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CALIBRATION OF A SAMPLING TOTAL ABSORPTION DETECTOR AT 200 GEV*

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Abstract

A sampling total absorption detector was calibrated at NAL in a 200 GeV beam. An energy resolution of ±8.6% was achieved, to be compared with a resolution of ±21% at 28.5 GeV.

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As part of a neutrino experiment at the National Accelerator Laboratory (NAL) a large area (5' x 5') sampling total absorption detector[1] (calorimeter) was built and is now in use. The purpose of this calorimeter is to measure the energy of the hadrons released in neutrino reactions, for example

$$\nu + N \rightarrow \mu^- + \text{hadrons}.$$

In order to calibrate[2] this detector, a scale model calorimeter of similar design but reduced transverse dimensions was constructed and placed in a hadron beam of well defined energy at NAL. A schematic of this scaled-down calorimeter is shown in Fig. 1. It consists of 14 stations, each made of a 4" thick plate of steel followed by a 3/8" thick plastic scintillator. In front of the calorimeter are three counters T1, T2 and T3 used to signal a single charged particle incident on the detector. The trigger is T1 T2 $\overline{T3}$. This scaled-down calorimeter is long enough to contain longitudinally the shower initiated by the incident hadron for present NAL energies, and its cross-section (10" x 14") is large enough to insure the lateral containment of the shower. To provide a calibrating one particle signal, the steel plates in the calorimeter are removable, in which case the particles pass through the counters without interacting. Each scintillator is equipped with its own phototube; the signals are separately pulse height analyzed for each event, and all data are written on magnetic tape.

The results of a run in a beam of 200 GeV positive particles are described below. Data were first taken with all steel removed in order to calibrate all 14 counters with single ionizing particles. The signals from the photomultipliers were amplified by a factor of

20 for this calibration. With the steel plates back in place we recorded about 4000 shower events. Because the hadron shower gives much larger pulse heights the signals were not amplified in this case. The pulse height distribution summed over the 14 counters is shown in Fig. 2a, where the abscissa is the number of equivalent single ionizing particles in the shower. Thus a shower initiated by a 200 GeV hadron is equivalent to about 1060 minimum ionizing particles in our detector. The energy resolution of ±8.6% is obtained by fitting the distribution to a gaussian. These results are in excellent agreement with a Monte Carlo calculation[3)] of a 200 GeV shower, which gives a value of 1040 minimum ionizing particles with a resolution of ±10%. This is to be compared with the resolution (±21%) which was achieved with this calorimeter in a 28.5 GeV proton beam at the Brookhaven National Laboratory AGS (Fig. 2b).

We have investigated the dependence of the calibration and resolution on the length of the calorimeter by selectively ignoring the last counter, last two counters, etc. This determines how deep (in interaction lengths) a calorimeter should be in order to totally contain the hadron shower and thus achieve its best resolution and stability of energy calibration. For this test an interaction is forced in the first module by requiring a large pulse height in the first counter. This more nearly simulates the case of a ν interaction where we know the vertex position. Fig. 3 shows the calibration and resolution of the calorimeter versus its length. We note from Fig. 3 that about five interaction lengths (~33.5") of steel are necessary to fully contain the shower initiated by a 200 GeV hadron. If the distance between the interaction point and the rear of the calorimeter is less than this value, both the calibration and resolution

are affected by the loss of energy due to escaping particles.

The longitudinal development of the shower in the calorimeter was also studied. Again an interaction is forced in the first plate. In Fig. 4 the average number of minimum ionizing particles in each counter is displayed. The exponential fall of the distribution has a characteristic length of about 230 g/cm^2. Also shown is the result of the above mentioned Monte Carlo calculation, which is in good agreement with the experimental data.

By making the appropriate sums of the calorimeter counters, we can investigate the effects of different counter spacing on resolution (for spacing greater than the nominal 4"). For example, adding the even counters allows a measurement of the resolution with 8" spacing (i.e. 8" of steel between scintillators). The result of this test is shown in Fig. 5 where we have plotted resolution vs. amount of steel between any two counters. The dependence is about linear between 4" and 12" (the curve is drawn to guide the eye). As already mentioned, the Monte Carlo calculation predicts a resolution of ~10% for 4" spacing of the counters. As we reduce the spacing from 4" the gain becomes much less than linear (2" spacing is predicted to be only about 30% better than 4"). The reason for this is that with 4" spacing we are sampling the electromagnetic shower reasonably well (hence this contribution to the resolution improves slowly with decreasing spacing) and the overall resolution becomes limited by fluctuations in the amount of energy deposited in the nucleus which is not sampled by the calorimeter.

Further investigations of this calorimeter are planned, with special emphasis on the behavior at different beam energies.

We wish to acknowledge the help of the NAL Neutrino Area staff.

References

1) V. S. Murzin, in Progress in Elementary Particles and Cosmic Ray Physics, vol. 9, page 245 (eds. J. G. Wilson and S. A. Wouthuysen; North-Holland Publ. Co., Amsterdam, 1967).

2) J. Engler, W. Flauger, B. Gibbard, F. Mönning, K. Runge and H. Schopper, Nuc. Instr. and Meth. 106 (1973) 189; H. Whiteside, C. J. Crannell, H. Crannell, J. F. Ormes, M. J. Ryan and W. V. Jones, Nuc. Instr. and Meth. 109 (1973) 375.

3) This Monte Carlo calculation is based on the work of W. V. Jones, Phys. Rev. 187 (1969) 1868.

Figure Captions

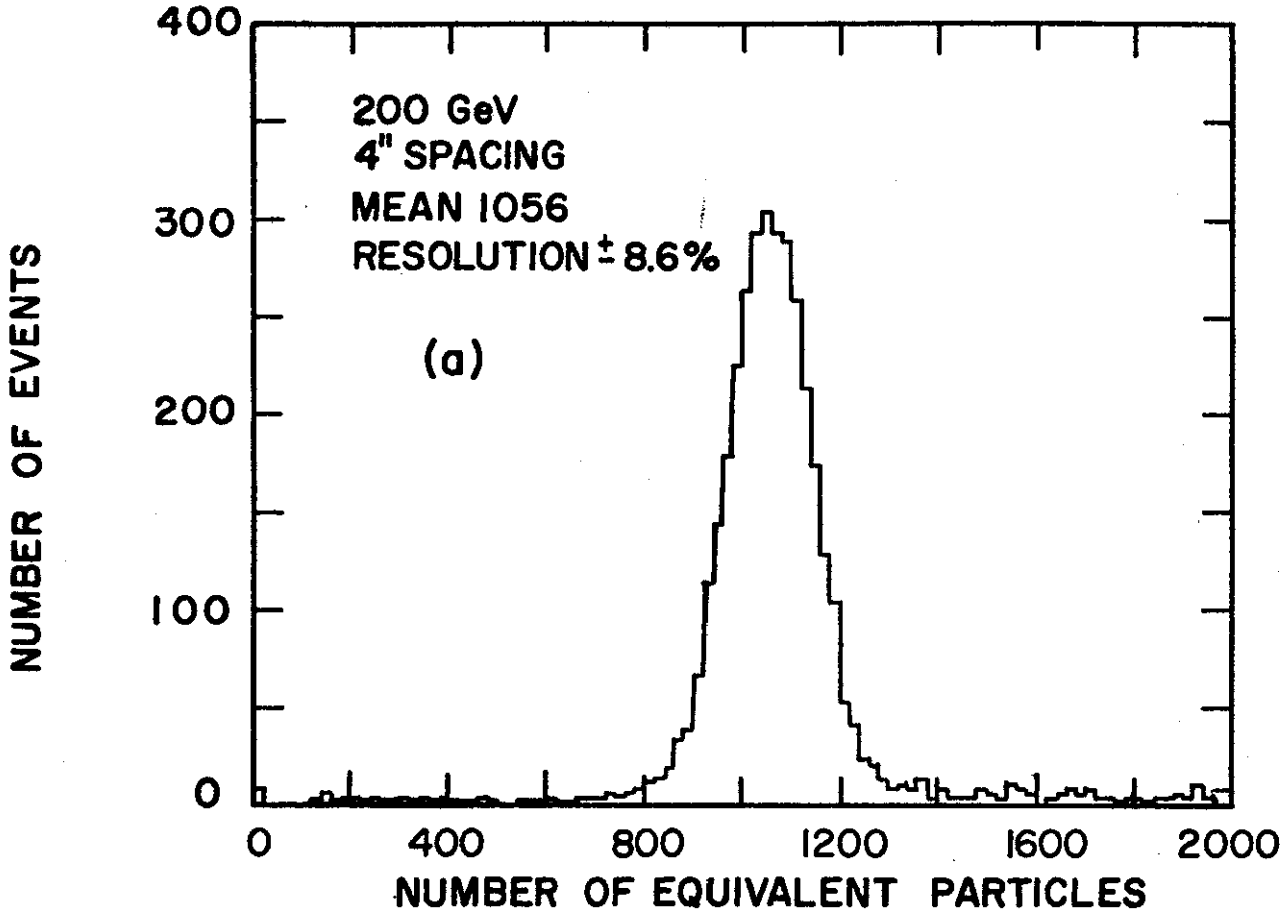
Figure 1 - Schematic of the test calorimeter.

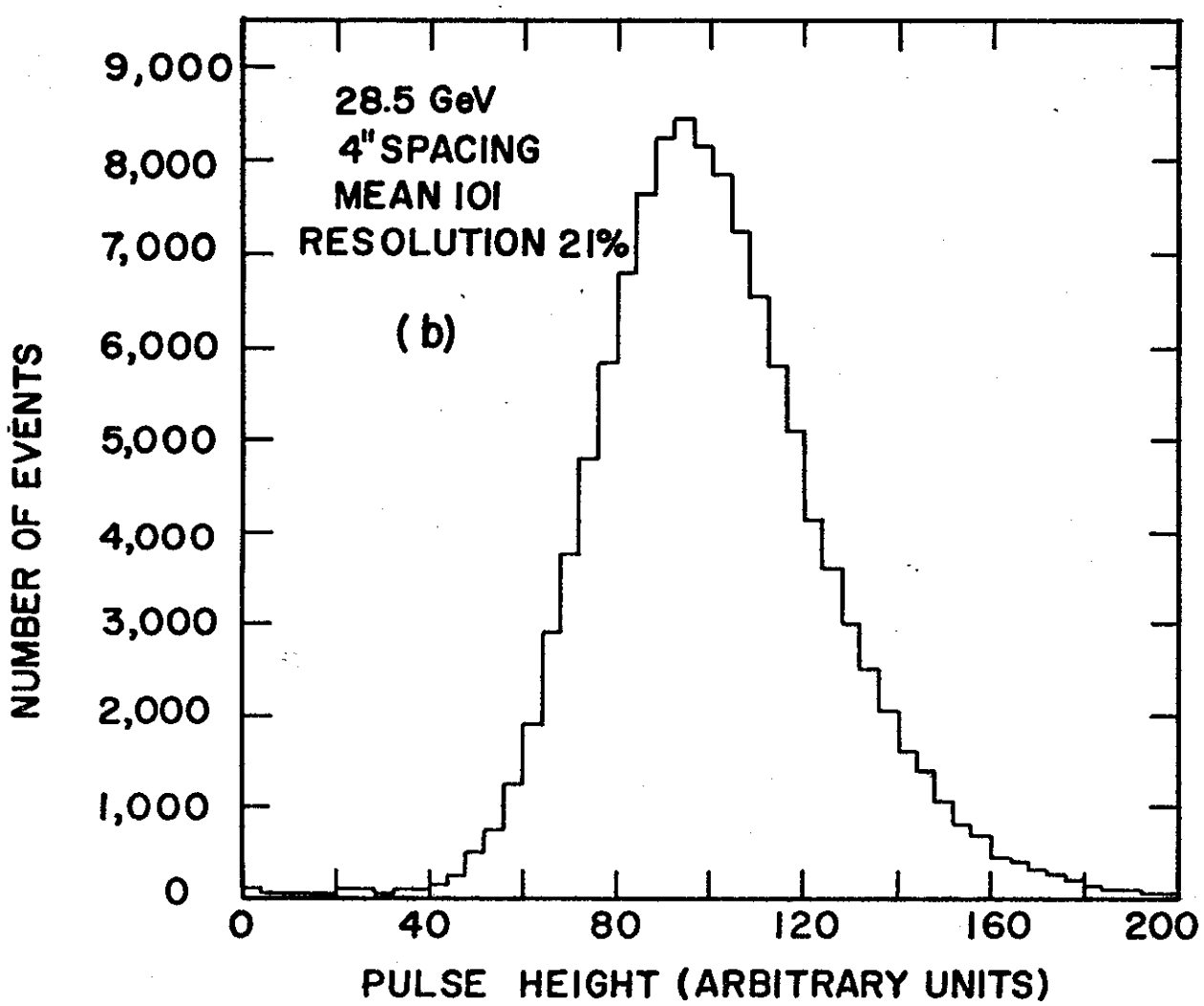
Figure 2 - Pulse height distribution summed over 14 counters. (a) 200 GeV incident particles. (b) 28.5 GeV incident particles (no calibration was done at this energy).

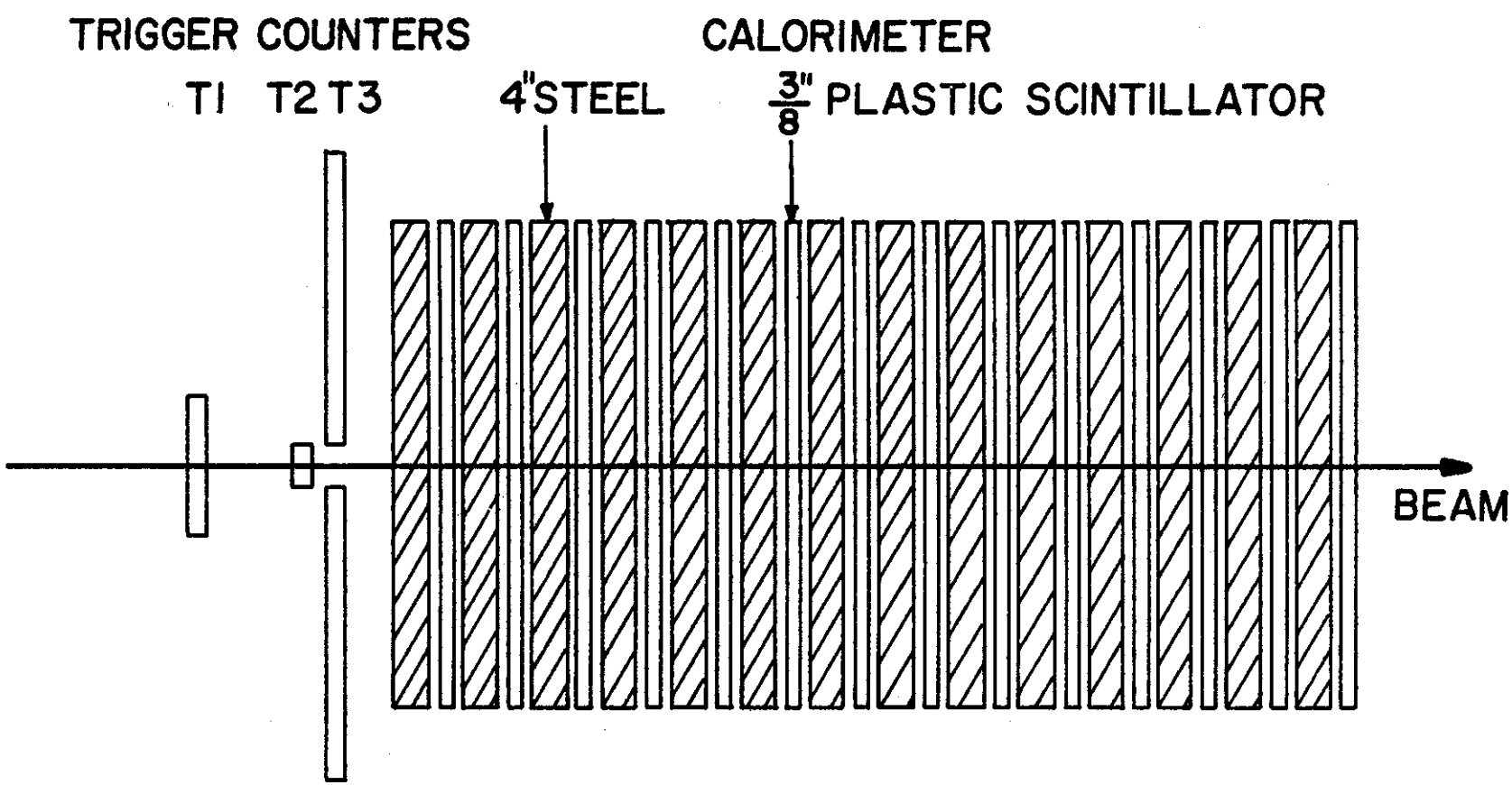
Figure 3 - Calibration (a) and resolution (b) vs. length of the calorimeter.

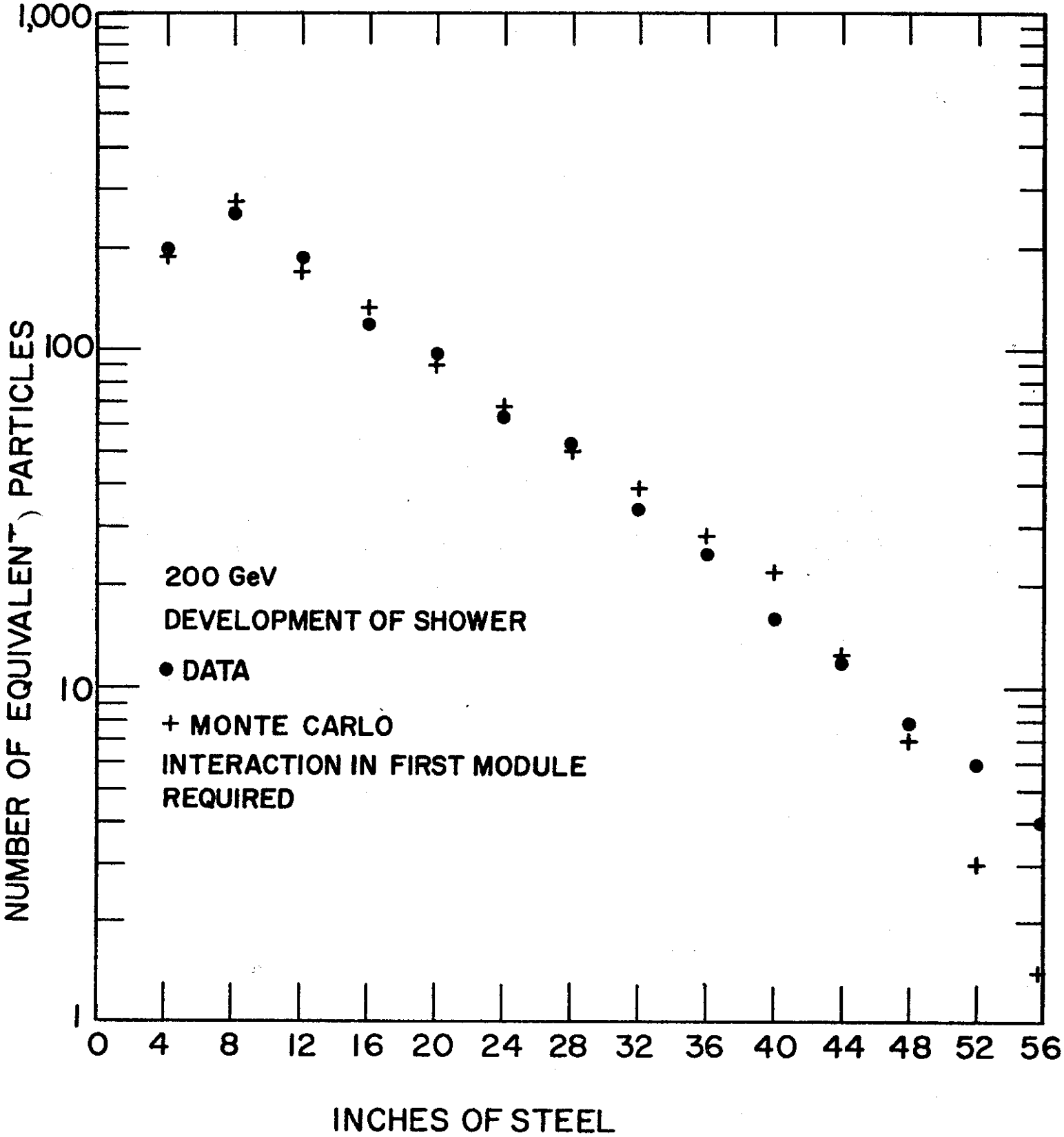
Figure 4 - Mean number of equivalent minimum ionizing particles in each counter.

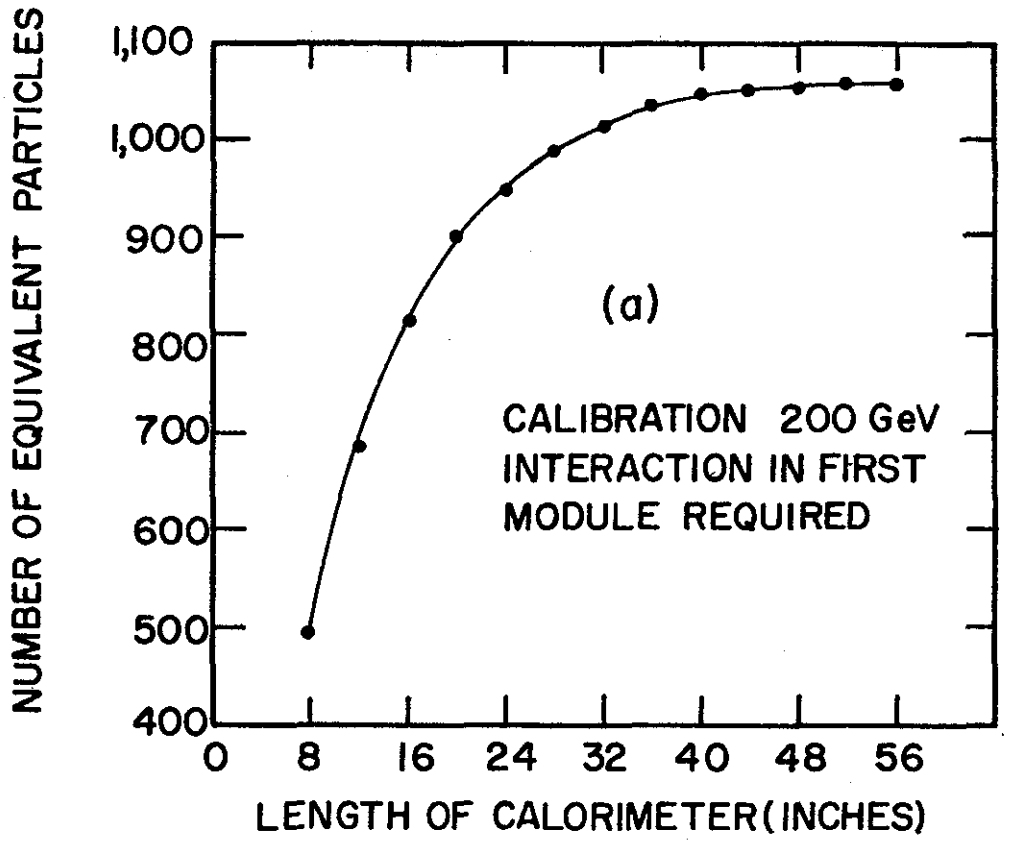
Figure 5 - Resolution vs. spacing between counters.

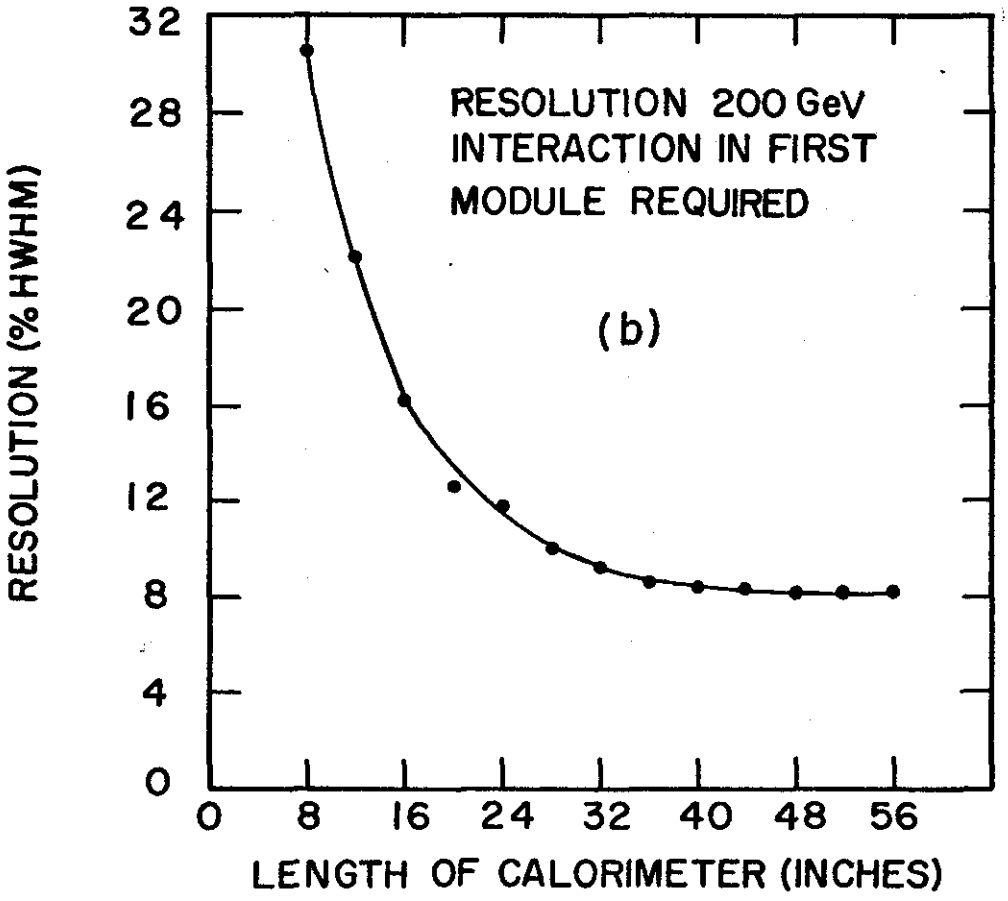

200 GeV
4" SPACING
MEAN 1056
RESOLUTION ± 8.6%
(a)
NUMBER OF EVENTS
0
100
200
300
400
0
400
800
1200
1600
2000
NUMBER OF EQUIVALENT PARTICLES

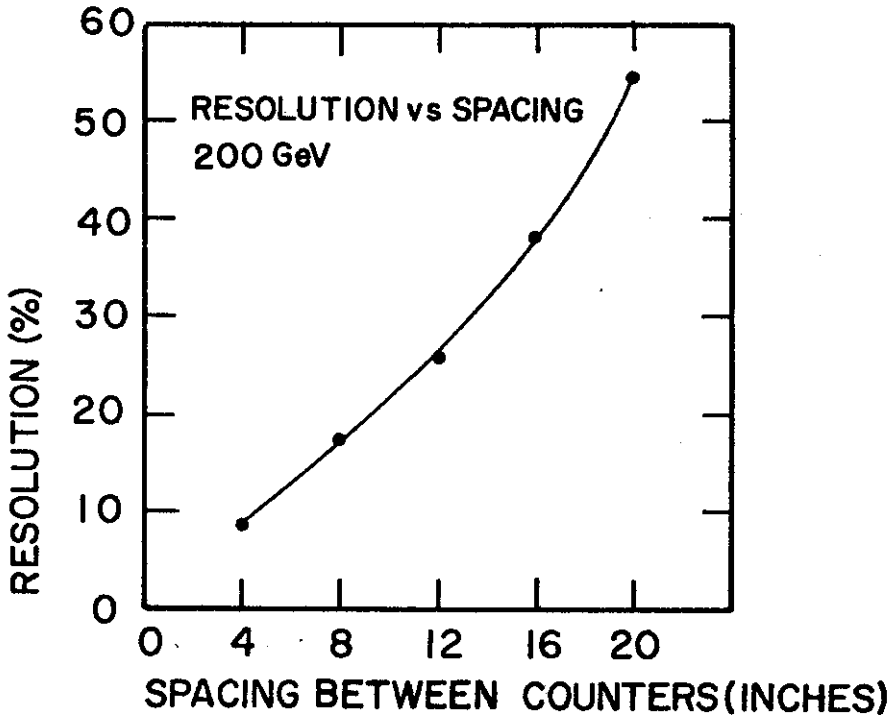

28.5 GeV
4" SPACING
MEAN 101
RESOLUTION 21%
(b)
NUMBER OF EVENTS
0
1,000
2,000
3,000
4,000
5,000
6,000
7,000
8,000
9,000
0
40
80
120
160
200
PULSE HEIGHT (ARBITRARY UNITS)


TRIGGER COUNTERS
T1 T2 T3
CALORIMETER
4" STEEL
3/8" PLASTIC SCINTILLATOR
BEAM


1,000
100
10
1
NUMBER OF EQUIVALENT PARTICLES
200 GeV
DEVELOPMENT OF SHOWER
● DATA
+ MONTE CARLO
INTERACTION IN FIRST MODULE
REQUIRED
0
4
8
12
16
20
24
28
32
36
40
44
48
52
56
INCHES OF STEEL


NUMBER OF EQUIVALENT PARTICLES
1,100
1,000
900
800
700
600
500
400
0
8
16
24
32
40
48
56
LENGTH OF CALORIMETER (INCHES)
(a)
CALIBRATION 200 GeV
INTERACTION IN FIRST
MODULE REQUIRED


RESOLUTION (% HWHM)
32
28
24
20
16
12
8
4
0
0
8
16
24
32
40
48
56
LENGTH OF CALORIMETER (INCHES)
RESOLUTION 200 GeV
INTERACTION IN FIRST
MODULE REQUIRED
(b)


RESOLUTION vs SPACING
200 GeV
RESOLUTION (%)
60
50
40
30
20
10
0
0
4
8
12
16
20
SPACING BETWEEN COUNTERS (INCHES)