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# CALORIMETER CALIBRATION*

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# CALORIMETER CALIBRATION

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At FNAL, protons of 200 and 300 GeV have been used to calibrate an iron and scintillator total absorption calorimeter. The resolution is 14.4% at 200 GeV and 12.8% at 300 GeV (FWHM) and the visible energy is found to be 72 ± 5% from calibration with muons. Data are compared with other accelerator calibrations of calorimeters, from which it becomes possible to more confidently design and evaluate calorimeters for cosmic ray applications.

1. Introduction. Since its introduction by Grigorov and Murzin,[1] the Ionization Calorimeter has proven a valuable and indeed almost indispensible tool in cosmic ray studies of hadronic interactions above 100 GeV. However it has only recently been possible to explore its properties in momentum-analyzed beams at these energies. More recently, such calorimeters have come into increasing use at particle accelerators, particularly at the Fermi National Accelerator Laboratory. This report summarizes experience with an iron-scintillator calorimeter studied at FNAL and its calibration in proton beams of 200 and 300 GeV.[2] Other FNAL and Cosmic Ray Groups have undertaken similar calibrations at that laboratory, with results compatible with these. Interest in this technique was evidenced recently by a two-day seminar at FNAL.[3]

2. Experiment. The calorimeter studied consisted of 900 $cm^{-2}$ of iron in the form of 30 plates each 61 x 61 x 3.81 $cm^3$ alternated with 30 plastic scintillators each 61 x 61 x 0.635 $cm^2$. The scintillators are viewed by four RCA 8575 phototubes, with each tube collecting light from 6 or 9 scintillators. As seen in Fig. 1 light is collected from alternate scintillators on opposite sides of the iron so that each tube collects light from scintillators spaced by 7.62 cm of iron.

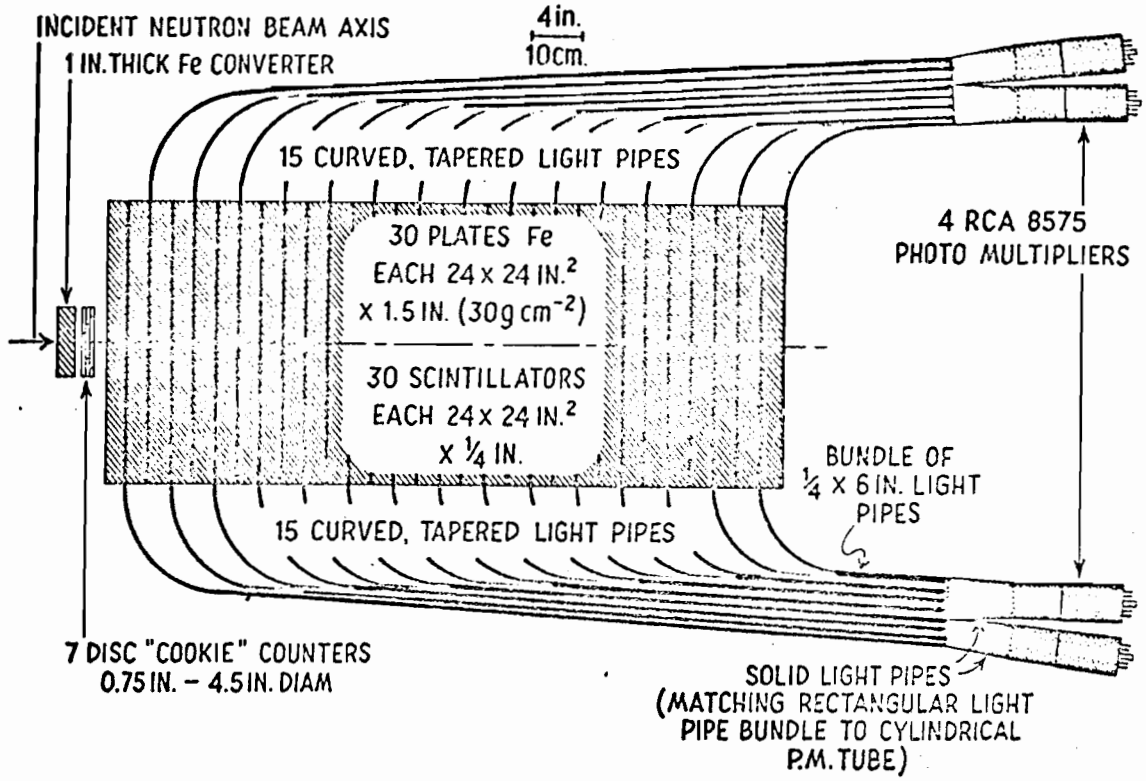


Figure 1. Michigan Neutron Calorimeter

Calibration was done by comparing pulse heights from muons with those from protons of 200 and 300 GeV. The resolution under various conditions and the ratio of "visible" to total energy were studied.

More recently, the same calorimeter has been used in a search for massive, neutral, stable hadrons at FNAL by studying the correlation between arrival time (relative to r.f. beam bunching) and pulse height. Although indirect, these data permit studies of resolution and "visible" energy with incident neutrons in the energy range 5-15 GeV.

3. Results. The pulse height spectra for 200 and 300 GeV protons on the calorimeter are given in Figure 2. In each case, protons were required to interact in an iron converter of 10 or 20 g $cm^{-2}$ ahead of the calorimeter. Resolution, referenced in terms of full width at half maximum, was determined for the entire calorimeter and for various subdivisions of it. The figures below are for 300 GeV protons.

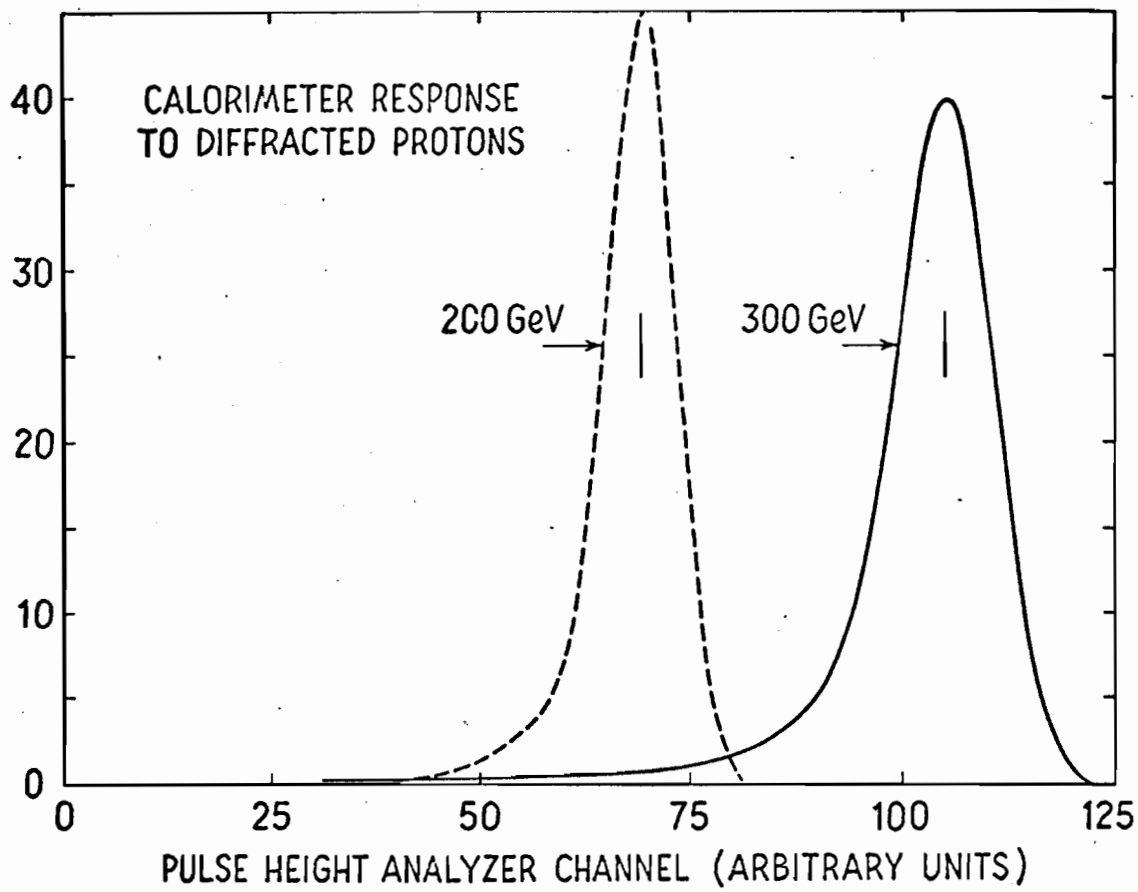


Figure 2. Pulse Height Analyzer Channel (Arbitrary Units)

The resolution with a 10 g $cm^{-2}$ converter was 12.5% - 13.5%; with a 20 g $cm^{-2}$ converter, 13.5% - 14%. Moving the converter 45 cm ahead of the calorimeter reduced resolution to 15.5%. When only half of the tubes are used (60 g $cm^{-2}$ iron between active scintillators) the resolution deteriorated by about $\sqrt{2}$ to 17%. With the tubes collecting light from the front 12 scintillators only (360 g $cm^{-2}$ of iron), again requiring an interaction in the converter ahead of the calorimeter, the resolution was 37%, and the peak pulse height had fallen to 80% of the peak with the full 900 g $cm^{-2}$. With only 6 scintillators (front 360 g $cm^{-2}$ of iron, scintillator every 60 g $cm^{-2}$) the resolution remained 37%. As observed in Fig. 2, the pulse distribution is asymmetrical, with a long tail extending to lower pulse heights. At 50% of the peak height, the tail is 1% of the peak amplitude. When protons were not required to interact ahead of the calorimeter, the resolution was 14%.

Calibration of visible energy was made using muons. There was no exact knowledge of muon energy, although plausible estimates range from 5 to 20 GeV. The relativistic rise in ionization over this range corresponds to 10% so that the calibration is correspondingly uncertain. A muon of 10 GeV loses 1.82 GeV (calculated) in the calorimeter. If $V_\mu$ is the pulse height from muons and $V_p$ is the pulse height from 300 GeV protons, the ratio of visible to total energy, k, may be defined as:

$$V_p/V_\mu = k\ (300/1.82) \quad .$$

From these data, $k = 0.72 \pm 0.05$. Calibration with 200 GeV protons gave the same value of k to ±2% experimental uncertainty, although the resolution deteriorated slightly to 14.4%.

Data taken with neutrons and time-of-flight energy determination indicate k falls from ~ .65 to ~ .60 as energy falls from ~15 to ~8 GeV, and resolution deteriorates to ~40% - 50% in this same energy range.

4. Discussion. The resolutions found here are compatible with performance reported with other calorimeters by Engler et al.[4] and by Barish et al.[5] when account is taken of the different iron configurations. It appears at this time that the resolution of this calorimeter exceeds any so far studied at FNAL. The value of k seen here (0.72) is lower than the corresponding value estimated for protons in the Echo Lake calorimeter (0.77%).[6] The values of k must be qualified by noting the possible longer pulses in plastic scintillators from nuclear stars as compared with minimum ionizing particles. The high energy calibration was done with pulses clipped to 5 ns; no systematic study has been made of this effect.

5. Conclusion. A magnetic spectrometer has a momentum resolution which falls with increasing momentum; $\Delta p/p \propto p$. The resolution of an ionization calorimeter slowly improves with incident energy, and as energies rise above 1 TeV, it becomes competitive with magnetic spectrometers, and is much less expensive while easily accommodating a large admittance. A compendium of parametric experience is accumulating with calorimeters at FNAL, and confident predictions of resolution for various absorber and detector configurations is becoming possible.[7] It appears that totally self-consistent values of k are not yet well determined.

Various other calorimeter modifications are also being pursued; incorporation with multiwire chambers for position determination, development of homogeneous (e.g. liquid argon and NaI) chambers, and very large chambers in neutrino experiments. It appears that the ionization calorimeter is firmly established as a valuable tool at particle accelerators as well as in cosmic ray research.

6. Acknowledgements. This research was supported by the U.S. National Science Foundation. The cooperation of the FNAL staff in this study was greatly appreciated.

1. N.L. Grigorov, V.S. Murzin, and I.D. Rappaport, J. Exptl. Theoret. Phys. 34, 506 (1958). V.S. Murzin, Progress in Elementary Particle and Cosmic Ray Physics, Vol. 9, North Holland Publ. Co. Amsterdam (1967).

2. L.W. Jones, et al., Nuc. Instr. and Meth., 118, 431 (1974).

3. M. Atac, Calorimeter Workshop, FNAL, May, 1975 (unpublished).

4. J. Engler et al., Nucl Instr. and Meth. 106, 189 (1973). V. Böhrmer et al., Nucl. Instr. and Meth. 122, 313 (1974).

5. B.C. Barish et al., Nucl. Instr. and Meth. 116, 413 (1974).

6. L.W. Jones et al., Nucl. Phys. B43, 477 (1972); G.D. DeMeester, Ph.D. Thesis, Univ. of Mich. UM-HE 71-5 (1971) (unpublished).

7. A. Baroncelli, Nucl Instr. and Meth. 118, 445 (1974).