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A High-Precision Time Measurement Circuit for Pixel Detectors Using a Two-Stage Timing Scheme

Pixel detectors are widely used in high-energy physics experiments for their superior position resolution. In applications such as X-ray polarization detection and particle 3D trajectory imaging, precise time measurement is essential for event reconstruction and improving detection accuracy. These demands impose stringent requirements on the time measurement circuit, necessitating high precision, low power consumption, and compact integration in pixel detector chips.

This paper presents a two-stage time measurement architecture that combines coarse timing and fine timing to improve time measurement accuracy. Coarse timing provides a global clock reference through a 10 MHz counter, while fine timing employs a time-to-amplitude converter (TAC) to overcome the limitations of counter accuracy and achieve higher time resolution. The pixel array in the design consists of 128×128 pixels, with each pixel unit measuring 50 μm $\times$ 50 μm, integrating a low-noise charge-sensitive amplifier (CSA), a comparator, and a TAC. Through this architecture, the proposed solution achieves picosecond-level time resolution, effectively enhancing the time measurement accuracy of particle collision events.

Experimental results indicate that the CSA achieves a charge conversion gain of 82.5 μV/e$^-$, an input dynamic range of 0 to 16.7 ke$^-$, and a non-linearity error below 4.5%, with an equivalent noise charge (ENC) of approximately 35 e$^-$, ensuring excellent low-noise performance. Furthermore, the time measurement path achieves a time resolution of approximately 76.7 ps with an effective range of 100 ns, validating its capability for high-precision timing applications. This work provides a viable solution for applying the Topmetal chip to low-energy X-ray polarization time measurement, as well as other high-precision timing applications.

Workshop topics

Front-end electronics and readout

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