Muon Signal in the Electromagnetic Barrel Calorimeter Module 0 from August -99 and May -00 Testbeam Data.

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Abstract

Test beam data from the Electromagnetic Barrel Calorimeter Module 0 has been analyzed, and the muon signal has been studied. The data was taken in August -99 and May -00 at CERN. The signal to noise ratio for muons has been determined for the different layers of the Calorimeter. The percentage of the total energy that was deposited in the Front, Middle and Back compartments has been determined.

1 Introduction

In August -99 and May -00 test beam measurements were performed on the Electromagnetic (EM) Barrel Calorimeter Module 0 in order to understand the performance of the module. This note presents a study of the muon signal in the detector. The fact that most muons do not shower in the detector enables us to make simple comparisons between the Monte Carlo Simulations and real data. Using muons, the more complicated effects from particle showering do not have to be taken into account.

2 The Testbeam Setup

The experimental setup in the two test periods was similar. A trigger was formed from the coincidence between three scintillators which were placed before the

calorimeter. The pulse height in the third scintillator was read out by an analog to digital converter (ADC). Three beam chambers were placed 31.8 m, 22.8 m, and 4.4 m up stream of the calorimeter. In the May -00 test period an extra beam chamber was positioned 2.9 m in front of the calorimeter. However, for the data that has been analyzed in this study this extra beam chamber was not connected. A pion identifier, consisting of a ∼10 cm thick block of lead and an active layer to measure the amount of deposited energy, was positioned downstream of the calorimeter. In the August-99 test period a muon counter, consisting of scintillators in coincidence, was placed after an iron block(∼1 m) as the last device along the beam line. The muon setup was not optimized, thus the efficiency was low, and the information from the muon counter was not used in this study. It was enough to use the information from the calorimeter and the pion counter to distinguish between muon, pion, and electron events.
The calorimeter pulse was sampled 5 times around the signal peak in 25 ns intervals for the August -99 data and 7 times for the May -00 data. The phase between the trigger and the sampling clock for the calorimeter signal was measured by a time division counter (TDC).

3 Determination of which cell the muon pass through

One of the main problems when searching for a muon signal is the uncertainty in the beam direction. This uncertainty makes it difficult to determine which cells the muon passed through. In the case of electrons this can be determined simply by looking at where the energy is deposited. When dealing with muons, the energy deposited is comparable to the level of noise in the detector, and determining which cell is hit is difficult; just simply taking the cell with the maximum signal gives an unacceptable bias. In this study beams containing both electrons and muons were therefore used. This allowed a relationship between the position in the beam chamber and the hit cells to be established by studying the electrons. The relationship was then used to determine which cells a muon passed through.
Electron events were selected by requiring a minimum of 75% of the beam energy deposited in the calorimeter (75 GeV for the 100 GeV beam and 15 GeV for the 20 GeV beam) and no pion signal in the pion identifier. The barycenter of the electron signal in each layer (Front, Middle, Back) was plotted against the position in the beam chamber closest to the calorimeter. As can be seen in figure 1, there is a clear relationship between the barycenter and the position of the signal in the last beam chamber. To determine which Front cell the muon passed through a line was fitted to the data. This linear function was then used to select the cell to build the cluster around. In the Middle and Back

compartments it was sufficient to use cuts on the beam chamber positions to select the cells. These cuts are shown in figure 1.
Attempts were made to use the information from more than one of the beam chambers, so that the direction of the particle could be determined and this knowledge could be used to make the relationship even clearer. No significant improvement was seen, hence this information was not used.

4 TDC Correction

The shape of the pulse in the calorimeter is approximately parabolic near the peak. When dealing with electrons, a parabola is fitted to the clock sample data, and the height of the parabola, corresponding to the total energy deposited, is determined [1].
In the case of muons, where the deposited energy is of the same magnitude as the electronic noise, the pulse shape (from signal+noise) is no longer parabolic, and the deposited energy can not be determined in this way. Instead only the 3rd clock pulse sample (the middle one) was used in this study. If the timing was perfect, the energy of the 3rd sample should, since it is the middle sample, be equal to the height of the pulse. This is however not the case. The 3rd sample always has slightly lower energy than the maximum height of the pulse. In order to compensate for this effect, the electrons (selected in the same way as in section 3) were used to establish a relationship between the TDC time for the sampling clock phase and the relative difference between the height of the parabola (E_P) and the energy of the 3rd clock pulse (E_{3rd}) sample, see figure 2. The relative difference $(E_P - E_{3rd})/E_P$ was plotted against the TDC time, for the Front, Middle and Back compartments separately. A parabola was fitted to the data. The result for the August -99 run is shown in figure 2. This time information from the TDC was used to correct for the energy difference between (E_P) and (E_{3rd}) for the muons. This correction obviously relies on the assumption that the shape of the pulses (without noise) are the same for muons and electrons.
This TDC correction could not be used for the May -00 data, since the time window was larger, and the relationship between the maximum energy and the TDC time was not clear.

5 Energy deposition of 100 GeV Muons (August -99 data)

A 100 GeV run was selected since around this energy the 'electron' [1] beams contain a large fraction of muons. 20000 events with the beam directed at (η=0.975, ϕ=0.260) were analyzed, in a run that was taken prior to the addition of a muon veto to the trigger.

Events were required to have the following general characteristics:

- Beam particle trigger (i.e. not calibration data)
- Events with exactly one particle passing through the detector were selected by requiring the deposited energy in the scintillator counter to correspond to 1 MIP.
- A time interval where the TDC corrections are not too large ($< 1\%$ in the Front and Middle compartments and $< 10\%$ in back) was selected: 680 $<$TDC counts$<$ 760

The beam contains a high fraction of electrons and pions. In order to select the muon events, the following cuts were chosen by studying the appropriate distributions:

- Since the muons deposit less energy in the calorimeter than electrons and pions, the total energy deposited in all the layers was required to be less than 6 GeV.
- Events with no pion signal in the pion identifier were selected.

After these cuts, and cuts on the position in the third beamchamber (see figure 1), there were 730 events left. The information from the beam chambers was used to determine through which cells the muon had passed. The energy in a cluster of cells surrounding the cell that was hit was summed up. Two cluster sizes were used. A larger cluster has the advantage that even if the determination of which cell is hit is incorrect, the cluster should still contain the energy. However, a larger cluster obviously results a larger noise value. The number of cells in the clusters were the following:

[1] I here refer to a beam that is predominately electrons

Small cluster	$[\eta * \phi]$	**Large cluster**	$[\eta * \phi]$
Front:	$3 * 1$	Front:	$7 * 1$
Middle:	$1 * 2$	Middle:	$3 * 3$
Back:	$1 * 2$	Back:	$1 * 3$

For each event, the percentage of the total energy that was deposited in the Front, Middle and Back compartments, after the TDC correction had been applied, was calculated. The resulting distributions are shown in figure 3.
The results are summarized in Table 1. The mean value of the data is shown as well as the mean of a Gaussian fit. The latter has the advantage that if there are pions left even after selection cuts, these would change the mean value of the data, but they do not significantly change the mean of a fitted Gaussian. However, as can be seen in figure 3, the distributions are not pure Gaussians. These results can be compared to Monte Carlo simulations of the detector table 2. When comparing the values one should be aware of that no noise has been added in the simulations. One should also keep in mind that the errors given are purely statistical and that the systematic errors, e.g. resulting error after the TDC correction, are not taken into account.

6 Signal to noise Ratio of 20 GeV Muons (May -00 Data)

70000 events from a 20 GeV predominantly 'electron' beam directed at (η=0.863,ϕ=0.260) was used for this study. The muon events were selected in a similar way as in section 5. The following cuts were used:

- Beam particle trigger
- 1 MIP in the scintillator counter
- 250 <TDC counts< 600
- The total energy deposited in all the layers was required to be less than 2 GeV.
- No pion signal in the pion identifier
- Cuts on the position in the third beam chamber was applied in order to know which cell that the muon passed through, in a similar way as for the 100 GeV muons. The limits correspond to $0.855 < \eta < 0.870$ and $0.255 < \phi < 0.270$.

1033 events fulfilled these cuts. These data showed no clear relationship between the TCD counter and the difference between (E_P) and (E_{3rd}) for the back compartment. I TDC correction was therefore not applied. Such a correction might improve the signal to noise ratio slightly.
The center of the cluster, i.e. the cell the muon passed through was determined by using the information from the beam chambers as described in section 3. To improve the signal to noise ratio, and to reduce the timing effects, the 5 (out of 7) central clock pulses were used. The energy deposited in the calorimeter during these 5 clock pulse samples was summed over the cells within th cluster for each calorimeter compartment. Since the signals from 5 clock pulse samples were added together and no TCD correction was applied, the result is in an unknown energy scale. However, since we are here only interested in the ratio between the signal and the electronic noise, this energy scale is not important.
The resulting energy distribution was fitted with a Landau function convoluted with a Gaussian, since the muon signal should be Landau distributed, and the noise should be Gaussian distributed. This has been shown to give a better fit than the commonly used Moyal function for the muon energy deposition in the Hadronic End-Cap calorimeter [4]. The same procedure was applied to pedestal events (physics=0), and a Gaussian was fitted to the resulting distribution. The signal to noise ratio was determined as the peak value of the Landau function divided by the RMS of the Gaussian from the noise distribution.
The results for the Front, Middle and Back compartments, taken separately, can be seen in figure 5. In figure 6 the signal from more than one compartment has been added together. By comparing the plots to the left (Front + Middle) to the plots to the right (Front+ Middle + Back) one sees that the Back compartment does not improve the signal to noise ratio. The top plots shows the result when only one cell has been used for the Middle and Back compartments. Because of ϕ modulation, a more correct result is obtained by using two cells in the ϕ direction for the Middle and Back compartments. This is shown in the lower plots. The result is summarized in table 3.

7 Conclusions

The energy deposition from muons in the Electromagnetic Barrel Calorimeter Module 0 has been analyzed. Using data from the August -99 test beam, where a TDC correction could be applied, the fraction of energy deposited in each compartment (Front, Middle, Back) of the calorimeter was determined. This fraction can be compared to what is expected from Monte Carlo simulations. When only the statistical errors are taken into account, the values differs with between 1 and 3 standard deviations for the large cluster, and up to 5 standard deviations for the small cluster. More statistics, better understanding of the systematical effects, and simulations which include noise are however required to draw conclusions on the compatibility. The signal to noise ratio for muon energy deposition in the calorimeter has been determined using test beam data from May -00. The highest ratio is given if the signal in the Front and Middle compartment of the calorimeter are added together. The Back compartment does not further increase the signal to noise ratio. A ratio of 9.2 can be achieved if the energy of 5 clock pulse samples are summed together, by using 3 cells in the Front Compartment and one cell in the Middle and Back compartments. Because of ϕ modulation it is more correct to use 2 cells in the ϕ direction in the Middle compartment, resulting in a signal to noise ratio of 8.1.

8 Acknowledgements

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References

[1] The ATLAS Collaboration, 'ATLAS Detector and Physics Performance Technical Design Report', ATLAS TDR 15, CERN/LHCC/99-15 (1999).

[2] Talk by Kostas Kordas,'Very Preliminary Geant 4 results for muons and electrons in the EM barrel' Orsay France, 18 May 2000. Based on work by Gaston Parrour.

[3] Privat communication; Kostas Kordas.

[4] Talk by M.S. Levitsky, 'Comparison Moyal Function and Landau distribution with MC and experimental data', at the HEC/FCAL Test Beam simulation/analysis meeting, 24 April 2000.

LAr energy fractions(%) in the 3 compartments	Small Cluster		Large Cluster	
	Mean_{Gauss}	$MeanValue$	Mean_{Gauss}	$MeanValue$
Front	10.8 ± 0.3	11.0 ± 0.3	10.7 ± 0.4	12.0 ± 0.5
Middle	71.8 ± 0.5	70.6 ± 0.4	71.2 ± 0.7	69.4 ± 0.7
Back	17.5 ± 0.5	18.5 ± 0.4	16.8 ± 0.6	18.7 ± 0.6

Table 1: *The fraction of total energy (in %) that is deposited in each compartment. Two values are given; The mean of the Gaussian fitted to the distribution and the mean value of the data.*

LAr energy fractions (%) in the 3 compartments	Geant3		Geant4	
	Mean_{Gauss}	$MeanValue$	Mean_{Gauss}	$MeanValue$
Front	9.7 ± 0.1	10.6 ± 0.2	10.17 ± 0.03	10.96 ± 0.05
Middle	68.4 ± 0.1	68.2 ± 0.3	69.28 ± 0.06	68.48 ± 0.09
Back	19.9 ± 0.1	21.2 ± 0.3	18.81 ± 0.05	20.55 ± 0.09

Table 2: *Monte Carlo simulations of the fraction of the energy (in %) deposited in each compartment. Two values are given; The mean of the Gaussian fitted to the distribution and the mean value of the data. Geant 3 data from [2] and Geant 4 data from [3]. The simulations were done without clustering (i.e. all energy in the layer was summed) and with no noise.*

Compartment(s)	Signal to Noise ratio
Front $(1*3)$	2.32 ± 0.08
Middle $(1*1)$	8.86 ± 0.20
Back $(1*1)$	0.59 ± 0.07
Front $(1*3)$ + Middle $(1*1)$	9.23 ± 0.23
Front $(1*3)$ + Middle $(1*1)$ + Back $(1*1)$	8.81 ± 0.22
Front $(1*3)$ + Middle $(1*2)$	8.10 ± 0.21
Front $(1*3)$ + Middle $(1*2)$ + Back $(1*2)$	7.64 ± 0.20

Table 3: *The signal to noise ratio for muons for different configurations of compartments and number of cells. The numbers inside the brackets denote the number of cells used in the cluster, in ($\eta * \phi$).*

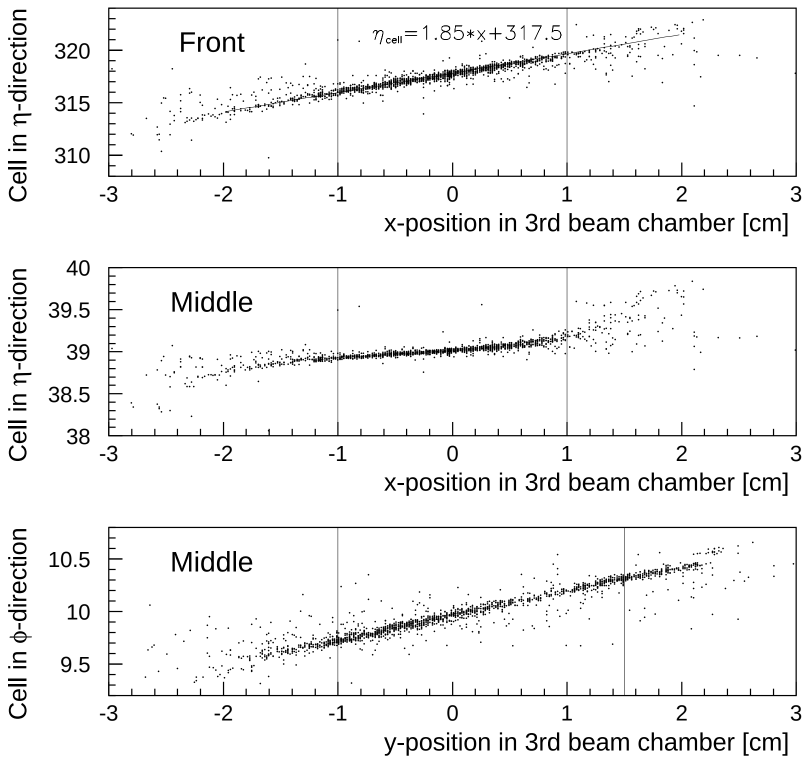

Figure 1: *The relationship between the position in the 3rd beam chamber and the barycenter in the Front and Middle compartment. In Front a line was fitted to the data and this linear function was used to select the cells. The vertical lines shows the cuts used on the 3rd beamchamber position.*

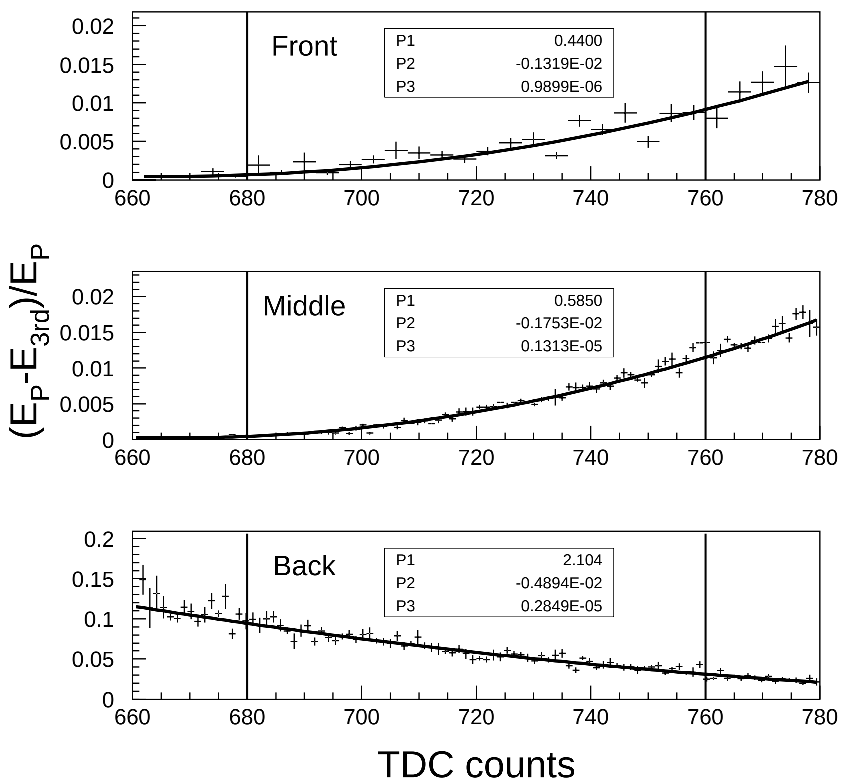

Figure 2: *The relative difference between the signal in the 3rd sample and the maximum height of the pulse* $(E_P - E_{3rd})/E_P$.

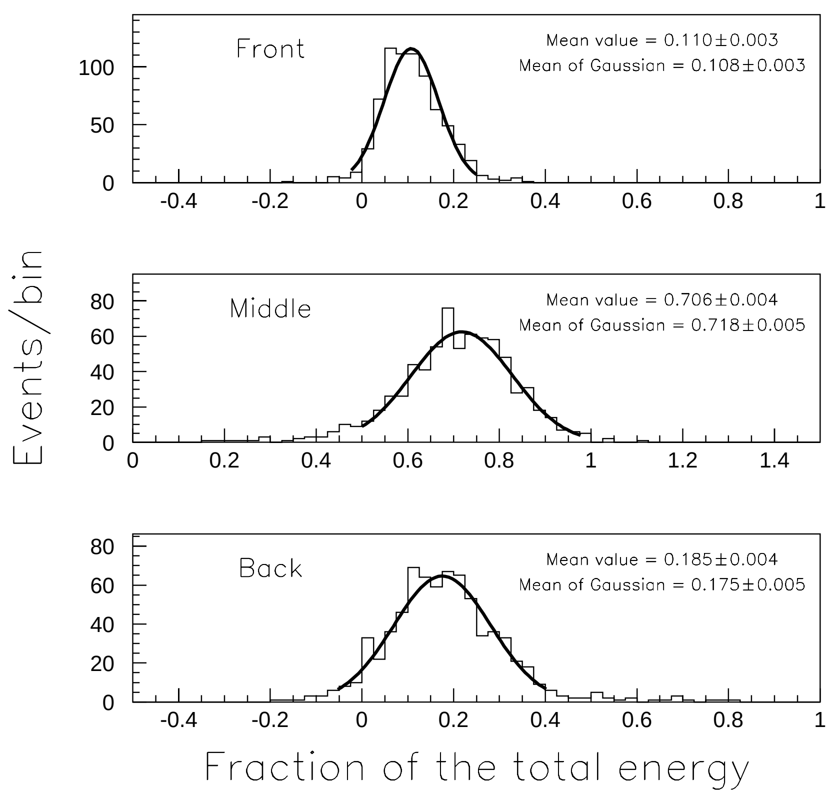

Figure 3: *The relative fraction of the total energy that is deposited in each of the compartments when a small cluster is used; 3 cells in Front, 2 cells in Middle and 2 cells in the Back compartment.*

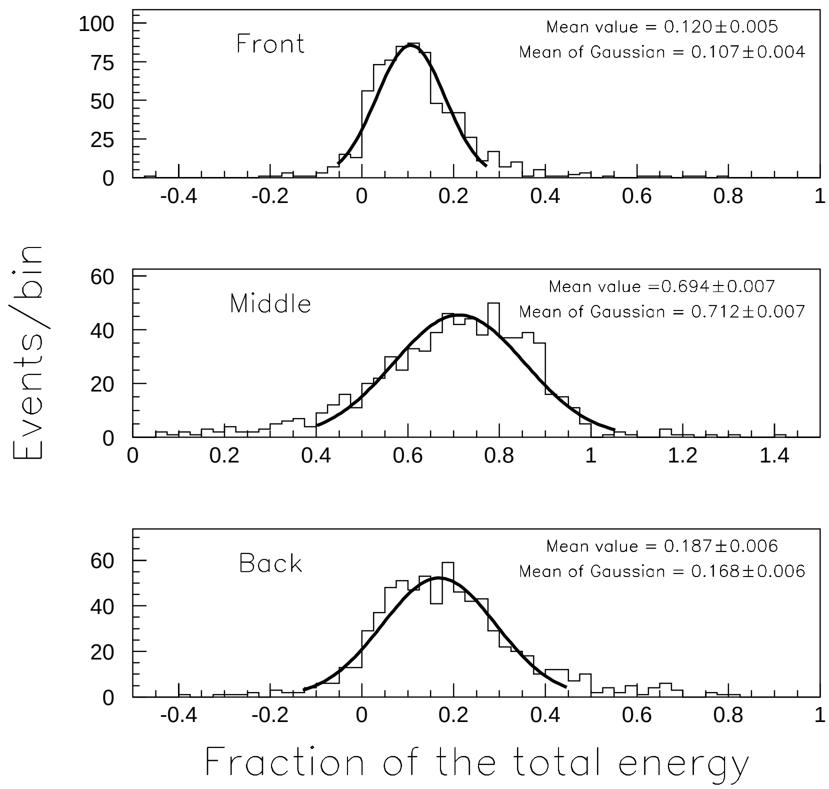

Figure 4: *The relative fraction of the total energy that is deposited in each of the compartments when using a big cluster; 7 cells in Front, 9 in Middle and 3 in Back.*

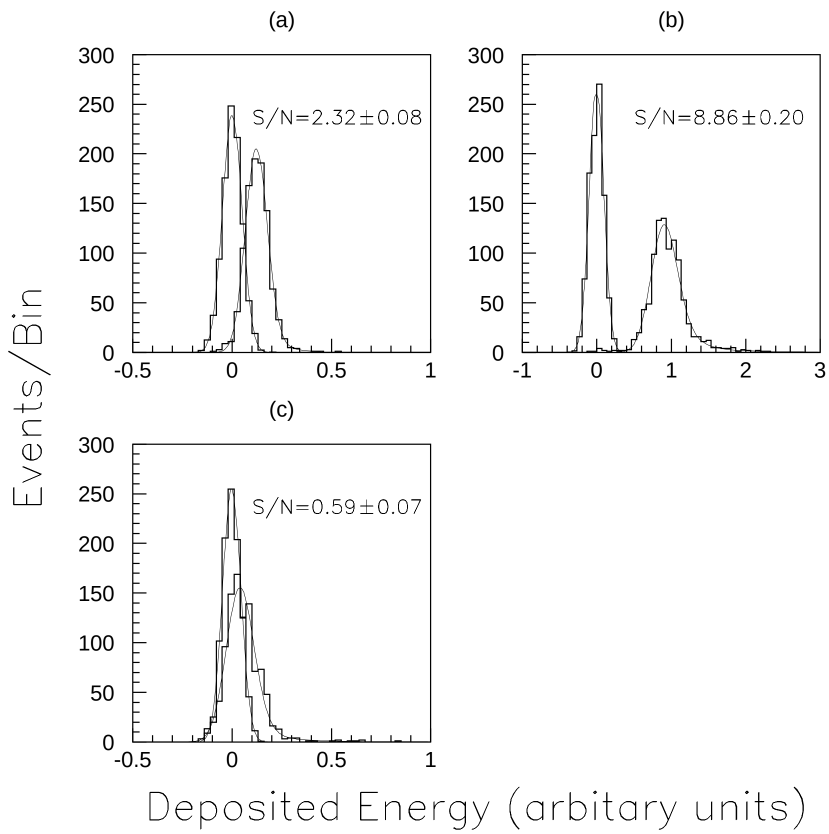

Figure 5: *Signal to noise ratio for muons, for: a) Front (3 cells), b) Middle (1 cell) and c) Back compartment (1 cell).*

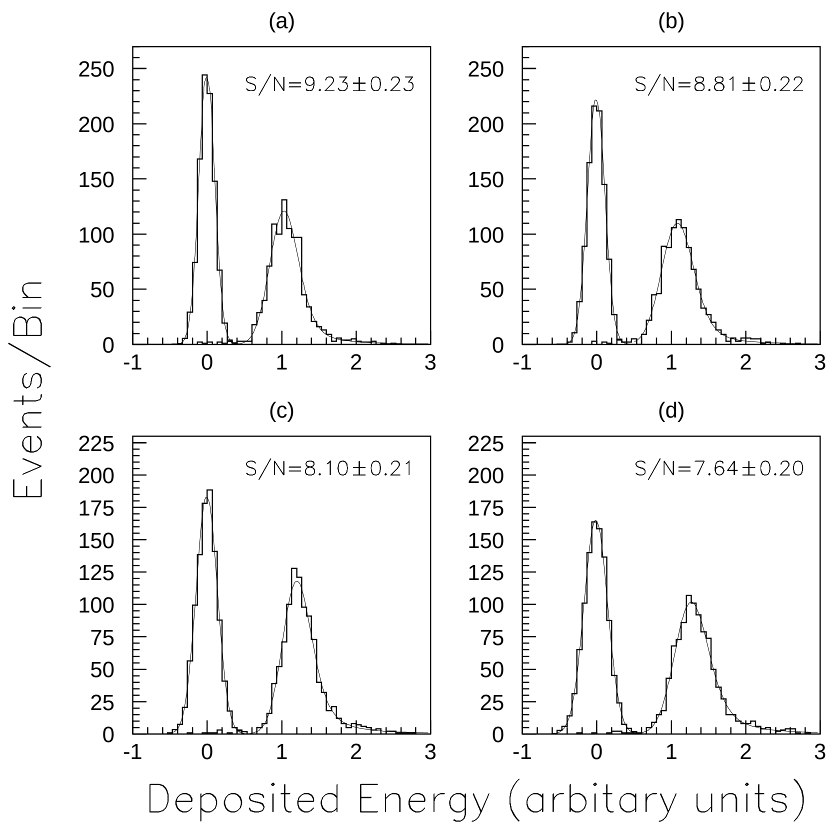

Figure 6: *Signal to noise ratio for muons, for the following compartments and number of cells (in $\eta * \phi$): a) Front($3 * 1$) + Middle($1 * 1$), b) Front($3 * 1$) + Middle($1 * 1$) + Back($1 * 1$), c) Front($3 * 1$) + Middle($1 * 2$), d) Front($3 * 1$) + Middle($1 * 2$) + Back($1 * 2$).*