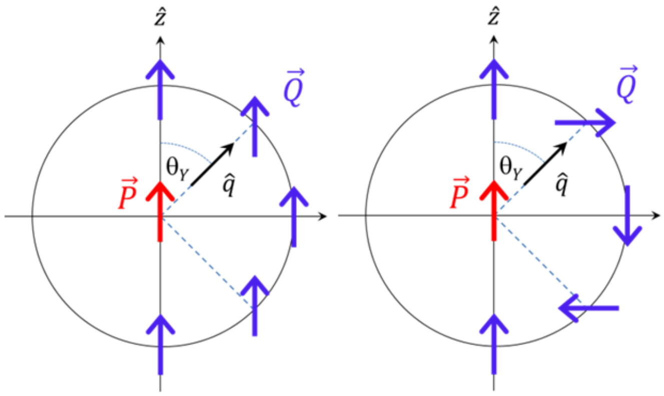
Spin and Parity of the Λ(1405) Baryon



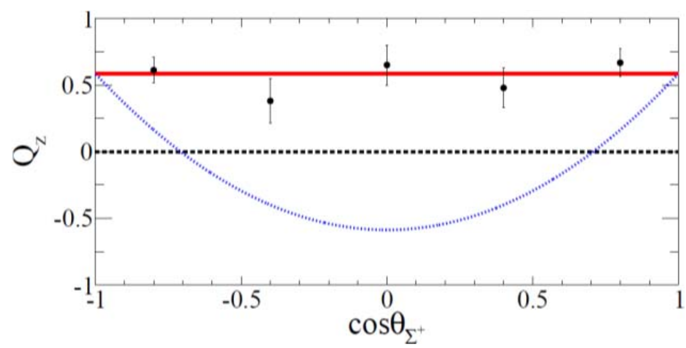
S-wave decay *P*-wave decay

Every subatomic particle has a set of properties that define its identity. Beyond mass, charge, and magnetic moment, each particle has discrete quantum numbers that include its spin angular momentum J and its intrinsic parity P. The spin comes in integer steps of $\hbar$ starting from ½ for 3-quark objects (baryons). The parity is either positive ("+") or negative ("–") depending on the inversion symmetry of its spatial wave function. For example, the familiar proton and neutron have spin ½ and positive parity.

Hyperons are 3-quark particles (baryons) which contain one or more "strange" quarks in place of the usual "up" and "down" quarks. Their strangeness is designated by an integer that specifies the number of strange quarks they contain. They are unstable, though the ground state hyperons can live long enough to travel some centimeters in the laboratory experiments before decaying to lighter particles. Properties of these "strange" particles are useful for understanding physics in areas as diverse as CP violation, the collective behavior of baryons in nuclei, and the structure of neutron stars. The Λ ("Lambda") hyperons are one such set: all are neutral, have one strange quark, but also have a variety of masses, decay modes, spins, and parities. The first excited state of this family of particles is the elusive and mysterious Λ(1405). While known for half a century, it is hard to study because its mass is less than the sum of the K meson and nucleon masses, making it challenging to create. In the quark model, it is expected to have $J^P = ½^-$, but some models predicted "+" for the parity.

The spin and parity of the Λ(1405) had never been definitively measured before the experiment summarized here [1], precisely because of the difficulty in producing it, and in particular because it must be produced spin polarized for a measurement to be made. We used photoproduction data from the CLAS detector at Jefferson Lab. The reaction $\gamma + p \rightarrow K^+ + \Lambda(1405)$ was analyzed in the decay channel $\Lambda(1405) \rightarrow \Sigma^+ + \pi^-$, where the decay distribution to $\Sigma^+ \pi^-$ and the variation of the Σ^+ polarization with respect to the Λ(1405) polarization direction determined the spin and parity. The Λ(1405) was produced in the c.m. energy range $2.55 < W < 2.85$ GeV and for $0.6 < \cos\theta^{K^+}_{c.m.} < 0.9$.

The decay angular distribution of the Λ(1405) in its rest frame was found to be isotropic, which means the particle is consistent with spin $J = ½$. The first figure illustrates how the polarization P of a parent particle with spin ½, in this case the Λ(1405), transfers polarization Q to the daughter baryon, in this case the Σ^+, depending on whether the decay is in a spatial S wave (L=0) or P wave (L=1). This distinction is what determines the parity of the final state, and hence of the parent. The polarization Q was measured through the parity violating weak decay of the Σ^+ hyperon into $p\,\pi^0$.



The second figure shows the z projection of the vector Q as a function of the decay angle between the Λ(1405) polarization direction and the momentum vector of the Σ^+. It is evident that the data for Q follows the constant distribution of S-wave decay, rather than the rotating direction for P-wave decay. This is the hallmark of negative parity for the Λ(1405). The figure shows one of nine kinematic bins that all showed the same result. As an additional outcome, over the full kinematic range for this reaction, the Λ(1405) was produced with polarization P = 0.45 ± 0.02 (stat) ± 0.07(syst). Thus, the Λ(1405) has spin-parity $J^P = ½^-$, as expected by most theories.

[1] K. Moriya, R. A. Schumacher *et al.* (CLAS Collaboration), *Spin and Parity Measurement of the Λ(1405) Baryon*, Physical Review Letters **112**, 082004 (2014). (This paper was selected as an "Editors' Suggestion" at PRL for being particularly interesting or well written.)