Eco-friendly gas mixtures for gaseous detectors at CERN and beyond

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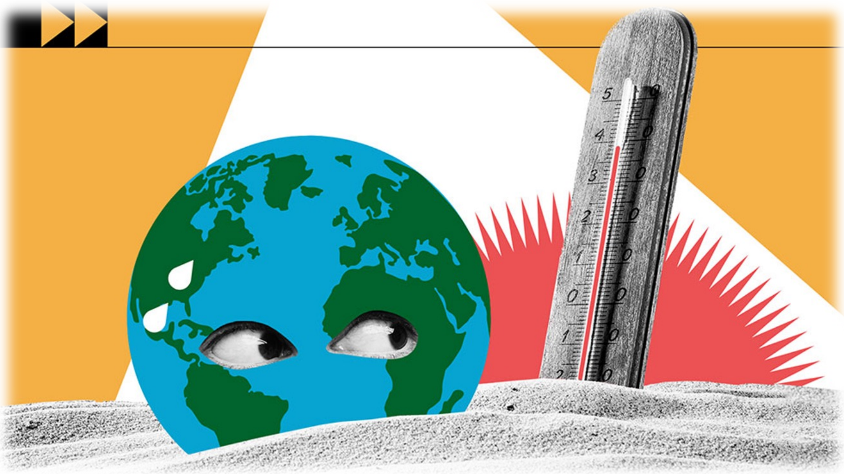
Introduction

- Climate change a growing concern
- Greenhouse Gas (GHG) emissions one of the major problems

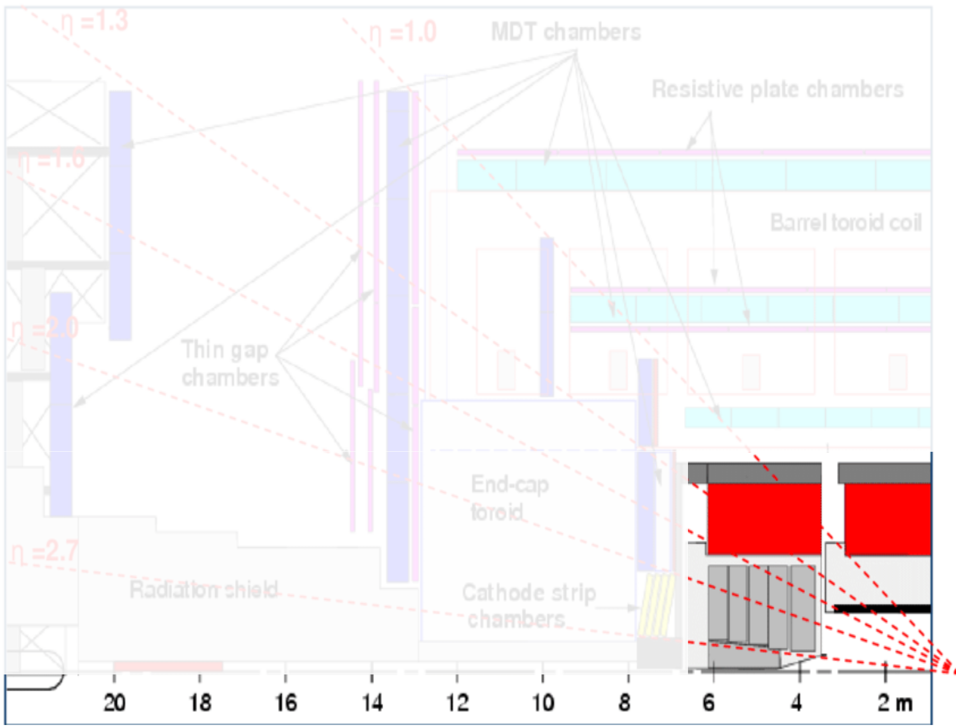


- The recent UN Climate Change Conference (COP26, 31 Oct. – 13 Nov., 2021) in Glasgow once again stressed the importance of combatting climate change through the reduction of GHG emissions

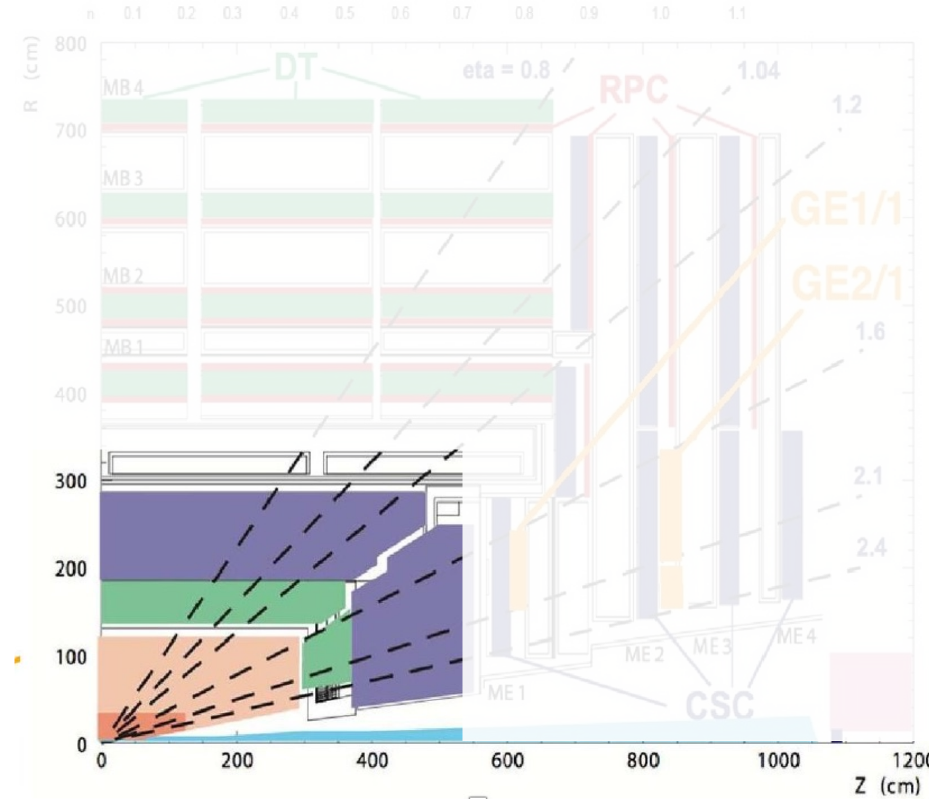
- HEP community committed to reducing its GHG emissions share

- The focus of this talk
  - > Provide an overview of the GHG emission problem
  - > Share ongoing activities and planned mitigation measures being undertaken by HEP community

Use of GHGs in HEP: Gaseous detectors in ATLAS and CMS



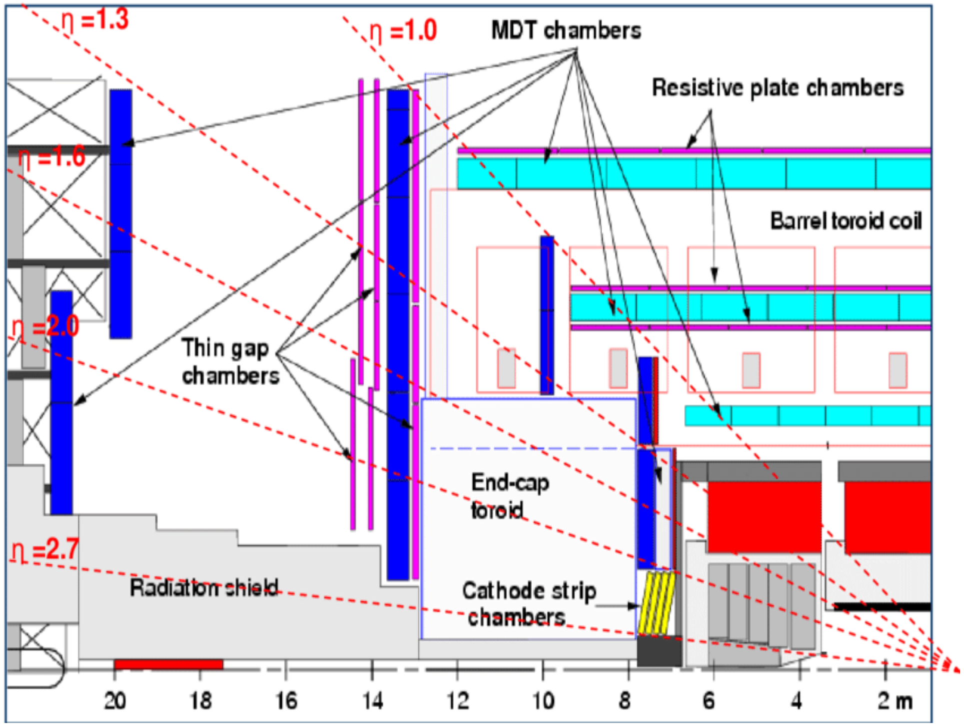
ATLAS



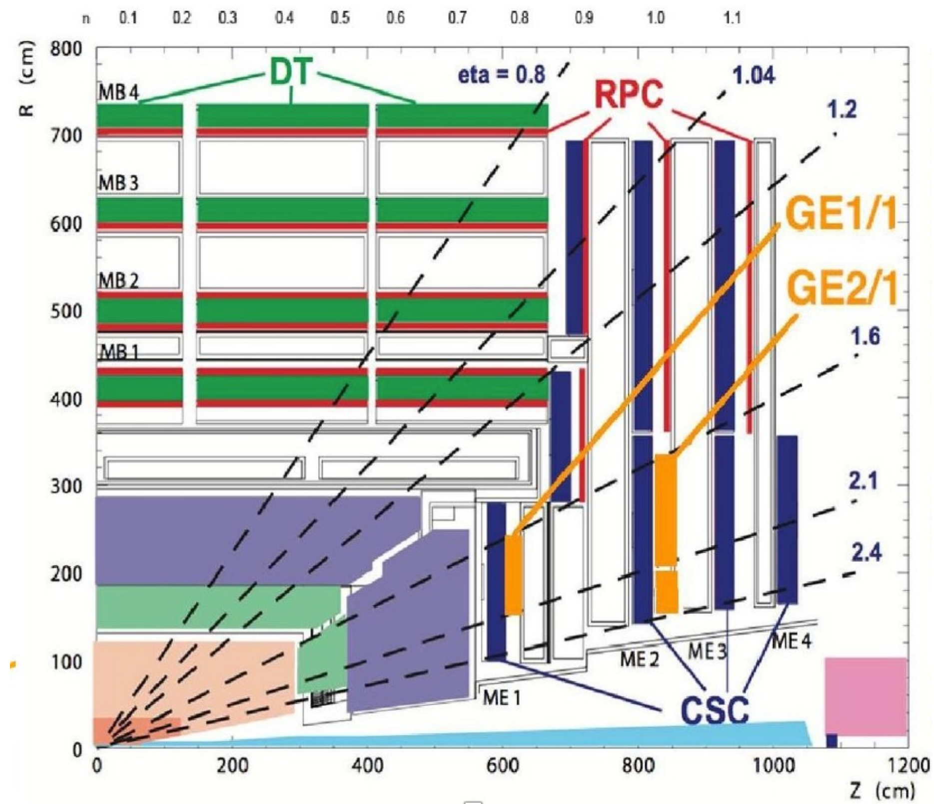
CMS

A schematic side-view of the ATLAS and CMS Muon Spectrometer systems, showing the different chamber technologies. A cross-section through a quarter of the detector in the z-y plane is shown

Use of GHGs in HEP: Gaseous detectors in ATLAS and CMS



ATLAS



CMS

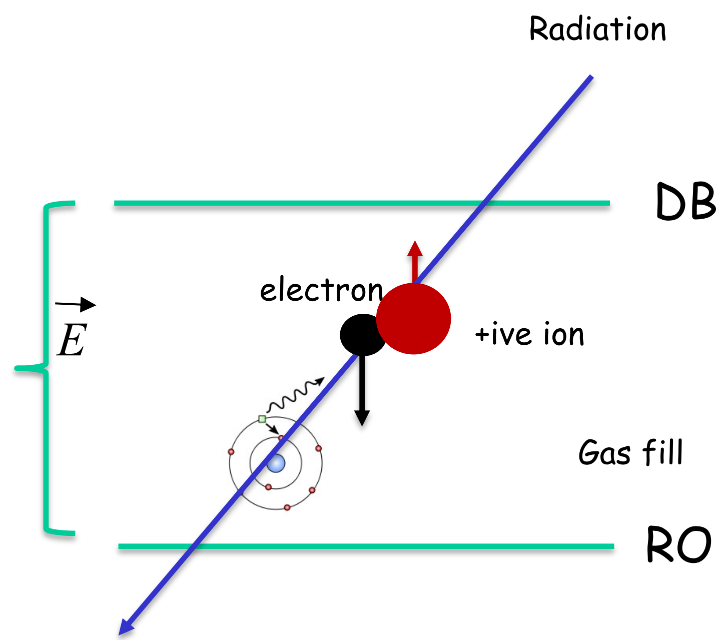
A schematic side-view of the ATLAS and CMS Muon Spectrometer systems, showing the different chamber technologies. A cross-section through a quarter of the detector in the z-y plane is shown

Operation: Use of different gases!

- Virtually any gas including air but Argon is chosen to increase the ionization density, inertness, cost factors and being readily available

- Addition of Quench gas such as methane, CO_2, etc. to suppress the photon-induced effects

- Basic properties of a fill gas can be changed significantly by small concentrations of a second gas, leading to better proportionality, improved fluctuations and energy resolution, etc.



- High-efficiency applications for the detection of gamma-ray photons by absorption within the gas, the heavier inert gases (krypton or xenon) are sometimes substituted

- In applications where the signal is used for coincidence or fast timing purposes, gases with high electron drift velocities (CF_4) are preferred

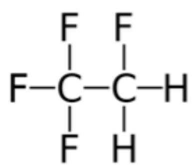
- **Experiments use gas mixtures mainly due to their properties necessary for optimal detector performance and long term operation**

Gas for particle detection at LHC experiments

- Argon/R134a serve as the main medium for interaction of minimum ionizing particles
- Isobutane is used to prevent the formation of secondary streamers by quenching the photons produced by de-excitation of molecules in the gas mixture R134a while SF_6 limits the avalanche size and development of streamers in transverse direction
- **Problem**: These systems are of the "once through" type, in which the exit gas is **vented to the atmosphere** (the gas can be recycled (very costly) also)

GWP is 1 for CO_2

GWP 1430

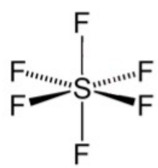


$C_2H_2F_4$

Containment of charge
Rate capability

Resistive Plate Chamber (RPC)

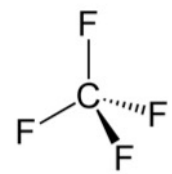
GWP 22800



SF_6

Electronegative: limiting charge development

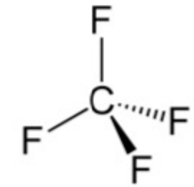
GWP 7390



CF_4

Time resolution
Gas Electron Multiplier (GEM)

GWP 8860



C_4F_{10}

Cherenkov radiator
Ring-imaging Cherenkov detector (RICH)

Mitigation of aging phenomena
Cathode Strip Chamber (CSC)
Multi Wire Proportional Chamber (MWPC)

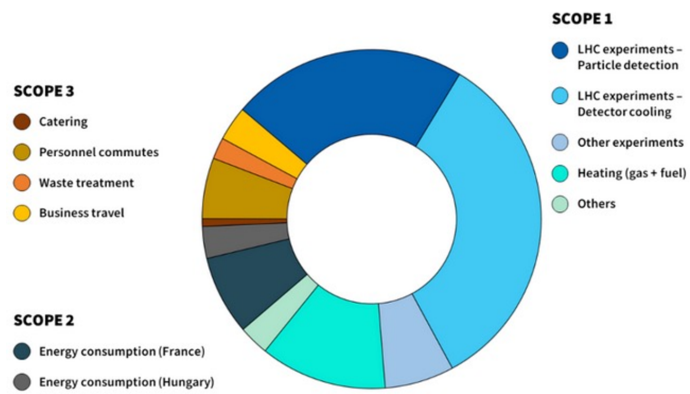
**GWP is the heat absorbed by any greenhouse gas in the atmosphere, as a multiple of the heat that would be absorbed by the same mass of carbon dioxide (CO_2), and GWP is 1 for CO_2*

Taken from the slides presented by Beatrice Mandelli elsewhere

GHG emissions at CERN: how much?

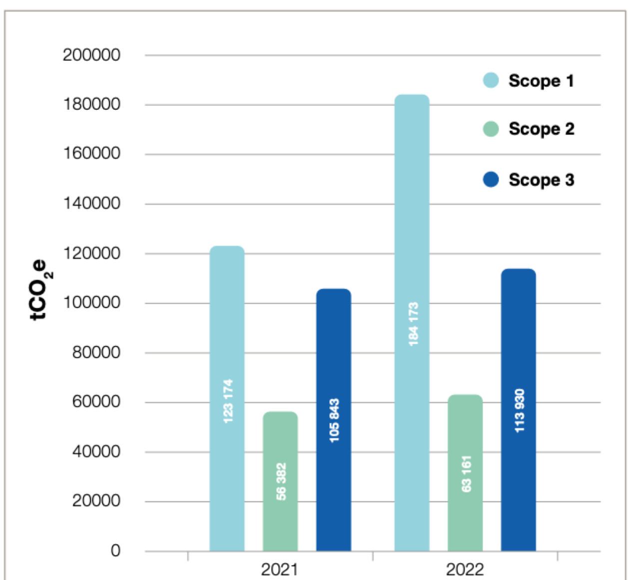
Greenhouse gas emissions at CERN arise from the operation of the Laboratory's research facilities. The majority of emissions come from CERN's core experiments and more than 78% are fluorinated gases

- **Scope 1** refers to the direct emissions resulting from an organisation's facilities and vehicles
- **Scope 2** refers to indirect emissions related to the generation of electricity, steam, heating or cooling purchased
- for an organisation's own use
- **Scope 3** refers to all other indirect emissions occurring upstream and downstream of an organisation's activities, such as business travel, personnel commutes, catering and procurement

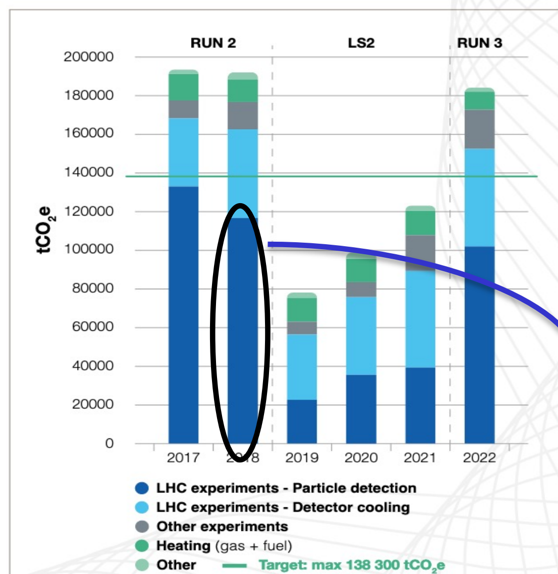


- ~90% of emissions related to large LHC experiments
- Most emissions from particle detection

GROUP	GASES	tCO_2e 2021	tCO_2e 2022
Perfluorocarbons (PFCs)	CF_4, C_2F_6, C_3F_8, C_4F_{10}, C_6F_{14}	55 921	68 989
Hydrochlorofluorocarbons (HFCs)	HFC-23 (CHF_3) HFC-32 (CH_2F_2) HFC-134a ($C_2H_2F_4$) HFC-404a HFC-407c HFC-410a HFC-507	36 557	86 211
Other F-gases	SF_6, NF_3	16 838	18 355
Hydrofluoroolefins (HFO)/HFCs	R-449 R1234ze NOVEC 649	86	199
	CO_2	13 771	10 419
Total Scope 1		123 174	184 173

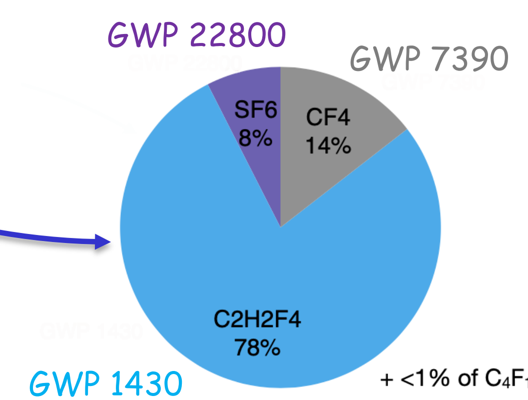


CERN'S TOTAL SCOPE 1, 2 AND 3 EMISSIONS 2021–2022



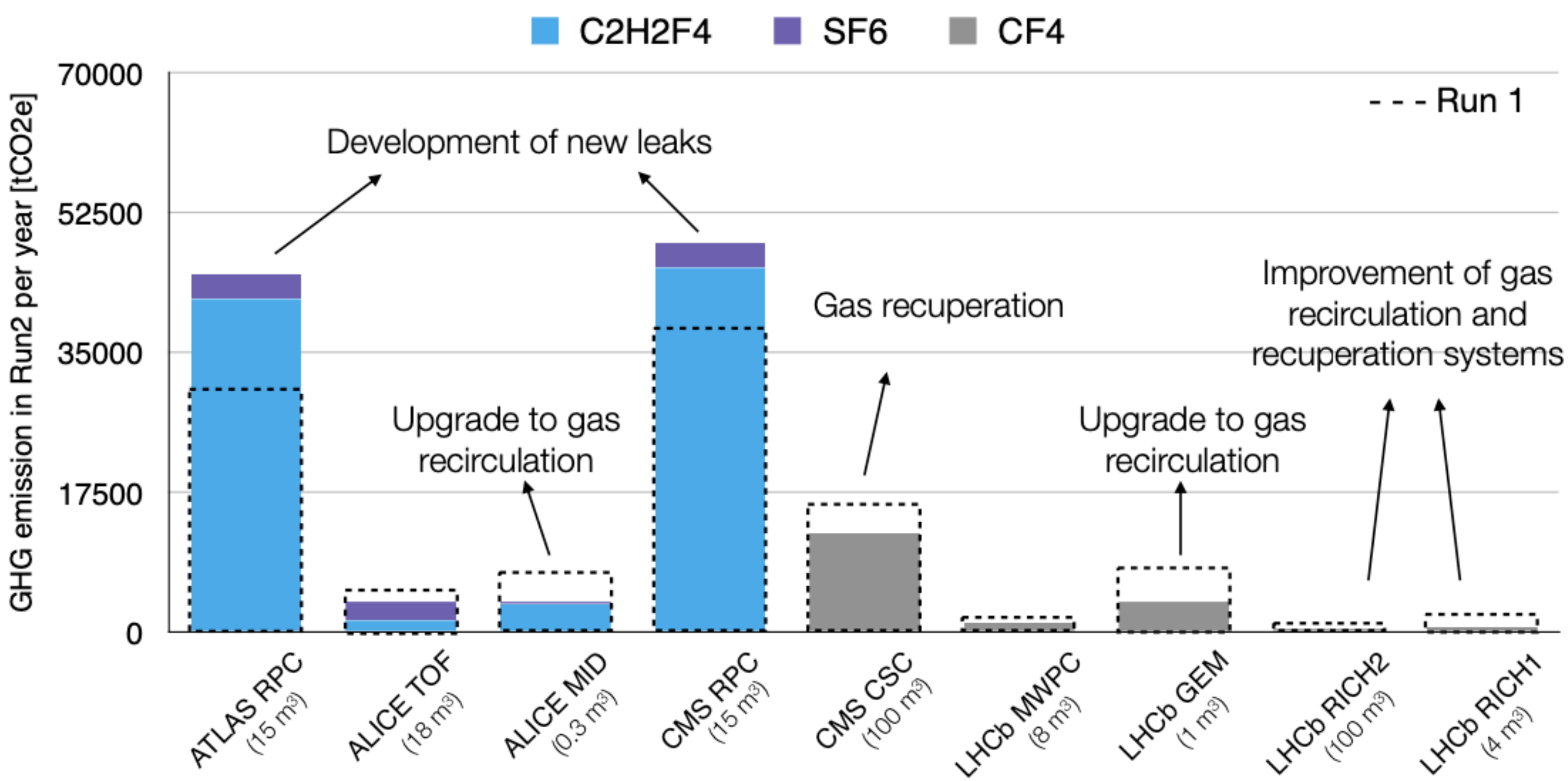
CERN SCOPE 1 EMISSIONS FOR 2017–2022 BY CATEGORY
"Other" includes air conditioning, electrical insulation, emergency generators and the fuel consumption of the CERN vehicle fleet.

The tCO_2e values calculated based on the real consumption of the different gases, weighted by their GWP



[CERN Environment Report 2021-2022]

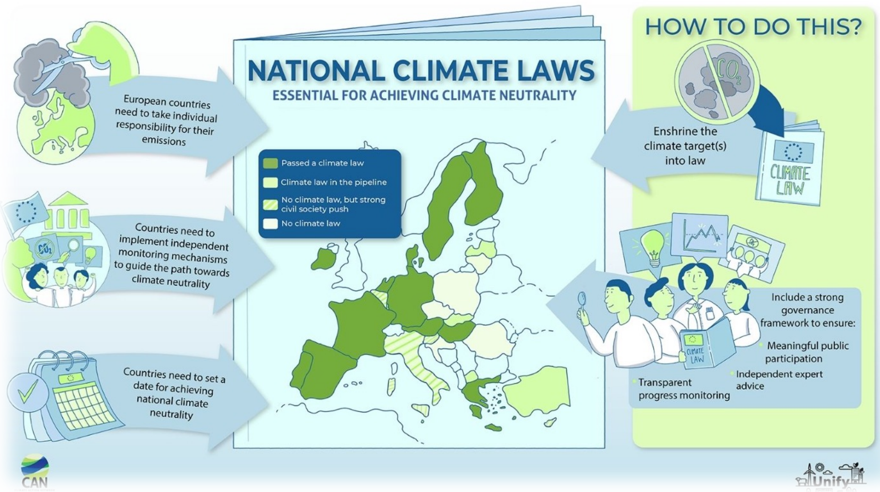
GHGs for particle detection at LHC: Run 1 Vs Run 2



- -40% GHG emissions from Run 1 to Run 2 excluding ATLAS and CMS RPC systems
- ATLAS and CMS RPC systems: +35% increase of GHG emissions due to development of new leaks
- All other detector systems: decrease of GHG emissions from -20% to -80% from Run 1 to Run 2
- Thanks to the different gas system upgrades

European Regulations

- Since 2015 onwards, the European Union defined a set of regulations* aiming at reducing the GHG emissions from **fluorinated gases** with the main points summarized as:
    - Restrict the placing on the market by reducing products availability of fluorinated GHGs
    - Ban the use of GHGs where eco-friendly alternatives are already available
    - Require regular and certified check controls on leaks for existing equipment
    - Require a recovery of the gases at the end of the equipment life



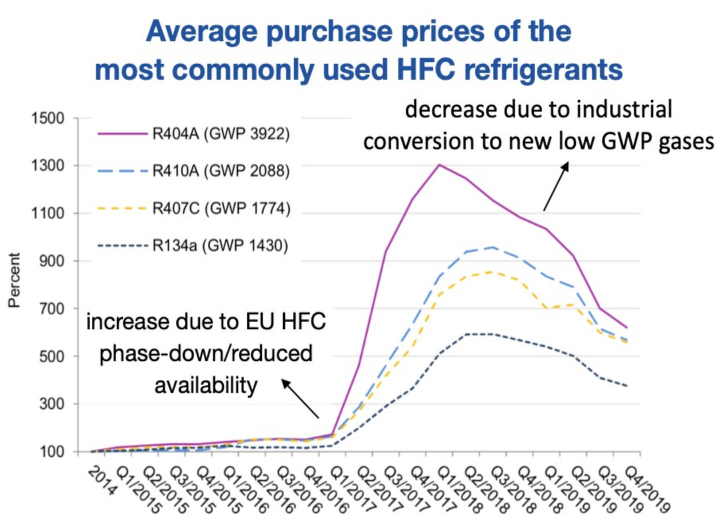
*Official Journal of the EU (L 150/95), vol. 57, 20 May 2014, ISSN 1977-0677.

The EU HFC Phase down policy

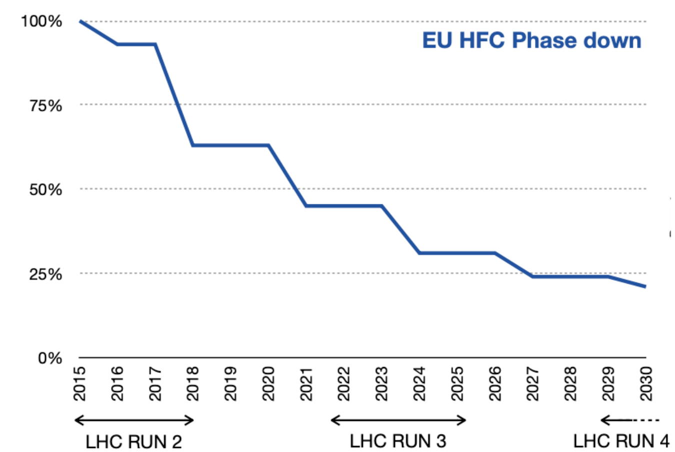
European Union "F-gas regulation"

- **Limiting the total amount** of the most important F-gases that can be sold in the EU from 2015 onwards and phasing them down in steps to one-fifth of 2014 sales in 2030
- **Banning the use** of F-gases in many new types of equipment where less harmful alternatives are widely available
- **Preventing emissions** of F-gases from existing equipment by requiring checks, proper servicing and recovery of the gases at the end of the equipment's life

Prices are increasing in EU and availability in the future is not known



Reduction of the use of F-gases is fundamental for future particle detector applications



- The search for new environmentally friendly gas mixtures is necessary to reduce GHG emissions and costs as well as to optimize detector/s performance

European Environment Agency, Fluorinated greenhouse gases 2019 report, Oko Recherche report, March 2020 J. Kleinschmidt et al.

CERN strategies for GHG reduction

- F-gases are the main focus of the mitigation efforts
- CERN prepared an R&D strategy based on gas recuperation, optimisation of current technologies and replacement with more environmentally friendly gases
- Steps towards replacing F-gases with CO_2,which has a substantially lower GWP, in detector cooling systems
- The experiments also carrying out leak repair campaigns from time to time
- Plan to investigate environmentally friendly gas mixtures

Short term

Gas Recirculation

- Optimization of current technologies
- Particular attention to operation
- Improve control and monitoring

Gas Recuperation

- Pressure Swing
- Membrane separation
- Cryogenic/Cold separation

Long term

Alternative Gases

- $C_2H_2F_4$
- SF_6
- CF_4
- … etc.

ANUBIS and Cavendish's interest

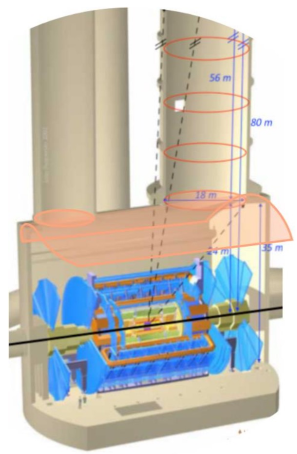
ANUBIS – AN Underground Belayed In-Shaft search experiment

- Proposal to search for LLPs at LHC CERN
  - Instrument the ceiling of the ATLAS Cavern at Point-1
  - Ceiling approximately 20 m away from the ATLAS IP
  - Include stations in the two service shafts (PX14, PX16)
  - Active volume ~ 4.3 x 10^4 m^3 and large detector area ~10^3 m^2

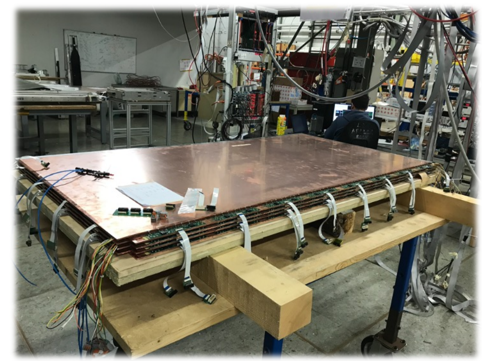
Proposal arXiv:1909.13022

Updates: https://twiki.cern.ch/twiki/bin/view/AN

Recent work: DOI: 10.22323/1.449.0051



Use of RPCs



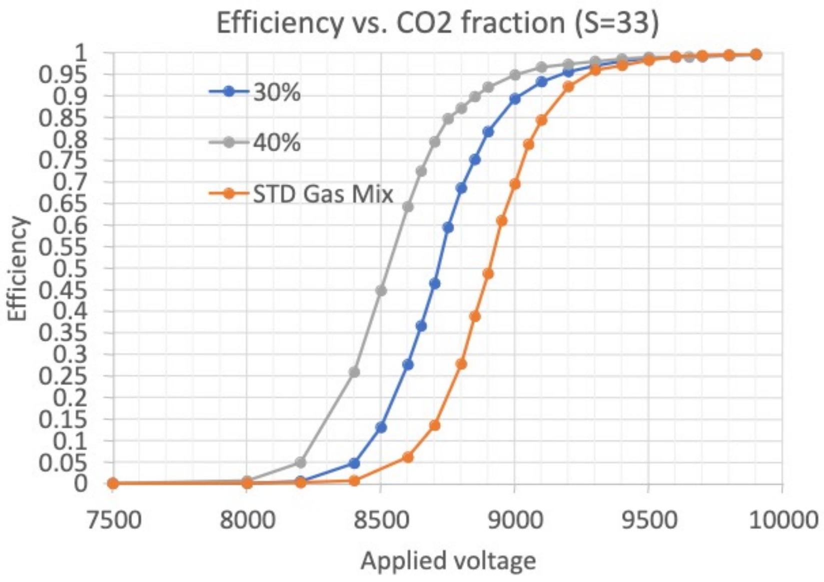
RPC's @ CERN BB5

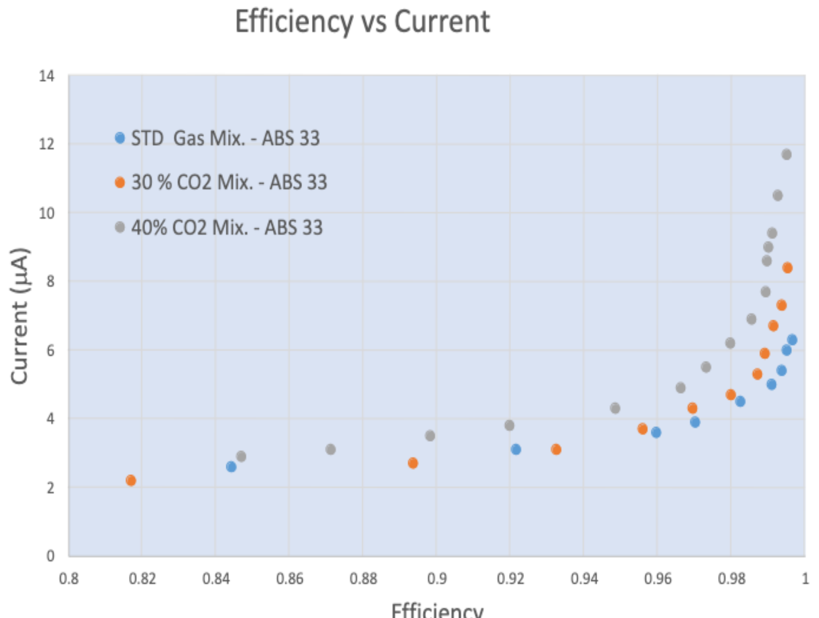
- RPC's operated with a Freon-based gas mixture
- The detectors are operated with a large fraction (between 90 and 95%) of $C_2H_2F_4$ known commercially as R-134a. In addition, 4.5% iC_4H_{10} and 0.3% of SF_6 is used to operate the RPCs in avalanche mode
- Large detector volume, so need to really step in …

Recent Involvement at CERN (ATLAS muon): short term goals

- Measured the efficiency for different mixtures, the working point anticipation of 200V for the CO_2 mixtures wrt. Standard gas mixture
- For 30% and 40% CO_2 gas mixtures, observed that the current is increasing by ~20% wrt. Standard gas mixtures

ATLAS RPC system switched to Standard + 30% CO_2 mixture in August, 2023

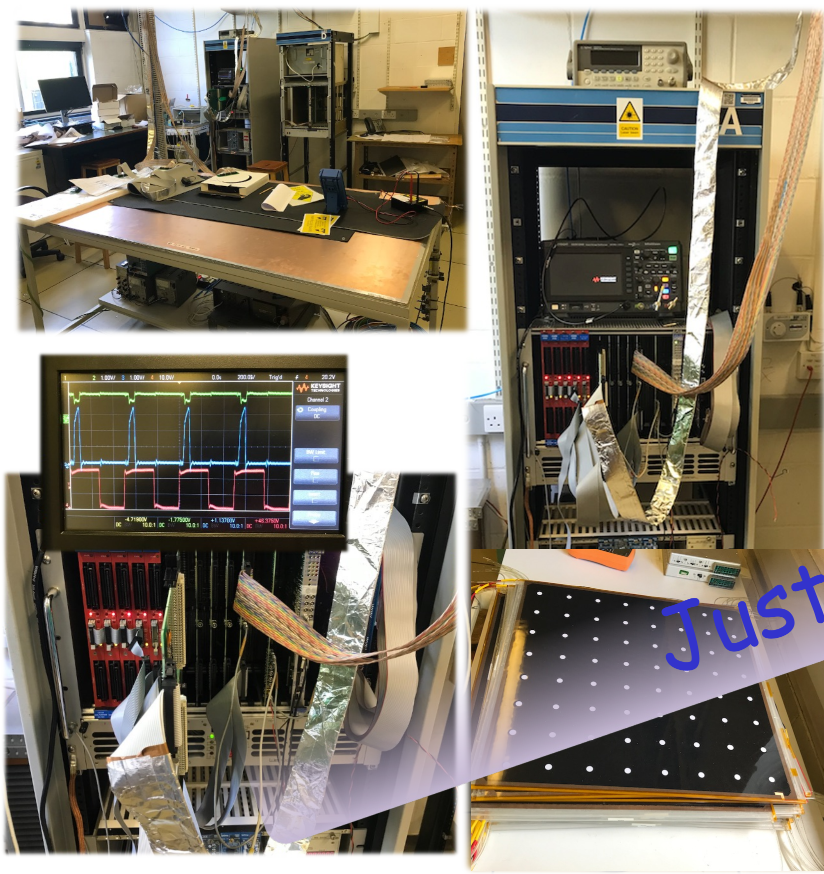




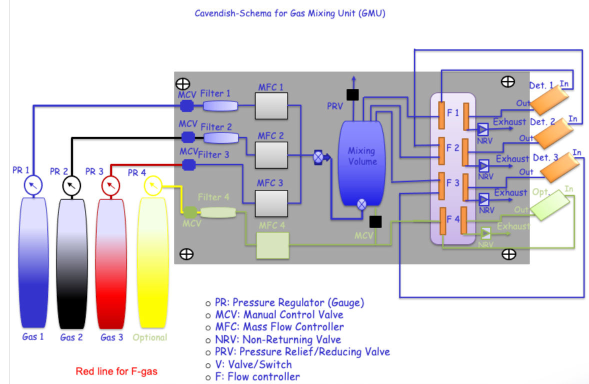
Ongoing R&D activities at Cavendish: Long term goals

Long term goals: Search for eco-friendly gas mixtures for HEP experiments in general and for ANUBIS in particular

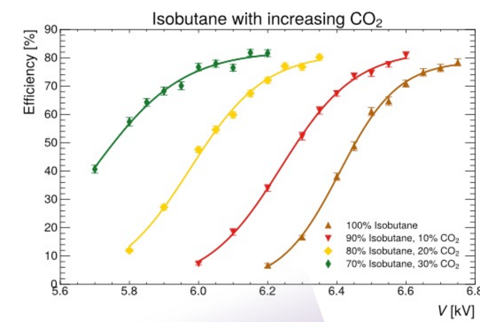
RPC detector and associated DAQ setup

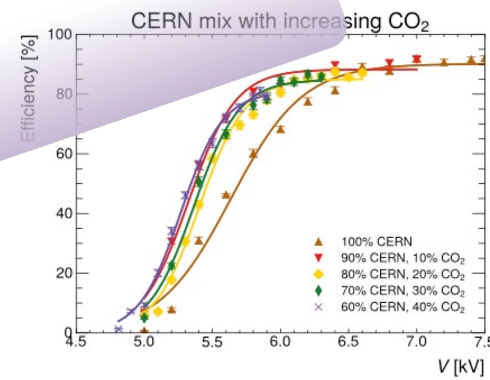


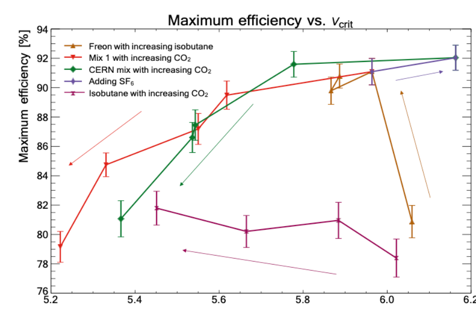
Gas mixing system



Some studies by our project students







Just a beginning…!!!!

Thank you!

Back-Up