The ePIC dRICH radiator gas

Fulvio Tessarotto (INFN-Trieste)
On behalf of the ePIC dRICH group

ePIC dRICH PID requirements

C_2F_6 properties: calculations and measurements

Challenges of ePIC dRICH gas system

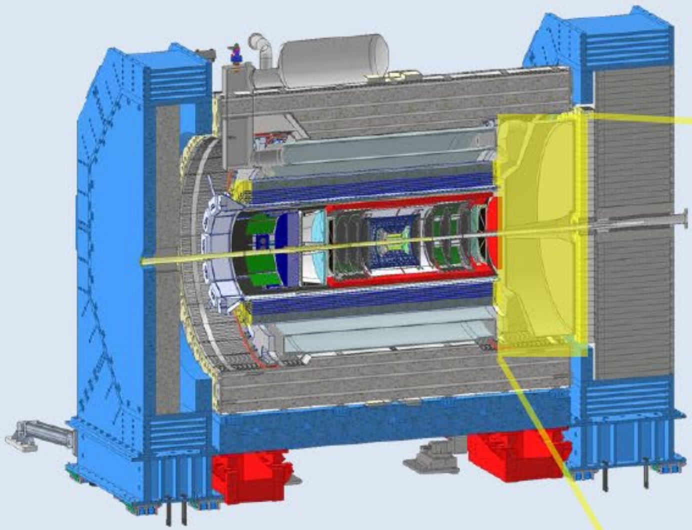
Membranes for gas separation

Monitoring tools: Jamin Interferometer

ePIC dRICH requirements

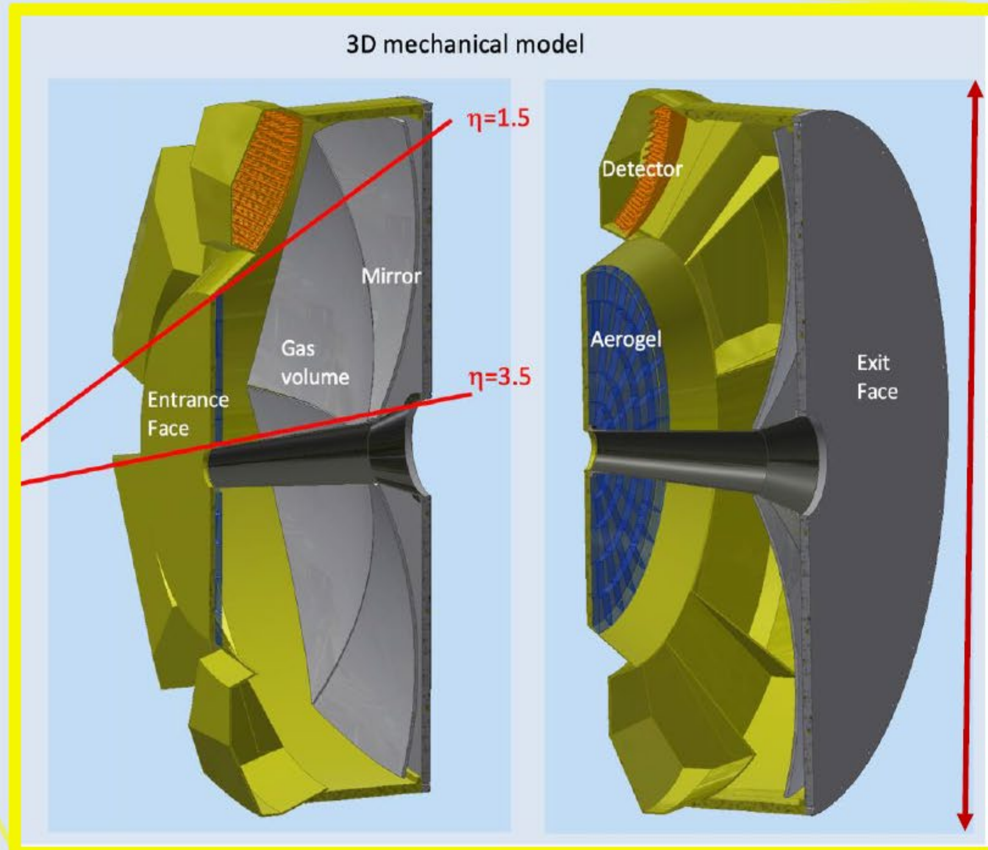
Dual-radiator Ring-imaging Cherenkov Detector (dRICH)

Essential to access flavor information



Goals:

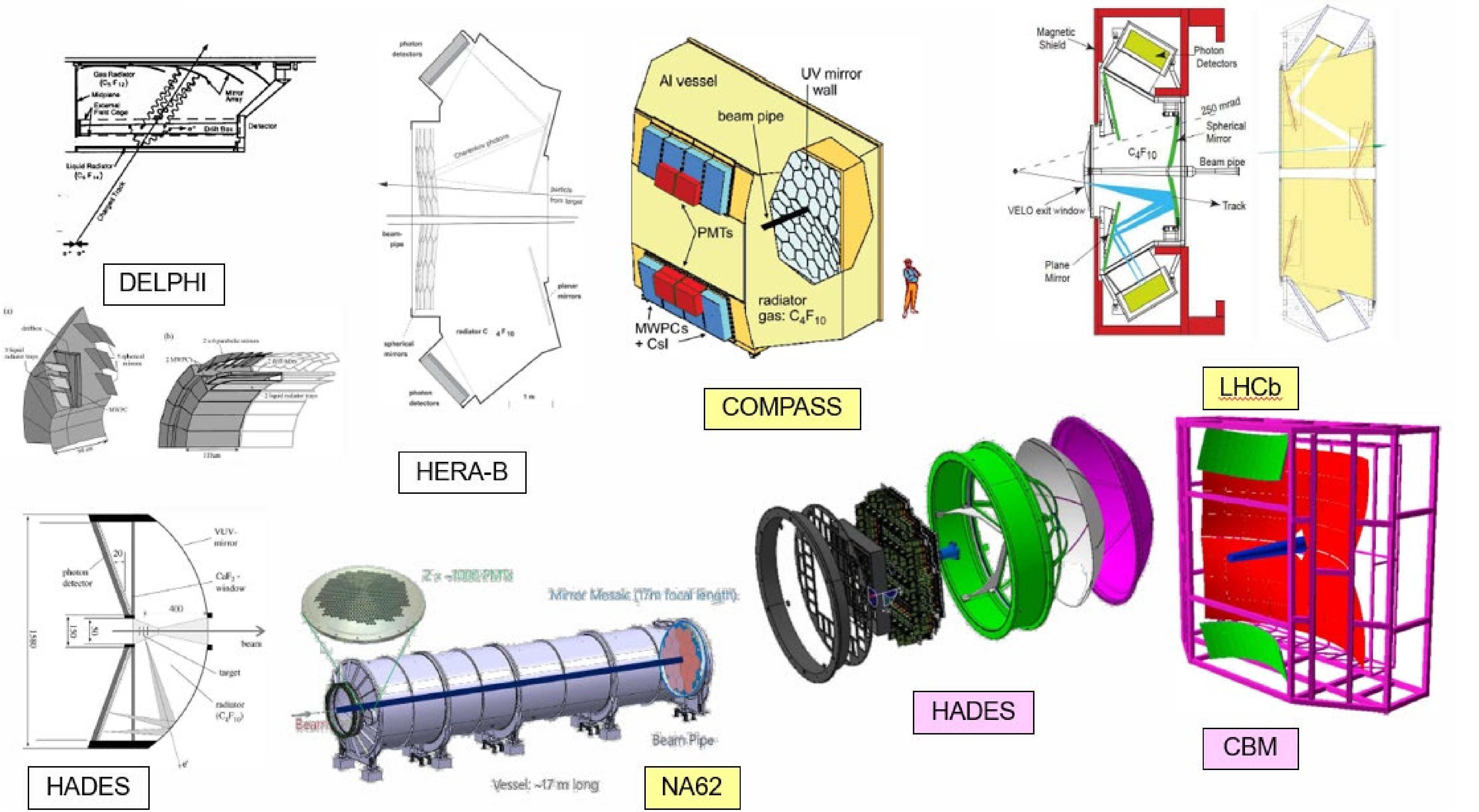
- Hadron 3σ–separation between 3 - 50 GeV/c
- Complement electron ID below 15 GeV/c
- Cover forward pseudorapidity 1.5 (barrel) - 3.5 (b. pipe)



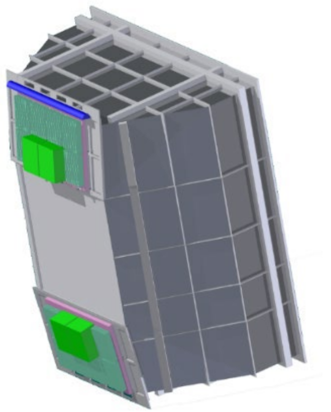
dRICH Features:

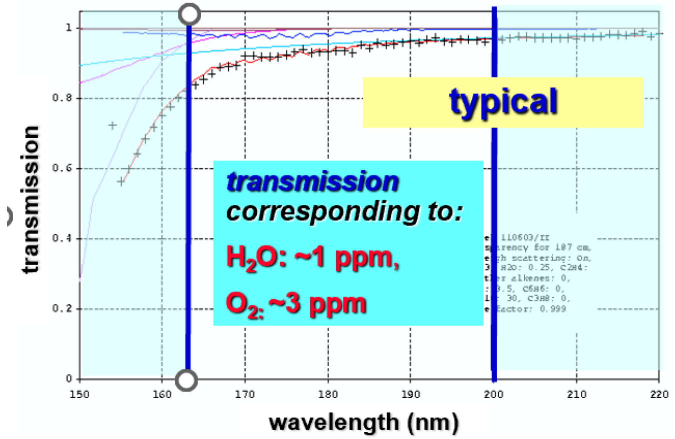
- Extended 3-50 GeV/c momentum range --> Dual radiator
- Single-photon detection in high Bfield --> SiPM
- Limited space --> Compact optics with curved detector

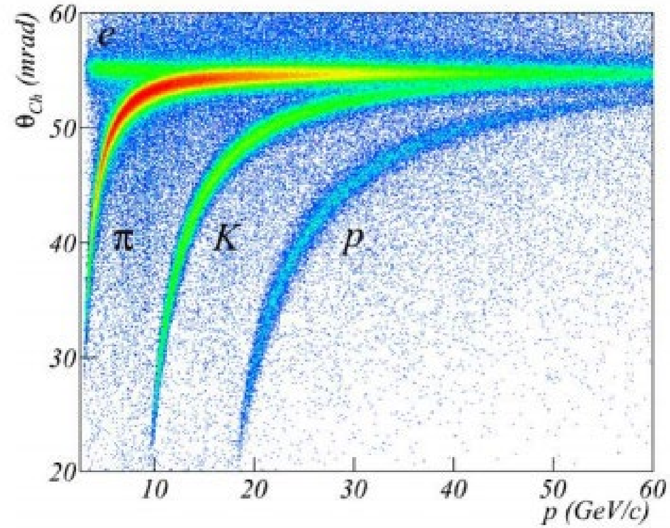
Experience from focusing RICH counters



20 years of C_4F_{10} in COMPASS RICH

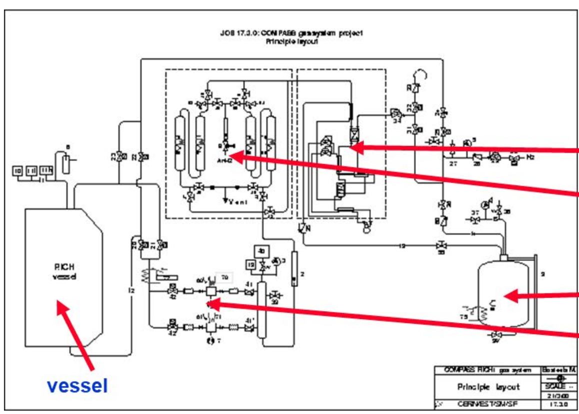


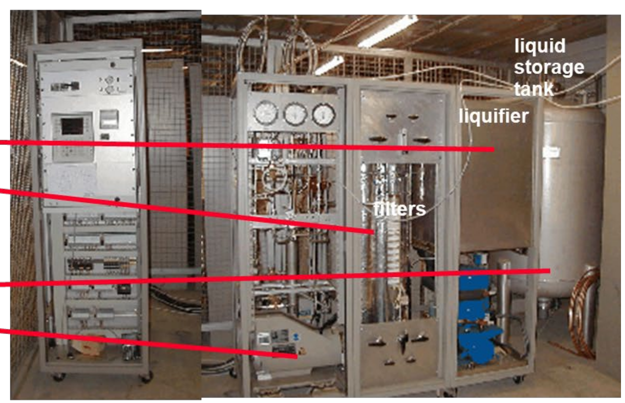




$$m^2 = p^2 \left[\frac{2(n-1) - \theta^2}{1-(n-1)} \right]$$

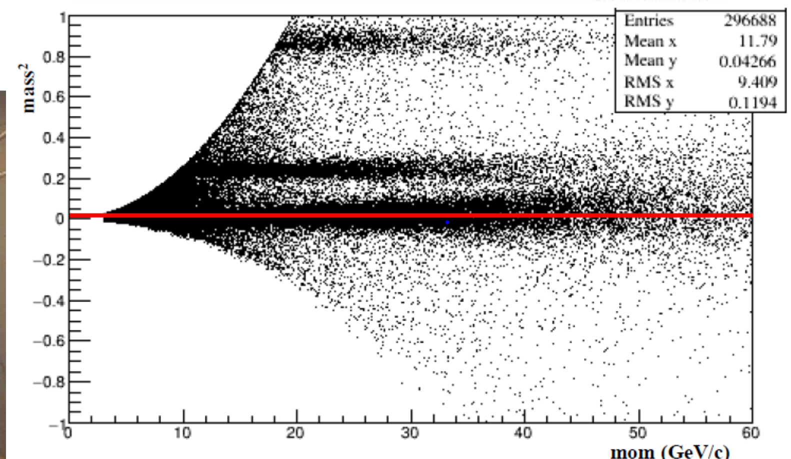
NIM A 553 (2005) 215; NIM A 587 (2008) 371;
NIM A 616 (2010) 21; NIM A 631 (2011) 26;
NIM A 936 (2019) 416; NIMA 970 (2020) 163768





PLC and electrical installation

compressors



PDG:
π mass: 0.13957 GeV/c²
K mass: 0.49368 GeV/c²
p mass: 0.93827 GeV/c²

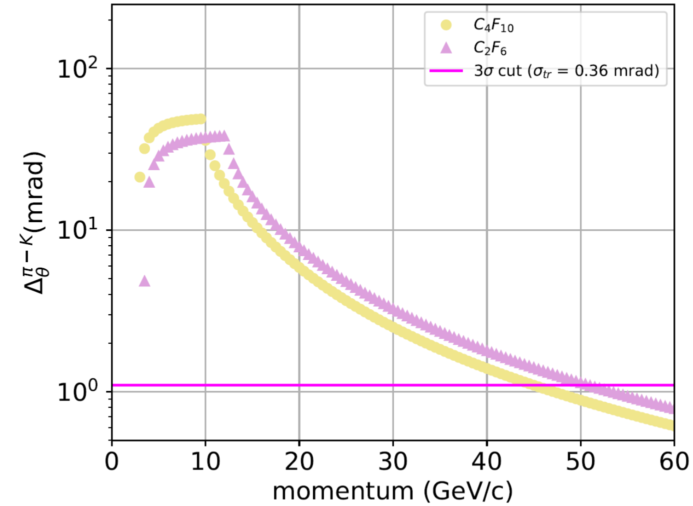
COMPASS RICH:
π mass: 0.138 GeV/c² = PDG value – ~2 MeV/c²
K mass: 0.490 GeV/c² = PDG value – ~4 MeV/c²
p mass: 0.932 GeV/c² = PDG value – ~6 MeV/c²

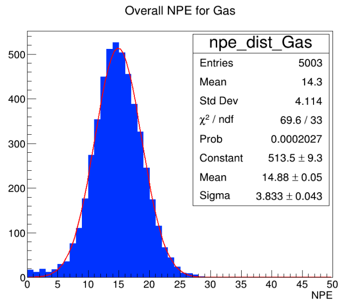
dRICH simulations and test beam: C_2F_6

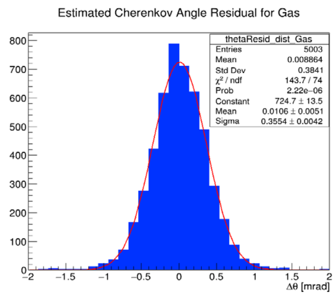
C_4F_{10} largely proven to perform well. In MC simulations C_2F_6 performs better.

Example: 50 GeV/c π and K shot at η = 3.0

Gas	Npe(π/K)	θ_π	θ_K	σ_π	σ_K	N_σ
C_2F_6	14.9/13.8	38.9	37.7	0.36	0.36	3.2
C_4F_{10}	25.0/24.2	51.3	50.4	0.35	0.35	2.6

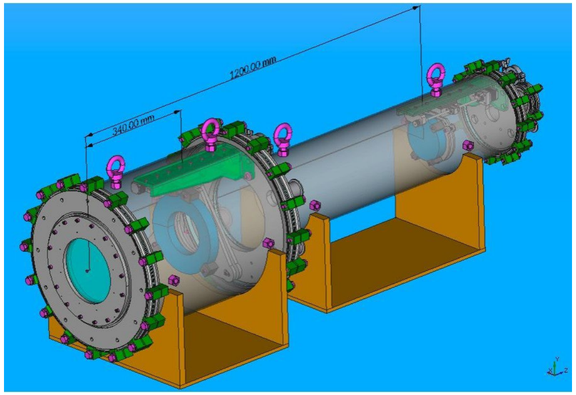


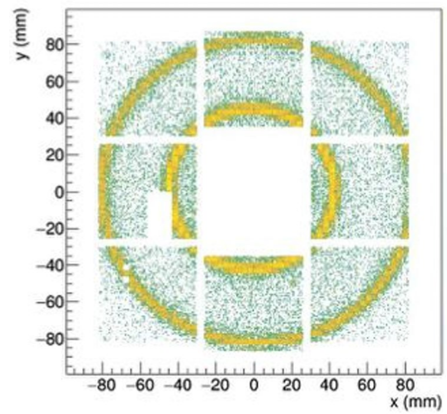


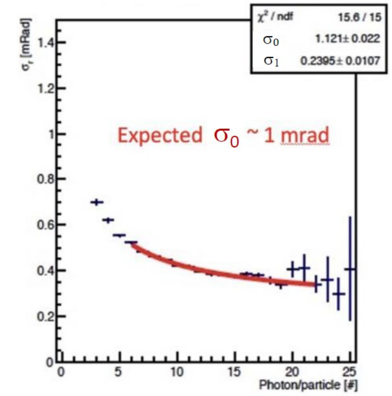


C_2F_6 with SiPM confirmed in test beam

(see talks of Nicola Rubini and Marco Contalbrigo)

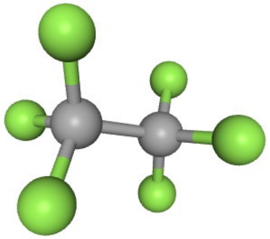


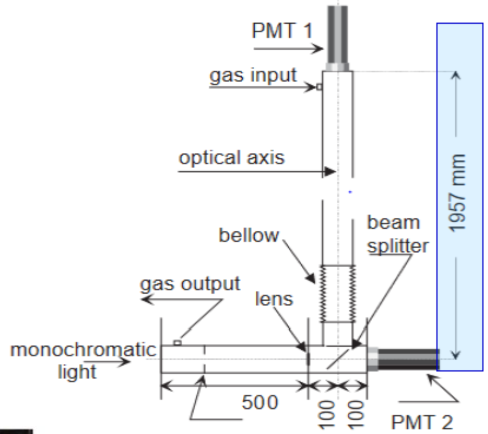




→ C_2F_6 present default choice for ePIC dRICH

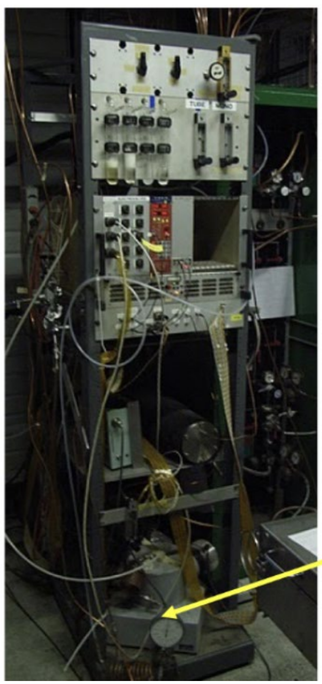
VUV Trasparency of C_2F_6



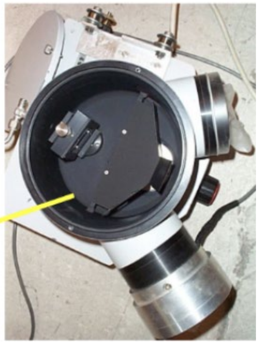


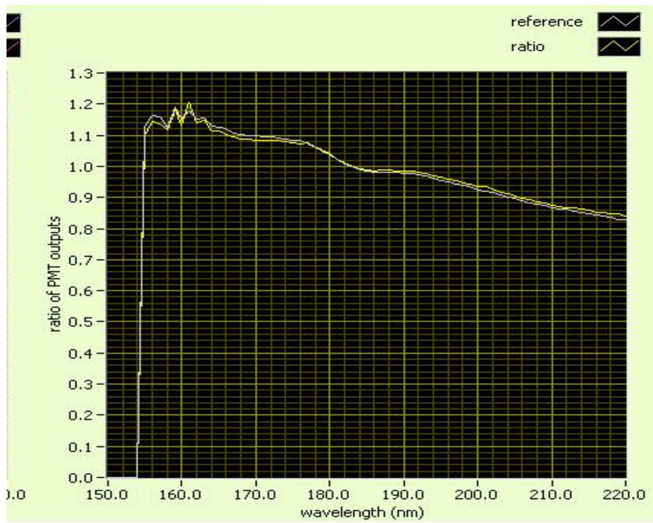
Hexafluoroethane 5.0 (CERN)
used for a test-beam,
stored in a bottle for years

Measured in the COMPASS setup



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

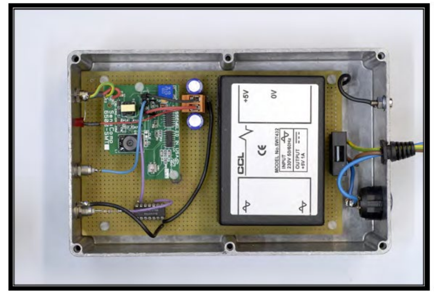




transparency > 98% for 170 nm < λ < 220 nm

C_2F_6 sonar measurement

Measured speed of sound provides gas density → mixture composition



COMPASS RICH sonar used to verify:

- Agreement with literature data
- Good resolution (~ 10^{-4})

Measured speed of sound in C_2F_6: 139.68 m/s

Fluid Phase Equilibria 351 (2013) 53–60

Contents lists available at SciVerse ScienceDirect

Fluid Phase Equilibria

journal homepage: www.elsevier.com/locate/fluid

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Velocity of sound in Perfluoropropane (C_3F_8), Perfluoroethane (C_2F_6) and their mixtures

Václav Vacek*, Michal Vítek, Martin Doubek

Czech Technical University in Prague, F. of Mech. Engineering, Department of Physics, Technická 4, Prague 6, 16607, Czech Republic

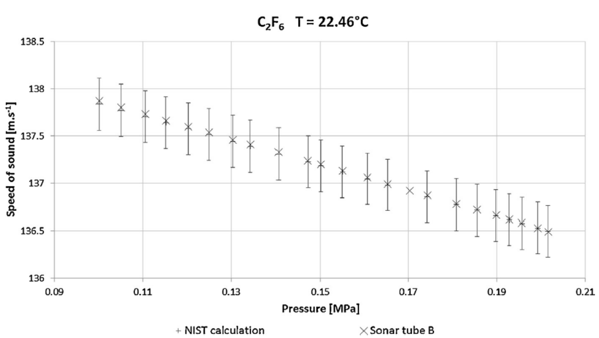
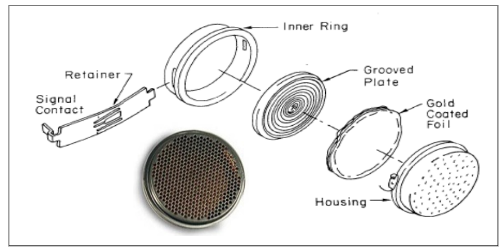


Fig. 5. Measurement in pure C_2F_6 along the 22.46 °C isotherm with varying pressure. Legend: + values calculated from NIST; × values measured in sonar

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…)

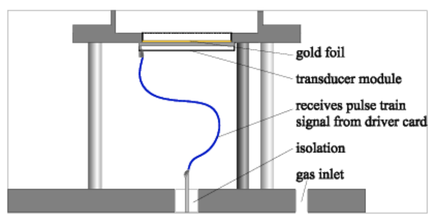


Figure. 1.7 The Sonar System Setup

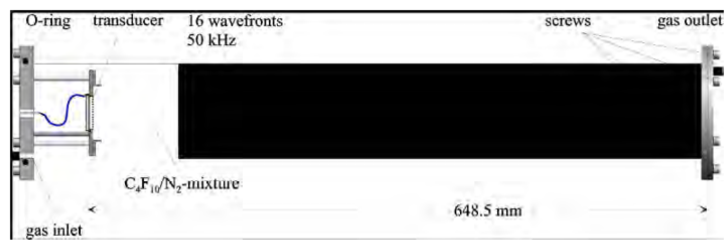


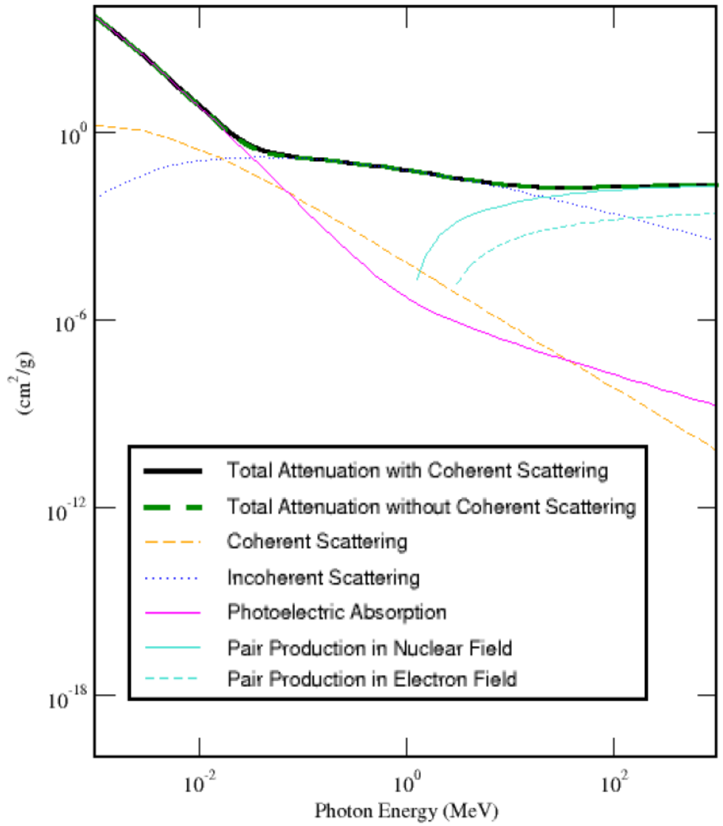
Figure. 1.6 The Sonar System Setup

C_2F_6 chemical computational studies

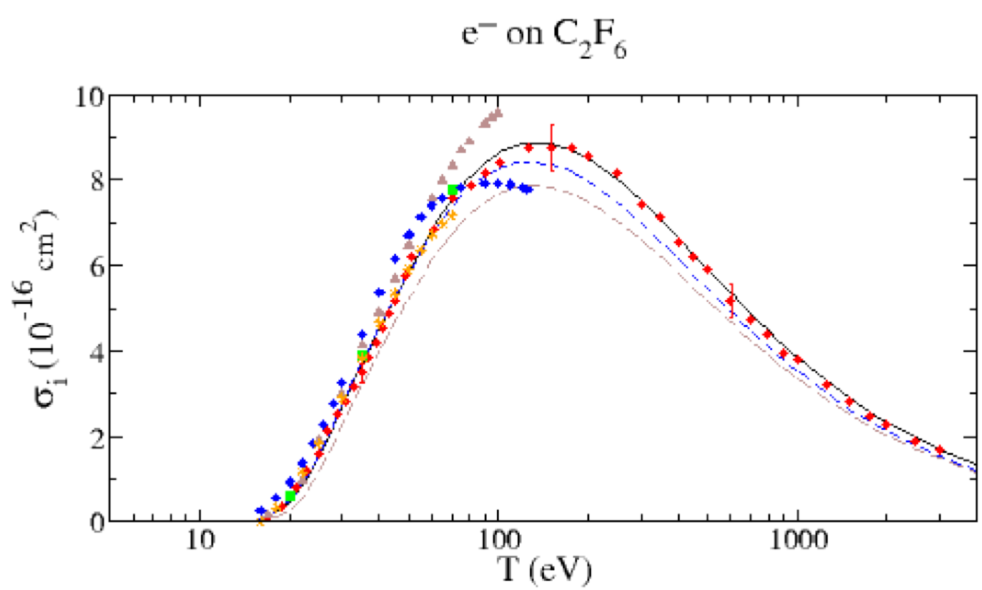
Dedicated QC calculations for C_2F_6 by Jelena Jovanovic and Nebojsa Begovic group (Institute of General and Physical Chemistry, Belgrade University)

Comparison with NIST XCOM results and experimental data, when available.

Result from XCOM calculation for C_2F_6



Data from NIST data base for cross section for ionization end **excitation**



* Black curve could be calculated by **QC**

C_2F_6 degrades in the interaction

Three main processes :

IP *ionization*
EA electron abstraction
EXC *excitation*

$[C_2F_6] \rightarrow IP \rightarrow CF_3^{½} + CF_3^{1/2} \Rightarrow CF_3^+ + \cdot CF_3$

$[C_2F_6] \rightarrow EA \rightarrow \cdot C_2F_5 + F^-$

$[C_2F_6] \rightarrow EXC \rightarrow \cdot CF_3 + \cdot CF_3$

$[CF_3^+] \rightarrow IP \rightarrow [\cdot CF_3]^{2+}$

$[CF_3^+] \rightarrow EA \rightarrow [\cdot CF_3]$

$[CF_3^+] \rightarrow EXC \rightarrow \cdot CF_2^+ + \cdot F$

$[\cdot C_2F_5] \rightarrow IP \rightarrow [C_2F_5]^+$

$[\cdot C_2F_5] \rightarrow EA \rightarrow [C_2F_5]^-$

$[\cdot C_2F_5] \rightarrow EXC \rightarrow [\cdot C_2F_5]^*$

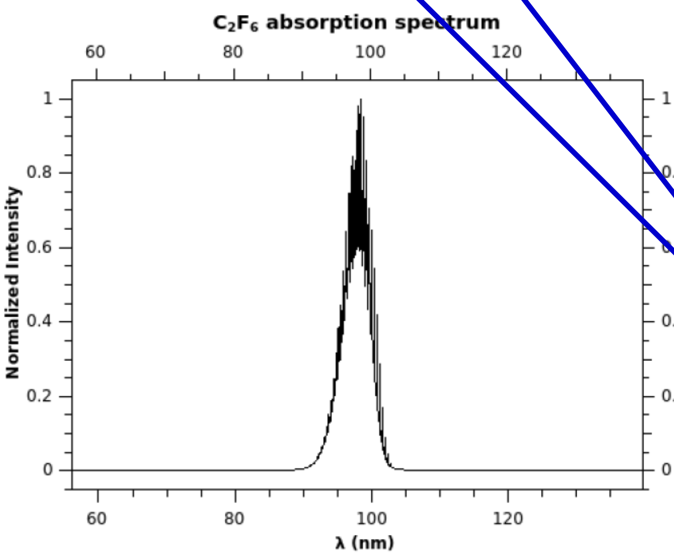
Tau=2.55E-08 s

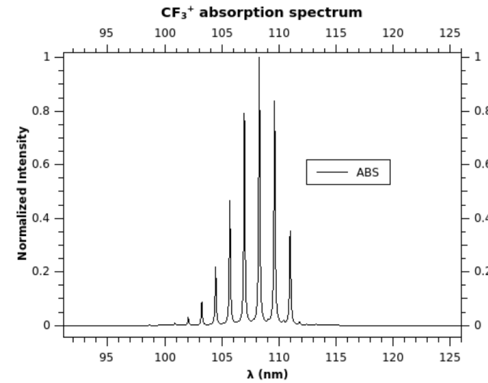
$[\cdot CF_3] \rightarrow IP \rightarrow [CF_3]^+$

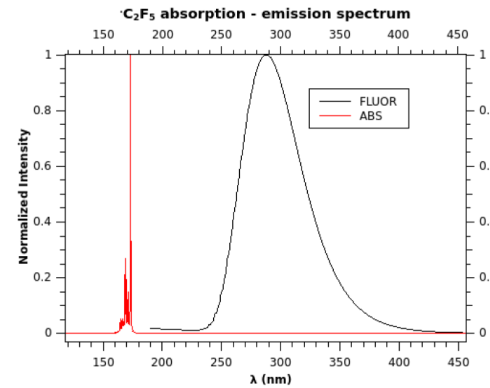
$[\cdot CF_3] \rightarrow EA \rightarrow [CF_3]^-$

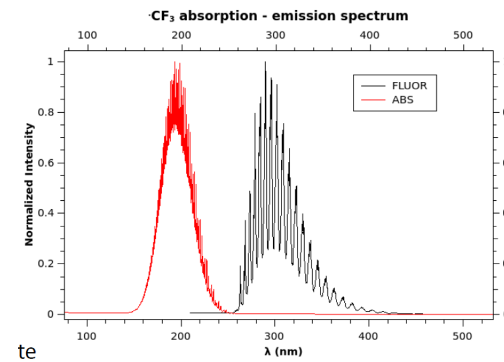
$[\cdot CF_3] \rightarrow EXC \rightarrow [\cdot CF_3]^*$

Tau= 9.11E-08 s









$C_2F_5^+$, $C_2F_5^-$, $\cdot CF_2^+$ degradation

$[\,C_2F_5^+\,] \rightarrow$ *IP* $\rightarrow [\,\cdot C_2F_5\,]^{2+} \rightarrow \cdot F + C_2F_4^{2+}$

$[\,C_2F_5^+\,] \rightarrow$ *EA* $\rightarrow [\,\cdot C_2F_5\,]$

$[\,C_2F_5^+\,] \rightarrow$ *EXC* $\rightarrow CF_2 + CF_3^+$

$[\,C_2F_5^-\,] \rightarrow$ *IP* $\rightarrow [\,\cdot C_2F_5\,]$

$[\,C_2F_5^-\,] \rightarrow$ *EA* $\rightarrow \cdot F + C_2F_4^{2-}$

$[\,C_2F_5^-\,] \rightarrow$ *EXC* $\rightarrow [\,C_2F_5^-\,]^*$

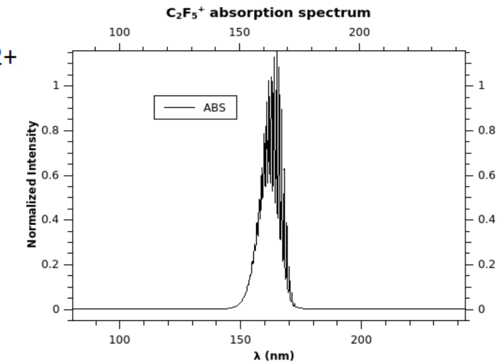
Tau = 3.26E-08 s

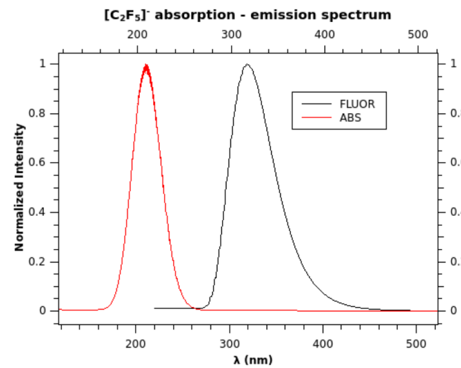
$[\,\cdot CF_2^+\,] \rightarrow$ *IP* $\rightarrow [\,CF_2\,]^{2+}$

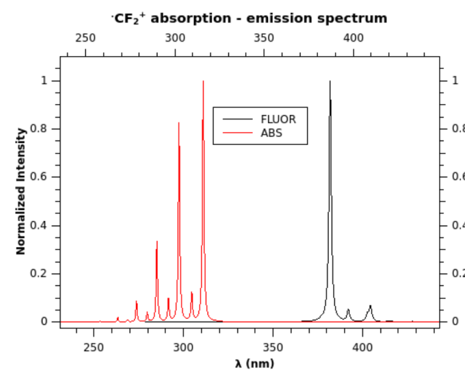
$[\,\cdot CF_2^+\,] \rightarrow$ *EA* $\rightarrow [\,CF_2\,]$

$[\,\cdot CF_2^+\,] \rightarrow$ *EXC* $\rightarrow [\,\cdot CF_2^+\,]^*$

Tau = 2.47E-07 s







Quantum Chemical calculations → full description of the degradation chain.

Optical and chemical properties of all produced molecules, reaction dynamics and lifetimes.

Measurement of transparency and fluorescence under irradiation is foreseen.

EU Directive on fluorinated gases

Document 32024R0573

Regulation (EU) 2024/573 of the European Parliament and of the Council of 7 February 2024 on fluorinated greenhouse gases, amending Directive (EU) 2019/1937 and repealing Regulation (EU) No 517/2014 (Text with EEA relevance)

PE/60/2023/REV/1

European Union

EUR-Lex
Access to European Union law

https://eur-lex.europa.eu/eli/reg/2024/573/oj

Fluorinated gases intensively used in industry:

- refrigeration & air conditioning
- power distribution
- automotive
- medical inhalers
- semiconductor and electronics

In some cases, not replaceable:
→ exemptions from banning rules?

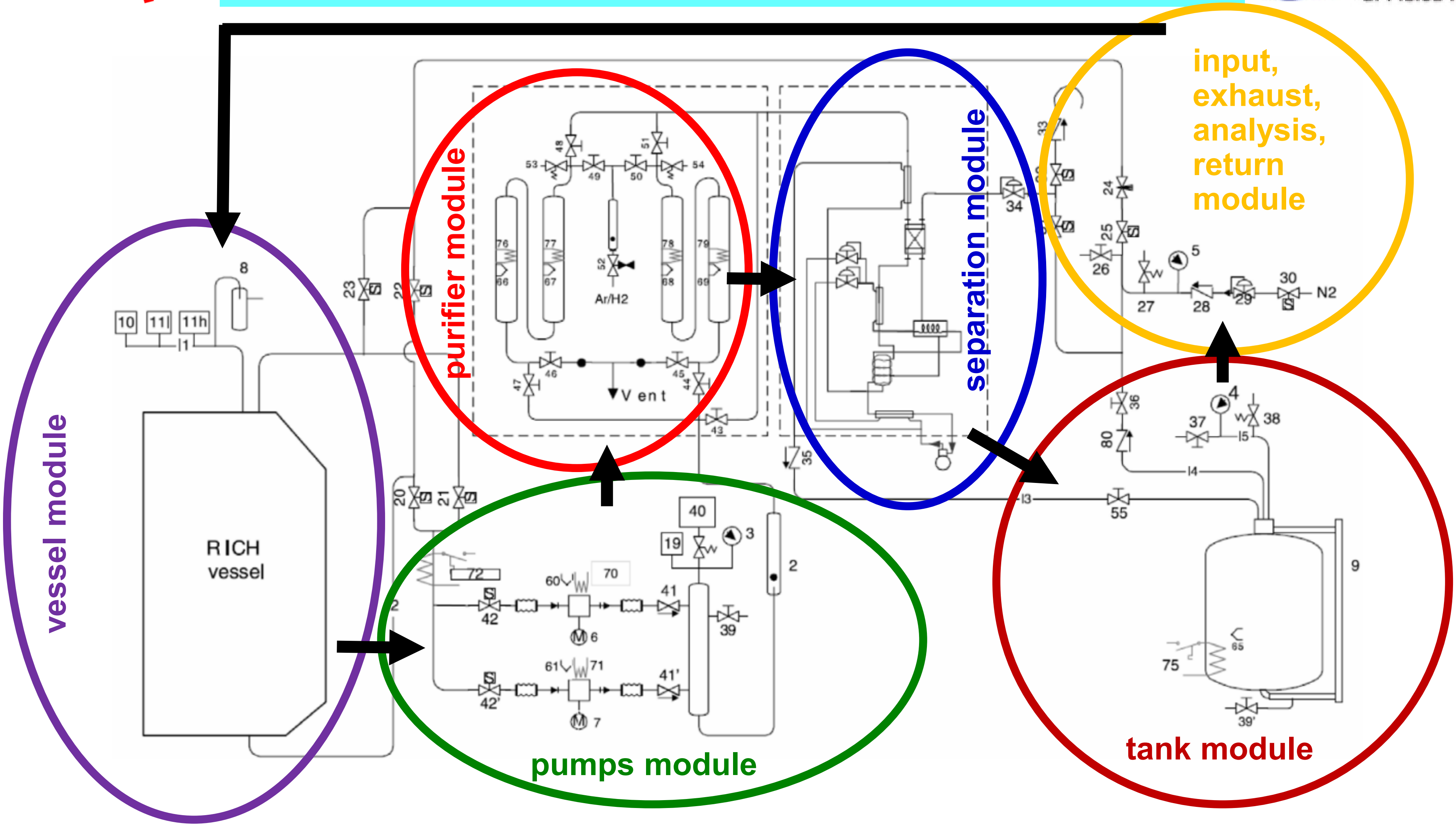
Substance			GWP 100 ([4])	GWP 20 ([4])
Industrial designation	Chemical name (Common name)	Chemical formula		
Section 2: Perfluorocarbons (PFCs)				
PFC-14	tetrafluoromethane (perfluoromethane, carbon tetrafluoride)	CF_4	7 380	5 300
PFC-116	Hexafluoroethane (perfluoroethane)	C_2F_6	12 400	8 940
PFC-218	octafluoropropane (perfluoropropane)	C_3F_8	9 290	6 770
PFC-3-1-10 (R-31-10)	decafluorobutane (perfluorobutane)	C_4F_{10}	10 000	7 300
PFC-4-1-12 (R-41-12)	dodecafluoropentane (perfluoropentane)	C_5F_{12}	9 220	6 680

Ecofriendly use of hexafluoroethane:

- No emission for precleaning → purchasing of clean gas.
- Minimization of leaks during operation → good vessel tightness, high quality components of gas system.
- No venting out of radiator gas used for measurements → challenging but possible.
- Minimal purge of trapped fluorocarbons in oxy- and hydro- filters. → feasible.
- Fully closed loop for filling and recovery → specific R&D ongoing.

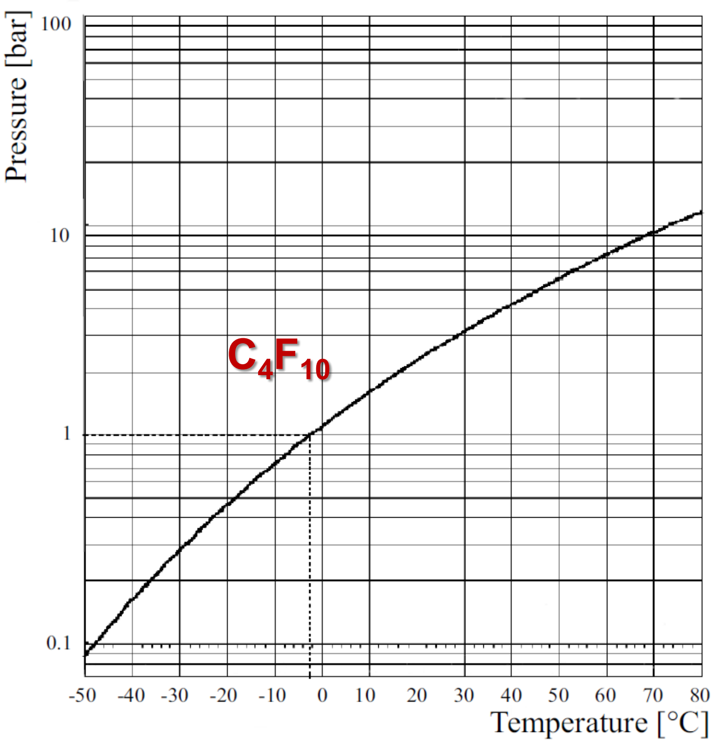
Alternative gases (see Greg Hallewell talk) and pressurized radiator option → R&D DRD1, DRD4, Otello

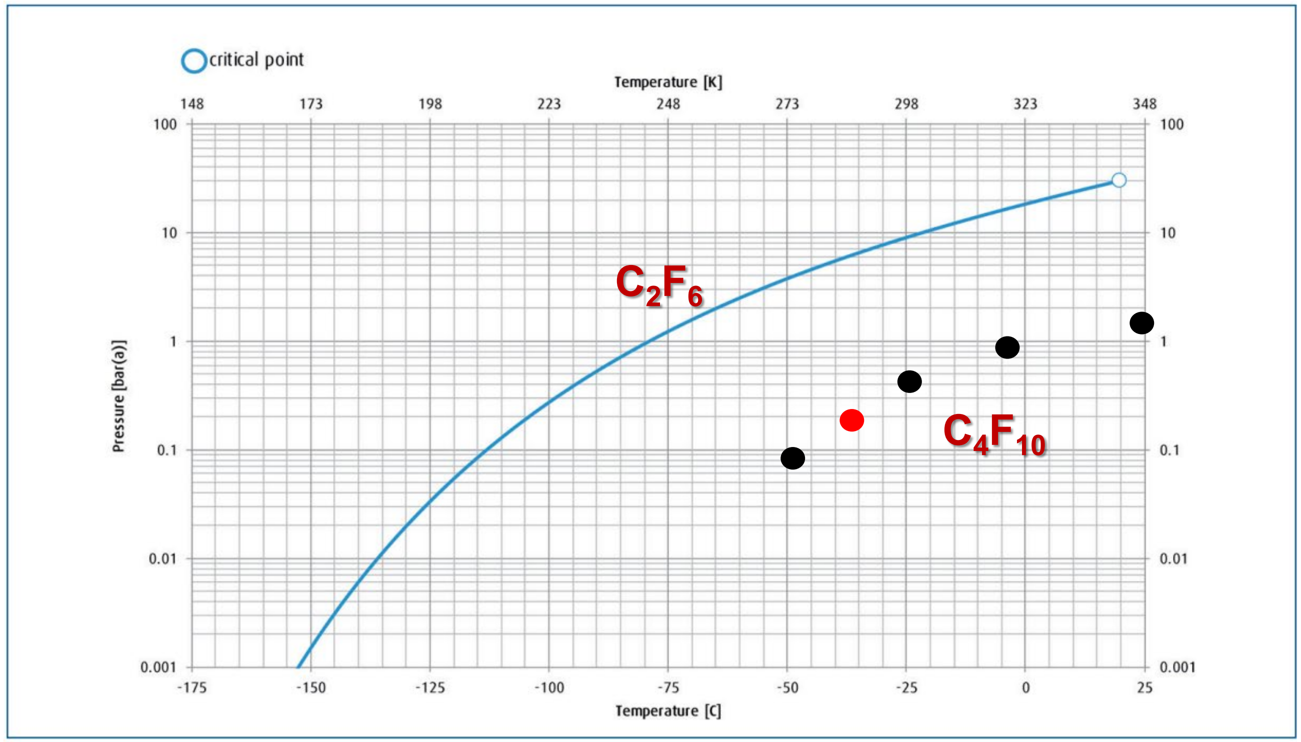
COMPASS RICH gas system



Challenges of ecofriendly gas system

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

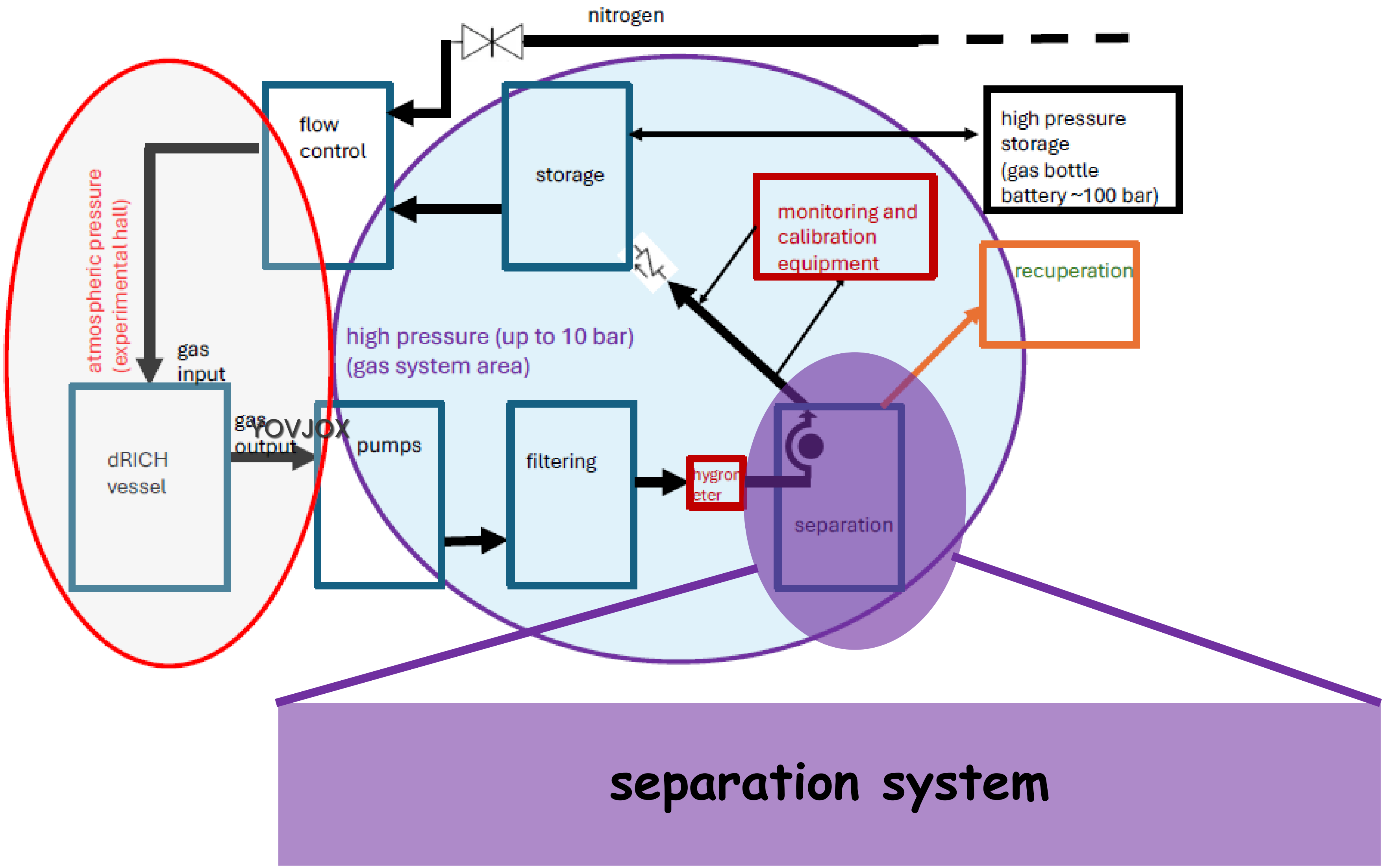




At - 36°C C_4F_{10} has 200 hPa vapor pressure. A separator working at 7 bars will purge 97% N_2 and 3% C_4F_{10}

To achieve analogous performance with C_2F_6 is challenging

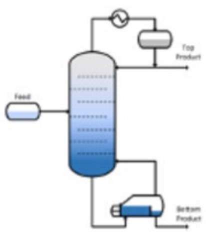
Block diagram of the dRICH gas system

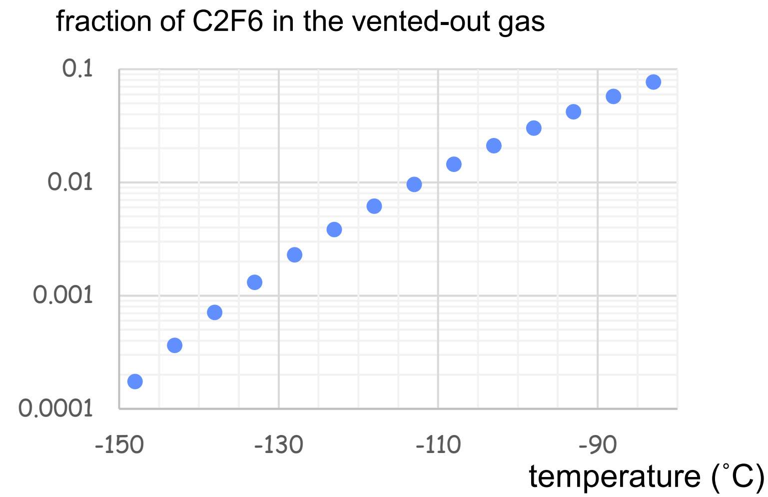


Separation possibilities

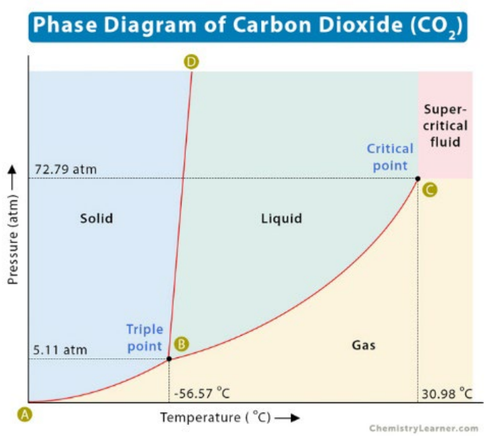
1) Phase separation by liquefying the radiator gas

Distillation → **implies operating at very low temperatures**



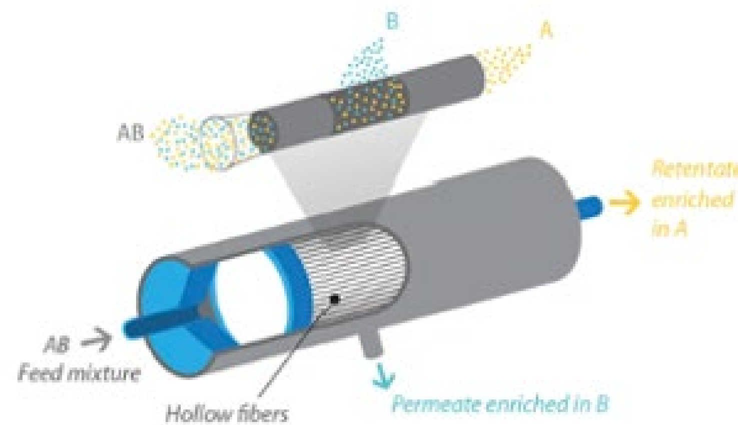


2) Phase separation by liquefying the other gas
→ **implies using CO_2 as neutral gas instead of nitrogen**



C_2F_6-CO_2 mixture and phase separation options: partial condensation, distillation column, crystallization, …

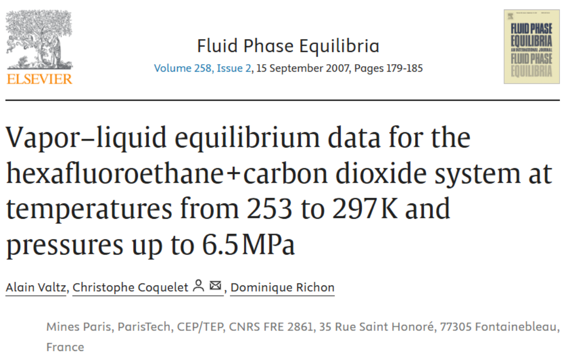
3) Separation by membrane filtering
implies developing a dedicated system



Separation of C_2F_6 from CO_2

Preliminary Studies: $CO_2 - C_2F_6$ Binary Mixture

Investigation performed by Damiano Galassi, chemical and process Engineer, EP-DT-FS Gas team, CERN



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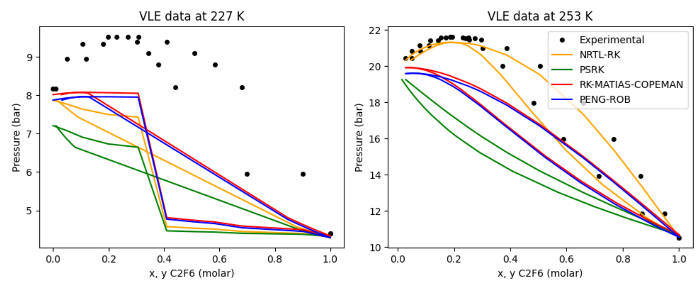
Fluid Phase Equilibria

Volume 258, Issue 2, 15 September 2007, Pages 179-185

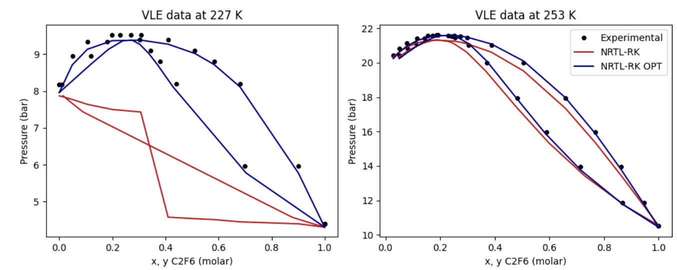
Vapor–liquid equilibrium data for the hexafluoroethane+carbon dioxide system at temperatures from 253 to 297 K and pressures up to 6.5 MPa

Alain Valtz, Christophe Coquelet, Dominique Richon

Mines Paris, ParisTech, CEP/TEP, CNRS FRE 2861, 35 Rue Saint Honoré, 77305 Fontainebleau, France

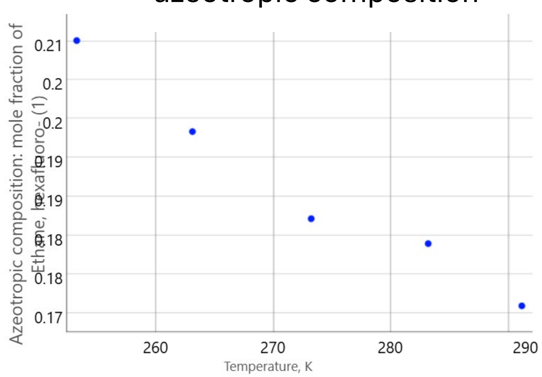


Models do not reproduce the data

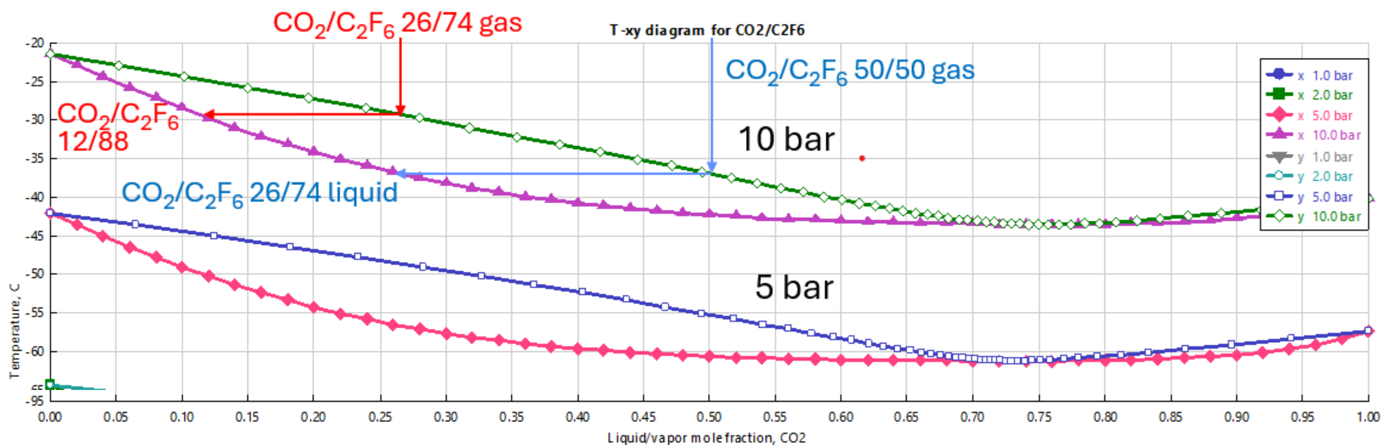


Blue: D. Galassi modified model: o.k.

Fraction of C2F6 in azeotropic composition



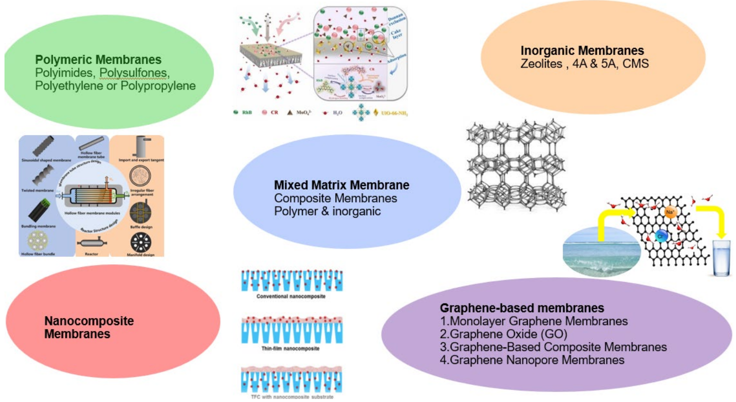
azeotropic→strong molecular interaction



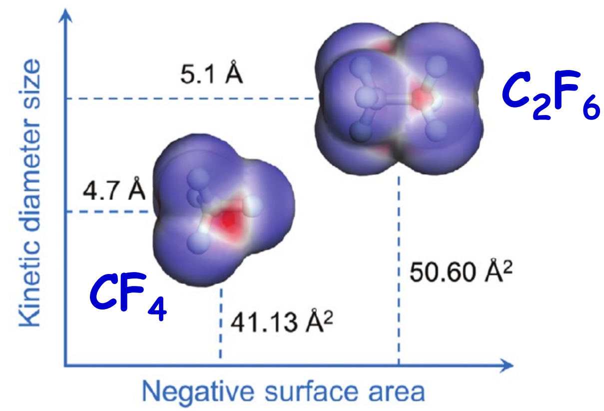
Possibility to use a distillation column for separation

Selective permeability for CO_2

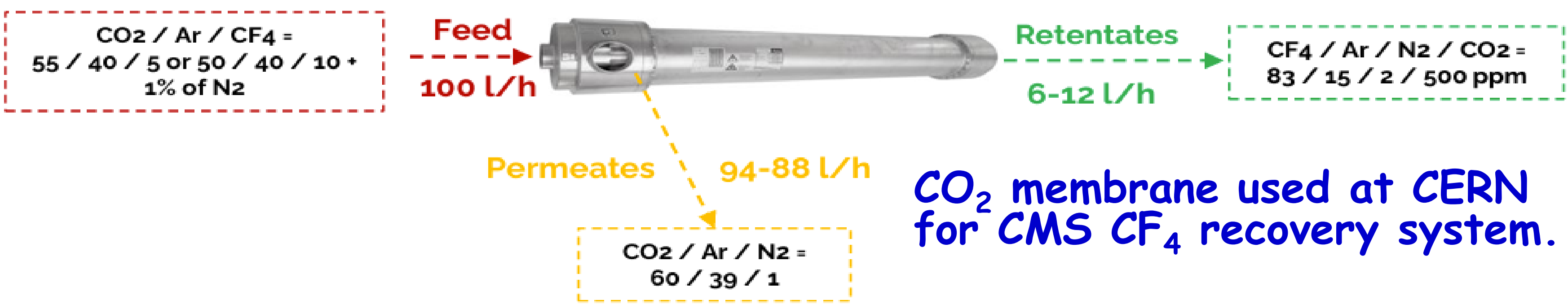
Selective permeabilities



CO_2 kinetic diameter: 3.3 Å



Maria Cristina Arena presentation at DRD1 Workshop "Sustainable gas mixtures for future detectors"



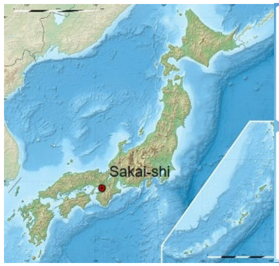
CO_2 membrane used at CERN for CMS CF_4 recovery system.

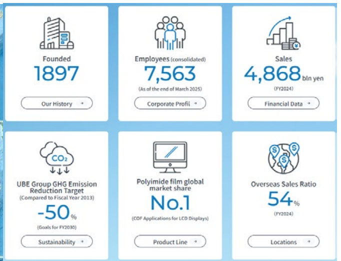
Example: (Maria Cristina Arena, EP-DT)

Composition input flow l/h				
CF4	CO2	Ar	O2	N2
21	214	157	0.6	7.920

Composition retentates flow l/h				
CF4	CO2	Ar	O2	N2
15	0.006	1	0.001	0.1

UBE membranes





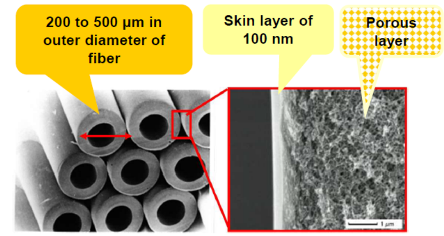
History of UBE's Membrane Business

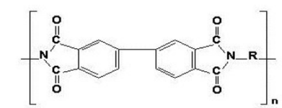
UBE Corporation
CS-001E_REV.K_250717
As a reference

- 1978 Started R&D Work
- 1981 Jointed MITI's C1 Project (National Project)
- 1983 First Membrane for H_2
  Field Tests at Ammonia Plant for H_2 Recovery
- 1985 Organized Membrane Dept.
- 1986 Supply First H_2 Recovery Unit
- 1989 First Membranes for CO_2 & Dryer
- 1989 First Membrane for Dehydration
- 1992 First Membrane for N_2/O_2 Separation
- \- Improving Membranes and Modules
- 2007 2nd Hollow Fiber Line in Ube City facility
  Module Assembly Line in Sakai.
- 2008 3rd Hollow Fiber Line in Ube.
- 2025 4th Hollow Fiber Line in Ube.
  Expansion in the Module Assembly facility in Sakai.

Polyimide Hollow Fiber Membranes

UBE Corporation
CS-001E_REV.K_250717
As a reference





BPDA-based polyimide

Permeation rate to gases in polyimide membrane

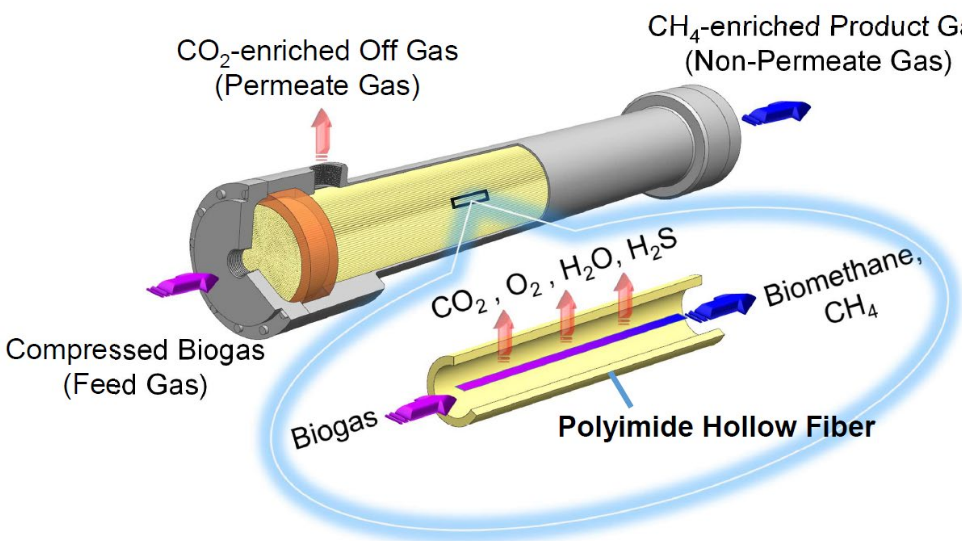
High permeation	H_2O
	H_2 He
dependent on solubility and molecule size	CO_2 H_2S
	O_2
	CO Ar
Equilibrium + Kinetic Separ.	N_2 CH_4 C_2H_5OH
	C_2H_6
Low	C_3+ Hydrocarbons

Benefits of BPDA-based polyimide as material for hollow fiber membrane

1) Good balance for permeability and selectivity
2) Good mechanical property
3) Excellent heat resistance
4) Good chemical resistance
5) Excellent lifetime
6) Easy to make fiber and thin skin layer

Module Structure - CO_2 Separator

UBE Corporation
CS-001E_REV.K_250717
As a reference



● Product Specification and Features

Hollow Fiber	Polyimide Resin
Housing	Aluminum
Operating Pressure	Housing type - Max. 1.4 MPaG Cartridge type - Max. 2.4 MPaG
Operation Temperature	up to 60°C
H_2S resistance up to 3 vol %	

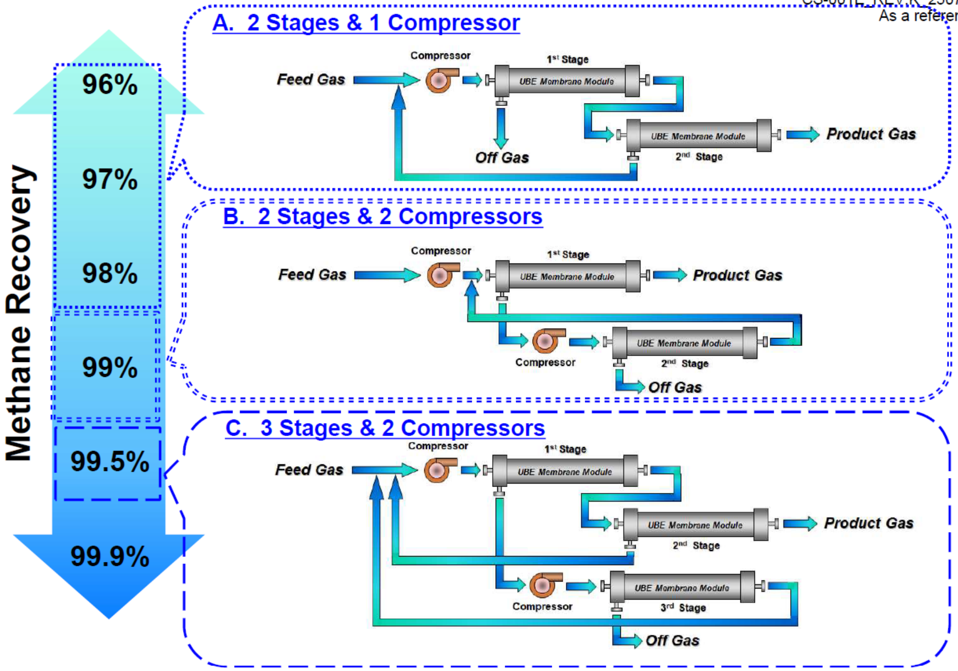
Biogas applications

System Configuration of Membranes **

**UBE supplies membrane module/cartridge only.

UBE Corporation

CS-001E_REV.K_250717
As a reference

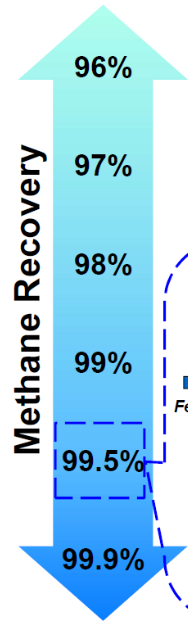


New System Configuration of Membranes **

**UBE supplies membrane module/cartridge only.

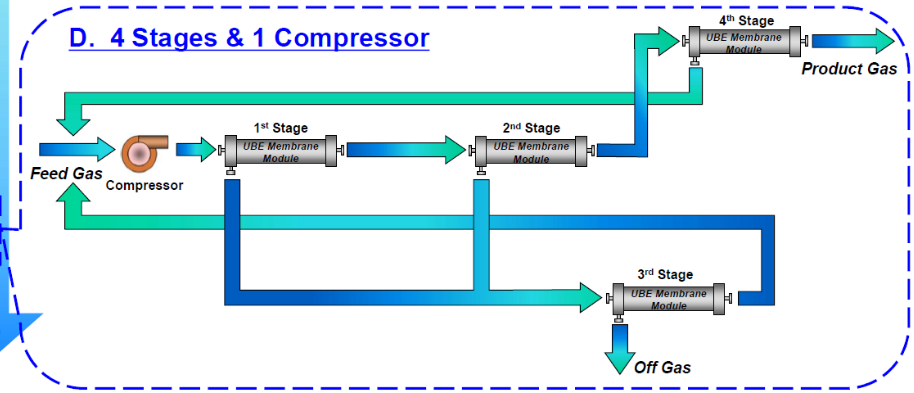
UBE Corporation

CS-001E_REV.K_250717
As a reference



Competitive Advantages

- 99.5 % recovery & 99.0 % purity CH_4, all in one go.
- Save energy with just one compressor.
- Big savings especially for small scale plants.



Feed Gas Flow Rate : 600 Nm^3/h (at 0 °C, 1013 mbara)

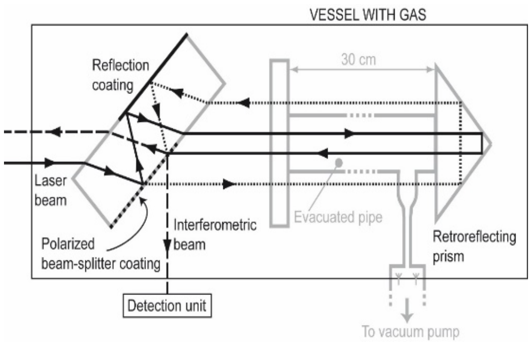
Feed Gas Composition : CO_2 40 %, CH_4 60 %

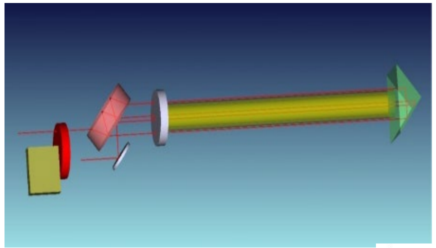
Product Gas Purity : CO_2 < 1 %

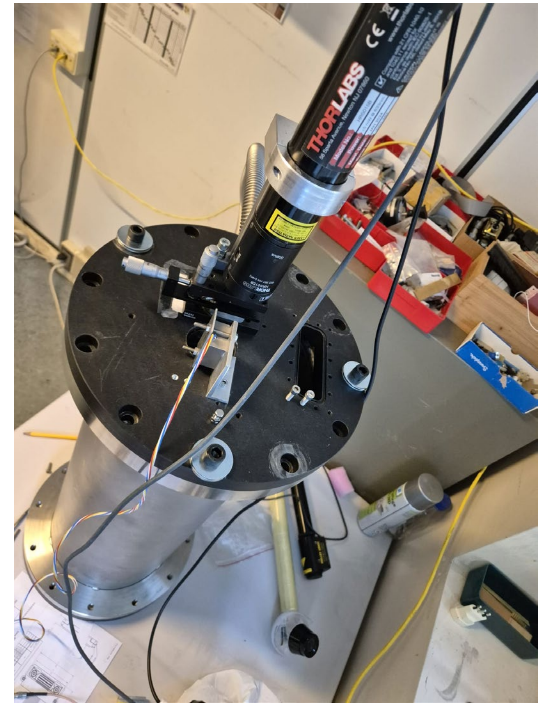
Operating Temperature : 25 °C (77 °F)*

*Maximum allowable temperature is 60 °C (140 °F).

Modified Jamin interferometer

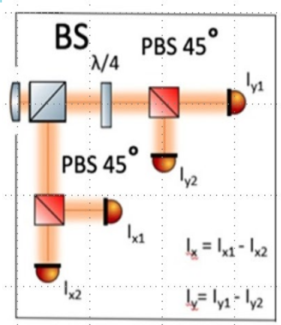


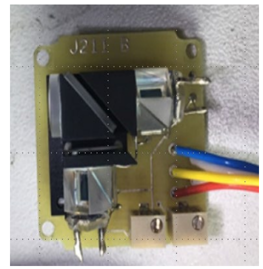


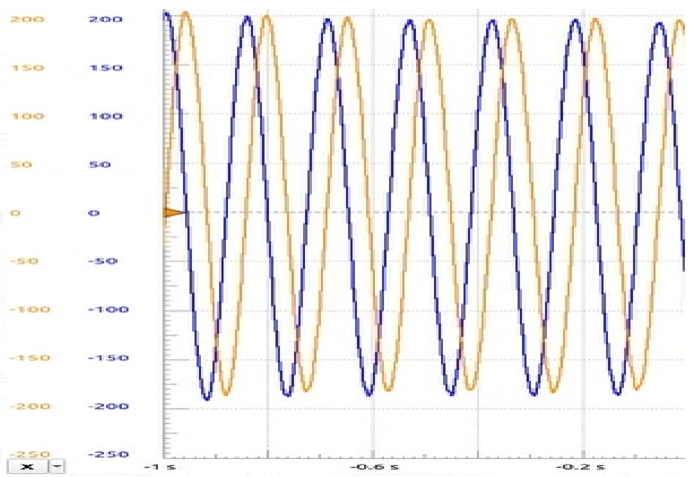


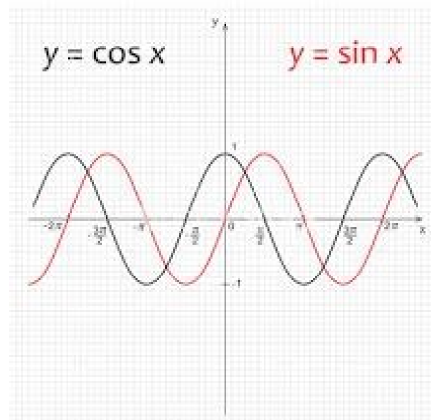
$$I = I_1 + I_2 + 2\sqrt{I_1 I_2}\,\Delta\phi(t)$$

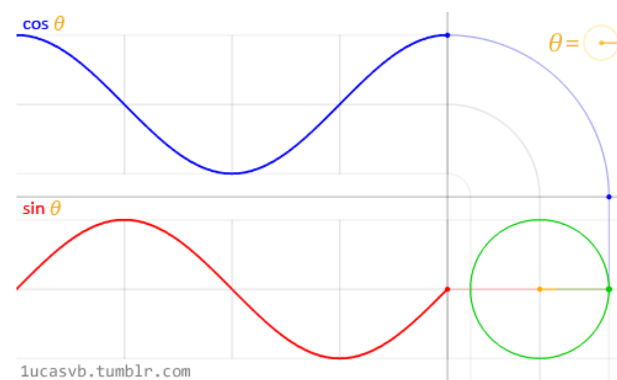
$$\Delta\phi(t) = \left(2\pi\ell/\lambda\right)\Delta n(t)$$



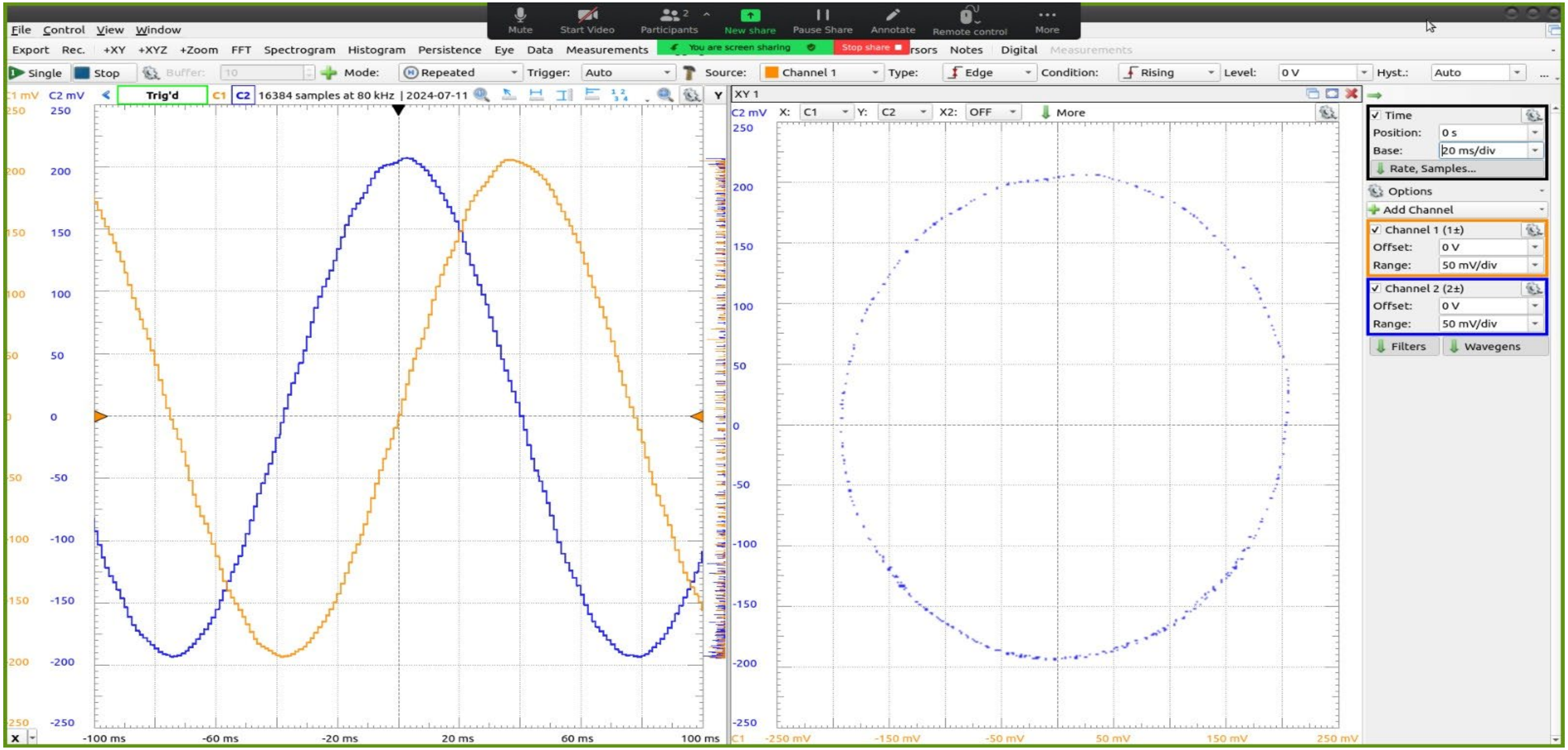








Interferometer resolution



one period (360˚) corrisponds to a variation of 1 ppm in the refractive index.
a resolution better than 10 ppb can be achieved in refractive index monitoring.

CONCLUSIONS

- ePIC dRICH preferred radiator gas: C_2F_6
  - Preliminary measurements and tests are being performed
  - Quantum chemical calculations ongoing
- Ecofriendly gas system presents challenges
  - Separation techniques under investigation
  - Selective permeability membranes look promising
- Radiator gas monitoring tools being developed
  - Jamin interferometer offers high precision refractive index measurement