Advanced GEM detectors for future collider experiments

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The new era of Particle Physics experiments is moving towards upgrades of present accelerators (Large Hadron Collider at CERN) and the design of very high intensity and very high energy particle accelerators such as **FCC-ee/hh** [1-2] and **Muon Collider** [3-4]. Cost effective, high efficiency particle detection in a high background and high radiation environment is fundamental to accomplish their physics program.

Micro-Pattern Gaseous Detectors (MPGDs) are radiation hard detectors, able to cope with rates of MHz/cm^2 rates, exhibit good spatial resolution (≤ 50 μm) and good time resolution of 5–10 ns [5] . They represent a cheaper solution compared to the well-established solid state detector technique. Such low material budget detectors have the potential of economically covering large areas and providing high tolerance against radiation damage, high spatial resolution, and good time resolution.

Gas Electron Multiplier (GEM) detectors are the most consolidated technology inside the MPGD family, and in the last decade they have been considered as tracking devices for Muon Systems in LHC experiments. In particular, Triple-GEM detectors have successfully been part of the LHCb experiment during Run1 and Run2 and were used for a very forward beam telescope (TOTEM).

The GEM detectors are being installed in the CMS Muon System to be operational from Run3 onwards, to cope with the high rate environment of the future phases of the LHC [6-7]. In the last decade several technological solutions and optimization of the operation parameters have been achieved in order to make the detector suitable for operation at HL-LHC. The CMS GEM detector represents the state-of-the-art of this technology instrumenting more than 200 m^2 of GEM foils thereby exploiting around 72 m^2 of sensitive surface in this hostile region. Overall 1000 m^2 of GEM foils will be installed until Long Shutdown 3. These detectors have been optimized to operate in challenging backgrounds with the utmost safety.

The challenge is now open for future colliders considering the high particle rates, discharge probabilities and accumulated doses expected at Future Colliders. Modifications or new detector configurations are to be investigated. Time resolutions of 30-100 ps per track are required to distinguish pile-up collisions and high background conditions, while sub-ns time resolutions are required for experiments at future colliders that will work at 200 MHz bunch crossing frequency. To cope with the very high particle density, time information will be used in a radically new way in conjunction with the purely spatial reconstruction of the trace for the so-called four-dimensional tracking (4D).
Future Colliders will operate at ever increasing collision rates, or very high background. Considering the high rate exposure of the detectors and the radiation hazard, very strong restrictions to access the detector for repairs and replacement are expected. Strong constraints on response stability (vis-à-vis charging up), discharge probability and space charge accumulation require further optimized and novel detector configurations with innovative technological solutions.

The future studies will aim at achieving major advances in the development of a new generation of MPGDs for several applications in HEP experiments at the future colliders, such as a **pre-shower for an electromagnetic calorimeter, active readout layers in sampling calorimeters, a muon tracking or**

tagging detector at FCC-ee/hh and Muon Collider or as the readout layer of a Time Projection Chamber. The use of the MPGD detector technology in a calorimetric high-rate environment will be explored for the first time.

The main objectives of the R&D are:

- operate in a stable and efficient manner with incident particle flows up to ~100 MHz/cm^2;
- guarantee radiation hardness and stability up to integrated charges of hundreds of C/cm^2;
- a very high granularity readout with dedicated electronics to operate efficiently at high fluxes;
- high timing resolution;
- manufacturing on an industrial scale in order to be able to produce large equipment (thousands of square metres) at low cost, by means of a process of technological transfer to the industry.

The main technological solution explored to optimize the operation of MPGD detectors in terms of speed and uniformity of response, damping and eliminating gas discharges, spatial resolution and gain, under particle flows expected at future accelerators, is the development of GEM foils with resistive electrodes. We will investigate new techniques in deposition that ensure controlled and reproducible Diamond-like carbon (DLC) resistivity, such as UV laser deposition and ion beam deposition. In particular, we will need to continue R&D dedicated to resistive materials (DLC and graphene), techniques for deposition and adhesion of films to kapton sheets; control of parameters (resistivity, uniformity over large areas) and the process of chemical etching of resistive kapton sheets for the creation of amplification structures is essential [8].

The **development of GEM foils with resistive electrodes** allows for new detector concepts such as the **Fast Timing MPGD** (FTM) [9], which can achieve a time resolution improved by an order of magnitude, delivering high rate capable detectors with high spatial resolution, matching FCC and Muon Collider requirements. The FTM relies on resistive high gain structures coupled to micro-drift gaps. The intrinsic resistive structure of the technology makes it naturally spark protected, resulting in large operational plateaus, even at harsh background particle rates.

New techniques (such as UV laser deposition and ion beam deposition) for deposition of DLC (or graphene) and adhesion of films to kapton sheets will ensure uniform and reproducibility resistivity over large areas. New Flexible Copper Clad Laminates (FCCLs) are designed to allow double-mask etching of thicker (125um) polyimide foils, whereas currently only the single mask technique can be used (limited to 50um polyimide foils), permitting an order of magnitude increase in gain, necessary for efficiently detecting single ionization clusters of a minimum ionizing particle. Prototype detectors with those new FCCLs are under test with a UV laser. Upon obtaining an efficient detector, FCCLs with different resistivity values will be produced in order to identify the best values for the expected performance.

Industrial partners are already involved in the development of new construction processes with two advantages: being at the forefront in the mass production phase of the detectors to be installed at future colliders and taking advantage of any spin-offs of these technologies in application areas outside HEP such as X-ray and neutron imaging systems in the industrial field, hadrontherapy in the medical field, muon tomography in geology and archaeology, and for national security systems [10].

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