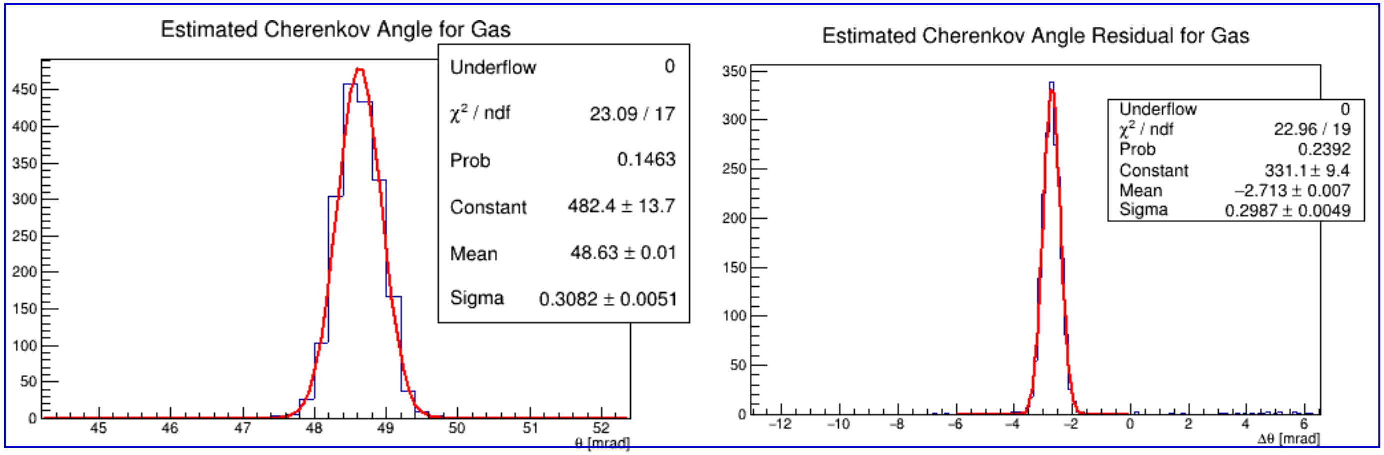
$\rho_{C2F6} = 1.8\%$; $\rho_{C4F10} = 2.4\%$;

Comparison of C_4F_{10} and C_2F_6 in ePIC simulations

50 GeV/c π and K shot at η = 2.5 (Chandra Chatterjee)

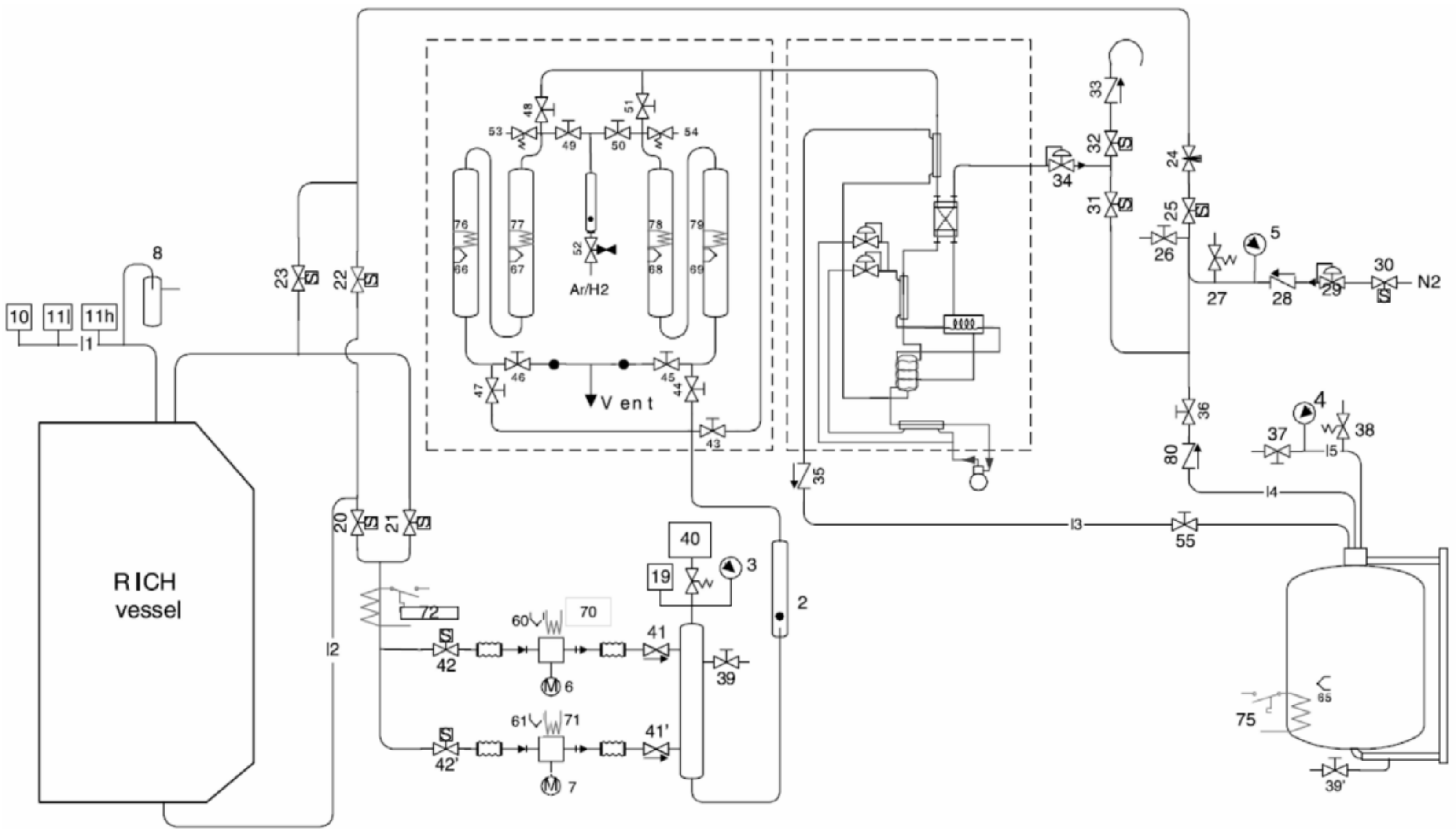
Gas	Npe(π/K)	Th_π	Th_K	Sig_π	Sig_K	N_Sig
C_2F_6	16.03/14.94	36.8	35.67	0.32	0.33	3.5
C_4F_{10}	24.8/23.8	48.63	47.8	0.29	0.30	2.8

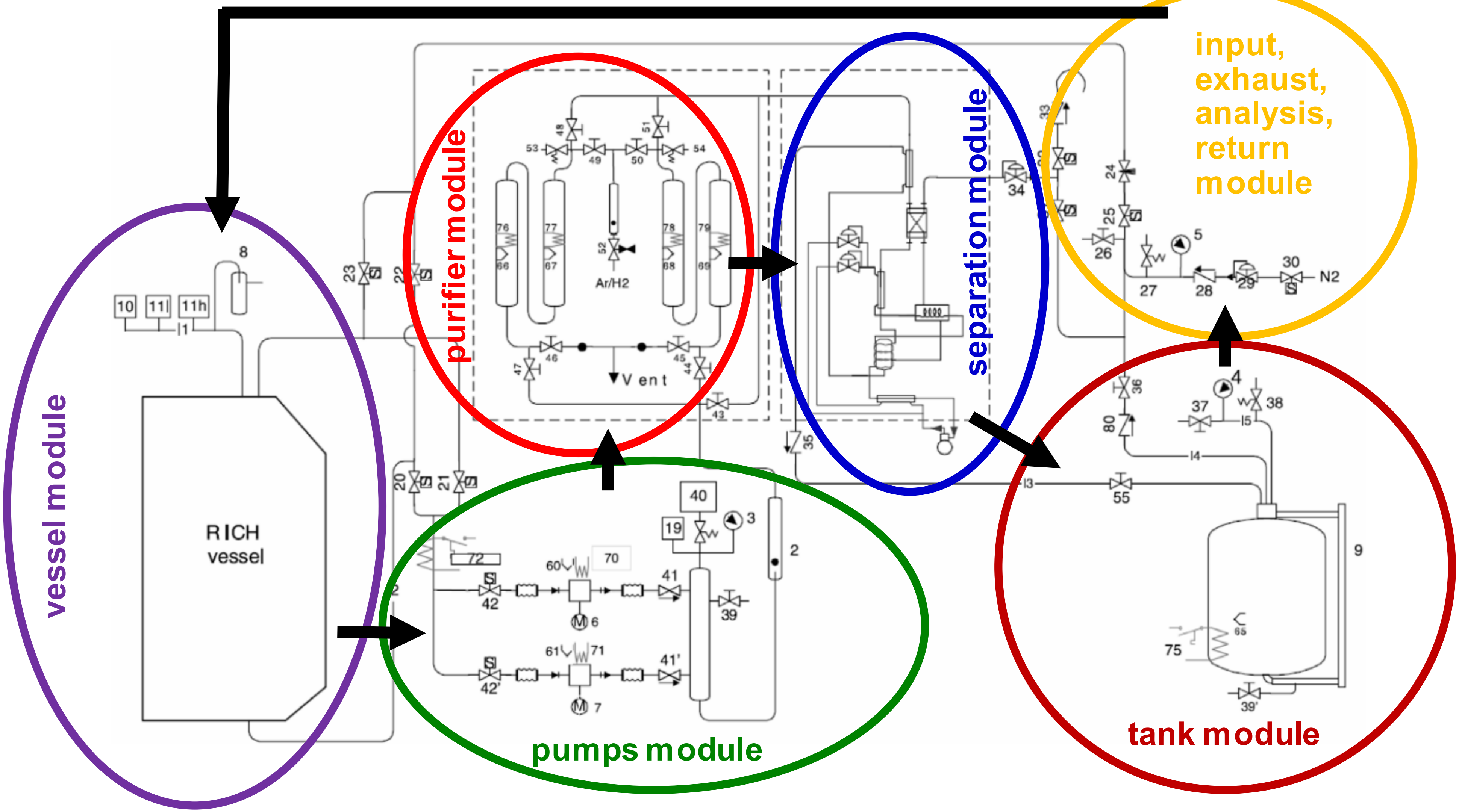




- **C_4F_{10} does not qualify the 3.5 σ test.**
- **Offset of 2 mrad in theta residual is present consistently in both gases.**
- **The number of photons compatible to COMPASS for C_4F_{10} (for PMTs we have <Npe> ~60 at saturation)**

the COMPASS gas system

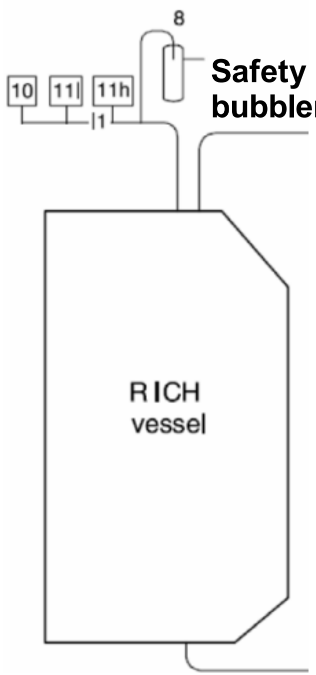



input,
exhaust,
analysis,
return
module
purifier module
separation module
vessel module
RICH
vessel
pumps module
tank module
Ar/H2
Vent
N2

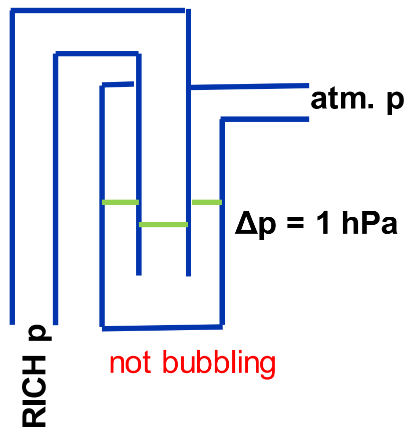
passive pressure safety system

pressure gauges and hardware alarms

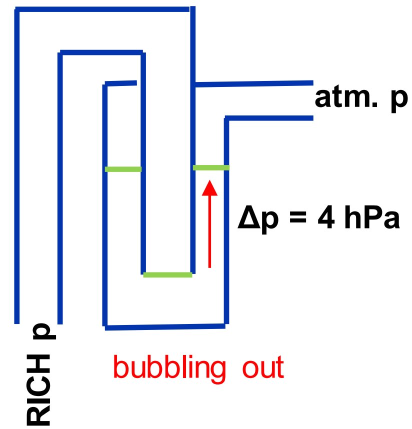
Safety bubbler:



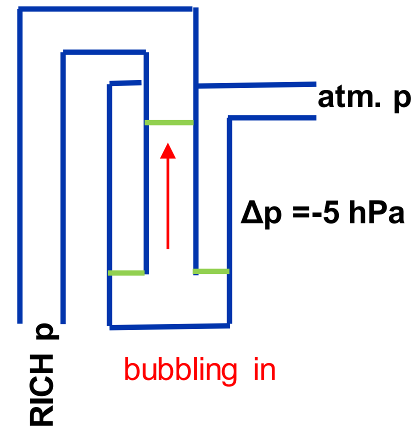
normal operation:



overpressure safety:



underpressure safety:



The safety Δp levels are defined by the inner/outer section surface ratio and the oil level

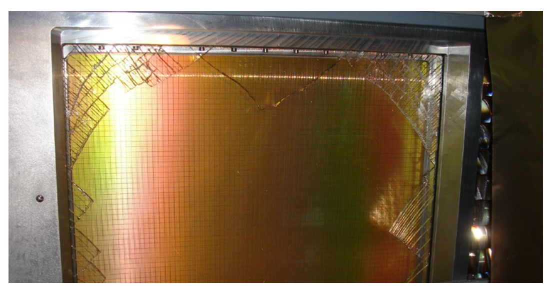
Large stainless-steel bubbler built for COMPASS RICH1 after choosing the safety levels

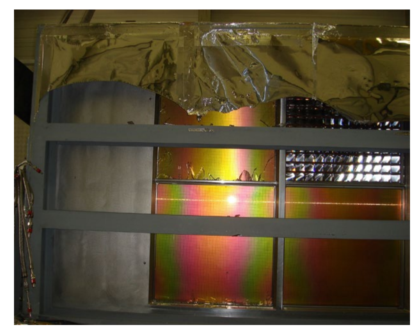
Protection of the fused silica windows, which are expected to be in danger for P > 30 hPa

Pressure set at atmospheric pressure + 1.00 hPa at the top of RICH volume

Feedback cycle tolerance < 0.1 hPa

High p alarms at + 2.0 hPa
Low p alarm at 0.0 hPa





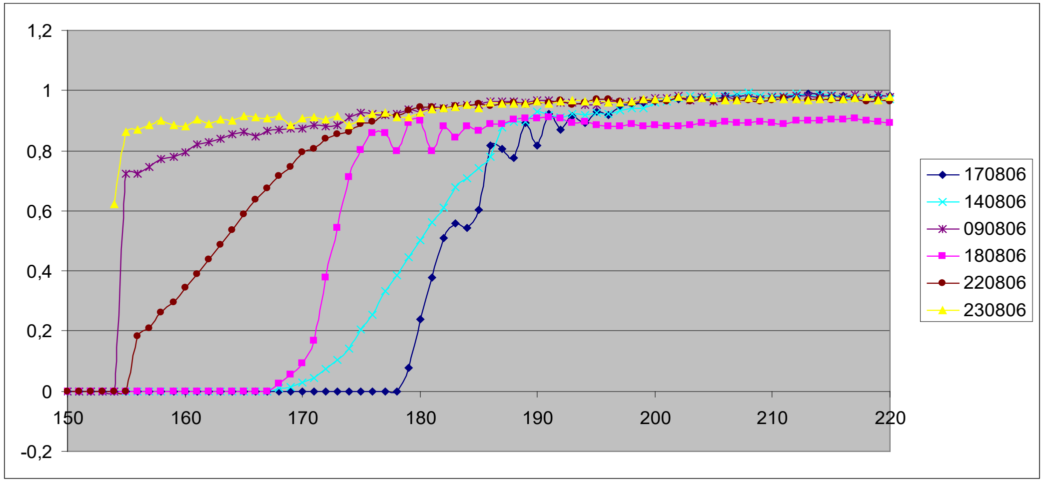
Fast change in atmospheric pressure

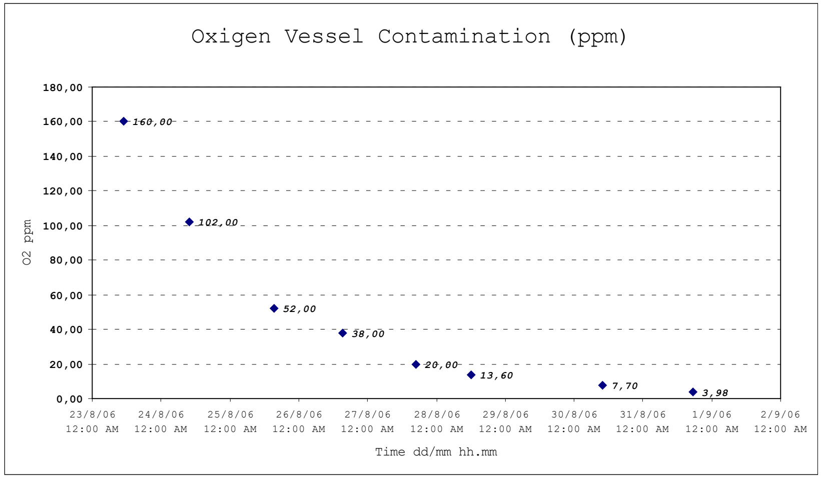
compressors in standard running conditions remove 0.7 l/s from the vessel, corresponding to 1 ‰ of the radiator gas content (80 l) in ~2 min.

In extreme cases (thunderstorms), Δp of several hPa can develop in < 1 min

→ overpressure alarm or (very rarely) even safety bubbler bubbling out.

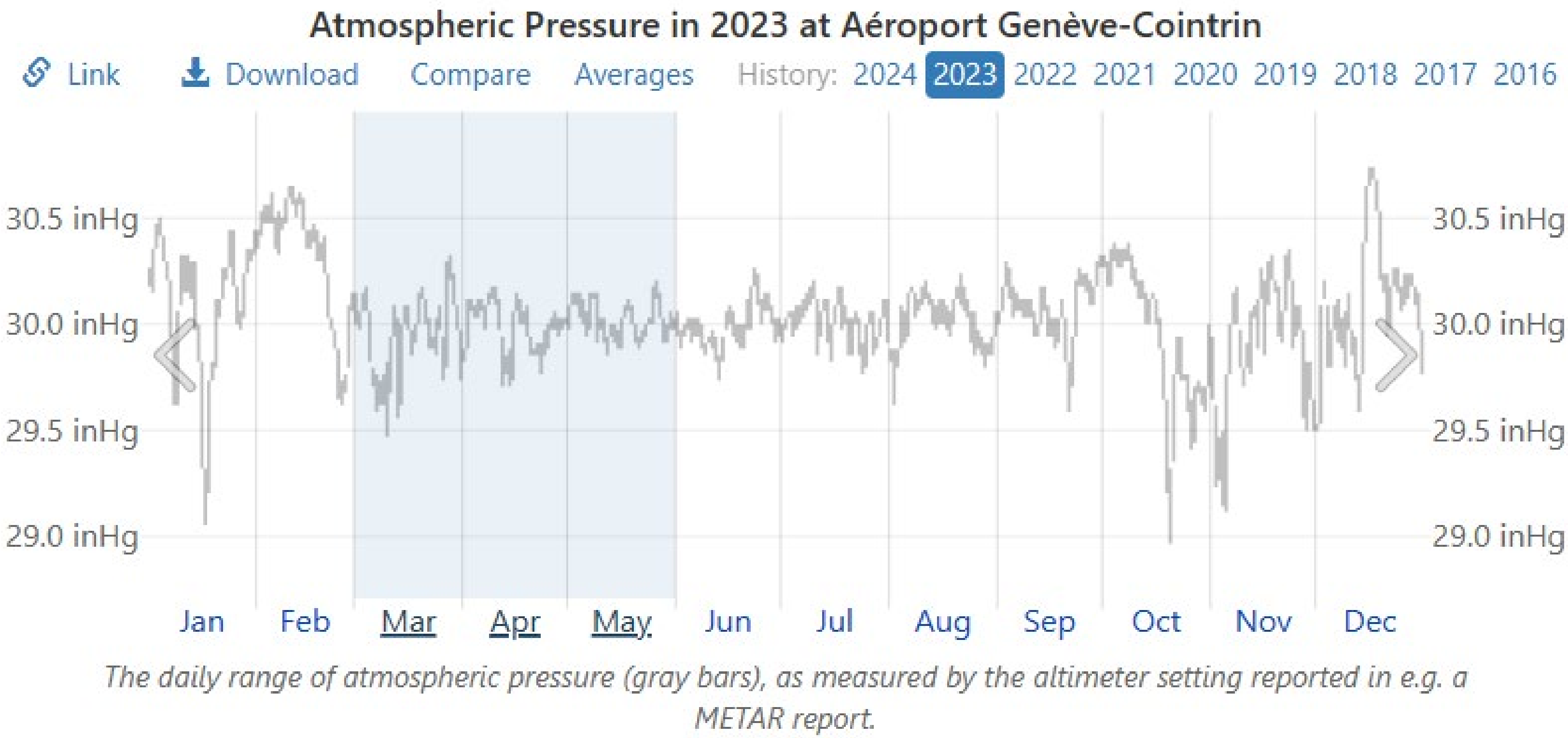
Very fast increase of atmospheric pressure → underpressure alarm (compressors stopped) or even safety bubbler bubbling in. This happened in 2006





Atmospheric pressure variations

If the system follows the atmospheric pressure, the density of the radiator will vary accordingly.



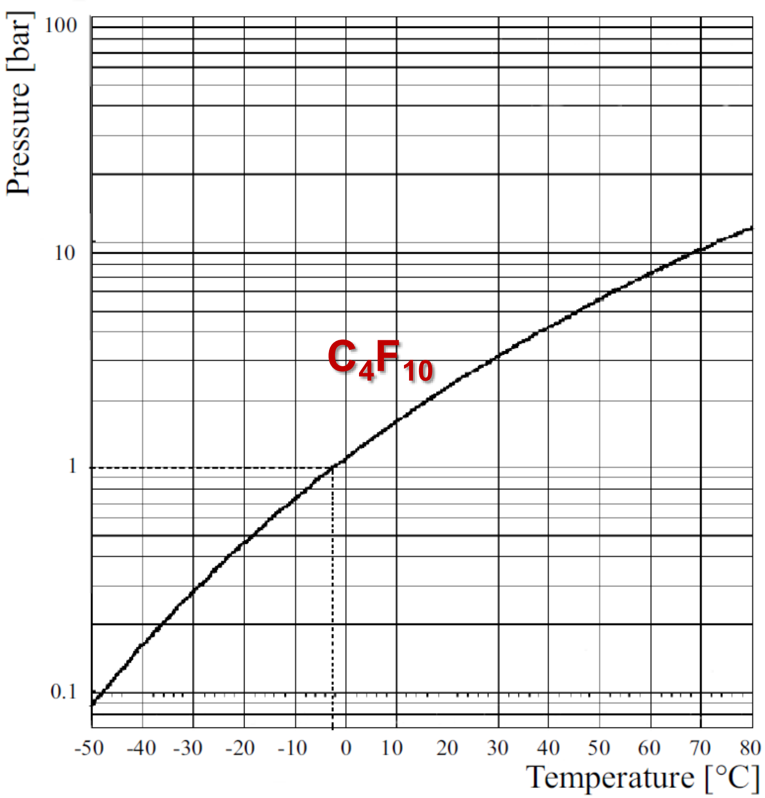
The daily range of atmospheric pressure (gray bars), as measured by the altimeter setting reported in e.g. a METAR report.

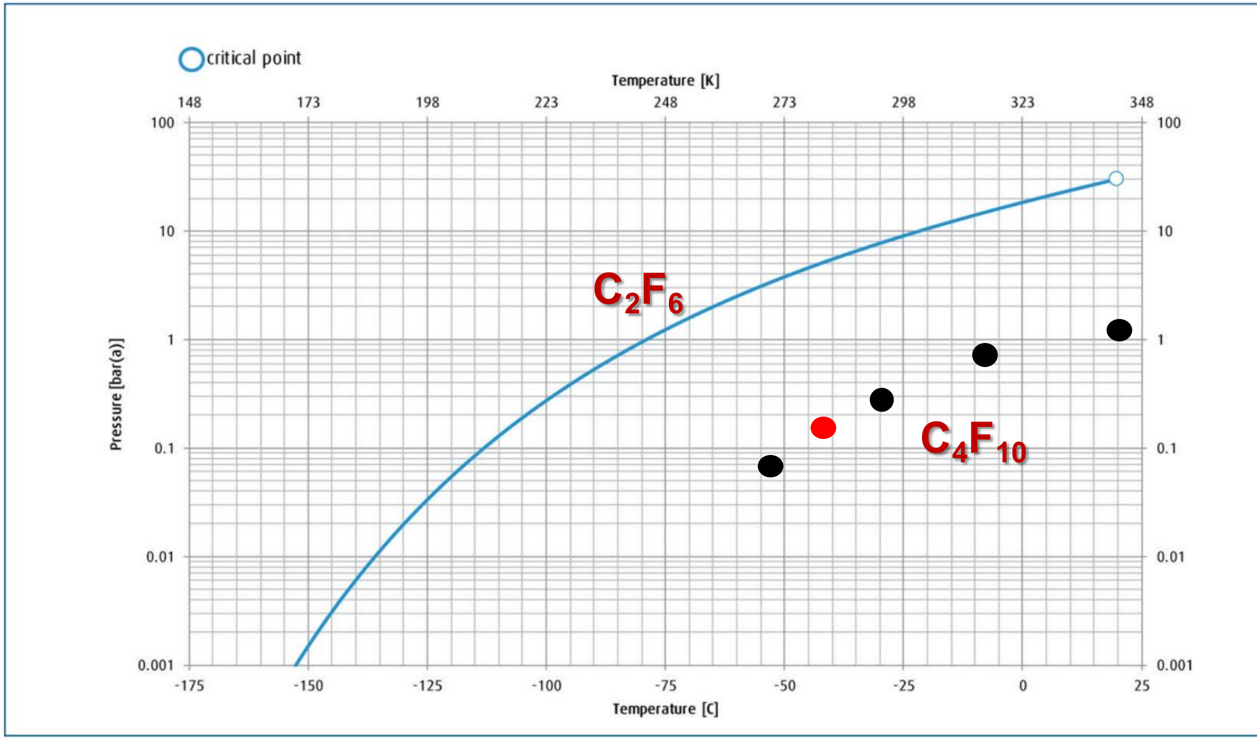
External pressure variation in Geneva in 2023 (same as in previous years)

Min: 28.9 inHg = 978 hPa   Max: 30.8 inHg = 1043 hPa   Δp = 65 hPa

C_2F_6 separation

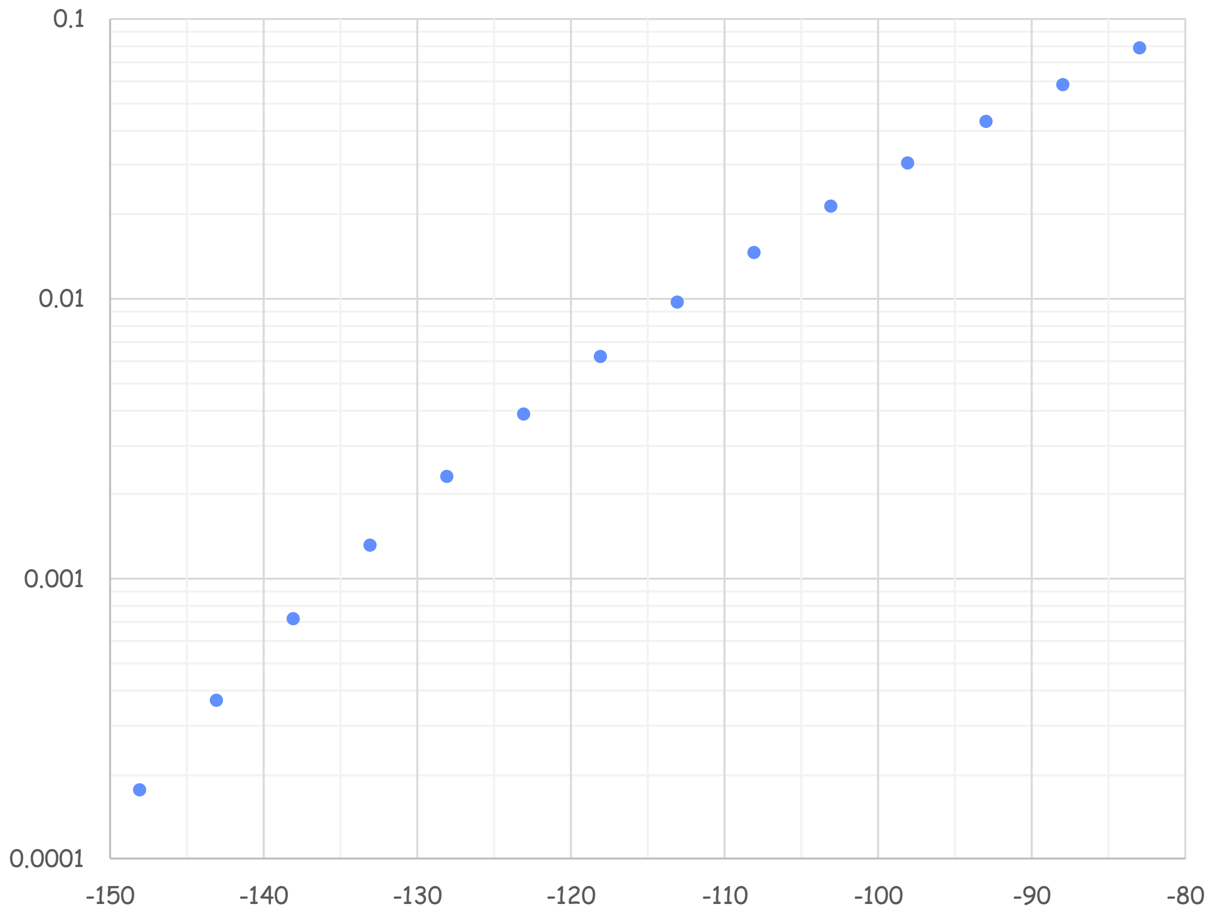
The partial pressures of C_2F_6 and C_4F_{10} are very different





At - 36°C C_4F_{10} has 200 hPa vapor pressure. A separator working at 7 bars will purge 97% N_2 and 3% C_4F_{10}

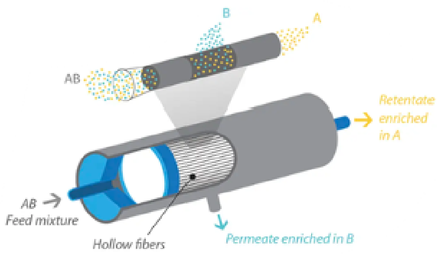
C_2F_6 fraction in vented gas at 10 bars



Discussion with Roberto Giuda at CERN to perform a test with a chiller at -98 °C and, possibly, -130 °C

Separation

Membrane separation

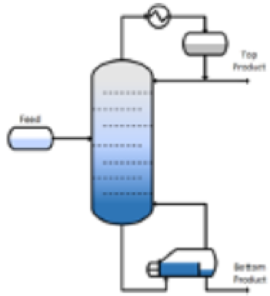


- **Difference** in **thermodynamic activities** existing across the membrane and **interacting forces** working between **membrane material** and permeating **molecules**
- Separation process driven by several factors
  - Permeability, Solubility, Diffusivity

Pressure and thermal swing adsorption

- Separation of gases according to the species **molecular characteristics** and affinity with an **absorbent material** (Molecular Sieve)
- **PSA**: the target gas absorbed in the MS is extracted by vacuum regeneration of the material
- **TSA**: the target gas absorbed in the MS is extracted by heating the material

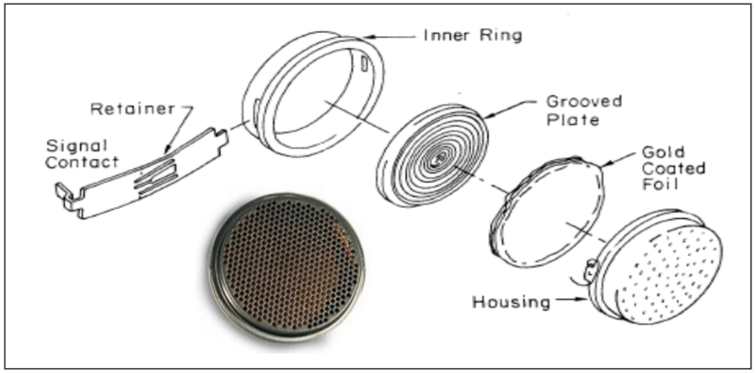
Distillation



- Purification method to separate 2 or more compounds based on **differences in boiling points** or **volatility**
- Simple distillation
- **Fractional** distillation
  - Subsequent vaporization-condensation event
- Difficult in case of **azeotropic** gas mixture

C_2F_6 refractive index and speed of sound

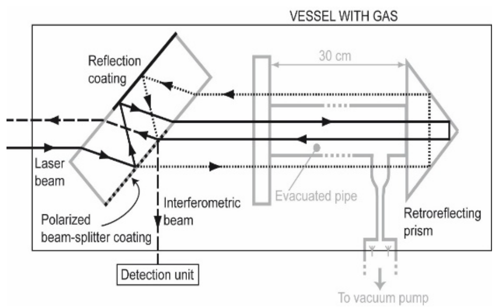
Polaroid Capacitative transducer components

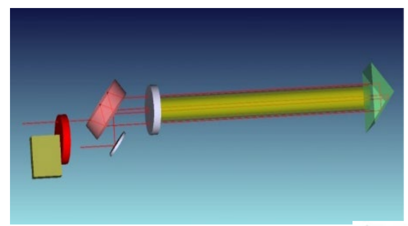


Capacitative 350V activation/ bias ➔ rapid response
37mm diameter determines 50 kHz dominant frequency: can operate over wide pressure range (50mbar ➔>35 bar…)

Continuous monitoring of the speed of sound in the radiator gas

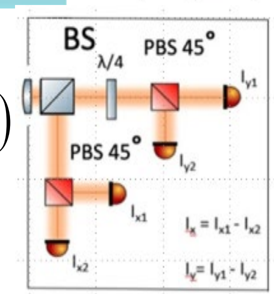
Monitoring of the refractive index can be performed by interferometry with an accuracy of 10 ppb





$$I = I_1 + I_2 + 2\sqrt{I_1 I_2}\,\Delta\phi(t)$$

$$\Delta\phi(t) = \left(2\pi\ell/\lambda\right)\Delta n(t)$$

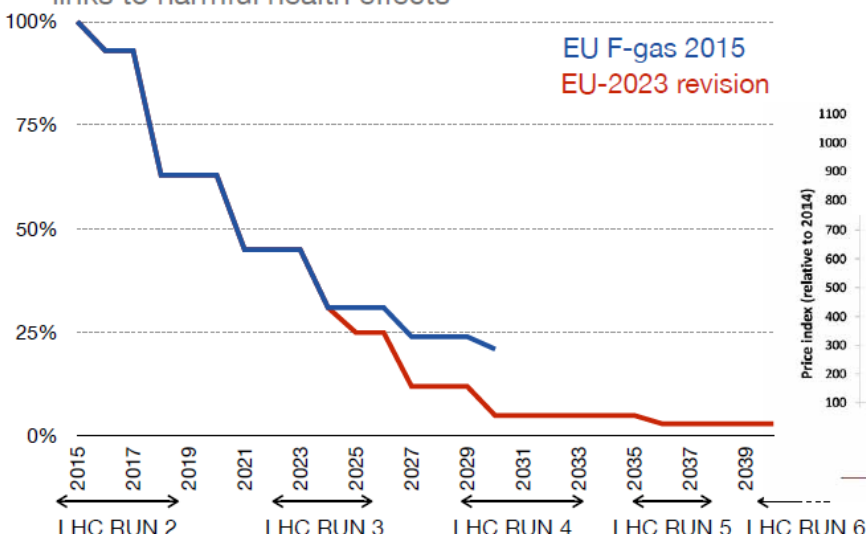


Will C_2F_6 be banned?

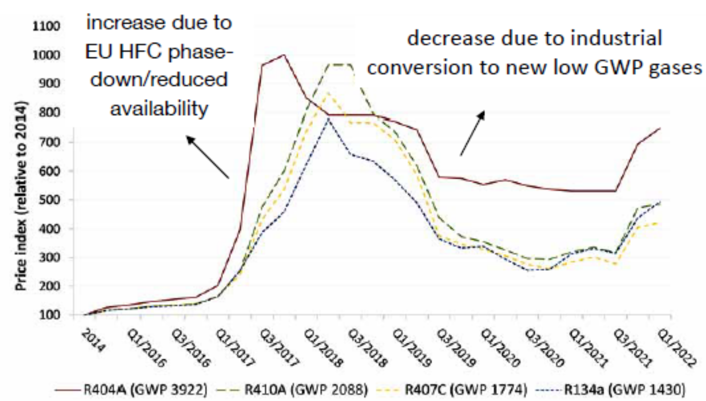
New F-gas regulation: from phase down to out

The new Regulation establishes the total elimination of hydrofluorocarbons by 2050

- It is a major step towards **climate neutrality**
- First goal: reduction of 55% GHG emissions by the end of this decade compared to 1990 levels
- New restrictions also in the use of SF_6 and especially for high GWP gases
- It will result in a reduction in production and **reduced quotas** for F-Gas refrigerants, leading to an inevitable **increase in prices** for higher GWP refrigerants
- Keywords: to **limit**, to **prevent**, to **ban** the use of F-gases
- In 2023, the European Chemicals Agency (ECHA) released a proposal regarding **PFAS restrictions**
  - PFAS: per- and polyfluoroalkyl substances
  - it envisages covers over 10,000 different PFAS, which are considered environmental pollutants with links to harmful health effects



Average purchase prices of the most commonly used HFC refrigerants



Beatrice Mandelli 2 19 Jun 2024

GHG reduction

CERN strategies for GHG reduction

CERN Strategies to reduce GHG emissions in particle detection

- **Gas Recirculation** (Since LHC started)
  - Optimisation of current technologies
  - Particular attention to operation
  - Improved control and monitoring
- **Gas Recuperation** (Since 2009)
  - Pressure swing
  - Membrane separation
  - Cryogenic/cold separation
- **Alternative Gases** (Since 2013)
  - To $C_2H_2F_4$
  - To SF_6
  - To CF_4

Already implemented

Long-term

R&D Topic in ECFA Roadmap

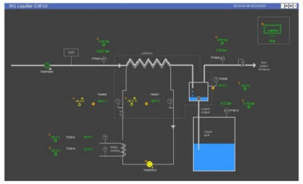
DRDT 1.3: Develop environmentally friendly gaseous detectors

< 2030 | 2030-2035 | 2035-2040 | 2040-2045 | > 2045

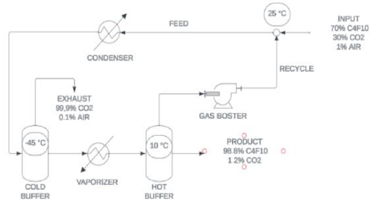
Gas recuperation: LHCb RICH1 C_4F_{10}

RICH1 Gas System

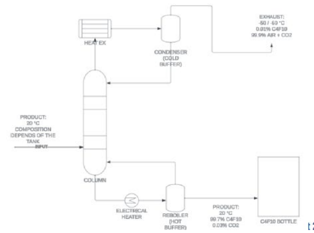
- Detector volume ~4 m³
- Gas mixture: **100% C_4F_{10}**
- Gas recirculation: ~100%
- Problem: air intake
  - Cleaning of gas during the year
- Emptying of detector during maintenance or long shutdown
  - Gas have to be recuperated



Double stage equilibrium



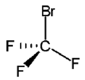
Distillation columns



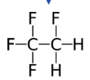
Alternatives gases

New eco-friendly liquids/gases have been developed for industry as refrigerants and HV insulating medium… not straightforward for detector operation

ODP Ozone Depletion Potential → GHG Greenhouse gases → "ECO" gases → Natural gases



R13B1 ($CBrF_3$)
GWP 6900 - ODP 10



R134a ($C_2H_2F_4$)
GWP 1430 - ODP 0

Hydro-Fluoro-Olefin (HFO)
- C=C double bond
- fluorine-containing
- hydrogen-containing

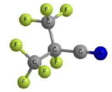
and

3M™ Novec™
GWP <10 - ODP 0

O=C=O
and
hydrocarbons
GWP 1 - ODP 0

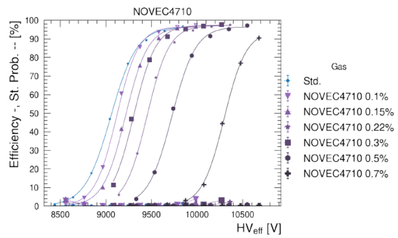
- ~20-30 years ago, it was the time to get rid of ODP gases
- There was not the awareness on the use of GHGs
  - Many gaseous detectors were conceived with use of GHGs
- Now it is time to address the usage of GHG worldwide, including particle detectors
- New concerns are already raising for the use of new "eco-friendly" gases, most of which are PFAS

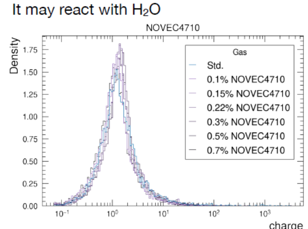
NOVEC 4710

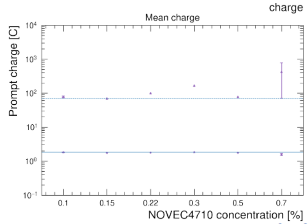


PRO
- Good vapour pressure
- Application in industry
- High dielectric strength

CONS
- GWP of 2200
- It may react with H_2O



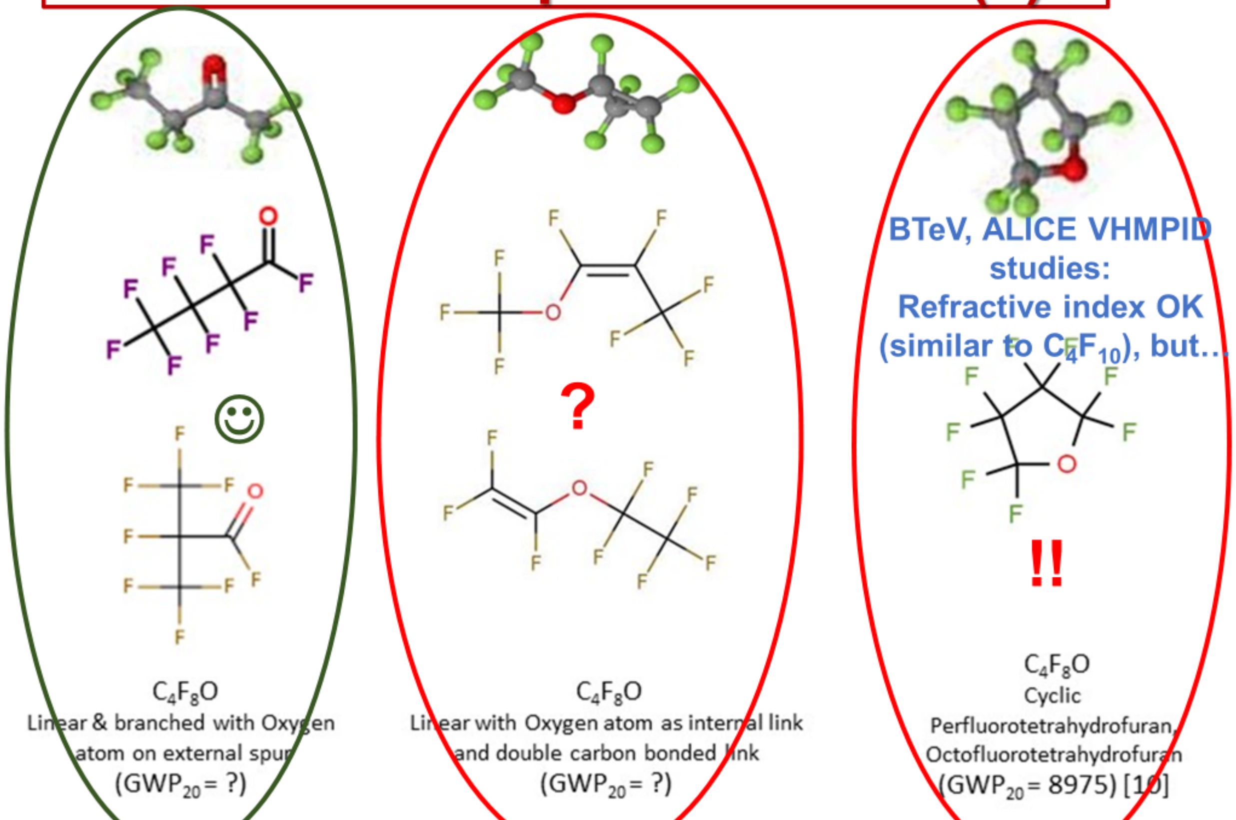




- Streamer probability always lower than std gas mixture
  - 0.1% of NOVEC 4710 already enough!
- Avalanche charge and cluster size lower than std gas mixture
- Higher working point for concentrations > 0.1%

Alternative gases

Molecular shapes and GWP (2)



Shape examples of cyclic, non-cyclic & non-cyclic double carbon-bonded C_4F_8O isomers refs at end.

G. Hallewell: DRD4 WG 2 Low GWP FC radiator gases: June 19 2024 4

Alternative gas mixtures

INFN Istituto Nazionale di Fisica Nucleare

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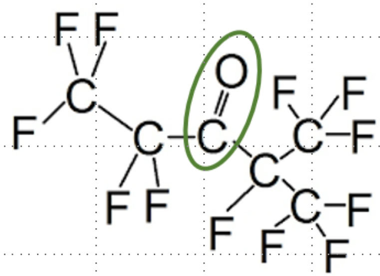
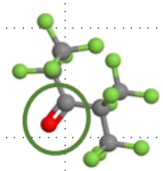
Q: But What gives NOVEC 649/1230 (a spurred-Oxygen fluoro-ketone) its low GWP?





NOVEC 649 $C_6F_{12}O$ (GWP_{20} = ≤ 1) [12] $CF_3CF_2C(O)CF(CF_3)_2$

A: Structure!: a *double-bonded oxygen atom on a peripheral spur* of the molecule

This fluoro-ketone configuration is: $CF_3CF_2C(O)CF(CF_3)_2$

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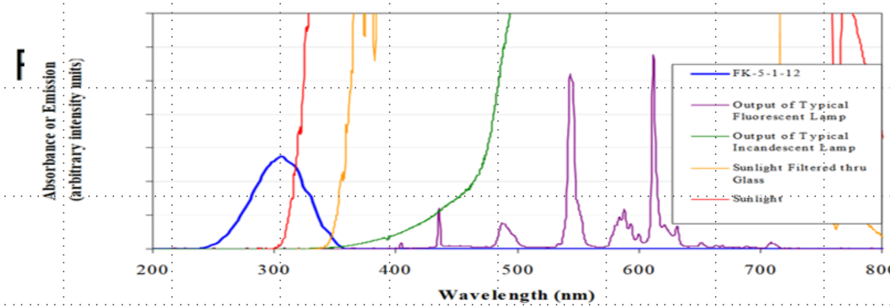
Q: What gives NOVEC 649/1230 its low GWP?

https://www.nist.gov/system/files/documents/el/fire_research/R0301570.pdf [15]

Figure 3. UV Absorption of FK-5-1-12 Compared to Light Sources



Scission by UV photons of λ around 300 nm
In the atmosphere (low pressure, high UV): the fragments do not reassociate* into saturated fluorocarbons of the type $C_nF_{(2n+2)}$ (which would have high GWP)

*The Environmental Impact of CFC Replacements HFCs and HCFCs
T. WALLINGTON et al *Environ.Sci.Technol.*1994(28)7 320A
https://doi.org/10.1021/es00056a714

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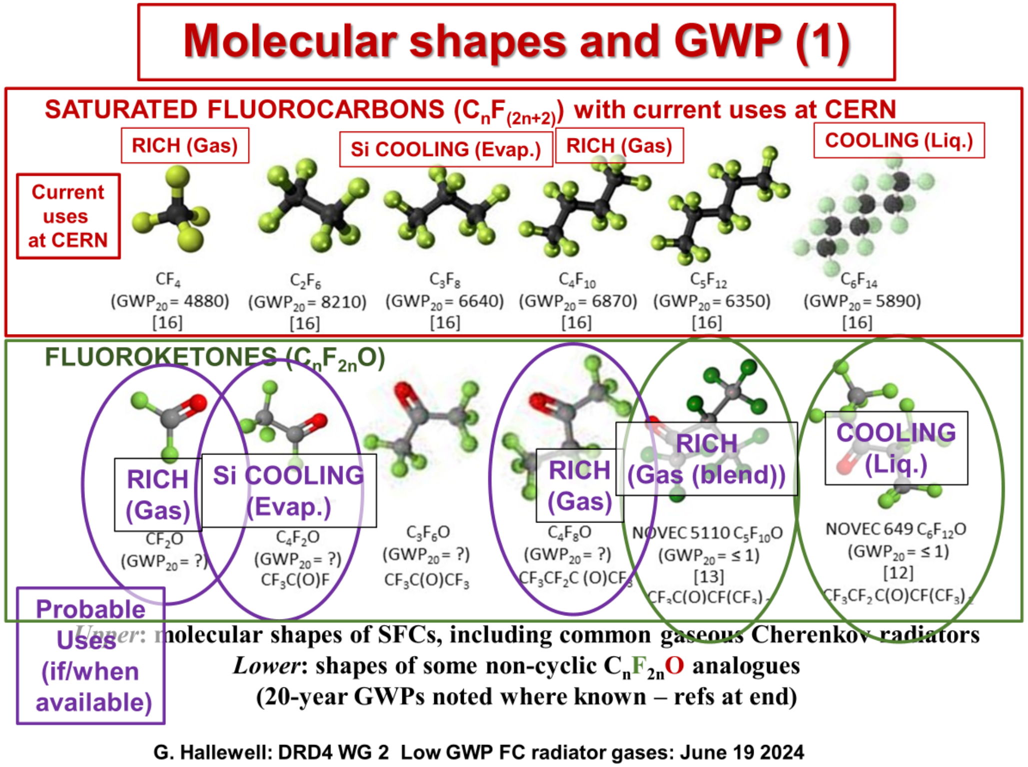
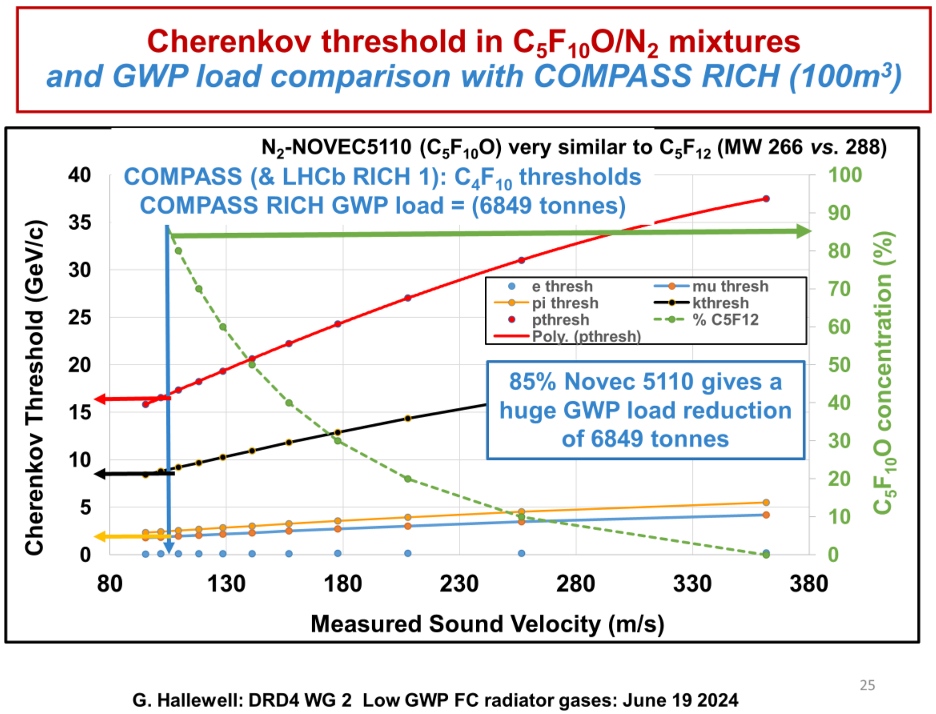
Alternative gases



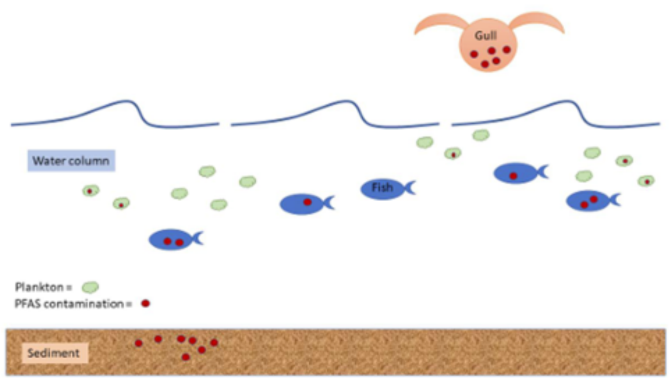


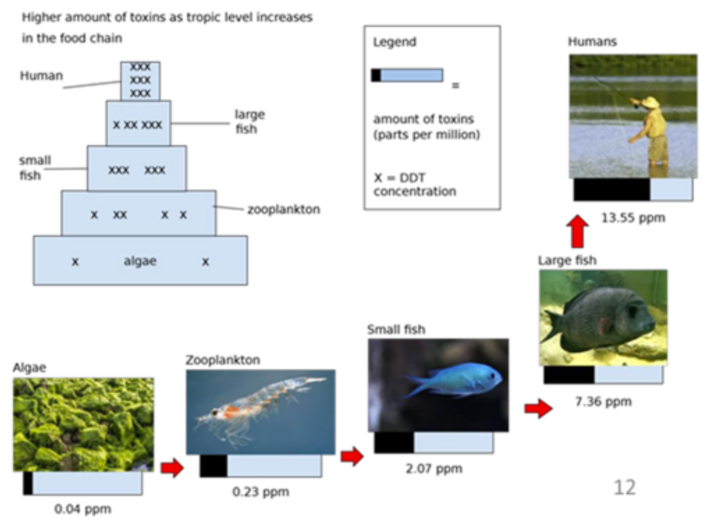
PFAS: per-(poly-)fluoroalkyl substances

PFASs are defined as fluorinated substances that contain at least one fully fluorinated methyl or methylene carbon atom (without any H/Cl/Br/I atom attached to it), i.e. with a few noted exceptions, any chemical with at least a perfluorinated methyl group (–CF3) or a perfluorinated methylene group (–CF2–) is a PFAS

PFASs play a key economic role for companies such as DuPont, 3M, and W. L. Gore & Associates because they are used in emulsion polymerization to produce fluoropolymers. They have two main markets: a $1 billion annual market for use in stain repellents, and a $100 million annual market for use in polishes, paints, and coatings. In 2022, 3M announced that it will end PFAS production by 2025.

Bioaccumulation and biomagnification





29/05/2023 Belgrade workshop 12

Roberto Guida, "Search for the ECO-friendly gas-mixtures for the muon detectors at LHC and beyond" 29/05/2023

PFAS: per-(poly-)fluoroalkyl substances

- The restriction was **proposed** by Germany, The Netherlands, Sweden, Denmark and Norway **for the EU**.
- It aims to be **biggest chemical ban** out of health considerations.
- **Imports will also be considered in the restriction.**

CONCLUSIONS

The optimal radiator gas for ePIC dRICH is C_2F_6

Detailed studies on C_2F_6 properties will be performed

The GWP of C_2F_6 is significant
but the emissions from dRICH can be reduced to a minimal level

The risk of C_2F_6 ban is not negligible

Alternatives are considered as backup solutions