Design and Implementation of TCSA-based Readout System for STCF ECAL

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1. Introduction

Super Tau-Charm Facility (STCF) will provide a unique platform for the research of tau-charm physics and hadron physics, which is one of the important options for accelerator-based particle physics after Beijing Electron-Positron Collider (BEPC-II) in China. The conceptual layouts of the collider and its detector are shown in figure-1. The electromagnetic calorimeter (ECAL), as am important part of the spectrometer, in addition to the demands of high-efficiency and high-precision gamma detection, also needs good enough time performance for background suppression and gamma-hadron discrimination, etc. The detection unit of ECAL is mainly composed of one pure CsI crystal and four avalanche photodiode (APD) due to the high radiation dose and high background level.

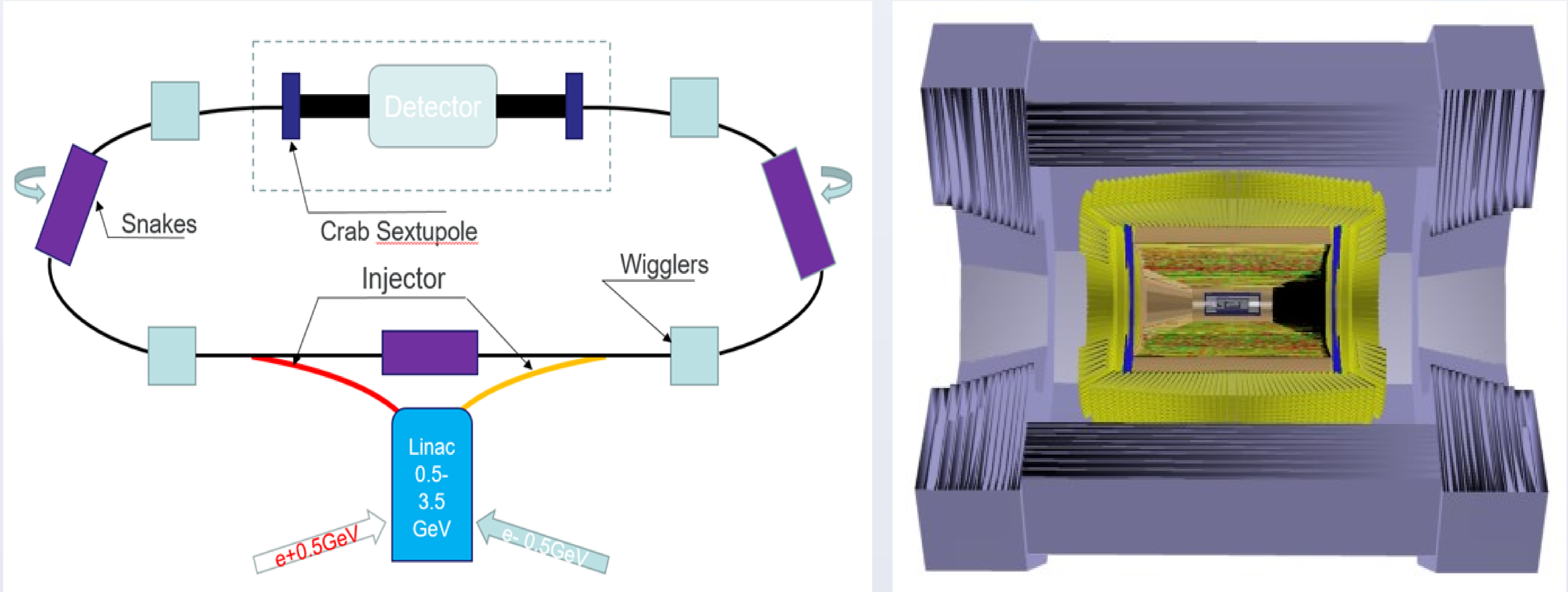


Figure-1. The conceptual layouts of STCF collider (left) and its detector (right).

In order to achieve the goal of precise energy measurement of photons and electrons for ECAL, a readout electronics, composed of time and charge sensitive amplifier (TCSA) with junction field effective transistor (JFET) input stage and CR-RC^2 shaper, is employed to realize a sufficient noise level. In time measurement, considering factors like system complexity, utilizing the integrated signal of TCSA for timing is a more efficient scheme. Therefore, this subject researches and compares two time measurement methods based on integral signals, which are leading edge timing and waveform fitting.

2. Design and performance of the readout system with leading-edge timing

The schematic layout of the electronics and PCB pictures for leading-edge timing are shown in figure-2. To avoid long-distance transmission of APD signals, a separate system, which consists of Front-End Board (FEB) and Back End Board (BEB), is proposed. On FEB, the current signal is integrated by TCSA with JFET input stage which can reduce the electronics noise induced by the large input capacitance. On BEB the amplified signal is discriminated by a fast comparator and the output step-like signal is sent to FPGA in which a Time-to-Digital converter (TDC) based on delay chain composed of 256 carry chain blocks is integrated. The digital data are pre-processed in FPGA and transmitted to the upper computer via Ethernet.

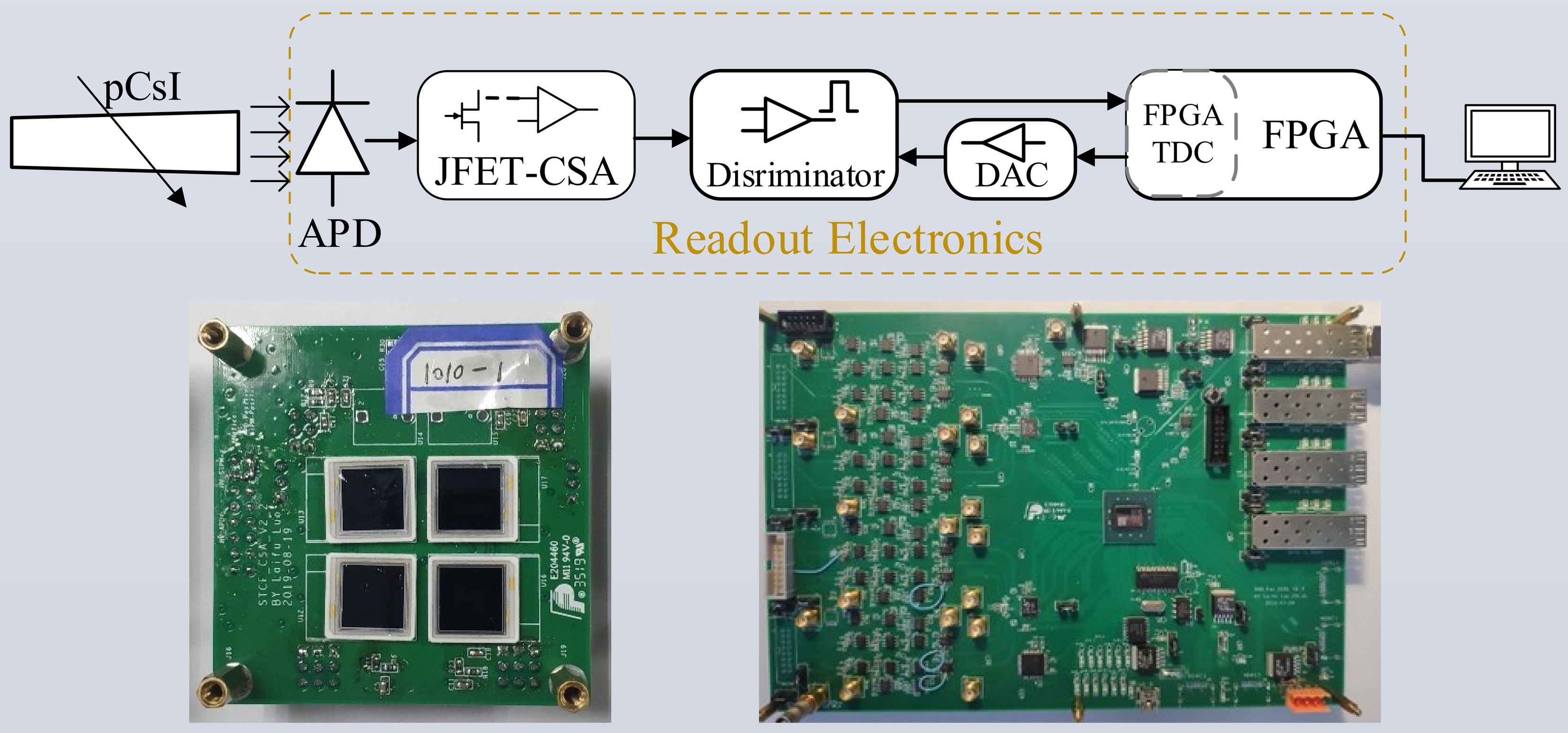
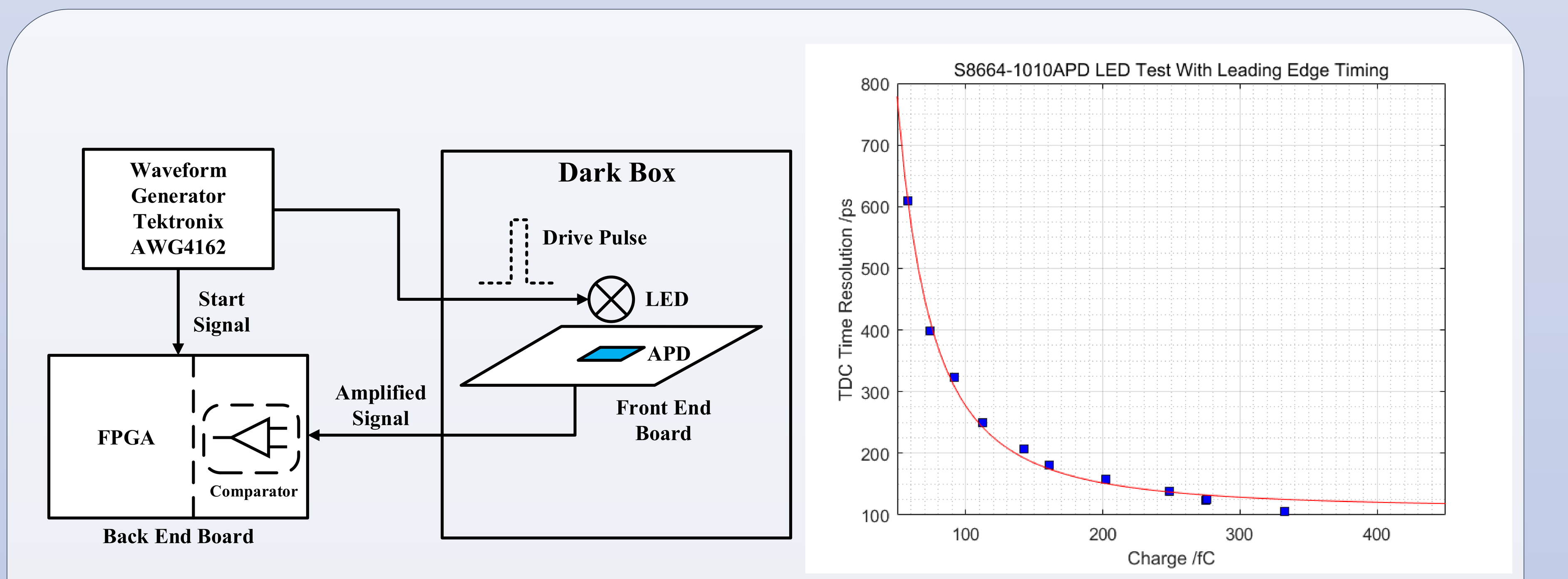


Figure-2. The schematic layout of the electronics (top) and PCB pictures (bottom) for leading-edge timing

On the basis of readout system, a LED experiment is conducted to verify the performance of the electronics utilizing leading edge timing. The block diagram of the experiment is shown in Figure-3(a). A blue LED is adopted to replace the pure CsI and driven by a pulse with a both rising and falling edge of 800 ps, a width of 10 ns and a frequency of 100 kHz generated by waveform generator AWG4162. The experiment results are shown in Figure-3(b). As can be seen in the correlation figure, the timing accuracy is inversely proportional to the amount of input charge. When the input charge is larger than 200 fC, the readout system can achieve a time resolution better than 150 ps.



(a) (b)

Figure-3. The block diagram (a) and the results (b) of LED experiment utilizing leading-edge timing.

3. Implementation and performance of the readout system with waveform fitting

The leading-edge timing has good performances in LED test, but it has serious shortcomings in high rate environment, that is, the time information of the accumulated signal is lost. Hence, a timing method based on waveform fitting is proposed and studied. The schematic diagram of the readout system for the time measurement of pure CsI crystal utilizing waveform fitting is shown in Figure-4.

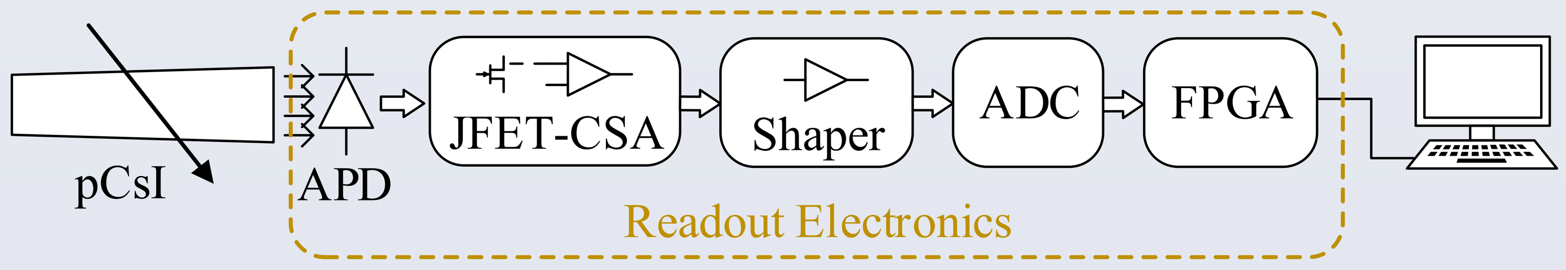


Figure-4 The schematic diagram of the readout system utilizing waveform fitting

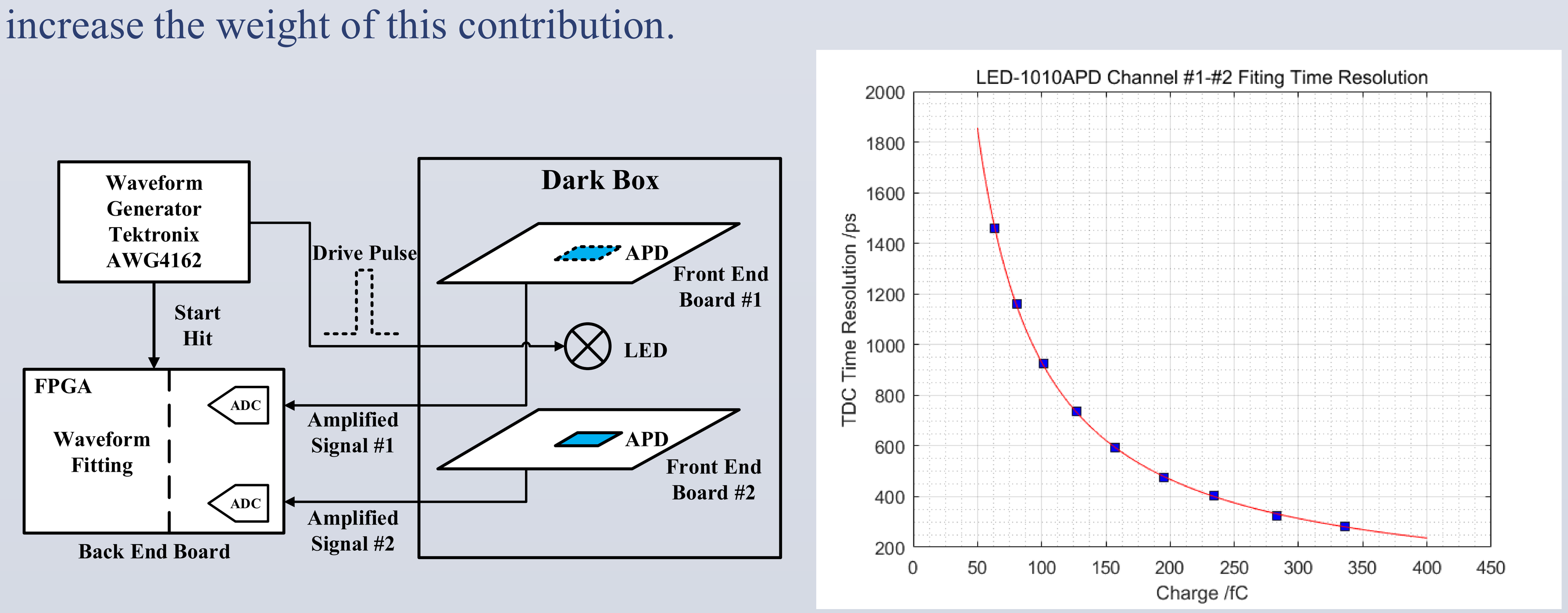
The waveform fitting algorithm is to calculate the minimum chi square in equation (3.1):

$$\chi^2 = \sum_{i,j} (y_i - A \cdot f(t_i - \tau) - p) \cdot S_{ij}^{-1} \cdot (y_j - A \cdot f(t_j - \tau) - p) \qquad (3.1)$$

Where $f(t)$ is the template shape function, A is the amplitude of the signal, τ is the signal arrival time with respect to template, p is the signal pedestal, y_i is the signal amplitude at t_i time point, $S_{ij} = \overline{(y_i - \overline{y_i})(y_j - \overline{y_j})}$ is the noise covariance matrix.

One LED experiment is also carried out for the readout system to verify the timing performance of waveform fitting. The block diagram and results are shown in Figure-5. As can be seen, when the equivalent input charge is larger than 200 fC, the electronic system can realize a time resolution better than 460 ps, which is worse than leading-edge timing.

In the time fluctuation of the waveform fitting, the main contribution comes from the noise of sampling points, and in particular, the noise covariance between sampling points will increase the weight of this contribution.



(a) (b)

Figure-5. The block diagram (a) and the results (b) of LED experiment utilizing waveform fitting.

4. Conclusion

A CSA-based electronics system is designed to readout the signal of pCsI crystal, which is the basic option of STCF ECAL. Two timing methods, leading edge timing and waveform fitting based on the readout system, are studied and tested. When the input charge is larger than 200 fC, a time resolution better than 150 ps and 460 ps is achieved in the two timing methods, in which the time fluctuation is mainly comes from noise influence.

5. Acknowledgement

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