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Why measure the polarisability of the pion?

The strong interaction not only binds quarks into protons and neutrons, it also binds protons and neutrons into nuclei. Inside those nuclei, pions - made up of a quark and an antiquark - mediate the interaction. Strong interaction theory makes a precise prediction on the polarisability of pions – the degree to which their oppositely-charged constituents can be separated in an electromagnetic field.

One way to study the strong binding between the quarks in a nucleon (proton or neutron) has been to measure their resistance to being pulled apart in an electromagnetic field. The level of difficulty is expressed in the electric and magnetic "polarisabilities" of the particles. These polarisabilities can be determined by measuring the probability (or cross-section) for Compton scattering, in which a photon scatters inelastically from a charged particle.

Polarisability is expressed as a volume. For atoms this "polarisability volume" is about the same size as the atoms themselves, but for nucleons it is four orders of magnitude smaller than the volume of the particles. The pion, with a diameter of about 10^{-15} m (or 1 femtometre) is of a roughly similar size to a proton.

Measuring the polarisability of the pion could help researchers in understanding more about the strong force between quarks and antiquarks. But the experiment to measure polarisability is harder to conduct with pions than with nucleons. This is mainly because – unlike nucleons - pions cannot be prepared as a fixed target.

For this reason, the experiment presented here uses a different method, based on the idea that the electric field around nuclei can serve as a source of photons on which incident charged particles can be scattered. This effect is sometimes referred to as Compton scattering in inverse kinematics.

Such pion-photon Compton scattering, also known as the Primakoff mechanism, was explored in the early 1980s in an experiment at Serpukhov, but the small data sample led to only a rather imprecise value for the polarisability.

Many efforts for alternative experimental approaches have been undertaken, with the goal of getting a hold on the pion’s Compton scattering cross-section. They all feature systematic shortcomings, and no trustworthy value has been incorporated into the list of properties in the "Review of Particle Physics" up to now.

Now the COMPASS experiment at CERN has achieved a modern Primakoff experiment. In the first run of data taking to determine the polarisability of the pion, it delivered about 10 times more statistics than the Serpukhov experiment, and a variety of systematic checks have been done to ensure that the effect is extracted as intended with high precision.

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

So, the pion turns out to be much more resistant to derformation in an electric field than previous experiments suggested, but this result confirms the prediction of QCD, a key component of the Standard Model of particle physics. For many colleagues in the field, this constitutes one of the most important messages in experimental hadron physics of the past years.