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New Ideas and Developments in Calorimetry

**Howard A. Gordon
Physics Department
Brookhaven National Laboratory
Upton, New York 11973**

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NEW IDEAS AND DEVELOPMENTS IN CALORIMETRY

Howard A. Gordon
Physics Department
Brookhaven National Laboratory
Upton, New York 11973

Abstract

The challenges for calorimeter performance in the next decade are reviewed. Some new ideas for calorimeters are described: (1) the test of a parallel plate calorimeter; (2) the use of vacuum photodiodes for calorimeters operating in a magnetic field; (3) the attempt to build high pressure gas sealed tubes as ion chambers in hadron calorimeters; (4) the progress in the attempt to mold plastic loaded with heavy metal for the inert material in gas calorimeters; (5) the use of the limited streamer mode in calorimeters.

Introduction - The Challenge

This is the decade of the high energy colliders: the pp variety at CERN and Fermilab, e^+e^- at LEP and pp at Brookhaven. Calorimeters will play a critical role in all the detectors for these machines. We consider here a specific physics problem that will make specific demands on the performance. We discuss the search for the η_T ,¹ the technicolor low lying state ~ 150 -250 GeV mass that will decay mainly into the heaviest fermions: presumably $t\bar{t}$ quarks. This search can be done solely with calorimeters, however, several details will have to be optimized: the energy resolution, the separation of leptons from the hadron jets, the calibration and the rate capability.

Energy Resolution: $E > 10$ GeV

The mass of this state is large enough that one wants the best energy resolution for two reasons: (1) to minimize the observed mass resolution of the η_T and (2) to ensure that the trigger on the calorimeter is efficient. Therefore we review the energy resolution of hadron calorimeters for $E > 10$ GeV. The electromagnetic calorimeter can have arbitrarily good energy resolution depending on the amount of sampling and so it need not be considered for the moment. Figure 1 shows the energy resolution obtained from a 2.5 cm iron-scintillator calorimeter by the CDHS collaboration² as a function of energy. The unweighted points show that the hadronic resolution rises with energy faster than $\sqrt{E}$. This is understood as being due to fluctuations in the amount of electromagnetic energy in a given event which can be quite large as the energy increases. It is well known² that hadron/electromagnetic response in such an iron calorimeter is ~ 0.7 at 10 GeV and rises with increasing energy to ~ 0.9 at 100 GeV as the hadronic shower has a larger electromagnetic component. This deterioration in resolution can be compensated for if a separate readout is made of every sampling layer. Clearly this is impractical in a colliding beam environment where the number of longitudinal samples is limited. A. Ervin³ has suggested that the electromagnetic component of the hadronic shower could be read out separately; however, this has not been proven yet to work.

For such a t -jet there can be 50 to 100 particles that hit the calorimeter. A good algorithm must be devised to do the best job of attributing the observed energy in any cell to electromagnetic or hadronic energy since the expected response is different. Some of the hadronic particles will start interacting in the electromagnetic part of the calorimeter. The use of uranium,⁴ of course, helps both the energy resolution problem and the e/h response. However, it is not known if the improvements deteriorate with energy as in the case of iron. Figure 1 shows some data up to 110 GeV hadrons

Figure 1. Energy resolution $(\sigma)/E \cdot \sqrt{E}$ for hadrons and electrons for 2.5 cm iron sampling calorimeter² and for hadrons for a 3 mm uranium/calorimeter⁵ versus energy.

in a uranium calorimeter.⁵ It appears that up until at least 40 GeV there is still significant improvement by using uranium. It is not known whether a weighting scheme described earlier for iron calorimeters would also lead to better energy resolution for uranium.

The MAC hadron calorimeter has very comparable energy resolution to a scintillator iron calorimeter with the same sampling thickness. An interesting question is whether uranium can be used in a gas sampling calorimeter and if so would the excellent energy resolution be preserved.

Identification of Electrons in the Jet and Trigger

The principal method of finding t -jets from the normal light jets and in particular c - and b -jets is expected to be by observing a lepton at large transverse momentum from its associated hadronic jet.⁶ This is easy to understand since there may be a large mass difference between the t and b quark so that the leptons (if a semileptonic decay) could have a large transverse momentum. To find such electrons, the electromagnetic section of the calorimeter must be very finely segmented. Also it is a challenge to devise an effective trigger identifying tracks as candidate electrons in the tracking part of the apparatus in corre-

relation with a localized electromagnetic energy deposition.

Calibration and Monitoring

In order to reap the benefits of the improved energy resolution of uranium (or lead glass in an electromagnetic calorimeter) the calibration and monitoring system must be automatic, redundant and precise. It must be automatic because there will be so many channels involved. It must be redundant because every component of the monitoring and calibration system can be expected to experience failures. For example in a light flasher system the light source could fail, any device measuring the light directly can fail or change gain, the light fibers could suffer radiation damage, become unglued, or break. It is interesting to speculate whether any large system involving phototubes could boast systematic errors $\leq 1\%$ as would be necessary to, for example, measure the width of the $Z^0 \rightarrow e^+e^-$ in a pp or $\bar{p}p$ machine.

Rate Effects

By their nature, calorimeters are rather slow devices. However, in order to see such a signal as the η with a total cross section of ~ 20 pb at $\sqrt{s} = 800$ GeV, one needs to be able to use the full luminosity of ISABELLE. With proper shaping the effects of pile-up can be minimized on both the trigger rate and the energy resolution. However, one must be ever conscious of this potential problem which might ultimately limit the maximum useful luminosity.

New Ideas

Parallel Plate Calorimeter

An electromagnetic calorimeter has been built and tested by a Princeton and BNL group⁸ that uses gas as a sampling media. It is different than a PWC in that there are no wires. A large voltage difference ~ 8000 V is applied to the parallel plates. The ionization electrons initiate a Townsend avalanche. Gains of $10^3 - 10^4$ were achieved in $1/4$ " gaps with 1 atmosphere of argon with 5% acetone. The intrinsic signal width is ~ 10 ns therefore the device can operate in a very high rate environment. Studies with a single gap chamber indicate a resolution in the deposited energy about 1.5 times worse than that of a PWC of similar geometry. Studies with electrons from a SLAC test beam of 4-16 GeV/c with a 30 plate chamber, each of $6'' \times 6'' \times 1/2''$ steel, confirmed the single gap studies: $\sigma/E \sim 40\%/\sqrt{E}$. One can understand that the resolution would be worse since the gain only occurs for ionization very close to the surface—therefore only part of the primary ionization is measured. An extrapolation of these results would predict $\sigma/E \sim 17\%/\sqrt{E}$ for electrons in a chamber with 2 mm lead plates. The plates have to be flat and parallel to $\sim 0.005''$. The simplicity of construction and operation suggest use in hadron calorimetry in large scale high rate applications. One could use strip or pad read out so that projective geometry would be possible. Low noise charge sensitive preamplifiers are used.

Vacuum Photodiodes in Calorimeters

In the Axial Field Spectrometer at the CERN ISR the study of direct single photons was to be extended after the installation of the uranium calorimeters. These uranium calorimeters have only coarse 20×20 cm² electromagnetic readouts and so could not distinguish π^0 from γ at energies where the γ/π^0 signal is large. The region between the drift chamber and the calorimeter face has only ~ 30 cm free space and the magnetic field is ~ 5 kGauss. A creative solution to

the problem⁹ is to use blocks of NaI viewed by vacuum photodiodes. The light output from the NaI is quite high and is sufficient to compensate for the fact that the photodiode has no gain. One nice feature of the vacuum photodiodes is that the calibration should not drift very much if conditions such as the temperature remain constant. This means that once the device is calibrated, monitoring could be purely electronic. The rms noise of the low noise FET preamplifier (~ 1000 electrons rms) corresponds to a signal in the NaI of ~ 3 MeV energy loss. In order to operate in the magnetic field with minimal systematic variations over a wide range of angles with respect to the field axis, the photocathode must be in close proximity (~ 1 mm) to a wire mesh anode. Assuming the successful testing of a prototype 3×3 block array this fall, the two 1200 block crystal walls will be installed in 1982.

Another idea was proposed by the Pennsylvania group¹⁰ using vacuum photodiodes called SPED: Scintillator-Photo-Electric-Diode. The hope is to be able to produce vacuum photodiodes of large area (50 cm x 50 cm) and 1-1.5 cm thick to read the light output of each scintillator sample in a typical sandwich calorimeter. The anodes could be segmented into strips or pads allowing flexibility of readout. Again the device would operate in a magnetic field and should have excellent time, energy and position resolution. The problem is whether such photodiodes can be made industrially at a reasonable cost. Silicon detectors would have the same advantages and be thinner, however, the cost is likely to remain prohibitive.

High Gas Pressure Tubes

A new idea is being pursued at CERN by W.J. Willis and his colleagues.¹¹ They are attempting to construct sealed tubes of ~ 1 cm in diameter with a coarse wire in the middle filled with argon at ~ 100 atmospheres. Such a tube could be operated as an ion chamber similar in operation to liquid argon but at room temperature. Giving up a factor of ~ 10 in density for the 100 atm. of gas vs. liquid argon would increase the minimum signal that could be detected above the noise of the preamplifier but this will not affect the performance at high energies. Such tubes could be placed in holes drilled in, for example, the iron return of a magnet or perhaps the tubes could be cast into the absorbing material. V. Radeka¹² points out that the idea of a pressurized gas calorimeter would lend itself to a large sealed vessel for a hadron calorimeter where the large wall thickness could be tolerated. Then the readout and absorber could be integrated in a natural way.

Heavy Metal Loaded into Plastic as an Absorber

S.D. Smith¹³ has been developing a new construction technique which should allow the simple and low cost assembly of high performance gas calorimeters at BNL. A mixture of approximately equal volumes of PbO and acrylic monomer produces a low viscosity slurry which may be poured into molds. Densities of ~ 5.5 gm/cm³ have been achieved. The molds are electro formed¹⁴ from a master plate which has grooves into which anode wires can be placed. The sheets are plated with conducting cathode strips running perpendicular to the grooves. Plates with 3 mm diameter grooves ~ 30 cm long are being molded at BNL with a prototype test soon. Also the possibility of using uranium oxide (UO₂ or U₃O₈) is being studied for possible use in a hadron calorimeter.

Use of the Limited Streamer Mode in Calorimeters

The use of the limited streamer mode in gas sampled calorimetry may offer substantial improvement com-

pared to operation in the proportional mode. The main contributions to the energy resolution in gas calorimeters other than intrinsic sampling fluctuations are the Landau fluctuations and path length fluctuations. The streamers can give a rather uniform signal to reduce the Landau fluctuations. The signals from the streamers are very large and therefore the electronics is simplified.

The use of 1 cm x 1 cm aluminum streamer tubes about 3 m long are inserted every radiation length in the CHARM neutrino detector.¹⁵ The main reason for this addition is to improve the vertex measurement of electromagnetic showers from νe^- scattering. This device is operated in the digital mode and so the response is not proportional to the electron energy. This is because there can be many tracks in a single streamer tube which get counted as only one track. The resolution for electrons above 5 GeV is 16% and independent of energy. The response for hadrons from 15 to 100 GeV has also been measured. The energy resolution is worse than obtained by scintillators sampling the same gaps. For example $\sigma/E = 18\%$ for the streamer tubes at 15 GeV whereas $\sigma/E = 12\%$ for the scintillators. M. Atac¹⁶ is studying the use of the streamer mode also in hadron calorimeters measuring the pulse height on each wire. Since the streamers are quite short in spacial extent this method may offer some improvement in linearity and energy resolution.

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