ALCOR: a SiPM readout chip for the ePIC-dRICH detector at the EIC

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Abstract

ALCOR (A Low-power Chip for Optical sensor Readout) is a mixed-signal ASIC developed for the readout of silicon photomultiplier (SiPM) sensors in the ePIC dual-radiator RICH (dRICH) detector at the future Electron–Ion Collider (EIC). The chip is designed to provide precise single-photon time measurements with low power consumption and a fully digital, trigger-less readout architecture. ALCOR has been extensively characterised in laboratory measurements and operated with different SiPM technologies. Its performance has been validated in beam-test campaigns using a dRICH prototype equipped with a large-area SiPM readout plane. A new version of the chip, ALCOR-64, has been developed to meet the specific requirements of the EIC environment, including increased channel density and bunch-crossing synchronisation. This contribution presents the main design concepts of the ALCOR ASIC, summarises the key performance results, and discusses the features introduced in the latest version for the ePIC-dRICH detector.

1. Introduction

The ePIC detector at the Electron–Ion Collider (EIC) includes a dual-radiator Ring Imaging Cherenkov detector (dRICH) designed to provide charged-hadron identification over a broad momentum range at forward rapidity (Figure 1). The dRICH concept combines aerogel and gaseous radiators in a compact and cost-effective layout, allowing separation of π, K, and p over a wide kinematic domain [1].

The dRICH photodetection system is based on silicon photomultiplier (SiPM) sensors, which cover an active surface of approximately 3 m^2 and consist of more than 3×10^5 readout channels. This scale and performance requirement motivated the development of a dedicated front-end ASIC optimised for single-photon time measurements, low power consumption, and trigger-less operation.

2. The ALCOR-64 Readout Chip

ALCOR-64 is a 64-channel mixed-signal ASIC designed in 0.11 μm CMOS technology for SiPM readout [2]. The chip

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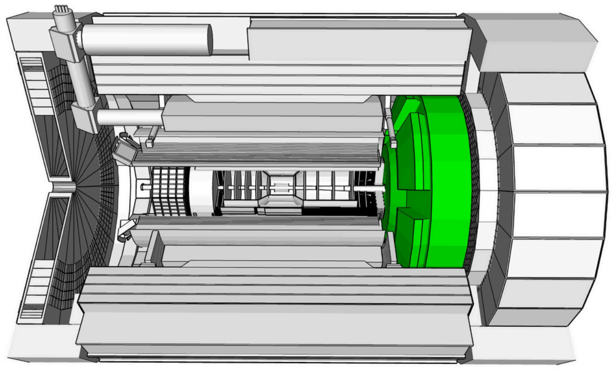

Figure 1: The dRICH detector highlighted inside the ePIC experiment at the EIC

provides on-chip signal amplification and supports time-over-threshold (ToT) measurements with a fully digital output and trigger-less readout architecture.

Each channel is optimised for single-photon detection and time tagging, with a power consumption of approximately 12 mW per channel.

Each ALCOR-64 channel integrates a low-impedance current-conveyor input stage based on a regulated common-gate topology, allowing operation with both positive and negative polarity SiPM signals. The analogue front-end provides four programmable gain settings and feeds two discriminators with independent 6-bit DAC thresholds. Precise time measurements are performed using quad-buffered, low-power time-to-digital converters with analogue interpolation, providing a time binning in the 25–50 ps range. In addition to timestamping, the ASIC supports time-over-threshold and slew-rate measurement modes, enabling an indirect estimation of signal amplitude for time-walk correction.

The ALCOR-64 chips are encapsulated in 256-ball BGA packages with a footprint of 17×17 mm^2 and a pitch of 1 mm. For the full dRICH system, nearly 5000 front-end electronics boards populated with ALCOR-64 ASICs are foreseen.

3. Photodetector Unit and Front-End Electronics

The photodetector unit (Figure 2) is designed to host four 64-channel SiPM arrays, providing a total of 256 readout channels per module. The mechanical structure ensures efficient cooling of the sensors and reliable routing of signals towards the electronics bay.

Each unit integrates four ALCOR-64-based front-end electronics boards (Figure 3) and one FPGA-based readout board [3], which manages data transmission to the data acquisition system. The modular approach simplifies installation and maintenance while ensuring scalability to the full detector size.

4. Timing Performance

The timing performance of the ALCOR-based readout has been characterised in laboratory measurements using single-photon laser events (Figure 4). The results show that the overall

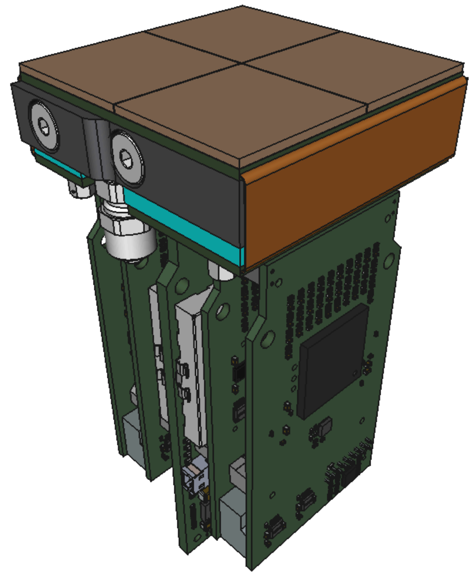

Figure 2: CAD drawing of the photodetector unit

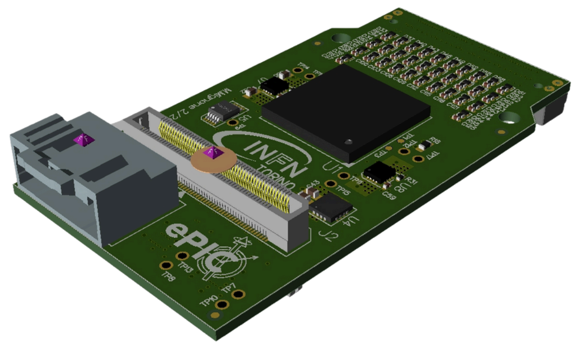

Figure 3: CAD drawing of the ALCOR-64 front-end board.

time resolution is comfortably below 150 ps RMS, even when operating at relatively low SiPM bias voltages.

An improvement in timing performance is observed for large-SPAD SiPM sensors, which is benefitted from their larger signal amplitudes and faster slew rates.

The ALCOR ASIC includes a slew-rate measurement mode, which enables effective time-walk correction since it relies only on the signal rising time and it is therefore insensitive to SiPM after-pulses. In contrast, the ToT mode is limited by its inability to distinguish after-pulses, characterised by slow rise times and large ToT values, and optical cross-talk events, which exhibit fast rise times and large ToT (Figure 5). This capability is particularly relevant for maintaining excellent timing resolution in high-channel-density SiPM systems.

5. Beam Test Results

Two successful beam tests were conducted in 2023 and 2024 at the CERN Proton Synchrotron, using a dRICH detector prototype equipped with more than 2000 SiPM sensors and the

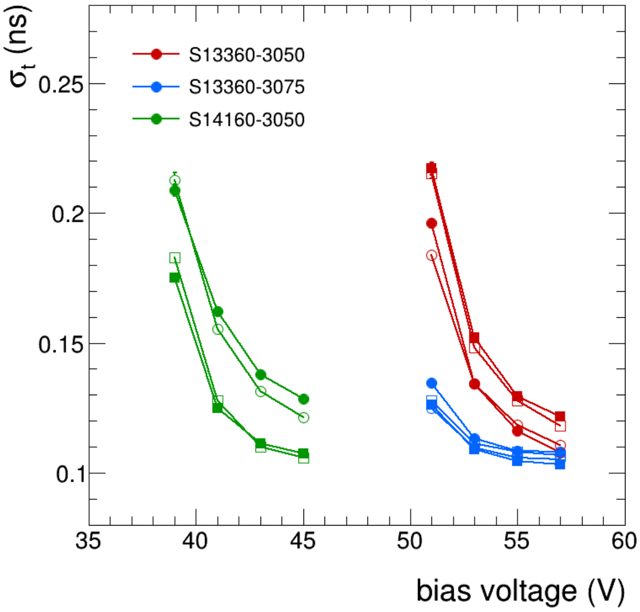

Figure 4: Laser time resolution measurements.

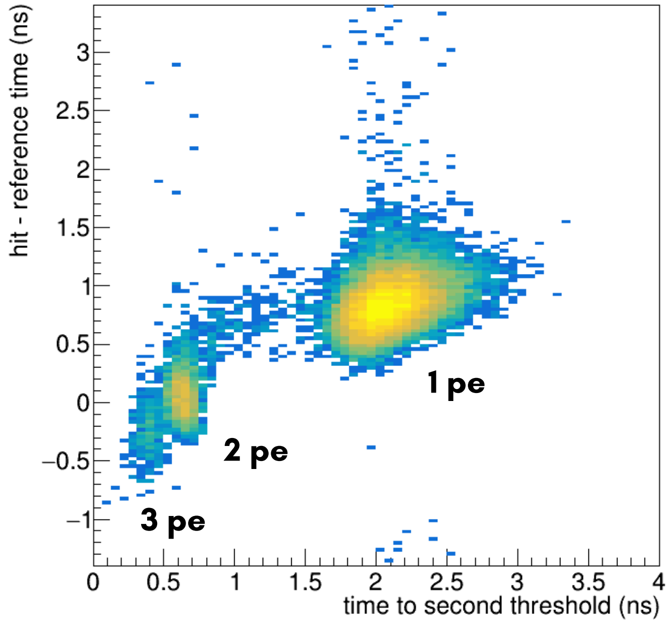

Figure 5: Time-walk correction vs. slew-rate.

ALCOR readout system [4]. The tests demonstrated stable operation of the electronics chain and confirmed the capability of the detector to perform ring imaging.

Accumulated hit maps show clear Cherenkov ring patterns for both aerogel and gaseous radiators. Reconstructed Cherenkov radii as a function of beam momentum are consistent with expectations and allow for efficient separation of electrons, pions, kaons, and protons across the targeted momentum range. These results validate the combined performance of the SiPM sensors, ALCOR readout, and detector geometry.

6. Conclusions

The ALCOR-64 ASIC and the associated photodetector unit constitute a robust and scalable solution for the SiPM-based readout of the ePIC-dRICH detector. Laboratory measurements demonstrate excellent timing performance, with resolutions below 150 ps RMS, and effective time-walk correction capabilities. Beam tests with a large-scale prototype confirm the suitability of the system for ring imaging and particle identification.

The demonstrated performance satisfies the requirements of the ePIC-dRICH detector and supports the adoption of the ALCOR-based readout for the full experiment.

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