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Triggers for a High Sensitivity Charm Experiment

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TRIGGERS FOR A HIGH SENSITIVITY CHARM EXPERIMENT

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Abstract

Any future charm experiment clearly should implement an E_T trigger and a μ trigger. In order to reach the 10^8 reconstructed charm level for hadronic final states, a high quality vertex trigger will almost certainly also be necessary. The best hope for the development of an offline quality vertex trigger lies in further development of the ideas of data-driven processing pioneered by the Nevis/U. Mass. group.

1 Introduction

In his introductory talk, Jeff Appel stressed that two technical developments have been crucial to the success of the Fermilab fixed target charm program. He cited the use of silicon microstrip detectors, which allow the selection of charm candidates through the detection of separated decay vertices, and the use of inexpensive high density tape and powerful offline computing farms. However, he also expressed the opinion that the exponential increase in the yield of charm reaped in the Fermilab fixed target program will not continue past the upcoming run without another technical breakthrough. Detector technology is continuing to evolve which will meet the needs of a "10^8 reconstructed charm" experiment. The breakthrough which is required is an offline-quality vertex trigger which will allow background events to be rejected in real time without losing a significant number of reconstructible charm decays.

In this talk I will review the short list of triggers that have been used successfully by charm experiments, and then present a partial review of development work related to vertex triggers.

2 E_T Triggers

The only unbiased trigger which has been shown to be effective for both photoproduction and hadroproduction of charm is the requirement of "large" global event E_T. A series of experiments in the Tagged Photon Laboratory have used E_T triggers, with different thresholds [1]. Experiment 831 (in the wideband photon beam) will use an E_T trigger in the next fixed target run [2]. For FNAL proposal 829 [3] we studied the use of the E791 calorimetry for an E_T trigger [1]. E791 ran with a 500 GeV/c π^- beam and triggered on E_T, but with a

[1]Most of this work was done by Ai Nguyen, Tom Carter, and Mike Halling.

threshold of 4 GeV/c, which rejected only about $\frac{1}{4}$ of the total cross section and was close to 100% efficient for charm. All of the information available to the E_T trigger logic was written to tape for every event, so it was possible to study what would have happened with higher E_T thresholds. We determined the fraction of events rejected as a function of E_T threshold using an unfiltered data sample. The efficiency for a variety of charm decays was determined using DST's culled from approximately $\frac{1}{3}$ of the full E791 data set. The charm efficiency as a function of E_T did not vary significantly depending on which decay mode was chosen. Figure 1 shows that a threshold of 8.6 GeV/c would have accepted only 20% of the total cross section, but would have retained 69% of the $D^{*\pm} \to D^0\pi^\pm(D^0 \to K^\mp\pi^\pm)$ decays reconstructed by E791, yielding a charm enrichment of $3\frac{1}{2}$.

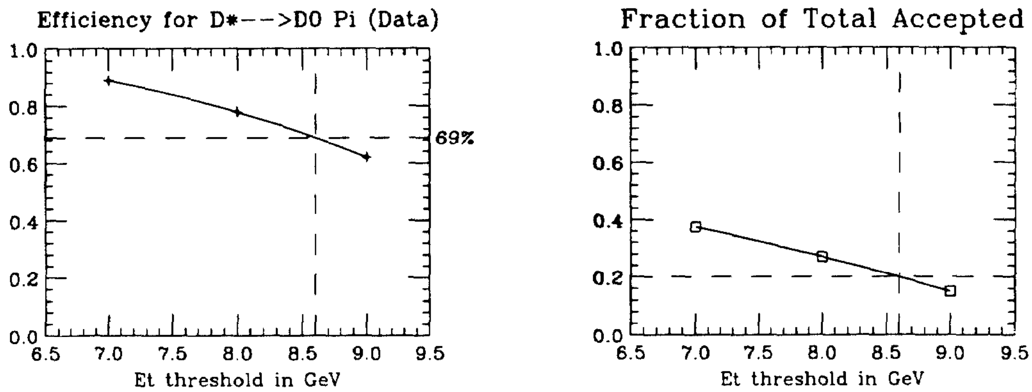

Figure 1: E_T trigger study for FNAL P829 performed using E791 data.

We also studied the effect of triggering on the sum of $|p_T|$ of tracks found by the E791 reconstruction programs. It was possible to achieve a slightly larger charm enrichment using this variable than using the measured E_T. It is likely that more modern calorimetry than that used by E791 would yield a slightly better E_T trigger[2].

The bottom line is: E_T *works as a charm trigger and can "easily" provide an enrichment of 3-5 while rejecting 80-90% of* σ_{tot}.

3 Muon Triggers

The other charm trigger which has been used successfully and has been widely proposed for future use is a μ trigger. E653 triggered on the presence of a μ with $p > 5$ GeV/c, and selected about $\frac{1}{30} \times \sigma_{tot}$ for 600 GeV/c π^- interactions in a nuclear emulsion target [4]. The E653 spectrometer was unusually short, specifically to minimize π decays in flight. A longer spectrometer would not get quite as large a rejection from a μ trigger without detecting and rejecting decays in flight. The inefficiency of a μ trigger is typically not much worse than the offline reconstruction inefficiency for μ identification, so a μ trigger need not introduce

[2]A similar study of E_T triggers, using Monte Carlo data, has been done by Kennedy, Karchin, and Harr in the context of possible fixed target b and c experiments at the Tevatron and at the SSC. Their memos were presented to the Trigger Group of this workshop.

bias, at least not for the study of semi-muonic decays. Moreover, since approximately 10% of charmed meson decays yield a μ, the trigger can yield an enriched sample of all charm decays, provided that the spectrometer acceptance for the "other" charmed particle is adequate. The combination of an E_T trigger and a μ trigger could likely reject 99.5% of σ_{tot} while being $\approx$ 50% efficient for semi-muonic charm decays[3]. Given an interaction rate of 5 MHz, this would yield 25 kHz to be read out and written to tape. This is easily within the reach of current technology. *If one wants to concentrate on semi-muonic decays, this combination will be very hard to beat - and there is no need for a triggering breakthrough.*

4 Vertex Triggers

It is almost uniformly accepted that all future fixed target charm studies will employ a very high resolution vertex detector and require that every charm candidate have a distinct decay vertex. If one could construct a vertex trigger that identified all reconstructible decay vertices online, one could substantially reduce the number of events which needed to be written to tape without throwing away any reconstructible charm. The E791 offline software filter accepts 9% of the events that passed the loose online E_T trigger, based on the existence of a secondary vertex seen in the silicon vertex detector[4]. If one used an E_T trigger to reduce the raw trigger rate by a factor of 5 and then rejected 90% of those triggers with an online vertex trigger, then a 5 MHz interaction rate would yield 100 kHz to be read out and written to tape. This is a factor of 5 higher rate than was envisioned in P829, and a factor of ten more than actually read out by E791, but not impossible to consider in the year 2000.

4.1 Simple/Fast Vertex Triggers

Vertex triggers may be divided into two types; those that don't require data from tracking detectors, and those that do. Triggers that don't require data from tracking detectors put much less strain on the front-end data acquisition system, but they generally have inefficiencies that are different from the inefficiencies of an offline event reconstruction algorithm. Significant progress has been made in the past few years on two types of fast vertex triggers which do not require information from tracking detectors.

4.1.1 Multiplicity Jump

Some of the first high energy physics experiments to use silicon detectors attempted to trigger on a multiplicity increase between planes, as a signal of a charm decay between the planes [5]. These attempts, and many subsequent attempts to trigger on a multiplicity step, were not very successful. The problem was that the the signal was due to energy loss, and

[3]This implies an enrichment of less than 5 for all charm decays, but as much as 100 for semi-muonic decays.

[4]This is with a cut at $dz > 6\sigma_{dz}$ for the dominant two prong vertices. Many E791 analyses employ a more stringent vertex separation cut.

the amount of energy lost per particle has large fluctuations. Moreover, the presence of slow nuclear fragments, which are very heavily ionizing, makes the trigger even more problematic. Halling and Kwan have suggested avoiding these problems by using the Cherenkov light produced in two quartz plates to estimate multiplicity [6]. This method is sensitive only to relativistic charged particles and the fluctuations are given simply by the Poisson statistics of the detected light. A beam test of this idea was performed using the E791 spectrometer during the last FNAL fixed target run. The amount of light detected per track was not large enough to provide an efficient charm trigger. If one increased the amount of light detected per track, either by using higher quantum efficiency photodetectors, or by using a radiator with a higher index of refraction, this might become a practical charm trigger. However, the Cherenkov radiator plates add material upstream of the silicon tracking detectors, which degrades the vertex resolution of the spectrometer. In addition, since a decay must occur between the radiator plates, this trigger is likely to be inefficient for the shortest lifetime charmed particles.

4.1.2 Optical Impact Parameter

The other fast vertex trigger that is being developed [7] also uses Cherenkov light, but in this case it is the uniqueness of the Cherenkov angle that is the key feature. The idea is to use a solid radiator made from two concentric spherical shells in contact with one another, placed so that the (point-like) interaction target is at its center. The two shells are made of materials chosen so that the difference of their refractive indices allows total internal reflection only for Cherenkov light made by tracks which do not originate at the center of the shells. The detection of the light produced by these nonradial tracks provides the trigger. Unfortunately, one can show that only light made along a length of radiator approximately equal to the particle's impact parameter with respect to the target is internally reflected. In addition, the materials chosen for the two shells must not only have appropriate refractive indices; their dispersion relations must also match. If the dispersion relations do not match, then one must use only a narrow band of wavelengths - outside of which tracks from the target may contribute totally internally reflected light and tracks with non-zero impact parameter may not contribute. These details severely limit the amount of light which can be detected per nonradial track. Much more development is needed before this idea is practical as a charm trigger.

4.2 Tracking Triggers

The second class of vertex triggers is those that require information from some or all of the tracking detectors. If such a trigger is to operate at level two in an experiment running with a 5 MHz interaction rate and approximately 1 MHz of level one triggers, it will require a much faster front-end data acquisition system than is familiar to most physicists. However, there are systems that either have been built, or soon will be built, that are more than fast enough. For example, the E771 silicon strip readout system is capable of digitizing and reading out more than 3 MHz of high multiplicity interactions with zero deadtime [8]. The digital phototube readout conceived for SDC and under construction for KTeV will be capable of similar or higher rates [9].

4.2.1 *Stored-Program Processor Farm*

Conceptually, the simplest way to implement an offline quality vertex trigger is to use a farm of conventional computers running the same program as is used for offline reconstruction. This is exactly the approach being taken by E781, which will run in the next FNAL fixed target run [11]. E781 does not plan to implement full vertex reconstruction online, but forward positive tracks will be found and projected with full offline precision to the production target so that an impact parameter can be calculated and cut upon.

Even with today's fastest processors it typically takes many milliseconds to reconstruct a single event. This implies that to implement a trigger similar to the E791 filter program, a farm would require thousands of nodes to process 1 MHz of level one triggers. This approach will probably be prohibitively expensive, even in the year 2000. Moreover, the problem of routing events into idle processors in such a farm would be quite challenging [5].

4.2.2 *Memory Lookup*

If a processor farm represents one end of the spectrum of possible tracking triggers, the other end is memory lookup. This approach is conceptually easy and typically very fast. One "simply" precomputes all patterns of hit data that represent legal tracks, and then uses the hit pattern from an event to access the memory and retrieve track parameters[6]. The limitation of this approach is that as the number of tracks per event and measurements per track are increased, the required memory size becomes enormous. It is currently far from possible to match offline precision with memory lookup. Nonetheless, the integration scale of VLSI memory continues to increase, the cost continues to drop exponentially, and progress continues to be made on "content addressing" schemes [12].

4.2.3 *Data-Driven Processor (Nevis/U.Mass.)*

The most promising prospect for implementing an offline quality tracking trigger for a high rate charm experiment is a data-driven processor of the type developed over the last decade at Columbia University Nevis Laboratories and the University of Massachusetts [14]. The Nevis/U.Mass. data-driven processor is a special purpose digital computer whose function is determined not by a stored program, but rather by its constituent modules and the interconnections between the modules. Data and control information flow from module to module and sequential steps in a calculation occur in sequential modules in the processor

[5] Perhaps this could be accomplished using one or more high speed switches similar to the type used by telephone companies [10].

[6] A related idea used in WA92 was described at this workshop by Dario Barberis [13].

pipeline. Data flows only on transitions of a synchronous clock which is centrally generated and fanned out to every module. All other control is local. The absence of shared resources such as central memory or I/O paths eliminates possible bottlenecks and makes the structure almost arbitrarily expandable. The processor is naturally parallel in that calculations that do not depend on one another can be done in parallel; however, most of the tremendous speed that is achievable derives from the pipelined architecture.

The processor implemented for FNAL E690 [15] consisted of approximately 800 functional modules of 45 different types. It was capable of track finding and least squares fitting at a rate of approximately 1μs per fit track. Track reconstruction of the full 5 billion event E690 data sample was performed in approximately 100 days.

The same processor modules have been used in E789 to trigger on charm decay vertices seen in a closed geometry spectrometer [16], and in a test at CERN (RD21) intended to demonstrate the use of a data-driven processor as the primary trigger for a collider b experiment (COBEX [17]). In that test, straight line tracks were found using information from silicon strip detectors. The tracks were then fit to the hypothesis that all of the tracks originated at a common vertex. Most events with b decays would fit this hypothesis poorly, whereas the vast majority of all interactions fit well. There was provision to avoid triggering on events with multiply scattered low momentum tracks by eliminating the one or two tracks contributing most to χ^2; finally events were selected with a large χ^2. The average time per 16 track event was 12 μsec. Since the COBEX design calls for a vertex detector which consists of four separate quadrants, the tracks in each quadrant could easily be found simultaneously in separate processor pipelines. This would reduce the time per event to approximately 3 μsec.

As an exercise for this workshop I have worked out another possible trigger algorithm. My goal was to find an algorithm that could operate at level two in our strawman 10^8 charm experiment, which I took to mean that it should be able to process 1 MHz of level one triggers. My approach was to try to avoid a loop over N^2 combinations for an event with N tracks. Here is what I came up with:

- Require the interaction point to be known in at least two dimensions.
- Locate the target in a weak magnetic field such that tracks below a momentum cut-off curve enough not to be found as straight lines (These tracks will often have large impact parameter because of multiple scattering).
- Eliminate points on straight lines between the primary vertex and one measurement plane (Requires only N cycles + the number of cycles to empty the pipeline).
- Find straight lines with the remaining hits (Requires $n \times m$ steps where n and m are the number of hits remaining in two seed planes).
- Trigger on events in which at least one (or two...) tracks are found with an impact parameter within a predefined window (The calculation of impact parameter is very

fast, requiring only about one clock cycle per track not originating at the primary vertex).

Assuming an average of 16 hits per plane, 5 of which do not lie on straight line trajectories from the primary vertex, I estimate that this algorithm would require no more than about 40 clock cycles in any given subroutine using existing processor modules. With a 30 nsec. clock cycle, this translates to 1.2 μsec/event - very close to 1 MHz.

The current Nevis/U.Mass. processor modules are based on 10 year old technology (all ECL 10K and 10KH). It would be possible to construct an even faster and more powerful data-driven pipeline if one were to update the processor using modern technology and larger scale integration (FIFO's, DSP's, ASIC's, etc.). This would also yield a system that would require fewer modules to perform a given calculation.

The principles of the Nevis/U.Mass. data-driven processor are well matched to the needs of a fast vertex trigger. Hopefully these ideas will continue to be developed. Fermilab participation in this development could be crucial.

4.3 Conclusions

The triggering tools are in hand now for a 10^8 level charm experiment which focusses on semi-muonic decays. In order to reach this level of sensitivity for hadronic decay modes, a breakthrough in triggering is required. The best hope for this breakthrough is the continued development of data-driven processing.

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