Strategies for optimizing the usage of greenhouse gases in particle detectors

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EP-DT Detector Technologies
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Introduction

- At the **LHC** experiments, a variety of gas mixtures are used to operate different gaseous detectors.
- Some of the used gases ($C_2H_2F_4$, C_4F_{10}, CF_4, SF_6) are powerful **Greenhouse Gases (GHGs)** with a high **Global Warming Potential (GWP)**
- Greenhouse Gas (GHG) Emissions must be reduced. This is driven not only by environmental concerns but also by **economic and regulatory pressures [1,2]**

To reduce the GHG emissions, the gas team (EP-DT-FS) identified three key strategies:

1. **Optimization of current technologies**: gas consumption is reduced through gas recirculation and the operation of the gas systems is optimized
2. **Gas recuperation**: recovering the gas that cannot be recirculated. Gas recuperation plants allow specific gases to be recovered from the gas mixture for future reuse
3. **Alternative gases**: the study of detectors operated with low-GWP, alternative gases

Key strategies:

1. Gas recirculation
2. Gas recuperation
3. Alternative gases
4. (Gas disposal)
→ Not economical

Greenhouse gases for particle detection

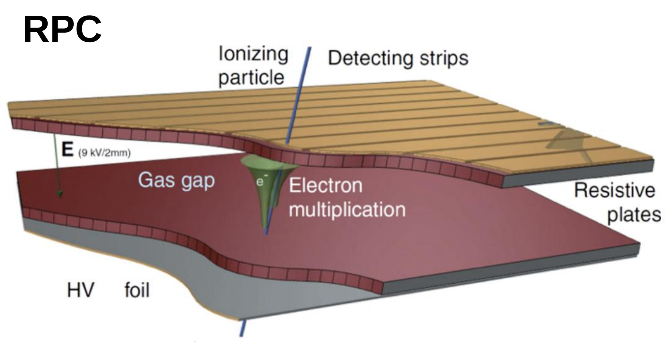
Muon systems

- Usually located in the outermost region of the detector, covering large surface areas.
- E.g. Resistive Plate Chamber (RPC) in ATLAS, CMS and ALICE
=> employed in fast space-time particle tracking required for the muon trigger
- Can also be closer to the interaction point in high-rate environments
- E.g. Resistive Plate Chamber (RPC), Cathode Strip Chamber (CSC), Multi Wire Proportional Chamber (MWPC), Gas Electron Multiplier (GEM)

Particle identification systems

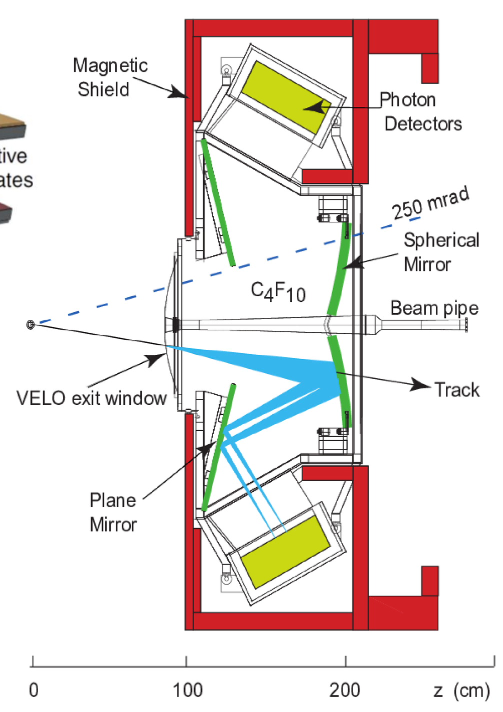
- Used to identify charged particle momenta
- E.g. Cherenkov detector (RICH)

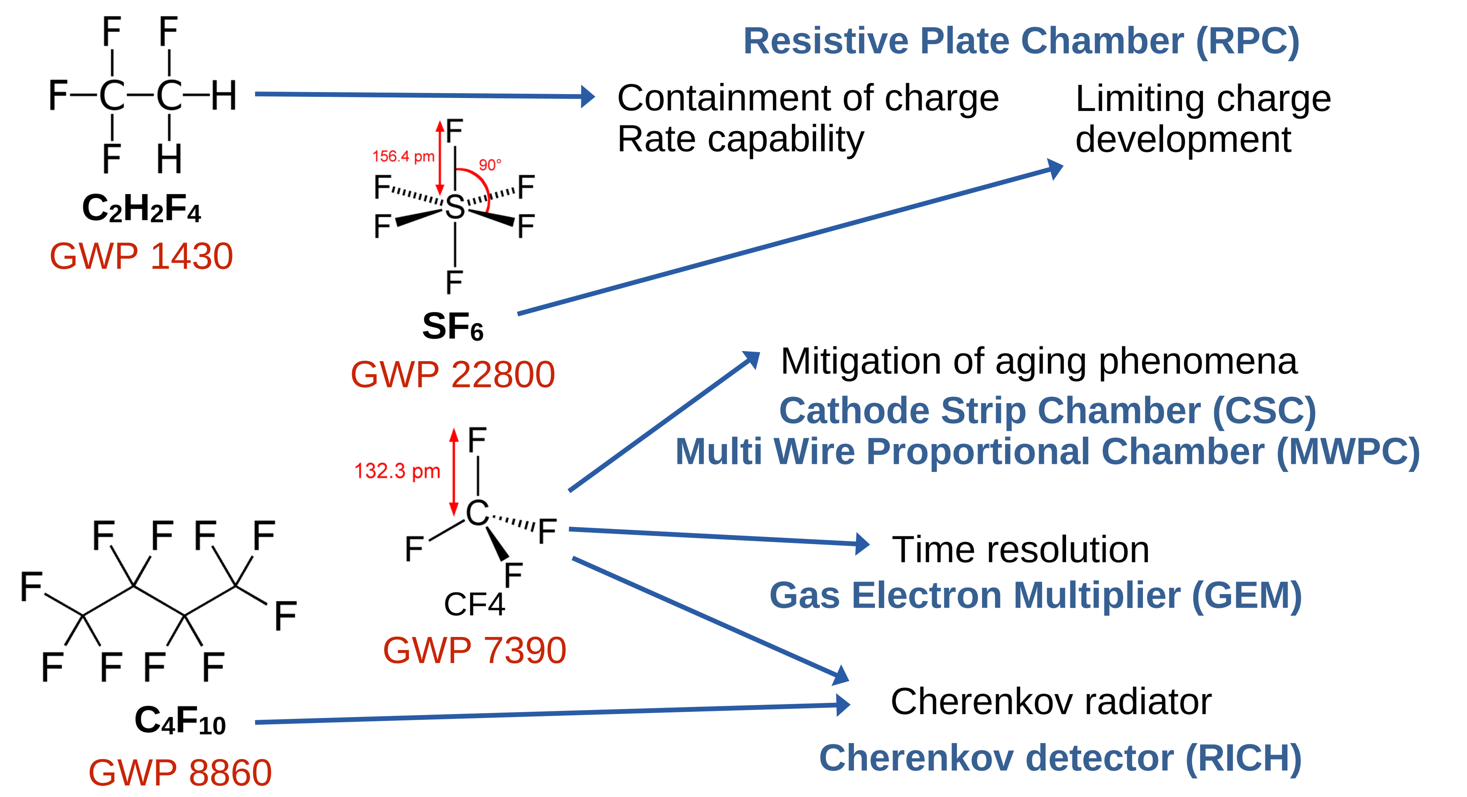
RPC



CMS CSC

LHCb RICH1





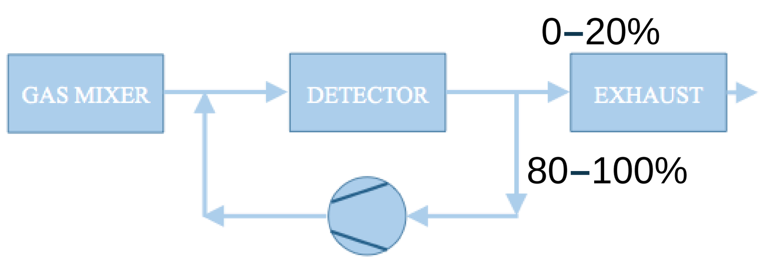
Gas recirculation

Basic gas system: open loop

Advantages:
- Easy to build and operate

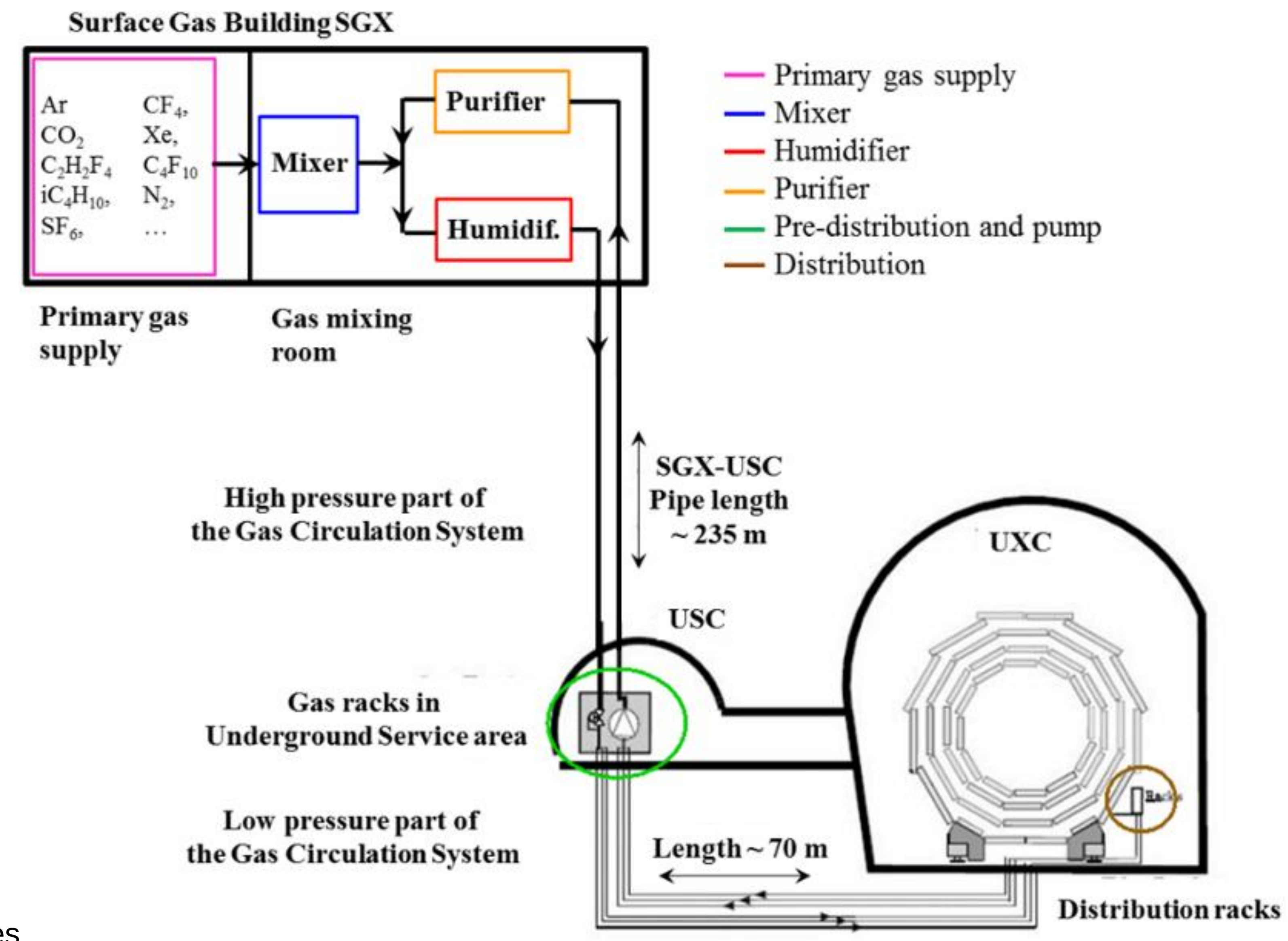
Disadvantages:
- Potential source of high gas consumption and high GHG emissions

Advanced gas systems: recirculating [3,4]



Advantages:
- Reduction of gas consumption

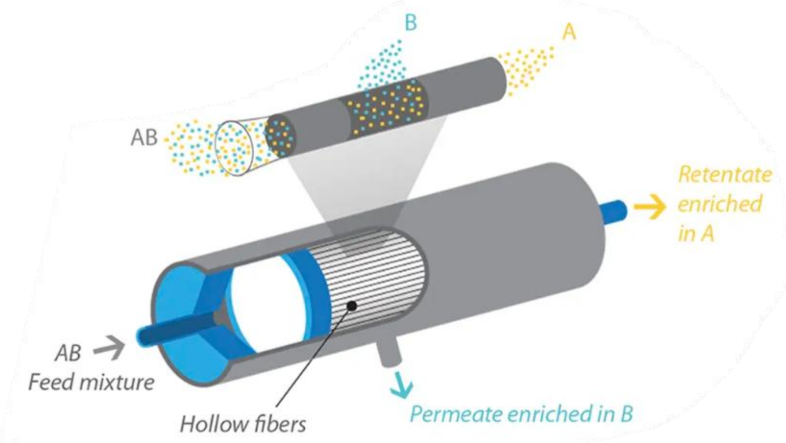
Disadvantages:
- Complex systems
- Constant monitoring (hardware and mixture composition)
- Accumulation of gas impurities
=> necessitates use of gas purifying techniques



Gas recuperation

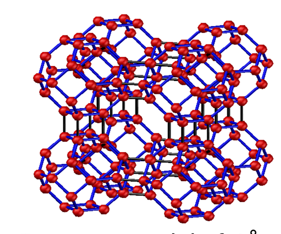
Membrane separation

- Gas separation using semi-permeable membranes to selectively allow certain gases to pass through faster than others based on **differences in molecular size/solubility**

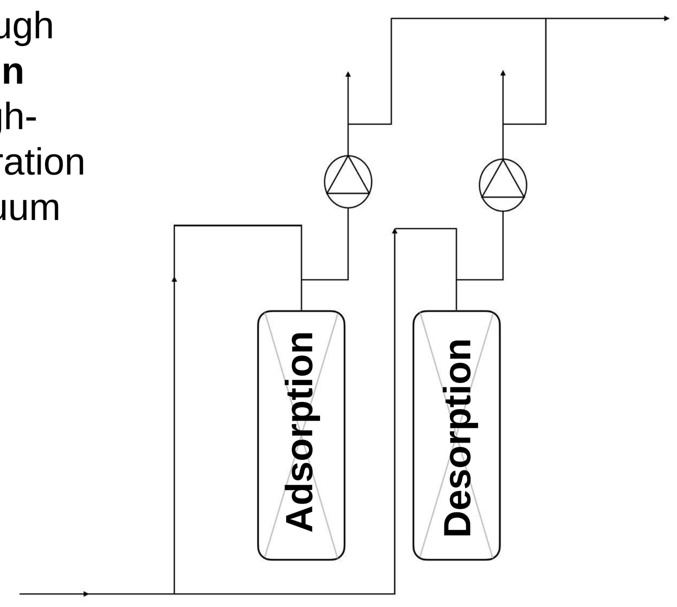


Thermal/pressure swing adsorption

- Gas separation through **selective adsorption**
- Desorption using high-temperature regeneration and/or applying vacuum pressure

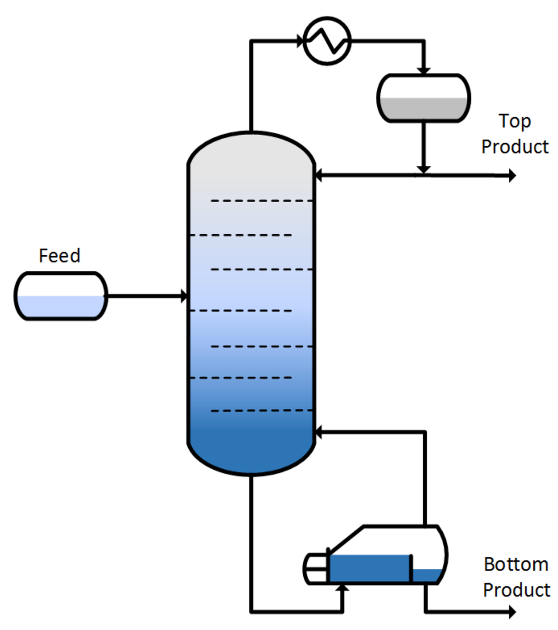


Structure model of 4Å molecular sieve



Distillation

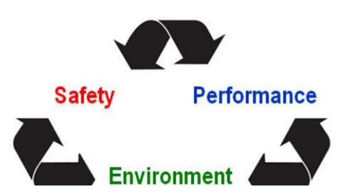
- Gas separation by exploiting difference in **boiling point**
- Simple distillation can be used when components have widely different boiling points (>25°C)
- Fractional distillation can be used to obtain components with higher purity



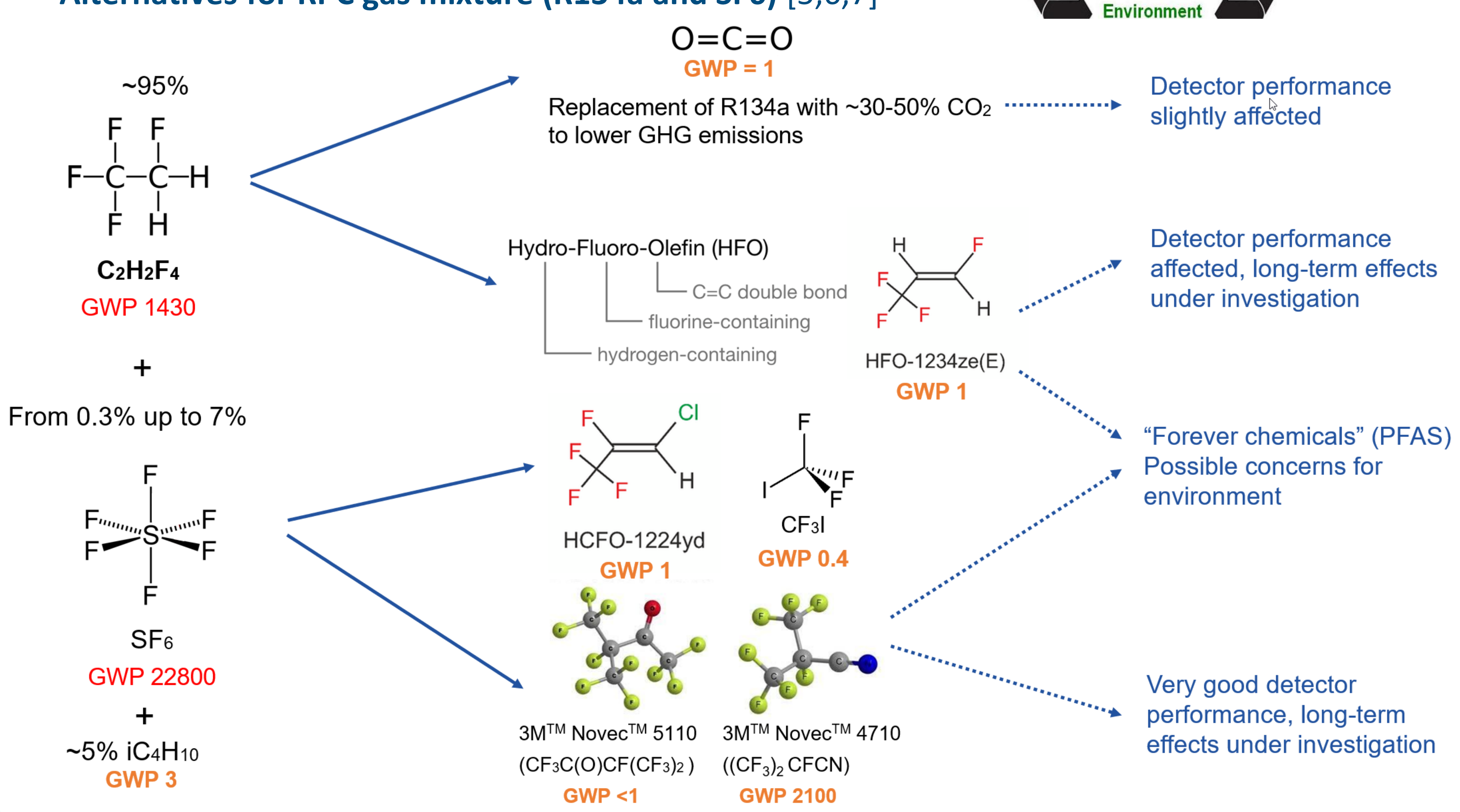
Statistics on LHC recovery systems

Gas	C2H2F4	CF4	SF6
Beginning of operation	2023	2012	~2025
Gas potentially recovered (2012 - 2025)	17200 kg	6505 kg	96 kg
Money saved (2012 - 2025)	~500 kCHF		
Money spent for construction – CAPEX	525 kCHF		
M&O, manpower	75 kCHF/year		

Alternative gases



Alternatives for RPC gas mixture (R134a and SF6) [5,6,7]



Safety

- Gas mixture must not be flammable
- Gas components should not have high toxicity levels

Performance

- Good quenching gases required for high-rate capability
- Radiation-hard gases required to minimize impurities affecting long term performances

Environment

GWP represents the main environmental concern. Low-GWP gases have short atmospheric lifetimes:
- Water solubility → Rain out
- OH- reactivity → Oxidation
- UV absorbance → Photolysis

Conclusions

Gaseous detectors used at the LHC result in significant GHG emissions. This poster outlines several strategies to utilize gaseous detectors more efficiently and sustainably for the next generation of particle detectors. Since many detectors inherently rely on gases with high global warming potential, the CERN gas team proposes three main approaches: optimizing gas systems via recirculation, recovering gases through separation technologies and developing eco-friendlier gas mixtures. There is a trade-off between environmental impact and detector performance and safety, especially for large-scale systems like RPCs, CSCs, GEMs, and RICH detectors. The overall goal is to make the next generation of particle detectors more sustainable and cost-effective without compromising on detector performance.

References

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