FIRST REPORT ON GEANT SIMULATION
by
C. C. Chang, University of Maryland

1 Introduction

This is the first report on GEANT simulation and it concentrates mainly on the study of collimator punch-through and the proposed solution to this problem. This study is done with the GEANT code.

2 Target Geometry

The pressurized ^{3}He gas at 220 lb/in^2 and 5^{o}K is contained in a tuna-can like container. The diameter of the ^{3}He volume is 4.063" and the thickness of the Al window is 0.013". This corresponds to a target density of 0.110 gm/cm^3. The computed radiation length is 199.7 cm.

3 Event Generation and GEANT Simulation

Six random numbers are generated for each event: one for the interaction point along z within the gas target (z), two for the x and y coordinates at the electron arm collimator opening (xxe and yye), two for the x and y coordinates at the hadron arm collimator opening (xxh and yyh), and one for the electron momentum (ep). θ_e, ϕ_e, θ_p, and ϕ_p are then calculated from xxe, yye, xxh, yyh, and z. A three-body kinematic program is used to calculate the proton momentum (pp) and the recoil momentum (pR) for the two-body and three-body breakups. Range of pR is limited between 0 and 50 MeV/c. It turns out the range of proton mentum is larger than the hadron arm momentum acceptance. Figure 1 shows the yy vs. xx plots for both arms. Note that events are generated with values of xxe, yye, xxh, and yyh larger than the physical opening of the collimators in order to see the effects of punch-through. The limits on yye is due to the accepted range in pR.

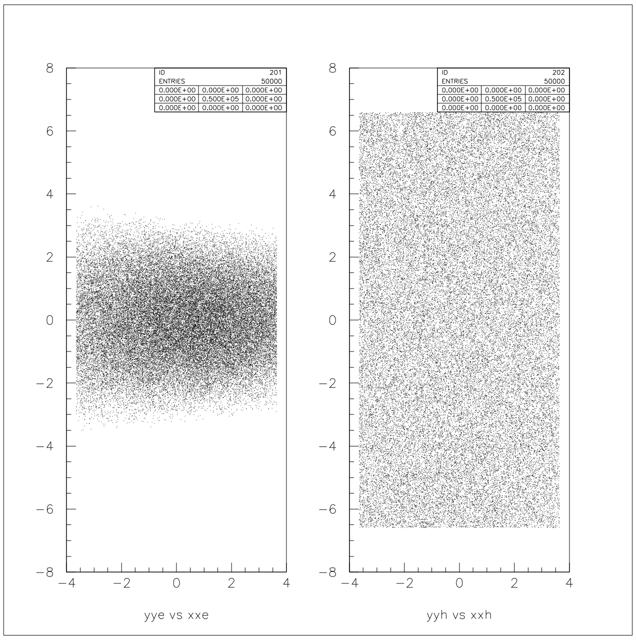

Fig. 1 yy vs. xx at the tungsten collimator openings for both arms.

Figure 2 shows the sampled momenta for electrons (ep) and the calculated proton momenta (pp).

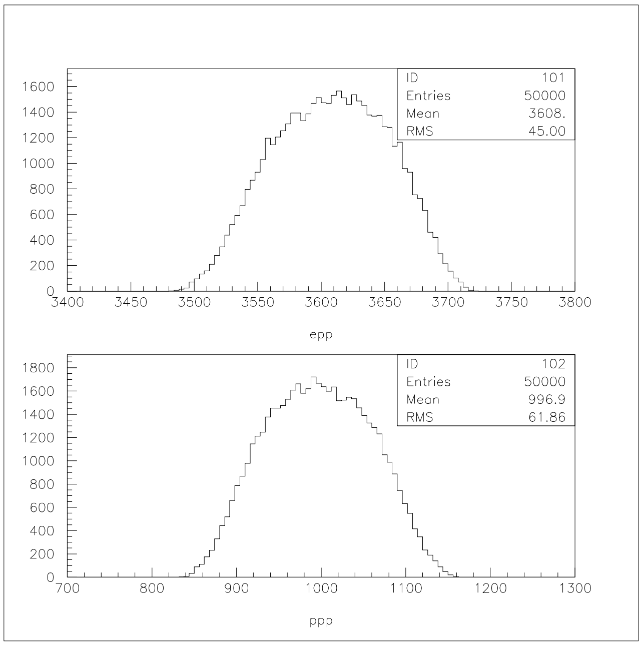

Fig. 2 Sampled electron momenta and the calculated proton momenta.

4 GEANT Simulation

GEANT transports both e and p through ^{3}He, the thin exit Al window, and beyond the tungsten collimators. The dominant processes for energy loss include multiple scattering, external bremsstrahlung (important for electrons), dE/dx ionization, and hadronic interaction (important for protons). No internal bremsstrahlung is included in this simulation. The energy loss for the incident electron before an (e,e'p) event is not included either. The position and momentum information for both e and p beyond the collimators are stored. These information are used to compute the intersections of e or p tracks with the x-y plane at z = 0 (in GEANT coordinate frame where +y is up) by a backward straight line extrapolation. Figure 3 shows the x0 and y0 plots for the electrons.

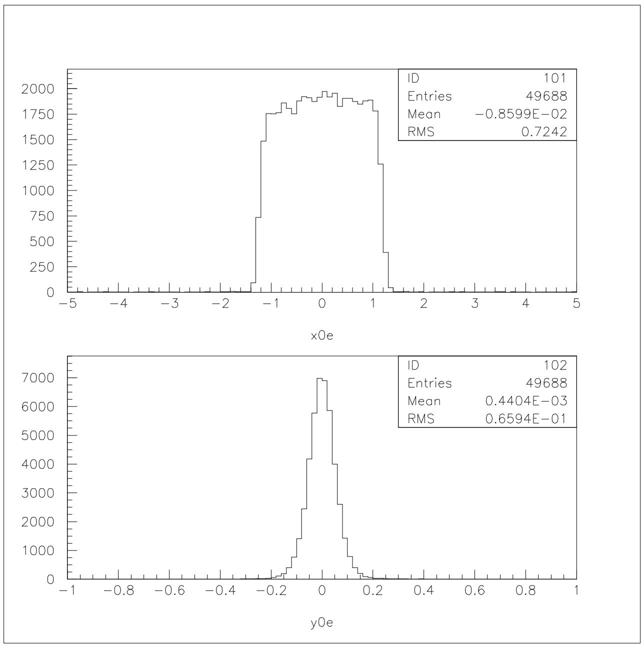

Fig. 3 x0 and y0 for the electron arm.

5 Optics

Variables in GEANT coordinate system (x0e, y0e, etc.) can be used to compute the corresponding variables in the beam transport coordinate system (where +x is down). These variables are x-target (xte or xth in cm), theta-target (thte or thth in mr), y-target (yte or yth), and phi-target (phte or phth). Figure 4 shows the xte and thte plots for the electron arm.

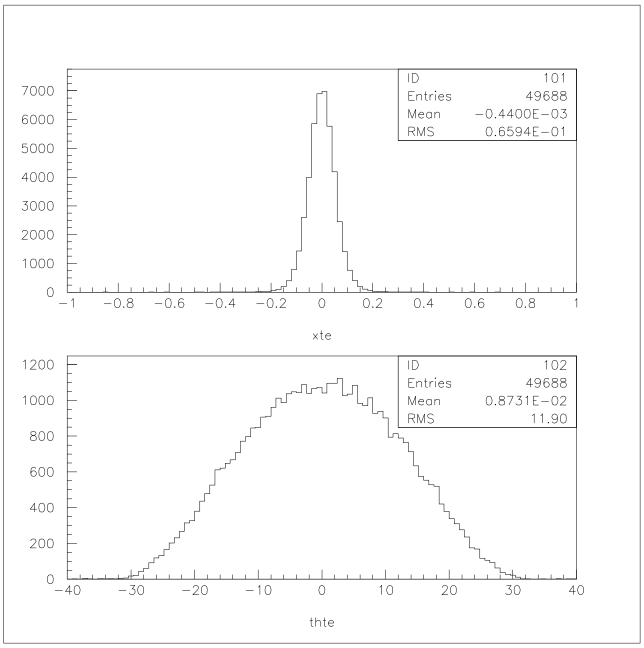

Fig. 4 Plot of x_{target} and θ_{target}.

A forward going transport function (matrix) is provided by John LeRose. This function takes the variables at the target to the focal planes (actually planes that are perpendicular to the optic axes). The variables at the focal planes are xfe, yfe, thfe, phfe, etc. Figure 5 shows the yfe vs. xfe for the electron arm.

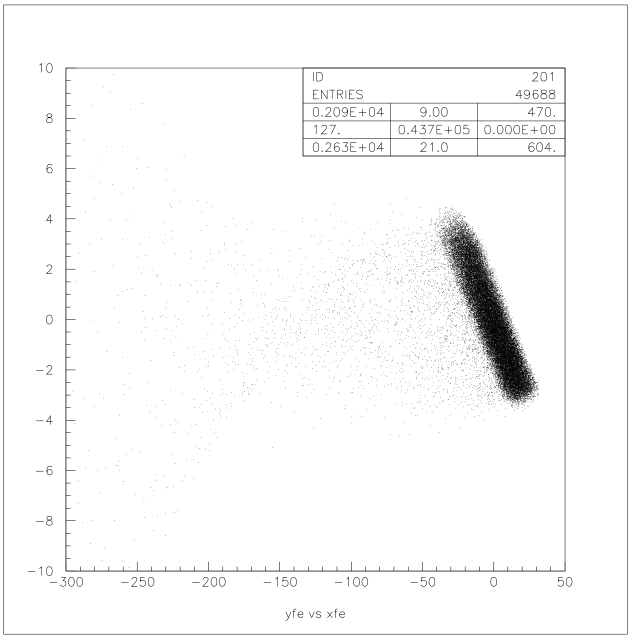

Fig. 5 Plot of y_{focal} vs. x_{focal} for the electron arm .

Functions are also provided by John LeRose which give the information on the limiting apertures at Q1, dipole, and Q3. Cuts on aperture limits have not been applied. Experimentally, variables at the focal planes are the ones obtained using the wire chamber information. A reverse function (from detector to target) is also provided by John LeRose. Instead of going through the entire process by applying the forward going function to the variables at the target and then reapplying the reverse function to the constructed variables to get back to target, I simply use the target variables as known for the rest of the study. One would need to go through the process if one takes into account the multiple scattering at the chamber windows, for example.

6 Punch-Through

Many solutions are suggested for removing the effects of collimator punch-through events. Punch-through events are troublesome in the high missing energy region (see Fig. 6).

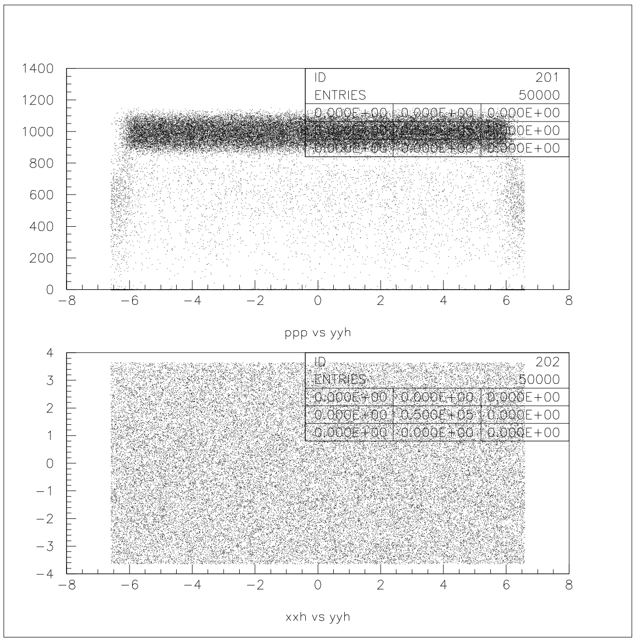

Fig. 6 Upper part of Fig. 6 shows the the plot of proton momentum beyond the collimator vs. .

One of the solutions is to put active collimators (such as NE102 plastic scintillators) in front of the tungsten collimators. This is easily implemented in GEANT simulation.

Figure 7 shows the energy lost in the active collimators.

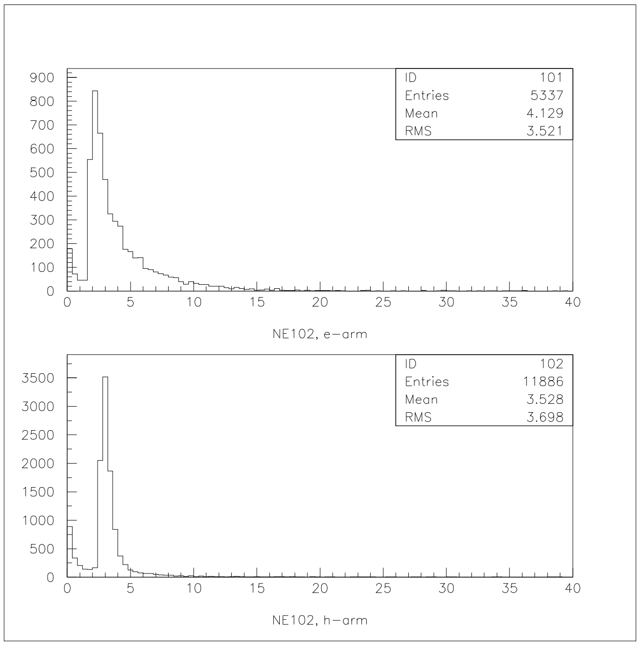

Fig. 7 Energy loss in NE102 active collimators.

Although this is a viable solution in principle (see Figs. 8 and 9), it would be difficult to implement in practice because the active collimators may not survise the high counting rates in an electron enviornment.

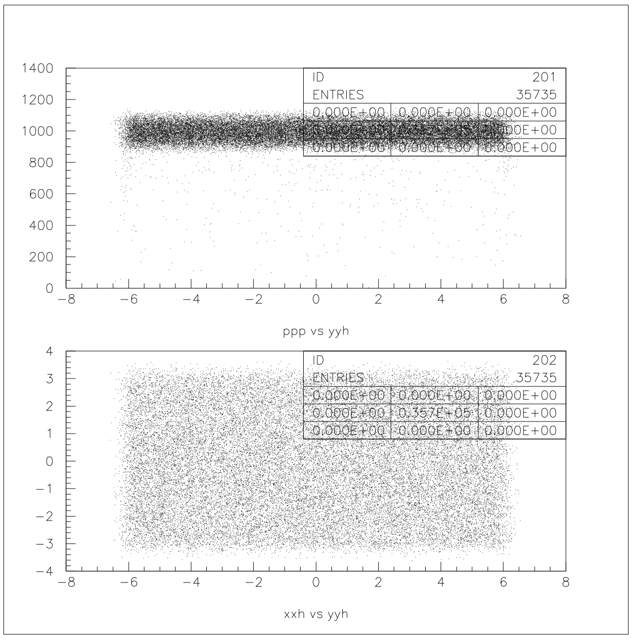

Fig. 8 Upper part of Fig. 8 shows the proton momenta beyond the tungsten collimator. Cut on active collimator signal is applied to remove the punch-through events.

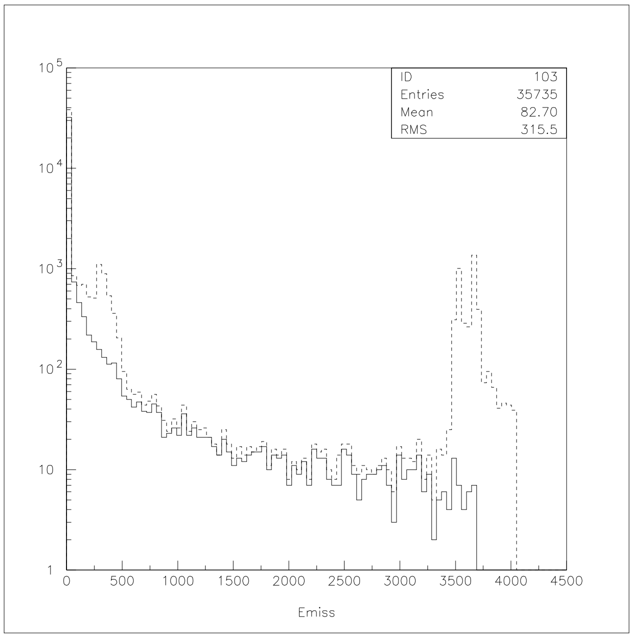

Fig. 9 Missing energy spectra with (solid line) and without (dashed line) cut on active collimator signals.

Another alternative solution is the one used by the VCS experiment. They compute a quantity called two-arm-x (twax). This is the x coordinate of the intersection between the two extrapolated e and p tracks back to the target in the x-z plane (in the GEANT frame). For non punch-through events twax should be near zero. Figure 10 shows the plot for twax.

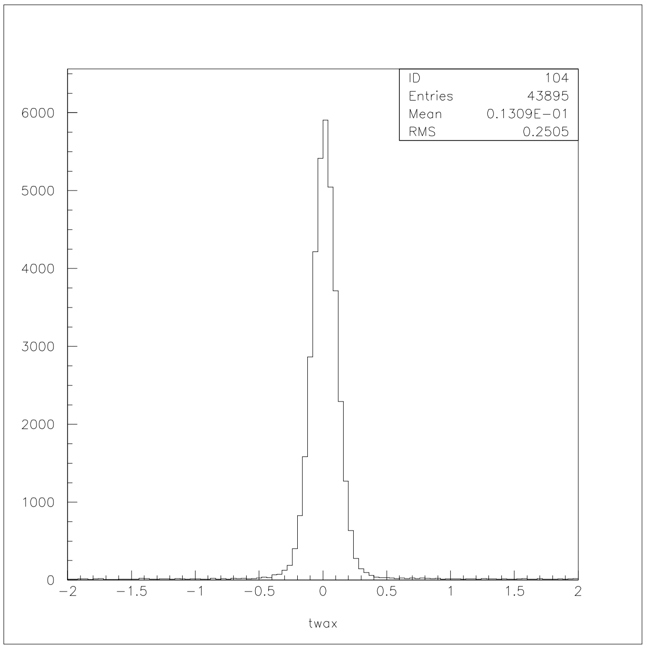

Fig. 10 Plot of the two-arm-x.

Figure 11 shows the effect of punch-through on twax. Cuts on the electron arm collimator opening and the upper and lower edges of the hadron arm collimator are applied.

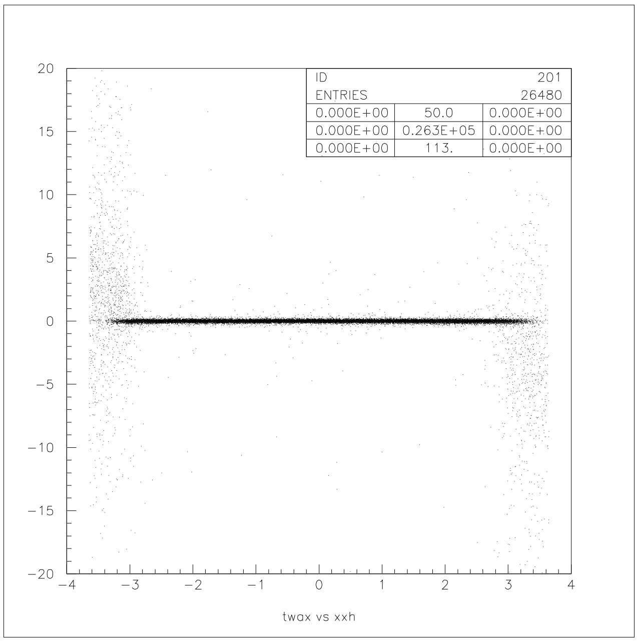

Fig. 11 Plot of twax as a function of xxh. The effect of punch-through on twax is clearly seen.

Figure 12 shows the plots of twax on various cuts on the collimator openings. The upper left plot has cuts on both openings. The upper-right and the lower-left plots show the effects of punch-through on the hadron arm collimator and the electron arm collimator, respectively. The lower-right plot has no cut applied.

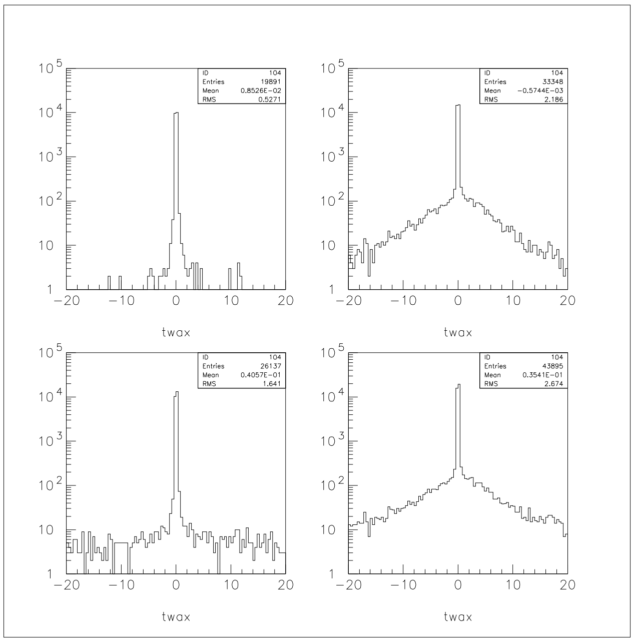

Fig. 12 Plots of twax for various cuts on collimator openings.

Figure 13 shows the effect on missing energy spectrum when cut on twax (between -0.5 cm and +0.5 cm, see Fig. 10) is applied. It is clear that the cut on twax is very effective in removing the punch-through events. There is no need to install active collimators.

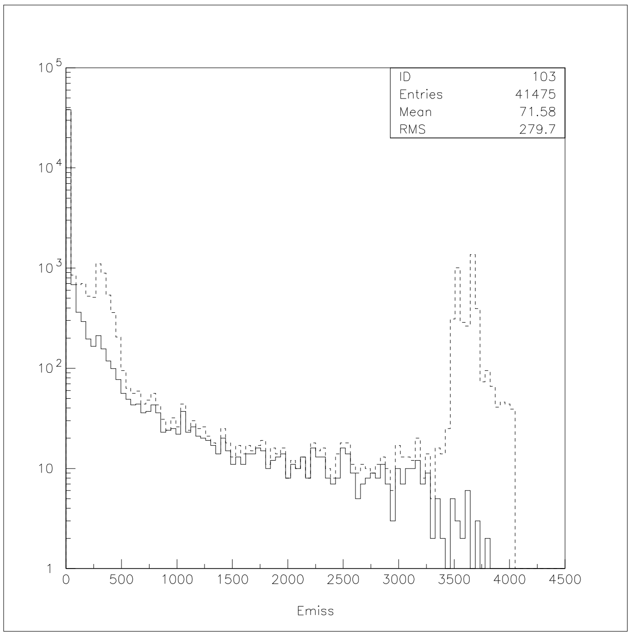

Fig. 13 Missing energy spectra with and without cut on twax.

7 Missing Energy Resolution

Another purpose for performing the GEANT simulation is to study the effects of high density ^{3}He gas (and the beam energy resolution) on the missing energy resolution. In addition to reconstructing the two-arm-x as described above, one can also reconstruct the z-coordinate of the intersection (zc). zc is an experimentally "measured" quantity while the sampled z is not. Figure 14 shows the plot of zc vs z. As one can see, the correlation is very good. Events due to punch-through are removed. The spread is due to the scattering in ^{3}He gas and in the exit Al window.

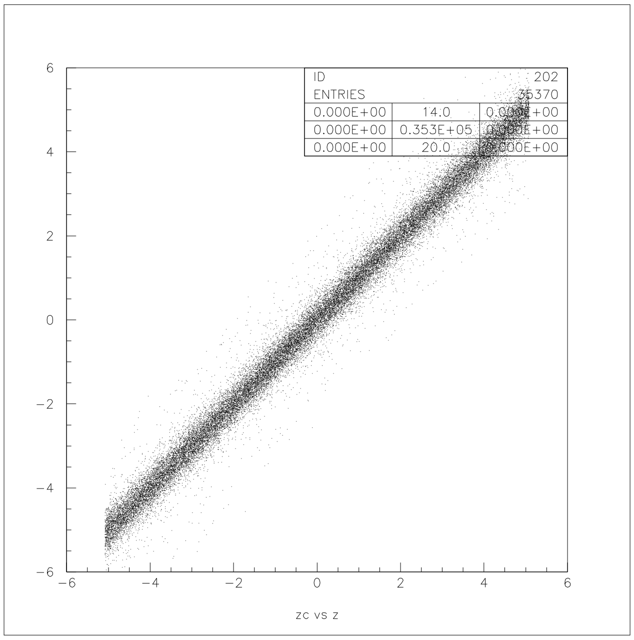

Fig. 14 Reconstructed vs. sampled z.

Figures 15 and 16 shows the missing energy with cuts on sampled (z) and constructed z (zc), respectively. As one can see, cuts on zc introduce additional uncertainty in the missing energy reconstruction, although the effect is small.

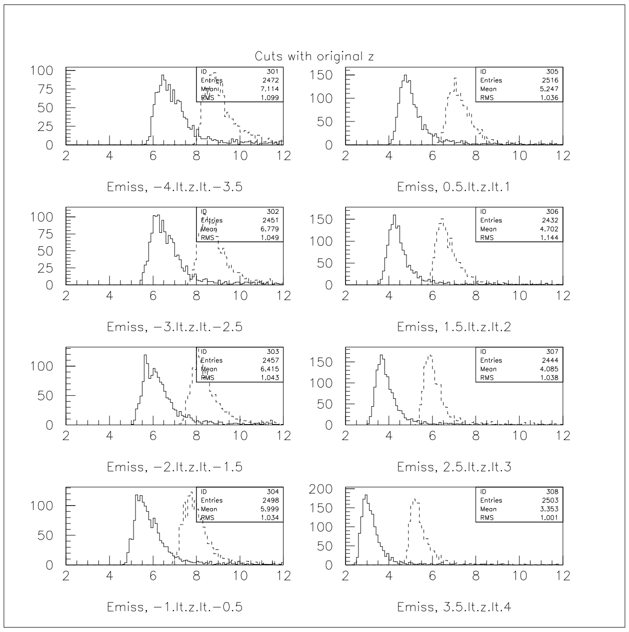

Fig. 15 Missing energy resolution with cuts on the sampled z.

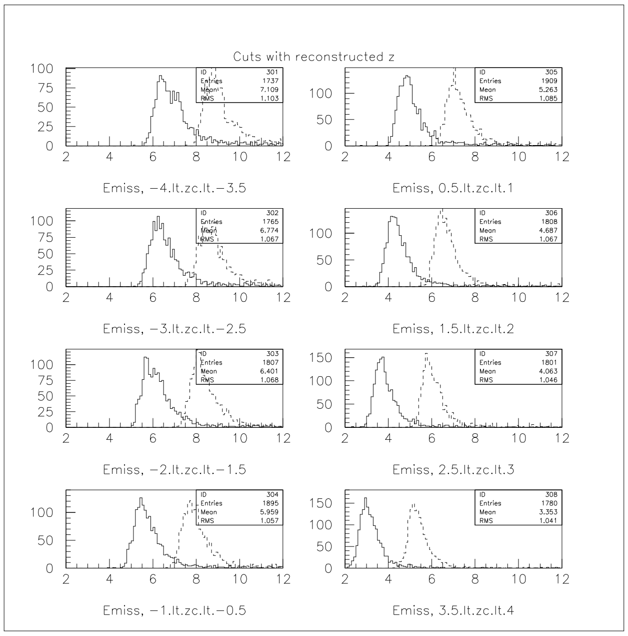

Fig. 16 Missing energy resolution with cuts on the reconstructed z.

Another factor which could contribute to the missing energy resolution is the spread (uncertainty) in the incident beam energy. In this study, $\Delta E_o/E_o = 2 * 10^{-4}$ is used. Figure 17 shows the effect of the uncertainty in incident beam energy on missing energy resolution. As one can see, the separation between two-body and three-body channels becomes marginal.

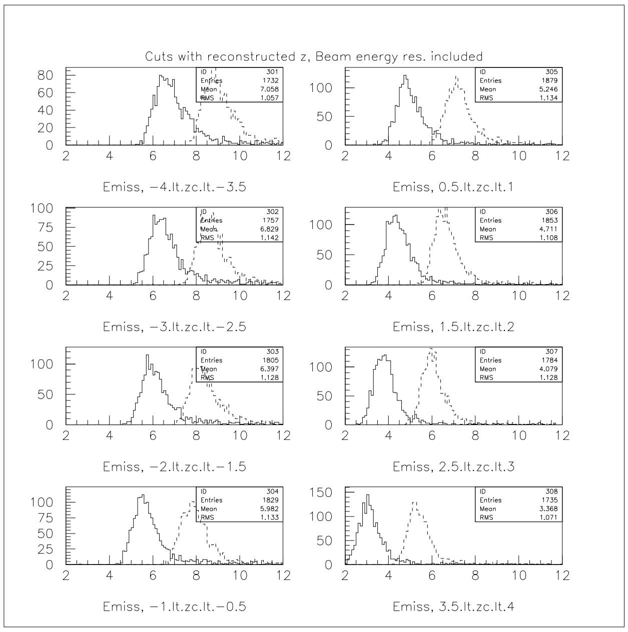

Fig. 17 Missing energy resolution with cuts on the reconstructed z. The spread (uncertainty) in the beam energy is included.

8 What Remain To Be Done

There are at least three items that could be included in this study:

1. Energy loss of the incident electron beam through the entrance Al window and the ^{3}He gas before an (e,e'p) event occurs. This effect could be substantial and the inclusion of this effect in GEANT simulation is not straightforward; but it can be done.
2. The internal bremsstrahlung. This could simply be a multiplicative factor which needs to be applied to the scattered electron before GEANT transports it through the ^{3}He gas and the exit Al window.
3. Inclusion of the spectral function in the event generation. This can be done; but it will take time.