Performance of a dual readout calorimeter with a BGO electromagnetic section

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Abstract. The dual readout technique has been tested on a hybrid calorimeter. The electromagnetic section of this instrument consists of 100 BGO crystals and the hadronic section is made out scintillating and Cherenkov fibers embedded in a copper matrix (DREAM). The electromagnetic fraction of hadronic showers is evaluated on an event-by-event basis from the relative amounts of Cherenkov and scintillation lights produced in the shower development. The performance of such a calorimeter in terms of energy resolution is presented. Effects of side leakage on detector performance are also studied.

1. Introduction

The response of an hadronic calorimeter can be expressed in term of the em shower fraction (f) and of the e/h ratio as

$$R = [ef + h(1-f)]E_0$$

where e and h are the detector response to em and non-em shower components, respectively. The event by event fluctuations of f represent one of the main limitation to the hadronic resolution of non compensating calorimeter, even if the h/e value is measured.

With the dual readout technique, one uses two different active media, one producing Cherenkov light (C) and one scintillation light (S), therefore with very different h/e ratios (let's say c and s, respectively). Their responses will be:

$$C = [f + c(1-f)]E_0 \qquad S = [f + s(1-f)]E_0$$

If c and s are known, it is possible to measure the electromagnetic fraction:

$$f = \frac{c - s(C/S)}{(C/S)(1-s) - (1-c)}$$

and thus the released energy, corrected for the fluctuations of f

$$E_0 = \frac{C - \lambda S}{1-\lambda}$$

where $\lambda = (1-c)/(1-s)$ is a constant of the calorimeter depending only on its mechanical structure [1]

In the following the application of this technique to an hybrid system made out a BGO matrix and the DREAM module is described. Before combining the energy measurements of the two sections, it is necessary to calibrate them and to determine the suitable corrections to the electromagnetic fraction fluctuation on an event-by-event basis. In particular, for the fiber detector the leakage contribution is evaluated, while for the BGO matrix we have focused on the resolution measurements.

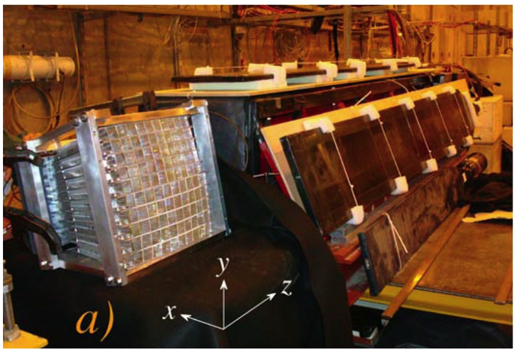

Figure 1. The hybrid calorimeter system: the 100-crystal BGO matrix located upstream of the fiber module. Scintillator paddles for the measurement of the leakage are visible.

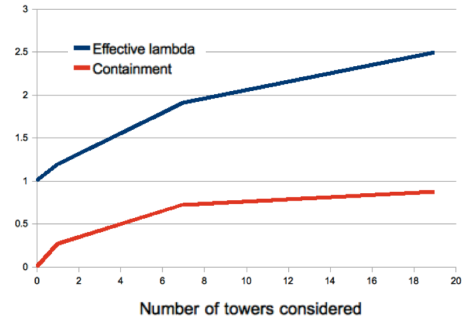

Figure 2. Effective lambda constant and the containment parameter as function of the number of the towers of the DREAM module summed in the measurement

2. Lateral leakage

Once the fluctuations of the e.m. fraction were successfully eliminated using the method described above, the resolution of the DREAM fiber calorimeter turned out to be limited mainly by the uncertainties on the lateral leakage. In fact, in present setup the fiber module was surrounded by 8 plastic scintillator paddles, as shown in Fig. 1, and the leakage was measured to be 5% - 10% for an 100 GeV pion beam steered in center of the detector. Measurements also show a good anti-correlation between the electromagnetic fraction measured in the fiber module and the leakage detector. As expected, the higher the electromagnetic content of the shower the better it is contained; moreover the em fraction increases with the beam energy as expected. From this information one can write the response for a not fully-containing detector for the two sensitive media, separately, as

$$C = [f + c\alpha(1-f)]E_0 \qquad\qquad S = [f + s\alpha(1-f)]E_0$$

where α is the contained fraction of the non-em part. Therefore the measured energy will be:

$$E_0 = \frac{C - \hat{\lambda}S}{1 - \hat{\lambda}}$$

defining $\hat{\lambda} = (1-\hat{c})/(1-\hat{s})$, $\hat{c} = \alpha c$ and $\hat{s} = \alpha s$. In Fig. 2 the effective constant $\hat{\lambda}$ and the containment parameter α are shown as a function of the number of towers of the DREAM module summed in the measurement. From the $\hat{\lambda}$ value extracted from the data, it is possible to determine the parameter α and therefore to correct the energy measurement for both the em fraction fluctuation and the leakage.

3. The BGO electromagnetic section

The electromagnetic section is a matrix made of 100 BGO crystal (Fig. 1). The matrix is readout by 12 PMTs (Photonis 3392B) arranged in 3 rows of 4 PMTs each. In order to extract the Cherenkov component from the light produced, we used UV filters [3]. For the data presented in this paper, the UV filters were used on the central PMT row only. The waveforms of the PMT signals were recorded using Domino Ring Samplers IV. A typical filtered signal is shown in Fig. 3. In order to extract the C and S contribution for filtered PMTs we fitted the acquired signals event-by-event.

The performance of the BGO matrix in terms of resolution and linearity has been evaluated using the sum of the scintillation contribution from all the PMTs and, for the Cherenkov light, the sum of the signals of the 4 filtered PMTs. The energy resolution measured with electrons in the range 10 - 150 GeV is

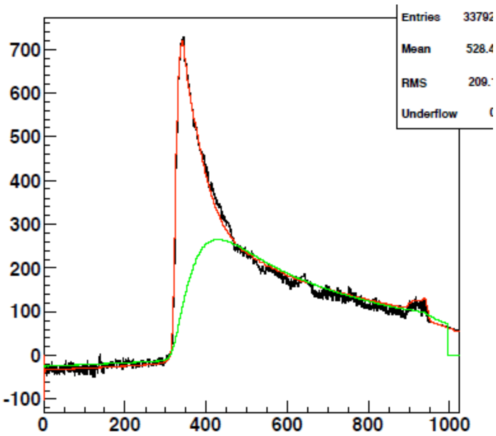

Figure 3. Fits used to disantangle Cherenkov (red line) and scintillation (green line) contributions in the signal from filtered PMT's

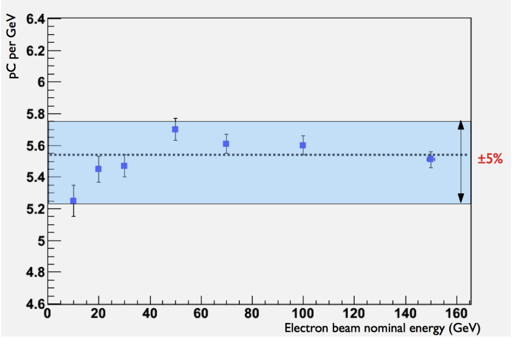

Figure 4. Linearity of the response for the Cherenkov signals as function of the electron beam nominal energy.

$$\frac{\sigma_{E_C}}{E} = \frac{36\%}{\sqrt{E}} \oplus 3\% \qquad\qquad \frac{\sigma_{E_S}}{E} = \frac{33\%}{\sqrt{E}} \oplus 1\%$$

for Cherenkov and Scintillation respectively. Linearity for the Cherenkov signal as a function of the nominal beam energy is shown in Fig. 4 and measured to be within ±5%. The resolution obtained is strongly limited as a consequence of the non optimized readout. An improved scheme has been realized for the 2010 test beam.

4. A complete Dual Readout calorimetry system

After a suitable calibration with electrons of the ECAL section, we started to study the performance of the whole calorimeter with pion beams. The information collected with the two sections are combined to obtain an overall evaluation of the electromagnetic fraction of the shower. In order to perform such a measurement we selected only those events in which pions start showering in the crystal section. For showers developing late in the BGO matrix, one could expect some correlation between the e.m. fractions measured in the two sections. In fact, the C/S ratios in the two calorimeters shows a good correlation (Fig. **??**).

In both sections, the resolution depends on the single resolutions on C and S, respectively, and on the correlation between these two quantities. The poor energy resolution resulting from both

the Cherenkov and scintillation contributions in the BGO matrix, as described above, makes the correlation in the ECAL section as low as 0.45. In DREAM the correlation was measured to be 0.8 0.9, despite the presence of lateral leakage.
The total energy measured is obtained by summing the energy measurements of each section, after corrections for both em fractions and leakage. The distribution of the total energy has a symmetric and amost gaussian shape (Fig. 6), with respect to the total Cherenkov and Scintillation spectra respectively, that show the typical response of a non compensating calorimeter.

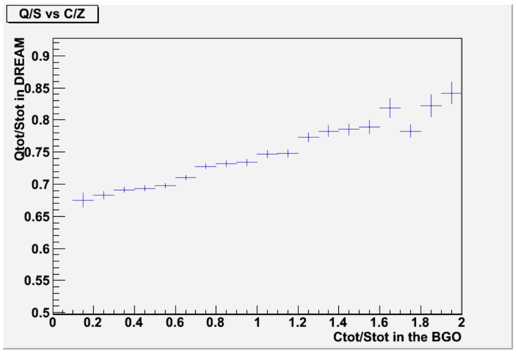

Figure 5. Correlation between the ratios of the scintillation and the Cherenkov signals in the two calorimeters

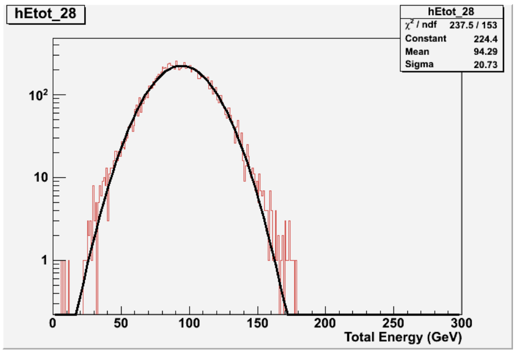

Figure 6. Total energy distribution obtained using both BGO and fiber detectors, corrected for both leakage and em fraction.

5. Conclusions

Dual readout calorimetry has been successful in measuring event by event the electromagnetic fraction of an hadronic shower. The knowledge of f allows to correct the response of a non compensating calorimeter. To realize a calorimeter with very good both em and hadronic resolution one could use an homogeneous em section. Scintillating crystals produce Cherenkov light in addition to scintillation. Therefore one can apply the dual readout technique also to this kind of detector. For the first time a complete dual readout calorimeter, with a BGO e.m. section, was built and tested. Although the non-perfect readout system adopted (only 4 PMTs with filters) the Dual Readout principle worked quite well. A clear correlation between the e.m. fraction measured in the two sections was found and the energy measured by the complete system showed a gaussian shape and didn't show the tail typical of a non-compensating calorimeter system. A better readout for the BGO matrix is being presently used for test beam at cern.

References

[1] N. Akchurin et al, NIM A537 (2005) 537-561
[2] N. Akchurin et al, NIM A610 (2009) 488-501
[3] N. Akchurin et al, NIM A595 (2008) 359-374