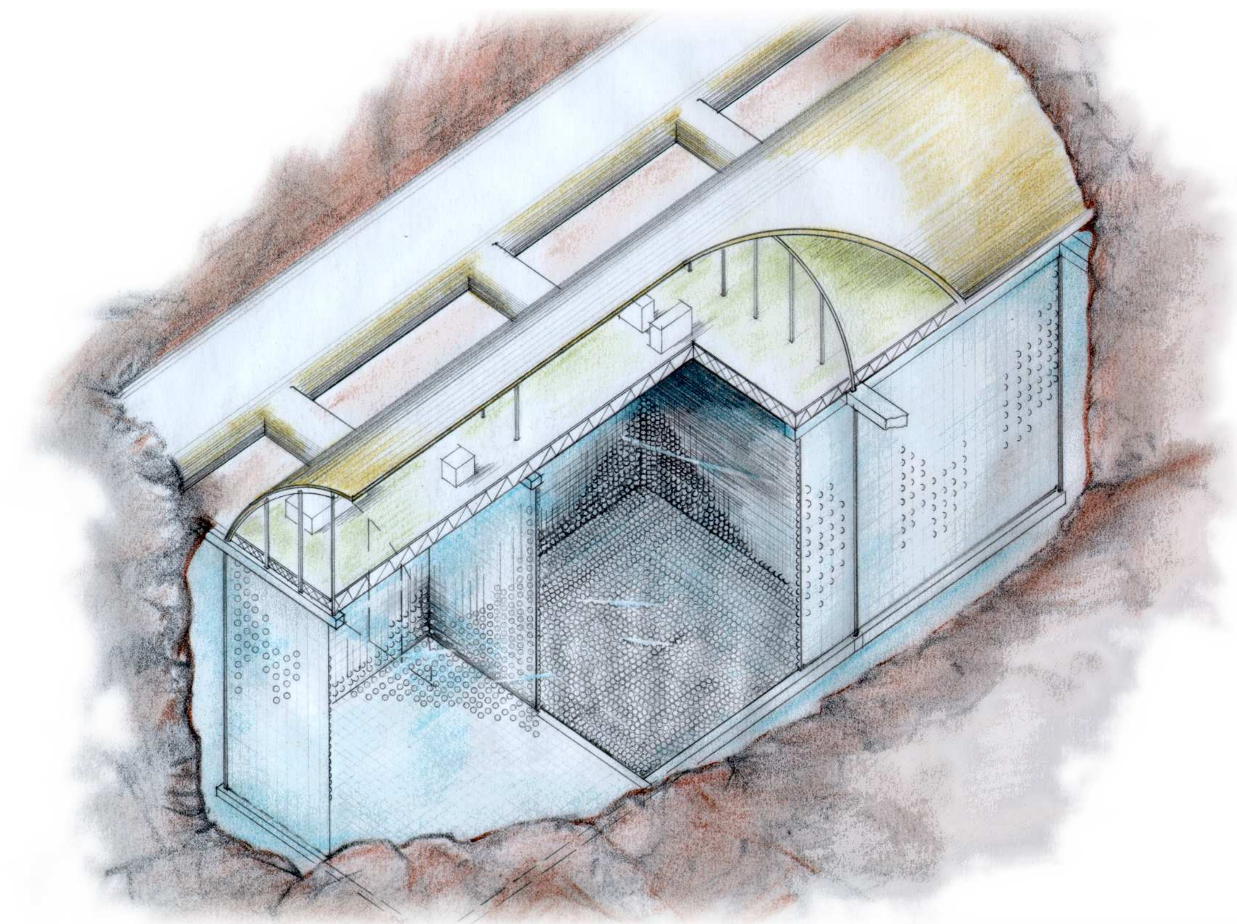
Expression of Interest

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



The UNO Collaboration

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Executive Summary

The UNO detector is proposed as a next generation underground water Cherenkov detector that probes physics beyond the sensitivities of the highly successful Super-Kamiokande (SuperK) detector utilizing a well- tested technology [1]. The baseline conceptual design 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. 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 is considered the most model independent mode of proton decay. Water Cherenkov technology is the only realistic detector technology available to allow 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 discover proton decay via the $K^+\bar{\nu}$ mode.

UNO as an astrophysical neutrino observatory will greatly extend our capabilities in this important field. It will be able to 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 local galactic supernova explosion, UNO will collect $\sim$100k 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 about 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 also provides rich neutrino physics programs, such as 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 difficult for larger, more coarse-grained undersea and under-ice detectors to cover.

A number of detector candidate sites are being considered: Henderson mine in Colorado, Homestake in South Dakota, Soudan mine in Minnesota, San Jacinto mountains in California and WIPP (The Waste Isolation Pilot Plant) in New Mexico. 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. In this document we introduce the Henderson mine, Colorado, which is currently considered by the UNO Collaboration as the most promising candidate site in the U.S. The detector technology has been well tested over two decades in running experiments. There are no significant technical obstacles in the 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 a 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 be 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 is planned to be measured as part of the SALTA project. In addition, we are considering a plan to make the UNO data available to public after a set period of time after data-taking.

The UNO collaboration is currently composed of 97 members from 40 institutions from 7 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.

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

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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 (2000-3000 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 and the results are very encouraging [3]. While the results of the study and the details of the plan need to be verified by more rigorous studies, 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 [4]. 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, and the HEPAP Facilities Committee in 2003.

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 96 experimental scientists and engineers, representing 37 institutions from 7 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) [5] and Europe (Fréjus) [6]. 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 [4]. 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.

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 20 times that of SuperK. We aim for broad physics capabilities and a simple, robust detector configuration.

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 concepts 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 be 40% photo-cathode coverage (equivalent to SuperK) and in the two outer modules to be 10% each. In this configuration, the trigger threshold for the two wings would be around 10 MeV, whereas the central module sensitivity is enhanced via reduction of its analysis threshold to 5 MeV. The lower analysis threshold of the central module allows efficient detection of 6 MeV γs from $p \rightarrow K^+\bar{\nu}$ decay, precision solar neutrino studies and extraction of additional information on core collapse from supernovae neutrinos, along with measurement of the ν_μ and ν_τ fluxes using neutral current excitation of oxygen.

The optimal detector overburden is influenced 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. With an outer detector veto and waveform electronics, known cosmic ray backgrounds even at modest depth ($\sim$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 would 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 Grand Unification Theories of fundamental particles and forces. Thus the discovery of proton decay would have 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 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 SUSY-favored decay modes such as $p \rightarrow \bar{\nu}K^+$. Also shown in the figure is one of the first few testable superstring theory predictions other than the supersymmetry, which was made recently by I. Klebanov and E. Witten on proton decay in intersecting D-brane models [7].

The motivation for proton decay search has recently been strengthened by theoretical and

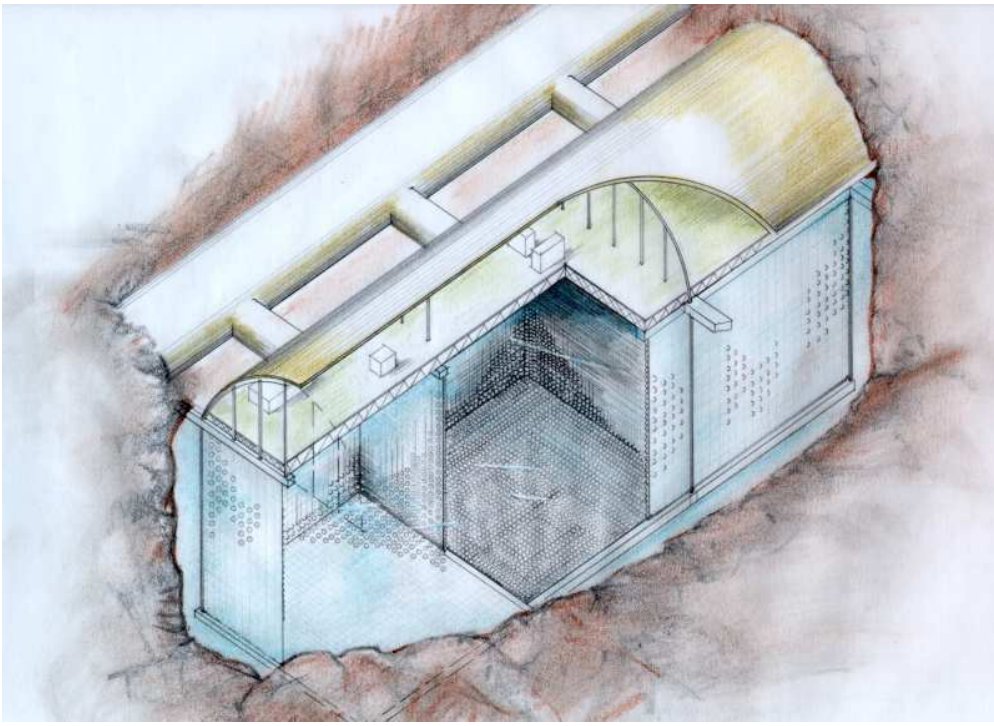

Figure 1: Baseline design of UNO showing the central detector module (40% photo-cathode coverage) with the outer wing modules (10% photo-cathode coverage).

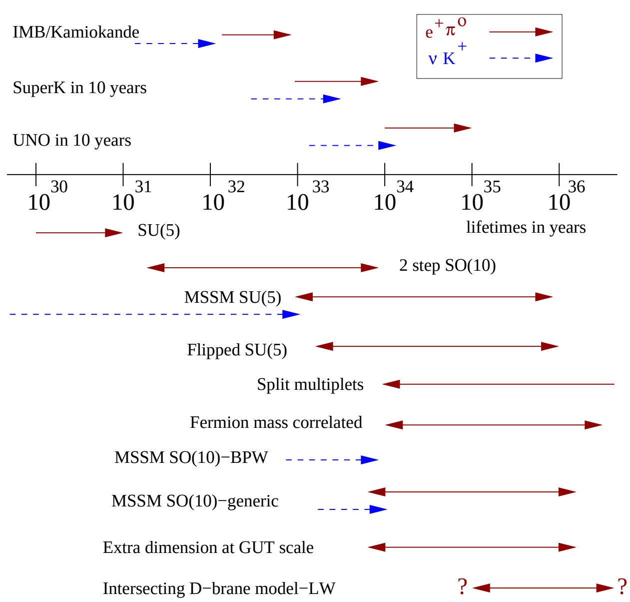

Figure 2: Theoretical predictions of proton decay compared to experimental reach

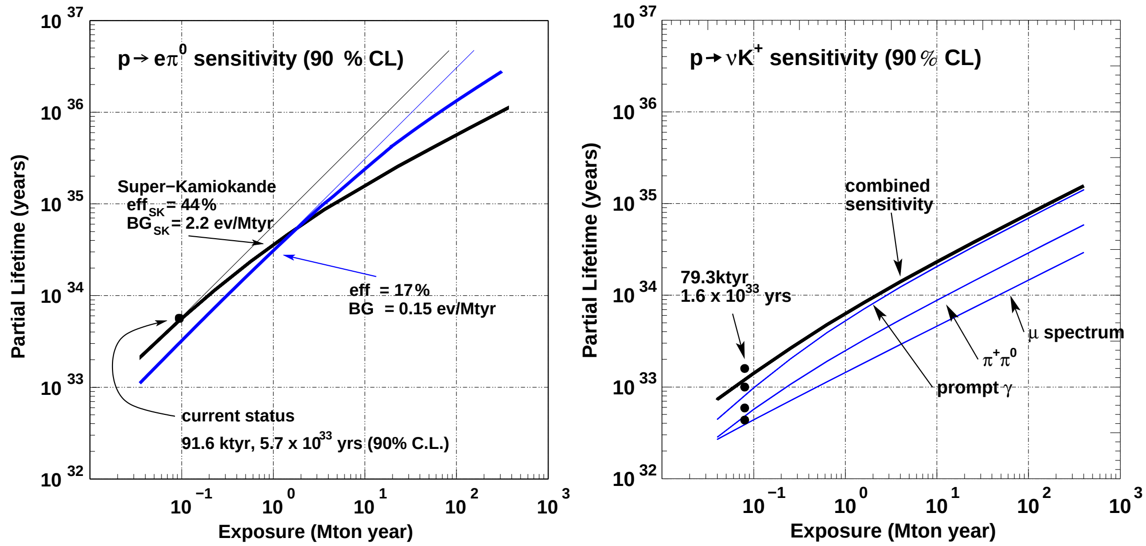

Figure 3: UNO sensitivity to the partial lifetimes of $p \to e^+\pi^0$ (left panel) and $p \to \bar{\nu}K^+$(right panel) as a function of total exposure at 90% confidence level.

experimental advances in other domains, namely: An improved calculation of the hadronic nucleon decay matrix element, β_H, based on lattice QCD [8], a smaller value of the strong coupling constant, $\alpha_s(m_Z)$ [9], 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 $g-2$ [10]. 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. 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 1 Mt·yr atmospheric neutrino exposure. By analyzing these data the predictions of the atmospheric neutrino background simulation have been verified. More than an equivalent of a 10 Mt·yr exposure will be collected by the end of the K2K run, permitting a far more precise estimation of the background. 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), will likewise refine our understanding 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

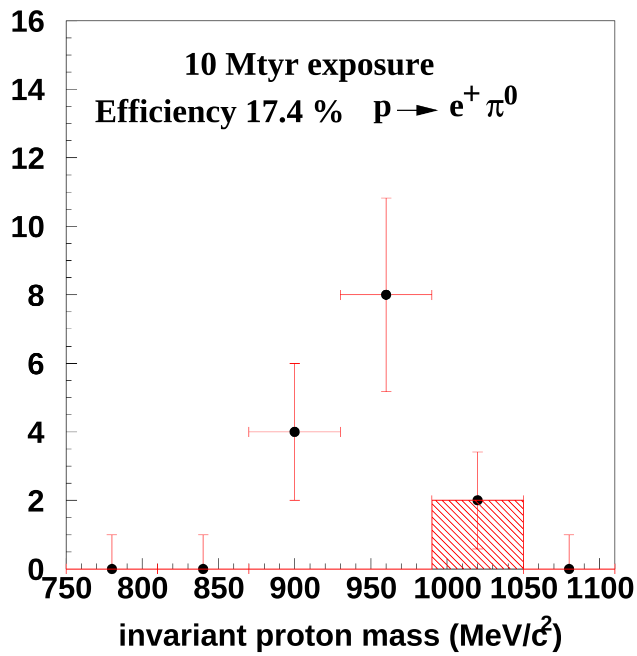

Figure 4: Expected invariant mass distribution of $p \to e^+\pi^0$ candidate events passing all selection criteria. Detector exposure of 5 Mt·yr and partial proton lifetime of $5{\times}10^{34}$ years are assumed. The hatched histograms represent the backgrounds.

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 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 $5{\times}10^{34}$ 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 most dominant. Thus the next generation detector should have search capabilities for broad range of these decay modes.

In a National Academy of Science report in 2001, titled "Six Grand Challenges", described the grand challenges in physics in a new era [11]. One of the grand challenges was "Unifying the Forces of Nature". In order to reach this goal in this century, we desperately need an experimental breakthrough. Observation of proton decay will provide an 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 beam (a “super-beam”), or a pure ν_e ($\bar{\nu}_e$) 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[4][12]; 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 [13].

A recent report by a working group at BNL proposes a neutrino super-beam at an upgraded AGS optimized for a very long baseline experiment [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 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 $\nu_\mu \leftrightarrow \nu_e$ oscillation in an appearance mode. UNO located either at Henderson (2,760 km), Homestake (2,540 km) or at WIPP (2,900 km) would be perfectly suitable as the proposed distant detector.

There is another proposal by a working group at Fermilab to install an off- axis detector along the NuMI beamline [14]. A preliminary study shows that a 500 kt water Cherenkov detector 15 mrad off axis with an exposure of five years at 735 km would have the sensitivity to exclude $\sin^2\theta_{13}$ down to about 0.006. With an upgrade to increase the neutrino beam intensity together with an anti-neutrino beam, we could look for CP violation in addition to more precise measurements on $\theta_{23}, \Delta m^2_{23}, \theta_{13}$ and Δm^2_{13} [15]. An UNO type detector is suitable for this proposal as well. Furthermore, if the BNL and Fermilab proposals are both realized, but the BNL neutrino beam is sent in the direction of Soudan mine, it could be possible to extract CP violation information from a variety of measurements with different baselines and energy spectra.

3.3 Supernova Neutrinos

Because of its sheer size, the number of neutrino events from a supernova collapse observed by UNO will outnumber that of all other proposed and existing detectors. In the case of a galactic supernova at 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.

As 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 [17] (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 [16]. 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 and radius 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 [17]. 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 [18].

- Relative proportions of $\nu_{\rm e}$, $\bar{\nu}_{\rm e}$, etc. will further test simulations and ought to 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 [19].

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, $\nu_x + {}^{16}O \to$

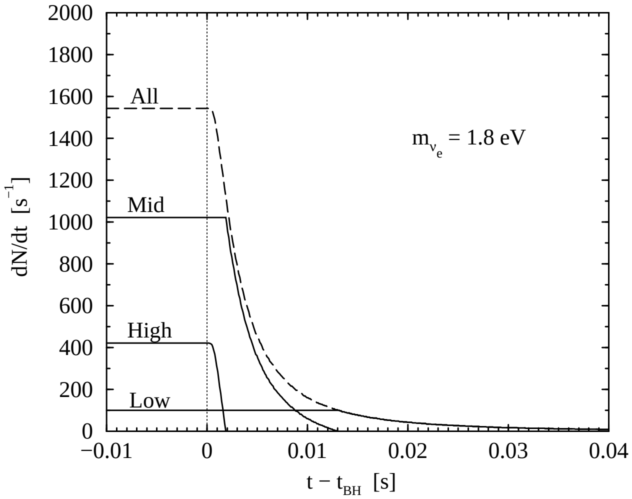

Figure 5: Detection of Black Hole Formation and ν_e Mass Determination. The neutrino data is subdivided according to energy range to provide a sharp "time zero" for the black hole formation (high energy) and well-defined delayed arrival times (middle energy). This delay is directly related to the mass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

$\nu_x + \gamma + X$. 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 [20] 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 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 little more than UNO's, since there are no major galaxies beyond the local group within the range of such a detector.

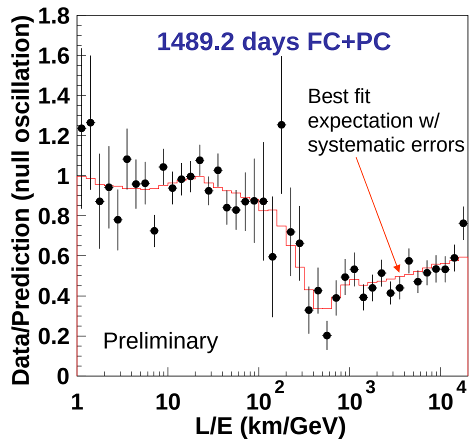

Figure 6: The ratio of the observed muon event rate to the expected rate without oscillation as a function of L/E based on the SuperK data corresponding to 1489 day livetime. The fitted curve is the best fit with the oscillation hypothesis. Note that there is a dip around L/E of 6×10^3.

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 $\bar{\nu}_e \cdot \mathrm{cm}^{-2} \cdot \mathrm{s}^{-1}$ [21]. 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 [22]. Very recently, evidence has been presented by SuperK using data samples selected for good resolution in L/E, that a dip corresponding to an oscillation minimum is being observed as shown in Figure 6 [23].

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 oscillation sinusoidal 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) $\sim$2.5.

New physics can be gleaned from the high statistics atmospheric samples of UNO by invoking "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 $\nu_{\rm e}$ oscillation resulting from matter resonances in the Earth as shown in Figure 8 [24]. 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

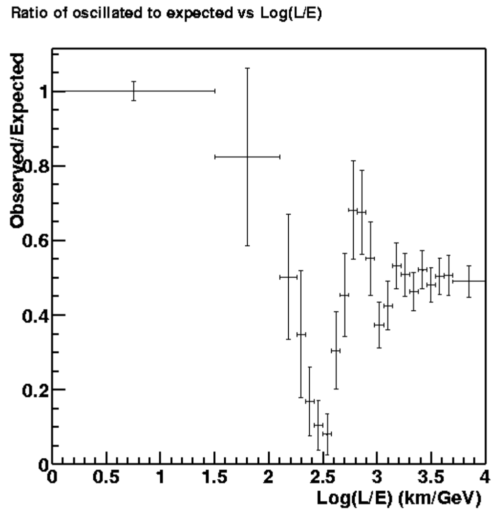

Figure 7: The ratio of the oscillated muon event rate to the expected rate as a function of L/E assuming a 2830 kt·yr exposure (a ~7 yr UNO run). The oscillated flux assumes the parameters are $\Delta m^2 = 0.003$ eV^2, and $\sin^2 2\theta$=1.

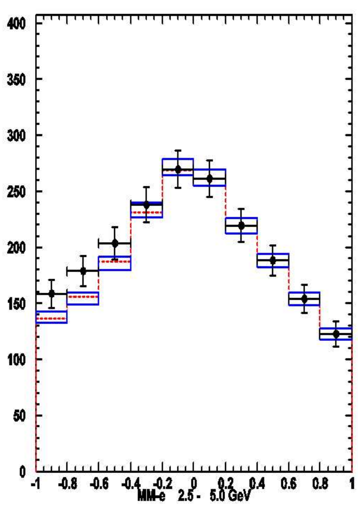

Figure 8: The cosine of the zenith angle distribution of atmospheric single- and multi-ring e-like events whose energies are between 2.5 and 5.0 GeV. Crosses, boxes and dashed histogram correspond to $\sin^2\theta_{13}$ of 0.05, 0.0, and no oscillation, respectively. In this plot the exposure is assumed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

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.

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;
- 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 currently known candidate sites for UNO within the continental U.S.A. Preliminary studies performed by regional experts indicate that all of the candidate sites presented below are geologically suitable to house an UNO size cavern.

Henderson Mine, Colorado: The Henderson mine is a new entry into the National Underground Science Lab (NUSL) discussion. It is located about 70 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. An overburden of 5,000-6,000 ft is attainable with a shallow grade horizontal access tunnel for an existing large diameter drift. The rock is largely competent granite. Access tunnel and cavity excavation costs are expected to be significantly lower than for other sites due to the extensive existing modern infrastructure, especially the high speed rock conveyor. Expansion to deeper levels is readily achievable if required for co-sited experiments that require extremely low cosmic background levels. The site owners are very enthusiastic supporters of this initiative and no additional environmental permits are expected to be necessary. A detailed description of the site is given in the Appendix.

Homestake, South Dakota The Homestake mine located in Lead, South Dakota has been a leading contender site for NUSL. 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. In 2000, a NIOSH study using measured Homestake rock properties determined that a cavity large enough to contain UNO could be excavated as deep as 6,800 ft.

San Jacinto, California The San Jacinto escarpment is one of the steepest and tallest fault bluffs in the United States. This unusual geologic formation allows deep underground access via a modest length horizontal bore into the mountain. The available overburden at San Jacinto is more than 2,500 m of hard rock (7,000 mwe). Because it will have horizontal access, it is expected that construction and operation will be easier, and operating costs are expected to be low, virtually independent of depth. An extensive and professional design of NUSL and an UNO size cavern at this site was performed. Located in populous southern California with many research universities and high-tech industries nearby, San Jacinto enjoys close proximity to many important assets essential to the creation and ongoing support of a world-class scientific facility.

Soudan Mine Soudan mine is home to the MINOS far detector and the target of the NuMI neutrino beam which will originate at Fermilab, 732 km away, by 2005. The NuMI beam energy can be tuned, but is expected to start in the Low Energy (LE) configuration. Using the Low Energy (Medium Energy, High Energy) beam, neutrino interactions are expected at Soudan with a rate of 470 (1270, 2740) per kiloton per 3.7×10^{20} protons on target, and a peak neutrino energy of 3 (8, 17) GeV. Recently there has been a serious effort to propose this site for a new multi-level, deep underground laboratory by a phased expansion of the existing Soudan Underground Laboratory. Phase 0 of this plan uses existing space at a depth of 2,100 mwe. Phase 1 is an expansion to a depth of 4,500 ft ($\sim$4,000 mwe). Phase 2 is an additional expansion to a third complex of rooms at 8,000 ft (7,200 mwe) for detectors that require extremely low background. The 4,500 ft level would be most suited for UNO. However, feasibility of housing an UNO size detector at this level has not been evaluated rigorously.

WIPP, New Mexico WIPP is located about 30 miles from Carlsbad, New Mexico. It it at a depth of 655 m in a bedded evaporate deposit of nearly pure salt, with a thickness of about 650 m. Underlying it is more salt and anhydrite beds of the Castile formation, down to a depth of about 1300 m, which sets a limit to the greatest possible depth for UNO. This depth barely achieves the optimal depth required by UNO physics goals. In 2001, WIPP was proposed as a candidate site for a NUSL. Since then WIPP received regulatory approval for mounting three experiments: Prototype supernova neutrino detector (R&D stage of OMNIS), SEGA/MEGA Segmented Germanium detector, and Prototype Xe-136 TPC. In addition, WIPP has assisted the UNO collaboration in conceptual design of the detector, and provided rough cost estimates for the creation of the cavities and associated facilities for the experiment.

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 1.

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
San Jacinto	3,860	8,610	2,620	8,150
Soudan	1,710	6,580	730	8,490
WIPP	2,930	8,160	1,770	8,880

Table 1: Baselines in km for potential experimental sites.

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 among several possible detector sites and a detailed engineering design. For the present, we project the costs as generically as possible, while attempting to account for dependencies upon the various sites wherever 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 2 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, or the deepest possible location at WIPP (3400 feet) with a new access shaft. The total cost for UNO then ranges between about \$410-440M. If UNO is built in an existing NUSL, the excavation cost could be reduced to about \$100M (according to the Homestake and San Jacinto proposals) for the detector cavity and auxiliary spaces. Similarly, if the WIPP site is to be developed as a NUSL and the new shaft cost can be absorbed by the NUSL budget, the excavation cost for the UNO cavity would be \$50M. In the case of the Henderson mine, the excavation cost is estimated to be about \$115M including the cost for access (∼\$8M). In either scenario, if UNO is constructed at a NUSL, the detector cost could be as low as \$350M. We thus estimate the UNO detector construction cost to be \$350M - \$420M. This estimate contains, however, only partial contingency. Thus by adding 20% - 25% contingency, we arrive at our nominal

Item	SuperK		UNO Hard Rock*	UNO@WIPP
Cavity Excavation	27,640	v	168,000	100,000
Water Piping and Pumps	630	v	4,082	4,082
Water Purification System	1,850	v	11,988	11,988
Power Station	720	v5	2,160	2,160
Crane	760	v5	2,280	2,280
Cavity Treatment/Water Tank	18,400	s	25,000	50,000
PMT Support Structure	4,580	s	23,019	23,019
Counting Room	330	s5	990	990
Computer Building	1,860	s2	2,232	2,232
Main Building	3,000	s2	3,600	3,600
20” PMT (including cables)	34,670	s	155,457	155,457
Electronics	6,330	s5	9,495	9,495
DAQ	1,090	s5	1,635	1,635
Air Conditioning	210	s5	315	315
Veto Instrumentation	3,000	s5	9,000	9,000
8” PMT (including cables)	2,262	s	17,881	17,881
Total	107,332		437,134	412,134
(1$ = 100 yen)			*Q=100, Horizontal Access	

Table 2: 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. For example, in the case of the Henderson mine, the cost is estimated to be as low as $115M, which includes the cost for access (∼$8M).

detector cost, $500M. More detailed cost estimation can only be done after rigorous and detailed design work on the detector.

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.

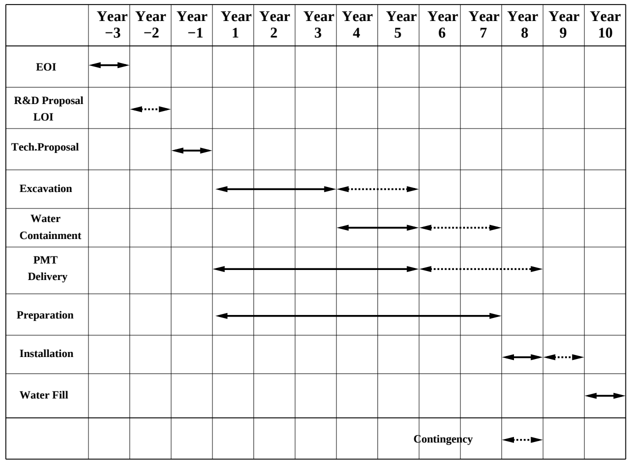

Figure 9: Conceptual UNO schedule.

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 discuss the main activities relating to construction.

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.

A material of especially low permeability to water vapor is Geothane, a polymer blend, polyurethene-based geo-membrane. Geothane liners are standard fare for large volume sewage holding tanks and advertised to have a maintenance-free life expectancy of 25 years. Extrapolating from industrial applications, a cavern-liner water seal for UNO might be implemented as follows: Subsequent to mechanical treatment of the excavated rock, a light steel grid-work would be deployed on the cavern walls and the floor. The grid-work would support a thick concrete layer which, after surface treatment, would comprise the substrate for a Geothane membrane liner. Recently, a cavity treatment scheme along these general lines has been considered for Hyper-Kamiokande

Radon level is an important factor for most of the underground experiments. As an active mine, radon levels inside the Henderson mine are monitored continously to ensure a safe working environment. Members of the UNO collaboration have analyzed the data over a 12 month period from more than a dozen locations under a variety of air flow conditions. The levels are similar to those at existing mines used for underground experiments, such as Super Kamiokande. For UNO, as with SuperK, the primary issue is not with ambient levels, but the ability to purify the tank water and air volume above the water. We will investigate the applicability of these purification methods to the larger UNO volume. In addition, since we have been limited to data from personnel health monitoring devices, UNO will perform independent measurements of radon and other radiation sources, possibly as part of our outreach program. These may be also of use to other experiments that may consider being sited at Henderson.

8 R&D Activities

PMTs account for 30-40% of the total detector cost. Hamamatsu Co. has provided an initial quote of $2,775$(1,200) per 20" (8") PMT, assuming an 8-year delivery schedule. It is possible to shorten the delivery time at an increased cost of a few hundred dollars per PMT. Lowering the detector cost without reducing light collection seems achievable, and this is one of the most active R&D areas. There are two approaches: one is simply to develop an automated PMT manufacturing method that is cost effective. The other is to develop new kinds of photo-detectors that have superior performance and/or lower cost.

There are three groups involved in photo-detector R&D. A group of physicists at ICRR, University of Tokyo has been collaborating with Hamamatsu to develop a new type of photo-sensor with performance comparable to the current SuperK 20" PMT, greater structure strength in a higher pressure environment, and reduced cost. The option under investigation is a spherical hybrid photo-sensor (HPD) using avalanche photodiodes at the center of a spherical glass envelope. Currently a 5" prototype with a conventional envelope shape has been tested. A good single photo-electron peak was observed and the dark current rate was measured to be 8 kHz. Planned activities are: (1) Testing of a 13” HPD prototype, (2) Development of a large avalanche photodiode and a low noise high voltage power supply, and (3) Design of 20” HPDs.

Another group at U.C. Davis has been developing a photo-sensor named ReFerence that allows photo-cathodes to operate in reflection mode. It uses a Winston cone to collect the light to the photocathode surface, and special electron optics, based on the same Winston cone shape, to focus photoelectrons to an electron sensor in the middle of the entrance window. The basic design was verified in extensive laboratory tests. The ITT Night Vision has produced several small single-pixel prototypes. DOE has been supporting this R&D under the Advanced Detector Research program. To provide an optimal industrial follow up, a startup company was formed and the company has applied for SBIR funding at DOE.

Finally, Burle Industries Inc., a leading manufacturer of specialized electron tubes and electro-optic products, has recently expressed interest in developing a large area PMT using their well developed mass production capabilities. The goal is to develop a large area PMT with performance that is comparable to the 20” Hamamatsu tubes used by SuperK, but at a substantially lower cost.

9 Outreach Activities

UNO has taken advantage of an existing outreach program, set up in 2001 as part of the Education and Outreach activities at the Snowmass-01 Workshop. The SALTA (Snowmass Area Large Time-coincidence Array) project, funded by private donations arranged by C. Quigg, was organized by J. Wilkes (U. of Washington), D. Claes and G. Snow (U. of Nebraska, Lincoln), based on school-network cosmic ray detector projects at their home universities. Claes and Wilkes are UNO Collaboration members.

During the week-long workshop at Snowmass [25], plastic-scintillator counters salvaged from the CASA experiment in Utah were distributed to teachers and students from four secondary schools in the Aspen Valley and Leadville. Participants were shown how to refurbish and test the counters, use oscilloscopes and NIM modules, and select optimal high voltage settings for photomultiplier tubes. They heard talks about basic particle physics, experimental techniques, and the physics of extremely high energy cosmic rays. The goal was for the SALTA schools to become an extension of the CROP outreach program at U. of Nebraska. While it proved to be difficult to maintain contact and provide adequate support for the schools after the workshop, all SALTA schools responded enthusiastically when contacted recently (11/03) and invited to a meeting at the Henderson Mine site, and in fact a fifth school joined the program.

Our plan is to use SALTA hardware, updated with new school-network cosmic ray data-acquisition hardware developed by a UNL/UW/FNAL team [26], to measure underground muon rates at various locations in the Henderson Mine. This provides teachers and students with an op-

Aspen High School, Aspen	Marc Whitley
Basalt High School, Basalt	Diana Kruis
Roaring Fork Valley High School, Carbondale	Laura French
Clear Creek High School, Empire	Nancy Spetzler
Lake County High School, Leadville	Michelle Ernzen

Table 3: Schools and teachers participating in the UNO outreach program (12/03)

portunity to do real physics and make a tangible contribution to UNO while learning more about particle physics and opportunities for students in basic research. From personal contacts, we know that the SALTA workshop inspired several high school students who had not previously thought of this option to pursue careers in physical science, and we are certain the same will be true for the current student group.

A preliminary meeting at the Henderson Mine, held on 12/4/03, was a great success. Teachers were extremely enthusiastic and eager to get started. Henderson Mine staff have been extremely cooperative, and proposed another meeting in February, 2004, to which students will be invited for a mine- safety orientation and introduction to the project. Several specific sites for muon telescopes were scouted and will be instrumented in early 2004.

Table 3 lists the participating teachers. D. Claes will manage UNO outreach programs, assisted by J. Wilkes. This effort has subsisted on residual SALTA funds, which are now exhausted. However, the attached budget includes a request for support needed to maintain the outreach program through the UNO R&D phase.

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 recent 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 discovery and precision measurements in a broad range of physics areas, especially when combined with a super-beam facility. As the largest underground experiment, UNO would be a natural anchor for the NUSL, 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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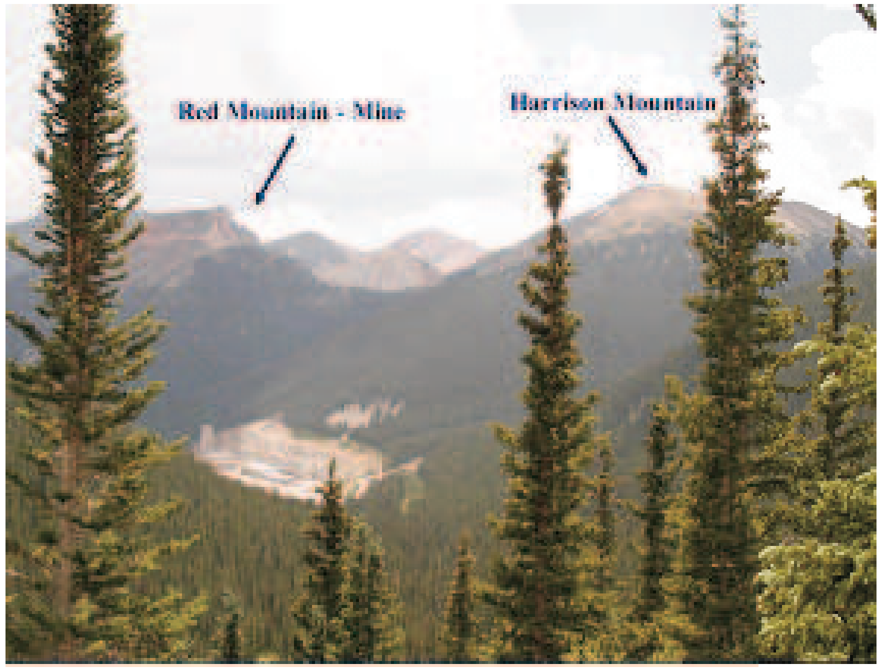

Figure 10: View of the Henderson Mine site showing mine buildings, Red Mountain mining area, and Harrison Mountain.

A Henderson Mine, Colorado

A.1 Introduction

The Henderson mine, located near Empire, Colorado, is situated in an area surrounded by snow-capped peaks and outdoor recreation facilities in Colorado's Rocky Mountains. Climax Molybdenum Company, a subsidiary of Phelps Dodge Corporation with corporate headquarters in Phoenix, Arizona, owns the Henderson Mine. Phelps Dodge is one of the largest mining companies in the world, and is primarily engaged in the production of copper and molybdenum from large open pit mines. The Henderson mine, which produces molybdenum ore by an underground mining method known as panel caving, is the company's only underground operation. Molybdenum is a grayish colored metal that is mainly used to produce high strength alloy steels. Other uses include chemicals and lubricants, and as filament supports in light bulbs.

The mine site is located 80.5 km (50 mi) west of Denver, Colorado and the surface facilities lie 3170 m (10,400 ft) above sea level on the eastern side of the Continental Divide. It can easily be reached from Denver International Airport (DIA) by taking Interstate 70 west to the Empire exit, Highway 40 approximately 16 km (10 mi) to the bottom of Berthoud Pass, and continuing approximately 3 km (2 mi) on the well maintained mine access road. The entire trip from DIA can be made in approximately 1.5 hours, or about 1 hour from the central Denver.

The mine site is within Clear Creek County and is surrounded by the Arapaho National Forest. The approximately 11.7 km^2 (2900 acre) of land containing the Henderson orebody, located underneath Red Mountain, as well as the proposed UNO site, located underneath Harrison Mountain (Fig 10), is entirely privately owned by Climax Molybdenum Company. Additionally, the 52- km^2 (12,800 acre) mill site located near Kremmling, Colorado is also entirely owned by the company.

From the beginning, the mine was designed as a high capacity operation, and the mine infrastructure is engineered to support production in excess of 30,000 tons per day, which equates to about 10 million tons per year, easily making the Henderson Mine one of the 10 largest underground mining operations in the world today. The mine is currently producing about 21,000 tons of raw ore per day. It is estimated that the mine has adequate reserves for about twenty more years of production. Upon closure of the Henderson Mine, the company plans to re-open the Climax Molybdenum Mine located near Leadville, Colorado.

A.2 Geologic Setting

The Henderson deposit is composed of two partially overlapping ore bodies that lie 1,080 m (3550 ft) beneath the summit of Red Mountain. The ore bodies are entirely within a Tertiary rhyolite porphyry intrusive complex that has intruded the Precambrian Silver Plume granite. The deposit is elliptical in plan, with overall dimensions of 670 m by 910 m (2200 ft by 3000 ft), with an average thickness of 185 m (600 ft). The top of the deposit is at an elevation of 2610 m (8560 ft), while the lower limits range from 2,340 m (7680 ft) on the west to 2,100 m (6900 ft) on the east. The mineralization is relatively continuous in the ore bodies and consists of molybdenite and quartz in random intersecting closely spaced veinlets. The general nature of the orebody and the surrounding host rock is that of very competent (high strength) granite with compressive strengths ranging from 100 to 275 Mpa (14,500 to 40,000 psi). Host rock areas that have very little molybdenite have been found to behave appropriately for medium-strength granite.

The proposed UNO facilities will be located under Harrison Mountain, which is situated just to the west of Red mountain (Figure 10). Regional geologic studies have indicated the Harrison Mountain area to be barren of mineral deposits, and for this reason extensive exploration drilling has not been performed. The Henderson Geology Staff carried out detailed surface mapping of Harrison Mountain in the early 1980's. This mapping revealed highly competent Precambrian Silver Plume Granite along the crest of the mountain, and on the northeast and southeast-facing slopes. Broad zones, up to 300 m (1000 ft) wide of northeast-trending broken and fractured granite were mapped along the upper northwest slopes below the ridgeline. This broken zone lies within the overall trend of the Vasquez Pass Shear Zone. The downward extent of this broken zone is not known. It does, however, project to the northwest of the proposed UNO excavation, one mile below the peak.

The only exploratory drill hole located on Harrison Mountain was CX-126, drilled in 1968 from an elevation of 3502 m (11,489 ft) on the southeastern slope. The hole was drilled from an access road below the saddle that separates Harrison from Red Mountain, and is above the trace of the proposed access tunnels on 7500 Level. The vast majority of the core was in Precambrian Silver Plume Granite, with minor intervals of Idaho Springs Schist that occur as inclusions. What is noteworthy in this hole is that the Silver Plume Granite becomes more competent with depth, beginning at around 2957 m (9,700 ft) in elevation. Rock competencies range between 6 to 8 (with 9 being maximum). The contact between Silver Plume and Urad Porphyry is at an elevation of 2654 m (8706 ft), with rock competencies remaining high to the end of the hole at an elevation of 2294 m (7526 ft). The bottom of this hole is very close to the 9HW-99LD intersection on 7500 Level. This intersection is the preferred location of a 600 m (2,000 ft) exploration drill hole to the west under Harrison Mountain. Diamond drill holes to the north of CX -126 corroborate the high rock competencies seen in that drill hole. Drill holes CX-135 and CX-103 both show high competencies in the Silver Plume Granite and in the Urad Porphyry. Silver Plume Granite has historically been a competent unit during underground development at the Henderson Mine. On the 7500 Level, the Granite remained competent in 9A and 9HW drifts. Based on the detailed geologic logs from surface exploration diamond drill holes and the information gathered by mining through the Precambrian units on the 7500 Level, the proposed large UNO excavation under Harrison Mountain should be in competent Precambrian Silver Plume Granite. Exploratory drill holes from the 7500 Level will be necessary to verify this conclusion.

A.3 Mine Description

The mine began operation in 1976 after a 10-year redevelopment program and a $500 million investment. The Henderson 2000 modernization program, which consisted of the new underground crusher room excavation, conveyor transfer station excavation and conveyor decline, was begun in 1996 and was completed in 1999.

The mine is accessed from the surface by an 8.53 m (28 foot) diameter personnel and material shaft that extends down to the 7500 level. (Note: In US mining parlance, levels are referred to by their altitude in feet above sea level, not by their depth underground.) The shaft cages can transport up to 200 people at a time, and the trip from the surface to the 7500 level takes about 5 minutes. The cage can accommodate loads with maximum dimensions 2.6 m wide, 7.1 m long, and 3.9 m high (8'-7"w × 23'-5"l × 12'-11"h) weighing up to 30 tons. Taller items up to 5 m in height (16' 4") can fit on the cage if they are small enough to fit in one corner. Loads of up to 50 tons can be carried if a crosshead is substituted for the cage and counterweights used. An inter-level ramp with a grade of about 7% extends from the 7500 level down to the 7065 truck level.

From the 7700 production level, ore is transported with large capacity Load Haul Dump units

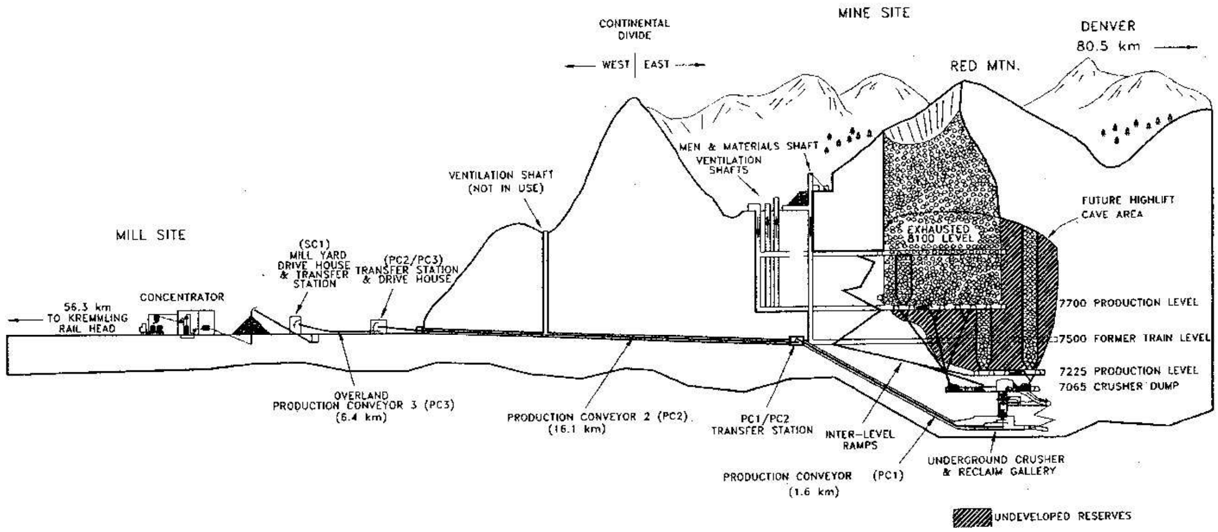

Figure 11: Idealized cross section of the Henderson Mine infrastructure.

(LHDs) with capacities of about 10 tons per scoop, to bored 2.5 m diameter ore passes that extend vertically down to the 7065 truck level. On the 7065 truck level, ore is loaded from large ore chutes at the bottom of the ore passes into 80 ton side dump underground haul trucks, (the largest underground trucks manufactured), which haul the ore to the underground crusher. The crusher reduces the size of the ore to pieces 8 inches or less, and has a capacity of 2300 tons per hour.

From the bottom of the crusher below the 7065 level, the ore is loaded on to the first of three conveyor belts, PC1, which transports the ore 1.6 km (1 mi) to the PC1/ PC2 transfer station located at the 7500 level. At the transfer station, the ore is then loaded onto the PC2 underground conveyor, and is transported 16.1 km (10 mi) under the continental divide to the PC2/PC3 transfer station. PC2 is the longest single flight conveyor in the world. At the PC2/PC3 transfer station the ore is loaded onto the 6.4 km (4 mi) long PC3 overland conveyor that transports the ore to stockpiles for subsequent processing at the mills. The entire journey from the bottom of the crusher to the mill stockpile takes about 2 hours. Mill tailings are placed in large containment areas that will be reclaimed and re-vegetated when the mine is closed. The operating permit allows for the deposition of in excess of 340 million tons of mill tailings. The UNO Cavity tailings will be a negligible addition to planned deposits.

From 1976 through 1991, approximately 98 million tons of ore were produced from the 8100 level. In 1992, the 7700 level was brought into production and over 70 million tones have been produced from this level so far. The next production level will be at the 7210 level, located 149 m below the 7700 level.

Ventilation to the production level is supplied by a multi horizon level 15 to 20 m (50 to 65 ft)

Figure 12: Large mining equipment used at the Henderson mine. a) 10 ton capacity Load Haul Dump unit (LHD). b) 80 ton capacity side dump underground haul truck.

below. Both intake and exhaust air are transported on two horizons to provide a general north-to-south fresh air-to-exhaust airflow. Each production ore pass is connected to exhaust air and has an associated intake raise from the intake drifts. This entire level is connected to an 8.5-m (28-ft) intake shaft and to 7- and 10-m (23- and 33-ft) exhaust shafts by way of several 5- by 5-m (16- by 16 ft) ventilation drifts. Approximately 3.2 million cubic meters per hour (1.9 million cfm) of air is moved through the mine.

Mine water is treated at the Urad Water Treatment Plant, which was built in 1996 with a $9.8 million capital investment. The plant is capable of treating 15 m^3/m (4000 gpm) using a two-stage lime precipitation process for removal of manganese, zinc, aluminum, and other metals. The treated mine water is discharged into Clear Creek and used by various communities down stream.

The Henderson Mine is the second largest consumer of electricity in Colorado. A permanent substation that is integrated into the statewide electricity distribution network is located on the property.

Two MSHA approved emergency escape routes for the safe evacuation of mine personnel in the event of a mine emergency exist. The primary escape way is Number 2 Shaft, and the secondary escape way is through the PC2 tunnel. These routes would be available for use in the UNO emergency evacuation plan.

The largest excavations in the mine were constructed as part of the Henderson 2000 project. These were the PC1/PC2 transfer station, 12.8 m wide × 27.5 m long × 17.7 m high (42 ft × 90 ft × 58 ft) constructed in Silver Plume Granite, and the underground crusher station 18.6 m wide × 28.3 m long × 14.6 m high (61 ft × 93 ft × 48 ft), constructed in the Vasquez Porphyry rock type.

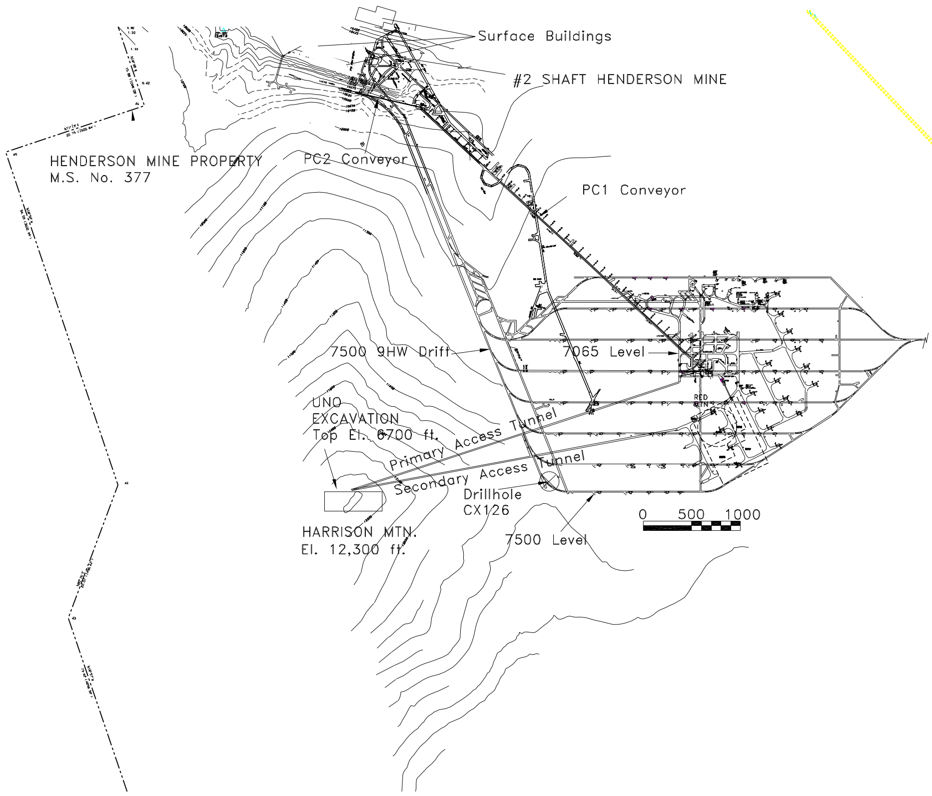

Figure 13: Plan view of Henderson Mine workings and proposed UNO location.

A.4 UNO Specifics

The proposed location of the UNO room (Fig H4) is directly below the summit of Harrison Mountain, elevation 3750 m (12,300 ft). Because of the availability of the large capacity shaft and mine tunnels developed as part of the infrastructure for the Henderson mining operation, the amount of development in the form of access tunnels for the proposed UNO laboratory will be minimal.

A number of different layouts could be used to access the area under Harrison Mountain from the existing mine tunnels. One possible approach is discussed below. While the details of the exact final layout will most likely differ slightly from that outlined, the final costs estimates are expected to be about the same as those summarized. Two tunnels would provide access (Fig. 13). The primary access tunnel would be driven from the 7065 truck level (elevation 2153 m) and would provide the access for people and materials to the UNO laboratory area. This tunnel would be 6 m wide and 5.5 m high (20 by 18 ft) in cross section and would be driven at a 10% grade downward for a distance of approximately 1103 m (3620 ft). The elevation at the end of the tunnel at the UNO room location would be about 2044 m (6705 ft), resulting in a total depth of 1705 m (5595 ft) below the summit of Harrison Mountain, which is somewhat deeper than the minimum depth specified for UNO, 1525 m (5000 ft). A vertical section through Harrison Mountain showing the approximate location of the UNO room relative to the surface is given in Figure 14. Note that the additional 110 m (360 feet) of elevation that can be gained by driving the access tunnel at a 10% decline rather than horizontal can be realized at a relatively minor additional cost, i.e. approximately 6 m (20 feet) of additional horizontal tunnel would be required to gain 110 m (360 feet) of depth. It is expected that large trucks carrying supplies would access the laboratory area through this tunnel. Although grades of up to 15% on haulage roads are occasionally used in the mining industry, it is felt that for safety reasons, grades greater than 10% should be avoided for the primary access tunnel.

A second tunnel will also be driven from the 7065 truck level. The purpose of this tunnel is to provide for ventilation requirements, and to serve as a secondary escape route. The dimensions on the secondary tunnel will be 3.7 m by 3.7 m (12 ft by 12 ft). This tunnel will be driven at a grade of 10.6% for a distance of 1036 m (3400 ft). A grade greater than 10% is acceptable since the secondary access tunnel will not be used for the transportation of personnel and materials. Although this tunnel will provide secondary access, if the UNO project is approved, this tunnel should be driven first since the overall cost per foot are lower than the larger primary access tunnel cost. It is expected that a second detailed program of diamond drilling in order to better quantify the geotechnical parameters of the rock mass to be used in the final design of the UNO laboratory will be done from this tunnel.

A short crosscut drift approximately 85 m (280 ft) in length will be driven connecting the primary and secondary drifts at approximately the location of the 9HW drift. To provide for ventilation requirements, two vertical 3 m (10 ft) diameter, 183 m (600 ft) long bored raises will connect the crosscut to the ventilation drift below the 9HW drift on the 7500 level. In addition to these openings, it is estimated that 150 m (500 ft) of tunnels 6 m × 5.5 m in area will also be required for various shops, access to the UNO chamber, etc. The total time required to construct the access tunnels would be around nine months to one year.

The proposed UNO room will have dimensions of 60 m wide, 60 m high, and 180 m long (200 × 200 × 600 ft). Including the arched opening over the room, it is estimated that about 1 million m^3 (35,315,000 ft^3) of rock will have to be removed for the excavation. Using a tonnage factor of 12.75 ft^3/ton, this volume represents about 2,780,000 tons. Including the volume required for the tunnels and other openings, the total tonnage required for the entire UNO excavation is estimated to be roughly 3 million tons. The waste rock produced will be removed by the Henderson ore transportation system at an estimated cost of $7.50/ton. A truck loading station will be constructed and used to load the broken rock into the underground haulage trucks. Broken rock will be trucked

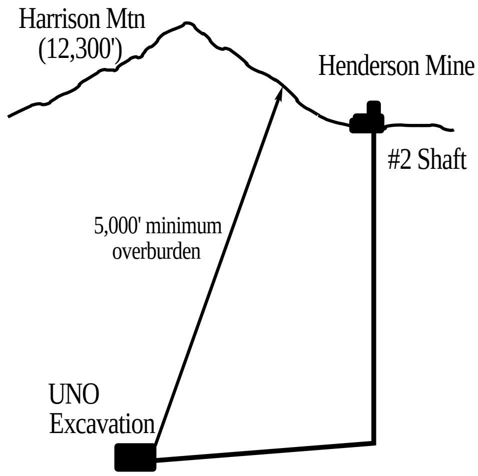

Figure 14: Vertical section through Harrison Mountain showing approximate location of the UNO room.

to the crusher station and removed from the mine using the existing conveyor system. Note that the total excavation volume of 3 million tons will easily fall within the current operating permit for the mine, which allows for the deposition of over 340 million tons at the mill site. 172 million tons have already been deposited and an additional 166 million tons will be deposited during the remaining mine life. No additional permitting should be required for the disposal of the waste rock produced by the UNO project.

Based on the above information, a preliminary estimate of the excavation costs for the proposed UNO laboratory has been performed (Table 4). Cost estimates are based on actual costs from the Henderson 2000 project. Costs for the large UNO chamber are estimated lower than the costs for mining the underground crusher chamber because of efficiencies that will be gained from the large volume of this chamber.

In order to facilitate the comparison with other potential sites, excavation costs have been broken down into access costs, and excavation costs for the large UNO room. Excavation costs for the UNO room will most likely be approximately the same regardless of where the laboratory is located. The total access cost of about $8 million is a fraction of the $50 to $150 million that would be required for access at other potential underground laboratory sites, (Homestake, Soudan, San Jacinto, Icicle Creek). Additionally, the $7.50 per ton cost for rock removal and permanent deposition is significantly lower than what would be expected at any of the above named sites.

At the anticipated depth of the UNO experiment of 4200 mwe under Harrison Mountain several other Gran Sasso style experimental halls could be provided to co-site additional experiments. The details of size and infrastructure needs would have to be discussed to include them in the planning process. If greater depths are required for an experiment a ramp (again with 10% slope) could

Cost Description	Units/Type	Units	$/unit	Cost
A. Initial exploration and ventilation tunnel (12'w × 12'h drifts)	A. Feet	3680	$ 500	$1,840,000
B. Ventilation	B. Mobilizaton	1	$29,200	$29,200
10 ft diameter	Setup	2	$18,000	$36,000
2× 600 ft	Feet	1200	$300	$360,000
C. Primary access tunnel (20'w × 18'h drifts)	C. Feet	3900	$1,100	$4,290,000
D. Truck loading station	D. Construction	1	$500,000	$500,000
E. Cost for rock removal	E. Tons	115,025	$7.50	$862,687
	Total-Access			$7,917,887
F. UNO room excavation	F. Cubic Feet	35,315,000	$1.70	$60,035,500
G. Cost for rock removal	G. Tons	2,769,804	$7.50	$20,773,529
	Total-UNO room			$80,809,029
H. Contingency		30%		$26,618,075
	Grand Total			$115,344,991

Table 4: Estimated UNO excavation costs.

branch off the ramp leading to the UNO site and wind down under Harrison Mountain. Secondary access would be provided by a smaller escape ramp. Using this style of access a depth of 5320 mwe could be provided for experiments with about $23 m additional cost.

It is estimated that the Henderson Mine will be in production for about twenty years. During the UNO construction period estimated to be about ten years, a certain amount of coordination between the mine and the construction personnel will be required regarding the use of the shared access routes such as the vertical shaft and the ramp down to the 7065 truck level. This coordination is not expected to be much of a problem since the mine infrastructure is currently under utilized, and the majority of the people involved in the construction phase will be trained mining personnel. The details of a suitable schedule for use of the shared access routes will have to be worked out for the 10 to 15 years that UNO facilities will be in use while the mine is in production. After production ceases, the mine infrastructure required to provide access and services to the UNO area will have to be operated and maintained.

The costs of operating the facility once the excavations are complete will be estimated at a later date when more information regarding the needs of the UNO project is available. It is expected that operating costs at Henderson would be in line or lower than operating costs that would be found at other potential underground laboratory sites. The exact details of the required operating contract as well as the long-term lease or ownership of the mine will also have to be worked out at a later date.

A summary of other mine infrastructure that exists as well as what would be available to the UNO project is given below:

- Mine ventilation: The mine ventilation system has a capacity of 1,900,000 cubic feet per minute (cfm) provided through three large surface fans. Of this total amount, about 200,000 cfm in excess capacity would be available to UNO, which is significantly more than the estimated 50,000 cfm that would be required to ventilate the large UNO room and access tunnels.

- Electricity: Two 24 MW transformers for a total of 48 MW are available at the mine site. The mine is currently using 10 MW, but also requires an additional 10 MW for backup. With the existing transformer stations, UNO would have 14 MW available with 14 Megawatt for backup. The electrical network has 100% redundant feed from the power company Xcel, from the Cabin Creek substation near Georgetown and Blue River substation located between Kremmling and Silverthorne.

- Mine dewatering: The mine pumping and dewatering system has a capacity of 5000 gpm. The mine is currently using about 1000 gpm. This would leave about 4000 gpm available for UNO. While the amount of water that would have to be pumped from the UNO excavations is unknown, based on previous mine experience it is estimated that a maximum capacity of 500 gpm will be required.

- Water treatment: The surface water treatment facility has a capacity of 4000 gpm. The mine is currently using about 1100 gpm normally and about 2000 gpm during spring runoff, leaving about 2000 gpm available for UNO. The estimated UNO need is 500 gpm.

- Compressed air: There are two 8000 cfm, one 6000 cfm, and one 1700 cfm compressors available as part of the mine compressed air system. The mine currently uses about 6000 cfm, leaving in excess of 16000 cfm available for UNO.

- Concrete batch plant: A concrete batch plant for mixing concrete and shotcrete that would be required during UNO construction is available. The batch plant has a capacity of 200 yd^3 per day, of which the mine is currently using about 60 yd^3 per day. About 140 yd^3 per day would be available to UNO.

- Rock conveyor system: The mine conveyor system for rock removal was designed for a capacity of 40,000 tons per day. The mine is currently using about 21,000 tons per day. The estimated maximum that would be required for mine production is 30,000 tons per day, leaving at least

10,000 tons per day available for UNO. During UNO construction, it is estimated that a capacity of 3,000 tons per day will be required.

- Office space: Office space in the main mine office building 60 ft by 60 ft in area will be immediately available to UNO.
- Outreach facilities: An area at the mine site about 4 acres in size is available for the construction of outreach facilities.

A.5 Summary

Considering only the primary factors such as geology, cost, quality, environmental impact, the Henderson Mine is a very strong competitor for siting UNO and other underground science experiments. When other important factors such as cooperation from mine ownership, accessibility, proximity to industry, technicians, and major academic institutions, are included, Henderson presents one of the most compelling choices for UNO. As a potential national facility, when such additional factors as quality of life, educational, recreational, and cultural amenities are also considered, Henderson offers a very attractive package.

An education and outreach activity on the site has already been started. The cosmic ray flux inside the Henderson mine is planned to be measured as part of the SALTA project. We envision that the multifaceted duties during the UNO construction will allow the involvement of undergraduate and graduate students from a variety of engineering and physical sciences disciplines as well as high school teachers and students.

With a minimum 5,000' overburden at the proposed location of the UNO excavation cavity, the Henderson Mine is deep enough to meet the low cosmic ray background levels required for UNO and most other proposed underground experiments. Deeper levels are readily achievable at relatively low cost. Preliminary estimates suggest that levels at 7,000' can be reached with primary and secondary tunnels in less than a year for around $20M. Preliminary geological studies indicate that the rock at the proposed excavation site is likely to be Silver Plume granite, ideally suited to large cavity excavation. In order to verify this assertion and to avoid unnecessary debates concerning the UNO candidate sites, a core-drilling to the UNO proposed location is planned and funding has been secured from university and community sources.

As a recently upgraded modern mine, Henderson is safe and has the infrastructure and excess capacity to accommodate easily the additional excavation and infrastructure support required for UNO. Its main shaft is large enough (28' diameter) to accommodate sea containers, and it has in place the necessary excess electrical power and water treatment capacity to meet the needs of an underground laboratory. Furthermore, the efficiencies of its high capacity excavation and rock removal methods using high speed conveyor will save tens of millions of dollars in excavation costs. It is also important to note that the environmental impact is fully accommodated within

Henderson's existing permits. When the mine ceases operations (estimated between 15-25 years), the conveyer tunnel could be modified to provide a convenient high capacity horizontal access as well.

The major local stake holders are very supportive of this project. Of particular importance is Phelps-Dodge, the parent company of the Climax Molybdenum Henderson Mine. They own not only the mining operations but all the land involved in the project. They have been fully cooperative and supportive, providing access to mine documents such as sites plans, environmental impact reports, radon levels, ventilation capacity etc. Though the legal relationship between the company and a national facility would need to be defined in detail, they have expressed a great willingness to pursue the initiative.

It is remarkable that, as one of the ten largest underground operating mines in the world, the Henderson Mine is located within minutes of an interstate highway and just an hour's drive from a major metropolitan area with its broad supporting base of technical industries, highly trained workforce, research universities, and a major international airport - not to mention four professional sports franchises. It is worth mentioning as well that seven major mountain and ski resorts, with extensive conference facilities, are located within an hour of the mine.

Henderson Mine provides an historically unique opportunity for the nation to create - at relatively modest cost and in a highly desirable location - the major underground facility needed to address some of the deepest questions of contemporary physics.