# Chapter 5

# Data Collection

The overall physics trigger is composed of a set of hardware triggers and a set of software triggers. The triggers are for different types of physics events. Presented in this chapter are the data readout, a description of the signals which form the electronics logic used for the hardware trigger, and the online processor program that includes the software trigger. Figure 5.1 is a schematic of the electronics, ACP system (CPUs) and data pathways which comprise the data acquisition system. Also included in this chapter is a step by step procedure of the data taking process for one beam fill or stack. The last section of this chapter describes the data taken during the 1991 FNAL fixed target run.

## 5.1 Data Readout

The data acquisition system includes two memory look-up units, MLUs, and a gatemaster. A MLU is a programmable logic module which forms four different

Figure 5.1: A schematic of the data acquisition system.

output logic signals from sixteen input logic signals. The two MLUs are called[1] the master MLU and charged MLU, and the outputs of these modules are labelled MMLU# and CMLU#, respectively. The next section describes the input signals to the MLUs; a description of the logic performed in the MLUs is in section 5.3. The gatemaster is a custom built module that initiates gates, initiates read out, and resets the electronics for different types of triggers. The different trigger types are prioritized by the gatemaster: in order of priority – luminosity, ACNET, scaler, MMLU1, MMLU2, MMLU3, MMLU4, minimum bias, pedestal, forward calorimeter cosmic ray, flashlamp, and other monitor or calibration triggers. The physics triggers are labelled MMLU#.

The timing signal[2], or strobe, for the electronics is the minimum bias signal, the OR of the 160 Level I central calorimeter sums (see section 2.9). The central calorimeter FERAs have a 150 ns gate width for physics triggers; the gate width is 300 ns for flashlamp triggers.

All CAMAC crates, the left column of figure 5.1, are read out for charged triggered interactions; whereas only the calorimeter and trigger CAMAC crates are read out for neutral triggers. Each CAMAC crate is read out by a Smart Crate Controller [74] (SCC). The data is sent directly to a set of VME based data buffers (RBUF).

[1] In 1990, the setup of the MLUs was different with a neutral MLU instead of a charged MLU.

[2] The OR of the H1 hodoscope elements is used as the timing strobe for the charged MLU.

For the non-physics triggers, the information from specific modules is recorded. The luminosity monitor data are recorded every five minutes from a qVt interface located in a trigger CAMAC crate. The $\bar{p}$ beam information provided by the accelerator network (ACNET data) is read out every three minutes by an interface module in one of the trigger CAMAC crates. Many of the signals that are connected to pattern units are also connected to scaler modules in a trigger CAMAC crate, which are read out every five minutes, and to visual scalers, which count for ten second intervals and then reset. The flashlamp system operates at a $\frac{1}{6}$ Hz and the counters' responses to each flash are recorded; the rate of recording the flashlamp monitor tubes' responses to the bismuth light pulsers (sections 4.2 and 4.4.1) is also $\frac{1}{6}$ Hz.

## 5.2 Logic Signals

The definitions of the charged MLU inputs are shown in table 5.1. A charged track is defined when both an H1 element and an H2 element are hit and are consistent with a particle coming from the interaction region. For every H1 element there are six H2 elements for the definition of a charged track for the 1991 data run[3]. The H2 cluster bit is a trial bit which can be used to search for $\bar{p}p \rightarrow \phi\phi X$ if both $\phi$'s decay into $K^+K^-$ which hit neighboring H2 elements (defining an H2 cluster). The H2 coplanarity requirement is one H2 element hit with one of the three opposite H2

[3]In 1990, there were only four H2 elements assigned to each H1 element.

| Bit | Symbol | Meaning |
|---|---|---|
| 1 | h | $\geq 1$ charged track |
| 2 | hh | $\geq 2$ charged tracks |
| 3 | H2=2 | #H2 element hits = 2 |
| 4 | H2>2 | #H2 element hits > 2 |
| 5 | H2=2 clus | #H2 cluster hits = 2 |
| 6 | H2>4 | #H2 element hits > 4 |
| 7 | H1>2 | #H1 element hits > 2 |
| 8 | H1>4 | #H1 element hits > 4 |
| 9 | e | #(Čerenkov cell with a charge track) $\geq 1$ |
| 10 | ee | #(Čerenkov cell with a charge track) $\geq 2$ |
| 11 | COPL | 2 H2 elements coplanar |
| 12 | FCH OR | $\geq 1$ forward hodoscope element hit |
| 13 | FCAL OR | $\geq 1$ forward calorimeter hit |
| 14 | unused | |
| 15 | unused | |
| 16 | unused | |

Table 5.1: The definition of the charged MLU input bits; some of the meanings are further explained in the text.

| Bit | Symbol | Meaning |
|---|---|---|
| 1 | 1 opposite 1 | Level II octants coplanarity |
| 2 | 1 opposite 3 PBG | Level II octants coplanarity |
| 3 | Any two adjacent | Level II octants |
| 4 | CCAL or | minimum bias |
| 5 | 1 e- psi trigger | One Level II super-block |
| 6 | CCAL veto | No Level II super-block |
| 7 | unused | |
| 8 | unused | |
| 9 | ETOT | Total energy |
| 10 | FCAL OR | Forward calorimeter hit > 100 MeV |
| 11 | CMLU1 | Charged MLU output CMLU1 |
| 12 | CMLU2 | Charged MLU output CMLU2 |
| 13 | CMLU3 | Charged MLU output CMLU3 |
| 14 | CMLU4 | Charged MLU output CMLU4 |
| 15 | FCH OR | $\geq 1$ Forward hodoscope element |
| 16 | H1 OR | $\geq 1$ H1 element |

Table 5.2: The definition of the master MLU input bits; some of the bits are further explained in the text.

elements being hit, roughly requiring two charged particles to be separated in the azimuth by $\pi \pm 0.5$ radians.

Table 5.2 shows the definitions of the master MLU input bits. The Level II octants are the OR of the five super-blocks' discriminators which come from the same octant. As discussed in section 2.9, the super-blocks' discriminator thresholds are based upon the expected energies of a $J/\psi$ decay; the total energy signal is also discussed in that section. The main central calorimeter requirement (master MLU bit 2) is that two large energy deposits are in different Level II octants separated by at least $90°$ in the azimuth. This is accomplished by a coplanarity requirement of the Level II octants: one octant and one of the three opposite octants having super-blocks above threshold[4] and will be referred to as the PBG bit. The threshold for the total energy bit is 85% of available lab energy deposited in the central calorimeter. The H1 and forward hodoscope bits are included to veto charged particles for the neutral event trigger. The forward calorimeter bit is also used as a veto requirement with the total energy trigger for neutral events. Master MLU trigger bits 3 to 6 are test bits and have not been used as requirements in the hardware trigger during data taking.

[4]A tighter coplanarity requirement of opposing octants having a super-block above threshold (master MLU bit 1) has been used for data taking at and below the $J/\psi$ formation energy.

## 5.3 Hardware Trigger

The previously described MLU input logic signals are the level 1 trigger; the master MLU's four outputs are the level 2 trigger and correspond to the four physics trigger inputs of the gatemaster. The primary charged physics trigger, MMLU1, is essentially an inclusive $J/\psi$ trigger,

$$\bar{p}p \rightarrow J/\psi X, \tag{5.1}$$

and the subsequent $J/\psi$ decay to $e^+e^-$. MMLU2 is the secondary charged physics trigger which looks for two-body events:

$$\bar{p}p \rightarrow \bar{p}p, \tag{5.2}$$

$$\bar{p}p \rightarrow \pi^+\pi^-, \tag{5.3}$$

$$\bar{p}p \rightarrow K^+K^-. \tag{5.4}$$

These events are also used as a monitor (the punch through signals as discussed in sections 4.3.2 and 4.4.2). Test triggers are investigated using MMLU3. The neutral trigger, MMLU4, is for two types of neutral events, which are defined by no signals in the H1 and forward charged hodoscopes. The first type is neutral events with two large coplanar energy deposits in the central calorimeter (PBG) which triggers upon

$$\bar{p}p \rightarrow \gamma\gamma, \tag{5.5}$$

$$\bar{p}p \rightarrow \eta_c X \rightarrow \gamma\gamma X. \tag{5.6}$$

Multi-gamma final states are the second neutral event type which are triggered upon by using the total energy bit.

| Bit # | Symbol Name | Logic Vector (1A) | (1B) |
|---|---|---|---|
| 1 | 1 opposite 1 | | |
| 2 | 1 opposite 3 PBG | 1 | |
| 3 | Any two adjacent | | |
| 4 | CCAL or | | |
| 5 | 1 e- psi | | |
| 6 | CCAL veto | | |
| 7 | unused | | |
| 8 | unused | | |
| 9 | ETOT 1 | | |
| 10 | ETOT 2 | | |
| 11 | CMLU1 | 1 | |
| 12 | CMLU2 | | 1 |
| 13 | CMLU3 | | |
| 14 | CMLU4 | | |
| 15 | FCH OR | | |
| 16 | H1 OR | | |

Table 5.3: MMLU1 bit requirements (1 representing that a bit must be ON) for the inclusive $J/\psi$ trigger. Logic vector (1A) requires PBG and some charged element requirements defined by a charged MLU output (CMLU1); a different charged MLU output (CMLU2) forms logic vector (1B) with no calorimeter requirement. The primary charged physics trigger (MMLU1) is the OR of logic vectors (1A) with (1B).

Before starting the data acquisition, the MLUs have to be programmed. A program allows for different bit requirements to be set for logic vectors and which logic vectors are to be ORed to form one of the four outputs. A logic vector in an MLU is the AND of all the input bits with requirements; requirement for a bit is either a bit is ON (1) or OFF (0). Below are the hardware trigger requirements that have been used during the 1991 data taking during the search for the $^1P_1$; the primary charged physics trigger is used to demonstrate how the logic vectors from both of the charged and master MLUs form the trigger.

| Bit # | Symbol Name | Logic Vector (1a) | (1b) |
|---|---|---|---|
| 1 | h | | |
| 2 | hh | | 1 |
| 3 | NH2=2 | | 1 |
| 4 | NH2>2 | | |
| 5 | NH2=2 clus | | |
| 6 | NH2>4 | 0 | |
| 7 | NH1>2 | | 0 |
| 8 | NH1>4 | 0 | |
| 9 | e | | 1 |
| 10 | ee | 1 | |
| 11 | COPL | | 1 |
| 12 | FCH OR | | |
| 13 | FCAL OR | | |
| 14 | unused | | |
| 15 | unused | | |
| 16 | unused | | |

Table 5.4: CMLU1 bit requirements (1 and 0 representing that a bit must be ON or OFF, respectively) of the inclusive $J/\psi$ trigger with central calorimeter requirement. Logic vector (1a) is the two electron sub-trigger; the one electron sub-trigger is logic vector (1b). The CMLU1 output is the OR of the logic vectors (1a) with (1b); the output is used in the master MLU logic vector (1A).

MMLU1, the primary charged physics trigger (inclusive $J/\psi$ trigger), relies upon the Čerenkov detector and large energy deposits in the central calorimeter. The hardware trigger consists of two master MLU logic vectors shown in table 5.3. Logic vector (1A) requires that there be two coplanar large energy deposits in the central calorimeter (PBG) and some charged element requirements (CMLU1), which are shown in table 5.4. The two charged MLU logic vectors, (1a) and (1b), are respectively the two and one electron sub-triggers, and the OR of these logic vectors is CMLU1. The one electron sub-trigger is more stringent about the number of

| Bit # | Symbol Name | Logic Vector (2a) |
|---|---|---|
| 1 | h | |
| 2 | hh | |
| 3 | NH2=2 | 1 |
| 4 | NH2>2 | |
| 5 | NH2=2 clus | |
| 6 | NH2>4 | |
| 7 | NH1>2 | 0 |
| 8 | NH1>4 | |
| 9 | e | |
| 10 | ee | 1 |
| 11 | COPL | 1 |
| 12 | FCH OR | |
| 13 | FCAL OR | |
| 14 | unused | |
| 15 | unused | |
| 16 | unused | |

Table 5.5: CMLU2 bit requirements (1 and 0 representing that a bit must be ON or OFF, respectively) of the inclusive $J/\psi$ trigger with no central calorimeter requirement. Logic vector (2a) is a stringent two electron sub-trigger. The CMLU2 output is used in the master MLU logic vector (1B).

H1 and H2 elements than the two electron sub-trigger[5]. The second logic vector of MMLU1, (1B), does not require information about the calorimeter and uses a very stringent two electron sub-trigger of the CMLU2 logic vector (2a), shown in table 5.5. Combining the logic vectors, the requirements can be written as three triggers:

$$(\mathrm{PBG}) \otimes (\mathrm{ee}) \otimes (\overline{\mathrm{H1}> 4}) \otimes (\overline{\mathrm{H2}> 4}), \tag{5.7}$$

$$(\mathrm{PBG}) \otimes (\mathrm{e}) \otimes (\mathrm{hh}) \otimes (\mathrm{COPL}) \otimes (\mathrm{H2}= 2) \otimes (\overline{\mathrm{H1}> 2}), \tag{5.8}$$

$$(\mathrm{ee}) \otimes (\mathrm{COPL}) \otimes (\mathrm{H2}= 2) \otimes (\overline{\mathrm{H1}> 2}), \tag{5.9}$$

[5]For some of the other resonance data taking, a third logic vector was included which was a zero electron sub-trigger.

where the bar over a bit's symbol represents the bit must be OFF – vetoing on the bit. The first is referred to as the two electron trigger while the second is called the one electron trigger. The last trigger is the strict two electron trigger with no central calorimeter requirements. The primary charged physics trigger MMLU1 is the OR of these three triggers.

The charged two body trigger, MMLU2, is nearly the same as the no central calorimeter–two electron trigger. The amount of light collected resulting from each hadron of reactions 5.2, 5.3 and 5.4 is a function of the type of interaction in the central calorimeter and distance from the phototube, or a punch through particle (just the Čerenkov light from traversing a counter). The hadron signals can be a wide range of possible *energy depositions* in the central calorimeter. Therefore, there is no central calorimeter signal requirement; a Čerenkov requirement is not applied since charged pions can produce Čerenkov light in the forward cells (section 2.5). All fully contained two body events correspond to signals only in the central calorimeter; the detectors in the forward direction are used as vetoes. The secondary charged trigger (MMLU2) is

$$(\mathrm{hh}) \otimes (\mathrm{H2{=}\ 2}) \otimes (\mathrm{COPL}) \otimes (\overline{\mathrm{H1{>}\ 2}}) \otimes (\overline{\mathrm{FCH\ OR}}) \otimes (\overline{\mathrm{FCAL\ OR}}). \tag{5.10}$$

The neutral physics trigger MMLU4 consists of two triggers. Both of the triggers require that there are no H1 or FCH elements hit. The first trigger requires two large energy deposits separated by 90° in the azimuth. The other trigger occurs when the central calorimeter total energy is greater than 85% of the expected total energy and there is no energy deposit in the forward calorimeter. The forward calorimeter has to be in veto for the total energy trigger in order to cut the rate of triggers from interactions that satisfy the total energy requirement in the central calorimeter. The two triggers are

$$(\mathrm{PBG}) \otimes (\overline{\mathrm{H1\ OR}}) \otimes (\overline{\mathrm{FCH\ OR}}), \tag{5.11}$$

$$(\mathrm{ETOT}) \otimes (\overline{\mathrm{H1\ OR}}) \otimes (\overline{\mathrm{FCH\ OR}}) \otimes (\overline{\mathrm{FCAL\ OR}}); \tag{5.12}$$

the OR of these two triggers forms the neutral trigger, MMLU4.

The rate of interactions which satisfies the charged two body trigger is large and is therefore prescaled. The prescaling occurs between the master MLU outputs and the inputs to the gatemaster. The MMLU2 prescaling has varied between 5 and 200 depending upon the instantaneous luminosity and center of mass energy. The test trigger (MMLU3) can be prescaled when it is used. The gatemaster includes a hardware minimum bias trigger that only requires a minimum bias signal (section 2.9), which is prescaled $10^5$ into the gatemaster.

## 5.4 ACP System

When the RBUFs are filled with the event's signals, the event information is read out by a node of the ACP system. The ACP system[75, 76] is a set of computing processors, CPUs, consisting of 25 slave nodes and one boss node located in two VME crates (see figure 5.1). The slave nodes run a three part program which is described below. The boss node polls each slave node to see whether or not the node can accept the RBUFs' event information. After the slave node's input event buffer is full, it informs the boss node to look for another slave node to accept events. The slave node with a full input event buffer then processes each event in the input event buffer.

The first part of the slave nodes' program organizes the event information. The signal information of an event is placed into two identical event buffer arrays. One of the event buffer arrays is passed to the other two parts of the program if the hardware trigger is a physics trigger or minimum bias trigger; the second event buffer array remains available to be copied to the output event buffer when the decision is made to keep the event. The non-physics types of data (luminosity, ACNET, scaler and so forth) are passed directly to the output event buffer.

The second part of the slave node's program (ACP2) analyzes some of the information of the charged detectors and fills a small summary array. Basically, ACP2 builds simple tracks from more elements than are used to build hardware tracks and puts this information into a summary array.

More information is supplied by the third part of the program (ACP3) in another summary array. The decision of whether to record a physics event occurs in ACP3 by use of the software trigger. ACP3 analyzes the calorimeters' signals treating both the central and forward calorimeters as one detector. A minor analysis of each event is done and software trigger bits are set. The software trigger bits are then compared with a list of software triggers bit requirements, which form the software trigger that allow filtration of the interesting interactions. Although many parameters used in the analysis can be changed on a run to run basis, the parameters have been constant throughout data taking; the parameters that can be changed are noted below.

ACP3 starts by converting all central calorimeter counter and forward calorimeter module signals to energies from gain constants, which are updated every few stacks. The counters and modules are then ordered in a list by energy (largest to smallest energy deposits). The list's top element is checked to see if the energy is above half the minimum energy threshold (a parameter for each calorimeter); 75 MeV and 150 MeV are the minimum energy thresholds for the central and forward calorimeters, respectively. The counters (modules) that form a $3 \times 3$ grid[6] about the list's top element form a cluster. If the resulting total energy from a cluster is above the minimum energy threshold, the counters and modules are assigned to that cluster and removed from the list. Clusters are identified until there are no more counters or modules greater than half the minimum threshold or no cluster total energy above threshold. Counters and modules from the two calorimeters are not combined together to form any clusters.

The clusters' centers of gravity are found in terms of ring and wedge numbers for the central calorimeter clusters (vertical and horizontal module numbers for the forward calorimeter) in tenths of block units. A lookup table is used to adjust the energy and position of the central calorimeter clusters due to energy lost between

[6]The size of the grid can be a function of ring number or forward calorimeter.

counters. The cluster energies are then summed with the counters and modules not used to make any clusters to calculate the total energy deposited in the calorimeters.

All pairs of clusters are combined to calculate all possible invariant masses. Since numerical operations involving real numbers are much slower than integer operations in the ACP system, all event calculations are done with integers; the square of each invariant mass is used. The resulting values are compared with a list of squares of neutral particle masses. If a pair's result is close enough to a particle's mass squared, a software trigger bit can be set.

Another software trigger bit can be set if a cluster's energy in a particular ring number is close enough to the energy of a photon from an electromagnetic decay: $\bar{p}p \rightarrow \gamma X$, where $X$ is a particle in a particle mass table down loaded to the slave node's program. The *recoil* gamma ray energy is a function of the expected total energy, the mass of $X$ and polar angle (ring number). The cluster energy is compared to a lookup table made when the slave node's program is initialized.

Two body kinematics are checked when both of the two greatest energy clusters are in the central calorimeter. The coplanarity of the cluster position has to be good to one block; the absolute difference in position of the two clusters in wedge block units has to be $32 \pm 1$ blocks. At initialization, a lookup table for the two body kinematics using ring numbers and $\bar{p}$ momentum is created. The look up table is created for the following two body systems: $\gamma\gamma$, $e^+e^-$, $\pi^+\pi^-$, $K^+K^-$, $\bar{n}n$ and $\bar{p}p$; note that the first four (last two) reactions have nearly the same kinematics.

| Bit | Name/Symbol | Description and Comment |
|---|---|---|
| 1 | $\geq 2.5$ | At least 1 invariant mass pair greater than 2.5 GeV |
| 2 | 1 cluster | Total # of clusters = 1 |
| 3 | 2 clusters | Total # of clusters = 2 |
| 4 | 3 clusters | Total # of clusters = 3 |
| 5 | 4 clusters | Total # of clusters = 4 |
| 6 | 5 clusters | Total # of clusters = 5 |
| 7 | 6 clusters | Total # of clusters = 6 |
| 8 | $\geq 7$ clusters | Total # of clusters $\geq 7$ |
| 9 | 1 $\pi^o$ | 1 exclusive $\pi^o$ |
| 10 | 2 $\pi^o$'s | 2 exclusive $\pi^o$'s |
| 11 | $\geq 3$ $\pi^o$'s | at least 3 exclusive $\pi^o$'s |
| 12 | $\geq 1$ $\pi^o$ | at least 1 exclusive $\pi^o$ |
| 13 | 1 $\eta$ | at least 1 $\eta$ formed |
| 14 | $\geq 2$ $\eta$s | at least 2 exclusive $\eta$'s |
| 15 | $J/\psi$, $\eta_c$ Inv Mass | formed by a pair of clusters |
| 16 | $\psi'$, $\eta_c'$, $\chi_2$ Inv Mass | formed by a pair of clusters |
| 17 | Any Punch Thru | Any 1 counter cluster |
| 18 | Recoil Mask | Cluster fits recoil $\gamma$ |
| 19 | 2 Body $e^+e^-$ | and $\gamma\gamma$; cluster energy requirement |
| 20 | 2 Body $\bar{p}p$ | and $\bar{n}n$; no cluster energy requirement |
| 21 | 2 Body $\pi^+\pi^-$ | and $K^+K^-$; no cluster energy requirement |
| 22 | $> 0.85$ E_total | Total Energy greater than 85% of lab energy |
| 23 | $> 0.90$ E_total | Total Energy greater than 90% of lab energy |
| 24 | $> 80\%$ E_perp | Total Momentum perpendicular to $\bar{p}$ direction |
| 25 | $\geq 2.0$ | At least 1 invariant mass pair greater than 2.0 GeV |
| 26 | MMLU1 | MMLU1 gatemaster trigger |
| 27 | MMLU2 | MMLU2 gatemaster trigger |
| 28 | MMLU3 | MMLU3 gatemaster trigger |
| 29 | MMLU4 | MMLU4 gatemaster trigger–neutral trigger |
| 30 | Minimum Bias | from gatemaster trigger |
| 31 | At least $1e^-$ | 1 cluster fits energy and 2 body kinematics |
| 32 | Error Mask | problem with event buffer |

Table 5.6: The bits that make up the software trigger bits in ACP3. Further explainations of the bits can be found in the text.

| Particle | Mass Window (MeV) | |
|---|---|---|
| | Lower Limit | Upper Limit |
| $\pi^o$ | 105 | 165 |
| $\eta$ | 460 | 640 |
| $\eta_c$ | 2535 | 3430 |
| $J/\psi$ | 2630 | 3560 |
| $\chi_2$ | 3020 | 4090 |
| $\eta_c'$ | 3050 | 4130 |
| $\psi'$ | 3130 | 4240 |

Table 5.7: The invariant mass windows for a pair of clusters used by the ACP slave node's program.

The software trigger bits[7] are shown in table 5.6; most of the names and comments are self explanatory. The difference between the *exclusive* (bits 9, 10, 11, 12, and 14) and the other *formed* invariant masses is that each of the clusters forming the exclusive invariant mass pair must not combine with other clusters to form one of the acceptable invariant masses. The formed invariant mass bits (13, 15, and 16) mean that at least one pair of clusters forms an invariant mass which is inside the mass window. The invariant mass windows are also parameters which have been constant throughout the data taking period and are shown in table 5.7. The mass windows for the $\pi^o$ and $\eta$ are the expected resolution of the detector while the charmonium mass windows are $\pm 15\%$ of the resonance mass. Notice that the $\eta_c$ and $J/\psi$ ($\chi_2$, $\eta_c'$ and $\psi'$) mass windows overlap and therefore the acceptable mass window for bit 15 (16) is 2535 to 3560 MeV (3020 to 4240 MeV). The recoil mask bit is $\pm 15\%$ of the expected energy of a gamma ray as a function of polar angle from the reaction $\bar{p}p \rightarrow \gamma X$ where $X$ can be $\gamma$, $\pi^o$, $\eta$, or any of the $\bar{c}c$ states as long as the center

[7]Note that some of the software trigger bits' definitions have changed between the 1990 and 1991 data runs.

of mass energy is 150 MeV greater than the mass of $X$. The 'any punch through', 'perpendicular energy' and 'at least 1 $e^-$' bits (17, 24 and 31) are not used for any triggers and are trial software trigger bits.

The resulting ACP3 software trigger bits are compared to a list of bit requirements for software triggers. The software trigger, or level 3 trigger, that has been used during the data taking is discussed in the next section. If there is a match, the second event buffer array with the two summary arrays, from ACP2 and ACP3, are written to the output event buffer. The ACP3 summary array consists of the total energy deposited, cluster information (energy and positions in counter/module unit numbers), and found particles and recoil gamma ray information.

When a slave output event buffer is full, the node notifies the boss node. When the boss node is not busy, the slave node's output event buffer is transferred to the input buffer of the controlling data acquisition program running on a $\mu$VAX II. This program writes the buffer events to 8 mm tape and distributes events to two computers for monitoring purposes.

## 5.5 Software Trigger

The software triggers have been consistent throughout the 1991 data run. The triggers are very general to ensure that good events are not thrown away by the ACP slave nodes' program. Table 5.8 shows the output of the program that prepares the

| Trigger Number | Mask Trigger | Mask Don't Care | Prescale Factor | Comment Description |
|---|---|---|---|---|
| 1 | 04100000 | 04100000 | 1 | MMLU2: $\pi^+\pi^-$ 2 body kin. |
| 2 | 04080000 | 04080000 | 1 | MMLU2: $\bar{p}p$ 2 body kin. |
| 3 | 11000000 | 11000000 | 1 | MMLU4: $\geq$ 2.0 GeV inv. mass |
| 4 | 10100000 | 10100000 | 1 | MMLU4: $\gamma\gamma$ 2 body kin. |
| 5 | 10080000 | 10080000 | 1 | MMLU4: $\bar{n}n$ 2 body kin. |
| 6 | 10400000 | 10400000 | 1 | MMLU4: Total Energy $\geq 90\%$ |
| 7 | 02000000 | 02000000 | 1 | MMLU1: Everything |
| 8 | 10000000 | 10000000 | 1000 | MMLU4: Neutral min. bias |
| 9 | 20000000 | 20000000 | 1 | Hardware minimum bias |

Table 5.8: The ACP software triggers used during the 1991 data taking period. The masks are in hexadecimal. The "Don't Care Mask" is a misnomer; the bits that are required to be OFF are the "Trigger Mask" subtracted from the "Don't Care Mask". In another words, the "Don't Care Mask" defines which software trigger bits have requirements and the "Trigger Mask" defines which of these are required to be ON. In 1991, no software trigger bits were required to be OFF; triggers which did veto upon software trigger bits were used during the 1990 data taking.

software triggers. The trigger masks are in hexadecimal. The table's caption explains how to understand which software trigger bits have requirements.

All primary charged trigger and hardware minimum bias trigger events are selected and therefore recorded: software triggers 7 (MMLU1) and 9 (Minimum Bias). The secondary charged trigger events are cut to only pass events where the highest energy deposits conform with the two body kinematics: software triggers 1 and 2 which are respectively

$$(\text{MMLU2}) \otimes (2 \text{ Body } \pi^+\pi^-), \tag{5.13}$$

$$(\text{MMLU2}) \otimes (2 \text{ Body } \bar{p}p). \tag{5.14}$$

Several neutral triggers have been used ranging from the two highest energy deposits fitting two body kinematics to 90% of the total available energy having been deposited.

The neutral two body kinematic software triggers are 4 and 5, which are respectively

$$(\text{MMLU4}) \otimes (2 \text{ Body } \pi^+\pi^-), \tag{5.15}$$

$$(\text{MMLU4}) \otimes (2 \text{ Body } \bar{p}p) \tag{5.16}$$

(using the appropriate softwarer trigger bit names from table 5.6); the former is for $\bar{p}p \to \gamma\gamma$ and the latter for $\bar{p}p \to \bar{n}n$ events. Software trigger 6,

$$(\text{MMLU4}) \otimes (> 90 \text{ E\_total}), \tag{5.17}$$

is the neutral total energy software trigger. The 2.0 GeV invariant mass trigger for neutral events is a general trigger to look for high mass objects which decay to $\gamma\gamma$; software trigger 4 can be considered a subset of software trigger 3,

$$(\text{MMLU4}) \otimes (\geq 2.0). \tag{5.18}$$

A neutral minimum bias, software trigger 8 (MMLU4), which accepts every thousandth neutral trigger which does not satisfy the other neutral software triggers is recorded to check the efficiency of the other neutral software triggers.

## 5.6 Procedure and Monitoring

The procedures for data taking and monitoring have been spread out among several sections of a *How To* binder which is located in the E760 counting room. The procedures have evolved with the data taking. Below is a summary of the procedures during data taking and monitoring.

The largest unit of E760 data taking is a beam fill or $\bar{p}$ stack. The accumulation of $\bar{p}$'s (stacking) takes between 1.5 and 3.0 days; stacking rates vary between 0.2 and 1.0 mA/hr. After stacking and initial beam cooling, the beam is decelerated to the correct momentum and further cooled to reduce the momentum spread. The time between the end of stacking and the beam being ready for data taking can be several hours.

While the beam is being cooled, several steps are necessary to prepare the read-out electronics and data acquisition system. All of the electronics are essentially reinitialized. The detector components are turned on to operating voltages to allow for some initial warmup period: 15 minutes has been sufficient. The programmable logic units other than the MLUs are set up; the outputs of these units define most of the hardware bits which are the inputs to the MLUs. The MLUs are programmed when the hardware triggers are downloaded to the units. The ACP system is initialized by loading the node programs on to the CPUs. The VAX data acquisition program is then used to take pedestals for all of the FERA ADCs with the gas jet off. A program analyzes and determines pedestal values; the shift crew then compares the pedestal values and widths to a previous set of pedestals. If the new set of pedestals is acceptable, the pedestal values and widths are recorded into a data base. The ACP software triggers can then be prepared; the calorimeter gain constants can also be prepared. The software triggers have been consistent; the gain constants are updated every few stacks.

When the beam has been determined stable and the spread of momentum is considered appropriate, the gas jet is turned on. The VAX data acquisition program is started, which requires the $\bar{p}$ momentum to be entered to within a few MeV/c. The $\bar{p}$ momentum, the software triggers, gain constants, pedestals and ACP3 parameters are downloaded to each slave node by the VAX data acquisition program. Each slave node program is then initialized and calculates the lookup tables discussed in section 5.4. The visual scalers are checked against previous rates while an initial instantaneous luminosity is determined. If both the rates and luminosity are acceptable, then the VAX data acquisition program initiates data acquisition.

The VAX data acquisition program passes events to two separate monitor programs. The non-physics events (e.g. ACNET and scaler data) are passed to the front end monitor program which allows monitoring the data acquisition for changes over a long period of time. A separate VAX workstation is dedicated to receiving the physics events and processing the events with an online detector program. The online detector program produces histograms of quantities, such as hit maps and energy spectra, to monitor all aspects of the components of the detector for a run.

After the data acquisition is started, the detector monitor program is used to monitor the detector components continually. The front end monitor does the same for the scaler and ACNET data. The scalar rates are checked visually every few hours. Once a shift, a gas check is done to monitor the amount of gas in reserve and the pressures for the gas jet and the detector components which use gases.

An E760 run constitutes a data set which is written to one 8 mm tape. The length of a run has varied in time (half an hour to several hours) and integrated luminosity (between 20 and 100 $pb^{-1}$). The change of runs is done without exiting the data acquisition program and takes less than a minute.

## 5.7 1991 Data Taking Summary

During the 1991 FNAL fixed target run, E760 collected $\approx 30$ $pb^{-1}$ of data ranging in center of mass energies from 2950 MeV (below the $\eta_c$ resonance) to 4200 MeV (the injection $\bar{p}$ momentum of 8.9 GeV/c). Nearly half of this was dedicated to the search for the $^1P_1$. The data was taken over the course of four months interspersed with data taking involving the resonances $\eta_c$, $J/\psi$, $\chi_2$, and $\psi'$, as well as searching for the $\eta_c'$.

Parts of sixteen stacks were dedicated for the $^1P_1$ search. The luminosity weighted center of mass energy and integrated luminosity involved for the charged and neutral analyses of this thesis is presented in table 5.9. The stacks are labelled in chronological order; the data and running conditions are sometimes referred to by stack number. The difference between the integrated luminosities of the charged and neutral analyses is due to trouble using the neutral DSTs (these DSTs are discussed in the next chapter) and the trigger conditions. The neutral DSTs start with the $3^{rd}$ stack due to the FCAL OR bit not being available to the trigger before this stack.

| Stack Number | Center of Mass Energy (MeV) | Integrated Luminosity ($nb^{-1}$) Charged An. | Neutral An. |
|---|---|---|---|
| 1 | 3524.197 | 822.71 | |
| 2 | 3523.902 | 783.71 | |
| 3 | 3522.498 | 979.91 | 924.04† |
| 4 | 3523.119 | 489.53 | 445.75† |
| 5 | 3524.867 | 1040.81 | 1040.81 |
| 6 | 3526.178 | 1336.72 | 1134.58 |
| 7 | 3525.468 | 1310.38 | 1251.92 |
| 8 | 3525.999 | 1364.09 | 1298.20 |
| 9 | 3526.460 | 1139.62 | 932.63 |
| 10 | 3525.133 | 1017.41 | 781.40 |
| 11 | 3527.011 | 1016.39 | 804.91 |
| 12 | 3525.713 | 885.00 | 818.73 |
| 13 | 3526.104 | 940.39 | 877.47 |
| 14 | 3525.914 | 980.30 | 527.69 |
| 15 | 3526.336 | 910.96 | 910.96 |
| 16 | 3526.074 | 875.59 | 667.55 |

Table 5.9: The energies and integrated luminosities for the charged and neutral analyses for the sixteen stacks dedicated to the $^1P_1$ search. Trouble with the neutral DSTs account for the different integrated luminosities; the neutral DSTs were not started until the $3^{rd}$ stack.
†The forward calorimeter was in veto for the neutral total energy trigger for part of stacks 3 and 4; the integrated luminosities used for events collected by this trigger for the $3^{rd}$ and $4^{th}$ stacks are 558.64 $nb^{-1}$ and 436.60 $nb^{-1}$, respectively.