Appendix to the E-615 Status Report of May 21, 1984

A TRIGGER PROCESSOR FOR A FERMILAB DI-MUON EXPERIMENT

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A trigger processor is described which is currently in use in Fermilab di-muon Experiment 615.

Introduction

Fermilab Experiment 615 is designed to study the characteristics of muon pairs produced in the forward direction by negative pion beams incident upon a tungsten target.[1] In the continuum region of mu-pair invariant masses between the J/ψ and Υ resonances, the production occurs predominantly through quark-antiquark annihilation (the Drell-Yan mechanism[2]), an electromagnetic process with extremely small cross section (less than 100 pb) compared to the total $\pi^- p$ cross section (~ 24 mb). Consequently, an experiment dedicated to studying specific kinematic regions with good statistics, such as this one, requires both a high intensity beam and a powerful means of rejecting unwanted events at the trigger level.

Overview of Apparatus and Trigger

A schematic of the apparatus is shown in Fig. 1. A 7.3-m-long dump consisting of BeO, Be, and C absorbs most of the particles produced in the target, except muons. The detection apparatus downstream is live through the beam region in order to achieve good acceptance at large x_F. The dump fills the tapered gap of a dipole magnet which tends to focus the low momentum member of asymmetrically produced muon pairs, thereby affording good acceptance in the interesting angular variable $\cos\theta^*$ from -1 to +1.[3] With its transverse momentum kick of 3.2 GeV/c, this "selection" magnet is largely responsible for the ability of the trigger processor to discriminate between sought after high mass muon pairs and background events, simply on the basis of the topology of the muon trajectories through the downstream apparatus.

Four scintillation counter hodoscope planes, C, D, E, and F, are used to

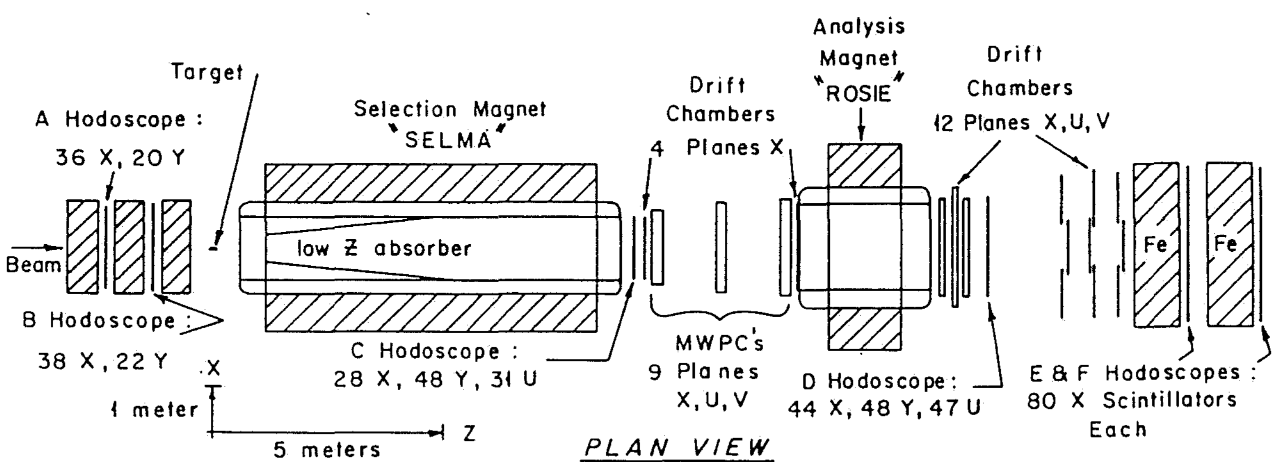


Figure 1. E615 apparatus in 250 GeV/c pion beam configuration

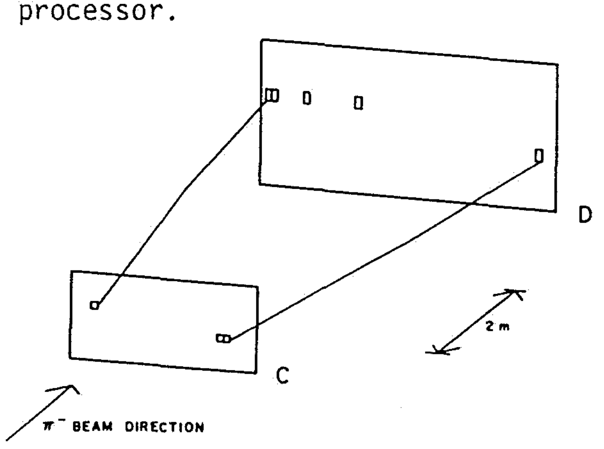
trigger the apparatus on muon pairs, and two others, A and B, to veto triggers containing muons from beam pion decays (halo muons). The E and F banks, situated behind one and two meters of steel, respectively, provide an unambiguous identification of muons.

The trigger for the experiment is made in three successive stages. Under normal data-taking conditions, only events satisfying all three levels of logic are written to tape. (Actually, one in a thousand Level 1 triggers also goes to tape for diagnostic purposes.) The first level of logic is designed to select events with at least two distinct muons that are in time coincidence with the accelerator rf signal and that have no beam halo particles among them. The second level logic insists that every event have at least two tracks that point back to the target in the non-bending (elevation) view. The Level 1 and Level 2 circuitry by itself constitutes a fairly sophisticated trigger. Nonetheless, a significant improvement in the trigger is achieved at the third level.

The third stage of the trigger imposes the requirement that the muon trajectories bear a resemblance to those of high mass pairs. Unlike some other trigger processors,[4] no mathematical computation of an invariant mass is actually made.[5] Instead, two 15 bit words are constructed, each one describing a trajectory through the C and D hodoscopes. In principle, these 30 bits could furnish an address into a 2^{30} bit memory, each location of which contains a 1 or 0 depending upon whether or not the candidate track pair is to be accepted or rejected. This is the essence of the philosophy adopted for the trigger processor described here, though the implementation does not actually use such a memory.

Level 3 Trigger

The "raw data" used in making the Level 3 trigger consist entirely of the latched signals from the C and D hodoscope X, Y, and U counters. Only those Y counters which contributed to a Level 2 trigger participate in Level 3. A three-fold coincidence of X, Y, and U counters (the result of which is also latched) creates rectangular "pads" in each hodoscope, as shown in Fig. 2, which depicts an actual event from the point of view of the third level processor.



E615 EVENT DISPLAY OF PAD HITS IN C AND D HODOSCOPES

Figure 2. Detector as seen by Level 3

Given a set of struck pads, a hardware "track pair finder" assigns pairs of pads, one in the C hodoscope and one in the D hodoscope, to a candidate particle trajectory. Two such candidates are constructed, called α and β. Ultimately, each track is described by a 15 bit word. The lowest order 5 bits specify the X coordinate of the struck pad in the C hodoscope, the next 6 bits give the X coordinate of the struck pad in the D hodoscope, and the remaining 4 bits identify the Y coordinate of the C hodoscope pad. The Y coordinate of the struck pad in the D hodoscope need not be encoded because the track pair finder will associate a given C hodoscope pad with only those pads in the D hososcope belonging to Y counters that are roughly on a line with the target, in keeping with the Level 2 logic. Furthermore, the track pair finder will not permit the α and β track pads to share a Y address in either hodoscope, in conformity with Level 1 nonadjacency requirements.

As can be seen in Fig. 2, it may be possible to construct many candidate track pairs for a given event (though only the tracks actually reconstructed using the wire chambers are shown in the figure). Accordingly, the track pair finder not only performs an encoding function, but "loops" over all possible pairs of candidate tracks, subject to the Level 1 and 2 trigger requirements. Each pair is presented in turn to Fermilab ECL/CAMAC Memory Look-Up modules (MLU's),[6] where a comparison is made with stored patterns. The track pair finder also knows when to quit. That depends not only upon the outcome of each comparison, but on the number of track pair candidates that have been constructed and compared so far, for a given event.

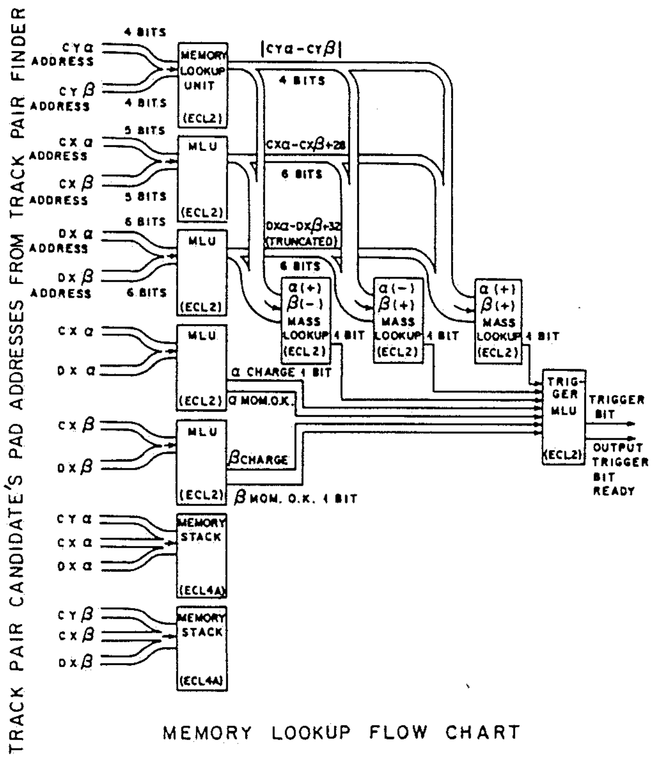


Figure 3. Memory look-up sequence

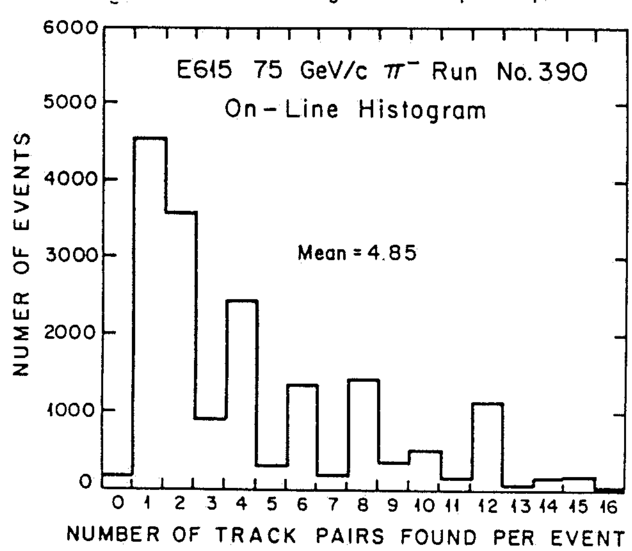


Figure 4. Typical track pair multiplicity

The MLU's are interconnected as shown in Fig. 3, though it should be emphasized that once the two words describing a track pair candidate are made available, the bits may be manipulated in any fashion desired, simply by re-cabling and re-loading the MLU's. In this experiment it has proven convenient to assign a charge to each track, to determine whether or not each track's curvature is compatible with a physically allowed momentum, and to determine whether or not the pair of tracks has a topology similar to that expected for high mass di-muons.

Charge is specified using a two-dimensional matrix that has the C hodoscope pad's X counter address providing one index and the D hodoscope pad's X counter address providing the other index. The elements of the matrix used to load the appropriate MLU's are set to 1 for positively charged tracks, and to 0 for negatively charged tracks.

A momentum selection ("good" or "bad") is based on another matrix with the same indices, loaded with ones in kinematically allowed regions and zeroes elsewhere.

Invariant mass is strongly correlated with the plan view track separation at the C hodoscope (ΔCX) and the track separation at the D hodoscope (ΔDX). The high mass region in the ΔCX vs. ΔDX plane varies according to the vertical separation of the tracks, so that a number of two-dimensional arrays must be specified (one for every $|\Delta CY|$) in order to load a Mass MLU. Separate Mass MLU's are needed for track pair candidates in which track α is assumed to have one charge and track β another, since the 16-bit-wide input to the MLU is exhausted by the ΔCX, ΔDX, and $|\Delta CY|$ inputs.

The Trigger MLU at the end of the chain is easily programmed to set the output "trigger bit" to 1 or 0 depending on the state of its seven input bits. An "output ready" signal tells the track pair finder when the trigger bit is valid so that it may decide whether to assemble the next track pair candidate or quit. An internal counter may be set so that no more than 1, 2, 4, 8, 16, or 32 track pair candidates are constructed. (Two 32-word-deep Memory Stack modules record, for diagnostic purposes, the 30 bit description of each track pair candidate presented to the MLU's.) During data-taking, the stack limit has been set to 16. Of course it is possible that no track pair candidates at all can be constructed for a given event, or that all possible track pair candidates are exhausted before the stack limit is reached. In the first case the event is rejected. In the latter case the event is rejected if none of the candidate pairs satisfied the Trigger MLU, and accepted otherwise. We have chosen to reject events when the stack limit is reached, regardless of the state of the trigger bit associated with the candidates tested. A representative histogram of the number of track pairs found per event is shown in Fig. 4. (The entires at 0 and 16 are associated with the prescaled Level 1 trigger.)

Electronics Design, Construction, and Testing

Most of the trigger electronics was designed and constructed at Princeton using ECL 10,000 series chips. The Level 1 and Level 2 circuits were built using a Multiwire technique.[7] The track pair finder (5 boards) and U counter-to-pad fanout modules (4 boards) were wired using the insulation displacement technique.[8] This permitted somewhat faster wiring than the wire-wrap method, but at the price of a greater susceptibility to bad contacts. Nevertheless, since having been debugged, the entire trigger processor has operated with only two or three failures during the last nine months, those failures having been single dropped bits in the MLU's. The veto hodoscope logic was designed and built at the University of Chicago. The only commercial electronic modules employed in the trigger are the phototube discriminators (LeCroy 4416's), a few latch modules (for the A, B, E, and F counters), and assorted NIM modules.

Operational Characteristics

The trigger processor has made possible a marked reduction in the number of events written to tape per beam spill while significantly enriching the sample of interesting events recorded on each tape.

Some typical rates per spill (~ 14 sec in duration) are tabulated below for runs with a 75 GeV/c π^- beam (400 GeV/c protons) and a 250 GeV/c π^- beam (800 GeV/c protons).

Typical Rates per Beam Spill

	75 GeV/c	250 GeV/c
protons on primary target	4.9×10^{12}	3.6×10^{12}
π^- on experiment's target	2.7×10^{9}	2.4×10^{9}
hits per downstream hodoscope	$\sim 10^{8}$	$\sim 10^{8}$
Level 1 triggers	2.4×10^{4}	6.3×10^{4}
Level 2 triggers	1.6×10^{4}	3.3×10^{4}
Level 3 triggers	1390	1260

The ratio of Level 1 to Level 3 triggers varies between 20 and 50. The deadtime of the experiment varies between 30% and 40%, most of it attributable to the on-line computer and the A/B veto rate. The deadtime introduced by the Level 3 logic is only about 2.5 μsec per Level 2 trigger. The minimum time interval between the start of the Level 3 logic and the assertion of the "trigger bit" is 570 nsec, about 370 nsec of which is spent in the sequence of memory look-ups. If no track pair candidates can be found, a minimum of 90 nsec passes before an abort is issued.

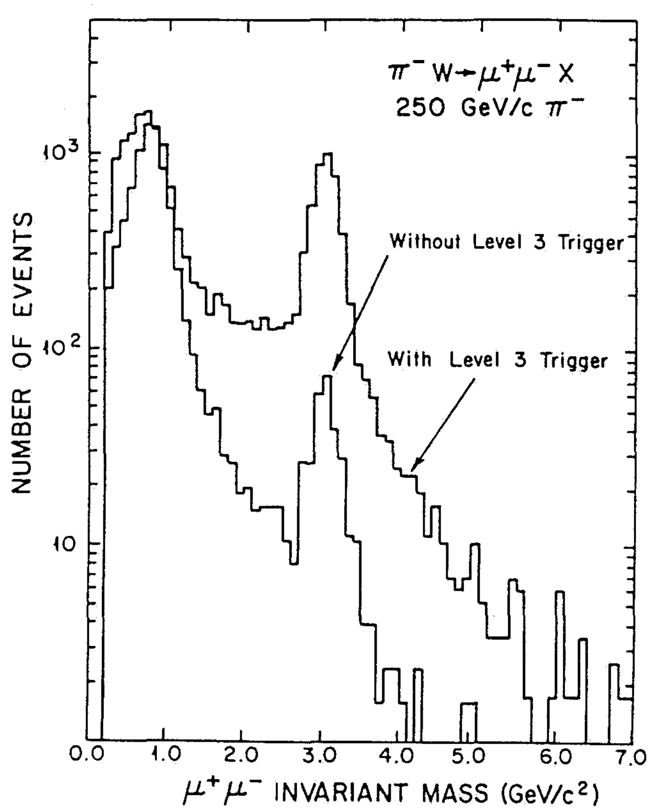


Figure 5. Analyzed data from two runs

Another measure of the effectiveness of the trigger processor is displayed in Fig. 5, which compares data taken with and without the Level 3 trigger, at a π^- beam momentum of 250 GeV/c. The $\mu^+\mu^-$ invariant mass spectrum reveals a suppression of events below the J/ψ relative to those above by more than a factor of 15 when the Level 3 trigger is employed. Both data sets have been normalized to 100,000 triggers written to tape. Minimal event selection criteria were imposed in the analysis of the data to make the comparison a fair one.

Summary

A fast, ECL-based trigger processor featuring a specialized, hard-wired "track pair finder" and modular, programmable memory look-up units has been implemented in a di-muon experiment at Fermilab, and has achieved better than an order of magnitude reduction in trigger rate and rejection of background events.

References

1. For brief descriptions of the experiment and its goals, see A. J. S. Smith, "Production of μ-Pairs in the Forward Direction: Fermilab Experiment 615," in Lepton Pair Production (Proceedings of the Moriond Workshop, Les Arcs, Savoie, France, January 25-31, 1981), pp. 141-147; W. C. Louis, "Status of Experiment 615 at Fermilab: Production of Muon Pairs in the Forward Direction," in Proceedings of the Drell Yan Workshop, Fermilab, October 7-8, 1982, pp. 271-277; W. C. Louis, "Status of Experiment 615 at Fermilab: Production of Muon Pairs in the Forward Direction," in Gluons and Heavy Flavours (Proceedings of the XVIIIth Recontre de Moriond, La Plagne, Savoie, France, January 23-29, 1983), pp. 407-412.

2. S. D. Drell and T.-M. Yan, Phys. Rev. Lett. 25, 316 (1970).

3. $\cos\theta^*$ gives the polar angle of the μ^+ with respect to some suitable axis, such as the beam direction, in the mu-pair c.m. frame.

4. See, for example, H. Areti et al., Nucl. Inst. Meth. 212, 135 (1983).

5. The basic scheme of this trigger processor is due to Kirk T. McDonald.

6. E. Barsotti et al., IEEE Trans. Nucl. Sci. NS-26, 686 (1979); ECL/CAMAC Trigger Processor System documentation, Fermilab TM-821, 2nd ed.

7. Multiwire is a trade-mark of Kollmorgen Corp., Photocircuits Division, Glen Cove, New York 11542.

8. Gold-plated pins supplied by Robinson-Nugent, Inc. were used with "kluge" boards fabricated at the Univ. of Chicago.