Trigger Development for Two-Photon Physics at CLEO III

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Abstract

The goal of this study was to develop trigger requirements to facilitate the detection of two-photon interactions producing η_c and f_2' mesons while minimizing the overall trigger rate of the CLEO III detector. Monte Carlo simulations of data were analyzed and a trigger simulation was created. Separate triggers were developed for decays producing charged daughters (*e.g.*, kaons or pions) and decays producing only photons.

Introduction

The CESR (Cornell Electron Storage Ring)e^+e^- beam collider and CLEO detector facility generate a small number of mesons through two-photon interactions; the analysis of these mesons' decay products yields insight as to the nature of the strong force. This study addresses trigger development for the two-photon-produced η_c and f_2' mesons, both of which are believed to be composed of a single-flavor quark-antiquark pair [1]. The electron-positron bound state (positronium) provides a convenient model for analysis of the mesons' "quarkonium" structure; the strong force interaction of the quark and antiquark is analogous to the electromagnetic interaction of the electron and positron [2].

Experimental difficulties of two-photon physics include the low frequency with which the interactions occur [2] and the discrepancies (in multiplicity and momentum transverse to the beam) between the expected decay products of two-photon-formed mesons and the decay products of other CLEO events. These combined obstacles necessitate development of a trigger designed to accept specifically the decay products of mesons produced in two-photon interactions. Such a trigger must achieve a high efficiency while admitting as few as possible of the Class 0 events - beam wall, beam gas, and cosmic ray events - that constitute much of the incoming data.

Theory of Two-Photon Physics

Two-photon interactions occur when an electron and positron at high energies and in close proximity emit a pair of photons which interact via the electromagnetic force to generate a fermion pair. These particles may be leptons, which are detected as such, or quarks. In some instances the quark pair draws other quarks into existence, forming two hadrons; in others the two quarks bind in a resonant state, creating a meson. This latter outcome is of primary interest to this project.

Two-photon interactions are an excellent meson generation mechanism because the electromagnetic interactions involved are well-understood, producing a "clean" particle whose decays may be analyzed and catalogued. Study of a meson's decay ratios allows researchers to draw conclusions as to the meson's quark composition and gain insight on the strong force.

The mesons addressed in this analysis fall within the little-studied middle portion of the meson mass spectrum. The η_c is the lowest-energy charmonium state and is composed of a $c\bar{c}$ quark pair [1]. The f_2' is likely composed of an $s\bar{s}$ quark pair [1]. The η_c and f_2' mesons, with masses of 2980 MeV/c^2 and 1525 MeV/c^2 respectively [1], facilitate analysis of both ends of the mass spectrum under consideration. In addition, many little-known particles, including mesons, glueballs, and hybrids, may have masses comparable to that of the the f_2'.

CLEO III Hardware

The CLEO III detector is well-suited to the study of middle-mass mesons through two-photon interactions due to its excellent K/π separation, good solid-angle coverage, and sufficient beam energy.

- Facilitation of K/π separation occurs through RICH (Ring Imaging Cherenkov Detector), which uses the Cherenkov radiation produced by decay products to calculate their velocity and, in combination with momentum measurements, allow mass determination. The K/π distinction is essential because kaons contain a strange quark; knowledge of the decay fractions of a mesons kaon decays contributes to an understanding of its quark composition.

- The considerable solid-angle coverage of the CLEO III detector is an additional qualification of the facility. Since most two-photon interactions have low transverse momentum, the decay products tend to have low momenta perpendicular to the beam. CLEO III is able to detect decay products which a detector with less extensive solid-angle coverage would be unable to capture.

- The energy of CESR's electron and positron beams is 5.29 GeV, which is adequate for the production of mesons in the mass range under study.

The CLEO III trigger is able to detect tracks, produced by charged particles, and showers, produced by both charged and neutral particles. In order to be captured by the trigger, a particle must have sufficient angular separation from the beam; otherwise it passes out of the drift chamber or calorimeter without entering the trigger hardware. Within the trigger, tracks are divided into axial and stereo tracks; stereo tracks have a higher minimum angular separation from the beam, and all stereo tracks are axial tracks. Stereo tracks are subdivided into low and high tracks based on the particle's transverse momentum. Showers are divided as well and may be low, medium, or high according to their energy; all showers that are "high" are also "medium" and "low". In addition, showers are divided into barrel showers and endcap showers; this distinction expresses the shower's location in the detector and was not found to be useful for this study.

Methods

It was first necessary to generate Monte Carlo simulations of η_c and f_2' decays within the CLEO III detector. The decays simulated were of two classifications: photon decays and charged decays. Photon decays were those in which the meson decayed into two photons and no charged particles; within this category only the η_c decay was modeled. The charged decays included decays to two or four charged particles (kaons or pions) as well as decays to two charged particles and one neutral η particle.

Among the Monte Carlo events, it was necessary to restrict analysis to those which would have been reconstructible had they appeared in real data. This entailed the examination of decay tree information for the parent meson of each event, as well as the creation of a trigger simulator for use with Monte Carlo data. A reconstructible event was defined as one for which all charged daughters, as well as all photon decay products of uncharged daughters, were directed such that the corresponding track or shower would occur within the geometrical confines of the trigger if the event appeared in real data. In addition, the criteria for reconstructibility required the simulated trigger to see the same number of charged particles as had been released in the decay: events with extra or missing tracks were not considered reconstructible for the purposes of this study.

Potential triggers were developed by examining the trigger simulation's analysis of reconstructible events as well as events from a minimum bias data run (a set of events collected with very lenient selection requirements; the data used was from run 106821). The objective was to develop a trigger which would catch as many of the reconstructible Monte Carlo events as possible while accepting very few Class 0 data events. Specifically, it was necessary to minimize the number of data events accepted that were not also accepted by a simulated "hadronic" trigger. The hadronic trigger accepted all events with at least three axial tracks and one barrel shower and was modeled after the hadronic trigger in use with all data runs in CLEO. Separate triggers were produced for decays containing charged particles and decays containing only photons; among the charged-particle decays, the decays to $\pi^+\pi^-$, $\pi^+\pi^-\eta$, and $K^+K^-\eta$ were considered most thoroughly.

Results

Two triggers were developed, a charged-daughter trigger and a photon-daughter trigger. Both were tested on Monte Carlo simulations for efficiency and on real CLEO III minimum bias data for amount of background admitted. All data events admitted were assumed to be background due to the low fraction of two-photon events in real data.

Charged Daughter Decays

The trigger developed for decays with charged daughters accepted events that met the following requirements:

- Two or more axial tracks
- One or more low stereo tracks
- Zero high stereo tracks
- Two or more showers
- Zero high showers

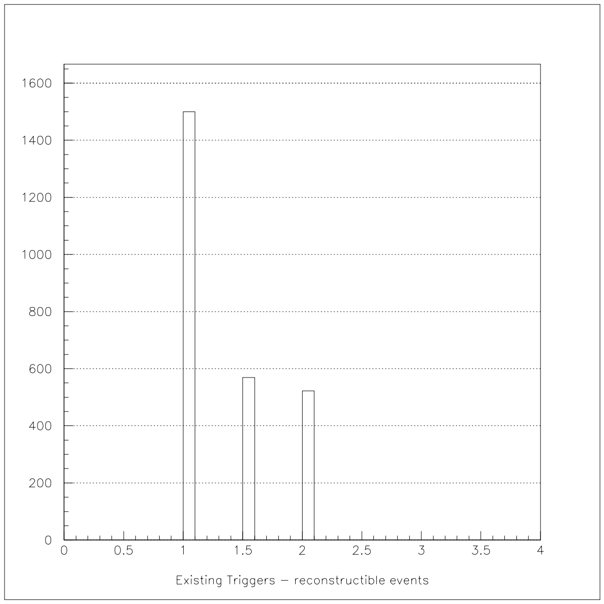

FIGURE 1. Charged-daughter trigger for simulated $\eta_c \to \eta\pi^+\pi^-$ events. The leftmost bar represents all events in the simulation, the middle bar denotes reconstructible events, and the rightmost bar shows events accepted by the trigger.

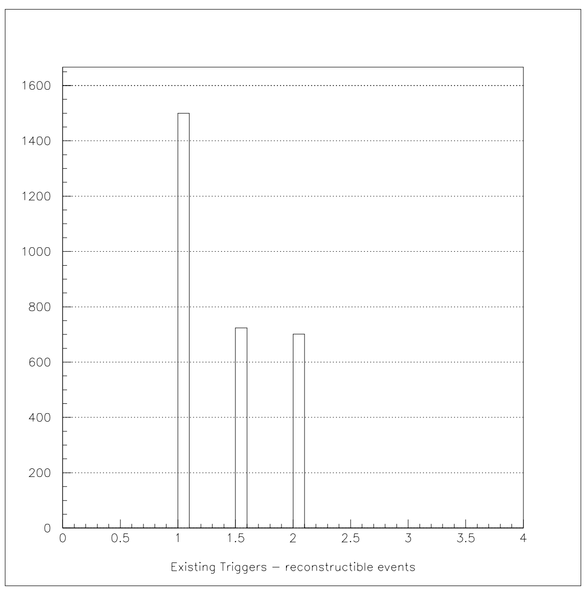

FIGURE 2. Charged-daughter trigger for simulated $f_2' \to \pi^+\pi^-$ events. The leftmost bar represents all events in the simulation, the middle bar denotes reconstructible events, and the rightmost bar shows events accepted by the trigger.

This trigger had an efficiency of roughly 70% in a multi-channel η_c decay (a Monte Carlo simulation which contained several different decays of the η_c, roughly modeling existing knowledge of the particle's decay fractions) and significantly higher efficiencies in the two-charged-daughter decays for which it was designed. In the $\eta_c \to \eta\pi^+\pi^-$ decay, for example,

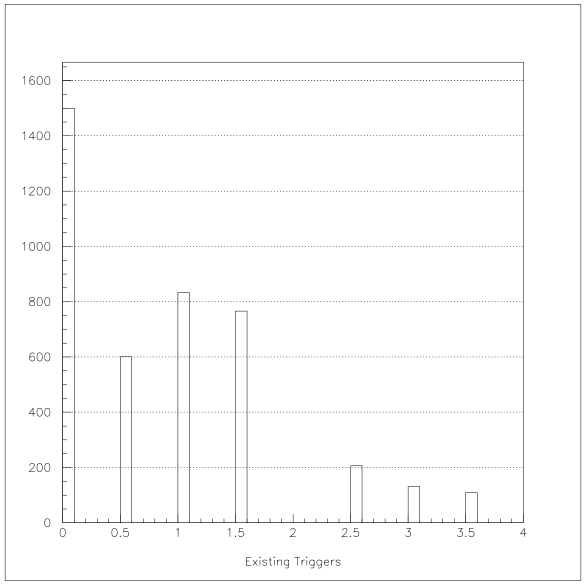

FIGURE 3. Charged-daughter trigger for real data events in the minimum bias run. The leftmost bar represents all events in the data set. The three bars to its immediate right show events accepted by various sub-triggers which, when combined, form the final trigger. The third bar from the right shows events accepted by the final trigger, and the bar to its right denotes events accepted by the final trigger which are not accepted by the hadron trigger. The rightmost bar represents events accepted by a simulation of the existing hadron trigger.

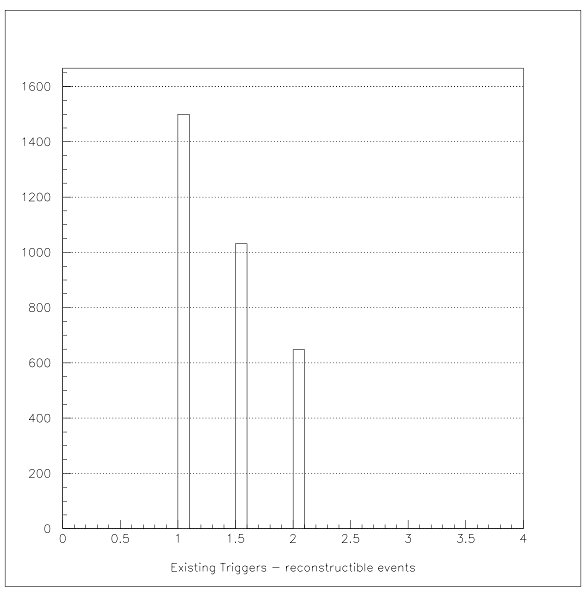

FIGURE 4. Photon-daughter trigger for simulated $\eta_c \to \gamma\gamma$ events. The leftmost bar represents all events in the simulation, the middle bar denotes reconstructible events, and the rightmost bar shows events accepted by the trigger.

an 87% efficiency was obtained (see Fig. 1), and in the $f_2' \to \pi^+\pi^-$ decay, a 94% efficiency

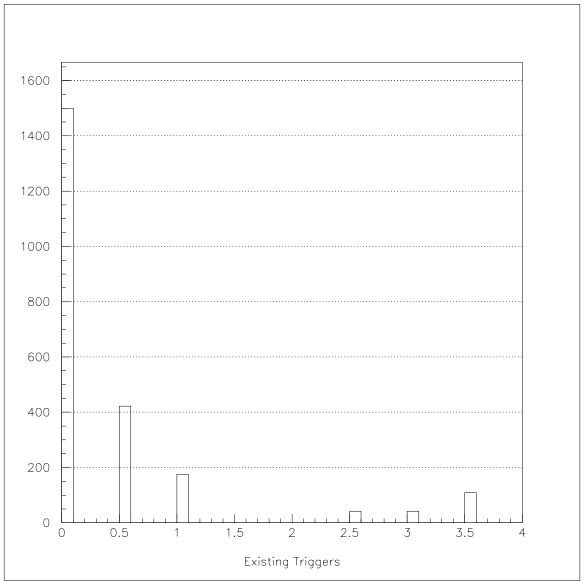

FIGURE 5. Photon-daughter trigger for real data events in the minimum bias run. The leftmost bar represents all events in the data set. The two bars to its immediate right show events accepted independently by the two trigger criteria. The third bar from the right shows events accepted by the final trigger, and the bar to its right denotes events accepted by the final trigger which are not accepted by the hadron trigger. The rightmost bar represents events accepted by a simulation of the existing hadron trigger.

was obtained (see Fig. 2). All efficiencies were calculated using the number of reconstructible events as the denominator. The trigger accepted a moderate number of real data events, somewhat more than doubling the trigger rate of the hadron trigger alone (see Fig. 3).

Photon Decays

The trigger developed for decays with only photon daughters accepted events that met the following requirements:

- Exactly two showers
- Zero low showers

This trigger had an efficiency of roughly 62% in the $\eta_c \to \gamma\gamma$ decay (see Fig. 4) and accepted fewer minimum bias events than the charged decay trigger, increasing the trigger rate by approximately 40% over the rate of the hadron trigger (see Fig. 5).

Conclusions

The expected product of this study was an analysis of the decay modes of η_c and f_2' mesons produced in two-photon interactions and the development of efficient triggers to detect these decays in CLEO III. Moderate success was achieved with the creation of separate triggers for decays generating charged daughters and decays producing only photons. Future research in this area could undertake to refine these triggers in order to improve their efficiency and especially to reduce their acceptance rates when implemented in CLEO. The eventual completion of two-photon triggers for CLEO III will allow two-photon events to be recorded and analyzed, perhaps leading to a greater understanding of the mesons involved.

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Footnotes and References

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