A BGO Electromagnetic Section for a Dual Readout Calorimeter

Davide Pinci on behalf of the DREAM collaboration

***Abstract*—A calorimeter made by a homogeneous electromagnetic section consisting of 100 BGO crystals and by a sampling hadronic section made of copper and optical fibers was tested with pion and electron beams. The presence of UV filters and the waveform analysis in the crystal section and the use of scintillating and undoped fibers in the hadronic part make possible to apply the dual readout method to the whole detector.**

The estimation of the electromagnetic fraction of hadronic showers developing in the whole system allows to correct the energy measurements for its electromagnetic fraction fluctuations upgrading the energy resolution. The performance obtained by the BGO section are reported in this paper.

***Index Terms*—Dual Readout Calorimetry, Scintillating Crystals.**

I. Introduction

In last years the calorimetry based on the dual readout method has achieved several interesting results [1]. The application of the method allows, event by event, the evaluation of the electromagnetic fraction of an hadronic shower resulting in a more accurate measurement of the single hadron and jet energy. The first calorimeter of this kind (Dual-Readout Module-DREAM, [2], [3]) was based on a copper absorber structure, equipped with two types of active media:

1 scintillating fibers for measuring the total energy deposited by the shower particles;
2 undoped optical fibers to collect the Cherenkov light generated by the charged, relativistic shower particles;

Moreover, it has been demonstrated that it is possible to separate the scintillation and the Cherenkov components of the signal produced by a scintillating crystal by studying the signal waveforms [4], [5]. Main consequence of this is the possibility of constructing a whole calorimeter with a homogeneous electromagnetic section and a sampling hadronic one, both with a double readout. This will give the possibility of upgrading the energy resolution also for those hadronic showers which develop in the whole system [6]. A complete dually readout calorimeter was set-up as it is shown in Fig. 1:

1 An electromagnetic section composed by 100 BGO crystals readout by 16 PMTs;
2 Each PMT was equipped with a UG11 filter to enhance the Cherenkov component with respect to the scintillation one;
3 The waveforms of the PMT signals were acquired by a 16 channels digitizer (DRS [7]) operated with 2.5 Gs/s in order to perform a suitable off-line analysis;
4 During the acquisitions with the pion beam, a brick of plexi-glass was placed in front of the matrix and used as an interaction target (IT) to produce particle-jets;
5 Downstream of the IT, a scintillator readout by a PMT was used to evaluate the multiplicity of the pseudo-jet;
6 The DREAM detector was sitting downstream of the matrix and it was used as the hadronic section of the detector;

In this paper the results obtained in tests performed with electron and pion beams at CERN are presented.

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II. The analysis of the waveforms

The use of a digitizer made possible to acquired the waveforms of all the signals produced by the 16 PMTs. In Fig. 2 an example of several superimposed signals is shown, while Fig. 3 presents the average waveform.

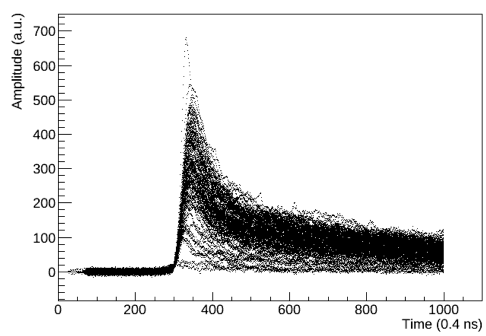

Fig. 2. Several acquired waveforms superimposed.

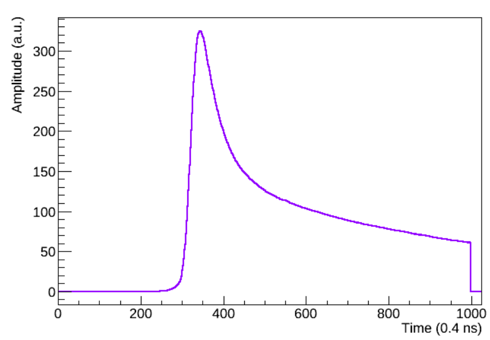

Fig. 3. Example of an average waveform.

It is clearly possible to see the two components of the signal:

1 Up to the bin 450 the fast peak due to the Cherenkov superimposed to the scintillation;

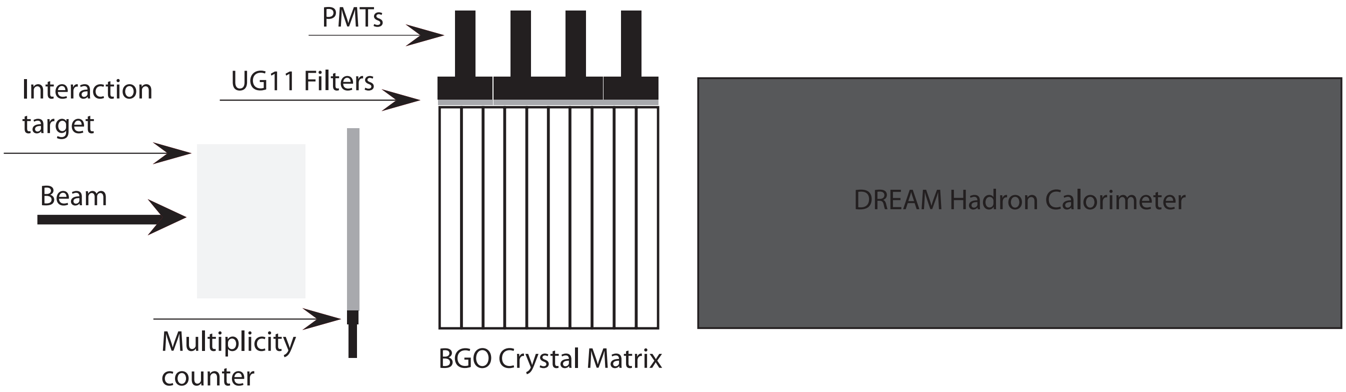

Fig. 1. System setup (not to scale).

2 From bin 450 the tail only due to the scintillation;

In order to evalute the amount of the scintillation light (S) and the Cherenokov one (C), the waveforms were numerically integrated in two gates: A (from bin 250 to bin 450) and B (from bin 450 to bin 1000). The charge integrated in B (Q_B) is used to evaluate the whole amount of scintillation light and also its contamination present in Q_A that resulted to be the 36% of Q_B. So that, it resulted:

$$S = 1.36 \times Q_B \quad (1)$$

$$C = Q_A - 0.36 \times Q_B \quad (2)$$

$$Q = C + S = Q_A + Q_B \quad (3)$$

III. Results with electrons

A. Energy resolution

A first set of measurements was performed with electron beams to study the reponse of the BGO matrix to the electromagnetic showers. The spectra obtained with 100 GeV electrons for Q, S and C are shown in Fig. 4, Fig. 5 and Fig. 6 respectively, with a superimposed gaussian fit.

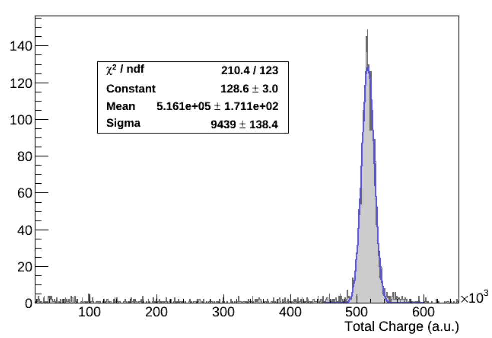

Fig. 4. Spectrum of the charge due to the whole light produced in the BGO matrix for 100 GeV electrons.

A relative resolution of 1.82 % was found with the total charge, that becomes 2.11 % for the only scintillation and 4.96 % for the Cherenkov.

The bahaviors of the releative energy resolution as a function of the beam energy are shown in Fig. 7.

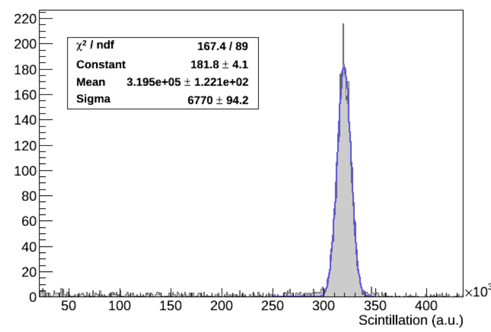

Fig. 5. Spectrum of the charge due to the scintillation light in the BGO matrix for 100 GeV electrons.

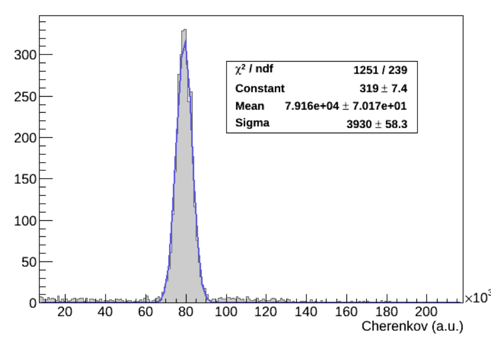

Fig. 6. Spectrum of the charge due to the Cherenkov light in the BGO matrix for 100 GeV electrons.

A linear fit was performed to the three sets of points. It resulted:

$$\frac{\sigma_C}{C} = \frac{36\%}{\sqrt{E[\mathrm{GeV}]}} + 1.49\% \quad (4)$$

$$\frac{\sigma_S}{S} = \frac{19\%}{\sqrt{E[\mathrm{GeV}]}} + 0.10\% \quad (5)$$

$$\frac{\sigma_Q}{Q} = \frac{16\%}{\sqrt{E[\mathrm{GeV}]}} + 0.16\% \quad (6)$$

$$(7)$$

The linearity of the responses was studied in the whole energy

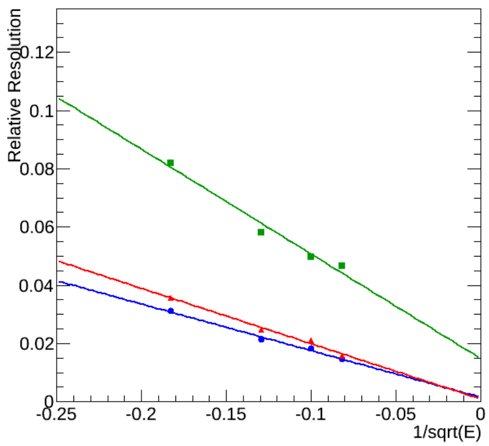

Fig. 7. Energy resolution as a function of the beam energy for the three different signals.

range. In Fig. 8 their behavior are shown as a function of the beam energy. In order to put all the three signals in the same plot, the Cherenkov values were multiplied by a factor 5. It resulted that there was about a factor 4 between

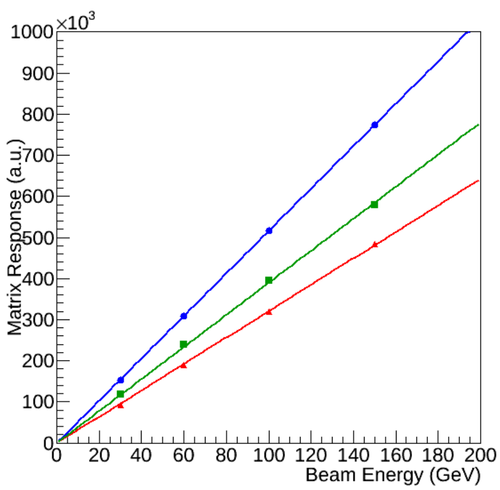

Fig. 8. Detector response as a function of the beam energy for the three different signals.

the Cherenkov and the scintillation components as resulted also in previous measurements [8]. The relative differences of the experimental measurements from the perfect linearity are shown in Fig. 9. All the points are whithin an interval of $\pm 3\%$ from the optimum behavior.

B. The C/S ratio

Along with the energy measurement, an important parameter required to a dual readout calorimeter, is the good evaluation of the electromagnetic fraction (f_{em}) of the shower. Since:

$$C/S = \frac{(1-[h/e]_c)f_{em}+c}{(1-[h/e]_s)f_{em}+s} \qquad (8)$$

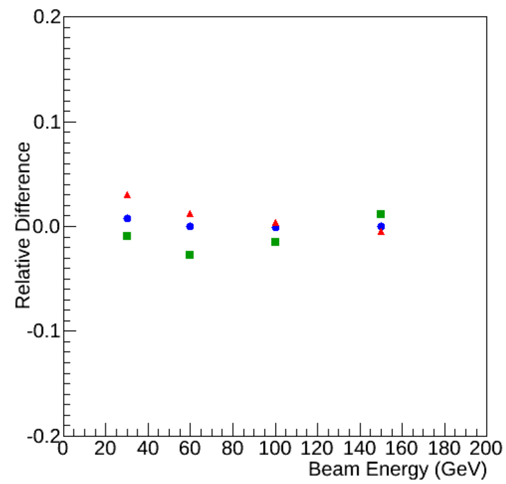

Fig. 9. Relative difference from the perfect linearity as a function of the beam energy for the three different signals.

the electromagnetic fraction can be expressed as:

$$f_{em} = \frac{[h/e]_c - [h/e]_s(C/S)}{(C/S)(1-[h/e]_s)-(1-[h/e]_c)}. \qquad (9)$$

It depends only on the ratio between the Cherenkov and the scintillation responses (C/S). For the electrons, the value of f_{em} is constant and so it is expected to be C/S. The spectrum obtained for 100 GeV electrons is shown in Fig. 10. A resolution of 5.92% was obtained. Fig. 11 shows the ratio

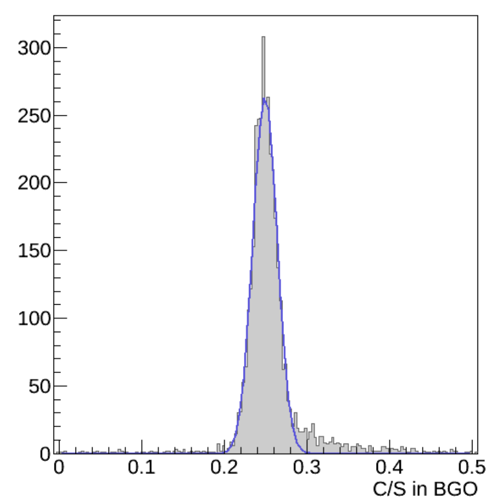

Fig. 10. Spectrum of the ratio C/S for 100 GeV electrons.

C/S as a function of the the beam energy. Its values and the resolutions obtained with Gaussian fits for different beam energies are quite stable.

Given the readout structure in Fig. 1, it is clear that the Cherenkov photons, produced in a cone of 27^o around the trajectories of the particles whithin the showers reach more easily the PMTs as long as the these particles are produced

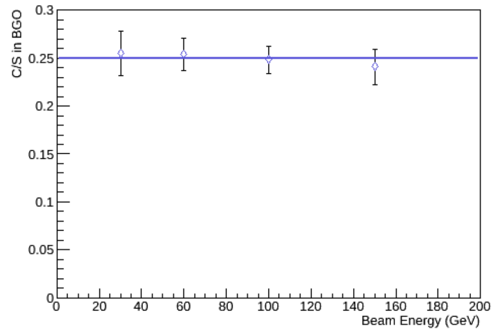

Fig. 11. Mean values of the ratio C/S obtained for different electron beam energies.

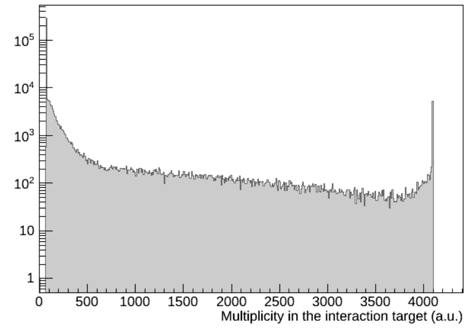

Fig. 13. Distribution of the energy released in the slim scintillator downstream of the interaction target. For the pseudo-jets analysis the events with a multiplicity larger than 700 a.u. were used.

isotropically. This effect is visible in Fig. 12, where the ratio C/S is shown for the different four rows of PMTs.

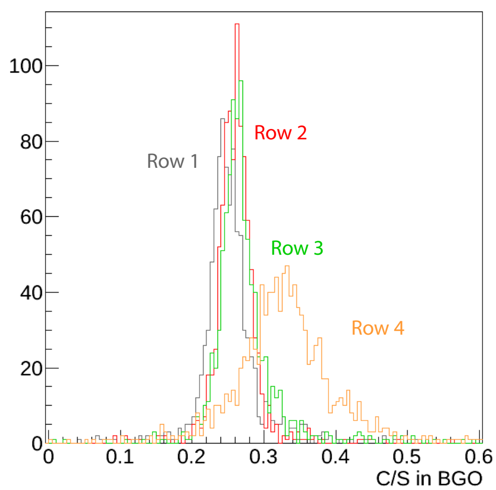

Fig. 12. Spectra of the ratio C/S for in the different rows of the BGO matrix. The incresing anisotropy of the electrons in the shower makes C increse more than S.

The mean values of C/S increase with the shower depth and, in particular, is very high for the PMTs in the last row of the calorimeter.

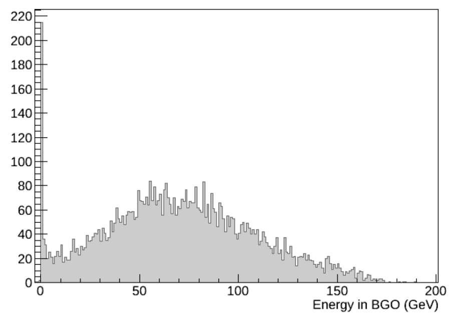

Fig. 14. Distribution of the energy released in the BGO matrix by the pseudo-jets. Almost 30% of them release more than half of their total energy (180 GeV) in the BGO matrix.

IV. Results with pseudo-jets

By making a 180 GeV pion beam passing through a plexiglass target it is possible to generate a jet of particles that simulates the jet created by the adronization of naked quark produced in the high energy beam collisions. The multiplicity of these "pseudo-jets" was measured by loooking at the light released in a thin scintillator slab placed between the interaction target and the BGO matrix (Fig. 1). The spectrum of the charge readout is shown in Fig. 13. Pseudo-jets are defined as the events with a light release larger than 700 a.u.

The spectrum of energy released by the pseudo-jets in the BGO matrix is shown in Fig. 14. It is visible that in almost 30% of cases more than half of their total energy (180 GeV) is released within the elecromagnetic calorimeter. This effect explains the need for a dual readout electromagnetic calorimeter.

The effect of the large fluctuations of the e.m. fraction within the hadronic shower are visible in Fig. 15. For the pseudo-jets the spectrum of the ratio C/S shows a long and asymmetric tail and is quite larger than for electrons.

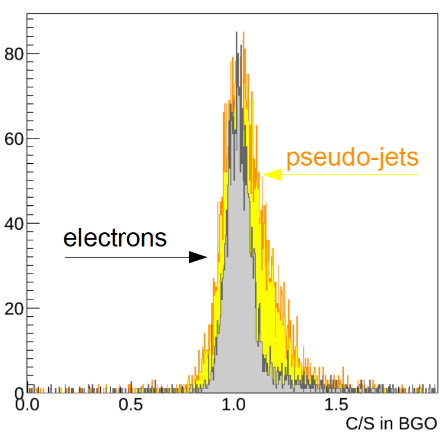

Fig. 15. Spectrum of the ratio C/S for the 100 GeV electrons superimposed to the spectrum of C/S for 180 GeV pseudo-jets.

V. Conclusion

As it is shown in this paper, hadrons and jets release a lot of their energy already within the electromagnetic calorimeter. Therefore the possibility of correcting for the fluctuations of the e.m. ratio in the electromanetic section is mandatory for a high precision hadron calorimetry.

BGO crystals, widely used for their high energy resolution, showed to have very interesting characteristics for evaluating the e.m. fraction of a hadronic shower by a simple pulse shape analysis.

A resolution of 1.8% was obtained on the total energy of 100 GeV electrons and of 5% on the ratio C/S.

The combined use of a BGO matrix and a dual readout hadron calorimeter seems very promising and it will be further investigated.

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