RD51 DLC Workshop Report

RD51 Mini Week 10-13 February 2020, CERN
https://indico.cern.ch/event/872501

Edited by:
RD51 Resistive DLC collaboration, RD51 Management Board

Abstract

This report highlights detector and technological aspects related to the Diamond Like Carbon (DLC) coatings that have been discussed during the RD51 DLC workshop. This event has been organized with the purpose of initiating a technical discussion on processes, problems and production centers with the aim of evaluating the impact and importance of enriching the existing MPT workshop infrastructure with a novel sputtering machine at CERN. In parallel, a survey has been conducted among the main suppliers to find an appropriate DLC coater. As an outcome, a Magnetron Sputtering Deposition refurbished DECORA 760+ [14] from ALLIANCE CONCEPT [15] was identified as a promising candidate, both in terms of production capabilities and cost. Such a machine would allow enlarging the current RD and manufacturing capabilities, in particular, in the context of coating the large surfaces (up to 1.7 x 0.6 m^2). The use of this machine would cover additional fields of research at CERN; in particular, aluminum deposition for low mass inner trackers conventional flex circuits and for direct flex-to-chip connection without wire bonding. The CERN-MPT workshop building has all necessary space and services for the installation of such a machine.

Geneva, Switzerland
February 19, 2021

Executive Summary

Micro Pattern Gas Detector (MPGD) technologies: the level of maturity allows these technologies to be widely disseminated in the LHC detector upgrades and be porposed for future experiments in High Energy Physics and beyond. Experiments, such as LHCb and TOTEM have used GEMs from the beginning of the LHC. ALICE, ATLAS and CMS are implementing MPGDs in the LS2 upgrades (ALICE TPC-GEM, ATLAS NSW micromegas, CMS Muon GEM) for large area systems. ATLAS, CMS and LHCb are working on future HL-LHC upgrades based on MPGDs.

Resistive electrodes: resistive electrodes have been already used in many existing families of MPGD technologies. The most important driving force behind this development is spark protection and quenching (particularly important for single-stage multiplication devices) and charge spreading technique to optimize readout plane (spatial resolution versus number of readout channels). **Diamond Like Carbon (DLC) coatings:** properties of DLC coatings have offered new possibilities opening the way to develop new detector structures. μRWELL is one of the examples of emerging MPGD technologies that are evolving and profiting from the ongoing developments on DLC.

Detection systems for large area coverage: detectors with simplified production and assembly procedures assuming similar performance and stability requirements, can significantly reduce the overall cost. New developments based on resistive electrodes can offer many advantages in this context.

RD51 Collaboration: the number of groups contributing to the development of resistive electrodes is large and continuously growing. Research activities performed in the context of the ATLAS collaboration for the NSW micromegas project resulted in a major boost of this technique for large-area applications. **RD51 Resistive DLC Collaboration:** in the context of the RD51 collaboration and in line with a general interest, a RD51-DLC common project has been initiated to bring together main players in detector development and DLC production.

The CERN EP-DT Micro Pattern Technology MPT workshop: closely linked to the RD51 collaboration, the MPT workshop is playing a crucial role in all MPGD developments, with the DLC coatings being one of them. Several new structures has been developed and tested through a collaborative effort between institutes capable of producing DLC layers, the CERN-MPT workshop and the research institutes involved in the detector design, characterization and tests.

Enlargement of the DLC production capabilities via a DLC coater at the MPT workshop: upgrading the CERN MPT workshop with a DLC sputtering machine is considered as a long-term investment to secure the future for these developments in the context of wider dissemination of MPGDs with DLC layers in experiments for large area systems. **MPT proposal:** a **refurbished DECORA 760+** [14] from **ALLIANCE CONCEPT** [15] has been identified by the MPT workshop as the best option, both in terms of production capabilities and cost. This machine offers very attractive MPGD *R&D* options and production perspectives (area, quality of the deposition, and different elements used in the deposition process). Several other applications at the LHC will also profit from the availability of the machine. In particular, aluminum deposition for low mass inner trackers flex circuits and flex-to-chip connection without wire bonding, B4C deposition for photocathodes and neutron detector, ITO, particle trapping layers for the LHC machine will become available.

Cost: The total cost is about **500kEUR**. Some preliminary discussions ongoing to find potential contributors both at CERN and outside. Strong interest has been shown by several RD51 groups that are part of INFN; their support would be the most welcome.

Technical competencies and installation: the MPT workshop **has already the necessary competencies** to operate such a machine. The new MPT facility (bdg.107) **has enough space and services** for the installation.

RD51 Management Board, the **RD51 Resistive DLC Collaboration** and several **individual RD51 groups**, directly involved in *R&D* with DLC-based MPGDs, **expressed a strong scientific support** to this proposal and consider it as an **important strategic step**. These developments are in-line with the future needs of experiments and enlarge the breadth and the depth of the MPGD domain.

EP-DT,the Detector Technologies group in the CERN EP department **supports the proposal**. The machine will **enrich the current production capabilities of the DT workshops**. The proposed machine will cover the needs of experiments **not only in the context of Micro Pattern Gas Detectors** and will open new *R&D* and production opportunities (e.g. low material budget circuits). The **investment**, taking into account the **existing competencies** in the workshop and the **available space and services**, is considered **very positively** by the EP-DT group.

Contents

1 Introduction

This report summarizes the contributions given at the DLC workshop organized during the RD51 Mini Week at CERN, in February 2020 [1].

2 RD51 Resistive DLC Collaboration

The *Resistive DLC collaboration* was initiated as a RD51 Common Project [7] in 2018. The collaboration is formed by several institutes: LICP, USTC, Kobe University, LNF-INFN and CERN (see fig.1). Many aspects of the DLC layers have been already explored within the collaboration: theoretical calculation, simulation, process tuning for different surface resistivities, DLC and copper coatings, homogeneity, reproducibility, large area coating, evolution of DLC properties under manufacturing processes, final detector production, stability under current load (bench tests w/irradiation), aging and spark studies on DLC-based detectors (using different types of radiation). The involvement of each group is schematically shown in fig. 1. The resistive DLC collaboration played a key role in the organization of the DLC workshop.

3 Micro Pattern Gas Detector and DLC coatings

Resistive coatings have been introduced in Micro Pattern Gas Detector primarily to improve spatial resolution via charge dispersion [1–3] and for spark suppression [4]. Depending from the requirements, different materials have been used. Today, there is a large interest in Diamond Like Carbon (DLC) coatings because of the values of achievable resistivity, thanks to production techniques available in industry. The use of DLC coatings as UV photocathodes is an emerging trend growing in the community [5, 6] with preliminary promising results. In 2019, a dedicated workshop on resistive coatings for gaseous detectors has been organized by INFN Bari[2], addressing many important aspects. In this section, research activities summarized in [8] will be presented.

[1] https://indico.cern.ch/event/872501/timetable
[2] https://agenda.infn.it/event/18156/timetable

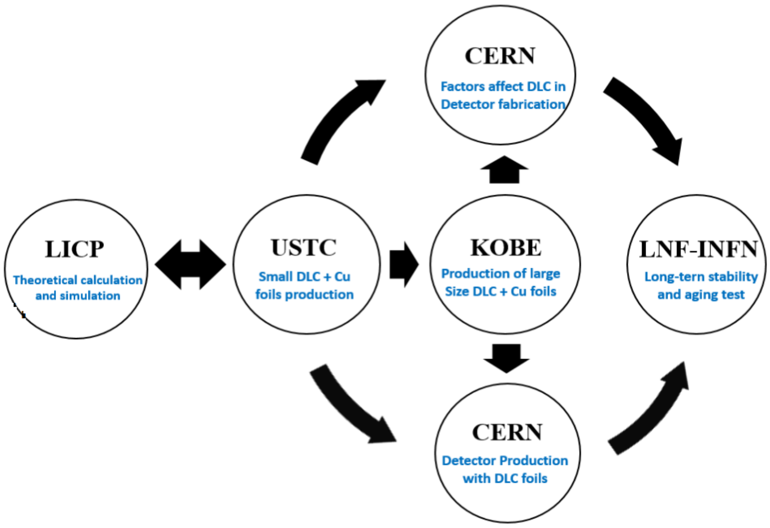

Figure 1: Resistive DLC Collaboration (initiated as a RD51 Common Project).

3.1 Spark Quenching

The use of resistive layers for spark protection and quenching, in particular for single-stage amplification detectors, has been one of the major trends in the recent years. The promising results achieved by the MAMMA collaboration for the ATLAS NSW micromegas [4] motivated a dissemination of the resistive techniques over almost all the existing MPGD structures. MPGD structures with DLC coatings as resistive layers are shown in fig.2. Whenever DLC layers are used to suppress sparks, it is important

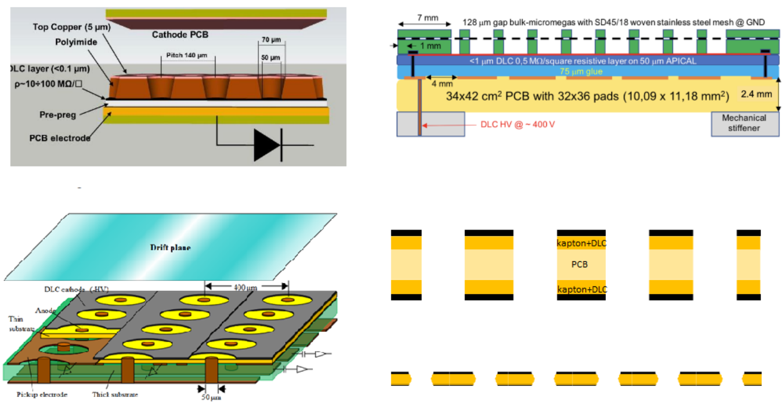

Figure 2: Use of DLC layers in μRWELL (top-left), micromegas (top-right), μ-PIC (bottom-left),THGEM and GEM (bottom-right).

to assure that the quality of DLC layers will not limit locally the breakdown voltage [9]. Impurities and cracks can, for instance, degrade the overall performance and have to be properly addressed in the production process. Once breakdown voltage is well known, it is essential to keep enough margin in the detector design, so that the voltage difference ΔV between two electrodes connected by the DLC layer is smaller than the relative breakdown voltage for the nominal operating conditions. Therefore, a new parameter has been introduced to quantify this: DOCA, the Distance Of Closest Approach, as shown in fig.3. If DOCA is satisfied everywhere in the detector, breakdown will be avoided and the protection scheme has to address how the energy is released in spark and how it is evacuated in the detector. Resistivity value, heat propagation and absorption will become important parameters that have to be properly controlled and defined. Once DOCA and layer properties are well defined, the uniformity (defined on case-by-case basis) and stability of layer properties are key factors in the production phase. Preliminary studies in this context has been presented in [8]. In general, resistive layers affect the rate capability of the detector. Therefore, the design and the layout of MPGD has to be optimized to reduce

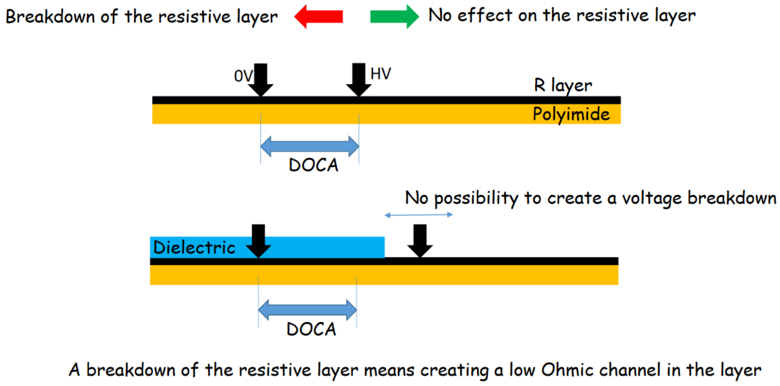

Figure 3: DOCA: Definition of Distance Of Closest Approach from [9]

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rate-dependent degradation to an acceptable level. Several options have been investigated on how to promptly evacuate the charge in the detector. "Vertical" evacuation through the readout electrodes via a resistive path is one method. Conductive grids, in contact with the resistive layers to minimize the intrinsic impedance of the layer, is another option. A few examples for μRWELL and micromegas are shown in fig.4. In all these options, DOCA requirement has to be satisfied.

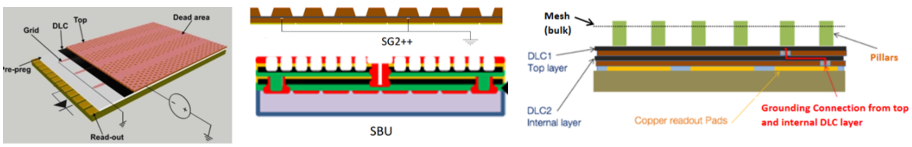

Figure 4: Detector design for applications where the rate capability can be an issue. Example for μRWELL and micromegas are shown. Internal conductive grid (SG++ configuration) or double DLC layer (SBU) can be used to promptly evacuate the charge.

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3.2 Charge Dispersion

Before their use as a spark protection in MPGDs, resistive layers have been optimized for spreading the charge on the readout plane to maintain good spatial resolution and to reduce the number of readout channels. R&D studies are currently ongoing within the LCTPC and T2K collaborations to optimize a micromegas readout plane for spark protection and spatial resolution. For the RC of about 100 ns/mm^2, a charge spread over a few mm^2 is achievable with integration time of the electronics of O(100 ns). The resistivity required is of the order of few hundreds $k\Omega/\square$ in the T2K case and of about few $M\Omega/\square$ for the ILC TPC. More studies are required to address DLC layers uniformity for low resistivity values.

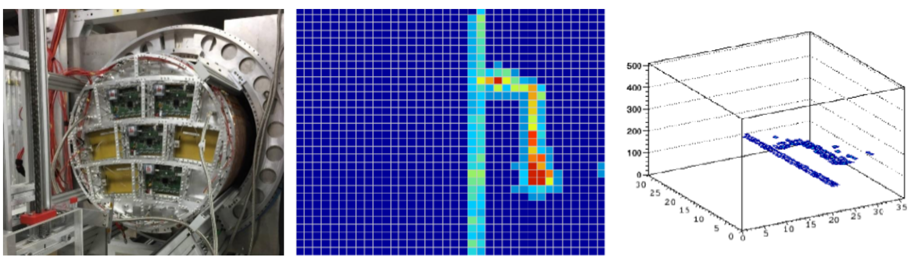

Figure 5: TPC studies for LCTPC and T2K using a pad readout micromegas with a DLC layers as resistive anode plane

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3.3 Photocathodes

Recent developments for a fast and precise timing with MPGD detectors are based on UV photocathodes. The RD51 PICOSEC micromegas collaboration has demonstrated time resolution of about 25 *ps* for MIP detection using CsI UV photocathode (PC). In order to overcome aging problems due to ion bombardment at the PC, other materials have been investigated. Using thin (few nm) DLC coatings as a PC, preliminary test-beam results have shown time resolution below 50 *ps*. Other materials, such as B4C, are also under investigation; these reveal promising QE (Quantum Efficiency) in laboratory measurements. Detector concept and quantum efficiency measurements performed in laboratory with DLC and B4C samples are shown in fig.6. The use of novel C-materials is part of the *R&D* program carried on by INFN Trieste and INFN Bari in the context of MPGD-based photon detectors for RICH applications.

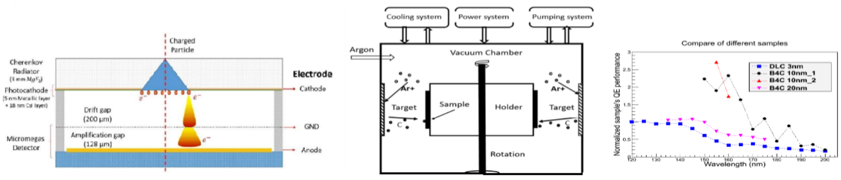

Figure 6: PICOSEC micromegas detector for precise timing measurements. Detector sketch (left), DLC photocathode deposition method (center), quantum efficiency measurements of different samples of DLC and B4C (right)

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3.4 Summary

There is a large MPGD Community interested in resistive gaseous detectors, already actively pursuing RD studies. There is an emerging need to better understand properties of the DLC layers and their production techniques have to be further advanced. The resistivity values required by various applications ranges from a few hundreds $k\Omega/\square$ to $G\Omega/\square$.

Among important requirements and aspects of the DLC layers that have to be studied are:

- Surface quality characterization and control.
- Control of the resistivity for the final detector-manufacturing steps.
- Proper adhesion with other materials (DLC on PI, Cu on DLC ...).
- Understanding and control of the resistivity changes during detector manufacturing.
- Stability of the layer properties.
- Stability under current load and under irradiation.
- Uniformity.
- Information exchange between manufacturers (procedure and specs) and users.

4 Production Processes

This section is based on the material presented in [9]. The use of resistive layers is particularly important for the detector production and assembly procedures in single stage and single structure detectors. Moreover, their use can offer several simplifications for building large detector systems, especially if performance and operational margins (stability) are compatible with the experiment requirements. In addition, production and assembly costs can be significantly minimized. Special attention has been devoted to exploring novel techniques that are compatible with reasonably large area detectors O(m2) and industrial processes.

Detector	Rate Requirements	Required DLC type
Micromegas	Moderate rate	DLC
	High Rate, Sequential Build Up (SBU)	2 x DLC+
	High Rate, Mix between DLC and screen printing	DLC
μRWELL	Moderate rate	DLC
	High Rate, Silver Grid (SG)	DLC+
	High Rate, Drill and Fill (DF)	DLC
	Sequential Build Up (SBU)	2 x DLC+
Resistive GEM (one side)		DLC+
Resistive GEM (both sides)		DLC++
THGEM		DLC

Table 1: Type of multi layers with DLC electrodes needed in different MPGDs technologies.

A schematic representation of the "DLC naming" convention used in the different multi-layers structures is given in fig.7. Summary of MPGD technologies together with the specific DLC element used (DLC, DLC+, DLC++ of fig.7) is shown in table 1. Proper adhesion between layers is the most

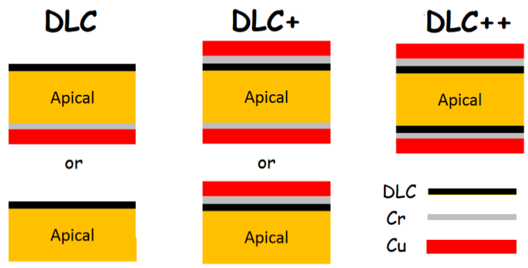

Figure 7: DLC naming. DLC(Left): DLC (black) on Apical (orange); one side only with DLC. DLC+(Center): Copper (red) on Chromium(grey) on DLC (black) on ApicalL (orange); one side only with DLC. DLC++(Right): Copper on Chromium on DLC on Apical; on both sides

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critical part of the process; in particular, adhesion above the sputtered DLC. Various detector layouts associated to the different MPGD technologies are shown in fig.8. While robust solution exist for simple DLC structures, there is a clear need for further improvement of the DLC+ and DLC++ production processes. DLC uniformity has to be more thoroughly investigated even though for some application current results are already satisfactory. Further studies related to the DOCA apporach should be continued in order to identify optimal materials and designs.

5 Production Centers

A special session of the workshop was dedicated to the DLC coating centers available for our community [3]. Reports from production centers in China, Japan, Italy and Sweden (ESS) have been presented with the description of the facilities and contacts. Some of the production centers are more suited for *R&D* studies on small area samples, others can cover large areas or offer different type of deposition.

1. **China** [10]: State Key Laboratory of Particle Detection and Electronics, University of Science and Technology of China, State Key Laboratory of Solid Lubrication, Lanzhou Institute of Chemical Physics, Chinese Academy of Sciences and Institute of Sensor Technology, Gansu Academy of Science.

[3] `https://indico.cern.ch/event/872501/timetable/#20200213.detailed`

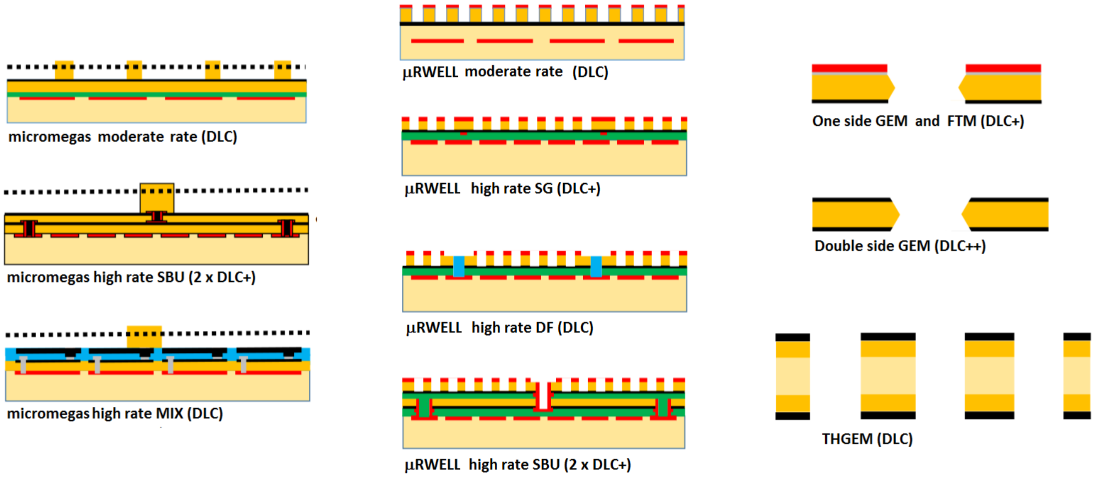

Figure 8: MPGD technologies and layouts. Left: micromegas detectors. Center: μRWELL. Right: GEM and THGEM.

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	Magnetron Sputtering Deposition	Vacuum Cathodic Arc Deposition	Pulsed Laser deposition
Available Machines	Teer (CHN) / Hauzer (CHN)	Hauzer (CHN)	A small machine (CHN)
Control of Parameters, cleanliness	High / High	High	Medium
Different deposition (graphite, B, B4C)	Yes (For B, need some upgrade now) / Yes (except B)	Yes	Yes
Doping	Yes	Yes	Yes (Limited by target, not flexible enough)
Uniformity on 10*10cm^2	Good / Good	Good	Impossible(up to 2cm)
Control of Resistivity	High/ High	Medium	No study
Surface treatment	No / No	No	No
Compatible with protection layers on CsI	No	No	No
Remarks	The always used method	DLC structure(more sp3 structure)	Some R&D study

Figure 9: DLC deposition techniques and properties

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2. **Japan** [11]: Be-Sputter Co, Ltd., (Industrial Company) with Kobe University support. Large area but not suited for *R&D*.
3. **Italy** [12]: INFN infrastructure, Ion Beam Deposition at INFN Bari and Pulsed Laser Deposition at INFN Lecce. Suitable for *R&D* but small area samples (few cm^2).
4. **Sweden** [13]: Linköping detector coating workshop, European Spallation Source (ESS). Several coating capabilities and specialized in B4C coatings. Interest on small area DLC coating *R&D* using a sputtering machine.

As of today, DLC coatings are produced in these four centers and later sent to the CERN-MPT workshop for additional processing steps and for the final detector manufacturing and construction.

6 CERN MPT workshop proposal

The DLC workshop has been organized to have an overview of DLC-based MPGDs and existing production facilities with the main goal of evaluating the possibility of enlarging the existing capabilities with a DLC coater at the CERN MPT workshop. A preliminary comparison from [8] of different deposition techniques is shown in fig.9. S. Ferry, from the CERN MPT workshop, has conducted a survey with aim to search for an appropriate DLC coater among main suppliers. As an outcome, a Magnetron Sputtering Deposition refurbished DECORA 760+ [14] from ALLIANCE CONCEPT [15]appears to be a promising candidate, both in terms of production capabilities and costs.

The main characteristics of the machine are:

- Deposition by HPCVD DC magnetron: DLC, Cu, Cr, Al, B4C
- Backing
- Cleaning: reverse sputtering of the substrate(RF plasma for dielectrics)
- Sputtering/ Co-sputtering: adjustable gradient of material or layer-by-layer coating
- Reactive sputtering: adding H2, N2, CH4, C4H10, Ne to Argon
- Large coating area with a good homogeneity of thickness to improve resistance homogeneity
- Refurbished machine to limit costs (about 500kEUR).

The maximum size of foil that the machine will be able to coat is of the order of 1.7m x 0.6m. Achievable homogeneity at different widths are shown in tab.2.

Width	homogeneity[%]
360	+/-4
450	+/-30
470	+/-50

Table 2: Achievable coating homogeneity with cathode of 500mm length and 127mm width.

CERN-MPT workshop has a long-term experience that would allow a proper operation of the machine:

- PVD coating for Low-Mass circuit in LHC detector (Aluminium bus circuit (Alice) 12microns to 35microns thickness).
- PVD coating for tribological characteristics (TiN, TiCN, TiAlN, CrN, BN in machining application, molded plastic application).
- PVD coating for decorative application (TiO2, Cr, Au, Ni).
- PECVD coating like DLC in automotive application
- Surface activation of polymer by Reactive Plasma RF
- Etching and reactive etching on polymer and metal
- Preparation by plasma (Grafting molecule Polyvinyl-pyroli done on medical implant)

The new MPT workshop building (107, see fig.10) has available space and services for the installation of such a machine. A few examples of the new possibilities opening up with a purchase of the DLC coater are discussed below. It has to be emphasized that not only MPGD technologies will profit from the new machine, but it might be also useful for other general-purpose experiments, in particular for:

- Aluminium deposition for low mass inner trackers conventional flex circuits
- Aluminium deposition for direct Flex to chip connection without wire bonding
- B4C layers for Neutron detection
- Modified B4C layers for photoelectric applications
- DLC for resistive protection of MPGD
- Modified DLC to lower the work function
- Low work function materials (down to 1eV)
- Particle trapping layers (for the LHC)
- ITO layers for transparent MPGD

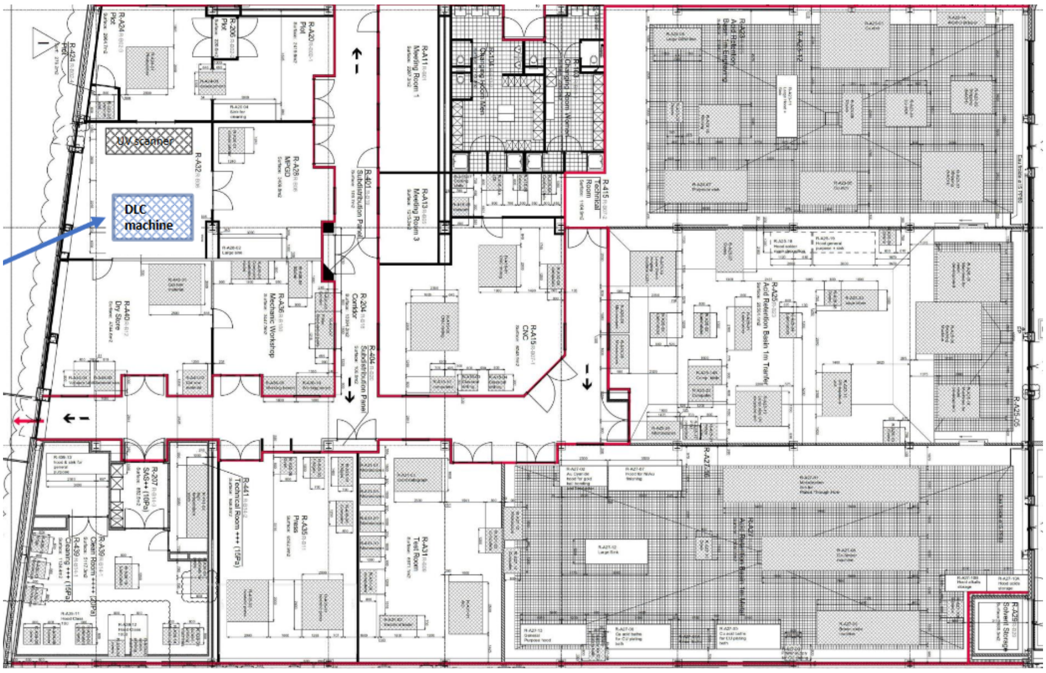

Figure 10: Installation of the machine in the MPT workshop, building 107

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7 Summary and conclusions

The RD51 DLC workshop in Feb. 2020 had a very wide attendance reflecting the interest and importance of the RD on DLC coatings for MPGDs and future experiments. The proposed machine will offer new opportunities of depositing different coatings and building up functional layers or structures. The machine can be used for different production processes, and can be of general interest to several other domains in addition to the MPGDs. For instance, aluminum coating can offer low material budget components and circuits for future inner detector upgrades. The location of the machine in the EP-DT MPT workshop is fundamental to enrich the breadth and depth of the MPGD domain. Proper machine tuning, validation in accordance with the manufacturing techniques and processes, will strongly facilitate future MPGD RDs program on CERN-site.

8 Contacts

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