Neutrino scattering from Hydrogen and Deuterium: What can we still learn?

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1. Introduction

Neutrino scattering can give precise flavor and valence/sea separations of parton distributions, and by scattering off the simplest nuclei known, we can best understand the parton distributions in free nucleons. Those distributions not only provide powerful constraints for proton collider measurements, but then can be leveraged against measurements on more complicated nuclei to best understand the nuclear enviornment. This in turn means that we can separate out measurements of nuclear structure from measurements of nuclear effects.

By comparing neutrino and anti-neutrino scattering on deuterium, one can finally understand if there is charge symmetry violation in the nucleon, which is something that have been suggested as the source of the NuTeV anomaly [1]. Alternatively, one can simply try to measure the weak mixing angle using the Paschos-Wolfenstein relation on the simplest isoscalar target, Deuterium.

There have been no neutrino measurements on hydrogen or deuterium since the bubble chamber era when neutrino beams were orders of magnitude less intense than the neutrino beams available today. With the beams that would become available in the Projext X era, one could do measurements on for example a three hundred kilogram cryogenic target and still get hundreds of thousands of events in a year long run.

2. Experimental Considerations

Two important ingredients for this measurement are of course the neutrino beam and the volume of liquid hydrogen or deuterium that is available. Studies have been done to study the physics reach for those targets [2], assuming the 2200 litre cryogenic vessel that is current operating with He underground in the NuMI beamline in front of the MINERvA detector[3]. The vessel is mechanically and cryogenically equiped to operate with either hydrogen or deuterium H_2 or D_2. Because the cryogenic target is not instrumented, there is a loss in acceptance since final state particles must leave the vessel to be detected in MINERvA [2]. Nevertheless, with a 1 year each neutrino and antineutrino run in the NuMI high energy configuration, (peak neutrino energy at 14 GeV) assuming 6×10^{20} protons on target per year, the sensitivity to the d/u ratio is quite impressive, as shown in figure 1. In the Project X era, the protons on target per year is expected to be over a factor of three above this rate, so the figure below could be reached in even less time, allowing for other measurements with deuterium to be made. It should be noted that in order to reach this level of experimental precision the flux uncertainties associated with neutrino versus antineutrino running must be kept under control.

One important aspect that must be addressed for these measurements to take place is the feasibility of storing large quantities of liquefied flammable gas in a deep underground location. There are currently investigations of what would be required to allow a measurement like this to proceed in the NOνA era. If the risk is too large to operate such a target deep underground, then these measurements would need to be made with a neutrino beam that has at least onne detector hall that is at ground level.

Ultimately a bubble chamber followed by downstream tracking, calorimetry and a muon spectrometer would provide a higher acceptance for events on hydrogen and deuterium than the configuration described above, since the threshold for seeing a final state proton would be significantly lower. The slower time response of the bubble chamber technology would have to be an inupt to the neutrino beam design, however, since the bubble formation takes a few milliseconds and would then have to be read out in between each neutrino beam spill. But the physics reach of such a device would surpass even the reach shown in figure 1.

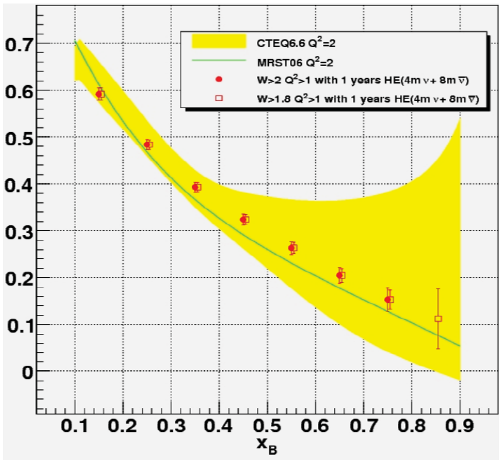

Figure 1: Statistical precision of a measurement of d over u quark distribution in hydrogen, for a 1 year run with neutrinos and antineutrinos with a high energy neutrino beam, as described in the text.

References

[1] G.P. Zeller *et al*, Phys.Rev.**D65**:111103,2002.

[2] Lingyan Zhu on behalf of MINERvA, talk given at the Short Baseline Neutrino Workshop at Fermilab `https://indico.fnal.gov/contributionDisplay.py?sessionId=10&contribId=37&confId=4157`

[3] The MINERvA Collaboration (D.W. Schmitz for the collaboration), "The MINERvA Neutrino Scattering Experiment at Fermilab", to appear in NuINT 2011 Proceedings