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Time-of-flight trigger with digital selection of events

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Abstract

The method of timing measurements and the realization of time-of-flight trigger with digital selection using a magnetic spectrometer are reported. The decision time of the time-of-flight trigger is 6 μs. A high rejection power of the trigger without losses confirms the effectiveness of the suggested method.

1. Introduction

Experiments on beams of relativistic nuclei at Dubna make it possible to investigate the structure of the lightest nuclei over a wide energy range from the nucleon–pion mode to possible manifestations of quark–gluon degrees of freedom.

The most difficult task in such experiments is to identify and to separate different kinds of particles.

Particle identification is achieved by measuring the times of flight and momenta of registered particles. The particle mass is determined from the equation:

$$M = p\sqrt{(tc/L)^2 - 1}\,, \qquad (1)$$

where M is the mass of the particle, p its momentum, t the time of flight of the particle at distance L, and c the speed of light.

Of particular interest is the possibility to discriminate against a specific type of particles (for example, protons or deuterons) at the trigger level in studying of processes having small cross sections in the presence of a high background rate. As an example of such a situation, Fig. 1 shows the time-of-flight spectrum of protons from dp backward elastic scattering at an angle of 180° and background inelastic deuterons of the same momentum. The ratio of deuterons to protons is of the order of 10^3, and therefore it is necessary to select protons at the trigger level for efficient data taking.

In this paper we describe the method of timing measurements and the realization of time-of-flight trigger with digital selection using the magnetic spectrometer "ALPHA" with a polarized deuteron beam at the Dubna synchrophasotron.

2. Timing measurements using the magnetic spectrometer "ALPHA"

To study deuteron–proton backward elastic scattering and deuteron breakup, it is necessary to provide both a reliable identification of protons and the possibility to discriminate against inelastic deuterons. A schematic view of the measurements is presented in Fig. 2. A slow extracted beam of deuterons with an intensity of $\cong 10^9$ particles per burst is incident on a hydrogen target T disposed in the focal plane F_3 of the beam line VP1. The momentum of deuterons varied from 3 to 6 GeV/c. The particles, produced by the interaction of the primary beam with the target T, are directed to the setup "ALPHA". Their angles and momenta are measured by the proportional chambers (PC) of the magnetic spectrometer "ALPHA".

The scintillator counters S_{t1}, S_{t2}, S_{t3}, S_{11}–S_{12} and S_{41}–S_{42} are used to measure the times of flight of particles. The counter S_{t3}, used as a start counter, is mounted at the setup "ALPHA" before an analyzing magnet, S_{t1}, S_{t2} and S_{11}–S_{12} in the focal plane F_4 of the beam line VP1 and the counter S_{41}–S_{42} after the proportional chambers of the spectrometer "ALPHA". The position of the counters at the focus F_4 allows one to minimize the influence of the material of the counters on beam parameters. The distance between S_{t2}, (S_{t1}) and S_{t3} is 42 m, between S_{11}–S_{12} and S_{41}–S_{42} about 50 m. The difference of the times of flight for deuterons and protons over a baseline of 42 m versus particle momentum is presented in Fig. 3a.

The Amperex XP2020 photomultipliers are used at one end of the scintillators of S_{t1}, S_{t2}, S_{t3} and at both ends of

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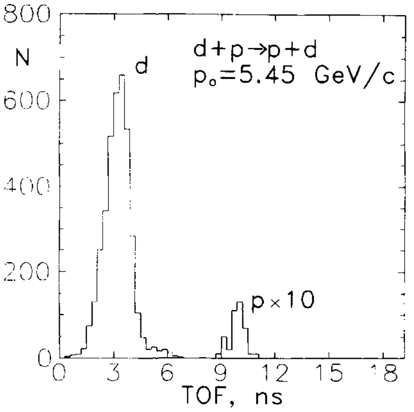

Fig. 1. Time-of-flight spectrum of protons from dp backward elastic scattering at 180° and background inelastic deuterons.

the S_{11}–S_{12} and S_{41}–S_{42} counters. The dimensions of the scintillators are $100 \times 100 \times 5$ mm^3 for S_{t3}, $150 \times 60 \times 5$ mm^3 for S_{t1} and S_{t2}, $60 \times 80 \times 10$ mm^3 for S_{11}–S_{12} and $600 \times 190 \times 20$ mm^3 for S_{41}–S_{42}.

The timing resolution of the TOF system is limited by [1,2]:

– fluctuations in the time of arrival of photons at the PMT due to the decay time of scintillator light (time dependence of hit intensity in the counter), dispersion of the path length of photons inside the scintillator, the conditions of light collection and so on,

– timing jitter of the photomultipliers,

– jitter of the spectrometer tracks and associated electronics.

$$\sigma_{TOF}^2 = \sigma_{sc}^2 + \sigma_{pm}^2 + \sigma_{el}^2, \qquad (2)$$

where σ_{sc} is the contribution of the scintillators to the jitter, σ_{pm} the timing jitter of the photomultipliers, σ_{el} the jitter of the electronics.

Achievements in improving the timing resolution of a scintillator counter are the design of scintillators with a low decay time, better light collection, viewing the scintillator by two or more PMTs, use of faster photomultipliers, time-walk corrections proportional to the total pulse height of a signal and so on. All of them make it possible to reach a time resolution of about 100 ps [3–6].

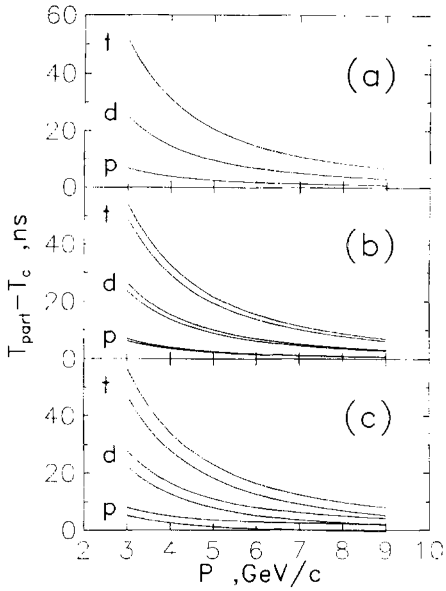

Fig. 3. Times of flight of protons, deuterons and tritons over a base line of 42 m versus their momenta: (a) theoretical curves; (b) taking into account the momentum acceptance of the magnetic spectrometer $\Delta p/p = 0.03$; (c) taking into account $\Delta p/p = 0.03$ and the internal resolution of the TOF system ($\sigma \cong 400$ ps).

In our case the internal resolution of the TOF system obtained from S_{t1} and S_{t2} information is $\cong 400$ ps (Fig. 4). The electronics timing jitter σ_{el} is $\cong 150$ ps, the jitter of the photomultipliers $\sigma_{pm} \cong 260 \div 300$ ps and the intrinsic resolution of the counters S_{t1}, S_{t2} and S_{t3} about $300 \div 350$ ps. The timing resolutions for S_{11}, S_{12}, S_{41} and S_{42} are the same.

The momentum spread of the beam also decreases the timing resolution of the TOF system. Taking into account the momentum acceptance of the magnetic spectrometer $\Delta p/p$, we select particles having the time of flight over the time interval:

$$\frac{\Delta t}{t_0} = -\left(\frac{1}{1+p^2/m^2}\right)\frac{\Delta p}{p_0}, \qquad (3)$$

(see Fig. 3b).

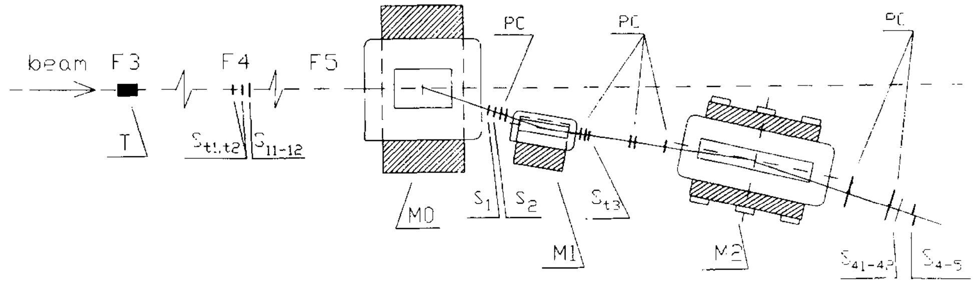

Fig. 2. Overview of the magnetic spectrometer "ALPHA". S_i – scintillator counters, PC – proportional chambers, M_i – magnetic elements.

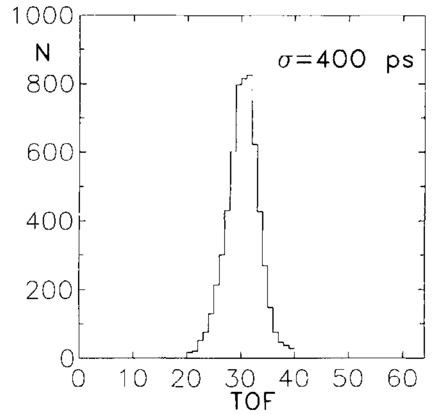

Fig. 4. Internal resolution of the time-of-flight system.

The curves describing the timing resolution of the TOF system for a baseline of 42 m, the momentum acceptance of the magnetic spectrometer $\Delta p/p = 0.03$ and an intrinsic resolution of $\cong 400$ ps versus the momentum of the registered particle are presented in Fig. 3c.

3. Electronics

Anode signals from the counters S_{t1}, S_{t2} and S_{t3} are split by a passive splitter. $\cong 0.7$ of the amplitudes are fed to the inputs of the constant fraction discriminators (CFD). The CFD output signal occurs independently of pulse height U_{in} and is created when the incoming pulse reaches αU_{in}, where $\alpha < 1$. Experience with time-of-flight systems shows that a better time resolution for the scintillator detectors is obtained providing $\alpha \cong 0.05 \div 0.2$ [7]. We use $\alpha = 0.2$. The CFD thresholds are $\cong 50$ mV. $\cong 0.15$ of the amplitudes go to the ADCs.

Anode signals from S_{11}–S_{12} and S_{41}–S_{42} are split by an asymmetric passive splitter, $\cong 0.7$ of the amplitude go to the timing discriminators and $\cong 0.15$ to the ADCs. The thresholds of the timing discriminators are $\cong 50$ mV.

Signals to the TDCs and ADCs are delayed by approximately $200 \div 250$ ns to allow time for the trigger logic decision to be made. The coincidence of the counters S_1, S_2, S_{t3} and $\Sigma_{i=4}^{5} S_i$ is used as a first level trigger.

The trigger jitter is $\cong 1$ ns. This allows one to establish the time-of-flight trigger neither by the analog method nor by using a coincidence circuit with short discrimination times [8] under the conditions of our measurements.

The choice of S_{t3} as a start counter decreases significantly the number of accidental starts of the system, because, firstly, the typical rates are 5×10^3 for S_{t3} and 5×10^5 for the counters placed at focus F_4 per burst (400 ms) and, secondly, S_{t3} is included in the logic of the first level trigger.

TDC information from stop-counter S_{t2} is used for the raw selection of protons against deuterons just at the trigger level. At an off-line data analysis, timing information from the S_{41}–S_{42} and S_{11}–S_{12} counters is used for the final discrimination of deuterons.

4. Realization of the time-of-flight trigger with digital selection of events

The idea of time-of-flight trigger is based on the use of a series of reference frequency signals of a time-to-digital converter (TDC). A schematic diagram of the time-of-flight trigger with digital selection and the timing diagrams explaining its operation are presented in Figs. 5 and 6, respectively.

The S_{t3} and S_{t2} signals of a $\cong 20$ ns duration shaped by the CFDs are passed through the coincidence circuits (SCC) strobed by a first level trigger signal (Gate1 and Gate2). The strobe duration is $\cong 60$ ns. It is determined by the time spread of stopping signals from deuterons and protons and by the duration of CDF output signals.

Event selection according to time of flight was made in two stages. At the first stage the mandatory presence of a signal S_{t2} is required. In the absence of this signal, "Clear1" is generated to clear information in the CAMAC crates and to reenable the data acquisition system. The decision time is $100 \div 150$ ns.

The type of particle is identified by the presence of a signal from the counter S_{t2}. For this purpose a series of reference signals with a frequency of 20 MHz taken from the TDC circuit is fed to the input of a frequency divider (DF) controlled either manually or by a CAMAC bus.

If the number of reference signals is larger than the set "N", the DF generates a signal which indicates that the time interval ($T_{stop} - T_{start}$) is longer than $N \times 0.125$ ns. In this case data-taking is initiated. When there is no DF signal, "Clear2" is generated to clear information in the

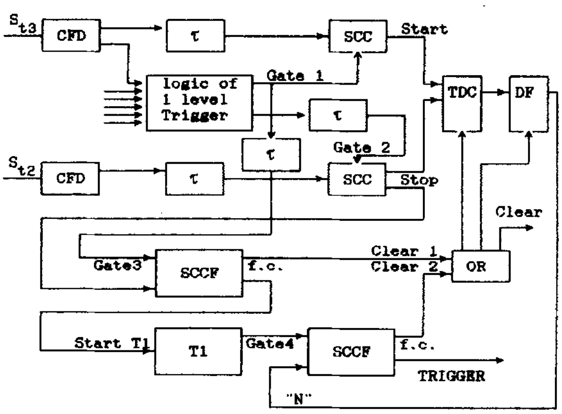

Fig. 5. Organization of the time-of-flight trigger with digital selection. CDF – constant fraction discriminators, SCC – strobed coincidence circuits, T_i – timers, TDC – time-to-digital converter, DF – frequency divider, τ – delays.

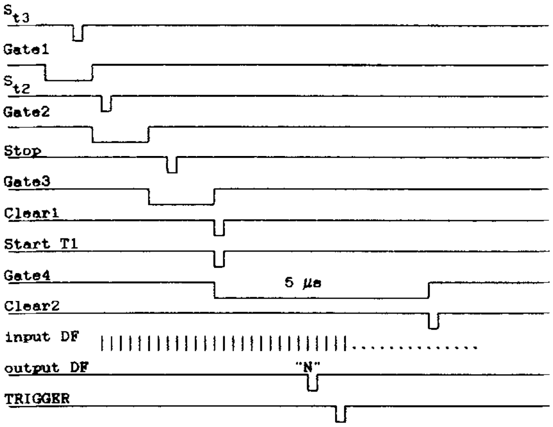

Fig. 6. Time diagram of time-of-flight trigger operation.

CAMAC crates and to reenable the data acquisition system. The total decision time of the trigger is $t_D \cong 6$ μs.

5. Results

If an additional element is introduced into the trigger logic, it brings a reduction in number of triggers from N_{off} to N_{on}. Following Ref. [9], one can define the reduction factor ρ as:

$$\rho = N_{off}/N_{on}, \tag{4}$$

The effect of applying the triggering system depends on its reduction factor ρ and decision time t_D, setup dead time t_R, and trigger rate N_T. The ratio of events recorded on tape with and without additional preselection by a factor of ρ is equal to:

$$R = \frac{1 + t_R N_T}{\rho + (t_D + t_R) N_T}. \tag{5}$$

The gain in the number of recorded "good" events with and without preselection is written as:

$$R_G = \frac{1 + t_R N_T}{1 + (t_D + t_R/\rho) N_T}. \tag{6}$$

In case of application of the two-step decision trigger, expressions (5)–(6) are more complicated in form. But in our case one can use expressions (5)–(6) for estimations since the decision time of the first stage $t_{D1} \cong 100 \div 150$ ns is much smaller, then the recording time $t_R \approx 1$ ms and the decision time of the second stage $t_{D2} \approx 6$ μs and the reduction factor $\rho_1 \approx 1.02$.

The ratios of recorded events R and recorded "good" events R_G with and without preselection are presented in Figs. 7a and 7b, respectively. One can see that using of the digital trigger brings the gain in the time of data taking by more than one order under typical conditions of our experiment.

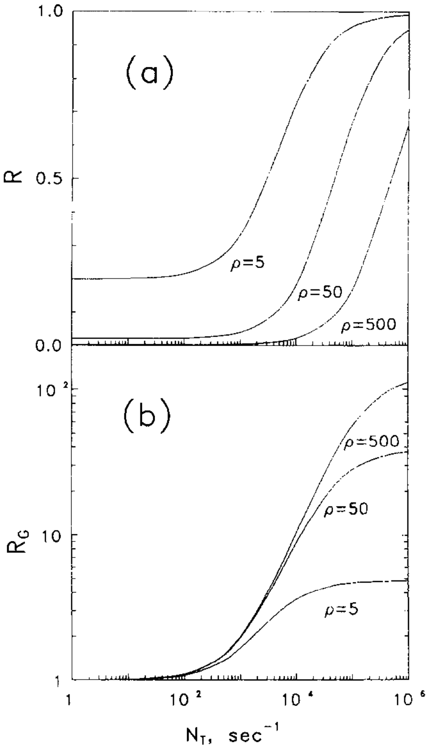

Fig. 7. Ratios of recorded events with and without preselection: (a) all events R; (b) "good" events R_G. The decision time of trigger is $t_D = 6$ μs, the recording time $t_R = 1$ ms.

The second question is the efficiency of the selection of "good" events ϵ_G and the efficiency of the rejection of "bad" events ϵ_B which show the quality of the triggering system.

The time-of-flight spectra (S_{t2}–S_{t3}) with time-of-flight selection is presented in Fig. 8. The ratio of background deuterons to protons is about 10^3. The used reduction factor of the time-of-flight trigger ρ is about 5×10^2. One

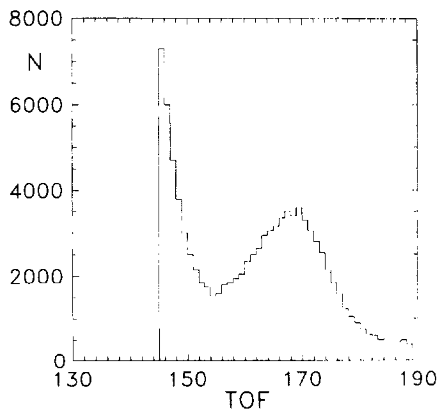

Fig. 8. Time-of-flight spectra of secondary particles with time-of-flight selection.

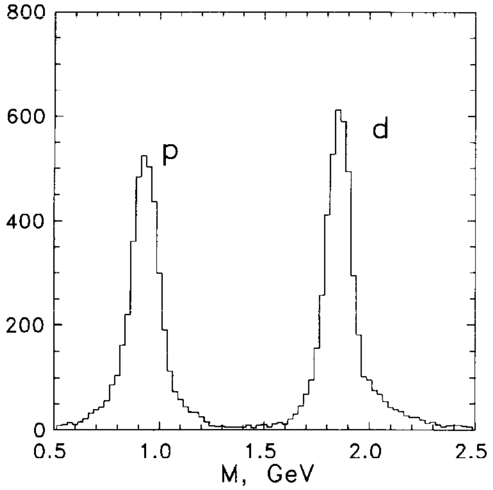

Fig. 9. Mass distribution of registered particles (deuterons are suppressed in part by the time-of-flight trigger).

can see, on the one hand, the efficiency of the selection of "good" events ϵ_G as a function of time of flight T is close to the ideal case, that means $\epsilon_G = 0$ at $T < T_{cut}$ and $\epsilon_G = 1$ at $T > T_{cut}$ and, on the other hand, the efficiency of the unwanted particle rejection ϵ_B equals 1.

For suppression accident events and the final selection of protons, we have used additional timing information from the S_{11}–S_{12} and S_{41}–S_{42} counters. The value of ΔT:

$$\Delta T = \tfrac{1}{2}((T_{41} + T_{42}) - (T_{11} + T_{12})), \quad (7)$$

where T_{41}, T_{42}, T_{11} and T_{12} are the "time-walk" corrected times of flight of particle over the base lines (S_{11}–S_{12})–S_{t3} and (S_{41}–S_{42})–S_{t3}, and information on the momentum of registered particle were used to reconstruct the particle mass M (Eq. (1)). The achieved mass separation is illustrated in Fig. 9.

6. Conclusions

The total suppression of unwanted particles, a high rejection power of the trigger without losses confirm the efficiency of the suggested method of time-of-flight trigger. Undoubtedly, advantages of the proposed method are also the possibility of computer control, the dialog regime included, and relative simplicity in tuning (in comparison with other methods of trigger realization) which are very essential in the analysis of rare processes.

To achieve the above method, standard electronics circuits made at the Laboratory of High Energies are used. A further development of the digital selection system is possible by decreasing the duration of CDF signals from 20 to 5 ns and the strobe duration from 60 to 30 ns, respectively, and by increasing the frequency of reference signals approximately by a factor of 10.

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