CEBAF Program Advisory Committee Nine
Extension and Update Cover Sheet

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Contact Person

Name: K. WANG
Institution: PHYSICS DEPT.
Address: McCORMICK RD
Address: CHARLOTTESVILLE, VA. 22903
City, State ZIP/Country:
Phone: (804) 924-6593 **FAX:**
E-Mail → Internet:

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PR 94-142

Experimental Study of Chiral Anomaly With Polarized Photons

(Letter of Intent for Extention)

E. S. Smith, and A.Yegneswaran
CEBAF, Newport News, Virginia

P. Degtyarenko, R. S. Hicks, R. A. Miskimen,
and G. A. Peterson
University of Massachusetts, Amherst, MA

A. M. Bernstein
Massachusetts Institute of Technology, Cambridge, MA

J. Calarco, and M. Kennedy
University of New Hampshire, Durham, NH

T. P. Welch
Oregon State University, Corvallis, OR

J. Napolitano
Rensselaer Polytechnic Institute, Troy, NY

B. E. Norum, and K. Wang
University of Virginia, Charlottesville, VA

and the CLAS

REAL PHOTON WORKING GROUP

Contact persons : K. Wang, and R. A. Miskimen

Abstract

We plan to extend the proposed experment PR-94-015 [1] with linearly polarized tagged photons in Hall B. With polarized photons, the contributions from t-channel one-pion exchange can be separated from other processes. Therefore, the $F^{3\pi}$ coupling constant can be measured through $\gamma\pi^+ \to \pi^+\pi^0$, as well as $\gamma\pi^0 \to \pi^+\pi^-$ scattering in $\gamma p \to \pi^+\pi^0 n$ and $\gamma p \to \pi^+\pi^- p$ reactions. The resolution will be improved, and the background will be further suppressed.

1 Chiral Anomaly

Just as PQCD is the appropriate approximation to the Standard Model (SM) at high energies, χPT (chiral perturbation theory) is the effective theory of the SM at low energies. Low energy scattering and decay processes can be described by expanding the effective chiral langrangian[2] in powers of field derivatives. The energy scale in χPT is set by F_π, the pion decay constant, which has been determined experimentally. The SM is a theory of a chiral quantum field. This chiral theory results in the existance of chiral anomaly[3]. Chiral anomaly occurs when a symmetry present in a classical lagrangian is broken upon quantization of the theory. The chiral anomaly component in the effective lagrangian is given by Wess, Zumino and Witten[4]. In spite of its considerable complexity, this chiral anomaly component does not have free parameters and depends only on N_c, the number of colors in QCD. Although the chiral anomaly is well understood theoretically, this important aspect of modern particle physics has not been well tested experimentally. The chiral anomaly manifests itself most clearly in the interactions of pseudoscaler mesons at low energies. For example, it predicts the pion decay amplitude for $\pi^0 \to 2\gamma$ to be

$$A^{th}_{\pi\gamma\gamma} = \frac{\alpha N_c}{3\pi F_\pi} = 0.025\ GeV^{-1}$$

for $N_c = 3$. The experimental value, $A^{exp}_{\pi\gamma\gamma} = (0.0240 \pm 0.0003) GeV^{-1}$, is in good agreement with the hypothesis that $N_c = 3$.

However, things are not as clear yet for the case of $\gamma \to 3\pi$ coupling. The amplitude $F^{3\pi}$ at the $\gamma \rightarrow 3\pi$ vertex is given by

$$F^{3\pi} = \frac{eN_c}{12\pi^2 F_\pi^3} = 9.5 GeV^{-3}$$

from the Wess-Zumino-Witten chiral anomaly component. The only experimental data[5] yield

$$F^{3\pi} = 12.9 \pm 0.9(stat) \pm 0.5(sys) GeV^{-3}$$

which is not in agreement with the theoretical prediction. A more recent calculation of the $F^{3\pi}$ amplitude [6], which includes $O(p^6)$ corrections, gives a value closer to the data,

$$F^{3\pi} = \frac{eN_c}{12\pi^2 F_\pi^3} = 10.5 GeV^{-3},$$

but due to the large error bars on the data, the comparison of theory to data is inconclusive. More precise experiments are required.

Two experiments have been proposed to investigate $F^{3\pi}$ amplitude. One is experiment E781 at FNAL [7] which focusses on the Primakoff process. The $\gamma \rightarrow 3\pi$ vertex is measured by $\pi^- + Z \rightarrow \pi^- + Z + \pi^0$ reaction, in which 600 GeV π^-'s are scattered from virtual photons in the coulomb field of the target nucleus. In the other proposal[1], 94-015 at CEBAF, unpolarized tagged photons are scattered from the virtual pion of a target proton through the reaction $\gamma p \rightarrow \pi^+ \pi^0 n$ reaction, in which π^+ is chosen as the exchanged meson in order to suppress the strong background from diffractive ρ^0 meson production. These two experiments are complementary.

The tagged photon experiment can be significantly improved through the use of linearly polarized photons. The polarization of the photons will add information on the angular correlation of the final products, which in turn will provide a powerful means of separating the t-channal OPE contribution from the diffractive and other possible processes. With the polarized photons, it will be possible to choose both π^+ and π^0 as the exchanged mesons, through the reactions $\gamma p \rightarrow \pi^+ \pi^0 n$ and $\gamma p \rightarrow \pi^+ \pi^- p$.

2 Chiral Anomaly study with polarized photons

In the kinematic region near threshold, there are a few competing processes in the two-pion photoproduction reaction. One is the VMD process, wherein the incoming photon couples to a vector meson ρ^0, scatters from the nucleon diffractively, then decays into two charged pions. This is classified as a natural parity change process. The second is the t-channel OPE process which is classified as an unnatural parity change process due to its pseudo-scaler nature. The third process is the s-channel $\Delta\pi$ production. In our measurement the OPE process contribution constitutes the signal while the strong diffractive and $\Delta\pi$ production constitute the background to be removed. There are two important variables in describing the two-pion photoproduction interaction. One is t, the invariant squared mass of the exchanged particle. The other is S, the squared invariant mass of the two-pion system.

Experiments with linearly polarized photons will shed more light into the mechanism of two-pion production since they allow the separation of the contributions from natural and unatural parity exchange processes. The angular correlation for the two pion production reaction can be found in [8]:

$$\begin{aligned} W(cos\theta,\phi,\Phi) \quad = \quad & \frac{3}{4\pi}\{\frac{1}{2}(1-\rho^0_{00})+\frac{1}{2}(3\rho^0_{00}-1)cos^2\theta-\sqrt{2}\Re\rho^0_{10}sin2\theta cos\phi \\ & -\rho^1_{1-1}sin^2\theta cos2\phi - P_\gamma cos2\Phi[\rho^1_{11}sin^2\theta+\rho^1_{00}cos^2\theta - \\ & \sqrt{2}\Re\rho^1_{10}sin2\theta cos\phi - \rho^1_{1-1}sin^2\theta cos2\phi] - P_\gamma sin2\Phi \\ & [\sqrt{2}\Im\rho^2_{10}sin2\theta sin\phi + \Im\rho^2_{1-1}sin^2\theta sin2\phi]\} \qquad (1) \end{aligned}$$

where P_γ is the degree of linear polarization of the photon, θ and ϕ are the polar and azimuthal angles of the π^+ in the helicity frame, Φ is the angle of the photon polariztion vector with respect to the production plane. The ρ_{ij}'s are the spin density matrix elements as defined in [8]. If the ρ messon is transversly polarized like the photon, then in the helicity frame,[9]

$$\rho^1_{1-1} = -\Im\rho^2_{1-1} = \frac{1}{2}$$

and all other matrix elements are negligible. Hence, the correlation is reduced to

$$W(cos\theta, \Psi) = \frac{3}{8\pi} sin^2\theta(1 + PP_\gamma cos2\Psi) \qquad (2)$$

where $P = 1$ for t-channel OPE process and $P = -1$ for diffractive process and $\Psi = \Phi - \phi$ is the angle between the pion decay plane and the photon polarization vector.

Therefore, it is possible to separate the two processes by means of their angular distributions. This separation makes it possible to study the chiral anomaly through the production of two charged pions with the exchange of a neutral pion. In the reaction $\gamma p \rightarrow \pi^+\pi^0 n$ the resolution and detection efficiency are limited by the need to detect the π^0 using the electromagnetic calorimeters. In the reaction $\gamma p \rightarrow \pi^+\pi^- p$ all three particles in the final state are charged. A major advantage of this approach is that the energy and direction of all particles in the final state can be measured much more precisely and efficiently using the three regions of drift chambers and the TOF detectors. The good resolution will greatly improve the background rejection. In addition, the observation of three charged particles will offer more flexibilities in handling the data. For instance, in the low t region, where the momentum of the proton is too low for the proton to be detected, the momentum of the proton can be reconstructed from knowledge of the two charged pions. In the high t region, where proton carries higher momentum, the very forward π^- momentum can be reconstructed from those π^+ and the proton. The polarity of the toroidal magnetic field is chosen so as to bend the positive charged particles away from the beam axis, so the detector efficiency for π^- is relatively low. This flexibility will increase the acceptance of the measurement and hence its efficiency. When t is close to 0, the diffractive background will be much higher than the OPE contribution. Hence, it will be more difficult to extract the t-channel OPE information. At some point, it will be necessary to rely on the data from π^0 production only. Since the diffractive channel is closed for $\pi^+\pi^0$ production, it will be a powerful reaction to study the relative contribution from the OPE and $\Delta\pi$ production. In practice, the two reactions will be measured simutaneously, thus enriching the experimental information.

Figure 1 shows the polar angle dependence in the helicity frame from the Monte Carlo event generator. Both diffractive and OPE processes have the same pattern. Figure 2 shows the azimuthal dependence of the t-channel OPE process, which favors a direction perpendicular to the polarization of the incoming photon. Figure 3 shows the azimuthal dependence of the diffractive VMD process, which favors a direction parallel to the polarization of the incoming photon. This signature can not be observed with unpolarized photons, since the effect from polarization is averaged. The difference in azimuthal angle dependences will enable us to extract much more information from the data. Firstly, we can fit the azimuthal spectrum using the known angular dependences (eqs. 1 and 2) to obtain the ratio of the contributions of the two processes. Secondly, we can place a narrow cut on the peak position at $\Psi = 0, \frac{\pi}{2}, \frac{3\pi}{2}$, and 2π, so the events from different processes can be sampled. These sampled events will help in the study of the t and S dependences of the OPE and VMD process.

3 Polarized Photon source

To make this extension possible, we need a high quality, polarized tagged photon beam. The energy of the photons must be between 1 to 2 GeV, the polarization must be nearly 100%, and the photon rate must be about $10^6 second^{-1} MeV^{-1}$. We also need to vary the polarization plane randomly in order to average out the detector effects. The proposed Compton Backscattering Facility (BCF) [10] in Hall B will meet these requirements.

The BCF is based on the head-on collision of polarized low energy photons with energetic electrons in which the scattered photons gain a tremendous amount of the energy from the electrons and are back scattered within a small cone. This technique has been used very succesfully in several labortories, such as Frascati, and LEGS at BNL. In these cases a relatively weak (1-10 W) laser beam is collided with an intense (≈100 mA) electron beam stored in a ring. In the proposed BCF, a conjugate arrangement is employed. A very intense photon beam stored in an optical cavity (input power ≈10 W, cavity gain ≈30,000) backscatters from the high energy but relatively weak (≈ 10μA) electron beam from the CEBAF CW accelerator to produce an intense, highly polarized photon beam.

There are a numerous advantages to such a facility. Firstly, the polarization approaches 100% across a wide range of energies. The polarization can be changed arbitrarily simply by rotating a half-wave plate. The short filling time (a few milliseconds) of the optical cavity makes it possible to change the polarization quickly and frequently. The photon beam can also be turned on and off instantaneously by controlling an acoustic-optical modulator, and so even the extremely low Bremsstrahlung background can be studied at random intervals. Secondly, There is no huge peak at the low energy side of the photon spectrum, as exists in a traditional Bremsstrahlung photon source. Therefore, we won't have to worry about prescaling the events from low energy photon scattering nor about the accidental coinsidences that the untagged low energy photons will generate. Thirdly, the resolution will be improved over a restricted energy region, in conjunction with the tagger improvement required for the measurement of ϕ photoproduction near threshold [11]. Finally, the background is extremely low compared with other photon sources, due to the lack of material in the path of the electrons. As this facility will meet the requirements of this experiment in terms of both energy and flux, hence it will make the extended measurements practical.

4 Summary

The experimental testing of chiral anomaly is very important to fundamental physics. After the results and experience obtained from unpolarized tagged photons, an extension of the experiment with polarized tagged photons will disclose more information on the mechanism of the reaction and will provide higher quality data with lower background and better resolution.

We need to study in more detail with Monte Carlo simulation of the contributions from different channels using different models. Parallel theoretical work is also under way on the calculation of the contribution from s-channel $\Delta-$ production and on the extrapolation technique of data analysis.

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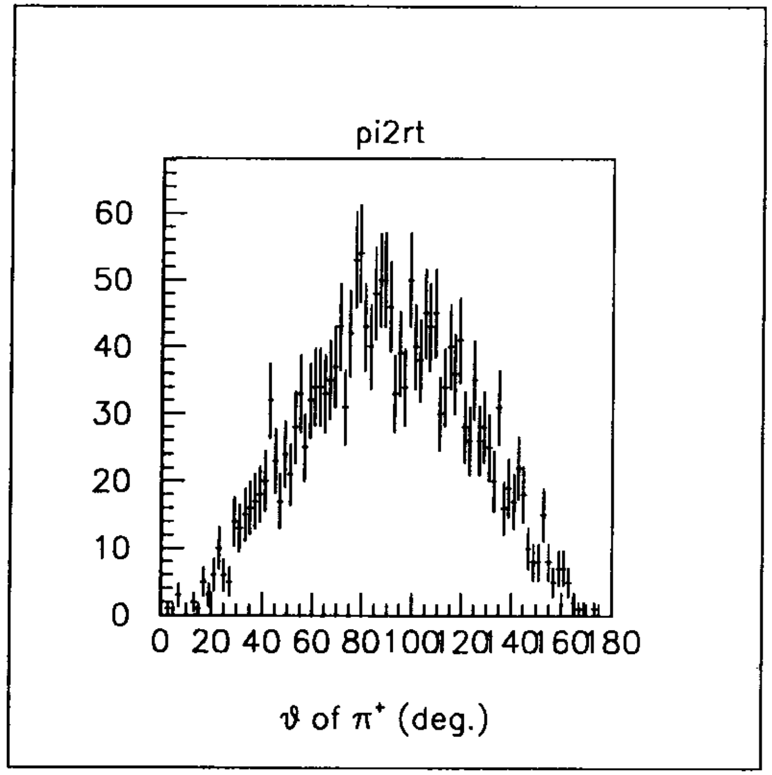

Figure 1: Angular distribution on polar angle θ of π^+ in the helicity system.

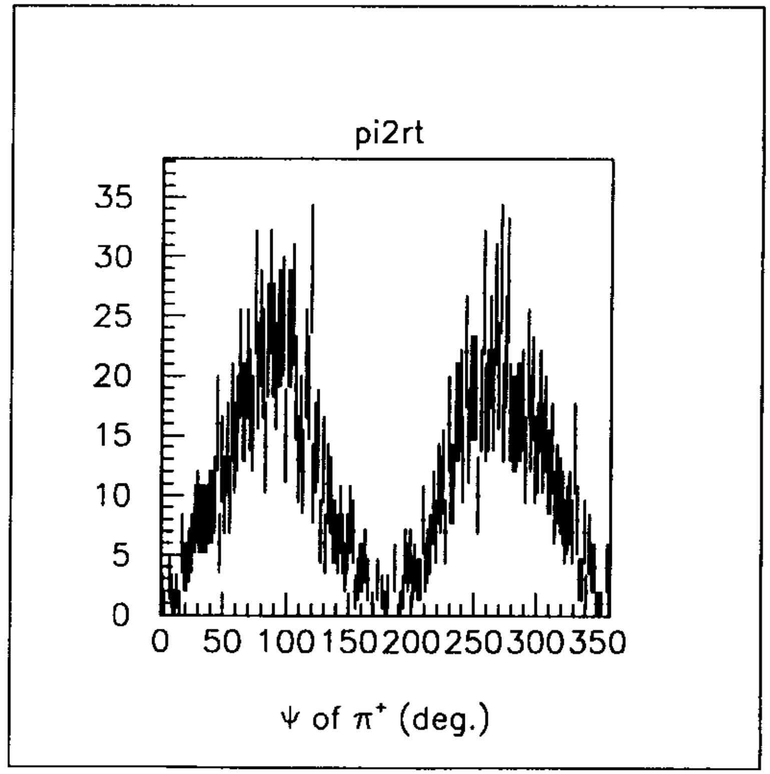

Figure 2: Angular distribution on asimuthal angle Ψ of π^+ for OPE process in the helicity system.

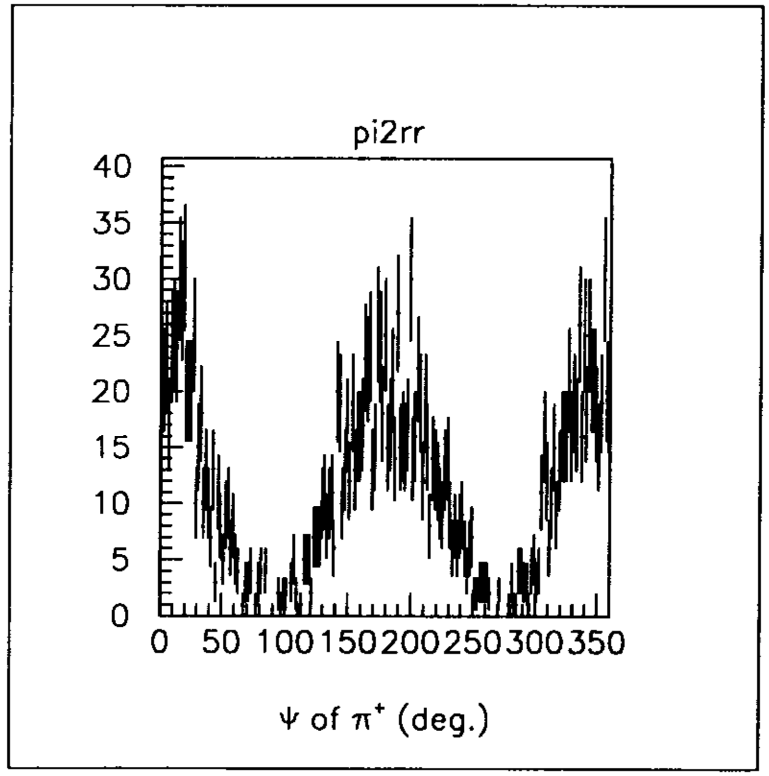

Figure 3: Angular distribution on asimuthal angle Ψ of π^+ for VMD process in the helicity system.