Letter of Intent: A Forward Calorimeter at the LHC

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August 31, 2020

We propose a forward electromagnetic and hadronic calorimeter (FoCal) as an upgrade to the ALICE experiment, to be installed during LS3 for data-taking in 2027–2029 at the LHC. The FoCal extends the scope of ALICE, which was designed for the comprehensive study of hot and dense partonic matter, by adding new capabilities to explore the small-x parton structure of nucleons and nuclei [1].

In particular, the FoCal provides unique capabilities at the LHC to investigate Parton Distribution Functions (PDFs) [2–4] in the as-yet unexplored regime of Bjorken-x down to $x \sim 10^{-6}$ and low momentum transfer $Q \sim 4$ GeV/c, where the PDFs are expected to evolve non-linearly [5–8] due to the high gluon densities, perhaps leading to *saturation* [9–14]. The primary objective of the FoCal is high-precision inclusive measurement of direct photons and jets, as well as coincident gamma-jet and jet-jet measurements, in pp and p–Pb collisions. These measurements by FoCal constitute an essential part of a comprehensive small-x program at the LHC down to $x \sim 10^{-6}$ and over a large range of Q^2 with a broad array of complementary probes, comprising —in addition to the photon measurements by FoCal and LHCb— Drell-Yan and open charm measurements planned by LHCb, as well as photon-induced reactions performed by all LHC experiments [15]. This program will provide by far the most extensive exploration of non-linear effects at small-x for the foreseeable future (Fig. 13 in [1]). Such effects are a necessary consequence of the non-Abelian nature of QCD, and their observation and characterization would be a landmark in our understanding of the strong interaction. Recent small-x computations at next-to-leader order [16–18] will be extended to higher order within the next decade, and will allow for powerful tests of the universality and process-independence of multi-parton correlators by comparing p–Pb and e–Au data at the LHC and EIC.

With the addition of FoCaL, ALICE will have unique capabilities at the LHC to perform photon-induced measurements as a function of rapidity gap to ensure exclusivity and to measure inclusive photo production in a wide variety of processes. Using FoCaL and the central ALICE detectors, angular correlations can be measured to probe EPR-type signals and quantum entanglement in a kinematic domain unavailable elsewhere [19]. The FoCal also significantly enhances the ALICE capabilities to study the origin of long range flow-like correlations in pp and p–Pb collisions, and to quantify jet quenching effects at forward rapidity in Pb–Pb collisions.

The FoCal layout consists of a high-granularity electromagnetic calorimeter backed by a hadron calorimeter, located outside the ALICE solenoid magnet at a distance of 7 m from the ALICE interaction point. The electromagnetic part of FoCal is a compact silicon-tungsten (Si+W) sampling electromagnetic calorimeter with longitudinal segmentation. The sampling in the current FoCal design consists of 18 layers of tungsten and silicon pads with low granularity ($\sim$1 cm^2) and two (or three) layers of tungsten and silicon pixels with high granularity ($\sim 30 \times 30\,\mu$m^2). The pad layers provide the measurement of the shower energy and profile, while the pixel layers enable two-photon separation with high spatial precision to discriminate between isolated photons and merged showers of decay photon pairs from neutral pions. The hadronic part of FoCal is a conventional metal/scintillating calorimeter with high granularity of up to 2.5×2.5 cm^2, which provides good hadronic resolution and compensation.

The proposed calorimeter will be unique in its capability to measure the inclusive direct photon distributions in pp and p–Pb collisions in the forward region for $2 < p_{\mathrm{T}} < 20$ GeV/c. An accuracy of 20% is reached at $p_{\mathrm{T}} \approx 4$ GeV/c which improves to about 5% at 10 GeV/c and above (Fig. 39 in [1]), strongly constraining especially nuclear PDFs below $x \sim 0.001$ [20]. In addition, the inclusive π^0 distribution in central Pb–Pb collisions can be measured with a systematic uncertainty below 10% for $p_{\mathrm{T}} > 10$ GeV/c (Fig. 46 in [1]), allowing for identified particle measurements at uniquely forward rapidity in Pb–Pb collisions at the LHC.

Several prototype detectors were constructed and their performance was studied to validate the design choices for the electromagnetic part of FoCal [21–24]. The results from these tests confirm the feasibility of the design concept. For the final design, more R&D on the integration of the system is necessary, while only modest additional R&D is needed to finalize the pad and pixel sensor readout. In addition, a prototype for clinical application in computer tomography based on proton tracking with a high-granularity (pixel based) digital tracking calorimeter is being constructed by members of the FoCal collaboration [25].

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