Task F: Neutrino

Task F-1 (neutrino) includes:	CCFR/NuTeV at Fermilab (past)
	MINERνA at FNAL/NuMI (present)
	JUPITER, e^- scattering at Jefferson Lab (present)
	T2K (long-term future)
	Neutrino Cross-Section Phenomenology (ongoing)
Task F-2 (lepton) includes:	PHOBOS at RHIC/BNL (past)
	MINERνA at FNAL/NuMI (present)
	JUPITER, e^- scattering at Jefferson Lab (present)
	T2K (long-term future)
	ILC (far future)

A. Participants

Current Participants:

Faculty: Prof. Arie Bodek, Prof. Kevin McFarland (F-1) Prof. Steven Manly (F-2)
Senior Scientists: Dr. Pawel de Barbaro (F-1),
Dr. Howard Budd (F-1), Dr. Willis K. Sakumoto (F-1)
Research Associates and Scientists: Dr. Sergei Avvakumov (F-1, MINERνA),
Dr. Robert Bradford (F-1, MINERνA, JUPITER)
Graduate Students: Mr. Jesse Chvojka (F-1, MINERνA), Mr. Jaewon Park (F-1, MINERνA),
Mr. James Steinman (F-2, MINERνA, JUPITER)
Undergraduates: Mr. Ian Kleckner (F-1, JUPITER),
Ms. Jennifer Cano (F-2, NSF-REU support, JUPITER), Mr. David Sher (F-2, NSF-REU support, JUPITER)
High School Teachers: *** Mr. Paul Conrow (F-1, T2K) (NSF-RET support)
Mechanical Engineer: Mr. Robert Flight (F-1, MINERνA)
Technicians: Mr. Daniel Ruggiero (F-1, MINERνA), Ms. Janina Gielata (F-1, MINERνA)

B. Highlights of Neutrino Activities 2005-2006

- MINERνA granted CD-0 by DOE
- McFarland scientific co-spokesperson for MINERνA.
- (MINERνA) Rochester leading experiment mechanical design, design, prototyping of optical path elements and module structure, development of detector assembly protocols, design of module scanner and “vertical slice” tests.
- (MINERνA) NSF MRI proposal approved to fund nuclear targets, module mapper and a test beam detector.
- (JUPITER) Steinman makes progress in thesis analysis studying F_2 and R on nuclear targets in the resonance region, i.e. MINERνA energy region.
- (JUPITER) Manly, Bradford, Sher, Kleckner, Cano take first look at at exclusive final states on nuclear targets (Hall B) in eA scattering in the MINERνA energy region.
- (T2K) McFarland serves as North American convener for 280 m (near) detector and on International Board of Representatives.
- T2K has Japanese approval and budget

- US Beamline and 280m Collaboration proposal submitted to DOE in Summer 2005 to support US activities ***
- (phenomenology) Bradford/Budd/Bodek/Arrington release a new parametrization of the elastic form factors so important in characterizing lepton-nucleon cross sections.
- (CCFR/NuTeV) *** need km update

C. Highlights of Proposed Research: 2006-2007

- MINERνA expected funding information ***
- (MINERνA)Complete design and fabrication procedures and quality control devices for optical cables and WLS fibers.
- (MINERνA) Complete module design and fabrication procedures.
- (MINERνA) Design and build module scanner.
- (MINERνA) Construction of full=scale prototype detector module.
- (MINERνA) Complete analysis of E04-001 F_2 and R
- (MINERνA) Studies of exclusive final states in CLAS (Hall B) data.
- (T2K) *** Finalize design of 280m (near) detector.
- (T2K) *** If proposal for US participation succeeds, construct optical cables (identical to MINERνA tasks for Rochester) and oversee scintillator production beginning in FY07
- (JUPITER) Integration of JUPITER data into neutrino Monte Carlo packages.
- (JUPITER and phenomenology) Continue work on quasi-elastic form factors and duality studies.

D. Activities and Future Plans by Experiment

MINERνA

MINERνA[1][1] has received Stage I approval from FNAL, has undergone a FNAL director's ("Temple") review of the construction project and, most recently, was granted Critical Decision 0 (CD-0) from DOE. We expect MINERνA to be funded as a construction project in ***. This year we plan to focus on our final prototyping and detailed design activities, including the construction of a detector module prototype and the module mapper.

Our group is active in many ways in the MINERνA experiment. Prof. McFarland, in his role as co-spokesperson of the experiment, is heavily involved in all aspects of the project. Our mechanical engineer, Mr. Flight, serves as the overall design supervisor for MINERνA and is the primary mechanical designer for the experiment. Dr. Budd is the level 2 manager responsible for the wavelength shifting fibers, optical cables and connectors. He is also in charge of the vertical slice test (VST), which will be discussed below. Dr. Bradford is the level 2 manager responsible for the assembly of detector modules which are QC'ed and subsequently installed in MINERνA. Prof. Manly works closely with Dr. Budd in the procurement of materials for and design of the optical system. Mr. Steinman works closely with Flight/Budd/Manly on optical cable R&D. Mr. Chvojka

[1]Much more information on MINERνA can be found at `http://www.pas.rochester.edu/minerva`

works with Budd/McFarland to understand the results of the MINERνA VST. Mr. Park is involved in optical fiber R&D with Dr. Budd and works with Prof. McFarland to understand the detector performance using simulations. Mr. Ruggiero works extensively with Dr. Budd on optical system tests and R&D and with Dr. Bradford on module assembly prototyping.

One of the more important tasks performed recently in MINERνA was the construction and analysis of data from the VST, which is small prototype consisting of 21 scintillator bars arranged in 3 layers with readout provided by prototype electronics. Comic ray data taken with this device yields proof of concept of our tracking and detector position resolution. Figure 1 shows the optical components of the VST. The mechanical parts of this system were designed by Mr. Flight. The system is read out using a MINOS PMT box with MINERνA prototype electronics. Data collected with the VST was analyzed by Mr. Chvojka and Prof. McFarland. Figure 2 demonstrates that the VST has a position resolution of 3.4 mm. These results agree very well with MINERνA Monte Carlo calculations.

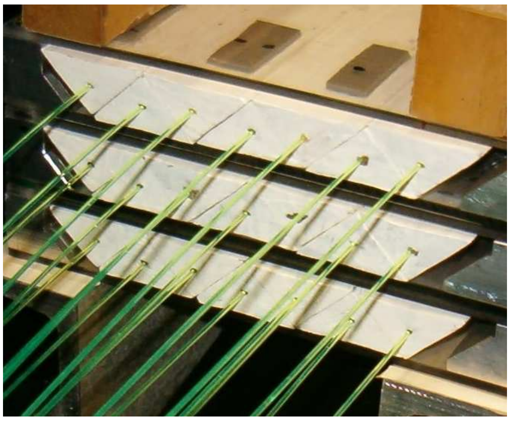

Figure 1: Picture of the VST showing the 3 layers. Scintillator counters above and below the array serve as the DAQ trigger.

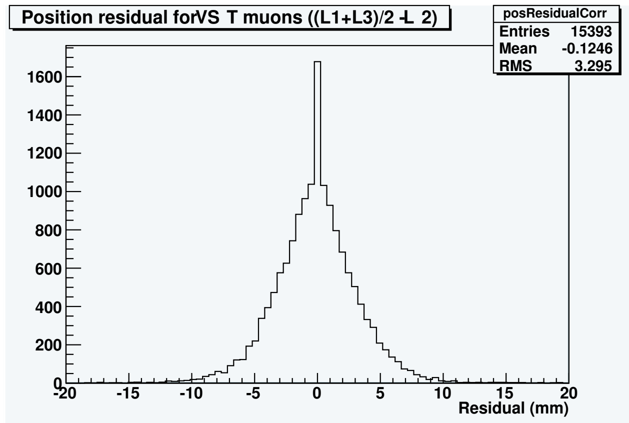

Figure 2: The position resolution of a track going through the 3-layer VST array.

The MINERνA light path is illustrated schematically in Fig. 3. Our group is responsible for the 30,000 channels of WLS fiber and the equal number of clear fibers grouped by bundles of 8 to form the cables that constitute the optical path. Consequently, much of our work in the last year has been (and continues to be) dedicated toward specifying and qualifying the fiber and connectors and developing procedures for fabricating and performing quality control on these parts. This year, our group (Budd/Ruggiero/Chvojka/Park) has performed a number of specific tests on the fibers determining things such as attenuation length, long-term fiber flexibility, and reflectivity at the sputtered mirror on the end of the WLS fiber. Also, procedures for fabrication and quality control of the fibers and cables have been developed. Our group (Manly/Budd) has chosen to use optical connectors from Fujikura/DDK (generically referred to as DDK connectors). This year DDK produced the first connectors for MINERνA and our group is currently working with the company to refine the design to alleviate a fit in the connection thought to be rather tight for production use. The optical transmissivity across the connectors was also measured and found to be suitable for

MINERνA use. Finally, the group (Steinman/Flight) has performed the R&D necessary to design and choose the material for the'boot' that makes the ends of the clear fiber cables light tight.

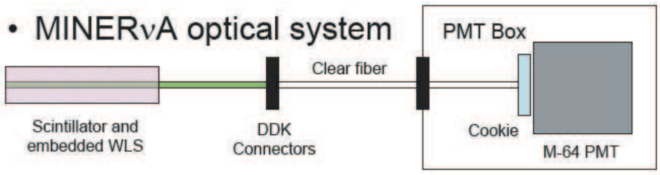

Figure 3: A diagram of the light path for each channel in MINERνA.

Figure 4: Mr. Ruggiero with partially assembled prototype module.

We plan on being able to produce production cables by the end of the summer. Currently, we are working on the final clear cable QC devices and their readouts. By the end of the summer, we expect to have the production QC hardware working and will test a small sample of cables with the QC devices.

Rochester is leading the mechanical design of the detector and associated hardware. Mr. Flight has produced the primary engineering drawings of most detector components. These drawings are the ultimate source of information for various detector parameters, including dimensions and the WLS fiber routing scheme. He also provides engineering support to various task groups throughout the collaboration, consulting on the design of manufacturing processes and fixtures.

Dr. Bradford is responsible for development of the module assembly protocols. This last year, members of the group (Dr. Bradford, Mr. Park, Mr. Flight, Mr. Ruggiero) fabricated scale model prototypes of MINERvA detector modules. Fig. 4 shows one of these prototypes under construction. These models were used to study various aspects of the detector and assembly procedures. Mr. Ruggiero, who will be the lead assembly technician, relocated to Rochester and spent two months conducting mock module assembly exercises with Dr. Bradford. These studies became the basis of the initial module assembly protocols. The models were used to test small hardware and fixtures that will be used during assembly. A full-scale model of PMT rack was also used to verify the suitability of the rack design, spec. the clear fiber cable lengths, and design the cable routing layouts.

In addition to the efforts described above, Rochester is responsible for designing and building a source scanner and using it to scan each of the modules with a Cs-137 source. This data will be used for quality control and to provide a calibration of the local response of each scintillator strip/WLS fiber in the detector. To date, Dr. Bradford and Mr. Flight are driving this design. This year the detailed design and fabrication of the module scanner will take place ***.

JUPITER

The purpose of the JUPITER program is to use electron scattering data to study (in the vector current) processes of interest for one–few *GeV* neutrino scattering. This data can be used to build models of neutrino cross-sections and provide a theoretical framework for the interpretation

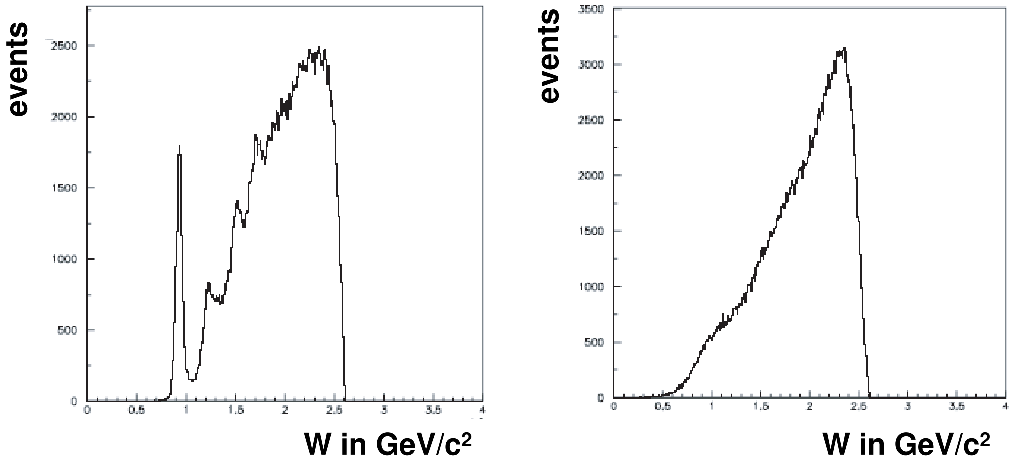

Figure 5: The mass of the hadronic system for 4.5 GeV electrons scattering off hydrogen (left) and carbon (right).

of MINERνA data. The JUPITER program has both a Hall C (inclusive scattering, E04-001) component and a Hall B (exclusive final states using the CLAS detector) component.

Mr. Steinman is analyzing data from JLab E04-001 (Bodek and Keppel spokespersons) [2] and JLab E02-109 [3]. He is making a detailed study of F_2 and R on nuclear targets in the resonance region $1 < W^2 < 4$ GeV^2. The selected target materials (H_2, D_2, C, Al, Fe) are appropriate for current and future neutrino oscillation detectors. Steinman's analysis of this data is well underway and will likely be completed in approximately one year.

Mr. Steinman's thesis work is complementary to, and important for, the MINERνA physics program. Since neutrino data are measured in nuclear targets, the separated vector structure functions from electron scattering, F_{2p}, F_{2n}, R_p, R_n for bound nucleons are needed in order to understand the axial structure function in neutrino scattering experiments. The precise data coming out of Steinman's work is required because an error of 0.2 in R gives an error of 10% in the predicted neutrino cross section and an error of 30% in the predicted anti-neutrino cross section. These new data taken on nuclear targets are expected to reduce the errors on the vector cross sections by a factor of 10 [2].

In the last year, Prof. Manly and Dr. Bradford worked with three undergraduates (David Sher from John's Hopkins University, Ian Kleckner from the University of Rochester and Jennifer Cano from the University of Virginia) on eA data taken using the CLAS detector facility in Hall B at JLAB. Specifically, the project involves mining the CLAS data to produce distributions on resonance and multihadron production that will be useful for tuning models of neutrino backgrounds and nuclear corrections. For example, in a recent paper [4] the authors show that very different nuclear corrections for charged and neutral pions in neutrino-oxygen scattering are expected to generate very different charged to neutral pion ratios in neutrino scattering off nuclear targets relative to hydrogen. We plan to look at this effect in eA scattering in order to test and tune this model, which is very relevant to MINERνA and the rest of the neutrino community. This is but one example of a result relevant to MINERνA that we hope to derive from this data-mining effort.

Figure 5 illustrates how important a role nuclear effects can play in lepton-nucleus scattering. These results were generated by our summer students using CLAS data taken with a hydrogen target on the left and carbon target on the right. Note that Fermi smearing largely wipes out the resonance structure in carbon. This summer we plan to learn to identify neutral pions in CLAS and study the charged to neutral pion ratio, among other topics relevant for MINERνA.

T2K

*** t2k placeholder, needs updating by KM ***

Our current activities for T2K are limited to participation in design studies. Prof. McFarland serves as the US convener for the 280 meter (near) detector and muon monitor working group, and is a member of the international board of the experiment. We are collaborators on the beamline and 280m detector US proposal to be submitted to DOE in summer 2005. US involvement on T2K is only in the proposal stage; if US participation is not supported, we may join another oscillation experiment for the far future.

Much of our motivation for pursuing the MINERνA physics program in fact is the need for more accurate cross-sections for T2K and NOvA. Our current focus on T2K is on the near detector, i.e., the detector that looks the most like MINERνA, but in a lower energy beam. Because of this synergy between the MINERνA and T2K efforts, we can already share technical and physics resources between the two efforts. The construction timescales for the two experiments overlap only slightly, and so we will be able to build identical components (optical cables, for example) for MINERνA and T2K. We see involvement in T2K as a logical future extension of our work on MINERνA and our work on MINERνA as a logical and necessary first step to doing T2K.

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Neutrino Phenomenology

Dr. Bradford, Prof. Bodek, and Dr. Budd, along with John Arrington of Argonne National Laboratory, developed a new parameterization (BBBA2005 parametrization) of the elastic nucleon form factors which characterize elastic e^- scattering off of the nucleon. The form factors account for the spatial extent of the nucleon, and separate the elastic and magnetic contributions to the cross section. As new data from Jefferson Lab [5, 6, 7] has invalidated the long-held belief that the elastic form factors were well parameterized by the dipole form factor, G_d, development of new parameterizations has been an important topic in recent years [8, 9, 10, 11, 12].

The new BBBA2005 parameterizations are shown in Figure 6. These parameterizations are largely an extension of earlier work done by Jim Kelly [12]. The work for the new parametrizations began with the Kelly dataset and fit function. BBBA differs from Kelly's in that it uses two duality based constraints in the fitting procedure to the poorly-measured neutron form factors. More details of the new parameterizations are available in [13].

Form factors are an important issue in neutrino physics.Through the conserved vector current hypothesis, the nucleon form factors can be related to the vector part of the quasi-elastic $\nu - A$ cross section. Thus, parameterizations of the nucleon form factors find broad use in neutrino simulations. The BBBA2005 parameterization has already been implemented in upgrades of the MINOS and MiniBoone simulation codes. In the future, they will also be used by the MINERvA experiment in an extraction of the axial form factor, F_A.

NuTeV/CCFR

NUTEV placeholder *** needs to be updated by KM *** The NuTeV experiment, which took data in 1996-1997, combined an upgraded CCFR detector, a new continuous hadron calibration beam, and a new SSQT neutrino beam. This combination offered improvements in determination

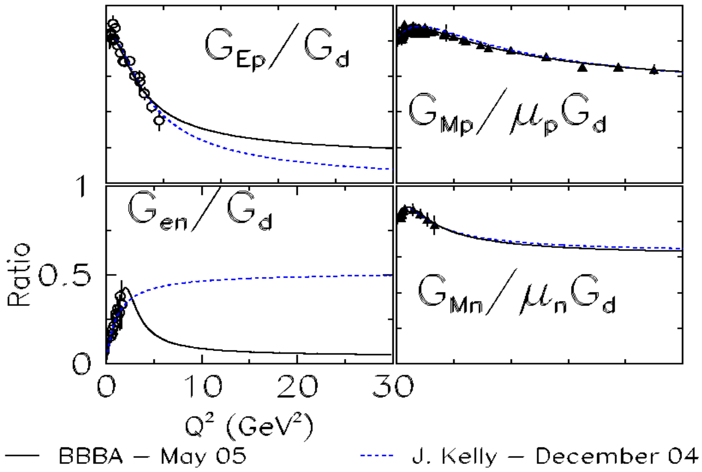

Figure 6: The solid blackline shows the ratio of the BBBA05 form factors to G_d, and the dashed blue line is the ratio of the Kelly form factors to G_d. The differences in the two parameterizations for $\frac{G_{Ep}}{G_d}$ and $\frac{G_{En}}{G_d}$ are due to the constraints applied to the BBBA05 form factors. All figures have a y-axis ranging from $Q^2 = 0\ GeV^2$ to $Q^2 = 30\ GeV^2$. In the lower limit ($Q^2 = 0\ GeV^2$), all ratios approach unity, except for G_{En}, which approaches zero.

of structure functions (calibration), electroweak parameters (anti-neutrino beam), and charm production from strange quarks (sign selection of beam). Rochester played a significant role in the construction (electronics and trigger, phototubes, veto wall, beamline components, testbeam), operation and analysis of the experiment. Data analysis highlights where Rochester played a key role include the electroweak mixing angle analysis (led by Prof. McFarland), structure functions (Prof. Bodek, Dr. Deborah Harris and Ph.D. Thesis of Un-Ki Yang), and on limits on oscillations (Profs. Bodek and McFarland, and Ph.D. thesis of Sergei Avvakumov). *** end nutev placeholder ****

E. Task F-2 NP to HEP transition issues

In the next year, Prof. Manly (PI for Task F-2) will complete the transition from a DOE-NP-supported group working at RHIC to a DOE-HEP-supported group working on neutrinos. Of the two remaining graduate students working on PHOBOS, one will finish this summer and the other will finish next summer. It is expected that DOE-NP will support the base salary of these students until they finish. This year DOE-NP is providing one month of summer salary for Prof. Manly and travel and computing support for F-2 work on JUPITER and MINERνA as well as RHIC-related activities. Since Prof. Manly's work on PHOBOS is being phased out this year while MINERνA effort is increasing, for next year, it is requested that DOE-HEP fund two months of Prof. Manly's summer salary and the JUPITER and MINERνA travel and computing as well as the expected (minor) residual RHIC related travel and computing expenses.

Mr. Steinman will continue working on MINERνA hardware and JUPITER analysis in then next year. So, continued support for him is requested. We also request support to start a second MINERνA graduate student on task F-2 in the next year. That student will be based primarily at Fermilab to help with the massive cable production and QC effort that will begin soon to build the MINERνA tracking prototype.

We also propose to hire a research associate to be based at Fermilab this year. This research associate will supervise the module scanning during construction of the tracking prototype and the detector as well as take charge of the fabrication and installation of the MINERνA scintillator veto wall. This research associate would also be expected to play a large role in the commissioning of the tracking prototype and detector.

References

[1] MINERνA Collaboration, Proposal P-938: A high statistics neutrino cross-section experiment for the NuMI beamline, hep-ex/0405002.
See also http://www.pas.rochester.edu/minerva.

[2] *Measurement of F_2 and $R = \sigma_L/\sigma_T$ on Nuclear-Targets in the Nucleon Resonance Region (First Stage of a Program to Investigate Quark Hadron Duality in Electron and Neutrino Scattering on Nucleons and Nuclei)*, JUPITER e-A E04-001, A. Bodek, C. E. Keppel spokespersons, see http://www.pas.rochester.edu/~bodek/jlab/F2-Rnuclear-HallC.pdf.

[3] JLab deuterium experiment (F2, R) in resonance region, E02-109, C.E. Keppel spokesperson, see http://www.jlab.org/exp_prog/proposals/02/PR02-109.ps.

[4] E.A. Paschos, I. Schienbein, J.-Y. Yu, hep-ph/0408148.

[5] M.K. Jones *et al*, PRL 84, 1398 (2000).

[6] O. Gayou *et al*, PRC 64, 038202 (2001).

[7] O. Gayou *et al*, PRL 88, 092301 (2002).

[8] J. Arrington, PRC 68, 034325 (2003).

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[10] J. Arrington, PRC 71, 015202 (2005).

[11] H. Budd, A. Bodek, and J. Arrington, arXiv:hep-ex/0410055 (2004).

[12] J.J. Kelly, PRC 70, 068202 (2004).

[13] R. Bradford, H. Budd, A. Bodek, and J. Arrington, arXiv:hep-ex/0206017 (2005).