Long term experience with C_4F_{10} in COMPASS RICH-1

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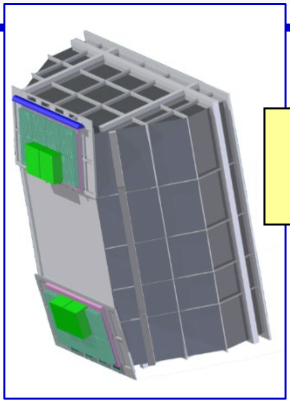
on behalf of the Trieste-COMPASS group

OUTLINE

- INTRODUCTION
- RADIATOR TRANSPARENCY
- REFRACTIVE INDEX: DETERMINATION and EVOLUTION
- GAS RADIATOR PERSPECTIVES
- CONCLUSIONS

INTRODUCTION



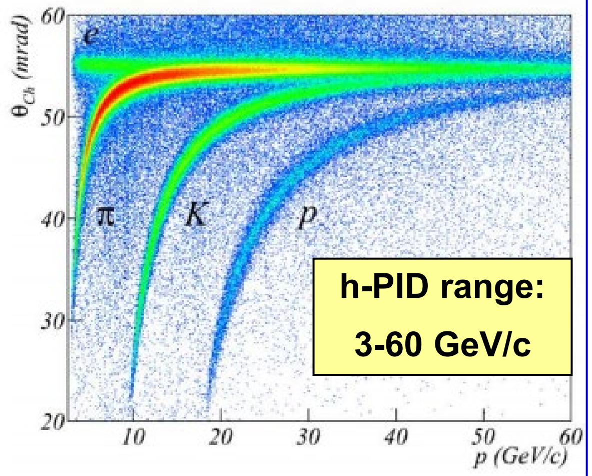
COMPASS RICH-1

- **RICHes with gaseous radiators still represent the only option for hadron PID at high momenta**

- **Fluorocarbons are privileged because they offer:**
  - **High Cherenkov photon yield**
  - **Low chromaticity**

both relevant parameters to obtain fine resolution in the Cherenkov angle measurement and, therefore, in determining the upper momentum limit for effective PID

- **We present**
  - ***items potentially of general interest related to our long-term (> 20 y) experience with C_4F_{10} as gaseous radiator in COMPASS RICH***
  - ***future perspectives for gaseous RICHes***



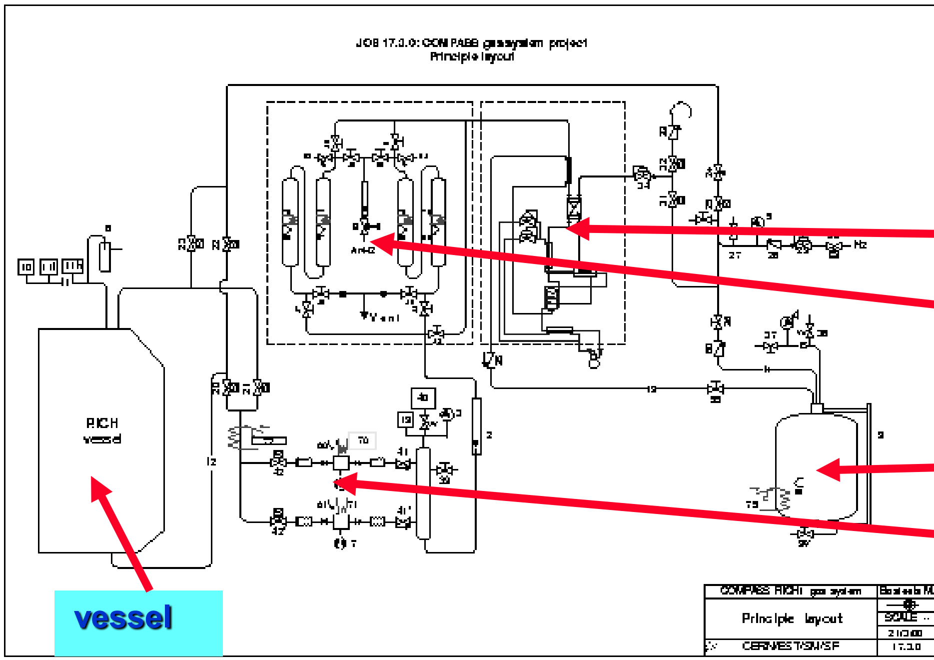
h-PID range: 3-60 GeV/c

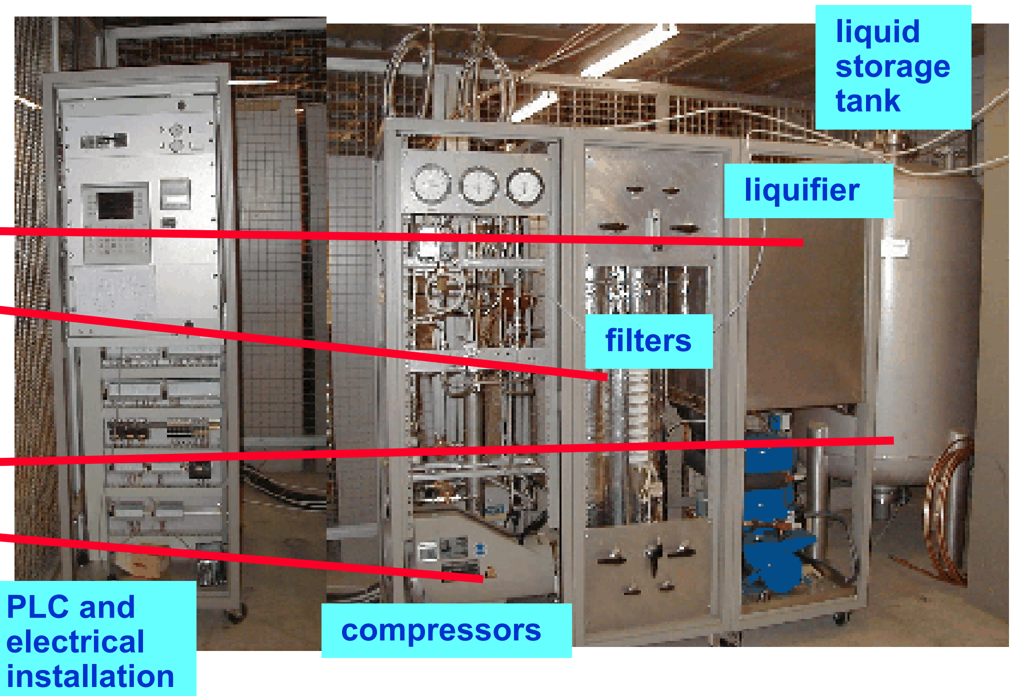
NIM A 553 (2005) 215; NIM A 587 (2008) 371;
NIM A 616 (2010) 21; NIM A 631 (2011) 26;
NIM A 936 (2019) 416; NIM A 970 (2020) 163768

HANDING THE RADIATOR GAS

Gas System for:

- relative P constant +/- 0.1 mbar
  to limit ΔP on - vessel windows
  quartz plates
  He beam pipe
- gas filtering (remove H_2O, O_2)
- filling with / recovering C_4F_{10}



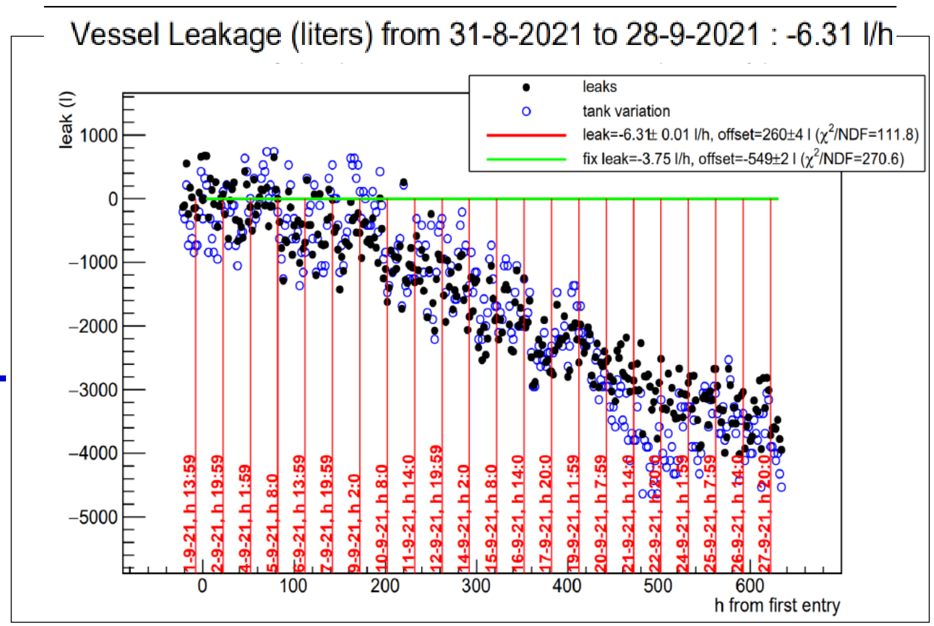


HANDING THE RADIATOR GAS

Amount of “cleaned” C4F10 needed per year of operation (assuming 6 m of data taking)

- **Vessel and gas system (filters included): 1000 kg**
- **Circulation losses: 300-400 kg**
- **loss for transparency measurements (two per month): 25 kg**
- **Lost during filling, emptying: 25 kg**

TOTAL: ~1400 kg



IDENTIFIED C_4F_{10} PROVIDERS

For large quantities:

3M(*): performance fluid PF-5040

- **Production stopped around 2010** (in the following few years they have sold out what remaining in stock)
- **Produced in different plants around the world**
- **Observed over years (also going back to DELPHI experience) : <u>different amount and nature of impurities</u>**
- **<u>Used in COMPASS till 2017</u>**

SPECIFICATIONS:

NOTE: These are introductory specifications based upon limited production data and are subject to change.

Property	Test Method	Unit	Lower Limit	Target	Upper Limit
Perfluorobutane	135.266	%mole	99.0	-	-
Water	300.201	ppm	-	-	10.0
High Boiling Impurities	1.13.5.9	%	-	-	0.05
Comment: (volume)					
Residue	1.13.5.9	ug/ml	-	-	100.0
Free Fluoride	53.23	ppm	-	-	0.14

(*) Minnesota Mining and Manufacturing Company, 3M Center, St. Paul, MN, USA

F2Chemicals(*): perfluorobutane, QS25

- **<u>Used in COMPASS after 2017</u>**

Assay (excluding air)		
Total Perfluorobutane	98 % v/v min	FC-40-011
Total impurities, by GLC	2 % v/v max	FC-40-011
Related Perfluorinated compounds		
Perfluoropropane	1% v/v max	FC-40-011
Perfluoromethane	0.5 % v/v max	FC-40-011
Perfluoroethane	0.5 % v/v max	FC-40-011
Perfluorocyclobutane	0.5 % v/v max	FC-40-011
Each single unknown	0.5 % area max	FC-40-011
Others		
Air	0.5 % v/v max	FC-40-011
Acetone	100 ppm w/w max	FC-40-012

Note - Analysis to be performed on the liquid phase.

(*) 2F2 Chemicals LTD, Lea Lane, Lea Town, Preston, Lancashire, PR4 ORZ, UK

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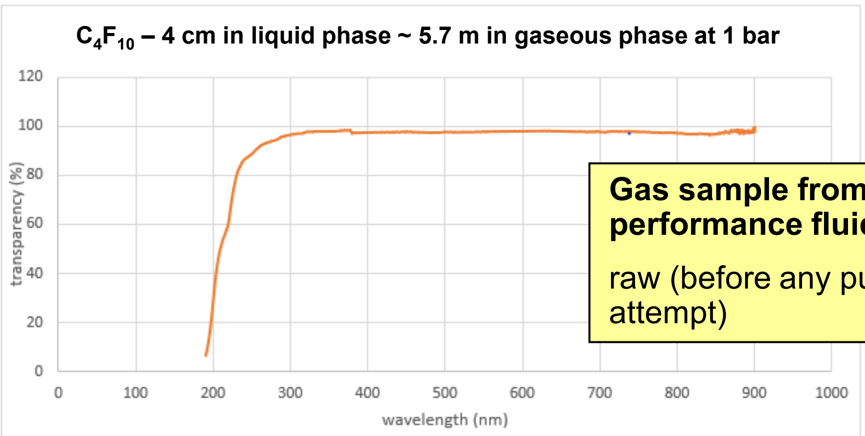
RADIATOR TRASPARENCY

The issue: **COMPASS RICH-1 makes use of gaseous sensors with CsI photoconverter → effective range:**

165 nm (quartz window) – 200 nm (CsI QE upper limit)

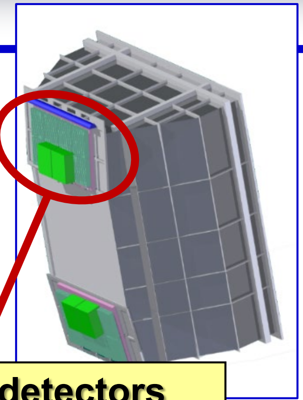
<u>The radiator light transmission can be critical in the UV range by the contaminants in the radiator</u> →

- **Light transmission measurement**
- **Remove the impurities**



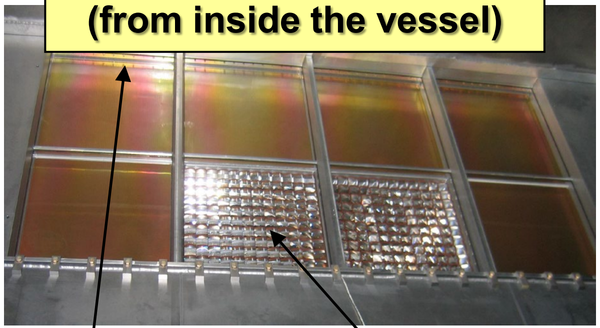
Gas sample from 3M, performance fluid PF-5040

raw (before any purification attempt)



Top photon detectors

(from inside the vessel)

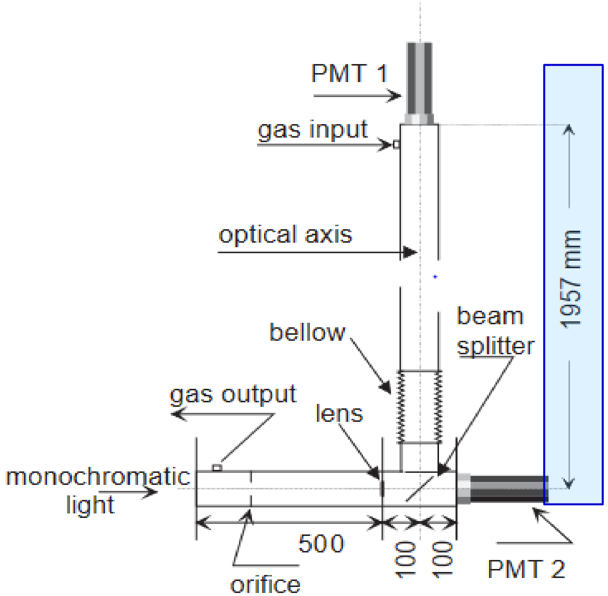


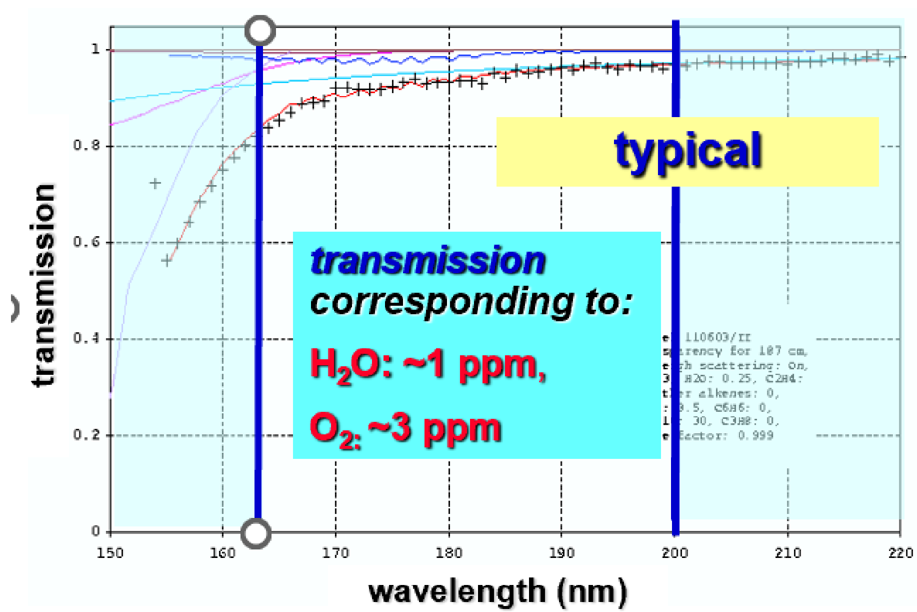
MAPMTs coupled to lens telescopes

Gaseous PDs with CsI

RADIATOR TRASPARENCY

Light ransmission measurement



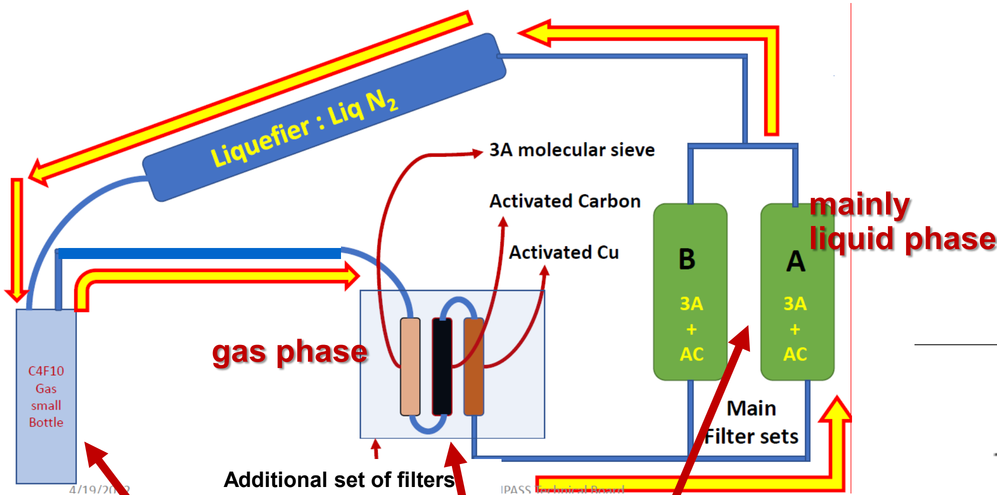


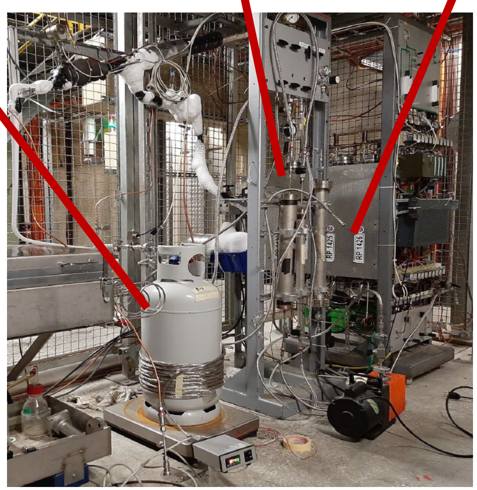
RADIATOR TRASPARENCY

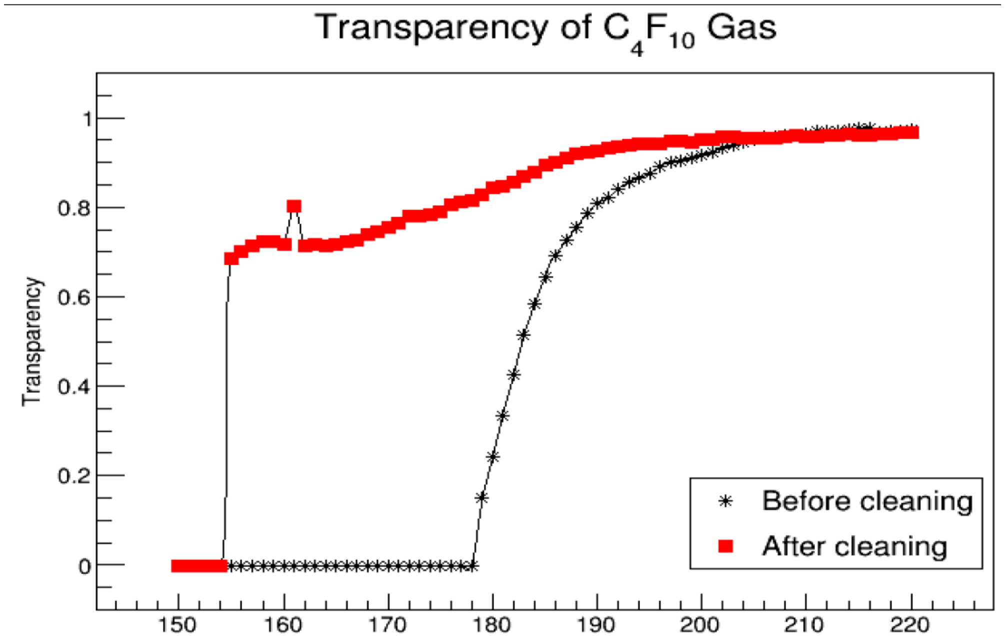
Remove the impurities / gas "cleaning"

Cleaning system revised and modified → Gas losses: ~ 30 % → 4% only !

NEW







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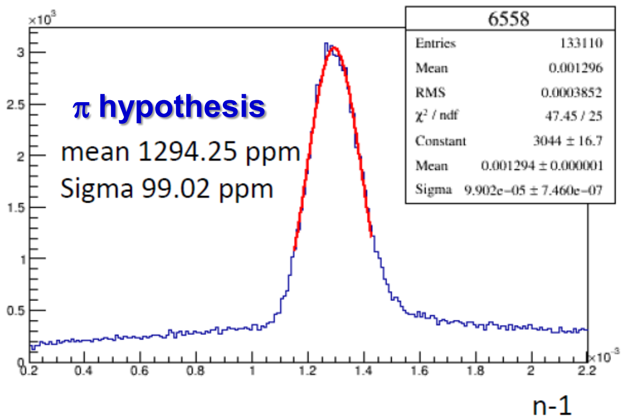
REFRACTIVE INDEX

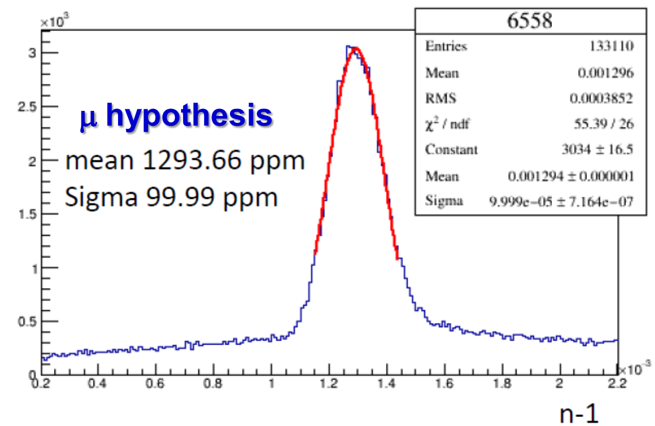
Refractive index value extracted from data (COMPASS approach)

- Use high momentum particles to take advantage of θ_{Ch} saturation
- Use measured particle trajectories and momenta

40-100 GeV/c

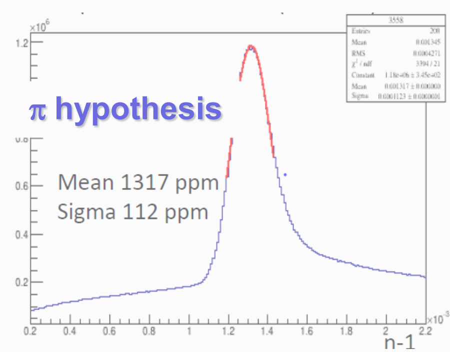
Δ(n-1) = 0.6 ppm





For comparison: < 30 GeV/c

Substantially different far from saturation region



REFRACTIVE INDEX

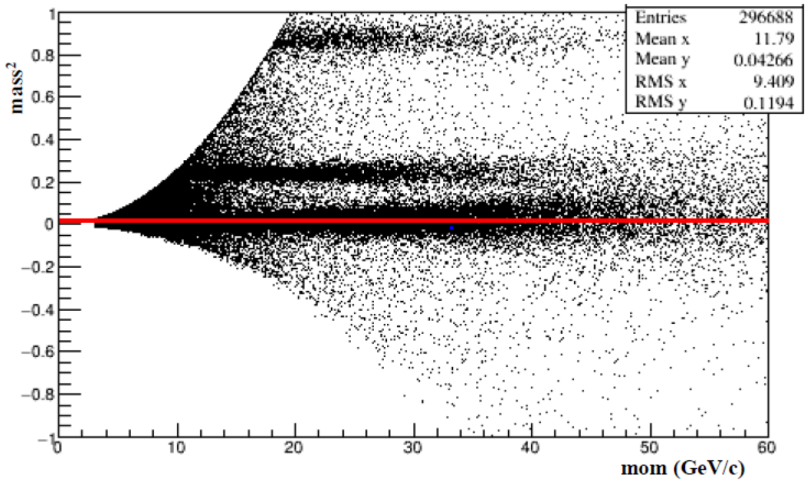
Cross-checking the refractive index value extracted from data

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

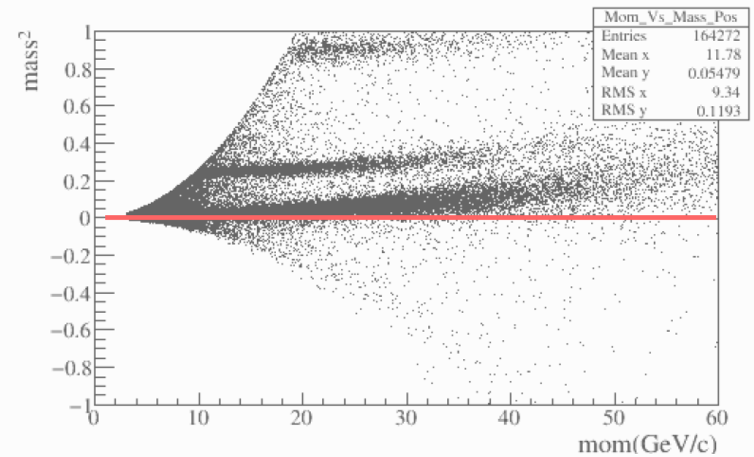
for a correctly calibrated RICH
straight bands are expected in the m^2 vs p plots
and the particle physics masses

band width:
$$\sigma_{m^2} \sim 2p^2\left(\theta\sigma_\theta\right)$$

(n-1) from 40-100 GeV/c particles



for comparison: (n-1) < 30 GeV/c particles



PDG:	*COMPASS spectrometer & RICH:*		
π mass: 0.13957 GeV/c^2	π mass: 0.138 GeV/c^2	= PDG value – ~2 MeV/c^2	
K mass: 0.49368 GeV/c^2	K mass: 0.490 GeV/c^2	= PDG value – ~4 MeV/c^2	~/< 1% discrepancy
p mass: 0.93827 GeV/c^2	p mass: 0.932 GeV/c^2	= PDG value – ~6 MeV/c^2	

The evolution of the refractive index

The refractive index –value depends on:

- Gas mixture (impurities, residual nitrogen)
- Temperature
- Pressure

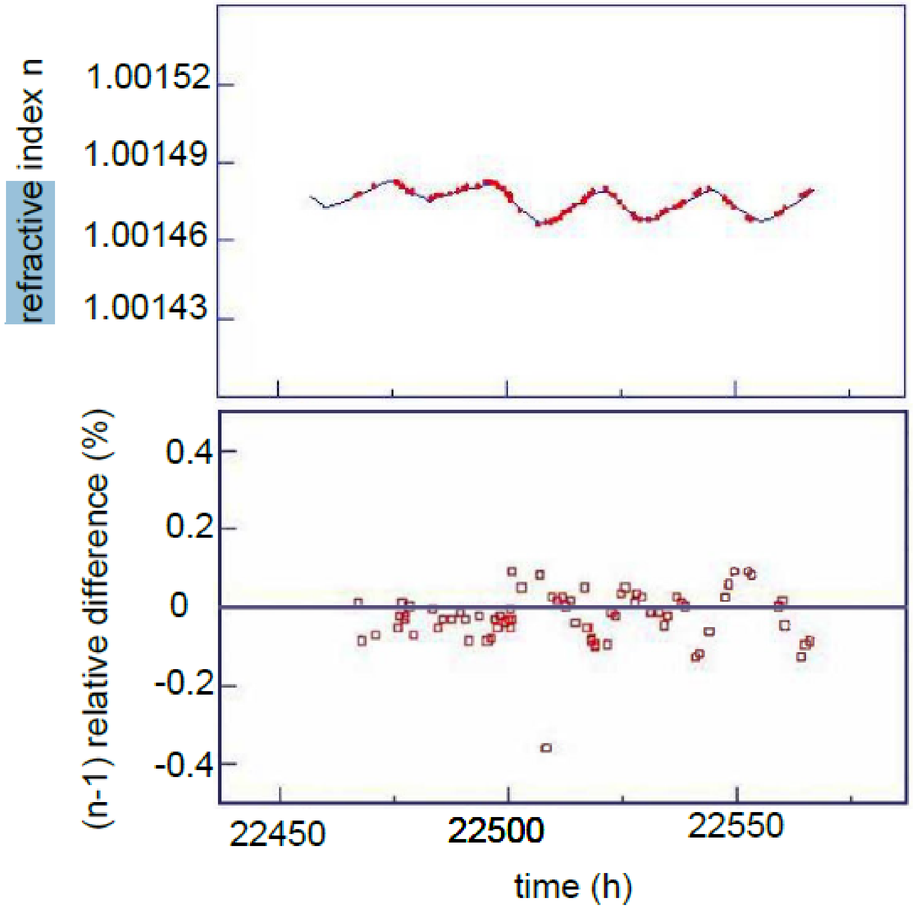
P, T variations dictate the short-term evolution causing oscillations of **(n-1) at the 2 % level**

In order to **avoid double data reconstruction**

- once to extract n
- a second one to process the data with the correct n-value cannot be afforded

evolve (n-1) according to P, T variation:

- **< 1 ‰ resolution, namely < 1 ppm**



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RICHes & FLUOROCARBONS

Fluorocarbons are used in RICHes:

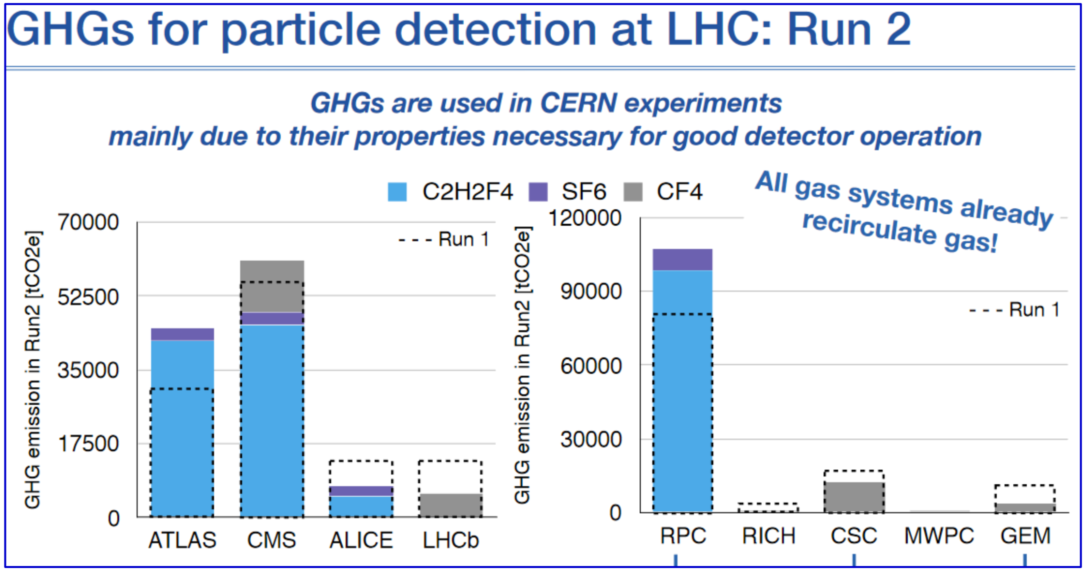
- Limited chromaticity
- High Cherenkov photon yield
- Both these parameters depend on the refractive index and its evolution with the wavelength (λ)

These gasses are not eco-friendly

- They attack O_3
- They have high Global Warming Potential (GWP) values (100 y)
  - C_4F_{10}: ~4800
  - CF_4 : ~6500
  - CO_2 : 1 (for comparison)
- These gasses are more and more banned

→

- Social impact of our community?
- Procurement ? Costs? Usage limitations ?



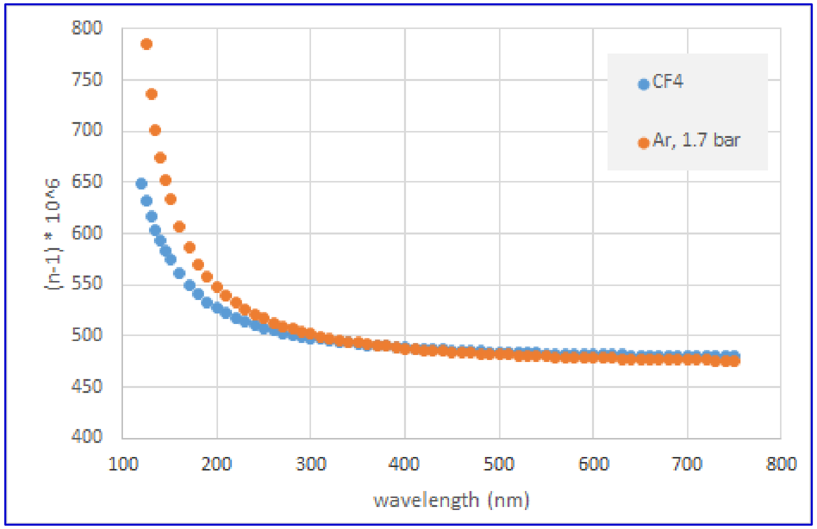
B. Mandelli,
ECFA Detector R&D Roadmap Symposium of Task Force 1, 29 April 2021

RICHes & FLUOROCARBONS

RICH 2022

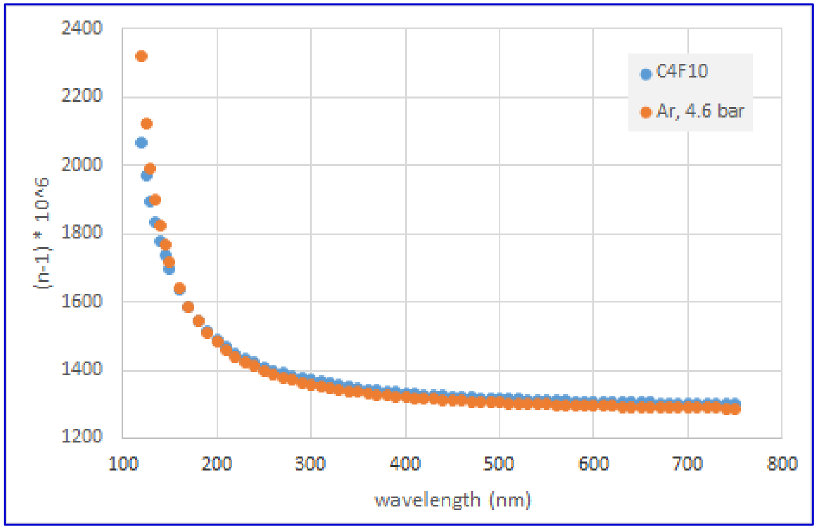
Fluorocarbons are used in RICHes:

- **Limited chromaticity**
- **High Cherenkov photon yield**
- **Both these parameters depend on the refractive index and its evolution with the wavelength (λ)**



Pressurized Ar

- It can reproduce the fluorocarbon refractive index very accurately, in particular in the visible range
- Studies for a **pressurized forward RICH at EIC** are ongoing



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CONCLUSIONS

- Important experiences about gaseous radiators for Cherenkov imaging applications gained with COMPASS RICH-1
  - About commercial fluorocarbon purification
  - About the measurement and monitoring of the refractive index
- Pressurized Ar proposed as radiator gas at the EIC
  - Fluorocarbon performance w/o fluorocarbon issues !

THANK YOU