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APPLICATION OF WIRE CHAMBERS FOR TRIGGERING PURPOSES

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ABSTRACT

The application of triggering systems in high-energy physics experiments and the kind of criteria used in triggering systems with wire chambers are briefly discussed.

A few examples of applications are given, in particular: multiplicity, direction, coplanarity, small-angle scattering, and momentum triggers.

Triggering systems of dimuon and charmed particle production experiments performed at the CERN Super Proton Synchrotron are described.

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1. INTRODUCTION

At the present time a large high-energy physics experiment needs about 10^{-6} s to measure one event, 10^{-2} s to store it, and 1 s to analyse it^{*)}. The long recording-time comes from the fact that the apparatus for an experiment is big and complicated, and produces a lot of data. The long analysis-time is due to high multiplicities at high energies and to strong background accompanying low cross-section experiments.

The above times have serious consequences for experiments:

- the amount of events accumulated may be limited owing to long read-out time and high trigger rate;
- it may be impossible to analyse all the events recorded (as a year has only $\sim \pi \times 10^{10}$ s, only about the same number of complicated events can be analysed).

Both limitations reduce the number of good events, which can be very critical for an experiment that is searching for "a needle in a haystack".

There is a lot of effort being put into improving the situation: a fast data transfer system is in preparation [1]; long buffer memories and high-density tape units are in use; and new computers and more powerful computer networks are on the way [2].

In parallel, triggering systems used in experiments are much more elaborate in order to cope with high background and to extract interesting events efficiently^{**) [3, 4]}. Progress in this field is due to the development of detectors, the appearance of new "intelligent" electronics, and, last but not least, the harder thinking of experimental physicists. The reduction of the trigger rate is a criterion of the success of a low cross-section experiment.

2. DEFINITIONS AND GENERAL CONSIDERATIONS

The philosophy of "the trigger" has changed a lot during recent years, since in most cases experimental apparatus is d.c. operating and is equipped with its own local memories -- now much more complicated criteria can be applied and much

^{*)} The numbers are for fast ADCs and a large computer such as the IBM-370/168.

^{**) Meeting on Trigger Logic, CERN, Jan/Feb. 1980.}

more time can be spent on checking events. "The trigger" means mostly "a preselection" of the data before writing them on tape. We can speak about three trigger levels [4]:

- the first one, which checks the simple correlations between the counters using NIM logic;
- the second one, applying more complicated criteria for arrays of counters (logic matrices);
- the third one, where some physical variables are calculated with the help of processors.

Let us specify a few parameters which define a triggering system: If an additional element is introduced into the trigger logic, it brings a reduction in the number of triggers from $N_{T \text{ off}}$ to $N_{T \text{ on}}$. Assuming no dead-time effect, we can define the reduction factor ρ :

$$\rho = \frac{N_{T \text{ off}}}{N_{T \text{ on}}}.$$

In reality, the effect of the application of such an element depends on its reduction factor ρ and decision time t_D , recording (dead)-time t_R , and trigger rate N_T . The fractional reduction of the recorded number of events, important to any kind of experiment dealing with their large volume, is equal (fig. 1a):

$$\frac{R_{\text{on}}}{R_{\text{off}}} = \frac{1 + t_R N_T}{\rho + (t_D + t_R) N_T}$$

(R_{on} , R_{off} are the number of events recorded with and without additional preselection by a factor of ρ).

This effect diminishes at high trigger rate, but at the same time the gain in the number of recorded good events (gain in the sensitivity) is more pronounced (fig. 1b):

$$\frac{R_{G \text{ on}}}{R_{G \text{ off}}} = \frac{1 + t_R N_T}{1 + (t_D + t_R / \rho) N_T}$$

($R_{G\text{ on}}$, $R_{G\text{ off}}$ are the number of recorded good events with and without additional preselection).

The gain is greater if the reduction factor ρ is larger and the decision time t_D short with respect to the read-out time t_R -- in such cases $R_{G\text{ on}}/R_{G\text{ off}} \rightarrow \rho$ (see also ref. 3).

Triggering systems can bring a lot of profit to the experiment but also can be very harmful for the data. The big question which always arises when a new triggering system is applied is that of its efficiency. This may have two meanings:

- i) the efficiency of the rejection of bad events ϵ_B , which shows the quality of the triggering system;
- ii) the efficiency of the selection of good events ϵ_G , which shows the influence of the triggering system on the measurements and thus is extremely important.

The convenient way of presenting these two parameters is to make a plot which shows the selection efficiency of events as a function of the selection parameter (e.g. multiplicity, scattering angle, mass, etc.); the typical picture is presented in fig. 2.

In a complicated experiment it is not easy to predict in detail the parameters of an applied triggering system. The answer can be partly given by the Monte Carlo study, but the final answer can be given only by the real data. The crucial number, i.e. the efficiency of selection of good events ϵ_G , must be known and well under control. There seems to be only one way of checking this efficiently: to run the experiment without a special triggering system in the trigger, but store its decision flag and analyse the data quickly. Some monitoring numbers, test triggers, and on-line analysis can help in checking its performance and the stability of parameters.

3. WIRE CHAMBERS FOR TRIGGERING PURPOSES

Already in the early days of wire chambers, their use for triggering purposes was foreseen [5]. Easy construction, a variety of shapes, low density, d.c.

operation, high efficiency, good spatial and time resolution, moderate prices -- all these are the features in favour of such use.

But, in addition to the standard construction, some special chambers have been developed and some special systems with wire chambers have been built for triggering.

3.1 Criteria for event selection

Using the wire chambers for triggering purposes, three basic criteria can be specified which can be applied in an experiment to select the required type of events:

- time correlations
- topology
- momentum (mass) calculations.

The first is commonly used to select particles which belong to one event. But as will be shown later, delayed coincidences can also be used for choosing tracks passing at a certain angle.

The topology can be subdivided into five classes of triggers (fig. 3):

- multiplicity: a certain number of hits and/or "tracks";
- directional: trajectories coming from a defined point or line;
- scattering (deflection): trajectories bent by some angle at a known point;
- opening angle: a certain angle between trajectories coming from the same point;
- coplanarity: the interaction point and trajectories lying in the same plane.

The most effective way of selecting events is to calculate variables such as momentum, transfer momentum, and invariant or missing mass, and to trigger the apparatus if they are within the range required. The systems able to do this, although rather complicated, are coming more and more into use.

3.2 Application in experiments

Although the use of wire chambers for triggering has not yet been fully explored, there have been a large number of achievements. Special systems with wire chambers have been used, not only in accelerator physics but also in cosmic-ray

experiments [6]; these systems trigger spark, streamer, and bubble chambers [7] and select the information from the other d.c. operating wire chambers; they have expanded from those with around one hundred wires [8] to the ones with more than ten thousand [9]. Large and sophisticated systems are in preparation.

In such a situation, it is not easy to choose examples; those selected represent experiments which have already been run, are running at present, or for which the preparation is well advanced. They also represent different types of triggers and, if possible, different techniques. Because they are more familiar to the author, most of the examples come from CERN (amongst them is the experiment in which the author is actually taking part [9]).

3.3 Multiplicity trigger

One of the simplest trigger conditions is to select the number of secondary particles ("tracks") after the target. Owing to its simplicity and because of the good spatial and time resolution of the chambers, the multiwire proportional chamber (MWPC) multiplicity trigger is in common use [8,10-16].

A typical system consists of MWPCs, shapers which provide standard current pulses from the wire hit, analog adders, and a discriminator to select required multiplicities. In some cases, the electronics also includes the possibility of suppressing adjacent hits. Analog electronics can safely resolve the multiplicities below (or around) ten -- the decision time is usually of the order of a few hundred nanoseconds.

A more elaborate solution is the digital one, which has better stability and better resolving power -- in this case the adders sum the number of hits.

A fast multiplicity decision can also be taken using the information from drift chambers.

In experiment R807 at the CERN Intersecting Storage Rings (ISR), analog electronics placed in front of a drift-time recording system (DTR) [17] will provide information about the number of wires hit in one sector of the cylindrical drift chamber. This information can be used to require a certain minimum number of hits

per sector for further selection of high p_T events, or to reject events with high multiplicity in the full volume of the detector [18].

In the NA11 experiment at the CERN Super Proton Synchrotron (SPS) [10], a system of electronics which will find the number of hits per plane has been tested. The signals from drift chamber discriminators were "spied" in front of a DTR system [17], shaped into pulses 5 ns wide, OR'ed in groups corresponding to a few wires, counted during the drift chamber sensitivity time (400 ns), and finally added. The information about multiplicity can be used to suppress some kinds of unwanted triggers (e.g. too many hits).

3.4 Directional trigger

The selection of particles coming from a defined interaction point presents much more powerful criteria for the rejection of unwanted events than does the simple counting of multiplicities. With wire chambers, this is usually done by requiring coincidences between specified chambers, cathode strips, a group of wires or even individual wires -- such coincidence matrices are used by many experimental teams [19-26].

The geometry of the chambers plays an important role and can be adapted to the topology of events. Alignment of the wires along the radial line crossing the interaction point is very common for cylindrical geometry; such an approach was also applied by the Nevis-Fermilab Group for planar chambers [22].

There is great flexibility in the geometry for wire chambers with cathodes made out of foils, as these can be printed in patterns of almost arbitrary shapes [23, 24]. The status of the art in this field is represented by the chambers of the CERN-Collège de France-Orsay-Palaiseau (Ecole Poly.)-Saclay Collaboration; the cathodes of these chambers (the use of which will be described later) consist of about 1300 elements each, pointing to the beam line and the target [25].

The direction of the tracks can be defined very precisely by timing the signals from drift chambers. The angular resolution of the Nevis-Fermilab set-up already mentioned was ~ 1 mrad over 12 cm distance; by delaying the signals, the

required angle can be chosen (the selection of the tracks can be done at the rate of 2×10^6 per wire) [22].

It is planned to use a system of high-pressure drift chambers for triggering the Time Projection Chamber (TCP) at PEP. By tight coincidences between the signals from corresponding wires of different cylinders, the event origin can be limited to within 1 cm of the beam line [26].

The TPC group also plans to use delayed coincidences between the dE/dx wire sectors of the end caps of the TPC in order to select events coming from the intersection point (within 30 cm). The coincidences must be performed in sequence from the outer to the inner radius, and within a certain time limit [27].

3.5 Small-angle scattering trigger

Small-angle elastic scattering presents the greatest interest in the region of the interference with Coulomb scattering, which at high energies corresponds to an angle ranging from a fraction of a milliradian to a few milliradians. The difficulty is to distinguish the scattered particles from the beam, which often has a divergence of the same order.

The selective triggering system with proportional wire chambers, developed by the Dubna Group for a small-angle scattering experiment, was probably one of the first that used MWPCs for triggering [8]. The system was based on an early idea of applying a special processor for calculating scattering angles from the coordinates of traversing particles; the set-up is shown schematically in fig. 4 [28].

The scattering angle in the X projection is given by the expression:

$$\theta_{SX} = AX_1 + BX_2 + CX_3 + D ,$$

where

$$A = \frac{1}{L_2} , \quad B = - \frac{L_1 + L_2}{L_1 L_2} , \quad C = \frac{1}{L_1}$$

$$D = \frac{(X_{30} - X_{20})L_2}{L_1 L_2} + \frac{(X_{10} - X_{20})L_1}{L_1 L_2} ;$$

$L_1, L_2, X_{10}, X_{20}, X_{30}$ are the geometrical constants according to fig. 4; X_1, X_2, X_3 are the coordinates of the particles.

The scattering angle in the Y projection θ_{SY} can be calculated in a similar fashion, and finally the scattering angle in space is equal to

$$\theta_S = \sqrt{\theta_{SX}^2 + \theta_{SY}^2}.$$

The formulae for calculating the scattering angle in one projection can be simple (coefficients are simple integers) if the geometry and wire spacing of the chambers are chosen correctly. Also, for selecting scattered particles the simplified criteria can be used:

$$\theta_{SX} \geq \theta_{\min} \quad \text{or} \quad \theta_{SY} \geq \theta_{\min},$$

selecting a square in space;

additionally:

$$\theta_{SX} + \theta_{SY} \geq \theta_{\min},$$

which defines the octagonal shape.

To solve the above equations, many processors, both analog and digital, were developed [29-36] and many experiments were successfully performed [37-40]. The decision time of the triggering systems was of the order of a few hundred nanoseconds, the attenuation of beam particles ~ 100 , the reduction in trigger rate 10-20, and the efficiency for scattering particles close to 1.

3.6 Coplanarity and opening angle

In the cylindrical chambers of PLUTO the coplanar events were selected with the aid of parallel-sequential logic [19]. For this purpose the Omega group at CERN used planar wire chambers with cathodes printed in ϕ strips [24].

To discriminate events with minimum separation between two tracks downstream of the target, the Notre Dame Group (experiment E456 at FNAL) used a very simple analog circuit [16].

A much more sophisticated system was developed at CERN for a large-angle scattering experiment (WA7) [41] to select events coplanar with the incident beam used and/or with the defined opening angle. This experiment used a large system of proportional chambers ($\sim 20,000$ wires), some of which were used in the trigger; fig. 5 shows the simplified layout. The data from the chambers were transferred to a special hard-wired processor [42] (in fact, three different processors) through a high-speed, non-destructive read-out system [43]. The processors checked the incoming data (the events with too many or too few hits were eliminated), calculated the space points of the hits in the chambers and compared them with the roads given by the hodoscopes, and finally checked the coplanarity and the opening angle. The following criteria were used:

$$|\text{COP}| \leq \epsilon_{\text{COP}} \quad \text{and/or} \quad |\text{OPA}| \leq \epsilon_{\text{OPA}} ,$$

where

$$\text{COP} = \Delta X_L \Delta Y_R - \Delta Y_L \Delta X_R + k_{\text{COP}} (\Delta Y_L - \Delta X_R) + K_{\text{COP}}$$

$$\text{OPA} = \Delta X_L \Delta X_R + \Delta Y_L \Delta Y_R + K_{\text{OPA}} ,$$

and

$\Delta X_L, \Delta X_R, \Delta Y_L, \Delta Y_R$ are the differences of the X and Y coordinates of the "left" and "right" particles measured in the different blocks of chambers (fig. 5);

$K_{\text{COP}}, k_{\text{COP}}, K_{\text{OPA}}$ are constants depending on the beam polarity.

For the two clean tracks the decision time was about 20 μs , but in the experiment it was of the order of 200 μs , which was a small fraction of the full read-out time (~ 2 ms) [44].

A more detailed discussion of the performances of this system is given in another paper [45].

3.7 Momentum (mass) trigger

This kind of trigger is being used more and more frequently and large systems of wire chambers and complicated electronics have been built for this purpose. In experiments with fixed targets, the momenta (transfer) of forward and recoil particles are measured [6, 9, 20, 26, 46-49] and the invariant missing mass can be

calculated [25, 47-49]; in colliding-beam experiments, usually a cut on transverse momentum is applied [18, 19, 21, 50].

As an example, a momentum trigger of the CERN-Neuchatel-Palaiseau (Ecole Poly.)-Paris (Collège de France) Collaboration, used in a baryonium study experiment at CERN, is presented [48, 51]. Figure 6 shows the layout of the apparatus. A system of MWPCs and MBNIM logic is used to select the protons in the range 12-18 GeV/c. Čerenkov counters identify p and π , and scintillation hodoscopes preselect the roads for the processor.

The momentum is calculated from three points on the trajectory according to the formula:

$$\frac{1}{p} = \alpha Y_1 + \beta Y_2 + \gamma Y_3 + \delta ,$$

where

Y_1, Y_2, Y_3 are coordinates from the MWPCs;

$\alpha, \beta, \gamma, \delta$ are coefficients found from the Monte Carlo calculation.

To calculate the momentum, the MBNIM logic needs 360 ns; at 10 GeV/c the accuracy is about ± 0.5 GeV/c.

The same group is searching for exotic mesons in the reaction

$$\pi^+ p \rightarrow \Delta_{fast}^0 (\rightarrow p \pi^-) M^{++} (\rightarrow p \pi^+ \bar{n} \text{ or } p \bar{\pi}^+ \pi^+) .$$

To improve the trigger rate, a mass cut is applied using the correlation

$$F(M_{X^{++}}) = p_p + p_\pi .$$

The momenta of π and p are calculated by two parallel branches of the MBNIM logic. For $p_p + p_\pi > 5$ GeV/c the efficiency of the trigger is about 90%.

3.8 Triggering system of dimuon experiment

Two groups, one at CERN (experiment NA3 [52, 53]), the other at Fermilab (experiment E400 [50]), searching for new particles in dimuon spectra, have developed powerful triggering systems for selecting outgoing particles with high transverse momenta and specified invariant mass.

The triggering system of the NA3 experiment [25] is briefly described here. Figure 7 shows the triggering elements of the apparatus [53]. The pretrigger defined by the hodoscopes T1, T2, and T3 strobes the proportional chambers M1 and M2. The cathodes of these chambers are printed in 20 horizontal strips, each being subdivided into 64 cells, corresponding to equal intervals of the tangent of the azimuthal angle ($\tan \phi_j - \tan \phi_{j-1} = \sqrt{3}/32$) [25]. The selection of the vertical component p_{TV} of the transverse momentum of the muons is achieved by using the data from these chambers and fast coincidence matrices. For the described geometry of the chambers, p_{TV} can be expressed as follows:

$$p_{TV} = q\beta \left(\frac{1}{Z_1} - \frac{1}{Z_2} \right) Z_c \frac{1}{N_1 - N_2} \frac{32}{\sqrt{3}},$$

where

- q is the charge of the particle,
- β is the bending power of the magnet,
- Z_1, Z_2, Z_c are the positions of M1, M2, and the centre of the magnet,
- N_1, N_2 are the addresses of the cells hit in M1 and M2.

For the constants of the experimental set-up,

$$p_{TV} = \frac{5.2}{\Delta} \text{ GeV/c}.$$

Twenty parallel units (one for every strip) calculate $\Delta = N_1 - N_2$, and the results are used as addresses for fast memories where decision bits are stored.

The runs were performed with the conditions $p_{TV} > 0.7 \text{ GeV/c}$ for both muons or $p_{TV} > 1 \text{ GeV/c}$ for one muon. The decision time was 110 ns, the reduction factor ~ 1000 (!); 30-80% of the recorded events (depending on the beam structure) were recognized as dimuons by the off-line analysis.

Parallel with p_{TV} , the invariant mass of dimuons can be calculated [25] from the formula

$$\frac{1}{M} = \frac{1}{\sqrt{p_{TV1} p_{TV2}}} \sqrt{\frac{\theta_{V1} \theta_{V2}}{\theta_{V1} + \theta_{V2}}} \cos \bar{\phi},$$

where

θ_{V1}, θ_{V2} are the angles of individual tracks in the vertical plane,
 $\bar{\phi}$ is the mean value of the azimuthal angles of the tracks.

P_{TV} can be estimated as previously; θ_V can be estimated from the horizontal strip number, $\bar{\phi}$ from the individual addresses of cells in M1. These functions can be found from programmable tables, which allow the selection of events within ~ 170 ns. The efficiency for $M \geq 5$ GeV was $\sim 95\%$.

3.9 Triggering system of the charmed particle production experiment

The Amsterdam-CERN-Cracow-Munich-Oxford-Rutherford-Bristol Collaboration is carrying out an experiment at the CERN SPS [9], the aim of which is to investigate the charmed particle production of hadrons in the reaction

$$\pi^- N \rightarrow D\bar{D}X.$$

The basic idea of the trigger is to select a prompt electron coming from one of the D's, which should be recognized by electron-Cherenkov and shower counters (fig. 8).

The experiment has two basic sources of background: hadrons accompanied by γ 's, and electron pairs (from γ conversion or Dalitz decay of π^0, η^0) which simulate "single electrons".

For the purpose of trigger-rate reduction, a large system of wire chambers has been built ($\sim 15,000$ wires). The information from these chambers is processed in the real time of data-taking by fast programmable processors (ESOP) developed at CERN [54]. A detailed description of the system will be given in a later publication^{*)}. Here, as an example, results of the application of a cut on the energy/momentum ratio of the triggering particle are presented (fig. 9), which reduce the hadronic background ($0.7 < E/p < 1.4$). The energy of the particle is calculated,

*) The implementation of the system into the NALL experiment is mainly due to the efforts of C. Damerell, A. Fucci, D. Giddings, T. Lingjaerde, G. Lütjens and F. Wickens.

by one of the ESOPs, from the pulse height given by the shower counters of the electron calorimeter; its momentum is found by the second ESOP by calculating the deviation of its trajectory from the straight (infinite momentum) line defined by the target and the segment of a track found in front of the calorimeter (fig. 8). In this case, the decision time of the system is about 800 μ s, the reduction in trigger rate ~ 4 , the gain in the number of good events ~ 2 (another factor of 2 is provided by other cuts), and the efficiency is $\sim 85\%$.

A large part of the MWPC system is installed in the magnet (fig. 8) to be used for electron pair rejection -- this part of the trigger is in the process of being implemented. Assuming a zero opening angle between electrons (Dalitz decay), a strong correlation in the Y position between an electron giving a trigger and the one seen in the MWPCs is observed.

For the same purpose, a "bidimensional drift chamber" [55] ("time projection chamber") has been placed inside the magnet (fig. 8); a schematic view of such a chamber is shown in fig. 10. An electron pair is expected to be in the same horizontal plane and can be recognized by majority coincidences of signals from detecting wires^{*)}. The usefulness of such a chamber was studied by Monte Carlo simulation^{**)}. The results show that with a separation of a few millimetres in the X (wire pitch) and Y the direction (time resolution of the coincidences) a large fraction of electron pairs can be recognized.

4. CLOSING REMARKS

From the examples given in the previous section, the main features of the triggering systems with wire chambers can be selected:

- the systems are adapted to the kind of experiment, the geometry, and the trigger rate;

^{*)} Proposed by E. Lorenz, NA11 experiment, CERN.

^{**)} Work done by F. Wickens, NA11 experiment, CERN.

- wire chambers provide coordinates of particles which are processed by special electronics; fast, non-destructive readout is used;
- the data from the chambers are strobed by a pretrigger; additional information (guidance) is given by the counters;
- a wide variety of electronics is used: special and programmable processors, modular logic, matrices, look-up tables, etc.

Up to now, wire chambers for triggering purposes have been used only in "digital mode"; a new concept may appear, due to the development of multistep avalanche chambers [56] and their use for Čerenkov imaging [56, 57]. Apart from this, there exists the completely unexplored field of using wire chambers working in the "linear mode" [58]; information about the ionization, shower size, and transition radiation can also be used for triggering.

It is certain that, in the future, more and more preprocessing will be done in the real time of an experiment, and many new projects are under way^{*)} [59]. Maybe some day we will write on tape only the good events -- On tape? then why not directly in the computerized Physics Letters ...?

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Figure captions

- Fig. 1 : a) Reduction of the amount of data and b) gain in number of good events, as a function of trigger rate for different values of the reduction factor ρ and decision time t_D .
- Fig. 2 : Typical curve of the efficiency of a triggering system as a function of the selection parameter.
- Fig. 3 : Different topological criteria applied in triggering systems with wire chambers: a) multiplicity, b) direction, c) scattering angle, d) opening angle, e) coplanarity.
- Fig. 4 : Simplified layout of a set-up for the selection of particles scattered at small angles [28].
- Fig. 5 : Simplified layout of a set-up for measuring the coplanarity and opening angle of two forward particles [41, 42].
- Fig. 6 : Layout of the Omega Spectrometer for the baryonium study experiment at CERN [51].
- Fig. 7 : Sketch of the triggering system of the NA3 spectrometer at CERN [53].
- Fig. 8 : Simplified layout of the first few metres of the NA11 spectrometer at CERN [9]; the main elements used for triggering are shown.
- Fig. 9 : Distribution of the triggering particles according to their energy/momentum ratio calculated by ESOPs for a) all events; b) accepted events; c) rejected events; d) calculated off-line for events rejected by ESOPs [a,b,c,d - cut: $0.7 < E/p < 1.4$, c) additional cut of high momenta, d) part of the events out of the range of the histogram].
- Fig. 10 : Schematic view of the two-dimensional drift chamber used for electron pair rejection.

Fig. 1

Fig. 2

Fig. 3

Fig. 4

Fig. 5

Fig. 6

Fig. 7

Fig. 8

Fig. 9 a) b)

Fig. 9 c) d)

Fig. 10