MEASUREMENT OF THE LINEAR POLARIZATION OF γ RAYS BY THE ELASTIC PHOTOPRODUCTION OF π^0 ON He^4

Nicola Cabibbo
Laboratori Nazionali di Frascati del Comitato Nazionale per l'Energia Nucleare, Frascati, Italia
and Istituto di Fisica dell'Università, Roma, Italia
(Received October 27, 1961)

It is of considerable interest for the study of elementary particle physics to perform experiments with beams of linearly polarized photons.[1] These experiments require an accurate knowledge of the degree of polarization of the beam. If the beam is produced in the conventional manner, which uses the natural polarization of the bremsstrahlung perpendicular to the plane of emission, the polarization can in principle be evaluated from the geometry of the beam itself.[2]

A second method, which could produce beams of higher intensity, is based on the fact that the bremsstrahlung coherently produced on a single-crystal target can, under certain conditions, be strongly linearly polarized.[3,4] The polarization of a beam produced by this method cannot be evaluated a priori with confidence and must therefore be measured in some way.

The measurement of linear polarization requires the observation of azimuthal asymmetries in processes initiated by the rays.

The only method presently well understood is based on pair production. The difficulty here is that at high energy pair production is restricted to a narrow forward cone, and the expected asymmetries are quite small, of the order of 20-30% even for a fully polarized beam and under the best conditions.

The use of processes involving strong interacting particles is in general unsatisfactory as one then requires some information on the details of the interaction. An exception seems to be the elastic photoproduction of a neutral pion on He^4 (or in general on a spin-0 nucleus):

$$\gamma + He^4 \rightarrow \pi^0 + He^4. \tag{1}$$

This process is particularly simple as only the photon, among the particles involved, has spin different from zero. The only vector quantities here are the photon polarization vector $\vec{\epsilon}$, its momentum $\vec{k}$, and the momentum of the emitted pion, $\vec{k}'$. The amplitude for the process will therefore be proportional to the only available pseudoscalar quantity,

$$\mathfrak{M} = \mathcal{A}[\vec{\epsilon} \cdot (\vec{k} \times \vec{k}')]. \tag{2}$$

$\mathcal{A}$ can depend on the photon energy and on the angle of emission of the pion. The cross section for a beam of linear polarization $\vec{P}$ is then

$$(d\sigma/d\Omega)_{\vec{P}} = [(1-|\vec{P}|)+2|\vec{P}|\sin^2\varphi](d\sigma/d\Omega)_{\vec{P}=0}, \tag{3}$$

where the azimuth φ is defined as the angle between the plane of emission $(\vec{k}, \vec{k}')$ and the plane of polarization $(\vec{k}, \vec{P})$.

For a fully polarized beam $(|\vec{P}|=1)$ the azimuthal distribution is simply $\sin^2\varphi$. The analyzing power of this process is therefore equal to that of a Nicol prism for visible light.

The ratio of the cross sections at 90° from $\vec{P}$ and parallel to $\vec{P}$ is

$$d\sigma_{\perp}/d\sigma_{\parallel} = (1+|\vec{P}|)/(1-|\vec{P}|). \tag{4}$$

This ratio is already 1.5 for a 20% polarization and increases very steeply. In this method statistics is not a problem; one should, however, be able to discriminate against such processes as

$$\gamma + He^4 \rightarrow \pi^0 + n + He^3, \tag{5}$$

$$\gamma + He^4 \rightarrow \pi^0 + \pi^0 + He^4, \text{ etc.}, \tag{6}$$

whose azimuthal distribution cannot be evaluated at present with confidence.[5]

The method proposed here has rather unique properties, especially for photons of high energy. The difficulties of the method based on pair production increase rapidly with energy, and also increasing is our ignorance of the details of other processes involving strongly interacting particles.[6]

The author is grateful to Dr. G. Diambrini and the other members of his group for discussions which led to the present work.

---

[1] G. T. Hoff, Phys. Rev. 122, 665 (1961); B. De Tollis and A. Verganelakis, Phys. Rev. Letters 6, 371 (1961); M. J. Moravcsik (to be published).

[2] M. May and G. C. Wick, Phys. Rev. 81, 628 (1951); M. May, Phys. Rev. 81, 265 (1951); H. Olsen and L. C. Maximon, Phys. Rev. 114, 897 (1959); R. E. Taylor and R. F. Mozley, Phys. Rev. 117, 835 (1960); R. C. Smith and R. F. Mozley, Proceedings of the 1960 Annual International Conference on High-Energy Physics at Rochester (Interscience Publishers, Inc., New York, 1960).

[3] H. Überall, Phys. Rev. 107, 223 (1957).

[4] Experiments with a beam produced in this manner are now in progress at Frascati (G. Bologna, G. Barbiellini, G. Diambrini, G. Murtas). See also J. W.

DeWire, Laboratori Nazionali di Frascati, Nota Interna No. 87 (unpublished).

[5]Near the threshold for process (6) the relative angular momentum of the two pions will be $l=0$ (the next permitted value is $l=2$); under these conditions the azimuthal distribution of the α recoil is again uniquely determined. It is in fact $\cos^2\varphi$ for complete polarization so that contributions of (6) can mask the asymmetry in (1).

[6]For γ-ray energies below the pion threshold there exist particular photodisintegration reactions with well-defined analyzing power for the photon polarization.

PIONIC FORM FACTOR EFFECTS IN PERIPHERAL NUCLEON-NUCLEON COLLISIONS

E. Ferrari and F. Selleri
CERN, Geneva, Switzerland
(Received October 17, 1961)

There is increasing evidence that in inelastic nucleon-nucleon collisions the one-pion exchange (OPE) contribution plays an important role.[1-8] This evidence rests: (i) at a few ($\simeq$1-3) Gev on the experimental lab energy distributions[2,4] and c.m. angular distributions[3]; (ii) at many ($\gtrsim$10) Gev on the analysis of quasi-elastic scattering data,[5] of general features of the interactions[6] of emulsion experiments,[7] and of cosmic-ray interactions.[8] A further step in the analysis of such reactions consists in understanding the quantitative importance of the direct many-particle exchanges, which are expected to be increasingly important with increasing momentum transfer. The effect of these exchanges cannot, however, be revealed by comparing the OPE calculations performed till now[1,2] with experiments, because such calculations are correct only for small values of the nucleon momentum transfer.

A method for understanding the limitations of the OPE approximation has been suggested by the authors.[9] Since the matrix element for off-shell pion-nucleon scattering in the region of the 3, 3 resonance has been calculated,[9] one can evaluate a peripheral graph for single (and possibly double) pion production in nucleon-nucleon collisions, by taking full account of the virtuality of the exchanged pion. This calculation is possible for energies of the πN scattering not too far from the 3, 3 resonance, and is undetermined only by an unknown multiplicative function of the squared four-momentum of the virtual pion. This function is simply related to the pionic form factor of the nucleon. These facts make possible a check of the peripheral model and possibly allow the determination of the pionic form factor. If the experimental data at different energies were fitted with a unique choice of this function, then one might conclude that the OPE contribution is probably dominant also for high-momentum transfer, because the discrepancies generated from the many-particle exchanges are expected to depend also on the initial energy.

In this Letter we show that the existing experimental data do indeed suggest full dominance of the OPE term and we obtain a tentative behavior of the pionic form factor. The expression found in reference 9 for the off-shell $T=J=\frac{3}{2}$ πN scattering amplitude is[10]

$$f_{33}(u,\Delta^2)\simeq K(\Delta^2)\left(1+\frac{\Delta^2}{4m^2}\right)^{1/2}\frac{p_1}{q_1}\frac{B_0(u_r,\Delta^2)}{B_0(u_r,-\mu^2)}f_{33}(u,-\mu^2), \tag{1}$$

where m and μ are the nucleon and pion masses, respectively; Δ^2 is the squared four-momentum of the virtual pion; $u=(\omega-m)/m$, ω being the total c.m. energy of the πN system; $u_r=0.314$ is the u value of the 3, 3 resonance; $p_1=(p_{10}{}^2-m^2)^{1/2}$ and $q_1=(q_{10}{}^2-m^2)^{1/2}$ are the off-shell and on-shell c.m. momenta, where

$$p_{10}=(\omega^2+m^2+\Delta^2)/2\omega,\quad q_{10}=(\omega^2+m^2-\mu^2)/2\omega. \tag{2}$$

Finally, $K(\Delta^2)$ is the pionic form factor of the nucleon and $B_0(u,\Delta^2)$ is given by

$$B_0(u,\Delta^2)=\frac{4}{3}\frac{f^2}{\mu^2}\frac{u}{(u+\delta)^2}\left[1+\frac{2\delta}{u+\delta}\right], \tag{3}$$

with $f^2=0.08$ and $\delta=(\Delta^2+\mu^2)/2m^2$.

In (1) only the factor p_1/q_1 depends on both Δ^2 and u. Its u dependence is particularly strong at threshold, where it diverges like $q_1{}^{-1}$. This divergence is, however, compensated from the threshold behavior of $f_{33}(u,-\mu^2)$ which vanishes like $q_1{}^2$. Therefore, the effect of the factor p_1/q_1 on the u dependence of $f_{33}(u,\Delta^2)$ should not be too large and we put simply $p_1{}^r/q_1{}^r$ in place of p_1/q_1, r meaning "calculated at resonance."