GEM TN-92-69

Muon Energy Loss in GEM BaF_2/Scintillating Fiber Calorimeter

R. McNeil-Louisiana State University

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A GEANT simulation study of energy losses for energetic muons passing through the GEM BaF_2 EM calorimeter + scintillating fiber hadron calorimeter is reported. Two choices for the absorber, lead and copper, are considered for the hadron section of the calorimeter. The energy loss distribution is parameterized and a subroutine described for fast simulation of muon energy loss in GEM.

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Introduction

In passing through material muons lose energy by ionization and radiation. The energy loss (E_{LOSS}) must be properly taken into account in measuring the muons. The GEM Muon Detector will only measure the the true muon energy less the energy loss, $P^{\mu}{}_{det} = P^{\mu}{}_{true} - E_{LOSS}/c$. The uncertainty in the energy loss ΔE_{LOSS} will then contribute to the muon measurement uncertainty,

$$\left(\frac{\Delta P}{P}\right)_{Total} = \left(\frac{\Delta P}{P}\right)_{meas} \oplus \left(\frac{\Delta E_{LOSS}}{P}\right)_{cal}$$

where the $\oplus$ means a sum in quadriture.

Since the muon momentum measurement uncertainty is small at low momentum, then the effect of muon energy loss in the calorimeter will be most prominant at lower momenta. In this paper, a simulation study of muon energy loss through one of the GEM calorimeter options is performed and the results reported. The technology option considered is an EM Section composed of BaF_2 followed by a hadronic section of absorber with scintillating fibers. The simulation study was performed using GEANT. A recent GEANT simulation study [1] of muon energy loss in the ZEUS barrel calorimeter (a Uranium/scintillator plate calorimeter) has shown good agreement with FNAL test beam results (figure 1).

Recently in an effort to make a more compact calorimeter for GEM, different materials for absorbers have been considered. For the fiber calorimeter, a lead alloy was originally considered. Currently, studies are underway to determine the cost and feasability of using a copper based absorber. The copper alloy would have a shorter nuclear interaction length than lead and allow for a smaller outer radius for the calorimeter while maintaining 10λ of total depth of hadronic calorimetry ($+1.7\lambda$ of BaF_2). The muon energy loss for these two absorber choices are compared in this paper.

The Simulation

GEANT V3.13 was used for the simulation study. All processes were enabled in the simulation including explicit delta ray production, bremstrahlung, pair production, and muon-nucleus interactions. Kinetic energy cutoffs for electrons and gammas were set to 50KeV which were the same as used for the ZEUS study [1]. A box volume of 80cm $\times$ 80cm $\times$ 11.7λ in length was the calorimeter geometry simulated. A 25 radiation length BaF_2 EM section was followed by a 10λ length hadronic section. The hadronic section was composed of absorber with 1.5mm diameter scintillating fibers separated by 8mm in X and Y direction. The packing fraction of fibers was 2.8% by volume. An absorber composed of a mixture of Bi:Pb:Sn:Cd with 49.5:27.3:13.1:10.1% fraction by weight and density 9.58g/cm^3 was used for what is here after called the Pb alloy. Also a mixture of Cu:Pb:Sn with 72:20:8% fraction by weight and density 8.71g/cm^3 was simulated and here after referred to as the Cu Alloy. It is estimated that the Pb alloy/scintillator calorimeter is 19.4cm per interaction length while the Cu alloy/scintillator calorimeter is 17.0cm per interaction length. Thus the BaF_2 + Pb/scintillator calorimeter simulated (here after called the lead calorimeter option) was 24cm longer than the BaF_2 + Cu/scintillator caloriemter (here after called the Copper calorimeter option). The total number of radiation lengths for the 12λ of the copper calorimeter option was 25 (BaF_2) + 120 (HAC) = 145 Total and for the lead calorimeter option 25 (BaF_2) + 280 (HAC) = 305 Total.

A magnetic field of 0.8T was perpendicular to the module simulated. Muons were incident on the front face of the calorimeter spread uniformly over a small area of 8cm $\times$ 8cm centered in the middle of the module. The muon direction was offset by 3° from the Z direction (fiber direction) so as to simulated the nonprojection geometry of the fibers. Events samples of muons of momentum 10, 20, 50, 100, 500, and 1000 GeV/c were simulated through each of the two calorimeter options.

Results

Figure 2 shows the energy loss distribution for muons in the 6 incident momentum bins for the copper calorimeter option. Figure 3 shows the same for the lead calorimeter option. It can be seen that the mean energy loss as well as the rms of the energy loss distribution increases with incident momentum. The lead calorimeter energy loss has a threshold at 3GeV while the copper calorimeter energy loss begins at a lower threshold of 2.5GeV. This is because there is a greater total length of lead calorimeter and lead has a slightly higher dE/dX minimum ionizing energy loss. While the width of the distribution appears larger for the lead than for the copper calorimeter option, the rms values are similar between the two for the three lower momentum bins simulated (10, 20, and 50GeV/c). This appears to be because the mean values are higher for lead than for copper and this offsets the higher widths since the rms value is taken about the mean and not the peak.

The GEM calorimeter may not be useful in measuring the small fluctuations about the mean energy loss. But the mean energy loss can be parameterized for a particular calorimeter choice as a function of incident muon momentum and this mean energy added to the momentum measured in the muon system. The calorimeter should be useful in tagging muons which experience large energy loss so that these few percent of the muons can be removed from the event samples and not worsen the momentum resolution. Then the RMS of the energy loss distribution (less than some cut value) divided by the incident muon momentum would be the contribution to the momentum resolution coming from energy loss in the calorimeter. From figures 2 and 3, the rms of the energy loss distributions can be seen for each incident momentum and calorimeter option simulated. For 10GeV/c, the fluctuations in the muon energy loss would us be 5.5-6% for both the copper and lead calorimeter options. At 100GeV/c, the

contribution to the momentum resolution from energy loss decreases to 2.0% (2.6%) for the copper (lead) options assuming that energy losses greater than 20Gehave been removed (2% of the total for the copper calorimeter option and 3% of the total for the lead). The contribution to the momentum resolution coming from energy loss fluctuations for muon momenta above 100GeV/c is relatively constant $\sim 1.3 - 1.5\%$ provided that muons which lose more than 10% of there incident energy are removed from the sample (2% of the total for the copper cal option and 5% of the total for lead). Effort is currently underway to study tagging of large energy losses in the calorimeter. As can be seen in figures 2 and 3, for $P \leq 50$GeV/c, the rms values are comparable for the copper and lead calorimeters, while the FWHM of the distribution is different. The tails of the distribution are thus dominating the rms value. A suitable cut on the value of E_{LOSS} which removes a certain fraction of the muons and thus is different for the two absorbers, would begin to reveal the difference between the two absorbers. For example, considering only the 20GeV/c incident momentum muon energy loss distributions for the two absorbers, the rms values for the lead and copper calorimeter are nearly the same (0.83 GeV) for $E_{loss} < 10$GeV. However, the E_{loss} value for which 5% of the muons exceed is 5.55GeV for the lead calorimeter and 4.65 GeV for the copper calorimeter. Consider the 95% of the muons which have energy below these values, the rms values are 0.41GeV for the copper calorimeter (below 4.65GeV energy loss) and 0.53GeV for the lead calorimeter (below 5.55GeV energy loss). Therefore, if the calorimeter can effectively tag muons which have energy losses exceeding about 3σ more than the average energy loss, there will be a clear advantage to having a copper calorimeter over a lead calorimeter considering <u>only</u> the remaining fluctuations in the energy losses which would not be measured.

A Fast Subroutine for Muon Energy Loss

A MINUIT fit to the energy loss distributions in figures 2 and 3 was performed to a 5 parameter function give by

$$P(x) = P_1 e^{-0.5((x-P_2)/\sigma)^2}$$

where x is the energy loss in GeV and σ is given by

$$\sigma = P_3 \text{ for } x \leq P_2 \quad \text{and} \quad P_3 + P_4(x - P_2)^{P_5} \text{ for } x > P_2$$

Each incident momentum and calorimeter option was fit and the 5 parameters from each fit incorporated in a subroutine ELOSS to simulate the energy loss for muons in GEM without need of a full scale GEANT simulation. Such a subroutine exists and can be found in

SSCVX1::USER4:[MCNEIL]ELOSS.FOR.

This subroutine will be updated to include other calorimeter options including LAR in the near future. Figures 4 and 5 show the energy loss distribtuion from ELOSS. The distributions agree with that from the GEANT simulations in figures 2 and 3 considering the statistics of the GEANT distributions. It appears that the energy loss distribution for GEANT simulation of the copper calorimeter agrees less well with the ELOSS distribution than does that for the lead calorimeter option. More statistics will be simulated with GEANT and perhaps more parameters used to fit the distribution in an effort to parameterize better the distributions. Presently only simple interpolation between incident momentum bins is performed by ELOSS and simple scaling fo the distribution for thickness different than the 12λ from which the parameters were derived. Also there is presently no simulation of catastrophic energy

loss so the energy loss is only produced up to some maximum value (see the code itself for details).

Conclusions

A simulation study of muon energy loss through the BaF_2 + scintillating fiber calorimeter for GEM has been performed for two choices of absorber in the hadronic section. For a 12λ thick calorimeter the small fluctuations in the energy loss contribution up to a 6% uncertainty in the momentum of a 10GeV/c muon where the muon resolution from the muon system is expected to be much better than 1% . The contribution ($\frac{\text{rms Eloss}}{P_{inc}}$) to the momentum resolution for the copper and lead calorimeter option is about the same for $P_{inc} < 100$GeV/c where this contribution is expected to minate. For $P_{inc} \geq 100$GeV/c, the copper has a smaller rms, but momentum measurement uncertainty is expected to begin to dominate the momentum resolution.

A fast subroutine, ELOSS, has been prepared which simulates muon energy losses through the calorimeter options reported in this paper. This routine is being incorporated into the momentum resolution calculations currently being performed and can also be used in physics studies. Because the energy loss fluctuations are expected to dominate the momentum resolution for low P_T muons, it will be very important to reconsider its effect on physics signals such as the low mass Higgs, $H \rightarrow ZZ^* \rightarrow 4\mu$. It will now be important to develop criteria by which the larger muon energy losses can be identified and removed with minimum loss in muon efficiency.

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References

[1] L. Chen et. al., Results of the analysis of Test Beam data collected at Fermilab with incident muons for the Hadronic Section of the ZEUS Barrel Calorimeter, ZEUS Note 92-023, 1992.

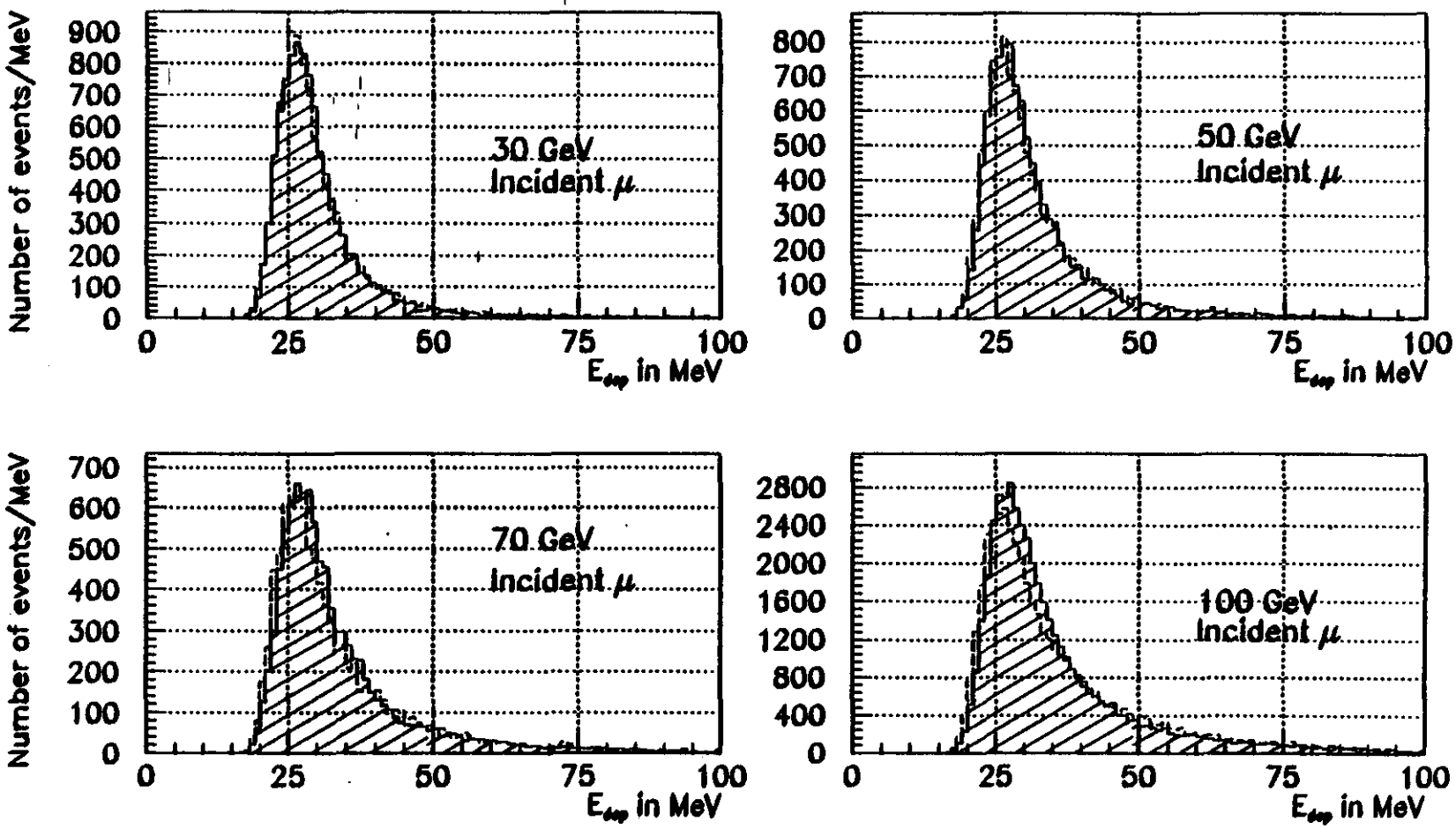

Figure 1 GEANT Simulation of Energy Deposited in hadronic section #1 (HAC 1) of ZEUS Barrel Calorimeter compared with experimental data from 1991 FNAL test beam run. Solid histogram is data, dashed histogram is GEANT Simulation.

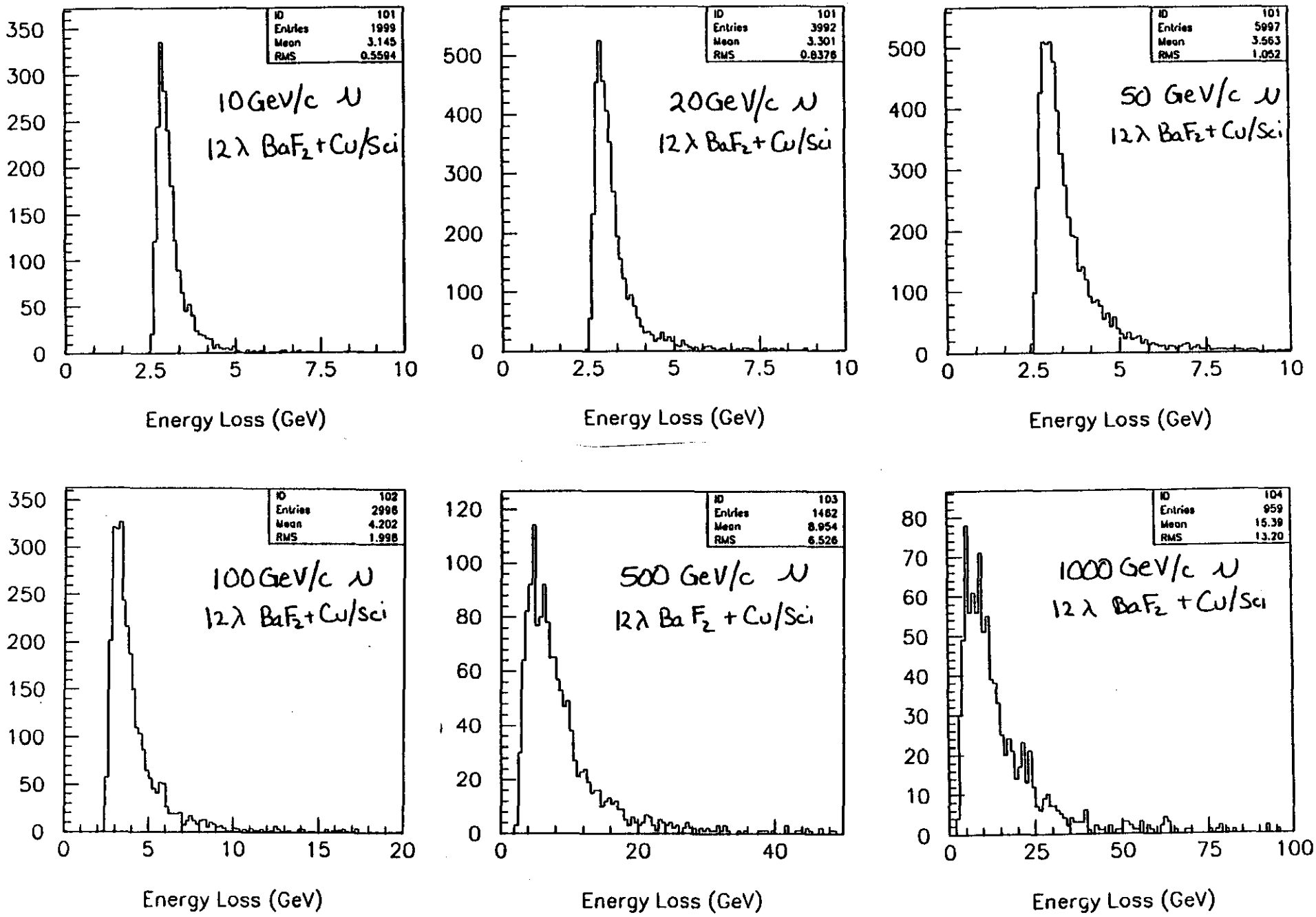

Figure 2. GEANT Simulation of BaF_2 + Cu/Scintillator Cal

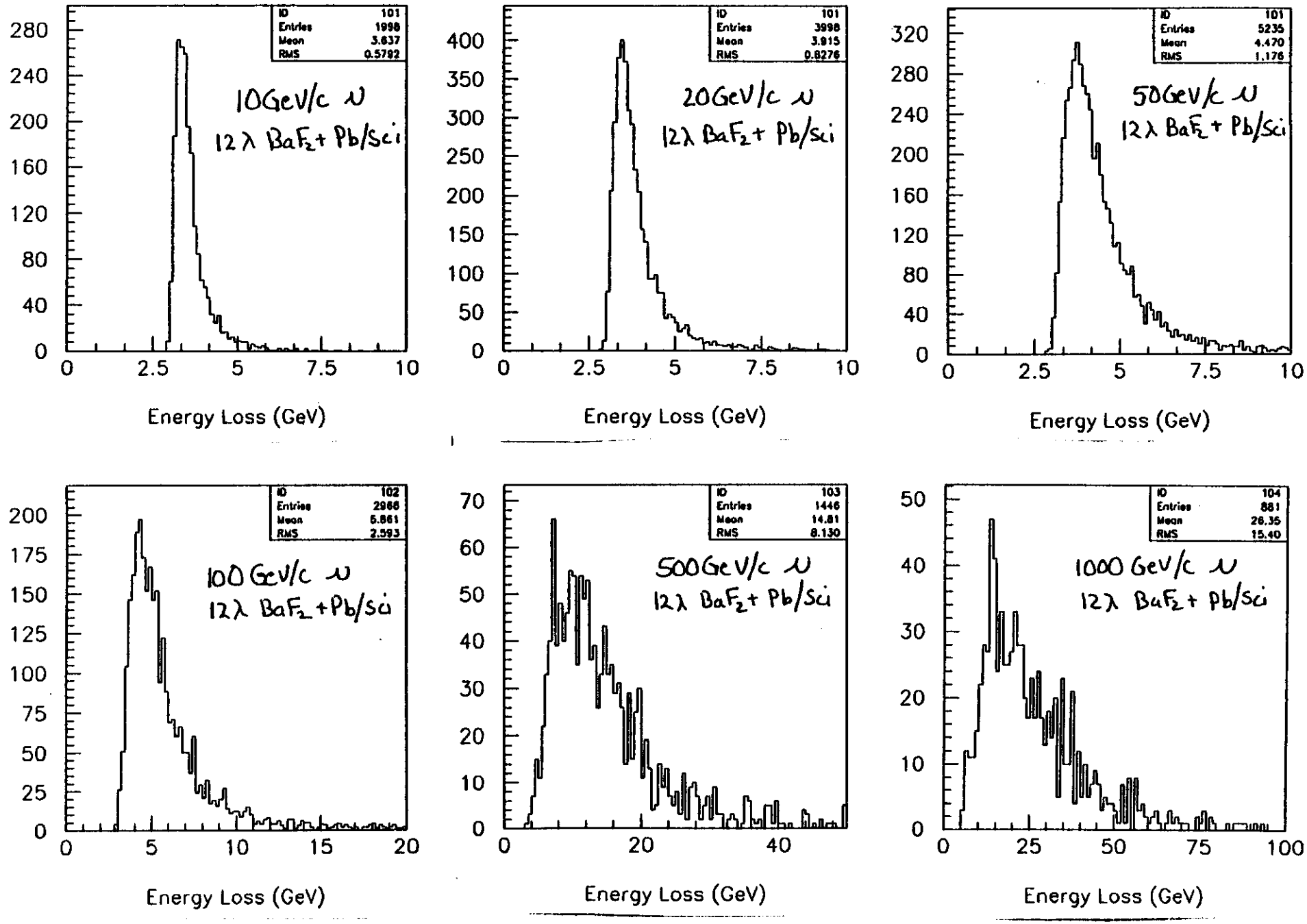

Figure 3. GEANT Simulation of BaF_2 + Pb/Scint Cal

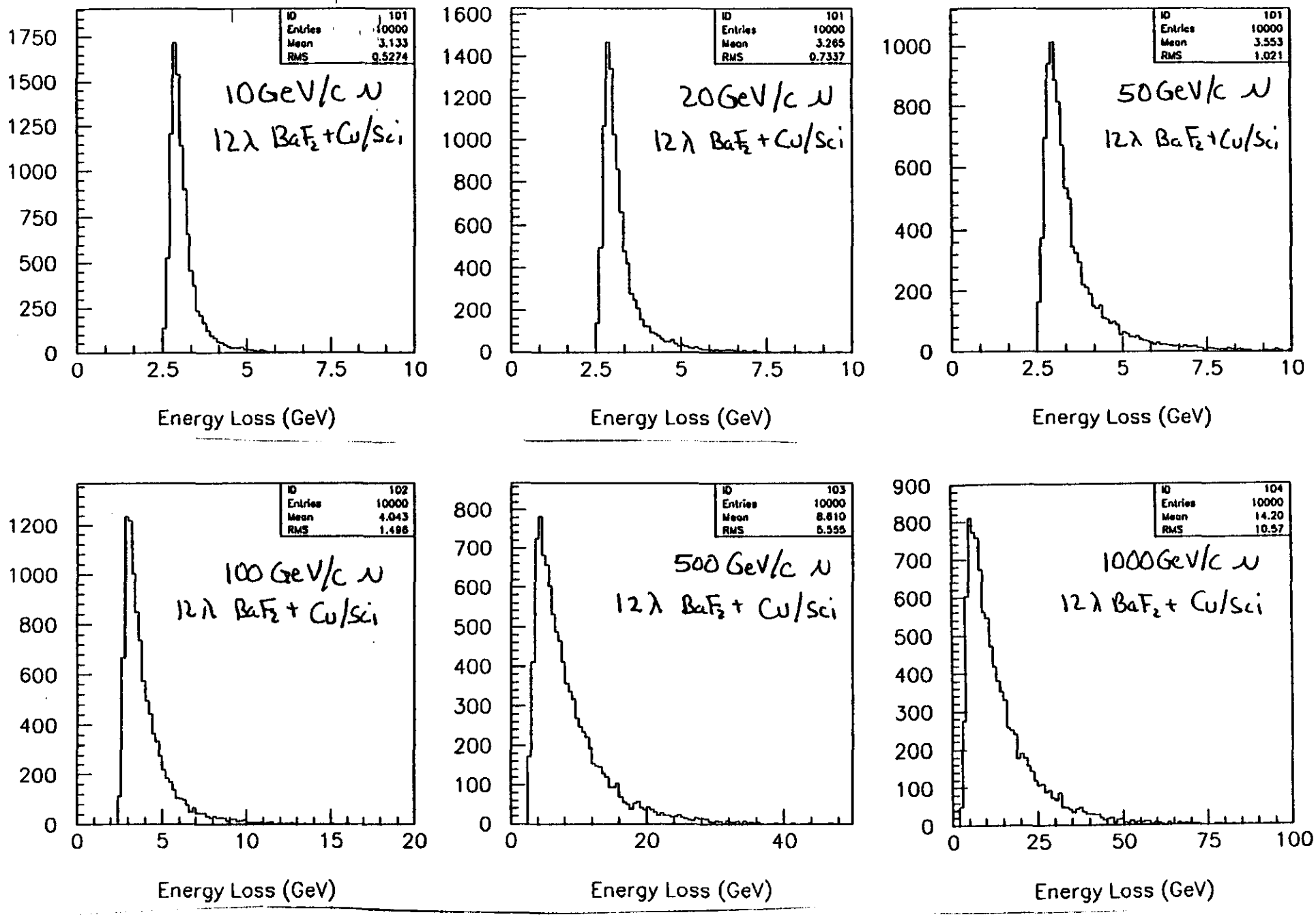

Figure 4. ELOSS Simulation of BaF_2 + Cu/Scint. Cal

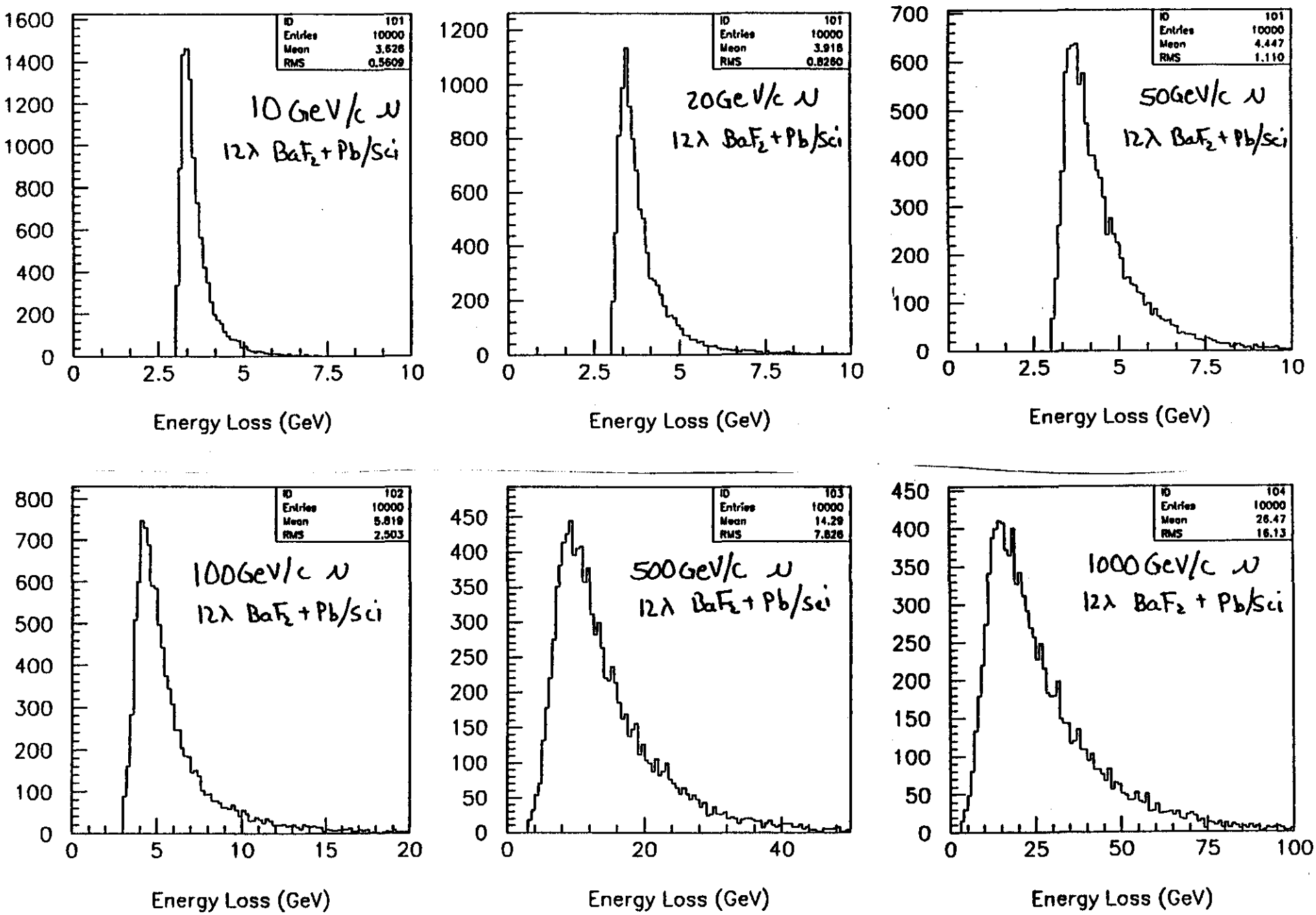

Figure 5. ELOSS Simulation of BaF_2 + Pb/Scint. Cal