Addendum to CALICE Analysis Note CAN-030
February 22, 2013

Analysis of DHCAL Muon Data

The CALICE Collaboration[1]

Abstract

This addendum to CAN-030 concerns three sets of plots: a) the average response as function of layer number as measured in November 2011, b) the average response per layer, as measured in so-called 'clean' regions and over the entire detector plane in October 2010. The plots also show comparisons with simulations, based on GEANT4 and the RPC_sim program, where the lateral distribution of charges is described with the sum of two exponentials, and c) the same as b), but using a single exponential to distribute the avalanche charge on the pad layer.

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1. The average response versus layer number

In November 2011 the DHCAL layers were removed from the CALICE HCAL structure and inserted into our assembly structure. The goal was to perform detailed measurements of hadronic showers at very low energies, ≤ 2 GeV, using the tertiary beam at the Fermilab Test Beam Facility (FTBF). The setup, shown in Fig. 1 consisted of 52 layers, corresponding to 479,232 readout channels. The thickness of each layer amounted to 0.4 radiation length, X_0, or 0.04 nuclear interaction length, λ_I. The distance between layers was 2.54 cm, leaving a gap of approximately 1.7 cm between cassettes. With this large gap and the help of a few fans the layers could be cooled efficienctly and uniformly, resulting in a significantly improved layer-to-layer unformity, compared to what was possible in previous tests using the CALICE HCAL structure.

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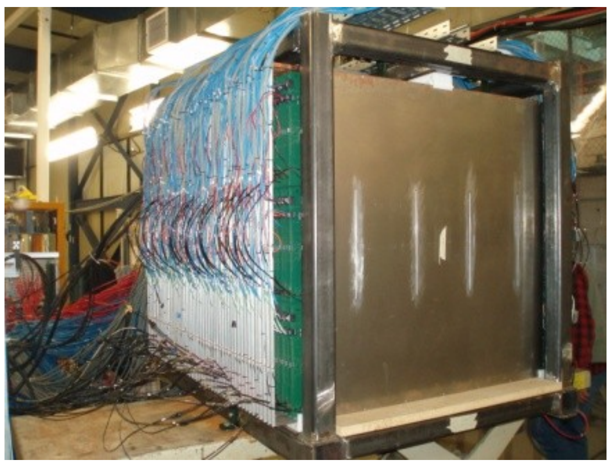


Figure 1. Photograph of the DHCAL in its configuration with minimal absorber plates.

Figure 2 shows the RPC performance parameters: efficiency, average pad multiplcity and their product, the calibration factors, as function of layer number. The latter were normalized by the average value of the calibration factors obtained in the October 2010 run [1]. The measurements were performed using both tracks through the calorimeter (reconstructed excluding the layer for which the performance is evaluated) and track segments (reconstructed using the neighboring layers to the layer being evaluated).

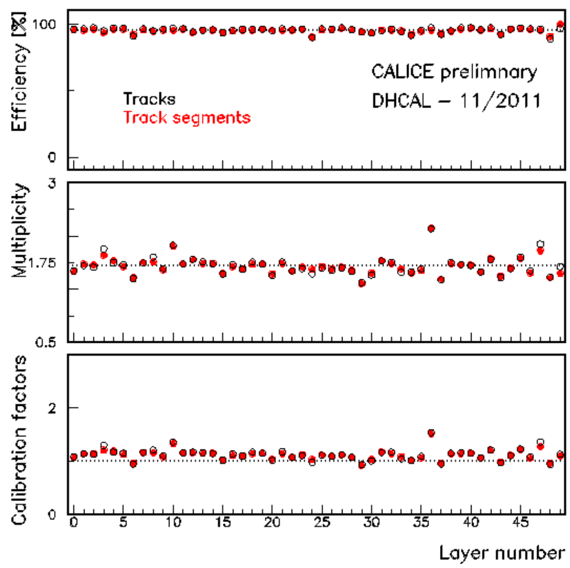


Figure 2. Performance parameters of the DHCAL as function of layer number as measured in November 2011. The dotted lines represent the average value (for the efficiency and pad multiplicity) and unity (for the calibration factors).

2. The average response per layer

This is an update of the analysis of the average response per layer, as reported in [1]. The measurements were performed in so-called 'clean' regions of the RPC-planes. In this update the definition of the 'clean' regions changed somewhat, taking into account the loss of efficiency at the edge of the chambers:

- Dead ASICs (cut away an area of 8 x 8 cm^2 plus a rim of 1 cm)
- Edges in x (cut away **6.0 cm** from the 2 edges in x)
- Edges in y (cut away **6.0 cm** from the 6 edges in y)
- Fishing lines (cut away ± 1 cm around fishing line)
- Layer 27 (which showed unusually high pad multiplicity)

The previous definition of 'clean' regions only excluded a rim of 0.5 cm along the x and y edges of the chambers.

The measured average response was simulated with GEANT4 and the RPC_sim program, which emulates the response of the RPCs. In RPC_sim_3 (RPC_sim_4) the charge of the avalanche is spread on the layer of pads using two (one) exponential. In both cases the parameters describing the response of the RPCs have been tuned to reproduce the measured response.

In addition, measurements of the average performance variables over the entire detector plane are shown. Again, the results are compared to the tuned simulation based on GEANT4 and the RPC_sim program.

2.1 RPC_sim_3 with 2 exponentials

Figure 3 shows the measured response per layer compared to the tuned simulation with RPC_sim_3. The response depends on six parameters. As a function of lateral distance r to a given generated avalanche, the induced charge in the plane of the readout pads is assumed to decrease according to the following formula:

$$\frac{dQ}{dr} \propto \frac{(1-R)\cdot e^{-r/a_1}}{a_1^2 \cdot (1-R_{\max}/a_1)} + \frac{R \cdot e^{-r/a_2}}{a_2^2 \cdot (1-R_{\max}/a_2)},$$

where R_{max} is the maximum distance considered for spreading the charge and is set to 4 cm. Table I list the tuned values.

Table I. Parameters of the tuned RPC_sim_3 program.

Parameter	**Value**
Slope a_1	0.0678
Slope a_2	0.671
Ratio R	0.345
Thershold T	0.3645
d_{cut}	0.092
Q_0	0.201

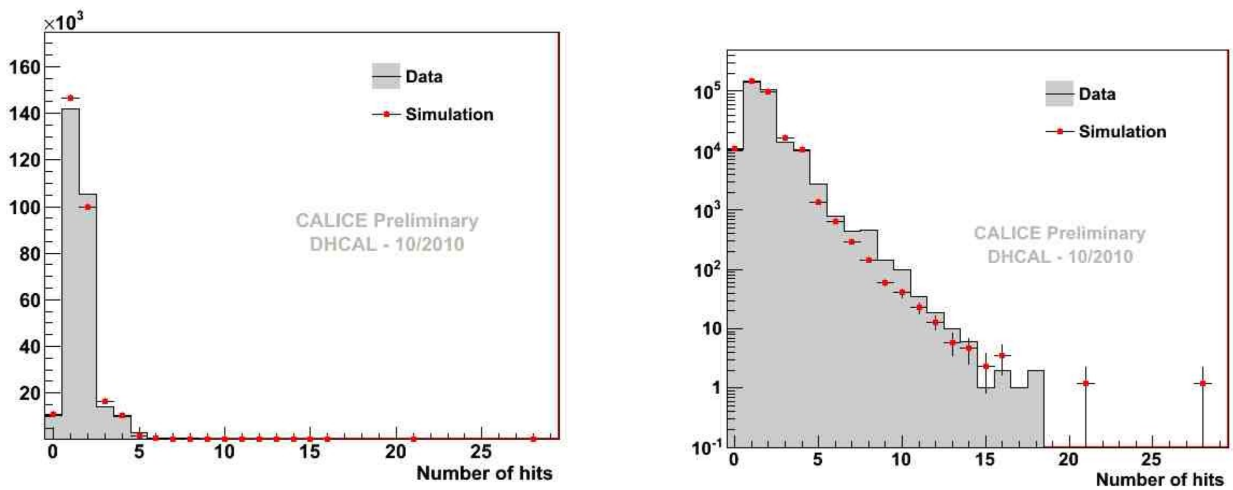


Figure 3. Average response per layer in 'clean' regions: data (histogram) and simulation based on RPC_sim_3 with two exponentials (red dots): Left with linear y-scale and right with logarithmic y-scale.

The following plots pertain to the response over the entire detector plane. Figure 4 shows again the average response per layer.

In order to reproduce the loss of efficiency close to the borders of the RPCs, the generated charge was attenuated for avalanches within 10 cm of the borders. The effects of the fishing lines was adequately reproduced by implementing these into the geometrical description of the DHCAL in

GEANT4. Figure 5 shows the inefficiency as a function of both the x and y coordinate in the vertical plane of the DHCAL.

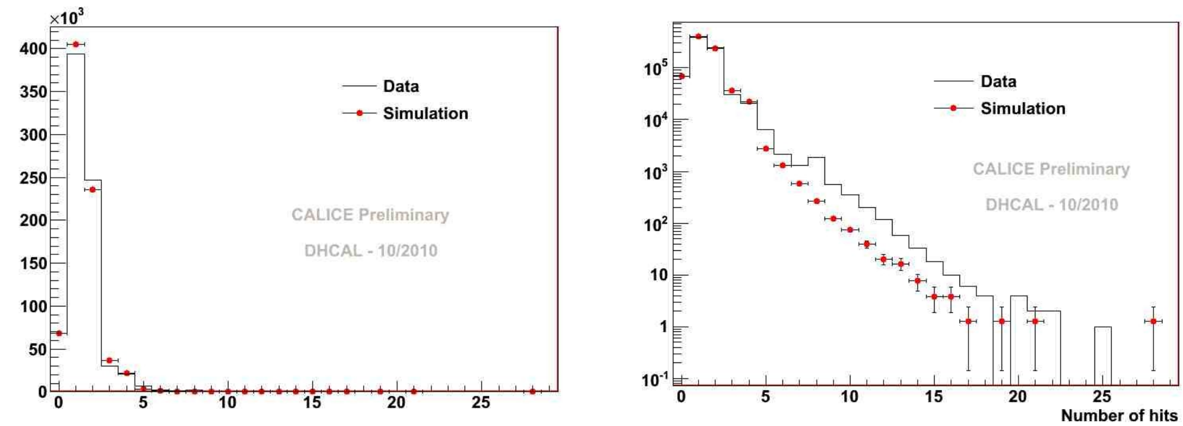


Figure 4. Average response over the entire detector plane: data (histogram) and simulation based on RPC_sim_3 with two exponentials (read dots): Left with linear and right with logarithmic y-scale.

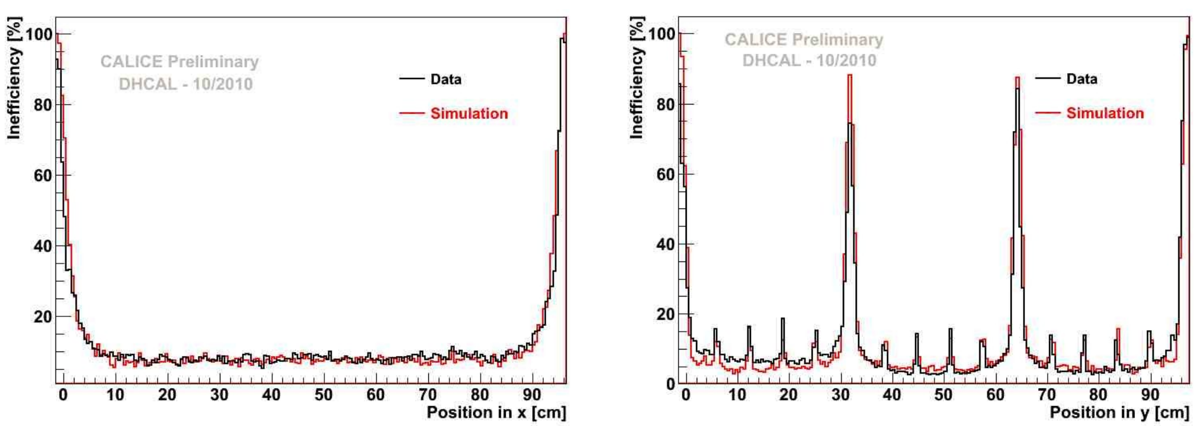
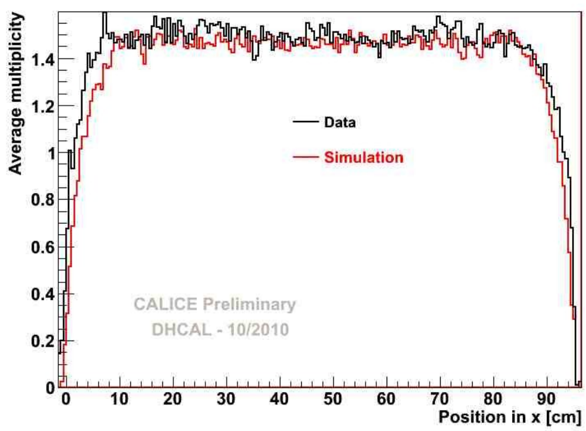


Figure 5. Inefficiency in the vertical plane of the DHCAL as function of the x (left) and y (right) coordinate: data (black histogram) and simulation using RPC_sim_3 (red histogram).

The average multiplicity as a function of the x and y coordinates in the vertical plane of the DHCAL is shown in Figure 6. The higher multiplicities observed in the top RPC are most likely due to the elevated temperature in the upper part of the detector.



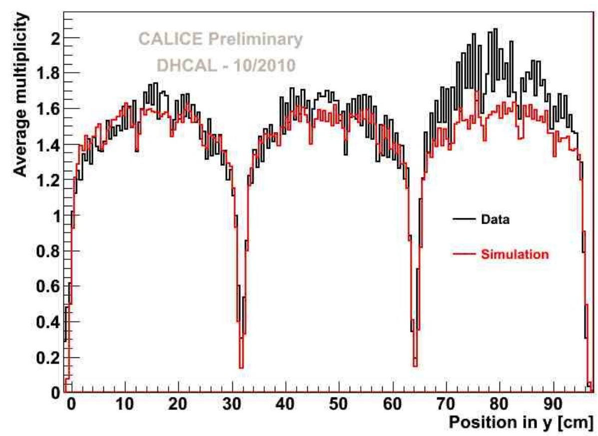


Figure 6. Average pad multiplicity as function of x (left) and y (right): data (black histogram) and simulation based on RPC-sim_3 (red histogram)

2.2 RPC_sim_4 with 1 exponential

The tuned parameter values of RPC_sim_4 are listed in Table II.

Table II. Parameters of the tuned RPC_sim_3 program.

Parameter	**Value**
Slope a	0.0843
Threshold	0.286
d_{cut}	0.092
Q_0	0.199

The following figures 7 – 10 correspond to the Fig. 3 – 6, shown above, where the simulation is now based on RPC_sim_4.

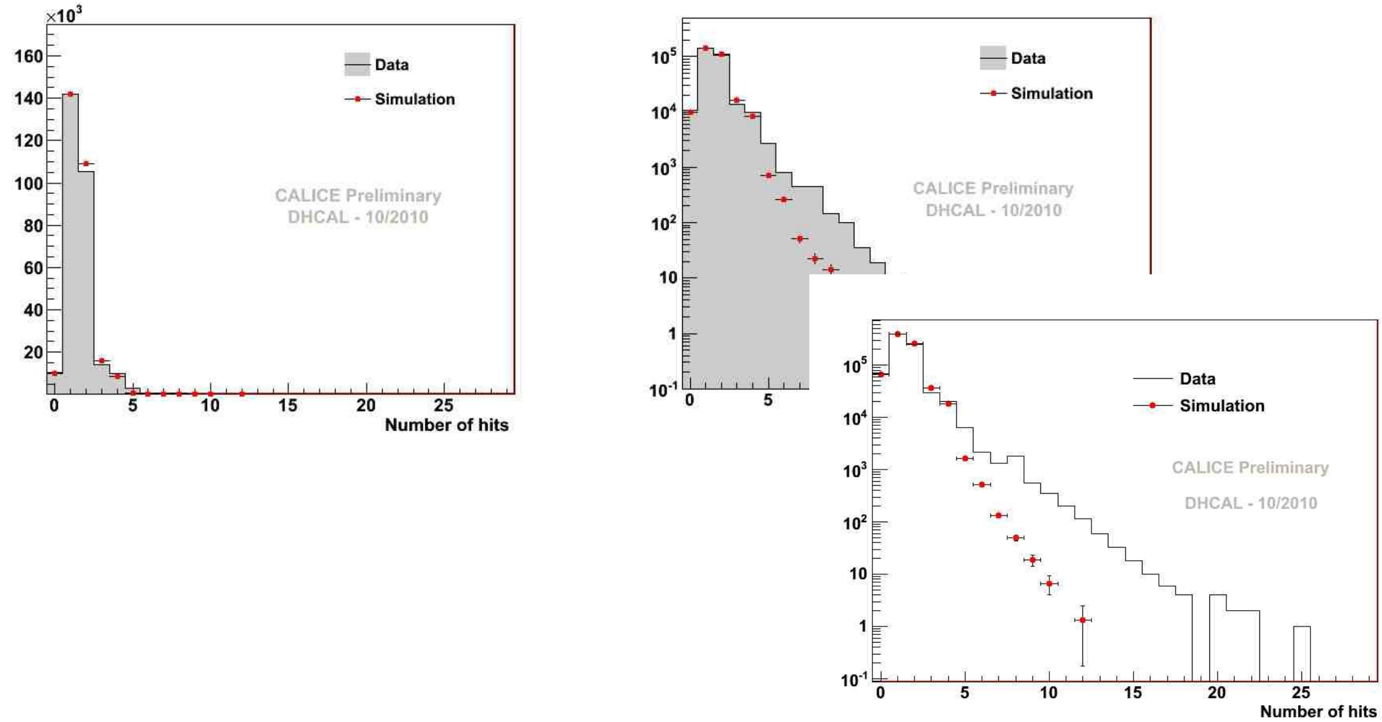


Figure 7. Average response per layer in ‘clean’ areas: data (histogram) and simulation based on RPC_sim_4 with one exponential (red dots): Left with linear y-scale and right with logarithmic y-scale.

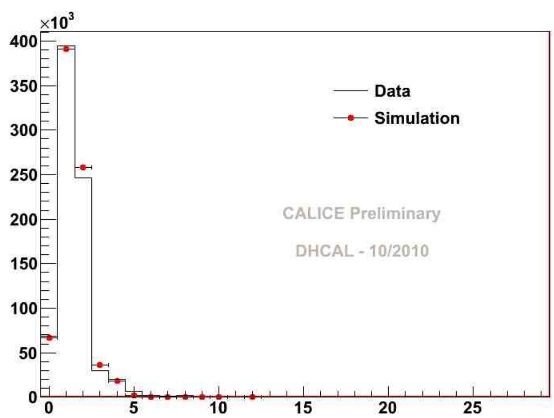


Figure 8. Average response over the entire detector plane: data (histogram) and simulation based on RPC_sim_4 with one exponential (read dots): Left with linear and right with logarithmic y-scale.

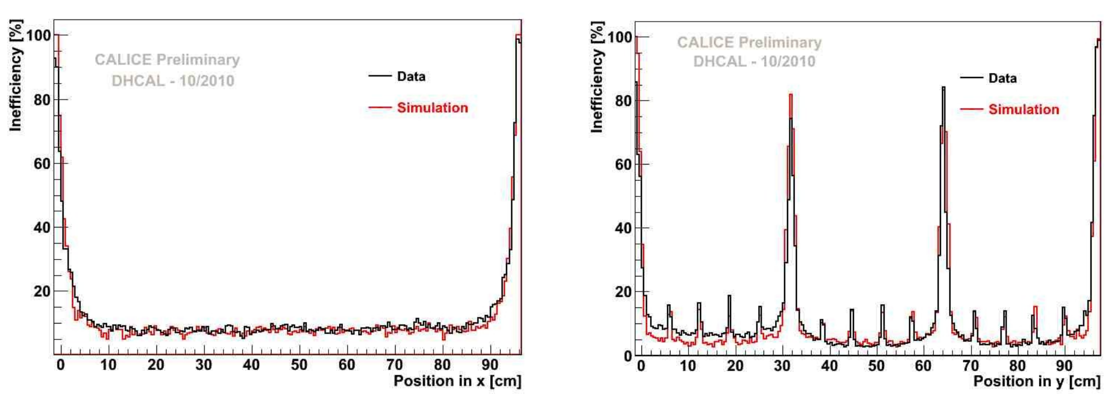


Figure 9. Inefficiency in the vertical plane of the DHCAL as function of the x (left) and y (right) coordinate: data (black histogram) and simulation using RPC_sim_4 (red histogram).

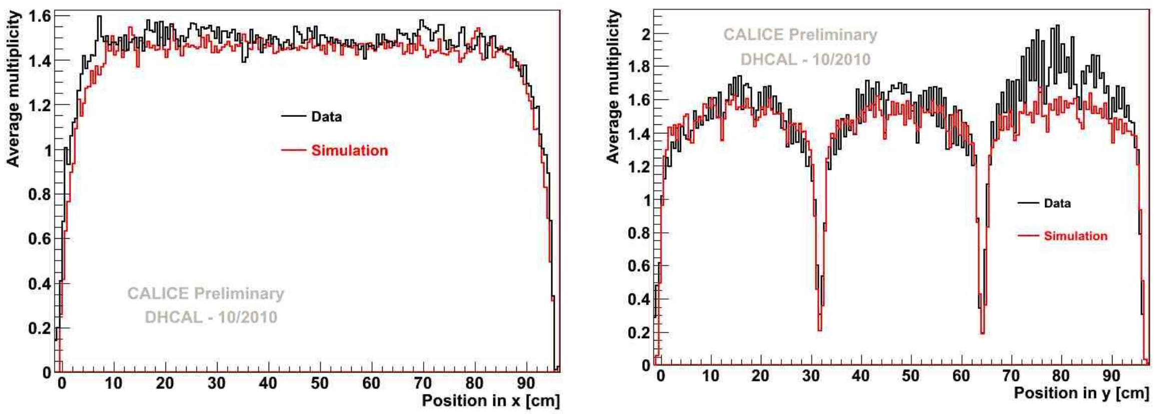


Figure 10. Average pad multiplicity as function of x (left) and y (right): data (black histogram) and simulation based on RPC-sim_4 (red histogram)

References

[1] "Analysis of DHCAL Muon Data", CAN-030