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Polarization Transfer in $\gamma + p \to K^+ + \Lambda^0$

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1 Introduction

There have been a number of recent experiments on kaon photoproduction from protons. Both Λ^0 and Σ^0 production were studied. Perhaps the most interesting one is a Thomas Jefferson Lab experiment with circularly polarized photons with c.m. energies in the range of about 1.6-2.5 GeV. These experiments show that for Λ^0, the polarization transfer along the photon momentum axis , C_z is close to 100%, independent of the scattering angle, measured for the K^+. These results hold, particularly for c.m. energies below 1.9 GeV.($E_\gamma \approx 1.5$ GeV) For higher energies, C_z decreases with increasing angle of the kaon. For kaons produced in the forward direction, the full transfer of polarization holds to about 2.1 GeV($E_\gamma \approx 2.7$ GeV). By contrast, the polarization transfer along an axis perpendicular to the photon axis, but in the plane of polarization, is found to be much smaller; see, e.g.[**?**]. The polarization produced in the reaction, perpendicular to the reaction plane, is also small, but the total polarization of the Λ^0 has a magnitude consistent with unity (within the errors) for all energies and production angles, when the beam is 100% polarized. There is a rigorous inequality [**?**]

$$R^2 = C_z^2 + C_x^2 + P_y^2 \leq 1. \tag{1}$$

Here P_y is the polarization of the Λ, defined by the density matrix

$$\rho_y = \frac{1}{2}(1 + \vec{\sigma} \cdot \vec{P}_y). \tag{2}$$

The value of R_Λ is close to 1 for all values of the c.m. energy and kaon angle. These results do not hold for the Σ^0, but we shall be concerned only with the Λ^0.

2 Model

There are numerous calculations of the spin transfer of the photon to the Λ^0. There are chiral quark models[**?**], but most of the models use many nucleon (and Δ) resonances[**?**]. There are then numerous parameters, which allows a fit to the data.

Despite the relatively low energies of the experiments, we use a relativistic quark model to calculate the cross section and polarization of the Λ^0 in the production process $\gamma + p \rightarrow K^+ + \Lambda^0$. As shown in Fig. 1, only the s and $\bar{s}$ quarks are involved to lowest order. The Λ^0 consists of an s quark and a spin zero ud diquark. The s quark contributes the spin of the Λ^0. The spin 1 diquark only contributes to the Σ^0, but not the Λ^0. To this order, and in this model, it is thus quite natural that the spin of the photon is transfered to the Λ and that the Λ is polarized in the direction of the photon.

We first calculate the Feynman diagram (e.g., Fig. 1).

: Of course, it is not possible to conserve both energy and momentum for the root diagram:$\gamma \rightarrow s + \bar{s}$. We assume that the s and $\bar{s}$ are bound in the Λ and kaon. The internal momenta of the bound particles then allows the reaction to proceed. For simplicity, we assume Gaussian wavefunctions for the bound states. We also take the masses of the diquark and s quark to be identical, 0.4 GeV; the u quark is taken to have a mss $m_u = \frac{1}{2} m_s$. The

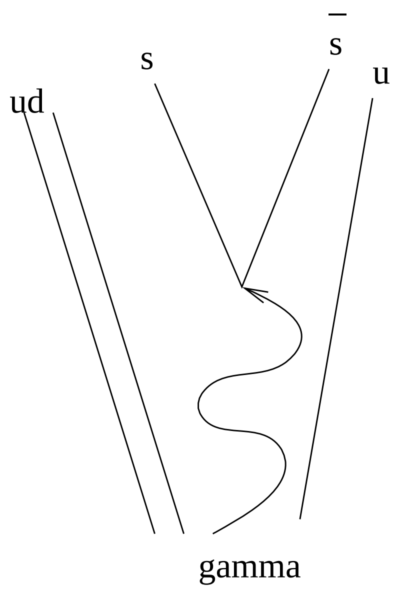

Figure 1: Lowest order Feynman diagram

results are not very sensitive to the quark masses. We have calculated the cross section and polarizations for $1.75GeV \leq E_\gamma \leq 2.25GeV$. Within this region, our results do not vary greatly, but the energy region is too narrow to obtain a dependence on energy for the results. The results obtained are compared to experiment at $E_\gamma = 2GeV$. Like the experimenters, we take the z-axis as that of the photon and use the scattering angle as that of the kaon. In the c.m,, all other momenta are then determined.We assume that the momenta of the relevant quarks are fractions of those of the particles in which they are located. These directions are

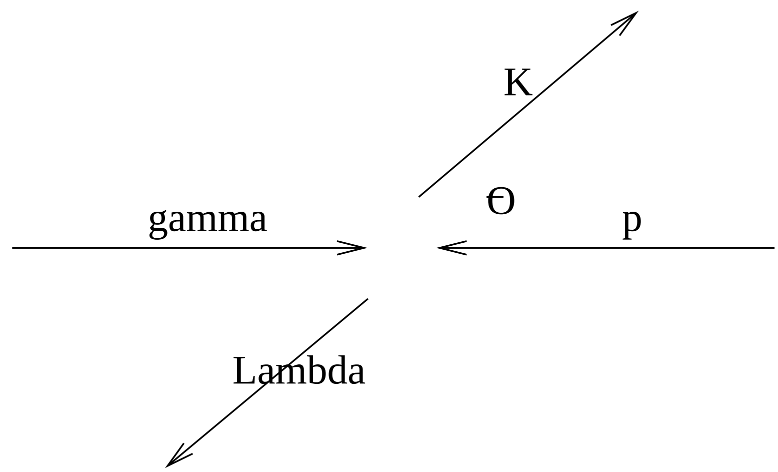

Figure 2: Directions of particles

shown in Fig. 2. The only adjustable variables are the exponents of those of the Gaussian wavefunctions. We take $exp(-p^2/\alpha^2)$, with $\alpha = 0.31$ GeV for the kaon and 0.215 GeV for the proton and Λ^0. We use relativistic Feynman diagrams. To lowest order we get a rate proportional to

$$m^{-2}(m^2 + s_0\bar{s}_0 - s_z\bar{s}_z), \tag{3}$$

with a polarization proportonal to

$$m^{-1}(s_0 + \bar{s}_0). \tag{4}$$

These results are multiplied by the square of 3-dimensional wavefunctions. The integrations are carried out on Mathematica.

To the next order, we include scattering between various quarks. Two possibilities are the exchange

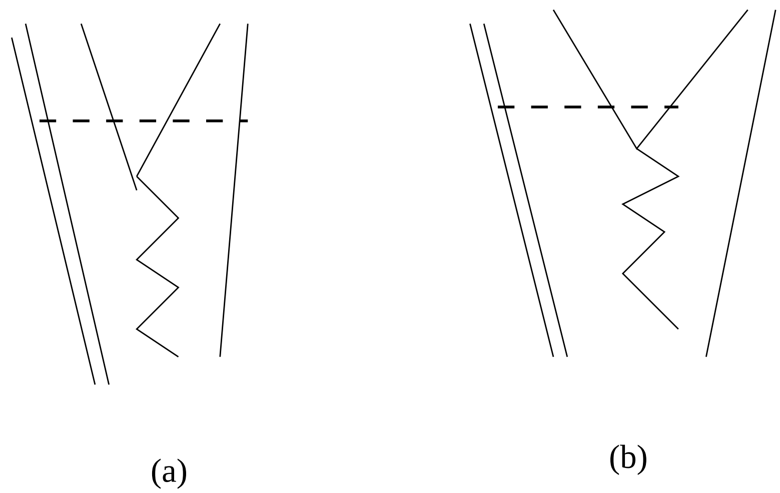

Figure 3: Second order Feynman diagrams

of gluons between the u quark and ud diquark (see Fig. 3a), or between the $\bar{s}$ and the ud diquark (see Fig. 3b). We have taken the latter here, and investigate the cross section and polarization of the Λ for three-dimensional a) delta function potential (a constant in momentum space) and b) a Gaussian interaction. The strengths of the potentials can be adjusted to give the magnitude of the cross section. The range of the Gaussian potential is taken to be α_K. The gamma algebra is done with the aid of Mathematica, as are the necessary integrations. Four-vectors are used throughout, except that the potentials are 3-dimensonal.

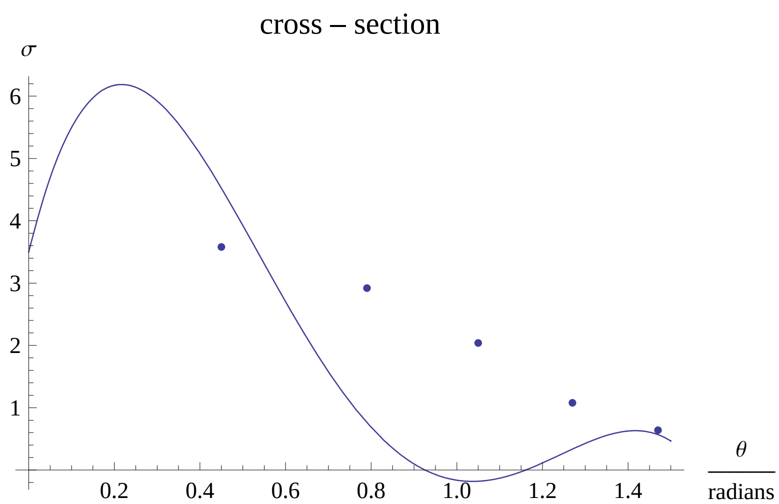

Figure 4: Differential cross section

3 Results

To compare to experiments, we choose the same coordinate axes in the c.m.as the experimenters [**?**]. The photon is along the z-axis and the scattering occurs in the x-z plane.

To first order the polarization is purely in the z-direction and the polarization transfer coefficient, $C_z = 1$ for all scattering angles.

Both our first order and second order differential cross sections are considerably sharper than experiment, as shown in Fig.4. To the next order, the polarization transfer need not be purely in the z-direction, but some of it can be in the x-direction,

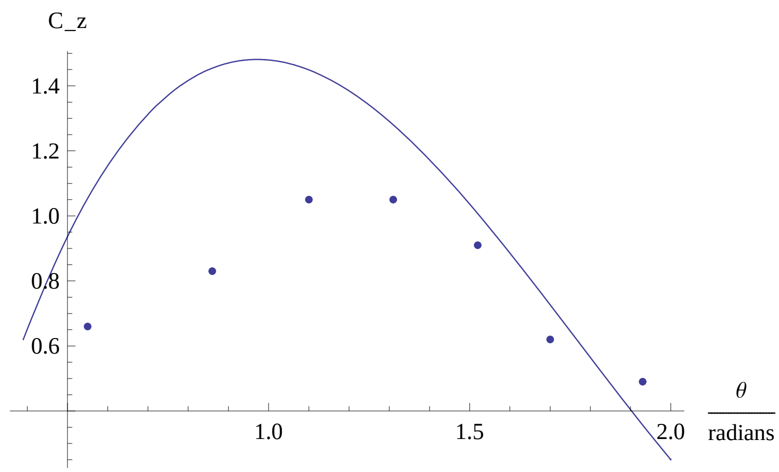

Figure 5: C_z

where x is in the scattering plane. The scattering may (and does) also induce a polarization perpendicular (to the scattering plane, i.e., along the y-direction. Both the x- and y-polarizations are small compared to that in the z-direction, as found experimentally. We compare the polarization transfer coefficients, C_z, C_x to experiment in Figs. 5 and 6.

In agreement with experiment, the polarizatin coeffcient in the z-directions remains close to 100%, and C_x is small. We find $R \approx 100\%$ for all angles. We carried out the calculation for $E_\gamma = 1.75$, 2.0 and $2.25 GeV$. The polarization in the y-direction is shown in Fig. 7 and compares reasonably with experiment.

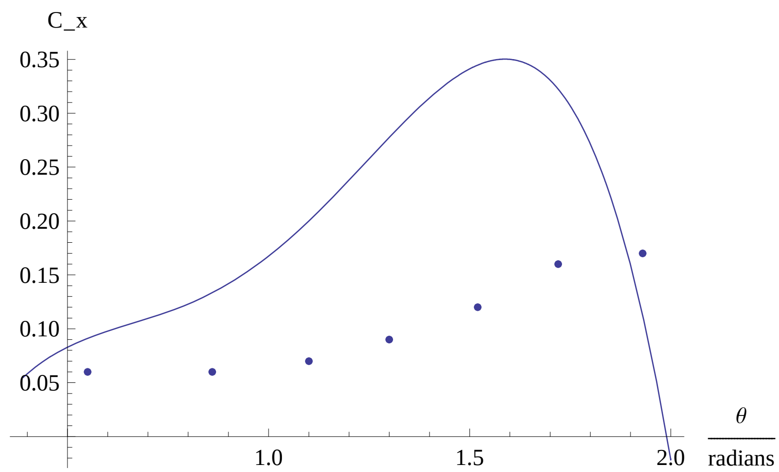

Figure 6: C_x

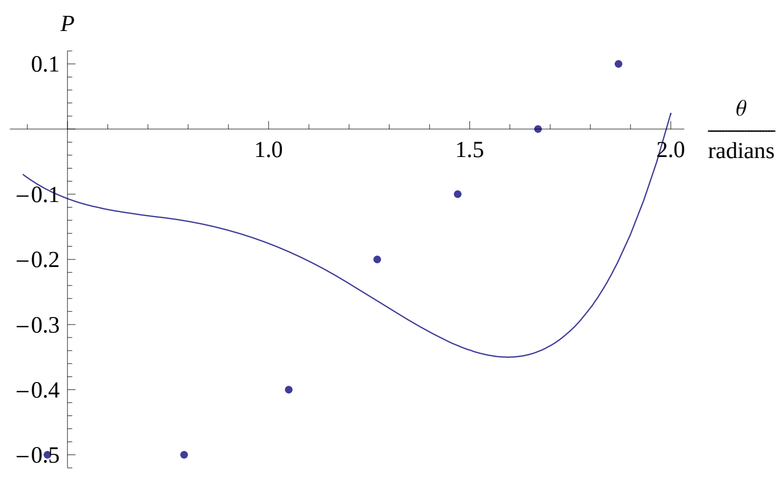

Figure 7: Induced polarization

However, in second order the differential cross section remains considerably sharper than experiment, similar to the lowest order result. Thus, the angular distribution is considerably sharper than experiment, but the polarizations are in approximate agreement with experiment.

The model which comes closest to ours is that of Keiner and of Alkofer et al[**?**]. Neither of these, however, is truly similar to our work.

4 Future Work

We intend to extend the energy range we have examined and to carry out the calculation for the other(Fig. 3a) rescattering diagram.