Performance studies of a SiPM-readout system with a pico-second timing chip

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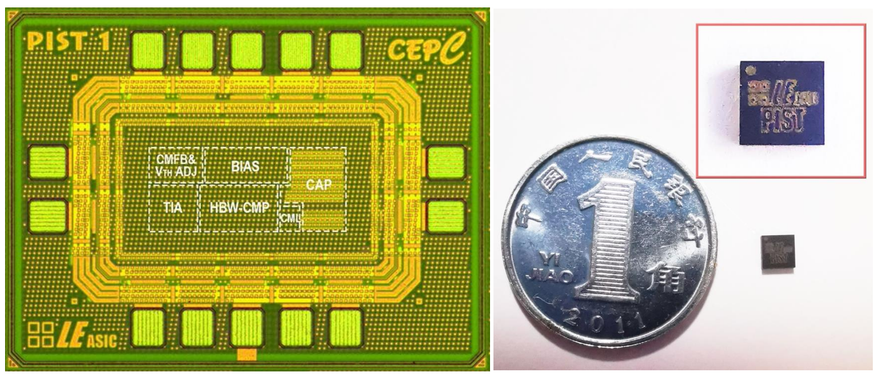
Introduction

High precision time information is crucial for the calorimetry of future electron-positron colliders

- Particle Identification (PID): High-precision time-of-flight (50 ps) measurement complement dE/dx measurement and improve PID performance
- Energy reconstruction: Cell-level high-precision timing information can enhance reconstruction performance of energy compensation algorithms
- PFA, pile-up ……

A pico-second timing (PIST) ASIC developed for SiPM readout

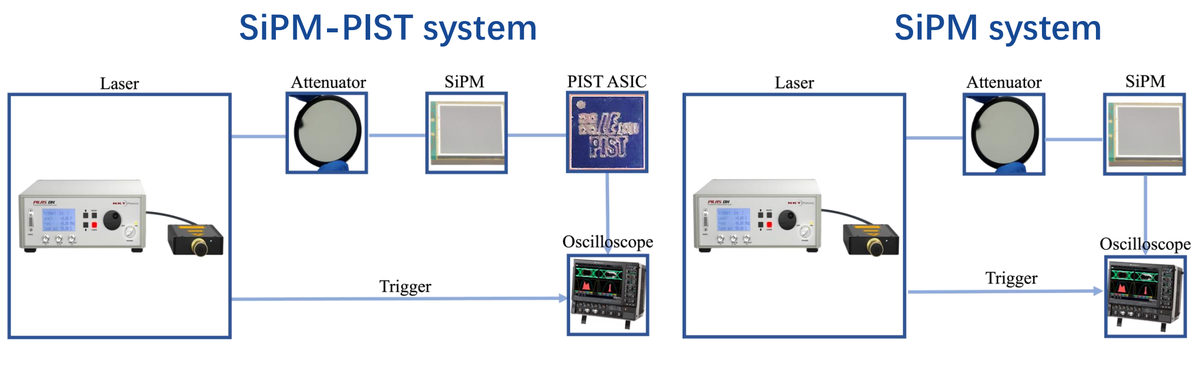
- 55 nm CMOS
- **15 mW/channel** power dissipation



Test Stands and Timing Methods

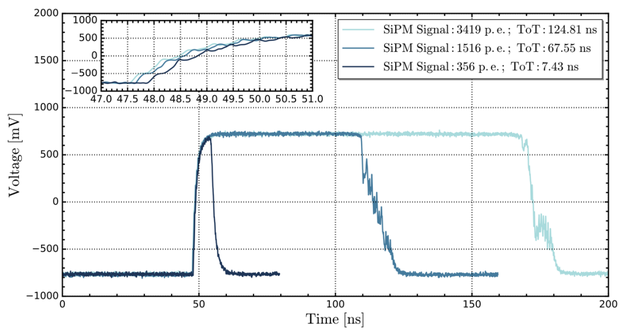
Two test stands with laser diode:

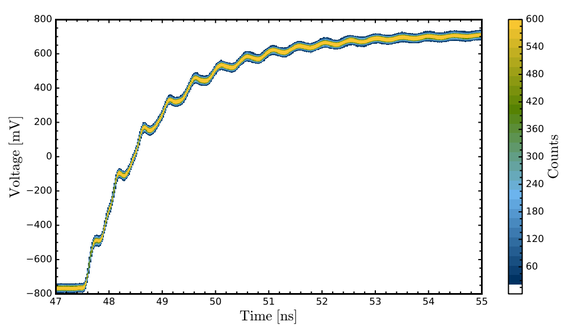
- SiPM-PIST system: to quantify the response of the PIST ASIC to SiPM signals
- SiPM system: to characterize the SiPM signals



PIST ASIC waveform description:

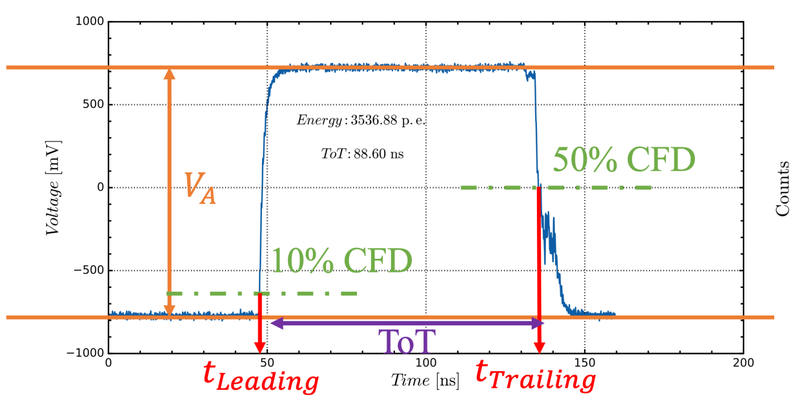
- Dynamic range: -780 mV to 780 mV
- Fast leading edge with low noise level, especially the **bottom of the leading edge**

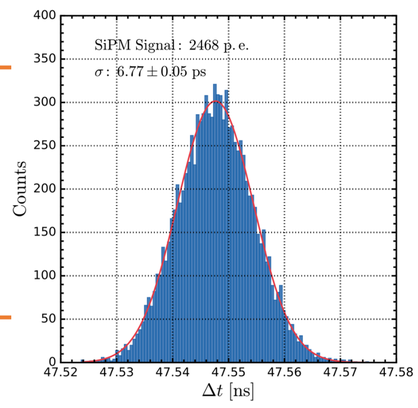




Timing methods:

- Constant Fraction Discriminator (CFD)
  - $V_{TH} = fraction \cdot V_A$
- Time of Arrival: timing measurement
  - $\Delta t = t_{Leading} - t_{Ref}$
    - t_{Ref}: time of laser synchronisation signal
    - Time resolution ($\boldsymbol{\sigma}$): sigma of Gaussian fit of Δt distribution with 10,000 waveforms
- Time-over-Threshold (ToT): energy measurements
  - $ToT = t_{Trailing} - t_{Leading}$

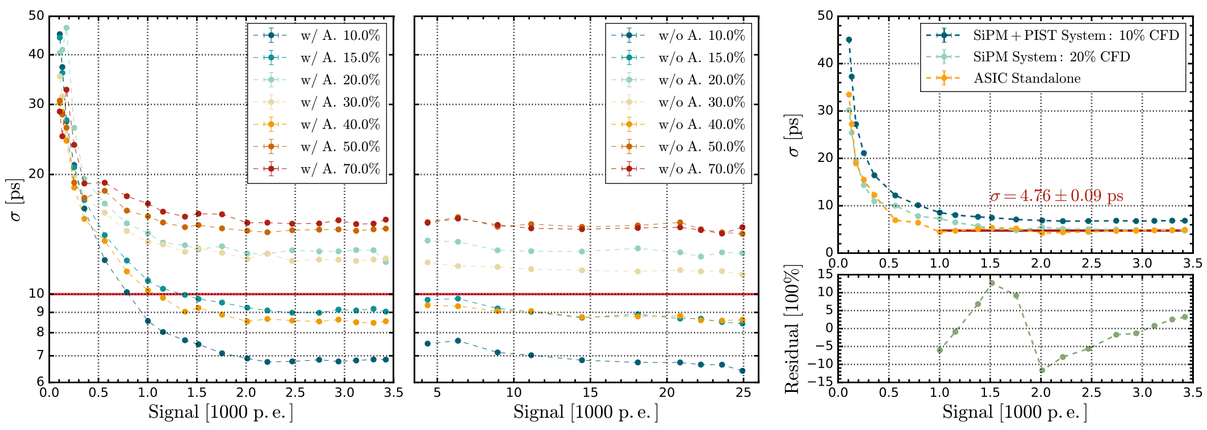




Experimental Results

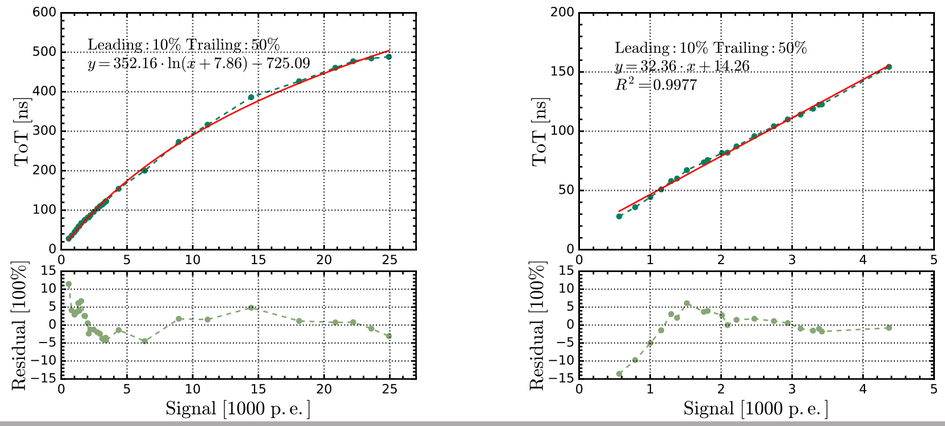
Timing performance (SiPM-PIST system):

- **10% CFD** turns out to be optimal for the timing performance
- Within the dynamic range from 100 p.e. to 25k p.e., σ < 50 ps, varies from **7 ps** (plateau) to **30 ps** (1 MIP = 200 p.e.)
- Decomposition analysis of time resolution contributions:
  - $\sigma_{SiPM+PIST} = \sigma_{SiPM} \oplus \sigma_{PIST} = (5.1 \oplus 4.8)$ ps



ToT performance:

- Follows a logarithmic function from 560 p.e. to 25000 p.e.
  - $ToT = 352.16 \cdot \ln(N_{p.e.} + 7.86) - 725.09$
- Follows a linear function from 560 p.e. to 4400 p.e.
  - $ToT = 32.36 \cdot N_{p.e.} + 14.26$



Conclusions

- Comprehensive studies have been performed to characterize fast timing performance of a SiPM-readout system with the PIST ASIC.
- Results show time resolution of SiPM-PIST system achieves 30 ps at MIP level and can achieve 7 ps with large enough SiPM signal.
- ToT response of the PIST ASIC can cover the SiPM response spanning from 560 p.e. to 25,000 p.e..

Reference and Publication

1. Lu, et al. Design and Characterization of a Picosecond Timing ASIC in 55-nm CMOS [J/OL]. IEEE Trans. Nucl. Sci., 2023, 70(6): 1230-1239. DOI: 10.1109/TNS.2023.3277522.
2. Xia, et al. Performance studies of a SiPM-readout system with a pico-second timing chip, Nucl. Instrum. Methods Phys. Res. A , 1064(2024), 169351, https://doi.org/10.1016/j.nima.2024.169351.