Photoproduction of the π^0 meson from 3.6 - 5.5 GeV

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Exclusive neutral pion photoproduction ($\gamma p \to p\pi^0$) was measured in the CLAS detector at the Thomas Jefferson National Facility. The experiment employed a 1.1-5.5 GeV bremsstrahlung photon beam from 5.6 GeV electron beam created in the Continuous Electron Beam Accelerator Facility (CEBAF). The photon beam energy was impinged on a liquid hydrogen target. The neutral pions were detected via external conversion, $\pi^0 \to \gamma\gamma \to e^+e^-\gamma$, and subsequent Dalitz decay, $\pi^0 \to \gamma^*\gamma \to e^+e^-\gamma$. Measured differential cross-sections, $\frac{d\sigma}{dt}$ and $\frac{d\sigma}{d\cos\theta}$ are compared with Regge and handbag theoretical calculations. The Regge theoretical calculations underestimate the differential cross sections between 3.9 and 4.6 GeV, but agree with data at photon energies 4.6-5.4 GeV. The handbag theoretical calculation significantly underestimates the data at center of mass energies, s $\sim$ 11 GeV.

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I. INTRODUCTION

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II. EXPERIMENTAL SETUP

The *g12* experiment ran during March - June 2008 with a total of 44 days of good beam time. It collected over 128 TB of raw data that consisted of $26 \cdot 10^9$ events, with an integrated luminosity of 68 pb^{-1}. A detailed explanation of the CLAS data reconstruction and explanation of the DAQ for *g12* can be found in [**?**]. This chapter will briefly overview aspects of the *g12* running conditions and data retrieval found in [**?**].

A. *g12* Data Acquisition and Triggering

The CLAS detector is comprised of several subsystems. Each subsystem in CLAS has its own electronics package to monitor its components and collect signals. Discriminators determine whether a signal each each channel a subsystem exceeds a given threshold. In the case of the DC the signal is supplied from the sense wire. For the ST, CC, TOF, EC subsystems, the signal is supplied by converting the current supplied by an anode of a PMT or cluster of PMT's into a voltage. Each subsystem has a preset voltage threshold. The discriminator compares the signal output of a subsystem to the preset threshold. Signals that exceed the preset threshold are digitized by two types of hardware, Time-to-digital converters (TDCs) and Analog-to-digital converters (ADCs). TDCs report the time at which a signal arrives, while ADCs report a number corresponding to the integral of the signal.

The presence of a signal in a single subsystem does not constitute a physics event. There are a number of unwanted sources that could produce unwanted signals, such as cosmic radiation, electronic noise, Fano noise etc. It is the job of the trigger to determine which sets of signals constituted a physics event. The trigger is a list of signals from various subsystems required for an event to be written out to disk. An item in the trigger list is known as a trigger "bit". The *g12* rungroup used a field-programmable gate array (FPGA) as the trigger supervisor. The FPGA allowed for 12 independent trigger configurations to be employed at one time during the running of *g12* as well as the ability to change the trigger configuration during running. The detector subsystems used in the first-level (L1) triggering system of *g12* are the TAGR, ST, CC, TOF, and EC. The TOF and ST are used to identify charged tracks, at the trigger level, by using coincidence of any one TOF hit in a given sector with any one ST hit in the same sector. Also, a coincidence between the EC and CC was included as a lepton trigger. Fig. 1 depicts the L1 trigger configuration for the subsystems mentioned except for the TAGR subsystem. During the *g12* experiment, the interval for a trigger coincidence was 100 ns. All subsystems of CLAS except for the DC can acquire signals in a few nanoseconds.

When a first-level trigger requirement is satisfied, a second-level (L2) trigger requirement is sometimes necessary to verify the L1 trigger. A L2 trigger is usually a software routine unlike the L1 trigger which is based on hardware. The L2 trigger is typically employed for measurements from the DC and is slower than the L1 trigger because it is software based. The software routine does coarse track reconstruction on the DC hits to confirm that the L1 coincidence was caused by particles traveling through CLAS rather than unwanted noise.

When a trigger configuration is completely satisfied,

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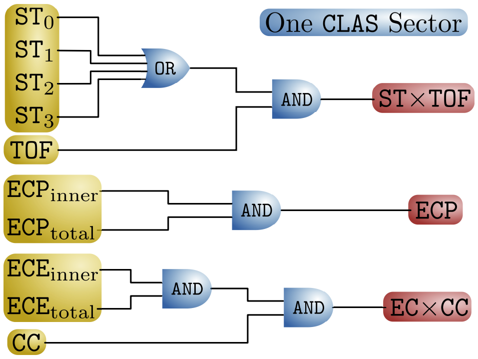

FIG. 1. Trigger logic for one of the six sectors of CLAS. The ST×TOF signal is a coincidence between any of the four start counter TDC signals (numbered from 0 to 3) and any of the 57 TOF TDC signals. The $\mathtt{ECE}_{\mathrm{inner}}$ and $\mathtt{ECE}_{\mathrm{total}}$ are the electron-threshold EC signals for the energy deposited in the *inner* layer and in *all* layers. These are combined with a CC signal to produce the EC×CC trigger for this sector. The ECP trigger signal is the photon-threshold EC signal. These trigger signals are discussed further in Sec. II A 1.

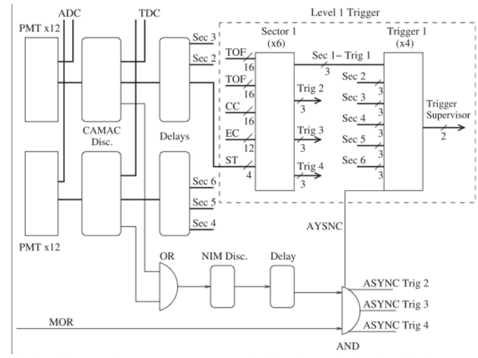

FIG. 2. Trigger logic for any of the six sectors of CLAS along with MOR asynchronous logic trigger input.

the data acquisition system (DAQ) collected the signals and wrote them to magnetic tape for future offline analysis. At the time *g12* was run, the DAQ was capable of running at 8 kHz.

1. g12 *Trigger Configuration*

The trigger configuration used in the *g12* running period are listed in Tables **??**, **??** and **??**. All but one "bit" required a (ST·TOF) to be present along with other requirements. The (ST·TOF) configuration required a track to have coincidence in one sector between any one of the four start counter paddles of that sector, and any one of the 57 time-of-flight paddles in the same sector. Any configuration listed in the Tables **??**, **??** and **??** with the suffix "× N" after a parenthesis grouped configuration requires that given configuration to have "N" coincidences in different sectors. To illustrate this the configuration (ST·TOF) requires one coincidence in the same sector, while (ST·TOF)× 2 requires two coincidences of (ST·TOF) in two different sectors and (ST·TOF)× 3 requires three coincidences of (ST·TOF) in three different sectors. The hardware and configuration did not allow triggering of two tracks in the same sector because there were only six signals coming from the TOF, one for each sector.

Another component that can be included into a trigger "bit" is "Master-OR," (MOR). This component is a signal with the photon tagger. These are defined in Table **??** and is illustrated with the other components of a "bit" in Fig. 2.

2. *Lepton Triggering and Neutral Triggering*

In *g12*, since the CC was filled with gas, it was possible to include the CC as a component of the trigger. There were three trigger "bits" used for lepton identification in *g12* as listed in Table **??**. Each "bit" used a (EC·CC) configuration to identify leptons. The (EC·CC) configuration required a coincidence between the electromagnetic calorimeter and the Cherenkov subsystems. This coincidence was established by using the voltage sum of the CC for a sector and the voltage sum of the EC for the same sector and comparing each sum to a preset threshold described in Table **??**. The EC voltage sum threshold comparison is done on both the $\mathtt{EC}_{\mathrm{inner}}$ and $\mathtt{EC}_{\mathrm{total}}$ which are the EC voltage signals for the energy deposited in the inner layer and in all layers. The labels of photon or electron specified in Table **??** are not actual photons or electrons, but were considered a first-order approximation for detection. The particle identification is done at the analysis level. The method for determining the (EC·CC) does not allow for multiple lepton triggering in the same sector. Determining multiple leptons in the same sector is done at the analysis level.

The "bit 6" trigger configuration, (ST·TOF)·(EC·CC) requires a ST and TOF coincidence previously described in II A 1 along with a coincidence between the electromagnetic calorimeter and the Cherenkov subsystems described above. The (ST·TOF) configuration of "bit 6" did not have to be in the same sector as the (EC·CC) configuration of "bit 6". The "bit 11" trigger configuration, (EC·CC)×2 requires two coincidences between the electromagnetic calorimeter and the Cherenkov subsystems described above, in two different sectors.

The "bit 5" trigger configuration was also established as a lepton trigger. It required EC hits in two sectors. The "bit 5" trigger configuration was also established to analyze physics involving two or more neutral particles accompanied with a charged track, such as exclusive π^0 production in which the π^0 decays via 2 photons. The method for "bit 5" voltage sum comparison is identical to the EC voltage sum of "bit 6" and "bit 11"

It should be noted that none of the lepton triggers required a `MOR` signal, allowing for physics involving leptons to be measured starting from *g12*'s lowest tagger detection value of 1.142 GeV.

III. *G12* RUN SUMMARY

The *g12* experiment was divided into 626 production runs, 37 single-prong runs, 13 special calibration runs and numerous diagnostic runs which were not recorded. Each run consisted of approximately 50 million triggered events. If a run did not have at least 1M triggered events or if the run was corrupt, the run was discarded. The *g12* experiment had several special calibration runs. These runs consist of normalization, zero-field, and empty-target data runs. The normalization runs were used to calibrate the tagger for the measurement of the total photon flux and consistency of the left and right `TDC` signals of the tagger. The zero-field data was taken with the main torus magnet off. This was done to account for the position and orientation of the drift-chambers in the reconstruction. The empty target runs were used to investigate the contributions of the target wall to the data sample.

IV. EVENT SELECTION

Pions were skimmed initially and then re-identified as leptons by changing the mass of the pion. This method is sufficient when the decaying particle's mass, i.e. m_{π^0}, is less than that of pions. If the event satisfied the requirements listed in Table I, then all `TOF`, `ST`, momentum and vertex information was outputted as well as `CC` and `EC` information for the $\pi^{\pm}$ particles to be used to identify leptons, as discussed in Sec **??**. To reduce the size of the data set, a cut was placed on the total missing mass of $\gamma p \to p\pi^+\pi^-$ to be less than 275 MeV. This cut was broad enough to not interfere with π^0 selection from single π^0 production i.e. $\gamma p \to p\pi^0$ when assigned the pion the lighter mass of a electron/positron. This broad cut also does not interfere with π^0 production from light meson decay, i.e $\gamma p \to p\omega \to p\pi^+\pi^-\pi^0$.

TABLE I. Requirements of initial skim

Requirement
One in-time beam photon
One proton
One π^+ or *"unknown"* of q^+
One π^- or *"unknown"* of q^-

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VI. SYSTEMATIC UNCERTAINTIES

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VII. NORMALIZATION

In the calculation of the differential cross-section, Sec. IX, accuracy of the total number of photons incident on the target will determine the accuracy of the cross-section measurement. The procedure for determining the total number of photons in CLAS has already been established in [**?**]. This procedure was performed for the *g12* data set and is discussed further in [**?**]. In this analysis, only events which were in the "good" scalar interval were considered. A "good" scalar interval relates to data recorded when the photon flux was recorded in "live-time". "Live-time" is the time that the data acquisition was ready to record events in conjunction with CLAS. For this analysis the photon flux, gflux, was binned in increments of 25 MeV and can be seen in Fig. **??**. The 25 MeV binning was chosen to compare past experiments differential cross-sections with this analysis.

VIII. CROSS-SECTIONS

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IX. COMPARISON WITH THEORETICAL MODELS

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