determination.

It is possible to define a "normal distribution" giving the ratios of meson yields in the electron-proton collision process as compared with those obtained in the photoproduction process. This essentially involves the Weizsäcker-Williams approximation of replacing the current matrix element by its transverse part corresponding to an electromagnetic wave propagating in the direction of the incident beam. The method is essentially that outlined in reference 1.

We start with the differential cross section for multiple meson photoproduction:

$$\int_{k_{\min}}^{k_{\max}} (d^2\sigma_k/d\omega_{\vec{q}}\,d\Omega_{\vec{q}})\,(dk/k)$$
$$= (1/128\,\pi^5)\int\cdots\int (M^2/E_{\vec{p}}E_{\vec{p}'})\,qq'\omega_{\vec{q}}\,\omega_{\vec{q}'}$$
$$\times (dk/k^2)\,d\Omega_{\vec{q}'}\,\Phi_T(\vec{k},\vec{q},\vec{q}). \qquad (2)$$

For the electron-proton collision process, the cross section is

$$(d^2\sigma_p/d\omega_{\vec{q}}\,d\Omega_{\vec{q}})$$
$$= (1/128\,\pi^7)\int\cdots\int (M^2/E_{\vec{p}}E_{\vec{p}'})\,dp'\,d\Omega p'\,d\Omega q'$$
$$\times\{qq'\,\omega_{\vec{q}}\,\omega_{\vec{q}'}/(k^2-k_0{}^2)^2\}\,\Phi(k,k_0,\vec{q},\vec{q}'). \qquad (3)$$

The notation here is that of reference 1. We may now substitute the transverse matrix element for current, as given in (2), into relation (3). The result is

$$|dY_p/dY_k| = N_e(p,p')\,k_f, \qquad (4)$$

where

$$Y_p = (d^3\sigma_p/d\omega_{\vec{q}}\,d\Omega_{\vec{q}}\,dp'),\quad Y_k = d^2\sigma_k/d\omega_{\vec{q}}\,d\Omega_{\vec{q}},$$

with

$$k_f = p - p_f{}'.$$

The latter quantities (Y's) can be determined experimentally by observing pion yields as functions of the energies of the incident beams. The right-hand side of (4) is the "normal distribution" defined in reference 1.

Equation (4) may be used as a basis of comparison, since the actual ratio will involve contributions from the longitudinal components of current as well as the transverse parts. The total effect has been computed using the Chew-Low matrix elements for the current.[3,4] As pointed out in reference 1, the static approximation to the longitudinal matrix elements ought to be modified by a factor

$$2k_0E/(E^2-M^2). \qquad (5)$$

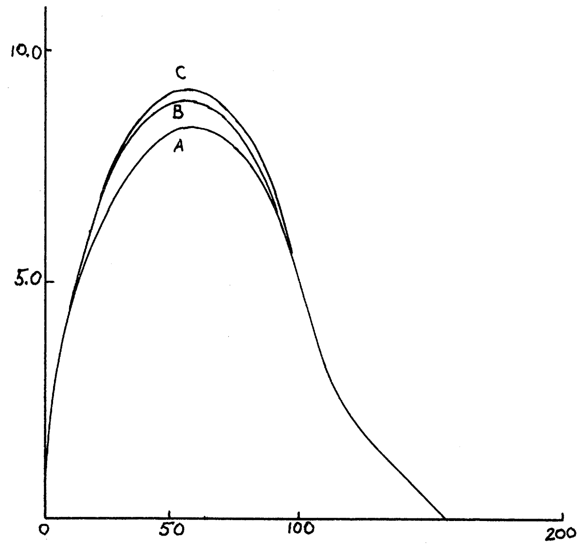

FIG. 1. Theoretical curve of $d^2\sigma_p/d\omega_{\vec{q}}\,d\Omega_{\vec{q}}$ in micro-microbarns per steradian per Mev as a function of the kinetic energy of the negative pions. Curve (A) represents the result obtained using the transverse matrix element alone. Curve (B) represents the result using both longitudiaal and transverse matrix elements. Curve (C) represents the result obtained if the longitudinal matrix element is used without the factor (5).

The results of the calculation are illustrated in Fig. 1 where it may be seen that the effect of the longitudinal current is fairly small. Thus it is not clear whether it is possible to construct an experiment sufficiently sensitive to detect the effect of a factor such as (5).

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BETA-NEUTRINO-ALPHA DIRECTIONAL CORRELATION*

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Recently we have proposed thirty-three possible experiments to decide the relative strength of scalar and vector interactions and that of tensor and axial vector interactions in beta decay.[1] Those are measurements of the recoil nucleus and of the nuclear fluorescence resonance in the decays involving beta-gamma, beta-gamma-gamma, and K capture-gamma-gamma cascades. Now a similar consideration is done for the decay involving a beta-alpha cascade.

The beta-neutrino-alpha directional correlation is immediately derived from the beta-neutrino-gamma angular correlation,[2] replacing $(L_1L_1'\,1\text{-}1\,|\,n0)$ in $F_n(L_1L_1'j_2j_1)$ by $-(L_1L_1'00\,|\,n0)$, where both L_1+L_1' and n are even.[3] The result for allowed beta transitions in the decay scheme $j(\beta)j_1(\alpha)j_2$ is

$$
\begin{aligned}
&W(\vec{p},\vec{q},\vec{k},E)\,dE\,d\Omega_e d\Omega_\nu d\Omega_\alpha \\
&\quad = F(Z,E)pq^2E\,dE\,d\Omega_e d\Omega_\nu d\Omega_\alpha\,\xi\Big([1+a(\vec{p}\cdot\vec{q}/Eq)+(b/E)][\textstyle\sum_{L_1}(j_2\,\|\,L_1\,\|\,j_1)^2]+c'[3(\vec{p}\cdot\vec{k})(\vec{q}\cdot\vec{k})-\vec{p}\cdot\vec{q}] \\
&\quad \times(Eq)^{-1}\{\textstyle\sum_{L_1,L_1'}(-)^{j_2-j_1}[(2j_1+1)(2L_1+1)(2L_1'+1)]^{\frac{1}{2}}(L_1L_1'00\,|\,20)W(j_1j_1L_1L_1';2j_2) \\
&\qquad\qquad \times(j_2\,\|\,L_1\,\|\,j_1)(j_2\,\|\,L_1'\,\|\,j_1)\}\Big)
\end{aligned}
\tag{1}
$$

Here we use the same notation as in reference 2, except that $\vec{k}$ is the unit momentum vector of the alpha particle and $(j_2\,\|\,L_1\,\|\,j_1)$ is the relative intensity of the L_1th partial wave of the alpha particle. c′ is given by

$$
\begin{aligned}
c'\xi = {}&[(|C_T|^2+|C_T'|^2-|C_A|^2-|C_A'|^2)\pm(\alpha Z/p) \\
&\times 2\,\mathrm{Im}(C_TC_A^*+C_T'C_A'^*)]M_{GT}^2 \\
&\times[(2j_1+3)(j_1+1)/45j_1(2j_1-1)]^{\frac{1}{2}}\Lambda_{jj_1}
\end{aligned}
\tag{2}
$$

for $\beta^\mp$, with

$$
\begin{aligned}
\Lambda_{jj_1} &= 1 && \text{for } j\to j_1=j+1, \\
&= -(2j_1-1)/(j_1+1) && \text{for } j\to j_1=j, \\
&= j_1(2j_1-1)/(2j_1+3)(j_1+1) && \text{for } j\to j_1=j-1.
\end{aligned}
$$

The directional correlation function of the beta and alpha particles and the recoil nucleus will be given from Eq. (1) by substituting $1\to 2\pi/q$ and $(\vec{p}\cdot\vec{q})$ and $(\vec{p}\cdot\vec{k})(\vec{q}\cdot\vec{k})\to -2\pi(\vec{p}\cdot\vec{k})(\vec{p}\cdot\vec{k}+\vec{R}\cdot\vec{k}+K)/q$, with $q\geq|\vec{p}\cdot\vec{k}+\vec{R}\cdot\vec{k}+K|$. $\vec{R}$ and K are the momentum of the nuclear recoil and the absolute value of the momentum of the alpha particle, respectively.

The simplest example of the beta-alpha cascade is $Li^8(\beta)Be^{8*}(\alpha)He^4$. In fact, an experiment for this beta decay has been done by Lauterjung, Schimmer, and Maier-Leibnitz.[4] They have counted the beta-alpha-alpha coincidence rate for the geometry indicated in Fig. 1, for which Eq. (1) reduces to

$$
\begin{aligned}
&W(\vec{p},\vec{q},\vec{k},E) \\
&\quad = F(Z,E)pq^2E[1+\alpha X(\vec{p}\cdot\vec{k}/E)(\vec{q}\cdot\vec{k}/q)],
\end{aligned}
\tag{3}
$$

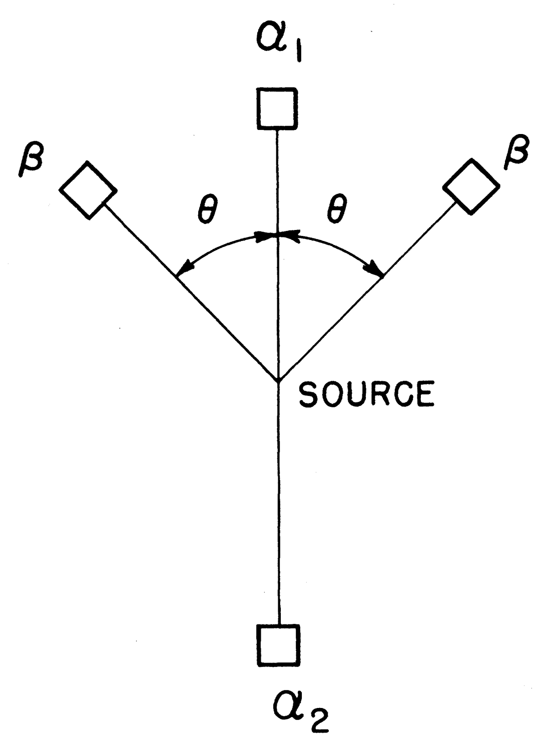

FIG. 1. Geometry for beta-alpha-alpha directional correlation adopted by Lauterjung, Schimmer, and Maier-Leibnitz,[4] and for Eq. (3) in the text. Two alpha counters, α_1, α_2, and two beta ones, β, are placed in a plane. Here α_1 and α_2 are in a line. The two β's have the same angle θ with respect to the direction of α_1. The coincidence rate of α_1, α_2, and β is measured.

with

$$\begin{aligned} \alpha &= -1/3 \quad \text{for } 1_+ \to 2_+ \to 0_+, \\ &= 1 \quad \text{for } 2_+ \to 2_+ \to 0_+, \\ &= 1/7 \quad \text{for } 3_+ \to 2_+ \to 0_+, \end{aligned}$$

and

$$X = (|C_T|^2 - |C_A|^2)/(C_T|^2 + |C_A|^2).$$

Here we assume $C_T = -C_T'$, $C_A = C_A'$, and $M_F = 0$. The last assumption comes from the selection rule of the isotopic spin. Therefore, if the decay scheme is $2_+ \to 2_+ \to 0_+$, this experiment is a more sensitive determination of $|C_T/C_A|^2$ than the electron-neutrino angular correlations of He^6 and Ne^{23}, because the anisotropy for the former is one while that of the latter is only one-third. If M_F is not equal to zero, αX for $2_+ \to 2_+ \to 0_+$ should be replaced by $[(-|C_S|^2 + |C_V|^2)M_F^2 + (|C_T|^2 - |C_A|^2)M_{GT}^2] / [(|C_S|^2 + |C_V|^2)M_F^2 + (|C_T|^2 + |C_A|^2)M_{GT}^2]$. In the case of $2_+ \to 2_+ \to 0_+$, Eq. (3) coincides with Eq. (1) in reference 4. Since the value of $d = \alpha X$ is large and negative with certain experimental error,[4] we can conclude not only that the axial vector is predominant, but also that the spin of Li^8 is 2+ and not 1+ or 3+.

Formulas for more complicated decay schemes involving alpha, beta, and gamma transitions will be derived easily from several formulas in reference 1 with the rule in reference 3.

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LARGE-ANGLE ELECTRON PAIR PRODUCTION FROM HYDROGEN*

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In this experiment, 70-Mev positrons produced in a liquid hydrogen target are detected at 90° to a 137-Mev peak energy bremsstrahlung beam made by passing the electron beam from the Stanford Mark III linear accelerator through a tantalum radiator. Figure 1 shows the two main Feynman diagrams for the process. It is important to note here that uncertainties in the pair-production calculation due to the influence of proton structure on the rescattering of the virtual intermediate lepton can be uniquely removed from the problem. The results of the electron-proton scattering experiments can be used to predict the effect of the proton in pair production. The e-p scattering form factors depend only on the four-momentum transfer and can be introduced phenomenologically into the pair-production calculation. This leaves the electrodynamics as the only source of error in the calculation. A complete calculation of the pair production cross section from protons with form factors including radiative corrections and Compton terms has been carried out by Bjorken, Drell, and Frautschi.[1]

In Fig. 1(a) a photon of momentum k produces a pair, and a positron of momentum p_+ comes directly out. For the conditions of this experiment the four-momentum transfer q at the pair vertex is given by $q^2 = 2kp_+$. In Fig. 1(b) the electron comes directly out and q is of the order of $m_e c$. The mean value of q for diagram 1(a)

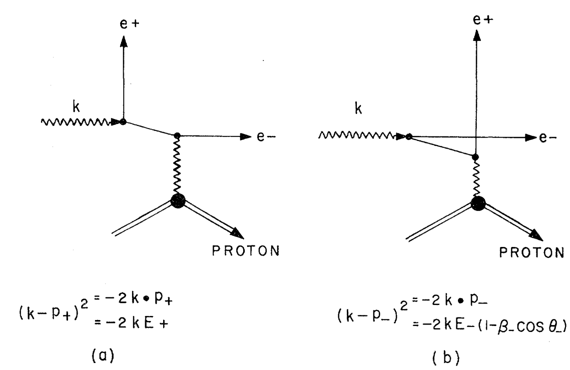

FIG. 1. Principal Feyman diagrams for pair production from a proton.