

CDR Status

Bruce Baller

March 20, 2009

Guiding Principles

- Audience
 - Collaboration, DOE, FNAL @ CD1 (Summer 2009)
- Intent
 - State physics goals → physics requirements → technical requirements
 - Describe the spectrum of detectors that might meet the technical requirements
 - Explain why all were rejected except for the detector we are proposing
 - Describe the detector design, aka the “recommended alternative”
 - Explain why the design is optimum (alternatives, optimization, value eng)
 - Describe risks (technical, vendor, cost, schedule)
 - Describe required steps to ensure detector is built properly (QC, QA)
 - Document how we will ensure the project satisfies federal regulations, DOE orders & FNAL standards
 - Cost, schedule, technical, ES&H, QA, public interests

The CD1 review will go much smoother if the CDR addresses all of these issues

Recent CDR's

- Minerva – 40 pages (6 CDR, 34 Proj)
 - Similar cost to uB, but...
 - TDR was well advanced when CDR was reviewed
- Nova – 210 pages (180 CDR, 30 Proj)
 - \$200M cost
 - Outline shown on the next few slides

Table of Contents

| | |
|--|-----------|
| PREFACE | 2 |
| TABLE OF CONTENTS | 3 |
| 1. EXECUTIVE SUMMARY | 9 |
| 1.1 INTRODUCTION | 9 |
| 1.2 PROJECT COMPONENTS | 9 |
| 1.3 USE OF EXISTING FACILITIES | 9 |
| 1.4 CAPABILITIES | 9 |
| 1.5 COST & SCHEDULE | 9 |
| 2. SCIENTIFIC PERFORMANCE REQUIREMENTS | 10 |
| 2.1 NOvA GOALS | 10 |
| 2.1.1 <i>Table of Scientific Performance Requirements</i> | 10 |
| 2.2 OVERVIEW OF NEUTRINO OSCILLATIONS | 10 |
| 2.3 DETAILS OF NEUTRINO OSCILLATIONS | 11 |
| 2.2.1 <i>Neutrino Mixing</i> | 11 |
| 2.2.2 <i>Matter Effects</i> | 12 |
| 2.2.3 <i>CP Violation</i> | 13 |
| 2.2.4 <i>Ambiguities</i> | 13 |
| 2.2.5 <i>Measurement of the Dominant Mode Oscillation Parameters</i> | 15 |
| 2.3 THE OFF-AXIS NEUTRINO BEAM | 16 |
| 2.3.1 <i>The NuMI Beam</i> | 16 |
| 2.3.2 <i>Off-Axis Concept</i> | 17 |
| 2.4 SITING REQUIREMENTS | 19 |
| 2.4.1 <i>Transverse Siting</i> | 19 |
| 2.4.2 <i>Longitudinal Siting</i> | 20 |
| 2.5 FAR DETECTOR REQUIREMENTS | 21 |
| 2.5.1 <i>Figure of Merit</i> | 21 |
| 2.5.2 <i>Energy Resolution</i> | 22 |
| 2.6 FAR DETECTOR HALL OVERBURDEN REQUIREMENT | 22 |
| 2.7 NEAR DETECTOR REQUIREMENTS | 23 |
| CHAPTER 2 REFERENCES | 24 |

Nova

2.1.1 Table of Scientific Performance Requirements

These NOVA goals translate into the scientific performance requirements summarized in Table 2.1. The requirements are developed in this chapter in the sections indicated in the table.

| Design Parameter | Scientific Performance Requirement | Section |
|--|--|---------|
| Distance off-axis | 11.5 to 12.0 km | 2.4.1 |
| Distance from Fermilab | As far from Fermilab as practically possible. | 2.4.2 |
| Experimental Sensitivity | Figure of merit greater than or equal to 30 (The Figure of Merit is defined as the number of ν_e signal events divided by the square root of the background for 32.5×10^{20} protons on the NuMI target at the oscillation values $\sin^2(2\theta_{13}) = 0.1$ and $\Delta m^2_{32} = 0.0025 \text{ eV}^2$ without regard to matter and atmospheric-solar interference effects.) | 2.5.1 |
| Energy resolution for ν_e Charged Current events | Less than 8% at 2 GeV | 2.5.2 |
| Energy resolution for Quasi-Elastic ν_μ Charged Current events | Less than 4% at 2 GeV | 2.5.2 |
| Far Detector overburden | 2 meters of rock with density 2.5 g/cm^3 | 2.6 |
| Near Detector | At least a 20 ton fiducial volume located about 1 kilometer from the NuMI target with sufficient transverse and longitudinal size for neutrino event containment. At least 62 tons if located at 2.5 km from the NuMI target. | 2.7 |

Table 2.1: Summary of the scientific requirements and the chapter sections in which they are established.

Minerva

The primary detector performance requirements are:

- Target mass:
 - 3-6 tons fiducial volume for analyses using the scintillator as a target
 - > 0.5 tons each of graphite, iron and lead (Pb) nuclear targets
- Tracking:
 - ability to efficiently reconstruct up to three final state tracks from charged minimum ionizing particles (μ , π , K, p)
 - ability to efficiently reconstruct a significant fraction of low momentum ($p < 1$ GeV/c) proton tracks in quasi-elastic events
 - ability to efficiently locate track vertices with a resolution of ~ 1 cm in three dimensions and to identify tracks not originating from the primary vertex to identify strange particle decays
 - ability to measure the starting time of tracks to $\lesssim 3$ ns resolution
- Calorimetry and track energy measurement
 - ability to identify and reconstruct photon (γ) showers for π^0 identification
 - ability to differentiate $e/\gamma/(\mu$ or $\pi)/K/p$ by track shape or energy deposited
 - ability to contain energy from e/γ showers in the electromagnetic calorimeters
 - ability to contain energy from deep inelastic scattering events in the hadronic calorimeters
- Ability to determine kinematic parameters with the resolutions shown in Table 6-1

Minerva

| | muon momentum resolution | muon angular resolution | Stopping muon momentum resolution | Hadron energy resolution | Neutrino energy resolution |
|-----------------------------|---------------------------------|--------------------------------------|-----------------------------------|--------------------------|----------------------------|
| Quasi - elastic scattering | $\lesssim 20\%$ | Only limits low Q^2 reach | Benefit if $\lesssim 5\%$ | $\leq 30\%/ E$ | $\leq 15\%$ at low energy |
| Coherent π production | Mild benefit if $\lesssim 12\%$ | $\leq 0.5^\circ$ | n/a | $\leq 20\%/ E$ | n/a |
| Deeply Inelastic Scattering | $\leq 12\%$ | Mild benefit if $\lesssim 0.5^\circ$ | n/a | $< 12\%$ at high y | n/a |

Table 6-1 A summary of kinematic requirements from different reactions. MINERvA proposes to study a wide variety of reactions over a wide kinematic range, and different requirements are set by different reactions. The most stringent kinematic requirements are listed in boldface type. n/a means not applicable.

| | |
|--|-----------|
| 3. OVERVIEW OF THE NOvA DESIGN | 25 |
| 3.1 INTRODUCTION | 25 |
| 3.2 FAR DETECTOR SITE: ASH RIVER..... | 25 |
| 3.3 NEAR DETECTOR SITE: FERMILAB NUMI ACCESS TUNNEL | 28 |
| 3.4 DESCRIPTION OF THE NOvA DETECTOR | 30 |
| 3.4.1 <i>The Basic NOvA Detector Element</i> | 30 |
| 3.4.2 <i>Liquid Scintillator</i> | 32 |
| 3.4.3 <i>Wavelength-shifting Fiber</i> | 32 |
| 3.4.4 <i>Rigid PVC Extrusions</i> | 32 |
| 3.4.5 <i>Extrusion Modules</i> | 34 |
| 3.4.6 <i>Photodetector and Electronics</i> | 35 |
| 3.4.7 <i>Data Acquisition System</i> | 35 |
| 3.4.8 <i>Assembly and Structure of the Far Detector</i> | 35 |
| 3.4.9 <i>Assembly and Structure of the Near Detector</i> | 39 |
| 3.5 PERFORMANCE OF THE SELECTED NOvA DESIGN..... | 41 |
| 3.5.1 <i>Measured Performance of a Single Cell</i> | 41 |
| 3.5.2 <i>Simulated Performance of the NOvA Detector: A Visual Overview</i> | 42 |
| 3.5.3 <i>Simulated Performance of the NOvA Detector: Quantitative Analysis</i> | 49 |
| 3.5.3 <i>Summary: Selected NOvA Design Performance vs. Scientific Requirements</i> | 52 |

A summary of the Far Detector parameters is given in Table 3.2 and more details of the structure and assembly are in Chapter 16.

| | |
|--|--|
| Total mass | 25,398 metric tons (includes epoxy and fiber) |
| Mass of rigid PVC extrusions | 6,854 metric tons |
| Mass of liquid scintillator | 18,463 metric tons |
| Liquid scintillator | Mineral oil base with 5% pseudocumene as the scintillant, PPO and bis-MSB wavershifters added. |
| Active mass fraction | 73% |
| Active height × width | 15.7 m × 15.7 m |
| Active length | 111 m |
| Number of layers | 1674 (864 vertical, 810 horizontal) 54 blocks of 31 planes each |
| Radiation length per layer | ~ 0.15 |
| Mass of epoxy between layers | ~ 67 tons |
| Extrusions per layer | 12 |
| Extrusion outer wall thickness | 3 mm in horizontal cells, 4.5 mm in vertical cells |
| Extrusion inner web thickness | 2 mm in horizontal cells, 3 mm in vertical cells |
| Extrusion width | 1.3 m |
| Extrusion length | 15.7 m |
| Maximum pressure in vertical cells | 19.2 psi |
| Cells per extrusion | 32 |
| Cell interior width × depth, horizontal cells vertical cells | 3.87 cm × 6.00 cm 3.76 cm × 5.70 cm |
| Total number of cells | 642,816 |
| Total number of extrusions | 20,088 |
| Wavelength-shifting fiber | 0.8 mm diameter double clad fiber with K27 wavershifting dye |
| Total WLS fiber length | 21,624 km |
| Total WLS fiber mass | 13.8 tons |
| Photodetector | Avalanche Photodiode |

Table 3.2: Summary of Far Detector parameters.

| | |
|--|-----------|
| 4. ALTERNATIVE NOvA DESIGNS CONSIDERED | 54 |
| 4.1 INTRODUCTION | 54 |
| 4.2 ALTERNATIVE FAR DETECTOR SITES | 54 |
| 4.2.1 <i>Lake Superior Sites</i> | 56 |
| 4.2.2 <i>Cliffs-Erie Site</i> | 56 |
| 4.2.3 <i>Peyla Site</i> | 56 |
| 4.2.4 <i>Orr-Buyck Site</i> | 56 |
| 4.2.5 <i>Alternatives at the Ash River Site</i> | 57 |
| 4.2.6 <i>Fort Frances – Mine Center Site</i> | 58 |
| 4.2.7 <i>Vermilion Bay Site</i> | 58 |
| 4.3 ALTERNATIVE NEAR DETECTOR SITES | 58 |
| 4.4 ALTERNATIVE DETECTOR TECHNOLOGIES | 59 |
| 4.4.1 <i>Water Cherenkov Detectors</i> | 59 |
| 4.4.2 <i>Liquid Argon TPC</i> | 60 |
| 4.4.3 <i>Low Z Sampling Calorimeters</i> | 60 |
| 4.4.4 <i>Performance of Alternative Low Z Sampling Calorimeters vs. the Selected NOvA Design</i> | 61 |
| 4.4.5 <i>Risk Analysis of Low Z Sampling Calorimeter Alternatives</i> | 63 |
| 4.4.6 <i>Conclusions on Low Z Sampling Calorimeter Alternatives</i> | 63 |
| 4.5 ALTERNATIVE STRUCTURES FOR THE SELECTED TOTALLY ACTIVE NOvA DESIGN | 63 |
| 4.5.1 <i>Less Vertically Challenging Alternative Detectors</i> | 63 |
| 4.5.2 <i>A “Vee” Design Alternative</i> | 64 |
| 4.5.3 <i>A Bathtub Design Alternative</i> | 65 |
| 4.5.4 <i>A Design Alternative based on International Shipping Containers</i> | 66 |
| CHAPTER 4 REFERENCES | 68 |

| | |
|---|------------|
| 12. PVC MODULES..... | 149 |
| 12.1 OVERVIEW | 149 |
| 12.2 THE RECOMMENDED DESIGN | 149 |
| <i>12.2.1 Bottom Closure Plate and Fiber Manifold</i> | <i>149</i> |
| <i>12.2.2 PVC Module Factories</i> | <i>152</i> |
| 12.3 ALTERNATIVES CONSIDERED | 152 |
| 12.4 MODULE AND FACTORY DESIGN OPTIMIZATION..... | 153 |
| 12.5 QUALITY ASSURANCE AND QUALITY CONTROL | 153 |
| 12.6 ES&H | 154 |
| 12.7 RISKS | 154 |
| 12.8 VALUE MANAGEMENT | 155 |
| CHAPTER 12 REFERENCES | 155 |

Standard format for each sub-system chapter

| | | | |
|---------|---|--------------------|---|
| 1. | Introduction | | 2 |
| 2. | Objectives | Proposal → Bruce | 4 |
| 2.1. | Scientific Goals | | 5 |
| 2.2. | Technical Goals | | 5 |
| 3. | Performance Parameters | Bonnie | 5 |
| 4. | Conceptual Design | Bruce | 5 |
| 4.1. | LAr Properties | Bruce | 5 |
| 4.2. | Cryostat, Cryogenics & Purification | Brian? | 5 |
| 4.3. | Active Detectors | Bonnie | 6 |
| 4.4. | Electronics & DAQ | Hucheng? & Leslie? | 6 |
| 4.5. | Detector Facility | Cat | 6 |
| 4.6. | Systems Integration & Installation | Bruce | 7 |
| 5. | Schedule and Cost Range | | 7 |
| 5.1. | Total Project Cost Range | | 7 |
| 5.2. | Funding Profile | | |
| 5.3. | Schedule Range | | |
| 6. | Alternatives Analysis | | |
| 7. | Site Selection | | |
| 8. | Safeguards and Securities Plan & Vulnerability Assessment | | |
| 9. | Work Breakdown Structure | | |
| 10. | Condition Assessments for the Facility | | |
| 11. | Environment, Safety and Health | | |
| 11.1. | ES&H Organizations | | |
| 11.2. | The National Environmental Policy Act (NEPA) | | |
| 11.3. | Safety Assessment Documents | | |
| 11.4. | Integrated Safety Management Plan | | |
| 11.4.1. | Defining the Scope of Work, Identifying Hazards | | |
| 11.4.2. | Developing and Implementing ES&H Controls | | |
| 11.4.3. | Assessing Performance for Continuous Improvement | | |
| 11.5. | Waste Minimization & Pollution Identification | | |
| 12. | Draft Decommissioning and Decontamination Plan | | |
| 13. | Public and Stakeholder Input | | |

MicroBooNE Current Outline @ Level 2

Suggested Section Editors

| | | |
|-------|--|----|
| 14. | Preliminary Interface Control Documents | 11 |
| 14.1. | Memoranda of Understanding | 11 |
| 14.2. | Project Management Plan | 12 |
| 15. | Reviews | 12 |
| 15.1. | Technical/QA Reviews | 12 |
| 15.2. | ES&H Reviews | 12 |
| 15.3. | Director's Reviews | 13 |
| 15.4. | Readiness Assessment and Review | 13 |
| 16. | Project End State | 13 |
| 17. | Project Constraints | 13 |
| 18. | Preliminary Plan for Demobilization of Facilities Being Replaced | 13 |
| 19. | Technical Considerations | 14 |
| 19.1. | Quality Assurance | 14 |
| 19.2. | Risk Management | 14 |
| 19.3. | Configuration Management | 14 |
| 19.4. | Value Engineering | 14 |

Drafting

Conceptual Design Sub-Sections

4.3.Active Detectors

4.3.1. Introduction

Short description of the technical scope

4.3.2. The Recommended Design

Add Level 4 headings as necessary
(e.g. 4.3.2.1 TPC, 4.3.2.2 Photo
Detectors)

4.3.3. Alternatives Considered

e.g. Use fibers instead of PMT's

4.3.4. Optimization

e.g. Why 3 mm wire space? Cost/benefit

4.3.5. Quality Control & Quality Assurance

e.g. control wire spacing uniformity

4.3.6. Risks

labor cost risk? Single vendor for PMT's

4.3.7. ES&H

Wire winding repetitive motion injuries?

4.3.8. Value Management

Wire winding: automatic, semi-
automatic, manual

Word Smithing Suggestions

- Use proposal text as a starting point
- If you are unsure of a number or date, use “XX” as a placeholder
- Highlight statements that are currently not supportable (but should be at CD1) in red font and/or use “(?)”
 - Example p7: “Communications and utility connections will be made to existing systems that were installed for MiniBooNE. **No upgrades to existing systems are required (?) for MicroBooNE.**”
- If you add a sub-section, be sure to use a heading style that matches the outline level
 - Use “Heading Style 4” for 4.3.2.1

Plan

- Each section editor should get a copy of the CDR (DocDB #340) and modify their section (4.1 – 4.6)
- Members of the system group should draft text and submit it to the section editor
- The section manager should
 - Ensure their section is coherent
 - Submit the entire CDR document to Bruce Baller by 8AM April 10
- All sections will be merged into CDR v2 and presented at the next collaboration meeting
 - I can't guarantee that late submittals will be included in v2
- Next Round
 - Internal reviewer (TBA) comments to section editors
 - Comments from everyone in the collaboration are welcome
 - Section editor updates to Bruce by May 18th
 - Present v3 at the May 22 collaboration meeting