

HIGH- T MESON PHOTO- AND ELECTROPRODUCTION: A WINDOW ON THE PARTONIC STRUCTURE OF HADRONS

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A consistent description of exclusive photoproduction of mesons at high momentum transfer t relies on a few effective degrees of freedom which can be checked against Lattice calculation or more effective models of QCD.

1. Introduction

Exclusive photoproduction of mesons at high momentum transfer t offers us a fantastic tool to investigate the partonic structure of hadrons. The high momentum transfer t implies that the impact parameter is small enough to allow a short distance interaction between, at least, one constituent of the probe and one constituent of the target. In addition, the exclusive nature of the reaction implies that all the constituents of the probe and the target be in the small interaction volume, in order to be able to recombine into the well defined particles emitted in the final state.

This enables us to identify, to determine the role and to access the interactions between each constituent of hadrons.

The relevant constituents depend on the scale of observation. At low momentum transfer t , a comprehensive description^{1,2} of available data is achieved by the exchange of a few Regge trajectories, between the probe and the target. At very high (asymptotic) momentum transfer t , the interaction should reduce to the exchange of the minimal number of gluons, in order to share the momentum transfer between all the current quarks which recombine into the initial and final hadrons³. Here, dimensional counting rules lead to the famous power law behavior of the various cross sections, but it is unlikely that the present generation of high luminosity facilities gives access to this regime.

To date, CEBAF at Jefferson Laboratory is the only facility which allows

to reach momentum transfers t up to 6 GeV^2 in *exclusive* reactions, at reasonably high energy (s up to 12 GeV^2). This range will be considerably enlarged when the 12 GeV CEBAF upgrade becomes a reality.

The range of momentum transfers accessible at JLab corresponds to a resolving power of the order of 0.1 to 0.2 fm. It is significantly smaller than the size of a nucleon, but comparable to the correlation lengths of partons (the distance beyond which a quark or a gluon cannot propagate and hadronizes). At this scale, the relevant degrees of freedom are the *constituent partons*, whose lifetime is short enough to prevent them to interact and form the mesons which may be exchanged in the t -channel, but is too long to allow to treat them as current quarks or gluons. This is the *non-perturbative partonic regime*, where the amplitude can be computed as a set of few dominant Feynman diagrams which involve dressed quarks and gluons, effective coupling constants and quark distributions ⁷. This resembles the treatment of meson exchange mechanisms at low energies ⁴.

The first results ^{5,6}, recently released by JLab, support such a picture and provide a link with Lattice QCD predictions on the gluon propagator ⁸, modelisations of quark wave functions in hadrons ⁹ and Regge saturating trajectories ¹.

2. Gluon exchange

Measurement of phi photoproduction selects gluon exchanges. Since the ϕ meson is predominantly made of a strange $s\bar{s}$ quark pair, and to the extent that the strangeness content of the nucleon is small, quark interchange mechanisms are suppressed.

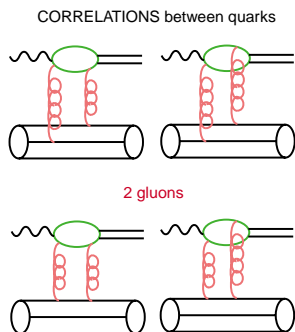


Figure 1. The four diagrams depicting two-gluon exchange mechanisms.

The destructive interference between the two graphs in the bottom of

Fig. 1 (where each gluon couples to the same quark in the nucleon, but may couple to a different quark in the vector meson) leads to a node in the cross-section (dashed line) depicted in Fig. 2. This node is filled when the two gluons are allowed to couple also to two different quarks in the proton (faint solid line), giving access to their correlation. At the largest momentum transfer t , nucleon exchange in the u -channel takes over, but the corresponding peak move towards higher t when the incoming photon energy increases (solid curves, marked 3.5 and 4.5 GeV), leaving more room to access the two gluon exchange contribution.

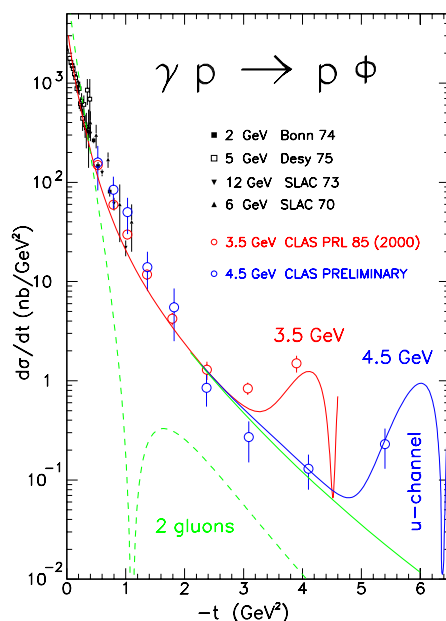


Figure 2. The ϕ meson photoproduction cross section at $\langle E_\gamma \rangle = 3.5$ and 4.5 GeV.

The combined use of the high luminosity of CEBAF and of the large acceptance of the CLAS set up at JLab made possible the measurement of cross sections, more than two orders of magnitude below previous ones, in a virgin domain up to $t = 5.5$ GeV². The data at $E_\gamma = 3.5$ GeV have been published ⁵, while the data at $E_\gamma = 4.5$ GeV are still preliminary and their errors will soon decrease. This is however good enough to exhibit the trend of the cross section, to confirm the move of the u -channel peak toward higher momentum transfers and to establish the relevance of the two gluon exchange description.

The key to the success of such a good agreement is the use ⁷ of the

correlated quark wave function of Ref. ⁹ and the Lattice gluon propagator of Ref. ⁸. For instance, if a perturbative gluon propagator had been used, one would have obtained a much more steep t dependency of the cross-section (see Ref. ⁵ for more details). In the gluon loop (Fig. 1), the virtuality of each gluon is on average $t/4$, *i.e.* about 1 GeV^2 at $t = 4 \text{ GeV}^2$ where, according to Fig. 2 in Ref. ⁸, the lattice gluon propagator exhibits strong non perturbative corrections. On the contrary, it reaches its asymptotic behavior around a virtuality of 4 GeV^2 : this requires a momentum transfer t of about 16 GeV^2 , which will be achievable when CEBAF is upgraded to 12 GeV .

I refer to the talk of K. McCormick ¹⁰ for the analysis of the tensor polarisation of the ϕ which confirms the dominance of the u -channel contribution at the highest momentum transfer.

3. Quark exchange

Quark exchange mechanisms are not suppressed in the photoproduction of ρ and ω mesons, which are mostly made of light quarks.

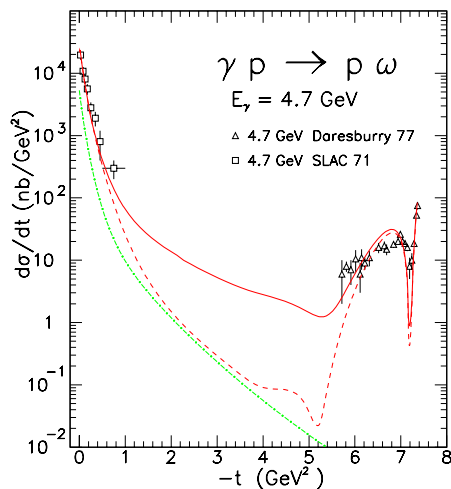


Figure 3. The ω meson photoproduction cross section at $E_\gamma = 4.7 \text{ GeV}$.

The most striking example is the photoproduction of ω meson (Fig. 3). At low momentum transfer, π exchange (dashed line) takes over two gluon exchange (dash-dotted line). At the largest momentum transfer, u -channel proton exchange dominates and accounts for the backward angle cross sec-

tion. Here the experimental node is well reproduced by the use of a non-degenerate Regge trajectory for the nucleon. At intermediate transfer, the use of a linear Regge trajectory for the π leads to a vanishing cross section, while the use of the saturated Regge trajectory (full line), which already led to a good accounting of the cross section of the $\gamma p \rightarrow \pi^+ n$ reaction¹, enhances the cross section by two orders of magnitude.

This is really a parameter free prediction, which has been beautifully confirmed by the recent CLAS data: I refer to the talk of M. Battaglieri⁶, for a more detailed discussion in the ω sector as well as the ρ sector.

4. Compton scattering

A few GeV real photon has a significant hadronic component. Due to the uncertainty principle, it fluctuates into vector mesons (or quark anti-quark pairs of various flavors) over a distance which exceeds the nucleon size. For instance, a 4 GeV real photon fluctuates into a ρ meson over about 2.7 fm. The real Compton scattering cross section is therefore related to the ρ meson photoproduction cross section by a simple multiplicative factor: $4\pi\alpha_{em}/f_V^2$, where f_V is the radiative decay constant of the vector meson. As shown in Fig. 4, the comparison with this model⁷ and the old Cornell data confirm this conjecture.

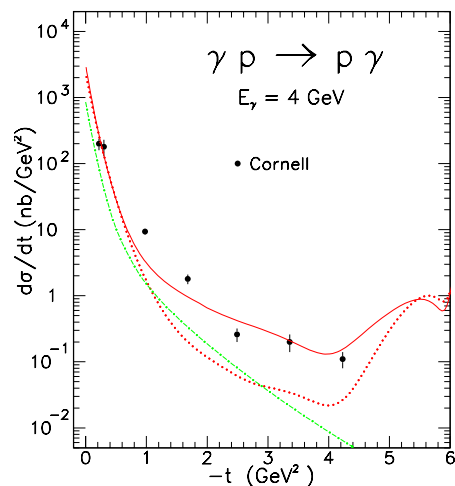


Figure 4. The Real Compton Scattering cross section at $E_\gamma = 4.0$ GeV. Dash-dotted line: two gluon exchange. Full (dotted) line: saturated (linear) Regge trajectories.

More interesting, the model predicts also spin observables. As an exam-

ple, Fig. 5 compares the predicted longitudinal spin (helicity) transfer (solid line in the upper part) to the hard scattering models ¹² (solid line in the bottom part) and the soft "handbag" model ¹³ (dashed line). The strong variation at backward angles comes from the u -channel baryon exchange. The preliminary data from Hall A at JLab confirms this prediction. I refer to the talk of A. Nathan ¹⁴, for a more detailed account and discussion of future experimental prospects.

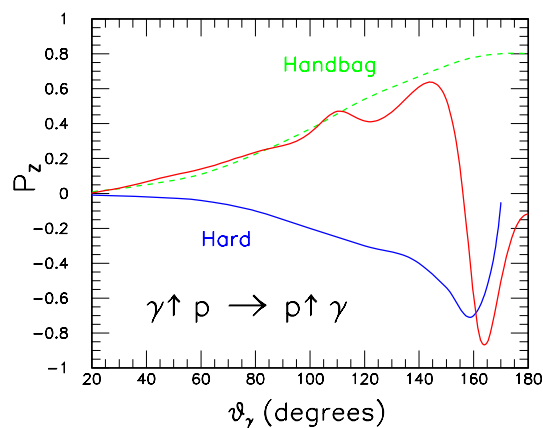


Figure 5. The longitudinal spin transfer coefficient in Real Compton Scattering at $E_\gamma = 4.0$ GeV.

5. Conclusion

A consistent picture is emerging from the study of exclusive photoproduction of vector meson and Compton scattering. At low momentum transfer, it relies on diffractive scattering of the hadronic contents of the photon, in a wide energy range from threshold up to the HERA energy domain. At higher momentum transfer, it relies on a partonic description of hard scattering mechanisms which provides us with a bridge with Lattice Gauge calculations. The dressed gluon and quark propagators have already been estimated on lattice. One may expect that correlated constituent quark wave functions (at least their first moments) will soon be available from lattice. An estimate, on lattice, of the saturating part of the Regge trajectories is definitely called for.

To day, JLab is the only laboratory which allows to explore this regime,

thanks to its high luminosity. Its current operation, at 4–6 GeV, has already revealed a few jewels. Its energy upgrade to 12 GeV will expand to higher values the accessible range in momentum transfer and allow to extend these studies to virtual photon induced reactions. It will permit, among others, a more comprehensive study of the onset of asymptotic hard scattering regime and of the role of correlations between quarks.

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