

Chapter 7

Summary and Conclusions

Strangeness production, using both real and virtual photons incident on the proton, has been studied via the reactions $\gamma p \rightarrow K^{*0}\Sigma^+$ and $ep \rightarrow e'K^{*0}\Sigma^+$. Two data sets for the above strange meson production reactions were analyzed: (1) data set for the K^{*0} photoproduction, taken at 3.115 GeV electron beam energy, using tagged photons, and (2) for the K^{*0} electroproduction reaction, data were taken using electron beam at 4.056 and 4.247 GeV.

Measurements and analyses of the data were completed and the cross sections for the above reactions are presented and compared with theory. After adjusting the parameters of the theoretical model, within the theoretical uncertainty, both sets of experimental data are in good agreement with a theoretical model based on a quark-meson formulation [47]. Some of these results have already been published and approved by CLAS working group [70, 71, 72]. A draft of a paper to be submitted for publication, including both photoproduction and electroproduction cross sections presented in this dissertation, is in progress [73].

The measured total and differential cross sections for the above reactions are presented in chapters 4 and 6. Differential as well as total cross sections for the K^{*0} photoproduction were determined. However, due to the limited statistical accuracy of the K^{*0} electroproduction reaction, we only measured the total cross section in this case. These data are the first of their kind, and will add to our knowledge of theoretical models of K^* couplings.

After adjusting the two free parameters of the model, *i.e.* the quark- K^* vector and tensor coupling constants (see Section 3.2), the angular dependence and the energy dependence of the photoproduction cross sections showed good agreement with the theoretical model of Zhao [47]. This suggests that this model for vector meson production is useful for predicting cross sections in kinematic regions that have not been measured directly.

Investigating nucleon resonances and their couplings to K^* vector mesons was a main motivation of this dissertation. However, this goal requires more theoretical development, which is beyond the scope of this dissertation. Nonetheless, the experimental results presented here provide valuable guidance to theorists who are attempting to understand vector meson production and the underlying quark structure of nucleon resonances. Only with a broad database of experimental cross sections will it be possible to tackle the question of what nucleon resonances exist and whether the so-called missing resonances are *really* missing or just an artifact of the quark model used to predict the spectrum of nucleon resonances.

7.1 K^{*0} Photoproduction

For the $\gamma p \rightarrow K^{*0}\Sigma^+$ reaction, the energy evolution of the differential cross sections, along with the corresponding predictions from theory, are shown in Fig. (4.13), while Fig. (4.14) shows the differential cross section as a function of the kaon production angle in the center-of-mass frame $\cos(\Theta_{K^*}^{c.m.})$. Although a detailed discussion of comparisons with the theoretical models has not been presented in previous chapters, it is instructional to summarize on-going discussions with theoretical colleagues. The main physics points that can be extracted from the current data, derived from these discussions, are presented below.

- **Large angles:** At middle to backward angles, cross sections show good agreement between the data and the model. In this non-forward angular region, cross sections are related to s - and u -channel production, which are sensitive to the two free parameters of the model, “ a ” and “ b ”, *i.e.* the quark- K^* vector and tensor coupling constants, see Sec. (3.2), and the nucleon resonances included

in this calculation. For the nonstrange sector, ω and ρ production, the value of “ a ” is in the range 2.5 to 3.5, consistent with vector current conservation in the SU(3) quark model. Our data favor a smaller value for this coupling constant, *i.e.* $a = 2.1$, which is consistent with that expected for the strange sector, mainly due to SU(3)-flavor symmetry breaking. In addition, theorists [47] predict the other free parameter (the tensor coupling “ b ”) to have the same order of magnitude as “ a ” which is also consistent with our data. The value of “ b ” extracted from our data is -1.45 . Future experimental data, with better statistical accuracy and smaller binning in the photon energy, can be used to further constrain the quark-vector-meson couplings within this model.

- **Forward angles:** At small angles, the sharp rise of our data show that the cross section is dominated by t -channel exchange. The t -channel production is adjusted by the model’s kaon exchange strength. The strength of this diagram is related to the $g_{K\Sigma N}$ coupling constant, which is somewhat unconstrained. Knowledge of this coupling constant comes indirectly from studies of kaon scattering and of kaon photoproduction. Our data suggest a stronger coupling constant (by about 25%) than that predicted from kaon photoproduction models. Our data can be used to extract a more precise value of this coupling. However, the K^* form factor, coming from the overlap of the quark wave functions, must also be taken into account, but this is expected [47] to make only a small contribution, as it is close to unity for our kinematics.

At the highest photon energy bin, there is some disagreement between the theoretical model and the data at forward angles. At higher energies, the forward-peaking moves out of our detector acceptance, as CLAS loses one (or both) of the decay particle of the K^* for $\cos(\Theta_{K^*0}^{c.m.}) > 0.9$ due to the beam-pipe hole through the center of CLAS. Although this loss of acceptance is partly compensated by use of Monte Carlo simulations, the forward-angle results at higher energies become model-dependent, and so data with $\cos(\Theta_{K^*0}^{c.m.}) > 0.9$ are not presented here, and comparisons with the theoretical model are not reliable in this kinematic region. Again, data with higher statistical accuracy at CLAS, or

data from other facilities, would be valuable to study the t -channel strength at higher energies.

7.2 K^{*0} Electroproduction

In the K^{*0} electroproduction experiment, the total cross sections were measured as a function of the center-of-mass energy W , Fig. (6.21), which also agrees with the theoretical model. The small difference between the two beam energies, could be due to the following factors:

1. Broad Q^2 bin: Due to the limited statistics, we had to bin our data with only one wide bin in the momentum transfer Q^2 , from 0.75 to 1.5 (GeV/c)², see Fig. (5.2). A difference between the average value of Q^2 within the bin (at a particular W value) could have contributed into the difference between the data of the two beam energies. To some extent, this average Q^2 dependence could be compensated, but the large statistical uncertainties of the data preclude a detailed systematic study of the Q^2 dependence.
2. ϵ dependence: The polarization constant ϵ has slightly different values for the two beam energies. This would propagate into the cross sections through the dependence of the virtual photon flux, Eq. (6.10), which is used in normalizing the cross sections, Eq. (6.9)).
3. Detector acceptance: Acceptances for the CLAS detector used in correcting the cross section, Eq. (6.8), were calculated from a model that is still imperfect, since the Q^2 dependence of the model is yet to be rigorously tested. Improving the model is expected to improve the acceptances, and therefore may narrow the difference between the cross sections of the two data sets.

7.3 Further Comparison of Theory and Data

The experimental result for the total cross section of K^{*0} photoproduction, integrated over the full angular range of our detector, is shown as a function of the

beam energy in the top panel of Fig. (7.1). The solid curve in this figure is calculated from the theoretical model of [47], after adjusting the two parameters of the model. For comparison, the calculation for the same model, before adjustment of the parameters, is shown in the bottom panel of Fig. (7.1), taken directly from their 2001 publication. The higher curves in the bottom panel are for K^{*+} production, which was not measured here, whereas the bottom curves are for K^{*0} production (as in the top panel). The two curves for each reaction (in the bottom panel) show the effect of including the t -channel or not. Because the t -channel only contributes at forward angles, where the solid angle is small, it does not have a large effect on the total cross sections. Clearly, the theoretical model has some predictive power, as the data in the top panel were not used as input to determine the parameters of the calculation in the bottom panel. However, a more careful comparison of data and the model in the angular distributions show that the total cross sections are not the whole story. Substantial improvement is gained in the angular distribution by adjusting the model parameters.

Since the K^* is not a point particle, it has a so-called form factor, and so the cross section will decrease with increasing Q^2 . As expected, the electroproduction cross sections, Fig. (6.21), are smaller than those from the photoproduction, Fig. (7.1), because of the suppression from electromagnetic form factors. If electroproduction data with improved statistical accuracy were available, we could extract the Q^2 dependence and the angular distribution of the cross sections. For the future, better electroproduction data may be used to extract the $\gamma K K^*$ transition form factor.

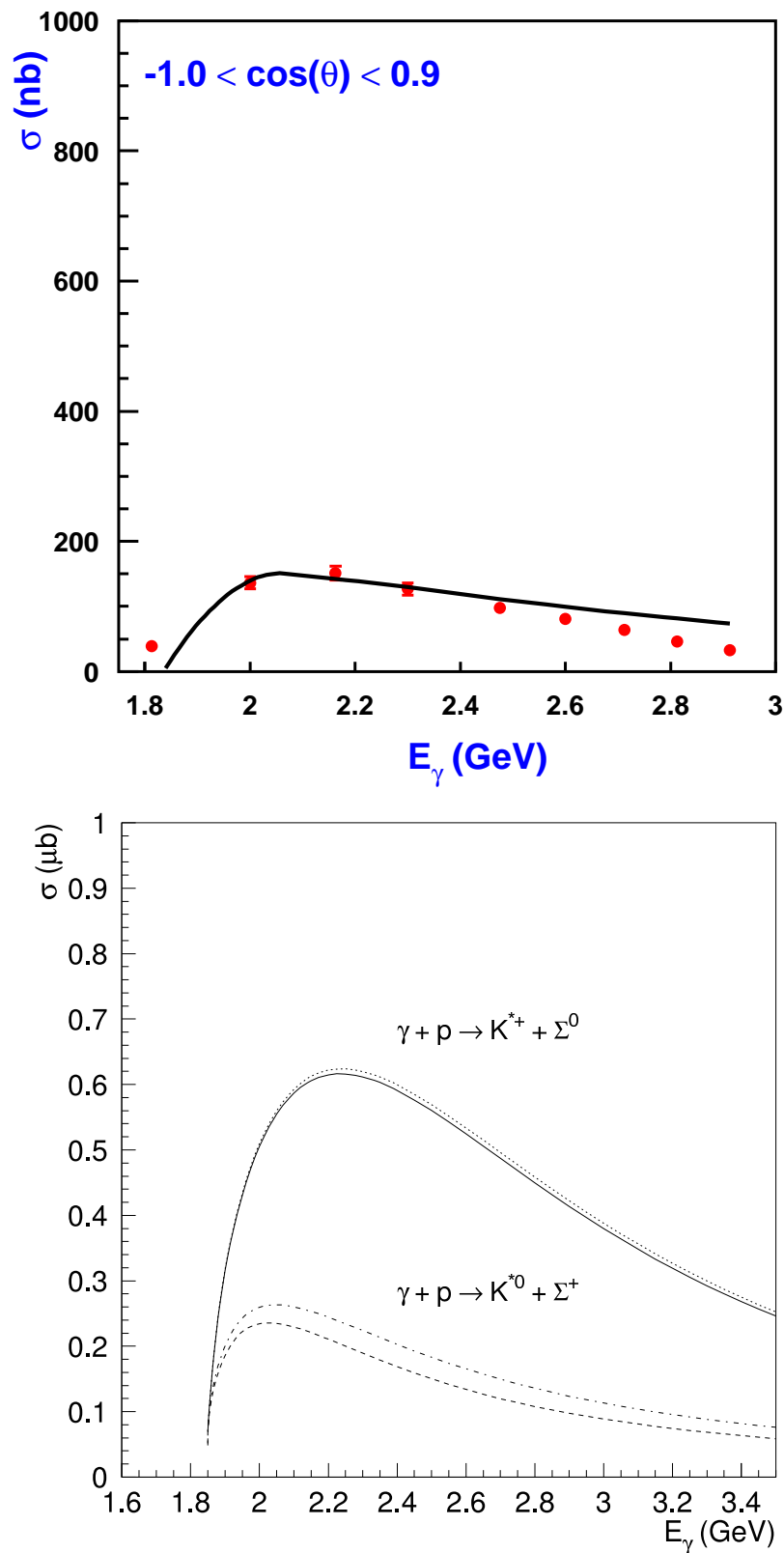


Figure 7.1: Total cross sections for the K^{*0} photoproduction. **Top:** measured and predicted cross sections for electron beam energy 3.115 GeV. **Bottom:** the lowest two curves are for K^{*0} photoproduction, before tuning the free parameters of the model [47]. The dot-dashed curve includes the t -channel K^0 exchange, while the dashed one is without the t -channel contribution.

7.4 Conclusions

Previous to this study, there were no precision data for the photoproduction or electroproduction of the K^* vector meson. This production mechanism is of interest to theorists, since it plays an important role as a virtual exchange particle in kaon production, and is expected to couple strongly to a number of nucleon resonances (N^* and Δ^* states). The present data are useful for testing theoretical predictions of K^* production, primarily in the quark-coupling model of Zhao and Bennhold [47] but also in other theoretical models [74]. By comparing data and models, we can determine effective parameters of the models, such as the $g_{KN\Sigma}$ coupling constant (at forward angles) and the quark- K^* vector and tensor couplings. These parameters can then be compared with those extracted from non-strange vector meson production (such as ρ and ω mesons) to study the degree of symmetry breaking in this as-yet untested sector of SU(3) flavor symmetry.

While the primary goal of learning about which N^* resonances exist (and whether the “missing” resonances are really missing) is a more general goal of the medium energy program at Jefferson Lab, this must wait until there is a broader database that can be used to approach this question. The K^* data presented here are one piece of this puzzle. Future data on K^* production, with higher statistics, will be useful in providing smaller bins in the total center-of-mass energy, W , along with detailed comparisons with the angular distributions, that will be needed to search for N^* resonances.

The importance of learning about the N^* spectrum is that this has a direct correspondence to the fundamental theory of the strong interaction, QCD. However, more theoretical development on topics such as lattice gauge calculations, will be necessary before the N^* spectrum can be used to test our understanding of non-perturbative QCD. The fact that quarks are confined into hadrons is well established, but understanding the structure of hadrons in terms of QCD will likely need guidance from experimental data.

The current results of K^* production cross sections are the first precise data of their kind, and provide one small piece in the larger picture of experimental data

needed to understand in detail how QCD confines quarks into hadrons. Hopefully, with both better experimental data and advances in theoretical calculations, this problem can be solved.