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A SIMULTANEOUS HIT FINDING AND TIMING METHOD FOR
PULSE SHAPE ANALYSIS OF DRIFT CHAMBER SIGNALS

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Abstract

An algorithm for the analysis of the digitized signal wave form of drift chamber pulses is described which yields a good multihit resolution and an accurate drift time determination with little processing time. The method has been tested and evaluated with measured pulse shapes from the Full Size Prototype of the OPAL Central Detector which were digitized by 100 MHz FADCs.

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1. Introduction

In large volume drift chambers the digitizing of pulse shapes has several advantages over simply recording drift time and charge: it provides at the same time a good energy determination and an accurate timing which is less sensitive to diffusion than conventional threshold electronics, and furthermore the details of the pulse shapes yield an excellent multihit resolution [1] . For these reasons a pulse shape digitization using 100 MHz Flash ADC's has been developed and will be used for the readout of the OPAL Central Detector Jet Chamber [2] . The experience with prototypes of the OPAL Central Detector Jet Chamber has shown that the accuracy of the time and charge determination matches the expectations. The waveform sampling generates on the other hand a vast amount of information from which the relevant quantities, the signal timings and charges, must be extracted as early as possible in the analysis chain in order to obtain a manageable data flow. The amount of processing time needed for an efficient double track resolution and an accurate drift time determination must therefore carefully be optimized. Recently a fast algorithm has been found which simultaneously provides an excellent hit finding mechanism and a timing accuracy superior to all methods applied so far.

2. Apparatus and test data sample

The algorithm is evaluated using data from the Full Size Prototype [3] of the OPAL Central Detector Jet Chamber [2] . The Full Size Prototype which is described in detail elsewhere [4] [5] contains two full size sectors out of the 24 for the final detector. A cross section of the Full Size Prototype is shown in fig. 1. Each sector has a single sense wire plane with 160 anode wires (gold-plated W-Re wires, diameter 25 μ) at 1 cm distance interspaced by

potential wires (Cu-Be wires, diameter 100 μ). All wires have a length of 4 m. The sectors are separated by cathode wire planes (also Cu-Be wires, diameter 100 μ) with a wire spacing of 3.3 mm. The maximum drift distance is 33.6 mm at the inner and 241.5 mm at the outer radius. The pulse shapes are recorded at both anode wire ends and digitized by FADC readout electronics [1] with a sampling frequency of 100 MHz. The analog-to-digital converters are based on monolithic 6-bit Flash-ADCs. To provide a better amplitude resolution and to expand the dynamic range of the converter, a non linear response curve is generated providing an effective range of 8 bit. Zero suppression is done by hardware in a fast search mode (FASTSCAN) after reading the data into memory [6] . The analysis is based on data taken at various angles and drift distances in the X5 test beam at the CERN SPS. The detector was operated at 4 bar with a gas mixture of 88.8 % Ar, 8.6 % CH₄ and 2.6 % isobutane. The drift field was 940 V/cm which corresponds to a drift velocity of 53 μ /ns.

3. Hit definition

Fig. 2a shows a typical pulse shape of a single hit, measured at one end of the signal wire. A similar pulse is recorded on the other wire end. For a single, well separated hit in the chamber the hit definition, time and charge measurement present no problem. The situation becomes however different for complex track patterns as they occur in jets. Here, hit finding techniques based on a search for local maxima can be quite time consuming.

Therefore a new algorithm was developed, based on the difference of amplitudes in neighbouring samples.

$$(1) \quad D_i = A_i - A_{i-1} \quad i=2, NS$$

where A_i is the amplitude in sample i after correction for the nonlinear response function, and NS is the total number of samples read out. This operation corresponds approximately to a differentiation of the original pulse shape (fig. 2b).

In order to test the algorithms with genuine multitrack events, a converter was introduced into the beam upstream of the detector. Fig. 3a shows typical pulse shapes at one wire of such a multitrack event. In fig. 3b the difference of samples calculated according to equ. (1) is displayed. A comparison with the original pulse shapes in fig. 3a shows that the large components of the difference correspond to the rising edges of the pulses. The hits can now be defined as a sequence of consecutive samples in the differentiated pulse above a certain threshold. The value of the threshold has to be optimised: a low threshold yields a better efficiency for single pulses with small amplitude and slow rise, a higher threshold is less sensitive to noise and it allows to recognize shoulders in the rising edge of the original pulse as double hits. The results below are obtained with a threshold of 4 counts, as indicated in fig. 3b. A further refinement of the method could be obtained by lowering this threshold and imposing some monotony criteria or by a double threshold technique. If the hit definition is applied to all 160 wires for the event corresponding to fig. 3, a track picture as shown in fig. 4 is obtained. Events with one clean track were used to determine the efficiency of hit detection. For these events the most probable maximum FADC amplitude is 17 ± 1 counts after correction for the nonlinear response function. The condition that both pulses at either wire end show a rise in amplitude of more than 4 counts discards 2.3 % of all pulses. For 4.5 % of all pulses a second hit is detected within a distance of 5 mm (100 ns). This number is a measure for the sensitivity of the algorithm to pedestal fluctuations and delta rays.

4. Drift time determination

Several methods were studied to extract the timing from the measured pulse shape. One method successfully applied to FADC data is the reference pulse timing which is described in detail elsewhere [1] [7] . Evaluated with data from the OPAL Full Size Prototype the single wire timing accuracy of this method ranges from $115\ \mu$ to $160\ \mu$ for drift distances of $2.5 - 16$ cm. Further refinements like smoothing the pulse by means of a principal component algorithm can improve the accuracy by about $15\ \mu$. In view of an on-line application faster methods have been sought. An algorithm looking for the time at which the charge of the pulse reaches a constant fraction of the total charge [8] was tested - the timing accuracy obtained for the same data as above was $110\ \mu$ to $150\ \mu$ over $2.5-16$ cm of drift. A weighted center of gravity evaluation using an optimized range of samples of the original pulse yields excellent results [7] which are only slightly worse than the accuracies obtained with the reference pulse method.

The identification and analysis of two closely spaced hits, using the algorithms described above, requires the unfolding of the two signals and is time consuming. The new approach of analysing the differentiated signal (fig. 3b) gives immediately a good hit definition also for close tracks. Furthermore it is found that the essential timing information is contained in a small region surrounding the peaks of the differentiated FADC pulse and can easily be extracted by a center of gravity calculation. The interval of evaluation and the weighting factors of the samples with respect to the peak sample have been optimised. The interval chosen was ± 2 samples around the peak sample of the differentiated pulse. Only consecutive samples above zero amplitude were taken into account. The samples used are indicated in fig. 2b by the cross shaded area . The timing accuracy is found to be insensitive (at the level of $0.1 - 0.2$ ns) to various weighting schemes for the center of

gravity evaluation. The weighting factors applied were: 2.0, 1.5, 1.0, 0.7, 0.5 (the weight 1.0 corresponds to the peak position). Using the weighting factors in reversed order reduces the accuracy by 0.2 - 0.3 ns. Fig. 5 displays the single wire timing accuracy obtained from triplets of adjacent wires as a function of drift distance. The data are taken from a run with the beam passing the detector at an angle of 5 degrees with respect to the anode plane. Over the drift distance covered (2.5-16 cm) the accuracies obtained range from 80 μ to 130 μ . The drift distance dependence of the timing accuracy is comparable with previous measurements using FADC electronics with other test chambers [7]. During the run shielded and non shielded twisted pair cables were used. The slight decrease in resolution between wire 49 and 96 coincides with the group of non shielded twisted pair cables which pick up more noise.

5. Two track resolution.

The two track resolving power can be tested by superimposing a random mixture of measured pulse shapes with known distances. Fig. 6 displays the efficiency curve for disentangling two superimposed pulses as function of separation distance. At 2 mm separation the efficiency is already 85 %, a 100 % efficiency is obtained at a separation of 5 mm. The influence of the track distance on the time determination can be studied by comparing the drift times t_{d1}, t_{d2} obtained for the superimposed hits to the drift times t_{s1}, t_{s2} of the single hits before superimposing (the index 1 or 2 refers to first and second hit, s and d denotes "single" and "double" hits respectively). The mean values of the time difference distributions $t_{d1} - t_{s1}$ and $t_{d2} - t_{s2}$ show a systematic shift caused by the timing algorithm, which can be corrected for in a final hit

analysis. The spread of the distribution has to be taken into account as additional contribution to the single hit timing accuracy. Due to the asymmetric pulse shape the influence of the first hit on the timing of the second hit is stronger than vice versa. In fig. 7 therefore only the effect of the first on the second hit as function of separation is shown. In fig. 7a the mean of the time difference for the second hit before and after the superposition is plotted, in fig. 7b the spread of this distribution. The bias value of 0.6 ns in fig. 7b (indicated by the dotted line) is an artefact, due to the fact that by the superposition technique not only the two pulses but also the noise contributions are added. This effect is absent for real multitrack events. Taking this into account, the influence of the first on the second pulse disappears for separations greater than 90 ns (about 5 mm). The time determination for the first hit is affected only if the second one is closer than 3 mm. Fig. 8 gives a qualitative example of the two track resolving power of the difference of samples method. The digitized pulses of the event shown in Fig. 4 are superimposed by themselves with a shift of 40 ns in time (corresponding to a separation of 2 mm in space). After this procedure the same tracks appear as in fig. 4 but nearly all hits (97%) are doubled. Original and differentiated pulse shapes at one wire for the superimposed event are given in fig. 9.

6. Interpretation of results

A timing algorithm has to extract the information which is contained in the distribution of arrival times of the primary electrons created within one cell. For the charge collection optics of the OPAL Central Detector Jet Chamber this distribution is asymmetric and peaked at short drift times [9]. An algorithm to be applied to long drift distances should be sensitive to the maximum of the arrival time distribution as its position is least influenced by diffusion.

Furthermore it should truncate the tails of the distribution which are due to long drift times to reduce the influence of cluster fluctuations. The difference of samples method fulfills these requirements: It uses the samples in the rising edge of the digitized chamber pulse and therefore includes the maximum of the arrival time distribution. Monte Carlo studies taking into account the time constants of the chamber and the amplifier response show that the strongest rise of the digitized chamber pulse is closely related to the maximum in the arrival time distribution. The application of weighting factors for the center of gravity evaluation within the differentiated pulse is a fine tuning which enhances the influence of electrons with short drift times.

The method is well suited for multiple hits as the drift time information is extracted only from the rising edge of the pulses and the difference of samples is small for the long tails of the pulses.

7. Summary

The difference of samples method when applied to data taken with the OPAL Jet Chamber Full Size Prototype, operated at 4 bar, yields a timing accuracy of $80\ \mu$ to $130\ \mu$ for a drift distance of 2.5 to 16 cm. The efficiency for double hit resolution is 85 % at 2 mm and reaches 100 % at 5 mm. The deterioration of the timing accuracy due to closely spaced hits is smaller than $50\ \mu$ at a separation of 2 mm, without the need to apply an elaborate subtraction scheme. As the method requires little processing time, the hit finding and final drift time determination can be done already on-line. The differentiated signal is not sufficient for charge determination but it provides the position of the signal and therefore the limits for the charge integration which then also can be performed on-line. The method may therefore have an impact on the data flow chart of big experiments.

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Figure captions

- Fig. 1: Cross section of the Full Size Prototype of the OPAL Central Detector Jet Chamber.
- Fig. 2: a) Typical single hit chamber pulse as digitized by the 100 MHz FADC.
b) Difference of consecutive samples of the pulse shown in a).
- Fig. 3: a) Digitized pulse shapes at one wire of the multitrack event of fig. 4.
b) Display of the difference of samples vector for the pulse shapes shown in a).
- Fig. 4: Hit display of a multitrack event. The inclined line at the upper left corner indicates the drift cell boundary.
- Fig. 5: Single wire timing accuracies obtained from wire triplets.
- Fig. 6: Efficiency of double pulse resolution
- Fig. 7: a) Systematic shift in time caused by a preceeding pulse as a function of separation
b) Additional contribution to the single wire accuracy caused by a preceeding pulse as a function of separation.
- Fig. 8: Hit display of the same multitrack event as in fig. 4. Before the hit definition procedure the pulse shapes of the event have been superimposed by themselves with a shift of 40 ns (2 mm in space)
- Fig. 9: a) Digitised pulses after superposition at one wire of the multitrack event shown in fig. 8.
b) Display of the difference of samples vector for the pulse shapes shown in a).

FIG. 1

FIG. 2

FIG. 3

FIG. 4

FIG. 5

FIG. 6

FIG. 7a

FIG. 7b

OPAL CD-FSP Run 132 Event 64736

FIG. 8

FIG. 9