The Axial U(1) Anomaly in Strong Interaction ◇

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In the limit of vanishing light quark masses m_u, m_d and m_s the QCD Lagrangian exhibits a symmetry under chiral $SU(3)_L \times SU(3)_R$ transformations which is broken down spontaneously to $SU(3)_V$ giving rise to the eight pseudoscalar Goldstone bosons (π, K, η). The interactions at low energies amongst the Goldstone bosons can be treated in a perturbative fashion within the framework of chiral perturbation theory (ChPT). The axial $U(1)$ anomaly of the QCD Lagrangian, on the other hand, prevents the corresponding pseudoscalar singlet from being a Goldstone boson. Indeed, the lightest candidate would be the η' with a mass of 958 MeV which is considerably heavier than the octet states. Therefore, in conventional ChPT the η' is not included explicitly, although its effects are hidden in a contribution to a coupling coefficient of the higher order Lagrangian. But in order to describe the physical processes involving the η', such as the hadronic decay modes $\eta' \to \eta\pi\pi, \pi\pi\pi$, the anomalous decays $\eta' \to \gamma\gamma, \pi^+\pi^-\gamma$, as well as photoproduction of the η' on the nucleons and η' production in pp collisions, it is necessary to include the η' explicitly within the effective theory.

In [1], we have calculated the dominant decay mode of the η', $\eta' \to \eta\pi\pi$, within the framework of infrared regularized $U(3)$ ChPT. We presented the most general effective Lagrangian up to fourth order in the derivative expansion which describes the interactions at low energies between the members of the lowest lying pseudoscalar nonet, (π, K, η, η'). Our calculation contains for the first time an investigation of all one-loop diagrams – both tadpoles and unitarity corrections – with vertices from the leading and next-to-leading order Lagrangians. In infrared regularization loop diagrams with a virtual η' contribute only at higher orders and are therefore neglected. We find that the Goldstone boson loop contributions are rather small indicating the convergence of the chiral series. Reasonable agreement with experimental data is obtained and both the decay width and its energy dependence on the Dalitz variables are well reproduced. However, our results are subject to the choice of parameters such as the omission of OZI violating couplings. Overall we can state, that infrared regularized $U(3)$ ChPT is suited to study the η' decay $\eta' \to \eta\pi\pi$.

In a second work [2], photo- and electroproduction of the η, η' mesons on nucleons are investigated within a relativistic chiral unitary approach based on coupled channels. The effective s-wave potentials for electroproduction and meson-baryon scattering are derived from a chiral effective Lagrangian and iterated in a Bethe-Salpeter equation to obtain cross sections for η, η' photo- and electroproduction from nucleons. The combination of chiral effective Lagrangians with such non-perturbative schemes have made it possible to generate resonances dynamically and to go to energies beyond the scale of chiral symmetry breaking $\Lambda_\chi = 4\pi F_\pi \approx 1.2$ GeV at which the perturbative expansion of the chiral series is expected to break down. Since we restrict ourselves to the threshold region, only s-wave contributions are taken into account which are dominant at the pertinent energies for most of the discussed reactions.

With only a few chiral parameters we performed a fit to a large amount of data, consisting of meson-baryon scattering and photoproduction of mesons on the proton. The s-wave approximation yields good agreement with the low-energy data in many channels, whereas in the remaining channels p-wave contributions are expected to be dominant. We clearly generate the appearance of the $S_{11}(1535)$ in the pion- and photo-induced production of the η, while the $S_{11}(1650)$ is produced in the $K\Lambda$ channels. We are also able to produce a resonance-like shape in the photoproduction of the η' which has been assigned to the $S_{11}(1897)$ in a recent experiment at ELSA, see Figure. The overall agreement of our results with data indicates that chiral dynamics and unitarity govern processes up to center-of-mass energies of $\sqrt{s}$ =2 GeV and that the η' can be included systematically in a chiral effective Lagrangian.

Having constrained the parameters of the approach, we can give predictions for further processes such as the pion-induced production of the η' in $\pi^- p \to \eta' n$ or η and η' electroproduction, which is more sensitive to the structures of the nucleon due to the longitudinal coupling of the virtual photon to the nucleon spin and provides a better test for our model when compared with data. The only available electroproduction data exists so far for the η with invariant momentum transfers Q^2 starting at 0.375 GeV^2. It exhibits an unusually slow Q^2 evolution which is in general difficult to understand. The inclusion of electromagnetic form factors in our model increases the predicted η electroproduction cross sections on the proton, providing a qualitative explanation for the hard form factor of the photocoupling amplitude observed at CLAS.

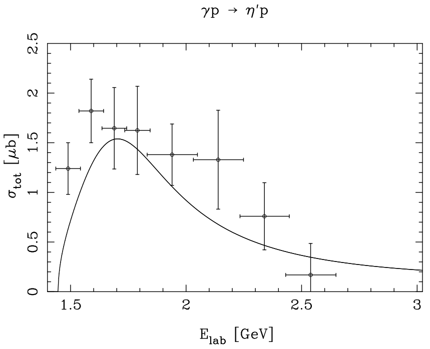

Figure: Given is the total cross section for η'-photoproduction of the proton and the data are taken from [3].

References

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