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An On-Line Trigger Processor for Large Transverse Energy Events*

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AN ON-LINE TRIGGER PROCESSOR FOR LARGE TRANSVERSE ENERGY EVENTS

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Abstract

A trigger processor for the selection of events in which photons of large transverse momentum are detected by a lead and scintillating glass calorimeter was designed, constructed, and operated at interaction rates ranging from 2 kHz to 2 MHz. The system achieved supressions of the raw interaction rate of as much as 1×10^{-5}. Raw distributions of tranverse momenta and direct photon event sensitivities are presented from data taken with 300 GeV/c pion and proton beams on a lithium target.

Introduction

A scintillation and lead glass electromagnetic calorimeter was built to study charmonium and direct photon production in hadronic collisions in experiment E705 at Fermilab [1].

A fast trigger processor, the Cluster Finder, was designed and built in order to select high transverse momentum (P_T) photon candidates above four thresholds, which could be set to any value. During the 1987 run of the experiment they were set to 1.7, 2.5, 3.5 and 4.5 GeV/c.

The data was taken with 300 GeV/c positive and negative pion and proton beams on a lithium target, at interaction rates ranging from 2 kHz to 2 MHz.

The Calorimeter

The calorimeter was located 10m from the center of a 33 cm long Li^7 target (13% of an interaction length). It was composed of three parts:

a) The Active Converter consisted of a Lead Gas Converter (LGC), measuring 105×195 cm^2 and covering the central region of the calorimeter [2] and two longitudinal layers of SCG1-C scintillation glass blocks covering the left and right outer regions. The LGC intended to measure positions of the photons and consisted of 8 sheets of lead (1.73 cm total thickness, 3.8 radiation lengths) interleaved with 8 layers of proportional tubes (1 cm wide) with vertical anode wires and horizontal cathode strips 1.25 cm wide. The eight longitudinal samples were ganged together in both anode and cathode forming channels that were read out by a 12-bit LeCroy 2280 ADC system. The two layers of SCG1-C blocks gave a total of 3.5 radiation lengths. Each block was $7.5 \times 7.5 \times 97.5$ cm^3, was read out by RCA 6342A photomultipliers and was digitized with the E705 precision ADC system [3].

b) The Main Array (fig.1) consisted of 392 glass blocks covering an area of 371×195 cm^2. The areas inside and outside the dashed lines contained SCG1-C scintillation glass blocks of 21 radiation lengths and SF5 lead glass blocks of 18 radiation lengths respectively. The small SCG1-C blocks had a cross section of 7.5×7.5 cm^2 and were read out by RCA 6342A photomultipliers. The large blocks had a cross section of 15×15 cm^2 and were read out by EMI 9791KB photomultipliers. A hole was left in the center measuring 30×15 cm^2.

c) The Gas Tube Hodoscope [4] was used to determine the photon positions in the regions not covered by the LGC. It consisted of two planes of conducting plastic proportional tubes (7 mm wide) with induced strip readout and was positioned between the scintillating glass active converter and the main array. The tube and strip signals were digitized with the same 12-bit LeCroy 2280 ADC system as the LGC.

The Trigger

In the Cluster Finder, all the blocks were processed in parallel within an event; events were processed in a pipeline mode as they occurred. The P_T trigger was formed in three steps:

a) Cluster Finding

A *cluster* was defined as a block and its neighbors (i.e. all the blocks that were sharing an edge or a corner with the central block), in order to contain nearly all the energy of a photon hit. Fig.1 shows such clusters in different regions of the main array. The number of blocks in a cluster could vary from 7 to 10. The criteria for finding a high P_T candidate cluster were: a) its central block would not be an edge block (next to the hole or in the outer layer of the calorimeter) and, b) the energy of this block would be greater than its nearest neighbors, as well as a common noise rejection threshold, set at 20 mVolts. In such a case the block was called a "Peak and Over Threshold" (POT) block.

b) Energy Summation and P_T Conversion

The energies of all the blocks in the cluster with a POT block were added together and the sum was multiplied by a scaling factor in order to be converted to P_T (*). This factor depended on the

(*) The term transverse momentum (P_T) is used instead of transverse energy. The two terms are equivalent since they refer to photons throughout the paper.

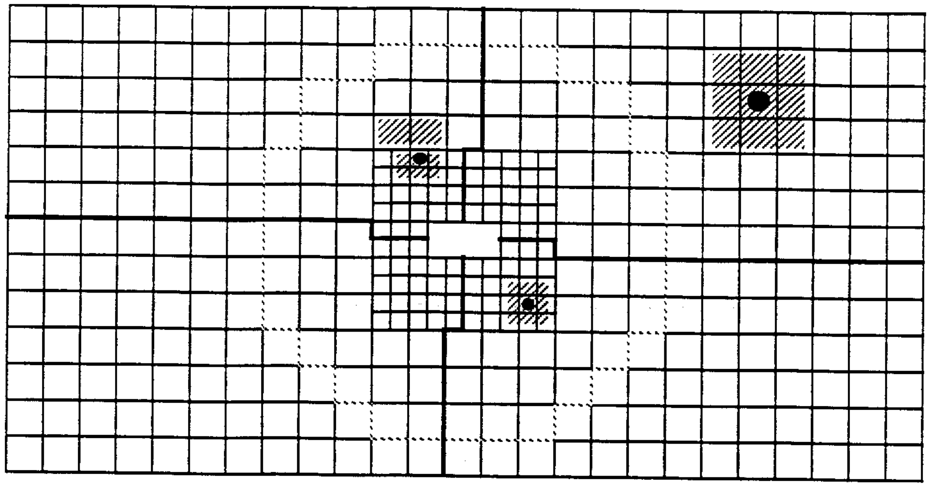

Fig. 1. Main Array. The thick lines show the boundaries of the four quadrants. The shadowed areas show different cluster types with their central blocks (black dots)

position of the POT block, and was equal to the sine of the angle between the beam and the center of the block, as seen from the center of the target.

c) Trigger Decision

The P_T of the cluster was compared to each of four thresholds (set to 1.7, 2.5, 3.5, 4.5 GeV/c) and the results, in coincidence with an interaction trigger, formed four trigger levels P_{T1}, P_{T2}, P_{T3}, P_{T4}. An interaction trigger consisted of a target interaction, defined as the coincidence of a beam particle with at least two hits in a charged particle hodoscope, located 9.5 m from the target. The four levels were formed separately in four quadrants (their boundaries are noted in fig.3 with thick lines) and then were ORed together forming four P_T triggers, which caused the readout of the event of interest, including the latches of the identified clusters and their P_T levels.

A diphoton trigger was also formed as the coincidence of two P_{T1} (or higher level) triggers from two opposite quadrants.

Functional Description and Implementation

Fig. 2 shows a schematic diagram of the modules and connections that form the P_T trigger.

The signals originating from the glass array/phototube system were carried by 392 RG-8 cables, 53.5m long, to the inputs of the charge integrating precision ADC cards. These cards provided 200 nsec analog pulses, proportional to the charge integrals of their input signals. Each pulse was sent to a corresponding channel of an interconnected system of 54 ICON ("interconnective") modules, where it was input as a central signal and "exported" to other channels, to serve as a neighbor signal.

Every ICON module had eight channels, each of which was assigned to one block of the Main Array. These modules resided in four custom made crates and were organized in four groups, corresponding to the four quadrants of the Main Array. All channels were processed in parallel in order to decide if they were POT channels, to sum their energies with the energies of their neighbors, to convert the total energies to transverse momenta, and to compare those with the four thresholds.

For each channel, the four bits, resulting from these comparisons, were latched by the interaction strobe and then fed simultaneously into the trigger pathway and the four PT EXTRACTOR modules (through backplane connections) which collected the P_T information of every channel. The latched P_T bits were ORed with the corresponding bits of the other channels of each ICON module and the results were in turn ORed with all the other ICONs assigned to a detector quadrant. A ribbon cable, acting as a wire OR bus, was used for this purpose, and also brought the interaction strobe and the reset to the ICON modules.

The four OR cables from the four quadrants were sent to the trigger logic which was implemented in the QUAD OR module. In this module, the bits of the same P_T of the four quadrants were ORed together, in order to form the triggers which selected events with photons of transverse momentum greater than the four corresponding thresholds. In addition, all the P_{T1} bits of every two opposite quadrants were also ANDed and the two results were ORed in order to form the diphoton trigger, which selected events with two photons of P_T greater than 1.7 GeV/c (first P_T threshold).

For monitoring purposes the P_T information from the PT EXTRACTOR modules was sent to LeCroy 4448 latches in order to be recorded. For the same purposes a cluster flag bit (Latched Peak and Over Threshold, or LPOT) of each channel was also sent to these latches.

ICON Circuit

The ICON module processed signals that arrived via an 8-channel ribbon coaxial cable from a corresponding ADC card. These eight lines formed the inputs to eight BUF-03 buffers that drove the signal distribution on a large wire-wrap backplane. On this backplane each channel was connected to neighbor channels via wire-wrap connections. The assignment of channels was such that each board handled signals from pairs of neighboring blocks. The eight channels per card thus came as four channel pairs. This minimized the necessary number of wire-wrap connections.

All these signals were input via a 200-pin AMP connector whose mated connector was part of the backplane. The signals of the

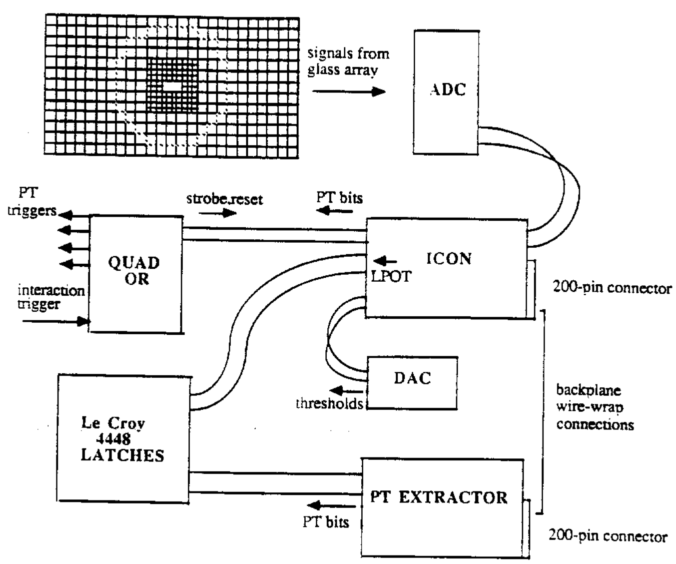

Fig. 2. Block diagram of the PT trigger processor.

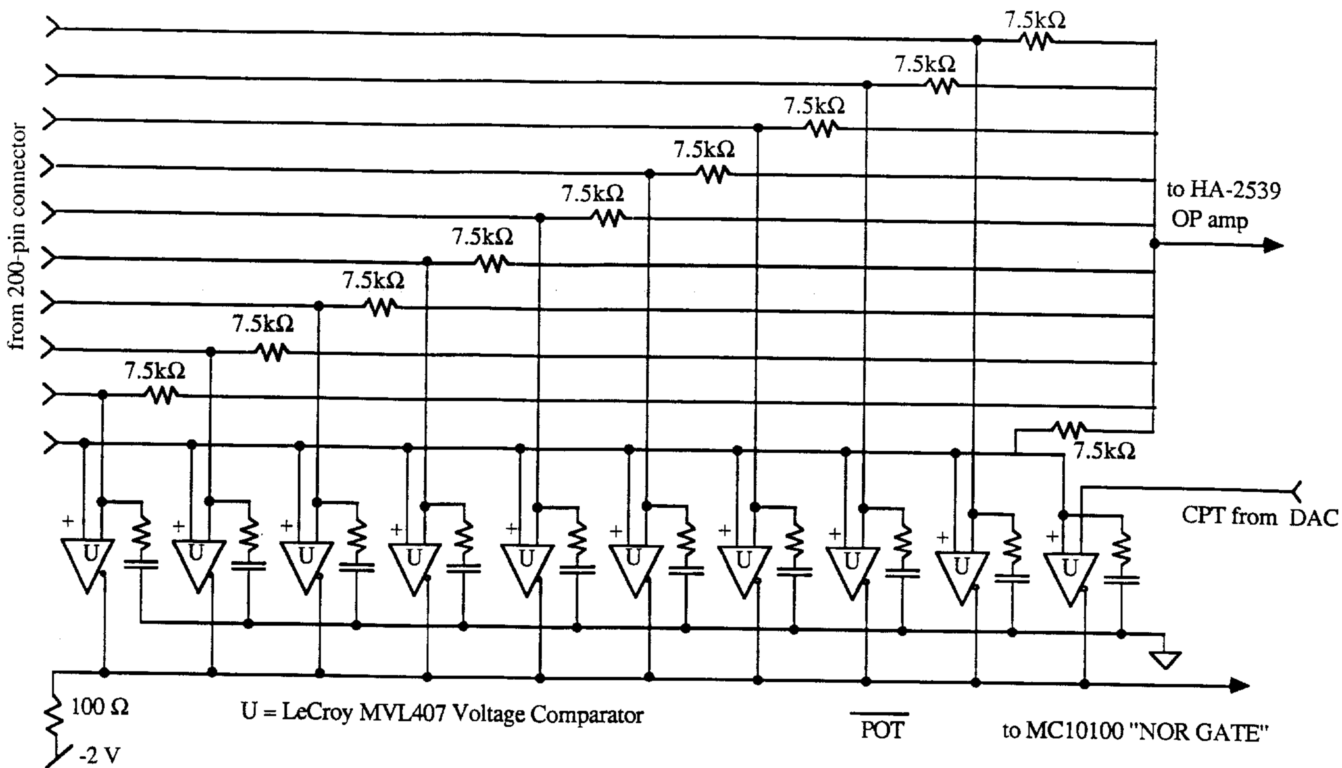

Fig. 3. Interchannel comparison circuit and summation resistors

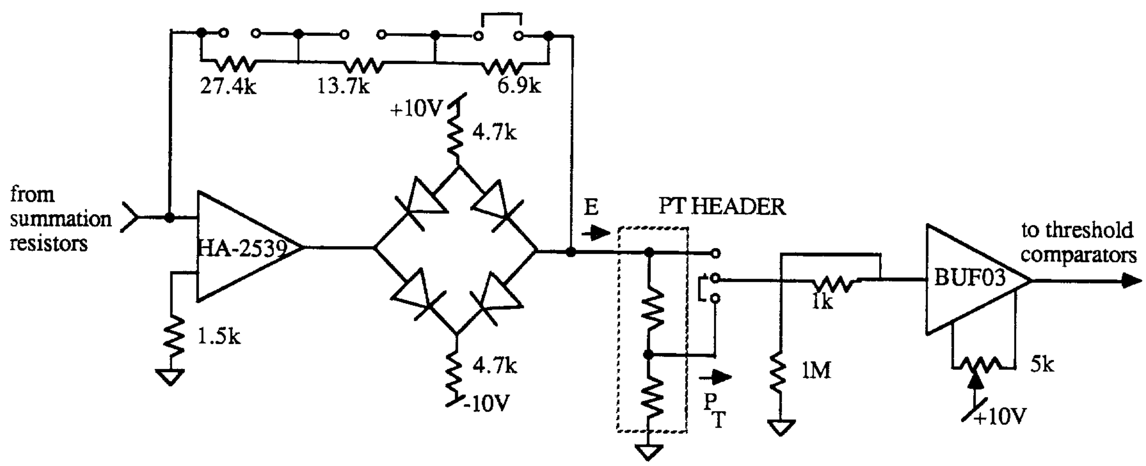

Fig. 4. Summing, energy to transverse momentum conversion, and DC offset cancelling circuits

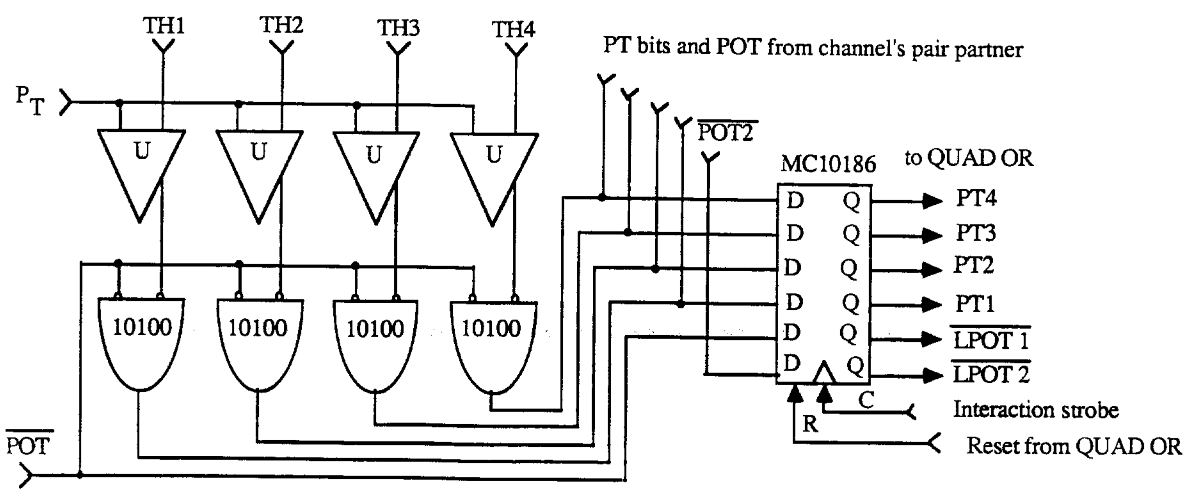

Fig. 5. P_T threshold comparison and P_T bits latching circuits

central block and its neighbors, within every cluster, were then parallel processed by both the interchannel comparison circuits and the summation Operational Amplifier (fig.3). The interchannel comparison circuitry sought to find if the signal of the central channel was above all of its neighbors (up to a maximum of nine) and a Common Peak Threshold (CPT) DC signal that acted as noise rejector. LeCroy MVL407 quad comparators were used for this purpose. To AND the ten comparators (9 neighbors + 1 threshold) together, the ten low true outputs were wired together to form a low true ECL wire AND. This signal was called POT (Peak and Over Threshold).

At the same time, the central block and its neighbor signals were summed by a Harris 2539 Op Amp using ten 7.5 kΩ summing input resistors and a 6.81 kΩ feedback resistor. The summing circuitry, shown in fig.4, fed its output to a 2 kΩ load (PT HEADER).

The 2 kΩ output load was part of the next stage processing, the conversion of energy to transverse momentum. The sum formed by the Op Amp was proportional to the energy deposited in the detector block and its neighbors. Conversion to transverse momentum meant multiplication by $\sin\theta$, where θ is the angle between the beam and the line connecting the center of the block with the center of the target. The 2 kΩ load was a voltage divider, whose output of was the input voltage times a constant multiple of $\sin\theta$. The constant multiple was equal to $1/\sin\theta_{max}$, where θ_{max} is the angle between the beam and the center of the farthest trigger block, as seen from the target's center. This increased the interval of the conversion factor from $[0, \sin\theta_{max}]$ to $[0, 1]$ and made the choice of the resistors more flexible. The two resistors were on an 8-pin Augat DIP header and their values varied from channel to channel. As a result, each ICON card was unique. The E to P_T conversion was optional; a jumper on each channel selected between the voltage divided and undivided signal. This made it easier to debug the system.

Next, the signal came to a BUF-03 which drove the P_T threshold comparators. The BUF-03 was connected to an offset canceling circuit, in order to adjust the DC offsets that appeared at the output of the buffer in every channel.

The P_T pulse then went to four LeCroy MVL407 comparators (fig.5), where it was compared with four DC levels (labeled TH1 through TH4) corresponding to the four P_T thresholds. The P_T and the CPT thresholds were derived from a 12 bit camac DAC module and were sent to the ICON modules through a common bus.

The result pulses of the comparisons were sent to a set of four MC10100 NOR gates, which were acting as low true input AND gates. Each gate had another input which was common to the four gates of the MC10100. This common input was connected to POT, so that a gate would only fire if the corresponding ten cluster identifying comparators had found that this gate's channel was a POT channel.

At this point, each of the four AND outputs of the channel were ORed with the corresponding outputs of the channel's paired partner. As was previously described in the first paragraph of this section, only adjacent detector blocks were members of a channel pair. Thus, only one member could assert POT.

The four P_T bits were then sent to an MC10186 hex latch along with the two POT lines of the channel pair. The strobe to this latch was a copy of the interaction trigger of the experiment, and the reset was a delayed copy of the strobe. The leading edge of the strobe was timed to coincide with the midpoint of the P_T bit pulses. All four 10186s per ICON were driven from an MC10188 digital buffer that received the strobe and the reset from a ribbon cable bus going to a 20-pin connector on the front of each ICON.

The 16 latched P_T bits were split and sent to the 200-pin connector to be distributed to the four PT EXTRACTOR modules, and to a set of MC10109 OR gates at the front of the card. Each of these four gates ORed the four bits of a particular P_T threshold, producing four Fast Trigger output lines. These lines went out the 20-pin connector, from which the latch strobe and reset were input, to the QUAD OR module where they formed the four P_T and the Diphoton triggers, previously described.

The total time to form the trigger, as determined from the leading edge of the P_T trigger pulse at the output of the ICON card to the peak of the analog pulse leaving the precision ADC cards, was of the order of 85 nsec.

Performance and Monitoring

The Cluster Finder trigger processor was first used in the 1985 run and was in full operation during the 1987 run of the Fermilab Experiment 705.

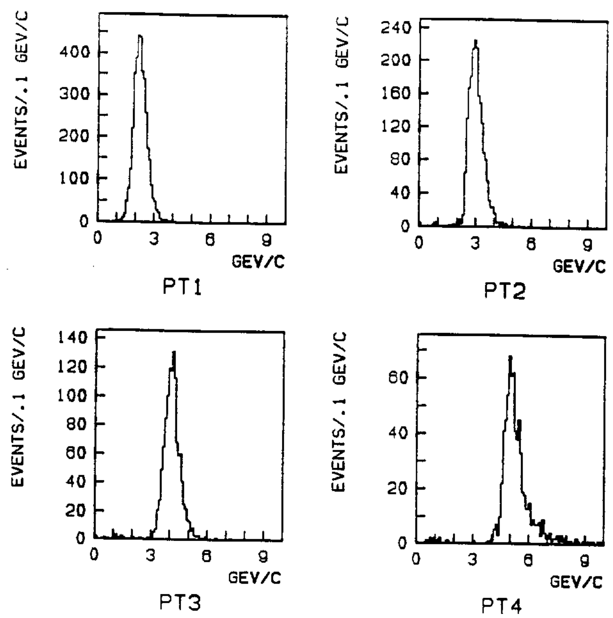

Fig. 6. Raw P_T distributions

During its operation, it was monitored by an on-line FORTRAN program which was a software simulation of the Cluster Finder. This program read the precision ADC cards and the 4448 latches. It converted the ADC counts of each channel to energy, formed clusters in the same way as the Cluster Finder, converted their energies to transverse momenta, and compared these values with the four P_T thresholds, forming a four bit word for every cluster. By combining the information of the 4448 LPOT and P_T latches, the program could also find which cluster hardware asserted what P_T. Thus, the monitor could check if the hardware and software clusters as well as their asserted P_T bits were in agreement.

Fig.6 shows the raw P_T distributions of the clusters that caused the trigger, as they were recorded from the on-line monitor. The four thresholds (1.7, 2.5, 3.5, 4.5 GeV/c) are clearly seen.

As previously mentioned, all thresholds were set by a Digital to Analog Converter module (DAC). The calibration of the DAC was done by using electron beam of 30 GeV/c momentum, hitting the centers of different blocks, whose positions were such that the corresponding channels of the cluster finder would see different values of P_T, in the interval of 0 to 6 GeV/c. For every block the maximum value of the threshold (in mV) that was causing the corresponding P_T trigger was recorded. The P_T threshold in GeV/c versus the Pulse Height in mVolts was plotted and fitted in a straight line by the formula:

$$P_T\,(\mathrm{GeV/c}) = 0.0418 + 0.0237 \cdot \mathrm{P.H.}\,(\mathrm{mV})$$

The noise level throughout the cluster finder was 8 mV, which corresponds to 190 MeV/c error in the transverse momentum threshold.

The experiment used four of the five implemented triggers, the PT2, PT3, PT4 and the Diphoton. The mean interaction rate at which the experiment ran was about 650 kHz. At this rate, the supression factors achieved by these triggers were of the order of 2.5×10^{-3}, 1.2×10^{-4}, 1.1×10^{-5} and 4.5×10^{-4} respectively.

During the 1987 run, the experiment recorded a good amount of data that should allow to study the direct photon production at high transverse momenta up to 8 GeV/c. Table 1. shows the event sensitivity for direct photon production for various beams, in comparison with the sensitivities reported by the CERN photon experiments NA24 [5], WA70 [6] and UA6 [7], which run in the same energy range. E705 has 2-5 times better sensitivity than NA24 and WA70 for $\pi^{\pm}$ induced production and about the same as WA70 for proton induced production.

TABLE 1 Direct photon event sensitivities

Experiment	Sensitivities (events/pb/nucleon)				Beam Momentum (GeV/c)	Target, Length
	$\pi-$	$\overline{p}$	$\pi+$	p		
E705	7.70	0.16	7.00	6.40	300	Li^7 33 cm
NA24	1.33	—	0.19	0.45	300	LH_2 1m
WA70	3.50	—	1.30	5.20	280	LH_2 1m
UA6	—	1.00	—	1.60	315	H_2 gas jet

Conclusion

A fast trigger processor was designed, built and used in order to select events with photons of high transverse momenta, produced by positive and negative pion and proton beams. The suppression factor in selecting events with cluster $P_T > 4.5$ GeV/c was of the order of 1×10^{-5}. The system was very reliable throughout its operation during the experiment run, allowing E705 to record a sample of events much higher than the preceding experiments, in order to study the direct photon production at transverse momenta up to 8 GeV/c.

Acknowledgments

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References

[1] Fermilab Proposal E-705, 1981.

[2] L. Spiegel, et al., "Performance of a Lead Radiator, Gas Tube Calorimeter," to be presented at the IEEE Conferance on Nuclear Science, Orlando, Florida, November 1988.

[3] S. W. Delchamps, et al., "Precision Charge Amplification and Digitization System for a lead and scintillating glass array," to be presented at the IEEE Conferance on Nuclear Science, Orlando, Florida, November 1988.

[4] C. M. Jenkins, et al., "Results from the E-705 Electromagnetic Shower Position Detector," to be presented at the IEEE Conferance on Nuclear Science, Orlando, Florida, November 1988.

[5] C. De Marzo, et al., "Measurement of direct photon production at large transverse momentum in π^-p, π^+p and pp collisions at 300 GeV/c," Phys. Rev. D, vol. 36, pp. 8-15, 1987.

[6] M. Bonesini, et al., "High Transverse Momentum prompt photon production by π^+ and π^- on protons at 280 GeV/c," Z. Phys. C, vol. 37, p. 535, 1988.

[7] A. Bernasconi, et al., "Preliminary results on inclusive γ cross section in $\overline{p}p$ collisions at $\sqrt{s} = 24.3$ GeV/c from UA6 experiment," presented at the International Europhysics Conferance on High Energy Physics, Uppsala, Sweden, July 1987.