Goldstone nature of the pion confirmed

The COMPASS experiment at CERN reports in a recent Physical Review Letter the first precise measurement of the electromagnetic polarisability of the charged pion.

The pions, exchanged copiously between the protons and neutrons in a nucleus, are the lightest particles that undergo – in the nucleus effectively mediate – the strong interaction. In the model of constituent quarks, where protons and neutrons (nucleons) are made up of three quarks, pions constitute quark-antiquark pairs. Accordingly, their stiffness against deformations is a direct measure of the strong binding force between the constituents.

As the name implies, the binding force between quarks is very strong, and the objects made of quarks are accordingly very compact and stiff. For the nucleons, this has been tested in great detail since many decades, by measuring their deformability in external electromagnetic fields. This is parameterized by the electromagnetic polarisabilities - quantities whose atomic equivalent have played a key role in exploring quantum electrodynamics during the past century. On the level of elemenary processes, they lead to a modification of the cross-section for photon (*i.e.* Compton) scattering. From Compton scattering off proton and neutron targets, their polarisabilities have been determined to an accuracy of about 10%. In natural units, the polarisabilities have the dimension of a volume. While for an atom this "polarisability volume" is comparable in size to the atom itself, the nucleon polarisabilities are more than a factor of 1000 smaller than their own volume.

In terms of understanding the interaction between quarks and antiquarks, the polarisability of the pion is of highest interest, however the experiment is much more challenging than for nucleons. The prime reason is that pions can not be prepared as a fixed target; there is no way to reach a target density as in the nucleon's case. The method employed in the COMPASS experiment is based on the idea that the strong electric field around nuclei can serve as a source of (almost) real photons, on which incident particles can be scattered, thus representing Compton scattering in inverse kinematics. This so-called Primakoff method has already been explored in the early 1980s in Serpukhov (Russia), but due to the small data sample, it only resulted in a rough value $[6.8\pm1.4(\mathrm{stat})]\cdot10^{-4}\,\mathrm{fm}^3$, presumably afflicted by a large, unaccounted systematic error.

Many efforts for alternative experimental approaches have been undertaken, with the goal to determine the Compton scattering cross-section for pions. They all feature systematic shortcomings, such that no trustworthy value was incorporated into the "Review of Particle Physics" list up to now.

With the COMPASS apparatus at CERN, a modern Primakoff experiment has been realized, delivering in the first data taking for the pion Compton scattering about a factor 10 more statistics than the Serpukhov experiment, and the pion electric polarisability value of $[2.0\pm0.6(\mathrm{stat})\pm0.7(\mathrm{syst})]\cdot10^{-4}\,\mathrm{fm}^3$. The COMPASS collaboration has been founded in 1996 and is in operation at SPS, the second largest accelerator ring of CERN. It comprises about 220 physicists from 13 countries around the world. It is a multipurpose detector of about 50 Meter length, used to study various phenomena in the field of strong interaction. For the presented measurement, it allows for the first time a variety of systematic checks, in order to assure that the intended effect is extracted with high precision.

Earlier measurements gave values that were more than a factor of two larger than the predicted value ($[2.7\pm0.5]\cdot10^{-4}\,\mathrm{fm}^3$) from the low-energy effective theory of the strong interaction (Quantum Chromodynamics).

The new COMPASS measurement strengthens the identification of the pion with the Goldstone boson of strong interaction, arising from a vacuum with spontaneous and explicit breaking of the chiral symmetry. The "Goldstone mode" corresponding to a nearly massless excitation is complementary to the "Higgs mode" representing a massive excitation. The Higgs particle, experimentally proven to exist at CERN in 2012, is interpreted as the elementary excitation of a scalar field. In the standard model, such a scalar field is responsible for electroweak symmetry breaking, allowing the W and Z gauge bosons to be heavy while leaving the photon massless.

Note prepared by Jan Friedrich, on the completion of the "2009 Primakoff data" analysis, January 2015