Comments for Nuclear and Particle Physics, Special Vienna Supplement

SLAC-PUB-612
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October 1968

ELECTROMAGNETIC THEORY AND EXPERIMENT

This note in Comments on contributions to the Vienna Conference in the field of electrodynamics relies heavily on the Rapporteurs reports of N. M. Kroll, W.K.H. Panofsky, B. Richter, and S.C.C. Ting. These excellent reviews will appear shortly with full references, and so I will present no bibliography, and I will select for the purposes of this note a sampling of work which opens the newer vistas in this field. This selection is not to be equated with importance or quality of the work relative to topics I omit.

An extensive body of information on the photoproduction of pseudoscalar scalar mesons was presented from CEA, DESY, and SLAC. By now there are enough data on the differential cross sections over a broad range of energies $s = M^2 + 2Mk^{\gamma}_{lab}$ and momentum transfers both to place severe restrictions on theoretical models as well as to defeat all their simplest versions. The outstanding features of the data on $\gamma + p \to n + \pi^+$ are: 1) a sharp peak in the forward differential cross section for $t \lesssim m_\pi^2$ with a magnitude at $\theta = 0^o$ that closely coincides with the simple Born approximation value; 2) a t dependence of $e^{-2.5t/M^2}$ out to $t \sim 0.6$ GeV^2 and thereafter a change in slope to e^{-3t/M^2}; 3) an energy dependence at fixed t that can be summarized over the range from several to ≈ 16 GeV by the form

$$\frac{d\sigma}{dt} = f(t)(s - M^2)^{2(\alpha(t)-1)}$$

where $\alpha(t) \sim 0$ out to $t \approx 1$ GeV^2 and for $t > 2$ GeV^2, with a slight apparent dip in between.

The isotopic character of the photoproduction amplitude can be learned from $\gamma + n \rightarrow \pi^- + p$ as deduced from an analysis of reactions on deuterium. The comparison of this with the π^+ photoproduction shows no clear simple relation. Suffice it to say that their ratio is unity only at the very small values of $t \lesssim m_\pi^2$ indicating that only one G parity is important in the t channel but that substantial contributions by both G parities are necessary at moderate values of t where the π^- cross section decreases to as little as 0.3 of the π^+ cross section at $t \sim .3\ \mathrm{GeV}^2$. Further information is supplied from the π^+ photoproduction by polarized γ's produced by coherent bremsstrahlung from a diamond crystal at DESY at 3.4 GeV. The production is found to be predominantly perpendicular to the production plane indicating that it takes place almost entirely by natural parity exchange--i.e., π exchange is unimportant.

In the face of these salient features only Regge pole models that rely heavily on contributions from cuts (in particular, the two π and ρ trajectories plus two cuts of Frøyland and Gordon) can survive. The data do not however challenge the success of the vector dominance model which equates the electromagnetic current to a superposition of ρ, ω, and ϕ vector meson fields and thus by time reversal invariance relates photoproduction of pions to pion production of neutral vector mesons in appropriate helicity states (i.e., transverse polarization). Within existing broad error limits vector meson dominance does fine.

The forward π^0 photoproduction has also been studied extensively with interesting and surprising results. Most simply one turns to the ω and B meson trajectories in seeking an explanation of the energy dependence and a dip near $t = 0.5\ \mathrm{GeV}^2$ has been attributed to a nonsense zero in the presumed donimant and linear ω trajectory which crosses $\alpha = 0$ at that value of t. However, the new high energy SLAC data shows that dip filling in and becoming less prominant and rules out such a simple model. This model also fails the test of the polarization measurements at CEA which show that the cross section is dominated by natural-spin parity exchange (the ω and not the B) in the region of t where the nonsense zero of the ω is presumed to occur. Detailed theoretical analysis by Harari based on vector dominance--and in particular that the photon is purely isoscalar in the region of $t \sim .5\ \text{GeV}^2$ where the ω trajectory goes through its nonsense zero--establishes quantitative discrepancies between this process and $\pi^- + p \rightarrow \omega^0_{\text{transverse}} + n$ that can be resolved only by appealing to very strange ω and ϕ trajectories, unknown particle trajectories, or once again cuts.

This brief summary has highlighted only a few of the problems that presently haunt the theorists as a result of a very major and beautiful outpouring of two body pseudoscalar (pion and kaon) photoproduction data. They fit into no simple theoretical pattern--except for the successes of vector dominance relations--and the bold strides towards better understanding have still to be taken. However, this process is clearly still rich with information. Indeed the whole question of the value of simple Regge pole theory with linear trajectories remains to be clarified for amplitudes containing one external photon line.

Whereas in past conference it has been the form factors summarizing the dynamics for elastic electron proton scattering that have held center stage, this time the inelastic electron scattering took the spotlight. Among the more interesting results we mention three.

First of all an experiment looking for evidence that the electromagnetic interactions of hadrons violate time reversal invariance was reported from CEA and with negative results. The idea due to Christ and Lee was to scatter electrons inelastically (incident momentum $\vec{p}$ and scattered momentum $\vec{p}'$) from a polarized target of spin orientation $\vec{\sigma}$ and look for an asymmetry of the form $(\vec{p} \times \vec{p}') \cdot \vec{\sigma}$. To lowest order in $e^2 = \frac{1}{137}$--i.e., with one photon exchange to the target--no such correlation can appear unless there is T violation which allows an interference between the (complex) amplitudes for transverse and longitudinal virtual photons. Although the absence of such a correlation does not <u>prove</u> T conservation the presence of one, together with a comparison of experiments with electron and positron beams to rule out the possibility of two photon exchange, would prove that T is violated. The experiment showed no correlation, the limit on the phase difference between the transverse and longitudinal amplitudes being less than $\approx 10^{\circ}$ for excitation of final proton resonances from 1238 MeV up to 1688 MeV. Absence of polarization of the recoil deuteron in elastic electron deuteron scattering as well as a lower upper limit on the neutron's electric dipole moment ($\approx 2 \pm 2 \times 10^{-23}$e cm) also further constrain the possibilities for T violation in the electromagnetic interactions of hadrons.

Secondly, a large amount of data now exists on excitation of the nucleon resonances at 1.24 GeV, 1.52 GeV, 1.68 GeV, and 1.92 GeV for various momentum transfers q^2. As is the case for elastic scattering there are two invariant form factors or cross sections for each of these resonances corresponding to their excitation by transverse or longitudinal virtual quanta. Also as is familiar from the elastic analyses, experiments must be performed at different energies and scattering angles at a fixed q^2 to allow the individual contributions to be separated. Thus separation has been accomplished in detail only for the $N^*(1238)$ up to $q^2 = 2.34$ GeV^2 at DESY and it is found that the longitudinal cross sections are consistent with zero beyond $q^2 \approx 0.7$ GeV^2. This result together with the behavior for lower q^2 was predicted by the models developed by Walecka and co-workers. A simplified version of this approach is to multiply the contribution to N of a set of single-pion electroproduction diagrams that are thought to be important excitation mechanisms (including a t channel ω exchange whose magnitude is determined from fitting the data) by a final-state enhancement factor, $\frac{1}{P}$, which then produces a resonant amplitude. Since all the vertises in this model are multiplied by the same form factor, the predicted resonance cross sections decrease with q^2 for large q^2 in the same manner as the elastic scattering ($\propto F^2(q^2) \propto \frac{1}{q^8}$)--and thus is in accord with observations made at SLAC out to $q^2 \sim 6$ GeV^2 (and assuming neglect of longitudinal cross sections). These remarks apply to all the resonances listed above. As for the "paper" resonance, its existence is not revealed by inelastic electron scattering either at DESY or SLAC.

A third subject of considerable interest is the continuum excitation of the proton in very inelastic electron scattering. There are now some detailed if incomplete studies of this region from SLAC and already some bold general features have begun to emerge and may be summarized as follows. The q^2 dependence of the inelastic scattering is very much weaker than in the resonance region. For elastic scattering or resonance excitation $(d\sigma/d\Omega) \Big/ \left(\frac{\alpha^2}{4E^2} \frac{\cos^2 \theta/2}{\sin^4 \theta/2}\right)$ drops by more than a factor of 20 over the range of momentum transfers $q^2 = 0.5$ GeV^2 to 2.0 GeV^2. This drop represents the proton form factor behavior since the donominator in the above expression is just the Mott cross section for a point Dirac proton. However, in the "deep" inelastic continuum corresponding to large electron energy losses ν (in the initial proton rest system) and final hadronic states of total mass $M^* > M_{res}$, viz.

$$\nu \equiv \frac{M^{*2} - M^2 + |q^2|}{2M}$$

the analogous ratio $\left(\frac{d^2\sigma}{d\Omega dE'}\right) \Big/ \left(\frac{d\sigma_{Mott}}{d\Omega}\right)$ changes by no more than a factor of ≈ 2 over the same range of q^2 for $M^* = 3$ GeV and $M^* = 2$ GeV.

Furthermore, if, following Bjorken, we write (E = incident electron energy, E' = scattered electron energy, and θ = scattering angle in the lab system)

$$\frac{d^2\sigma}{d\Omega dE'} = \frac{\alpha^2}{4E^2 \sin^4 \theta/2} \left[W_2(q^2, \nu) \cos^2 \theta/2 + W_1(q^2, \nu) \sin^2 \theta/2\right]$$

and neglect the W_1 term as unimportant in the analysis of the SLAC experiments at $\theta = 6^o$ we find that the data are not inconsistent with $\nu W_2(q^2, \nu) = F(q^2/\nu)$ where F is a universal function in the limited range $q^2 = .7$ GeV^2 to 2.3 GeV^2. Over the range $\frac{\nu}{q^2} \approx 2$ to 7 GeV^{-1} the value of F changes little if at all. The possible emergence of a universal function $F(q^2/\nu)$ for $q^2, \nu \to \infty$ and q^2/ν = finite was theorized by Bjorken using the local Gell Mann current algebra for the densities at high momentum transfers or small distances. The possible extension and verification of these present trends to larger q^2 and ν values will be crucial to the survival of the physical notion of point like charged structures within a nucleon since point interaction currents or point quarks provide a possible basis for the Gell Mann algebra of current densities used by Bjorken.

Experimental work with colliding rings was very prominent and impressive and there is no doubt that this important new field of experimental technology has earned its golden spurs. Colliding electron beams each with 550 MeV checked the Möller scattering cross section so well in the Princeton-Stanford experiment that the length $1/R^2$ introduced via a form factor $\frac{1}{1 - q^2/R^2}$ at each electron vertex must be decreased to

$$\frac{1}{R^2} = (-5 \pm 5) \times 10^{-15} \text{ cm} .$$

The colliding $e^- e^+$ beams at Orsay gave very impressive data on the leptonic decays as well as total decay rates for the ρ^0, ω, and ϕ vector mesons--and joined together with ρ^0 data from the Novosobirsh rings and with production data from CERN, DESY, and Dubna go far to fix the coupling constants and mixing parameters of the vector mesons with photons. A detailed analysis of the quantitative fate of the vector dominance model must await a future note in Comments but listed below are several important parameters as averaged from world data in Ting's report:

	$\Gamma_{V \to \ell\bar{\ell}}$ (kev)	Γ_{tot} (MeV)
$\rho \to e^+ e^-$	$6.52 \pm .75$	108.0 ± 8.5
$\omega \to e^+ e^-$	$.74 \pm .16$	12.0 ± 1.3
$\phi \to e^+ e^-$	$1.49 \pm .35$	4.2 ± 0.9

Finally two new results were reported from experiments in search of a difference between muons and electrons other than their rest masses. The latest from the muon storage ring at CERN on the g-2 measurement was announced as

which exceeds the quoted theoretical value by $(54 \pm 31)^{10^{-8}}$. This difference is smaller than previously quoted values and is now less clear evidence of a discrepancy with pure electrodynamics. The experimental error still exceeds the estimated hadronic contribution due to vector mesons as well as the weak interaction contribution which is first order weak if intermediate vector bosons exist. The muon-proton elastic scattering on hydrogen done at Brookhaven has not demonstrated any differences from electron scattering up to $q^2 = 0.9$ GeV^2 within errors though its overall normalization error of 8% remains unexplained.