

# XVII Conference on Resistive Plate Chambers and Related Detectors



## Report of Abstracts

Abstract ID : 1

# Performance and long-term ageing studies on Eco-Friendly Resistive Plate Chamber detectors

## Content

In High Energy Physics Resistive Plate Chamber (RPC) detectors are typically operated in avalanche mode, making use of a high-performance gas mixture whose main component, Tetrafluoroethane ( $C_2H_2F_4$ ), is classified as a fluorinated high Global Warming Potential greenhouse gas.

The RPC EcoGas@GIF++ Collaboration is pursuing an intensive R&D on new gas mixtures for RPC detectors to explore environmentally friendly alternatives complying with recent European regulations. During the last few years, the performance of RPCs characterized by different layouts and read-out electronics have been studied with Tetrafluoropropene ( $C_3H_2F_4$ )- $CO_2$  based gas mixtures at the CERN Gamma Irradiation Facility. A long-term ageing test campaign was launched in 2022 and is still on-going. In 2023 and 2024 all detector systems underwent evaluation by means of dedicated beam tests.

Preliminary results on these studies will be presented in this talk together with their future perspectives.

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**Status:** ACCEPTED

Submitted by **PASTORE, Alessandra** on **Friday, 9 February 2024**

Abstract ID : 2

# Improved streamer inception criterion to numerically estimate streamer probabilities of resistive plate chambers for environmentally friendly gas mixture alternatives

## Content

F-gas regulations foresee restrictions and bans of highly potent greenhouse gases such as R134a and SF<sub>6</sub> used in RPCs. Current research is dedicated to finding an environmentally friendly gas mixture replacement for RPCs. Simulations of RPCs are crucial in supporting and extending the mostly experimental-based research of identifying suitable eco-friendly alternatives.

To date, there is no comprehensive quantitative description of the avalanche-to-streamer transition in uniform electric fields. Particularly in the context of RPCs, this is essential for estimating the streamer probability of a certain mixture, to accurately predict the avalanche-streamer separation. An improved form of the classical streamer criterion introduced predicting the transition phase to overcome this problem. The criterion is entirely based on the space-charge field of the many superimposed avalanches due to primary ionization. A rigorous simulation of the single-gap high-pressure laminated RPC (HPL-RPC) is developed to integrate and test the improved streamer criterion along with the capability to estimate other performance parameters, for example, the detector's efficiency. The simulation is based on Garfield++ and is extended for this study to include the axis-symmetric space-charge model originally developed by Christian Lippmann. Additionally, a dedicated electrical signal transmission system is modeled to accurately replicate the experimental setup. Validation of the simulation is achieved through comparison with acquired performance data of the experimental HPL-RPC setup at the GIF++ muon beam experiment for several eco-friendly gas mixtures.

This contribution intends to present the detailed modeling of the RPC simulation and to show that for CO<sub>2</sub>-based standard mixtures (CO<sub>2</sub>/R134/i-C<sub>4</sub>H<sub>10</sub>/SF<sub>6</sub>) the experimentally measured avalanche-streamer separation is accurately modeled by the improved streamer criterion.

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**Presenter:** STOCCO, Dario (ETH Zürich)

**Status:** ACCEPTED

Submitted by **STOCCO, Dario** on **Friday, 3 May 2024**

Abstract ID : 3

## Characterization of Glass Multigap RPC Detector with alternative gas to R134a and SF6

### Content

Glass Multigap Resistive Plate Chamber (MRPC) detectors are primarily used for their excellent time resolution properties in High Energy Physics and Tomography application. Typically, they are operated with a freon-based gas mixture containing C<sub>2</sub>H<sub>2</sub>F<sub>4</sub> (R134a) and SF<sub>6</sub>, both greenhouse gases (GHG) with high global warming potential.

This study focuses on the construction and characterization of new prototypes of 4-gap glass MRPC detectors, along with their performance evaluation. The construction employs an alternative method for spacer placement, using one-side glued circular spacers, making the construction process easier.

The detector's performances with alternative gas mixtures will be presented. Initially, a partial substitution of the R134a with CO<sub>2</sub> and HFO will be considered, followed using NOVEC 4710 as an SF<sub>6</sub> alternative. The detectors are characterized with cosmic muons to evaluate efficiency, current, streamer probability, prompt charge, and cluster size.

Finally, the time resolution of the different gas mixture will be analyzed, using the combination of two MRPC and the PETIROC 2A front-end ASIC.

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**Presenter:** VERZEROLI, Mattia (Universite Claude Bernard Lyon I (FR))

**Status:** ACCEPTED

Submitted by **VERZEROLI, Mattia** on **Friday, 10 May 2024**

Abstract ID : 4

## Carbonless and self-sealed MRPC for MARQ experiment in Japan

### Content

The MARQ (Multi-Purpose Analyzer for Resonance and Quark dynamics Spectrometer) experiment, a future experiment in Japan, involves the construction of two types of Multigap Resistive Plate Chambers (RPCs): Time-Of-Flight RPCs and tracking RPCs. The former will be utilized for  $\pi/K/p$  separation below 1.7 GeV/c, while the latter will serve for muon identification downstream. However, the development of these detectors has encountered various challenges. Notably, the supplier of carbon tape is no longer available. To solve this problem, we built a carbonless RPC in configuration of 1 stack, 5 gaps, a 0.26mm gap, and a 20cm x 20cm active area. The carbonless electrode consists of an array of 1cm x 1cm copper pads interconnected with several MOhm resistors to simulate the function of the carbon electrode and reduce the chamber's current draw during operation. The side advantage of carbonless is the relatively easier production since the electrode and readout strip are integrated into the same PCB. Additionally, we have encountered constant issues with gas leaks in the glue-sealed Acrylic cases, attributed to transportation damage. To address this, we designed an O-ring gas-sealed chamber with the electrode-readout PCBs as the top and bottom covers, named self-sealed chamber. The material budget is reduced and the production is also simplified with this design. A recent interest of replacing fishline with Mylar spacer is also tested with this chamber. The beam tests were performed at SPring-8 to evaluate the performance. We will present the development and share the test results.

**Primary authors:** CHANG, Wen-Chen (Academia Sinica (TW)); Dr CHU, Ming-Lee (Academia Sinica); HSIEH, Chia-Yu (Academia Sinica (TW)); KOIKE, Ryotaro (Kyoto University); TOMIDA, Natsuki

**Presenter:** HSIEH, Chia-Yu (Academia Sinica (TW))

**Status:** ACCEPTED

Submitted by **HSIEH, Chia-Yu** on **Tuesday, 14 May 2024**

Abstract ID : 5

## Studies of F- Impurities Formation in ALICE MID RPC detectors: A Comparison between RUN2 and RUN3

### Content

ALICE MID system consists of 72 single-gap Resistive Plate Chamber (RPC) detectors, operated with a gas mixture composed of C<sub>2</sub>H<sub>2</sub>F<sub>4</sub> (R134a)/iC<sub>4</sub>H<sub>10</sub>/SF<sub>6</sub> - 89.7%/10%/0.3%, along with about 40% of relative humidity. The combined effects of background irradiation and the electric field within the detector's gas result in the production of F- ions and F-based impurities, also due to the high concentration of fluorinated gases used to operate the detector.

During RUN2, a preliminary setup was installed to monitor the formation of these impurities, which could lead to the formation of hydrofluoric acid, potentially damaging the detectors and the gas system irreparably. This setup successfully demonstrated the production of HF and other impurities, and the purifier's capability to trap them, ensuring the feasibility of operating the gas system in recirculation mode.

During LS2, the set up was improved and was commissioned for the restart of RUN3. It consists of a gas chromatograph to monitor the correct composition of the gas mixture and F-based impurities and an Ion Selective Electrode (ISE) setup for detecting the F- concentration.

This study provides a comprehensive overview of the creation of impurities in the RPC detectors under irradiation. Furthermore, it presents a comparative analysis between the results obtained during RUN2 and those ongoing in RUN3.

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**Status:** ACCEPTED

Submitted by VERZEROLI, Mattia on Friday, 17 May 2024

Abstract ID : 6

# A TOF-tracker MRPC for simultaneous measurements of timing and position at the pi20 beamline of J-PARC

## Content

In the Hadron Hall of J-PARC, we plan to measure the cross sections for exclusive Drell-Yan reaction ( $\bar{p} \rightarrow ^+ n$ ) aiming to determine the generalized parton distribution functions (GPDs) of nucleons. The experiment will be conducted in the  $\pi 20$  beamline and MRPCs will be utilized for muon identification. An area of  $1.8 \text{ m} \times 2.4 \text{ m}$  will be covered by a MRPC that is designed to identify a muon pair from the Drell-Yan reaction. It is important to distinguish the desired muon pair from random combinatorial muons. For that purpose, we designed a MRPC that can measure timing and position simultaneously, which we call a TOF-tracker MRPC. We have designed 2-dimensional read-out strips for both zero-degree and 90-degree configurations. In the zero-degree read-out (X-direction), we utilize positive signals, while in the 90-degree configuration (Y-direction), we employ negative signals. The configuration is 1 stack,  $0.26 \text{ mm} \times 5 \text{ gaps}$ ,  $500 \text{ mm} \times 1000 \text{ mm}$  active area, and a 5 mm of strip pitch. We conducted a beam test at the LEPS2 beamline in the SPring-8 facility. We achieved more than 99 % efficiency, 65 ps time resolution, and 0.8 mm position resolution. The results satisfy the performance requirements, which are 99 % efficiency, 100 ps time resolution, and 1 mm position resolution. However, we are facing a shortage of carbon sheets that we have been using for the HV electrodes. As an alternative, we are exploring the possibility of utilizing several kinds of polymer-based conductive coatings. The performance of the prototype TOF-tracker and the test results of alternative electrodes will be presented in this report.

**Primary authors:** CHANG, Wen-Chen (Academia Sinica (TW)); CHU, Ming-Lee (Academia Sinica(TW)); HAYASHI, Hutaba (Osaka University); HSIEH, Chia-Yu (Academia Sinica (TW)); KOIKE, Ryotaro (Kyoto University); OKAZAKI, Rintaro (Kyoto University); SUZUKI, Ken (RCNP); TOMIDA, Natsuki (Kyoto University); UDA, Ryusuke (Osaka University)

**Presenter:** KOIKE, Ryotaro (Kyoto University)

**Status:** ACCEPTED

Submitted by **KOIKE, Ryotaro** on **Wednesday, 22 May 2024**

Abstract ID : 7

## A Novel Anti-Aging TBS MRPC For CBM-TOF

### Content

The Compressed Baryonic Matter (CBM) experiment is an ongoing high-rate fixed-target experiment at the Facility for Antiproton and Ion Research (FAIR) in Germany. The Time-of-Flight (TOF) system in the CBM experiment subjects Multi-gap Resistive Plate Chambers (MRPCs) to flux rates ranging from several hundred Hz/cm<sup>2</sup> to 25 kHz/cm<sup>2</sup>. In such high-rate environments, traditional MRPCs with fishline spacers experience aging effects due to the extremely strong electric field and insufficient gas exchange near the fishlines, leading to ionization of the working gas and the formation of deposits, thereby affecting the performance of MRPCs.

To address this issue, we propose a novel solution by replacing traditional fishline spacers with cylindrical thermal bonding spacers (TBS) as support structures, based on MRPC3, one of the CBM-TOF components, developing a new type of TBS MRPC detector. We tested the detector's performance under cosmic rays. And particularly, we conducted comparative testing with traditional MRPCs, focusing on the performance of the TBS MRPC in high flux environments under X-ray irradiation. Furthermore, we performed a microscopic study using scanning electron microscopy (SEM) to inspect the glass electrodes before and after irradiation. The research results suggest that, under high irradiation flux environments, the TBS MRPC detector shows better anti-aging performance compared to traditional MRPCs with fishline spacers. Based on the research, the TBS MRPC is expected to be used in the future CBM experiment.

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**Presenter:** Mr YAO, Ming (USTC)

**Status:** ACCEPTED

Submitted by **YAO, ming** on **Thursday, 23 May 2024**



Abstract ID : 8

# Noise and Performance Study of Sealed MRPC Detectors with Different Spacers Based on Simulation and Cosmic Ray Test

## Content

MRPC detectors, known for their excellent time resolution, are widely used in Time of Flight (TOF) systems for high-energy physics experiments. The CBM experiment requires detectors that can handle an intensity greater than 20 kHz/cm<sup>2</sup>. MRPCs with low-resistance glass and pad spacers meet these requirements. Tsinghua University undertook the development and production of the CBM-TOF MRPC2. This paper primarily investigates three main aspects.

Firstly, this paper presents a theoretical study on the noise performance of sealed MRPCs based on simulations, discussing the noise performance of pad spacer sealed and fishline spacer sealed MRPCs.

Secondly, cosmic ray tests with the self-trigger method were conducted on pad spacer and fishline spacer MRPCs. High voltage scans were performed to test the dark currents and noise signal frequency as a function of voltage. The noise count rate of both types of MRPC follows an exponential increase with operating voltage. For pad-sealed MRPCs, under the same high voltage, the noise rate per unit area is approximately one percent of the fishline-sealed MRPCs. Additionally, the study obtains hit position maps of the self-trigger cosmic ray tests, which noise signals occupy the majority. The position maps clearly show higher noise rates at the spacer locations, and a statistical analysis of the noise rate differences between the spacer locations and other parts of the detector is also conducted. This research systematically studies the noise principles and performance of pad spacer and fishline spacer sealed MRPC detectors.

Finally, an external-trigger cosmic test scans the efficiency and time resolution performances of both MRPC2 types. Both sealed MRPC2 with different spacers reached a time resolution of better than 90 ps and an efficiency of better than 95% at a high voltage of 5700V. Additionally, a coincidence self-trigger cosmic test is also held, providing a faster testing method for the performance of MRPC2 in mass production.

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**Presenter:** Mr SUN, Kai (Tsinghua University)

**Status:** ACCEPTED

Submitted by **Mr SUN, Kai** on **Monday, 27 May 2024**

Abstract ID : 9

## Mass production and quality control of CEE iTOF-MRPC

### Content

Multi-gap resistive plate chamber (MRPC) has been adopted to construct the inner Time-of-Flight (TOF) detector for the CEE experiment at HLEF. Its mass production started in May 2024. The production procedure and related quality control (QC) are described. A preliminary status of the MRPC production and the test results with cosmic rays is given. The inner TOF covers a total area of approximately  $3.4 m^2$  and uses 24 high time resolution MRPC modules. With strict QC throughout the production process, the cosmic ray test results indicate that the time resolution is better than 40 ps and the efficiency exceeds 95%.

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**Status:** ACCEPTED

Submitted by 周, 英杰 on **Tuesday, 28 May 2024**

Abstract ID : 10

## New RPC Gas Mixtures for Sustainable Operation in the CMS Experiment

### Content

The current operation of the Resistive Plate Chamber (RPC) system within the CMS experiment involves approximately 95% tetrafluoroethane ( $C_2H_2F_4$ , TFE). However, in response to climate change concerns, the European Union has instituted a ban on TFE owing to its elevated Global Warming Potential (GWP), resulting in an associated increase in market prices. In this framework, shared endeavors within the RPC EcoGas@GIF++ Collaboration, have been dedicated to investigating novel ecological gas mixtures based on tetrafluoropropene ( $C_3H_2F_4$ , HFO-1234ze) to ensure the sustainable functionality of RPCs. This presentation will delve into the performance outcomes derived from improved RPC gas gaps operating on HFO/ $CO_2$ -based mixtures as ecologically viable alternatives, particularly in anticipation of the High Luminosity LHC phase. Additionally, the utilization of TFE/ $CO_2$  mixtures will be explored as a pragmatic strategy to swiftly alleviate gas-related operational costs.

**Primary author:** COLLABORATION, CMS

**Presenter:** COLLABORATION, CMS

### Comments:

The abstract is submitted on behalf of the CMS collaboration. Speaker to be announced. Please, accept it as a talk.

**Status:** ACCEPTED

Submitted by **PAVLOV, Borislav** on **Tuesday, 28 May 2024**

Abstract ID : 11

## CMS RPC performance and operation in LHC Run 3

### Content

The CMS experiment has collected more than  $74 \text{ fb}^{-1}$  of proton-proton collision data at a 13.6 TeV center-of-mass energy in Run 3 data taking (2022, 2023 and early 2024). The CMS RPC system faces the challenge of the LHC expected delivered instantaneous luminosity of up to  $7.5 \times 10^{34} \text{ cm}^{-2}\text{s}^{-1}$ , providing redundant information for robust muon triggering, reconstruction and identification. To ensure stable data taking, the CMS RPC collaboration has performed a series of detector operation, calibration and performance studies, including the development and maintenance of various software monitoring tools. The detector operation and overall performance at 13.6 TeV, as well as the encountered problems and their corresponding solutions will be presented.

**Primary author:** COLLABORATION, CMS

**Presenter:** COLLABORATION, CMS

### Comments:

The abstract is submitted on behalf of the CMS collaboration. Speaker to be announced. Please, accept it as a talk.

**Status:** ACCEPTED

Submitted by **PAVLOV, Borislav** on **Tuesday, 28 May 2024**

Abstract ID : 12

# CMS RPC Background studies in LHC Run 2 and Run 3

## Content

The Compact Muon Solenoid (CMS) is a general purpose experiment to explore the physics of the TeV scale in pp-collisions provided by the CERN LHC. Muons constitute an important signature of new physics and their detection, triggering, reconstruction and identification is guaranteed by various sub-detectors using different detection systems: Drift Tubes (DT) and Resistive Plate Chambers (RPC) in the central region and Cathode Strip Chambers (CSC) and RPC in the endcap. During Run 2 and Run 3 the higher instantaneous luminosity leads to a substantial background in the muon system. In this contribution we will describe the method used to measure these backgrounds in the RPC detectors. The analysis is based on data collected in pp collisions at 13 and 13.6 TeV in 2018 and 2022-2023, respectively, with instantaneous luminosities up to  $2.2 \cdot 10^{34} \text{ cm}^{-2}\text{s}^{-1}$ . Thorough understanding of the background rates provides the base for the upgrade of the muon detectors for the High-Luminosity LHC, where the instantaneous luminosity will reach  $5\text{-}7.5 \cdot 10^{34} \text{ cm}^{-2}\text{s}^{-1}$ , resulting in 140-200 simultaneous pp-collisions. We will discuss in detail the origin and characteristics of the background introduced by the pp-collisions, we will analyze the response of the RPC detectors and illustrate the dependence of the background on the instantaneous luminosity and the LHC fill scheme. The reported analysis allows to distinguish and showcase the contributions from long-lived background rates and the promptly induced background.

**Primary author:** COLLABORATION, CMS

**Presenter:** COLLABORATION, CMS

**Comments:**

The abstract is submitted on behalf of the CMS collaboration. Speaker to be announced. Please, accept it as a talk.

**Status:** ACCEPTED

Submitted by **PAVLOV, Borislav** on **Tuesday, 28 May 2024**

Abstract ID : 13

## Novel ideas for CMS L1 trigger using RPC timing

### Content

The quest for understanding the universe's fundamental constituents and their interactions leads us to probe beyond the Standard Model of particle physics. Long lived particles (LLP) offer a tantalizing glimpse into such new physics, potentially providing clues about dark matter, supersymmetry, and other beyond-the-Standard-Model theories. This talk explores possible ways to revolutionize the search for LLP at the Compact Muon Solenoid (CMS) experiment, specifically tailored for the upcoming HL-LHC phase. In the talk we discuss innovative trigger algorithms and offline analysis techniques designed to detect LLP more effectively than ever before. The objective is to focus on particles that either decay into SM muons in the outer layers of the detector or are inherently muon-like heavy stable charged particles (HSCP). Special attention will be given to the capabilities of the CMS Muon system, especially the impact of the improved timing provided by the newly installed improved Resistive Plate Chambers (iRPCs) and the enhanced existing Resistive Plate Chambers (RPCs). This discussion will highlight the potential of these technological advances to transform our search for new physics.

**Primary author:** COLLABORATION, CMS

**Presenter:** COLLABORATION, CMS

### Comments:

The abstract is submitted on behalf of the CMS collaboration. Speaker to be announced. Please, accept it as a talk.

**Status:** ACCEPTED

Submitted by **PAVLOV, Borislav** on **Tuesday, 28 May 2024**

Abstract ID : 14

## CMS RPC L1 Trigger primitives in HL-LHC

### Content

This talk delves into the crucial enhancements of the RPC system as part of the comprehensive upgrades to the CMS Level-1 Trigger, tailored to address the increased luminosity challenges at the HL-LHC. The revised Level-1 architecture maximizes the integration and utility of the muon subsystems—CSC, DT, and particularly the RPC—to ensure superior performance and reliability under extreme operational conditions. The presentation will focus on the specific advancements and strategic role of the RPC upgrades in enhancing muon trigger efficiency and robustness. It will present a newly developed clustering algorithm, detailing the first results from cosmic and test beam evaluations of the new Trigger Primitives with upgraded backend boards.

**Primary author:** COLLABORATION, CMS

**Presenter:** COLLABORATION, CMS

### Comments:

The abstract is submitted on behalf of the CMS collaboration. Speaker to be announced. Please, accept it as a talk.

**Status:** ACCEPTED

Submitted by **PAVLOV, Borislav** on **Tuesday, 28 May 2024**

Abstract ID : 15

## Use and application of the CMS RPC in future experiments

### Content

The RPC chambers are the only detector in the muon system of the CMS experiment that covers the barrel and the endcap. During the entire time of operation in CMS, they have demonstrated their robustness, exceeding the ten-year limit for which they were originally designed. Moreover, for the high luminosity LHC period, an upgrade of the electronic boards will be performed to exploit the full potential of their time resolution (in the order of 1-2 ns), increasing even more their importance in the trigger system of the CMS experiment. RPC is a low cost and low maintenance detector (compared to other gaseous detectors) and the experience accumulated in the CMS experiment shows that it is a great alternative to be used in new physics experiments that require a large amount of detection area with high temporal resolution. During this talk we will explore some alternatives for the use of RPC chambers in new experiments, and some examples of physics analysis in which they can be used.

**Primary author:** COLLABORATION, CMS

**Presenter:** COLLABORATION, CMS

### Comments:

The abstract is submitted on behalf of the CMS collaboration. Speaker to be announced. Please, accept it as a talk.

**Status:** ACCEPTED

Submitted by **PAVLOV, Borislav** on **Tuesday, 28 May 2024**



Abstract ID : 16

## iRPC front-end board readout electronics

### Content

Advanced front-end electronics are designed for the new improved RPCs of CMS experiment to cope with the HL-LHC era challenges. The front-end electronics (FEB) are equipped with a new ASIC, iRPCROC, which reads the strips and digitises incoming signals, triggering the Cyclone V FPGA to stamp the time of each signal accurately. This electronics was developed to read out the RPC detectors from both ends of a signal strip, using timing information to identify the position along it. The challenges and successful performance of the FEB in nominal conditions, as well as the mass production details will be presented.

**Primary author:** COLLABORATION, CMS

**Presenter:** COLLABORATION, CMS

### Comments:

The abstract is submitted on behalf of the CMS collaboration. Speaker to be announced. Please, accept it as a talk.

**Status:** ACCEPTED

Submitted by **PAVLOV, Borislav** on **Tuesday, 28 May 2024**

Abstract ID : 17

## **iRPCROC and LIROC - chips adapted to RPC applications**

### **Content**

The Petiroc2, an AMS 0.35  $\mu\text{m}$  SiGe technology ASIC, was initially designed for PET, but during the latest years, it evolved into the iRPCROC chip optimized for RPC operations. The chip's evolution and a detailed optimization of the performances, such as threshold ( $\sim 30\text{-}50$  fC) and time resolution (better than 100), will be presented. Moreover, a mitigation strategy was developed and implemented for the residual cross-talk and retriggering. The detailed performance of the iRPCROC on the iRPC chamber in conditions similar to the HL-LHC was studied and its radiation hardness was validated. The next generation of RPC chips, such as LiROC, will also be discussed.

**Primary author:** COLLABORATION, CMS

**Presenter:** COLLABORATION, CMS

### **Comments:**

The abstract is submitted on behalf of the CMS collaboration. Speaker to be announced. Please, accept it as a talk.

**Status:** ACCEPTED

Submitted by **PAVLOV, Borislav** on **Tuesday, 28 May 2024**

Abstract ID : 18

## Radiation mitigation on the RPC Link System

### Content

The RPC sub-system is a vital component of the CMS Muon System, working in tandem with DT on the Barrel and CSC and GEM on the Endcap regions to provide redundant and robust muon detection, triggering and identification. Each RPC chamber is equipped with a front-end board that amplifies and discriminates the muon hits, converting them into digital form pulses. The FEBs' outputs are then connected to another electronic system adjacent to the CMS on the tower racks, known as the Link System. Each RPC Link System is composed of two types of electronic boards: The Link Board and the Control Board. However, the tower racks' proximity to the CMS means that moderate radiation levels are a constant challenge, stemming from the proton-proton and heavy ion head-to-head collision at the CMS interaction point. Consequently, the Link System's electronics have to withstand radiation effects such as single-event upset (SEU) and single-event latch-up (SEL). This work details the radiation mitigation of the RPC new Link System's firmware and presents the irradiation test results of these electronics on the CHARM irradiation facility at CERN.

**Primary author:** COLLABORATION, CMS

**Presenter:** COLLABORATION, CMS

### Comments:

The abstract is submitted on behalf of the CMS collaboration. Speaker to be announced. Please, accept it as a talk.

**Status:** ACCEPTED

Submitted by **PAVLOV, Borislav** on **Tuesday, 28 May 2024**

Abstract ID : 19

## Evaluation of the Link System using CMS RPC chamber

### Content

In the CMS Muon System, the RPC subsystem plays a vital role to complementary muon detection, robust triggering and identification with DT on the Barrel and CSC and GEM on the Endcap regions. The RPC detector has an inherently high time resolution of less than a nanosecond. For this reason, the RPC subsystem has mainly been deployed as a CMS Muon time trigger. However, as a result of the deficiency of the electronics readout system, the resolution of muon hit time has always been limited to the timing of the bunch crossing, 25 ns. The primary purpose of the RPC new Link System upgrade for Phase 2 is to utilize the timing resolution of the RPCs without losing any hits at the high luminosity LHC. To achieve this, the electronics of the new Link System have been designed based on the latest generation of the field programmable gate array (FPGA) from the AMD-Xilinx Kintex 7 family, and the muon hit time stamping firmware has been deployed on the FPGA. In this work, we will review how the muon time stamping captures and tags time to each RPC hit at the level of sub-bunch crossing. Then, we will explain the results of the performance of the Link System on a test setup using the CMS RE1/1 detector in CERN.

**Primary author:** COLLABORATION, CMS

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### Comments:

The abstract is submitted on behalf of the CMS collaboration. Speaker to be announced. Please, accept it as a talk.

**Status:** ACCEPTED

Submitted by **PAVLOV, Borislav** on **Tuesday, 28 May 2024**

Abstract ID : 20

## Innovative Resistive Plate Chambers for the CMS Phase 2 Upgrade: Project Summary, Construction, and Quality Assurance

### Content

In view of the Phase-2 of the LHC physics program, called High Luminosity LHC (HL-LHC), the CMS muon system will be upgraded to maintain a robust muon triggering and reconstruction performance. Therefore RE3/1 and RE4/1 stations of the forward muon system will be equipped with new improved Resistive Plate Chambers (iRPC) as dedicated detectors for muon triggering in CMS. The new iRPC detectors have a different design and geometry w.r.t the present RPC system to improve the rate capability and survive the harsh background condition during HL-LHC. This talk summarizes the iRPC project including the iRPC design and production process, details of the ongoing detector production, quality control procedures at the production sites and results of performance studies with high energy muon beam under intense gamma radiation at the CERN Gamma Irradiation Facility (GIF++) facility.

**Primary author:** COLLABORATION, CMS

**Presenter:** COLLABORATION, CMS

### Comments:

The abstract is submitted on behalf of the CMS collaboration. Speaker to be announced. Please, accept it as a talk.

**Status:** ACCEPTED

Submitted by **PAVLOV, Borislav** on **Tuesday, 28 May 2024**

Abstract ID : 21

## Performance and longevity of CO<sub>2</sub> based mixtures in CMS Improved Resistive Plate Chambers in the HL-LHC environment

### Content

Resistive Plate Chamber (RPC) detectors in the Compact Muon Solenoid (CMS) experiment operate with a gas mixture comprised of 95.2% of C<sub>2</sub>H<sub>2</sub>F<sub>4</sub>, that provides a high number of ion-electron pairs, 4.5% of iC<sub>4</sub>H<sub>10</sub>, that ensures the suppression of photon-feedback effects and 0.3% of SF<sub>6</sub>, used as an electron quencher to further operate the detector in streamer-free mode. C<sub>2</sub>H<sub>2</sub>F<sub>4</sub> is known to be a Greenhouse gas with a global warming potential (GWP) of 1430. Several ECO-friendly alternatives to C<sub>2</sub>H<sub>2</sub>F<sub>4</sub> have been studied in the last few years. In this context, one short-mid term approach for the next years of the Large Hadron Collider (LHC) operation could be to focus on reducing the GWP of the RPC gas mixture by adding CO<sub>2</sub> in the place of C<sub>2</sub>H<sub>2</sub>F<sub>4</sub>. The studies are done at CERN Gamma Irradiation Facility (GIF++) in the North Area of SPS, where a 13.6TBq radiation source and a muon beam from SPS are used to mimic the conditions of Phase-II of LHC. This work will present the performance and aging of a 1.4mm gap RPC chamber with three different CO<sub>2</sub> based mixtures under a high gamma background, as well as the first results after 80 mC/cm<sup>2</sup> integrated charge in the longevity campaign.

**Primary author:** COLLABORATION, CMS

**Presenter:** COLLABORATION, CMS

### Comments:

The abstract is submitted on behalf of the CMS collaboration. Speaker to be announced. Please, accept it as a talk.

**Status:** ACCEPTED

Submitted by **PAVLOV, Borislav** on **Tuesday, 28 May 2024**

Abstract ID : 22

## CMS RPC non-physics event data automation

### Content

This paper introduces a novel framework designed to process and analyze raw condition data retrieved from the non-physics event bus of the CERN Compact Muon Solenoid (CMS) experiment in real time. Utilizing advanced data streaming techniques, the framework aims to explore correlations between key operational parameters of the Resistive Plate Chamber (RPC) detector at the CMS experiment, including currents and rates, with CERN Large Hadron Collider (LHC) instantaneous luminosity and environmental conditions. Additionally, the framework seeks to study the evolution of the main parameters over time and to further predict future detector behavior by modeling performance based on these correlations. The CMS RPC automation framework, developed in Java, comprises over 30 automates categorized into main, auxiliary, and study groups, each performing distinct tasks. The four main automates process asynchronous data from the CMS RPC PVSS condition schema into synchronized tables within the CMS\_RPC\_COND schema on the OMDs instance of the CMS ONR production database. These automates handle raw data for RPC currents, LHC modes, and environmental conditions. The fourth main automate processes raw RPC link board histograms from ROOT files for further analysis of RPC rates data. The auxiliary automates segment the LHC filling cycle into four blocks, standardizing condition data. The study automates are the integrated and accumulated integrated charge, current evolution, HV Conditioning, HV Conditioning Fit, and analyses of current and rate dependencies on LHC instantaneous luminosity and RPC charge per hit. All studies concerning currents and rates are extended to newly created virtual objects representing larger granularity objects of the CMS detector, such as regions, wheels, disks, stations, and sectors. The RPC automation, operating on a 4-hour cycle, has effectively processed and analyzed extensive datasets from the CMS experiment. This routine automation enables continuous monitoring and analysis of RPC currents and rates, with data stored across multiple database tables designed for rapid visualization. The capability to produce predictive models and granular analyses through virtual detector objects has significantly enhanced our understanding and forecasting of detector behavior.

**Primary author:** COLLABORATION, CMS

**Presenter:** COLLABORATION, CMS

**Comments:**

The abstract is submitted on behalf of the CMS collaboration. Speaker to be announced. Please, accept it as a talk.

**Status:** ACCEPTED

Submitted by **PAVLOV, Borislav** on **Tuesday, 28 May 2024**

Abstract ID : 23

# Machine Learning approach to CMS RPC HV scan data analysis

## Content

The HV scan is a crucial sequence of calibration runs typically conducted at the onset of each data-taking year with the initial collisions of the CERN Large Hadron Collider (LHC) at nominal luminosity. This procedure ensures the proper functioning of the Resistive Plate Chamber (RPC) detectors at the Compact Muon Solenoid (CMS) experiment at CERN by establishing correct working points. In the past, aspects of the HV scan analysis were performed manually, leading to time-consuming procedures. This study endeavors to revolutionize the analysis of RPC HV scan data by integrating machine learning (ML) algorithms. The primary objective is to automate and expedite manual steps in the analysis process, thereby enhancing the efficiency and speed of task deliverables. Through the application of ML techniques, this research seeks to optimize RPC detector performance analysis, facilitating quicker decision-making processes and ensuring timely adjustments to detector settings for optimal data collection during LHC operations. The HV scan measures efficiency and cluster size as functions of operating voltage for each RPC double gap, within the effective voltage range of [8600, 9800]V. Our methodology prioritizes parametrizing efficiency curves to enable the evaluation of RPC double gap efficiency at arbitrary voltage values. To achieve this, we employ an artificial neural network (ANN) capable of discarding outliers and approximating efficiency behavior, even in cases when data is missing within the efficiency plateau. We developed a dedicated autoencoder ANN that operates in Fourier space to approximate efficiency vs. HV curves per double gap. This autoencoder takes measured efficiency at various supply voltage values and estimates detector efficiency within the voltage interval of 8.0 to 10.5 kV. Subsequently, the refined curve undergoes sigmoidal function fitting, and resulting parameters are utilized in the working point definition procedure. Once the working HV point per double gap is established, a specialized optimization procedure is employed to evaluate working points per HV channel. Multiple double gaps share a single HV supply line, and voltage adjustments are made to fulfill efficiency and cluster size requirements, providing the necessary output for analysis. Thanks to novel technologies and the applied methodology, the time required to analyze the calibration data of the CMS RPC HV scan can be reduced from over 3 months to less than a week.

**Primary author:** COLLABORATION, CMS

**Presenter:** COLLABORATION, CMS

**Comments:**

The abstract is submitted on behalf of the CMS collaboration. Speaker to be announced. Please, accept it as a poster.

**Status:** ACCEPTED

Submitted by **PAVLOV, Borislav** on **Tuesday, 28 May 2024**



Abstract ID : 24

## **CMS RPC efficiency using tag-and-probe method in LHC Run 3**

### **Content**

The CMS experiment is collecting proton-proton collisions at the center-of-mass energy of 13.6TeV in LHC Run 3. RPC detector is one of the sub-detectors of the CMS muon system which is capable of triggering and reconstruction of muons. In this poster, efficiency of the CMS RPC detector during the Run 3 data taking period is presented. The Tag-and-Probe method with the decay of the Z boson to two muons was used in measuring the efficiency of the operating RPC detector. Efficiency is derived from the matching of RPC hits with probe muons extrapolated up to the RPC.

**Primary author:** COLLABORATION, CMS

**Presenter:** COLLABORATION, CMS

### **Comments:**

The abstract is submitted on behalf of the CMS collaboration. Speaker to be announced. Please, accept it as a poster.

**Status:** ACCEPTED

Submitted by **PAVLOV, Borislav** on **Tuesday, 28 May 2024**

Abstract ID : 25

## CMS RPC L1 Trigger clustering at CMSSW

### Content

This poster presents the development of RPC L1 Trigger clustering within the CMS software framework, CMSSW, incorporating the improved timing capabilities of RPC chambers. The integration of these upgrades significantly enhances the resolution and reliability of the L1 Trigger emulator, enabling more precise trigger responses. The presentation will detail the technical advancements in digitisation, the integration with CMSSW, and the benefits observed in preliminary tests, demonstrating the system's improved performance in particle tracking and data handling using MC simulations.

**Primary author:** COLLABORATION, CMS

**Presenter:** COLLABORATION, CMS

### Comments:

The abstract is submitted on behalf of the CMS collaboration. Speaker to be announced. Please, accept it as a poster.

**Status:** ACCEPTED

Submitted by **PAVLOV, Borislav** on **Tuesday, 28 May 2024**

Abstract ID : 26

## A novel solution for managing latency in the CMS iRPC backend: Check-Sort-Push

### Content

This poster presents the “Check-Sort-Push” approach, a novel solution to manage backend processing latency in the CMS RPC system, particularly under conditions of high occupancy and hit rates. Utilizing unified high-speed links, this method improves control and data handling between the front-end and back-end electronics, even when channels share a common link with varying read-out priorities. Through simulation studies, this proposal demonstrates enhanced predictability and reduced latency in trigger preprocessing and data readout. The poster will detail the design and its application and results in iRPC emulator electronics system and CMS iRPC electronics system. In addition, iRPC demonstrator system data taking in CMS detector is undergoing and its results in CMS also will be shown.

**Primary author:** COLLABORATION, CMS

**Presenter:** COLLABORATION, CMS

### Comments:

The abstract is submitted on behalf of the CMS collaboration. Speaker to be announced. Please, accept it as a poster.

**Status:** ACCEPTED

Submitted by **PAVLOV, Borislav** on **Tuesday, 28 May 2024**

Abstract ID : 27

## **An extension to the Analytical Method clustering algorithm for BMTL1 benefitting from CMS RPC timing**

### **Content**

This poster introduces an extension to the Analytical Method clustering algorithm designed for the Barrel Muon Track Finder Layer 1 (BMTL1) for HL-LHC. The new extension leverages the enhanced timing capabilities of the CMS RPC system. The new algorithm significantly reduces the pre-firing of muons. This method addresses challenges associated with high particle flux environments, ensuring robust and reliable muon track reconstruction. The presentation will cover the algorithm's development, its integration with existing CMS infrastructure, and comparative results demonstrating its performance improvements over traditional clustering methods. Data from MC simulations, which showcase the algorithm's effectiveness, will also be shared.

**Primary author:** COLLABORATION, CMS

**Presenter:** COLLABORATION, CMS

### **Comments:**

The abstract is submitted on behalf of the CMS collaboration. Speaker to be announced. Please, accept it as a poster.

**Status:** ACCEPTED

Submitted by **PAVLOV, Borislav** on **Tuesday, 28 May 2024**

Abstract ID : 28

## CMS RPC Link System Tester and Quality Control

### Content

In the CMS Muon system, the RPC Link System will upgrade to cope with High Luminosity LHC conditions and improve the time resolution of the Muon hits detected by the RPC chambers. The upgrade program for the RPC Link System was started in 2017, and in 2027, brand-new electronics will be installed on the CMS detector. The new Link System comprises the Link Board, Control Board, high-speed front panel, and control front panel. Up to nine Link Boards and a Control Board are located on each Link System's RPC Link System Half Box (LBB). These electronics communicate through two electronic cards - a high-speed front panel and a control front panel. Fifteen hundred boards will be produced by the end of 2027. The production plan is divided into two consecutive phases: pilot and full production. Only ten percent of the total fifteen hundred boards will be produced in the pilot production to secure the quality of electronic boards and understand any probable complexity of this process. As a result, specific tests and control mechanisms are needed to ensure the quality of the electronics soon after the components are mounted on the PCB board. Moreover, to improve the precision and duration of the test routines, we have designed and fabricated a tester board called Link Board Tester and a tiny board to test the quality of the high-speed interface bus on the Link Board high-speed front panel section. In this work, we will review the tests foreseen to control the Link Board and Control Board qualities and functionalities and describe how effectively using the Link Board Tester facilitates the test procedure.

**Primary author:** COLLABORATION, CMS

**Presenter:** COLLABORATION, CMS

**Comments:**

The abstract is submitted on behalf of the CMS collaboration. Speaker to be announced. Please, accept it as a poster.

**Status:** ACCEPTED

Submitted by **PAVLOV, Borislav** on **Tuesday, 28 May 2024**

Abstract ID : 29

## iRPC clustering algorithm and hit reconstruction

### Content

One of the upgrades of CMS RPC system is the installation of new chambers - the improved RPC - with a new readout technology, achieving a space resolution along the strip of about ~2cm, enabling the inclusion of the RPC hit in the CMS muon reconstruction. The main characteristic of the iRPC is the two side strip readout which makes a new clusterization algorithm necessary. The algorithm was developed during the test beams at GIF++ and its implementation at CMS Software is under development. In this poster we present the main idea of the algorithm, the final hit reconstruction in the chamber, and the results obtained in the test beams.

**Primary author:** COLLABORATION, CMS

**Presenter:** COLLABORATION, CMS

### Comments:

The abstract is submitted on behalf of the CMS collaboration. Speaker to be announced. Please, accept it as a poster.

**Status:** ACCEPTED

Submitted by **PAVLOV, Borislav** on **Tuesday, 28 May 2024**

Abstract ID : 30

## CMS RPC Link System fiber planning and qualification

### Content

During LHC Long Shutdown 3, the new RPC Link System will be installed. The new Link System will allow us to exploit the high time resolution of the detector from the current 25 ns, due to a limitation in the electronics of the existing system, to the order of 1 to 2 ns with the upgrade. Utilizing the performance of the new electronics will require a low attenuation loss fiber optic infrastructure for high-speed data transmission at the rate of 10 Gbps, which will be replaced with current optical links. It is worth mentioning that the new electronics include, by default, two redundant channels for data transmission on the master link board and two redundant channels on the control boards. Profiting from redundancy requires detailed planning to define the number of fiber optic lines needed, the choice of the number and location of patch panels, the available optical power budget due to different connectors and transmission distances, the fiber type, etc. This poster will show how all these factors led to the current design for the fiber optic infrastructure and how this can serve as an experience for detectors with similar needs.

**Primary author:** COLLABORATION, CMS

**Presenter:** COLLABORATION, CMS

### Comments:

The abstract is submitted on behalf of the CMS collaboration. Speaker to be announced. Please, accept it as a poster.

**Status:** ACCEPTED

Submitted by **PAVLOV, Borislav** on **Tuesday, 28 May 2024**

Abstract ID : 31

## iRPC FEB cooling system

### Content

In view of the High Luminosity upgrade of CERN LHC, the forward CMS Muon spectrometer will be extended with two new stations of improved Resistive Plate Chambers (iRPC), covering the pseudorapidity range from 1.8 to 2.4. A new Front-End-Board (FEB) is designed to readout iRPC signals with a very low threshold and a Time Digital Converter (TDC) embedded into a Cyclone V INTEL FPGA. In contrast to the previous RPC boards, this one produces 22 W of heat in a rather confined space that needs to be carefully evacuated. A cheap and robust cooling system was designed based on a copper plate and water cooling. This system was first simulated with a CFD package, Ansys Fluent and then optimized with thermal measurements. In this poster the system and its prominent features are described. A quantitative comparison between the experimental measurements in the laboratory with the simulation is provided proving the robustness of the former.

**Primary author:** COLLABORATION, CMS

**Presenter:** COLLABORATION, CMS

**Comments:**

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**Status:** ACCEPTED

Submitted by **PAVLOV, Borislav** on **Tuesday, 28 May 2024**



Abstract ID : 32

## Quality control of iRPC electronic components (FEB + strip PCBs) and tests in hard radiation environment

### Content

Advanced front-end electronics are designed for the new improved RPC of the CMS experiment to cope with the HL-LHC era challenges. The front-end electronics (FEB) are equipped with a new ASIC, iRPCROC, which reads the strips and digitizes incoming signals, triggering the Cyclone V FPGA to stamp the time of each signal accurately. This electronics was developed to readout the RPC detectors from both ends of a signal strip, using timing information to identify the position along it. The signal strip was embedded into a large, very flat PCB designed with a highly controlled impedance level. The mass production of the FEB by French company FEDD and strip PCBs by French company ELVIA is finished, and Quality Control is ongoing. The first results will be presented in this poster.

**Primary author:** COLLABORATION, CMS

**Presenter:** COLLABORATION, CMS

### Comments:

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**Status:** ACCEPTED

Submitted by **PAVLOV, Borislav** on **Tuesday, 28 May 2024**

Abstract ID : 33

## Gas gaps and chambers quality control of improved resistive plate chambers (iRPC)

### Content

In preparation for the Phase II Upgrade for the HL-LHC program, 72 improved Resistive Plate Chambers (iRPCs) will be installed in the third and fourth endcap disks of the Compact Muon Solenoid (CMS) during the next year-end technical stop (YETS). These new generation RPC detectors will operate in a low-angle momentum (extending RPC coverage from  $|\eta| = 1.9$  to 2.4), in a high radiation environment, and will bring a better space and time resolution for this challenging region. Assembly of the new detectors is taking place at CERN 904 laboratory and Ghent University. To ensure proper performance, iRPC chambers undergo a series of quality control (QC) tests at each stage of the assembly chain. These tests include QC1 for the basic components, QC2 for chamber elements such as gaps and cooling, QC3 for evaluating the full chamber performance after production, which includes noise, efficiency, and current, and lastly and QC4 for the final validation test. In this poster, we present the summary results of the QC tests for the newly built iRPC chambers in the assembly sites.

**Primary author:** COLLABORATION, CMS

**Presenter:** COLLABORATION, CMS

### Comments:

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**Status:** ACCEPTED

Submitted by **PAVLOV, Borislav** on **Tuesday, 28 May 2024**

Abstract ID : 34

## Preliminary aging studies of improved RPC gaps operated with HFO based mixtures

### Content

Resistive Plate Chambers (RPC) at the CMS experiment are operated with a gas mixture containing around 95% Tetrafluoroethane (C<sub>2</sub>H<sub>2</sub>F<sub>4</sub>), commonly known as R-134a, which has a global warming potential (GWP) of 1430. In the framework of the CMS Upgrade project for the High Luminosity phase, new improved RPC detectors (iRPC) have been developed to enhance the legacy performances in the most RPC forward region of the experiment. To comply with European regulations and explore environmentally friendly gaseous mixture alternatives for long-term RPC operation, CMS RPC within the RPC EcoGas@GIF++ collaboration has launched a longevity study operating the chambers with HFO/CO<sub>2</sub>-based eco-friendly candidate mixture. Through this poster can be found the preliminary aging analysis of the gaps resulting after around one year of irradiation at the Gamma Irradiation Facility at CERN.

**Primary author:** COLLABORATION, CMS

**Presenter:** COLLABORATION, CMS

### Comments:

The abstract is submitted on behalf of the CMS collaboration. Speaker to be announced. Please, accept it as a poster.

**Status:** ACCEPTED

Submitted by **PAVLOV, Borislav** on **Tuesday, 28 May 2024**

Abstract ID : 35

## RPC online software migration/update and future plans

### Content

The RPC Online Software is an integral component of the CMS detector's subsystems, facilitating seamless integration with the Detector Control System (DCS) and specialized management for Readout Units. It employs Linux device drivers and C++ Application Programming Interfaces (APIs) to achieve precise control over hardware operations. Additionally, it incorporates automated testing scripts to boost operational efficiency. The primary aim of this project is to develop a robust migration strategy for transitioning the RPC Online Software from its current platform on Linux CC7 to Linux Alma 9, the latter being the standard operating system adopted by the CMS and Data Acquisition (DAQ) subsystems. This transition is essential for the Muon system's functionality. The project also explores the migration of physical servers at Point 5 (P5) to a virtualized environment. This strategic shift aims to maintain optimal functionality of the control and communication chain within the subsystem, ensuring seamless operation and enhanced system resilience.

**Primary author:** COLLABORATION, CMS

**Presenter:** COLLABORATION, CMS

### Comments:

The abstract is submitted on behalf of the CMS collaboration. Speaker to be announced. Please, accept it as a poster.

**Status:** ACCEPTED

Submitted by **PAVLOV, Borislav** on **Tuesday, 28 May 2024**

Abstract ID : 36

# Theoretical Time Cost to Distinguish Special Nuclear Materials in Different Scenarios through MRPC-ToF based MST

## Content

Muon scattering tomography (MST), which has gained significant attention in recent years, is a novel radiation imaging technique evolving into two research directions: rapid inspection and detailed imaging. Increasing research shows that fully utilizing the momentum information of muons is essential to achieve satisfactory results for both two directions. MRPC (Multi-gap Resistive Plate Chamber) detectors are renowned for their excellent time resolution and high detection efficiency for charged particles and are widely used in Time-of-Flight (ToF) systems in high-energy physics experiments. Our recent research shows the time resolution of very narrow gaps MRPC can reach 16 ps. Therefore, MRPC holds great potential in muon imaging where momentum information needs to be considered.

In this study, using the GEANT4 toolkit and ROOT's TMVA toolkit, focusing on rapid inspection, we conducted detailed simulations under various background conditions, including different volumes, geometrical setups, materials and shielding methods. We evaluated the rapid response capability of the MST system for typical special nuclear materials using MRPC detectors as ToF to obtain muon momentum and true muon momentum, applying unsupervised classification methods like EM-GMM and supervised classification methods like BDT, CNN and DNN. The results show that using CNN for classification, the MRPC-ToF based MST system can achieve an accuracy of over 92.8% within 45 seconds with a geometrical acceptance of 45.2%. When the geometrical acceptance is 18.8%, the accuracy is then 81.26%, which demonstrates that using MRPC detectors as ToF to acquire muon momentum information for a fast-responsive MST system is highly feasible.

**Primary author:** CHEN, Ziyang (Tsinghua University)

**Presenter:** CHEN, Ziyang (Tsinghua University)

**Status:** ACCEPTED

Submitted by CHEN, Ziyang on Wednesday, 29 May 2024

Abstract ID : 37

## Operation and performance of the ALICE Muon Identifier RPCs during LHC Run 3

### Content

ALICE stands for “A Large Ion Collider Experiment”, and it is designed to study proton–proton and heavy-ion collisions at ultra-relativistic energies at the LHC. The main goal of ALICE is to assess the properties of quark gluon plasma (QGP), a state of matter reached in extreme conditions of temperature and energy density where quarks and gluons are deconfined.

One of the main observables used to study the QGP is the production of heavy quarks in Pb–Pb collisions. In order to detect heavy quarks via their muonic decays, ALICE is equipped with a forward muon spectrometer (MS).

During the LHC Run 1 and Run 2 the selection of interesting events for muon physics in ALICE was performed with a dedicated muon trigger system based on Resistive Plate Chambers operated in maxi-avalanche mode. During the long shutdown 2 (2019-2021) of LHC, ALICE achieved a major upgrade of its apparatus. The upgrade enables a new ambitious program of high-precision measurements. Moreover, in order to fully profit from the increased interaction rate to 50 kHz in Pb–Pb collisions (was 10 kHz in Run 2) the ALICE experiment is running in continuous readout (triggerless) mode, hence the muon trigger became the Muon Identifier (MID).

In order to prevent ageing effects and to improve the RPC rate capability, it was chosen to operate the detector with a lower gain, keeping the same gas mixture and decreasing significantly the working voltage. The front-end and readout electronics of the Muon Identification System have been upgraded in order to support low-gain operation and triggerless readout.

The stability and performance of the MID RPCs during the first two and a half years of Run 3, at the unprecedented center-of-mass energies of 13.6 TeV for pp collisions and 5.36 TeV/nucleon pair for Pb–Pb collisions, will be discussed in this talk.

**Primary author:** TERLIZZI, Livia (Universita e INFN Torino (IT))

**Presenter:** TERLIZZI, Livia (Universita e INFN Torino (IT))

**Status:** ACCEPTED

Submitted by **TERLIZZI, Livia** on **Wednesday, 29 May 2024**

Abstract ID : 38

# Developmental Studies on the Performance Enhancement of Gas-Tight Resistive Plate Chambers (RPCs) for Muography Applications

## Content

Muon-based radiography, also known as “muography”, is an application of particle physics based on muons naturally produced from cosmic rays in the upper atmosphere. Muography determines the average density of an object by measuring the muon flux passing through it and comparing it with a reference flux through the unobstructed sky.

In this talk, we report on the status of our development of a portable muon hodoscope built using glass-RPC detectors with an active area of  $16\text{ cm} \times 16\text{ cm}$ , featuring a readout strip with a pitch of  $1.0\text{ cm}$  and a strip width of  $0.9\text{ cm}$ . The goal of this project is to use this detector for muography applications in confined locations (e.g. underground tunnels or cramped rooms), with complex logistics that are common for field work in archaeology, cultural heritage studies and geophysics. Therefore, some of the most important design considerations are portability, compactness, low weight, low cost, autonomy and versatility.

As RPCs are gas detectors, leaks are a concern in confined spaces; moreover, we need to minimize refills. This leads to emphasis on assessing and minimizing the dependence on time of the detector performance metrics on timescales of hours, days, weeks or months. Thus, in this talk, we present our studies on the long-term stability of these detectors, covering aspects such as efficiency, time response, and gas stability, in addition to some preliminary results from an absorption muography study conducted with various objects to assess the feasibility and performance of the current version of the detector.

**Primary author:** BASNET, Samip (UCL - CP3)

**Co-authors:** AL MOUSSAWI, Marwa; Prof. CORTINA GIL, Eduardo (CP3-UCLouvain); DEMIN, Pavel (Universite Catholique de Louvain (UCL) (BE)); GIAMMANCO, Andrea (Universite Catholique de Louvain (UCL) (BE)); Dr KARNAM, Raveendrababu (National Institute of Science Education and Research (NISER) (IN)); SAMALAN, Amrutha (Paul Scherrer Institute (CH)); TYTGAT, Michael (Vrije Universiteit Brussel (BE)); Prof. YOUSSEF, Ayman (Lebanese University); Mr KUMAR, vishal (UCL - CP3)

**Presenter:** BASNET, Samip (UCL - CP3)

**Status:** ACCEPTED

Submitted by **BASNET, Samip** on **Wednesday, 29 May 2024**

Abstract ID : 39

## A high rate and high timing gaseous photodetector prototype with RPC structure

### Content

In order to meet the requirements of high-rate and high time resolution in future high energy physics experiments, a prototype of gaseous photodetector with RPC structure was developed in this paper. The performance of the detector was simulated in Garfield++, and the single-photoelectron performance in different gases was tested using ultraviolet laser. The detector used a low resistivity ( $\sim 1.4 \times 10^{10} \Omega \cdot \text{cm}$ ) float glass, so that it has high-rate capability, the laser test results show that in MRPC gas, the single-photoelectron time resolution is best to reach  $\sim 20$  ps at a gain of  $\sim 7 \times 10^6$  Qe. This detector can quantitatively test the single-photoelectron performance of different gases, and will be used to find eco-friendly MRPC gases.

**Primary author:** Mr ZHAO, Yiding (USTC(University of Science and Technology of China))

**Presenter:** Mr ZHAO, Yiding (USTC(University of Science and Technology of China))

**Status:** ACCEPTED

Submitted by **ZHAO, Yiding** on **Thursday, 30 May 2024**



Abstract ID : 40

# Swarm Measurements in HFO1234ze(E) at High Electric Field Strengths for Extracting Cross Sections

## Content

The environmentally friendly refrigerant HFO1234ze(E) is a promising alternative to substitute R134a in the standard mixture operating in gaseous particle detectors. Finding the optimal mixture concentration in terms of detector performance is based on simulations, which require the electron molecule cross sections as input. Cross sections can be deduced from the electron transport coefficients obtained in swarm experiments.

The mean electron energies in the discharges inside detectors are in the order of a few electron volts, thereby requiring the cross sections to be at least accurate up to the tens of electron volt regime. Comparable mean electron energies are achieved in swarm experiments ranging up to 1000 Td, which are challenging, but crucial to obtain reliable cross sections suitable for detector simulations.

HFO1234ze(E) swarm measurements performed on a Pulsed Townsend apparatus above 200 Td have revealed strong ionization. The measurements are restricted to short distances and low pressures to ensure no electric breakdown induced by significant swarm growth. Low pressure and short distances, however, lead to displacement currents rendering the piecewise analysis based on the standard Gaussian-traveling-pulse solution inapplicable. A more in-depth analysis including boundary effects was proposed, but the resulting uncertainties remain to be investigated.

In this contribution, the electron drift velocity, diffusion, and ionization coefficient are extracted from high-electric-field measurements in HFO1234ze(E). The uncertainties are discussed regarding bandwidth limitations, mixture impurities, and boundary effects. Acquiring multiple measurements over varying distances is shown to be an effective method in mitigating boundary effects at the electron injection phase.

**Primary author:** METTING VAN RIJN, Marnik

**Presenter:** METTING VAN RIJN, Marnik

**Status:** ACCEPTED

Submitted by **METTING VAN RIJN, Marnik** on **Thursday, 30 May 2024**

Abstract ID : 41

# A modular muon telescope for tomography and radiography applications

## Content

Muography is a non-invasive technique that exploits the absorption and scattering features of cosmic-ray muons and produces projectional image of a target volume. We are studying different muon telescope configurations for use in tomography applications such as imaging the spent nuclear fuel dry cask, border controls of transport, and radiography applications such as to investigate cavities/shafts present in railway tunnels, archaeological cultural heritage sites.

A portable muon telescope is being developed in a modular form with four layers. Each module houses a glass Resistive Plate Chamber (RPC) of  $16 \times 16$  cm<sup>2</sup> active area. The RPC is sandwiched between two Printed Circuit Board (PCB) strip readout panels, with strip pitch of 1 cm, placed orthogonally to each other to trace the X and Y position of the muon hit.

The muon telescope has been simulated in Geant4 [1] and with EcoMug [2] as the cosmic-ray muon generator. The spacing between different layers in the telescope has been optimized to achieve the best possible position and intrinsic angular resolutions of 7.3 mm and 4 mrad, respectively. Using the Point of Closest Approach (PoCA) algorithm [3], the image of a Lead block of size  $100 \times 100 \times 100$  mm<sup>3</sup> is reconstructed and the scattering angle distributions are used to distinguish the high and medium Z materials. The image reconstruction is further improved by implementing the Binned Clustering Algorithm (BCA) [4].

For building the proposed muon telescope, glass RPCs are constructed and characterized using PCB based readout panels. The RPCs are operated in avalanche mode and showed a muon detection efficiency > 95 %. The charge collection and time resolutions of the RPCs are measured. An acrylic chamber has been developed to house the RPC and the air-tightness studies have been carried out. The results and the future plans will be discussed in the workshop.

[1] <https://geant4.web.cern.ch/>

[2] D. Pagano et al., Nucl. Inst. and Meth. in Phys. Res. A 1014 (2021) 165732.

[3] L.J. Schultz et al., Nucl. Inst. and Meth. in Phys. Res. A 519 (2004) 687–694.

[4] C. Thomay et al., JINST 8 (2013) P10013.

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**Presenter:** Dr KARNAM, Raveendrababu (National Institute of Science Education and Research (NISER) (IN))

**Status:** ACCEPTED

Submitted by **Dr KARNAM, Raveendrababu** on **Thursday, 30 May 2024**

Abstract ID : 42

# Utilizing open-source toolkits for the simulation of avalanche formation and space-charge effects in Resistive Cylindrical Chambers

## Content

An investigation of avalanche formation in Resistive Chambers with a cylindrical geometry is presented in this report. Resistive Cylindrical Chambers (RCC) were proposed in the last decade with the purpose of improving conventional Resistive Plate Chambers (RPC). The new geometry allows for the increase of gas pressure in the gas gap, leading to an increase in efficiency as well as a slightly inhomogeneous field which might lead to better containment of the electron avalanche. The development of RCC which will manifest these advantages, requires R&D studies, including an interplay between prototype testing and simulations.

In this report, we present a detailed numerical calculation of the field, a simulation of the interaction between the gas molecules in the working volume and a passing ionizing particle and the subsequent gas multiplication process. For considerable avalanche charges, local perturbations of the electric field arise, known as space-charge effects. The simulations have been performed using a collection of open-source software packages: gmsh for geometry and mesh generation, FEniCS for FEM numerical calculations and Garfield++ for modeling particle interactions, detection of a passing ionizing particle, and the probing of the resulting signal. Space-charge effects have been simulated by recursively adjusting the field in the gas gap during the formation of the avalanche. In addition, alternative gas mixtures are considered in view of the transition to eco-friendly gas mixtures for detectors used in modern-day high-energy experiments. The results are compared to conventional RPC detectors currently in use.

**Primary author:** SHUMKA, Elton (University of Sofia - St. Kliment Ohridski (BG))

**Presenter:** SHUMKA, Elton (University of Sofia - St. Kliment Ohridski (BG))

**Status:** ACCEPTED

Submitted by **SHUMKA, Elton** on **Thursday, 30 May 2024**

Abstract ID : 43

## Radiation hard Multi-Strip Multi-Gap Resistive Plate Chamber architecture for low polar angles of the CBM-TOF wall

### Content

The Multi-Strip, Multi-Gap Resistive Plate Chambers (MSMGRPCs) developed to fulfill the high counting rate and granularity requirements of the low polar angle region of the CBM-TOF wall showed very good performances in time resolution (50 ps) and efficiency (>90%), up to 30 kHz/ cm<sup>2</sup> counting rate, exposed on the whole active area. Considering that CBM will run in the average 2 months/year for about 10 years, comprehensive studies of the behavior of such detectors at high irradiation dose are mandatory.

Detailed studies of the aging effects induced in a MSMGRPC by high  $\gamma$  irradiation dose showed a gas pollution effect. Higher deposition of radicals of different types on the whole surface, on both sides of the floating glass electrodes and noise rates around the spacers were evidenced with impact on the detector performance and artificial increase of the data volume in a free-running data acquisition mode. The solutions for the mitigation of such effects have been the design of MSMGRPC prototypes with a direct flow of the gas mixture, (100% gas transmission through the gas gaps) and replacement of the fishing line by discrete spacers. The exposure to high X-ray flux of a prototype with the new design demonstrated negligible aging effects even for rather low gas flow. We report in this contribution the construction details of the new architecture, results of extensive aging tests using high X-ray flux as well as the performance of the prototypes in terms of efficiency and time resolution obtained in the in-beam tests performed at SIS18, GSI-Darmstadt in the mCBM experimental setup. Details on the implementation of direct flow MSMGRPCs in the first CBM-TOF inner wall module –module M0- whose configuration is the most complex among the twelve CBM-TOF inner wall modules, will be presented.

**Primary author:** PETRIS, Mariana (Horia Hulubei National Institute of Physics and Nuclear Engineering (RO))

**Presenter:** PETRIS, Mariana (Horia Hulubei National Institute of Physics and Nuclear Engineering (RO))

### Comments:

Dear Conference Committee,

I would like to have an oral presentation at the XVII Conference on Resistive Plate Chambers and Related Detectors with the title "Radiation hard Multi-Strip Multi-Gap Resistive Plate Chamber architecture for low polar angles of the CBM-TOF wall".

Thank you and best regards,

Mariana Petris

**Status:** ACCEPTED

Submitted by **PETRIS, Mariana** on **Friday, 31 May 2024**

Abstract ID : 44

# Studies on electron swarms and streamer discharges in environmentally friendly RPC gas mixtures under LHC-like conditions

## Content

One of the key challenges in R&D strategies for RPCs is the replacement of currently used  $C_2H_2F_4$  and  $SF_6$  with environmentally friendly alternatives. Usually, the  $C_2H_2F_4$  is replaced by a proper mixture of  $C_3H_2F_4$  and  $CO_2$ , while  $CF_3I$ ,  $C_4F_7N$  and  $C_5F_{10}O$  were considered as alternatives to  $SF_6$ . In the first part of this work, we propose complete and consistent sets of cross sections for electron scattering in  $C_3H_2F_4$  and  $C_3HF_5$ . The cross sections are validated through a series of comparisons between swarm data calculated using a numerical solution of Boltzmann's equation and Monte Carlo simulation, and experimental data obtained under pulsed-Townsend conditions. Swarm analysis has also been performed for  $CF_3I$ ,  $C_4F_7N$ , and  $C_5F_{10}O$  and gases, which are considered as potential replacements of  $SF_6$  in typical RPC mixtures. Other sets of cross sections for these gases that are available in the literature are also used as input in our numerical codes to test their completeness, consistency, and accuracy. In particular, we discuss the dependence of transport coefficients on the pressure, temperature, and composition of RPC gas mixtures made of these gases. We also study the explicit and implicit effects of non-conservative collisions on the transport of electrons and the induced kinetic phenomena such as negative differential conductivity.

In the second part of this work, we study the development of an electron avalanche and its transition into a streamer discharge in environmentally friendly RPC gas mixtures under LHC-like conditions. Recently, we have developed a 3D streamer model in the AMReX environment. AMReX is an open-source C++ library for massively parallel block structured adaptive mesh refinement applications. AMReX has in-built geometric multigrid solvers for solving elliptic differential equations, and it supports MPI and OpenMP parallelization on CPUs as well as parallelization on GPUs. The classical fluid model, which involves the drift-diffusion approximation and local field approximation, is implemented assuming a certain level of background ionization to simulate the inception and propagation of positive streamers. The time integration is performed by employing the second order Runge-Kutta method, while the spatial discretization is performed by using the finite volume method. We calculate the electron and ion densities, electric field, and velocity of streamers as a function of the applied electric field for various RPC mixtures. We also look at the development of electron avalanches in the presence of space charge effects. The results of these simulations, in association with the scattering and transport data for electrons in environmentally friendly RPC gas mixtures, should be considered in experimental measurements and modelling efforts to test the performance of RPCs.

**Acknowledgment:** This work is supported by the Science Fund of the Republic of Serbia, Grant No. 7749560, Exploring ultra-low global warming potential gases for insulation in high-voltage technology: Experiments and modelling EGWIn.

**Primary author:** DUJKO, Saša (Institute of Physics Belgrade)

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**Presenter:** DUJKO, Saša (Institute of Physics Belgrade)

**Comments:**

This abstract is for my talk that I was invited to give at the conference.

**Status:** ACCEPTED

Submitted by **DUJKO, Saša** on **Friday, 31 May 2024**

Abstract ID : 45

## Microscopic and fluid modelling of RPCs under LHC-like conditions

### Content

We present a 2.5D Particle-in-Cell Monte Carlo collision (PIC/MCC) and a 2D fluid model of RPCs. The PIC/MCC model uses a Monte Carlo technique and a 2D numerical grid coupled with Poisson equation solver to track individual electrons and their collisions with the background gas in 3D. The fluid model is based on drift-diffusion-reaction equation and local field approximation. Both models rely on axis symmetry and are developed using the AMReX software framework. AMReX is an open-source C++ library for massively parallel block structured adaptive mesh refinement applications. The presented RPC models are employed to study the signal induction, space charge effects and avalanche to streamer transition in RPCs under LHC-like conditions. The conditions assume a 2 mm gas gap with a standard gas mixture based on C<sub>2</sub>H<sub>2</sub>F<sub>4</sub>, or eco-friendly alternatives based on C<sub>3</sub>H<sub>2</sub>F<sub>4</sub> and CO<sub>2</sub>. In addition, we also employ a microscopic Monte Carlo model to calculate the efficiency and time response functions for these RPC configurations.

**Acknowledgment:** This work is supported by the Science Fund of the Republic of Serbia, Grant No. 7749560, Exploring ultra-low global warming potential gases for insulation in high-voltage technology: Experiments and modelling EGWIIn.

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### Comments:

This abstract is for my talk that I was invited to give at the conference.

**Status:** ACCEPTED

Submitted by **BOŠNJAKOVIĆ, Danko** on **Friday, 31 May 2024**



Abstract ID : 48

# Time Resolution in Resistive Plate Chambers from Statistical Considerations

## Content

The quest for optimal time resolution remains one of the most intense areas of current research on Resistive Plate Chambers (RPCs). Achieving superior time resolution is crucial for a wide range of applications, from high-energy physics experiments to medical imaging technologies. Various technological solutions are proposed, each aiming to enhance the performance of RPCs, whose actual effectiveness must be experimentally verified.

However, beyond technological advancements, there are fundamental statistical considerations inherent to the process of signal formation in RPCs that set theoretical limits on the best time resolution achievable. These considerations stem from the stochastic nature of particle interactions and signal generation within the chamber. Understanding these statistical constraints is important for setting realistic expectations and guiding the development of new technologies.

This talk will delve into these statistical limitations, offering an overview of how they influence the time resolution of RPCs. We will explore the primary factors contributing to these limits. Furthermore, the discussion will extend to potential solutions and strategies for optimizing time resolution within these statistical bounds.

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**Status:** ACCEPTED

Submitted by **ABBRESCIA, Marcello** on **Friday, 31 May 2024**

Abstract ID : 49

## Characterisation of Resistive Plate Chambers Operated with different HFCs and HFOs based Gas Mixtures

### Content

Gaseous detectors are essential in particle physics due to their precise particle tracking and detection. Among these are high-pressure laminate resistive plate chambers (HPL-RPCs), which typically operate with a gas mixture of ~64-95% C<sub>2</sub>H<sub>2</sub>F<sub>4</sub> (R-134a), ~4-5% i-C<sub>4</sub>H<sub>10</sub>, ~0.3-1% SF<sub>6</sub> and 30% CO<sub>2</sub> depending on the LHC experiment. These mixtures, however, contain notable ratios of high-global warming potential (GWP) gases, R-134a, with a GWP of 1430 and SF<sub>6</sub>, 22800, respectively. To address their environmental impact, CERN's gas group is actively researching lower-GWP gas mixtures for use in these detectors, to align with stricter environmental regulations and sustainability goals.

Different research lines focus on characterising HPL-RPCs with different hydrofluorocarbons (HFCs), hydrofluoroolefins (HFOs) or CO<sub>2</sub> based gas mixtures to reduce the R-134a consumption. This study will focus on comparing the performance of R-134a based gas mixture with that of alternative HFCs and HFOs. Several molecules are considered, containing one, two or three Carbon atoms and different numbers of Fluorine atoms. The HFCs and HFOs under consideration include R-32, R-1336mz, R-1233zd, R-236ea, R-152a, R-245fa, and R-236fa.

The characterisation process involves assessing key performance parameters such as raw signal analysis, efficiency, streamer probability, detector currents, operational voltage, charge distribution, time and spatial resolution. Results will show the difference in performance between these alternative gases and the standard CMS HPL-RPC gas mixture.

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**Presenter:** JUKS, Stefania-Alexandra (Université Paris-Saclay (FR))

**Status:** ACCEPTED

Submitted by **JUKS, Stefania-Alexandra** on **Friday, 31 May 2024**

Abstract ID : 50

## 15 Years Young: the ALICE TOF detector in LHC RUN 3

### Content

The ALICE Time Of Flight (TOF) detector, composed of 1593 Multigap Resistive Plate Chambers (RPCs) with a gas mixture of Freon (93%) and SF<sub>6</sub> (7%), covers an active area of approximately 140 m<sup>2</sup> and includes over 150000 readout channels. During the LHC long shutdown in 2018-2022, the detector underwent a major upgrade of its readout, allowing for continuous data taking and, therefore, to handle the current increase in interaction rate provided by the LHC.

After 15 years of operation, the detector's stability remains excellent, with no observable degradation in the driven current, the global rate and uniformity, or in particle detection efficiency. In this contribution, the detector performance achieved so far in LHC Run3 will be presented.

The continuous readout of the MRPC signal wouldn't be possible without the low and stable background rate of the single MRPC pad, which can now be monitored continuously, differently from the selected trigger matching window approach used in LHC Run 1 and Run 2. The calibration procedure for the detector in the continuous readout scheme will be discussed, with an overall time resolution better than the target design of 80 ps, along with the implications for particle identification performance. A few examples of PID applications in physics analysis will also be described.

**Primary author:** STRAZZI, Sofia (University and INFN, Bologna)

**Presenter:** STRAZZI, Sofia (University and INFN, Bologna)

**Status:** ACCEPTED

Submitted by **STRAZZI, Sofia** on **Saturday, 1 June 2024**

Abstract ID : 52

## R134a recuperation and SF6 recuperation plants: status and plan

### Content

Particle detectors at the LHC experiments are very often characterized by large detector volumes and by the need of using very specific gases. Since the early phase, the gas consumption optimization was one of the design criteria. CERN is today strongly committed to reduce GHGs emissions from particle detector operation. In addition, GHGs are now subject to a phase down policy in Europe that started to affect the market with price increase and, in the long term, may cause a decrease in their availability.

Four different strategies have been identified to optimize the GHGs usage: gas recirculation systems optimization, gas recuperation, new environmentally friendly gases, and gas abatement. This contribution will focus on results obtained for the present gas systems' optimization and on the R&D studies for the development of gas recuperation plants. Gas recuperation plants are systems designed to extract GHGs from the exhaust of gas recirculation systems allowing further re-use and, therefore, reducing drastically GHGs emissions without changing detectors operation conditions. Recent developments are concerning systems for CF<sub>4</sub>, C<sub>2</sub>H<sub>2</sub>F<sub>4</sub> (also called R134a), C<sub>4</sub>F<sub>10</sub> and SF<sub>6</sub> recuperation.

A first R134a recuperation plant is connected to the CMS-RPC system and operational since July 2023. The use of R134a for the ATLAS and CMS RPC detector systems operation represents about 80% of the GHGs emission from particle detectors at CERN experiments. The separation process resulted more complicated than expected because R134a and iC<sub>4</sub>H<sub>10</sub> forms an azeotropic mixture. R&D studies to design a SF<sub>6</sub> recuperation plant are also ongoing.

Results (gas quality, efficiency, plant reliability, ..) from the first operational experience with the R134a recuperation plant and status of the R&D for the SF<sub>6</sub> recuperation plant will be presented.

**Primary authors:** ARENA, Maria Cristina (Pavia University and INFN (IT)); GUIDA, Roberto (CERN); MANDELLI, Beatrice (CERN); RIGOLETTI, Gianluca (CERN)

**Presenter:** GUIDA, Roberto (CERN)

**Status:** SUBMITTED

Submitted by **GUIDA, Roberto** on **Thursday, 6 June 2024**

Abstract ID : 53

## A new generation of RPCs for the ALICE Muon Identifier

### Content

A Large Ion Collider Experiment (ALICE) is one of the four large experiments at the CERN Large Hadron Collider (LHC) and it is designed to study the physics of Quark Gluon Plasma (QGP) using ultra-relativistic Pb-Pb collisions. To study the muonic decays of heavy quarks, ALICE is equipped with a Muon Spectrometer located at forward rapidity, which includes the Muon Identifier (MID), a system of 72 Resistive Plate Chambers (RPCs) arranged in four detection planes, covering a total area of about 140 m<sup>2</sup>.

The peak interaction rate of Pb-Pb collisions increased from < 10 kHz to ~ 50 kHz between Run 2 and Run 3. To cope with the new running conditions, the front-end and readout electronics were upgraded.

However, the RPCs currently operating are still, by a large fraction, the ones installed before the LHC Run 1, in 2006. Some of these RPCs have integrated a non-negligible charge, compared to their certified life-time (50 mC/cm<sup>2</sup>). To prevent any degradation of the system performance, a new generation of RPCs is needed to replace the ones currently operating if needed.

In 2021, after several interactions with the manufacturing company, a new production of spare RPCs was launched, using a new type of bakelite laminates. These new RPCs are now undergoing full characterization in the INFN Torino laboratory and a few of them have been already installed in the ALICE cavern.

In this talk the first results of tests on a significant number of spare RPCs will be presented, along with the performance of those that are already operating in the experiment.

**Primary author:** GARETTI, Sara (Universita e INFN Torino (IT))

**Presenter:** GARETTI, Sara (Universita e INFN Torino (IT))

**Status:** SUBMITTED

Submitted by **GARETTI, Sara** on **Friday, 7 June 2024**

Abstract ID : 55

## Progress with the nRPC-4D detector concept for neutron scattering applications: assessment of XYZ-position and nTOF readout capability in beam tests

### Content

Building upon our prior work on the development of the neutron RPC detection technology [1, 2], we have recently introduced the nRPC-4D detector concept. It provides high cold/ thermal neutron detection efficiency and the capability to simultaneously readout the XYZ-position of each detected neutron and its time-of-flight (nToF). For the simplicity of construction and maintenance, the detector architecture is based on stand-alone neutron detection modules. Each module features a double gap timing RPC with  $^{10}\text{B}_4\text{C}$ -coated cathodes, faced on both sides with arrays of signal pickup strips for X- and Y-position readout. We are conducting the development of this type of detector for neutron scattering applications, such as time-of-flight neutron diffraction and time resolved neutron imaging. The concept also shows good potential for other applications benefiting from simultaneous readout of the neutron events position and time.

We will report on the recent progress related to this detector concept along with the implementation details of a prototype. It will be shown that the new arrangement of the signal pickup strips allows one to identify the  $^{10}\text{B}_4\text{C}$  layer along the stack where a neutron is captured. This enables the determination of the nToF with an unprecedented precision and allows to correct misalignment between the planes of signal pickup strip arrays, which can spoil the spatial resolution. Finally, in-beam experimental results on the XYZ-position resolution, nToF measurements and counting rate capability will also be presented.

### Acknowledgements

This work was funded by the Portuguese national funds OE and FCT-Portugal (<http://doi.org/10.54499/EXPL/FIS-NUC/0538/2021>). L. Margato acknowledges FCT-Portugal support through contract CEECINST/00106/2018/CP1494/CT0001

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- [2] L.M.S. Margato et al 2020 JINST 15 P06007, DOI: 10.1088/1748-0221/15/06/P06007

**Primary author:** MARGATO, Luís (Laboratory of Instrumentation and Experimental Particles Physics, Dep. of Physics, University of Coimbra)

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**Presenter:** MARGATO, Luís (Laboratory of Instrumentation and Experimental Particles Physics, Dep. of Physics, University of Coimbra)

**Status:** SUBMITTED

Submitted by **Dr MARGATO, Luís** on **Monday, 17 June 2024**

Abstract ID : 56

## New Readout Codification in Large-Area Multi-Gap Timing RPCs for Muon Scattering Tomography

### Content

A novel readout technique was designed for applications covering large surfaces, such as the muon scattering tomography. Knowing that the FEE is often the driving cost of RPCs, the new codification was developed with the initial intention of significantly reducing the dependence of the number of electronic channels on the detector area, without substantial decrease of its performance.

The technique was first tested with a multi-gap timing RPC, composed of a double stack of 6 gaps of 300  $\mu\text{m}$  and sensitive area of 30 cm x 30 cm, using 24+24 preamps to read out 120+120 strips. A new setup is currently being prepared with a detector area tenfold larger: 120 cm x 90 cm, while the same 24+24 preamps will be used to read out a much higher number of strips.

The new readout scheme used with the 30 cm x 30 cm RPC resulted in a spatial resolution better than 1 mm and time resolution below 100 ps. Details about the new readout codification and preliminary results obtained with the larger RPC will be presented in this communication.

FLUKA simulations were performed in order to demonstrate the relevance for the scattering tomography technique of having not only a submillimetric spatial resolution, but also a very good time resolution. These calculations will be presented too.

**Primary authors:** DE CARVALHO SARAIVA, Joao Pedro (Laboratory of Instrumentation and Experimental Particle Physics (PT)); BLANCO CASTRO, Alberto

**Presenter:** DE CARVALHO SARAIVA, Joao Pedro (Laboratory of Instrumentation and Experimental Particle Physics (PT))

**Status:** SUBMITTED

Submitted by **DE CARVALHO SARAIVA, Joao Pedro** on **Tuesday, 18 June 2024**



Abstract ID : 57

## Signal shape studies and rate dependence of HFO-based gas mixtures in RPC detectors

### Content

The RPCs employed at the LHC experiments are currently operated in avalanche mode, with a mixture containing a large fraction of C<sub>2</sub>H<sub>2</sub>F<sub>4</sub> (> 90%) with the addition of i-C<sub>4</sub>H<sub>10</sub> and SF<sub>6</sub> in slightly different concentrations (depending on the experiments). However, C<sub>2</sub>H<sub>2</sub>F<sub>4</sub> and SF<sub>6</sub> are fluorinated greenhouse gases (F-gases) with GWP of ~1400 and ~22800 respectively. EU regulations imposed a progressive phase-down of C<sub>2</sub>H<sub>2</sub>F<sub>4</sub> production and consumption, aiming at strongly reducing its emission. This is already resulting in an increase of its price and reduction in availability.

The most desirable long-term solution to this problem is to find an alternative, F-gases free gas mixture, able to maintain similar detector performance. To address this challenge, the RPC ECO-gas@GIF++ collaboration (including RPC experts of ALICE, ATLAS, CMS SHiP/LHCb and the CERN EP-DT group) was created in 2019. The collaboration is currently studying a gas from the olefine family, the C<sub>3</sub>H<sub>2</sub>F<sub>4</sub> (or simply HFO, with GWP~6), to be used, in combination with CO<sub>2</sub>, a substitute for C<sub>2</sub>H<sub>2</sub>F<sub>4</sub>.

This contribution will focus on the signal shape studies that have been carried out by the collaboration during dedicated beam test periods. The methodology used in the data analysis will be presented, together with the results obtained with several HFO-based gas mixtures, compared to the currently employed one. Furthermore, results on the counting-rate dependence of the RPC performance, obtained by combining the muon beam with the GIF++ 137Cs source with different attenuation factors, will also be presented.

**Primary author:** COLLABORATION, RPC ECOGas@GIF++

**Co-authors:** PASTORE, Alessandra (Universita e INFN, Bari (IT)); PICCOLO, Davide (INFN e Laboratori Nazionali di Frascati (IT))

**Presenter:** COLLABORATION, RPC ECOGas@GIF++

**Status:** SUBMITTED

Submitted by **PASTORE, Alessandra** on **Tuesday, 18 June 2024**

Abstract ID : 58

## Study of environment-friendly SF<sub>6</sub> substitute for the Resistive Plate Chambers

### Content

The standard gas mixture for the Resistive Plate Chambers (RPC), composed of C<sub>2</sub>H<sub>2</sub>F<sub>4</sub>/i-C<sub>4</sub>H<sub>10</sub>/SF<sub>6</sub>, allows the detector operation in avalanche mode, as required by the high-luminosity collider experiments. The gas density, the low current and the comfortable avalanche-streamer separation guarantee high detection efficiency, rate capability and slow detector ageing. This gas mixture has a high Global Warming Potential (GWP~1430) due to the presence of C<sub>2</sub>H<sub>2</sub>F<sub>4</sub>(GWP~1450) and SF<sub>6</sub> (GWP~22400).

The C<sub>2</sub>H<sub>2</sub>F<sub>4</sub> and SF<sub>6</sub> are not recommended for industrial uses anymore, thus their availability will be increasingly difficult over time and the search for an alternative gas mixture is then of absolute priority within the RPC community.

Moreover, CERN is pursuing a campaign toward the reduction of these gases, because they represent most of the LHC particle detectors greenhouse gas emission.

There are several studies on going aimed at replacing the C<sub>2</sub>H<sub>2</sub>F<sub>4</sub>. All these studies require the increase of the SF<sub>6</sub> concentration from 0.3% (standard gas mixture) to 1% to achieve an avalanche-streamer separation of 300 V. This means that the GWP of the alternative gas mixtures can not be below ~200 and the increase of SF<sub>6</sub> should be avoided to maintain the GWP at low level. A very promising alternative to the SF<sub>6</sub>, the C<sub>3</sub>H<sub>2</sub>ClF<sub>3</sub>, has been found and is presented in this work. This gas has a GWP≤1, paving the way to the possibility to operate the RPC detector with a completely environment friendly gas mixture. The tests of the performance and longevity operating the RPC with this gas are reported. The tests have been performed at the Gamma Irradiation Facility (GIF++) at CERN using a 1 mm gas gap RPC.

**Primary authors:** KORTNER, Oliver (Max Planck Society (DE)); KROHA, Hubert (Max Planck Society (DE)); PROTO, Giorgia (Max Planck Society (DE)); SOYK, Daniel (Max Planck Society (DE))

**Presenter:** PROTO, Giorgia (Max Planck Society (DE))

**Status:** SUBMITTED

Submitted by **PROTO, Giorgia** on **Thursday, 20 June 2024**

Abstract ID : 59

## Sealed Resistive Plate Chambers: A Case Study from the SND@LHC Experiment

### Content

The phase-out of Hydro-fluorocarbons, due to their high Global Warming Power, affecting the main gas used in Resistive Plate Chambers (RPCs), tetrafluorethane  $C_2H_2F_4$ , has increased pressure on existing systems and imposes strong restrictions on its use in new systems. A possible solution to the problem is the substitution of this gas by others with a much lower Global Warming Potential.

But there could be another possibility, which is the construction of sealed chambers, i.e. chambers that do not need a continuous gas flow to operate (in a similar way to Geiger-Muller counters). This possibility would allow continuing to use HFCs or eventually other types of gases that are already banned. It would also greatly simplify the detector, not requiring the complex and expensive gas systems normally used. This simplification could be very relevant for the use of this type of technology outdoor.

After an initial development in the laboratory, the first practical use of this technology in the Scatter Neutrino Detector (SND@LHC) is described in this work. A telescope composed of four planes of sealed RPCs has been installed in front of the SND detector to measure the muon flux, the main background source of the experiment. The most relevant parameters in the continuous operation of the detector will be presented, showing no evident differences with RPCs operating in continuous gas flow, demonstrating the possibility of using this technology, over several months and exposed to a low particle rate of around a few Hz/cm<sup>2</sup>.

**Primary authors:** BLANCO, Alberto; FONTE, Paulo; LOPES, Luis (LIP)

**Presenter:** BLANCO, Alberto

**Comments:**

This talk will be presented on behalf of SND@LHC colalboration

**Status:** SUBMITTED

Submitted by **BLANCO CASTRO, Alberto** on **Friday, 21 June 2024**

Abstract ID : 60

## New RPC readout for EAS mapping in ground based cosmic ray detectors

### Content

Besides High Energy Physics experiments, RPCs have been successfully employed also in cosmic ray physics, as demonstrated by ARGO experiment.

The detector readout is however very different from that used for particle tracking in collider experiments, based on strips behaving as transmission lines with non-negligible signal propagation time.

Cosmic ray detection with ground-based apparatuses requires mapping extensive air showers with good accuracy. The detector requirements, based on simulations as well as on past experiments, are a modest rate capability (the cosmic rays one) coupled to good capability of measuring high hit densities (up to  $10^6/\text{m}^2$  around the core region); a time resolution of the order of the ns is also required for the incident direction reconstruction. A space resolution of the order of 10 cm is sufficient, due to intrinsic fluctuations of the shower front. Given the large area to be covered, the detector must be simple, robust, reliable and economic.

To fulfill these requirements we will present a new readout, based on squared pads of area around  $40 \times 40 \text{ cm}^2$ , which compared to Argo, can reduce the number of read-out channels down to about an order of magnitude without losing space and time resolutions. Another innovative aspect of the new readout is the signal pick-up point that is localized not at the pad edge but at its center.

Preliminary studies about signal pick-up will also be presented.

**Primary authors:** Prof. CAMARRI, Paolo (INFN - Roma2); Mr DI STANTE, Luigi (INFN - Roma2); Dr LIBERTI, Barbara (INFN - Roma2); Dr MEOLA, Sabino (INFN - LNF); Dr PAOLONI, Alessandro (INFN - LNF); Dr PASTORI, Enrico (INFN - Roma2); Dr PICCOLO, Davide (INFN - LNF); Dr ROCCHI, Alessandro (INFN - Roma2); Prof. SANTONICO, Rinaldo (INFN - Roma2)

**Presenter:** Dr PAOLONI, Alessandro (INFN - LNF)

**Status:** SUBMITTED

Submitted by **PAOLONI, Alessandro** on **Monday, 24 June 2024**

Abstract ID : 61

## COmpact DEtector for EXotics at LHCb: CODEX-b

### Content

The COmpact DEtector for EXotics at LHCb (CODEX-b) is a particle physics detector dedicated to displaced decays of exotic long-lived particles (LLPs), compelling signatures of dark sectors Beyond the Standard Model, which arise in theories containing a hierarchy of scales and small parameters. The CODEX-b detector is a cube with 10m per side with two internal sections, planned to be installed near the LHCb interaction point. It is built of a new generation of high performance RPCs triplet chambers, derived from the ATLAS upgrade RPC technology, providing a space x time resolution of a few mm x 300 ps per individual detector layer. It will have a zero background environment, hence complementing the new-searches program of other detectors like ATLAS or CMS. A demonstrator detector, CODEX- $\pi$ , is being assembled now to take data beginning in 2025. It will validate the design and physics case for the future CODEX-b. CODEX- $\pi$  will be responsible for validating the background estimations for CODEX-b, demonstrating integration in the LHCb readout system, and showing the suitability of the baseline tracking and its mechanical support. This talk will present the latest developments and will focus on the status and plans for CODEX- $\pi$ .

**Primary author:** PETERS, Michael Jacob (University of Cincinnati (US))

**Co-author:** ALIMENA, Juliette (DESY)

**Presenter:** PETERS, Michael Jacob (University of Cincinnati (US))

**Status:** SUBMITTED

Submitted by **ALIMENA, Juliette** on **Friday, 28 June 2024**

Abstract ID : 62

## The first miniTRASGO Cosmic Ray telescope

### Content

Since their discovery in 1912, cosmic rays have been an invaluable source of information about the distant universe, constituting one of the pillars of the so-called multi-messenger astronomy. Also, they act as a penetrating radiation providing information about near-Earth space and the solar activity. In order to deepen our knowledge in cosmic rays, a new family of detectors called Trasgos has been proposed. These high granularity tracking devices employ Resistive Plate Chambers (RPCs) to detect ionizing secondary cosmic rays in a plug&play philosophy. The 0.1 m<sup>2</sup> small size Trasgo here presented includes pressure, temperature and humidity sensors as well as built-in rate monitoring software and hit maps. The detector performance and calibration procedures are outlined, along with results from measurements and preliminary analyses. This study not only proves the scientific potential of the miniTRASGO concept, including the observation of a Forbush Decrease, but also sets the stage for its future integration into a international muon telescope network, which aims to enhance global cosmic ray research.

**Primary author:** SONEIRA-LANDÍN, Cayetano (GFN - Complutense University of Madrid)

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**Presenter:** SONEIRA-LANDÍN, Cayetano (GFN - Complutense University of Madrid)

**Status:** SUBMITTED

Submitted by **SONEIRA LANDÍN, Cayetano** on **Friday, 28 June 2024**

Abstract ID : 64

## Status of the CBM Time-Of-Flight project

### Content

In order to provide an excellent particle identification (PID) of charged hadrons at the future high-rate Compressed Baryonic Matter (CBM) experiment the CBM-TOF group has developed a concept of a 120 m<sup>2</sup> large Time-of-Flight (ToF) wall (about 90000 channels) with a system time resolution below 80 ps based on Multi-gap Resistive Plate Chambers (MRPC). Prior to its destined operation at the Facility for Antiproton and Ion Research (FAIR), a preproduction series of MRPCs is being used for physics research at two scientific pillars of the FAIR Phase0 program. At STAR, the fixed-target program of the Beam Energy Scan II (BES-II) relies on 108 CBM MRPC detectors enabling forward PID for center of mass energies in the range of 3 to 7.7 AGeV Au+Au collisions. At miniCBM, high-performance benchmark runs of  $\Lambda$  production at top SIS18 energies (1.5/1.9 AGeV for Au/Ni beams) and CBM design interaction rates of 10 MHz became feasible. Apart from the physics perspectives, these FAIR Phase-0 involvements allowed for high rate detector tests including aging studies and long term stability tests. The MRPC detectors of different granularities were extensively tested in several beam campaigns at particle fluxes of up to a 30 kHz/cm<sup>2</sup> and reached by now the final design so that for some MRPC types the mass production could be started recently. Latest detector performance results and the status of the CBM TOF project including counter mass production, the infrastructure and time line will be discussed.

**Primary author:** DEPPNER, Ingo-Martin (Physikalisches Institut der Universität Heidelberg)

**Presenter:** DEPPNER, Ingo-Martin (Physikalisches Institut der Universität Heidelberg)

**Status:** SUBMITTED

Submitted by **DEPPNER, Ingo-Martin** on **Friday, 28 June 2024**

Abstract ID : 65

# Evaluating the Performance and Long-Term Stability with LHC-like Background Irradiation of RPC Detectors with a CO<sub>2</sub>-based Gas Mixtures

## Content

Resistive Plate Chamber (RPC) detectors at CERN's LHC experiments traditionally use a Freon-based gas mixture containing C<sub>2</sub>H<sub>2</sub>F<sub>4</sub> (R-134a) and SF<sub>6</sub>, both of which are high global warming potential (GWP) gases. To reduce greenhouse gas emissions, operational costs, and optimize RPC performance, the best compromise is the gas mixture with a substitution of 30% of R-134a with CO<sub>2</sub> in the standard gas mixture. This gas mixture that we proposed it is in use in the ATLAS RPC system since Summer 2023.

This study investigates the detector's performance when CO<sub>2</sub> is introduced into the standard gas mixture as a medium-term solution to minimize emissions while maintaining compatibility with current CERN RPC systems.

Conducted at the CERN Gamma Irradiation Facility, this research uses a 12 TBq <sup>137</sup>Cs source and a muon beam to simulate the LHC experiment's background radiation. The setup includes five 2 mm single-gap High Pressure Laminate (HPL) RPCs placed at different distances (outside the irradiation bunker, 5m, and 12m from the gamma source).

Since March 2023, the detectors inside the bunker have been continuously irradiated to study long-term performance, aiming to achieve the integrated charge expected for ATLAS RPC detectors during LHC Run 3 and the High Luminosity LHC phase. Monitoring is performed with various metrics such as gas analysis, oxygen, humidity, dose, environmental parameters, and flow measurements to ensure the gas system operates correctly.

Several periodic test beam periods are conducted to assess muon performance parameters, including efficiency, current, streamer probability, mean prompt charge, cluster size, and time resolution. Results for the ageing studies, using our proposed 30% CO<sub>2</sub> gas mixture, will be presented.

**Primary authors:** GUIDA, Roberto (CERN); JUKS, Stefania-Alexandra (Université Paris-Saclay (FR)); MANDELLI, Beatrice (CERN); RIGOLETTI, Gianluca (CERN); VERZEROLI, Mattia (Universite Claude Bernard Lyon I (FR))

**Presenter:** VERZEROLI, Mattia (Universite Claude Bernard Lyon I (FR))

**Status:** SUBMITTED

Submitted by **VERZEROLI, Mattia** on **Friday, 28 June 2024**



Abstract ID : 66

## New Facilities for the Production of 1 mm gap Resistive Plate Chambers for the Upgrade of the ATLAS Muon Spectrometer

### Content

The ATLAS Muon Spectrometer is set for a significant upgrade as part of the High-Luminosity LHC (HL- LHC) program, which includes the installation of three additional full coverage layers of new generation thin-gap Resistive Plate Chambers (RPCs) in the inner barrel region. These RPCs feature a reduced gas gap thickness of 1 mm between high-pressure phenolic laminate (HPL) electrodes, enhancing their background rate capability and longevity. This upgrade aims to maximize the muon trigger acceptance and efficiency. To achieve this, nearly 1000 RPC gas gaps need to be produced. To mitigate reliance on a single supplier and expedite production, the ATLAS muon community has partnered with two new companies in Germany and the Max Planck Institute for Physics in Munich. The gas gap assembly procedure was adapted to the infrastructure and tools available at the industrial manufacturers, facilitating the transfer of technology to industry after the prototyping phase. The certification of the manufacturers was achieved by constructing several small- and full-size RPC gas gap prototypes at each facility. The prototypes underwent rigorous testing at CERN's Gamma Irradiation Facility (GIF++), where their efficiency and time resolution were measured under different gamma background levels. The performance of these prototypes met the requirements for ATLAS at the HL-LHC. Additionally, the prototypes successfully passed an accelerated aging test at the GIF++, where they were exposed to the maximum photon dose expected during HL-LHC operations. This contribution will present the gas gap manufacturing procedures, the results of the certification tests, and the comparative analysis of the production methods investigated to ensure the reliability and efficiency of RPC production at external companies. The outcomes demonstrate that the new facilities are capable of producing high-quality RPCs according to the industrial standards.

**Primary author:** COMMUNITY, ATLAS Muon (ATLAS)

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**Comments:**

Presenter will be selected at a later stage

**Status:** SUBMITTED

Submitted by **BRUNI, Alessia** on **Friday, 28 June 2024**

Abstract ID : 67

## Production and test of the RPC detectors for the large sectors of the ATLAS Inner Barrel (BIL) Phase II upgrade

### Content

The current RPC system is undergoing a major upgrade, consisting in the installation of approximately 1000 RPC detector units of new generation in the innermost barrel layer of the ATLAS Muon Spectrometer. The goal of the project is to increase the detector coverage, currently limited to approximately 80%, and improve the trigger robustness and efficiency. The production of the gas volumes takes place in a factory in Italy, in MPI and USTC, while the readout panels in Cosenza and USTC. The Italian collaboration is taking care of the construction and test of the chambers located in the large sectors of the ATLAS barrel (BIL).

Here we present the state of the art of the production, certification and logistics related to all the components produced at the Italian sites, as well as the assembly line and characterization of the BIL chambers at CERN. In particular, we describe the protocols defined and the instrumentation created for the certification of gas volumes at the Italian production factory, for the construction and

certification of the read-out panels in Cosenza and for the assembly and certification with cosmic rays of the detectors at CERN. The certification results of the components produced are analyzed and discussed.

**Primary author:** COMMUNITY, ATLAS Muon (ATLAS)

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**Comments:**

Presenter will be selected at a later stage

**Status:** SUBMITTED

Submitted by **BRUNI, Alessia** on **Friday, 28 June 2024**

Abstract ID : 68

## The ATLAS RPC Phase II upgrade for High Luminosity LHC era

### Content

RPC detectors play a crucial role in triggering events containing muons in the central region of ATLAS. In view of the HL-LHC program, the existing RPC system, consisting of six independent concentric cylindrical detector layers each providing a full space time localization of hits, is currently facing a significant upgrade. In the next few years, 306 triplets of new generation RPCs will be installed in the innermost region of the ATLAS Muon Barrel Spectrometer, increasing from 6 to 9 the number of tracking layers, doubling the trigger lever arm. This allows a substantial enhancement of the present trigger redundancy, increasing the coverage from 76% to 96% approximately. The new chamber design is based on a very efficient integration of an innovative front-end electronics within the detector Faraday cage, allowing to operate the RPCs with an order of magnitude less of average charge per count, correspondingly increasing rate capability and longevity. Fitting new chambers in the narrow space left in ATLAS inner barrel was a challenge, achieved by optimizing RPC materials and thickness, featuring a 1 mm gas gap (instead of 2 mm), and 1.4 mm resistive electrodes (instead of 1.8 mm). Both sides of RPCs are readout by strip panels oriented to measure the bending coordinate of the muon spectrometer, while the second coordinate is reconstructed from the time difference of signal drift at opposite detector's ends. To achieve such results, a 100 ps precise TDC has been integrated in the front-end electronics ASIC. The expected time resolution of a single 1 mm RPC gas gap is approximately 300 ps, and the possibility of a stand-alone Time of Flight measurement will have a huge impact on ATLAS searches for massive long-lived particles. An overview and the present status of the ATLAS RPC Phase II project will be presented.

**Primary author:** COMMUNITY, ATLAS Muon (ATLAS)

**Presenter:** COMMUNITY, ATLAS Muon (ATLAS)

**Comments:**

Presenter will be selected at a lagter stage

**Status:** SUBMITTED

Submitted by **BRUNI, Alessia** on **Friday, 28 June 2024**

Abstract ID : 69

## Performance of ATLAS RPC detectors and L1 Muon Barrel Trigger with a new CO<sub>2</sub>-based gas mixture

### Content

Resistive Plate Chambers are used in the ATLAS experiment for triggering muons in the barrel region. These detectors use a Freon-based gas mixture containing C<sub>2</sub>H<sub>2</sub>F<sub>4</sub> and SF<sub>6</sub>, high global warming potential greenhouse gases. To reduce the greenhouse gas emissions and cost, it is crucial to search for new environmentally friendly gas mixtures. In August 2023, at the end of the proton-proton data-taking campaign, ATLAS collaboration decided to replace the standard gas mixture (94.7% C<sub>2</sub>H<sub>2</sub>F<sub>4</sub>, 5.0% i-C<sub>4</sub>H<sub>10</sub>, 0.3% SF<sub>6</sub>) with a new CO<sub>2</sub>-based gas mixture: 64% C<sub>2</sub>H<sub>2</sub>F<sub>4</sub>, 30% CO<sub>2</sub>, 5.0% i-C<sub>4</sub>H<sub>10</sub>, 1% SF<sub>6</sub>. The performance of the RPC detectors with the new gas mixture will be presented with a particular emphasis on detector efficiency, cluster size and timing performance, as well as the efficiency of the L1 Muon Barrel trigger system.

**Primary author:** COMMUNITY, ATLAS Muon (ATLAS)

**Presenter:** COMMUNITY, ATLAS Muon (ATLAS)

**Comments:**

Presenter will be selected at a later stage

**Status:** SUBMITTED

Submitted by **BRUNI, Alessia** on **Friday, 28 June 2024**

Abstract ID : 70

## On the performance of the novel front-end electronics for the ATLAS BI RPC upgrade at HL-LHC developed in SiGe BiCMOS technology

### Content

The High Luminosity phase of LHC will require a vast improvement of the ATLAS detector in terms of performance, since the entire apparatus will be operated in much harsher conditions. The BI project is one of the ATLAS Phase-2 upgrades, ensuring the demands coming from the physics for the next 20 years. In this framework, a novel dedicated Front-End electronics has been developed, which exploits a BJT-based preamplifier, a fast discriminator (minimum threshold achievable 1-2 fC) and a high resolution (<100ps) Time-To-Digital converter in SiGe BiCMOS technology, to vastly enhance the detector rate capability (1 order of magnitude with respect to the RPC currently installed in ATLAS). This front-end electronics is integrated for the first time within the detector Faraday cage, largely reducing the effects of induced and self-induced noise, allowing a minimum effective charge threshold on the induced signal of 1-2 fC. The integration of the front-end electronics directly within the detector Faraday cage is also permitted by the low power consumption of 15 mW/ch. The RPC coupled with this novel front-end electronics represents a new generation of large area timing detectors, granting a record time resolution of 350 ps on a single gas gap of 1 mm and operated with the ATLAS standard gas mixture. The effect of the extremely low threshold has also an impact on the gas mixture, enabling the usage of eco-friendly gas mixtures which would not be usable elsewhere.

The latest performance of this newly developed front-end electronics along with the results achieved with RPC detector coupled with it will be shown.

**Primary author:** COMMUNITY, ATLAS Muon (ATLAS)

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**Comments:**

Presenter will be selected at a later stage

**Status:** SUBMITTED

Submitted by **BRUNI, Alessia** on **Friday, 28 June 2024**

Abstract ID : 71

## Triplet assembly and certification of the new generation of RPC for the ATLAS phase-2 upgrade at Max Planck Institute

### Content

A new generation of Resistive Plate Chambers have been developed for the ATLAS phase-2 upgrade in sight of the High-Luminosity phase of the Large Hadron Collider. These RPCs consist in three independent 1 mm gas gaps(singlets) equipped with a newly low-threshold Front-End electronics, assembled in the same mechanical structure(triplet). During 2024 the production of the phase-2 RPCs started and the detectors will undergo (2024-2025) a certification test before the installation in the ATLAS cavern. The triplet assembly and the certification with cosmic rays of the BIS-type detectors is performed at the Max-Planck-Institute for Physics (MPI) in Munich. The architecture of the cosmic rays test stand has been built at MPI and has been studied in order to provide an efficient and robust structure to ensure an excellent quality control and study precisely the whole RPC performance needed to certify the detectors for the ATLAS experiment. In this presentation the assembly procedure, the architecture of the test stand and the certification protocols will be presented along with the validation tests to characterize the RPC performance.

**Primary author:** COMMUNITY, ATLAS Muon (ATLAS)

**Presenter:** COMMUNITY, ATLAS Muon (ATLAS)

**Comments:**

Presenter will be selected at a later stage

**Status:** SUBMITTED

Submitted by **BRUNI, Alessia** on **Friday, 28 June 2024**

Abstract ID : 72

## Performance and ageing studies of a ATLAS RPC prototype using a CO<sub>2</sub>-R134A based mixture and projection on long term performance and longevity of ATLAS RPCs

### Content

The ATLAS Resistive Plate Chambers (RPCs) are critical components for the muon triggering and measurement of the azimuthal coordinate in the barrel region in ATLAS. The RPCs use a gas mixture consisting of 95.2% C<sub>2</sub>H<sub>2</sub>F<sub>4</sub> (Tetrafluoroethane - R134a), 4.5% i-C<sub>4</sub>H<sub>10</sub> (Isobutane), and 0.3% SF<sub>6</sub> (Sulfur Hexafluoride), known as the RPC standard gas mixture. However, the high Global Warming Potential (GWP) of C<sub>2</sub>H<sub>2</sub>F<sub>4</sub> and SF<sub>6</sub> presents significant environmental challenges due to their greenhouse gas emissions. Additionally, gas leakage issues in ATLAS have aggravated the contribution of RPC detectors to global warming. Nearly 3800 RPC gas gaps in the ATLAS cavern are being damaged due to the high sensitivity of the materials used for gas inlets. This results in approximately 800-1000 liters of RPC gas leakage per hour, significantly contributing to CERN's overall greenhouse gas emissions.

A solution to this problem is replacing the current RPC gas mixture with another that offers similar performance but has a lower GWP. Initial studies with various ratios of CO<sub>2</sub>, aim to reduce the GWP without compromising detector efficiency, time resolution, and longevity and have shown promising results. This study presents the results of the performance tests and aging study of the 50 cm x 50 cm RPC prototype with 30% and 40% CO<sub>2</sub> gases as a replacement of C<sub>4</sub>H<sub>10</sub>.

**Primary author:** COMMUNITY, ATLAS Muon (ATLAS)

**Presenter:** COMMUNITY, ATLAS Muon (ATLAS)

**Comments:**

Presenter will be selected at a later stage

**Status:** SUBMITTED

Submitted by **BRUNI, Alessia** on **Friday, 28 June 2024**

Abstract ID : 73

## Mass production of RPC readout panels for ATLAS Phase-II upgrade and R&D on thin gas gap production at USTC

### Content

In order to cope with the High-Luminosity Large Hadron Collider, the current ATLAS Muon system foresees a significant upgrade during the Long Shutdown-3.

For the muon trigger, three layers of thin-gap Resistive Plate Chambers (RPC) will be added to the BI (Barrel Inner) region.

This new generation of RPC benefits from the thin-gap structure to achieve the required higher rate capability.

At the same time, it is also very challenging for detector production, quality assurance, and quality control.

Our Chinese ATLAS group undertook the construction of 912 readout panels, the fabrication of 72 BI gas gaps, and the assembly of 360 singlets for the upgrade.

To fulfill the BI-RPC project in China, we have established and optimized the vacuum-bag-based method for honeycomb readout panel production in our laboratory at USTC.

The same method is also applied to the production of readout panels in the industry. The speed and quality of readout panel production have been significantly accelerated.

The production procedures of the gas gap prototypes at USTC are presented. The gas gaps are oiled at a room temperature of 40°C and flushed with heptane before applying the Linseed oil.

This process can significantly enhance the quality of linseed oiling on the inner surfaces of the Bakelite RPC.

The quality of those gas gap prototypes are checked and the results are very promising.

**Primary author:** COMMUNITY, ATLAS Muon (ATLAS)

**Presenter:** COMMUNITY, ATLAS Muon (ATLAS)

**Comments:**

Presenter will be selected at a later stage

**Status:** SUBMITTED

Submitted by **BRUNI, Alessia** on **Friday, 28 June 2024**



Abstract ID : 74

## Outdoor MARTA RPCs performance update

### Content

Over the last two decades, the possibility of using RPCs in outdoors systems has increased considerably. Our group has participated in this effort having installed several systems and continues to work on their optimization, while simultaneously studying and developing new approaches that can to use of RPCs in outdoor applications.

In particular, some detectors were deployed in the field at the Pierre Auger Observatory in 2019 remained inactive, awaiting the commissioning of support systems. During the pandemic the detectors were left without gas flow for more than two years, until 2022 when the were fill with gas and turn HV on,

The behavior of 5 large area RPCs deployed under one of the AUGER water Cherenkov tanks will be presented.

**Primary author:** VIEIRA LOPES, Luis Alberto (Laboratory of Instrumentation and Experimental Particle Physics (PT))

**Presenter:** VIEIRA LOPES, Luis Alberto (Laboratory of Instrumentation and Experimental Particle Physics (PT))

**Status:** SUBMITTED

Submitted by **VIEIRA LOPES, Luis Alberto** on **Saturday, 29 June 2024**

Abstract ID : 75

## T-SDHCAL Hadronic Calorimeter for future Higgs factory

### Content

The CALICE technological RPC-based SDHCAL prototype that fulfils all the requirements of compactness, hermeticity and power budget of the future lepton accelerator experiments, has been extensively tested and has provided excellent results in terms of the energy resolution and shower separation.

New phase of R&D to validate completely the SDHCAL option for the International Linear Detector (ILD) project of the ILC and also the Circular Electron Positron Collider (CEPC and FCCee) has started with the conception and the realization of new prototypes.

The new prototype proposes to exploit the excellent time resolution provided by (M)RPC detectors in order to better build the hadronic showers with the aim to separate close-by ones and also to single out the contribution of delayed neutrons with the purpose to improve on the Particle Flow Algorithm (PFA) performances and better reconstruct the showers energy.

A new technique to build MRPC has been developed and first results confirm the excellent efficiency of the ne detectors. Timing performance is under study using the PETIROC ASIC developed by OMEGA group. The new activities are part of the new collaborations DRD1 and DRD6.

The progress realized on the different aspects of the new concept will be presented and the future steps will be discussed.

**Primary author:** LAKTINEH, Imad (Centre National de la Recherche Scientifique (FR))

**Presenter:** LAKTINEH, Imad (Centre National de la Recherche Scientifique (FR))

### Comments:

This is on behalf of the T-SDHCAL groups. The speaker will be selected later

**Status:** SUBMITTED

Submitted by **LAKTINEH, Imad** on **Sunday, 30 June 2024**

Abstract ID : 76

## Upgraded simulation of the CERN Gamma Irradiation Facility (GIF++)

### Content

GIF++ irradiation facility at CERN is a unique infrastructure for performance test and long term characterization of gaseous detectors under severe gamma background conditions. Also, a muon beam line is available to ensure precise detector studies. The gamma flux is originated by a 14 TBq  $^{137}\text{Cs}$  source and can be modulated in a wide range by means of various absorption filters which can be controlled remotely.

To understand the detector response, an evaluation of the dose and the gamma flux at the detector position is needed. To this aim we have performed a detailed GEANT 4 simulation of the area, and the ambient equivalent dose rate has been computed. The results are validated by comparison with some measurement campaigns which have been taken using fixed and portable gamma dosimeters at various distance from the source and different attenuation filter combinations

Once calibrated with experimental measurements, the simulation offer the possibility to compute the gamma flux on a given detector and therefore estimated the expected hit rate.

**Primary author:** FERRARA, Nicola (Universita e INFN, Bari (IT))

**Co-authors:** IASELLI, Giuseppe (Universita e INFN, Bari (IT)); PUGLIESE, Gabriella (Universita e INFN, Bari (IT)); RAMOS LOPEZ, Dayron (Universita e INFN, Bari (IT))

**Presenter:** FERRARA, Nicola (Universita e INFN, Bari (IT))

**Status:** SUBMITTED

Submitted by **FERRARA, Nicola** on **Monday, 1 July 2024**

Abstract ID : 77

## ANUBIS: future large-scale application of RPC detectors

### Content

An important potential large-scale application of RPC detectors in the near future is the ANUBIS detector at the HL-LHC, with a total gas gap area of about  $8,000 \text{ m}^2$ . The primary physics goal for the ANUBIS detector is searching for new long-lived particles (LLP) that are predicted in many extensions of the Standard Model with Dark Matter candidates. The ANUBIS detector will provide unprecedented sensitivity to LLPs with decay lengths of  $O(10\text{m})$  and above produced at the electroweak scale. After a brief review of the ANUBIS physics case, the performance benchmarks that are dictated by the physics case will be discussed, and a proposed design of the ANUBIS detector will be outlined. This year, a first complete prototype detector module called proANUBIS has been taking data in the ATLAS cavern. The physics case for proANUBIS and its relevance to ANUBIS physics case will be outlined.

**Primary author:** BRANDT, Oleg (University of Cambridge (GB))

**Presenter:** BRANDT, Oleg (University of Cambridge (GB))

**Status:** SUBMITTED

Submitted by **BRANDT, Oleg** on **Monday, 1 July 2024**

Abstract ID : 78

## Operation of 1 mm HPL RPCs with low-GWP gas mixtures

### Content

RPCs have traditionally used a gas mixture with a high Global Warming Potential (GWP). To reduce the environmental impact, promising low-GWP gases and the addition of CO<sub>2</sub> to the standard mixture have been explored on small 50 x 50 cm<sup>2</sup> RPC prototypes using a 1 mm single-gap HPL-based technology. Preliminary measurements of key performance metrics like efficiency, streamer probability, induced charge, cluster size, and time resolution are presented, highlighting their impact on detector performance and potential broader applications.

**Primary author:** BRANDT, Oleg (University of Cambridge (GB))

**Presenter:** BRANDT, Oleg (University of Cambridge (GB))

**Status:** SUBMITTED

Submitted by **BRANDT, Oleg** on **Monday, 1 July 2024**

Abstract ID : 79

## Quality assurance tests and techniques to investigate and increase hermetic sealing of ATLAS Phase II RPC detectors

### Content

The Phase II upgrade of the ATLAS Muon Spectrometer plans to install approximately 1000 new-generation Resistive Plate Chambers (RPCs). This upgrade will enhance detector coverage, increase hit efficiency and timing precision, improving the trigger precision and robustness.

The chamber production is ongoing and gas volumes are commercially produced in Italy. To investigate and improve the integrity of the gas volumes, their mechanical property and the gas tightness, several techniques have been proposed and applied.

This talk describes experiences on ATLAS gas gaps with thermal cycling (TC) performed between -30°C and +30°C, and the subsequent impact in the context of gas leaks, as well as techniques to investigate and improve gas tightness.

The goal is to produce leak-tight detectors preventing the emission of gases having impact on global warming.

**Primary author:** COMMUNITY, ATLAS Muon (ATLAS)

**Presenter:** COMMUNITY, ATLAS Muon (ATLAS)

**Comments:**

presenter will be discussed at a later stage

**Status:** SUBMITTED

Submitted by **BRUNI, Alessia** on **Monday, 1 July 2024**

Abstract ID : 80

# Investigating RPC Gas Flow and Ion Transport Using Computational Models

## Content

The CMS Experiment utilizes advanced muon detection systems comprising various gas-based technologies, such as Drift Tubes, Cathode Strip Chambers, and Resistive Plate Chambers (RPCs). RPCs are notable for their rapid response, which is crucial for the system's triggering mechanism. The CMS RPC system features a 2 mm gas gap filled with a mixture of 95.2% C<sub>2</sub>H<sub>2</sub>F<sub>4</sub>, 4.5% iC<sub>4</sub>H<sub>10</sub>, and 0.3% SF<sub>6</sub>. This mixture reacts under high radiation levels and intense high voltage (approximately 10 kV), producing fluorine ions that contribute to the aging of the chambers. Recent studies indicate that increasing gas flux can help disperse these ions, thereby delaying the aging process. With the LHC Phase-2 upgrade, the CMS will introduce 72 new RPCs with a reduced gas gap of 1.4 mm in areas expected to experience significantly higher radiation levels. Understanding the relationship between gas flux and aging is crucial for this upgrade. This study builds on initial research to enhance RPC longevity by developing mathematical and computational models for gas flow and fluorine ion transport. Using the Navier-Stokes equations for fluid dynamics and incorporating ion diffusion, migration under electric fields, and convection, these models are discretized using finite element methods via the Gridap library. This research underscores the importance of optimizing RPC design by carefully considering geometry and flow dynamics to minimize aging effects. Such advancements not only enhance the performance and durability of RPCs but also contribute to more cost-effective and reliable detection technologies in high-energy physics.

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Submitted by **THIEL, Mauricio** on **Monday, 1 July 2024**

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# The miniTrasgo International Research Network

## Content

The Trasgo detectors were proposed a few years ago for the measurement of cosmic rays at ground level with a very high angular resolution, with the ability to measure bundles of particles and with an electron/muon PID carried out by software. Now a new generation of detectors, the miniTrasgos, of only 0.1m<sup>2</sup> of surface, has been launched and several of them have already been built and distributed in different universities in Madrid (Spain), Warsaw (Poland) and Puebla (Mexico). Other detectors are still under construction. All detectors share layout and both reconstruction and analysis software. In this poster we show details of the network, the characteristics of each node and some preliminary results of the detectors already active.

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## Comments:

The poster will be presented "on behalf of the miniTrasgo Research Network Collaboration"

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## A method to design a fast hybrid photodetector based on the RPC structure

### Content

The idea of using gaseous detectors to amplify photo-electrons emitted by an embedded photocathode has been declined in many ways in the last decades, using different gaseous detector structures, including RPCs. Moreover, coupling such structures with a radiator element, enables these devices to detect charged particles, through the radiated photons.

There are at least two main challenges in building such structures: the combined yield of the radiator and the photocathode may be too low to gain high detection efficiency; high yield photocathode materials, also sensitive to a wider photon spectrum are very fragile and easy to oxidize, quickly degrading under the ionic flow typically generated in gaseous detectors.

In this paper we will present a method to exploit the most significant aspects of RPC physics to design an efficient hybrid detector, significantly enhancing most of the present gaseous detectors features and limitations.

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## Insights from the proANUBIS demonstrator using Run 3 LHC collision data

### Content

The proposed AN Underground Belayed In-Shaft (ANUBIS) experiment aims to search for long-lived particles (LLPs) within CERN's ATLAS underground cavern. Recent efforts to realise this experiment include the installation and commissioning of a prototype detector, proANUBIS, which has been collecting LHC collision data since in 2024. The key point physics programme of the proANUBIS demonstrator is the study of expected backgrounds for the ANUBIS experiment. The demonstrator employs the ATLAS BIS78 RPCs, which feature a 1mm gas gap, in contrast to the 2mm used in the legacy ATLAS RPCs. In this presentation, we will discuss the quality control and performance studies of these RPCs using cosmic ray flux. Additionally, we will report on the performance of proANUBIS, including hit multiplicity, cluster size, and reconstruction efficiency of these RPCs, based on recent data collected by the demonstrator during Run 3 LHC collisions.

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