Letter of intent for the HORIZON-INFRA-2025-01 call

CD_nLGAD_NuHEP

Characterization and Development of novel LGAD sensors for Nuclear and High Energy Physics

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1. Research objectives

Motivation

Novel generations of Low Gain Avalanche Diode (LGAD)-based sensors are one of the most promising concepts for 4D Tracking [1] to satisfy future collider experiment needs of σ(10-20 μm) and σ(10-20 ps) of spatial and timing resolution, respectively. The objective of this project is to develop and characterize solid-state sensors based on LGAD technology for applications in tracking and vertexing in Nuclear and High Energy Physics (HEP), aiming at improved performances in terms of spatial and timing resolution (4D Tracking) and radiation hardness, as well as minimization of material budget. LGAD-based sensors, such as Alternatively Coupled current (AC-) and Trench-Isolated (TI-) LGADs are of most interest as they feature an excellent timing resolution associated to an excellent spatial resolution. Within the framework of short-term R&D projects, this proposal includes the characterization of systems composed of AC-LGAD sensors coupled to optimized readout chips, EICROC, which will instrument detectors of the electron Proton Ion Collider (ePIC) experiment at the Electron Ion Collider (EIC), which is being built at Brookhaven National Laboratory (BNL). Our project will also address the study of TI-LGAD sensors being developed in view of future HEP experiments.

LGAD sensors

LGADs essentially consist on simple p-n junctions with an added amplification layer that provides a controlled avalanche signal, which is high enough to provide a faster signal than conventional diodes, and low enough to avoid high gain drawbacks such as higher noise, higher leakage current, higher thermal load, early breakdown, etc. In addition to this, the required timing performance is possible only in thin sensors, which is convenient to reduce the material budget [1]. However, some improvements should still be done in terms of fill factor and radiation hardness in view of HEP experiments.

State-of-the Art

Pixelated Direct Coupled current (DC-) LGAD sensors are to be implemented in ATLAS and CMS detectors, High Granularity Timing Detector (HGTD) and End cap Timing Layer (ETL) respectively, in the framework of High Luminosity (HL) LHC era. These 1.3 x 1.3 mm^2 pixel size sensors will be read out by dedicated ASICs, ALTIROC and ETROC, developed respectively at OMEGA and FermiLab.

Since the end of the previous decade, novel generations of LGAD sensors have been developed, such as AC-LGADs and TI-LGADs. Compared to DC-LGADs, AC-LGAD sensors feature much smaller pads and thanks to a common dielectric layer allow charge sharing among neighboring pixels providing, by interpolation, a very good spatial resolution (~20 μm), keeping LGAD timing resolution (~20 ps). Given AC-LGAD 4D-tracking capability, several ePIC detectors, in particular far-forward (Roman Pots, Off-Momentum) and forward Time-Of-Flight detectors, rely on pixelated AC-LGADs of 500 x 500 μm^2 pixel size which call for an optimized readout chip, EICROC, developed by OMEGA. The characterization of the performances of systems consisting of an AC-LGAD coupled to an EICROC is carried out at IJCLab. Other R&D efforts in view of future HEP experiments concern high granularity LGAD sensors such as fine pitch (< 100 μm) AC-LGADs, based on a higher n+ implant resistivity to reduce the charge sharing, and TI-LGAD, which are DC-coupled and rely on deep trenches to prevent cross-talk.

Project objectives

We propose in this project to study the performances of two different pixelated LGAD designs (capacitive-coupled AC-LGAD and DC-coupled TI-LGAD), which aim at maximizing the fill factor, exploiting complementary techniques available in our laboratories such as Transient Current Technique (TCT) with an infrared laser, IV-CV (probe station) and Beta source measurements, as well as taking advantage of beam test facilities (CERN, MaMi, JLab) to determine the achievable resolutions and to study the radiation hardness.

The participating institutes will share their expertise in LGADs: IJCLab coordinates the characterization of AC-LGAD sensors coupled to EICROC ASIC for ePIC far-forward detectors, LPNHE leverages the advancements achieved with thin planar sensors during the ATLAS ITk tracker upgrade for the HL-LHC phase by incorporating an amplification layer into its latest sensor designs, and UZH is leading the development of TI-LGADs (DRD3 project) and is deeply involved in the CMS tracker upgrade.

Our collaboration will allow us to establish a solid experimental basis on LGAD sensors produced by different partners (BNL [2] and Hamamatsu [3] for AC-LGAD, FBK [4] for TI-LGAD), with the added interest of testing the dedicated ASICs which are being developed in parallel: EICROC for AC-LGAD (by OMEGA [5]) and IGNITE or PicoPix for TI-LGAD (28-nm CMOS timing ASICs which are being developed for LHCb VELO upgrade II [6]). Besides, this proposal will benefit from the tight collaboration with physicists from BNL within the ePIC collaboration, and from KEK and Tsukuba University within the French Japanese Particle Physics Network.

This project is in line with the key technological developments identified by ECFA Detector Research and Development Roadmap [1] to be primordial to the progress of research in Particle Physics. It will contribute to fostering the growth of a research community highly specialized on leading-edge technological developments and experimental techniques.

2. Connection to Transnational Access infrastructures (TAs)

This R&D project is by its own goals strongly linked to CERN and BNL where we foresee topical meetings. This project will also greatly benefit from facilitated accesses to test beam facilities such as CERN, MaMi, DESY and Jefferson Lab in the framework of LGAD performance characterization and radiation hardness evaluation.

3. Estimated budget request

In order to strengthen our team and our impact in this challenging and demanding R&D, we foresee to hire **1 PhD student for 3 years** (01/10/2026 - 30/09/2029), based at IJCLab and co-supervised between IJCLab and LPNHE, both located in Paris region, to work jointly and strongly interacting with UZH on sensor design using dedicated semiconductor simulation software, to actively take part to characterization measurements and to optimize signal analysis algorithms. Research activities will include data analysis of test bench and test beam data, as well GEANT4 simulated data dedicated to processes of interest in Hadronics and HEP physics exploiting novel LGADs.

We also ask for travel expenses **for each partner** to support collaborative work: travel (meetings and beam tests) and organization of project-related meetings (at least one at each institute -or at CERN- during the duration of the project).

The total budget requested amounts for **179 998,75 €** (indirect costs included), as detailed in the table below.

A. Personnel costs	
PhD (36 months, IJCLab)	125 618,00 €
B. Travel expenses	
IJCLab	6 127,00 €
LPNHE	6 127,00 €
Zürich University	6 127,00 €
Sub-total	**143 999,00 €**
Indirect costs (25%)	**35 999,75 €**
Total	**179 998,75 €**

4. Participating and partner institutions

- CNRS / IN2P3 / IJCLab, Orsay, France
- CNRS / IN2P3 / LPNHE, Paris, France
- Zürich University - UZH, Zürich, Switzerland

References

[1] LGAD-based and silicon Sensors for 4D Detectors", Gabriele Giacomini, Sensors 2023, 23(4), 2132, https://doi.org/10.3390/s23042132.

[2] "Fabrication and performance of AC-coupled LGADs", G. Giacomini et al., JINST 14 (2019) 09, P09004.

[3] "First Prototype of Finely Segmented HPK AC-LGAD Detectors", K. Nakamura et al., contribution to the proceedings of VERTEX 2020, JPS Conf. Prc. 34 (2021) 010016.

[4] "Development of LGAD sensors at FBK", A. Bisht et al., NIMA 1039 (2022) 167018.

[5] "EICROC: an ASIC to read-out the AC-LGAD sensors for the Electron-Ion Collider (EIC)", A. Verplancke et al., contribution to the proceedings of the Topical Workshop on Electronics for Particle Physics, Sept. 30th – Oct. 04th, 2024, Glasgow, UK, JINST 20 (2025) C04014.

[6] "The LHCb VELO upgrade II: design and development of readout electronics", A. Fernández Prieto, Journal of Instrumentation, Volume 19, May 2024.

[7] https://indico.cern.ch/event/957057/page/23281-the-roadmap-document