ABSTRACT

Quantum Chromodynamics (QCD) is the field theory governing the strong interactions of hadrons. At high energies, due to asymptotic freedom, perturbation theory is applicable, whereas at low energies relevant for hadronic bound states (strong QCD), non-perturbative techniques are required. One of these techniques, the field theoretical approach of the Dyson-Schwinger Equations (DSEs), is utilized in the present study.

Mesons are the simplest hadrons, and thus are an excellent "laboratory" to investigate strong QCD. In particular the properties of the pion, the lightest pseudoscalar meson, is determined by non-perturbative effects such as dynamical chiral symmetry breaking (DCSB). In order to gain a deeper understanding of strong QCD, we investigate two rather different aspects of non-perturbative dynamics for meson physics in this work.

The first aspect deals with the transition between the perturbative and non-perturbative regimes of QCD, in particular the determination of the distance scale for the onset of non-perturbative dynamics. Correlation functions (correlators) with meson quantum numbers, which are vacuum expectation values of products of gauge-invariant local operators, are ideally suited for this type of investigation. We consider the vector and axial-vector correlators built from vector and axial-vector currents respectively. We investigate the difference (V-A correlator), sum (V+A correlator), and ratio of the difference and sum of these correlators. In the chiral (massless) limit, to any finite order of perturbation theory, the vector and axial-vector correlators are identical. Thus the way the difference (V-A) correlator increases as momentum decreases is a measure of the onset of non-perturbative dynamics. It can provide information on the associated distance scale and the four quark condensate. The V+A correlator remains close to free-field behavior for distances as large as 1 fm. We therefore use the ratio of the V-A and V+A correlators as a probe. The requisite non-perturbative inputs to the calculation are DSE solution for the dressed quark propagator and an Ansatz for the vector and axial vector vertices.

The extracted four-quark condensate is compared to results from other models and to the prediction of the vacuum saturation Ansatz. Using Fourier transforms, we calculate the distance scale relevant to the onset of dynamical chiral symmetry breaking and, by implication, of non-perturbative dynamics. Our results are compared to results from QCD sum rule calculations, lattice QCD, and instanton physics.

The second aspect involves the evaluation of the valence quark distributions in the light pseudoscalar mesons: pion and kaon. Quark distributions in hadrons are intrinsically non-perturbative and thus are currently determined from structure functions measured experimentally in processes like the deep inelastic hadron-lepton scattering and the Drell-Yan lepton-pair production. These distributions give the probability densities of finding a quark carrying a fraction x of the parent hadron's momentum, at a resolving scale Q. We work in the Bjorken limit (very large Q) and concentrate on the valence quark for which the so-called "handbag" diagram mechanism is considered sufficient. Non-perturbative inputs such as the dressed quark propagators and the bound state wave function are taken from DSE solution and Bethe-Salpeter solution respectively. The valence quark distributions in the pion and kaon are compared to available data. This is the first time that bound state descriptions of the quality provided Bethe-Salpeter solutions have been compared to the quark distributions measured in deep inelastic scattering.

Using the leading order DGLAP evolution equation for the nonsinglet structure function to evolve to relevant experimental scales, we compare our results with existing FermiLab data on the pion at $Q = 4.05$ GeV, the recent reanalysis of data at $Q = 5.2$ GeV, and an earlier theoretical model which is a primative version of the current model. We also compare the ratio of the kaon to pion distributions with the Drell-Yan experimental data that produced such information. Approximations used in the formulation are critically evaluated and discussed.