Summed trigger analysis method for resistive dual-axis duo lateral position sensitive silicon detectors

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Recently, the telescope detectors of FAUST have been upgraded with position sensitive silicon detectors that measure the position of incident particles through resistive charge splitting [1-3]. The Dual-Axis Duo-Lateral detector (DADL) provides excellent angular resolution while reducing the number of electronics channels necessitated if using double sided strip silicon detectors of similar resolution. However, conventional electronics yield position and energy non-linearities. This work presents a new waveform analysis method that significantly reduces these distortions.

The DADL detectors are 300 µm thick silicon diodes fabricated by Micron Semiconductor, each with a 20 mm x 20 mm active area as shown in Fig. 1(a) [4]. Vertical position information is obtained by measuring charge obtained at the contacts F1 (bottom) and F2 (top). Horizontal position information is obtained by measuring charge obtained at the contacts B1 (left) and B2 (right). The detector is reverse biased by applying -40 V to the front p-type face (F1 and F2). Ionizing radiation excites electrons that are attracted to the back face of the detector and the holes are attracted to the front face of the detector. These charge carriers then split due to the resistivity of each face and are collected on the contacts. Conductive strips are embedded on each face of the detector to promote the spreading of charge for complete charge collection at each contact. The measured charge on each contact is used to calculate the local position coordinates $X = c_x * (Q_{Right} - Q_{Left})/(Q_{Right} + Q_{Left})$ and $Y = c_y * (Q_{Top} - Q_{Bottom})/(Q_{Top} + Q_{Bottom})$. The total charge collected on a single face is proportional to the energy deposited in the detector $E = E_F \propto Q_{Bottom} + Q_{Top}$.

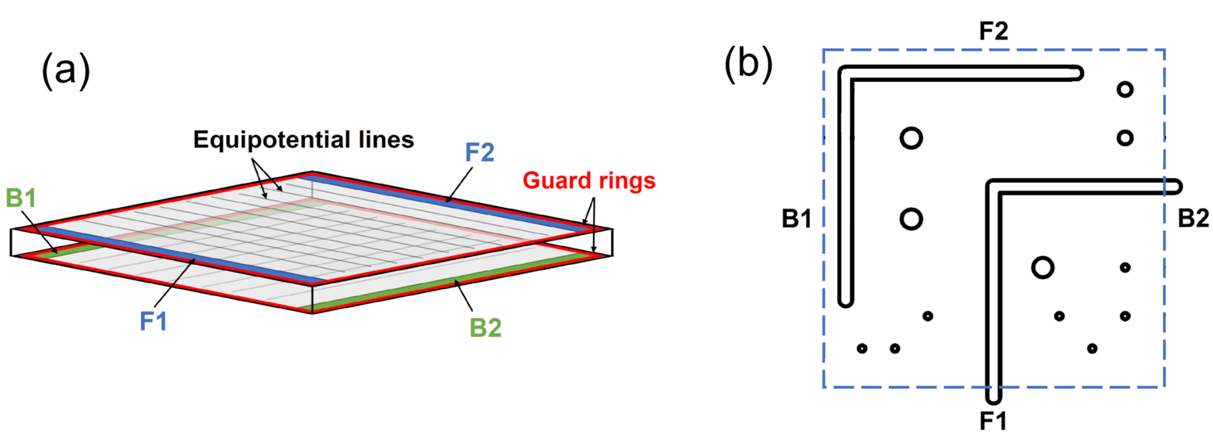

Fig. 1. (a) Schematic of a DADL detector. Charge is collected on the contacts F1 and F2 on the front face and B1 and B2 on the back face. The equipotential conductive lines help facilitate charge movement and the guard rings help to prevent charge bleeding. (b) Schematic of the brass mask with precision holes and slots. The dashed blue line marks the approximate position of the DADL detector behind the mask.

To test the performance characteristics of the DADL detector, a physical mask with precision slots and holes was constructed of 0.25-inch-thick brass whose dimensions are depicted in Fig. 1(b). This mask was placed 0.5 inches in front of the DADL detector to block incident radiation. A beam of 7.22 MeV/nucleon alpha particles was impinged on this detector configuration. The signals from the four contacts were sent to ZeptoSystems 45mV/MeV charge-sensitive preamplifiers and the resulting signals were digitized using a Struck SIS3316 waveform digitizer using 4 ns bins over 32 μs.

All waveforms from the four contacts from a single event are shown in Fig. 2(a). Waveform F1 clearly shows anomalous features, where it continues to rise over the entire range displayed. Additionally, the waveform does not have a fast-initial rise as expected, but instead dips below the baseline before rising as seen in Fig. 2(b). The inconsistent trigger timing that results from the range of observed waveform shapes ultimately leads to the distortions subsequently discussed. To approximate charge values like those obtained using conventional shaping electronics, each waveform was integrated for 0.25 us once the waveform reached a threshold of 300 channels above baseline as depicted in Fig. 2(c). This individual trigger analysis method gives position reconstruction that has severe pin-cushioning distortions as shown in Fig. 2(d). These distortions have been observed in previous experiments; however, the distortion is noticeably more severe in this work due to the short integration window and lack of shaping electronics [5].

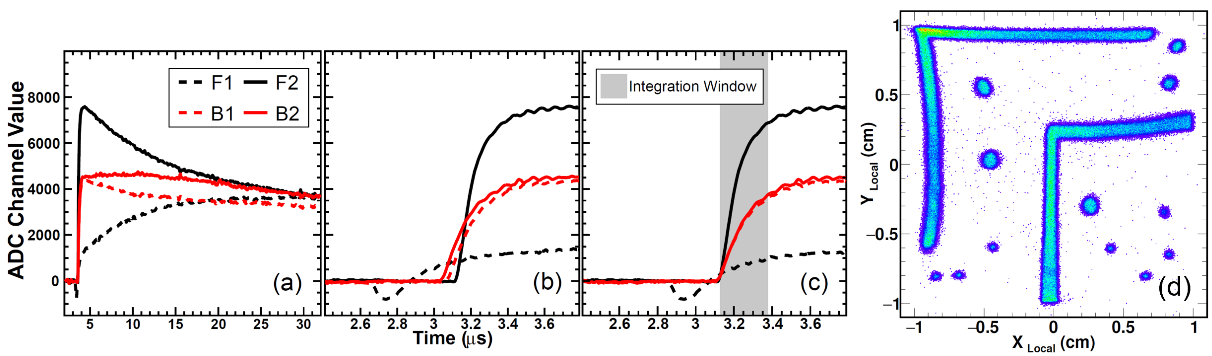

Fig. 2. Individual trigger analysis method. (a): Full 32 us length of baseline-corrected waveforms. (b): Same as (a) with time range to show initial rise. (c): Waveforms shifted so each reaches threshold at same time for demonstration purposes. Each waveform is integrated for 0.25 us (gray box). (d): Position plot using individual trigger method.

A new analysis method was developed that makes use of the fact that the distortions in the sum waveform of F1 + F2 (B1 + B2) are less severe than those seen in F1 and F2 (B1 and B2). To obtain the sum waveform, the individual waveforms needed to have the same absolute timing. The waveform digitizer records a time stamp of when each waveform is triggered. Each waveform was shifted in time by their respective differences in time stamps to that of F2 (arbitrarily chosen as reference) as shown in Fig. 3(b). The time-corrected waveforms for each face were then summed (F1+F2 and B1+B2), giving total energy signals as shown in Fig. 3(c). The integration start time for the individual waveforms (i.e. F1 and F2) was found by delaying the time that the respective summed waveform (i.e. F1+F2) reaches threshold by 0.6 us. The summed trigger analysis method yields considerable improvement in position reconstruction as seen in Fig. 3(d). Notice that the curvature and inconsistent strip widths seen using the individual trigger method are markedly improved.

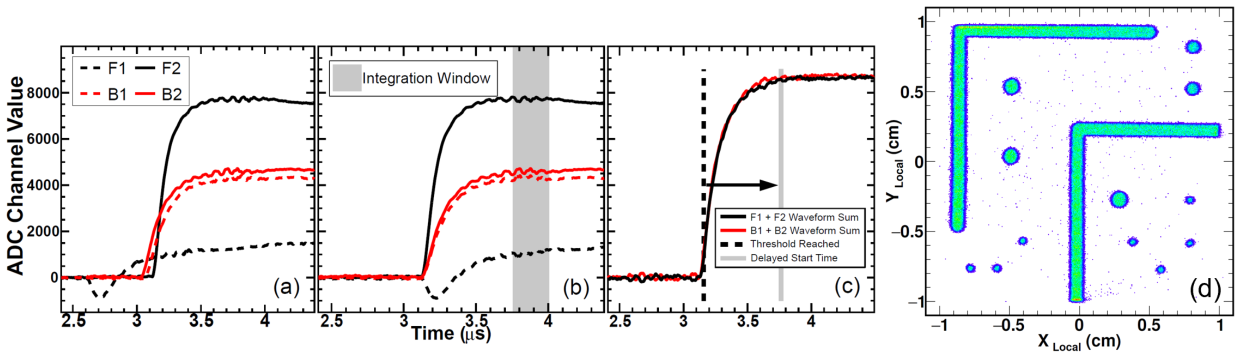

Fig. 3. Summed trigger analysis method. (a): Analogous to Fig. 2(b). (b): Waveforms have been shifted in time based on the 3316 digitizer time stamp relative to F2. (c): Sum of time shifted front (black) and back (red) waveforms. The time that the summed waveform reaches threshold (dashed line) is delayed by 0.6 us (gray line) and is used as the integration start time in panel (b). (d): Position plot using summed trigger method.

The improved linearity in position reconstruction using the summed trigger analysis method can be understood by a previous study that modelled DADL-type detectors [6]. In this work, it was found that there exist position dependent capacitively induced currents, which are the source of the inconsistent pulse shapes. As a result, there is an effective “settling time” that depends on the capacitance of the detector and the resistance relevant for any given position. By delaying the integration window past this settling time and measuring the charge for all contacts over the same time interval, these distortions are largely avoided.

[1] L.A. Heilborn, PhD thesis, Texas A&M University, 2018; http://hdl.handle.net/1969.1/174435.
[2] L.A. McIntosh *et al.,* Nucl. Instrum. Methods Phys. Res. **A** (Submitted).
[3] S.N. Soisson *et al.,* Nucl. Instrum. Methods Phys. Res., Sect. **A613**, 240 (2010).