Journal of Physics: Conference Series **2374** (2022) 012139 doi:10.1088/1742-6596/2374/1/012139

Construction of an RPC using additive manufacturing technology

Stefano Colafranceschi

E-mail: stefano.colafranceschi@emu.edu

Abstract. In this work, we report the progress in the design and construction of an RPC detector fully built using additive manufacturing technology, an emerging/interdisciplinary engineering domain only partially utilized in HEP. Our novel design of the 3D detector stack can be automatically and fully constructed in a short time, ensuring repeatability and accuracy, while minimizing construction mistakes. 3D printing, applied to instrumentation for physics enhances detector performance and capabilities, cutting construction costs and improving standardization over large-scale productions. The delivered detector constitutes a new generation of RPC detectors, electrically equivalent to the existing ones but mechanically better and standardized according to the prescribed specifications.

We aim at proving the feasibility studies of a 3D printed detector that features state-of-art performance, at a fraction of the cost and potentially constructed without the need of external industrial partners.

1. Introduction

Among gaseous detectors, Resistive Plate Counters (RPCs) were and are widely utilized in several major High Energy Physics (HEP) and Neutrino experiments. This family of detector, introduced decades ago[1], proved performance, reliability, durability, and a relative construction simplicity[2].

In the RPC community, the main adopted materials are Bakelite and linseed oil, chosen for their peculiar electrical resistivity and for polishing the inner part of the electrode, respectively. RPC production for experiments has always been limited in quantity, even for the large LHC experiments like CMS[3] and ATLAS. In our globalized economy and market, the existing industrial production lines cannot be converted to process Bakelite-related plastics sheets for just small batches. This industrial/economical limiting factor is an obstacle to detector production, as other more modern detectors technologies are now successfully exploring industrial partnerships while advancing the material science and the semiconductor fields.

For the widely used RPC, the commercial availability of the Bakelite and the economical sustainability of the production/treatment are major issues that require a new paradigm, namely new raw material and construction technology.

Although Bakelite can be produced, due to the fact that is industrially disused and superseeded, it is poorly reproducible[9] as no production line is and will be optimized for that. In addition, Bakelite offers modest mechanical properties (compared to new plastic materials). For example, since Bakelite is lacking sheet stiffness, plastic deformations occur when the detector surface exceeds 0.5 m^2 just due to material weight. Usually in RPC detectors, to solve this problem, a serie of glued spacers was often used with side effects: aging of the glue, breakage of the spacers, and a reduced active area.

Other existing research proposals, focused on a glass electrode, represent an alternative to Bakelite. Thanks to glass's higher stiffness, the spacers might be not needed but intrinsic glass mechanical fragility, material chemical instability in presence of radicals collected in the gas system and glass poor standardization are stringent limits to glass electrode adoption. Glass industry also is not easily customizable and the resistivity of the Glass is two orders of magnitude higher than Bakelite, limiting the rate capability of glass RPC detectors.

2. Methodology

We are exploring additive manufacturing as a breakthrough technology for the field of particle detection to integrate all the detector components in a single design that could be manufactured without human intervention and using commercially available/standard and well-characterized raw materials. The ultimate goal is to introduce future broader impact of additive manufacturing technology in the field of particle detectors. In Section 3, we report a Computer-Aided Design (CAD) of the entire RPC detector, defining all material properties and geometries.

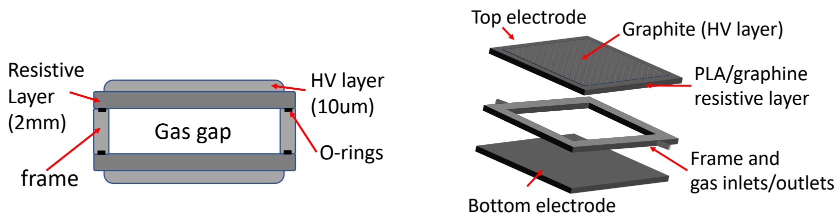
While exploring additive manufacturing, we realized that we had to produce a custom-made plastic filament with the desired electrical properties. After an initial campaign, where we investigated different plastics, namely PLA, ABS and Nylon, we decided to focus our attention to the PLA. This plastic is commonly used even in desktop printers as the extrusion temperature is relatively low at 200°C, it is environmentally friendly, non toxic and with sufficient mechanical properties to be used as a active part of a large-size detector. PLA itself is an insulator and it won't work as-is in the electrode role. Our first research point was to develop a new filament doping the PLA with chemicals to change the electrical properties of the plastics and to deliver high resistivity plastics, with a bulk resistivity of 10^{10} Ohm/cm, compatible with the RPC detectors installed at LHC Experiments. The data campaign included the production of several different plastic filament spools. This production was performed using a dedicated extrusion machine while tuning extrusion temperature, spool speed, and certainly filament thickness. This last attribute was revealed to be very complex to handle and to ensure a filament produced with a tolerance of 0.05 mm. The extruded filament is then used in a commercial desktop 3D printer, properly configured to handle the custom filament.

3. Detector design principles

An RPC detector[8] is made of several parts and components. Among these, the gas inlets/outlets are the most fragile parts that are demonstrated to increase detector operating costs (due to frequent gas leaks in that spot). These parts are made of plastic and are usually glued into the Bakelite, over time they experience a mechanical ductile-brittle transition that culminates with broken inlet/outlets. An optimal 3D printed RPC detector CAD design consists of built-in inlets/outlets printed within the body of the detector so that no glue or additional parts are needed. Definitively this integrated approach provides better mechanical properties and decreases the chance of failures and issues. Another variable that 3D printing technology can control is the resistivity of the electrodes. By doping the raw material used in a 3D printer, potentially any resistivity could be achieved. Comparisons can be made with the Bakelite RPC, whose resistivity can vary by a factor of 5$\sim$10, in other words, it is non-uniform.

Fig. 1 shows two sketches of the most important parts that will be constructed via additive manufacturing. The introduction of the use of 3D printers in the production of particle detectors will allow: a) a reduction of the number of components used, b) an engineered material design with adequate mechanical characteristics to the structures, c) material homogeneity and thus better compatibility between the components, d) a reduction of design and production costs,

Journal of Physics: Conference Series **2374** (2022) 012139 doi:10.1088/1742-6596/2374/1/012139



(a) A sketch view of an RPC detector fully printed with additive manufacturing technology.

(b) An exploded view of the simple RPC design.

Figure 1: Detector Design Sketches

e) a reduction of operating costs through less prone to breakage and lack of glues, f) increased detector production yield, g) future device embedding into the 3D printed detectors.

4. Proposed Electrode Plastics

The two electrodes of the detectors, shown in Fig. 1(b), are fabricated using PLA doped with graphene to obtain the same resistivity of the bakelite RPC. Fig. 2 shows our finding: by doping PLA with graphene, any desired resistivity can be obtained configuring the extruder with different ratio of PLA/graphene pellets. The doping takes place using a filament extrusion machine that produces a filament to be used with the 3D printer. Depending on the amount of graphene added to the PLA during the extrusion, a specific resistivity value can be obtained. The resistivity of the electrode is tested using a dedicated power supply at 100 V while measuring the leakage current.

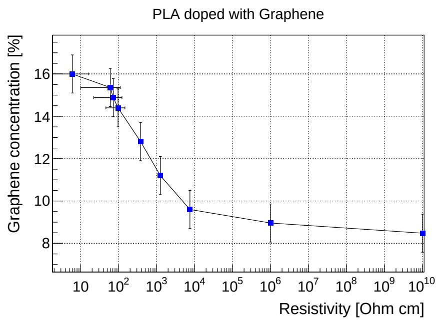
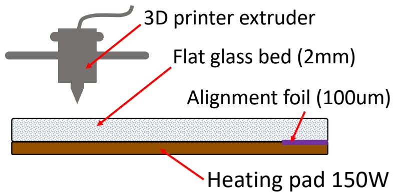


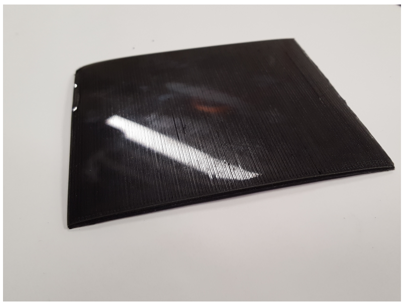
Figure 2: Measured resistivity of PLA mixed with graphene.

Due to the current limitations of 3D printing, it is not yet possible to manufacture layers with precision below 10um, so we customized the printer, as depicted by Fig. 3 (a), to obtain a mirror-like surface as needed to avoid any detector discharge during the HV ramping up and operation. A borosilicate heated glass was added as a printer bed, to smooth the surface at sub-micron level. Initially, without the heated plate, we observed that the PLA manufactured electrode started to warp due to the inefficient heat conductivity of the glass. The heated plate made the temperature of the glass uniform and resolved the warping issue.

Instead of relying on a thin HV distribution layer to be applied to the electrode, we intended to use additive manufacturing too. Using a dedicated smaller 3D printer head, we successfully printed a 50μm thick layer of again graphene doped PLA on top of the resistive electrode.



(a) 3D printer experimental setup configuration.



(b) First graphene-based RPC electrode.

Figure 3: Printer setup and constructed electrode

The last part to seal the detector is the lateral frame. This insulating plastic frame is 2 mm thick and features two grooves that accommodate two o-rings. This part has been designed with CAD and constructed using a laser cut to achieve a precision below 50μm.

5. Conclusions

The emerging additive manufacturing technology could potentially allow decreasing construction costs and time while increasing the quality of the product. The biggest plus of 3D printing is the adoption of new plastics, inexpensive and available that would replace the commercially unavailable and economically unsustainable Bakelite.

Although 3D print is already playing a role in High-Energy physics, much of the available literature and research carried out in detector construction does not yet describe the full adoption of 3D printing, but rather minor parts and/or components. Additive manufacturing features a two-fold benefit: reduce prototyping costs and delivering standardized detectors[6]. Thanks to additive manufacturing and new plastics materials, the RPC detector production will reach the industrial standards that other HEP technologies achieved.

Acknowledgments

This work is supported by the Jeffress Trust Awards Program in Interdisciplinary Research.

References

[1] R. Santonico and R. Cardarelli, "Development Of Resistive Plate Counters," Nucl. Instrum. Meth. **187** (1981) 377.
[2] S. Colafranceschi, L. Benussi, S. Bianco, L. Fabbri, M. Giardoni, B. Ortenzi, A. Paolozzi and L. Passamonti *et al.*, "Operational experience of the gas gain monitoring system of the CMS RPC muon detectors," Nucl. Instrum. Meth. A **617** (2010) 146.
[3] CMS Collaboration, "The CMS experiment at the CERN LHC," JINST **3** (2008) S08004.
[4] CMS Collaboration, The Muon Project, CMS Technical Design Report, CERN/LHCC 97-32; CMS-TDR-003.
[5] L. Benussi, S. Bianco, S. Colafranceschi, D. Colonna, L. Daniello, F. L. Fabbri, M. Giardoni and B. Ortenzi *et al.*, "The CMS RPC gas gain monitoring system: An Overview and preliminary results," Nucl. Instrum. Meth. A **602** (2009) 805 [arXiv:0812.1108 [physics.ins-det]].
[6] M. Hohlmann "Printing out Particle Detectors with 3D-Printers, a Potentially Transformational Advance for HEP Instrumentation", arXiv:1309.0842
[7] S. Bianco, S. Colafranceschi, D. Colonna, F. Felli, T. Greci, A. Paolozzi, L. Passamonti and D. Pierluigi *et al.*, "Chemical Analyses Of Materials Used In The Cms Rpc Muon Detector," CERN-CMS-NOTE-2010-006.
[8] M. Abbrescia *et al.*, "Cosmic ray tests of double-gap resistive plate chambers for the CMS experiment", Nucl. Instrum. Meth. A **550**, 116 (2005).
[9] L. Benussi *et al.*, "Study of gas purifiers for the CMS RPC detector" Nucl. Instrum. Meth. A **661**, (2012). S241-S244