Nuclear Instruments and Methods in Physics Research A 617 (2010) 129–133

Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research A

journal homepage: www.elsevier.com/locate/nima

The DREAM project—Towards the ultimate in calorimetry

Richard Wigmans [1]

Department of Physics, Texas Tech University, Lubbock, TX 79409-1051, USA

ARTICLE INFO

Available online 8 October 2009

Keywords:
Calorimetry
Dual-readout
Linear collider

ABSTRACT

High-precision jet spectroscopy will be increasingly important in future high-energy accelerator experiments, particularly at a linear e^+e^- collider. The dual-readout technique makes it possible to meet and exceed the requirements on calorimeter performance in experiments at such a collider. The DREAM Collaboration is exploring the limits of the possibilities offered by this technique, by systematically eliminating the limiting factors, one after the other. Powerful tools in this context are the simultaneous measurement of scintillation light and Cherenkov light generated in the shower development process, and a detailed measurement of the time structure of the signals. In this talk, the latest results of this generic detector R&D project are presented. In particular, I report on the first tests of a hybrid dual-readout calorimeter system, in which a BGO crystal matrix served as the electromagnetic section.

1. Introduction

DREAM[2] started in 2002 as a generic detector R&D project, intended to explore (and, if possible, eliminate) the obstacles that prevent calorimetric detection of hadrons and jets with a comparable level of precision as we have grown accustomed to for electrons and photons. The initial collaboration, consisting of fewer than 10 physicists, built a prototype detector based on optical fibers, which was successfully tested at the SPS in 2003 and 2004. The excellent results obtained in these tests generated a lot of interest, and the collaboration has considerably expanded since that time.

In the early tests, we concentrated on the dominating source of fluctuations, i.e. fluctuations in the electromagnetic content of hadron showers. After these initial studies, in which the effects of these fluctuations on hadronic calorimeter performance were successfully eliminated, the collaboration has focused on the remaining effects, which rose to prominence as a result: sampling fluctuations, signal quantum statistics and nuclear breakup effects.

In this context, we have also carried out (in 2006–2008) a series of successful studies of crystal calorimeters, and of methods to split the signals from these crystals into scintillation and Cherenkov components. Recently, a full-size crystal matrix consisting of 100 BGO crystals served as the em section of a hybrid calorimeter system, in which the original fiber calorimeter formed the hadronic section. Some preliminary results from these tests are shown in this contribution.

We have now reached the point where we believe that we have all the ingredients in hand to build the perfect calorimeter system, or at least a calorimeter system that meets and exceeds the performance requirements of experiments at the ILC and CLIC. Proposals to build such a calorimeter have been submitted to our funding agencies. Some aspects of such a calorimeter are discussed in this contribution.

2. The DREAM approach to ultimate calorimetry

In almost all calorimeters, fluctuations in the electromagnetic shower fraction (f_{em}) dominate the energy resolution for hadrons and jets. These fluctuations, and their energy-dependent characteristics, are also responsible for other undesirable calorimeter characteristics, such as hadronic signal non-linearity and a non-Gaussian response function. There are two possible approaches to eliminate (the effects of) these fluctuations [1]: by designing the calorimeter such that the response to em and non-em energy deposit is the same (compensation, $e/h = 1.0$), or by measuring f_{em} event by event. The DREAM project follows the latter approach. Therefore, calorimeters built according to the DREAM principles are *not* subject to the limitations imposed by the requirements for compensating calorimetry: a small sampling fraction (and the corresponding large sampling fluctuations), and the need to integrate the signals over a very large detector volume (because of the crucial signal contributions of soft neutrons).

2.1. The unique benefits of Cherenkov light

Detecting Cherenkov light generated in shower development is a crucial ingredient of DREAM calorimeters. Since Cherenkov light

E-mail address: wigmans@ttu.edu
[1] On behalf of the DREAM Collaboration
[2] The name DREAM stands for Dual-REAdout Method.

0168-9002/$ - see front matter © 2009 Elsevier B.V. All rights reserved.
doi:10.1016/j.nima.2009.09.118

is in practice almost exclusively generated by the em shower component, a comparison between the Cherenkov signals and those from a medium based on dE/dx measurements (e.g. scintillator) generated by the *same shower* makes it possible to measure f_{em} for that shower.

The DREAM principle is illustrated in Fig. 1. The two types of signals generated by 100 GeV π^- are shown in a scatter plot, in which each event is represented by a dot. The fact that these dots do *not* cluster around the diagonal demonstrates that the two signals provide complementary information about the shower development. The two signals, Q and S, depend on the energy of the showering particle (E), on the em shower fraction (f_{em}) and on the (energy-independent) e/h value, which suppresses the response to the non-em shower component (Eqs. (1) and (2)). The dual-readout method works because the two e/h values, $(e/h)_S$ and $(e/h)_Q$, are very different: in our fiber calorimeter they were measured to be 1.3 for the copper/scintillator structure and 4.7 for the copper/Cherenkov fiber structure, respectively. Eqs. (1) and (2) thus can be solved for either of the two unknown quantities, f_{em} or E. If we divide 1 by 2, the shower energy is eliminated and the resulting Eq. (3) gives a simple, *energy-independent* relationship between the ratio of the two measured signals and the em shower fraction. A measurement of this ratio thus provides directly the value of f_{em} for each individual event.

One can also solve Eqs. (1) and (2) for the shower energy E. This results in Eq. (4), which provides a simple recipe to determine that energy for each individual event on the basis of the two measured signals and one constant (χ) characteristic for the calorimeter system.

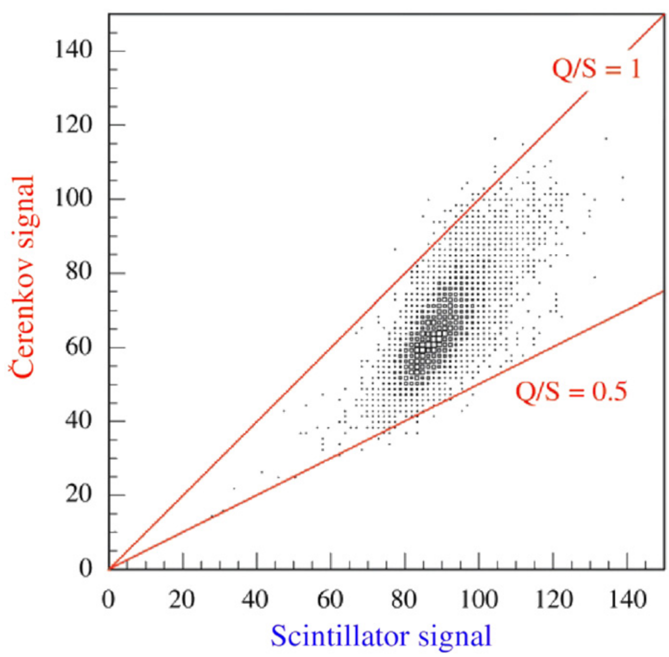
The DREAM fiber calorimeter, as well as many results obtained in beam tests of this device, have been described in detail in a number of papers [2]. The recipe described above turned out to work very well indeed. Among the results obtained by applying Eqs. (3) and (4), we mention:

- When the calorimeter was calibrated with electrons, hadronic energies determined with this recipe were within a few percent equal to their nominal values.
- Hadronic signal linearity was restored.
- Hadronic response functions became Gaussian.
- Hadronic energy resolutions improved considerably, especially at the highest energies.
- Deviations from $E^{-1/2}$ scaling in the hadronic energy resolution were eliminated.

All these results were not only observed for single hadrons, but also for multiparticle "jets", which were mimicked by means of high-multiplicity interactions in an upstream target.

2.2. Further improvements

The elimination of (the effects of) this dominant source of fluctuations meant that other types of fluctuations now dominated the detector performance. Further improvements should be obtained by concentrating on these. Three types of fluctuations dominated and limited the energy resolution of the DREAM fiber calorimeter:



$$Q = E\left[f_{em} + \frac{1}{(e/h)_Q}(1 - f_{em})\right] \qquad (1)$$

$$S = E\left[f_{em} + \frac{1}{(e/h)_S}(1 - f_{em})\right] \qquad (2)$$

e.g. If $e/h = 1.3$ (S), 4.7 (Q)

$$\boxed{\frac{Q}{S} = \frac{f_{em} + 0.21\,(1 - f_{em})}{f_{em} + 0.77\,(1 - f_{em})}} \qquad (3)$$

$$\boxed{E = \frac{S - \chi Q}{1 - \chi}} \qquad (4)$$

with $\chi = \dfrac{1 - (h/e)_S}{1 - (h/e)_Q} \sim 0.3$

Fig. 1. Scatter plot of the Cherenkov signals for 100 GeV π^- mesons versus those generated by the scintillating fibers in the DREAM calorimeter. Each event is represented by a dot. Also shown are the equations that form the basis of the dual-readout method. The use of the symbol Q for the Cherenkov signals derives from the fact that these signals were generated by quartz fibers in the original DREAM calorimeter.

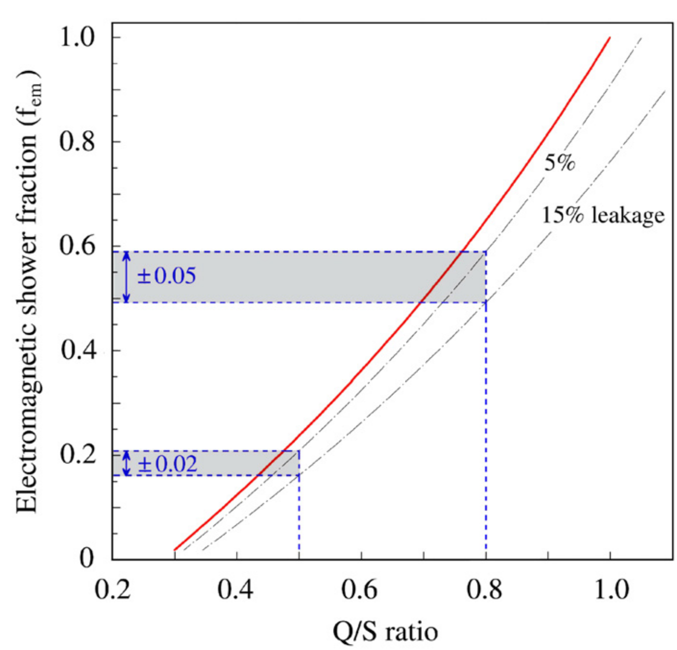


Fig. 2. The relationship between the Q/S signal ratio and the em shower fraction, f_{em} (Eq. (3)). Also shown is how a shower leakage of $10 \pm 5\%$ translates into an uncertainty in the em shower fraction.