Reply to "Comment on 'Kaon photoproduction, data consistency, coupling constants, and polarization observables'"

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Replying to a recent Comment by R. L. Workman, it is shown that our analysis [Phys. Rev. C **42**, 108 (1990)] of the elementary kaon photoproduction reaction allows a meaningful determination of the relevant coupling constants.

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In a recent paper [1], the reaction $\gamma p \rightarrow K^+\Lambda$ from threshold up to $E_\gamma \leq 1.4$ GeV was investigated using a phenomenological approach. The main aim of our study was to find out why for more than 25 years the extracted coupling constants have been in disagreement with SU(3)-symmetry predictions. Through a diagrammatic method, we performed a χ^2 analysis on the differential cross sections of *all* the existing kaon photoproduction data. Starting with Born terms, we examined every possible configuration including several resonances: 2 kaonic, 7 nucleonic, and 7 hyperonic resonances (Ref. [1], Table V). Given the large number of "models" (4096 configurations), we checked how many of them fulfilled the following criteria:

(i) Fundamental constraint. The main coupling constants ought to be in agreement with the SU(3) predictions, namely $-3.0 \leq g_{K\Lambda N}/\sqrt{4\pi} \leq -4.4$ and $+0.9 \leq g_{K\Sigma N}/\sqrt{4\pi} \leq +1.3$;

(ii) Fitting quality. A reasonable reduced χ^2 (≤ 1.4);

(iii) Simplicity of the reaction mechanism. This is a hope rather than a criteria and, if satisfied, it ensures that the elementary reaction can be understood quite well and will allow producing a realistic and simple elementary operator to be used in electromagnetic production of strangeness from nuclei;

(iv) Predictivity. Model(s) satisfying (*i*) to (*iii*) will have to reproduce the existing polarization data with a comparable χ^2, giving credibility to the predictions of the unmeasured observables.

In our study, the criterion (*ii*) reduced the number of candidate configurations from 4096 to about 3000, then applying the *fundamental constraint* left us with only two models. The remaining two models happened to satisfy the *simplicity* criterion equally well (Ref. [1], Table IV). Finally the *predictivity* requirement discriminated against one of them. So, there is only one configuration (hereafter referred to as model 1) left fulfilling all four criteria.

However, Workman (RLW) in a Comment [2] offers some criticisms of our work. The crucial one is the claim that, through our phenomenological analysis, the $K\Sigma N$ coupling constant is *virtually undetermined.* This would imply that the *fundamental constraint* that showed, by far, the highest selectivity among the candidate configurations could not be used as a meaningful criteria. This point is examined closely in the next paragraph.

In phenomenological analyses requiring fits to data the most performant and commonly used code is, to our knowledge, the MINUIT program [3] from the CERN-LIBRARY. The results of this code for our model 1 are reported in Table I. To check the *meaningfulness* [3] of the uncertainties, we present the indispensable correlation coefficients (Table II). Given that these coefficients are all (much) smaller than 0.9 guarantees [3] that the relevant free parameters are independent enough and so the error bars are reliable. Notice that although the uncertainty on $g_{K\Sigma N}$ is larger than the 20% estimate given in our original paper [1], the sign and the magnitude of the $K\Sigma N$ coupling are still quite well determined. Thus model 1 respects the *fundamental constraint.*

At this point, we wish to comment about the sets 1 to 3 reported [2] by RLW. The first one corresponds to the same reaction mechanism as our model 1 with the same coupling constants. Nevertheless, RLW finds much larger uncertainties than those obtained from MINUIT (Table I). We believe that checking the code of RLW against the MINUIT program is needed to settle this problem.

Sets 2 and 3 fulfill only the criteria (*ii*) and (*iii*); namely, they give smaller χ^2 and suggest simpler reaction mechanisms. Nevertheless, both sets suffer from a major shortcoming: Having run the MINUIT code for these configurations, we note that correlation coefficients are mostly close to 1.0 (for the sake of brevity we reproduce only the results for set 3 in Table II). Notice that the

TABLE I. Coupling constants of model 1 [1], including uncertainties, as obtained from least squares analysis using the MINUIT code [3].

Couplings	Model 1
$g_{K\Lambda N}/\sqrt{4\pi}$	-4.17 ± 0.75
$g_{K\Sigma N}/\sqrt{4\pi}$	$+1.18\pm0.66$
$G_V/4\pi$	-0.43 ± 0.07
$G_T/4\pi$	$+0.20\pm0.12$
$G_{N1}/\sqrt{4\pi}$	-1.41 ± 0.60
$G_{Y3}/\sqrt{4\pi}$	-3.17 ± 0.86
$G_V^{K1}/4\pi$	-0.10 ± 0.06
$G_T^{K1}/4\pi$	-1.21 ± 0.33

TABLE II. Correlation coefficients [3] for the free parameters of model 1 [1]. The same quantities for the set 3 [2] are given in parentheses.

Coupling	$g_{K\Lambda N}$	$g_{K\Sigma N}$	G_V	G_T	G_{N1} (G_{N4})	G_{Y3}	G_V^{K1}	G_T^{K1}
$g_{K\Lambda N}$	1.000	0.183 (0.978)	0.618 (−0.944)	0.478 (0.975)	0.235 (0.850)	0.897	−0.329	0.935
$g_{K\Sigma N}$		1.000	−0.584 (−0.975)	0.576 (0.983)	−0.813 (0.928)	−0.253	−0.191	0.198
G_V			1.000	0.166 (−0.988)	0.841 (−0.881)	0.851	−0.366	0.542
G_T				1.000	−0.185 (0.854)	0.187	−0.858	0.388
G_{N1}					1.000	0.611	−0.002	0.187
G_{Y3}						1.000	−0.169	0.848
G_V^{K1}							1.000	−0.223
G_T^{K1}								1.000

coefficient with regard to the two main couplings is 0.978, meaning [3] that the corresponding uncertainties are not reliable. This finding implies that the configurations considered in Ref. [2] are not appropriate to fit the data base under consideration. A simple check of the unrealistic nature of these sets consists in producing predictions for the Λ-polarization asymmetry: at $\theta_{K^+}^{\text{c.m.}}=90°$ the results of sets 2 and 3 are 2 times larger (in magnitude) than the prediction of our model 1 (Ref. [1], Fig. 5(a)), increasing the χ^2 per point roughly from 1 (model 1) to 3 (sets 2 and 3).

The available data base has been discussed in detail in our paper [1] (Sec. II C) where we have shown that even *including* the Orsay data [4] in the fitting procedure criteria (*i*), (*ii*), and (*iv*) are satisfied. We emphasize that the coupling constants come out in agreement with SU(3) predictions but with rather complex reaction mechanism (seven baryonic resonances instead of two in model 1).

The reason why we have removed the Orsay data is because of the *internal inconsistency* revealed [1] within this data set and *not* due to the fact that criterion (*iii*) is not being satisfied. Actually, disregarding this set of data removes a large number of backward angle results. Nevertheless, since in the reaction under consideration no exotic phenomena has been suspected, there is *a priori* no reason why the reaction mechanism would change *so drastically* in going from the forward to the backward hemisphere. As mentioned before [1], the proposals at CEBAF are expected to provide the data, including backward angle cross sections, needed for improving our understanding of the strangeness physics.

To summarize, the criteria chosen by RLW, namely the simplicity of the reaction mechanism and a small value of χ^2, *are not sufficient* to provide any knowledge about the reaction mechanism. One needs to implement the constraints brought in by the fundamental SU(3) symmetry.

A careful check by RLW with regard to the double polarization observables leads to the sign changes for both E and H shown in Figs. 9 and 10 of Ref. [1]. This interesting remark, however, does not affect the two major consequences of the numerical results in which we were interested: (i) the sensitivity of the polarization observables to the ingredients of the reaction mechanism, (ii) the absolute magnitudes of the observables.

Finally, we would like to take this opportunity to correct the expressions for E and H observables in Table II and point out a few misprints in Eqs. (7c) and (7d) of our paper [1]:

$$E\cdot\{d\sigma/d\Omega\}/\mathcal{N}=-2\,\mathrm{Re}(b_1b_3^*+b_2b_4^*)\,,$$

$$H\cdot\{d\sigma/d\Omega\}/\mathcal{N}=+2\,\mathrm{Re}(b_1b_3^*-b_2b_4^*)\,,$$

$$\mathcal{I}_3=\frac{|\mathbf{p}_\gamma||\mathbf{p}_K|}{(E_\Lambda+M_\Lambda)}[2p_\gamma\cdot p_\Lambda\mathcal{A}_2-(\sqrt{s}+M_\Lambda)\mathcal{A}_4]\,,$$

$$\mathcal{I}_4=\frac{|\mathbf{p}_K|^2}{(E_p+M_p)}[2p_\gamma\cdot p_\Lambda\mathcal{A}_2+(\sqrt{s}-M_\Lambda)\mathcal{A}_4]\,.$$

[1] R. A. Adelseck and B. Saghai, Phys. Rev. C **42**, 108 (1990).

[2] R. L. Workman, Phys. Rev. C **44**, 552 (1991).

[3] See the MINUIT-LONG WRITE UP, CERN-D506, October 1990; F. James, *Function Minimization,* Proceedings of the 1972 CERN Computing and Data Processing School, Pertisau, Austria, 1972 (CERN Report 72-21); F. James and M. Roos, *MINUIT Functional Minimization and Error Analysis,* D506-MINUIT, CERN (1989) and references therein.

[4] *Photoproduction of Elementary Particles,* Vol. 8 of *Landolt-Bornstein Numerical Data and Functional Relationships in Science and Technology,* edited by H. Genzel, P. Joos, and W. Pfeil (Springer, New York, 1973), pp. 287–290.