Studies of a large dynamic range SiPM readout ASIC MPT2321-B

Baohua Qi[1,2,*], *Yong* Liu[1,2,**] *Huangchao* Shi[3], *Danqi* Wang[3], *Zhiyu* Zhao[4,5], and *Hongbo* Zhu[3]

[1]Institute of High Energy Physics, Chinese Academy of Sciences. Yuquan Road 19B, 100049 Beijing, China
[2]University of Chinese Academy of Sciences. Yuquan Road 19A, 100049 Beijing, China
[3]Zhejiang University. 866 Yuhangtang Road, 310058 Hangzhou, China
[4]Tsung-Dao Lee Institute, Shanghai Jiao Tong University. 520 Shengrong Road, 201210 Shanghai, China
[5]Shanghai Jiao Tong University. 800 Dongchuan Road, 200240 Shanghai, China

Abstract. A new commercially available SiPM-readout 32-channel ASIC with a large dynamic range has been first tested for the development of future high-granularity calorimeters. The response linearity and the single-photon calibration have been fully characterised. Beamtests were conducted with high-energy particle beams, crystals, and SiPMs for the quantitative study of its dynamic range. The first results show this chip has an excellent signal-to-noise ratio and a large dynamic range.

1 Introduction

The high-granularity calorimeters, designed for future Higgs Factories, are anticipated to significantly improve jet reconstruction capabilities with 5D information (3D spatial, timing and energy). Particle-flow oriented crystal electromagnetic calorimeters (ECALs) with finely segmented structures and silicon photomultiplier (SiPM) readout have been proposed for an optimal electromagnetic energy resolution[1]. With this new calorimeter option, the substantial energy deposition within single crystal cells under the collision energy up to 240 GeV (Higgs Mode) will generate tens of thousands of photons, posing significant challenges to the dynamic range of the electronics.

The electronics system requires a high signal-to-noise ratio to fully exploit the advantages of SiPMs, and a large dynamic range for detecting photons up to 10^5 level, representing a critical issue for crystal ECAL. The novel high-precision multi-channel Application-Specific Integrated Circuit (ASIC) MPT2321-B developed by MicroParity could be a promising candidate.

This chip features 32 readout channels designed specifically for SiPM-based applications, employing a 12-bit Analogue-to-Digital Converter (ADC) with a large dynamic range, and a 20-bit Time-to-Digital Converter (TDC) with excellent time resolution.

In this context, we have performed preliminary studies on an MPT2321-B evaluation board for future 5D crystal ECAL R&D, focusing on the characterisation of its dynamic range with laboratory and beam experiments.

*e-mail: qibh@ihep.ac.cn
**Corresponding author. e-mail: liuyong@ihep.ac.cn

2 Lab characterisations

As shown in Figure 1, an evaluation board equipped with an MPT2321-B chip has been used for the first performance characterisation. To gain an initial understanding of the chip, the response linearity for different gain modes was studied in the laboratory.

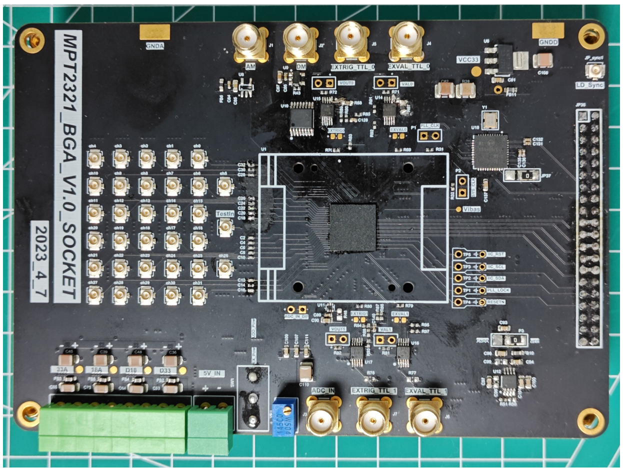

Figure 1. The MPT2321-B evaluation board designed by MicroParity.

2.1 Response linearity

The chip offers 8 distinct gain modes, including 4 high-gain modes and 4 low-gain modes. The high-gain modes provide a good signal-to-noise ratio for single photon calibration, while the low-gain modes can extend the dynamic range for the SiPM signals to be measured.

The response linearity for these modes has been evaluated in the laboratory, employing the charge injection

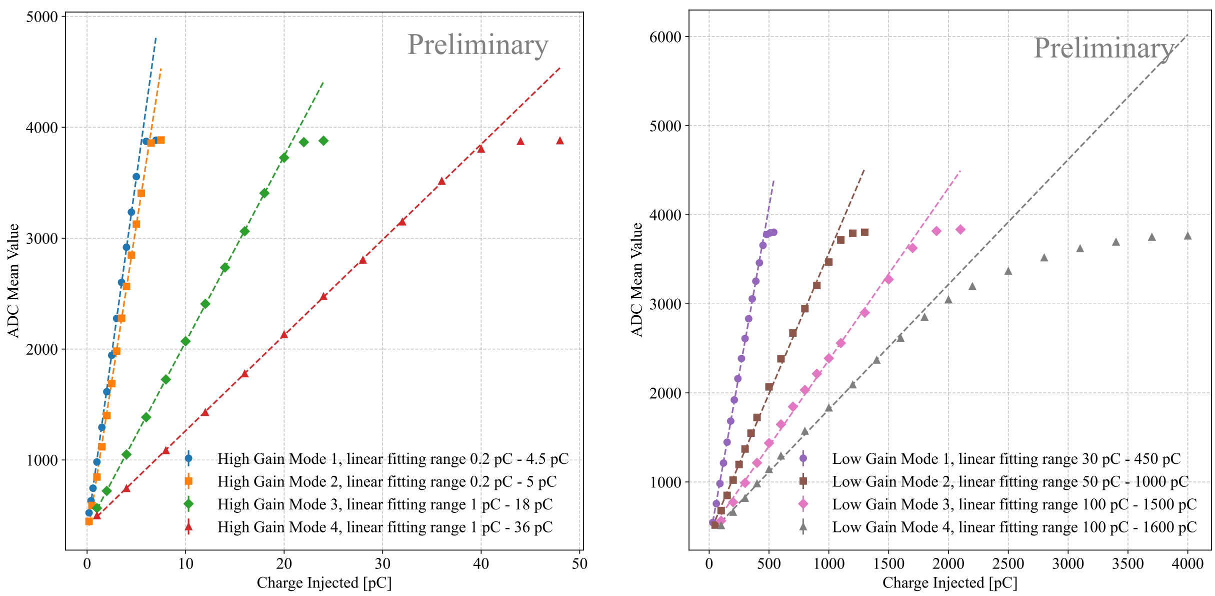

Figure 2. Response linearity under high-gain (left) and low-gain (right) modes.

method. Different levels of pulse voltages were applied to capacitors of 100 pF for high-gain modes and 1 nF for low-gain modes, generating a series of signals with charges with specific values. Upon injecting the signals into the chip, corresponding ADC counts were obtained. All gain modes have been tested until they reach full saturation.

A set of response linearity curves was obtained, as shown in Figure 2. The full saturation points in all gain modes are consistently around 3800 ADC counts. Overall, the linearity of the high-gain modes is better than that of the low-gain modes. With a 1 nC capacitor, the maximum linear range reaches up to 1.8 nC under Low Gain Mode 4. A noticeable deviation towards non-linear response is observed when the injected charge exceeds 1.8 nC. It is important to note that, under the same shaping time setting of the chip, injecting the same charge from capacitors with different values will result in different charge-discharge characteristics, leading to non-identical ADC counts measured by the chip. Therefore, an additional test with a 100 pF capacitor for Low Gain Mode 4 has been performed for future inter-calibration.

2.2 Single-photon spectrum

Single-photon calibrations have been conducted under the highest gain with the 25 μm pixel pitch SiPMs (HPK S13360-3025PE[2]) and an LED calibration system. The single-photon spectrum is shown in Figure 3. Therefore, the single-photon response which is around 14 ADC counts can be obtained under High Gain Mode 1. Thus, the corresponding values under Low Gain Mode 4 can be derived with the information from the previous sub-section for dynamic range studies.

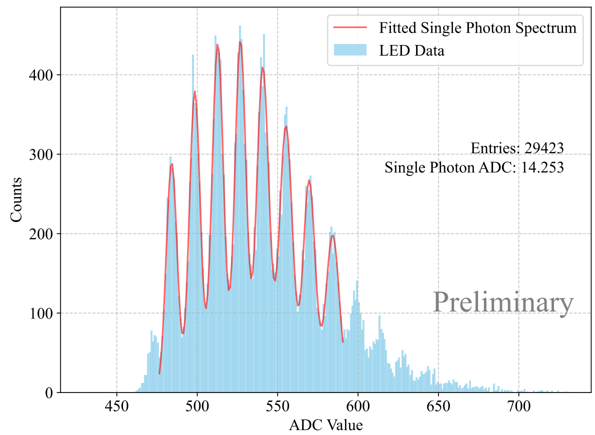

Figure 3. Single-photon spectrum of an HPK S13360-3025PE SiPM under High Gain Mode 1.

3 Beamtest for dynamic range studies

To evaluate the dynamic range of the chip, hence assessing its application potential in the high-granularity crystal ECAL, a beamtest was carried out at the Deutsches Elektronen-Synchrotron (DESY) T22 beamline.

The experiment utilised 2.5×2.5×5 cm^3 ESR-wrapped Lutetium Yttrium Oxyorthosilicate (LYSO) crystals, air-coupled to S13360-3025PE SiPMs. 5 GeV/c electron beams were incident along the length of the crystals. A coincidence trigger system consisting of two 1 cm^3 plastic scintillator cubes was used to provide an external trigger signal to the chip, as shown in Figure 4. Pedestal calibrations and single-photon calibrations have also been done at the beam site, ensuring that the data were taken under approximately consistent temperatures.

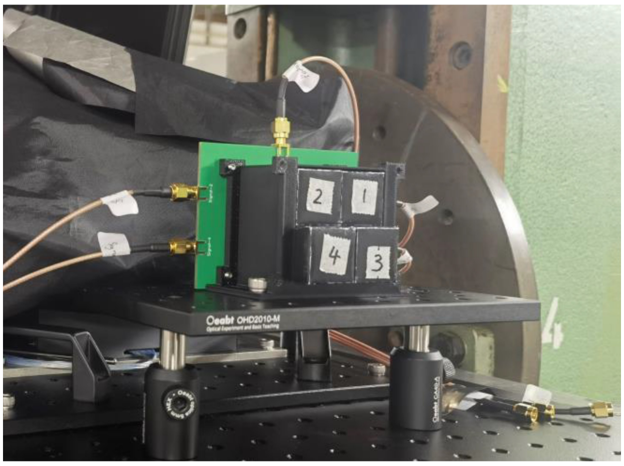

Figure 4. A photo of beamtest setup at DESY.

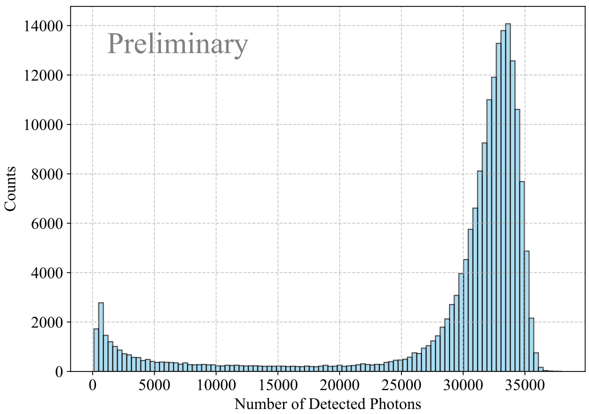

Figure 5. Energy response of 5 cm LYSO crystal to 5 GeV/c electrons, presented in the number of photons.

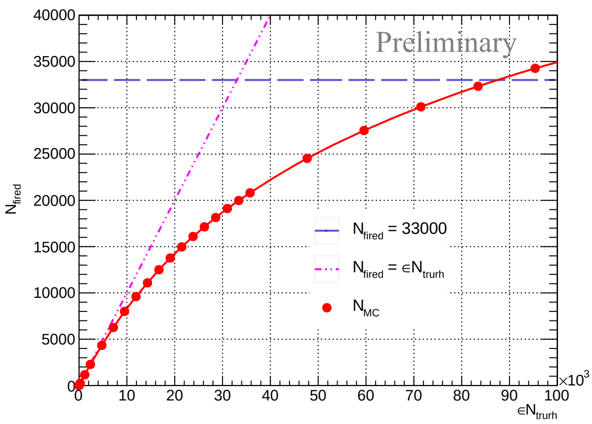

Figure 6. Toy Monte Carlo simulation of the SiPM non-linear response.

The data acquisition was conducted under Low Gain Mode 4. After subtracting the pedestals, the energy deposition distributions corresponding to the SiPM signal with the electron beam were obtained. The photon number calibration has been done with the information from the charge injection test and the single-photon calibration. The energy response (presented in the number of photons) is finally shown in Figure 5. The result shows the most probable value of the number of detected photons is around 33,000, representing around 3.7 nC charge. The fully saturation region was not observed in this experiment. Furthermore, the dynamic range could be improved by utilising SiPMs with lower gains, reducing shaping time, etc.

Due to the saturation effect of SiPM under high light intensity, a toy Monte Carlo simulation has been done considering the effects from photon generation, transmission, detection, as well as the recovery of SiPM, etc. The simulated non-linear response curve is shown in Figure 6. With 33,000 fired pixels of the SiPM, the incident photon is around 89,000, which is consistent with the value from Geant4[3] optical simulation.

4 Conclusion and outlook

The state-of-the-art large dynamic range SiPM-readout chip MPT2321-B developed for future calorimeters has been first studied. Preliminary results show that the chip can achieve a high signal-to-noise ratio for the SiPM single-photon calibration and a large dynamic range of detecting approximately 33,000 photons. The results are in good agreement with the simulations. Further combined studies with the crystal calorimeter module are planned as future beamtest activities.

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