Kaon Physics using Polarized Beams and Targets

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Introduction

Hypernuclear physics is expected to play a large part in the TJNAF physics program. Several experiments in Halls A and C[1, 2, 4] have been approved to measure properties of bound hyperons. These experiments focus on measurements of the ΛN potential. The goal is to extract enough information to constrain the potential. The ΛN potential can be written as:

$\mathrm{V_{\Lambda N} = V(r) + V_N(r) s_N \cdot l_{\Lambda N} + V_\Lambda(r) s_\Lambda \cdot l_{\Lambda N} + V_\sigma(r) s_\Lambda \cdot s_N + V_T(r) S_{12}}$

where $\mathrm{V(r)}$ is the central part of the potential, $\mathrm{V_N(r)s_N \cdot l_{\Lambda N}}$ is the spin-orbit part of the nucleon-hyperon and $\mathrm{V_\Lambda(r)s_\Lambda \cdot l_{\Lambda N}}$ is the spin-orbit part of the hyperon-nucleon interactions, $\mathrm{V_\sigma(r)s_\Lambda \cdot s_N}$ is the spin-spin part of the potential and $\mathrm{V_T(r)S_{12}}$ is the tensor part of the interaction.

Current estimates of the potential are given here, where the potential has been re-written in more usual nomenclature as: Δ (spin-spin parameter), S_Λ (Λ spin-orbit parameter), S_N (N spin-orbit parameter), and T (tensor parameter).

	Gal *et. al.*, (1978)	Millener *et. al.*, (1985)	Fetisov *et. al.*, (1991)
Δ	0.15	0.50	0.30
S_Λ	0.57	-0.04	-0.02
S_N	-0.21	-0.08	-0.10
T	0	0.04	0.02

The presently approved program focusses on the spin-orbit piece of the potential. Thsese experiments will use spectroscopy to measure the excitation levels of light hypernuclei. However, by using spin degrees-of-freedom, it is possible to also measure the spin-spin piece fo the potential.

The $^3\vec{\mathrm{He}}(\mathrm{e}, \mathrm{e}'\mathrm{K}^+)$ Reaction

The $^3\vec{\mathrm{He}}$ polarized nucleus is aproximately a polarized neutron target, plus 2 unpolarized protons. Similarly, the polarized incident electron and the recoil electron can be thought of as a source of tagged polarized virtual photons.

The reaction is $\vec{\gamma_v} + p \to K^+ + \Lambda$. The only way to manufacture a Λ is from one of the protons (due to charge or isospin conservation). The Λ is actually a polarized $\vec{\Lambda}$, whose polarization at the simplest level can be thought of as due to polarization transfer from the electron via the virtual photon. The polarized neutron is a "spectator" in the reaction. We can independently change the electron spin and the $^3\vec{\mathrm{He}}$ target spin, or the spin of the $\vec{\Lambda}$ and the $\vec{\mathrm{n}}$.

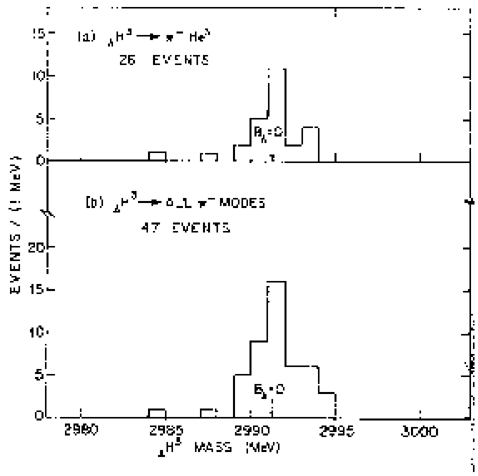
There is an assumption that the spin-flip amplitudes are at the very least important in the reaction process. [Normally, the spin flip amplitudes are considered the dominant amplitudes for kaon electroproduction.]

The Experiment

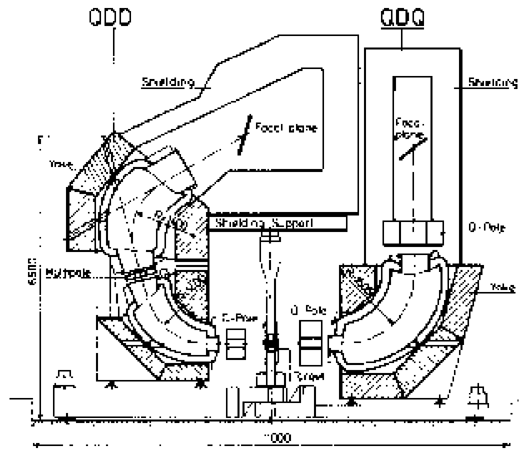
The observables are the cross section asymmetries as a function of the misss-ing mass of the final hadronic system (consisting of a proton, a neutron and a Lambda particle, $pn\Lambda$). There are 3 distinct energy ranges of interest.

- Region I) The bound state hypernuclear system
- Region II) The 2-particle d-Λ system. A 2 body state which will dominate the cross section for the first 5 MeV of excitation energy. Here the deuteron (which includes the initially poalrized neutron) and the spectator proton form one body and the hyperon forms the second. There is no Λ-N bound state and therefore we know the final state is the deuteron and hyperon.
- Region III) The unbound 3 hadron continuum system which will occupy the rest of the missing mass spectrum.

Region I is the hypernuclear system. With sufficient resolution we could see the spin-spin splitting due to having the spins of the neutron and the Lambda parallel or antiparallel. This would be the first direct measurement of the spin-spin part of the hyperon-nucleon potential. Such a measurement of $V_\sigma(r)s_\Lambda \cdot s_N$ would be very significant. However the level splitting is expected to be small (< 1 MeV) and is unknown. Further, since the binding energy of the $^3\mathrm{H}_\Lambda$ hypertriton is only about 0.25 ± 0.31[6] MeV, it is possible that one of the two states is unbound. Although the experiment will have ~ 0.5 MeV of resolution for this experiment (most likely not enough to directly observe the splitting), a shift in the centroid can be observed with greater resolution. In this case, limited to only 2 peaks and controlling the spins remotely, the experiment might measure the centroid to < 0.1 MeV. However, as shown in the next section the count rates for this channel are small. Total counts in the hypernuclear peak will be a few hundred. That makes region I the least promising. However it will make a nice "bonus" to the experiment and has a clear theoretical interpretation.



G. Keyes *et. al.*, Phys. Rev. D, **66** (1970).



The NIKHEF QDQ spectrometer

Region II tests spin-flip dominance. If the reaction proceeds via spin flip, a longitudinally polarized virtual photon must strike an anti-longitudinal proton to create the Λ. It leaves a longitudinal spectator proton (since the 2 protons sum to spin-0). However, to form a (spin-1) deuteron, the neutron needs to be longitudinal. Flipping the spin of the neutron from longitudinal to anti-longitudinal generates an asymmetry of 1.00. [Similar arguments apply for an anti-longitudinal photon.

Region II and III both look like a large quasi-elastic bump in the missing mass spectrum. Limits are difficult to accurately determine, since the unseen state are "continuum" states – region II has 2 particles in the final state which can share energy as they wish and region III has 3 particles in the final state. Since it requires a minimum of 2.2 MeV to break-up the deuteron, a cut of < 2.2 MeV of energy above threshold should select Region II. Count rates are significantly better than for region I and should be sufficient.

Region III places a polarized Λ, a polarized neutron, and a (polarized) proton together. The angular distributions will measure also the hyperon-nucleon potential (especially the spin-dependent pieces). If we assume the 2 protons in the $^3\vec{\mathrm{He}}$ are in an s-state, and the neutron as well, then orbital angular momentum does not contribute. Again this tests not only the spin-spin potential but the reaction process (i.e., the spin-flip assumption) as well. However the understanding is model dependent. A "simple" estimate of how big the asymmetry is requires an calculation; such calculations are presently underway [5].

Spin-flip dominance is an assumption of helicity conservation. If an electron polarized anti-parallel to the $\vec{q}$ is scattered from a nucleon, the virtual photon will be longitudinally polarized parallel to $\vec{q}$. The longitudinally polarized virtual photon can only be absorbed by a spin-1/2 particle if the spin of the initial particle is in the anti-parallel direction and the spin of the final particle is in the parallel direction (if helicity is conserved).

Kinematics and Conclusions

Three kinematics were considered. A 4 and a 6 GeV incident beam and the two septa magnets in Hall A at 6 degrees, with the kaon detected along the virtual photon direction, and a 6 GeV beam using the septum magnet for the electron arm but the NIKHEF QDQ spectrometer for the hadron arm. In the first case, in a two week run period about 30 counts in region I could be detected. In the second case, 80 counts in region I and in the thrid case about 700 counts could be detected. Regions II and III always had several tens of thousands of counts. Resolutions of about .5 MeV can be expected for any of the kinematics (with incident beam energy resolution being an important limitation)

Region I is a challenging measurement however both Regions II and III exibit enough count rate to measure a small asymmetry. The physics is interest is obvious, but it is still open how important each of the three regions are. The only real chance to measure Region I would be to use a 6 GeV beam, with the QDQ spectrometer.

References

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[4] S. Cotanch, private communication.

[5] G. Keyes *et. al.,* Phys. Rev. D, 66 (1970).