Studies of R134a and SF_6 alternative gas mixtures for HPL and Glass RPC detectors for High Energy Physics Applications

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16th Topical Seminar on Innovative Particle and Radiation Detectors

EP-DT
Detector Technologies

HPL Resistive Plate Chamber detectors

Structure:

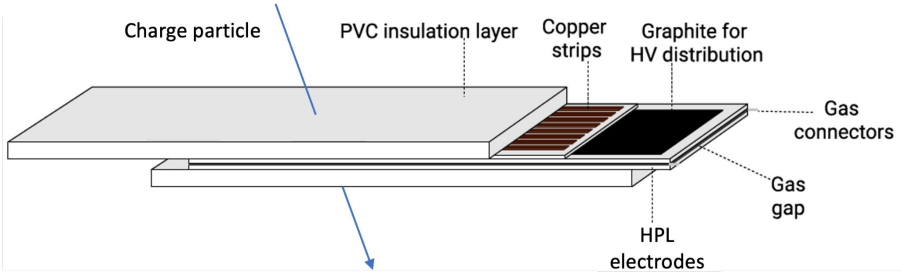
- Planar resistive electrodes made of HPL;
- Electrodes separated by spacers;
- Gas gap between the electrodes filled with gas mixture;
- Copper strips for signal readout.

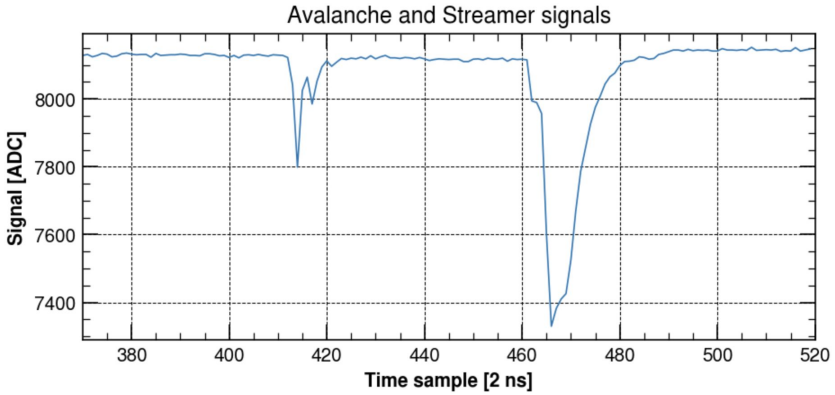
Operating principle:

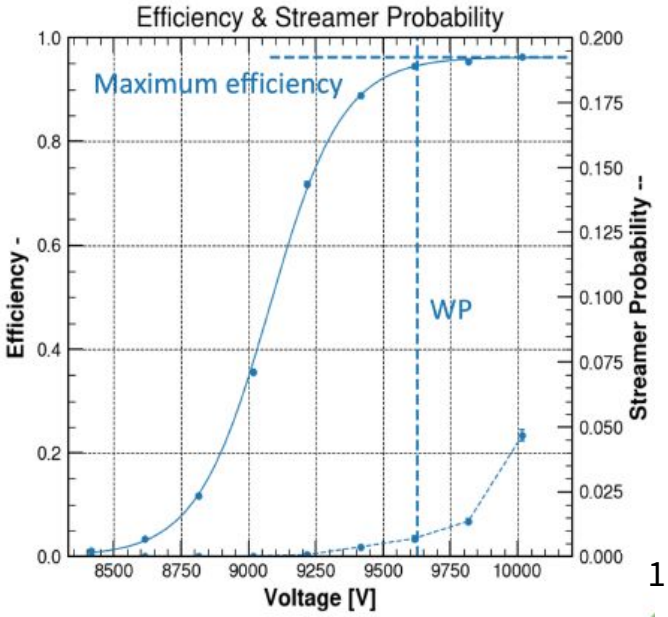
- High voltage applied to the electrodes;
- Gas ionization inside the gap;
- Charge multiplication;
- Charge induction on readout strips

Foremost parameters:

- Detector currents;
- Prompt charge:
  Avalanche ($<10^8$ e^-);
  Streamer ($>10^8$ e^-);
- Streamer probability:
  N. streamers/N. signals;
- Efficiency;
- Working point: voltage where the efficiency reach 95% of its maximal values, plus 150 V.



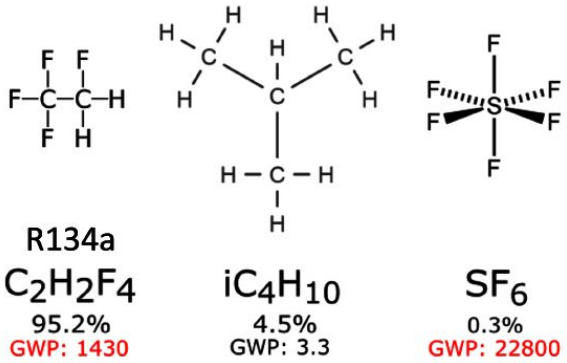




Greenhouse gas emissions at CERN

RPCs dominate CERN GHG emissions:

- Large area (5000 m^2 / experiment);
- Large volume (15 m^3 / experiment);
- Gas leaks at detector levels;
- High GWP mixture:



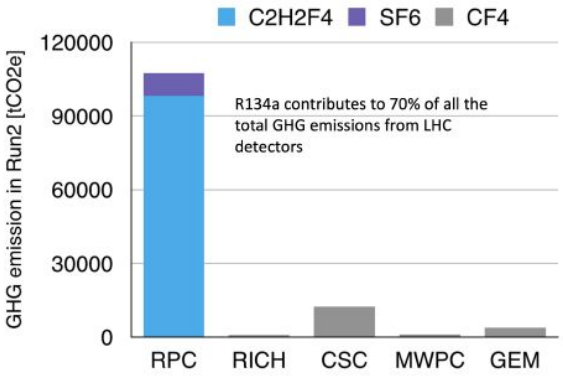
Standard Gas Mixture

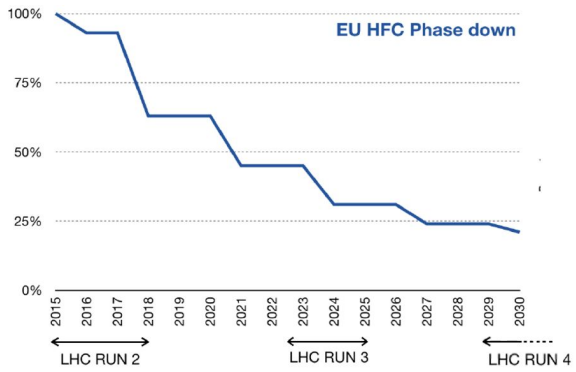
CERN Environmental Report:

- Reduce GHG emissions by 28% by the end of 2024;

EU fluorinated gases regulation (2014):

- Reducing products availability of fluorinated GHGs;
- This regulation already affected fluorinated gases prices.





CERN gas team developed different strategies to reduce GHG emissions:

- Optimization of current gas systems technologies;
- Development of gas recirculation systems;
- Gas recuperation;
- Research on alternative eco-friendly gases.

The **goal** of this work is to find an eco-friendly gas mixture that is compatible with the current LHC RPC systems (HV supply, FEB electronics, gas systems…) and that allows to have a good detectors performance.

Research outline

R134a Alternatives

- ➔ He
- ➔ HFO1234ze
- ➔ R32
- ➔ N_2
- ➔ Ar…

\+ market available

(Rigoletti, Guida, Mandelli, 2023)

selected → CO_2 based gas mixture 30-60%

- Reduction of the tCO2e emissions
- Laboratory Studies to fine-tune the concentration.

based on performance → **30% CO2 + 64% R134a + 5% iC4H10 + 1% SF6**

- Constant monitoring of the detector status
- Periodical Test Beam Monitoring

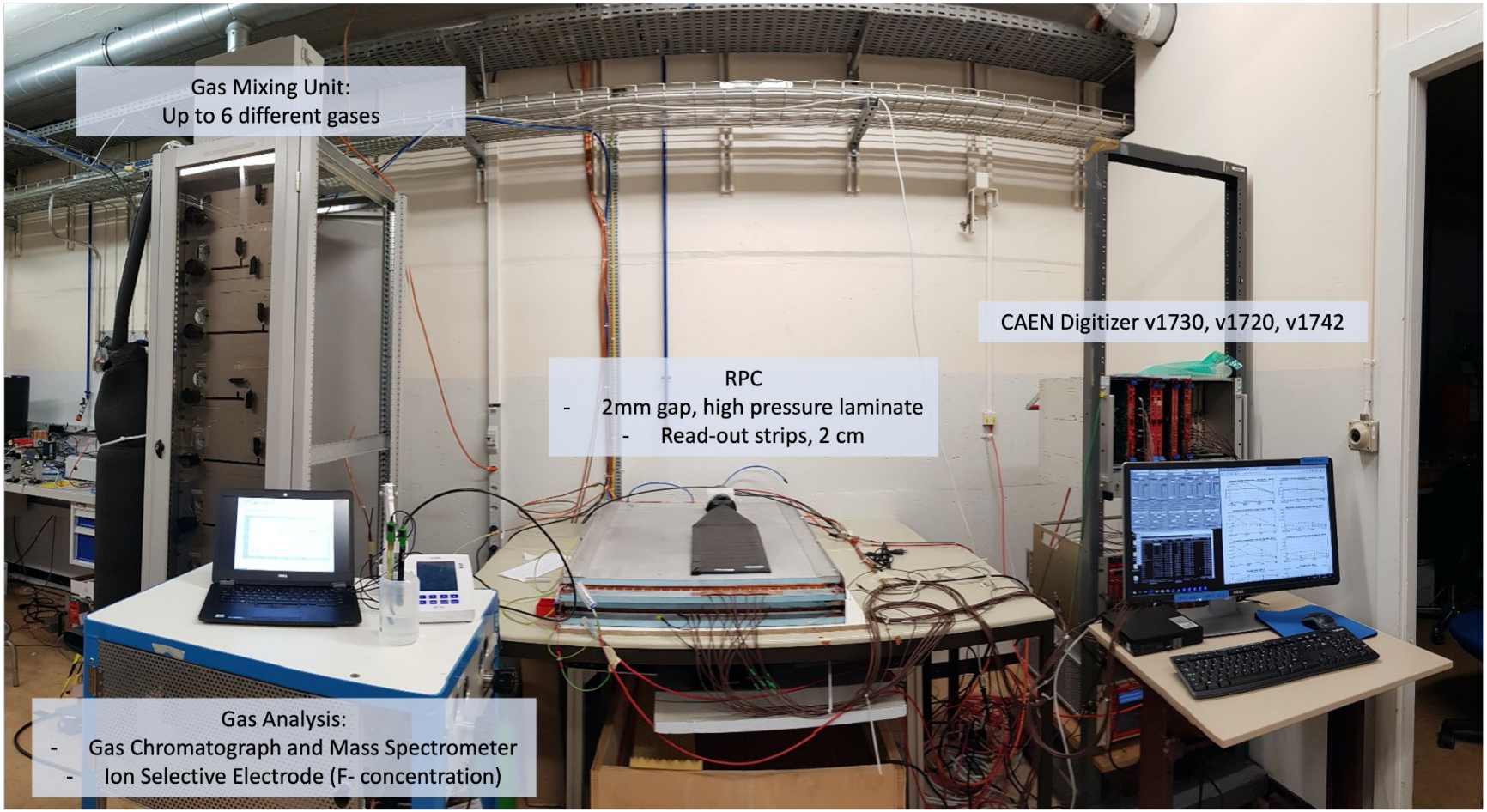
SF_6 alternatives

- ➔ Amolea 1224yd
- ➔ Novec 4710

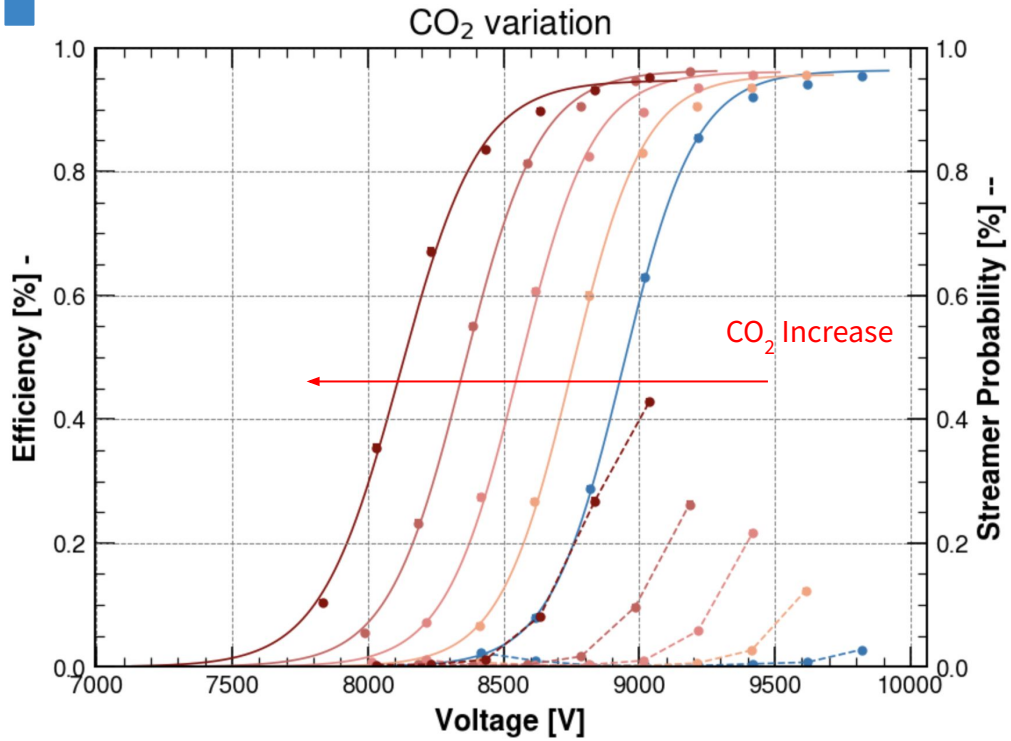
laboratory studies → **0.5% Amolea 1224yd**
0.1% Novec 4710

→ study on going also for glass MGRPC

Laboratory set-up



STD mixture with addition of CO_2

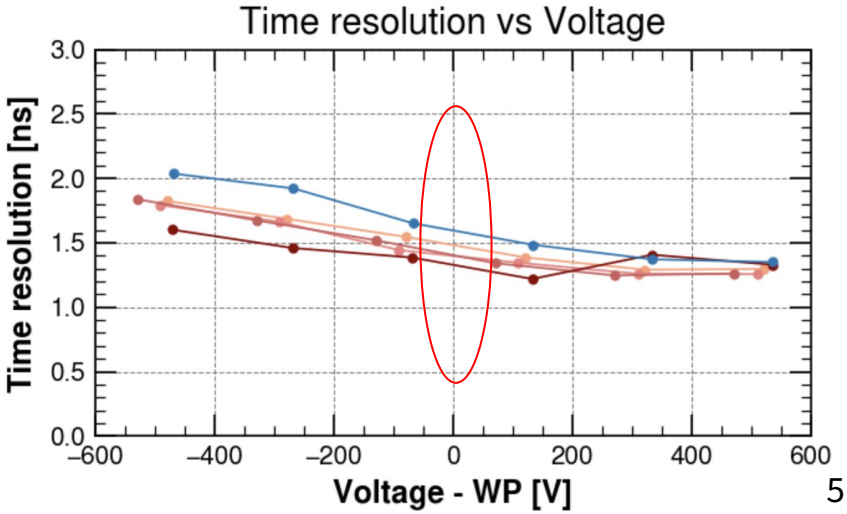


STD	$R134a/iC_4H_{10}/SF_6$	- 95.2/4.5/0.3
30% CO_2	$CO2/R134a/iC_4H_{10}/SF_6$	- 30/64.0/5.0/1
40% CO_2	$CO2/R134a/iC_4H_{10}/SF_6$	- 40/54.0/5.0/1
50% CO_2	$CO2/R134a/iC_4H_{10}/SF_6$	- 50/44.0/5.0/1
60% CO_2	$CO2/R134a/iC_4H_{10}/SF_6$	- 60/34.0/5.0/1

- +10% CO2 -> WP -200 V;
- Maximum efficiency similar to STD;
- Time resolution at WP lower than STD.

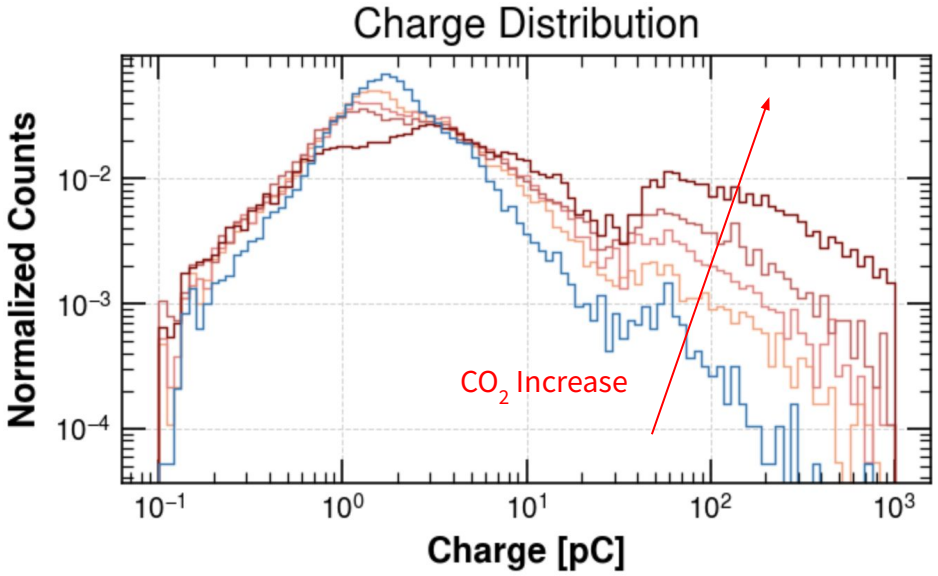
- Higher streamer probability:

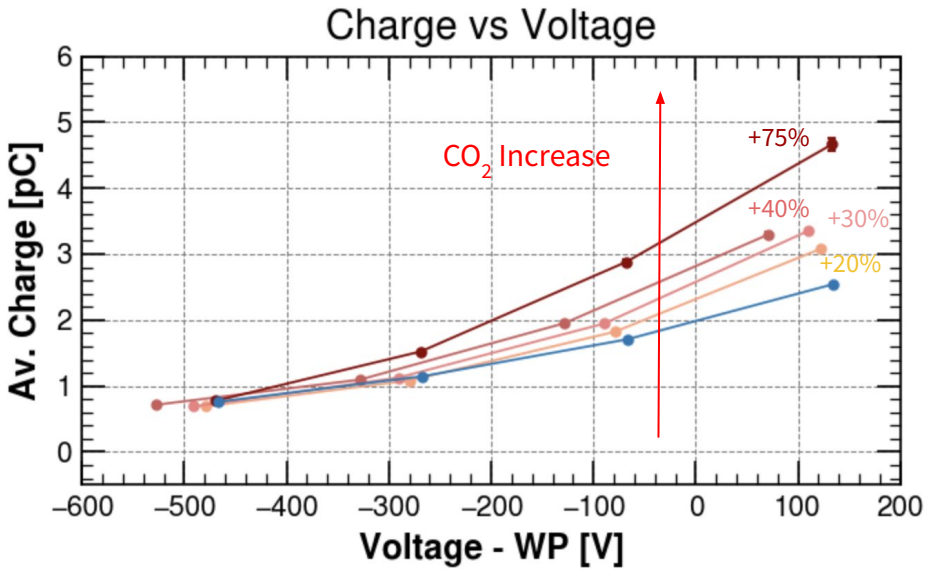
  STD = 0.5%
  30% CO2 < 1.5%
  40% CO2 < 3.5%
  50% CO2 < 7%
  60% CO2 < 15%



1% SF_6 selected in precedent studies to mitigate the streamer probability.

STD mixture with addition of CO_2





STD	$R134a/iC_4H_{10}/SF_6$ - 95.2/4.5/0.3	
30% CO_2	$CO2/R134a/iC_4H_{10}/SF_6$ - 30/64.0/5.0/1	-15% GWP
40% CO_2	$CO2/R134a/iC_4H_{10}/SF_6$ - 40/54.0/5.0/1	-25% GWP
50% CO_2	$CO2/R134a/iC_4H_{10}/SF_6$ - 50/44.0/5.0/1	-34% GWP
60% CO_2	$CO2/R134a/iC_4H_{10}/SF_6$ - 60/34.0/5.0/1	-44% GWP

- Higher avalanche charge wrt STD:
  30% CO_2 -> +20% 40% CO_2 -> +30%
  50% CO_2 -> +40% 60% CO_2 -> +75%

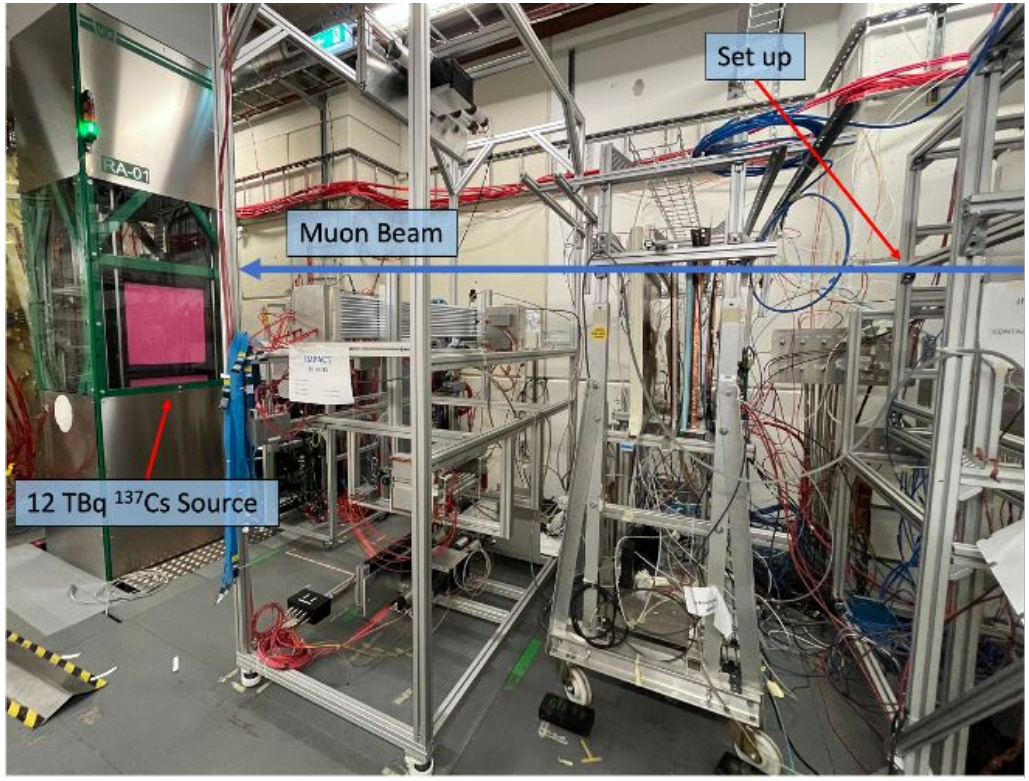
- Higher Streamer probability and Streamer Charge

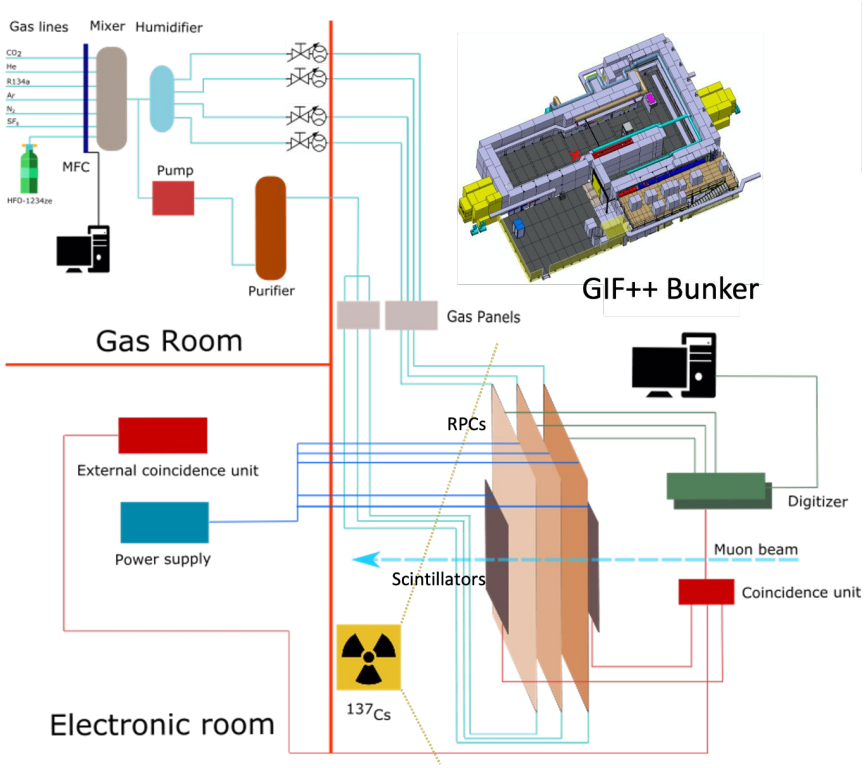
Due to its good performances, 30% CO_2 gas mixture was selected for long term aging at the Gamma Irradiation Facility (GIF++) at CERN:

-> Collaboration with ATLAS RPC and CMS RPC groups

Possibility to further study also 40% CO_2 gas mixture.

Long term studies: GIF++ set-up





Attenuation factor (ABS): from 69 to 2.2 (~20 Hz/cm^2 to ~500 Hz/cm^2)

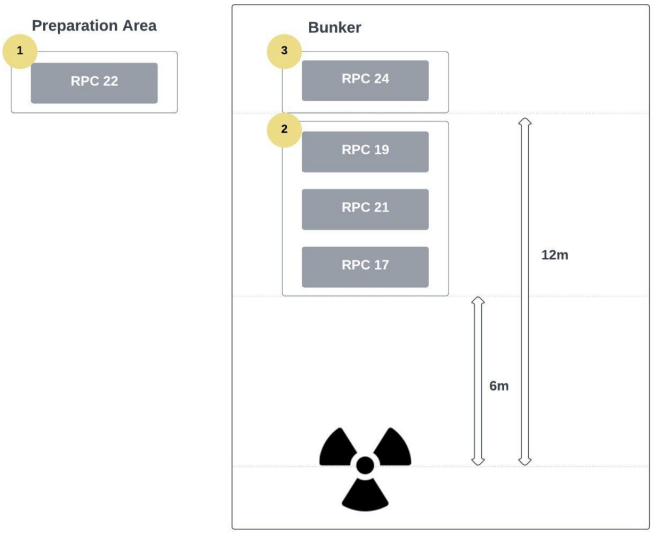
Long term studies: Irradiation Campaign

Starting date: 1st March 2023

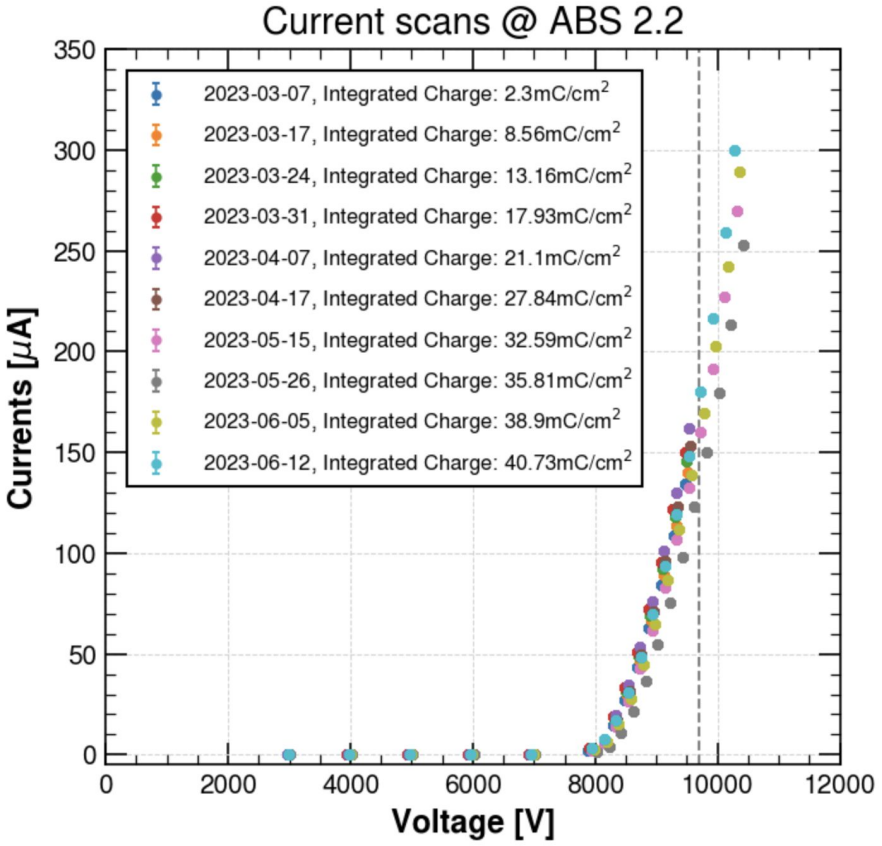
Gas Mixture: **30% CO_2** [CO_2/R134a/iC_4H_{10}/SF_6 - 30/64.0/5.0/1]

Integration goal: **25 mC/cm²** -> From ATLAS RPC prediction for Run 3

Detector hit rate: **400 Hz/cm²**, with detector at 50% of the maximum efficiency



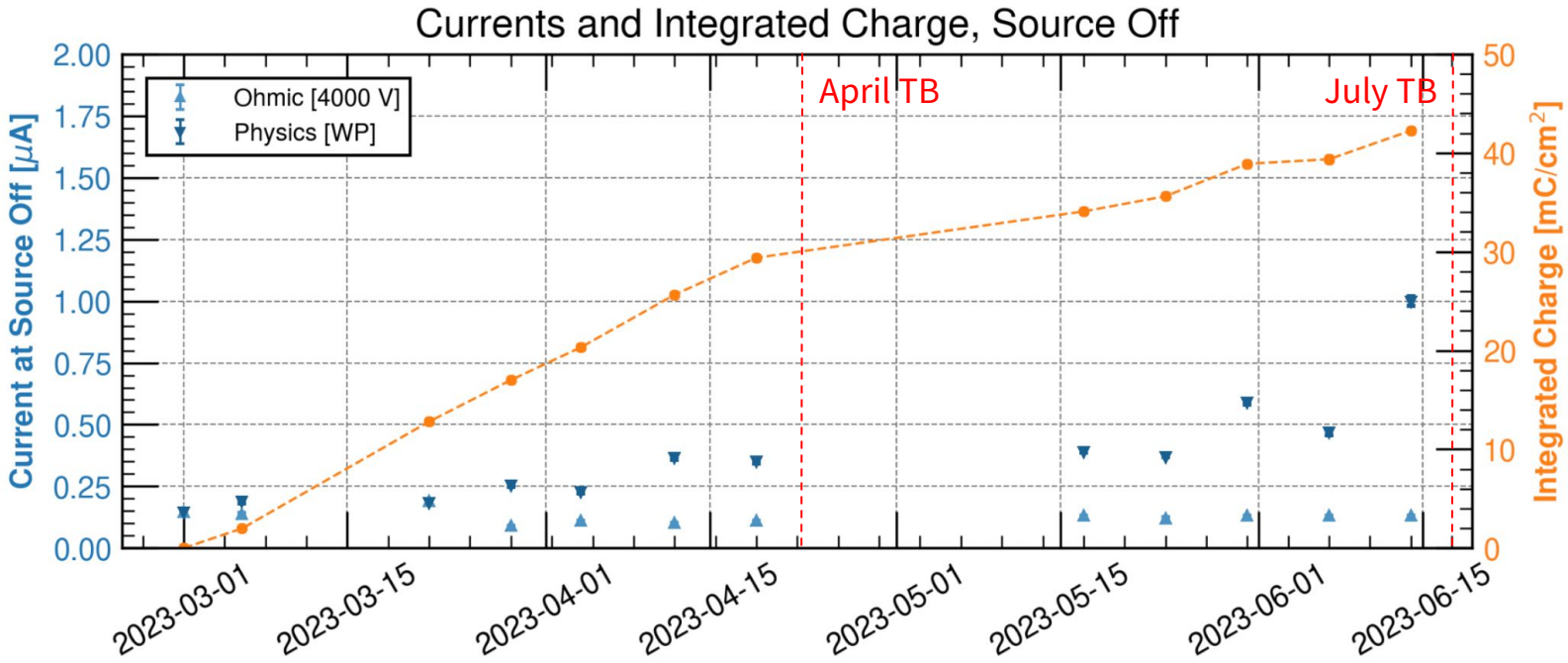
1. Source off
2. 100 Hz/cm²
3. 400 Hz/cm²



For Source On:

- Currents remain stable before 25 mC/cm²;
- Physics currents slightly increase after 35 mC/cm²;
- Similar behavior in all the detectors irradiated.

Long term studies: Irradiation Campaign



For Source Off:

- Ohmic currents remain stable up to 45 mC/cm^2;
- Physics currents start to increase after 35 mC/cm^2:

  -> Same trend for Source On values
- Similar behavior in all the detectors irradiated.

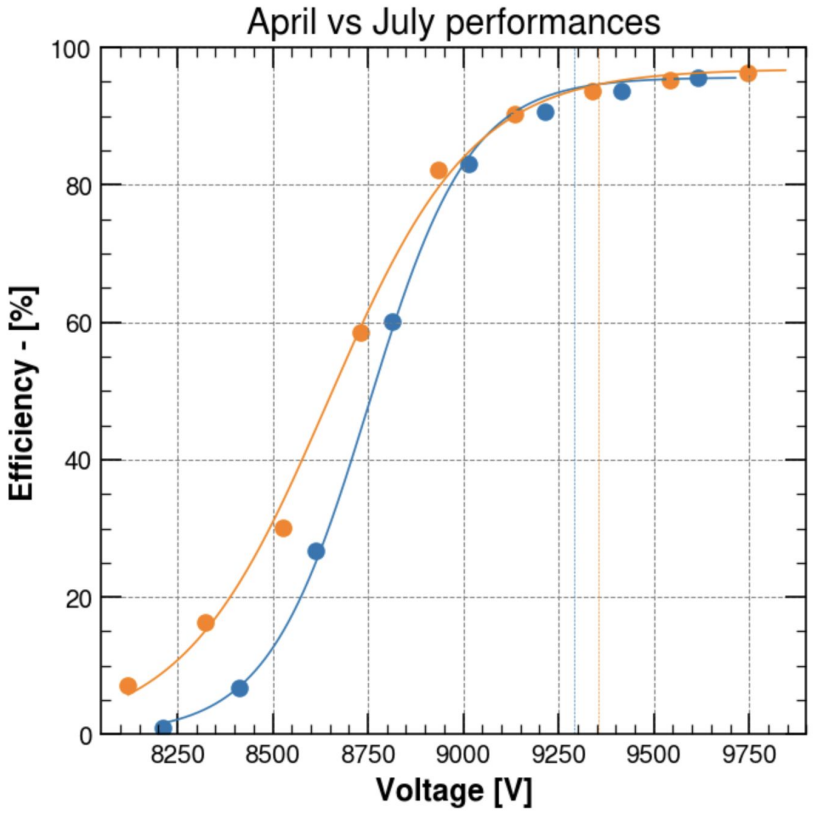
Under investigation:
implemented GC gas quality monitoring and planned gas system upgrade

Promising results obtain during ageing campaign:
detector stability validated up to 35 mC/cm^2 at least.

-> Monitoring of the detector status:
April and July test beam

Long term studies: Test Beam Performance

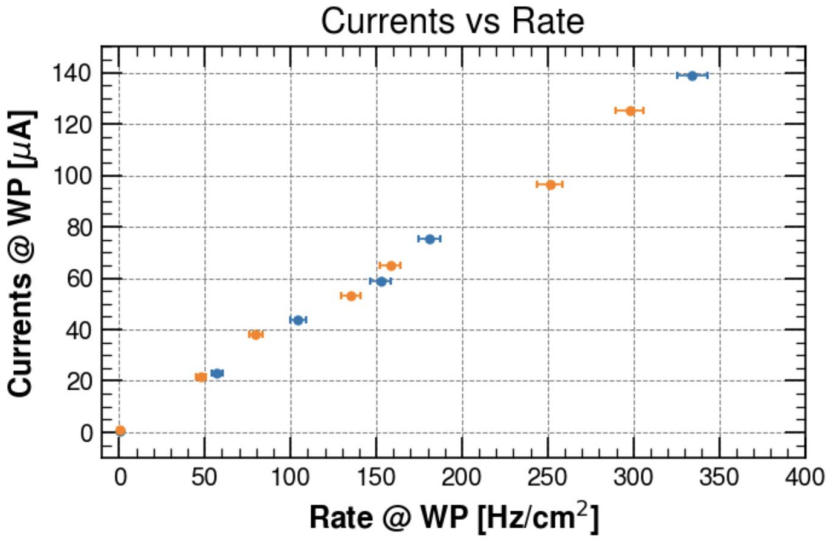
April 30% CO_2 CO2/R134a/iC_4H_{10}/SF_6 - 30/64.0/5.0/1
July 30% CO_2 CO2/R134a/iC_4H_{10}/SF_6 - 30/64.0/5.0/1



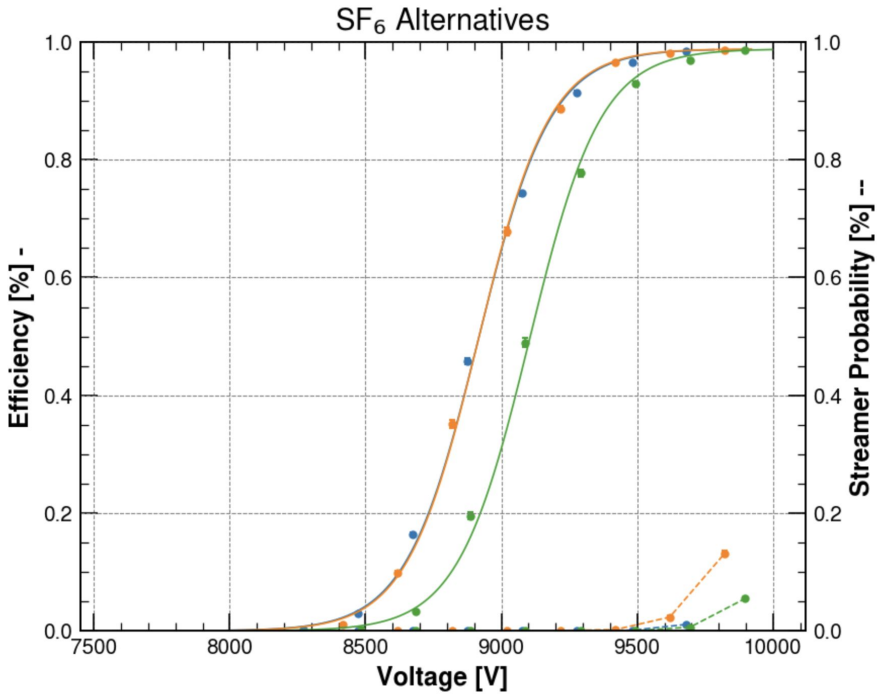
- Similar behavior between April and July test beam:
  - Similar Working Point and Efficiency;
  - Similar behavior Currents vs Rate.

No significantly change between the four months of irradiation, after 35 mC/cm^2 .

This gas mixture was recently validated for ATLAS Run 3.
-> to continue to reach HL-LHC prevision (~300 mC/cm^2)



SF_6 Alternatives in STD gas mixture

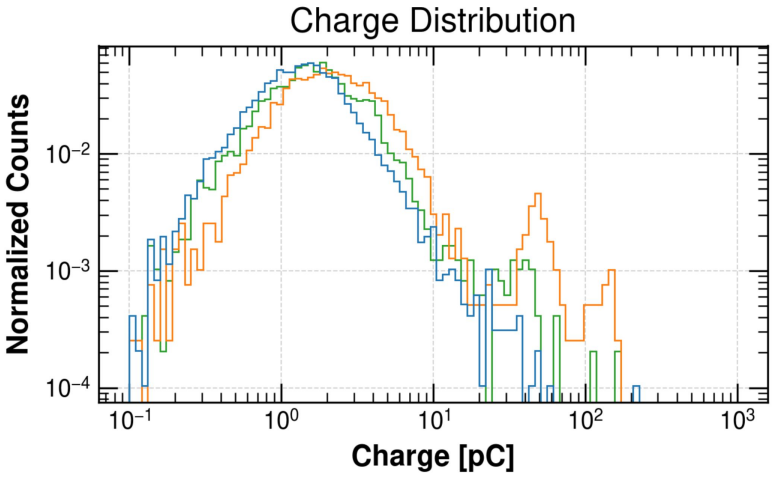


STD	$R134a/iC_4H_{10}/SF_6$	- 95.2/4.5/0.3
0.1% Novec 4710	$R134a/iC_4H_{10}$/Novec 4710	- 95.4/4.5/0.1
0.5% Amolea 1224yd	$R134a/iC_4H_{10}$/Amolea 1224yd	- 95/4.5/0.5

Tested as SF_6 Alternatives:

- Novec 4710;
- Amolea 1224yd.

Promising result for 0.1% Novec 4710 and 0.5% Amolea 1224yd substitution.



<u>0.1% Novec 4710</u>:

- Same STD WP
- Similar STD Streamer Probability

<u>0.5% Amolea 1224yd</u>:

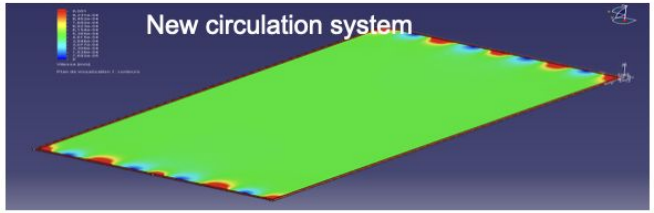
- +200 V WP
- Similar STD Streamer Probability

Glass MultiGap RPCs studies

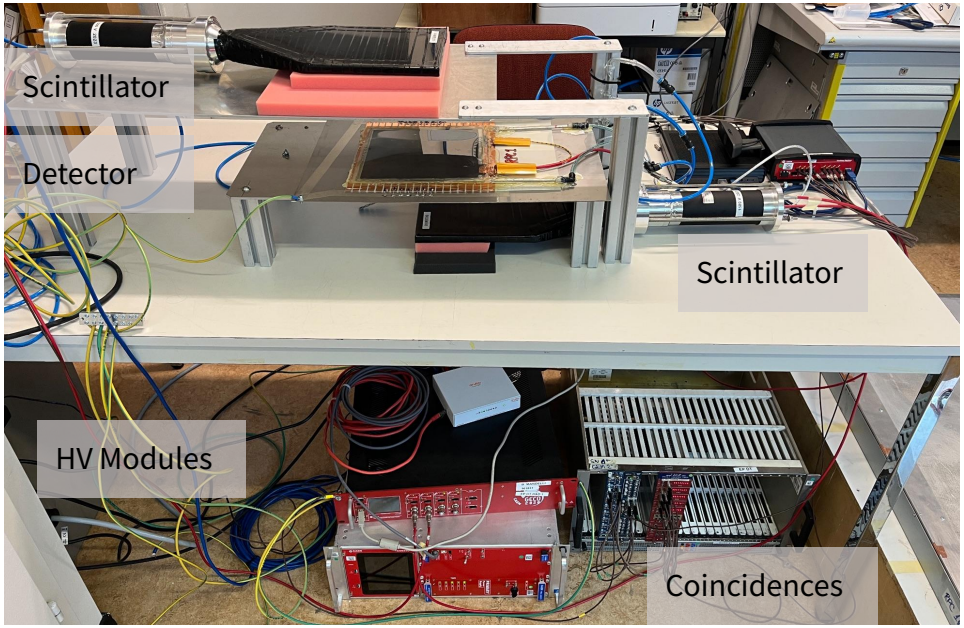
Collaboration with Université Claude Bernard Lyon I.

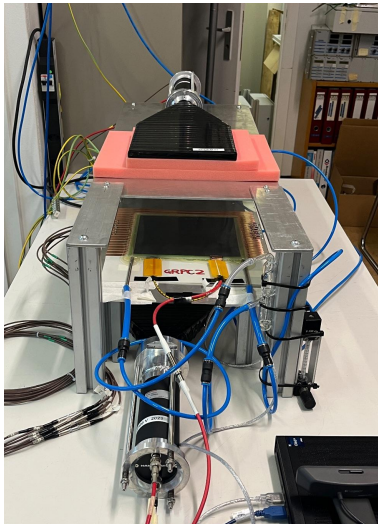
Glass MGRPC prototype:

- 4-7 gaps, 250 µm each;
- 7 readout strips, 1 cm wide.

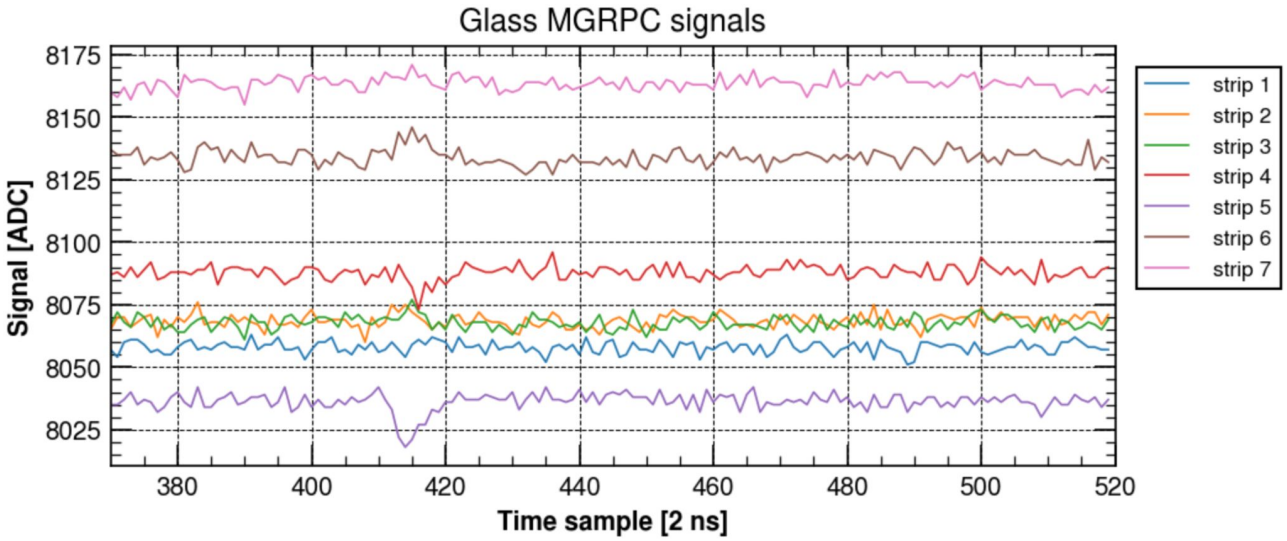


I. Laktineh, Eloisatron 2022





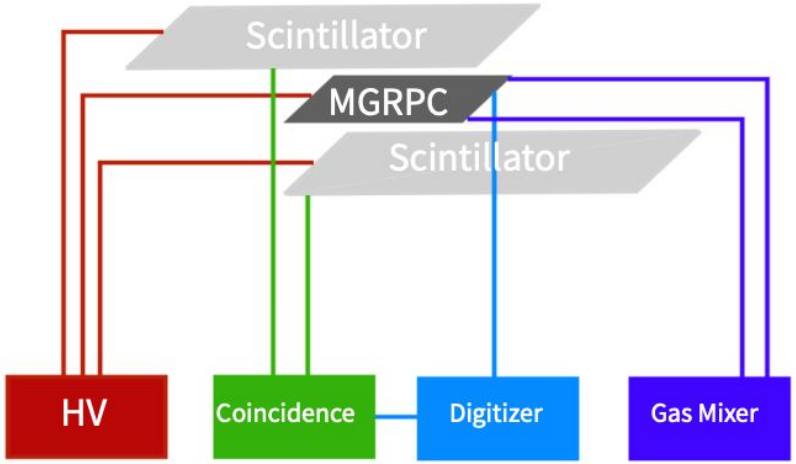
Glass MultiGap RPCs studies



New measurement campaign ongoing to test SF_6 alternative with Glass MultiGap RPCs:

- High SF_6 concentration used (about 7%);
- Dry gas mixture used:
  Compatibility with Novec 4710;
- Focus on time resolution performances.

-> then move to R134a alternatives.



Conclusion

R134a Alternatives:

- Performances of 30% - 40% CO_2 based gas mixture similar to the Standard Gas Mixture;
- Same Test Beam performance after 4 month of irradiation with 30% CO_2 gas mixture;
- 30% CO_2 gas mixture validated at the Gamma Irradiation Facility up to 35 mC/cm^2:
  -> ATLAS Run 3.

SF_6 Alternatives:

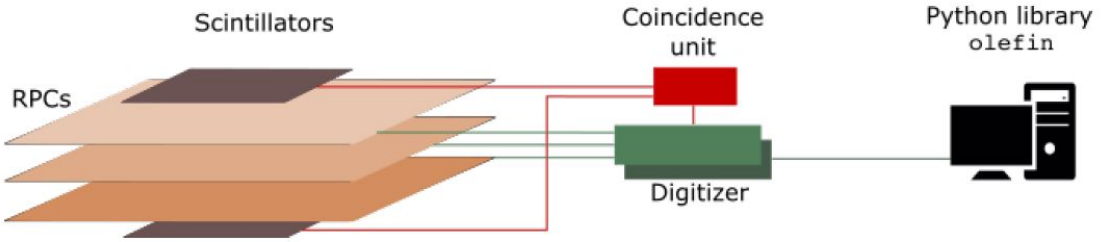
- Performances of 0.1% Novec gas mixture comparable to Standard Gas Mixture
  (= WP, ~ Str. Prob.);
- Performances of 0.5% Amolea 1224yd similar to Standard Gas Mixture
  (+200 V WP, ~ Str. Prob.).

Glass MGRPC studies:

- Initial studies on going for SF6 alternatives:
  - Novec 4710;
  - time resolution performances;
- R134a alternative studies foreseen.

Backup slides

Data analysis: Signal and Event analysis

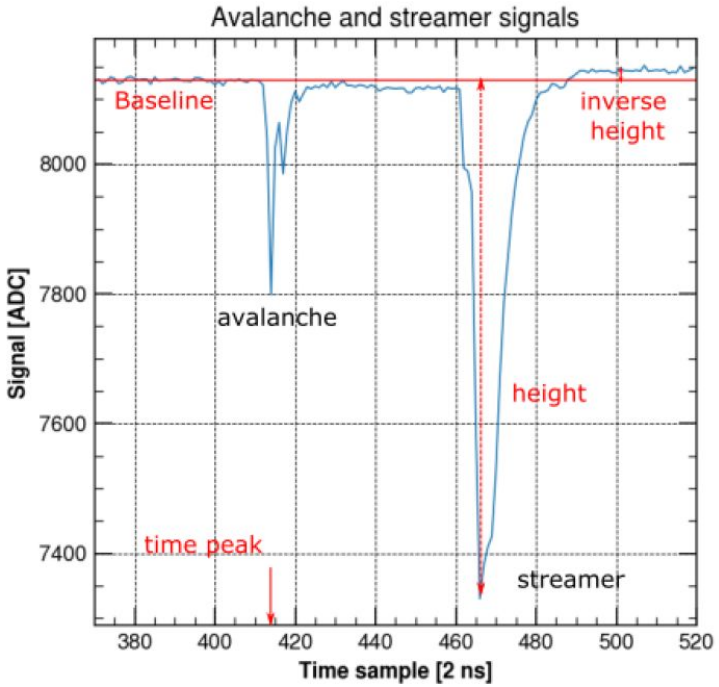


Signal Analysis
Single waveform

Event Analysis
All strips @ fixed trigger event

Acquistion Analysis
All event @ fixed HV

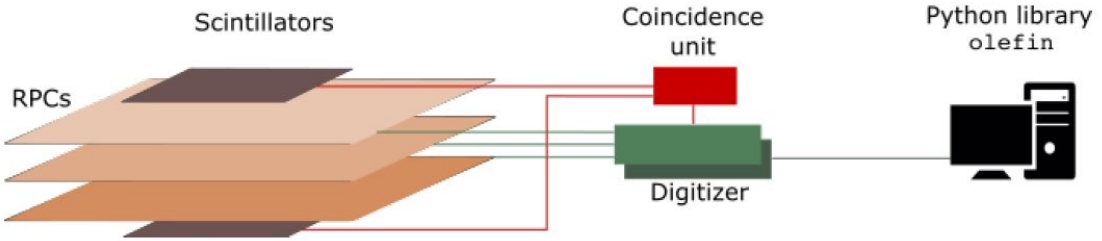
Run Analysis
Final features



Main features:

- Noise filtering;
- Baseline subtraction;
- Signal height, charge;
- Time of the minimum;
- Total charge;
- Cluster size.

Data analysis: Acquisition analysis



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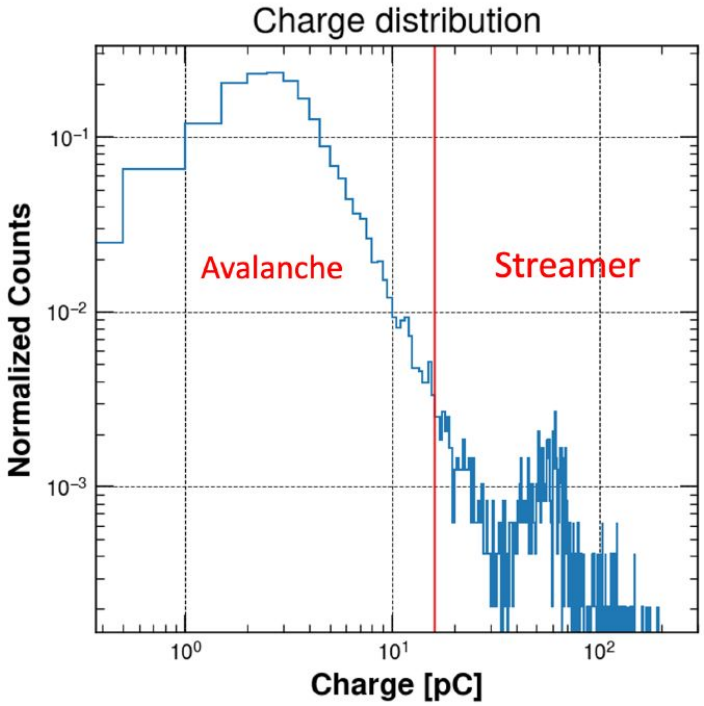
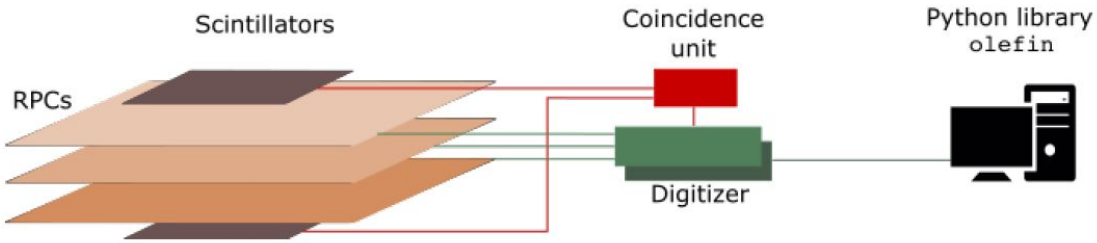


Main features:

- Efficiency;
- Streamer probability;
- Average charge;
- Average cluster size;
- Average time resolution.

Data analysis: Run analysis



Signal Analysis
Single waveform

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All strips @ fixed trigger event

Acquistion Analysis
All event @ fixed HV

Run Analysis
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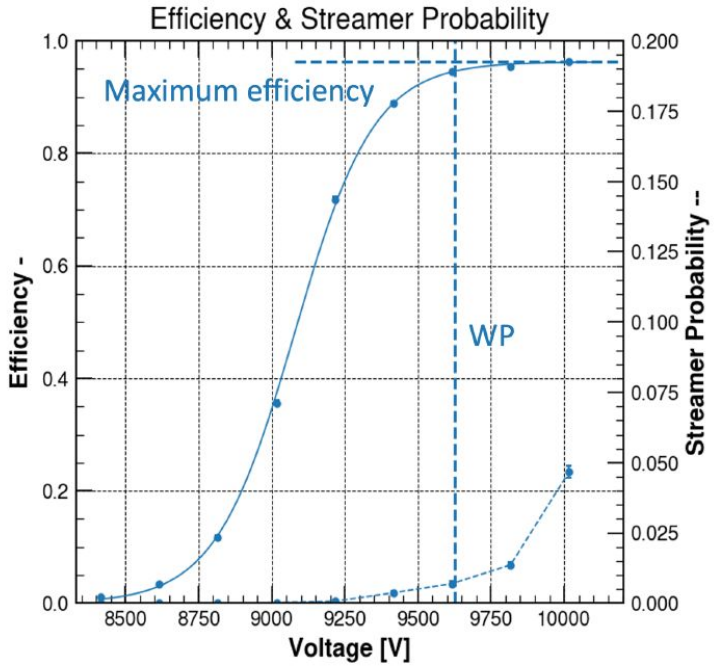

Main features at working point:

- Maximum efficiency;
- Working point (WP);
- Streamer probability;
- Charge;
- Cluster size;
- Time resolution.

Lab. CO_2 30% Avalanche charge increase