Embedding Sustainability in Gaseous Particle Detector Technologies

PHENIICS Days 2025

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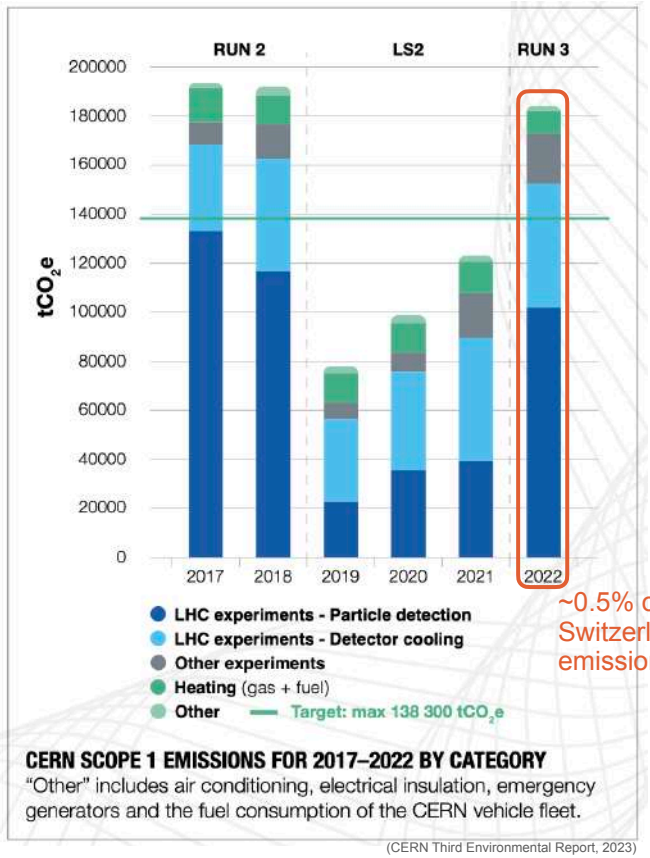
The 4th of July 2025

Greenhouse gases from Particle Detectors at CERN

Context

78% of CERN's emissions from the use of **Fluorinated gases** (F-gases).



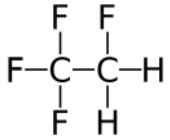
~0.5% of Switzerland's emissions

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.

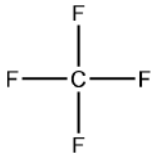
(CERN Third Environmental Report, 2023)

Problem

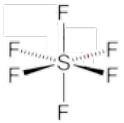
The EU rules are fastly changing and becoming more strict.

$C_2H_2F_4$ 

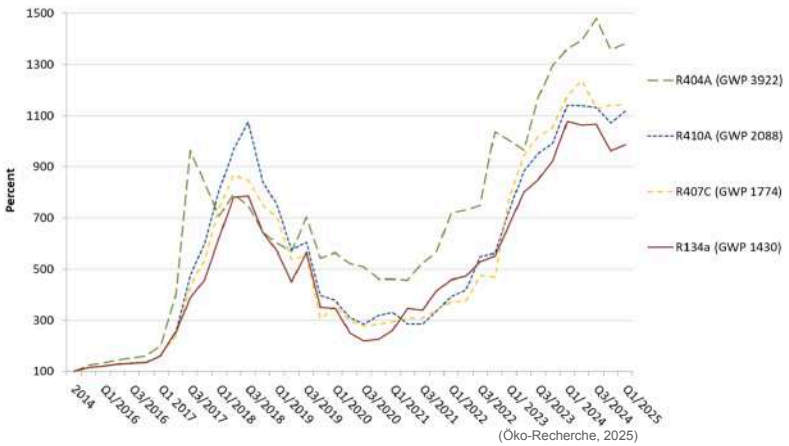
- GWP: **1430**

CF_4 

- GWP: **7390**

SF_6 

- GWP: **22800**



(Öko-Recherche, 2025)

Mitigation Strategies

Different strategies to mitigate the consumption of GHGs.

Searching for eco-friendly alternatives.

Extended for smaller laboratory sized systems.

Gas Recuperation

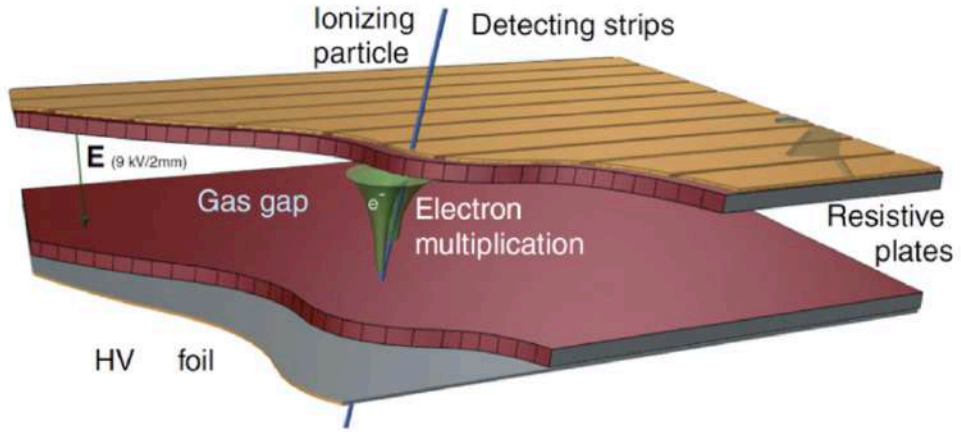
Newly installed system in LHCb.

GHG Consumption Reduction

For Resistive Plate Chamber (RPCs) Detectors

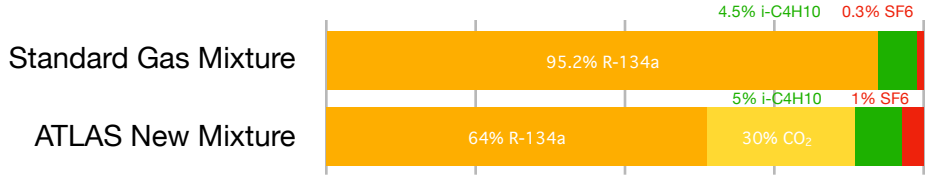
GHG Consumption Reduction

For Resistive Plate Chamber (RPCs) Detectors



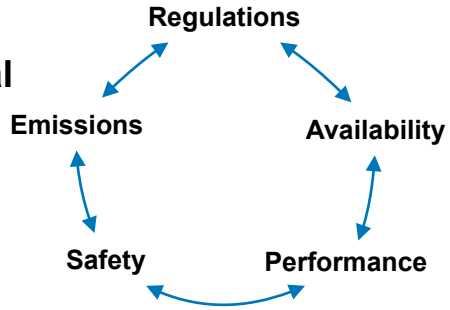
Principle of Operation.

- Employed in **fast space-time particle tracking** required for the **muon trigger** at ATLAS, CMS and ALICE.
- Accounting for 85% of the emissions during CERN's RUN2.



Constraints:

- Choosing an alternative gas is **NOT trivial** for currently installed RPC or new RPCs.
- The new mixture **cannot induce any changes** in the LHC current systems:
  - High Voltage (HV) Modules
  - Front-end Electronics
  - Detectors



Alternatives:

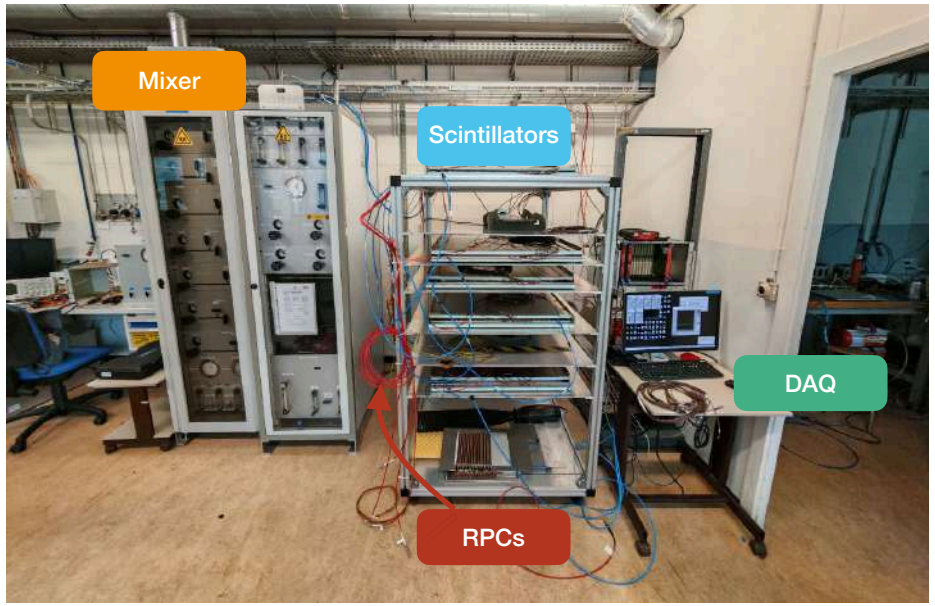
- R-1234ze (HFO)
- R-1336mzz
- R-152a
- R-32
- R-236fa
- R-236ea
- R-245fa
- R-1233zd
- R-1224yd, the Amolea
- Novec™ 4710

For R-134a consumption reduction: **CO_2**, He, Ar, N_2, N_2O, Xe, O_2, Ne

Set-up and Methodology

LAB256 & GIF++

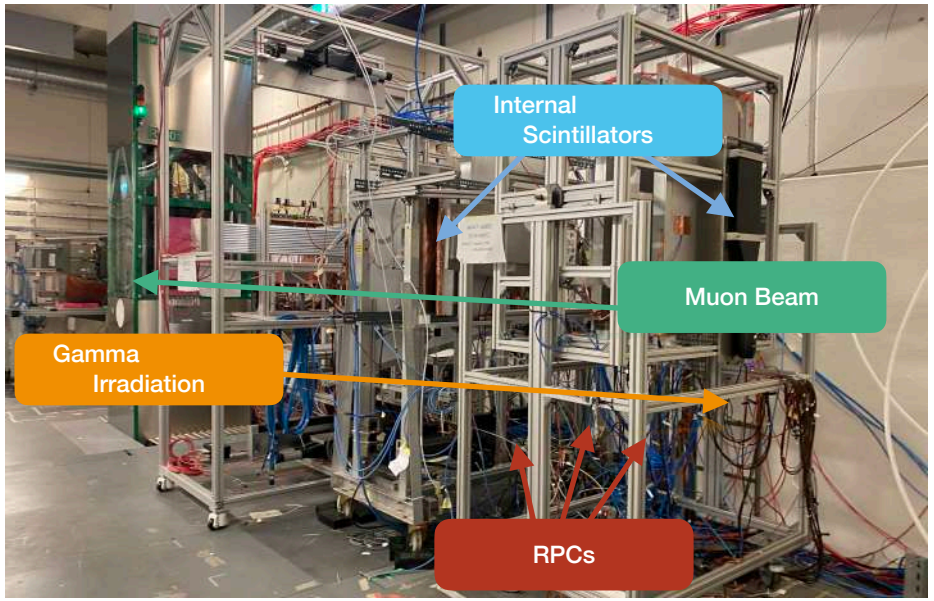
- Testing new gas mixtures with cosmic muons
  - Gas mixing Unit
    - Up to 6 components
  - RPC detectors
    - 2mm gap, high pressure laminates (HPL), strip size between 2 - 2.5cm



Detector and Mixture Characterisation

Test Beams Campaigns

Ageing Tests



- Performance studies under LHC-like conditions with muon beam
  - ^{137}Cs, 12.5TBq irradiator
    - Pb Filters are used to regulate the gamma background intensity
  - DAQ
    - CAEN digitizer V1730, resolution 0.12mV, sampling 500MS/s

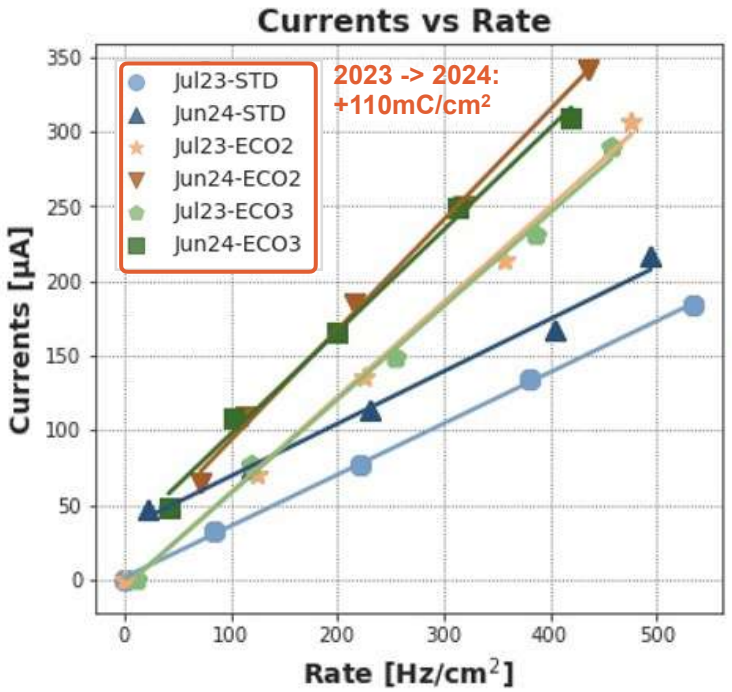
Alternatives to $C_2H_2F_4$ (R-134a)

R-1234ze & CO_2

ECOGAS Studies within the RPC EcoGas@GIF++ Collaboration

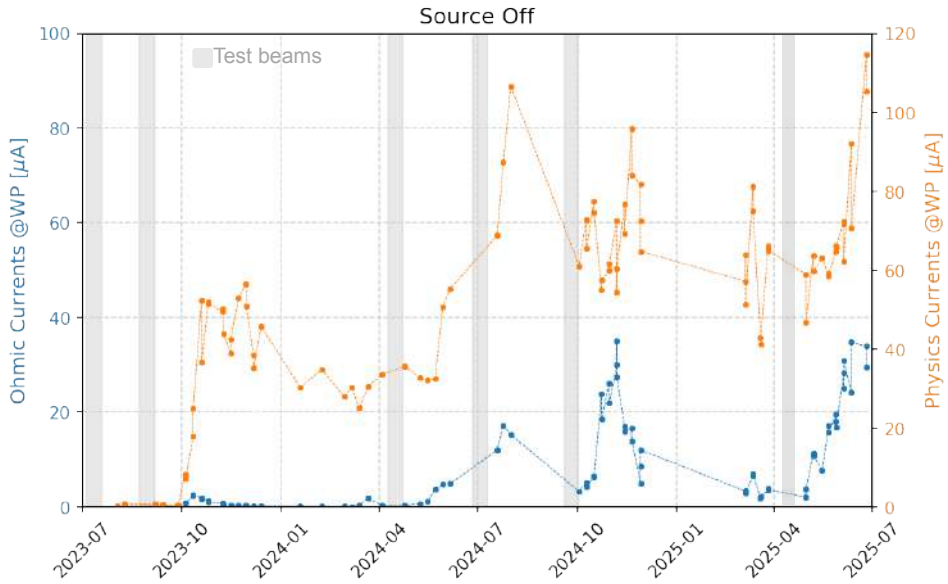
Mixture under test: 35% HFO, 60% CO_2, 4% i-C_4H_{10}, 1% SF_6 (ECO2)

- **HFO cannot replace R-134a in 1:1** ratio due to its increased working point.



- During test beams, the three mixtures of interest: STD, ECO2, ECO3 are re-checked
- The **HFO mixtures show higher currents** at the same rate.
- There is a current increase at the rate over one year in all tested mixtures.

Ageing campaign



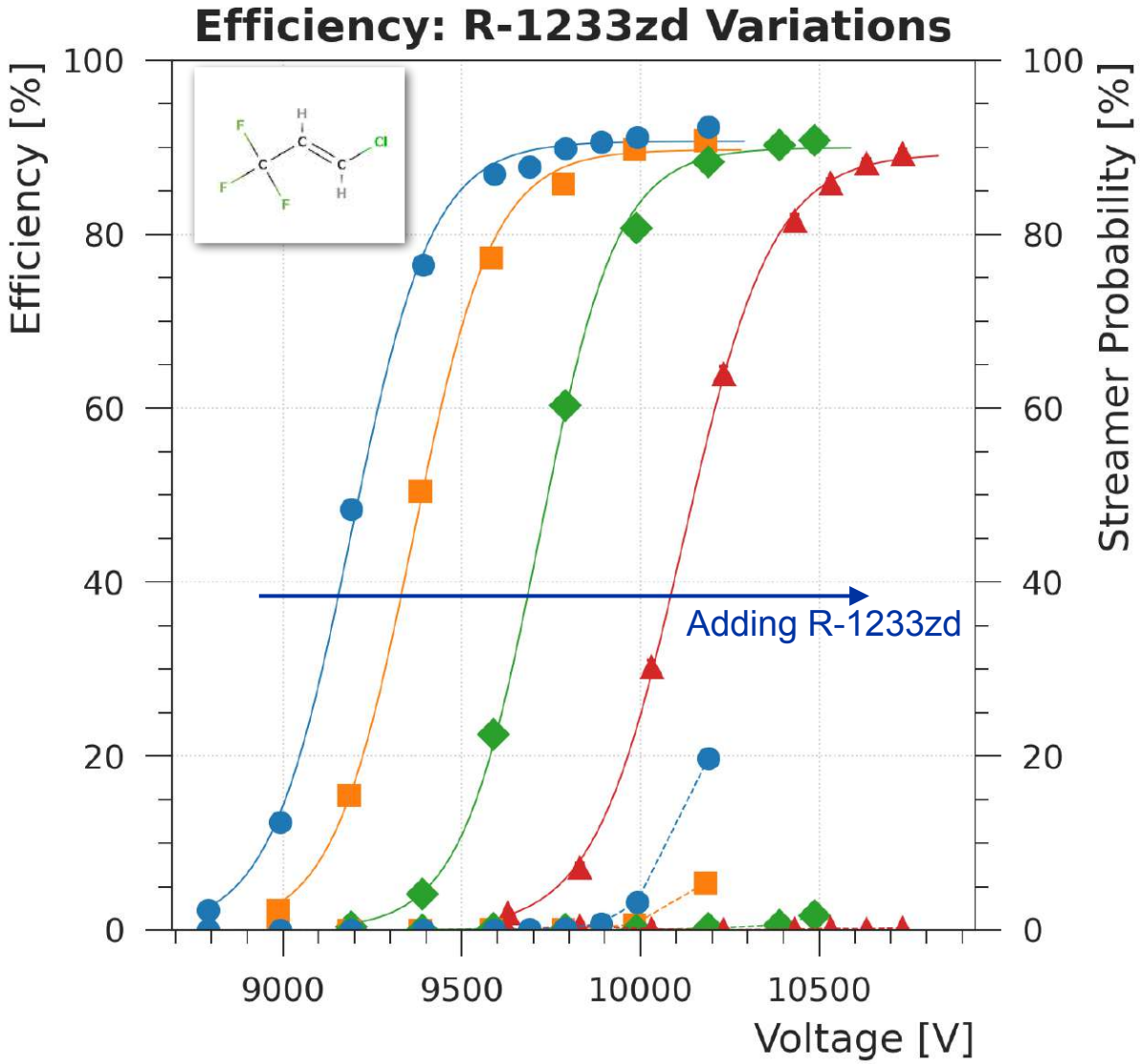
- **Focus:** Monitor ageing and current increase in RPCs with ECO2.
- **Ongoing work:** Testing performance vs. standard mixture.
- **Next steps:** Reduce or eliminate SF_6.

Alternatives to SF_6

R-1233zd

- Standard Gas Mixture:
  - 95.2% R-134a + 4.5% i-C_4H_{10} + ~~0.3% SF_6~~
    -> replaced with 0.3%, 0.6%, 1% R-1233zd

- **R-1233zd increases the working point** of the gas mixture by ~350V every 0.3% added.
- It shows **higher streamer probability** wrt to the Standard Mixture, **but still <1%**.
- Shows **comparable efficiencies**.
- **Tests need to be performed** since this gas contains Cl, that could potentially damage the internal surface of the detector.



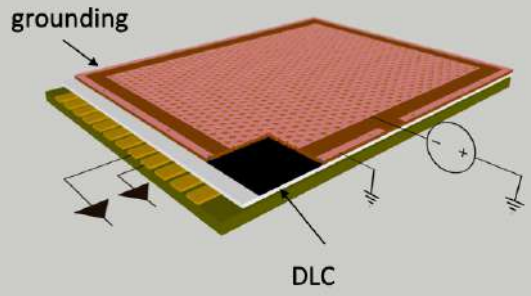
GHG Consumption Reduction

For μRWELL

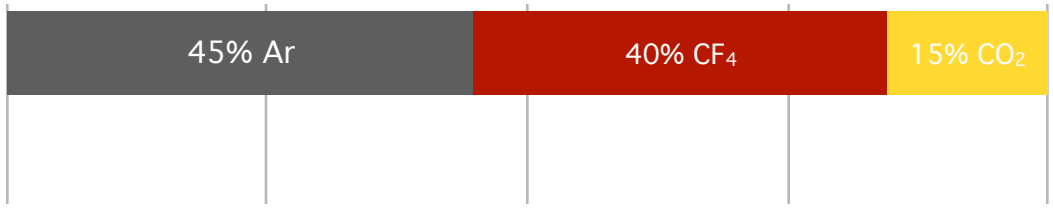
Studies on μRWELL Detectors

The technology and motivation for the study

micro-Resistive Well Detector (μRWELL)



- Future **detector** to be used for the **LHCb Upgrade II** instead of the MWPC
- **Rate capability up to 1MHz/cm²** per single detector gap
- Uses **CF_4 for better time resolution**



CF_4

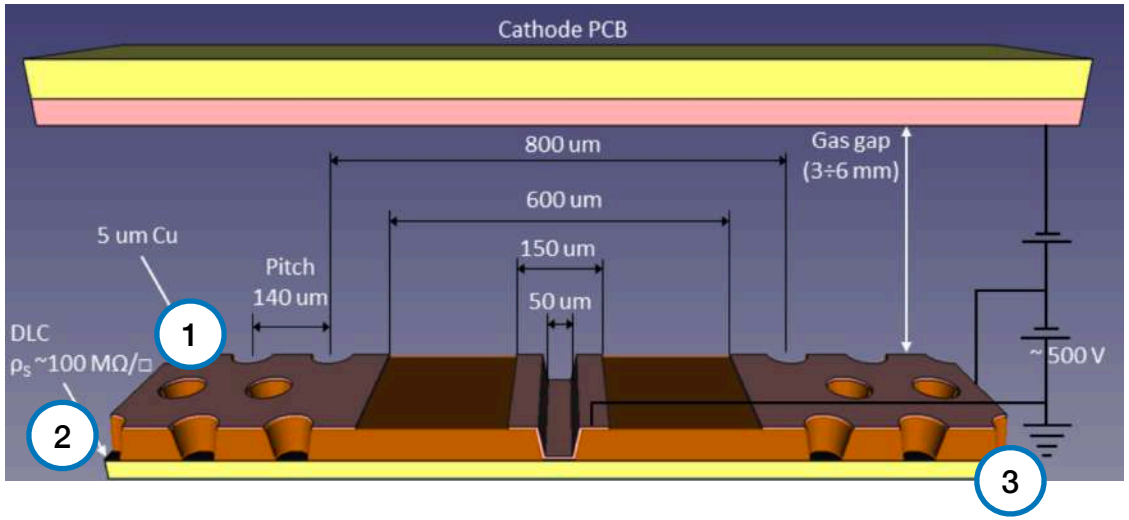
- GWP: **7390**

used for its fast electron drift and quenching properties for time resolution

Goal: Characterise the detector and aim at replacing the CF_4 due to its high GWP.

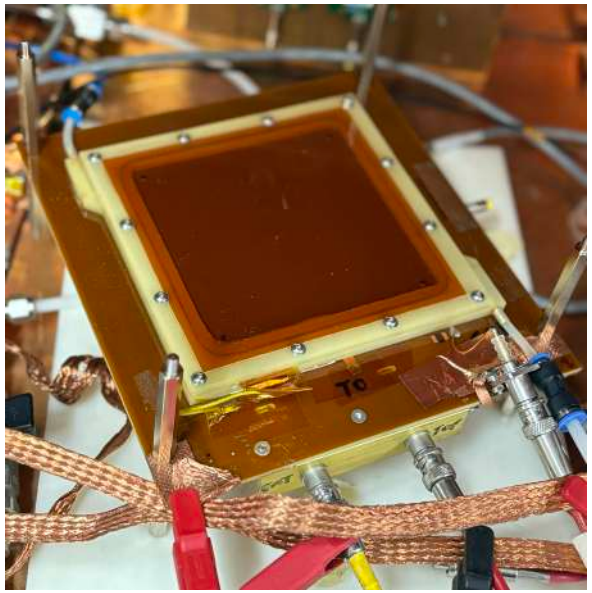
- Single-stage amplification Micro Pattern Gaseous Detector (MPGD)
- Composed only of a cathode and PCB-embedded anode comprising 3 elements:
  1. WELL patterned Kapton layer
  2. Resistive Diamond-like-Carbon (DLC) layer*
  3. Standard PCB layer

★ Newly introduced - has the role to suppress the streamer to spark transition -> large gains (>10^4) can be achieved



Studies on µRWELL Detectors

Detector Characterisation



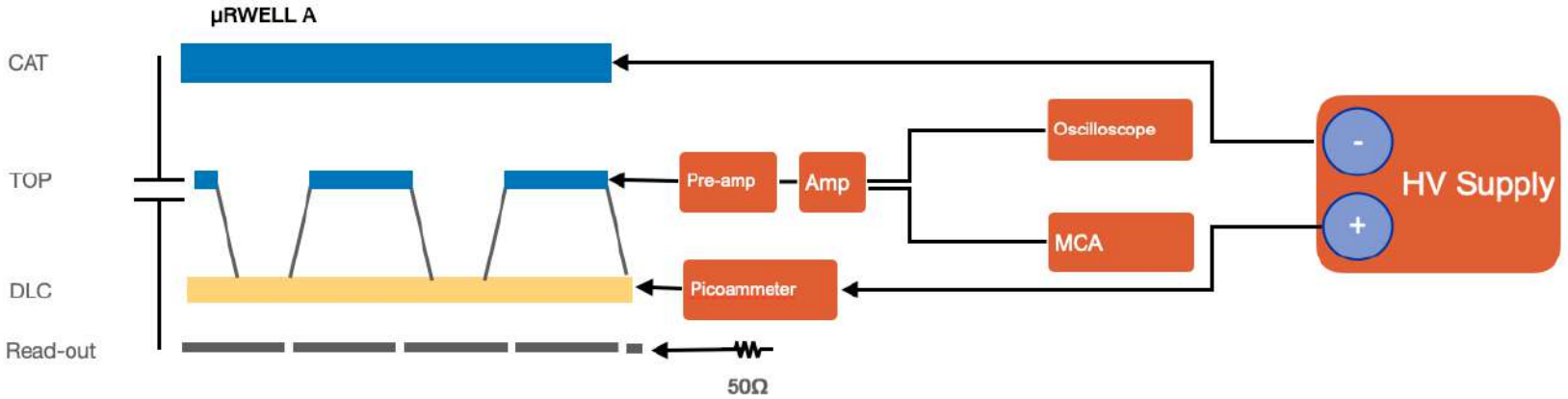
10 x 10 cm µRWELL prototype

Drift gap: 6mm

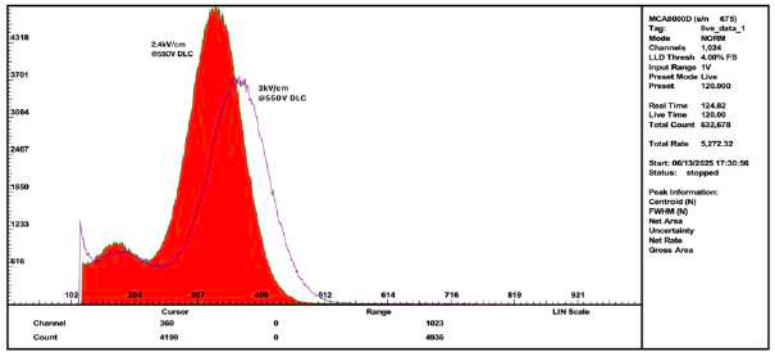
Read-out pads: 1 × 1 cm²

Read-out channels: 121

DAQ: VMM



Spectra recorded with Fe-55 Source

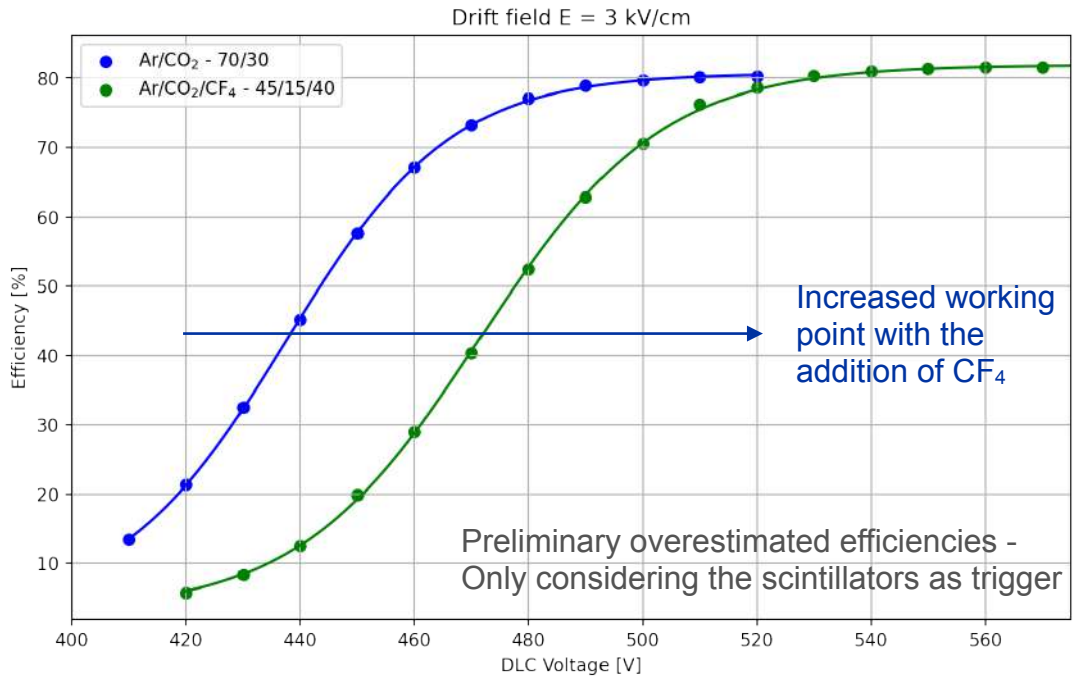


- Testing with Ar/CO_2 - 70/30 for gain measurements
- Checking the Fe-55 spectra for different drift fields.

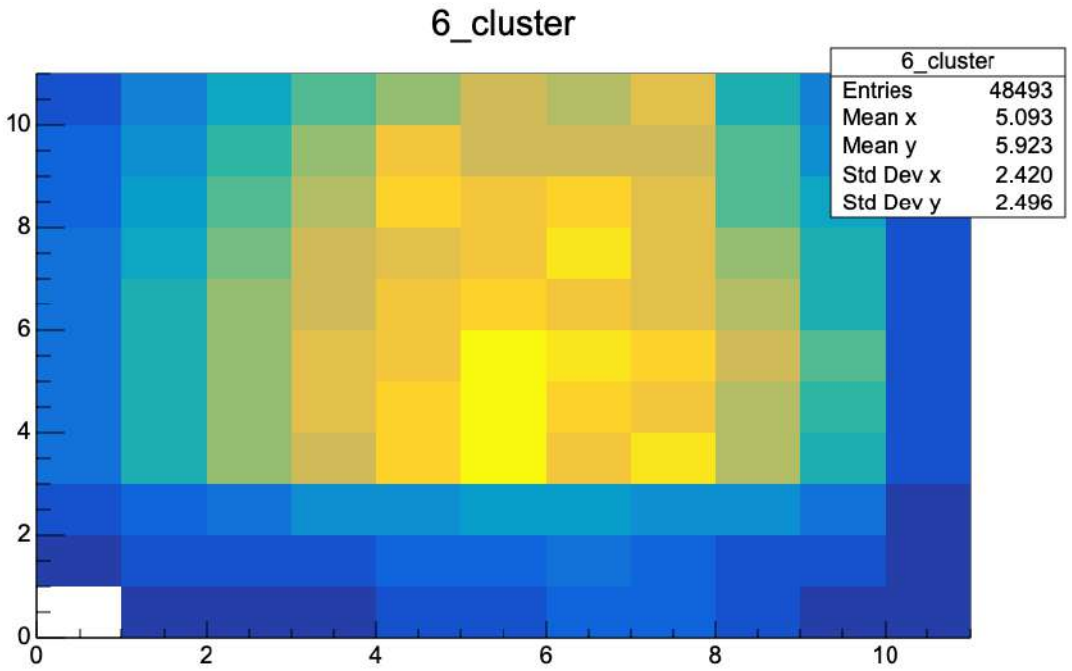
Studies on µRWELL Detectors

Preliminary results

- Detector (10 x 10 cm µRWELL) tested during the previous Test Beam with the DRD1 Collaboration:
  - **Ar/CO_2 - 70/30**
  - **$Ar/CO_2/CF_4$ - 45/15/40**



- The detector has 1 x 1 cm^2 pads
- 121 channels connected to the VMM3a read-out chip.
- We can check the beam's hit profile.



µRecirculation Systems

For Gaseous Particle Detectors

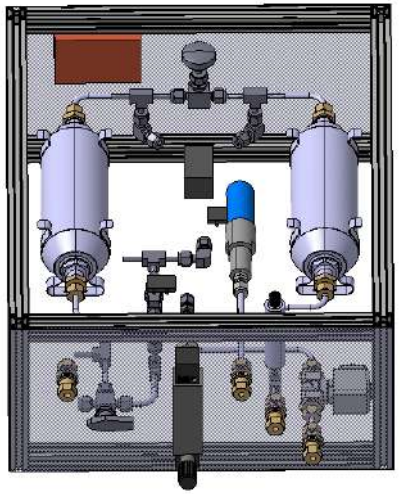
Gas recirculation

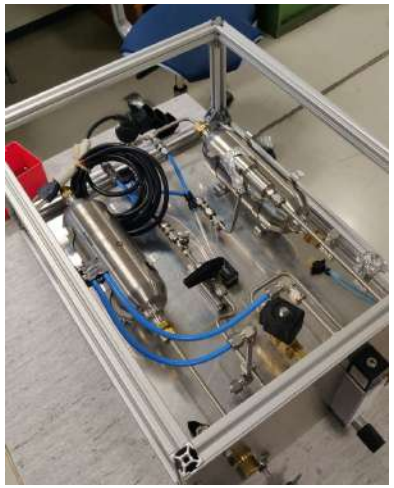
GOAL: spare gas consumption for: smaller laboratory, remote and cost-constrained setups.

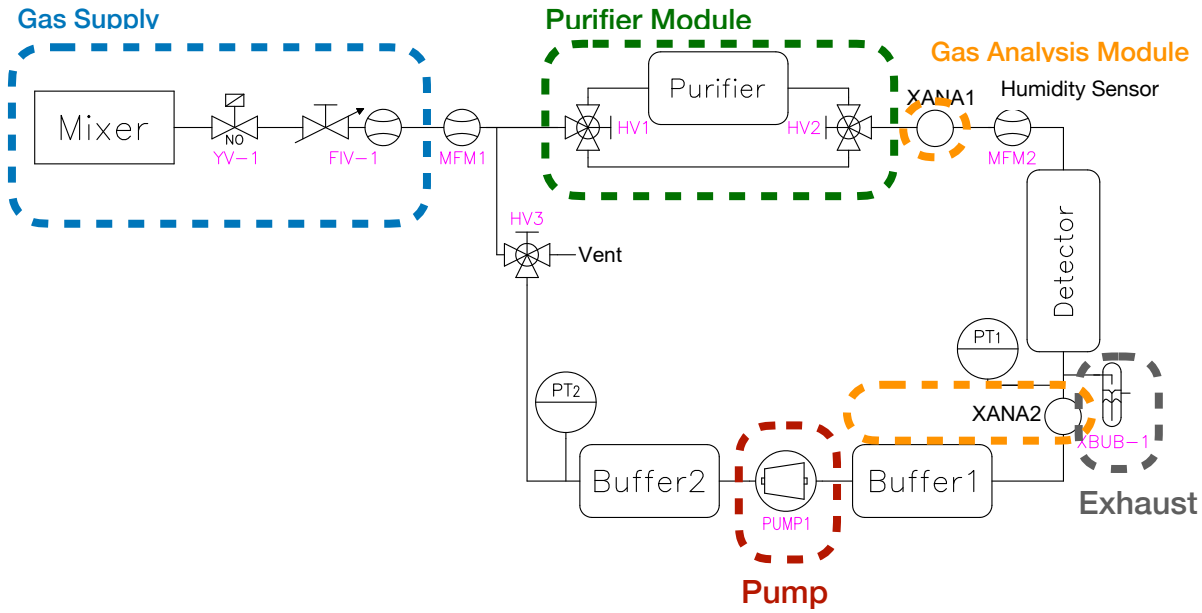
Compact: Designed to mimic the performance of larger systems while drastically reducing size.

Affordable: Components are low-cost and commercially available.

Modular Design: Highly modular system, adaptable for various applications.







Schematics of the micro-closed loop recirculation system.

Prototypes deployed at:

- **CERN's Science Gateway**
- **EEE telescope**
- **PicoSec detector**

Next steps

Alternative gases for Resistive Plate Chamber detectors

- Test different SF_6 alternatives
- To be tested during the following test beam (mid-July) under muon beam

Studies on the effect of CF_4 in µRWELL detectors

- In the following test beam, to evaluate how the addition of CF_4 affects performance in µRWELL detectors, focusing on:
  - Efficiency
  - Time and spatial resolution
  - Hit profile, using the VMM read-out chip
- For lower CF_4 concentrations and alternatives

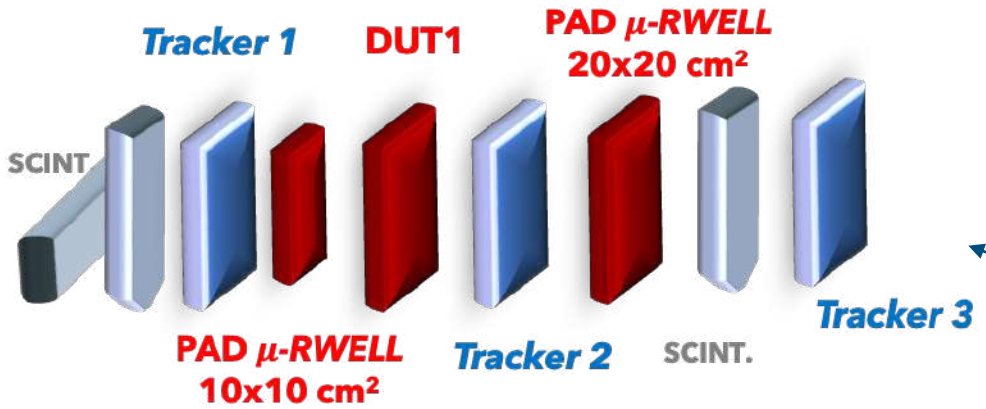
µRecirculation systems

- Finalise the pump tests to decide upon the final component
- Test the addition of a purifier for H_2O and O_2 removal

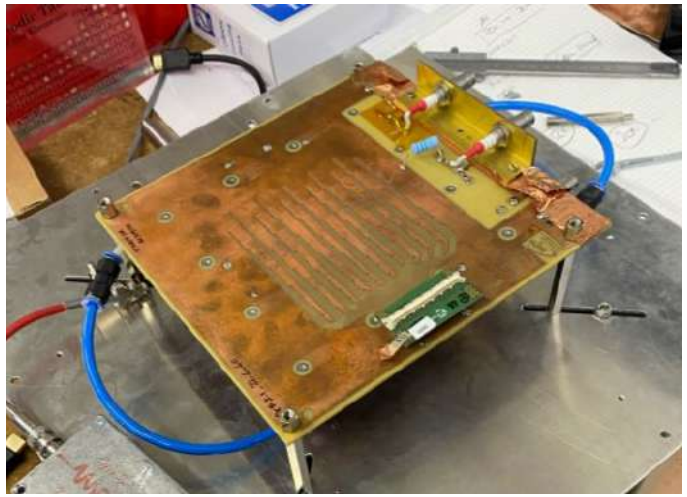
Thank you!

Back-up

µRWEL - Sept. Test Beam



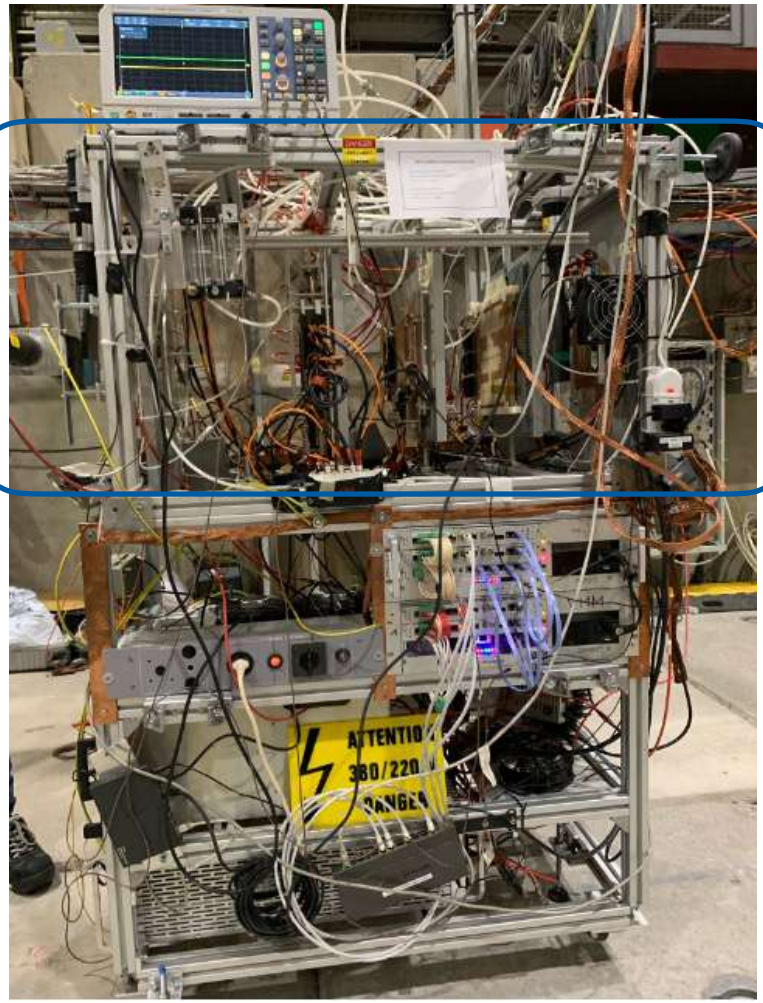
Pad-uRWELL Groove Detector



Set-up

- 3 scintillators in coincidence trigger
- 3 triple GEM trackers for reference
- 3 detectors under test

DRD1 Telescope



180,000 Metric Tons **of Carbon Dioxide (CO_2) equivalent**

This is equivalent to greenhouse gas emissions from:

41,986 gasoline-powered passenger vehicles driven for one year	**158,968** electric-powered passenger vehicles driven for one year
458,380,720 miles driven by an average gasoline-powered passenger vehicle	

This is equivalent to CO_2 emissions from:

20,254,304 gallons of gasoline consumed	**17,681,729** gallons of diesel consumed
199,946,681 pounds of coal burned	**2,383** tanker trucks' worth of gasoline
24,173 homes' energy use for one year	**37,511** homes' electricity use for one year