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# Characterisation studies of two front-end electronics chips for SiPM-based detectors

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A new front-end ASIC named "PIST" (pico-second timing) has been successfully developed using 55 nm CMOS technology for silicon photomultiplier (SiPM) readout with a major aim at fast timing. Extensive tests have been performed to evaluate the timing performance using a dedicated test stand equipped with a PIST chip. The results demonstrate that the system timing resolution can be below 10 ps for large SiPM signals, while the intrinsic timing resolution of the PIST is better than 7 ps. The dynamic range of the PIST has been further extended using the time-over-threshold (ToT) technique. Meanwhile, a new commercial SiPM-readout 32-channel ASIC was characterised for future high-granularity crystal calorimetry developments, including the single-photon calibration and the dynamic range with different gain modes. Comprehensive measurements were made with charge injections and high-energy particles along with scintillating crystals and SiPMs. Preliminary results show that this chip has a promising signal-to-noise ratio and a large dynamic range. This contribution will introduce the two ASICs and present highlighted testing results, including the timing resolution, the single-photon calibration, and the dynamic range.

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## 1. Introduction

A high-granularity crystal electromagnetic calorimeter (ECAL) has been proposed as a novel and promising technical option for future Higgs factories, featuring finely segmented scintillating crystals and silicon photomultiplier (SiPM) readout [1]. As a homogeneous calorimeter with high granularity readout, the crystal ECAL is expected to achieve an excellent electromagnetic energy resolution and to be compatible with the particle-flow algorithms. The readout scheme poses a stringent requirement to a considerable large dynamic range of the electronics. In addition, superior timing resolution has the potential to enhance particle identification capabilities, hadronic energy resolution, and particle-flow performance. In this context, dedicated tests have been performed on two state-of-art SiPM-readout ASICs for future calorimetry developments. Section 2 focuses on the timing performance and Section 3 presents preliminary testing results on the dynamic range, followed by conclusions and prospects in Section 4.

## 2. PIST chip characterisation studies

A picosecond timing ASIC (named ''PIST'') was successfully developed for the SiPM readout for excellent timing performance [2], which targets a timing resolution better than 50 ps at the signal level of a single minimum ionizing particle (MIP). It provides information including the Time of Arrival (ToA) and the Time over Threshold (ToT), with an expected power consumption of 15 mW per channel. A dedicated laser test stand (Fig. 1 was developed to study the timing performance with a SiPM. Typical output waveforms range from -780 mV to 780 mV, featuring an ultra-fast leading edge and a low noise level. As shown in Fig. 2, the Constant Fraction Discrimination at the threshold of 10% of the maximum amplitude of the PIST output waveforms was found to lead to the optimal timing resolution. In the signal range of 100 p.e. (photon equivalent) to 25,000 p.e., the timing resolution demonstrated to meet the requirement of 50 ps and achieved 7 ps with large signals and 30 ps at a single MIP level (i.e. 200 p.e./MIP) [3].

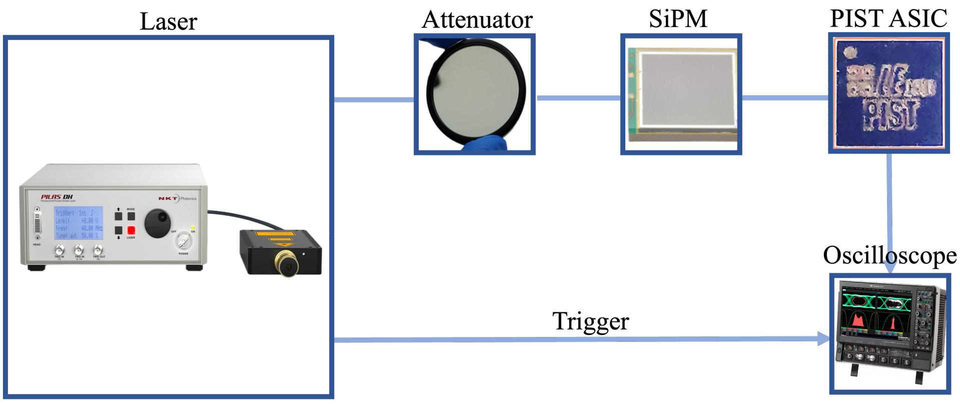


**Figure 1:** Pico-second laser setup for testing PIST timing performance [3]

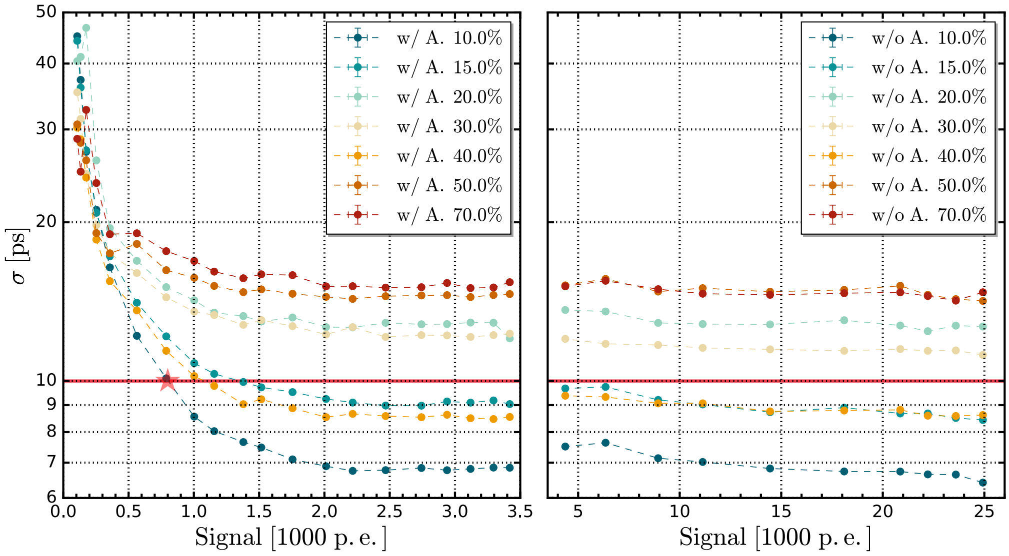


**Figure 2:** PIST timing resolution with different signals by varying laser intensity [3]

## 3. MPT chip in lab and beam tests

The crystal ECAL requires its readout electronics to achieve a high signal-to-noise ratio to fully utilize the SiPM advantages with the single photon calibration and to maintain a good response linearity in a large dynamic range (with the number of detected optical photons in a single crystal up to the $10^5$ level). A high-precision chip named MPT2321 for SiPM readout with 32 channels could be a promising candidate. This chip features low-power design and is equipped a 12-bit Analogue-to-Digital Converter (ADC) and a 20-bit Time-to-Digital Converter (TDC) for each channel. Dedicated measurements were performed with an evaluation board equipped with an MPT2321 chip, as shown in Fig. 3. The response linearity in a wide signal range with different gain modes was first studied in the laboratory with charge injections and a beam test was followed with 5 GeV electrons.

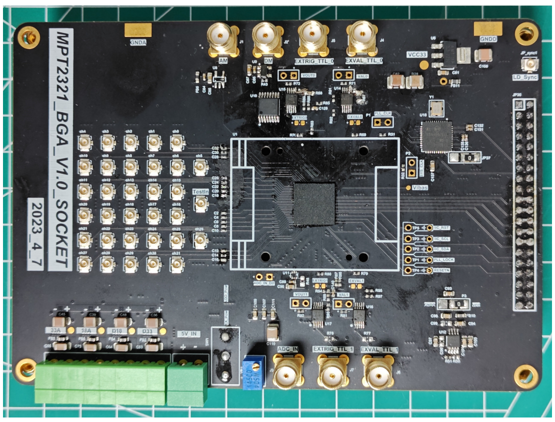


**Figure 3:** The MPT2321-B evaluation board.

The chip offers eight gain modes, including four High-Gain (HG) modes and four Low-Gain (LG) modes. The response linearity for these modes was tested by injecting charges. Different levels of pulse voltages were applied to capacitors of 100 pF for high-gain modes and 1 nF for low-gain modes to generate signals with pre-defined charge values, where the ADC counts of the chip were obtained for each injected charge signal. The full saturation points for 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 nF capacitor, the maximum linear range reaches up to 1.8 nC with the LG Mode 4.

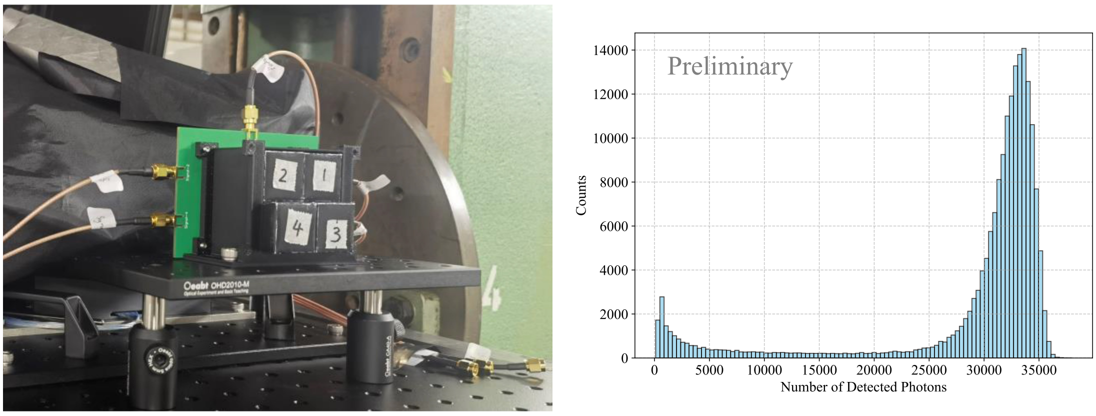


**Figure 4:** Beamtest setup (left). Energy response of 5 cm LYSO crystal to 5 GeV/c electrons, presented in the number of photons (right).

To evaluate the dynamic range of the chip, a beam test was conducted at the DESY-II beamline 22, with Lutetium Yttrium Oxyorthosilicate (LYSO) 2×2 arrays. Each LYSO crystal (2.5×2.5×4/5 $cm^3$) was wrapped with ESR foils and directly coupled with one SiPM (HPK S13360-3025PE). The impact position of the 5 GeV/c electron beam was aligned to be in the centre of the LYSO crystals, as shown in Fig. 4 (left). The beam data were taken in the LG Mode 4. As shown in Figure 4 (right), the preliminary results indicate that the most probable value of the number of detected photons is around 33,000. With more photons generated in the LYSO crystals than the total number of effective SiPM pixels, the SiPM response was expected to have a significant saturation effect. Based a simulation model [4] to describe the SiPM non-linearity effects, which also takes into account the SiPM pixel recovery effect during the scintillation and photon propagation processes, the expected number of detected photons for the beam test result was estimated to be around 88,000 photons. These preliminary results indicate that the MPT chip is promising to detect up to 100,000 photons, when a high pixel-density SiPM is used and its saturation effect is mostly corrected. It would be an excellent front-end chip option for the future calorimetry developments.

## 4. Conclusions and outlook

Two SiPM-readout chips developed for future calorimeters have been extensively studied using laser and beam test setups. Promising results indicate that the PIST chip can achieve a timing resolution of 30 ps for 1-MIP signals and better than 7 ps for large SiPM signals. The MPT chip was demonstrated to achieve a high signal-to-noise ratio for the SiPM single-photon calibration and a large dynamic range. Further studies are planned with crystal calorimeter modules equipped with the chips and high pixel-density SiPMs.

## References

[1] Baohua Qi et al., R&D of a Novel High Granularity Crystal Electromagnetic Calorimeter. Instruments **6**, 40 (2022). https://doi.org/10.3390/instruments6030040

[2] Bo Lu et al., Design and Characterization of a Picosecond Timing ASIC in 55-nm CMOS, IEEE Transactions on Nuclear Science (Volume: 70, Issue: 6, June 2023) https://doi.org/10.1109/TNS.2023.3277522

[3] Xin Xia et al., Performance studies of a SiPM-readout system with a pico-second timing chip, Nucl. Instrum. Meth. A 1064 (2024) 169351 https://doi.org/10.1016/j.nima.2024.169351

[4] Zhiyu Zhao et al., Dynamic Range of SiPMs with High Pixel Densities, https://doi.org/10.48550/arXiv.2407.17794