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Single Pion Response in the Central Calorimeter

Abstract

We describe new results for the response of the Central Calorimeter to single pions, based on extrapolated CTC tracks from the 1989 MinBias data and 1985-1987 Test-Beam data. Results are compared to a new tuning of the QFL detector simulation package.

The 1989 CDF data includes many high statistics jet samples. Understanding the detector's response to such jets with a reasonable systematic uncertainty requires a knowledge of the calorimeter response to hadrons over a large momentum range. In this note, we describe measurements of the Central Calorimeter response to single pions and compare these results with the recently tuned QFL detector simulation (Version 3.2). Pions in the energy range .75 GeV $\leq E \leq$ 20 GeV are extracted from isolated tracks in minimum bias and stiff-track trigger data. Test beam information is used to study pions at higher energy (57 and 145 GeV).

1 Response at Low P

We have remeasured the Central Calorimeter response to isolated tracks in the 1989 MinBias data-sample using essentially the same method described in CDF-583, "Response of the Central Calorimeter to Low-Energy Charged Particles." Improvements over the original 1987 study include: (1) an enlarged data-sample featuring a set of runs in which a stiff CTC track was required in the trigger, which has resulted in a greatly extended momentum range; and (2) a substantial reduction in systematic error from the π^0 subtraction. These improvements have given us a relatively precise measurement (statistical and systematic errors of 10% or less) of the response for pions between 0.75 and 20 GeV.

Event selection and track isolation requirements were those of CDF-583, with the exception that the detector η interval for pions was changed to Towers 0:8. However, to reduce π^0 overlap, the calorimeter energy associated with the projected track was redefined to be the energy in the *target* CEM tower plus the 3x3 square of CHA towers behind it, rather than the 3x3 sum in both calorimeter compartments. This redefinition reduces the solid angle for π^0 overlap by a factor of 9. In conjunction, to minimize shower leakage out of the target CEM tower (which could mimic a nonlinearity of response), tracks were required to extrapolate within the inner 36% of the area of the tower-face in η-ϕ. This cut was determined using response-maps obtained from the low-P data-sample. In Fig. 1 we Lego-plot the quantity E_{target}/E_9, the ratio of energy in the target tower to the energy in the 3x3 square of towers, vs. the normalized (η,ϕ) pion impact point, defined at R=R_{CEM}; one "corner" of the tower-face is shown, and the two calorimeter compartments, CEM and CHA, are plotted separately. (We note that π^0 overlap produces a constant, flat background in the CEM compartment.) The "flatness" of the observed CEM energy for impact points in the inner 49% of the tower (an η-ϕ rectangle of 0.7x0.7, in units of tower half-widths) indicates that the transverse leakage for these showers is small ($<$ 5-10 %) and roughly constant. To be conservative in terms of the CEM shower containment, we demanded a tighter extrapolation cut, requiring impact points to be within the inner 36% of the area (a 0.6x0.6 rectangle) both at the inner and outer radius of the CEM. Pions in the momentum bite 1-3 GeV were used to generate this plot; plots of response for other slices of momentum have been examined and are consistent within available statistics.

Distributions of E/P for pions which pass the extraolation requirement are shown in Fig. 2 (solid) for various slices of momentum; QFL simulation results (dots) are also shown. Data above P=5 GeV have come primarily from the CTC Trigger runs (20192, 20446-20448), which required a track with P_t above 5 or 10 GeV. Lower momentum pions were obtained using minimum bias data. We note that below 5 GeV or so, a substantial fraction of particles leave less than 15% of their momentum in the calorimeter; we call these tracks "zero's". The fraction of "zero's" (f_0) is plotted vs. P in Fig. 3. In addition to the P dependence, a strong η dependence is also seen: in Fig. 4(a), f_0 for pions between 1-2 GeV is plotted vs. the target tower number (tower numbers go from 0:8 in each arch). When one plots f_0 divided by the amount of uninstrumented dead material before the start of the active region of the CEM, this η dependence is basically accounted for (Fig. 4(b)). We therefore believe that these zero's are caused by the absorption of low energy pions in the material in front of the CEM and have chosen to parametrize the probability of zero energy in QFL as a function of momentum and of the amount uninstrumented material (in interaction lengths).

The observed average value of E/P measured at tower centers (i.e., using tracks extrapolating to the inner 35% of the tower-face) is plotted vs. P in Fig. 5(a). Two corrections must be applied to this plot to obtain the *average response* to single particles: π^0 background into the target CEM tower must be estimated, and the effect of cracks in η and ϕ and face-response, which we've avoided by demanding a tower-center extrapolation, must be included.

Background from overlapping π^0's has been estimated using the energy found in the 8 border CEM towers (E_8) around the target tower. The average fractional energy found in each border tower, $(< E_8 > /8)/P$, is plotted vs. P in Fig. 5(b). We see that this per-tower energy is on average a few percent of P; the functional dependence is $0.014 + 0.012/P(\mathrm{GeV})$ (but kept constant at 0.017 for $P > 5$ GeV), signifying the presence of both a constant energy density of 12 MeV from "ambient" or isotropic π^0's (or noise) and a source of background energy that scales with charged-particle P. We take this curve as our estimate of background energy in the target CEM tower.

We make two caveats on this technique for estimating the neutral background. First, the scaling term may result in part from shower leakage out of the target tower; and second, we might expect to find somewhat more π^0 energy in the target tower than in a typical border tower. However, because the average border energy is so small (of order 2% of P), we have not investigated these effects further, but have instead assigned a conservative 5% systematic error to the overall average pion response.

The effect of losses in cracks was studied using the kind of face-maps shown earlier in Fig. 1; we find a 4-5% overall loss of E in cracks, independent of momentum to within statistics.

In Fig. 6 we plot the mean response, $< E/P >$, for pions in the central calorimeter, averaged over the tower face (derived from Fig. 5(a), with neutral background subtracted and the losses in cracks included); also shown is the associated band of systematic error. Comparison to tuned QFL will be made in the second section of this note. Figures 7(a) and 7(b) give $< E_{CEM}/P >$ and $< E_{CHA}/P >$ vs. P, respectively, together with comparisons to QFL.

Fig. 8(a) compares the new result for $< E/P >$ with the 1987 result (for comparison purposes, the 1989 result in this plot has been restricted to Towers 0:5). The systematic uncertainty on the 1987 data is shown, illustrating the improvement in accuracy of the new response measurement as well as the increase in momentum range. As an interesting exercise, we also compare our results against low-P Test Beam data into the UA1 Hadron Calorimeter (Fig. 8(b)). To account for the difference in the CDF and UA1 calibration procedures, we have used $1.2E_{CEM} + E_{CHA}$ to define the calorimeter energy (also, UA1 data has been normalized at 50 GeV to give the CDF Test Beam result at 50 GeV). Bewilderingly good agreement is observed.

2 Response to TestBeam Pions

We have compared QFL to test beam data taken at two energies. The 57.1 GeV sample, obtained during the 1987 test beam run and analyzed by Hans Jensen was previously used to tune QFL (see CDF-753). An additional point at 145.5 GeV (taken during the 1985 test beam run) was provided by Barry Wicklund and analyzed. In both cases, pions were shot into Tower 2.

We have chosen to study four distributions for each energy:

1. E_{MIP}: The amount of energy observed in the CHA for pions selected to be minimum ionizing in the CEM compartment ($E_{CEM} < 0.66$ GeV). The energy of this peak *defines* the calibration of the CHA. The width is a measure of the hadron calorimeter resolution.

2. E_{TOT}: The sum of the energy observed in the CEM and CHA ($E_{TOT} = E_{CEM} + E_{CHA}$) for all test beam pions. A cut of $E_{TOT} > 5$ GeV is imposed to remove muon background in the sample.

3. E_{CHA}: The observed energy in the CHA for all test beam pions with $E_{TOT} > 5$ GeV.

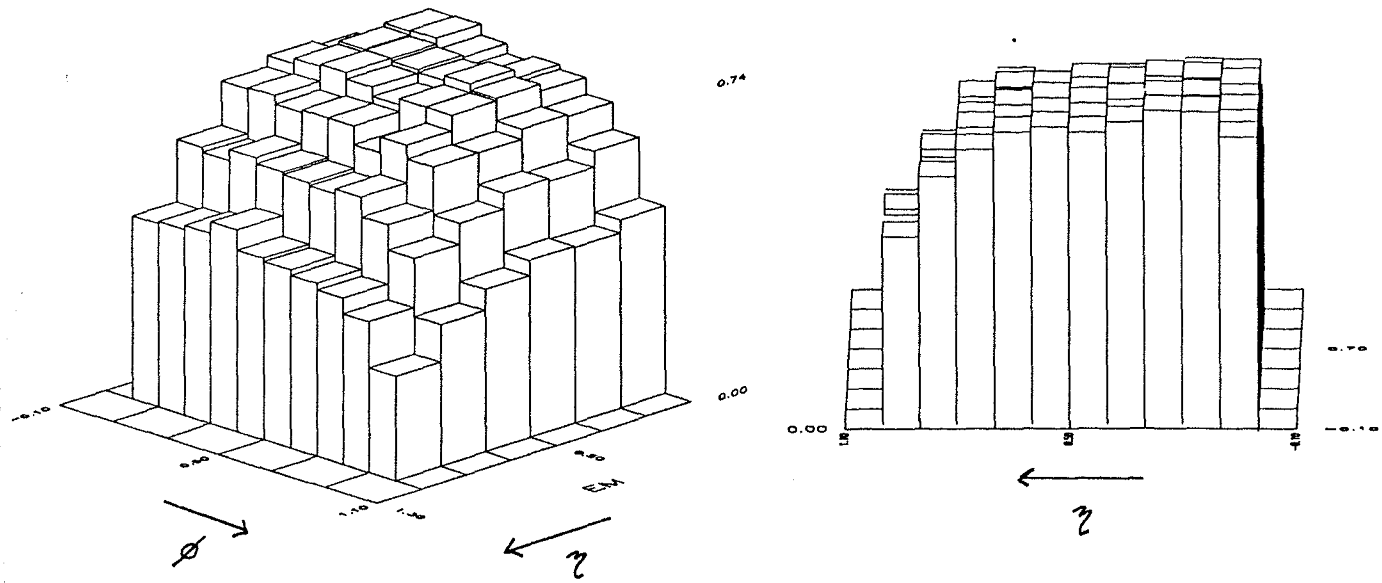
4. E_{CEM}: The observed energy in the CEM for all test beam pions with $E_{TOT} > 5$ GeV.

Figures 9*a*-*d* and 10*a*-*d* show the comparison of data and QFL for the 57.1 GeV and 145.5 GeV data respectively. In both figures, the scale shown on the y axis of the plots gives the number of Monte Carlo events per bin. The test beam data have been scaled to the total number of pions observed with $E_{TOT} > 5$ GeV. Thus, the agreement between Monte Carlo and data in Fig. 9*a* and 10*a* indicates that QFL is correctly reproducing the probability of a pion reaching the CHA without interacting. The pion response, resolution and EMF are also reasonably reproduced.

Figure 11 shows the minimum ionizing peak for pions in the CEM. Again, both the normalization and shape of the QFL plots agree well with the data.

Figure 12 summarizes average pion response results from Test-Beam and MinBias. MinBias data-points are those of Fig. 6; the Test Beam values are taken from the average of the E_{TOT} distributions in Figures 9&10, but reduced by 4% to account for the average loss in ϕ-cracks (see CDF-684). We must note that in a certain sense Fig. 12 compares "apples and oranges", since the Test-Beam results are for Tower 2 only, and thus do not reflect any η dependence to the response, observed in the low-P sample, which may persist at Test Beam energies. Systematic error is also shown (at Test-Beam energies, this results from the uncertainty in ϕ-crack response in the presence of a second particle in the tower), represented as a band centered on a smooth curve which attempts to join the MinBias and Test Beam data-points. Results from QFL (also shown in Fig. 12) lie well within this error-band for all pion energies.

(a) CEM Map, two views.



(b) CHA Map.

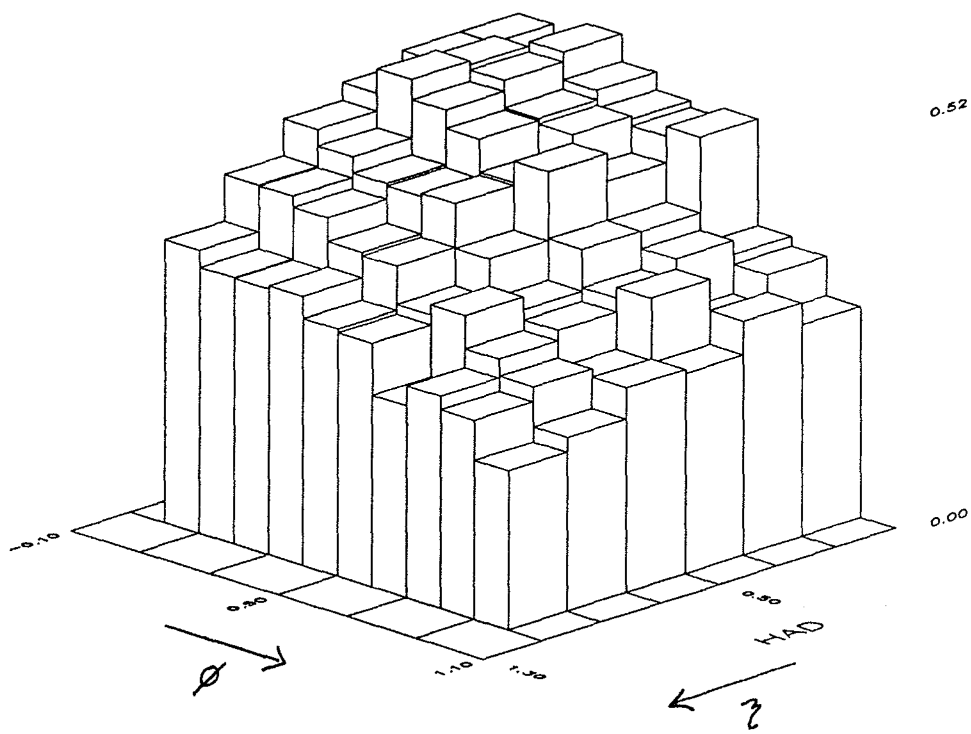


FIGURE 1

Single Pion Energy Distributions

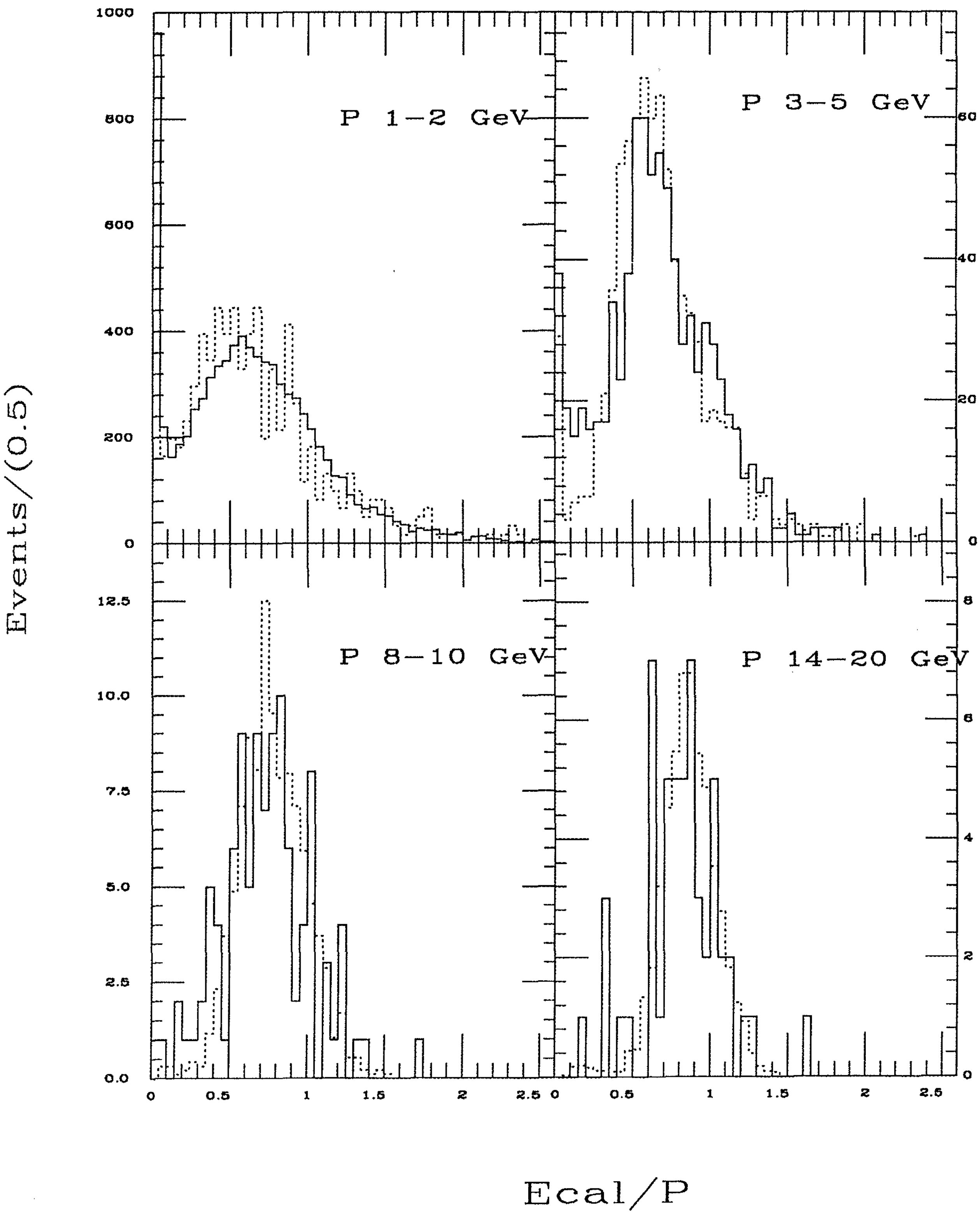


FIGURE 2

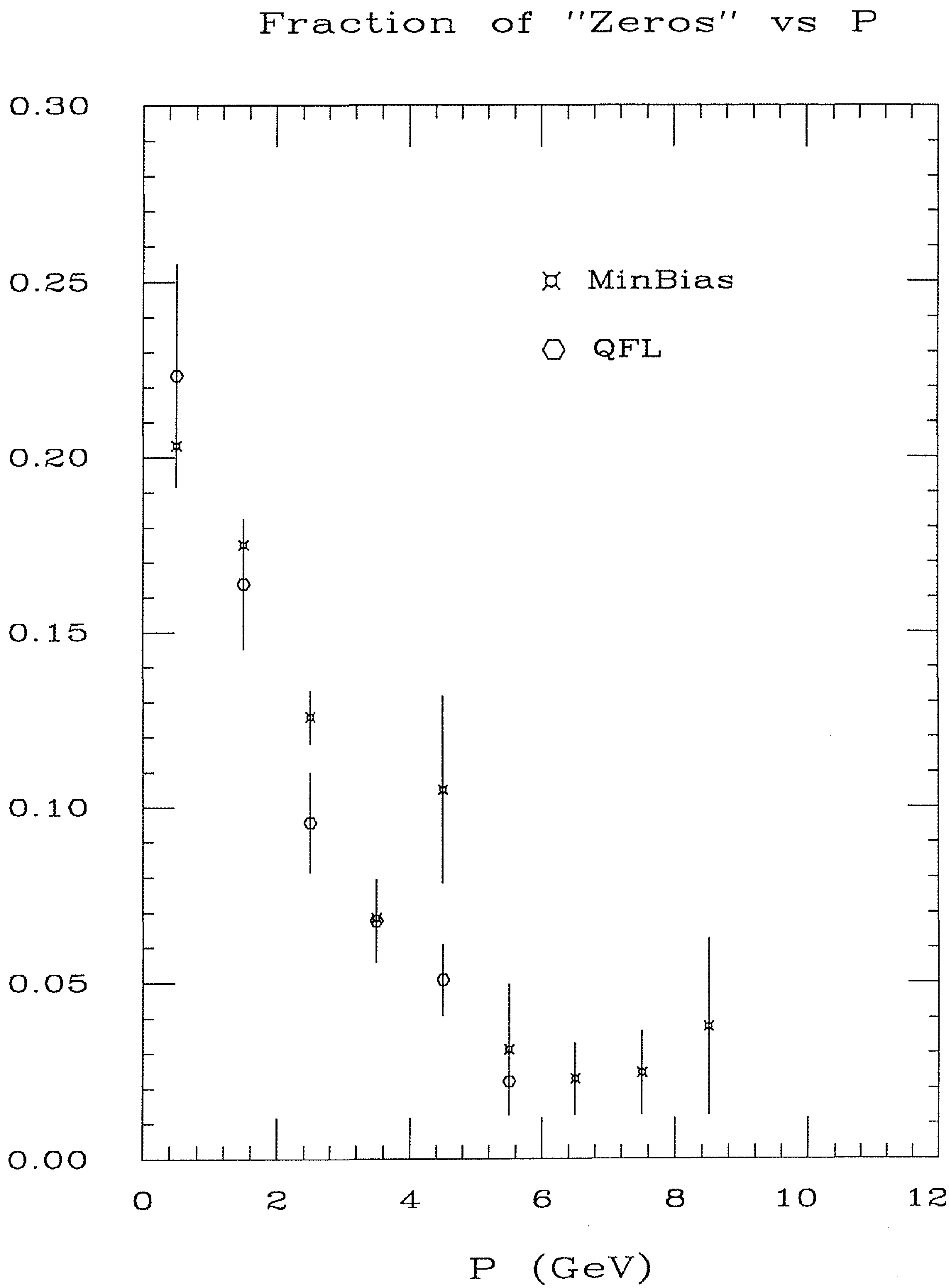

Fraction of "Zeros" vs P
0.30
0.25
0.20
0.15
0.10
0.05
0.00
MinBias
QFL
0
2
4
6
8
10
12
P (GeV)

FIGURE 3

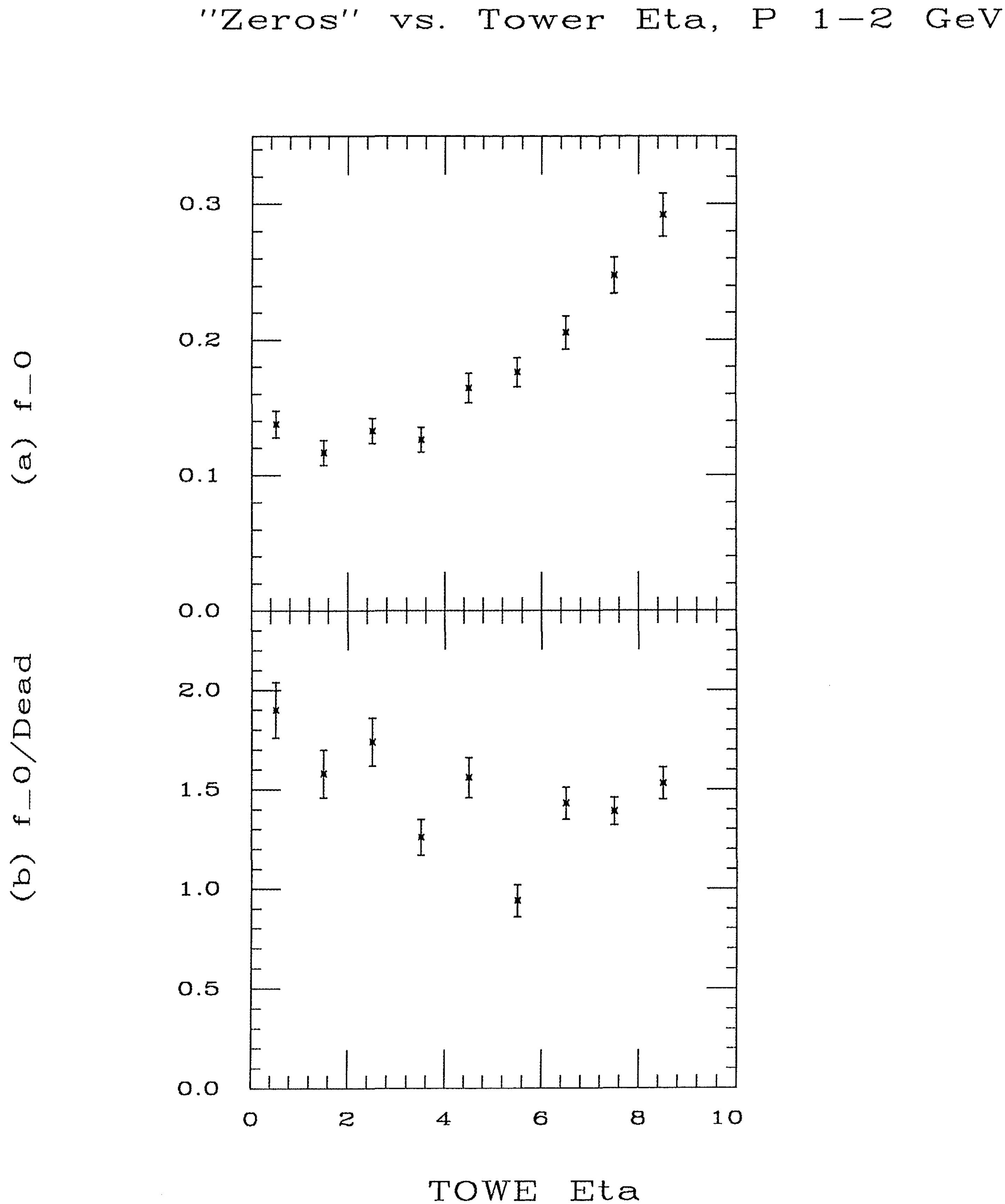
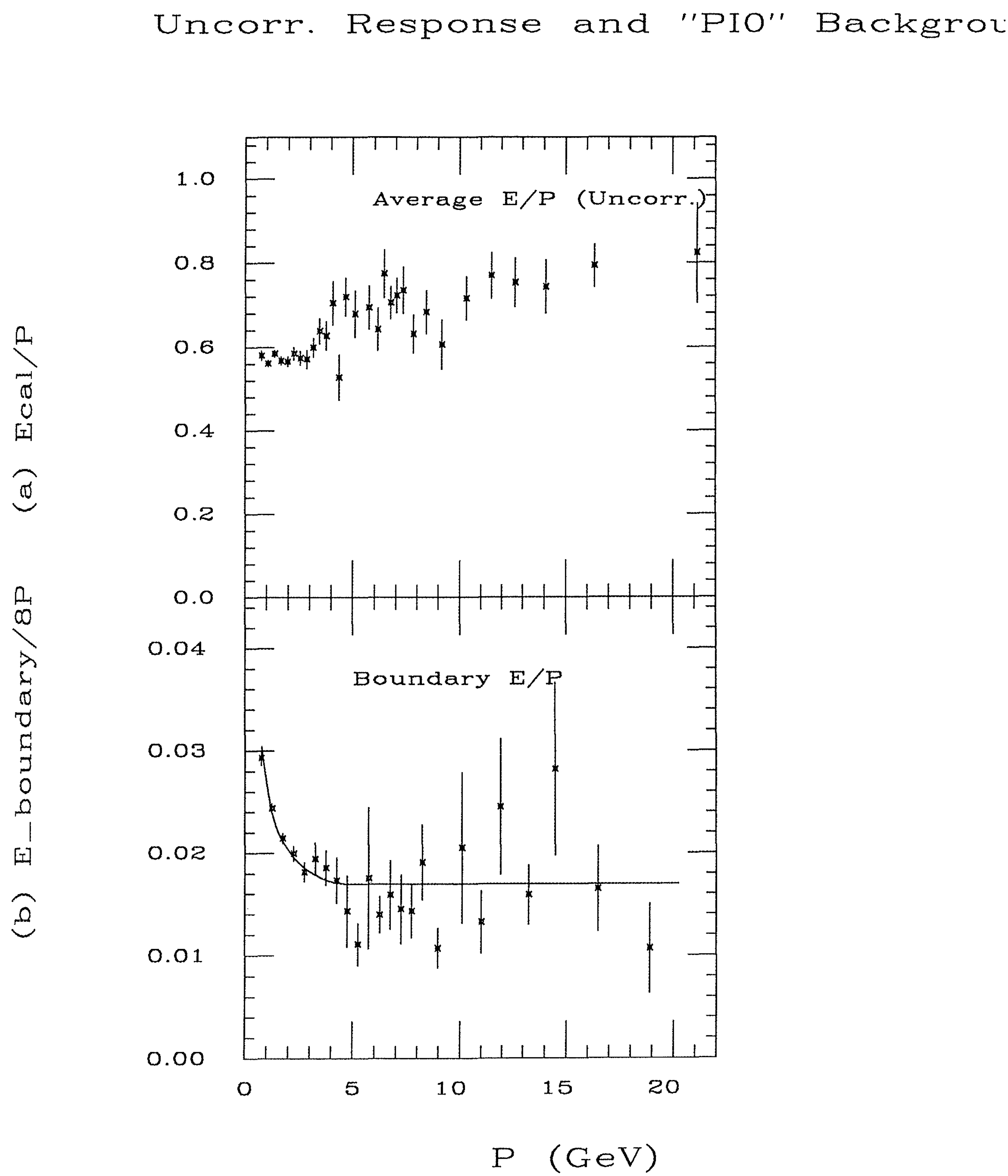

"Zeros" vs. Tower Eta, P 1-2 GeV
(a) f_0
(b) f_0/Dead
0.3
0.2
0.1
0.0
2.0
1.5
1.0
0.5
0.0
0
2
4
6
8
10
TOWE Eta

FIGURE 4



Uncorr. Response and "PIO" Backgrou
Average E/P (Uncorr.)
Boundary E/P
(a) Ecal/P
(b) E_boundary/8P
1.0
0.8
0.6
0.4
0.2
0.0
0.04
0.03
0.02
0.01
0.00
0
5
10
15
20
P (GeV)

FIGURE 5

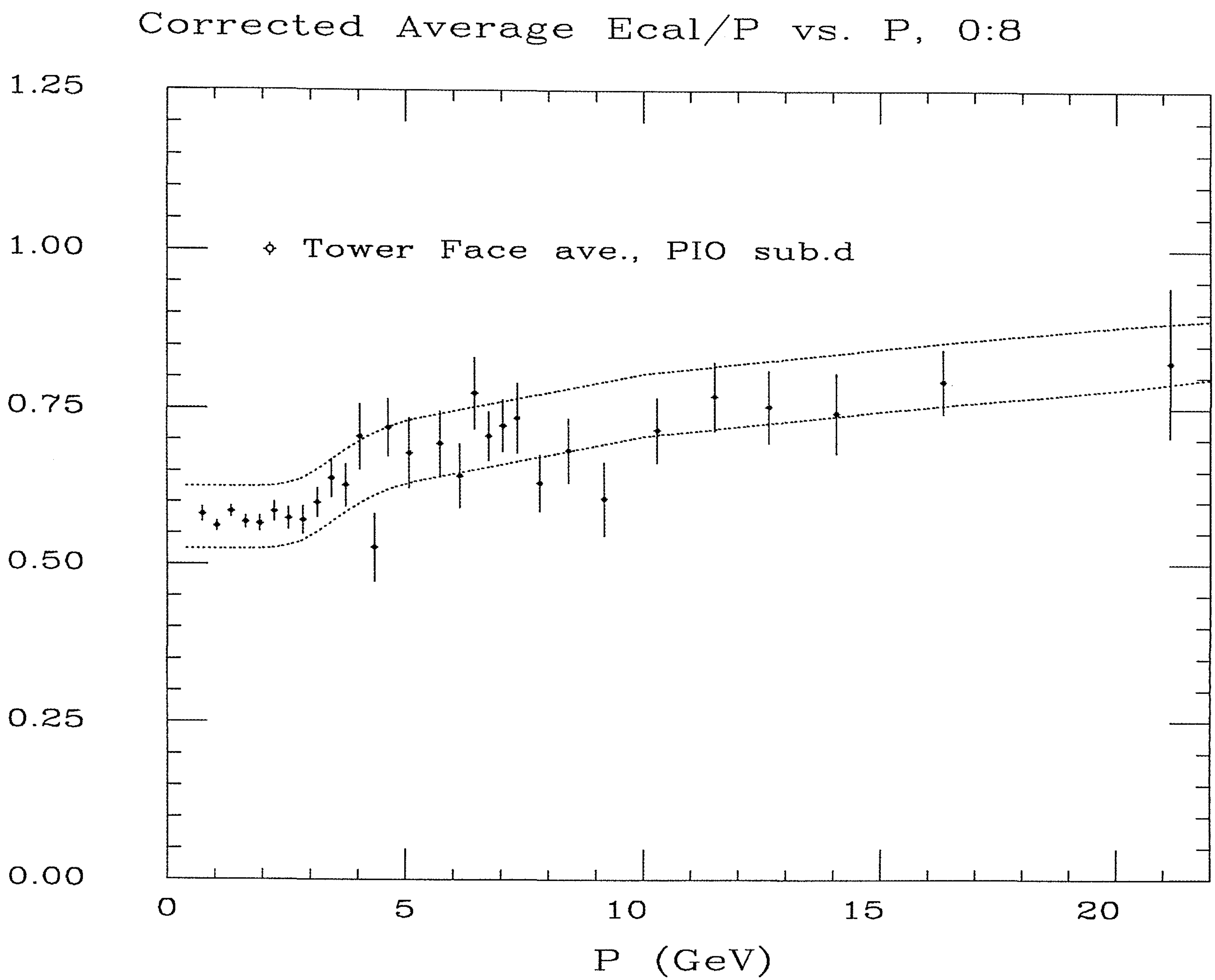

Corrected Average Ecal/P vs. P, 0:8
1.25
1.00
0.75
0.50
0.25
0.00
Tower Face ave., PIO sub.d
0
5
10
15
20
P (GeV)

FIGURE 6

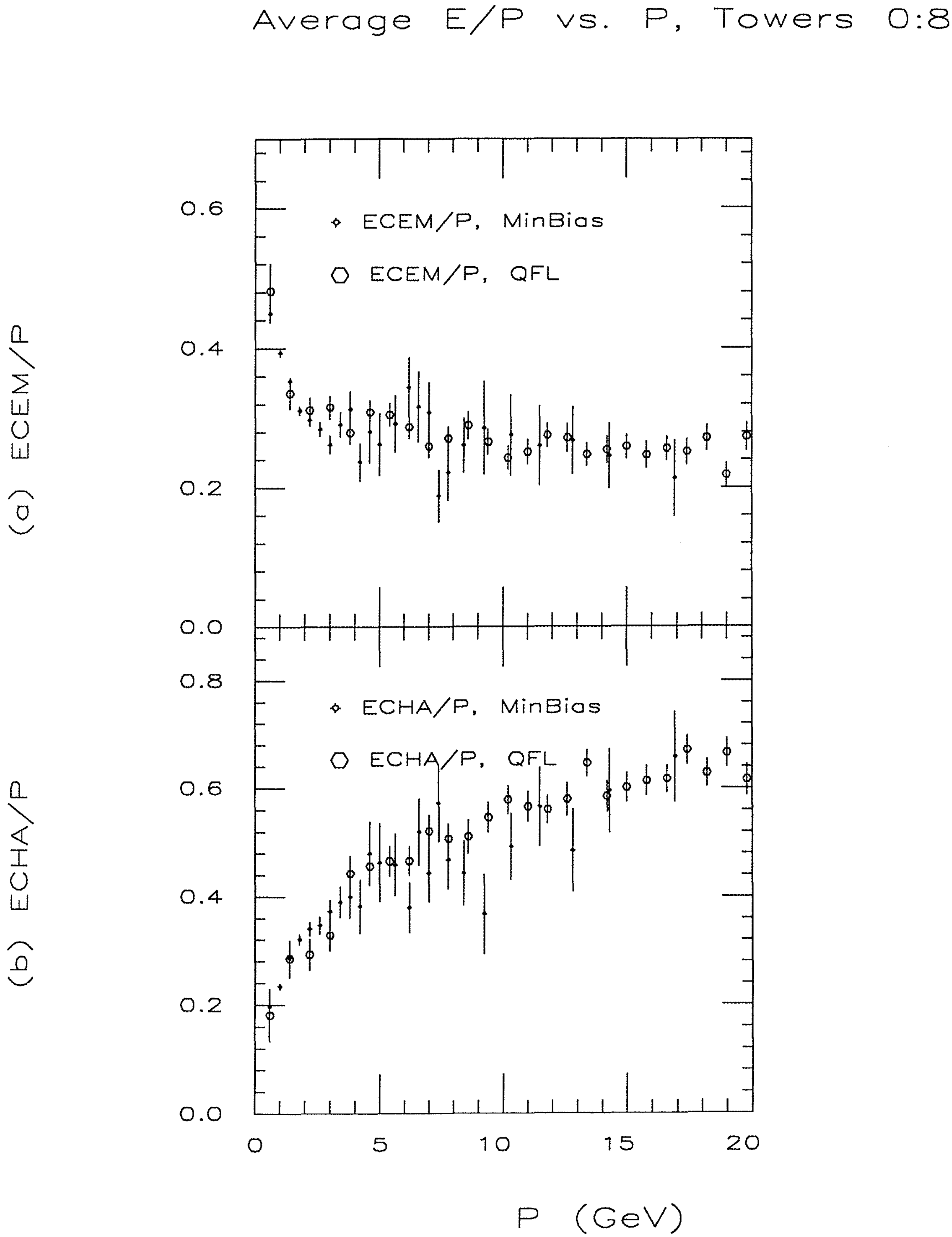

Average E/P vs. P, Towers 0:8
(a) ECEM/P
ECEM/P, MinBias
ECEM/P, QFL
(b) ECHA/P
ECHA/P, MinBias
ECHA/P, QFL
0.0
0.2
0.4
0.6
0.8
0
5
10
15
20
P (GeV)

FIGURE 7

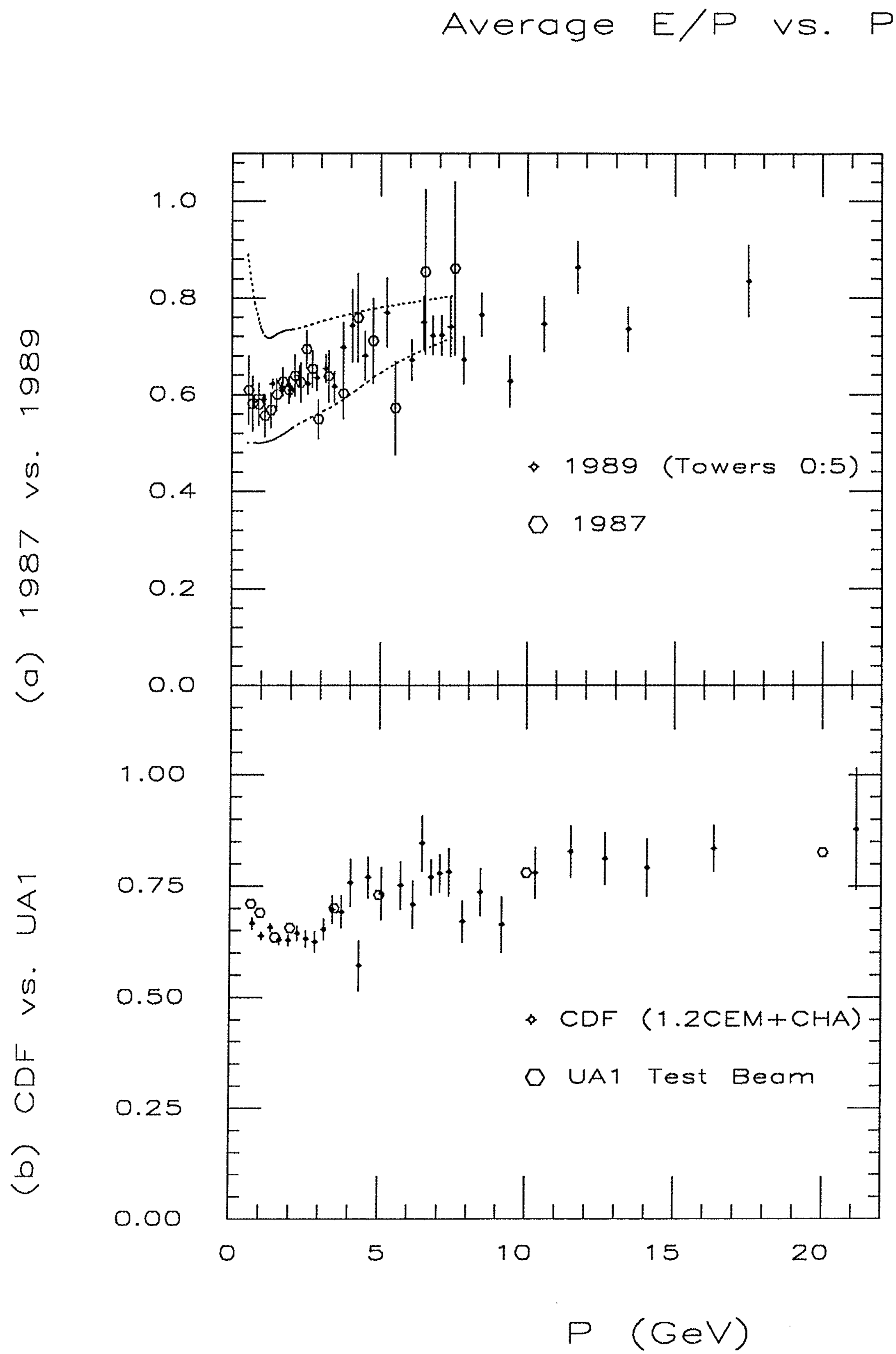
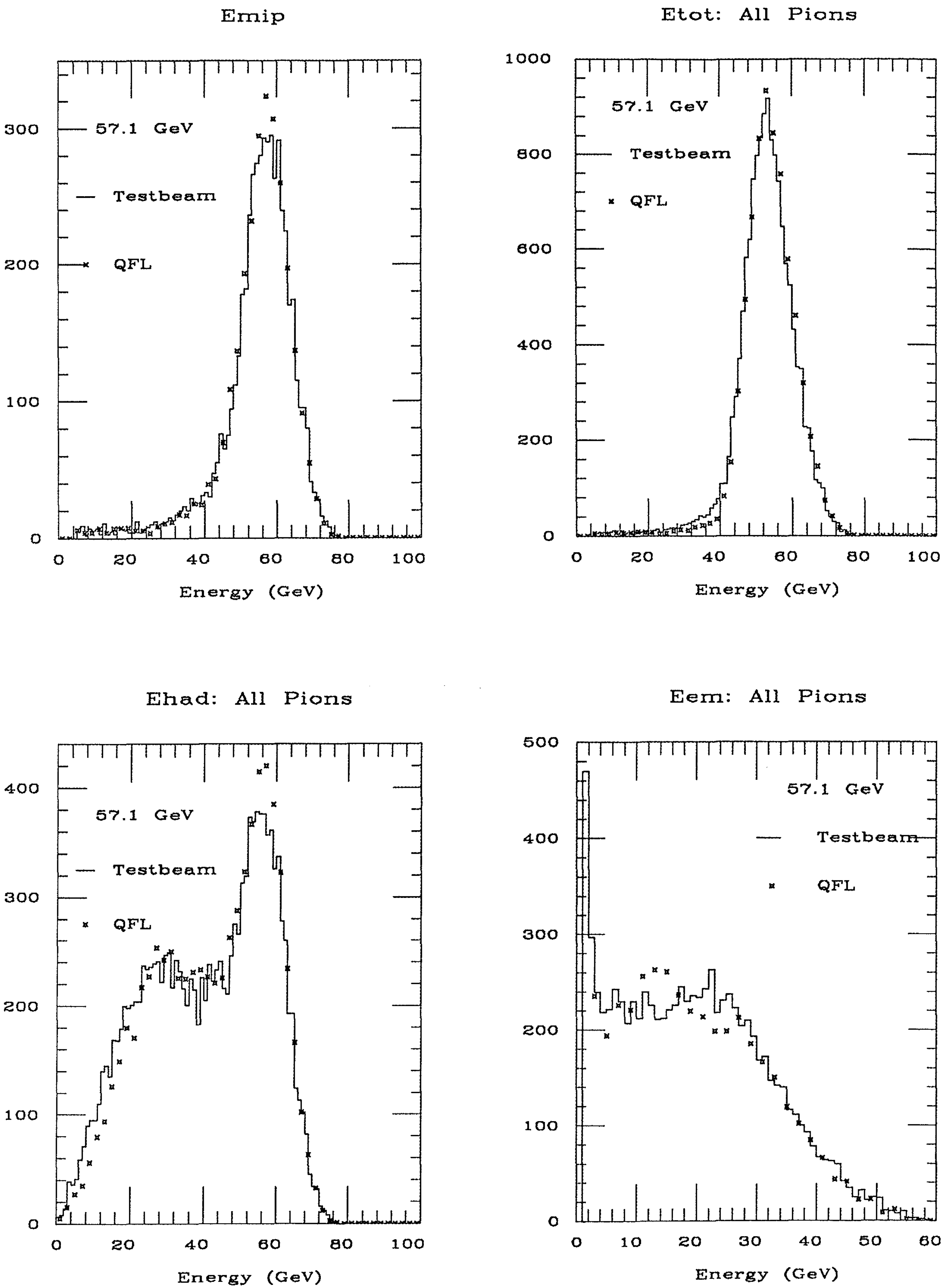

Average E/P vs. P
(a) 1987 vs. 1989
1.0
0.8
0.6
0.4
0.2
0.0
1989 (Towers 0:5)
1987
(b) CDF vs. UA1
1.00
0.75
0.50
0.25
0.00
CDF (1.2CEM+CHA)
UA1 Test Beam
0
5
10
15
20
P (GeV)

FIGURE 8



Emip
57.1 GeV
Testbeam
QFL
Energy (GeV)
Etot: All Pions
57.1 GeV
Testbeam
QFL
Energy (GeV)
Ehad: All Pions
57.1 GeV
Testbeam
QFL
Energy (GeV)
Eem: All Pions
57.1 GeV
Testbeam
QFL
Energy (GeV)

FIGURE 9

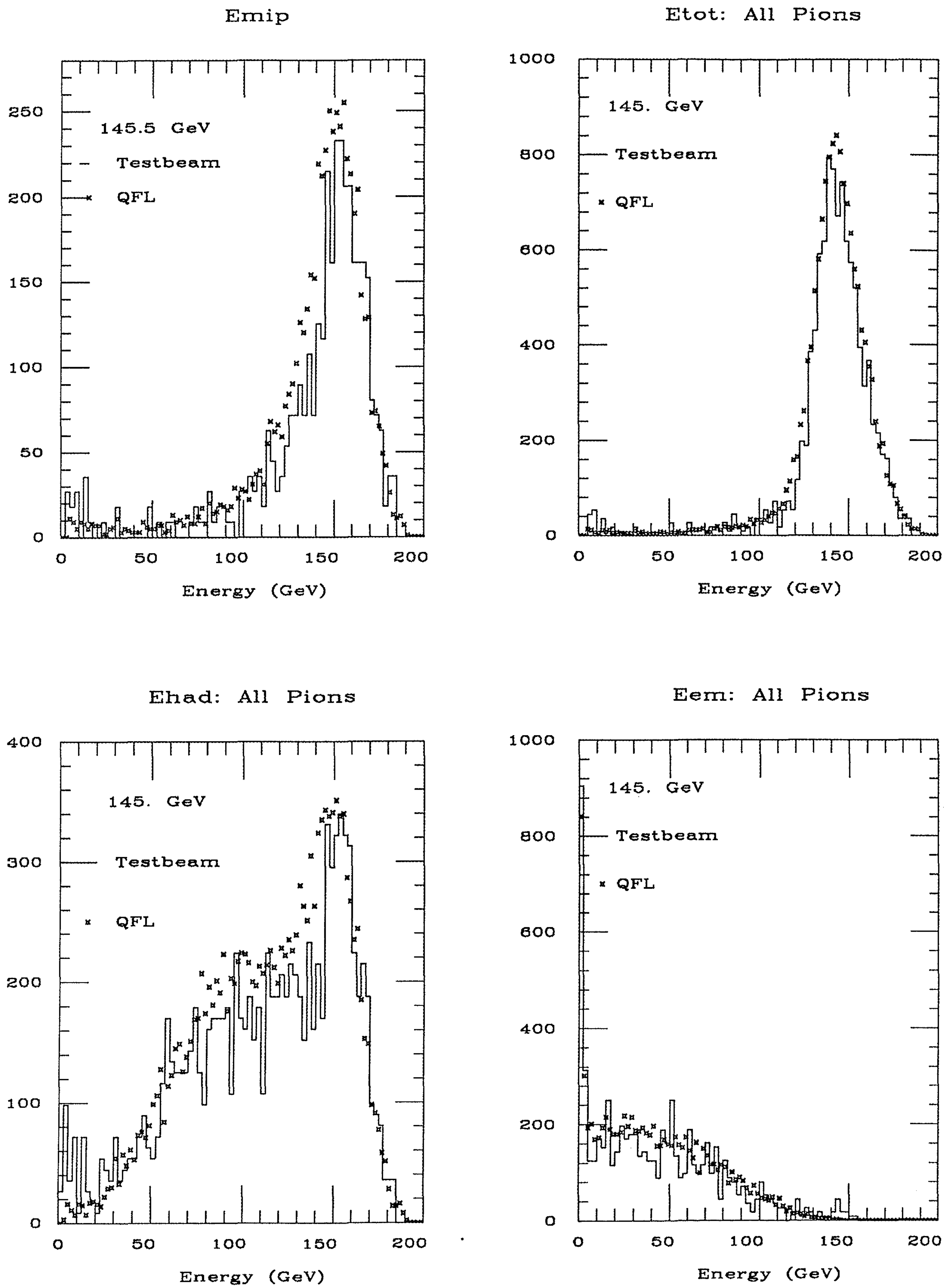

Emip
145.5 GeV
Testbeam
QFL
Energy (GeV)
Etot: All Pions
145. GeV
Testbeam
QFL
Energy (GeV)
Ehad: All Pions
145. GeV
Testbeam
QFL
Energy (GeV)
Eem: All Pions
145. GeV
Testbeam
QFL
Energy (GeV)

FIGURE 10

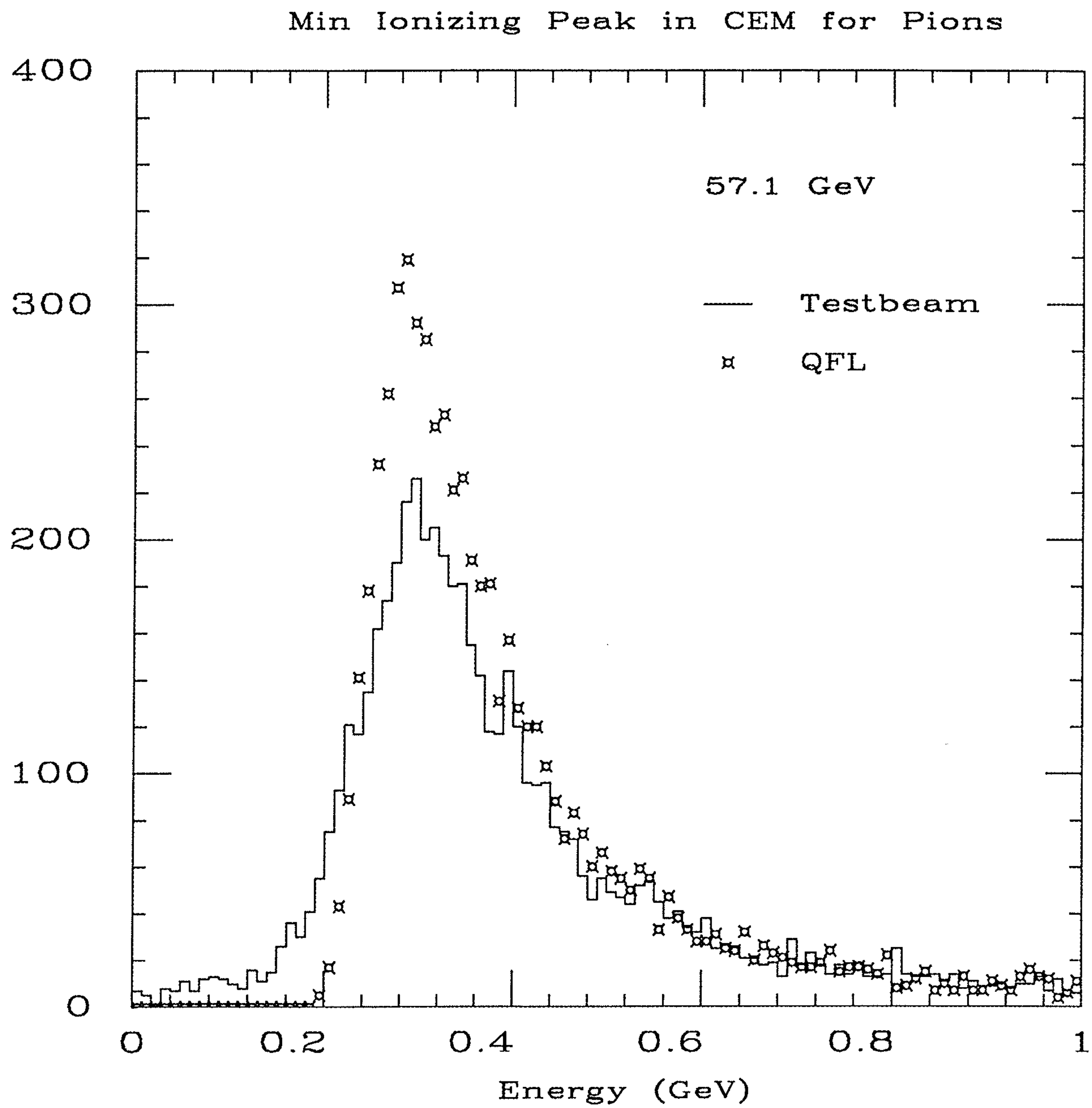
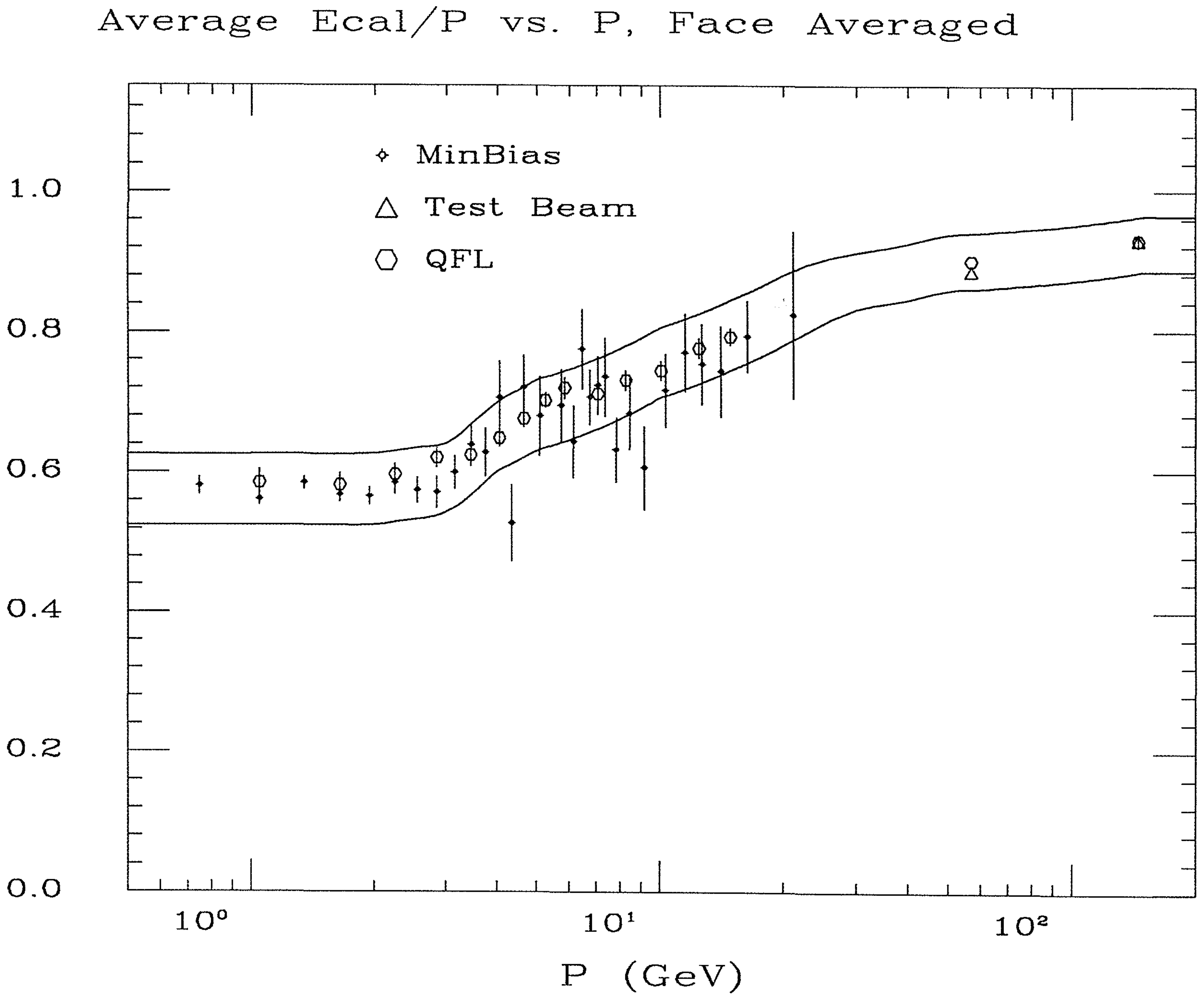

Min Ionizing Peak in CEM for Pions
400
300
200
100
0
57.1 GeV
Testbeam
QFL
0
0.2
0.4
0.6
0.8
1
Energy (GeV)

FIGURE 11



Average Ecal/P vs. P, Face Averaged
MinBias
Test Beam
QFL
1.0
0.8
0.6
0.4
0.2
0.0
10^0
10^1
10^2
P (GeV)

FIGURE 12