Study of environment-friendly gas mixtures for the Resistive Plate Chambers of the ATLAS phase-2 upgrade

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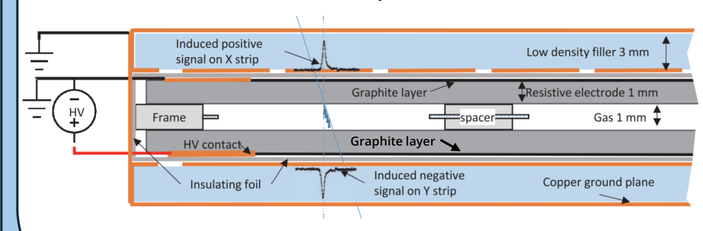
Introduction to the ATLAS RPC phase-2 upgrade for the High-Luminosity Large Hadron Collider (HL-LHC)

The Resistive Plate Chamber

The Resistive Plate Chambers (RPC) are very fast gaseous detectors with an excellent time resolution and are used to trigger on muons in the barrel region of the ATLAS Muon Spectrometer (MS)



(I)

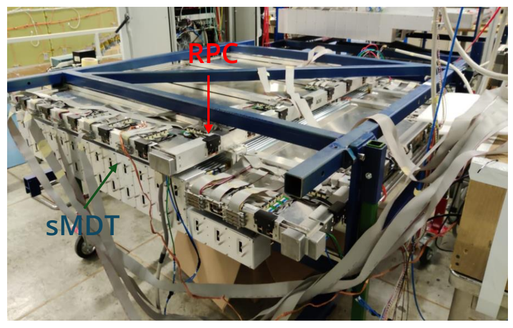
ATLAS RPC phase-2 upgrade (BI project)

The present RPC system allows to select muons with both low-pT (4 Gev < pT < 10 GeV) and high-pT (11 Gev < pT < 20 GeV) thresholds.

ATLAS phase-2 upgrade[1] : Installation of an additional layer of new generation of RPC ($|\eta|$<1.3) in order to improve the acceptance, redundancy and pT selectivity of the trigger in sight of the higher particle rate expected during HL-LHC.

(II)

The new generation of RPC for the HL-LHC (BI RPC)



The most relevant innovations of the system lie in the reduced gas gap width and in the new FE electronics. **The 1 mm gas gap width** allows to lower the operating voltage (WP ~5.4 kV) and to improve the time resolution (0.4 ns) wrt the legacy 2 mm RPC (WP~ 9.6 kV, time resolution ~1 ns)

The new Front-end electronics with a low threshold (1-4 fC) allows to reduce the total charge delivered inside the gas and improve the rate capability at fixed current, therefore with no impact on the detector aging

(III)

Search of an environment friendly gas mixtures for the upgrade RPC

The ATLAS standard gas mixture

94.7%$C_2H_2F_4$(primary target)/5%i-C_4H_{10}(quencher)/0.3%SF_6(streamer suppressor).

- High density gas ensuring high detection efficiency (98.6% for a 1 mm gas gap)
- Modest working current (μA) and high rate capability (10 kHz/cm^2)
- Comfortable avalanche-streamer separation (300 V for a 1 mm gas gap)

High Global Warming Potential (GWP ~ 1450) due to $C_2H_2F_4$**(GWP ~ 1450)** and SF_6 **(GWP ~ 22400)**

Search of an alternative gas mixture to reduce the ATLAS RPC greenhouse gas emissions (IV)

Alternative gas mixtures with GWP ~ 200

$C_3H_2F_4/CO_2$/i-C_4H_{10}/ SF_6

✓ **Pros :** Significant reduction of the GWP thanks to the full substitution of $C_2H_2F_4$ with $C_3H_2F_4/CO_2$ **(GWP ~1)**

✘ **Cons :** The double C-C bond of the $C_3H_2F_4$ increases its susceptibility to breakage, resulting in higher production of F^-radicals that can potentially accelerate aging

Gas mixtures studied

ECO3 : 25% $C_3H_2F_4$ /70% CO_2 /4% i-C_4H_{10} /1% SF_6

ECO2 : 35% $C_3H_2F_4$ /60% CO_2 /4% i-C_4H_{10} /1% SF_6

ECO55 : 55% $C_3H_2F_4$ /40% CO_2 /4% i-C_4H_{10} /1% SF_6

ECO65 : 65% $C_3H_2F_4$ /30% CO_2 /4% i-C_4H_{10} /1% SF_6

(V)

Alternative gas mixtures with GWP ~ 1100

$C_2H_2F_4/CO_2$i-C_4H_{10}/SF_6

✓ **Pros:** Minimal impact on the detector longevity is expected due to the similarity in composition to the standard gas

✘ **Cons:** not significant reduction of the GWP

Gas mixtures studied

65% $C_2H_2F_4$ /30% CO_2 /4% i-C_4H_{10} /1% SF_6
(Used in ATLAS since August 2023)

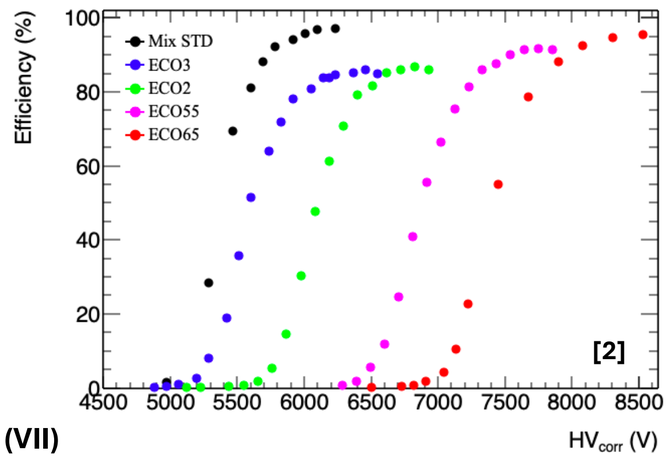
55% $C_2H_2F_4$ /40% CO_2 /4% i-C_4H_{10} /1% SF_6

65.5% $C_2H_2F_4$ /30% CO_2 /4% i-C_4H_{10} /0.5% SF_6

(VI)

Results at the Gamma Irradiation Facility (GIF++) at CERN with muon beam and under γ-irradiation

$C_3H_2F_4/CO_2$ based gas mixtures

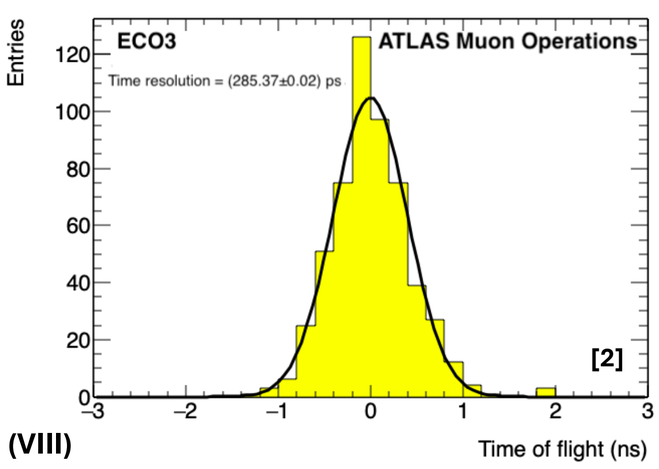


(VII)

$C_3H_2F_4$ concentration above 50% (ECO55 and ECO65) is needed in order to achieve efficiency > 90%.

The ECO65 efficiency (97%) is comparable with the one of the standard gas (98.5%)

Next step : study of the fluorine production due to the high $C_3H_2F_4$ concentration

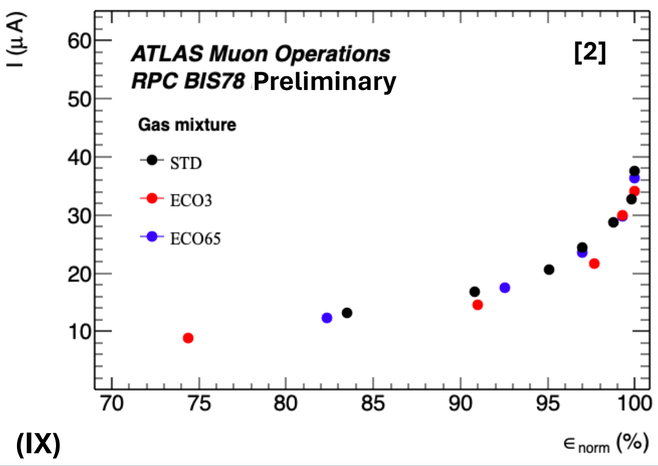


(VIII)

The time resolution is improved of 24% wrt the standard gas, due to the higher drift speed in CO_2 than $C_2H_2F_4$

σ_{STD} = (330 ± 18) ps

σ_{ECO3} = (285 ± 0.02) ps



(IX)

The **STD**, **ECO3** and **ECO65** gas mixtures present the same photon current at the same normalized efficiency when operated with (1-4) fC threshold

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Eco gases might guarantee the same aging and the same rate capability of the standard gas in this conditions

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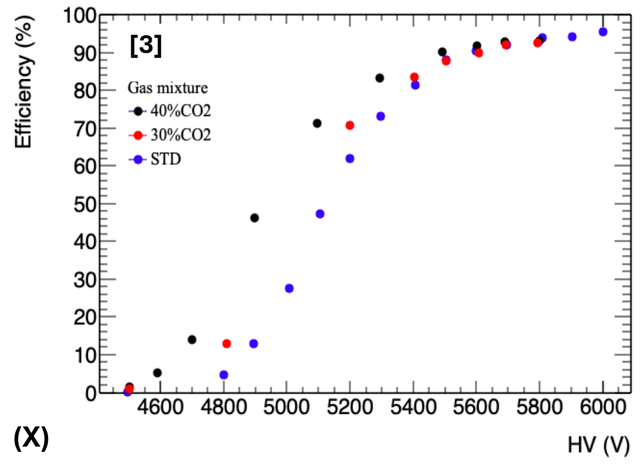
Possibility to work with high $C_3H_2F_4$ concentration

$C_2H_2F_4/CO_2$ based gas mixtures

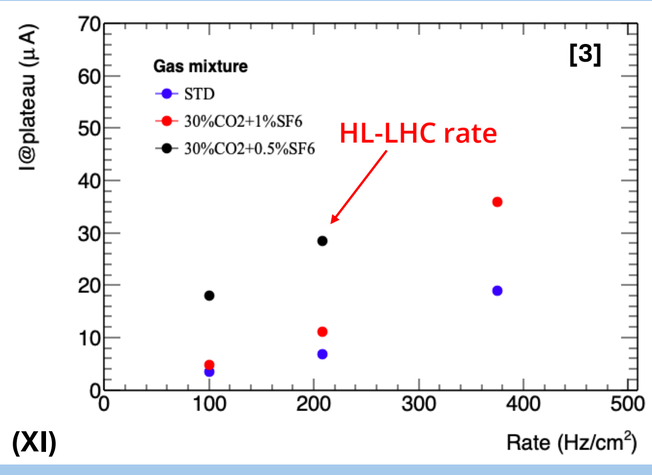


(X)

The gas mixtures containing CO_2 achieve efficiency of 94%, 2% smaller than the standard gas (96%)

Higher currents have been observed with the mixture containing 40% CO_2 due to the premature appereance of high-charge events (streamers and/or transition events)

The gas mixture with 30% CO_2 is the most promising



(XI)

Possibility to reduce the SF_6 from 1% to 0.5% to reduce the GWP

Same performance in terms of efficiency but the reduction of the SF_6 leads to an increase of the current due to the premature appearance of streamers

The gas mixture with 1% SF_6 is the most promising

Conclusions and next steps

The gas mixtures 65% $C_3H_2F_4$ /30% CO_2 /4% i-C_4H_{10} /1% SF_6 and 65% $C_2H_2F_4$ /30% CO_2 /4% i-C_4H_{10} /1% SF_6 are the most promising in sight of the operation of the ATLAS phase-2 RPC.
They show excellent performance in terms of efficiency, current under irradiation and time resolution.
The aging campaign is currently on going with the aim to certify these gas mixtures for their operation at the HL-LHC

(XII)

References :
(1) ATLAS Collaboration, CERN-LHCC-97-022, https://cds.cern.ch/record/331068
(2)G.Proto, 'Study of environment-friendly gas mixtures for Resistive Plate Chambers in view of future applications' https://cds.cern.ch/record/2873955/files/CERN-THESIS-2022-383.pdf
(3) https://indico.cern.ch/event/1237829/contributions/5609576/attachments/2749134/4784556/aging_confGP.pdf

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