# Letter of Intent: A Forward Calorimeter at the LHC

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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) in the as-yet unexplored regime of Bjorken-$x$ down to a few $x \sim 10^{-6}$ and low momentum transfer $Q \sim 4$ GeV/$c$, where it is expected that the hadronic structure evolves non-linearly due to the high gluon densities. 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 photoproduction studies by all experiments. 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. 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.

An essential ability of FoCal is the reconstruction of $\pi^0$ decays at forward rapidity up to large transverse momenta $p_{\mathrm{T}} \sim 20$ GeV/$c$. By taking advantage of the longitudinal momentum boost of a forward rapidity measurement, the FoCal provides excellent identification capabilities for decay photons, with the capability to reconstruct photon pairs with a spatial separation of a few mm at the surface of the detector. This allows precise discrimination between direct photons and decay photons, enabling direct photon measurements from low transverse momentum up to $\sim 20$ GeV/$c$ at large rapidity.

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 $2.5 \times 2.5$ cm$^2$, which provides good hadronic resolution and compensation. For an outer radius of 0.5 m with 18 pad and 2 pixel layers, a total sensor area of about 14.5 and 1.5 m$^2$, respectively, is needed for the electromagnetic calorimeter, instrumented with about 150 K individual pad channels and about 4 K pixel sensors. The estimated costs (material only) anticipated for FoCal are $\approx 9$ MCHF for the electromagnetic and $\approx 2$ MCHF for the hadronic calorimeter.

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 $2 < p_T < 20$ GeV/$c$. An accuracy of 20% is reached at $p_T \approx 4$ GeV/$c$ which improves to about 5% at 10 GeV/$c$ and above (Fig. 39 in [1]), strongly constraining especially nuclear PDFs below $x \sim 0.001$. In addition, the inclusive $\pi^0$ distribution in central Pb–Pb collisions can be measured with a systematic uncertainty below 10% for $p_T > 10$ 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 [2–5]. For the pixel layer, a prototype that was fully instrumented with MIMOSA-23 pixel sensors was constructed and tested with beams. Similar tests with a new prototype using ALPIDE sensors have recently been started. For the silicon pad technology, several prototypes have been constructed, with pad sensors from different vendors and different choices for the readout electronics. The prototype detectors have been tested with electron beams from the CERN PS and SPS, as well as with pp collisions at $\sqrt{s} = 13$ TeV in the ALICE cavern. The results from these tests confirm the feasibility of the design concept. In addition, a proton computer tomography prototype for clinical application based on proton tracking with a high-granularity (pixel based) digital tracking calorimeter is being constructed by members of the FoCal collaboration [6]. 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.

## References


[1] **ALICE** Collaboration, "Letter of Intent: A Forward Calorimeter (FoCal) in the ALICE experiment",.

[2] S. Muhuri, S. Mukhopadhyay, V. B. Chandratre, M. Sukhwani, S. Jena, S. A. Khan, T. K. Nayak, J. Saini, and R. N. Singaraju, "Test and characterization of a prototype silicon–tungsten electromagnetic calorimeter", *Nucl. Instrum. Meth.* **A764** (2014) 24–29, `arXiv:1407.5724 [physics.ins-det]`.

[3] de Haas A.P̃. *et al.*, "The FoCal prototype—an extremely fine-grained electromagnetic calorimeter using CMOS pixel sensors", *JINST* **13** no. 01, (2018) P01014, `arXiv:1708.05164 [physics.ins-det]`.

[4] S. Muhuri *et al.*, "Fabrication and beam test of a silicon-tungsten electromagnetic calorimeter", `arXiv:1911.00743 [physics.ins-det]`.

[5] T. Awes *et al.*, "Design and Performance of a Silicon Tungsten Calorimeter Prototype Module and the Associated Readout", `arXiv:1912.11115 [physics.ins-det]`.

[6] H. E. S. Pettersen *et al.*, "Design optimization of a pixel-based range telescope for proton computed tomography", *Physica Medica* **63** (2019) 87–97.