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SHOWER MAXIMUM TRIGGER FOR ELECTRONS AND PHOTONS AT CDF

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ABSTRACT

For the 1994 Tevatron collider run, CDF has upgraded the electron and photon trigger hardware to make use of shower maximum information from the central shower maximum detector. For electrons, the upgrade has resulted in a 50% reduction in backgrounds while retaining approximately 90% of the signal. The new trigger also eliminates the background to photon triggers from single-phototube discharge.

1. Introduction

Inclusive central electron triggers have provided CDF with a rich stream of data. Studies of the W and Z bosons, as well as the search for and study of the top quark, are carried out in part using electron triggers with a threshold of typically 15-20 GeV. Topics in b physics, including production properties, the identification of exclusive decays, lifetime studies, and in particular the search for rare processes, demand a lower trigger threshold. In addition, the low-threshold electron trigger provides important calibration samples. In the 1992-93 Tevatron collider run, the inclusive electron threshold was 9 GeV, with a 6 GeV threshold trigger prescaled. Instantaneous luminosity was $2-8\times10^{30}\text{cm}^{-2}\text{sec}^{-1}$. The inclusive electron trigger represented about 18% (0.5 μb) of the events accepted by the CDF hardware trigger. A significant improvement in luminosity was anticipated for 1994. A means for reducing the cross section of this trigger without raising the threshold was therefore necessary in order to preserve as much physics potential as possible while keeping the rate of accepted events from becoming unmanageably high. We have alleviated this problem by bringing the shower position information from the central strip chambers (CES) into the second level trigger decision for both the electron and photon triggers.

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The CDF detector and trigger system have been described in detail elsewhere.[1,2] The detector components of interest for this discussion are the central tracking chamber (CTC),[3] the central electromagnetic and hadronic calorimeters (CEM and CHA), and the CES.[4] The CTC, which is located inside a 1.4-T solenoidal magnetic field, is a cylindrical drift chamber with 84 layers, grouped into five axial and four stereo superlayers. Fast timing information from the axial layers is used by a hardware track finder, the Central Fast Tracker[5] (CFT), which has a transverse momentum resolution of $\delta P_T/P_T = 3.5\% \times P_T$. The CEM and CHA are located outside the solenoid and cover the pseudorapidity region $|\eta| < 1.1$. The calorimeters are segmented into projective towers in η-ϕ space of size $0.1\times15°$, where ϕ is the azimuthal angle. The towers are further grouped into wedge modules of size $1.1\times15°$. Fast analog outputs on these calorimeters make the energy in "trigger towers" of size $0.2\times15°$ available for immediate use by the trigger. The CES, which is located inside the CEM near EM shower maximum at a depth of six radiation lengths, provides shower position and amplitude information in both the r-ϕ and z views. Until the present upgrade, this information was not available to the hardware triggers.

Both the electron and photon hardware triggers consist of two levels. Level-1 operates without deadtime in the 3.5 μsec window between beam crossings and requires at least 8 GeV of transverse energy, E_T, in a CEM trigger tower. At level-2, a hardware cluster-finder identifies clusters of transverse energy with at least 87.5% electromagnetic energy. The electron trigger then requires a match in momentum and azimuth between the cluster and a CFT track with $P_T > 7.5$ GeV/c. The photon trigger works similarly, but with an independent threshold and no track-match requirement. Events that satisfy these requirements are passed to the third level of the trigger, a software trigger that uses the full detector information. The rate of events into Level-3 is bandwidth-limited, hence the need to reduce the rate out of Level-2.

Fewer than 10% of events that pass the Level-2 electron trigger actually contain good primary electrons. The remaining events consist of conversions, hadronic showers that fluctuate into predominantly electromagnetic energy, and π^0-$\pi^\pm$ overlaps (where the neutral pion provides the electromagnetic shower and the charged pion provides the track). While conversions constitute a valuable control sample, the remaining backgrounds can be significantly reduced by making use of shower position information from the CES. This is because the tower-based trigger can make only a 15° match between the track and the EM cluster, much too loose to reject overlaps. In addition, the tower-based trigger does not know the depth within the CEM at which energy was deposited, so it cannot reject early hadronic showers that take place in the back portion of the CEM, after EM shower maximum. Similarly, the background to photon triggers from single-phototube discharges, which average approximately 1 Hz out of the overall 25-50 Hz allotted for all level-2 accepts, can be rejected by requiring energy in the CES.

2. Hardware

The wires of CES are strung parallel to the beam axis. They are split in the middle and read out at both ends of each wedge module. There are 32 channels per end, with each channel representing a segment of azimuthal angle approximately 0.5°

in size. The wires are read out by two 32-channel RABBIT cards[6] per module, one for each end. For the trigger upgrade, we have constructed new readout cards (known as XCES boards) which retain the same readout function as the previous cards but include additional trigger functions, shown in Figure 1. The XCES boards perform a fast sum of the pulse height on groups of four adjacent CES wires, corresponding to a 2° ϕ segment, for a total of 8 ϕ channels per wedge module. The sums are compared to a threshold supplied by an on-board adjustable DAC. The resulting on/off bits are OR'ed between the two ends of the chamber at the front panel of the XCES boards, forming eight bits for each of the 24 15° wedge modules in each half of the detector, for a total of $8 \cdot 24 \cdot 2 = 384$ bits. The two longitudinal halves of the detector are referred to as west or east, and each contain half of the possible trigger towers. The 8 bits per module are sent as differential TTL signals from the XCES front panel and travel through approximately 200 feet of shielded cable to the trigger electronics room.

The signals are received in the trigger room by an active patch panel and converted to single-ended TTL before being passed to a new trigger Fastbus board known as CERES. A block diagram of CERES is shown in Fig 2. The 384 bits are latched into the CERES board following a Level-1 accept. The CERES board is a double-width surface-mounted Fastbus board which has two trigger paths. One path is used for the level-2 photon trigger and the other path is used for the level-2 electron trigger.

For the photon trigger, the 8 bits per wedge module are OR'ed to produce 1 bit per wedge (48 "OR bits") and passed to a latch which is read out by the Level-2 processors. The 48 OR bits are used to reject the single-phototube background to the photon trigger by requiring that the CEM tower that gave the trigger also have the relevant wedge module "OR bit" set.

For the electron trigger, following a Level-1 accept, a sequential list of (two-dimensional) tracks with a sign bit, 3 bits for P_T and 11 bits for ϕ keyed to the wires of the outer superlayer of the CTC is passed to the CERES board from the fast track processor.[5] CERES identifies tracks associated with CES clusters by using the track bits in a sequence of lookup tables and generates one bit for each track identifying whether a track- cluster match has occurred. The memory content is determined by projecting a track of the appropriate sign, P_T and ϕ to the CES and identifying the corresponding XCES ϕ bits. The road width used in this projection allows for the finite width of P_T bins, alignment error, and multiple scattering; more than one XCES ϕ bit may be associated with a track. The memory for the lookups is downloaded through Fastbus at the start of data-taking. The track-cluster matching is done in parallel for both west and east.

West and east CERES bits are then clocked out to a new Fastbus hardware memory, known as the track list board.[7] The track list board latches the CFT tracks along with CES match bits produced by CERES and makes this information available to the Level-2 processors. The electron trigger at Level-2 then operates as before, with the additional requirement that the track associated to the EM cluster be flagged by the appropriate XCES/CERES match.

As implemented in the CDF trigger for the current collider run, the XCES-based electron trigger requires an EM cluster with $E_T > 8$ GeV, associated to a CFT track with $P_T > 7.5$ GeV, that is required to match to a CES cluster. At luminosities above

$10^{31}cm^{-2}sec^{-1}$ the trigger is prescaled by a factor of 2. A backup trigger, without the XCES requirement, is prescaled by an additional factor of 8. An unprescaled electron trigger for $E_T > 16$ GeV operates without XCES.

3. Performance

3.1. Initial Setup

For commissioning of the 1994 run, we initially installed two XCES cards on one wedge of the detector during the latter part of the 1993 run. Thus we were able to study with beam conditions the performance of the shower max trigger. At the startup of the 1994 run, after all XCES cards had been installed, many additional studies were performed by reading out the trigger information without using it in triggering. Even after the triggers had been fully implemented, prescaled versions without the shower max requirements were retained for monitoring.

The readout function of the XCES cards was readily established as reproducing the former performance. The initial concern was to set a viable trigger threshold. Fig. 3 shows the efficiency for producing a trigger bit in XCES versus pulse height summed for the relevant 4 wires from the readout. The threshold is reasonably clean, and the value of 3500 counts corresponds to about 5 GeV, an acceptable value for an electron E_T threshold of 8 GeV. The "OR-bits" are used as a coincidence with the 16 GeV photon trigger in order to suppress single phototube discharges, as is illustrated in Fig. 4. These single phototube discharges dominate the photon rate at low luminosity and would represent a noticeable bandwidth even at high luminosity if not suppressed in the hardware trigger.

The cross section for the 8 GeV trigger is shown in Fig. 5 as a function of the road size used in the lookup tables. The nominal CES threshold of 3500 ADC counts (see Fig. 3) was used for this study. For comparison, the cross section for this trigger with no XCES requirement is also shown, as is the Level-3 electron cross section. Even with a very wide road the Level-2 rate is reduced by a factor of 1.4, indicating the effect of requiring a CES cluster above threshold anywhere in the wedge. For the nominal road size of 3 cm the trigger cross section is reduced by more than a factor of two, from 840 nb to 400 nb. The Level-3 rate shows loss of signal only for road sizes of less than 3 cm.

3.2. Efficiency and Background Studies

In order to characterize the performance of the shower max electron trigger we define a reasonably pure sample of electrons in the transverse energy region of the threshold. For this we use a sample of good quality electrons from photon conversions. The electron is identified using tight cuts but keeping CES requirements to a minimum, and is required to form a low invariant mass with a nearby oppositely-charged track. A control sample of "fake electrons" is also defined using good quality electrons, but by requiring rather than vetoing the energy in the hadron calorimeter with other requirements the same.

Because the CES is in a plane, its pulse height response is proportional to $1/\sin(\theta)$ as well as to energy. Fig. 6 shows CES pulse height, scaled to the predicted mean value for electrons of appropriate P_T and angle, for (a) Level-3 selected electrons, (b) conversion candidates and (c) the fakes. The characteristics of the CES measurement and the usefulness of the shower max trigger are apparent.

The conversion sample is used to study the XCES threshold. Fig. 7 shows the four-wire CES pulse height distribution for conversion electrons. The integral plot shows that the threshold of 3500 counts is $> 85\%$ efficient for the conversion electrons. The transverse energy dependence of the shower max trigger efficiency is shown in Fig. 8. The efficiency rises from about 80% at threshold to nearly 100% above 18 GeV.

4. Conclusions

We have built and commissioned a shower maximum trigger that has allowed us to reduce the Level-2 electron trigger cross section by a factor of two while remaining highly efficient for good electrons. The electron threshold for inclusives for calibration and b-physics has been lowered from 9 to 8 Gev. This would have doubled the inclusive electron trigger cross section, but with the shower max requirement, the trigger cross section for 8 GeV is 0.42 μb, which at modest luminosity is 19% of the 1994 bandwidth. The 1992-3 cross section was 0.5 μb for 9 GeV inclusive electrons. At high luminosity, above about 15×10^{30} cm^{-2} sec^{-1}, this inclusive electron trigger may be prescaled by a factor of $\times 0.5$. Even with the prescale factor, the number of real electron events per inverse nanobarn is only slightly less than in the 1992-3 run because the fraction of good electrons in inclusive Level-2 electron triggers has doubled.

Acknowledgements

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References

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6. G. Drake *et al.*, Nucl. Instr. Meth. **A269**, 68 (1988).
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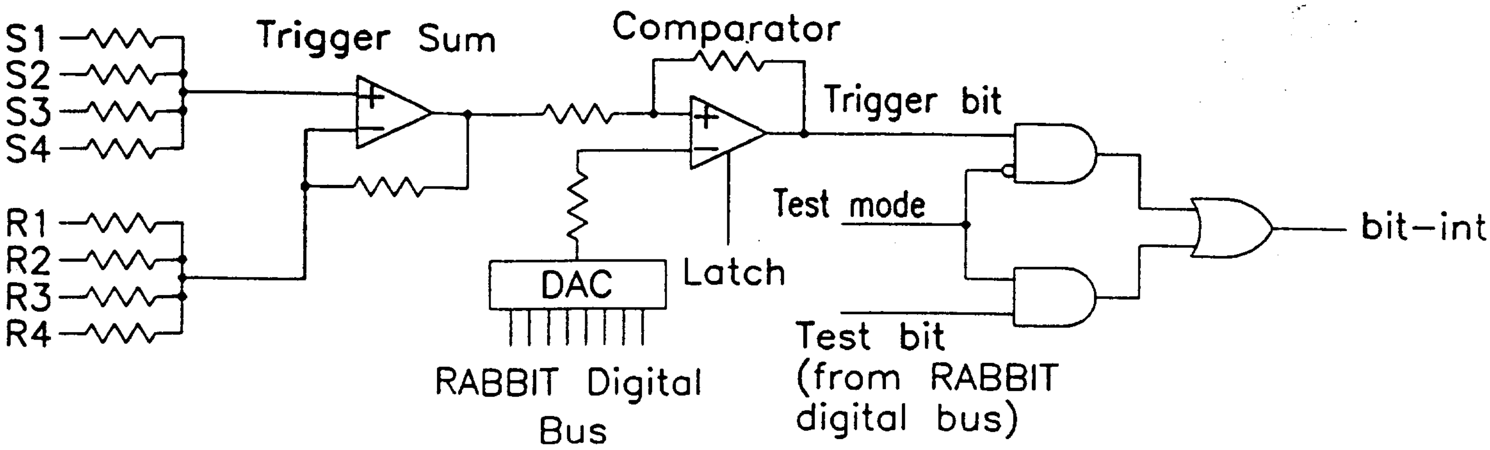
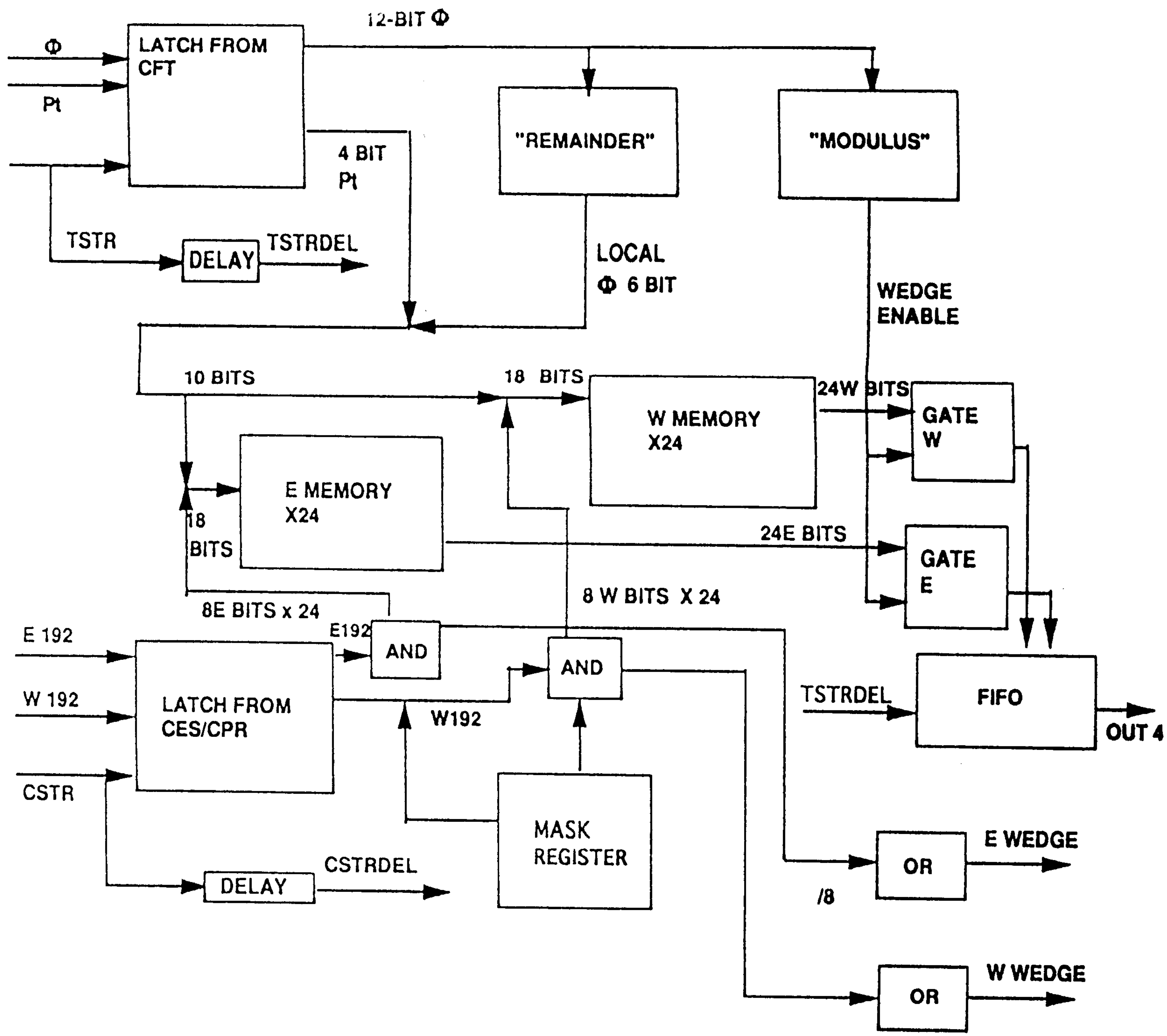

S1
S2
S3
S4
R1
R2
R3
R4
Trigger Sum
Comparator
Trigger bit
Test mode
DAC
Latch
RABBIT Digital Bus
Test bit (from RABBIT digital bus)
bit-int

Figure 1



CES/CPR TRIGGER FASTBUS CARD

9/8/94 Figure 2

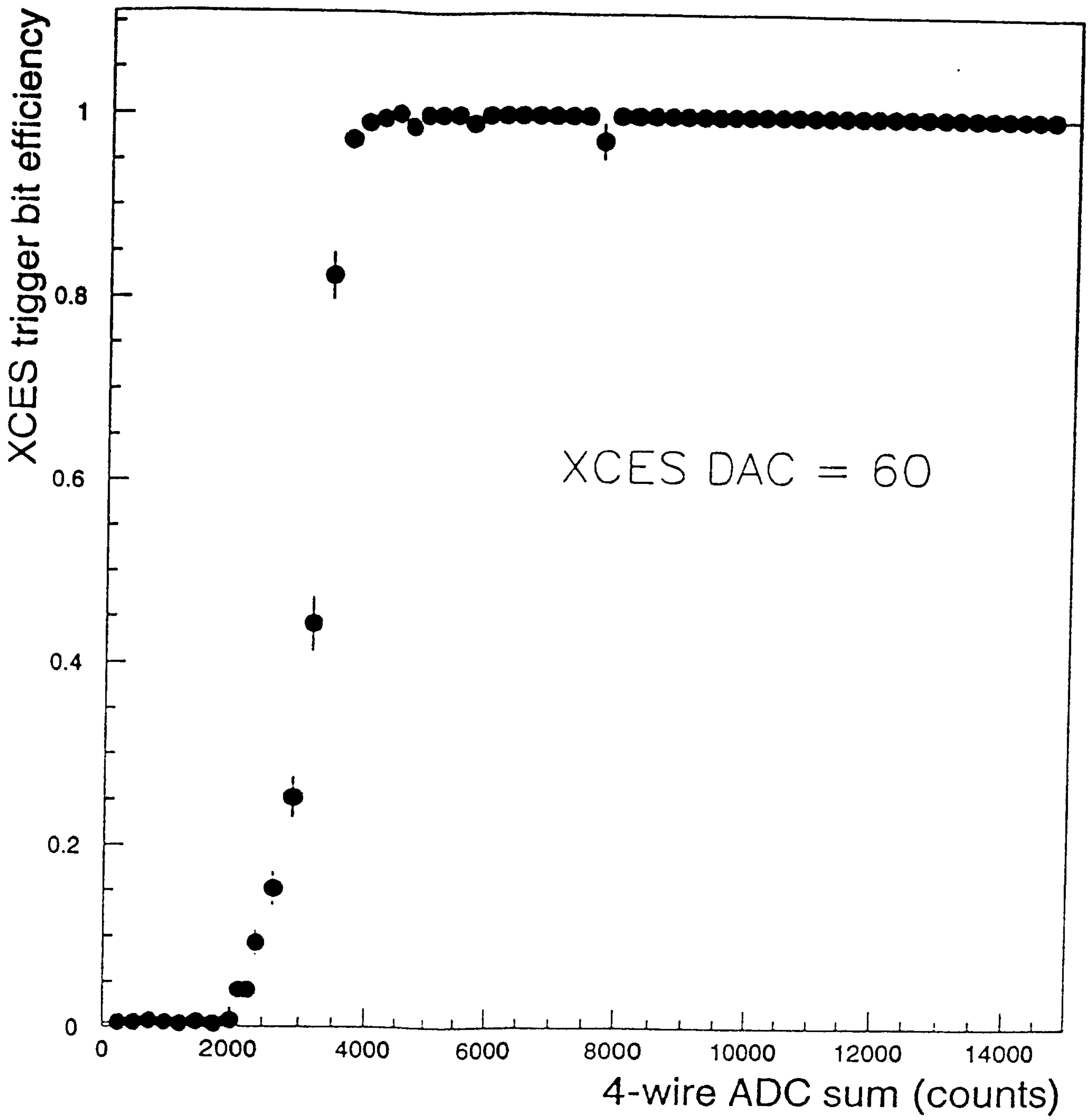
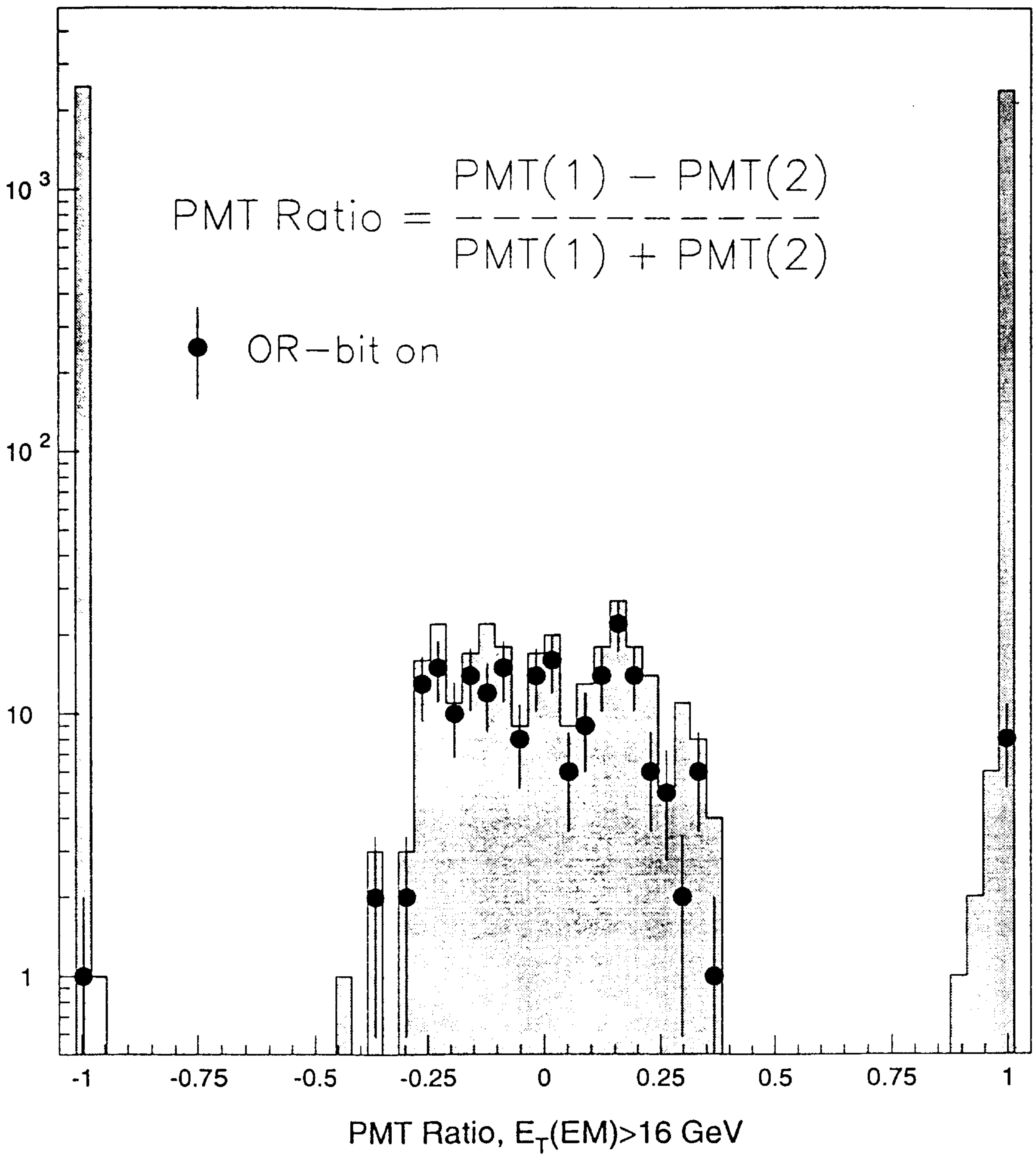
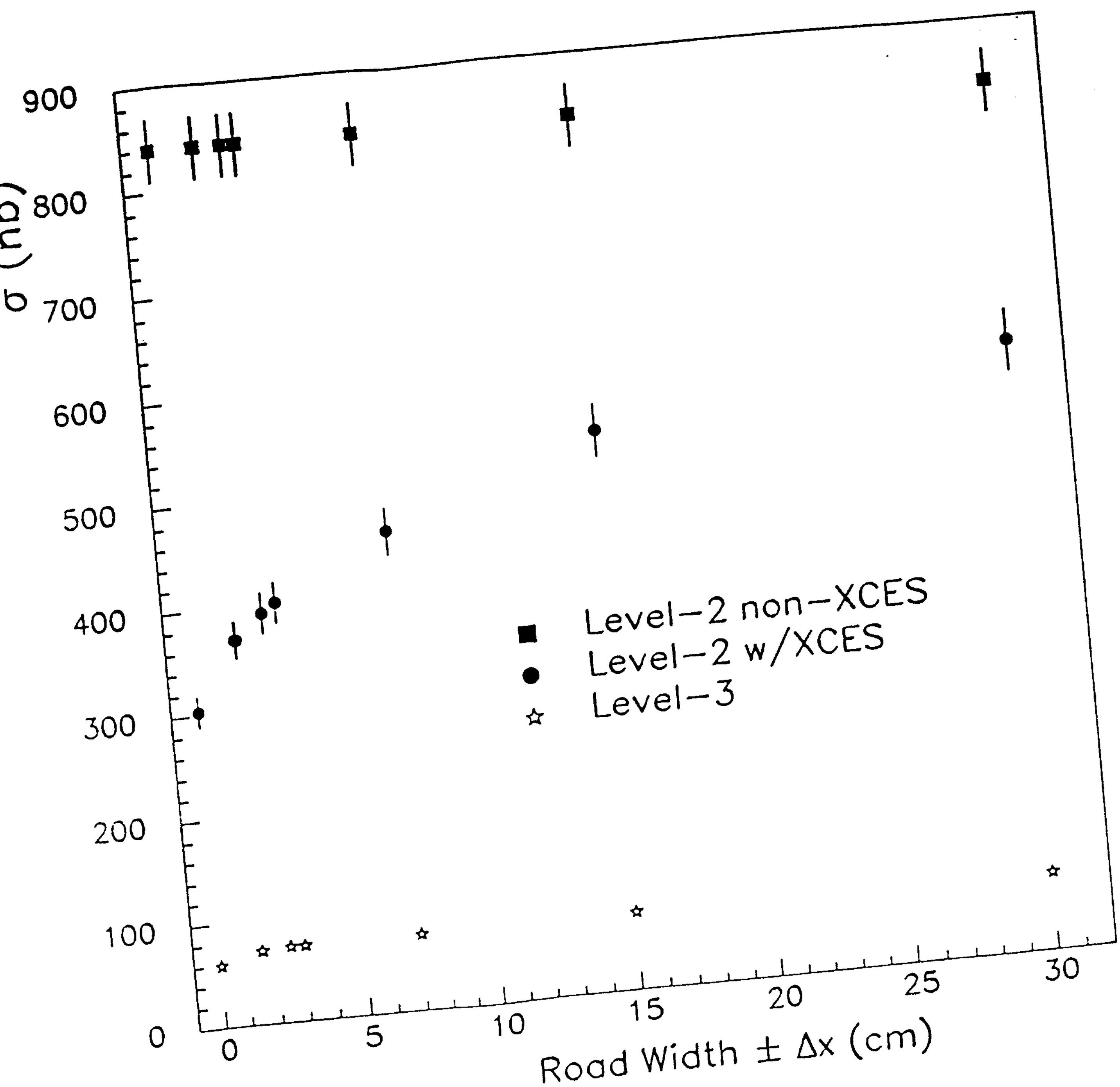

XCES trigger bit efficiency
1
0.8
0.6
0.4
0.2
0
0
2000
4000
6000
8000
10000
12000
14000
4-wire ADC sum (counts)
XCES DAC = 60

Figure 3



PMT Ratio = PMT(1) − PMT(2) / PMT(1) + PMT(2)
OR−bit on
10^3
10^2
10
1
-1
-0.75
-0.5
-0.25
0
0.25
0.5
0.75
1
PMT Ratio, E_T(EM)>16 GeV

Figure 4



σ (nb)
900
800
700
600
500
400
300
200
100
0
0
5
10
15
20
25
30
Road Width ± Δx (cm)
Level-2 non-XCES
Level-2 w/XCES
Level-3

Figure 5

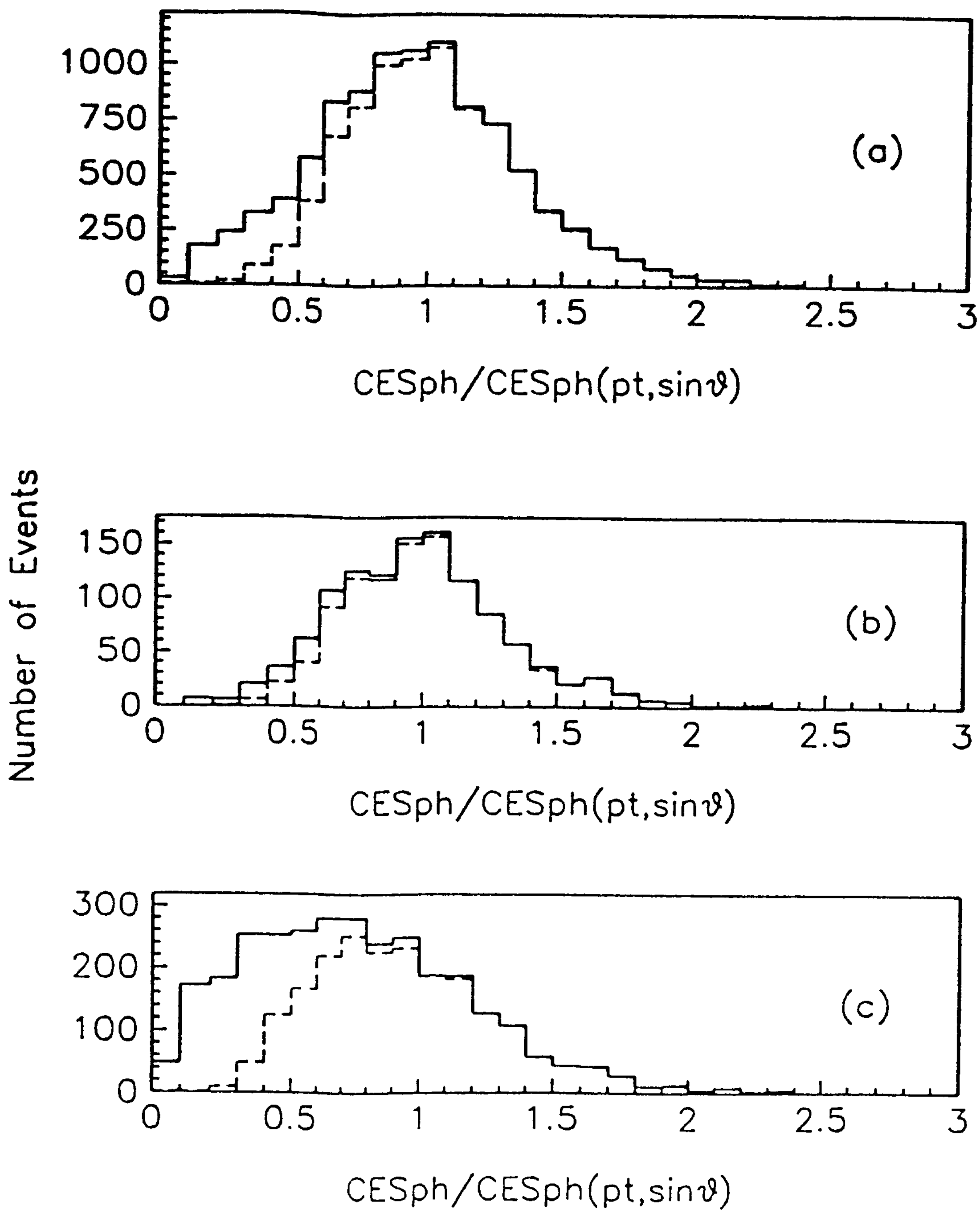

1000
750
500
250
0
0
0.5
1
1.5
2
2.5
3
(a)
CESph/CESph(pt,sinϑ)
Number of Events
150
100
50
0
(b)
CESph/CESph(pt,sinϑ)
300
200
100
0
(c)
CESph/CESph(pt,sinϑ)

Figure 6

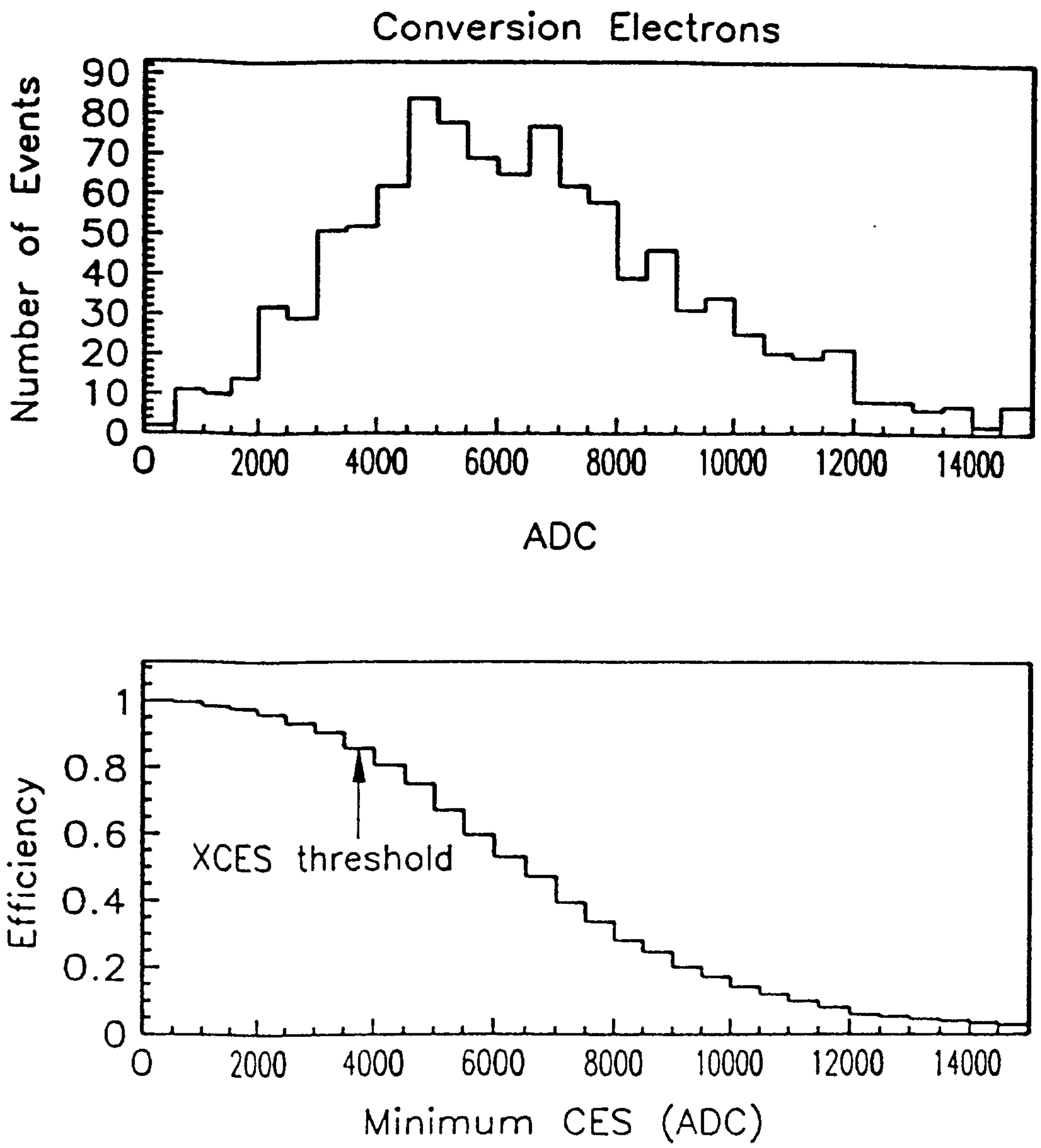
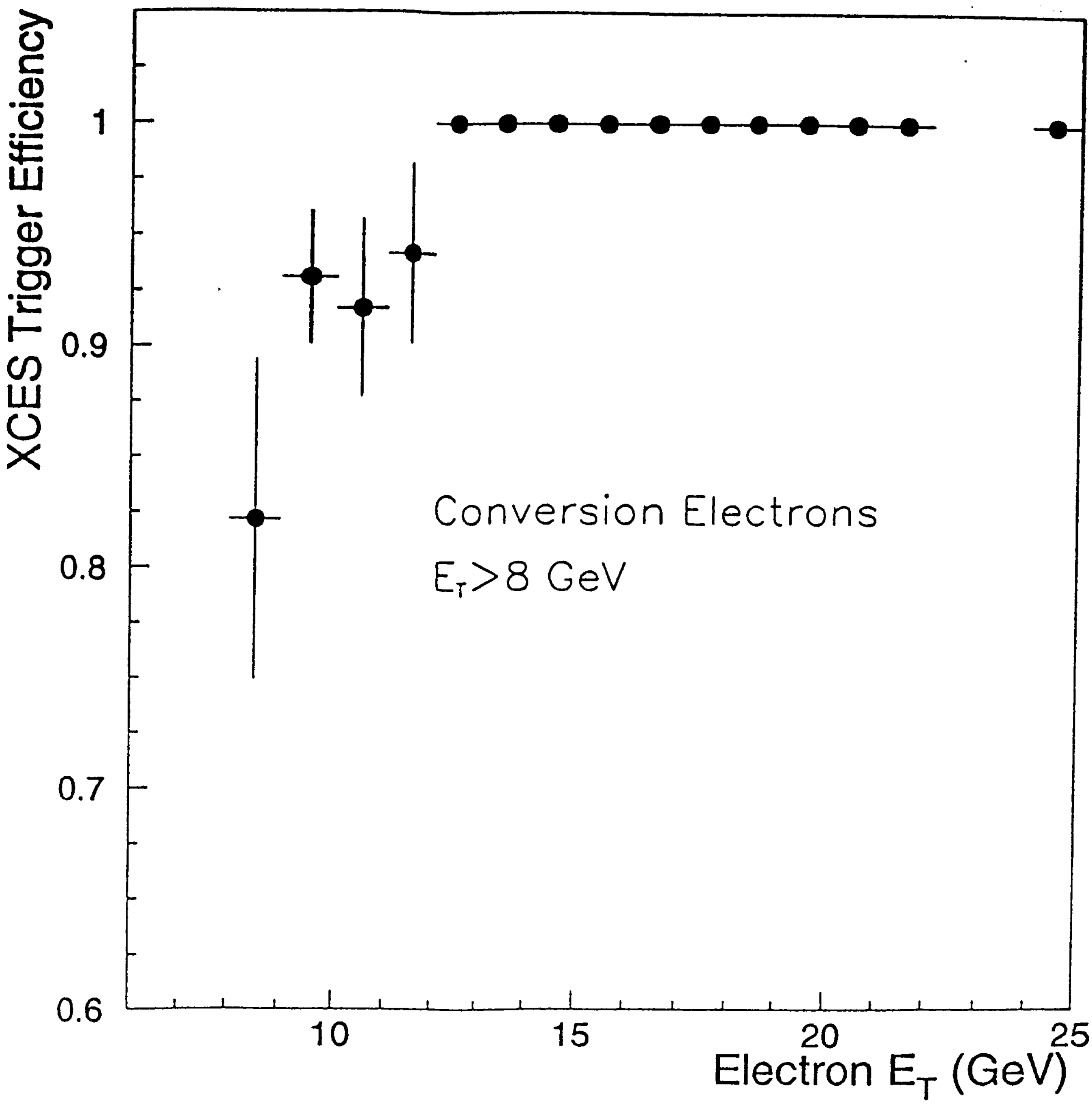

Conversion Electrons
Number of Events
90
80
70
60
50
40
30
20
10
0
0
2000
4000
6000
8000
10000
12000
14000
ADC
Efficiency
1
0.8
0.6
0.4
0.2
0
XCES threshold
0
2000
4000
6000
8000
10000
12000
14000
Minimum CES (ADC)

Figure 7



XCES Trigger Efficiency
1
0.9
0.8
0.7
0.6
10
15
20
25
Electron E_T (GeV)
Conversion Electrons
E_T>8 GeV

Figure 8