Precision Measurements of the Electromagnetic Properties of Light Pseudoscalar Mesons at JLAB via the Primakoff Effect

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The appearance of chiral anomaly and the prediction of the Goldstone bosons due to spontaneous breaking of chiral symmetry are two basic characteristics of QCD at low energies. Understanding the properties of pseudoscalar mesons, which involve both Goldstone bosons and the chiral anomaly, are fundamentally important in confinement scale QCD. The three neutral pseudoscalar mesons π^0, η and η', with the first two being Goldstone bosons, represent one of the most interesting systems in low energy QCD. This system contains fundamental information about the effects of SU(3) and isospin breaking by the u, d, and s quark masses, leading to important mixing effects among the mesons, as well as two types of chiral anomalies. Therefore, a study of the two-photon decays of the π^0, η and η' and their transition form factors at very small Q^2 will allow one to determine the η, η' mixing angle and one constant $\mathcal{O}(p^6)$ in the chiral Lagrangian, providing a test of the low energy limit of QCD in a relatively clean setting.

Because of the small mass of π^0 meson, the prediction of the chiral anomaly for the $\pi^0 \to \gamma\gamma$ decay width is more accurate and exact in the limit when the u- and d-quark masses vanish. In this limit the predicted decay width depends only on the number of color in QCD (N_c) and the pion decay constant (F_π)[1]:

$$\Gamma(\pi^0 \to \gamma\gamma) = (\alpha_{\mathrm{em}}^2 N_c^2 M_\pi^3)/(576\pi^3 F_\pi^2) \tag{1}$$

However, the real world current-quark masses are of the order of 5-7 MeV. The total estimated value of corrections due to this explicit breaking of chiral symmetry is at the level of $\sim$2%[1]. Given the definite precision of the theoretical prediction, it should be experimentally tested to a level of accuracy which is consistent with theoretical uncertainties.

The PrimEx collaboration at Jefferson Lab is planning to perform a precision measurement of the neutral pion lifetime using the small angle coherent photoproduction of π^0's in the Coulomb field of a nucleus, *i.e.*, the Primakoff effect[2]. This measurement will be a state-of-the-art experimental determination of the lifetime with a precision of less than 1.5%.

In the past, three general experimental techniques have been used to access the neutral pion decay width: direct measurement of the lifetime, $\gamma\gamma$ collisions, and the Primakoff effect. The result from the most recent lifetime measurement[3] has the smallest quoted error ($\pm$3.5%) and lies nearly two sigma below the value predicted from ChPT. It is interesting to note that the loop corrections ($\sim 2\%$) tend to increase the predicted width. All Primakoff type of experiments so far have been performed with bremsstrahlung beams and have a typical error about $\sim 10\%$ [4]. The present experimental knowledge of the π^0 lifetime is at the $\sim 7\%$ level. Therefore, the proposed measurement at the percent level will fill this important gap between theory and experiment.

The PrimEx experiment will use the Jefferson Lab Hall B high intensity and high energy CW tagged photon facility which will provide two distinct advantages over previous experiments involving bremsstrahlung beams. First, the quasi-monochromatic nature of the tagged beam will enable a clean kinematical separation of the Primakoff mechanism from various background processes, and secondly, the tagging technique will enable significantly better control of systematic errors associated with the photon flux normalization. The primary experimental equipment includes: the Hall B photon tagger, three 5% r.l. solid π^0 production targets, a pair production luminosity monitor, and an electromagnetic hybrid calorimeter (HYCAL) for the π^0 decay photons, with Pb-glass modules and a central insertion of high resolution $PbWO_4$ crystals.

We will take data with sufficient angular resolution to check the shape of the Primakoff peak. Three spin zero targets will be studied (^{12}C, ^{116}Sn, and ^{208}Pb). These nuclei have form factors which are well known and will be used to test the Z^2 dependence of the cross section. The strong energy dependence of the cross section on E_γ will be measured in the range from 4.6 to 5.7 GeV. The study of the Primakoff peak as a function of these three variables will be used to empirically determine the systematic errors.

Currently, we are in the stage of preparation of the experimental setup. We plan to have all detectors ready for the beam tests by the end of year 2001. We expect to have the first experimental data for the pion lifetime in 2002.

With the 12 GeV CEBAF energy upgrade we will be able to perform the second part of this experimental program: radiative width and electromagnetic transition form factor measurements for the more massive η and η' mesons [5]. This comprehensive program will provide fundamental tests of both QCD and QCD inspired models.

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References

1. J.F. Donoghue, *et al.*, *Dynamics of the Standard Model*, (1992).
2. Jefferson Lab proposal E99014 (url: www.jlab.org/primex).
3. H.W. Atherton *et al.*, *Phys. Lett.* B **158**, 81 (1985).
4. A. Browman *et al.*, *Phys. Rev. Lett.* **33**, 1400 (1974).
5. See url: www.jlab.org/div_dept/physics_division/GeV.html.