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A large-area SiPM readout plane for the ePIC-dRICH detector at the EIC: Realisation and beam test results

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ABSTRACT

The current status of the R&D performed for the ePIC-dRICH detector at the EIC is presented. A special focus will be given to the beam test results obtained with the dRICH prototype SiPM optical readout. A large-area readout plane consisting of a total of 1280 3×3 mm^2 SiPM sensors was built and tested with particle beams at CERN-PS in October 2023. The modular photodetector is based on a novel EIC-driven prototype photodetection unit (PDU) developed by INFN, which integrates 256 SiPM pixel sensors, cooling and TDC electronics in a volume of roughly $5\times5\times14$ cm^3. The data have been collected with a complete chain of front-end and readout electronics based on the ALCOR chip, developed by INFN Torino. The features of the PDU and the performance of the full dRICH SiPM prototype system will be highlighted.

1. Introduction

The Electron-Ion Collider (EIC) [1] will be built at Brookhaven National Laboratory (USA) taking advange of the currently present Relativistic Heavy Ion Collider (RHIC) facility and it is foreseen to start its operations in the early 2030s. The EIC will provide polarised electron–proton and light ion collisions, as well as electron-nucleus collisions, with the aim to explore the Quantum-Chromo Dynamics (QCD) mechanisms. One of the foreseen interaction point (IP6) will be dedicated to the Electron-Proton/Ion Collider (ePIC) experiment. Within this framework our collaboration is taking care of the particle identification detector in the hadronic endcap. Infact, the ePIC experiment at EIC includes a dual-radiator RICH (dRICH) [2] detector for PID in the forward region. The dRICH will be equipped with 3×3 mm^2 silicon photomultipliers (SiPM) for Cherenkov light detection over a surface of roughly 3 m^2 ($\sim$ 300k readout channels), representing the first HEP application of SiPMs for single-photon detection [3]. SiPMs are chosen for their low cost and high efficiency in magnetic fields (about 1 T at the dRICH location). However, as SiPMs are not radiation hard, careful testing is required to preserve single-photon counting capabilities and maintain the dark count rates (DCR) below $\sim$ 100

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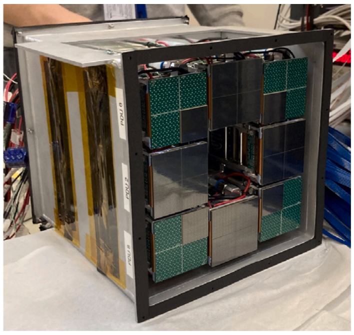

Fig. 1. Detector box for 2023 test beam at T10 CERN-PS. Four fully equipped PDUs plus four 1/4 equipped PDUs in the corners.

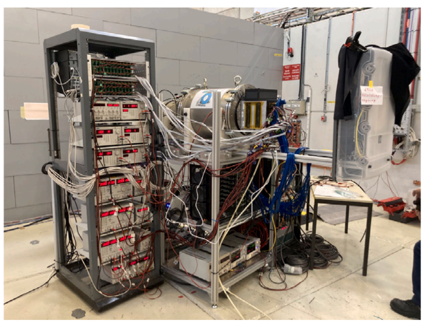

Fig. 2. Complete setup mounted at T10 CERN-PS experimental area.

kHz/mm^2, corresponding to about 1MHz for a 3×3 mm^2 [4]. DCR control can be achieved with operation at low temperature (down to -30 °C) and recovery of the radiation damage via high-temperature annealing cycles [3]. The integration of the SiPMs precise timing with fast time-to-digital converter (TDC) electronics helps to reduce further the effect of DCR as background signal via time gating at both hardware and software levels.

2. ePIC-dRICH prototype and SiPM readout integration

A dual-radiator Ring Imaging Cherenkov (dRICH) detector allows a cost-effective solution for the extensive momentum coverage needed at forward rapidity. It achieves 3σ separation between kaons and pions from a few GeV/c up to 50 GeV/c. The detector comprises aerogel and gaseous (C_2F_6) Cherenkov radiators with refractive indices of ~ 1.02 and 1.0008, respectively. Cherenkov photon detection is then carried out by 8 PDUs arranged in the photodetector box. Each PDU integrates up to four 64-channel SiPM (Hamamatsu S13360-3050VS) matrices together with the cooling system and the ALCOR-based front-end electronics [5]. Four front-end cards, hosting two ALCOR, are placed inside the PDU aluminum structure in a volume of $5{\times}5{\times}14$ cm^3. A fully equipped detector box features 2048 channel in a total volume of $20 \times 20 \times 20$ cm^3 (see Fig. 1). An FPGA-based system provides the readout control, data concentration and acquisition.

2.1. Test beam at CERN-PS results

During October 2023 a test beam in T10 at CERN Proton Synchrotron was carried out with the aim of validating the described setup, shown in Fig. 2. Cherenkov rings for aerogel and gas are clearly visible in Fig. 3 for the negative 10 GeV beam; similar images were obtained for the positive beam, proving the ability to correctly distinguish kaons from pions by discriminating the ring radius [6].

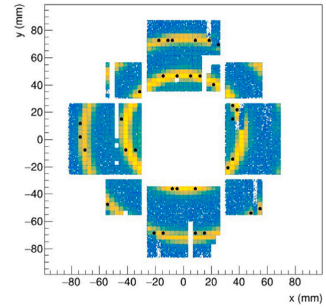

Fig. 3. Dual radiator configuration for 10 GeV negative beam. The outer and innermost rings correspond to Cherenkov photons produced respectively in the aerogel and in the C_2F_6 radiator gas.

3. Conclusions

The ePIC dRICH with SiPM sensors for the optical readout has been tested to validate its performances together with an ALCOR-based front end electronics. The R&D path for this project started with irradiation and high-temperature annealing studies followed by measurements of the timing performance of the prototype readout chain. A previous beam test has been successfully performed in October 2022 utilising the SiPM prototype sensor boards readout by a different electronics in October 2023 the complete ALCOR-based readout chain together with the dRICH detector prototype with SiPM optical readout has been successfully tested showing the expected behaviour. Another beam test with fully equipped detector box has been concluded in June.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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