Internal Structure of the Neutron

The proton and the neutron are the two charge states of the nucleon. The valence up (*u*) quarks in the neutron play the role of the down (*d*) quarks in the proton and vice versa. Therefore, to separate the *u* and *d* contributions to the nucleon's structure, one must scatter electrons from both protons and neutrons separately. This has been easy for the proton but very hard for the neutron. Viable neutron targets are impossible to make because a neutron has no charge by which it can be confined, and it decays in 15 minutes. Within a nucleus it does not stand still, its internal structure is modified in the bound state, and it interacts with its surroundings when struck. The preferred target of choice to study the neutron is deuterium, but up until now there has been no way to separate the scattering from protons and neutrons. Proton scattering, taken from other experiments, must be subtracted off from the deuterium measurement after applying elaborate and uncertain theoretical prescriptions for all of the nuclear effects.

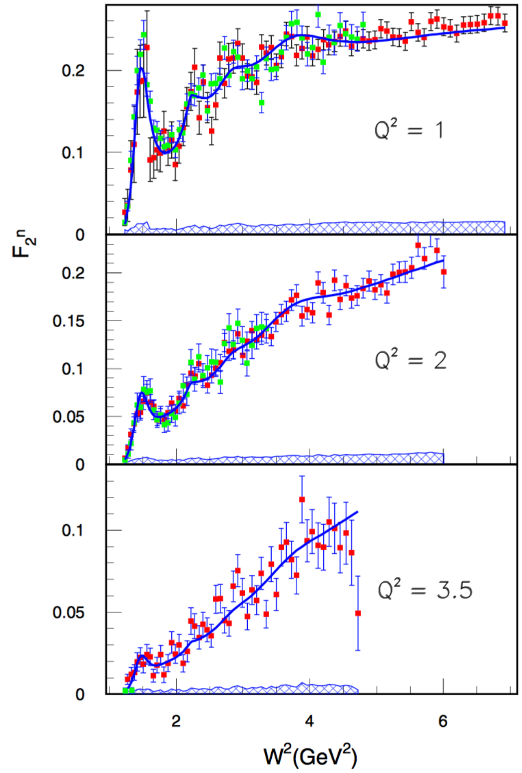

Fig. 1. Representative measurements of the neutron form factor, F_2^n as a function of the squared invariant mass of the struck neutron for three values of 4-momentum transfer squared Q^2. Data were taken at 4 (green) and 5 GeV (red) beam energies. The curves show a fit to world data before BoNuS.

The Barely Off-Shell Nucleon Structure Experiment (BoNuS) in Hall B used a unique radial time projection chamber with a deuterium target to detect backward-going spectator protons down to momenta of 70 MeV/c. The identified proton indicated that the electron had scattered from the neutron in deuterium; the proton's momentum determined the neutron's motion before scattering; and the backward-going spectators ensured that the neutron had little or no interaction on the way out of the nucleus. BoNuS confirmed these assumptions by showing that the extracted neutron structure was independent of spectator momentum. Fig. 1 shows some of the data taken. The large peak to the left is the Δ resonance, and the bumps and wiggles that follow are other neutron resonance states. The curves, which summarize previous data, show that the neutron's structure is somewhat different than that deduced from experiments without tagging. Fig. 2 shows the ratio of neutron to proton scattering, which is proportionate to the *u/d* quark ratio in the proton. How *u/d* behaves at high momentum fraction *x* is an important test of QCD. BoNuS at 12 GeV will extend this ratio to higher *x* with significantly better precision.

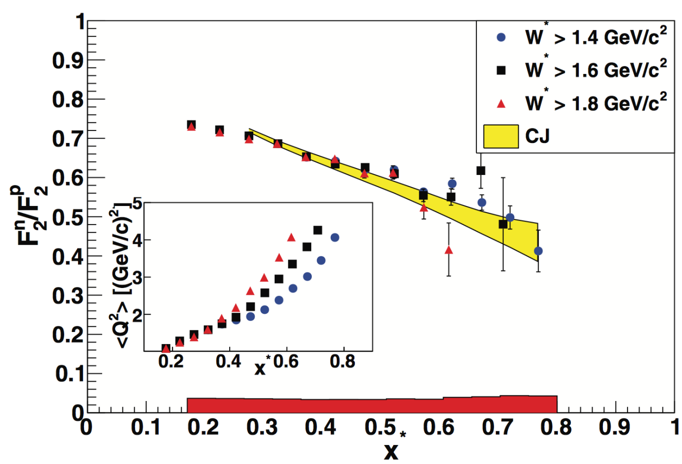

Fig. 2. The ratio of the neutron and proton structure functions vs. the momentum fraction *x* of the struck quark for three thresholds in the struck neutron's invariant mass. The inset shows the average Q^2 vs. *x*, and the yellow band shows a fit to the world deep-inelastic data.

Reference: S. Tkachenko, *et al.*, Phys. Rev. C **89**, 045206 (2014)