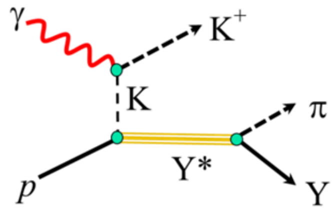
Photoproduction Line Shapes for Σπ Near the Λ(1405)

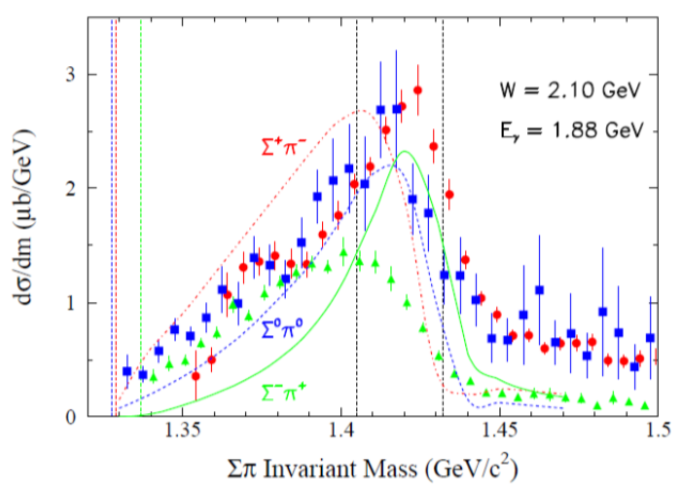


Subatomic particles that are unstable exhibit finite widths of their mass-energy due to the Heisenberg Uncertainty Principle. The shorter their lifetimes are, the wider their distributions in mass. Particles (or "resonances") that are created in collisions reveal something of their character via their mass distributions or "line shapes". A single isolated particle resonance has a "Lorentzian" or "Breit-Wigner" line shape, the details of which are related to the angular momentum of its decay and to the opening of the phase space of its decay channels.

In this experiment [1], CLAS investigated one unusual and peculiar state, the Λ(1405), which is the first excited state in the Λ family of 3-quark particles (baryons) that contain at least one strange quark (hyperons). Its line shape was found to be very non-Breit-Wigner in form, providing clues to its internal structure and to the hadronic environment in which it was created. Its mass is nominally 1,405 MeV (hence its name), a value located between the summed masses of the ground state Σ hyperon plus a pion, and the summed masses of the ordinary nucleon plus a kaon. The Λ(1405) decays into Σπ, but into $N\bar{K}$ only through the high-mass "tail" of its line shape. Although it has its place in the standard quark model, it may not be a simple 3-quark baryon, but rather a mixed state with one or more molecular-like bound states interactions, coupling together the octet baryons and pseudo-scalar mesons.

The experiment created the Λ(1405) hyperon using photoproduction (called Y* in the small figure). With the large kinematic acceptance of CLAS, this was done comprehensively for the first time. The experiment showed interference effects in the Σπ line shapes that suggested contribution in the 1405 MeV mass region of yet another amplitude that has the character of isospin one. It was suggested that this could be the signal of a new Σ-like resonant state that overlaps the Λ(1405) mass range. More theoretical work is needed to develop this idea, but it is something that has been put forward by so-called chiral unitary models and models based on a diquark ansatz of baryonic structure.

More specifically, the reaction $\gamma + p \rightarrow K^+ + \Sigma + \pi$ was used to determine the invariant mass distributions of the $\Sigma^+\pi^-$, $\Sigma^-\pi^+$ and $\Sigma^0\pi^0$ final states, from threshold at 1328 MeV/c^2 through the mass range of the Λ(1405) and the Λ(1520). The measurements were made using tagged real photons, for center-of-mass energies $1.95 < W < 2.85$ GeV. The three mass distributions differ strongly in the vicinity of the $I = 0$ Λ(1405), indicating the presence of substantial $I = 1$ strength in the reaction. Background contributions from the $\Sigma^0(1385)$ and from $K^*\Sigma$ production were shown to have negligible influence. To separate the isospin amplitudes, model fits were made that included distortion effects due to the opening of, and coupling to, the $N\bar{K}$ final state (Flatté effect). A best fit was obtained after including a phenomenological $I = 1$, $J^P = 1/2^-$ amplitude with a centroid at 1394 ± 20 MeV/c^2 and a second $I = 1$ amplitude at 1413 ± 10 MeV/c^2. The centroid of the $I = 0$ Λ(1405) strength was found at the Σπ threshold, with the observed shape determined largely by channel-coupling, leading to an apparent overall peak near 1405 MeV/c^2.



The figure above shows the data for one W bin, illustrating the differences between the Σπ charge states. For comparison, the curves are predictions of a model using an effective-Lagrangian approach. The accuracy of the prediction is seen to be poor, but it correctly shows that differences in line shapes of the observed order were to be expected. This line of research has sparked community interest and is being followed up at accelerator laboratories in Germany (Bonn/ELSA) and Japan (Osaka/Spring-8).

[1] K. Moriya, R. A. Schumacher *et al.* (CLAS Collaboration), *Measurement of the Σπ Photoproduction Line Shapes Near the Λ(1405)*, Physical Review C **87**, 035206 (2013).