Empirical Study of Backgrounds for HAPPEX in Elastic Electron-Proton Scattering

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Backgrounds in the elastic scattering of electrons from protons in the Hall A spectrometers have been studied, and the corrections and systematic errors for HAPPEX evaluated. The data analysis is from three sources: 1) Analysis of 20 runs of e-P scattering from the experiment E91026 taken in Fall 1997. The runs cover a continuous range of Q^2 from 0.37 to 3.63 GeV^2. Various observables of backgrounds are defined and a model is developed to explain these observables over the entire data set. If this is successful, it means we have a complete understanding of where backgrounds originate. The model is applied to the HAPPEX kinematics. 2) Analysis of a "proton tagging" run from March 1998. In this run the electron and hadron spectrometers were deliberately mispointed so that the protons could "tag" electrons that might hit the pole tips. The electron arm detectors, including leadglass, was read out for every event, thus giving an unbiased measure of backgrounds. 3) Analysis of HAPPEX triggered data, in which the HAPPEX detector served as the trigger for the spectrometer detector package DAQ.

I OBSERVABLES OF BACKGROUNDS

Figure 1 shows the correlation for the energy in the leadglass verus the momentum for a typical medium–Q^2 run. Region one which has large energy in the leadglass is evidentally due to one rectangular region of the shower counter (not the preshower) which is incorrectly calibrated by 20%, and it is not background. The region two at $\delta P/P \geq 0.01$ is unphysical for elastic e-P and is called the "superelastic" tail. I should point out that in this plot, all events in the data file are plotted, but there is a suppression of single–arm triggers due to prescale factors. The prescale factors were taken into account in the analysis of backgrounds, and they are important because backgrounds occur in greater proportion in the single–arm triggers. I believe that most of the superelastic tail is due to quasielastic scattering from the aluminum frames of the target, as discussed in section 2. The third region in figure 1 is at low energy. As we will try to prove later, region three contains backgrounds due partly to pions and partly to inelastically scattered electrons that rebound in the spectrometer. In the particular run shown in figure 1 there are virtually no pions. Figure 2 is the same as figure 1, except that it is a lego plot.

In figure 3 is shown the definitions of the observables used to analyze backgrounds. Backgrounds are defined by cuts on abnormalities: 1) Energy in leadglass too low; 2) Momentum of electron too high; 3) Y-target is outside region of target; 4) Vertical angle is outside region of target; 5) Horizontal angle is outside region of target. Note that these observables are correlated somewhat. Also note that in figure 3 there are non–statistical fluctuations because the single–arm events were multiplied by their prescale factor before adding to coincidence triggers.

Figure 4 shows how these backgrounds grow with Q^2 for the 20 elastic e-P runs. The 4 lowest energy runs, in the few hundred MeV range, were not very useful and were not shown for the leadglass. At the highest Q^2 we see evidence for pions, as shown by the particle ID cuts in figure 5. About 22% of these pions point directly back to the target, many of the rest may be pions produced in the target which punch through the collimator. If we subtract the pions off from the leadglass distribution, the leadglass backgrounds agree fairly well with the target–pointing backgrounds. The "superelastic" backround in $\delta P/P$ does not grow with Q^2, but this is probably because it is caused by quasielastic scattering and is a different background than the other observables.

II SCATTERING FROM TARGET END CAPS

In figure 6 is shown the Y-target distribution for different scattering angles, in the elastic peak and for the superelastic tail from E91026 data. Y-target is defined as the distance, in the scattering plane and perpindicular to the central trajectory, between the scattering point and the central trajectory. The plots indicate an enhancement in Y-target near the target edges for the superelastic, meaning that much of this background comes from the end caps. Figure 7 shows the background in the momentum spectrum from the dummy target, which is a direct measure of the background from end cap scattering. This shows that about 1.5% of the background comes from end caps, where we normalized to the target walls thicknesses of the dummy and normal targets. One problem with this picture is that there is still a substantial superelastic tail which is not explained by the end caps. This deserves further study. It may be due to "splashback" from the HAPPEX detector which was in this setup, or to reconstruction problems in about 1% of the events in the VDCs.

III RESCATTERING IN THE SPECTROMETER

I have tried to explain one of origins of background as being due to rescattering of inelastically scattered electrons in the spectrometer. Accordingly the fraction of data which is background would be given by the following formula

$$B = \int_{E_0}^{E_{max}} dE \int d\Omega \ \mathrm{P_{rs}}(E) \times R(E)$$

where $\mathrm{P_{rs}}$ is the product of the probabilty to rescatter in the spectrometer and the energy deposited by the scattered electron and this product is normalized to 1.0 for elastic scattering

$$\mathrm{P_{rs}} = (\text{energy deposited}) \times (\text{probability to rescatter})$$

and $R(E)$ is the ratio of inelastic to elastic cross section.

$$R(E) = \frac{\left(\frac{d\sigma}{d\Omega dE}\right)_{\text{inelastic}}}{\left(\frac{d\sigma}{d\Omega}\right)_{\text{elastic}}}$$

and the integral extends from the inelastic threshold to the maximum energy loss that could contribute to this effect, about 20%.

Measurements of the rescattering function $\mathrm{P_{rs}}$ are shown in figure 8. The measurements with the spectrometer DAQ used ADC amplitudes in the HAPPEX detector to measure the energy deposition and trigger rates to measure the probability to rescatter. These measurements agreed with the HAPPEX DAQ, which integrates the HAPPEX signal and is a direct measure of $\mathrm{P_{rs}}$. The two methods were consistent.

In figure 8 we also show the ratio $R(E)$ for the HAPPEX kinematics. One sees that the Δ resonance contributes about 0.2% to our signal. Estimating the physics asymmetry of the Δ to be 2.8 times the asymmetry for elastic scattering, the correction is 0.56% (and it has the same sign as elastic scattering). We assume this calculation is uncertain by a factor of 3.0, stemming from the model uncertainty and the measurements of background, which leads to a systematic error of 1.7%.

In figure 9 we show the ratio $R(E)$ for four representative kinematics from amoung the 20 we analyzed. The inelastic cross section was computed using a parameterization of SLAC data. Its the same as used in figure 8. We have tried to demonstrate how well the rescattering model works by comparing to measurements of the observed backgrounds in E91026. In figure 10 is shown the ratio of observed backgrounds to the model integrated backgrounds

$$(\text{observed background}) \ / \ \int_{E_0}^{E_{max}} dE \int d\Omega \ \mathrm{p_{rs}}(E) \times R(E)$$

where now $\mathrm{p_{rs}}$ is the probability to rescatter unweighted by energy deposition.

Several comments can be made about this comparison. For the leadglass observable, the pion–subtracted data are most relevant since these are probably the rescattered electrons. The four observables agree reasonably with the model, since the ratio is about 1.0 for all Q^2. The vertical angle is the best correlator to rescattering backgrounds, as one can see by imagining the projection back to the target of a low energy track that bounces in the vicinity of Q3. The four observables are partly independent, so having a ratio less than one is reasonable. Evidently, at high Q^2 the model is wrong by a factor of 2, but since HAPPEX runs at $Q^2 = 0.5\text{GeV}^2$, we are will not worry about this breakdown. There are many kinds of backgrounds, but we believe the rescattering to be the most important for HAPPEX kinematics.

IV POLE TIP SCATTERING

A measurement was made in March 1998 to study the potential problem of pole–tip scattering which could lead to a large false asymmetry due to the polarization of the iron in the poles. In order to study this we set up the two spectrometers for elastic e-P scattering but with the spectrometers slightly mispointed (figure 11), so that for electrons that come at the edge of the acceptance the corresponding protons are well within the hadron arm acceptance (see dotted lines in figure 11). Thus, the protons can "tag" electrons which may hit the pole tips. In addition, when the proton hits the edge of its acceptance the corresponding electron is well within the electron acceptance (dashed lines). As a measure of the backgrounds in the electron arm we use the leadglass detector, which is read out in a bias–free way for every trigger. There is one complication that if the trigger is not accompanied by a charged particle on the electron arm, the ADC gate for the leadglass will be shifted late by about 100 nsec which will be about 50 nsec too late for the signal. But something should appear in the ADCs even for this case, which we refer to as the "neutral trigger bias". In figure 12 we show on 2D plots of the leadglass energy versus the hadron arm scattering angle. The five plots correspond to five vertical slices of the collimator acceptance. It turned out that the five slices are rather similar. On the left part of these plots, near -0.02 radians, are protons corresponding to electrons that hit the electron arm collimator. To realize this you have to know the correlation between the scattering angles in the convention of ESPACE – see figure 13. On the right part, near +0.02 radians, is the hadron arm collimator, showing clear evidence of protons punching through the collimator. The collimation of the electrons, however, is fairly clean. If there were pole–tip scattering, one might expect some low energy background in the leadglass near the left part of these spectra. No enhancement is observed, which means the collimator defines the acceptance.

In figure 14 is shown the correlation of leadglass ADC versus scattering angle for for various trigger types. For the hadron arm singles trigger, only some small signals near pedestal appear. The following analysis was done to determine the fraction of poletip scattering. The correlation plots were divided into regions of signal, poletip candidates, and other backgrounds. The signal region is for energy in the leadglass above a reasonable cut. The poletip and other backgrounds share the region below the energy cut and are divided by a proton angle cut which exactly subdivides the signal region. The poletip region is on the side near where the electron might hit. We define an amplitude summed over bins i, $A = \sum E_i N_i$ where E_i is the energy in the leadglass and N_i is the number of events. Letting A_s, A_p, and A_b represent the amplitude for the signal, poletip, and background region respectively, the fraction of poletip scattering is

$$Poletip \;\; fraction = (A_p - A_b)/A_s$$

and is plotted in figure 15. A second way to evaluate this was done to try to account for the "neutral trigger bias" mentioned above. For energies below 10% of the peak we multiply the amplitude by 4. There is some arbitrariness to this procedure, but I believe it over–compensates for the shift in ADC gate. It did not have much effect on the conclusion that the fraction of energy deposited in our detector from poletip scattering is probably less than 10^{-4}, and we may say conservatively less than 0.1%.

V ANALYSIS OF HAPPEX TRIGGERED DATA

This section concerns analysis of the data taken using the HAPPEX detector to define the trigger. A signal above a discriminator threshold, which was typically 60 mV, was used to trigger the spectrometer DAQ and read out the VDCs and other focal plane detectors. ESPACE was used to study the backgrounds.

Most people already know the story about backgrounds coming from the HAPPEX detector frame, which I showed during the Dec 1997 run. They are not a problem since they are very low energy and not a large fraction of the events, and I haven't included the results here.

We reconstruct tracks in these events and trace them back to Q3 or to the collimator. The percentage of tracks that miss Q3 or miss the collimator is a measure of the background as well as other problems. The tracking inefficiency is at present on the order of 1.5%. This was measured by seeing how many events have "wild" tracks that seem to have abnormal track parameters. Of course, such a cut is subjective and was not applied for any background study, but it gives an idea of the level of present problems in tracking efficiency which we believe are due to backgrounds from "splashback" from the HAPPEX detector and reconstruction problems. These problems deserve further investigation to develop methods to eliminate them from the real backgrounds. A legal cut to clean up these tracks was applied – to require that they intersect the HAPPEX detector. The logic of such a cut is that if a track does not hit the detector, then either it is fake or it missed the detector. Note that this is fine for cleaning up the tracks, but *not* for cleaning up the events. The events with bad tracks may well be showers. Using this cut we get the results shown in figure 16 for the traceback to Q3 and to the collimator. A fraction of $\approx 0.5\%$ miss Q3 and a larger fraction $\approx 2\%$ miss the collimator. The collimator miss–rate is larger, probably because the HAPPEX detector is not a very strong lever arm to reject wild tracks and the extrapolation to the collimator is far away which amplifies the problem.

We can also use the VDC information to study neutrals. In figure 17 is shown the correlation of the ADC signal in the HAPPEX detector and the multiplicity in the VDCs. A clear peak at zero multiplicity is seen, which corresponds to a low energy deposition in the HAPPEX detector. The 2D plot is shown both as a histogram and as a lego plot. In the bottom part of figure 17 is shown the HAPPEX ADC signal under the cut requirement that the VDC multiplicity is greater than 10 (left plot) and less than 10 (right plot). The fraction of events with a neutral was 0.01, and these neutrals deposit energy in the detector which is a factor ≤ 0.2 times the energy deposited by the main signal, so the background contribution to our data from this process is of the order 0.2%. It probably comes from rescattering in the spectrometer.

VI CONCLUSIONS AND SYSTEMATIC ERRORS

Several kinds of backgrounds have been studied, and we can reach preliminary conclusions about the corrections to our physics asymmetry and the systematic errors, which are the errors in the corrections. The worst remaining problem is the $\approx$1% of bad events in the data with the HAPPEX detector near the VDCs – events which don't trace back to the target, contribute to the superelastic tail, etc. It will be worthwhile to clean these events up and verify that they are not physics backgrounds. Also, I didn't consider some backgrounds like π^0 production.

1) The contribution of the end caps is 1.5%. Assuming the asymmetry from quasielastic scattering to be no more than 50% different from elastic scattering, we obtain a systematic error of 0.75%.

2) The asymmetry from the Δ is -47 ppm and the Δ is the most important contribution of rescattering background. This is about 2.8 times the e-P asymmetry using the Standard Model with no strange quarks. This background is about 0.2%. Therefore the correction is 0.094 ppm or about 0.56%. We assume the uncertainty in this is 50% for the asymmetry and 100% for the level of background. Therefore the systematic error is taken to be a factor of three of the correction, or 0.28 ppm = 1.7%. This can probably be improved before the next run.

3) The correction due to poletip scattering is negligible. The uncertainty in the fraction of energy deposited is less than 0.1%. Combining this with a raw asymmetry from Møller scattering of less than 10^{-4} the resulting uncertainty in the asymmetry may be estimated to be less than 0.1 ppm which is to be compared to the raw asymmetry of the e-P scattering.

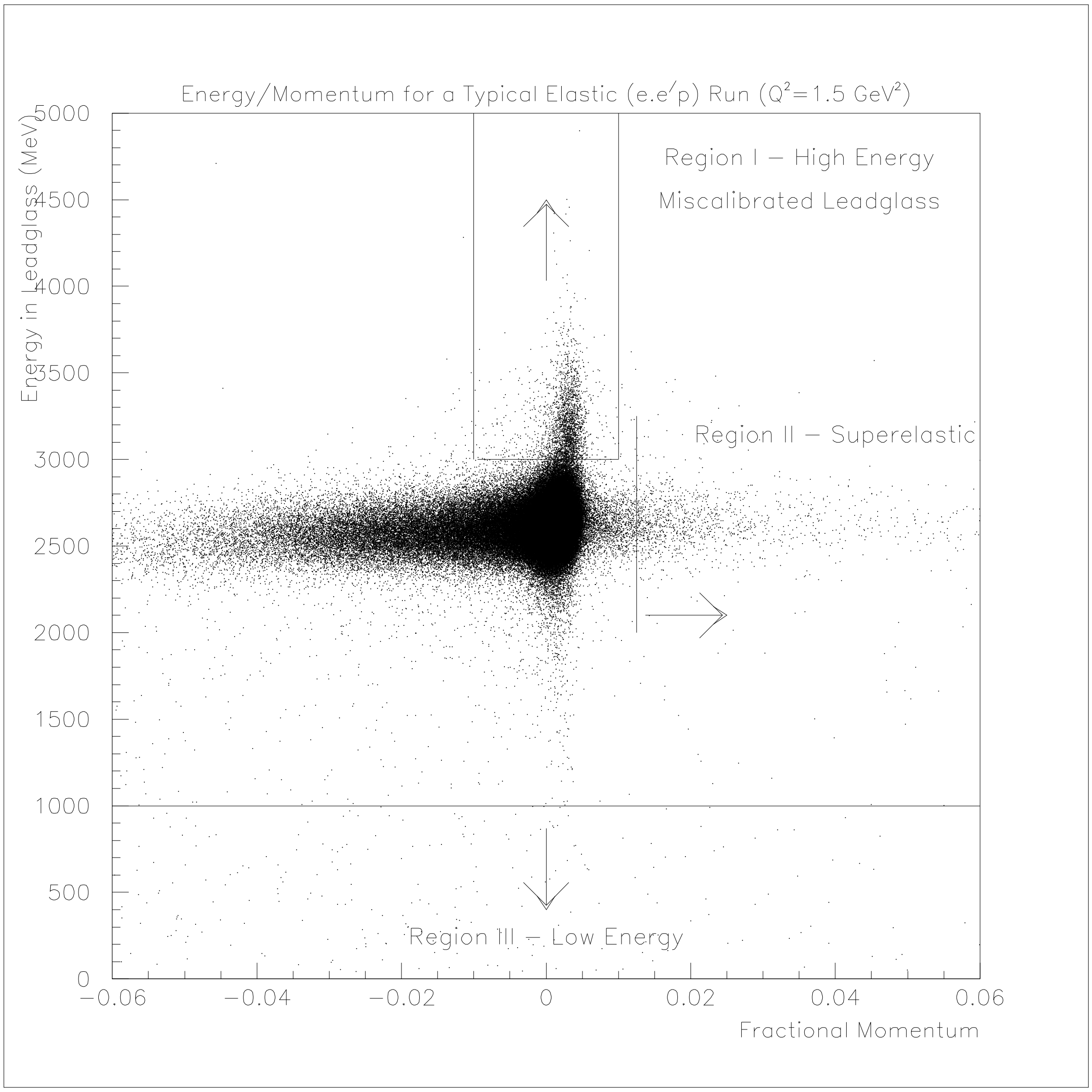

FIGURE 1. Energy versus Momentum for a Typical e-P Elastic Run. Shown is the elastic peak and radiative tail, as well as three regions of problems or backgrounds.

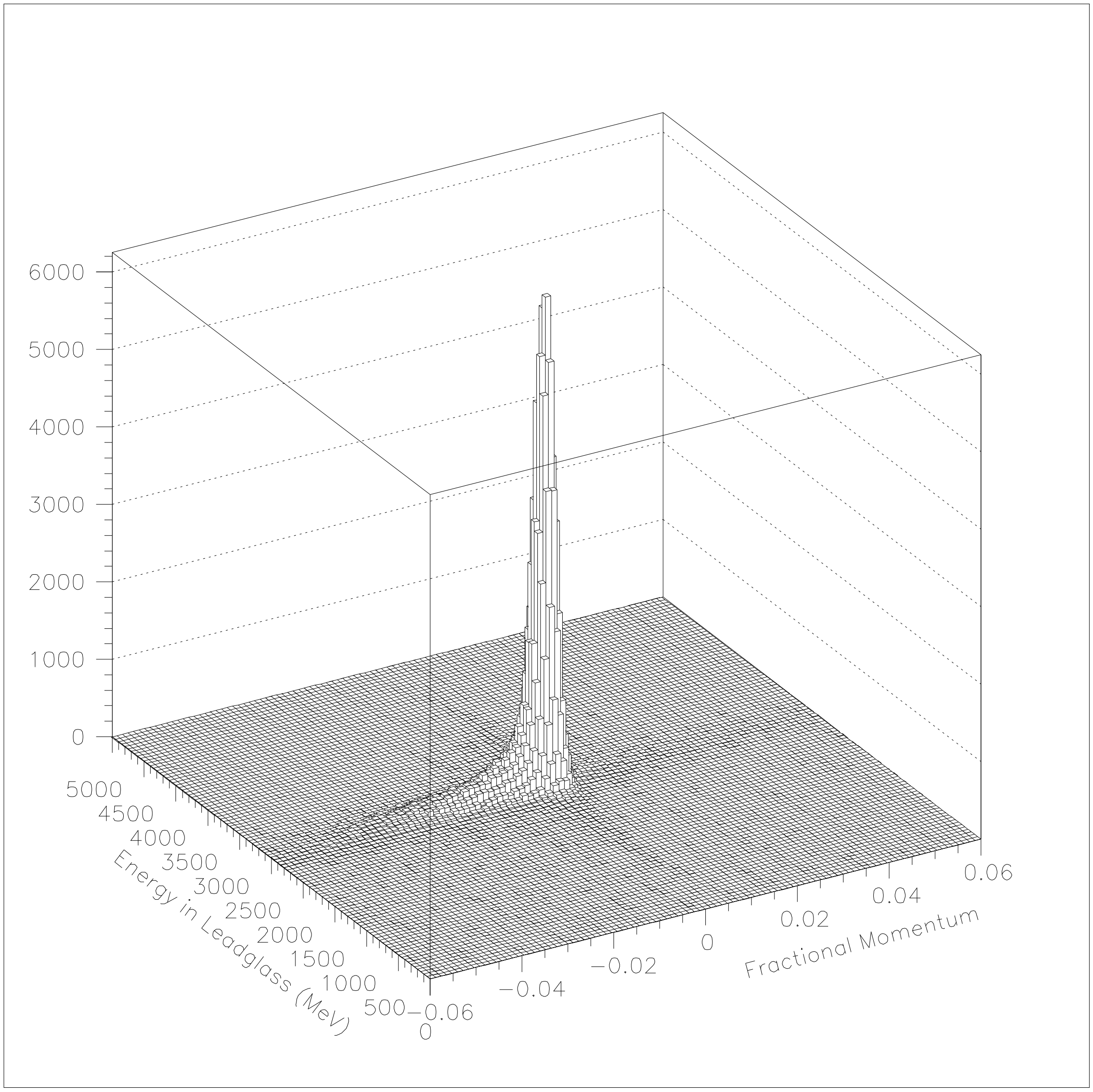

FIGURE 2. LEGO Plot Version of Figure 1

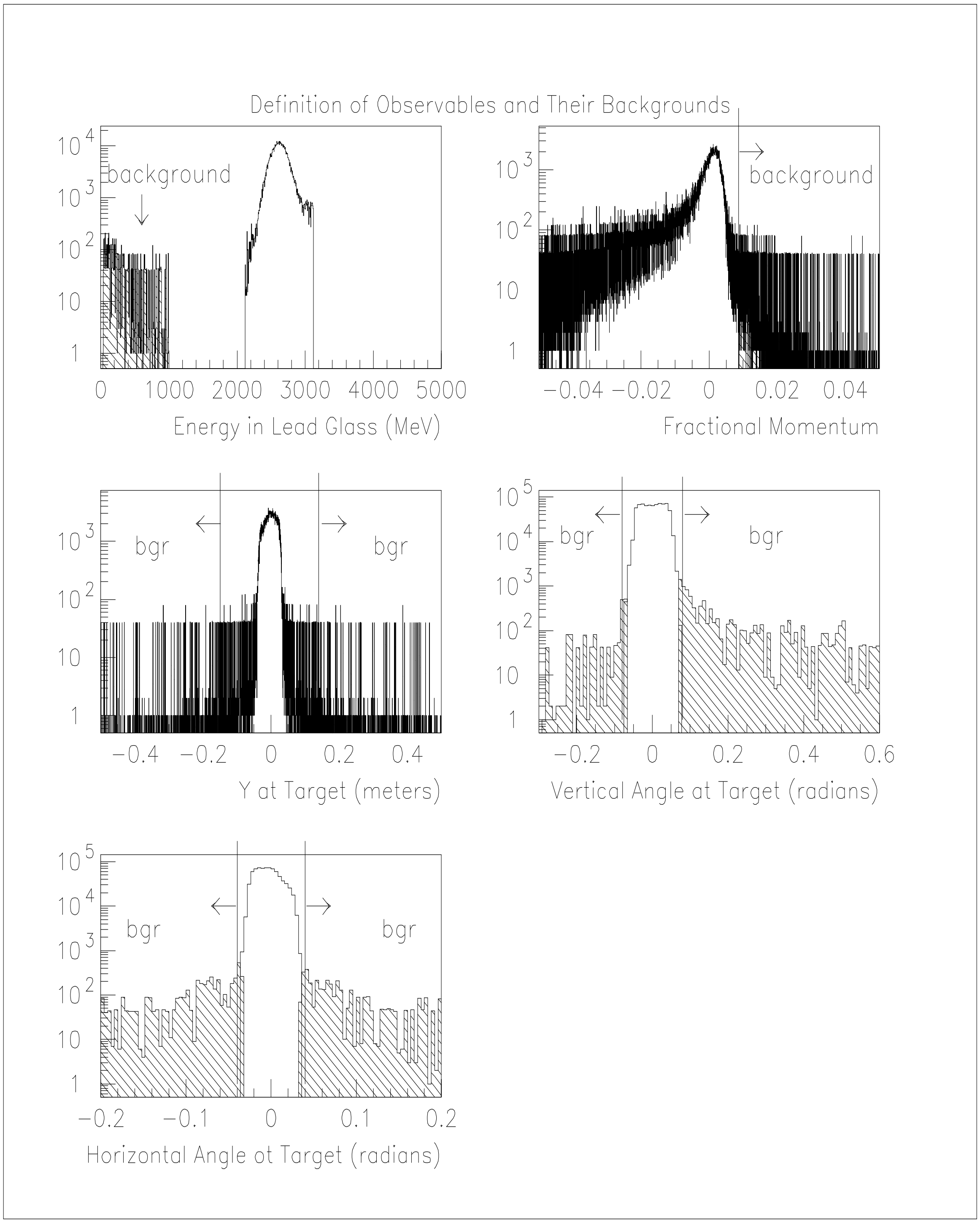

FIGURE 3. Five Observables Used to Study Backgrounds. The normal signals are shown by the unhatched histogram, and the backgrounds are indicated by the hatched region. The nonstatistical fluctuations are caused by prescale factors for singles triggers which were added to coincidences.

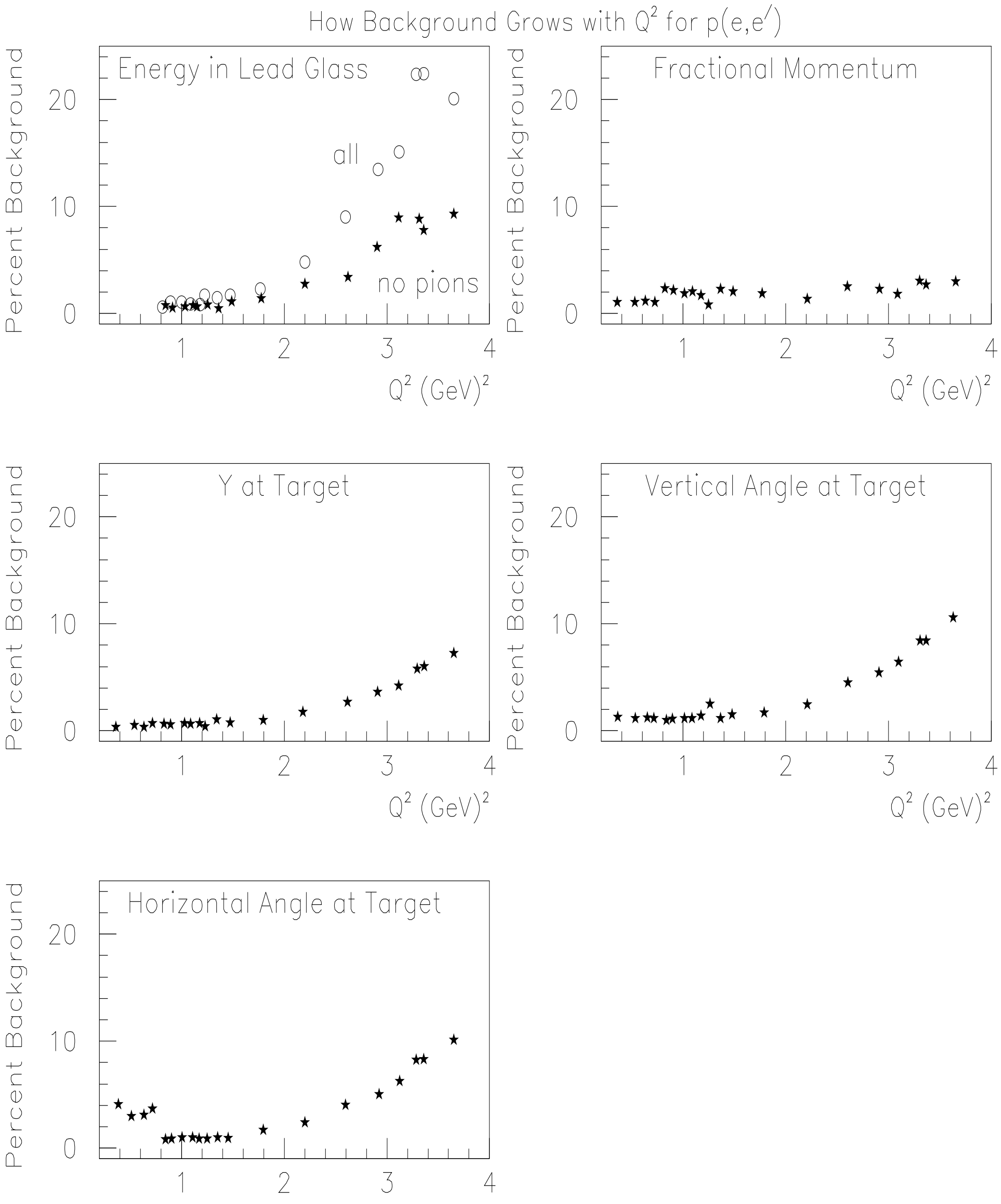

FIGURE 4. For the five observables of backgrounds, shown is the growth with Q^2 of the percentage of background in the E91026 experiment for elastic e-P runs.

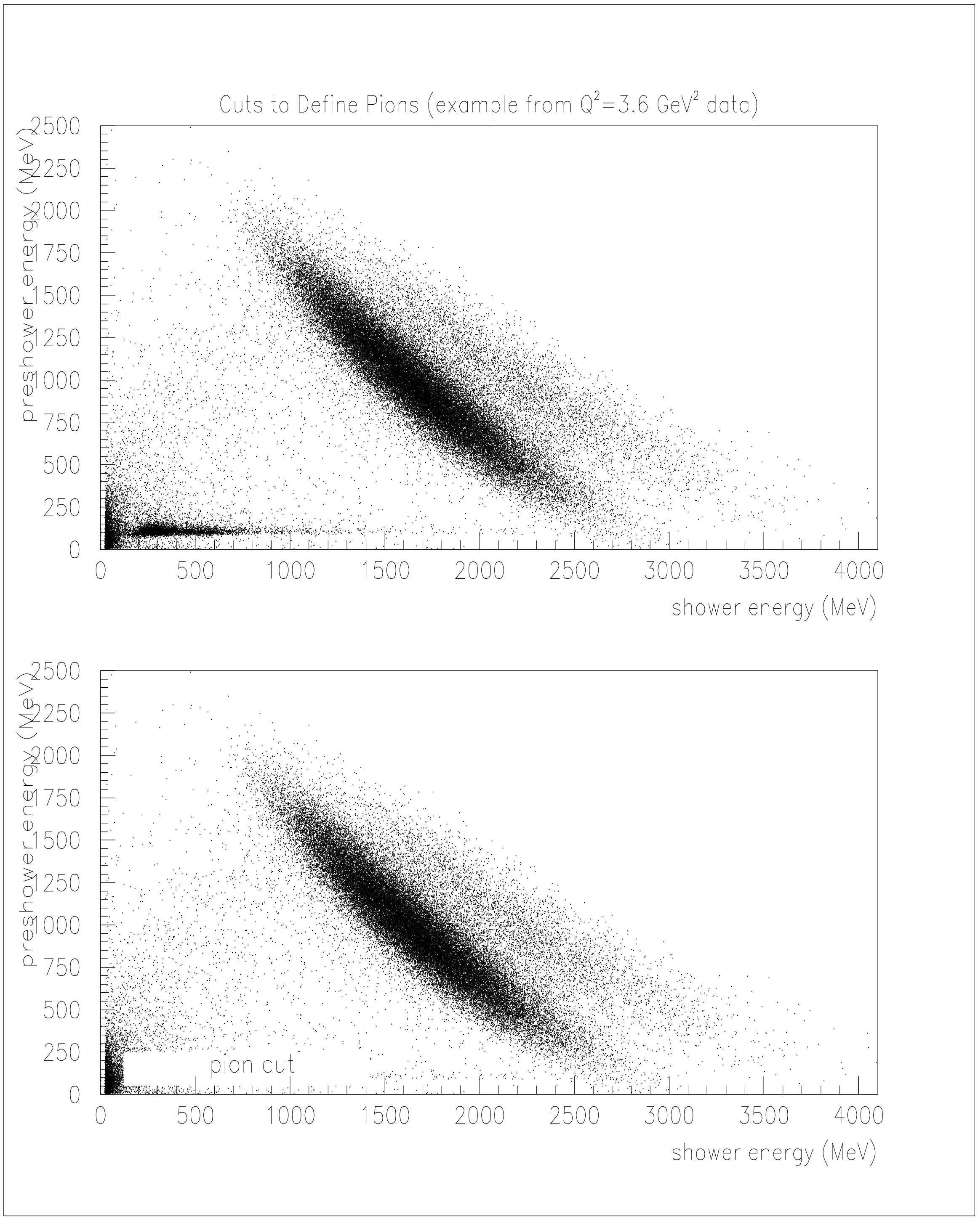

FIGURE 5. Shower and Preshower Signal Correlation with Definition of Pion Cut.

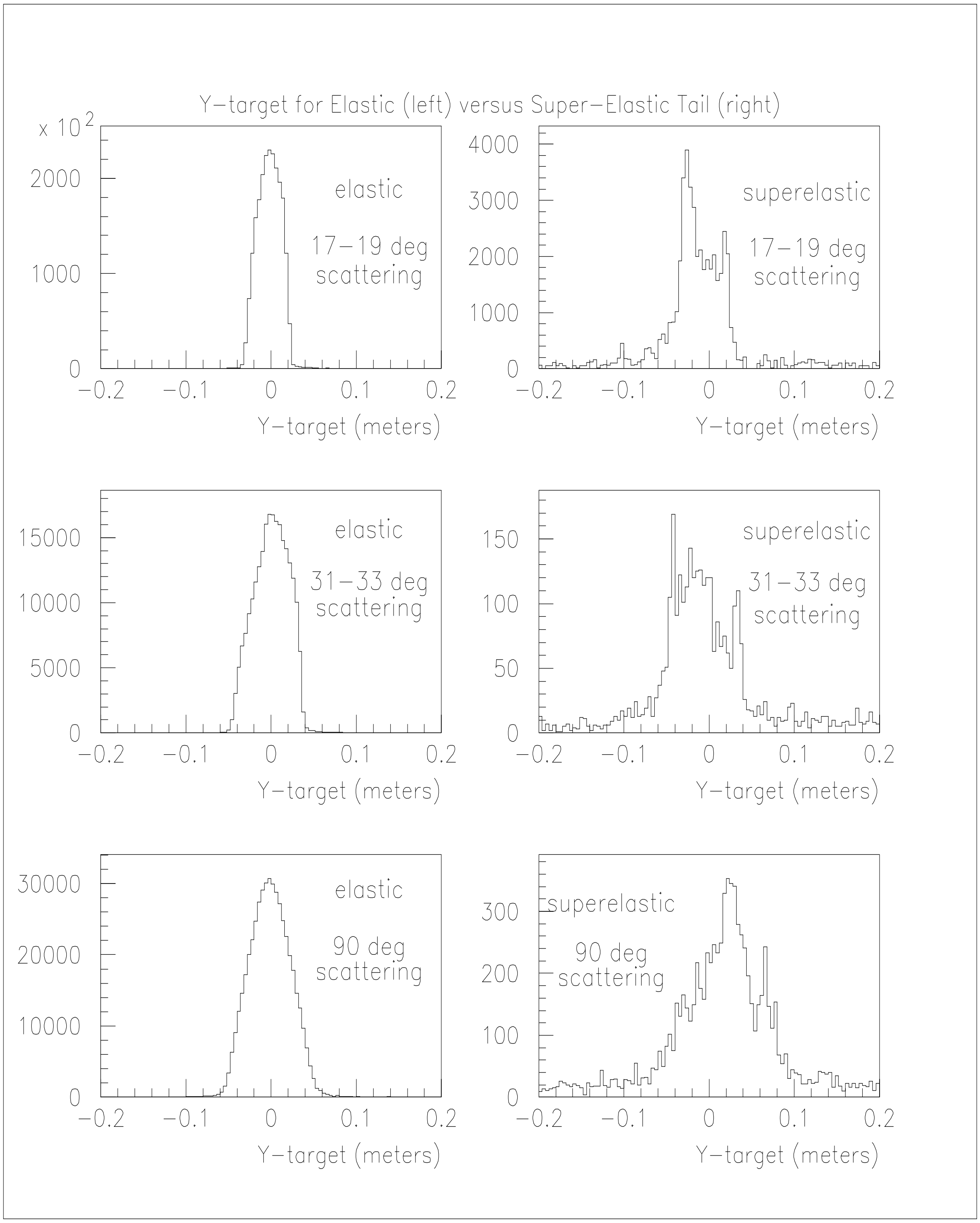

FIGURE 6. Y-target distribution for elastic e-P (plots on left) and superelastic tail (plots on right), indicating that much of the superelastic tail is due to scattering from target end caps.

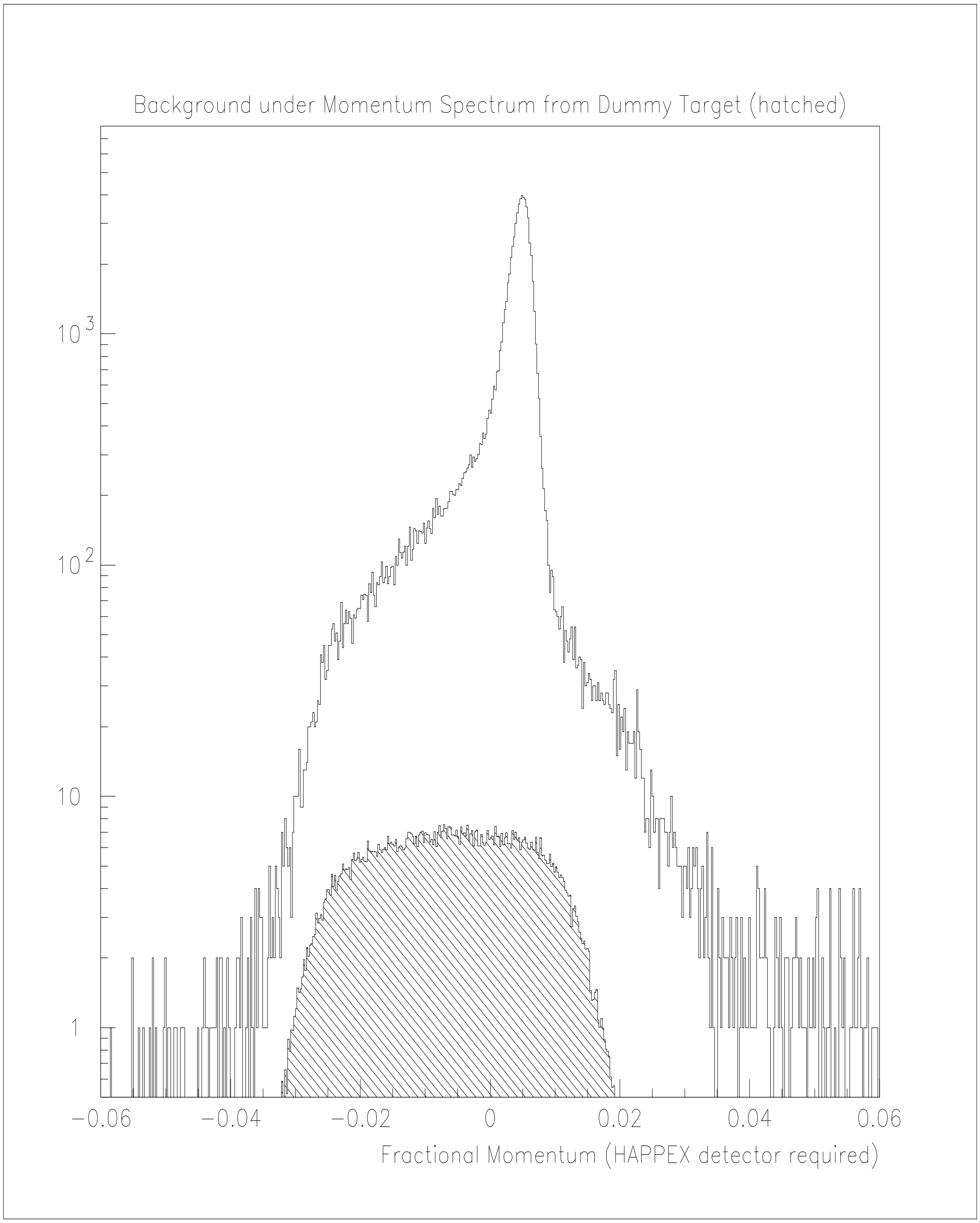

FIGURE 7. Normal Target versus Dummy Target for HAPPEX Triggered e-P Data. The dummy target data are in the hatched histogram and are a 1.5% background under the elastic peak, when normalized for target wall thickness of dummy cell.

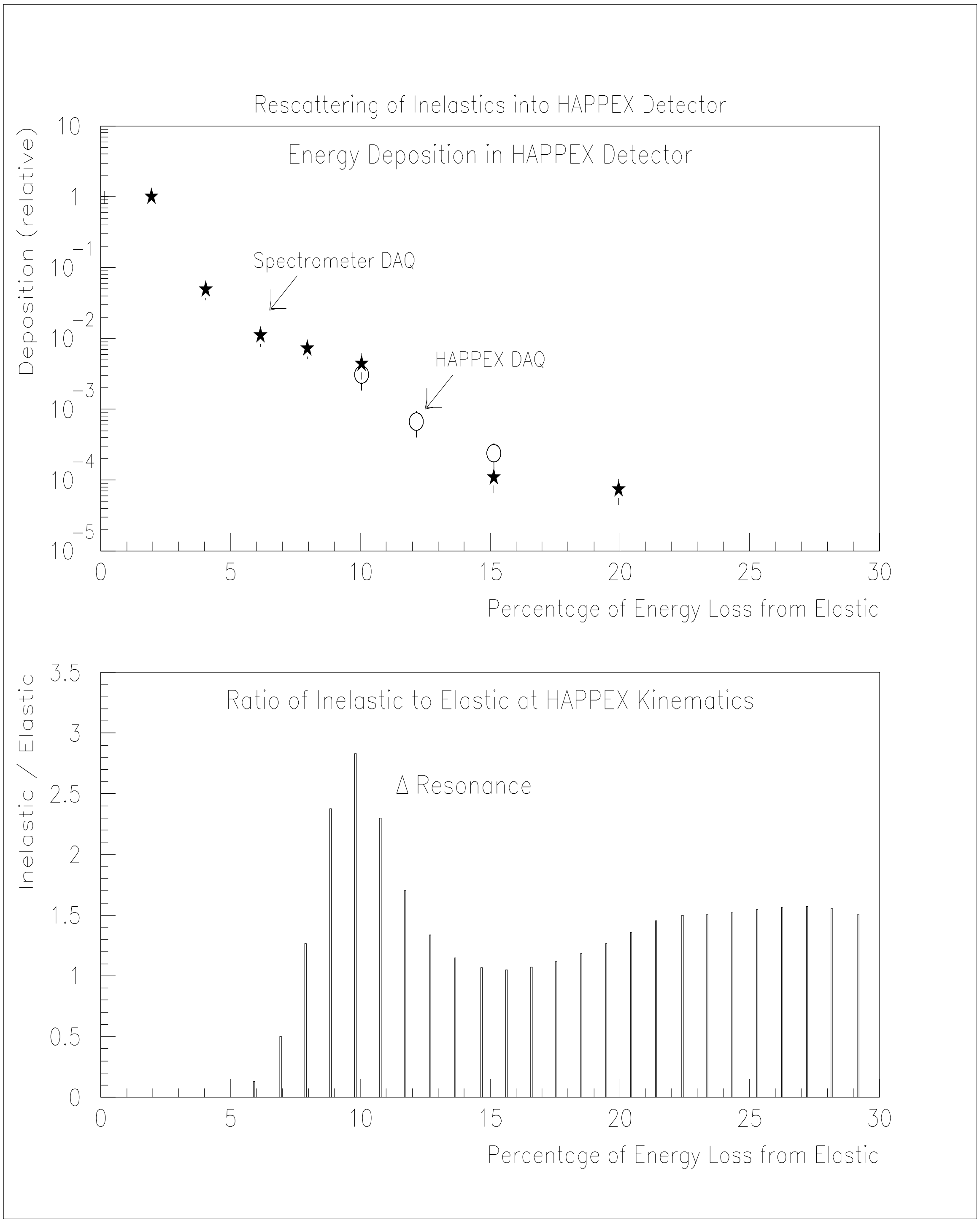

FIGURE 8. Top Figure – Energy deposition in HAPPEX detector versus energy of electron, as measured by adjusting the magnets to simulate lower energy electrons. Bottom Figure – Ratio of inelastic to elastic as a function of the energy of the electron for HAPPEX kinematics. The integrated product of the two figures is a 0.2% background due to rescattering in the spectrometer.

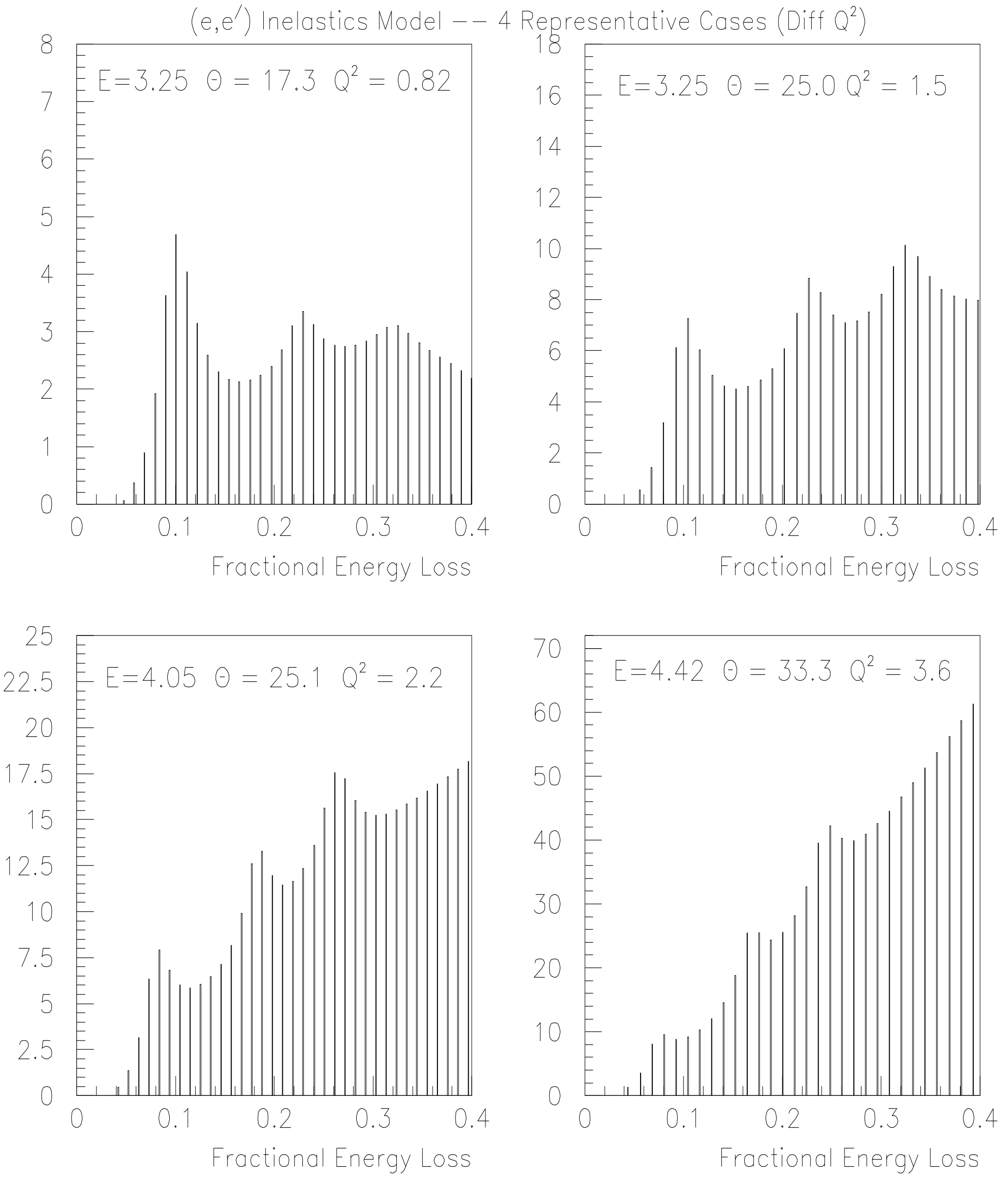

FIGURE 9. Ratio of inelastic cross section $d\sigma/d\Omega dE$ to elastic scattering cross section $d\sigma/d\Omega$ versus energy for four represtantive cases of increasing Q^2 in e-P scattering

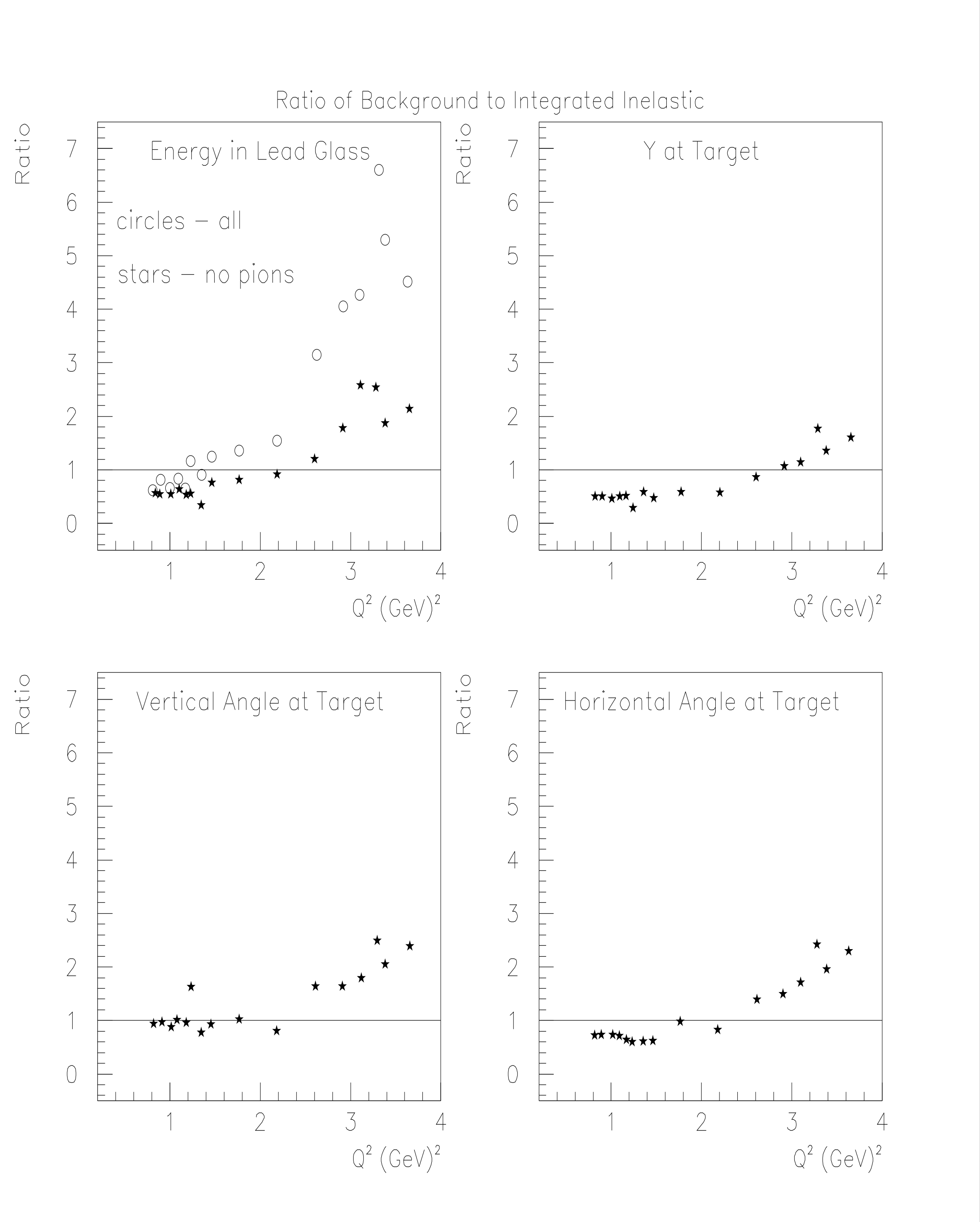

FIGURE 10. Ratio of background observed to the background calculated using the spectrometer rescattering model discussed in the text. A ratio of 1.0 means perfect agreement. A ratio somewhat less than 1.0 is reasonable at our Q^2 of 0.5 GeV^2 since the observables are partly independent. The vertical angle at target should the best correlator to this kind of background.

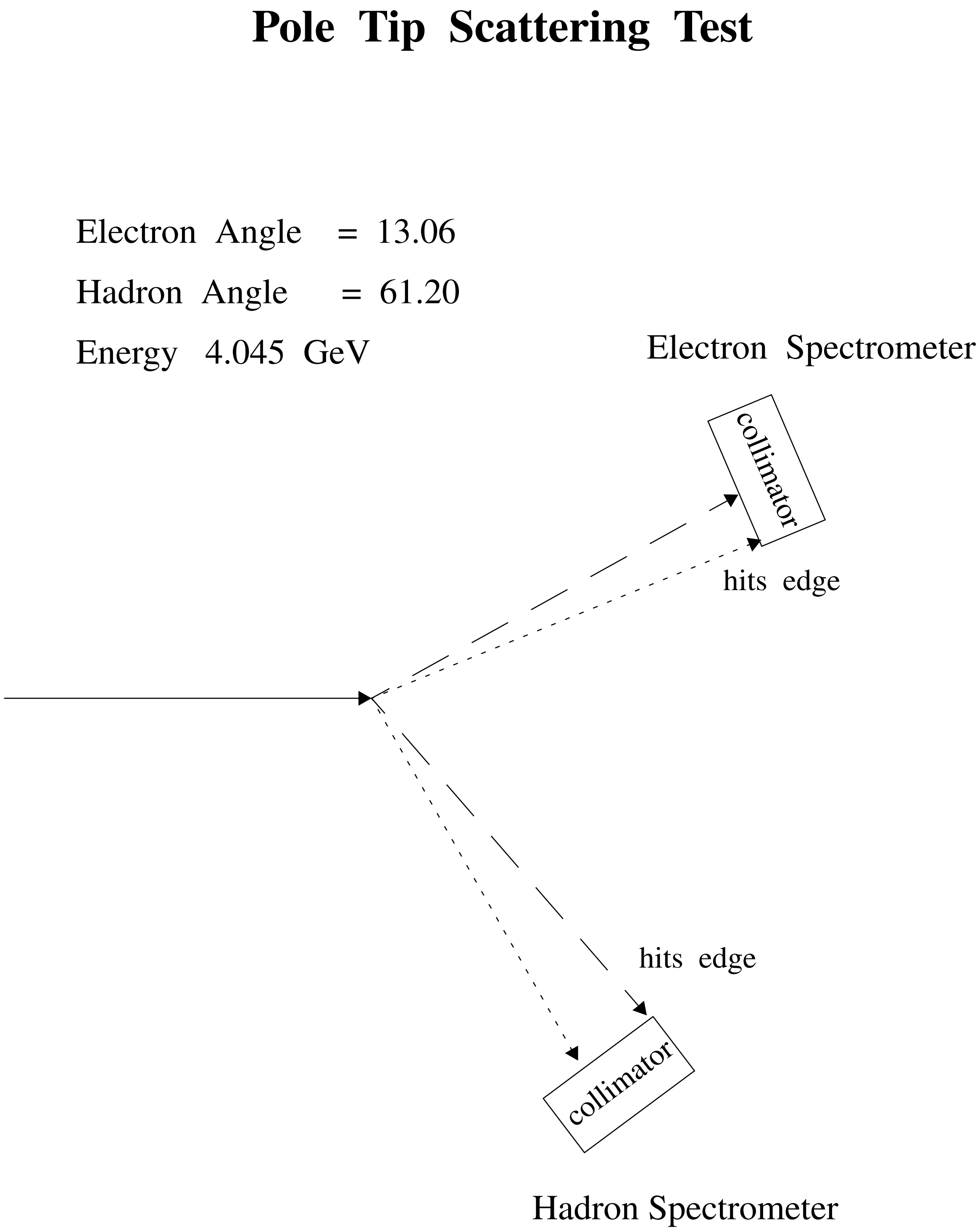

FIGURE 11. Setup used to study poletip scattering by using protons in the hadron spectrometer to tag the direction of electrons, and using an unbiased readout of the electron detectors including the leadglass to find electrons and backgrounds.

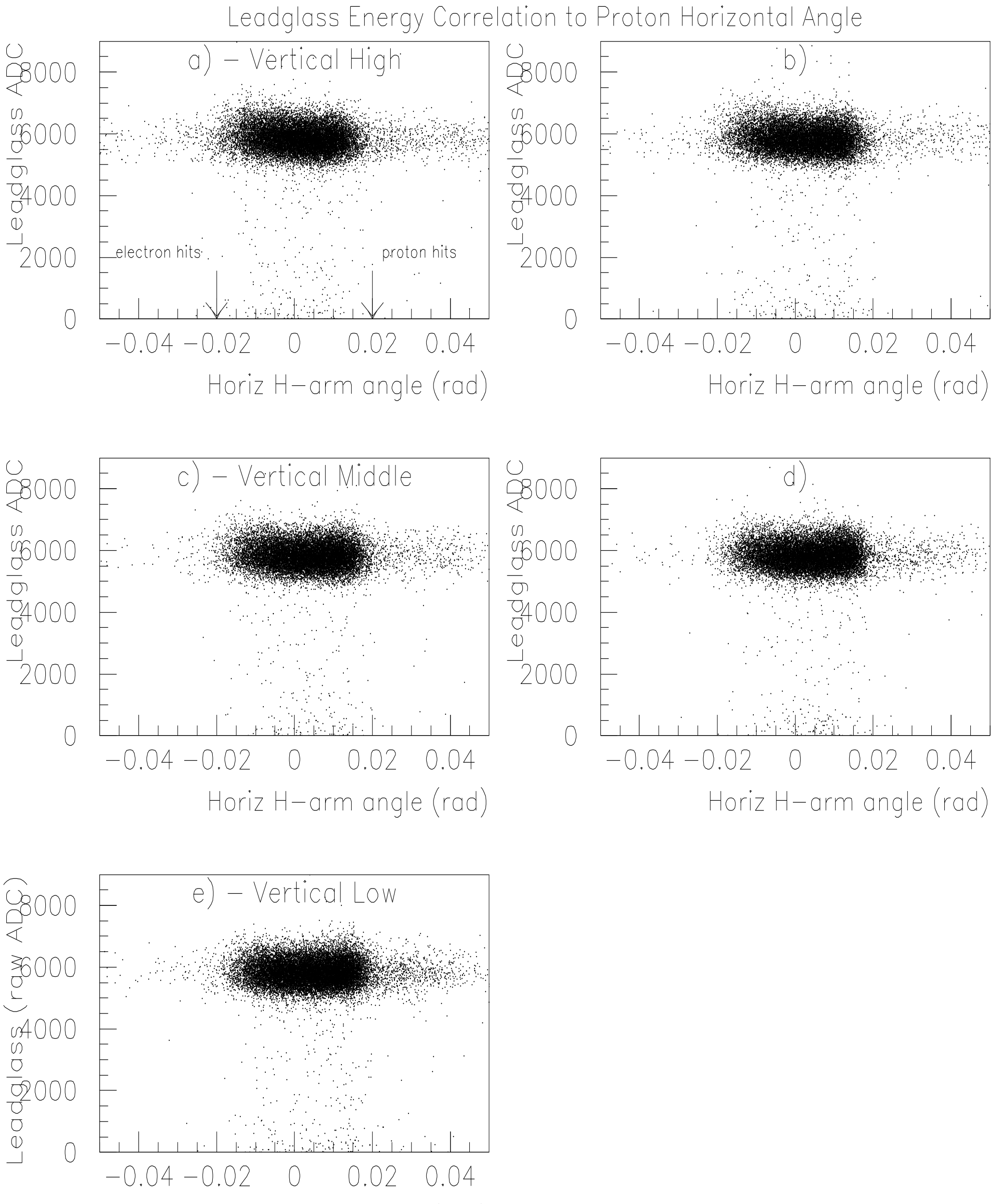

FIGURE 12. Leadglass Energy Correlation to Proton Horizontal Angle. The analysis is broken up into 5 slices of vertical angle of the proton, highest to lowest a) - e) across the acceptance. Each slice is similar. Evidence of poletip scattering would show up as a low energy tail towards the left edge of the acceptance where the electron may hit the poletip.

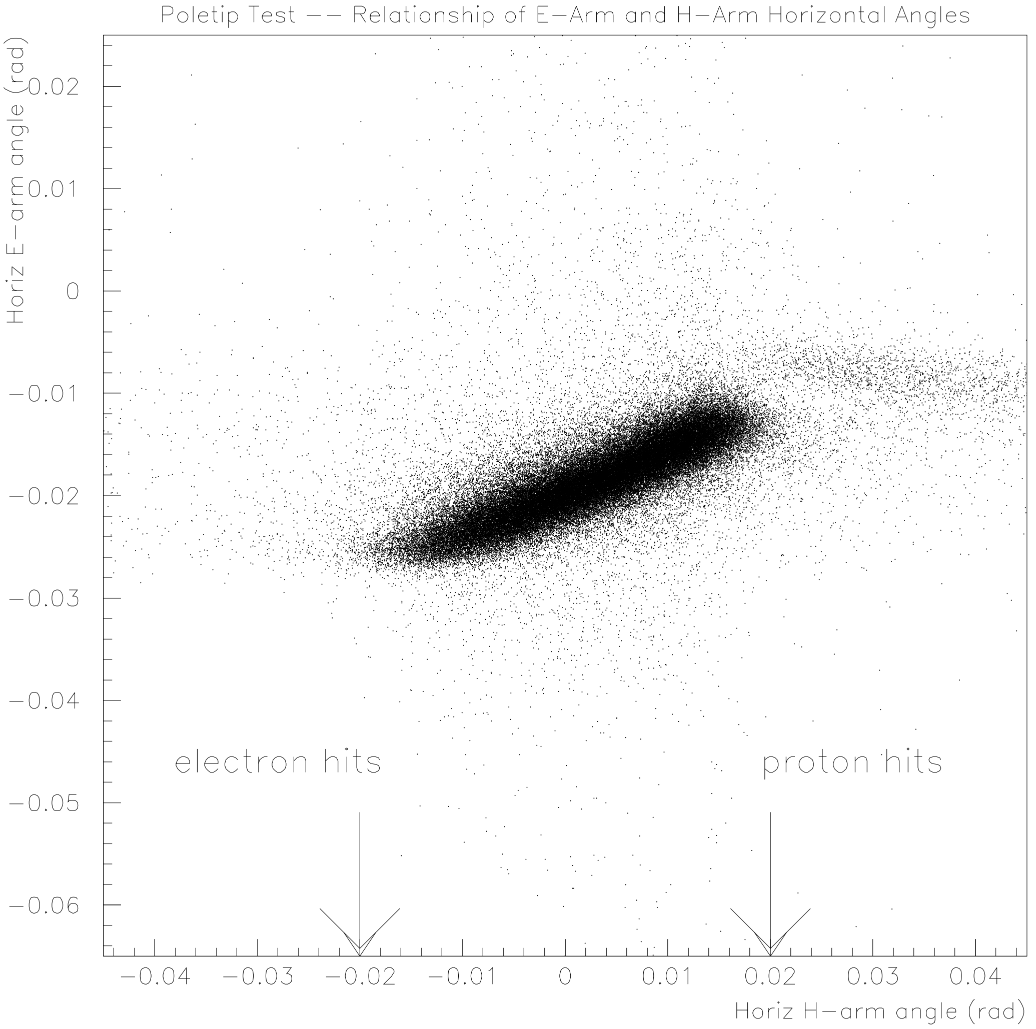

FIGURE 13. Relation between the electron and proton horizontal angle, showing the ability to tag the electron direction with the protons. The background on the upper right are due to protons punching through the collimator.

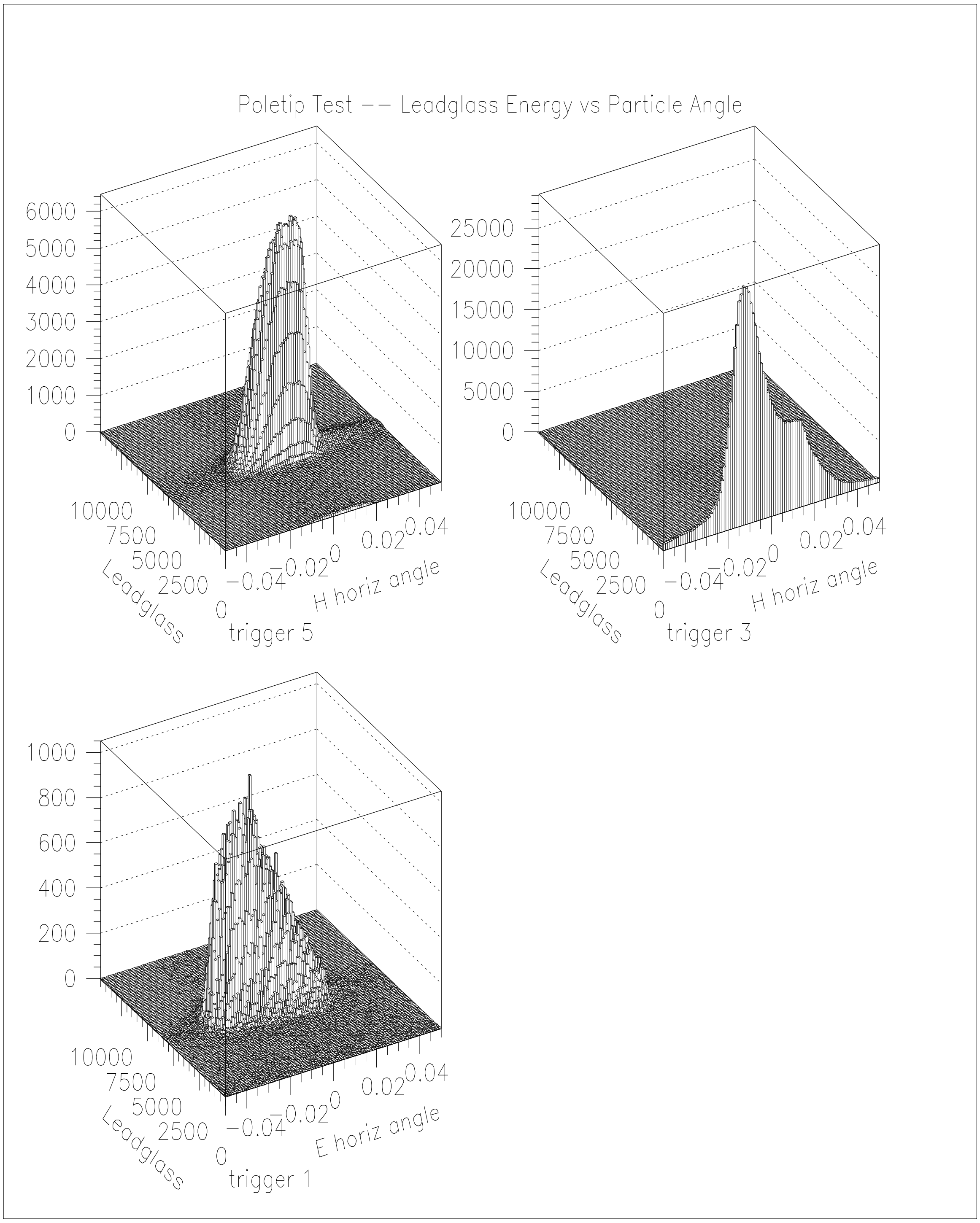

FIGURE 14. Leadglass Energy versus Angle of Proton or Electron. Trigger 5 (upper left) are coincidences and the proton angle is shown. Trigger 3 (upper right) are H-arm singles. Trigger 1 (bottom) are E-arm singles and the electron angle is shown. Poletip scattering would show up as a low energy tail especially near the edges of acceptance.

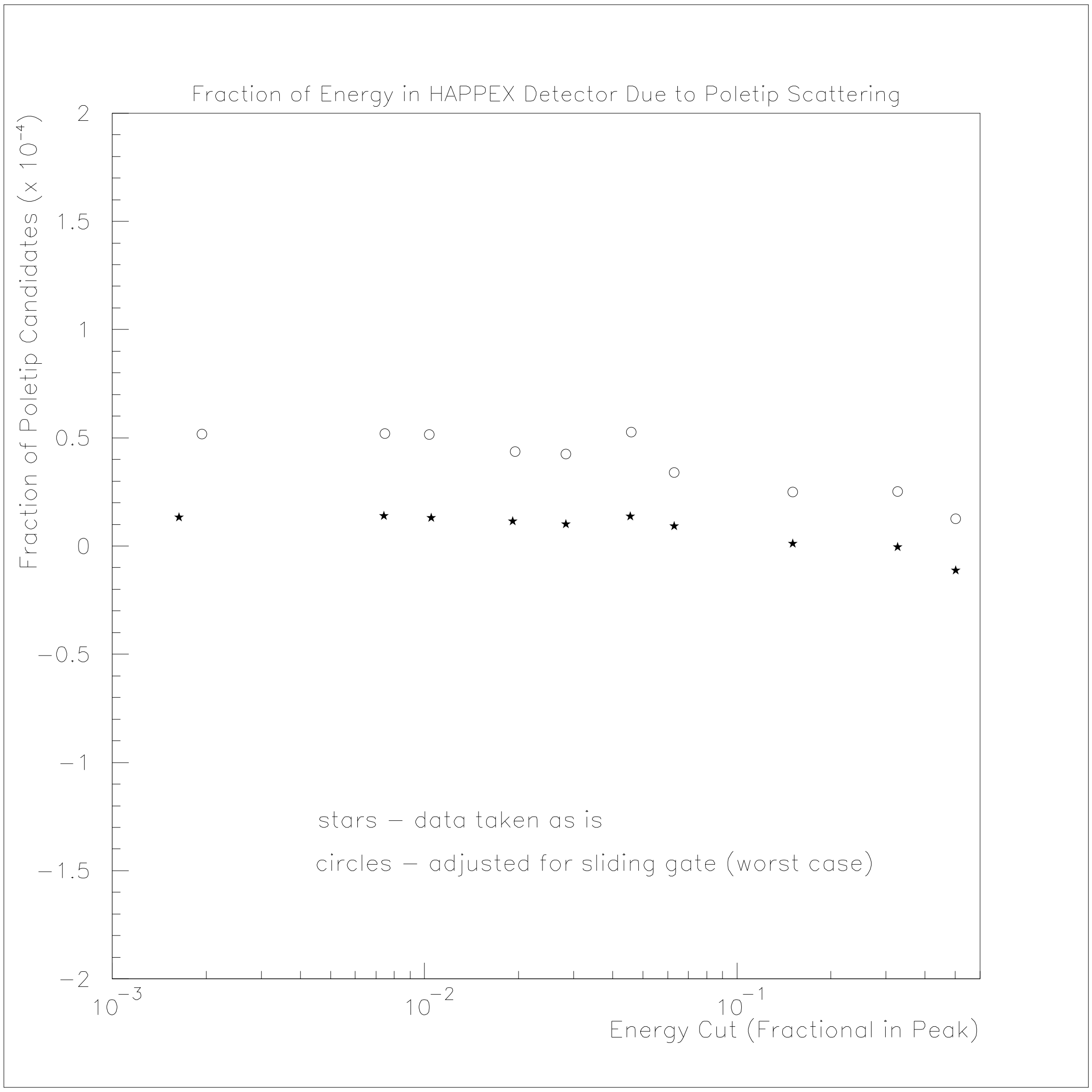

FIGURE 15. Fraction of poletip candidates using the analysis methods described in the text, plotted versus the cut in the energy. A reasonable cut is at 0.5. The lower cuts illustrate possible enhancement near pedestal. The picture suggests that less than 10^{-4} of the energy in the HAPPEX detector comes from poletip scattering. A reasonable upper bound is therefore 0.1% for this background.

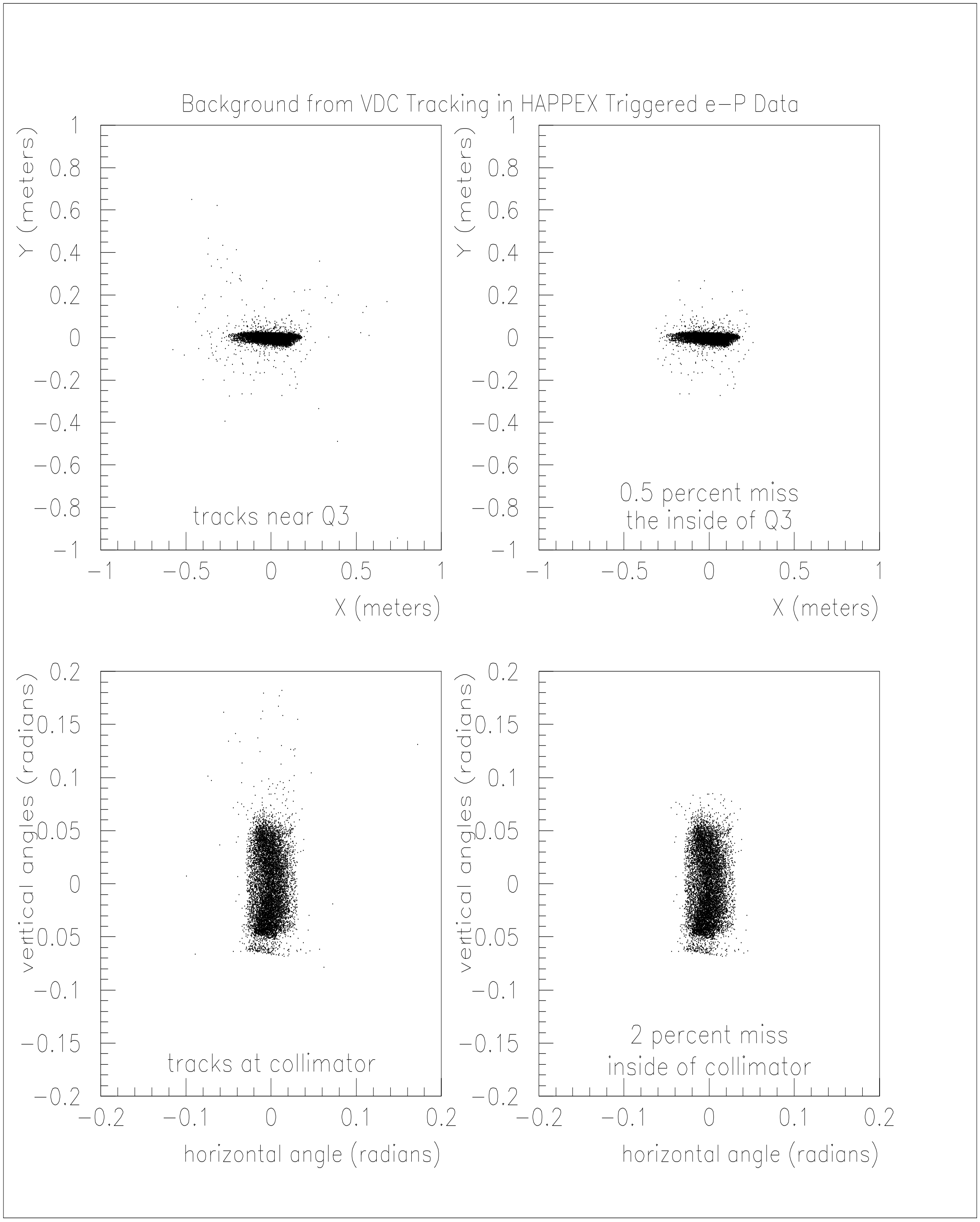

FIGURE 16. Using tracks from VDCs in HAPPEX triggered data, we extrapolate back into the spectrometer to see where they came from. Abnormal tracks which miss Q3 or miss the collimator are background candidates. These are respectively 0.5% and 2% for this run. Other explanations are splashback from HAPPEX detector and reconstruction problems.

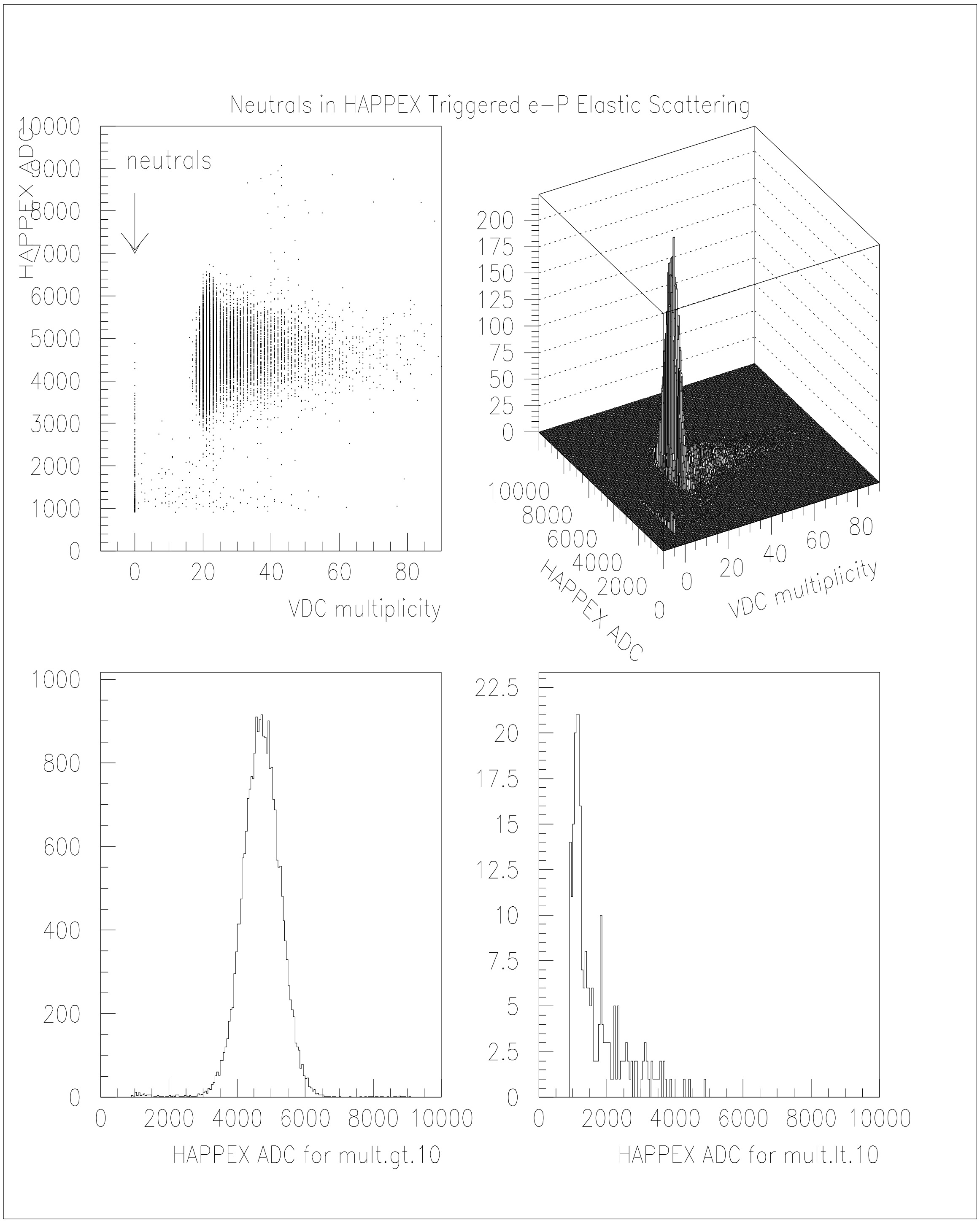

FIGURE 17. Contributions of Neutral Pariticles in HAPPEX Trigger. Top left – HAPPEX ADC spectra verus VDC multiplicity, indicating a fraction of 0.01 of neutrals. Top right – same plot, LEGO style. Bottom left – HAPPEX ADC spectra requiring a VDC multiplicity of 10 (charged signal). Bottom right – HAPPEX ADC for multiplicity less than 10. The ratio of energy deposited by neutrals to that due to the main signal is ≤ 0.2, so the overall contribution of neutrals is $\leq 0.2\%$.