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Obtaining exact time information of hits in silicon strip sensors read out by the APV25 front-end chip

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Abstract

Silicon strip detectors feature good spatial resolution thanks to the high granularity of the strips. However, they do not provide useful time information due to the long shaping time of the subsequent amplifier. In a system with many off-time background hits and high occupancy, such as the innermost layer of the BELLE Silicon Vertex Detector (SVD), this leads to many measured hit points which do not belong to the triggered event. The APV25 front-end chip was developed for the CMS Silicon Tracker and operates at 40 MHz with a shaping time of 50 ns. In CMS, a "deconvolution" is performed on the chip which narrows the sampled waveform down to one clock cycle, but requires synchronicity between beam and clock. Hence, it cannot be applied in BELLE because of its quasi-continuous beam. Nevertheless, we have developed a method to measure the peak time of the shaping curve with a precision of a few nanoseconds using the multi-peak mode of the APV25, where three (or 6,9,12,...) consecutive samples along the shaping curve are recorded with each trigger. We present details and variations of the method, results obtained in a beam test and the intended implementation of the time finding based on FPGAs.

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1. Introduction

Silicon strip detectors are typically used to measure particle tracks, since they provide good spatial resolution. Even though the actual detector signal has very precise timing, this information is lost when using amplifiers with long shaping time. However, preserving the time information can be essential for tracking in modern experiments with high particle density and frequency, such that detected hits which do not belong to the event of interest can be discarded. Thus, the measured data can be significantly reduced on-line, which is our ultimate goal.

The present Silicon Vertex Detector (SVD) [1] of the BELLE experiment at KEK is facing the limits imposed by the slow front-end amplifier, particularly the shaping time which causes an occupancy of about 10% in the innermost layer at the present luminosity of about 1.6×10^{34} $\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$.

2. The APV25 front-end chip

The APV25 [2] was developed for the CMS experiment at the LHC. It features a default shaping time of 50 ns (adjustable) and includes a 192-cell deep pipeline for each of the 128 channels, where sampled values of the shaper output are stored at the beam synchronous clock frequency of 40 MHz.

Moreover, a switched capacitor filter on the chip performs a "deconvolution" [3], which is the weighted sum of three consecutive samples. This results in a narrowed output pulse which is (ideally) just a single clock wide, and hence the originating bunch crossing of a hit can

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be unambiguously identified. This gain in time resolution is traded off against a higher noise figure.

The "deconvolution" method requires shaper output sampling (APV25 clock) which is synchronous to the bunch crossings, as it is the case at the LHC. In BELLE, however, with its quasi-continuous beam, this feature does not work. However, the APV25 also offers the functionality to read out three consecutive samples without processing. By repeatedly sending a trigger pulse in this "multi-peak" mode, one can read out up to 30 consecutive samples of the shaper output, spaced by the clock period of 25 ns.

3. Peak time determination

Peak time and amplitude can be obtained by applying a fit function to the sampled shaper output values. Fig. 1 shows a typical event with 12 samples, where two different fit functions were applied: the function

$$v_{\mathrm{out}} = A\frac{t}{T_p}\mathrm{e}^{-t/T_p} \tag{1}$$

denoted "Exp fit" is the output of an ideal CR-RC shaper with the shaping time T_p, but the actual output slightly deviates from this waveform, particularly in the rising edge and the tail. Hence, another fit was performed with the waveform obtained by internal calibration of the APV25, where the measured points were connected with cubic splines ("IntCal fit"), which yields better fit results.

4. Experimental results

In order to study the peak time finding, a silicon detector (striplet [4] design) with double-sided APV25 readout was tested in a beam. The APVs were operated at 40 MHz which was completely unrelated to the particle beam. Since the APV25 only accepts clock-synchronous triggers, a jitter of ±12.5 ns, corresponding to the width of one clock cycle, is introduced by the synchronization of the scintillator/photomultiplier trigger signal. In order to obtain a reference time, the distance between the unsynchronized trigger and the next clock edge was measured by a TDC.

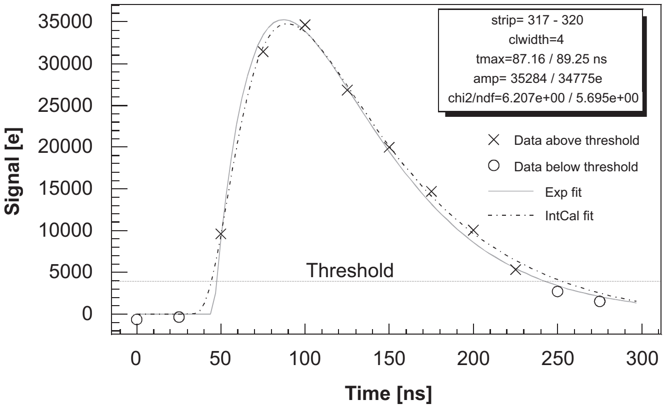

Fig. 1. Sampled shaper output values with two different fit functions applied. See text for details.

The distribution of the TDC measurement is entirely flat which confirms the independence of beam and clock. Fig. 2 shows the correlations between TDC measurement and fitted peak time (using the "IntCal fit") and the residual distributions (error) for both p- and n-sides. An RMS resolution of about 2 ns was obtained, including the uncertainty of the scintillator/photomultiplier which is estimated to be about 1 ns.

These measurements were performed with a cluster signal-to-noise of 25. Obviously, the precision of the time finding method strongly depends on that number. Simulation indicates that the RMS resolution is roughly doubled when the signal-to-noise ratio is reduced to 10.

5. Future implementation

Applying a fit function to each event is feasible for beam test analysis, but not applicable to real-time processing in an experiment with a large number of channels. Hence, we will replace the fitting algorithm by a look-up table which can be implemented in an FPGA. It has been shown that the timing information is essentially contained within three samples around the peak which reduces both readout and processing effort.

The amplitudes of the three samples around the peak will be combined to form the address of the look-up table (RAM array). Each memory cell contains peak time, amplitude and a quality value that specifies their reliability (similar to the χ^2 value of a fit). In parallel, the trigger timing is measured with a TDC. If that TDC value corresponds to the peak time from the look-up table, the hit belongs to the triggered event and can be passed on to the data acquisition (DAQ) system. If not, the hit is off-time background and could be discarded, although this feature will not be enabled in the beginning in order to study the efficiency of the system. Later, as luminosity and trigger rate will increase and the process is optimized, discarding such off-time hits is an efficient method to reduce the amount of data on-line.

No matter whether a numeric fit or a look-up table is used, the peak time measurement is not exact due to the noise, hence a certain tolerance is allowed depending on the quality value. In "strange" cases where no peak time can be found in the look-up table (e.g. a pile-up of two subsequent hits), the data are labelled accordingly and passed on for potential off-line processing. The internal calibration feature of the APV25 can be used to fill such a look-up table. Timing and amplitude are specified and sample triplets are measured.

The FADC processor module for an upgrade of the BELLE SVD is being developed. This board does not only digitize incoming APV data, but also performs pedestal subtraction, a two-pass common mode correction, and zero suppression (sparsification). Finally, the timing of hits will be determined by a look-up table as described above.

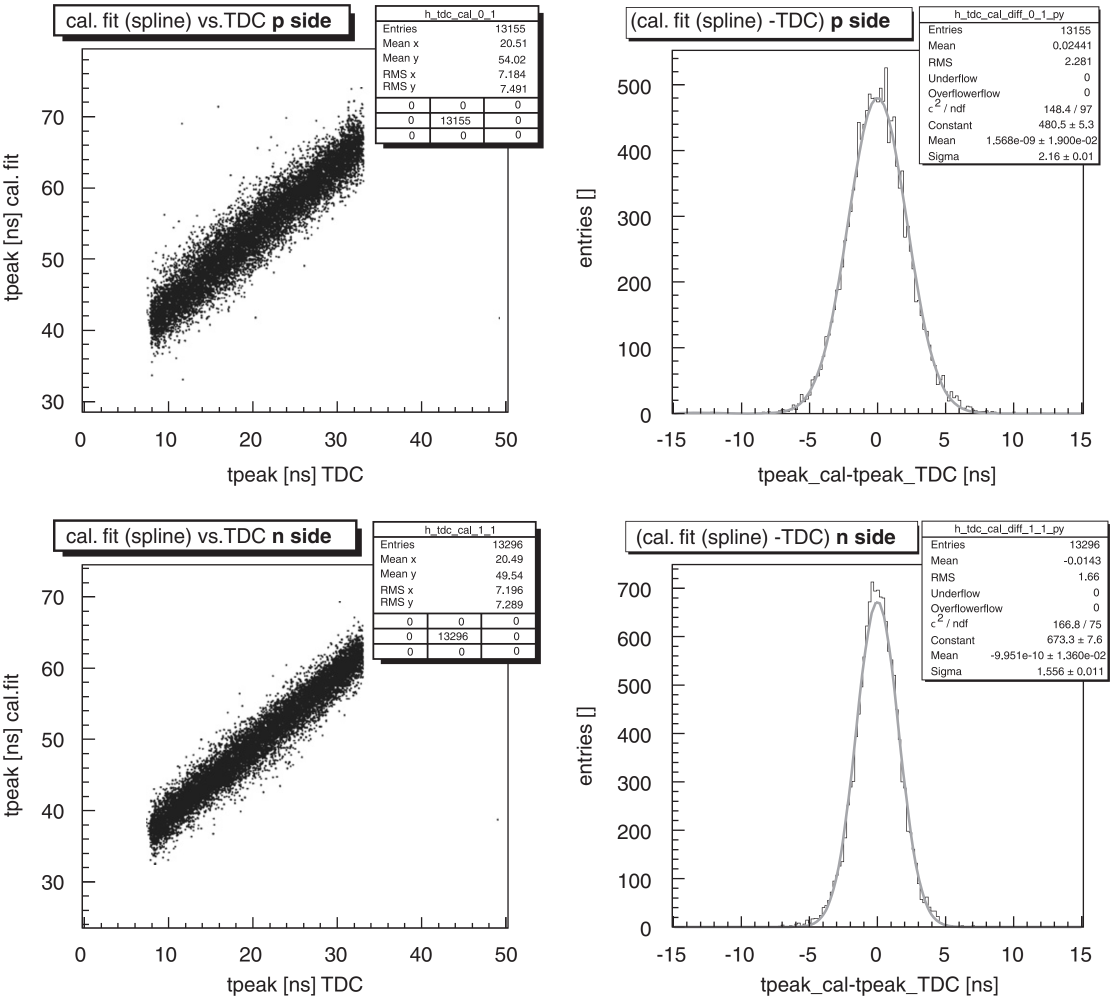

Fig. 2. Top row: p-side. Bottom row: n-side. Left column: correlation between TDC and fitted peak time (offsets are arbitrary). Right column: residual distribution (error) of the fitted peak time. See text for details.

Several variants of such a look-up table, all compatible with the FPGA used for processing, were evaluated by computer simulation and compared to the fit method. Only minor differences were observed between the implementations, and the deviation from the fit results was negligible compared to the required precision.

6. Summary

It has been shown that the APV25 front-end chip preserves the timing information of silicon detectors. Using the built-in "deconvolution" circuit, which is the default mode of operation for CMS at LHC, each particle signal can be assigned to a certain bunch crossing. Since this function cannot be used with a quasi-continuous beam, we developed an alternative method based on waveform reconstruction of the shaper output. In a beam test with a double-sided detector, an RMS accuracy of about 2 ns was obtained for the peak time finding w.r.t. a reference TDC measurement, using a numeric fit for each event. Moreover, it was also shown that a look-up table can be used instead of the fit function with similar results. This method will be implemented in FPGAs for an upgrade of the BELLE SVD, allowing a high trigger rate with significant on-line data reduction.

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