



EP-DT
Detector Technologies

R&D for the optimization of the use of greenhouse gases in particle detector systems

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on behalf of the CERN Gas Team

CERN

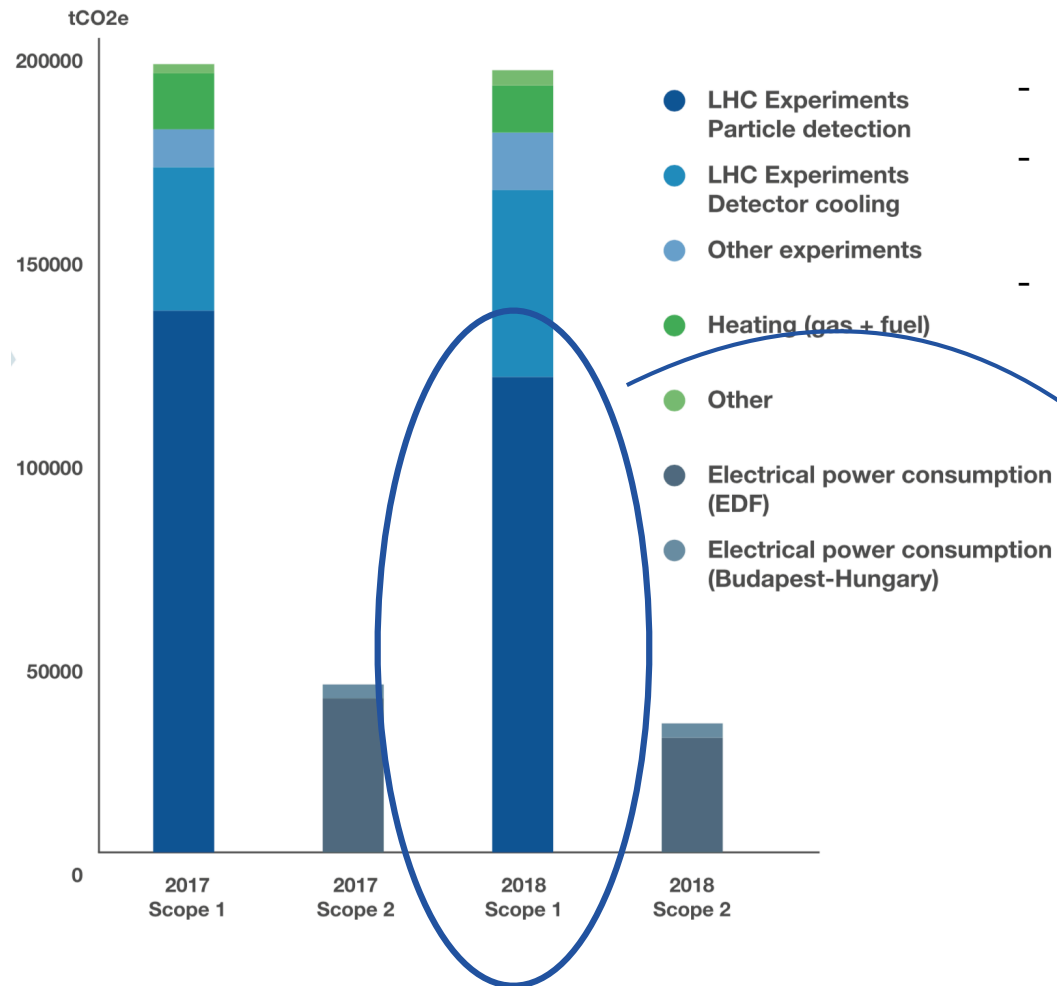
Mini-Workshop on gas transport parameters
for present and future generation of experiments

CERN, 22 April 2021

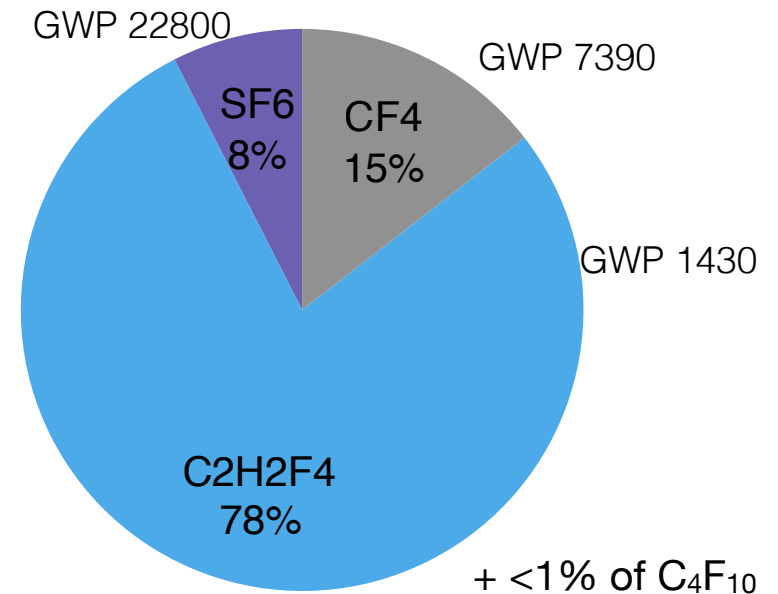
CERN commitment to reduce GHG emissions

Greenhouse gas emissions at CERN arise from the operation of the Laboratory's research facilities.

With climate change a growing concern, the Organization is committed to reducing its direct greenhouse gas emissions.



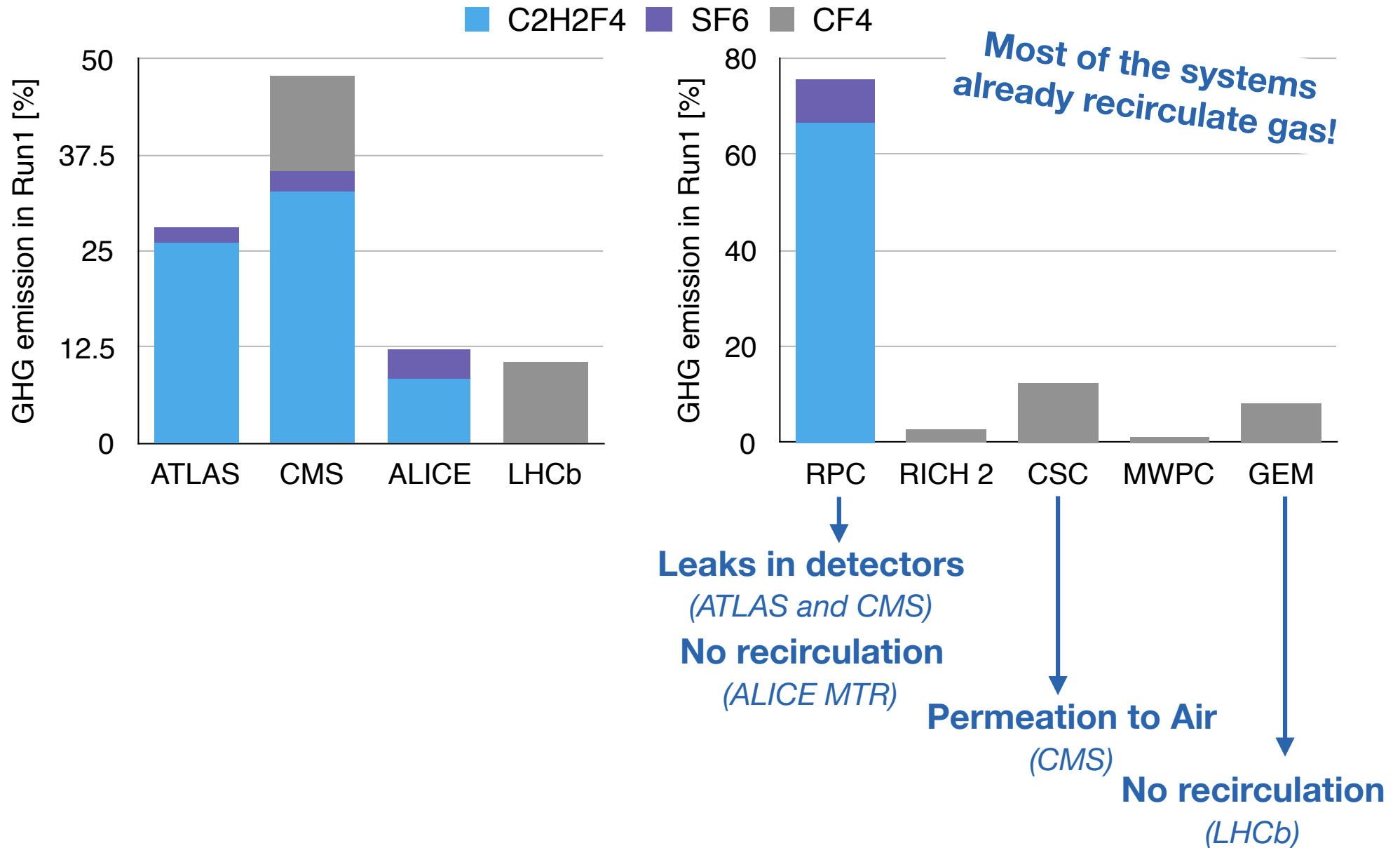
- 192.000 tCO₂e in 2018
- 92% of emissions related to large LHC experiments
- Most emissions from particle detection



https://e-publishing.cern.ch/index.php/CERN_Environment_Report/index

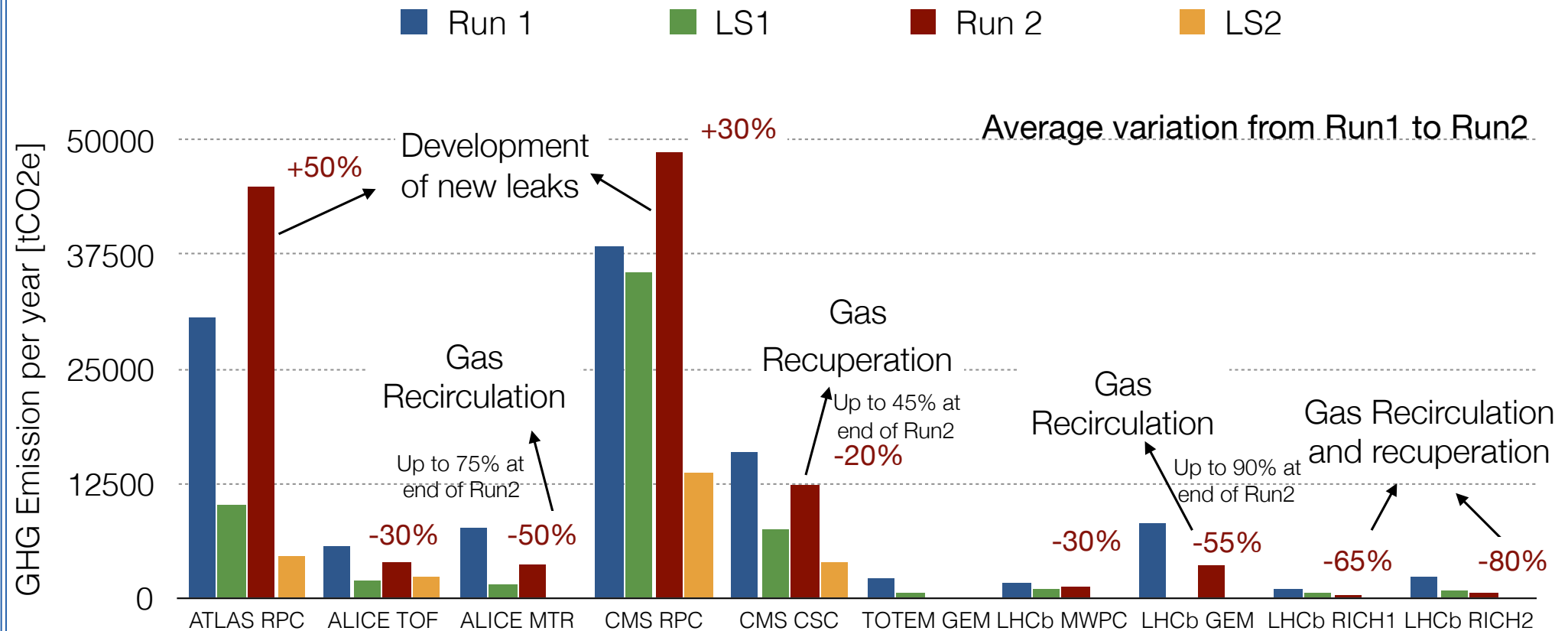
GHGs for particle detection at LHC: Run 1

From where we started...



GHGs for particle detection at LHC: Run1 vs Run2

... where we were at end of Run 2

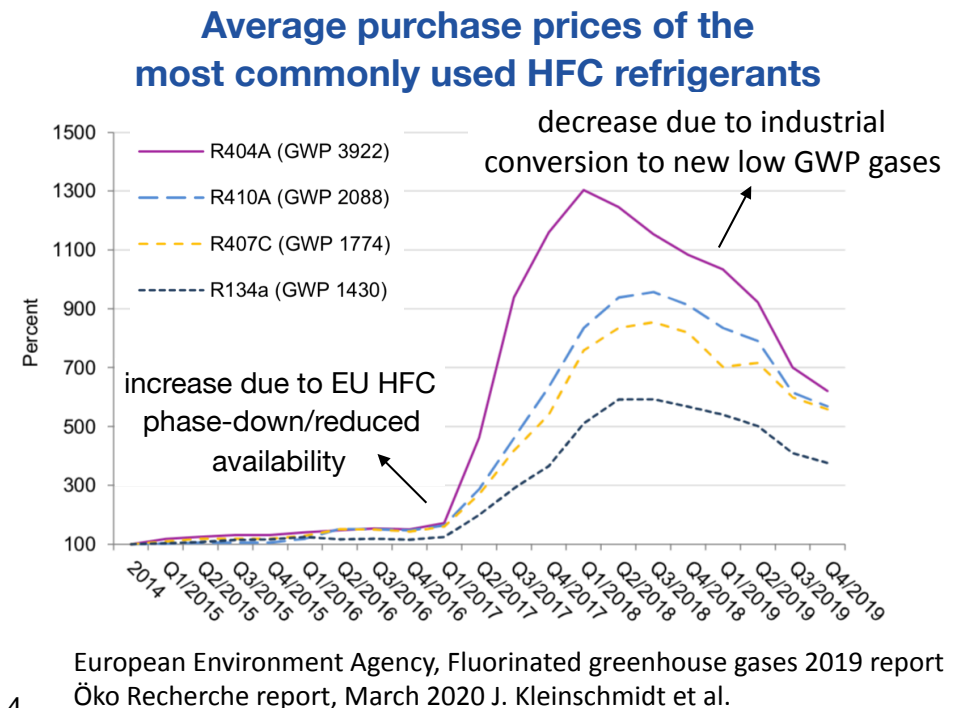
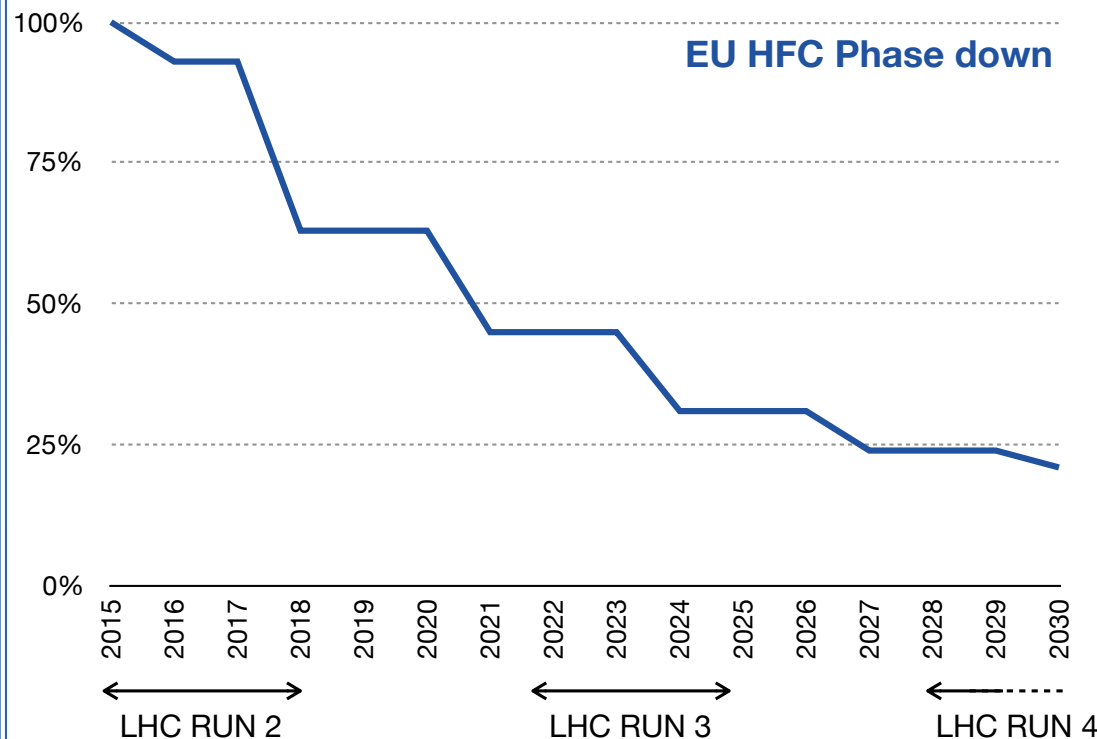


- From Run1 to Run2 only increase of emissions is ATLAS and CMS RPC due to development of new leaks at detector level
- All other detector systems had a decrease of GHG emission from -20% to 80%
- Thanks to the different gas system upgrades performed and a major attention on GHG use

EU HFC phase-down policy

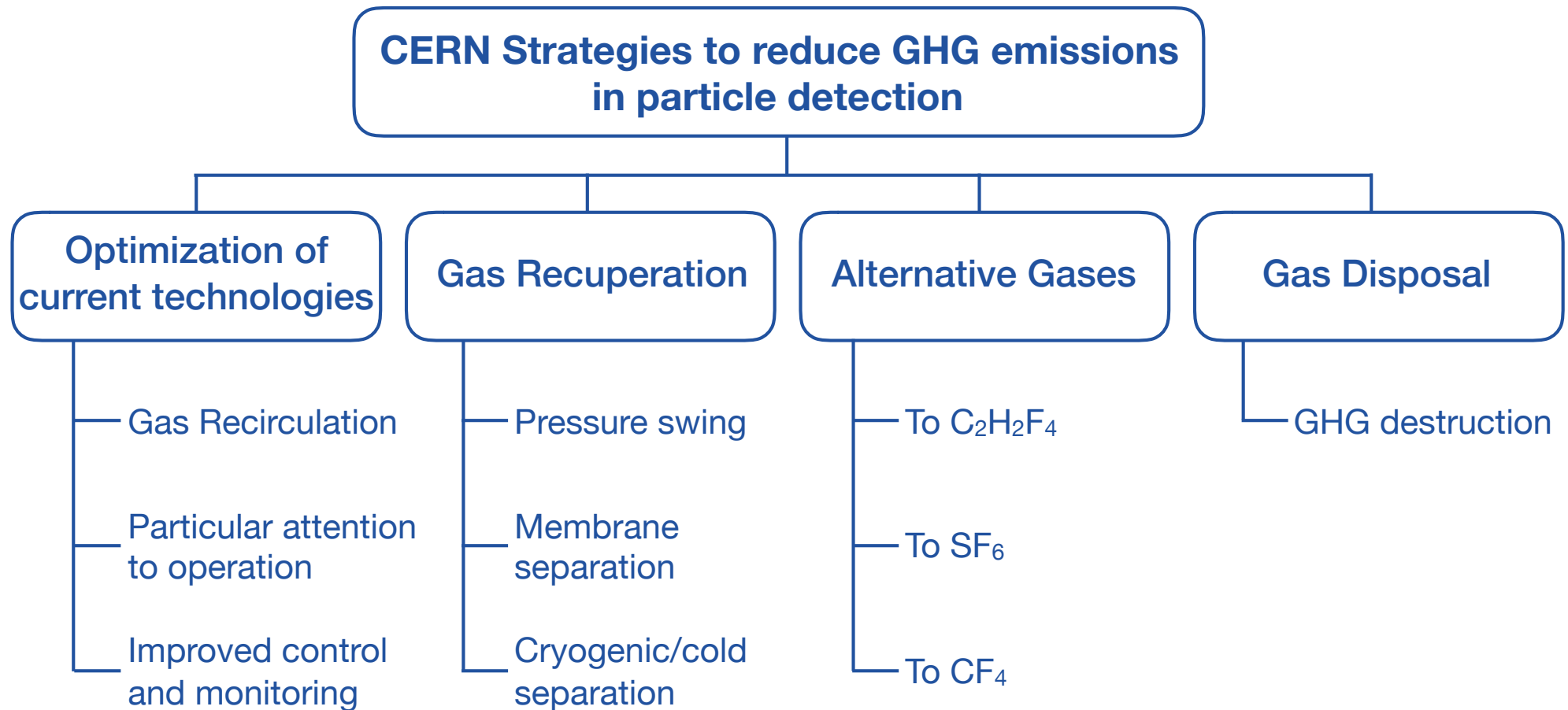
European Union “F-gas regulation”:

- **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 could increase in EU and availability in the future is not known.
Reduction of the use of F-gases is fundamental for future particle detector applications***

CERN strategies for GHG reduction



Gas Systems at the LHC experiments

*The gas systems are complex apparatus that extend over several hundred meters and have to ensure an extremely high reliability in terms of **stability** and **quality** of the gas mixture delivered to the detectors*

At LHC Experiments we have 30 gas systems for a total of ~300 modules interconnected with ~90 km of pipes and controlled/monitored with PLCs and > 1000 sensors

Reliability

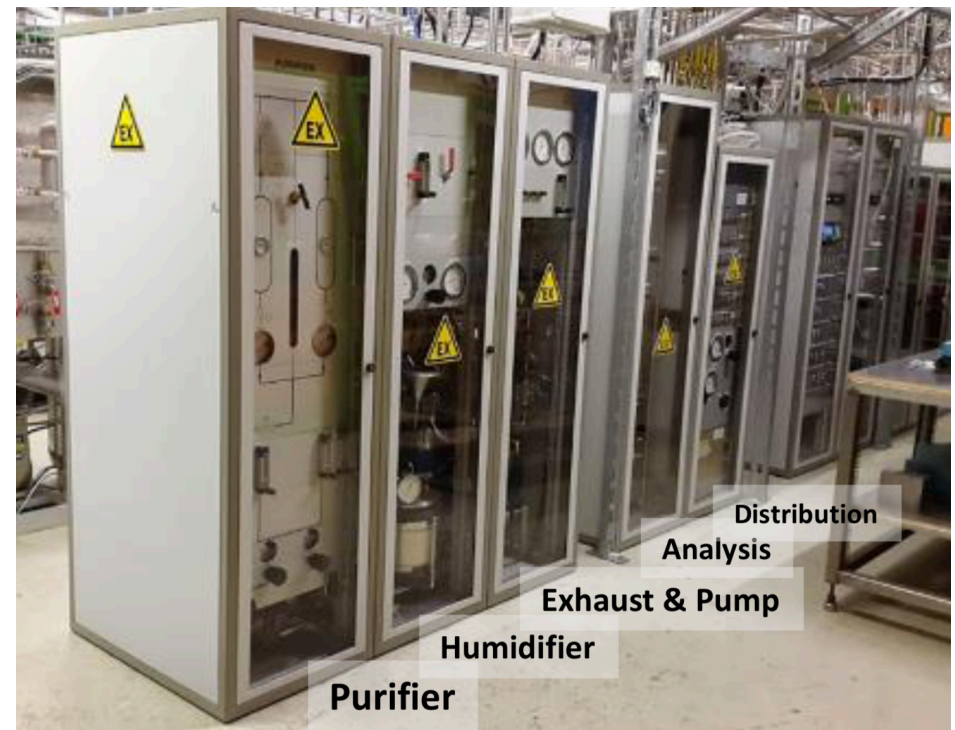
- LHC experiments are operational 24/24 7/7
- Gas systems must be available all time

Automation

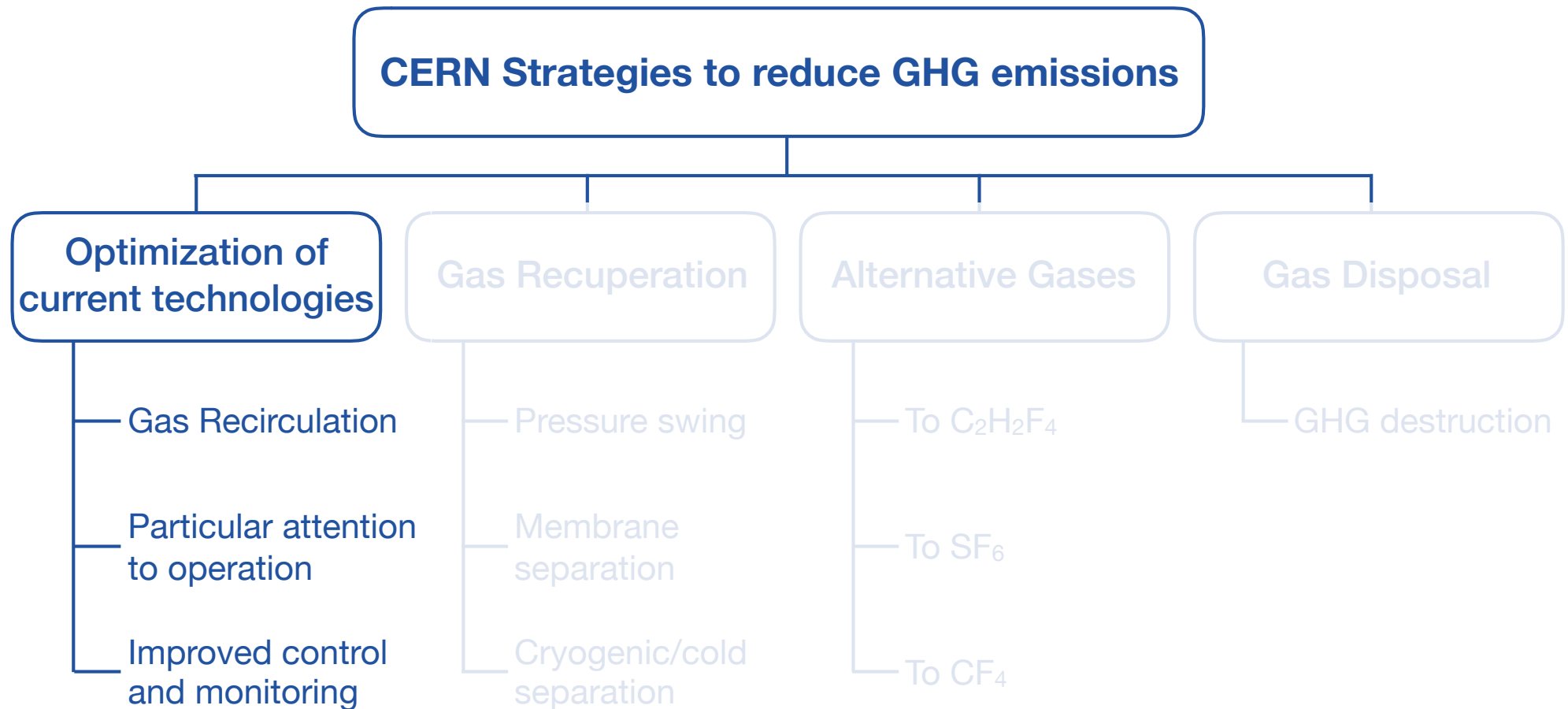
- Large and complex infrastructure
- Resources for operation
- Repeatability of conditions

Stability

- Detector performance are strictly related with stable conditions (mixture composition, pressures, flows, ...)

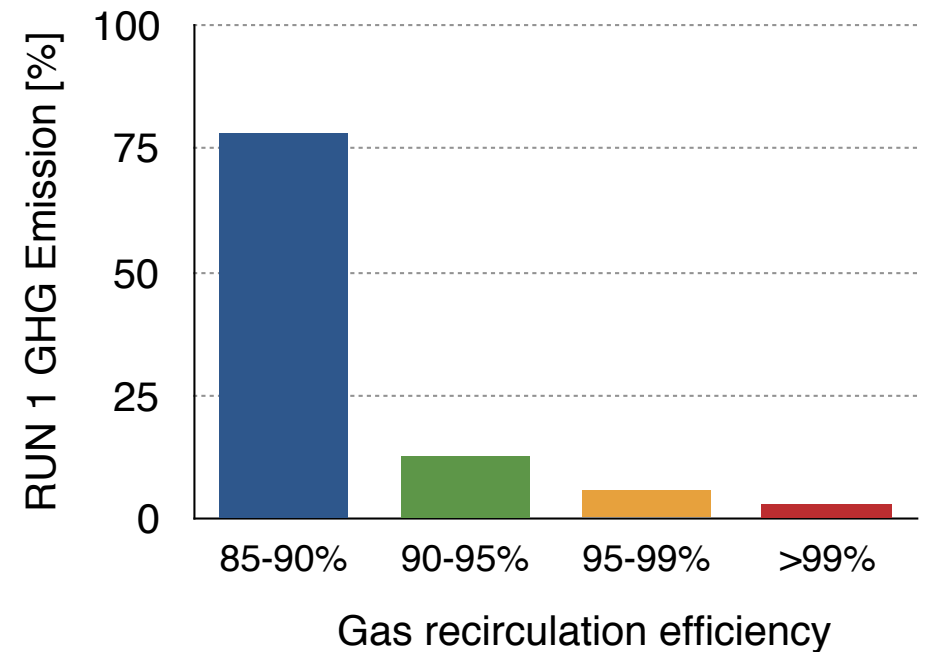
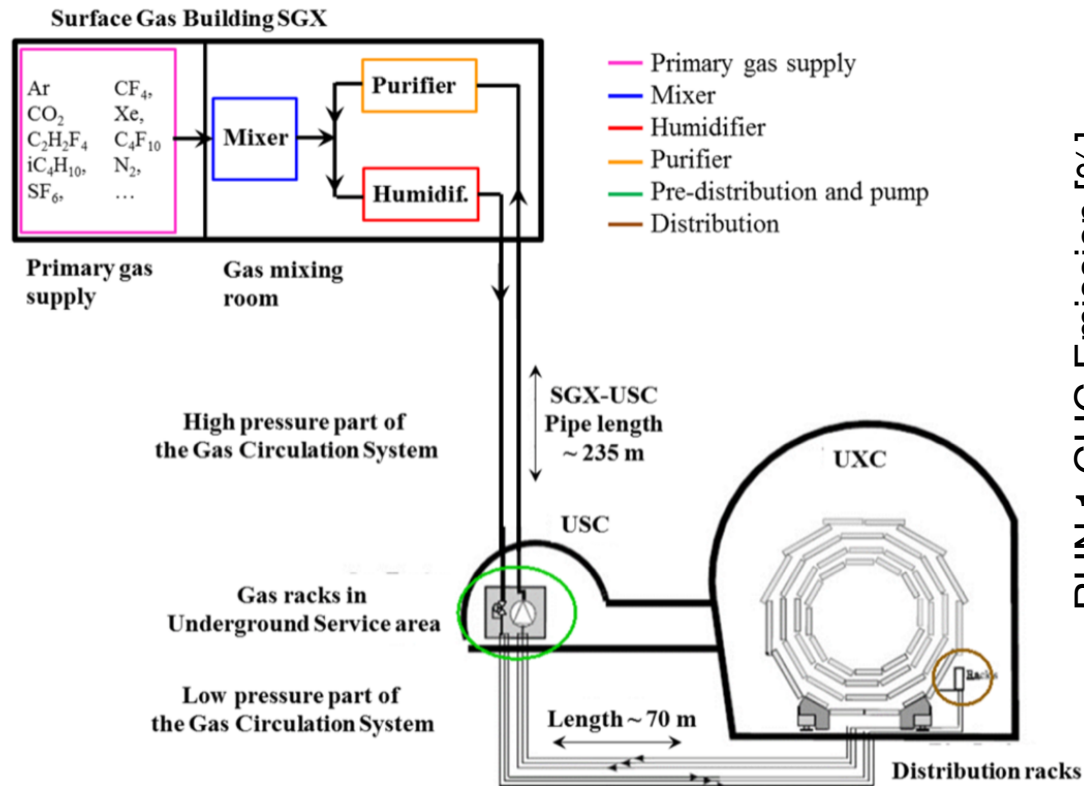


CERN strategies for GHG reduction



Gas recirculation systems

Thanks to gas recirculation GHG emission already reduced by > 90%!!!



Nevertheless...

- 85% of remaining emission still from gas recirculation systems in Run 1... why?
 - Large detector volumes, detector requirements and presence of detector leaks
- 15% of remaining emission from open mode gas systems in Run 1
 - Upgrade to gas recirculation!

Gas recirculation systems: complexity

- Gas recirculation system is more complex
 - Pressure and flow fluctuations, etc
- Creation of impurities
 - They could accumulate in the gas system
 - Their concentration depends on luminosity and recirculation fraction
 - They could affect long-term detector operation
- Compulsory use of cleaning agents
 - Needed to absorb impurities
 - Destabilisation of gas mixture composition

ALICE MTR

Gas mixture: 89.7% $\text{C}_2\text{H}_2\text{F}_4$, 10% iC_4H_{10} , 0.3% SF_6

GHG reduction from Run1 to Run2 up to **75%**

- Several studies needed to allow increase of recirculation fraction

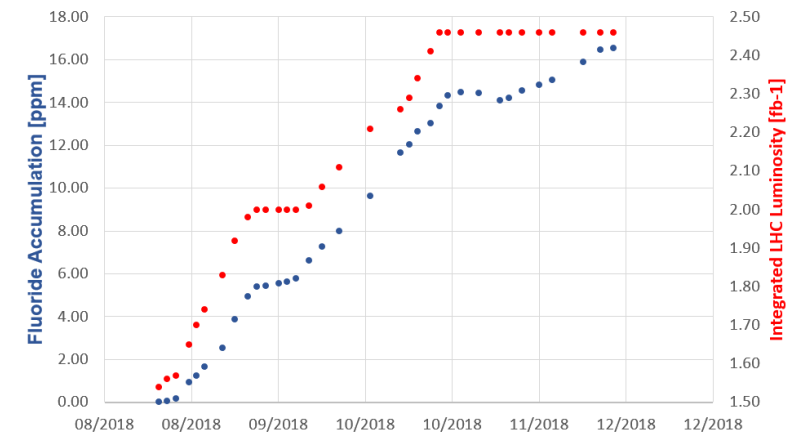
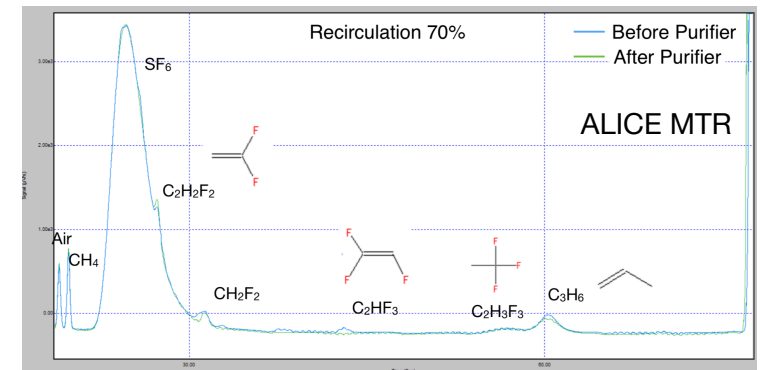
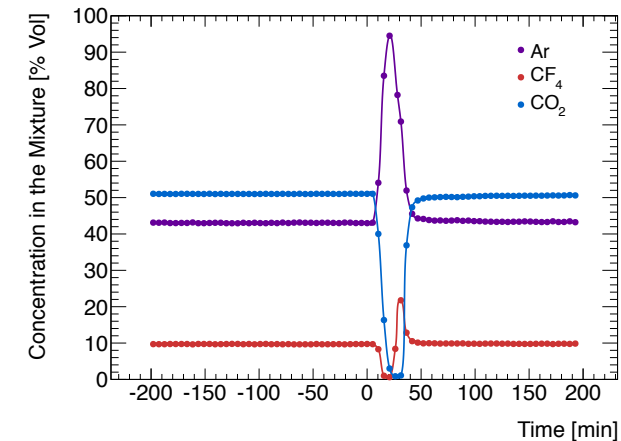
LHCb GEM

Gas mixture: 45% Ar, 40% CF_4 , 15% CO_2

GHG reduction from Run1 to Run2 up to **90%**

- Dedicated R&D needed as it was the first time GEM were operated in gas recirculation

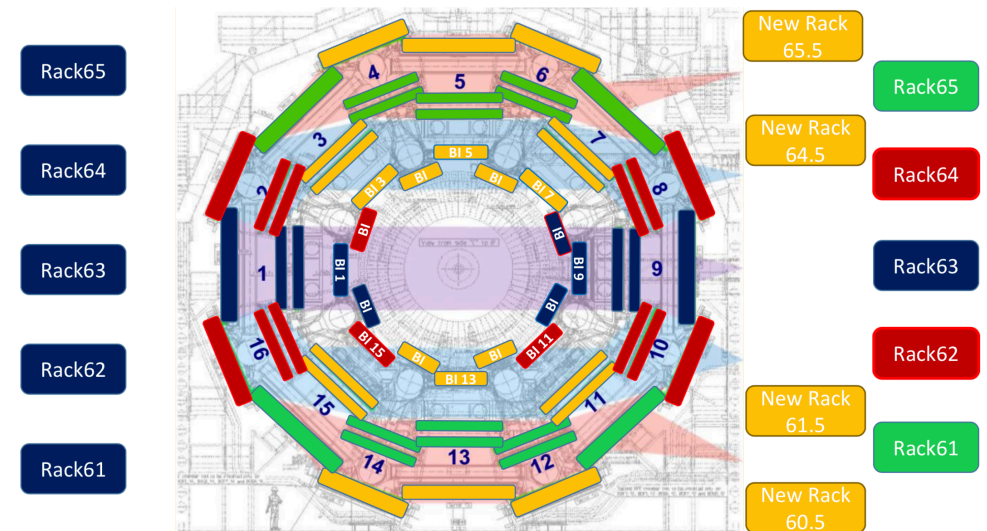
Purifier: destabilisation of gas mixture



Optimization of distribution systems: ATLAS RPC

Goal: to minimize the hydrostatic pressure on the detectors

- The RPC gas mixture has a high hydrostatic pressure: ~ 0.3 mbar/m
- The gas distribution racks are located in the cavern on different levels
- The addition of 4 new distribution racks will allow a better pressure equalisation between the chambers (total 9 racks)

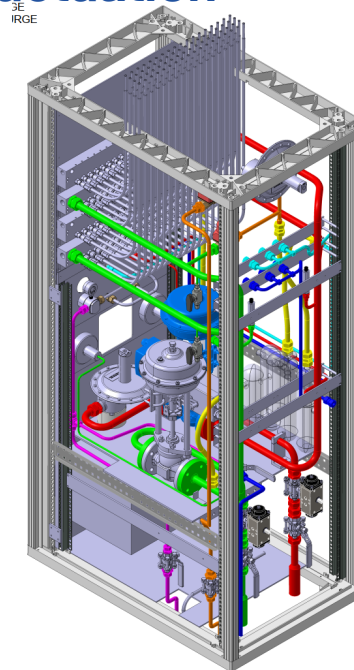


Goal: to minimize any chamber pressure/flow fluctuation from some 0.1 to ~ 0.1 mbar

Addition of regulation valves: to better regulate and smooth the input pressure going to the flow distribution

Reference chamber: to have a good reference for the regulation of the detectors pressure

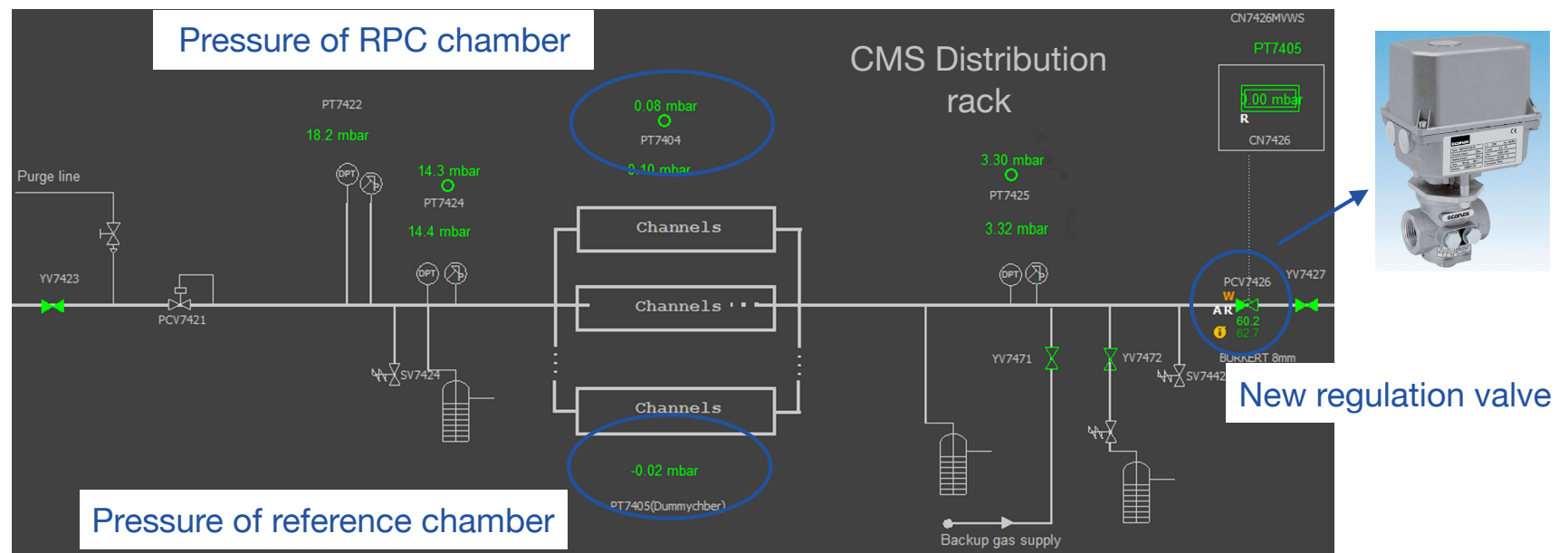
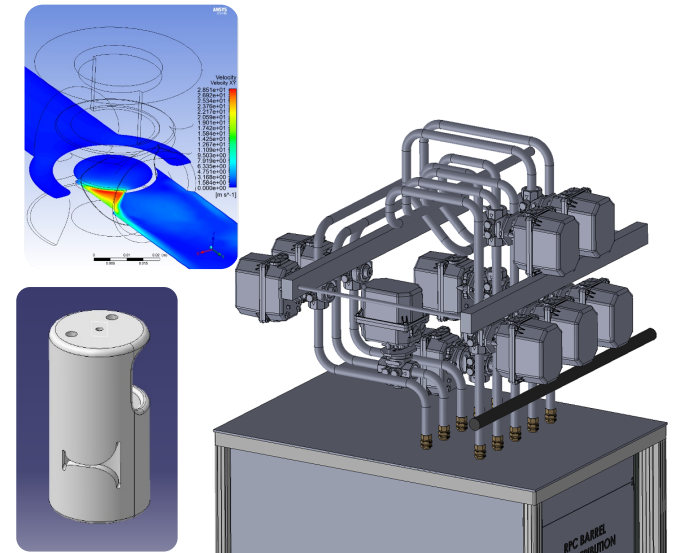
Gas impedance: to smooth pressure and flow fluctuations at the output of distribution system, i.e. pressure and flow seen by the detectors



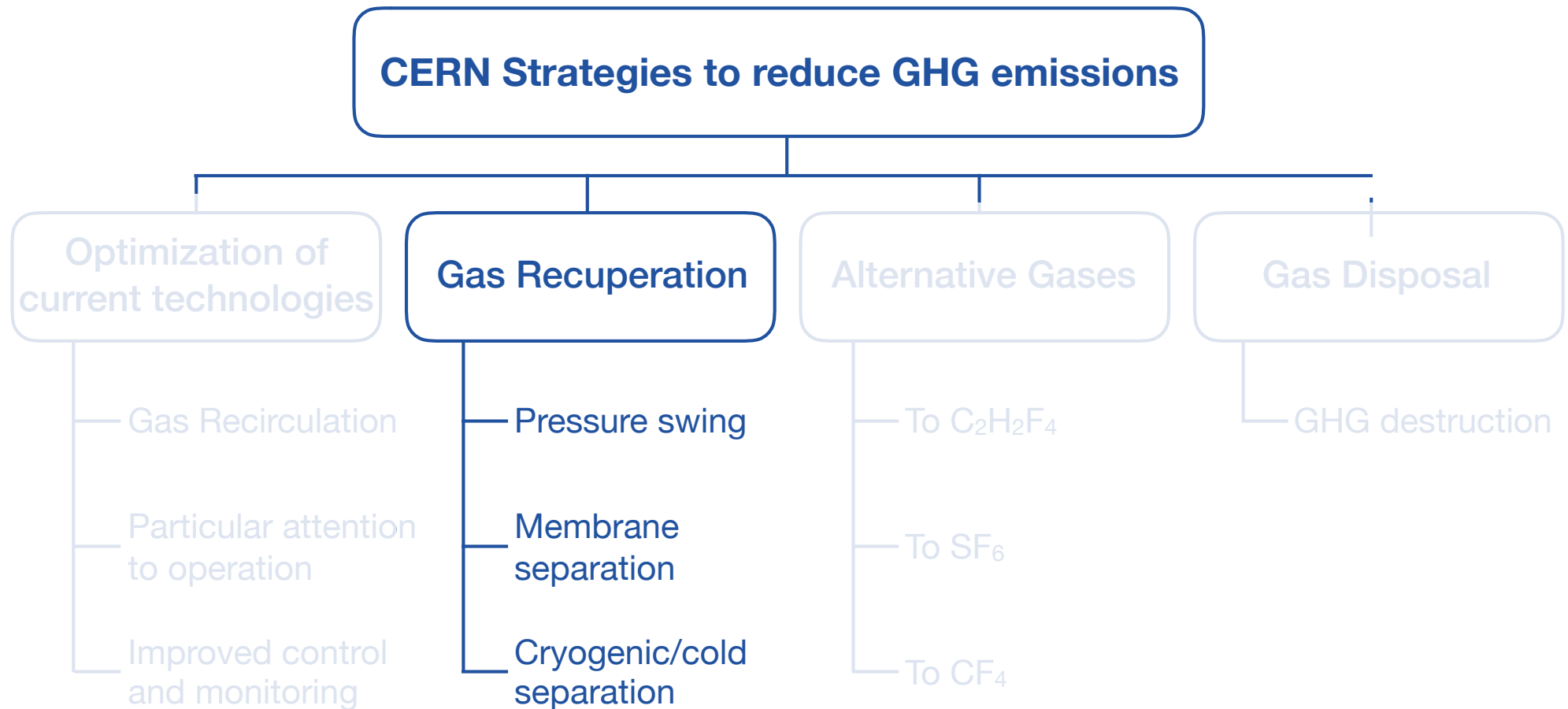
Optimization of distribution systems: CMS RPC

Goal: to try to minimise as much as possible any fluctuation of pressure and flow at the detector level

- New automated regulation valves on the return of each distribution rack to minimize any pressure changes
- To decrease the risk of developing new leaks at the detector level
- 30 distribution racks for Barrel and Endcap divided into top and bottom
- Different valve seats depending on pressure, flow, etc.
- Installation of 30 reference volumes
- To have a good reference for the regulation of the detectors pressure

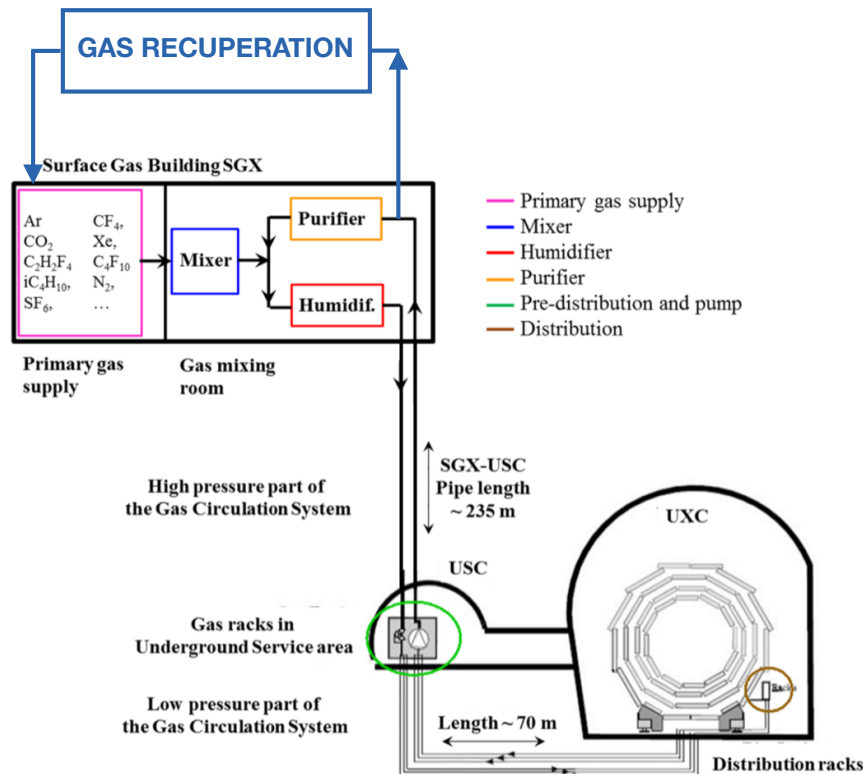


CERN strategies for GHG reduction



Gas Recuperation systems at LHC experiments

- Sometimes it is not possible to recirculate 100% of the gas mixture and a fraction cannot be re-used and therefore it would have been sent to atmosphere
 - Detector permeability, detector requirements (max recirculation fraction tested), impurities, etc.
 - To keep lower N_2 concentration
- This fraction of gas mixture is sent to a recuperation plant where the most valuable component is extracted, stored and re-used
 - Often challenging to extract a single component
 - The quality of recuperated gas is fundamental



Many LHC gas systems with gas recuperation

Advantages:

- further reduction of gas consumption

Disadvantages:

- higher level of complexity
- dedicated R&D
- gas mixture monitoring

Gas recuperation: CMS CSC CF₄

CSC Gas System

- Detector volume ~90 m³
- Gas mixture: 50% CO₂, 40% Ar, **10% CF₄**
- Gas recirculation: 90%
- No possible to increase due to detector permeability to Air
- ~600 l/h at exhaust -> 60 l/h of CF₄

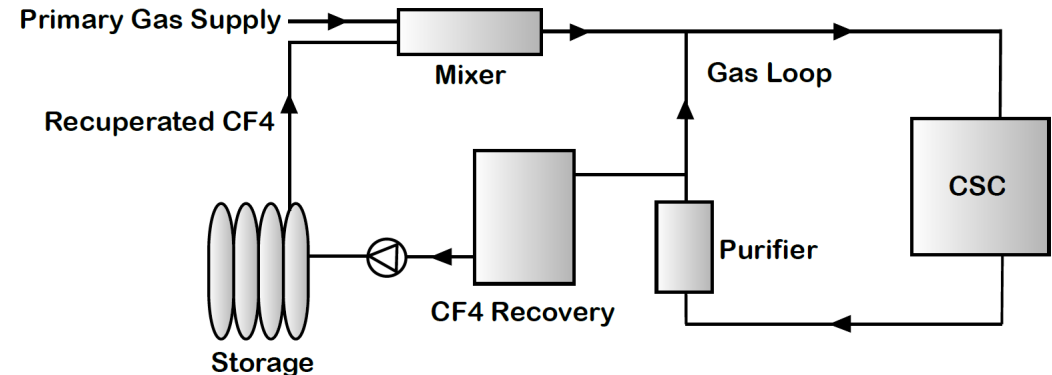
CSC Recuperation System

- Recuperation of CF₄ with warm separation
- 3 phases needed
- Several parameters affect recuperation efficiency
- Recuperated CF₄ quality to monitor

Performance

- Current recuperation efficiency ~65%
- About 100 m³ of CF₄ recuperated during Run 1 and 350 m³ in Run 2
- CF₄ quality satisfactory
- CSC detectors operated with recuperated CF₄ during Run 2
- No change in the CSC performance observed

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



Phase 0:

CSC gas mixture from the exhaust

Ar	40%
CO ₂	50%
CF ₄	10%

Ar	65%
CO ₂	~ppm
CF ₄	35%

Phase 2:

Absorption of remaining CO₂

Non permeate
CO₂, Ar, trace of CF₄
O₂, N₂

Ar	63%
CO ₂	<1%
CF ₄	37%

Phase 1:

Absorption of CO₂
CF₄ bulk separation

Mol Sieve 4A
Filter remaining CO₂

Mol Sieve 13X
Traps CF₄

Phase 3a:

CF₄ absorption

Mol Sieve 13X
Traps CF₄

Phase 3b:

CF₄ extraction

Ar	10%
CO ₂	~ppm
CF ₄	90%

Gas recuperation: LHCb RICH2 CF₄

RICH2 Gas System

- Detector volume ~100 m³
- Gas mixture: **92% CF₄**, 8% CO₂
- Gas recirculation: ~100%
- Small quantity lost in leaks or for gas system operation

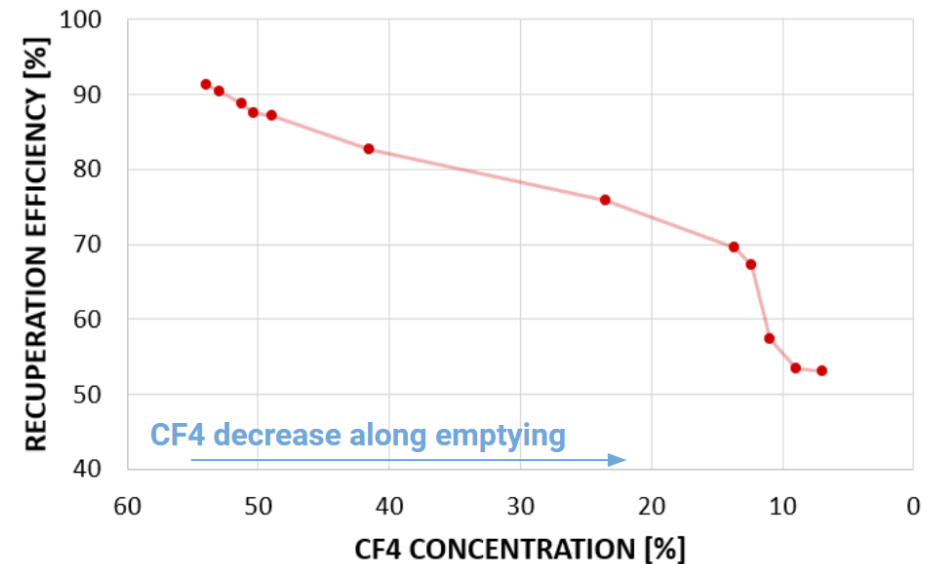
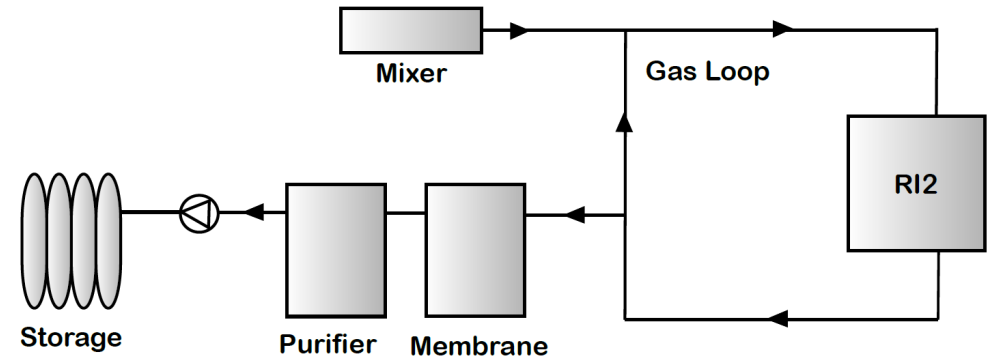
RICH2 Recuperation System

- Two recuperation modes (warm separation)
- During long shutdown: emptying detector
- During Run: recuperation of small quantities otherwise lost in gas modules
- New system implemented in LS2
- Upgrades on-going

Performance

- Recuperation efficiency ~60%
- About 30 m³ of CF₄ recuperated in LS2
- CF₄ quality satisfactory
- CF₄ recuperated will be re-used for Run 3 operation

GHG reduction from Run1 to Run2 up to **60%**



Gas Recuperation: $\text{C}_2\text{H}_2\text{F}_4$ for RPC detectors

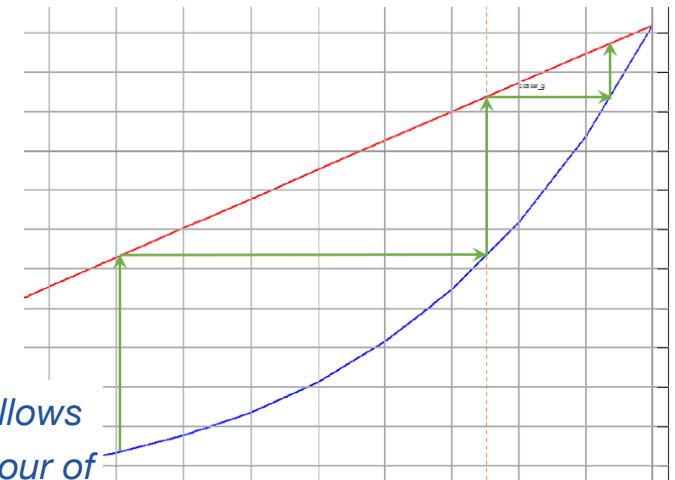
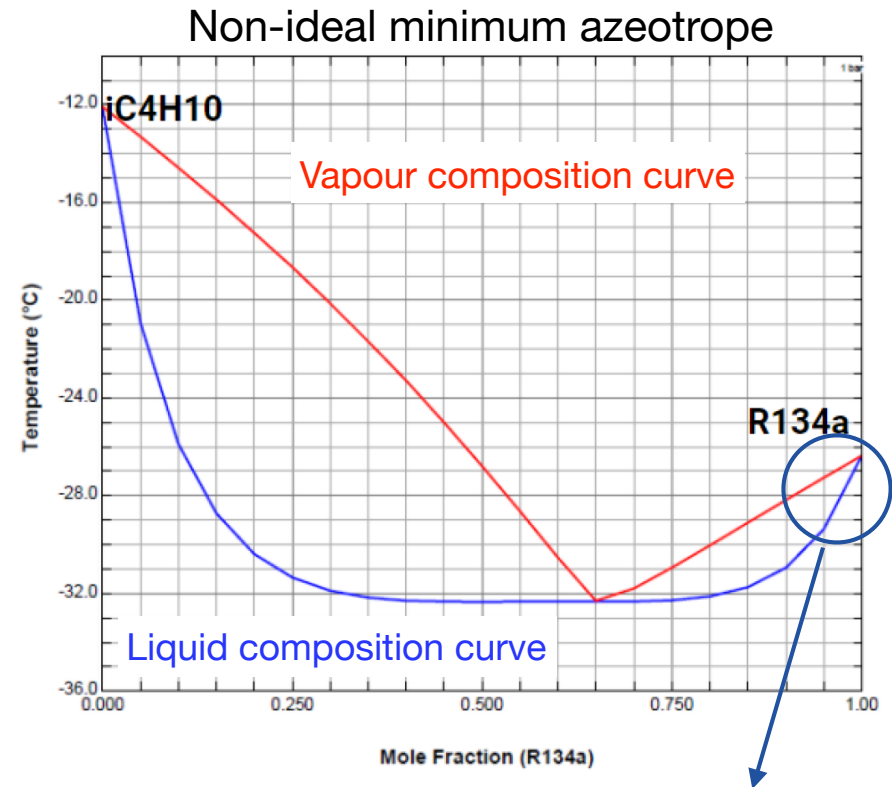
ATLAS and CMS RPC Gas Systems

- Detector volume $\sim 15 \text{ m}^3$
- Gas mixture: $\sim 95\% \text{ C}_2\text{H}_2\text{F}_4$, $\sim 5\% \text{ iC}_4\text{H}_{10}$, $0.3\% \text{ SF}_6$
- Gas recirculation: $\sim 90\%$
 - maximum recirculation validated for RPC detectors
- Fundamental to repair detector leaks
 - To have the gas at the exhaust (600-1000 l/h)

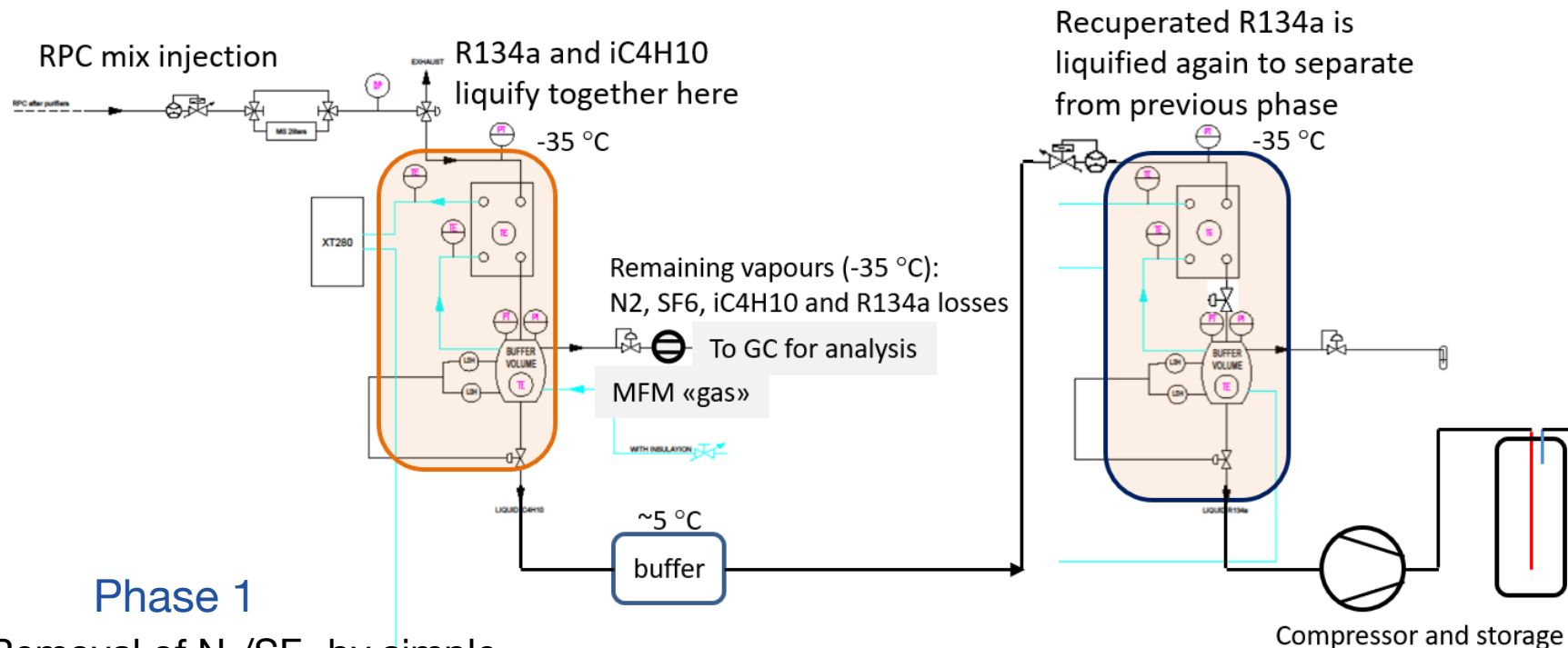
RPC Recuperation System

- Not convenient to recuperate the gas mixture
- Cold separation for R134a
 - Thermodynamic phase transitions
- R134a and iC_4H_{10} form an azeotrope
 - A mixture of liquids whose proportions cannot be altered or changed by simple distillation
 - Intramolecular force of same-species is much higher than the reciprocal attraction separation by quasi-static increase of temperature

Slow heating of the liquified azeotrope allows to enrich the liquid of R134a and the vapour of iC_4H_{10} , obtaining the separation



Gas Recuperation: C₂H₂F₄ for RPC detectors



Phase 1

- Removal of N₂/SF₆ by simple distillation
- Gas mixture in buffer 1 cools down at -35 °C
- N₂/SF₆ in vapour phase

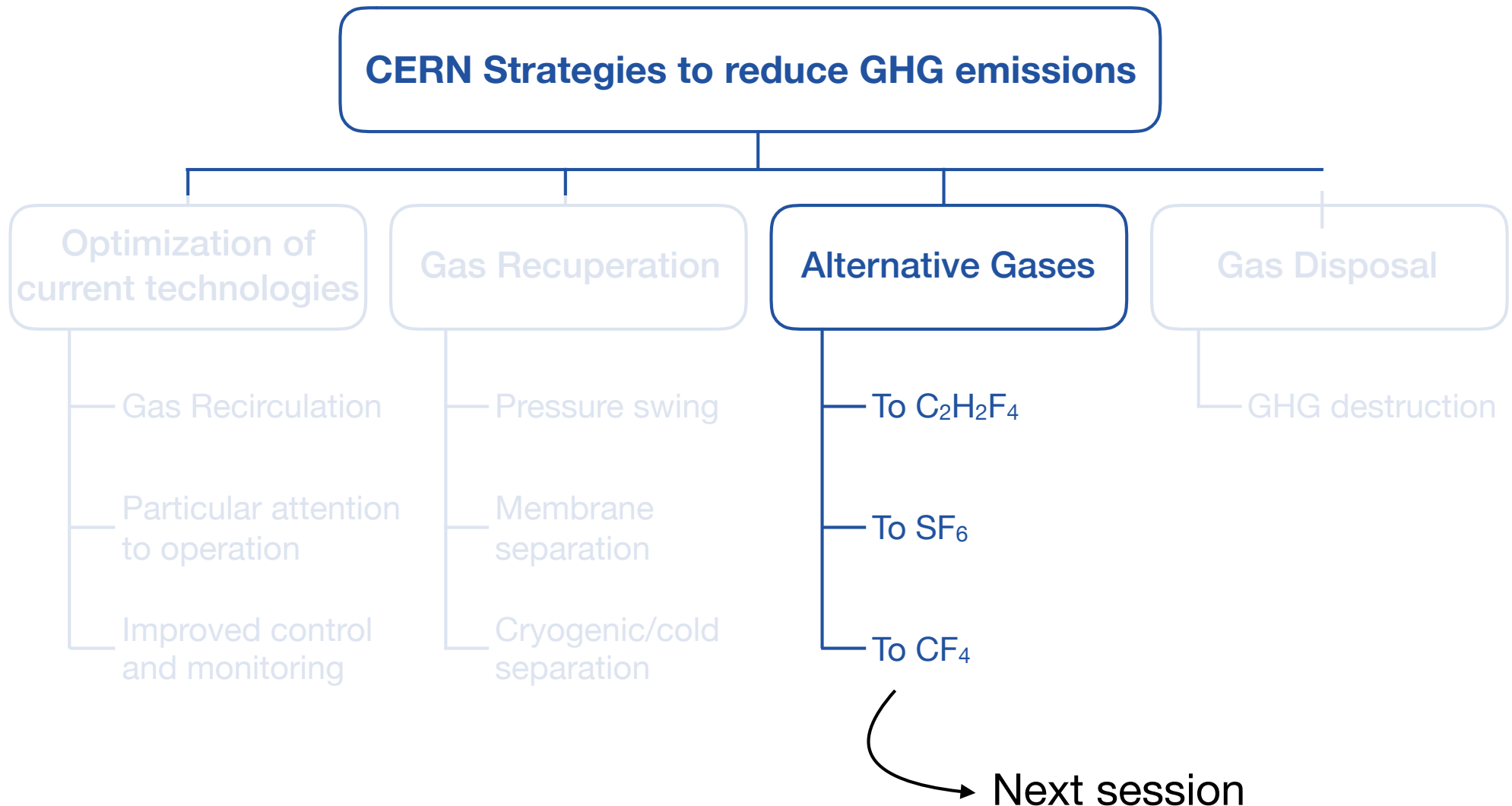
Phase 2

- Detachment of R134a from iC₄H₁₀
- Liquid heats up and vapour is made of azeotrope
- Vapours go back in buffer 1
- Liquid R134a go in buffer 2

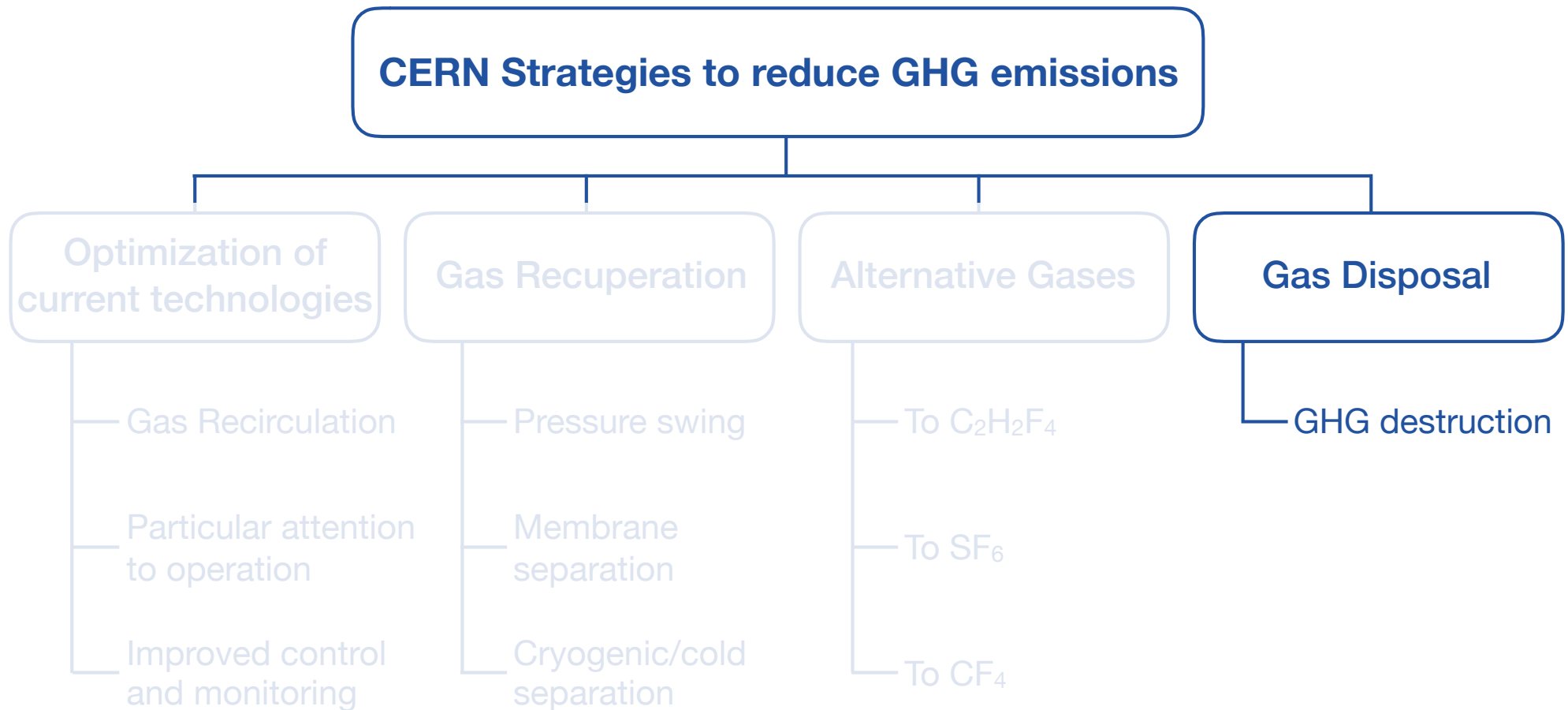
Phase 3

- Compression of R134a
- Vapour is compressed in liquid storage

CERN strategies for GHG reduction



CERN strategies for GHG reduction



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:

- CH₄/city gas + O₂ supply + N₂ supply
- Waste water treatment
- PFC/HFC are converted in CO₂ + 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



Conclusions

*With climate change a growing concern,
CERN is committed to reducing its direct greenhouse gas emissions*

Optimization of current technologies

- Gas recirculation systems are the best way to reduce GHG consumption
- Nowadays upgrades of gas systems beyond original design

Gas recuperation plants

- Used when not possible to recirculate 100% of the gas
- Very complex and different technologies depending on the GHG to recuperate
- CF₄ recuperation plants well advanced
- C₂H₂F₄ recuperation plants: studies on-going

Alternative gases

- A lot of work in RPC communities but also for other detectors
- See next session

GHG Disposal

- Very last alternative: only if previous strategies will not work