Why to measure the pion polarisability?

The pions, whirring copiously around the protons and neutrons in a nucleus, are the lightest particles that undergo – in the nucleus in fact mediate – the strong interaction. In the model of constituent quarks, in which the protons and neutrons (the nucleons) are made up of three quarks, pions constitue a quark-antiquark pair. Accordingly, their stiffness against deformability is a direct measure of the binding force between the two constituents.

The binding force between quarks is, giving it the name, strong, and the objects made of quarks are accordingly very dense and stiff. For the nucleons, this has been tested in great detail since many decades, by measuring their resistance against deformation under electromagnetic forces. This is encoded in the electric and magnetic polarisabilities. On the particle level, they become apparent as 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 on the 10% level. Owing to the correspondence of distance and inverse energy/momentum in quantum mechanics, the polarisability is measured in units of a volume. While for atoms this "polarisability volume" is in the same order of magnitude as the atom itself, for the tiny nucleons, their polarisability is even four orders of magnitude smaller than themselves.

In terms of understanding the color force between quarks and antiquarks, the polarisability of the pion is obviously of highest interest, however the experiment is much more challenging than that for the 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 presented experiment bases on the idea that the electric field around nuclei can serve as a source of (almost) real photons, on which incident particles can be scattered, sometimes referred to as Compton scattering in inverse kinematics. This method, also dubbed as Primakoff mechanism, has been explored already in the early 1980s in Serpukhov (Russia), but due to the small achieved data sample, it only resulted in a rough value ($6.8\pm1.2 \pm (?) \times 10^{-4}\,\mathrm{fm}^3$). It is presumably afflicted by a large, unaccounted systematic error.

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

The presented approach has realized a modern Primakoff experiment with the COMPASS apparatus at CERN, delivering in the first data taking for the pion polarisability about a factor 10 more statistics than the Serpukhov experiment. A variety of systematic checks was done, in order to assure that the intended effect is extracted with high precision.

The result confirms the expectation from the low-energy expansion of the generally accepted quantum field theory of the strong interaction (Quantum Chromodynamics). It is at variance with the previously published values, which overestimated the pion polarisability by more than a factor of two.

So, the pion turns out to be much stiffer than previous experiments suggested, but confirming the prediction of the standard model QCD. For many colleagues in the field, this constitutes one of the most important messages in experimental hadron physics of the past years.