maximum and $|\xi|=1$. It is concluded that these data are adequately fit by V-A theory.

VIII. ACKNOWLEDGMENTS

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Anelasticity of p-p Collisions at 2.7 Bev*†

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By following the tracks of particles in a direction generally contrary to that of the incident 2.7-Bev proton beam, a series of observations interpreted as p-p collisions has been made in nuclear emulsions. The angular and momentum distributions of particles outgoing from these interactions, and hence the relative occurrence of p-p collisions with different pion multiplicities, are in reasonable accord with foregoing work. An attempt is made to distinguish triple pion production processes from those of double production. Even though the c.m. kinetic energy distributions for the respective production modes are markedly different, the corresponding anelasticity characteristics show a general similarity.

INTRODUCTION

As observations of increasingly energetic collisions between fundamental particles become possible, it is of interest to examine the concept of collision anelasticity. This appears as a variable quantity in Heisenberg's theory of multiple pion production in nucleon-nucleon interactions.[1] A number of determinations of this quantity has been made on cosmic-ray jets, under some far-reaching assumptions.[2] Direct determination of the anelasticity is only possible when the interaction results in the creation of particles with characteristics clearly distinguishable from those of the primary particles. Then, even if charge exchange occurs, the anelasticity may be defined as the fraction of the available energy in the center-of-mass system of the colliding particles that is carried away by the created particles. When one or more of the created particles is indistinguishable from one of the primaries, it is still possible to test a prediction of the anelasticity characteristic. This is done by designating the created particles in accordance with a convenient rule, and computing the effect of this rule in distorting the theoretical anelasticity characteristic. By this means it has been shown that in the direct creation of an electron pair by a fast electron, the fractional energy loss of the primary to the created pair is satisfactorily predicted by the theory.[3] For those interactions for which the initial particles are not among the products, the term anelasticity must be redefined.

In this study we have determined the anelasticity of a number of proton-proton collisions in emulsion at 2.7 Bev. The measurements were confined to interactions from which at least two charged pions emerged. This enables a comparison of double and triple pion production at an energy for which quadruple production is negligible,[4] yet derived from about 40% of all proton-proton interactions.[4-6] With some exceptions, the determination of anelasticity for collisions in which two charged pions are produced must be regarded as a lower limit of a possible triple pion production process in which the third, neutral, pion escapes undetected.

The nucleon isobar theory has had considerable success in the interpretation of single pion production processes by nucleons,[7] pions,[8] and photons[9] of energies up to about 1 Bev. A prediction of the c.m. kinetic energy distribution of the pions arising from double production

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in a nucleon-nucleon collision has been made using this theory.[10] A prediction of the two-pion anelasticity characteristic at a given energy can then be obtained.

Triple pion production occurs in approximately ten percent of all proton-proton collisions at 2.7 Bev. Although the c.m. momentum distribution of the pions has been derived on the basis of the statistical theory,[11] it is not yet possible to extend the nucleon isobar theory to this case.

EXPERIMENTAL

Ilford *G*5 emulsions 400 microns thick were exposed in the scattered internal beam of the Cosmotron. The energy and spread of the incident protons were checked by two methods. Direct measurement of the relative multiple scattering was made over a total distance of 5 cm in which two beam tracks were simultaneously observed.[12] Then for ten two-prong stars which were initiated by beam particles and which satisfied a condition ($<2°$) of coplanarity, the incident energy was determined from the polar angles of the emergent tracks. The spread of individual determinations of beam energy by both relative scattering and dynamical methods was about $\pm 10\%$, and within these limits the two methods were in agreement.

Collisions of beam particles with hydrogen nuclei were found both by beam track following and by random track selection with backward following.[13–15] No attempt was made to determine absolute cross sections. We find, however, reasonable agreement with the Rochester group in prong distribution when we apply similar criteria for the designation of proton-proton collisions.[5] Thus, among 105 "hydrogen" collisions we find 85 which have only two charged products and of these we identify only ten as elastic and another ten as quasi-elastic. Applying missing mass evaluations as far as possible, our conclusion of multiplicity distribution is $0:1:2:3 = 19\pm 4:39\pm 10:31\pm 12:11\pm 4\%$, again in agreement with the work of Cester *et al.* Where the transverse momenta are determined, they are found to be ~ 300 Mev/c.

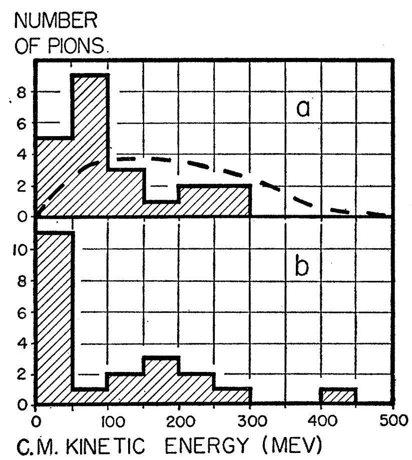

FIG. 1. The observed distribution of pion kinetic energies in the c.m. system for (a) double pion production, and (b) triple pion production in 2.7-Bev p-p collisions. The dashed curve in (a) indicates the prediction of the double-isobar model with isotropic emission.

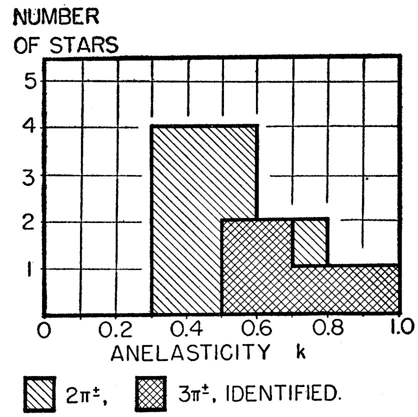

FIG. 2. Distribution in k value for 18 p-p interactions at 2.7 Bev from which originate at least two charged pions. For two of the triple production collisions, the third pion is neutral. The k-threshold values for double and triple production are 0.28 and 0.42, respectively.

In Fig. 1 the c.m. kinetic energy distribution for pions from double production collisions is compared with that for triple production; the maximum of the former distribution appears to be significantly higher than for the latter. However, for our measurements on double pion production, both the peak value of c.m. kinetic energy and the width of the peak appear to be smaller than might be expected from the double isobar model, represented by the dashed normalized curve in Fig. 1(a). This curve is derived from the work of Lindenbaum and Sternheimer and assumes isotropic emission of the isobars.

We have determined for eighteen p-p collisions the anelasticity k as the ratio of the sum of pion total energies in the c.m. to the available energy in the c.m. The k-value distribution for eleven p-p collisions from which two charged pions are emitted is shown in Fig. 2. Among these are eight four-prong stars with two identifiable charged pions. The assignments ($pp+-$), ($pp+-0$), or ($pn++-$) are possible. The other three are two-prong stars, for which both outgoing tracks are due to charged pions. These are assigned as ($nn++$) or ($nn++0$). On account of the uncertainty of assignment for these eleven collisions, the k values determined can only be regarded as a lower limit. The threshold k value for double production is 0.28. Also shown in Fig. 2 is the k-value distribution for seven triple-production interactions. Five of these are distinguished as

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($pn++-$), and the remaining two are completely analyzed with missing mass evaluation consistent with single neutral pion emission ($pp+-0$). The k values of these seven triple production collisions are distributed between 0.5 and unity with a threshold value of 0.42.

It might be expected that the anelasticity characteristic of a nucleon-nucleon collision would rise from a threshold, determined by the pion multiplicity, and exhibit a form dependent on the primary energy. Our results indicate that the characteristics for both double and triple production pass through broad maxima about 50% above the respective thresholds, then fall to a low value as k approaches unity. This similarity occurs even though the c.m. kinetic energy distribution of pions from triple production collisions differs from that for double production, as shown in Fig. 2. Our limited information regarding the velocities and directions of motion of the emitted nucleons enables, for some of the interactions, the determination of Q values of possible isobaric states.

It is evident that the measurements shown in Fig. 2 must be regarded with reserve. This caution is necessary because a fraction of the emergent pions in these experiments is not identified. The reason for this is twofold—failure to distinguish pions from protons close to the forward direction and emission at large laboratory-system angles when produced in the backward hemisphere. Also, the selection of stars on the basis of analyzable pions might introduce a bias in favor of low values of k. On the other hand, the chance inclusion of a proton-nucleus collision, which otherwise satisfies all the criteria for a p-p collision, might lead to the inference of unduly high anelasticity.

As the available energy in the c.m. system increases, the threshold values of k for production of a few pions drop toward zero. Measurements on jets[16] suggest that at very large energies the maximum of the k distribution may follow the threshold down. The observations made here indicate that this tendency is true even at low energies.

Our present results lead to an average value of k for double and triple production, $k=0.55\pm0.10$, similar to results obtained at higher energies and comprising multiplicities up to six.[17] The widespread nature of the k distribution, however, shows that an average value of k is not very meaningful.

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Implications of the Intermediate Boson Basis of the Weak Interactions: Existence of a Quartet of Intermediate Bosons and Their Dual Isotopic Spin Transformation Properties

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Assuming that all weak interactions are transmitted through an intermediate boson field W, it is shown that the observed $|\Delta\mathbf{I}|=\frac{1}{2}$ rule and the small observed mass difference between K_1 and K_2 lead to the conclusion that there exist four W particles: $W^{\pm}$, W^0, and $\bar{W}^0$. Furthermore, a natural assignment of the isotopic spin transformation property of these W particles follows a dual scheme in which the W's behave sometimes as $I=\frac{1}{2}$ and sometimes as $I=1$ particles. Various experimental implications are discussed, including neutrino capture experiments, strong collisions exhibiting apparent nonconservation of strangeness, and strong collisions with apparent lepton production.

I. INTRODUCTION

It is the purpose of this paper to study the consequences of the following three propositions:

(i) All weak interactions are transmitted through an intermediate boson field W.

(ii) The mass difference between K_1 and K_2 is of the order of $\sim10^{-5}$ ev and not ~10 ev. This implies[1] that $\Delta S=\pm2$ interactions are absent in the usual weak interactions.

(iii) The $|\Delta\mathbf{I}|=\frac{1}{2}$ rule holds for the strangeness nonconserving decays of particles, where $\mathbf{I}$ is the total isotopic spin of the strongly interacting particles (i.e., baryons and the K and π mesons).

Of these propositions, (iii) has had quite impressive experimental support.[2] Evidence for (ii) has been re-

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