Development of the Micro-Pattern Gaseous Detector Technologies: an overview of the CERN-RD51 Collaboration

Contact persons: S. Dalla Torre (INFN Trieste), E. Oliveri (CERN), L. Ropelewski (CERN), M. Titov (CEA Saclay)

Representing the RD51 Collaboration

e-mail addresses:

Silvia.DallaTorre@ts.infn.it, Eraldo.Oliveri@cern.ch, Leszek.Ropelewski@cern.ch, Maxim.Titov@cea.fr

Abstract:

RD51 is a well-established collaboration with the aim to develop Micro-Pattern Gaseous Detector (MPGD) technologies, to support experiments using this technology, and to disseminate the technology within particle physics and in other fields. Originally created for a five-year term in 2008, RD51 was extended for a third five years term beyond 2018. The rich portfolio of MPGD projects, under constant expansion, is accompanied by novel ideas on further developments and applications. The cultural, infrastructure and networking support offered by RD51 has been essential in this process: this effort will continue thanks to the RD51 extension. Also in the next years, a collaborative R&D phase and the right environment will have a strong impact on project-oriented activities - similarly to the current scenario where three of the major upgrades for the LHC experiments benefited from the RD51 framework. The vast R&D program requires acquiring additional, up-to-date expertise in advanced technologies; it is also expected to enrich our basic knowledge in detector physics, to form a generation of young detector experts - paving the way to new detector concepts and applications.

RD51 and MPGD success is related to the RD51 model in performing R&D: combination of generic and focused R&D with bottom-top decision processes, full sharing of "know-how", information, common infrastructures. This model has to be continued and can be exported to other detector domains.

I) Introduction

Improvements in detector technology often come from capitalizing on industrial progress. Over the past two decades, advances in photolithography, microelectronics and printed circuits has favored the invention of novel micro-structured gas-amplification devices. By 2008, interest in the development and use of MPGD technologies led to the establishment at CERN of the RD51 collaboration [1]. Since its foundation, the RD51 collaboration has provided important stimulus for the development of MPGDs and focused on a broad networking effort to share and disseminate the "know-how" and the technologies, and to promote generic R&D: a seminal activity for the enlargement of the application portfolio. Important consolidation of the some better-established MPGD technologies has been achieved within the RD51 collaboration, often driven by the working conditions of large collider experiments; in parallel, the portfolio of MPGD applications in fundamental research has been enlarged in other science sectors. Envisaging the needs for R&D activities on MPGD, RD51 is structured in several working groups focusing on various aspects of gas-detector technologies: detector physics and measurements, new technologies, simulations and modeling, electronics, production techniques, industrialization, and common testing facilities. This structure facilitates interactions within the community and effectively focuses efforts and resources.

The collaboration is widely distributed in terms of institutes and countries. Initially in 2008, the participation was mainly limited to Europe and nearby countries. Over the years, the number of collaborating Institutes from other continents, like from China, India, Japan, USA, has greatly increased - reinforcing the RD51 world-wide vocation and enhancing the geographical diversity and expertise of the MPGD community; today it comprises of 90 institutes in 25 countries.

II) RD51 Collaboration Extension Beyond 2018

In 2018, the RD51 Collaboration, in charge of the development and dissemination of MPGD, proposed to extend its activity, beyond 2018, for a further five-year term. The scope and activities for the RD51 prolongation cluster around two main missions: novel R&D developments towards reaching or overcoming performance limits and the continuation and reinforcement of the support actions for the community and MPGD dissemination. Highlights of the future R&D scenario, based on the ongoing projects and plans to explore new materials and technologies, are summarized thoroughly in the recent proposal, dated May 2018; it is also appended to the present document [2]. The Research Board extended RD51 for a further five years, following the LHCC recommendation stating: "The LHCC considers the working mode of RD51, with a small but focused core team and corresponding infrastructure at CERN, attracting contributions and bright ideas to be explored from collaborators around the world, to be an excellent setup [3]." The collaboration plans to maintain the current organization, characterized by a simple and effective management, and the existing structure based on the working groups.

III) MPGD Applications and Dissemination

During the past 10 years, the deployment of MPGDs in operational experiments has increased enormously, and RD51 serves a broad user community, driving the MPGD domain and any potential commercial applications that may arise. Nowadays, several MPGD technologies, such as: Gas Electron Multiplier (GEM), Micro-Mesh Gaseous Structure (MicroMegas, MM), THick GEMs (THGEM), also referred to in the literature as Large Electron Multipliers (LEM), GEM-derived architecture (μ-RWELL), Micro-Pixel Gas Chamber (μ-PIC), and integrated pixel readout (InGrid) are being optimized for a broad range of applications. Scaling up MPGD detectors, while preserving the typical properties of small prototypes, allowed the use of major MPGD technologies in the current upgrades of large experiments, e.g. that of the LHC. The consolidation of the better-established techniques has been accompanied by the flourishing of modern ones, often specific to well-defined applications. Novel technologies have been derived from Micromegas and GEM concepts, hybrid approaches combining different MPGDs, gaseous with non-gaseous multipliers; others are based entirely on new concepts and architectures. The international RD51 collaboration is primarily involved in the development for fundamental-research application and in generic R&D; also activities focused on applications beyond basic research are continuously growing.

The choice of MPGDs for relevant upgrades of CERN experiments indicates the degree of maturity of given detector technologies for constructing large-size detectors, the level of dissemination within the HEP community and their reliability. During the last five years, there have been major MPGDs developments for ATLAS, CMS, ALICE and COMPASS upgrades, towards establishing technology goals and technical requirements, and addressing engineering and integration challenges. Thus, the potentiality of MPGD technologies became evident and the interest in their applications has started growing not only in HEP, but also in hadron/heavy ion /nuclear physics, photon detectors and calorimetry, neutron detection and beam diagnostics, neutrino physics and dark matter detection (also at cryogenic temperatures), X-ray imaging and γ-ray polarimetry. Beyond fundamental research, MPGDs are in use and considered for applications of scientific, social and industrial interest; this includes the fields of medical imaging, non-destructive tests and large-size object inspection, homeland security, nuclear plant and radioactive-waste monitoring, micro-dosimetry, medical-beam monitoring, tokamak diagnostic, geological studies by muon radiography.

Since its early stages, the RD51 collaboration has also paid attention to building a proper environment for performing high-quality advanced R&D on MPGDs; it continues to advance the MPGD domain with scientific, technological, and educational initiatives. The dissemination of MPGDs beyond fundamental research is one of the major vectors of the collaboration activities; a series of Academy-Industry matching events, organized by the RD51 in collaboration with HEPTECH, was dedicated to neutron and photon detection. These events provided a platform where academic institutions, potential users and industry could meet to foster collaboration with people interested in MPGD technology. More in general, RD51 has contributed to the broad scientific and technological "know-how" in the MPGD field by networking activity providing financial support to the general-interest collaborative efforts and to the specific common facilities and tools. Given the ever-growing interest in MPGDs, RD51 re-established an international conference series on the detectors every second year and organizes the schools and specialized workshops.

IV) RD51 Legacy, Expertize and Infrastructures

The main objective of the RD51 is to advance technological development and application of MPGDs. It is a worldwide open scientific and technological forum on MPGDs, and RD51 has invested resources during ten years in forming expertise, organizing common infrastructures and developing common research tools. Starting new generic research projects to explore innovative ideas has been strongly boosted by fruitful discussions and exchanges within the broad MPGD community and associated experts. The progress in various R&D projects has been made possible by open access to facilities and research tools. There is no similar detector R&D consortium, world-wide, relying on such freedom and diversity of research groups and their interests. Over the ten RD51 years, many of the achieved results went, in some cases, beyond original expectations.

In addition to the support mechanisms and facilities tools, the RD51 portfolio is rich and diversified, including: maintenance and development of simulation software dedicated to gaseous detectors, development of SRS [4], a complete read-out chain designed to operate in a laboratory context, also expandable to large read-out systems, realization of affordable laboratory instruments dedicated to MPGD developments, and more. Last, but not least, the RD51 community has open access to the instrumentation, services and infrastructures of the large and well-equipped Gas Detector Development (GDD) laboratory at CERN, continuously hosting several parallel R&D activities. In addition, the common test beam infrastructure at the H4 test-beam area at SPS, available usually three times a year during the periods of beam availability for RD51, allows several groups to investigate in parallel their R&D projects.

V) RD51 R&D Program on Advanced MPGD Concepts

Technological and scientific advances have led to improved detector performances - also when scaling up the new technologies to large-area detectors. This progress has been particularly crucial in HEP experiments upgrades worldwide; examples are the incorporation of GEM, MM, THGEM and their hybrid combinations in several large experiments. The RD51 collaboration has been playing a crucial role in this progress - boosting exchanges and cooperation within the community on both scientific and technological matters. Common facilities and availability of experts and expertise have greatly contributed to the very noticeable progress.

The better understanding of the physics processes, originating from experiment-validated model simulations, paved the way towards novel detector concepts. A clear direction for future developments is that of the resistive materials and related detector architectures. Their usage improves detector stability, making possible higher gain in a single multiplication layer, a remarkable advantage for assembly, mass production and cost. Robust single-stage MPGDs with embedded electronics are expected to advance particle-flow based calorimetry (ILC-DHCAL) or high-precision tracking systems in high-fluence environments. They may also pave the road to very large detection systems and civil imaging applications (e.g. radiography, homeland security); industrial production would simplify the detector assembly procedures and possibly reduce the costs.

The frontier of fast and precise timing is moved forward by novel developments for picosecond-time tagging or filtering measurements, e.g. for high-luminosity colliders. Very encouraging trends are obtained by coupling gaseous detectors and Cherenkov radiators to take advantage from the prompt radiation emission. Correspondingly, high data-transfer bandwidth readout systems and novel electronics can advance some potential applications.

A variety of novel opportunities is offered by MPGD hybridization, a strategy aiming to strengthen the detector performance combining the advantages offered by a variety of approaches. It is obtained both by combining MPGD technologies and by coupling gaseous detectors to different detection technologies, as is the case for optical read-out of gaseous detectors, which can reach unprecedented performances. New concepts of charge and light sensing in noble-liquid detectors, may lead to progress in neutrino experiments and rare-event searches (e.g. Dark matter). Portable or sealed detectors would be obvious solutions to medical, cultural heritage, safety and security applications.

Contributions to the detector concepts from up-to-date material science are required for several domains: resistive materials, solid-state photon and neutron converters, innovative nanotechnology components. Material studies can contribute to requirements related to low out-gassing, radiation hardness, radio purity, converter robustness and eco-friendly gases. The development of the next generation of MPGDs can largely profit of novel emerging technologies as those related to nanomaterials, MicroElectroMechanical Systems (MEMS), sputtering, novel photoconverters, 3-D printing options, etc. It is expected that, both at CERN and within the R&D community, these new needs will result in the formation of synergies and networks between scientists devoted to detector R&D and groups and institutions mastering the novel technologies. Advanced materials and techniques can evolve into new sensitive or amplifying structures, extending the current detection sensitivities. This is just a partial list of fascinating R&D lines that MPGDs will see in the years to come.

VI) Summary and Conclusions

Future RD51 activities aims at bringing a number of detector concepts to maturity, initiating new developments and continuing the support to the community. Among leading proposed projects are ultrafast, high-rate MPGDs; discharge-free, high-resolution imaging detectors with resistive elements and high-granularity integrated electronics; novel noble-liquid detector concepts, including electroluminescence in gas bubbles; studies of environment-friendly counting gases and long-term sealed-mode operation; optical-readout detectors with radiation-hard imagers for fundamental research experiments, radiography and other domains. Material science is entering strongly in our field and can provide alternative MPGD materials, new structures, protection layers, etc. RD51 intends investigating MicroElectroMechanical Systems (MEMS)-like, nano-production techniques and 3D printing with conductive and insulating materials.

The support actions towards the community are aimed to preserve and enrich the present scenario, including: networking activity, with focus on training and education, further development of dedicated simulation tools, advances in electronics tools, continuation of the collaborative interactions with strategic CERN workshops.

RD51 and MPGD success is related to the RD51 model in performing R&D: combination of generic and focused R&D with bottom-top decision processes, full sharing of "know-how", information, common infrastructures. This model has to be continued and can be exported to other detector domains.

References:

[1] R&D Proposal, "Development of Micro-Pattern Gas Detectors Technologies", CERN-LHCC-2008-011 (2008)

[2] R&D Proposal, "RD51 Extension Beyond 2018", arXiv:1806.09955 (2018)

[3] https://cds.cern.ch/record/2622164/files/M-225.pdf; Research Board Minutes, 225th Meeting of the Research Board, June 6 (2018); https://cds.cern.ch/record/2621145/files/LHCC-134.pdf; LHCC Minutes, 134th Meeting of the Large Hadron Collider Committee, May 30-31 (2018)

[4] S. Martoiu, et al., Development of the scalable readout system for micropattern gas detectors and other application, 2013 JINST 8 C03015.