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The A-Dependence of the Ratio R_A for Charged Particle Production In p-Nucleus Interactions.

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From nuclear emulsion data, we show that, for incident proton energies at least equal to 27 GeV, the value of the exponent α in the expression $R_A = A^{\alpha}$ is constant and equal to 0.19, provided that R_A is defined to be the ratio of the charged particles created in p-nucleus and p-p interactions.

The effect of the size of the target nucleus on particle production in hadron-nucleus collisions at high energies is usually determined by comparing the average number of relativistic, charged particles (shower particles) produced with the average charged-particle multiplicity in p-p interactions. The dependence of this ratio on the atomic weight of the target nucleus may be expressed in the following way[1,2]:

$$R_A = \langle n_s \rangle_{p-A} / \langle n_{ch} \rangle_{p-p} = A^{\alpha} \qquad (1)$$

where the value of the exponent α can be determined from experimental data.

In the case of nuclear emulsion experiments, the composite nature of the target has to be taken into account. The value of the ratio for emulsion may be expressed as

$$R_{em} = \langle n_s \rangle / \langle n_{ch} \rangle = \Sigma p_i A_i^{\alpha} , \qquad (2)$$

where the interaction probabilities, p_i, for the various constituent nuclei in emulsion can be calculated from the p-nucleus inelastic cross-sections[3]. The experimental value of $\langle n_s \rangle$ is the average number of particles having a velocity above a certain cut-off (in our case $\beta > .7$) and the value of $\langle n_{ch} \rangle$ is obtained from hydrogen bubble chamber data. The experimental values of R_{em} and the corresponding values of α which give the best fit to the data are given in Table I for incident proton energies from 6.2 GeV to 300 GeV[4-11].

The value of α is seen to increase with increasing energy up

to 200 GeV. At current FNAL energies, α may have reached its limiting value or it may still be a slowly varying function of energy.

The negative values of α at the lower energies are due to the fact that the values of $\langle n_s \rangle$ have fallen below the values of $\langle n_{ch} \rangle$. It is obvious, therefore, that the ratio R_{em}, as defined above is not a meaningful way of comparing particle production in p-nucleus collisions with the multiplicity in p-p collisions. The main reason for the inconsistency in the value of α is that the charged particle multiplicity in p-p interactions always includes, in addition to the particles created, the incident and the target protons. On the other hand, in the case of p-nucleus collisions in emulsion, slow target protons are not included in the value of $\langle n_s \rangle$.

A much more meaningful comparison of the multiplicities in p-nucleus and p-p collisions is obtained by comparing only the average number of charged particles created in the interaction. In the case of p-p collisions, this number is obviously $\langle n_{ch} \rangle - 2$. For emulsion interactions, assuming successive collisons, the correction to be applied to the value of $\langle n_s \rangle$ can be estimated from hydrogen bubble chamber data and ISR experiments. This was done by Calucci et al[12] who found that the average number of slow charged particles ($\beta < 0.7$) emitted in a p-p interaction is 0.62, of which 0.48 are slow protons and 0.14 are slow, charged pions[13]. Knowing the average number of collisions suffered by a proton inside a nucleus[14] and the number of target protons involved, we can estimate

the number of target protons which will be ejected as shower particles. Making the additional correction for the slow, charged pions which are not counted in the shower and removing the incident proton, we can estimate that the average number of charged particles created in a p-emulsion interaction is $\langle n_s \rangle - 1.2$.

We have recalculated the values of R_{em} from the expression

$$R_{em} = \langle n_s - 1.2 \rangle / \langle n_{ch} - 2 \rangle \qquad (3)$$

The new values of R_{em} and the corresponding values of α, for the same experimental data, are tabulated in Table II.

It is seen that R_{em} and hence α, has already reached a constant value at 27 GeV. At this energy, the nuclear response seems to have settled down as indicated by the constancy of $\langle N_h \rangle$[15] [the average number of slow (mainly evaporation) particles resulting from the interaction]. It is interesting to note that the constant value of 0.19 for α has been predicted by the hydrodynamical model[1], in which R_A is equal to the ratio of the entropy change in p-nucleus and p-p collisions and hence refers only to the created particles. The hydrodynamical model is expected to be valid only for energies at least equal to 30 GeV.

The values of R_A (for created particles only) for data with pure targets[16,17] and for emulsion[10,11] are listed in Table III and compared with the predictions of the hydrodynamical model[1], the energy flux cascade model[18] and the multiperipheral model of Lehman and Winbow[19].

We see that the hydrodynamical model is in excellent agreement with practically all of the experimental data. The model of Lehman and Winbow compares more favorably with the data than does the energy flux cascade model. However, detailed information on the rapidity distributions for different targets at various incident energies is required before a decision can be made as to which model gives the best description of multiparticle production from nuclear targets.

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TABLE I. Values of R_{em} and α

Energy (GeV)	$R_{em} = \langle n_s \rangle / \langle n_{ch} \rangle$	α
6.2	0.95 ± 0.02	-0.013 ± 0.006
9.0	0.99 ± 0.06	-0.003 ± 0.016
20.5	1.29 ± 0.03	0.064 ± 0.006
27.0	1.41 ± 0.05	0.084 ± 0.008
67[7]	1.62 ± 0.04	0.125 ± 0.006
200[8]	1.73 ± 0.06	0.141 ± 0.005
300[9]	1.78 ± 0.05	0.145 ± 0.005

TABLE II. Values of $R_{em} = \langle n_s - 1.2 \rangle / \langle n_{ch} - 2 \rangle$ and α

Energy (GeV)	R_{em}	α
6.2	1.66 ± 0.10	0.129 ± 0.015
9.0	1.58 ± 0.20	0.117 ± 0.031
20.5	1.93 ± 0.10	0.166 ± 0.012
27.0	2.18 ± 0.08	0.193 ± 0.010
67	2.14 ± 0.10	0.193 ± 0.012
200	2.12 ± 0.10	0.189 ± 0.011
300	2.14 ± 0.07	0.192 ± 0.008

TABLE III. Experimental and theoretical values of R_A

Energy (GeV)	Target	Experiment	Hydrodynamical Model	Energy Flux Cascade Model	Model of Lehman and Winbow
160	Al	1.89 ± 0.15	1.87	1.32	1.51
160	Fe	2.08 ± 0.17	2.15	1.49	2.00
160	Sn	2.26 ± 0.21	2.48	1.71	2.70
160	Pb	2.55 ± 0.26	2.75	1.90	3.38
260	Al	1.87 ± 0.19	1.87	1.32	1.44
260	Fe	1.92 ± 0.19	2.15	1.49	1.85
260	Sn	2.24 ± 0.23	2.48	1.71	2.45
260	Pb	2.31 ± 0.24	2.75	1.90	3.03
520	Al	1.73 ± 0.35	1.87	1.32	1.36
520	Fe	2.00 ± 0.39	2.15	1.49	1.72
520	Sn	2.14 ± 0.49	2.48	1.71	2.22
200	AgBr	2.41 ± 0.19	2.37	1.64	2.37
200	CNO	1.59 ± 0.22	1.64	1.20	1.19
200	Em	2.12 ± 0.10	2.13	1.50	2.02
200	W	2.97 ± 0.76	2.69	1.87	3.08
300	AgBr	2.37 ± 0.12	2.37	1.64	2.20
300	CNO	1.65 ± 0.12	1.64	1.20	1.17
300	W	2.66 ± 0.28	2.69	1.87	2.82
300	Cr	1.92 ± 0.22	2.12	1.48	1.77