dRICH gas system and monitoring

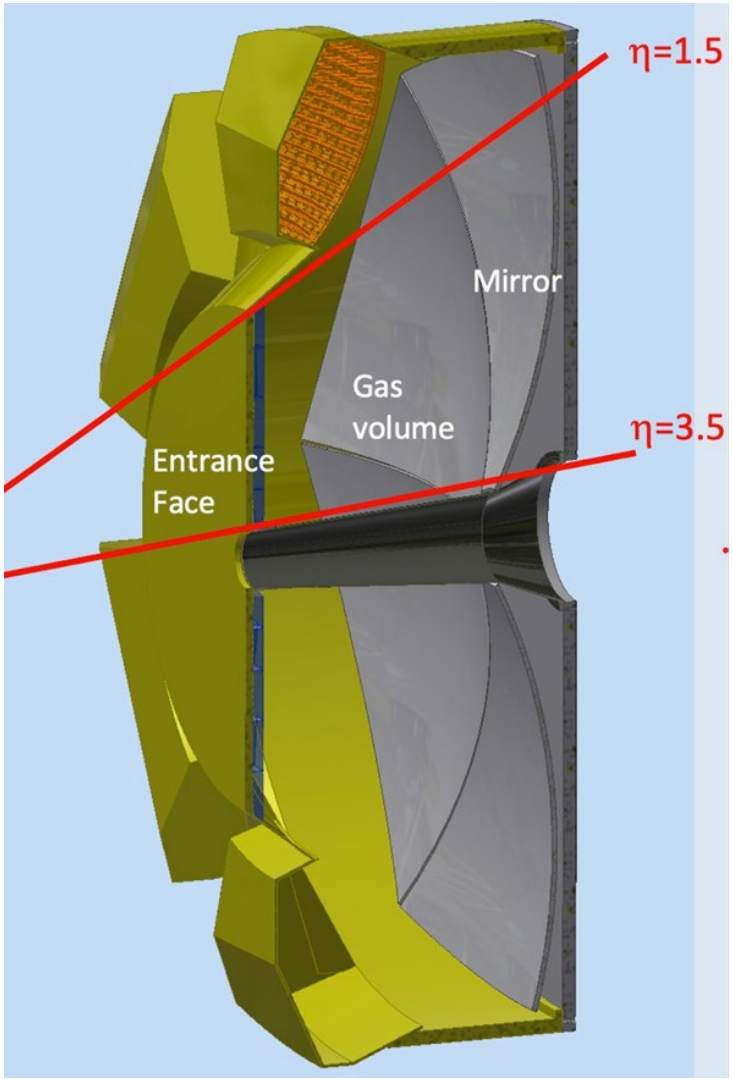
ePIC - Incontro con i referee INFN

16 luglio 2024

Silvia Dalla Torre – Fulvio Tessarotto

INFN – Sezione di Trieste

ePIC dRICH



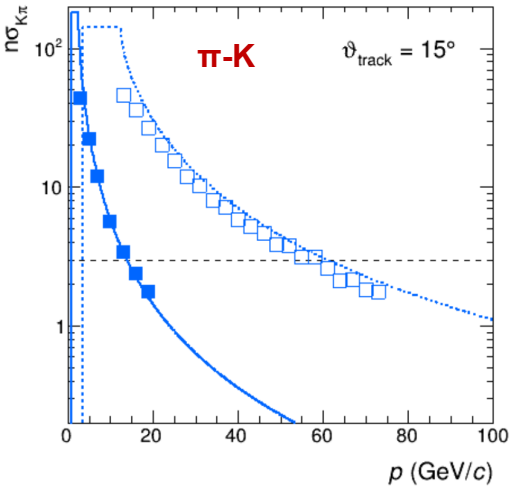
Intervallo di impulsi per separazione π-K: 3-50 GeV/c
Rinforzo separazione π-e:
Accettanza angolare: 1.5 < η < 3.5
Campo magnetico: ~ 1 T
Spazio ridotto: diam. ~3600 mm, L ~1200 mm

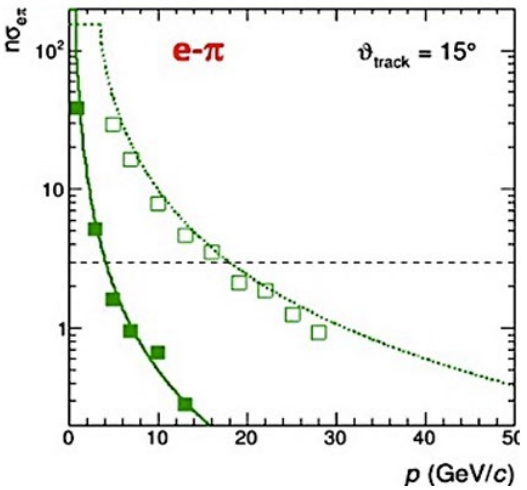
➔ **E` necessario usare due radiatori, aerogel e gas**

Aerogel n = 1.02 -1.03 **Gas n ~ 1.0008**

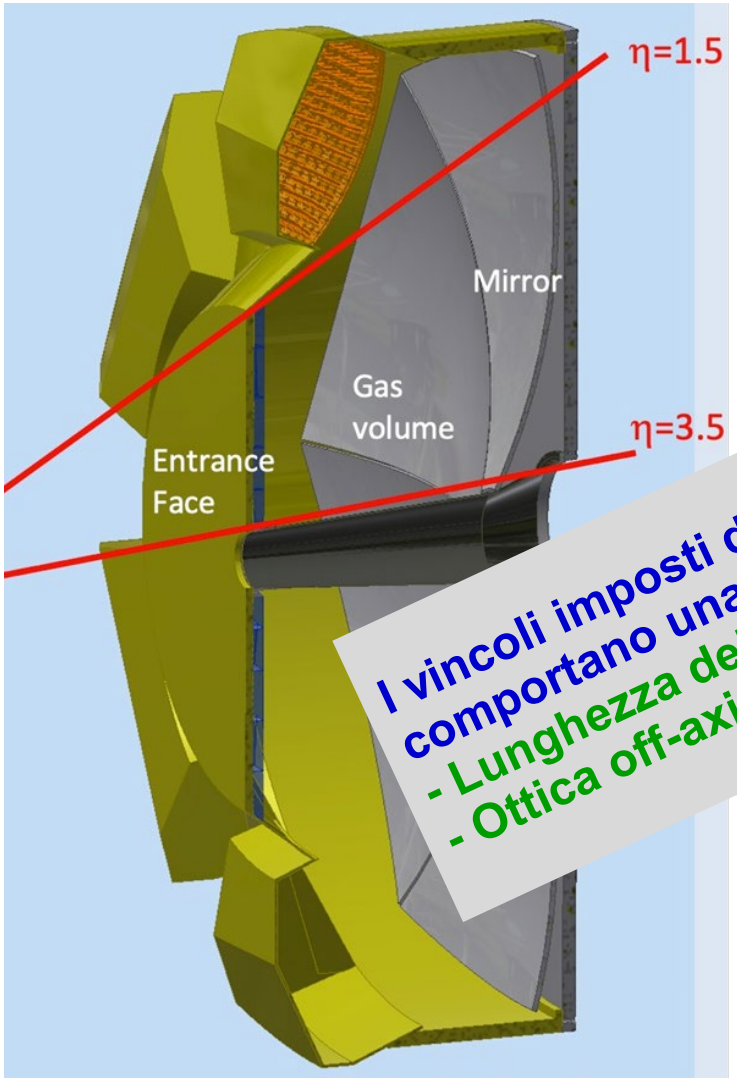
6 Specchi **Rivelatori a superficie curva**

Fotorivelatori: 6 · 0.5 m^2 SiPM 3 ·3 mm^2 raffreddati (-30 ˚C)





ePIC dRICH



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Spazio ridotto: diam

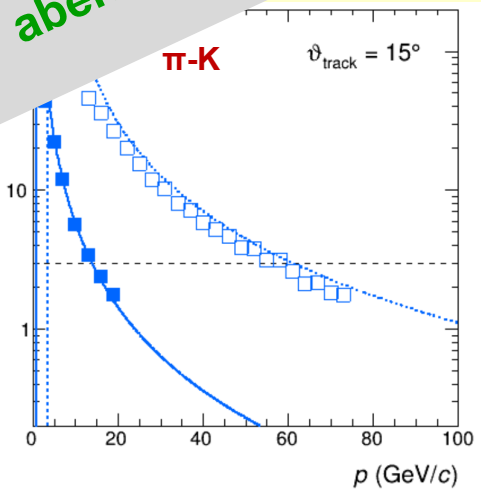
➔ E` necess **l e gas**

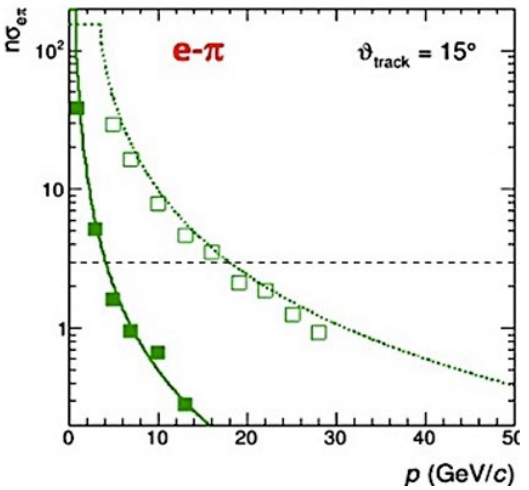
Ae **008**

ivelatori a superficie curva

SiPM 3 ·3 mm² raffreddati (-30 ˚C)

I vincoli imposti dal layout della zona di interazione comportano una geometria critica per l'uso del gas:
- Lunghezza del radiatore gassoso
- Ottica off-axis ➔ aberrazioni sferiche dominanti





overview

gas system

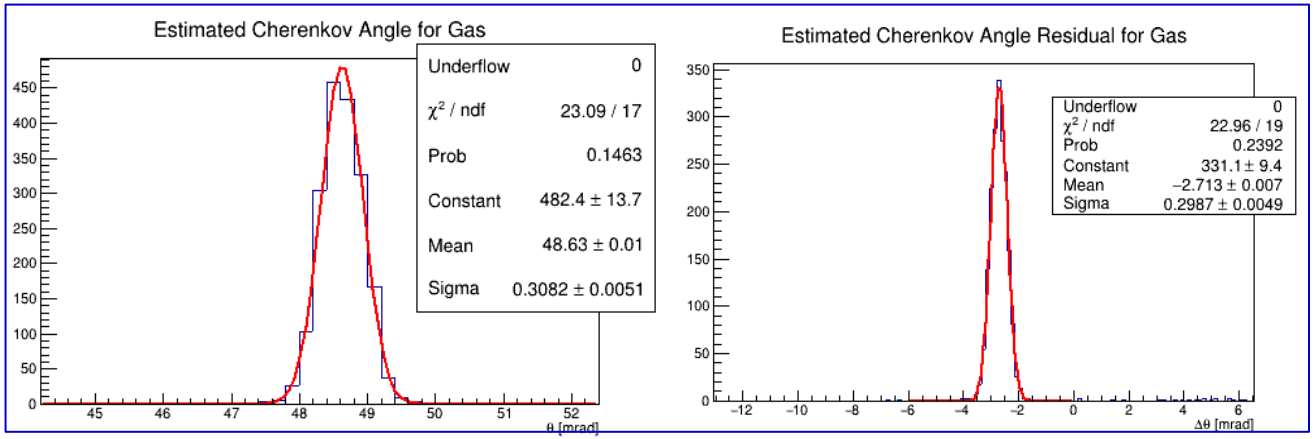
gas studies and monitoring

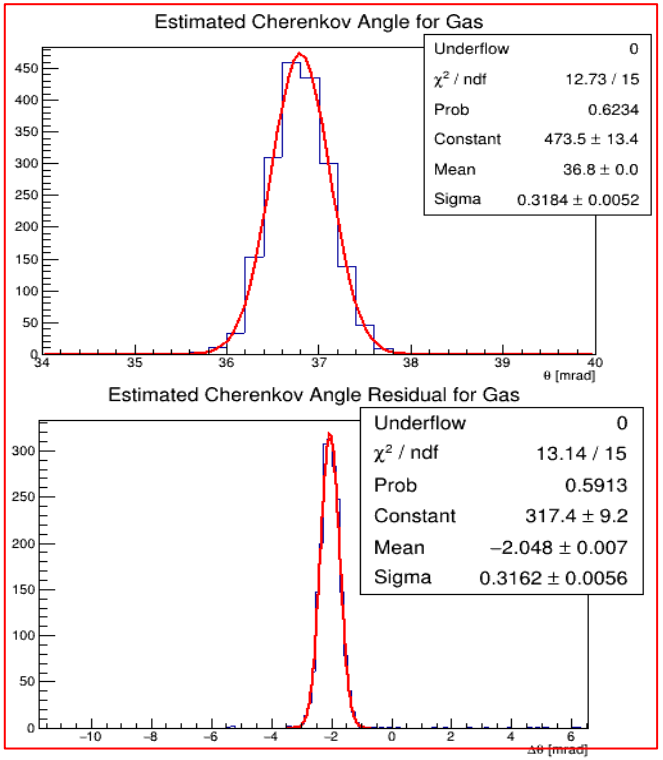
C_4F_{10} and C_2F_6 in ePIC simulations

Le simulazioni indicano una preferenza per il C_2F_6

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

Gas	Npe(π/K)	θ_π	θ_K	σ_π	σ_K	N_σ
C_2F_6	16.0/14.9	36.8	35.7	0.32	0.33	3.5
C_4F_{10}	24.8/23.8	48.6	47.8	0.29	0.30	2.8

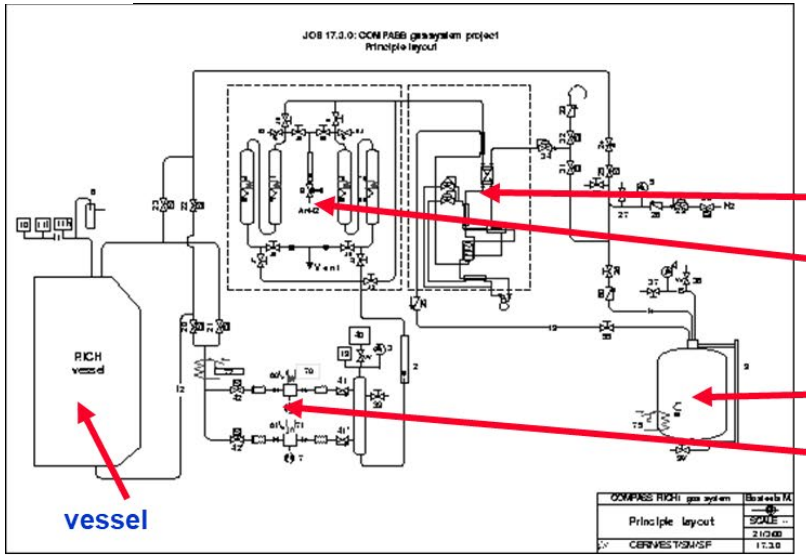


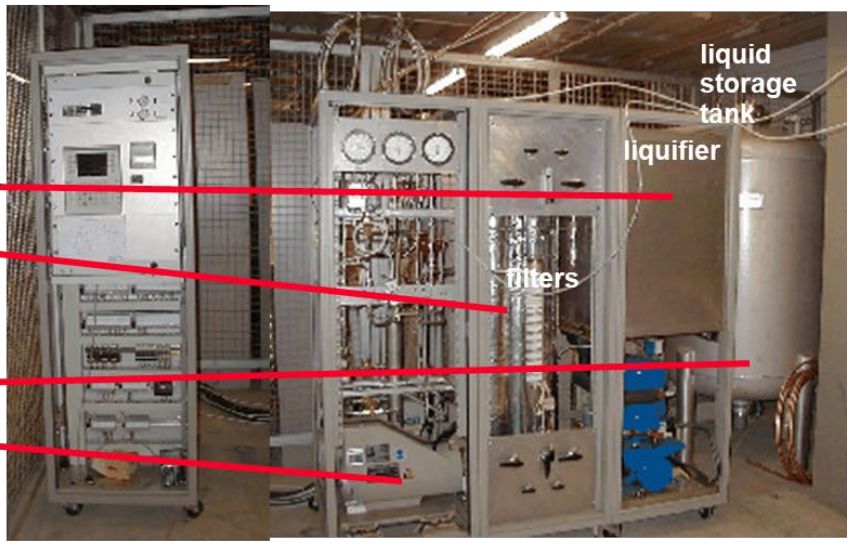


Il C_2F_6 è stato validato in combinazione con SiPM da misure su test-beam (senza aberrazioni)

Il C_2F_6 è il default ma modifiche dei vincoli esterni → diversa scelta

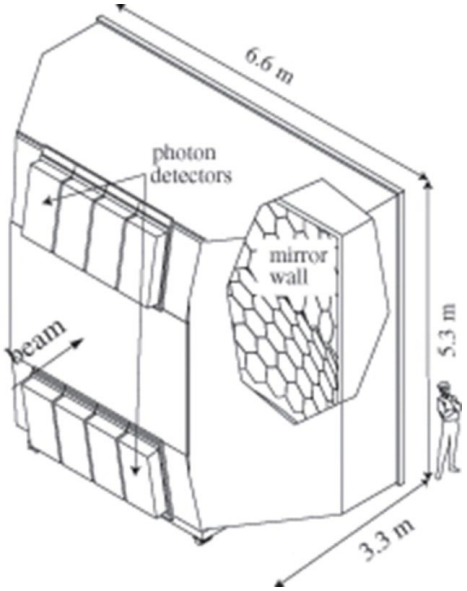
gas radiatore di COMPASS: C_4F_{10}

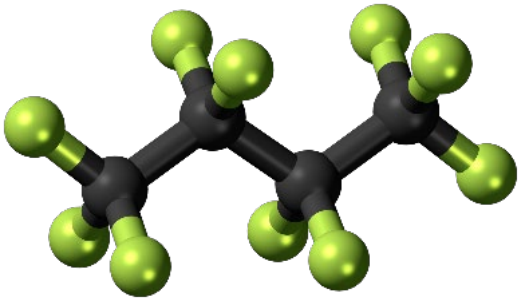


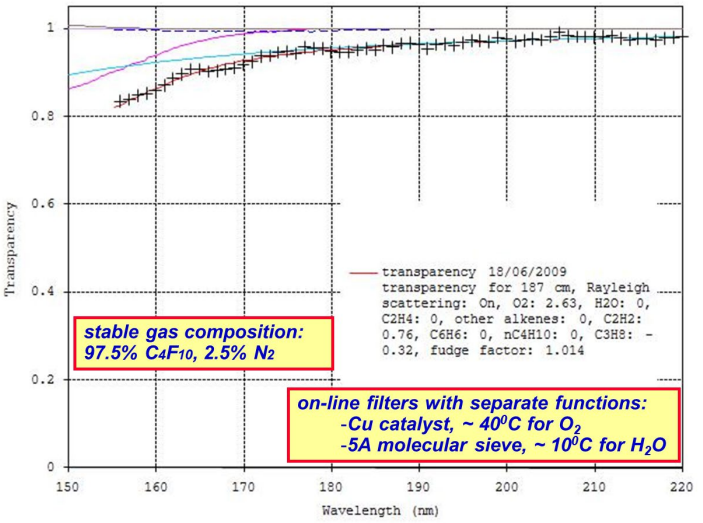


PLC and electrical installation

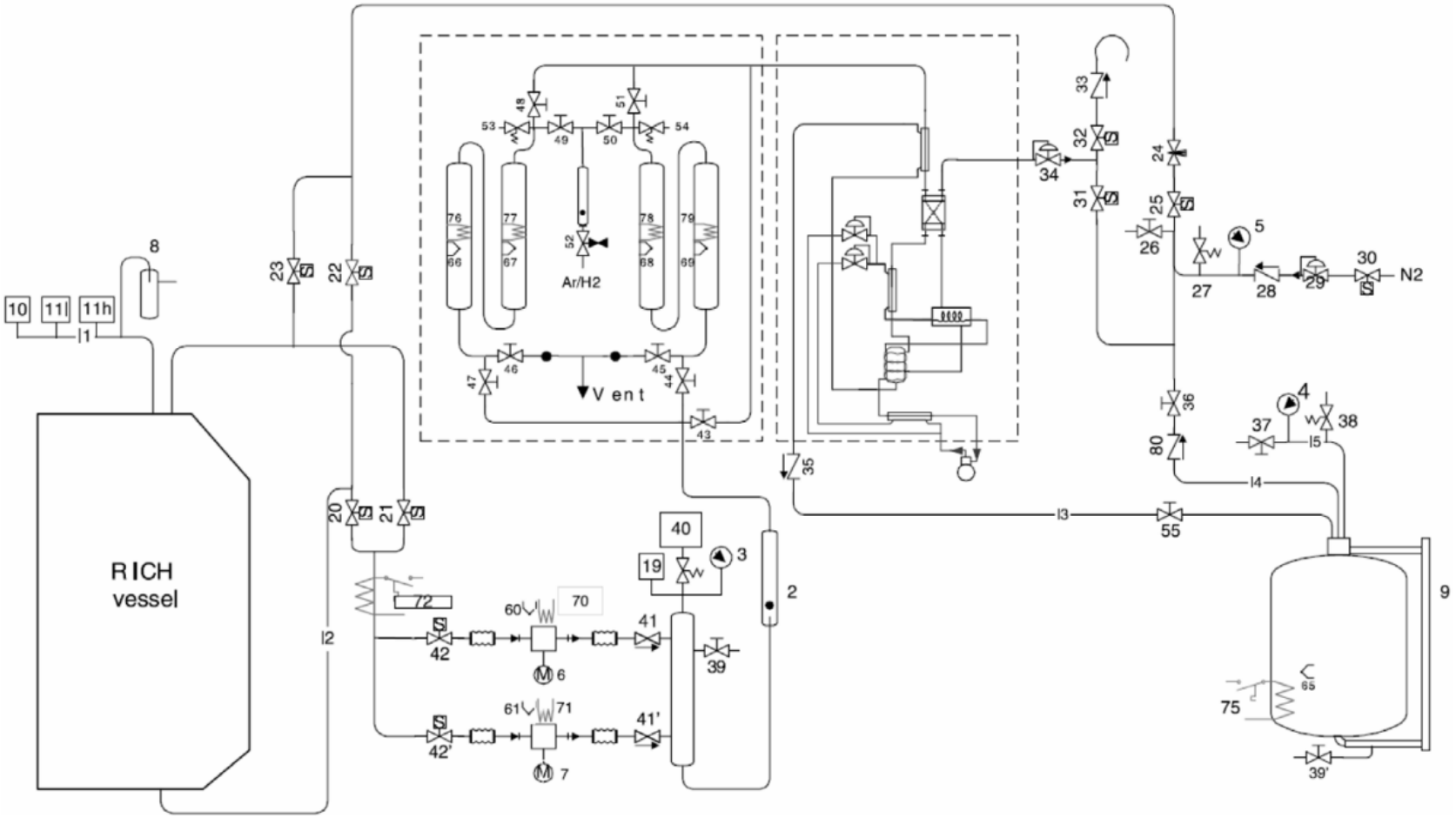
compressors



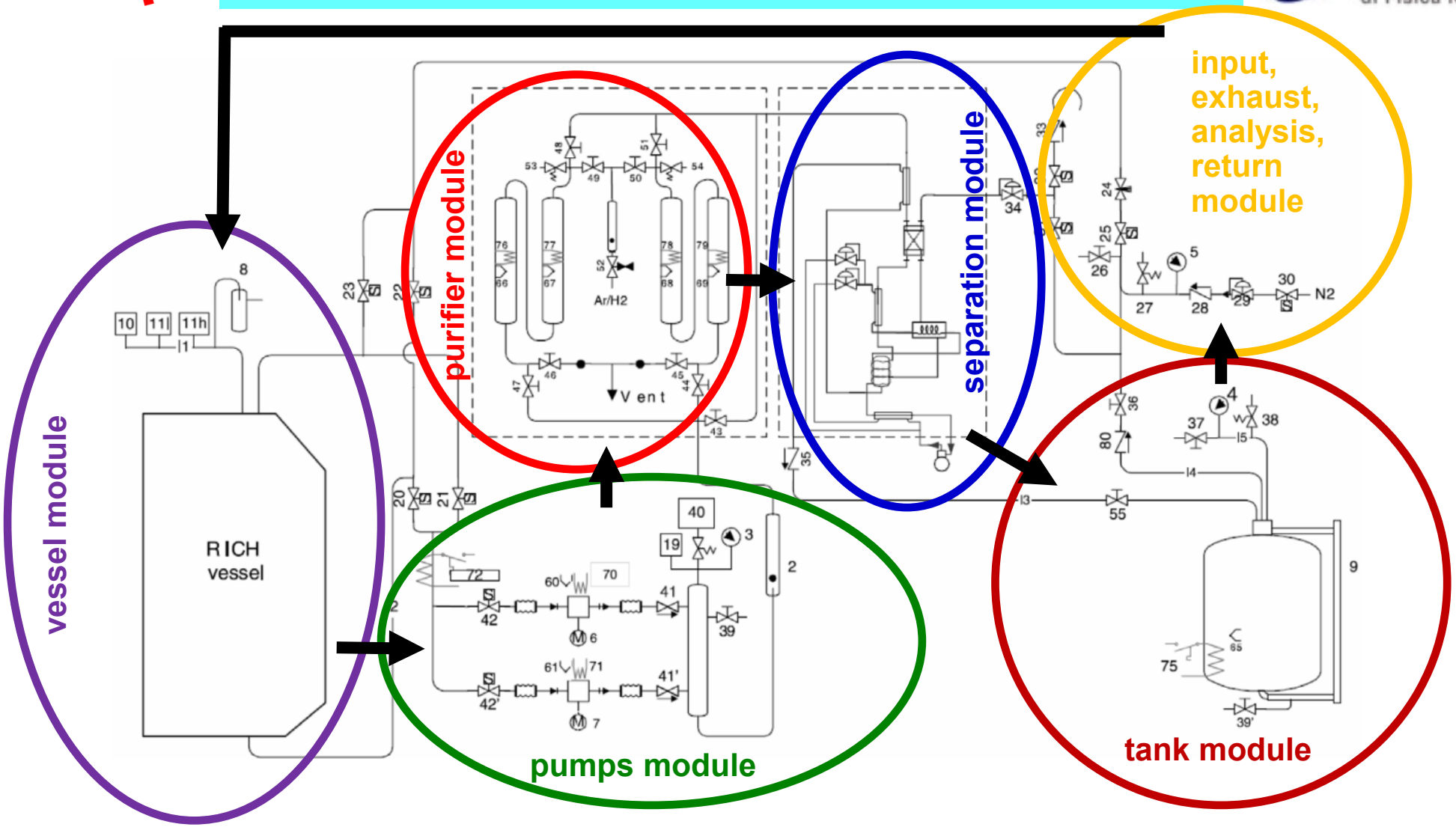




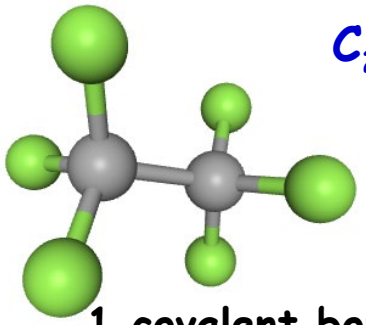
il Sistema gas di COMPASS



il Sistema gas di COMPASS



Proprietà fisiche del C_2F_6



1 covalent bond

6 hydrogen bond

esafluoroetano

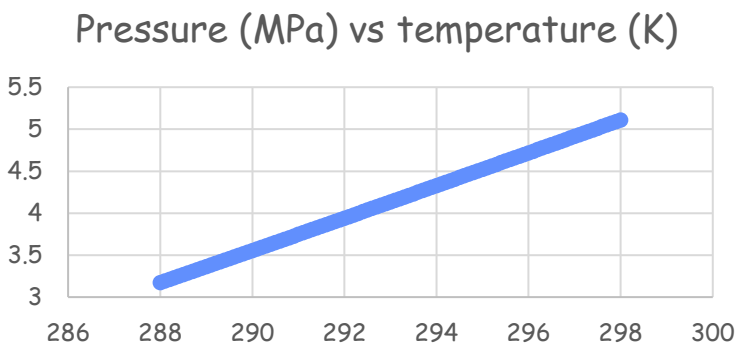
C_2F_6 molecular weight: 138.01 g/mol

boiling point: -78.1 °C

melting point: -100.6 °C

density: 5.734 kg/m³ at 24 °C

density: 16.08 kg/m³ at -78 °C



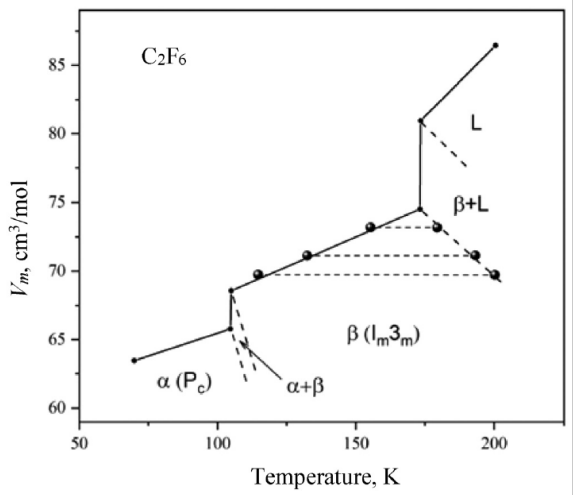
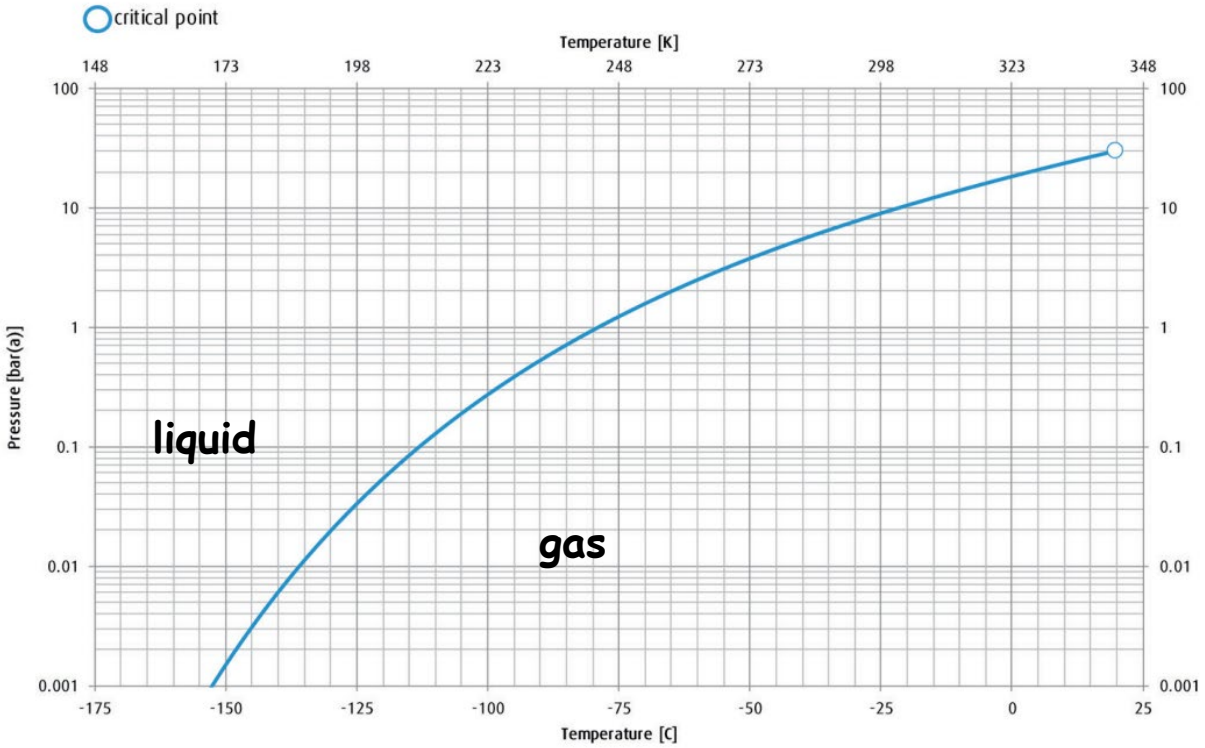
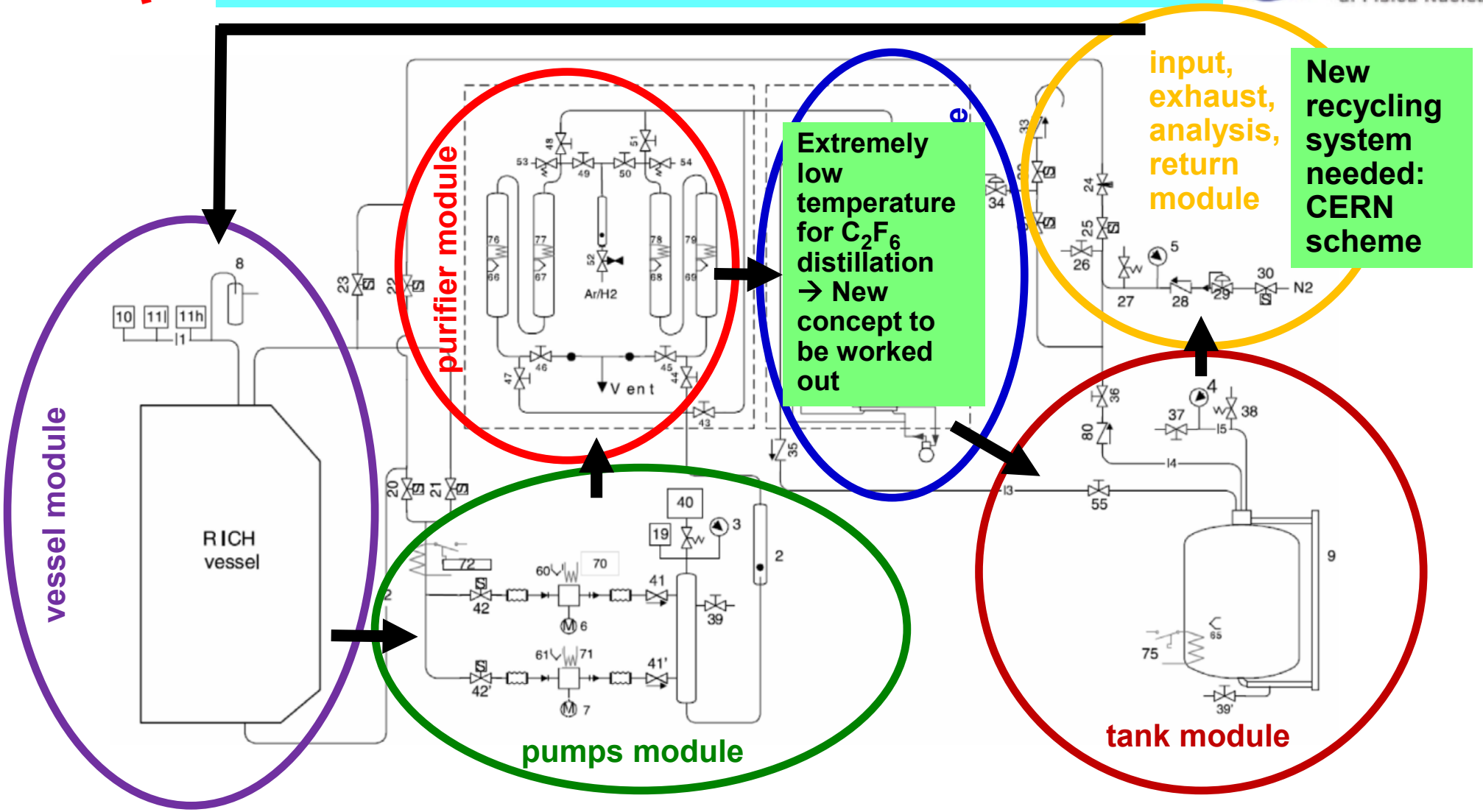


FIG. 2. Phase *V–T* diagram of hexafluoroethane (freon F-116). The short-dashed lines show the molar volumes of the studied samples, the solid line is the dependence of the molar volume on the temperature at saturated vapor pressure,[11] dashed lines represent the boundaries of the existence of phases,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

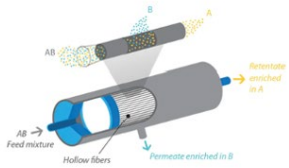


il Sistema gas di ePIC



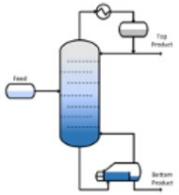
Separazione del C_2F_6 tramite membrane

Membrane separation



Pressure and thermal swing adsorption

Distillation

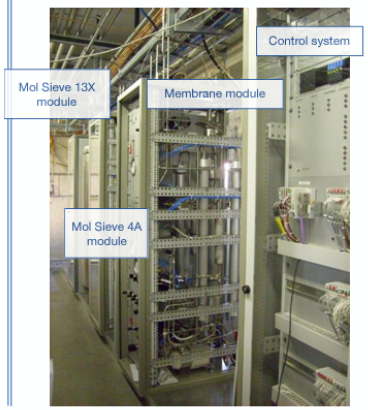


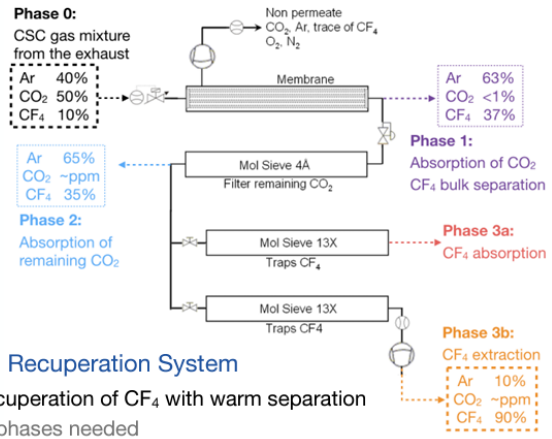
Gas recuperation: CMS CSC CF_4

GHG reduction from Run1 to Run2 up to **45%**

CSC Gas System

- Detector volume ~90 m³
- Gas mixture: 50% CO_2, 40% Ar, **10% CF_4**
- Gas recirculation: 90%
  - No possibile to increase due to detector permeability to Air
- ~600 l/h at exhaust -> 60 l/h of CF_4





CSC Recuperation System

- Recuperation of CF_4 with warm separation
  - 3 phases needed
- Current recuperation efficiency ~70%
  - Several parameters affect recuperation efficiency
- CF_4 quality satisfactory
  - Recuperated CF_4 quality to monitor
- CSC detectors operated with recuperated CF_4 during Run 2
  - No change in the CSC performance observed

Gas Sorption, Diffusion, and Permeation in Poly(dimethylsiloxane)

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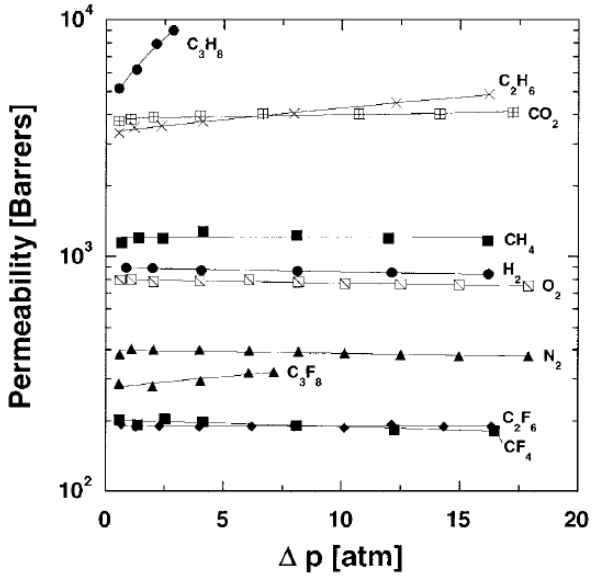
Received 4 November 1998; revised 16 September 1999; accepted 1 November 1999



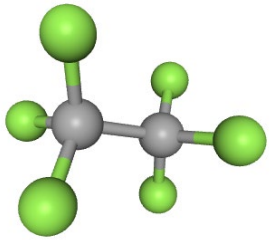
Accordi con Beatrice Mandelli per effettuare prove di separazione di C_2F_6 con l'uso di membrane (DRD1-DRD4 synergy discussion)

overview

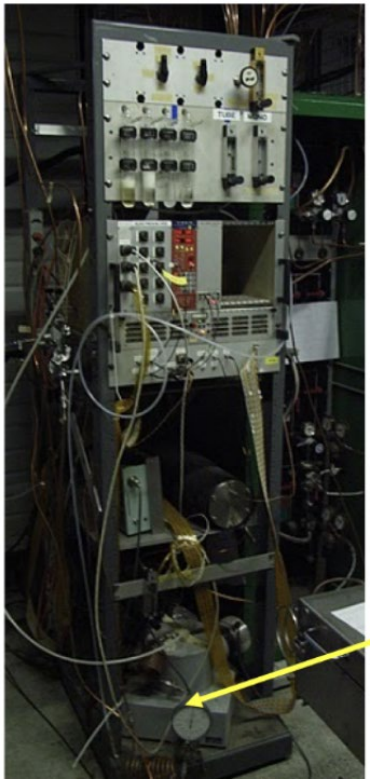
gas system

gas studies and monitoring

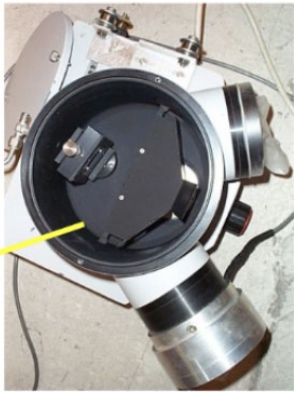
Trasparenza del C_2F_6 nell'UV



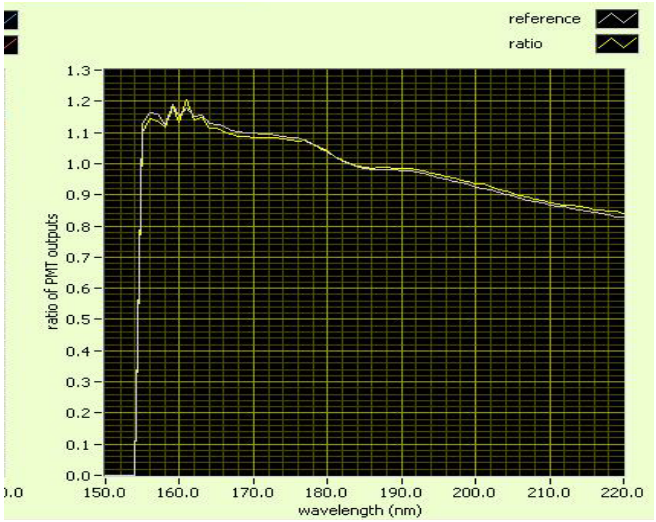
Esafluoroetano 5.0 al CERN
Usato per il test-beam

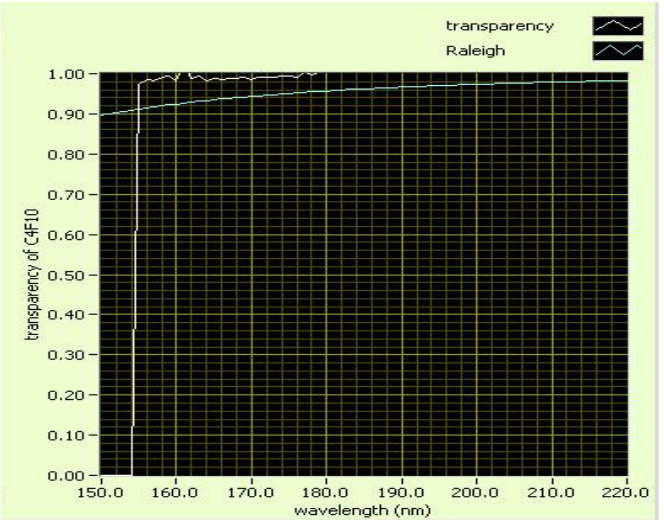


Deuterium UV lamp, Monochromator system, 1.6 m column for gas transparency measurement



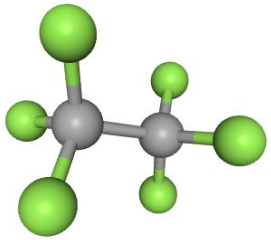
Misurato nel set-up di AMBER





transparenza > 98%
per 170 nm < λ < 220 nm

Trasparenza nel visibile



Essenziale garantire la trasparenza del gas radiatore nella zona di sensibilità dei SiPM

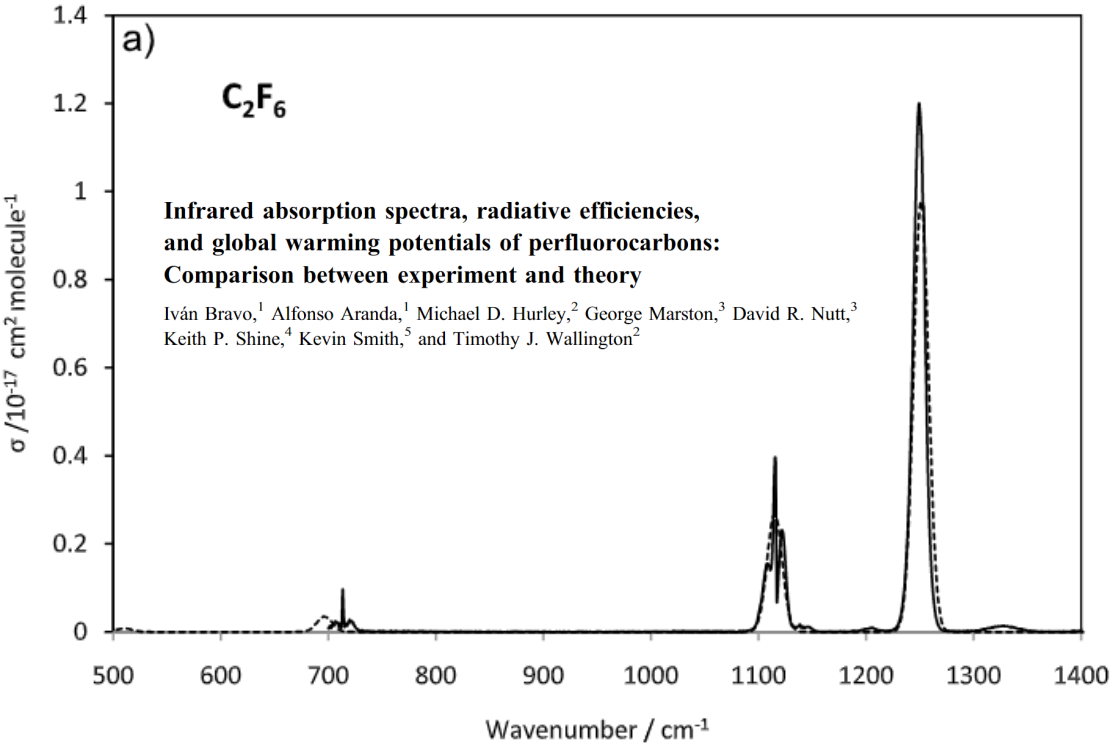
Spettrofotometro Lambda 850+
e cella per C_2F_6 in pressione

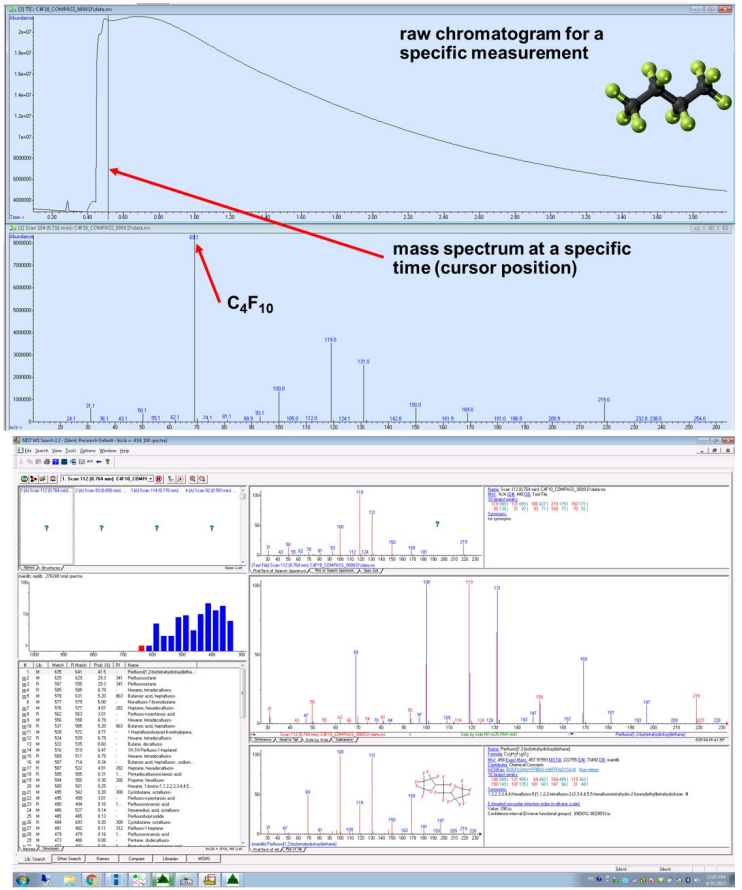
Studi di compatibilità dei materiali, outgassing, microperdite, ecc.

offerta nei preventivi

Assorbimento e scintillazione del C_2F_6

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

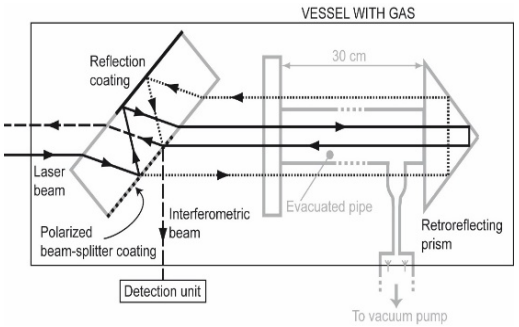


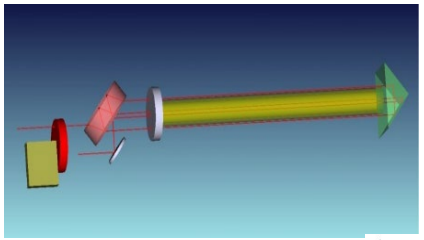


Collaborazione per la misura con

Institute of General and Physical Chemistry, Belgrade University (IGPC, Serbia)

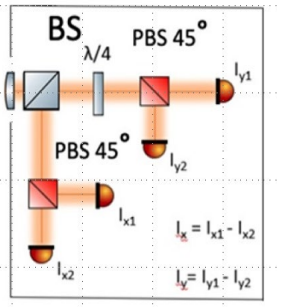
Interferometro Jamin

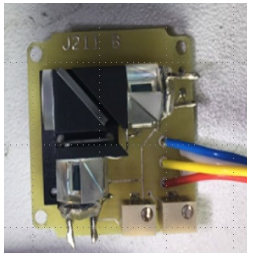


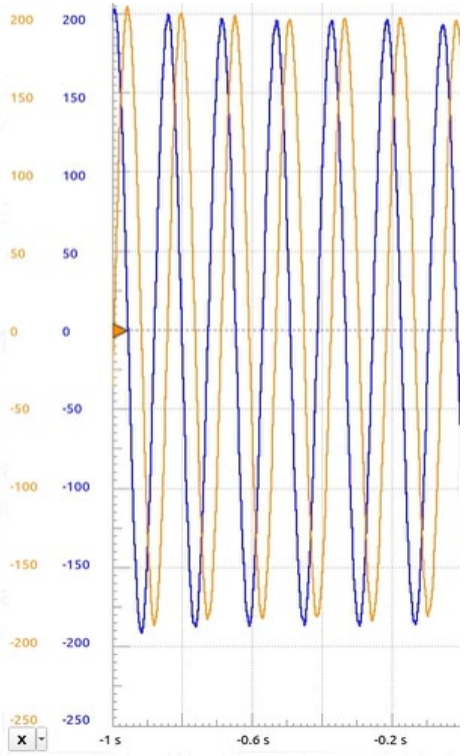


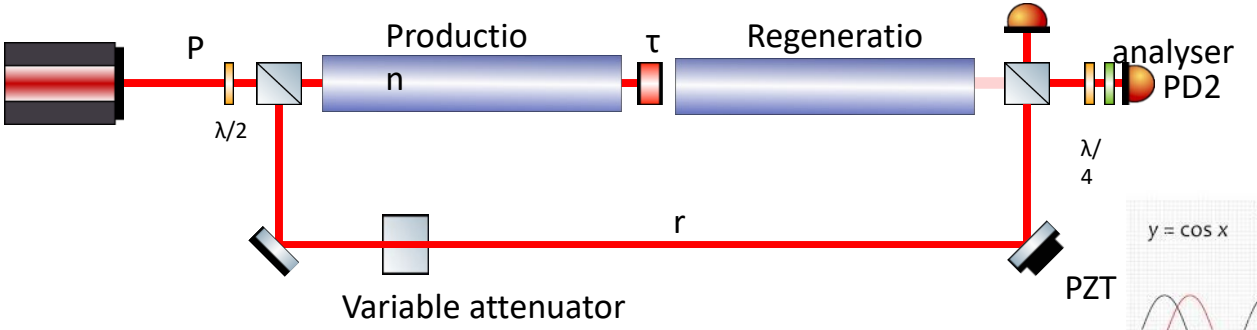
$$I = I_1 + I_2 + 2\sqrt{I_1 I_2}\,\Delta\phi(t)$$

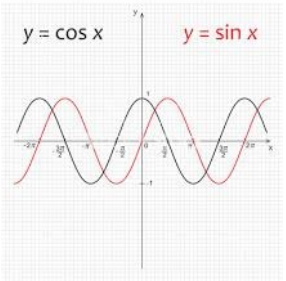
$$\Delta\phi(t) = \left(2\pi\ell/\lambda\right)\Delta n(t)$$

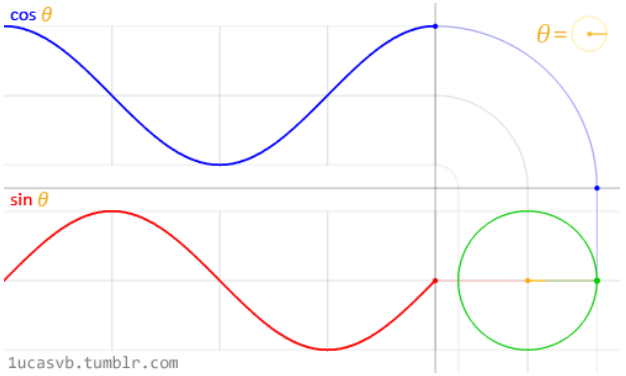








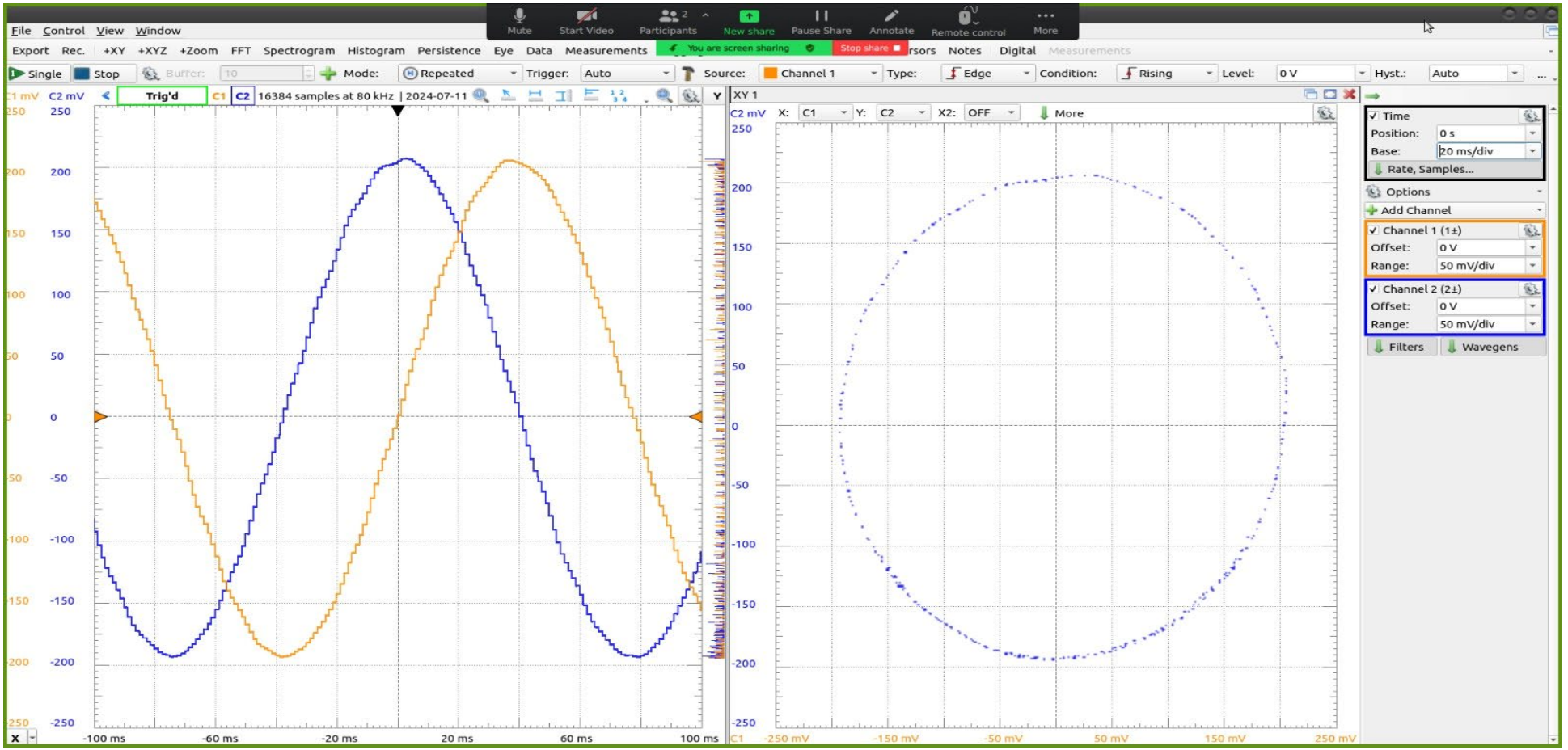




the signal from a detector is shifted about π/2 by quarter-wave plate with the respect to the second one

Interferometro Jamin

Attualmente usiamo un Raspberry pi e un oscilloscopio USB Digilent Analog Discovery 3



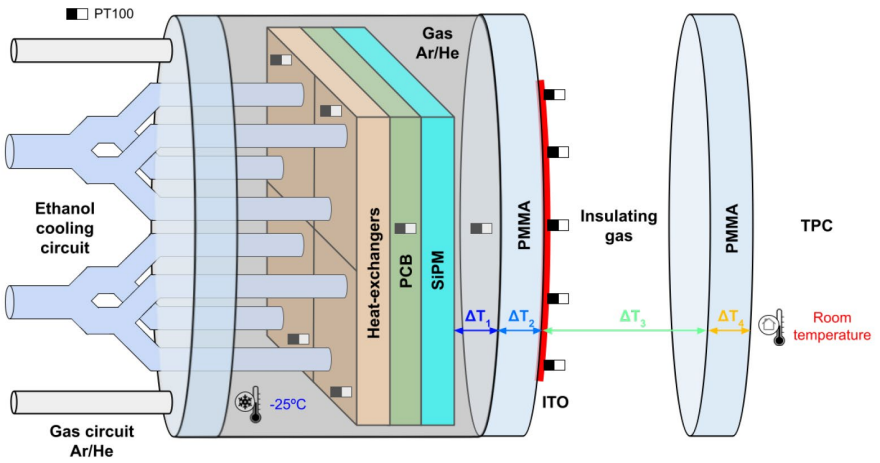
Un periodo (360˚) corrisponde a 1 ppm di variazione dell'indice di rifrazione

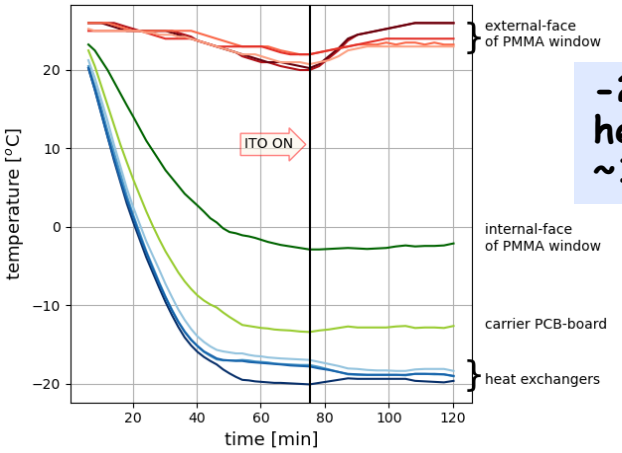
La risoluzione consente la misura di variazioni di n inferiori a 10 ppb

Active insulation

Efficient insulation obtained combining passive insulation (gas,PMMA,gas,PMMA) with active heating ITO (indium-tin oxide) conductive film

Measurement performed by D. González-Díaz et al. arXiv:2401.09920v1





-20 °C → -20 °C heating power: ~100 W/m²

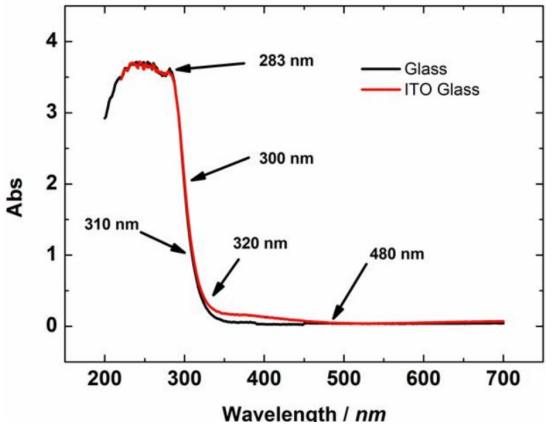
ITO properties depend on composition, production, thickness, temperature, etc.

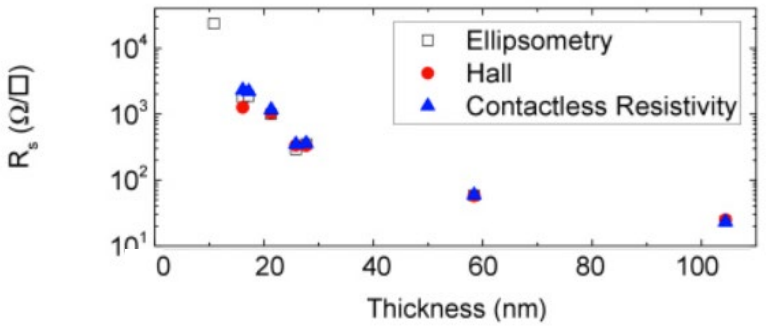
Typical oxygen-saturated composition:

74% In, 8% Sn, 18% O

Options: thin layer, strips, …

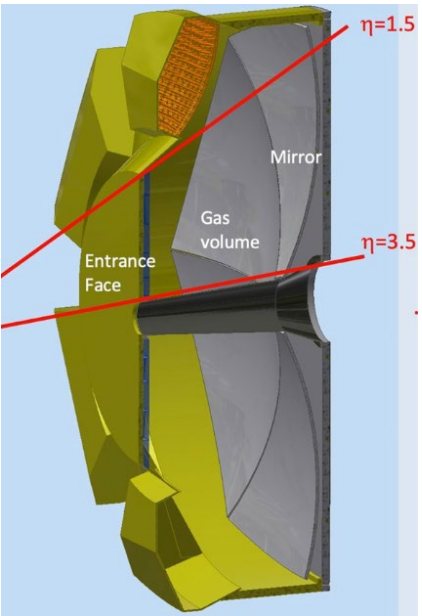
CERN expertise on ITO: T. Schneider



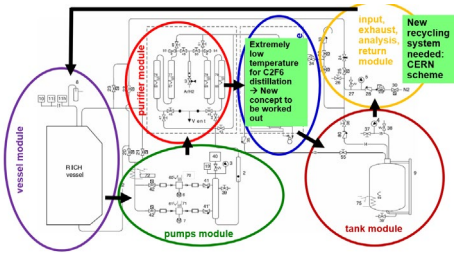


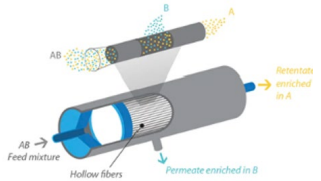
Optical Material Express Vol. **8**, Issue 5, pp. 1231-1245 (2018)

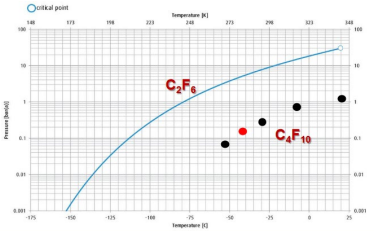
Attività 2025

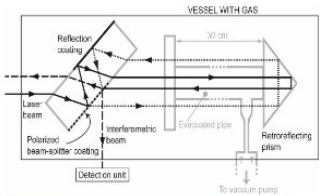


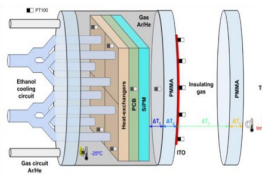
- **1st activity line:**
  - The design of the radiator gas system (2024, 2025)
    - COMPASS RICH-inspired
    - Different physical properties C_2F_6 vs C_4F_{10}
    - Fluorocarbon recovery (greenhouse effect!)
- **2nd activity line:**
  - Characterization and monitoring equipment
    - Jamin interferometer for real-time monitoring of the refractive index (2024, 2025)
    - Measuring/monitoring the gas transparency – spectrophotometer with a high-pressure cell (2025)
    - The active temperature screen, exploratory exercises (2025)

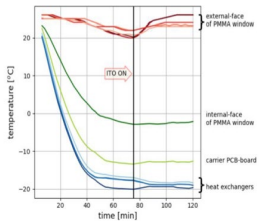






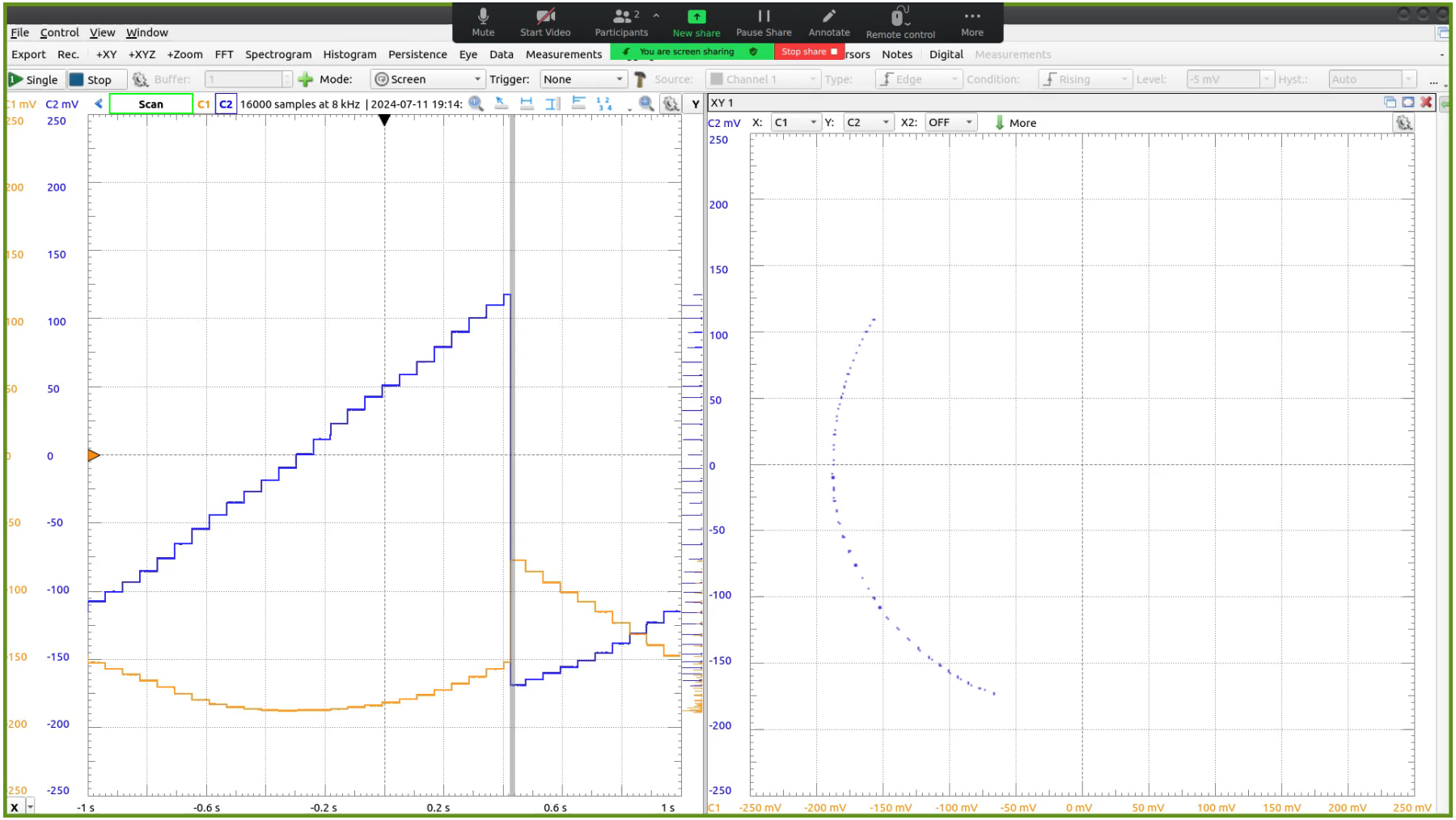






Backup slides

Interferometro



La risoluzione consente la misura di variazioni di n inferiori a 10 ppb

Readout dell'interferometro

Attualmente usiamo un Raspberry pi e un oscilloscopio USB
Digilent Analog Discovery 3

E facciamo sampling a 8 kHz

DIGILENT
Digilent is now part of Emerson.

Analog Discovery 3: 125 MS/s USB Oscilloscope, Waveform Generator, Logic Analyzer, and Variable Power Supply

In futuro useremo un Red Pitaya SoC Single board computer commerciale

Developer	Spin-off company of Instrumentation Technologies
Type	Single-board computer
Operating system	Linux
CPU	Dual-core ARM Cortex A9+ and FPGA
Memory	DDR3 RAM 512 MB (4 Gb)
Storage	microSD up to 32Gb
Power	max 10 W

https://www.redpitaya.com/

- Due input RF 125 MS/s
- Due output RF 125 MS/s
- 50 MHz analogue bandwidth
- 14-bit ADC and DAC.

IO ports collegati ad un FPGA in comune
ADC ausiliario a 250 kS/s e IO digitale.

Tre porte USB 2.0, Wi-Fi, connettore Ethernet.
Freely available software:
oscilloscope, spectrum analyzer, signal generator, ecc.

Sonar system

Continuous monitoring of the speed of sound in the radiator gas

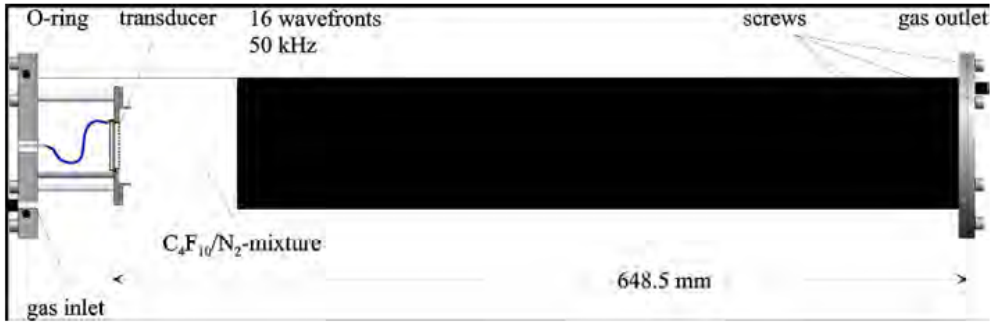
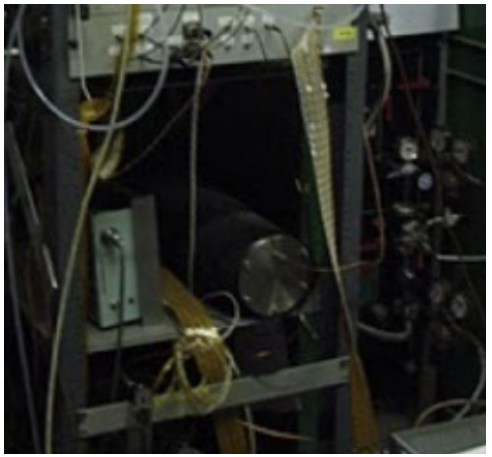


Figure. 1.6 The Sonar System Setup



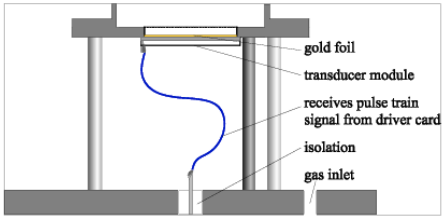
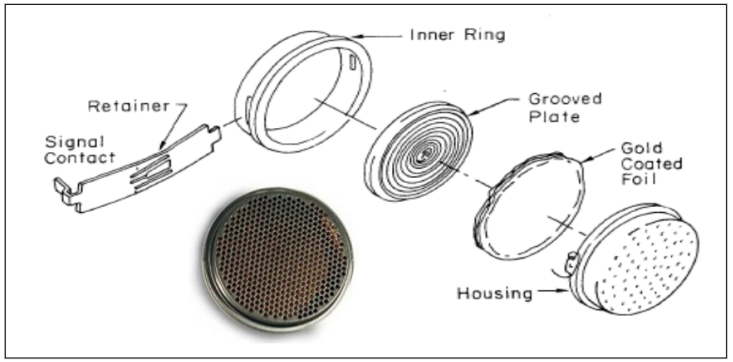
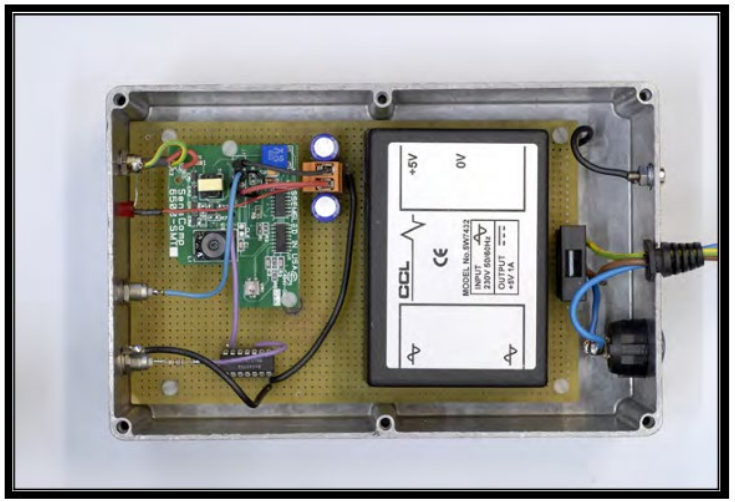


Figure. 1.7 The Sonar System Setup

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…)



Offerta Perkin Elmer Lambda 850+

PerkinElmer
For the Better

dr.ssa Silvia Dalla Torre
INFN Sezione di Trieste
Via Valerio, 2
34127, Trieste, IT

silvia.dallatorre@ts.infn.it

PerkinElmer Scientifica Italia Srl
P.Iva 10453490962
Viale dell'Innovazione, 3
20126 Milano (MI), Italia
Telephone: 800 790 758
Dealer: Newproject Srl 0423 541046
Website: http://las.perkinelmer.com

SALES QUOTATION
GRMEUR0728

Referente Mariana Rispoli

Quotation Date: 03/07/2024
Expiry Date: 01/09/2024
Your Ref:

Spettrofotometro Lambda 850+

Part Number	Quantity	Description
L6020035	1	LAMBDA 850+ Base Instrument
09991415	1	EU Power Cord - 1.0MM SQ 2.5M 250V 10A
L6100127	1	KIT - UVWINLAB V7.4 STD SOFTWARE
N0235009	1	UVS Adv Onsite Train Per Day 4 Seat Max
REGDELUVS	1	Shipping & Handling fee
SDS-NRUVS	1	Special Delivery services not required

Total **47.071,62**

Optional items, not included in Quote or Freight Total:

09406556	1	Dell XE4 - ITALY 32GB & SSD	2.920,00
09406326	1	24inch monitor - Dell (EDC)	
09406322	1	PCIE Network Card	

Spettrofotometro Lambda 850+

Notes

CONDIZIONI ECONOMICHE:

Prezzo a Listino:	**EUR**	**47.071,62**
Sconto a Voi riservato 35%:	**EUR**	**-17.071,62**
Totale scontato:	**EUR**	**30.000,00**

CONDIZIONI DI FORNITURA:

Resa: **Franco destino**
Imballo: **Compreso**
Installazione e collaudo: **a ns. carico e spese**
Garanzia: **12 mesi**
Training : **1 gg con specialista di linea**
Pagamento: **da concordare**

Referente: Arno Pellizzer 335 7622545 arno.pellizzer@perkinelmer.com

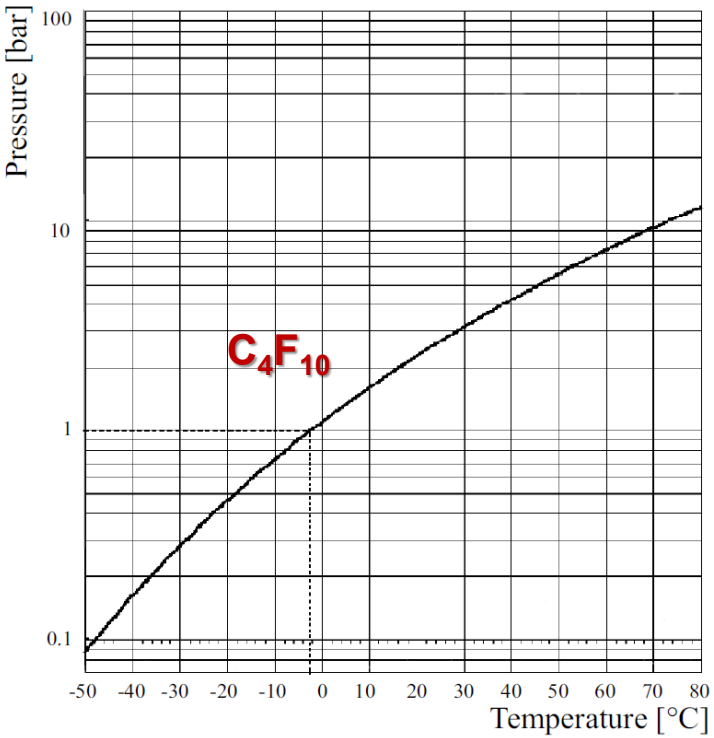
This quotation excluding taxes. Any orders resulting from this document are subject to the PerkinElmer Standard Terms and Conditions, available on request, and to final acceptance by PerkinElmer LAS.

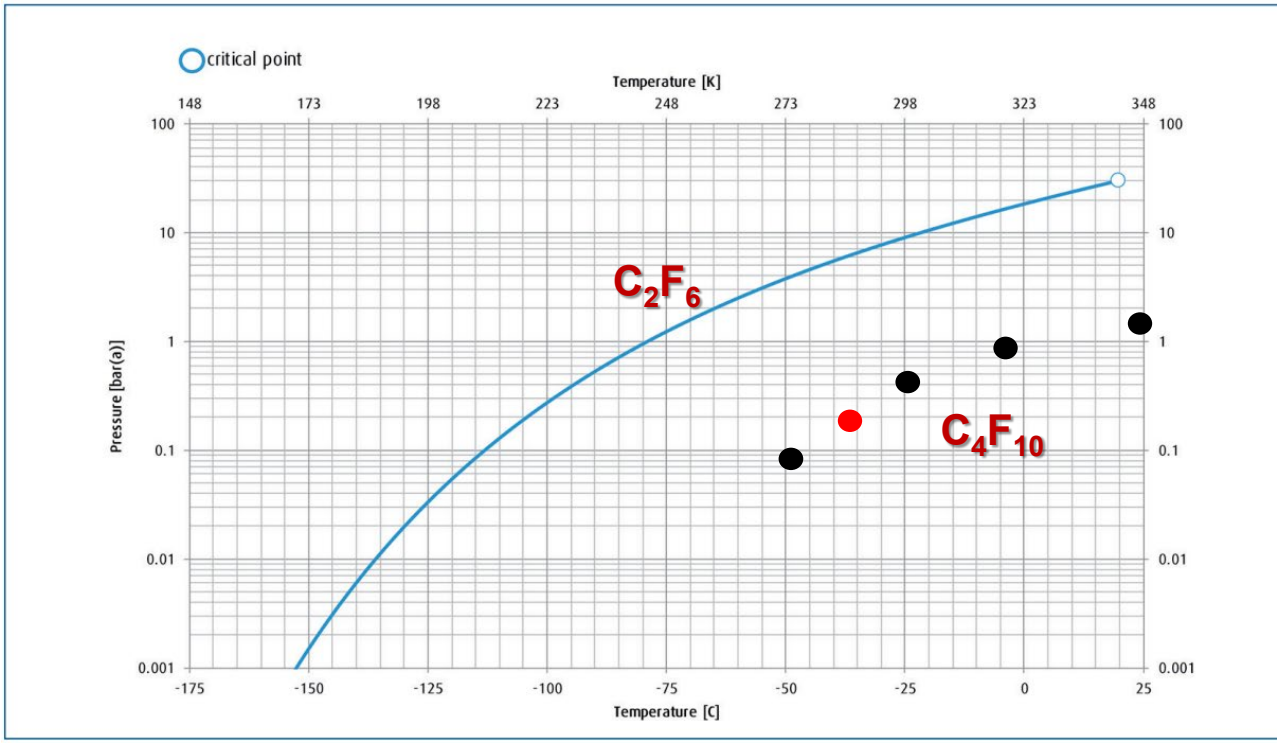
We have transformed. Visit https://www.perkinelmer.com/customer-transformation-hub.html for key updates to ensure a smooth buying experience, as some customers may need to update our vendor records in their system (eg, legal entity, banking details, remit-to).

EMETTENDO UN ORDINE DI ACQUISTO PER QUALSIASI PRODOTTO E/O SERVIZIO LEGATO A QUESTA OFFERTA, IL CLIENTE ACCETTA I TERMINI E LE CONDIZIONI CHE SI TROVANO AL LINK http://www.perkinelmer.com/corporate/policies/, E SONO QUI INCORPORATI E APPLICABILI. PERKINELMER SI RISERVA IL DIRITTO DI AGGIORNARE I SUOI TERMINI E CONDIZIONI IN OGNI MOMENTO; TUTTAVIA, A TALE ACQUISTO SI APPLICHERANNO I TERMINI E LE CONDIZIONI IN VIGORE ALLA DATA DELL'ORDINE DI ACQUISTO RELATIVO AL PRESENTE PREVENTIVO. TERMINI SOGGETTI AD APPROVAZIONE DEL CREDITO.

C_2F_6 separation

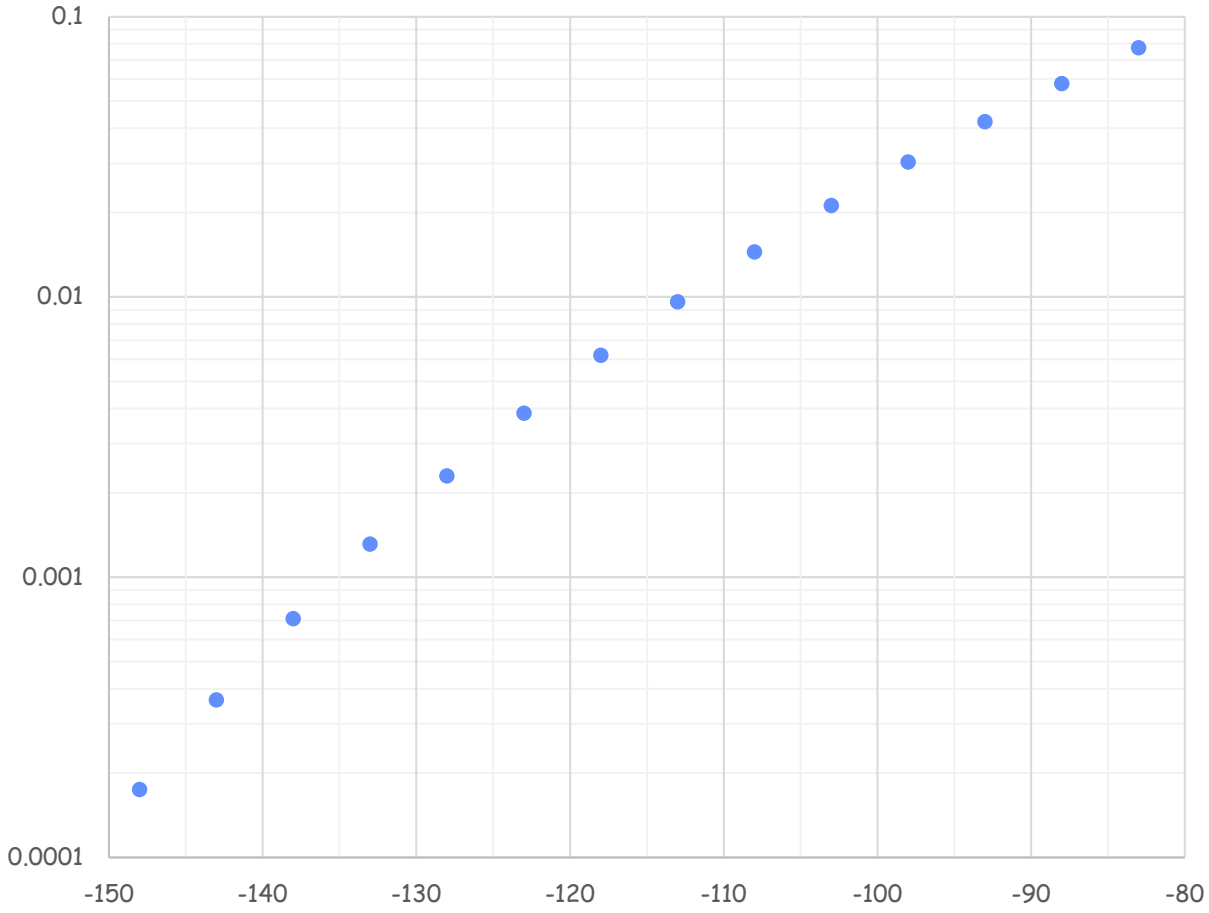
The partial pressures of C_2F_6 and C_4F_{10} are very different





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}

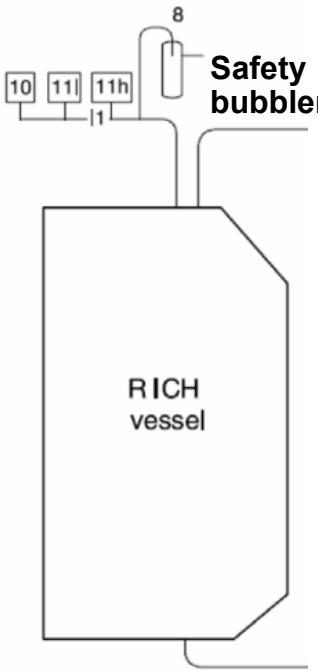
C_2F_6 fraction in vented gas at 10 bars

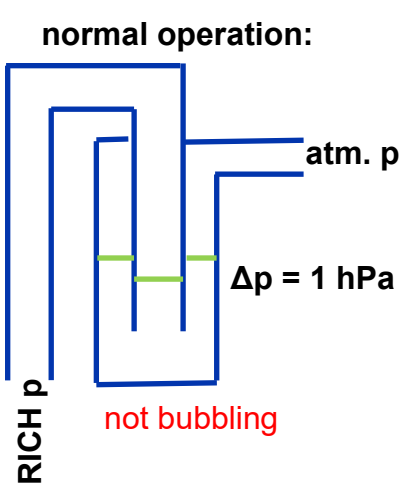


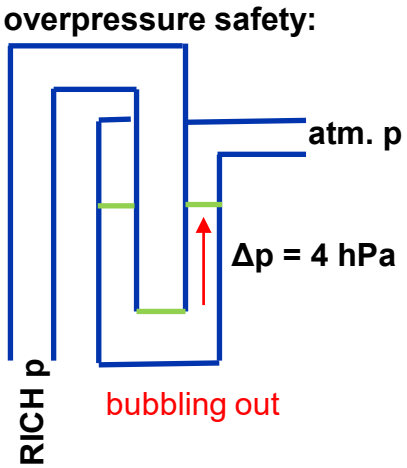
Discussion with Roberto Giuda at CERN to perform a test with a chiller at -98 °C and, possibly, -130 °C

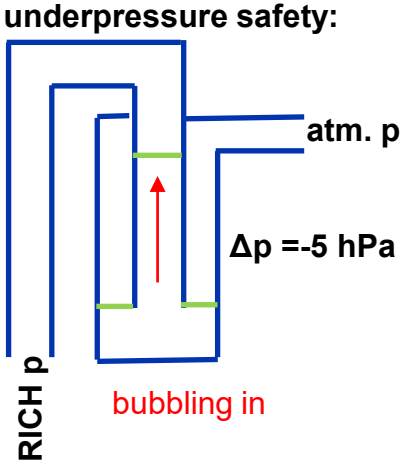
passive pressure safety system

pressure gauges and hardware alarms









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

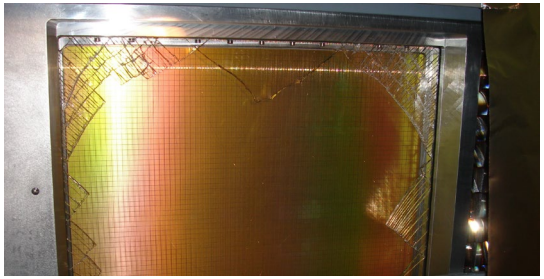
Large stainless-steel bubbler built for COMPASS RICH1 after choosing the safety levels

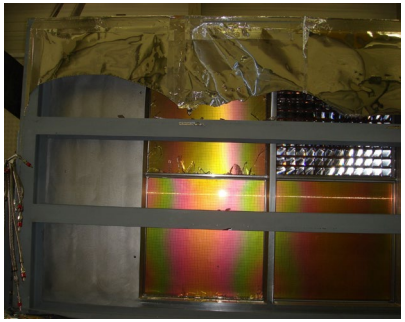
Pressure set at atmospheric pressure + 1.00 hPa at the top of RICH volume

Feedback cycle tolerance < 0.1 hPa

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

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





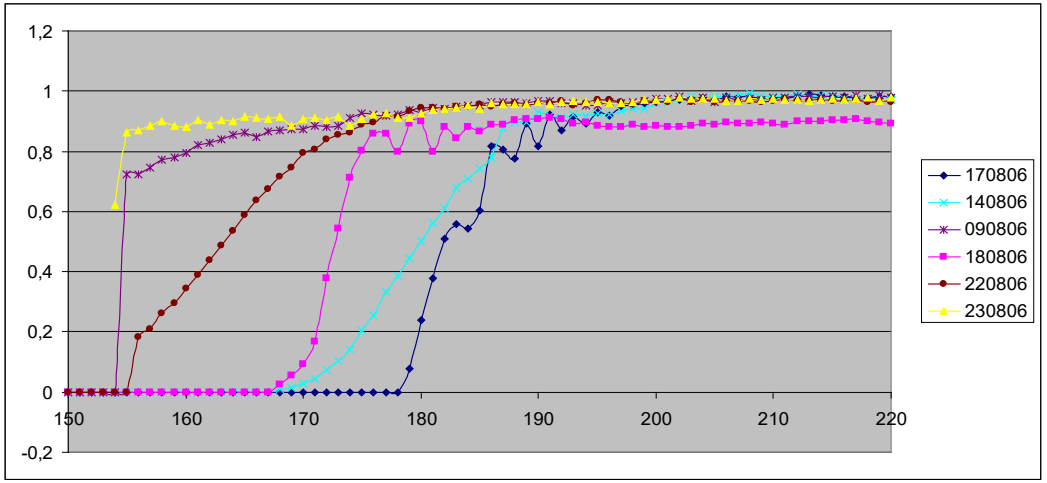
Fast change in atmospheric pressure

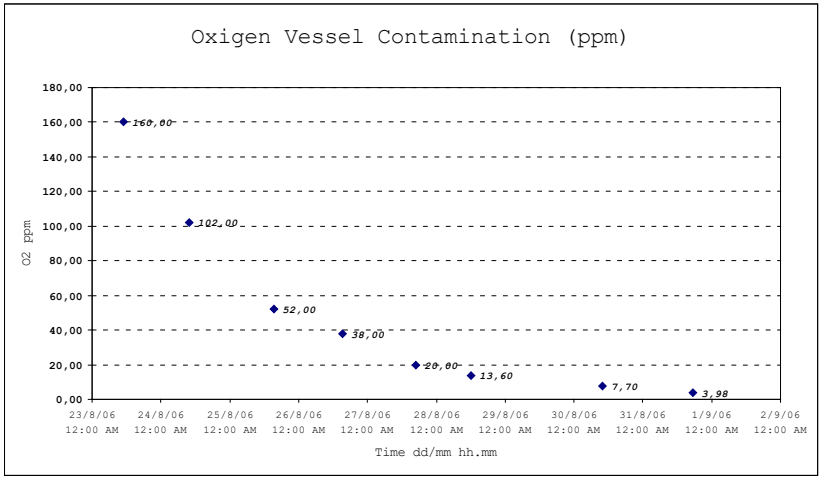
compressors in standard running conditions remove 0.7 l/s from the vessel, corresponding to 1 ‰ of the radiator gas content (80 l) in ~2 min.

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.

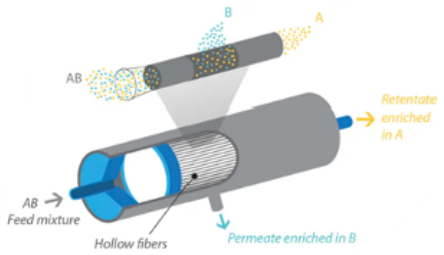
The daily range of atmospheric pressure (gray bars), as measured by the altimeter setting reported in e.g. a METAR report.

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

Separation

Membrane separation

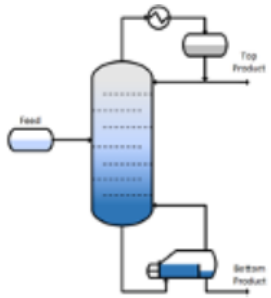


- **Difference** in **thermodynamic activities** existing across the membrane and **interacting forces** working between **membrane material** and permeating **molecules**
- Separation process driven by several factors
  - Permeability, Solubility, Diffusivity

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

GHG disposal

Gas disposal

Abatement plants are employed when GHGs are polluted and therefore are not reusable

In case all studies on recuperation will not bring to efficient recuperation plants, industrial system able to destroy GHGs avoiding their emission into the atmosphere have been considered

Quite heavy infrastructure required:

- CH_4/city gas + O_2 supply + N_2 supply
- Waste water treatment
- PFC/HFC are converted in CO_2 + HF acid dissolved in water
- disposal of remaining waste/mud
  - To have the gas at the exhaust (600-1000 l/h)

Joint CMS and EP-DT gas team is studying the feasibility

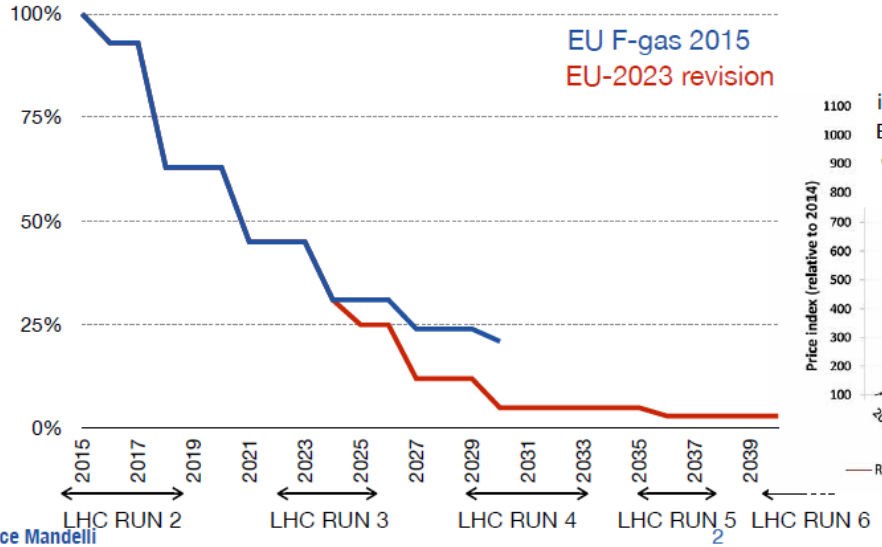
Found also companies available to take PFC/HFC based mixture for disposal: but extremely expensive

Will C_2F_6 be banned?

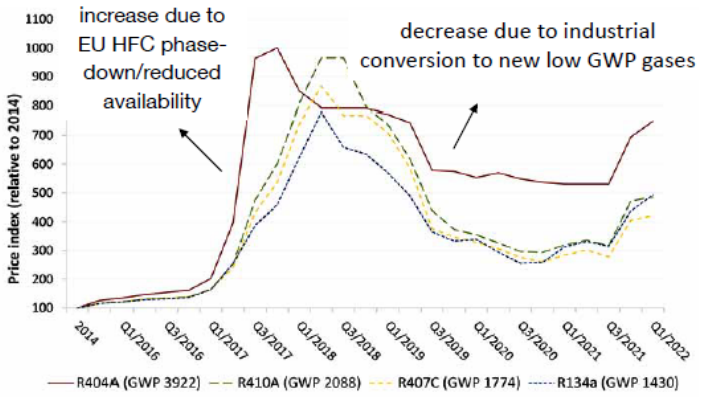
New F-gas regulation: from phase down to out

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

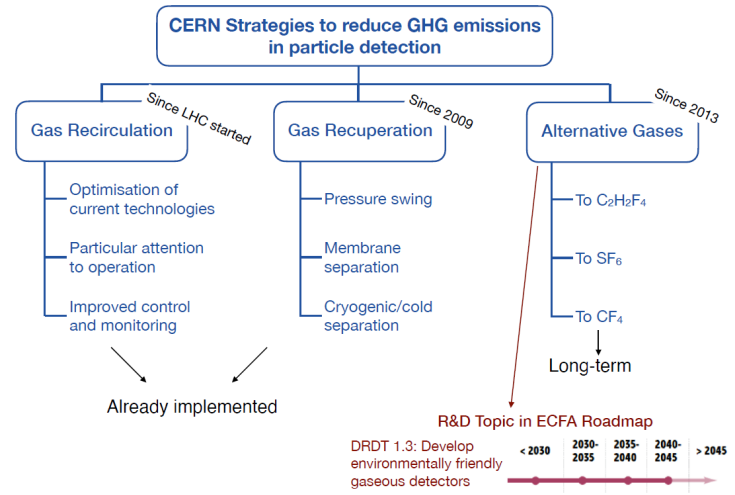


Average purchase prices of the most commonly used HFC refrigerants



GHG reduction

CERN strategies for GHG reduction

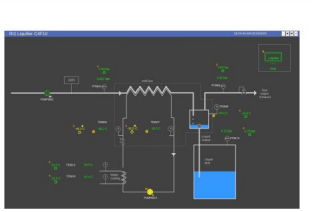


Beatrice Mandelli 5 19 Jun 2024

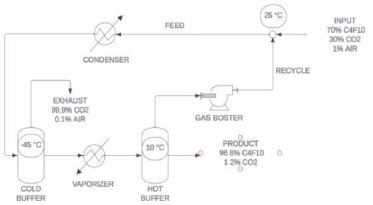
Gas recuperation: LHCb RICH1 C_4F_{10}

RICH1 Gas System

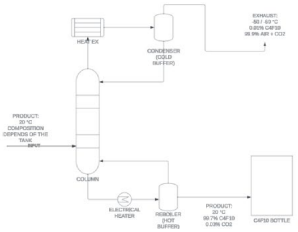
- Detector volume ~4 m³
- Gas mixture: **100% C_4F_{10}**
- Gas recirculation: ~100%
- Problem: air intake
  - Cleaning of gas during the year
- Emptying of detector during maintenance or long shutdown
  - Gas have to be recuperated



Double stage equilibrium



Distillation columns

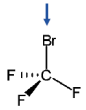


Beatrice Mandelli 12 2022

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



R13B1
($CBrF_3$)
GWP 6900 - ODP 10

GHG
Greenhouse gases

R134a
($C_2H_2F_4$)
GWP 1430 - ODP 0

"ECO" gases

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

and

3M™ Novec™
GWP <10 - ODP 0

Natural gases

O=C=O

and

hydrocarbons
GWP 1 - ODP 0

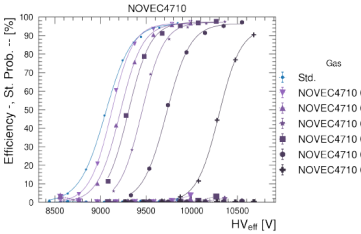
- ~20-30 years ago, it was the time to get rid of ODP gases
- There was not the awareness on the use of GHGs
  - Many gaseous detectors were conceived with use of GHGs
- Now it is time to address the usage of GHG worldwide, including particle detectors
- New concerns are already raising for the use of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

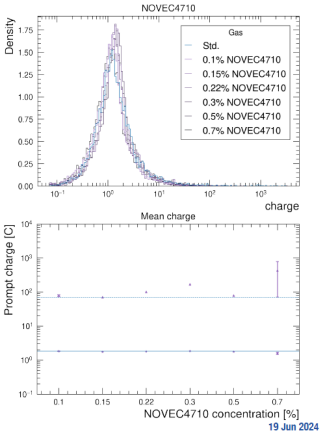
Beatrice Mandelli 14 19 Jun 2024

NOVEC 4710

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

CONS
- GWP of 2200
- It may react with H_2O



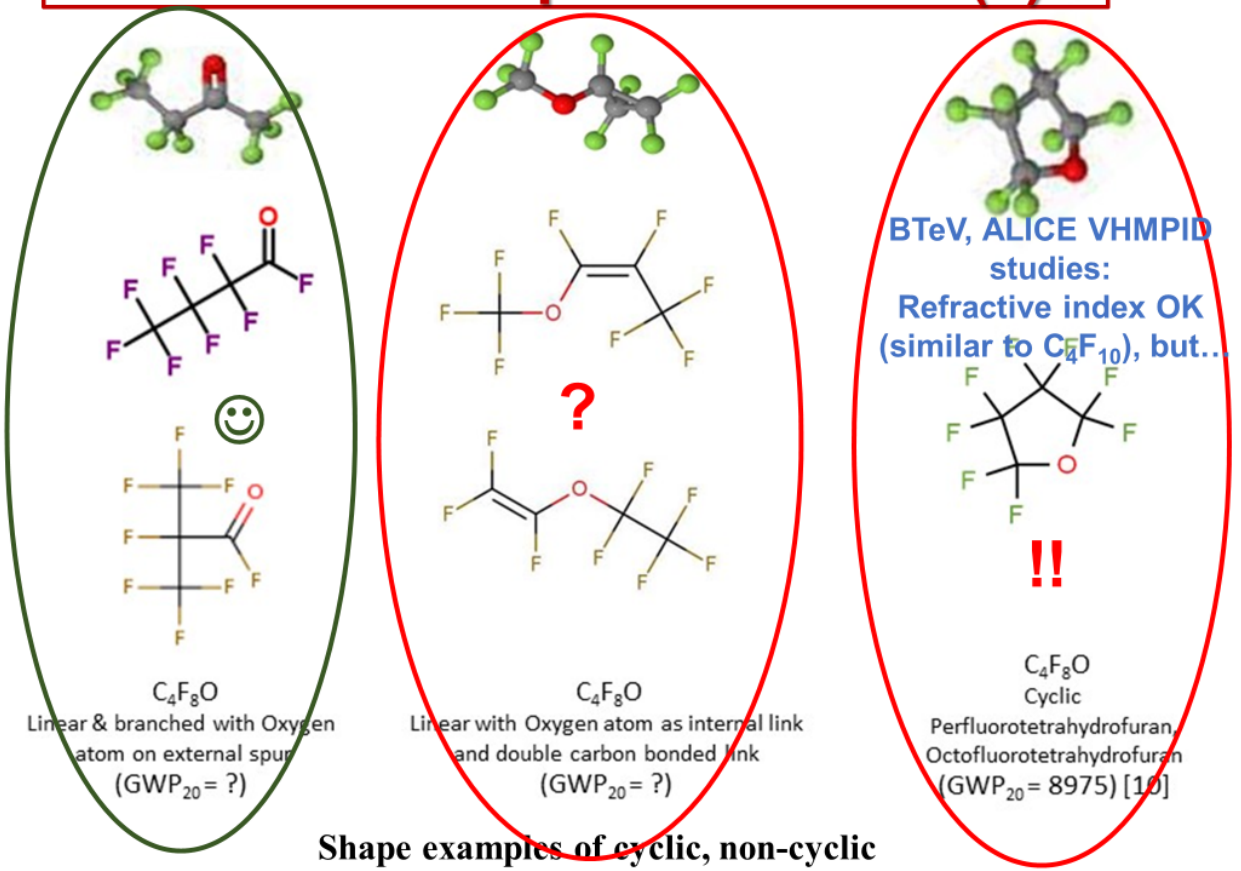


- Streamer probability always lower than std gas mixture
  - 0.1% of NOVEC 4710 already enough!
- Avalanche charge and cluster size lower than std gas mixture
- Higher working point for concentrations > 0.1%

Beatrice Mandelli 26 19 Jun 2024

Alternative gases

Molecular shapes and GWP (2)

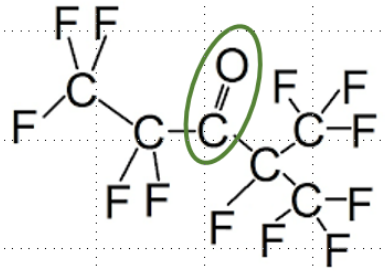


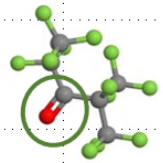
Shape examples of cyclic, non-cyclic & non-cyclic double carbon-bonded C_4F_8O isomers refs at end.

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

Alternative gas mixtures

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]
$CF_3CF_2C(O)CF(CF_3)_2$

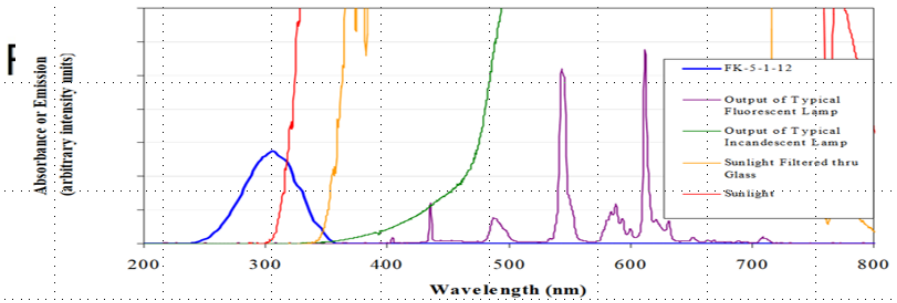
A: Structure!: a *double-bonded oxygen atom on a peripheral spur* of the molecule

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

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

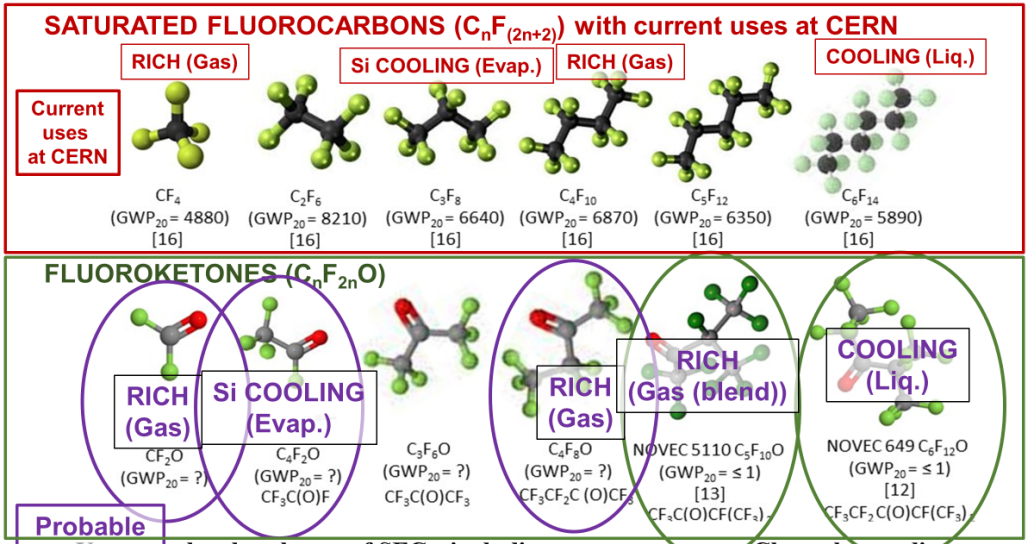


Scission by UV photons of λ around 300 nm
In the atmosphere (low pressure, high UV): the fragments do not reassociate* into saturated fluorocarbons of the type $C_nF_{(2n+2)}$ (which would have high GWP)

*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

Alternative gases

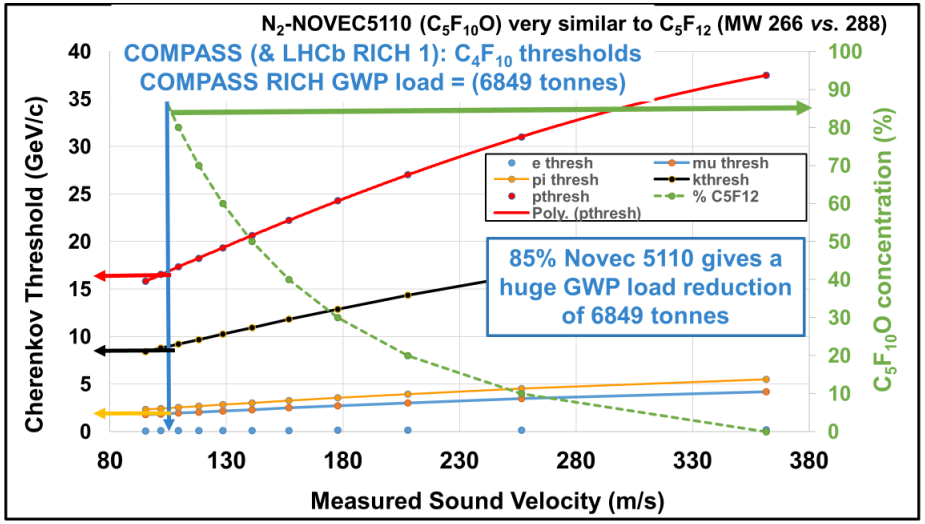
Molecular shapes and GWP (1)



Upper: molecular shapes of SFCs, including common gaseous Cherenkov radiators
Lower: shapes of some non-cyclic $C_nF_{2n}O$ analogues
(20-year GWPs noted where known – refs at end)

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

Cherenkov threshold in $C_5F_{10}O/N_2$ mixtures
and GWP load comparison with COMPASS RICH (100m³)



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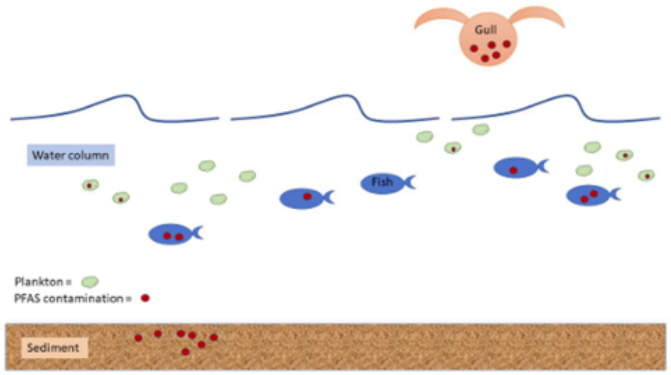
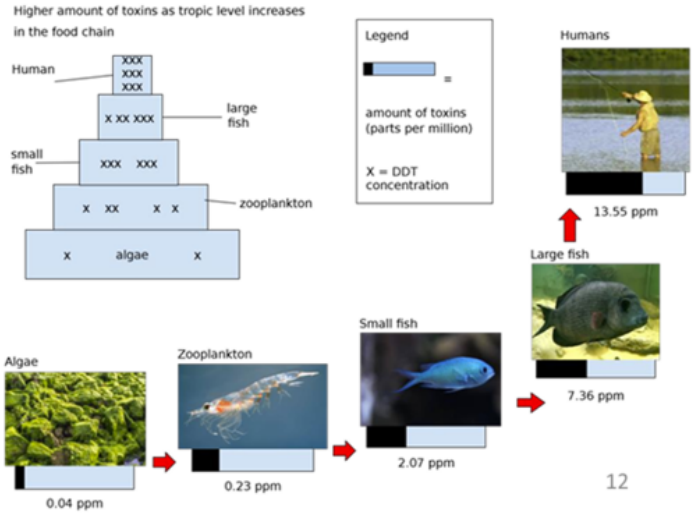
PFAS: per-(poly-)fluoroalkyl substances

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





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.**