How to Measure the Flux at LBNE

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Outline:

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Motivation and Technique Outline

- Neutrino fluxes for energies between 0.3 and 4.0 GeV are not well known. Neutrino flux errors to date are ~5-10%. Given 20-30% x-factor seen by many neutrino experiments, e.g. MiniBooNE, etc, it could be even higher.
- It is crucial to independently determine the in-situ flux at the ND in order:
  - to absolutely measure the neutrino cross sections as a function of neutrino energy as current uncertainties are at the 20-30% level.
  - to correct MC prediction of the flux at near and far position.
- Require use of Hydrogenic (light) targets where we have good estimates of the cross sections.
  - minimizes Fermi motion and other nuclear effects, especially at low Q^2.
- Need momentum and angle of the interaction recoil nucleon(s).
- Need a self contained device that safely stores the liquid H/D.
- The above requirements drive the need for Bubble Chamber technology.
- Require accurate muon momentum and angle measurement to determine neutrino energy and identify the event as CCQE (down stream spectrometer).

Hydrogen Target (Anti-Neutrino Flux)

- CCQE interactions $\overline{\nu}_u + p \rightarrow \mu^+ + n$
- We do not cleanly see the neutron, but can reconstruct the muon momentum and direction (down stream tracker/spectrometer).
  - Since this is pure 2-body, can determine the neutrino energy and Q^2 from the reconstructed lepton energy and angle (forward events).
- At $Q^2 = 0$, we know the cross section from (neglecting muon mass effects)

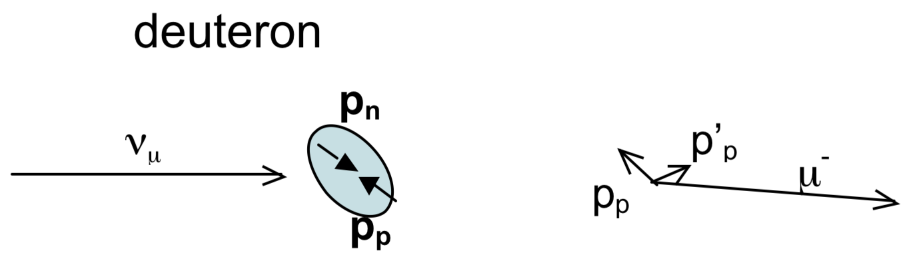
Neglecting terms in $(m_\mu/M_n)^2$ (=1.25%), at Q^2=0 this QE cross section is, independent of neutrino energy once $(2E_\nu M_n)^{1/2} > m_\mu$.

$$\frac{d\sigma}{dQ^2}\left|Q^2 = 0\right| = \frac{G^2\cos^2\theta_c}{2\pi}[F_1^2(0) + G_A^2(0)]$$

$$= \frac{G^2\cos^2\theta_c}{2\pi}[1 + 1.267^2] = 2.08x10^{-38}\,cm^2 GeV^{-2}$$

Deuterium Target (Neutrino Flux)

- CCQE interactions v_u + d -> μ^- + p + p
- We can reconstruct the muon momentum and direction (down stream tacker/spectrometer).
- With a bubble chamber we can reconstruct the recoil protons momentum and direction to get Q^2 directly.



$$E_{\nu\mu}=E_{\mu-}+E_{p'}+E_p$$
$$Q^2=k^2=\mathbf{k}^2-\omega^2$$
$$Q^2=(p_\nu-p_\mu)^2=(p'_p-p_n)^2=(p'_n+p_p)^2$$

- Current neutrino-deuterium cross section errors at the >5% level. Can be reduce to a ~2% at low Q^2 via the use of effective field theory.

Bubble Chamber Design

- Need high rates and fully contain protons.
  - 0.6 GeV proton range about 140 cm
  - 1 Ton target mass (2.3m cube) large enough to contain proton events.
  - Event rates will be high enough to zero in on low Q^2 region
- Safety is a huge concern! However, bubble chambers have been operated in the past without problems.
  - Work with engineers at an early stage to ensure safety designed into the system (Jan Boissevain and Larry Bartoszek).
- Upgrade optics to CCD readout to digitize events for computer analysis (no hand scanning!)

R&D Efforts

- Work with theorists to reduce deuterium cross section errors.
  - a target goal of ~2%
- Write detailed GEANT4 simulation code to answer some basic questions:
  - Estimate proton and muon reconstruction efficiencies and errors, what is the estimated error in flux estimates?
  - What Q^2 range will work, currently thinking 0 - 0.05 GeV.
  - Specify requirements of muon spectrometer? Do we need a magnetic field?
  - At what level do mis-reconstructed events (NCpi0, Ccpi+, etc) create a background?
- Research and develop CCD camera optic chain and DAQ.
- Begin design and costing a bubble chamber
  - pay close attention to safety issues.

Costs and Schedule

- Don’t really have one yet. Will begin thinking about it…

Summary

- Hydrogenic targets are ideal since the cross sections are fairly well know.
  - Quasielastic cross sections on H and D will be calculated to better than 5% with restrictions on the magnitudes of the momentum and energy transfer.
- Using H and D Bubble chamber, the extracted event rates at low Q^2 can be used to measure flux.
  - The flux times cross section (as a function of E) degeneracy can be broken.
- Only have begun work, much R&D needed before a robust design in hand.
- Can be used to determine the flux for other neutrino beams to extract cross sections on multiple targets.