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EP-DT Detector Technologies

Performance studies of RPC detectors operated with new environmentally friendly gas mixtures in presence of LHC-like radiation background

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Use of GHGs for RPC at CERN and possible eco-friendly alternatives

Characterisation of RPC with different eco-friendly gas mixtures

RPC operated with environmentally friendly gas mixtures at GIF++

GHG emissions at CERN



CERN GHG emissions from particle detectors

- Main contributor is C₂H₂F₄ used for ALICE, ATLAS and CMS RPC systems
- **Emissions mainly due to leaks** at detector level (fragile connectors) in ATLAS and CMS.
- On-going campaign for leaks reparation in LS2

 CERN strategies: see Roberto Guida's talk

 RPC
 RICH
 CERN strategies: see Roberto Guida's talk

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 where less harmful alternatives are widely available.
- **Preventing emissions** of F-gases from existing equipment by requiring checks, proper servicing and recovery



Prices are increasing in EU and availability in the future is not known. Reduction of use of $C_2H_2F_4$ is fundamental for next LHC Runs

Possible alternatives to C₂H₂F₄ and SF₆

New eco-friendly liquids/gases have been developed for industry as refrigerants and HV insulating medium... not straightforward for RPC operation R134a SF₆ $(C_2H_2F_4)$ **GWP 23900 GWP 1430** + others H_2C HFO-1234yf (flam) HFO-1234ze 3M[™] Novec[™] 5110 3M[™] Novec[™] 4710 $(C_3H_2F_4)$ $(C_{3}H_{2}F_{4})$ $(CF_{3}C(O)CF(CF_{3})_{2})$ $((CF_{a}), CFCN)$ **GWP** 4 **GWP** 6 **GWP** <1 **GWP 2100**

The goal is to find an <u>eco-friendly gas mixture</u> that is compatible with the <u>current ATLAS and CMS RPC systems</u> (i.e. no change in HV cables, FEB electronics, gas system, etc.)

Experimental set-up for RPC characterisation

Gas Mixing Unit - Up to 6 different gases - Gas system component validation CAEN Digitizer V1730 - 16 Channels - Resolution: 0.24 mV - Sampling: 500 MS/s **RPC** - 2 mm gap, high pressure laminate - read-out strips 2 cm Off-line data analysis: pulse charge, pulse height, time, etc. efficiency, avalanche/streamer ratio, **Gas Analysis** cluster size, time resolution, etc. - Gas Chromatograph and Mass Spectrometer - Ion Selective Electrode (F⁻ concentration)

HFO-based gas mixtures

HFO cannot directly replace C₂H₂F₄

- Higher applied voltage necessary (>12kV)
 - One C more with a double bond
- Small avalanche signal

Addition of He to lower the HV working point

- Helium helps in reducing the HV working point
 - in first approximation it doesn't take part in the avalanche processes
 - reduction of mixture density (gas pressure):
 +10%He —> 1 kV
- Addition of He in different concentrations
 - 20% 50% but increase of streamer probability when replacing C₂H₂F₄ with HFO
 - slight increase of SF₆ does not help
- Try with gas mixtures containing both HFO and C₂H₂F₄
 - HFO reduces the GWP
 - $C_2H_2F_4$ reduces the signal charge
- He discarded because of incompatibility problems with experiments
 - Presence of photomultipliers in the experimental caverns





HFO-based gas mixtures

Addition of CO₂ to lower the HV working point

- CO₂ is used as quencher gas in gaseous detectors
 - typically used in wire chambers and MPGDs
 - CO₂ has different quenching properties wrt iC₄H₁₀ (different absorption coefficient)
- CO_2 helps in reducing the HV working point: +10% CO_2 —> 800 V
- But streamer probability higher than RPC standard gas mixture
 - Necessary to keep a bit of $C_2H_2F_4$ and to increase the SF₆ concentration



SF₆ replacements

SF₆ has a very high GWP and it contributes for ~5% in the GWP of RPC gas mixture

3M[™] Novec[™] Dielectric fluids

- Very good alternative to SF₆ for arc quenching and insulation applications
 - Developed few years ago
 - Dielectric breakdown strength approximately 1.4-2 times that of SF₆
 - Especially used in HV industrial plants
- Novec 4710 (GWP 2100)
 - Very good performance but...
 - It may react with water
- Novec 5110 (GWP <1)
 - Very low GWP but..
 - RPC performance not optimal
 - sensitive to UV radiation

Other alternatives

- Looks for other gases not used only for HV plants
 - Other electronegative gases could work
- CF₃I (GWP 0.4)
 - Good performance but...
 - Toxic, mutagenic, ODP 0.008
- C₄F₈O (GWP ~8000)
 - Good performance at 1.5%
 - 1.5% C₄F₈O GWP equivalent to 0.5% SF₆



CERN Gamma Irradiation Facility (GIF++)

RPC performance studied at different gamma rates for 3 gas mixtures: standard gas mixture and two eco-friendly gas mixtures

★ 95.2/4.5/0.3 R134a/iC4H10/SF6
 ★ 22.25/22.25/50/4.5/1 R134a/HFO CO2/iC4H10/SF6
 ★ 27.25/27.25/40/4.5/1 R134a/HFO/CO2/iC4H10/SF6

- Gamma source

- ¹³⁷Cs of 14 Tb -> 662 keV gamma
- Lead filters to allow attenuation factors (ABS) between 1 and 46000

- Muon Beam

- 100 GeV and 10⁴ muons/spill (core beam size 10 cm x 10 cm)



ADS					
100	55.3				
220	41.2				
2200	3.75				
22000	0.774				



preparatior zone

Detector performance





- Test-beam measurements confirm laboratory tests
 - HV shift when operating with HFO gas mixtures
 - Higher streamer probability for HFO gas mixtures
- Detector currents are higher for both HFO gas mixtures
 - The voltage drop due to high radiation is higher with the HFO-based gas mixtures
- The efficiency as a function of HV_{gas} does not depends on the background radiation for the three gas mixtures
 - The streamer probability decreases with the increase of background radiation due to space charge effects

Beatrice Mandelli

Detector performance



- The avalanche charge is higher for these eco-friendly gas mixtures
- The streamer charge is lower for these eco-friendly gas mixtures
 - They decrease with the increase of radiation, probably due to charge development effects

Creation of impurities under irradiation

Impurities created from R134a and HFO breaking

- Under the effects of high background radiation and electric field, freon molecules break into fluorine radicals
 - Creation of F- radical free: very chemical reactive
 - Sub-products in the order of hundreds ppm
 - Accumulation in case of closed loop system
- Impurities present in the RPCs at LHC experiments in Run 2
 - Not well know the maximum limit for safety of the detector





HFO breaks ~10 times more easily than C₂H₂F₄ ↓ Is there any risk for long-term detector

operation?

Conclusions

R&D goal: to find an eco-friendly gas mixture that is compatible with the current ATLAS and CMS RPC systems

Eco-friendly gas mixtures for RPCs

- Direct substitution of C₂H₂F₄ and SF₆ with corresponding eco-gases available in the market is not suitable to achieve RPC performance needed
- No many alternatives available on the market

Characterisation of RPCs with different eco-friendly gas mixtures

- More than 50 gas mixtures tested (often gas mixtures made of 4-6 components)
- Necessary to add a gas to lower the HV working point of HFO-based gas mixtures
- Few eco-eco-friendly gas mixtures show similar properties with respect to standard gas mixture

RPC operation with eco-friendly gas mixtures under high background radiation

- RPC tested up to ~ 300 Hz/cm²
- Higher currents and streamer probability with HFO-based gas mixtures
- HFO seems to break more easily than C₂H₂F₄: studies on-going to understand possible effects

Back-up slides

Summary table of gas mixtures tested

More than 50 gas mixtures tested

	Chem struc	GWPmix	HV (V)	Streamer (%)	Pulse charge (pC)	∆V Eff- Stream (V)	Clu Size (strip)
R32-iC ₄ H ₁₀ -SF ₆ 0.6	С	1030	7500	14	0.5 / 6.5	600	1.5
R134a-iC4H10-SF6 0.3	C-C	1490	9600	1.5	0.5/6	1000	1.5
R152a-iC ₄ H ₁₀ -SF ₆ 0.6	C-C	430	10000	10	1 / 8.5	760	1.6
R245fa-iC ₄ H ₁₀ -SF ₆ 0.6-He 50	C-C-C	1260	6600	20	1/7	610	2
HFO-iC ₄ H ₁₀ -SF ₆ 0.3-Ar 42.5	C=C-C	130	8900	70	2/15	160	4
HFO-iC4H10-SF6 0.6-He 50	C=C-C	370	9000	20	1.5/8	700	4
HFO-R134 37.45-iC ₄ H ₁₀ -SF ₆ 0.6-He 20	с=с-с	890	10500	1.8	0.5/6	970	1.6
HFO-R134a 50-iC ₄ H ₁₀ -He 20	C=C-C	430	10800	50	1.5 / 8	400	2.5
HFO-R134a 22.5 -iC ₄ H ₁₀ -CO ₂ 50- SF ₆ 1	C=C-C	560	10500	5	1.5 / 7.5	950	1.5

- C and C2 structures -> direct operation
- C3 structure (HFO) —> addition of Ar, He or CO₂
 - Ar brings to high streamer probability
 - He and CO₂ based gas mixtures look promising but need to add more SF₆
- Still necessary to have R134a in the mixture to be competitive to standard gas mixture

Why is difficult to find good GHG alternatives?

Eco-friendly alternatives are developed for industry and not for gaseous detectors!

- Ionisation processes not well understood
 - What are the differences between HFO and C₂H₂F₄?
 - Substitution 1 by 1 does not work in RPC detectors
- Even more difficult in case of LHC RPC systems
 - not possible to change FEB, HV cables, etc.
- Operation can be difficult
 - Flammability, toxicity, liquefaction, sub-products, etc.

The GWP is determined by atmospheric lifetime and IR absorption cross sections



Gas recirculation

RPC detectors at LHC are working under gas recirculation: important to validate RPC operation under gas recirculation and high background rate

- RPCs operated under gas recirculation with ecofriendly gas mixture in laboratory
 - Cosmics (low currents)
 - Performance were stable
- Now RPCs under gas recirculation at GIF++
 - Very high gamma rate
 - Up to 100% recirculation
 - Creation of impurities with radiation
- Monitoring of currents and performance



Gas mixture: 22.25/22.25/50/4.5/1R134a/HFO/CO₂/iC₄H₁₀/SF₆



What about other HFCs?

