# THE MICROPROGRAMMABLE PROCESSOR ESOP IN THE AFS TRIGGER SYSTEM

S. Cairanti[2], B. Heck[2], J.E. Hooper[3], T. Killian[1], S.O. Nielsen[3],
L. Rosselet[2], B.L. Schistad[3].

## ABSTRACT

A programmable processor is used on-line in the trigger system of the Axial Field Spectrometer for selecting events with a charged particle of high transverse momentum. After having formed a pretrigger by using signals from proportional chambers, a selected part of the data from the cylindrical drift chamber is transfered into the memory of the processor. The track sagitta of the triggering particle is calculated. Only if it is smaller than a predefined value the event is accepted and recorded on magnetic tape. The implementation of the processor in the electronics of the experiment and the software procedures are discussed together with the performance of the system.

## 1. INTRODUCTION

Two of the most remarkable features of QCD are its conceptual simplicity on the one hand, and its success in resisting clear-cut experimental verification on the other. Constituent quark scattering is expected to occur in p-p collisions, but there is no obvious algorithm for extracting q-q cross-sections by looking at a large sample of multi-prong p-p events. It is reasonable, however, that if the momentum transfer in the q-q interaction is large enough, the dressing of the scattered quarks will not be strongly influenced by the remaining, spectator quarks. This leads one to look at events which have one or more particles at high transverse momentum. The ESOP system discussed in this paper is part of a general experimental program to study high $p_T$ phenomena[1]. In this instance, we are interested in the structure of events triggered on a single particle of high $p_T$, e.g., the structure of recoil jets. We also wish to extend the single-particle inclusive spectra out to around 10.0 GeV/c.

## 2. HARDWARE DESCRIPTION

A general layout of the apparatus is shown in Fig. 1. The magnetic field is pointing into the plane of the paper, parallel to the beam direction. The proportional and drift chamber wires are strung parallel to the field, so as to measure distances in the bent direction.

The drift chamber is subdivided radially into three electrically distinct "crowns" , and azimuthally into $4^{o}$ "sectors". In addition, it is split vertically into two halves to facilitate rapid access. The drift chamber is shown in detail in Fig. 2. The sense wires are staggered by ± 400 $\mu$ with respect to the radius vector. This helps resolve the well-known left-right ambiguity, and is essential to the ESOP algorithm.

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1) Brookhaven National Laboratory, Upton. N.Y., USA.

2) CERN, Geneva, Switzerland.

3) Niels Bohr Institute, Copenhagen, Denmark.

### 2.1. The Trigger

The earliest trigger decision is taken by coincidence logic involving the barrel hodoscope counters and the proportional chambers. Signals from 16-wire groups in the chambers are OR'ed together and sent up to the counting room on fast air-core cables, along with information from the scintillators. A three-fold coincidence is required such that a barrel counter and groups from PC1 and PC2 are consistent with a track coming from the interaction diamond. The roadwidths involved correspond to a nominal threshold of about 1.0 GeV/c.

If this coincidence is satisfied, the wire numbers from PC1 and PC2 are used to address a random access memory to determine if there is a possible track with $p_T$ above a given threshold, which may be varied from 2.5 to 5.0 GeV/c. The RAM contains a sparse matrix of 0's and 1's, the latter being stored as PC 1/2 wire address combinations corresponding to desired tracks. The "width" of the 1's pattern determines the momentum threshold. The RAM is described in detail in reference 2).

A valid track candidate generates a pointer to a pair of drift chamber sectors through which the track should pass. More than one track is allowed; in general a list of up to three sector pairs is produced. These sectors will be analysed in detail by ESOP.

If the event does not pass muster according to the RAM, it is aborted immediately. Otherwise, the data acquisition system begins digitization and readout. Here we are only concerned with a small part of this process, namely, how drift chamber time information finds its way to ESOP.

### 2.2. The DTR System

The drift chamber timing is done with a CERN standard, the so-called drift time recorder (DTR) system, described in reference 3). It is an individual start, common stop, system, with a basic clock period of 4 ns. The stop time, interpolated to 1 ns, is available but is not used by ESOP. (Every 2ns of drift is fairly precisely 100 μ). Up to 16 hits per wire are allowed.

Readout follows a CAMAC protocol, and results in a list of words made up of module number (3 bits), channel number within module (4 bits) and drift time (7 bits). Data from groups of 10 or 11 modules are separated by block marker words.

The wires are assigned to DTR units in an essentially azimuthal fashion, so that measurements on a given track will be independent. Within each sector, however, sixteen so-called ESOP wires are singled out for special treatment. They are routed to their own DTR unit so they can be easily read out separately by ESOP on a sector by sector basis.

One of the difficulties with the DTR's is that reading them out clears their memories. Consequently it is not possible for the ESOP DTR's to be read both by ESOP itself and then subsequently by the data-acquisition computer. This problem is avoided by reading the ESOP DTR's into a buffer memory, which is accessible by both ESOP and the data acquisition CAMAC system.

### 2.3. The Processor

ESOP is a sixteen-bit, microprogrammable processor, with associated data and buffer memory, and a separate instruction memory. It has 4096 words of data memory, and 1024 words of 48-bit instruction memory. It communicates with the outside world via CAMAC. Its basic cycle time is 125 ns. ESOP is described in detail in reference[5).]

## 3. SOFTWARE DESCRIPTION

ESOP is programmed exclusively in machine language, with the aid of a cross-assembler which runs on CERN's IBM/370. Programs may be tested on a simulator which runs on the IBM. Editing and maintenance are performed using the WYLBUR system. Object files are loaded into ESOP from the data-acquisition PDP-11/60, which communicates with the IBM via the CERNET network. A basically parallel system, with the exception of the ESOP hardware, is implemented on the UNIVAC 1110 at the Niels Bohr Institute.

In addition to the track-finding program described below, we have developed a variety of diagnostic routines which ensure the correct functioning of the various parts of the system.

The philosophy used in programming has been that all data structures should be integral binary, e.g., array lengths should be a power of 2; packing, where necessary, is done bit-wise; etc. Multiplication and division are forbidden except when they can be implemented as a shift.

The trigger program (TRIGGR) may be naturally divided into three parts: an 1/0 section (INOUT), a data-formating section (PREPRO), and the track-finding algorithm (STAGGR). INOUT is entered on receipt of an external interrupt from the trigger system. It reads the DTR's indicated by the RAM pointer(s) into ESOP's data memory, and is basically a CAMAC program . PREPRO and STAGGR are then executed once for each RAM pointer.

### 3.1. Data Formating

The 16 wires from each sector used by ESOP consist of 4 batches of 4 wires each (cf. Fig. 2). The centers of batches are equally spaced along the radius of the drift chamber. The RAM pointer always indicates a pair of adjacent sectors, so there are 8 batches to be examined.

Before starting any analysis the total amount of DTR data available is required to be within certain lower and upper limits. If the sectors are too sparse or too noisy, they are not processed.

PREPRO rearranges the raw data into fixed-format blocks, one for each sector. A block in turn consists of 4 sub-blocks, one for each batch. A sub-block has 1 word for sector identifier, 2 data words for each wire, and 3 counters, making 12 words in all. The counters are:

- the number of hits in the batch;
- the sum of the hit times (MPSUM). If, as is often the case, there is one hit per wire, MPSUM is the average drift time in ns, and is referred to as the master point for the batch. (Notice that the wire staggering cancels out);
- the sum of the hit times on the odd numbered wires, minus the sum of the hit times on the even numbered wires (QSUM). Due to the staggering, the sign of QSUM indicates

on which side of the wire plane the particle passed (that is, if there is one hit per wire, and the track is not crossing the wire plane in the middle of the batch).

The DTR time is subtracted from the common stop time before being stored. The resulting drift time is required to be less than the maximum possible time. The latter is different for each batch since the cells widen with radius.

### 3.2. The Track-finding Algorithm

In the simplest cases, STAGGR looks only at the master points calculated in PREPRO. They must have QSUM's not too large in absolute value. If they fall in the second sector of the RAM pair, they are translated into the coordinate system of the first. If there are not exactly 4 hits in a particular batch, however, the situation is more complicated. If there are less than three hits, the batch is abandoned. Otherwise, the missing wire, if any, is assigned the time of its neighbour, and a loop over the individual drift times in the batch is performed to generate a list of master points.

Once the lists of master points for each batch have been assembled, the track-finding proper begins. Pairs of master points from batches 2 and 3 are examined to see if the line joining them points back towards the diamond. If such a pair is found, it is checked against all possible pairs of master points from batches 1 and 4, and the curvature of the best parabola passing near all four points is calculated. (The curvature is a linear function of the four points, and because of the equal radial spacing of the points, is essentially the sum of points 1 and 4 minus the sum of points 2 and 3). No chi-squared is calculated, but the slopes of the 1-4 and 2-3 lines are checked to eliminate the "zig-zag" cases. Whenever a sufficiently small curvature is found, the event is accepted immediately. Conversely, all possible master point combinations must be tested before the event is rejected.

## 4. PERFORMANCE

Perhaps the major problem to be addressed by the experimental set-up is that of rates. The total event rate at typical ISR luminosities is of the order of 0.7 MHz, whereas the rate for events having a particles with $p_T > 5.0$ GeV/c is only about 1 Hz. The trigger is required to reject events with high efficiency if the dead time is not to be unmanageably large. A more detailed breakdown of the rates at different levels in the trigger is shown in Table 1. The numbers are for a typical luminosity of $2 \times 10^{31}/\text{cm}^2/\text{s}$

| System | Rate | Decision time |
|---|---|---|
| Barrel counters | $6 \times 10^5$/s | 10 ns |
| PC OR Pretrigger | $6 \times 10^4$/s | 60 ns |
| RAM system | $1 \times 10^4$/s | 700 ns |
| ESOP | few /s | 250 μs |

Table 1: Rates within the high $p_T$ single particle trigger.

Fig. 3 shows the distribution of the number of processor cycles required to accept or reject a pretriggered event. The peaks at small times are from simple 1-hit-per-wire events, and there is a long tail from pathological cases.

The lifetime of the system running at a threshold of 5.0 GeV/c is only about 20%, but this is an order of magnitude better than what might be expected if ESOP were replaced by an ordinary minicomputer. It is nearly three orders of magnitude better what one would get by writing all pretriggers to tape, since this takes about 30 ms per events.

### 4.2. Acceptance

The total efficiency of the trigger chain is very high. At a threshold of 5.0 GeV/c, we find 95% acceptance for the PC OR condition, 80% for the RAM, and 65% for the full chain. The number increases with the momentum of the triggering particle, as shown in Fig. 4.

It is found after final analysis that only some fraction of ESOP triggered events in fact have a particle above threshold. There are two reasons for this. First of all, the resolution of the drift chamber is considerably reduced by using only 16 wires to measure the track, and secondly, the ESOP algorithm, being optimized for speed, can be easily fooled by multiple low $p_T$ tracks in a sector.

The situation is summarized in Table 2. Even though the final fraction of events used decreases with $p_T$ (which is to be expected, given the limited resolution and steeply falling spectrum), the rejection factor increases, so the trigger remains "cost-effective".

| Threshold (GeV) | $\Delta p/p^2$ ($GeV^{-2}$) | Rejection factor | Final fraction | Reject time | Accept time |
|---|---|---|---|---|---|
| 2.5 | 10% | 500 | 7.5% | 120μs | 290μs |
| 5.0 | 10% | 2000 | 1.5% | 120μs | 370μs |

Table 2: Accept/reject factors for the high $p_T$ trigger

## 5. CONCLUSION

The ESOP system provides an effective means of triggering on events with a single high $p_T$ particle. Speed, efficiency, and contamination in the final sample are all acceptable. We feel that the system as it stands is a fairly optimal match between hardware and software effort and performance.

## REFERENCES

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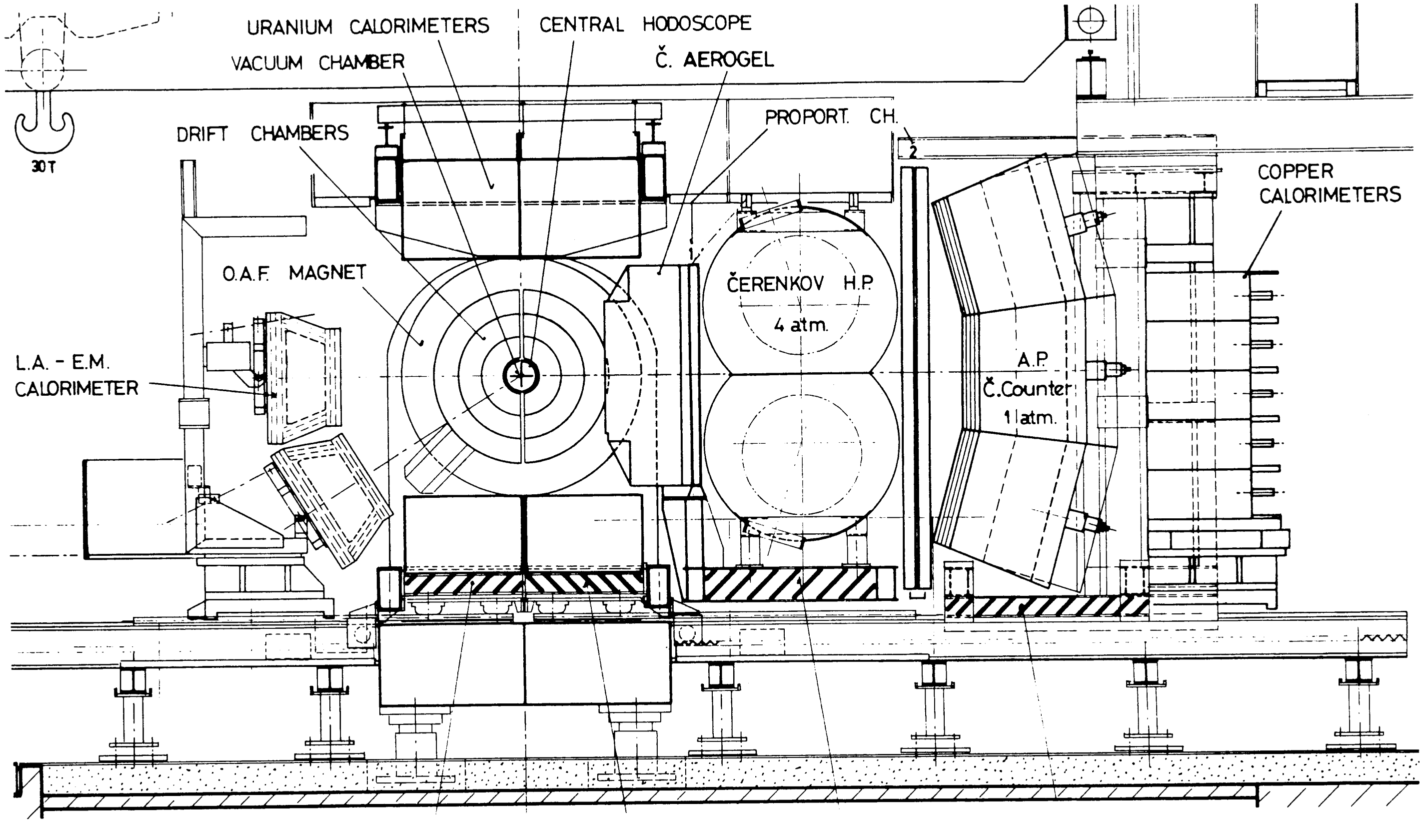

FIG.1: LAYOUT OF THE AFS DETECTOR

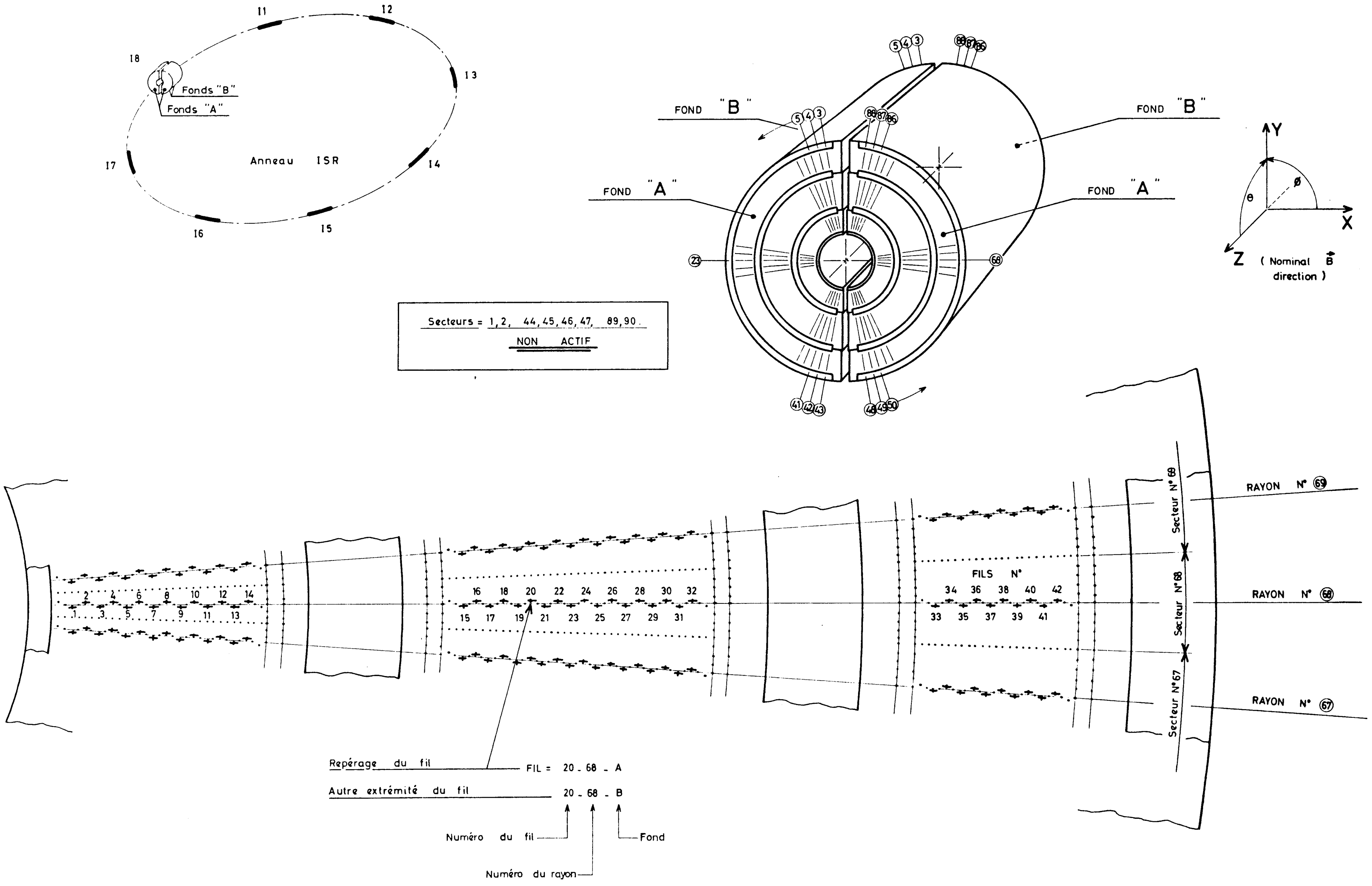

FIG. 2: LAYOUT OF THE AFS DRIFT CHAMBER

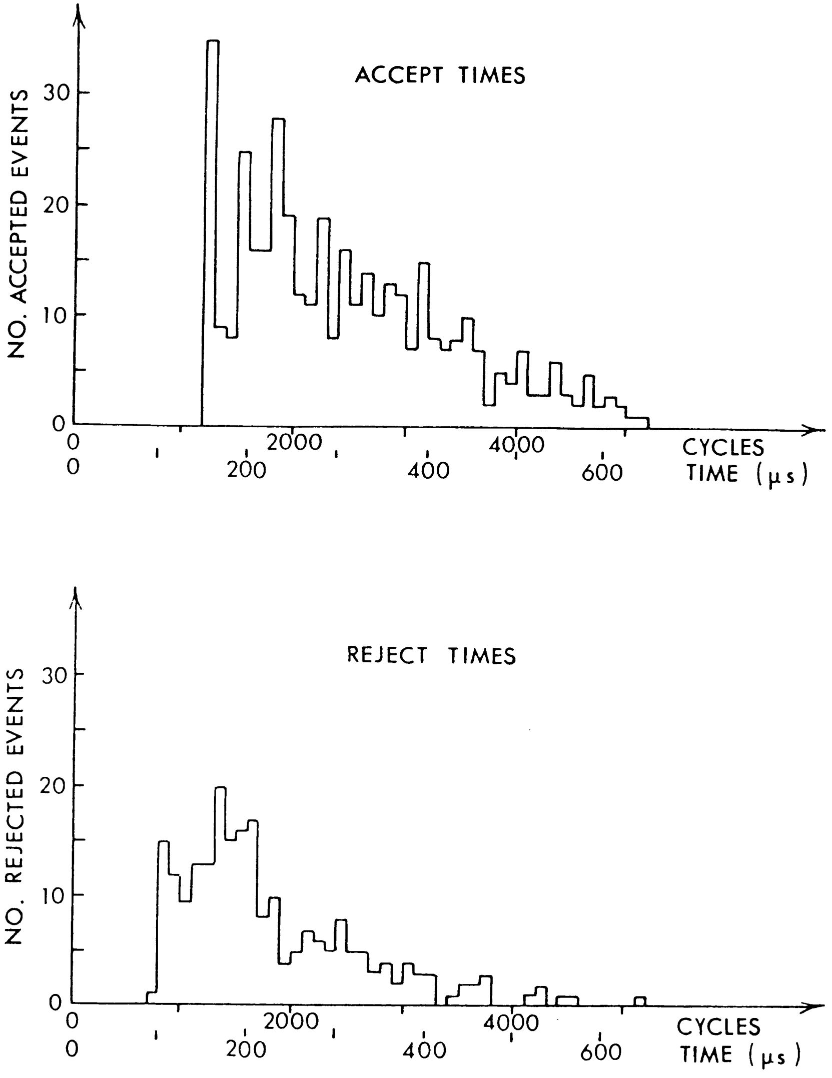

FIG. 3: ACCEPT AND REJECT TIMES OF THE ESOP ALGORITHM

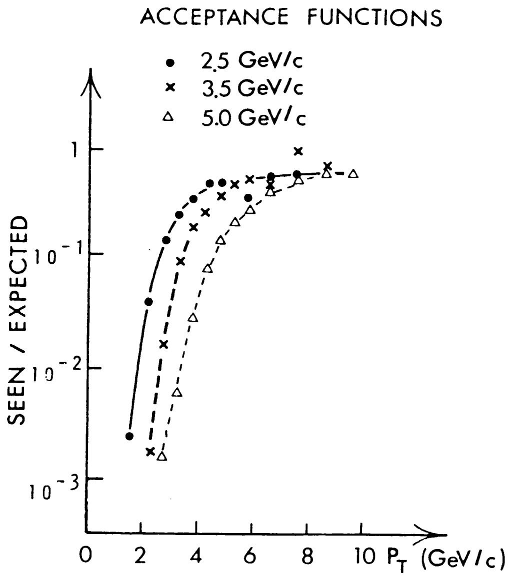

FIG. 4: EFFICIENCY OF THE TRIGGER FOR VARIOUS THRESHOLDS