The protoype of Hi‘Beam-SEE, a fast, high resolution particle position locating platform

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Abstract: The single event effect (SEE) test precise positioning is a key technology that needs to be solved urgently in the world. A non-interceptive and high-resolution beam position monitor device, named Hi'Beam-SEE, has been designed for Heavy Ion Research Facility at Lanzhou (HIRFL). The Hi'Beam-SEE consists of the detector system and the readout system. The novel Topmetal-M silicon pixel chip in the detector system directly collects negative ions generated by the heavy ions ionized air under the electric field. The readout system consists of a readout control module (RCM) and a Data Collection Summary module (DCM). We conducted tests on the Hi'Beam-SEE prototype to evaluate the performance. This paper will discuss the design, characterization, and test of Hi'Beam-SEE.

Introduction

With the demand for testing a lot of radiation-hardened chips, we urgently need to improve the efficiency and accuracy of single event effect (SEE) research at Heavy Ion Research Facility at Lanzhou (HIRFL). Accurately obtaining each chip's sensitive area can effectively guide the radiation hardening of chips and reduce the number of iterations and development cycles. Therefore, developing an efficient micron-level positioning device for SEE testing of chips is very important. The device can precisely locate the hitting position of each heavy ion generating SEE on the chips and obtain the SEE sensitive area distribution of the chips.

The Hi'Beam-SEE prototype principle

The schematic diagram of the Hi'Beam-SEE prototype is shown in Fig.1. The heavy ion beam is incident along the Z direction, and the negative ions generated by the heavy ions ionized air are absorbed by the anode of the track detector under the electric field. The anode of the detector adopts the charge-collecting pixel prototype chip developed by ourselves, named Topmetal-M. The Topmetal-M measures 20.48 mm×4 mm and contains a matrix of 512×128 pixels, the size of each pixel is 40 μm×40 μm. Two detector units placed perpendicular to each other can measure the projection of the heavy ion track on the X-Z and Y-Z planes (as shown in the yellow part in Figure 1). After fitting the projections in the two directions, the flight trajectory of each heavy ion can be accurately obtained. In addition, the chip monitoring system provides a trigger signal to Hi'Beam-SEE, which can mark the hitting position of the heavy ion when SEE occurs. By recording the hit position of SEE triggered by each heavy ion, the sensitive area of SEE is given accurately, which provides accurate experimental data for the study of the relationship between the chip design and SEE, the mechanism of SEE generation, and radiation hardening.

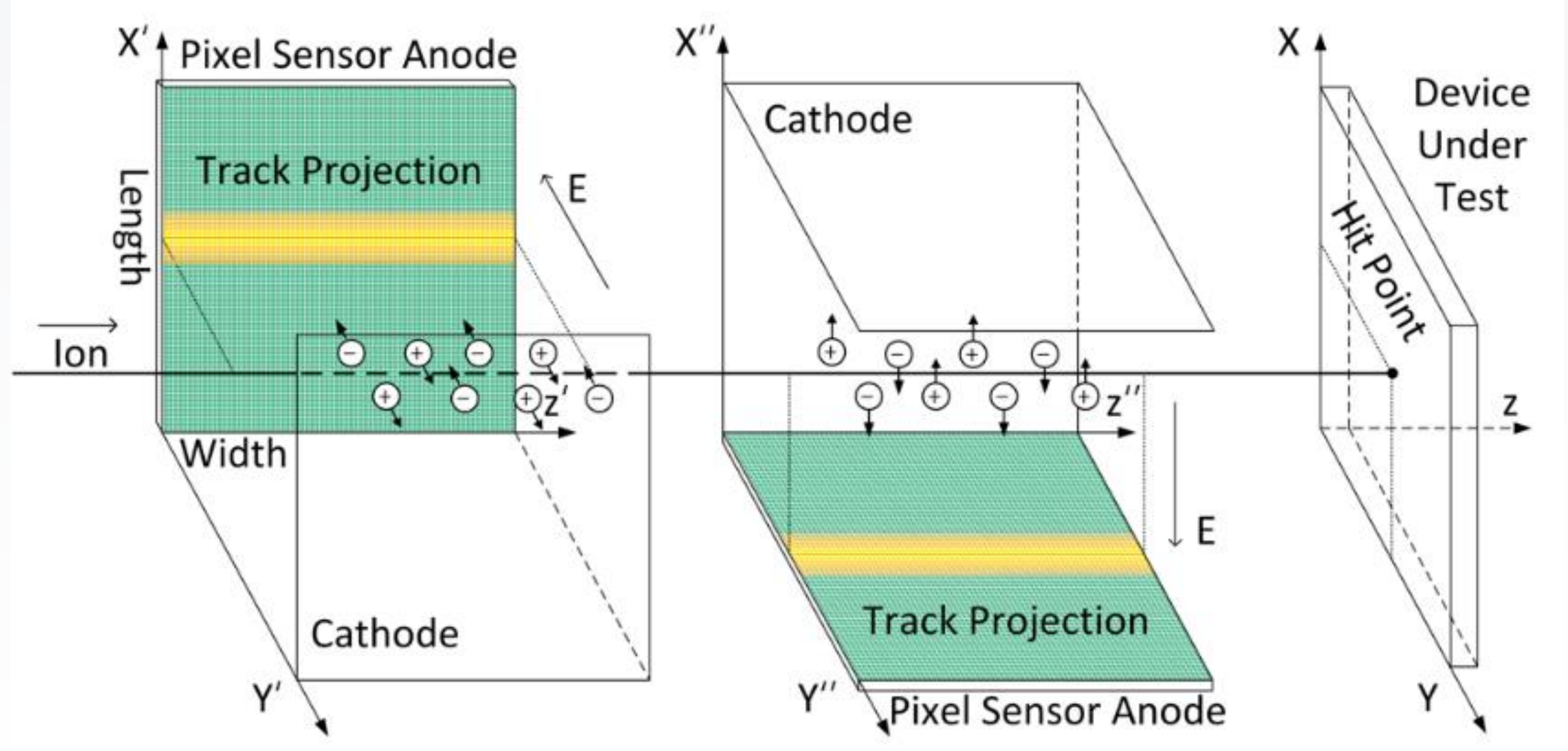

Fig. 1. Schematic diagram of the of the Hi'Beam-SEE prototype

The Hi'Beam-SEE system

As shown in Fig.2, the Hi'Beam-SEE prototype consists of the detector system and the readout system. Two pixel detectors are placed perpendicular to each other. It collects the negative ions generated while the beam ionizes the air, converts them into analog signals, and transmits them to the readout system. The readout control module (RCM) converts the analog signals from the detector into digital processes and sends them to the Data Collection module (DCM) via optical link.

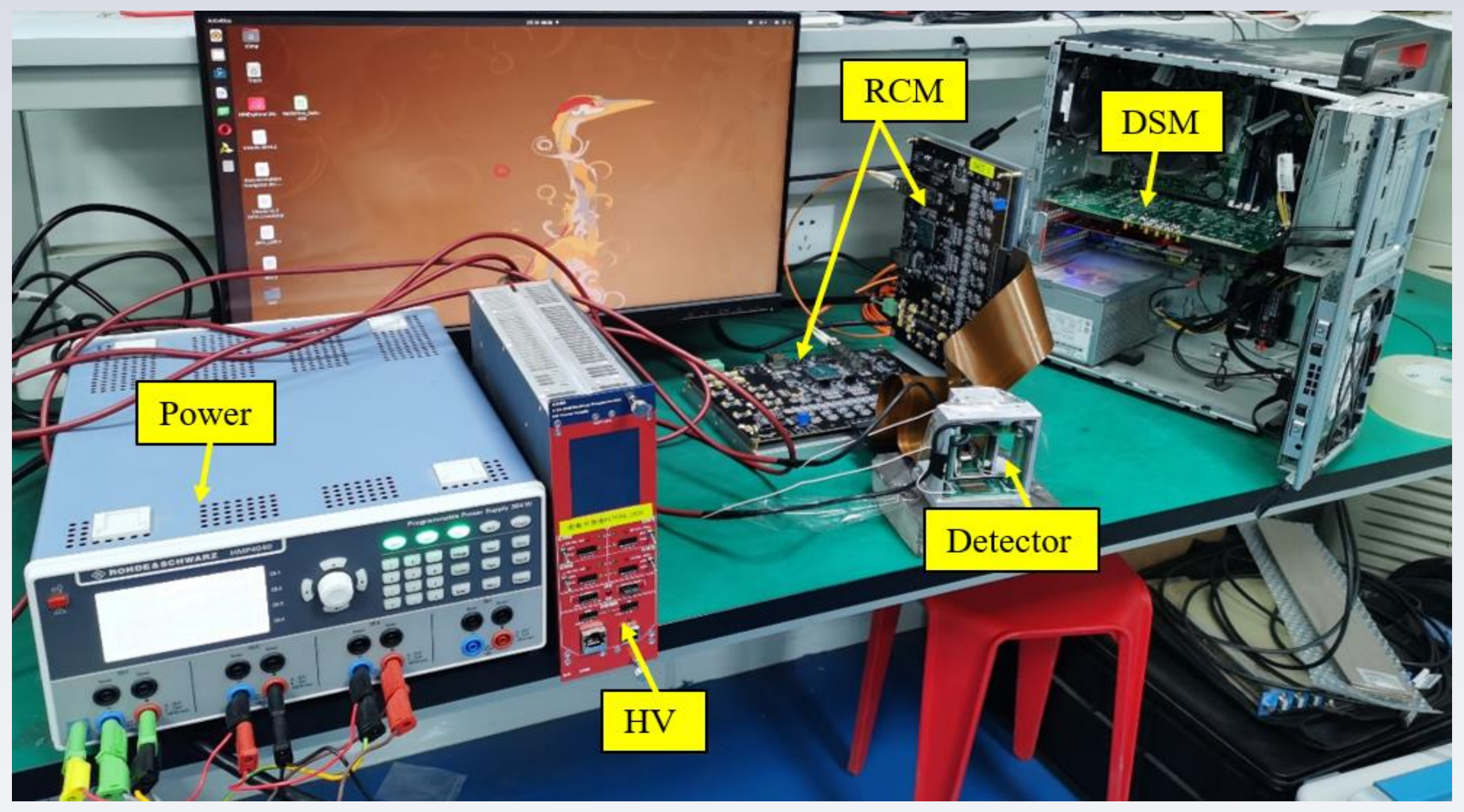

Fig. 2. The setup of the Hi'Beam-SEE prototyp

As shown in Fig.3, the detector system is composed of Topmetal-M chip bonding board, metal parts, and field cages. The Topmetal-M is bonded on a rectangular PCB and mounted on a metal part as the anode. Another metal part is mounted at a certain distance above Topmetal-M bonding PCB as the cathode. The field cage is fixed between the anode and cathode to make the drift electric field perpendicular to the electrode. This constitutes an independent charge collection device. Fig. 4 shows the picture of the RCM, and the RCM mainly consists of the main field-programmable gate array, the analog buffer circuit, high-resolution ADC (AD9249), current monitoring circuit, power supply circuit, and the optical link. The analog signal from the Topmetal-M transmitters through FPC to the analog buffer circuit is filtered and transmitted to the ADC for digitization. Then, the FPGA packs the data, adds timestamp and RCM number, and finally communicates with the DCM via optical link.

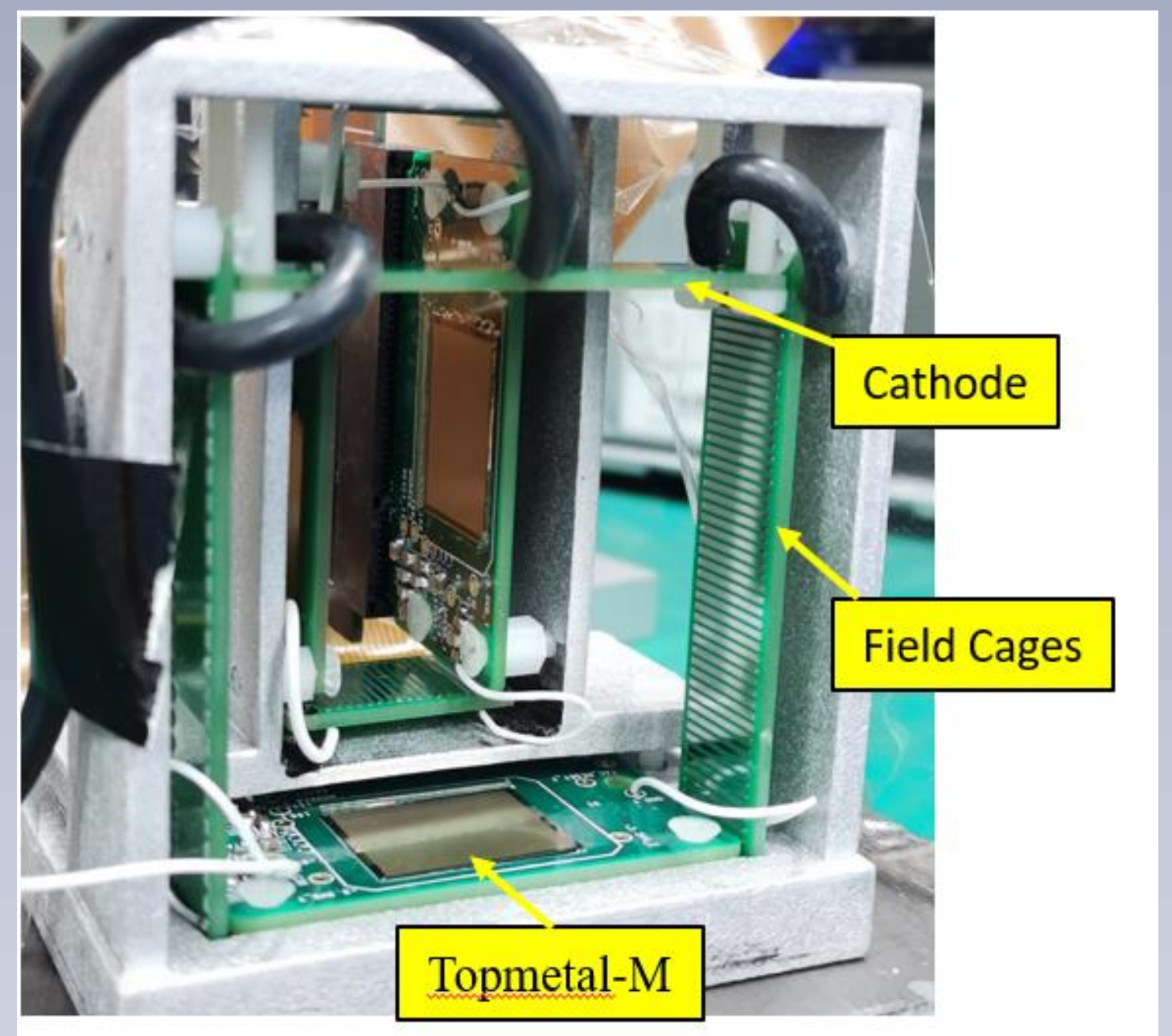

Fig. 3. The picture of the detector.

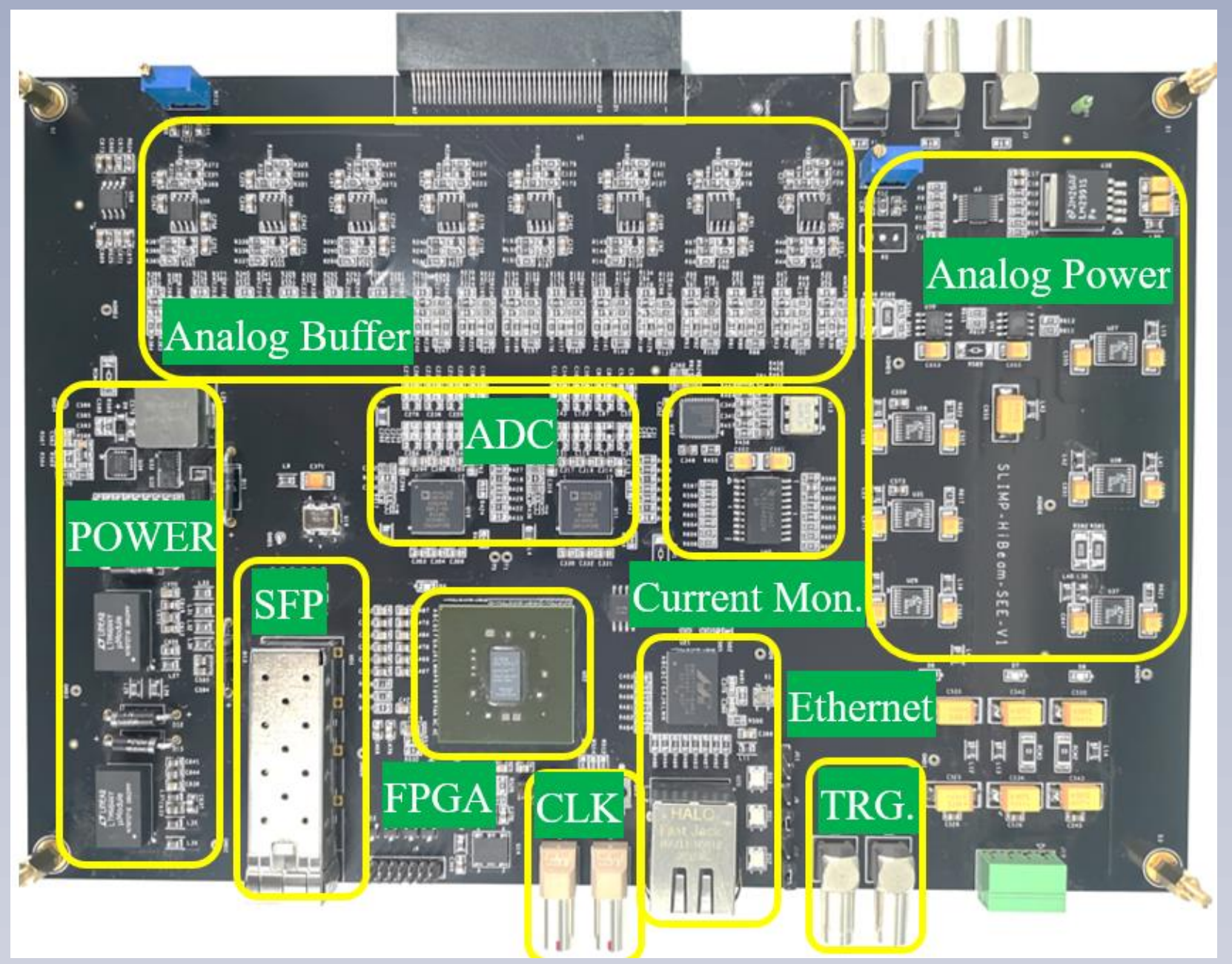

Fig. 4. The picture of RCM..

Fig. 5 shows the picture of the DSM. The geometry of the DSM is designed according to the PCIe specification. The central component on the board is Xilinx Kintex Ultrascale FPGA, which has 20 GTH Transceivers. The DCM exchanges data from the RCMs with four serial full-duplex optical links with SFP modules. The DSM hosts four DDR4 SRAMs with a total size of 16 Gbytes and a maximum data rate of 2400 Mbps.

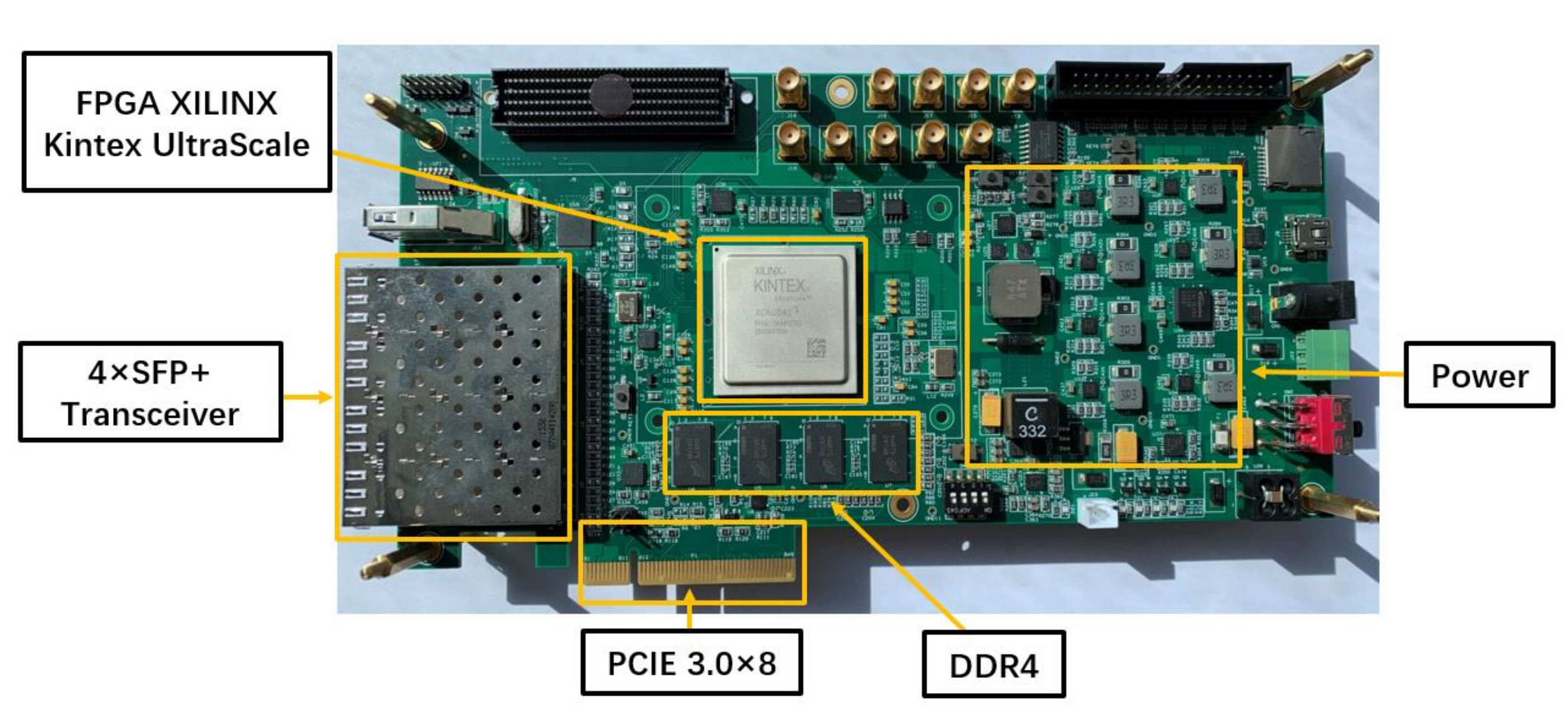

Fig. 5. The picture of the DCM.

We got a space resolution of about 1.6 μm [1] in the previous test, and the test of the new version will be carried out in the next.

[1]. Yang, Haibo, et al., IEEE Transactions on Nuclear Science 68.12 (2021) 2794-2800.