

# Resistive Plate Chamber HV Control System for the MATHUSLA experiment

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## Abstract

MATHUSLA is a proposed dedicated large-volume displaced vertex detector on the surface for the High Luminosity Large Hadron Collider (HL-LHC) to study Ultra Long-Lived Particles (ULLP) produced at LHC. This project involves the development of a system to control the high voltage applied to the Resistive Plate Chamber according to the environmental conditions.

## Introduction

The Standard Model (SM) is consistent with almost all of the phenomena observed at the colliders. Even so, there are some unsolved problems, such as dark matter, neutrino masses, matter-antimatter asymmetry, among others. To date, no search has observed evidence of Beyond Standard Model (BSM) physics. One possible reason might be the fact that those have an incorrect assumption about what the BSM signals look like. Most searches focus on the production of heavy new states at or above the weak scale, which promptly decay and give rise to high-energy visible final states including jets, leptons, photons, or stable invisible particles that are detectable as missing energy. But this is not the only possibility for BSM signals. Currently, many BSM models suggest the existence of long-lived particles (LLP) with a macroscopic decay length, that can decay into SM particles, such as leptons and/or jets. LLPs could be colored, electrically charged, or neutral.

The LLP search program at the LHC is growing, but it is limited by the detectors size and by a large background. The MATHUSLA experiment is being proposed to increase the sensitivity for neutral LLPs, and it will be done by looking for a displaced Decay Vertex (DV) away from the LHC Interaction Point (IP).

## The MATHUSLA experiment

The proposed MATHUSLA200 [1,2] experiment will consist of an air-filled-decay volume, surrounded by a 1 cm thick plastic scintillator, and a multilayer of a Resistive Plate Chamber (RPC). Its location, on the surface above and slightly displaced from the ATLAS or CMS (main detector) interaction point, will extend the lifetime range of LLP searches by three orders of magnitude compared to the main detector. Such particles are often referred to as ULLP.

This detector aims to measure ULLP produced in  $pp$  collisions that, because of their long lifetime, decay to charged SM particles far from the main detector. When producing ULLPs in exotic Higgs decays, the number of observed ULLP is roughly:

$$N_{obs} \sim N_h \times Br(h \rightarrow ULLP \rightarrow SM) \times \epsilon_{geometric} \times \frac{L}{bc\tau} \quad (1)$$

where  $N_h$  is the number of produced Higgs bosons at the LHC,  $Br(h \rightarrow ULLP \rightarrow SM)$  is the decay branching fraction,  $\epsilon_{geometric}$  is the chance that the ULLP will pass through the detector (i.e. geometric coverage),  $L$  is the linear size of the detector, and  $b$  is the Lorentz boost  $|\vec{p}|/m$  of the produced ULLP.

## The test stand

In order to provide empirical information on potential background coming from the LHC as well as from cosmic rays, a MATHUSLA test stand (Fig. 1) was assembled at CERN in November 2017. The structure of  $\sim 6.5 \times 2.5 \times 2.5 m^3$  is much smaller than the proposed one, and it is located on top of the ATLAS' interaction point. The test stand also makes use of pieces from other experiments, the scintillators were provided by Fermilab (Tevatron DØ experiment), and the RPCs were provided by the University of Tor Vergata (Argo-YBJ experiment). The geometry itself also differs from the one expected for MATHUSLA. For those reasons, the test stand is not considered a prototype of the main detector, but it can still provide very useful information for the design of the future MATHUSLA detector. The present work is focused on the RPC's response.

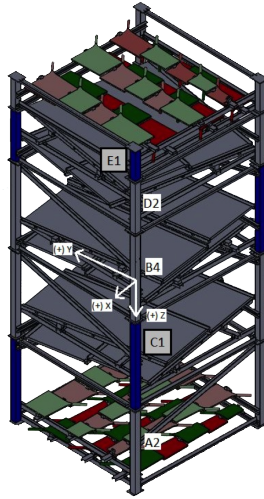


Figure 1: Schematic view of the MATHUSLA test stand. There are three layers of RPC (gray), and two layers of scintillators (green and red).

## Operating voltage on the RPCs

The RPCs' behavior is well known, since they were previously used in the ARGO-YBJ experiment [3]. Therefore, it is known that the gas gain depends on the environmental conditions, such as temperature and pressure. It means that if any of those parameters vary, the gas performance is going to be modified as well. It is crucial for an experiment to have a stable detector response, independent of external conditions. According to [4], the effective voltage in the chamber is

$$V_{eff} = V_{app} \frac{T}{T_0} \frac{p_0}{p}, \quad (2)$$

where  $T_0$  and  $p_0$ , are the initial temperature (K) and pressure (mBar), respectively, and  $V_{app}$  is the applied voltage. Therefore, if we want the  $V_{eff}$  to be constant and equal to  $V_0$ , we should apply

$$V_{app}(t) = V_0 \frac{T_0}{p_0} \frac{p(t)}{T(t-1h)} . \quad (3)$$

Studies made on the Argo-YBJ experiment showed that the effects on the voltage due to the pressure are immediate, but those due to the temperature are delayed by one hour.

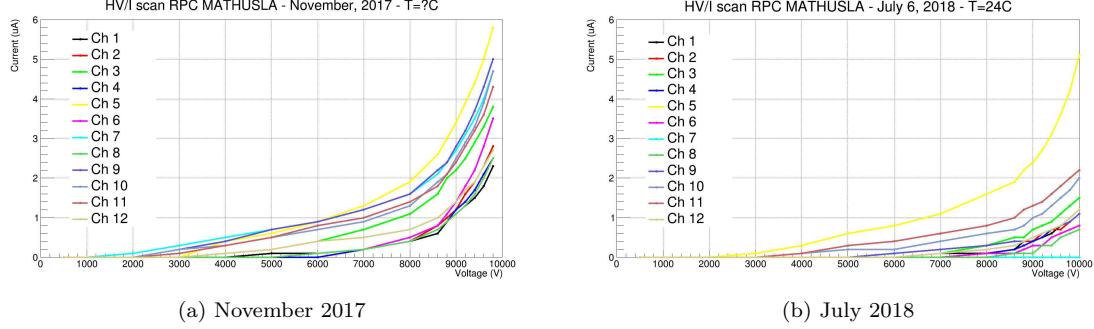


Figure 2: Measured current for each chamber in two different temperature, pressure and gas mixture conditions. It is clear from the plots that the RPC response depends on those parameters. On average, the mean value of the currents in 2018 is lower than in 2017 due to the different gas mixture (the percentage of argon was slightly higher in November 2017). In 2018 chamber 5 shows a much higher current than the average. The reason of this behaviour is still under investigation at the time of the writing of this report.

## RPC performance optimization

The procedure developed during this project consists of an algorithm to stabilize the gas gain, and it can be divided into the following topics:

### Gas mixture monitoring

The gas flowing inside the RPC for the test stand is made of a mixture of argon, isobutane, sulfur hexafluoride and tetrafluoroethane. Each of the gas has a specific role in the RPC performance, therefore, it is important to keep a controlled gas mixture. It is possible to visually check if the gas is flowing (Fig. 3), but I developed a system that tracks the flow every 5 seconds and emails the collaboration in case the value crosses a certain threshold. This monitoring is important, not only to make sure that the data is being taken with the same gas mixture but also because a flow variation could damage the chamber. Moreover, this system is important to keep a safe experiment since isobutane is a flammable gas.

### Environmental conditions monitoring

As mentioned previously, the gas response depends on the environmental conditions, so it is important also to keep track of those parameters. A BME 280 Bosch sensor, attached to an Arduino UNO board, was used for this purpose (Fig. 4). The BME 280 sensor measures the temperature, the barometric pressure, and also the humidity. Fig. 4 shows the Arduino system used for this project. This system was placed inside the ATLAS SX1 building close to the test stand, to have a more precise and realistic measurement of the environmental conditions.

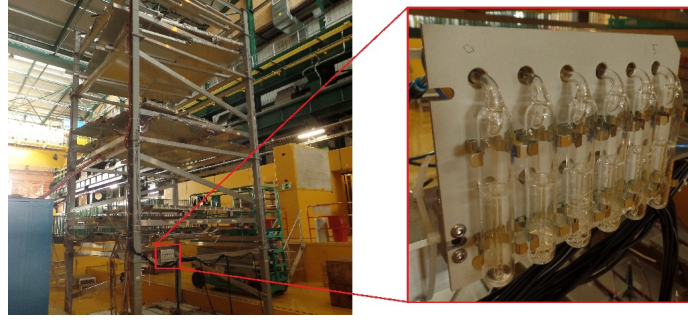


Figure 3: Visual gas flow monitoring. The presence of those bubbles indicates the gas flow.

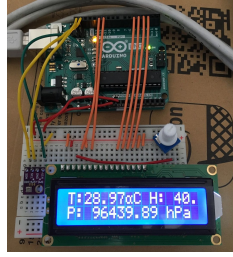


Figure 4: Arduino system used to track the environmental conditions.

Data are saved into the MATHUSLA computer every 5 seconds. The environmental information can also be easily accessed online since plots showing the measurements recorded in the last 4 days (Fig. 5) are displayed on the experiment DAQ monitoring website.

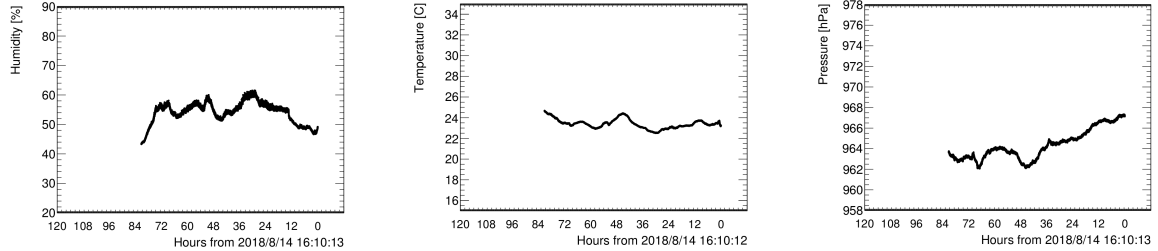


Figure 5: Environmental condition monitoring available online.

## High voltage control

Currently, the test stand has been using an SY2527 CAEN power supply system. All 12 chambers are separately connected to it, which enables an individual HV control for each one. As you can see in Fig. 2, the current measured for the same environmental conditions and for the same gas mixture varies for each chamber, so it is important to have individual HV control.

According to Eq. (3), the applied voltage depends on the initial conditions. The data displayed on this report considered  $T_0 = 24.3^\circ\text{C}$  and  $p_0 = 963.17\text{hPa}$  as the initial environmental conditions, and

$V_0^1$	$V_0^2$	$V_0^3$	$V_0^4$	$V_0^5$	$V_0^6$	$V_0^7$	$V_0^8$	$V_0^9$	$V_0^{10}$	$V_0^{11}$	$V_0^{12}$
9801	9799	9802	9802	9302	9802	9797	4994	9798	9802	9800	9797

as the initial voltages (V). Since August 12th, chamber 8 started having problems with HV. For this reason, in the measurements showed in this report, the applied voltage is set to  $\sim 5$  KV. The problems are related to the HV CAEN module that will be replaced.

The HV control algorithm calculates the applied voltage given the initial conditions, the current pressure and the temperature one hour before, and changes the HV on the CAEN power supply accordingly. This correction is made every minute.

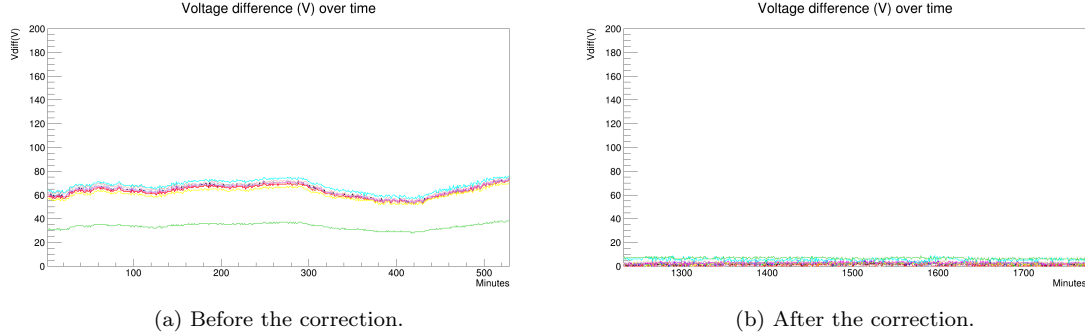


Figure 6: Absolute difference between the calculated voltage,  $V_{app}$  according Eq. (3), and the measured current from the CAEN.

Before applying the high voltage correction algorithm, the actual voltage was differing from the calculated one by  $\sim 70$  V. This difference means the change of the environmental conditions since the initial day affected the chamber's performance. This effect would have been fixed by changing the voltage  $\sim 70$  V. After applying the high voltage correction algorithm, the difference between the calculated voltage (to keep the same initial performance) and the actual voltage was near zero (Fig. 6) which means that the voltage correction has been successfully applied.

## Conclusion

MATHUSLA is a promising experiment idea to study BSM particle physics, and its design is under development. A test stand with a layout similar to the one envisioned for the MATHUSLA detector was assembled on top of ATLAS' interaction point, and it is going to provide empirical information on potential backgrounds. Besides that, another crucial study is on the experiment efficiency. It is well known that the RPC performance depends on the environmental conditions, such as temperature and pressure. In this project, I worked on the implementation of an algorithm to automatically maintain a constant effective voltage on all the chambers. The algorithm is working, and it was done in such a way to easily set all the main parameters. This is an important step to start studying the RPC's efficiency.

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