A Measurement of Δs via Neutral Current Neutrino Scattering at Fermilab

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The strange quark contribution to the nucleon spin (Δs) remains an unresolved problem after several decades of work via deep-inelastic scattering experiments. A measurement of neutral-current elastic (NC-elastic) scattering in the Fermilab Booster neutrino beam would allow Δs to be extracted with higher precision and less model-dependence than the deep-inelastic scattering measurements. This would provide the strange-quark piece of the proton spin puzzle. This measurement could be performed via the SciBooNE experiment with additional run time (beyond that currently approved) and with detector upgrades to better identify NC-elastic scattering events.

In polarized, inclusive, lepton deep-inelastic scattering (DIS) the strange quark contribution to the nucleon spin (Δs) is measured to be about -0.1 that of the total proton spin. Recent results from semi-inclusive leptonic deep-inelastic scattering indicate that Δs is consistent with zero (and inconsistent with the inclusive measurements). These are precise results, however interpretations are clouded due to the dependence on a model for the quark structure functions. This model dependence may explain the conflicting results between inclusive and semi-inclusive DIS.

In addition to the goal of better understanding the structure of the nucleon, a measurement of Δs has cosmological implications. The NC-elastic interaction is dominant for μ and τ neutrinos in core-collapse supernovae. It will also provide information about the interaction rate of certain dark matter particles in detectors. The spin-dependent part of the interaction cross section can be significant.

Neutrino neutral-current elastic scattering is uniquely sensitive to the nucleon axial structure and offers the best method for extracting Δs. This is because any strange quark contribution to the nucleon spin shows up in the nucleon axial form factor and does not depend on models of the quark helicities as a function of quark momenta (as in deep inelastic scattering). The optimum experimental strategy was studied for the proposed FINeSSE experiment (http://www-finesse.fnal.gov/FNAL_LOI_032105.pdf). It was determined that, by measuring the ratio of neutral-current to charged-current elastic events on carbon in the Booster neutrino beam, a measurement of Δs could be made with precision comparable to DIS and with less model-dependence. In addition, a measurement with antineutrinos would further reduce systematic errors.

The BNL-E734 experiment measured neutrino NC-elastic scattering in the late 1980's. These results have generated a large amount of interest in the topic. However, the systematic and statistical errors on this data do not allow a sufficiently precise measurement of Δs. MiniBooNE has recently reported preliminary results on NC elastic scattering. Unfortunately, the MiniBooNE detector does not have adequate tracking to separate NC-elastic scattering on protons from that on neutrons. A separation of $\nu p \rightarrow \nu p$ and $\nu n \rightarrow \nu n$ events is requisite to measure Δs because the strange part of the axial form factor contributes with opposite sign in those two processes.

The recent commissioning of the SciBooNE experiment at Fermilab offers the opportunity to move toward a precise measurement of Δs. A measurement of NC-elastic scattering in SciBooNE will be made, however, it will not result in a measurement of sufficient precision for a definitive measurement of Δs. That will require additional run time and detector upgrades.

A precise and robust measurement of Δs would require approximately 2×10^{20} POT in neutrino mode and 4×10^{20} POT (numbers obtained from FINeSSE LOI). This would require 2-3 more years of beam time as is currently allocated to SciBooNE. In addition, detector upgrades may be required. This could include additional neutron shielding, upgraded electronics, or perhaps a new tracking detector to better measure the NC elastic recoil nucleons.