The Axial Form Factor of the Proton

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The Axial Form Factor of the Proton: Physics Highlights

$$G_A^p\left(Q^2\right)=\frac{1}{2}\left[-G_A^u\left(Q^2\right)+G_A^d\left(Q^2\right)+G_A^s\left(Q^2\right)\right]$$

G_A^p is a fundamental proton matrix element, as are the vector form factors (G_E^p, G_M^p). The vector form factors are most easily measured in electron-nucleon scattering, while the axial form factor is most easily measured in neutrino-nucleon scattering. The full axial form factor can be measured in neutral-current neutrino elastic scattering, e.g. $\nu p \to \nu p$ or $\bar{\nu} p \to \bar{\nu} p$. The up-down part ($-G_A^u + G_A^d$) can also be separately measured in charged-current scattering, e.g. $\nu n \to \mu p$ or $\bar{\nu} p \to \mu n$. Then the strangeness contribution, G_A^s, can be isolated, which in turn determines the full strangeness contribution to the proton spin: $\Delta S = G_A^s\left(Q^2 = 0\right)$.

Measurement of the strangeness contribution to the axial form factor is critical to our studies of nucleon substructure. It is also vital for searches for heavy dark matter particles [Ellis, Olive, & Savage, PhysRevD.77.065026].

The Axial Form Factor of the Proton: Current Status

$(-G_A^u + G_A^d)$ **measured in charged-current scattering, e.g.** $\nu n \rightarrow \mu p$ **or** $\bar{\nu} p \rightarrow \mu n$

Many measurements over the last 40 years, with high statistics in recent experiments [K2K, T2K, MiniBooNE, SciBooNE, MINERvA]. Many recent reviews: see especially Formaggio & Zeller, Rev. Mod. Phys. 84, 1307 (2012).

G_A^p **measured in neutral-current neutrino elastic scattering, e.g.** $\nu p \rightarrow \nu p$ **or** $\bar{\nu} p \rightarrow \bar{\nu} p$

Only a handful of measurements, and no data for $Q^2 < 0.45$ GeV^2. [BNL E734, MiniBooNE] As a result, we have only scarce data on the strangeness contribution.

Combining data from neutrino-nucleon and electron-nucleon experiments, the strangeness contribution to the vector and axial form factors has been determined for several points in the range $0.45 < Q^2 < 1.0$ GeV^2. [Pate, McKee, & Papavassiliou, PhysRevC.78.015207]

Additional $\nu p \rightarrow \nu p$ data are needed for $Q^2 < 0.45$ GeV^2 to establish the strangeness contribution to the proton spin, ΔS.

[While the polarized parton distribution function $\Delta S(x)$ has been determined in polarized leptonic deep-inelastic scattering for $x > 0.005$, the full integral value ΔS has not. See, for example, Chang & Peng, arXiv:1406.1260.]

The Axial Form Factor of the Proton: Future Prospects

MicroBooNE is a large (2.3 × 2.6 × 10.4 m^3, 86-ton active volume) liquid argon time-projection chamber at Fermilab, positioned in the Booster Neutrino Beam (E_ν~ 1 GeV). Neutrino-nucleon cross section measurements are among the priority physics goals for this experiment that will begin taking data early in 2015. <u>It is ideally suited for measurement of neutral-current events as it can identify very low energy (down to ~40 MeV) isolated proton tracks.</u>

Yes, argon is a ***nucleus***. To obtain neutrino-***nucleon*** cross sections from these data it will be necessary to understand the nuclear physics. Much is already known from electron- and neutrino-scattering experiments on other nuclei. There is an approved (A-) experiment at Jefferson Lab to measure the proton spectral function of argon [Benhar, Mariani, Jen, Day, Higinbotham, arxiv:1406.4080]. There is a considerable theoretical effort to understand the necessary physics [Martini et al., PhysRevC.84.055502; Ruiz Simo et al., PhysRevD.90.033012; Meucci et al., PhysRevD.88.013006; Lalakulich et al., PhysRevC.86.014614; and many more].

A simulation of the neutral-current and charged-current events at MicroBooNE, combined with electron-nucleon data, shows it is possible to determine the strangeness contribution to the axial form factor in the range $0.1 < Q^2 < 1.0$ GeV^2 and determine ΔS to better than ±0.05 [Pate & Trujillo, arxiv:1308.5694].

<u>**The Long Range Plan needs to recognize the importance of the opportunity to explore nucleon and nuclear substructure with medium-energy neutrino beams.**</u> In these 3 slides I have only been able to give you a small glimpse.