Available online at www.sciencedirect.com
ScienceDirect
Nuclear Instruments and Methods in Physics Research A 572 (2007) 215–217
NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A
www.elsevier.com/locate/nima

The DREAM Project—Results and plans

Richard Wigmans*

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

Available online 17 November 2006

Abstract

High-precision jet spectroscopy will be increasingly important in future high-energy accelerator experiments, particularly at a Linear e^+e^- Collider. DREAM, a novel type of calorimeter, appears to be well suited for this task. The key aspect of this detector is the simultaneous measurement of the scintillation light and the Cherenkov light generated in the shower development process. By comparing these two signals (which are provided by different types of optical fibers), the electromagnetic shower fraction can be measured event by event, both for single hadrons and for jets, and the effects of fluctuations in this fraction can be eliminated. As a result, the DREAM calorimeter has impressive performance characteristics. The application of the DREAM principles in homogeneous calorimeters, which has the potential of providing ultimate calorimeter performance, is also discussed.

PACS: 29.40.Ka; 29.40.Mc; 29.40.Vj

Keywords: Calorimetry; Dual-Readout; Linear collider

The energy resolution of calorimeters is determined by fluctuations. If one wants to improve that resolution significantly, then one has to address the dominating source of these fluctuations. In almost all calorimeters (i.e. the ones with $e/h \neq 1.0$), 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, in particular 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 project discussed here follows the latter approach.

Calorimeters based on Cherenkov light as the signal source are, for all practical purposes, only responding to the em fraction of hadronic showers [2]. This is because the electrons/positrons through which the energy is deposited in the em shower component are relativistic down to energies of only 200 keV. On the other hand, most of the non-em energy in hadron showers is deposited by non-relativistic protons generated in nuclear reactions [1]. However, in other types of active media (scintillator, LAr), such protons do generate signals. The detector that is the topic of this presentation uses two active media, hence the name DREAM (Dual REAdout Module): scintillating fibers measure $\mathrm{d}E/\mathrm{d}x$, while clear fibers measure the Cherenkov light generated in the shower development. By comparing the two signals, f_{em} can be measured event by event, and the total shower energy can be reconstructed using the known e/h value(s) of the calorimeter.

The DREAM calorimeter, as well as many results obtained in beam tests of this device, have been described in detail in a number of papers [3]. In the following, we only illustrate that this principle works very well. Fig. 1 shows the Cherenkov signal distribution for 100 GeV π^- showers (top diagram), as well as the signal distributions for event samples selected for 3 bins of the em shower fraction (bottom diagram). The larger the value of f_{em}, the larger the calorimeter signal. The overall signal distribution (top) is evidently a superposition of many narrow distributions such as the ones in the bottom diagram. By using the measured value of f_{em}, the total signal distribution can be

*Tel.: +1 806 742 3779; fax: +1 806 742 1182.
E-mail address: wigmans@ttu.edu.

0168-9002/$ - see front matter
doi:10.1016/j.nima.2006.10.211

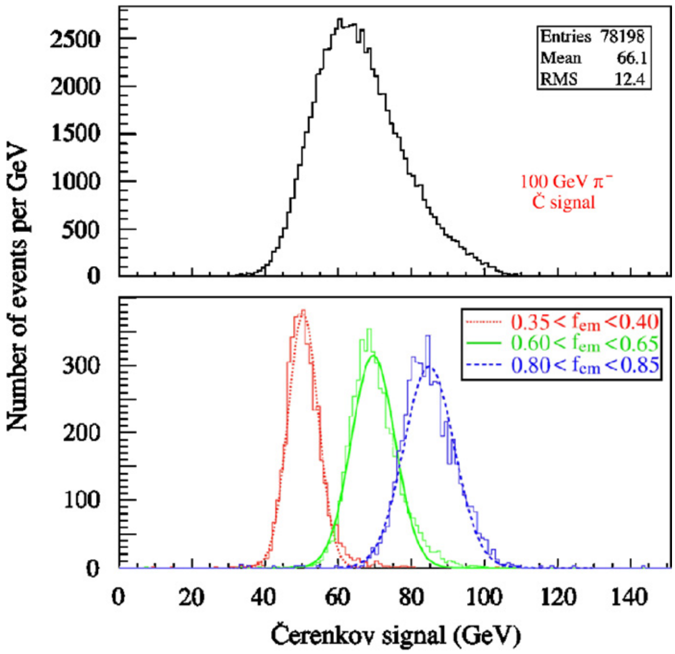

Fig. 1. Cherenkov signal distributions for 100 GeV π^-. Shown are all events (top) and samples selected on the basis of their electromagnetic shower content (bottom).

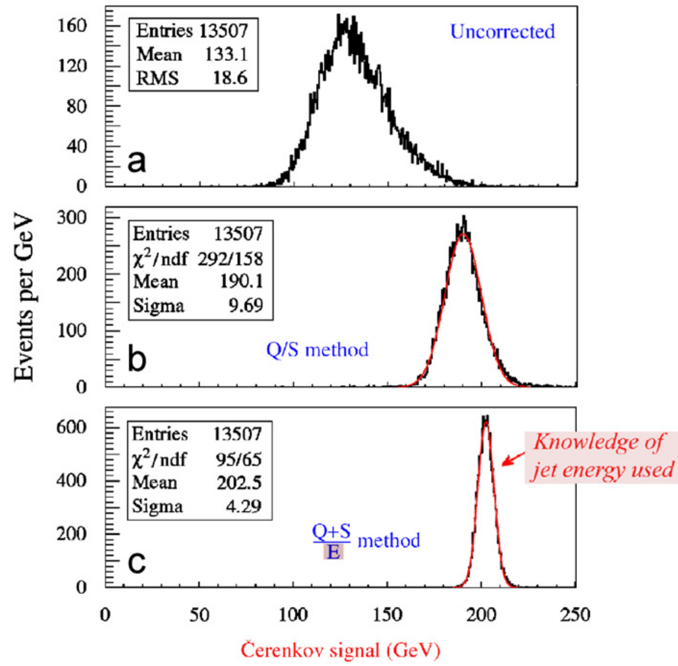

Fig. 2. Cherenkov signal distributions for 200 GeV multi-particle events. Shown are the raw data (a), and the signal distributions obtained after application of the corrections based on the measured em shower content, with (c) or without (b) using knowledge about the total "jet" energy.

transformed into a narrow one, with the correct central value, i.e. the signal one would find for pure em showers of the nominal energy. This is illustrated in Fig. 2, which concerns the signal distributions from 200 GeV multi-particle events (reaction products from an upstream target, intended to mimick jets). The raw Cherenkov signal distribution (a) shows the usual characteristics: asymmetric, broad and a central value that is much too small (133 GeV). After applying the correction method based on event-by-event measurements of f_{em}, this distribution is transformed into the one shown in Fig. 2b, which is almost perfectly symmetric, much more narrow, and centered around approximately the correct energy value (190 GeV). It should be emphasized that the value of f_{em} was uniquely determined on the basis of the *ratio* of the two measured signals (the so-called Q/S method[1]), no other information was used. Because of the relatively small detector size (1200 kg), this result is dominated by fluctuations in (lateral) leakage. We have demonstrated that, by using knowledge of the total shower energy, this effect could be eliminated and the signal distribution improved to the one shown in Fig. 2c.

The beam tests of the DREAM detector have shown that, simply by using the ratio of the Cherenkov and scintillation signals, all detrimental effects of fluctuations in the em shower fraction could be eliminated: hadronic signal linearity was restored, deviations from $E^{-1/2}$ scaling in the hadronic energy resolution were eliminated, a Gaussian response function was obtained and, most importantly, the hadronic energy scale was the same as the electromagnetic one, so that the entire instrument could be calibrated with electrons [3].

The elimination of (the effects of) this dominant source of fluctuations means that other types of fluctuations now dominate the detector performance. Further improvements may be obtained by concentrating on these. Three types of fluctuations now limit the energy resolution of the DREAM calorimeter:

- Leakage fluctuations.
- Fluctuations in Cherenkov light yield.
- Sampling fluctuations.

The first source can be eliminated by making the detector sufficiently large. The tested instrument had an effective radius of only $0.8\lambda_{int}$. Side leakage amounted, on average, to about 10% of the shower energy, and fluctuations in this fraction played a dominant role (Fig. 2). The small Cherenkov light yield (eight photoelectrons per GeV) contributed more than $35\%/\sqrt{E}$ to the measured hadronic energy resolution.

There is absolutely no reason why the DREAM principles should be limited to fiber calorimeters. In particular, they could be applied to *homogeneous* detectors, provided that a way is found to distinguish the Cherenkov and scintillation light produced by such a detector. To that end, we have started a series of studies with crystals, and in particular $PbWO_4$. This material has the advantage of producing very little scintillation light, while the high

[1]The symbol Q refers to the quartz fibers that measured the Cherenkov light.

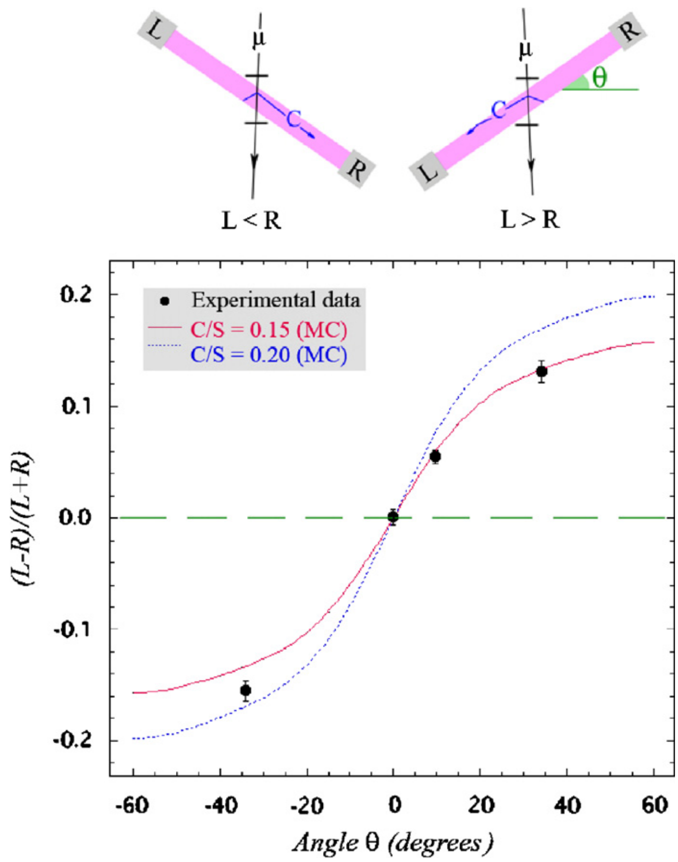

Fig. 3. Left–right asymmetry measured for cosmic rays traversing a $PbWO_4$ crystal, as a function of the orientation of this crystal. The curves represent the results of calculations for a fixed ratio of the numbers of Cherenkov and scintillation photons produced in this process.

effective Z value promises a substantial Cherenkov light yield. We have measured the ratios of the two types of signals for cosmic rays, which traversed a crystal that was read out from both ends. By changing the orientation of the crystal, the acceptance for (directional) Cherenkov light was varied, and by measuring the left/right asymmetry of the total signal as a function of the angle θ, we were able to establish that 15–20% of the photons were actually generated by the Cherenkov mechanism (Fig. 3). This result was corroborated by measuring the time structure of the signals. The signals from the PMT that "saw" the Cherenkov component exhibited a clear fast component that was absent in the signals from the other PMT which, because of the crystal orientation, only detected scintillation light (Fig. 4).

In conclusion, we have established that the dual-readout approach combines the advantages of compensating calorimetry with a reasonable amount of design flexibility. Since there is no limitation on the sampling fraction, the dominating factors that limited the energy resolution of compensating calorimeters (SPACAL, ZEUS) to $\sim 30\%/\sqrt{E}$ can be eliminated, and the theoretical resolution limit of $\sim 15\%/\sqrt{E}$ seems to be within reach. Dual-readout detectors thus hold the promise of high-quality calorimetry for *all* types of particles, with an instrument that can be calibrated with electrons.

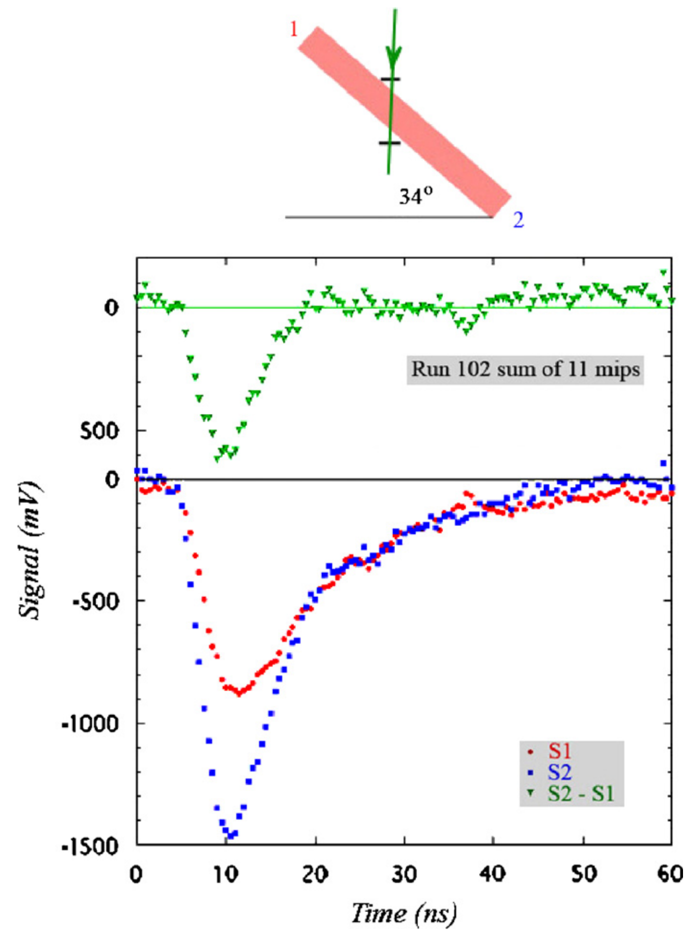

Fig. 4. Time structure of cosmic ray events. Shown are the pulse shapes for the signals measured in the 2 PMTs reading out the $PbWO_4$ crystal, as well as the difference between these two pulse shapes. The pulses represent the sum of 11 randomly chosen events that generated signals in the most probable region of the Landau distribution. The crystal is oriented as shown.

References

[1] R. Wigmans, Calorimetry, Energy Measurement in Particle Physics, International Series of Monographs on Physics, vol. 107, Oxford University Press, Oxford, 2000.
[2] N. Akchurin, et al., Nucl. Instr. and Meth. A 399 (1997) 202.
[3] N. Akchurin, et al., Nucl. Instr. and Meth. A 533 (2004) 305; N. Akchurin, et al., Nucl. Instr. and Meth. A 536 (2005) 29; N. Akchurin, et al., Nucl. Instr. and Meth. A 537 (2005) 537; N. Akchurin, et al., Nucl. Instr. and Meth. A 548 (2005) 336; N. Akchurin, et al., Nucl. Instr. and Meth. A 550 (2005) 185.