DIRECT PRODUCTION OF ELECTRON-POSITRON PAIRS BY 16.2-BeV/c NEGATIVE PIONS*

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In this experiment direct production of electron-positron pairs by 16.2-BeV/c negative pions in nuclear emulsion is investigated. Previous experiments[1,2] generally have agreed with more recent theoretical cross-section calculations[3,4] and have shown that earlier calculations[5] were inadequate. The present experiment, with better statistics, disagrees with both previous experimental results and theoretical results, particularly at large pair energies.

Electron-positron pairs used in this analysis were obtained by scanning 903 m of track. A scanning rate of about 23 cm per hour was used after a sample scan indicated results comparable with those at a rate of 14 cm/h. Events were identified as examples of direct pair production after careful analysis of three possible sources of selection error: (i) gamma conversion pairs with pair origins coincident with the pion track (coincidence pairs), (ii) knock-on electrons, and (iii) pion-nucleon interactions which yield an observable final state of three minimum-ionizing tracks, one of which is directed within 1° of the incident pion direction.

Coincidence pairs originate mainly from two sources: conversion of forward bremsstrahlung gamma rays from the beam pions and conversion of gamma rays from the decays of neutral pions produced upstream in nuclear interactions. Such coincidence pairs will be indistinguishable from directly produced pairs if they originate within the minimum resolvable distance in emulsion (<1 μ in Ilford K-5). An estimation of the number of unresolved coincidence pairs was obtained by observing the number of resolved coincidence pairs originating within 6 μ of the pion track and from this determining the number expected to have originated within 1 μ of the track, assuming an isotropic distribution within these distances. The use of 1 μ as the minimum resolvable distance between pair origin and pion track is an overestimate which gives an upper limit to the number of coincidence pairs identified as directly produced pairs. In a sample scan of 258 m of track, 21 resolvable coincidence pairs were found to originate within 6 μ of the pion track. Estimating a 70% detection efficiency for these pairs indicates that 3 coincidence pairs should be found within 1 μ of the 903 m of tract scanned.

Piron et al.[6] have made a theoretical investigation of the expected number of bremsstrahlung coincidence pairs. From this result we estimate that in 903 m of 16-BeV pion tract, 0.02 coincidence pairs should be found with origins within 1 μ of the pion track. It is expected that bremsstrahlung coincidence pairs will dominate random-background coincidence pairs. The theoretical result appears to give a considerable underestimate of the number of coincidence pairs.

The second source of selection error arises because some pair events occur with one of the electrons having a very low energy. These events, unless carefully analyzed, may be misinterpreted as knock-on electrons. Since the knock-on process is a two-body process, a determination of the emission angle of a knock-on electron determines its energy. All apparent knock-on electrons which did not satisfy this energy-angle relationship were examined very carefully for a possible second low-energy track.

Two types of final states from pion-nucleon strong interactions resemble direct electron-pair production. One of these is the final state with three visible secondary particles, all minimum ionizing, with one track directed within 1° of the incident pion direction. These events were separated from electron-pair events by making use of the large fractional energy loss by electrons as they traverse matter.

The second type of strong interaction event resembling directly produced electron pairs is single π^0 production and subsequent decay into an electron-positron pair. The number of such Dalitz pairs expected in our sample can be estimated by determining the number of pion-nucleon interactions with two, three, or four minimum-ionizing secondaries only and applying charge independence. From the numbers of such events found in the experiment we estimate that there is about one event in 900 m of track where the final state is a single charged pion, whose direction is within 1° of the incident direction, and one or more neutral pions. Since the probability for π^0 decay into an electron pair is about 1% of the total decay probability, we anticipate $\ll$1 Dalitz pairs to be identified as directly

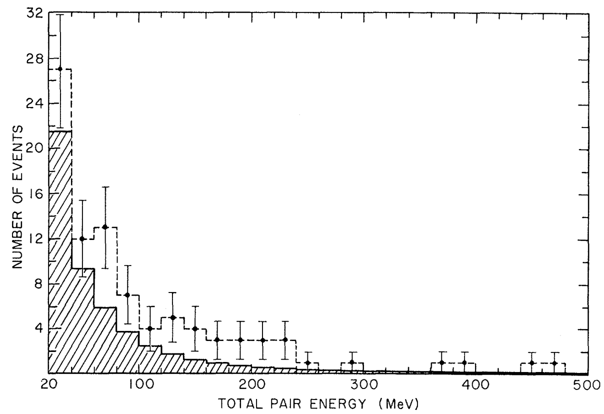

FIG. 1. Distribution of the total number of electron pairs per 20-MeV total pair energy found in 903 m of tract (indicated by dashed line) with the number predicted by Ternovskii superposed (cross-hatched area).

produced pairs in this experiment.

Electron energies were measured by multiple Coulomb scattering using a modification of the Barkas method.[7] The reliability of the method was checked by measuring the known (from angles of emission) momenta of knock-on electrons having a spectrum of momenta representative of those measured for pairs. The scattering method used was shown to have a high probability of giving momenta within error of the actual momenta (as determined from angle of emission) for the knock-on electrons. However, there was a tendency for measured energies to be on the lower rather than the upper side of the expected energy. Since electrons can radiate large amounts of energy in small distances, the scattering method gave reasonable results.

99 electron pairs with total pair energy >10 MeV were determined to be directly produced pairs. Of these, 90 had total energy greater than 20 MeV. Because of decreased detection efficiency at low energies, the data below 20 MeV is probably not reliable. A histogram of the data is shown in Fig. 1, where a comparison with the calculation of Ternovskii[4] is given. The figure indicates a large discrepancy between experiment and theory, especially above about 60-MeV total pair energy. A detailed examination of the theoretical calculation indicates that the result can be normalized, if necessary, to fit the data. The type of normalization indicated is approximately a multiplicative scaling of the differential cross section. Table I includes such results, where the theoretical cross section has been normalized to fit the data in the energy interval between 20 and 40 MeV. This energy interval was chosen since this is the region where the theory should be most reliable. Even when the theory is normalized, the experimental cross section is nearly three times the theoretical cross section for the region of pair energies

Table I. Comparison of experiment and theory for various energy intervals (N = number of electron pair events; σ = cross section in mb).

Total Pair Energy Interval (MeV)	Experiment		Ternovskii[4]		Ternovskii (Normalized)		Murota[3] (Normalized)	
	N	σ	N	σ	N	σ	N	σ
20-1000	90	12.7 ± 1.9	52.4	7.5	64.5	9.1	65.0	9.2
20-60	39	5.5 ± .9	31.8	4.6	39.6	5.6	39.9	5.6
60-1000	51	7.2 ± 1.0	20.6	2.9	24.9	3.5	25.1	3.5
20-80	52	7.3 ± 1.0	37.7	5.3	46.8	6.6	47.4	6.7
80-1000	38	5.3 ± .9	14.7	2.1	17.7	2.5	17.6	2.5
20-100	59	8.3 ± 1.1	41.6	5.8	51.4	7.2	52.0	7.3
100-1000	31	4.4 ± .8	11.0	1.5	13.1	1.8	13.0	1.8
20-120	63	8.9 ± 1.1	44.0	6.2	54.4	7.6	55.1	7.7
120-1000	27	3.7 ± .7	8.5	1.2	10.1	1.4	9.9	1.4
20-140	68	9.5 ± 1.1	46.2	6.5	52.2	7.3	57.3	8.0
140-1000	22	3.1 ± .7	6.3	.9	7.9	1.1	7.7	1.1

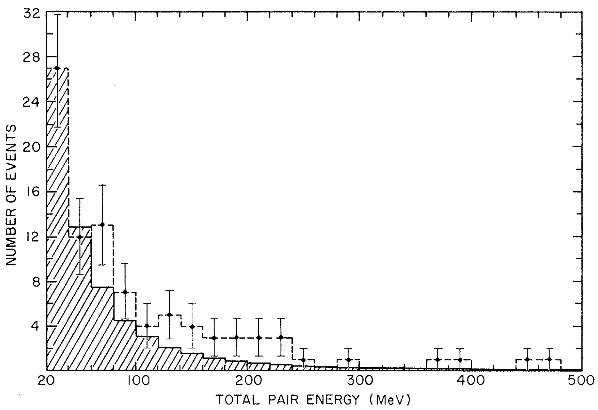

FIG. 2. Distribution of the total number of electron pairs per 20-MeV total pair energy interval found in 903 m of track (indicated by dashed line) with the theoretical results (cross-hatched area) of Murota et al., normalized to fit at low energies, superposed.

above about 100 MeV.

Figure 2 gives a similar comparison of the experimental results with the theoretical results of Murota et al., which were calculated for spin-$\frac{1}{2}$ primaries only. This cross section contains a normalizing factor, α_m, which must be determined experimentally. A value $\alpha_m = 2.1$ gives agreement between theory and experiment in the interval of total pair energy between 20 and 40 MeV. Again, normalization is performed at low energies because this is the region where the theoretical calculation is expected to be most valid. Disagreement is still found at energies >60 MeV, with fractional disagreement increasing at higher energies (see Table I). As can be seen, there is a considerable difference between the shapes of the experimental and the theoretical distributions. As shown in the table, the normalized results of Ternovskii and of Murota et al. are quite similar over the entire energy region.

The data given here do not take into account several sources of error. First, scanning efficiency has not been included. Rescan, azimuthal angular distributions, and consistency checks indicate around 80% detection efficiency for pairs with total energy greater than 20 MeV. Taking this into account increases the discrepancy between theory and experiment. In addition, measured electron energies showed a slight tendency to be too low. If this effect were taken into account, it would displace the experimental curve to the right-hand side in Fig. 1 and again increase the discrepancy between theory and experiment.

Thus, the experimental result for the total cross section for the direct production of electron-positron pairs of 16-BeV negative pions appears to be in marked disagreement with theoretical predictions. More data are being collected, and a more complete description of the experiment will be published. A more detailed analysis of this experiment can be found in the unpublished work of Kinzer.[8]

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