SECOND REPORT ON GEANT SIMULATION
by
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1 Introduction

In this report, I will concentrate and expand on the study of missing energy resolution. This was the original motivation for doing the GEANT simulation. In my previous report on the collimator punch-through, two effects are included in the simulation: (1) the dE/dx ionization and (external) bremsstrahlung energy losses in gas target and the exit Al window for e and p after the reaction, and (2) the spread (uncertainty) in the incident beam energy. In this report energy loss for the incoming electrons in the entrance Al window and the pressurized ^{3}He before an (e,e'p) event is also included in the simulation.

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.

Energy loss of the incident electron through the entrance Al window and in the gas target before the (e,e'p) event can not be incorporated into GEANT simulation directly. To include this effect, a beam data file of the "effective" incident electron beam energy for various target thickness (in steps of 1 mm) is first generated with a separate GEANT code. This beam data file is used as input to the main GEANT simulation. After the interaction point along z is determined, this z is used to pick out the "effective" beam energy in the generation of an (e,e'p) event. The spread (uncertainty) in the incident beam energy can also be included in the simulation by adding the beam energy spread to (or substracting it from) the "effective" beam energy.

GEANT then transports both e and p from the interaction point through ^{3}He and the thin exit Al window to 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.

4 Missing Energy Resolution

As stated in my previous report, one can also reconstruct the z-coordinate of the intersection point (zc) in addition to the two-arm-x. zc is an experimentally "measured" quantity while the sampled z is not. Figure 1 shows the plot of zc vs z. As one can see, the correlation is very good. Events due to punch-through are removed. The width of this distribution is due mainly to the scattering in ^{3}He gas and in the exit Al window.

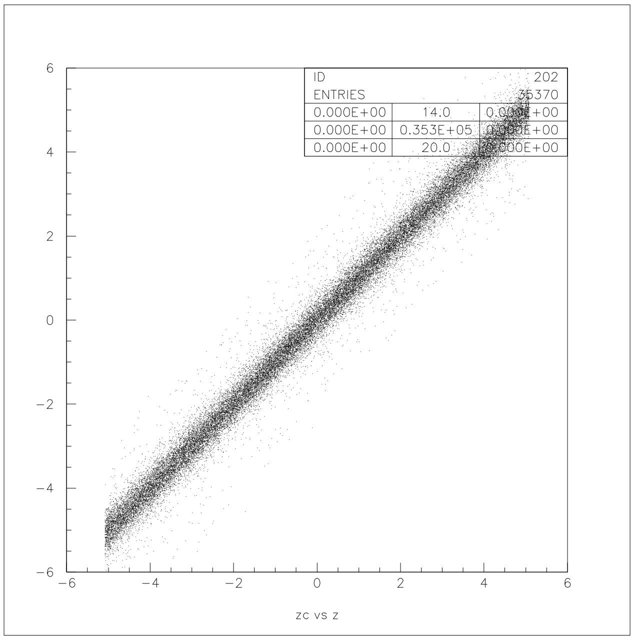

Fig. 1 Reconstructed vs. sampled z.

Figures 2 and 3 shows the missing energy spectra with cuts on sampled (z) and reconstructed z (zc), respectively. As one can see, cuts on zc introduce additional uncertainty in the missing energy reconstruction, although the effect is small.

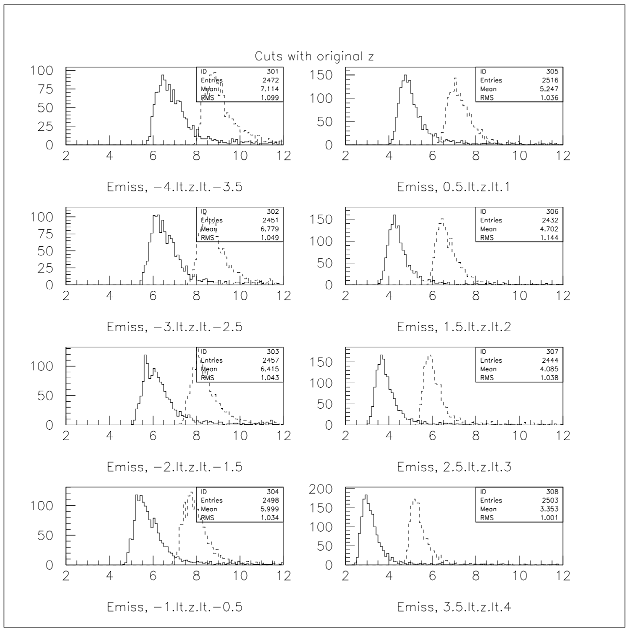

Fig. 2 Missing energy resolution with cuts on the sampled z.

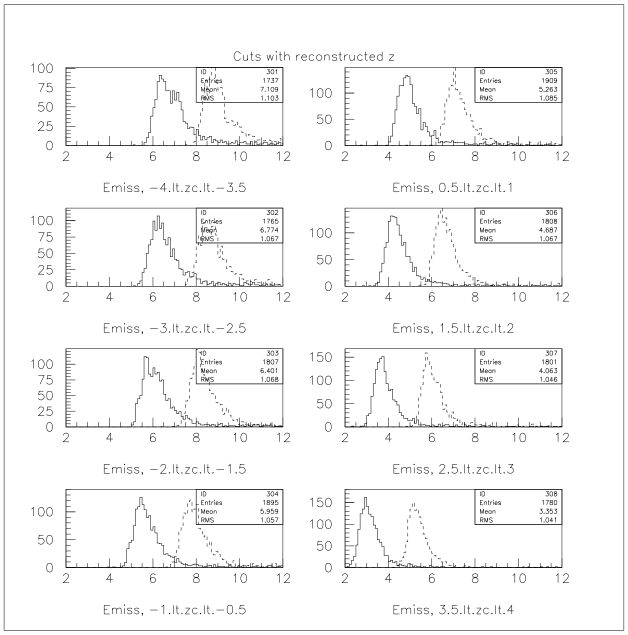

Fig. 3 Missing energy resolution with cuts on the reconstructed z.

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

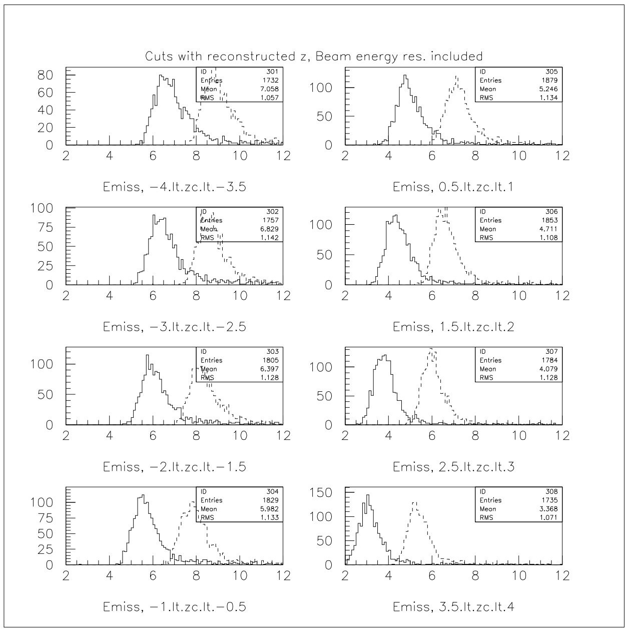

Fig. 4 Missing energy resolution with cuts on the reconstructed z. The spread (uncertainty) in the beam energy is included.

Figure 5 shows the effect on the missing energy resolution when the beam energy loss before the interaction is included. The separation between two-body and three-body channels is now very marginal.

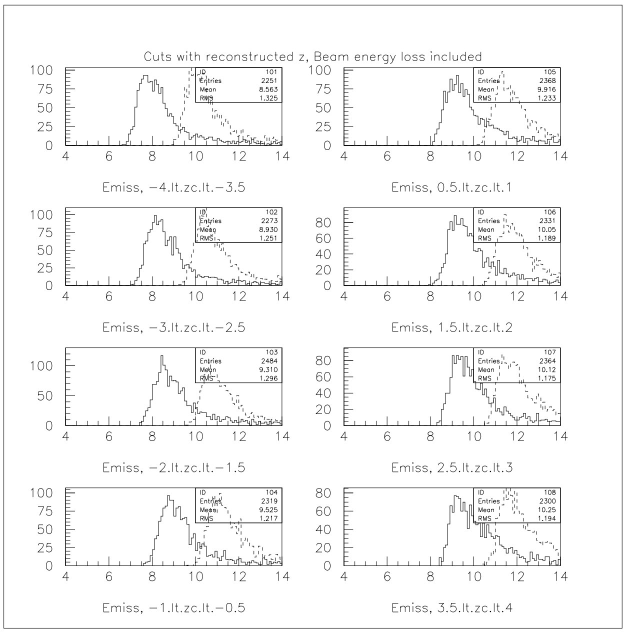

Fig. 5 Missing energy resolution with cuts on the reconstructed z. The beam energy loss in target before interaction is included.

Figure 6 is the same as Fig. 5 except the beam energy spread is also included.

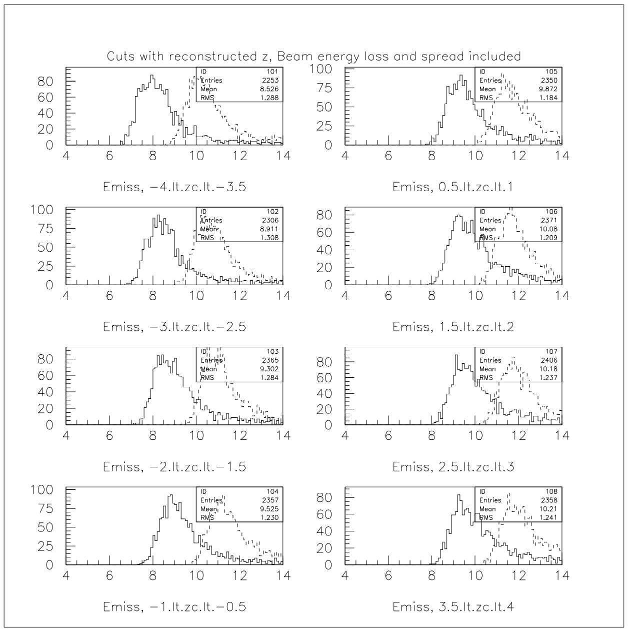

Fig. 6 Missing energy resolution with cuts on the reconstructed z. The beam energy spread and the energy loss before interaction are included.

The main difference between Fig. 3 (or Fig. 4) and Fig. 5 (or Fig. 6) is that Fig. 5 includes the beam energy loss before interaction. One notices that the missing energy spectra in Fig. 3 move to a lower value as one moves from the up-stream end of the target (negative zc) toward the down-stream end of the target (positive zc) (see also Fig. 7). The opposite is true for Fig. 5 (see also Fig. 8).

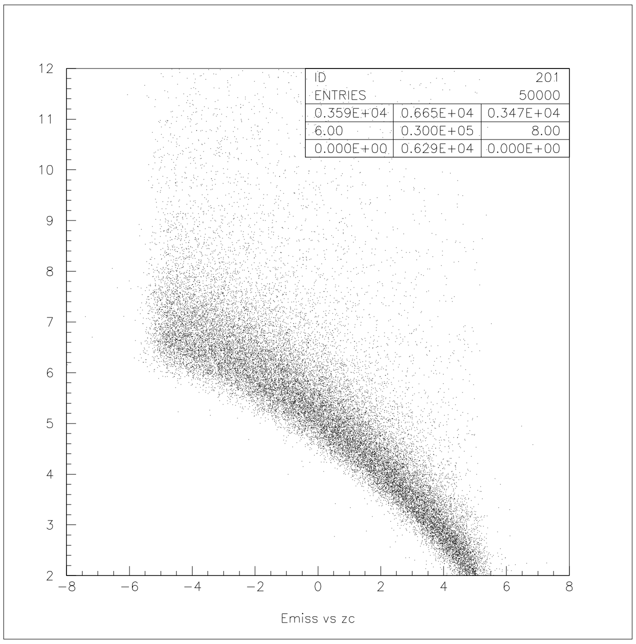

Fig. 7 Missing energy resolution as a function of the reconstructed z. No beam energy loss before interaction is included.

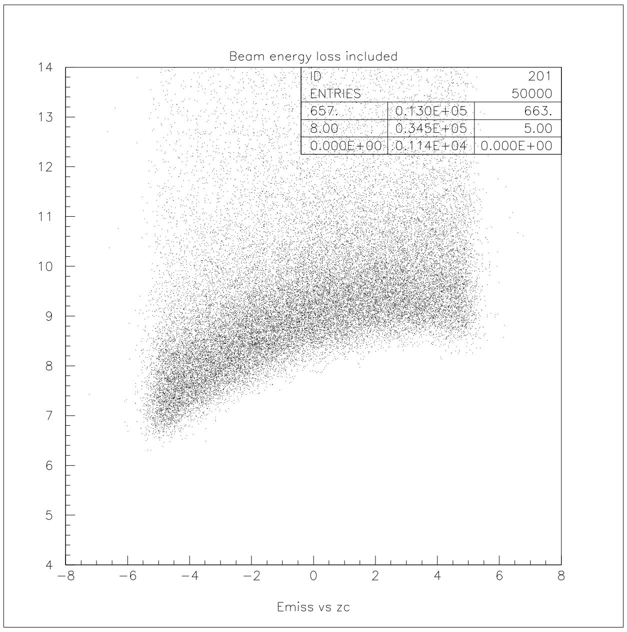

Fig. 8 Missing energy resolution as a function of the reconstructed z. The beam energy loss before interaction is included.

This is easily understood because, if the energy loss of the incoming electron beam is ignored the energy loss can only come from the outgoing electron and proton as they move through the target gas and the exit Al window. The path lengths would be the shortest if the interaction occurs at the down-stream end of the target. If one takes into account the beam energy loss before interaction, more energy loss will result if the interaction occurs at the down-stream end of the target. As one can see, the energy loss by the incoming electron beam is rather substantial.

5 Bremsstrahlung vs. Ionization Energy Loss

An electron can loose its energy mainly by the following two processes: (1) bremsstrahlung and (2) dE/dx ionization. The bremsstrahlung process can generate a radiative tail, but it will not shift the peak energy (an electron either radiates or it does not). On the other hand, the ionization process will not only generate a small tail (Landau tail), it will also shift the peak energy. Figure 9 shows the residual energy of 4.045 GeV electrons after passing through 8 cm of pressurized ^{3}He gas (and 0.013" of Al window). Dotted line includes the bremsstrahlung process, the long dashed line includes the dE/dx ionization process, and the solid line includes both processes.

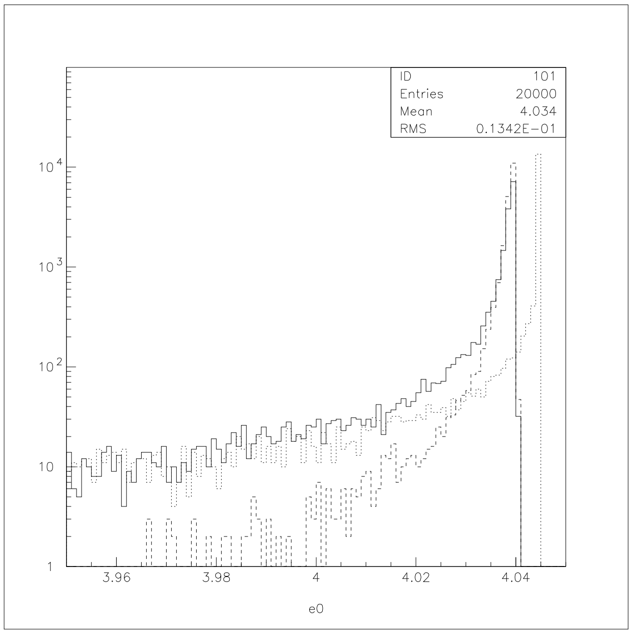

Fig. 9 Residual beam energy as 4.045 GeV electrons pass through 8 cm of pressurized ^{3}He gas and the thin Al window.

Therefore, the shift in missing energy shown above (Figs. 2-6) is due to the dE/dx ionization loss. One might argue that dE/dx ionization process may be more important to the missing energy resolution while the bremsstrahlung process may be more important to the missing energy spectrum at the higher missing energy region. This statement can be verified by re-doing Fig. 6 with the either the bremsstrahlung or the dE/dx ionization process turned off in the GEANT simulation. The results are shown in Figs. 10-12.

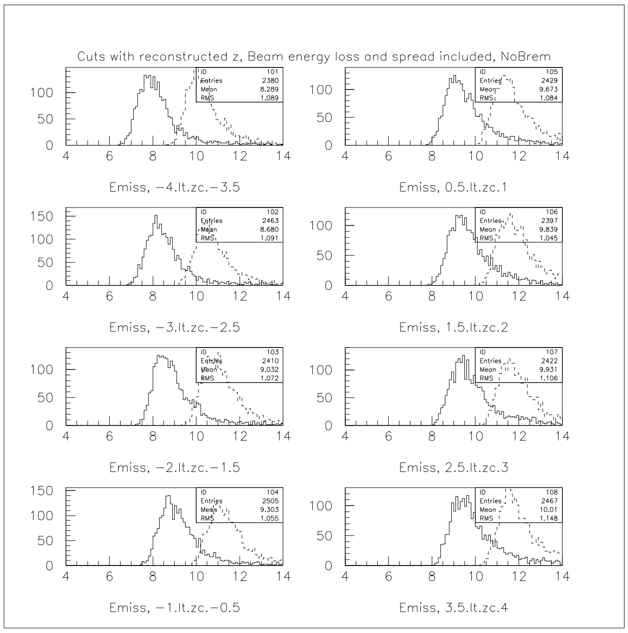

Fig. 10 Missing energy resolution with cuts on the reconstructed z. The beam energy spread and the energy loss before interaction are included. Bremsstrahlung process is turned off.

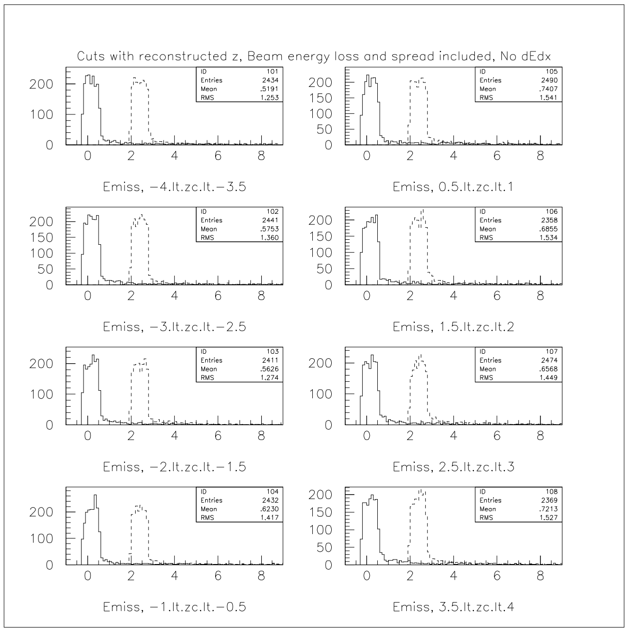

Fig. 11 Missing energy resolution with cuts on the reconstructed z. The beam energy spread and the energy loss before interaction are included. dE/dx ionization process is turned off.

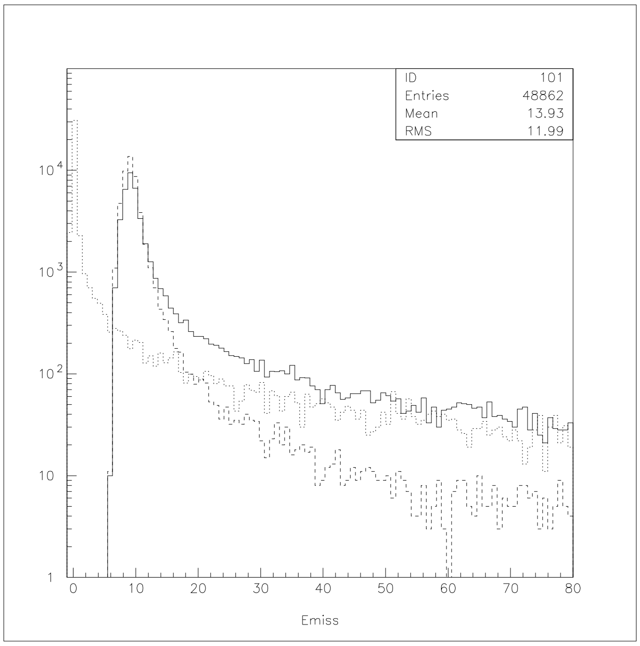

Fig. 12 Missing energy resolution as a function of the reconstructed z. The beam energy spread and the energy loss before interaction are included. Dotted line includes the bremsstrahlung process, the long dashed line includes the dE/dx ionization process, and the solid line includes both processes.

A few comments are in order. First, as one can see, Fig. 10 is almost identical to Fig. 6, suggesting that dE/dx ionization is indeed the main source of poor energy resolution. By comparing the solid and long dashed curves in Fig. 12, one see the important of the bremsstrahlung process in the high missing energy region. The width of both peaks in Fig. 11 is due to the $2 * 10^{-4}$ uncertainty in the incident beam energy.

6 Half Gas Density

Another useful thing to study is to repeat the simulation with, for example, half of the ^{3}He gas density just to see how much the lower gas density will improve the missing energy resolution. Figure 13 shows the results with half of the gas density. This is to be compared with Fig. 6. As one can see, the missing energy resolution is much improved as expected.

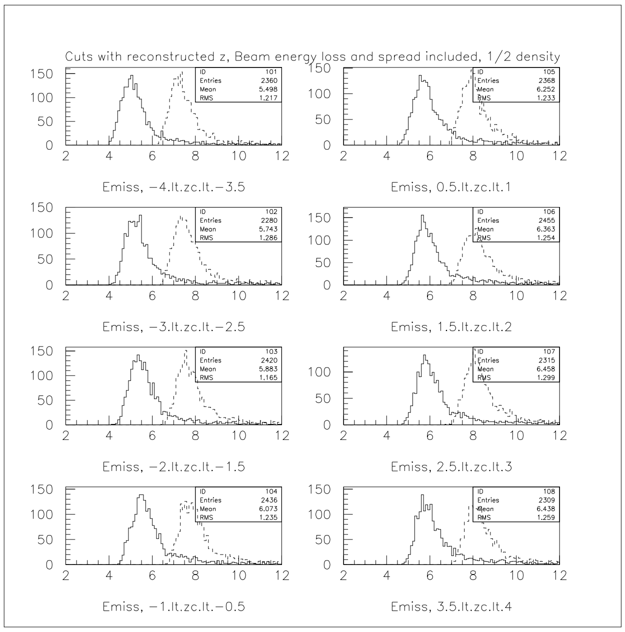

Fig. 13 Missing energy resolution for half gas density with cuts on the reconstructed z. The beam energy spread and the energy loss before interaction are included.