5 Software

5.1 Overview

Software and computing resources are an integral part of the MINERνA project. These resources will be used to accommodate two primary tasks for MINERνA:

1. Data storage after acquisition under experimental running conditions
2. Data analysis and numerical modeling.

Detailed numerical modeling is necessary for the experimenters on MINERνA to gain the most complete understanding of the detector as possible. Data event selection and reconstruction goes together with the detailed detector model to both improve understanding of the detector response and analyze physics production data. Physical computing resources, including:

1. Raw and processed data storage
2. Detector model output and analysis storage
3. Raw and modeling data processing computer processor usage

are needed to complete analysis of MINERνA physics data. The MINERνA project has developed a technical design for obtaining these software and computing resources.

Data processing needs for the MINERνA experiment are divided into two main categories:

1. Generation and analysis of detector modeling events.
2. Event selection and reconstruction of real physics data from the physical MINERνA detector.

Certainly, it can be argued that these are not exclusive needs. For example the reconstruction packages used in the reconstruction of real physics events are, or at least may be, the same as those used for certain analysis of real physics data. Software which must be developed or implemented for this experiment includes but is not limited to:

1. The generation of neutrino events, including models of nuclear effects on neutrino-nucleon interactions.
2. Accurate descriptions of the MINERνA detector during design and after construction (as-built).
3. Codes to perform offline calibration and alignment of the detector in a timely fashion
4. A method of relaying accurate commissioning and calibration information to both simulation software and reconstruction software for real physics data.
5. Reconstruction and event selection routines suitable for use with both simulated and real physics data.

6. Analysis and visualization software for interpreting and displaying the results.

These needs can be met using a combination of pre-existing software and new software development or implementation.

The use of pre-existing software packages, particularly those which have been designed with physics analysis as their primary function, will help reduce the amount of time required to meet the software development needs of the MINERνAproject. For example, many packages already exist which can be used for data analysis and visualization. These packages are readily available at little or no cost to the experiment, or individual collaborator's institutions. The software development plan for simulation, reconstruction, and analysis requires the best-use of object-oriented programming techniques. The use of object-oriented programming techniques will allow MINERνA experimenters to use modern, well-supported, software tools to their best advantage, as well as making the use of varying analysis and reconstruction routines reasonably seamless. As of the writing of this document the following software packages were under review (but need not be limited to):

- GAUDI, a framework package, and its support packages.
- Geant4, a simulation package.
- ROOT, a data visualization and analysis package.
- A database, MySQL or Oracle are the current candidates.

Studies of the consistency between Geant3 and Geant4 based models are underway. Collaborators have also been developing specific classes for use with the MINERνA detector.

Meeting these software and physical computing needs is a collaborative effort. The members of the MINERνA collaboration are providing individuals to organize, develop, and train the full collaboration in the proper use of the software under construction. Physical computing resources will need to be provided from various sources, not the least of which is the Fermi Lab Computing Division. From the Laboratory, the MINERνA project will require mass-storage of raw, reconstructed, and simulated data. Centralized access to developed software and data will also be a necessity. These, among other needs from the Fermi Lab Computing Division are addressed in a formal Memorandum of Understanding between the project and the Computing Division. Clearly, meeting the computing needs of the MINERνA project is a collaborative effort.

5.2 Beam Simulation and Neutrino Event Generation

In order to produce a useful numerical model of the MINERνA detector two inputs are required:

1. A high quality model for the neutrino beam energy spectrum.
2. A generator of neutrino-interaction events.

At this time, the members of the MINERνA collaboration plan to neither manufacture nor maintain the external software which provides these necessary components of detector simulation. This decision was made pursuant to the availability of readily available software providing both beam energy spectra for the NuMI beam and not less than two reliable neutrino-event generators.

The neutrino beam energy spectra are provided to the MINERνA project from the NuMI working group of the Fermilab Neutrino Department. Neutrino energy spectra are produced using a numerical modeling package called GNuMI. This model was expressly developed for the NuMI beam line at Fermi Lab, and can provide profiles for various arrangements of the tuning horns along the beam line. These spectra are delivered, and used by the MINERνAcollaboration as text vectors.

Neutrino-interaction events are, in general, generated using one of two readily available neutrino event generators, NEUGEN and NUANCE. Both of these event generators can be used to simulate the four classifications of interactions of interest to the MINERνA project:

1. Quasi-elastic neutrino scattering.
2. Resonance production from neutrino scattering.
3. Deeply-Inelastic neutrino scattering.
4. Coherent production from neutrino scattering.

These event generators have been designed to incorporate nuclear effects in neutrino-interactions by incorporating the best available theoretical models and data. Appropriate accommodation will be made for use output of these event generators as input to numerical simulation of the detector. The MINERνAcollaboration has members who are instrumental in the design and maintenance of these generators through the respective collaborations designing them. Further information containing the methods used in NUANCE and NEUGEN can be found in references [172] and [138].

5.3 Code Management

Maintaining the quality and accessibility of computer code is imperative for the MINERνA collaboration. Proper code management requires two primary objectives:

1. Proper version maintenance and propagation.
2. Enforcement of best-practices in program design and documentation as determined by the members of the MINERνA collaboration.

Laboratory infrastructure and MINERνA collaboration effort are necessary to assist in attaining these objectives.

A Concurrent Versions System (CVS) server has been established at Fermi Lab for use by the MINERνA collaboration for storing and propagating necessary tools and other information. This server, setup by the Computing Division and maintained by the Collaboration, was negotiated as part of the MINERνAMemorandum of Understanding with the Fermi Lab Computing Division. Through CVS multiple versions of the same software can be made available as corrections are made and features are added without loss of the previous versions. This server is availability only to members of the MINERνA collaboration and is not publicly accessible.

The enforcement of best-practices in conforming to the object-oriented nature of the simulation and analysis software development plan is the job of a software librarian. This individual is identified

internally by the MINERνA collaboration. The software librarian is responsible for assisting those working on software projects in understanding the best-practices established by the collaboration, ensuring that tests for quality assurance and consistency are performed by developers before releasing new or corrected software for collaboration use, and insisting upon the proper documentation of software projects is produced such that all collaboration members can make use of simulation and analysis software.

5.4 Data Processing (Handling), CPU, and Storage

Data processing, CPU, and data storage requirements are detailed in the Memorandum of Understanding (MOU) between the Computing Division at Fermi Lab and the "project". These requirements are likely to change as the simulation and reconstruction software is better understood. The current understanding of computing needs for, Monte Carlo generation, is summarized in Table 1

Year	MC Data Store (GB)	MC CPU-year
2009	675	2.25
2010	1350	4.50
2011	4000	13.33
2012	4000	13.33
Total	10025	33.41

Table 1: Current understanding of Monte Carlo computing needs.

During the upcoming prototyping phase of MINERνA, an improved understanding of our offline computing needs will emerge. The prototyping itself, of course, requires some computing resources. At this time 30 GB of mass storage space has been requested from the Computing Division at FNAL as stipulated in the MOU.

5.5 On-line Software

Software support is needed for data acquisition (DAQ). The explicit requirements are under investigation as of the writing of this document and are discussed in section 3 under DAQ and Control and Monitoring.

The prototyping phase of the project will help determine and refine the on-line software needs for MINERνA.

Part I
Bibliography

References

[1] MINOS Collaboration, "MINOS Technical Design Report", NuMI-NOTE-GEN-0337 (1998).

[2] N. V. Mokhov, "The MARS Monte Carlo", FERMILAB FN-628 (1995); N. V. Mokhov and O. E. Krivosheev, "MARS Code Status", FERMILAB-Conf-00/181 (20 00); http://www-ap.fnal.gov/MARS/.

[3] N. Mokhov and A. Van Ginneken, J. Nucl. Sci. Tech. **S1**, 172 (2000).

[4] M. Messier (private communication)

[5] Y. Hayato, To be published in *Proceedings of the Second Workshop on Neutrino-Nucleus Interactions in the Few-GeV Region (NUINT02),* Irvine, California (2002).

[6] G. Ambrosini *et al.* [NA56/SPY Collaboration], Eur. Phys. J. C **10**, 605 (1999).

[7] P-907: Proposal to Measure Particle Production in the Meson Area Using Main Injector Primary and Secondary Beams, May 2000

(http://ppd.fnal.gov/experiments/e907/Proposal/E907_Propsal.html)

[8] NuMI Technical Design Handbook

(http://www-numi.fnal.gov/numiwork/tdh/tdh_index.html)

[9] K. Kodama *et al.*, Nucl. Phys. Proc. Suppl **98**, 43-47 (2001)

[10] M. Hasegawa *et al.* [K2K Collaboration], Phys. Rev. Lett. **95**, 252301 (2005) [arXiv:hep-ex/0506008].

[11] S. Kopp, Z. Pavlovic, and D. Indurthy, "Systematic Uncertainties in the NuMI Beam Flux" MINOS-doc-1283, (2006)

[12] C.H. Llewellyn Smith, Phys. Rep. 3C (1972).

[13] J. Arrington, nucl-ex[0305009].

[14] M. K. Jones *et al.*, Phys. Rev. Lett, 84, (2000) 1398 ; O. Gayou *et al.*, Phys. Rev. Lett, 88 (2002) 092301.

[15] J.J. Kelly, Phys. Rev. C70 (2004) 068202.

[16] R. Bradford, et al., hep[ex0602017].

[17] H. Budd, A. Bodek and J. Arrington, hep-ex[0308005].

[18] R. F. Wagenbrunn *et al.*, hep-ph[0212190].

[19] R. C. Merenyi *et al.*, Phys. Rev. D 45, 743 (1992)

[20] V. Bernard, L. Elouadrhiri, U.G. Meissner, J.Phys.G28 (2002), hep-ph[0107088].

[21] G. Zeller, private communication.

[22] K. Tsushima, Hungchong Kim, K. Saito, hep-ph[0307013].

[23] T. Kitagaki *et al.*, Phys. Rev. D26 (1983) 436.

[24] T. Kitagaki *et al.*, Phys. Rev. D42 (1990) 1331.

[25] S.J. Barish *et al.*, Phys. Rev. D16 (1977) 3103.
BNL D2

[26] N.J. Baker *et al.*, Phys. Rev. D23 (1981) 2499.

[27] W.A. Mann *et al.*, Phys. Rev. Lett. 31 (1973) 844.

[28] J. Brunner *et al.*, Z. Phys. C45 (1990) 551.

[29] M. Pohl *et al.*, Lett. Nuovo Cimento 26 (1979) 332.

[30] D. Allasia *et al.* Nucl. Phys. B **343** (1990) 285

[31] S.V. Belikov *et al.*, Z. Phys. A320 (1985) 625.

[32] S. Bonetti *et al.*, Nuovo Cimento 38 (1977) 260.

[33] K.L. Miller *et al.*, Phys. Rev. D26 (1982) 537.

[34] Glen Cowan, Statistical Data Analysis, Oxford Clarendon Press (1 998)

[35] H. Budd, A. Bodek and J. Arrington, hep-ex[0410055].

[36] D. Casper, Nucl. Phys. Proc. Suppl. 112 (2002) 161.

[37] R.A. Smith and E.J. Moniz, Nucl. Phys. B43 (1972) 605.

[38] Ghent Theory group in Belgium, Jan Ryckebusch (jan@inwpent5.UGent.be).

[39] D. Rein and L. M. Sehgal, Annals Phys. **133**, 79 (1981).

[40] M.H. Ahn, et al. (K2K), Submitted to PRD, hep-ex/0606032.

[41] T. Sato, D. Uno, and T.-S.H. Lee, Phys. Rev. C**67** 065201 (2003).

[42] E. Paschos, M. Sakuda, J.-Y. Yu, Phys. Rev. D**69** 014013 (2004).

[43] E. Paschos, et al., Proc. NuInt04 (L'Aquila), hep-ph/0408185.

[44] O. Lalakulich and E. Paschos, Phys. Rev. D**71** 074003 (2005).

[45] O. Lalakulich, E. Paschos, G. Piranishvili, Phys. Rev. D**74** 014009 (2006).

[46] T. Sato, et al., Proc. NuInt05 (Okayama),nucl-th/0601069.

[47] T. Kitagaki, et al., Phys. Rev. D**34** 2554 (1986).

[48] T. Kitagaki, et al., Phys. Rev. D**42** 1331 (1990).

[49] M. Hasegawa, et al. (K2K), Phys. Rev. Lett. **95** 252301 (2005).

[50] M. Wascko (MiniBoone), Proc. NuInt05 (Okayama), hep-ex/060 2050.

[51] D. Rein and L. M. Sehgal, Nucl. Phys. **B223**, 29 (1983).

[52] E. A. Paschos and A. V. Kartavtsev, (2003), hep-ph/0309148.

[53] Super-Kamiokande and K2K, C. Mauger, Nucl. Phys. Proc. Suppl. **112**, 146 (2002).

[54] BooNE, J. L. Raaf, Nucl. Phys. Proc. Suppl. **139**, 47 (2005), hep-ex/0408015.

[55] B. Z. Kopeliovich, Nucl. Phys. Proc. Suppl. **139**, 219 (2005), hep-ph/0409079.

[56] E. A. Paschos, A. Kartavtsev, and G. J. Gounaris, (2005), hep-ph/0512139.

[57] D. Rein and L. M. Sehgal, (2006), hep-ph/0606185.

[58] S. K. Singh, M. Sajjad Athar, and S. Ahmad, (2006), nucl-th/0601045.

[59] MiniBooNE, J. Monroe, Nucl. Phys. Proc. Suppl. **139**, 59 (2005), hep-ex/0408019.

[60] K2K, T. Ishida, Prepared for 1st Workshop on Neutrino - Nucleus Interactions in the Few GeV Region (NuInt01), Tsukuba, Japan, 13-16 Dec 2001.

[61] N.J. Baker *et al.*, Phys. Rev. D **24**, 2779 (1981).

[62] A. Alavi-Harati *et al.*, Phys. Rev. **87** 132001 (2001).

[63] P.G. Ratcliffe, Phys. Rev. **D59**, 014038 (1999).

[64] N. Cabibbo *et al.*, Semileptonic Hyperon Decay and CKM Unitarity, [arXiv:hep-ph/0307214] (July 2003).

[65] T. Alexopoulos *et al.* (KTeV Collaboration), Phys. Rev. Lett. **93**, 181802 (2004).

[66] T. Nakano *et al.*, [arXiv:hep-ex/0301020]; V.V. Barmin
em et al., [arXiv:hep-ex0304040]; S. Stepanyan [arXiv:hep-ex/0307018].

[67] R. Jaffe and F. Wilczek, Di-quarks and Exotic Spectroscopy, [arXiv:hep-ph/0307341] (July 2003).

[68] S. Kuhlmann *et al.*, Phys. Lett. B **476**, 291 (2000).

[69] H. Deden and et al., [Gargamelle Neutrino Collaboration], "Experimental Study Of Structure Functions And Sum Rules In Charge Changing Interactions Of Neutrinos And Anti-Neutrinos On Nucleons," Nucl. Phys. **B85**, 269 (1975).

[70] K. Varvell *et al.* [BEBC WA59 Collaboration], Z. Phys. C **36**, 1 (1987)

[71] M. Shifman, Handbook of QCD, Volume 3, 1451, World Scientific (2001)

[72] F. E. Close and N. Isgur, Phys. Lett. B **509**, 81 (2001)

[73] W. Melnitchouk, R. Ent and C. Keppel, Phys. Rept. **406**, 127 (2005) [arXiv:hep-ph/0501217].

[74] I. Niculescu *et al.*, Phys. Rev. Lett. **85**, 1186 (2000)

[75] C. E. Keppel, *Prepared for Exclusive Processes at High Momentum Transfer, Newport News, Virginia, 15-18 May 2002*

[76] J. Arrington, R. Ent, C. E. Keppel, J. Mammei and I. Niculescu, arXiv:nucl-ex/0307012 (submitted to Phys. Rev. Lett.)

[77] A. Fantoni [HERMES Collaboration], Eur. Phys. J. A **17**, 385 (2003).

[78] I. Niculescu *et al.*, Phys. Rev. Lett. **85**, 1182 (2000).

[79] A. Bodek and U. K. Yang, arXiv:hep-ex/0203009.

[80] D. Dolgov *et al.* [LHPC collaboration], Phys. Rev. D **66**, 034506 (2002) [arXiv:hep-lat/0201021].

[81] I. Niculescu, J. Arrington, R. Ent and C. E. Keppel, Phys. Rev. C **73**, 045206 (2006) [arXiv:hep-ph/0509241].

[82] X. Ji, Phys. Rev. Lett. **78**, 610 (1997).

[83] X. Ji, Phys. Rev. **D55**, 7114 (1997).

[84] A. V. Radyushkin, Phys. Lett. **B380**, 417 (1996).

[85] A. V. Radyushkin, Phys. Lett. **B385**, 333 (1996).

[86] J.C. Collins, L. Frankfurt, and M. Strikman, Phys. Rev. **D56**, 2982 (1997).

[87] A. V. Radyushkin, Nucl. Phys. **A711**, 99 (2002).

[88] M. Vanderhaeghen, Nucl. Phys. **A711**, 109 (2002).

[89] M. Diehl, hep-ph/0307382 (2003).

[90] C. Munoz Camacho, et al. nucl-ex/0607029 (2006).

[91] A. Psaker, W. Melnitchouk and A. Radyushkin, in preparation.

[92] D. Drakoulakos *et al.* [Minerva Collaboration], fine-grained detector in the NuMI beam," arXiv:hep-ex/0405002. Pgs. 99 - 108, 192 - 200.

[93] B.Z. Kopeliovich, hep-ph/0409079.

[94] M.K. Jones *et al.*, Phys. Rev. **C48**, 2800 (1993); R.D. Ransome *et al.*, Phys. Rev. **C46**, 273 (1992); R.D. Ransome *et al.*, Phys. Rev. **C45**, R509 (1992).

[95] D. Rowntree *et al.*, Phys. Rev. **C60**, 054610 (1999); B. Kotlinksi *et al.*, Eur. Phys. J. **A9**, 537 (2000).

[96] E. A. Paschos, M. Sakuda, I. Schienbein and J. Y. Yu, arXiv:hep-ph/0408185.

[97] M. Arneodo, Phys. Rept. **240**, 301 (1994).

[98] G. Piller and W. Weise, Phys. Rept. **330**, 1 (2000).

[99] B. L. Ioffe, V. A. Khoze, and L. N. Lipatov, *Hard processes: Phenomenology, Quark-Parton Model* (Elsevier Science Publishers, North Holland, 1984).

[100] G.B. West, Ann. Phys. **74** (1972) 464.

[101] S. V. Akulinichev, S. A. Kulagin, and G. M. Vagradov, Phys. Lett. B **158**, 485 (1985); S. V. Akulinichev, S. Shlomo, S. A. Kulagin, and G. M. Vagradov, Phys. Rev. Lett. **55**, 2239 (1985).

[102] S. A. Kulagin, Nucl. Phys. A **500**, 653 (1989).

[103] C. Ciofi degli Atti and S. Liuti, Phys. Rev. C **41**, 1100 (1990).

[104] F. Gross and S. Liuti, Phys. Rev. C **45**, 1374 (1992).

[105] S. A. Kulagin, G. Piller and W. Weise, Phys. Rev. C **50**, 1154 (1994).

[106] S. A. Kulagin, W. Melnitchouk, G. Piller, and W. Weise, Phys. Rev. C **52**, 932 (1995).

[107] S. A. Kulagin, Nucl. Phys. A **A 640**, 435 (1998).

[108] W. Melnitchouk, A. W. Schreiber and A. W. Thomas, Phys. Rev. D **49**, 1183 (1994).

[109] J. Gomez, *et al.,* Phys. Rev. D **49**, 4348 (1994).

[110] S. I. Alekhin, S. A. Kulagin and S. Liuti, Phys Rev. D **69**, 114009 (2004).

[111] S. A. Kulagin and R. Petti, paper in preparation.

[112] T. H. Bauer, R. D. Spital, D. R. Yennie and F. M. Pipkin, Rev. Mod. Phys. **50**, 261 (1978) [Erratum-ibid. **51**, 407 (1979)].

[113] C. A. Pickety, and L. Stodolsky, Nucl. Phys. B **15**, 571 (1970).

[114] S. L. Adler, Phys. Rev. **135**, B963 (1964).

[115] R. J. Glauber, Phys. Rev. **100**, 242 (1955).

[116] V. N. Gribov, Sov. Phys. JETP **29**, 483 (1970) [Zh. Eksp. Teor. Fiz. **56**, 892 (1969)] ; Sov. Phys. JETP **30**, 709 (1970) [Zh. Eksp. Teor. Fiz. **57**, 1306 (1969)].

[117] B. Z. Kopeliovich, and P. Marage, Int. J. Mod. Phys. A **8**, 1513 (1993).

[118] S. A. Kulagin, arXiv:hep-ph/9812532.

[119] E. A. Paschos and L. Wolfenstein, Phys. Rev. D **7**, 91 (1973).

[120] G. P. Zeller *et al.* [NuTeV Collaboration], Phys. Rev. Lett. **88**, 091802 (2002) [Erratum-ibid. **90**, 239902 (2003)] [arXiv:hep-ex/0110059].

[121] S. A. Kulagin, Phys. Rev. D **67**, 091301 (2003) [arXiv:hep-ph/0301045].

[122] S. A. Kulagin, arXiv:hep-ph/0406220.

[123] S. A. Kulagin, arXiv:hep-ph/0409057.

[124] D. H. Lu, A.W. Thomas, and K. Tsushima, arXiv:nucl- th/0112001, K. Tsushima, H. Kim, and K. Saito, Phys. Rev. C **70**, 038501 (2004)

[125] J.J. Aubert et al., Phys. Lett. **123B**, 275 (1983); D.F. Geesaman, K. Saito, and A.W. Thomas, Annu. Rev. Nucl. Part. Sci. **45**, 337 (1995).

[126] B. Buck and S.M. Perez, Phys. Rev. Lett. **50**, 1975 (1983).

[127] S. Dieterich, et al., Phys. Lett. B **500**, 47 (2001), S. Strauch et al., Phys. Rev. Lett. **91**, 052301 (2003).

[128] JLab experiment E3-104, co-spokespersons R. Ent, R. Ransome, S. Struach, P. Ulmer. `http://www.jlab.org/exp_prog/proposals/03/PR03-104.ps`

[129] C.H.Q. Ingram, Nucl. Phys. A **684**, 122 (2001).

[130] M. K. Jones *et al.*, Phys. Rev. C **48**, 2800 (1993).

[131] M. Nakahata *et al*, Nucl. Instrum. Meth. **A421**, 113 (1 999); E. Blaufuss *et al*, Nucl. Instrum. Meth. **A458** 638 (2001).

[132] M. Diwan and J. Nelson, NuMI-NOTE-STEEL-0639 (2000)

[133] PhD Thesis of C. Smith, University College London, London, 2002 *Calibration of the MINOS Detectors and Extraction of Neutrino Oscillation Parameters*; PhD Thesis of R. Nichol, University College London, London, 2003 *Calibration of the MINOS Detectors*

[134] PhD thesis of M. A. Kordosky, University of Texas at Austin, August 2004 *Hadronic Interactions in the MINOS Detectors*

[135] PhD thesis of P. L. Vahle, University of Texas at Austin, August 2004 *Electromagnetic Interactions in the MINOS Detectors*

[136] E. A. Paschos, L. Pasquali and J. Y. Yu, Nucl. Phys. B **588**, 263 (2000) and E. A. Paschos, J. Y. Yu and M. Sakuda [arXiv:hep-ph/0308130].

[137] D. Ashery *et al.*, Phys. Rev. **C23**, 2173 (1981).

[138] H. Gallagher, Nucl. Phys. Proc. Suppl. **112**, 188 (2002)

[139] NuMI Fluxes courtesy of Mark Messier

[140] The simulation assumed the active material was resistive plate chambers and the absorber was particle board (hydrocarbons).

[141] G.P.Zeller, submitted to proceedings of 2nd International Workshop on Neutrino - Nucleus Interactions in the Few GeV Region (NUINT 02), Irvine, California, 12-15 Dec 2002 [hep-ex/0312061]

[142] Kamiokande Collaboration, S. Hatakeyama *et al.*, Phys. Rev. Lett. **81** (1998) 2016; Soudan-2 Collaboration, W. W. Allison *et al*, Phys. Lett. **B 449** (1999) 137; MACRO Collaboration, Ambrosio *et al*, Phys. Lett. **B434**, 451 (1998)

[143] Y. Fukuda et al., *Phys. Rev. Lett.* **81** (1998) 1158; Erratum **81** (1998) 4279, B.T. Cleveland et al., *Astrophys. J.* **496** (1998) 505. W. Hampel et al. (GALLEX Collaboration), *Phys.Lett.* **B 447** (1999) 127., J.N. Abdurashitov et al. (SAGE Collaboration), *Phys. Rev.* **C 60** (1999) 055801 [astro-ph/9907113]

[144] Q.R. Ahmad *et al.* Phys.Rev.Lett.**89** (2002) 011302 nucl-ex/0204009

[145] Y. Fukuda *et al.*, Phys.Rev.Lett.**81** (1998) 1562 [hep-ex/9807003]; M. Sanchez et al., Phys. Rev. **D 68**, 113004 (2003)

[146] KamLAND Collaboration (K. Eguchi et al.), Phys. Rev. Lett.**90** (2003) 021802 [hep-ex/0212021]

[147] K2K Collaboration (M.H. Ahn et al.), Phys.Rev.Lett.**90** (2003) 41801 [hep-ex/0212007]

[148] B. Pontecorvo and J. Exptl, Theoret. Phys. **34** 247 (1958); Z. Maki, M. Nakagawa and S. Sakata, Prog. Theor. Phys. **28**, 870 (1962).

[149] M. Maltoni *et al*, submitted to New J. Phys, [hep-ph/0405172]

[150] By CHOOZ Collaboration (M. Apollonio et al.), Phys.Lett.**B466** (1999) 415 [hep-ex/9907037]

[151] W. Grimus and L. Lavoura, Phys. Lett. **B572**, 189 (2003); A. Aranda, C.D. Carone, R.F. Lebed, Phys. Rev. **D62**, 016009 (2000).

[152] "A Long Baseline Neutrino Oscillation Experiment at Fermilab", E.Ables *et al*, FERMILAB-PROPOSAL-0875, Feb. 1995, 241pp.

[153] "NOVA: Proposal to build an Off-Axis Detector to Study $\nu_\mu \rightarrow \nu_e$ oscillations in the NuMI Beamline", I. Ambats *et al.*, FERMILAB-PROPOSAL-0929, Mar 2004.

[154] Y. Itow *et al*, "The JHF-Kamioka Neutrino Project", KEK report 2001-4, June 2001. [hep-ex/0106019]

[155] J. Nelson, "MINOS Oscillation Results", Neutrino 2006, Santa Fe, NM, June, 2006.
bibitemingram C.H.Q. Ingram, Nucl. Phys. A **684**, 122 (2001).

[156] E. Gallas & J. Li., "Polishing Optical Fibers for the D0 ICD in Run II", FNAL-TM-2062, 1998.

[157] The MINERνA Collaboration,
Proposal to perform a high-statistics neutrino scattering experiment using a fine-grained detector in the NuMI beam, Fermilab Proposal P-938, e-print hep-ex/0405002; see Sect. 16.5.2.

[158] M. Bonkowski, *Magnetic Field Measurement Results*,
MINERνA note MINERvA-doc-88-v1, (measurements of December 2004).

[159] D. Cherdack and W.A. Mann, *Magnetic Shielding Capabilities of the MINERvA PMT Box*, MINERνA note MINERvA-doc-164-v1.

[160] P. Adamson, et al., Nucl. Inst. Meth. A**492**,
325 (2002).

[161] P. Shanahan, priv. comm. (Nov., 2005).

[162] A. Cabrera, et al., NuMI-934 internal report.

[163] P. Harris (Sussex Univ.) provided excellent
guidance and some pieces necessary for prototyping.

[164] "MCM II and the Trip Chip", J. Estrada, C. Garcia, B. Hoeneisen and P. Rubinov, August 2002, FERMILAB-TM-2226.

[165] MINOS Technical Design Report, Chapter 5: Scintillator detector fabrication, Fermilab Public

[166] Specification 9216.000-ES-435360. Available through the Fermilab Particle Physics Division.

[167] Specification 9216.000-ES-435361. Available through the Fermilab Particle Physics Division.

[168] R. Bradford, *Assembly Roadmap from Prototype Studies*, posted to FNAL MINERνA Docdb as document number 561.

[169] R. Flight, *Detector Assembly Drawings, as of 11/15/05*, available in MINERνA Docdb as document number 226.

[170] R. Flight, *Mapper Drawings*, available in MINERνA Docdb as document number 897.

[171] R. Flight, *Fiber Routing Update*, available in MINERνA Docdb as document number 741.

[172] D. Casper, "The `nuance` Neutrino Physics Simulation, and the Future", *http://nuint.ps.uci.edu/nuance/files/nuance_nuint01.pdf*

[173] O. Benhar, [arXiv:nucl-th/0307061].

[174] K. Ruddick (private communication).

[175] L. Mualem (private communication).

[176] MINOS Collaboration, P. Adamson *et al.*, IEEE Trans. Nucl. Sci. **49**, 861 (2002).

[177] R. Fruhwirth, Nucl. Inst. Meth. **A262**, 444 (1987).

[178] "Studies of Extruded Plastic Scintillator for MINOS", Karol Lang and Todd Soesby, NuMI-NOTE-L-250, Feb 1997.

[179] M. Andrews, MINERνA Hazard Assessment, MINERνA Document 310 (2006)

[180] MINERνA Project Management Plan, MINERνA Document 59 (2006)

[181] L. Mualem, *The case for using Cesium-137 on the module mapper instead of Co-60*, NuMI-L-0653 (2000)

[182] American Institute of Steel Construction, Inc., *Manual of Steel Construction, Allowable Stress Design*, Ninth Edition

[183] American National Standard ANSI/ASME B30.20, *Below-the-hook lifting devices*

[184] Gage-Babcock & Associates, Inc. *Fire Protection/Life Safety Recommendations for the Fermilab NuMI Project* (1998)

[185] Fermilab ES&H Manual, Chapter 5032.2, Guidelines for the Design, Review and Approval of Liquid Cryogenic Targets (1995)

[186] J. Livengood, Letter to G. Brown, *National Environmental Policy Act (NEPA) Determination at Fermi National Accelerator Laboratory - "Main Injector Neutrino ExpeRiment ν–A(MINERνA)"* MINERνA Document 311 (December 2, 2005)