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A MODULAR CALORIMETER SYSTEM FOR USE IN HIGH ENERGY PHYSICS

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ABSTRACT

We have designed and built a modular hadron calorimeter for the study of high energy particle interactions which produce particles of high transverse momentum. The energy resolution of this system, and the triggering method for selecting the interactions of interest are described.

INTRODUCTION

Calorimeters, including our own device, have gone through many stages of development since their introduction. The development of our particular calorimeter was dictated by the physics in which we were interested, namely "high p_T-jets"[1,2] We needed a calorimeter with the following attributes:

1. Good energy resolution in the 10 to 30 GeV region;
2. Segmented character;
3. The ability to distinguish between hadronic and electro-magnetic showers;
4. Large angular coverage in the center of mass.

Our early development work gave information useful in designing such a system, while at the same time showing difficulties to which we had to find solutions.[3,4]

This paper describes the design and performance of the two-arm segmented calorimeter which we finally built. The major advantages of this design are:

1. High efficiency in the rejection of spurious events;
2. Distinction between hadronic and electro-magnetic showers;
3. Good spatial resolution for multiparticle groups;
4. Uniformity of response;
5. Ease of calibration;
6. Design flexibility;
7. Good energy resolution.

EXPERIMENTAL LAYOUT

The calorimeter used by our experiment (E395) at Fermilab consists of two independent arms, as shown in Figure 1.[2,5] The "right" arm covers approximately 1.5 sr. in the c.m. at 200 GeV/c for both hadrons and π^0's. The "left" arm covers approximately 1.5 sr. in the c.m. for π^0's about 1 sr. in the c.m. for hadrons. (The π^0 detector in the left arm was of a different design which will not be discussed here.)

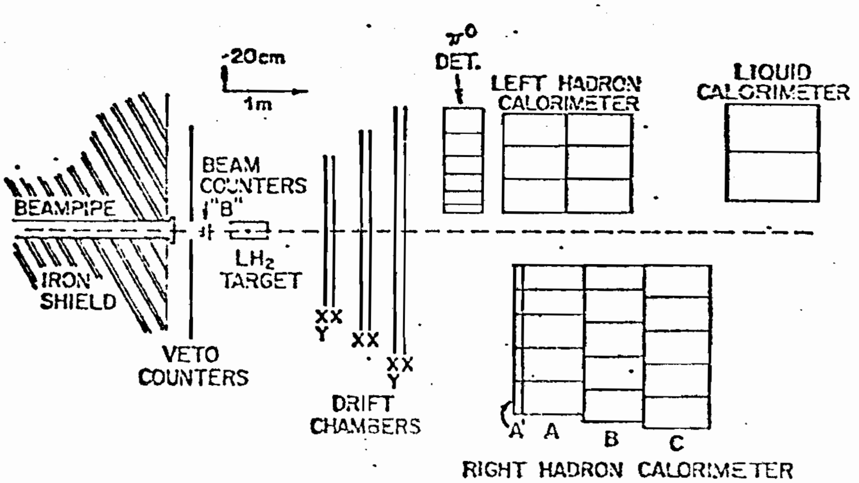

Figure 1
Experimental Apparatus for Fermilab Experiment 395

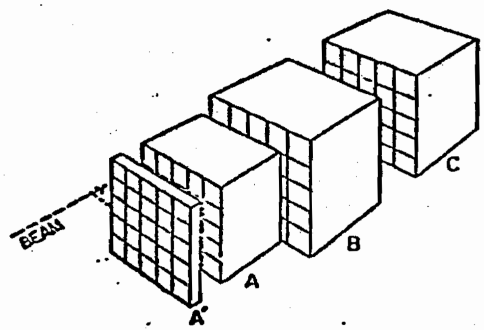

Figure 2
Beam View of the Right Arm of the Calorimeter

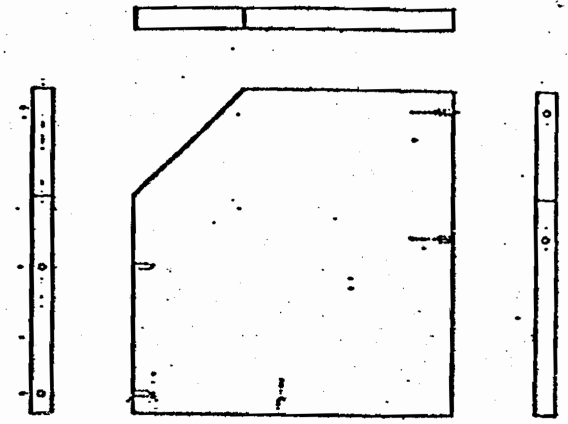

Figure 3
A 20 cm x 20 cm Fe Plate

The "right" arm is made up of 105 modules, arranged into 25 longitudinal segments which form an array 5 segments high and 5 wide. Each segment has four layers of modules, except for the column closest to the beam, which has 5. Each module is of sampling or sandwich construction, with alternating layers of metal and scintillator. A beam's eye view of the right arm is shown schematically in Figure 2.

Each longitudinal segment contains two different types of modules: A lead-scintillator sandwich 5 radiation lengths thick (A´) as shown in Figure 2, and an iron-scintillator sandwich approximately 2 absorption lengths thick (A,B,C, and sometimes D). The segments are roughly aimed at the target and grow in area as the distance from the target increases. The sizes of the modules are determined by the transverse development of the showers.[4] Further details on the scintillator and the florescent wave-shifter light collection system can be found in elsewhere.[6,7]

The energy calibration utilized three techniques: Uniform pulse height response from, 1) minimum ionizing particles (muons), 2) mono-energetic electrons, and 3) mono-energetic hadrons (pions and protons). Each module was balanced by these techniques to give uniform response to ±4% over the entire apparatus. The performance of individual modules and of the complete apparatus was constantly monitored throughout the duration of the experiment using LED's mounted on each module.

MODULE DESIGN AND CONSTRUCTION

The calorimeter array is assembled from modules of three different designs, which differ in, 1) number of gaps or sampling stations, 2) thickness of metal, and 3) material in the metal plates. All modules use 12mm thick acrylic scintillator.[8] In addition, modules of all designs are made in two different sizes: 15 and 20 cm square.

The first layer of the calorimeter array is assembled using modules of a lead-scintillator sandwich construction, designated as A´ modules. The purpose of these modules is to distinguish between hadronic and electro-magnetic showers. Since the radiation length of lead is much shorter than its absorption length, an electro-magnetic shower will develop in lead much more rapidly than will a hadronic shower. Thus, the A´ modules have only 3 gaps, while the iron-scintillator sandwich modules have either 16 or 20 gaps. The basic differences between the module types are shown in Table I. (L_{abs} is the length in absorption lengths, L_{rad} in radiation lengths.)

The iron-scintillator sandwich module is the heart of the calorimeter array. The 16-gap modules are used in the two column closest to the beam, while the three outer columns use the 20-gap modules. The 20-gap modules have steel plates that are thinner than the 16-gap modules (12.7mm compared to 19.0mm). These 20-gap modules were located at the larger laboratory angles where the

Table I

Design	Plate Material	Plate Thickness (mm)	Number of Plates	L_{abs}/L_{rad}
I	Fe	19.0	16	2.15/18.2
II	Fe	12.7	20	1.94/15.5
III	Pb	9.5	3	.24/ 5.3

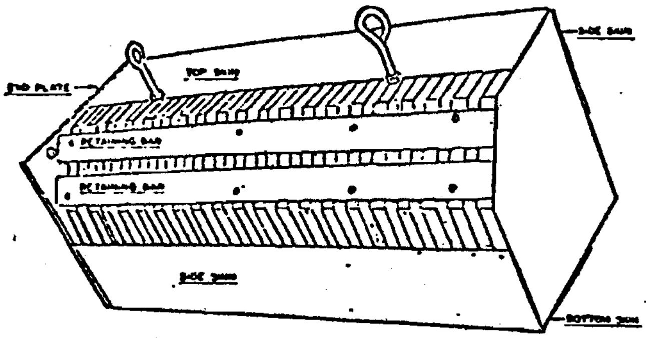

Figure 4
Partially Assembled Module

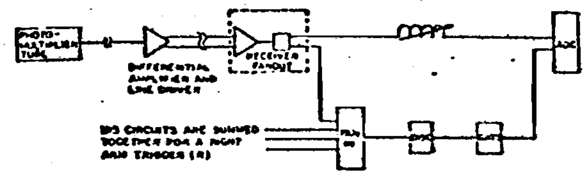

Figure 5
Basic Trigger Electronics

laboratory energy of the particles of interest is typically 5-10 GeV. For such low energy particles, the sampling frequency must be increased to provide good energy resolution.

Each module is constructed of either 12.7mm or 19mm zinc-plated steel plates, either 15 cm or 20 cm square. Each plate has 6 dowel pins, 2 each on the two "side" edges of the plate, and two on the bottom edge. The module is assembled by aligning thin covers over the dowel pins and then tightening screws in tapped holes. This technique causes each cold-rolled steel plate to be parallel to the design direction to within approximately 0.2mm. Figure 3 shows a 20 cm x 20 cm plate with dowel pin positions. Note that the corner of the plate is truncated to provide space to bring light pipes out to a photomultiplier tube. The top of the module is left open for the insertion of the reflectors, scintillators, light collecting bars, and light pipes. A top cover is attached after the module is completely assembled. The scintillator triangles are held in place by a retainer bar, while the light pipes are held by plastic straps. Figure 4 shows a module without the light pipes or scintillator.

Once assembled, the module may be rotated 90 degrees about the longitudinal axis in either direction. Modules can also be close-stacked, horizontally and vertically. The front face of the first plate and the rear face of the last plate have tapped holes so that modules may be strapped together for greater stability.

METHOD OF EVENT SELECTION

The modular design of our calorimeter system allows us to select many different types of interesting events. These events may be selected according to polar angle, energy deposition, or transverse momentum (p_T). The various triggers are formed by requiring the weighted sum of the pulse heights in a selected group of modules to be greater than some adjustable threshold. The weighting used for the signal from each module is proportional to the sine of the module andle with respect to the beam in the lab ($p_T = p \sin \theta$). In forming the triggers, we add the p_T magnitudes and not the vector p_T's.

During our data acquisition for E395, we took data with four basic transverse momentum triggers: A right arm trigger (R), a left arm trigger (L), a summed trigger (L + R) and a single particle trigger (SP) for both the left and right arms. Data for all triggers were taken simultaneously to reduce the possibility of systematic errors. Figure 5 shows the basic electronics necessary to implement a given trigger.

PERFORMANCE AND RESULTS

We determined the response of the calorimeter to different particles and different energies by positioning the calorimeter in beams of various particles at 10, 20 and 50 GeV. By rotating the calorimeter we were able to simulate the trajectories of particles coming from the target when the calorimeter was in its actual data taking position.

Figures 6a and 6b show the pulse height distributions for 20 GeV/c hadrons and electrons. The two positions simulate particles coming from the target with laboratory angles of 150 mr and 200 mr respectively. At 150 mr the hadronic pulse height distribution ends at the peak of the electron pulse height distribution. At 200 mr the hadronic pulse height distribution is approximately the same as for 150 mr, but the electron pulse height distribution is depressed slightly, probably due to error in balancing the module outputs.[9]

The resolution (FWHM/PEAK) at 20 GeV/c if 43% for hadrons and 15% for electrons. This is equivalent to a standard deviation of 18% for hadrons and 6% for electrons.

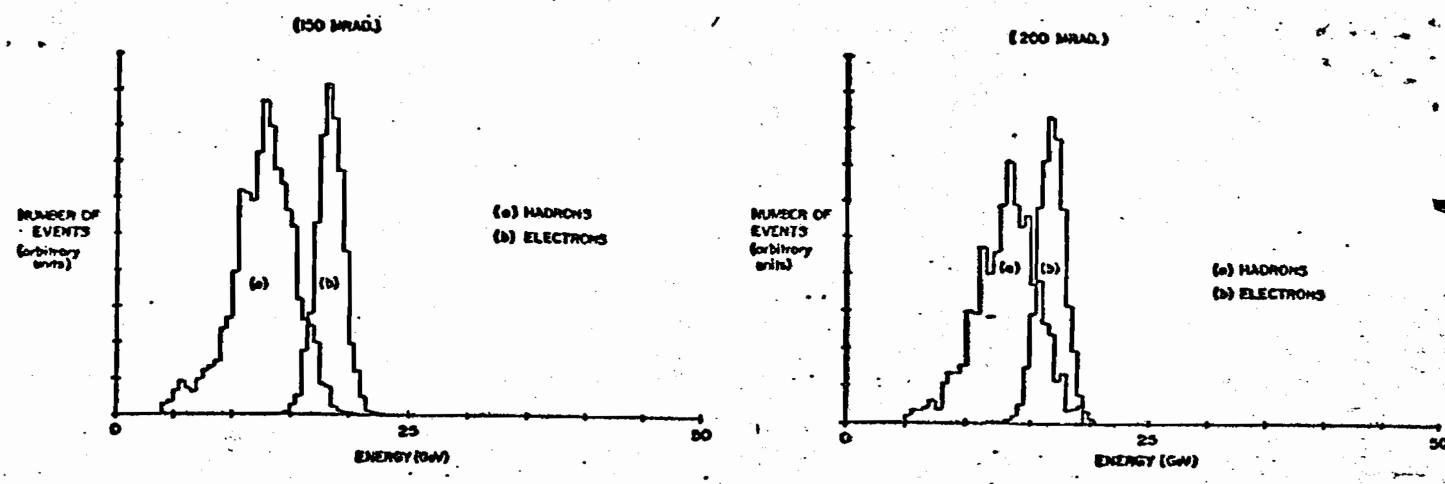

Figure 6
20 GeV/c Pulse Height Distributions at (a) 150 mr and (b) 200 mr

Our results typically show that the hadronic pulse height distribution ends near the peak of the pulse height distribution from electrons at the same energy and position. This is especially important for unfolding the calorimeter resolution from the steeply falling p_T distribution. If the hadronic pulse height distribution had an extended tail, i.e., if the hadronic pulse height distribution extended appreciably past the peak of the corresponding electron pulse height distribution, then unfolding the calorimeter resolution from a steep p_T distribution could become extremely difficult.[10,11] As an example of the magnitude of the resolution effect, the resolution shown in Figure 6, used with particles of about 4 GeV/c p_T, gives an apparent cross section at 400 GeV/c, which is 1.9 times the actual cross section.

We measured the p_T distribution for single particles and for multi-particle clusters. The results from the multi-particle case cannot be readily compared with results from other experiments since no other closely equivalent experiments have been carried out. However, results from our single particle measurements can be compared. We measured a single particle π^0 invariant cross section[5] for p_T up to about 4 GeV/c which compares well to that of the π^+, π^- data of D.Antreasyan et al[12] and with the π^0 data of Busser et al.[13] Our estimate of error due to calibration and systematic errors is about ±5% in the momentum scale.

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FOOTNOTES AND REFERENCES

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1 W.Selove et al., "A Study of High p_T Hadronic Interactions", Fermilab Proposal 246A, May 1977 (unpublished)

2 W.Selove et al., "Calorimeter-Array Study of High p_T Events", Fermilab Proposal 395, May 1975 (unpublished)

3 F.Turkot et al., "Performance of a Sampling Calorimeter at 3 to 17 GeV. A preliminary Report", University of Pennsylvania Internal Report, October 1973 (unpublished)

4 A.R.Erwin et al., "Some Early Results from a Segmented Calorimeter", Proceedings of the Calorimeter Workshop, (M.Atac, editor), Fermilab, May 1975.

5 L.Cormell et al., "Evidence for Jets and for Correlated Jets in High p_T Events", Fermilab Report No.77-89, October 1977 (unpublished)

6 W.Selove et al., "Fluorescent-Wave-Shifters and Scintillators for Calorimeters", University of Pennsylvania Report UPR-43E, July 1978, Nuclear Instruments and Methods (to be published).

7 Further details of the construction and testing of individual modules are described in a separate report, L.Cormell et al., in preparation.

8 Developed by W.Kienzle and associates at CERN in collaboration with Rohm GmbH Darmstadt, Federal Republic of Germany.

9 All modules were balanced with muons to ± 4%. The muon signal is averaged over the complete module, (16 or 20 gaps) while the electron signal comes dominantly from the first part of the A′ module. This fact could account for the shift in the peak position.

10 W.Selove, CERN Report NP 72-25, December 1972 (unpublished).

11 M.Dris, "Effect of Calorimeter Resolution on High-pT Particle Distributions", University of Pensylvania Report, UPR-0056E, September 1978 (unpublished)

12 D.Antreasyan et al., Physical Review Letters, 38, 112, January 1977.

13 F.W.Busser et al., Physics Letters, 46B, 471, October 1973