Eur. Phys. J. A **18**, 425–427 (2003)
DOI 10.1140/epja/i2002-10251-1

THE EUROPEAN
PHYSICAL JOURNAL A

Prospects for measurements of parity-violating photoproduction of $\pi^\pm$

J.W. Martin[a]

W.K. Kellogg Radiation Laboratory 106-38, California Institute of Technology, Pasadena, CA 91125, USA

Received: 30 September 2002 /
Published online: 22 October 2003 –

Abstract. I address the experimental feasibility of two measurements related to the photoproduction of pions, in the context of the G^0 experiment. The first involves an extraction of the parity-violating pion-nucleon coupling constant $h^{(1)}_{\pi NN}$ via a measurement of parity-violating threshold pion photoproduction. The second involves an extraction of d_Δ, which parameterizes parity-violating photoproduction of pions on the Δ-resonance. The second process might have an anomalously large asymmetry, from a model based on hyperon decays.

PACS. 11.30.Er Charge conjugation, parity, time reversal, and other discrete symmetries – 13.60.Le Meson production – 14.20.Gk Baryon resonances with $S = 0$

1 Physics and motivation

1.1 Threshold pion photoproduction: a possibility to extract $\mathbf{h^{(1)}_{\pi NN}}$

The constant $h^{(1)}_{\pi NN}$ (sometimes called h_π, H^1_π, f_π, etc.) is the parity-violating isovector pion-nucleon coupling. This coupling constant is believed to be particularly sensitive to weak neutral currents inside the nucleon. It is also poorly constrained both theoretically and experimentally.

Theoretical estimates give $h^{(1)}_{\pi NN} = 0$–11×10^{-7}, and a commonly referred to theoretical benchmark is the Desplanques, Donohue, and Holstein (DDH) "best value" [1] $h^{(1)}_{\pi NN}(\text{DDH}) = 4.6 \times 10^{-7}$. The current experimental results span the full theoretical range and tend to disagree with one another. The most sensitive measurements have been performed using various nuclei. This situation motivates new precise measurements with light nuclei.

Parity-violating threshold photoproduction of pions has recently been theoretically related to $h^{(1)}_{\pi NN}$ in the framework of chiral perturbation theory [2]. Calculations of the cross-section in this framework are good to roughly 10%.

The asymmetry in the parity-violating process is directly proportional to $h^{(1)}_{\pi NN}$. For the DDH value of $h^{(1)}_{\pi NN}$, the resultant asymmetry is $A_\gamma(\text{DDH}) = 2.5 \times 10^{-7}$.

1.2 Photoproduction of pions on the $\mathbf{\Delta}$-resonance: a measurement of $\mathbf{d_\Delta}$

As part of the G^0 backward angle measurements [3] of parity-violating elastic and quasi-elastic electron scattering, inelastic electron scattering will also be detected. A separate proposal exists for the inelastic measurements that will be carried out [4].

Recently, the electroweak radiative corrections to this process were calculated [5]. They depend on two new parameters that are theoretically difficult to estimate: a_Δ and d_Δ. The contribution of d_Δ is expected to be larger. However, d_Δ can be extracted from charged-pion photoproduction on the Δ-resonance [6].

The size of d_Δ has been estimated from a model of hyperon non-leptonic and weak-radiative decays, referred to as the resonance saturation model [7]. This model is known to solve two problems in hyperon decay:

– it fits simultaneously the S-wave and P-wave strength in hyperon non-leptonic decay,
– it generates the large asymmetries observed in hyperon weak-radiative decays that are forbidden by $SU(3)$ symmetry.

The model accomplishes this by allowing for mixing with intermediate negative-parity states that are higher resonances. Incorporating all the resonances allows enough freedom to adequately describe the hyperon decay data.

In the case of the $N \to \Delta$ transition, this gives extra freedom in the ranges that d_Δ can have. Constraining the mixing amplitudes based on the resonance saturation model gives a value for d_Δ in the range 10–25 g_π,

[a] For the G^0 Collaboration; e-mail: `jmartin@krl.caltech.edu`

where $g_\pi \equiv G_F F_\pi^2/2\sqrt{2} = 5 \times 10^{-8}$ is the scale of weak charged-current hadronic processes. This is many times the result obtained from naive dimensional analysis, which would give $d_\Delta \sim g_\pi$. The asymmetry could be further enhanced by V_{ud}/V_{us} as well as neutral-current contributions, increasing the value of d_Δ by up to a factor of four. The authors of ref. [6] therefore quote a "reasonable range" of $d_\Delta = 1 - 100g_\pi$, with a best value $d_\Delta(\text{ZHMRM}) = 25g_\pi$. The charged-pion photoproduction asymmetry is directly proportional to d_Δ, and for the best value of d_Δ, the parity-violation asymmetry has a value $A_\gamma(\text{ZHMRM}) = 1.3 \times 10^{-6}$.

2 Experimental possibilities for G^0

The G^0 experiment will measure quasi-elastic electron scattering from an LD_2 target at backward angles. A large background from the photoproduction of π^-, will exist for these backward angles. Čerenkov detectors will be constructed to reject this pion background [3]. Instead we may try to use these photoproduced pions for physics.

2.1 $h^{(1)}_{\pi NN}$

The G^0 backward angle measurements are conducted at too high an energy and with too low a luminosity for them to be useful for a measurement of $h^{(1)}_{\pi NN}$. The beam energy would have to be reduced to 335 MeV, and the beam current increased to about 400 μA. Such a low-energy, high-current beam has never been produced at Jefferson Lab and significant development would have to be done.

Nonetheless, given the chance of such a beam, we can study the experimental feasibility of such a measurement.

Such a high current would cause significant boiling in any known liquid target. One way to get around this problem would be to run the beam through a radiator, then divert the scattered electrons to a beam dump, keeping only the polarized photons to interact with the liquid target. Another possibility would be to use a solid nuclear target (such as a 20% radiation length of carbon) that will not boil. However, this solution is less attractive, as it requires a nucleus, and would possibly introduce nuclear uncertainties into the extraction of $h^{(1)}_{\pi NN}$.

Two studies were carried out for G^0:

– using a liquid-hydrogen target and diverting the electron beam after a 10% radiator to achieve a polarized photon beam,
– using a thick (20% r.l.) solid carbon target which itself provides a Bremsstrahlung flux of real photons.

The G^0 spectrometer magnet current and beam energy were chosen to maximize pion rates in the threshold region (defined in ref. [2]). The experimental parameters for the two possibilities, and the resultant G^0 coincidence rates and statistical uncertainties for 800 hours of running are shown in table 1. From these studies, it can be seen that a several hundred MHz rate must be accepted in order to achieve a reasonable statistical accuracy. Because this would result in unacceptably high accidental coincidence rates, it would likely be necessary to convert the G^0 CED/FPD setup to an integrating mode. This would make the apparatus more susceptible to backgrounds, and would require further study.

Table 1. Experimental parameters for two possible versions of an $h^{(1)}_{\pi NN}$ measurement using the G^0 apparatus.

Beam energy	335 MeV	
Beam current	400 μA	
Beam polarization	80%	
Target	40 cm LH_2	20% r.l. carbon
Radiator thickness	10% r.l.	half of target
CED/FPD coincidence rate	396 MHz	500 MHz
A_γ(DDH)	2.4×10^{-7}	
δA_γ(DDH)	18%	16%

In order to perform this experiment using the G^0 apparatus, significant changes to the setup would have to be made.

2.2 d_Δ

By contrast, an extraction of d_Δ appears to be within the reach of the backward-angle phase of the G^0 experiment, with a few relatively minor modifications. In fact the π^- that would be accepted by the experiment in a future run at 424 MeV beam energy on an LD_2 target would have kinematics such that they are on or very close to the Δ-resonance! The experiment could be conducted with either positive pions and a liquid-hydrogen target, or negative pions and a liquid-deuterium target.

Two cases were explored for the possibility of measuring d_Δ:

– Normal G^0 running at 424 MeV on LD_2 target with nominal 40 μA beam currrent and nominal G^0 spectrometer magnet settings.
– Additional running with the spectrometer tuned to maximally accept pions on the Δ-resonance.

Note that the first case would require additional electronics to be purchased for the experiment. The second case would require additional running, and therefore the addition of a radiator to boost the photoproduction rate was also considered.

The asymmetry calculated in ref. [6] assumes no background. However, physics backgrounds due to non-resonant pion production and multi-pion production can occur. For non-resonant background, it can be argued that the asymmetry is likely small, due to the fact that the asymmetry must be proportional to $h^{(1)}_{\pi NN}$. Therefore, this background can be treated as a dilution. A preliminary estimate of the non-resonant background finds that this background accounts for roughly 40% of the total rate. Multi-pion production was found to be nearly kinematically forbidden, and the background due to this process is therefore negligible.

Table 2. Experimental parameters for two possible versions of a d_{Δ} measurement using the G^0 apparatus.

	Standard G^0	Δ Tune
Beam energy	424 MeV	
Beam current	40 μA	
Beam polarization	80%	
Radiator thickness	half target + virtual photons	
Pion rate	6.8 MHz	22 MHz
A_{γ}(ZHMRM)	1.3×10^{-6}	
δA_{γ}(ZHMRM)	47%	27%
δd_{Δ}	$12 g_{\pi}$	$7 g_{\pi}$

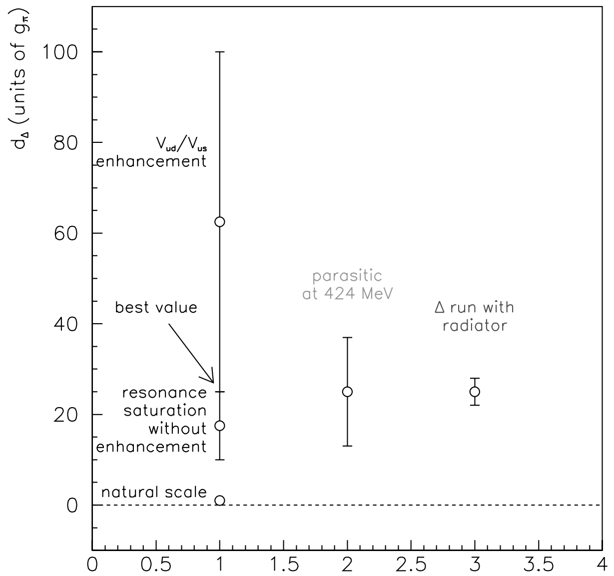

Fig. 1. Summary of theoretical predictions and the two cases studied for the G^0 experiment to contribute to the knowledge of d_{Δ}.

Table 2 shows the experimental settings and resultant rates for the two cases considered. The results again assume 800 hours of running time.

If we were to propose a dedicated Δ run, it would be wise to boost the photoproduction rate by placing a radiator upstream of the G^0 liquid target. For instance, a 10% radiation length radiator would boost the pion rate to 103 MHz. This would yield a 12% or $\delta d_{\Delta} = 3 g_{\pi}$ extraction. We see no immediate problem with placing a radiator upstream of the target. For a 10% radiator, multiple scattering will increase the electron beam angular divergence by about 0.5°. This level of divergence would not cause the primary beam to hit the small entrance window to the target. The beam spot radius at the beam dump would be roughly 0.5 ft, which is smaller than the dump size and therefore should not strongly affect background rates in the detector.

Figure 1 summarizes the theoretical predictions for d_{Δ} and the two possibilities for G^0 to contribute.

The author would like to thank S.-L. Zhu, C. Maekawa, and M.J. Ramsey-Musolf for useful discussions, and R.D. McKeown for help in developing these ideas. This work was supported by NSF grant PHY-0071856.

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