Calculation of the difference in TOF of two particles hitting counters of FD

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1 Introduction

In this write-up we describe a method for calculation of the difference between arrival times of two particles hitting a pair of counters of the forward hodoscope. Knowledge of this difference is used, in particular, for investigation of the d-breakup reaction $pd \to ppn$: both for selection of proton pairs and the reconstruction of the reaction kinematics.

We considered the cases when two particles hit:

- two counters in the first hodoscope plane,
- one counter in the first plane, and two adjacent counters in the second [plane.

We do the following assumption: each meantimer TDC has linear T, N (here T is the difference of the times between stop and start signals,N is the code, generated by TDC) characteristics. Because different TDC's may have different values of one channel(in terms of time) we denote it by m_i, where i is the number of counter.

In the following consideration we neglect the distance between the first and the second planes, which can easily be taken into account in the actual data processing.

In fig. 1 we show the case when two particles with arrival times T_1 and T_4 hit counters 1 and 4 of the first plane and the same counter 3 of the second plane.

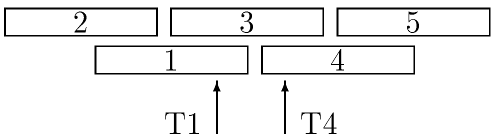

Рис. 1: Boxes mean counters, arrows are particles. T1,T4 are particles hit times.

2 Calculation of $T_1 - T_4$

Let us assume that two adjacent counters 1 and 4 in the first plane were fired with the hitting (astronomical) times T_1 and T_4 and the trigger signal was generated by counter 4. Then, our aim is to find the difference $T_1 - T_4$. (It is very easy to find out which counter generated the trigger, and we will not explain it here). For the $start_1$ and $stop_1$ signals of TDC1 we can write

$$start_1 = T_4 + (DT_4)_{tr}, \tag{1}$$

$$stop_1 = T_1 + (DT_1)_{sig}. \tag{2}$$

Here $(DT_4)_{tr}$ is a delay time, caused by the trigger channel of counter 4 and $(DT_1)_{sig}$ is a delay time, caused by the signal channel of counter 1.

Then,

$$stop_1 - start_1 = T_1 - T_4 + (DT_1)_{sig} - (DT_4)_{tr}. \tag{3}$$

TDC1 measures the difference $stop_1 - start_1$. Let us denote this difference by $D_1^4 \cdot m_1$, where m_1 means the value of one channel of TDC1, index 1 means TDC number and superindex 4 means, that the trigger was generated by counter 4.

Then previous equation can be rewritten :

$$D_1^4 \cdot m_1 = T_1 - T_4 + (DT_1)_{sig} - (DT_4)_{tr}, \tag{4}$$

and:

$$D_1^4 \cdot m_1 = T_1 - T_4 + (DT_1)_{sig} - (DT_1)_{tr} + (DT_1)_{tr} - (DT_4)_{tr} \tag{5}$$

Equation 5 was obtained from equation 4 by addition and subtraction $(DT_1)_{tr}$

Now let us consider one particle event, when particle hits counter 1 in the first plane and counter 3 in the second. Then the trigger channel of the counter 1 creates a trigger for whole FD system and TDC1 measures exactly the difference $(DT_1)_{sig} - (DT_1)_{tr}$.The code, generated by TDC1 in this case we denote as $(DT_1)_{sig} - (DT_1)_{tr} = N_1^1 \cdot m_1$. Here index and superinex are equal, because the same counter 1 produces both the start(trigger) and stop signals. As in a previous case m_1 is the value of of one channel of TDC1. Since now we will denote TDC codes of fired counters in one particle events by letter N.

If we substitute $N_1^1 \cdot m_1$ into the previous equation we obtain:

$$D_1^4 \cdot m_1 = T_1 - T_4 + N_1^1 \cdot m_1 + (DT_1)_{tr} - (DT_4)_{tr}. \tag{6}$$

We see that the final value to be found is $(DT_1)_{tr} - (DT_4)_{tr}$.

Again let us consider first a subset of events, when one particle hits counters 1 and 3. Then we can write:

$$stop_3 - start_1 = (DT_3)_{sig} - (DT_1)_{tr}. \tag{7}$$

In such a case, TDC3 measures exactly the value $stop_3 - start_1$ (As it was said above, we neglect particle propagation time from counter 1 to counter 3). Let us denote $stop_3 - start_1$ as $N_3^1 \cdot m_3$. We remind, that the low index denotes the number of TDC, the upper index is the trigger counter number. So we have:

$$N_3^1 \cdot m_3 = (DT_3)_{sig} - (DT_1)_{tr}. \tag{8}$$

This time let us consider a subset of events, when one particle hits counters 4 and 3. Then we can write:

$$stop_3 - start_4 = (DT_3)_{sig} - (DT_4)_{tr}. \tag{9}$$

In such a case TDC3 measures the value $stop_3 - start_4$, which we denote as $N_3^4 \cdot m_3$. Then,

$$N_3^4 \cdot m_3 = (DT_3)_{sig} - (DT_4)_{tr}. \tag{10}$$

After substracting equation 11 from equation 8 one gets

$$(N_3^1 - N_3^4) \cdot m_3 = (DT_4)_{tr} - (DT_1)_{tr} \tag{11}$$

Substituting in equation 6 instead of $(DT_1)_{tr} - (DT_4)_{tr}$ the value $(N_3^4 - N_3^1) \cdot m_3$, we obtain:

$$D_1^4 \cdot m_1 = T_1 - T_4 + N_1^1 \cdot m_1 + (N_3^4 - N_3^1) \cdot m_3. \tag{12}$$

Finally:

$$T_1 - T_4 = (D_1^4 - N_1^1) \cdot m_1 + (N_3^1 - N_3^4) \cdot m_3. \tag{13}$$

Let us remind the meaning of different values: $T_1 - T_4$ is the difference in TOF of particles hitting counters 4 and 1, when counter 4 is trigger counter. D_1^4 is the code, generated by TDC1, when the trigger counter is counter 4 (the more speedy particle hits counter 4 and the more slow particle hits counter 1).

N_1^1 is the code, generated by TDC1, when it itself is the trigger counter. N_3^1 is the code, generated by TDC3, when the trigger counter is counter 1 (i.e. one particle crosses counters 1 and 3 simultaneously).

N_3^4 is the code, generated by TDC3, when the trigger counter is counter 4 (i.e. one particle crosses counters 4 and 3 simultaneously).

3 Calculation of $T_1 - T_4$ in arbitrary case

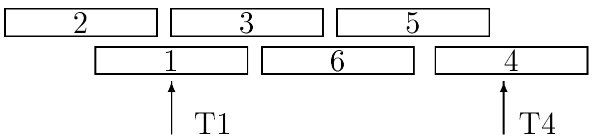

Рис. 2: A case when there is one counter between the two fired counters. The notations are as in Fig. 1

Now we consider a case when the two counters fired are not adjacent (see Fig.2).

Applying the arguments brought in the previous section, we obtain the following result:

$$T_1 - T_4 = (D_1^4 - N_1^1) \cdot m_1 + (N_3^1 - N_3^6) \cdot m_3 + (N_5^6 - N_5^4) \cdot m_5. \tag{14}$$

Here N_3^6, N_3^1 are the TDC3 codes, generated when one particle crosses at first, either counter 6 or counter 1, correspondingly, and then counter 3.

Analogously N_5^4, N_5^6 are the TDC5 codes, generated, when one particle crosses either counter 4 or counter 6, correspondingly, and then counter 5. m_5 means the value of one channel of TDC5.

It is easy to produce a suitable formulae for the case, when there are more than one counter between the two counters hit.

4 The case when two particles cross the same counter in the first plane and two adjacent counters in the second plane

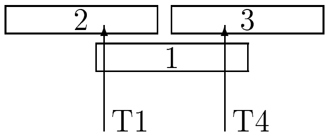

Рис. 3: The case when two particles cross forward counter 1 in the first plane and two adjacent counters in the second plane.

Now we consider the case when two particles cross counter 1 in the first plane of FD hodoscope and two adjacent ones (2 and 3) in the second plane. T1, T4 are particle hit times and T4 is the astronomical time of trigger. Then we can write

$$start_3 = T_4 + (DT_1)_{tr}, \tag{15}$$

$$stop_3 = T_4 + (DT_3)_{sig}. \tag{16}$$

And

$$stop_3 - start_3 = N_3^1 \cdot m3 = (DT_3)_{sig} - (DT_1)_{tr}. \tag{17}$$

In analogy $start_2 = T_4 + (DT_1)_{tr}$, $stop_2 = T_1 + (DT_2)_{sig}$,
$stop_2 - start_2 = D_2^1 \cdot m_2 = T_1 - T_4 + (DT_2)_{sig} - (DT_1)_{tr}$

$$D_2^1 \cdot m_2 = T_1 - T_4 + (DT_3)_{sig} - (DT_1)_{tr} + (DT_2)_{sig} - (DT_3)_{sig}. \tag{18}$$

In the latter equation $(DT_3)_{sig} - (DT_1)_{tr} = N_3^1 \cdot m_3$, so we should find the value $(DT_2)_{sig} - (DT_3)_{sig}$.

For this we again consider one-particle events, the cases, when a particle crosses counters 1 and 2. We can write down:

$$N_2^1 \cdot m_2 = (DT_2)_{sig} - (DT_1)_{tr} \tag{19}$$

In analogy, when the particle crosses counters 1 and 3.

$$N_3^1 \cdot m_3 = (DT_3)_{sig} - (DT_1)_{tr} \tag{20}$$

Subtracting equation 22 from equation 21, we find

$$(DT_2)_{sig} - (DT_3)_{sig} = N_2^1 \cdot m_2 - N_3^1 \cdot m_3. \tag{21}$$

After substituting equation 23 into 20 we come to the result

$$T_1 - T_4 = (D_2^1 - N_2^1) \cdot m_2. \tag{22}$$

It is important here that the trigger particle crossed counter 3.

5 Conclusion

It is shown how the difference of TOF of two particles, hitting:

- either two different counters in the first hodoscope plane
- or one counter in the first plane of FD hodiscope and two adjacent counters in the second hodoscope plane

can be found without using two-track events. The only thing to be made, are some calculations, involving one-particle events, number of which is abundant.

The assumptions, made above, can easily be taken into account by a suitable simulation. As it is demonstrated in section 3, the method can be extended for the case of an arbitrary pair of counters from the both hodoscope walls.