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TRIGGERING FOR CHARM, BEAUTY AND TRUTH*

Jeffrey A. Appel

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INTRODUCTION

As the search for more and more rare processes accelerates, the need for more and more effective event triggers also accelerates. In the earliest experiments, a simple coincidence often sufficed not only as the event trigger, but as the complete record of an event of interest. In today s experiments, not only has the fast trigger become more sophisticated, but one or more additional level of trigger processing precedes writing event data to magnetic tape for later analysis. Future search experiments will certainly require further expansion in the number of trigger levels required to filter those rare events of particular interest.

VARIETY OF TRIGGER LEVELS

With the large variety of triggered devices appearing in experiments today, it is useful to class them according to the time required for a decision at each level. The time associated with each level limits the kind of hardware available to make that decision. The hardware in turn limits the kind of calculation or logic which can be economically implemented at that level. Table I shows the correlation between decision times and hardware characteristics.

In the current climate, experiments tend to emphasize one or another of the trigger levels in combination with the first, fast pre-trigger. At Fermilab, this emphasis has been centered primarily on hardwired devices. At the CERN SPS, there has been a greater emphasis on microprocessor devices. Finally, at the various colliding beam facilities, the microcomputer system has found most favor. An excellent summary of the many devices in use today is provided in the proceedings[1] of the Microprocessor Conference at CERN. The existing trigger processors have been selected to reduce the rate of triggers such that the dead time does not seriously limit the physics of the experiment. As the search for Beauty and Truth continues, the ability of any one or two levels of trigger to achieve this feat will be reduced, and we will see the multiplicity of trigger levels growing in experiments. At the same time, the size of collaborations and the subdivision of labor on experiments is increasing. This will place a premium on the ability to maintain a coherent trigger program throughout the various levels. The program will include integration of the detector design with the trigger philosophy. This integration has been almost second nature in the case of the fast pretrigger. However, there has been an increase in the generality and related cost of higher level devices as the logical distance from the detector has grown.

In addition to the increase in trigger level multiplicity, it is possible to see now the coming increase in the local storage of data in front-end processors, a system of distributed intelligence to work on the locally stored data, and a increase in the parallelism of such processes. Each of these three developments is being discussed in detail in current designs and is basic to such explicit next generation hardware as the FASTBUS system[2].

TPS TRIGGER PROCESSOR

The Tagged Photon Spectrometer trigger processor provides an example of what can be achieved in a modular hardwire triggered system. Since it is less familiar to a European audience, some of its features and the lessons it provides will be described. As used in the Tagged Photon Spectrometer, the processor reduces the fast pre-trigger rate of 2000/second to less than 100/second. An average event requires ten microseconds for complete processor analysis and results in a 2% deadtime. As input to the processor are three ten-bit addresses, one from each of three evenly spaced cylindrical PWC s. In addition, there are six channels of 8-bit timing and pulse height information from each of 15 sectors surrounding the target. Each sector has four layers of scintillator. Combining these data with similar information from the photon tagging system allows identification of recoiling protons whose forward effective missing mass lies between 2 and 11 GeV/c^2.

The processor (with the logic indicated in Table II) begins with a hardwired "do loop" searching for "tracks" where the average of the inner and outer hit PWC wire addresses matches a hit from the middle PWC. Given such a track, a memory look up unit is used to project the track information into the first layer of scintilator. An additional "do loop" finds the sector (one of 15) in which the end-to-end timing corresponds to the track location. Given the appropriate sector, each of the 7 bits of DE/DX pulse height is combined with 6 bits of position information to "calculate" an attenuation and photomultiplier saturation corrected DE/DX (5 bit output). The "calculation" consists of using the input bit pattern to provide the address in a memory whose stored data is the desired output. The information in the memory lookup modules has been precalculated and preloaded so that the results on-line are available in less than 50 nanoseconds. The DE/DX information from two layers is combined with 3 bits of track angle information to "calculate" a predicted kinetic energy (5 bits) and two bits of information, one identifying consistency with a proton input pattern, the other for a pion pattern.

The modularity of the "do loop" controller and memory lookup modules, among others, have led to their use in an entirely different application finding tracks in a forward spectrometer in another experiment at Fermilab.

In addition to the useful modularity of the TPS system, the division of effort between arithmatic units and memory lookup devices is worth noting. Even with the low prices of highly integrated memory chips, the calculations involving numbers requiring 10 bits are more appropriate for arithmatic units (e.g., the track calculation). On the other hand, when a smaller number of bits is sufficient for a number of parameters, even complicated transcendental functions can be precalculated for use in memory lookup devices (e.g., the identification of DE/DX patterns consistent with a recoiling proton). The ability to combine both types of techniques in one system is one of the strengths of the TPS trigger processor.

A final lesson of the TPS experience is that the integration of the apparatus design with the details of the trigger processor capability save effort and cost. The equal spacing of PWC layers in the tracking apparatus is one example of this. However, one less obvious example which is even more important is the uniformity of similar information channels. For example, the attenuation and gain of the 15 scintallator—photomultiplier—ADC combinations in each layer are expected to be the same. The equality of the ADC gain times photomultiplier times light output for each channel must be established early and maintained throughout the course of the experiment. This places a premium on the understanding and the stability of the detector from the earliest possible time.

TRIGGER POSSIBILITIES FOR C, B, AND T

Quite a number of triggering requirements have been proposed in the search for Charm, Beauty and Truth. A nearly complete list of such trigger requirements appears in Table III. Those which have already been used in experiments are indicated with an asterisk in the Table. A number of the trigger requirements which have yet to be used deserve consideration for the future. Many of them become even more effective as the mass of the heavy quark increases. As indicators of Beauty and Truth, they may become more attractive than they have been heretofore.

An example of the mass dependence of the trigger requirement is the minimum momentum transfer, t_{min}, needed for diffractive production of a heavy forward mass, M. The minimum momentum transfer is directly related to a minimum kinetic energy for the recoiling target particle m_r. For example, a minimum kinetic energy of 30 MeV is required for the pair photoproduction of naked Beauty with a hydrogen target. The minimum energy requirement is inversely proportional to the atomic weight of (m_r = A) a nuclear target. Such minimum kinetic energies are easy to detect in real time, either by placing DE/DX counters around the target or by use of active target elements.

The opposite requirement of no measureable recoil can be used when the Primakoff effect is the sought after production mechanism. This is a potentially valuable technique for observing the photoproduction of η_b, assuming the two photon decay is large enough.

High transverse momentum has been a popular trigger for Charm, especially leptons with high p_T. However, this type of trigger may become less useful as one goes to higher mass and a typically larger number of decay products, n_d. The typical transverse momentum for a particle of mass M is M/n_d. On the other hand, if one can add the transverse momentum of all of the particles from a given parent or even all the particles produced in the interaction, there will still be a dependence on the effective mass of such a forward going state. Calorimeters can be used for such purposes with relative ease. A signal approximately proportional to transverse momentum can be obtained by weighting individual calorimeter elements in a sum by their distance from the beam line. It is also possible to consider non-linear expressions of this type. A signal proportional to p_T^2 is of interest here, for example. It is trivial to have the weighting proportional to the square of the distance from the beam line. The requirement of a signal proportional to the square of the energy deposit is less trivial. However, an amplifier[2] whose output is proportional to the square of the input voltage placed in the summing circuit of a trigger system can easily produce signals proportional to p_T^2. One more elaborate quantity might be the square of the effective width of showers produced from a single parent. Such a term would be proportional to the mass squared of the parent particle. Although such techniques may become popular with physicists studying jets, their applicability in the search for Charm, Beauty and Truth should not be overlooked.

Finally, we seem to be at the threshold of the use of active targets for observing changes in ionization corresponding to the charged decay of heavy particles. Such techniques are difficult to implement for particles with very short lifetimes because of the combined effects of Landau fluctations of ionization and nuclear breakup products masking the step in ionization near the interaction point. On the other hand, the existence of a coherently recoiling nucleus may be useful in identifying events for which it will be possible to reconstruct tracks near to the interaction point, either in a next level of trigger processing or off-line.

CONCLUSION

In the past, thinking has tended to concentrate on a single triggering concept. Any number of the trigger possibilities listed in Table III could be rejected on such a basis as being insufficiently sensitive to the decay of interest. On the other hand, as multiple levels of triggering become more prevalent, they may be very useful in reducing the throughput to a higher level of trigger processing. Thus, the deadtime for the experiment may be kept at an acceptable level. Without enhancing the signal of interest, one trigger stage may be very useful in suppressing background. The design decision about trigger processing depends on the signal over background improvement at each stage of the process, consistent with deadtime and total number of events of interest. Thus, the future is likely to bring a greater variety of trigger requirements as well as trigger levels in each experiment.

REFERENCES

1. Proceedings, Topical Conference on the Application of Microprocessors to High-Energy Physics Experiments, CERN, May 4-6, 1981; CERN 81-07.

2. Cordon Kerns, Fermilab Physics Section, has prototyped such a device.