**Calibration Calculations of Hadronic
Cascades Induced by High-Energy Muons
in Iron/Plastic Calorimeters**

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CALIBRATION CALCULATIONS OF HADRONIC CASCADES INDUCED BY
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Abstract

Calculations have been performed to determine the response of an iron-plastic calorimeter to muon-induced nuclear interactions. The calculated data include energy resolutions and average pulse-height signals as a function of energy transfer, energy-transfer angle, and spatial-interaction point.

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1. INTRODUCTION

Calorimeters that are used to detect low-probability muon-nuclear interactions are usually substantially larger in the longitudinal direction than are the typical $\sim 1000\text{-g/cm}^2$ -thick hadronic devices. A large longitudinal device ensures that the muon has a reasonable chance for interaction at a sufficient distance upstream from the end of the calorimeter so that the ensuing energy transferred to the hadronic and/or electromagnetic cascade can be contained. The transverse dimensions of the muon calorimeter do not necessarily have to be much larger than those of typical hadronic devices since the angles associated with the transferred energy are usually small.

Presented in this paper are calculated calibration data for a muon calorimeter composed of 104 iron blocks ($25.4 \times 25.4 \times 5.08 \text{ cm}^3$) sandwiched between 104 plastic sheets ($25.4 \times 25.4 \times 0.953 \text{ cm}^3$); no gaps between the iron and plastic have been introduced. The energy range, i.e., the range of energy transferred by the muon to the hadronic and/or electromagnetic cascade, considered in these calculations is 20 to 180 GeV. The energy-transfer angle range, i.e., the angle range in which the hadronic and/or electromagnetic cascade is generated, is 0 to 200 mrad. The calculated data include energy resolutions and average pulse-height signals as a function of energy transfer, energy-transfer angle, and spatial-interaction point, as well as selected pulse-height distributions. Some comparisons are also made with experimental data to partly validate the results.

Other than the approximation associated with the initial muon-nuclear interaction, the methods employed in the calculations are the same as those discussed previously¹⁻³). To obtain the type and momentum of particles

that emerge from a muon-induced star, it was assumed that particles emerging from x-GeV proton stars are similar to those that are expected from muon-induced stars when the transfer of energy amounts to x-GeV.

2. CALCULATED RESULTS AND DISCUSSION

In all the results presented here the ionization signal of the muon has been omitted. If a minimum ionizing muon transverses the entire device, the total signal can amount to ~ 200 MeV.

The resolution of the muon calorimeter as a function of energy transfer, energy-transfer angle, and radial distance from the center of the calorimeter is given in fig. 1a and b. These data are for muon collisions which occur in the iron blocks ≥ 10 but ≤ 80 . Also included in fig. 1b is a comparison with experimental data⁴⁾ for incident 30-, 60-, 90-, and 150-GeV hadrons. The calorimeter used to obtain the experimental data is basically the same as the one described here except longitudinally it is much shorter (~ 1000 g/cm²). The agreement is quite good.

The increase in the resolution, as indicated in fig. 1a, as the initial interaction point approaches the edge of the calorimeter is due to a rapid increase in the amount of transverse leakage energy. It has been pointed out many times^{5,6)} that small changes in the total signal can have a drastic effect upon the performance of a calorimeter. This increase in lateral hadronic energy loss for 50- and 95-GeV energy transfers is shown in fig. 2 as a function of energy-transfer angle and radial distance from the edge of the calorimeter.

The longitudinal variations of the resolution for 0- and 200-mrad energy-transfer angles are presented in figs. 3 and 4, respectively, as a function of energy transfer, radial distance from the center of the

Fig. 1. Resolution of the muon calorimeter as a function of energy transfer, energy-transfer angle, and radial distance from the center of the calorimeter.

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Fig. 2. Lateral hadronic energy loss as a function of energy transfer, energy-transfer angle, and radial distance from the center of the calorimeter.

Fig. 3. Longitudinal variation of the resolution as a function of energy transfer, radial distance from the center of the calorimeter, and the iron block in which the first interaction occurs for an energy-transfer angle of 0 mrad.

Fig. 4. Longitudinal variation of the resolution as a function of energy transfer, radial distance from the center of the calorimeter, and the iron block in which the first interaction occurs for an energy-transfer angle of 200 mrad.

calorimeter, and the iron block in which the first interaction occurs. No requirements are placed on the initial muon star produced in the n th iron block — for example, more electromagnetic than hadronic or vice versa.

The average pulse-height signal as a function of energy transfer, energy-transfer angle, and radial distance from the center of the calorimeter for the initial interaction occurring in iron blocks ≥ 10 but ≤ 80 is shown in fig. 5. Given in fig. 6 are similar data but with no restriction on the initial interaction.

Additional comparisons between the present calculated results and experimental data⁷⁻⁹⁾ are given in fig. 7. An exact comparison is not possible as the calorimeters and particle energies in the figure are not totally equivalent to those considered here. However, general trends should exist. The comparison with the data of Baum *et al.*⁷⁾ (fig. 7a) is quite good and shows how the pulse-height signal and resolution should change as the thickness of the calorimeter is reduced. Similar comparisons are shown in fig. 7b and 7c.

In determining the location of the first star, experimentalists often favor initial collisions which yield large electromagnetic or hadronic components, thereby obtaining smaller resolutions and shorter containment distances than would be the case if no restrictions were placed on the initial collision. This trend is shown in fig. 7b and c by comparing the calculated data when no restrictions are placed on the initial collision and when a set of conditions must be met before, by definition, an initial collision has occurred at a given point in the calorimeter. It should be pointed out that no restrictions on the initial interaction have been placed on the majority of the data presented. Therefore, if stringent requirements are

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Fig. 5. Average pulse-height signal as a function of energy transfer, energy-transfer angle, and radial distance from the center of the calorimeter. (Initial interactions occur in iron blocks ≥ 10 but ≤ 80 .)

Fig. 6. Average pulse-height signal as a function of energy transfer, energy-transfer angle, radial distance from the center of the calorimeter, and the iron block in which the first interaction occurs.

Fig. 7. Variations in the average pulse-height signal and resolution due to a decrease in calorimeter thickness.

placed on defining an initial collision, then this should be taken into account when using the data given here.

In figs. 8, 9, and 10 are shown representative pulse-height distributions for different energy transfers, energy-transfer angles, radial distances from the center of the calorimeter, and the iron block in which the first interaction occurs.

Fig. 8. Pulse-height distributions for energy transfers of 20 GeV.

Fig. 9. Pulse-height distributions for energy transfers of 50 GeV.

Fig. 10. Pulse-height distributions for energy transfers of 95 GeV.*

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