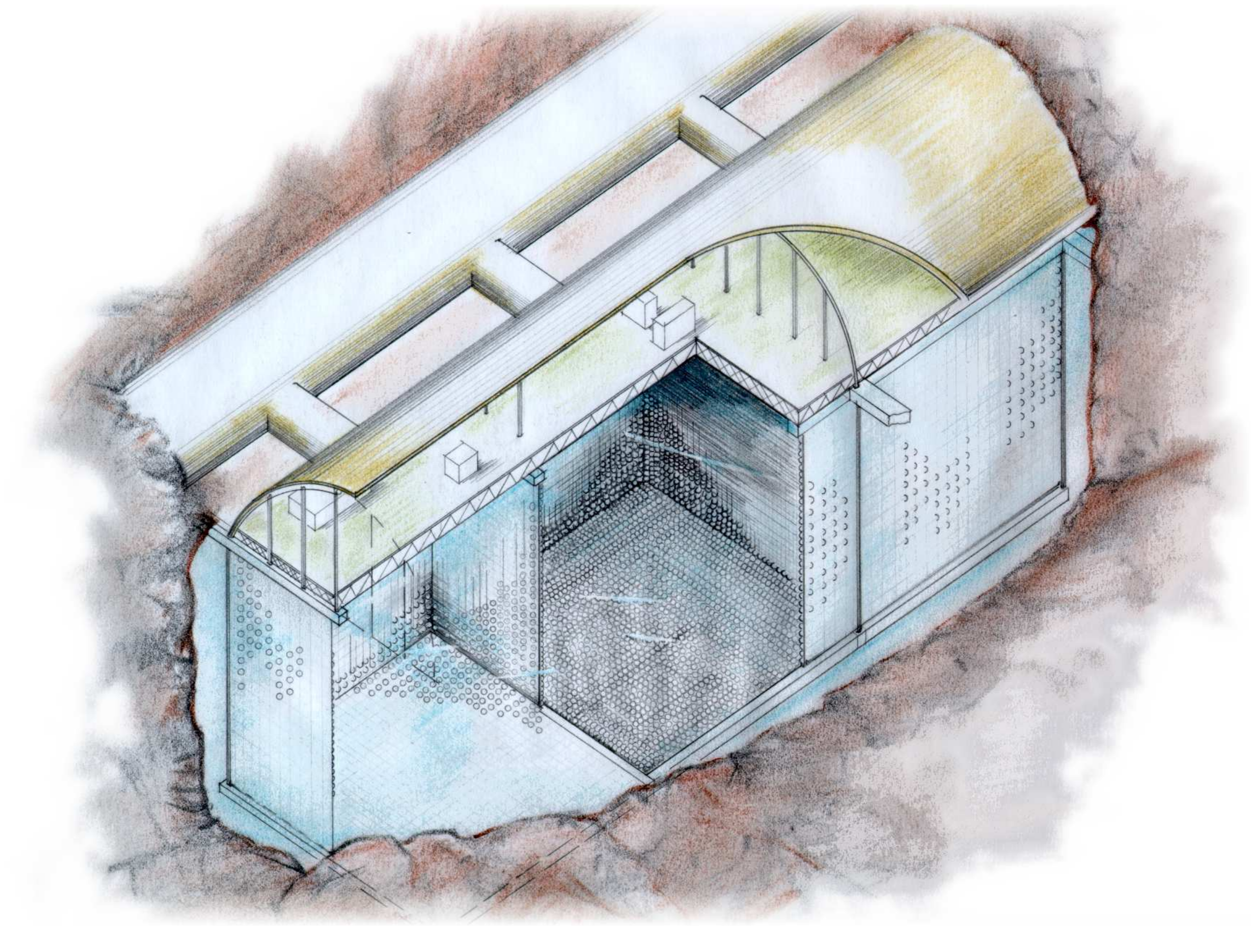
Expression of Interest and R&D Proposal
(October 2 version)

for the Study of Nucleon Decay and Neutrino Physics
Using a Large Underground Water Cherenkov Detector

UNO



The UNO Collaboration

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Executive Summary

In this document, we describe the physics potential and feasiblity of the UNO detector, and propose an initial R&D program. This proposal is submitted to both the U.S. Department of Energy and National Science Foundation.

The UNO detector is a next-generation underground water Cherenkov detector that probes physics far beyond the sensitivities of the highly successful Super-Kamiokande (SuperK) detector while utilizing a well- tested technology [1]. The baseline concept of the detector is a "Multi-Cubical" design with outer dimensions of $60 \times 60 \times 180$ m^3. The detector has three optically independent cubical compartments; the central cube has a photocathode coverage of 40%, while the side cubes have 10% coverage. This design optimizes the physics reach for nucleon decay searches and a variety of neutrino physics studies while keeping the detector cost at a minimum. The total (fiducial) mass of the detector is 650 (440) kton, which is about 13 (20) times larger than the SuperK detector. In terms of underground location the optimal depth of the detector is about 4000 mwe. A deeper location would reduce cosmogenic backgrounds, but may introduce additional complexity such as higher rock temperature and rock instability, and add cost to the construction and operation.

The discovery potential of the UNO detector is multifaceted. UNO will be capable of observing proton decay through the vector boson mediated $e^+\pi^0$ mode in ∼50% of the lifetime ranges predicted by the current Grand Unification Theories (GUTs). This mode of proton decay is considered the most model independent. Water Cherenkov technology is the only realistic detector technology presently available that allows a search for this decay mode for proton lifetimes up to 10^{35} years. More striking yet, if predictions of current super-symmetric GUT, such as SUSY SO(10), are correct, UNO would in fact discover proton decay via the $K^+\bar{\nu}$ mode.

UNO as an astrophysical neutrino observatory will greatly extend our capabilities in this important and timely field. It will detect neutrinos from supernova explosions as far away as the Andromeda galaxy. The expected rate of observation of neutrinos from supernovae explosions is about one in every 10 to 15 years. In the case of a galactic supernova explosion at a distance of 10kpc, UNO will collect ∼140k neutrino events, from which the millisecond neutrino flux timing structure can be extracted. This could provide us with an observation of black hole formation in real-time as well as a wealth of information to understand the core collapse mechanism in detail.

Discovery of supernova relic neutrinos (SRN) is also within the reach of UNO. The predicted values of the SRN flux by various theoretical models, when taken most conservatively, are at most six times smaller than the current SuperK limit. Though some models have been excluded by

SuperK, UNO's much larger fiducial mass and lower cosmogenic spallation background will cover the entire predicted flux range. Discovery of SRN will greatly impact our understanding of the evolution of the Universe.

UNO is an ideal distant detector for a long-baseline neutrino oscillation experiment with neutrino beam energies below 10 GeV, providing a synergy between accelerator and non-accelerator physics. Thus it can play a crucial role in precision measurements of neutrino oscillation parameters and eventual discovery of CP violation in the lepton sector. Our ultimate understanding of the matter-antimatter asymmetry in the universe will likely require knowledge of both proton decay and the CP violation in the lepton sector.

UNO provides several additional rich physics programs, such as the capability to observe multiple oscillation minima and ν_τ appearance in the atmospheric neutrinos; precision measurement of temporal changes in the solar neutrino fluxes; and searches for astrophysical point sources of neutrinos and dark matter in an energy range that is difficult to cover for larger, more coarse-grained undersea and under-ice detectors.

At this moment two detector candidate sites are being considered in the U.S.: the Henderson mine in Colorado and the Homestake mine in South Dakota, In addition, there is a serious effort in Europe to build an UNO-like detector in the Fréjus tunnel at the French-Italian border. Preliminary studies performed by the local experts show that UNO can be built at any of these sites.

The detector technology that is proposed for UNO has been well tested over two decades in running experiments. No significant technical obstacles stand in the way of construction of the detector since all detector components can be obtained without further R&D. Rigorous professional civil and mechanical engineering design of the detector awaits choice of the final site. We expect the detector could be completed within ten years of ground breaking. Preliminary cost estimates indicate the UNO detector would cost approximately $500M including a contingency estimate, but a substantial component (1/3-1/2) of this estimate is site dependent.

An important role for any major scientific facility is outreach to the public. We have already begun an outreach activity in Colorado taking advantage of an existing program, the SALTA (Snowmass Area Large Time-coincidence Array) project, started in 2001 and based on high school-network cosmic ray detector projects at the University of Nebraska and the University Washington. The cosmic ray fluxes inside the Henderson mine have been measured as part of the SALTA project. In addition, we are considering a plan to make the UNO data available to the public after a set period of time after data-taking.

The UNO collaboration is currently composed of xx members from yy institutions from zz countries. The collaboration is supported by a Theoretical Advisory Committee, which is composed of 10 deeply interested theorists and an Advisory Committee, which is composed of 11 experimentalists including members from Japan and Europe. The collaboration membership is expected to grow continuously. Recognizing the importance of international participation and collaboration in a future large project such as UNO, the collaboration is making a serious effort to increase international membership.

Uno has been reviewed by various national committees over the last several years. Most recently, the APS joint neutrino study recommended R&D for very large muti-purpose detectors for a comprehensive neutrino physics program in U.S., and for other fundamental and vitally important studies beyond the field of neutrino physics, such as the search for proton decay. We, thus, propose to do 2 years of R&D in order to make a more realistc feasibility studies, conceptual design and cost evaluation. The total funding we request for these activities is $1.5M.

The UNO R&D is multi-disciplinary in nature and involves participation of industry partners. It pushes the deep and large underground cavity construction technology to an uncharted territory beyond the limit of the current experience and understanding. The results of the R&D can be applicable and beneficial to construction of future large underground storage, living and facility space for civilian usage and for the purpose of the homeland security.

UNO will provide a bold and comprehensive nucleon decay and neutrino physics program that could result in fundamental discoveries with far reaching impact to astrophysics, nuclear physics, and particle physics.

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1 Introduction

Over the past two decades, large underground water Cherenkov experiments - SuperK and its predecessors IMB and Kamiokande - have established a remarkable record of success. Their more notable accomplishments include: Exclusion of the minimal SU(5) GUT and MSSM SU(5); first real time, directional measurement of solar neutrinos; confirmation of the solar neutrino flux deficit and contribution to the resolution of the solar neutrino problem; discovery of atmospheric neutrino oscillation and neutrino mass; first detection of accelerator-produced neutrinos with a $\sim$100 km baseline; observation of neutrinos from Supernova 1987A; and establishment of the world's best limits on nucleon decay.

Although originally designed to search for nucleon decay, the above resumé highlights the versatility of these detectors. Capitalizing on this versatility, UNO is proposed as a multi-purpose detector rather than a single purpose proton decay detector. It provides a comprehensive nucleon decay and neutrino physics program for lepton flavor physics including CP violation, grand unification scale physics, supernova mechanisms, and the evolution of the Universe.

The versatility of UNO is further enhanced by the recent realization that CP violation in neutrino sector can be measured using a conventional neutrino super-beam and a large water Cherenkov detector with very long baselines (1000-3000 km) utilizing the secondary oscillation maxima. [2] A preliminary study of such an application using a wide-band neutrino beam produced by the upgraded BNL-AGS accelerator was performed by a BNL group [3] and the Stony Brook Nucleon decay and Neutrino (NN) group [**?**]. The results are very encouraging. When combined with the results from our earlier study with a baseline of 130 km, this study adds flexibility for UNO in choosing the baseline for CP violation studies, and provides a novel way of measuring neutrino oscillation parameters and CP violation using a conventional high flux wide band neutrino beam.

UNO was first proposed at the NNN99 Workshop in Sep. 1999 [1]. An informal UNO proto-collaboration was formed in 2000. A comprehensive study of the physics potential and feasibility of the detector was carried out and the results were presented in June 2001 at the Snowmass Workshop [5]. Since the NNN99 Workshop, a series of workshops has been held in US and Europe, and the possibility of building a next generation water Cherenkov detector has attracted worldwide interest.

Numerous invited presentations were made on various aspects of the UNO experiment at various national committee meetings, such as the HEPAP sub-panel on Long Range Planning in 2001, the Committee on the Physics of Universe (CPU) in 2001, the Neutrino Facility Assessment Committee (NFAC) sponsored by the National Academy of Science in 2002, the HEPAP Facilities Committee in 2003, and the APS Joint Study on the Future of Neutrino Physics in 2004.

In 2003, after the discovery of an excellent candidate detector site, the Henderson Mine, it was decided that the proto-collaboration be transformed to a formal collaboration to prepare for a formal proposal to funding agencies. At present, the UNO collaboration consists of xx experimental scientists and engineers, representing yy institutions from z countries. The collaboration is supported by a 10 member Theoretical Advisory Committee, 11 member Advisory Committee composed of experimentalists and other interested researchers from Canada, China, Europe, Japan, and the United States, numbering about 150 in total.

Parallel to the UNO initiative, the possibility of similar next-generation underground water Cherenkov detectors are being discussed in Japan (Hyper- Kamiokande) [6] and Europe (Fréjus) [7]. The UNO collaboration views these efforts as reinforcing. Taken together, they demonstrate a broad endorsement of the physics objectives we aim to address, and a global commitment to the shared goal of constructing a next-generation water Cherenkov detector. Indeed, many of the physicists involved in these other projects have participated fruitfully in our discussions and made significant contributions to the UNO Whitepaper [5]. The Japanese and European leaders of these initiatives serve on the UNO Advisory Committee. Acutely recognizing a necessity of international participation and collaboration for a future large project like UNO, we are committed to make the collaboration truly international and make it a vehicle for the international community ultimately to build a large water Cherenkov detector somewhere in the world.

This proposal is composed of two parts: an Expression of Interest (EOI) that lays out the physics potential and feasibility of the UNO experiment, and a R&D proposal that describes a 2-year R&D program and makes a corresponding funding request.

2 The UNO Detector

UNO's design philosophy begins with the well-established water Cherenkov detector technology of SuperK. Extension of the technique to achieve an order of magnitude better sensitivity to nucleon decay and neutrino physics presents no serious technical challenges. To strike a balance between increased physics reach and practical considerations of cost, the benchmark fiducial volume of the UNO detector is set at 20 times that of SuperK. We aim for broad physics capabilities and a simple, robust detector configuration that can be installed and operated in a deep underground location.

Several design options have been considered, keeping in mind two practical constraints on the water Cherenkov technique, namely: the water depth is limited by the pressure tolerance of the glass bulb of the PMT ($\sim$8 atm, for current 20" Hamamatsu PMTs); and the finite attenuation length of Cherenkov light in pure water ($\sim$80 m at $\lambda = 400$ nm in SuperK).

Three detector geometries have been studied: cubical, toroidal and multi- cubical. We conclude that a large underground water Cherenkov detector with a multi-cubical, segmented configuration is the best choice for UNO. Such a detector could be operational within 10 years, with assured performance and reliability. No large-scale R&D is required. The baseline conceptual design of the UNO detector is shown in Figure 1. The detector has a total (fiducial) mass of 648 (445) kton. The outer detector region serves as a veto shield of 2.5 m depth, and is instrumented with 14,901 outward-facing 8" PMTs at a density of 0.33 PMT/m^2. The inner detector regions are viewed by 56,650 20" PMTs. UNO's PMT density is chosen to allow excellent sensitivity to a broad range of nucleon decay and neutrino physics while keeping the instrumentation costs under control. The PMT density in the central sub-detector module is chosen to provide 40% photocathode coverage (equivalent to SuperK) and in the two outer modules to provide 10% for each. In this configuration, the trigger threshold for the two wings would be around 10 MeV, whereas the central module sensitivity is enhanced by reduction of its analysis threshold to 5 MeV. The lower analysis threshold of the central module allows efficient detection of 6 MeV γ-rays from $p \rightarrow K^+\bar{\nu}$ decay, precision solar neutrino studies, and extraction of additional information on the core collapse from supernovae neutrinos, along with measurement of the ν_μ and ν_τ fluxes using neutral current excitation of ^{16}O.

The optimal detector overburden is determined by a number of factors, including physics goals, cosmic ray backgrounds, excavation and installation costs, structural stability and rock temperature. Thus, the optimization is non-trivial and the choice depends on the specific characteristics of a given site. Using an outer detector veto and waveform electronics, the known cosmic ray backgrounds, even at modest depth (∼2,000 mwe), will not compromise nucleon decay studies. However, less well understood backgrounds such as cosmogenic fast neutrons could be a problem at this shallow depth. Furthermore the greater demands of a supernova relic neutrino search and a solar neutrino physics program will require a depth of at least 3,000 mwe to avoid unacceptable inefficiency or background from muon-induced spallation products. In order to ensure our physics goals, we choose 4,000 mwe or deeper as our optimal depth of the detector.

3 Physics Potential of UNO

3.1 Nucleon Decay

Proton decay offers a unique window to explore physics at truly short distances ($< 10^{-30}$ cm). It is a crucial prediction of Unification Theories of fundamental particles and forces. Thus the discovery of proton decay would have a far-reaching impact on our understanding of nature at the highest energy scale.

The recent discovery of neutrino oscillations represents a watershed in particle physics. This breakthrough demonstrates that neutrino masses are non-zero and very small (assuming no degeneracy), which in turn suggests a new, very high-energy mass scale that could generate small neutrino masses via the "see-saw" mechanism.

Many theoretical models based on unification theories predict nucleon decay (see Figure 2). As can be seen in the figure, some of the predicted rates are within reach of SuperK, especially in

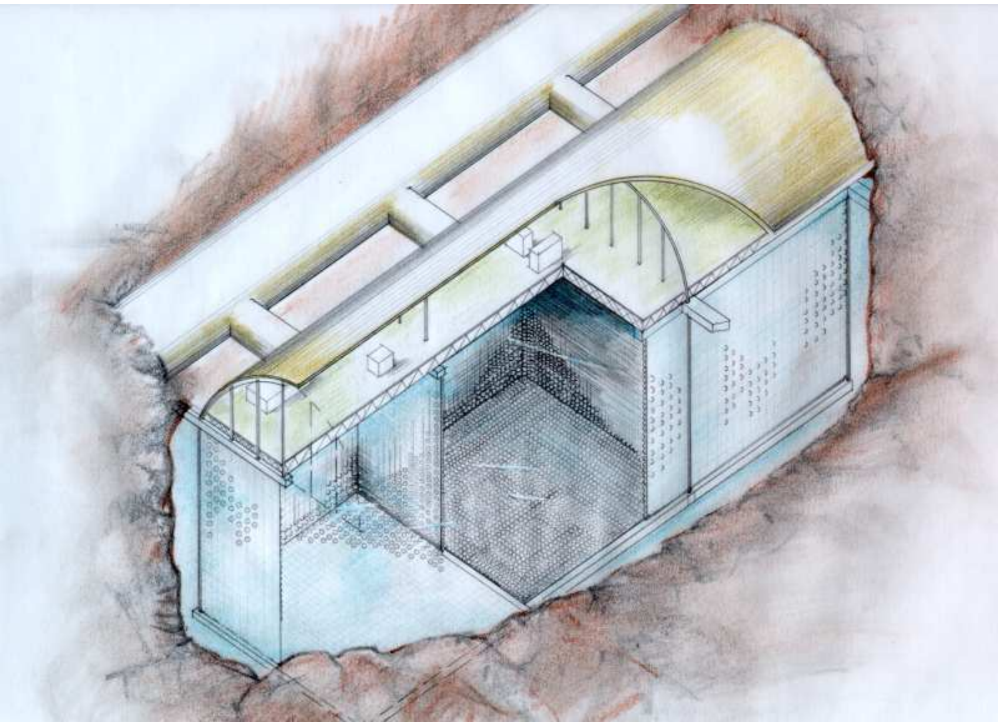

Figure 1: Baseline design of UNO showing the central detector module (40% photo-cathode coverage) with the outer wing modules (10% photo-cathode coverage).

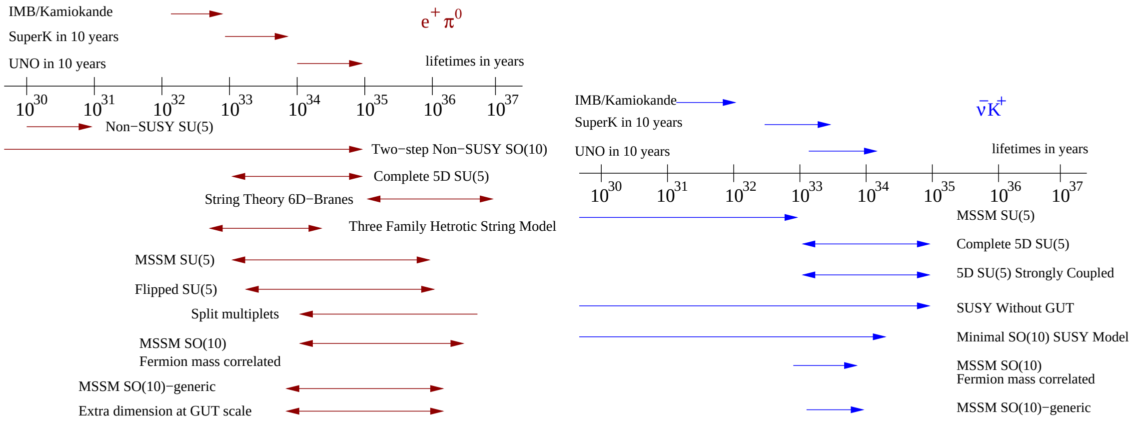

Figure 2: Theoretical predictions of proton decay compared to experimental reach: Left $p \longrightarrow e\pi^0$, Right $p \longrightarrow \overline{\nu}K^+$.

Model	Authors	Decay modes	Prediction	References
Complete 5D SU(5)	Y. Nomura, L. Hall	$e^+\pi^0, \mu^+\pi 0$ e^+K^0, μ^+K^0 $\overline{\nu}\pi^+, \overline{\nu}K^+$	$10^{33} - 10^{35}$	[9]
Two Step Non-SUSY SO(10) (Landscape inspired)	D.G. Lee *et al.*	$e^+\pi^0$	$10^{28.5} - 10^{35}$	[10]
5D SU(5) Strongly Coupled	Y. Nomura	$\mu^+K^0, \overline{\nu}K^+$	$10^{33} - 10^{35}$	[8]
SUSY Without GUT	R. Harnick *et al.*	$\overline{\nu}K^+$	$10^{28} - 10^{35}$	[11]
SUSY Minimal SO(10)	R. Dermisek *et al.*	$\overline{\nu}K^+$	$< 2 \times 10^{34}$	[12]
SUSY Minimal SO(10) With 126 Higgs	H.S. Goh *et al.*	$\overline{\nu}\pi^+$ $n \to \overline{\nu}K^0$	$< 6.5 \times 10^{32}$ $< 3 \times 10^{33}$	[13] [13]
String Theory 6D-Branes	I. Klebanov, E. Witten	$e^+\pi^0$	$10^{35} - 10^{37}$	[14]
Three Family Hetrotic String Model	T. Kobayashi *et al.*	$e^+\pi^0$	0.4×10^{33} -2.4×10^{34}	[15]

Table 1: Summary of recent predictions on proton partial lifetimes.

SUSY-favored decay modes such as $p \to \bar{\nu}K^+$. Also shown in the figure are some of the first few testable superstring theory predictions other than the GUT models. And Table 1 summarizes these recent predictions in more detail.

The motivation for proton decay search has recently been strengthened by theoretical and experimental advances in other domains, namely: An improved calculation of the hadronic nucleon decay matrix element, β_H, based on lattice QCD [16], a smaller value of the strong coupling constant, $\alpha_s(m_Z)$ [17], which consequently lowers the unification scale, and a larger value of the ratio of Higgs vacuum expectation values, $\tan\beta$, suggested by both LEP data and recent measurements of $g-2$ [18]. All of these factors increase the expected rate of nucleon decay with respect to earlier predictions, making its detection an attainable goal.

Background for nucleon decay arises mostly from atmospheric neutrino interactions in the detector. The vast majority of atmospheric neutrino interactions bear little resemblance to nucleon decay, but a small fraction are indistinguishable from the signal. Fortunately, the K2K 1 kt water Cherenkov detector has collected a neutrino interaction data sample that approximates a 10 Mt·yr atmospheric neutrino exposure. By analyzing these data the predictions of the atmospheric neutrino background simulation have been quantitatively verified. More sophisticated calculations of atmospheric neutrino production in the atmosphere, coupled with data on primary cosmic-ray fluxes (BESS) and secondary particle production (HARP and E907), can refine our understanding

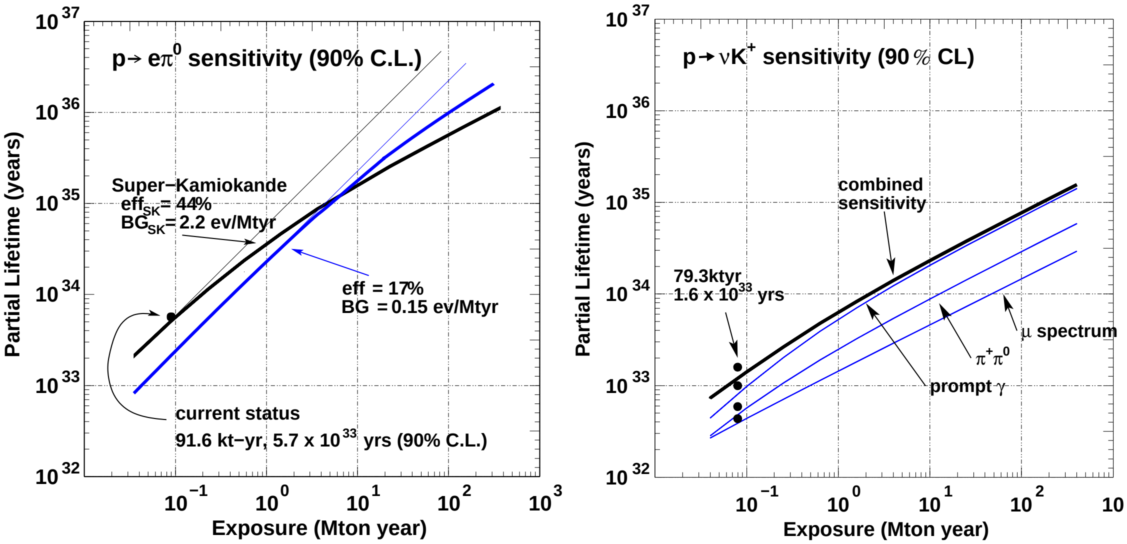

Figure 3: UNO sensitivity to the partial lifetimes of $p \to e^+\pi^0$ (left panel) and $p \to \bar{\nu}K^+$(right panel) as a function of total exposure at 90% confidence level.

of the atmospheric neutrino fluxes in the near future.

To study the sensitivity of nucleon decay searches, a 20 Mt·yr exposure of atmospheric neutrino background events and large samples of nucleon decay candidate events have been simulated and reconstructed using the SuperK neutrino interaction and detector simulations with varying PMT coverage (40% and 10%). The resulting proton decay sensitivity is shown as a function of detector exposure in Figure 3. In the absence of a signal, five years of UNO data will extend the lifetime limit for two "benchmark" decay modes ($p \to e^+\pi^0$ and $p \to \bar{\nu}K^+$) by roughly an order of magnitude over present limits to $\sim 5\times 10^{34}$ yr and $\sim 10^{34}$ yr, respectively. The expected limit for $p \to e^+\pi^0$ reaches 10^{35} yr after a 13-year UNO exposure (6 Mt·yr). Figure 4 shows the expected invariant mass distribution for $p \to e^+\pi^0$ candidates with 40% PMT coverage and a 5 Mt·yr exposure assuming partial proton lifetimes of 5×10^{34} yr.

Observation of nucleon decay would be far more than a mere "existence proof" for a Grand Unified Theory - it would give us direct experimental evidence for which theoretical model describes Nature best. In this respect, the search for nucleon decay is the ultimate experiment at the "energy frontier": probing physics at a scale ($\sim 10^{16}$ GeV) far beyond the reach of any imaginable accelerator. There are some 40 or so possible nucleon decay modes, and it is not known a priori which is the dominant one. Thus the next generation detector should have the capability to search for a broad range of these decay modes.

A National Academy of Science report in 2001, titled "Six Grand Challenges", described the grand challenges in physics in a new era [19]. One of the grand challenges was "Unifying the Forces of Nature". In order to reach this goal in this century, we need an experimental breakthrough.

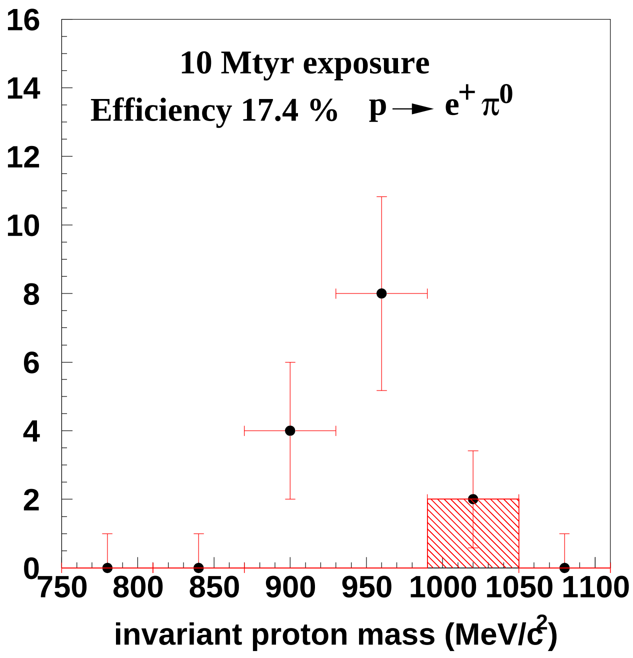

Figure 4: Expected invariant mass distribution of $p \to e^+\pi^0$ candidate events passing all selection criteria. Detector exposure of 5 Mt·yr and partial proton lifetime of $5{\times}10^{34}$ years are assumed. The hatched histograms represent the backgrounds.

Observation of proton decay will provide such a breakthrough unequivocally.

3.2 Long Baseline Neutrino Oscillation Experiments

UNO is well suited as a distant detector for future long-baseline neutrino oscillation experiments. The neutrino source could be either a high-intensity conventional neutrino beam (a “super-beam”), or a pure ν_e ($\bar{\nu}_\mathrm{e}$) beam from the beta decay of short-lived isotopes using a relatively low energy storage ring (a “beta-beam”).

There have been a number of proposals for a long baseline neutrino oscillation using a super-beam. Our earlier case study of a 130 km baseline experiment using the CERN SPL and UNO at Fréjus[5][20]; and another study by the JHFnu (now called T2K) working group of the T2K Phase II experiment using 4 MW proton driver and Hyper-Kamiokande with a 295 km baseline demonstrated that CP violation in the lepton sector can be observed in these experiments using a super-beam and a large water Cherenkov detector [21].

A recent report by a working group at BNL proposes a neutrino super-beam at an upgraded AGS optimized for a very long baseline neutrino oscillation experiment (VLBNO) [3]. This report concludes that with the proposed beam pointing at a 500 kt water Cherenkov detector at distances over 2,500 km, we would be able to achieve all of the following: (1) Measurement of $\sin^2\theta_{13}$ to below

0.005; (2) Determination of the sign of Δm^2_{31}; (3) Measurement of $\sin\delta$ (and $\cos\delta$) to about 25% level thus determining J_{CP} and δ; (4) Measurement of Δm^2_{21} and θ_{12} from the $\nu_\mu \leftrightarrow \nu_\mathrm{e}$ oscillation in an appearance mode. UNO located either at Henderson (2,760 km) or at Homestake (2,540 km) would be perfectly suitable as the proposed distant detector.

In order to make an independent investigation of merits of the BNL VLBNO idea, the Stony Brook NN group has performed detailed MC simulation studies. Although the initial BNL report contained somewhat optimistic assumptions, Stony Brook group's work has shown that with a realistic simulation including the detector response based on the Super-Kamiokande MC, a reasonable event rate and a good signal-to-background ratio, similar to the level obtained by the BNL group, can be achieved [4]. Thus, we believe that the idea of a VLBNO experiment using UNO as a far detector is fundamentally sound, and it can be applied to baselines from Fermilab as well as from BNL to the western states.

3.3 Supernova Neutrinos

Because of the sheer detector volume of UNO, the number of neutrino events from a supernova collapse observed by UNO will outnumber that of all other proposed or existing detectors. In the case of a galactic supernova at a distance of 10 kpc, a total of ~140,000 neutrino events are expected to be recorded by UNO. Considering the fact that there have only been a total of 20 supernova neutrino events observed in history, such a high-statistics measurement will revolutionize the field.

To cite one example, it will allow investigation of the millisecond scale behavior of the light curve, especially at early times, providing information on core collapse mechanisms. It will also allow us to examine the late time behavior of the light curve. Generally we expect the rate of neutrinos from a supernova to gradually decrease over tens of seconds. However, if a black hole forms during a supernova explosion (with an expected probability of about 50%), the neutrino flux will be cut off as the event horizon envelops the neutrino-sphere of the imploding star [25] (see Figure 5). Observation of such a cutoff will provide "direct" evidence for the birth of a black hole. For a galactic supernova, UNO will be able to observe the formation of a black hole after a few or even several tens of seconds.

Other important new results which can be derived from such a large data set include:

- A calorimetric measurement of the total energy radiated in neutrinos will yield the neutron star binding energy [24]. To a good approximation for most equations of state, the dimensionless binding energy is given by $BE/M \sim \frac{3}{5}(\frac{GM}{Rc^2})(1-\frac{GM}{2Rc^2})^{-1}$ constraining the mass M and radius R of the remnant neutron star.

- Simultaneous flux and spectral information at each epoch, combined with simulations, can yield the angular size $\frac{R_\infty}{D} = \frac{R(t)}{D\sqrt{1-(2GM/R(t)c^2)}}$ of the proto-neutron star at each epoch. If the distance D to the supernova can be otherwise measured, this would result in an independent measurement of mass and radius. Combined with measurement of the total radiated neutrino energy, which refers to the late-time radius $R_\infty = R(t \to \infty)$, both the mass and radius can be inferred.

- Should the flux suddenly disappear before passing below the threshold of detection, one could infer that the proto-neutron star was metastable and collapsed into a black hole as mentioned above [25]. Deleptonization of the star could result in a new phase appearing, such as hyperons, a kaon or pion condensate, or quark matter, that effectively reduces the maximum mass below the star's actual mass.

- Details of the neutrino flux curve and time evolution of the average neutrino energy (i.e., when the average energy peaks, when neutrino transparency sets in, etc.) will additionally constrain opacities and the proto-neutron star mass [26].

- Relative proportions of ν_e, $\bar{\nu}_\mathrm{e}$, etc. will further test simulations and reveal details of neutrino oscillations.

- Furthermore, when supernova neutrinos happen to pass through enough Earth's matter, matter effect may reveal more information of neutrino oscillation parameters [27].

Another interesting measurement made feasible by the sheer size of UNO and the low energy threshold in the central module is the observation of the neutral current reaction, $\nu_x + {}^{16}O \to \nu_x + \gamma + X$. This reaction results in mono-energetic photons with energies between 5-10 MeV. Since boosting ${}^{16}O$ into the nuclear continuum requires significant energy, these reactions are extremely sensitive to the temperature of the neutrino spectrum. Consequently, observation of these sharp energy lines tells a great deal about the stellar conditions which produced the heavy neutrino flavors as well as any flavor oscillations occurring in flight.

UNO is sensitive to supernovae occurring throughout the local group of galaxies, notably M31 (the Andromeda Galaxy), which is larger in terms of star content than our own Galaxy, although recent estimates [28] suggest its dark matter content and thus total mass is actually smaller. The total number of events would be modest, but having this additional reach will allow UNO to observe supernovae three times more frequently than detectors that are limited to our own galactic neighborhood. Moreover, since the terrestrial telescopes can view M31 face-on, the chance of observing the optical counterpart for a neutrino burst is about three times greater than in the obliquely-viewed Milky Way. UNO is in fact an optimal size detector that effectively covers the local group. A detector 100 times the size of UNO would have a detection reach a little larger than UNO's, since there are no major galaxies beyond the local group within the range of such a detector.

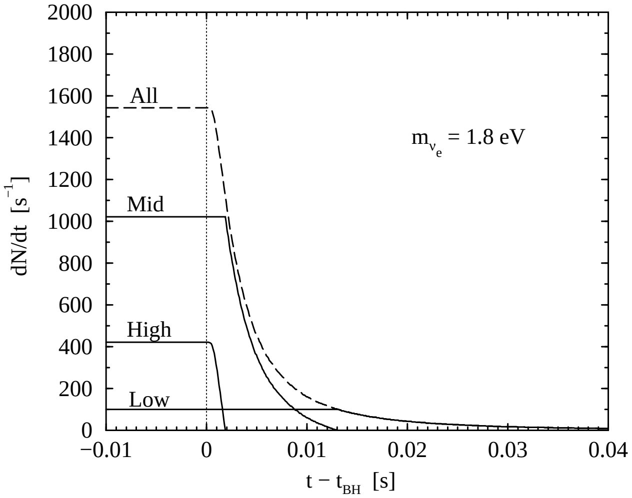

Figure 5: Detection of Black Hole Formation and ν_e Mass Determination. The neutrino data is subdivided according to energy range to provide a sharp "time zero" for the black hole formation (high energy) and well-defined delayed arrival times (middle energy). This delay is directly related to the mass of ν_e. (The event rates shown correspond to detection in SuperK of a supernova at 10 kpc from Earth.

3.4 Supernova Relic Neutrinos (SRN)

Supernova relic neutrinos are a low intensity isotropic background of cosmic neutrinos originating from core-collapse supernovae. The contribution to this flux from any single supernova is negligible, yet after integrating over all past supernovae, theorists calculate that there should be a total flux that is in the range of 5.4-54 $\bar{\nu}_e \cdot \mathrm{cm}^{-2} \cdot \mathrm{s}^{-1}$. Recently, SuperK conducted a search for SRN using $\bar{\nu}_e p \rightarrow n e^+$ interaction in the energy range E > 19 MeV. At these energies, the predicted fluxes are 0.20-3.1 $\bar{\nu}_e \cdot \mathrm{cm}^{-2} \cdot \mathrm{s}^{-1}$ [29]. In the absence of a signal, a 90% C.L. limit of 1.2 $\bar{\nu}_e \cdot \mathrm{cm}^{-2} \cdot \mathrm{s}^{-1}$ was set. While this limit is stringent enough to eliminate some theoretical models, it must be reduced by a factor of six to test all of the current predictions.

Using Monte Carlo simulations, UNO's sensitivity to the SRN was tested for several different detector depths. If UNO were to be built at a depth comparable to SK, it would take nine years to probe all SRN models. At a depth of 4,000 mwe, UNO would achieve the same result within six years; at a depth of 5,000 mwe within five years; and at 6,000 mwe, UNO should be able to detect an SRN signal within four years.

3.5 Atmospheric Neutrinos

The SuperK experiment has presented compelling evidence for atmospheric muon neutrino disappearance [30]. Very recently, evidence has been presented by SuperK using data samples selected

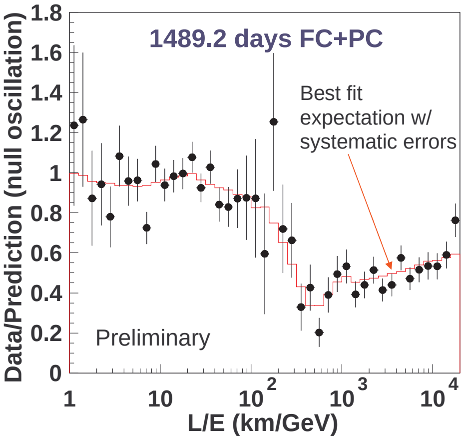

Figure 6: The ratio of the observed muon event rate to the expected rate without oscillation as a function of L/E based on the SuperK data corresponding to 1489 day livetime. The fitted curve is the best fit with the oscillation hypothesis. Note that there is a dip around L/E of $6{\times}10^3$.

for good resolution in L/E, that a dip corresponding to an oscillation minimum is being observed as shown in Figure 6 [31].

However, the possibility is not yet excluded at a high confidence level that the observed behavior is of some other form than neutrino oscillation. In fact, several models have been proposed where the expected disappearance of ν_μ is of the form $e^{-\alpha L/E}$ with α determined by the model. Thus observing an unambiguous oscillatory pattern that is unique to the neutrino oscillation will put this question to rest.

The multiple sinusoidal oscillation pattern expected from neutrino oscillation can be established conclusively by measurements of atmospheric neutrinos in a larger detector. Although SuperK has good direction and energy resolutions, the detector's dimensions are too small to efficiently contain muons with energies above several GeV, which is crucial for observing oscillatory behavior in atmospheric neutrinos. UNO, which can contain muons with energies up to 40 GeV will remedy this "Achilles Heel". The resulting gain in L/E resolution, together with a corresponding increase in event rate, will unambiguously establish whether oscillation or some more exotic phenomenon is at work and allow high-precision measurements of the oscillation parameters involved. Figure 7 shows the effect of oscillations on the ratio of signal to expectation where the oscillation parameters have been assumed to be $\Delta m^2 = 0.003$ eV^2 and $\sin^2 2\theta$=1. It should be noted that this analysis would be more sensitive if the true value of Δm^2 were smaller than 0.003 eV^2. A clear neutrino oscillation signature is evident in the atmospheric flux arriving from below the horizon as a dip at Log(L/E) ~2.5.

New physics can be gleaned from the high statistics atmospheric samples of UNO by invok-

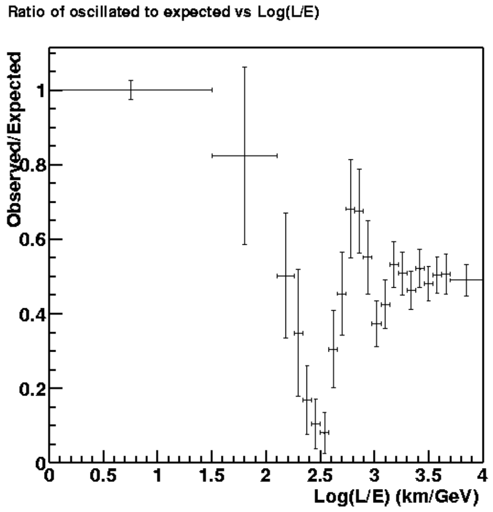

Figure 7: The ratio of the oscillated muon event rate to the expected rate as a function of L/E assuming a 2830 kt·yr exposure (a ∼7 yr UNO run). The oscillated flux assumes the parameters are $\Delta m^2 = 0.003$ eV^2, and $\sin^2 2\theta$=1.

ing "global" fits for three-generation neutrino mixing. For example, global fits will establish (or otherwise discern) new, constraining limits for possible sub-dominant contributions from sterile neutrinos. In addition, UNO can search for amplification of sub-dominant ν_μ to ν_e oscillation resulting from matter resonances in the Earth as shown in Figure 8 [32]. The current SuperK data favor $\nu_\mu \leftrightarrow \nu_\tau$ as an explanation for the atmospheric neutrino zenith angle distributions. Assuming full and two component mixing, approximately one ν_τ charged current (CC) event is expected per kiloton-year of exposure. Thus we expect about 400 ν_τ CC events per year in UNO, which will results in more than a three standard deviation excess after one year exposure.

3.6 Solar Neutrinos

UNO can make a unique and important test of matter oscillations using ^{8}B solar neutrinos. Only a very large detector like UNO will have an event rate that is sufficiently high to detect with statistical confidence the day-night effect with solar neutrinos, an effect which is a characteristic signal of matter-induced neutrino oscillations (the MSW effect). UNO has a central module with 40% photo-cathode coverage, which can detect neutrino-electron scattering above 6 MeV. The best-fit LMA solution predicts a 2% day-night difference in event rates, which can be observed as a 4σ effect with UNO in approximately ten years. The experiment will also provide the best measurement (much better than 1%) of the total event rate for the scattering of ^{8}B solar neutrinos by electrons. The event rate for ^{8}B solar neutrinos in UNO is enormous, about $3{\times}10^4$ events per year.

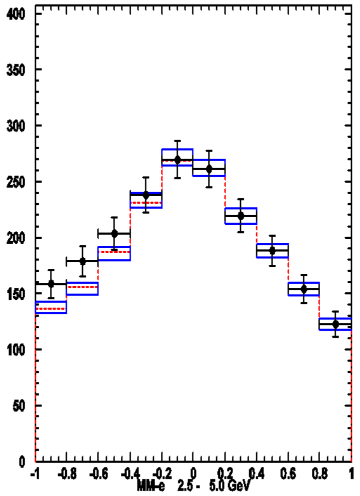

Figure 8: The cosine of the zenith angle distribution of atmospheric single- and multi-ring e-like events whose energies are between 2.5 and 5.0 GeV. Crosses, boxes and dashed histogram correspond to $\sin^2\theta_{13}$ of 0.05, 0.0, and no oscillation, respectively. In this plot the exposure is assumed to be 20 years of SuperK livetime, equivalently about one year of UNO livetime.

The endpoint of ^{8}B solar neutrinos, $\sim$ 16 MeV, is very sensitive to any underlying background. The hep process, $^3He+p \rightarrow^4 He+e^+ + \nu_e$, is a rare branch of the *pp* chain in the Sun. It produces the highest energy solar neutrinos, up to 18.78 MeV. The Standard Solar Model predicts a hep neutrino flux three orders of magnitude smaller than the flux of ^{8}B neutrinos. These measurements can only be done by a very large detector like UNO. Super-Kamiokande have performed a MC study to extract hep neutrinos [33] and have found that the optimum hep neutrino search is 18-21 MeV. In the window, 4.9 pm 2.7 events were observed in 5 years of measurements (1496 effective days) where one hep neutrino interaction is expected. UNO's large statistics will extend by one order of magnitude the search for hep neutrinos.

3.7 Neutrino Astrophysics

Neutrinos offer a unique probe to investigate the deep universe, the far side of our own Galaxy, and the interiors of astrophysical objects. Detectors that are much larger than UNO may be needed to do detailed observational neutrino astrophysics. But, the field is still in the exploration phase; no direct observation of a non-transient neutrino source more distant than the Sun has been made, despite the fact that neutrinos must be produced by the same meson decay processes that produce high energy gamma rays, in proportionate abundance. Furthermore, underground neutrino detectors can provide enormous effective mass by detecting upward-going muons. These events represent the highest-energy sample of neutrino interactions the experiment can collect. Searches can be performed and new limits can be set for a variety of physics areas: for example, point sources of high energy neutrinos such as AGNs, neutrinos from GRBs and WIMP annihilations at the center of the Earth, the Sun and our Galaxy.

UNO can fully contain muons with energies up to ∼40 GeV, and can observe through-going muons with energies of hundreds of GeV. Thus, it can provide means to search for astrophysical neutrino sources in the range not covered by the large under-ice or underwater detectors.

4 Candidate Detector Sites

Because of the unprecedented size of the underground cavity required, the choice of the site for the UNO experiment is of great importance for the project. Some of the major factors that will determine the best site for UNO are:

- Optimal depth for the detector location;
- Quality of rock at the proposed detector location;
- Estimated cost for excavation and infrastructure;
- Availability of the site;
- Accessibility to the experimental site and proximity to major airports and highways;
- Environmental impact and readily available permits;
- Availability of infrastructure and expertise for safety;
- Surrounding community, access to technical services, and nearby research institutions;
- Regional and community support; and
- Distance from the major accelerator facilities such as Fermilab and BNL for possible future long baseline neutrino oscillation experiments using neutrino superbeam.

The relative importance of these factors are not necessarily the same for UNO and other smaller underground experiments. In other words, the site requirements for UNO are rather unique to UNO. Thus, the UNO collaboration views the choice of the site as an integral part of the experimental proposal.

In the following, we present two current candidate sites for UNO within the continental U.S.A. These sites have been recently chosen by the NSF's DUSEL (Deep Underground Science and Engineering Lab) panel as the initial candidate sites for DUSEL. Preliminary studies performed by regional experts indicate that both of the candidate sites presented below are geologically suitable to house an UNO size cavern.

Detector site	Neutrino source			
	BNL	CERN	Fermilab	JAERI
Fréjus	5,980	130	6,830	8,900
Gran Sasso	6,530	730	7,340	8,830
Henderson	2,760	7,750	1,480	8,410
Homestake	2,530	7,350	1,280	8,240
Kamioka	9,630	8,750	9,130	290

Table 2: Baselines in km for potential experimental sites.

Henderson Mine, Colorado: The Henderson mine is is located about 60 miles west of the Denver airport, and is easily accessible via major highways (only about 10 miles from the interstate freeway 70). It is a modern mine with excellent infrastructure including power, water and communications. There are two entrances: at the east entrance there is a 28' diameter shaft that travels down about 3000 ft; the west entrance provides horizontal access to the mine tunnel, which is currently used for a high speed rock conveyor system. A Henderson DUSEL conceptual design allows a central campus area with overburden of 5,000-6,000 ft where UNO can be housed. The rock is largely competent granite. Access tunnel and cavity excavation costs are expected to be significantly low due to the extensive existing modern infrastructure, especially the high speed rock conveyor. The site owners are very enthusiastic supporters of this initiative and no additional environmental permits are expected to be necessary.

Homestake, South Dakota The Homestake mine is located in Lead, South Dakota. The depth of the mine, the strength of the rock and the absence of seismic activity, makes it also a potential host for UNO. This mine is the deepest in the United States with over 50 separate levels between the surface of the Earth and a depth of 2,500 m (7,000 mwe). The best known location in this mine, namely the Davis Experiment site at the 4850 ft is near an optimum depth for UNO, particularly for solar neutrino studies and supernova relic searches.

The distances from various accelerator labs in the world to possible detector sites for a next generation water Cherenkov detector are of great interest for designing future long baseline neutrino oscillation experiments. These distances are summarized in Table 2.

5 Preliminary Estimates of the Detector Cost

To obtain a realistic cost estimate for UNO, we rely on quotes from Hamamatsu Photonics in Japan for PMTs, preliminary estimates by mining engineers for excavation at potential sites and data extrapolated from experience with SuperK. More refined cost estimates will require a choice

Item	SuperK		UNO Hard Rock*
Cavity Excavation	27,640	v	168,000
Water Piping and Pumps	630	v	4,082
Water Purification System	1,850	v	11,988
Power Station	720	v5	2,160
Crane	760	v5	2,280
Cavity Treatment/Water Tank	18,400	s	25,000
PMT Support Structure	4,580	s	23,019
Counting Room	330	s5	990
Computer Building	1,860	s2	2,232
Main Building	3,000	s2	3,600
20" PMT (including cables)	34,670	s	155,457
Electronics	6,330	s5	9,495
DAQ	1,090	s5	1,635
Air Conditioning	210	s5	315
Veto Instrumentation	3,000	s5	9,000
8" PMT (including cables)	2,262	s	17,881
Total	107,332		437,134
(1$ = 100 yen)			*Q=100, Horizontal Access

Table 3: Preliminary estimates of the UNO detector cost and its breakdown. In estimating, we used $1=100 yen conversion. The cavity excavation cost is strongly site dependent.

of a specific detector site and a detailed engineering design. For the present, we project the costs as generically as possible. These estimates assume the UNO baseline configuration and using off-the-shelf PMT technology. The major expenses can be divided into two categories according to their correlation with detector size: volume-like or surface-like scaling. Reasonable guesses are required to determine the ultimate scaling factor from SuperK to UNO. Table 3 shows an initial, itemized estimate of costs for UNO along with the actual costs for SuperK. This table assumes that UNO will be built at a new site without an established underground laboratory infrastructure: a hard rock site with a horizontal access. If UNO is built in an existing DUSEL, the excavation cost could be reduced to about $100M for the detector cavity and auxiliary spaces, making the total detector cost to be under $400M. This estimates contain, however, only partial contingency. Thus by adding 20% - 25% additional contingency, we arrive at our nominal detector cost, $500M. More detailed cost estimation can only be done after rigorous and detailed design work on the detector.

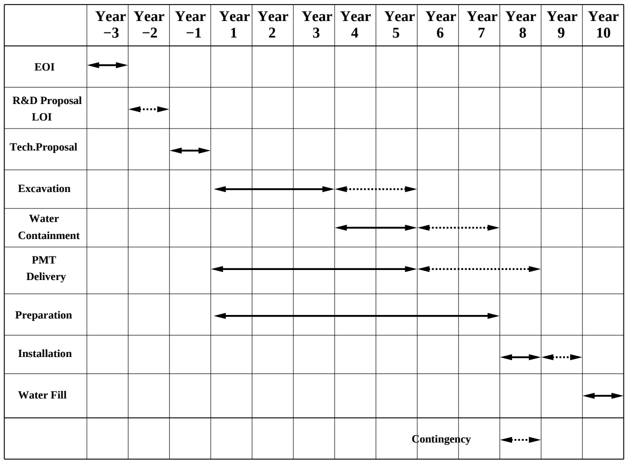

Figure 9: Conceptual UNO schedule.

6 Preliminary Project Schedule

Construction of UNO will require about 10 years. A conceptual breakdown of the schedule is shown in Figure 9. This schedule contains two years of contingency (dashed arrows) in the excavation schedule and one year of contingency in the overall schedule. The PMT delivery time can be reduced with additional cost.

7 Planning Activities

UNO's application of the underground water Cherenkov technique minimizes the number of critical R&D items and allows completion of detector construction within ten years from groundbreaking. Thus much of the current R&D program is devoted to reduction of detector cost. In this section we introduce the key activities relating to the detector construction and physics potential studies and in the next section detailed descriptions of each R&D item will be given. The key R&D and planning activities will include the following;

- Cavity Excavation R&D; research into large cavern engineering and construction.
- Cavity Liner R&D; research, development and testing of cavity liners in the Henderson Mine to contain the water volume of the UNO detector.
- Photomultiplier Tube mounting R&D; design and prototype construction of PMT mounting supports.
- μUNO detector; small scale test water Cherenkov detector in the Henderson Mine.
- Photosensor Development; development of PMT test facilities.

- Software R&D; development of detailed software simulations of UNO physics including very long baseline neutrino studies to measure CP violation.

Besides these R&D activities regular collaboration meetings, and participation in the relevant conferences and workshops will be needed to organize and discuss these activities.

We propose 2-year R&D and planning activities.

8 Proposed R & D Activities

8.1 Cavity Excavation R&D

With dimensions of 60m wide, 60m high, and 180m long, the proposed UNO excavation would be the largest underground civil structure ever constructed anywhere in the world. Before attempting such an ambitious project, it is imperative that a comprehensive research program be conducted regarding the design parameters, excavation procedure, support system, rock mass property requirements, and long-term stability issues that will be critical to the success of the UNO project. The research outlined in this proposal would provide a significant contribution to the understanding of large cavern engineering and construction.

The Colorado School of Mines (CSM), having broad expertise in underground mining, underground construction, and geotechnical engineering, is highly qualified to perform the work outlined in this proposal. The Itasca Consulting Group is a geotechnical consultancy company specializing in the fields of rock engineering and underground construction, and are the developers of the industry standard numerical modeling software tools that will be used extensively in this project. CNA Consulting Engineers has extensive experience in design of occupied underground space, including underground space for physics experiments, which include the Soudan 2 experiment, MINOS experiment, VLHC at FermiLab feasibility study, off-axis experiment (now called Nova), and the SNOLAB expansion.

Cavern design may be either empirical or rational: empirical methods use rock mass classification methods and past experience to determine the cavern design, while rational methods compare rock mass strength (with support and reinforcement) to rock stresses resulting from in situ stresses, cavern shape and rock mass behavior. Empirical design, which relies on past experience, may prove to be of limited value for UNO design, because the cavern is outside current experience. Rational design requires the following:

- Characterization of the candidate rock mass or masses on an unprecedented physical scale
- Determination of rock mass strength, both peak and postpeak, also at an unprecedented physical scale
- Determination of in situ stress in the rock mass

- Numerical modeling tools that adequately capture the behavior of the rock mass (and its constituents: inhomogeneities at several scales and discontinuities at several scales), the sequence of construction (because rock behavior is path dependent) and the mechanisms of rock mass deformation and failure

- Acceptable estimates of cavern short- and long-term deflection, which affect in-service performance of the cavern Most the research tasks described below follow support the common thread of rational cavern design.

The specific research objectives and associated tasks to be performed are:

1 : Utilize Global Experience in Large Cavern Design and Construction at Great Depth.

As noted above, the UNO cavern is a combination of span, volume and depth beyond current global experience. However, there have been caverns of similar span, similar volume or similar depth. In the work tasks of this Objective, the global experience base will be used to confirm project feasibility and focus the details of Objectives 2 through 7. The first task is to conduct a comprehensive literature survey to include cavern size, cavern shape, site investigation, design methodology, construction methods, rock support and reinforcement, construction schedule, construction cost, and end use for similar large underground excavations that have been successfully completed (or attempted) throughout the world. Based on the first task, Colorado School of Mines will convene an invited workshop of academics, designers and constructors from around the world having fundamental knowledge or experience in the construction of large underground excavations. The workshop will further explore the design, construction and operations issues listed under the first task. The third task is to prepare a comprehensive technical report summarizing the results of the literature survey, design workshop, and identifying any critical topics requiring further research.

2 : Define Rock Mass Characterization Issues for UNO

A substantial volume of rock, both inside and outside the future UNO cavern, must be characterized prior to design and construction. The characterization issues arise from both the volume that must be characterized and the identification of the rock mass volume that typifies behavior of the rock mass. Specific tasks are:

- Investigate and document rock mass characterization and investigation methods that will be required for the proper design of the UNO cavern such a drilling, down-the-hole testing, remote sensing, horizontal and vertical stress determinations, etc.
- Identify and investigate rock mass scale issues involved in scaling up from existing cavern sizes to the dimensions required for UNO.

- Investigate the requirements for initial pilot excavations.

3 : Numerical Models for UNO Design

This task evaluates and uses numerical models for the rational design of the UNO cavern. The issues are: which models are necessary for representing rock mass strength, are there significant limitations of state-of-the-art modeling software, which models are most appropriate for the various rock mass characteristics that may be encountered.

- Investigate limitations (if any) of numerical models for large cavern design.
- Perform numerical modeling of the UNO excavation including cavern shape, excavation sequence, excavation method, rock support and reinforcement, and excavation rate. In particular, this task will use numerical methods to analyze the stress concentrations and excavation stability at various stages of the excavations in order to identify a preferred excavation sequence that will maximize overall stability during excavation, and minimize the potential undesired stability problems such as rock bursts.
- Investigate how variations in site characteristics (depth, in situ stresses, rock mass strength, discontinuity orientation and spacing, etc.) affect the conceptual design. This parametric study will identify the ranges of cavern shape, rock support, rock reinforcement, etc. that might occur as a function of site characteristics.

4 : Investigate Construction Issues for UNO

The method and sequence of UNO cavern construction will have a profound influence on construction cost. Conventional methods and sequences from either mining or civil construction may not adapt to the UNO project.

The first task is to develop three different strategies for the excavation method and sequence for the UNO cavern. The strategies will include the development drifts, ventilation, power, haulage, equipment, materials and personnel necessary for cavern construction.

The second task is to identify any significant limitations of current materials, methods, procedures, equipment, and personnel for each of the three excavation strategies.

The third task is to develop a discrete event simulation (using a simulation language like GPSS/H or ARENA) capable of addressing the key activities necessary to construct the UNO cavern. The purpose is to compare and contrast the equipment, personnel, schedule and cost of the excavation strategies.

5 : Prepare Conceptual Design for UNO

Site selection for the UNO experiment can occur several years in the future. Hence, conceptual design of the UNO main cavern must be based on nonsite-specific information. Many, if not most site characteristics have a significant effect on construction of a cavern like UNO. The research tasks under this objective produce a meaningful conceptual design (and estimated construction cost) within the context of the site uncertainty.

The first task is to prepare generic (i.e. nonsite-specific) descriptions of the construction and rock mass environments with which the UNO cavern may be constructed. The generic descriptions will include rock type, in situ stresses, rock mass characteristics, and means of access for construction. These descriptions may or may not be based on specific possible sites, but must include realistic variation in site characteristics in order to be meaningful.

The second task addresses interfaces with other project components, including water containment, bulkheads, PMT mounting structures and deck structures.

The third task is to estimate the relative cost of UNO construction. Input to this task comes from several of the other Objectives, including the workshop, possible construction methods and sequence, the discrete event model and the conceptual geomechanics design. The output is cost versus depth curves for the various options considered.

6 : In-Service Performance

Many of the preceding Objectives are focused on providing a structurally stable cavern. For UNO, however, long-term performance of the cavern, internal structures, and water containment membranes is equally critical. There are at least three principal concerns: ongoing deflection of the cavern, filling and emptying cycles for the cavern, and service life issues related to materials, corrosion, long-term rock behavior.

The first task is to establish a preliminary but realistic service life design criteria for the experimental cavern. This service life may depend upon many factors, including the specific site, proximity to other caverns, research objectives, etc.

The second task is to establish a database of long-term deflection measurements from the literature for caverns approaching this scale and depth.

The third task is to predict long-term deflection of the UNO cavern, based on the preceding tasks. These predictions will be focused on the critical locations of internal structures (PMT mounting, experimental decks, etc.), and on the general requirements of maintaining water containment. Filling and emptying cycles may also influence in-service performance and will be modeled.

The fourth task is to identify critical service life items, specifically related to material corrosion. A tentative list of critical items is rock reinforcement, rock hangers, and all internal structures. Alternative materials or corrosion protection measures will be developed for items with inadequate or marginal service life.

7 : Risk Management Strategies

Subsurface construction projects like UNO are risk-prone, due to the uncertainty of the subsurface materials that will be encountered and how these materials will perform during construction. Complex project also tend to be more risk prone. One measure of project complexity is the 25/25/25 rule (Hatem, 1998). A project is complex (and deserves special risk management strategies) if the cost is more than $25 million, more than 25 percent of the cost is related to geomechanics and the project has more than 25 interfaces between stakeholders. Based on this rule, UNO cavern construction clearly is deserving of risk management strategies. All risk management strategies use the same basic approach: identify the risks, mitigate the risks where and to the extent appropriate and assign the remaining risks to the project stakeholders.

The first task is to identify likely project risks in all project phases, including site investigation, site selection, project design, project procurement, construction and operation; and to identify project stakeholders, including funding agencies, collaborating institutions, managing institution, site owner, etc.

The second task is to identify mitigation measures for each of the risks identified in the first task. Preliminary estimates of the extent of risk mitigation will be made.

The third task is to make a preliminary assignment of unmitigated risks, based on current best-practices recommended by subsurface industry trade groups.

Summary of Cavity Research by Institution

The work involved with objectives 1 to 4 will primarily be conducted by CSM. The Itasca consulting group will assist with tasks 1 to 4, and will be primarily responsible for the numerical modeling to be performed in tasks 3. CNA Engineering will perform the work outlined in objectives 5 to 7. However, considerable interaction and sharing of results between the two originations will be required while completing the tasks outlined. This interaction will take place with phone meetings, email, and face-to-face meetings throughout the project life.

The results of these investigations will be made available through a series of technical reports, and through various documents to be made available through a dedicated UNO web page.

8.1.1 Cavity Excavation R&D Budget discussion

In Table 4, we summarize the costing and budget of the items as estimated by Colorado School of Mines, CNA and ITASCA.

Table 4: Summary of Cavity Excavation R&D Costs

Item	Costs Yr1	Costs Yr2	Total
Engr. Faculty, 3 weeks	8233	8562	16795
Grad. Res. Asst.	19200	19968	39168
Fac. Fringe	2182	2269	4451
M&S	2,000	2000	4000
Travel (see travel section)	0	0	0
CSM indirects	36009	29515	65524
CSM subtotal	67624	62314	129938
ITASCA	50000	50000	100000
CNA	50,000	50000	100000
Cavity Excavation R&D TOTAL	167624	162314	329938

8.2 Cavity Spray-on Membrane Liner R&D

The UNO detector requires reliable, long-term containment of its 648 kton water volume situated in a deep-site underground excavation. With previous water Cherenkov experiments deployed underground, two different water containment strategies have been used, either of which can be scaled to the UNO mission. The more common approach, used in the HPW, Kamiokande and SuperK experiments, is to deploy a containment vessel with structural supports to transfer the load to the cavern floor and walls. In SuperK, the 50 kton water volume is held in a stainless steel tank. Larger tanks approaching one hundred ktons capacity are not uncommon in certain sectors of industry, e.g. for liquid methane storage, and so utilization of containment vessel(s) for UNO is feasible. Free-standing vessels allow certain flexibilities provided that working access to vessel outer walls and to cavern surfaces is realized. On the other hand, the cost of vessel(s), structural framework, plus installation underground is significant. It is therefore tempting to consider whether the cavern rock itself could serve as the containing structure. That is, one could deploy a cavern-liner water seal on a prepared rock or concrete substrate. A prerequisite for any consideration of water containment - vessel containment included - is that structural stability of excavated rock surfaces be assured. Typically this is done by covering the surfaces with chain-link fence held in place by rock bolts; the surfaces may then be coated with shotcrete or sprayed with a plastic geomembrane such as Mineguard (produced by Urylon), which provides an effective barrier to radon flow. Layers of materials to provide a water seal are presumably installed subsequent to and inside of, surface treatments required for mechanical stability. This type of method is used by SNO and KamLAND.

The basic concept for the proposed cavity with the arrays of PMT's in a cavity filled with water is shown in Figure 10.

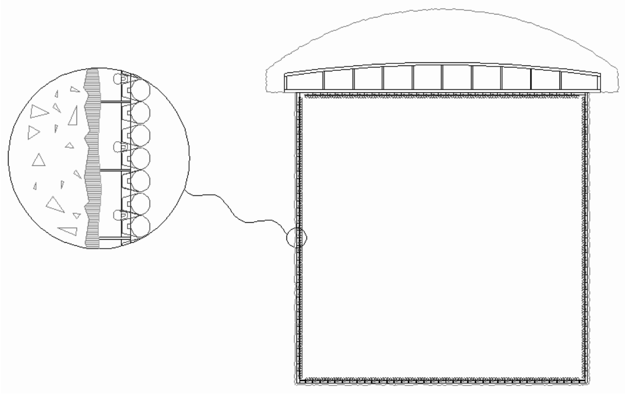

Figure 10: A cross section of the UNO cavity, excavated in solid rock, is shown is lined with shotcrete and filled with water. The arrays of PMT's with a support structure surrounding the water are shown in the expanded detail.

This proposal outlines a 2-year plan at Colorado State University (CSU) and Colorado School of Mines (CSM) to investigate cavity liner technologies. The proposal includes research into existing experience, initial testing of materials which might be appropriate for cavity liners (including accelerated aging studies), and small-scale testing of liner systems underground at both the CSM educational mine located in Idaho Springs and in Henderson Mine.

8.2.1 Introduction

Cavern support systems are typically comprised of spray-on concrete (referred to as shotcrete) and spray-on polymeric membranes (TSMs). Both of these technologies are widely used in cavern support, but a review of the literature shows that support system design is still largely an empirical process. This is particularly the case for TSMs.

Shotcrete is typically used as the primary mechanical support for large-scale excavations underground. As the name implies, shotcrete is blown onto the cavern walls after excavation and cleaning of the cavern wall, and after installation of required additional ground support, such as rock bolts. TSMs are one or two component polymeric layers typically between 0.3 and 1cm thick. Applied alone or in conjunction with shotcrete, these membranes provide stabilization and support to the exposed rock surfaces of the cavern. Spray on membranes have several beneficial aspects for rock wall support, including:

- Filling cracks and gaps in the rock surface.
- Preventing water seepage through the rock wall which might compromise the shotcrete/cavern wall bond.

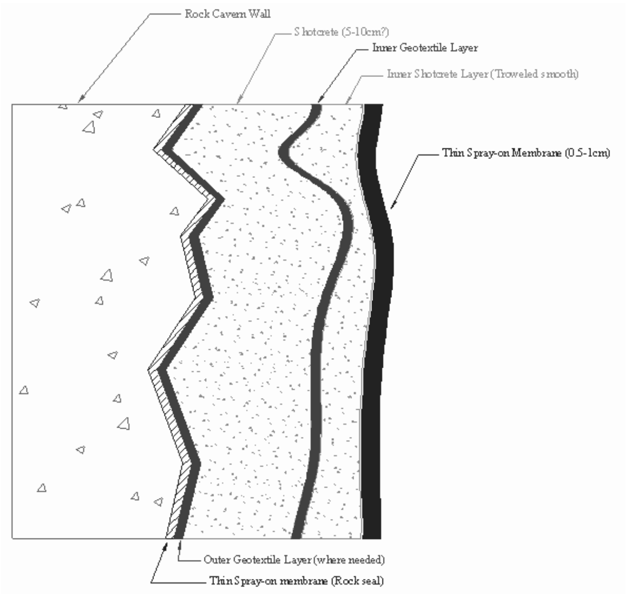

Figure 11: Section of UNO cavern wall after surface treatment..

- Minimizing seepage of water, radon, and other contaminants from the rock wall into the cavern.

- Potential significant reduction in cavity excavation costs and time due to rapid deployment of cavity support structure.

In addition to providing mechanical support, we anticipate using a spray-on liner for water containment. Using the cavity walls as the primary water containment system eliminates the great costs involved in building a stainless steel containment system used in earlier detectors such as Super-Kamiokanda. This method has been used with success in SNO and Kamland. TSM technology is a relatively new development in the mining industry, and much of the published literature is empirical or anecdotal in nature. Many shotcrete and TSM products are available, and research is required to select the optimal combination for our use. Some guidance can be had by examining the results from SNO and Kamland, but these results must be verified and tested, particularly given the required 50-year lifetime of the experiment and the extremely large size of the UNO cavern. The basic concept for the proposed cavity liner is shown in Figure 11.

After cleaning the cavern wall, geotextile “wicks” would be applied to obvious sources of ground water leaking through the rock wall, carrying them to a “sump” at the base of the cavern and allowing the ground water to be pumped out during routine operation. Next, a layer of TSL may be applied to the wall to initially stabilize the cavity. After installation of rock bolts and other primary ground support, a thick layer of Shotcrete (along with steel mesh reinforcement as required) would be applied. This would complete the “mechanical” portion of the liner. Next, a layer of geomembrane would be applied to allow water penetrating the inner cavern TSL to flow down to the sump, followed by a thin layer of shotcrete and the inner TSL membrane, which would provide for water containment.

The critical performance requirements for the cavern liner system can be divided into two main classes: 1) Mechanical cavern support and 2) Water containment and contaminant exclusion. Mechanically, the liner system must provide sufficient mechanical support to the cavern to prevent local instabilities (”rockbursts”) from spreading; provide a strong mechanical bond to the cavity surface; allow for rapid, cost effective deployment to facilitate excavation operations; and remain mechanically and chemically stable for long periods of time (approximately 50 years). As a water containment system, the cavity liner must both avoid contaminating the water volume due to leaching of extractable contaminants in the TSM material itself and also prevent unacceptable amounts of external contamination (more than can be handled by the water filtration system) from entering the detector volume, again for a design life of 50 years.

8.2.2 Proposed Research Program

Year 1 Research

(1) Research of existing examples and materials

We will conduct a thorough investigation of the available literature and experience of experts in underground cavity liner construction, particularly underground water containment systems. CSM will focus on the ground support (mechanical) aspects of the liner system, taking advantage of their extensive experience with ground support in mining and underground construction efforts. Additionally, CSM will interface with the cavity design and excavation R&D effort. CSU will focus on the water volume containment issues, leveraging their experience with water containment systems in plastic liners for the Pierre Auger observatory. CSU will also remain in contact with the PMT mount structure design team. The results of this research will be an expanded understanding of the requirements of the liner system, a solidified proposal for a liner system, and a list of proposed materials to be tested.

(2) Initial studies of liner materials and installation techniques

Mechanical properties of shotcrete/TSM liner system: Holmgren [36] has stressed the great importance of interface adhesion properties on the creation of stable openings with shotcrete. Kuchta, Hustrulid and Lorig [37] showed that the shotcrete thickness required to support a rock wedge increases rapidly with decreasing interface strength. Kuchta [39] and Malmgren [38] have shown that the adhesion strength of shotcrete applied to a concrete test wall and rock at LKAB’s Kiruna mine respectively increases by a factor of three to four when the surface is first cleaned with a high-pressure waterjet at 3000 psi as compared to the 100 psi normally used for surface

Figure 12: Photograph of liner testing in a mine.

cleaning. Pressures of 3000 psi can be achieved using a prototype waterjet scaling system that has been developed and tested at CSM, (Kuchta, Hustrulid and Lorig, 2004), and is available for use in this project.

The proposed cavity liner system will become an integral part of the overall cavity support system. Since previous research has shown that the performance of the ground support system is a function of the adhesion strength of the shotcrete, it is crucial that the bond strength of the TSM to rock interface as well as the bond strength of the shotcrete to TSM interface is known, and that proper procedures are determined for obtaining maximum bond strengths.

A series of tests will be performed at the CSM Experimental Mine with the purpose of determining the bond strength of shotcrete to TSMs, and TSMs to shotcrete. The rock type at the mine is Idaho Springs gneiss of varying compositions and rock strengths. A concrete test wall will be constructed at an appropriate location in one of the underground tunnels and will serve as a reference for the adhesion testing. The TSM's to be tested will be sprayed on the wall and the adhesion strength measured. A shotcrete layer will be applied over the top of the TSMs and the bond strength of the shotcrete to the TSM will also be measured. These same two types of tests will also be performed using the selected TSMs on a section of tunnel wall at an appropriate underground location. In both cases, half the tests will be performed on the concrete or rock that has first been cleaned using the CSM waterjet scaling equipment, before applying the TSM. The adhesion measurements will be performed using sophisticated testing equipment available at CSM that has been specifically designed for determining the adhesive strength of shotcrete against rock and between various. A photograph of liner testing is shown in Figure 12.

The Idaho Springs gneiss rock type has been found to have very low tensile strength, and thus determining the bond strength of shotcrete and TSMs to the rock surface may not be possible. A series of tests will also be performed at the Henderson mine at a suitable location in either the Silver

Plume granite or Urad Porphyry rock types, both of which are known to be extremely competent and similar in strength characteristics to that which will be required for the construction of UNO. A series of 6 test panels 3 ft wide and 4 ft high will be cleaned with water pressures from 100 psi to 6000 psi, coated with a shotcrete layer, and subsequent adhesion measurements will be performed. A similar series of tests will be performed using one or two candidate TSMs.

This phase is principally a CSM responsibility, and will be primarily conducted by Kuchta during the month of summer research supported by this project, assisted by a research associate supported full-time for one semester by this project.

Accelerated aging of water containment materials: Samples of candidate TSM materials will be immersed in high-purity deionized (DI) water. The samples will be monitored for materials properties including tensile strength, elongation and ductility as a function of time exposed to the water. Additionally, the samples of the DI water will periodically tested for contaminants by a commercial testing lab to determine the quantity and identity of chemicals which might leach from the TSM. Additionally, we will attempt to simulate the effect of longer aging times by heating the DI water and seeing if this accelerates any degeneration of the materials.

This test will be primarily conducted at CSU, using a water filtration unit which will be purchased for this project and an aging chamber custom manufactured for this project. Measurements of tensile strength and ductility will be conducted in the materials science lab at CSU.

We propose to use 150 hours of CSU engineering time and 240 hours of CSU technician time for this research.

Year 2 Research

In situ Water Exposure and Aging: A series of test water-containing caverns (”Cisterns”) approximately 2.5m × 2.5m in area, 1.5 m deep, will be constructed to allow us to experiment with the long-term behavior of the liner as a water containment system, and additionally to allow us to experiment with installation of a PMT support structure. The cisterns will be constructed at the end of an existing drift in the mine, simply by constructing a 2m tall concrete wall near the end of the drift, leaving a water containment region roughly 2.5m × 2.5m in area with one concrete and four exposed rock surfaces (the bottom and 3 sides, ***to be added See fig. XXX ***). A small laboratory/operations area will be set up in the drift behind the cistern and walled of with a plastic barrier. This area will be provided filtered air, and will house the water purification and other test equipment as needed. Water, air, electricity and a fiberoptic data communication lines will be provided by the mine and run to the operations area. For the two-cistern test area in the

Henderson mine, the cisterns will be constructed in a y-shaped configuration (***to be added see fig. XXX ***), allowing us to utilize the same operations area for both cisterns.

Our tests will consist of applying our candidate cavity liner system to cavern walls and filling the cistern with DI water, to determine the effect of DI water on actual liners and to monitor leaching through the liner. The water volume will be continually filtered using the water filtration system developed in Year 1 at CSU, and heated to simulate accelerated aging. Liner properties will be measured using the CSM apparatus used in section 2 above, and water samples will be measured for extractables by a commercial testing lab. This setup will also allow us to simulate multiple fill/empty cycles for the UNO tank. In addition, a segmented water collection trench or "Sump" will be made around the periphery of the cistern, outside the liner, to monitor leak rates and to allow us to locate leaks in the cistern liner system and evaluate the performance of the geotextile layers.

We plan to build one initial cistern at the CSM Experimental Mine, where we have easy continuous access to develop the techniques necessary to build and operate such a cistern. After completing the CSM test, we will build two additional cavities at the Henderson mine, allowing us to experiment with rock walls more representative of those likely to be found in an UNO excavation, and additionally to experiment with operating scientific experiments in an operating mine.

In addition to these liner tests, the Henderson test cisterns will be used to test candidate PMT support systems and housings, which could be installed into the cisterns and read out. This will allow for testing the integration of the PMT supports with the liner. Finally, these stations will allow us to investigate reading PMTs in a subterranean cavern at Henderson mine, gaining valuable experience operating an experiment in a functioning mine, as described in the μUNO section of this proposal.

This phase of the project will be a joint CSU/CSM project. We project needing 150 hours of CSU Engineering and 240 hours of CSU Tech time The required work at CSM will be conducted by Kuchta and a graduate student.

Miscellaneous requirements: In addition to the personnel and equipment listed above, we require 120 hours of project management and supervision time, and approximately 120 hours of technician time for miscellaneous testing, ordering, coordinating, and other "Overhead" for the project.

8.2.3 Cavity Liner R&D Budget Discussion

In Table 5, we list the costing and budgets as estimated by CSU and CSM.

Table 5: Summary of Liner R&D Costs

CSU Item	Costs Yr1	Costs Yr2	Total
Engineering, 480 hrs	26400	26456	52856
Grad. RA	4700	4888	9588
Engineering, Fringe		0	0
Grad. RA Fringe	0	0	0
Water Filter System	3,500	3500	7000
Aging Station	7,500		7500
Materials Testing	5,500	3500	9000
Travel (see travel section)	0	0	0
M&S	3,500	3500	7000
CSU Indirects	23,706	41334	65040
CSU Subtotal	74,806	83178	157984
**Cistern excavation (Henderson)	0	45000	45000
Engr. Faculty, 4 weeks	$15,150	15756	30906
Faculty Fringe	4,015	4333	8348
Grad. RA, 50%, 9 mon.	19,200	19968	39168
Grad Tuition	24,088	25292	49380
Shotcrete Appl.	5,000	2500	7500
Membrane Appl.	6,000	3000	9000
Test Cavern Excavation	0	8000	8000
Pump Maintenance	4,000	0	4000
Instr. Calication	1,000	0	1000
M&S	2,000	2000	4000
CSM Indirects	26,491	26112	52603
CSM subtotal	106,944	106961	213905
Cavity Liner TOTAL	181,750	235139	416889

8.3 PMT Mounting Design R&D

8.3.1 Introduction

UNO presents a number of interesting but clearly solvable problems in terms of mechanical design and consruction logistics for the PMT mounting structure. A program of R&D will be undertaken, based at the University of Washington but including contributions from collaborators at Colorado State University, the Colorado School of Mines, and other institutes. Members of the UNO group at UW have extensive previous experience in designing and implementing mechanical structures to support and define coordinates for large-scale particle physics detectors, as will be detailed below.

Goals of the R&D program will be to define a preliminary design for a PMT mounting structure, and provide a preliminary estimate of its construction cost and timeline, to be included as part of a future UNO construction proposal. Experience with Super-Kamiokande provides a baseline scheme as well as ideas for improvements and new approaches to reduce cost, improve construction efficiency, and simplify later maintenance.

The mounting scheme must satisfactorily address several separate considerations:

- Physics issues

  To meet the physics goals of UNO, the PMT mounting structure must define PMT positions without interfering with light propagation or introducing radioactive backgrounds. This means:

  - The mounting system must ensure that PMT coordinates are known to the required accuracy (taken as $\delta_x = \pm 1\text{cm}$ until detailed MC studies proposed here provide a more accurate specification).

    In this context, "known" means the coordinates must be well-defined, well-known, and constant over a reasonable time period. The support mounting must therefore be designed so that reference points (e.g., the center of the PMT base) have well-defined relationship to the structural members, taking into account practical construction allowances. The structure must provide fiducial points that can be readily surveyed with sufficient accuracy at the time of initial construction, and resurveyed at later times (possibly even in the presence of water), to relate structural members, and hence PMT coordinates, to absolute geodetic coordinates.

  - The structure must be sufficiently rigid to maintain the measured positions within the required δ_x, given anticipated earth movement (seismic as well as due to anticipated nearby mining operations), water flow due to purification and recirculation, and buoyancy effects due to the PMTs themselves, each of which experiences a ~ 50 lb upward force when submerged.
  - The structure must be designed to minimize any negative impact on Cherenkov light propagation and detection, such as shadowing of PMTs or reflection of light.
  - The structure must be made of materials that will not break down in or otherwise contaminate ultra-pure water. Components must not contain radioactive materials, or fluorescent materials, whether naturally occuring or introduced for fabrication purposes, that may contribute to backgrounds. Past experience, in Super-Kamiokande and other experiments, demonstrates that it is especially important to perform careful long-term testing of all proposed materials and components for these factors before finalizing the design.

- Construction issues

Due to the huge scale of UNO and the limited size of access tunnels, the PMT mounting framework presents an interesting "ship in a bottle" problem in construction logistics. The structure must be designed to avoid the introduction of assembly and deployment problems. Not the least of these considerations is the problem of ensuring that the structure is safely self-supporting during all stages of assembly. In addition, the proposed structure must avoid negative impact on the water containment system, for example by minimizing the number of penetrations to bedrock and carefully designing them to avoid water leaks. As with all aspects of UNO, our goal is to break no new ground and use only proven techniques wherever possible. Constructability (both of components and assembly of the whole system) will be tested by testing scale models of proposed structures.

- Operational issues

  Super-Kamiokande experience has shown that it will be necessary to access the PMTs for replacement and possible upgrade. Some members of the UNO Collaboration are now preparing to (re)construct Super-Kamiokande for the fourth time; they are intimately familiar with the downstream costs in time and effort of seemingly innocuous design decisions. Any structural design must include features allowing individual PMT access for replacement, and possibly future insertion of additional PMTs, with minimal difficulty – if possible by unskilled labor and with minimal effort. The design should anticipate the need for floating platforms, cranes, winch-borne gondolas, or other access devices, and provide means of access and deployment for them.

- Cost

  The PMT mounting structure should avoid the use of high-cost materials and/or materials with a high cost for parts fabrication. To the extent possible, off the shelf components should be considered. It must be designed for efficient and cost effective construction. In addition, labor costs associated with initial construction and future maintenance must be minimized.

8.3.2 Baseline design concepts

For the present proposal we will assume that UNO uses 50cm PMTs of the same type used in Super-Kamiokande. We also assume, as in Super-Kamiokande, that it will be necessary to house the PMTs in rigid cases to baffle the shock-wave produced by a single tube imploding, and prevent a chain reaction. (This may in fact only be needed for the higher-density central cube in UNO). Figure 14 shows the protective cases used in Super-Kamiokande. The photocathode area is covered by a transparent dome of clear acrylic, which is known to introduce negligible light attenuation, and also minimal reflectance, since its refractive index is close to that of water. The back side of the tube is surrounded by a case made of opaque plastic which is stronger, lighter and cheaper than acrylic. Opacity is desirable to prevent entry of light through the neck of the PMT, causing false, out of time signals. In Super-Kamiokande, rear-entering light generated by discharges in gassy PMTs ("flashers") was a significant problem, tying up the data stream until the offending PMT could be disconnected. For the same reason, the open spaces between PMT faces must be covered with flexible opaque plastic sheets. The two sections of each case are bolted together, with the flange providing convenient mounting attachment points for the PMT module, and clamping the inter-PMT black sheet. The cases are not pressure vessels, unlike the Benthos spheres used in DUMAND and AMANDA, and have holes to permit water to enter and equalize pressures; their purpose is merely to slow down propagation of pressure waves from a potential PMT implosion. Tests at Super-Kamiokande show that cases of this type are highly effective. Due to recent concerns about possible low-level fluorescence of materials used in the fiber reinforced plastic (FRP) back cases use in Super-Kamiokande, we need to first identify a suitable replacement material which is light, cheap, strong and opaque in the appropriate wavelength range.

Unlike Super-Kamiokande, where water was contained in a welded stainless steel tank (which of course leaked, as do all containment vessels, but at an acceptable rate), the UNO water containment scheme will use a multilayer plastic liner applied directly to the cavity walls after excavation and Shotcrete lining. Since any penetration through the liner is likely to leak, it is highly desirable to avoid directly connecting the internal support structure to the underlying rock. We will therefore aim to design a support system which applies only compressive loads to the floor and walls of the tank cavity. These can be accomodated by metal load distribution pads mounted on the walls and floor before final application of the watertight liner material.

Most of the load borne by vertical elements of the PMT support structure will be transferred to I-beam strong backs mounted over the tank. These beams are arched so their load is in turn transferred to the rock shelf surrounding the tank, as a downward force (Figure 13). The arched beams will be covered with opaque, gas-tight sheeting to make the entire enclosed volume lightproof and protected from ambient radon gas. (The tank liner is Rn-proof as well as waterproof.) When access for maintenance is required during detector operation, the air volume at the top of the tank can be flushed using radon-free compressed air brought in from outside the mine. Depending on site facilities and costs, it may also be possible to provide a special duct to channel Rn-free outside air to the dome, as was done at Super-Kamiokande.

For the UNO mounting structure, we will take Super-Kamiokande experience as a starting point, and first study a rigid structure made from I-beams of stainless steel or possibly inert plastic or composite materials. The webs of the beams provide convenient channels for routing cables. In this case, we would use preassembled multi-PMT modules, the same scheme used in Super-Kamiokande, to simplify construction effort. An array of 3 × 3 or 4 × 4 PMTs would be mounted on a frame, complete with cabling and light-proofing sheets. Modules can then be lowered into the tank and bolted into place using pre-drilled holes on the support beams (Figure 15).

Since space in the dome over the tank is limited, the vertical I-beam elements can be bolted together as they are inserted. Horizontal and diagonal struts provide rigidity. Horizontal braces prevent buckling and fix the structure to the walls and floor of the cavity via compressive loads only, without connecting through the liner material. The horizontal struts can include spring elements to ensure outward pressure. Each vertical beam will be designed with net weight minimially exceeding the buoyancy of its PMTs, taking into account mounting hardware and cabling, so it applies a small downward force to the tank floor when in water. Of course, the structure must also be strong enough to support the full weight of itself and the PMT array when the tank is drained.

We can alternatively envision a lighter, flexible mounting structure similar to the "strings" used in large-scale undersea or under-ice neutrino experiments[40, 41], where PMTs are mounted on anchored stainless steel cables. This is likely to be cheaper in terms of component cost and labor than building a rigid structure. Detailed analyses will be required to determine if such a scheme will maintain desired positional accuracy adequately, given water purifier system circulation currents, but this is highly likely given the relatively low flow rates expected. Figure 16 shows how such a mounting scheme might look. Again, multi-PMT modules would be assembled and then attached to pairs of cables equipped with preattached mounting plates. Stainless steel cable rigging is inexpensive (compared to stainless I-beams) and easy to fabricate, and cable segments can be made up in situ as assembly proceeds. At the bottom of each string there would be a deadweight anchor to ensure minimal but adequate force on the tank-bottom pressure pad.

8.3.3 Proposed Research

Members of the UNO group at UW have extensive experience designing mounting structures and planning installation logistics for large-scale particle physics experiments. Colin Daley is a senior Professor in the UW Department of Mechanical Engineering, while Henry Lubatti and Jeffrey Wilkes are senior faculty in the Department of Physics. Other UW team members include research engineers Hans-Gerd Berns, William Kuykendall and Joshua Wang who will participate in the R&D effort in addition to their work on other funded projects. Also, Daly will provide two part-time graduate students from the M.E. Department, to help with modelling and analysis work.

Wilkes and Berns were responsible for the phototube locating system and deployment logistics in the DUMAND detector[40], and also for installation and survey planning for the Scintillating Fiber (Scifi) Detector at K2K[42]. Daly and other UW team members were responsible for mechanical design and analysis of the muon detector technology for SDC at the SSC[43], in particular for detailed design of the barrel part of the muon subsystem as well as the production and assembly of very large proportional chamber modules (9x9x2.5 m), aluminum structures which were very light, rigid and precise. They brought this experience to the ATLAS collaboration, where they were responsible for all mechanical and thermal design on the end cap muon chambers for the ATLAS detector at the LHC[44]. These aluminum chambers were smaller (up to 6x2x0.35m) but more precisely defined than the SDC chambers. They also contributed to the design and analysis of the large wheel-like support frames for the inner and middle layers of the end cap muon subsystem for ATLAS. These are large (up to 23 m diameter) aluminum structures. Most recently, they provided mechanical and thermal design and fabrication of the carbon fiber structures used in the inner layers of the Run2b silicon detector system on DØat FNAL[45]. For these projects, finite-element analysis (FEA) was performed using Ansys software in conjunction with the EDS Unigraphics CAD/CAM system. These and similar tools and procedures are available at UW and will be applied to the UNO PMT structure design task.

We will need to allow for two months of summer salary for Daly. Research engineers will work 2 months FTE on the UNO R&D project. Two graduate student research assistants will be employed for three academic quarters (0.75 FTE-year) to run analysis and CAD/CAM software, and to investigate materials properties and other background tasks for the project.

Materials, supplies and machine shop time requirements are estimated in the attached budget. We anticipate building scale models of proposed designs. The UW Department of Physics has an exceptionally well equipped Instrument Shop, with 6 FTE skilled Master Instrument Makers, and state-of-the-art machine tools and other equipment for all conventional, and many unconventional, fabrication tasks. The Department of Physics provides state funds to subsidize 62% of Instrument Shop charges for projects submitted by Physics faculty. The effective hourly rate is thus very low compared to typical shop rates. Overhead and other loads are included in the attached budget at standard negotiated rates for NSF grants at UW.

8.3.4 PMT Mounting R&D Budget Discussion

In Table 6, we list the costing and budgets as estimated by University of Washington.

8.4 μUNO R&D

The test cavity described in a previous section, to be used for evaluating liner materials, will provide an opportunity to build a small-scale water Cherenkov detector in the mine. We propose to set up such a detector, which we call "μUNO", an array of 16 PMTs on the floor of the test cavity (see Fig. 17), after liner material evaluation has been completed.

The main purpose of μUNO will be to let us gain direct experience building and operating an experiment in the Henderson Mine environment. This experience is likely to provide critical insight into the validity of our preconceptions regarding full-scale detector construction and operation. By setting up a fully operational but micro-scale detector system, and porting its data out through the mine network, we can perform a realistic end-to-end shakedown test to see what unforeseen issues may arise when trying to do physics in the mine. As many UNO members have learned

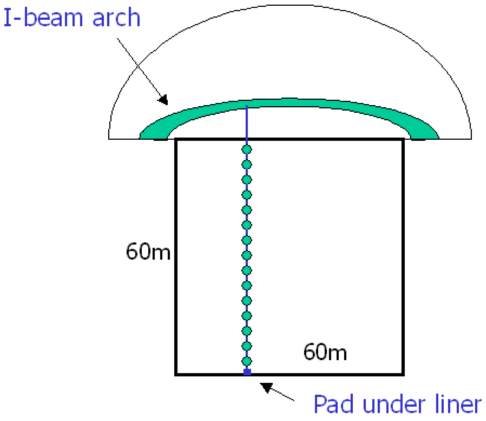

Figure 13: Conceptual diagram of PMT mounting scheme, showing tank and dome with support beam for PMT support structure.

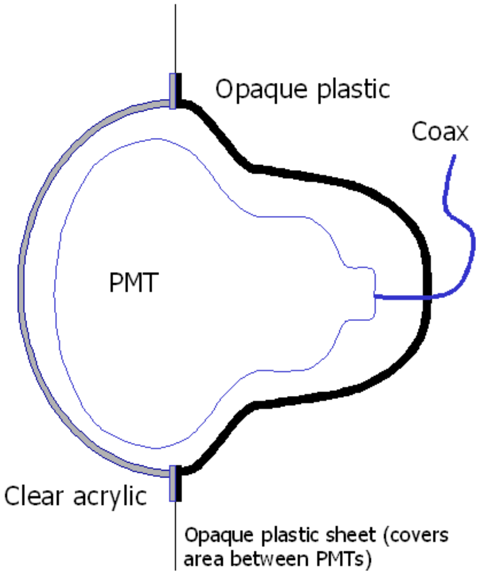

Figure 14: Cases for 20-inch PMTs.

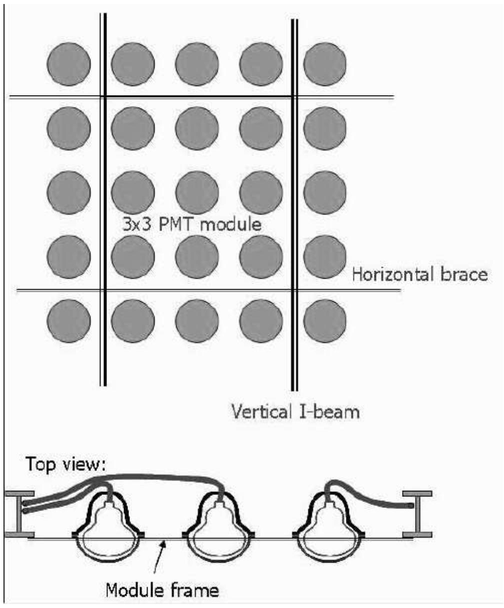

Figure 15: Conceptual design for a rigid PMT support structure. PMT modules (here, a 3 × 3 array) are shown mounted on a rigid framework of vertical stainless steel I-beams, connected by lighter horizontal struts.

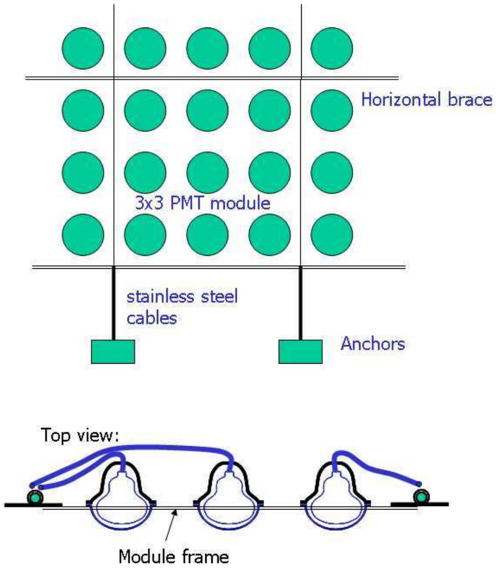

Figure 16: Conceptual design for a PMT support structure using flexible cables. PMT modules (here, a 3 × 3 array), are mounted in vertical “strings” using stainless steel cables, connected by light horizontal struts.

Table 6: Summary of PMT Mounting R&D Costs

Item	Costs Yr1	Costs Yr2	Total
Engr. Faculty 2+1 months	16,458	8229	24687
engineer, 1+2 month	4,328	8656	12984
engineer, 2+1 month	6,994	3497	10491
Grad.Res. Asst, 12m	15,300	0	15300
Grad. Res. Asst., 12 month	0	15300	15300
U.Grad Hourlies, 800hrs	800	4000	4800
benfits/Fringe	8,478	7075	15553
UW mach.shop, 100+100 hrs	1860	1860	3720
Travel (see travel section)	$0	0	0
M&S+software	6000	6000	12000
grad fees, 2 years	6000	6000	12000
UW indirects	72073	0	72073
PMT MOUNTING TOTAL	138291	60617	198908

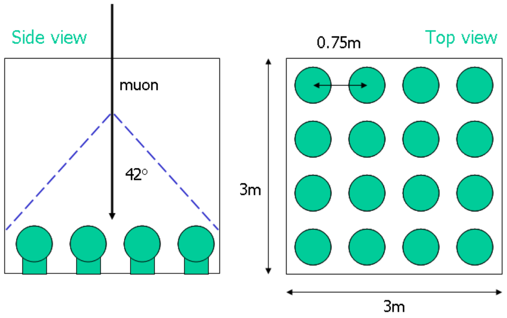

Figure 17: Schematic view of the proposed μUNO PMT array in the Henderson Mine test cavity. The Cherenkov light cone from a downward muon is shown.

by working on earlier underground experiments, it takes time to learn how to solve the routine, everyday problems that arise when doing a physics experiment in a working mine. Discovering which mine staff member should be contacted regarding a given specific issue, how safety regulations and operating routines interact with the needs of the experiment, and actual in situ experience with the operating-level environment in terms of temperature, electrical power, and data link stability, are all steps on the learning curve that we can jump-start by building a test array *before* detailing plans for large-scale construction. The DAQ system will include basic environmental monitoring (water temperature, air temperature, power-line voltage, etc.). We will set up μUNO for remote operation and monitoring via a networked PC. Running the test array on a continuous, long-term basis will help uncover further potential problems, and provide valuable time series of environmental data.

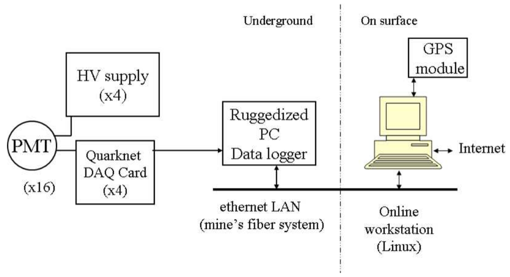

Figure 18: Block diagram of low-cost DAQ system for μUNO. Conventional modular electronics will be used instead if available from K2K in time.

With the understanding that detector testing is parasitic to liner testing, which is the primary purpose of the test cavity, we propose to install a small array of PMTs during the second year of the R&D effort. The attached budget estimates costs associated with a three-month effort to set up and operate μUNO, assuming two senior physicists, one graduate student and one research engineer will participate. Salaries for these personnel are assumed to be covered by existing sources, but travel and logistical expenses for this task are included here.

The test cavity must be excavated anyway for engineering tests, and the cost of of instrumentating it should actually be very low, since collaboration members already have most of the needed hardware on hand from previous experiments such as K2K. However, in the budget we have taken a conservative approach and assume that PMTs and DAQ electronics will have to be purchased, since it is possible that needed equipment will not be released from K2K in time due to delays in ongoing post-run calibrations and tests.

We will need 18 Hamamatsu 8-inch PMTs with integral cable sets, instrumenting a 4X4 array, and providing 2 spares. As explained, we expect to be able to supply PMTs and DAQ electronics from the K2K experiment, but we include the costs for the PMTs in the budget in case further testing currently underway at KEK prevents recovery of the equipment in a timely manner. If conventional modular front-end electronics from K2K is not available, we have budgeted for the purchase of five Quarknet DAQ cards[51], each with 4 channels of preamp, discriminator, TDCs, and trigger logic, as well as integral GPS timing and computer interface. Compact 4-channel HV supplies salvaged from the CASA experiment are already on hand at UW. Members of our collaboration participated in the design of these DAQ cards and are thus very familiar with their operation. The Quarknet cards provide a very convenient and extremely low-cost DAQ system for a small PMT-based detector like μUNO, and are also used in the SALTA outreach program. Fig. 18 shows the system.

8.4.1 μUNO Budget Discussion

In Table 7, we list the costing and budgets as estimated by University of Washington, CSU and SUNYSB. The costs include support for removal of the PMT's from K2K that covers summer graduate student support, travel to Japan, and PMT+cable crating and shipping costs. In addition, support for travel and living expenses for the μUNO installation the Henderson mine is added to the travel costs to cover five physicist for one week and one student for 4 weeks.

Table 7: Summary of μUNO R&D Costs

Item	Costs Yr1	Costs Yr2	Total
Machine Shop, 80 hr		14888	14888
QuarkNet DAQ, 4 cards		2000	2000
Data Logger PC, 1		700	700
M&S		2000	2000
Travel (see travel section)		0	0
K2K PMT shipping		4015	4015
crating PMT's		3000	3000
Grad.Res.Asst., summer	5500	5500	11000
MicroUNO total	5500	32103	37603

8.5 Photosensor Development R&D

Large area photosensors are a critical part of the UNO detector. The baseline design envisions roughly 57,000 20-inch and 15,000 8-inch photomultiplier tubes; the system represents the single-largest expense in the UNO project.

UNO collaboration has been actively involved in photosensor research and optimization since conception. The collaboration (Stony Brook group) is working with Burle Inc., a US-based optical detector firm which is developing new, large area PMTs supported by an SBIR award from the DOE. We are also in communication with research groups that are developing large-area novel photosensors, such as Hamamatsu PMT/APD hybrid photodetector being developed at University of Tokyo in collaboration with Hamamatsu, and ReFerence photosensors being developed at University of California at Davis.

We propose to continue this effort as part of the UNO R&D program, by building a photosensor test tank, LED-based illumination system, scintillator hodoscope, and associated test electronics (described in greater detail in the budget justification section below). This, along with our extensive experience with photosensors, will allow us to address the following important tasks:

1. *Preliminary studies of new large-area phototube designs from PMT manufacturers*

Several PMT manufacturers, such as Burle, Hamamatsu and EMI, have expressed interest in developing photomultiplier tubes for the next generation of large-scale water Cherenkov detectors. It is critical that UNO be represented at the early stages of this development, to allow us to influence and guide these designs to meet our needs.

Stony Brook has acquired expertise with PMT tests through the PMT test and preparation for Super-Kamiokande and K2K, and through an on-going test for T2K. In addition, Stony Brook has established a special relation with Burle regarding to development of large PMTs and performance testing of the Planacon (micro-channel plate multianode-PMT), which is underway. Burle is in the final stage of development of a 5" PMT as a step towards developing cheaper production methods for larger devices. They have requested evaluation and feedback of these first samples to guide them in the design. Currently, the PMT test facility is used to evaluate the Planacon as a candidate photosensor for T2K. Thorough evaluation of these newly developed PMTs will require a modest upgrade of the existing facility.

2. *Testing and re-characterization of 8" PMTs to be used in a μUNO prototype*

   Elsewhere in this proposal we describe a request to develop a "μUNO detector" planned for the test cistern at Henderson Mine following the completion of liner studies. This detector will use up to 18 8" PMTs recovered from the K2K experiment in Japan. While these PMTs have been used in previous experiments, it will be necessary to re-test and characterize them before using them underground.

3. *Investigation of photosensor enclosures for optical properties and prevention of chain-reaction photosensor failure such as that occurred in Super-K*

   The photosensors must operate in the water tank at depths of up to 60 meters, without failing either structurally or electronically, for periods of up to 30 years. While extensive experience with operating large, submerged photosensor arrays exists within the field, the unfortunate accident in Super Kamiokande provides a vivid reminder that careful research must be conducted to ensure satisfactory results.

   The Super-K experiment has developed and successfully tested an anti-water-shock system for protecting against chain reaction implosion accidents in a large water tanks. The UNO experiment will operate at significantly greater pressure, with a different mounting scheme, possibly with different PMTs, and may thus require modifications to the protection system. We will pressurize the test tank to approximately 100 PSI (approximately equivalent to that experienced by a photosensor under 60 m of water) to test for PMT failure, prove the anti-chain-reaction protection, and determine the impact of this system on photosensor performance.

4. *Testing of alternative photosensors*

> As sample novel photosensors become available, they will be studied in the test facilities to determine their suitability for use in a large Cherenkov detector. The facilities will be designed with enough flexibility to accommodate a variety detector configurations.

The SBU and CSU HEP groups are particularly well positioned to undertake this work. The groups have significant experience with detection of Cherenkov light using PMTs for Super-K, BaBar DIRC, and Pierre Auger Observatory. We also have significant experience working with deionized water containment systems from the Pierre Auger Observatory, and will produce a deionized water filtration system as part of the cavity liner development in this proposal. In addition, we are experienced in novel photosensor research. The CSU group is currently involved in testing solid state Geiger-mode Avalanche Photodiodes as part of a DOE SBIR award to aPeak, Inc., and have developed a LabVIEW-based data collection setup and associated CAMAC-NIM readout electronics. In addition to the micro-channel plate multi-channel PMT, the SBU group is testing a Geiger-mode silicon PM made in Russia and possibly will test another silicon PM made by Hamamatsu for use in the proposed T2K experiment.

In addition to this experience, the CSU group has recently been awarded a $100,000 grant from the University (part of a larger facilities enhancement grant awarded the HEP group) to upgrade the current HEP lab to include photosensor test facility and for development of necessary infrastructure to test photosensor systems. This grant represents a significant opportunity to leverage University funds for UNO's benefit, as the facility development could be guided by needs of UNO.

8.5.1 Budget Justification:

The centerpiece of this proposal is the PMT test stand to be built at CSU. The test stand will be loosely modeled after a test stand built for testing 8" PMTs for the Pierre Auger Observatory. The stand will consist of a cylindrical aluminum water tank approximately 1 m in diameter and 1 m tall. The cylinder will be a welded tube of Aluminum 6061-T6, 6 mm thick, which can withstand internal pressures of approximately 150 PSI. Multiple, interchangeable "yokes" holding an array of LEDs and fiber-optic lightguides will allow illumination of the photosensitive surface of the detector under test at several wavelengths, positions, and angles. A schematic of the tank and LED yokes is shown in Figure 19. Additionally, a scintillator hodoscope will be positioned above and below the test tank, allowing us to investigate the response of the photosensor to water Cherenkov light. We will exploit the flexibility inherent in this system to allow us to test multiple detector sizes and geometries as they become available.

A LabVIEW-based test program will be produced, using National Instruments DAQ boards to pulse the LEDs and record the photosensor responses automatically. This will allow us to rapidly subject the detectors to a standard battery of qualification testing, and should serve as the base for the more-extensive test platform necessary for the full UNO detector.

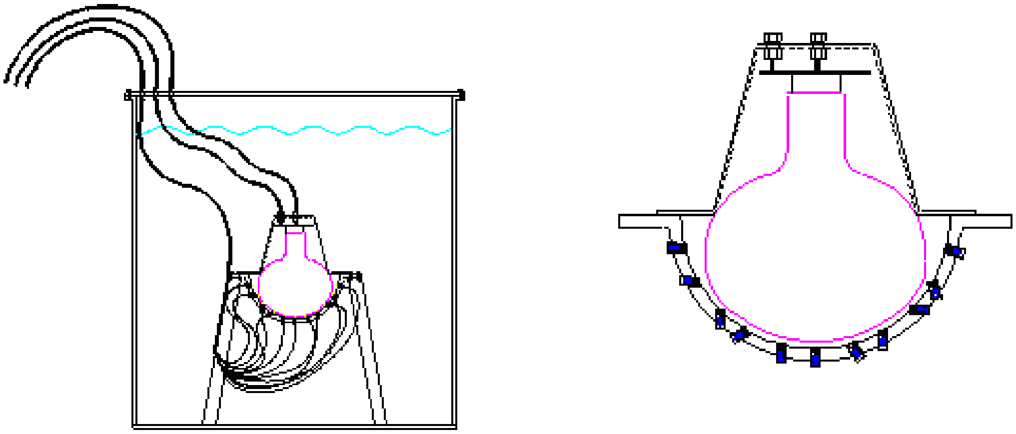

Figure 19: 8” PMT mounted in test stand (left); detail of PMT illuminated by the LED Yoke (right).

Initially, the test tank will operate at low pressure, allowing for rapid installation and removal of photosensors. In year 2, the system will be modified for use as a pressure chamber for testing photosensor envelopes and shock containment systems.

In Year 1 we are requesting 3 months of engineering support to interact with photosensor manufacturers, develop the test tank, electronics setup, hodoscope, and commissioning of the system. We also request a year of graduate student support for software development, operation of the test stand, and data analysis. The equipment cost for the test stand, electronics, and machine shop and technician time is included, as well as miscellaneous M&S to support the effort. Currently the SBU test facility uses a data acquisition based on a Tektronics digital scope read by a GPIB-PC card. Since the scope is loaned for a short term, it needs to be replaced by a dedicated one for the longer term test described here.

In Year 2 we request 2.5 months of engineering support to modify the test tank to be used as a pressure vessel, including the associated safety containment system. We also request continuing graduate student support for operations, testing, and data analysis. The equipment line will cover the modifications to the test stand, and associated technician and machine shop charges. Additional miscellaneous M&S charges are also included.

8.5.2 Proposed Photodetector R&D budget:

In Table 8, we list the costing and budgets as estimated by CSU and SBU.

Table 8: Summary of Photodetector R&D Costs

Item	Costs Yr1	Costs Yr2	Total
EDIA (CSU)	25440	21200	46640
Grad. Res. Asst., 12 months	17,400	17400	34800
Tuition	7500	7500	15000
Travel (see travel section)			0
M&S (CSU)	5000	5000	10000
Equipment	15000	8000	23000
Tektronix Digital Scope	9000	0	9000
Gauss meter	1000	0	1000
M&S (SBU)	1000	1000	2000
CSU Indirects	22926	20976	43902
PhotoDet. total	104266	81076	185342

8.6 Software R&D

8.6.1 Physics Goals of Software R&D

The goal of the software R&D is to produce detailed Monte Carlo simulations of the key physics measurements in the UNO experiment. These physics measurements include the sensitivity of a

- Proton decay lifetime measurement of the decays $p \to \pi^0 e^+$ and $p \to \overline{\nu} K^+$
- Measurement of the neutrino oscillation parameters, $\sin^2\theta_{13}$ and δ_{CP}, in ν_μ disappearance and ν_e appearance measurements produced by a very long baseline (VLBL) muon neutrino beam.

The strategies and techniques to search for proton decay in water Cherenkov detectors have been well developed by the Kamiokande Collaboration in $p \to \pi^0 e^+$[46] and $p \to \overline{\nu} K^+$[47]. These techniques[48] rely on well understood track reconstruction algorithms that identify rings of PMT hits to find candidate tracks.

Determination of neutrino oscillation parameters[3] has been proposed by measuring neutrino electron appearance events produced from very long baseline muon neutrino and anti-neutrino beams from BNL or FNAL. Maximizing the sensitivity of $\sin^2 2\theta_{13}$ and δ_{CP} measurements, requires a balance between L_0, the detector - neutrino source distance, the choice of beam (wide band vs off-axis), the detector design and the reconstruction software (loss of efficiency vs. background rejection). The CP effects[2] will be improved with longer baselines due to the matter effects that enhance (assuming normal neutrino mass ordering) measurements of oscillation nodes at higher energies where backgrounds are significantly reduced. However, the neutrino flux as a function

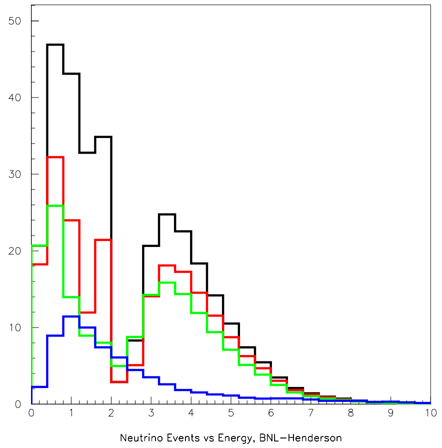

Figure 20: Electron appearance neutrino energy distributions using a BNL wideband muon neutrino beam detected in a water cerenkov detector in Henderson mine. The four detected electron neutrino distributions from top to bottom are for $\delta_{CP} = 45^o,\ 0^o,\ -45^o$, and the electron beam backgrounds. There is no energy smearing and quasi-elastic electron neutrino cross sections are used to obtain the rates.

of energy is falling exponentially and with longer baselines the neutrino flux at the detector is decreasing as the square of the distance, so these tradeoff's need to be carefully interpreted. In Figure 20 the electron appearance neutrino distributions are shown with different CP angles for a wideband BNL beam directed at a water cerenkov detector in the Henderson mine. This preliminary simulation used the software packages, NUANCE [49] for quasi-elastic neutrino cross sections and GLOBES [50] for electron neutrino appearance probabilities through matter. However, no neutrino reconstruction was performed. Also preliminary toy MC studies based entirely on GLOBES have been performed. It has been estimated [2] that the CP sensitivity is approximately independent of L_0. However a complete Monte Carlo simulation of an UNO detector is required to accurately determine the neutrino/antineutrino efficiencies and the anticipated electron neutrino backgrounds. Also careful likelihood fitting of the resulting signal neutrino and anti-neutrino events distributions with proper backgrounds will be required to accurately estimate the sensitivity of these physics measurements. These complete UNO detector simulations are what we propose to carry out.

In this proposal, the simulations will be performed initially with a baseline UNO detector design. After the necessary software is well developed and tested with the baseline, design variations will be tried to optimize the measurement sensitivity and to minimize the detector costs. These site independent VLBL studies will investigated with various distances using different sources (ex. BNL and FNAL) and different underground sites (ex. Henderson and Homestake). We anticipate the VLBL results will be submitted for publication in Phys.Rev.D. due to the immense physics interest.

In addition to the studies of these key measurements, we plan to study other UNO physics capability such as supernova and atmospheric neutrino physics.

Our UNO software R&D proposal aims to develop the necessary full simulation and reconstruction software and to process the required samples of simulation events with proper backgrounds to determine these sensitivities. Using these samples and various physics analysis tools to reject specific backgrounds such as π^0's, we will estimate the measurement sensitivity using the UNO detector for a five year time period. These studies can be used to determine the tradeoffs in electron appearance measurements between beam types (wide-band vs. off axis), source-detector distances and detector designs.

These software R&D goals require the following;

- New reconstruction software for detecting and measuring particle tracks in a water Cherenkov detector
- Support for personnel to develop software and process the events samples
- Software infrastructure to support multiple university and laboratory sites running UNO software
- PC/LINUX computing equipment and hardware maintenance support

In the following sections we describe the proposed simulation plan and the baseline design, the status of the UNO software, the proposed software developments, the simulation samples to be created, the computing equipment, personnel and a summary of this software R&D section.

8.6.2 Simulation Plan and Baseline Design

The simulation plan for the long baseline neutrino study would include the following steps;

- set up and finalize a baseline detector design
- generate and store simulations of an equivalent
    - 5 year sample of VLBL muon neutrinos and electron neutrinos
    - 5 year sample of atmospheric muon neutrinos and electron neutrinos
- test and develop reconstruction algorithms for muons, electrons, pizeros, etc.
- finalize reconstruction software and process simulation event samples.
- determine the sensitivity of $\sin\theta_{13}$ and δ_{cp} measurements using event weighting of the incident muon and electron neutrino samples.

The main baseline detector design [1] is listed below with first set of parameters. We plan to start with the baseline detector design simulation (5 year sample) and after some experience is gained, we will vary parameters and run a new set of simulations which will be studied (1 year samples). The design parameters for a specific detector configuration include; detector shape and dimension of $60 \times 60 \times 180m$; 15,000 (8") and 56,650 (20") PMT's; reflectivity of materials using nominal SuperK values; average water attenuation length of 80 m; dead space inner-outer section of 50 cm.

Each particular detector configuration will require a separate processing to produce a large simulation event sample. The effect of varying other parameters on the measurement sensitivity may be achieved by reweighting the flavor, energy, angle and position of the incident neutrinos. The energy distribution of the neutrinos in the detector fiducial volume for a particular neutrino beam, a set of neutrino parameters and a fixed source-detector distance will be obtained from the Globes program [50]. The starting baseline value of the parameters whose effect can be implemented by reweighting events include; the beam spectrum (wide and off-axis); L_0 distances between source and detector sites, BNL-Henderson, BNL-Homestake, FNAL-Henderson,FNAL-Homestake, etc.; ρ earth density of 2.8 gm/cm^3; and overburden on UNO of 4200 mwe.

8.6.3 UNO Software

The existing UNO software includes a complete detector simulation of a water Cherenkov volume surrounded by arrays of photomultiplier tubes. However, currently there is no reconstruction software and physics tools software. The detector simulation software (CSIM/ESIM) is based on GEANT4. The software for the neutrino interactions in water is based on the Nuance package. The software generates neutrinos that will interact in the water to produce charged and neutral secondaries and Cherenkov photons which are tracked to the individual PMT's. The detector simulation outputs in ROOT format. The event output includes the time of flight (TOF) and the charge pulse height for each PMT and Monte Carlo truth information about the event. The simulation uses ROOT to create event graphics. This flexiable package permits different detector configurations to be easily set up.

New Software to be Developed: The current UNO software does not have a reconstruction package that takes as input the simulation output and reconstructs lists of candidate vertices and candidate tracks (protons, muons, electrons, pizeros, photons). The proposed new reconstruction modules would include the following

- Preliminary vertex reconstruction

- Cherenkov ring finding using templates
  - using the preliminary vertex, apply pattern recognition algorithms find rings of PMT hits and determine candidate track position, energy and momentum
- Physics analysis tools that use PMT hits as input
  - develop π^0/electron separators and π^0 finders
- Event shape reconstruction that use track candidates as input
  - sphericity, thrust, Fisher Discriminant, neural nets etc.

We plan to develop reconstruction algorithms following those methods from the Super K collaboration [ref.]. The Cherenkov ring reconstruction algorithm would use templates of track candidates that would superimpose and match ring patterns of phototube hits to the events. After the ring reconstruction is developed, we plan to develop special programs or analysis tools to identify and separate π^0's from electrons. This particular analysis tool will be important to reject neutral current background events, $\nu_\mu + p \rightarrow \nu_\mu + \pi^0 + X$, that are expected to be the dominant background to ν_e appearance measurements. Simple cuts on the angle between the incoming neutrino and electron direction, the two gamma mass, the differences in single and double ring likelihoods and the energy fraction of the lower ring have been shown in the T2K letter of intent [ref] to reduce the neutral current backgrounds by a factor ten. Other higher level physics tools would include Fisher discriminants and neural nets to help reject background. Such physics tools first invented by CLEO [9 cone ref] for separating signal B mesons from background continuum events, have been extensively developed and used by BaBar and Belle and may prove to be useful in separating signal (ex. electron ring events) from background (ex. π^0 events).

Software Infrastructure: This effort to develop the necessary software, to process events samples and to analyze and determine the measurement sensitivities, is a joint collaboration of Stony Brook University, Colorado State University and BNL. The computing is planned to be done at multiple sites and requires CVS maintenance of libraries and software releases. This maintenance is proposed to be done at Stony Brook which will have the main code repository and the responsibility to produce new code releases. Also Stony Brook will provide support to offsite users to maintain up to update code on their local machines. The offsite users will develop new software and will be involved in the production of the large simulation samples.

8.6.4 Simulation files

Here we estimate the computing requirements for the simulations. One year of atmospheric data requires ˜35 CPU days and one year of the VLBL neutrino data sample with 10^{22} protons on target would require ˜5 CPU days on a 1Ghz PC LINUX computer. Below we summarize the computing estimates.

Table 9: Computing Estimates for 1 year of data.

Reaction	Events/year	$\langle E \rangle$	CPU days (1Ghz P4)	Diskspace
10^{22} P.O.T	6×10^3	$1.5GeV$	5 days	10 Gb
atmospheric ν	60×10^3	$1.0GeV$	35 days	100 Gb

A complete 5 year data sample (ν_μ and ν_e samples for both atmospheric and long baseline) for a given detector configuration would require about 400 CPU days and 0.6TB of disk storage where we assume about 50% live time computing efficiency. The current plan is to generate a complete 5 year sample for the baseline detector and then generate 1 year samples with different values of design parameters which are found to most directly affect the measurement sensitivities. After accounting for bugs, corrections and software improvements we anticipate realistically that we would reprocess at least 3-4 times the large samples and we expect after the reconstruction software is finalized, we would generate at least ˜10 different detector models.

8.6.5 Computing Equipment

The UNO simulation package (CSIM/ESIM) operates on PC LINUX machines. It has been ported from SBU to CSU, where it has been successfully run and benchmarked by graduate students. The UNO software R&D requires compute clients, disk storage for simulation files and desktop development machines.

For the compute clients we propose AMD 64, model 3200, 2.0Ghz CPU. It would be expected that this would be about a factor ˜2 faster than a 1Ghz P4 and it should provide a CPU that has reasonable longevity as an upgrade path for future platforms. The disk storage would be a RAID5 diskserver based on the 3WARE Escalade interface card that supports 8 or 12 EIDE drive. For software development, special desktops with 2GB memory and two 7200 rpm hard drives operating in RAID0 mode will facilitate software development. The larger memory and the faster hard drives will enable faster compilations. In addition a gigabit network switch would be required to network these PC's. The CSU group has had extensive experience in constructing and operating PC-LINUX machines for the BaBar experiment. The CSU farm includes +70 CPU clients and 6TB of RAID5 diskstorage based on the 3WARE card.

Equipment Prices

Below we estimate the costs of the components in the following table.

Table 10: Summary of Compute Farm Equipment Costs by system

Single Compute Clients Items	Costs
CPU, AMD Athlon 64, 3200, 64bit, 2.0Ghz, 512kb cache	$200
Abit KV8PRO motherboard w/gigabit ethernet	$100
Memory, two-512mb, DDR PC3200, non-parity, Crucial memory	$200
EIDE 200GB hard drive, 7200rpm, Maxtor	$110
Case and power supply	$100
TOTAL (per compute client)	$710
Disk Server (dual CPU, Raid5) 2.4TB	costs
3Ware Raid5 card, Escalade, 12 channel	$700
Athlon MP 2.8Ghz, dual cpu and motherboard Tyan S2466N-4M	$400
Athlon MP 2.8Ghz cpu (2nd cpu)	$200
2GB memory, Crucial memory, DDR PC2100, ECC, Registered	$620
13 - 200GB maxtor 7200rpm drives	$1430
case and power supply	$200
TOTAL (per disk server)	$4000
Network Equipment	cost
Dell Gigabit Power Connect Model 2624, 24 channel	$240
cat5 cables	$100
TOTAL (per networking switch)	$340
Desktop development PC's (64bit, 2.0 Ghz)	cost
3Ware Raid5 card, Escalade, 12 channel	$700
Athlon MP 2.8Ghz, dual cpu and motherboard Tyan S2466N-4M	$400
Athlon MP 2.8Ghz cpu (2nd cpu)	$200
2GB memory, Crucial memory, DDR PC2100, ECC, Registered	$620
13 - 200GB maxtor 7200rpm drives	$1430
case and power supply	$200
TOTAL (per desktop)	$4000

We estimate one 2.0 Ghz CPU would require 200 days of continuous running (50% livetime) to produce a complete 5 year sample. Hence 20 CPU's would process a five year data sample in about two weeks. We estimate the total cost of the farm equipment to be $20K.

Equipment Maintenance

The maintenance of a PC-LINUX system requires the occasional support to repair failed disks, exchange RAID5 disks, upgrade system software, to apply security patches, etc. This usually is provided by a LINUX system administrator. In rare instances, research groups can have this work done by experienced graduate students or this might be provided by university or department groups. We propose to have this service provided by hourly contract service to maintain PC/LINUX machines. The hourly contract service might be useful for helping multiple sites to setup and maintain their setups where remote login would suffice for their maintenance.

8.6.6 Personnel Support

Physicist/Programmer

The design of the UNO software libraries and analysis algorithm will be critical to the success of the proposed studies. This work requires a Physicist/Programmer with library design and physics analysis experience. The responsibilities of the position will include developing specifications for various software components, directing graduate students who will do much of the programming and providing the required infrastructure support for release management of the UNO software libraries. We propose 12 month support for one physicist/programmer.

Graduate Student Support

The development of the software, assembly of computing equipment, processing of simulation samples and analysis of sensitivity is proposed to be done by graduate students guided by senior faculty and staff. As UNO is in the proposal stage, it cannot be a graduate thesis experiment. This software/simulation work would be done by graduate students who finished their course work but who have not yet started on a mature experiment (ex. SuperK, BaBar, etc.) which would likely be their Phd thesis experiment. Here we propose 12 month support for two graduate students.

Travel Support

We plan to have two meetings with four travellers to discuss the software and simulations, one at Stony Brook and another at Fort Collins. The anticipated costs are approximately $800 per person for flight, car, motel and per diem.

8.6.7 Software R&D Budget Discussion

Below we summarize the costs for the 2-year period. The personnel proposed costs include support for a programmer/physicist personnel, for two graduate students and hourly consulting support for the compute farm maintenance. The equipment costs include two computing sites, with two compute farms and four development desktops. In Table 11, we list the costing and budgets as estimated by SBU, CSU, and BNL.

Table 11: Summary of Software Costs

Item	Costs Yr1	Costs Yr2	Total
Programmer, 12 mon., w/indirects	70000	0	70000
Grad.Res. Asst, 12 mon., w/indirects	29500	29500	59000
Grad.Res. Asst, 12 mon, w/indirects	29500	29500	59000
compute farm (2x20cpu's)	40000	0	40000
desktop (4 each)	6400	0	6400
Linux maintenance support	18000	18000	36000
Travel (see travel section)	0	0	0
SBU subtotal	122700		122700
CSU subtotal	70700	47500	118200
SOFTWARE subtotal	193400	77000	270400

8.7 Travel Budgets

Here we summarize the travel budgets from each R&D section in Table 12. The travel request description was given in each R&D section. We also include travel costs for holding general UNO collaboration meetings, and participation in the conference and workshops.

Table 12: Summary of Travel Costs

CSU Item	Costs Yr1	Costs Yr2	Total
Cavity Excavation	20000	5000	25000
Cavity Liner	1000	3000	4000
PMT support	9460	4180	13640
PhoDet. R&D	2000	2000	4000
MicroUNO installation		9930	9930
K2K PMT removal		7500	7500
Software	6400	6400	12800
General UNO meetings	20000	20000	40000
Conference/Workshop participation	20000	20000	40000
TRAVEL TOTAL	78860	78010	156870

9 Detailed Budget

In Tables 13, 14, and 15, we list the costing and budgets of all sections. The total budget is listed at the end of Table 15.

Table 13: Budget summary of all sections

item description	Year1	Year2	Year1+2
***LARGE CAVERN DESIGN (2yr)			
Engr. Faculty, 3 weeks	8233	8562	16795
Grad. Res. Asst.	19200	19968	39168
Fac. Fringe	2182	2269	4451
M&S	$2,000	2000	4000
Travel (see travel section)	0	0	0
CSM indirects	36009	29515	65524
CSM subtotal	67624	62314	129938
ITASCA	50000	50000	100000
CSA	$50,000	50000	100000
Cavern Design TOTAL	167624	162314	329938
***CAVITY LINER R&D			
Engineering, 480 hrs	26400	26456	52856
Grad. Res.	4700	4888	9588
Engineering, Fringe		0	0
Grad. Res. Fringe	0	0	0
Water Filter System	3,500	3500	7000
Aging station	7,500		7500
Materials testing	5,500	3500	9000
Travel (see travel section)	0	0	0
M&S	3,500	3500	7000
CSU Indirects	23,706	41334	65040
CSU subtotal	74,806	83178	157984
**Cistern excavation (Henderson)	0	45000	45000
Engr. Faculty, 4 weeks	$15,150	15756	30906
Faculty fringe	4,015	4333	8348
Grad.Res.Asst., 50%, 9m	19,200	19968	39168
Grad tuition	24,088	25292	49380
Shotcrete appl.	5,000	2500	7500
Membrane Appl.	6,000	3000	9000
Test Cavern excavation	0	8000	8000
Pump maintenance	4,000	0	4000
Instr. Calication	1,000	0	1000
M&S	2,000	2000	4000
CSM Indirects	26,491	26112	52603
CSM subtotal	106,944	106961	213905
Cavity Liner TOTAL	181,750	235139	416889

Table 14: Budget summary of all sections, continued

item description	Year1	Year2	Year1+2
***PMT MOUNTING R&D			
Engr. Faculty 2+1 months	$16,458	8229	24687
engineer, 1+2 month	$4,328	8656	12984
engineer, 2+1 month	$6,994	3497	10491
Grad.Res. Asst, 12m	$15,300	0	15300
Grad. Res. Asst., 12 month	$0	15300	15300
U.Grad Hourlies, 800hrs	$800	4000	4800
benfits/Fringe	$8,478	7075	15553
UW mach.shop, 100+100 hrs	1860	1860	3720
Travel (see travel section)	$0	0	0
M&S+software	6000	6000	12000
grad fees, 2 years	6000	6000	12000
UW indirects	72073	0	72073
PMT MOUNTING TOTAL	138291	60617	198908
***PhotoDet. R&D			
EDIA (CSU)	25440	21200	46640
Grad. Res. Asst., 12 months	17,400	17400	34800
Tuition	7500	7500	15000
Travel (see travel section)			0
M&S (CSU)	5000	5000	10000
Equipment	15000	8000	23000
Tektronix Digital Scope	9000	0	9000
Gauss meter	1000	0	1000
M&S (SUNYSB)	1000	1000	2000
CSU Indirects	22926	20976	43902
PhotoDet. total	104266	81076	185342
***MicroUNO R&D			
Machine Shop, 80 hr		14888	14888
QuarkNet DAQ, 4 cards		2000	2000
Data Logger PC, 1		700	700
M&S		2000	2000
Travel (see travel section)		0	0
K2K PMT shipping		4015	4015
crating PMT's		3000	3000
Grad.Res.Asst., summer	5500	5500	11000
MicroUNO total	5500	32103	37603

Table 15: Budget summary of all sections, continued

item description	Year1	Year2	Year1+2
***SOFTWARE R&D			
Programmer, 12m, w/indirects	70000	0	70000
Grad.Res. Asst, 12m, w/indirects	29500	29500	59000
Grad.Res. Asst, 12m, w/indirects	29500	29500	59000
compute farm (2x20cpu's)	40000	0	40000
desktop (4 each)	6400	0	6400
Linux maintenance support	18000	18000	36000
Travel (see travel section)	0	0	0
SUNY subtotal	122700		122700
CSU subtotal	70700	47500	118200
SOFTWARE subtotal	193400	77000	270400
***TRAVEL BUDGET			
Cavity Excavation	20000	5000	25000
Cavity Liner	1000	3000	4000
PMT support	9460	4180	13640
PhoDet. R&D	2000	2000	4000
MicroUNO installation		9930	9930
K2K PMT removal		7500	7500
Software	6400	6400	12800
General UNO meetings			
TRAVEL TOTAL	38860	38010	76870
TOTAL (all sections)	829,691	686259	1515950

10 Conclusion

UNO utilizes well-tested water Cherenkov detector technology and is a reasonable extension of the current detectors. Feasibility and physics potential of the detector have been well studied. The conclusions are based on the experience gained from past and currently running experiments. All detector components can be obtained without further R&D and there are no known significant technical obstacles. We expect ground breaking within two to three years of project approval.

We agree with the statement made by the HEPAP sub-panel on long range planning in their 2001 report, which reads *If proton decays, their lifetimes are long, so proton decay experiments require massive detectors... Such a detector should be at least an order of magnitude larger than SuperK... Current thinking favors the use of a large water Cherenkov detector as in the UNO approach... Given its strong science program, and assuming that an affordable design can be reached, we believe it is likely that a proton decay detector will be proposed somewhere in the world, and that U.S.*

physicists will participate in its construction and utilization...

We however stress that UNO is far more than a proton decay detector. It is a multi-purpose detector with high potential for major discoveries and precision measurements in a broad range of physics areas, especially when combined with a super-beam facility. As the largest underground experiment if UNO is built at DUSEL, it would be a natural anchor for the DUSEL, contributing greatly to a synergism between particle physics, astrophysics and other science fields. Discoveries and precision measurements made by UNO will contribute to our understanding of matter-antimatter asymmetry in the Universe, Grand Unification scale physics, possibly super-symmetry, supernova and solar mechanisms, evolution of the Universe, and lepton flavor physics.

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