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NUCLEAR-ELECTROMAGNETIC CASCADES FROM ALPHA PARTICLES INCIDENT ON AN IRON ABSORBER

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Mean values and fluctuations of the nuclear-electromagnetic cascade development resulting from alpha particles incident on an iron absorber have been determined for the primary energy range 10-300 GeV/nucleon. This has been accomplished by using a three-dimensional Monte Carlo simulation of the cascade process. The model used was first adjusted until it gave predictions for a small ionization spectrometer which agreed with measurements obtained by exposing the same spectrometer to 10, 20.5, and 28 GeV/c protons at an accelerator. The calculations were then modified to apply to high energy alpha particles. The results show that measurements of the energies of alpha particles incident on an iron spectrometer with six interaction lengths total depth can be made with accuracies ranging from ~5% at 300 GeV/nucleon to ~16% at 10 GeV/nucleon.

A Monte Carlo simulation of the nuclear-electromagnetic cascade development in ionization spectrometers has been carried out at Louisiana State University in Baton Rouge. Work reported previous by Jones (1969a,b,c; 1970) on these calculations concerned protons incident on glass, iron, and tungsten absorbers. To be reported here are some results of the calculations for alpha particles incident on an iron absorber. Further work is being done on simulation of the cascade development for heavier nuclei.

The calculations for protons were fitted with measurements made by Jones et al (1969) using an actual iron-absorber spectrometer which was exposed to 10, 20.5, and 28 GeV/c protons from the Brookhaven Alternating Gradient Synchrotron. The extension of the calculations to higher energies and other absorbers was based on the nuclear-electromagnetic cascade model used in the calculations. Details of the model used will not be given here. However, it should be stated that the calculations for alpha particles differ from those for protons, in that each alpha particle was treated as involving four nucleons originally traveling as one nucleus.

In the calculations it was assumed that each nucleon carried 1/4 of the total energy of the alpha particle. Alpha particles incident on the absorber were allowed to interact for the first time at depths governed by random selection from an expontial distribution which had a mean value equal to the mean free path for alpha particles in iron ($\lambda_{\alpha\text{-Fe}} = 0.55\lambda_{p\text{-Fe}}$). The number (1, 2, 3, or 4) of nucleons participating in the interaction was selected at random from a uniform distribution. The nucleons selected as having participated in the interaction were considered as having begun nuclear-electromagnetic cascades by transferring a portion of their energy to produced secondary particles at the interaction point of the alpha particle. The remaining nucleons were assumed to have survived the interaction with no energy loss.

After the first interaction of the alpha particle, each nucleon was treated independently; i.e.; they were treated in the same manner as individual hadrons, undergoing interactions and producing nuclear-electromagnetic cascades. The total number of particles in the cascades produced in this way constitute the number of cascade particles from the original alpha particle.

Figure 1 shows the average number of particles in the nuclear electromagnetic cascade as a function of the depth in the iron absorber. Curves are given for 10, 30, 100, and 300 GeV/nucleon. At each depth there are approximately four times as many particles in the cascade initiated by alpha particles as there are in a cascade initiated by individual protons having the same energy per nucleon. This is to be expected since the alpha particle consists of four nucleons, each capable of generating individual cascades.

Figure 2 shows the relative standard deviation of the number of particles in the cascades as a function of absorber depth. One can see that the fluctuations are quite large at individual depths. The minimum fluctuations occur

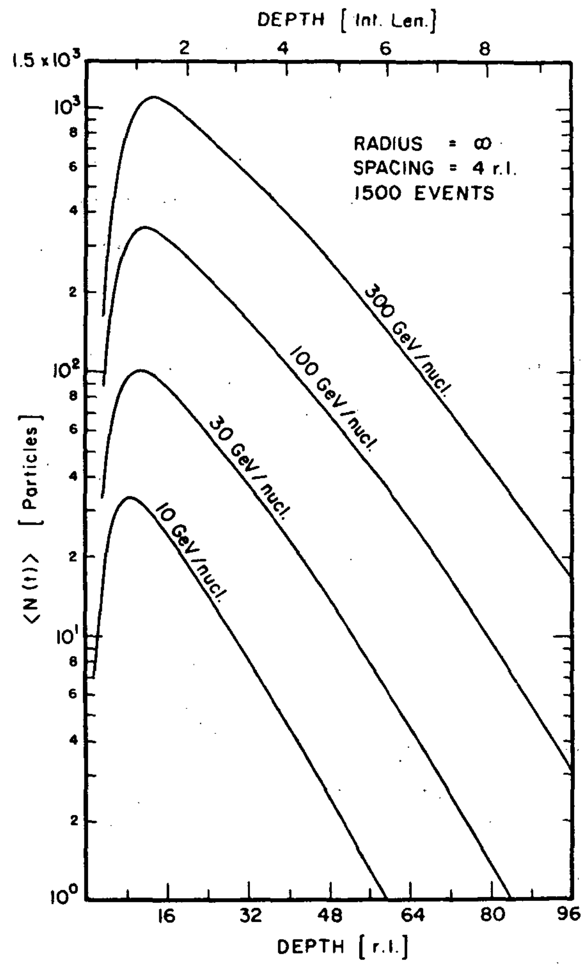

Fig. 1

somewhat later than the maximum of the average cascades. At large depths the fluctuations are smaller for higher energies. If one compares these fluctuations with the fluctuations in cascades initiated by individual protons, one finds that the fluctuations for alpha particles are about 1/2 the fluctuations for protons. This is what one would expect just from statistical fluctuations of the numbers involved.

Figure 3 shows the relative standard deviation of the total number of particles in the cascades summed over consecutive "particle counters" spaced every 4 radiation lengths (r.l.) in the iron. The standard deviations indicate the errors which would be made in using an ionization spectrometer which has similar spacing of the particle counters (ionization sampling layers) for the same total absorber depth. It can be seen that for large absorber depths the relative standard deviations become quite small. To give a specific example, the relative standard deviations for a spectrometer having 5 interaction lengths (int. len.) total depth (and counter spacing every 4 r.l.) are about 15% at 10 GeV/nucleon, 13% at 30 GeV/nucleon, 11% at 100 GeV/nucleon and 10% at 300 GeV/nucleon. For the maximum depth calculated, about 10 int. len., the corresponding standard deviations are 16, 10, 6, and 4.5% for 10, 30, 100 and 300 GeV/nucleon, respectively. Therefore, a spectrometer of sufficiently large depth can provide quite reliable energy measurements.

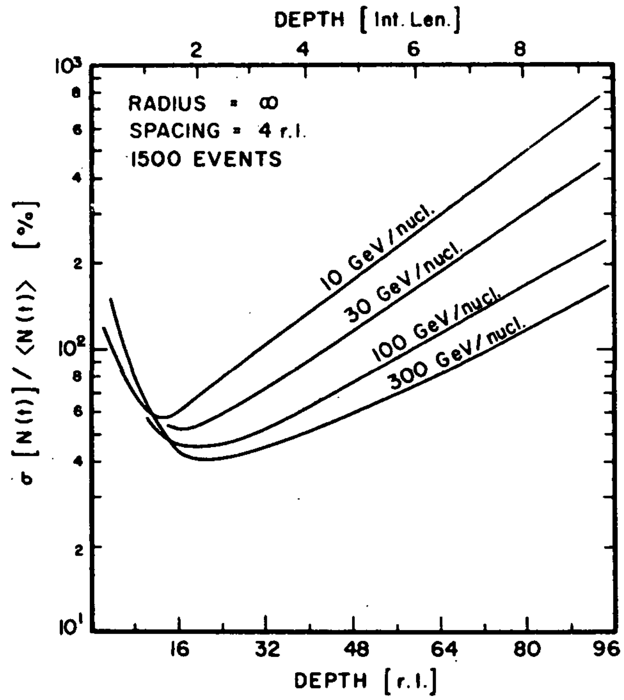

Fig. 2

Figure 4 shows the distributions obtained for a primary energy of 100 GeV/nucleon for three different depths; 2.5, 5, and 10 int. len. For shallow depths (e.g., 2.5 int. len.) some of the incident alpha particles will penetrate the entire absorber without interacting or produce relatively few particles, so that a long lead tail exists in the distribution. For larger depths the distributions are rather narrow. It is obvious than an increase in absorber depth from 2.5 to 5 int. len. results in a greater improvement in the accuracy of primary energy measurements than does an increase from 5 to 10 int. len.

So far, the results given have been for spectrometers having infinite lateral dimensions. However, the calculations were three-dimensional and, therefore, they provide information about the lateral spread of the cascade development. Figure 5 shows the relative number of particles in the cascade as function of the radius R from cascade axis for a total depth of 5 int. len. For infinite radius all the curves go to 100%. A R = 9 r.l., the fraction of the particles contained is 90% at 10 GeV/nucleon, 92.5% at 30 GeV/nucleon, 95% at 100 GeV/nucleon, and 97.5% at 300 GeV/nucleon. In general, the lateral spread is relatively greater for lower energies and larger absorber depths.

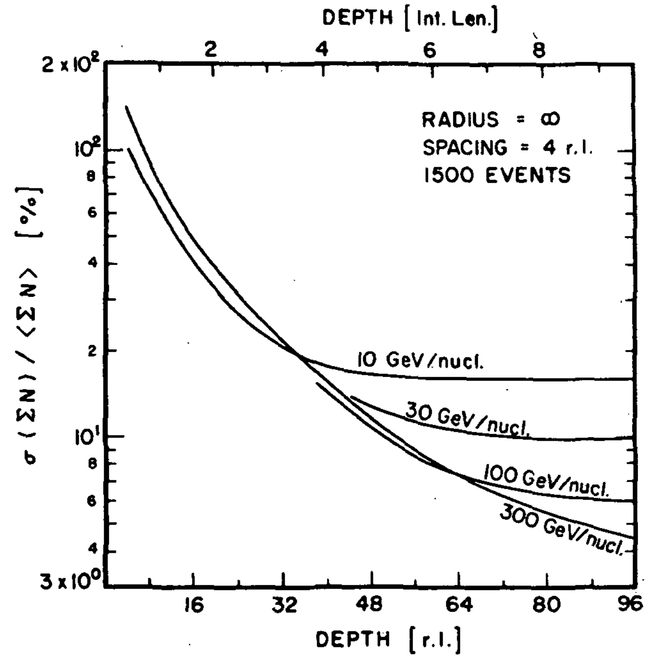

Fig. 3

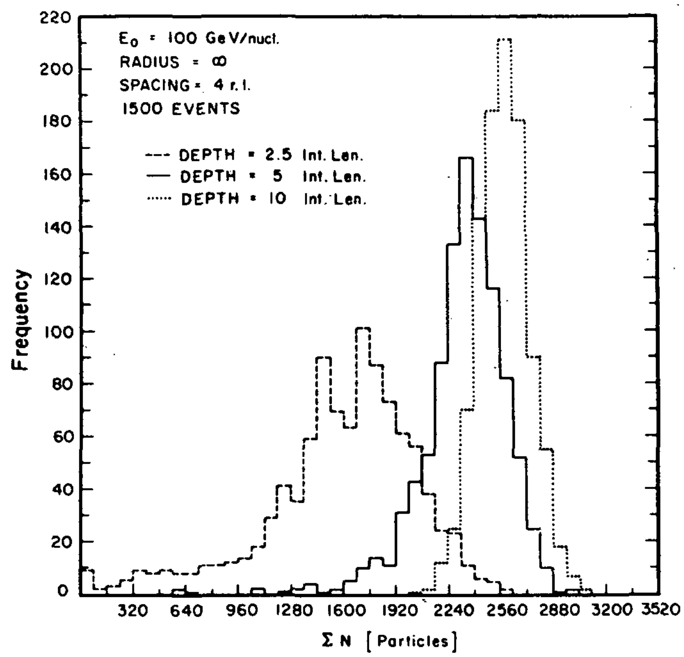
E_0 = 100 GeV/nucl.
RADIUS = ∞
SPACING = 4 r.l.
1500 EVENTS
DEPTH = 2.5 Int. Len.
DEPTH = 5 Int. Len.
DEPTH = 10 Int. Len.
Frequency
ΣN [Particles]
0
20
40
60
80
100
120
140
160
180
200
220
320
640
960
1280
1600
1920
2240
2560
2880
3200
3520

Fig. 4

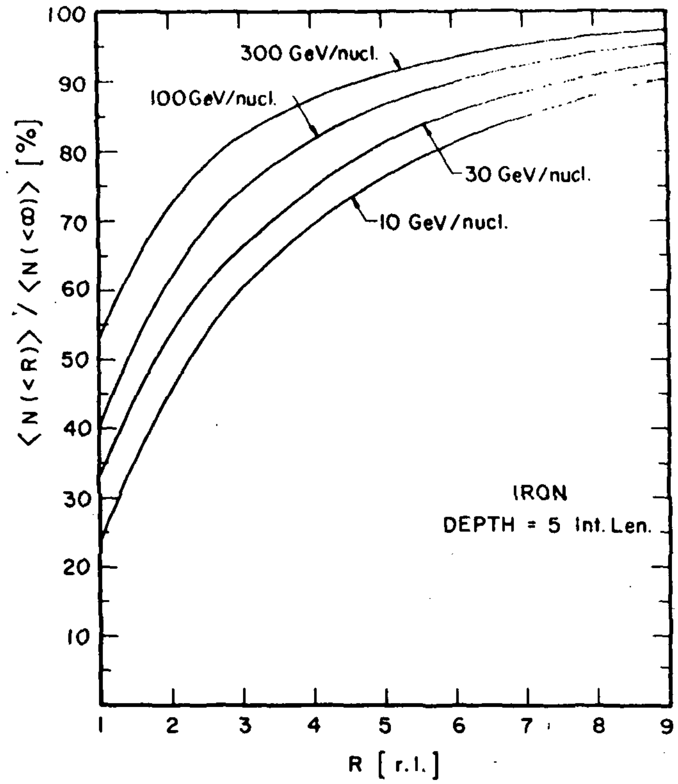

Fig. 5

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