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SOLENOIDAL DETECTOR NOTES

DEPTH OF CALORIMETRY FOR SSC EXPERIMENTS

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Abstract

The depth of calorimetry required for SSC experiments is investigated using data of hadronic shower development in neutrino detectors and a parameterization of average hadronic shower shapes. The effect of hadronic shower fluctuations is included. A depth of nine to ten proton absorption lengths in iron is found to be sufficient to contain at least 95% of the energy of 95% of 1 TeV jets.

DEPTH OF CALORIMETRY FOR SSC EXPERIMENTS

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Abstract

The depth of calorimetry required for SSC experiments is investigated using data of hadronic shower development in neutrino detectors and a parameterization of average hadronic shower shapes. The effect of hadronic shower fluctuations is included. A depth of nine to ten proton absorption lengths in iron is found to be sufficient to contain at least 95% of the energy of 95% of 1 TeV jets.

1. INTRODUCTION

This paper investigates the depth of hadronic calorimetry necessary to contain the energy of single hadrons and of approximately 1 TeV jets. A parametrization of average longitudinal hadronic shower shapes and data of hadronic shower development taken during the calibration of neutrino detectors with hadron beams are used in this study. Event-by-event data from a neutrino detector calibration allows the effect of hadronic shower flucuations to be included in the determination of containment depths.

2. CONTAINMENT OF SINGLE HADRON SHOWERS

Figure 1 presents the depth in iron from start of calorimeter for containment of 95% and 99% of single hadron energy based on average shower shape as a function of single hadron energy. Containment depths from the calibration of two neutrino detectors[1,2] (referred to as CCFR and CDHS) and from a parameterization of average

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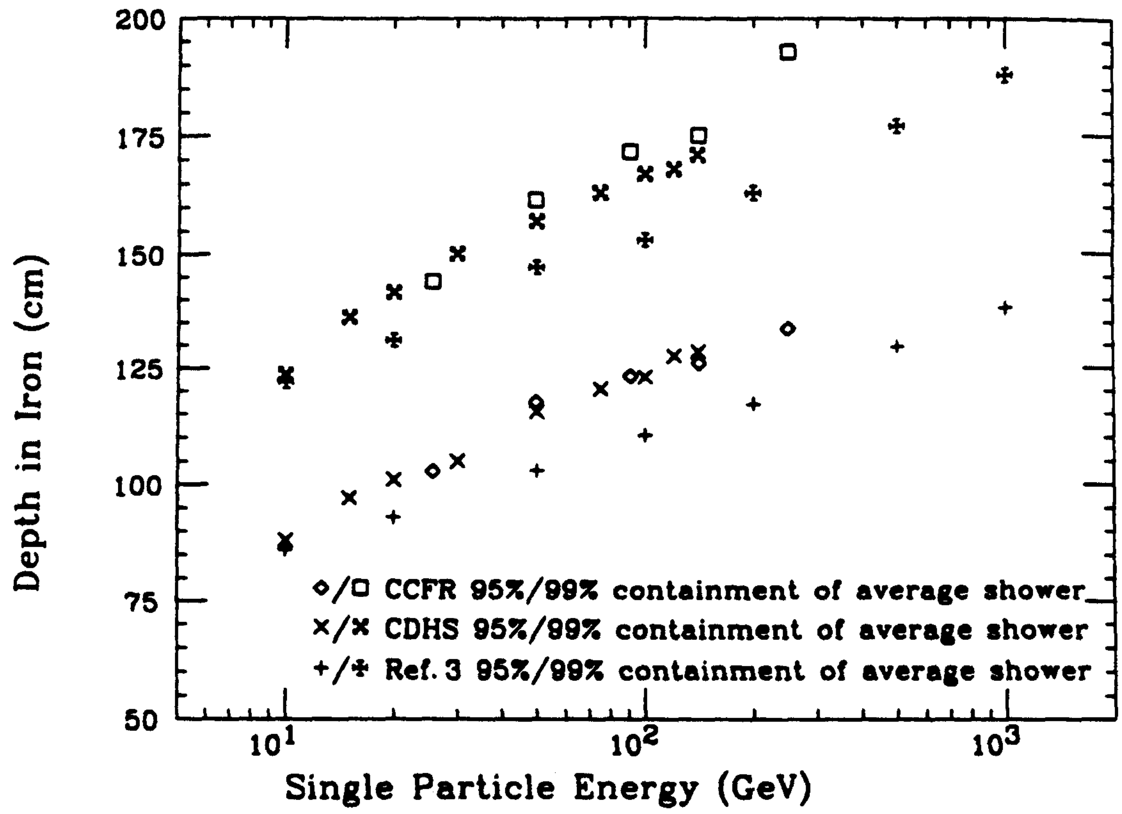

Figure 1. Depth in centimeters of iron from calorimeter start for containment of 95% and 99% of the energy of average hadronic showers versus incident single particle energy.

shower shapes[3] are plotted. Both neutrino detectors are iron-scintillator detectors. Scintillator is included in depth calculations as iron equivalent. The average proton absorption lengths of the CCFR and CDHS neutrino detectors are approximately 30 cm and 20 cm respectively.[4] Average hadronic shower shapes from the detectors are obtained by summing the output of each detector slice over thousands of events. The parameterization was determined by the study of average shower shapes from the calibration of neutrino detectors and other calorimeters.[5] Since the parameterization of shower shape of Ref. 3 is from shower start, variations in the start of shower as $e^{-x/\lambda}$ have been included in calculating the points of Ref. 3 in Fig. 1.

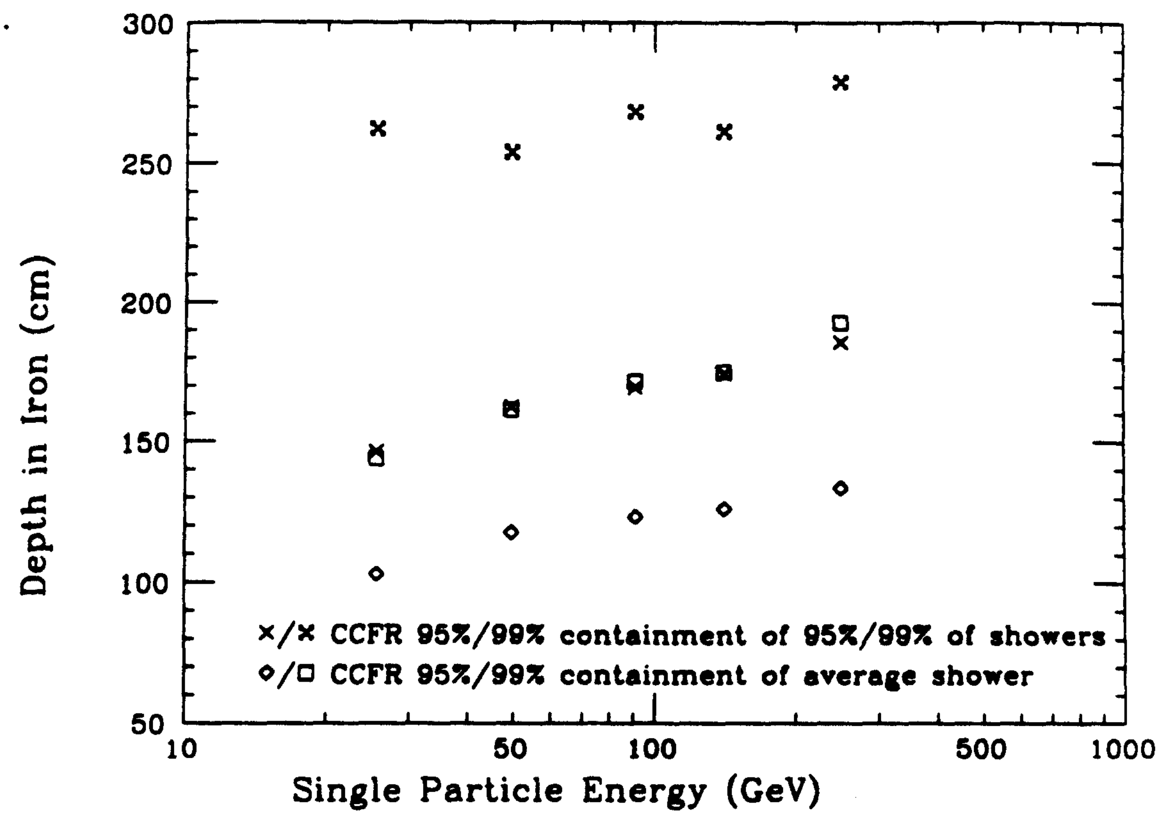

Figure 2. Depth in centimeters of iron from calorimeter start for containment of at least 95% (99%) of shower energy for 95% (99%) of showers and for containment of 95% (99%) of the energy of average showers versus incident single particle energy.

The containment depths of average showers do not consider the fluctuations in hadronic shower development. Data from a calibration of the CCFR neutrino detector was analyzed on an event-by-event basis to include shower fluctuation in containment measures. Event-by-event data at energies of 25, 50, 90, 140, and 250 GeV were analysed. Figure 2 plots depths for containing at least 95% (99%) of shower energy for 95% (99%) of showers and for containing 95% (99%) of shower energy for average showers versus incident single hadron energy. The at-least-95% (99%) containment of 95% (99%) of showers provides a measure of how fluctuations in individual showers affect containment. Depth in Fig. 2 is defined from calorimeter start. It can be seen that to contain at least 95% of shower energy for 95% of showers, 40 to 50 cm of iron are required beyond the depth to contain 95% of shower energy for average showers . The depths to contain at least 99% of shower energy for 99% of showers also show a large increase over the containment depths for 99% of energy for average showers. However, the containment depths for at-least-99% of shower energy for 99% of showers for the three lowest energies are strongly affected by pedestal jitter and shower-generated soft muons and should be considered as upper limits.

3. CONTAINMENT OF JETS

Figure 3 presents depth in proton absorption lengths in iron from calorimeter start for the containment of hadronic jets versus jet energy. The Pythia-Ref. 3

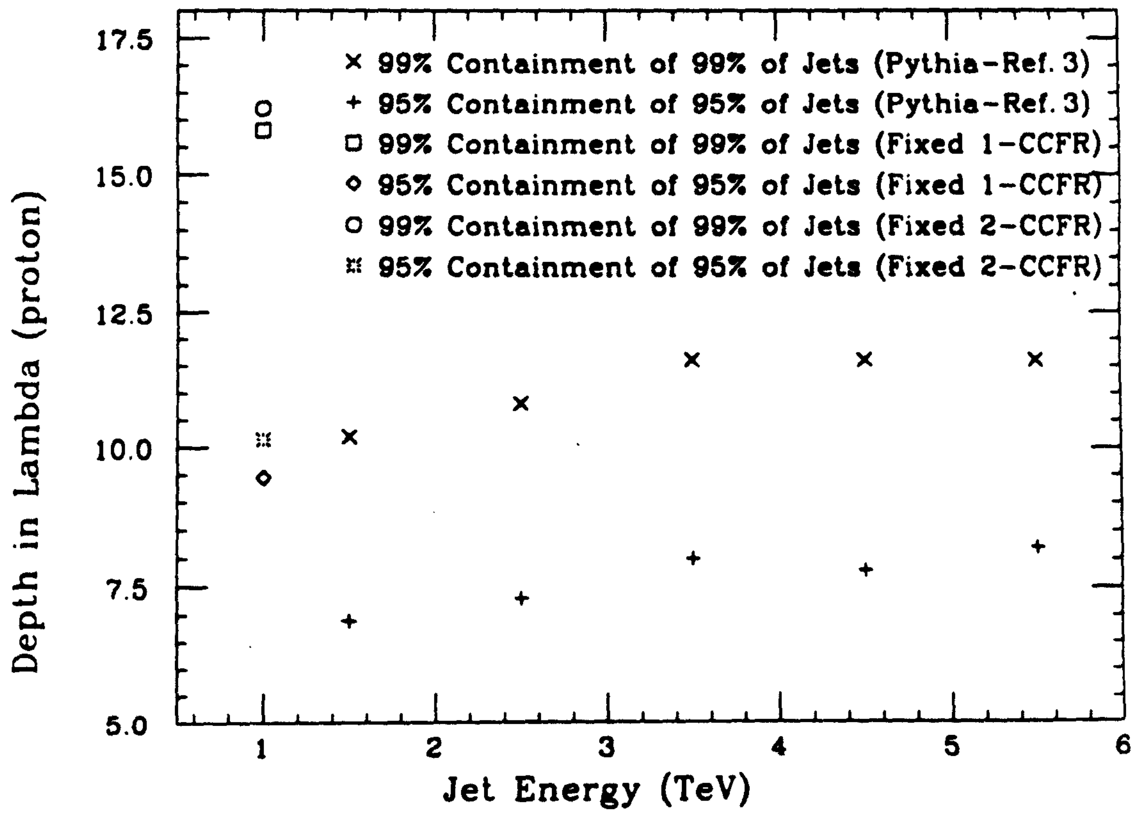

Figure 3. Depth in proton absorption lengths (lambda) in iron from calorimeter start for containment of jet energy versus jet energy. See text for definition of jets.

points were calculated using Pythia[6] Monte Carlo generated hadronic jets in conjunction with the parameterized shower shapes of Ref. 3 (with $e^{-x/\lambda}$ variation in shower start) for individual hadrons of the jet. The individual parameterized average shower shapes were overlayed and a containment depth for 95% and 99% of each jet's energy was then calculated. Electromagnetic particles were assumed to be totally contained in the first few absorption lengths. Muons and neutrinos were not included in jet energy. Thus the Pythia–Ref. 3 points include jet composition fluctuations but not individual hadron shower shape fluctuations. The Fixed-CCFR points were calculated using two fixed composition jets with individual hadronic showers supplied by the event-by-event CCFR calibration data. The first fixed composition jet (Fixed 1) imitates an average 1 TeV Pythia-generated jet with a sum of one 250 GeV, one 140 GeV, one 90 GeV, two 50 GeV and six 25 GeV hadronic events, for a total of approximately 730 GeV hadronic energy, and with the remainder of the 1 TeV jet assigned to electromagnetic particles. The second fixed composition jet (Fixed 2) is intended to be a hard 1 TeV jet and is composed of three 250 GeV events with the remainder of the 1 TeV assigned to electromagnetic particles. For both fixed composition jets the individual hadron events were overlayed and containment depths calculated. Again the electromagnetic energy was assumed to be contained in the first few absorption lengths. Thus the fixed composition jets include individual hadron shower shape fluctuations but not jet composition variations. Calculating containment for fixed composition jets with energy much greater than 1 TeV using the CCFR data will produce only soft jets as the leading hadron energy is limited to 250 GeV. Figure 3 indicates that the individual hadron shower fluctuations impose a greater depth requirement for jet containment than do variations in jet composition. Nine to ten absorption lengths are sufficient for containing at least 95% of the energy for 95% of 1 TeV jets.

4. AVERAGE ENERGY AND RESOLUTION VERSUS DEPTH

The average detected energy and resolution of the hadronic portion of the first fixed composition jet ($250 + 140 + 90 + 2 \times 50 + 6 \times 25$ GeV) as a function of calorimeter depth are shown in Figs. 4 and 5 respectively. The fixed composition

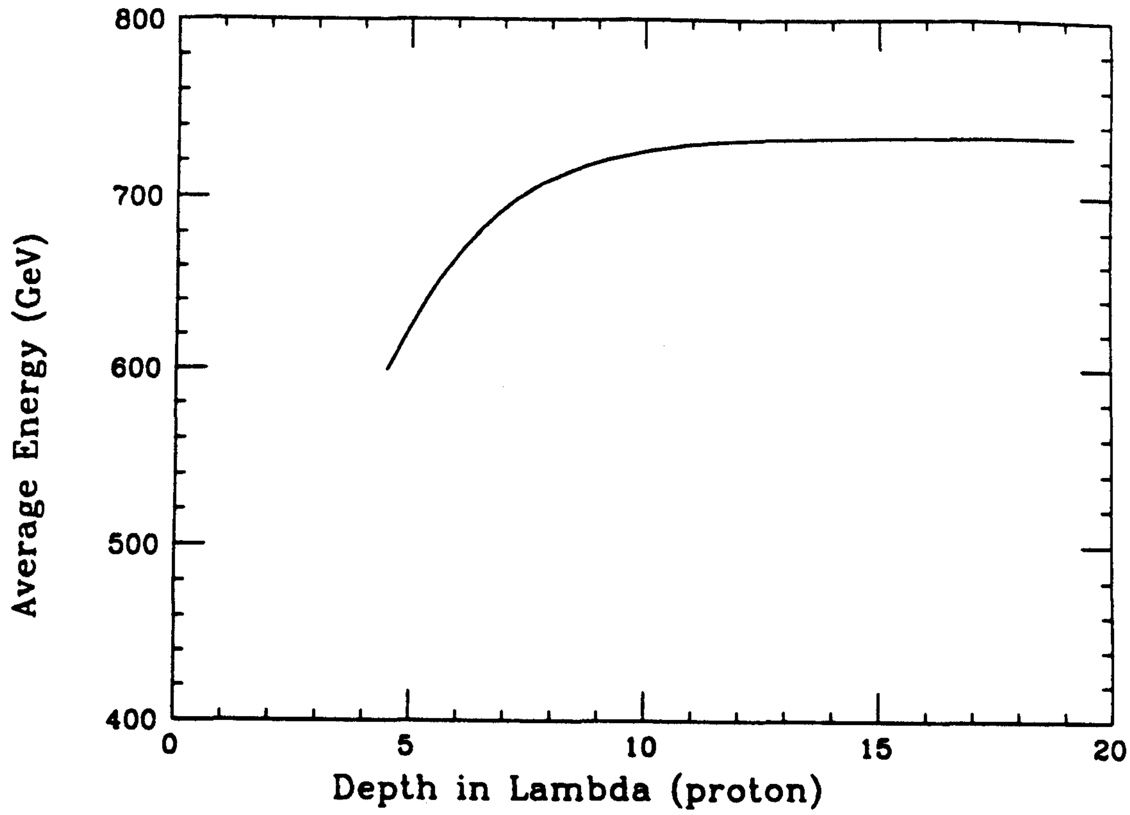

Figure 4. Average detected energy for the hadronic portion of the first fixed-composition jet (250 + 140 + 90 + 2 × 50 + 6 × 25 GeV) of the text versus read-out depth of the CCFR calorimeter in proton absorption lengths (lambda).

jets, as explained above, are composed of overlayed individual hadron showers from the CCFR calibration data. It can be seen from Figure 4 that a depth of approximately nine to ten proton absorption lengths achieves plateau for average detected energy. Similarly it can be seen that a depth of nine to ten proton absorption lengths achieves plateau in resolution. Resolution is defined as the rms of the energy distribution. The CCFR calorimeter has an individual hadronic energy resolution of $\sim 0.9/\sqrt{E(\mathrm{GeV})}$. The electro-magnetic portion of the fixed composition jets was not included in the average energy or resolution calculations.

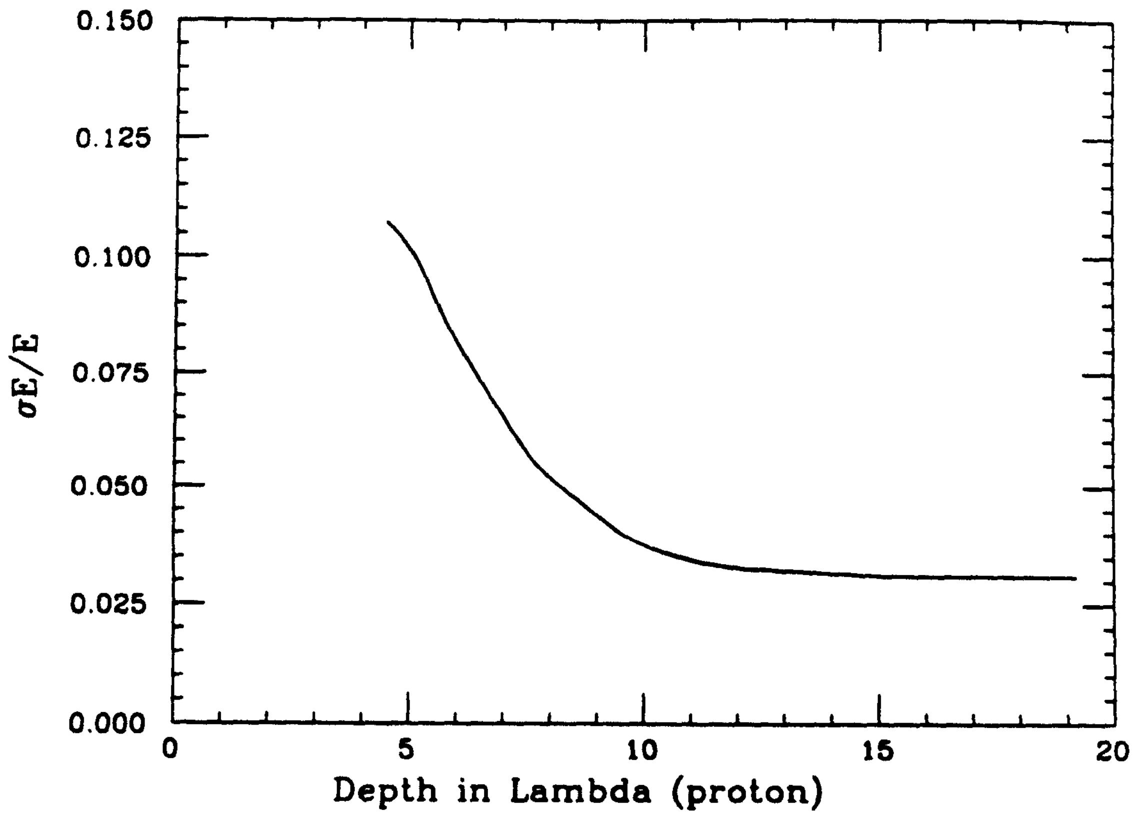

Figure 5. Resolution calculated as the rms of the energy distribution divided by the average detected energy for the hadronic portion of the first fixed-composition jet (250 + 140 + 90 + 2 × 50 + 6 × 25 GeV) of the text versus read-out depth of the CCFR calorimeter in proton absorption lengths (lambda).

5. CONCLUSIONS

Longitudinal fluctuations in hadronic showers are seen to have a significant impact on the depth of calorimetry required for containment. A depth of nine to ten proton absorption lengths in iron is sufficient to contain at least 95% of the energy of 95% of 1 TeV jets, including the effects of shower fluctuations. This depth also insures that the average detected hadronic energy and the hadronic energy resolution are within a few percent of their asymtotic values.

REFERENCES

1. Event-by-event data of a calibration of the CCFR (Chicago-Columbia-Fermilab-Rochester) neutrino detector at Fermilab provided by John Yoh of Fermilab with the aid of the Fermilab computing department. A. Bodek of the University of Rochester also provided useful information about the calibration and the CCFR detector. For a description of the CCFR neutrino detector see F. S. Merritt et al., Nucl. Instrum. Meth. **A245** (1986) 27.
2. E. Hughes, "Measurement of Hadronic and Electromagnetic Shower Development between 10 and 140 GeV by an Iron-Scintillator Calorimeter," unpublished CDHS (CERN-Dortmund-Heidelberg-Saclay) Internal Report, (August 1986), and private communications with A. Para.
3. R. K. Bock, T. Hansl-Kozanecka, and T. P. Shah, Nucl. Instrum. Meth. **186** (1981) 533.
4. The absorption length for iron used in this paper is 16.76 cm and is taken from the Particle Data Booklet.
5. For a comparison of four longitudinal hadronic shower parameterizations see A. Bay et al., "Requirements for Calorimetric Jet Mass Reconstruction for High $P_{\perp}$ Jets at the SSC," Proceedings of Snowmass 1988, to be published.
6. H. U. Bengtsson and T. Sjostran, Physics of the Superconducting Super Collider, edited by R. Donaldson and J. Marx (Snowmass, CO, 1986) p.311.