Using the Tracker for probing the Calorimeter response

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Abstract

This note is devoted to the performance of the extrapolation of the trajectory determined by the tracker into the calorimeter for cosmic muons. As an application relevant to the I&T activity, the generation of crystal images is described.

1 Introduction

A wealth of applications regarding the calorimeter response will be enabled by using the information from the tracker to extrapolate the trajectory within the calorimeter. A few examples of these applications are listed below.

1. The homogeneity of the crystal response can be investigated through the dependence of the average energy deposited by muons on the trajectory position in the crystal. By plotting this energy as a function of the transverse and longitudinal positions, one obtains maps of the crystal response ("images").

2. By averaging the energies observed in the images described above over the transverse direction, the tapering coefficients can be obtained and checked against those determined during the calorimeter calibration at NRL.

3. The relative alignment of the calorimeter vis respect to the tracker can be tested.

4. The CAL trigger efficiency can be tested.

5. The performance of the trajectory determination with the CAL can be established for different particles (muons, protons, ions, photons).

6. It has recently become clear that in some cases the energy measured on one side cannot be exploited and if so, the energy from the other side should be corrected for attenuation. Two examples of such cases are when the shower leaves substantial direct energy deposit within a photodiode

or when its core passes less than a few centimeters away from a photodiode, as the direct light contribution is sizable and varies greatly with the transverse position. In that case, the longitudinal position determined from the tracker can be used for identifying these cases and correcting the valid information for attenuation.

7. On flight, the energy calibration will be performed with cosmic-ray ions, a suitable algorithm based on the trajectory extrapolation determining for which log the hit is considered as valid for the purpose of calibration.

For all these applications, it is important to determine the resolution associated with the extrapolation. The present note focuses on the case of atmospheric muons, and specializes in the creation of the images mentioned above for the two-tower configuration pertinent to I&T.

2 Spatial resolution of the extrapolation

The spatial resolution of the trajectory extrapolation depends primarily on:

1. the finite resolution of the tracker in determining the position and direction of the incident particle on the one hand, the effect being amplified by the lever arm between the TKR layers and the CAL;
2. the effect of multiple scattering within the TKR and the CAL.

The TKR recon must provide the best estimate of the actual trajectory taking two important facts into account:

1. The incident particle is a muon, not a gamma-ray, which has the consequence that the energy deposited in the CAL (about 100 MeV) is a very poor estimator of the particle kinetic energy. As the TKR recon algorithm requires a reasonable estimate of this energy, it is sufficient to set the energy to a minimum (large) value like 2000 MeV in the jobOptions.txt file for the trajectory to be determined with a good accuracy.
2. The final trajectory (i.e leaving the tracker) is of interest in the case considered here, not the initial one as in the case of photon detection. In the latter case, the track reconstruction algorithm uses the information available as close as possible to the conversion point to mitigate the adverse effect of multiple scattering. For the trajectory extrapolation into the CAL, it is more sensible to use the information provided by the TKR bottom trays, the so-called end-of-track parameters.

The work presented here was carried out with simple root macros, in which the geometrical constants were put by hand. In the future, it is foreseen that a service, implemented as a root library, fetches these constants from the proper GlastRelease xml files.

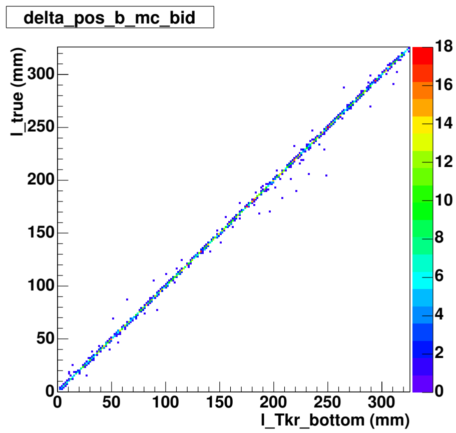

Figure 1: Comparison of the extrapolated position at mid-height of the first CsI layer with the true one.

In order to establish the resolution of the trajectory extrapolation, the actual longitudinal position along the crystal length was used as a reference. Two different ways of getting this position was used. In dedicated simulations, the level of the noise added to the energies collected on the two ends of the crystal was set to zero, and the position was deduced as follows:

$$l = 0.5CsILength(\frac{(1+\alpha)(E_+ - E_-)}{(1-\alpha)(E_+ + E_-)} + 1)$$

where α is the light attenuation coefficient and $CsILength = 326$mm is the crystal length. This formula is just the reverse of that used in the simulation to compute the energies collected on the two ends, $E_+$and E_-. This procedure allowed the position to be deduced without using the Monte-Carlo root file. In other cases, the McIntegratingHit collection contained in the Monte-Carlo root file was used.

The correctness of the trajectory-extrapolation algorithm can be checked in Fig. 1 comparing the longitudinal position found from the extrapolation using the end-of-track parameters (l_Tkr_bottom), evaluated at mid-height of the upper CAL layer, and the real position (l_true) from the Monte-Carlo file. The distributions of extrapolated positions with respect to the true ones are displayed in Fig. 2for the 8 layers of the CAL, using either the start-of-track (blue histograms) of end-of-track (red histograms) parameters. These distributions were obtained for atmospheric muons with a realistic energy distribution. Since these distributions result from the superposition of gaussian distributions with different widths depending on the muon energy, they are not gaussian.

The extrapolation with the end-of-track parameters ("eotp") provides a better resolution than that with the start-of-track ones ("sotp"), the RMS of the distributions of Fig. 2being plotted in Fig.3 as a function of the layer number. Using the end-of-track parameters enables the extrapolation to be much less sensitive to multiple scattering taking place within the TKR, leading to a better resolution. The effect of this multiple scattering can be dramatic for low-energy muons, the resolution in layer 0 reaching 9 mm with the sotp instead of 1 mm with the eotp for 500 MeV muons. In layer 7, the resolutions are 13 mm and 5 mm respectively. On the average, a resolution ranging from 1 to 2 mm is obtained via the extrapolation. These values should be compared to the resolutions of 5-10 mm obtained in the EM data by using the light asymmetry as described above (only the longitudinal position is available that way). The latter resolution is dominated by the electronic noise and statistical fluctuations in the number of collected visible photons (the current simulation predicts a resolution of 16 mm since the noise level is overestimated). For heavy ions depositing a greater energy, the resolutions may become more comparable.

The TKR information can efficiently be used to discard these low-energy muons, since the chisquare of the trajectory fit is bad for these particles. Fig.4 shows the effect of a cut Tkr1Chisq$<$3 on the muon energy distribution, only the muons with energy lower than 1.2 GeV being significantly reduced.

3 Crystal Imaging

In creating an image, a hit is declared valid for a particular crystal if the muon trajectory crosses both the upper and lower horizontal faces of the crystal. There is of course at most one valid hit per layer. Let us first consider the deposited-energy (ΔE) distributions. The upper panel of Fig. 5shows the distribution of ΔE corrected for slant (i.e. multiplied by cos Θ) for all crystals with ΔE$>$2 MeV (blue histogram) and the corresponding distribution obtained for valid hits. The former distribution exhibits a population of events with ΔE$<$10 MeV corresponding to "edge hits" in which the muon escapes the crystal across a vertical face, leading to a reduced ΔE. This population is essentially absent for valid hits, as desired. These distributions were obtained with a SVAC ntuple with 219041 events created from a 4M-event sample. The number of valid hits is 303191. Only about 600 of these (0.2%) are observed to be associated with ΔE=0, the muon missing the crystal that the extrapolation algorithm found corresponding to a valid hit. On the other hand, 2.9% of the valid hits were actually observed to be associated with ΔE$>$2 MeV in at least two neighboring crystals ("doubles"). The corresponding ΔE distribution is displayed in the lower panel of Fig. 5. While the average energy deposited for valid hits is 13.6 MeV, it is found much higher (21.97 MeV) for these doubles, proving that these events are due to the emission of δ-electrons. To conclude on statistics, Fig. 6shows the expected cumulated number of valid hits per crystal for 4000 s of counting time, as a function of the crystal position in the two towers (the layer labeling is opposite to that commonly used to have layer 0 at the top as it is in reality). The current extrapolation algorithm rejects the events that deposit energy in both calorimeters, causing the observed depletion of hits along the gap between

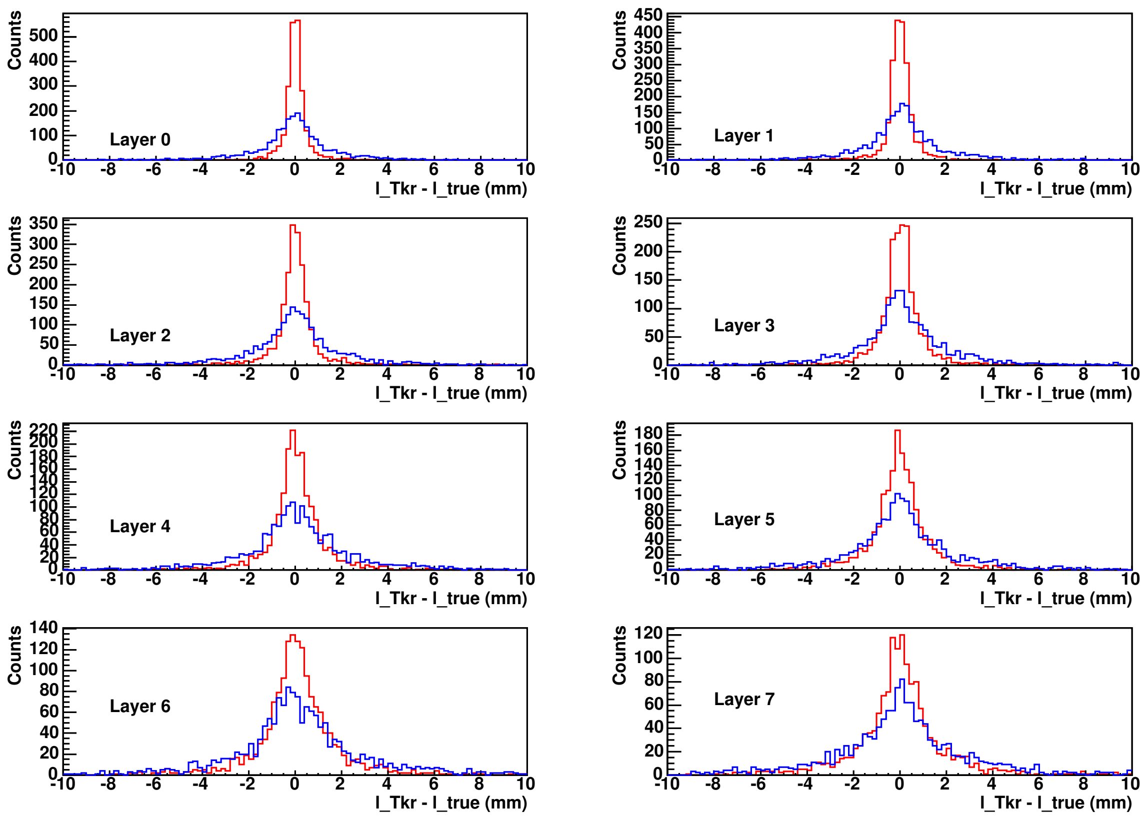

Figure 2: Longitudinal position given by the extrapolation with respect to the actual position, for the eight calorimeter layers. The blue (red) histograms correspond to the extrapolation with the start(end)-of-track parameters.

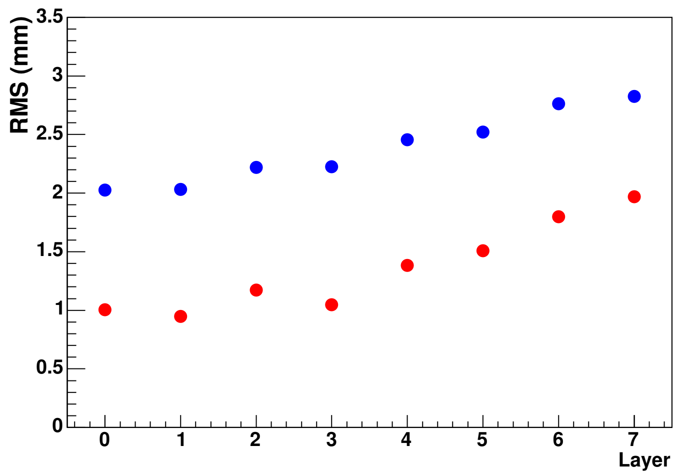

Figure 3: Localization resolutions of the extrapolation using the start-of-track parameters (blue dots) ot the end-of-track ones (red dots).

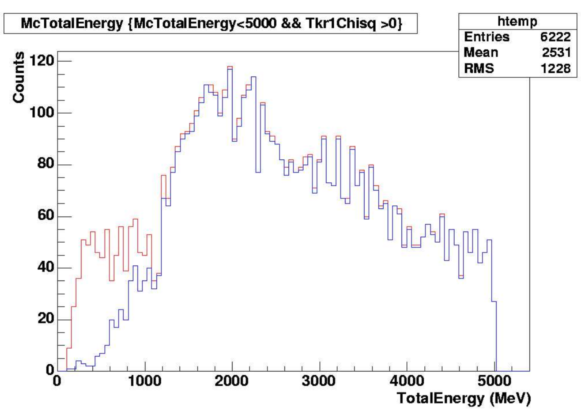

Figure 4: Muon energy distribution: without (blue histogram) and with the cut: Tkr1Chisq<3 (red histogram).

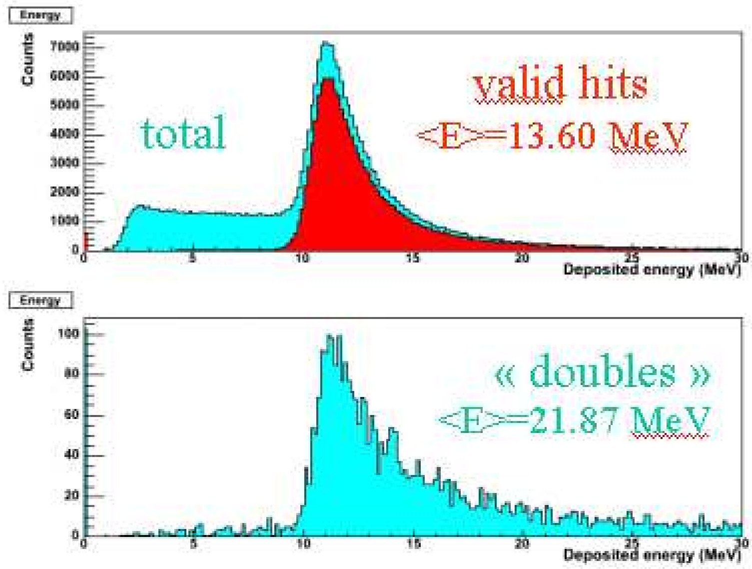

Figure 5: Deposited-energy distributions for all hits (upper panel, blue) for valid hits (upper panel:red) and for the double hits defined in the text.

the two towers. There is no good reason behind this feature, which should go away in the future. The trigger rate is 55 Hz according to these simulations. For one day of exposure to muons, more than 20000 valid hits are expected even for the lowermost crystals.

Finally, the crystal images are presented in Fig. 7(the images of all crystal have been summed up to increase statistics). The upper panel displays the distribution of valid hits over the crystal area. As naively expected, a depletion is observed along the crystal boundary, shown as a red frame in the figure. The lower panel represents the average deposited energy collected from the right-hand side, associated with the hits shown in the upper panel. The variation of average energy as a fonction of the longitudinal position reflects the light tapering in the crystal. Non-uniformity in the crystal response will manifest itself as deviation from this image. It is already known from a study carried out at NRL that such an non-uniformity exists in the region close to the photodiode due to the additional contribution from direct light. Other effects could be revealed through the inspection of such images, like a misalignment between CAL and TKR.

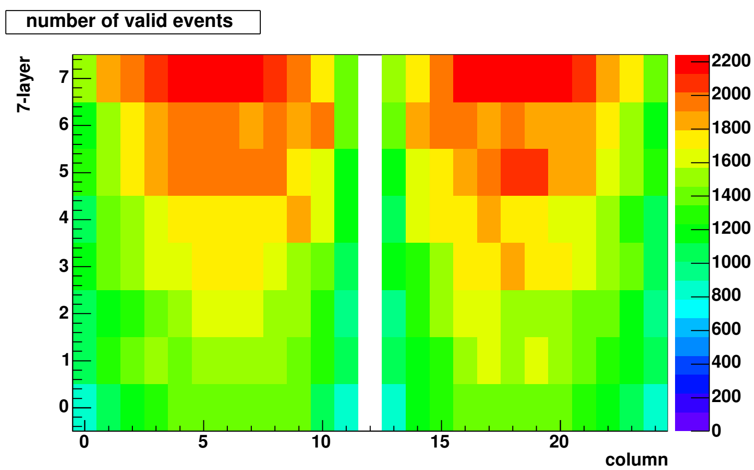

Figure 6: Cumulated statistics of valid hits after 4000s.

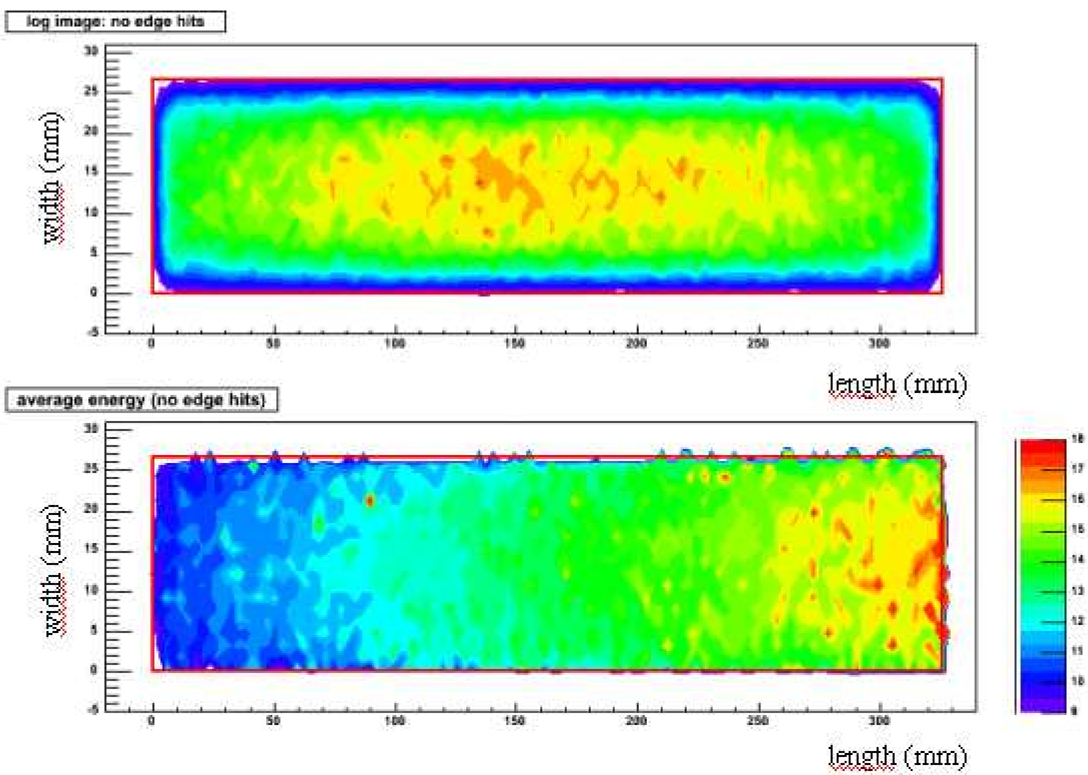

Figure 7: Crystal Images. Upper panel: count map. Lower panel: Map of average energy seen by the right-hand photodiode.