# THE FUTURE OF DIS BY NEUTRINO BEAMS

D. MASON
*University of Oregon, Eugene, OR*
*email: dmason@fnal.gov*

The current status and future prospects of DIS scattering experiments by neutrino beams is reviewed. Recent and soon expected results from past neutrino DIS experiments (NuTeV, CHORUS, and NOMAD) are briefly discussed. The prospects of DIS measurements by MINOS and the upcoming MINER$\nu$A experiment are then reviewed.

For over 30 years, neutrino deep inelastic scattering ($\nu$-DIS) has brought important contributions to our understanding of nucleon structure and QCD. Beginning in the 1970's with the Gargamelle bubble chamber at CERN, and HPWF and Caltech-Fermilab experiments at Fermilab, both the quality and quantity of data has steadily improved to allow many precision measurements to be performed. This precision is evident in the latest generation of experimental results represented here by NuTeV, CHORUS and NOMAD.

Experimental $\nu$-DIS is currently transitioning from experiments whose data was taken in beams with relatively high energies (tens to hundreds of GeV), to now low energy (few GeV or lower) neutrino beams, designed for the study of neutrino oscillations. These new beams bring the benefit of unprecedentedly high neutrino intensities, opening up the possibility of performing measurements with lower density, finer resolution detectors. The low energies of these beams however also bring the challenge of requiring a more detailed understanding of "background" reactions such as quasielastic scattering and resonant production, as well as how interactions within different kinds of nuclei affect measured physical quantities[1].

As a reflection of this transition this talk/document is divided into two parts: The first is an attempt at "settling the books" with respect to outstanding and expected measurements from the past generation of $\nu - DIS$ experiments. The second part brings us through the present day, with a discussion of DIS measurement possibilities at the currently running MINOS experiment in the Fermilab NuMI beam. We then reach into the future with a discussion of the proposed MINER$\nu$A experiment, planned to begin taking data upstream of the MINOS near detector in 2009.

## 1. Settling the Books on Past $\nu$-DIS Experiments

Three $\nu$-DIS experiments executed in the past decade NuTeV, CHORUS, and NOMAD, are still generating interesting QCD results, with more expected in the near future.

The NuTeV experiment[2], ran during the Fermilab fixed target run from 1996 to 1997, and accumulated $3.15 \times 10^{18}$ protons on its target with highly pure sign selected neutrino and antineutrino beams. This *a priori* knowledge of whether events were produced by neutrino or antineutrino scattering enabled NuTeV to isolate the strange and antistrange sea distributions independently, with the final results of that analysis presented at this conference[3].

Final NLO QCD structure function fit results are also expected later this year. NuTeV has performed preliminary NLO fits to $xF_3$ alone, and combined fits including $F_2$ as well. These fits use the full correlation matrix from the NuTeV charged current cross section data[4], and will be the first $\nu - N$ DIS measurement of $\Lambda_{QCD}$ including a full NLO treatment of charm production. The left half of figure 1 compares the NuTeV preliminary $\alpha_s$ measurement (highlighted in red) with other measurements.

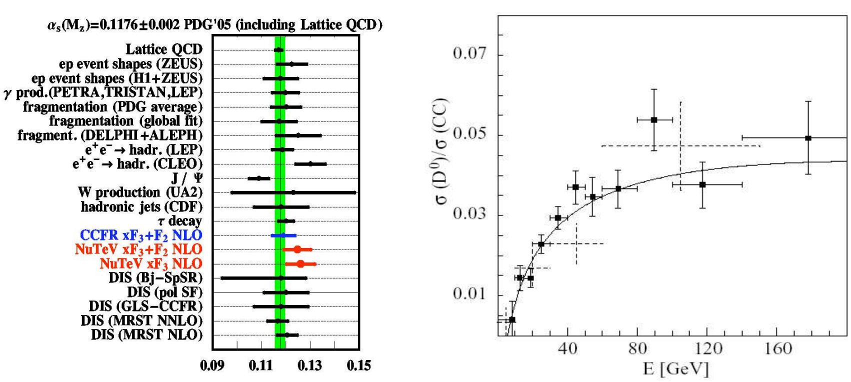


Figure 1. Left: Preliminary $\alpha_s$ fit results from NuTeV, compared with the world average and other measurements. Right: The CHORUS $D^0$ production cross section ratio plotted vs. neutrino energy. Dashed lines are FNAL E531 data.

The CHORUS[5] and NOMAD[6] experiments ran in the horn focused wide band neutrino beam from the CERN SPS from 1995-98, taking over an order of magnitude more protons on target than NuTeV, at a lower average energy: $\langle E_\nu \rangle = 27$ GeV. These experiments employed fine grained detectors designed to observe $\nu_\mu \rightarrow \nu_\tau$ oscillations.

CHORUS has presented measurements of 1048 charged current events with a final state $D^0$ identified in its emulsion target[7]. The CHORUS $D^0$ production cross section ratio is plotted on the right half of figure 1 as a function of incident neutrino energy, compared to FNAL E531 measurements. CHORUS also expects to complete a first ever measurement of the total neutrino and antineutrino charm production cross sections, both separately for neutral and charged current, as well as as a function of prong multiplicity later this year.

CHORUS swapped out its emulsions for nuclear targets in 1998, and this year produced new $\nu$-Pb cross section results from close to a million neutrino and about 160k antineutrino events. The left half of figure 2 shows $F_2$ as a function of $Q^2$ compared with CCFR and CDHSW data[8]. As can be seen in the plots, CHORUS $F_2$ measurement favors CCFR over CDHSW at low $x$. It is not yet clear however, whether the NuTeV or CCFR data is favored at high $x$ [9].

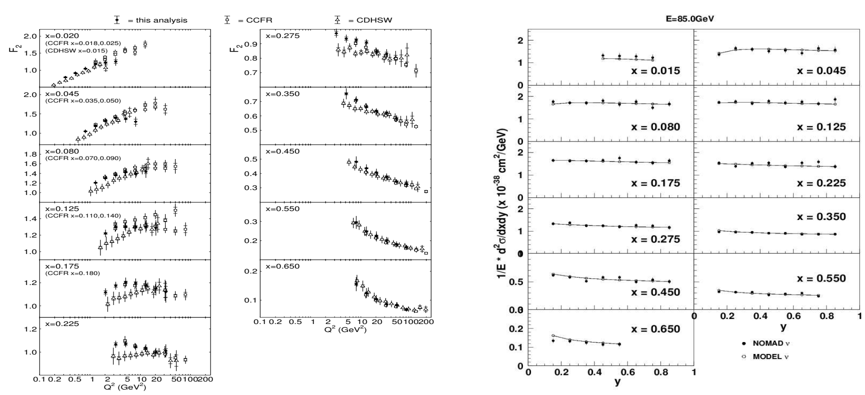


Figure 2. Left: $F_2$ from the CHORUS Pb cross section measurement. Right: Preliminary cross section results from NOMAD

The NOMAD experiment has preliminary inclusive charged current cross section measurement results, shown on the right of figure 2. When finalized, this will be the first inclusive cross section measurement on a carbon target at relatively large $Q^2$.

NOMAD is also actively working on analyzing its large sample of approximately 14k opposite sign dimuon events from its front iron calorimeter.

They plan to measure the cross section ratio with respect to the inclusive cross section, extracting the strange sea at NLO and charm production parameters. These data are near the charm threshold, and are expected to have high sensitivity to the charm mass.

## 2. $\nu$-DIS in the $\nu$ Oscillation Era: MINOS and MINER$\nu$A

The latest generation of neutrino experiments are designed to search for and expand our knowledge of neutrino oscillations. The low energies required to perform these measurements provide an opportunity to revisit (indeed, require revisiting) long neglected regions of phase space. Three neutrino beam facilities will be online or coming online in the near future: The JPARC facility in Tokai, Japan, expected to turn on in 2009, will direct a low energy, high power neutrino beam to Kamioka serving the T2K experiment. The CNGS beam at CERN is (as of this writing) set to turn on in July this year, and directs a moderately high energy beam to the ICARUS and OPERA experiments at Gran Sasso. Fermilab boasts two neutrino beams, one based on the 8 GeV booster ring, serving the BooNE experiment, and the Main Injector based NuMI beam, currently delivering neutrinos to the MINOS experiment, as well as the MINER$\nu$A and NO$\nu$A experiments in the next few years.

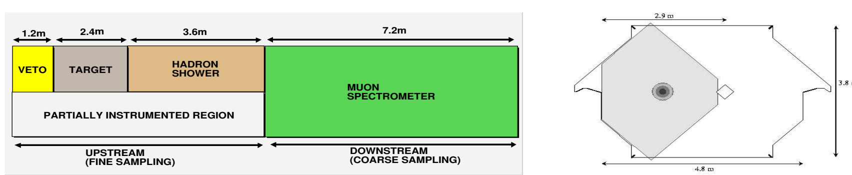


Figure 3. Top and cross sectional views of the MINOS near detector. The beam is centered on the partially instrumented region, shown as a black dot in view on the right.

MINOS is a neutrino oscillation experiment employing two detectors, a far detector in the Soudan Mine in Minnesota, and a similar near detector at Fermilab to provide a cross section and flux measurement to reduce systematics. Views of the MINOS near detector are shown in figure 3. The MINOS experiment has been accumulating data since May of 2005, with a large sample of DIS events already recorded in the near detector. Figure 4 shows the kinematic reach of MINOS compared to that of other experiments, and the predicted statistical errors of a MINOS measurement of $F_2$. Systematics due to energy scale uncertainties should dominate however.

The MINOS experiment, as well as T2K and the proposed NO$\nu$A experiment will be limited by the current lack of precision in cross sections at

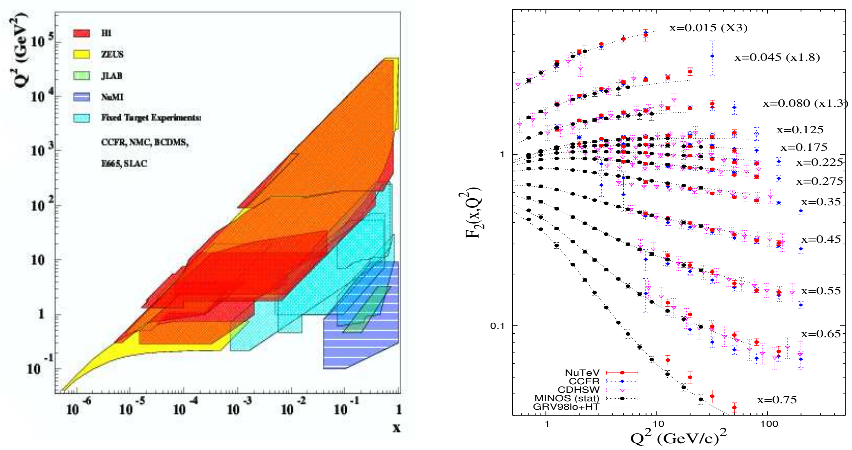


Figure 4. Left: A map of the phase space covered by various DIS experiments. NuMI covers the shaded region at high $x$ and low $Q^2$ in the lower right corner. Right: Predicted $F_2$ for MINOS, black, (statistical errors only) compared to past $\nu$-DIS measurements.

low $\nu$ energies, as well as a near absence of understanding how those measurements are affected by different nuclear environments. The MINER$\nu$A experiment[10] has been proposed to address this area of need.

FNAL E-938, MINER$\nu$A, is currently working towards a turn-on in mid 2009. The detector, shown in figure 5, is to be placed ahead of the MINOS near detector, which will also be used as a muon spectrometer. The detector has a conservative design, built upon existing technology. It features a scintillator strip based active core, which is surrounded by EM and hadronic calorimeters. Interleaved between the scintillator planes will be several planes of carbon, iron and lead nuclear targets. The active scintillator core is to be based on sandwiched planes of arrays of triangular scintillator bars, shown in figure 6. Light sharing between the scintillator bars is expected to yield resolutions down to the few millimeter range.

The physics program for MINER$\nu$A is wide ranging, with large event samples expected for a variety of processes of interest to this conference. Specifically: approximately 2 million events are expected in the resonance to DIS transition region, over 4M DIS events, roughly 13M events in the different nuclear targets, the majority ($\sim$8.6M) of which in the organic scintillator, at least 200k fully reconstructed strange and charm production events, and about 10k events for the extraction of generalized pdf's.

The MINER$\nu$A collaboration is engaging in an aggressive program of detector R & D, including a vertical slice test of the detector this year, and the construction and running of a 20% tracking prototype during the

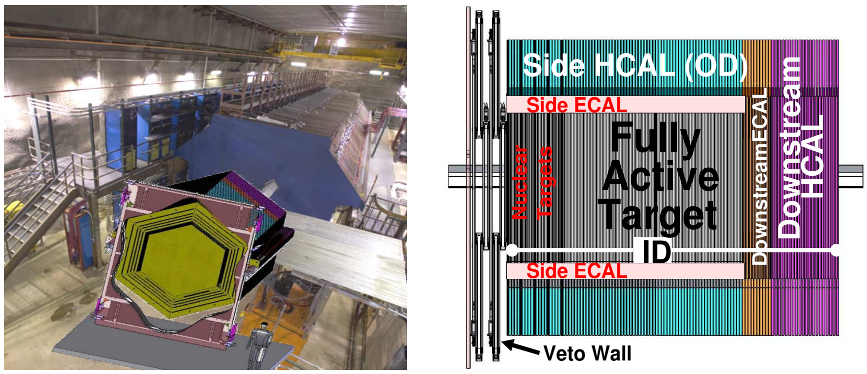


Figure 5. Left: Positioning of the MINER$\nu$A detector in front of the MINOS near detector. Right: Side view schematic of the MINER$\nu$A detector

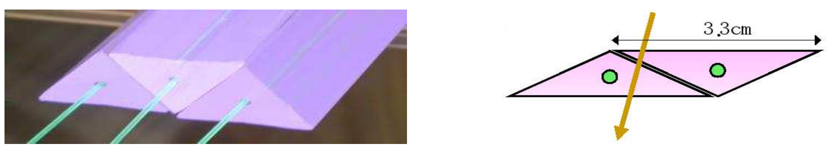


Figure 6. Cross sectional views of the MINER$\nu$A extruded scintillator bars which will make up its active target.

next two years. By 2009 it is expected that detector construction should be complete, and data taking to commence for an expected ∼4 year run.

## 3. Acknowledgements

The author wishes to thank the conference organizers for travel support, as well as Kevin McFarland, Pasquale Migliozzi, Jorge Morfin, Donna Naples, Roberto Petti, and Voica Radescu for plots and many helpful discussions.

## References

1. D. A. Harris *et al.* [MINERvA Collaboration], arXiv:hep-ex/0410005.
2. For more information on NuTeV results: `http://www-e815.fnal.gov`
3. D. Mason *et al.* [NuTeV Collaboration], these proceedings
4. M. Tzanov *et al.* [NuTeV Collaboration], arXiv:hep-ex/0509010.
5. CHORUS publications may be found at: `http://choruswww.cern.ch/Publications/papers.html`
6. NOMAD publications may be found at: `http://nomad-info.web.cern.ch/nomad-info/Public/PUBLICATIONS/public_pub.html`
7. G. Onengut *et al.* [CHORUS Collaboration], Phys. Lett. B **613**, 105 (2005).
8. G. Onengut *et al.* [CHORUS Collaboration], Phys. Lett. B **632**, 65 (2006).
9. See for example Tzanov et al, as well as talks in the first SF session at this conference.
10. D. Drakoulakos *et al.* [Minerva Collaboration], arXiv:hep-ex/0405002.