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ELECTROPRODUCTION OF π^0 - A CRUCIAL TEST OF DIP MECHANISMS*

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Abstract

Dips in differential cross sections of inelastic hadronic reactions may be caused by nonsense zeroes or by geometrical effects. A direct way of resolving this question is to change the interaction radius in a reaction, while keeping all other parameters fixed, and to see whether the dips move. The "radius" of a virtual spacelike photon has been predicted to change with its mass. If this is verified (e.g., in ρ^0-electroproduction), a study of the dip in π^0-electroproduction should decide between the two schools of dip mechanisms.

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One of the most striking features of hadronic reactions is the appearance of dips in many differential cross sections. It is widely believed that these dips may yield crucial clues to the correct phenomenological description of hadronic processes, and many explanations have been offered for their observed properties. These explanations can be classified into two main schools of thought.

The first school (the "nonsense school") claims that the positions of the dips are determined by the properties of the exchanged objects in the t-channel.[1] The dips may be due to "nonsense factors," "ghost killing factors," and other such entities which are all characteristic of the exchanged system but are essentially independent of the colliding hadrons. In other words, the positions of such dips are completely determined by parameters of the exchanged poles (mass, slope, intercept, etc.), they are independent of energy, and if the dips are due to the same exchange in different processes, their positions do not depend on the identity of the initial and final particles in these processes.

The second school (the "radius school") asserts that the dips have a geometrical origin and that they are determined by simple features of the impact parameter representation of the scattering amplitude.[2] The positions of such dips depend on the effective radius for the interaction and on the dominant helicity amplitude. The radius may depend on energy and/or on the properties of the colliding particles.

It is always possible to translate a simple Regge pole model into an extremely complicated and ugly impact parameter description. It is equally possible to produce a hopelessly artificial mixture of poles and cuts that will reproduce a simple geometrical picture. The distinction between the two schools of thought is therefore not in the language that they may use (because both languages can always be used) but in the description which is most simply and directly related to the observed properties of the dips.

Our (biased) opinion[3] is that the experimental evidence, so far, is heavily in favor of the "radius school." However, a decisive test is lacking. Most of the observed dips in inelastic processes are around $|t| \sim 0.5\ \mathrm{BeV}^2$. This is a "nonsense point" for all $\alpha(t) \sim 0.5+t$ trajectories. It is also a zero of $J_{\Delta\lambda}(r\sqrt{-t})$ for $\Delta\lambda = 1$ and $r \sim 1$ fermi. Since the observed dips are seen in processes allowing vector and tensor (i.e., $\alpha \sim 0.5+t$) exchanges, and since in all cases[3] the helicity flip amplitude (i.e., $\Delta\lambda = 1$) seems to dominate, it is hard to distinguish between the two possibilities.

An ideal test would be to change either the trajectory parameters or the radius while keeping all other factors fixed and to see whether or not the observed dips move. However, the trajectory parameters cannot be changed at will and the radius changes, if at all, very slowly (at most like log s). Consequently, such a test has not been performed, so far.[4] What is obviously lacking is an easy experimental way of changing the hadronic radius by a substantial amount.

In this note we propose an experiment, which, <u>subject to one crucial preliminary condition</u>, might resolve the controversy between the "nonsense school" and the "radius school" in a simple and direct way. Our starting point is the observation that photoproduction processes are qualitatively similar to pure hadronic processes and that their dip systematics are also very similar, <u>according to both schools</u>. The photon has, however, one property which may help us—we can change its mass (at least in the spacelike region) without too much difficulty, by performing electroproduction experiments. This leads us to an interesting question: What happens to the interaction radius when the mass of one of the colliding particles is changed? Several arguments, based on field theory models, have recently been advanced, predicting that <u>as the mass of the spacelike photon increases, the effective interaction radius decreases</u>.[5] In such models,[6] as $q^2 \longrightarrow \infty$:

$$r \propto \frac{1}{\sqrt{q^2}}$$

A more relevant practical question is whether the radius changes significantly at small q^2. A recent estimate by Kogut[7] actually indicates that, within the field theory model, the radius should change significantly between $q^2 = 0$ and $q^2 = 1 \ \mathrm{BeV}^2$.

A direct, model independent, measurement of this radius as a function of q^2 can be performed by studying the reaction[5]

$$e^- + p \longrightarrow e^- + \rho^0 + p$$

This process is supposed to be predominantly diffractive for all photon masses. For any given value of q^2, the slope (in t) of the diffraction peak measures the squared effective radius of the interaction.[8] This is true in all models. The field theory models then predict[5] that the slope becomes smaller as q^2 increases. Preliminary results from SLAC seem to support this remarkable prediction,[5] while a recent Cornell experiment is inconclusive.[9,10] The verification of this prediction is the crucial preliminary condition mentioned above. If the ρ^0-electroproduction slope does not vary significantly between, say, $q^2 = 0$ and $q^2 = 1$, we lose our chance of having an easily controlled varying radius. If, however, a significant q^2-dependence is confirmed, we will be able to use electroproduction experiments as an extremely powerful tool for studying problems of hadron phenomenology.

In particular, we may then perform the crucial experiment that will decide between the two schools of dip phenomenology. The process which should settle this issue is electroproduction of π^0:

$$e^- + p \longrightarrow e^- + \pi^0 + \rho$$

In π^0-photoproduction[11] a clear dip is observed[12] at $|t| \sim 0.5 \ \mathrm{BeV}^2$. The "nonsense school" relates it to the nonsense zero of the ω-trajectory (undoubtedly the dominant exchange in this process). According to the "radius school," the proton helicity is approximately conserved in ω-exchange and the initial photon and the final π^o differ by a unit of helicity. Hence, the dominant amplitude has $\Delta\lambda = 1$ and the dip corresponds to a zero of $J_1(r\sqrt{-t})$ for $r \sim 1$ fermi.[2] A π^o-electroproduction experiment will now enable us to measure the photoproduction of π^o by transversally polarized virtual photons of mass q^2. ω-exchange would still dominate in the t-channel and its nonsense zero is obviously unchanged by the photon mass. According to the "nonsĕnse school," the dip in π^o-electroproduction should therefore remain at the same t-value as in π^o-photoproduction. On the other hand, if the interaction radius decreases significantly when $|q^2|$ increases, the zeroes of $J_1(r\sqrt{-t})$ should move in t. According to the "radius school," the dip in π^o-electroproduction should then significantly move to larger t-values, as q^2 increases.

In practical terms, such an experiment may be feasible in the very near future. The laboratory energy of the incoming virtual photon (i.e., the energy loss ν of the electron) may be as low as 3 - 5 BeV or so, since at such energies the dip in π^o-photoproduction is already observed. The predicted shift in t for the dip, according to the "radius school," may vary between different detailed models but should be, at least, 40% of the observed change in the diffractive slope in ρ^o-electroproduction for comparable q^2-values.[13] Thus, if at a given q^2-value, the ρ^o-electroproduction slope is approximately one-half of its value in ρ^o-photoproduction, the "radius school" would predict that π^o-electroproduction at the same value of q^2 exhibits a dip somewhere between $|t| \sim 0.7$ and $|t| \sim 1$, while the "nonsense school" would predict a $|t| \sim 0.5$ dip. Such an effect should be detectable. The obvious difficulty in performing this experiment is that a detection of the final electron and proton is probably not sufficient, since the π^o-signal in the missing mass would be "covered" by an enormous background from the radiative process $e^- + p \longrightarrow e^- + \gamma + p$. A detection of at least one of the π^o-photons seems to be necessary. Another important requirement is the necessity of isolating the transverse photon component of the π^o-electroproduction cross section, since this component corresponds to the photoproduction case. This can be achieved by changing θ, the electron scattering angle, and ϕ, the azimuthal angle between the electron scattering plane and the photoproduction plane.[14]

One cannot exclude the possibility of a totally unforeseen surprise in such an experiment, such as the disappearance of the dip for $q^2 \neq 0$ or some other equally mysterious result. In such a case, our "decisive test" will not fulfill our expectations, but we will certainly have the benefit of witnessing a totally new phenomenon, which will presumably be interesting by itself.

Finally, we should again emphasize the different nature of the ρ^o-electroproduction slope and the π^o-electroproduction dip. The first is related to the diffractive radius[8] in all models and it has no direct bearing on the different dip phenomenologies. Once this radius is determined, and is found to vary with q^2, we can proceed to use the π^o dip as a test between the models. If the ρ^o-slope does not change with q^2, our entire discussion becomes purely academic.

We hope that a study of π^o-electroproduction will soon be performed and that it will enable us to resolve the dispute between the different phenomenological approaches to the dip problem.

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Footnotes and References

1. For a detailed discussion of dip mechanisms in Regge theory, see, e.g., L. Bertocchi, Proceedings of the Heidelberg Conference, 1967.
2. For a review of dip mechanisms in geometrical models, see, e.g., A. Dar, Proceedings of the Columbia Conference, 1969, and H. Harari, Proceedings of the Liverpool Conference, 1969. A more recent discussion is given in reference 3.
3. H. Harari, Phys. Rev. Letters 26, 1400 (1971) and SLAC-PUB-914, to be published in the Proceedings of the Tel Aviv Conference on Duality and Symmetry in Hadron Physics, 1971.
4. One should really distinguish between two different radii (see, e.g., H. Harari and A. Schwimmer, SLAC-PUB-952 , to be published). One is the radius corresponding to the diffractive component of the hadronic amplitude. It can be determined unambiguously from the slope of the forward diffraction peak in elastic scattering, and as $s \rightarrow \infty$ it may approach a constant or increase like log s. The second radius characterizes the dominant (peripheral) impact parameters in the nondiffractive component. This radius may also reach a constant or increase logarithmically with energy. The two radii are somehow connected by unitarity but the relation is not simple. The most direct way of "measuring" the nondiffractive radius is actually to study the positions of dips as a function of energy. Consequently, we cannot use this same information as a decisive test (unless the dips move very significantly with energy).
5. H. Cheng and T. T. Wu, Phys. Rev. 183, 1324 (1969); J. D. Bjorken, J. B. Kogut and D. E. Soper, Phys. Rev. D3, 1382 (1971); J. D. Bjorken, SLAC-PUB-905, to be published in the Proceedings of the Tel Aviv Conference, 1971.
6. Bjorken (reference 5) actually remarks that r should only decrease by about

50% as $q^2 \to \infty$, since the "proton radius" remains fixed while the "photon radius" presumably shrinks to zero.

7. J. B. Kogut, private communication, unpublished.

8. This is the radius corresponding to the diffractive component. However, if this radius changes, say, by a factor of two between two different q^2-values at the same incident energy, it is very hard to believe that the radius describing the nondiffractive component remains unchanged.

9. D. E. Andrews et al., Cornell preprint CLNS-169, contributed paper to the Cornell Conference, August 1971; E. D. Bloom et al., SLAC-PUB-955, contributed paper to the Cornell Conference, August 1971.

10. In addition to the obvious necessity of improving the data, it is important to verify that the measured slope actually applies to ρ^o - electroproduction via transversally polarized photons, and that the significant background is not distorting the picture. These points have been emphasized by the authors of reference 9 and we hope that future experiments will soon settle them.

11. Photoproduction of π^o is actually the only photoproduction process showing a dip.

12. For the latest data, see, e.g., R. L. Anderson et al., SLAC-PUB-925, to be published.

13. A "minimalistic" model would assume: (i) "γ" + p $\longrightarrow \pi^o$ + p is dominated by s-channel resonances; (ii) "γ" + p couples mainly to resonances in partial waves corresponding to a radius $r_1(q^2)$ which decreases as q^2 increases; (iii) π^o + p couples mainly to resonances in partial waves corresponding to a fixed radius r_2. The effective dominant radius will then be roughly given by $r \sim \frac{1}{2}\left[r_1(q^2) + r_2\right]$. If $r_1(q^2)$ is determined by the slope B in ρ^o-electroproduction, we have $B(q^2) \propto \left[r_1(q^2)\right]^2$. On the other hand, $t_{dip} \propto \frac{1}{r^2}$.

Hence as $B(q^2)$ decreases, say, by a factor of two, t_{dip} should increase at least by 40%. We refer to this model as "minimalistic" since all other variants of the "radius school" seem to lead to stronger effects, up to a relation of the form $t_{dip} \propto \frac{1}{B}$.

14. The double differential cross section for $e^- + p \longrightarrow e^- + \pi^o + p$ involves, among others, terms of the form $(\sigma_\perp + \sigma_\parallel)$ and $(\sigma_\perp - \sigma_\parallel)$, where the subscript denotes the photon polarization. Since in π^o-photoproduction $\sigma_\perp$ is completely dominant (reference 12), any measured combination of $\sigma_\perp$ and $\sigma_\parallel$ would probably be sufficient for our purpose. (The only exception being the case $\epsilon = 1$, $\phi = 0$ where only $\sigma_\parallel$ contributes.) A measurement at $\phi = 90^o$ would be the cleanest, since only $\sigma_\perp$ and σ_{long} contribute there.